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Shoreline Evolution Chesapeake Bay Shoreline City of Norfolk, VA

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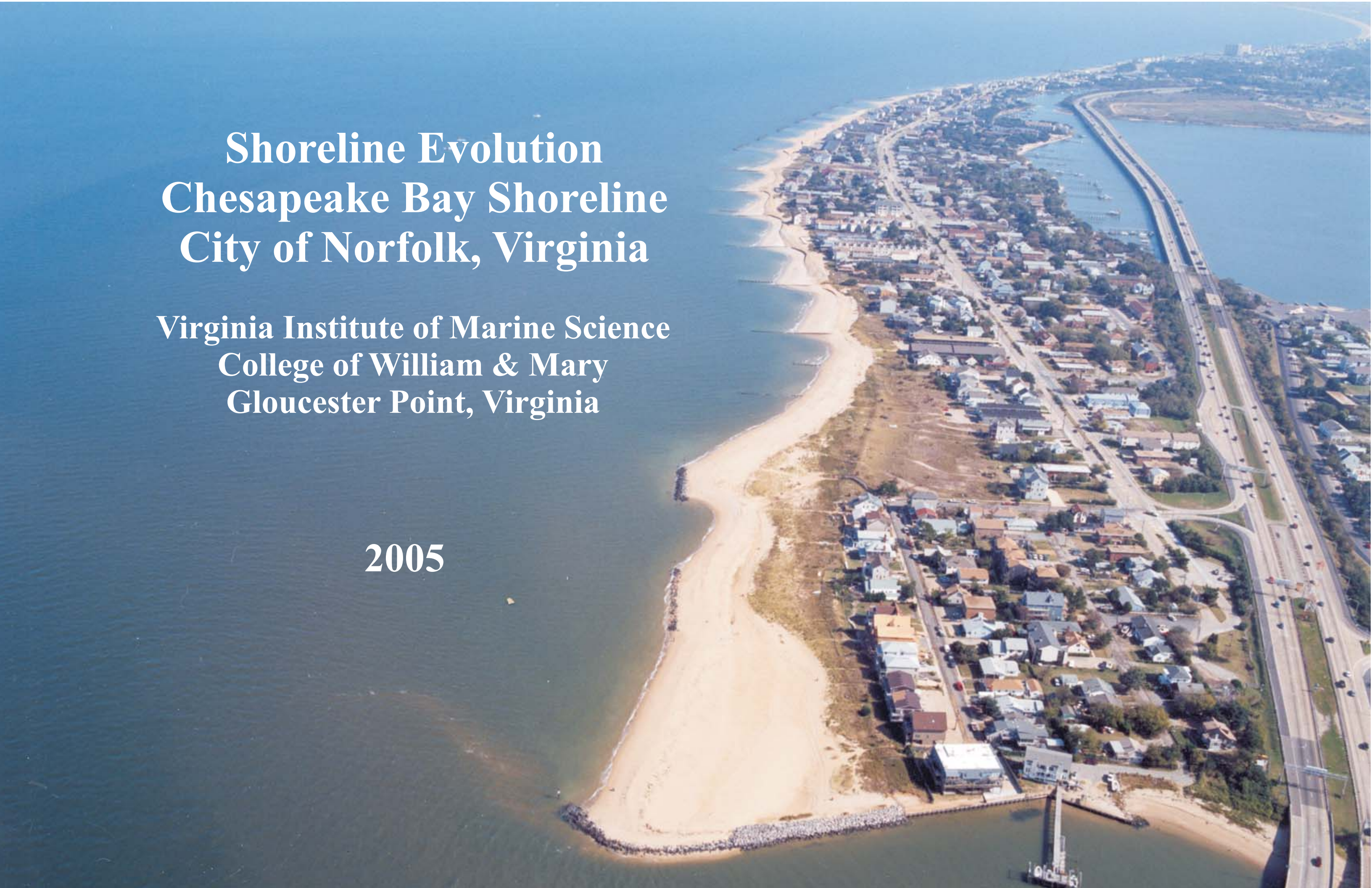
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Chesapeake Bay Shoreline
City of Norfolk, Virginia**

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

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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: Willoughby Spit in the City of Norfolk. Photo taken by Shoreline Studies Program on 26 October 2004

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 together 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 Chesapeake Bay shore of Norfolk (Figure 1) has evolved since 1937. This is the first year that aerial imagery was taken for most of the Bay region, 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, beach nourishment or inlet stabilization will come to dominate a given shore reach. Most of the change in shore positions will be quantified in this report. Others, particularly around inlets and very irregular coasts, will be interpreted.

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 Norfolk 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)¹. 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 Norfolk Dune Inventory. That report detailed the location and nature of the jurisdictional primary dunes along the Bay shore of Norfolk, 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 visit in 2000. This information is not intended to be used for jurisdictional determinations regarding dunes.

¹The 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 Norfolk is located between Little Creek Inlet and Willoughby Spit and consists of about 7 miles of tidal shoreline along the Chesapeake Bay side of the Norfolk coast. The shorelines are exposed to open bay fetch conditions as well as some oceanic conditions. Historic shore change rates vary from 0 ft/yr to over 2.5 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 Norfolk is exclusively Holocene beach sands which overlie earlier Holocene sands, mud and clays (Figure 3). 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 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 present 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 and is significant to shore change since the beaches, dunes, and nearshore sand bars must keep pace with rising sea levels. 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 1933. 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).

The Norfolk shoreline is one long curvilinear coast that is mostly beach and dune with individual sites separated by bulkheads and groins. The Norfolk coast and, in particular, those shorelines 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). The littoral system is sand rich from material coming through the mouth of the Bay. This is evidenced by mostly sand beaches along the coast and a complex system of offshore sand bars. These sand bars greatly influence and are themselves influenced by the impinging wave climate. The Norfolk coast is divided into four shoreline plates, each of which will be discussed individually (Figure 4).

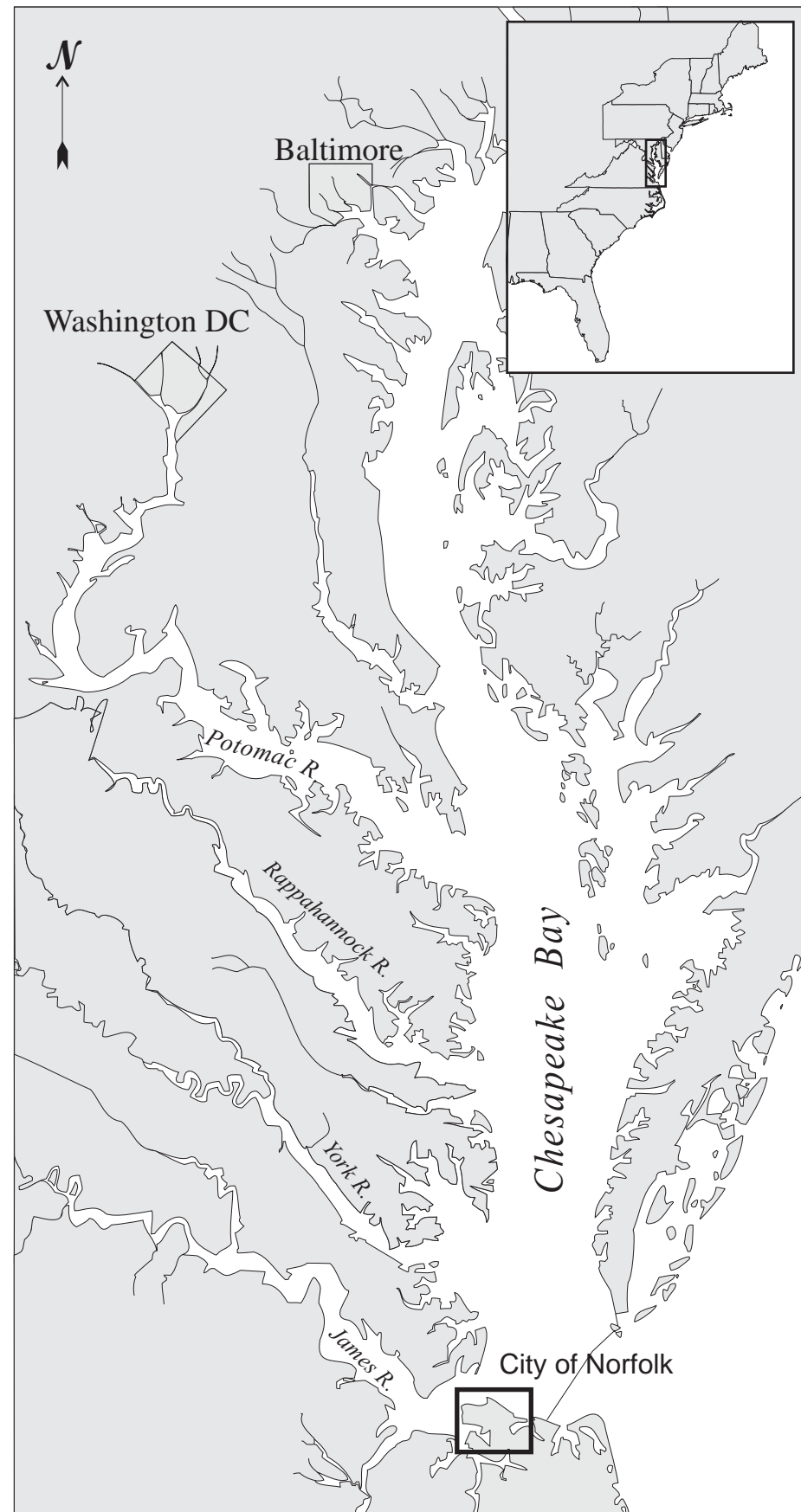


Figure 1. Approximate location of the City of Norfolk within the Chesapeake Bay estuarine system.

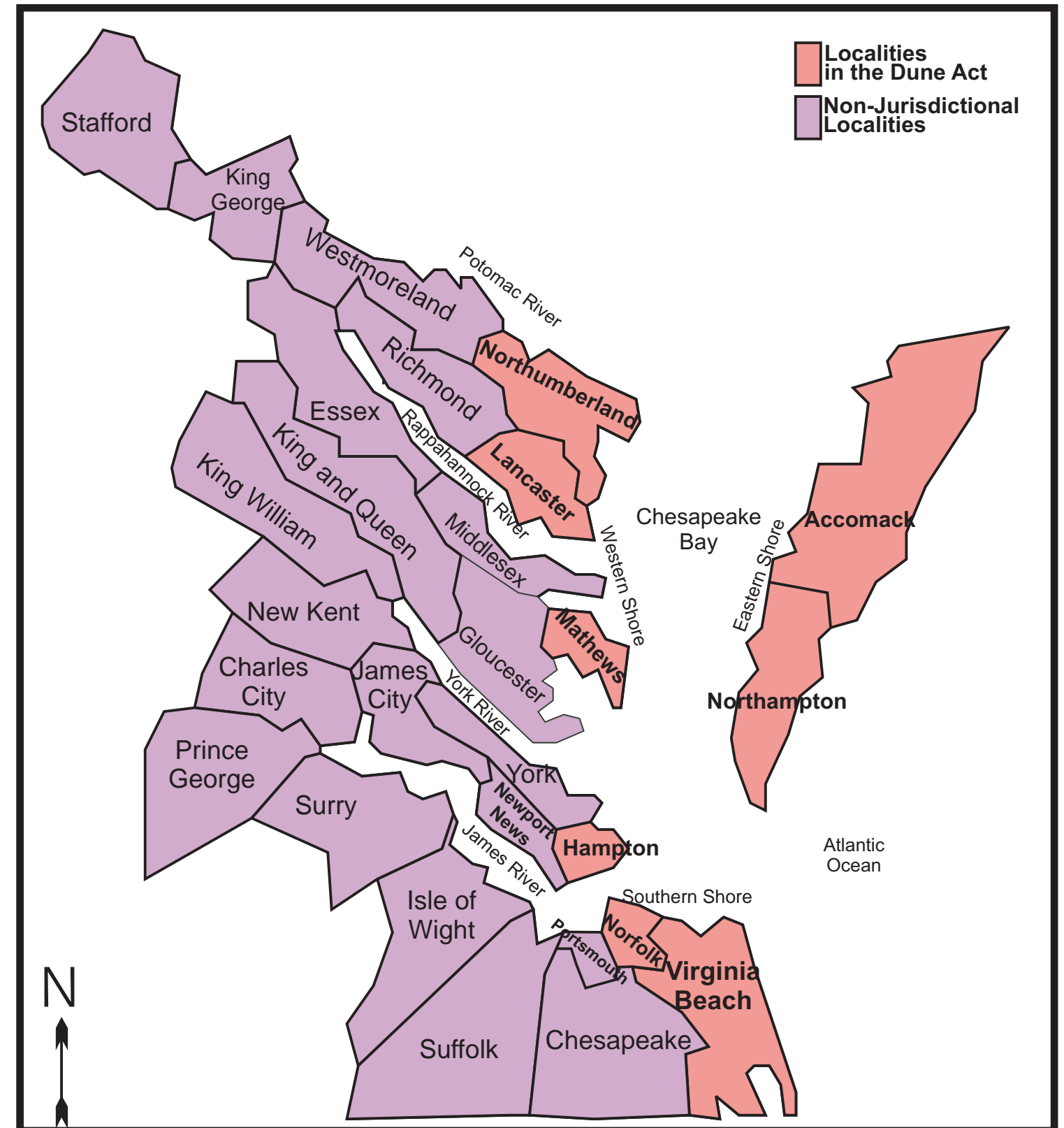
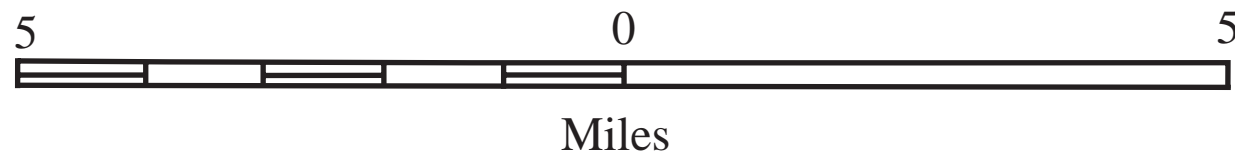


Figure 2. Location of localities in the Dune Act with jurisdictional and non-jurisdictional localities noted.

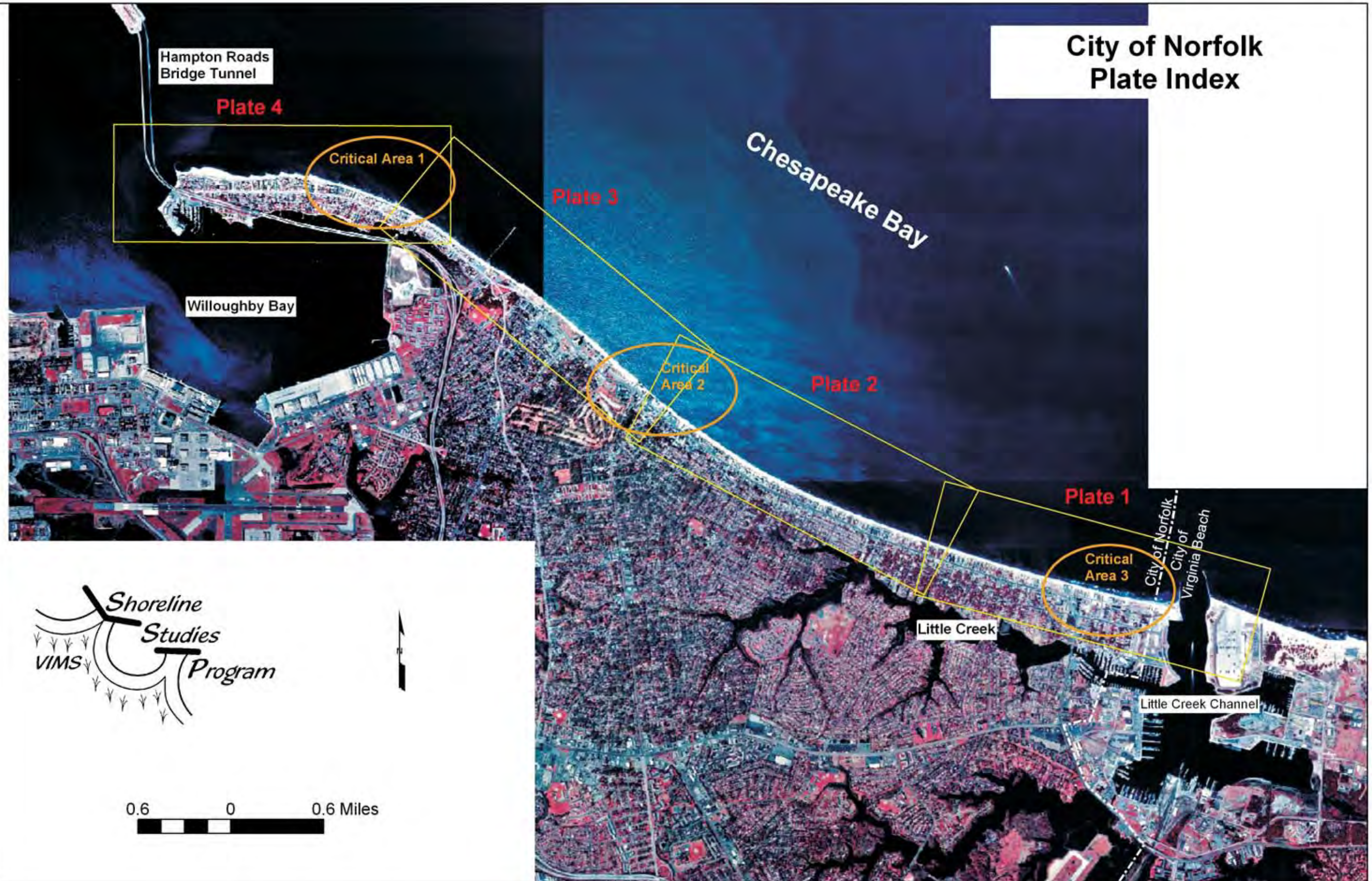


- Qs** **Holocene Sand** - Pale gray to light-yellowish gray, fine to coarse, poorly sorted to well sorted, shelly in part; contains angular to rounded fragments and whole valves of mollusks. Comprises deposits of coastal barrier islands and narrow beach-dune ridges bordering brackish-water marshes of Chesapeake Bay. As much as 40 ft in thickness.
- Qtl** **Lynnhaven Member** - 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. Unit is surficial deposit of broad swale extending southward from Norfolk and of extensive lowlands bounded on landward side by rivers-, bay-, and ocean-facing scarps having toe altitudes of 15-18 ft. Thickness is 0-20 ft.
- Qts** **Sedgefield Member** - Pebbly to bouldery, clayey sand and fine to medium, shelly sand grading upward to sandy and clayey silt; locally, channel fill at base of unit includes as much as 50 ft of fine to coarse, crossbedded sand and clayey silt and peat containing in situ tree stumps. Sandy bay facies commonly contains *Crassostrea* biostromes, *Mercenaria*, *Anadara*, *Polynices*, *Ensis*, and other mollusks. Specimens of the coral *Astrangia* have yielded estimated uranium-series ages averaging 71,000 +/- 7,000 yrs B.P. (Mixon and others, 1982). 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 3. Geologic map of the City of Norfolk (from Mixon *et al.*, 1989).



City of Norfolk Plate Index



B. Hydrodynamic Setting

Mean tide range along the Bay coast of Norfolk is about 2.9 ft. The wind/wave climate impacting the Norfolk coast is defined by large fetch exposures to the Northwest, North, 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). Norfolk's Bay shorelines 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 Norfolk 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 Norfolk 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 ⁺ | 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

III. METHODS

A. Photo Rectification and Shoreline Digitizing

Recent and historic aerial photography were used to estimate, observe, and analyze past shoreline positions and trends involving shore evolution for the City of Norfolk. 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, 1958, 1960, 1970, 1976, 1980, 1994, and 2002. High level black and white aerials were available for 1937, 1958, 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's 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 Norfolk, 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 Norfolk dune site profiles are displayed in [Figure 5](#) describing the high variability in beach/dune shoreline. [Figure 6](#) shows the relationship of approximate MHW, MLW and beach/dune system components.

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 Project, Norfolk

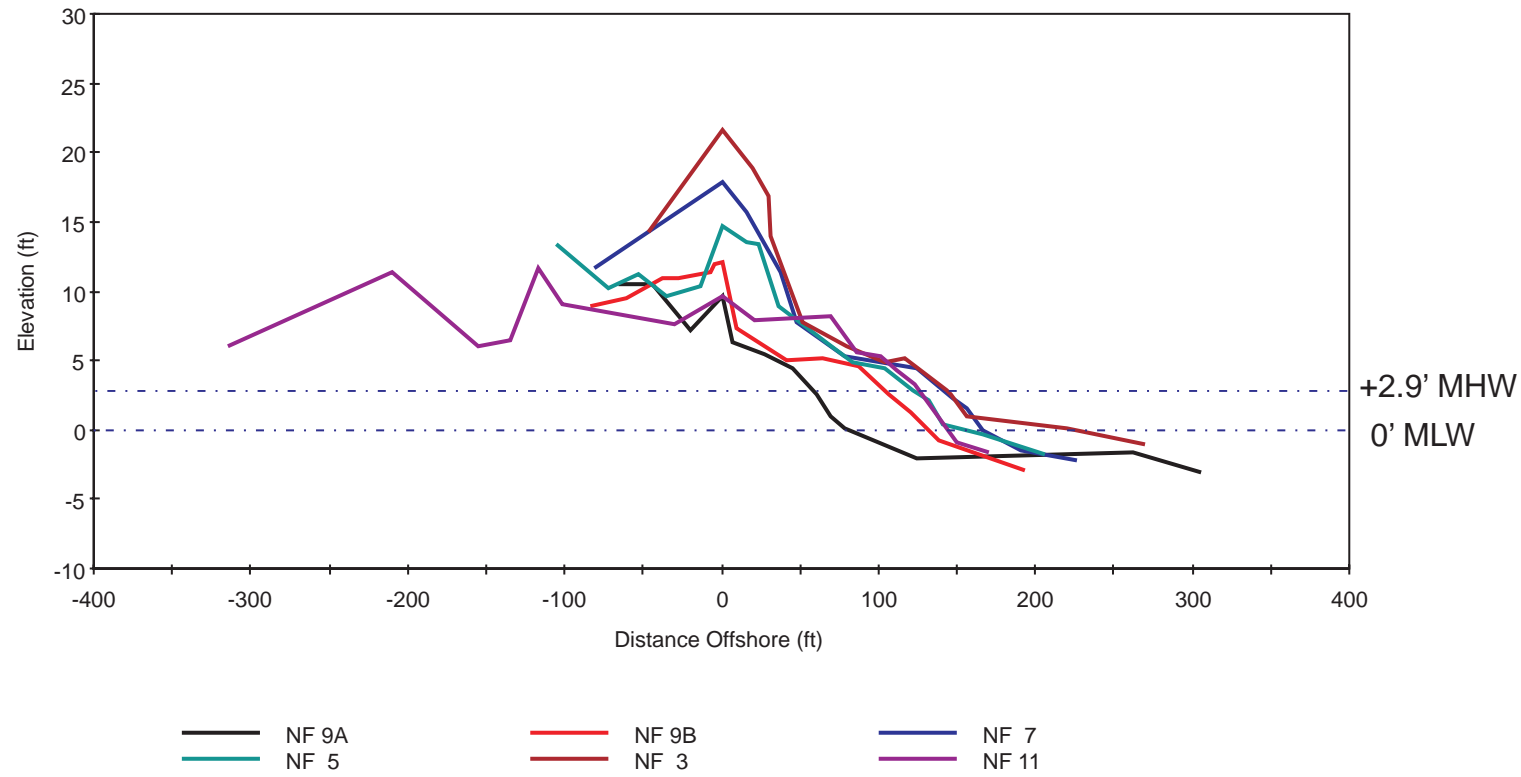


Figure 5. Variability of dune and beach profiles in the City of Norfolk.

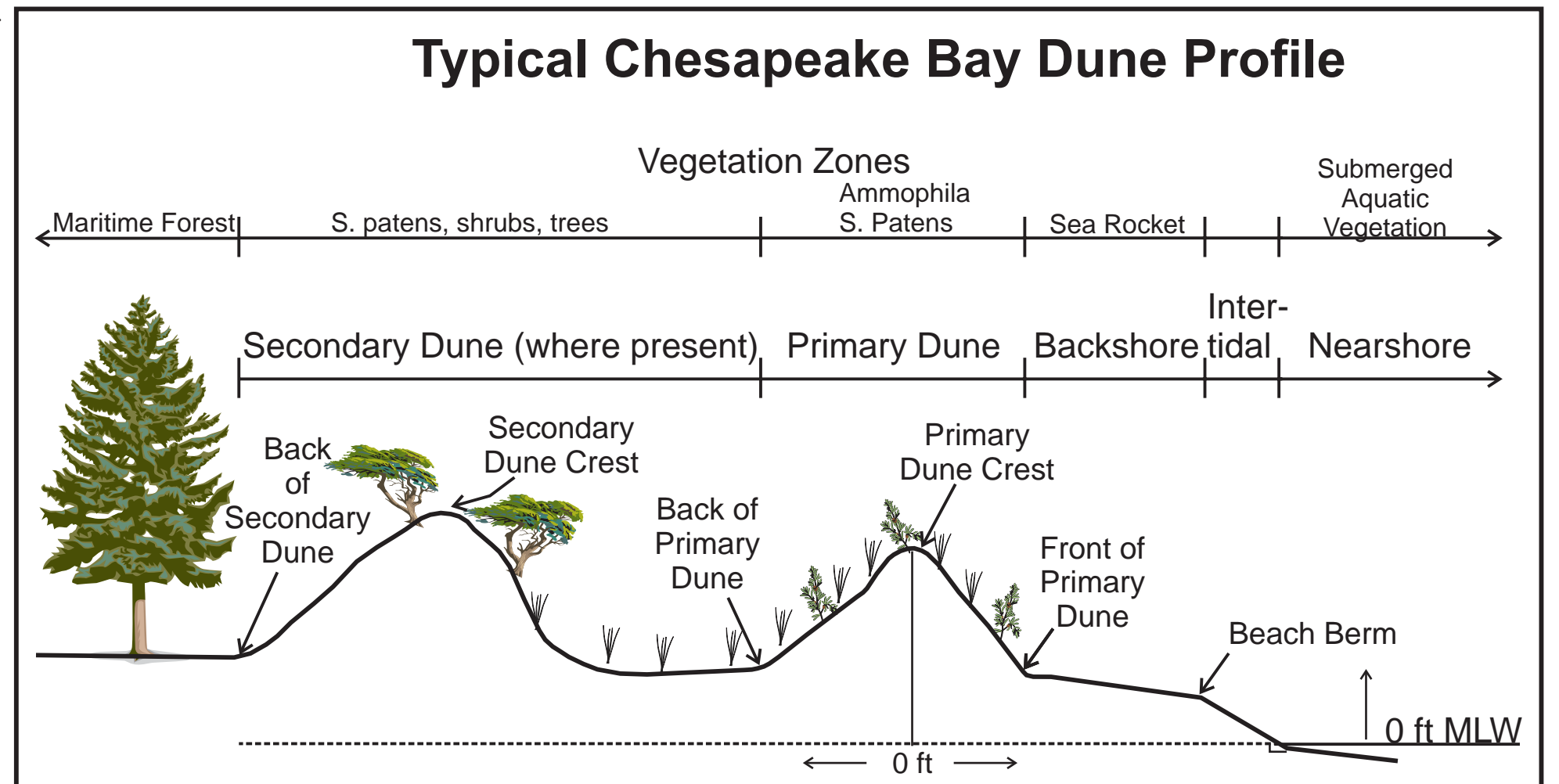


Figure 6. Typical profile of a Chesapeake Bay dune system (from Hardaway *et al.*, 2001).

IV. RESULTS

The figures 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 Norfolk 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.

Plate 1 includes dune sites NF3 and part of NF4 (See 2002 photo). Site NF3 and NF4 are separated by a single bulkheaded lot so they are essentially continuous features. The dune sites are erosional remnants of a continuous beach/dune system that can be seen in 1937. By 1958, development can be seen along the Plate 1 coast. Accretion is shown between 1937 and 1958 along the shoreline closest to Little Creek Inlet. This is primarily due to disposal of dredge material in 1948 (50,000cy) and 1953 (700,000 cy) from Little Creek. Additional material (159,000 cy) was placed in 1960. The overall rates are positive for the 1976-1980 and 1980-1994 time frames. This also is likely due to dredge material placement (Hardway *et al.*, 1997). Known projects took place in 1982 (400,000 cy), 1989 (133,000 cy), and 2002 (3,438 cy). The net shoreline trend (1937-2002) has been erosional with significant recession from the jetty to Station 5000. In response to a shore management plan which identified this East Ocean View area as Critical Area 3 along the City's Chesapeake Bay shoreline, the City installed a series of offshore breakwaters in 2000 and 2001. A large beach fill was performed in 2003.

The Plate 2 coast includes NF4 and NF5, a continuation of the beach/dune system along Norfolk's Bay coast. A 200 ft break in the primary dune separates the system. The shoreline continues the slight erosional trend from Plate 1 from station 0 to about station 4000. The rest of the plate shows slight advances and retreats over time with a recent, 1994 - 2002, trend of accretion from station 6,500 to 10,500. Critical Area #2 begins at about station 10,500 where groins have been installed since 1937 and a break in the primary dune occurs. In 1937, this coast was already being developed just behind the primary dune.

Plate 3 begins at Critical Area 2. From here west to the end of Willoughby Spit, a series of groins have been installed since 1937 in an effort to maintain the beach front. In 1999, breakwaters and beach fill were placed in Ocean View at Critical Area 2. Plate 3 includes dune sites NF6, NF7 and NF8. Fragmentation of these isolated dune sites can be seen as early as 1937 and has continued until the present. The shoreline trend along Plate 3 is a series of subtle advances and retreats controlled in large part by the extensive groin field. The net trend (1937-2002) is close to zero.

Plate 4 includes dune sites NF9 and NF11. Once again, these are all erosion remnants of a more extensive beach/dune system. The 1937 imagery shows the groin field and its associated "downdrift" offsets. Significant shore change has occurred at the dune sites as groins and beach fill were added over time. A large beach nourishment project (540,000 cy) was performed in 1984 from about station 6,000 to the end of Willoughby Spit. In 1987, approximately 50,000 cy of sand was back-passed from west of the terminal groin to Willoughby Spit. The large terminal groin was raised and two breakwaters were completed in 1990 at the distal

end of the Spit. Also, a series of 7 offshore breakwaters were completed in 1996 at Critical Area 1. Sand back passing also was done several time to move sand eastward that had accreted at the distal end of Willoughby Spit. Shore change has been quite variable over time due to these series of efforts with accretion of 1.7 ft/yr being the net result.

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.

The dune site, NF3 in Plate 1 appears to be a stable situation, especially with the large beach fill recently placed behind the breakwater system to the east. With net sediment drift from east to west, NF3 should benefit in the short term as the beach fill adjusts. The photo depicting NF3 ([Figure 7](#)) and Critical Area 3 was taken just a few months after the passage of Hurricane Isabel. The dune shows some scarping. Dune site NF4 is relatively stable and NF5 ([Figure 8](#)) appears to have long-term stability as seen in the Plate 2 shore change results ([Table 2](#)). Although periods of erosion and accretion have occurred since 1937, the net change is 0 for both sites combined.

Dunes in Plate 3 have largely been controlled by a groin field since at least 1937, and the net change has been about 0. This includes dune sites NF6, NF7 and NF8 ([Figure 9](#)). Dune sites NF9A, NF9B in Plate 4 are isolated dune sites residing in an historically accretional subreach and should be stable in the near future ([Figure 10](#)). Dune site NF11 is in a stable embayment created by a wood groin on Willoughby Spit, the terminal groin, and breakwater system ([Figure 11](#)). Numerous sand bypassing project from the end of Willoughby Spit to Critical Area 1 have helped maintain the Plate 4 dune sites.

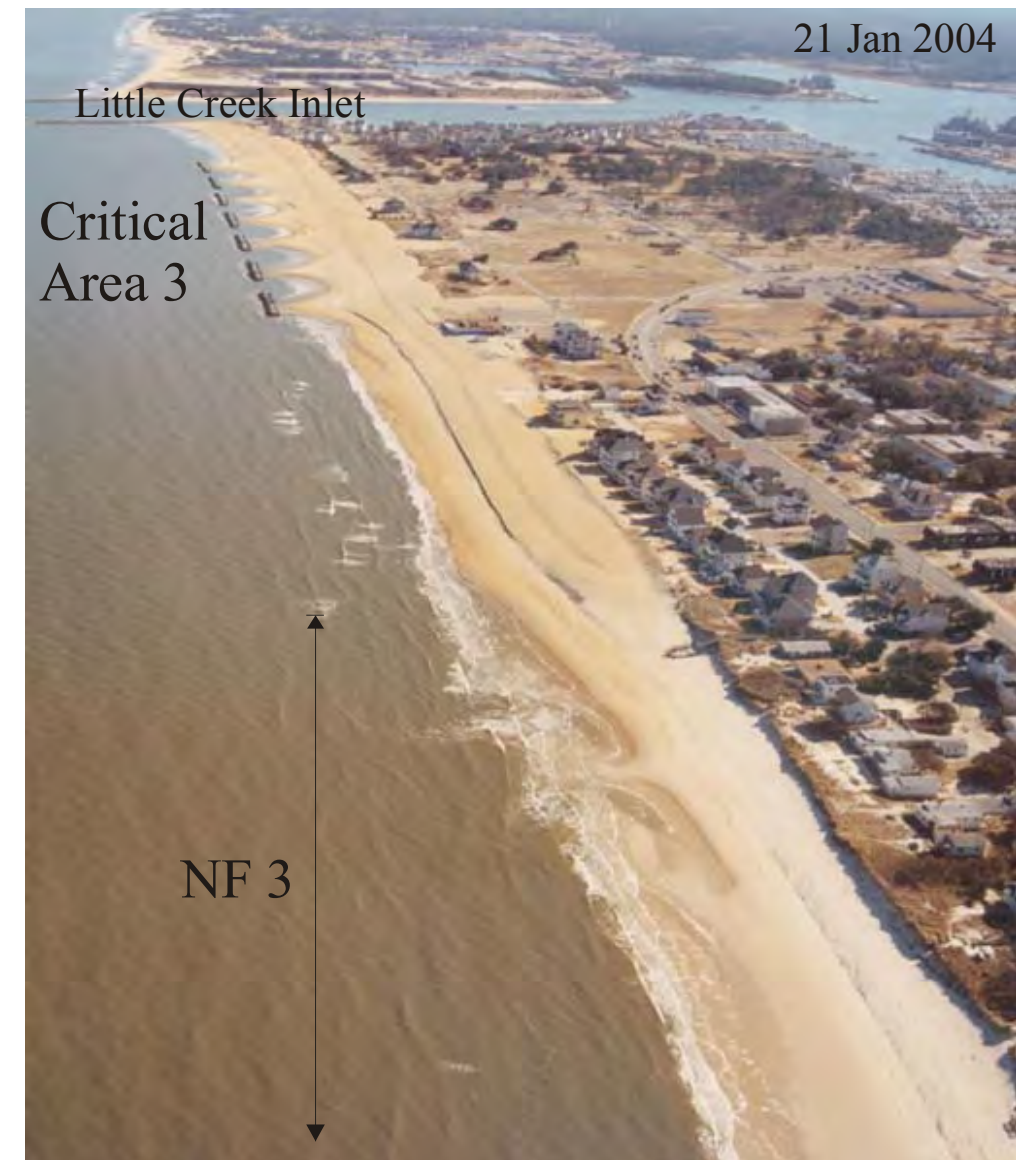


Figure 7. Photo of the Norfolk shoreline showing dune site NF3 and Critical Area 3.

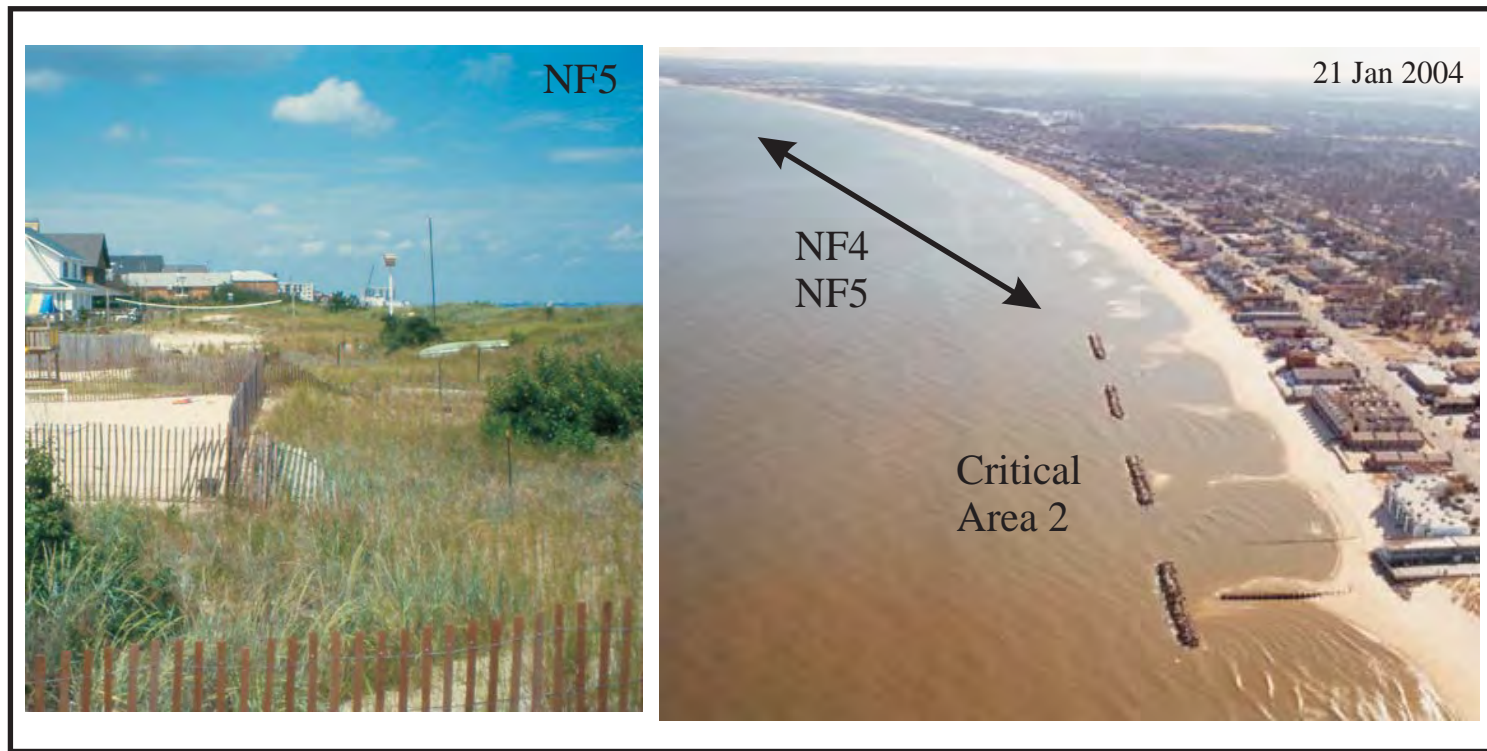


Figure 8. Photos of the Norfolk shoreline showing dune sites NF4 and NF5.



Figure 10. Photos of the Norfolk shoreline showing dune sites NF9 and NF9B1.

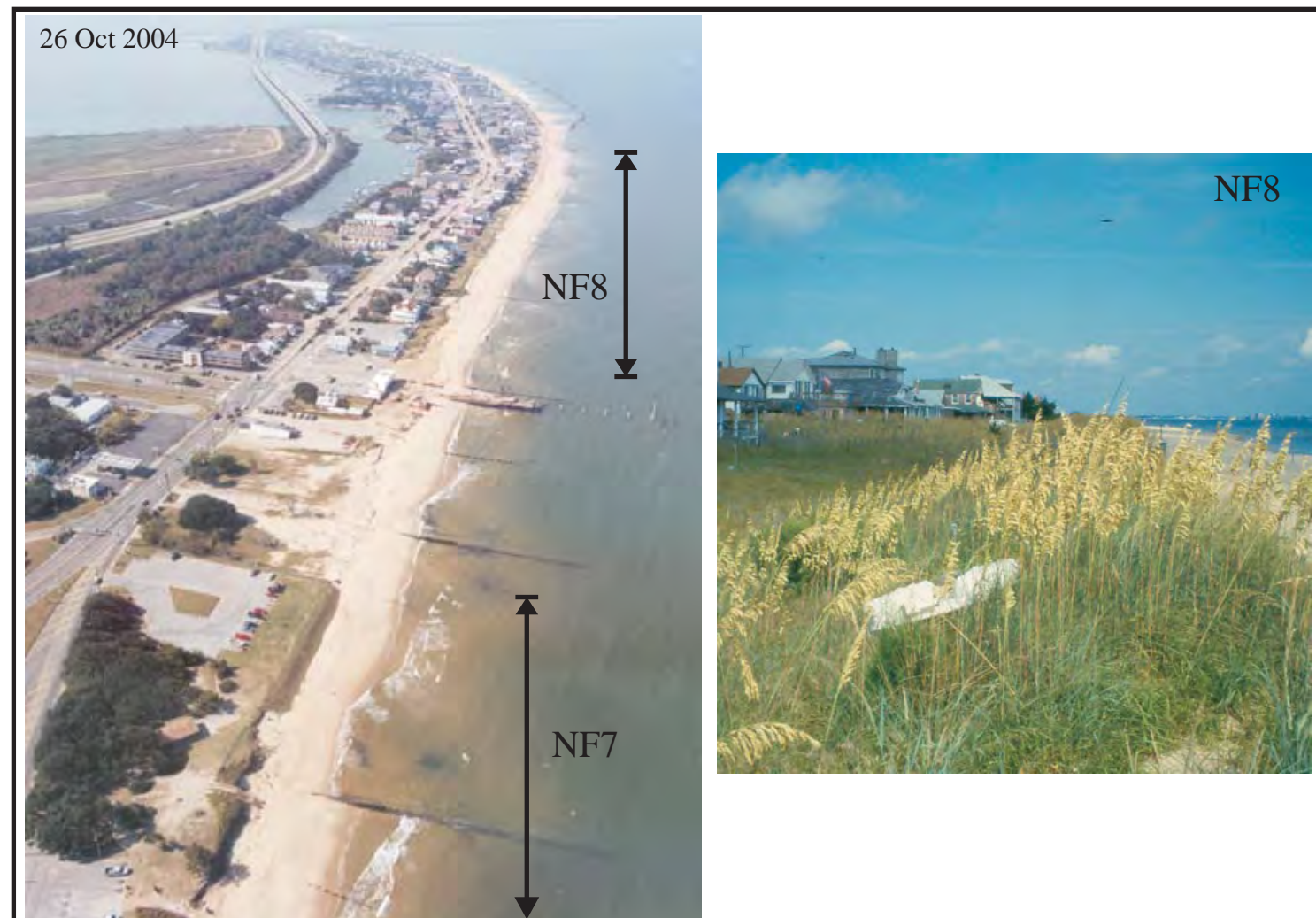


Figure 9. Photos of the Norfolk shoreline showing dune sites NF7 and NF8.



Figure 11. Photos of the Norfolk shoreline showing dune site NF11.

VI. SUMMARY

The Chesapeake Bay coast of the City of Norfolk 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. The Norfolk 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 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 Norfolk. 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 [Table 2](#) for eight 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). For instance, on Plate 4 between 1958 and 1960, the standard deviation is nearly double the average rate of change indicating that the overall rate is probably not indicative of the change 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 1937 and 1958 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.

The long-term shoreline change along the Bay shoreline of Norfolk is a modest +0.2 ft/yr, thus indicating that the City of Norfolk has a relatively balanced coastline partly due to anthropogenic forces. 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.

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

| Plate No. | Mean Shore Change 1937-1958 | | Mean Shore Change 1958-1960 | | 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 | |
|----------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------|
| | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) | (ft/yr) | Std Dev (ft/yr) |
| Plate 1 | -0.5 | 2.5 | -5.2 | 12.8 | -9.5 | 5.7 | -5.4 | 6.7 | 4.5 | 8.1 | 2.6 | 1.5 | -3.2 | 4.8 | -1.3 | 0.6 |
| Plate 2 | -1.5 | 1.5 | 6.8 | 6.9 | -6.1 | 1.1 | 4.1 | 2.9 | -1.3 | 3.9 | 2.9 | 1.2 | 2.3 | 2.3 | 0.0 | 0.7 |
| Plate 3 | 2.2 | 1.0 | 2.4 | 10.0 | -4.1 | 1.5 | 5.7 | 2.4 | -4.9 | 7.9 | 0.6 | 1.2 | -1.3 | 2.7 | 0.2 | 0.4 |
| Plate 4 | 2.4 | 2.3 | -7.4 | 14.6 | -0.2 | 6.4 | 3.3 | 2.3 | 10.5 | 4.3 | 2.0 | 6.2 | -1.8 | 6.4 | 1.7 | 1.7 |
| Total | 0.6 | 2.5 | -1.8 | 11.1 | -4.9 | 5.2 | 2.1 | 5.6 | 2.3 | 8.3 | 2.0 | 3.3 | -0.7 | 4.6 | 0.2 | 1.4 |

VII. REFERENCES

- Boone, J., 2003. The Three Faces of Isabel: Storm Surge, Storm Tide, and Sea Level Rise. Informal Paper. <http://www.vims.edu/physical/research/isabel>.
- Boone, J. D., D. A. Hepworth, K. D. Suh, and F. H. Farmer, 1993. Chesapeake Bay wave climate. Data Report No. 44, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 35 pp. + app.
- Byrne, R. J. and G. L. Anderson, 1978. Shoreline Erosion in Tidewater Virginia. SRAMSOE Number 111. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 102 pp.
- Hardaway, C. S., Jr., D. A. Milligan, J. P.-Y Maa, and G. R. Thomas, 1997. Little Creek Naval Amphibious Base Chesapeake Bay Shoreline, Shoreline Management Plan and Officer's Beach Shore Protection Evaluation. Technical Report, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.
- Hardaway, C. S., Jr., D. A. Milligan, L. M. Varnell, G. R. Thomas, W. I. Priest, L. M. Meneghini, T. A. Barnard, and C. Wilcox, 2004. City of Norfolk Dune Inventory. Technical Report, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.
- Hardaway, C. S., Jr., L. M. Varnell, D. A. Milligan, G. R. Thomas, and C. H. Hobbs, III, 2001. Chesapeake Bay Dune Systems: Evolution and Status. Technical Report. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.
- Mixon, R. B., C. R. Berquist, Jr., W. L. Newell, and G. H. Johnson, 1989. Geologic Map and Generalized Cross Sections of the Coastal Plain and Adjacent Parts of the Piedmont, Virginia. U.S. Geological Survey Map I-2033 (Sheet 1 of 2).

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.

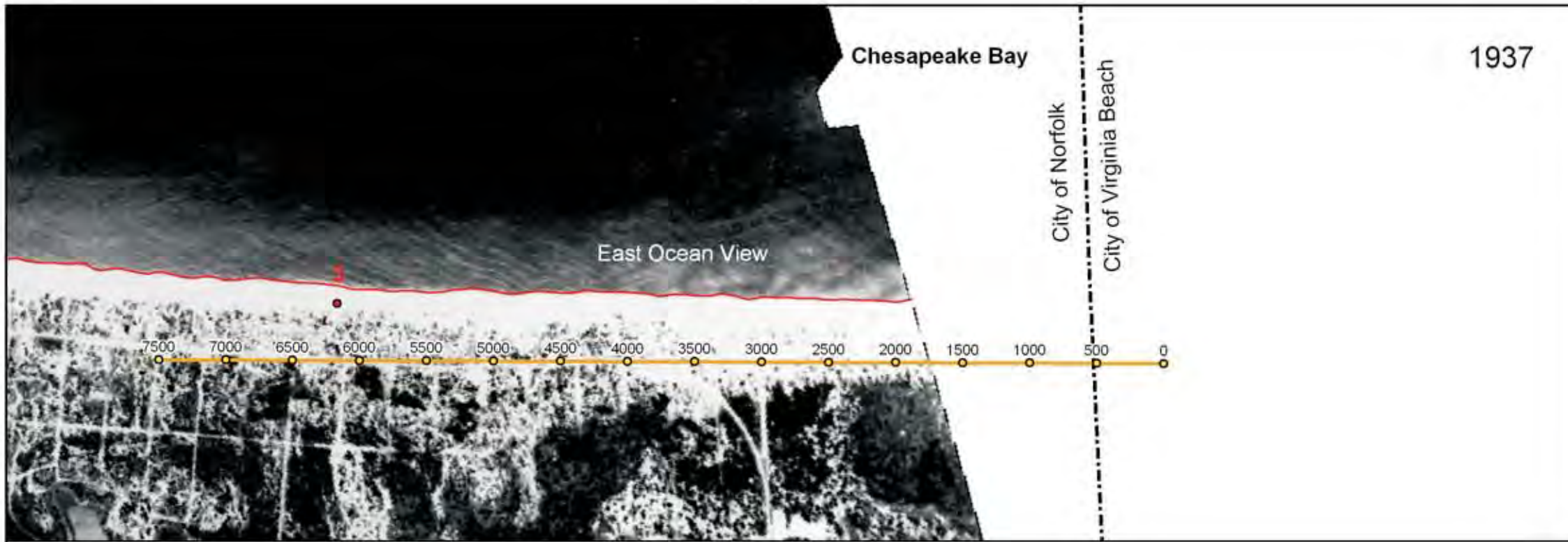
This data is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.

Plate 1 - 1937 & 1958
Plate 1 - 1960 & 1970
Plate 1 - 1976 & 1980
Plate 1 - 1994 & 2002
Plate 1 - Shoreline Change

Plate 2 - 1937 & 1958
Plate 2 - 1960 & 1970
Plate 2 - 1976 & 1980
Plate 2 - 1994 & 2002
Plate 2 - Shoreline Change

Plate 3 - 1937 & 1958
Plate 3 - 1960 & 1970
Plate 3 - 1976 & 1980
Plate 3 - 1994 & 2002
Plate 3 - Shoreline Change

Plate 4 - 1937 & 1958
Plate 4 - 1960 & 1970
Plate 4 - 1976 & 1980
Plate 4 - 1994 & 2002
Plate 4 - Shoreline Change



City of Norfolk

Plate 1

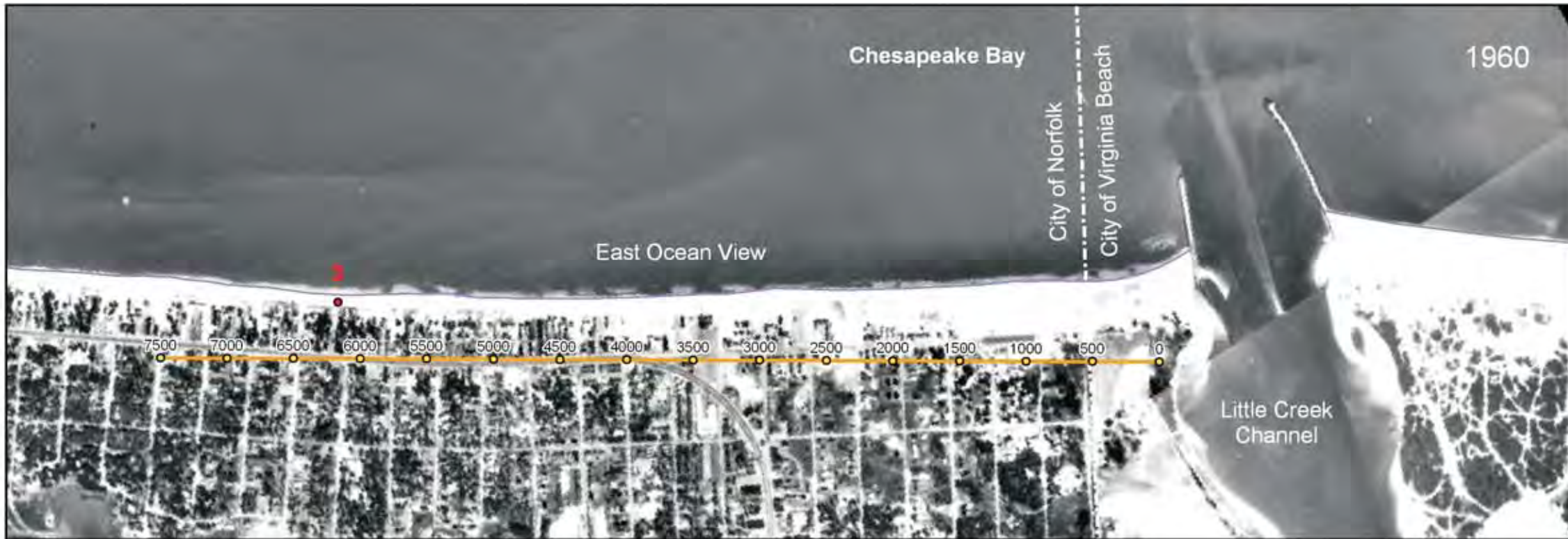
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet



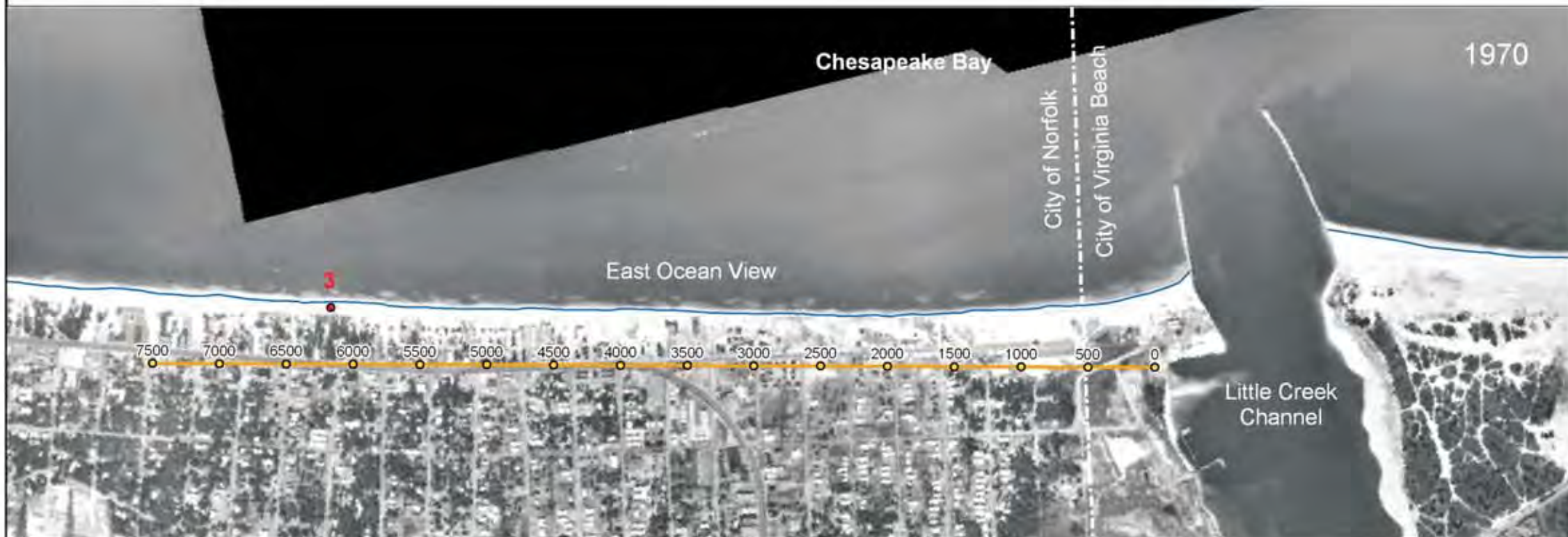
1960

City of Norfolk

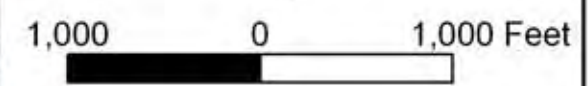
Plate 1

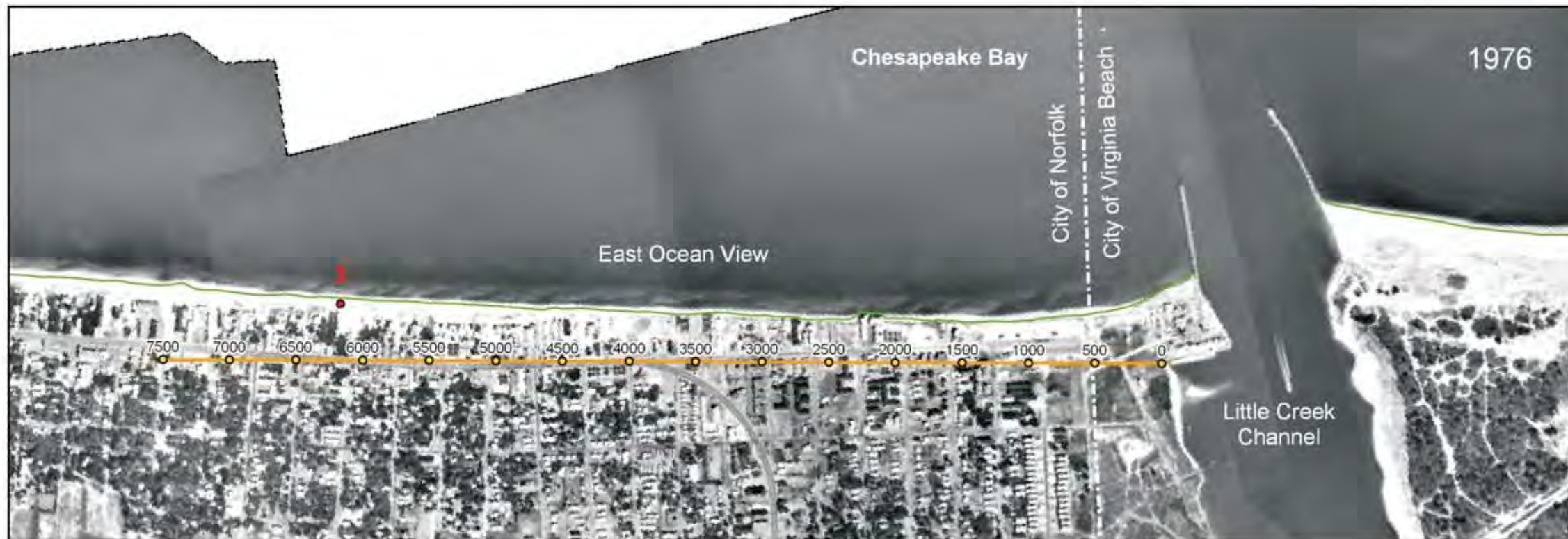
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1960 Shoreline
- 1970 Shoreline



1970



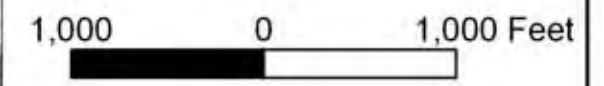
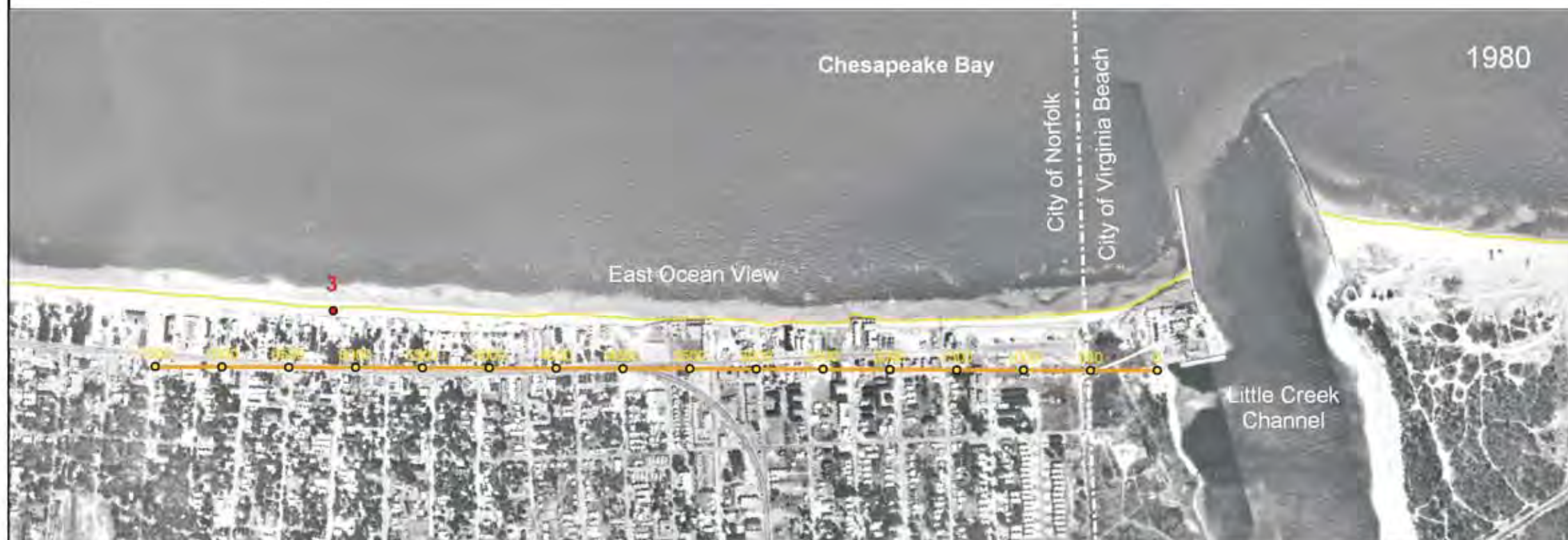


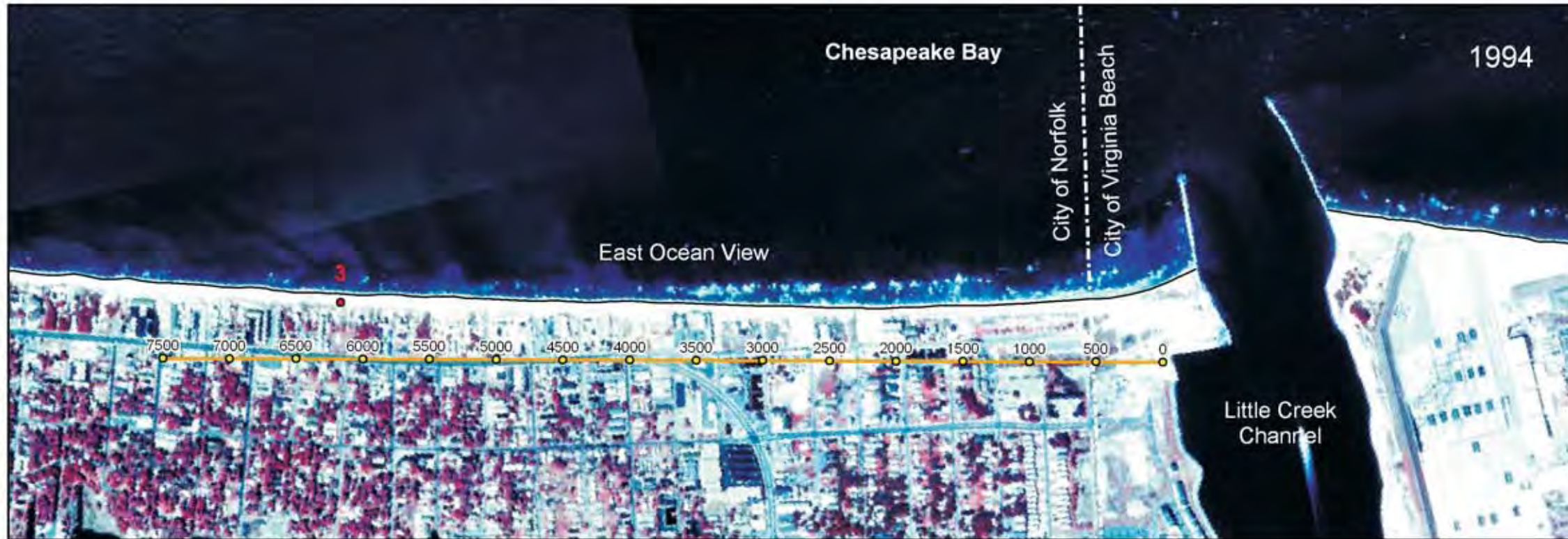
City of Norfolk

Plate 1

Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1976 Shoreline
- 1980 Shoreline





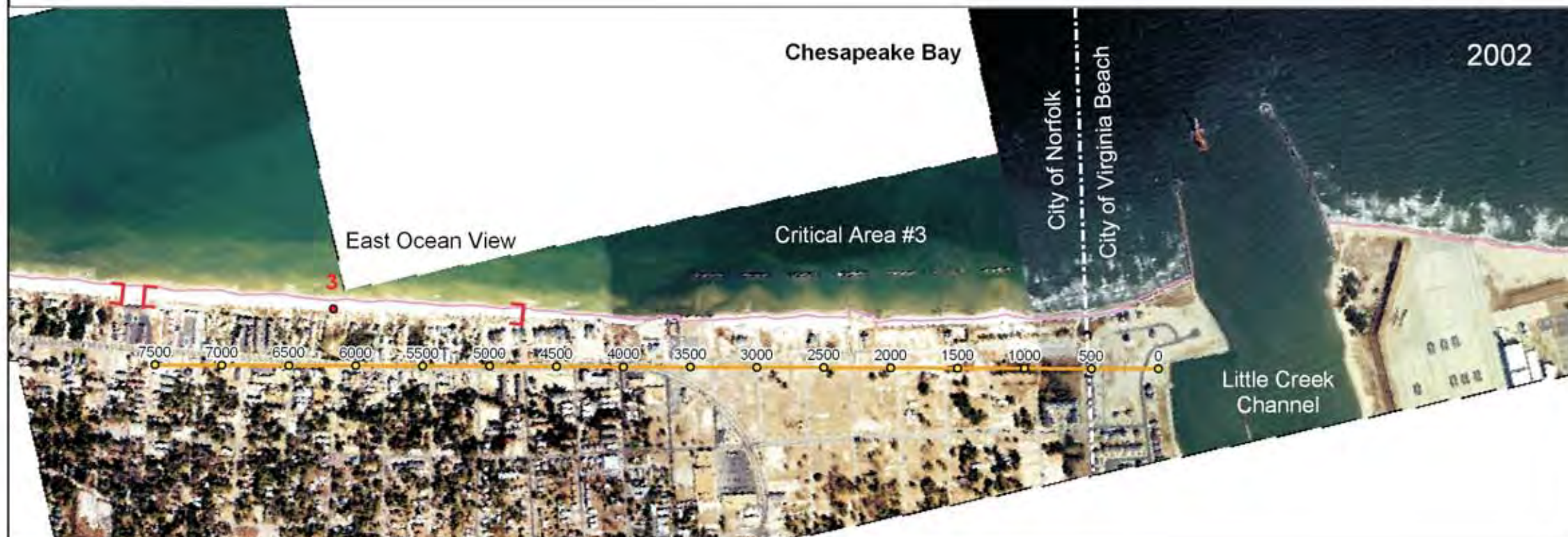
1994

City of Norfolk

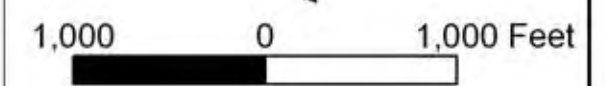
Plate 1

Legend

- Identified Dune Sites
- Dune Site Limits
- Transect Point
- Baseline
- 1994 Shoreline
- 2002 Shoreline



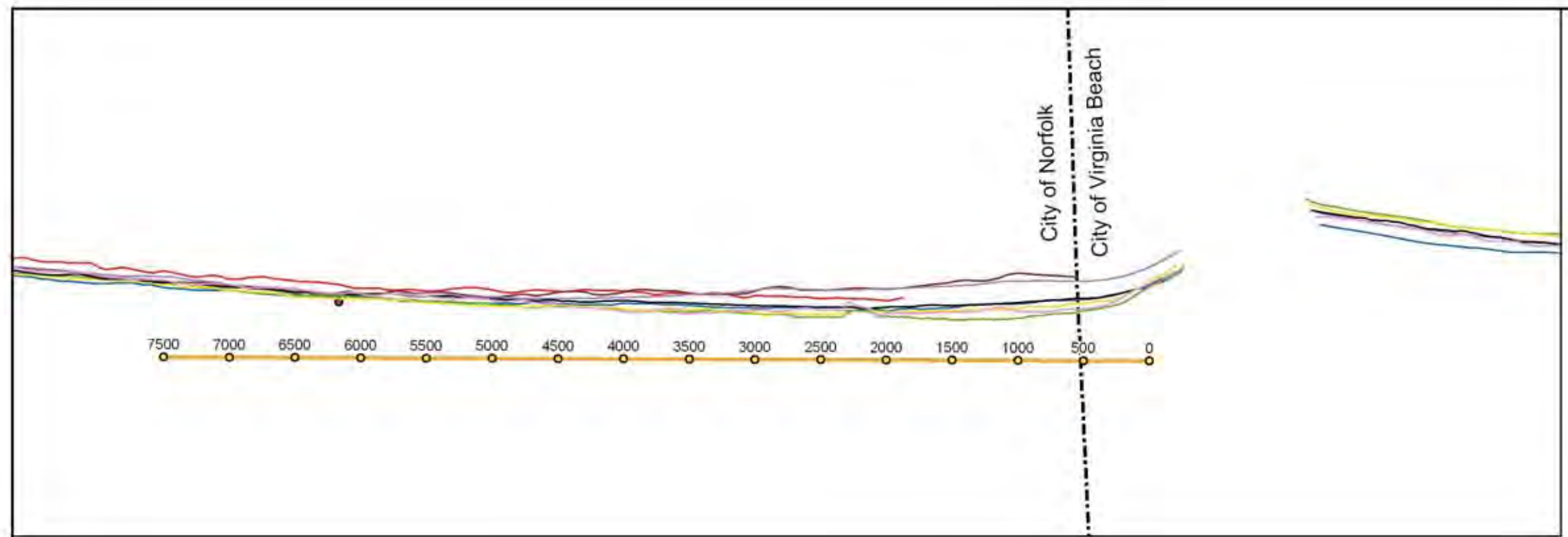
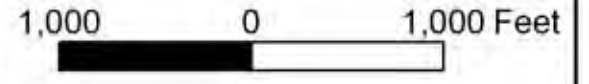
2002



City of Norfolk Plate 1

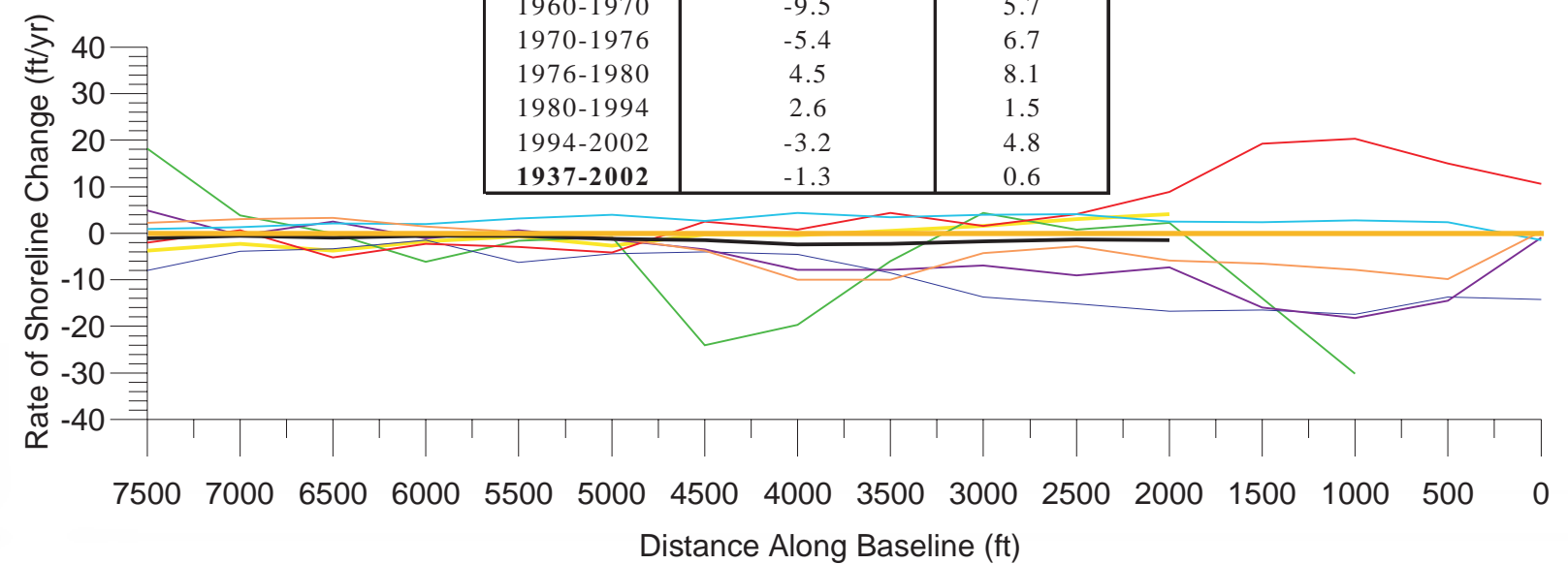
Legend

- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



| Imagery Dates | Average Rate of Change (ft/yr) | Standard Deviation |
|------------------|--------------------------------|--------------------|
| 1937-1958 | -0.5 | 2.5 |
| 1958-1960 | -5.2 | 12.8 |
| 1960-1970 | -9.5 | 5.7 |
| 1970-1976 | -5.4 | 6.7 |
| 1976-1980 | 4.5 | 8.1 |
| 1980-1994 | 2.6 | 1.5 |
| 1994-2002 | -3.2 | 4.8 |
| 1937-2002 | -1.3 | 0.6 |

- 1937-1958
- 1958-1960
- 1960-1970
- 1970-1976
- 1976-1980
- 1980-1994
- 1994-2002
- 1937-2002



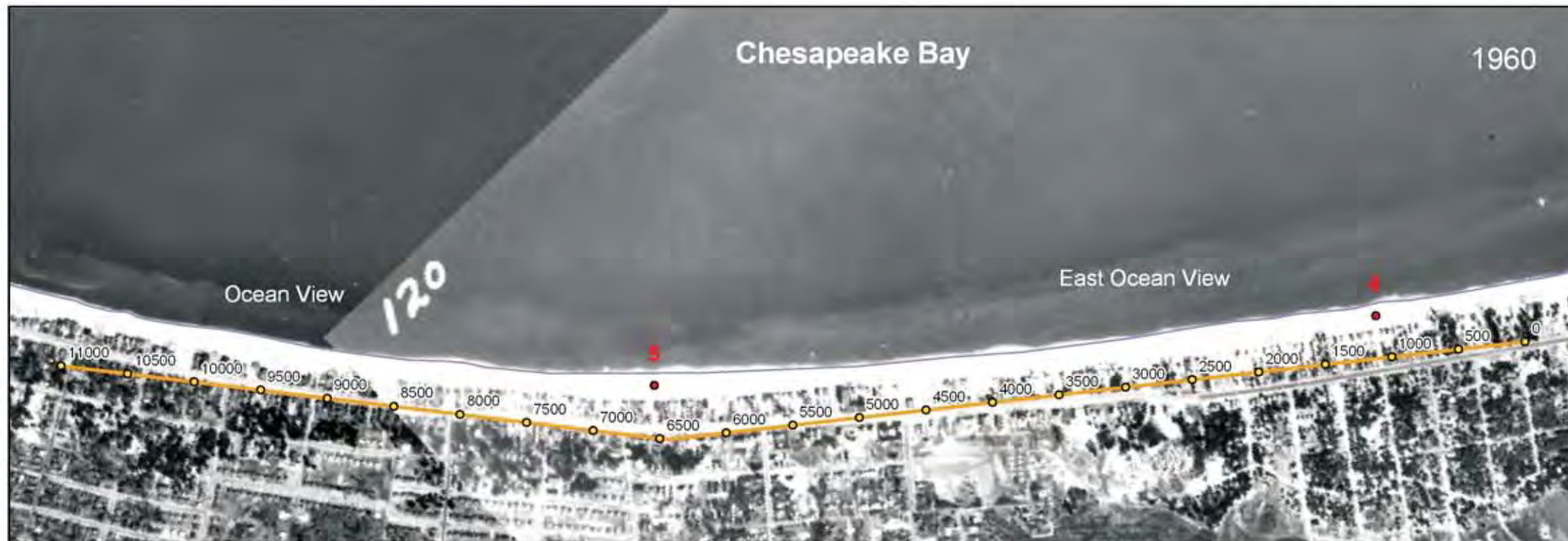


City of Norfolk
Plate 2

Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline



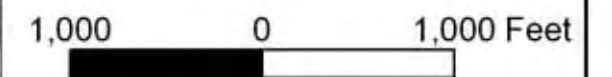
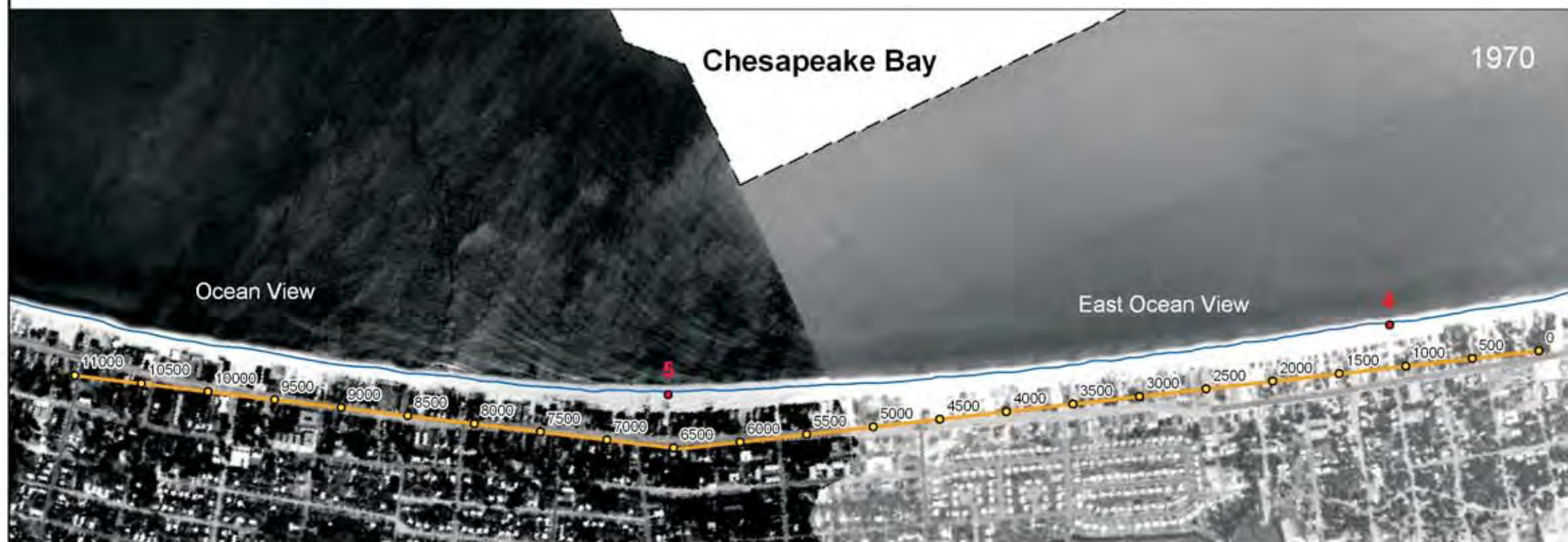


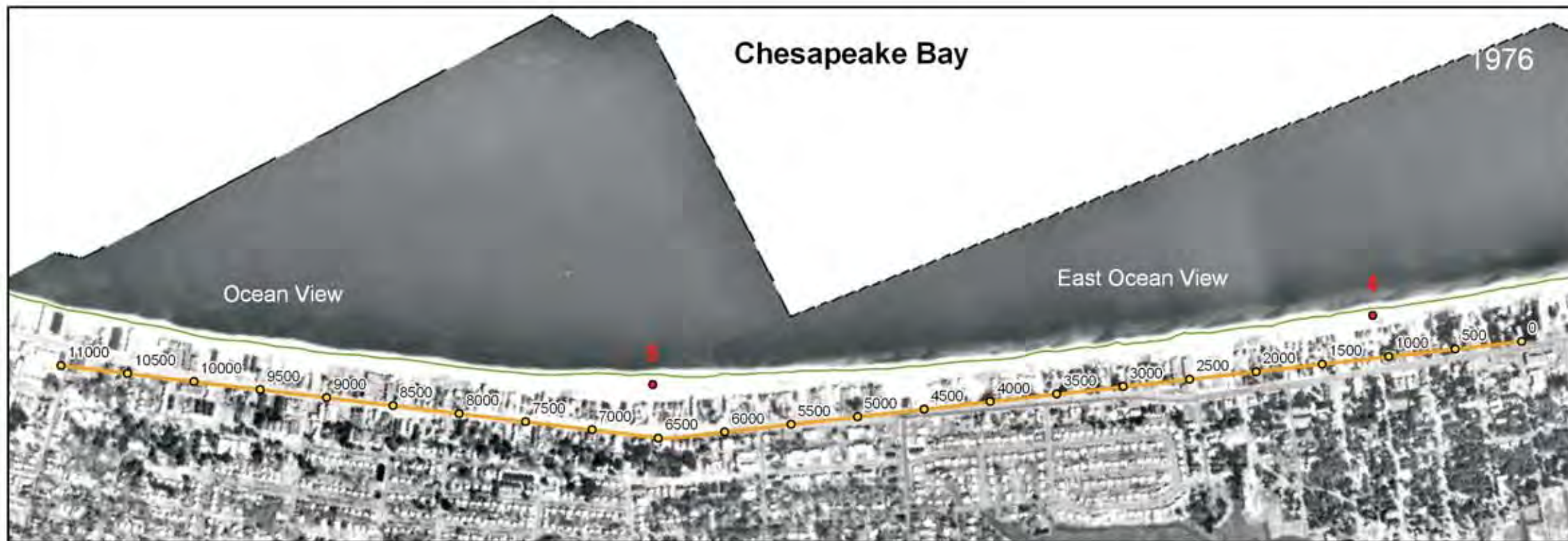
City of Norfolk

Plate 2

Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1960 Shoreline
- 1970 Shoreline






City of Norfolk


Plate 2

Legend

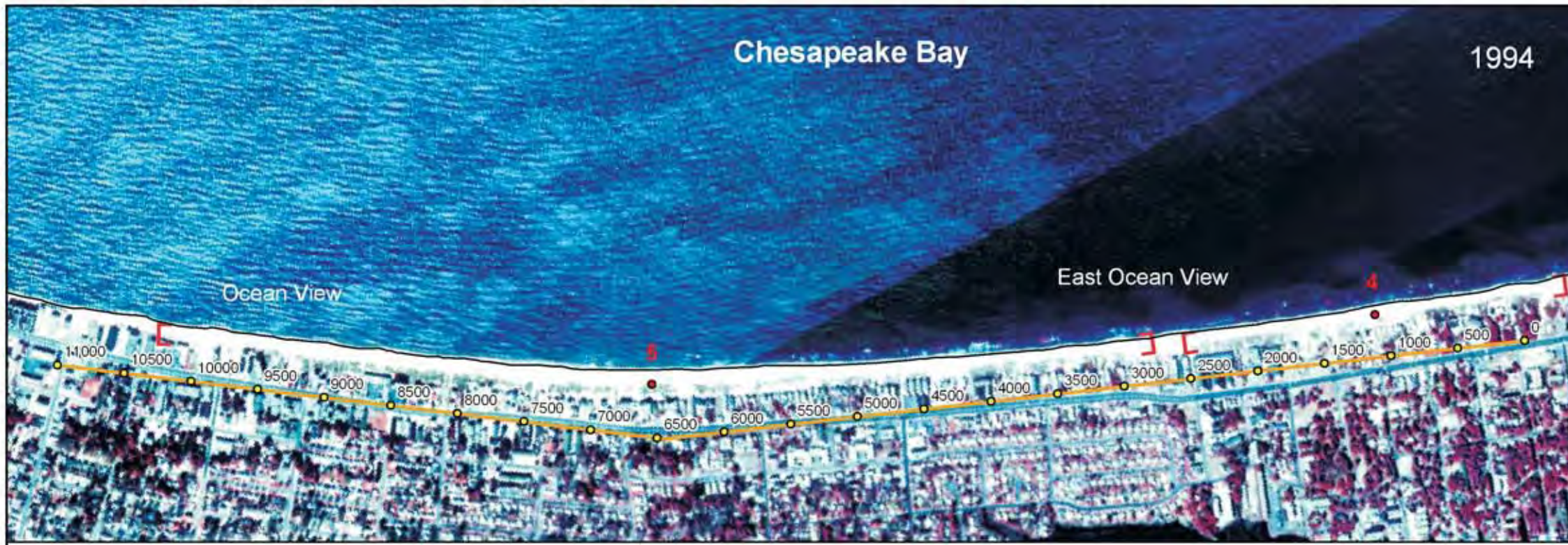
- Identified Dune Sites
- Transect Point
- Baseline
- 1976 Shoreline
- 1980 Shoreline

Shoreline Studies Program
VIMS



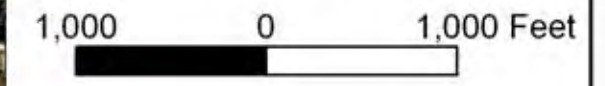
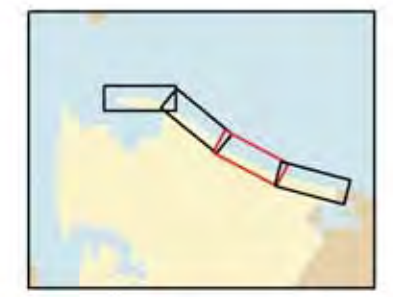
1,000 0 1,000 Feet



City of Norfolk
Plate 2

Legend

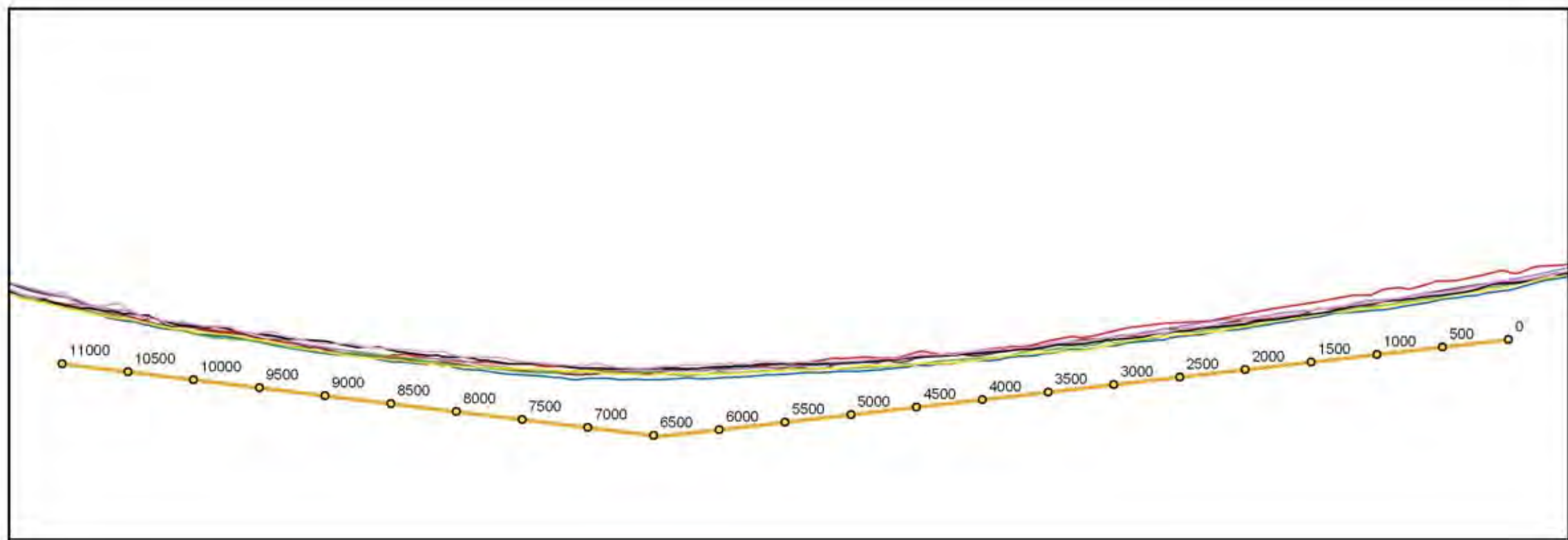
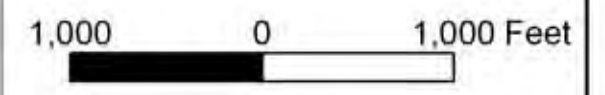
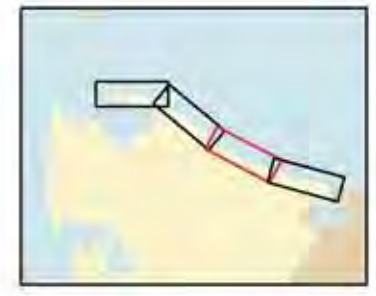
- Identified Dune Sites
- Dune Site Limits
- Transect Point
- Baseline
- 1994 Shoreline
- 2002 Shoreline



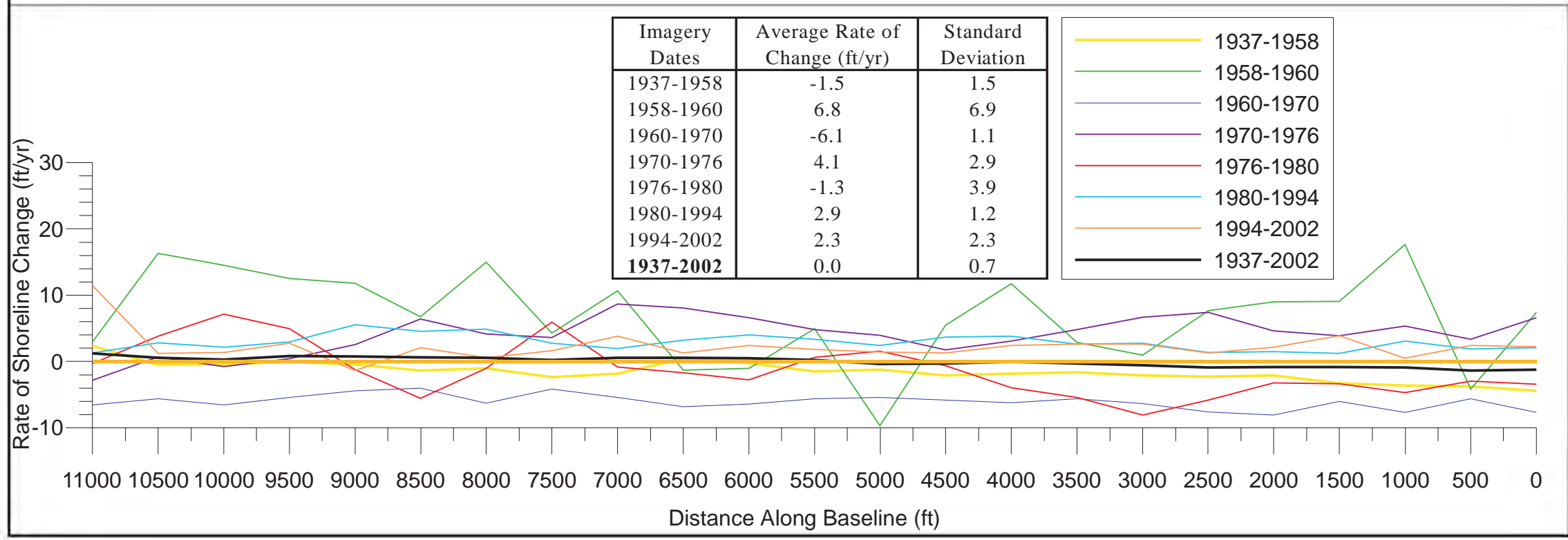
City of Norfolk Plate 2

Legend

- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



| Imagery Dates | Average Rate of Change (ft/yr) | Standard Deviation |
|------------------|--------------------------------|--------------------|
| 1937-1958 | -1.5 | 1.5 |
| 1958-1960 | 6.8 | 6.9 |
| 1960-1970 | -6.1 | 1.1 |
| 1970-1976 | 4.1 | 2.9 |
| 1976-1980 | -1.3 | 3.9 |
| 1980-1994 | 2.9 | 1.2 |
| 1994-2002 | 2.3 | 2.3 |
| 1937-2002 | 0.0 | 0.7 |





City of Norfolk

Plate 3

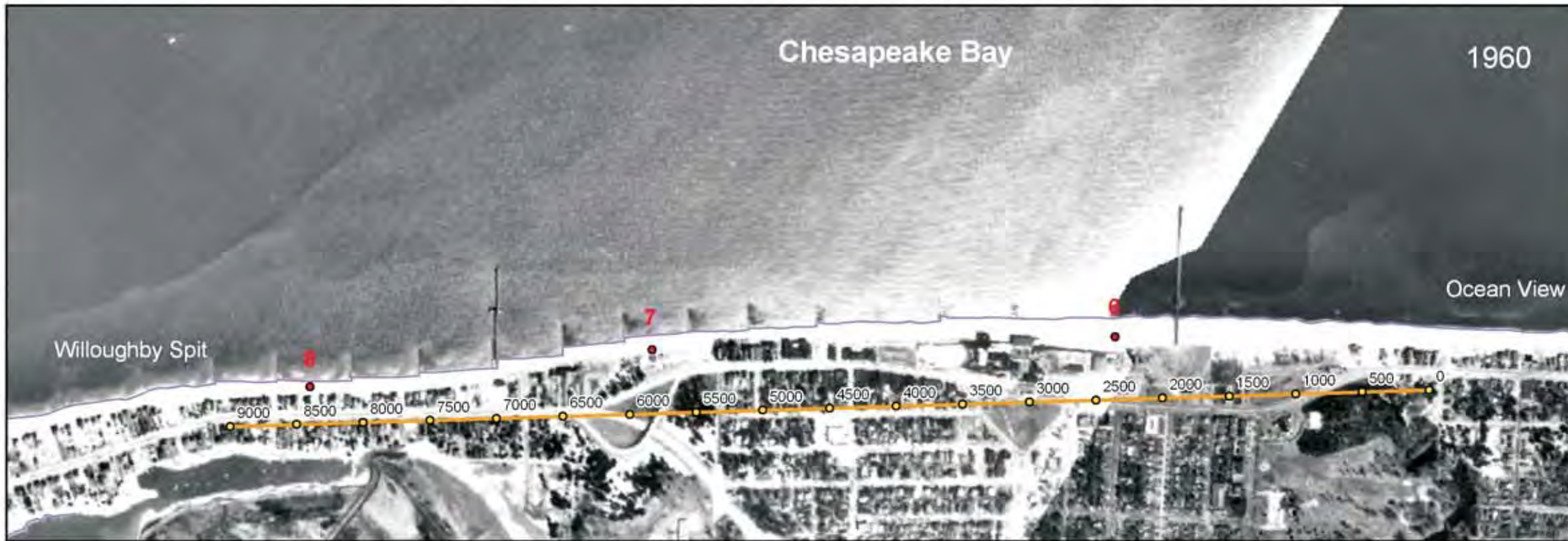
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet



City of Norfolk

Plate 3

Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1960 Shoreline
- 1970 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet




City of Norfolk
Plate 3


Legend

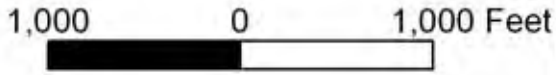
- Identified Dune Sites
- Transect Point
- Baseline
- 1976 Shoreline
- 1980 Shoreline





Shoreline Studies Program
VIMS





1,000 0 1,000 Feet



1994

Ocean View

Willoughby Spit

City of Norfolk Plate 3

Legend

- Identified Dune Sites
- Dune Site Limits
- Transect Point
- Baseline
- 1994 Shoreline
- 2002 Shoreline



2002

Critical Area #2

Ocean View

Willoughby Spit

Shoreline Studies Program
VIMS

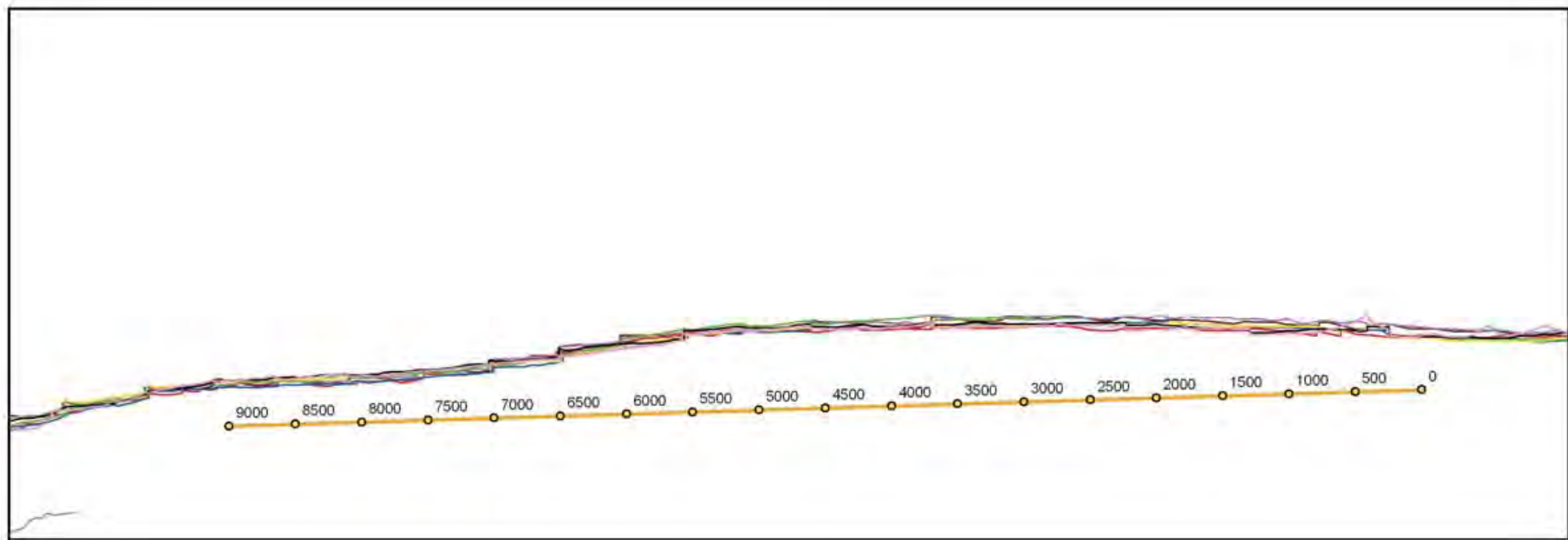
1,000 0 1,000 Feet

City of Norfolk

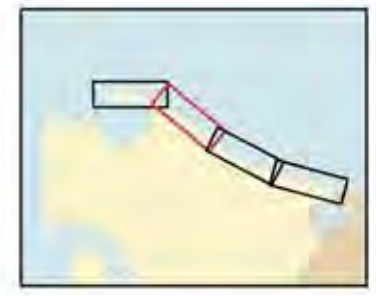
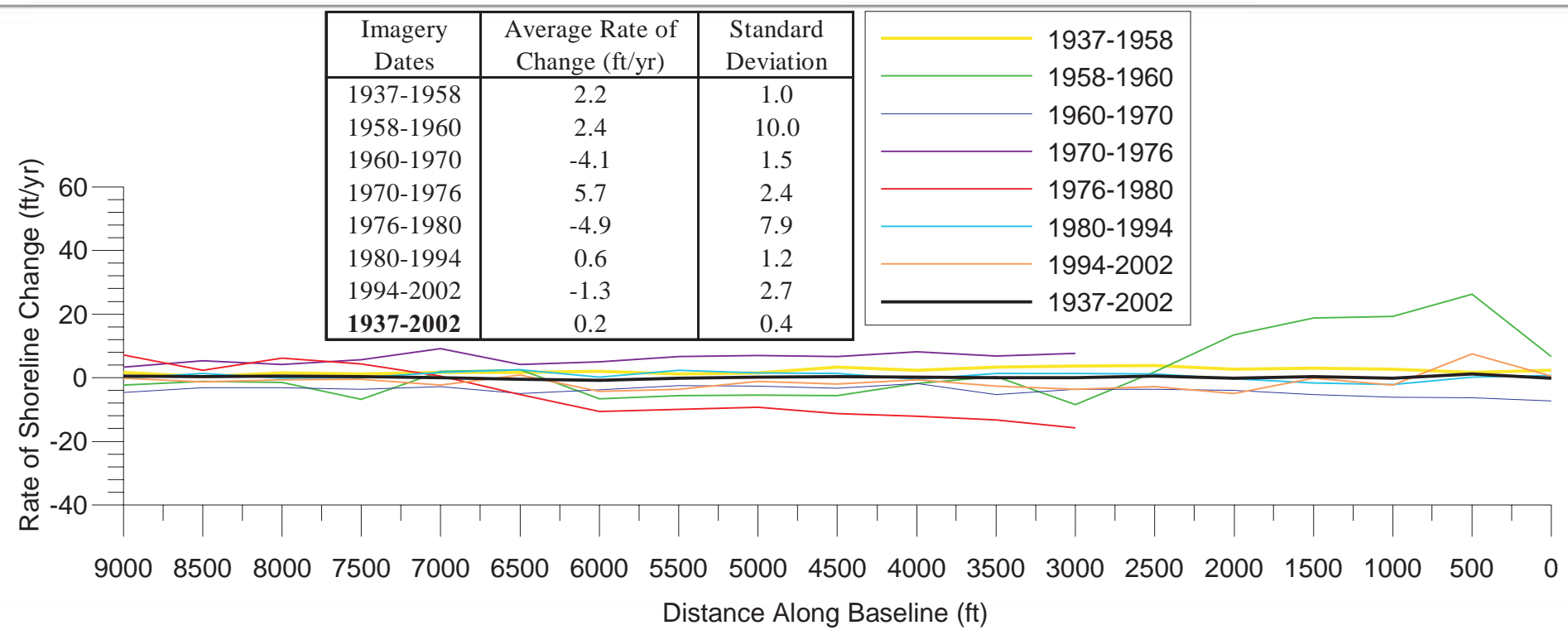
Plate 3

Legend

- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



| Imagery Dates | Average Rate of Change (ft/yr) | Standard Deviation |
|------------------|--------------------------------|--------------------|
| 1937-1958 | 2.2 | 1.0 |
| 1958-1960 | 2.4 | 10.0 |
| 1960-1970 | -4.1 | 1.5 |
| 1970-1976 | 5.7 | 2.4 |
| 1976-1980 | -4.9 | 7.9 |
| 1980-1994 | 0.6 | 1.2 |
| 1994-2002 | -1.3 | 2.7 |
| 1937-2002 | 0.2 | 0.4 |





1937

City of Norfolk

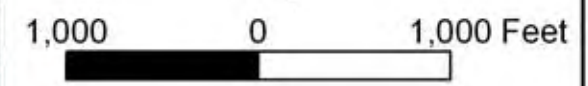
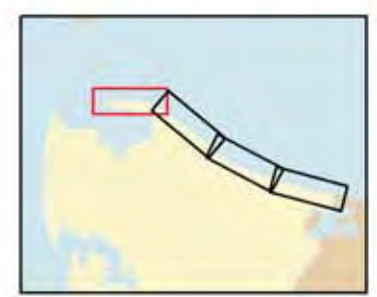
Plate 4

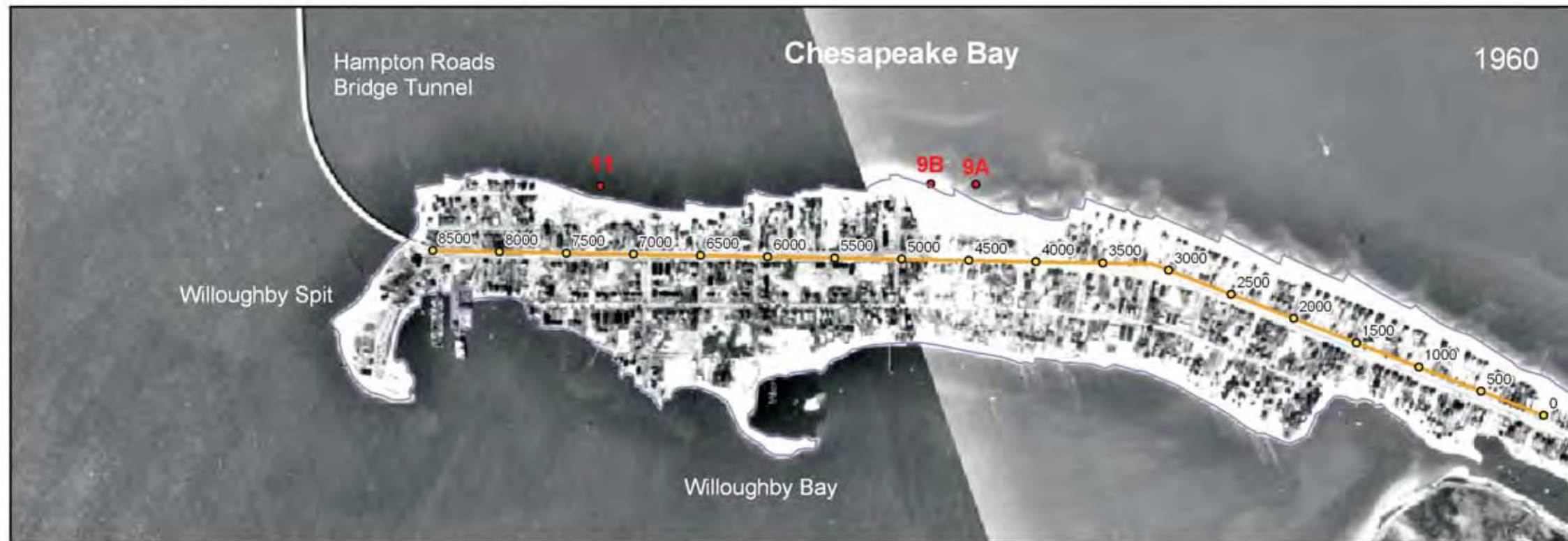
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline



1958



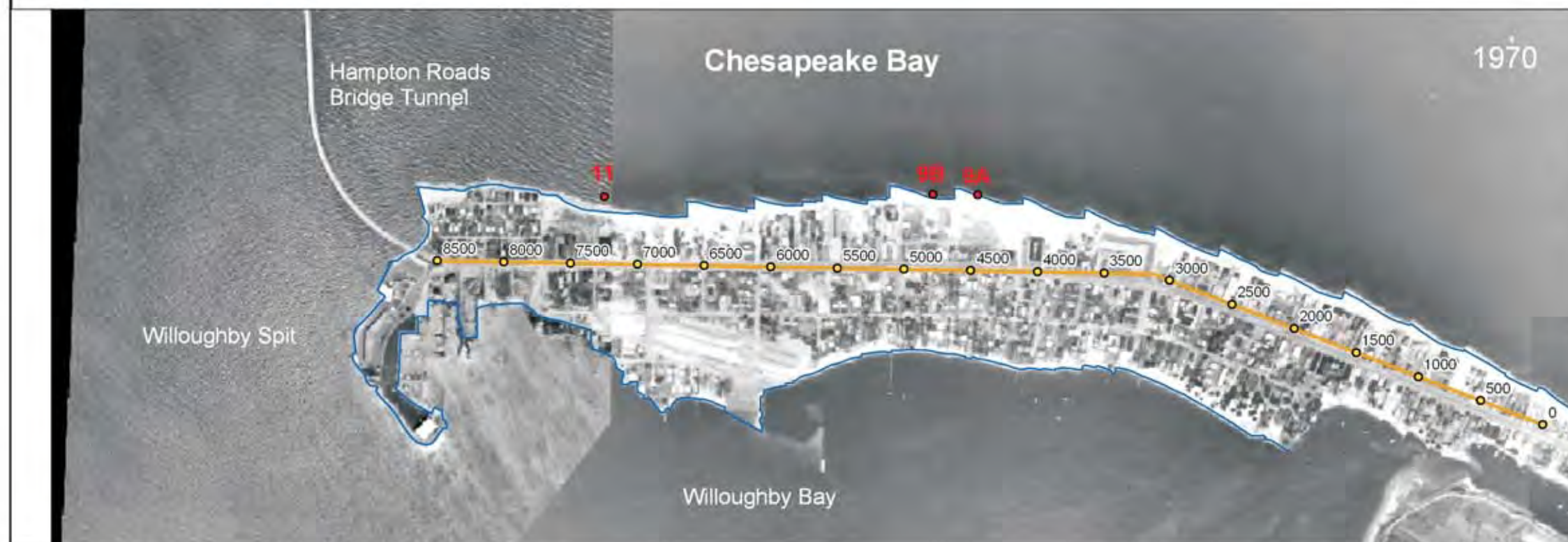


City of Norfolk

Plate 4

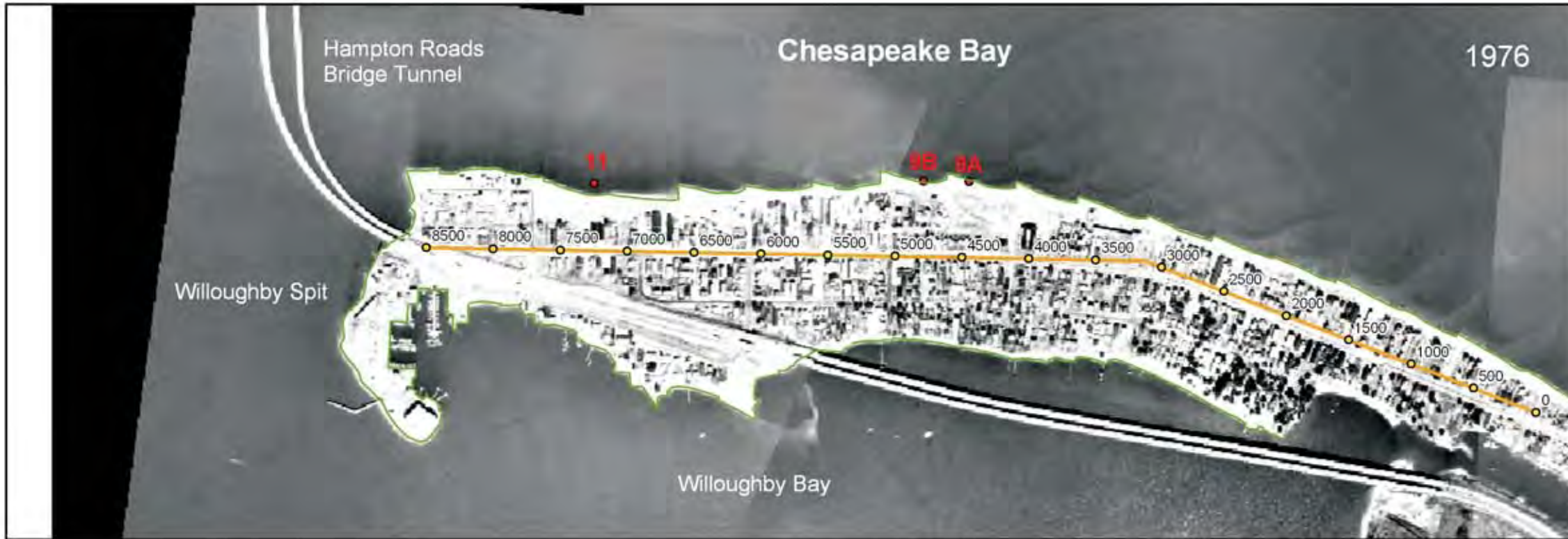
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1960 Shoreline
- 1970 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet



City of Norfolk

Plate 4

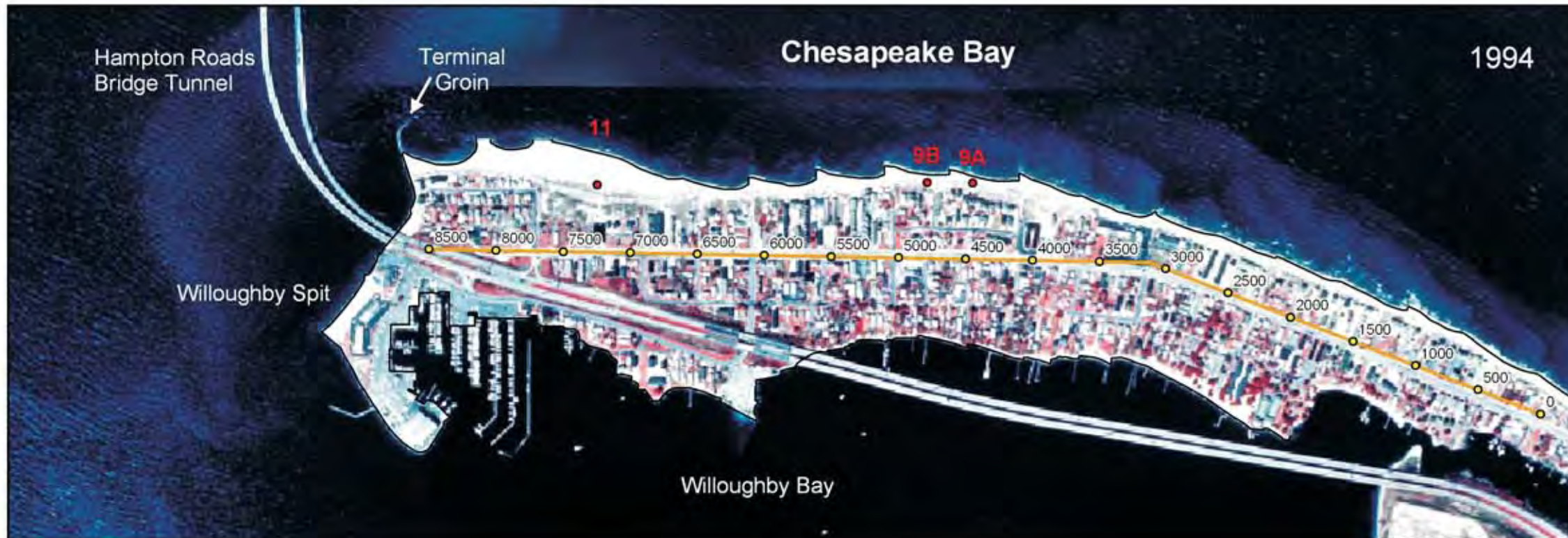
Legend

- Identified Dune Sites
- Transect Point
- Baseline
- 1976 Shoreline
- 1980 Shoreline



Shoreline Studies Program
VIMS

1,000 0 1,000 Feet

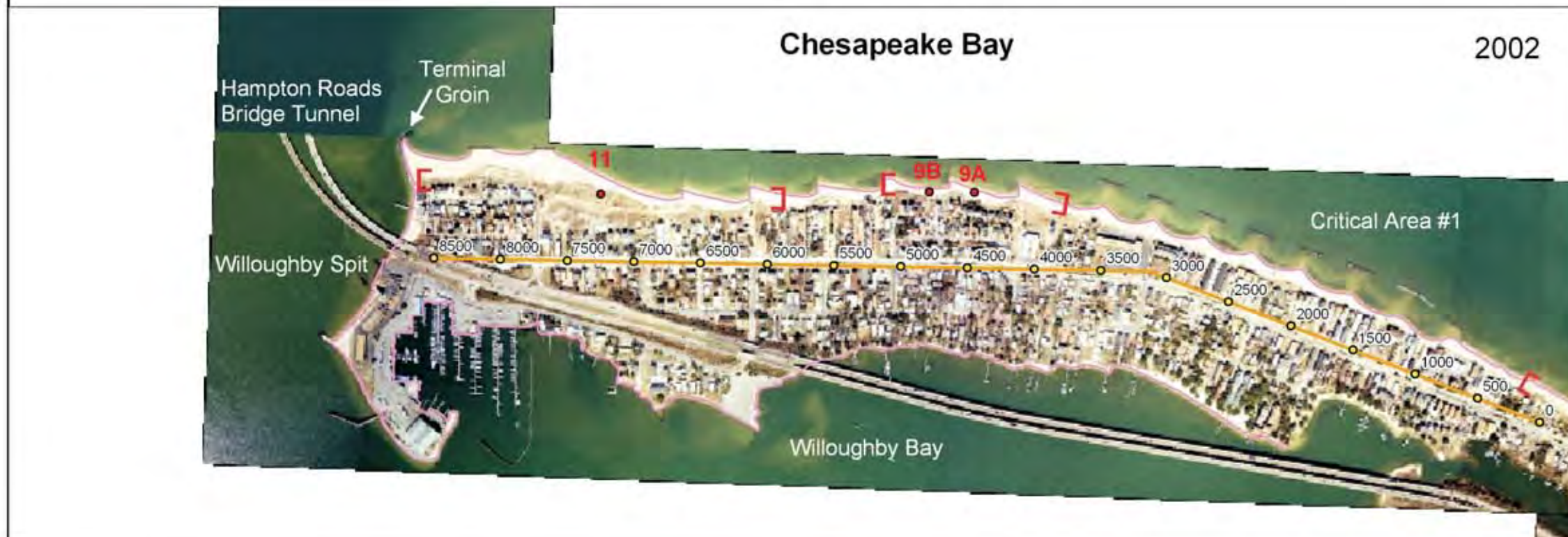


1994

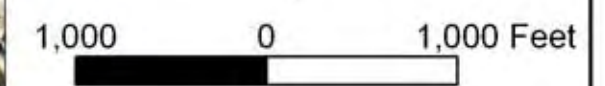
City of Norfolk
Plate 4

Legend

- Identified Dune Sites
- Dune Site Limits
- Transect Point
- Baseline
- 1994 Shoreline
- 2002 Shoreline

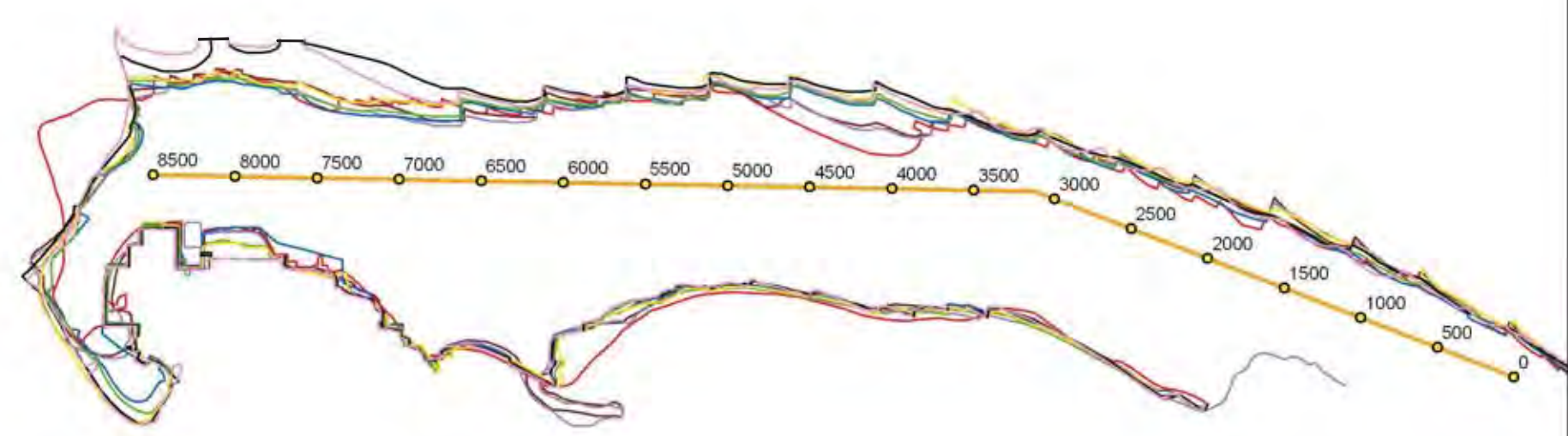


2002



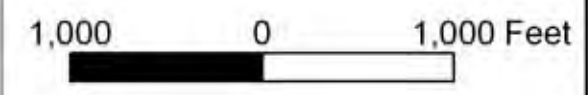
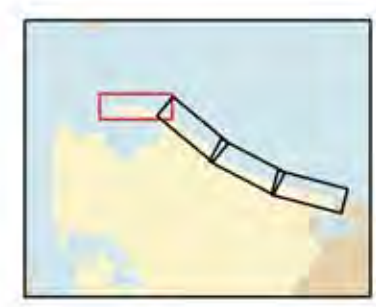
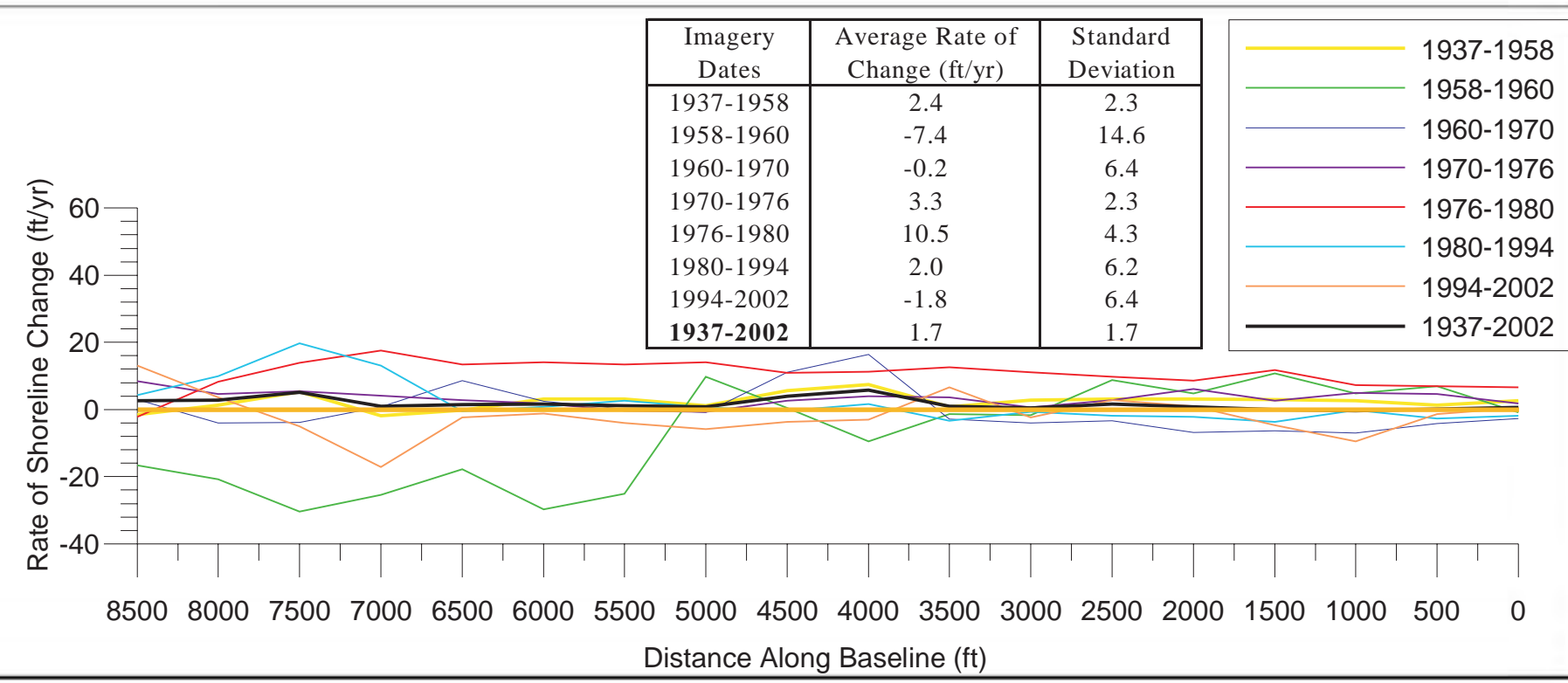
City of Norfolk

Plate 4



Legend

- Transect Point
- Baseline
- 1937 Shoreline
- 1958 Shoreline
- 1960 Shoreline
- 1970 Shoreline
- 1976 Shoreline
- 1980 Shoreline
- 1994 Shoreline
- 2002 Shoreline



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 Norfolk as of 2000.

| Dune Site No. | Location [^] | | Date Visited | Dune Shore Length (Feet) | Primary Dune Site? | Secondary Dune Site? |
|---------------|-----------------------|-----------------|--------------|--------------------------|--------------------|----------------------|
| | Easting (Feet) | Northing (Feet) | | | | |
| 3 | 2,672,300 | 226,250 | Aug 3, 2000 | 2,750 | Yes | No |
| 4 | 2,669,000 | 227,300 | Aug 3, 2000 | 2,780 | Yes | No |
| 5 | 2,663,600 | 229,300 | Aug 3, 2000 | 7,390 | Yes | Yes |
| 6 | 2,658,250 | 233,200 | Aug 3, 2000 | 3,530 | Yes | No |
| 7 | 2,655,050 | 235,550 | Aug 3, 2000 | 680 | Yes | No |
| 8 | 2,653,500 | 236,350 | Aug 3, 2000 | 2,500 | Yes | Yes |
| 9A | 2,647,400 | 238,850 | Aug 3, 2000 | 1,300 | Yes | Yes |
| 9B | 2,647,100 | 238,900 | Aug 3, 2000 | 250 | Yes | Yes |
| 11 | 2,644,800 | 238,650 | Jul 6, 2000 | 2,680 | Yes | Yes |

[^]Location is in Virginia State Plane South, NAD 1927.

Dune site measurements for the City of Norfolk as of 2000.

| Dune Site Measurements | | | | | | | | | |
|------------------------|--------------------------|--------------------|--|---------------|-----------------|--------------------|-----------------------------------|---------------------------|---|
| Site No. | Dune Shore Length (feet) | Primary Dune | | | Secondary Dunes | | | | |
| | | Crest Elev (ftMLW) | Distance from Crest landward to back base (feet) | To MLW (feet) | 2nd Dune Site | Crest Elev (ftMLW) | Primary Crest to 2nd Crest (feet) | 2nd Crest landward (feet) | 2nd Crest seaward to 1st back base (feet) |
| 3 | 2,750 | 21.6 | 46 | 227 | No | | | | |
| 4 | 2,780 | 20.7 | 27 | 166 | No | | | | |
| 5 | 7,390 | 14.7 | 35 | 156 | Yes | 11.3 | 54 | 19 | 18 |
| 6 | 3,530 | 13.9 | 32 | 97 | No | | | | |
| 7 | 680 | 17.8 | 81 | 166 | No | | | | |
| 8 | 2,500 | 11.7 | 24 | 85 | Yes | 11.7 | 53 | 23 | 29 |
| 9A | 1,300 | 9.6 | 20 | 82 | Yes | 10.5 | 44 | 22 | 24 |
| 9B | 250 | 12.1 | 27 | 132 | Yes | 10.9 | 38 | 46 | 11 |
| 11 | 2,680 | 9.7 | 30 | 144 | Yes | 11.6 | 117 | 198 | 87 |

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 Norfolk as of 2000.

| Site No. | Type | Dune Site Parameters | | | | | | | | |
|----------|----------|----------------------|-----------------------------|--------------------|---------|---------------------|--------------------|----------------------|-----------------------|--|
| | | Fetch Exposure | Shoreline Direction of Face | Nearshore Gradient | | Morphologic Setting | Relative Stability | Underlying Substrate | Structure or Fill | |
| | | A | B | C | | D | E | F | G | |
| NF 3 | Man Inf | Open Bay | North | Steep | Bars | Dune Field, linear | Erosional | Upland | Beach Raking | |
| NF 4 | Man Inf | Open Bay | North | Steep | Bars | Dune Field, linear | Stable | Upland | Beach Raking | |
| NF 5 | Man Inf | Open Bay | North | Steep | Bars | Dune Field, linear | Stable | Upland | Beach Raking | |
| NF 6 | Man Inf | Open Bay | Northeast | Steep | Bars | Dune Field, linear | Erosional | Upland | Groin | |
| NF 7 | Man Inf | Open Bay | Northeast | Steep | No Bars | Dune Field, linear | Erosional | Upland | Groin | |
| NF 8 | Man Inf | Open Bay | Northeast | Steep | No Bars | Dune Field, linear | Erosional | Upland | Groin, BW | |
| NF 9A | Man Inf | Open Bay | North | Steep | No Bars | Dune Field, pocket | Erosional | Upland | Groin | |
| NF 9B | Man Inf | Open Bay | North | Steep | No Bars | Isolated, pocket | Erosional | Upland | Groin | |
| NF 11 | Man Made | Open Bay | North | Medium | No Bars | Dune Field, linear | Accretionary | Upland | Groin, BW, Beach Fill | |

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

| Site No. | Long-Term Stability 1937-2002 | Recent Stability 1994-2002 | Near Future Prediction |
|----------|-------------------------------|----------------------------|------------------------|
| 3 | Erosional | Stable | Stable |
| 4 | Erosional | Accretionary | Stable |
| 5 | Stable | Accretionary | Stable |
| 6 | Stable | Erosional | Stable |
| 7 | Stable | Erosional | Stable |
| 8 | Stable | Erosional | Stable |
| 9A | Accretionary | Erosional | Stable |
| 9B | Accretionary | Erosional | Stable |
| 11 | Accretionary | Erosional | Stable |