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Reports

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2005

## Shoreline evolution, Chesapeake Bay shoreline, City of Virginia Beach, Virginia

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An aerial photograph of a coastline in 2005. The image shows a wide, sandy beach curving along the shore of the Chesapeake Bay. To the left of the beach is the ocean, with a large red and white ship visible in the distance. To the right of the beach is a dune area with sparse vegetation, followed by a residential area with several houses and a road. The background shows a dense forest of trees. The sky is clear and blue.

**Shoreline Evolution  
Chesapeake Bay Shoreline  
City of Virginia Beach, Virginia**

**Virginia Institute of Marine Science  
College of William & Mary  
Gloucester Point, Virginia**

**2005**

# Shoreline Evolution Chesapeake Bay Shoreline City of Virginia Beach, Virginia

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2005

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The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies or DEQ.



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**Cover Photo:** First Landing State Park in the City of Virginia Beach. Photo taken by Shoreline Studies Program on 24 September 2003.

## I. INTRODUCTION

### A. General Information

Shoreline evolution is the change in shore position through time. In fact, it is the material resistance of the coastal geologic underpinnings against the impinging hydrodynamic (and aerodynamic) forces. Along the shores of Chesapeake Bay, it is a process-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 report is to document how the Bay shore of Virginia Beach (Figure 1) has evolved since 1937. Aerial imagery was taken for most of the Bay region beginning that year, and it is this imagery that allows one to assess the geomorphic nature of shore change. Aerial imagery shows how the nature of 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. Most of the change in shore positions will be quantified in this report. Others, particularly very irregular coasts, around inlets, and other areas will be subject to interpretation.

### B. Chesapeake Bay Dunes

The primary reason for developing this Shoreline Evolution report is to be able to determine how dunes and beaches along the Bay coast of Virginia Beach have and will evolve through time. The premise is that, in order to determine future trends of these important shore features, one must understand how they got to their present state. Beaches and dunes are protected by the Coastal Primary Sand Dune Protection Act of 1980 (Act)<sup>1</sup>. Research by Hardaway *et al.* (2001) located, classified and enumerated jurisdictional dunes and dune fields within the eight localities listed in the Act. These include the counties of Accomack, Lancaster, Mathews, Northampton and Northumberland and the cities of Hampton, Norfolk and Virginia Beach (Figure 2). Only Chesapeake Bay and river sites were considered in that study.

In 2004, Hardaway *et al.* created the Virginia Beach Dune Inventory. That report detailed the location and nature of the jurisdictional primary dunes along the Bay shore of Virginia Beach and those results appear in Appendix B. For this study, the positions of the dune sites are presented using the latest imagery in order to see how the sites sit in the context of past shoreline positions. The dune location information has not been field verified since the original visits in 2000. This information is not intended to be used for jurisdictional determinations regarding dunes.

<sup>1</sup>The General Assembly of Virginia enacted the Coastal Primary Sand Dune Protection Act (the Dune Act) in 1980. The Dune Act was originally codified in § 62.1-13.21 to -13.28. The Dune Act is now recodified as Coastal Primary Sand Dunes and Beaches in § 28.2-1400 to -1420.

## II. SHORE SETTING

### A. Physical Setting

The Bay shoreline of the City of Virginia Beach is located between Cape Henry and Little Creek. The city has about 8 miles of tidal shoreline along the Chesapeake Bay from the west boundary of Fort Story to the west side of Little Creek Inlet. The shorelines are exposed to waves from the open Bay as well as the Atlantic Ocean. Historic shore change rates vary from 0 ft/yr to more than 4.5 ft/yr for both shore recession and shore advance (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. The Chesapeake Bay coast of Virginia Beach is exclusively Holocene beach sands which overlie earlier Holocene sands, mud, and clays (Figure 3). The Atlantic Ocean has come and gone numerous times on the Virginia coastal plain over the past million years. The effect has been to rework older deposits into beach and lagoonal deposits at time of the transgressions.

During the last sea level low stand, sea level was about 300 ft lower than it is today, which forced the ocean coast about 60 miles to the east causing the coastal plain to be broad and low. The current estuarine system was a series of rivers working their way to the coast. About 18,000 years ago, 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. As shorelines recede or erode, the bank material provides the sands for the offshore bars, beaches, and dunes.

Sea level is continuing to rise in the Tidewater Region. Tide data collected at Sewells Point in Norfolk show that sea level has risen 4.42 mm/yr (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 4 cm or about an inch and a half, 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 41 cm (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 (2002), which means the impact of sea level rise to shore change is significant. The beaches, dunes, and nearshore sand bars try to keep pace with the rising sea levels.

Two main shore reaches occur along the Bay shore of Virginia Beach. These reaches are divided into five plates for discussion and are presented in Figure 4. Reach I extends from Cape Henry to Lynnhaven Inlet and Reach II from Lynnhaven Inlet to the entrance of Little Creek Inlet. The littoral system is sand rich from transport into the Bay. Net longshore transport is to the west.

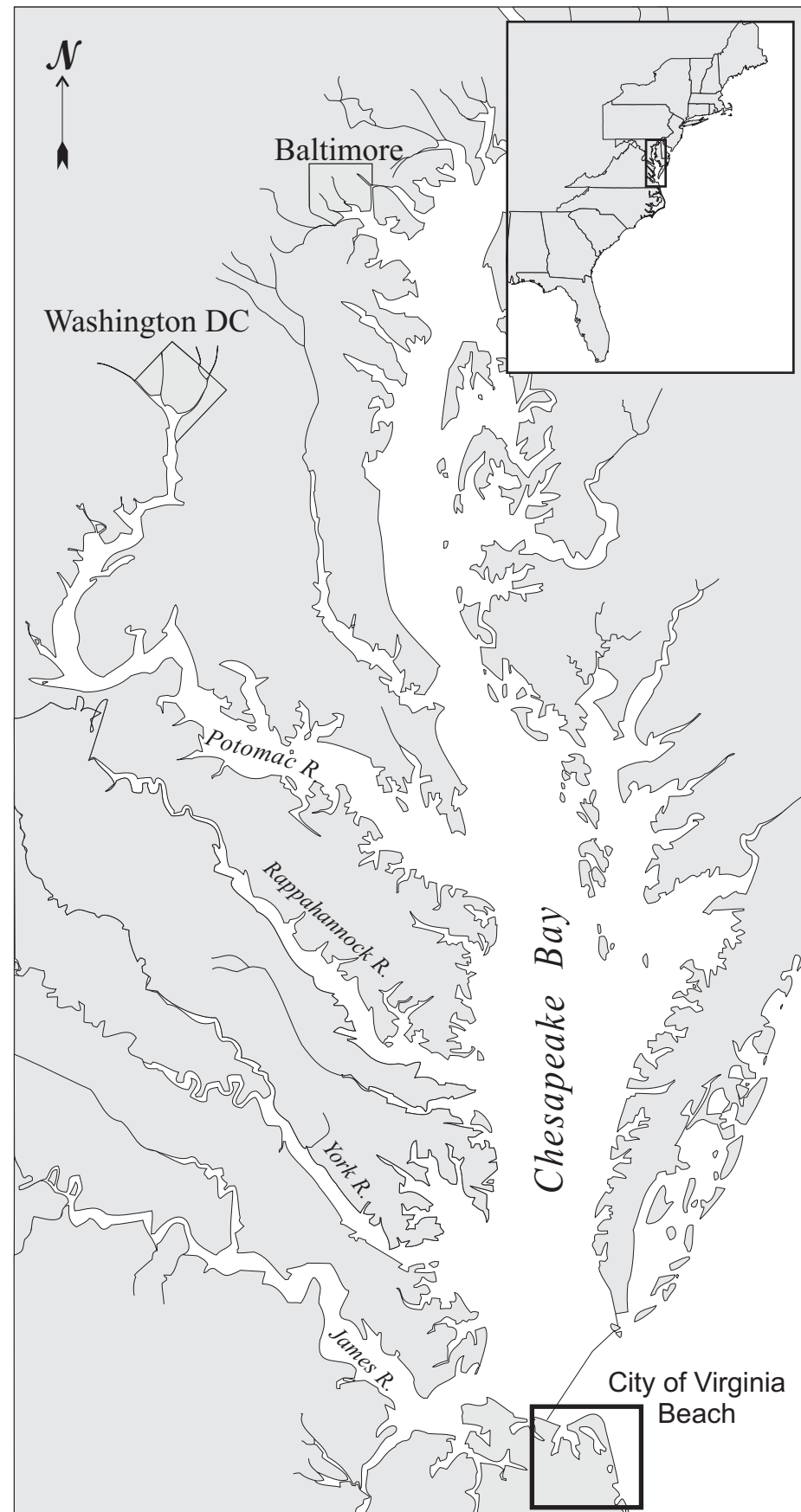


Figure 1. Location of the City of Virginia Beach within the Chesapeake Bay estuarine system.

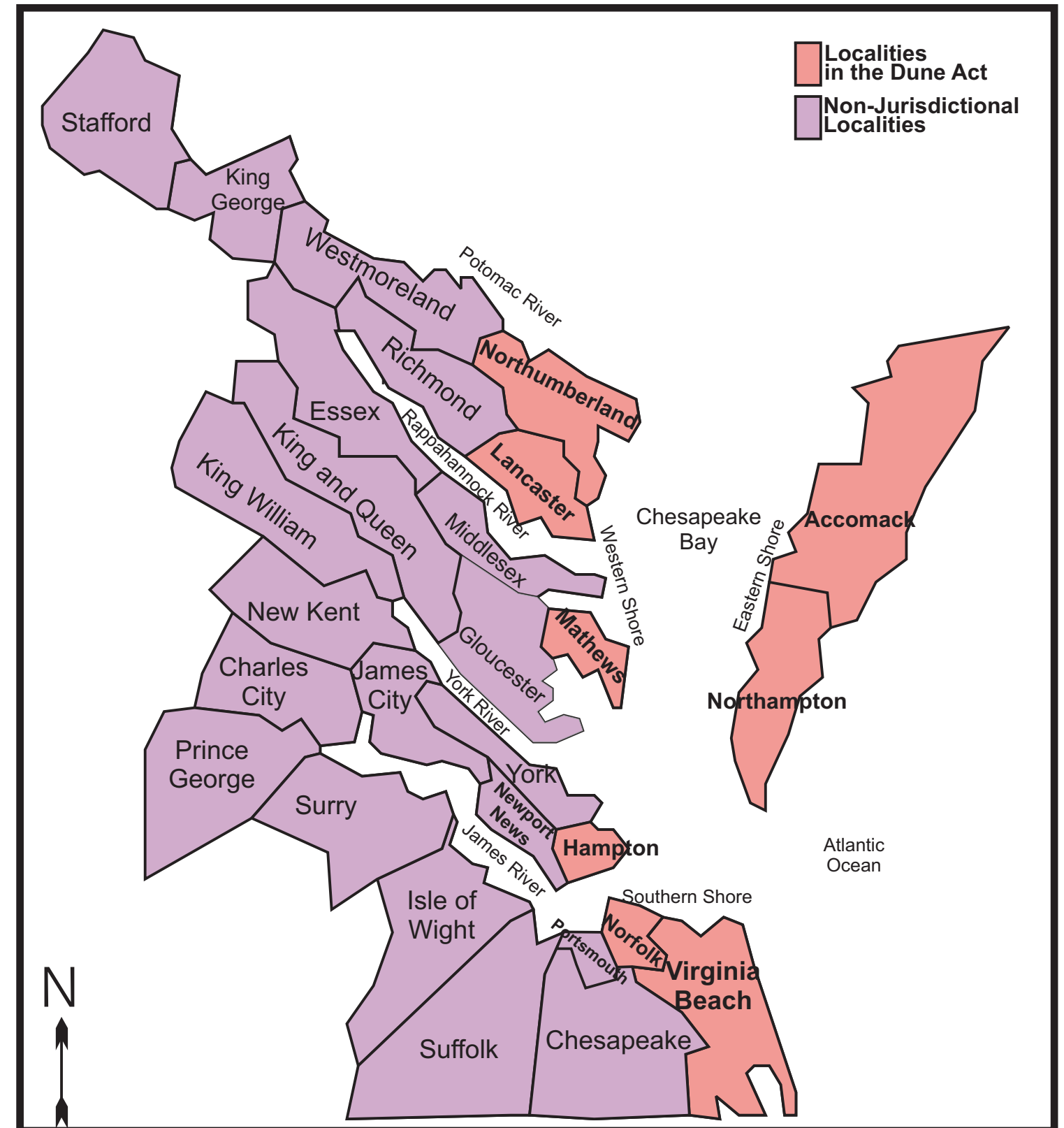


Figure 2. Location of localities in the Dune Act with jurisdictional and non-jurisdictional localities noted.

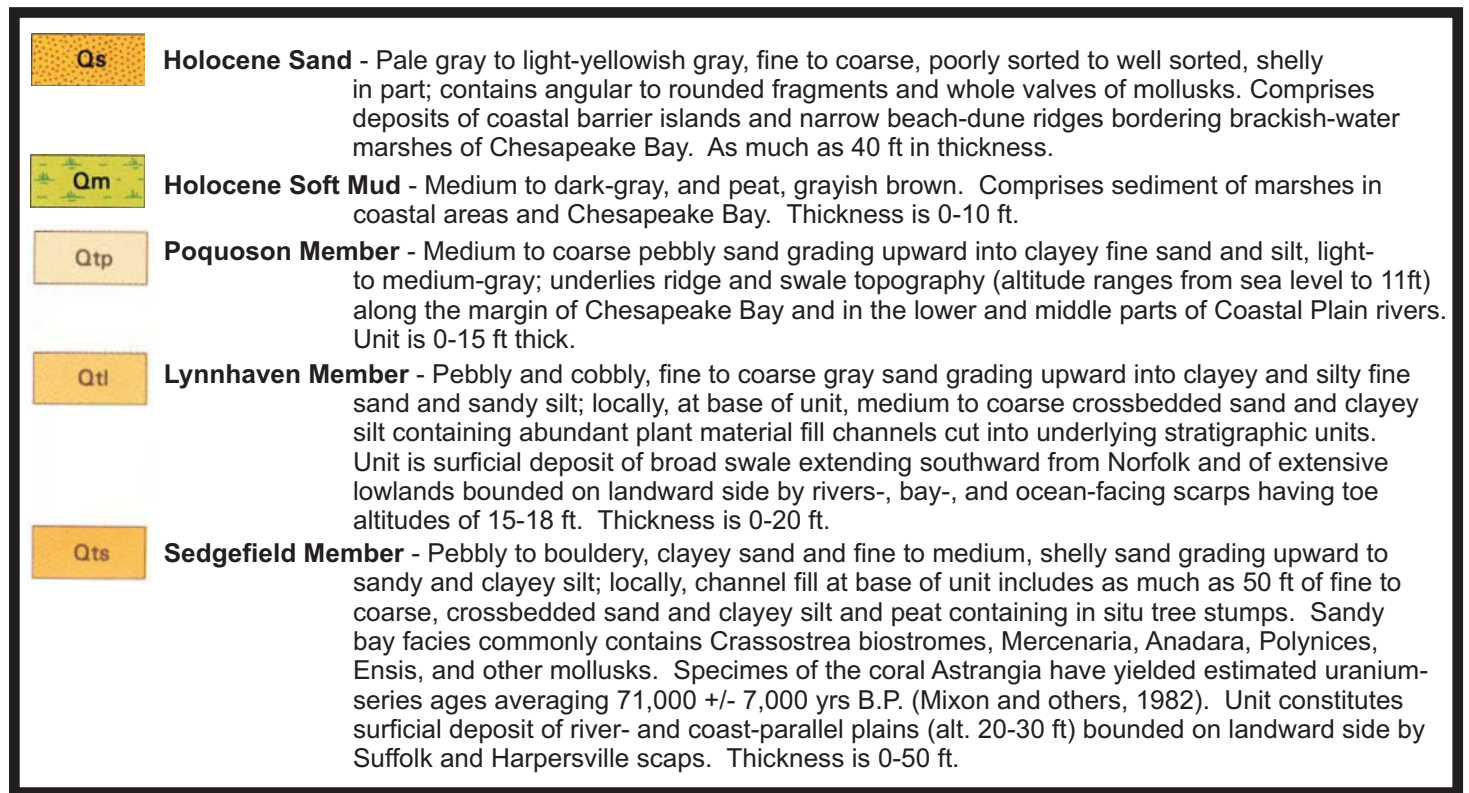
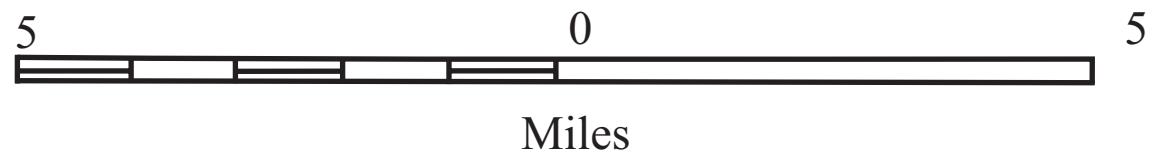


Figure 3. Geologic map of the City of Virginia Beach (from Mixon *et al.*, 1989).





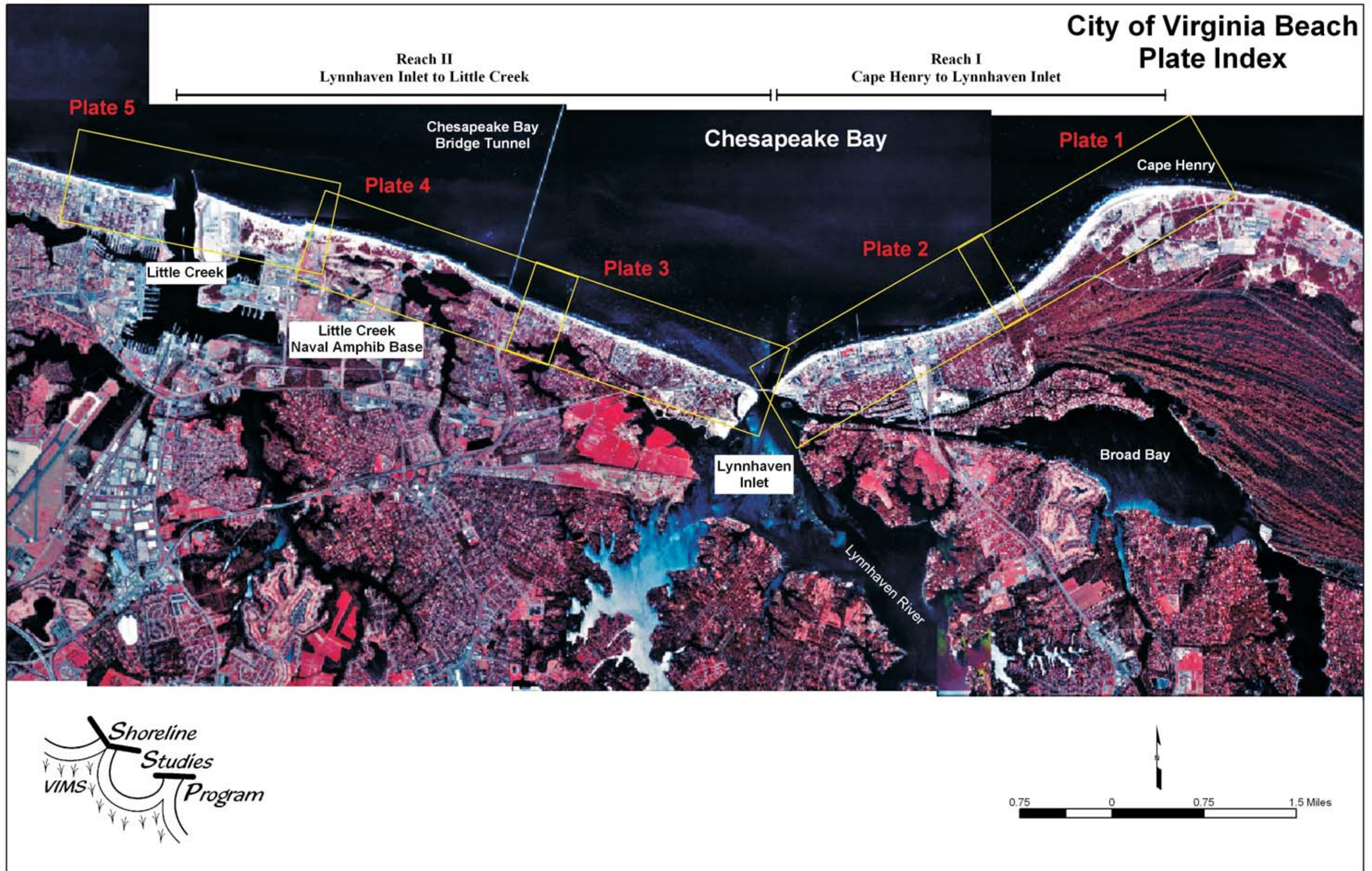


Figure 4. Index of shoreline plates.

B. Hydrodynamic Setting

Mean tide range along the Bay coast of Virginia Beach is about 2.9 ft. The wind/wave climate impacting the Virginia Beach Bay coast is defined by large fetch exposures to the northwest, west and northeast across Chesapeake Bay. Wind data from Norfolk International Airport reflect the frequency and speeds of wind occurrences from 1960 to 1990 (Table 1). The shorelines of Reach I and Reach II also are partially impacted by incoming ocean swell (Boon *et al.*, 1993). Northeast storms also are significant in terms of beach and dune erosion due to their storm surge and waves. These storms typically last several tidal cycles leading to an increased reach inland of storm waves and surge.

Hurricanes, depending on their proximity and path, have impacted the Virginia Beach 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. Beach erosion and dune scarping were significant but areas with wide beaches offered more protection to the adjacent dunes. Storm surges along the Virginia Beach coast were significant but not as severe as areas further up the 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 <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
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      <sup>+</sup>Percent

### III. METHODS

#### A. Photo Rectification and Shoreline Digitizing

Recent and historic aerial photography was used to estimate, observe, and analyze past shoreline positions and trends involving shore evolution for the City of Virginia Beach. Some of the photographs were available in fully geographically referenced (georeferenced) digital form, but most were scanned and orthorectified for this project.

Aerial photos from VIMS's Shoreline Studies and Submerged Aquatic Vegetation (SAV) Programs, United States Geological Survey (USGS), Hampton Roads Planning District Commission (HRPDC), and Virginia Base Mapping Program (VBMP) archives were acquired. The years included 1937, 1960, 1970, 1976, 1980, 1994, and 2002. High level black and white aerials were available for 1937, 1960, 1970, 1976, and 1980. Color aerials were obtained for 1994 and 2002. The 1994 imagery was already processed and mosaicked by USGS, while the 2002 imagery was processed and mosaicked by VBMP. The aerials for the remaining flight lines were processed and mosaicked by the VIMS Shoreline Study Program.

The 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 Quarterquadrangles (DOQQ) from USGS. The original DOQQs were in MrSid format but were converted into .img format as well. ERDAS Orthobase image processing software was used to orthographically correct the individual flightlines using a bundle block solution. Camera lens calibration data was 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 were used per image, allowing two points per overlap area. The exterior and interior models were combined with a 30-meter resolution digital elevation model (DEM) from the USGS National Elevation Dataset (NED) 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 an .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 are permanent features such as manmade features and stable natural landmarks. The maximum root mean square (RMS) error allowed is 3 for each block.

Once the aerial photos were orthorectified and mosaicked, the shorelines were digitized in ArcMap with the mosaics in the background to help delineate and locate the shoreline. For the bay coast of Virginia Beach, an approximation to mean high water (MHW) was digitized. This often was defined as the "wetted perimeter" on the beach sand as the last high water location. In areas where the shoreline was not clearly delineated on the aerial photography, the location was estimated based on the experience of the digitizer. Digitizing the shoreline brings in, perhaps, the greatest amount of potential error because of the problems of image clarity and definition of shore features. A series of Virginia Beach dune site profiles are displayed in [Figure 5](#) which shows beach/dune variability. [Figure 6](#) shows the relationship of MHW, MLW and beach/dune system components. The final format the shorelines are in is a shapefile format. One shapefile was produced for each year that was

mosaicked. In areas where the shoreline was not clearly delineated on the aerial photography, the location was estimated based on the experience of the digitizer.

#### B. Rate of Change Analysis

An Arcview extension called "shoreline" was used to analyze shoreline rate of change. A straight, approximately shore parallel baseline is drawn landward of the shoreline. The extension creates equally-spaced transects along the baseline and calculates distance from the baseline at that location to each year's shoreline. The output from the extension are perpendicular transects of a length and interval specified by the user. The extension provides the transect number, the distance from beginning baseline to each transect, and the distance from the baseline to each digitized shoreline in an attribute table. The attribute table is exported to a spreadsheet, and the distances of the digitized shoreline from the baseline are used to determine the rates of change. The rates of change are summarized as mean or average rates and standard deviations for each Plate.

It is very important to note that this extension is only useful on relatively straight shorelines. In areas that have unique shoreline morphology, such as creek mouths and spits, the data collected by this extension may not provide an accurate representation of true shoreline change. The shore change data was manually checked for accuracy. However, where the shoreline and baseline are not parallel, the rates may not give a true indication of the rate of shoreline change.

### Dune, Virginia Beach

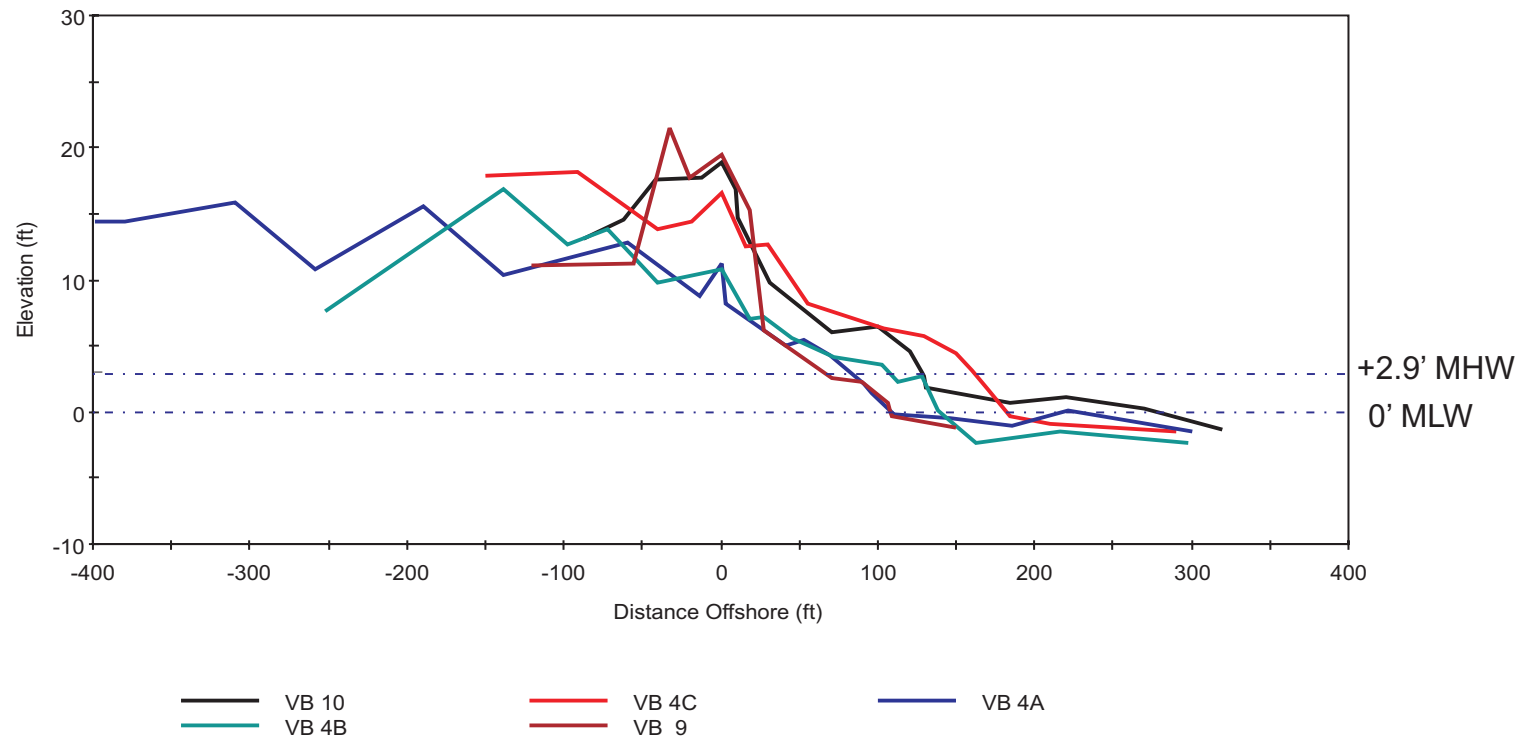


Figure 5. Variability of dune and beach profiles in the City of Virginia Beach.

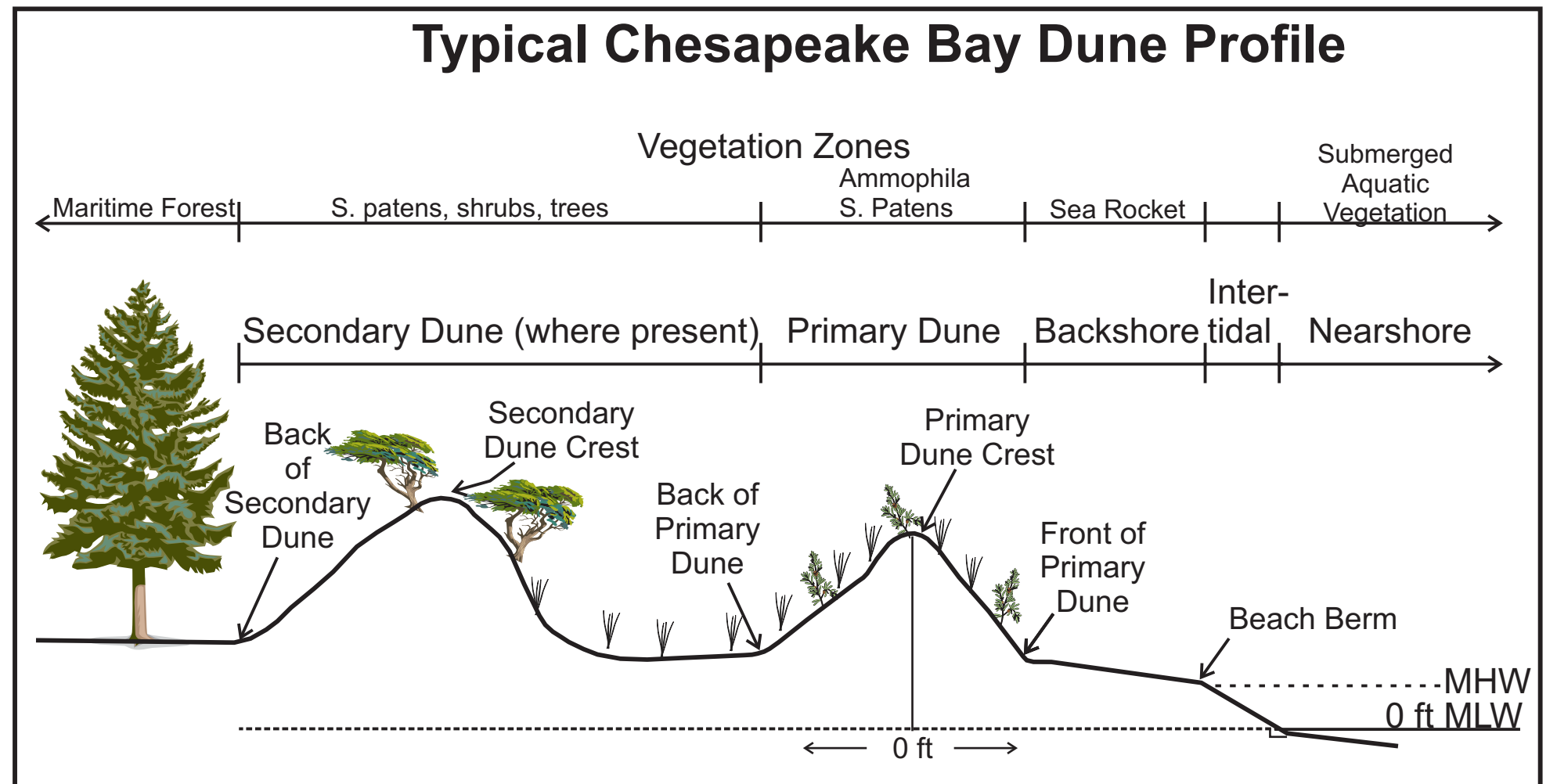


Figure 6. Typical profile of a Chesapeake Bay dune system (from Hardaway *et al.*, 2001).

## IV. RESULTS

The Plates referenced in the following sections are in [Appendix A](#). Dune locations are shown on all photo dates for reference only. Dune sites and lengths are positioned accurately on the 2002 photo. Because of changes in coastal morphology, the actual dune site might not have existed earlier. Site information tables are in [Appendix B](#). More detailed information about Chesapeake Bay dunes and individual dune sites in the City of Virginia Beach can be found in Hardaway *et al.* (2001) and Hardaway *et al.* (2004). Since much of the dune data were collected several years ago and the beach and dune systems may have changed, this report is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.

### A. Reach I

Reach I includes Plates 1 and 2 along with the dune sites denoted as VB4A, VB4B, VB4C and VB6. VB4 is a continuous dune feature with VB4A and VB4B representing subreaches along First Landing State Park's extensive natural dune field (Plate 1). This subreach has experienced significant net (1937-2002) accretion since 1937 causing the primary dune to advance bayward leaving behind a series of "secondary" dunes, particularly between Stations 3,500 and 9,500.

The Plate 2 coast continues the net accretionary trend from stations 0 to about 2,000, then the shoreline trends become very stable with minor advances and retreats to about station 8,500 where shoreline advance becomes the dominant trend. Dune site VB4C is the westward extension from Plate 1 and stops at about Station 5,500. At that station condominiums begin to occupy the coast, and the primary dune has been developed. This development continues to about Station 9,000 where the primary dune begins again and continues around to the entrance of Lynnhaven Inlet as VB6.

### B. Reach II

Reach II includes Plates 3, 4 and 5 and extends from Lynnhaven Inlet to Little Creek Inlet and contains dune sites VB8, VB9, VB10, VB11, VB12, VB12 and VB15 (A, B, and C). Plate 3 shorelines show relative stability over time. Significant shore retreat can be seen in 1960 from station 1,500 to 5,000 with adjacent advances both west of station 9,000 and into Lynnhaven Inlet. The large spit that grew inside Lynnhaven Inlet is and was the result of channel dredging and consequent sediment disposal. Some of the dredged sand was placed on the Ocean Park coast causing the shoreline advance of 2002. A beach nourishment project also was undertaken in 1987 at Ocean Park, but the sand addition was not captured by the shore change analysis. Dune sites VB9 and VB10 are the erosional remnants of a more extensive beach dune system that existed in 1937. Some development can be seen in 1960, but extensive development occurs between VB9 and VB10 by 1976. The 1970 shoreline was not included in the rate of change analysis since it only covered a small portion of the plate.

Plate 4 includes dune sites VB11, VB12, VB13, VB15A, VB15B and part of VB15C. The shoreline trend of this plate has been erosional between 1960 and 1976 except for a small area between stations 6,500 and 7,500 where a slight advance occurred. Dune site VB11 is separated from VB12 by a single bulkheaded lot. The same exists for the boundaries between VB12 and VB13. VB13 and VB15 are part of the Little Creek Naval Amphibious Base (NAB). VB15 is actually a continuous beach/dune feature with three slightly different shore morphologies. It is bounded on the east by a stone revetment and on the west by the Enlisted Beach parking lot. The area from station 3,500 to 5,000 has been impacted by groins, breakwaters and revetments

since 1994. The shore was erosional between 1994 and 2002 from stations 5,000 to about station 9,000. Beyond station 9,000, the shore had been accretionary since 1970 because the littoral transport was interrupted when a large groin was installed sometime between 1970 and 1976 and beach nourishment was placed along the shore. Large rubble groins were installed in the early 1970s at stations approximately stations 3,000, 4,000, 4,500 and 9,800. Shore offsets on the west side and advances on the east side indicate net alongshore sand movement to the west.

The shorelines on Plate 5 surrounding Little Creek Inlet have a long history of anthropogenic impacts. The Inlet jetties were completed between 1926 and 1928, and since then, the entrance channel has been dredged many times. The material from this dredging and that of the channel at Little Creek ferry terminal has been placed on both sides of the inlet and in the nearshore (Hardaway *et al.*, 1997). Known dredging and subsequent placement on the military's shoreline took place in 1951 (300,000 cy) and 1975 (805,000 cy). The shorelines of Plate 5 show a linear retreating shoreline except between 1970 and 1976. No "typical" primary dune features exist between stations 0 to 4,500 because of the long term history of amphibious operations across the beach and backshore region. Therefore, mostly isolated dune hummocks occur in that region.

## V. DISCUSSION: NEAR FUTURE TRENDS OF DUNE SITES

The following discussion is a delineation of shoreline trends based on past performance. Ongoing shore development, shore stabilization and/or beach fill, and storms will have local impacts on the near term. “Near Future” is quite subjective and only implies a reasonable expectation for a given shore reach to continue on its historic course for the next 10 to 20 years. In addition, the basis for the predictions are the shorelines digitized on geo-rectified aerial photography which have an error associated with them (see Methods, Section III). Each site’s long-term and recent stability as well as a near future prediction are shown in a table in [Appendix B](#). **This data is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.**

### A. Reach I

Shoreline advances at and west of Cape Henry are historically significant. One factor that may have played a role has been ongoing beach nourishment project at the Virginia Beach resort area several miles down the coast from Cape Henry. This area has had beach fill and sand bypassing operations in effect to one degree or another since the mid-1950s whereby several million cubic yards of sand have been placed in the littoral system whose net transport is to the north toward and around Cape Henry. The effect along the coast of Reach I is an ongoing advance of the coast resulting in the primary dune becoming the secondary dune and subsequently the tertiary dune over time. The dune sites VB4A and VB4B at First Landing State Park exhibit this trend as they are natural dunes with little or no development ([Figure 7](#)).

The dune system west of First Landing State Park, VB4C, has been extensively developed, but the primary dune feature was not significantly impacted. It is only the area further west where condominiums were built on the primary dune that the dune is severely impacted. Many shoreline condos were bulkheaded as the beach narrowed and the dune disappeared thereby losing the natural protection the dune offered. This section of coast between station 5,000 and 9,000 was historically slightly erosional but as one proceeds further west toward Lynnhaven Inlet, an accretionary trend evolves and the condos there enjoy a wide beach and stable dune (*i.e.* VB6).

### B. Reach II

Lynnhaven Inlet has been dredged numerous times, and the sandy dredge material has been deposited in various places including along the Bay shore at Ocean Park and inside the Inlet along its west shore. The Bay shore disposal of dredge material temporarily increases the beach width and provides a source of sand to the westward moving littoral system. The shoreline from Lynnhaven Inlet to Little Creek Inlet was once a continuous beach/dune coast. Development over time has segmented the dunes.

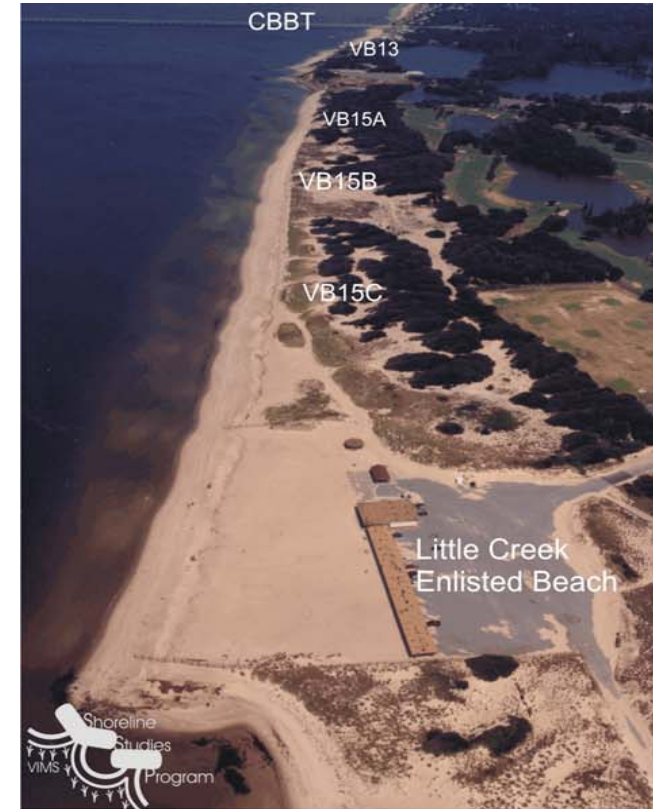
The Ocean Park shoreline (Plate 3) is mostly bulkhead from station 500 to about station 2,700 and the beach is generally narrow with no dune. From Ocean Park to about station 9,000, dune sites VB9 and VB10 are separated by a single bulkheaded lot. This area seems relatively stable and may be supported by the beach nourishment at Ocean Park over time. However, scarping of the dune face seems to be a chronic condition.

Bulkheading is again encountered east of the Chesapeake Bay Bridge Tunnel. Further west, VB11 and VB12 exist partially bounded by the bulkheads to the east and a protruding bulkheaded lot at station 2,700 on the west. These dunes appear to be relatively stable at this point in time.

The shoreline at dune site VB13 ([Figure 8](#)) has migrated east and west between the rubble groin on the Little Creek NAB boundary and the groins and breakwaters at the Officer’s Club Beach (Station 4,000). This trend is likely to continue. The beach/dune along VB15 has 3 morphologic subreaches, A, B and C. VB15A is erosional as the shoreline migrates landward, partially in response to the shore structures installed at the Officer’s Club beach over the past 20 years. The combination of groins, breakwaters and large revetments have created a headland feature that is now working in combination with the large rubble groin at the Enlisted Beach to create a long curvilinear embayed coast. VB15B is a transitional area ([Figure 8](#)), and VB15C has accreted to its maximum extent and is now relatively stable. VB15A will continue to recede toward equilibrium which could take 20 years or more unless the Navy intervenes with additional structures.



Looking east toward the mouth of the Bay on 24 October 2004.



Looking east toward the Chesapeake Bay Bridge Tunnel on 12 June 2002.

At dune site VB4A looking east toward the mouth of the Bay on 22 Dec 2004.



At dune site VB13 looking east toward the CBBT on 19 June 2002.



At dune site VB4B looking west toward dune site VB4C on 22 Dec 2004.



At dune site VB15B looking east toward dune site VB15A and the CBBT on 19 June 2002.



Figure 7. Photos of the Virginia Beach shoreline showing dune sites VB4A, VB4B and VB4C.

Figure 8. Photos of the Virginia Beach shoreline showing dune sites VB13, VB15A, VB15B and VB15C.

## VI. SUMMARY

The Chesapeake Bay coast of the City of Virginia Beach is very dynamic in terms of shoreline change and sediment transport processes. The overall net movement of sands along the coast is to the west, due in part, to the impacts of oceanic swell. Virginia Beach coast is rich in sand along the shoreline and nearshore due to transport into the Bay's mouth. The complex series of offshore sand bars migrate through time and influence the rate and patterns of shoreline change. Shoreline change is often accretionary which leads to the development of extensive modern dune fields like the ones at First Landing State Park. Table 2 is a summary of the shoreline change average for each plate. The long-term net (1937-2002) trend for Reach I is accretionary while Reach II is mostly erosional.

Shoreline change rates are based on aerial imagery taken at a particular point in time. We have attempted to portray the same shoreline feature for each date along the coast of the City of Virginia Beach. Every 500 feet along each baseline on each plate, the rate of change was calculated. The mean or average rate for each plate is shown in Tables 2 and 3 for seven time periods with the long-term rate determined between 1937 and 2002. The total average and standard deviation (Std Dev) for the entire data set of individual rates is also given. The standard deviation shows the relative spread of values about the mean or average. Larger standard deviation values relative to the mean indicates a wider scatter of erosion rates about the mean while lower standard deviation values indicates erosion rates are concentrated near the mean (*i.e.* all the rates calculated for the entire plate were similar). The largest variability in mean shore change rates and standard deviations were recorded for the shoreline on Plate 3. For instance, between 1976 and 1980, the standard deviation is nearly double the average rate of change indicating that the overall rate is probably not indicative of the change which occurred on this section of shore. However, not all of the dates for this section of shore had mean shore change rates with large standard deviations. For the period between 1980 and 1994, the mean shore change rate and the standard deviation were the same, indicating that the shore change rates were relatively consistent for that time period. When short time frames are used to determine rates of shoreline change, shore alterations may seem amplified. The rates based on short-time frames can modify the overall net rates of change.

Table 2. Summary shoreline rates of change and their standard deviation for Reach 1.

Plate No.	Mean Shore Change 1937-1960		Mean Shore Change 1960-1970		Mean Shore Change 1970-1976		Mean Shore Change 1976-1980		Mean Shore Change 1980-1994		Mean Shore Change 1994-2002		Mean Shore Change 1937-2002	
	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)
<b>Plate 1</b>	2.2	3.3	12.6	6.9	-7.6	4.9	14.7	8.5	10.2	7.6	1.1	3.8	5.2	3.7
<b>Plate 2</b>	3.0	4.6	2.8	6.0	-4.8	7.7	9.4	5.1	2.5	3.2	-0.2	4.9	2.2	2.4
<b>Total</b>	<b>2.6</b>	<b>4.0</b>	<b>7.5</b>	<b>8.1</b>	<b>-6.1</b>	<b>6.6</b>	<b>11.9</b>	<b>7.4</b>	<b>6.2</b>	<b>6.9</b>	<b>0.4</b>	<b>4.4</b>	<b>3.6</b>	<b>3.4</b>

Table 3. Summary shoreline rates of change and their standard deviation for Reach 2.

Plate No.	Mean Shore Change 1937-1960		Mean Shore Change 1960-1970		Mean Shore Change 1970-1976		Mean Shore Change 1976-1980		Mean Shore Change 1980-1994		Mean Shore Change 1994-2002		Mean Shore Change 1937-2002	
	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)	Mean Shore Change (ft/yr)	Std Dev (ft/yr)
<b>Plate 3</b>	-3.4	2.4	7.0*	8.1*			4.9	8.7	-1.9	1.9	2.2	8.1	0.7	1.4
<b>Plate 4</b>			-10.2	3.3	8.8	7.4	2.6	10.9	-0.2	3.1	-3.0	3.5	-1.9	2.3
<b>Plate 5</b>			-8.6	1.5	22.1	6.1	-4.4	13.2	-4.2	2.7	-0.5	3.0	-0.8	1.6
<b>Total</b>	<b>-3.4</b>	<b>2.4</b>	<b>-4.3</b>	<b>11.7</b>	<b>9.8</b>	<b>16.1</b>	<b>2.0</b>	<b>11.0</b>	<b>-1.8</b>	<b>2.9</b>	<b>-0.3</b>	<b>6.2</b>	<b>-0.8<sup>^</sup></b>	<b>2.1<sup>^</sup></b>

<sup>^</sup>Long-term rates for Plates 4 and 5 calculated using the 1960-2002 Mean Shore Change Data.

\*Represents 1960-1976 Mean Shore Change Data for Plate 3.

Developed shoreline areas are increasing in size and scope. They have segmented the once continuous dune/beach coasts from Cape Henry to Lynnhaven Inlet (Reach I) and from Lynnhaven Inlet to Little Creek Inlet (Reach II). Hopefully, the shore change patterns shown in this report along with the aerial imagery will indicate how the coast will evolve based on past trends and can be used to provide the basis for appropriate shoreline management plans and strategies. Dunes and beaches are a valuable resource that should be either maintained, enhanced or created in order to abate shoreline erosion.



## VII. REFERENCES

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## Acknowledgments

The authors would like to thank Dr. Carl Hobbs for his critical review and editorial suggestions that made this a better report, Katherine Farnsworth for her work on developing the original methodology for determining shoreline change and updating our custom ArcView "shoreline" extension, Sharon Killeen with the Comprehensive Coastal Inventory at VIMS for her early work in digitizing the shoreline, and the personnel in VIMS' Publications Center, particularly Susan Stein, Ruth Hershner, and Sylvia Motley, for their work in printing and compiling the final report.

## APPENDIX A

For each Plate shown on [Figure 4](#) (Page 5), Appendix A contains orthorectified aerial photography flown in 1937, 1960, 1970, 1976, 1980, 1994, and 2002. Also shown are the digitized shorelines, identified dune sites, and an arbitrarily created baseline. Another copy of the recent photo depicts the relationship of historical shorelines to the present. Finally, a plot shows only the relative locations of the shorelines while another one depicts the rate of shore change between dates. A summary of the average Plate rate of change in ft/yr as well as the standard deviation for each rate is also shown.

**This data is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.**

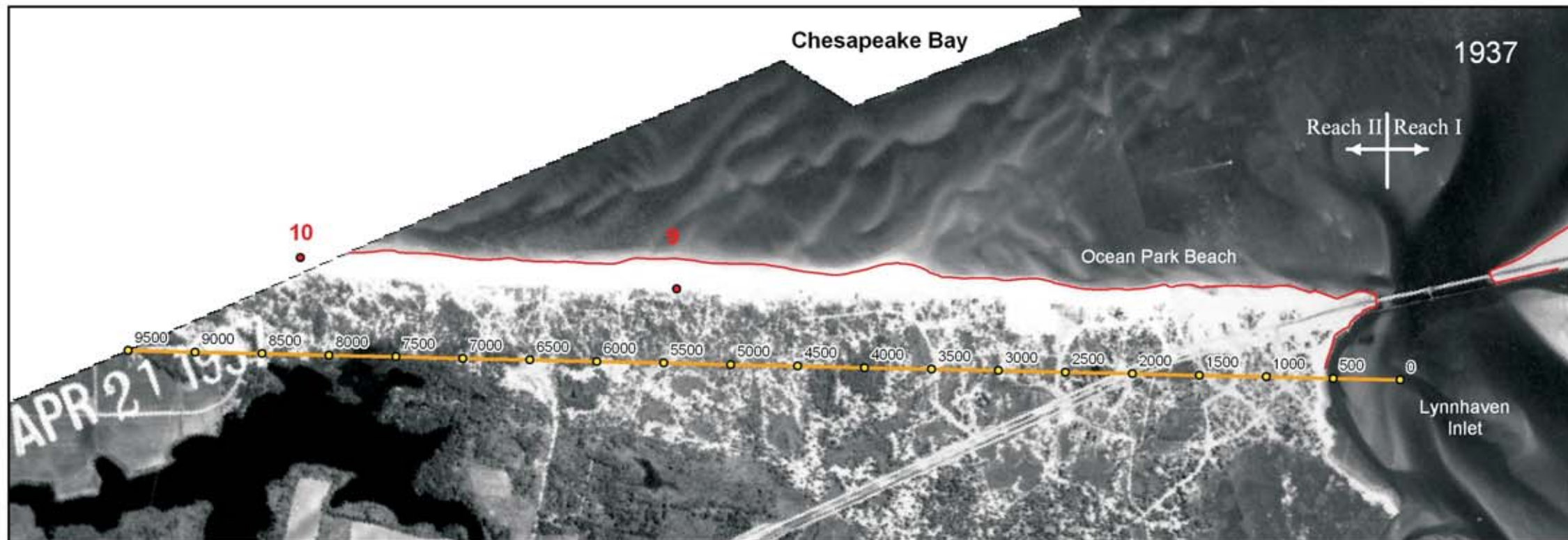
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Plate 1 - 1970 & 1976  
Plate 1 - 1980 & 1994  
Plate 1 - 2002  
Plate 1 - Shoreline Change

Plate 2 - 1937 & 1960  
Plate 2 - 1970 & 1976  
Plate 2 - 1980 & 1994  
Plate 2 - 2002  
Plate 2 - Shoreline Change

Plate 3 - 1937 & 1960  
Plate 3 - 1970 & 1976  
Plate 3 - 1980 & 1994  
Plate 3 - 2002  
Plate 3 - Shoreline Change

Plate 4 - 1960  
Plate 4 - 1970 & 1976  
Plate 4 - 1980 & 1994  
Plate 4 - 2002  
Plate 4 - Shoreline Change

Plate 5 - 1960  
Plate 5 - 1970 & 1976  
Plate 5 - 1980 & 1994  
Plate 5 - 2002  
Plate 5 - Shoreline Change



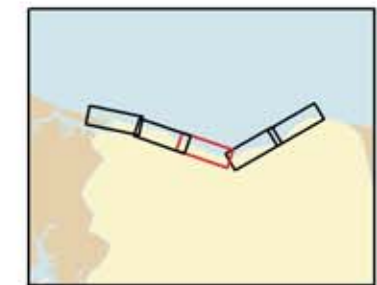
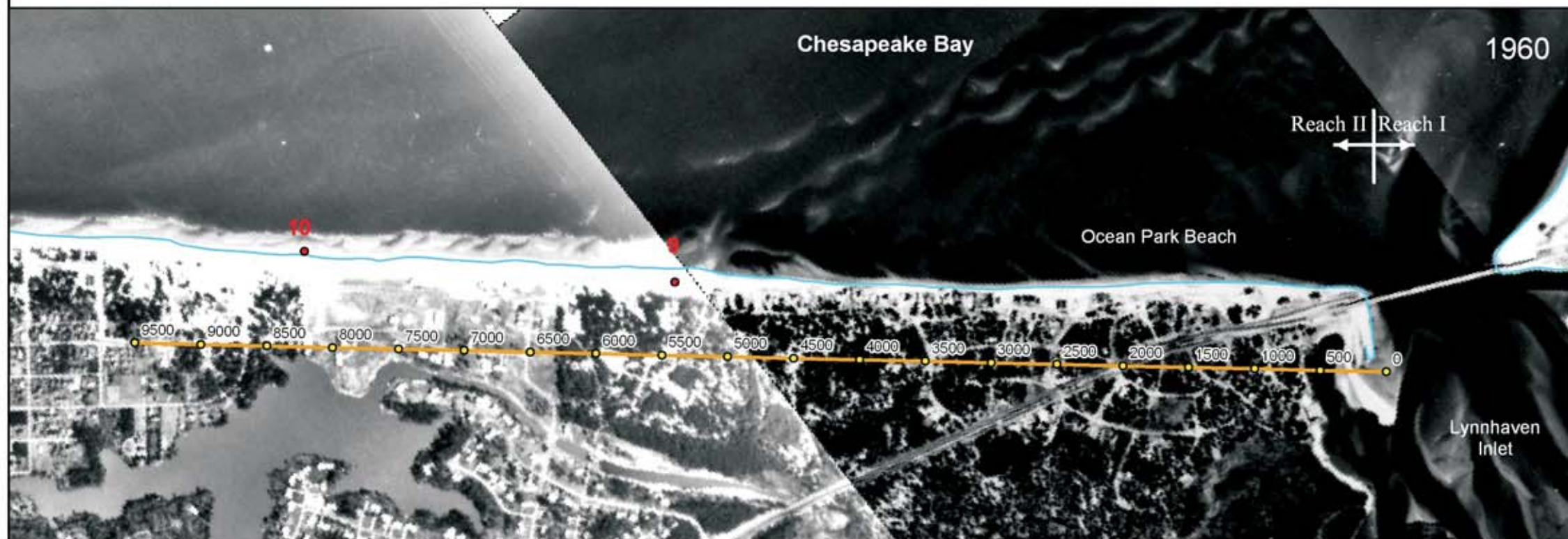
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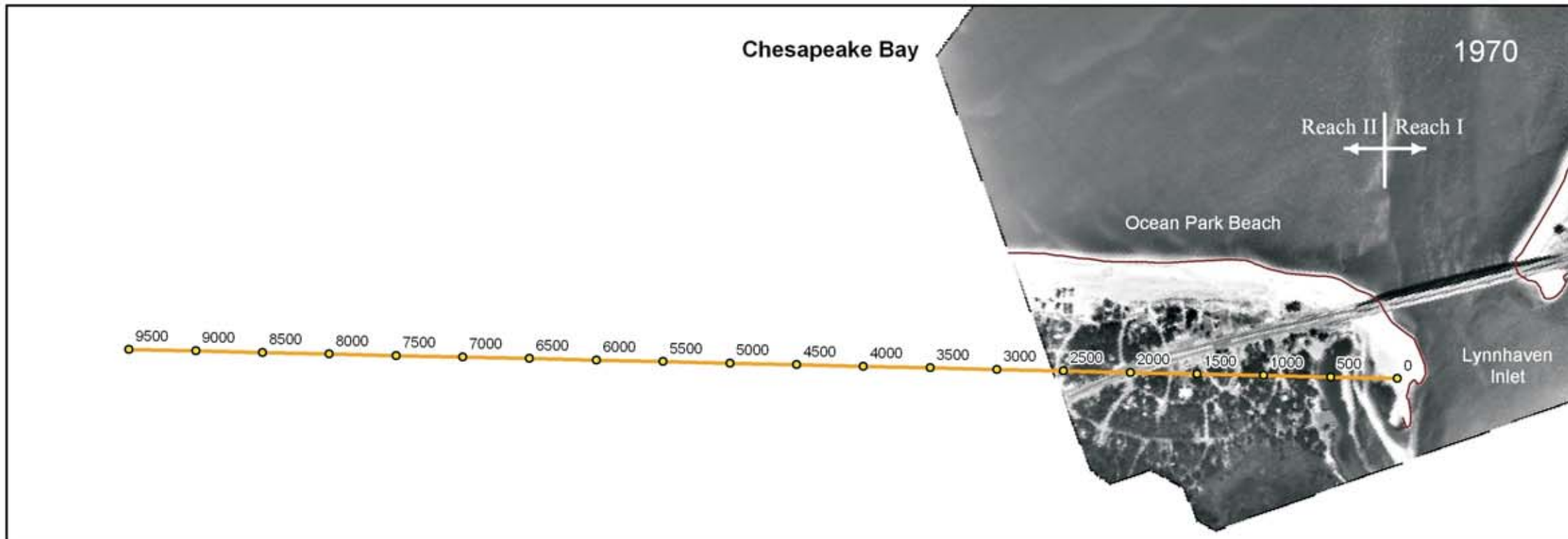
## Plate 3

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline





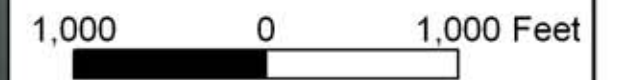
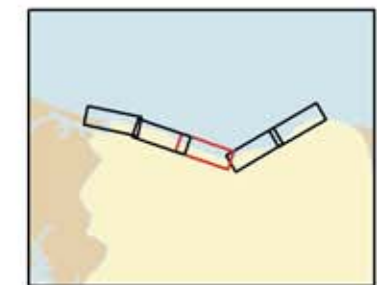
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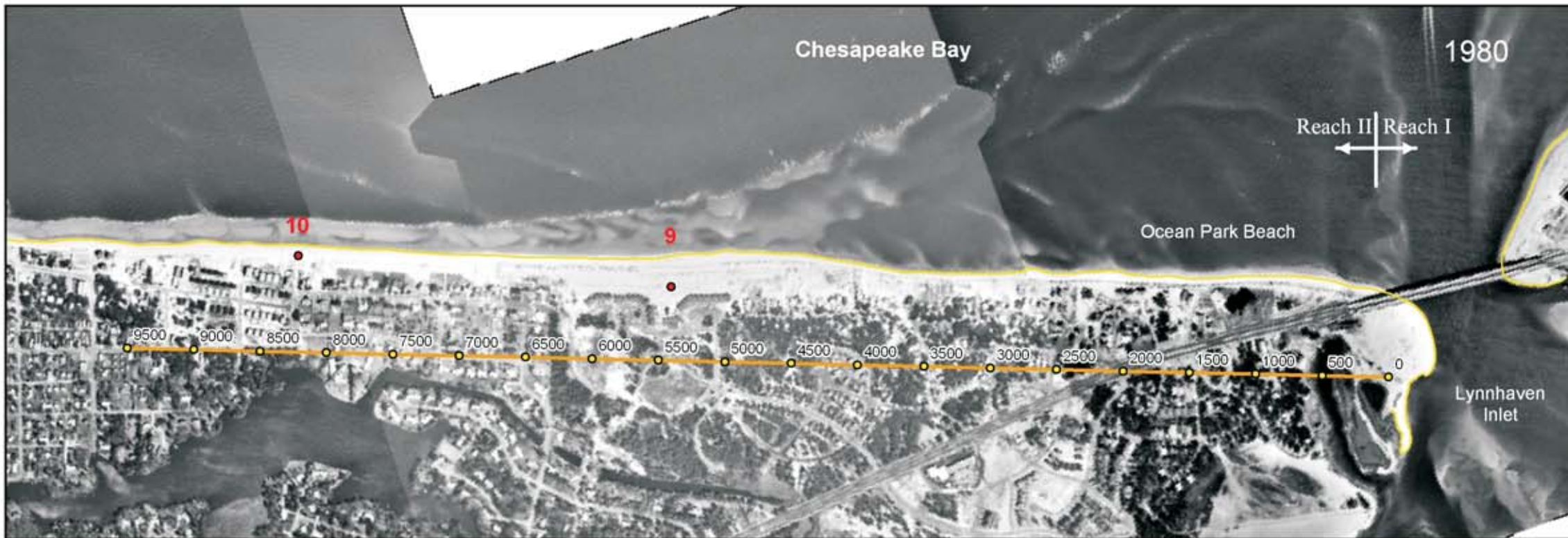
## Plate 3

Morphological Reach II  
Lynnhaven Inlet to Little Creek

**Legend**

- Identified Dune Sites
- Transect Points
- Baseline
- 1970 Shoreline
- 1976 Shoreline





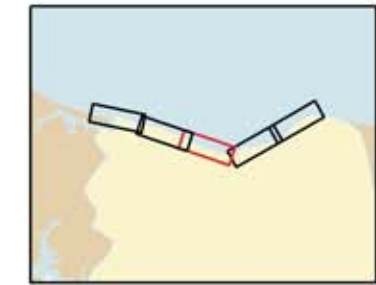
# City of Virginia Beach

## Plate 3

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1980 Shoreline
- 1994 Shoreline



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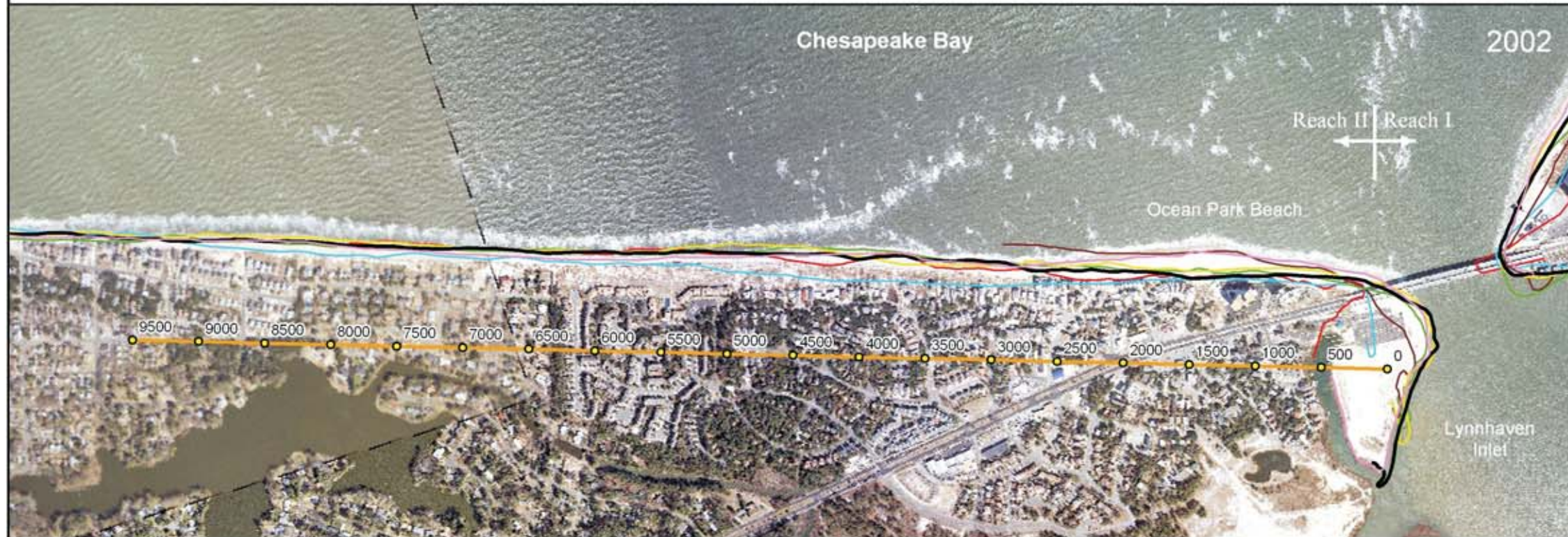
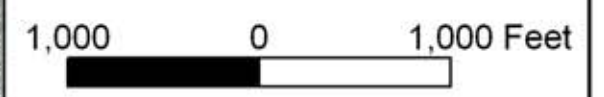
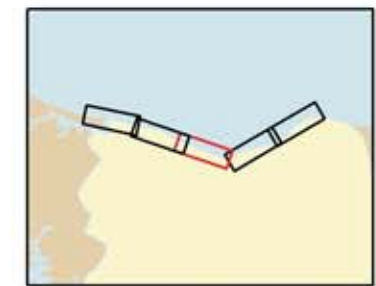


# City of Virginia Beach

## Plate 3 Morphological Reach II Lynnhaven Inlet to Little Creek

**Legend**

- Identified Dune Sites
- Dune Site Limits
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



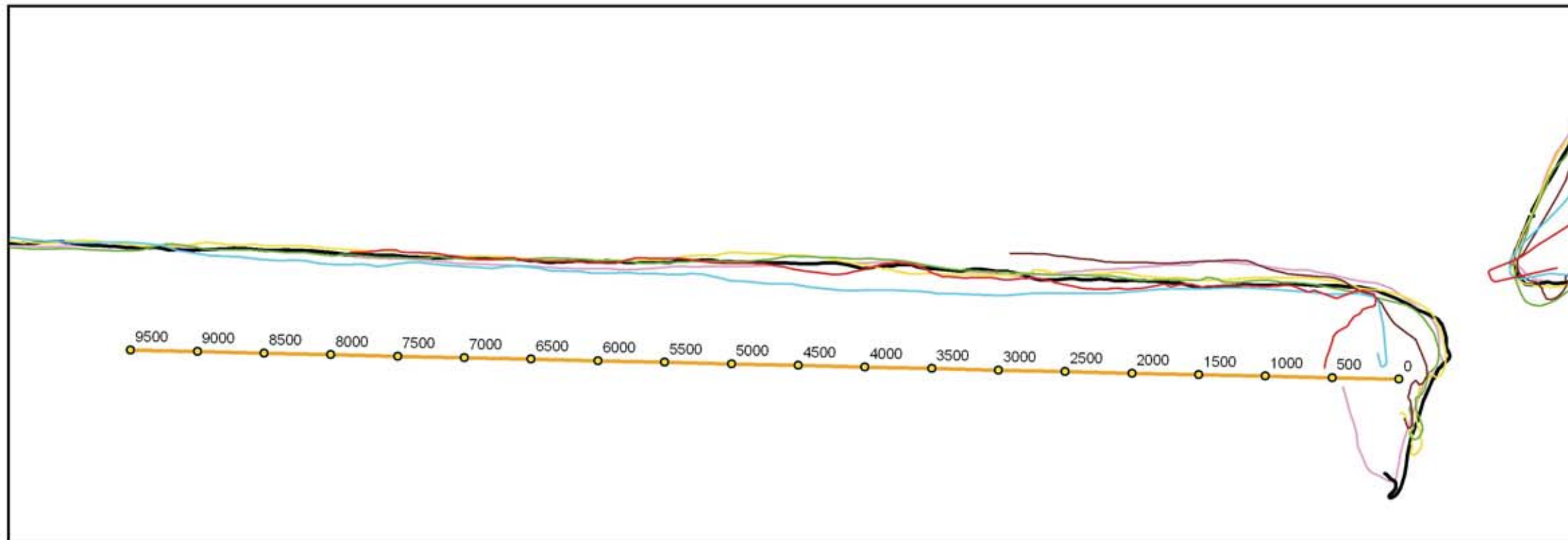
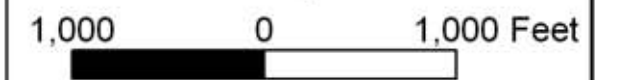
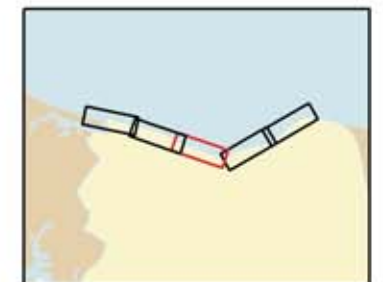
# City of Virginia Beach

## Plate 3

Morphological Reach II  
Lynnhaven Inlet to Little Creek

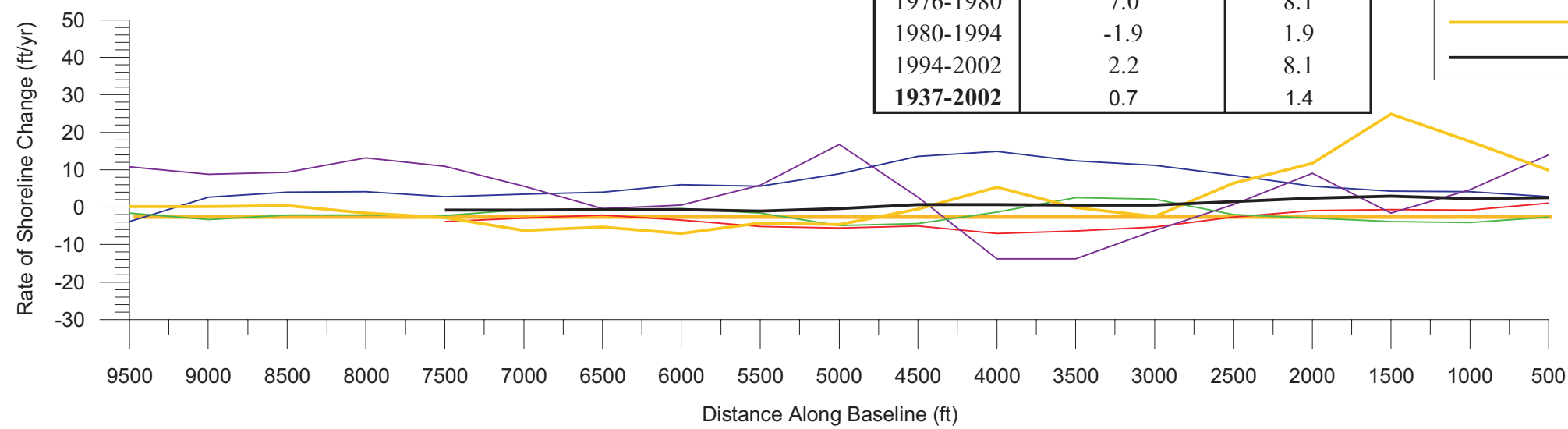
### Legend

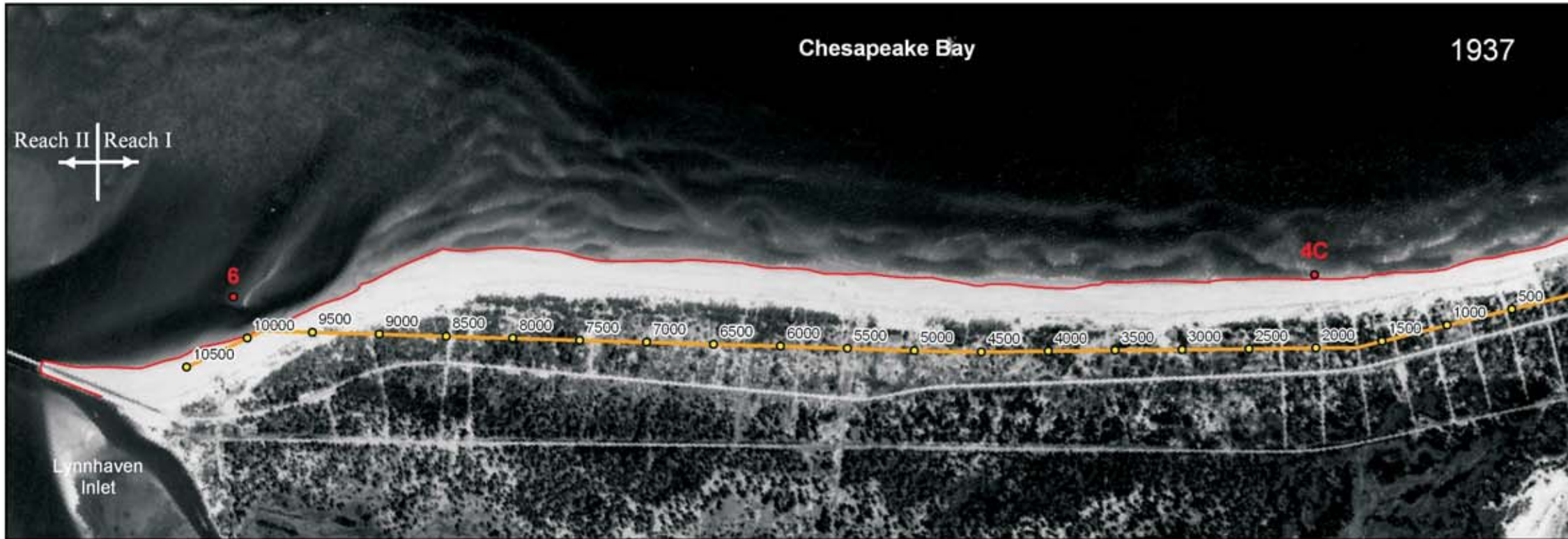
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



Imagery Dates	Average Rate of Change (ft/yr)	Standard Deviation
1937-1960	-3.4	2.4
1960-1976	19.4	5.9
1976-1980	7.0	8.1
1980-1994	-1.9	1.9
1994-2002	2.2	8.1
<b>1937-2002</b>	<b>0.7</b>	<b>1.4</b>

- 1937-1960
- 1960-1976
- 1976-1980
- 1980-1994
- 1994-2002
- 1937-2002



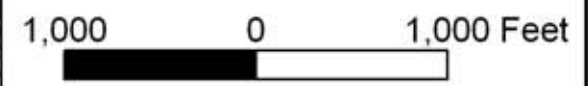
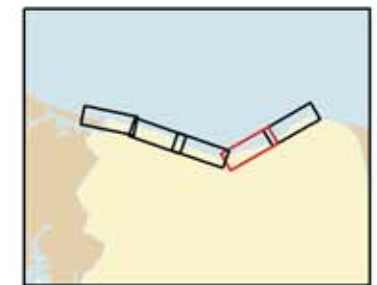
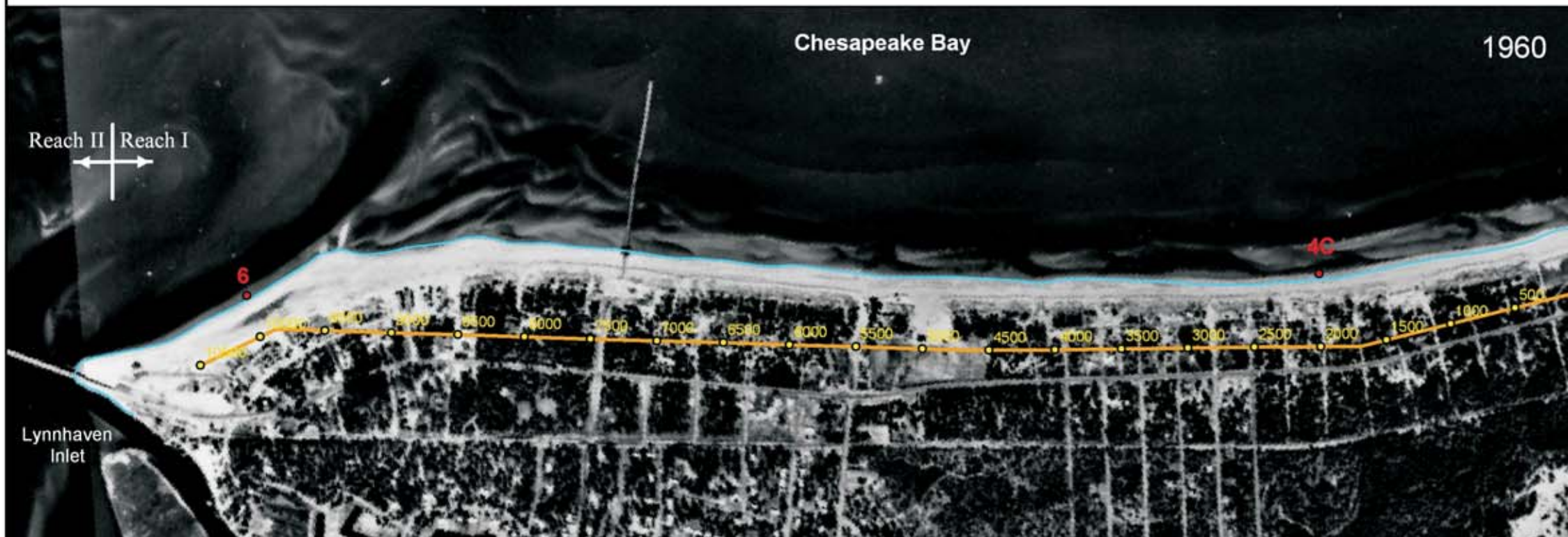


## City of Virginia Beach Plate 2

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline







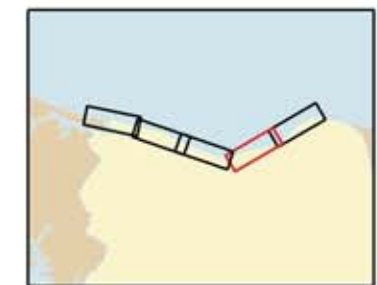
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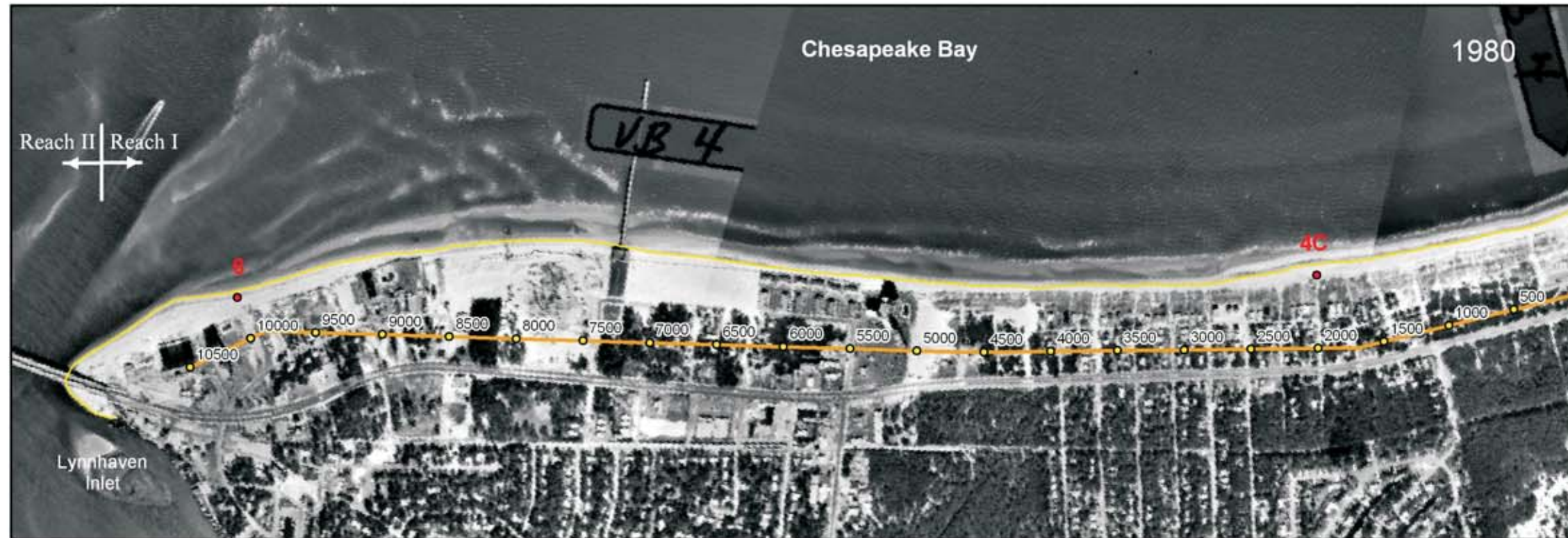
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Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1970 Shoreline
- 1976 Shoreline





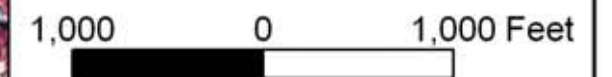
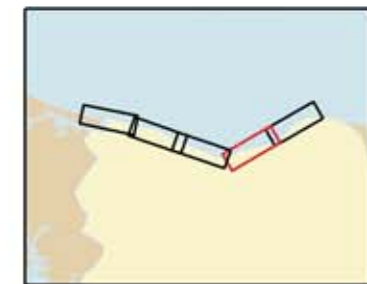
# City of Virginia Beach

## Plate 2

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1980 Shoreline
- 1994 Shoreline





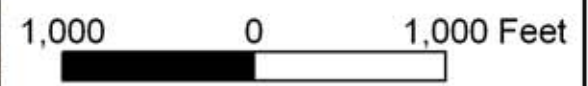
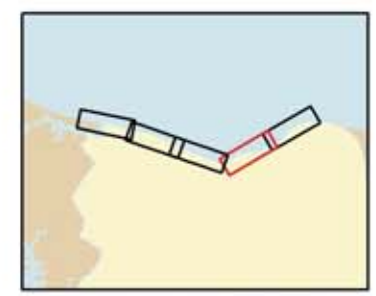
# City of Virginia Beach

## Plate 2

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Identified Dune Sites
- Dune Site Limits
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



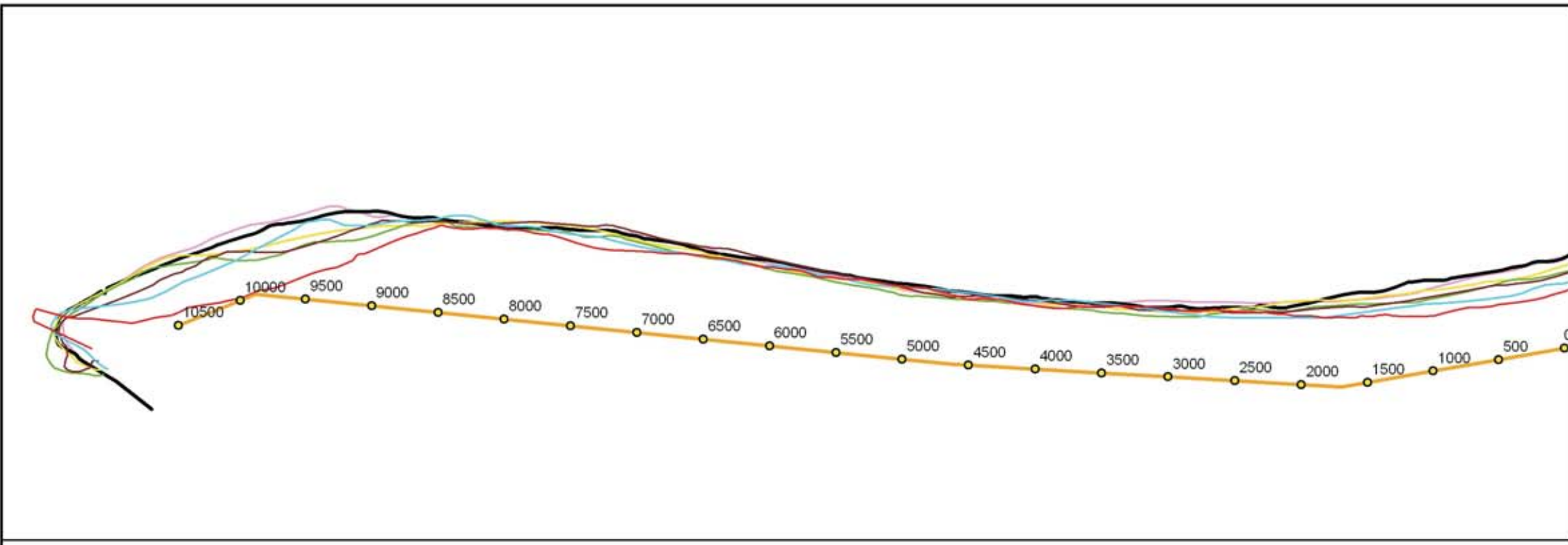
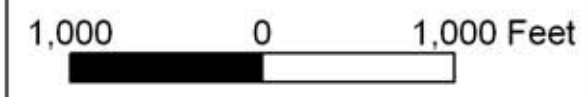
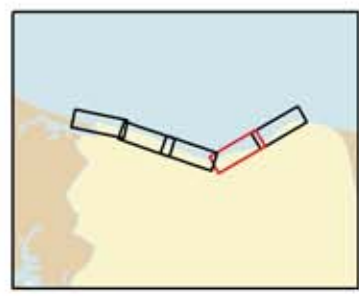
# City of Virginia Beach

## Plate 2

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

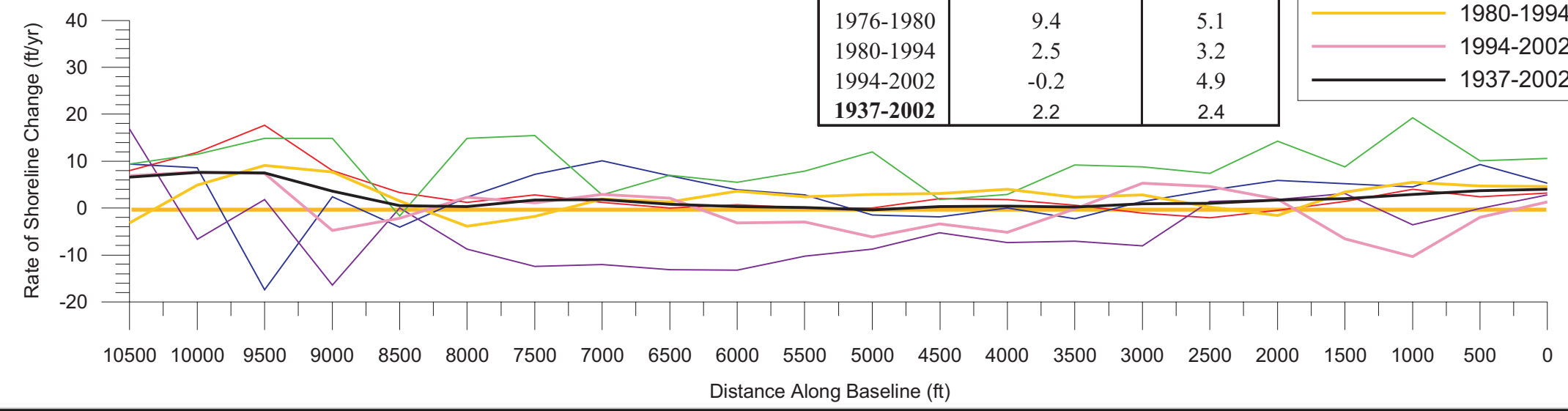
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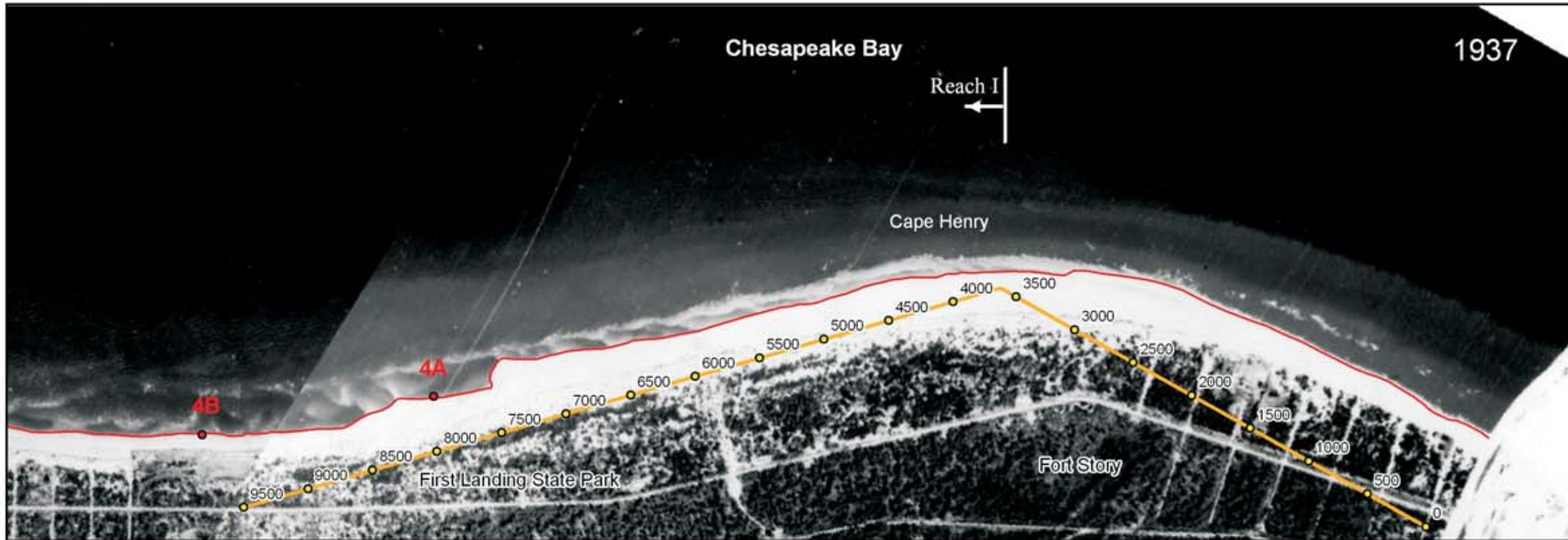
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



Imagery Dates	Average Rate of Change (ft/yr)	Standard Deviation
1937-1960	3.0	4.6
1960-1970	2.8	6.0
1970-1976	-4.8	7.7
1976-1980	9.4	5.1
1980-1994	2.5	3.2
1994-2002	-0.2	4.9
<b>1937-2002</b>	<b>2.2</b>	<b>2.4</b>

- 1937-1960
- 1960-1970
- 1970-1976
- 1976-1980
- 1980-1994
- 1994-2002
- 1937-2002





1937

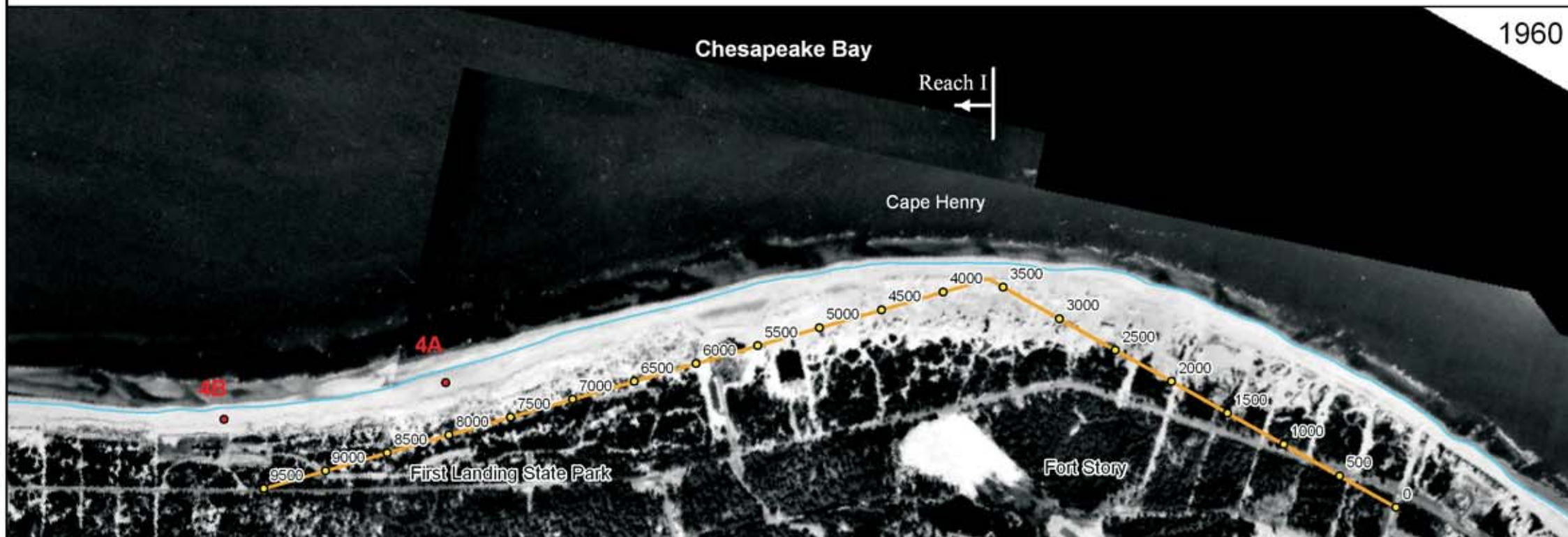
# City of Virginia Beach

## Plate 1

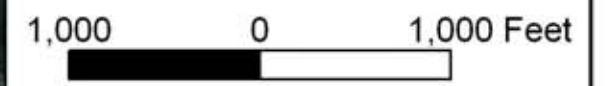
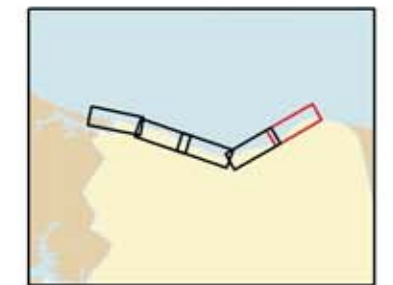
Morphological Reach I  
Cape Henry to Lynnhaven Inlet

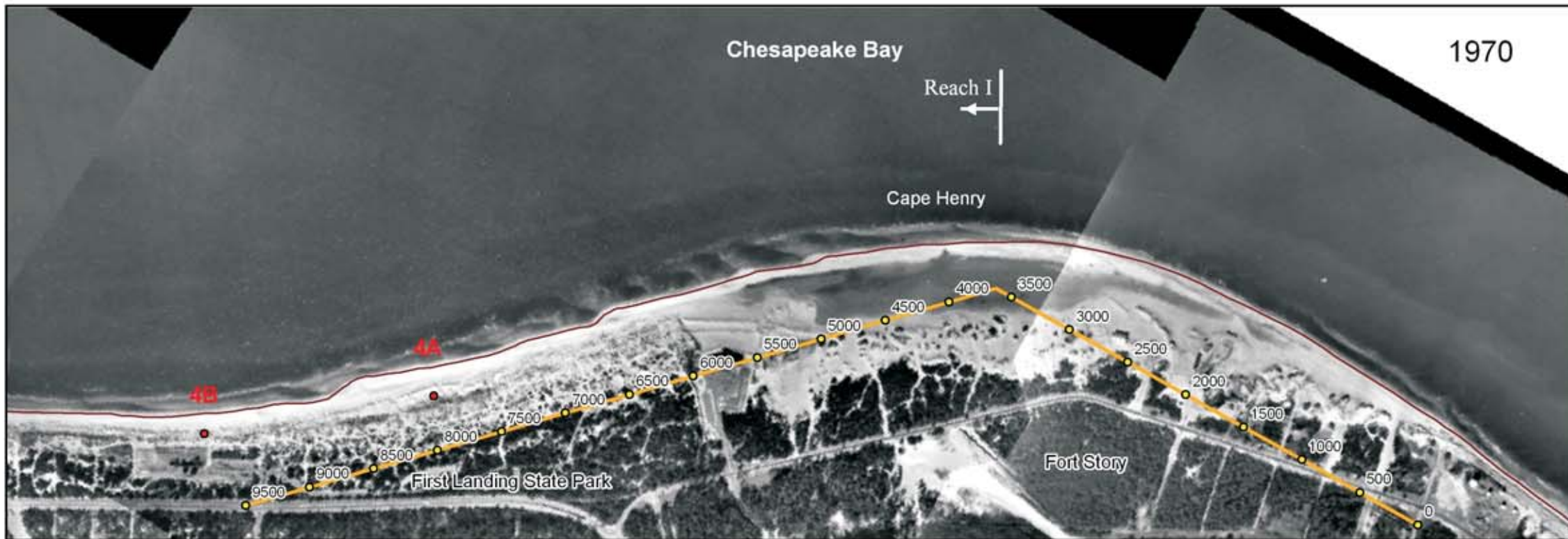
**Legend**

- Identified Dune Sites
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline



1960



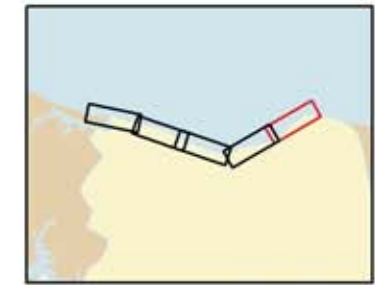
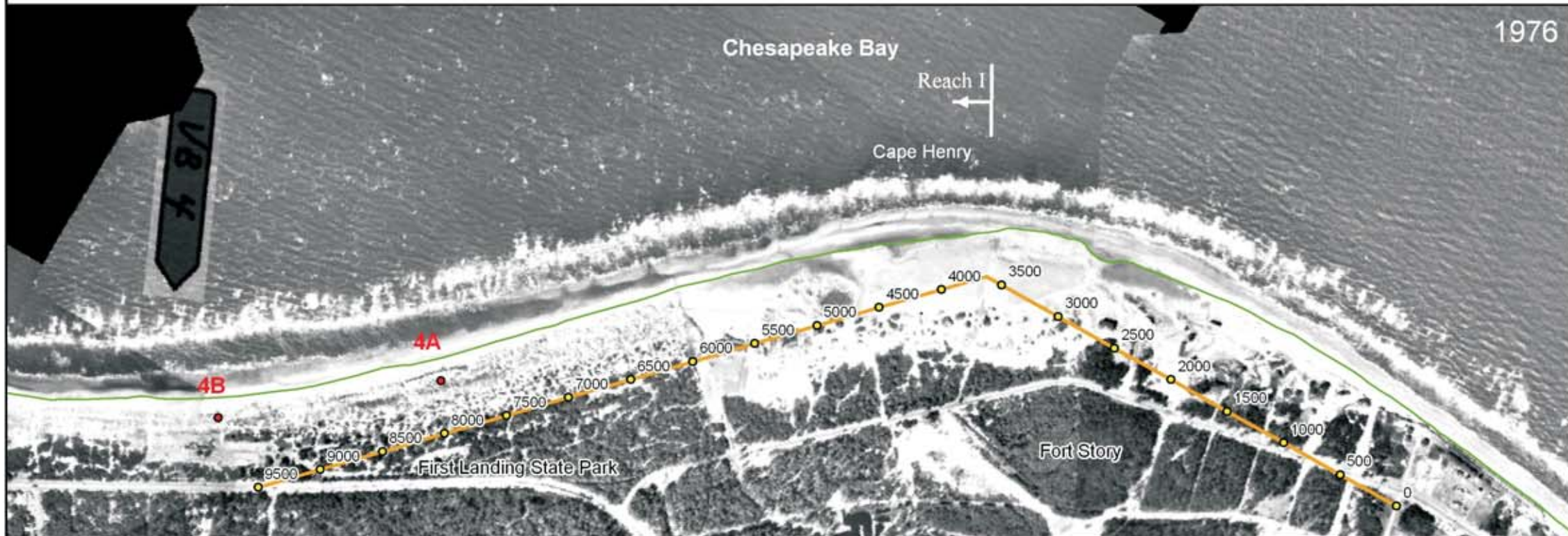


# City of Virginia Beach

## Plate 1 Morphological Reach I Cape Henry to Lynnhaven Inlet

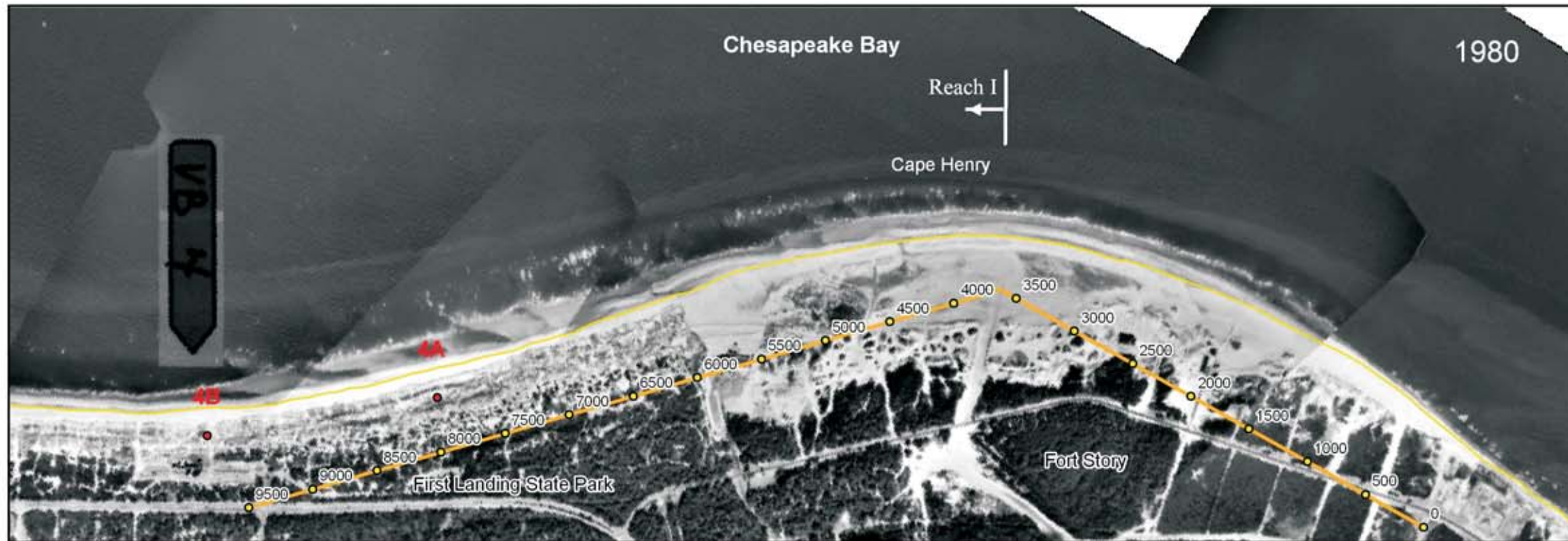
**Legend**

- Identified Dune Sites
- Transect Points
- Baseline
- 1970 Shoreline
- 1976 Shoreline



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1,000 0 1,000 Feet



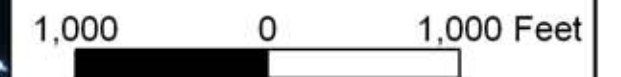
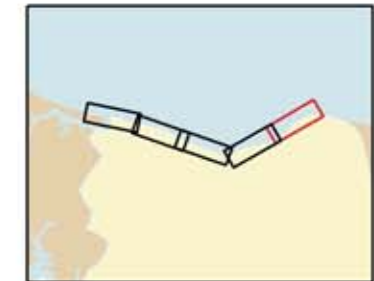
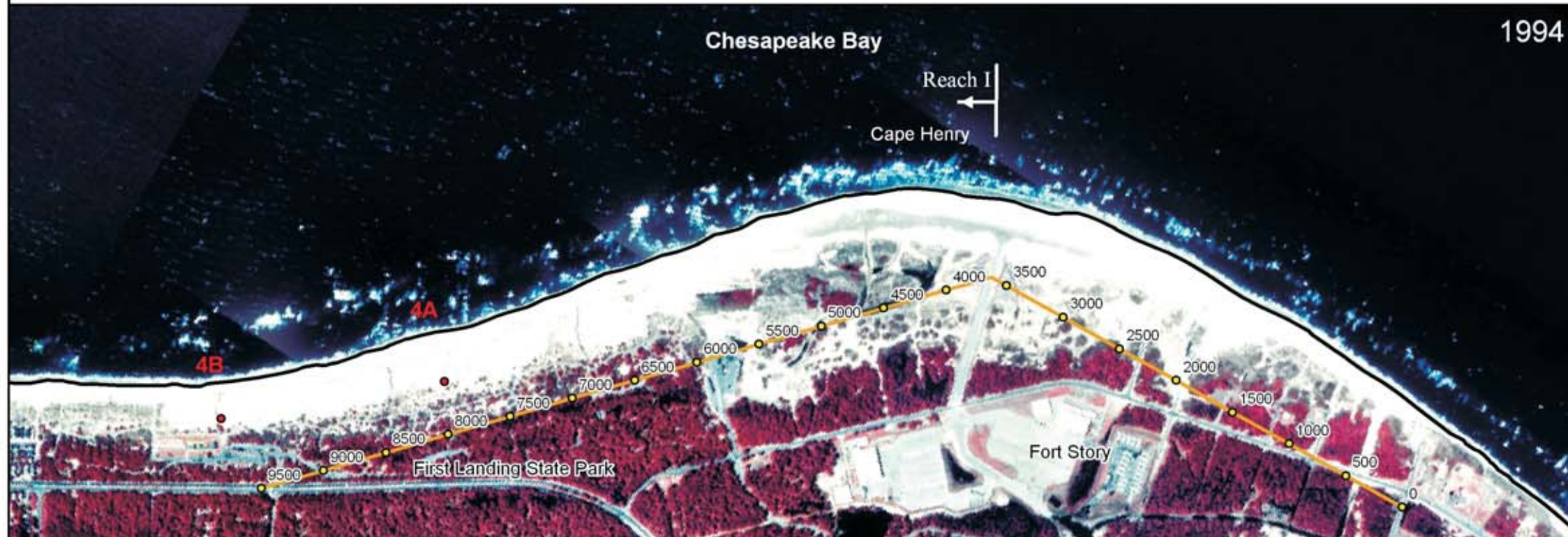
# City of Virginia Beach

## Plate 1

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1980 Shoreline
- 1994 Shoreline





2002

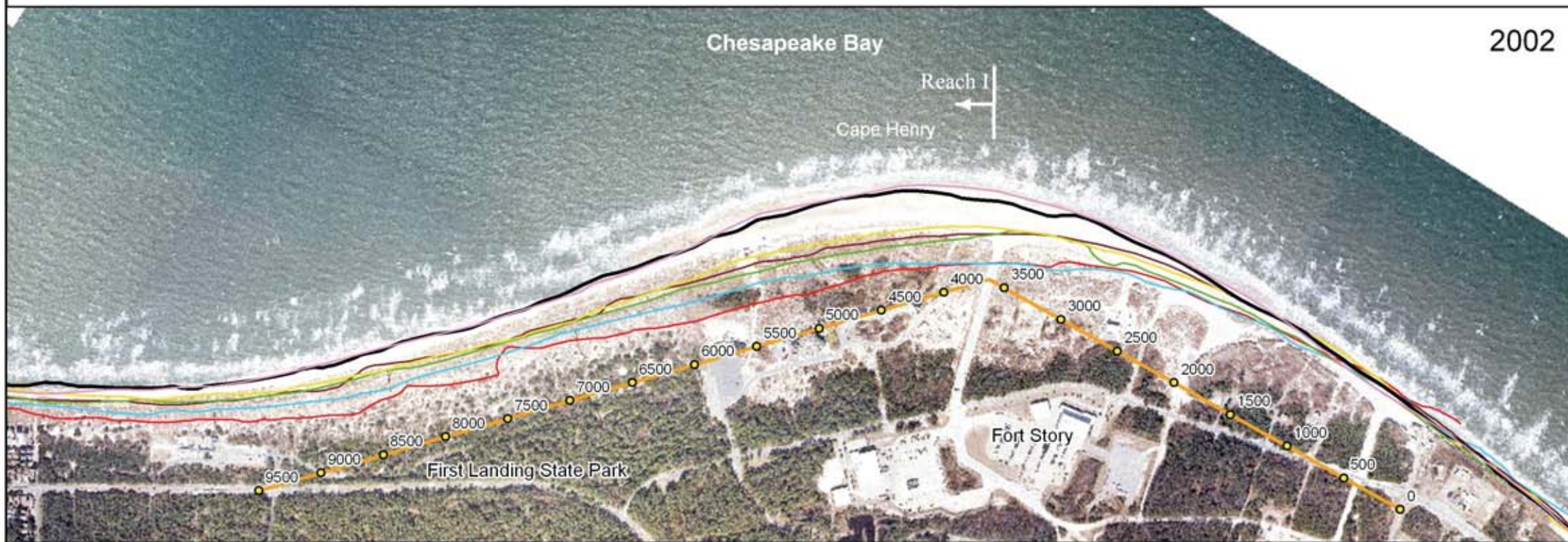
# City of Virginia Beach

## Plate 1

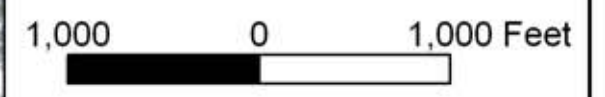
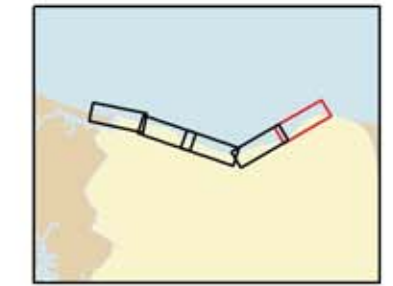
Morphological Reach I  
Cape Henry to Lynnhaven Inlet

**Legend**

- Identified Dune Sites
- ☐ Dune Site Limits
- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



2002





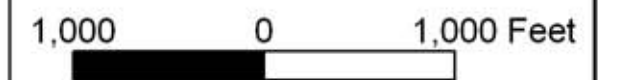
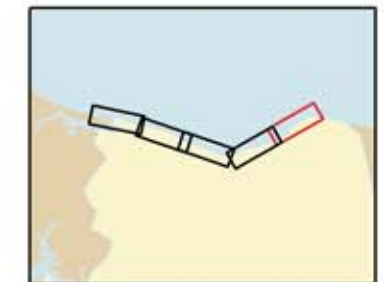
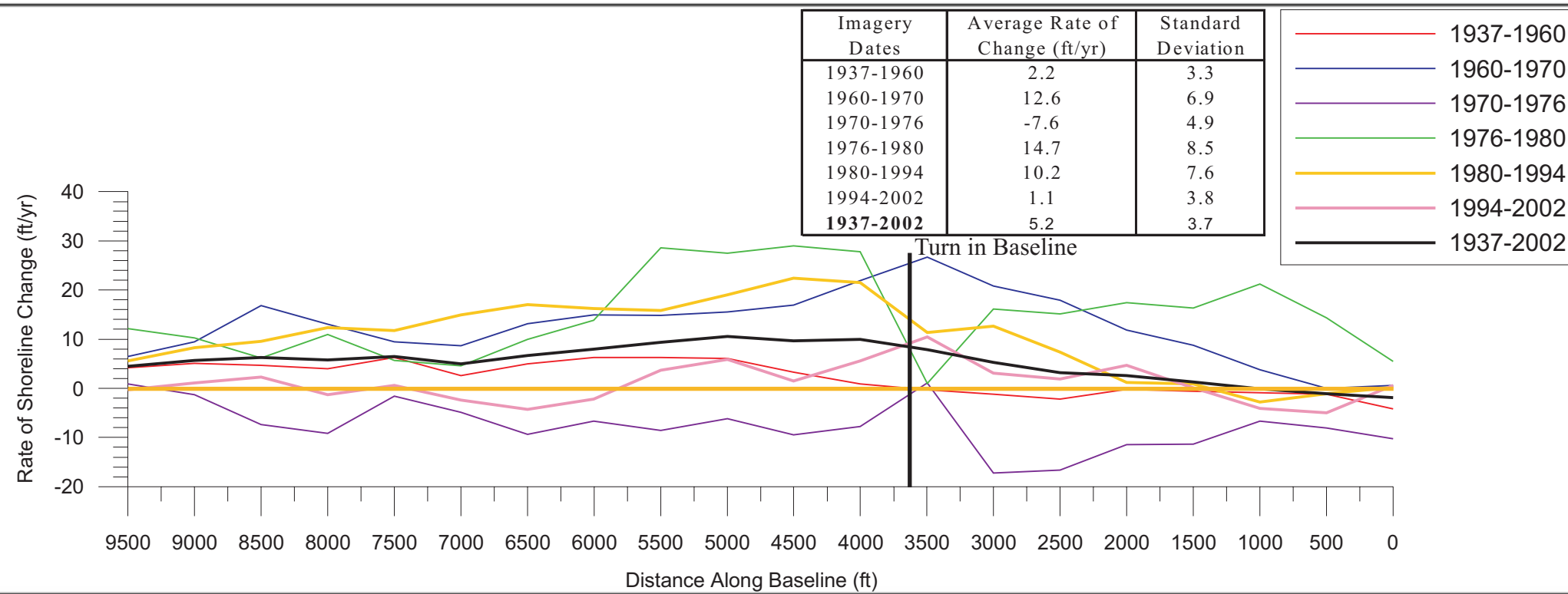
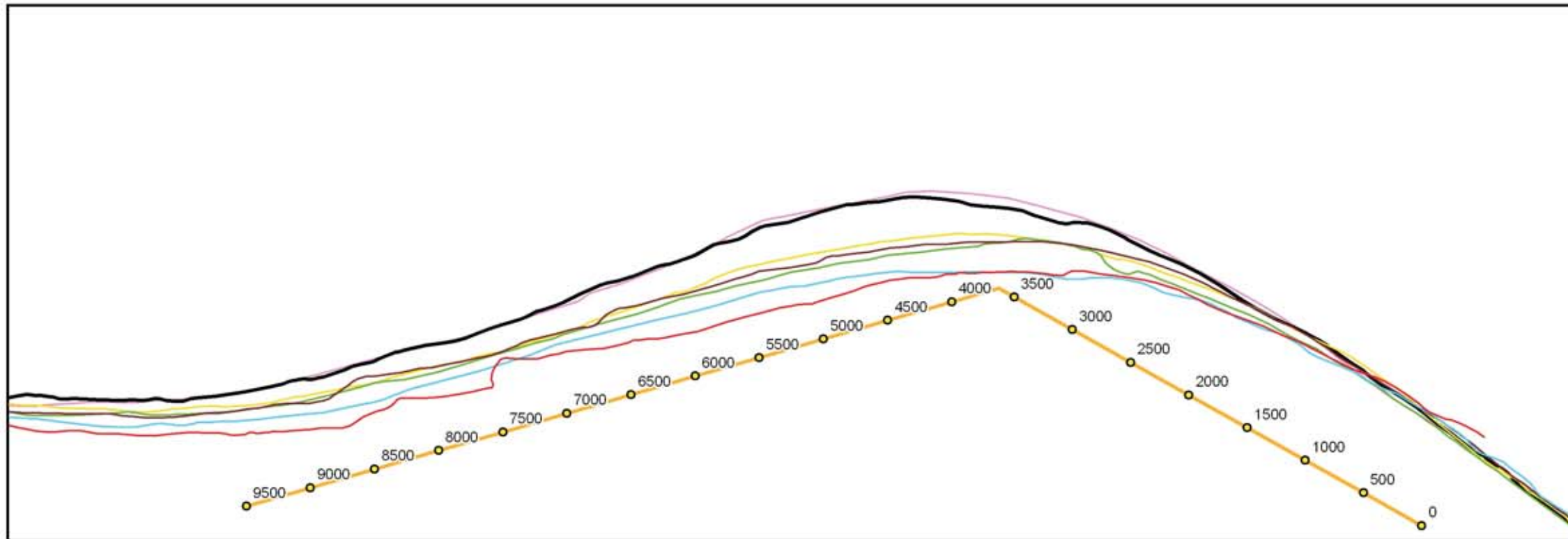
# City of Virginia Beach

## Plate 1

Morphological Reach I  
Cape Henry to Lynnhaven Inlet

### Legend

- Transect Points
- Baseline
- 1937 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



Chesapeake Bay

1937

No Data Available

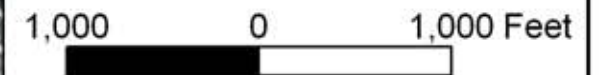
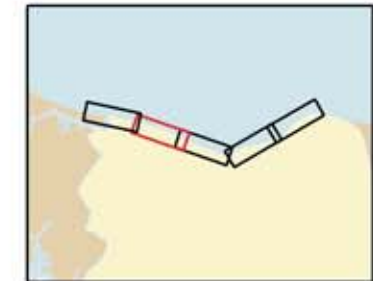
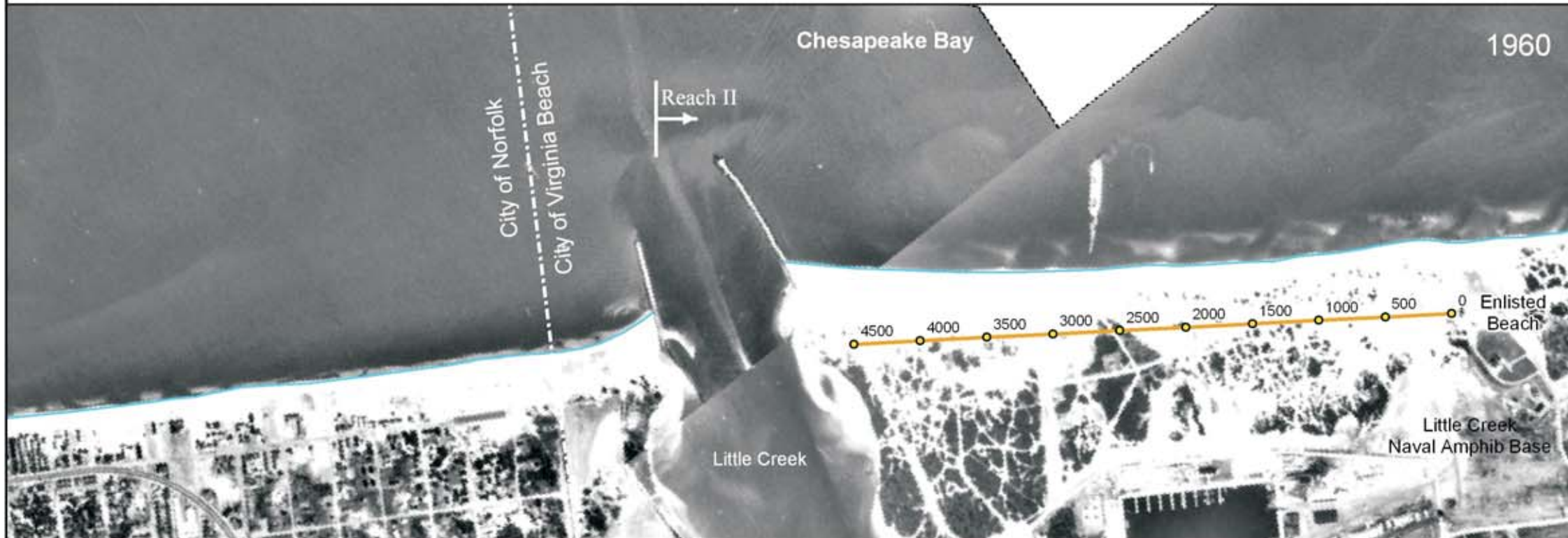
# City of Virginia Beach

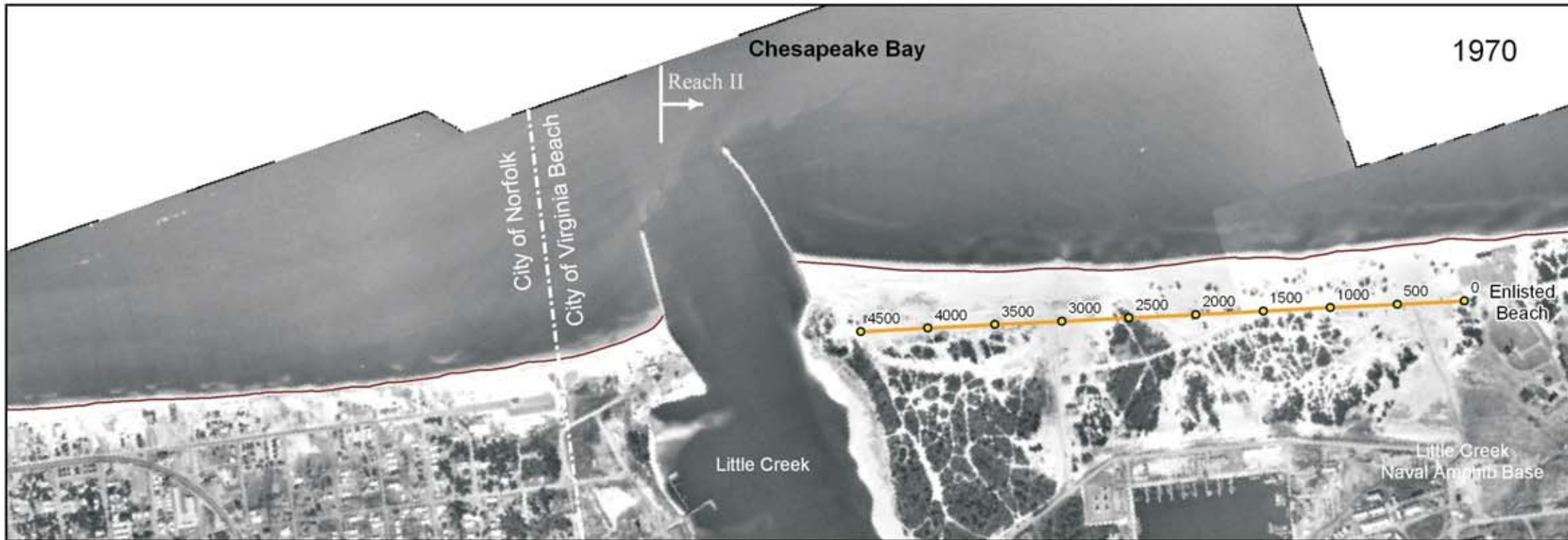
## Plate 5

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Transect Points
- Baseline
- 1960 Shoreline





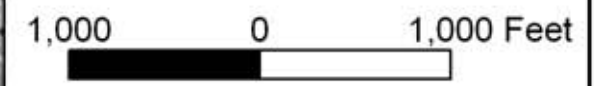
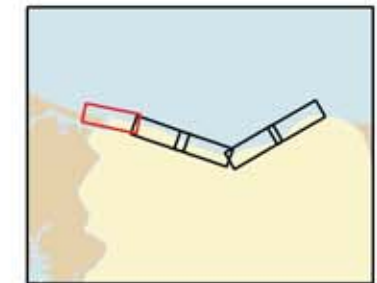
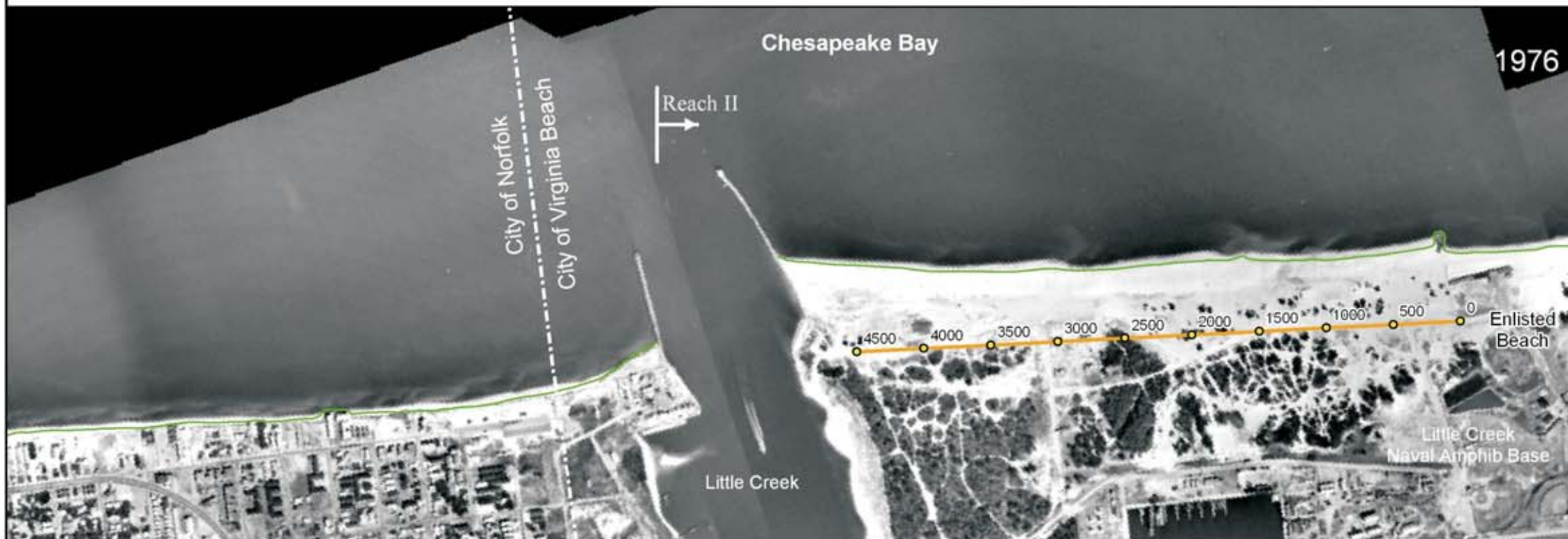
# City of Virginia Beach

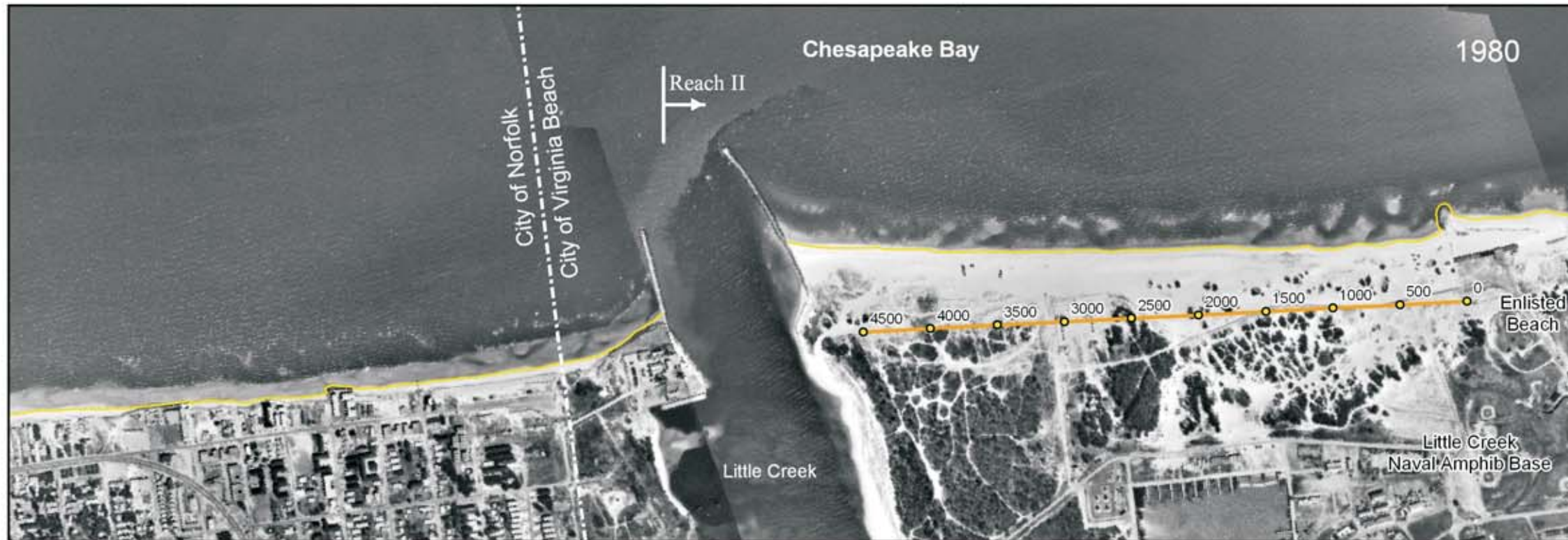
## Plate 5

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Transect Points
- Baseline
- 1970 Shoreline
- 1976 Shoreline

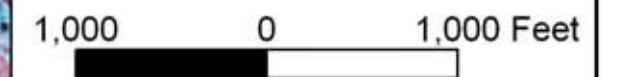
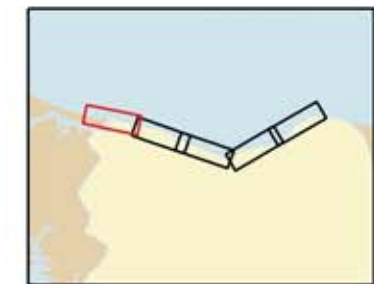
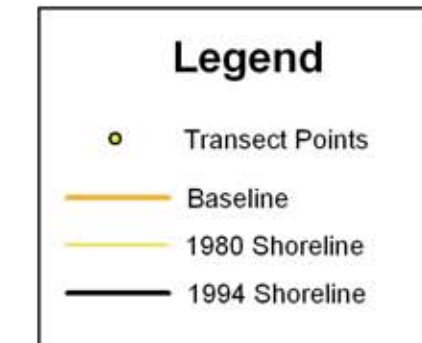




# City of Virginia Beach

## Plate 5

Morphological Reach II  
Lynnhaven Inlet to Little Creek





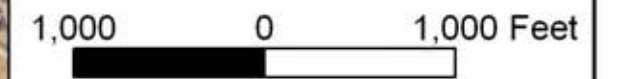
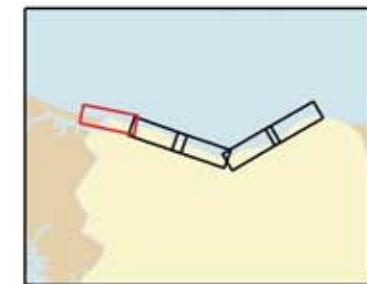
# City of Virginia Beach

## Plate 5

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Transect Points
- Baseline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



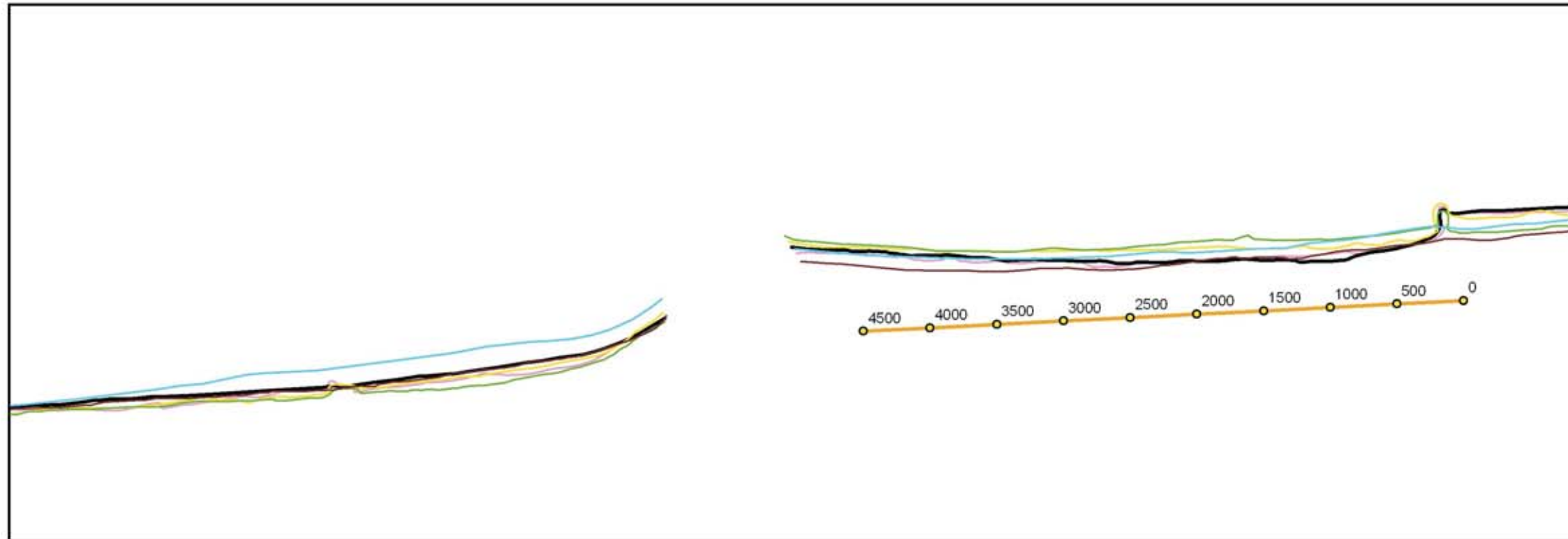
# City of Virginia Beach

## Plate 5

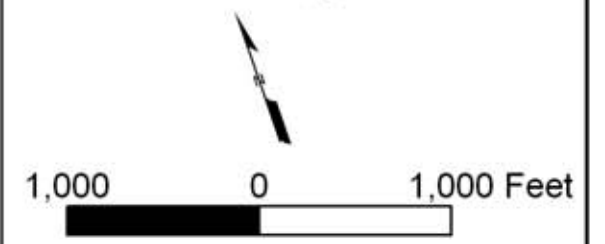
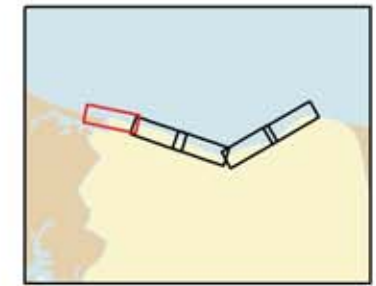
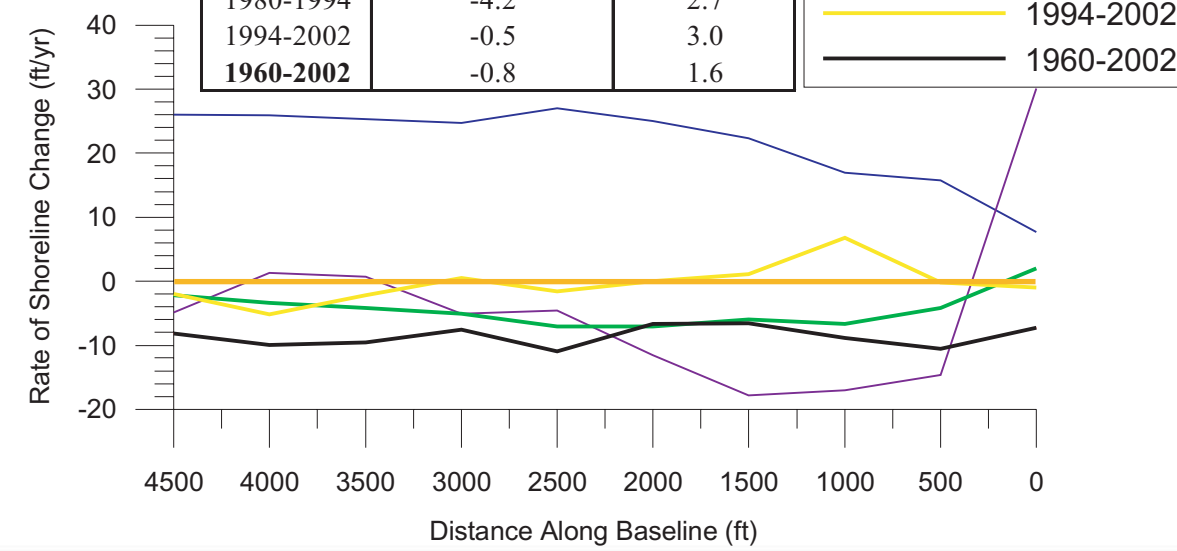
Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Transect Points
- Baseline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



Imagery Dates	Average Rate of Change (ft/yr)	Standard Deviation
1960-1970	-8.6	1.5
1970-1976	22.1	6.1
1976-1980	-4.4	13.2
1980-1994	-4.2	2.7
1994-2002	-0.5	3.0
<b>1960-2002</b>	<b>-0.8</b>	<b>1.6</b>



Chesapeake Bay

1937

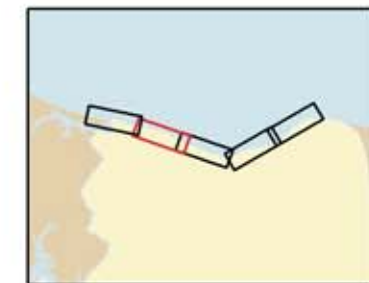
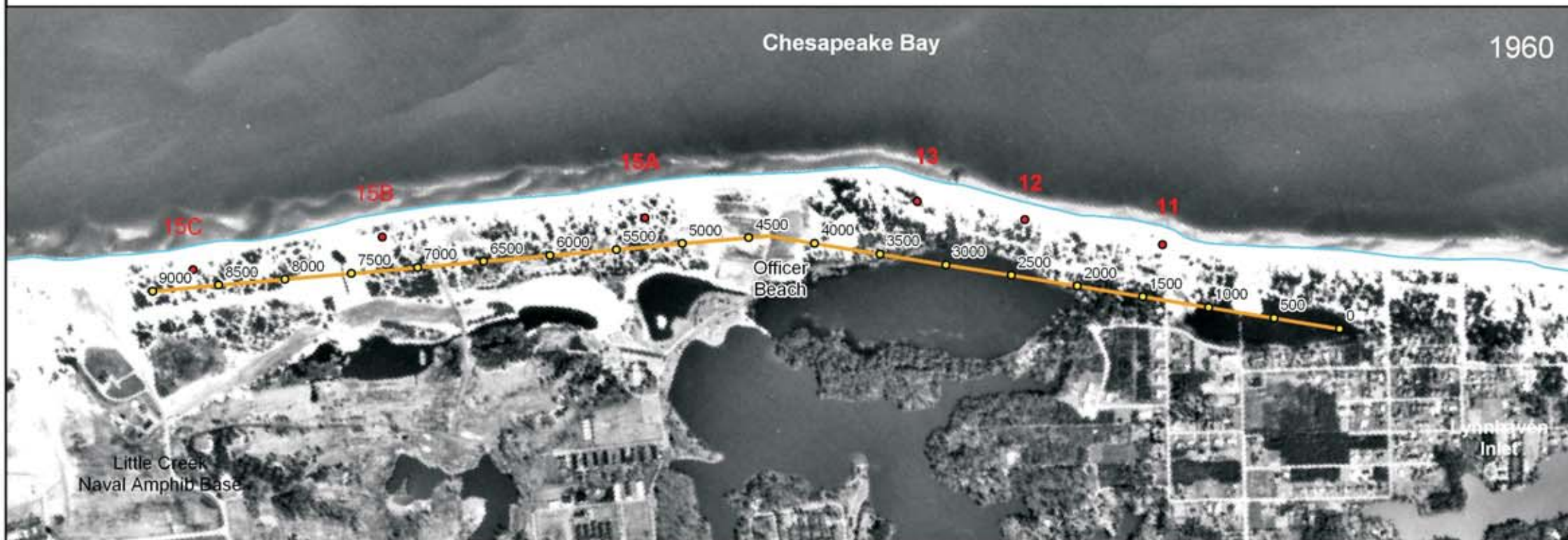
No Data Available

# City of Virginia Beach

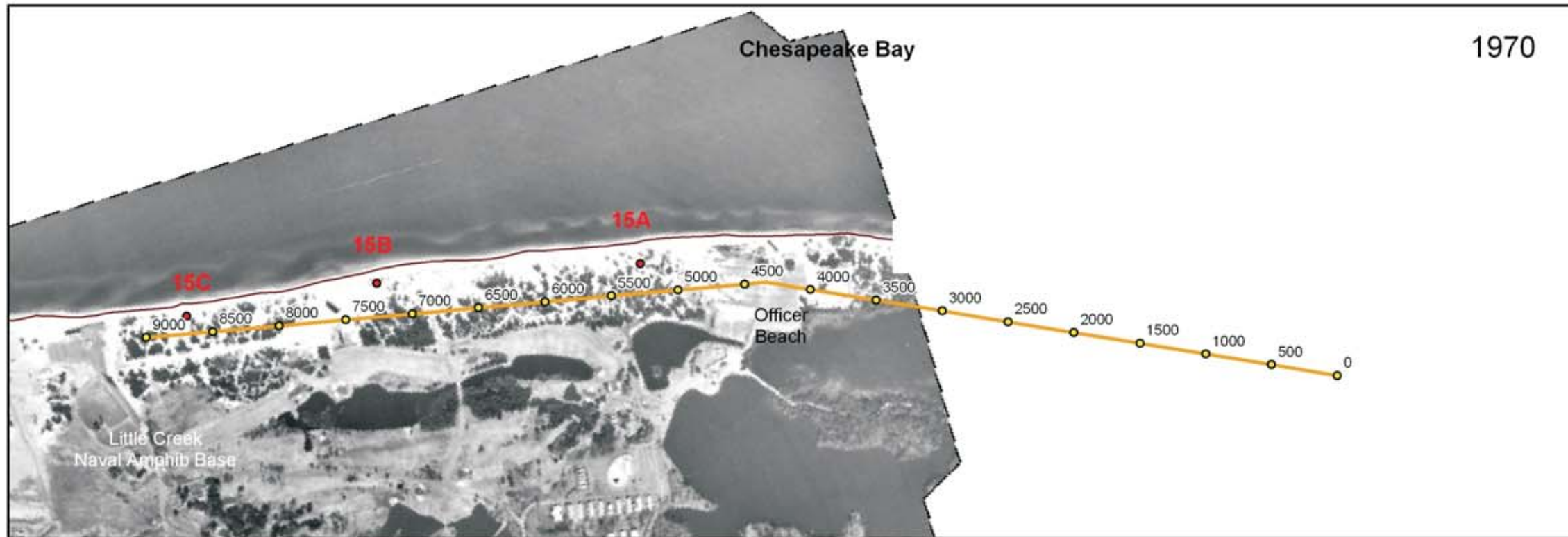
Plate 4  
Morphological Reach II  
Lynnhaven Inlet to Little Creek

## Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1960 Shoreline



1,000 0 1,000 Feet



1970

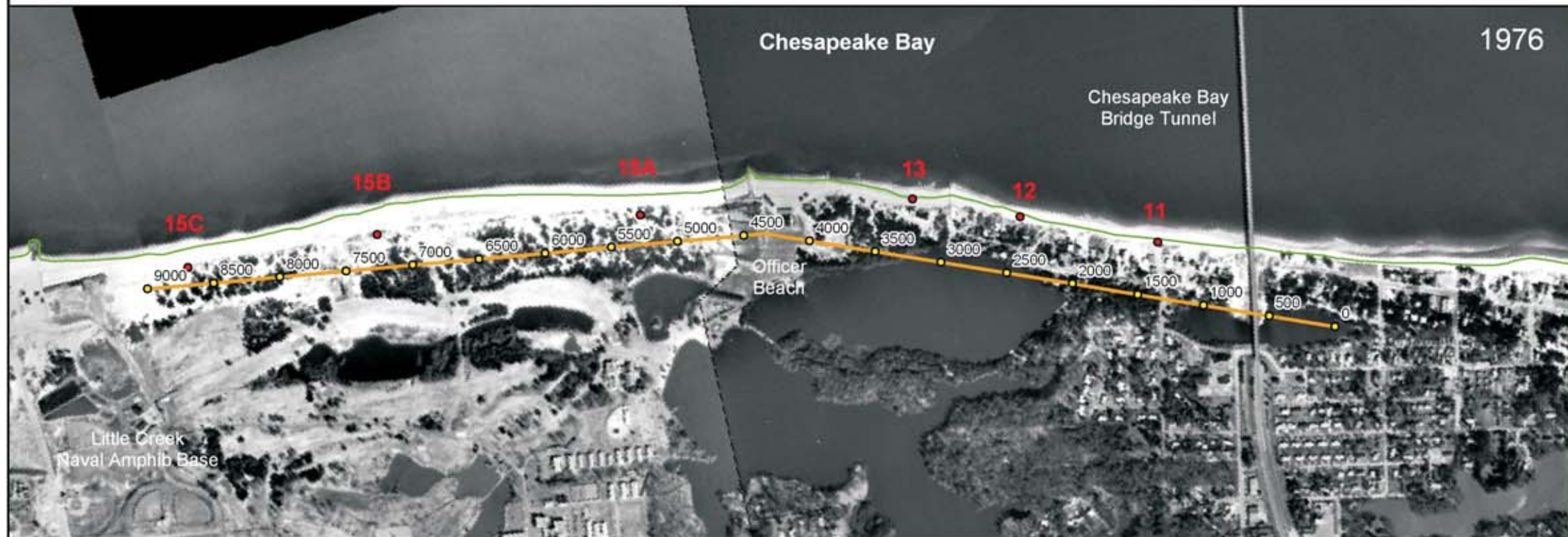
# City of Virginia Beach

## Plate 4

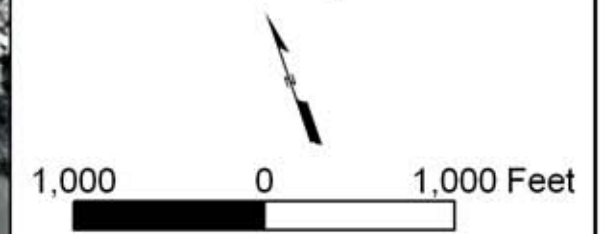
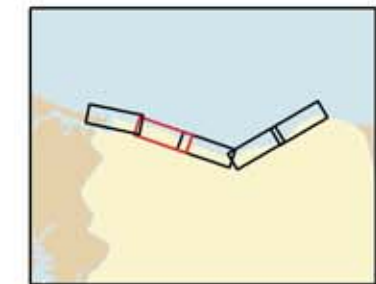
Morphological Reach II  
Lynnhaven Inlet to Little Creek

**Legend**

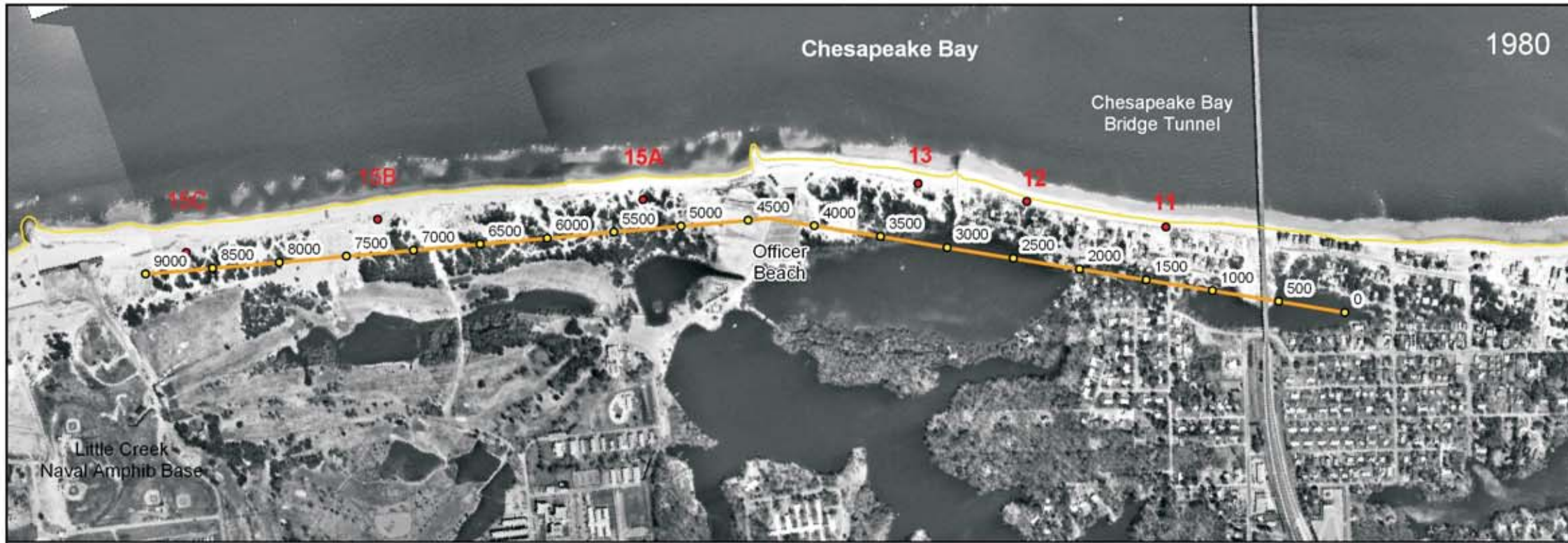
- Identified Dune Sites
- Transect Points
- Baseline
- 1970 Shoreline
- 1976 Shoreline



1976







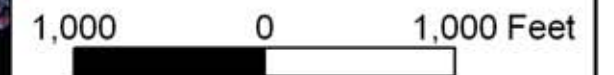
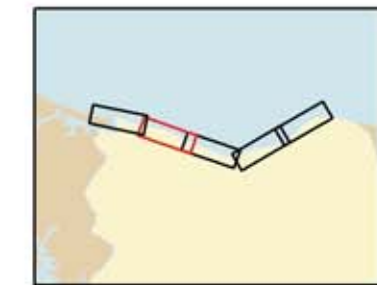
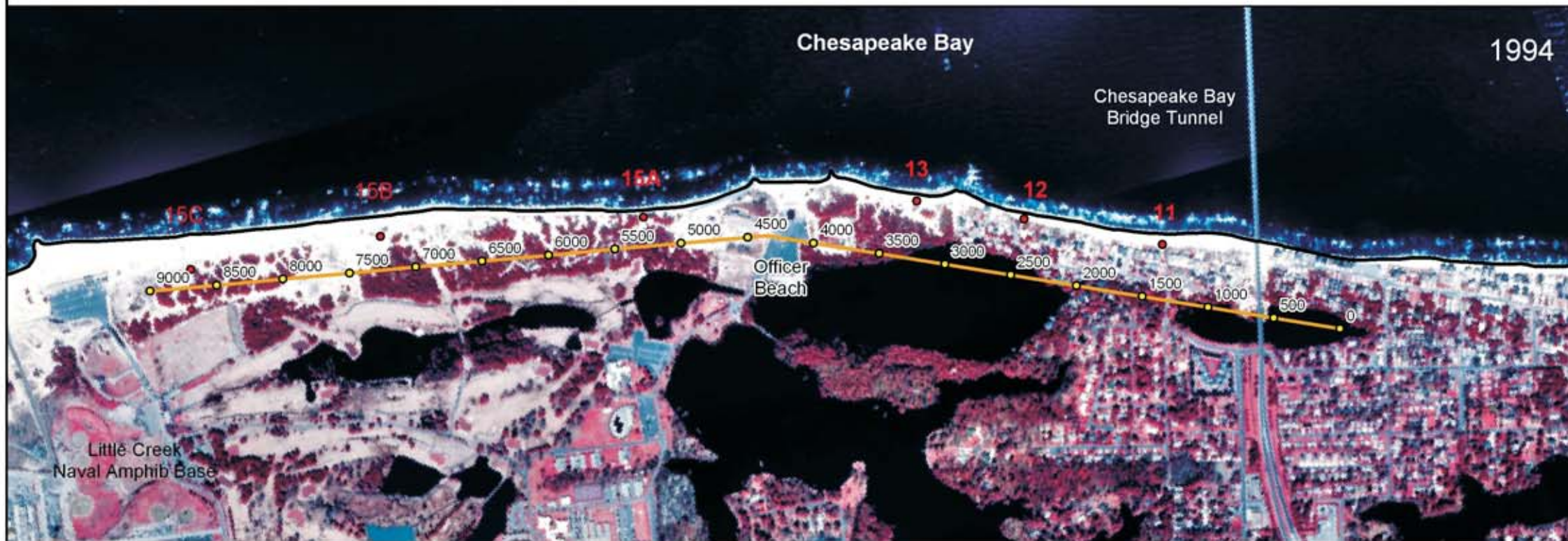
# City of Virginia Beach

## Plate 4

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Identified Dune Sites
- Transect Points
- Baseline
- 1980 Shoreline
- 1994 Shoreline





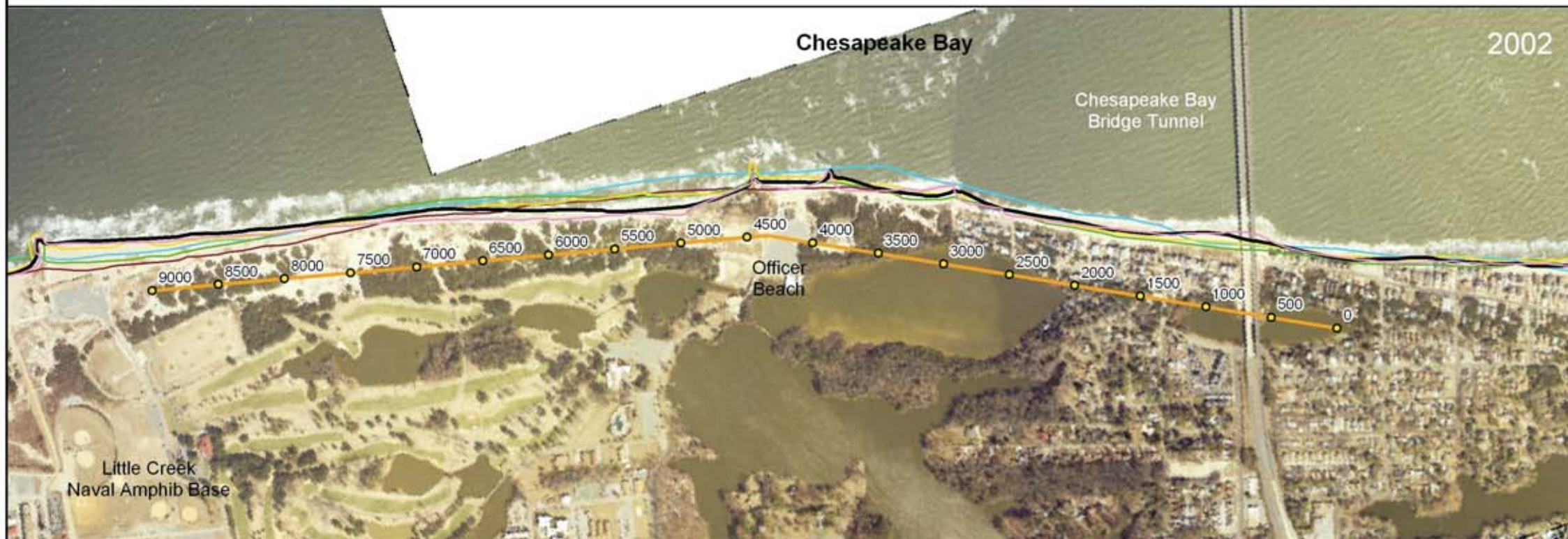
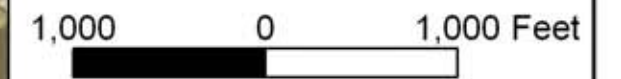
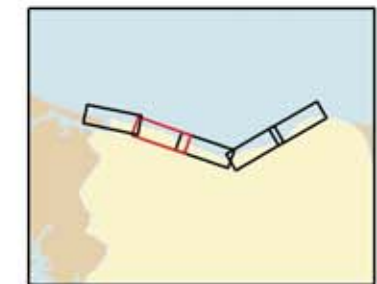
# City of Virginia Beach

## Plate 4

Morphological Reach II  
Lynnhaven Inlet to Little Creek

### Legend

- Identified Dune Sites
- ⌈ Dune Site Limits
- Transect Points
- Baseline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



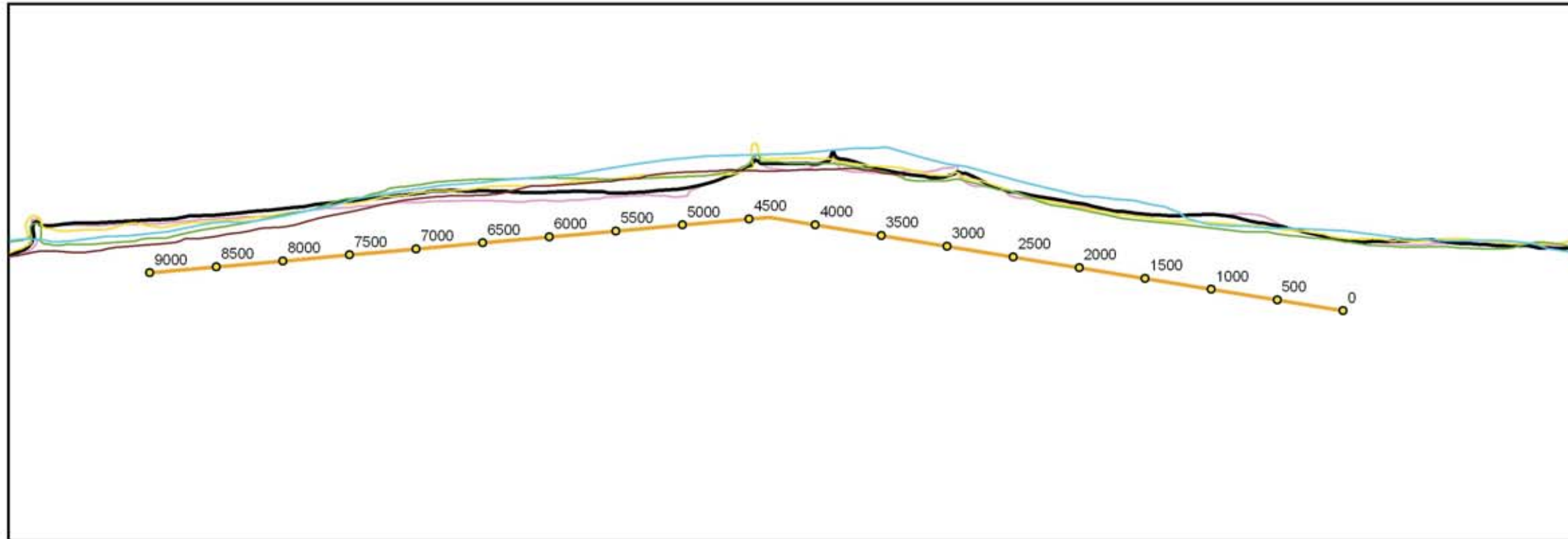
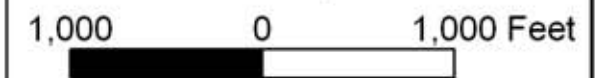
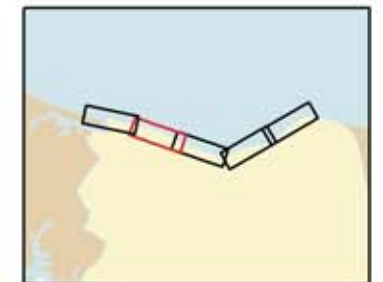
# City of Virginia Beach

## Plate 4

Morphological Reach II  
Lynnhaven Inlet to Little Creek

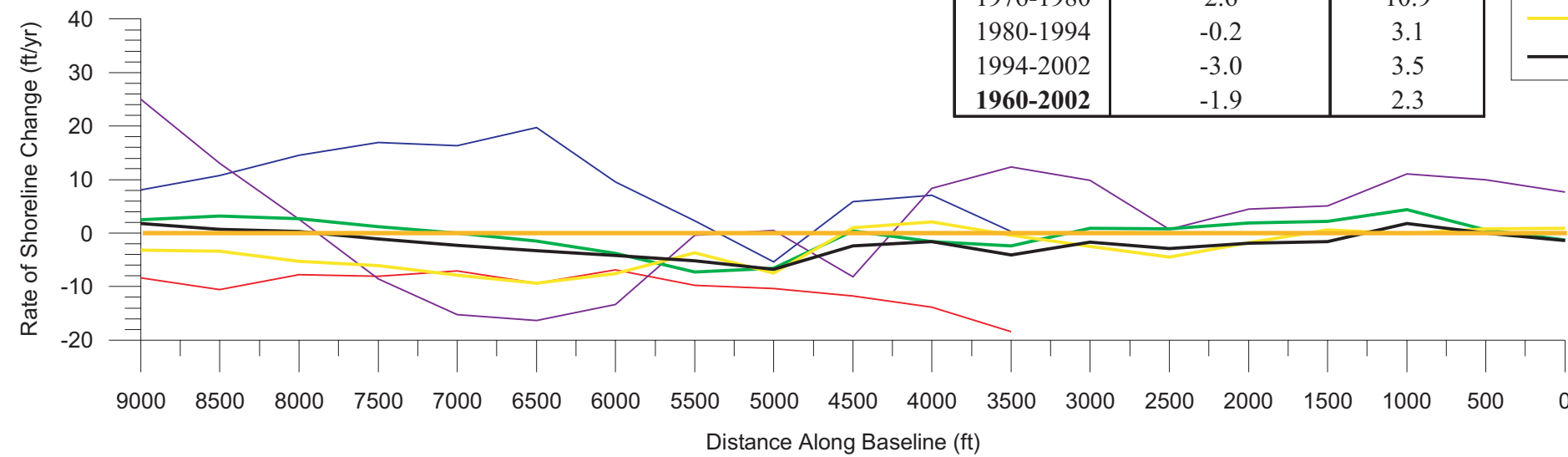
### Legend

- Transect Points
- Baseline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



Imagery Dates	Average Rate of Change (ft/yr)	Standard Deviation
1960-1970	-10.2	3.3
1970-1976	8.8	7.4
1976-1980	2.6	10.9
1980-1994	-0.2	3.1
1994-2002	-3.0	3.5
<b>1960-2002</b>	<b>-1.9</b>	<b>2.3</b>

- 1960-1970
- 1970-1976
- 1976-1980
- 1980-1994
- 1994-2002
- 1960-2002



## APPENDIX B

The data shown in the following tables were primarily collected as part of the Chesapeake Bay Dune: Evolution and Status report and presented in Hardaway *et al.* (2001) and Hardaway *et al.* (2004). Individual site characteristics may now be different due to natural or man-induced shoreline change.

An additional table presents the results of this analysis and describes each dune site's relative long-term, recent, and near-future predicted stability. This data results from the position of the digitized shorelines which have an error associated with them (see Methods, Section III).

**Since much of the dune data were collected several years ago and the beach and dune systems may have changed, this report is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.**

These data were collected as part of the Chesapeake Bay Dune: Evolution and Status Report (Hardaway *et al.*, 2001). Site characteristics may now be different due to natural or man-induced shoreline change.

Identified dune site information for the City of Virginia Beach as of 2000.

Dune Site No.	Location <sup>^</sup>		Date Visited	Dune Shore Length (Feet)	Primary Dune Site?	Secondary Dune Site?	*Public Ownership?
	Easting (Feet)	Northing (Feet)					
4A'	2,716,250	223,550	Jul 6, 2000	3,700	Yes	Yes	Yes
4B'	2,714,950	222,400	Jul 6, 2000	1,850	Yes	Yes	Yes
4C'	2,713,200	221,350	Jul 6, 2000	3,750	Yes	Yes	
6	2,705,600	218,750	Aug 16, 2000	2,450	Yes	Yes	
9	2,698,350	219,650	Aug 16, 2000	3,620	Yes		
10	2,695,600	220,550	Aug 16, 2000	2,850	Yes		
11	2,692,150	221,950	Aug 16, 2000	1,020	Yes		
12	2,691,200	222,500	Aug 16, 2000	1,020	Yes		
13	2,690,050	223,050	Jun 19, 2002	1,250	Yes	Yes	Yes
15A'	2,687,900	223,450	Aug 16, 2000	2,160	Yes	Yes	Yes
15B'	2,685,850	223,800	Aug 16, 2000	1,070	Yes	Yes	Yes
15C'	2,685,050	223,900	Aug 16, 2000	1,200	Yes	Yes	Yes

Dune site measurements for the City of Virginia Beach as of 2000.

Dune Site Measurements									
Site No.	Dune Shore Length (Feet)	Primary Dune			Secondary Dune				
		Crest Elev (ft MLW)	Distance from Crest landward to back base (Feet)	To MLW (Feet)	2nd Dune Site	Crest Elev (ft MLW)	Primary Crest to 2 <sup>nd</sup> Crest (Feet)	2nd Crest landward (Feet)	2nd Crest seaward to 1st back base (Feet)
VB 4A	3,700	11.2	14	109	Yes	12.8	59	340	45
VB 4B	1,850	10.8	40	138	Yes	13.8	72	180	32
VB 4C	3,750	16.6	40	182	Yes	18.2	91	59	51
VB 6	2,450	12.2	113	228	Yes	19.2	177	no data	64
VB 9	3,620	19.5	55	108					
VB 10	2,850	19.0	62	278					
VB 11	1,020	16.7	18	210					
VB 12	1,020	18.8	29	207					
VB 13	1,250	25	no data	155	Yes	no data	no data	no data	no data
VB 15A	2,160	20.8	48	111	Yes	16.7	83	no data	144
VB 15B	1,070	15.6	45	107	Yes	19.2	79	no data	34
VB 15C	1,200	20.5	50	227	Yes	17.9	192	45	33

\*Public ownership includes governmental entities including local, state, and federal; otherwise ownership is by private parties.

<sup>^</sup>Location is in Virginia State Plane South, NAD 1927.

These data were collected as part of the Chesapeake Bay Dune: Evolution and Status Report (Hardaway *et al.*, 2001). Site characteristics may now be different due to natural or man-induced shoreline change.

Dune site parameters in the City of Virginia Beach as of 2000.

		Dune Site Parameters								
		Fetch Exposure	Shoreline Direction of Face	Nearshore Gradient		Morphologic Setting	Relative Stability	Underlying Substrate	Structure or Fill	
Site No.	Type	A	B	C		D	E	F	G	
VB 4A	Natural	Open Bay	Northwest	Steep	Bars	Dune Field, linear	Accretion	Upland		
VB 4B	Natural	Open Bay	Northwest	Steep	Bars	Dune Field, Sh. Bay	Stable	Upland		
VB 4C	Natural	Open Bay	Northwest	Steep	Bars	Dune Field, linear	Stable	Upland		
VB 6	Man Inf	Open Bay	Northwest	Steep	Bars	Dune Field, linear	Stable	Upland		
VB 9	Man Inf	Open Bay	North	Steep	Bars	Dune Field, linear	Stable	Upland	Fill	
VB 10	Man Inf	Open Bay	North	Steep	Bars	Dune Field, linear	Stable	Upland	Fill	
VB 11	Man Inf	Open Bay	Northeast	Steep	No Bars	Dune Field, linear	Erosional	Upland	Fill&fencing	
VB 12	Man Inf	Open Bay	Northeast	Steep	No Bars	Isolated, linear	Erosional	Upland	BH	
VB 13	Man Inf	Open Bay	North	Steep	Bars	Dune Field, linear	Erosional	Upland	Groin	
VB 15A	Man Inf	Open Bay	North	Steep	Bars	Dune Field, linear	Erosional	Upland	Revet/BH	
VB 15B	Natural	Open Bay	North	Steep	Bars	Dune Field, linear	Erosional	Upland		
VB 15C	Natural	Open Bay	North	Steep	Bars	Dune Field, linear	Stable	Upland		

Long term, recent stability, and future predictions of sediment erosion and accretion rates for dune sites in the City of Virginia Beach.

Site No.	Long-Term Stability 1937-2002	Recent Stability 1994-2002	Near Future Prediction
4A	Accretionary	Stable	Stable
4B	Accretionary	Stable	Stable
4C	Accretionary	Erosional	Stable
6	Accretionary	Accretionary	Accretionary
9	Stable	Erosional	Erosional
10	Stable	Stable	Stable
11*	Erosional	Stable	Stable
12*	Erosional	Erosional	Erosional
13*	Erosional	Erosional	Erosional
15A*	Erosional	Erosional	Erosional
15B*	Erosional	Erosional	Erosional
15C*	Accretionary	Erosional	Stable

\*Long-term rates are 1960-2002 since a 1937 shoreline was unavailable.