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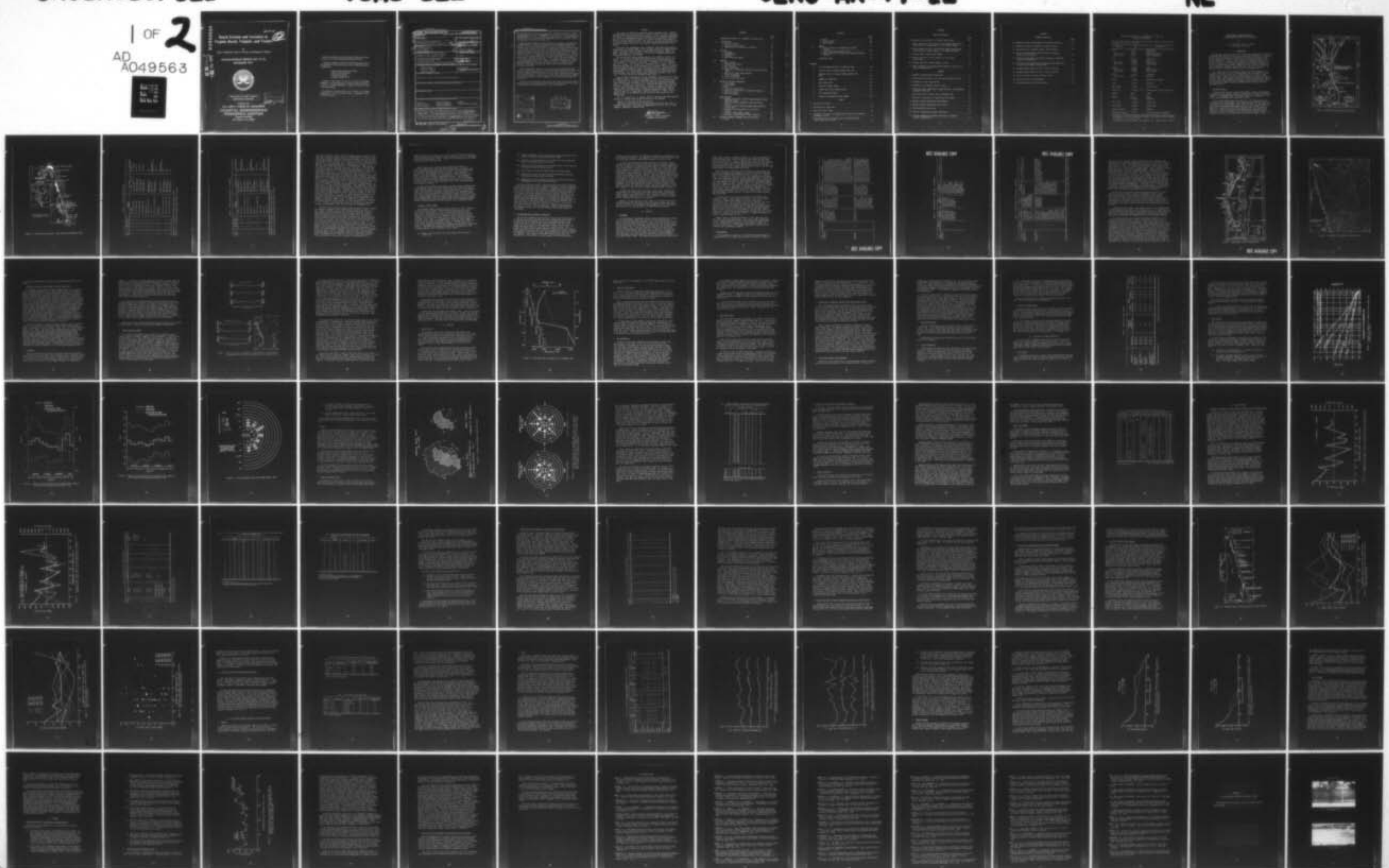

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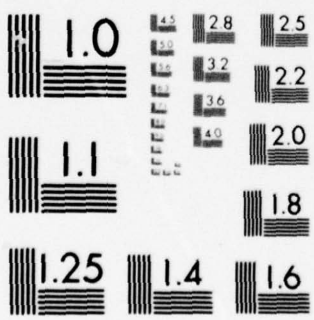

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MR 77-12

Beach Erosion and Accretion at Virginia Beach, Virginia, and Vicinity

by
Victor Goldsmith, Susan C. Sturm, and George R. Thomas

MISCELLANEOUS REPORT NO. 77-12
DECEMBER 1977

Approved for public release; distribution unlimited.

Prepared for
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Eighteen profile lines from Fort Story south to the Virginia-North Carolina State line were surveyed monthly for 27 months (September 1974 to December 1976). Net volume changes were moderate, with maximum rates of accretion at the north and south ends of the study area. A statistical analysis using earlier surveys going back to November 1956 confirms the pattern of accretion in the north and south separated by erosion in the middle.

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Maximum annualized accretion rate during the 27-month study was 18.9 cubic meters ~~per~~ meter of beach front ~~per~~ year at ~~profile line 1~~ (Fort Story), and maximum erosion rate 11.6 cubic meters per meter per year at ~~profile line 9~~ (Sandbridge). The ridge-and-runnel morphology typical of many active shorelines was not observed in the study area.

(4) Under present conditions, rates of erosion and accretion are independent of the ~~four~~ types of shore usage defined for this ~~study~~ area--(commercial, natural, military, and residential). The narrow, erosional beaches are located at the center of the study area in Back Bay National Wildlife Refuge (natural area), Dam Neck (military), and Sandbridge (residential); the wide, accretional beaches are located at the north and south ends ~~of the study area~~ in Fort Story (military) and False Cape State Park (natural). Instead of beach usage, it is suggested that the observed differences result from a nodal zone of diverging longshore transport in the middle of the study area (approximately Dam Neck to Back Bay). North of this zone, net transport is to the north, and south of this zone, it is hypothesized that net transport is to the south. The net, but irregular, movement of sediment out of the middle area explains the narrow, relatively inactive, erosional beaches observed in the middle and the wide, more active, accretional beaches observed on the ends.

This interpretation supports existing bypassing and sand nourishment procedures which place sand at the south end of the Virginia Beach commercial reach for natural longshore processes to distribute to the north. The measured volume changes of beach sand in this reach, especially when compared with adjacent reaches, strongly indicate that the bypassing and nourishment procedures are needed for the maintenance of the Virginia Beach commercial beach area.

Results of reconnaissance inspections of the shores of Currituck County, North Carolina, are included to better relate the Virginia Beach study area to the CERC Field Research Facility at Duck, North Carolina.

PREFACE

This report is published to provide coastal engineers with a description of beach erosion and accretion at Virginia Beach, Virginia, including the effect of continuing beach replenishment, and the apparent unimportance of land use in determining erosion. This report also provides bench-mark data on coastal processes at the shore north of the CERC Field Research Facility at Duck, North Carolina. The work was carried out under the beach evaluation program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by Victor Goldsmith (principal investigator), Susan Sturm, and George Thomas of the Virginia Institute of Marine Science (VIMS), Gloucester Point, Virginia, under CERC Contract No. DACW72-74-C-0008. Work under this contract is also reported in Applied Science and Ocean Engineering No. 122 of VIMS.

The authors give special appreciation to R.J. Byrne, C. Everts, C.J. Galvin, Jr., and M.T. Czerniak, who provided advice during parts of the study. Original profile data and helpful discussions were provided by P.A. Bullock, L.E. Fausak, W. Harrison, J.F. McHone, Jr., G.L. Shideler, and D.J.P. Swift. C.H. Sutton, A.H. Sallenger, Jr., F. Smith, and Y.E. Goldsmith provided able field assistance on a voluntary basis in bimonthly beach profiling during the 1972-74 precontract period. Fieldwork assistance by numerous graduate students and researchers at VIMS is gratefully acknowledged. A.L. Gutman and W.S. Richardson provided unpublished wind and storm data from the Currituck Beach Lighthouse, Corolla, North Carolina. A.Frisch assisted in the beach-trend analysis.

Special thanks and appreciation are extended to the wave observers who contributed data to this study, including R. Fields of Back Bay, Lt. Comdr. C.A. Tarver and Lt. D. Jones of Dam Neck, and R.W. Klise of Sandbridge. The cooperation and assistance of the following are gratefully acknowledged: D. Hollands, R. Fields, and F. Smith of Back Bay Wildlife Refuge; W. Taylor of False Cape State Park; E. Bichner, G. Austin, and others of Corolla, North Carolina; and A. Gilbert and the Virginia Beach Erosion Commission for providing monthly assistance during the study. Special contributions by C. Diggs and N. Blake of VIMS and A.E. DeWall and P.I. Campos of CERC in the preparation and analysis of the report are also acknowledged.

Drs. C.J. Galvin, Jr., C. Everts, and M.T. Czerniak were CERC contract monitors at various times during the period of the contract.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

John H. Cousins

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

ASOF

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

BEACH EROSION AND ACCRETION AT VIRGINIA BEACH, VIRGINIA, AND VICINITY

by

Victor Goldsmith, Susan C. Sturm, and George R. Thomas

I. INTRODUCTION

The National Shoreline Study (U.S. Army, Corps of Engineers (1971a) concluded that more than half of Virginia's 933-mile shoreline is undergoing severe erosion (26 percent) or noncritical erosion (30 percent). The cost of improvement of the Virginia area was estimated at $89.5 million (in 1971 dollars). Since the only significant shoreline population center in Virginia is the major commercial area of Virginia Beach, this is the area of greatest economic importance, with respect to shoreline erosion problems. However, within this area, the shoreline changes are quite irregular (Goldsmith, 1975c; Sutton and Goldsmith, 1976).

This study presents and analyzes beach survey data measured at 18 profile lines (Figs. 1 and 2) from September 1974 to December 1976 and integrates these data with older surveyed data at 14 of the 18 same profile lines. Additionally, to provide background information needed to better plan and understand studies at the CERC Field Research Facility, which is just to the south of the southern end of the study area, data and observations made in Currituck County, North Carolina, are also included (Fig. 1).

1. Previous Studies.

Previous beach studies at those beach profile lines that have been reoccupied in this present study, are summarized in Table 1 and shown in Figure 2. Photographs from these profile lines are in Appendix A. Previous studies are detailed in Goldsmith (1975a).

Watts (1959) studied effects of beach fill on Virginia Beach and calculated net volume changes in the nearshore and intertidal parts of the profile line between 1946, 1952, 1955, and 1958. He concluded that 84 percent of the nourishment material placed on the beach between Rudee Inlet and 46th Street between September 1964 and June 1952 had been lost. However, the beach width remained the same during this period due to the nourishment. The first detailed studies of beach changes in Virginia were undertaken by Harrison and Wagner (1964). In

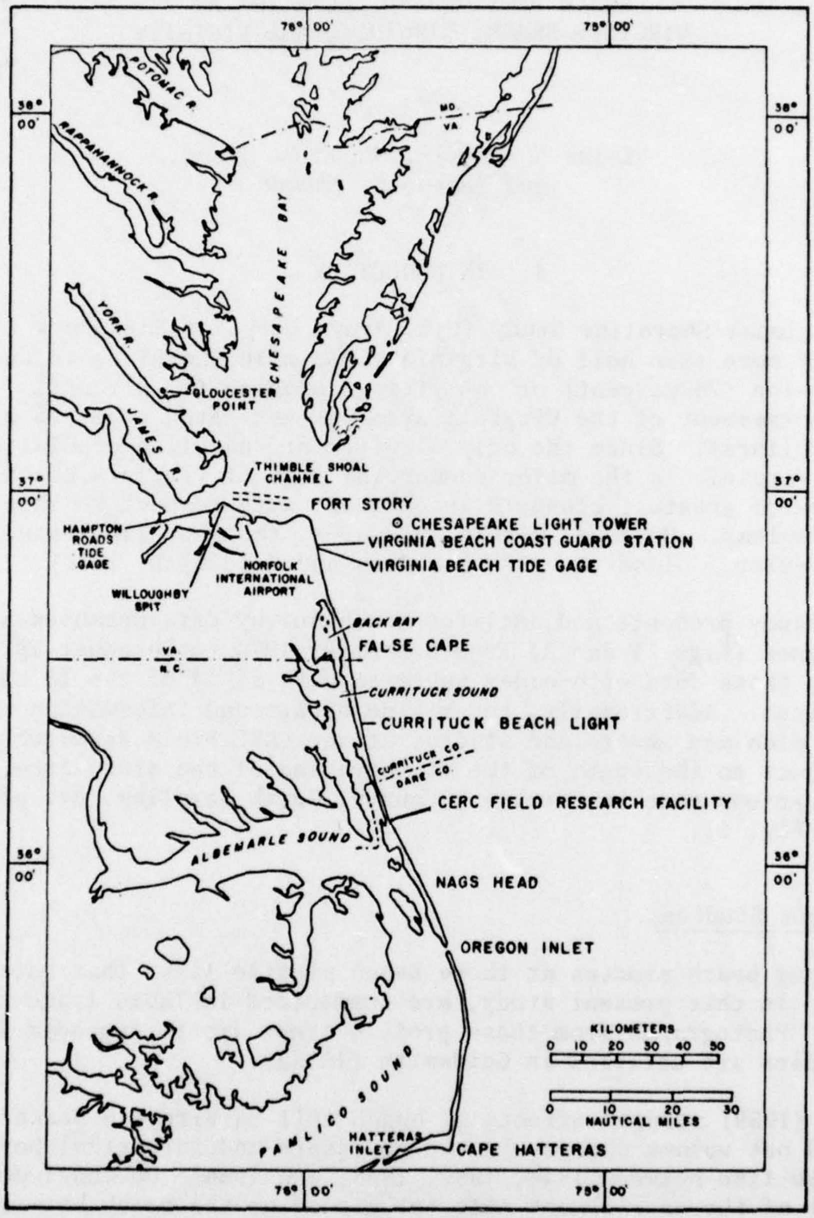

Figure 1. Regional location map of study area.

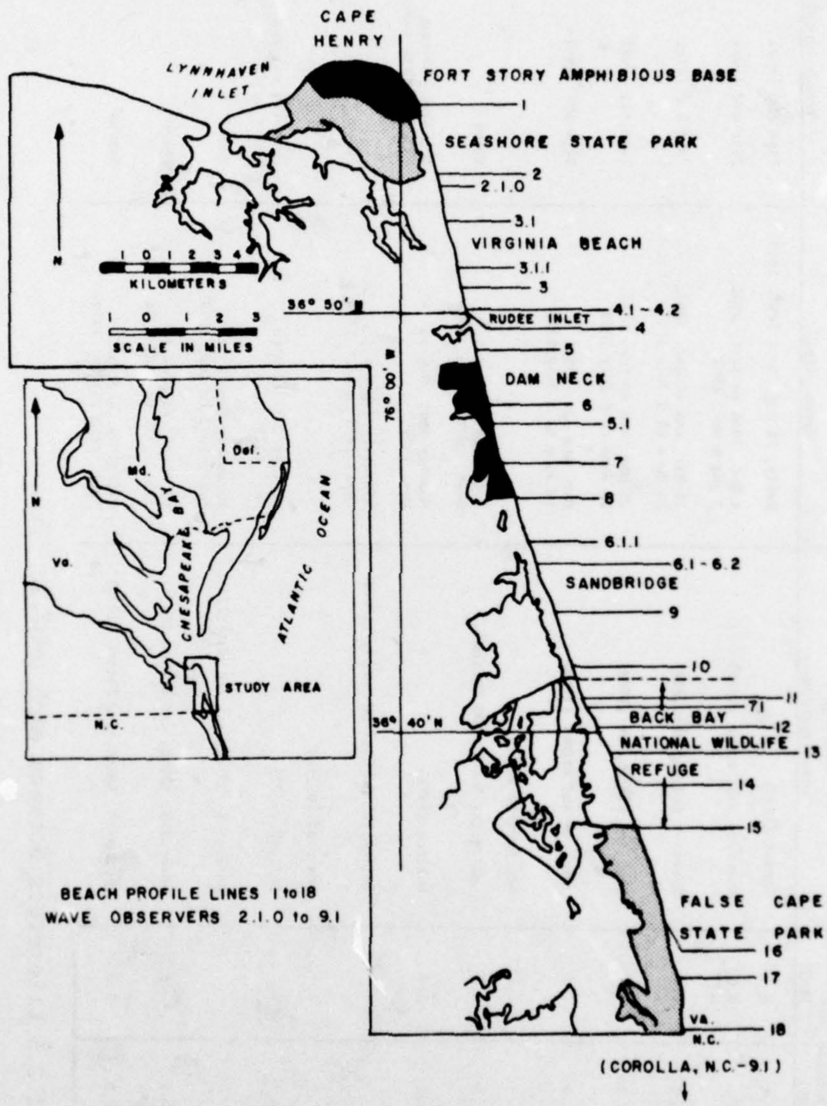

Figure 2. Location map of profile lines and wave observation sites.

Table 1. Beach profile history.

Profile line[1]	Distance to next profile line[1] (mi)	(km)	Previous investigators	Dates sampled	Survey technique
1	2.0	3.2	Fausak (1970)	Daily, 10 Aug. to 9 Sept. 1969	Tape and level
2	3.1	5.0	Harrison and Wagner (1964)	4 Nov. 1956 to Sept. 1958, 7 and 8 Mar. 1962	Tape and level
3	0.9	1.4	Harrison and Wagner (1964)	25 Mar. and 10 Apr. 1963, 11 June to 5 July 1963	Tape and level
4	0.9	1.4	Harrison and Wagner (1964)	25 Mar. and 10 Apr. 1963, 11 June to 5 July 1963	Tape and level
5	1.4	2.2	Harrison and Wagner (1964)	Mar. and Apr. 1963, 10 June to 5 July 1963	Tape and level
6	1.7	2.7	New profile line		
7	1.0	1.6	Goldsmith, Smith, and Sutton[2]	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
8	3.1	5.0	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one-man beach profile technique
			Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
9	1.7	2.7	New profile line		
10	1.3	2.1	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one-man beach profile technique
			Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
11	0.5	0.8	Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
12	0.8	1.3	Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery

[1]Average of 2.5 kilometers between each profile line.

[2]Total of 42.2 kilometers between profile lines 1 and 18.

Table 1. Beach profile history.--continued

Profile line[1]	Distance to next profile line[1] (mi)	Distance to next profile line[1] (km)	Previous investigators	Dates sampled	Survey technique
13	0.5	0.8	Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
14	1.6	2.6	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one-man beach profile technique
			Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
15	2.9	4.7	Goldsmith, Smith, and Sutton (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
16	1.3	2.1	Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one-man beach profile technique
			Goldsmith[1]	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
17	1.5	2.4	Shideler, Swift, and McHone (1971)	Oct. 1970 to Oct. 1971	Tape and level
			Goldsmith (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery
18			Bullock (1971)	Monthly July 1969 to Mar. 1971	Schwartz one-man beach profile technique
			Goldsmith (1974)	Bimonthly (approx.) Sept. 1972 to Jan. 1974	Emery

[1]Average of 2.5 kilometers between each profile line.

[2]Total of 42.2 kilometers between profile lines 1 and 18.

this study, monthly, weekly, and daily changes were monitored at four locations in Virginia Beach and one at Camp Pendleton. These profile lines were measured intermittently between November 1956 and May 1963. The maximum vertical change at the 61st Street profile line, observed during this 27-month period, was 2.0 meters and occurred midway between mean sea level and mean high water. Approximately one-half of the dune was lost during the storm of 7 to 8 March 1962. With respect to the profile lines at 15th and 3d Streets, the data "... do not show convincing differences between winter and summer profiles" (Harrison and Wagner, 1964, p. 27). Poststorm changes measured on both the beach and nearshore area out to depths of 5 meters indicated "... that under great storm conditions the foreshore slope and beach ridge will undergo greater change than the nearshore bottom" (Harrison and Wagner, 1964, p. 9). The precise locations of these beach profile lines have been reoccupied. Additional studies were conducted at Fort Story, north of Virginia Beach, by Harrison, et al. (1968), in which more than a dozen environmental variables were measured over a 28-day period. No discussions or conclusions were mentioned. The importance of the beach water table response to tidal fluctuations in the Fort Story area was investigated by Fausak (1970). He found that the water table fluctuations decreased about 60 meters from the beach. Studies of the beach water table at Camp Pendleton in 1966, and at Fort Story in 1969, are reported in Harrison, et al. (1971). Multiregression analysis of the data show that the most important variables influencing changes in quantity of foreshore sand (in decreasing order of importance) were changes in ocean stillwater level, an index of groundwater head, and the number of swash events per unit of time (Harrison, et al., 1971, p. 43). Fausak's Fort Story beach profile line, which was monitored in August and September 1969, was reoccupied in September 1972.

A detailed study of beach changes along the outer coast of Virginia was reported in Bullock (1971) and Harrison and Bullock (1972). In this study, 16 beach locations were surveyed between the Virginia-Maryland and the Virginia-North Carolina State lines for 20 months. These data were then used to calibrate a model which attempted to forecast changes in beach sand volume resulting from storm conditions. "The results indicated that it may be possible to develop prediction equations to forecast beach changes for sections of ocean beach that do not exhibit complex offshore bathymetry" (Bullock, 1971, p. 61) and that initial beach volume was a strong determinant of beach volume change. Six out of seven of these beach profile lines in the Virginia Beach coastal compartment were precisely located and remeasured at bimonthly intervals between September 1972 and January 1974, by Goldsmith, Smith, and Sutton (1974). Numerous studies of the False Cape area, including beach survey measurements, have been conducted by Shideler, Swift, and McHone (1971). Three out of four of these beach profile lines, going back to 1969, were reoccupied in September 1972 by

Virginia Institute of Marine Science (VIMS) and Old Dominion University (ODU) personnel, and by Goldsmith, Smith, and Sutton (1974), at bimonthly intervals, through January 1974. Copies of all the above previous beach profile data are stored at VIMS.

Beach changes were monitored once a month (since 1966) at 1,000-foot (305 meters) intervals between 49th Street and Rudee Inlet by an engineering firm under contract to the City of Virginia Beach and the U.S. Army Engineer District, Norfolk. Each June these profile lines are extended out to depths of 25 feet (8 meters) (H.J. Fine, Chief, Water Resources Planning Branch, U.S. Army Engineer District, Norfolk, personal communication, 1972). This 4-kilometer stretch of shoreline includes the major zone of public concern about beach erosion, but less than 10 percent of the total ocean shoreline of southeastern Virginia.

A beach survey network consisting of 13 beach survey locations over a 24-kilometer stretch of coast between Rudee Inlet and the Virginia-North Carolina border was set up in the summer of 1972. These profile lines were surveyed at bimonthly intervals with the cooperation and assistance of the personnel of the Back Bay National Wildlife Refuge, U.S. Fish and Wildlife Service, and graduate student volunteers at VIMS. This survey network consisted of three older profile lines of Shideler, Swift, McHone (1971), the five profile lines of the Back Bay National Wildlife Refuge personnel, and five profile lines of Bullock (1971).

2. Purposes of This Study.

The previous studies indicate large variations in beach response at these different profile lines from both storms and daily low wave energy-type processes. Thus, the primary objective of this study was to investigate beach behavior by measuring beach profile changes for 27 months over a 45-kilometer stretch of coastline containing a variety of beach types and an irregular offshore bathymetry. Included in this study is a comprehensive report on beach changes along this coast and a collection of data in uniform format that will be available for future engineering studies. The data from these analyses are summarized in the form of graphs and included in Appendixes B and C. The data were analyzed to obtain the information on the following general topics discussed in this report:

(a) Changes at each profile line from monthly and poststorm survey data.

(b) Long-term changes at each survey location from data from earlier studies and monthly surveys during this study.

(c) Character of beach behavior in the study area from ground and aerial reconnaissance and survey data.

(d) Character of beach behavior in Currituck County, North Carolina from quarterly ground reconnaissance.

(e) Wave climate in study area from visual wave observations.

(f) Comparison of long- and short-term wave and beach conditions from survey data and visual wave data.

(g) Comparison of beach response in natural, residential, military, and commercial use areas from survey data.

Special attention was paid to the variations in cultural usage and to the location of the focus of longshore transport reversal as possible causes of the differing beach response. Although this 1974-76 interval was a time of relatively low storm-induced beach erosion (discussed in Section IV), there were storm events of sufficient intensity (App. D) as to clearly delineate differing erosional responses between survey locations. The interpretation of these variations is assisted by concomitant shoreline wave observations, and ground and aerial photos. Probably the most important purpose is to relate the VIMS-CERC profile lines (1974-76) to the older survey data in order to delineate the long-term trends (by surveying standards) of between 4 and 18 years at 14 of these locations (App. C) since such lengthy survey histories are relatively rare in the United States. Further, the application of standard statistics to test and delineate these beach trends is illustrated.

3. <u>Engineering and Scientific Usefulness</u>.

The two most immediate applications of these data and analyses are to furnish the Norfolk District with basic information that extends aerially beyond the Virginia Beach area undergoing extensive sand nourishment, and to furnish CERC with "base-line" data for future studies on the processes in the immediate vicinity of the nearly completed CERC Field Research Facility, Duck, North Carolina. For example, documentation of beach changes to either side of the Virginia Beach commercial beaches would aid in the planning of projects involving the pumping of sand from the south side of Rudee Inlet onto the commercial beaches. With respect to the CERC Field Research Facility, documentation of characteristics and changes on the beaches north of the pier, as well as data illustrating the importance of seasonal versus storm-dependent changes in the immediate vicinity, should materially aid the design and timing of experimental studies at the pier site.

If significantly different long-term trends on adjacent natural beaches are shown, then the need for detailed site-specific studies before the instigation of remedial measures would be further emphasized. If these variations in beach behavior are shown to be related to beach usage (commercial, residential, military, or natural), then additional information can be involved in the coastal zone planning process that would add to improved results. Specifically, use zoning could be considered for the more erosional beaches. The Back Bay National Wildlife Refuge and False Cape State Park are currently reevaluating their roles with respect to future services to the recreational public, and are requiring this base-line information on shoreline trends for their planning. Since Back Bay may tend to have narrow erosional beaches, documentation of these and future trends is of great interest to the Back Bay planners (D. Hollands, manager, personal communication, 1974) with respect to vehicular access, dune fencing programs, and others.

An important application, unrelated to this study, involves the comparison of the long-term beach trends and specific storm-induced profile changes with computed wave data from the Virginian Sea Wave Climate Model (Goldsmith, et al., 1974b; Goldsmith, 1975c) to further refine the model and extend its usefulness.

However, the main thrust of this report is to provide base-line, interpreted data for the large variety of Federal, State, and local agencies involved in the planning and management of this 42-kilometer-long coastal area, varying widely in usage and beach behavior.

II. LOCALITY

1. Geography.

The nomenclature "southeast Virginia coastal compartment," defined here as the concave-seaward stretch of coast between Cape Henry and the Virginia-North Carolina State line, is unique to this investigator, but is not arbitrary usage. Historically, the northern limit of the Outer Banks was at Old Currituck Inlet near the Virginia-North Carolina State line. The inlet has been closed since about 1829. From a coastal processes point of view, it is best to consider the stretch of coast between Cape Henry and Cape Hatteras (encompassing the study area) as a classic coastal spit-barrier island complex, with Cape Henry being the headland, and the net annual transport to the south (Fisher, 1967). The northern two-thirds of this coast (with

Oregon Inlet being the southern boundary) is a long, continuous spit called Currituck Spit. This spit may be subdivided into two long concave-seaward parts of coast, separated by a convex-seaward bulge called False Cape. The northern concave-seaward stretch of coast from False Cape to Cape Henry is the beach profile study area, and the northern portion of the southern concave-seaward coast is the Currituck County quarterly reconnaissance study area.

The beach survey study area, which includes the 18 profile line locations, encompasses 42 kilometers of coast in Virginia from Cape Henry to the Virginia-North Carolina State line (Fig. 2). Profile line 1 is located at Fort Story, a U.S. Army transportation training center with amphibious vehicles frequently on the beach. Profile lines 2 to 5 are in Virginia Beach, a densely populated (especially during the summer months) residential (above 40th Street and south of Rudee Inlet) and commercial area. Profile lines 6, 7, and 8 are located in Dam Neck, at the U.S. Naval Anti-Air Warfare Training Center. Profile lines 9 and 10 are in Sandbridge, a residential area which has a significantly higher population during the summer months. Back Bay National Wildlife Refuge is the location of Profile lines 11 to 15. The southernmost profile lines 16, 17, and 18 are located in False Cape State Park.

In a broad sense the study area consists of two basic beach morphologic types: wide beaches which may be very active, either accreting or eroding from 1 month to the next; and fairly narrow beaches with little overall accretion or erosion. The wider beaches have lower slope gradients than the narrower beaches. Generally, the narrower beaches tend to show more extensive changes after storms and are usually slower to recover from storm effects. Profile lines 1 and 14 to 18 are generally wide and flat; profile lines 3 to 12 tend to be narrow and steep, although there are several exceptions. All 629 surveys are notable by a complete absence of classic ridge and runnel activity.

Table 2 gives a complete description of the study area from the "Shore Protection Guidelines," (U.S. Army, Corps of Engineers, 1971b). Names mentioned in Table 2 can be found in Figures 1 and 2. The information is reorganized in the table by reaches and subjects; these reaches are related to population zonation of the coast and not to geological aspects.

2. Geomorphology.

The physiography and geology, both immediately underlying the study area and at the surface to the west, are directly related to

Table 2. Description of study area.

Reach	VIMS-CERC profile lines	Physical characteristics	Shore ownership	Shore use and development	Shore history
Willoughby Spit to Cape Henry	None	Characterized by an irregular dune line with a beach width varying from 100 to 125 feet at an average elevation of about 5 feet mean sea level (MSL). The dune elevation is generally about 12 feet MSL.	Encompasses two military reservations--Little Creek Amphibious Base and Fort Story, the Seashore State Park, and the commercial beach of Ocean View. Of the shoreline composing Ocean View, 4 miles are owned privately and 5 miles publicly.	Used extensively for public and private recreation. Several miles of nonrecreational shoreline are devoted to the Little Creek Amphibious Base. Segments of this reach near the western tip have, of necessity, been stabilized with timber groins.	West of Cape Henry to Little Creek, the shoreline has shown alternate periods of erosion and accretion with the overall trend being one of gradual accretion. Between 1891 and 1916 the 4.8-mile section of shoreline between Lynnhaven Inlet and Little Creek eroded at an average rate of 12 feet per year. Since then, the overall trend has been one of gradual accretion. Based on complete shoreline surveys of the 4.9-mile reach between the lighthouse and Lynnhaven Inlet, made in 1962, and the 4.8 miles of beach between Lynnhaven Inlet and Little Creek, made in 1946, the average annual rate of accretion was 1.98 cubic feet, which is equivalent to slightly more than 100,000 cubic yards per year. The 11-mile segment of shoreline from Little Creek Inlet to Willoughby Spit has been relatively static to change in recent years. Erosion has removed material from this reach during storm periods, but natural return has usually occurred. Transport west of Cape Henry to Willoughby Spit is westerly. Rates in this zone are moderate to small. No information on transport west of Willoughby is available.
Cape Henry to 49th Street	1 2	Characterized by an irregular dune line.	The 2.7-mile segment between 49th Street and 89th Street, known as North Virginia Beach, is centered about 3 miles south of Cape Henry and is publicly owned. Fort Story extends along the Atlantic Ocean for about 1.1 miles from 89th Street to a point opposite Cape Henry Lighthouse which is the south point of Chesapeake Bay.	The stretch of shore north of Rudee Inlet to Fort Story is publicly used for recreational purposes. In 1970, the annual visitation at the Virginia Beach commercial areas was 4,320,000 persons. Development is residential and commercial.	Material placed to rebuild the Atlantic Ocean shoreline at Sandbridge, Virginia Beach proper, and North Virginia Beach after the 6-8 March 1962 storm has continued to erode at rates comparable to those experienced historically. Except for a few segments of beach accreting, there has been a general recession of the entire shoreline. Based on the latest complete survey of 1968 for the segment from the State line to the Cape Henry Lighthouse, the 27.0 miles of beach front along the Atlantic Ocean was undergoing an average annual rate of erosion of 0.72 cubic foot, which is equivalent to approximately 100,000 cubic yards per year.

Table 2. Description of study area.--continued

Reach	VIMS-CERC profile lines	Physical characteristics	Shore ownership	Shore use and development	Shore history
49th Street to Rudee Inlet	3 4	From Rudee Inlet to Cape Henry, a distance of 7 miles, is a flat, unstable sandy beach, 100 to 200 feet wide and averaging 5 feet MSL in elevation. The 3.3 miles of shoreline between 49th Street and Rudee Inlet is devoid of dunes.	The 3.3 miles of beach between 49th Street and Rudee Inlet is publicly owned and constitutes the most significant ocean front area of Virginia Beach, in terms of mass recreational use and commercial development.	The segment of shore north of Rudee Inlet to Fort Story is publicly used for recreational purposes. Two piers and a boardwalk have been constructed for public use. In 1970, the annual visitation at the Virginia Beach commercial areas was 4,320,000 persons. Development is residential and commercial. This segment of beach is visited annually by more tourists than any commercial beach in Virginia.	See Cape Henry to 49th Street Shore History.

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Table 2. Description of study area.--continued

Reach	VIMS-CERC profile lines	Physical characteristics	Shore ownership	Shore use and development	Shore history
Rudee Inlet to Dam Neck/Sandbridge Boundary	5, 6, 7, 8	The beach narrows and is separated from the mainland by low dunes. Beach grasses have been planted along sections of this segment in an attempt to stabilize the sands.	Largely occupied by the Fleet Combat Direction Systems Training Center Atlantic at Dam Neck. A segment of publicly owned beach does, however, exist immediately south of Rudee Inlet.	Development is primarily military.	See Cape Henry to 49th Street Shore History.
Dam Neck/Sandbridge Boundary to North Carolina line	9, 10, 11, 12, 13, 14, 15, 16, 17, 18	Narrow undeveloped barrier strip of land with a sandy beach facing the Atlantic Ocean on one side and several bays on the other extends a distance of 9 miles before approaching the rapidly developing commercial area of Sandbridge Beach. This relatively undisturbed segment varies in width from 0.25 to 1.5 miles and is frequently breached by both sound and ocean waters during storm periods. Access to this area is limited to vehicles capable of traveling on sand since no paved roads exist.	The 12 miles of beach is divided among Federal, public, and private interests. Sandbridge Beach, a segment of 3 miles, is publicly owned.	The shoreline south of Sandbridge is generally undeveloped and publicly used for recreation. The Back Bay National Wildlife Refuge and the Little Island Municipal Park are located in this segment. Sandbridge Beach is privately used for recreational purposes and developed for summer residence. Summer residential development south of Sandbridge is expected to continue. Some additional development as parks and conservation areas is likely.	Observations indicate that south of False Cape, an area approximately 25 miles south of Cape Henry, the transport is southerly. North of False Cape, the transport has a net northerly component. The rate and volume of transport in this zone are relatively large.

(from U.S. Army, Corps of Engineers, 1971b) the six or more Pliocene(?) and Pleistocene cycles of emergence and submergence, with maximum submergent sea levels near +45 feet (14 meters) (Oaks and Coch, 1973). The Sandbridge Formation, youngest Pleistocene (Oaks and Coch, 1973), was observed by the authors after storms in the intertidal zone at 44th Street, Virginia Beach. Other aspects of coastal plain geology are discussed by Sanford (1912), Wentworth (1930), Cederstrom (1941), Richards (1950), and the early literature is summarized by Ruhle (1965). Harrison, et al. (1965) presents evidence for a late Pleistocene uplift in the area. Pleistocene sea level changes are discussed by Milliman and Emery (1968) and Oaks and Coch (1963). Holocene geomorphology and stratigraphy at the Chesapeake Bay entrance are detailed by Meisburger (1972) and Nelson (1972), who discussed the relationships between the ancestral Pleistocene Susquehanna River and the present baymouth configuration. Meisburger (1972) indicates that the present gross bottom morphology in the bay entrance is largely due to Holocene sedimentation (estimated at 1.37 X 10^9 cubic meters) and bears little relation to the buried Pleistocene topography.

The Holocene evolution of a part of the Hatteras barrier island chain has been discussed by Pierce and Colquhoun (1970a, 1970b). Based on subsurface core information from Duck to Cape Lookout, North Carolina, they suggest that this present barrier complex has evolved from a combination of primary barrier landward retreat and the development of secondary barriers by spit elongation. White (1966) has suggested that these capes formed initially from Pleistocene river deltas.

A definitive wave climate study summarizing the shelf geomorphology of the Chesapeake Bight part of the Virginian Sea (i.e., Cape Henry to Cape Hatteras) and the complex relationships between the shelf geomorphology and the ocean surface wave climate over the shelf and along the shoreline, is presented in Goldsmith, Farrell, and Goldsmith (1974a).

This latter study clearly showed the important influence of the Virginia Beach Massif (Figs. 3 and 4) on the wave climate of the southeast Virginia coastal compartment. The Virginia Beach Massif is an extensive, shallow, relatively level-topped topographic high, between the depth contours of 18.3 and 21.9 meters and occurs between the relic Susquehanna Valley and the Virginia Beach Valley. (The term "massif" was applied to this feature by Swift, et al., (1972) because the original subaerial mountain massifs in France are also flanked by river valleys.) This imposing large-scale relic feature, of hypothesized interfluve origin, contains a superimposed irregular ridge and swale bathymetry, which is delineated by the depth contour of 18.3 meters. The Virginia Beach Valley, flanked to the northeast by the Virginia Beach ridges on the topographic high and to the southeast by the False Cape ridges, is suggestive of a series of relic ebb tidal deltas formed as the sea level

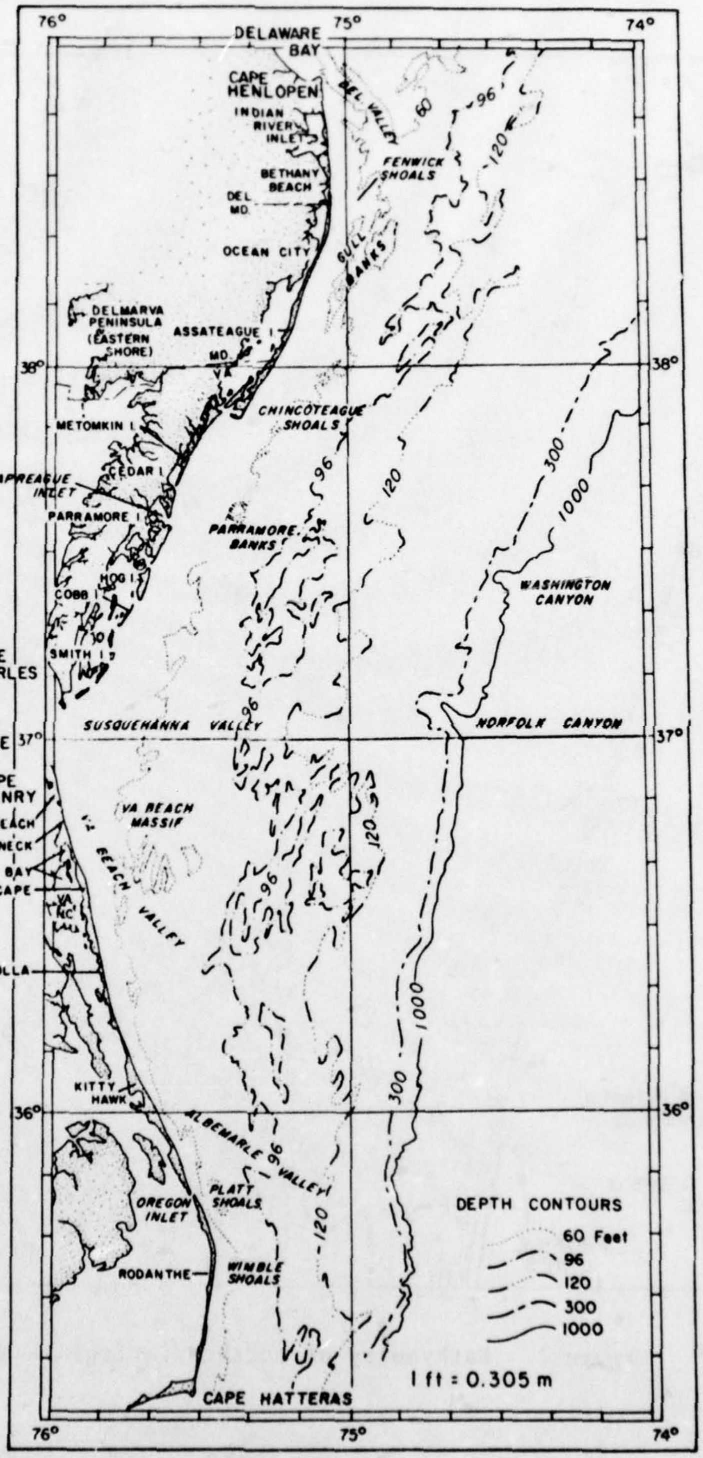


Figure 3. Bathymetry of the Virginian Sea.

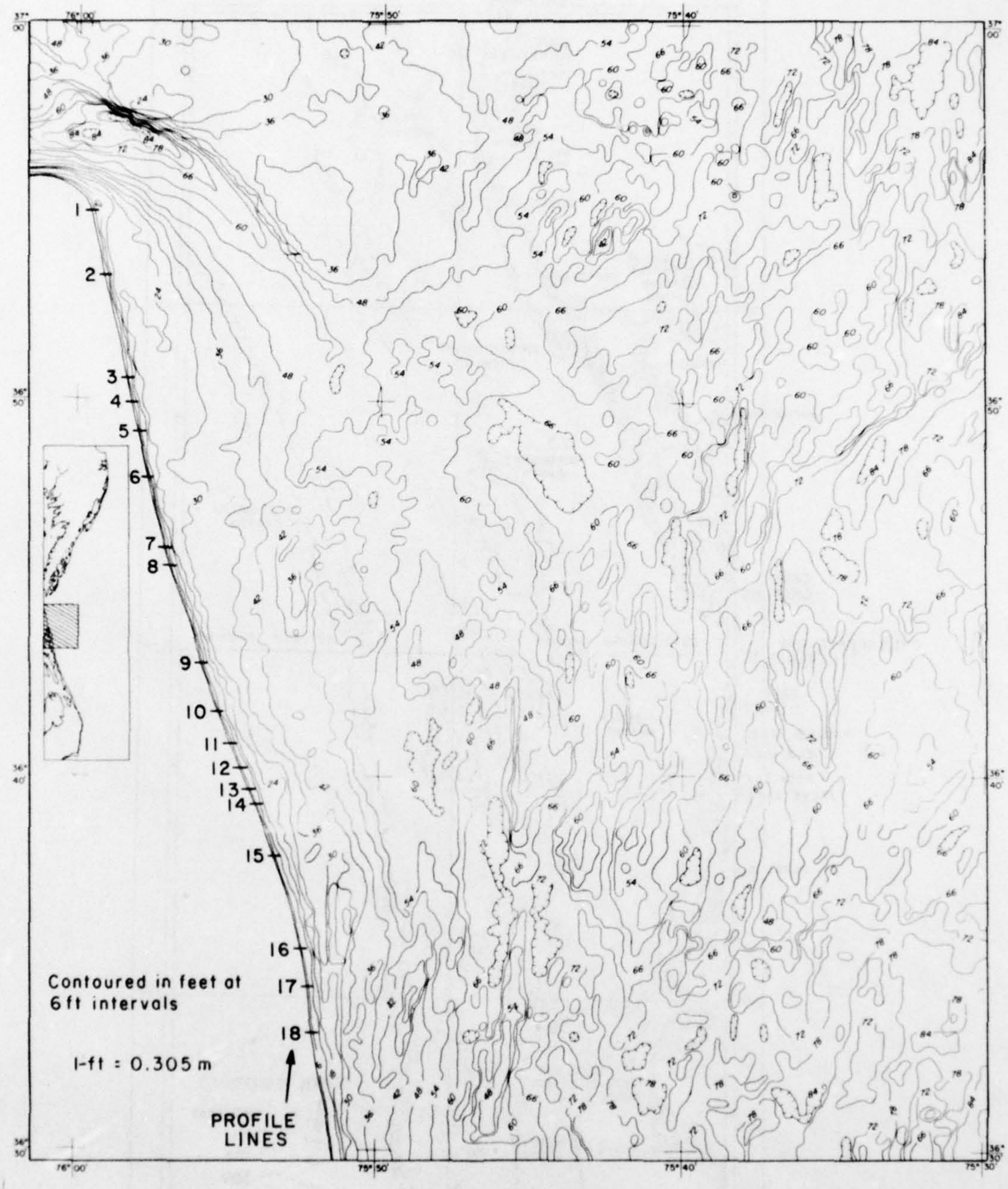


Figure 4. Bathymetry of southeast Virginia shelf.

rose and the estuary mouth retreated, as hypothesized by Swift, et al. (1972).

Goldsmith, Farrell, and Goldsmith (1974a) state that:

"An example of the effects of these offshore shoal areas on nearshore circulation patterns can be seen in the vicinity of Virginia Beach, Virginia, which is greatly affected by the adjacent, extensive Virginia Beach Massif. Here, the waves with periods of 10 seconds or shorter from the north-northeast, northeast, and east-northeast are, for the most part, refracted away from the resort area by the Virginia Beach Massif to the Chesapeake Bay entrance and the Back Bay-False Cape area. In a similar manner, waves from the east-southeast, southeast, and south-southeast are concentrated in the Virginia Beach and adjacent offshore area. These phenomena result in the dominant northward longshore transport observed in the Virginia Beach area; this might be because greater wave energy reaches the area from the southern quadrants than from the north, resulting in a net nearshore sediment transport to the north. Harrison, et al., 1964 suggested that the observed northward sediment transport in the Virginia Beach area was due to a large nontidal eddy related to the circulation originating at the mouth of the Chesapeake Bay. It should therefore be noted that both effects may be occurring and that neither the wave or current-induced circulation patterns are mutually exclusive."

The most significant nearshore features along the middle Atlantic Bight are the nearshore, shoreline-attached, linear ridge systems, shown in Goldsmith, Sutton, and Davis (1973) (Fig. 3), and discussed in Swift, et al. (1972). One of the most notable and most studied ridge systems is the False Cape ridge system consisting of three large linear ridges attached to the shoreline in False Cape State Park. McHone (1972) pointed out the process interaction between the beach and the nearshore morphology via the development and removal of "saddles" across the False Cape ridge system. Unpublished profile data collected separately by Swift, Shideler, McHone, and Goldsmith indicate that the False Cape ridge system has an important influence on the behavior of the adjacent beaches. Further discussions on the nearshore geomorphology are in Goldsmith, et al. (1974b) and Goldsmith (1975c).

3. Sediments.

Beach sedimentological studies of the Outer Banks have been made by Swift, et al. (1971), Swift, Dill and McHone (1971), Shideler (1973a, 1973b, 1973c, 1974), and Sabet (1973). These studies, which show that the interpretation of coastal processes from grain size and mineralogical data in this area is a very complex problem, are summarized in

Figure 5. *In general, the sand composing the beach and dunes south of* Rudee Inlet is relatively uniform with mean (phi) ≈ 1.0 to 2.0 (0.5 to 0.25 millimeter); standard deviation ≈ 0.8 (0.6 millimeter) along the berm and 0.5 (0.7 millimeter) in the dunes (Shideler, 1973b). The major exception is the addition of a coarse red (2 to 1.0 phi), iron-stained quartz and feldspar sand component. The northern limit of this coarse red sand varies dramatically between Corolla and Duck (discussed in Section V). This area is referred to locally as the "area of treacherous red sands" because of its adverse affect on four-wheel drive vehicles traveling the beach.

The sand behavior of Virginia Beach has been studied by Harrison and Alamo (1964), who tabulated the settling velocities of sand in the vicinity of Rudee Inlet, and by Tuck (1969). Tuck suggested that a reversal in the slope grain-size relationship occurs under storm conditions on the beach coincident with profile changes, and that such a reversal is generally present in the "zone of shoaling waves" part of the beach at Virginia Beach. The slope grain-size relationship referred to here is the increase in beach slope with increase in grain size. As noted by Tuck (1969) and discussed in Sections V, 5 and VII, 3 of this report, there are many exceptions to this relationship.

Mineralogical data between Cape Henry and Cape Hatteras are detailed by Swift, et al. (1971), who indicate very complex relationships.

4. Beach Usage and Impact.

The study area encompasses four categories as defined by beach usage: Natural, military, commercial, and residential. Profile lines 1 (Fort Story), 6, 7, and 8 (Dam Neck) are military. The beach at Fort Story is probably the most disturbed (of the four profile lines) as far as vehicular traffic is concerned. Amphibious vehicles are driven in the waters just off the beach, followed by landing maneuvers on the beach itself. In addition, a road grader was used at times to keep the beach, from the base of the dune seaward, as flat and smooth as possible. All these events have occurred directly at Profile line 1. There is less vehicular beach traffic on the beaches at Dam Neck, although amphibious vehicles have been observed on occasion. The Marines conduct drill exercises on the lower beach, but avoid the dunes. There is a recognition of the importance of dunes at Dam Neck as indicated by an extensive and active sand fencing program and an effort to keep everyone out of the dunes.

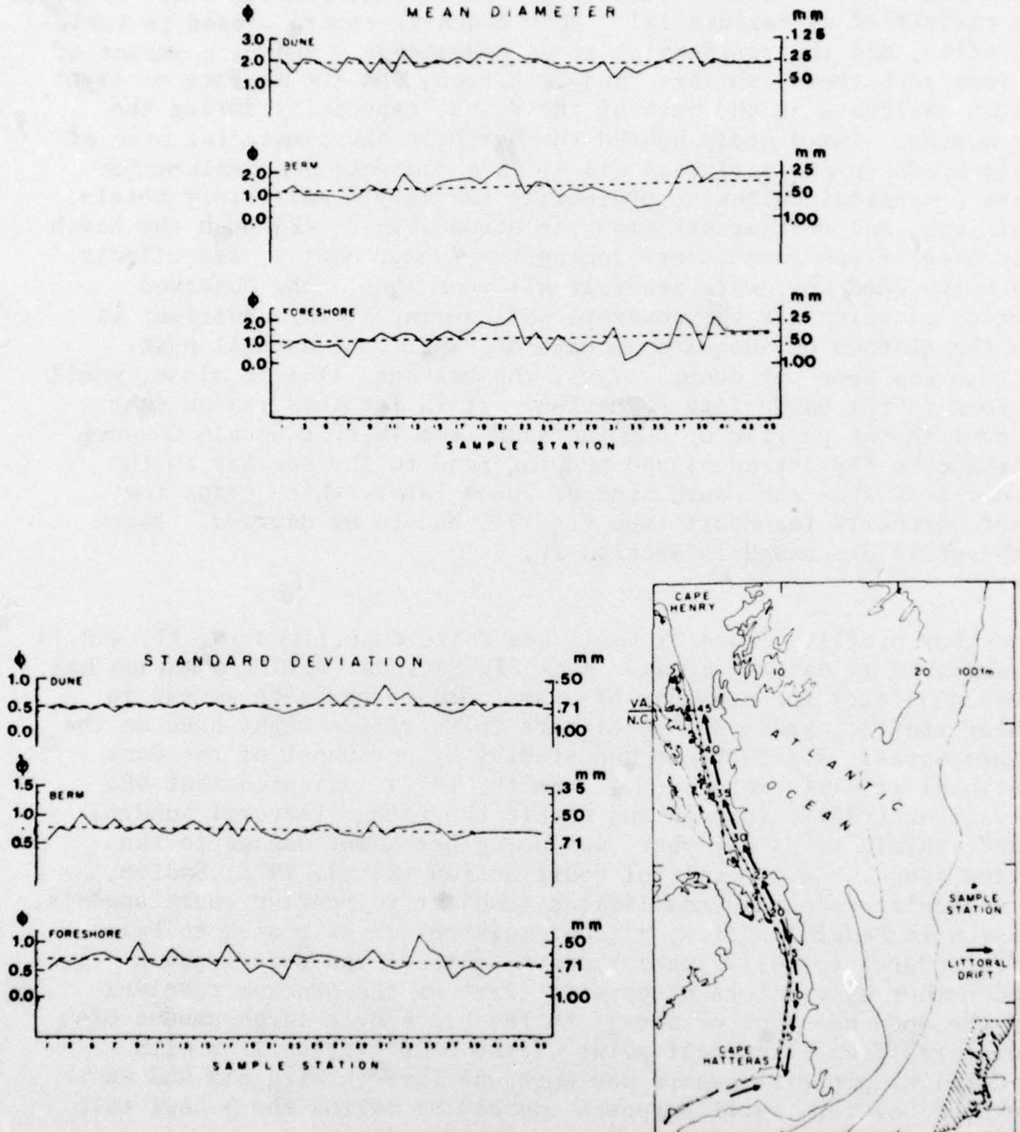


Figure 5. Grain-size data, Cape Henry to Cape Hatteras, and longshore transport direction (arrows) hypothesized by Shideler (1973b).

Virginia Beach Profile lines 3 and 4 may be classified as commercial, Virginia Beach profile lines 2 and 5 and Sandbridge profile lines 9 and 10 may be classified as residential. Both beach areas are closed to vehicular traffic, and the residential areas experience a moderate amount of usage from sunbathers, surfers, and fishermen, and the storage of light catamaran sailboats at the base of the dunes, especially during the summer months. Immediately behind the beach in the commercial area of Virginia Beach (profile lines 3 and 4) is a concrete boardwalk which contains a vertical bulkhead, protecting the city's multistory hotels, condominiums, and restaurants from the ocean waves. Although the beach is only used by sun-worshippers during the summer months, the effects of the bulkheaded boardwalk are felt all year long. The observed reflection of waves off the concrete wall during storm conditions is due to the absence of adequate amounts of sand. The natural post-storm recovery does not occur. Thus, the beaches, if left alone, would erode down to the Sandbridge Formation. It is for this reason that a beach nourishment program of dumping sand from Thimble Shoals Channel (in Chesapeake Bay entrance) and pumping sand to the beaches to the north directly from the south side of Rudee Inlet, which traps the dominant northerly transport (see Fig. 2), had to be devised. Beach nourishment is discussed in Section IV, 7.

Back Bay profiles lines 11 to 15 and False Cape lines 16, 17, and 18 are designated as natural areas. Back Bay National Wildlife Refuge has received publicity for a number of years concerning beach access to vehicular traffic, and possible effects this traffic might have on the beach processes. Observations and studies by personnel of the Back Bay National Wildlife Refuge (e.g., Smith, 1972) indicated that the heavy visitor traffic through and within the refuge (several hundred thousand vehicle trips per year) was doing permanent damage to the flora and fauna. As a result of court action (Baird, 1973; Smolen, 1973) vehicular access is now limited (subject to pending court appeals, a revision in Federal policy, or contemplated access routes to False Cape State Park) to full-time residents south of the refuge and a limited number of visitors by permit. Part of the problem revolves around the open question of damage to the beach by a large amount of vehicular traffic. The focal point of the court action lies with North Carolina property owners who work and live in Virginia and want to use Back Bay for travel purposes instead of making the 3-hour trip (161 kilometers) through Kitty Hawk, North Carolina.

False Cape State Park is open to vehicular traffic, but because of limited access to Back Bay, traffic here is not as heavy as it could be. Access to False Cape State Park, located between the Back Bay National Wildlife Refuge and the Virginia-North Carolina State line (Fig. 2), is presently limited to four-wheel drive vehicles passing along the beach and back dune areas and is subject to the limitations discussed previously. A study of various proposed access routes by Zeigler and Marcellus (1972) concluded that all proposed hard-surfaced automobile routes would ultimately cause permanent damage to the area and that the only acceptable access to False Cape State Park would be: (a) A monorail or rapid transit system, or (b) a ferry crossing from Knotts Island, North Carolina, across Back Bay to the bay side of Currituck Spit at False Cape Landing. State-sponsored studies of this problem are continuing (Division of Parks, 1975) and decisions are expected in the next 2 years.

During each survey, a bird census was taken of both numbers of species and numbers of individuals. It was observed that where human population was densest and beach usage was most intensified, the bird population was lower, and conversely, bird populations were highest in natural, restricted areas of Back Bay National Wildlife Refuge and False Cape State Park where human activity was minimal (Fig. 6 and App. E).

The same was true for ghost crabs (Smith, 1972). None was observed in areas experiencing a great deal of vehicular traffic, but they have been observed in Back Bay and False Cape, with a notable increase in numbers after vehicular access was severely curtailed in 1973 (F. Smith, Wildlife Biologist, Back Bay National Wildlife Refuge, personal communication, 1974). Few ghost crabs were observed north of Sandbridge.

III. METHODS

1. Beach Surveys.

The 18 profile lines were surveyed once each month for 27 months and after eight storms or periods of high waves (some storms did not bring high waves to Virginia Beach, as discussed in Sec. V, 2). Vertical distances were measured with a Dietzgen automatic level and a telescoping fiberglass leveling rod graduated to 0.01 foot (0.003 meter). Horizontal distances were measured with a fiberglass-polyester woven tape graduated to 0.05 foot (0.015 meter).

Each profile line was measured from the top of the most seaward of three pipes (pipe 1) taking vertical and horizontal readings at all significant breaks in slope, to as far seaward of mean sea level as possible under the existing wave climate. Scarps, berms, last high tide lines, and the waterline (or swash zones) were points also measured and specifically noted on the specially designed VIMS Beach Survey form (App. F) along with other pertinent data gathered at the survey locations. The advantage of this form is that it can be

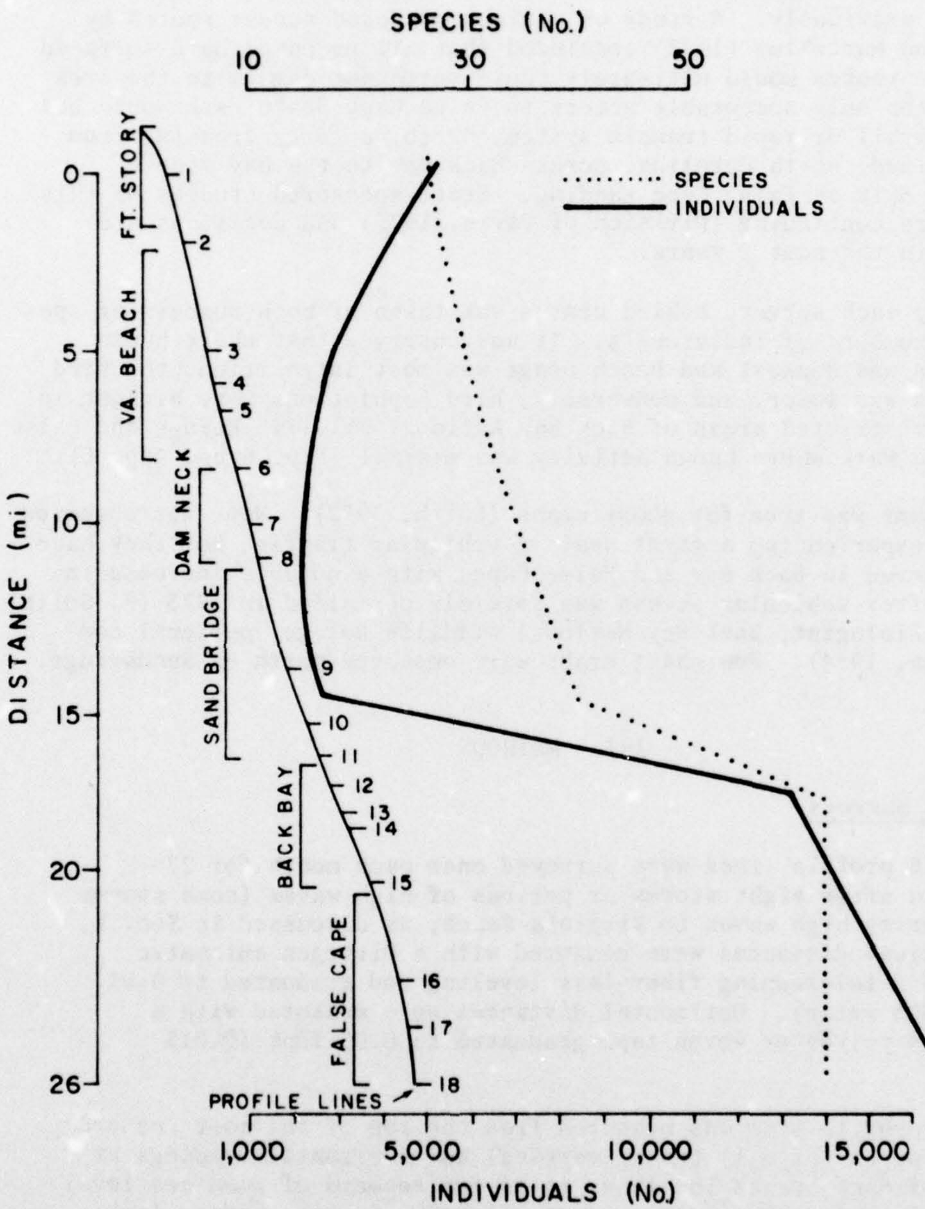


Figure 6. Bird census data, October 1974 to February 1976.

handed directly to the keypuncher at the VIMS Computer Center for data processing.

2. Surveyed Bench Marks.

Three 0.5-inch (1.3 centimeters) galvanized iron pipes, 4 to 5 feet (1.2 to 1.5 meters) long, were driven approximately 3 to 4 feet (0.9 to 1.2 meters) into the dune area at each of the 18 survey locations, except profile line 3 at Virginia Beach where the east face of the concrete seawall was used in place of a pipe.

Pipe 1, generally placed on the most seaward dune where there was an unobstructed view of the profile line to the sea, was then used as the reference point at each of the profile lines. Pipe 2 was usually placed on the adjacent dune ridge landward to pipe 1. This pipe was surveyed into various local landmarks (i.e., houses, power poles, and other stakes) by magnetic bearing and distance at the beginning of the study. Pipe 3 was placed near the edge of heavy dune vegetation, or other area well back from the traveled section of dunes and beach, and concealed from public view. The three pipes formed a straight line oriented perpendicular, or nearly so, to the existing shoreline.

All three pipes at each profile location were surveyed to third-order accuracy by Freeman and Johnson, Engineers and Surveyors, of Virginia Beach, Virginia, in April 1976 (App. G). All elevations are measured from the top of each pipe to MSL. The elevations for the most seaward pipes range from 7.45 to 22.24 feet (2.27 to 6.78 meters) above MSL. The distances from these pipes to the waterline range from 30 to 130 meters. Some distances have been shorter or longer due either to storm high tides, or extreme low tides.

3. Wave Observers.

As part of this study, volunteers were recruited to make daily observations of wave data at one of the 10 observation sites. The volunteer's estimates of the wave period, the breaker height, the wave angle at the breaker, and the breaker type were recorded on a wave observation report form made specifically for this study. Wave period was measured using a stopwatch, from which the observer read the time elapsed during the passage of 11 wave crests past a fixed point. Breaker types were categorized as either spilling, plunging, surging, spilling-plunging, or collapsing. Breaker heights were estimated visually to the nearest one-half foot, and the number recorded was the average of the highest one-third of the breakers. The angle a breaker made with the shoreline was measured to the nearest degree with a protractor furnished on the back of the observation form.

The volunteer observer program was only partly successful. Observers were recruited through newspaper advertisements, telephone calls, and invitations to onlookers who expressed interest during the surveys. U.S. Naval officers, hotel personnel, charter boat captains, housewives, and schoolteachers were among those who volunteered to become wave observers.

Observations were made over a period of 29 months between July 1974 and November 1976. A complete outline of wave observer history is in Appendix H; seasonal averages of wave observations for each site are in Section VI.

Visual wave observations at the 18 profile lines were also made by the authors on most of their monthly and poststorm surveying trips. The resulting data were punched on cards and mean wave heights, periods, and standard deviations were plotted at VIMS. These data are also discussed in Section VI.

4. Data Processing.

Raw survey data (distance and height) were taken in the field on specially designed computer keypunch forms (App. F-I). The data were punched directly from these forms onto cards at VIMS and processed in a computer program that generated data which was then transcribed onto CERC Form No. 121-72. Another set of VIMS punched cards was run in a second program called COMPARE. The COMPARE program literally compared each survey with the survey measured at the same location from the previous month, and gave the beach change (either erosional or accretional) as the cumulative volume (cubic meters of sand/linear meter of beach) (Colonell and Goldsmith, 1972; Goldsmith, Colonell, and Turbide, 1972).

CERC similarly processed the beach volume changes from their forms, and the computational results were similar. However, CERC's computations are presented and used throughout this report (App. B) to promote uniformity with other CERC studies. The VIMS area computations are used in the long-term trend analyses (App. C) because of uniformity with the VIMS profile data bank.

For both the CERC and VIMS computations, erosion was defined as a negative net volume change, and accretion as a positive net volume change, for the area surveyed along the profile line. The profile line extended from the MSL datum determined by the surveyors, landward to an arbitrary point at, or equivalent to, the crest of the foredune ridge (i.e., the number one pipe). Thus, this net volume change may represent the algebraic sum of erosion in one part of the profile line and accretion on another part, as it often does. Only in three poststorm, high surf, and high surge conditions (1 July 1975, 25 November 1975, and 10 April 1976) did a few of the surveys not extended seaward all the way to the MSL datum, although they were quite close. However, because of the location on the profile line and the extent of the beach volume changes, discussed in detail in Section V, these slightly shortened surveys did not influence the volume computations to any great degree, nor the comparison of changes between profile lines, nor the conclusions.

5. Comparison of VIMS-CERC Surveys With Older Profile Data.

This was accomplished by finding and using in the new surveys, the exact profile pipes that were used in the older surveys (locations 8, 10, 12, 13, 14, 15, 16, 17, and 18) and using detailed descriptions in the literature, field visits, informal correspondence with the previous investigators and photographs (locations 1, 2, 3, 4, and 5). The stakes at survey locations 7 and 11, which had been surveyed by Goldsmith in 1972 to 1974, had been removed, so only their approximate location (approximately 1 meter horizontally) could be reoccupied and therefore, comparisons between the older and newer survey data were not made for these two locations.

For the locations precisely reoccupied (Goldsmith, Colonell, and Turbide, 1972), the computer program was modified to calculate beach volume changes using the original survey data. Only the last survey at each profile line was recalculated into the CERC format to compare directly with the first VIMS-CERC survey. These data were on the original punchcards generated by the previous investigators. Since the survey techniques employed were the Schwartz one-man beach profile technique and the Emery method, the accuracy of these older data may be below CERC's standards. Also, since all the surveys did not reach the same MLW datum as the later surveys, volume calculations of the older data and comparisons between the newest surveys of the previous investigator, and the oldest survey of this study did not involve the same length of profile line. Despite these weaknesses in the older data, it is interesting that the same erosion and accretion trends exhibited in the newer VIMS-CERC survey computations are also exhibited in the older data at the same survey locations.

6. Statistical Beach Trend Analyses.

Because of large fluctuations in volume changes between surveys at each of the survey locations, it is often difficult to discern net erosion or accretion trends at a profile line. Also, even when trends are apparent, some appear to be "stronger" at some locations than at others. In order to quantify this, heretofore, subjective evaluation of the main factor describing the beach activity, erosion versus accretion, a statistical scheme was developed and first used in Goldsmith, Farrell, and Goldsmith (1974a). This scheme was adopted in this study, and is described below.

To test for statistically significant erosion or accretion trends at each beach profile line, a linear regression line was calculated for cumulative beach volume change against time (in weeks) using a standard canned program on the VIMS IBM 370 computer. The null hypothesis assumed that the calculated regression line represented the distribution of beach volume change with time (i.e., significantly different from chance within the 27 months of survey measurements). This was tested at various levels of statistical significance (e.g., 1, 5, 10, and 50 percent) and the null hypothesis was accordingly rejected at the appropriate significant level, and the erosion-accretion trend was considered to be statistically significant at that level. It is interesting to note that all eight profile lines exhibiting trends considered statistically significant (at 1 percent level) showed a large statistical difference from the other profile lines (i.e., there was a major break in the groupings of the significance levels).

7. Ground Photography.

Numerous 35-millimeter color slides were taken on each of the surveying trips. Views up and down the beach, as well as along the profile line, were included along with other interesting features such as scarps, vegetation, surf conditions, and usage. These slides are stored in the Coastal Engineering Information Analysis Center at CERC.

Photographs of various beach conditions at each of the 18 profile lines are in Appendix A.

8. Aerial Inspection.

Aerial flights were made over the study area at altitudes between 130 and 300 meters, as close to the time of surveying as weather permitted. Oblique 35-millimeter color slides generally overlap, showing the beach area between the profile lines, as well as the profile sites. Beach features such as scarps, overwash areas, dune orientation, suspended sediment plumes in the surf zone, and nearshore bars can be readily seen in slides taken from low-altitude aircraft.

This information is helpful in supplementing the survey measurements to give a third-dimensional view of beach changes and processes in the study area. A 1.2-meter by 2.4-meter sheet of plywood, painted international orange, was placed near pipe 3 at each of the five Back Bay National Wildlife Refuge Profile lines (11 to 15). This helped in locating the profile line from the air. The targets were oriented to the profile line, and were easily seen from the air. All other profile lines had sufficient local features to aid in the exact location of the survey sites from the air and in the photos.

Photos from these flights showing the 18 profile locations and other interesting features are in Appendix A.

9. Currituck Reconnaissance.

Beginning with the third quarter of the study, a quarterly ground reconnaissance trip to Currituck County, North Carolina, was conducted. Beach sampling stations were established every 6.4 kilometers from the Virginia-North Carolina State line to 38.6 kilometers south of the line, ending just north of the construction site of the CERC Field Research Facility.

At each station, foreshore slope angle and sand grain size were measured at a location approximately two-thirds of the way up the beach face. Slope angle was measured in tenths of a degree with a Brunton Pocket Transit. Sand grain size was measured in quarter-phi units (using a pocket-size, "phi-size finder") and the beachface surface grains were recorded as to the extent of size sorting. The VIMS form used during the reconnaissance is in Appendix F-2.

IV. REVIEW OF LITTORAL PROCESSES

In this section, information and previous work on the various processes that affect beaches in the study area are reviewed and summarized. These include tidal range, wave climate, winds, storms and related surges, nearshore circulation eolian activity, and most importantly for this area, the role of man.

1. Tidal Range.

The neap and spring tides recorded at the Hampton Roads tide gage within Chesapeake Bay entrance, and the predicted tides for Virginia Beach and False Cape, which straddle the study area, are shown in Table 3.

Table 3. Study area tidal ranges.[1]

Location	Coordinates	Kilometers south of Chesapeake Bay	Range: Mean (ft)	Range: Mean (m)	Range: Spring (ft)	Range: Spring (m)	Mean tide level (ft)	Mean tide level (m)
Cape Henry, Virginia	36° 56′ N. 76° 00′ W.	0	2.8	0.9	3.4	1.0	1.4	0.4
Virginia Beach, Virginia	36° 51′ N. 75° 58′ W.	8	3.4	1.0	4.1	1.2	1.7	0.5
False Cape, Virginia	36° 36′ N. 75° 53′ W.	32	3.6	1.1	4.3	1.3	1.8	0.5
Currituck Beach Lighthouse, North Carolina	36° 23′ N. 75° 50′ W.	53	3.6	1.1	4.3	1.3	1.8	0.5

[1]Datum is mean low water.

(National Oceanic and Atmospheric Administration, 1976)

In this study area, the tidal ranges at four local tidal reference stations (Cape Henry, Virginia Beach, False Cape, and Currituck Beach Lighthouse) vary from 2.5 to 3.6 feet (0.8 to 1.1 meters) for mean tidal range and 3.0 to 4.3 feet (0.9 to 1.3 meters) for spring tidal range. Hampton Roads, Virginia, within Chesapeake Bay, is the nearest National Ocean Survey (NOS) tide gage to the study beaches. Tides at Cape Henry, Virginia Beach, False Cape, and Currituck Beach Lighthouse are determined by applying tabulated corrections at these locations, to those predicted at Hampton Roads.

Mean and spring ranges, and mean tide levels tend to increase as the distance from the influence of the Chesapeake Bay increases (Table 3).

It is important to note that with this relatively low range, the wind can have an important effect on the water level. It was observed that with either strong onshore or strong offshore winds, the resulting beach tide level remained either high or low, respectively, throughout the 12-hour tidal cycle.

2. Wave Climate.

Wave climate data in this area have been summarized, synthesized, and contrasted from six data sources by Gutman (1976). These sources include Marsden square ship wave observations for Marsden 1^{o} subsquare 65 of Marsden square 116 (1948 to 1973) and Chesapeake light observations on the shelf, Virginia Beach gage (1964-1969), Cooperative Surf Observations Programs (COSOP), and VIMS-CERC wave observers at the shoreline, and Sverdrup-Munk-Bretschneider (SMB) hindcast data for 1948-1950 by Saville (1954).

Percent frequency occurrence of significant wave heights for all these sources, and monthly averages of significant wave heights and periods for the Virginia Beach gage (located at Profile line 3) are shown in Figures 7, 8, and 9. Ship wave observations by direction and height are shown in Figure 10 (Gutman, 1976). These data show that:

(a) The highest shoreline waves ($\geq$ 2.3 meters) occur only 0.1 percent of the time (COSOP data).

(b) the highest average significant waves occur in October, February, September, January, March, and April (in order of decreasing heights), and range between 0.9 and 0.6 meter. The lowest heights occur May to August.

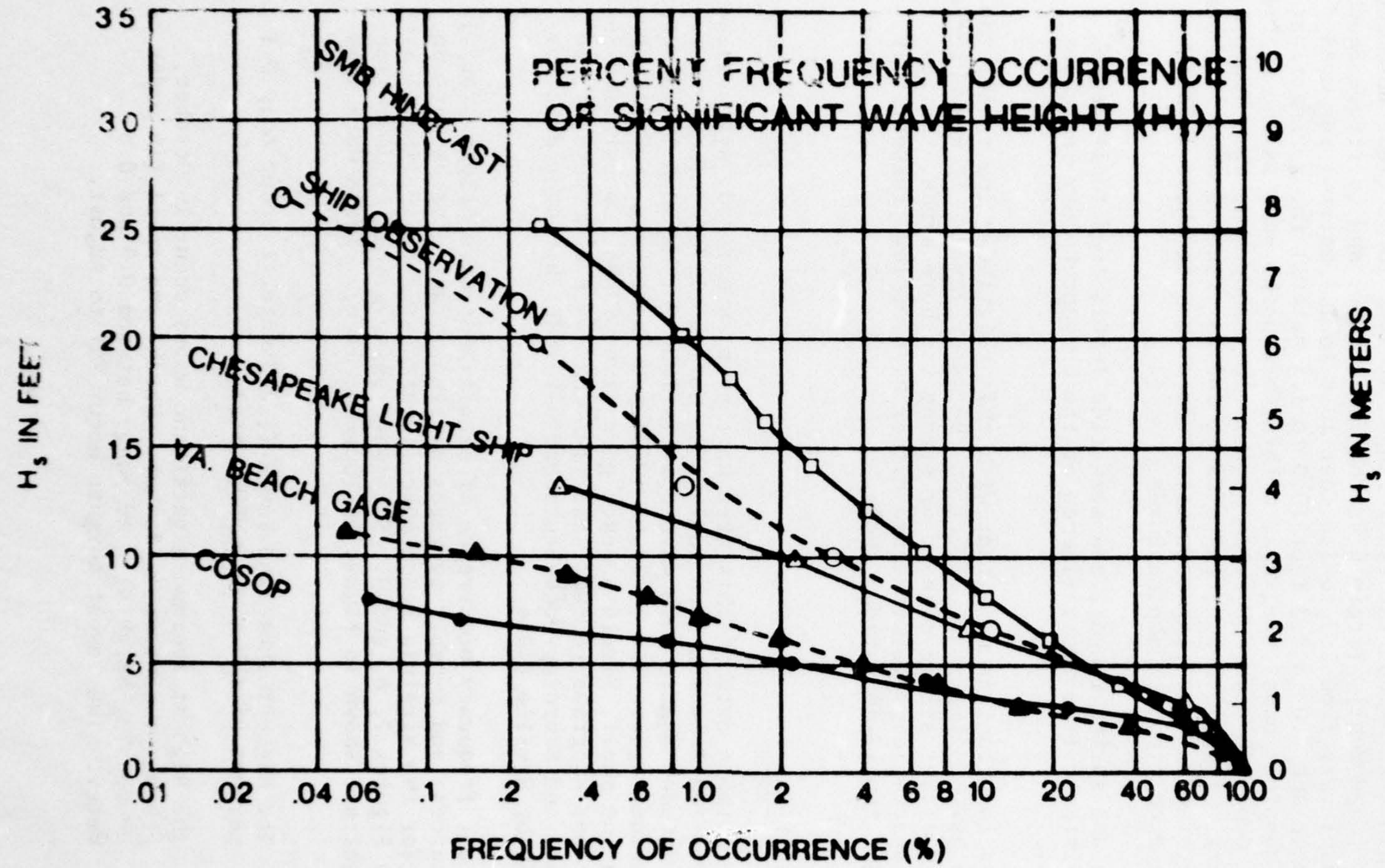


Figure 7. Percent of occurrence of significant wave heights ($\overline{H}_s$) (from Gutman, 1976).

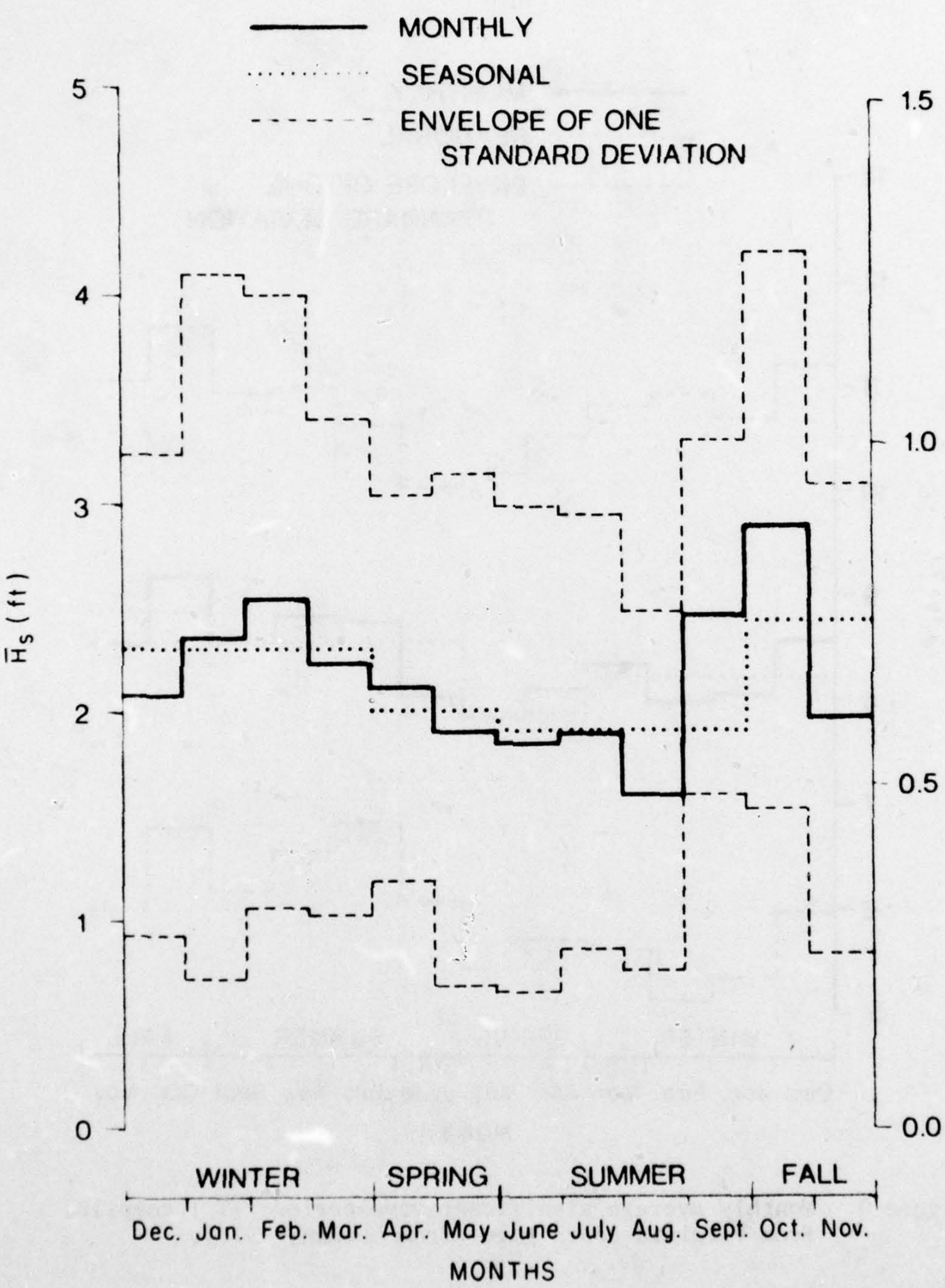


Figure 8. Monthly average significant wave heights ($\overline{H}_s$) compiled from Virginia Beach gage (from Gutman, 1976).

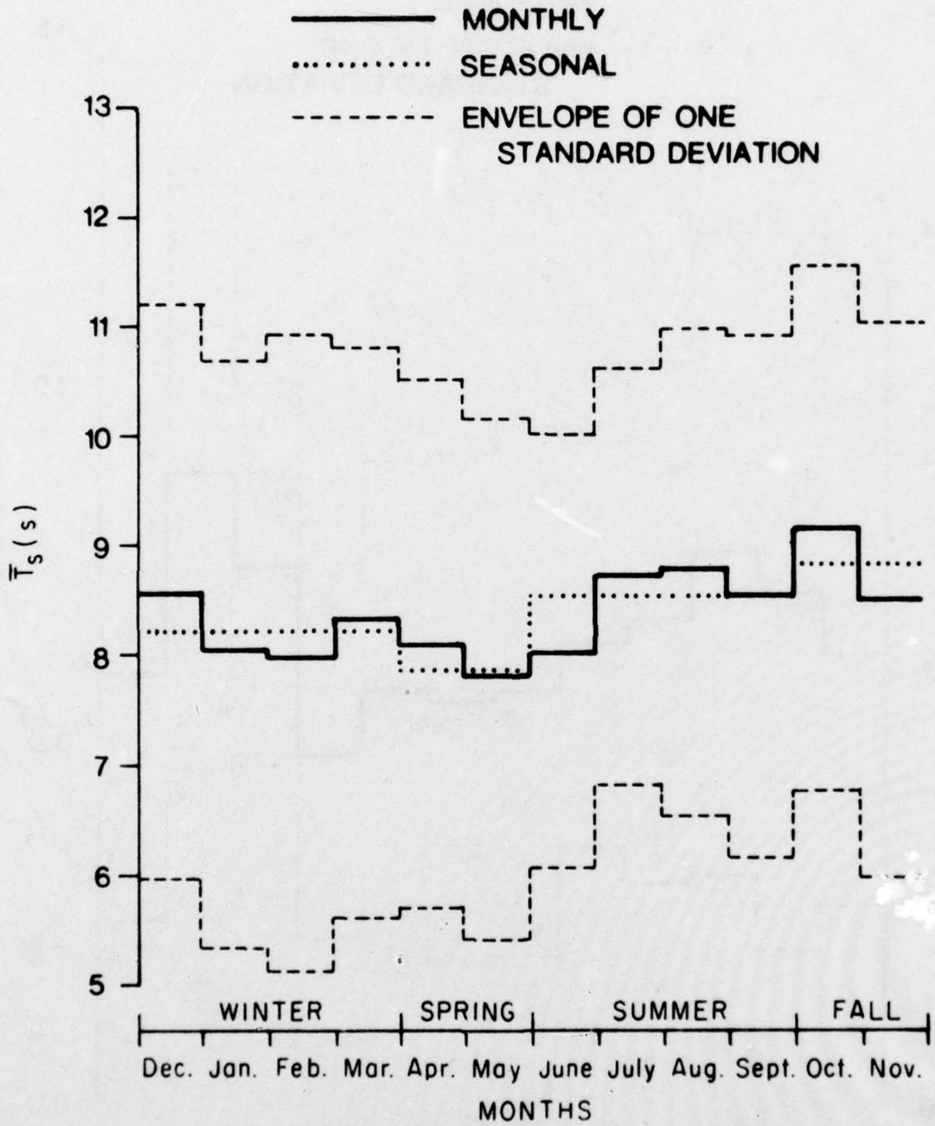


Figure 9. Monthly average significant wave periods ($\overline{T}_s$) compiled from Virginia Beach gage (from Gutman, 1976).

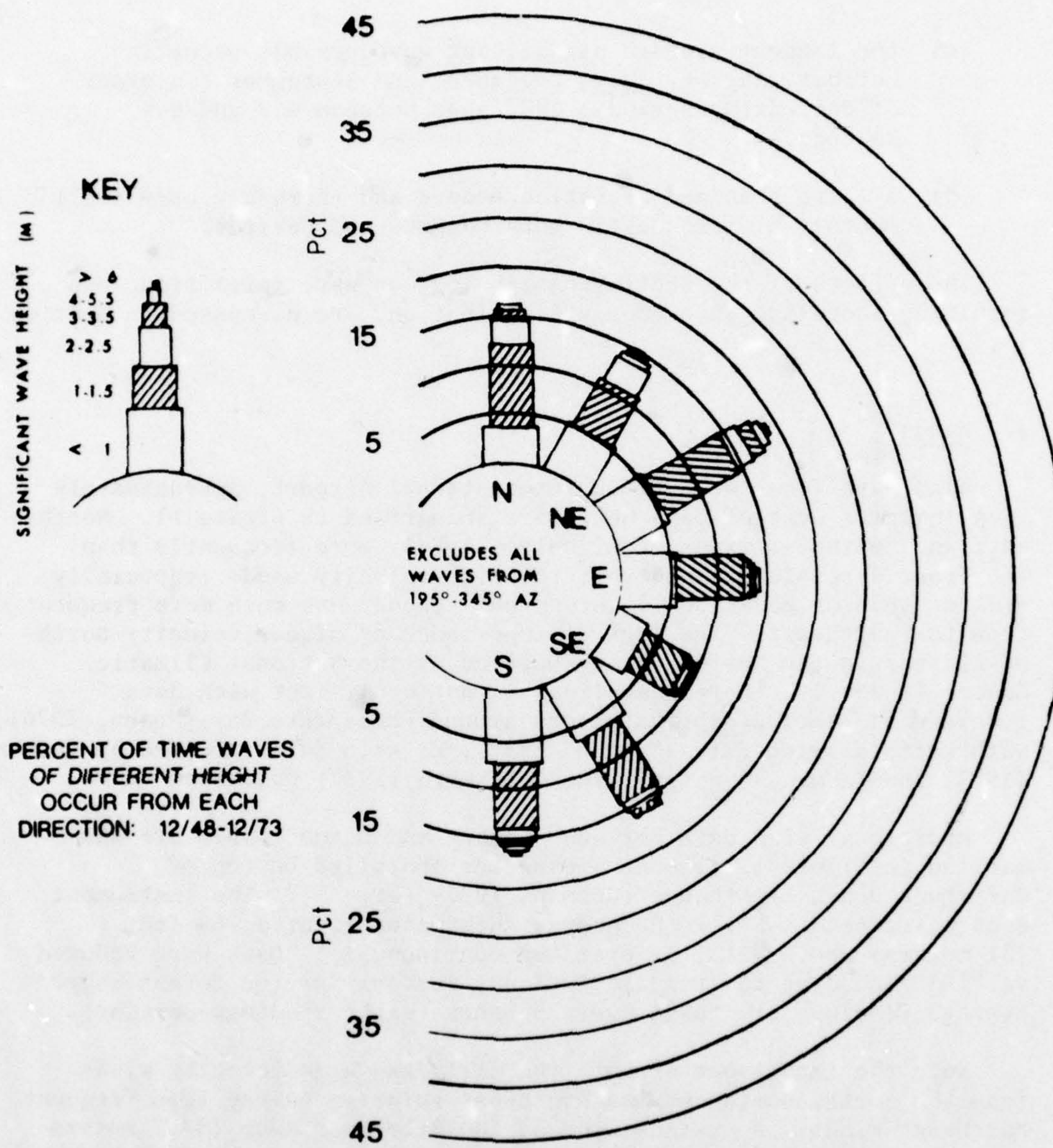


Figure 10. Ship observation wave rose (from Gutman, 1976).

(c) the longest average significant wave periods occur in October, August, July, December, and September (in order of decreasing periods) and range between 9.2 and 8.5 seconds.

(d) a large standard deviation occurs and there are very small monthly differences in both heights and periods.

The effects of the shelf geomorphology on wave refraction, and resulting shoreline wave energy distribution, are discussed in Section II, 2.

3. Winds.

Wind data from the Norfolk International Airport, approximately 16 kilometers west of Cape Henry are summarized in Figure 11. Northeast and southwest winds occur only slightly more frequently than the other directions. However, the high velocity winds (especially greater than or equal to 11 meters per second) are much more frequent from the northeast. The lack of importance of higher velocity northwest winds in the Norfolk data supplied by the National Climatic Center (Asheville, North Carolina) is not consistent with data recorded at other weather stations around Chesapeake Bay (Rosen, 1976), with Hatteras wind data (Gutman, 1977), or with data recorded by Gutman (1977) and Gutman, Hennigar, and Goldsmith (1977) described below.

Additional wind data between January and October 1976 are summarized in Figure 12 from an anemometer installed on top of Currituck Beach Lighthouse (Gutman, 1977) (Fig. 1). The instrument used was a Bendix-Frieze Recording Anemometer located 168 feet (51 meters) above MSL. It operated continuously. Data were reduced at VIMS according to standard National Weather Service format where average readings are taken every 3 hours (eight readings per day).

Note the importance of both the daily and high velocity winds from the north, northwest, and southwest relative to the less frequent northeast winds. A maximum wind of 100 miles per hour (44.7 meters per second) was recorded on 9 October 1976, due to a tornado which actually touched down in Corolla.

4. Storms and Storm Tides.

Extratropical storms (1956 to 1969), tropical storms (1964 to 1969), and the time of operation of the Virginia Beach gage (1964 to 1969) were summarized by Gutman (1976) from information provided by

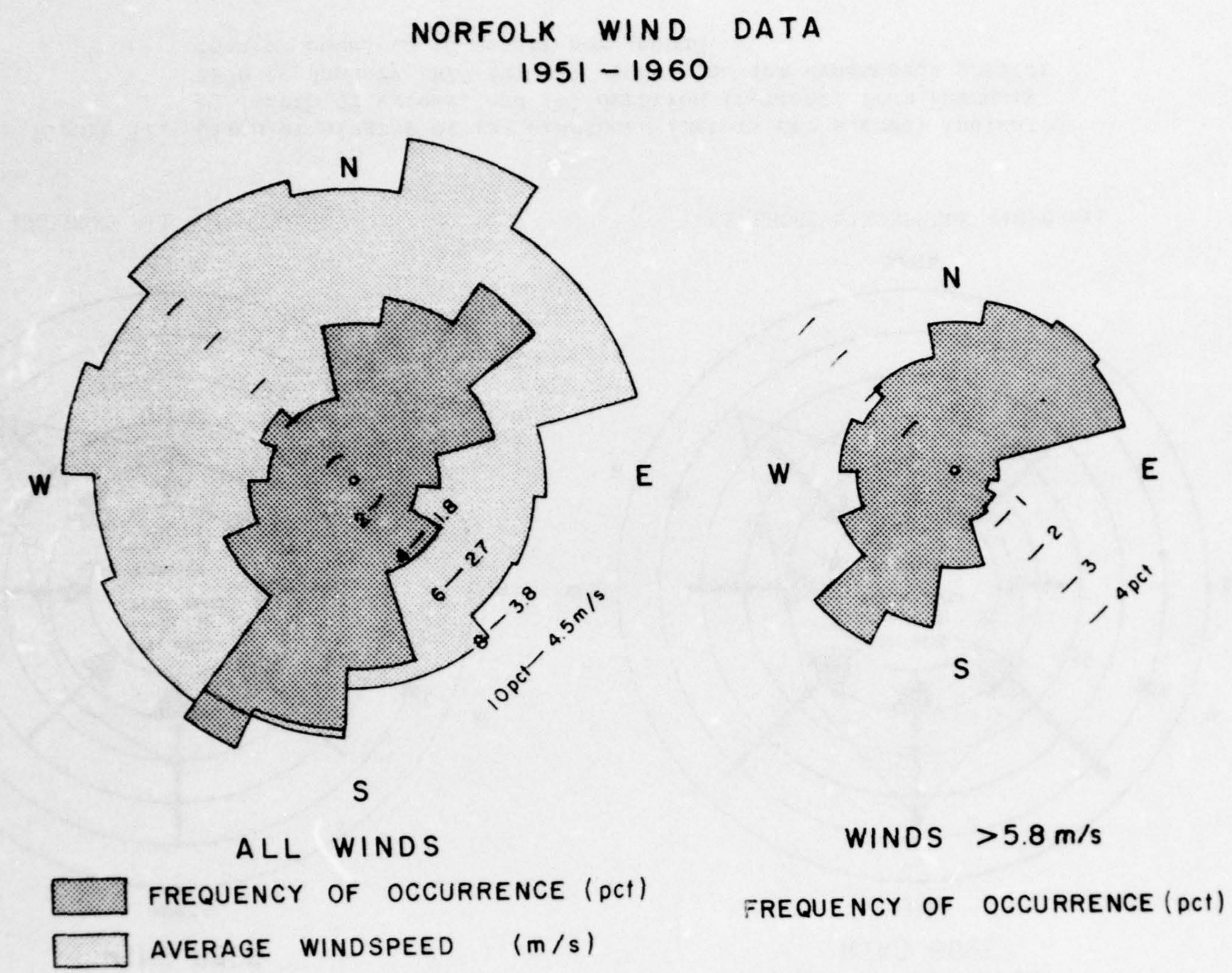
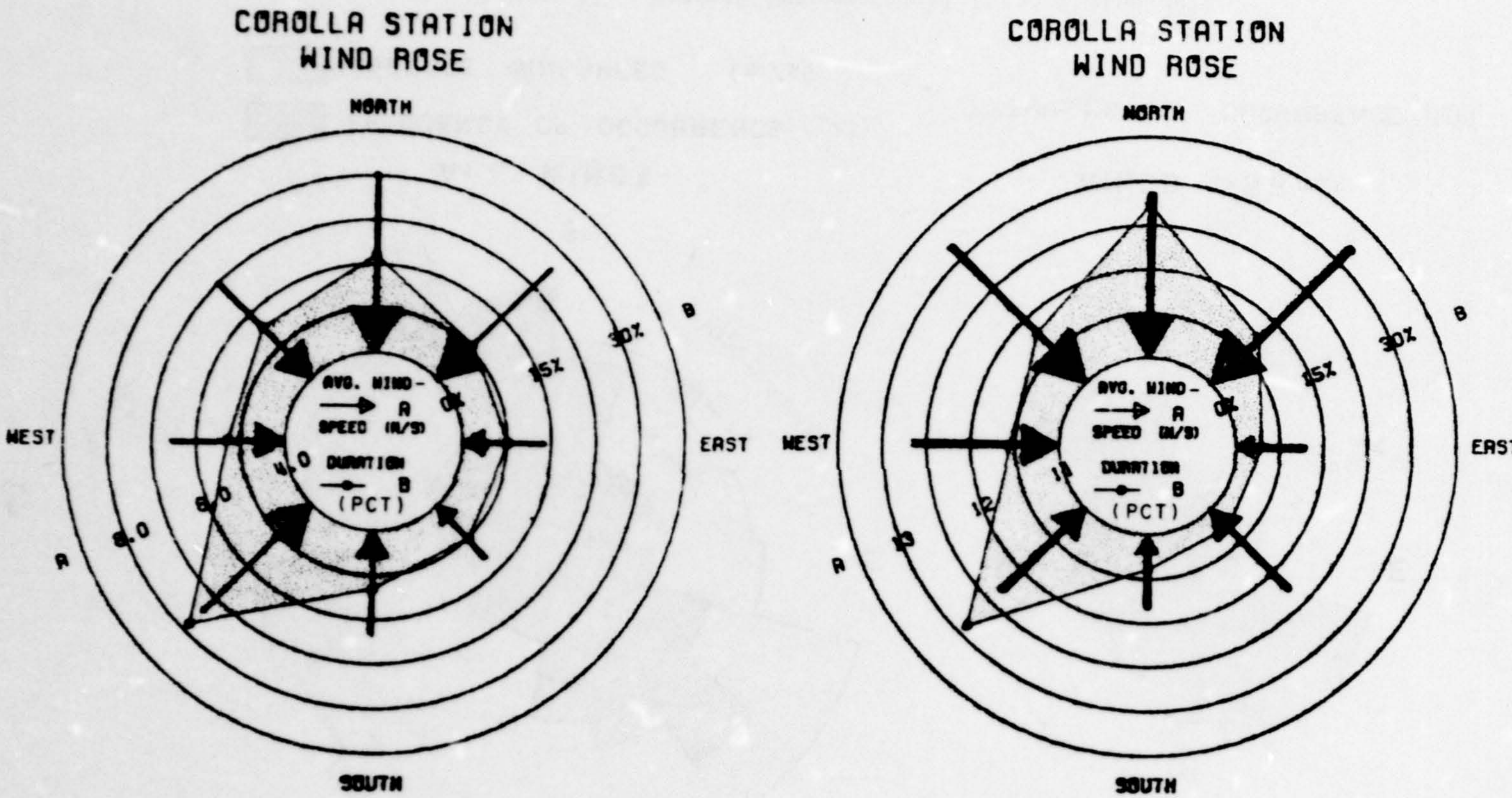


Figure 11. Norfolk International Airport wind data.



INCLUDES ALL WINDSPEEDS

EXCLUDES WINDSPEEDS <10.0 m/s

Figure 12. Circular diagram of (a) windspeed (meters per second) indicated by length of arrows, and (b) duration (percent) from February 1976 to January 1977 for all winds, and for windspeeds greater than or equal to 10 meters per second.

W.S. Richardson, Techniques Development Laboratory, National Weather Service (personal communication, 1976). This list includes all "storms" defined as having a recorded tide gage surge greater than 0.6 meter (Table 4) but only for the months of November through March (i.e., storms occurring in the other months were not tabulated by Pore, Richardson, and Perrotti, 1974). This average of extratropical storms of three per year agrees well with other longer term averages for the Hampton Roads area (Pore, Richardson, and Perrotti, 1974, Fig. 4). Beach observations in this study indicate that the major factor concerning the occurrence of erosion is the height of the storm surge, which allows even moderate-size waves to erode parts of the beach (Warnke, et al., 1966).

There are, of course, problems in relating storm surges measured at Hampton Roads, within the southwest part of Chesapeake Bay, to storm-induced erosion occurrences on the ocean shoreline which lacks sufficient tide gage records. However, Richardson's data show that at the time of most measured surge occurrences, the peak winds were blowing from the northeast or east. Although the peak winds given in Table 4 are the daily peaks, these data were cross-checked by Richardson against peak winds at 3-hour intervals, to verify the directions as representative of surge conditions. The surge height was the maximum hourly observed value, with most surges lasting at least several hours. (W. S. Richardson, personal communication, 1977).

These surges are generated by hurricanes (Harris, 1963) and extratropical storms (Pore, 1964). The surges associated with hurricanes are generally higher than those surges associated with extratropical storms. However, the duration of the hurricane surge is generally shorter than the duration of the extratropical surge. The long duration of the extratropical surge almost guarantees that it will last through one high tide, while the shorter lived hurricane surge may completely miss a high tide (e.g., Hurricane Belle in August 1976).

The time of occurrence of the storm surge with respect to the normal high tide is of great importance because it can mean the difference between serious and minor flooding. The Norfolk harbor experienced serious flooding during an August 1933 hurricane when water levels of 8 feet (2.4 meters) above MSL were recorded (U.S. Army Corps of Engineers, 1970). Unfortunately, as previously indicated, these data are from inside the bay, which may be quite different from the ocean shoreline study area which lacks a tidal gage.

Table 4. Occurrence of storms in Virginia Beach area for the months of November to March[1]. (from W.S. Richardson, U.S. Weather Service, personal communication, 1976)

Storm	Date	Surge (m)	Wind Speed (kn)	Wind Direction
Extratropical (1956 to 1969)				
	11 Jan. 1956	1.04	33	NE.
	11 Apr. 1956	1.3	62	N.
	3 Nov. 1956	0.61	29	NE.
	28 Feb. 1957	0.73	33	NE.
	8 Mar. 1957	0.67	27	NE.
	1 Nov. 1957	0.82	28	NE.
	25 Jan. 1958	0.70	44	E.
	1 Feb. 1958	0.67	30	W.
	19 Mar. 1958	0.67	21	NE.
	27 Mar. 1958	0.79	20	N.
	11 Dec. 1958	0.64	27	NE.
	29 Dec. 1958	0.70	38	E.
	12 Apr. 1959	0.76	45	NE.
	19 Dec. 1959	0.64	29	N.
	31 Jan. 1960	0.91	42	NE.
	13 Feb. 1960	0.70	49	NE.
	3 Mar. 1960	0.88	52	E.
	12 Dec. 1960	0.61	40	W.
	16 Jan. 1961	0.61	13	W.
	8 Feb. 1961	0.73	27	NE.
	22 Mar. 1961	0.67	33	E.
	28 Nov. 1961	0.61	23	NW.
	28 Jan. 1962	0.67	37	NE.
	7 Mar. 1962	1.70	41	NE.
	22 Mar. 1962	0.73	20	N.
	3 Nov. 1962	0.76	33	N.
	26 Nov. 1962	1.02	41	N.
	8 Feb. 1963	0.70	30	NE.
	6 Nov. 1963	0.73	38	E.
	4 Jan. 1964[2]	0.6	28	W.
	12 Jan. 1964[2]	0.8	42	E.
	12 Feb. 1964[2]	0.6	32	E.
	16 Jan. 1965[2]	1.2	35	NE.
	22 Jan. 1965	0.9	36	E.
	29 Jan. 1966[2]	1.1	37	E.
	24 Dec. 1966[2]	0.7	31	NE.
	7 Feb. 1967[2]	0.8	33	NE.
	12 Dec. 1967[2]	0.6	30	E.
	29 Dec. 1967[2]	0.6	31	W.
	14 Jan. 1968[2]	0.7	33	E.
	8 Feb. 1968[2]	0.8	30	NE.
	10 Nov. 1968[2]	1.3	34	N.
	12 Nov. 1968[2]	0.8	47	NE.
	2 Mar. 1969[2]	1.8	40	N.
	2 Nov. 1969[2]	0.8	36	NE.
Tropical (1964 to 1968)				
Cleo	1 Sept. 1964[2]	0.3	42	ESE.
Dora	13 Sept. 1964[2]	1.1	61	NE.
Gladys	23 Sept. 1964[2]	0.7	44	N.
Isabell	16 Oct. 1964[2]	0.8	50	NE.
Alma	13 June 1966[2]	0.3	40	N.
Doria	16 Sept. 1967[2]	1.2	55	N.
Gladys	20 Oct. 1968[2]	0.4	46	NE.

[1]Defined as having a surge ≥2 feet (0.6 meter) at Hampton Roads tide gage.

[2]Virginia Beach gage operating (?).

5. Nearshore Circulation and Longshore Transport.

On the basis of field studies, Harrison and Wagner (1964) proposed that a nontidal drift eddy, with clockwise motion, exists between Cape Henry and Rudee Inlet.

An investigation of the rate of longshore transport between Cape Henry and the Virginia-North Carolina line by an analysis of wave energy (as computed from Saville's (1954) hindcast data) was made by Weinman (1971). He determined a net annual transport to the north of 9.8 X 10^5 cubic yards per year (7.4 X 10^5 cubic meters per year). Although this total is probably too high, the detailed results qualitatively agree with other studies, and emphasize the importance of southeast waves in this area (Goldsmith, et al., 1974b), as discussed earlier.

Longshore transport rates were also calculated from tracer analyses at Rudee Inlet by Bunch (1969). An approximate mean northerly transport of 70,000 cubic yards per year (53,000 cubic meters per year) was calculated from five tests conducted between 8 November 1968 and 20 March 1969, during times of moderate wave heights.

An additional indication of the amount of northerly transport is available from dredging data for *Thimble Shoal Channel* (U.S. Army Engineer District, Norfolk, 1971). Approximately 1 X 10^6 cubic yards (0.76 X 10^6 cubic meters) of material is removed every 2 to 3 years from just the main channel, located within the Chesapeake Bay entrance (Fig. 1). Thus, the dredging data probably give only a minimal estimate of the longshore transport along the study area.

Critical to any research and coastal engineering effort in this area is the location of the nodal transport zone; i.e., the zone where the "net" longshore transport is zero. More specifically, how far south of Rudee Inlet (where sediment accumulates on the south side of the inlet jetties) is the zone where the net southerly transport resumes transport to the south is prevalent on most of the U.S. east coast?

6. Eolian Processes.

In relation to long-term viability and preservation of Currituck Spit, the most important processes appear to be eolian.

There are three basic types of dunes in the study area (except for Profile lines 3 and 4): (a) Vegetated dunes, (b) medaños (i.e., a transverse sand hill on the seashore), and (c) parabolic dunes.

Vegetated dunes accumulate around vegetation, which act as sand-trapping baffles (vertical growth of 0.3 to 1.0 meter per year), and also as an internal skeleton fixing the dunes in place, and result in a characteristic internal geometry containing low-angle dipping beds (mean = 12^{o}) and polymodal dip directions (Goldsmith, 1973; 1975b). The vegetated foredunes are highest and most prominent at Profile line 2 (61st Street, Virginia Beach), in Back Bay, and in False Cape where they reach elevations of 10 meters. At Cape Henry and in Currituck County, the foredunes are lower in elevation (usually about 3 meters) and grade landward into sparsely vegetated eolian flats containing multiple lines of sand fencing.

Medaños are large, isolated unvegetated hills of sand, 10 to 25 meters in elevation, and asymmetric in profile. They migrate downwind up to tens of meters per year by a process which produces characteristic slipfaces of unconsolidated sand dipping at the angle of repose on the leeward side of the dune. About a dozen medaños occur in Currituck County, with elevations up to 25 meters (Lewark Hill) and migration rates up to 20 meters per year (Jones Hill, 1955-1975). In total, they represent a significant amount of sand (i.e., many times the annual longshore transport rate).

Parabolic dunes, defined by their characteristic planimetric view, are similar to medaños in that they have a slipface formed in direct response to the dominant wind, and a deflation zone within their upwind concave side, but are different in that they have an internal geometry more characteristic of vegetated dunes and may be fixed in place depending on their recent vegetation history. Parabolics occur prominently in False Cape State Park, and also in Currituck County where their aerial distribution typically grades from vegetated parabolics to transverse dunes (i.e., medaños) in an upwind direction. Parabolics also show *in situ* temporal changes to other dune types. These dunes are discussed further in Goldsmith, et al. (1977).

Ongoing studies at VIMS indicate that sand is blown from beach to dune and back throughout the width of Currituck Spit. The classic idea of sand blowing from the beach landward into the dunes may be overly simplistic to the point of being incorrect. Further complicating this matter is man, through the active sand fencing program since the 1930's, which has built up the foredunes along the area south of Sandbridge. These foredunes, which result from natural processes around an artificially heightened dune, may result in a different type of dune, and unforeseen consequences. Also, as shown by Leatherman (1976), eolian transport of sand from overwashes back onto the foredunes and onto the beach is a very significant process. Artificial heightening of the foredunes in this area has cut off the sand supply to the interior, which has permitted vegetation to stabilize the interior (Gutman, Hennigar, and Goldsmith, 1977).

An active program of grass planting is being carried out adjacent to, and on either side of, profile line 2. Back Bay's active sand fencing program in the dunes ended in 1974 by order of the Department of Interior (D. Hollands, Manager, Back Bay National Wildlife Refuge, personal communication, 1977). The placement of sand fencing was observed to be effective in accumulating sand and building up the dunes; e.g., at profile line 14, a 1.8-meter-high fence was completely encased in sand within a 2-year period (1972-1974).

7. Beach Nourishment.

Since 1952, a beach nourishment program for Virginia Beach has been conducted along an 8-kilometer shoreline from Cape Henry to Rudee Inlet. Concentration of this effort has centered in the 5.5 kilometers just north of Rudee Inlet, of which 3 kilometers has been bulkheaded with a concrete "boardwalk" in the area of the ocean-front hotels.

By the end of fiscal year 1976 it was reported by the Norfolk District that a total of 5.9 million cubic yards (4.5 million cubic meters) of sand had been placed on the beach (Table 5) to replace the material lost due to a northerly transport and other erosional factors.

Various means of supplying the sand were: (a) Hauling by truck from a distant sand stockpile at Cape Henry where the dredged material from Thimble Shoal Channel in Chesapeake Bay entrance has been pumped ashore and stored; (b) dredging of Rudee Inlet; (c) sand sources dredged by enlarging "Rudee Harbor"; and (d) bypassing of ocean-front sand from the south side of the inlet jetty to the north side of the inlet.

Approximately 9 percent of the total volume that has been used to nourish the beaches, or 515,040 cubic yards (391,000 cubic meters), has been placed on the beach since the beginning of fiscal year 1975. Most of this has been either inlet-bypassed, or truck-hauled from the Thimble Shoals stockpile at Cape Henry.

It has been observed that much of the nourished sand is usually removed by the first small or moderate storm. Therefore, nourishment is required, more or less, continuously. The net northerly transport moves some of this sand to the north to Cape Henry and Thimble Shoal Channel, where with the aid of man, the sand is recycled back into the transport system.

Table 5. Gross quantities of material placed on Virginia Beach, fiscal years 1952 to 1976.

Fiscal year	Initial restoration (yd³)	Truck haul (yd³)	Early inlet dredging (yd³)	Inlet bypassing (yd³)	Owl's Creek (yd³)	P.L. 875 dredging (yd³)	Inlet "new source" (yd³)	Total (yd³)
1952	20,000							20,000
1953	1,363,000							1,363,000
1954	60,000	34,000	44,000					138,000
1955		30,000		17,500				47,500
1956				35,000				35,000
1957				44,000	80,000			124,000
1958				50,000	70,000			120,000
1959				46,000	93,000			139,000
1960				48,000	84,000			132,000
1961				62,000	91,000			153,000
1962		113,000[1]		53,000	101,000	205,000		472,000
1963					121,000			121,000
1964					215,000			215,000
1965					218,000			218,000
1966					174,000			174,000
1967					177,500			177,500
1968				139,000	8,400			147,400
1969				100,500	0			100,500
1970				104,000	143,800			247,800
1971				127,000	103,600			230,600
1972		43,100		114,900	230,500		101,300	489,800
1973		12,000		86,300	260,300			358,600
1974		12,500		103,300	49,700			167,500
1975		112,470		160,960				273,430
1976		98,980		142,630				241,610
								5,900,000 Total

[1]Truck haul placed under P.L. 875.

(from U.S. Army Engineer District, Norfolk, 1971)

V. BEACH CHANGES

1. Regional Variations in Beach Volume Changes During VIMS-CERC Study.

In analyzing 27 months of data from the study area, it became evident that certain areas had usually accreted, some had usually eroded, and some were either stable or fluctuated too much for any discernible trend to be recognized. Appendix I gives the total cumulative volume changes with time for each of the 18 profile lines. Plots of profile line cumulative volume changes with time (18 VIMS-CERC profile lines) are in Appendix B. Figure 13 represents graphically the 27-month total cumulative volume at each profile line, and Figure 14 shows similar data at 9-month intervals, using CERC's volume calculations. All these volume data represent net changes along the profile line between the number 1 pipe and the MSL intercept determined by the surveyers, as discussed in Section III, 4. A qualitative description of the 27-month volume trends and major events is presented in Table 6. Statistical analyses of beach trends for the 27-month study and the historical changes are given in Tables 7 and 8, respectively, and are shown graphically in Appendixes B and C.

Fort Story (Profile line 1) appears to have accreted throughout the study. Even the severest storms did little damage at this survey location. Although the 1 July 1975 storm was followed by significant accretion, the 25 November 1975 storm was followed by minor erosion. However, one factor, whose influence remains unknown, is the occasional leveling of the wide beach area with a road grader by the U.S. Army.

The Virginia Beach area (profile lines 2, 3, and 4) tended to erode, but this was offset with beach nourishment. The total volume of the profile lines fluctuated considerably and is probably due, to some extent, to sand nourishment. However, it would seem accurate to assume that the area would be erosional, without beach nourishment (see Section VII, 2). Profile line 5, updrift of Rudee Inlet, displayed a slight, statistically non-significant accretional trend.

In the Dam Neck area, profile line 6 appears to be erosional; while Profile lines 7 and 8 seem to be slightly accretional to no trend because of "very active" volume changes. Profile line 8 follows a fence which separates Dam Neck from Sandbridge and observations clearly indicate that the sand level has been rising next to the fence above the high tide line, while the beach face has remained the same or slightly eroded during the study.

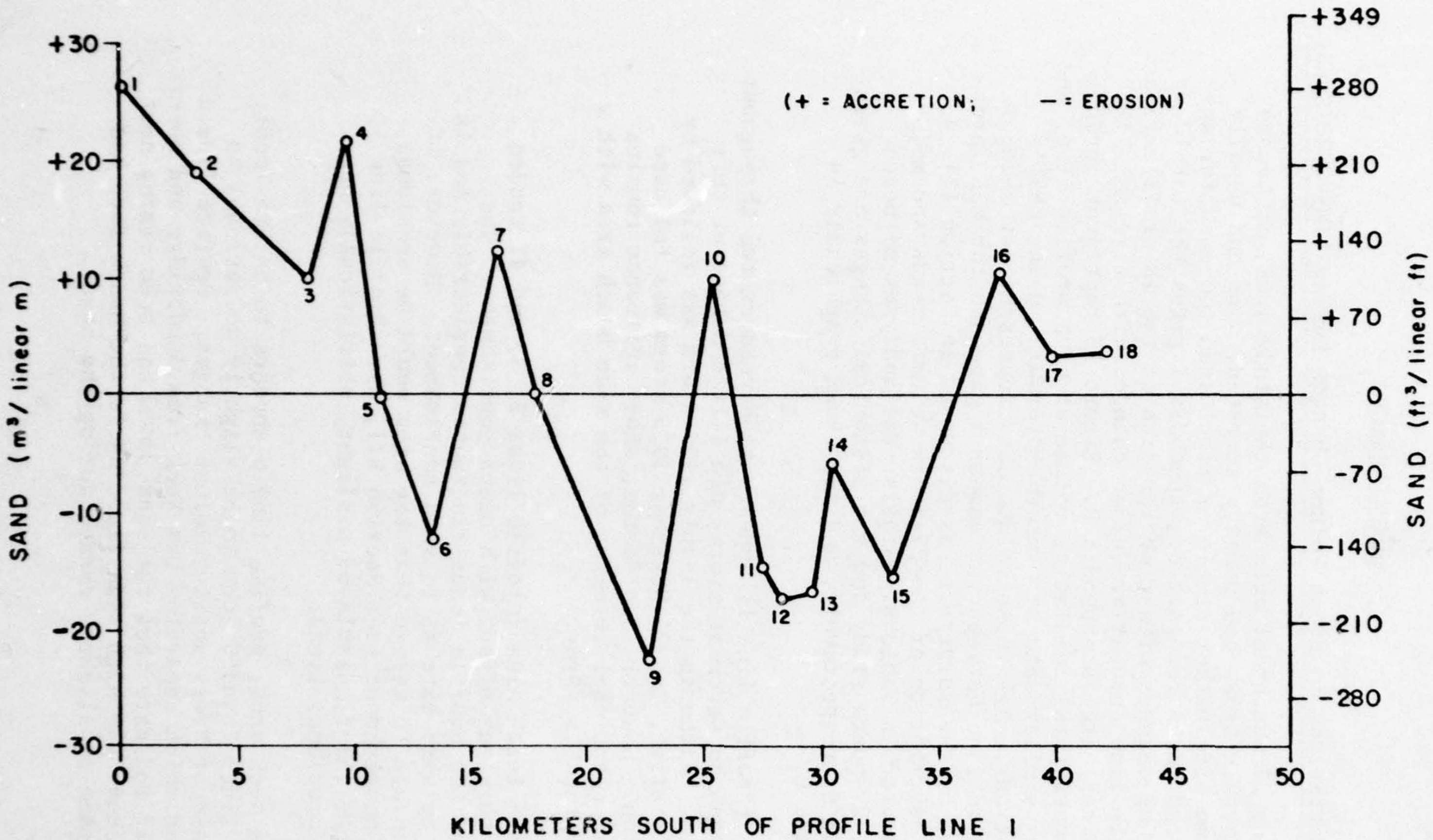


Figure 13. Cumulative beach volume change at 18 profile locations, September 1974 to November 1976. Numbers 1 to 18 on volume line indicate the profile lines.

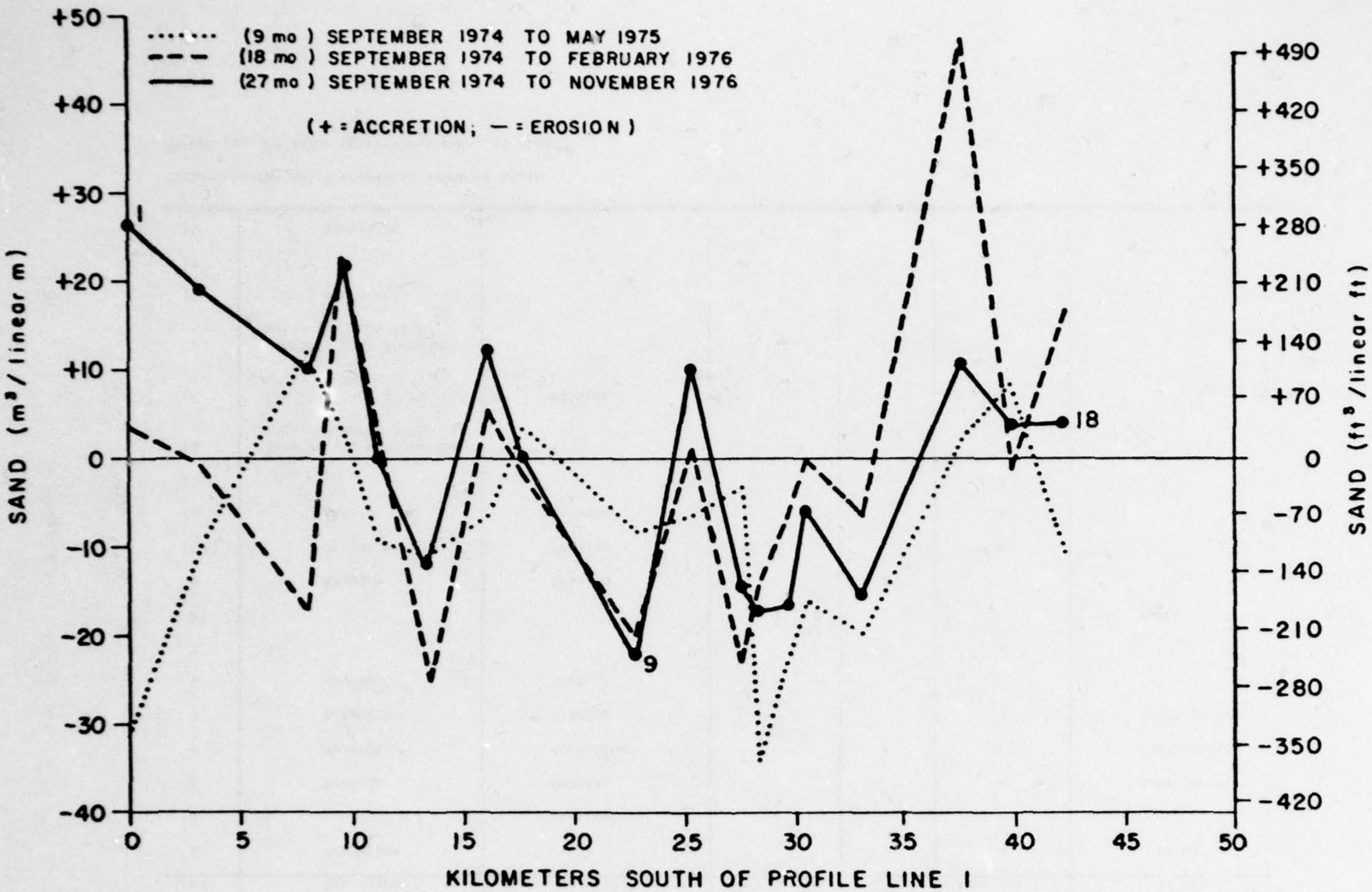


Figure 14. Cumulative beach area change at 9-month intervals, September 1974 to November 1976. Numbers 1, 9, and 18 indicate profile lines.

Table 6. Qualitative description of 27-month beach trends.

Profile line	Net trend	Effect of 25 November 1975 storm	Rate of beach change (x) Very active	Active	Less active	Significant activities of man
1	Accretion				x	Grading
2	-	Erosion[1]	x			
3	Erosion	Erosion			x	Nourishment
4	Erosion	Accretion[2]		x		Nourishment
5	Accretion	Erosion			x	Inlet jetty
6	Erosion	Erosion	x			
7	-				x	
8	-		x			Fence
9	Erosion	Erosion		x		
10	Accretion	Erosion			x	
11	Erosion	Erosion			x	
12	-				x	
13	Erosion, then accretion after 10 March 1975				x	
14	Erosion, then accretion after 10 March 1975	Erosion			x	
15	Erosion, then accretion after 10 March 1975			x		
16	Accretion			x		
17	-				x	
18	Accretion		x			

[1]Storm was the major erosional event of study.

[2]Storm was the major accretional event of study.

Table 7. Linear regression lines fitted to the beach volume trends and statistical significance of the 27-**month trends.** September 1974 to November 1976 (See Section III, 6 for explanation and App. B)

Profile line	Estimated coefficient	Y Intercept	T Statistic	R^1	Significance[2]	Trend[1]
1	6.40	-2053.81	7.47	0.67	0.001	+
2	0.14	- 88.76	0.26	0.001	0.80	+
3	-3.02	914.63	-3.80	0.33	0.001	-
4	-0.50	233.36	-0.78	0.02	0.50	-
5	0.14	- 74.65	0.34	0.001	0.75	+
6	-2.94	790.22	-5.39	0.50	0.001	-
7	0.73	- 195.27	1.56	0.08	0.20	+
8	0.17	- 51.78	0.24	0.001	0.95	+
9	-2.16	524.26	-4.48	0.41	0.001	-
10	0.92	- 305.47	2.23	0.16	0.05	+
11	-2.15	586.32	-3.85	0.36	0.001	-
12	2.47	- 241.60	0.37	0.01	0.70	+
13	0.84	- 404.56	1.68	0.09	0.25	+
14	1.61	- 573.04	3.01	0.24	0.01	+
15	0.72	- 308.91	1.59	0.08	0.20	+
16	2.15	- 619.17	3.50	0.29	0.01	+
17	0.40	- 130.00	1.01	0.03	0.40	+
18	1.65	- 544.24	3.25	0.26	0.01	+

[1]+, accretion; -, erosion.

[2]The lower the number, the higher the significance; e.g., 0.001 indicates that the erosion or accretion trend is <u>not</u> due to chance at the 99.9 percent level.

Table 8. Linear regression lines fitted to the beach volume trends and statistical significance of the long-term trends. (See Sec. III, 6 for explanation and App. C.)

Profile line	Estimated coefficient	Y Intercept	R^1	Significance[2]	Trend[1]
1[3]					
2[3]					
3[3]					
4[3]					
5[3]					
8	-0.52	151.59	0.14	0.001	-
10	0.16	- 27.49	0.03	0.20	+
12	6.74	-2203.28	0.68	0.001	+
13	1.09	- 489.12	0.06	0.10	+
14	4.08	-1399.52	0.88	0.001	+
15	-0.05	- 85.93	0.001	0.90	-
16	0.04	46.60	0.001	0.001	+
17	1.26	- 232.90	0.31	0.001	+
18	5.47	-1743.74	0.92	0.001	+

[1]+, accretion; -, erosion.

[2]The lower the number, the higher the significance; e.g., 0.001 indicates that the erosion or accretion trend is not due to chance at the 99.9 percent level.

[3]Data does not meet basic assumptions.

In Sandbridge, profile line 9 appears to have an erosional trend. This profile line has proved to be vulnerable to storms, and storm recovery has usually been slow. Profile line 10 has a slight accretional trend, with the exception of the major influence of the 25 November 1975 storm.

The Back Bay area (profile lines 11 to 15) appears to be in an accretional state, except for profile line 11 which appears to be erosional due mainly to the effects of the 25 November 1975 storm. Beginning with profile line 14, and moving south, the beaches become wider and flatter, and from the survey data, tend to display "net" accretional trends.

The entire False Cape area (profile lines 16, 17, and 18) appears to be accretional (with profile line 17 less accretional). An intertidal and subtidal area of stumps believed to be the remnants of a cypress forest, is located in the northern section of this area between profile lines 15 and 16. Most of the time these stumps are nearly covered with sand, and are most often exposed only after storms. In general, the stumps were most exposed (since 1972) in November 1975, and gradually became covered during the following year. Although storm effects may be fairly severe, recovery is usually very fast, and the long-term trend is accretional.

In general, the trends readily apparent are:

(a) Accretion at the north and south ends of the study area (profile lines 1 and 2 and 12 to 18). Profile lines 1, 14, 16, and 18 have statistically very significant (99.0 percent) accretional trends.

(b) Erosional profile lines are, in general, in the center of the study area. Profile lines 3, 6, 9, and 11 have statistically very significant (99.9 percent) erosional trends.

(c) Most active profile lines (i.e., large fluctuations in beach volume changes) also tend to be at the north and south ends (profile line 2, 5, 7, and 17) and the most inactive profile lines (9 to 13) are in the center (Table 6).

Superimposed on these trends are many exceptions (e.g., accretion at profile line 10 between two erosional profile lines) and extensive masking of the natural trends by man's activities (e.g., profile lines 1, 3, 4, 5, and 8).

2. Differing Profile Response to Specific Storm Events.

During the study, the study beaches were additionally surveyed after eight storms. (Actually a total of 9 storms, including the 3 to 4 December 1974 storm which was surveyed during a regular monthly profile session.) The storms of 1 July 1975 and 10 August 1976 were tropical storms; the other seven were extratropical. The dates of the storm surveys were 15 and 20 March, 1 July, 3 September, and 25 November 1975; and 12 March, 10 April, and 10 August 1976. The most devastating storm effects were surveyed 25 November 1975, and the second worst erosion occurred from Hurricane Amy, surveyed 1 July 1975. Table 9 describes qualitatively the highly variable effects of each storm at each survey location. Appendix D details the various parameters of each storm, and Appendix I presents the precise surveyed volume and MSL intercept changes.

The first storm event surveyed was 15 March 1975; this storm appeared to be the least eventful and least damaging of the nine storms involved. Five profile lines (1 at Fort Story, 6 and 7 in Dam Neck, 10 in Sandbridge, and 12 in Back Bay) actually showed net sand volume accretion, especially in the area between the base of the dune and the berm. Four profile lines (4 in Virginia Beach, and 11, 13, and 14 in Back Bay) appeared to be virtually unchanged from the preceding surveys in February. The remaining profile lines were erosional, but only to a minimal degree, and this erosion was mostly confined to the area of the berm seaward to MSL.

The second March storm was surveyed 20 March 1975, and was of greater intensity than the first, but the effects were certainly not devastating. Four profile lines (7 at Dam Neck, 9 at Sandbridge, and 14 and 15 at Back Bay) were slightly accretional. Profile line 4 (Virginia Beach), 6 (Dam Neck), and 18 (False Cape) remained virtually unchanged from the previous measurements. The other 11 profile lines were erosional. Profile line 3 (Virginia Beach) was the most dramatically affected; it was erosional over the entire length of the profile line (-12.3 cubic meters per meter). The remaining profile lines were mostly erosional over the entire profile length, but to a lesser extent.

Hurricane Amy passed through the study area 28 to 30 June and the beaches were surveyed 1 July 1975. Although winds were recorded at 22 knots (App. D), the high seas were probably the most influential factor affecting beach erosion. Only profile line 1 at Fort Story showed any accretion, although there was a fairly significant amount of erosion below the berm area. However, there was also a significant amount of accretion in the backshore area. Only profile line 11 in Back Bay showed very little change from the previous survey in June. All other locations showed a significant amount of

Table 9. Variable beach changes from storms.

Profile line	15 Mar. 1975	20 Mar. 1975	1 July 1975	3 Sept. 1975	25 Nov. 1975	12 Mar. 1976	10 Apr. 1976	10 Aug. 1976
1	+[1]	+	++[2]	+	-[3]	-	+	++
2	-	-	--[4]	--	--	-	-	+
3	-	--	--	-	-	--	-	0[5]
4	0	0	[6]	-	+	+	-	-
5	-	-	-	-	--	--	0	-
6	+	0	-	-	-	+	+	0
7	+	-	-	-	--	-	0	+
8	-	-	--	--	--	-	0	-
9	-	+	--	-	--	--	-	+
10	+	-	--	-	--	+	0	+
11	0	-	0	-	-	-	-	-
12	+	-	-	-	--	+	-	-
13	0	-	-	+	-	+	+	--
14	0	+	-	-	--	-	0	+
15	-	+	-	+	-	0	0	-
16	-	-	-	-	--	0	-	-
17	-	-	--	-	--	-	-	-
18	-	0	-	-	--	-	-	--

[1]+ = accretion.
[2]++ = accretion more than 9 cubic meters per linear meter in volume.
[3]- = erosion.
[4]-- = erosion more than 9 cubic meters per linear meter in volume.
[5]0 = no change.
[6]Not surveyed.

erosion, especially in the area from the berm seaward and including the swash zone. Profile line 9 at Sandbridge was erosional (-16.4 cubic meters per linear meter) from the base of the dune to swash. After the hurricane at profile line 3 in the heart of the commerical area of Virginia Beach, there was essentially no "beach" at this location. With the abnormally high tide and strong easterly winds, heavy surf reached to the seawall at midtide, removing the beach. Ponding occurred at profile line 15 and behind a fairly high berm at profile line 1. There were wind shadows behind the front dune at profile line 12. Most beaches had at least partially recovered by the time of the next profiling (9 July). Only profile line 18 continued in an erosional state. Total recovery had occurred at all locations by August.

The 2 to 3 September storm was not as erosional as Hurricane Amy. However, all but three locations (1, 5, and 15) showed some degree of erosion, and perhaps even more significant, recovery at most sites was very slow. Many locations still had not fully recovered by early November. Only profile lines 2, 8, 11, 12, and 16 showed any recovery later in September at the next surveying trip. Here again most of the beach loss occurred in the berm area.

The 23 to 25 November 1975 storm was certainly the most destructive in terms of beach loss and prolonged recovery time for the entire study area. Only profile line 4 in Virginia Beach showed any accretion. A slight amount of beach loss near the berm occurred, but there was a significant amount of accretion on the lower beach face extending to the swash zone. All other locations showed a significant amount of erosion, many from the base of the foredune seaward to below the berm. The storm high tide line at False Cape and Back Bay was observed to have reached the front line of dunes, and the high water tide appeared to have penetrated through the dunes at profile line 10 (Sandbridge). Ponding was observed at profile lines 1, 10, and 15. Again, profile line 3 in Virginia Beach was dramatically affected. With the aid of sand pumping, the beach normally slopes gradually from the bulkhead to the waterline, but as a result of the storm, sand was removed by high water within about 0.5 meter horizontally of the boardwalk. The result was a 1-meter vertical scarp less than 0.7 meter from the boardwalk, and a concave-shaped profile.

Recovery from this storm was also very prolonged. Only profile lines 16 and 18 showed any signs of recovery in December. Profile lines 1, 2, 8, 9, 11, and 17 continued to lose sand into December and did not begin to recover until January or February.

The only beach locations showing any significant erosion after the 12 March 1976 storm were at profile lines 3, 5, 7, and 11. A 0.8-meter-high scarp was observed at profile line 6, and several asymmetric cusps oriented northeast through southwest were observed at profile line 7, suggesting that profile line 7 recovered faster than 6, or was significantly less eroded. Profile lines 4, 6, 10, 12, and 13 showed slight accretion, and profile lines 15 and 16 appeared unchanged.

The 10 April 1976 storm was also not a significant storm event. The only profile lines showing any significant erosion were 2, 4, 9, 11, and 12. Remaining unchanged were profile lines 5, 6, 7, 8, 10, 14, and 15. Beach-shore ponding was observed both north and south of profile line 1. Late in the afternoon of 10 April, plunging waves, 45 to 65 meters offshore, were observed in the Virginia Beach area. These waves were significant because they were attaining heights of 3 to 4 meters.

On 10 August 1976, the storm effects from the passing of Hurricane Belle through the study area were surveyed. The only erosion was observed at profile lines 5, 11, 12, 16, and 18. Profile lines 1, 7, 9, 10, and 14 showed overall accretional tendencies, while profile lines 2, 6, and 13 remained unchanged. From the survey data it appeared that sand from the foreshore was eroded and transported onshore with the storm's high water and deposited on the upper beach area. The hurricane passed at low tide, which was probably why erosion was only minimal. Ponding was observed at profile lines 1 and 14.

In summary, there are large variations in beach behavior among the 18 profile locations resulting from storms. Storm erosion was most severe at profile lines 3 (Virginia Beach), 9 (Sandbridge), 11 (Back Bay), and 18 (False Cape). However, some storm events which do a lot of damage at one location, may leave another virtually untouched; e.g., profile line 11 after the 15 March 1975 storm. Recovery time varied directly with severity of storm; the most destructive storms resulted in a longer time of recovery. Beaches in the Virginia Beach area required the most time for storm recovery and is possibly due to the presence of the bulkhead behind the beach. Much of the recovery in the Virginia Beach area is due to sand nourishment, which is increased following storms.

3. Erosion-Accretion Trends Encompassing Historical Profile Data.

A great deal of work has been done in the study area previous to the VIMS-CERC study by a variety of investigators (Table 1). Net volume changes were computed directly from these original survey data (discussed in Sec. III, 5), and then were plotted with the VIMS-CERC data to determine if there appeared to be any long-term trends, and if so, what they were. The plots of survey volume changes with time combined with the older survey data are given in Appendix C. Despite possible weaknesses in the older survey data, several strong trends are clearly apparent. Most of these historical trends coincide with the trends delineated in this VIMS-CERC study.

Fort Story (profile line 1) has been in a definite accretional trend since Fausak's work in 1969. The foredune area has been especially accretional.

Unfortunately, a true picture of exactly what has been going on in the Virginia Beach area cannot be concluded from available data; again the influence of artificial beach nourishment masks the true beach processes here. Of the four locations involved (2 to 5), profile line 2 is probably the least affected. The erosional influence of the Ash Wednesday, 1962 storm and the slow but steady recovery of the location are clearly reflected in the data. Since that storm, the foredune has built vertically some 3 to 4 meters, and the total sand volume is greater than before the storm. This profile line is located in a residential area, and the residents have taken great pains to plant and protect dune grasses and sea oats. Certainly this planting, combined with the downdrift nourishment, has had a major effect on dune recovery and restoration. The remaining Virginia Beach profile lines show slight long-term erosional trends in spite of sand nourishment.

Profile line 8 is the only Dam Neck location for which there is any long-term data. This location, which has appeared to be experiencing an accretional trend (most notably above the high tide line) since the VIMS-CERC study began, appears to be in an erosional (statistically significant) long-term trend.

In Sandbridge, profile line 10 appears to remain in an almost unchanged (only very slightly accretional) long-term trend since July 1969. Surveyed beach volume fluctuations appear to have varied much more widely (i.e., more active) from July 1969 to March 1971, than during the VIMS-CERC study.

The only Back Bay profile line suggestive of a long-term erosional trend appears to be profile line 15. The remaining profile lines (12, 13, and 14) have tended to be accretional, with profile line 14 having the most statistically significant trend of all the Back Bay survey locations.

The three False Cape profile lines (16, 17, and 18) demonstrate long-term accretional trends, with profile line 18 being statistically the most significant. In the foredune areas, some of the pipes have currently almost disappeared from vertical sand accumulation. The statistical significance of the long-term trends is given in Table 8.

In summary, the locations with statistically significant long-term trends that coincide with the 27-month trends of the VIMS-CERC study, are the accretional trends at profile lines 14, 17, and 18. Profile line 8 had a statistically significant long-term erosional trend, and a statistically nonsignificant short-term accretional trend.

4. Periodicity and Seasonality in Long-Term Trends.

Shepard (1958) calls an erosional beach, a winter beach, and an accretional beach, a summer beach because, in California, the damaging waves are in the winter and the "accretional" waves in the summer. Both the yearly beach cycles and long-term cycles (i.e., multiyear) coincide with local climatic conditions.

However, Shepard's winter-summer concept of erosion and accretion may not be directly applicable to southeast Virginia. Galvin and Hayes (1969) state:

"Development of winter profiles on beaches of the U.S. Atlantic coast north of Delaware Bay, and on beaches of the California coast, differs in a way that appears to depend on mean wave climates, and seasonal changes in wave climates of the two regions. Eroded winter profiles, typical of California, are less well developed and sometimes absent on northern Atlantic beaches."

Sonu (1966) also found "profiles resembling the accepted summer and winter type barely several hundred meters apart on the same section of beach," at Cape Hatteras, North Carolina. The seasonal (winter-summer) differential in mean monthly wave heights are much greater for the west coast of the United States than for the east coast. (SPM, Fig. 4-10, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975).

Frisch (1977) calculated the percent time of erosion and accretion at each profile location from the slope of the profile volume change computations in Appendixes B and C (i.e., a time of erosion is defined as the time interval when the profile volume curve has a negative slope, and accretion as the time when the curve has a positive slope). The resulting tables and graphs were then divided into calendar seasons, and the percent of the total time per season that a profile was erosional was calculated.

These data indicated that there is a seasonal cycle of beach changes in southeast Virginia which is dominated by erosion in the fall (late September through late December). This is followed by general accretion, of widely varying amount and spatial distribution, throughout the rest of the year. The percent time of erosion for the falls of 1969, 1970, and 1972 to 1976 were 55, 74, 60, 54, 82, 58, and 78 percent, respectively. The spring was the most accretional period, with an average of 76 percent of the springtime being accretional. The fall erosional trend is very consistent from Cape Henry to the Virginia-North Carolina State line, but the time of accretion varies between profile locations.

5. Currituck County Beach Changes.

Eight trips to the Currituck County ocean front (February 1975 to September 1976) revealed low-gradient, broad beaches for the first 30 kilometers south of the Virginia-North Carolina State line (Figs. 15 and 16). (The VIMS-CERC Currituck County reconnaissance stations, at intervals of 6.4 kilometers starting at the Virginia-North Carolina State line, are indicated on Figure 15.) The next 8 to 9 kilometers of beach encompasses the southern part of Currituck County (the area of the now closed Caffey Inlet in upper Dare County) and beaches just north of the CERC Field Research Facility. This section is represented by narrow, steep beaches with dune scarps, and copious amounts of coarse sand, locally known as "treacherous red sands" because of the difficulty of driving. However, these sands were beginning to show farther north in 1976.

Over the 19 months that data were taken in quarterly reconnaisance trips to this area, little change was observed in the beach widths. The steepness of beach-face slopes decreased slightly (Fig. 16) and beach-face sand grain size remained about the same (Fig. 17). Figure 18 compares the beach-face slope angle to the beach-face sand grain size.

Field observations indicate that the measured high-angle beach faces represent convex-upward accretional berm conditions, and the low-angle beach-face slope angles represent concave erosional beach profile lines. The lowest-angle beaches (i.e., erosional) were measured in April 1976, February 1975, July 1976, and January 1976, and the steepest beaches (i.e., accretional) were measured in May 1975, August 1975, September 1976, and November 1975. These data are thus suggestive of seasonality with erosional beaches in winter and early spring (with one exception in July 1976) and accretional beaches in late spring, summer, and fall.

Richardson (1977) has summarized beach erosion occurrences between 1 November and 30 April for the U.S. east coast (Maine to Virginia) from the U.S. Weather Service records. This tabulation (Table 4) indicates a fall storm period (November and December) and a late winter-early spring storm period (March and April), with a lull in January. Thus, these Currituck County beach slope data

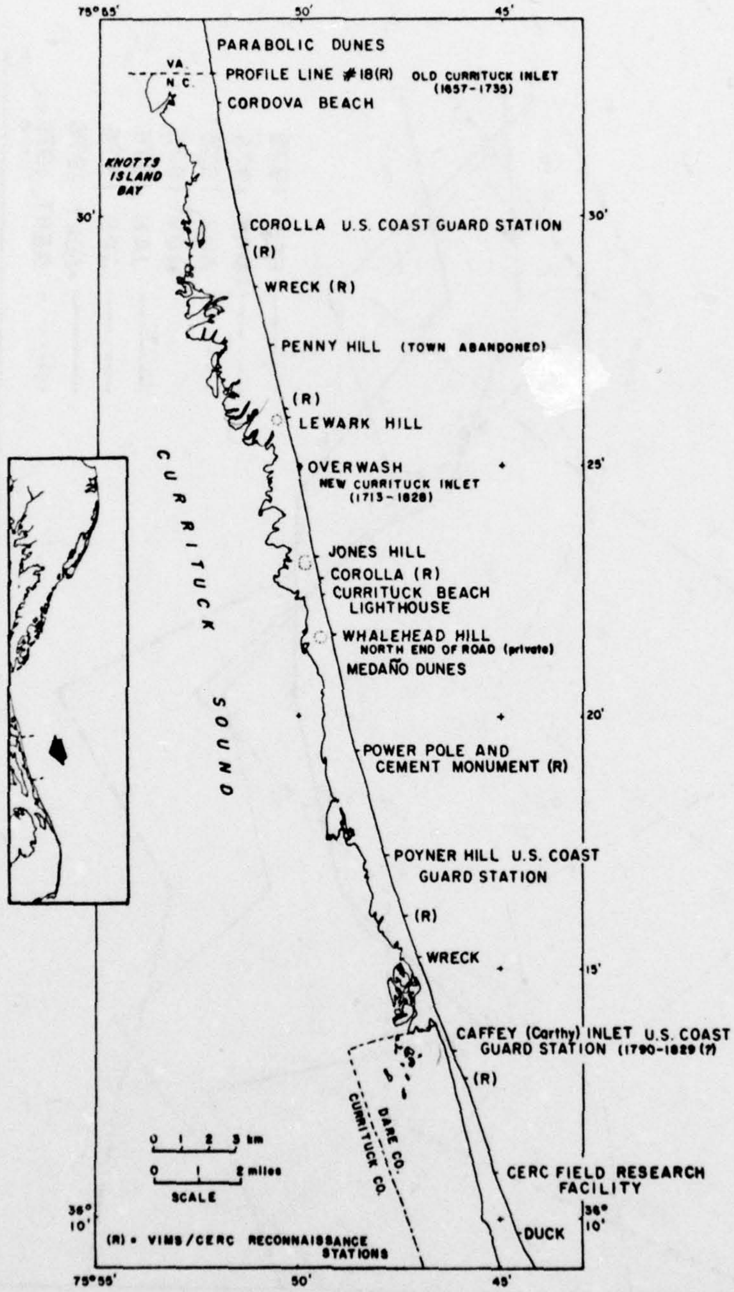


Figure 15. Shoreline map of Currituck County, North Carolina.

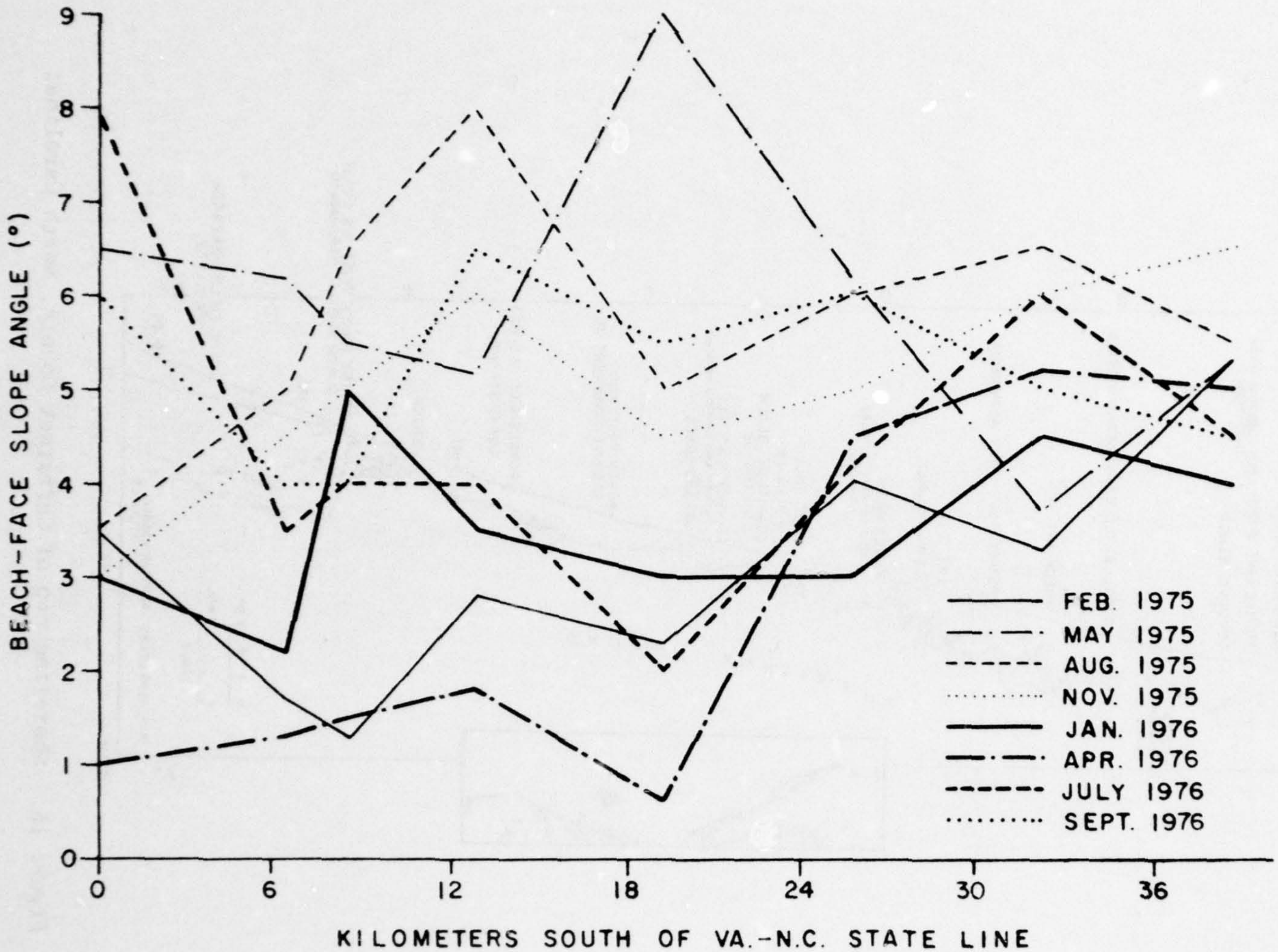


Figure 16. *Beach-face slope angle versus distance in Currituck County, North Carolina.*

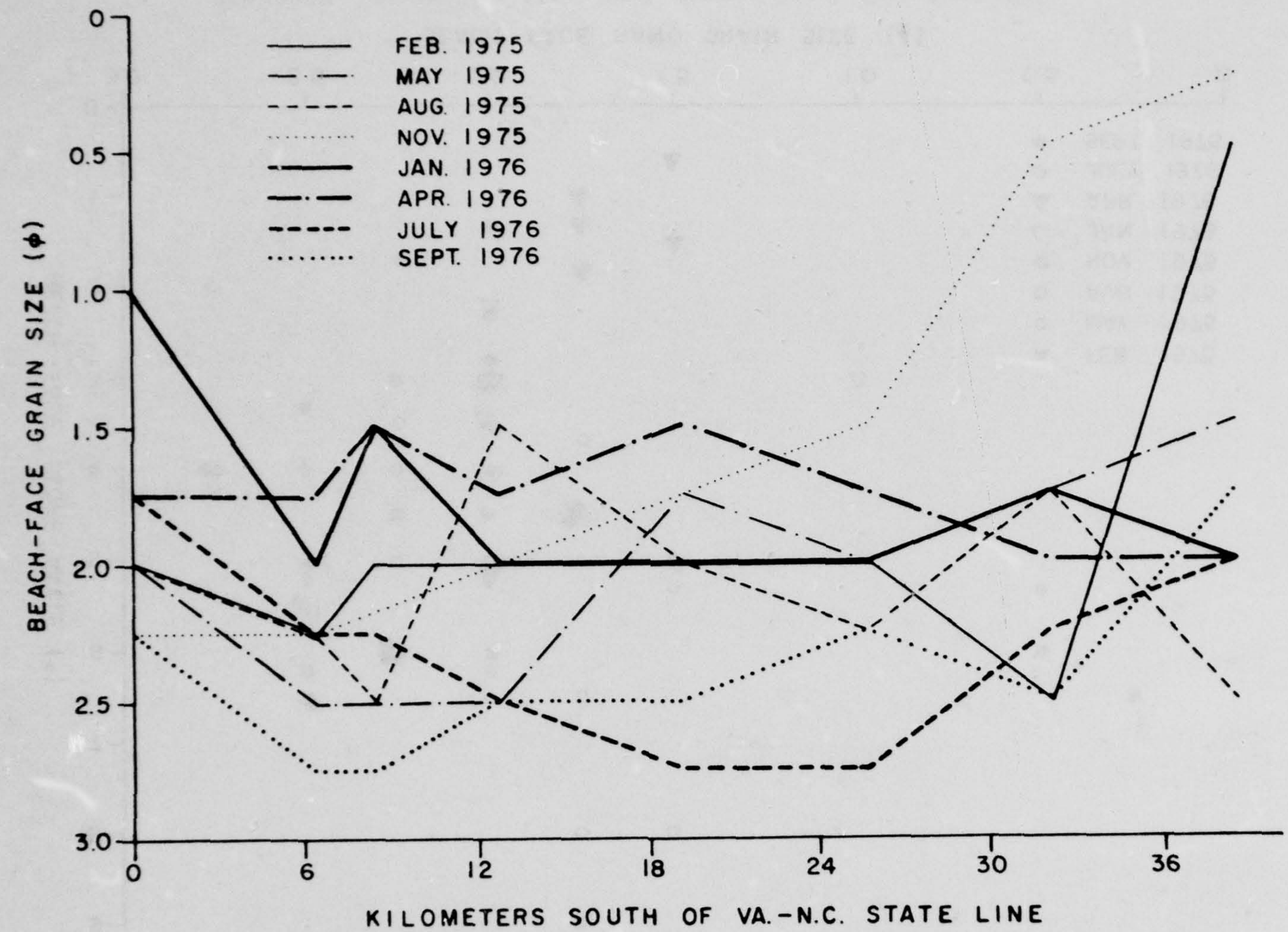


Figure 17. Beach-face sand grain size versus distance in Currituck County, North Carolina.

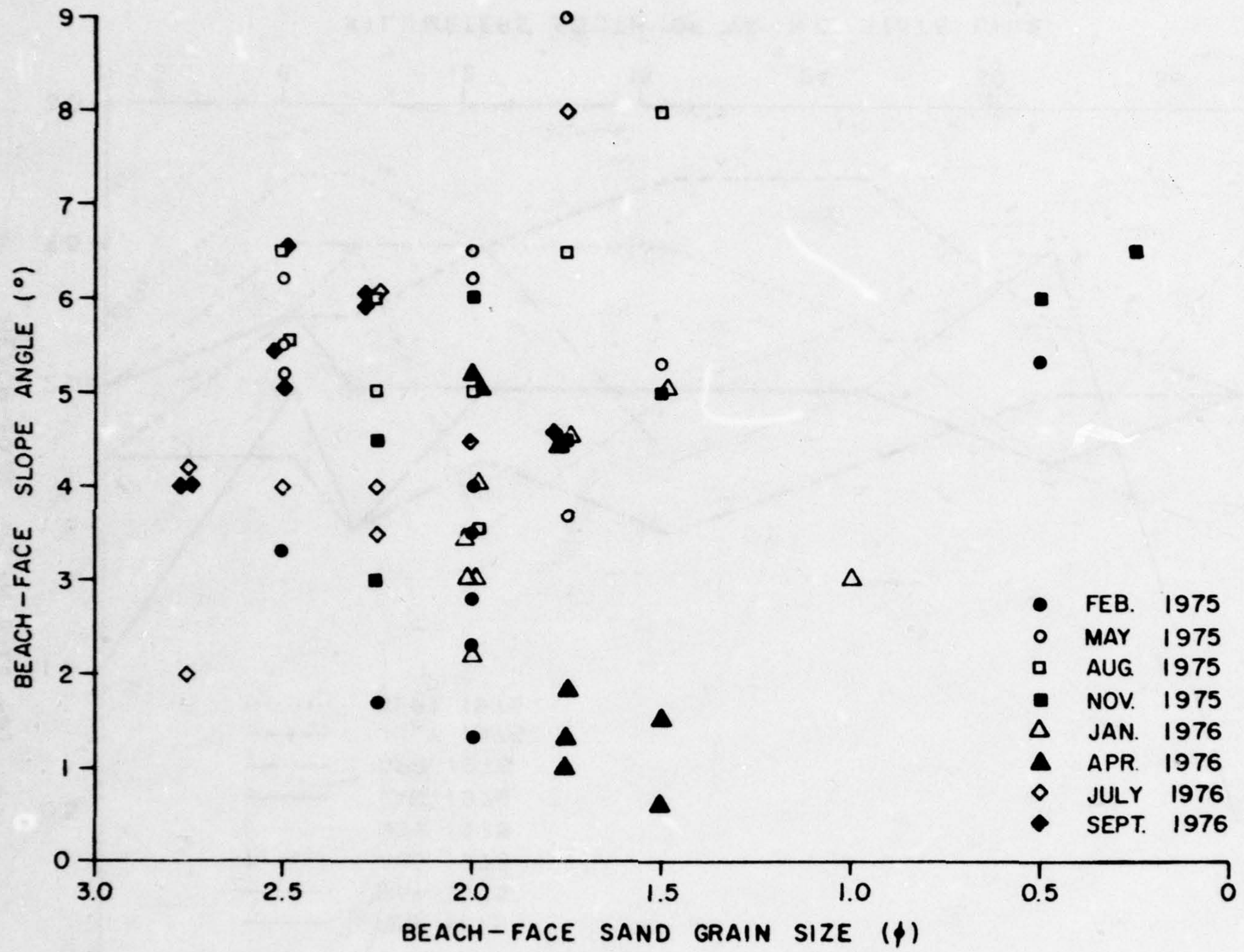


Figure 18. Beach-face slope angle versus beach-face sand grain size in Currituck County, North Carolina.

generally fit other beach erosion seasonality data, with these Currituck data having two exceptions, a fall storm season later than usual in 1975, and a summer storm in July 1976.

Generally, a representative beach in Currituck County would be expected to have a beach-face slope of from 2.5^{o} to 6.5^{o} and a sand grain size ranging from 2.5 to 1.5 phi, with both parameters varying widely. The northern two-thirds of Currituck County has a rather broad beach, with low dunes, and has an increasing amount of coarse red sand showing on the beach surface.

6. Influence of Beach Usage on Beach Behavior.

The study area is divided into four categories by beach usage: natural, residential, commercial (resort), and military (Fig. 2, Sec. II, 4). The area can also be divided into reaches (Table 2). Tables 10 and 11 examine to what degree this variability in beach usage or geographic reaches is reflected in measured beach changes.

It does seem apparent from the high accretion in the commercial area of Virginia Beach (Table 11) that the sand nourishment program is both necessary and successful. As for the erosional value for the natural area, many profile lines in this location are eroding, due in part to the high wave energy concentration in this area (Goldsmith, et al., 1974b). The natural processes appear to dominate over usage effects, as shown by the volume change averages (using CERC's computations), and correlate closely with the variations in beach morphology. It appears that the Virginia Beach commercial area would be far more erosional without the extensive sand nourishment and that this beach fill is necessary for the long-term stability of the Virginia Beach commercial beaches (sec. VII, 3).

VI. RELATIONS BETWEEN PROCESSES AND BEACH CHANGES

1. Storms.

Storms have definite and sometimes long-lasting effects on beach activity in this area (see Section V). The factors affecting storm intensity (of those monitored) are wind direction, windspeed, wind duration, barometric pressure, wind-generated seas, and time of

Table 10. Average cumulative volume changes for four beach usage types.

Beach type	Profile lines	Avg. cum. vol. change[1] (m^3/m)	Annual avg. cum. vol. change ($m^3/m/yr$)
Military	1, 6, 7, 8	+ 6.5	+2.89
Residential	2, 9, 10	+ 2.1	+0.93
Commercial	3, 4, 5	+10.6	+4.71
Natural	11 to 18	- 6.6	-2.93

[1]Over the 27-month survey period.

Table 11. Average cumulative volume changes by reach.

Beach type	Profile lines	Reach	Avg. cum. vol. change[1] (m^3/m)	Annual avg. cum. vol. change ($m^3/m/yr$)
Residential	1, 2	Virginia Beach	+23.7	+10.5
Commercial	3, 4	Virginia Beach	+15.8	+ 7.0
Military	5 to 8	Dam Neck	0.0	0.0
Residential	9, 10	Sandbridge	- 6.5	- 2.9
Natural	11 to 15	Back Bay	-13.6	- 6.0
Natural	16, 17, 18	False Cape	+ 9.6	+ 4.3

[1]Over the 27-month survey period.

tide. If all these factors are in the right conjunction, any given storm (even one considered "moderate") may be extremely destructive; i.e., result in large beach volume changes. However, if some of these factors are working against each other, such as the wind direction and time of tide, the storm may have an insignificant effect on the beach. A summary of storm-related data of storms which occurred during the 27-month study period is given in Appendix D.

Storms are responsible for certain beach features which are only observed during and immediately after storm events. These include ponding, overwash, dune scarps, peat exposure at low tide (after low-intensity storms), and tree stump exposure (at False Cape). Generally, after a particularly high-intensity storm, the entire beach profile is flattened and lowered. Recovery rate appears to be proportional to the duration and intensity of the storm.

All significant beach changes can be related to storm events (and poststorm recovery). However, the largest percent time of erosion is in the fall (Frisch, 1977). The two most dramatic storm events surveyed, Hurricane Amy in July 1975 and the November 1975 storm, were almost equally destructive. These storms came at different times of the year, and neither occurred during the winter (i.e., December 21 to March 21). From the data in Appendix D, it would appear that the common factors for both storms were maximum wave heights greater than 1.5 meters, and a swell height (greater than or equal to 1.5 meters) duration of 12 hours or more. Swells for both storms were east-southeasterly and northeasterly, respectively. Similar data for the other storm events did not reach this intensity.

However, these two storms were only of moderate intensity compared to erosional events observed along these beaches in the 1972 to 1974 pre-CERC study period, and this 27-month study period was a time of relatively low storm-erosion activity in this area. Nevertheless, lack of winter storm-induced beach erosion occurrences (four storms in late March and early April, two in the summer, and three in the fall), despite the small sample, is indeed instructive and correlates well with other studies on the east coast (Bullock, 1971; Goldsmith, 1972; Goldsmith, Farrell, and Goldsmith, 1974a). If the storm sample is limited to the four most erosional events (25 November, 1 July, 1 December, and 3 September), there does indeed appear to the fall extra-tropical storm, beach-erosion period, and an early tropical storm season in 1976. The appears to correlate with the data of Richardson (1977), as discussed in Section V, 5. In summary, neither the beach survey data, nor the storm occurrences during this study, support the "classic winter erosion and summer accretion" on beaches observed on the U.S. west coast.

2. Waves

During the 27 months of study, wave data were collected daily at various locations (see Fig. 2 and App. H) and included wave period (in seconds), wave height (in feet), and wave direction (degrees). Wave data were also taken at each monthly surveying session.

Inspection of the data showed that often there was significant variance between locations in data taken on the same days, most notably in wave periods. This variance is believed to be due to a human factor rather than dramatic shoreline variations in wave periods.

Table 12 represents a compilation of the daily volunteer wave observer data organized according to location and season. It is apparent that there is too much variance in the data and too few locations to organize the data according to beach type (e.g., commercial versus natural beaches) and to attempt any detailed analyses. In organizing the data by seasons it appears that the largest wave heights occur in the summer months and the lowest wave heights in the spring and winter, while the longest wave periods seem to occur during the summer. Most of the storms surveyed occurred during the fall and spring. However, these wave data vary widely between observers (especially wave periods), and the seasonal differences for most observers are probably statistically nonsignificant.

Figures 19 and 20 are compiled from wave observations made at each surveying session. The plots represent average breaker height and average wave period plus or minus one standard deviation, for each of the 18 survey locations. These data were taken during nonstorm conditions at 1-month intervals and during different stages of the tide and time of day. Average breaker height (Fig. 19) appears to have a slight trend of increasing wave height to the south (0.8 plus or minus 0.3 meter at the south end and 0.6 plus or minus 0.3 meter at the north end), which would correlate with the narrowing of the Continental Shelf to the south. This trend is missing from average wave period (Fig. 20), which appears to show more variation between locations.

Wave refraction and the effect the resulting nonuniform shoreline wave energy concentration has on beach behavior, are presented in refraction diagrams in Goldsmith, et al. (1974b) and the Virginian Sea Wave Climate Model Data Bank at VIMS. In summary, the shoreline wave energy distributions for this area correlate well with the observed beach changes. Specifically:

Table 12. Daily volunteer wave observations averaged by season, July 1974 to November 1976. (See Fig. 2 for locations)

	Winter			Spring			Summer			Fall			
Observation sites (north to south)	Period (s)	Wave Height (ft)	Direction (°)	Period (s)	Wave Height (ft)	Direction (°)	Period (s)	Wave Height (ft)	Direction (°)	Period (s)	Wave Height (ft)	Direction (°)	Total Observations
73d St.	6.5	1.7	94.5	6.7	1.7	89.1							168
39th St.	8.1	2.0	83.4										28
Howard Johnson				7.7	1.5	100.8							9
Hilton Inn							6.5	1.9	90.4	5.3	1.2	90.9	306
7th St., Virginia Beach	10.8	1.9	91.1	9.7	2.3	91.4	10.8	2.0	98.0	10.9	2.6	91.7	341
Dam Neck	8.7	1.5	91.3	8.6	1.3	91.4	10.5	2.0	97.5	10.3	2.1	89.9	529
Sandbridge	9.4	1.9	93.3	8.3	2.7	87.1							39
Beacon	7.0	1.7	75.5	8.9	1.4	93.0	8.4	2.5	93.4	9.9	1.9	94.5	268
Back Bay	7.9	1.3	76.9	7.5	1.2	88.5	7.9	3.5	85.0	4.4	1.6	70.0	120
Currituck Beach Lt.				8.1	2.2	87.8	7.7	2.2	91.3				74
Total Observations													1,882
Mean	8.5	1.7		8.6	1.6		9.2	2.2		8.9	2.0		
Standard deviation	1.5	0.2		0.9	0.4		1.6	0.4		2.4	0.5		

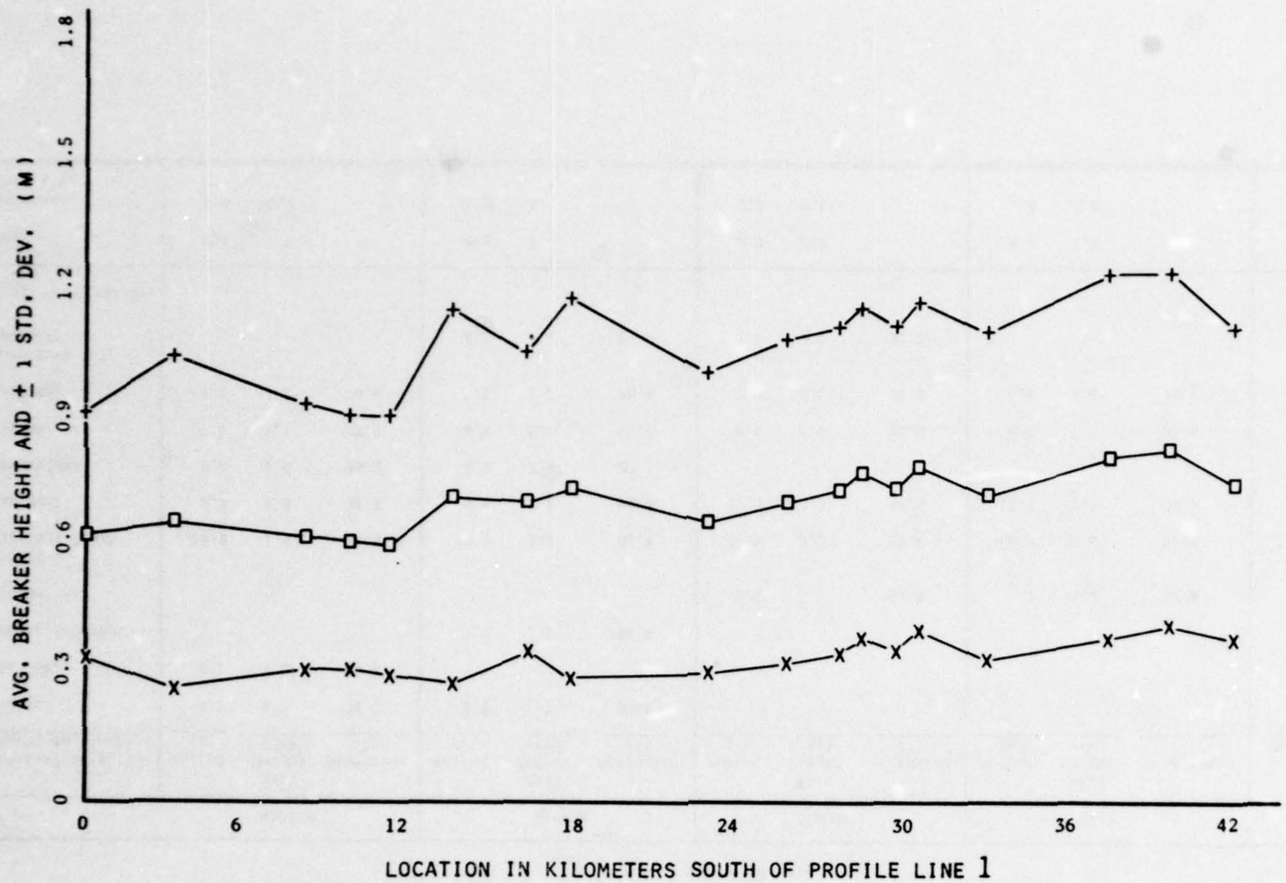


Figure 19. Average breaker height at the 18 survey locations based on 25 observations at each profile location (1974-1976).

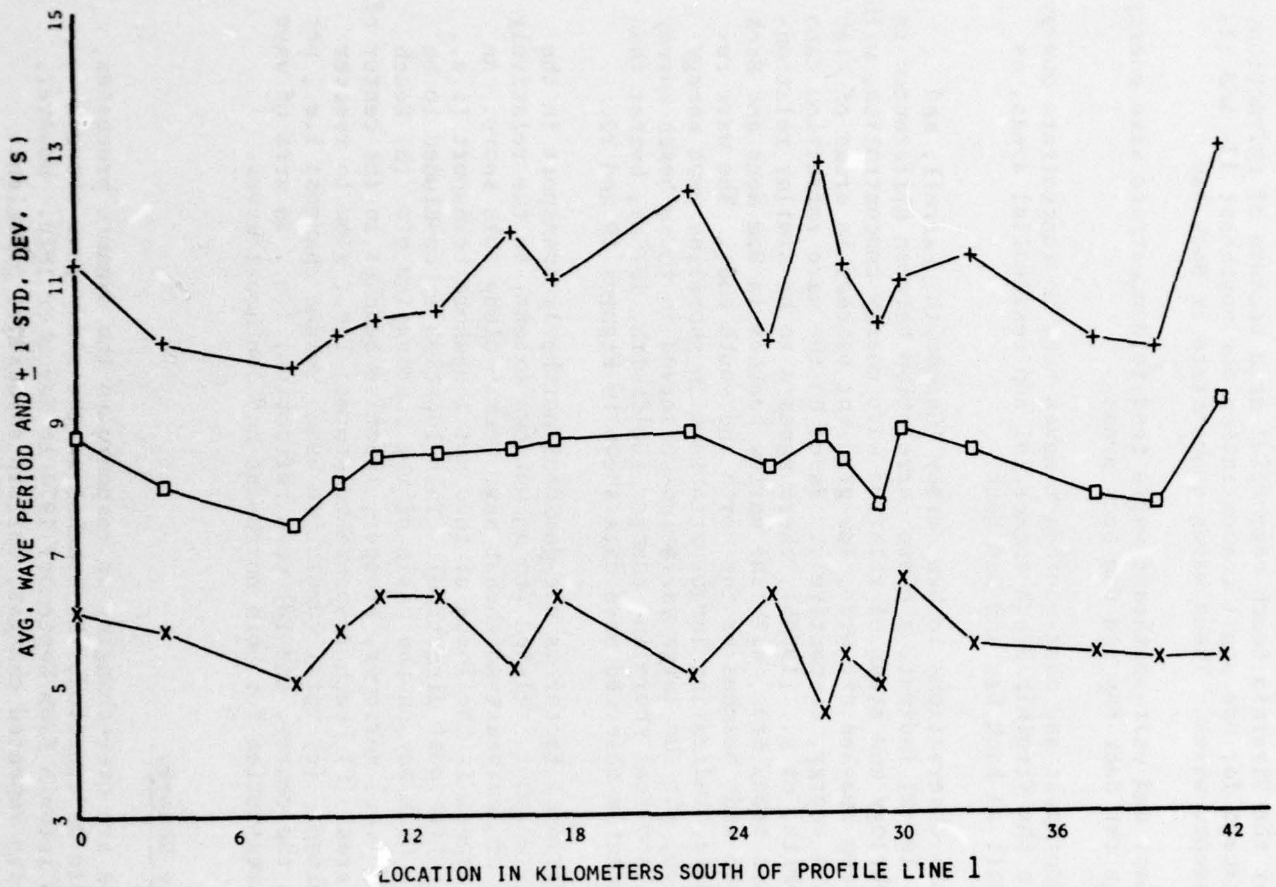


Figure 20. Average breaker period at the 18 survey locations based on 25 observations at each profile location (1974-1976).

(a) Northeast, north-northeast and east-northeast waves of periods greater than or equal to 8 seconds are diminished in intensity at the Virginia Beach commercial area because of refraction, except for one small concentration for northeast 12- and 14-second waves. These waves concentrate in Back Bay.

(b) East and east-southeast waves tend to concentrate wave energy in the Back Bay and Dam Neck areas.

(c) Southeast and east-southeast waves tend to concentrate energy in the Virginia Beach commercial and residential areas, as well as Back Bay and Dam Neck.

Previous observations in New Jersey (Goldsmith, Farrell, and Goldsmith, 1974a) indicate a close correlation between differences in beach morphology and areas of relative wave energy concentration, with narrow, steep beaches and wide, low-gradient beaches in areas of high and low wave energy, respectively. Based on the wave refraction data from Goldsmith, et al. (1974b), there appears to be similar relationship in this study area, with the narrow beaches in Dam Neck and Back Bay, and the wide beaches at the north and south ends. The wave refraction data, indicating large variations in shoreline wave energy distribution, fit the large variations observed in these beach survey data and historical shoreline changes (Goldsmith, 1975c), better than the infrequently observed wave data shown in Figures 19 and 20.

An additional factor is the dominant northerly transport in the study area, which is related (to an unknown extent) to the relatively high ratio of southeast-northeast wave energy along this shore. An important aspect is the locus of zero net longshore transport (i.e., reversal of transport direction). This location is concluded to be adjacent to Back Bay on the basis of the combination of: (a) Beach morphology; i.e., narrower, steeper, inactive beaches in the center of the study area, (b) beach response to storms; i.e., slow to recover eroded sediment, (c) total cumulative beach volume changes; i.e., net erosion in the center, and (d) wave refraction; i.e., an area of wave energy concentration for both northeast and southeast waves.

3. Profile Shapes.

Beaches are ever-changing in response to the dynamic processes, and as would be expected, the beaches in the study have changed during the interim from September 1974 to November 1976. However, despite these repeated changes, certain shapes are prevalent.

Generally, beaches at profile lines 1 and 14 to 18 are wide and flat; profile lines 2 to 13 are narrow and steep with a well-defined convex-upward profile shape. Whereas, profile lines 2 to 8 and 14 to 17 tend to be active, profile lines 9 to 13 tend to be inactive. These characteristics were maintained throughout the course of the study; however, individual profile lines have changed somewhat in shape. These two general types of shapes are exemplified in comparisons of profile lines 1 and 9 (Figs. 21 and 22).

Profile line 1 has accreted phenomenally, especially from the berm area seaward. Also, the beach has become even flatter in appearance.

It is difficult to assess natural beach processes in Virginia Beach (profile lines 2 to 5) because of the presence of the concrete bulkhead behind the beach, and because of the influence of the beach nourishment program. None of the profile lines in this area have changed much in appearance, although profile lines 4 and 5 have eroded slightly above the berm and accreted slightly from just below the berm area to MLW.

At Dam Neck, profile lines 6 and 8 have accreted somewhat in the dune area. At profile line 6, it is now necessary to dig down into the sand to find the survey pipe (in September 1974 the pipe height was 0.4 meter above the sand level; in November 1976 the pipe was 0.2 meter below the sand level), resulting in a prevailing concave-upward shape.

Profile line 7 has accreted slightly, especially in the area of the berm, but remains otherwise unchanged.

In the Sandbridge area profile line 9 has maintained a slight overall erosional trend over the survey location, while profile line 10 has accreted in the foredune area and eroded from the berm area seaward.

In the Back Bay National Wildlife Refuge area (profile lines 11 to 15), possibly the most dramatic change in shape has taken place at profile line 12 between pipe 1 and the narrow front foredune. Here the wind has blown sand into an area that had been scoured out, and while the area has not been entirely filled, the change has been significant. Profile line 11 has lost sand from the base of the dune seaward; profile lines 12 and 15 have remained virtually unchanged in shape. Profile lines 13 and 14 have accreted from the dune to the berm area, and eroded from the berm seaward.

In False Cape, profile line 16 has accreted at the top of the dune, and remains otherwise almost unchanged. Profile line 17 has built up from the Raydist pole (location of pipe 1) to the base of the dune and

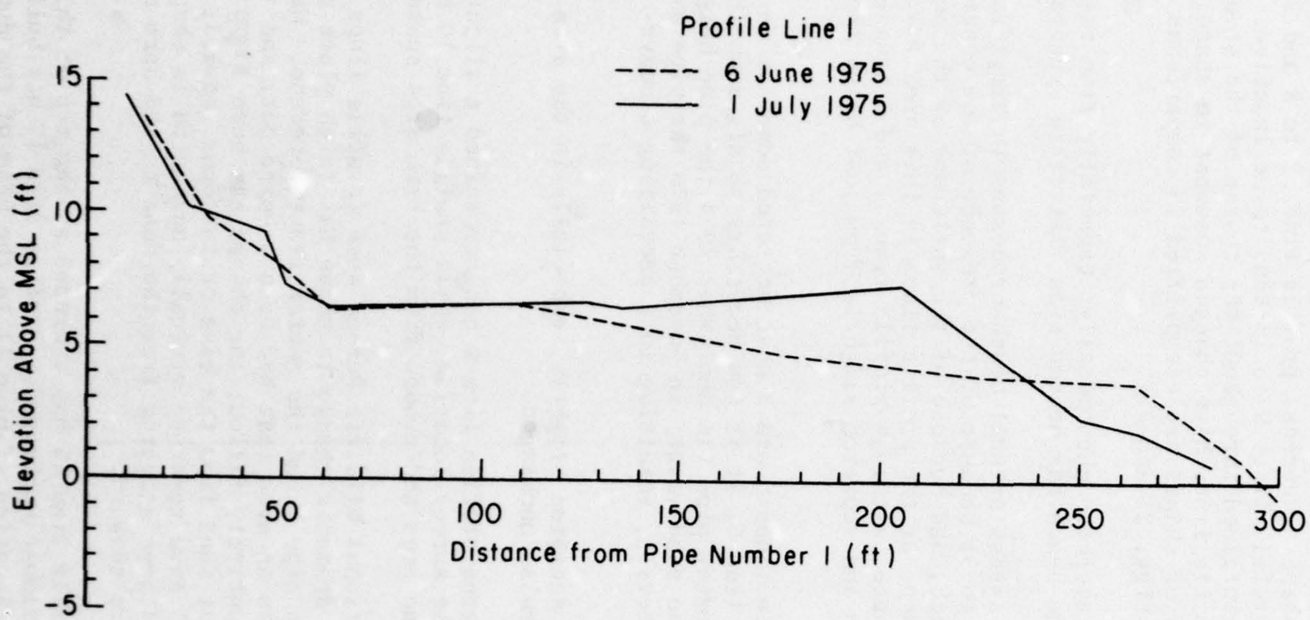


Figure 21. Typical profiles at wide, accreting beach showing both accretional (6 June 1975) and erosional (1 July 1975) shapes. Dropoff at seaward end due to channel.

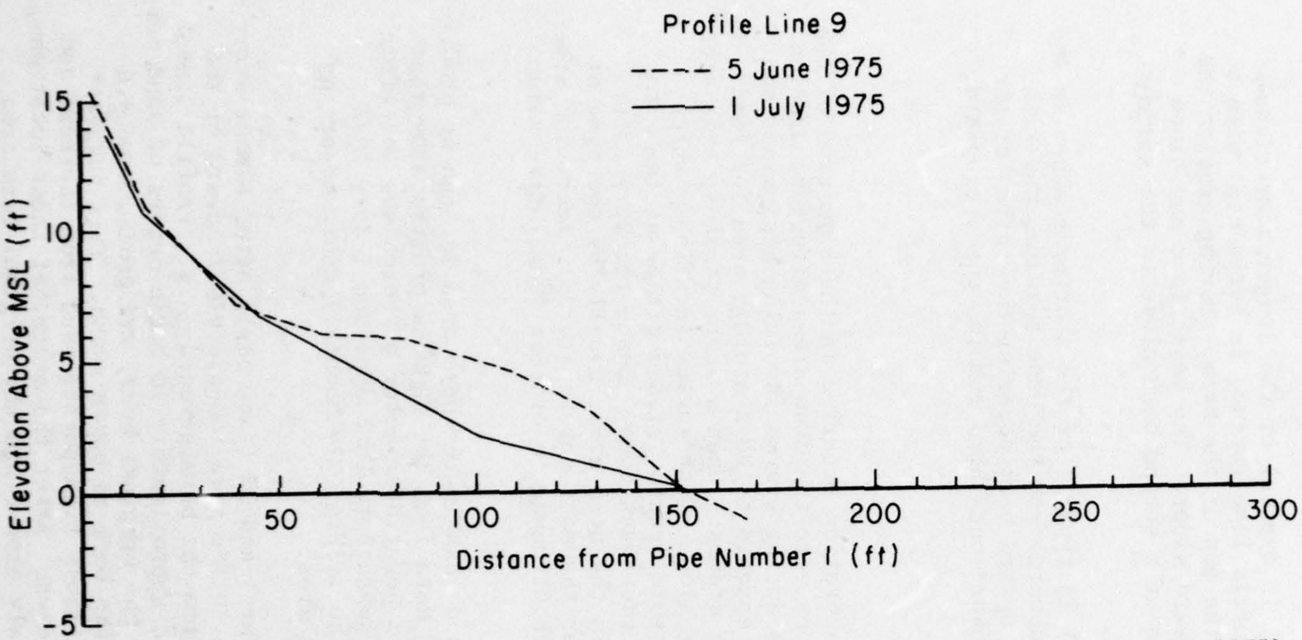


Figure 22. Typical profiles at narrow beach showing both accretional (5 June 1975) and erosional (1 July 1975) shapes. Compare with changes at profile line 1 during same period (Fig. 21).

has eroded from the area below the berm seaward. Profile line 18 has demonstrated very little change in shape.

Profile line 1 (Fig. 21) is typical of the longer, accretional beaches. Generally, the profile line surface is horizontal with a slight landward slope from the top of the berm. During erosion the beach face has a concave-upward slope. The beach face may slope convex-upward with formation of a second berm close to the spring high tide swash.

Profile line 9 (Fig. 22) is typical of the shorter beaches in the study area. It is concave-upward from the dune seaward, and with accretion there is a convex-upward berm covering two-thirds of the profile. The remaining landward one-third remains concave-upward.

4. Sand Storage.

Generally, erosion and accretion occurred in the berm area of the beach. On only rare occasions were the dune areas affected; erosion only occurred in these areas during storms involving high winds and high storm tides. The berm appears to be a storage area for sand during quiet periods between storms. When a storm strikes, this area is the most vulnerable to erosion. Most survey locations, which experienced erosion during storm events, eroded either at the berm, or from the berm seaward to the swash zone. Beach recovery after storms was most noticeable in the berm area, usually by the time of the next survey, except after the most severe storms. Accretion after storm recovery was usually about equal to erosion (cumulative volume) during the storm event.

A specific example of sand loss in the berm area is seen at profile line 9 (Fig. 22). Computing data from the COMPARE program show that about 15 cubic meters of sand per linear meter of beach was lost from the base of the dune to MLW swash between 6 June and 1 July 1975. Concomitantly, at profile line 1 (Fig. 21) about 17 cubic meters of sand accumulated in the berm area.

Profile lines 1 (Cape Henry) and 12 (Back Bay), after almost every storm, experienced accretion in the area immediately landward of the original berm, and erosion from the berm seaward; e.g., Profile line 1 during Hurricane Amy accreted approximately 16 cubic meters of sand per linear meter of beach behind the original berm, and eroded some 4.6 cubic meters per meter from the berm to upper swash. This suggests that high water and winds possibly transported sand from the berm and deposited it higher on the beach. After the storm, at these locations, the storm accretion area slowly eroded and the original berm area began to rebuild. The beaches at profile lines 2 (Virginia Beach), 8 (Dam Neck), 9 (Sandbridge), and 11 (Back Bay) usually experienced overall total erosion from the base of the foredune seaward. The remaining profile lines were usually erosional only in the berm area.

In the Virginia Beach area (especially profile line 3), the berm appears to be "moving" seaward. This is probably due to the effects of sand pumping (beach nourishment) in the area.

Since wave-induced, dune-scarp erosion was negligible during this study, nothing can be said here about the dunes as storage and replacement for beach wave erosion. However, there was significant wind erosion (from southwesterly winds) in the narrow foredune (5 meters wide) adjacent to profile line 12. This wind erosion resulted in a "breakthrough" in this dune from the landward side about halfway through the study, and significant eolian transport through this opening was subsequently observed. Also, it was apparent that significant eolian transport was occurring in both onshore and offshore directions through this opening, and resulted in significant infilling between pipe 1 and the front foredune. This infilling occurred from both the beach and the back part of the island, and further supports Leatherman's (1976) studies on Assateague (as discussed in Section IV, 6).

VII. SUMMARY

1. Characteristics of Southeastern Virginia Beaches.

The extensive data reported in this study may be succinctly summarized as follows:

(a) The shore in this area is characterized by two reaches of net accretion, separated by one reach of net erosion. Cape Henry (profile line 1) at the north end and False Cape State Park (profile lines 15 and 18) at the south end are accreting at an average rate of 4.9 cubic meters per meter per year while the reach from Dam Neck to Back Bay (profile lines 8 to 15) is eroding at an average rate of -4.7 cubic meters per meter per year (Figs. 13 and 14 and Table 11).

(b) Most profile lines underwent large monthly volume changes relative to total net volume changes (App. I). Statistically significant (at 99 percent level) 27-month accretional trends are delineated at profile lines 1, 14, 16, and 18, and statistically significant erosional trends are delineated at profile lines 3, 6, 9, and 11 (Table 7 and App. B).

(c) When combined with older survey data at 14 of the same 18 locations, the same erosion and accretion trends are apparent at most locations for the past 8 years, which encompasses a time of greater storm-induced erosion (1972-1974) than the 1974-1976 VIMS-CERC study (Table 8 and App. C).

(d) The erosion and accretion measured at these locations correlate well with the observed beach morphology, with wide, low-gradient, active beaches at the ends of the study area, and narrow, steep, relatively inactive beaches in the middle (Figs. 21, 22, and 23).

(e) The ridge and runnel features which characterize the post-storm rebuilding of beaches in many localities were totally absent in the study area.

(f) The 27-month study period was a time of relatively low storm-induced beach erosion, when compared with beach surveys measured during the 1972-1974 time period. Two moderate storms (25 November 1975 and 1 July 1975) caused erosion, which varied widely in amount and time of recovery among the survey locations.

(g) Analysis of both the 27-month and long-term profile data by Frisch (1977) indicated a seasonal cycle of beach changes in southeast Virginia which is dominated by erosion in the fall. Between 1972 and 1976, the average percent time of erosion in the fall was 65 percent. Fall is defined by Frisch (1977) as late September through late December.

(h) There was no apparent relation between beach response and the four major usage types defined for this area (commercial, residential, military, and natural)(Table 10).

(i) The Virginia Beach commercial area would be erosional without the extensive sand nourishment which is necessary for the maintenance of the commercial beaches.

2. Coastal Engineering Implications.

It is important to understand the basic processes of the area to undertake any remedial measurements. Remedial measures, in the form

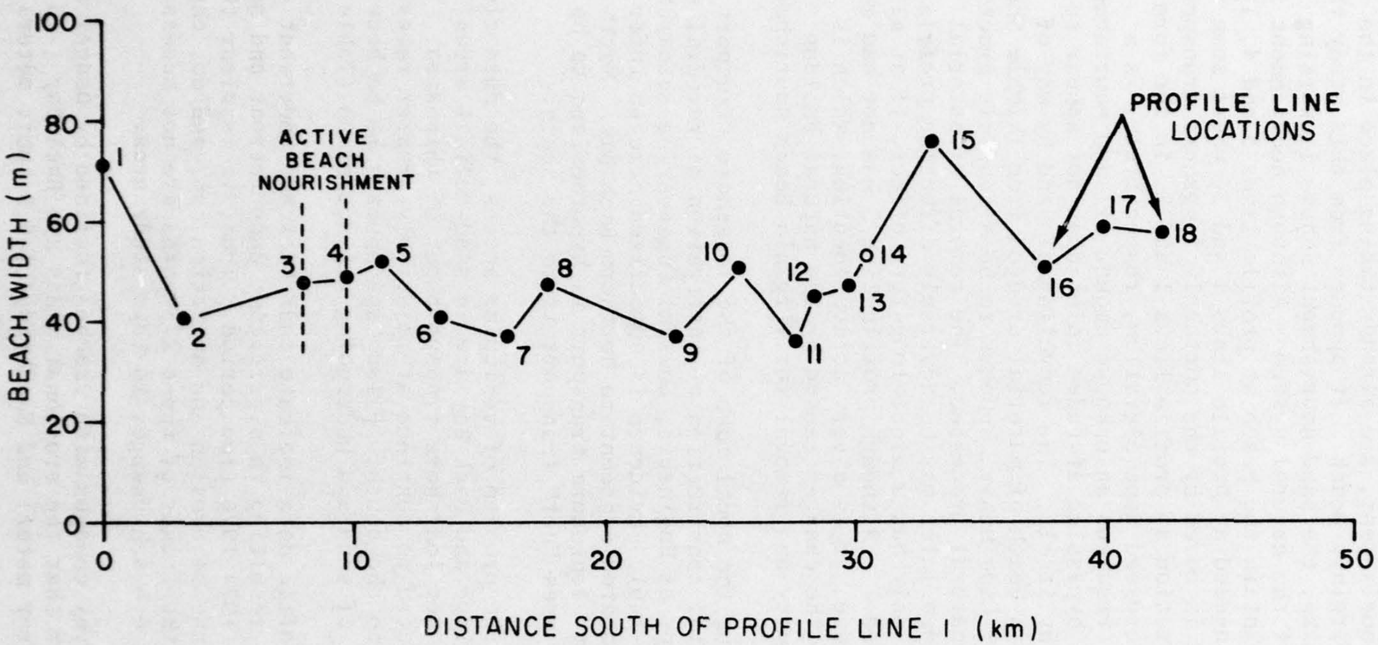


Figure 23. Mean beach width at 18 profile lines, September 1974 to November 1976. "Beach width" is from mean sea level to the base of the dune, or equivalent.

of extensive beach nourishment, are already taking place in the commercial area of Virginia Beach. It appears from this study that, as presently undertaken, the sand nourishment scheme is working within the context of the natural system. Although nourishment is clearly needed to maintain the beach at profile lines 3 and 4, it is unclear if it is needed at profile lines 1 and 2, where some of the nourishment sand is moved by the northerly longshore transport system. The net accretion at profile lines 1 and 2, in the form of widened beach and increased dune elevation, respectively, is a natural process, but requires an unknown amount of sand nourishment to occur. The inlet bypassing at Rudee Inlet does not appear to be a sufficient supply by itself. The recycling of sand by way of truck haul to Virginia Beach of material dredged from Thimble Shoals Channel, northwest of Cape Henry, appears to be a sensible practice with respect to the natural processes. The removal of material from the south side of Rudee Inlet may be adversely affecting profile line 5, but probably only has a minor long-term effect, if at all, on profile lines 6 and 7. Although profile line 5 has not had much net beach volume change, it is a very active location, which is probably affected by the changes caused by the natural buildup behind Rudee Inlet jetty and removal for Virginia Beach nourishment.

Certainly, knowing the nodal zone of the longshore transport is critical to any coastal construction or instigation of remedial measures (SPM, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975, pp. 4-142 to 4-146). Evidence is summarized here to infer that this nodal zone is located adjacent to northern Back Bay. North of this area the "net" longshore transport is hypothesized to be to the north; south of this area "net" transport is to the south.

With respect to the problem of vehicular access, the data clearly indicate that Sandbridge and Back Bay are in sand-deficit areas, which is attributed to the net longshore transport out of this area. Thus, erosion may be predicted to continue at relatively greater rates than perhaps, False Cape to the south. False Cape appears to be benefiting by a relative influx of sand and undergoing net accretion (Table 11).

The 1972-1974 profile data indicate that Back Bay underwent much more severe erosion, resulting in significant dune retreat and narrower beaches, than in the 1974-1976 time period. Thus, it is clear that both rates and patterns of erosion and accretion can, and do, change with time, and that the trends of these 27 months are not necessarily an indicator of future beach changes in this study area.

When the net survey changes with reaches (defined by usage) are averaged, it is clear that the erosional areas are Back Bay (-13.6 cubic meters per linear meter) and Sandbridge (-6.5 cubic meters per linear meter) (Table 11), at the middle of the study area, and the most accretional area is Virginia Beach, residential (+23.7 cubic meters per linear meter). False Cape, at the end of the study area, is also accretional (+9.6 cubic meters per linear meter).

Since the commercial area of Virginia Beach has been very slightly net accretional (Table 11) during the 27-month study, it is of some interest to determine how much of this is natural and how much is due to the ongoing sand nourishment program. Table 5 indicates an average annual fill (over the last 25 years) of 236,000 cubic yards per year (179,360 cubic meters). Based on field observations and aerial photographs between profile measurements, it is estimated that the reach most directly affected by the fill placement is about 3.4 miles (5.5 kilometers) long, north from Rudee Inlet. This calculates (236,000 cubic yards per 17,952 feet) to 13.1 cubic yards per linear foot of beach (32.8 cubic meters per linear meter). Further, assuming that only about 50 percent of the beach fill is retained (because of size characteristics and profile adjustments, as observed), this further reduces to +6.5 cubic yards per foot per year (16.3 cubic meters per linear meter). Since the annual average measured volume change (Table 11) in this reach was +7.0 cubic meters per linear meter, or far less than the average annual nourishment (about 43 percent), it becomes quite evident that beach nourishment is essential. Further, without the beach nourishment in this section, the expected beach erosion is estimated to be about -9 cubic meters per linear meter of beach per year. Although these calculations are only an approximation, it is quite clear that a continuing nourishment program is required for these beaches. It should also be noted that the nourishment also has a very beneficial effect on the updrift Virginia Beach residential area (Table 11) due to the longshore transport processes, though this amount is much harder to determine.

3. Implications for the CERC Field Research Facility Studies.

The new research pier is located in northern Dare County, North Carolina, approximately 5 kilometers south of the Currituck-Dare County line and approximately 42 kilometers south of the Virginia-North Carolina State line. In general, the beaches in this immediate vicinity are narrow and steep, with very apparent dune scarps (greater than or equal to 3 meters) reached by every storm. These beaches do not resemble, in morphology or response, those closer to the Virginia State line or those in southeast Virginia.

With respect to beach-face slope and grain size, the 4-kilometer area immediately north of Duck was relatively stable in 1975 and

1976. However, there were wide variations in these parameters in the northernmost 30 kilometers of North Carolina beach, with no apparent relation between beach-face slope and grain size.

The large variations in grain size were observed to be due to longshore fluctuations in the coarse red sand. These fluctuations, which ranged between 4 and 20 kilometers north of Duck, were quite visible during the monthly aerial flights.

The high- and low-angle beach faces measured in Currituck County were observed to be indications of convex-accretional and concave-erosional profile lines, respectively. The steepest beaches were measured in May, August, September, and November; the lowest angle beaches were measured in April, February, July, and January, respectively.

These data provide background information useful for planning of experiments at the new CERC Field Research Facility, just as the Virginia data provide information useful for study and analysis of that shore area.

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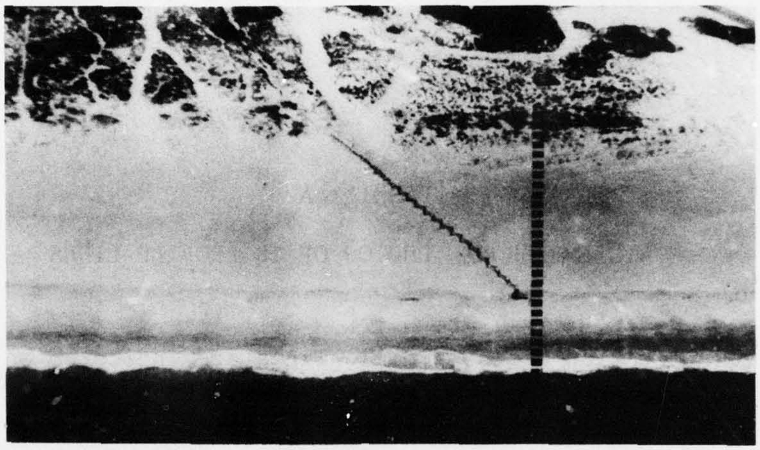
APPENDIX A

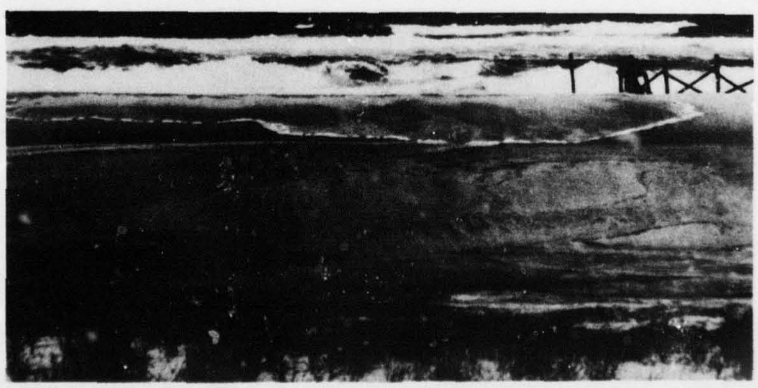
AIR AND GROUND PHOTOS OF 18 PROFILE LINES

The location of the profile lines are indicated on the aerial photos.

Profile Line 1



12 February 1976



1 July 1975

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BEACH EROSION AND ACCRETION AT VIRGINIA BEACH, VIRGINIA, AND VI--ETC(U)
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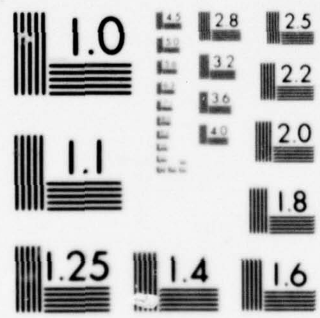

MICROCOPY RESOLUTION TEST CHART
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Profile Line 1

6 August 1975

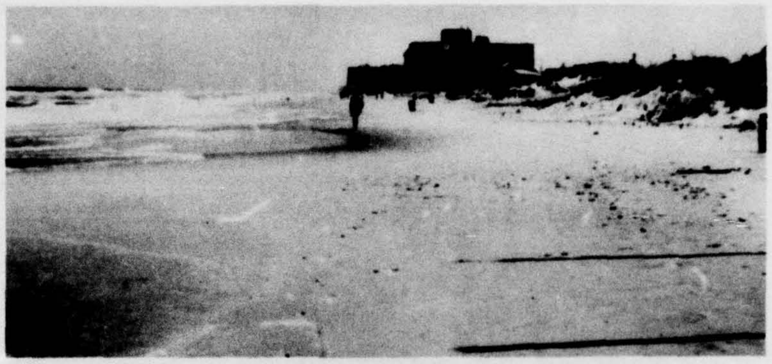
10 August 1976

Profile Line 2

12 February 1976

5 May 1975

Profile Line 2



1 July 1975

12 February 1976

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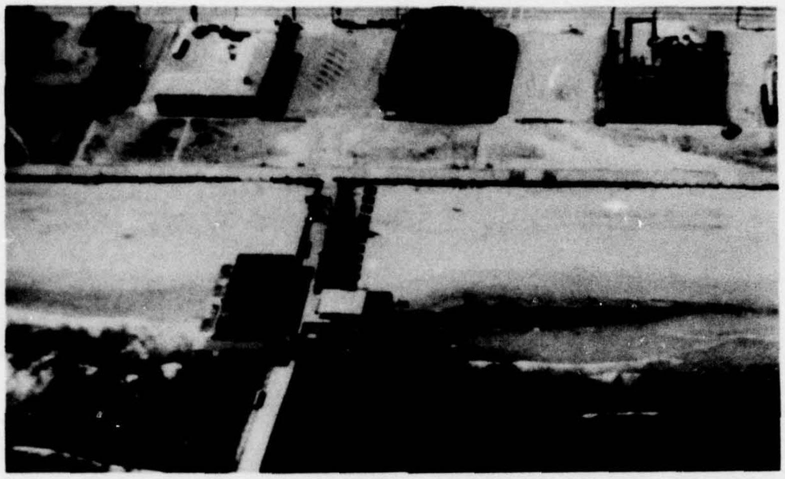


12 February 1976

1 July 1975

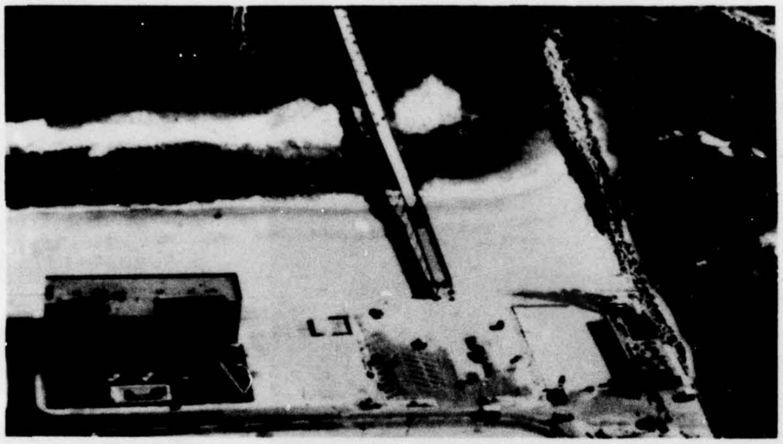
Profile Line 3

5 August 1975

25 November 1975

9 June 1976

Profile Line 4



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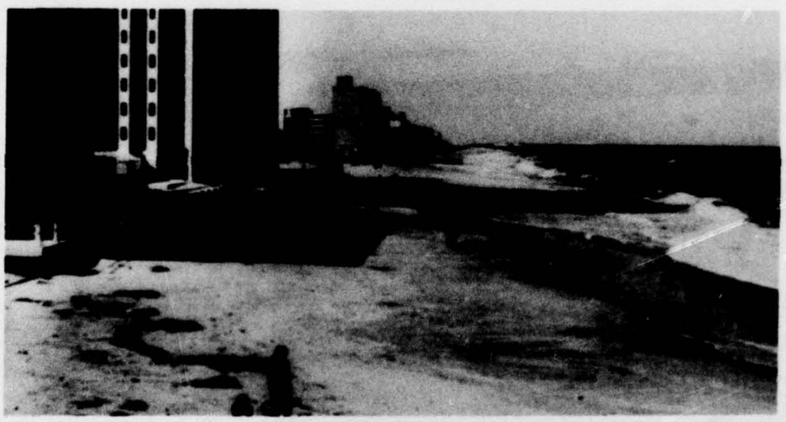
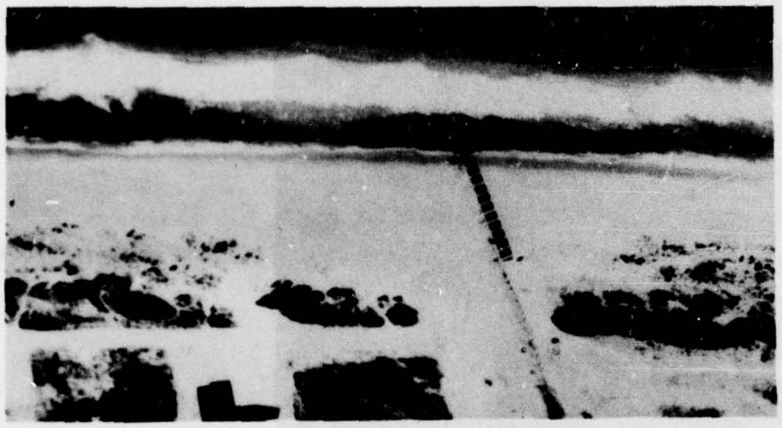


20 March 1975

3 September 1975

Profile Line 5



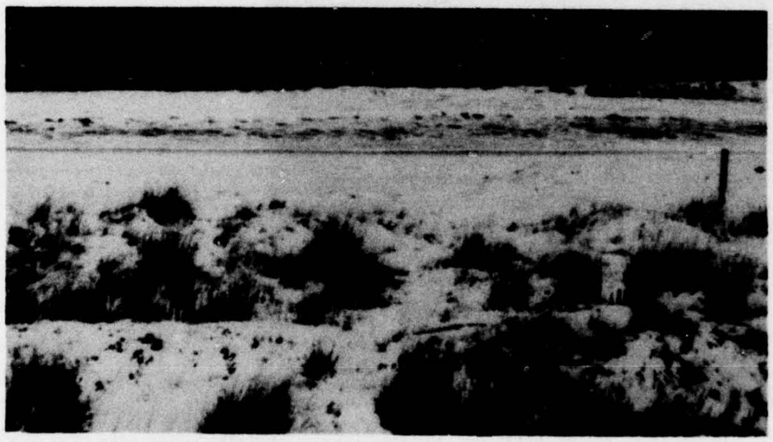
12 February 1976

10 April 1976

5 June 1975

Profile Line 6

12 February 1976



7 April 1975

1 July 1975

Profile Line 7

12 February 1976

5 May 1975

5 October 1976

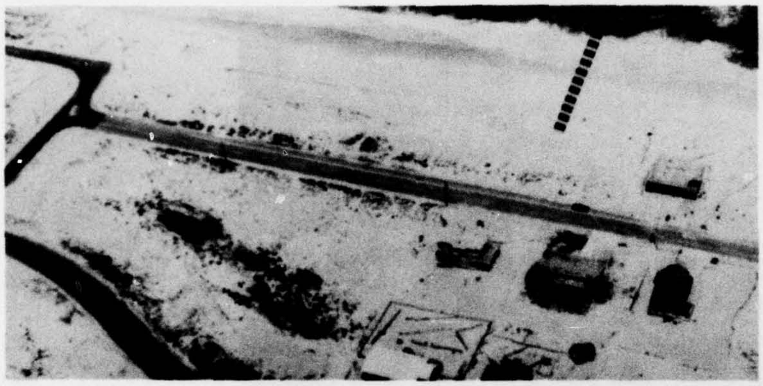
Profile Line 8

12 February 1976

5 August 1975

25 November 1975

Profile Line 9



4 May 1976

8 September 1975

25 November 1975

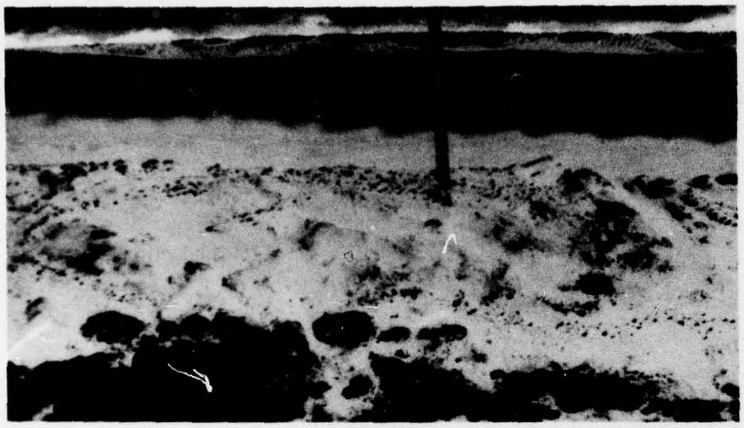
Profile Line 10

12 February 1976

5 May 1975

25 November 1975

Profile Line 11

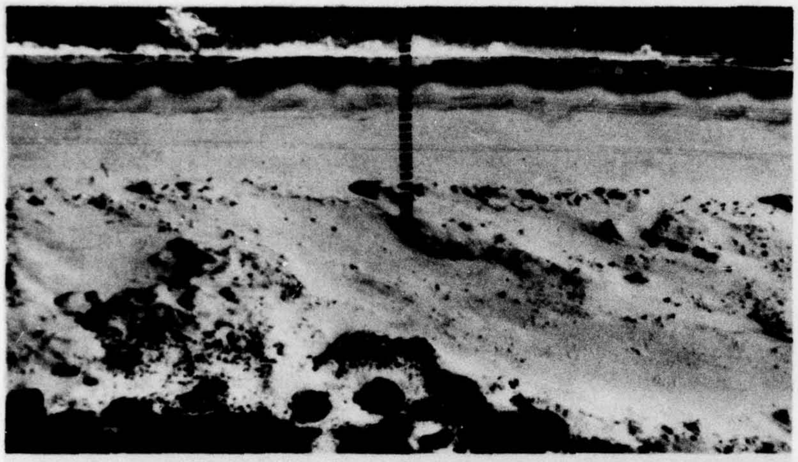


12 February 1976

25 November 1975

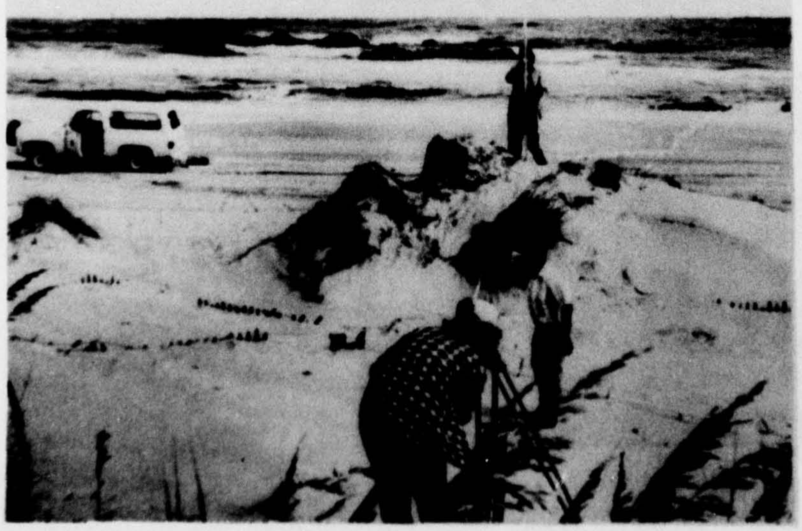
12 February 1976

Profile Line 12



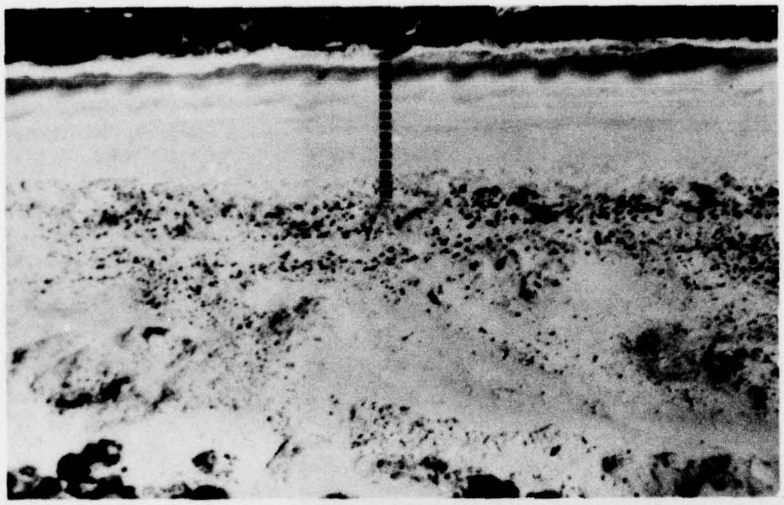
12 February 1976

12 February 1976



5 October 1976

Profile Line 13

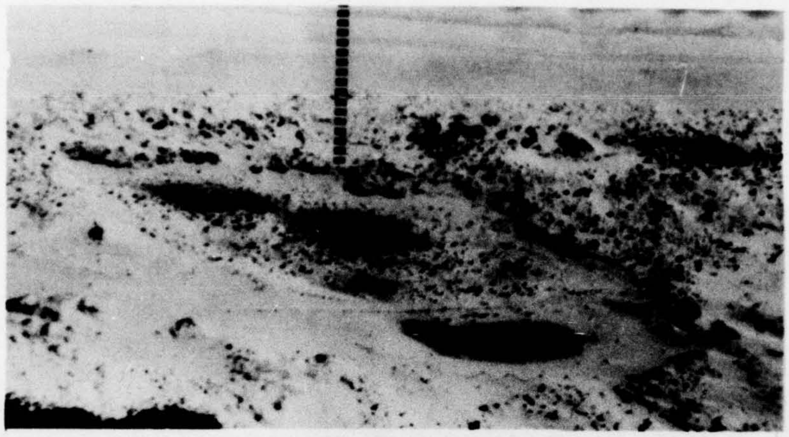


12 February 1976

10 April 1976

5 October 1976

Profile Line 14

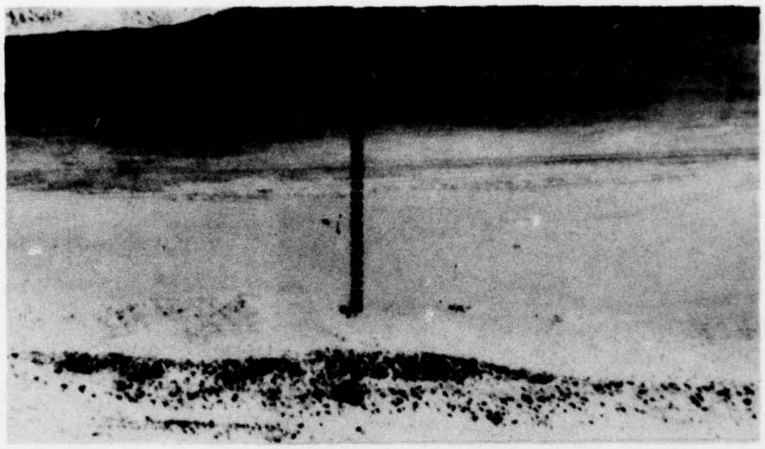


12 February 1976

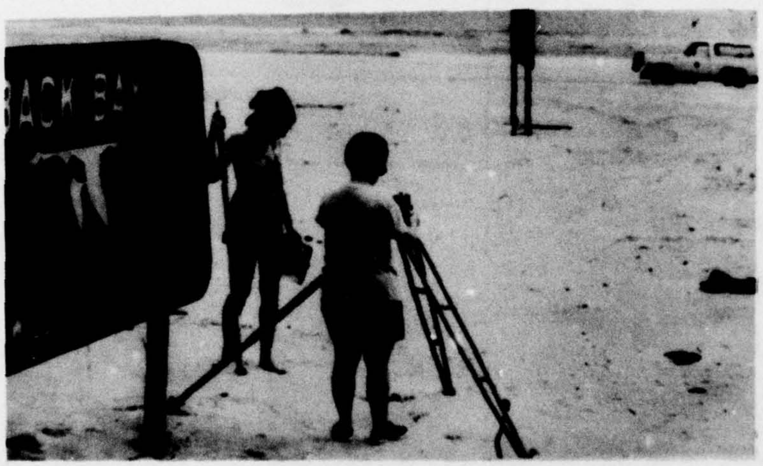
8 September 1975

8 March 1976

Profile Line 15



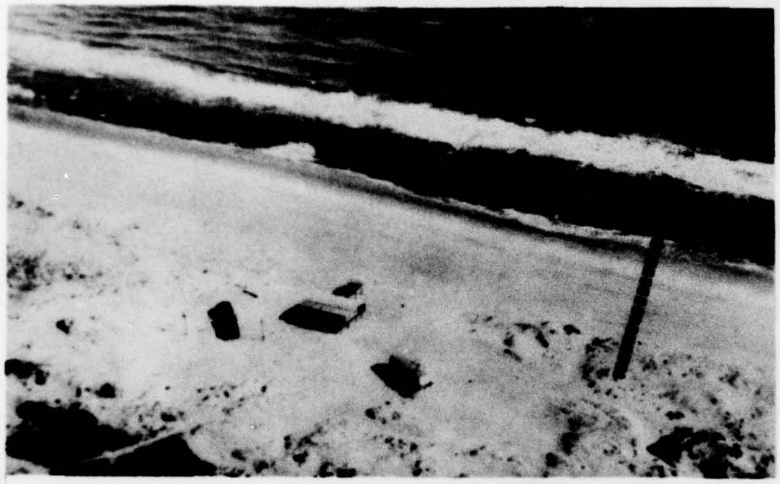
12 February 1976



6 July 1976

5 October 1976

Profile Line 16

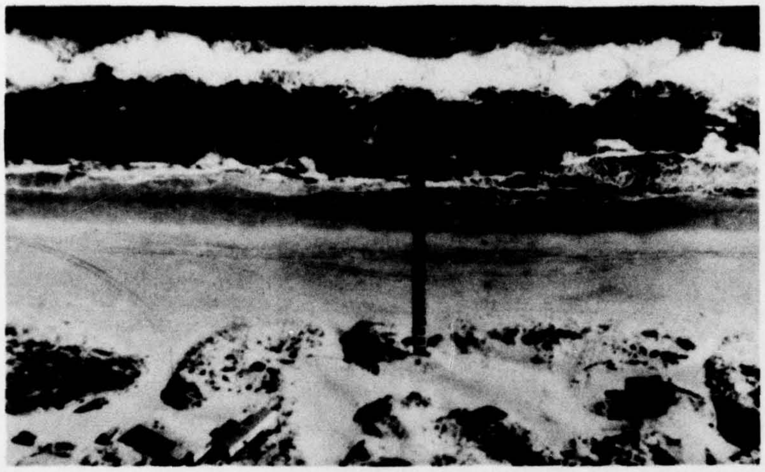


12 February 1976

7 November 1974

5 June 1975

Profile Line 17



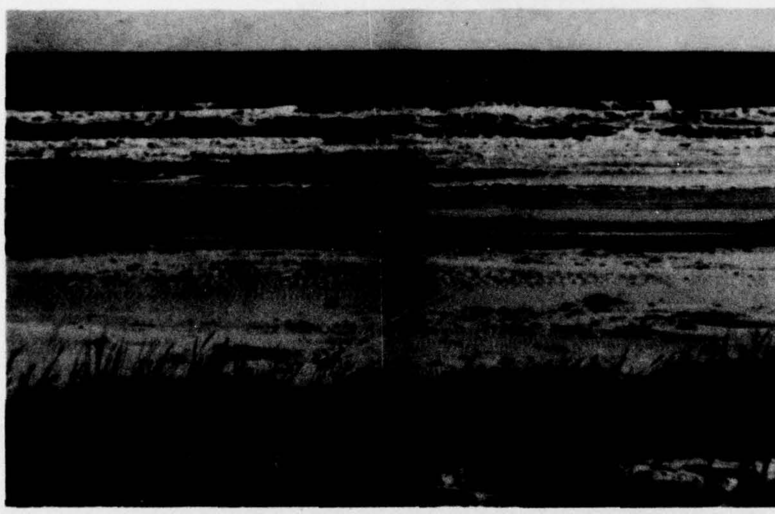
12 February 1976

6 July 1976

2 August 1976

Profile Line 18

4 May 1976



10 February 1975

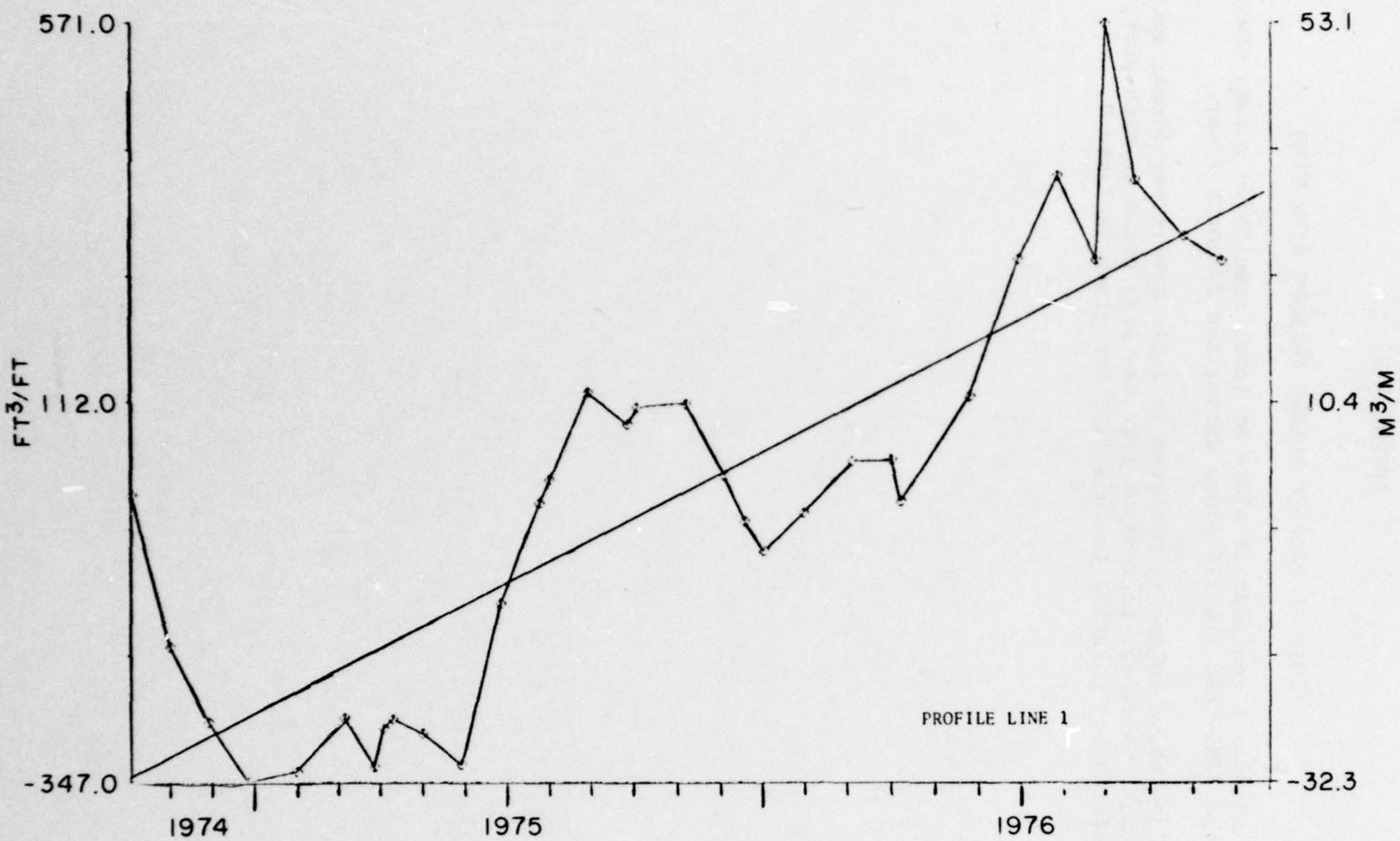
5 June 1975

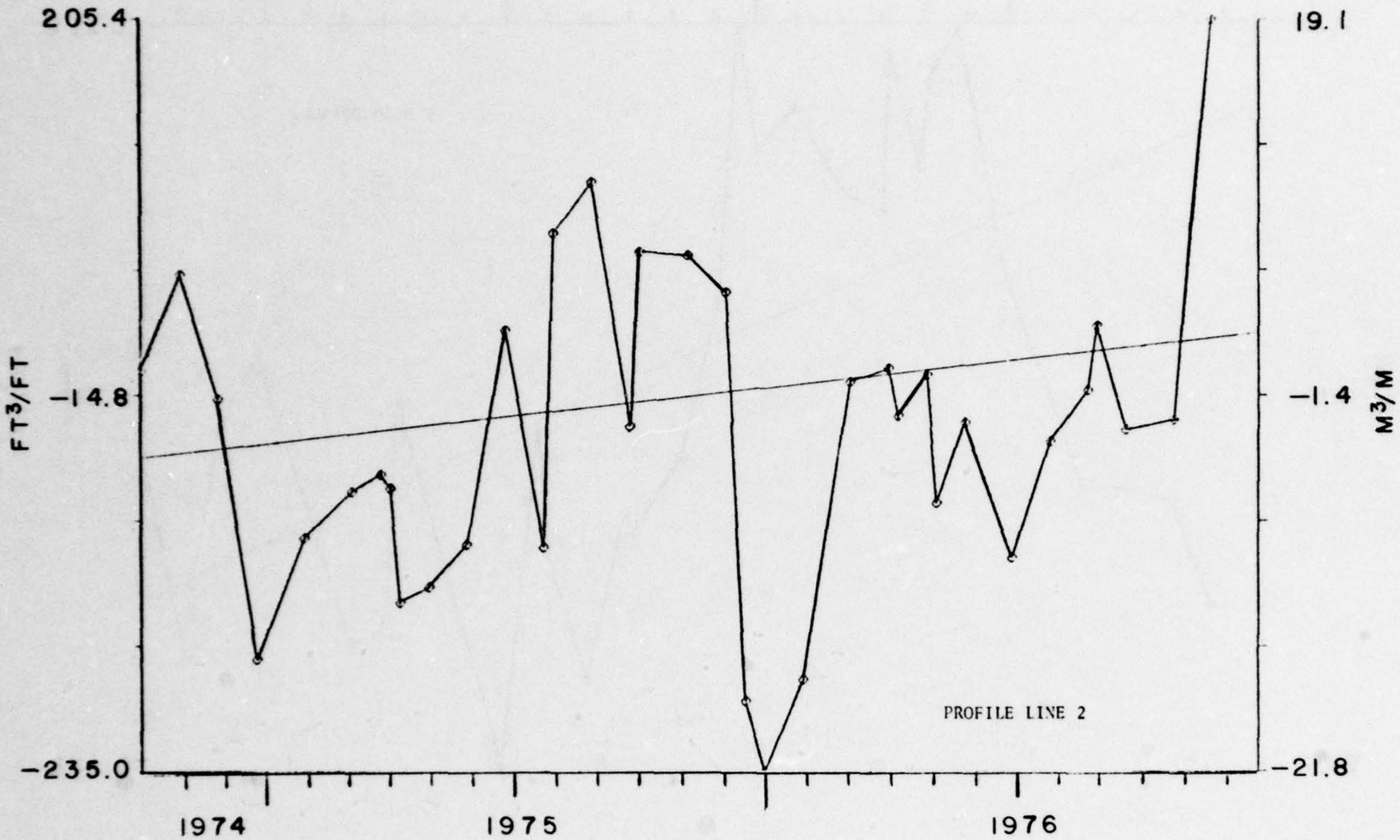
APPENDIX B

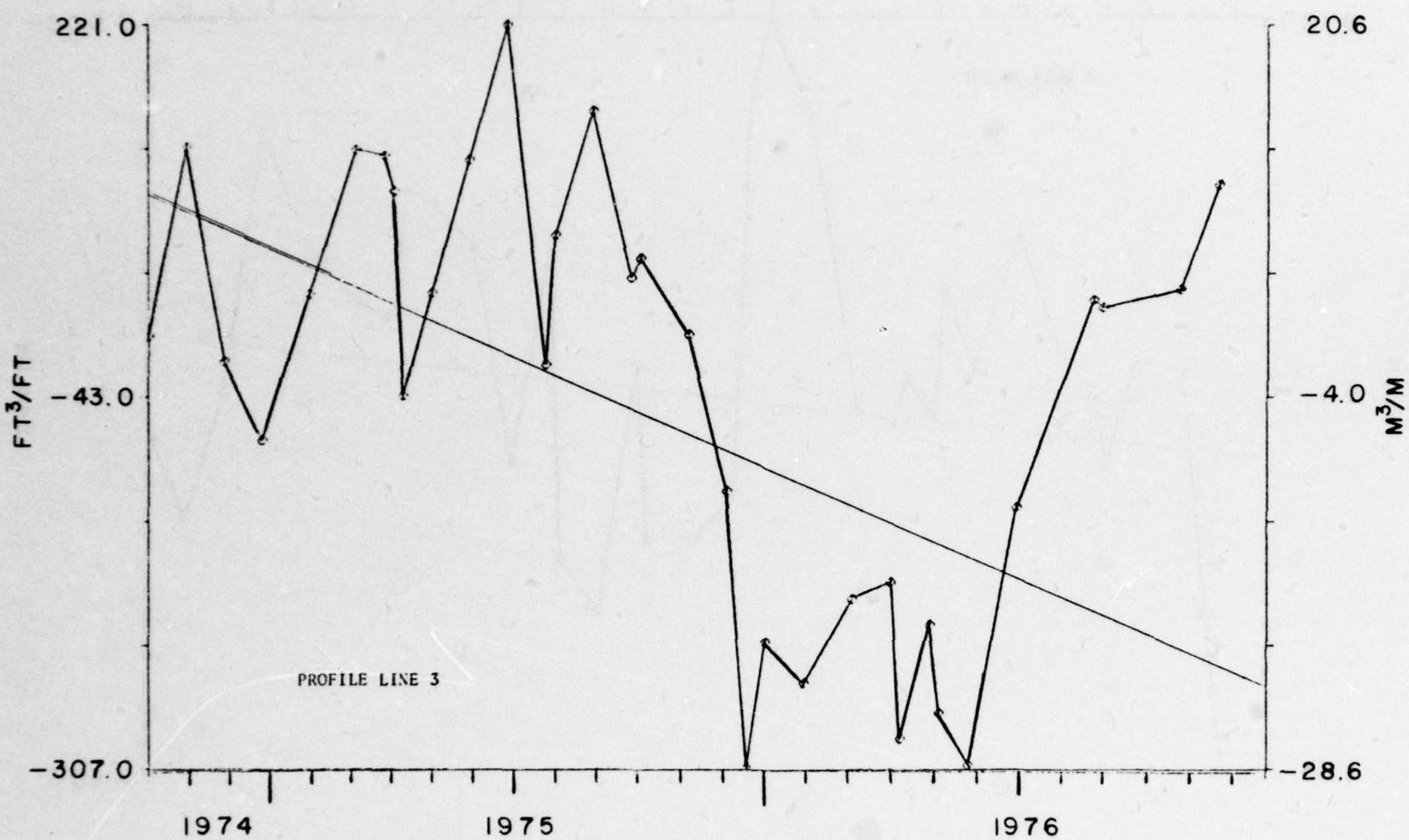
PLOTS OF PROFILE VOLUME CHANGES WITH TIME

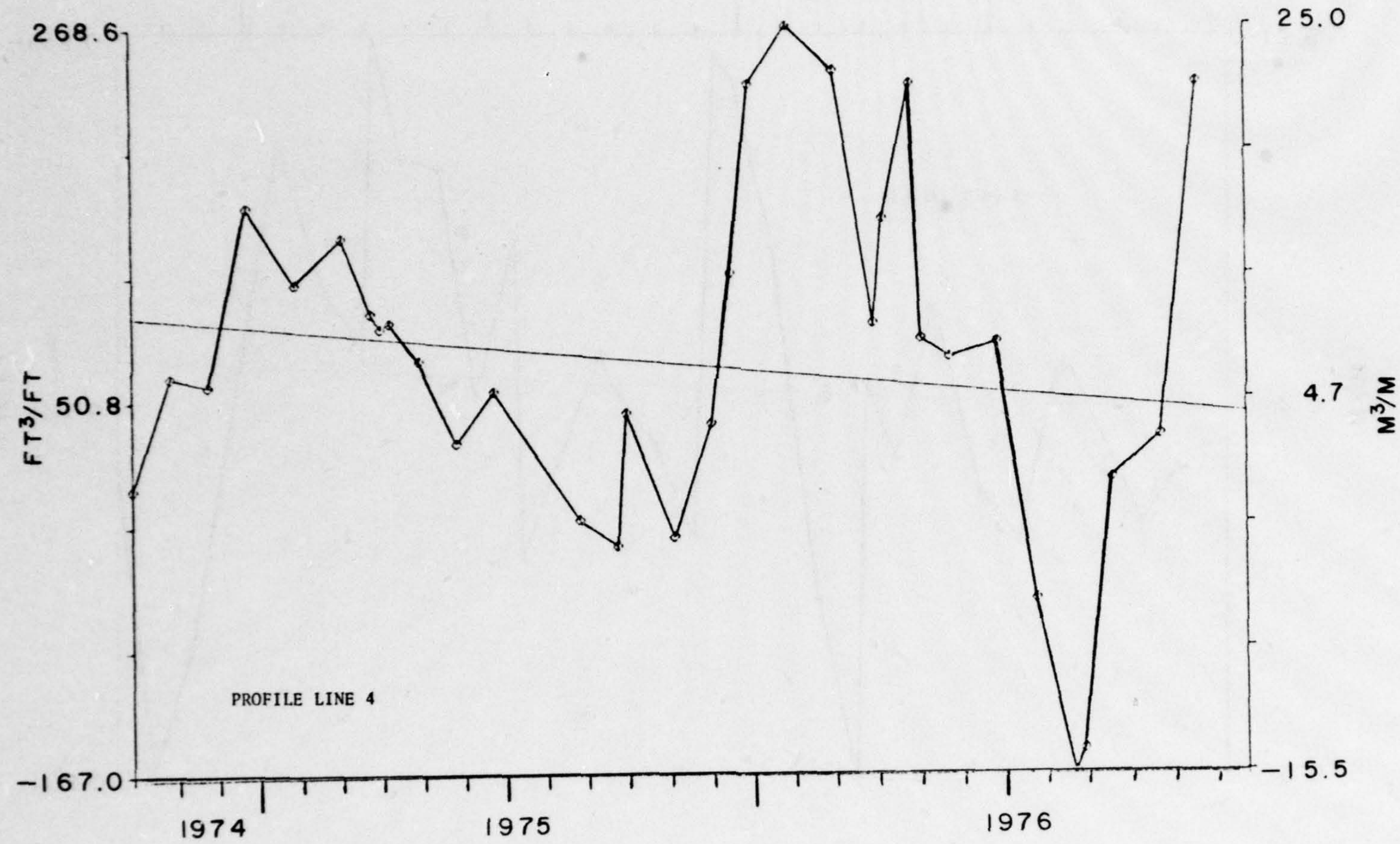
Appendix B contains 18 plots of total cumulative volume changes for the VIMS-CERC profile lines during the 27-month study.

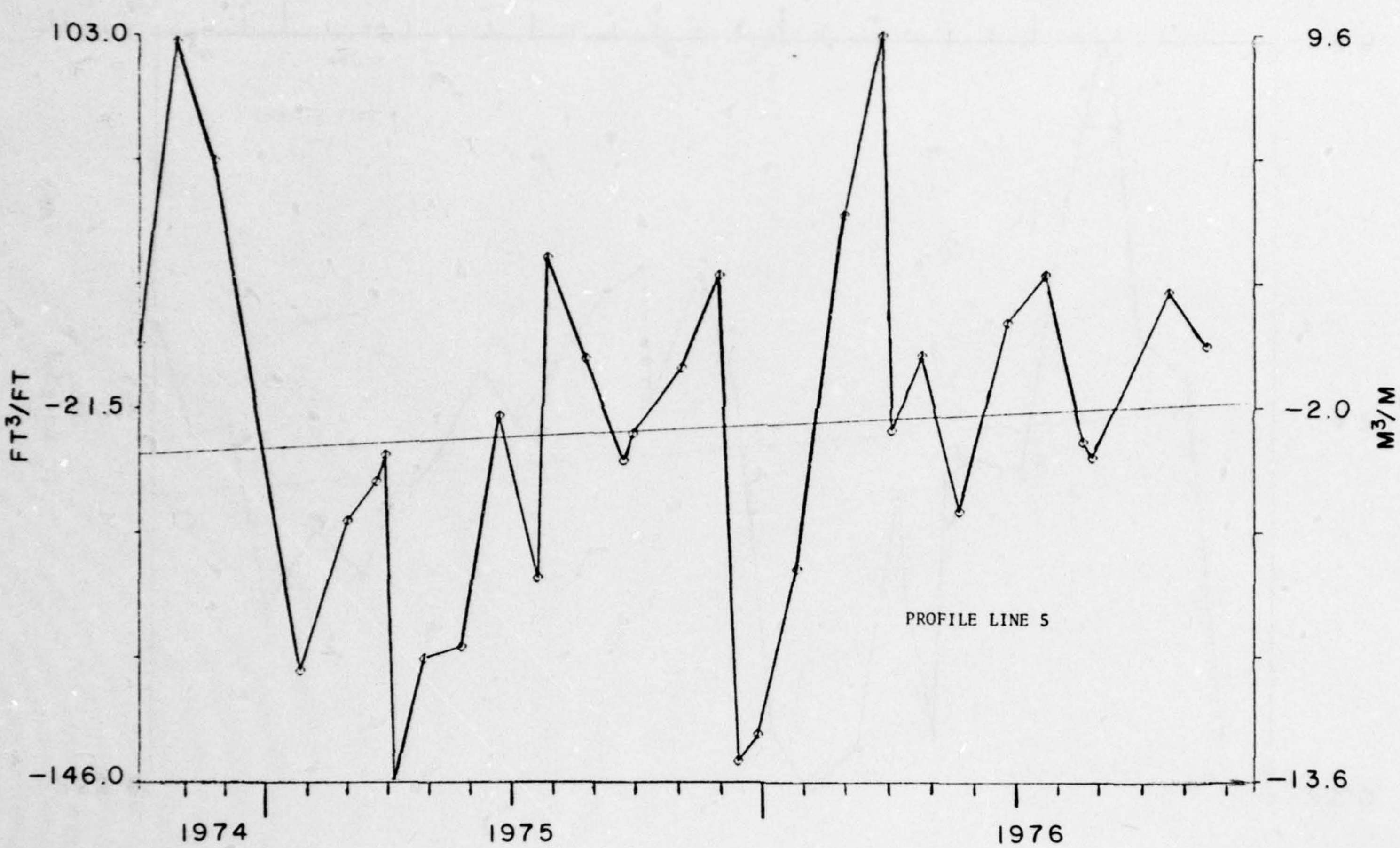
Cumulative volume is measured in cubic meters per linear meter of beach. A linear regression line has been drawn on each plot, and the statistics relating to this line are given in Table 7.

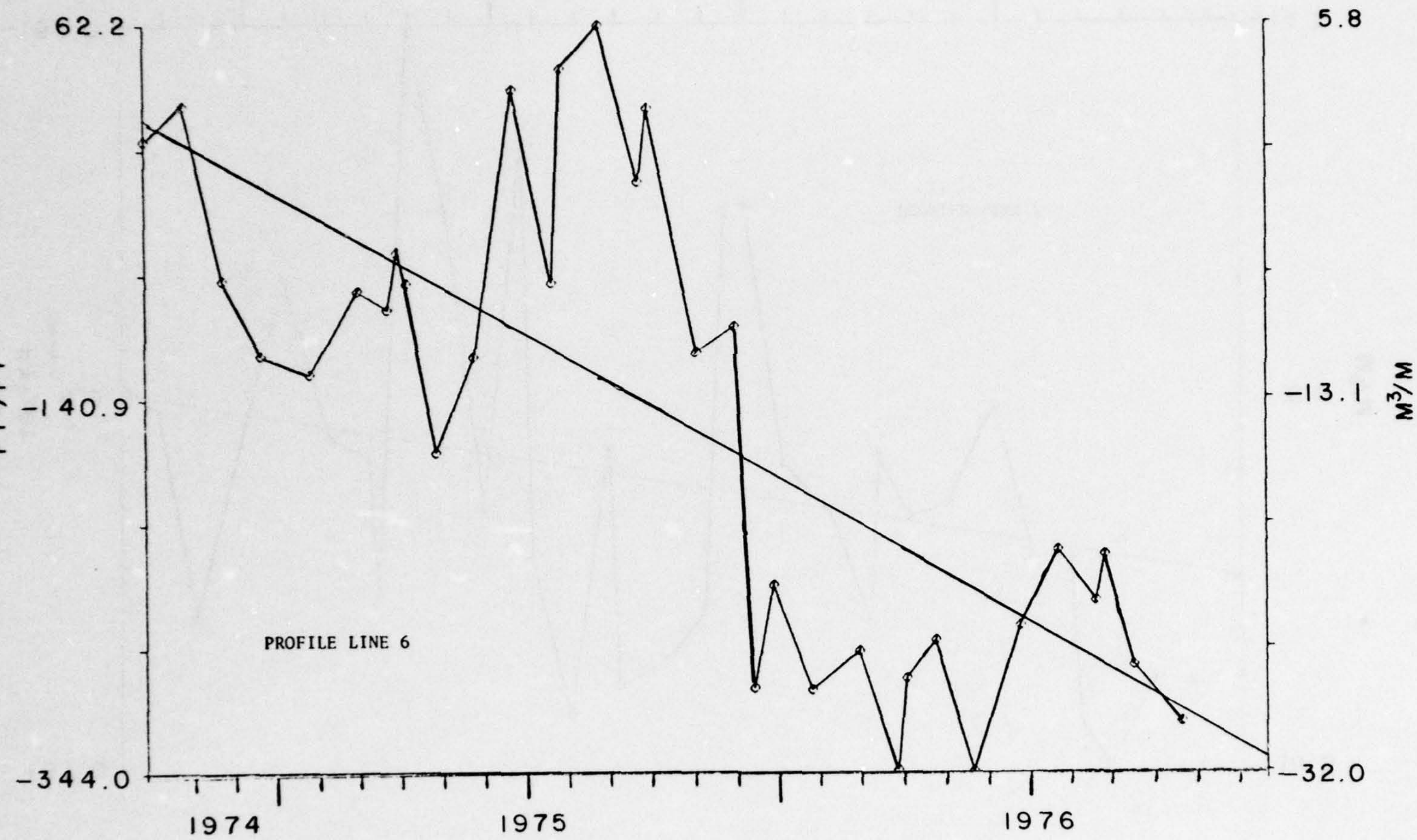

571.0
112.0
-347.0
FT3/FT
53.1
10.4
-32.3
M3/M
1974
1975
1976
PROFILE LINE 1

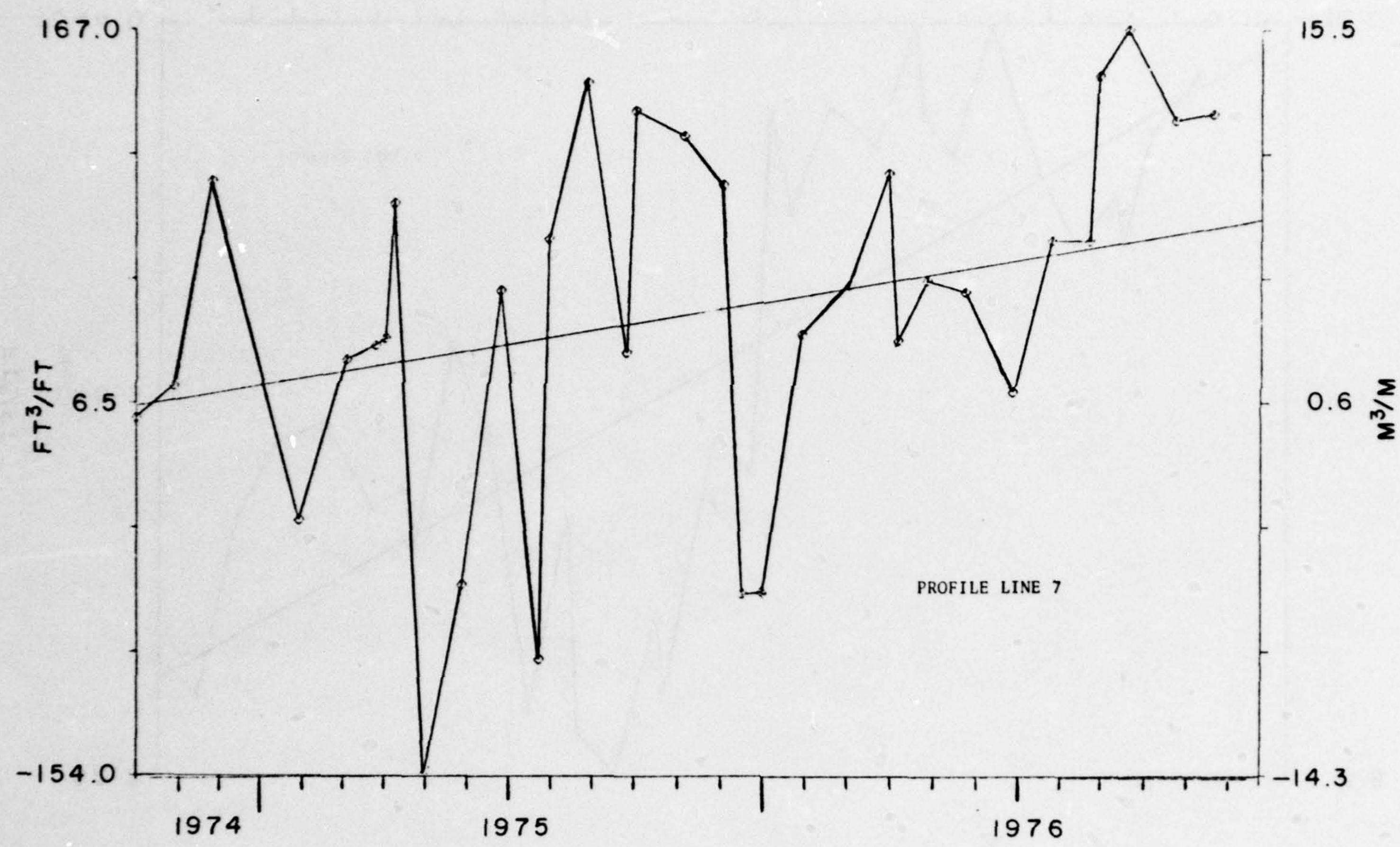

205.4
-14.8
-235.0
FT3/FT
19.1
-1.4
-21.8
M3/M
1974
1975
1976
PROFILE LINE 2


221.0
-43.0
-307.0
FT3/FT
20.6
-4.0
-28.6
M3/M
1974
1975
1976
PROFILE LINE 3

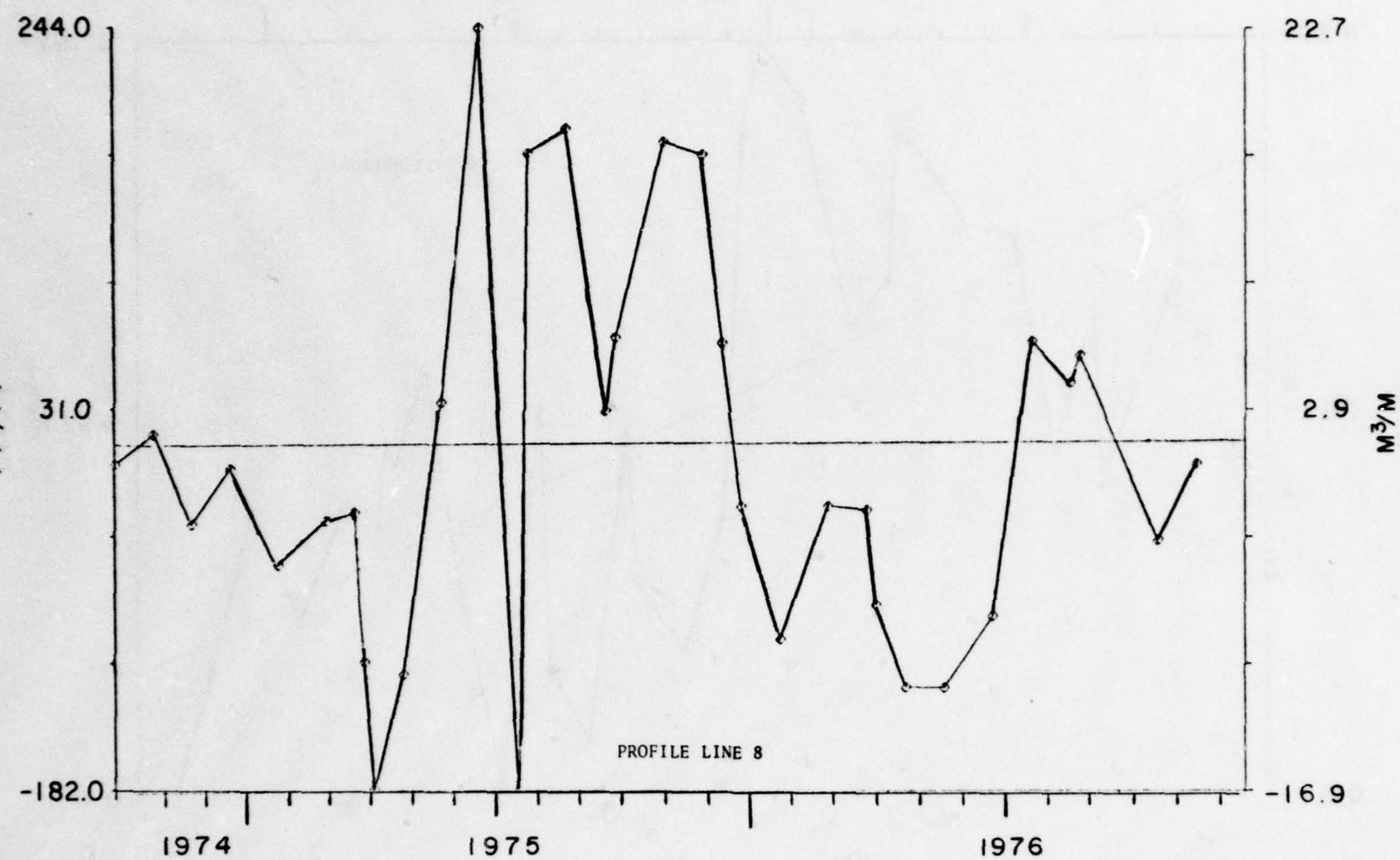

268.6
50.8
-167.0
FT3/FT
25.0
4.7
-15.5
M3/M
1974
1975
1976
PROFILE LINE 4

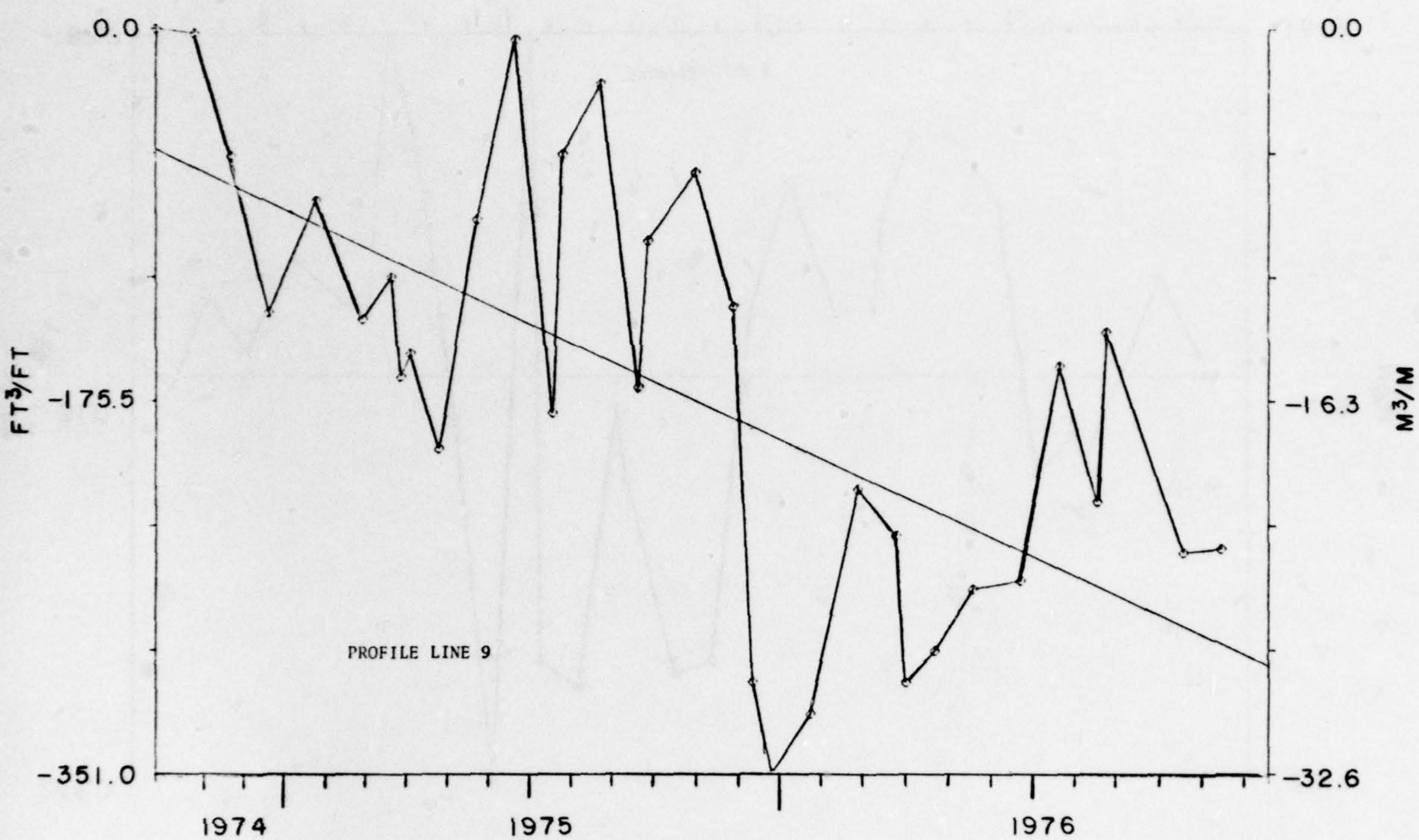

103.0
-21.5
-146.0
FT3/FT
9.6
-2.0
-13.6
M3/M
1974
1975
1976
PROFILE LINE 5


62.2
-140.9
-344.0
FT³/FT
5.8
-13.1
-32.0
M³/M
1974
1975
1976
PROFILE LINE 6

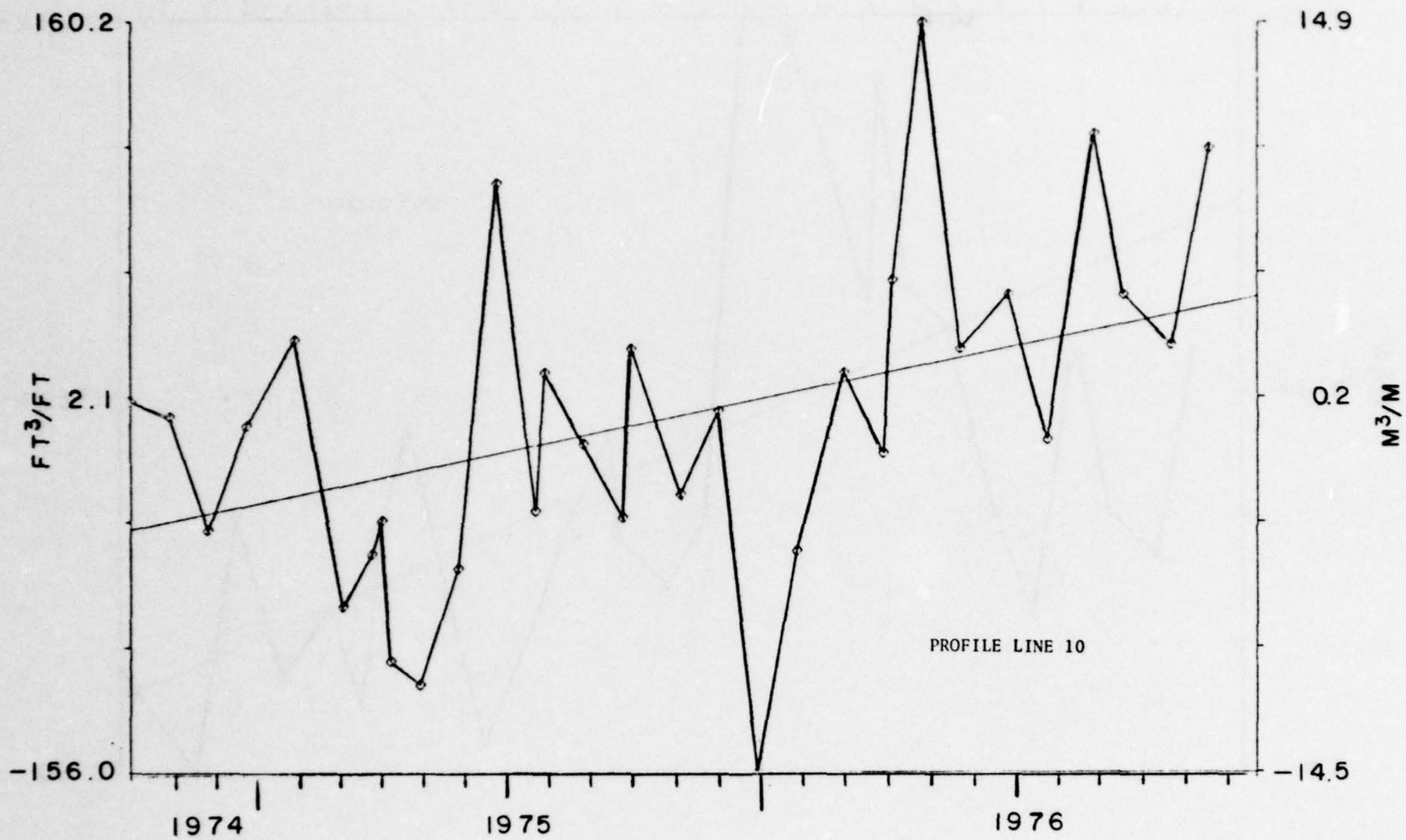


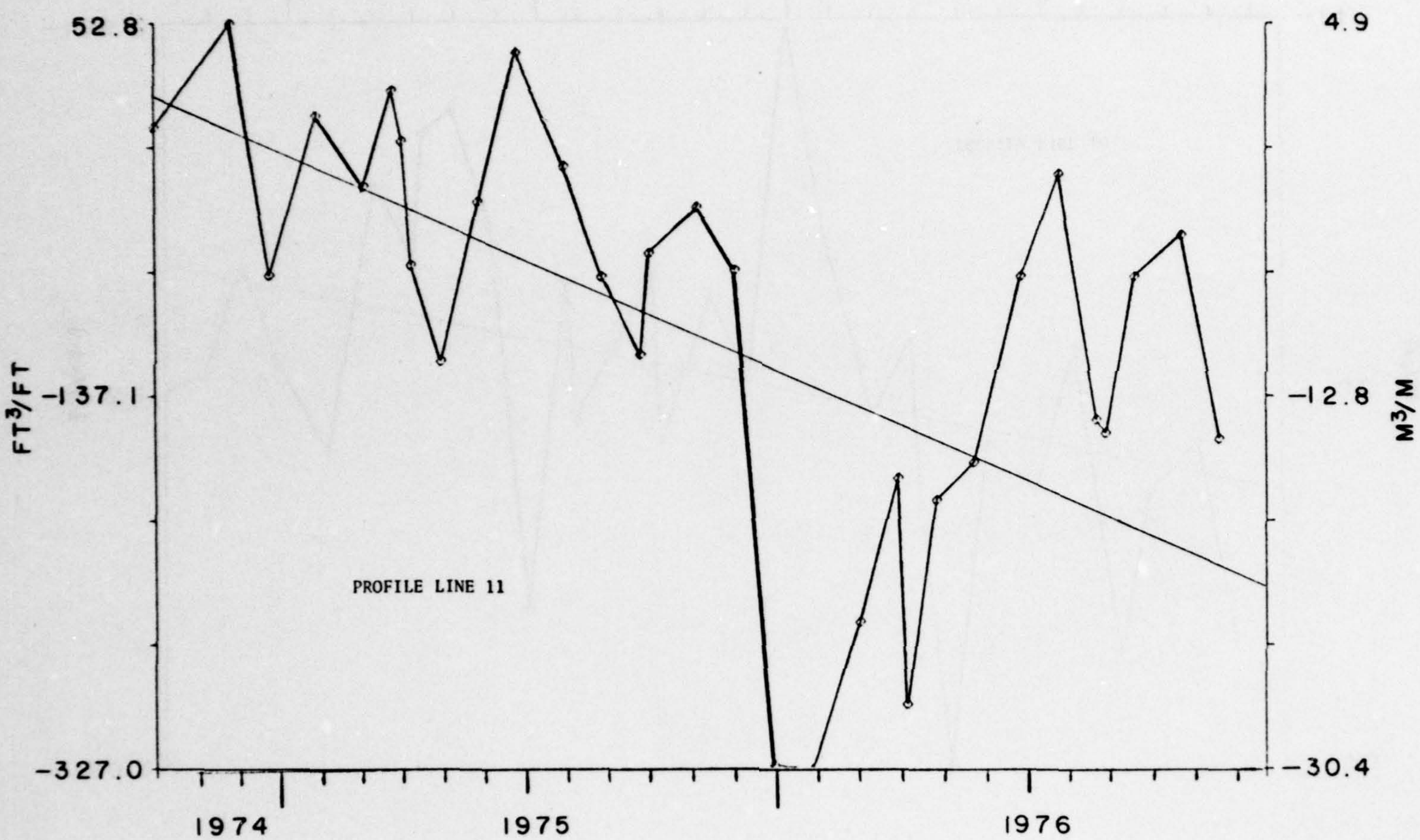
167.0
6.5
-154.0
FT^3/FT
15.5
0.6
-14.3
M^3/M
1974
1975
1976
PROFILE LINE 7

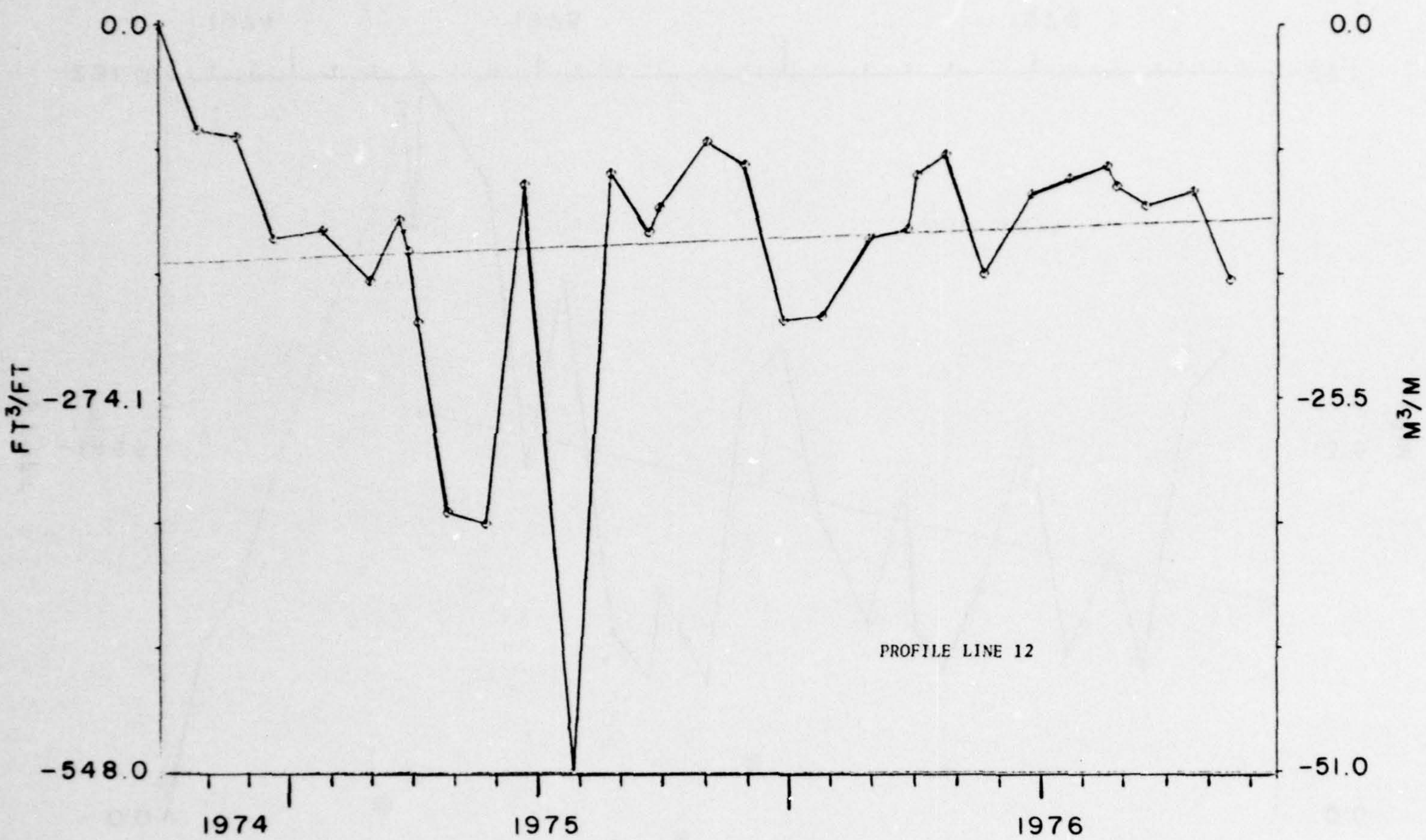

244.0
31.0
-182.0
FT3/FT
22.7
2.9
-16.9
M3/M
1974
1975
1976
PROFILE LINE 8



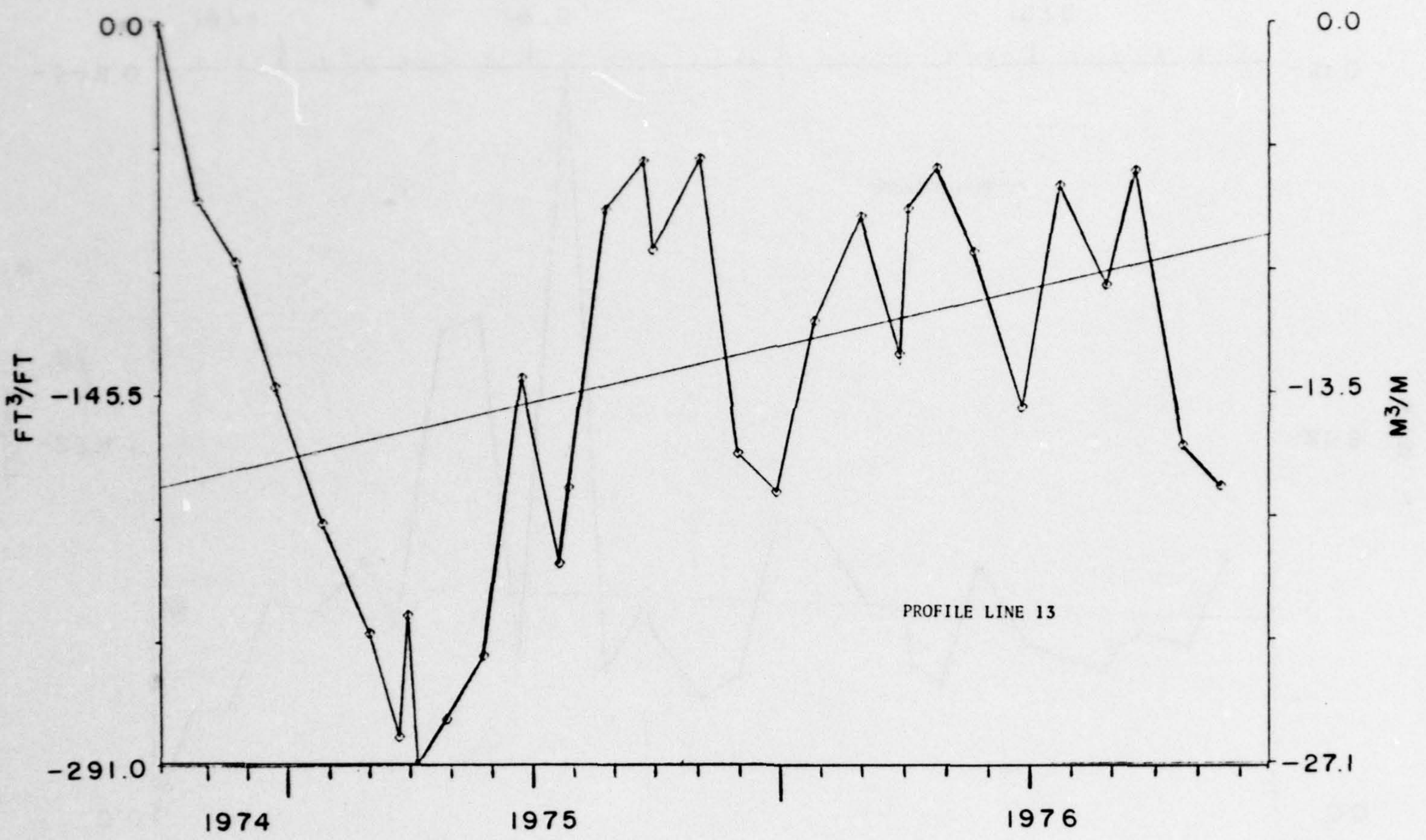
0.0
-175.5
-351.0
FT^3/FT
0.0
-16.3
-32.6
M^3/M
1974
1975
1976
PROFILE LINE 9


160.2
2.1
-156.0
FT³/FT
14.9
0.2
-14.5
M³/M
1974
1975
1976
PROFILE LINE 10

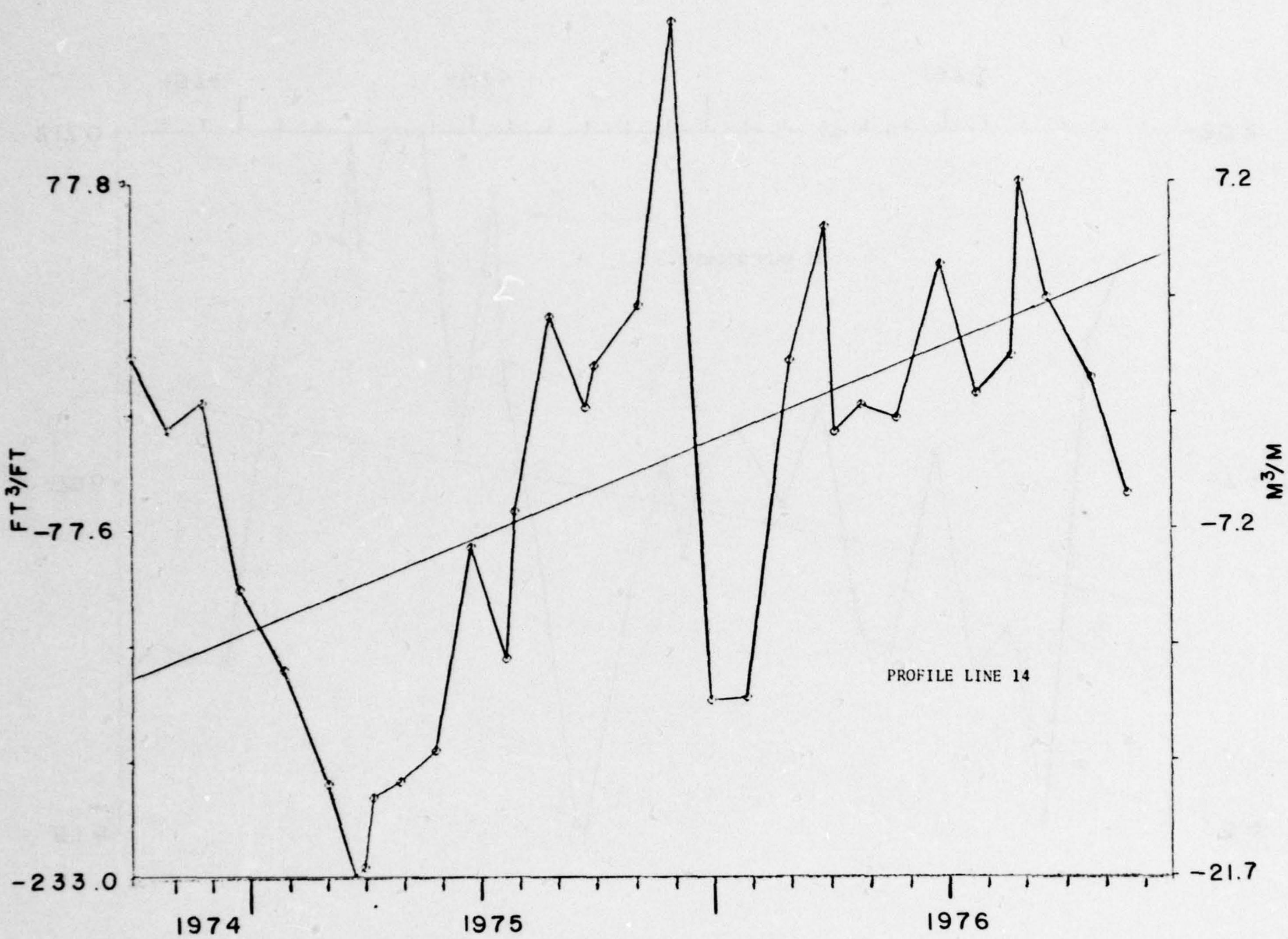

52.8
-137.1
-327.0
FT³/FT
4.9
-12.8
-30.4
M³/M
1974
1975
1976
PROFILE LINE 11

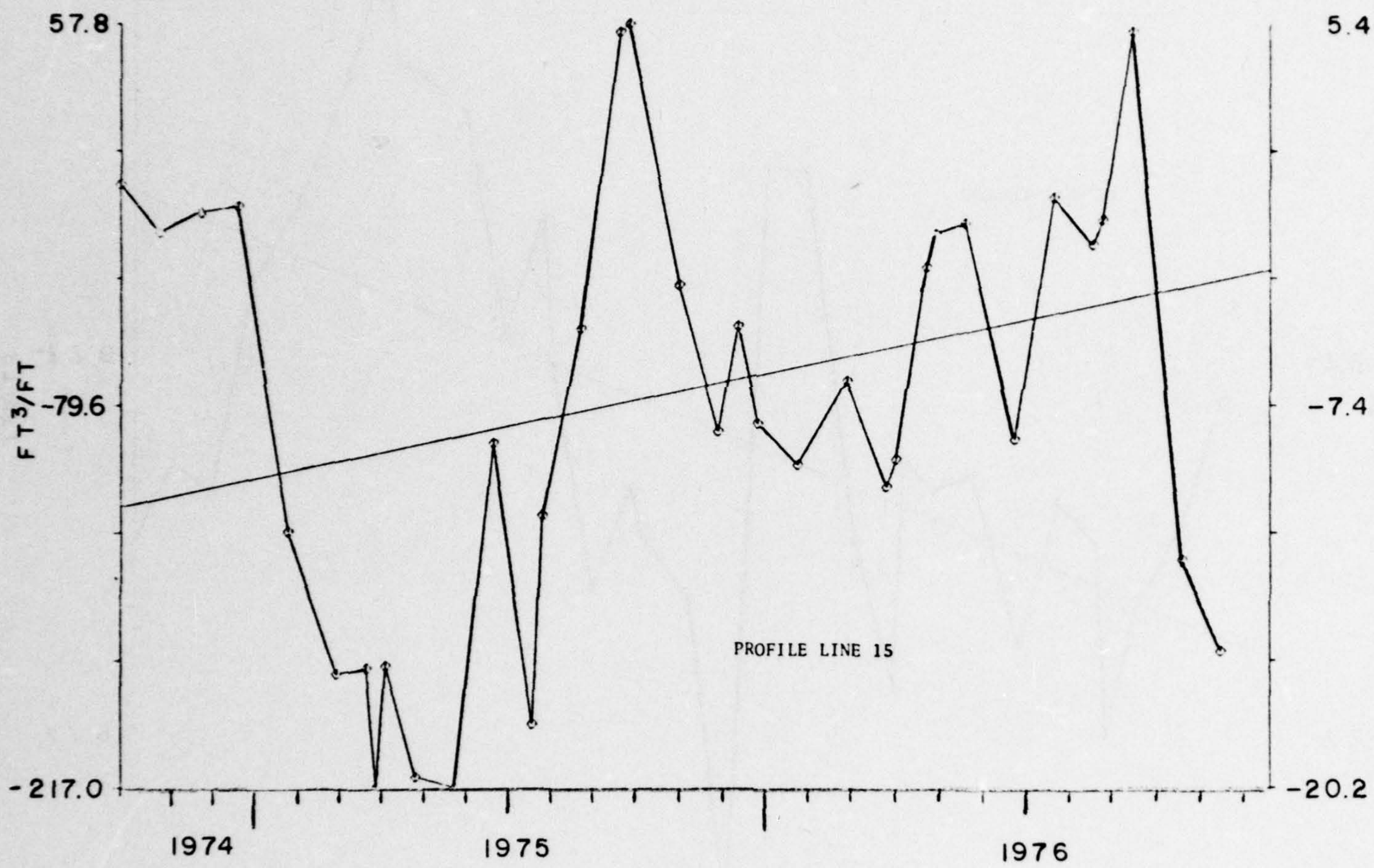


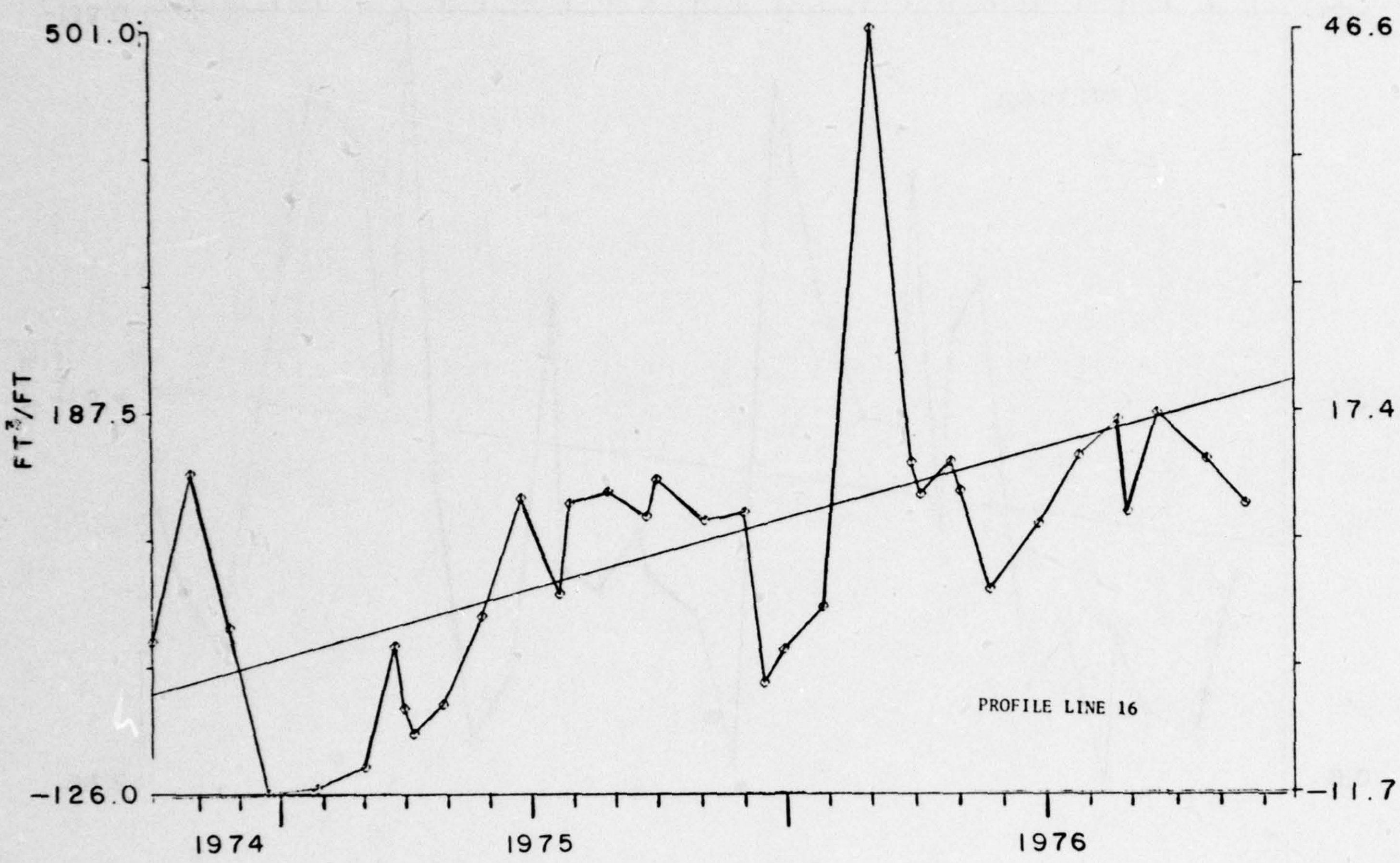
0.0
-274.1
-548.0
FT³/FT
0.0
-25.5
-51.0
M³/M
1974
1975
1976
PROFILE LINE 12

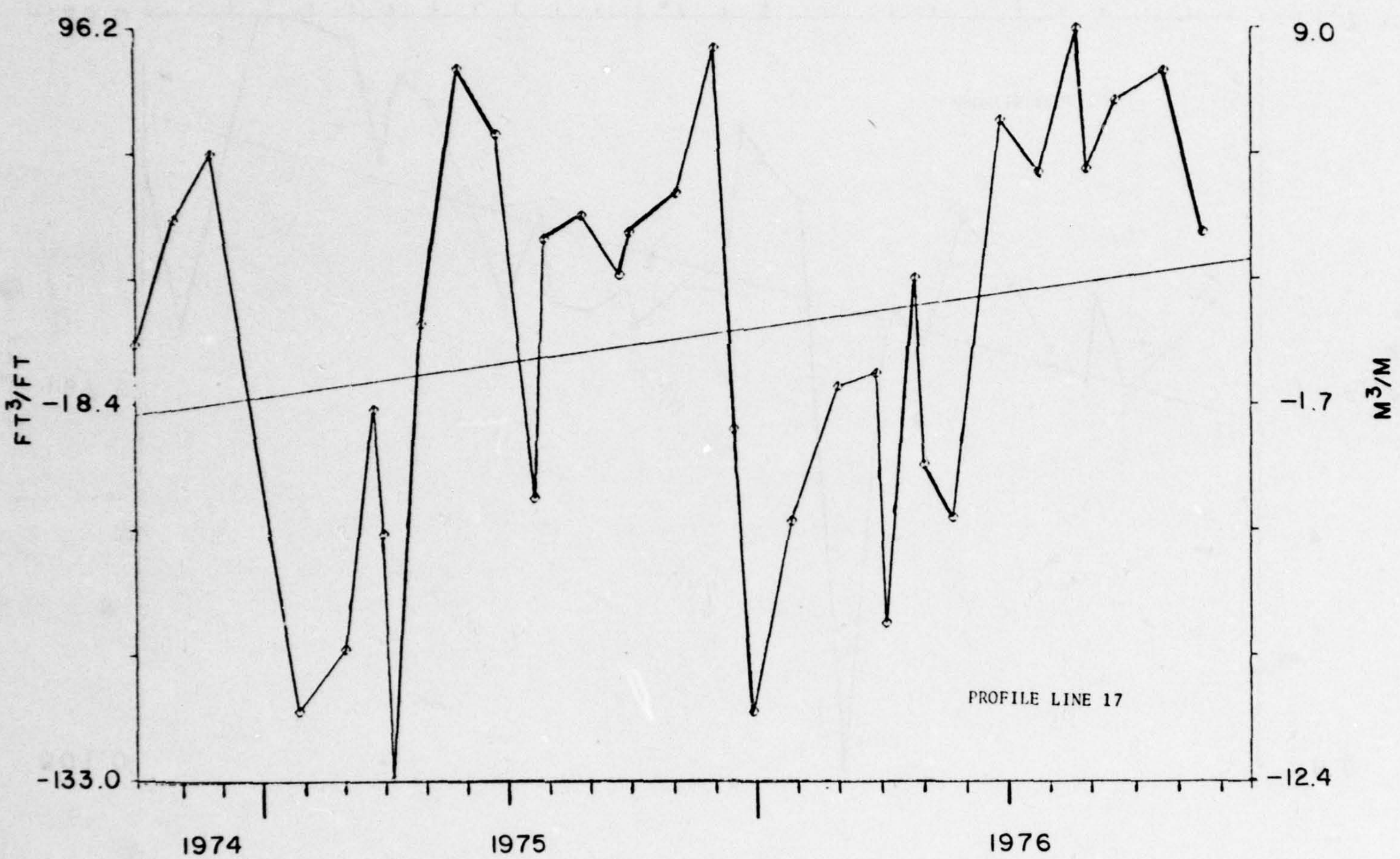


0.0
-145.5
-291.0
FT³/FT
0.0
-13.5
-27.1
M³/M
1974
1975
1976
PROFILE LINE 13

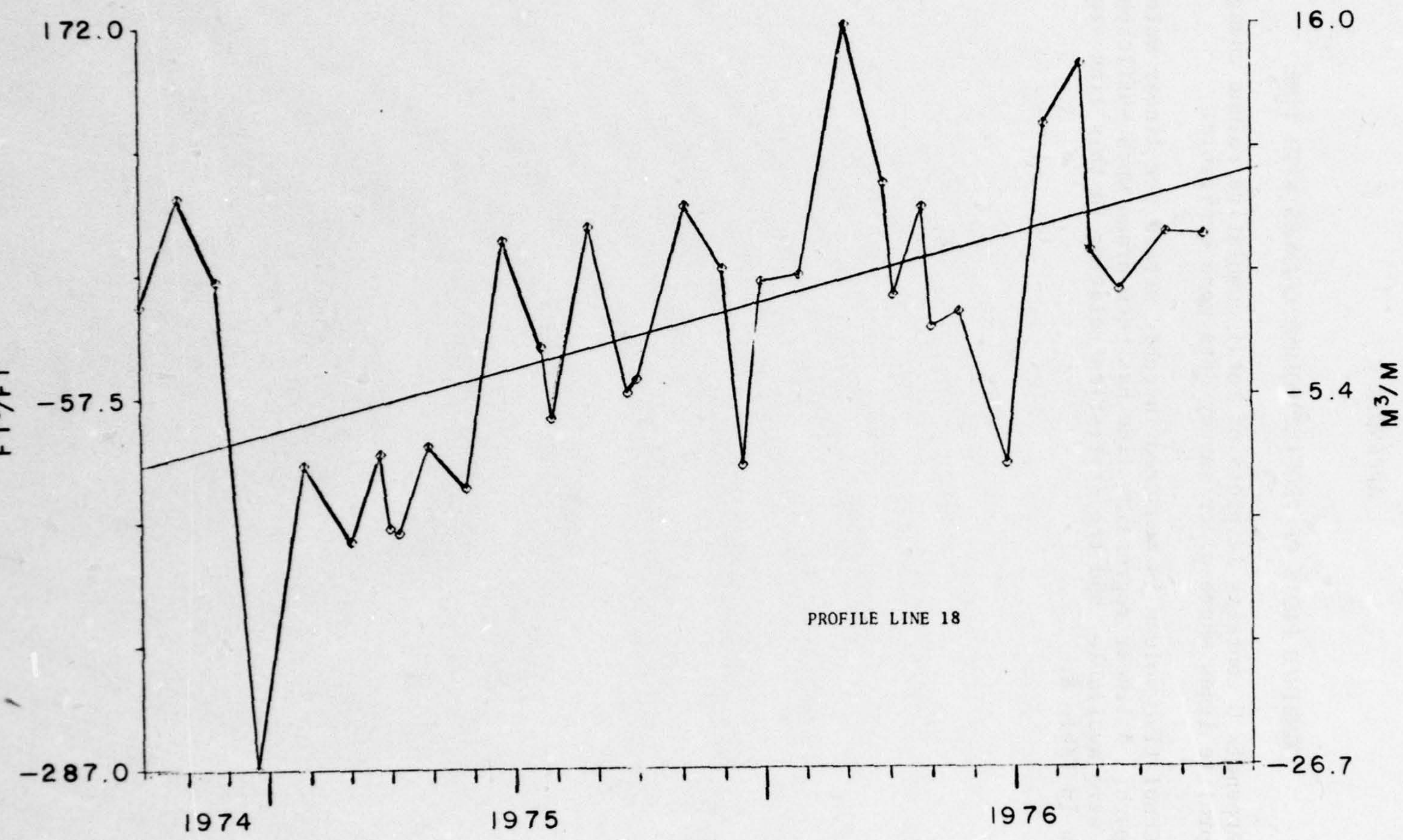

77.8
-77.6
-233.0
FT3/FT
7.2
-7.2
-21.7
M3/M
1974
1975
1976
PROFILE LINE 14


57.8
-79.6
-217.0
FT³/FT
5.4
-7.4
-20.2
M³/M
1974
1975
1976
PROFILE LINE 15


501.0
187.5
-126.0
FT³/FT
46.6
17.4
-11.7
M³/M
1974
1975
1976
PROFILE LINE 16



96.2
-18.4
-133.0
FT^3/FT
9.0
-1.7
-12.4
M^3/M
1974
1975
1976
PROFILE LINE 17

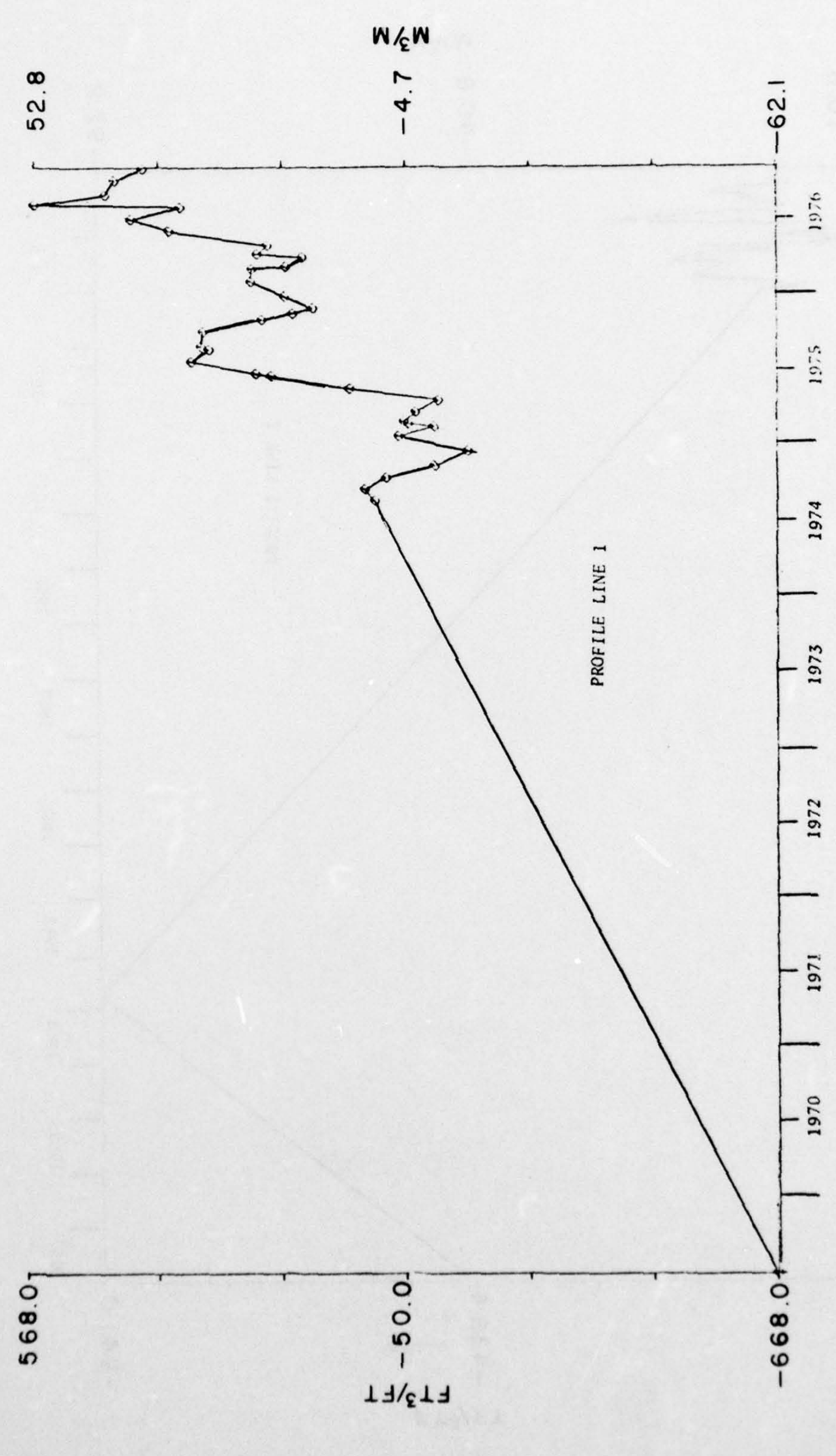

172.0
-57.5
-287.0
FT³/FT
16.0
-5.4
-26.7
M³/M
1974
1975
1976
PROFILE LINE 18

APPENDIX C

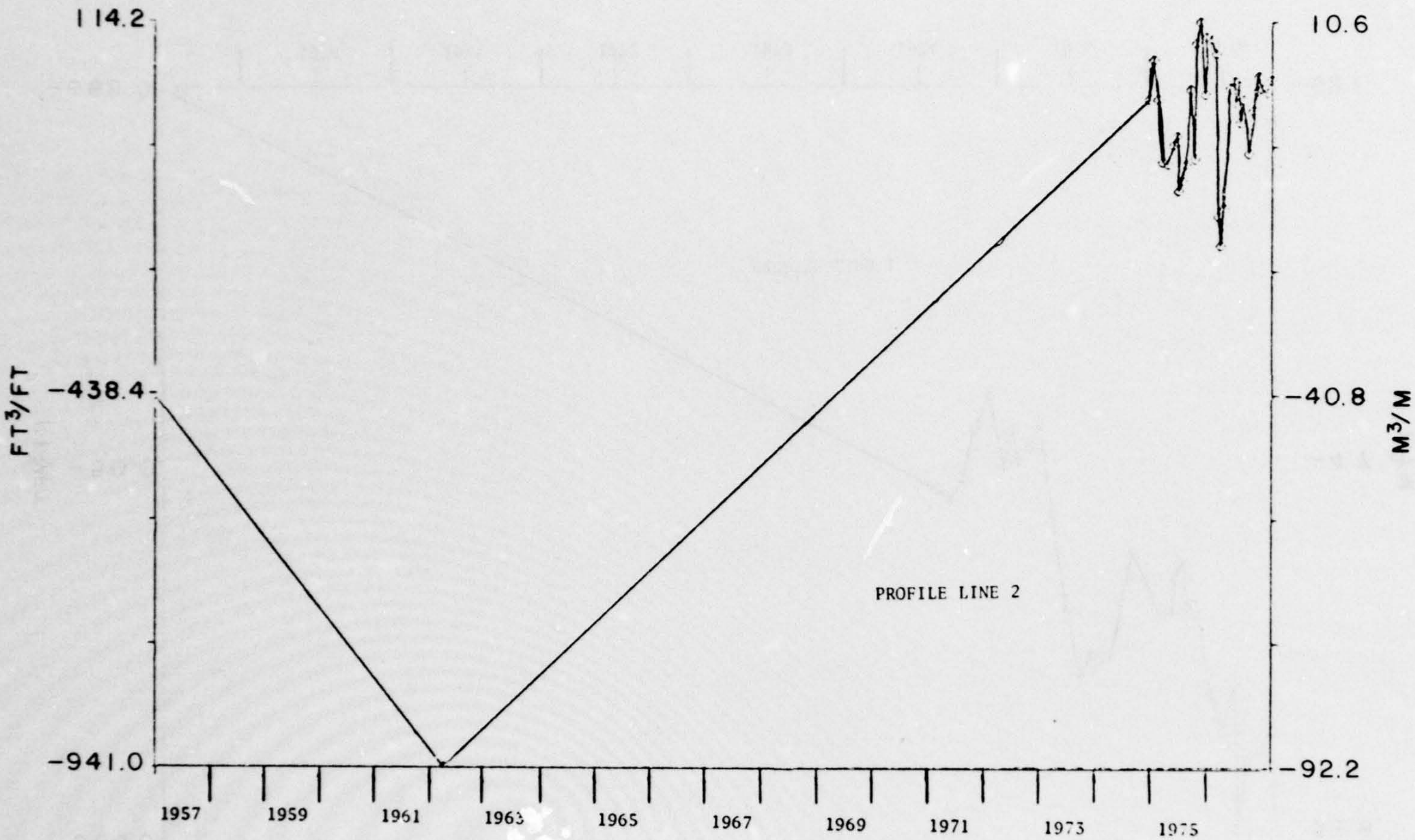
COMBINED PLOTS OF PROFILE VOLUME CHANGES WITH TIME

Appendix C contains 14 plots of total cumulative volume changes for profile lines where older survey data were available.

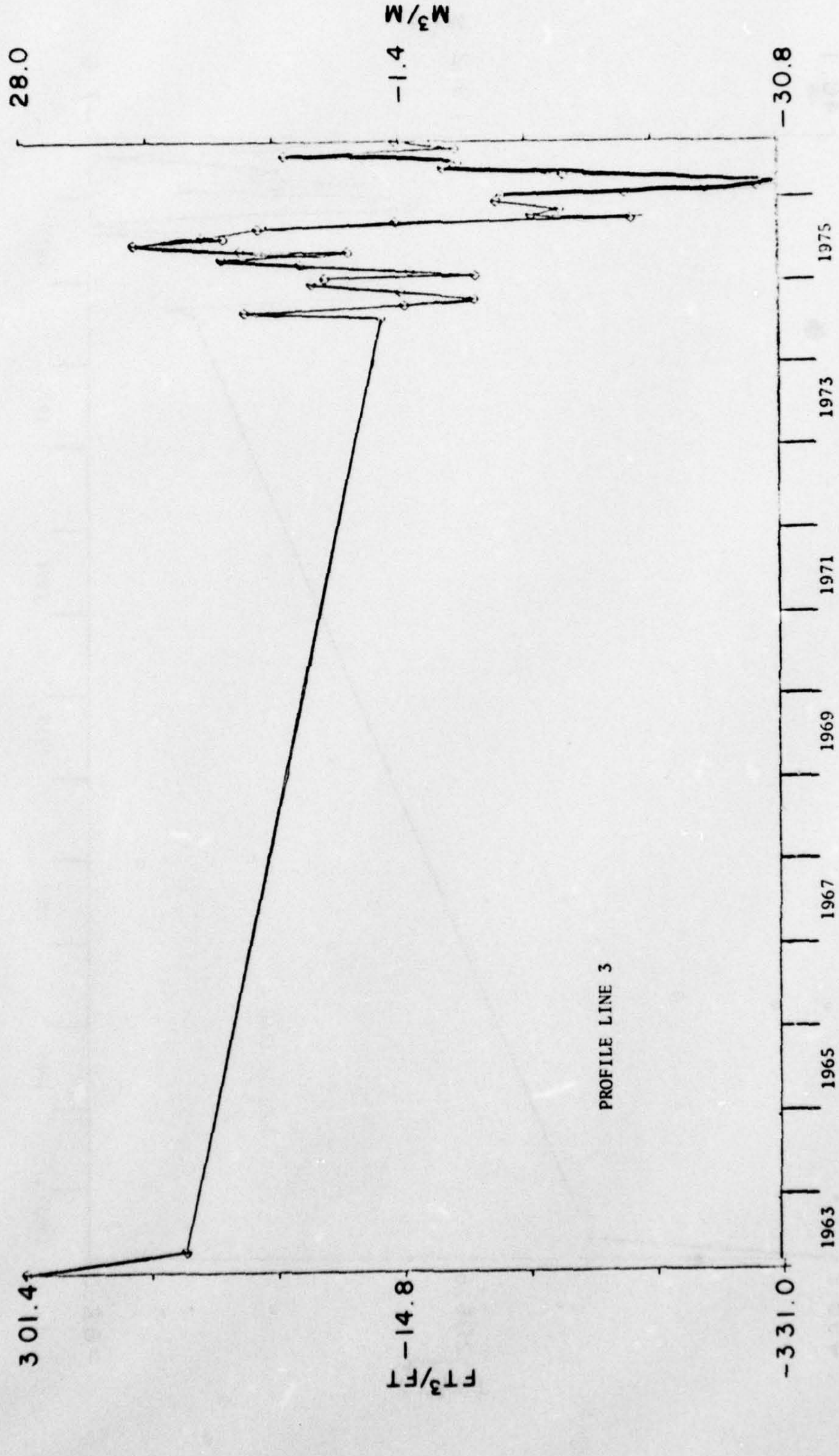
Cumulative volume is measured in cubic meters per linear meter of beach. A linear regression line has been drawn when sufficient data were available, and the statistics relating to this line are given in Table 8.

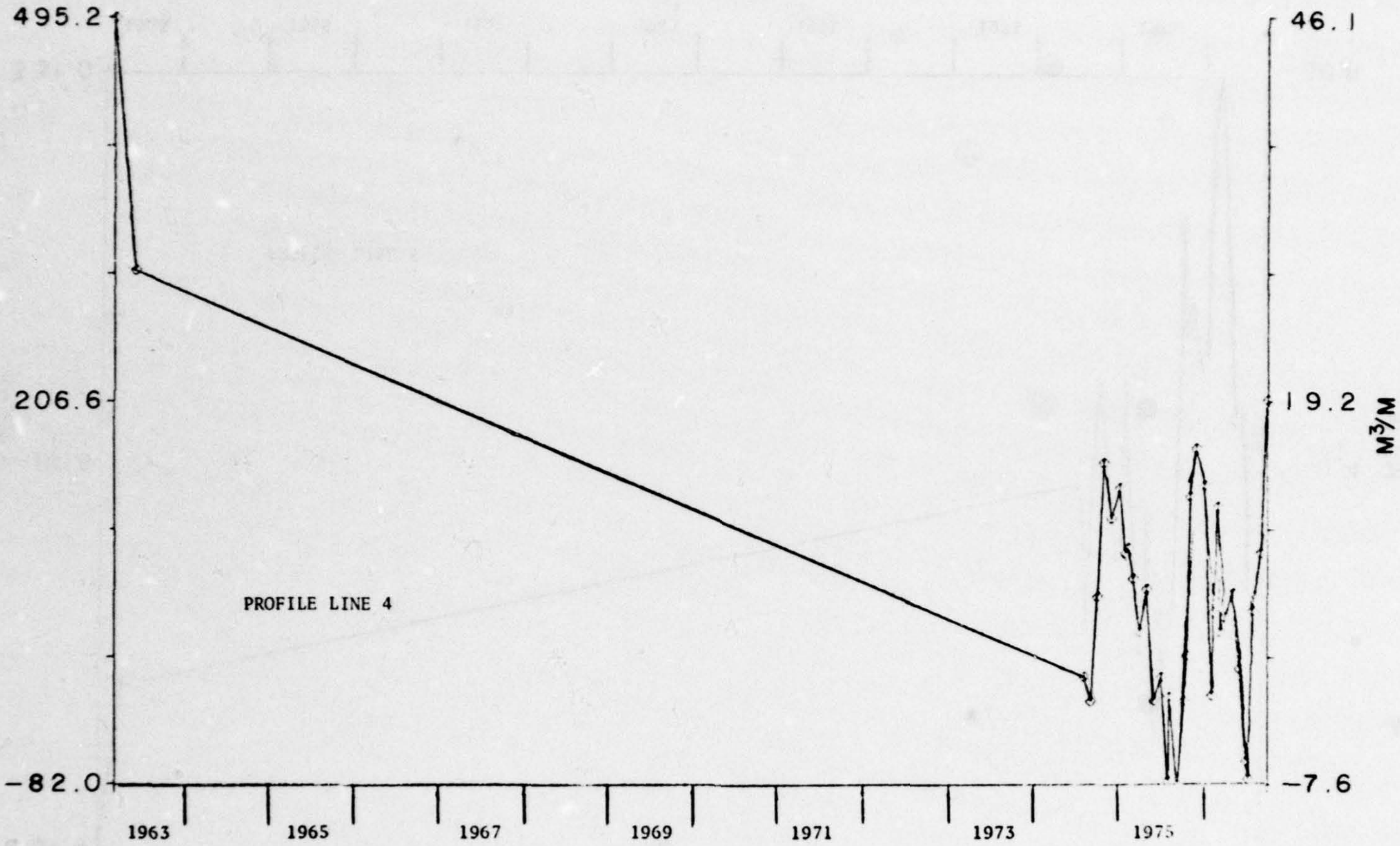


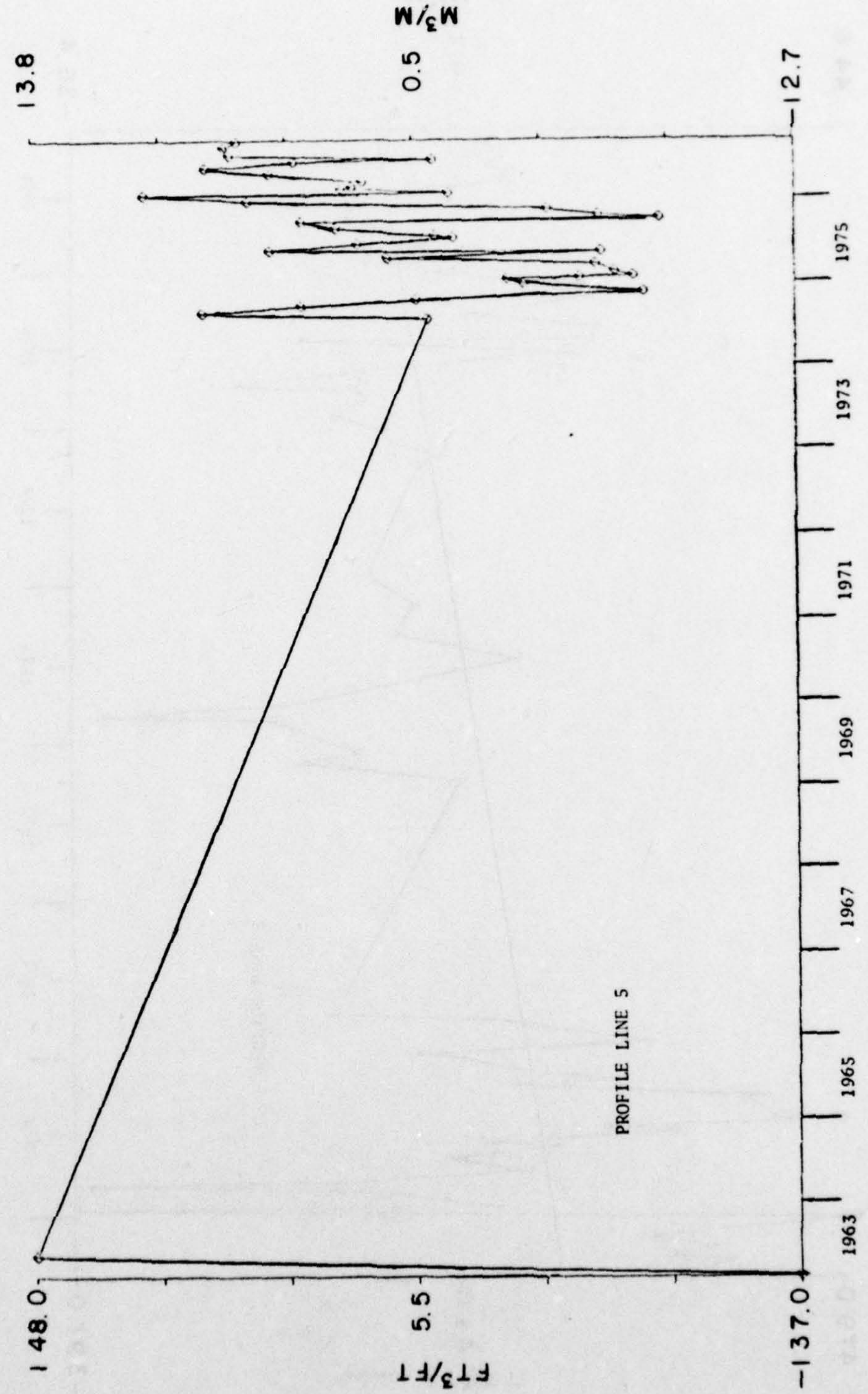
PROFILE LINE 1
568.0
-50.0
-668.0
FT3/FT
52.8
-4.7
-62.1
M3/M
1970
1971
1972
1973
1974
1975
1976

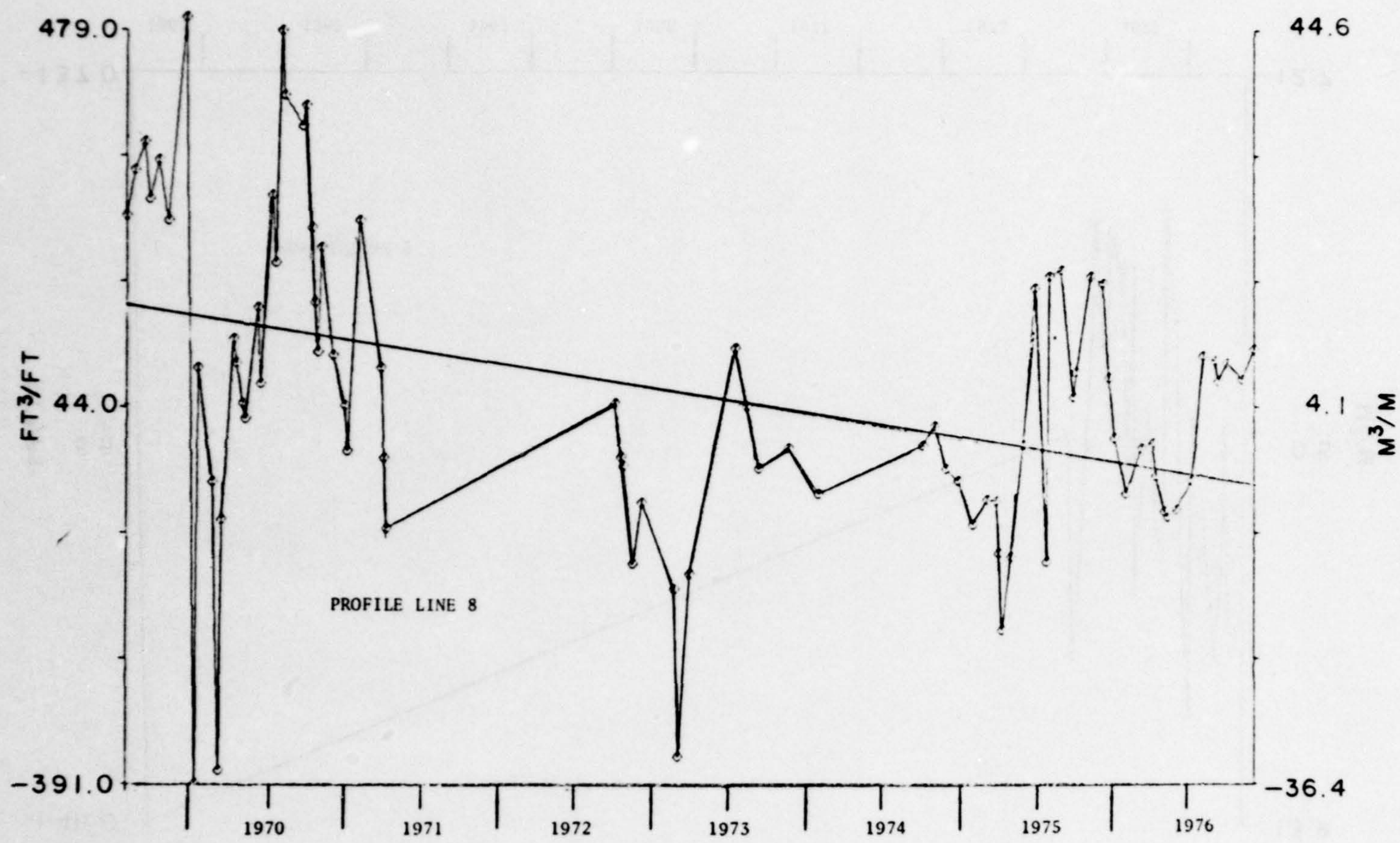


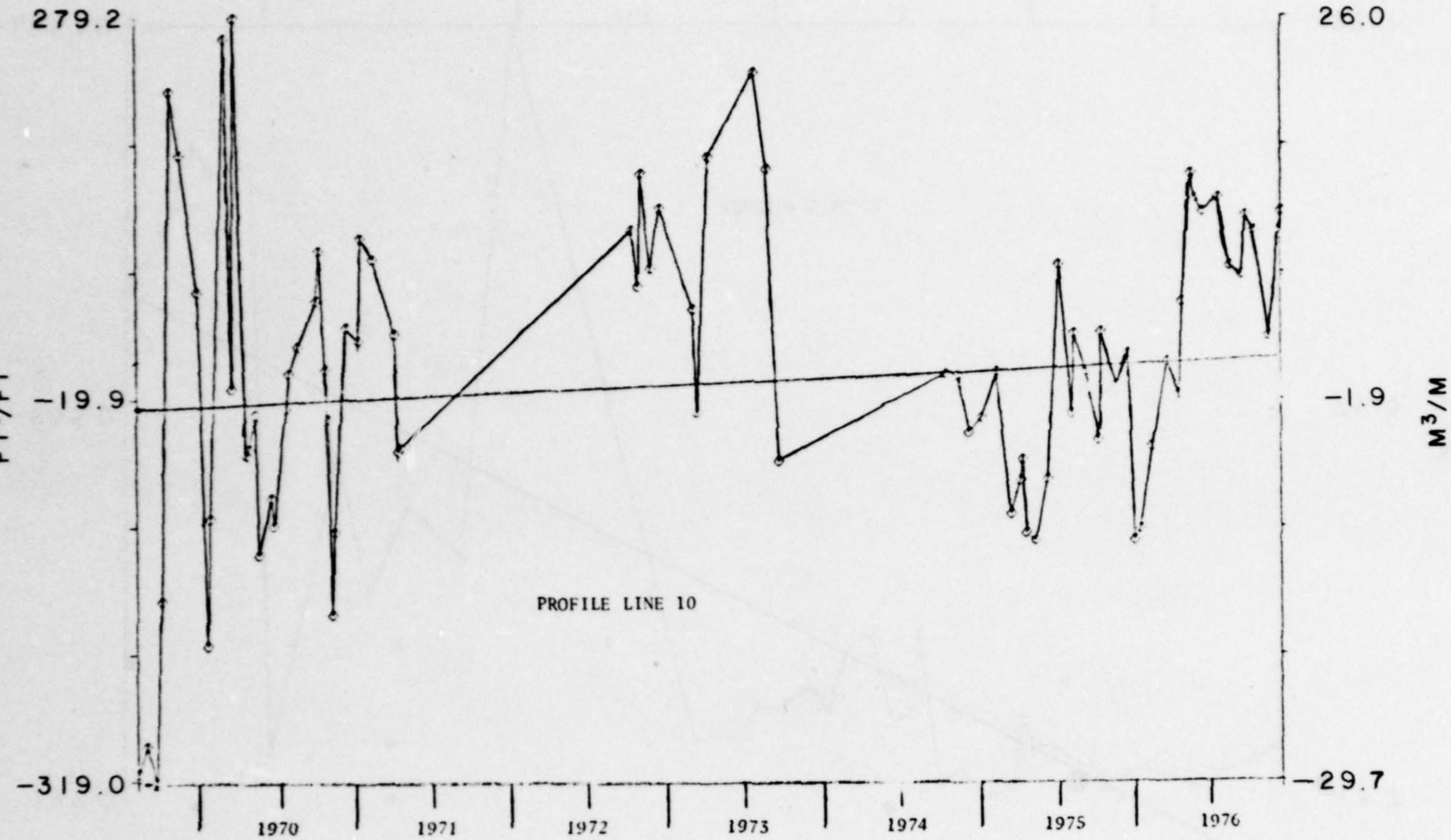
114.2
-438.4
-941.0
FT3/FT
10.6
-40.8
-92.2
M3/M
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
PROFILE LINE 2


28.0
-1.4
-30.8
M³/M
301.4
-14.8
-331.0
FT³/FT
1963
1965
1967
1969
1971
1973
1975
PROFILE LINE 3

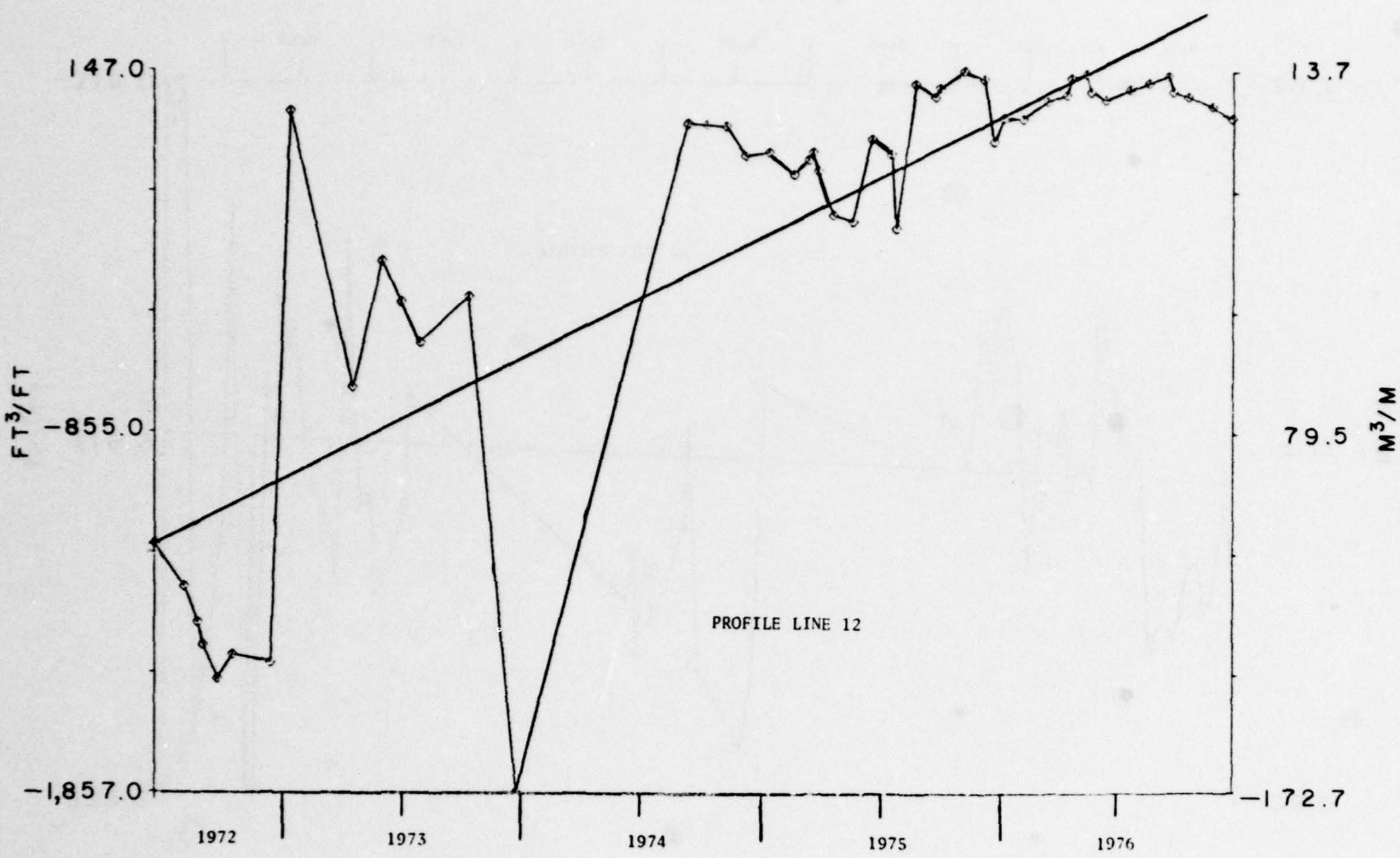

495.2
206.6
-82.0
FT3/FT
46.1
19.2
-7.6
M3/M
PROFILE LINE 4
1963
1965
1967
1969
1971
1973
1975

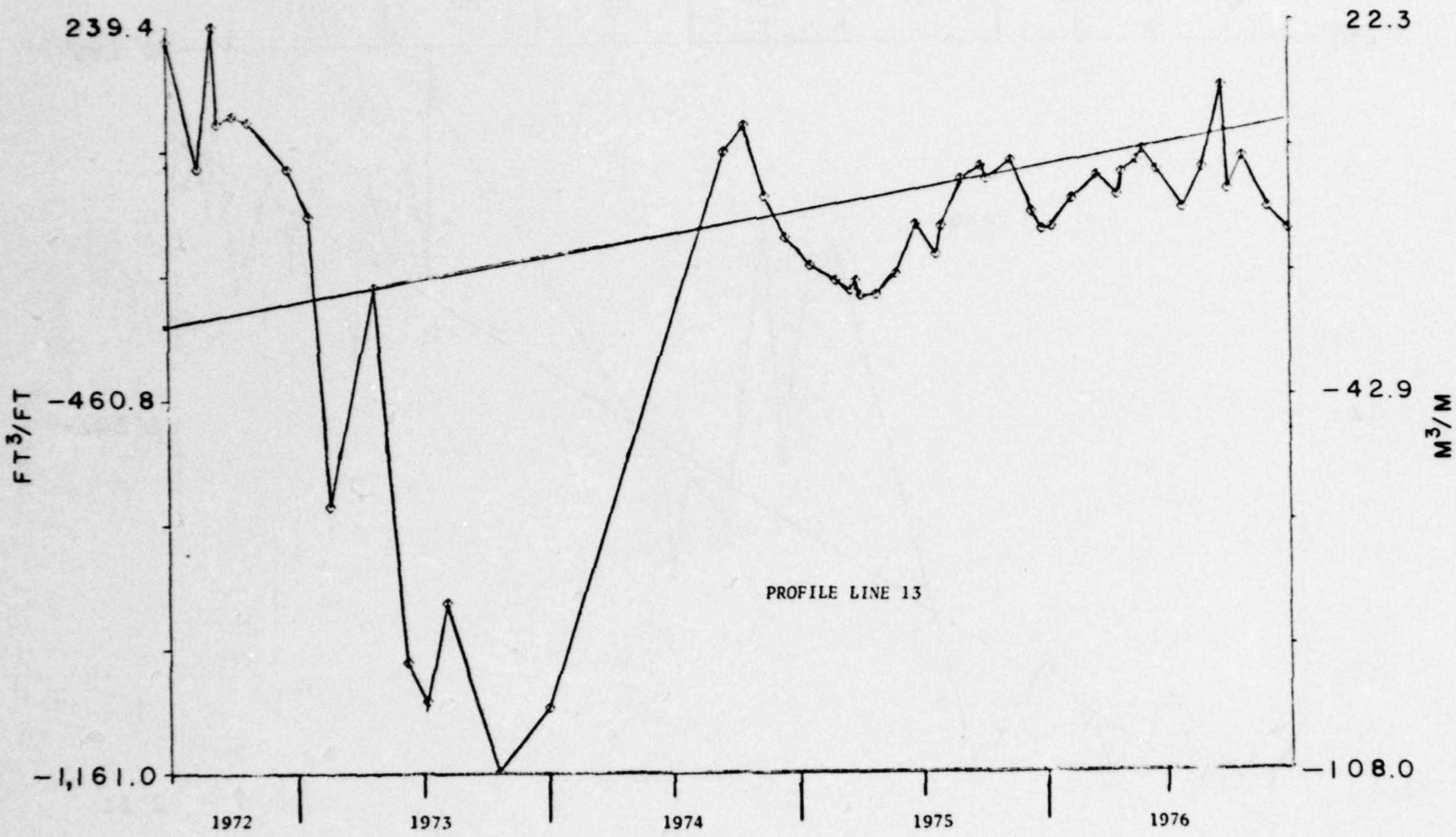

13.8
0.5
-12.7
M^3/M
148.0
5.5
-137.0
FT^3/FT
1963
1965
1967
1969
1971
1973
1975
PROFILE LINE 5

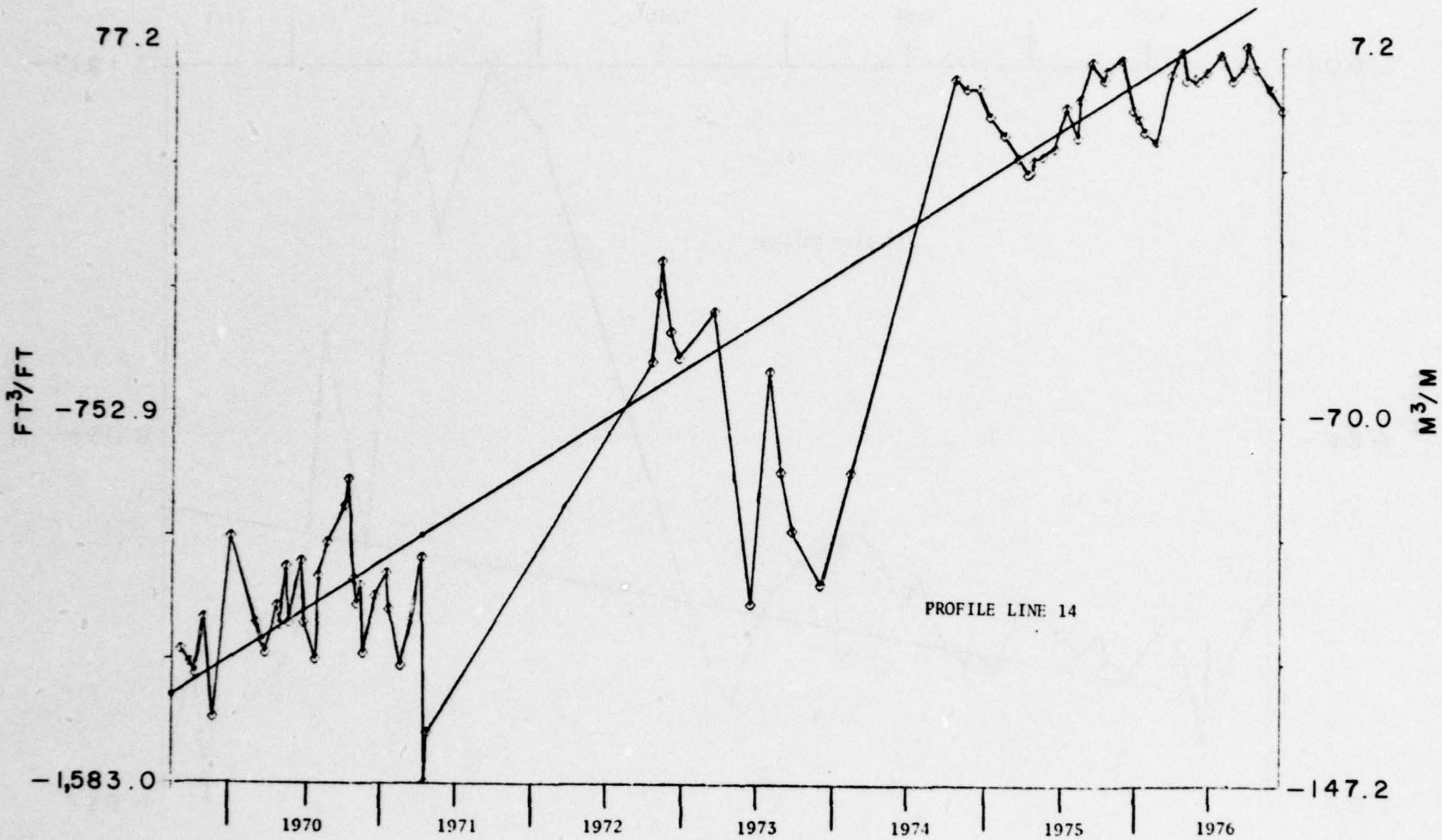

479.0
44.0
-391.0
FT3/FT
44.6
4.1
-36.4
M3/M
PROFILE LINE 8
1970
1971
1972
1973
1974
1975
1976

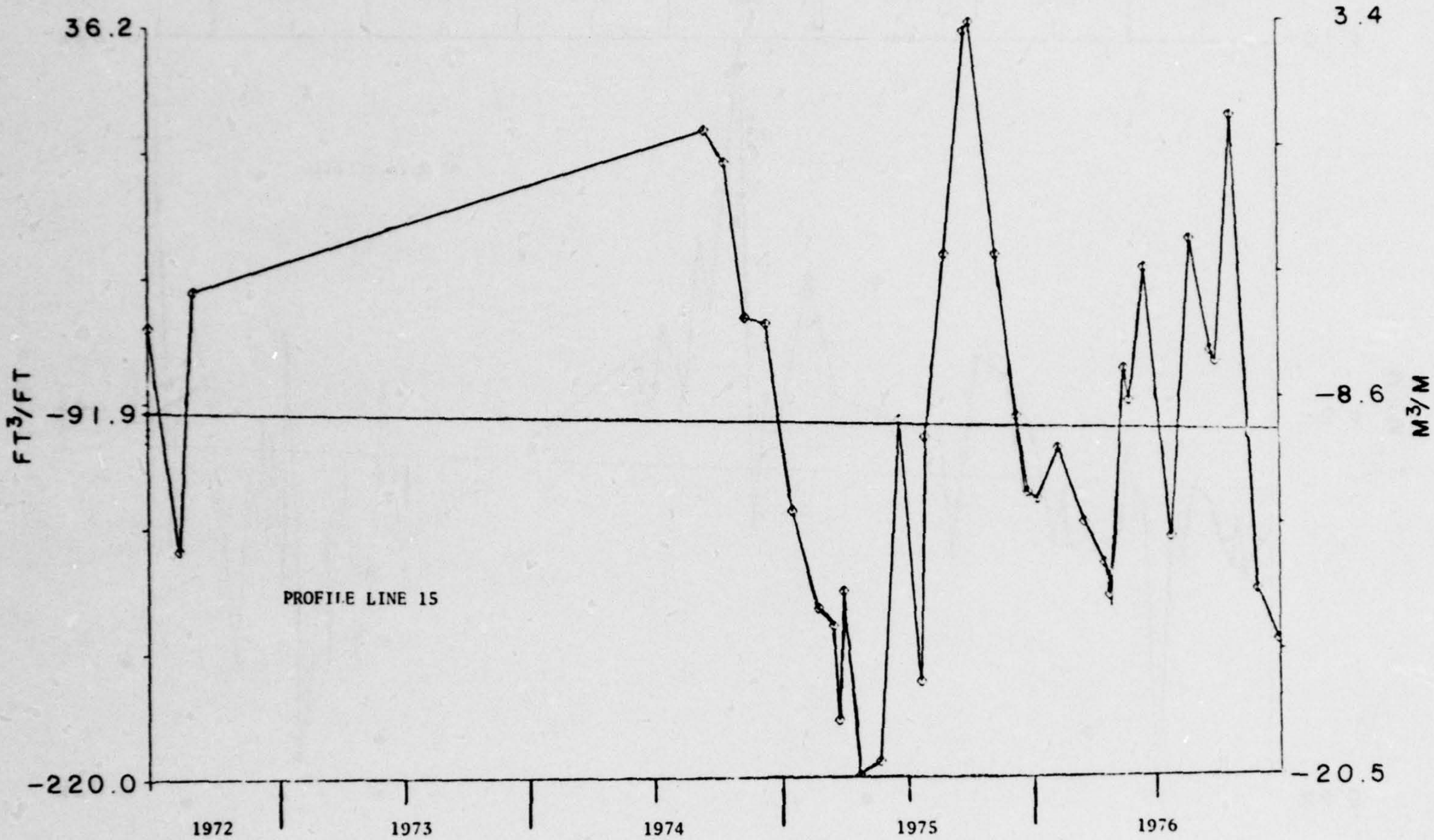


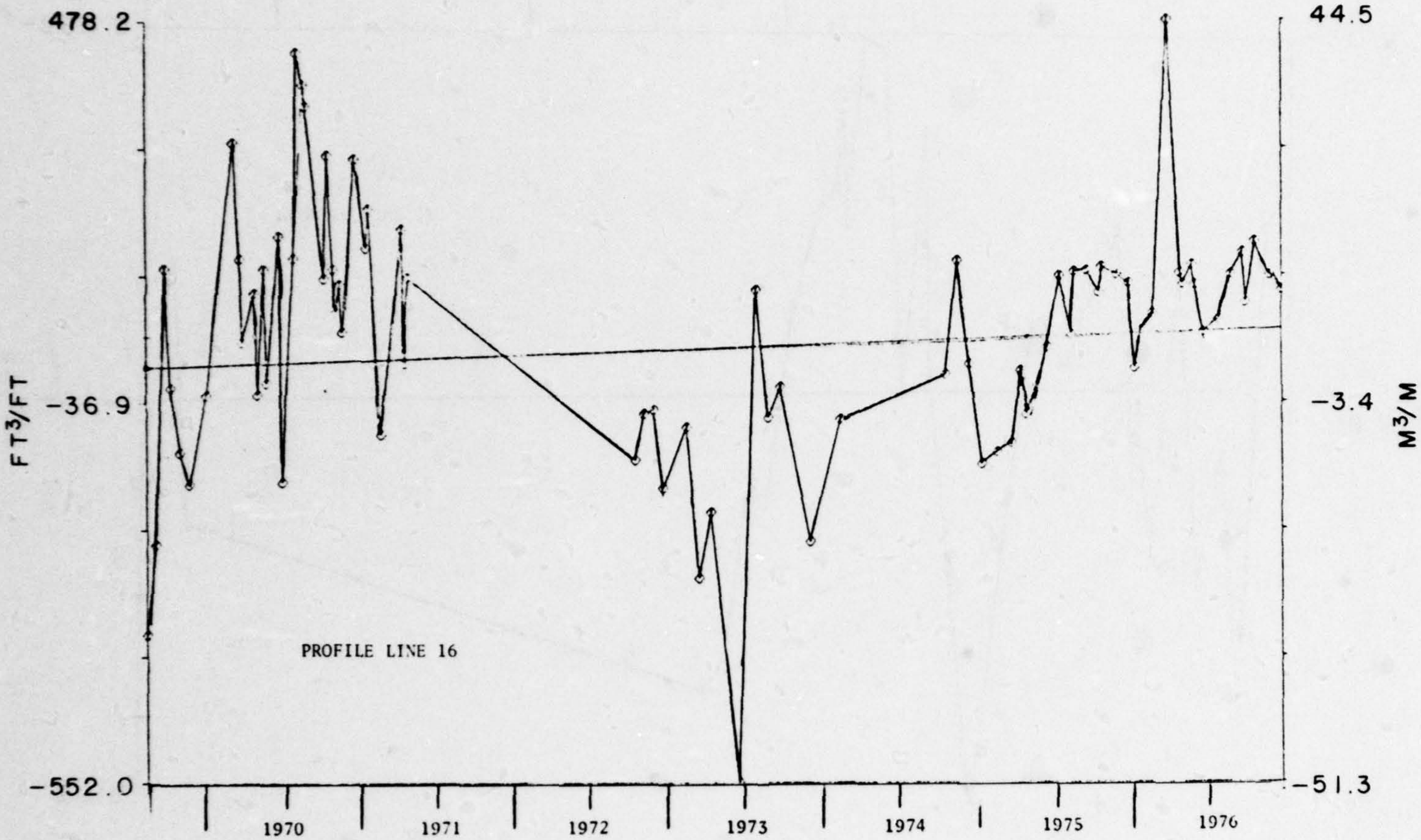
279.2
-19.9
-319.0
FT³/FT
26.0
-1.9
-29.7
M³/M
1970
1971
1972
1973
1974
1975
1976
PROFILE LINE 10


147.0
-855.0
-1,857.0
FT³/FT
13.7
79.5
-172.7
M³/M
PROFILE LINE 12
1972
1973
1974
1975
1976

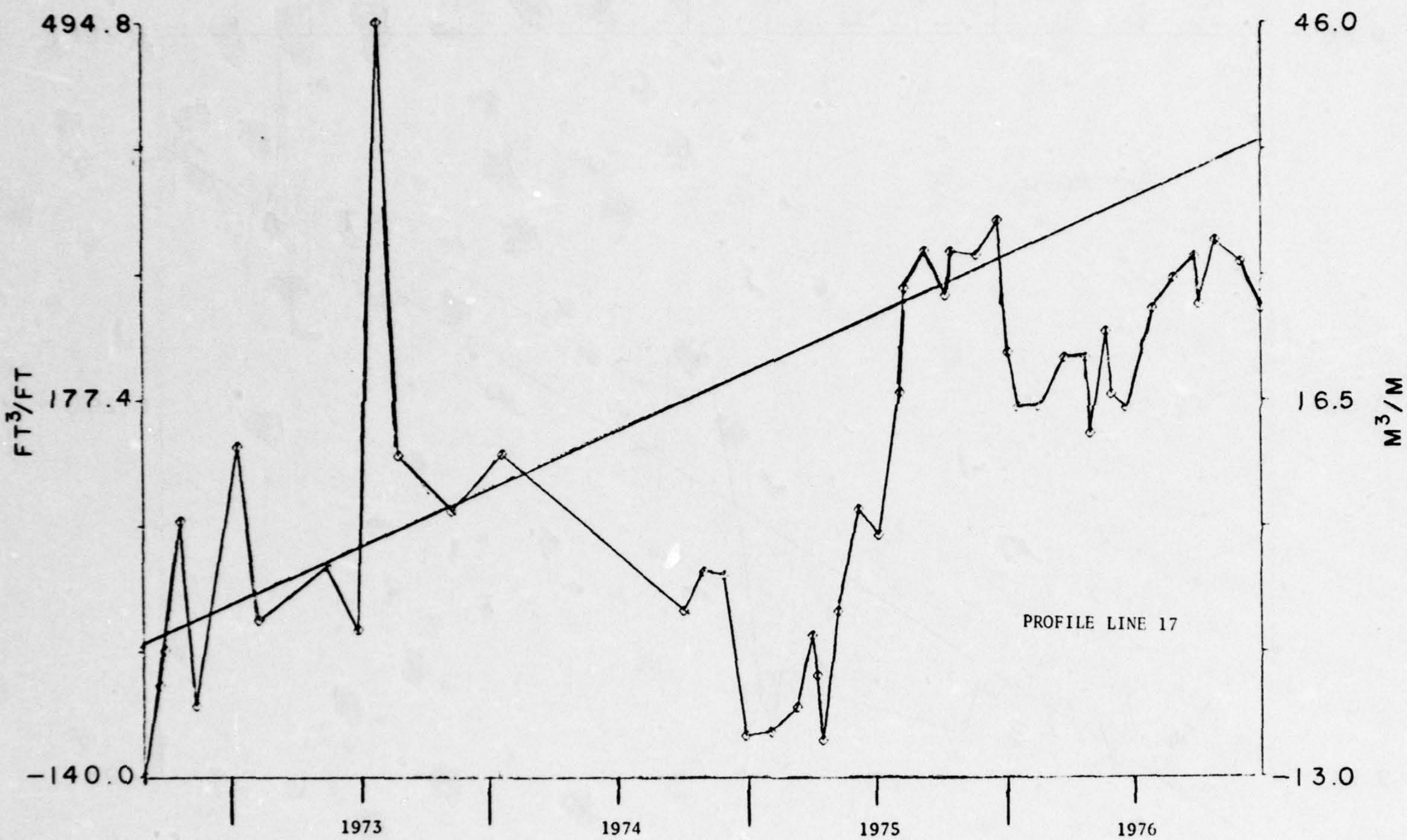

239.4
-460.8
-1,161.0
FT³/FT
22.3
-42.9
-108.0
M³/M
PROFILE LINE 13
1972
1973
1974
1975
1976

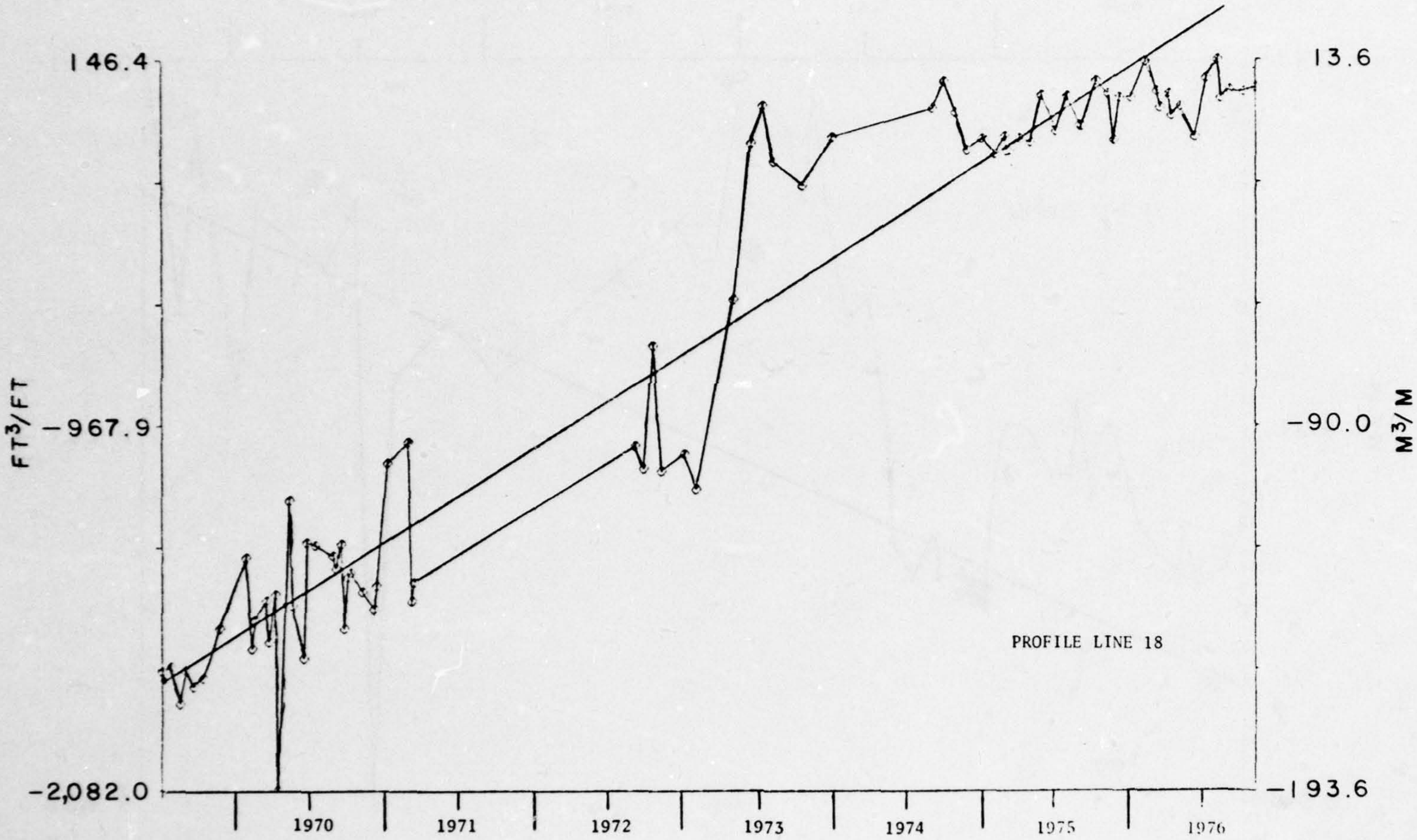

77.2
-752.9
-1,583.0
FT³/FT
7.2
-70.0
-147.2
M³/M
1970
1971
1972
1973
1974
1975
1976
PROFILE LINE 14


36.2
-91.9
-220.0
FT3/FT
3.4
-8.6
-20.5
M3/M
PROFILE LINE 15
1972
1973
1974
1975
1976



478.2
-36.9
-552.0
FT3/FT
44.5
-3.4
-51.3
M3/M
PROFILE LINE 16
1970
1971
1972
1973
1974
1975
1976


494.8
177.4
-140.0
FT3/FT
46.0
16.5
-13.0
M3/M
1973
1974
1975
1976
PROFILE LINE 17


PROFILE LINE 18
146.4
-967.9
-2,082.0
FT^3/FT
13.6
-90.0
-193.6
M^3/M
1970
1971
1972
1973
1974
1975
1976

APPENDIX D

SUMMARY OF STORM DATA

Appendix D contains a summary of storm data for 4 December 1974 to 9 August 1976. Information was obtained from the Chesapeake Lightship, Currituck Beach Lighthouse, North Carolina; and the Norfolk International Airport.

Storm parameters include tide height, maximum wave height, and wave duration equal to or greater than 1 meter; maximum swell height, direction, period, and swell duration equal to or greater than 1.5 meters; and maximum wind direction, speed, and duration equal to or greater than 25 knots.

CHESAPEAKE LIGHT

Date	Time (e.s.t.)	False Cape tide height (m)	Max. wave height (m)	Wave height duration ≥ 1 m (h)	Max. swell height (m)	Max. swell direction (true)	Max. swell period (s)	Swell height duration ≥ 1.5 m (h)	Max. wind direction (true)	Max. wind speed (kn)	Wind duration ≥ 25 kn (h)
4 Dec. 1974	0431	-0.1 low[1]									
	0800								NW.[2]	35	12
	1051	1.2 high									
	1700		0.9	0	1.5	NNE.	5	15			
14 Mar. 1975	0208	-0.1 low									
	0400		1.2	9							
	0700								NNE.	38	6
	1300				1.8	E.	6	24			
19 Mar. 1975	0528	0.1 low									
	1000								SE.	34	12
	1127	0.9 high									
	1600		0.9	0							
	1900				2.1	ESE.	6	18			
30 June 1975	1814	0.1 low									
	2130		1.8	9	2.7	ESE.	5	12			
1 July 1975	0009	1.0 high									
31 Aug. 1975	2047	0.2 low									
1 Sept. 1975	0100		0.9	0	1.2	E.	6	0	NE.	28	27
	0242	1.0 high									
	0847	0.1 low									
23 Nov. 1975	2233	1.0 high									
	2305								NE.	72	30
24 Nov. 1975	0230		1.5	15	2.4	NE.	6	33			
	0436	0.0 low									
	1057	1.1 high									
9 Mar. 1976	1918	0.0 low									
10 Mar. 1976	0100								NW.	40	21
	0150	1.0 high									
	0400		0.9	0	1.5	ENE.	6	1			
	0814	0.1 low									
9 Apr. 1976	0700								N.	30	21
	1449	1.0 high									
	1900		1.2	9	1.2	N.	5	0			
	2103	0.0 low									
9 Aug. 1976	1353	0.0 low									

[1]Predicted tides at False Cape, Virginia, from National Ocean Survey Tide Tables.

[2]Sea and Wind conditions at Chesapeake Light, Virginia.

			Currituck Beach Light			Norfolk International Airport		
Date	Time (e.s.t.)	False Cape tide height (m)	Max. wind direction (true)	Max. windspeed (kn)	Wind duration ≥ 25 kn (h)	Max. wind direction (true)	Max. wind-speed (kn)	Wind duration ≥ 25 kn (h)
4 Dec. 1974	0030					NW.[3]	17	0
	0431	-0.1 low						
	1051	1.2 high						
14 Mar. 1975	0200					NE.	24	0
	0208	-0.1 low						
19 Mar. 1975	0528	0.1 low						
	0830					S.	23	0
	1127	0.9 high						
30 June 1975	1814	0.1 low						
	2200					NNE.	22	0
1 July 1975	0009	1.0 high						
	0200					NE.	22	0
31 Aug. 1975	1700					SE.	16	0
	2047	0.2 low						
1 Sept. 1975	0242	1.0 high						
	0400					ESE.	12	0
	0847	0.1 low						
23 Nov. 1975	2000					NNE.	25	1
	2233	1.0 high						
24 Nov. 1975	0436	0.0 low				NNE.	27	1
	1057	1.1 high						
9 Mar. 1976	0700		NE.[4]	25	1			
	1918	0.0 low						
	2300					NNW.	21	0
10 Mar. 1976	0030					NNW.	21	0
	0150	1.0 high						
	0814	0.1 low						
9 Apr. 1976	1400		NNW.	38	21	N.	21	0
	1449	1.0 high						
	2103	0.0 low						
9 Aug. 1976	1150		NW.	62	8	N.	28	1
	1353	0.0 low						

[3]Wind conditions at Norfolk International Airport, Norfolk, Virginia.

[4]Wind conditions at Currituck Beach Light, Corolla, North Carolina.

APPENDIX E

BIRD CENSUS DATA

Appendix E contains bird census data collected at the profile locations from October 1974 to February 1976 by S. Sturm. Both species of birds and numbers of individuals are included.

Bird Census Data

Southeastern Virginia bird observations
(Total number individuals observed October 1974 to February 1976)

Species	Fort Story (military)	Virginia Beach (commercial)	Dam Neck (military)	Sandbridge (residential)	Back Bay (natural)	False Cape (natural)
Common Loon		1	1	12	31	8
Horned Grebe		4	2	8	4	2
Gannet	35	49	50	27	53	189
Double-Crested Cormorant	18	101	5	86	659	671
Canada Goose		19	22		392	6
Snow Goose					762	22
White-Winged Scoter					2	5
Red-Breasted Merganser	20	58	11	43	971	810
Osprey			2		1	2
Black-Bellied Plover	12	2	3	16	145	62
Marbeled Godwit					2	
Willet	1	10	33	77	191	118
Ruddy Turnstone		1		1	43	34
Dunlin			23	30	478	1,652
Sanderling	113	146	570	476	1,419	3,677
Great Black-Backed Gull	14	16	65	30	513	696
Herring Gull	1,330	1,507	662	661	2,846	3,772
Ring-Billed Gull	1,949	686	166	534	1,071	1,731
Laughing Gull	45	121	298	66	315	321
Royal Tern	31	28	123	3	96	202
Caspian Tern	25	3	39		55	66
Pigeon		231				
Barn Swallow			2	4	10	36
Carolina Wren	2			1	2	
Starling		12		2	9	1
Yellow-Rumped Warbler				2	37	33
Yellow Throat				3	12	2
House Sparrow		12				
Boat-Tailed Grackle	2	33	29	52	95	103
Song Sparrow		2	3		8	23
Total number individuals	3,611	3,042	2,109	2,134	10,222	14,244
Total number species	14	21	20	21	28	26

APPENDIX F

VIMS-CERC SURVEY FORMS

Appendix F contains two original field forms developed and used by VIMS in tabulating data for CERC.

VIMS - BEACH SURVEY FORM

Location____________________ Recorder____________ Page __of __

Weather____________________ Wind dir. & vel.____________

	DATE	TIME		STAKE HTS.		
loc	mo day yr	start	finish	rear	middle	front
1 2	3 4 5 6 7 8	10 11 12 13	14 15 16 17	19 20 21 22 23 24	25 26 27 28 29 30	31 32 33 34 35 36

	STAKE ELEV.			TIDE					
ht.level	rear	middle	front	time-low	range				
38 39 40 41	43 44 45 46 47	48 49 50 51 52	53 54 55 56 57	59 60 61 62	63 64 65	67 68 69 70 71	73	75 76	80

HORIZ.	VERT.	HORIZ.	VERT.	HORIZ.	VERT.
1 2 3 4 5 6	7 8 9 10 11	1 2 3 4 5 6	7 8 9 10 11	1 2 3 4 5 6	7 8 9 10 11
12 13 14 15 16 17	18 19 20 21 22	12 13 14 15 16 17	18 19 20 21 22	12 13 14 15 16 17	18 19 20 21 22
23 24 25 26 27 28	29 30 31 32 33	23 24 25 26 27 28	29 30 31 32 33	23 24 25 26 27 28	29 30 31 32 33
34 35 36 37 38 39	40 41 42 43 44	34 35 36 37 38 39	40 41 42 43 44	34 35 36 37 38 39	40 41 42 43 44
45 46 47 48 49 50	51 52 53 54 55	45 46 47 48 49 50	51 52 53 54 55	45 46 47 48 49 50	51 52 53 54 55
56 57 58 59 60 61	62 63 64 65 66	56 57 58 59 60 61	62 63 64 65 66	56 57 58 59 60 61	62 63 64 65 66
67 68 69 70 71 72 (7)		67 68 69 70 71 72 (7)		67 68 69 70 71 72 (7)	

Page___of___

QUARTERLY RECONNAISSANCE -- CURRITUCK COUNTY -- DATA AND OBSERVATIONS

for CERC by VIMS

Date: ______________________ General Conditions, Prev. Meteorological Events, etc. ______________________

Observers:

ODOMETER MILEAGE	MILEAGE (South of State Line)	FORESHORE SLOPE (°)	GRAIN SIZE & LOCATION	PROMINANT FEATURE (if any)	SAND LEVEL (against feature)	PHOTO Nos.	GENERAL CONDITION (Eros.-Accret., trafficability, scarping, etc.)

APPENDIX G

SURVEY DATA FOR 18 PROFILE LINES

Appendix G contains the survey data and sketches of the horizontal controls for the 18 profile lines.

Heights are listed in feet and meters above MSL, as surveyed in April 1976 by Freeman and Johnson, Consulting Engineers and Land Surveyors, 62052 Bonney Road, Virginia Beach, Virginia, 23462.

VIMS-CERC PROFILE LINES, CAPE HENRY TO VIRGINIA-NORTH CAROLINA STATE LINE

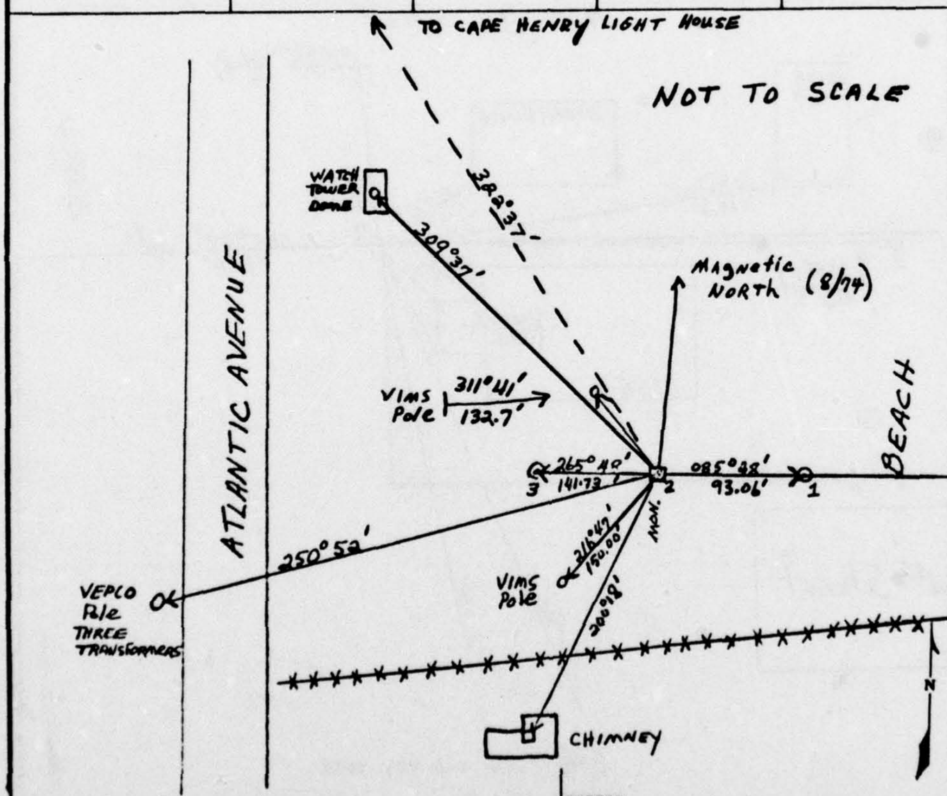
Profile line	Pipe 1		Pipe 2		Pipe 3	
	(ft)	(m)	(ft)	(m)	(ft)	(m)
1	16.17	4.93	19.97	6.09	14.19	4.33
2	18.94	5.77	15.48	4.72	10.54	3.21
3	11.65	3.55	15.30	4.66	16.30	4.97
4	7.87	2.40	10.17	3.10	10.68	3.26
5	14.88	4.54	19.45	5.93	14.58	4.44
6	11.82	3.60	22.43	6.84	12.34	3.76
7	16.62	5.07	15.91	4.85	18.43	5.62
8	15.13	4.61	15.56	4.74	15.03	4.68
9	16.17	4.93	15.24	4.65	10.55	3.22
10	16.51	5.03	9.33	2.84	9.02	2.75
11	20.04	6.11	20.27	6.18	19.57	5.97
12	15.20	4.63	18.42	5.61	20.36	6.21
13	14.69	4.48	20.01	6.10	24.21	7.38
14	22.24	6.78	9.76	2.97	21.25	6.48
15	7.45	2.27	12.47	3.80	15.92	4.85
16	19.44	5.93	23.32	7.11	11.62	3.54
17	16.47	5.02	23.79	7.25	21.51	6.56
18	21.08	6.43	26.80	8.17	10.97	3.34

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Fort Story Profile line 1 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 1-2	VIMS-CERC	19.97
LATITUDE	LONGITUDE	DATUM	DATUM
36° 54' 55"	75° 59' 36"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2732772.44 E	221605.84 N	Lambert, Va.-South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			Apr. 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

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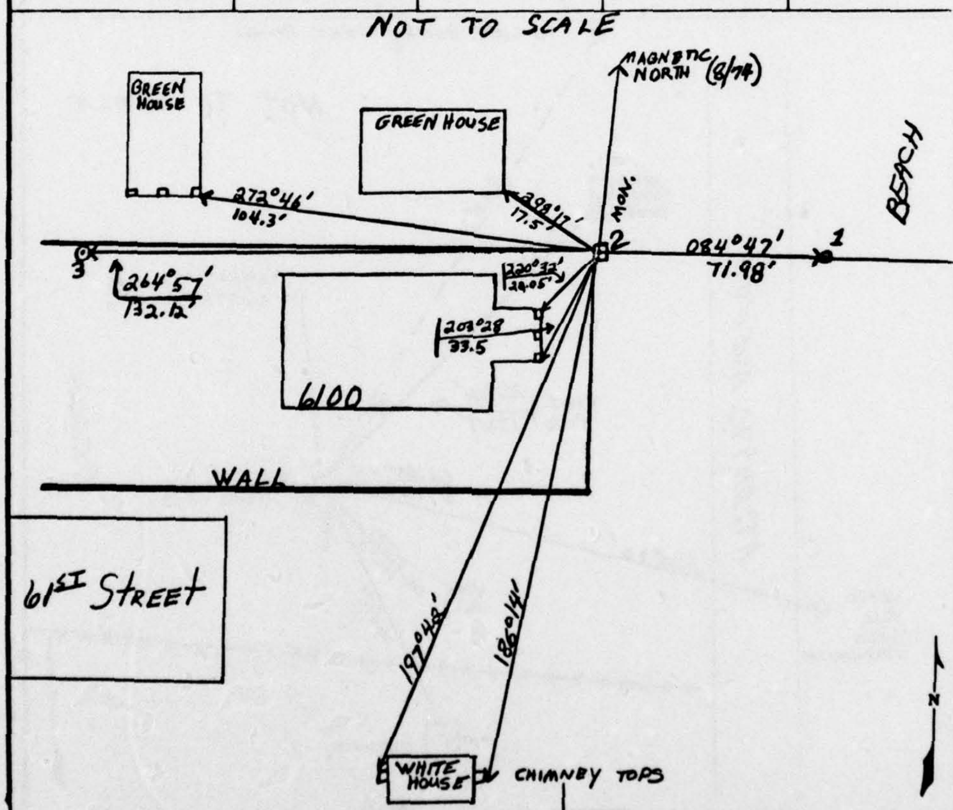
COUNTRY: U.S.A.	TYPE OF MARK: Concrete monument with disk	STATION: VIMS 2 61st Street, Va. Beach Profile line 2

LOCALITY: Virginia Beach, Va.	STAMPING ON MARK: PRO 2-2	AGENCY (CAST IN MARKS): VIMS-CERC	ELEVATION (FT): 15.48
LATITUDE: 36° 53' 12.7"	LONGITUDE: 75° 59' 8.9"	DATUM: North America 1927	DATUM: MSL
(NORTHING)(EASTING) (FT): 2735225.58 E	(EASTING)(NORTHING) (FT): 211321.77 N	GRID AND ZONE: Lambert-Va. South	ESTABLISHED BY (AGENCY): Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: Apr. 1976 — ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



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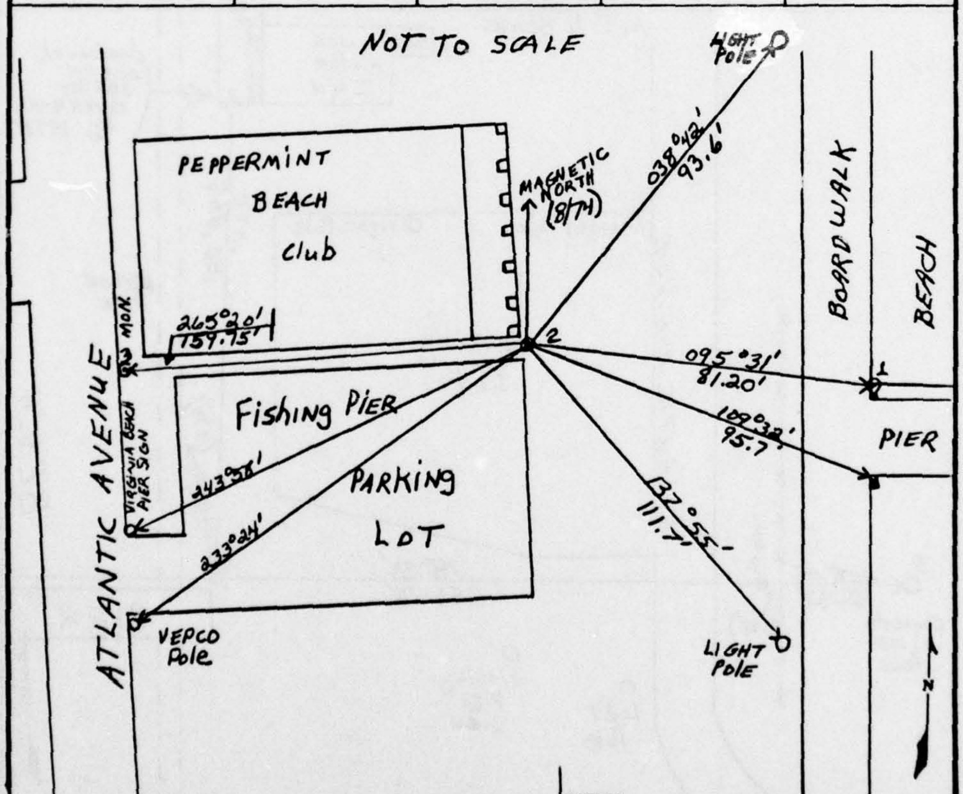
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	15th St. Pier Profile line 3 VIMS 3	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT)
Virginia Beach, Va.	PRO 3-3	VIMS-CERC	16.30
LATITUDE	LONGITUDE	DATUM	DATUM
36° 50' 35.6"	75° 58' 23.2"	North America 1927	MSL
(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2739364.12 E	195540.44 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



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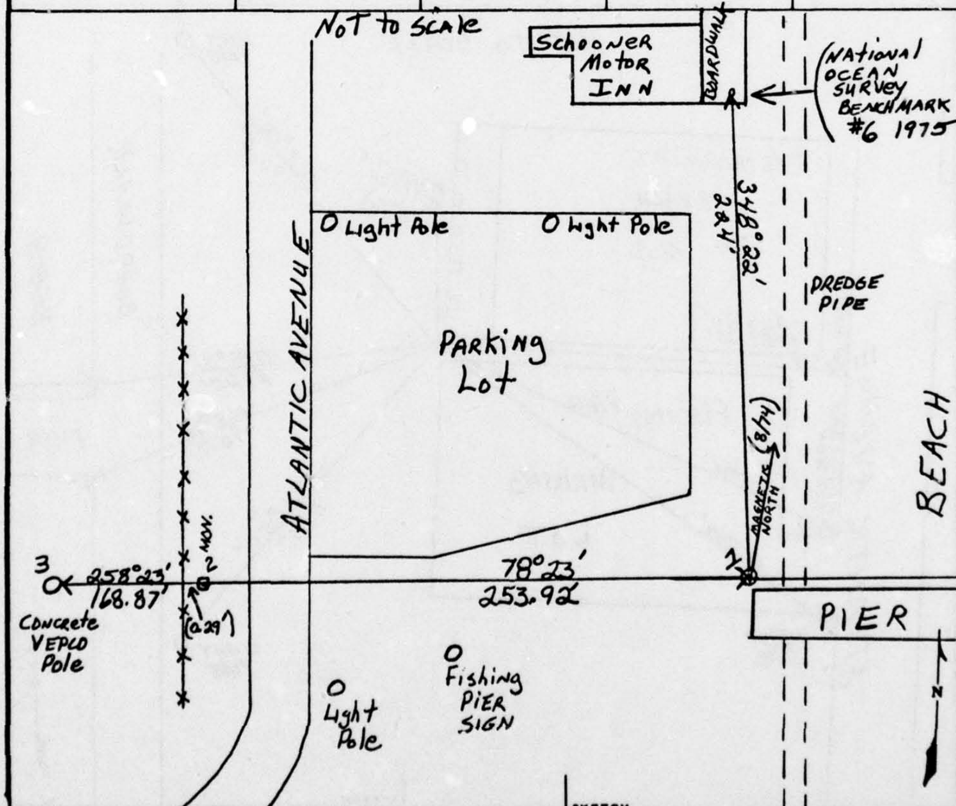
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	1st St. Pier Profile line 4 VIMS 2	
LOCALITY	**STAMPING ON MARK**	**AGENCY (CAST IN MARKS)**	**ELEVATION (FT) (M)**
Virginia Beach, Va.	PRO 4-2	VIMS-CERC	10.17
LATITUDE	**LONGITUDE**	**DATUM**	**DATUM**
36° 49' 50.3"	75° 58' 11.7"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	**(EASTING)(NORTHING) (FT) (M)**	**GRID AND ZONE**	**ESTABLISHED BY (AGENCY)**
2740424.10 E	190978.97 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	**(EASTING)(NORTHING) (FT) (M)**	**GRID AND ZONE**	**DATE** / **ORDER**
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



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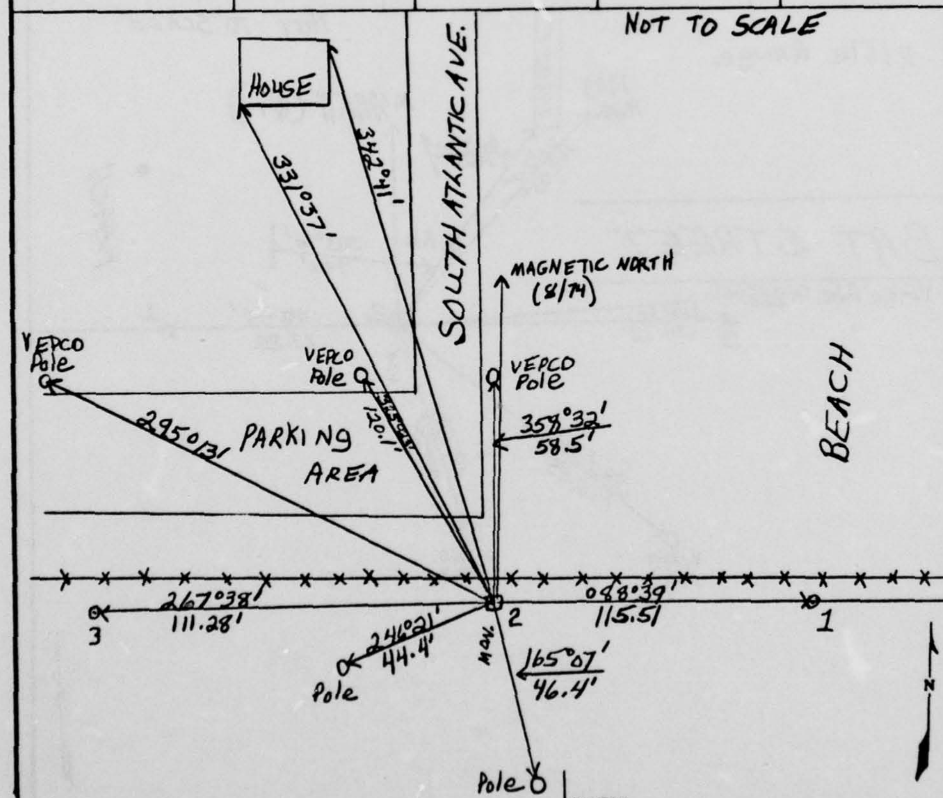
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Camp Pendleton North Boundary Profile line 5 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) ~~(M)~~
Virginia Beach, Va.	PRO 5-2	VIMS-CERC	19.45
LATITUDE	LONGITUDE	DATUM	DATUM
36° 49' 6.2"	75° 58' 3.5"	North America 1927	MSL
(NORTHING)(EASTING) (FT) ~~(M)~~	(EASTING)(NORTHING) (FT) ~~(M)~~	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2741209.22 E	186545.06 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



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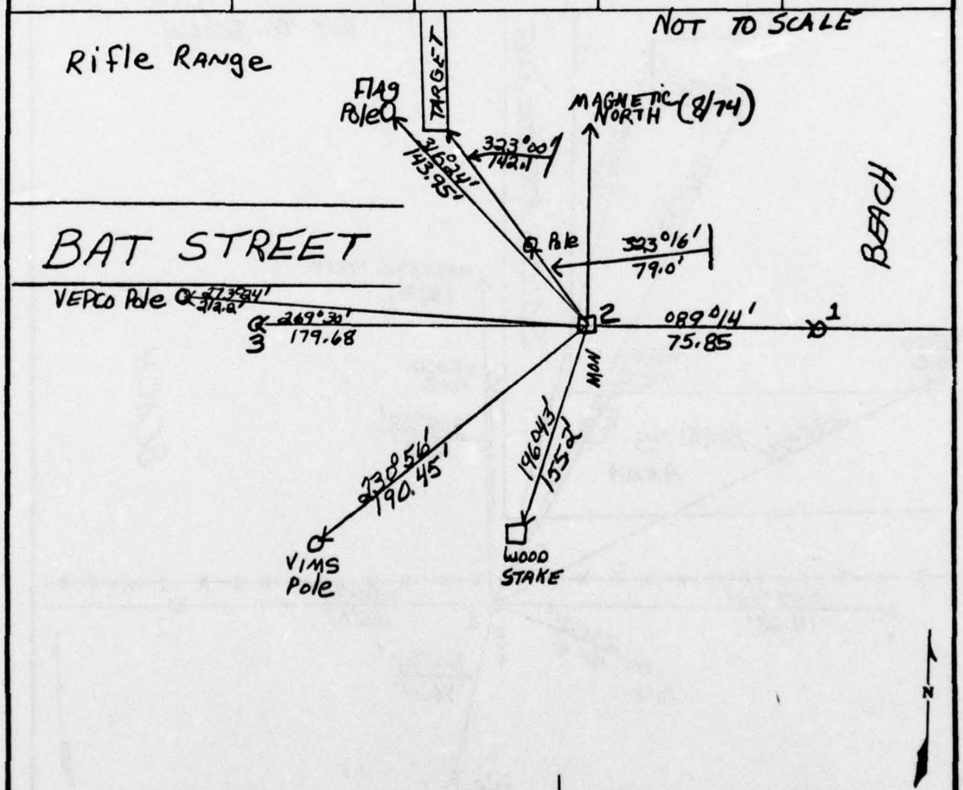
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Dam Neck Rifle Range Profile line 6	VIMS 2
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT)
Virginia Beach, Va.	PRO 6-2	VIMS-CERC	22.43
LATITUDE	LONGITUDE	DATUM	DATUM
36° 47' 51.6"	75° 57' 44"	North America 1927	MSL
(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2742999.56 E	179040.97 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN	GRID AZIMUTH, ADD ° ' "	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ. (ADD)(SUB.) ° ' "	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

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DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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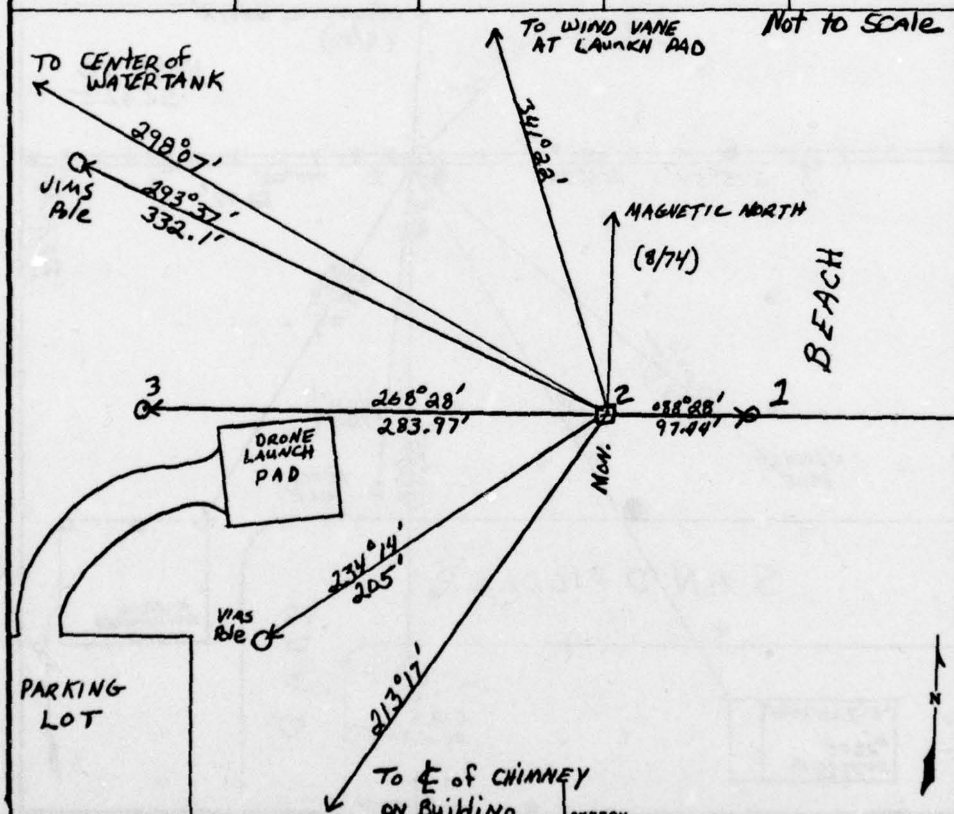
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Dam Neck Drone Launch Area Profile Line 7	VIMS 2
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 7-2	VIMS-CERC	15.91
LATITUDE	LONGITUDE	DATUM	DATUM
36° 46' 1.6"	75° 57' 8.7"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2746164.99 E	167999.80 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

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DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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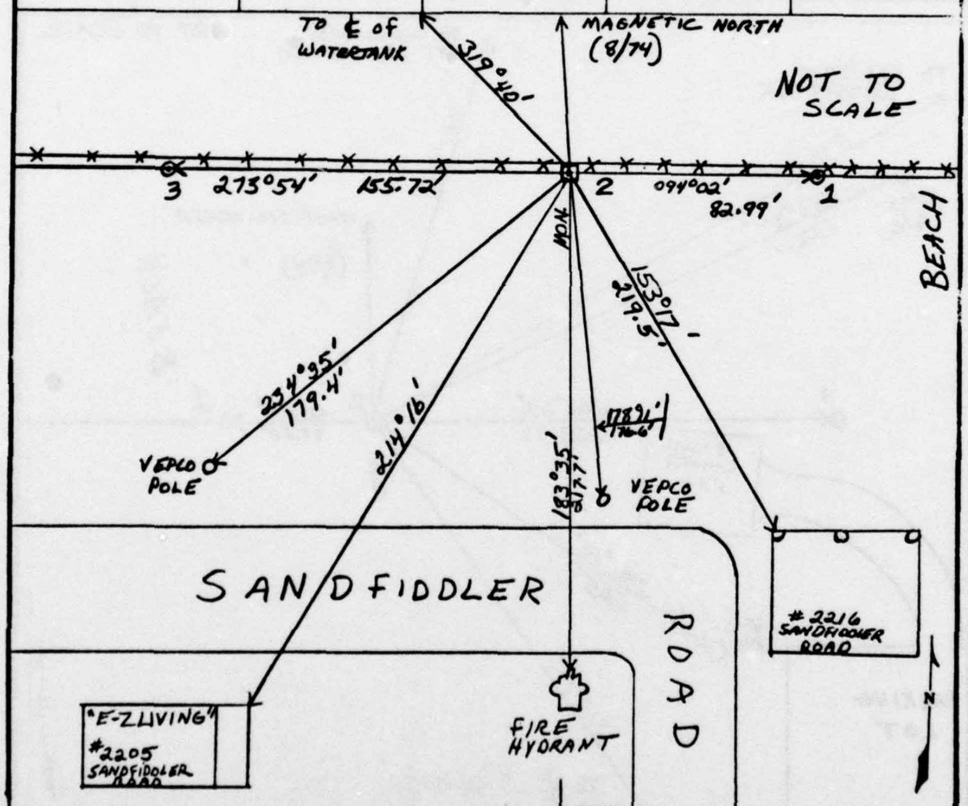
COUNTRY U.S.A.	TYPE OF MARK Concrete monument with disk	STATION Dam Neck South Boundary Profile line 8 VIMS 2	
LOCALITY Virginia Beach, Va.	STAMPING ON MARK PRO 8-2	AGENCY (CAST IN MARKS) VIMS-CERC	ELEVATION (FT) 15.56 ~~(M)~~
LATITUDE 36° 45' 38.1"	LONGITUDE 75° 57' 0.5"	DATUM North America 1927	DATUM MSL
(NORTHING)(EASTING) (FT) ~~(M)~~ 2746895.63 E	(EASTING)(NORTHING) (FT) ~~(M)~~ 165637.64 N	GRID AND ZONE Lambert-Va. South	ESTABLISHED BY (AGENCY) Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE April 1976 — ORDER 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

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DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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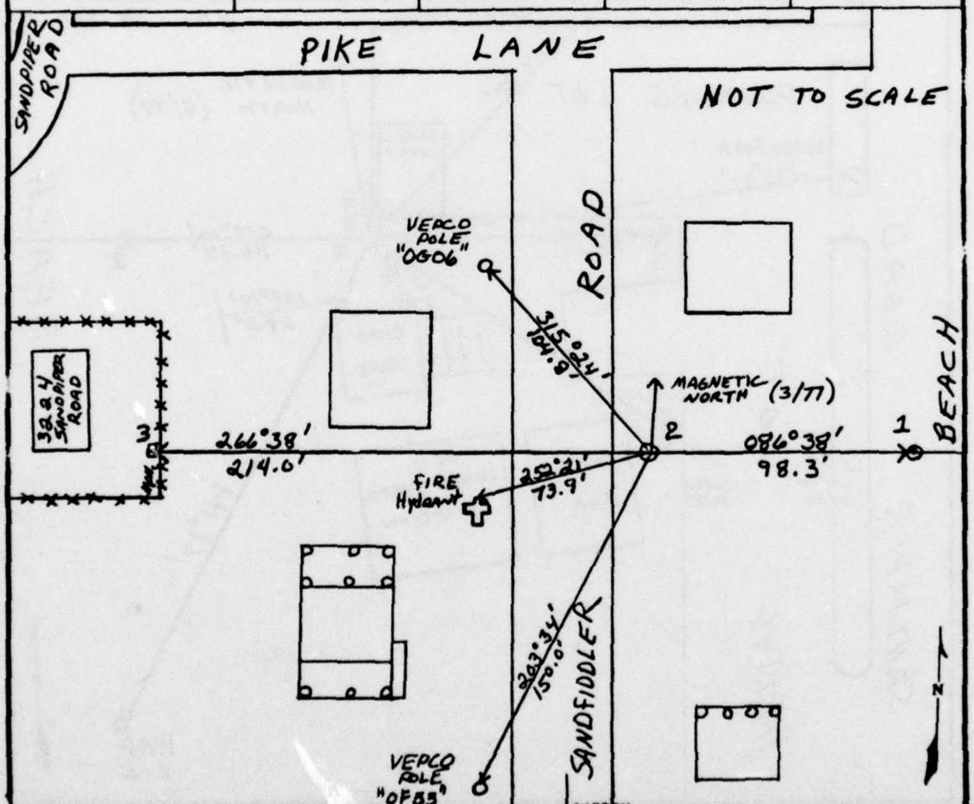
COUNTRY U.S.A.	TYPE OF MARK Concrete monument with disk	STATION Sandbridge Profile line 9 VIMS 3	
LOCALITY Virginia Beach, Va.	STAMPING ON MARK PRO 9-3	AGENCY (CAST IN MARKS) VIMS-CERC	ELEVATION (FT) 10.55
LATITUDE 36° 42' 59.8"	LONGITUDE 75° 55' 59.5"	DATUM North America 1927	DATUM MSL
(NORTHING)(EASTING) (FT) 2752298.01 E	(EASTING)(NORTHING) (FT) 149772.42 N	GRID AND ZONE Lambert-Va. South	ESTABLISHED BY (AGENCY) Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE April 1976 / ORDER 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

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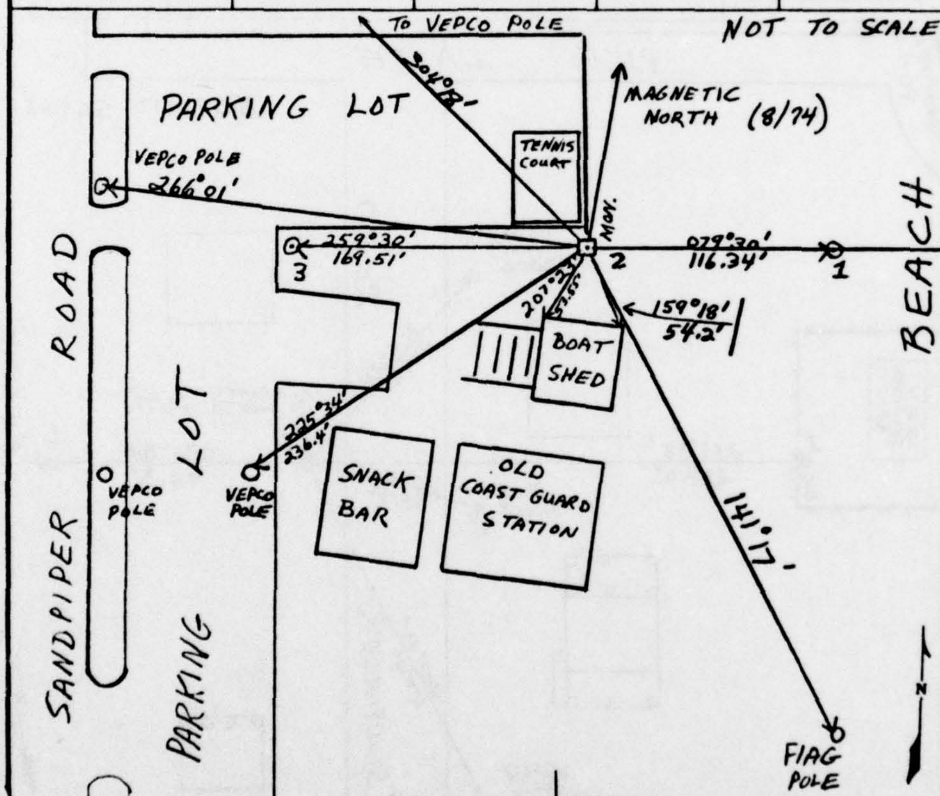
DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Little Island Recreation Area Profile line 10 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 10-2	VIMS-CERC	9.33
LATITUDE	LONGITUDE	DATUM	DATUM
36^{o} 41' 40.05"	75^{o} 55' 30.0"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2755115.52 E	141780.54 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

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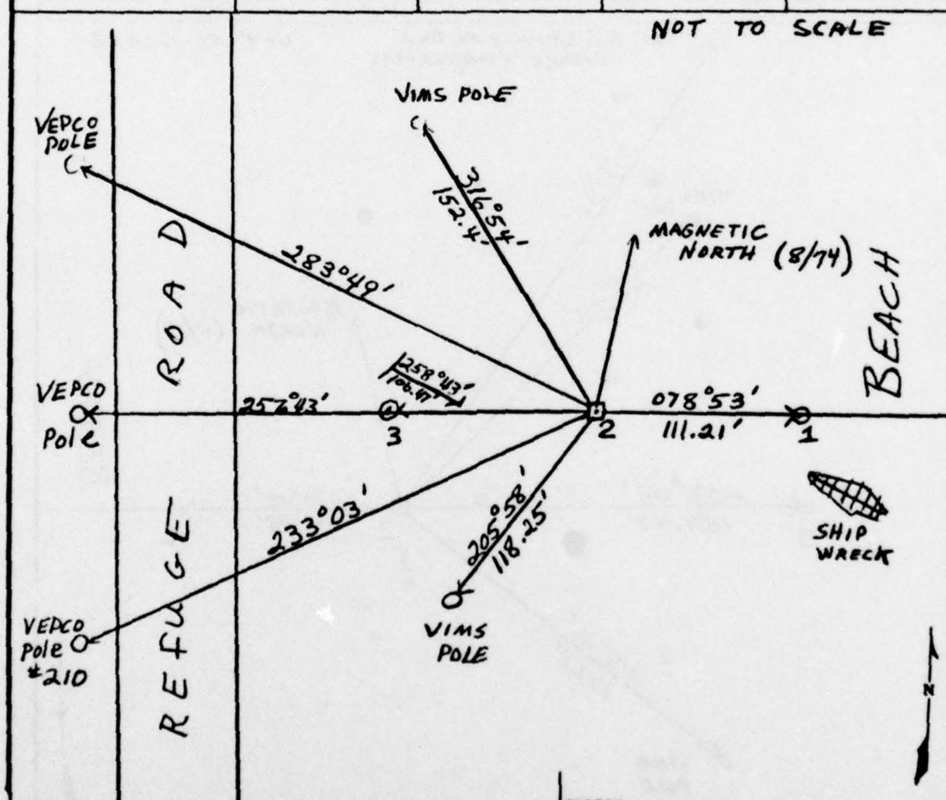
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Back Bay National Wildlife Refuge Profile line 11 VIMS 2	
LOCALITY	**STAMPING ON MARK**	**AGENCY (CAST IN MARKS)**	**ELEVATION (FT)**
Virginia Beach, Va.	PRO 11-2	VIMS-CERC	20.27
LATITUDE	**LONGITUDE**	**DATUM**	**DATUM**
36° 40' 49.2"	75° 55' 0.7"	North America 1927	MSL
(NORTHING)(EASTING) (FT)	**(EASTING)(NORTHING) (FT)**	**GRID AND ZONE**	**ESTABLISHED BY (AGENCY)**
2757446.68 E	136697.33 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	**(EASTING)(NORTHING) (FT) (M)**	**GRID AND ZONE**	**DATE** / **ORDER**
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

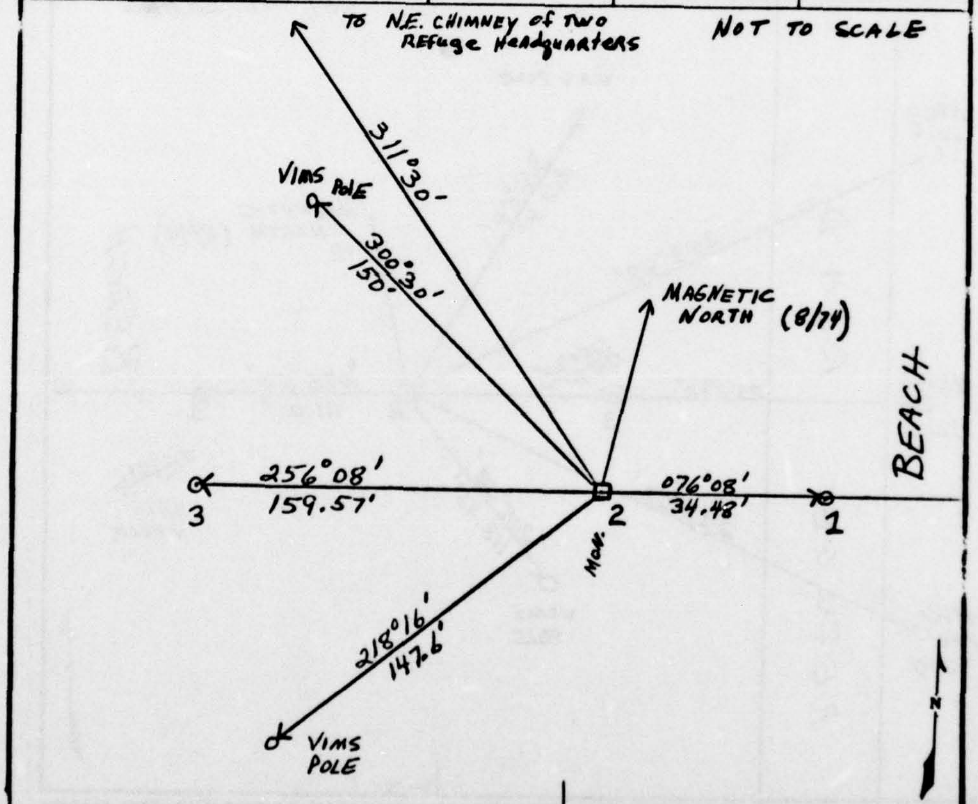
DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Back Bay National Wildlife Refuge Profile line 12 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 12-2	VIMS-CERC	18.42
LATITUDE	LONGITUDE	DATUM	DATUM
36° 40' 11.8"	75° 54' 40.9"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2759159.17 E	132963.37 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION

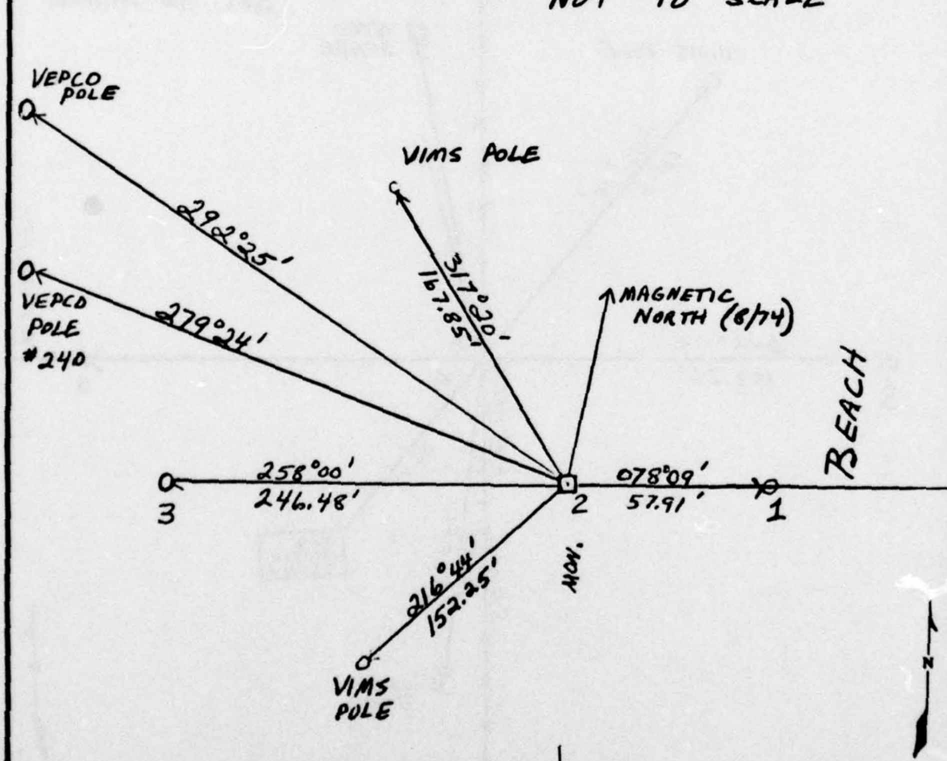
For use of this form, see TM 5-237; the proponent agency is U.S.Continental Army Command.

COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Back Bay National Wildlife Refuge Profile line 13 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 13-2	VIMS-CERC	20.01 ~~M~~
LATITUDE	LONGITUDE	DATUM	DATUM
36° 39' 35.5"	75° 54' 21.6"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2760833.59 E ~~M~~	129334.02 N ~~M~~	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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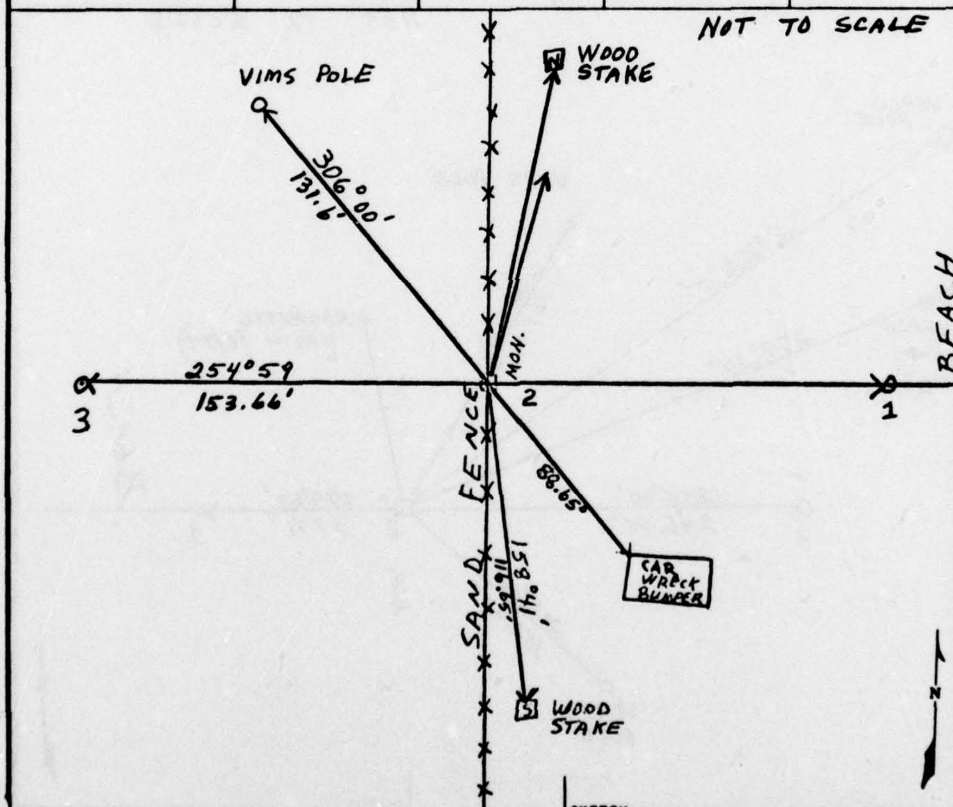
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Back Bay National Wildlife Refuge VIMS 2 Profile line 14	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT)
Virginia Beach, Va.	PRO 14-2	VIMS-CERC	9.76
LATITUDE	LONGITUDE	DATUM	DATUM
36° 39' 13.7"	75° 54' 11.4"	North America 1927	MSL
(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2761720.30 E	127152.12 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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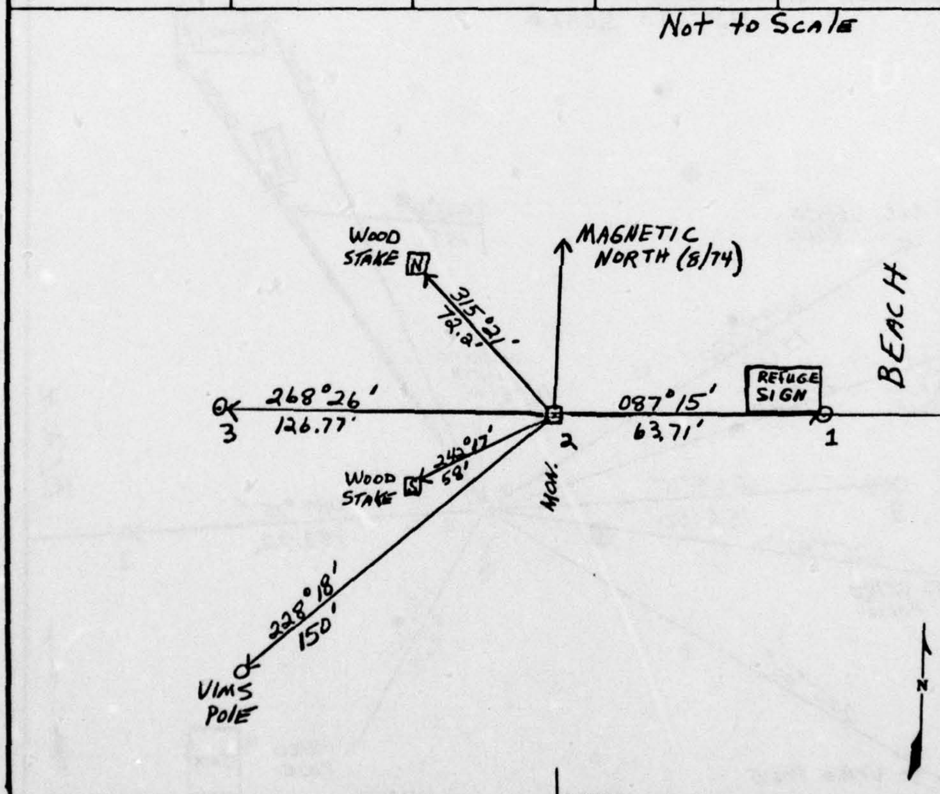
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Back Bay National Wildlife Refuge South Boundary Profile line 15 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT)
Virginia Beach, Va.	PRO 15-2	VIMS-CERC	12.47
LATITUDE	LONGITUDE	DATUM	DATUM
36° 37' 50.7"	75° 53' 31.2"	North America 1927	MSL
(NORTHING)(EASTING) (FT)	(EASTING)(NORTHING) (FT)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2765228.19 E	118857.93 N.	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER
			April 1976 / 3d

TO OBTAIN GRID AZIMUTH, ADD ° TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

DA FORM 1959, 1 OCT 64 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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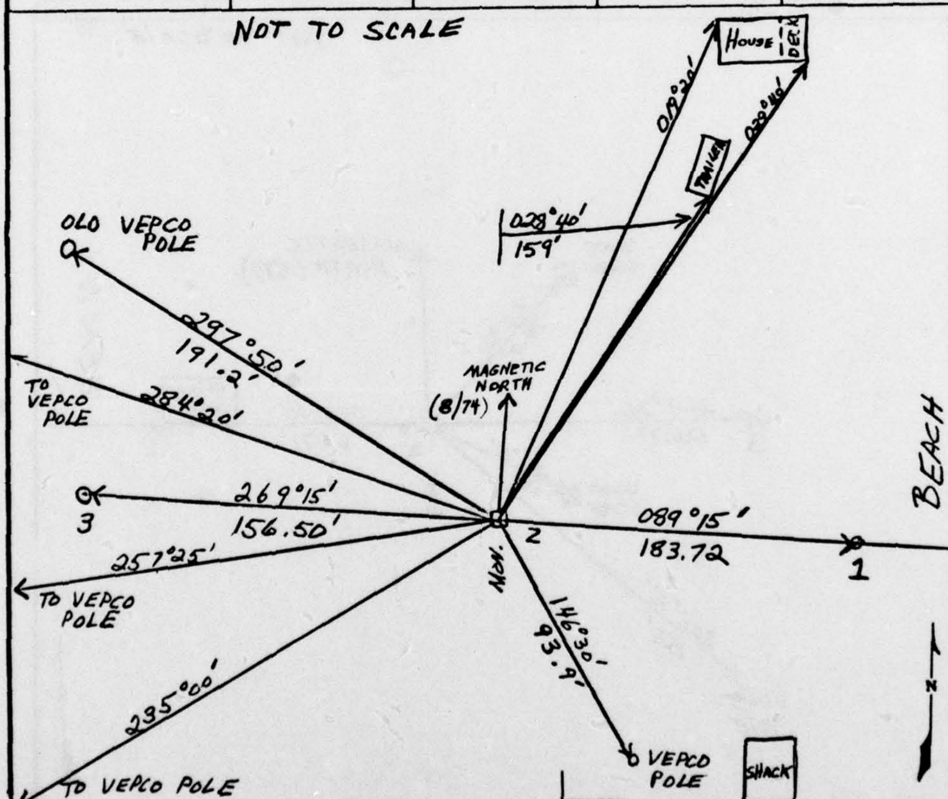
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	False Cape State Park Profile line 16 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
Virginia Beach, Va.	PRO 16-2	VIMS-CERC	23.32
LATITUDE	LONGITUDE	DATUM	DATUM
36° 35' 21.8"	75° 52' 37.3"	North America 1927	MSL
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2770041.24 E	103927.28 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN	GRID AZIMUTH, ADD	° ' "	TO THE GEODETIC AZIMUTH
TO OBTAIN	GRID AZ. (ADD)(SUB.)	° ' "	TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID) (MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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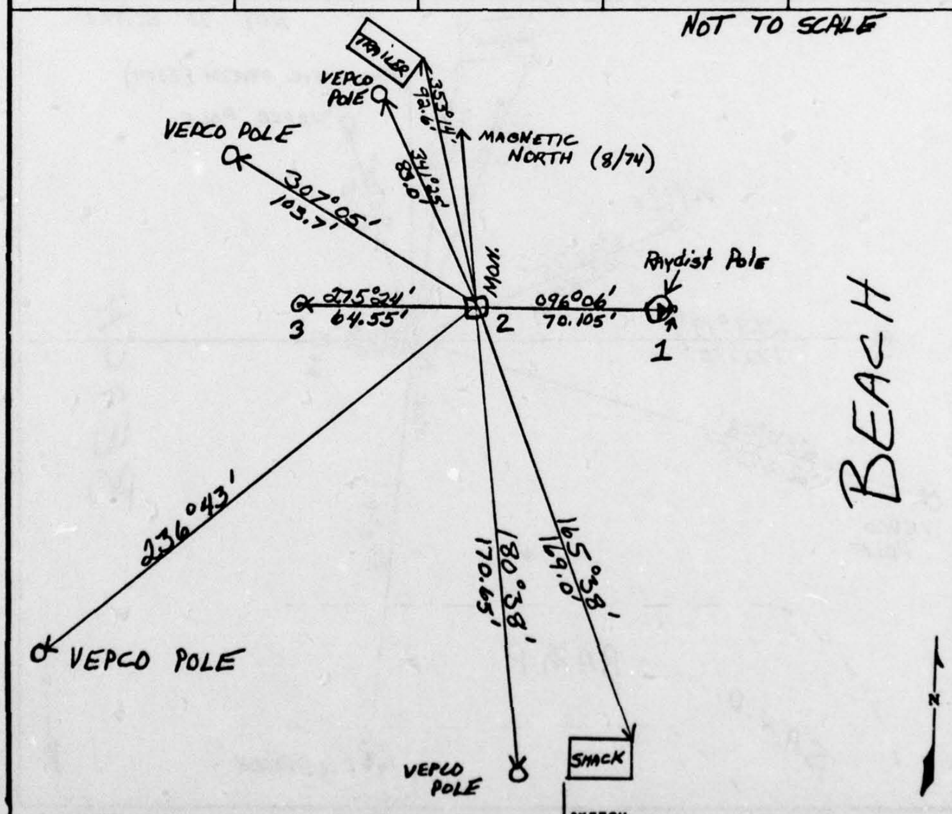
COUNTRY	TYPE OF MARK	STATION	
U.S.A	Concrete monument with disk	False Cape State Park Profile line 17 VIMS 2	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) ~~(M)~~
Virginia Beach, Va.	PRO 17-2	VIMS-CERC	23.79
LATITUDE	LONGITUDE	DATUM	DATUM
36^{o} 34' 18.6"	75^{o} 52' 22.4"	North America 1927	MSL
(NORTHING)(EASTING) (FT) ~~(M)~~	(EASTING)(NORTHING) (FT) ~~(M)~~	GRID AND ZONE	ESTABLISHED BY (AGENCY)
2771431.53 E	97563.51 N	Lambert-Va. South	Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 / ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC) ° ' "	BACK AZIMUTH ° ' "	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

DESCRIPTION OR RECOVERY OF HORIZONTAL CONTROL STATION
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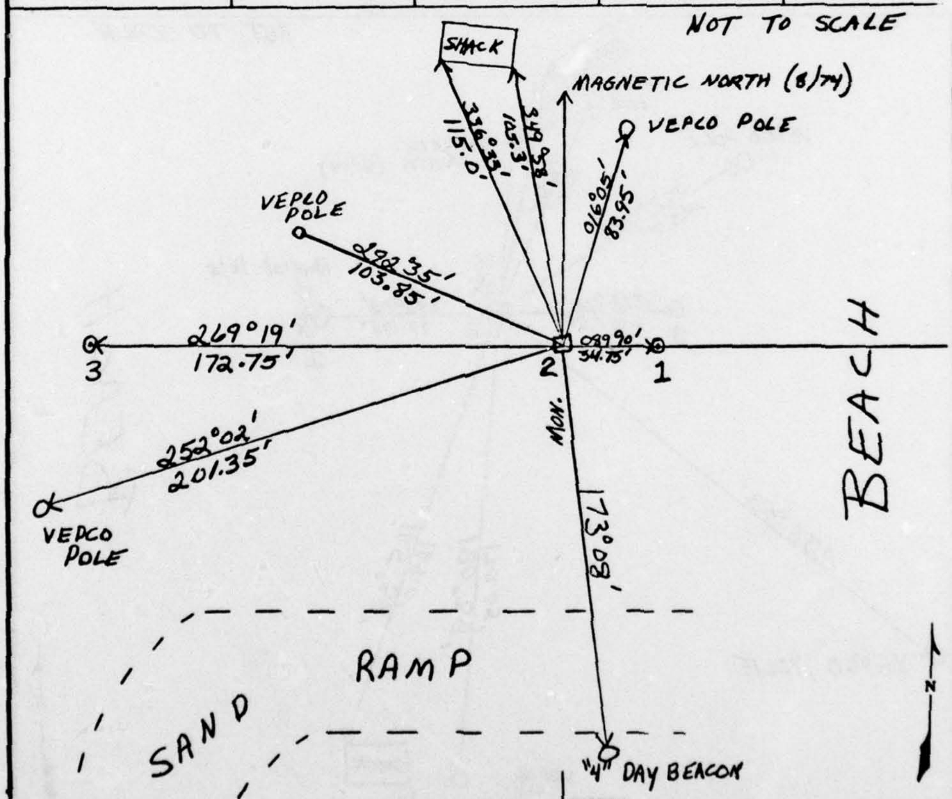
COUNTRY	TYPE OF MARK	STATION	
U.S.A.	Concrete monument with disk	Virginia-North Carolina State line Profile line 18 VIMS 2	
LOCALITY: Virginia Beach, Va.	STAMPING ON MARK: PRO 18-2	AGENCY (CAST IN MARKS): VIMS-CERC	ELEVATION (FT): 26.80
LATITUDE: 36° 33' 2.9"	LONGITUDE: 75° 52' 7.5"	DATUM: North America 1927	DATUM: MSL
(NORTHING)(EASTING) (FT): 2772859.84 E	(EASTING)(NORTHING) (FT): 89953.69 N	GRID AND ZONE: Lambert-Va. South	ESTABLISHED BY (AGENCY): Freeman and Johnson
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE: April 1976 · ORDER: 3d

TO OBTAIN GRID AZIMUTH, ADD ° ' " TO THE GEODETIC AZIMUTH

TO OBTAIN GRID AZ. (ADD)(SUB.) ° ' " TO THE GEODETIC AZIMUTH

OBJECT	AZIMUTH OR DIRECTION (GEODETIC)(GRID)(MAGNETIC)	BACK AZIMUTH	GEOD. DISTANCE (METERS) (FEET)	GRID DISTANCE (METERS) (FEET)
	° ' "	° ' "		



SKETCH

DA FORM 1 OCT 64 1959 REPLACES DA FORMS 1959 AND 1960, 1 FEB 57, WHICH ARE OBSOLETE.

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APPENDIX H

WAVE OBSERVER HISTORY

Appendix H contains the months data were received from wave observers.

Wave Observer History

Name of observer	Code number[1]	1974 July	1974 Aug.	1974 Sept.	1974 Oct.	1974 Nov.	1974 Dec.	1975 Jan.	1975 Feb.	1975 Mar.	1975 Apr.	1975 May	1975 June	1975 July	1975 Aug.	1975 Sept.	1975 Oct.	1975 Nov.	1975 Dec.
Willis	2.1.0					x		x	x	x	x								
Welch	2.2.0																	x	
Byrd	3.1.0										x								
Keeley	3.1.1											x	x	x	x	x			
Gilliland	4.1.0	x	x	x	x	x													
Gilbert	4.2.0						x	x	x	x	x	x	x	x	x	x	x	x	x
Tarver	5.1.0		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	
Jones	5.2.0																		x
Smith	6.1.0	x	x	x	x	x													
Fields	6.2.0						x	x	x	x	x	x		x		x	x		x
McLamb	6.1.1						x	x	x	x	x								
Klise	6.2.1																		
Smith	7.1.0	x	x	x	x	x													
Fields	7.2.0						x	x	x	x	x	x		x		x	x		x
Bichner	9.1.0		x	x	x	x				x	x	x	x						

[1]See Figure 2 for location of wave observer.

Wave Observer History--Continued

Name of observer	Code number	1976 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Willis	2.1.0											
Welch	2.2.0											
Byrd	3.1.0											
Keeley	3.1.1											
Gilliland	4.1.0											
Gilbert	4.2.0	x	x	x	x	x	x	x	x	x	x	x
Tarver	5.1.0											
Jones	5.2.0	x		x		x	x	x	x	x	x	x
Smith	6.1.0											
Fields	6.2.0	x										
McLamb	6.1.1											
Klise	6.2.1				x	x	x	x	x	x	x	x
Smith	7.1.0											
Fields	7.2.0	x					x	x	x			
Bichner	9.1.0											

APPENDIX I

SHORELINE AND CROSS-SECTION CHANGES

Appendix I shows changes between successive surveys at the 18 profile lines in this study. Column 1 is the date of the second of the two successive surveys. Column 2 is the distance between positions of the MSL shoreline on the profiles. Column 3 is the change in cross-sectional area under the profiles. The area under the profiles is bounded on the landward side by a vertical line passing through a point common to all surveys of that profile line, on the bottom by the MSL datum, and on the top and seaward sides by the surveyed profiles. Where profile lines cross MSL more than once, the landwardmost intercept terminates the area. Negative signs indicate erosion between surveys.

Changes were computed at CERC using program PRCHAR. To obtain unit volume loss in cubic yards per foot of shoreline, divide the figure in column 3 by 27.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 01					
74	10	10	4.19	-9.61	29
74	11	8	-47.85	-81.78	29
74	12	4	12.39	-72.22	26
75	1	9	28.53	13.25	36
75	2	11	7.47	63.77	33
75	3	10	-1.38	-59.20	27
75	3	15	-12.33	46.98	5
75	3	20	1.63	11.12	5
75	4	7	0.88	-17.54	18
75	5	5	12.82	-36.91	28
75	6	6	18.38	194.84	32
75	7	1	-7.10	120.64	25
75	7	9	-3.49	28.99	8
75	8	6	5.37	105.15	28
75	9	3	-6.41	-38.29	28
75	9	9	9.97	21.55	6
75	10	15	-8.00	4.00	36
75	11	12	-15.39	-87.40	28
75	11	25	9.20	-54.64	13
75	12	9	-3.80	-39.32	14
76	1	5	18.72	48.95	27
76	2	12	7.94	63.17	38
76	3	8	2.39	0.76	25
76	3	12	-10.53	-49.97	4
76	5	3	26.64	127.15	52
76	6	9	42.60	166.15	37
76	7	6	9.27	100.86	27
76	8	2	-23.94	-102.42	27
76	8	10	37.02	286.80	8
76	9	3	-38.16	-189.78	24
76	10	5	-32.57	-67.49	32
76	11	4	23.65	-31.14	30
Profile line 03					
74	10	11	39.01	133.91	30
74	11	8	-31.83	-152.06	28
74	12	4	-2.40	-55.94	26
75	1	9	22.88	103.67	36
75	2	11	46.33	102.64	33
75	3	10	13.42	-3.92	27
75	3	15	-39.35	-25.33	5
75	3	20	-26.17	-144.83	5
75	4	7	28.03	73.07	18
75	5	5	-4.86	94.09	28
75	6	5	12.95	95.75	31
75	7	1	-34.13	-240.57	26
75	7	9	9.33	91.83	8
75	8	5	-2.20	87.24	27
75	9	3	-28.53	-118.99	29
75	9	8	-2.75	14.86	5
75	10	15	-14.05	-54.68	37
75	11	12	15.73	-110.66	28
75	11	25	6.25	-197.25	13
75	12	9	1.24	90.13	14
76	1	5	0.16	-28.58	27
76	2	12	-8.01	59.67	38
76	3	8	-18.67	11.50	25
76	3	12	-10.77	-111.02	4
76	4	7	23.21	81.97	26
76	4	10	-13.15	-63.41	3
76	5	3	-13.31	-37.18	23
76	6	9	49.85	183.50	37
76	8	2	18.57	146.97	54
76	8	10	-12.52	-5.49	8
76	10	5	24.15	12.85	56
76	11	4	-8.09	73.69	30

NOTE.--Surveys on 760706 and 760903 did not reach MSL and are not included.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 02					
74	10	11	4.03	56.49	30
74	11	8	-9.11	-73.27	28
74	12	4	-9.32	-151.83	26
75	1	9	33.19	70.18	36
75	2	11	-7.47	27.82	33
75	3	10	12.29	9.65	27
75	3	15	-12.20	-7.85	5
75	3	20	-12.14	-67.44	5
75	4	7	5.65	9.02	18
75	5	5	1.20	25.51	28
75	6	5	6.57	125.00	31
75	7	1	4.27	-127.66	26
75	7	9	-5.04	184.59	8
75	8	6	2.43	29.90	28
75	9	3	-18.87	-142.64	28
75	9	9	14.98	101.81	6
75	10	15	-5.22	-1.87	36
75	11	12	-13.61	-22.37	28
75	11	25	3.77	-238.63	13
75	12	9	-9.36	-41.45	14
76	1	5	-0.21	54.19	27
76	2	12	26.81	173.80	38
76	3	8	-3.24	8.34	25
76	3	12	-4.04	-28.49	4
76	4	7	1.95	24.67	26
76	4	10	-8.56	-75.85	3
76	5	3	4.15	47.82	23
76	6	9	-11.64	-79.54	37
76	7	6	6.74	68.41	27
76	8	2	10.04	29.84	27
76	8	10	8.42	37.87	8
76	9	3	-20.72	-60.99	24
76	10	5	11.68	5.67	32
76	11	4	129.81	233.74	30
Profile line 04					
74	10	11	17.41	65.16	30
74	11	8	2.59	-5.06	28
74	12	3	32.61	103.40	25
75	1	9	-7.81	-44.55	37
75	2	11	23.92	26.63	33
75	3	10	2.73	-43.29	27
75	3	15	-22.62	-9.05	5
75	3	20	-15.92	2.74	5
75	4	7	6.18	-22.01	18
75	5	5	-12.93	-47.59	28
75	6	5	-10.29	29.66	31
75	7	9	-24.47	-93.84	34
75	8	5	3.06	18.78	27
75	9	3	6.13	-14.92	29
75	9	8	19.04	76.72	5
75	10	15	-12.91	-71.41	37
75	11	12	-1.03	65.74	28
75	11	25	80.70	86.44	13
75	12	9	-16.44	111.57	14
76	1	5	-8.51	33.51	27
76	2	12	-16.85	-26.03	38
76	3	8	-35.61	-148.16	25
76	3	12	24.49	61.47	4
76	4	7	3.31	78.77	26
76	4	10	-10.28	-148.35	3
76	5	3	-16.81	-11.78	23
76	6	9	38.00	8.93	37
76	7	6	-63.59	-149.24	27
76	8	2	-18.20	-101.75	27
76	8	10	21.28	13.62	8
76	9	3	57.30	157.75	24
76	10	5	-22.97	24.73	32
76	11	4	34.67	205.94	30

Profile line 05

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	11	8.33	100.75	30
74	11	7	-0.73	-39.50	27
75	1	8	-9.27	-170.39	62
75	2	11	2.42	50.02	34
75	3	10	7.85	13.52	27
75	3	15	9.83	8.63	5
75	3	20	-40.86	-108.67	5
75	4	7	44.17	40.71	18
75	5	5	-18.78	3.84	28
75	6	5	-5.42	76.80	31
75	7	1	28.80	-53.29	26
75	7	9	-21.81	106.17	8
75	8	5	-1.77	-33.51	27
75	9	3	6.37	-34.24	29
75	9	8	-2.40	8.86	5
75	10	15	-17.73	22.14	37
75	11	12	19.83	30.73	28
75	11	25	-10.35	-161.44	13
75	12	9	-11.60	9.33	14
76	1	5	31.20	54.76	27
76	2	12	2.32	118.19	38
76	3	8	16.58	59.85	25
76	3	12	-16.53	-131.92	4
76	4	7	-13.38	24.83	26
76	5	3	-14.54	-52.57	26
76	6	9	20.48	63.87	37
76	7	6	1.20	15.46	27
76	8	2	-9.23	-55.78	27
76	8	10	29.38	-4.98	8
76	10	5	-7.76	55.01	56
76	11	4	-20.70	-17.87	30

NOTE.--Surveys on 741204, 760410, and 760903 did not reach MSL and are not included.

Profile line 06

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	11	11.31	19.36	30
74	11	8	-21.17	-94.94	28
74	12	4	4.81	-40.97	26
75	1	9	26.84	-10.13	36
75	2	10	10.53	44.45	32
75	3	10	-9.83	-9.89	28
75	3	15	-8.92	31.35	5
75	3	20	-15.20	-17.63	5
75	4	7	-4.29	-91.10	18
75	5	5	14.68	51.52	28
75	6	5	11.96	144.73	31
75	7	1	1.50	-104.38	26
75	7	9	-1.85	116.00	8
75	8	5	0.61	23.94	27
75	9	3	4.72	-85.77	29
75	9	8	-5.25	40.19	5
75	10	15	-25.15	-133.12	37
75	11	12	-9.58	14.74	28
75	11	25	0.84	-196.20	13
75	12	9	-7.07	55.54	14
76	1	5	9.61	-56.36	27
76	2	12	14.19	20.88	38
76	3	8	-33.40	-64.96	25
76	3	12	19.10	50.06	4
76	4	7	-1.28	20.68	26
76	5	3	-19.88	-71.68	26
76	6	9	33.40	80.00	37
76	7	6	-22.35	40.75	27
76	8	2	0.18	-27.69	27
76	8	10	11.42	24.97	8
76	9	3	-18.31	-60.05	24
76	10	5	44.55	-31.01	32
76	11	4	-9.25	185.18	30

NOTE.--Survey on 760410 did not reach MSL and is not included.

Profile line 07

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	11	-8.33	14.50	30
74	11	8	32.24	87.54	28
75	1	9	-11.79	-146.87	62
75	2	10	17.82	19.50	32
75	3	10	-7.66	-5.66	28
75	3	15	-7.94	-2.91	5
75	3	20	-7.32	-58.39	5
75	4	7	-20.60	-62.04	18
75	5	5	9.58	82.22	28
75	6	5	20.05	127.16	31
75	7	1	-24.63	-159.39	26
75	7	9	9.00	181.65	8
75	8	5	16.50	66.55	27
75	9	3	-26.50	-115.50	29
75	9	8	38.67	103.48	5
75	10	15	-38.19	-10.82	37
75	11	12	10.09	-21.15	28
75	11	25	6.43	-175.51	13
75	12	9	6.50	0.78	14
76	1	5	6.83	110.61	27
76	2	12	-1.17	21.50	38
76	3	8	-1.35	47.72	25
76	3	12	-10.33	-71.97	4
76	4	7	0.19	25.78	26
76	5	3	-11.17	-5.24	26
76	6	9	24.81	-42.26	37
76	7	6	8.31	64.90	27
76	8	2	-29.62	0.09	27
76	8	10	19.74	70.72	8
76	9	3	-12.03	19.52	24
76	10	5	23.95	-38.53	32
76	11	4	-21.67	2.88	30

NOTE.--Surveys on 741204 and 760410 did not reach MSL and are not included.

Profile line 08

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	10	-0.32	17.24	29
74	11	7	-6.08	-50.04	28
74	12	3	54.62	31.29	26
75	1	8	0.68	-54.49	36
75	2	10	-3.73	24.69	33
75	3	10	5.07	4.29	28
75	3	15	-26.67	-83.22	5
75	3	20	1.03	-70.62	5
75	4	7	-13.01	63.74	18
75	5	5	29.50	151.73	28
75	6	5	3.60	209.55	31
75	7	1	-5.88	-425.79	26
75	7	9	-13.65	355.68	8
75	8	5	8.33	13.83	27
75	9	3	-29.55	-157.98	29
75	9	8	14.96	40.97	5
75	10	15	-6.07	109.23	37
75	11	12	8.99	-7.41	28
75	11	25	9.09	-105.03	13
75	12	9	-20.37	-91.15	14
76	1	5	-2.47	-73.79	27
76	2	12	21.23	74.52	38
76	3	8	-12.24	-1.79	25
76	3	12	-16.10	-53.03	4
76	4	7	-7.50	-46.08	26
76	5	3	-3.73	-0.32	26
76	6	9	8.66	40.17	37
76	7	6	6.81	152.49	27
76	8	2	-9.07	-22.28	27
76	8	10	26.64	14.61	8
76	10	5	-31.50	-102.66	56
76	11	4	36.34	43.44	30

NOTE.--Surveys on 760410 and 760903 did not reach MSL and are not included.

Profile line 09

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	10	-1.79	-1.59	28
74	11	7	-20.30	-58.78	28
74	12	3	10.77	-73.28	26
75	1	8	15.03	52.93	36
75	2	10	8.38	-55.95	33
75	3	10	-5.65	19.71	28
75	3	15	-12.29	-46.54	5
75	3	20	-10.86	10.65	5
75	4	7	-3.47	-45.13	18
75	5	5	3.82	107.96	28
75	6	5	16.00	85.08	31
75	7	1	-2.13	-176.21	26
75	7	9	-18.24	122.19	8
75	8	5	10.91	32.68	27
75	9	3	8.97	-143.02	29
75	9	8	-11.19	69.09	5
75	10	15	-5.71	31.74	37
75	11	12	-4.66	-62.35	28
75	11	25	-7.71	-177.17	13
75	12	9	-18.12	-42.83	14
76	1	5	21.38	28.11	27
76	2	12	12.40	106.03	38
76	3	8	-10.67	-22.59	25
76	3	12	-0.56	-68.39	4
76	4	7	-17.17	15.04	26
76	5	3	13.42	28.73	26
76	6	9	0.56	4.20	37
76	7	6	16.96	100.62	27
76	8	2	-11.66	-64.37	27
76	8	10	20.54	80.07	8
76	10	5	-7.31	-103.86	56
76	11	4	-12.18	2.21	30

NOTE.--Surveys on 760410 and 760903 did not reach MSL and are not included.

Profile line 10

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	10	-1.83	-5.80	28
74	11	7	-8.57	-48.20	28
74	12	3	33.87	43.72	26
75	1	8	5.03	36.71	36
75	2	10	-5.00	-112.56	33
75	3	10	-1.59	22.48	28
75	3	15	-8.00	14.07	5
75	3	20	-3.63	-59.45	5
75	4	7	-1.29	-9.88	18
75	5	5	-2.91	48.54	28
75	6	5	-7.80	162.38	31
75	7	1	-4.34	-138.00	26
75	7	9	-7.00	58.35	8
75	8	5	1.98	-30.25	27
75	9	3	23.68	-31.04	29
75	9	8	-18.80	70.94	5
75	10	15	-21.19	-60.89	37
75	11	12	7.07	34.75	28
75	12	9	-7.50	-152.07	27
76	1	5	32.00	93.24	27
76	2	12	-4.56	75.24	38
76	3	8	-8.44	-34.02	25
76	3	12	1.51	73.01	4
76	4	7	7.36	108.31	26
76	5	3	-24.57	-137.87	26
76	6	9	22.91	23.71	37
76	7	6	-14.08	-61.84	27
76	8	10	31.07	129.86	35
76	9	3	-38.74	-68.39	24
76	10	5	60.40	-20.75	32
76	11	4	-23.49	82.55	30

NOTE.--Surveys on 751125, 760410, and 760802 did not reach MSL and are not included.

Profile line 11

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	11	7	13.26	53.19	56
74	12	3	-15.74	-128.01	26
75	1	8	26.30	81.30	36
75	2	10	18.06	-36.96	33
75	3	10	-0.90	49.31	28
75	3	15	-15.87	-25.64	5
75	3	20	-18.84	-63.05	5
75	4	7	-6.35	-48.84	18
75	5	5	17.75	80.80	28
75	6	5	6.74	75.59	31
75	7	9	-27.93	-57.50	34
75	8	5	-4.27	-56.46	27
75	9	3	4.18	-39.45	29
75	9	8	14.54	51.93	5
75	10	15	-18.76	22.34	37
75	11	12	5.57	-31.73	28
75	12	9	-24.75	-251.37	27
76	1	5	2.62	-2.94	27
76	2	12	9.62	75.63	38
76	3	8	20.57	72.45	25
76	3	12	-8.44	-114.16	4
76	4	7	-12.11	103.15	26
76	5	3	18.54	19.11	26
76	6	9	8.56	94.89	37
76	7	6	2.20	52.22	27
76	8	2	-16.02	-124.52	27
76	8	10	17.28	-6.91	8
76	9	3	-9.70	80.03	24
76	10	5	8.51	20.65	32
76	11	4	6.66	-104.47	30

NOTE.--Surveys on 741010, 750701, 751125, and 760410 did not reach MSL and are not included.

Profile line 12

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
74	10	10	7.22	-77.04	28
74	11	7	-8.03	-5.19	28
74	12	3	2.78	-74.90	26
75	1	8	10.38	5.71	36
75	2	10	21.56	-36.30	33
75	3	10	-10.40	44.70	28
75	3	15	-26.14	-22.61	5
75	3	20	-7.89	-52.01	5
75	4	7	-9.51	-139.77	18
75	5	5	21.40	-8.15	28
75	6	5	14.57	248.50	31
75	7	9	-59.66	-431.18	34
75	8	5	47.10	439.18	27
75	9	3	-5.58	-42.51	29
75	9	8	-3.80	17.16	5
75	10	15	-6.33	48.85	37
75	11	12	5.30	-17.47	28
75	12	9	3.50	-113.49	27
76	1	5	4.99	2.79	27
76	2	12	3.85	56.34	38
76	3	8	-11.34	6.88	25
76	3	12	-0.21	40.51	4
76	4	7	-3.04	14.69	26
76	5	3	-3.71	-87.69	26
76	6	9	35.02	59.19	37
76	7	6	-12.00	10.32	27
76	8	2	-10.67	9.31	27
76	8	10	21.98	-14.60	8
76	9	3	-1.34	-13.84	24
76	10	5	33.55	11.08	32
76	11	4	-26.04	-64.99	30

NOTE.--Surveys on 750701, 751125, and 760410 did not reach MSL and are not included.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 13					
74	10	10	20.54	69.27	28
74	11	7	-24.81	-162.10	28
74	12	3	22.45	-48.91	26
75	1	8	25.28	-54.31	36
75	2	10	-26.19	-43.04	33
75	3	10	-8.41	-41.27	28
75	3	15	17.55	48.86	5
75	3	20	-22.80	-59.84	5
75	4	7	4.81	18.73	18
75	5	5	-10.33	24.30	28
75	6	5	9.15	109.13	31
75	7	1	-11.10	-72.80	26
75	7	9	-14.91	29.86	8
75	8	5	19.12	109.45	27
75	9	3	-7.66	18.29	29
75	9	8	-10.23	-35.06	5
75	10	15	4.10	36.27	37
75	11	12	-15.68	-115.37	28
75	12	9	14.87	-15.92	27
76	1	5	17.94	67.12	27
76	2	12	-9.19	41.84	38
76	3	8	-15.07	-54.15	25
76	3	12	11.40	56.28	4
76	4	7	-7.39	16.09	26
76	5	3	-7.22	-32.81	26
76	6	9	14.48	-61.30	37
76	7	6	8.60	86.98	27
76	8	10	-0.46	-38.68	35
76	9	3	-13.34	45.41	24
76	10	5	-17.20	-108.27	32
76	11	4	34.04	-16.32	30

NOTE.--Surveys on 751125, 760410, and 760802 did not reach MSL and are not included.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 14					
74	10	10	2.10	-32.45	28
74	11	7	-7.06	11.98	28
74	12	3	-24.58	-83.57	26
75	1	8	43.02	-36.05	36
75	2	10	-3.06	-50.82	33
75	3	10	-10.30	-42.56	28
75	3	15	-0.02	5.89	5
75	3	20	8.28	31.06	5
75	4	7	-4.24	6.74	18
75	5	5	-11.99	13.87	28
75	6	5	-8.93	91.15	31
75	7	1	35.74	-50.43	26
75	7	9	-40.87	65.70	8
75	8	5	12.99	87.26	27
75	9	3	-4.40	-40.66	29
75	9	8	0.51	18.86	5
75	10	15	3.90	27.02	37
75	11	12	-5.28	126.63	28
75	12	9	-21.91	-303.79	27
76	1	5	29.16	0.88	27
76	2	12	-7.35	150.85	38
76	3	8	27.44	60.65	25
76	3	12	-37.36	-92.64	4
76	4	7	17.93	12.77	26
76	5	3	-19.49	-6.29	26
76	6	9	29.82	68.57	37
76	7	6	-6.34	-57.18	27
76	8	2	-19.00	16.45	27
76	8	10	24.86	77.63	8
76	9	3	-1.50	-51.82	24
76	10	5	30.91	-36.01	32
76	11	4	-10.77	-51.78	30

NOTE.--Surveys on 751125 and 760410 did not reach MSL and are not included.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 15					
74	10	10	-14.56	-16.84	28
74	11	7	24.78	6.55	28
74	12	3	18.13	1.91	26
75	1	8	-12.95	-116.41	36
75	2	10	-33.10	-50.76	33
75	3	10	29.88	1.07	28
75	3	15	-20.96	-42.71	5
75	3	20	2.92	44.39	5
75	4	7	21.48	-39.81	18
75	5	5	-19.82	-4.63	28
75	6	5	8.97	124.39	31
75	7	1	-11.49	-101.02	26
75	7	9	-0.00	75.12	8
75	8	5	-10.21	66.38	27
75	9	3	31.29	107.14	29
75	9	8	2.49	2.99	5
75	10	15	9.67	-94.18	37
75	11	12	[illegible]	-52.17	28
75	11	25	38.71	37.74	13
75	12	9	-32.90	-35.04	14
76	1	5	-14.48	-15.27	27
76	2	12	40.33	29.69	38
76	3	8	-28.55	-38.01	25
76	3	12	13.41	10.84	4
76	4	7	-3.23	68.64	26
76	4	10	30.33	12.37	3
76	5	3	-46.28	3.29	23
76	6	9	13.63	-77.74	37
76	7	6	-27.54	86.60	27
76	8	2	28.30	-16.12	27
76	8	10	16.79	8.69	8
76	9	3	-22.70	67.61	24
76	10	5	-33.90	-189.53	32
76	11	4	-20.49	-33.20	30

NOTE.--Survey on 741203 did not reach MSL and is not included.

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 16					
74	10	10	-15.74	137.51	28
74	11	7	1.54	-126.33	28
74	12	3	-2.17	-136.90	26
75	1	8	5.24	4.15	36
75	2	10	3.86	17.68	33
75	3	10	-16.30	98.94	28
75	3	15	-30.03	-51.30	5
75	3	20	32.83	-20.92	5
75	4	7	-10.03	24.35	18
75	5	5	20.44	72.60	28
75	6	5	-7.23	86.90	31
75	7	1	7.50	-79.05	26
75	7	9	-16.82	75.85	8
75	8	5	10.69	8.28	27
75	9	3	13.79	-19.87	29
75	9	8	-9.30	29.80	5
75	10	15	-27.28	-33.66	37
75	11	12	27.27	7.40	28
75	11	25	-19.92	-140.44	13
75	12	9	-21.28	27.17	14
76	1	5	14.74	34.94	27
76	2	12	43.76	474.51	38
76	3	8	-10.09	-357.03	25
76	3	12	-11.73	-25.77	4
76	4	7	-3.01	26.71	26
76	4	10	4.46	-23.41	3
76	5	3	-17.59	-80.94	23
76	6	9	41.08	53.57	37
76	7	6	1.48	55.87	27
76	8	2	-0.18	29.78	27
76	8	10	-12.20	-75.76	8
76	9	3	-12.70	81.08	24
76	10	5	25.72	-37.84	32
76	11	4	-28.78	-37.45	30

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 17					
74	10	10	-12.55	38.24	28
74	11	7	15.19	19.68	28
75	1	8	-14.22	-169.91	62
75	2	10	-21.66	19.28	33
75	3	10	21.30	72.59	28
75	3	15	-7.28	-37.96	5
75	3	20	-11.17	-74.63	5
75	4	7	16.70	139.08	18
75	5	5	-13.22	77.65	28
75	6	5	0.42	-19.79	31
75	7	1	14.51	-111.48	26
75	7	9	-6.53	79.26	8
75	8	5	-5.15	6.55	27
75	9	3	0.97	-17.36	29
75	9	8	-20.80	12.42	5
75	10	15	15.19	12.86	37
75	11	12	6.36	43.97	28
75	11	25	-5.92	-116.58	13
75	12	9	-20.83	-85.80	14
76	1	5	12.74	58.06	27
76	2	12	-0.65	40.46	38
76	3	8	0.36	4.01	25
76	3	12	-4.85	-75.40	4
76	4	7	17.00	104.30	26
76	4	10	3.37	-56.21	[illegible]
76	5	3	-13.24	-15.85	23
76	6	9	30.30	120.09	37
76	7	6	-20.29	-15.49	27
76	8	2	8.52	44.00	27
76	8	10	2.45	-42.61	8
76	9	3	-26.19	20.58	24
76	10	5	30.70	8.66	32
76	11	4	-14.06	-48.81	30

Date (yr)	(mo)	(d)	Change in MSL shoreline between surveys (ft)	Change in cross-sectional area between surveys (ft^2)	Days between surveys (No.)
Profile line 18					
74	10	10	-7.18	67.21	28
74	11	7	11.95	-52.69	28
74	12	3	2.47	-301.58	26
75	1	8	8.93	187.74	36
75	2	10	-7.80	-46.86	33
75	3	10	-3.80	54.05	28
75	3	15	-6.72	-45.69	5
75	3	20	-0.88	-3.24	5
75	4	7	16.17	54.42	18
75	5	5	-10.36	-26.70	28
75	6	5	6.25	153.42	31
75	7	1	12.33	-66.00	26
75	7	9	-11.30	-44.45	8
75	8	5	20.67	118.82	27
75	9	3	-15.17	-103.05	29
75	9	8	11.80	8.31	5
75	10	15	-33.91	107.34	37
75	11	12	-3.93	-39.53	28
75	11	25	18.09	-121.66	13
75	12	9	-16.42	113.74	14
76	1	5	0.74	4.22	27
76	2	12	23.83	153.79	38
76	3	8	-12.20	-97.30	25
76	3	12	2.25	-69.79	4
76	4	7	0.64	54.40	26
76	4	10	-2.89	-74.22	3
76	5	3	-31.43	8.86	23
76	6	9	15.97	-94.02	37
76	7	6	46.01	210.84	27
76	8	2	-27.76	36.81	27
76	8	10	-0.19	-115.04	8
76	9	3	-52.49	-25.20	24
76	10	5	52.51	36.29	32
76	11	4	-24.60	-2.43	30

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