5-1-1997

Naval Amphibious Base Little Creek, Chesapeake Bay Shoreline Shoreline Management Plan and Officer's Beach Shore Protection Evaluation

C. Scott Hardaway Jr.
Virginia Institute of Marine Science

Donna A. Milligan
Virginia Institute of Marine Science

Jerome P. Y Maa
Virginia Institute of Marine Science

George R. Thomas
Virginia Institute of Marine Science

NAVAL AMPHIBIOUS BASE LITTLE CREEK, CHESAPEAKE BAY SHORELINE

SHORELINE MANAGEMENT PLAN

and

OFFICER'S BEACH SHORE PROTECTION EVALUATION

by

C. Scott Hardaway, Jr.
Donna A. Milligan
Jerome P. -Y Maa
George R. Thomas

Special Report in Applied Marine Science
and Ocean Engineering Number 340

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, VA

May 1997

NAVAL AMPHIBIOUS BASE LITTLE CREEK,
CHESAPEAKE BAY SHORELINE

SHORELINE MANAGEMENT PLAN

and

OFFICER'S BEACH
SHORE PROTECTION
EVALUATION

by

C. Scott Hardaway, Jr.
Donna A. Milligan
Jerome P. -Y Maa
George R. Thomas

Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA

May 1997

EXECUTIVE SUMMARY

The Naval Amphibious Base (NAB) Little Creek shoreline resides in a larger reach of shore that extends from Cape Henry westward to Willoughby Spit. Specifically, NAB Little Creek lies within a discreet subreach that is bounded by Lynnhaven Inlet on the east and Little Creek Inlet and its associated jetties on the west. Most of this shoreline has an average erosion rate of 4.4 ft/yr; the shore just east of Little Creek Inlet has an accretion rate of 1.2 ft/year (Byrne and Anderson, 1978).

The purpose of this report is to assess the rates and patterns of beach change along the Chesapeake Bay shoreline at NAB Little Creek in order to develop a shoreline management plan, particularly for the Officer's Beach. Field survey data, hydrographic survey, historical aerial photos, empirical models and computer models were used to address these objectives.

Both the impinging wave climate, with the consequent littoral processes, and man's actions have had significant impact on the NAB shoreline. Since Little Creek is located at the southernmost end of the Chesapeake Bay, it receives waves generated over the whole north-to-south fetch of the Bay. In addition, westward-traveling ocean swell entering the Chesapeake Bay are refracted such that they impact the NAB shoreline. Anthropogenic impacts have included structures as well as dredging and fill placement that have reshaped the shoreline and nearshore areas of the reach. The Little Creek Inlet East Jetty was built in the late 1920's; Groin #1, near the east property line, was constructed prior to 1971. This littoral barrier caused shoreline instability for about 3,000 ft downdrift of the groin leading to the construction of the second and third groins that define the Officer's Beach. A fourth groin was constructed just west of the Enlisted Beach prior to 1974. Recently, a revetment was built just west of the Officer's Beach. These structures have allowed the Little Creek shoreline to evolve into several long, curvilinear, semi-stable embayments.

In general, net sediment transport is from east to west along the southern shore of the Chesapeake Bay from Lynnhaven Inlet to Willoughby Spit. Das (1974) calculated that net east to west transport along NAB Little Creek shoreline was 36,000 cubic yards/year. Calculations based on the infilling of a dredged "hole" just east of Little Creek Inlet compare favorably to Das's estimate. In 1953/54, 1,240,000 cubic yards of material was dredged from a hole about 7,000 ft long and 400 ft wide and which extended into 25 ft deep water. Between 1965 and 1980, the "hole" infilled at a rate of 44,800 cubic yards/year; between 1980 and 1996, it filled at a rate of 36,200 cubic yards/year. Presently, the hole has filled in such that it cannot be distinguished from the surrounding bathymetry.

These relationships and analyses were integrated into a shoreline management plan. This plan is based on the Navy's desire to prepare for long-term shoreline changes as well as potential changes in landuse. By utilizing the geomorphic shore planforms that have evolved through time, headland control can be achieved through enhancement of the existing groin features with stone breakwaters and the addition of structures at strategic points. A "leaky" system is proposed to minimize downdrift impacts. The breakwaters would have a low profile so that sand would attach at a reduced elevation so that limited transport could occur. They would also be broad in order to attenuate wave energy during storms. In addition, spurs would be used on several of the groins in place of a breakwater. At the Officer's Beach, groin and revetment rehabilitation also is recommended.

Two computer models were utilized in order to evaluate the effectiveness of the proposed shoreline management plan. GENESIS and Model Tombolos are one-line numerical models that predict shoreline change. GENESIS was used on the entire proposed management plan; the grid created for this model extended from Little Creek Inlet to the Chesapeake Bay Bridge Tunnel. Model Tombolos permits the formation and growth (or decay) of tombolos in the lee of impermeable offshore breakwaters; it's grid only consisted of the vicinity of the Officer's Beach.

Both models require a series of wave conditions, specifically wave height, period and direction, as input. Wave data from a gage located at Thimble Shoals were used to create a time series. Since there is complex bathymetry between the wave gage and the Little Creek shoreline, RCPWAVE was used to transform the wave series. It is impractical to transform all possible wave events recorded by the gage so the data in the time series were banded and 62 wave conditions were run through RCPWAVE. From the RCPWAVE output, two separate artificial time series were created -- one for GENESIS and one for Model Tombolos.

GENESIS was run on the 1996 shoreline over a three year simulation period for three different scenarios. Without any additional structures placed along the shoreline, erosion would continue downdrift of groins #3 and 4. When a breakwater is added in front of the revetment (Plan structure #4), the shoreline offset downdrift of the revetment is alleviated and the chance of flanking is reduced. However, impacts are translated alongshore. Adding Plan structure #3 at Point "A" would create two stable embayments along this section of shore.

When Model Tombolos was run on the proposed management plan at the Officer's Beach, the model predicted that placement of breakwaters off the groins that delineate the Officer's Beach would result in a stable planform at this beach and accretion to the east. Since sand transport would be reduced to the west the model indicated severe erosion just west of the Officer's Beach. However, this region has already been partially addressed by a revetment constructed in 1994 which holds the shoreline in place. Unfortunately, as sand is locked up in the beaches, the erosion problem translates toward the west.

To further evaluate beach planform evolution at the Officer's Beach proposed breakwaters, Model SEB (Static Equilibrium Bay) was used. This model utilizes empirical relationships of bay shape to the dominate direction of wave approach. Selected output from RCPWAVE analysis were used for this effort.

Integration of these analyses with the Navy's long- and short-term goals resulted in the development of a Shoreline Management Plan for the NAB Little Creek. This Plan enhances the existing groins at the Officer's Beach with spur breakwaters and adds two separate structures between the Officer's Beach and the Enlisted Beach to provide headland control along the whole length of the Base shore.

ACKNOWLEDGMENTS

Shoreline position data were obtained from Das (1974) and Byrne and Anderson (1978). The U.S. Army Corps of Engineers and U.S. Navy supplied aerial imagery for this report. Thanks to John Boon for taking the time to provide the color contour plot of the study area. Kea Duckenfield put in a lot of time on some of the figures and calculations. Thanks to William Niven and Catherine Zielske for input to the report from a Navy perspective.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. Background and Purpose

The Naval Amphibious Base (NAB or Base) Little Creek shoreline resides in a larger reach of shore that extends from Cape Henry westward to Willoughby Spit (Figure 1). Specifically, NAB Little Creek lies within a discreet subreach that is bounded by Lynnhaven Inlet on the east and Little Creek Inlet and its associated jetties on the west. Impacts to this reach include the creation and maintenance of Little Creek Inlet, maintenance dredging of Lynnhaven, periodic beach nourishment within the subreach from material related to dredging of both inlets, and the installation of groins on the Bay shoreline of NAB Little Creek.

Byrne and Anderson (1978) found an erosion rate of 4.4 ft/yr (1.3 m/yr) for the shoreline 0.8 miles (1.3 km) east of Little Creek Inlet to the Chesapeake Bay Bridge Tunnel. They also found that the shoreline from Little Creek Inlet east jetty to 0.3 miles (0.5 km) east accreting at rate of 1.2 ft/yr (0.4 m/yr). A detailed analysis of the Virginia Beach shoreline in this region (Owen *et al.*, 1978) described accretion along the shoreline fronting the noise berm west to the jetty, and there was little or no change along the shoreline between the berm and the Enlisted Beach (E.B.). From the E.B. to the west edge of the golf course, moderate erosion occurred. The rest of Little Creek had severe erosion (Owen *et al.*, 1978). Today, the severest erosion occurs along 2,000 ft (600 m) of shoreline west of the Officers Beach (O.B.).

The net direction of littoral or sand transport in the subreach is to the west with a minor reversal just west of Lynnhaven Inlet. Maintenance dredging of Lynnhaven Inlet has occurred over the years and, occasionally, sandy dredge material is placed along the Ocean Park shoreline where it is subsequently transported westward and offshore. These dredge deposits have, no doubt, worked their way toward the Base shoreline as part of the overall littoral transport system. The Little Creek channel, jetties, and groins have all acted to modify the natural littoral processes and have brought the shore morphology to its present state where significant erosion occurs along the eastern third of the Little Creek shoreline.

The purpose of this report is twofold: 1) to assess the rates and patterns of beach change along the Chesapeake Bay shoreline at NAB Little Creek in order to develop a shoreline management plan and 2) to address beach erosion at the Officer's Beach as well as to recommend strategies for beach stabilization and protection to upland improvements. The Officer's Beach became unstable and erosional after the west groin was lowered as part of the revetment rehabilitation project in 1994.

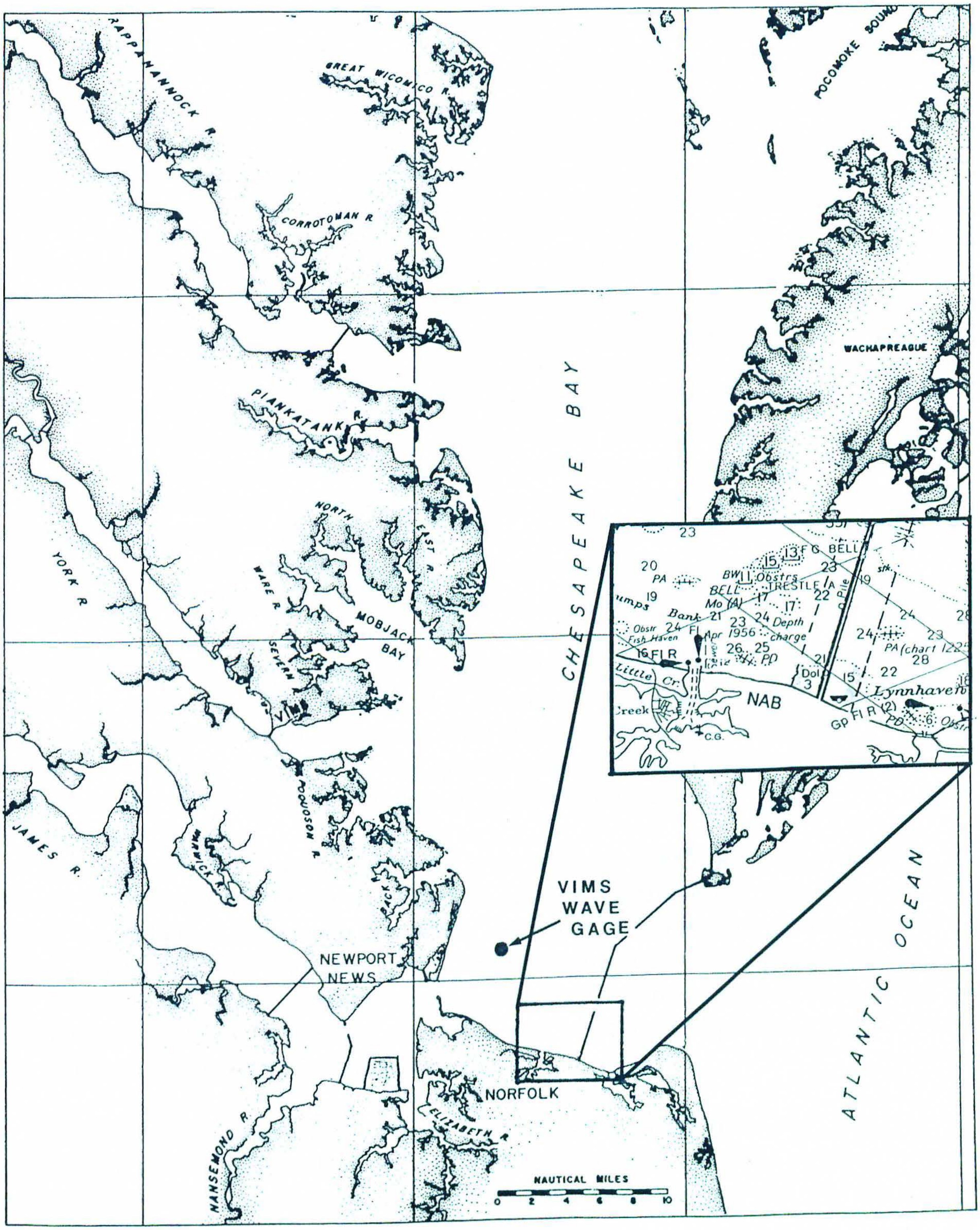


Figure 1. Study site location with wave gage location.

Recommended strategies at the Officer's Beach are part of the overall shoreline management plan at Little Creek.

B. Shore Management Strategy

There are four basic approaches to shoreline management: 1) No action; 2) Defend an erosional area with a defensive structures such as bulkheads, seawalls or revetments; 3) Maintain and/or enhance existing shore zone features such as beach and dunes that presently offer limited protection; or 4) Create a shore zone system of beaches and dunes, generally using headland control with stone breakwaters.

A management strategy based on the first approach listed above may be appropriate in areas where no property improvements are threatened by erosion and/or the shoreline is stable or accretional; although accretion in the form of a spit or a widening beach may pose problems to navigation or access to the waterfront. Defending an erosional area generally means protecting upland structures threatened by erosion and not the beach in front of the structure. Defensive structures such as seawalls and revetments can, in some cases, increase erosion rates in front of it and, in many cases, alter the natural beach profile. Approaches 3 and 4 are similar in that a shore zone system is either maintained or created along an entire shoreline reach. Generally, this is accomplished with groins, breakwaters and/or headland control. Beach nourishment or maintaining beach features are part of this approach.

Headland control is a concept that can allow long stretches of shoreline to be addressed in a more cost/effective way. It is accomplished by accentuating existing features or creating permanent headlands that allow adjacent, relatively wide embayments to become stable. This can greatly reduce the cost of managing the shoreline reach by reducing the linear feet of structure necessary.

Headlands generally are created with a breakwater. Offshore breakwaters are considered an "offensive" strategy to shoreline erosion control since they address the impinging waves before they reach the shore. However, breakwaters, groins, seawalls and beach nourishment all may play a part in developing a shoreline protection system. The dimensions and position of any shore protection system are dependent on wave climate, costs, what is being protected and what level of protection is desired (e.g. for a design storm surge and wave height).

The use of breakwaters for headland control has been tested in the Chesapeake Bay. Since 1981, over 60 attached or headland breakwater systems have been built in the Chesapeake Bay for the purposes of shoreline erosion control and maintaining recreational beaches. Hardaway *et al.* (1991) evaluated 15 breakwater systems in terms of numerous parameters including breakwater length, gap, distance offshore and the indentation of the adjacent embayments. These breakwater installations have also shown that a stable beach planform can exist with subtidal attachments. The advantage to a subtidal attachment is that wetland habitat is increased in the breakwater's lee, but beach stability is not compromised.

Of the four aforementioned shoreline management strategies, the use of headland control is the most appropriate to the over 2 miles (3 km) of shoreline at NAB. The proposed shoreline management plan was developed with input from the Navy and is the first step in addressing beach stability for long term shoreline protection, recreation and an environment for military training.

II. APPROACH and METHODOLOGY

A. Limits of the Study Area

The study area extends from Lynnhaven Inlet to Little Creek (Figure 1) and approximately 10 km (5.4 nm) bayward. Overall, the study area extends from Cape Henry to Little Creek Inlet; however, only the shore reach between Lynnhaven and Little Creek Inlets have been subjected to analysis. The shore management plan only includes the NAB's Chesapeake Bay shoreline.

A bathymetric grid of the study region was compiled using data from a hydrographic survey, beach profile data, NOS digital data, and a digitized shoreline from a navigational chart. The plot (Figure 2), which extends from Cape Henry to Little Creek Inlet and about 10 km (5.4 nm) bayward, shows the bathymetric conditions affecting the waves that impact Little Creek shoreline. Obvious on the plot is the dredged Thimble Shoals channel, the nearshore channel running along the southern shore of the Bay called the Beach channel by Ludwick (1987), the scour around the tunnels of the Chesapeake Bay Bridge Tunnel (CBBT) as well as the large shoal in the vicinity of where the Bridge Tunnel extends into the Bay.

B. Data Preparation

Field survey data, hydrographic survey, historical aerial photos, empirical models and computer modeling were used to address the aforementioned report objectives. Data analyzed for this report include beach profiles surveyed by the City of Virginia Beach. The vertical and horizontal controls are based on benchmarks established by the City; the vertical datum is mean sea level (MSL). The City of Virginia Beach profiled NAB from 1981 to 1985. It's profiles along the Chesapeake Bay shoreline subreach are shown on Figure 3. These profiles were analyzed for shoreline change. Historic and recent aerial images also were evaluated to map changes in shoreline position.

VIMS performed a hydrographic survey using differential Global Positioning System (GPS) and tide-correlated fathometer and established profiles for surveying NAB Little Creek. Appendix I shows both VIMS and City profile locations, lists their coordinates, and contains the profile plots. These data were used with the hydrographic survey and NAB topographic data to create a contour map of the shoreline and nearshore of NAB. Sediment sampling was done on O.B. profiles (Figure 3) numbered F2, E4, and D2.

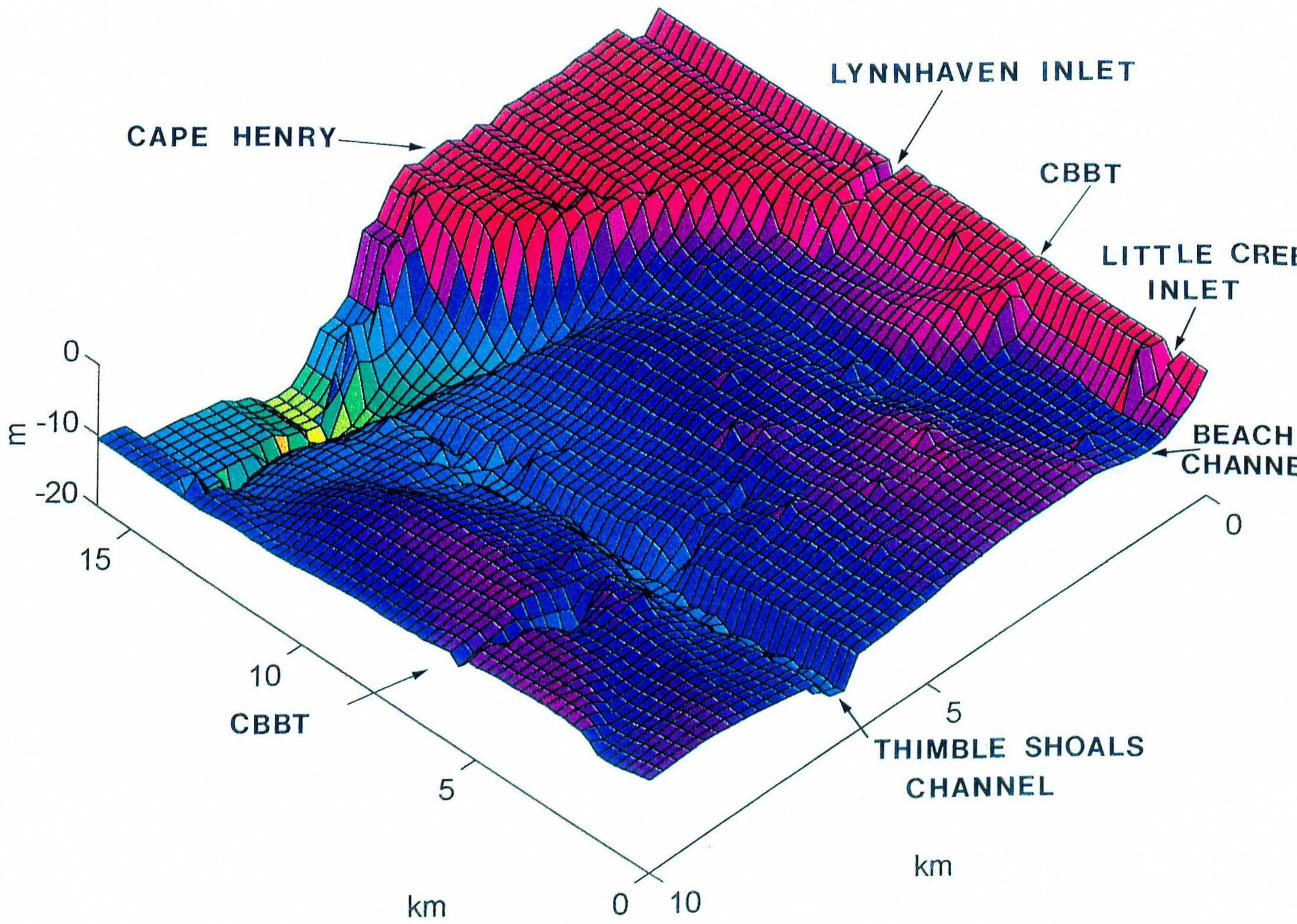


Figure 2. Contour plot of the study location.

Figure 3. Virginia Beach and VIMS profile line locations.

Figure 4 gives a pictorial definition of the profile terminology used in this report particularly in the analysis of the Virginia Beach survey data. The nearshore data were calculated by taking into account all the sand below MLW to the end of each profile. The subaerial beach occurs above MLW and is divided into beach face and backshore regions.

For this report, the hydrodynamic forces acting along the NAB beaches were evaluated using RCPWAVE, a computer model developed by the US Army Corps of Engineers (Ebersole *et al.*, 1986). RCPWAVE is a linear wave propagation model designed for engineering applications. This model computes changes in wave characteristics that result naturally from refraction, shoaling, and diffraction over complex shoreface topography. To this fundamental linear theory based model, oceanographers at VIMS have added routines which employ recently developed understandings of wave bottom boundary layers to estimate wave energy dissipation due to bottom friction (Wright *et al.*, 1987). Other computers models used in the analysis of the shoreline were GENESIS (Hanson and Kraus, 1989 and Gravens *et al.*, 1991) and Model Tombolos (Suh and Hardaway, 1994).

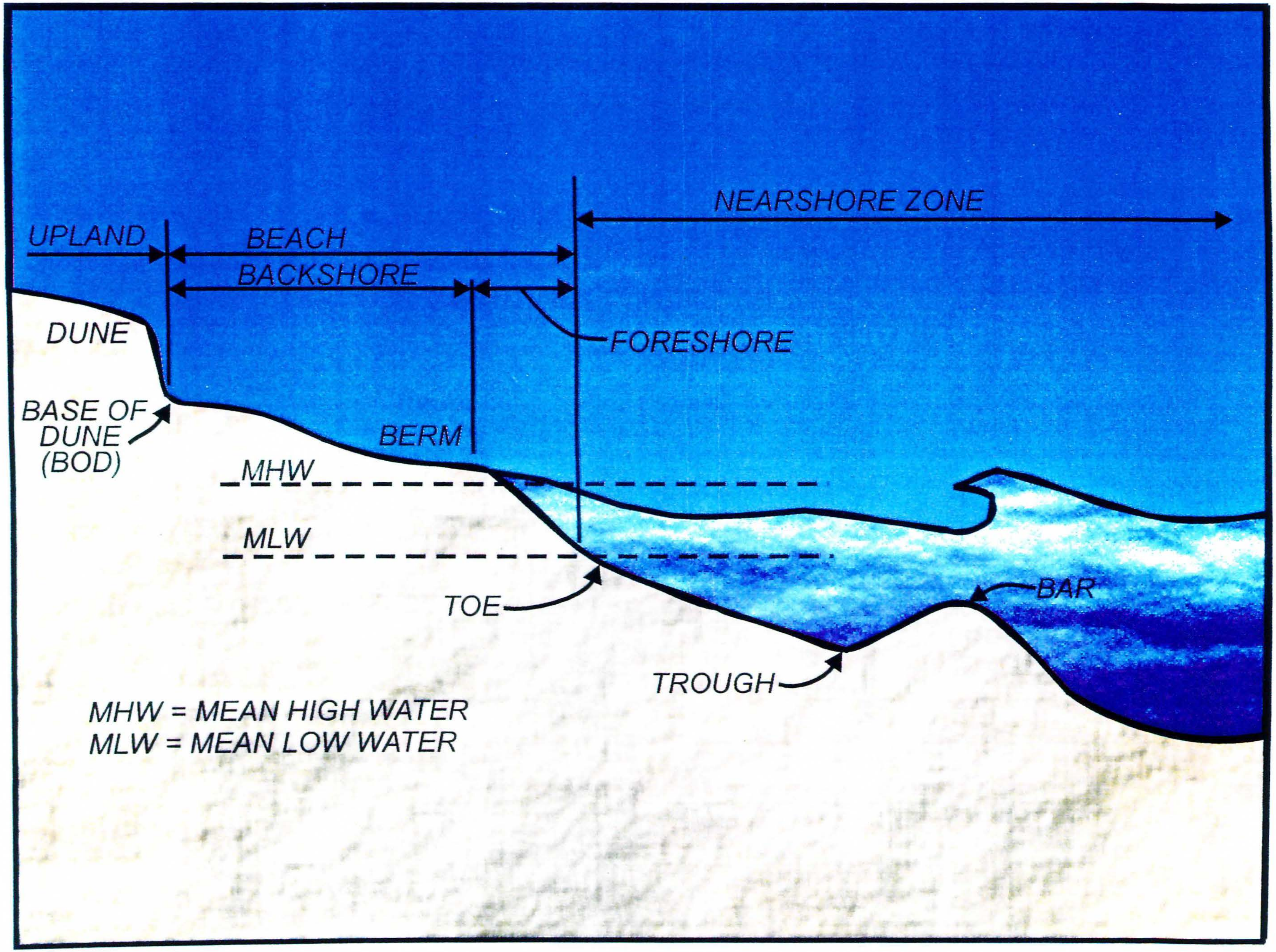


Figure 4. Typical beach profile demonstrating terminology used in report.

III. COASTAL SETTING

A. Hydrodynamic Processes

1. Wave Climate

The wave climate within lower Chesapeake Bay has been the focus of recent study (Boon *et al.*, 1990; Boon *et al.*, 1992; Boon *et al.*, 1993). VIMS has deployed a bottom-mounted wave gage in the Thimble Shoals area of lower Chesapeake Bay since 1988 about 6 nm (11 km) northwest of NAB (Figure 1). The wave and current data sensed and recorded at this station are used as input of the RCPWAVE model to obtain wave conditions at Little Creek.

One of the unique features reported in the Thimble Shoals wave data set is the bimodal distribution of wave directions reflecting dual energy sources which impact this area. Boon *et al.* (1990) found that 40 to 60% of all waves measured each month were between 0.67 feet (0.2 m) and 1.97 feet (0.6 m) in height. During late spring and summer months, about 80% of the measured waves were generated outside the Bay and directed west-northwest. During fall and winter months, only slightly more than half of the 0.67 feet (0.2 m) to 1.97 feet (0.6 m) waves were generated outside the Bay. Bay-external waves result from swell and shelf-originated wind waves.

Of the fall and winter waves with heights greater than 1.97 feet (0.60 m), almost all were directed south, thus generated within the Bay. These fall and winter waves result from northeasters (extratropical storms) and northwesters, which produce strong north winds along the maximum fetch of the Bay. As NAB Little Creek is located at the southernmost end of Chesapeake Bay, it receives waves generated over the whole north-to-south fetch of the Bay (over 100 miles, 160 km). The passage of extratropical, low pressure storms also produces elevated water levels which further increases the reach of wave energy and strongly impacts NAB's shoreline. In the summer months, locally generated waves reached only minimal heights. Thus, the higher wave energy in winter generally causes beach erosion while calmer conditions in summer tend to cause beach accretion.

Although the largest wave heights recorded were associated with waves generated inside the Bay, these waves were relatively infrequent. The more typical waves were intermediate in height, 0.67 to 1.97 feet (0.20 to 0.60 m), with approximately 50% of these waves generated outside the Bay in the fall and winter and 80% in the summer. However, these Bay-external waves have already been altered by the bathymetry of the Bay by the time they reach the wave gage. Each of these energy sources contribute to the conditions at NAB, and each plays an important role in altering the shore's morphology.

The onshore wave climate along the southern shore of the Chesapeake Bay is characterized by low to medium wave energy; the waves are directed from the northern sector often at an angle of approximately 10° to 30° to the coast. Norfolk Airport wind data from 1960-1990 were analyzed to determine the long-term wind frequencies (Table 1). The north component is dominant followed by the south, southwest, and northeast while the northwest is minor. Since the southerly winds generate north and northeast traveling waves, they do not directly impact the NAB shoreline. However, the wind analysis does not describe swell and shelf-originating wind waves that enter the mouth of the Chesapeake and impact NAB shoreline.

Waves with periods less than 2 seconds are considered wind chop typically developed for a period of several hours following a temporary increase in wind speed (Ludwick, 1987). Waves in the 2 to 5 second band are local wind waves, developed over a Bay fetch at persistent wind speeds from 10 to 35 mph (16 to 56 kmph). Waves in the 5 to 12 second band were interpreted as wind waves propagating in from the Atlantic Ocean through the entrance to the Chesapeake Bay. These observations are consistent with findings from Boon *et al.* (1990).

Table 1. Summary of Norfolk Airport wind data from 1960-1990.

Wind Speed	North	North east	East	South east	South	South west	West	North west	Total Row %
<5 mph	13.78	0.79	1.39	1.15	2.12	1.28	0.83	0.47	21.81
5-11 mph	4.25	5.06	3.84	3.54	8.13	5.87	3.57	2.48	36.74
11-21 mph	8.41	6.45	2.20	1.66	5.70	6.87	4.23	3.24	38.76
21-31 mph	0.75	0.43	0.06	0.02	0.23	0.38	0.35	0.29	2.51
31-41 mph	0.06	0.04	0.00	0.00	0.01	0.03	0.02	0.01	0.17
41-51 mph	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Dir %	27.25	12.77	7.49	6.37	16.19	14.43	9.00	6.49	100.00

2. Tides

The mean tide range at NAB Little Creek is 2.7 feet (82 cm) with a spring tide range of 3.2 feet (98 cm). Tidal currents acting along the southern shorelines of Chesapeake Bay were evaluated by Ludwick (1987), Das (1974), and Fleischer *et al.* (1977). Each study indicates that sediment transport along the nearshore region, including the area off Little Creek, is influenced by tidal currents.

Fleischer *et al.* (1977) state that current velocities and bottom sediment erosion and transport tend to increase from Little Creek westward toward Willoughby Spit as the current floods. Ebb flow tends to spread out as it leaves Hampton Roads thus losing velocity and competence. Therefore, along the Little Creek shoreline, flooding mean tidal currents add a slightly westward component to the overall littoral drift system.

3. *Storm Surge*

The historical occurrence of storm-related high water levels was determined by the U.S. Army Corps of Engineers by listing the annual maximum elevation of water surface each year since 1928 for a gage at Fort Norfolk (U.S. Army Corps of Engineers, 1983) (Table 2).

Table 2. Storm-elevated water levels at Fort Norfolk and their estimated recurrence times.

Feet Above Mean Sea Level	Estimated Recurrence Time in Years	Feet Above Mean Sea Level	Estimated Recurrence Time in Years
>9.5	345	>6.5	20
>9.0	200	>6.0	13.7
>8.5	117.6	>5.5	8.3
>8.0	71.4	>5.0	4.55
>7.5	47.6	>4.5	2.38
>7.0	29.4	>4.0	1.22

Boon *et al.* (1978) determined statistically storm surge frequency for both extratropical and tropical storm events. In the Hampton Roads area, the storm surge levels above MSL for 10 year, 25 year, 50 year and 100 year events are 4.5 feet (1.4 m), 4.8 feet (1.5 m), 5.5 feet (1.7 m), and 6.1 feet (1.9 m), respectively. There is an obvious discrepancy between the two data sources due to differences in calculation methods. In reality, true storm surges probably lie somewhere between the two data sources but neither can be discounted in any calculations for which storm surge is used.

B. Physical Setting

1. Shore Evolution

a. Dredging and beach fill History

Little Creek's Bay shoreline has a long history of anthropogenic impacts. Not only have shoreline structures been built, but dredging and filling have reshaped the shoreline and nearshore areas of the reach. Much of this information comes from a draft report supplied by the U.S. Navy entitled "History of Development and Maintenance of Little Creek Channels, Harbor, and Structures". This is by no means a complete summary, but structures, harbor dredging, and placement of material are discussed to emphasize the impact man has had on this reach of shoreline.

Changes to the Little Creek shoreline began early in this century when the creek and adjacent property was owned by the Pennsylvania Railroad Company. The Little Creek Inlet east jetty was started in December 1926 and completed in January 1928. In November 1928, the west stone jetty was completed. The entrance channel to Little Creek Inlet was dredged between March 1927 and July 1928. In August 1929, an additional 300 feet (91 m) was added to the channel width. May 1930 saw the completion of timber breakwaters at the shore ends of the stone jetties to prevent breaching by wave action. In March 1941, facilities were completed to establish the Little Creek Mine Base for the U.S. Army (Harbor Defenses of Chesapeake Bay). Between July 1942 and May 1943, Little Creek channel was dredged to a depth of 20 feet (6 m) and width of 400 feet (122 m). 96,000 cubic yards (cy) (73,400 m^3) of sand was dredged in the vicinity of Annex 1&2, Little Creek Amphibious Base, with shore disposal on Navy property in August 1947. An additional 33,000 cy (25,200 m^3) was dredged in November of the same year and disposed of on Tail of the Horseshoe in the Chesapeake Bay.

The channel at Little Creek ferry terminal was dredged to a depth of 15 feet (5 m) in January 1948 and approximately 50,000 cy (38,200 m^3) was disposed of on East Ocean View in Norfolk. In 1951, 800,000 cy (611,700 m^3) was dredged with disposal of about 300,000 cy (230,000 m^3) on Navy shore property and 500,000 cy (382,300 m^3) on Tail of the Horseshoe in the Bay. In November 1953, a total of about 700,000 cy (535,000 m^3) was pumped onto the south shore of the Chesapeake Bay immediately adjacent to and west of Little Creek Entrance Channel (i.e. East Ocean View). Also in 1953, a large offshore area was excavated immediately east of the Inlet. The "hole" was about 7,000 feet (2,100 m) long parallel to the shoreline and about 400 feet (120 m) wide. Approximately 1,240,000 cy (948,000 m^3) of sand was removed, according to after-dredging surveys, from depths approaching 25 feet (8 m). About 560,000 cy (428,000 m^3) of this material was placed either on the south shore of the Chesapeake Bay west of the Inlet jetties and/or on Navy property inside Little Creek. Maintenance dredging of the channel occurred in April 1957; an estimated 252,300 cy (192,900 m^3) of material was removed and deposited on an upland area on the western bank of the Inlet adjacent to the channel.

In 1960, a total of 159,300 cy (121,800 m^3) was dredged from Little Creek and deposited on the 800 feet (244 m) west of the jetty. In 1965, maintenance dredging of the 20 foot deep by 400 foot wide (6 m x 122 m) entrance channel resulted in 173,000 cy (132,300 m^3) being deposited on a 1 square mile disposal area in the Chesapeake Bay. The existing entrance was widened and deepened in 1975; an estimated 805,000 cy (615,500 m^3) of material was deposited along 9,000 feet (2,740 m) of NAB beach shoreline east of the Inlet.

Lynnhaven Inlet, located east of NAB, has been dredged to maintain its channel. The amounts dredged were :

Jun 1965-Jan 1966	970,879 cy	742,334 m^3	(dredged)
Mar-Jun 1968	266,720 cy	203,934 m^3	(dredged)
Jul-Nov 1970	190,274 cy	145,483 m^3	(dredged)
Aug-Oct 1972	123,751 cy	94,620 m^3	(dredged)
Apr 1987	136,000 cy	103,986 m^3	(placed at Ocean Park)
Jan 1991	70,000 cy	53,522 m^3	(placed at Ocean Park)
May 1995	50,000 cy	38,200 m^3	(placed at Ocean Park)

Some of this dredged sand was stockpiled or used in other projects, but either way, it was out of the southern Bay shoreline system (U.S. Army Corps of Engineers). Sand from the 1965, 1968, 1987, 1991 and latest fill were placed west of Lynnhaven at Ocean Park Beach. Exact amounts placed at Ocean Park in 1965 and 1968 are not known. It's doubtful that sand east of Lynnhaven will bypass the Inlet because Lynnhaven's extensive ebb shoals effectively hold on to the sand, or the sand is transported into the channel (Hardaway *et al.*, 1993). However, sand placed west of Lynnhaven Inlet at Ocean Park will be transported westward.

b. Shore Morphology and Groin History

Severe erosion occurred along most of the Little Creek shoreline between 1852 and 1949 at an average rate of 4.4 ft/yr (1.3 m/yr) (Byrne and Anderson, 1978). The region where Groin #3 is presently located (Figure 5) has a bend in the shoreline and

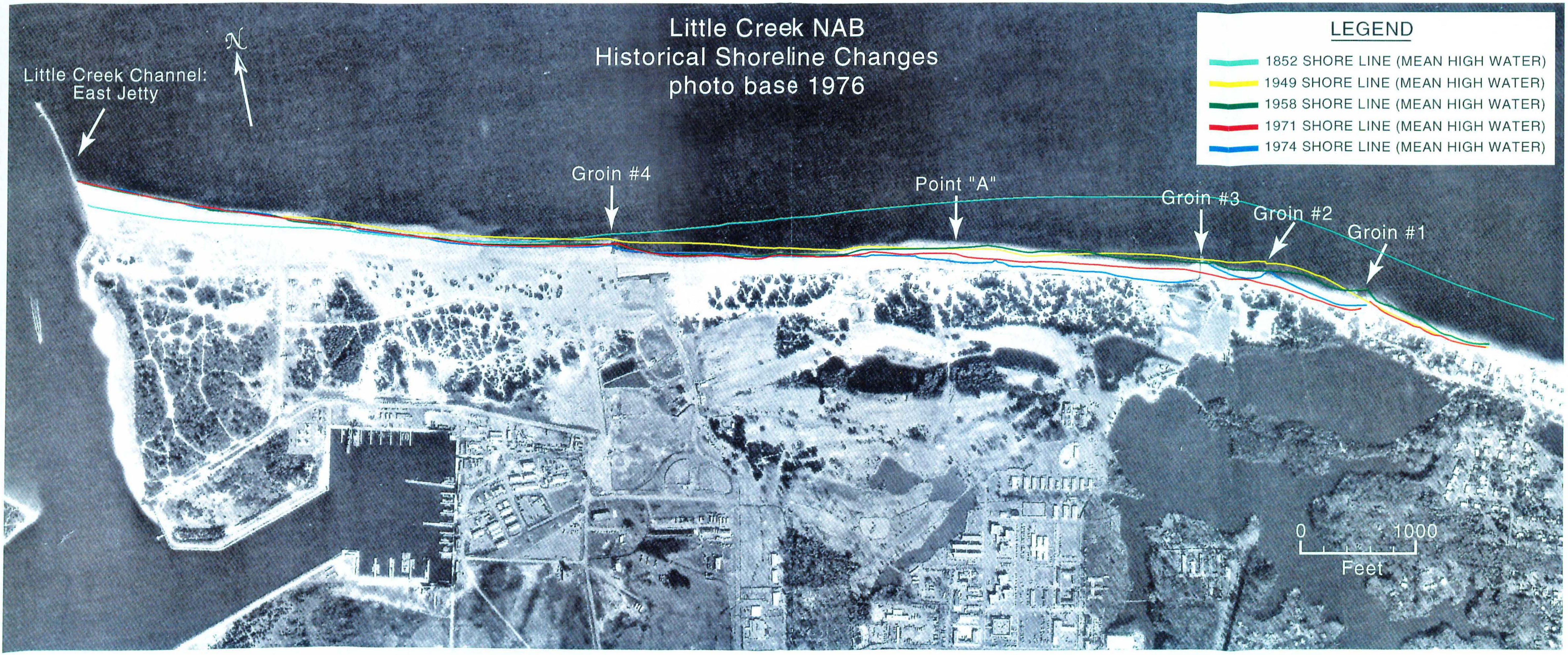


Figure 5. Photo base 1976 showing MHW shoreline positions in 1852, 1949, 1958, 1971, and 1974.

showed the most erosion; it lost 530 feet (160 m) during this period, an average of 5 ft/yr (1.5 m/yr). The areas around Groin #3 showed decreasing erosion from this most active region. The region, where Groins #2 and #1 are presently located, lost 490 feet (150 m) and 460 feet (140 m), respectively, during this same time period. At Point "A", the shoreline receded 400 feet (120 m) between 1852 and 1949. Eroded sand was transported west and offshore by the littoral system, and after the jetties were built at Little Creek Inlet in the late 1920's, sand accreted downdrift of the jetty at a rate of 1.2 ft/yr (0.4 m/yr)(Byrne and Anderson, 1978).

Between 1949 and 1958, the movement of the shoreline at Little Creek varied. However, from 1958 to 1971, the region between Groins #1 and #4 eroded (Figure 5). Most erosion (110 feet) occurred just downdrift of Groin #1 and decreased to the west. The region where Groin #2 and Groin #3 are presently located (these groins had not been built yet) receded 90 feet (27 m) and 70 feet (21 m), and Point "A" lost 60 feet (18 m). Groin construction along the Little Creek shoreline began with Groin #1 near the east property line prior to 1971 (Figure 5). According to Das (1974), this littoral barrier created accretion on the east side (updrift) and shoreline recession of up to 200 feet (60 m) on the west side (downdrift). The shoreline instability was felt for about 3000 feet (900 m) downdrift of the groin, the amount of erosion decreasing westward as a function of distance from the groin.

This progressive change in the shoreline configuration would have continued until the shoreline reached a dynamic equilibrium when the altered material-energy balanced. However, allowing this equilibrium to be attained would have involved continued loss of Navy property downdrift of Groin #1 (Das, 1974). Therefore, to prevent further erosion a second and, subsequently, a third groin were constructed; these define the present day Officer's Beach (O.B.). A fourth groin was built prior to 1974 just west of the present day Enlisted Beach (E.B.).

The impacts of the groin installations and the nature of shoreline change are shown in Figures 5 and 6. Shoreline offsets are noted at the position of each groin prior to the 1976 shoreline (Figure 5). A beach fill was placed on the NAB shoreline in 1975 resulting in a wider beach, particularly in the embayment between Point "A" and the O.B., and a reduction in the offsets downdrift of the groins. However, by 1980 (Figure 6), the shoreline had eroded particularly between Point "A" and the O.B. and downdrift offsets were once again apparent. By 1982 and 1985, Groins #1,#2, and #3 were unable to maintain a protective beach, and erosion threatened upland improvements around the O.B. Groin #4 is somewhat higher than the other three groins and appears to be more of a headland and, therefore, a controlling feature.

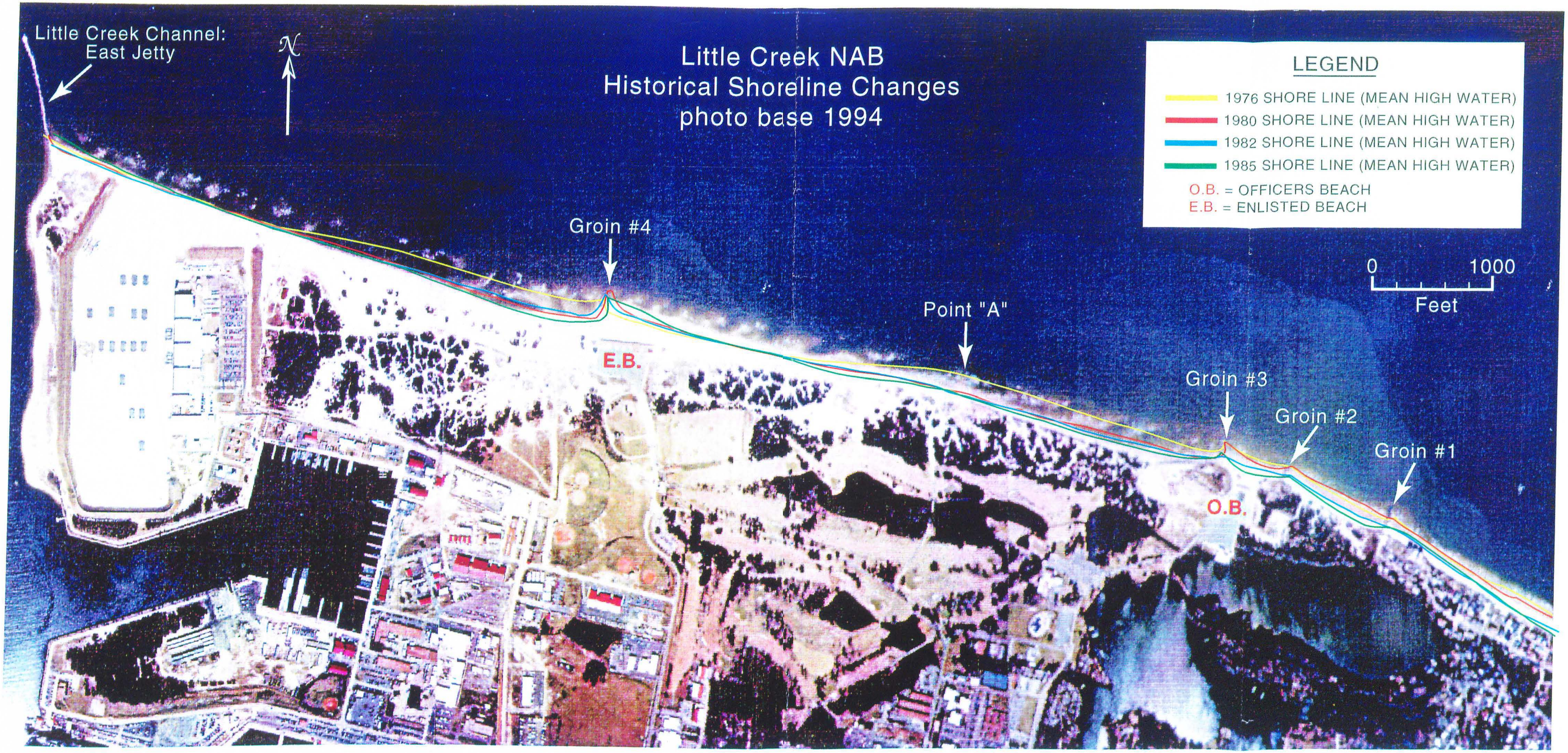


Figure 6. Photo base 1994 showing MHW shoreline positions in 1976, 1980, 1982, and 1985.

By 1994 much of the shoreline had reached a somewhat stable state except for the O.B. and the shore segment from Groin #3 to Point A. Today this shore segment has the severest erosion along the base shoreline, especially just downdrift of the recently installed stone revetment west of the O.B.

Table 3 is a summary of shoreline change reduced to annual rates of change in the position of MHW and corresponding sand volumes. The rates are computed every 500 feet (152 m) and averaged for each shoreline segment. Volume computations are based on a simple formulas used by Das (1974) where one square foot of shore change equals one cubic yard. For example, to determine the rate of change (ft/yr) and volume of change (cy/yr) between the Jetty and Groin #4 from 1852 to 1949, the position of MHW was measured every 500 feet (152 m) along the shoreline. The average change in the position of MHW was 75 feet (23 m) over 97 years resulting in a rate of 0.8 ft/yr (0.2 m/yr). Volume change was calculated by multiplying the change in position of MHW by the distance between measurements (usually 500 feet or 152 m). Since feet^2 is equal to cy, the feet^2 divided by 97 years results in a calculated volume change per year. The cy/yr are summed along the shoreline to get a net shoreline volume rate of change of 3,991 cy/yr (3,050 m^3). To determine the overall change, the average change (in feet) along the entire Little Creek shoreline was divided by the number of years. The volume rate of change was summed along the shoreline resulting in a net overall rate of change.

Table 3. Shoreline change along segments of the Little Creek shore.

	Over	all	Jetty to	Groin 4	Groin 4 to	Point A	Point A to	Groin 3	Groin 3 to 2	(O.B.)	Groin 2 to	Groin 1
Year	ft/yr	cy/yr	ft/yr	cy/yr	ft/yr	cy/yr	ft/yr	cy/yr	ft/yr	cy/yr	ft/yr	cy/yr
1852-1949	-2.2	-22,797	0.8	3,991	-2.6	8,601	-5.1	-11,797	-4.9	-2,525	-4.6	-3,866
1949-58	-5.0	-60,908	-3.6	-16,528	-7.3	-22,833	-7.9	-19,618	-7.5	-3,825	1.4	1,896
1958-71	-2.1	-17,913	0.0	-173	0.0	0	-1.8	-2,933	-9.2	-4,479	-12.3	-10,328
1971-74	-3.9	-54,852	-1.3	-5,612	-4.1	-12,335	-19.4	-51,805	13.0	6,233	11.3	8,667
1974-76	31.1	328,078	-2.8	-14,125	23.1	71,250	80.8	188,428	53.8	25,585	69.5	56,940
1976-80	-11.1	-142,454	-12.6	-64,390	-5.3	-21,969	-23.0	-54,565	-6.9	-3,521	1.7	1,993
1980-82	-8.3	-74,358	-3.2	-11,990	-3.6	-6,884	-11.8	-22,812	-13.6	-6,324	-30.7	-26,348
1982-85	-2.5	-39,684	-1.7	-7,881	0.0	-3,444	-5.8	-17,686	-7.6	-3,424	-9.2	-7,249
1985-94	0.3	2,792	-1.4	-7,213	2.2	8,209	0.1	-1,103	0.6	66	3.4	2,833

The noticeable increase in beach volume in the 1974-1976 period reflects the large beach fill during that time. The overall rate of shore recession has steadily decreased since that time to where there is an almost zero net change (i.e. 0.3 ft/yr). Minor variations occur within each shore segment. This trend supports the dynamic equilibrium state the shoreline has appeared to have evolved into and is the major basis for the Shoreline Management Plan.

2. *Beach and Nearshore Sediments*

Sediment samples were taken from the nearshore region and at specific morphologic points at VIMS profiles F2, E4, and D2 (Figure 7). The location and logs of the cores taken at the O.B. in the vicinity of the proposed structures are shown on this figure. The beach sediment samples were taken just after the passage of Hurricane Fran. In general, the sediments at the O.B. consist of sand. The silt and clay content in the samples is less than five percent and will be disregarded in this analysis. Gravel was present only in the toe sample and in the cores.

The backshore (BS) samples represent the area of the beach that is influenced by eolian transport and by run-up from occasional storm events. Sediments were also taken at BERM crest, last high tide (LHT), midbeach (MB), toe, and offshore (OS). The toe of the beach is located at the break in slope between the beach face and the nearshore region. It is sometimes evidenced by a distinct change in sediment type. See Figure 4 for definition. The mean sand size (in mm) is the average size of the sand fraction while the median sand size (D_{50}) is the diameter of the 50th percentile.

The grain size distribution of beach sand generally varies across shore and, to a lesser degree, alongshore as a function of the mode of deposition. The coarsest sand particles usually are found where the backwash meets the incoming swash in a zone of maximum turbulence at the base of the subaerial beach; here the sand is abruptly deposited creating a step or toe. Just offshore, the sand becomes finer. Another area of coarse particle accumulation is the berm crest, which is sometimes coincident with LHT, where runup deposits all grain sizes as the swash momentarily stops before the backwash starts. The dune or backshore generally contains the finest particles because deposition here is limited by the wind's ability to entrain and move sand (Bascom, 1959; Stauble *et al.*, 1993). This is typical of estuarine beaches in the Chesapeake Bay (Hardaway *et al.*, 1991).

In general, the sediments sampled to characterize the O.B. do not follow the model proposed above (Figure 7). While the toe does contain the coarsest material, the berm crest and midbeach contain the finest. This can be attributed to the adjustment of the profile to storm conditions and erosion of the top layer of sediment

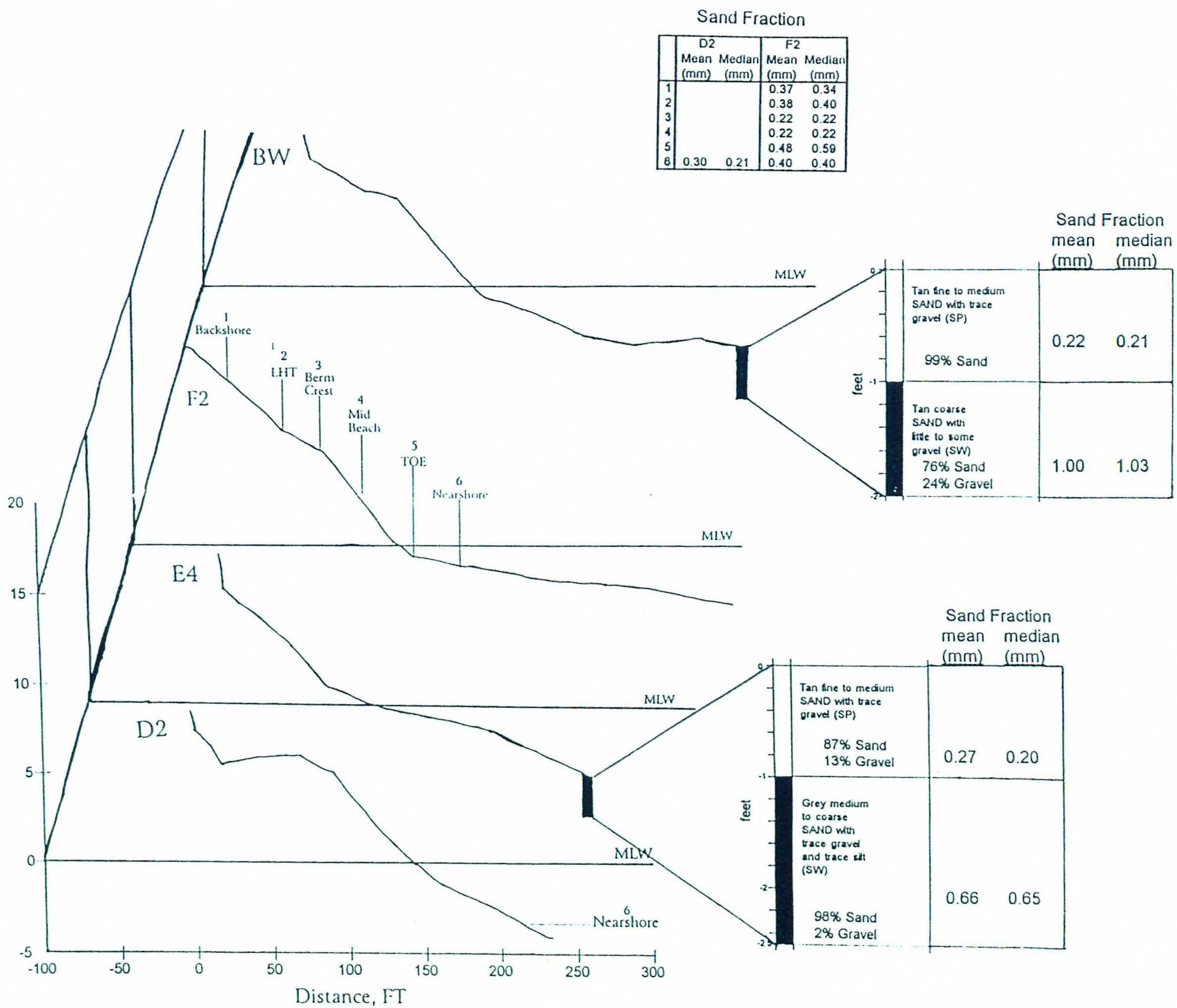


Figure 7. VIMS profiles BW, F2, E4, and D2 with beach and nearshore sediment sample locations.

from the beach. The LHT sample was taken higher than usual do to increased tide levels and shows a median sand size the same as the nearshore sample.

3. *Sediment Transport*

As previously mentioned, net sediment transport is from east to west along the southern shore of the Chesapeake Bay from Lynnhaven Inlet to Willoughby Spit. However, inlet tidal currents and refracted waves can cause local reversals. Several morphologic features also alter waves in the nearshore. An east-west trending channel occurs between 0.5 miles (0.8 km) and 1.5 miles (2.4 km) offshore. Ludwick (1987) called it the Beach channel (Figure 2), the axis of which trends approximately parallel to the southern shoreline of the Chesapeake Bay from Cape Henry westward past Lynnhaven Inlet, Little Creek entrance and on to Willoughby Spit. The water depth in this channel is approximately 28 feet (8.5 m) along much of its length. The flood currents in the Beach Channel near the bottom are stronger and longer in duration than the ebb currents. This channel may strongly affect the local wave climate.

Das (1974) calculated sediment transport rates at Little Creek using the empirical relationship:

$$Q=2H^2$$

where, Q = longshore transport rate in 100,000 cy/yr (76,500 m^3/yr)
and H = mean breaker height in feet

which is based on Galvin's (1972) formula for gross longshore transport. Das (1974) determined the annual longshore transport from east to west due to waves from the east and northeast to be 74,500 cy (57,000 m^3) and the annual transport west to east due to waves from the north and northwest to be 38,500 cy (30,000 m^3). Therefore, the **net** east to west transport is 36,000 cy/yr (28,000 m^3/yr) while the **gross** transport is 113,000 cy/yr (86,000 m^3/yr).

Just east of Little Creek Inlet, approximately 1,240,000 cy (948,000 m^3) of material was dredged sometime in 1953-54. The "hole" was about 7,000 feet (2,100 m) long and 400 feet (120 m) wide and extended into 25 foot (8 m) deep water (Figure 8). Since that time, the "hole" has been infilling. Based on calculations from topographic maps, between 1965-1980, it had infilled at a rate of 44,800 cy/yr (34,000 m^3/yr). From 1980 to 1996, it had filled at a rate of 36,200 cy/yr (28,000 m^3/yr). These rates compare favorably with Das's estimates of net westward longshore transport. Presently, the hole has filled in such that it cannot be distinguished from the surrounding bathymetry. As the Little Creek shoreline has evolved into long, curvilinear, semi-stable embayments, longshore transport may becoming more onshore\offshore.

1952
DATUM
FEET-MLW

1967
DATUM
FEET-MLW

1980
DATUM
METERS-MLW

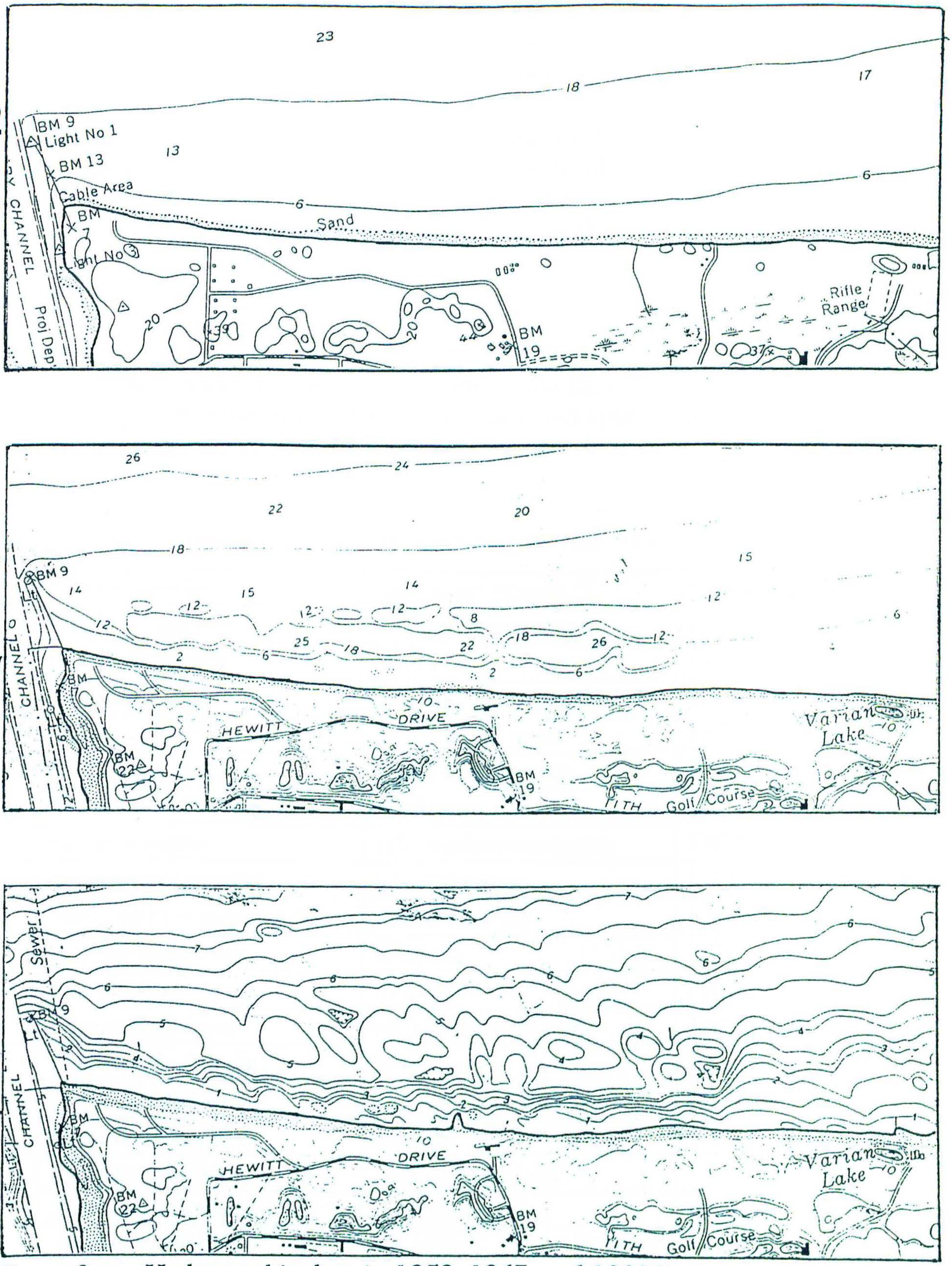


Figure 8. Hydrographic data in 1952, 1967, and 1980 just east of Little Creek Inlet showing the "hole".

An extensive offshore bar system has persisted between the O.B. and the Little Creek Inlet East Jetty since at least 1970. The bar system is a function of sediment supply, wave climate and tidal currents. The bars attach and detach from shore causing the beach to advance and retreat at these points. East of the O.B., these bars do not exist to the same extent but reoccur past the Chesapeake Bay Bridge Tunnel (CBBT) toward Lynnhaven Inlet. The area around the O.B. appears to be a shear zone with beach and nearshore sands bypassing but not residing for long.

4. *Environmental Assessment*

Any work done along the shoreline will affect the flora and fauna inhabiting an area. Table 4 lists the flora found on the beach and in the dunes on either side of the Officer's Beach. Figure 9 shows the morphologic region and approximate location of each plant sample (indicated by number from Table 3) as well as where some of the fauna were located.

Table 4. Flora found on beach and dunes surrounding the Officer's Beach.

Number	Genus species	Common Name	Classification
1	*Cakile edentula*	American searocket	FACU
2	*Diodia virginiana*	buttonweed	FACW
3	*Distichlis spicata*	seashore saltgrass	FACW+
4	*Panicum amarum*	bitter panic grass	FACU-
5	*Solidago sempervirens*	seaside goldenrod	FAC
6	*Cenchrus tribuloides*	sandspur	UPL
7	*Spartina patens*	saltmeadow cordgrass	FACW+
8	*Andropogon scoparius*	little bluestem	UPL
9	*Parthenocissus quinquefolia*	virginia creper	FACU+
10	*Erigeron bonariensis*	fleabane	UPL
11	*Quercus virginiana*	live oak	FACU
12	*Lactuca canadensis*	wild yellow lettuce	FACU
13	*Strophostyles helvola*	beach pea	FACU-
14	*Persea borbonia*	red bay	FACW
15	*Achillea millefolium*	yarrow	UPL
16	*Lespedeza cuneata*	sericea lespedeza	
17	*Xanthium strumarium*	cocklebur	FAC

FACU Facultative Upland — FACW Facultative Wetland
UPL Upland — FAC Facultative

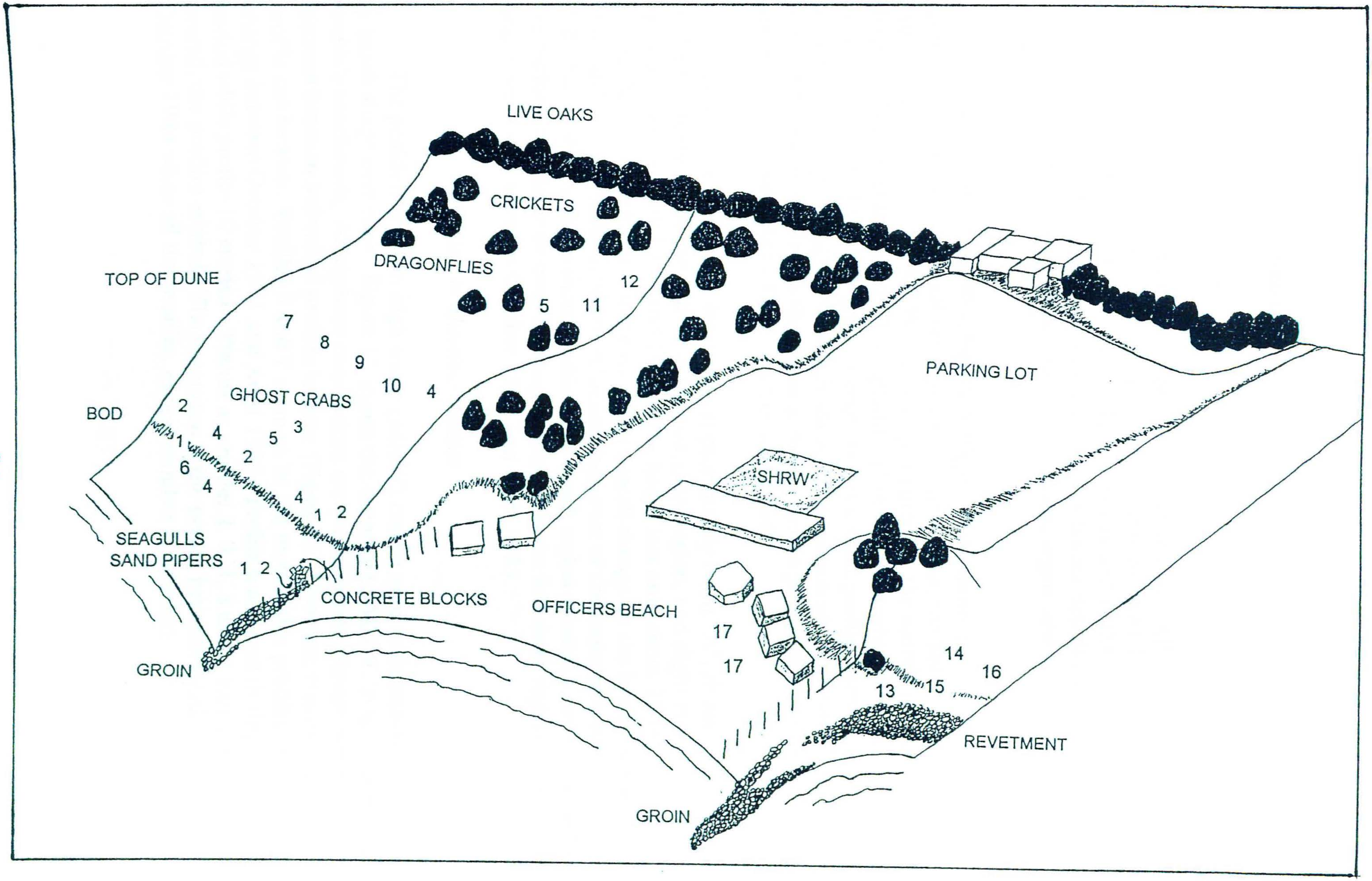


Figure 9. Location of flora samples and fauna at and on either side of the Officer's Beach.

C. Beach Characteristics

1. Beach Profiles and their Variability

Virginia Beach's profiles 2 through 5 are located on NAB shoreline (Figure 3). They were surveyed by Virginia Beach personnel only between 1980 and 1985. Figures 10A through 10D show the profile surveys as well as the morphologic regions of the data. Average conditions between survey dates are described as Erosion, Accretion or Little Change within each morphologic region and are shown on the plots.

Between 1980 and 1985, Profile 2 (Figure 10A) showed a net trend of erosion along the foreshore and backshore regions. In these areas, the beach receded an average of 40 feet (12 m) MLW. Accretion occurred in the nearshore region, but deeper, offshore areas eroded. The upland region was relatively unchanged. Profile 3, which is just east of the E.B. groin (Groin #4), is a short profile, barely extending into the nearshore region. Again the beach showed net erosion of the shoreline between 1980 and 1985 even though there was accretion on the profile of about 90 feet (27 m) at MLW between April 1982 and October 1984.

Profile line 4, which is located at approximately Point "A", showed net erosion in the beach region, net accretion in the nearshore region, and slight erosion in the offshore zone between 1980 and 1984. The beach lost only about 20 feet at MLW during this time period, and there was little overall change on the beach between 1982 and 1984. Profile 5, which is located just west of the westernmost groin at the O.B. (Groin #3), is also a short profile. The beach region showed a net accretion in the backshore while little overall change occurred in the foreshore region. The nearshore eroded between October 1984 and April 1985.

2. Variability in Shoreline Position

The position of mean high water (MHW) can be used to demonstrate change in beach shape over time. Figure 11 shows the distance to MHW, in feet, from each profile's benchmark. Alongshore correlations are probably not relevant since the distance between individual profiles is large (Figure 3). However, trends at each profile can be seen. Profiles 5 and 7 seem to be the most stable profiles with little change between October 1981 and April 1985. Profile 6 accreted during this same period while profile 10 eroded. Trends at profiles 2, 3, 4, 8 and 9 varied although, overall, the profiles eroded. The exception is the period between April 1982 and October 1984 when all the profiles, except number 8, accreted.

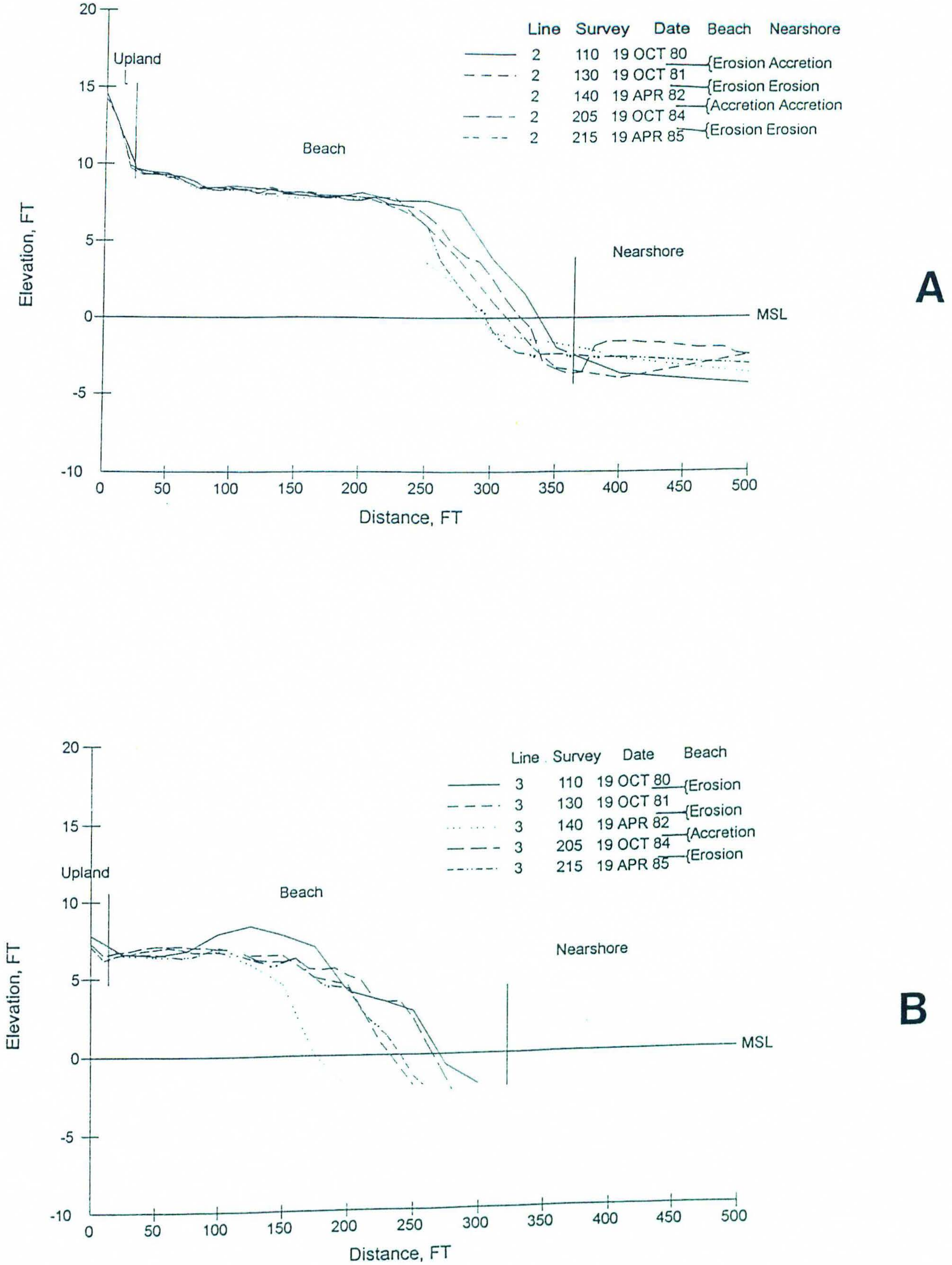
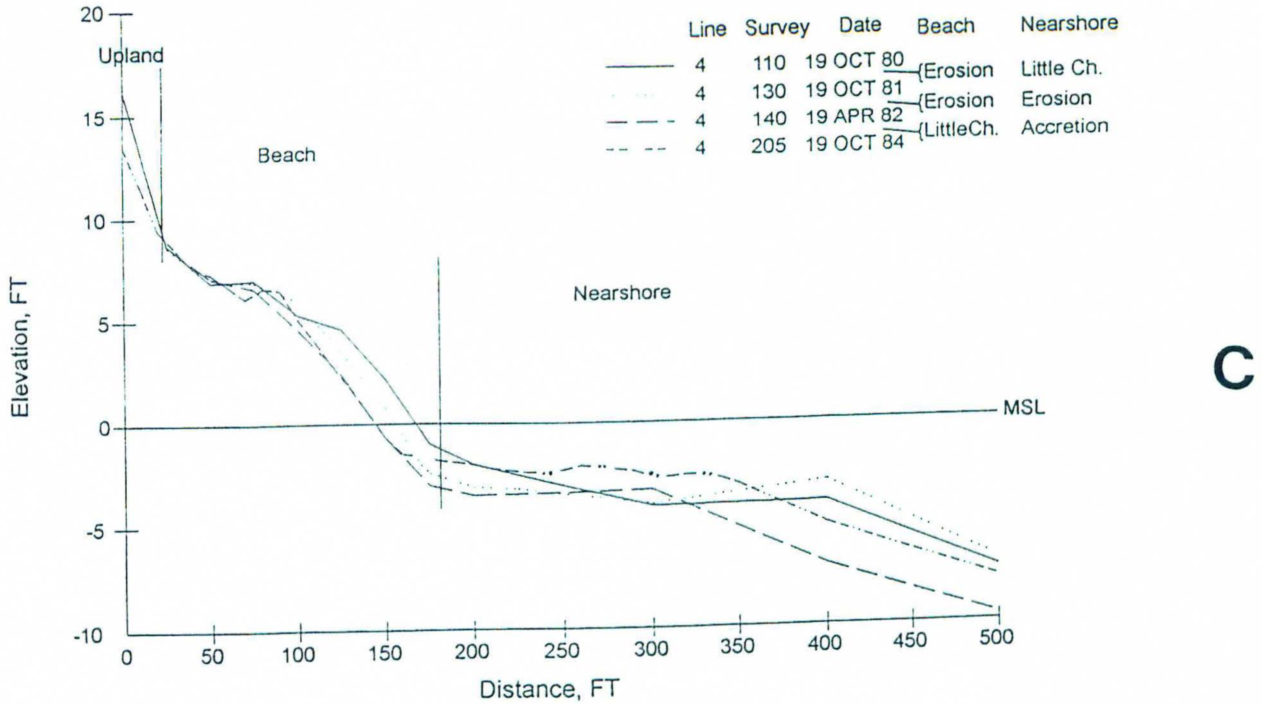


Figure 10. Virginia Beach surveys at A.) profile 2 and B.) profile 3.



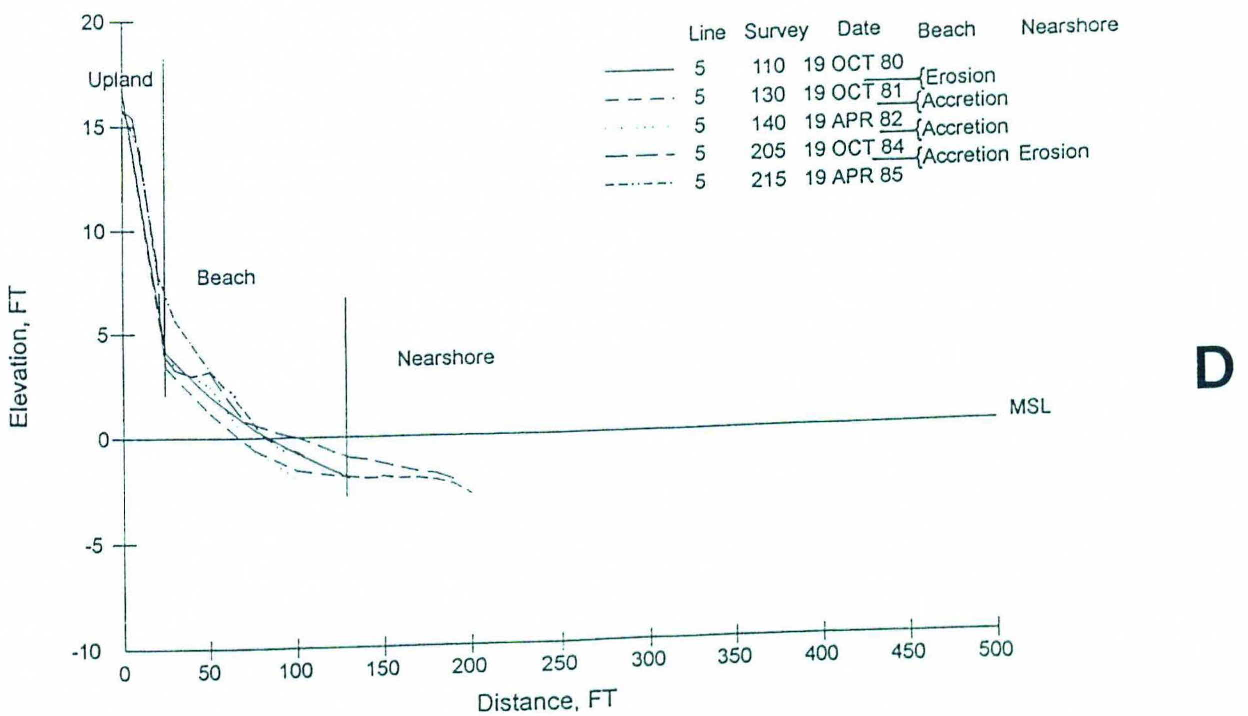


Figure 10. Virginia Beach surveys at C.) profile 4 and D.) profile 5.

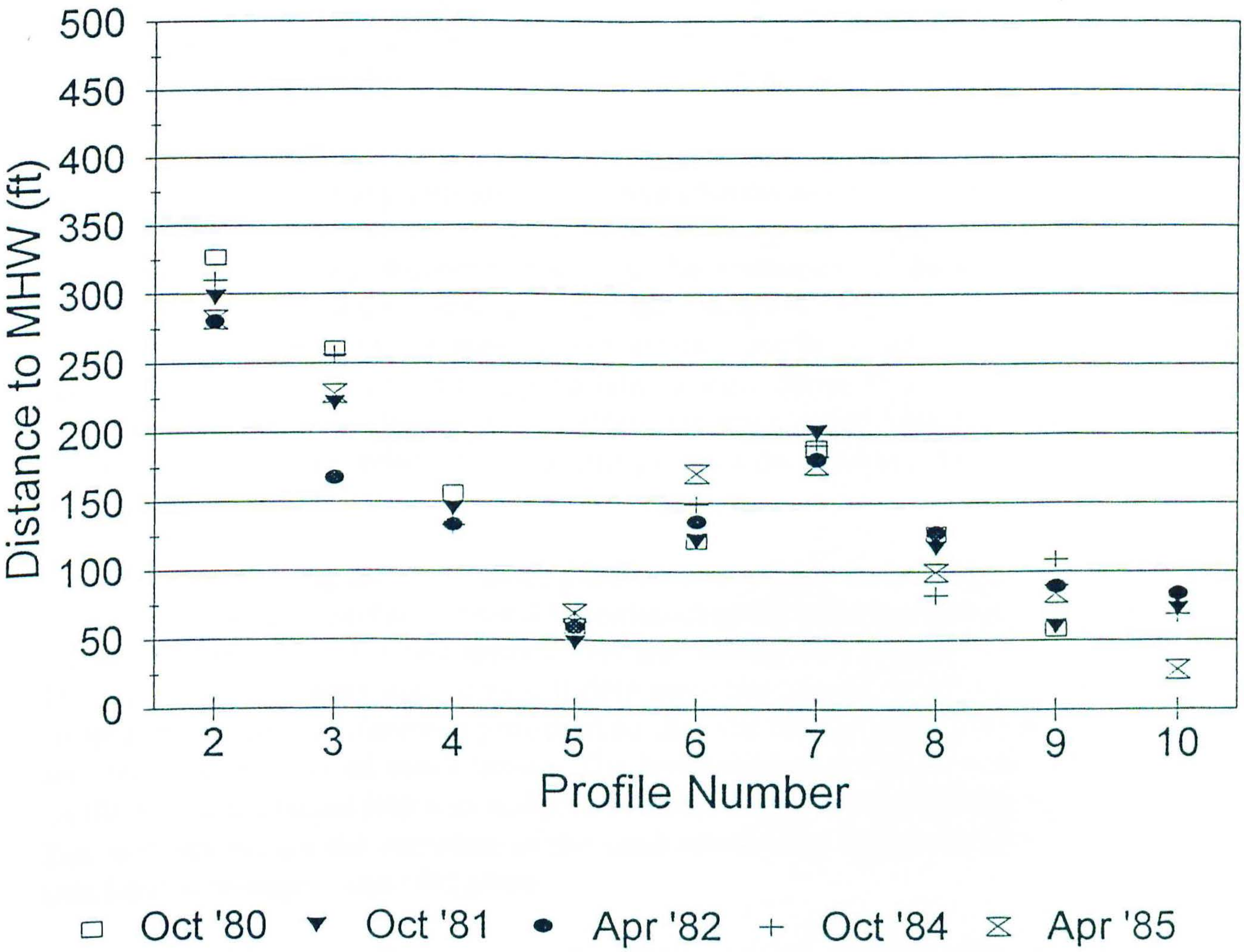


Figure 11. Distance to MHW from the profile benchmark.

IV. LITTLE CREEK CHESAPEAKE BAY SHORELINE RECOMMENDATIONS

A. Shoreline Management Plan, NAB

This plan is based on the Navy's desire to prepare for the long-term changes within the Lynnhaven to Little Creek subreach as well as potential changes in landuse. In addition, the Navy wanted to achieve a stable beach zone that offers a moderate degree of storm protection, provides recreational areas (e.g.. Officer's Beach and Enlisted Beach), and insures the maintenance of military training areas.

The history of the Little Creek shoreline has been influenced by varied man-made activities that, along with an active wave climate and consequent littoral processes, have had significant impacts on shore change. The major component that will determine long-term shoreline changes is the availability of sand. This plan seeks to address long term beach stability even if sand supplies from the east are reduced. Since the existing groins have dominated the beach planform and have established hard points along the shore, it is appropriate to begin planning around these features. However, the groins themselves do not attenuate wave action during storm events; the beach created (or eroded) by the groins protects (or exposes) the upland regions to wave action.

Utilizing the geomorphic shore planforms that have evolved through time, it is reasonable to apply headland control by enhancing the existing headland features (i.e. the existing groins) with stone breakwaters and adding structures at strategic points. The dimensions of these structures will determine the impact to the shoreline. At this point a "leaky" littoral system is proposed so that the littoral sands can move east and west through low-crested restrictions. The breakwaters need to have not only a low profile but also a broad width in order to attenuate wave energy during storm events. This also will reduce the elevation of the sand attachment behind the structures so that limited transport can take place.

Figure 12 depicts the proposed shoreline management plan. Caution is recommended in that the proposed rock structures are an initial phase that will require ongoing monitoring as the shoreline adjusts toward dynamic equilibrium. The following discussion pertains the rationale for each structural element of the plan:

Structure #1 - 150 foot (46 m) spur: This structure is an addition to an already functioning littoral barrier, the Little Creek Inlet's east jetty. Sediment transport reversals have been noted in this region, and the spur would provide a fixed

Figure 12. Little Creek shoreline management plan.

point for holding the west end of the embayment between Groin #4 and the east jetty.

Structure #2 - 200 foot (61 m) spur: This breakwater/spur structure would be placed to work in conjunction with Groin #4 to stabilize the beach within the embayment between Groin #4 and the east jetty as well as address northwesterly wave approach and potential impacts to the Enlisted Beach. A low weir connection would allow sand transport in the lee of the structure yet maintain a perched beach.

Structure #3 - 200 foot (61 m) reef breakwater: The exact position of this structure could vary depending on the impacts to any structural element emplaced at the Officer's Beach. Presently, it is located at Point "A". Point “A” has persisted over the past decade and is the western limit of severe dune-face erosion that occurs between Point "A" east to the revetment adjacent to the O.B. This breakwater would work in conjunction with the structures placed at the O.B. (listed below)and structure #4 to develop an equilibrium embayment. Additional loss of dune can be expected until equilibrium is reached. The height of structure #3 must be low and semi-attached, initially, until the impact to the shoreline from Point "A" to the E.B. is assessed.

Structure #4 - 150 foot (46 m) reef breakwater: This is an interfacing structure to prevent flanking of the existing revetment but is intended to work with structure #3 and the spur portion of structure #5. Beach sand attachment should be low, even intertidal.

Structure #5 - 70 foot (21 m) reef breakwater with 30 foot (9 m) spur: This structure is meant to work with the existing groin (Groin #3) to perch the downdrift end of the O.B.; it will also allow limited sand transport across the low groin. The main structure will also address the north and northwesterly component of the wave climate impinging on the O.B..

Structure #6 - 130 foot (40 m)reef breakwater: This offensive structure placed off Groin #2 at the O.B. will address the dominate northeasterly component to the local wave climate as well as the westerly bearing swell conditions. This structure needs to be both broad, in order to attenuate longer period waves, and low, to perch a beach that will set an equilibrium embayment but also allow limited sand transport into and out of the embayment.

Structure #7 - 100 foot (31 m) spur: This low spur structure is meant to set the embayment between Groins #1 and #2. An equilibrium bay can be developed within this segment of shore without significant loss to dune. Sand will still transport into the bay from the east.

Structure #8 - Revetment/Groin Rehab: Installing a revetment and rehabilitating Groin #3 where it meets the existing revetment will insure the O.B. has a downdrift backshore barrier as well as an upland defense under severe storm wave attack.

Structure #9 - Revetment/Groin Rehab: The same rationale hold for this structural element at Groin #2 as for structure #8.

Additional reef breakwaters could be placed along the Little Creek shoreline to create more equilibrium embayments. The initial costs would be high for such a venture, but long-term control of the shore could be achieved. This proposed plan is meant essentially as phase one; by allowing the shoreline to evolve after the installation of the structures, a wiser, cost-effective use of future funds can be achieved since additional structures can then be installed at the best locations.

B. GENESIS

1. Introduction

GENESIS was used to assess the general concept of the proposed shoreline management plan for the entire Little Creek shoreline. Shoreline change models such as GENESIS utilize longshore transport formulae to force shore movement based on impinging wave energies. In particular, GENESIS describes long-term trends of beach plan shape as the shoreline moves toward equilibrium under imposed wave conditions, boundary conditions, configurations of coastal structures and other input parameters. GENESIS works best when distinct changes occur in the shoreline such as when the shore adjusts to a project (Gravens *et al.*, 1991).

GENESIS is not applicable to simulating a randomly fluctuating beach system in which there is no evident change in shore position. Table 5 , from Gravens *et al.* (1991), gives a short summary of the capabilities and limitations of GENESIS.

Table 5. Major capabilities and limitations of GENESIS (Gravens *et al.*, 1991).

	Capabilities
1)	Almost arbitrary numbers and combinations of groins, jetties, detached breakwaters, beach fills, and seawalls
2)	Compound structures such as T-shaped, Y-shaped, and spur groins
3)	Bypassing of sand around and transmission through groins and jetties
4)	Diffraction at detached breakwaters, jetties and groins
5)	Coverage of wide spatial extent
6)	Offshore input of waves of arbitrary height, period, and direction
7)	Multiple wave trains (as from independent wave generation sources)
8)	Sand transport due to oblique wave incidence and longshore gradient in height
9)	Wave transmission at detached breakwaters
	Limitations
1)	No wave reflection from structures
2)	No tombolo development (shoreline cannot touch a detached breakwater)
3)	Minor restrictions on placement, shape, and orientation of structures
4)	No direct provision for changing tide level
5)	Basic limitations of shoreline change modeling theory

The major limitation for this particular application of GENESIS is that the program does not provide for tombolo attachment. In fact, the program will stop if a tombolo attaches while it is running. Most of the components of the shore management plan listed above are designed to attach at some level to the shoreline making the use of GENESIS difficult.

2. Methods

The first step of the computer modeling was to create a time series from existing wave data that would represent wave conditions at the site of the proposed structures and which could be used in both GENESIS and Model Tombolos. Both models require the wave parameters height, period and direction at the site as input. Because the wave gage was located 6 nm (11 km) away and the complex bathymetry between the wave gage and the NAB shoreline significantly alters waves crossing it, a direct application of the wave gage data to the shoreline is not practical. A wave refraction model can be used to transform the data and make it applicable at the Base shoreline.

Wave data from the six deployments of the Thimble Shoals wave gage were utilized in the analysis. Deployment dates were as follows: 27 Sep 1988 to 17 Oct 1989; 8 Oct 1990 to 23 Aug 1991; 14 Nov 1991 to 25 Jun 1992; 24 Oct 1992 to 2 Jun 1993; 19 Oct 1993 to 14 Apr 1994; and 19 Sep 1994 to 13 Mar 1995. The gage "burst-sampled" once every three hours. The data used in the analysis included the zero-moment wave height (Hmo), which is considered equivalent to the significant wave height, the average zero-crossing wave period (Tz), and the principal wave direction (WavDir). For more information on the wave gage, a detailed analysis of its data as well as definition of terms, see Boon *et al.*, 1990, 1992 and 1993.

The grid was designed to extend from the shoreline to the vicinity of the VIMS wave gage so that wave data could be directly used as input for RCPWAVE, which is a wave propagation model. Output from RCPWAVE was used as input for both shoreline change models, GENESIS and Model Tombolos. The corner coordinates of the grid #1 (Figure 13) as well as the location of VIMS's wave gage are:

Lower Right	SE	36°53.3'N	76°01.6'W
Lower Left	SW	36°55.7'N	76°11.4'W
Upper Left	NW	37°01.1'N	76°09.3'W
Upper Right	NE	36°58.6'N	75°59.5'W
Wave Gage		37°02.4'N	76°12.5'W

In order to create the time series, the original wave gage data file was edited to eliminate waves that: were outside the site's wave window (136°-256°); had wave heights less than 0.15 m (0.5 ft); and had periods less than 2.0 secs. Because it is impractical to run all the recorded wave events through RCPWAVE, the wave data were categorized by height, period and direction. The categories, referred to as bands, describe the number of wave events eventually run through RCPWAVE. The boundaries are shown in Table 6. The first height band is from 0.15 m to 0.65 m (0.5 ft to 2.1 ft); the second height band is from 0.65 m to 1.15 m (2.1 ft to 3.8 ft); the third is from 1.15 m to 1.65 m (3.8 ft to 5.4 ft); the fourth is from 1.65 m to 2.15 m (5.4 ft to 7.1 ft) . The same process was used on the periods and angles within the wave gage data.

Table 6. Wave data banding parameters for Bay-generated waves.

Parameter	Minimum	Maximum	Interval	No. of Bands
Height (m)	0.15	2.15	0.5	4
Period (sec)	3.5	17.5	2.0	7
Direction (deg TN)	136	256	20	6
Total possible cases				168

For the boundaries of the bands listed in the table, 168 possible bands exist. However, when the wave gage data was actually categorized into these bands, only 42 of the 168 possible cases existed within the data. These cases are representative of the Bay-generated wave conditions at the wave gage and had to be transformed into nearshore wave conditions that are necessary for input to Model Tombolos and GENESIS. In order to model the ocean swell impacting the NAB shoreline, the original grid (#1) was rotated 90° and shortened (grid #2) (Figure 13)so that waves entering through the Bay mouth within the wave window 256°-296° could be modeled. The same banding procedure was used on the ocean swell data (Table 7), and 25 out of 56 total possible cases existed within the wave data.

Table 7. Wave data banding parameters for ocean swell.

Parameter	Minimum	Maximum	Interval	No. of Bands
Height (m)	0.15	2.15	0.5	4
Period (sec)	3.5	17.5	2.0	7
Direction (deg TN)	256	296	20	2
Total possible cases				56

The representative wave conditions were entered at the bayward edge of the RCPWAVE grid (Figure 13) and allowed to travel across the bathymetry to the nearshore region at NAB. Since the wave series has to serve two basic purposes 1) input to GENESIS, 2) input to Model Tombolos, two separate idealized wave series had to be created. For GENESIS, the wave conditions for the RCPWAVE cell at the seaward side of the GENESIS grid was exported and averaged to come up with one condition across the whole GENESIS grid. For Model Tombolos, several cells of transformed wave parameters in the vicinity of the Officer's Beach were exported from the overall RCPWAVE output file. Both of these outputs were then averaged in

Figure 13. Bathymetry of original grid (1) and rotated grid (2).

order to obtain one representative condition for each of the 67 input cases (Table 8 and Table 9). This application does not include the effects of tidal currents.

In order to have a complete time series for use in GENESIS and Model Tombolos, the output conditions of the 67 cases replaced the wave parameters in the modified wave gage data file thereby creating an artificial time series. Only wave height and direction changed; wave period was the same. In order to show the average wave conditions that will impact the study area, the wave angles of the artificial time series were averaged. The angles are listed grid relative; negative numbers indicate right of normal to the grid or waves coming from northeast or east. Table 10 indicates that most of the waves are coming through the Bay mouth.

Table 10. Input wave series and average wave angle of the time series used in the model runs.

Model Run	Average Wave Angle (grid relative)
Year 1	-60
Year 2	-66
Year 3	-60
Year 4	-59
Year 5	-50
Year 6	-49

Westward-traveling waves entering the Chesapeake Bay that would seem not to affect the southern shoreline are refracted by the complex bathymetry in the Bay mouth region. Figures 14A and 14B show the wave vectors and trajectories of these waves resulting from RCPWAVE analysis. Wave vectors indicate the change in wave height from the edge of the grid to the shoreline while wave trajectories indicate the path of waves and how the wave energy is affected by the bathymetry. In this case, the waves are refracted so that the impact they have on the shoreline is to drive the sediment westward. Figure 14B also indicates a concentration of energy at the Officers Beach which has evolved into an obvious shoreline protuberance or headland.

The GENESIS modeling system is designed to simulate long-term shoreline change at coastal structures (Hanson and Kraus, 1989). A grid extending from Little Creek Inlet eastward, approximately 14,000 feet (4,300 m), to the Chesapeake Bay

Table 8. RCPWAVE results for use in Genesis.

Number	Height in (m)	Period (sec)	Direction in (deg TN)	Height out (m)	Direction out (deg TN)
1	0.40	4.50	146.00	0.57	169.69
2	0.40	4.50	166.00	0.36	178.35
3	0.40	4.50	186.00	0.38	189.32
4	0.40	4.50	206.00	0.39	201.03
5	0.40	4.50	226.00	0.37	212.47
6	0.40	4.50	246.00	0.69	218.60
7	0.40	6.50	146.00	0.46	177.78
8	0.40	6.50	166.00	0.40	183.92
9	0.40	6.50	186.00	0.41	191.58
10	0.40	6.50	206.00	0.42	200.79
11	0.40	6.50	226.00	0.42	210.00
12	0.40	6.50	246.00	1.35	217.29
13	0.40	8.50	146.00	0.54	182.62
14	0.40	8.50	166.00	0.37	187.03
15	0.40	8.50	186.00	0.35	192.70
16	0.40	8.50	206.00	0.39	199.70
17	0.40	8.50	226.00	0.71	208.28
18	0.40	8.50	246.00	1.22	213.87
19	0.40	10.50	186.00	0.36	193.27
20	0.40	10.50	246.00	1.12	209.49
21	0.90	6.50	146.00	0.80	177.86
22	0.90	4.50	166.00	0.74	178.36
23	0.90	6.50	166.00	0.79	183.95
24	0.90	4.50	186.00	0.77	189.32
25	0.90	6.50	186.00	0.77	191.55
26	0.90	8.50	186.00	0.61	192.68
27	0.90	4.50	206.00	0.77	201.00
28	0.90	6.50	206.00	0.87	200.78
29	0.90	4.50	226.00	0.74	212.43
30	0.90	6.50	226.00	0.83	209.94
31	0.90	4.50	246.00	0.98	221.17
32	0.90	8.50	246.00	1.24	213.31
33	1.40	6.50	166.00	1.11	183.97
34	1.40	4.50	186.00	1.08	189.30
35	1.40	6.50	186.00	1.02	191.55
36	1.40	4.50	206.00	1.10	201.00
37	1.40	6.50	206.00	1.12	200.76
38	1.40	6.50	226.00	1.16	209.95
39	1.40	4.50	246.00	1.13	220.89
40	1.40	6.50	246.00	1.38	217.81
41	1.90	6.50	186.00	1.12	191.57
42	1.90	6.50	206.00	1.24	200.77
43	0.40	4.50	266.00	0.18	263.33
44	0.40	4.50	286.00	0.12	271.31
45	0.40	6.50	266.00	0.17	259.35
46	0.40	6.50	286.00	0.11	266.67
47	0.40	8.50	266.00	0.13	263.79
48	0.40	8.50	286.00	0.10	265.31
49	0.40	10.50	266.00	0.10	263.84
50	0.40	10.50	286.00	0.10	264.61
51	0.40	12.50	266.00	0.10	263.71
52	0.40	12.50	286.00	0.10	264.06
53	0.40	14.50	266.00	0.09	263.63
54	0.40	16.50	266.00	0.09	264.05
55	0.40	16.50	286.00	0.10	264.15
56	0.90	4.50	266.00	0.40	263.33
57	0.90	4.50	286.00	0.26	271.30
58	0.90	6.50	266.00	0.37	259.41
59	0.90	6.50	286.00	0.23	266.54
60	0.90	8.50	266.00	0.27	263.72
61	0.90	8.50	286.00	0.21	265.12
62	0.90	10.50	286.00	0.21	264.63
63	1.40	4.50	266.00	0.60	263.33
64	1.40	6.50	266.00	0.57	259.33
65	1.40	6.50	286.00	0.35	266.59
66	1.40	8.50	286.00	0.31	265.27
67	1.90	6.50	266.00	0.74	259.40

Table 9. RCPWAVE results for use in Tombolos.

Number	Height in (m)	Period (sec)	Direction in (deg TN)	Height out (m)	Direction out (deg TN)
1	0.40	4.50	146.00	0.31	162.38
2	0.40	4.50	166.00	0.36	172.19
3	0.40	4.50	186.00	0.41	182.53
4	0.40	4.50	206.00	0.39	192.77
5	0.40	4.50	226.00	0.31	200.84
6	0.40	4.50	246.00	0.37	202.26
7	0.40	6.50	146.00	0.42	174.17
8	0.40	6.50	166.00	0.42	173.72
9	0.40	6.50	186.00	0.58	183.37
10	0.40	6.50	206.00	0.45	192.18
11	0.40	6.50	226.00	0.42	198.43
12	0.40	6.50	246.00	0.49	200.31
13	0.40	8.50	146.00	0.46	174.41
14	0.40	8.50	166.00	0.36	177.72
15	0.40	8.50	186.00	0.49	186.89
16	0.40	8.50	206.00	0.48	191.80
17	0.40	8.50	226.00	0.41	198.70
18	0.40	8.50	246.00	0.47	198.61
19	0.40	10.50	186.00	0.53	186.98
20	0.40	10.50	246.00	0.50	195.55
21	0.90	6.50	146.00	0.95	173.69
22	0.90	4.50	166.00	0.82	172.20
23	0.90	6.50	166.00	0.93	173.90
24	0.90	4.50	186.00	0.92	182.53
25	0.90	6.50	186.00	1.28	183.29
26	0.90	8.50	186.00	1.10	186.97
27	0.90	4.50	206.00	0.89	192.77
28	0.90	6.50	206.00	1.01	192.18
29	0.90	4.50	226.00	0.71	200.84
30	0.90	6.50	226.00	0.97	198.35
31	0.90	4.50	246.00	0.51	204.43
32	0.90	8.50	246.00	1.19	198.73
33	1.40	6.50	166.00	1.24	174.07
34	1.40	4.50	186.00	1.30	182.54
35	1.40	6.50	186.00	1.26	183.37
36	1.40	4.50	206.00	1.30	192.76
37	1.40	6.50	206.00	1.20	192.26
38	1.40	6.50	226.00	1.27	198.37
39	1.40	4.50	246.00	1.27	203.93
40	1.40	6.50	246.00	1.17	200.97
41	1.90	6.50	186.00	1.18	183.52
42	1.90	6.50	206.00	1.28	192.21
43	0.40	4.50	266.00	0.22	264.15
44	0.40	4.50	286.00	0.19	273.60
45	0.40	6.50	266.00	0.23	259.40
46	0.40	6.50	286.00	0.21	268.50
47	0.40	8.50	266.00	0.21	264.45
48	0.40	8.50	286.00	0.20	266.26
49	0.40	10.50	266.00	0.18	264.62
50	0.40	10.50	286.00	0.21	265.78
51	0.40	12.50	266.00	0.19	264.32
52	0.40	12.50	286.00	0.21	264.96
53	0.40	14.50	266.00	0.17	264.31
54	0.40	16.50	266.00	0.17	265.12
55	0.40	16.50	286.00	0.21	264.84
56	0.90	4.50	266.00	0.47	264.15
57	0.90	4.50	286.00	0.43	273.59
58	0.90	6.50	266.00	0.44	259.40
59	0.90	6.50	286.00	0.42	268.50
60	0.90	8.50	266.00	0.41	263.93
61	0.90	8.50	286.00	0.35	266.30
62	0.90	10.50	286.00	0.36	265.69
63	1.40	4.50	266.00	0.66	264.15
64	1.40	6.50	266.00	0.60	259.40
65	1.40	6.50	286.00	0.55	268.48
66	1.40	8.50	286.00	0.48	266.39
67	1.90	6.50	266.00	0.72	259.60

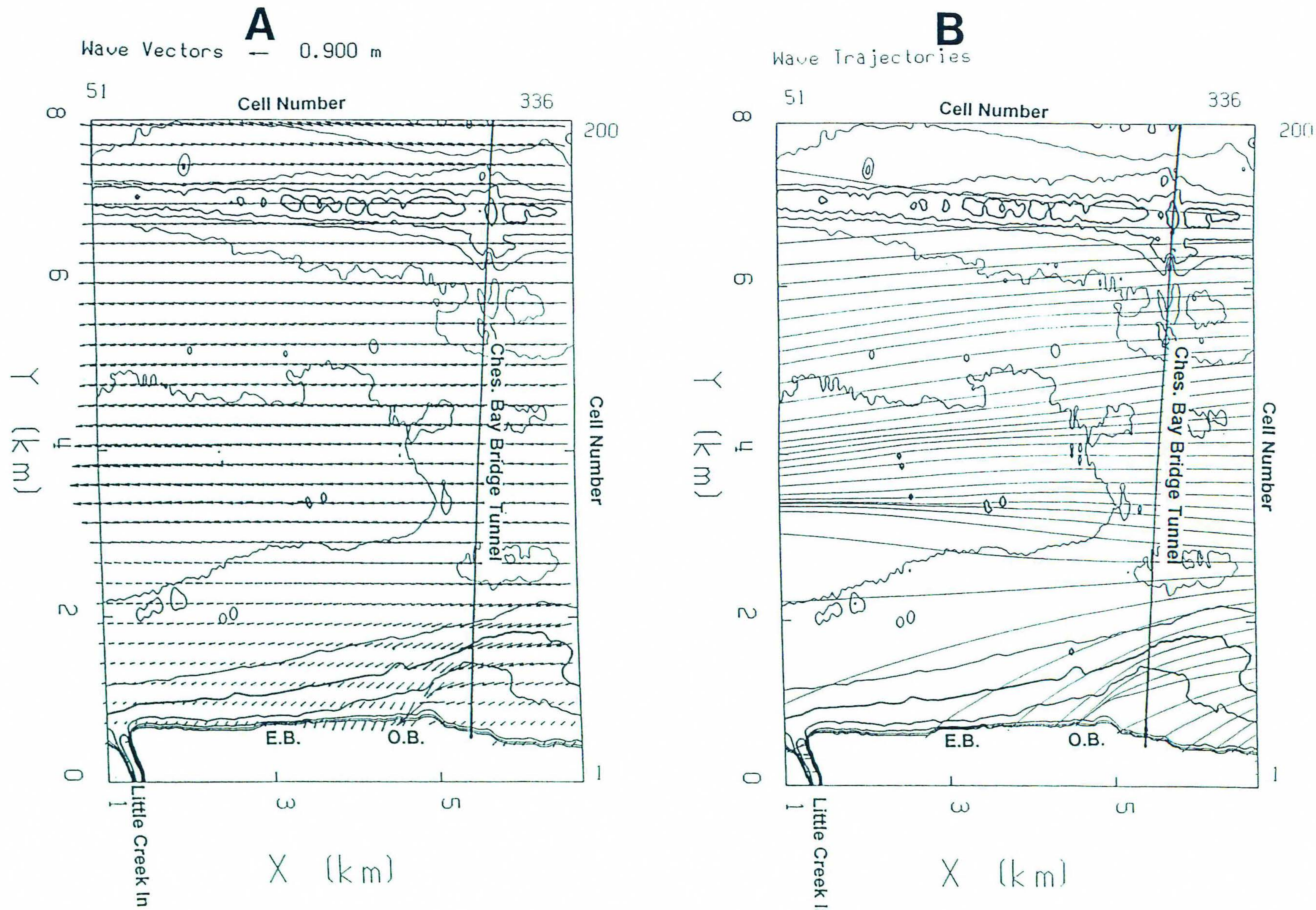


Figure 14. Plots on the rotated grid for wave A.) vectors and B.) trajectories.

Bridge Tunnel was created (Figure 15). The alongshore (X) axis has an orientation of 286° TN, the same as the RCPWAVE grid, and alongshore cell spacing was 30 m (98 ft). Groins 1, 2, 3, and 4 as well as Little Creek Inlet east jetty and the revetment west of the O.B. were included in the analysis. The shoreline positions used for calibration and verification of the model were digitized from three separate sets of aerial photos taken on 9 March 1982, 24 August 1985 and 15 June 1996. These dates were chosen because shoreline position change could be checked with profile data. The 1996 shoreline was also used as the initial shoreline for the shore management plan run.

Calibration is the procedure of determining values of adjustable coefficients within the model that reproduce the a shoreline position measured over a certain time interval (Gravens *et al.*, 1991). In the verification procedure, these same coefficients are applied to a different time period in order to reproduce another measured shoreline. Calibration took place for the 1982 and 1985 shorelines and verification for the 1985 to 1996 shorelines. Of note, GENESIS tended to show more accretion updrift of the E.B. groin and more erosion downdrift than actually occurred in both the calibration and verification runs.

3. *Results*

The calibrated and verified model data was applied to the 1996 shoreline to determine conditions over three years if nothing was done to the shoreline (Figure 16A). Specific damage for severe storm conditions with elevated water levels are not accounted for in this analysis. These must be part of the design detail for each segment of the Shoreline Management Plan. Figure 16A shows that continued erosion would occur downdrift of both Groins # 3 and #4. This planform would evolve as the shore moved into a state of dynamic equilibrium. The groins are modeled as non-diffracting structures so the spur breakwater modifications (i.e. proposed offshore structures #1, #2, #5, #6, and #7) shown on the Plan (Figure 12) would enhance the efficiency of the existing groins and set the updrift and downdrift headland diffraction points.

According to GENESIS, the average net alongshore sediment transport rate is 38,327m^3 (49,825cy) to the west over the three year simulation (Figure 16B). Western transport is indicated by the negative numbers on Figure 16B. GENESIS results showed only minor transport to the east along the Little Creek shoreline resulting in a large net westerly sediment transport system. Transport rates vary along the shoreline with greater rates adjacent to structures (i.e. Groins #3 and #4). While the amounts of west to east transport and east to west transport varied, the net

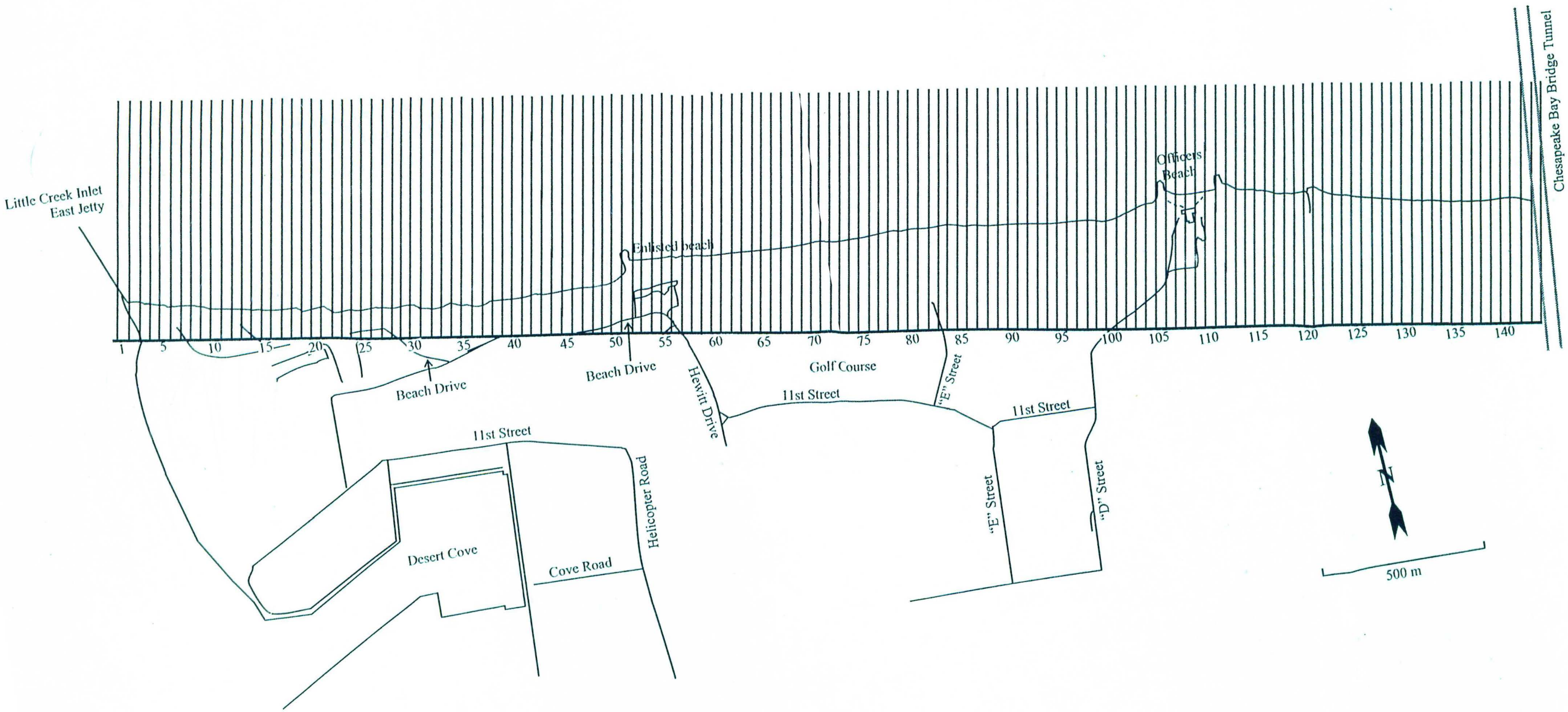


Figure 15. GENESIS baseline and grid.

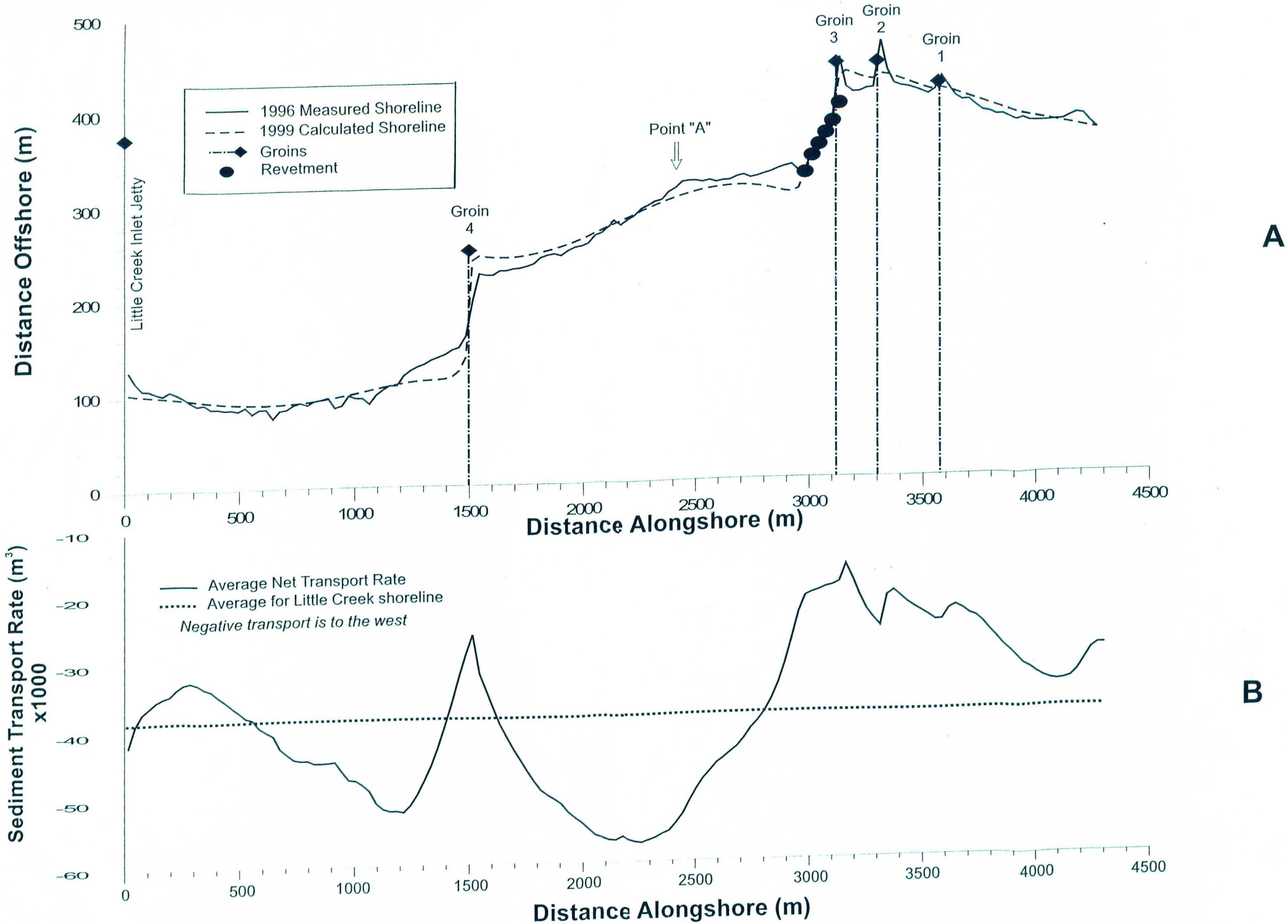


Figure 16. GENESIS run on the 1996 measured shoreline without any additional structures over a three year simulation period. A.) shows the calculated shoreline, and B.) shows the net transport rate along the shoreline.

westerly transport reported by Das (1974) (36,000 cy or 27,700 m^3) is similar in magnitude to the amount calculated by GENESIS.

The shoreline offset, shown by GENESIS, west of the existing revetment (Figure 16A) would be alleviated with the addition of proposed reef breakwater structure #4 (Figure 17A). GENESIS requires this structure to be at least 40 feet (12 m) offshore and to act as a detached breakwater. The downdrift impact is translated westward toward Point 'A'. Adding proposed structure #3 (Figure 17B) would segment and reduce that impact by creating a stable embayment between proposed structure #3 and #4 but would also create a slight downdrift impact and an embayment toward the E.B. The key features of reef breakwaters are their low elevation and large width that allow a semi-attached tombolo to exist such that “excess” sediment can move through the system and storm waves will be reduced before they reach the beach.

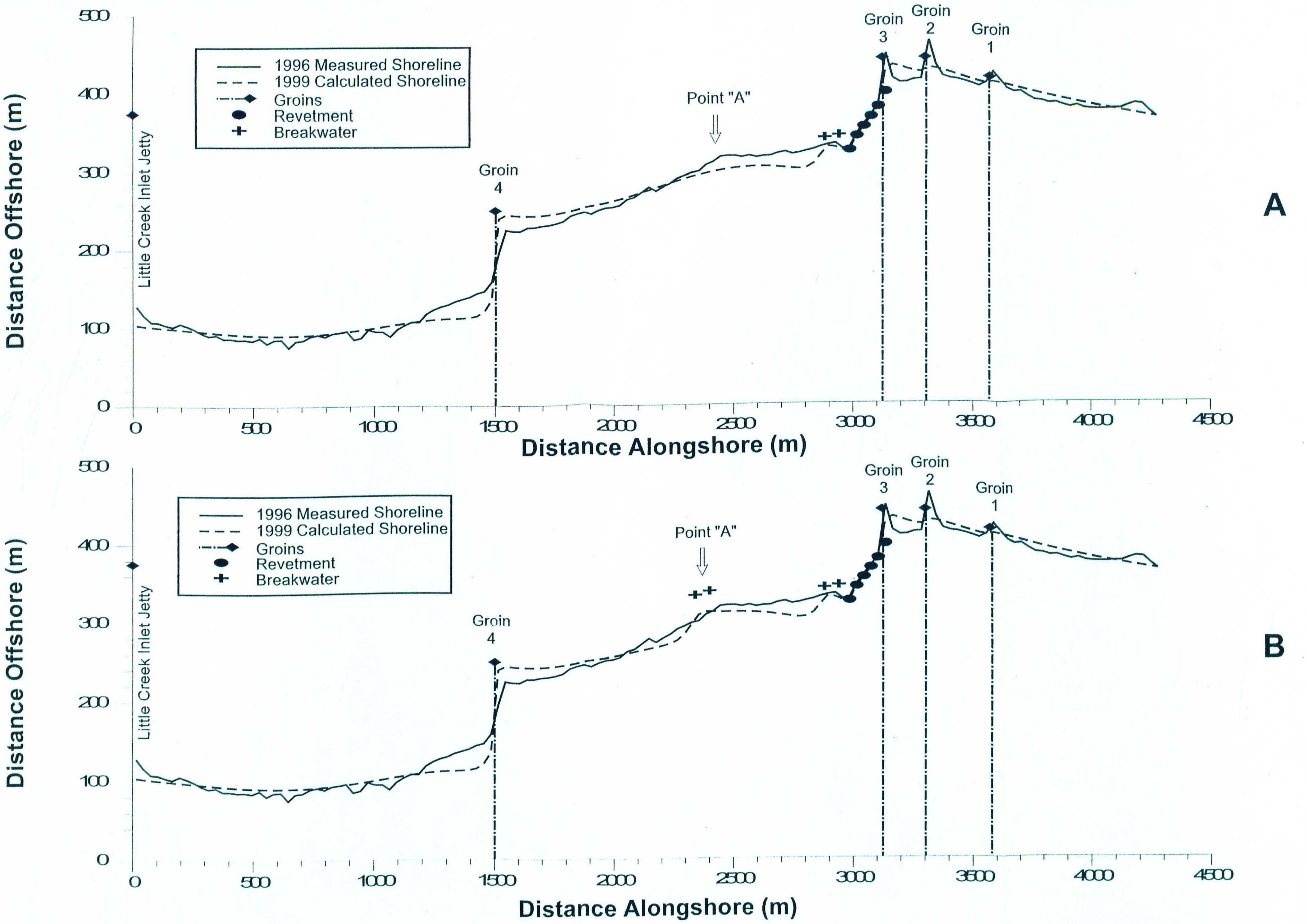


Figure 17. GENESIS 1996 measured shoreline and calculated shoreline after a three year simulation period with Management Plan A.) Breakwater #4, and B.) Breakwaters #4 and #3.

V. OFFICER'S BEACH

A. Shoreline Management Options

The Officer's Beach is the second element in the overall shoreline management plan. Special attention has been paid to this beach in the context of the long term implications of the shoreline management plan. The goal at the Officer's Beach was to create a wider, more stable, recreational beach. Modifications and enhancement of the existing groin system was the selected course of action in line with the overall shoreline management plan. However, in order to put the proposed plan in perspective, it is necessary to evaluate other options as follows:

1) No Action: By doing nothing the same general trends in beach and dune erosion at and adjacent to the O.B. will continue.

2) Rehabilitate Groins #2 and #3: A possible first step in regaining beach stability would be to increase the elevation of the groins by adding armor stone. This would provide a "stacking" mechanism for the sand at the O.B. However, there is a potential for increased downdrift impacts, and beach sands still may exit during storm events leaving the dune and backshore vulnerable.

3) Rehabilitate Groins #2 and #3 and build revetments: At Groin #3 this would entail extending the existing revetment to the east behind the existing beach bath houses. A new revetment would be needed landward of Groin #2. It would extend along the dune face and return on each end into the dune in order to address the potential for flanking during storms.

4) Proposed Plan: Figure 18 portrays a reasonable plan for the O.B. with angled offshore breakwaters that will encapsulate the beach and provide protection from waves. This plan includes groin rehabilitation and defensive revetments as described in options 2 and 3. The breakwaters should have a low profile and be wide in order to address storm waves and allow some sand transport in their lee across the groins. Increased sand residency, and consequently increased backshore protection, can be achieved by increasing the breakwater elevations. Potential downdrift impacts also increase if the elevations are raised.

5) Proposed plan with beach fill: In order to alleviate initial downdrift impacts, beach fill could be added to offer a sand "continuum" to the downdrift shore.

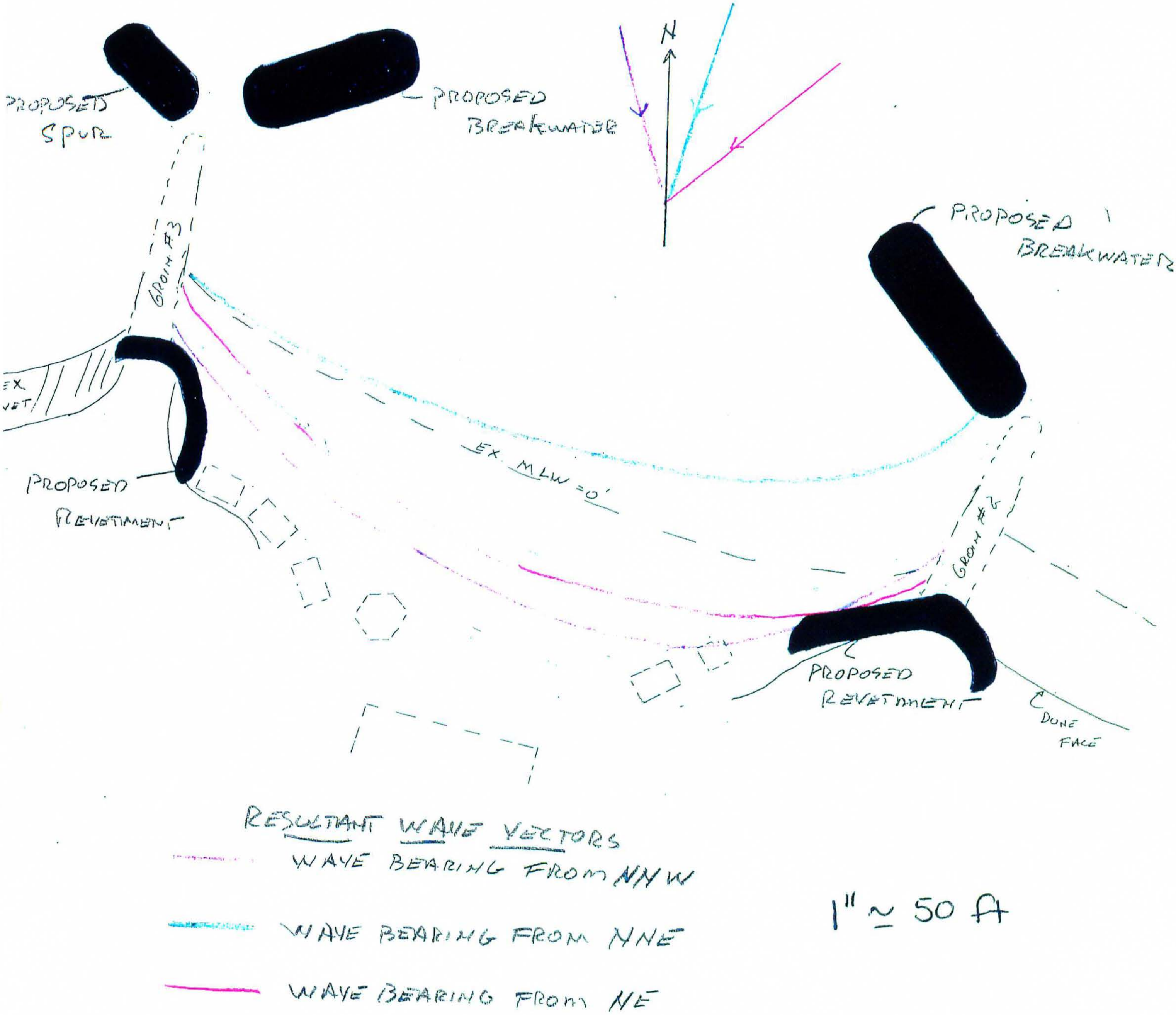


Figure 18. Officer's Beach proposed project shoreline planform calculations.

6) Modified Plan #4: This option is based on cost estimates from the Navy to implement option #4. If the Navy is not going to implement option #4 with the full complement of spur breakwaters, then the east spur breakwater should be installed in order to maintain a beach in its lee to set the beach planform. The rationale for this is that with the improved groin and revetment on the east side of the O.B., wave diffraction during storms will be more pronounced, and sand loss on the east side of the O.B. may be exacerbated. The low spur breakwater would abate that potential and store sand for that event. By not emplacing the spur breakwaters off the west groin, sand will bypass through the system more rapidly. The west revetment and groin improvements will act to extend the limits of the tangential section of the O.B. and act in concert with the spur breakwater on the east groin.

About 1,200 cy (900 m^3) of sand will be necessary to create the stable beach planform with the east spur modification. That is, about 1,200 cy (900 m^3) of sand must enter the O.B. before bypassing through the west groin would occur. These modifications will address the original project goals at a reduced cost.

Whatever is done at the O.B. will most likely have some impact on downdrift shorelines. It would be prudent to prepare to construct additional structures in the area between the O.B. and Point "A", as portrayed in the overall shoreline management plan for the base, and/or to place sand in the impacted regions.

B. Model SEB

To further evaluate beach planform predictions between possible headland breakwaters at the O.B., procedures developed by Silvester and Hsu (1993) called the Static Equilibrium Bay model (SEB) were used. This involves empirical relationships of bay shape to the dominate direction of wave approach (Figure 19). This relationship is established by defining the control line between two headland features and plotting theta and R. The SEB model was used in developing the recommended offshore breakwater configuration at the O.B. Model SEB was also used to predict beach planforms that would evolve due to several different wave scenarios impinging on the preliminary structural configuration at the O.B. (Figure 18).

Selected output from the RCPWAVE analysis are shown in Figures 20A, B, C. These plots are examples of the plots used to determine the average wave climate impacting the O.B. Figure 20A describes the northwester condition in the lower Bay; Figure 20B the north northeasterly wave conditions; Figure 20C, which was run on the rotated grid, describes the easterly wave conditions generated outside the Bay. Notice the accentuated refraction off of the O.B. under easterly conditions.

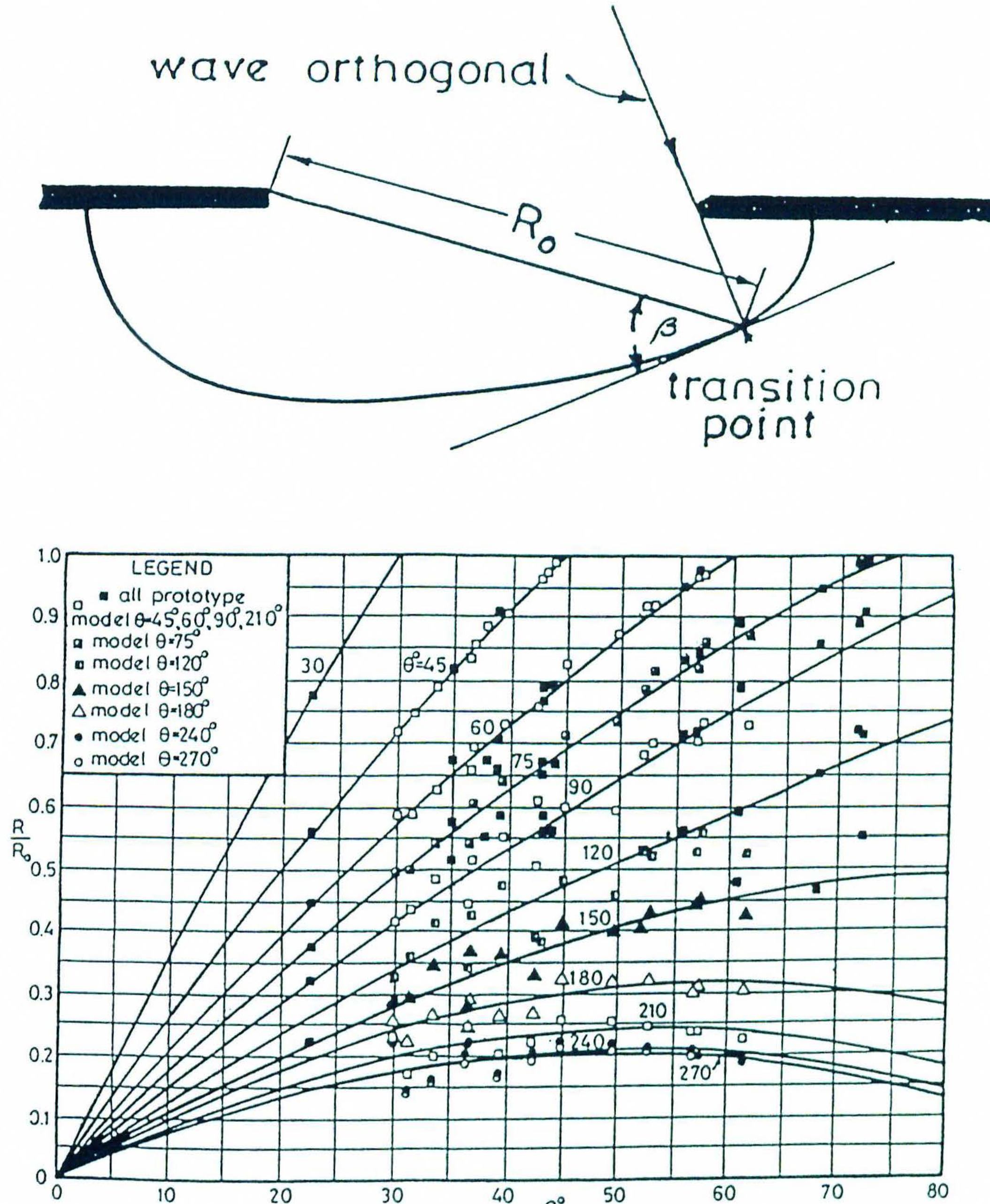


Figure 19. Equilibrium bay computation graphic and computation variables (after Hsu *et al.*, 1989).

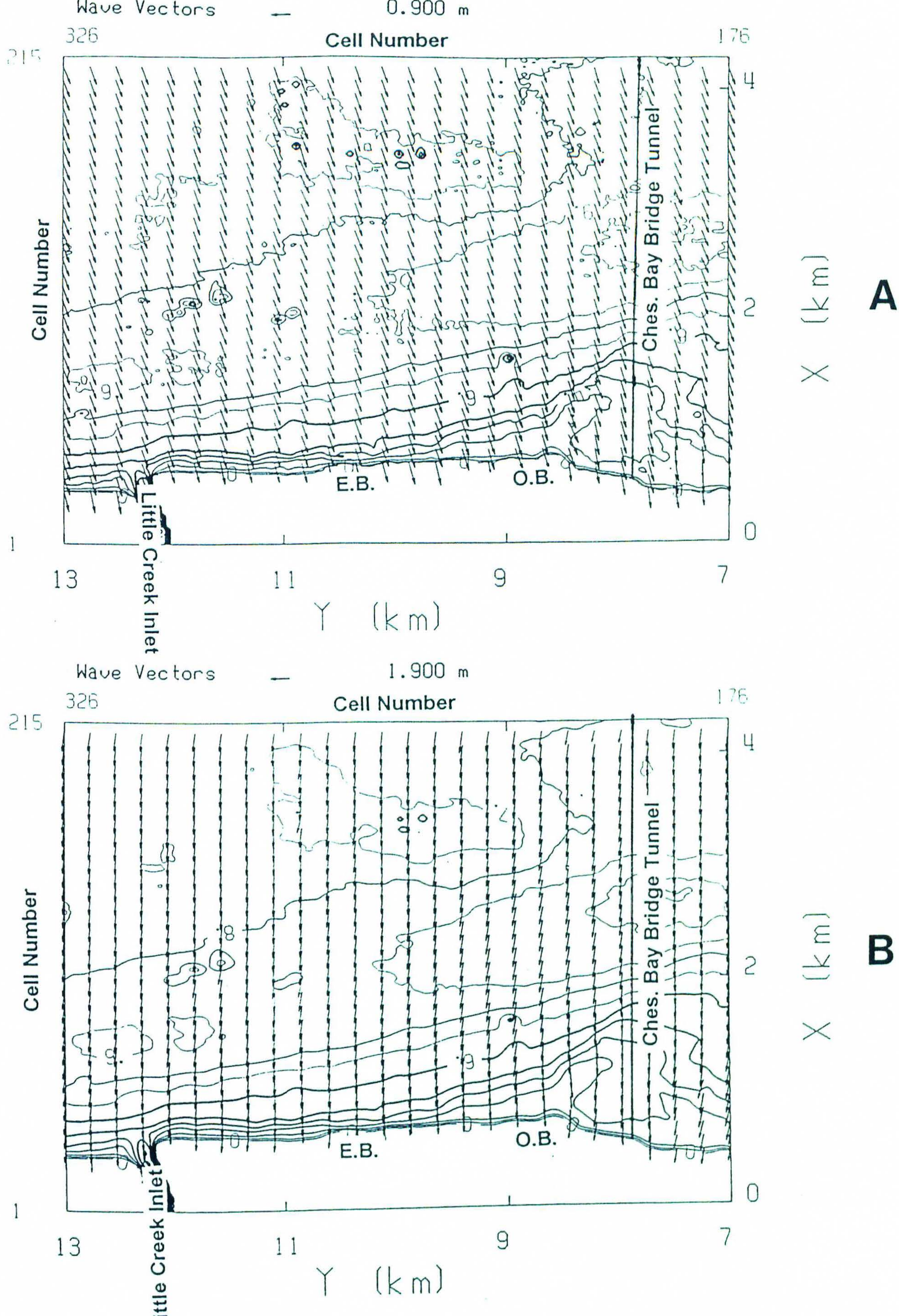


Figure 20. Original grid RCPWAVE output for A.)H=0.9 m, T=6.5 sec, Ang=166° TN and B.) H=1.9 m, T=6.5 sec, Ang=206° TN.

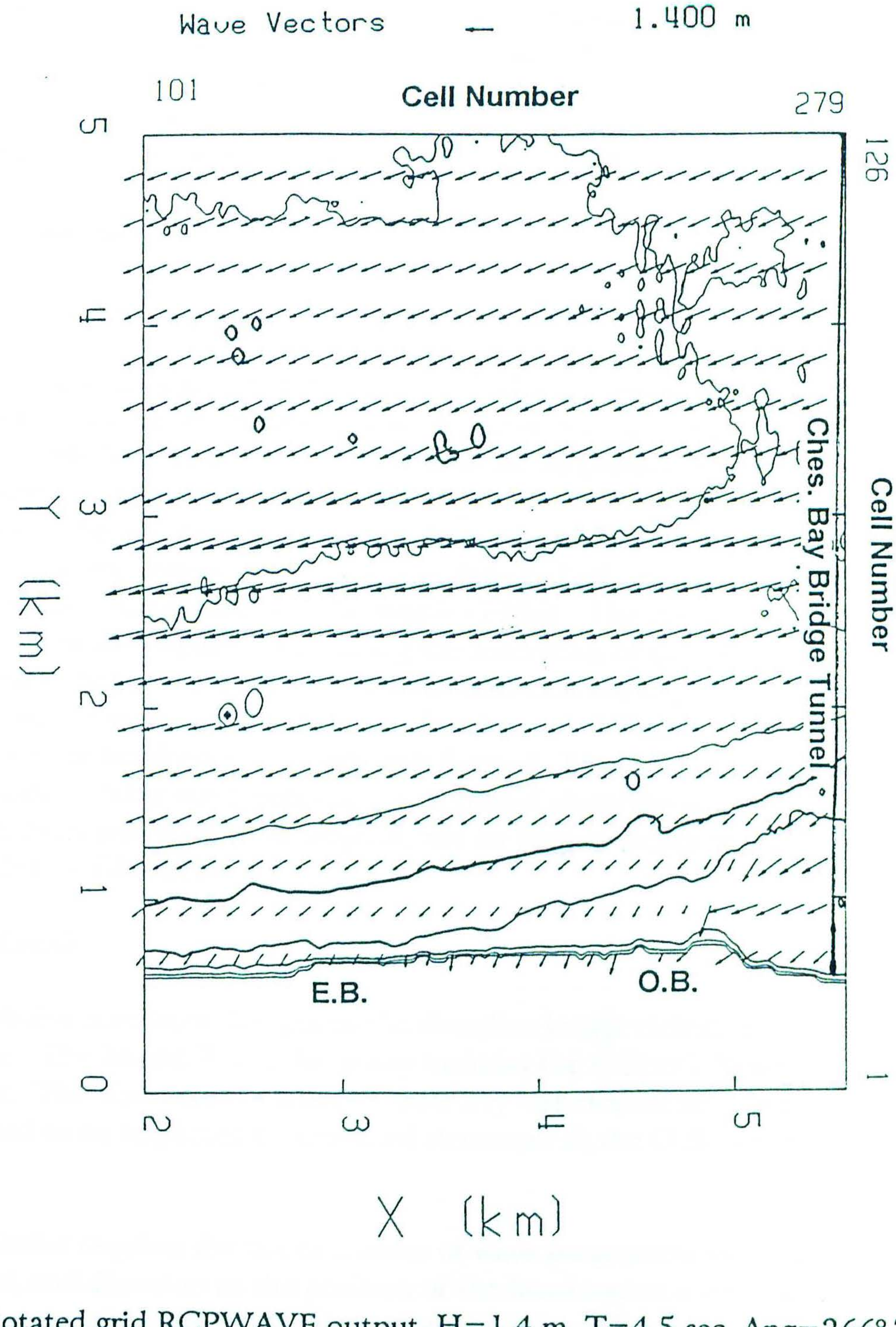


Figure 20C. Rotated grid RCPWAVE output, H=1.4 m, T=4.5 sec, Ang=266° TN.

A crest height of +5 ft (1.5m) MLW for the proposed breakwaters would protect the shore from storm surge levels that occur once a year, according to both the U.S. Army Corps of Engineers (1983) and Boon *et al.* (1978). The waves associated with such an event, primarily northeasters, have heights on the order of 4 feet (1.2m) at the -6 foot (1.8m) MLW contour. Projected wave heights at the -6 foot (1.8 m) contour for a 50 yr storm event are 9 to 10 ft (2.7 to 3.0m).

C. Model Tombolos

1. Introduction

In response to the inability of present shoreline change models to accurately predict beach planform in the lee of attached breakwaters, Suh and Hardaway (1994) developed Model Tombolos. This one-line numerical model predicts shoreline change in the vicinity of offshore breakwaters by permitting the formation and growth (or decay) of tombolos in the lee of impermeable offshore breakwaters. The model uses curvilinear coordinates that follow the shoreline as done in LeBlond (1972), Uda (1983), Suh (1985), and Kobayashi and Dalrymple (1986). The curvilinear coordinates make the model capable of handling the formation of tombolos as well as the growth of salients. Salients are formed by sediments that are deposited by wave-generated currents in the sheltered area behind a breakwater. When a salient grows until its apex reaches the breakwater, a tombolo is formed. Model Tombolos is a fairly restrictive model. Other structures cannot be placed along the shoreline, and the model has only been tested on local projects, not on long stretches of shoreline such as that modeled by GENESIS.

2. Methods

Model Tombolos simulates changes to the shoreline in the vicinity of breakwater systems. The Model Tombolos study includes the Officer's Beach and adjacent revetment. The Tombolos baseline (Figure 21) was created so that the reach of shoreline expected to be impacted by proposed structures at the O.B. could be modeled.

Model Tombolos requires the use of a series of wave parameters as input. The wave height, period, and direction at the position of the breakwaters are required. These parameters can be obtained by a variety of methods including wave hindcasting, but since wave data were available, it seemed appropriate to use those data at NAB Little Creek. The original wave gage data was reduced using the

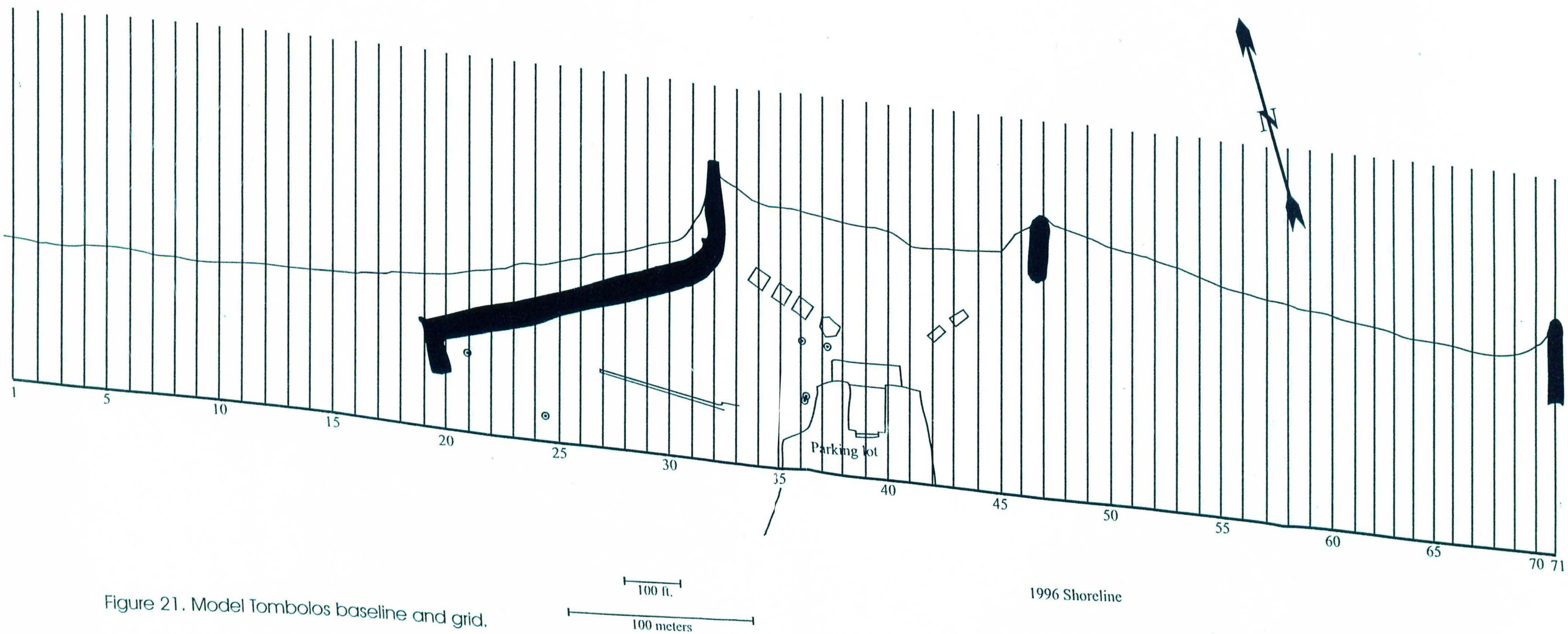


Figure 21. Model Tombolos baseline and grid.

procedures outlined in Section IV, B, 2 of this report and the results are listed in Table 9.

The Model Tombolos baseline (Figure 21) is at the same angle to true north (286° TN) as the RCPWAVE baseline. The initial shoreline date was July 1996. The revetment and the two rock and broken concrete groins that bound the O.B. are not included as input conditions. Other input include the representative grain size, 0.35 mm, specific gravity of beach sand, which is 2.65, and it's porosity, 0.4.

K1 and K2 are longshore transport coefficients and for Tombolos are estimated empirically. K1 controls the time scale of the simulated shoreline change, as well as the magnitude of the longshore transport rate. In order to determine K1, the simple relationship between K1 and D_{50} proposed by del Valle *et al.* (1993).

$$K1 = 1.4\exp(-2.5D_{50})$$

K2 is simply K1 divided by 2. The values of 0.68 and 0.34, respectively, were used. The depth of closure is 13 feet (4 m) (Das, 1974).

The boundary conditions used in the model runs were fixed on both ends of the baseline. A fixed boundary implies that the amount of sand transported remains constant near the boundaries so that the beach retains an equilibrium state there. The fixed boundary is applicable when the length of the beach is long enough so that the sediment transport at the boundaries does not affect the region where the coastal structures are simulated (Suh, 1985).

3. *Results*

Figure 22A shows the shoreline change as described by Model Tombolos. Model Tombolos suggests accretion will occur between the existing Groin #2 and the eastern end of the baseline as well as behind the structures placed at the O.B. Severe erosion would occur west of the O.B.; however, this erosion problem has already been addressed with a revetment. Figure 22B demonstrates the shoreline change with the addition of a 150 foot (46 m) offshore breakwater (Management Plan Structure #4) at the end of the revetment to prevent flanking. This greatly modifies the potential erosion in this area with a semi-attached breakwater structure.

The result of the Model Tombolos run and empirical model predictions (Hsu *et al.*, 1989) indicate stable beach planforms at the O.B. for the proposed plan. If more protection is desired, higher breakwaters can be emplaced. However, these may

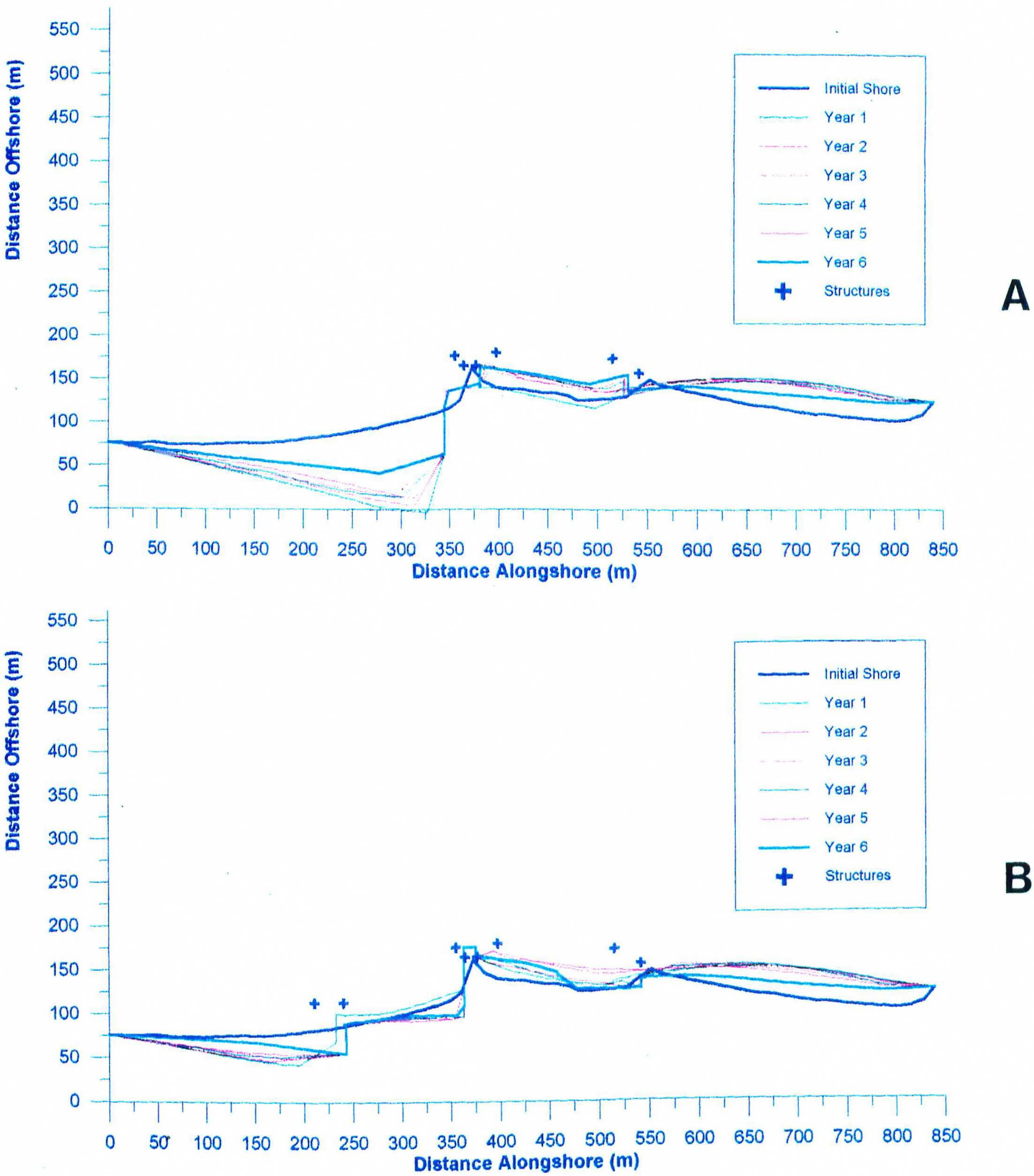


Figure 22. Tombolos calculated shoreline for A.) Officer's Beach Management Plan and B.) the Plan with an additional breakwater at the revetment.

further restrict sediment movement and adversely impact the downdrift shore. This may force the installation of Management Plan Structure #4 as part of the O.B. shoreline project.

VI. MONITORING

Monitoring of the shoreline is an important source of data necessary for determining longshore trends as well as planning future projects. Beach profiles were surveyed by the City of Virginia Beach between 1980 and 1985. The benchmark positioning data are located in Appendix I. VIMS personnel created a baseline, based on the City's benchmarks, but increased the number of profiles surveyed along the NAB Little Creek shoreline. The State Plane coordinates of these profiles also are listed in Appendix I.

In general, long-term monitoring of the shoreline should include beach profiles surveyed twice per year. One survey in the spring and one in the fall will capture the seasonal changes of the shoreline. These surveys should extend to at least 4 or 5 feet below (1.2 or 1.5 m) MLW, but longer profiles, which show the nearshore region, are preferred. Another part of long-term monitoring is vertical aerial photography. These photos should be taken within the same time frame as the shoreline is profiled.

If a project is to be constructed, additional monitoring is warranted. Profiles should be taken prior to a project, immediately following a project, and quarterly for a year following the project. It may be necessary to establish new profile lines to fit the project. Widely spaced profile lines will not provide the information needed to discuss the suitability of a project.

VII. SUMMARY

The shoreline at NAB Little Creek has been retreating, for the most part, since 1852. To reduce sand movement into Little Creek's dredged channel, the Inlet jetties were built in the late 1920's. In order to combat erosion, four groins were constructed in the early 1970's. These groins segmented the shoreline and, in some areas, served to at least reduce erosion for a time. In other areas, particularly the Enlisted Beach, sand was trapped updrift of the groin creating a wide recreational beach. Immediately downdrift of this groin, however, the shoreline retreated as it adjusted toward a new equilibrium. In 1994, a stone revetment was built just west of the Officer's Beach in order to address erosion problems there.

Integration of results from an analysis of historical shoreline trends, wave climate analysis, and shoreline change modeling with the Navy's long- and short-term goals resulted in the development of a Shoreline Management Plan for the NAB Little Creek. This Plan intends to enhance the existing groins with spur breakwaters and add two seperate structures between the O.B. and E.B. to provide headland control along the whole length of the Base shore.

VIII. REFERENCES

Bascom, W.N., 1959. The relationship between sand size and beach face slope. *Am. Geophys. Union Transactions* 32(6): 866-874.

Boon, J.D., C.S. Welch, H.S. Chen, R.J. Lukens, C.S. Fang, and J.M. Zeigler, 1978. *A Storm Surge Model Study: Volume I. Storm Surge Height-Frequency Analysis and Model Prediction for Chesapeake Bay*. Special Report No. 189 in Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 155 pp.

Boon, J.D., S.M. Kimball, K.D. Suh, and D.A. Hepworth, 1990. *Chesapeake Bay Wave Climate*. Data Report No. 32, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 38 pp. + app.

Boon, J.D., D.A. Hepworth and F.H. Farmer, 1992. *Chesapeake Bay -Wave Climate*. Data Report No. 42, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 30 pp. + app.

Boon, 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, VA, 102 pp.

Das, M.M., 1974. *Beach Erosion Study -- Little Creek Naval Amphibious Base, Virginia.* Technical Report TR-248, Department of the Navy, Naval Oceanographic Office, Washington, DC, 69 pp.

Ebersole, B.A., M.A. Cialone, and M.D. Prater, 1986. *RCPWAVE - A Linear Wave Propagation Model for Engineering Use*. U.S. Army Corps of Engineers Report, CERC-86-4, 260 pp.

Fleischer, P., G.J. McRee, and J.J. Brady, 1977. *Beach Dynamics and Erosion Control, Ocean View Section, Norfolk, Virginia*. Technical Report No. 50, Institute of Oceanography, Old Dominion University, Norfolk, VA, 185 pp.

Galvin, C.J., Jr., 1972. A Gross Longshore Transport Rate Formula. *Proceedings, 13th Coastal Engineering Conference, Vancouver, B.C.*

Gravens, M.B., N.C. Kraus, and H. Hanson, 1991. *GENESIS: Generalized Model for Simulating Shoreline Change, Report 2.* Technical Report, CERC-89-19, Department of the Army, US Army Corps of Engineers, Washington, DC, 345 pp + app.

Hanson, H. and N.C. Kraus, 1989. *GENESIS: Generalized Model for Simulating Shoreline Change.* Technical Report CERC-89-19. Coastal Engineering Research Center, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 185 pp. +app.

Hardaway, C.S. and J.R. Gunn, 1991. Headland breakwaters in the Chesapeake Bay. *Proceedings, Coastal Zone '91*, Vol. 2, p. 1267-1281.

Hardaway, C.S., G.R. Thomas, and J.H. Li, 1991. Chesapeake Bay shoreline studies: Headland breakwaters and pocket beaches for shoreline erosion control. *Special Report in Applied Marine Science and Ocean Engineering* No. 313, Virginia Institute of Marine Science, Gloucester Point, VA, 153 pp.

Hardaway, C.S., Jr., D.A. Milligan and G.R. Thomas, 1993. *Public Beach Assessment Report: Ocean Park Beach, Virginia Beach, Virginia.* Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 58 pp + app.

Hsu, J.R.C., R. Silvester, and Y.M. Xia, 1989. Generalities on static equilibrium bays. *Coastal Engineering*, 12:353-369.

Kobayashi, N. and R.A. Dalrymple, 1986. *Erosion of Unprotected Causeway due to Waves.* Res. Rep. No. CE-86-58, Dept. of Civil Engineering, Univ. of Delaware, Newark, DE.

LeBlond, P.H. 1972. On the formation of spiral beaches. American Society of Civil Engineers, *Proceedings, 13th Conference on Coastal Engineering*, 1331-1345.

Ludwick, J.C., 1987. *Mechanisms of Sand Loss from an Estuarine Groin System Following an Artificial Sand Fill.* Department of Oceanography Technical Report 87-2, Old Dominion University, Norfolk, VA, 89 pp.

Owen, D.W., L. Morgan and N.M. Sturm, 1978. *Shoreline Situation Report - City of Virginia Beach.* SRAMSOE Number 163. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, 91 pp.

Silvester, R., and J.R.C. Hsu, 1993. *Coastal Stabilization, Innovative Concepts.* Prentice Hall, Inc., Englewood Cliffs, NJ, 578 pp.

Stauble, D.K., A.W. Garcia, N.C. Kraus, W.G. Grosskopf, and G.P. Bass, 1993. *Beach Nourishment Project Response and Design Evaluation: Ocean City, Maryland.* Technical Report CERC-93-13, Coastal Engineering Research Center, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Suh, K.D., 1985. *Modeling of Beach Erosion Control Measures in a Spiral Wave Basin.* Unpublished Thesis, University of Delaware, Newark, DE.

Suh, K.D. and C.S. Hardaway, 1994. Calculation of tombolo in shoreline numerical model. *Proceedings, 24th International Conference on Coastal Engineering,* Coastal Engineering Research Council/ASCE, October 23-28, 1994, Kobe, Japan. Chapter 192: 2653-2667.

Uda, T., 1983. Predictive model of planform change of a spit at a river mouth. *Coastal Engineering in Japan,* **26**:137-150.

U.S. Army Corps of Engineers. *Dredging Quantities and Disposal Areas.* Norfolk District, Corps of Engineers, Norfolk, VA.

U.S. Army Corps of Engineers. 1983. *Willoughby Spit and vicinity, Norfolk, Virginia, Hurricane Protection and Beach Erosion Control Study.* Feasibility Report and Final Impact Statement, Parts 1 and 2, Supporting Documentation.

del Valle, R., R. Medina and M.A. Losada, 1993. *J. Waterway, Port, Coastal and Ocean Engineering, ASCE,* **119(5)**: 568-574.

Wright, L.D., C.S. Kim, C.S., Hardaway, Jr., S.M. Kimball, and M.O. Green, 1987. *Shoreface and Beach Dynamics of the Coastal Region from Cape Henry to False Cape, Virginia.* Technical Report, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

APPENDIX I

Profile Information and Plots

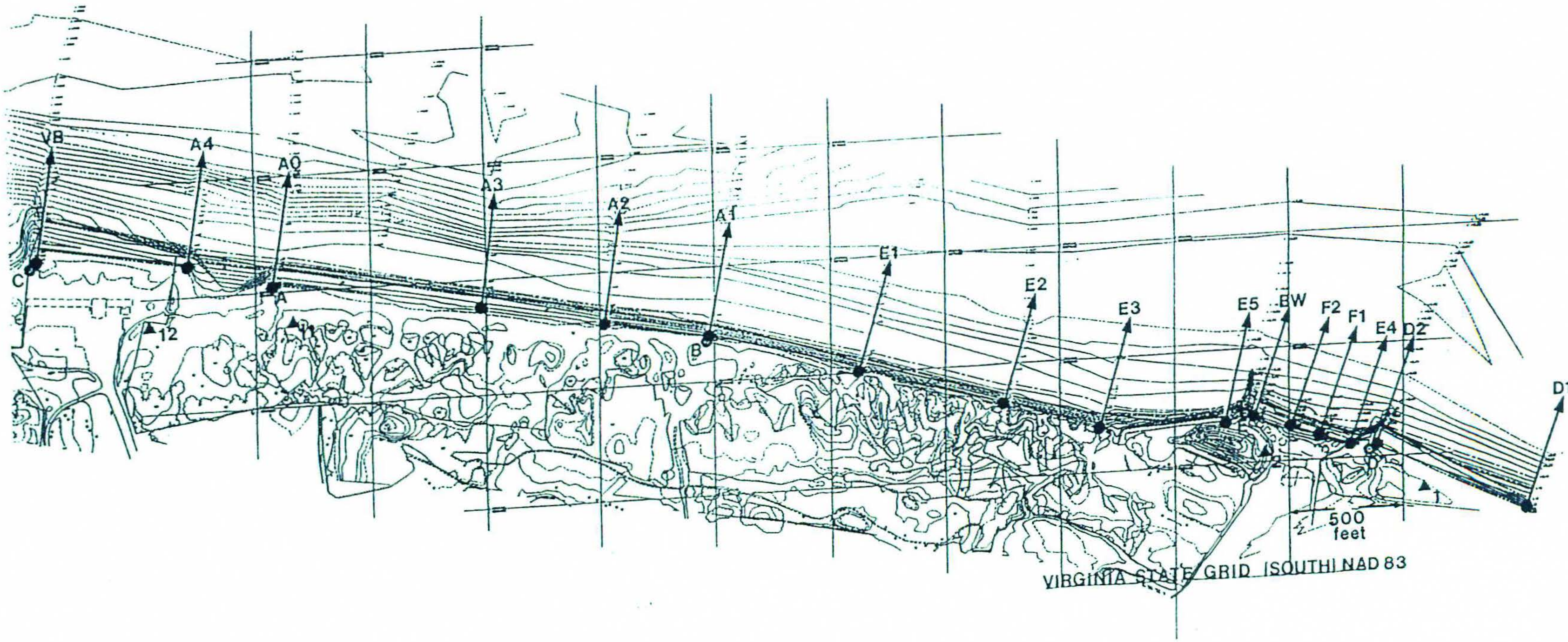
Little Creek Profile and Control Benchmark Positions

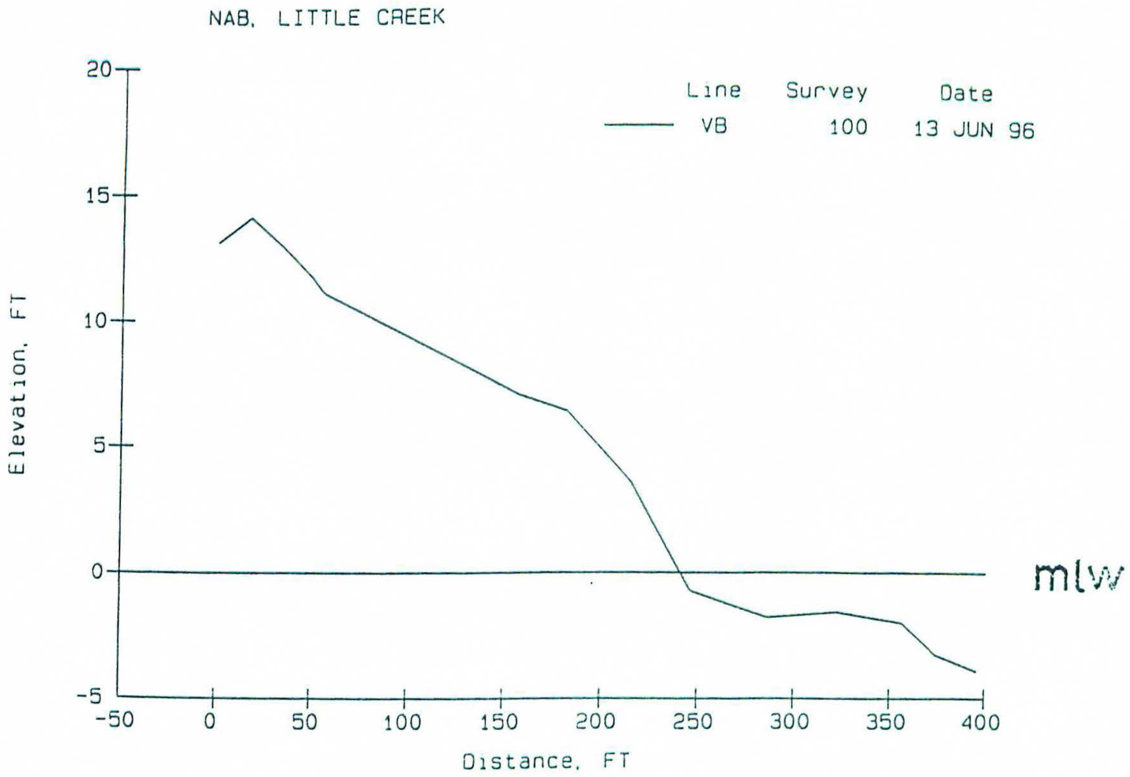
Horizontal - Virginia State Grid (South) NAD 83 (feet)
Vertical - National Ocean Survey, Mean Low Water (feet)

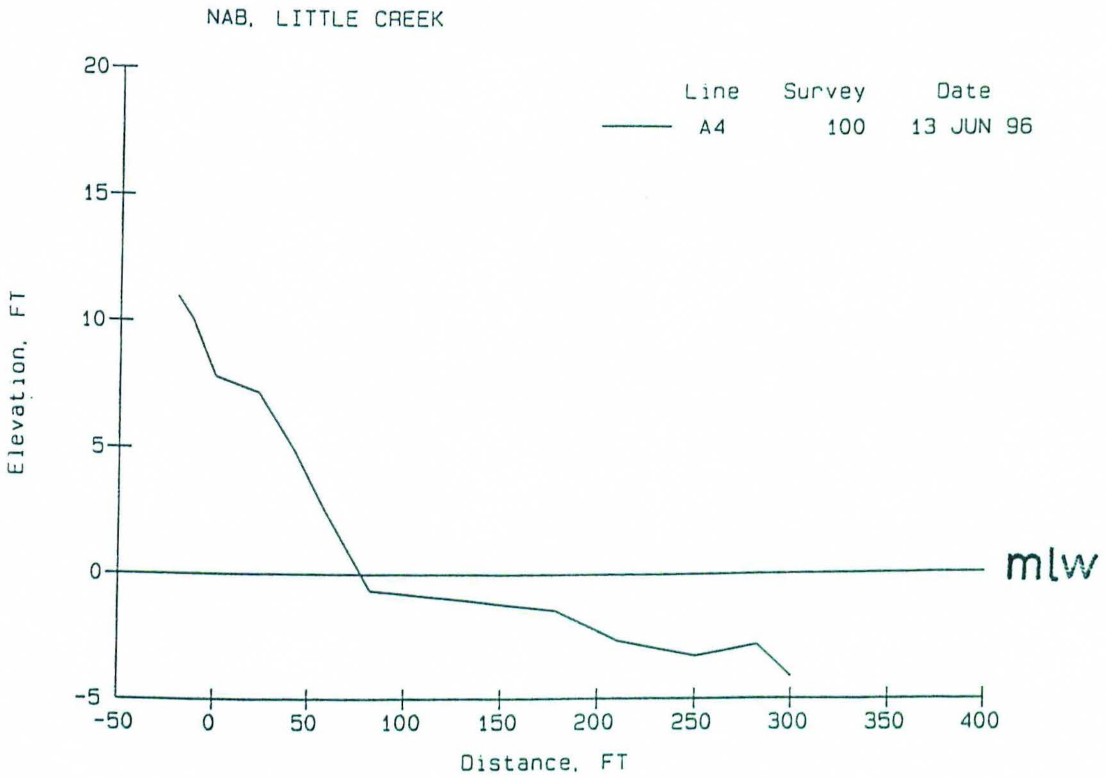
Profile	Northing	Easting	Elevation	Control	Northing	Easting	Elevation
VB	3505187	12167039	13.51	C(VIMS)	3505158	12167012	15.37
A4	3505147	12167708	8.99	A(VIMS)	3505020	12168072	16.75
A0	3505020	12168072	16.75	B(VIMS)	3504680	12169975	16.11
A3	3504879	12168977	9.01	E(VIMS)	3504218	12172326	17.41
A2	3504781	12169517	8.91	D(VIMS)	3504046	12172868	18.12
A1	3504705	12169977	8.81	12(NABLC)	3504882	12167563	22.14
E1	3504502	12170620	8.70	11(NABLC)	3504867	12168183	15.43
E2	3504321	12171248	8.80	2(NABLC)	3504036	12172410	25.57
E3	3504191	12171674	8.76	1(NABLC)	3503861	12173113	17.57
E5	3504180	12172246	20.78				
BW	3504206	12172364	8.25				
F2	3504154	12172527	6.23*				
F1	3504115	12172650	5.58*				
E4	3504073	12172783	6.88				
D2	3504061	12172888	8.33				
D1	3503735	12173537	9.05				

*Temporary benchmark

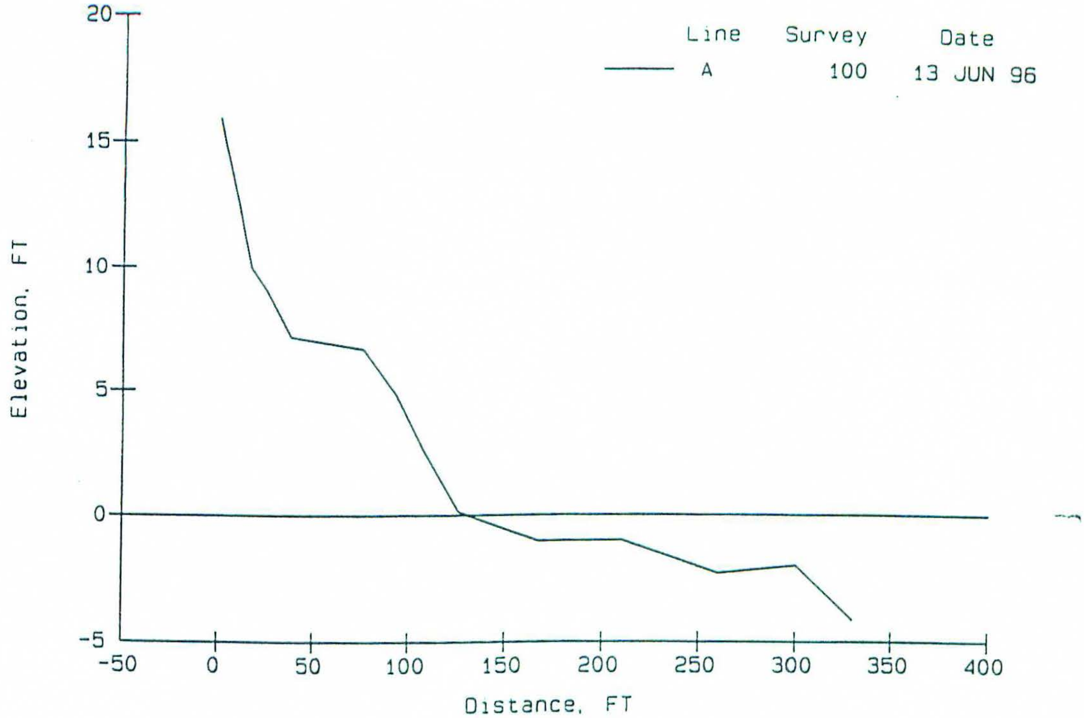
Profile locations are shown on Figure A1-1, and profile plots follow.


VB
C
A4
12
A0
A
11
A3
A2
A1
B
E1
E2
E3
E5
EW
F2
F1
E4
D2
D1
2
1
500
feet
VIRGINIA STATE GRID (SOUTH) NAD 83

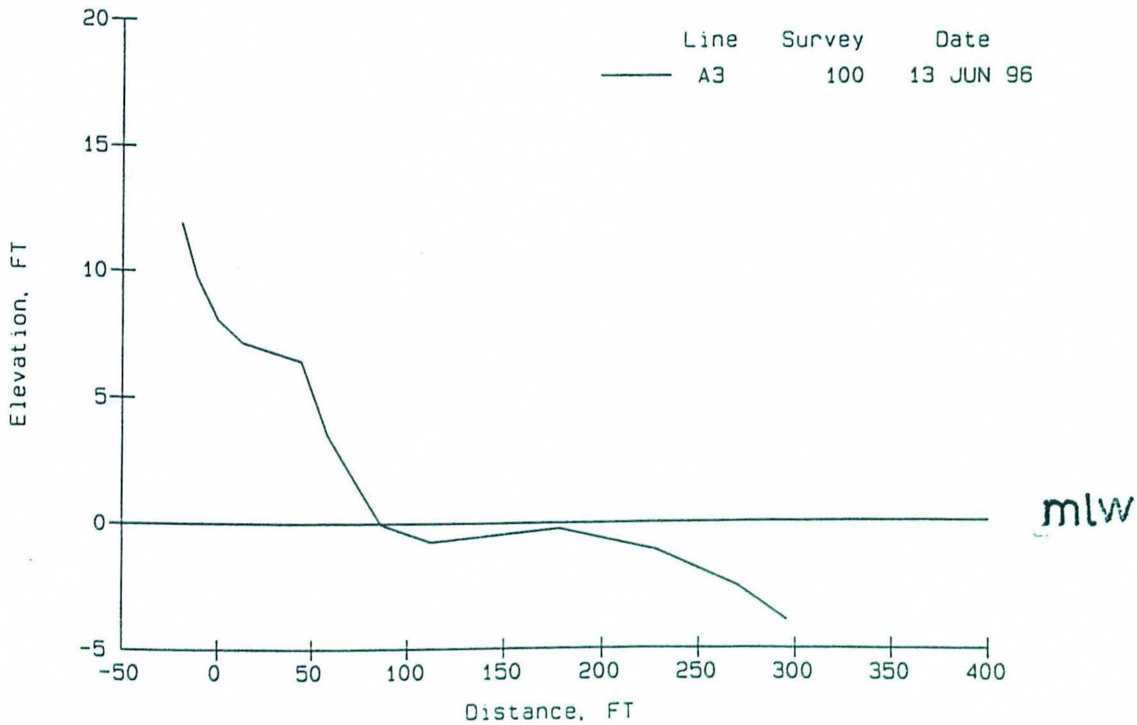

NAB, LITTLE CREEK
Line Survey Date
VB 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400

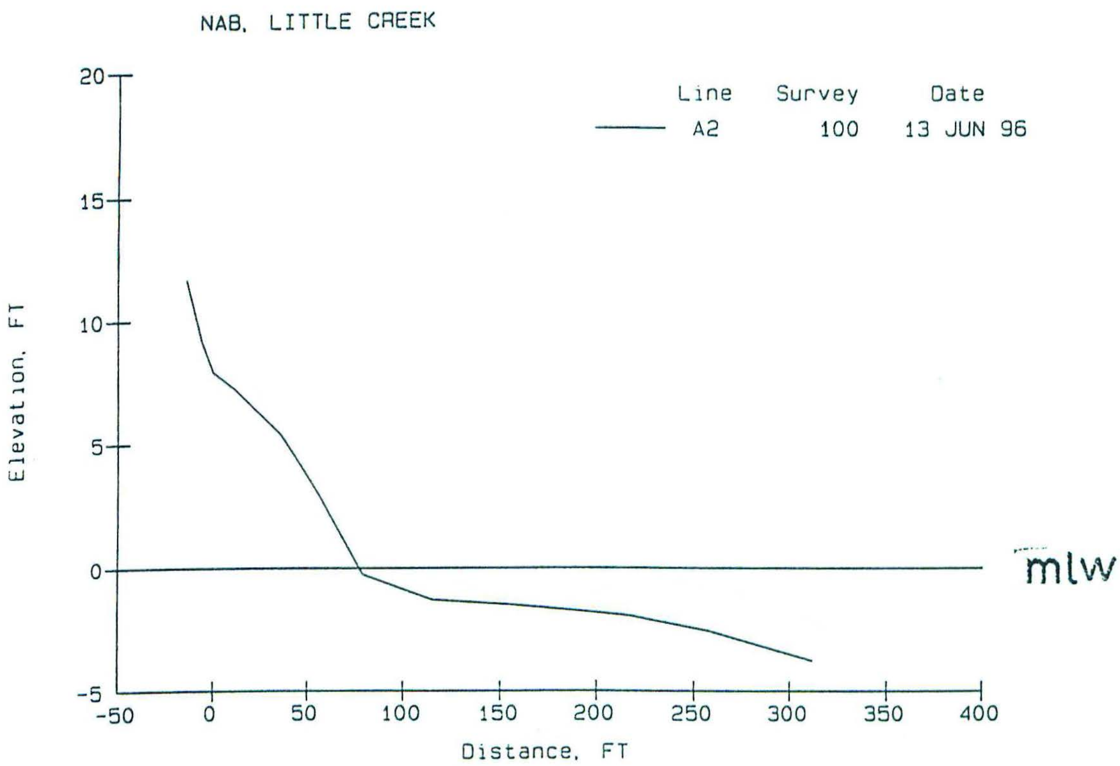

NAB, LITTLE CREEK
Line Survey Date
A4 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400

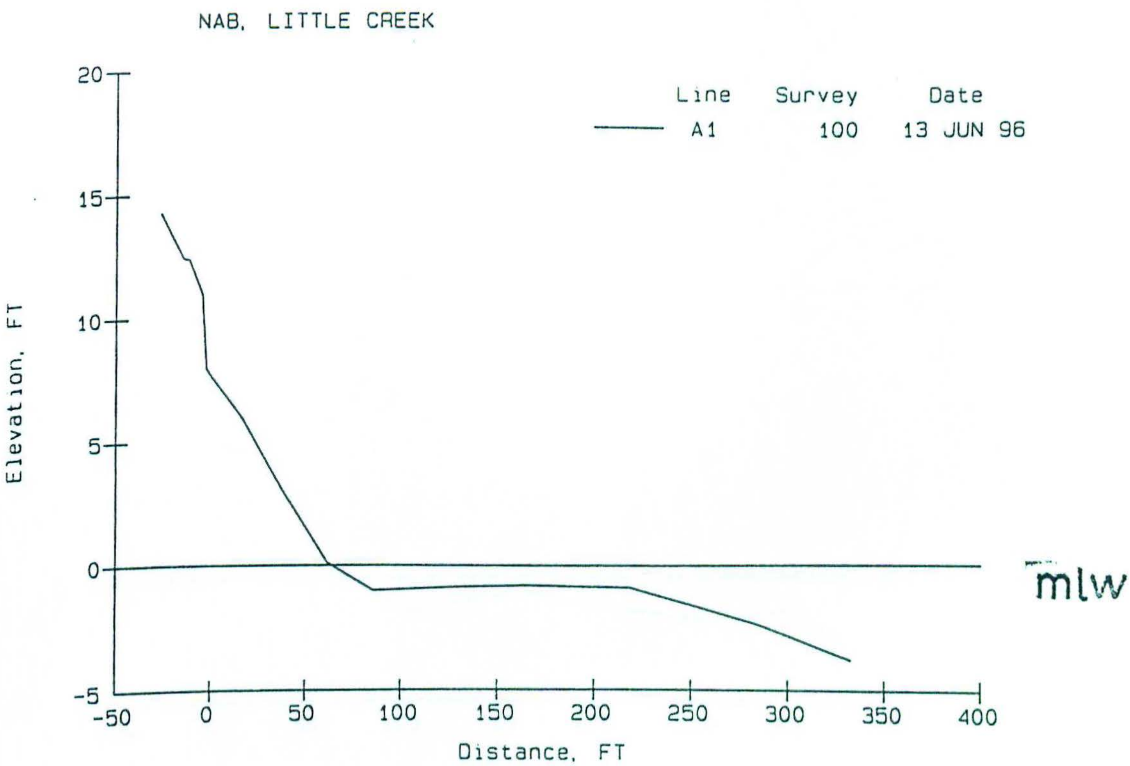
NAB, LITTLE CREEK

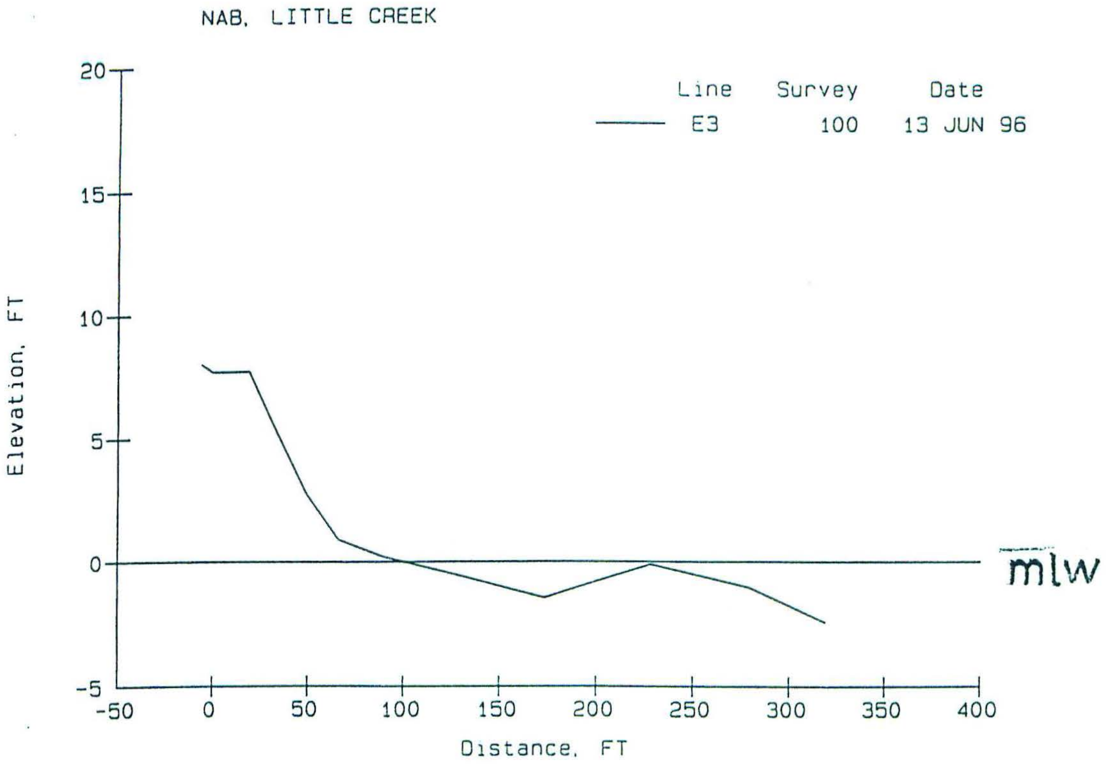


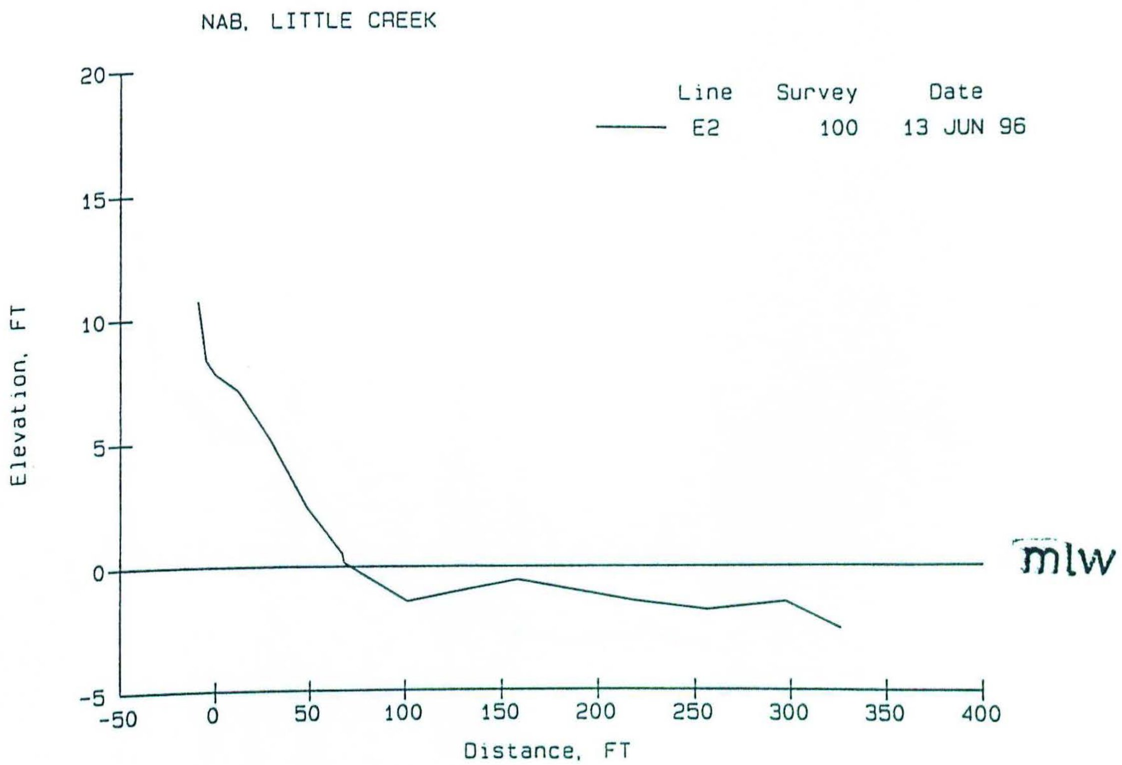
NAB, LITTLE CREEK

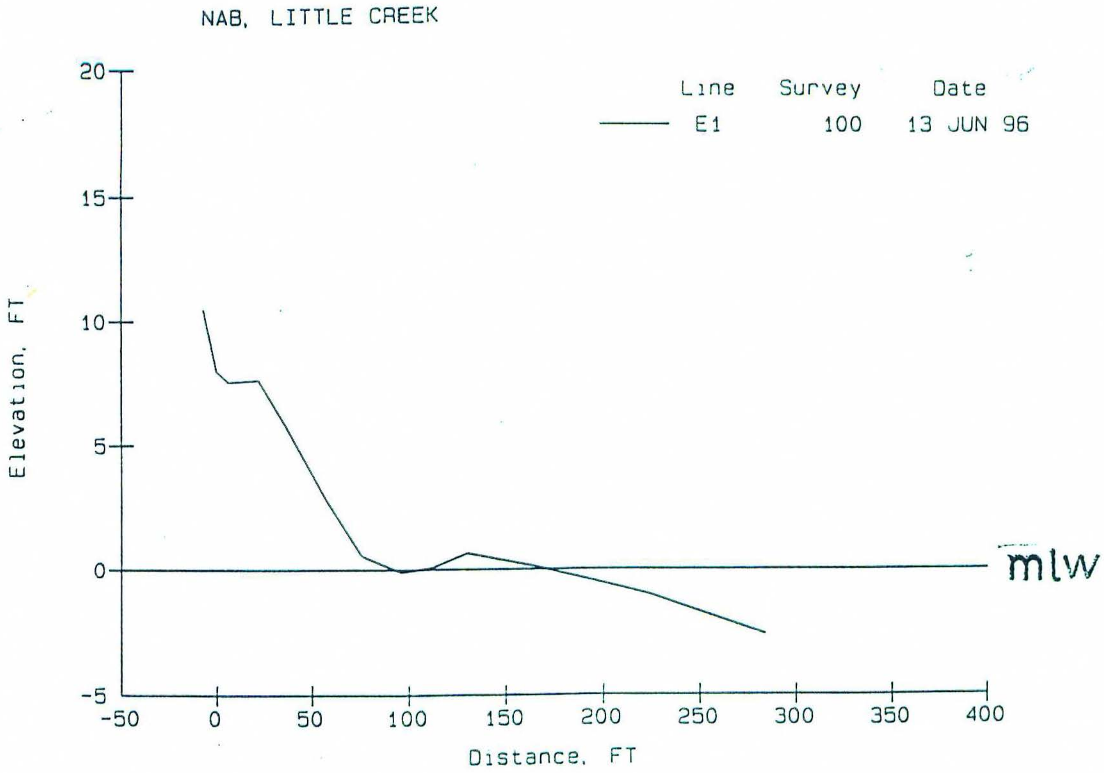


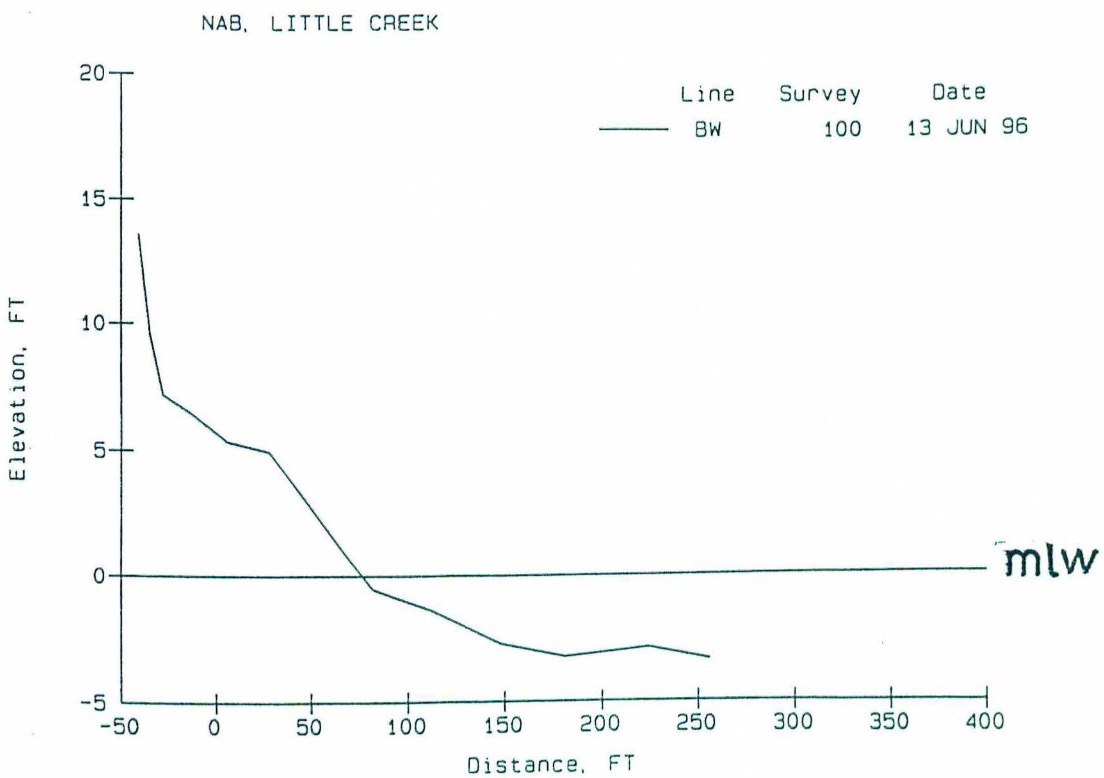

NAB, LITTLE CREEK
Line Survey Date
A2 100 13 JUN 96
Elevation, FT
Distance, FT
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400
mlw

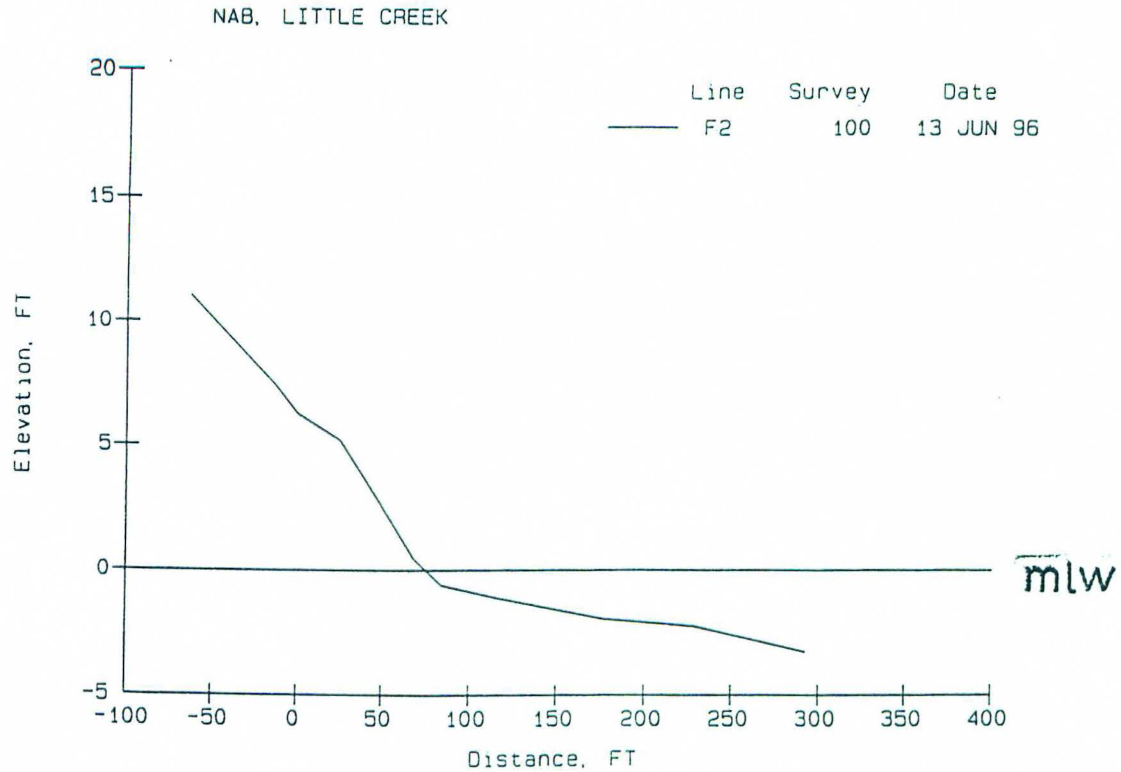

NAB, LITTLE CREEK
Line Survey Date
A1 100 13 JUN 96
Elevation, FT
Distance, FT
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400
mlw

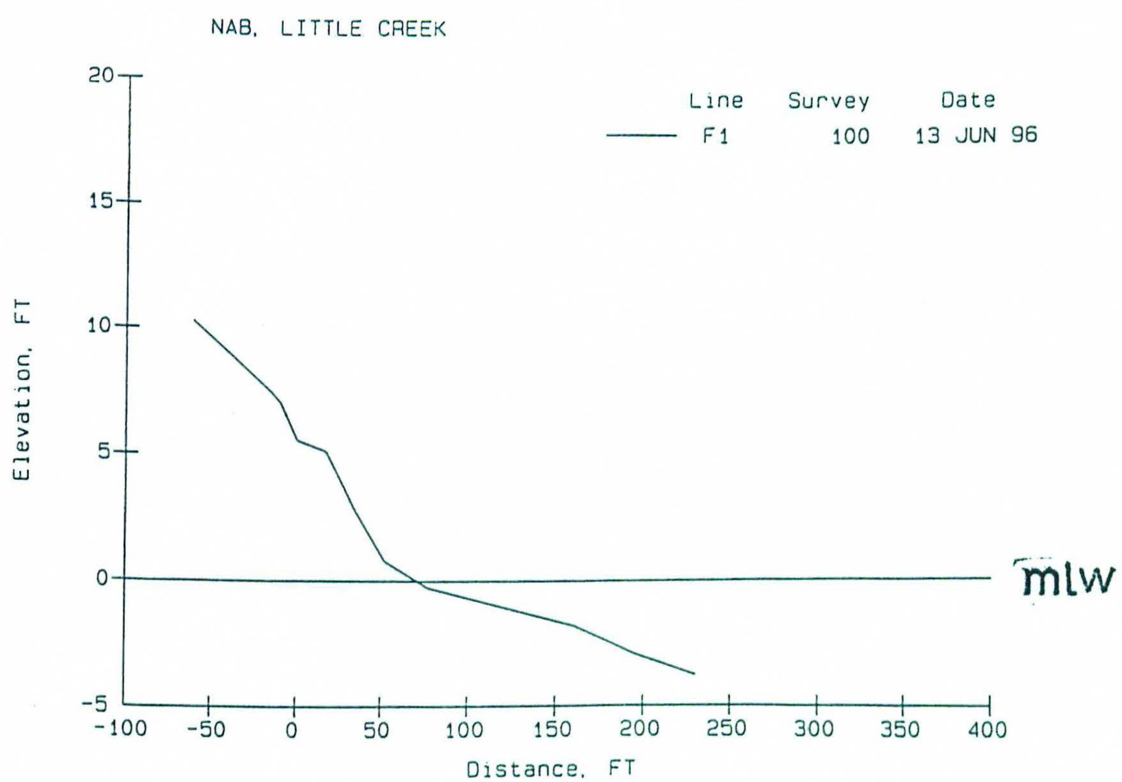

NAB, LITTLE CREEK
Line Survey Date
E3 100 13 JUN 96
Elevation, FT
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400
Distance, FT
mlw

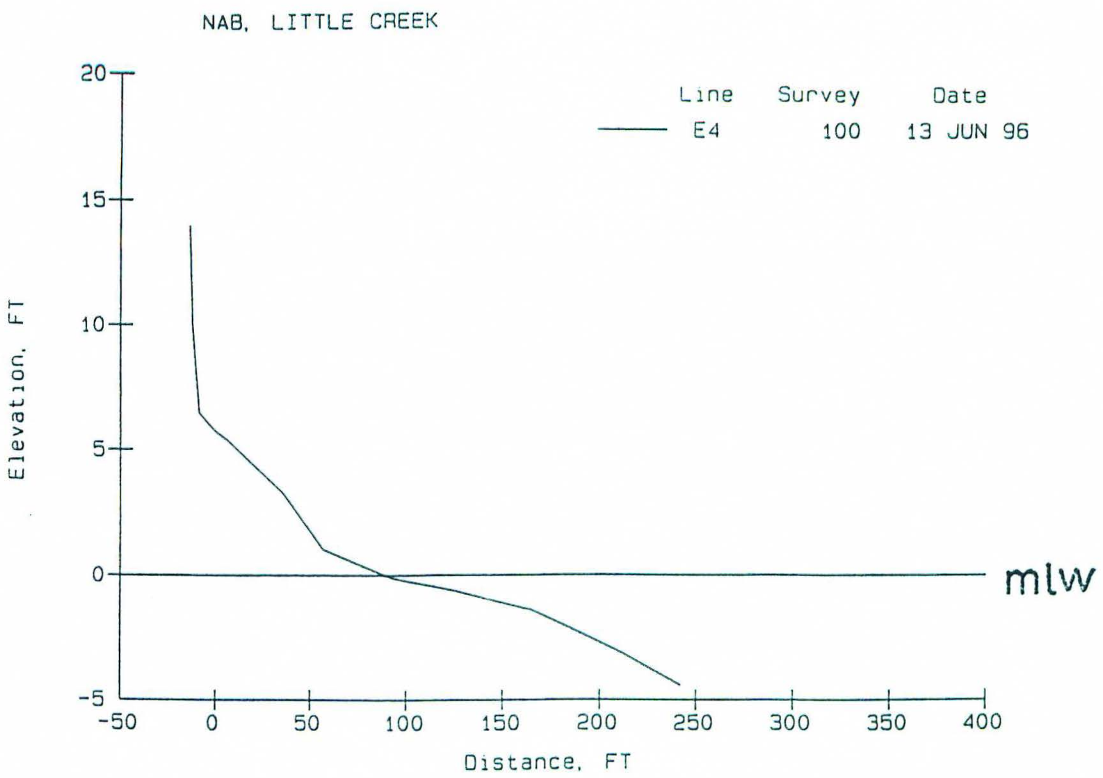

NAB, LITTLE CREEK
Line Survey Date
E2 100 13 JUN 96
Elevation, FT
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400
Distance, FT
mlw

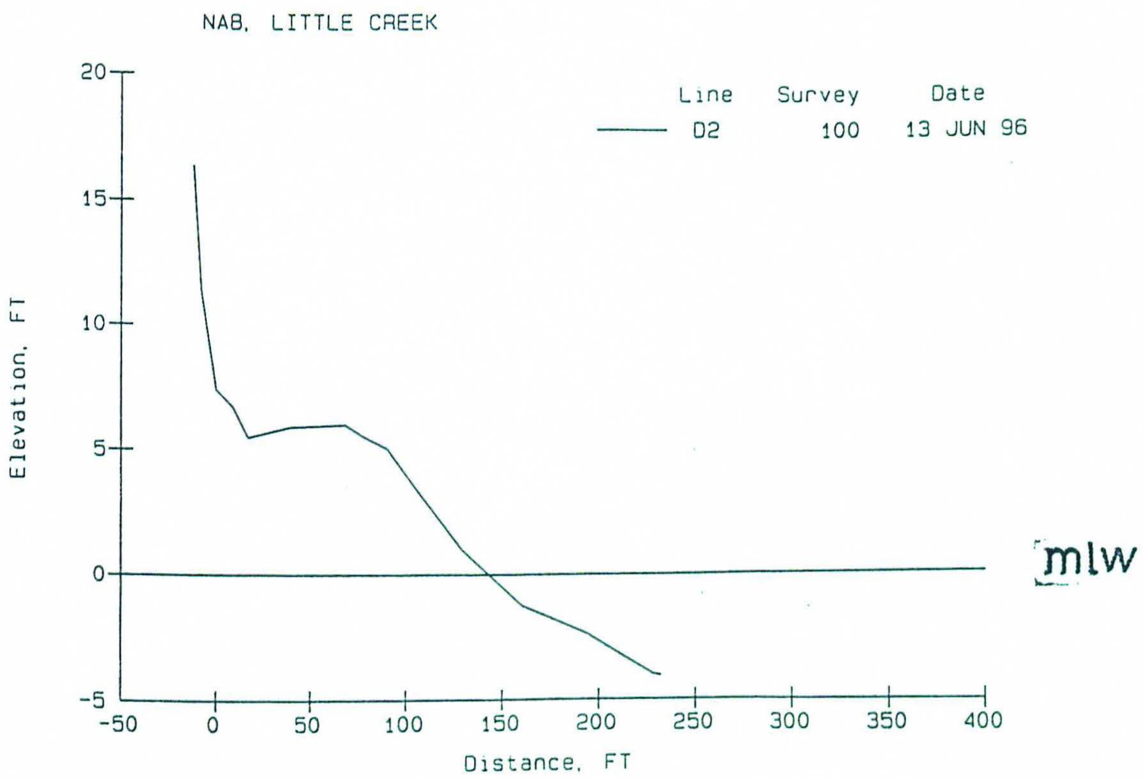

NAB, LITTLE CREEK
Line
Survey
Date
E1
100
13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400

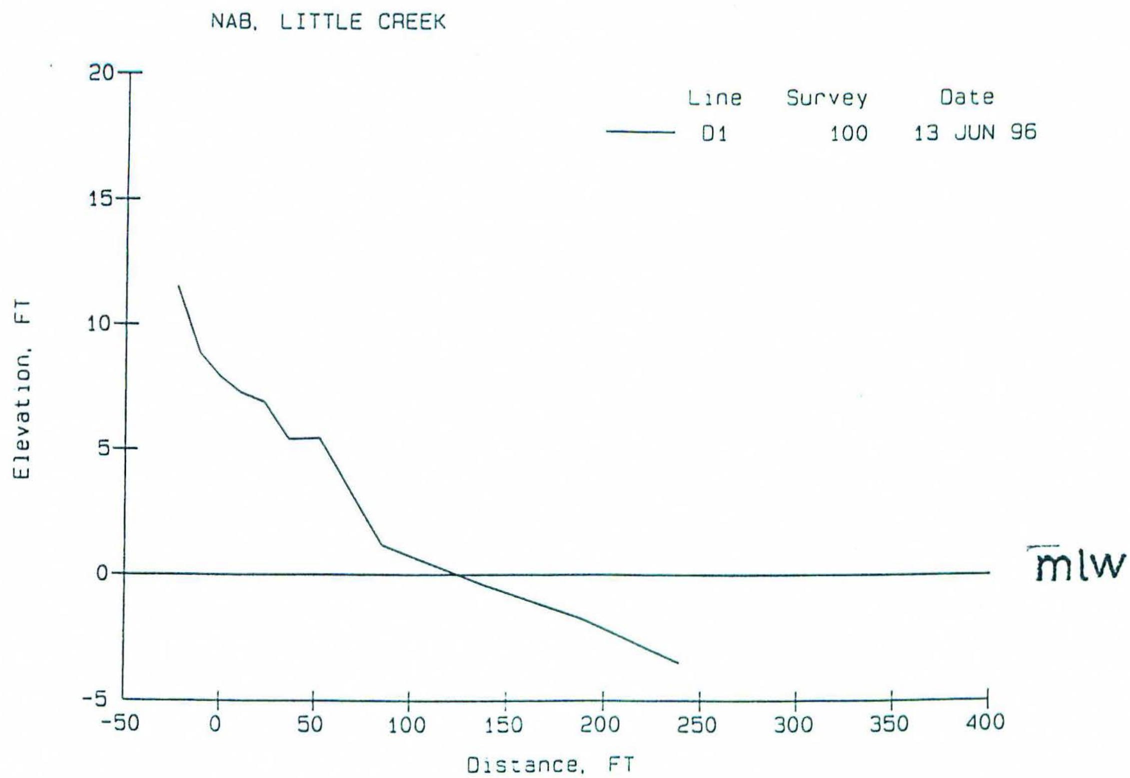

NAB, LITTLE CREEK
Line
Survey
Date
BW
100
13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400


NAB, LITTLE CREEK
Line Survey Date
F2 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-100 -50 0 50 100 150 200 250 300 350 400


NAB, LITTLE CREEK
Line Survey Date
F1 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-100 -50 0 50 100 150 200 250 300 350 400


NAB, LITTLE CREEK
Line Survey Date
E4 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400


NAB, LITTLE CREEK
Line Survey Date
D2 100 13 JUN 96
Elevation, FT
Distance, FT
mlw
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400


NAB, LITTLE CREEK
Line Survey Date
D1 100 13 JUN 96
Elevation, FT
20
15
10
5
0
-5
-50
0
50
100
150
200
250
300
350
400
Distance, FT
mlw

City of Virginia Beach Monitoring Control Disks

Horizontal: Virginia State Grid (South)

NAD 1929 (survey lines 2, 4, 5, 8) (feet)

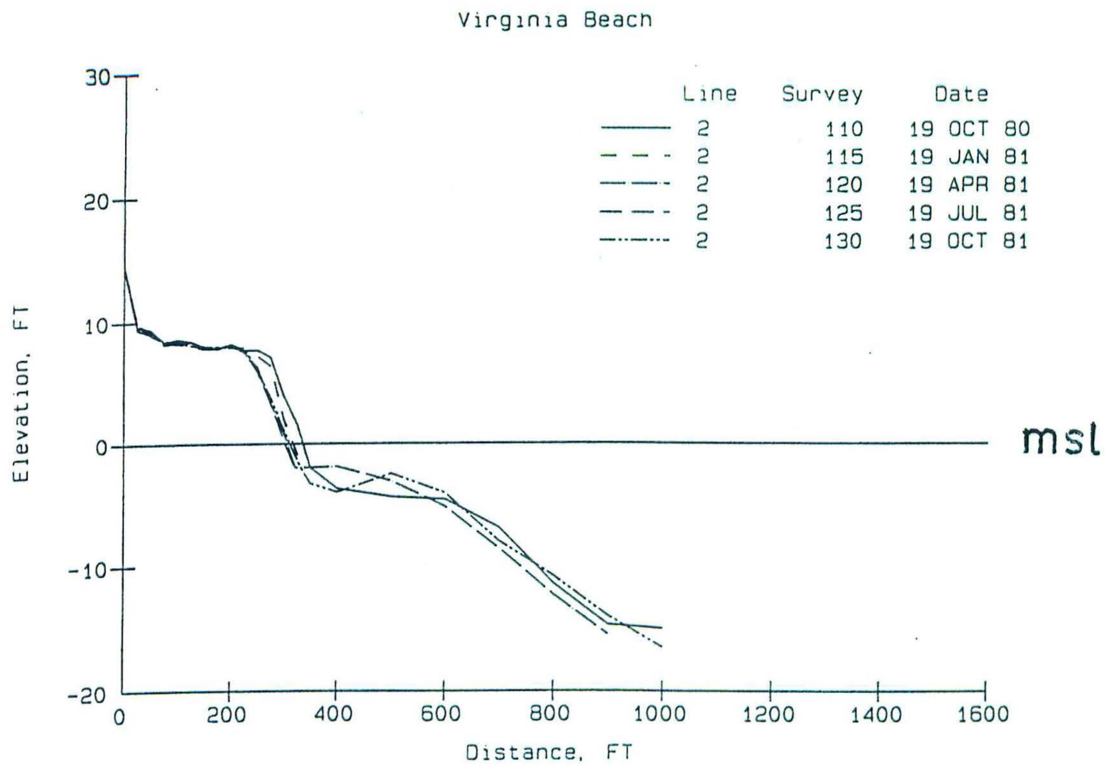
NAD 1983 (survey lines 3, 6, 7, 9, 10) (feet)

Vertical: National Ocean Survey, NGVD 1929 (feet)

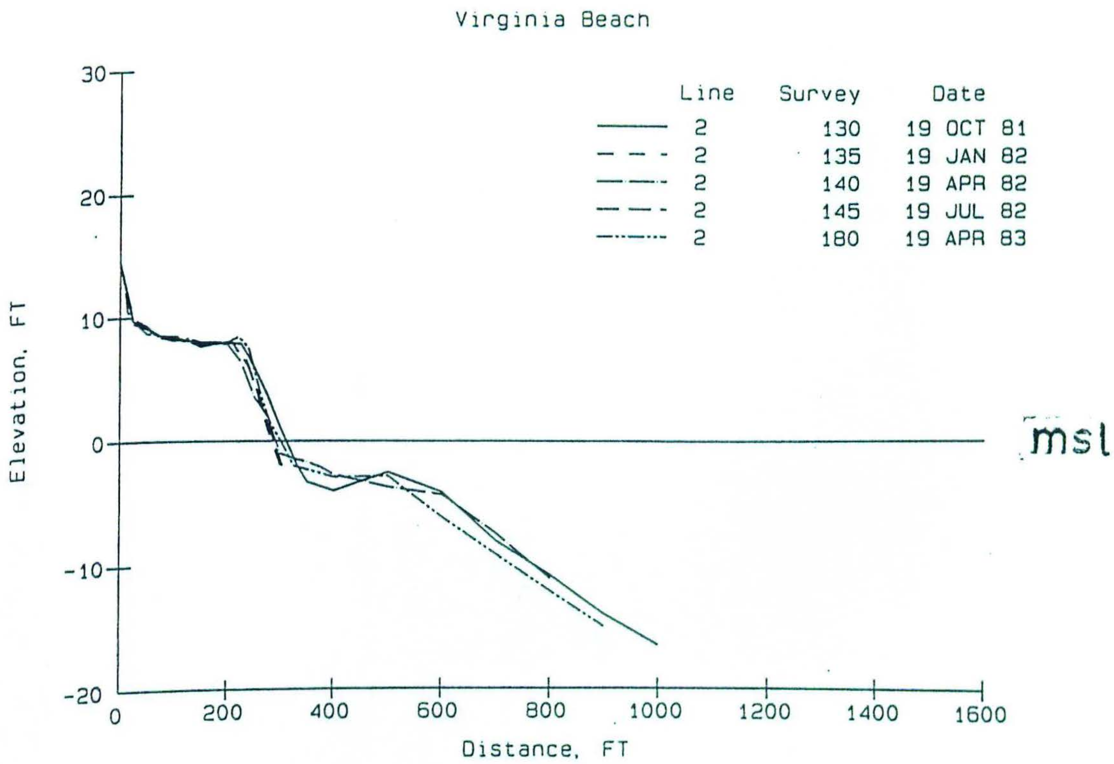
VIMS No.	City No.	Northing	Easting	Elevation
2	C-01A	225,169.639	2,679,872.264	14.567
3	D-02B	3,505,190.072	12,167,040.605	12.020
4	D-02A	223,755.562	2,686,801.382	16.176
5	E-02	223,287.780	2,689,245.179	16.708
6	E-02B	3,502,564.748	12,175,820.793	19.330
7	F-02A	3,501,535.732	12,178,584.242	17.620
8	F-02	220,058.566	2,697,448.296	13.329
9	G-02A	3,499,927.920	12,183,232.474	No Data
10	G-03	3,499,223.597	12,185,639.716	11.942

Profile locations are shown on Figure A1-2, and profile plots follow.

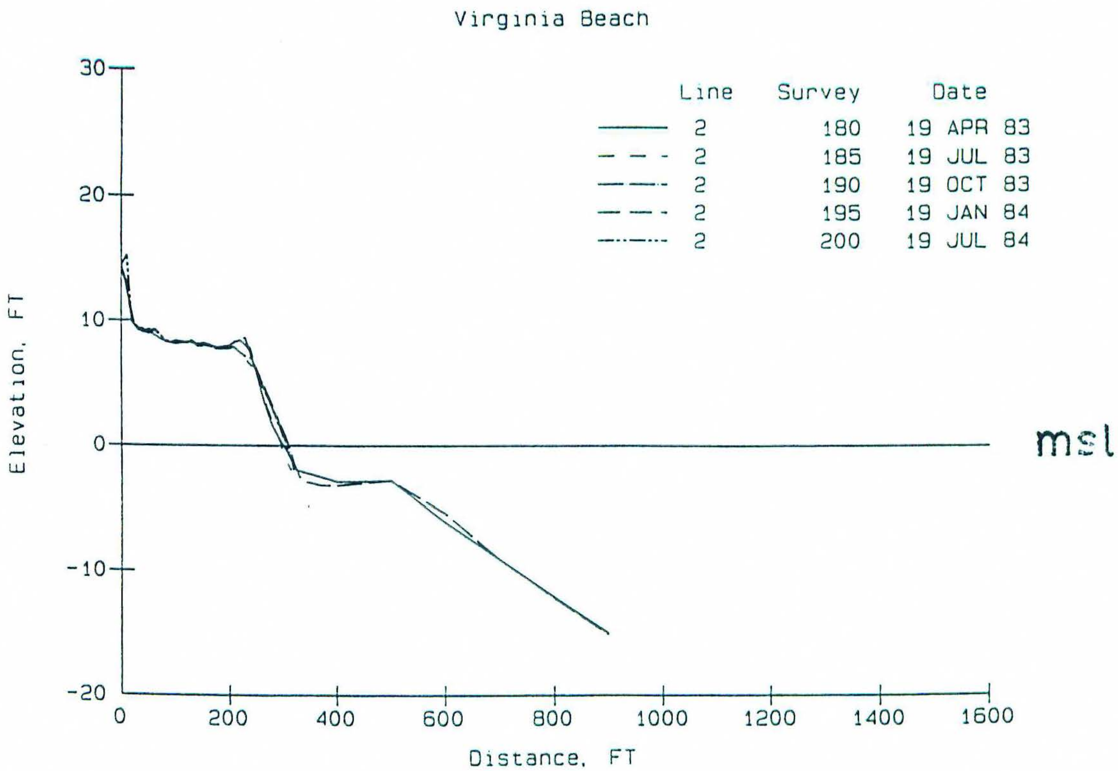
NORFOLK CITY
VIRGINIA BEACH CITY
LITTLE CREEK CHANNEL
2
3
4
5
6
7
8
9
10
LYNNHAVEN
Desert Cove
U S NAVAL RESERVATION
LITTLE CREEK AMPHIBIOUS BASE
Little Creek Cove
HARBOR DEFENSES
Golf Course
Chub Lake
Chesapeake Beach
Lake Joyce
Baylake Pines
Baylake Beach
Ocean Park
Lynnhaven Inlet
LYNNHAVEN RIVER
Pleasure House Point
Pleasure House Creek
Bayville Park
Lake Shores
Little Creek Reservoir
Garden Wood Park
Beechwood
VIRGINIA BEACH
Thoroughgood
Humes Island
Great Neck
Grassy Pt
Lake Smith Fishing Sta
SHORE DRIVE
SOUTHERN



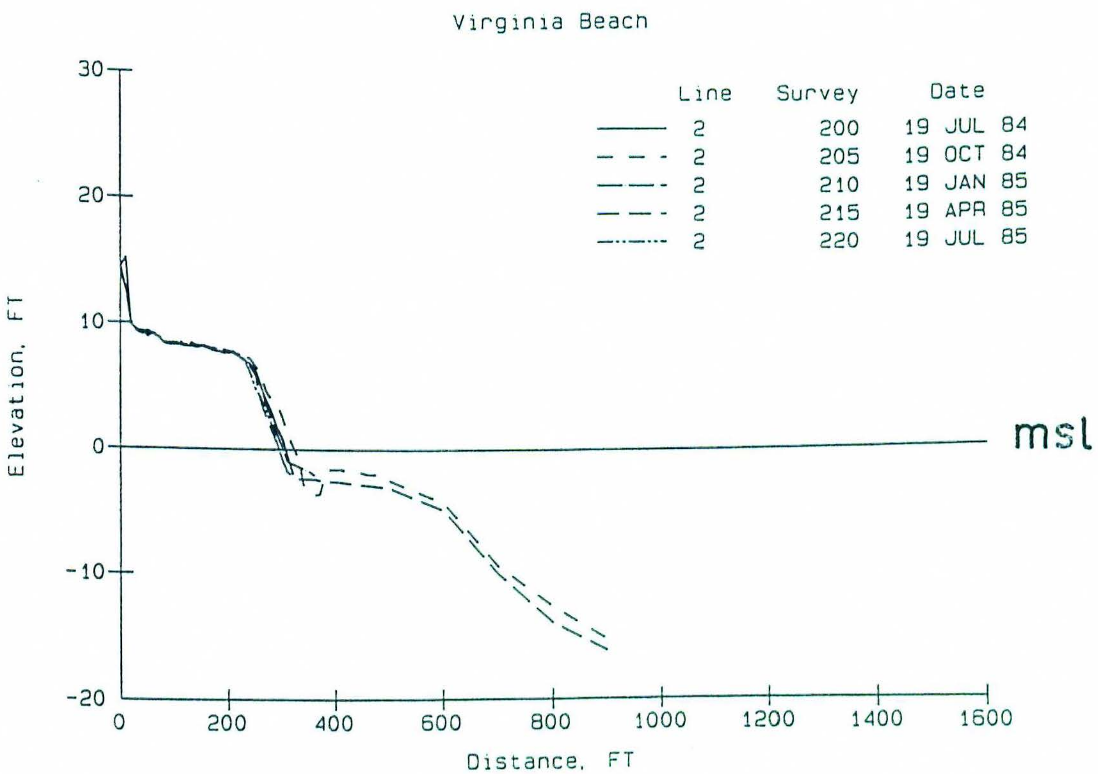
Virginia Beach
Line Survey Date
2 110 19 OCT 80
2 115 19 JAN 81
2 120 19 APR 81
2 125 19 JUL 81
2 130 19 OCT 81
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0 200 400 600 800 1000 1200 1400 1600



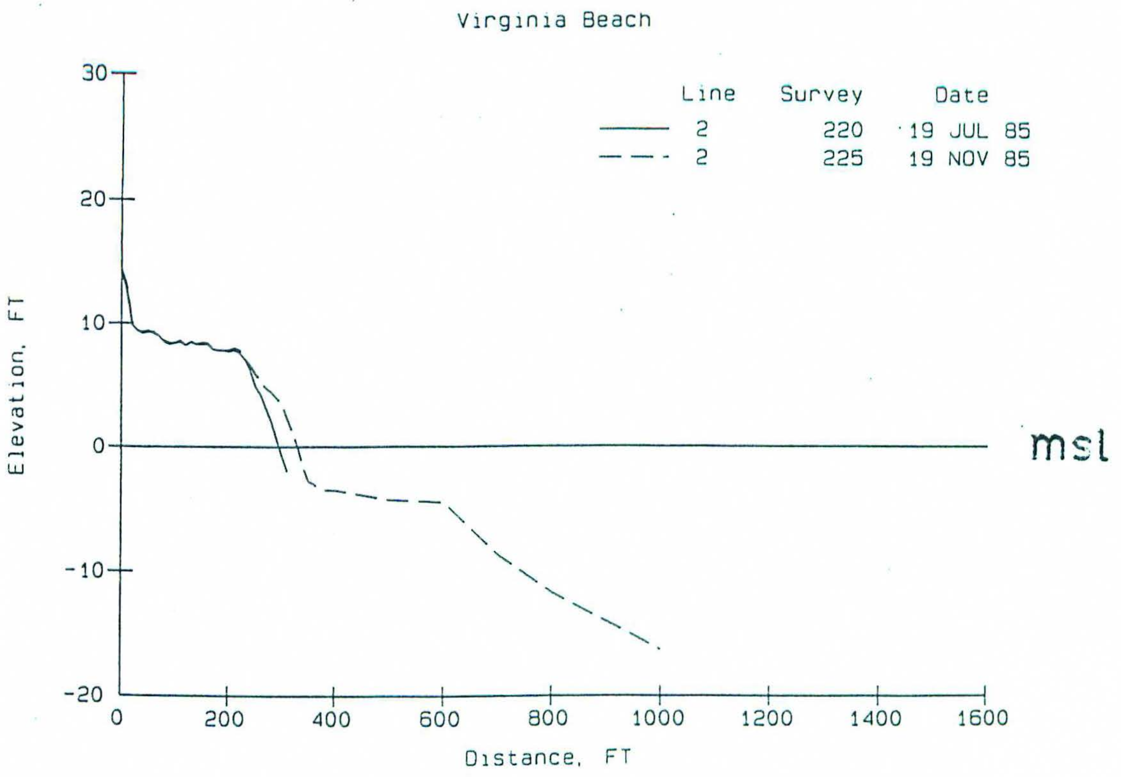
Virginia Beach
Line Survey Date
2 130 19 OCT 81
2 135 19 JAN 82
2 140 19 APR 82
2 145 19 JUL 82
2 180 19 APR 83
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0 200 400 600 800 1000 1200 1400 1600



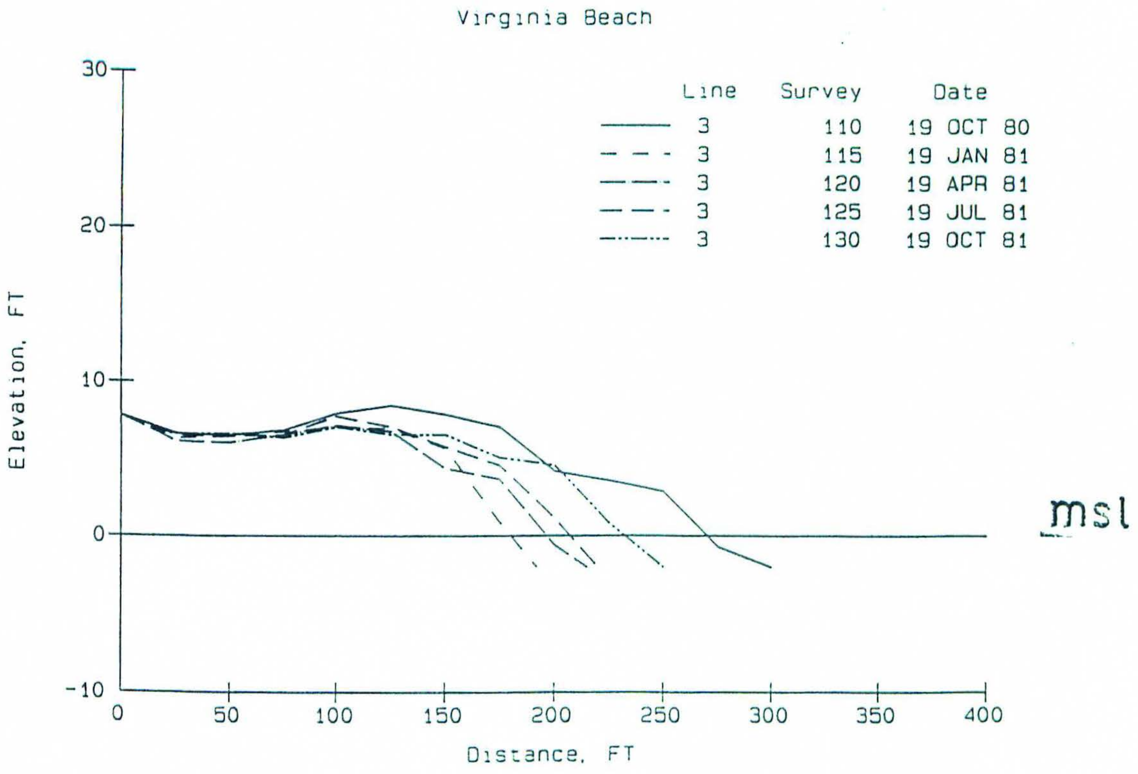
Virginia Beach
Line Survey Date
2 180 19 APR 83
2 185 19 JUL 83
2 190 19 OCT 83
2 195 19 JAN 84
2 200 19 JUL 84
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0 200 400 600 800 1000 1200 1400 1600

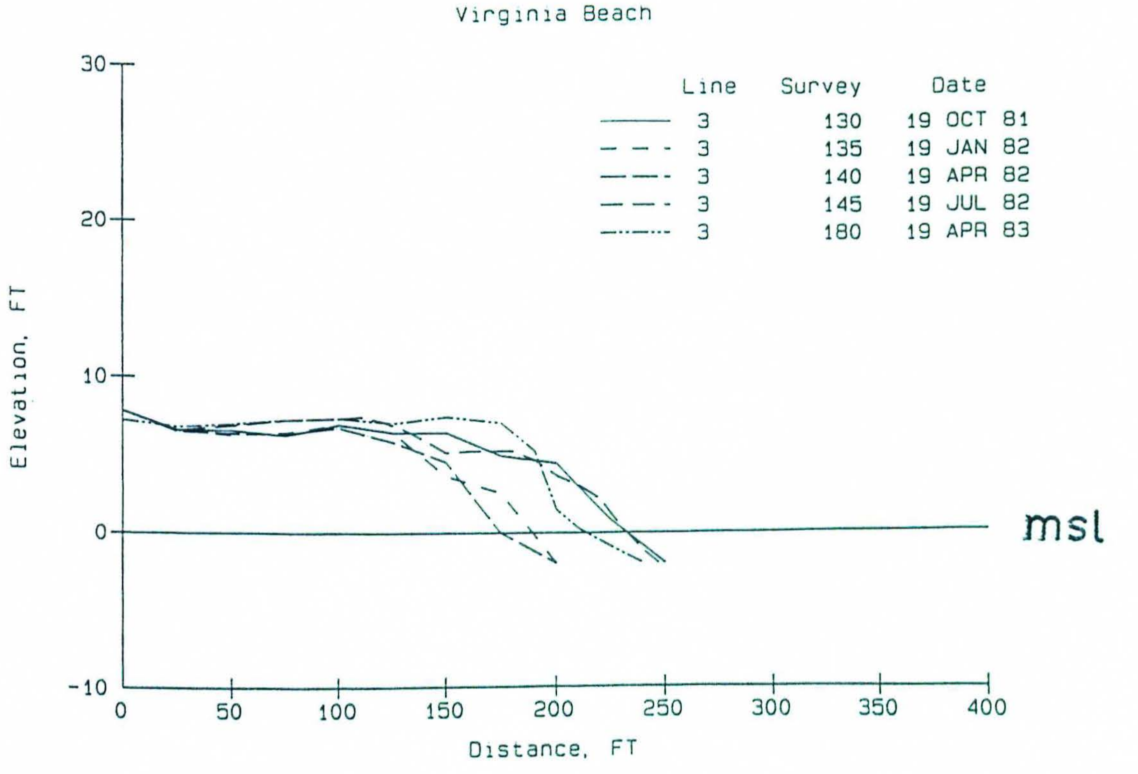


Virginia Beach
Line Survey Date
2 200 19 JUL 84
2 205 19 OCT 84
2 210 19 JAN 85
2 215 19 APR 85
2 220 19 JUL 85
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0 200 400 600 800 1000 1200 1400 1600

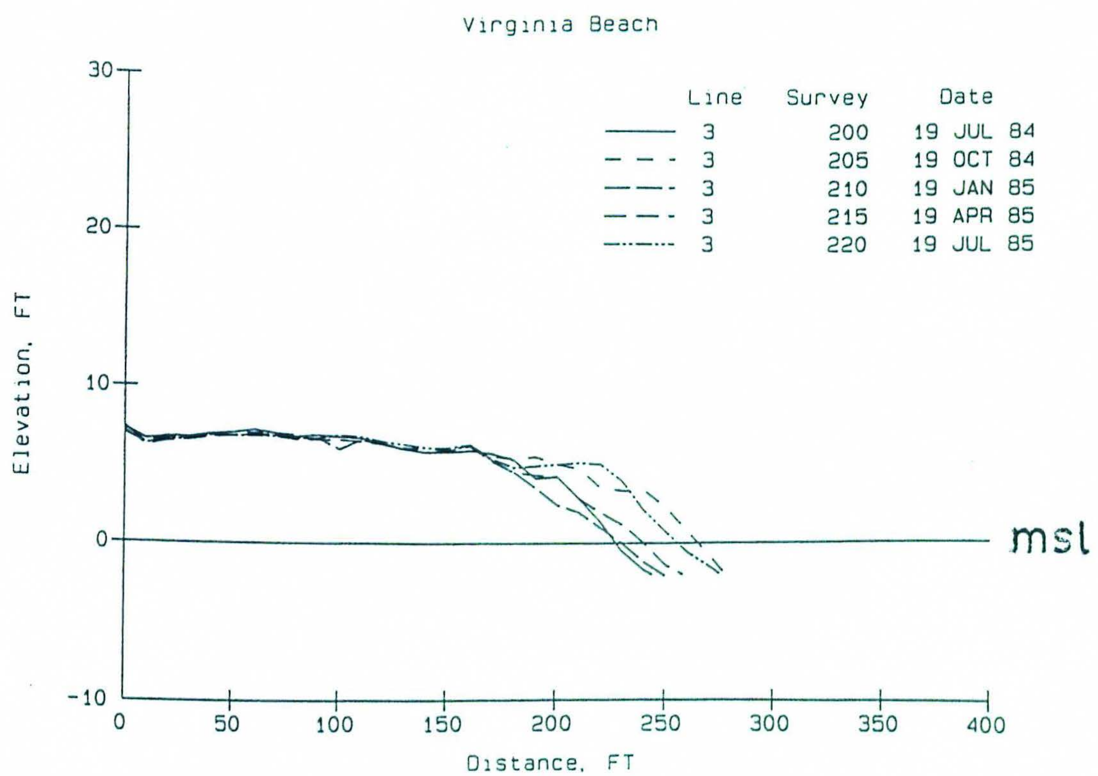


Virginia Beach
Line Survey Date
2 220 19 JUL 85
2 225 19 NOV 85
30
20
10
0
-10
-20
Elevation, FT
0
200
400
600
800
1000
1200
1400
1600
Distance, FT
msl

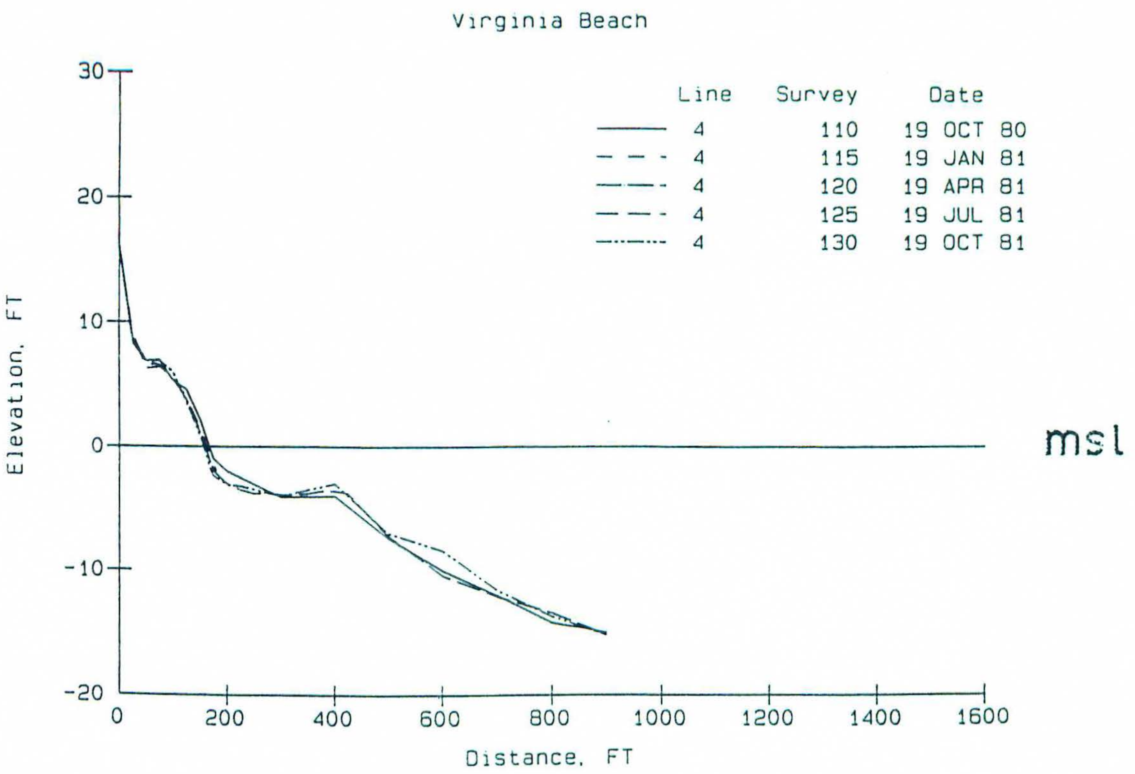

Virginia Beach
Line Survey Date
3 110 19 OCT 80
3 115 19 JAN 81
3 120 19 APR 81
3 125 19 JUL 81
3 130 19 OCT 81
Elevation, FT
Distance, FT
msl


Virginia Beach
Line Survey Date
3 130 19 OCT 81
3 135 19 JAN 82
3 140 19 APR 82
3 145 19 JUL 82
3 180 19 APR 83
Elevation, FT
Distance, FT
msl

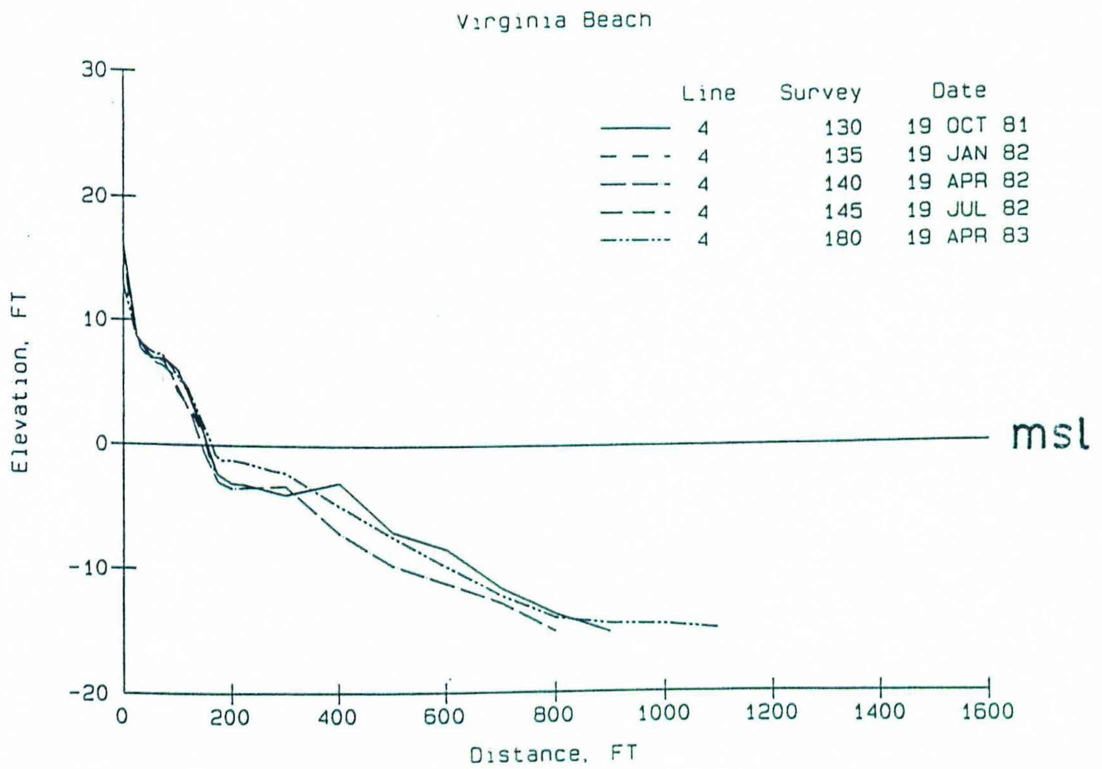
Virginia Beach
Line Survey Date
3 180 19 APR 83
3 185 19 JUL 83
3 190 19 OCT 83
3 195 19 JAN 84
3 200 19 JUL 84
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
0 50 100 150 200 250 300 350 400



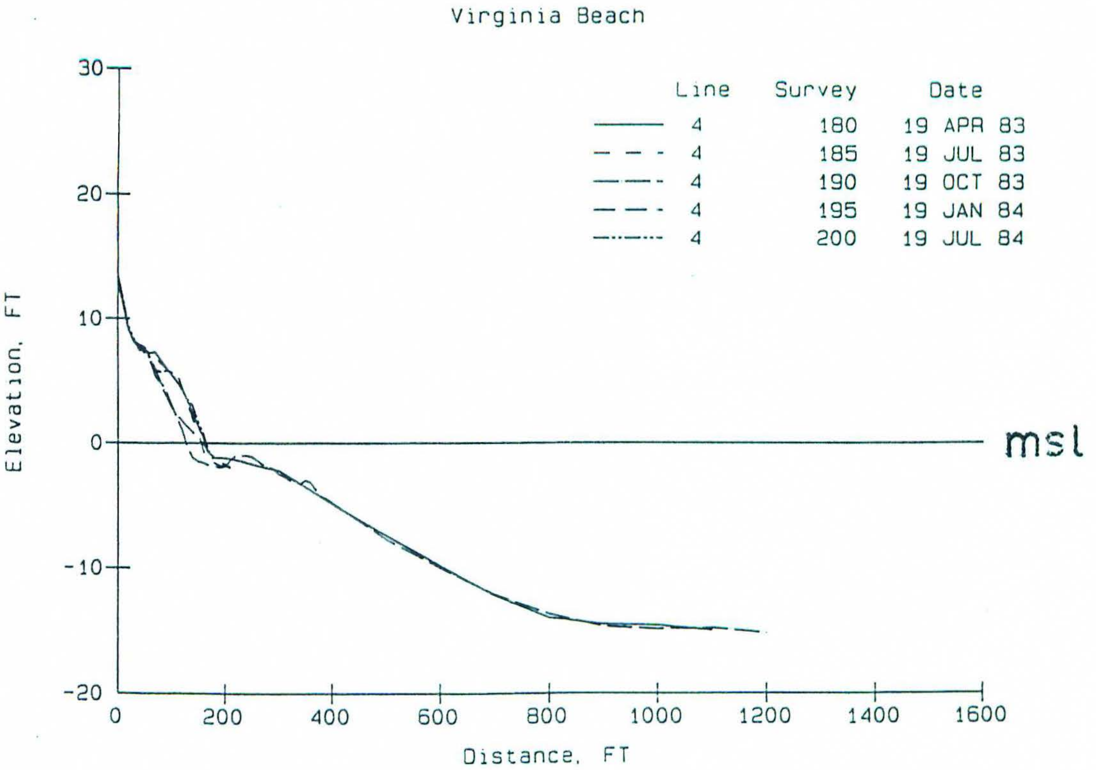
Virginia Beach
Line Survey Date
3 200 19 JUL 84
3 205 19 OCT 84
3 210 19 JAN 85
3 215 19 APR 85
3 220 19 JUL 85
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
0 50 100 150 200 250 300 350 400

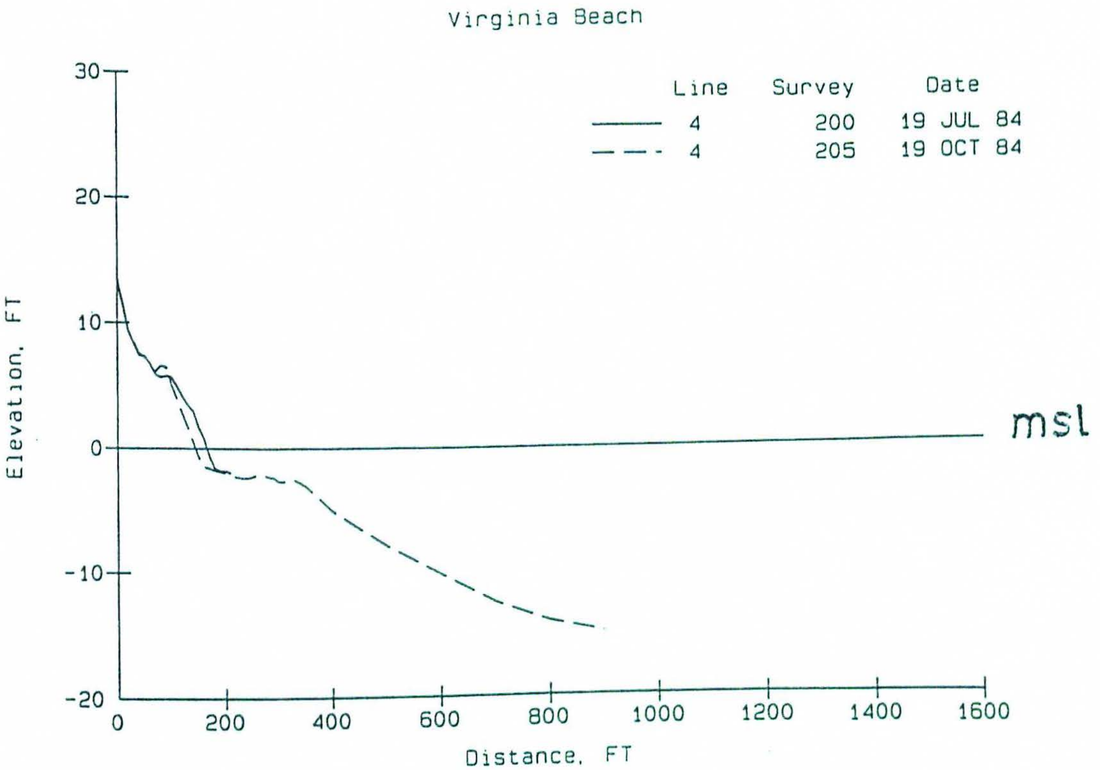


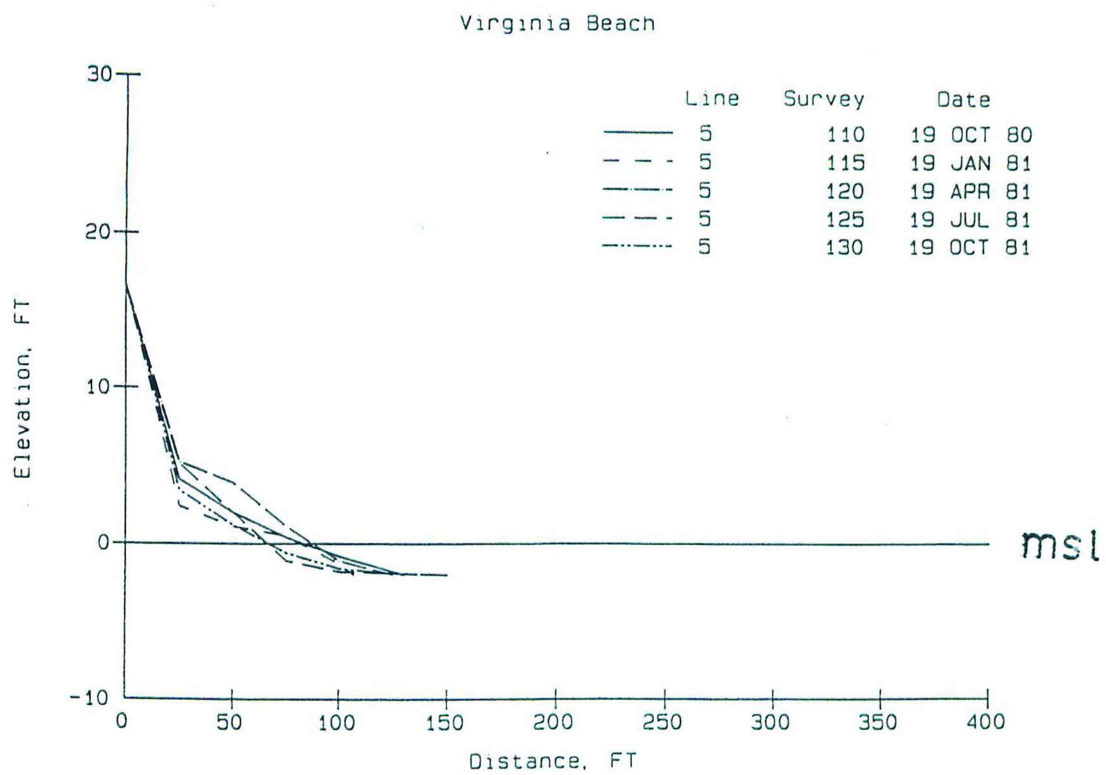
Virginia Beach
Line Survey Date
4 110 19 OCT 80
4 115 19 JAN 81
4 120 19 APR 81
4 125 19 JUL 81
4 130 19 OCT 81
Elevation, FT
30
20
10
0
-10
-20
msl
0 200 400 600 800 1000 1200 1400 1600
Distance, FT



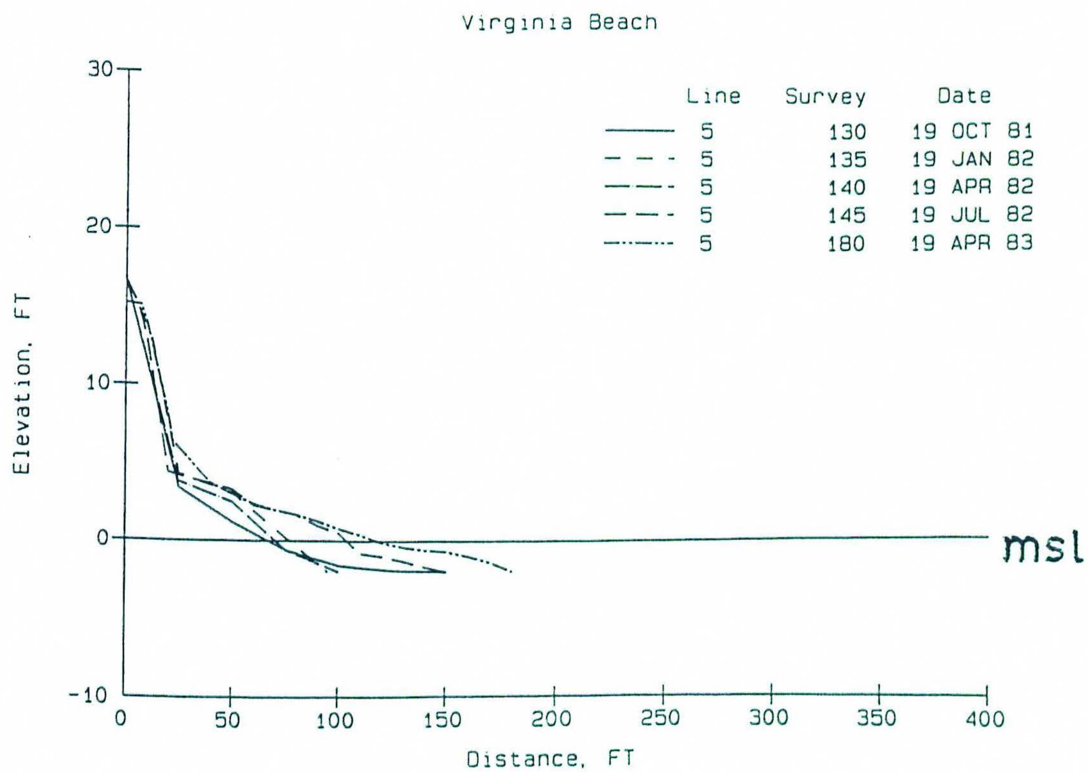
Virginia Beach
Line Survey Date
4 130 19 OCT 81
4 135 19 JAN 82
4 140 19 APR 82
4 145 19 JUL 82
4 180 19 APR 83
Elevation, FT
30
20
10
0
-10
-20
msl
0 200 400 600 800 1000 1200 1400 1600
Distance, FT


Virginia Beach
Line Survey Date
4 180 19 APR 83
4 185 19 JUL 83
4 190 19 OCT 83
4 195 19 JAN 84
4 200 19 JUL 84
Elevation, FT
30
20
10
0
-10
-20
msl
0
200
400
600
800
1000
1200
1400
1600
Distance, FT


Virginia Beach
Line Survey Date
4 200 19 JUL 84
4 205 19 OCT 84
Elevation, FT
30
20
10
0
-10
-20
msl
0
200
400
600
800
1000
1200
1400
1600
Distance, FT

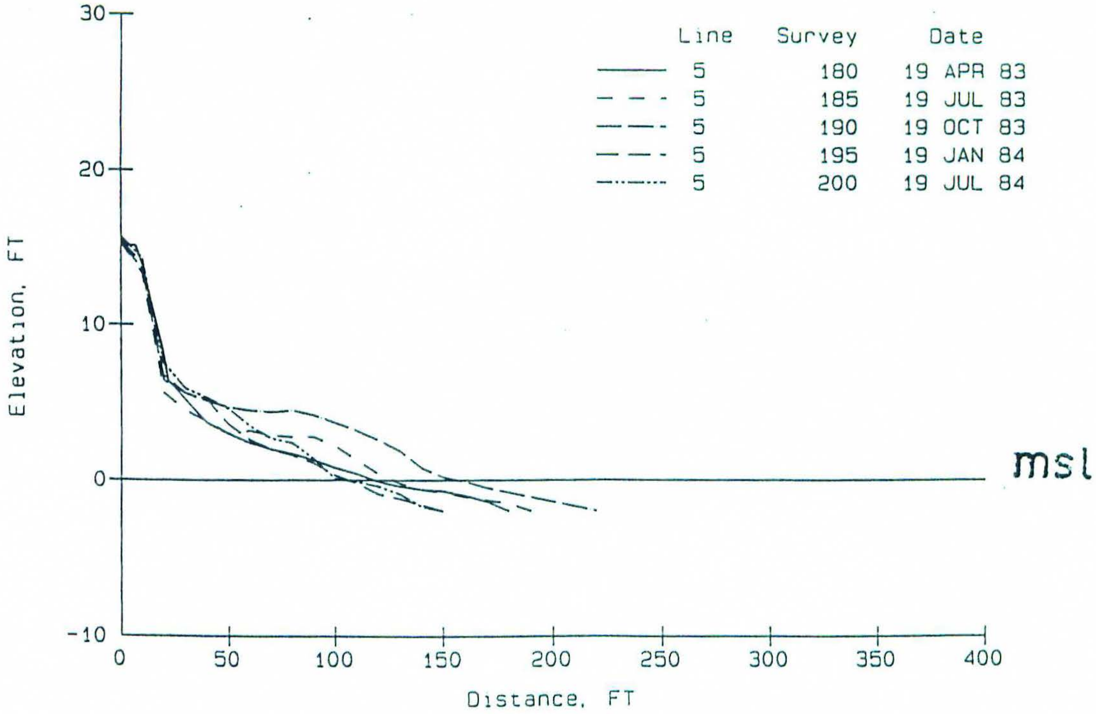


Virginia Beach
Line Survey Date
5 110 19 OCT 80
5 115 19 JAN 81
5 120 19 APR 81
5 125 19 JUL 81
5 130 19 OCT 81
Elevation, FT
Distance, FT
msl

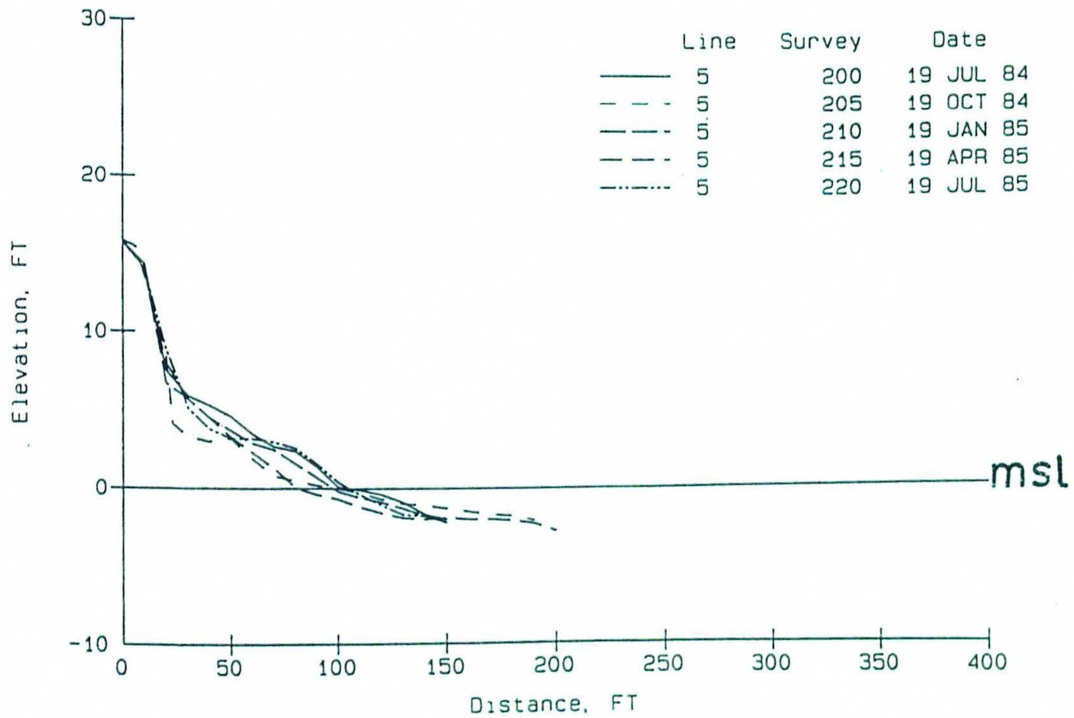


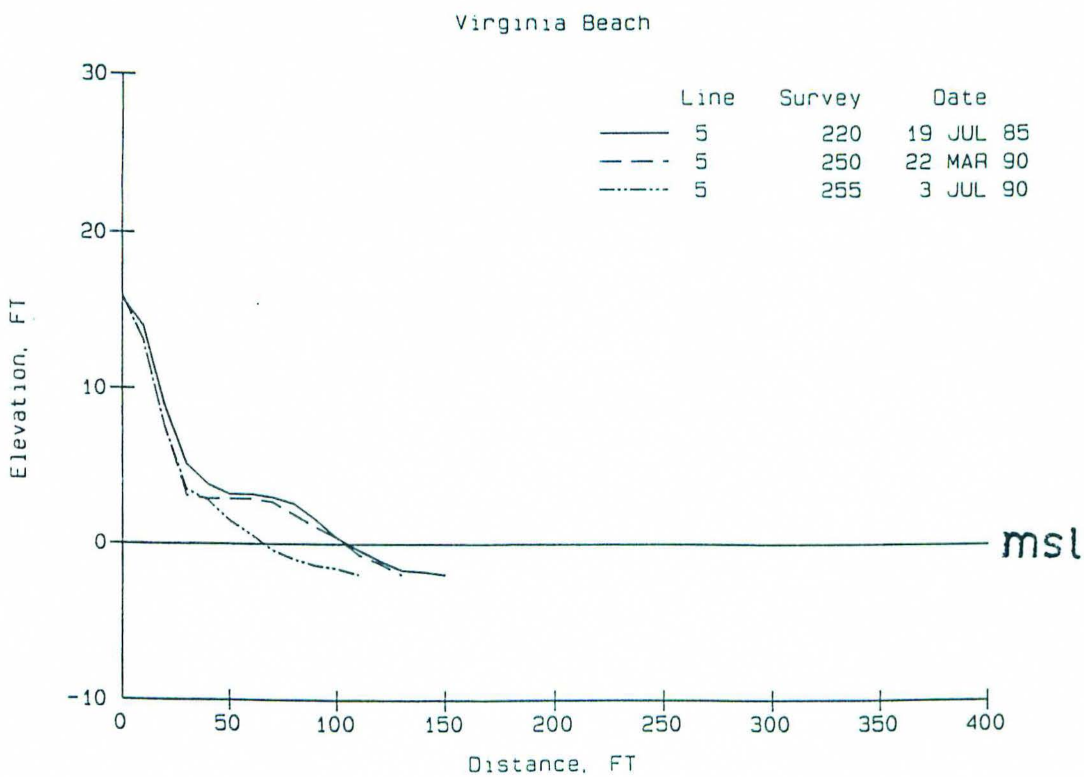
Virginia Beach
Line Survey Date
5 130 19 OCT 81
5 135 19 JAN 82
5 140 19 APR 82
5 145 19 JUL 82
5 180 19 APR 83
Elevation, FT
Distance, FT
msl

Virginia Beach

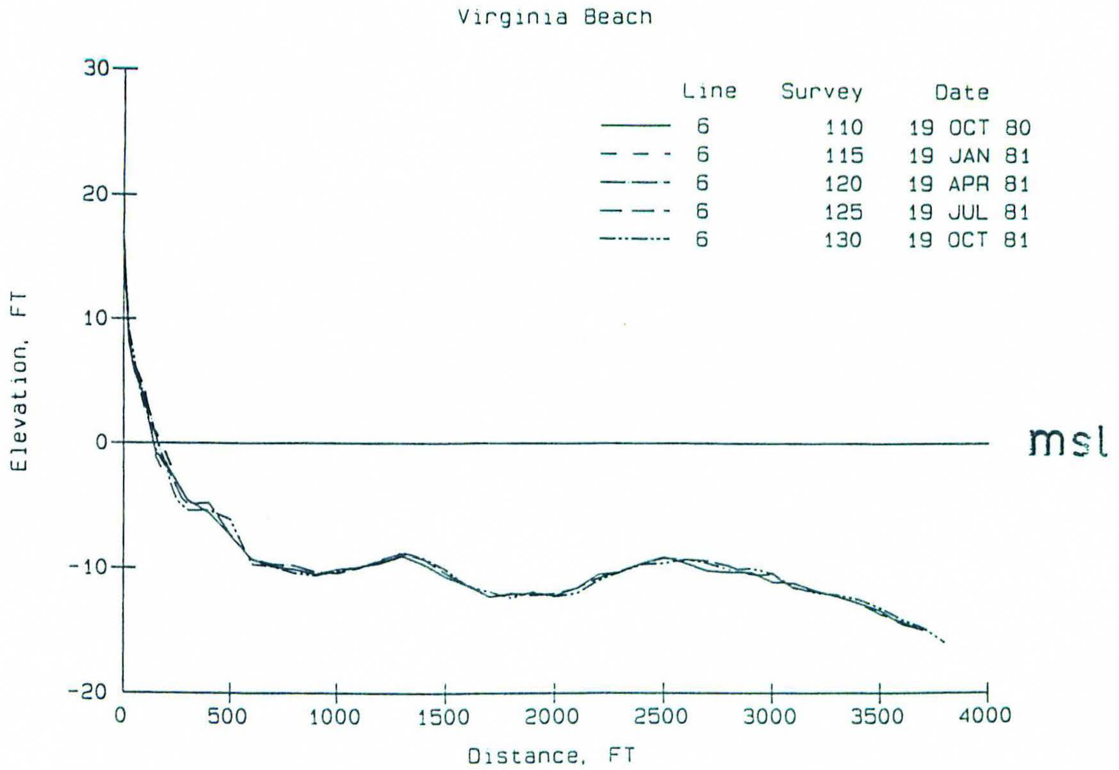


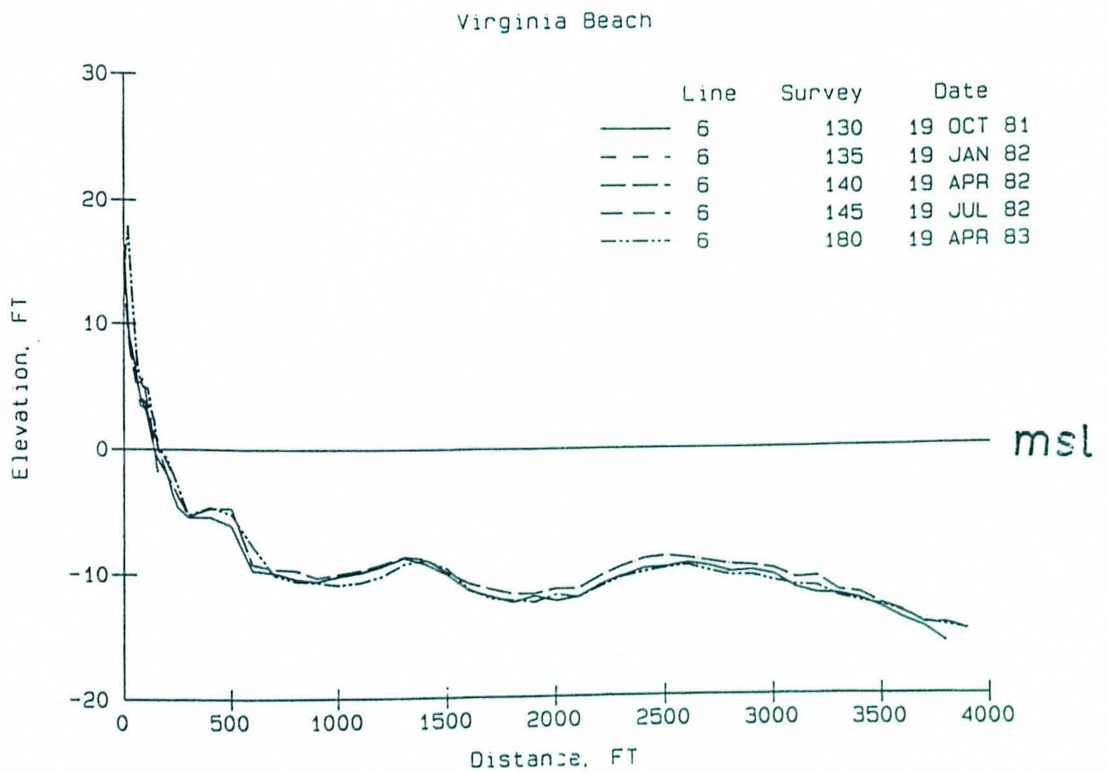
Virginia Beach

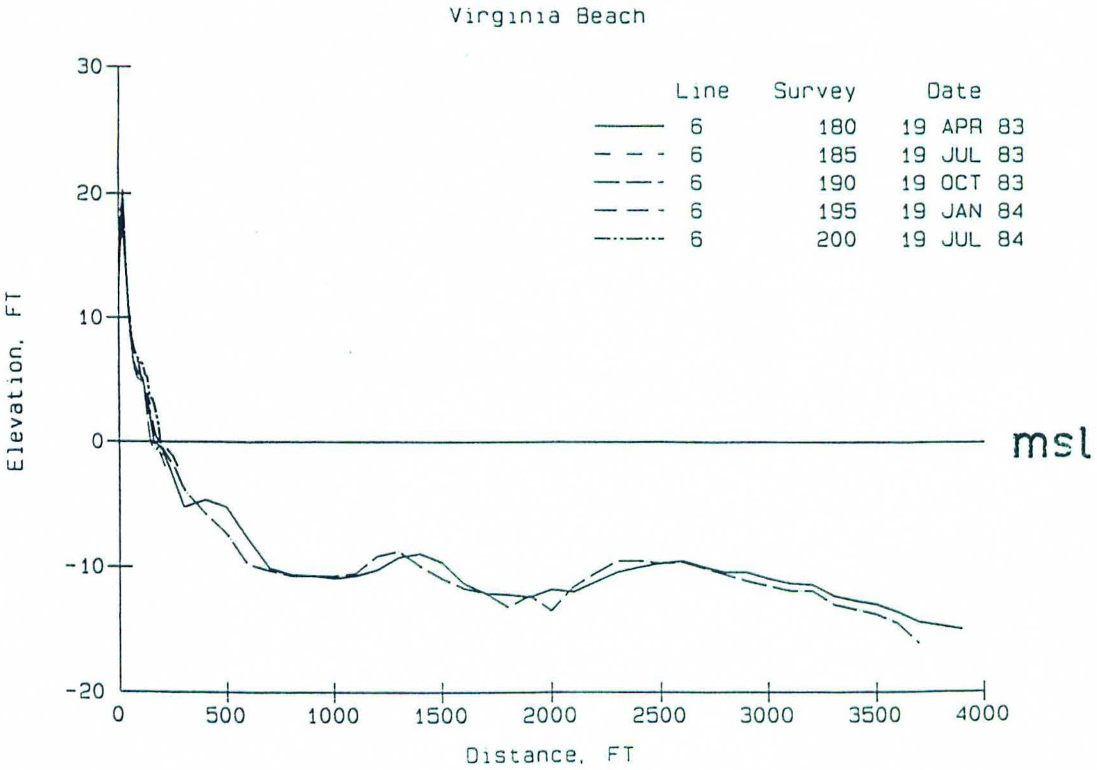




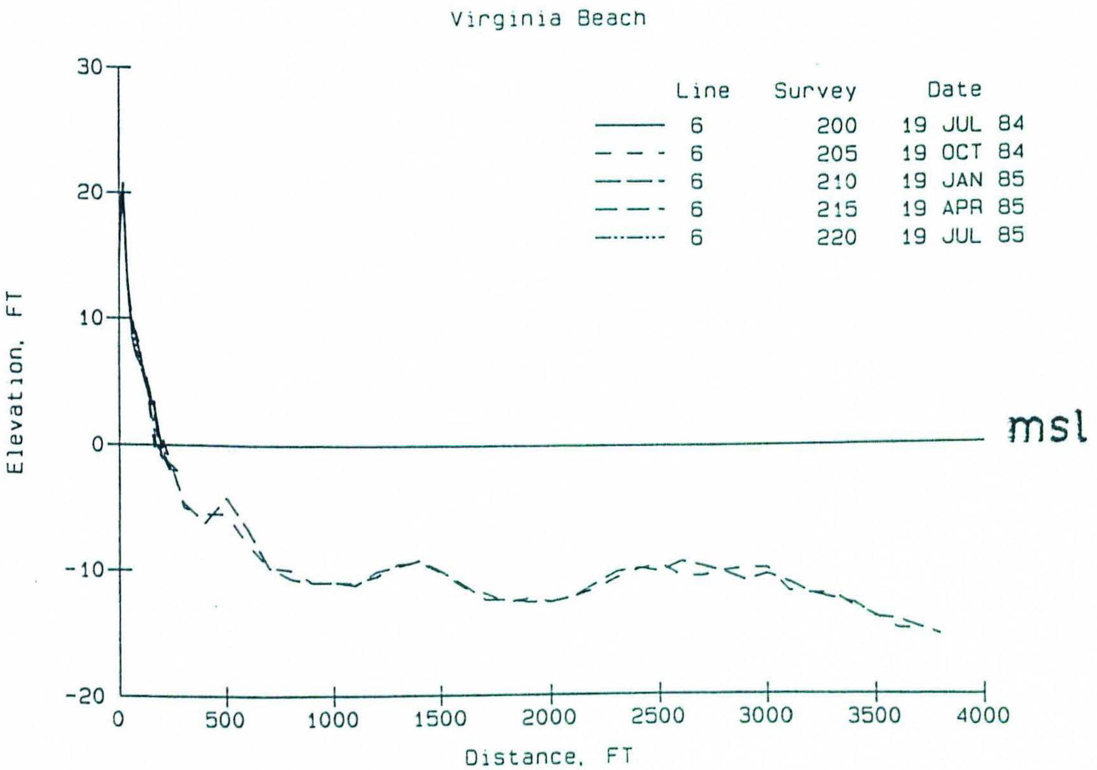
Virginia Beach
Line Survey Date
5 220 19 JUL 85
5 250 22 MAR 90
5 255 3 JUL 90
Elevation, FT
Distance, FT
30
20
10
0
-10
0 50 100 150 200 250 300 350 400
msl


Virginia Beach
Line Survey Date
6 110 19 OCT 80
6 115 19 JAN 81
6 120 19 APR 81
6 125 19 JUL 81
6 130 19 OCT 81
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000

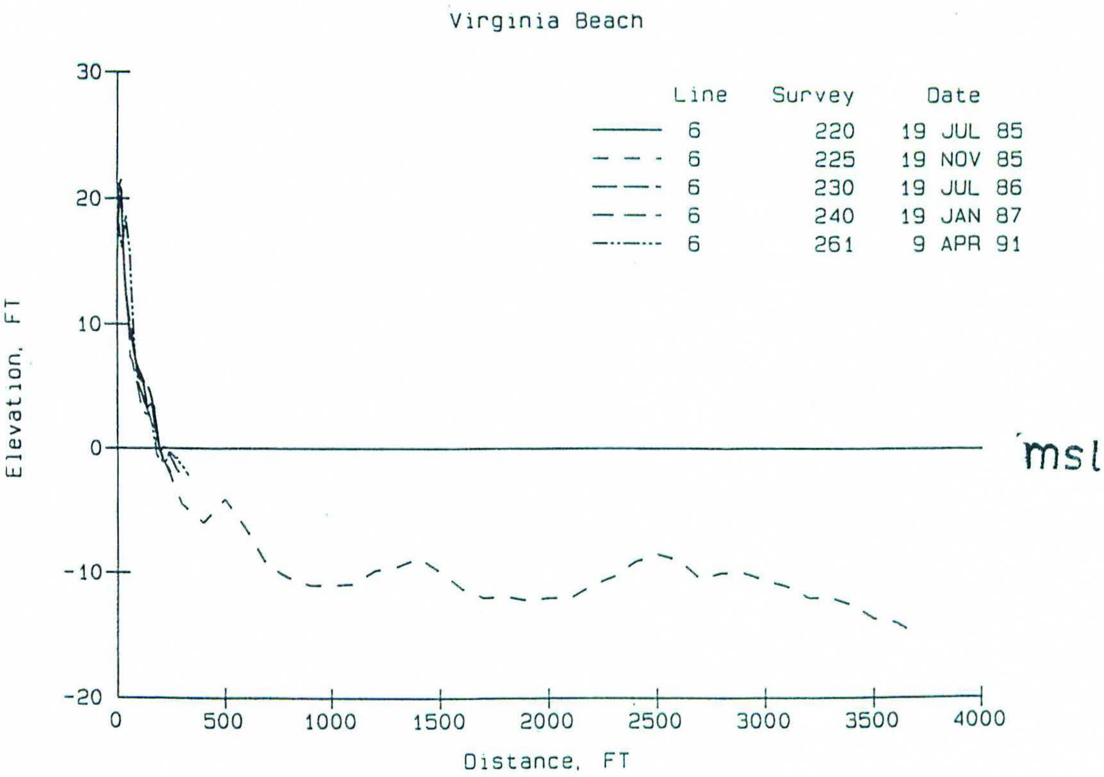

Virginia Beach
Line Survey Date
6 130 19 OCT 81
6 135 19 JAN 82
6 140 19 APR 82
6 145 19 JUL 82
6 180 19 APR 83
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000



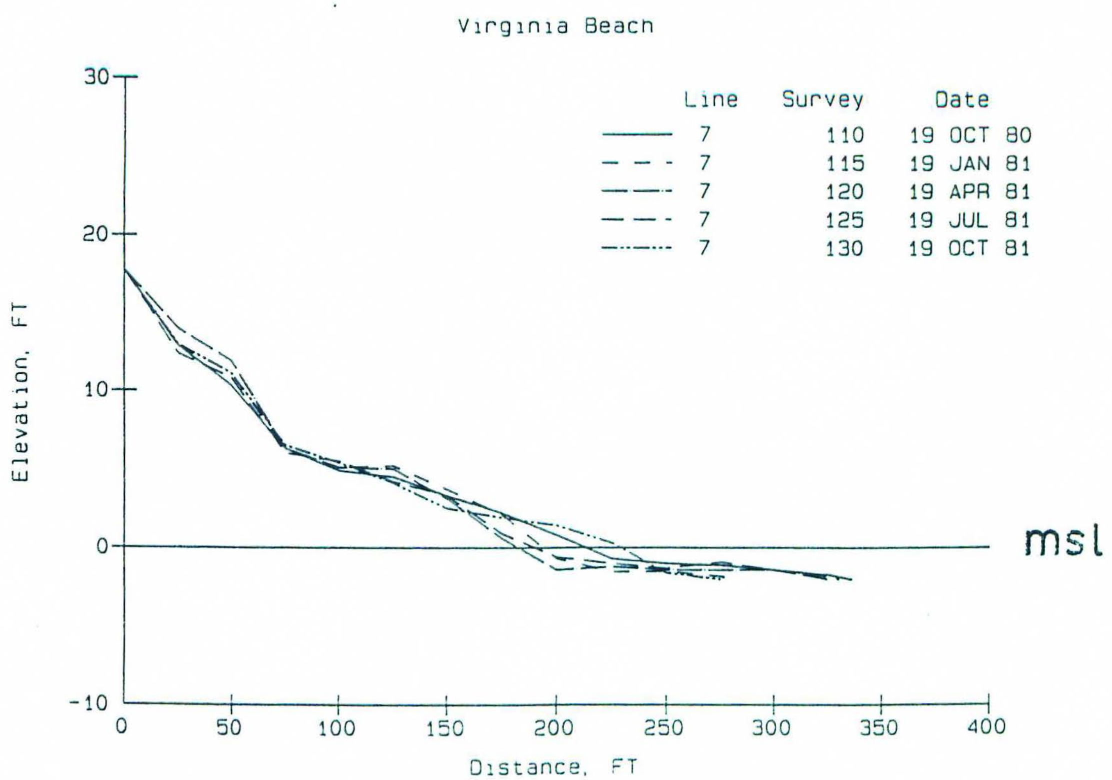
Virginia Beach
Line Survey Date
6 180 19 APR 83
6 185 19 JUL 83
6 190 19 OCT 83
6 195 19 JAN 84
6 200 19 JUL 84
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000

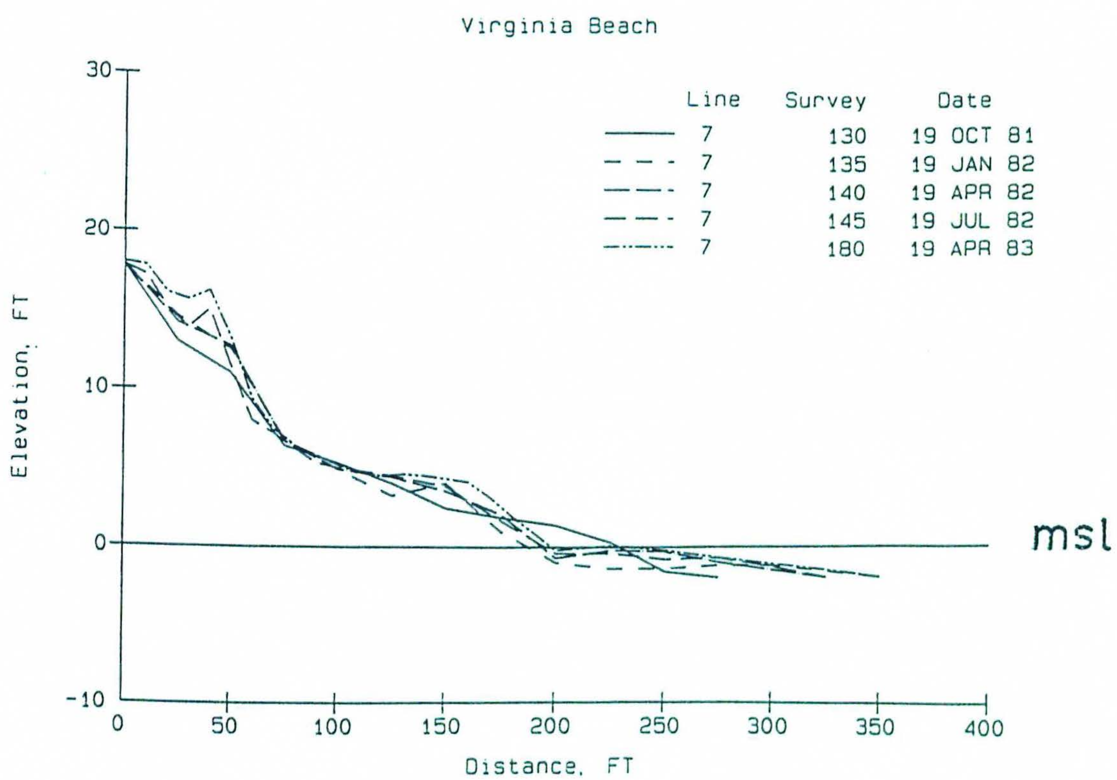


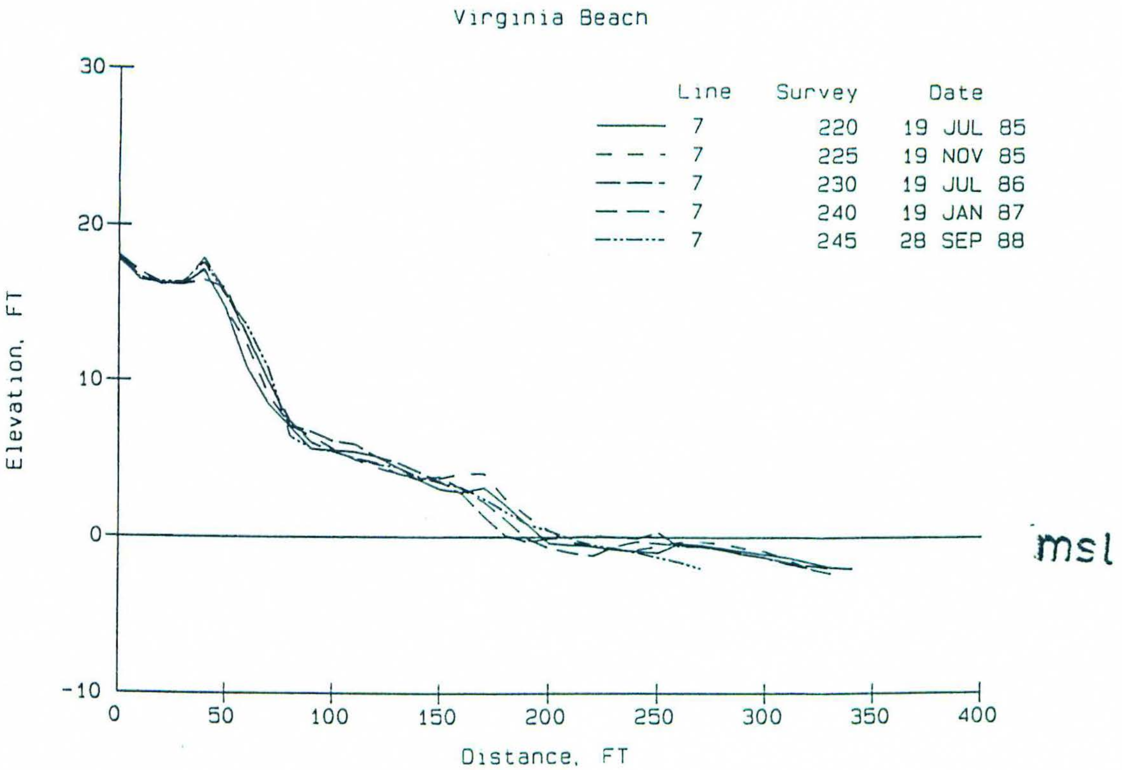
Virginia Beach
Line Survey Date
6 200 19 JUL 84
6 205 19 OCT 84
6 210 19 JAN 85
6 215 19 APR 85
6 220 19 JUL 85
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000



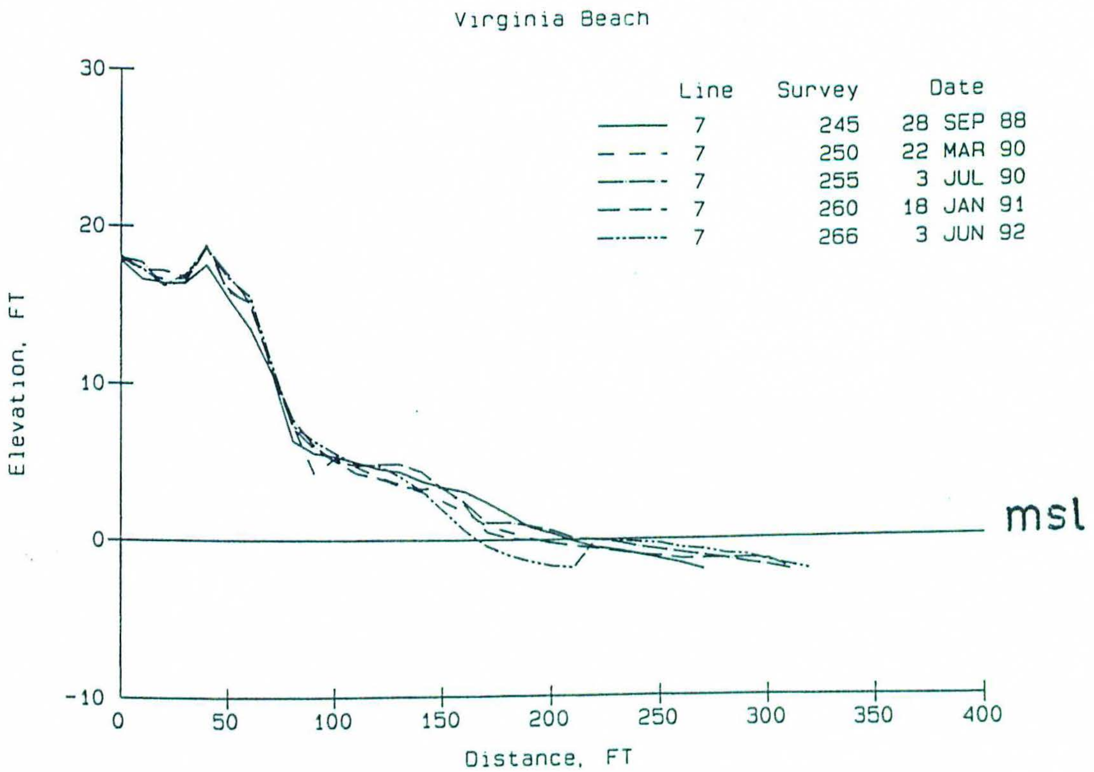
Virginia Beach
Line Survey Date
6 220 19 JUL 85
6 225 19 NOV 85
6 230 19 JUL 86
6 240 19 JAN 87
6 261 9 APR 91
Elevation, FT
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000
Distance, FT
msl


Virginia Beach
Line
Survey
Date
7 110 19 OCT 80
7 115 19 JAN 81
7 120 19 APR 81
7 125 19 JUL 81
7 130 19 OCT 81
30
20
10
0
-10
Elevation, FT
0
50
100
150
200
250
300
350
400
Distance, FT
msl

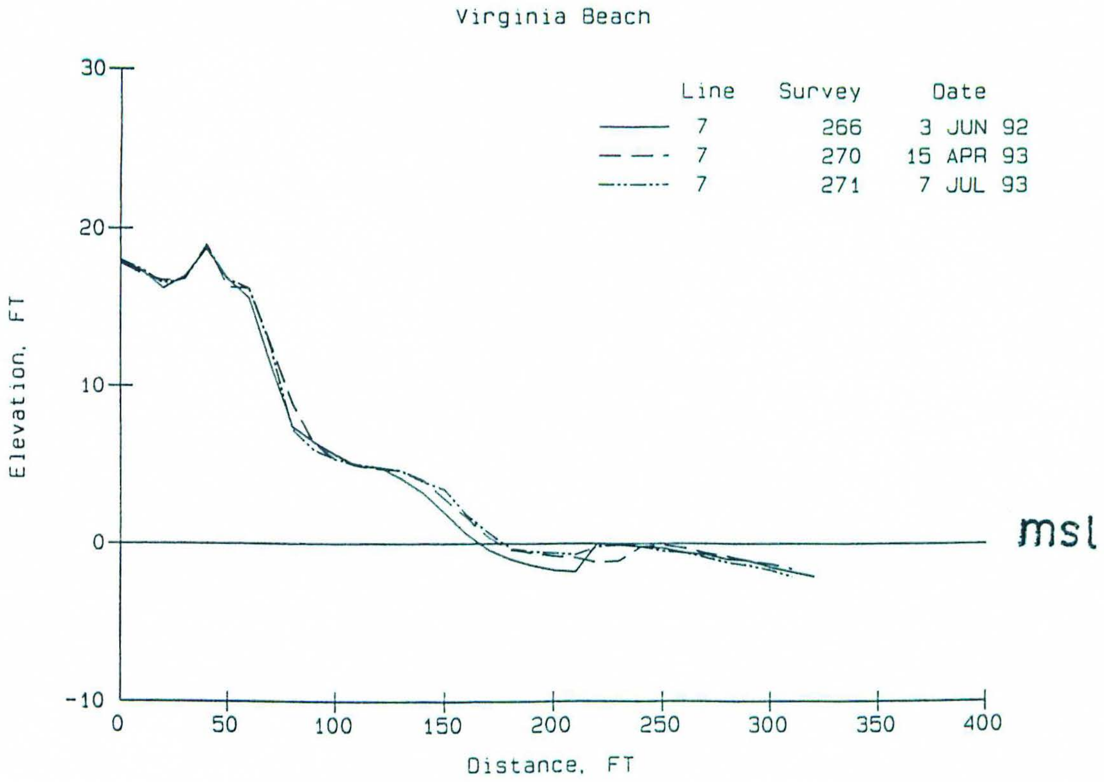

Virginia Beach
Line
Survey
Date
7 130 19 OCT 81
7 135 19 JAN 82
7 140 19 APR 82
7 145 19 JUL 82
7 180 19 APR 83
30
20
10
0
-10
Elevation, FT
0
50
100
150
200
250
300
350
400
Distance, FT
msl



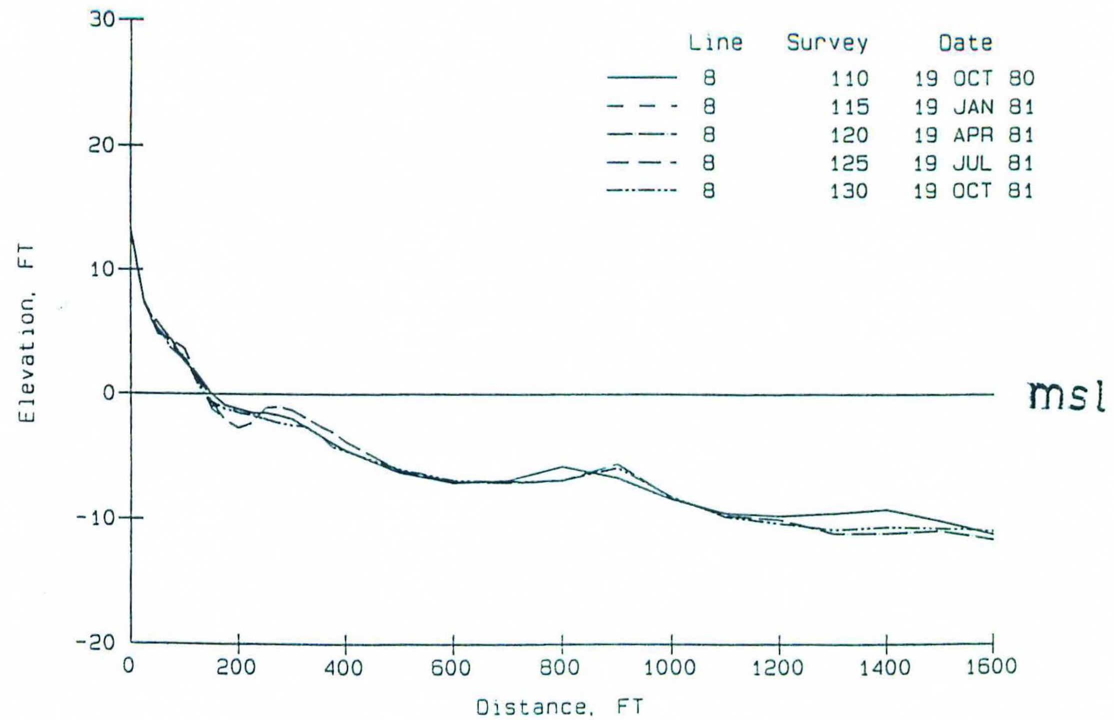
Virginia Beach
Line Survey Date
7 220 19 JUL 85
7 225 19 NOV 85
7 230 19 JUL 86
7 240 19 JAN 87
7 245 28 SEP 88
Elevation, FT
Distance, FT
30
20
10
0
-10
0 50 100 150 200 250 300 350 400
msl



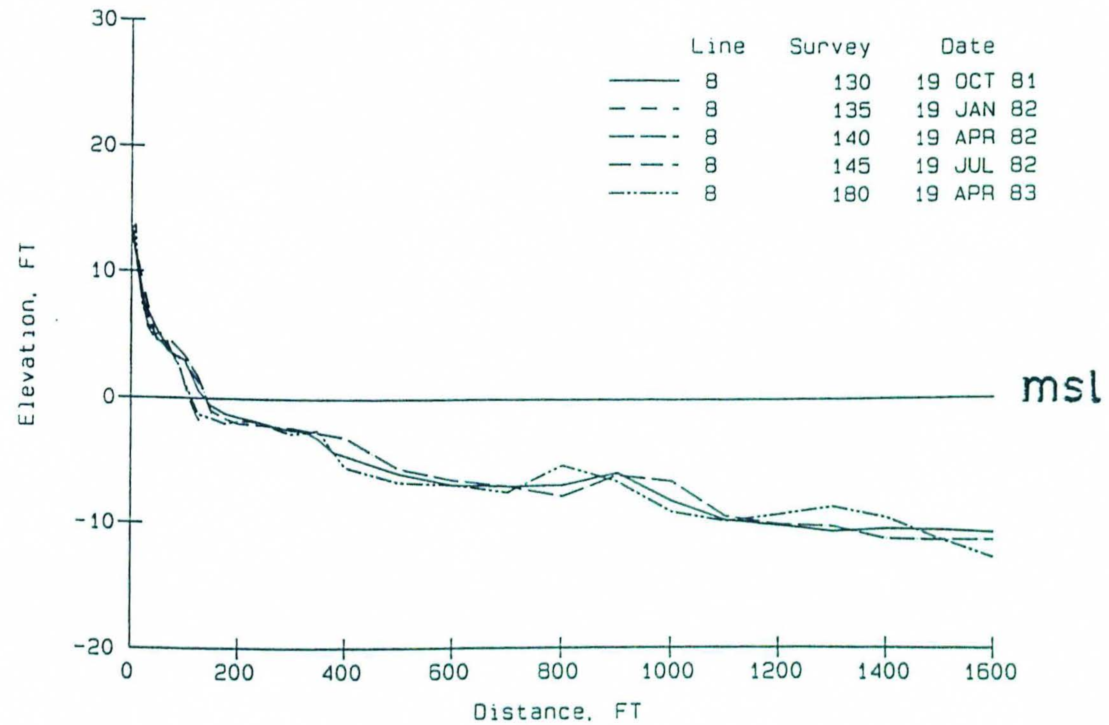
Virginia Beach
Line Survey Date
7 245 28 SEP 88
7 250 22 MAR 90
7 255 3 JUL 90
7 260 18 JAN 91
7 266 3 JUN 92
Elevation, FT
Distance, FT
30
20
10
0
-10
0 50 100 150 200 250 300 350 400
msl

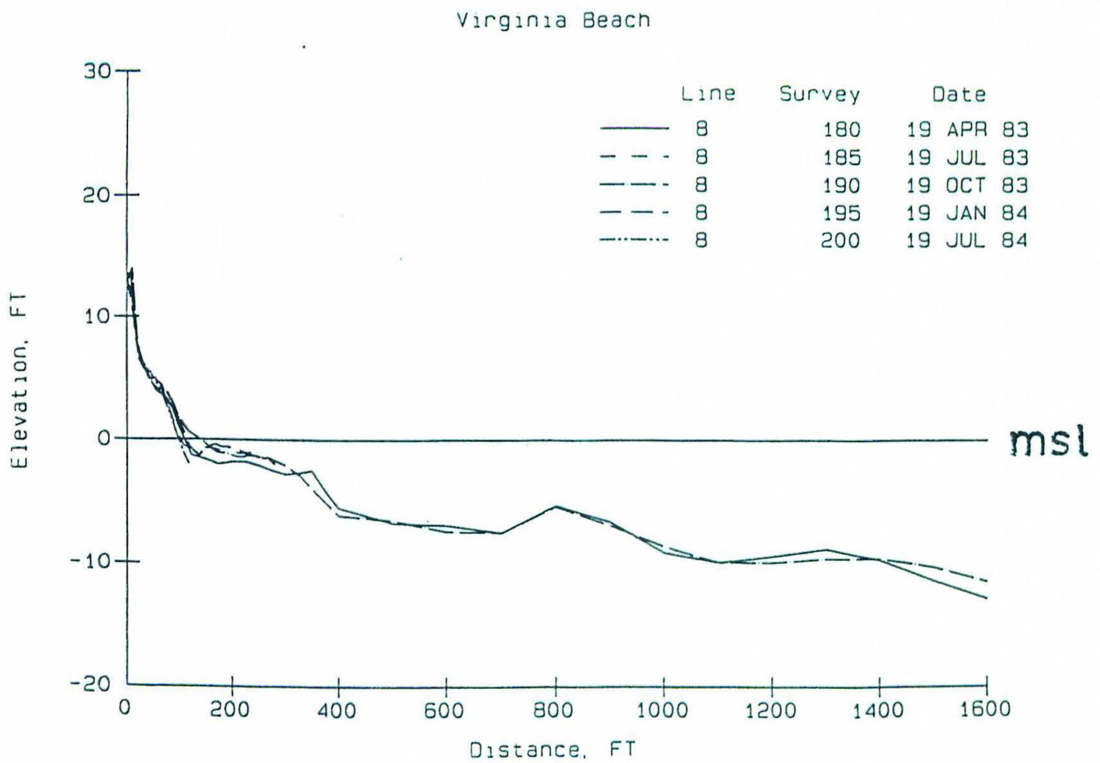

Virginia Beach
Line Survey Date
7 266 3 JUN 92
7 270 15 APR 93
7 271 7 JUL 93
Elevation, FT
30
20
10
0
-10
0 50 100 150 200 250 300 350 400
Distance, FT
msl

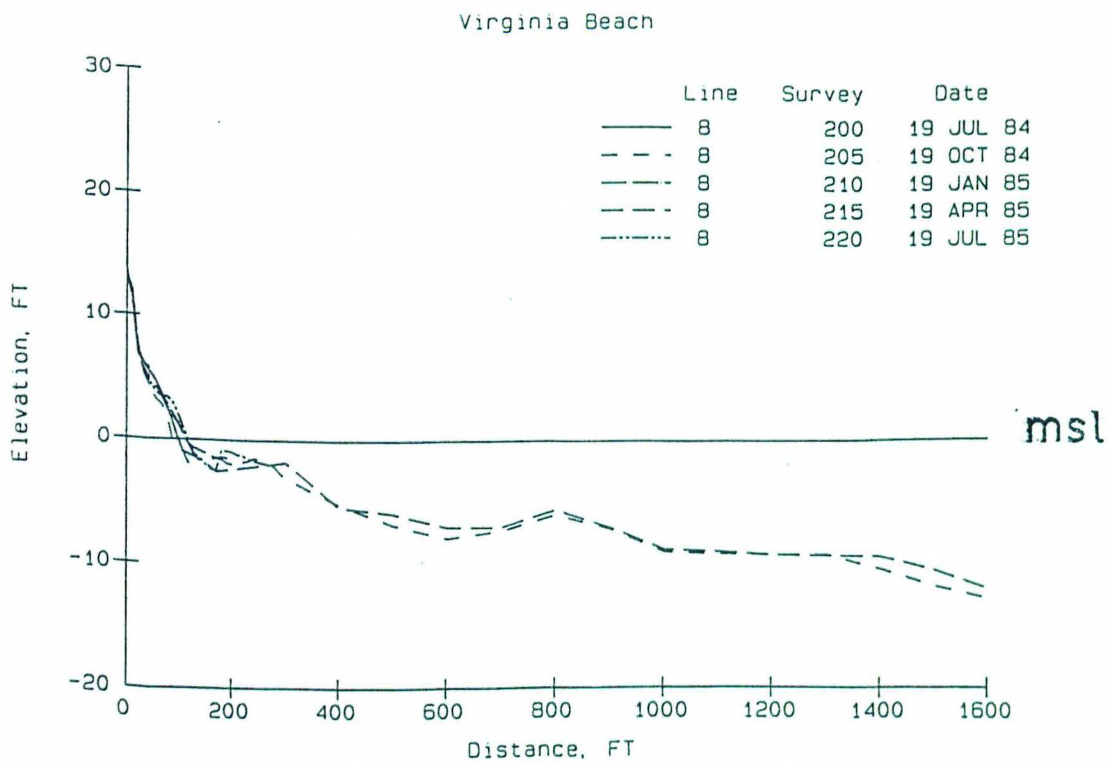
Virginia Beach

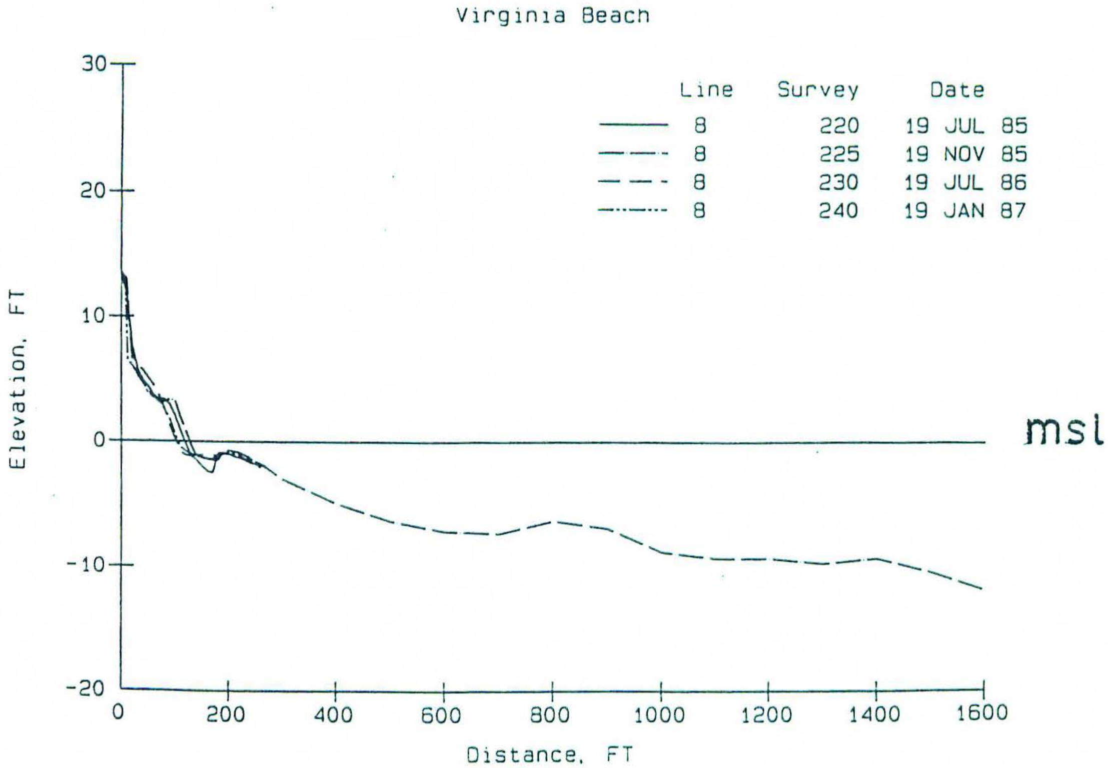


Virginia Beach

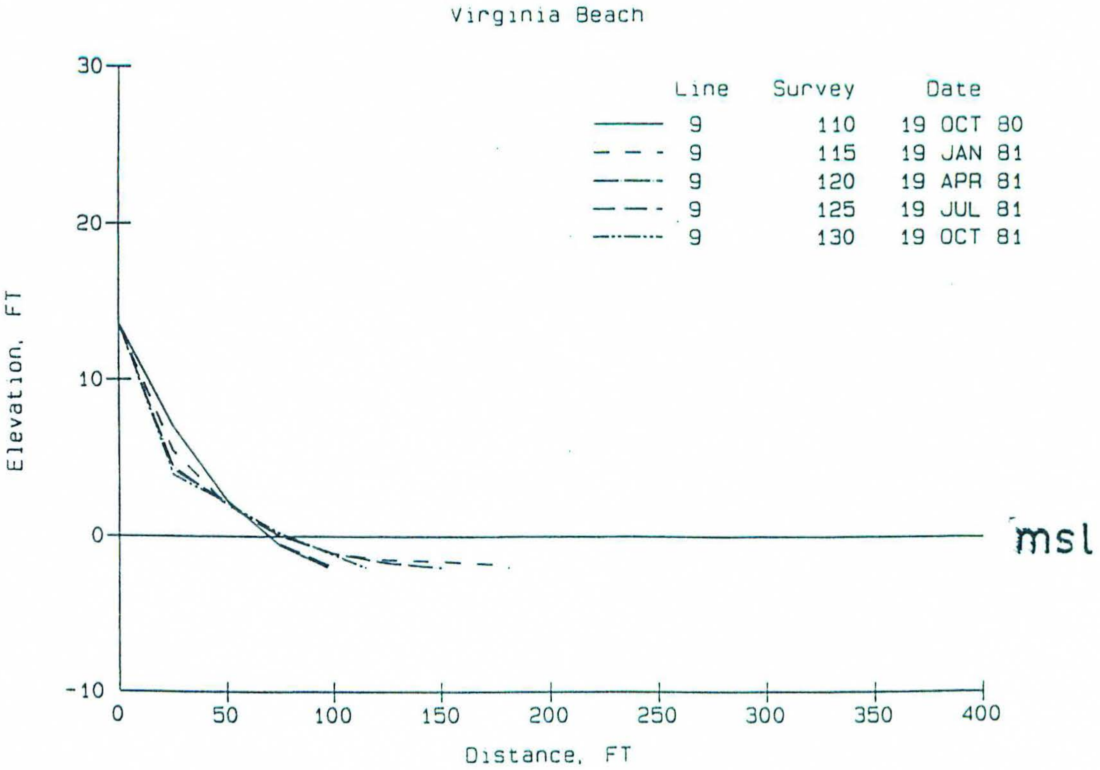


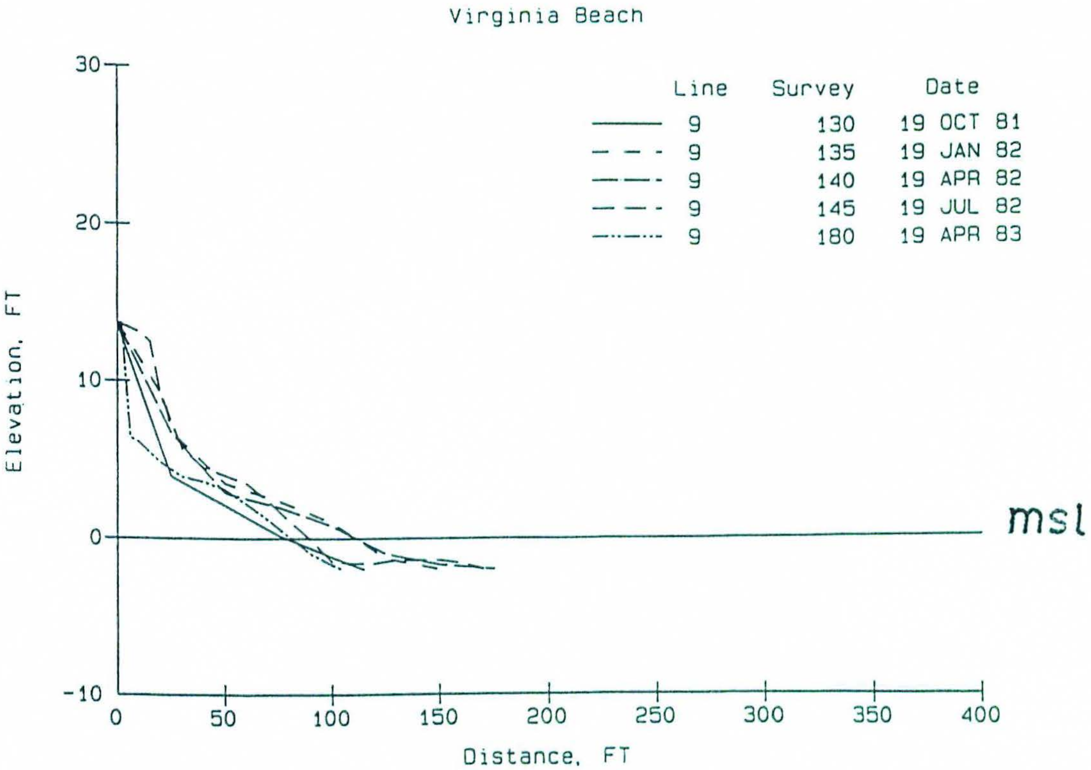

Virginia Beach
Line Survey Date
8 180 19 APR 83
8 185 19 JUL 83
8 190 19 OCT 83
8 195 19 JAN 84
8 200 19 JUL 84
Elevation, FT
30
20
10
0
-10
-20
msl
0
200
400
600
800
1000
1200
1400
1600
Distance, FT

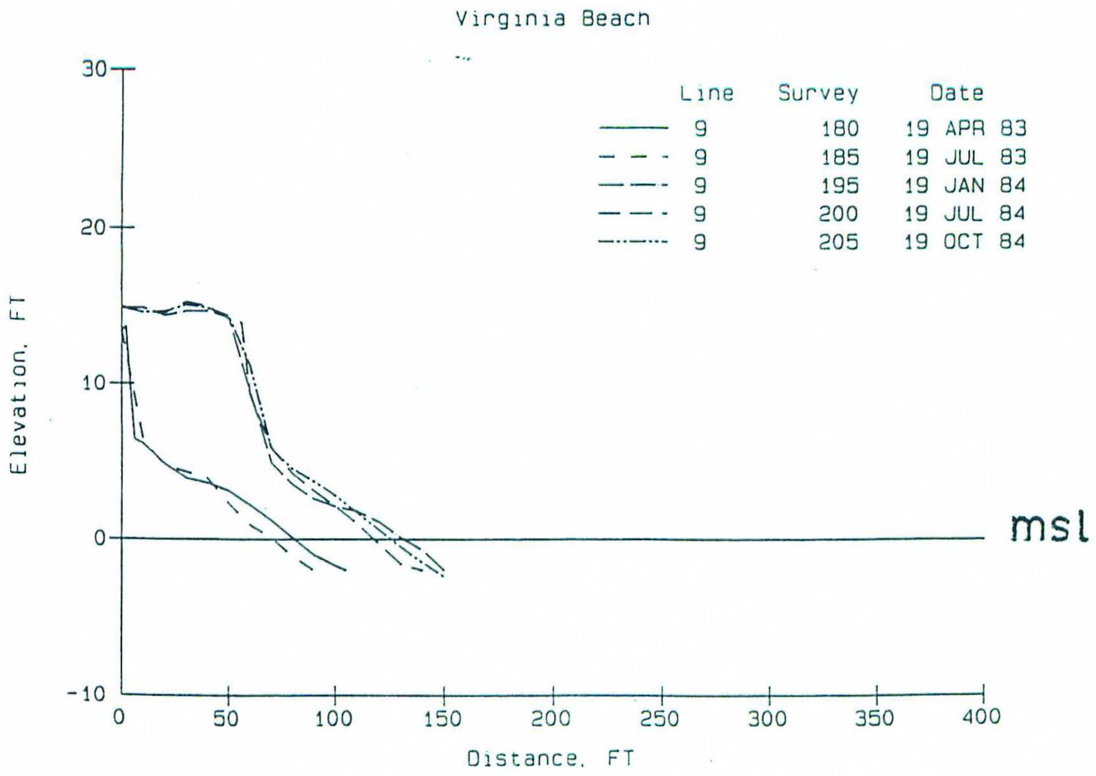

Virginia Beach
Line Survey Date
8 200 19 JUL 84
8 205 19 OCT 84
8 210 19 JAN 85
8 215 19 APR 85
8 220 19 JUL 85
Elevation, FT
30
20
10
0
-10
-20
msl
0
200
400
600
800
1000
1200
1400
1600
Distance, FT



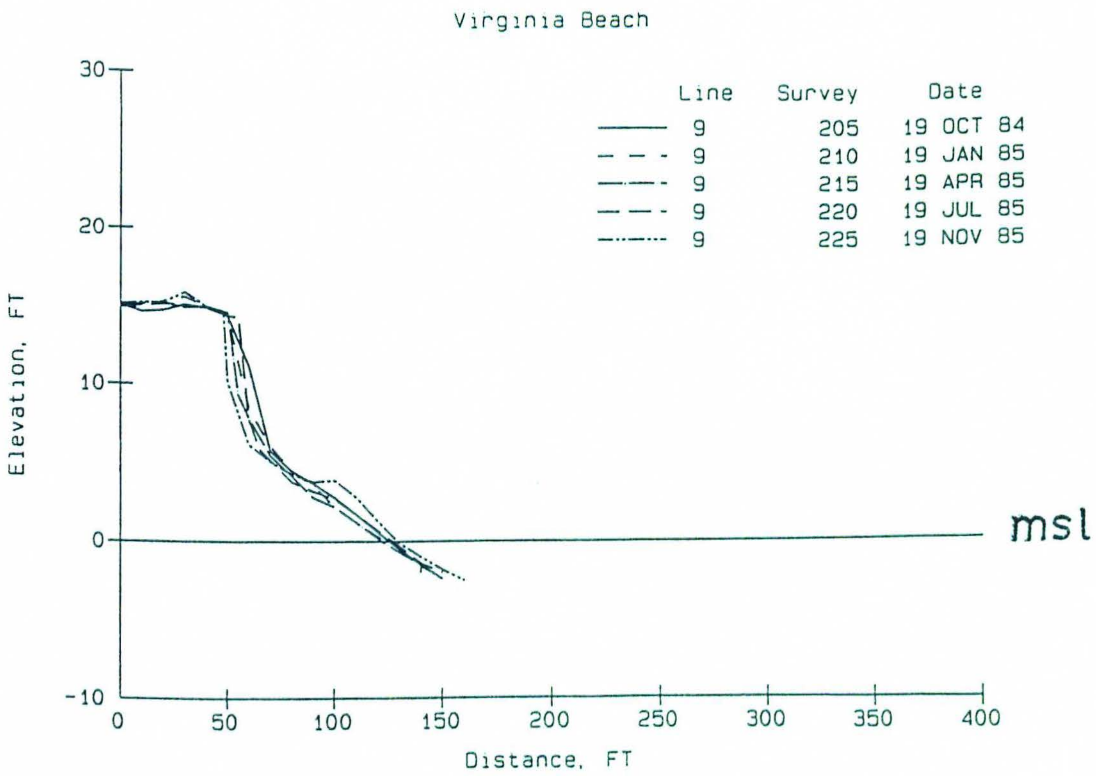
Virginia Beach
Line Survey Date
8 220 19 JUL 85
8 225 19 NOV 85
8 230 19 JUL 86
8 240 19 JAN 87
Elevation, FT
30
20
10
0
-10
-20
msl
0 200 400 600 800 1000 1200 1400 1600
Distance, FT


Virginia Beach
Line Survey Date
9 110 19 OCT 80
9 115 19 JAN 81
9 120 19 APR 81
9 125 19 JUL 81
9 130 19 OCT 81
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
0 50 100 150 200 250 300 350 400

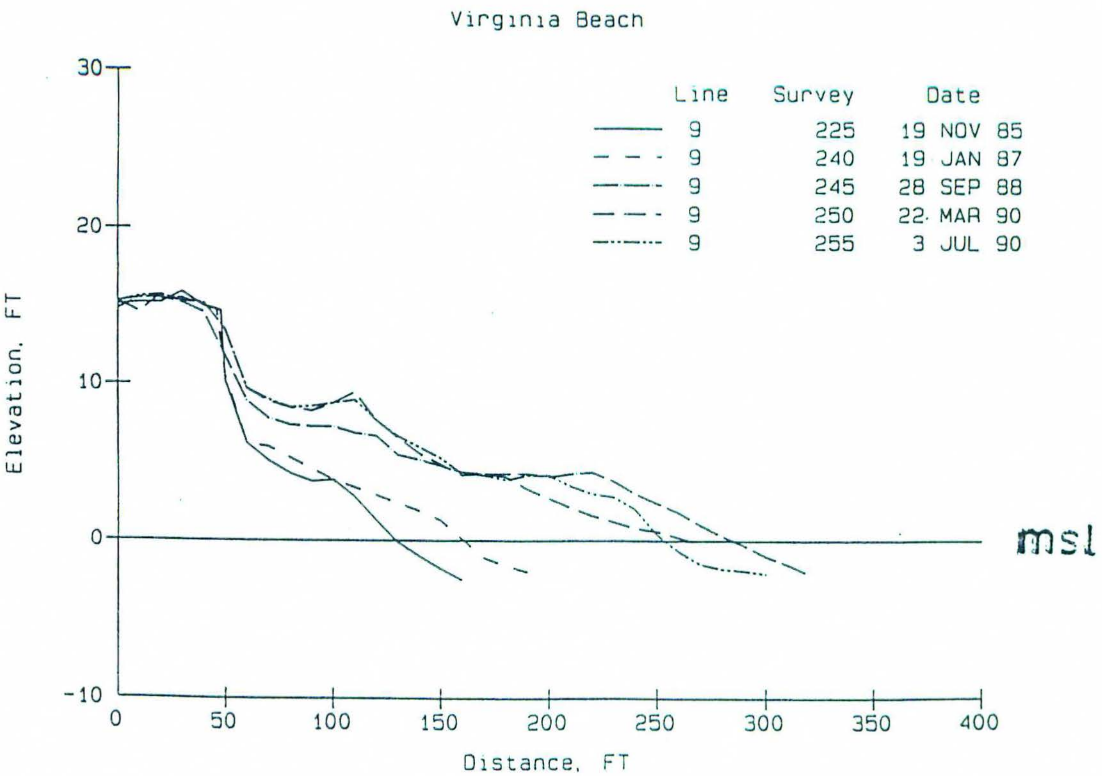

Virginia Beach
Line Survey Date
9 130 19 OCT 81
9 135 19 JAN 82
9 140 19 APR 82
9 145 19 JUL 82
9 180 19 APR 83
Elevation, FT
Distance, FT
msl
30
20
10
0
-10
0 50 100 150 200 250 300 350 400

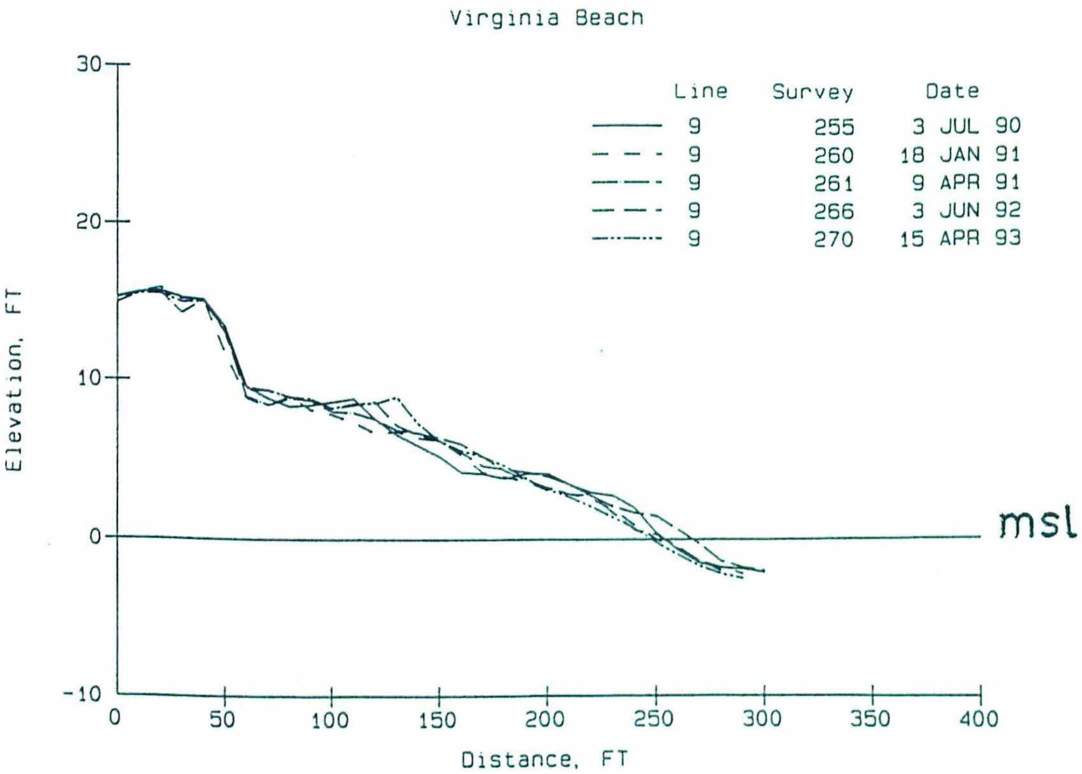


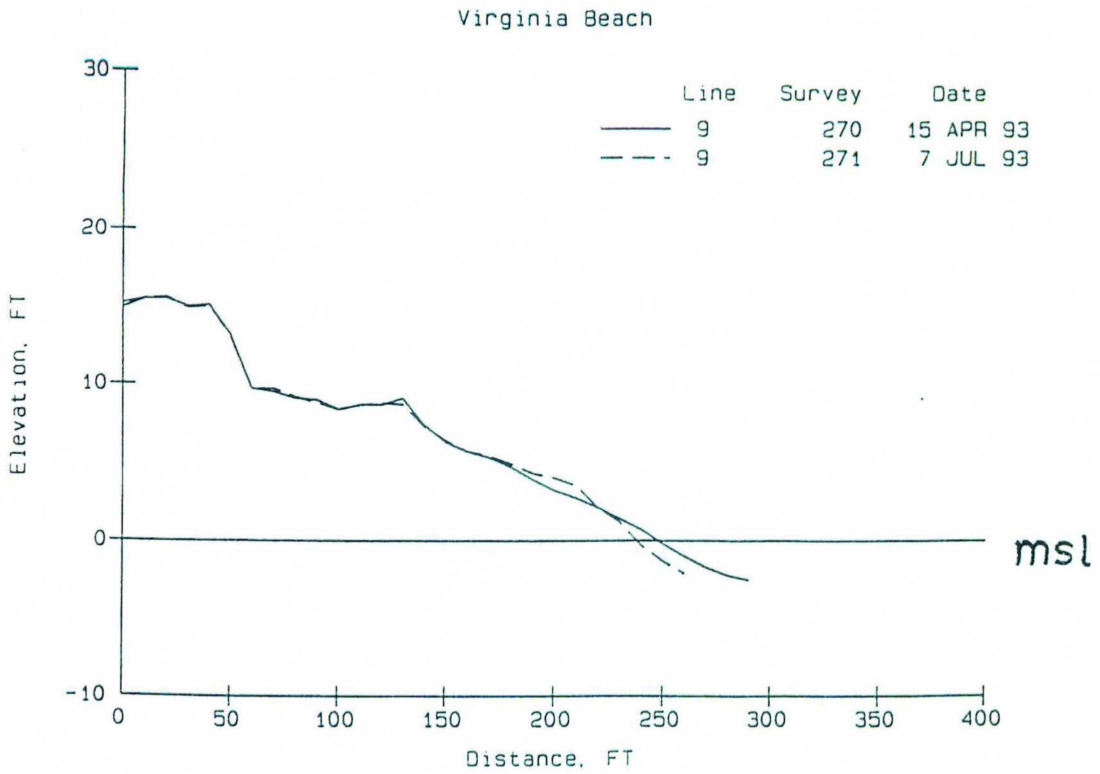
Virginia Beach
Line Survey Date
9 180 19 APR 83
9 185 19 JUL 83
9 195 19 JAN 84
9 200 19 JUL 84
9 205 19 OCT 84
Elevation, FT
30
20
10
0
-10
msl
0 50 100 150 200 250 300 350 400
Distance, FT



Virginia Beach
Line Survey Date
9 205 19 OCT 84
9 210 19 JAN 85
9 215 19 APR 85
9 220 19 JUL 85
9 225 19 NOV 85
Elevation, FT
30
20
10
0
-10
msl
0 50 100 150 200 250 300 350 400
Distance, FT

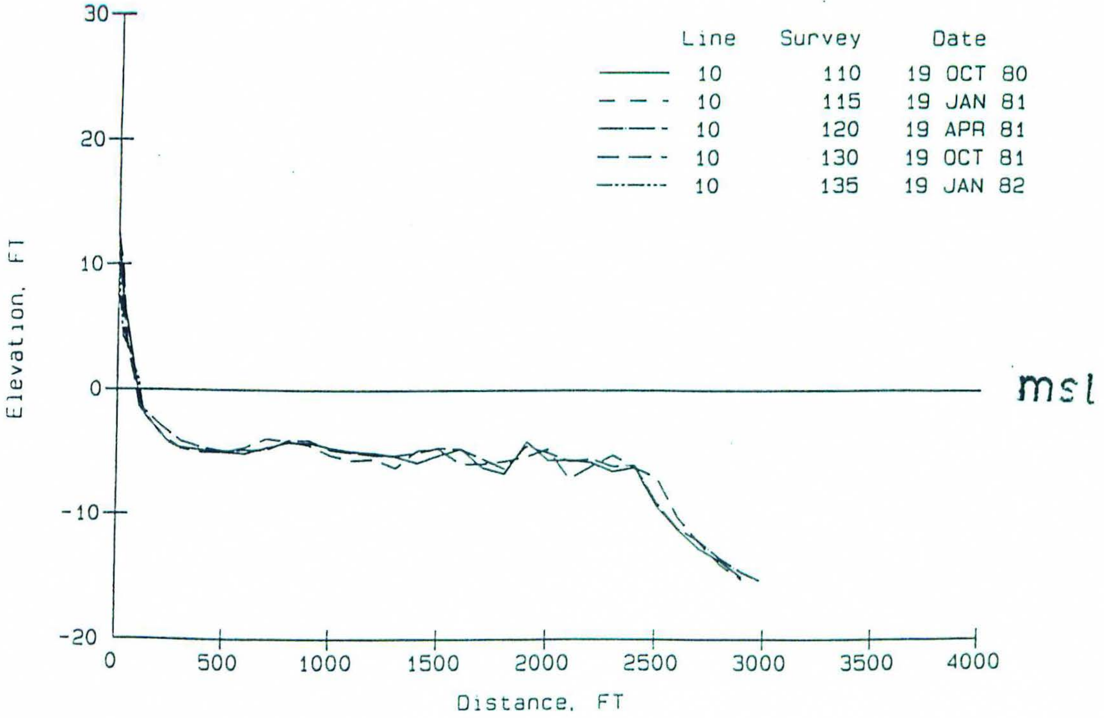

Virginia Beach
Line Survey Date
9 225 19 NOV 85
9 240 19 JAN 87
9 245 28 SEP 88
9 250 22 MAR 90
9 255 3 JUL 90
Elevation, FT
Distance, FT
msl


Virginia Beach
Line Survey Date
9 255 3 JUL 90
9 260 18 JAN 91
9 261 9 APR 91
9 266 3 JUN 92
9 270 15 APR 93
Elevation, FT
Distance, FT
msl

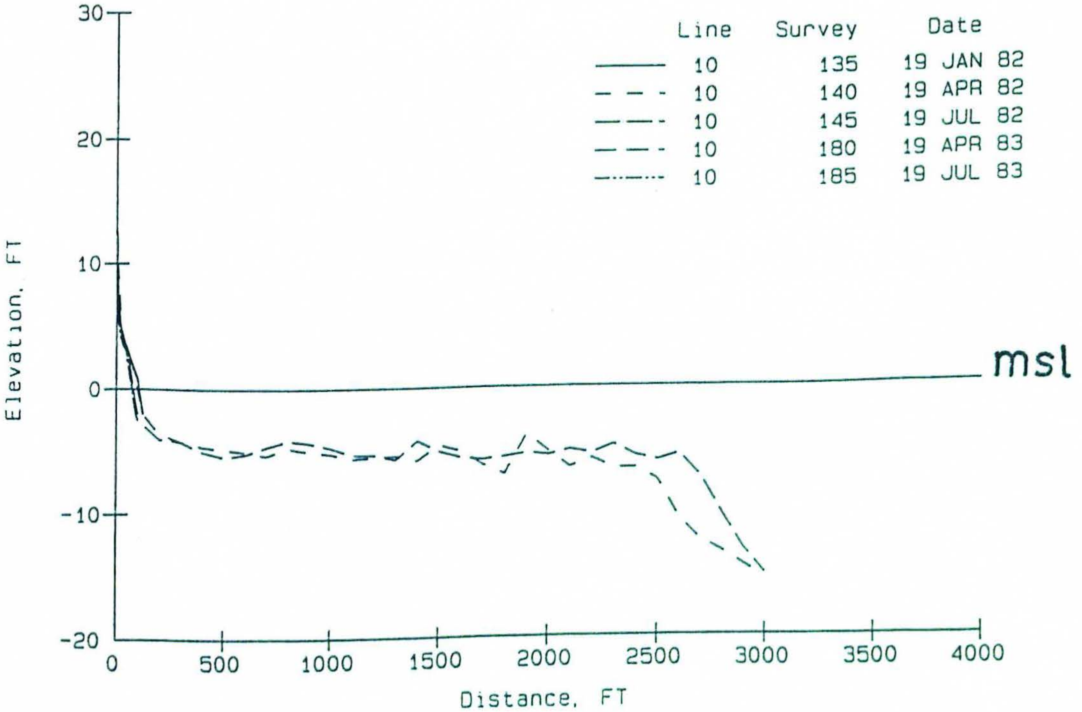


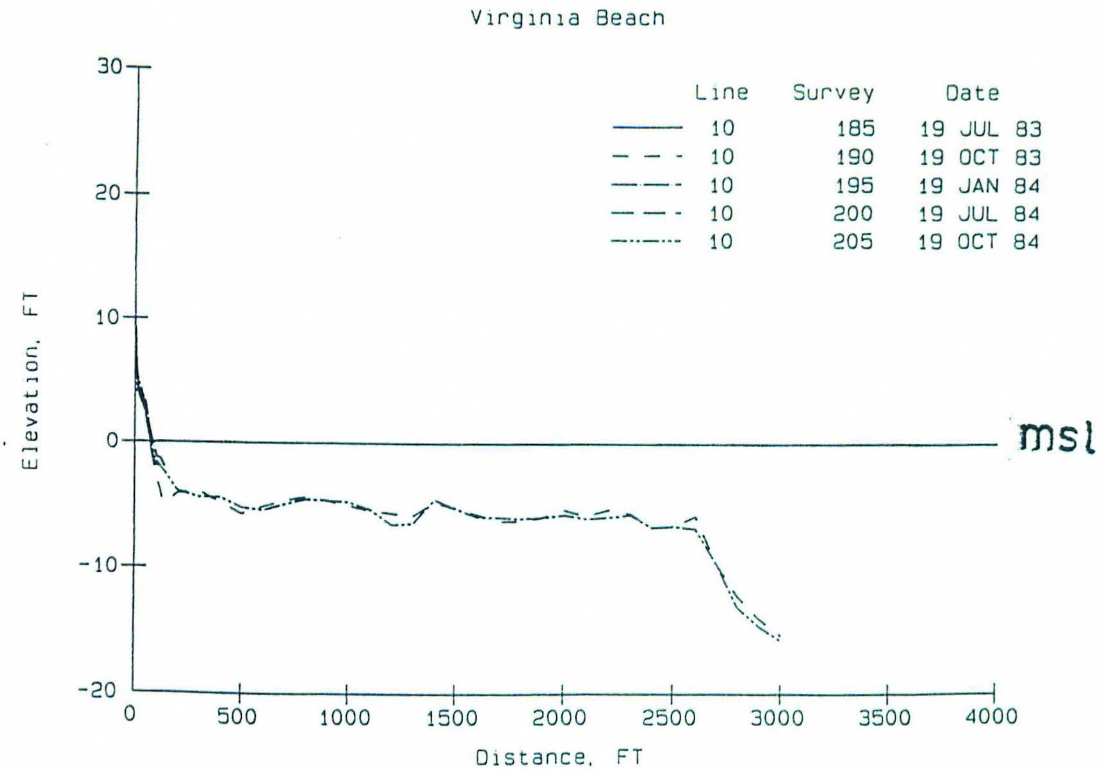
Virginia Beach
Line Survey Date
9 270 15 APR 93
9 271 7 JUL 93
Elevation, FT
30
20
10
0
-10
msl
0
50
100
150
200
250
300
350
400
Distance, FT

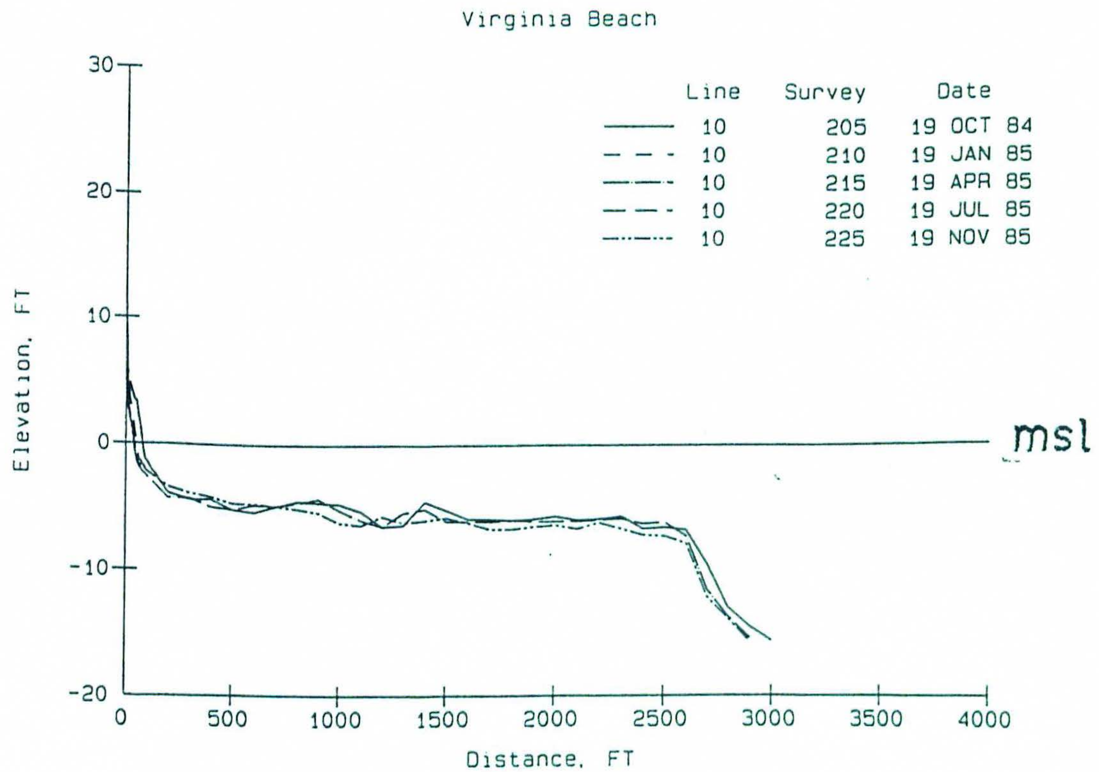
Virginia Beach

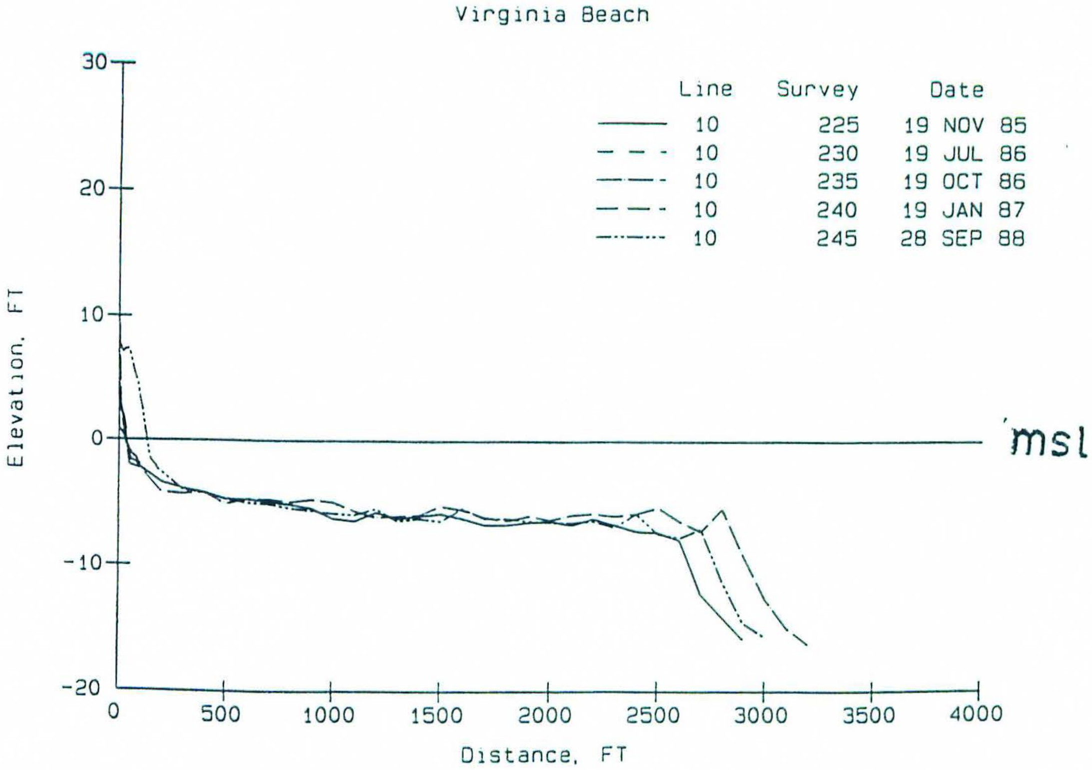


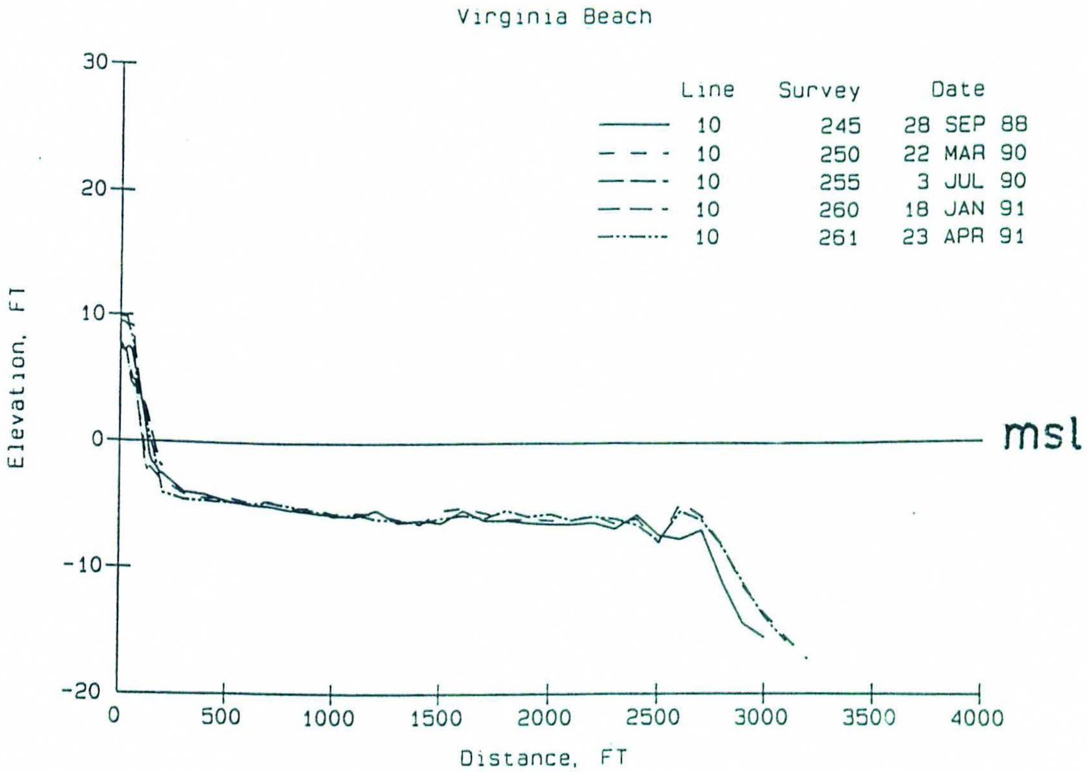
Virginia Beach

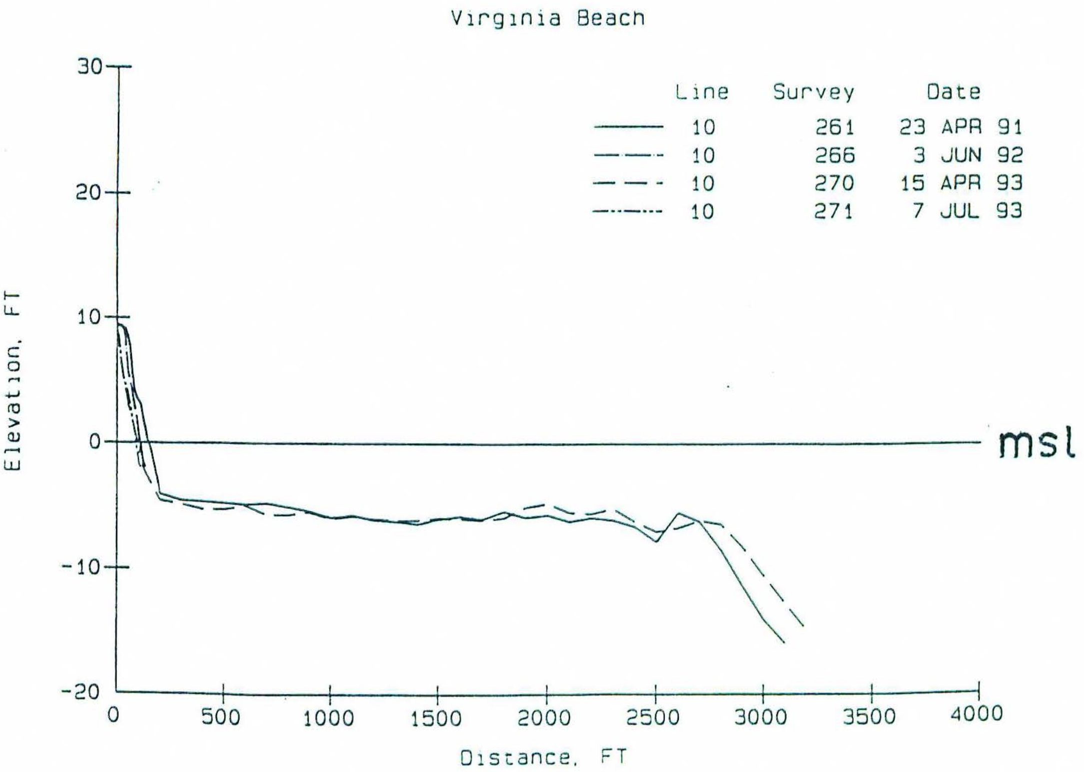



Virginia Beach
Line Survey Date
10 185 19 JUL 83
10 190 19 OCT 83
10 195 19 JAN 84
10 200 19 JUL 84
10 205 19 OCT 84
30
20
10
0
-10
-20
Elevation, FT
msl
0 500 1000 1500 2000 2500 3000 3500 4000
Distance, FT


Virginia Beach
Line Survey Date
10 205 19 OCT 84
10 210 19 JAN 85
10 215 19 APR 85
10 220 19 JUL 85
10 225 19 NOV 85
30
20
10
0
-10
-20
Elevation, FT
msl
0 500 1000 1500 2000 2500 3000 3500 4000
Distance, FT


Virginia Beach
Line Survey Date
10 225 19 NOV 85
10 230 19 JUL 86
10 235 19 OCT 86
10 240 19 JAN 87
10 245 28 SEP 88
Elevation, FT
msl
Distance, FT


Virginia Beach
Line Survey Date
10 245 28 SEP 88
10 250 22 MAR 90
10 255 3 JUL 90
10 260 18 JAN 91
10 261 23 APR 91
Elevation, FT
msl
Distance, FT


Virginia Beach
Line Survey Date
10 261 23 APR 91
10 266 3 JUN 92
10 270 15 APR 93
10 271 7 JUL 93
Elevation, FT
msl
Distance, FT
30
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
3500
4000