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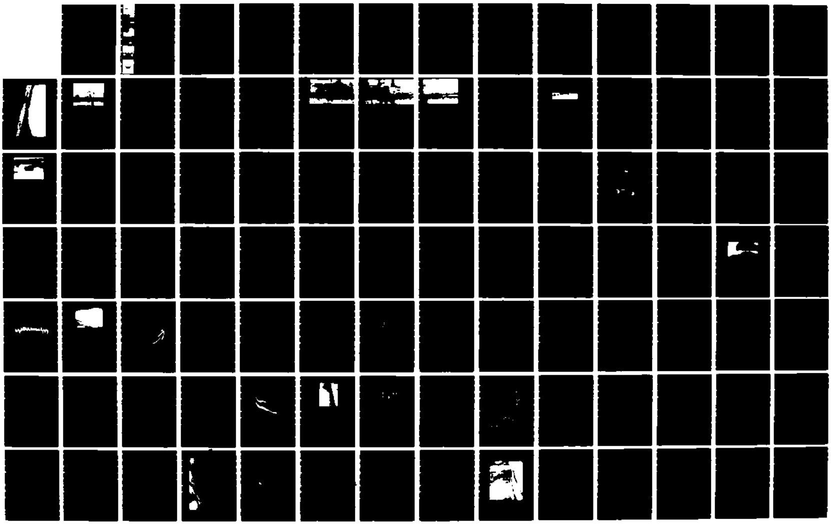

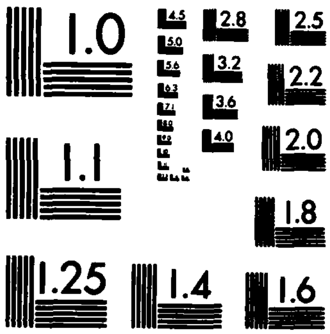

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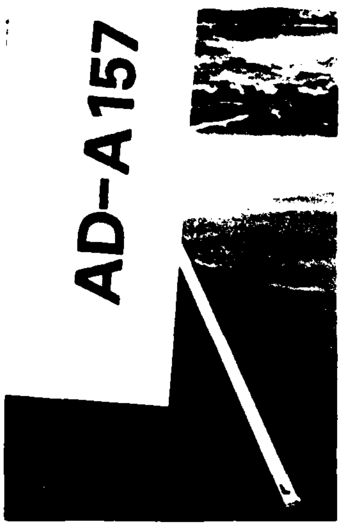

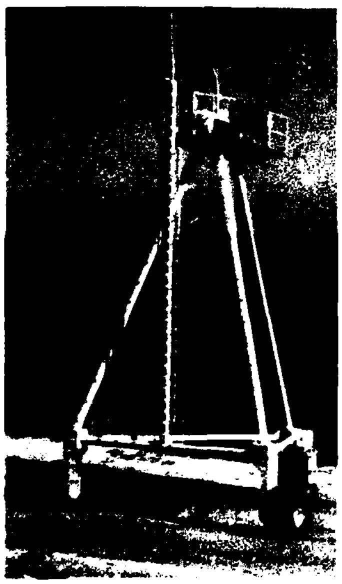

INSTRUCTION REPORT CERC-85-1

A USER'S GUIDE TO THE COASTAL ENGINEERING RESEARCH CENTER'S (CERC'S) FIELD RESEARCH FACILITY

by

William A. Birkemeier, H. Carl Miller, Stanton D. Wilhelm,
Allen E. DeWall, and Carol S. Gorbics

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

May 1985
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Prepared for

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) at Duck, N. C., is a 561-m-(1,840-ft-)long pier and laboratory dedicated to basic and applied coastal research. This report, which describes the facility, the instrumentation and data being collected, and the local area, is designed to be used as an aid in planning experiments to be conducted at the facility. Use of the FRF by coastal researchers is encouraged.		

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PREFACE

This report provides basic information about the Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) at Duck, N. C. Although the primary purpose of the facility is to support CERC's research programs, other agencies and organizations are encouraged to use the facility and the data being collected there. CERC's Waves and Coastal Flooding Program was responsible for the work on this report.

Stanton D. Wilhelm, William A. Birkemeier, and H. Carl Miller, under the supervision of Curtis Mason, FRF Group, Research Division, prepared this report as a revision of the original User's Guide to CERC's FRF published in 1981. Allan E. DeWall and Carol S. Gorbics prepared sections of the report.

The authors acknowledge the assistance of the following members of the CERC staff: Gene Bichner, Charles Judge, and Ray Townsend for collecting much of the data; Jennifer Miller, John Headland, and Mary Beth Lester for their analyses of beach profile and sand sample data; Karen Jacobs for compiling the bibliography; Harriet Klein for her acute knowledge of the local area; and Curtis Mason, Rudolph P. Savage, Dennis Berg, Charles Judge, Gene Bichner, Harriet Klein, Arthur Hurme, and Jack Pullen for their reviews which contributed greatly to the quality of the final report.

On 1 July 1983, CERC became part of the US Army Engineer Waterways Experiment Station (WES) under the direction of Dr. Robert W. Whalin, Chief.

Commander and Director of WES during the publication of this revised user's guide was COL Robert C. Lee, CE. Mr. Frederick R. Brown was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	0.40469	hectares
cubic yards	0.7646	cubic metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
foot-pounds per foot	4.448	Newton metres per metre
inches	2.54	centimetres
miles (US statute)	1609.347	kilometres
miles per hour	1.609344	kilometres per hour
pounds (mass)	0.453924	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32).

A USER'S GUIDE TO THE COASTAL ENGINEERING RESEARCH CENTER'S (CERC'S) FIELD RESEARCH FACILITY

PART I: INTRODUCTION

1. Federal interest in coastal engineering began in the 1920's as a result of the increasing shoreline erosion along the recreational beaches in New Jersey. This concern led to the formation of the Beach Erosion Board (BEB) in July 1930 as a part of the civil works program of the US Army Corps of Engineers. The BEB functioned largely as an advisor to the states with coastal erosion problems; however, the increasing need for research became evident. In recognition of that need, the BEB began expanding to include an official research program. In 1963, Congress established the Coastal Engineering Research Center (CERC), abolishing the BEB, and broadened the BEB's general investigation responsibilities to form the research mission of CERC.

2. CERC is one of five Corps Research and Development Laboratories at the US Army Engineer Waterways Experiment Station (WES) in Vicksburg, Miss. CERC's mission is to conceive, plan, and conduct research and data collection in coastal and ocean engineering and nearshore oceanography to provide a better understanding of waves, winds, water levels, tides, currents, and the resultant coastal processes. Also considered are the interactions of these forces and processes with shores and beaches, inlets and inner continental shelves, coastal and offshore structures, and the materials forming them. CERC's research focuses on shore and beach erosion control, flooding, sand bypassing, dredging, navigation improvements, recreation, environment, and the design, construction, operation, and maintenance of coastal and offshore structures.

3. CERC conducts coastal engineering research through laboratory experiments, theoretical investigations, and field studies. To support its field investigations, CERC has a 175-acre* Field Research Facility (FRF) at Duck, N. C. (Figure 1). Located at 36°10'54.6" N and 75°45'5.2" W (landward end), the FRF consists of a 561-m- (1,840 ft-) long pier (Figure 2), which was completed in August 1976, a 418-m^2 (4,500-ft^2) laboratory and office building completed in March 1980, and a 307-m^2 (3,300-ft^2) garage and storage building (Figure 3). The FRF is designed to fulfill four major objectives:

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* A table of factors for converting non-SI units of measurement to SI (metric units) is presented on page 7.

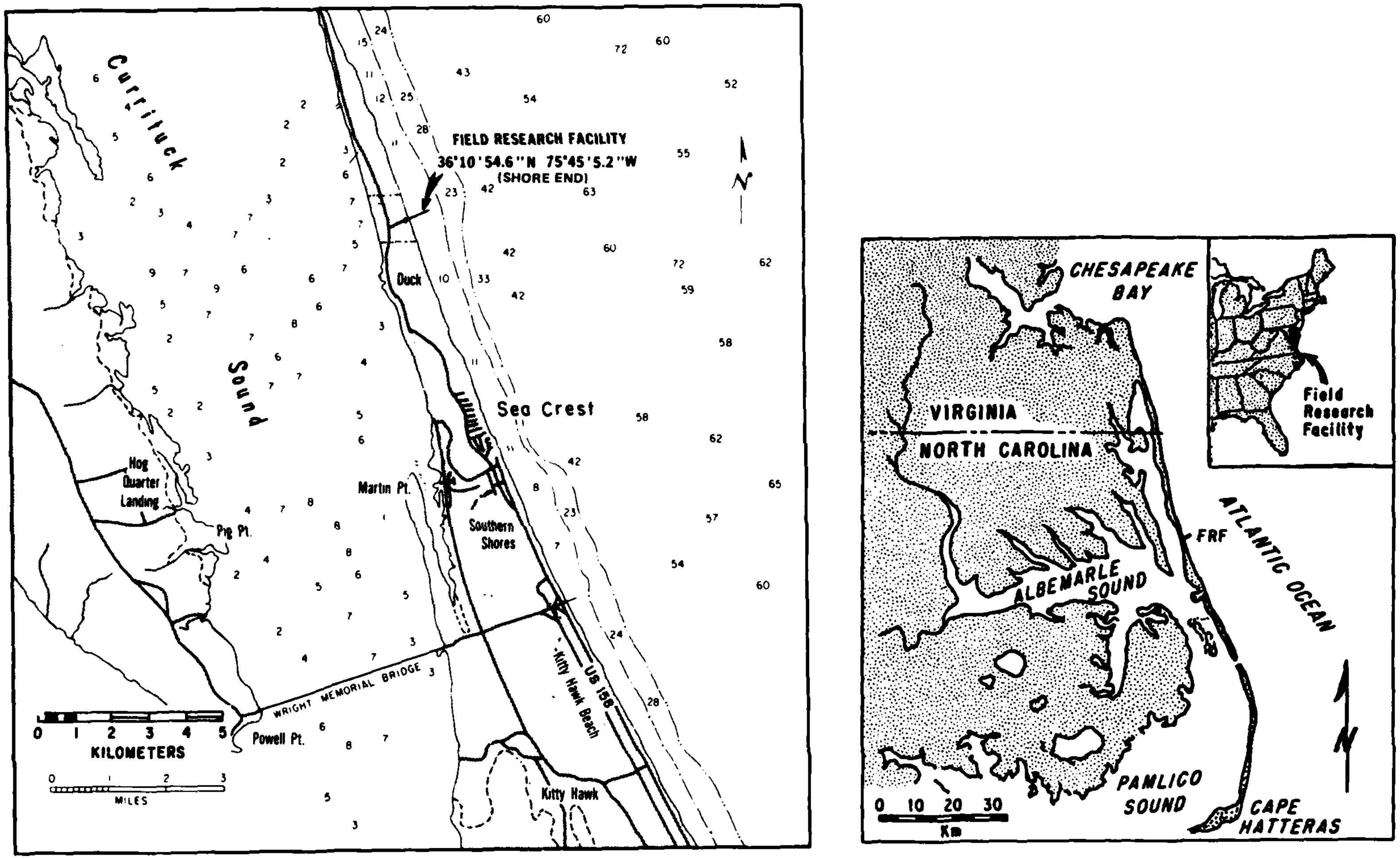

Figure 1. Location of the FRF

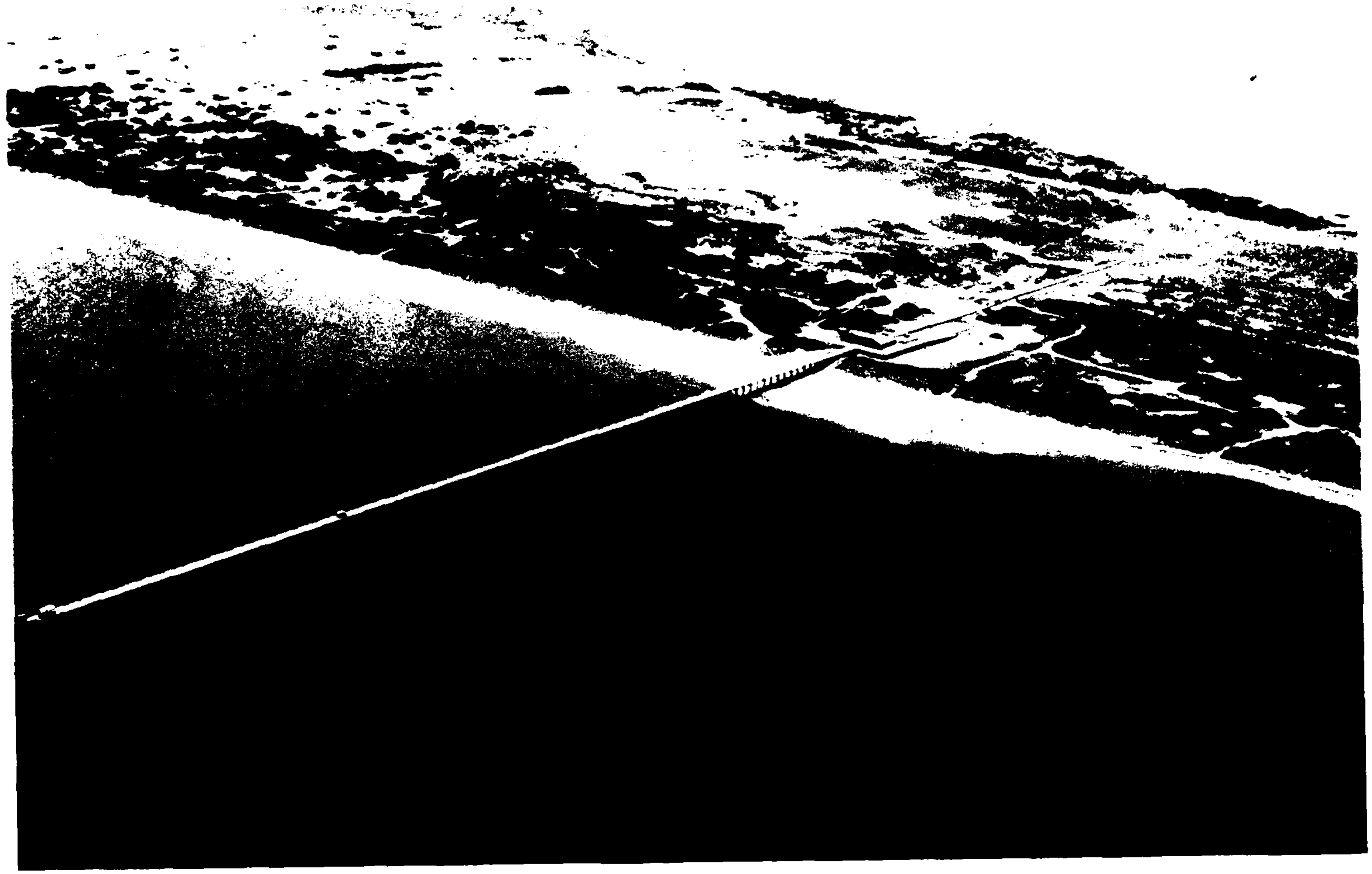

Figure 2. CERC's FRF

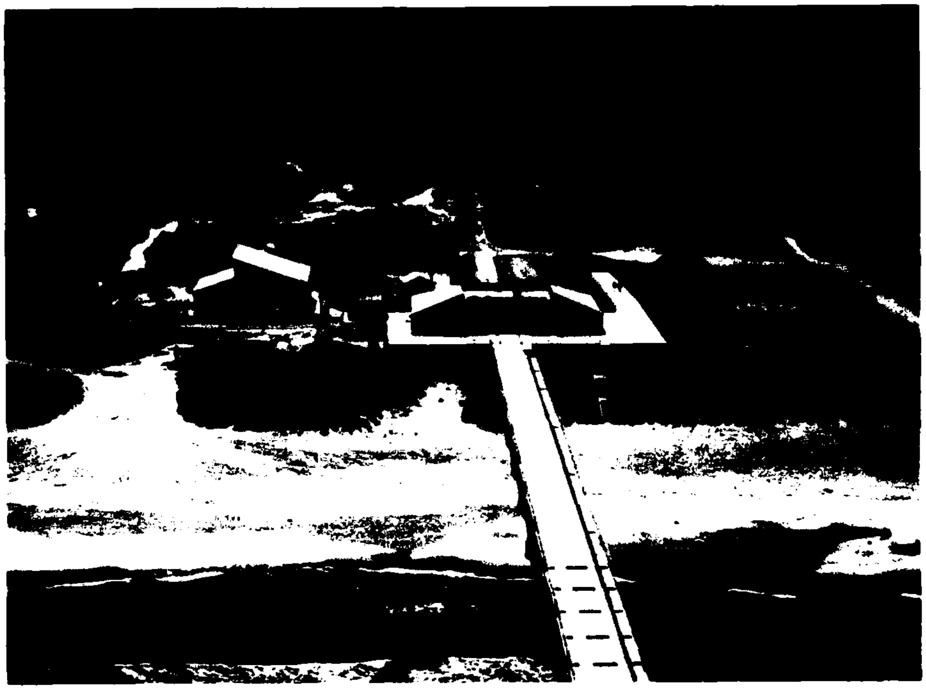

Figure 3. The laboratory building

a. To provide a rigid platform from the land, across the dunes, beach, and surf zone out to the 6-m (20-ft) water depth from which waves, currents, water levels, and bottom elevations can be measured, especially during severe storms.

b. To serve as a permanent field base of operations for physical and biological studies of the site, the adjacent sound, bay, and ocean region by CERC, other Federal agencies, universities, and private industry.

c. To provide CERC with field experience and data that will complement laboratory and analytical studies and provide a better understanding of the influence of field conditions on measurements and design practices.

d. To provide a manned field facility for testing new instrumentation.

4. Although primarily intended for CERC research studies, the FRF and the data collected there can be used by other organizations. This guide provides potential users with helpful information about the facility, the area, the climate, and the data being collected. Any questions which are not addressed in this guide should be directed to:

Chief, Field Research Facility
SR Box 271
Kitty Hawk, N. C. 27949
(919) 261-3511 or (703) 370-6576

Local callers from the Washington, DC, area can dial 370-6576.

Use of the FRF

Obtaining permission

5. It is necessary to obtain written permission to use the FRF. This can be done by sending a synopsis of the research to:

Chief
Coastal Engineering Research Center
US Army Engineer Waterways Experiment Station
PO Box 631
Vicksburg, Miss. 39180-0631

A copy should also be furnished to the Chief, FRF. Included in this letter should be the following information:

a. Description of the planned research.

b. Dates involved in performing the research.

c. Approximate number of participants.

d. Statement of the FRF resources required (e.g., support, data).

6. Because of the occasionally harsh environment at the FRF, it is imperative that potential users be aware of the prevailing conditions at the time of their experiment and have good advance planning (with regard to both people and equipment). Although this user's guide will help in that respect, all experiments should be discussed with the FRF staff before a formal request for use is submitted.

7. Particular attention will be given to those experiments requiring equipment to either be mounted directly on the pier or placed in the water. The area seaward of the FRF is a popular commercial fishing area with heavy use from October to December. Because of this, experimental equipment placed in this area should be marked with a pinger (acoustic beacon) and a large, lighted radar reflective buoy. Experiments within the pier length should be marked by a buoy (a pinger is desirable). Any installation requiring diver maintenance should be marked by a buoy or be attached by a handline to a nearby buoy for easy locating. Mooring lines should be large diameter rope or steel cable. The US Coast Guard should be properly informed of all

navigational obstructions. Experiment plans must also include plans for removal of equipment.

Funding and costs of research

8. If the planned research relates to the CERC mission, use of the facility and of the data being collected there is free to most users. Costs for projects not relating to the CERC mission will be assessed according to the user's purpose and resources. Reimbursement will be required for all applications of FRF staff and equipment to specific user projects such as special data collection runs or assistance with equipment installation.

Determining liability

9. Users of the FRF are responsible for their own liability and will be asked to sign a release form (see Appendix A).

Description of the Area

10. The FRF is located near Duck, N. C., along a 100-km (62-mile) unbroken stretch of shoreline extending south from Rudee Inlet to Oregon Inlet. It is bordered by the Atlantic Ocean to the east and Currituck Sound to the west. An aerial view of the area is shown in Figure 4. Except for five fishing piers and the FRF pier, there are no major coastal structures or littoral barriers along the entire reach.

11. This location, one of 12 sites originally considered, was selected because it best (but not completely) satisfied the following list of desirable physical characteristics:

a. Sand size typical of US coasts and sufficient depth of sand to prevent exposure of underlayers.

b. A wave climate and storm exposure representative of US coasts.

c. Regular offshore bottom topography free of features which may affect the wave climate.

d. A tidal range of 0.5 to 2.0 m (1.5 to 6 ft).

e. A representative nearshore slope such that the 6-m- (18-ft-) depth contour is not appreciably more than 600 m (2,000 ft) from shore.

f. A straight coastline outside the range of the effects of any significant littoral barrier.

g. Easy access by vehicle.

h. Control of the pier and surrounding area by CERC to avoid interruptions in research programs.

a. Aer

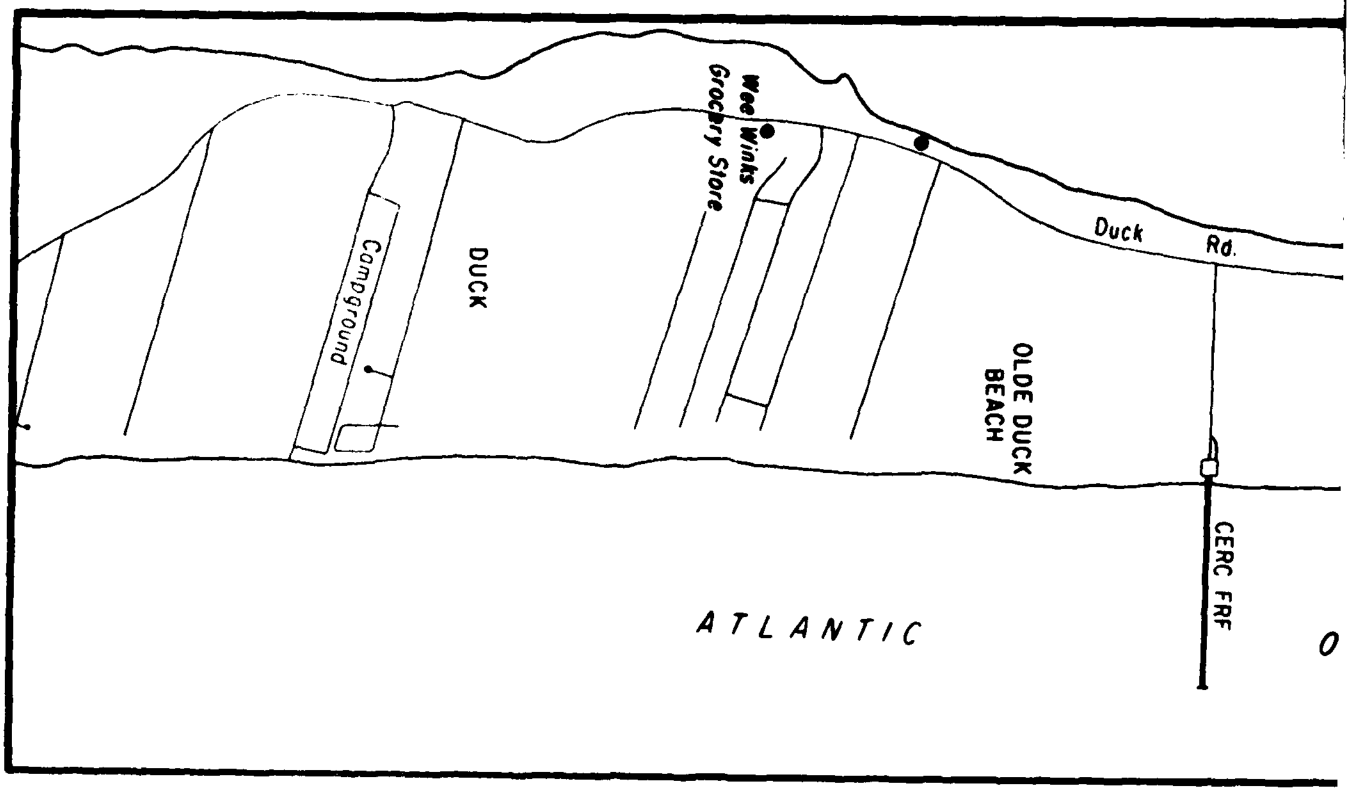

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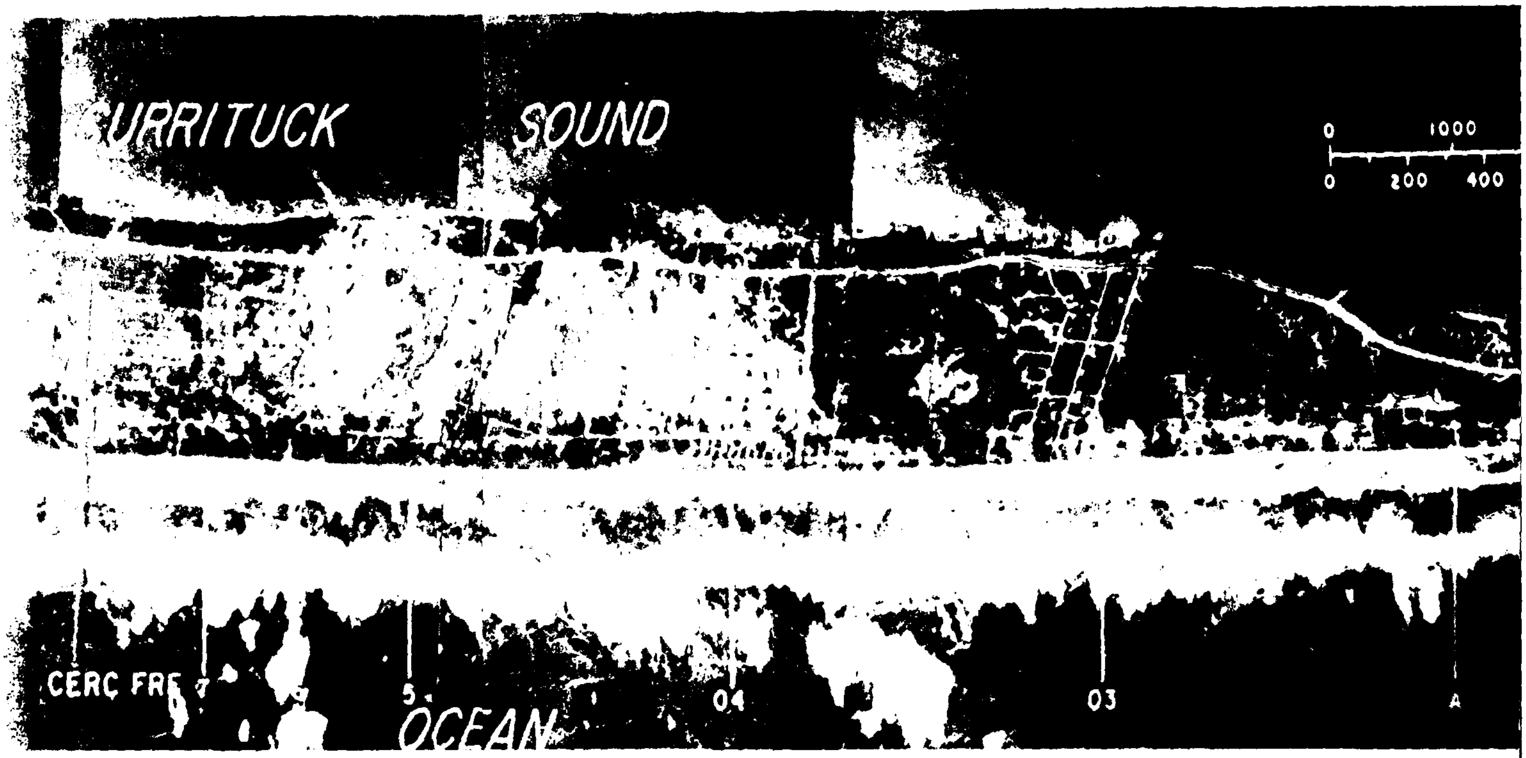
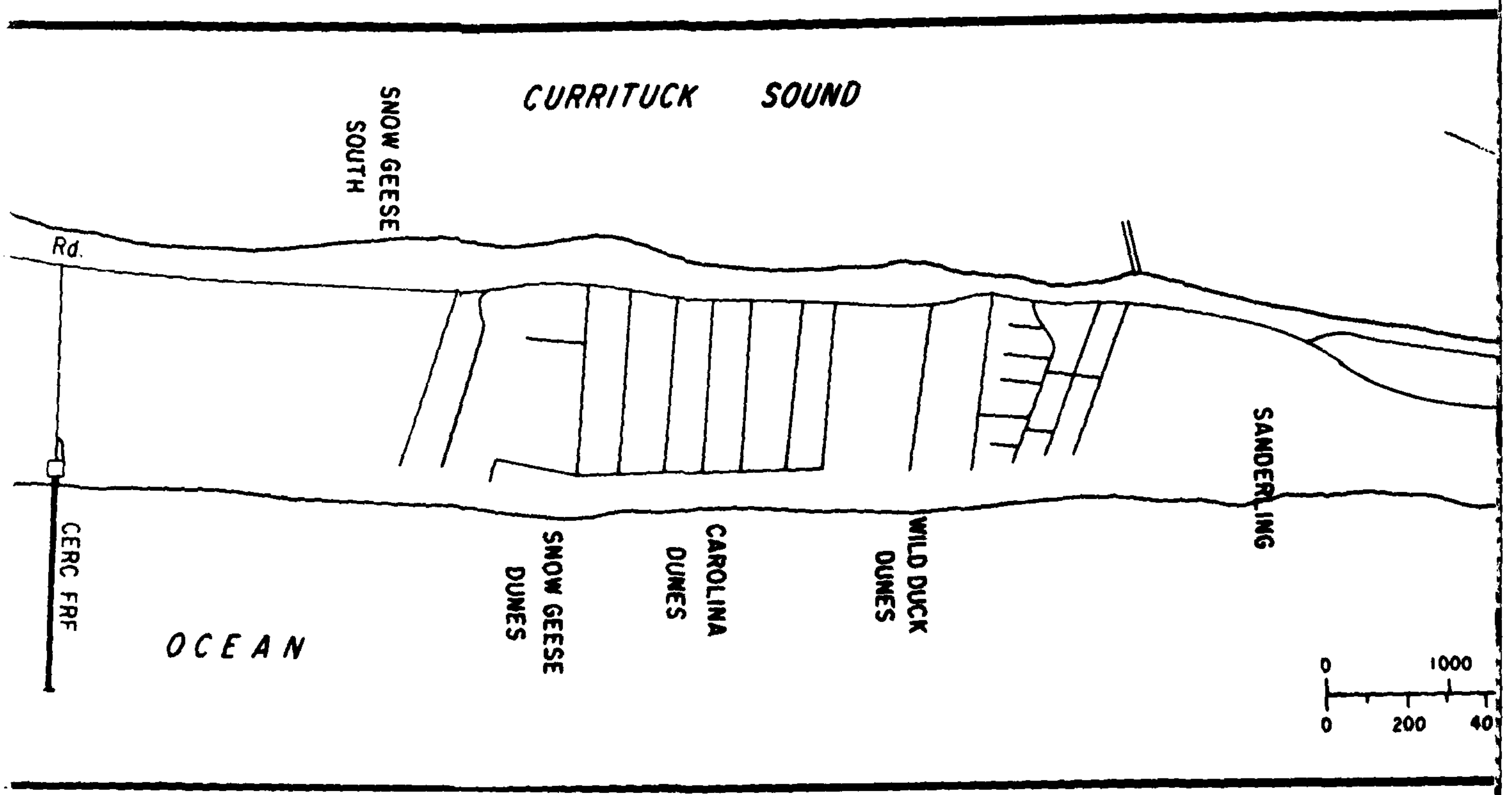
Figure 4. Aer



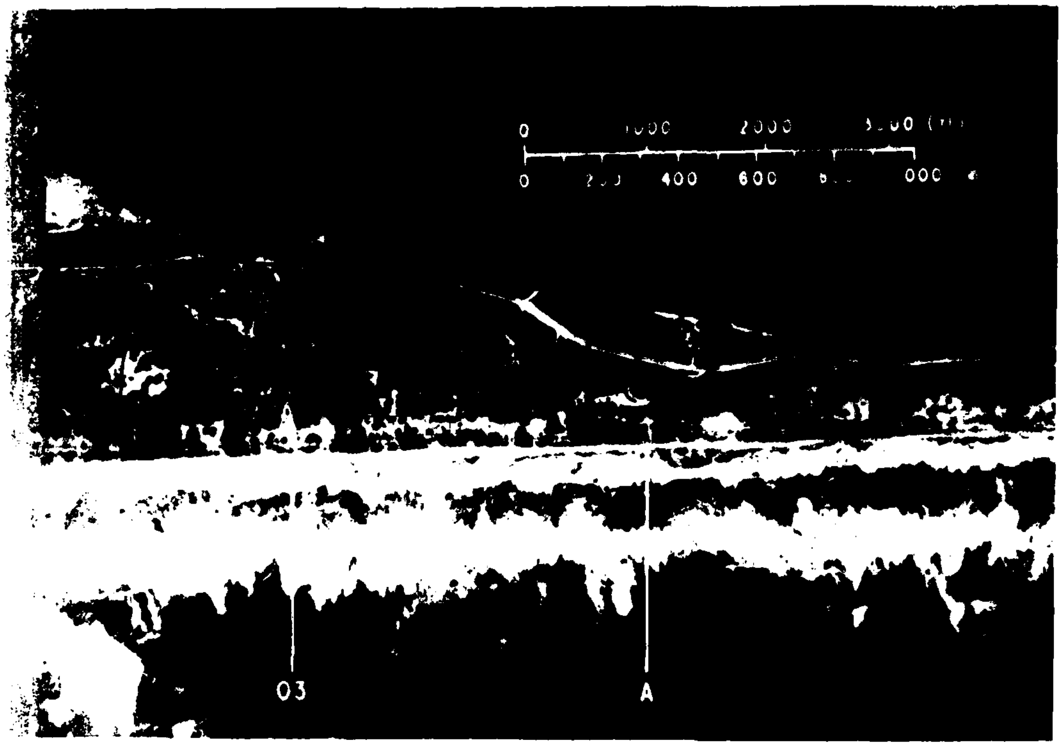
a. Aerial mosaic of FRF pier site



b. Map of FRF pier site

gure 4. Aerial mosaic and map of FRF pier site

21 3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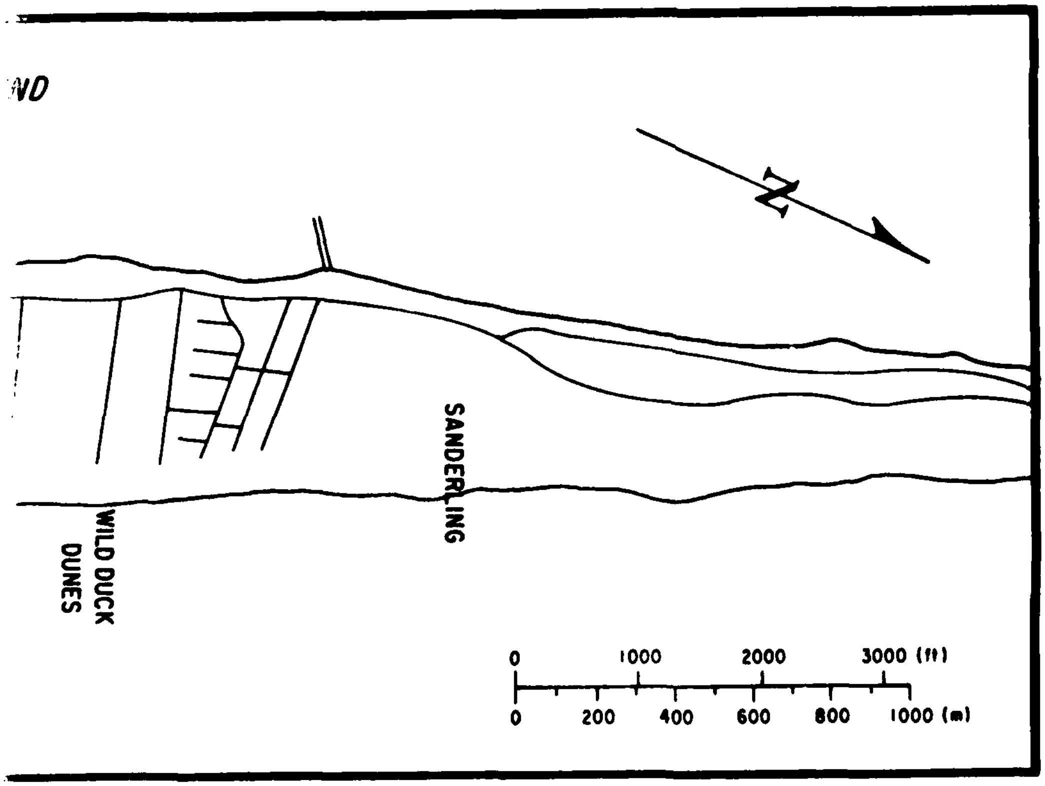
ND
N
SANDERLING
WILD DUCK
DUNES
0 1000 2000 3000 (ft)
0 200 400 600 800 1000 (m)

i. An adjacent sound or estuary area.

j. Availability of commercial power and communication facilities.

k. An area usually free of fog or cloud cover to permit frequent use of aerial remote sensing.

l. A stable coastline (on a time scale of 50 years).

m. Natural dunes.

Establishment of the Site

12. Duck, N. C., was established around 1909 as a small fishing village, with eel and carp as the predominant fishery resources. When CERC selected the Duck site in 1972 there were relatively few homes in the area; however, this situation has changed considerably. Duck has become a popular summer resort, and fast-growing resort communities are located both north and south of the area. The site had been used previously by the Navy as a practice bombing range, and occasionally practice rounds of ammunition are found on the property.

Pier construction

13. Construction of the FRF pier began in August 1975. The pier was constructed in two phases, the first being accomplished by using a temporary second pier with closely spaced bents (pile groups 4.9 m (16 ft) apart with four piles per bent) located along the south side of the pier (Figure 5). During the first phase of construction, 183 m (600 ft) of pier was completed and the construction pier was removed. The second phase began in March 1976 with the reconstruction of the second pier. The entire FRF pier was completed by August 1976, and the temporary pier was removed by January 1977.

Pier specifications

14. A cross section of the pier is shown in Figure 6. The 561.1-m- (1,840.9-ft-) long pier is a reinforced concrete structure supported on concrete-filled steel pilings spaced 12.2 m (40 ft) on center along the pier length and 4.6 m (15 ft) on center across the width (Figure 5). Inshore bents (numbered 6 to 20) are supported on 76-cm- (30-in.-) diam. piles; the outer piles (bents 21 to 52) are 91 cm (36 in.) in diam. The piles are embedded about 15 to 18 m (50 to 60 ft) into the ocean bottom. Concrete erosion collars, 120 and 137 cm (48 and 54 in.) in diam., protect the pilings from sand abrasion; and a cathodic system provides protection from corrosion. The pier deck is 6.1 m (20 ft) wide, extends from behind the dune line to about the

Figure 5. The pier during construction, with temporary second pier in foreground

6-m- (20-ft-) depth contour, and is 7.7 m (25.4 ft) above the National Geodetic Vertical Datum (NGVD). One set of railroad rails, 3.1 m (10 ft) apart and extending from the garage of the laboratory building to the end of the pier, is used to transport heavy loads. Instrumentation cables run the length of the pier in a trough along the north side of the deck. Outlet boxes for both 220- and 115-V power are located at 12-m (40-ft) intervals along the south side. Removable gratings in the pier deck can be used for lowering instrumentation. There are two telephones on the pier--one at the end and one midway.

15. Locations on the pier are referenced by distance in feet from a monumented baseline located landward of the laboratory and perpendicular to the pier center line; for example, the end of the pier is at sta 19+60 (see Figure 6), and the midpier telephone is at sta 10+80. Five steel piles with an outside diameter (OD) of 16.83 cm (6-5/8 in.) suitable for mounting instrumentation, are located midway between the piles at sta 7+00, 7+80, 9+00, 10+60, and 14+20. These piles extend from the pier deck to the sea bottom.

16. The laboratory building includes offices, a kitchen, a library, a computer room, a multipurpose area, and a diving locker. The computer room houses a Digital Equipment VAX-750 and a WICAT 150 microcomputer. An emergency generator combined with a Westinghouse uninterrupted power supply provides a continuous stable flow of electricity to the data collection equipment. The roof of the building provides a flat observation deck with an elevation of 12.63 m (41.44 ft) above NGVD.

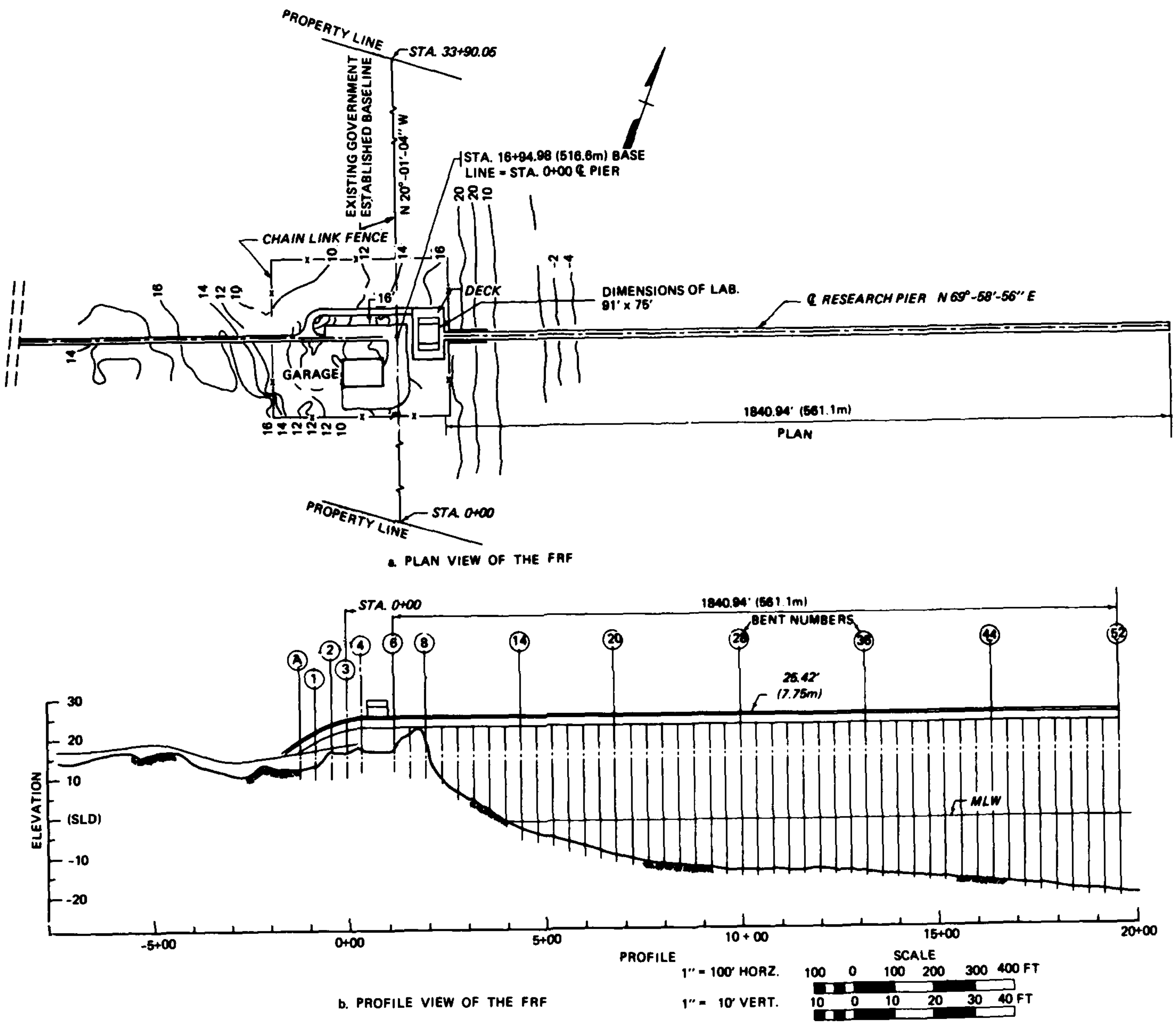

Figure 6. Plan and profile views of the FRF

PART II: LOCAL INFORMATION

17. This part addresses both the available research support and the living accommodations. Much of the information has been obtained from the local telephone directory, the Dare County Tourist Bureau, and the Outer Banks Chamber of Commerce. CERC does not endorse any of the businesses listed.

Research Support

18. The FRF staff of 9 includes the Chief, 2 scientists, 4 technicians, a computer operator, and a secretary. Requests for personnel assistance should be directed to the FRF Chief. The use of FRF personnel will require reimbursement of salaries and overhead.

Hours of operation

19. Normal hours of operation of the FRF are from 0700 to 1700 weekdays. Special arrangements can be made for extended hours (including round-the-clock) and for weekends.

Laboratory space

20. A 15- by 3-m (50- by 10-ft) trailer with electricity, heat, and air-conditioning (no water) is available to visiting scientists. An effort will also be made to accommodate sensitive instruments and recording or computing equipment inside the laboratory. Nearby rental cottages may provide adequate temporary space. An air-conditioned van at the end of the pier is available to house instrumentation for pier-end experiments. Free laboratory space may also be available at the North Carolina Marine Resources Center in Manteo, N. C. (see Figure 7), located 54 km (34 miles) from the FRF. For further information contact:

Director
North Carolina Marine Resources Center
Manteo, N. C. 27954
(919) 473-3493

Airports and plane rentals

21. The nearest major airport is in Norfolk, Virginia, approximately 113 km (70 miles) from the facility. Manteo Airport (Figure 7), the nearest local airport, has commuting service to Norfolk. Facilities include aviation gas, keyed lighting for night flights, and automatic direction finder (ADF) approach (refer to Charlotte Sectional). Aircraft can also land at First

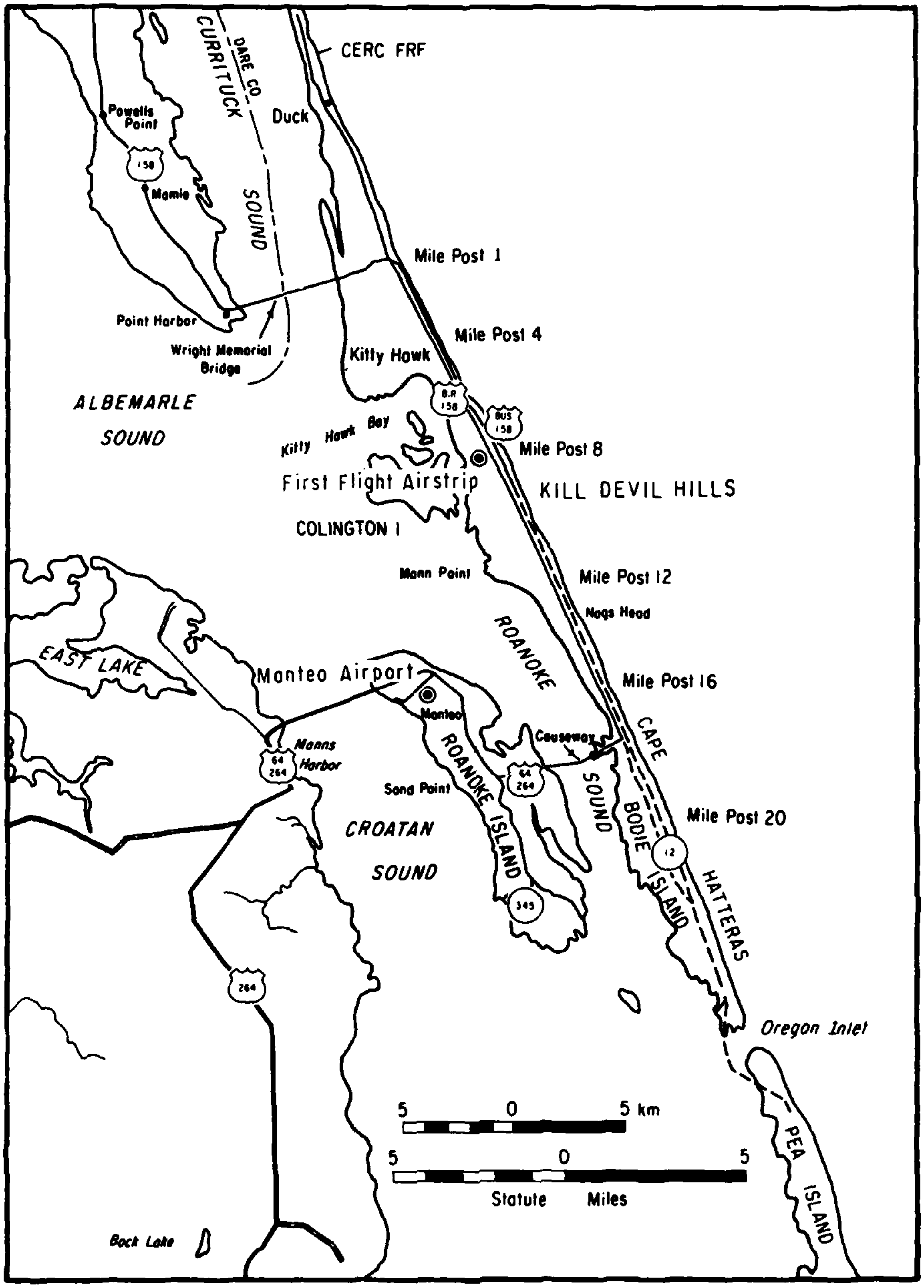

Figure 7. Map of local area*

* Modified from United States Geological Survey (USGS) maps NJ 18-8, -11; NI 18-2.

Flight Air Strip located in Kill Devil Hills just 23 km (14.5 miles) south of the FRF (Figure 7). Ground time is limited to 24 hr, and the only accommodation is a telephone booth. With prior approval from the FRF, helicopters may land at the pier site. Local charter air service is available from:

Albemarle Flying Service
Kill Devil Hills, N. C. 27948
(919) 441-3176 or (919) 441-6235

Kitty Hawk Aero Tours
Nags Head, N. C. 27954
(919) 441-4124 or (919) 473-3305

Coastal Air Service
Columbia, N. C. 27925
(919) 796-3406

Vehicle use and rentals

22. Vehicles with an axle width less than 3.1 m (10.17 ft) and a weight under 900 kg (2,000 lb) per wheel may be driven on the pier with permission of the FRF Chief. Beach access is provided just south of the pier. To minimize any damage to the beach, all dune and beach vehicular traffic is restricted to permanent trails. During special studies or experiments, vehicular traffic will be detoured off the beach and around the property. Beach travel in Dare County is prohibited from Memorial Day to Labor Day. Rental automobiles are available at the Norfolk Airport. They may also be obtained from the Manteo Airport and, between 15 May and 15 November, from the First Flight Air Strip in Kill Devil Hills by contacting:

National Car Rental System
Kill Devil Hills, N. C. 27948
(919) 441-5488

Boat use

23. Except under special circumstances, visiting scientists should plan to provide their own boats. The FRF has an inflatable boat with outboard motors and a LARC-V amphibious vehicle (Figure 8), but these are not usually available to outside users. Small boats for ocean use must be launched from the shore. A boat ramp for Currituck Sound is located about 1.6 km (1 mile) south of the FRF. Larger boats must use Oregon Inlet, 56 km (35 miles) south of the facility. Large charter boats are available, and arrangements may be made by contacting:

Figure 8. LARC-V amphibious vehicle

Oregon Inlet Fishing Center
Box 533
Manteo, N. C. 27954
(919) 441-6301

Scuba diving

24. All nongovernment scuba diving at the pier must comply with OSHA Commercial Diving Regulations (Department of Labor 1977). Copies of the regulation may be obtained from the Diving Officer at the FRF. Divers are required to sign a statement that they have read this regulation and are in compliance. Specialized equipment required by the regulation (e.g., first-aid kit, resuscitator) is available at the FRF.

25. Before diving permission at the pier is granted, a written dive plan (see form in Appendix B) must be submitted 2 weeks in advance to the FRF Diving Officer for approval. Only no-decompression diving is permitted. In addition, the FRF Diving Officer or his assistant may cancel any diving activity if conditions warrant.

26. Diving conditions around the FRF vary considerably. Visibility ranges from 0 to 6 m (0 to 20 ft) with marginal visibility being the norm. Monthly surface water temperatures range from a mean of 3.8° C (39.8° F) in February to 23.1° C (73.6° F) in September. Environmental conditions are

discussed further in Part IV. Use of a small inflatable boat is recommended since there is no way for divers to enter or leave the water from the pier.

Onsite data processing

27. The FRF is equipped with a Digital Equipment VAX-750 minicomputer used for collecting, editing, and analyzing the basic set of routine measurements. This computer has the capacity to handle 64 channels of analog or digital data. While this computer is not normally available to outside users, it will be used to obtain near real-time analysis of the measurements. This analysis permits users to obtain required data summaries while their experiments are under way.

28. Provisions have been made for users to record the output signal of a particular CERC gage or instrument. It may be possible also to have a special magnetic tape created of the data from one or a number of the CERC sensors. As mentioned previously, accommodations will be made (space permitting) for sensitive instruments inside the laboratory building. If a long period of recording of a special instrument is required, it may be possible to obtain a channel in the VAX-750. For additional information concerning the use of data collection equipment at the FRF, contact the FRF Chief.

Living Accommodations

29. Because of the resort nature of the area, it is important when planning an experiment to arrange for accommodations as early as possible, particularly for June, July, and August. There are sufficient year-round facilities (hotels, restaurants, shopping centers) in the area to accommodate any size group and budget. Table 1 summarizes some basic details about the 20 motels closest to the FRF. The milepost values given in the table refer to the local reference system shown in Figure 7. Milepost 1 is the point where Route 158 divides into Route 158-Business, which follows along the ocean, and Route 158-Bypass. Table 2 is a partial list of companies which handle house rentals. Many of them have brochures describing their listings. The nearest campground is located 1.6 km (1 mile) south of the FRF. For further information contact:

Ocean Beach Campground
Box 223D
Kitty Hawk, N. C. 27949
(919) 261-2200

Table 1

Motels Closest to the FRF

Motel and Telephone No.	Address*	Relative Cost**	Distance to FRF, miles	Milepost†	Comments††
Sea Hawk (919) 261-2424	SR-Box 130T Kitty Hawk, N. C.	L-H	6.6	1	CYLTA
Sea Kove Motel (919) 261-9771	Box 168B Kitty Hawk, N. C.	L-M	7.8	3	SCLTA
The Buccaneer (919) 261-2030	SR-Box 53 Kitty Hawk, N. C.	L-M	10.1	5.25	SCYLTA
Bel Air Motel (919) 441-6132	Box 37T Kill Devil Hills, N. C.	M-H	10.6	5.8	SCLTA
Tan-A-Rama Motel (919) 441-7315	Box 1325T Kill Devil Hills, N. C.	H-E	11.1	6.5	SCLTA
Mariner Motel (919) 441-7255	Box 407T Kill Devil Hills, N. C.	H-E	11.8	7	SCLTA
Sea Ranch Motel (919) 441-7126	Box 633T Kill Devil Hills, N. C.	H-E	11.8	7	SCYLRTA
Nettlewood Motel (919) 441-5039	Box 367 Kill Devil Hills, N. C.	L-M	11.9	7	CYLTA
Chart House Motel (919) 441-7418	Box 432T Kill Devil Hills, N. C.	M-H	11.9	7	SCLTA
The Croatan Inn (919) 441-7232	Kill Devil Hills, N. C.	L-H	12.5	7.5	LRTA
Colony IV Motel (919) 441-5581	Box 287R Kill Devil Hills, N. C.	H-E	13.6	8.5	SCYLTA
The Cavalier (919) 441-5584	Box 385 Kill Devil Hills, N. C.	L-H	13.6	8.5	SCYLTA
First Flight Inn (919) 441-5007	Box 698 Kill Devil Hills, N. C.	M-H	13.8	9	SCLTA
Holiday Inn (919) 441-6333	Box 308T Kill Devil Hills, N. C.	H-E	14.6	10	SCYLRTA
Outer Banks Motor Lodge (919) 441-7404	Box 747T Nags Head, N. C.	M-E	14.6	10	SCLTA
John Yancey Motor Inn (919) 441-7727	Box 422D Kill Devil Hills, N. C.	M-H	14.8	10	SCYLTA
Carolinian (919) 441-7171	Box 370 Nags Head, N. C.	M-H	15.3	10.5	SYLRTA
Cabana East Motel (919) 441-7106	Box 969T Nags Head, N. C.	--	15.9	11	SCYLRTA

* All motels are located along Route 158-Business. Zip codes include: Kitty Hawk, 27949; Kill Devil Hills, 27948; and Nags Head, 27959.

** L, low; M, moderate; H, high; E, expensive.

† Refers to reference system in Figure 7.

†† S, swimming pool; C, cooking; Y, open all year; L, low offseason rates; R, restaurant; T, television; A, air-conditioned.

Table 2

Rental Companies*

Company and Telephone No.	Address**	Approximate No. Cottages
Atlantic Realty (919) 261-2154 (toll free) 1-800-334-8401	SR Box 48V Kitty Hawk, N. C.	--
Cove Realty (919) 441-6391	PO Box 967 Nags Head, N. C.	--
Kitty Dunes Realty (919) 261-2171	PO Box 275 Kitty Hawk, N. C.	110
Kitty Hawk Realty & Rentals (919) 441-7166	Box 69T Kill Devil Hills, N. C.	--
Joe Lamb, Jr. & Associates (919) 441-5541	Box 609 Nags Head, N. C.	200
Midgett Realty (919) 441-6666	Box 1066 Kill Devil Hills, N. C.	44
Nags Head Realty (919) 441-4311	Box 726 Nags Head, N. C.	10
Ocean Acres Realty, Inc. (919) 441-5528	Box 656 Kill Devil Hills, N. C.	30
Outer Banks, Ltd. (919) 441-5000	Box 129T Nags Head, N. C.	132
Real Escapes (Frost Morrison Realty) (919) 261-3211	Box 299F Kitty Hawk, N. C.	28
Rollason & Wood Realty, Inc. (919) 441-5551	Box 326 Kill Devil Hills, N. C.	105
Southern Shores Realty Co., Inc. (919) 261-2000	Box 150 Kitty Hawk, N. C.	200
Sun Realty (919) 441-7033	PO Box 320 Kitty Hawk, N. C.	--
Todd Realty, Inc. (919) 441-6306	PO Box 1955 Kill Devil Hills, N. C.	--
Twenty-Twenty Realty, Ltd. (919) 441-7073	Box 2020 Nags Head, N. C.	13
Wright Realty (919) 261-2186	Box 166 Kitty Hawk, N. C.	85
Robert A. Young & Associates (919) 441-5544	Box 285 Kill Devil Hills, N. C.	350
Twiddy and Company (919) 261-3521	SR Box 232C Kitty Hawk, N. C.	--

* This alphabetical list of licensed rental agents is taken from the 1979 Dare County and Outer Banks Chamber of Commerce Accommodation Directories. Not all agents necessarily have rentals near the FRF.

** Zip codes include: Kitty Hawk, 27949; Kill Devil Hills, 27948; and Nags Head, 27959.

30. More complete information on the area facilities is available in annual brochures published by:

Outer Banks Chamber of Commerce
PO Box 90D
Kitty Hawk, N. C. 27949
(919) 261-2626 and (919) 261-3801

Dare County Tourist Bureau
PO Box 399
Manteo, N. C. 27954
(919) 473-2138

During the tourist season, the Outer Banks Chamber of Commerce also operates a vacancy referral service which identifies the motels with vacancies.

PART III: BASIC FRF MEASUREMENTS

31. A measurement program was established in 1977 to monitor local oceanographic and meteorological conditions at the FRF. Daily measurements are made of wind speed, wind direction, air temperature, atmospheric pressure, precipitation, waves, currents, tide and water levels, water temperature, surface water visibility, water density, and beach condition. Monthly beach and bathymetric surveys and quarterly aerial photographic overflights are also performed. Since October 1980, monthly reports have been published which provide preliminary summaries of the measurements soon after collection. More detailed summaries are available in an ongoing series of annual reports; Miller (1982, 1984a, 1984b, in prep).

32. The data are available to anyone interested and may be obtained by writing to:

Coastal Engineering Research Center
Coastal Engineering Information and Analysis Center (WESCV-I)
US Army Engineer Waterways Experiment Station
Vicksburg, Miss. 39180-0631
(601) 634-2017

Requests for data should be specific, and the requestor will be responsible for reproduction and mailing costs.

Instrumentation

33. A variety of oceanographic and meteorological instruments has been installed at the FRF to collect data on local conditions (Miller 1980). Table 3 summarizes the instrument installations included in the measurement program; locations are shown in Figure 9. The X-band radar, located on the laboratory building roof, is used to obtain wave directions. Details of the radar system are reported by Mattie and Harris (1979). The pressure gage slope array, sometimes referred to as an S_{xy} gage, consists of an array of four pressure sensors capable of measuring directional wave spectra. The data and analyses are available interactively via a computer terminal and in monthly data reports published by Scripps Institute of Oceanography. Directional wave spectra are also measured 500 m (1,650 ft) south of the pier using a combination of a pressure wave gage (CERC gage 621) and a biaxial electromagnetic

Table 3

Summary of Instrumentation

Sensor No.	Type of Sensor	Type of Data	Location	Elevation (NGVD) ft	Elevation (NGVD) m	Data Record	Beginning of Proper Operation	Major Gaps in Data
615*	Continuous-wire staff (Baylor Co.)	Wave	Station 6+20 FRF pier	-7	-2	20-min digital record 4 pts/sec; 4 times/day	Nov 1978	Jan-Feb 1979
625*	Continuous-wire staff (Baylor Co.)	Wave	Station 19+00 FRF pier	-27	-8	20-min digital record 4 pts/sec; 4 times/day	Nov 1978	Jan 1979, 25 Jun-23 Jul 1981
610	Waverider buoy (1-m diam) (Datawell)	Wave	220 m (721 ft) north, 200 m (656 ft) east of seaward end of FRF pier	-23	-7	20-min digital record 4 pts/sec; 4 times/day	Nov 1978	12 Jun-12 Aug 1980, installation terminated 26 Aug 1982
620*	Waverider buoy (1-m diam) (Datawell)	Wave	2.1 km (1.3 miles) east of seaward end of FRF pier	-59	-18	20-min digital record 4 pts/sec; 4 times/day	Nov 1978	Jan 1979, Apr 1979
640*	Waverider buoy (1-m diam) (Datawell)	Wave	380 m (1,245 ft) east of seaward end of FRF pier	-30	-9	20-min digital record 4 pts/sec; 4 times/day	Jan 1984	--
621*	Pressure gage	Wave	600 m (2,000 ft) offshore, 500 m (1,700 ft) south of pier	-20	-6	20-min digital record 4 pts/sec; 4 times/day	Apr 1982	--
619*	Electromagnetic current meter (Marsh-McBirney)	Mean and wave-induced bottom currents	Station 7+00 FRF pier	-7	-2	20-min digital record 4 pts/sec; 4 times/day	--	To present, intermittent
639*	Electromagnetic current meter (Marsh-McBirney)	Mean and wave-induced bottom currents	Station 14+20 FRF pier	-13	-4	20-min digital record 4 pts/sec; 4 times/day	--	To present, intermittent
679*	Electromagnetic current meter (Marsh-McBirney)	Mean and wave-induced bottom currents	600 m (2,000 ft) offshore 500 m (1,700 ft) south of pier	-20	-6	20-min digital record 4 pts/sec; 4 times/day	--	To present, intermittent
865-1370*	Float-activated tide gage (Leupold-Stevens)	Water level	Station 19+60 FRF pier end	-27	-8	Digital record one sample/6 min	Oct 1978	--
865-1376*	Bubbler (pressure) tide gage	Water level	305 m (1,000 ft) west, Currituck Sound shore	-5	-1.5	Continuous analog strip chart	Oct 1977	Installation terminated Feb 1978
865-1376*	Pressure tide gage (Metercraft)	Water level	305 m (1,000 ft) west, Currituck Sound shore	-4	-1.2	Continuous analog strip chart	Jul 1978	Feb 1979, Feb-Jul 1980, Dec 1980-Apr 1981, Dec 1981-Jan 1982, Apr 1983-Sep 1983
	Pressure gage slope array (S_{xy})	Directional wave spectra	600 m (2,000 ft) offshore 500 m (1,700 ft) north of pier	-20	-6	20-min digital record 4 pts/sec; 4 times/day	--	
	X-band radar	Wave direction	Station 19+00 FRF pier end	--	--	1-min film record 4 times/day	Jun 1978	Terminated Sep 1980
	X-band radar	Wave direction	Laboratory building roof	--	--	1-min film record 4 times/day	Oct 1980	Terminated Jun 1981
	X-band radar*	Wave direction	Laboratory building roof	--	--	Daily Polaroid photographs near 0700 EST	Jul 1981	--
	F420 anemometer (National Weather Service)	Wind speed and direction	76 m (250 ft) landward of dune	21	6	Daily reading by technician	Feb 1978	Installation terminated Sep 1980
	F420 anemometer (National Weather Service)	Wind speed and direction	Laboratory building roof	62	19	Continuous analog strip chart	Oct 1980	Replaced Mar 1982
632: Speed* 633: Direction*	Weather measure Skyvane (W102P)	Wind speed and direction	Laboratory building roof	62	19	Analog & 20-min digital 4 pts/sec; 4 times/day	Mar 1982	--

(Continued)

* Location shown in Figure 9.

Table 3 (Concluded)

Sensor No.	Type of Sensor	Type of Data	Location	Elevation (NGVD) ft	Elevation (NGVD) m	Data Record	Beginning of Proper Operation	Major Gaps in Data
	Microbarograph (Belfort Instr. Co.)	Atmospheric pressure	Laboratory building (inside)*	--	--	Continuous analog strip chart	Mar 1978	--
	Aneroid barometer (National Weather Service)	Atmospheric pressure	Laboratory building (inside)*	--	--	Daily reading by technician	Mar 1978	--
616	Barometer (Yellow Springs Instr. Co.)	Atmospheric pressure	Instrumentation shelter 43 m (138 ft) landward of dune	3	1	20-min digital record 4 pts/arc; 4 times/day	Feb 1982	--
	Weksler thermometers (National Weather Service)	Max/min air temperature	Instrumentation shelter 90 m (300 ft) landward of dune	--	--	Daily reading by technician	Mar 1978	Feb 1981 shelter moved
	Weksler thermometers (National Weather Service)	Max/min air temperature	Instrumentation shelter 43 m (138 ft) landward of dune	--	--	Daily reading by technician	Feb 1981	--
624	Thermometer (Yellow Springs Instr. Co.)	Air temperature	Instrumentation shelter 41 m (138 ft) landward of dune	--	--	20-min digital record 4 pts/sec; 4 times/day	Feb 1981	--
	30-cm weighing rain gage (Belfort Instr. Co.)	Precipitation	87 m (288 ft) landward of dune	--	--	Continuous analog strip chart	Mar 1978	Moved Feb 1981
	30-cm weighing rain gage (Belfort Instr. Co.)	Precipitation	46 m (150 ft) landward of dune	--	--	Continuous analog strip chart	Feb 1981	Upgraded Jun 1983
604*	30-cm weighing rain gage (Belfort Instr. Co.)	Precipitation	46 m (150 ft) landward of dune	--	--	Continuous analog & 20-min digital; 4 times/day	Jun 1983	--
	15-cm rain gage (Edwards Mfg. Co.)	Precipitation	82 m (270 ft) landward of dune	--	--	Daily reading by technician	Mar 1978	Moved Feb 1981
	15-cm rain gage (Edwards Mfg. Co.)	Precipitation	46 m (150 ft) landward of dune	--	--	Daily reading by technician	Feb 1981	--
	Weksler sling psychrometer (National Weather Service)	Dew point	Instrumentation shelter 43 m (138 ft) landward of dune	--	--	Daily reading by technician	Dec 1978	--
	Mechanical pyranograph (Weather Measure Corp.)	Solar radiation	Instrumentation shelter 43 m (138 ft) landward of dune	--	--	Continuous analog strip chart	Jan 1979	Terminated 1 Jan 1982

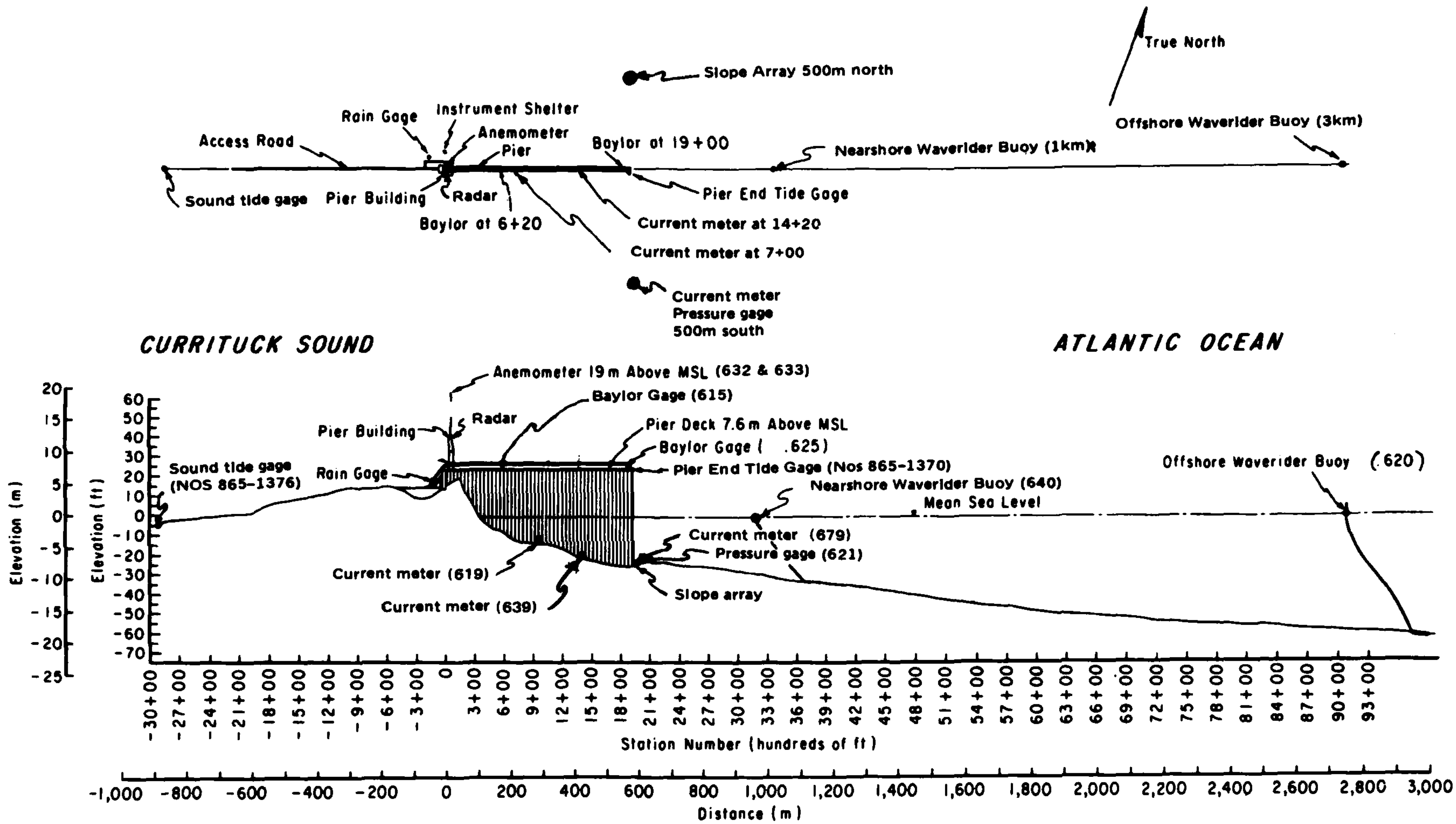

Figure 9. Instrument locations at FRF

current meter (CERC gage 679). This combined gage is commonly referred to as a PUV meter.

34. A visual observation program which supplements the instrument measurements includes daily measurements of the direction of wave approach, breaker angle and location, breaker type, width of the surf zone, littoral currents, beach slope, and the presence of rip currents.

Surveying

35. Leadline surveys were made weekly from July 1977 to July 1982 along both the north and south sides of the pier using a graduated surveying tape with a weight attached. The same positions along the pier are measured midway between the pier bents to minimize the effect of the scour around the pilings. Since July 1982, leadline surveys are done monthly coincident with routine bathymetric surveys. Periodic surveys to a depth of 9 m (30 ft) are also made of profile lines located approximately 500 m (1,650 ft) north and south of the pier.

36. The area around the pier is surveyed using the Coastal Research Amphibious Buggy (CRAB) (Figure 10), the innovative three-legged vehicle, designed and constructed by the Wilmington District (Birkemeier and Mason 1984). The CRAB provides a stable platform in wave heights up to 1.8 m (6 ft). Top speed is 3 kph (2 mph). Position and elevation are determined by targeting a prism mounted on the CRAB with a Zeiss electronic survey system which produces computer compatible data. Surveying of the beach from the baseline to the waterline is done using the same system with a person holding a prism at each survey point.

37. Pre-1981 surveys used more conventional surveying procedures. Generally, a sea sled or fathometer was used for the nearshore (out to 700 m (12,300 ft)) and a fathometer for the offshore (out to 3,000 m (10,000 ft)).

Surveying Control

Local control

38. There is extensive monumentation on the sound and ocean sides of the FRF site (Figure 11). Large-scale versions of Figure 11 with complete monumentation are available from the FRF. The primary oceanside monuments

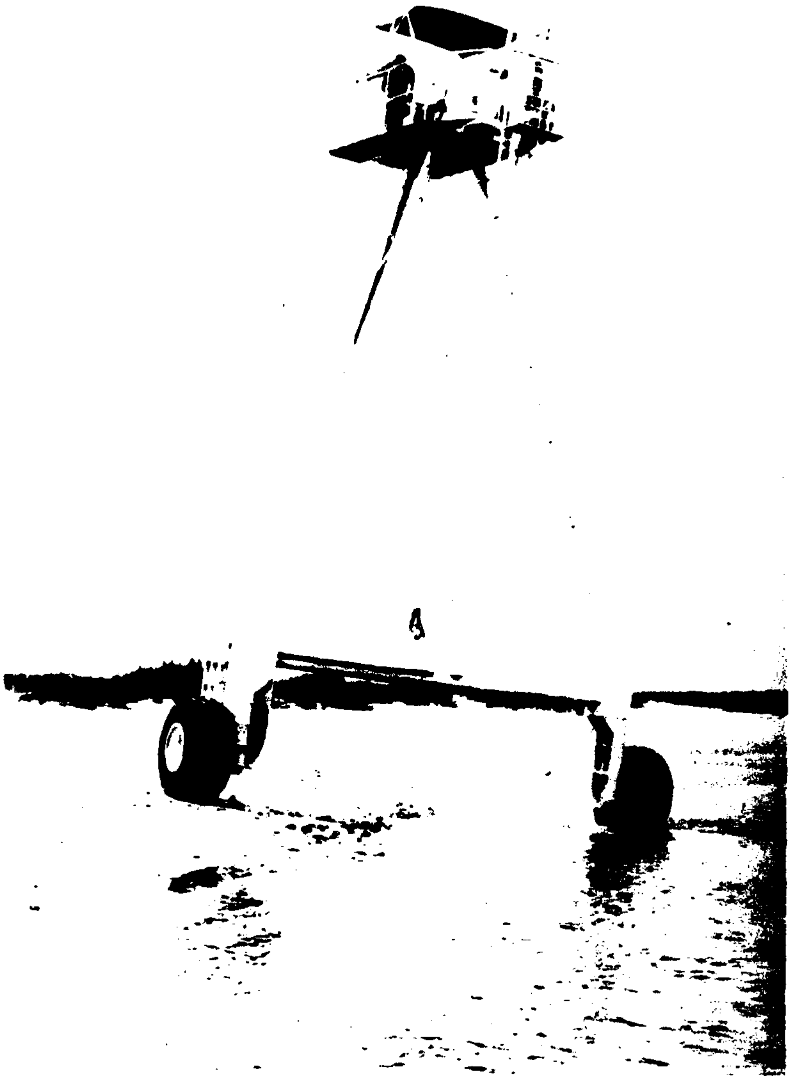

Figure 10. Coastal Research Amphibious Buggy (CRAB)

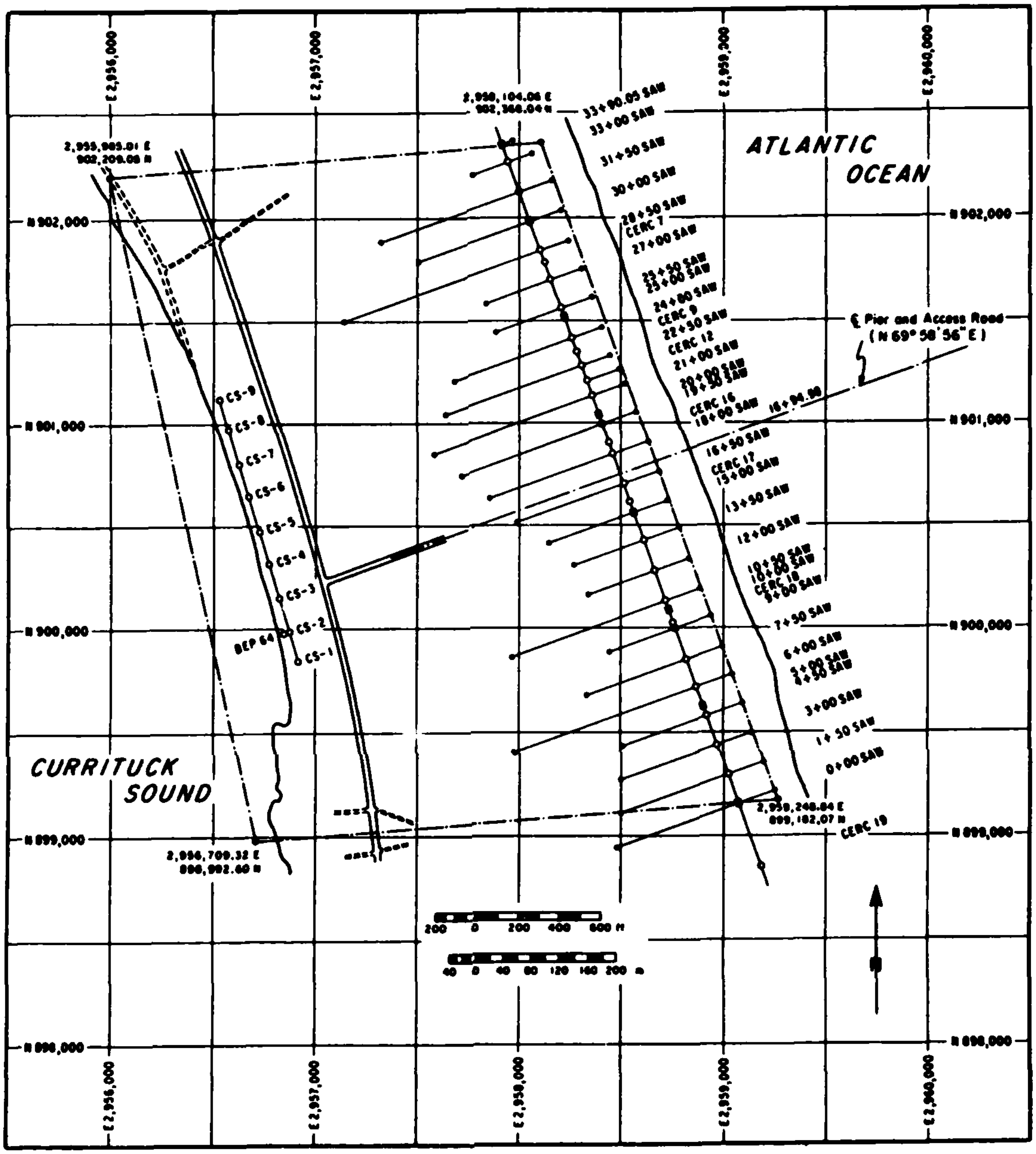

Figure 11. Map of FRF site showing location of primary survey monuments. (Large-scale copies with more complete documentation are available. Grid system used is North Carolina state system).

are along a baseline located landward of the laboratory and perpendicular to the pier center line. US Army Engineer District, Wilmington (SAW), has established a series of concrete monuments along this baseline at 45.72- and 152.4-m (150- and 500-ft) intervals. Other monuments at varying intervals have been established in support of CERC beach and bathymetric surveys. Many of the monuments along the baseline have permanent pipe monuments (front and back) to define profile azimuths perpendicular to the baseline. Table 4 provides a summary of the baseline monumentation according to distance along the baseline and distance from the pier center line. All these have been surveyed to third-order accuracy. Documentation on each monument is available.

39. One concrete monument and two series of profile lines have been established on the sound side to monitor sound changes. Further details about these lines are given in Part VII.

40. A number of benchmarks with first order control have been established by the National Oceanic and Atmospheric Administration (NOAA) in support of the tide gaging program. Information about these monuments is available at the FRF.

41. Because of the profusion of monuments at the FRF, users are requested to use established monuments if possible. Owners must clearly label temporary monuments, stakes, and pipes and remove them on completion of their study. To ensure that valuable monuments are not removed or lost during extended studies, the monuments should be documented as to location, markings, and date of installation using Form DA 1959 (Appendix C). A copy of the form should be given to the FRF Chief. Special care should be taken to minimize pedestrian effects on the dune and beach.

Island control

42. The CERC monuments indicated in Table 4 are part of the series of 62 profile lines shown in Figure 12. Each line has three monuments: a brass disk on a concrete post and two pipes (front and rear) to define the profile azimuth. Additionally, third-order vertical control has been established on each of the five fishing piers. Complete documentation for the profile lines may be obtained from the FRF Chief. All the lines are on private property, so written permission to survey must be obtained in advance from the owners. Data collected at these lines under CERC's Beach Evaluation Program (BEP) from May 1974 to January 1977 are discussed in Part VI.

Table 4

FRF Baseline Monumentation

Profile No.	Pre-1980 Designation	Distance Along Baseline* ft	Distance Along Baseline* m	Distance From ℄ of Pier** ft	Distance From ℄ of Pier** m	Elevation (NGVD) ft	Elevation (NGVD) m	Type of Monument†
25	A	14,195††	4,326.00	-12,500††	-3,810.00	12.55	3.83	C1
30	CERC 3	10,476.91††	3,193.36	-8,781.93††	-2,676.73	13.41	4.09	C1
40	CERC 4	7,163.73	2,183.50	-5,468.75	-1,666.88	15.85	4.83	C1
50	CERC 5	4,663.73	1,421.50	-2,968.75	-904.88	14.79	4.51	C1‡
58	--	3,600.00	1,097.38	-1,905.12	-580.68	--	--	--
39	--	3,450.00	1,051.56	-1,755.02	-534.93	--	--	--
60	CERC 6	3,413.73	1,040.50	-1,718.75	-523.88	12.36	3.77	D
61	SAW 33+90.05	3,390.05	1,033.29	-1,695.07	-516.66	14.45	4.40	C
62	SAW 33+00	3,300.00	1,005.84	-1,605.02	-489.21	13.15	4.01	P1
64	SAW 31+50	3,150.00	960.12	-1,455.02	-443.49	12.52	3.82	P1
66	SAW 30+00	3,000.00	914.40	-1,305.02	-387.77	14.70	4.48	P1
67	SAW 28+50	2,850.00	868.68	-1,155.02	-352.05	12.36	3.77	P1
70	CERC 7	2,788.73	850.00	-1,093.75	-333.38	12.92	3.94	C1
73	SAW 27+00	2,700.00	822.96	-1,005.02	-306.33	13.14	4.01	P1
76	SAW 25+50	2,550.00	777.24	-855.02	-260.61	12.00	3.66	P1
78	SAW 25+00	2,500.00	762.00	-805.02	-245.37	12.33	3.76	C
80	CERC 8	2,476.23	754.75	-781.25	-238.13	12.75	3.89	C1
85	SAW 24+00	2,400.00	731.52	-705.02	-214.89	12.24	3.73	P1
90	CERC 9	2,319.98	707.13	-625.00	-190.50	12.51	3.81	C1
95	SAW 22+50	2,250.00	685.80	-555.02	-169.17	13.26	4.04	P1
100	CERC 10	2,241.86	683.32	-546.88	-166.69	13.31	4.06	C1
110	CERC 11	2,202.80	671.41	-507.82	-154.78	14.99	4.57	C1
120	CERC 12	2,163.73	659.50	-468.75	-142.88	12.50	3.81	C1
130	CERC 13	2,124.66	647.60	-429.58	-130.94	13.04	3.97	C1
135	SAW 21+00	2,100.00	640.08	-405.02	-123.45	16.14	4.92	P1
140	CERC 14	2,085.60	635.69	-390.62	-119.06	13.45	4.10	C1
150	CERC 15	2,007.48	611.88	-312.50	-95.25	12.88	3.93	C1
151	SAW 20+00	2,000.00	609.60	-305.02	-92.97	13.10	3.99	C
155	SAW 19+50	1,950.00	594.36	-255.02	-77.73	13.80	4.21	P1
	CERC 16	1,851.23	564.25	-156.25	-47.63	14.18	4.32	C1
160	--	1,830.00	557.83	-135.02	-41.15	--	--	--
161	SAW 18+00	1,800.00	548.64	-105.02	-32.01	15.76	4.80	P1
162	B	1,769.98	539.49	-75.00	-22.86	16.05	4.89	P2
163		1,725.00	525.78	-30.02	-9.15	17.77	5.42	

(Continued)

* Distances given along the baseline are relative to a monument on the south property line (positive to the north).

** Pier coordinate system: positive distance seaward and to the south.

† Monument types: C, concrete; C1, concrete with front and rear pipes; D, monument destroyed; NP, north pier edge; P1, capped pipe with front and rear pipes; P2, pipe with front pipe only; SP, south pier edge.

†† Monument not on baseline; distance approximate.

‡ Monument buried.

Table 4 (Concluded)

Profile No.	Pre-1980 Designation	Distance Along Baseline ft	Distance Along Baseline m	Distance From ℄ of Pier ft	Distance From ℄ of Pier m	Elevation (NGVD) ft	Elevation (NGVD) m	Type of Monument
164	CERC 68	1,704.98	519.68	-10.0	-3.05			NP
165	SAW 16+94.98	1,694.98	516.63			17.56	5.35	D
166	CERC 69	1,684.98	513.58	10.0	3.05			SP
167	SAW 16+50	1,650.00	502.92	44.98	13.71	19.04	5.80	P1
	C	1,619.98	493.77	75.00	22.86	17.55	5.35	P2
168	--	1,610.00	490.73	84.98	25.90	--	--	--
169	--	1,575.00	480.06	119.98	36.57	16.65	5.07	P1
170	CERC 17	1,538.73	469.00	156.25	47.63	14.11	4.30	C1
171	SAW 15+00	1,500.00	457.20	194.98	59.43	15.10	4.60	C1
173	D	1,375.00	419.10	319.98	97.53	16.97	5.17	P2
174	SAW 13+50	1,350.00	411.48	344.98	105.15	14.89	4.54	P1
175	E	1,295.00	394.72	399.98	121.91	14.71	4.48	P2
176	SAW 12+00	1,200.00	365.76	494.98	150.87	17.59	5.36	P1
178	SAW 10+50	1,050.00	320.04	644.98	196.59	16.15	4.92	P1
179	SAW 10+00	1,000.00	304.80	694.98	211.83	15.70	4.79	C
180	CERC 18	913.73	278.50	781.25	238.13	14.36	4.38	
181	SAW 9+00	900.00	274.32	794.93	242.29	14.23	4.34	P1
182	SAW 7+50	750.00	228.60	944.98	288.03	16.24	4.95	P1
183	SAW 6+00	600.00	182.88	1,094.98	333.75	14.16	4.32	P1
184	SAW 5+00	500.00	152.40	1,194.98	364.23	13.48	4.11	C
185	SAW 4+50	450.00	137.16	1,244.98	379.47	14.76	4.50	P1
186	SAW 3+00	300.00	91.44	1,394.98	425.19	15.10	4.60	P1
187	SAW 1+50	150.00	45.72	1,544.98	470.91	14.90	4.54	P1
188	SAW 0+00	0.00	0.00	1,694.98	516.63	15.14	4.61	C1
189		-150.00	-45.72	1,844.98	562.35	--	--	--
190	--	-300.00	-91.40	1,994.98	608.07	--	--	--
--	CERC 19	-336.27	-102.50	2,031.25	619.13	16.14	4.92	C1
200	CERC 20	-2,836.27	-864.50	4,531.25	1,381.13	16.05	4.89	C1
207	F	-5,805.00††	-1,769.00	7,500.00††	2,286.00	16.44	5.01	C1
220	CERC 22	-10,884.00††	-3,317.00	12,579.00††	3,834.00	19.16	5.84	C1

†† Monument not on baseline; distance approximate.

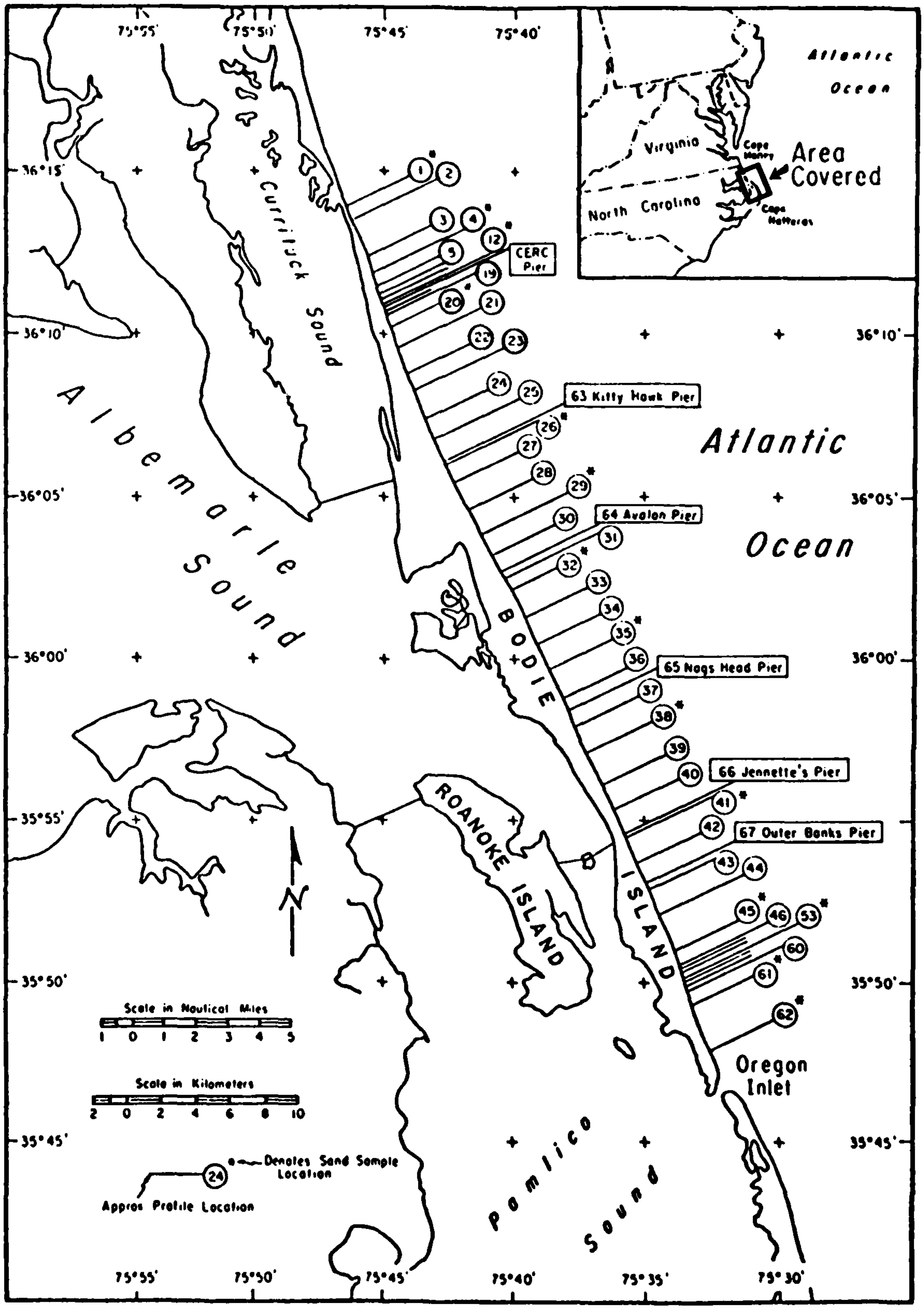

Figure 12. CERC profile line locations, pre-1980 designations

Aerial Photography

43. Table 5 summarizes known existing aerial photography of the FRF area. Flight paths vary in extent, but all cover the ocean shoreline. Regularly scheduled quarterly flights cover the immediate area ±8 km (5 miles) north and south of the FRF with at least one flight per year extending from Cape Henry at the Chesapeake Bay mouth to Cape Hatteras.

Table 5

Aerial Photography of the FRF and Vicinity

Date	Format*	Scale	Source	Project
21 Oct 1940	B & W	1:24,000	USGS	Barrier reefs, N. C. coast (F9885)
29 Mar 1955	B & W	1:20,000	NOAA	55W
5 Dec 1958	B & W	1:20,000	ASCS	AOL
13 Mar 1962	B & W	1:5,000	USGS	MATS 62-1
3 May 1962	B & W	1:20,000	USGS	MATS 62-1/MISS-77
25 Jun 1963	B & W	1:5,000	NOAA	62 W
Aug 1971	B & W	1:12,000	CERC	
1 Nov 1971	B & W	1:12,000	CERC	VT33TRTS013-UNC
6 Nov 1972	B & W	1:12,000	CERC	VT33TRTS090-AGMU
30 Jan 1973	B & W	1:130,000	NASA	73-013C
13 Feb 1973	Color IR	1:12,000	CERC	
Sep 1973	B & W		CERC	
2 Feb 1977	Color/Color IR	Varies	CERC	Quarterly
29 Jul 1977	Color	1:6,000/ 1:12,000	CERC	Quarterly
10 Aug 1977	Color	1:6,000	CERC	Quarterly
11 Nov 1977	Color	Varies	CERC	Quarterly
8 Feb 1978	Color	Varies	CERC	Quarterly
16 May 1978	B & W	1:2,000/ 1:6,000/ 1:12,000	CERC	Quarterly
12 Sep 1978	Color/Color IR	Varies	CERC	Duck-X flight

(Continued)

* All are standard 9- × 9-in. format except 15 Oct 1980 which is 5 × 5 in.

Table 5 (Concluded)

Date	Format	Scale	Source	Project
13 Sep 1978	B & W	1:12,000	CERC	Duck-X flight
18 Oct 1978	B & W	1:12,000	CERC	Quarterly
2 Dec 1978	B & W	1:12,000	CERC	Quarterly
21 Apr 1979	B & W/Color IR	1:6,000/ 1:12,000	CERC	Quarterly
20 Sep 1979	B & W/Color IR	1:6,000/ 1:12,000	CERC	Quarterly
15 Oct 1979	B & W	1:12,000	CERC	Quarterly
25 Oct 1979	B & W/Color IR	1:6,000/ 1:12,000	CERC	SEAP
16 Jan 1980	B & W/Color IR	1:6,000/ 1:12,000	CERC	Quarterly
3 Mar 1980	Color	1:12,000	SAW	Poststorm
15 Apr 1980	B & W/Color	1:6,000/ 1:12,000	CERC	Quarterly
15 Jul 1980	B & W	1:6,000/ 1:12,000	CERC	Quarterly
15 Oct 1980	B & W	1:12,000	CERC	Quarterly
24 Mar 1981	Color	1:12,000	CERC	Quarterly
27 Aug 1981	B & W	1:12,000	CERC	Quarterly
24 Sep 1981	Color/B & W	1:12,000	CERC	Quarterly
24 Nov 1981	B & W	1:6,000/ 1:12,000	CERC	Quarterly
7 Feb 1982	B & W	1:6,000	CERC	Quarterly
11 May 1982	Color	1:6,000	CERC	Quarterly
14 Jul 1982	B & W	1:12,000	CERC	Quarterly
27 Oct 1982	B & W/Color	1:12,000	CERC	Quarterly
26 Jan 1982	B & W/Color	1:12,000	CERC	Quarterly
27 Apr 1983	B & W/Color	1:12,000	CERC	Quarterly
8 Jul 1983	B & W	1:12,000	CERC	Quarterly
3 Oct 1983	B & W/Color	1:12,000	CERC	Quarterly
31 Jan 1984	B & W/Color	1:12,000	CERC	Quarterly
11 Apr 1984	B & W/Color	1:12,000	CERC	Quarterly
19 Sep 1984	B & W/Color	1:12,000	CERC	Quarterly
3 Oct 1984	B & W/Color	1:12,000	CERC	Quarterly

PART IV: CLIMATOLOGICAL CHARACTERISTICS

44. This section summarizes available meteorological, oceanographic, and sediment transport data useful for planning studies at the FRF.

General Weather

45. The FRF has a favorable marine climate with mild winters and warm temperate summers. The nearest weather stations with long periods of record are Cape Hatteras, N. C., and Norfolk, Va. Table 6 provides a NOAA summary of the normal, mean, and extreme meteorological data for each of these stations. More detailed information, including monthly summaries and three-hourly measurements, can be obtained from:

Environmental Data and Information Service
The National Climatic Center
Federal Building
Asheville, N. C. 28801

46. The maritime climate at the FRF tends to moderate the seasons with winters that are warmer and summers that tend to be cooler than on the mainland. Large temperature differences between day and night occur during late fall and spring due to the slow response of the ocean to changing temperature trends and frequent land and sea breeze effects. Air and water temperatures at the FRF tend to be lowest in January and February and highest during June through August. Precipitation is fairly well distributed throughout the year with an average of 84 mm (3.3 in.) per month.

47. Although warm in the summer and chilly in the winter, a persistent breeze blows at the FRF; seldom is it dead calm. Occasionally, severe winds blow as a result of either extra-tropical (northeasters) or tropical (hurricanes) cyclones. Summer winds are predominantly from the southwest, while winter winds are from northern directions. Figure 13 provides a plot of annual and seasonal wind roses compiled using 3 years of observations from the anemometer atop the laboratory building. Resultant wind speed and direction values given in Figure 13 are computed by adding each observation vectorally. Wind distribution varies considerably from month to month.

Table 6

1982 Meteorological Data: Normals, Means, and Extremes

a. Norfolk, Va.

Month	Temperatures °F: Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Extremes: Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct.: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F: Max. (b) 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Average station pressure mb. Elev. 30 feet m.s.l.
(a)				34		34					34		34		34		34		34		34	34	34	34	34	15	10	10		21	34	34	34	34	34	34	34	34	34	34	34	34	10
J	48.8	32.2	40.5	78	1970	5	1977	760	0	3.35	6.47	1979	1.05	1981	3.80	1967	14.2	1966	9.1	1973	73	74	59	67	11.5	SW	39	23	1978	56	6.2	9	7	15	10	1	*	2	0	3	17	0	1017.8
F	50.0	32.7	41.4	81	1976	8	1965	661	0	3.31	5.81	1982	0.86	1950	1.87	1970	10.9	1980	12.4	1980	72	74	56	65	11.9	NNE	44	36	1973	59	6.1	9	5	14	10	1	1	3	0	1	15	0	1016.1
M	57.3	38.9	48.1	85	1968	18	1980	532	0	3.42	7.80	1978	1.34	1967	3.18	1958	13.7	1980	9.9	1980	71	73	54	62	12.3	SW	46	22	1973	63	6.1	9	7	15	11	*	2	2	0	*	6	0	1016.3
A	67.7	47.9	57.8	97	1960	28	1982	226	15	2.71	7.00	1979	0.99	1976	2.76	1979	1.2	1964	1.2	1964	73	73	50	60	11.8	SW	39	06	1978	66	5.8	9	9	12	10	*	3	1	*	0	*	0	1015.8
M	76.2	57.2	66.7	97	1956	36	1966	53	96	3.34	10.12	1979	1.48	1965	3.41	1980	0.0		0.0		81	77	56	67	10.2	SW	38	02	1979	65	6.1	8	10	13	10	0	5	2	1	0	0	0	1014.4
J	83.5	65.5	74.5	101	1964	45	1967	0	282	3.62	9.72	1963	0.37	1954	6.85	1963	0.0		0.0		83	79	57	67	9.6	SW	46	30	1977	68	5.8	8	11	11	9	0	6	1	6	0	0	0	1015.1
J	86.6	69.9	78.3	103	1952	54	1979	0	415	5.70	13.73	1975	1.69	1961	5.66	1969	0.0		0.0		85	82	59	71	8.8	SW	46	34	1973	65	6.0	8	11	12	11	0	9	1	11	0	0	0	1015.6
A	84.9	68.9	76.9	104	1980	49	1982	0	394	5.92	11.19	1967	0.74	1975	11.40	1964	0.0		0.0		86	84	61	74	8.8	SW	46	35	1979	65	5.8	8	12	11	10	0	7	1	9	0	0	0	1017.0
S	79.6	63.9	71.8	98	1954	45	1967	9	225	4.20	13.80	1979	0.36	1958	6.79	1959	0.0		0.0		86	84	61	75	9.5	NE	30	06	1979	64	5.7	9	10	11	8	0	3	1	3	0	0	0	1016.9
O	70.1	53.3	61.7	95	1954	27	1976	141	31	3.06	10.12	1971	0.93	1967	4.38	1971	0.0		0.0		82	83	60	75	10.4	NE	48	04	1982	60	5.4	12	7	12	8	0	1	2	*	0	*	0	1018.2
N	60.5	42.6	51.6	86	1974	20	1950	402	0	2.94	7.01	1951	0.49	1965	3.35	1952	0.6	1950	0.6	1950	76	79	56	69	10.6	SW	32	21	1973	59	5.4	11	8	11	8	0	1	2	0	0	3	0	1018.9
D	50.6	34.0	42.3	80	1978	14	1980	704	0	3.11	5.83	1973	0.98	1979	2.12	1958	14.7	1958	11.4	1958	73	75	59	68	11.0	SW	36	36	1982	57	6.0	10	7	14	9	*	*	2	0	1	14	0	1018.6
YR	68.0	50.6	59.3	104	AUG 1980	5	JAN 1977	3488	1458	44.68	13.80	SEP 1979	0.36	SEP 1958	11.40	AUG 1964	18.9	FEB 1980	12.4	FEB 1980	78	78	57	69	10.5	SW	48	04	OCT 1982	63	5.9	110	104	151	115	2	37	22	31	5	55	0	1016.9

b. Cape Hatteras, N. C.

Month	Temperatures °F: Normal: Daily maximum	Normal: Daily minimum	Normal: Monthly	Extremes: Record highest	Year	Extremes: Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct.: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile #: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F: Max. (b) 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Average station pressure mb. Elev. 11 feet m.s.l.
(a)				25		25					25		25		25		25		25		25	25	25	25	25	6	12	12		20	25	25	25	25	25	25	25	25	25	25	25	25	10
J	52.3	38.2	45.3	75	1972	11	1982	611	0	4.26	9.72	1979	1.75	1981	5.00	1979	3.5	1962	3.5	1962	79	80	68	78	12.5	NNE	32	N35	1982	50	6.2	9	7	15	11	*	1	3	0	1	11	0	1018.7
F	53.1	38.5	45.8	76	1971	14	1958	538	0	4.15	7.48	1963	1.42	1976	2.92	1970	4.4	1978	4.4	1978	79	80	65	76	12.8	NNE	44	S04	1973	53	6.0	9	5	14	10	*	2	3	0	*	10	0	1018.8
M	57.9	43.2	50.6	79	1977	19	1967	458	6	3.84	8.94	1980	0.98	1967	2.91	1982	8.5	1960	7.3	1980	80	80	62	76	12.2	SW	48	N02	1980	68	6.0	10	7	14	10	*	2	3	0	0	4	0	1017.2
A	66.3	51.5	58.9	85	1967	26	1972	188	12	3.07	7.10	1962	0.59	1976	5.60	1963	0.0		0.0		81	78	59	76	12.2	SW	35	S23	1982	65	5.5	10	9	11	8	0	3	1	0	0	*	0	1017.2
M	73.8	60.2	67.0	88	1962	39	1971	47	96	3.28	11.44	1972	0.61	1962	3.28	1958	0.0		0.0		84	82	64	80	11.2	SW	35	18	1972	61	6.1	8	10	13	10	0	6	1	0	0	0	0	1015.5
J	80.5	68.1	74.3	95	1978	44	1966	0	270	4.83	10.80	1962	0.38	1978	6.63	1962	0.0		0.0		88	83	69	80	10.8	SSW	37	N29	1972	61	6.3	7	10	13	9	0	5	*	1	0	0	0	1016.3
J	83.8	72.1	78.0	95	1969	54	1972	0	409	5.90	9.99	1965	0.45	1958	5.53	1967	0.0		0.0		89	85	70	82	10.3	SW	26	22	1982	61	6.5	6	10	15	12	0	9	*	1	0	0	0	1016.8
A	83.4	71.5	77.5	94	1968	56	1979	0	409	6.75	11.73	1976	1.04	1978	8.11	1962	0.0		0.0		89	86	69	83	9.7	SW	41	16	1971	61	6.2	8	10	13	10	0	8	*	2	0	0	0	1018.0
S	79.5	67.8	73.7	92	1978	45	1970	0	276	5.76	12.78	1979	0.73	1978	5.46	1979	0.0		0.0		85	84	67	80	10.6	NE	44	12	1971	60	5.7	9	10	11	9	0	4	*	*	0	0	0	1017.2
O	71.3	59.1	65.2	86	1959	32	1979	76	72	4.79	11.24	1971	1.34	1973	5.35	1974	0.0		0.0		82	82	65	79	11.3	NNE	44	N02	1982	59	5.4	11	7	13	9	0	2	1	0	0	*	0	1018.3
N	63.1	48.8	56.0	81	1971	22	1967	277	6	4.45	14.63	1962	1.23	1973	7.59	1977	T	1970	T	1970	80	82	64	78	11.2	NNE	35	18	1971	56	5.4	11	7	12	9	0	1	1	0	0	1	0	1019.4
D	54.8	40.5	47.7	77	1982	10	1981	536	0	4.54	8.63	1962	2.07	1971	3.59	1979	2.5	1970	2.5	1970	79	81	66	78	11.8	NNE	39	N22	1972	47	5.9	10	7	14	10	*	1	2	0	*	7	0	1019.3
YR	68.3	55.0	61.7	95	JUN 1978	11	JAN 1982	2731	1556	55.62	14.63	NOV 1962	0.38	JUN 1978	8.11	AUG 1962	8.5	MAR 1960	7.3	MAR 1980	83	82	66	79	11.4	SW	48	N02	MAR 1980	58	5.9	108	99	158	120	1	43	16	4	1	34	0	1017.7

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

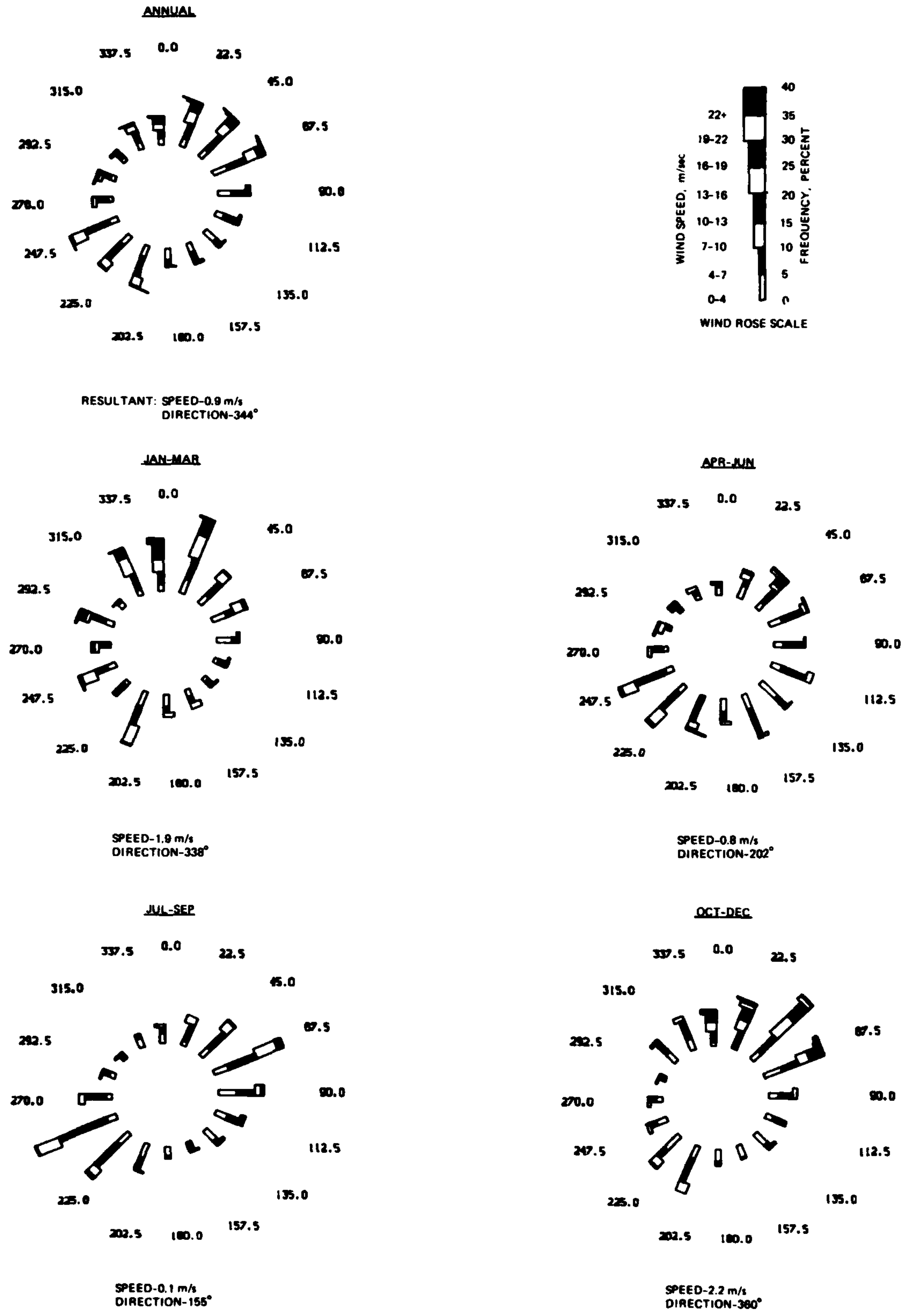

Figure 13. Annual and seasonal wind roses for the FRF, 1980 to 1982 (directions are given relative to true north)

Waves

Ocean

48. The wave heights at the FRF vary as a function of season. The annual average wave height (as measured by gage 625 at the seaward end of the pier) is 0.9 ± 0.6 m (3 ± 2 ft) with an average peak spectral period of 8.7 ± 2.8 sec. Wave heights tend to be lowest from April to September and highest from October to December. Table 7 gives the joint distributions of wave height and period for 1980-82 for both the offshore Waverider buoy and the pier end wave gage. Figure 14 shows the variation in mean and standard deviation of the monthly wave height and period values for the pier end gage. Table 8 shows the corresponding annual, seasonal, and monthly mean, standard deviation, and extreme wave statistics. Seasonal joint distributions for the pier end gage are given in Appendix D.

49. Wave direction information is obtained from daily (near 0700 EST) visual measurements of the angle of wave approach at the seaward end of the FRF pier near the location of the pier end wave gage. Figure 15 shows annual and seasonal wave roses for 1980-1982. Wave directions throughout the year are approximately equally divided between northerly and southerly directions relative to the pier. During spring and summer, waves tend to approach from the south. Extreme waves occur during October through March and are predominantly from the north. Figure 16 shows wave action during an October 1980 storm when the wave height reached 3.5 m (11.5 ft).

Sound

50. Because of the limited fetch across Currituck Sound, waves on the sound shore are usually an irregular chop of less than 15 cm (0.5 ft). The average fetch is 7.3 km (4.4 miles); the longest fetch is 8.9 km (5.3 miles). The sound is extremely shallow with a gently sloping nearshore shelf (less than 1 percent). The deepest areas, which average only 2.7 m (9 ft) in depth, are on the western shore. Wave heights and setup during extreme events have not been documented.

Currents

51. Visual measurements of surface currents have been made from the pier and in the surf zone by timing the movement of a dye patch. Mean monthly and

Table 7

Joint Wave Height-Period Distributions for 1980-1982 from Gage 620* and Gage 625**

Gage 620

ANNUAL

PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)													TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	
0.00 - .49	1	1	3	7	8	13	26	29	13	5	15	8	1	130
.50 - .99	2	12	29	49	56	48	63	64	58	39	25	20	2	467
1.00 - 1.49	.	1	11	34	57	31	20	17	25	18	20	6	1	241
1.50 - 1.99	.	.	1	9	28	12	8	5	10	6	8	6	.	93
2.00 - 2.49	.	.	.	2	8	7	4	4	3	4	7	5	1	45
2.50 - 2.99	.	.	.	.	1	3	1	1	1	2	3	1	.	13
3.00 - 3.49	.	.	.	.	.	.	2	1	.	1	1	.	.	5
3.50 - 3.99	.	.	.	.	.	.	.	1	1	1	1	1	.	5
4.00 - 4.49	.	.	.	.	.	.	.	.	.	1	.	.	.	1
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	3	14	44	101	158	114	124	122	111	77	80	47	5	

Gage 625

ANNUAL

PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)													TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	
0.00 - .49	.	2	2	3	11	20	28	33	25	10	18	17	1	170
.50 - .99	.	6	30	36	58	49	53	69	68	39	30	23	5	466
1.00 - 1.49	.	.	6	28	46	33	15	17	28	15	21	6	.	215
1.50 - 1.99	.	.	1	7	20	13	4	4	8	7	9	8	1	82
2.00 - 2.49	.	.	.	.	3	5	3	3	2	5	8	9	1	39
2.50 - 2.99	.	.	.	.	1	2	3	2	2	1	5	3	1	20
3.00 - 3.49	.	.	.	.	.	.	1	1	1	1	1	1	.	6
3.50 - 3.99	.	.	.	.	.	.	.	.	1	.	1	.	.	2
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	8	39	74	139	122	107	129	135	78	93	67	9	

* Waverider buoy 2.1 km east of the pier.

** Wave gage at seaward end of FRF pier.

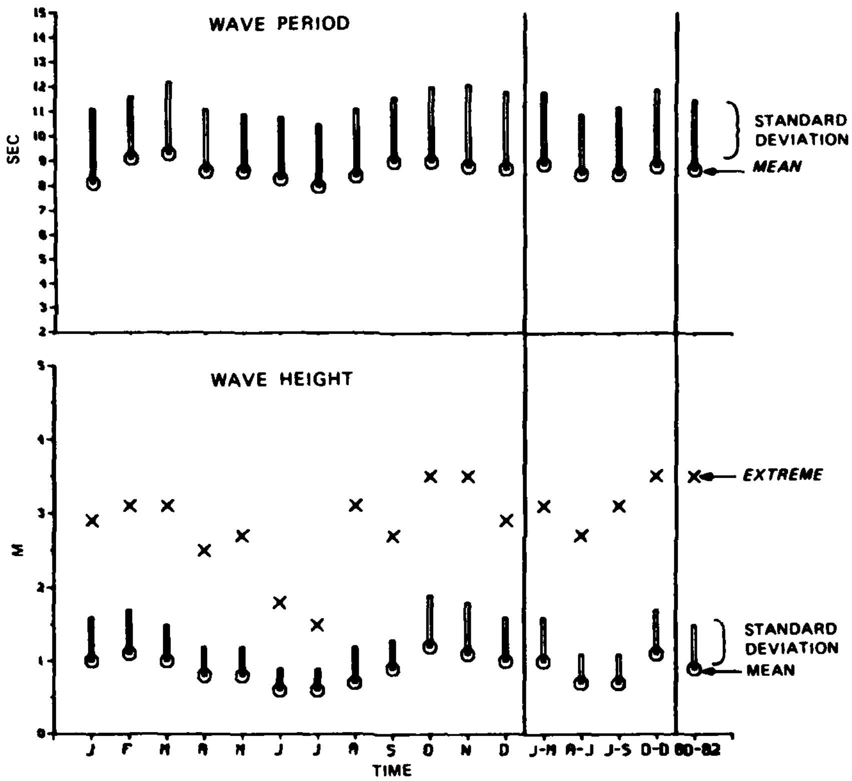

Figure 14. Monthly variation in mean significant wave height and mean peak spectral period (from gage 625 at seaward end of FRF pier, 1980-1982)

Table 8

Summary of Wave Statistics from Wave Gage 625 Located at Seaward End of FRF Pier, 1980-1982

Month	Mean Height, m	Standard Deviation Height, m	Mean Period, sec	Standard Deviation Period, sec	Extreme Height, m
Jan	1.0	0.6	8.1	3.0	2.9
Feb	1.1	0.6	9.1	2.5	3.1
Mar	1.0	0.5	9.3	2.9	3.1
Apr	0.8	0.4	8.6	2.5	2.5
May	0.8	0.4	8.6	2.3	2.7
Jun	0.6	0.3	8.3	2.5	1.8
Jul	0.6	0.3	8.0	2.5	1.5
Aug	0.7	0.5	8.4	2.7	3.1
Sep	0.9	0.4	9.0	2.6	2.7
Oct	1.2	0.7	9.0	3.0	3.5
Nov	1.1	0.7	8.8	3.3	3.5
Dec	1.0	0.6	8.7	3.1	2.9
Annual	0.9	0.6	8.7	2.8	3.5
Jan-Mar	1.0	0.6	8.9	2.9	3.1
Apr-Jun	0.7	0.4	8.5	2.4	2.7
Jul-Sep	0.7	0.4	8.5	2.7	3.1
Oct-Dec	1.1	0.6	8.8	3.1	3.5

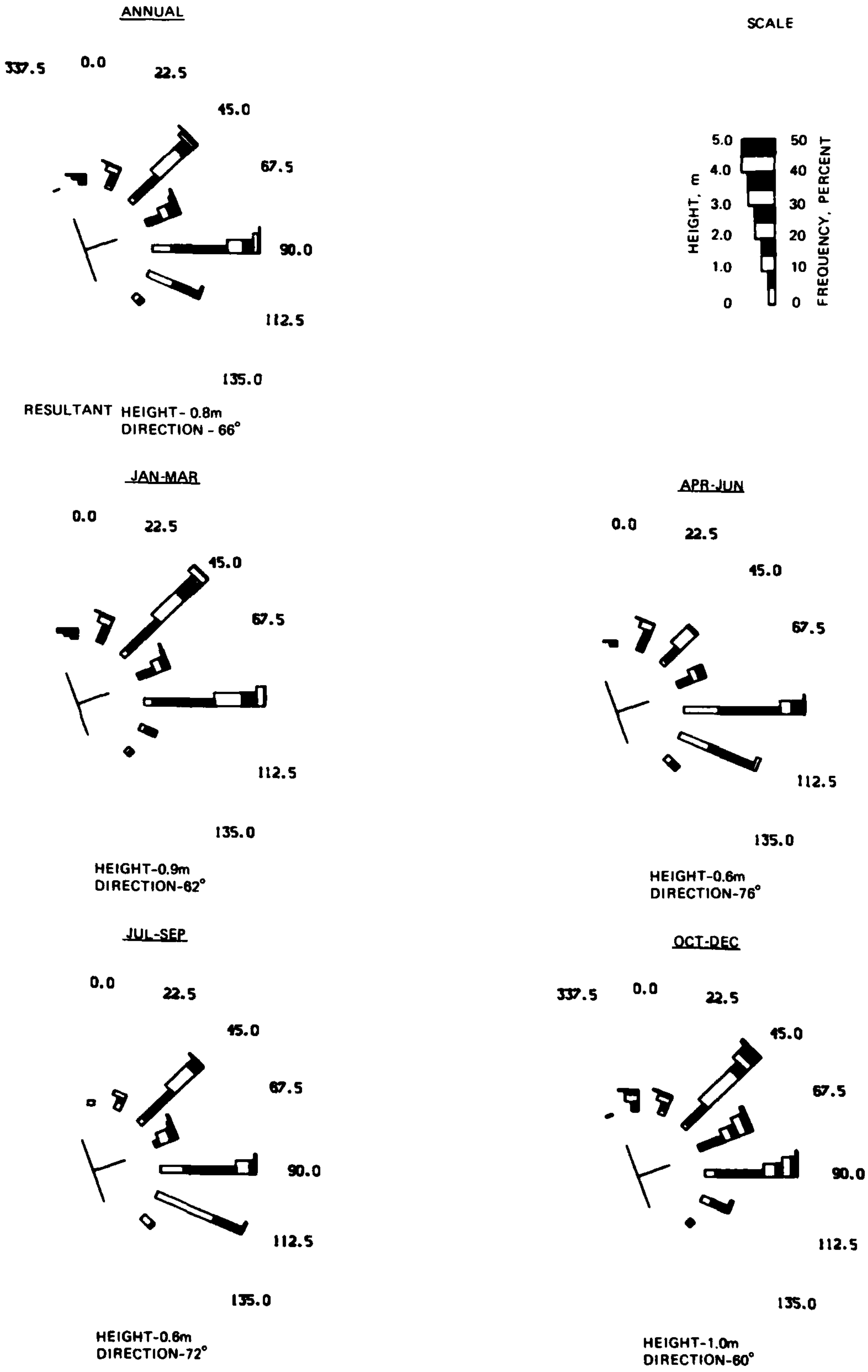

Figure 15. Annual and seasonal wave roses for 1980-1982 (Directions are relative to true north; pier orientation included for reference)

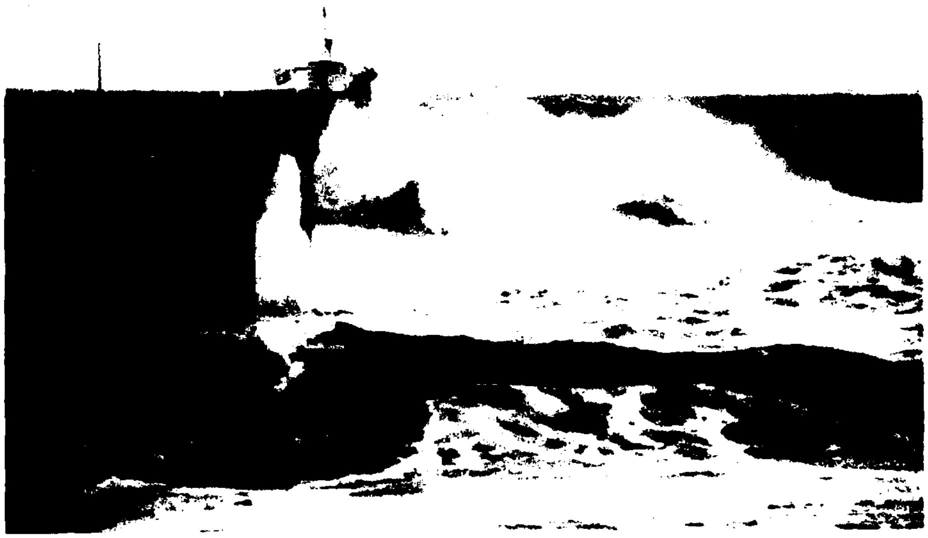

Figure 16. Storm waves breaking along the FRF, 25 October 1980

annual longshore current speeds are shown in Figure 17 for three different locations. Current speed and direction vary both with location and season. Daily current measurements for the mid-surf zone position under the pier for 1982 are shown in Figure 18. Frequent reversals in direction are common throughout the year though extended periods of constant direction do occur, particularly during the summer months. Extreme surface current speeds in excess of 2 m/sec (6.6 ft/sec) occur during periods of high waves and winds from both the north and south (see January and October in Figure 18). Other currents which affect the area are rip currents, low salinity water masses, and Gulf Stream eddies.

52. Rip currents are frequently found at varying locations along the beach including under the pier. The low-salinity water masses, believed to originate in the Chesapeake Bay, are huge slugs of lower salinity water which move southward along the shore. The edge is clearly discernible by both water color and turbulence. The phenomenon is shown in Figure 19. Warm, clear water masses, presumably resulting from Gulf Stream eddies, have also been observed. These masses sometimes have a foam-lined edge and often contain tropical fish.

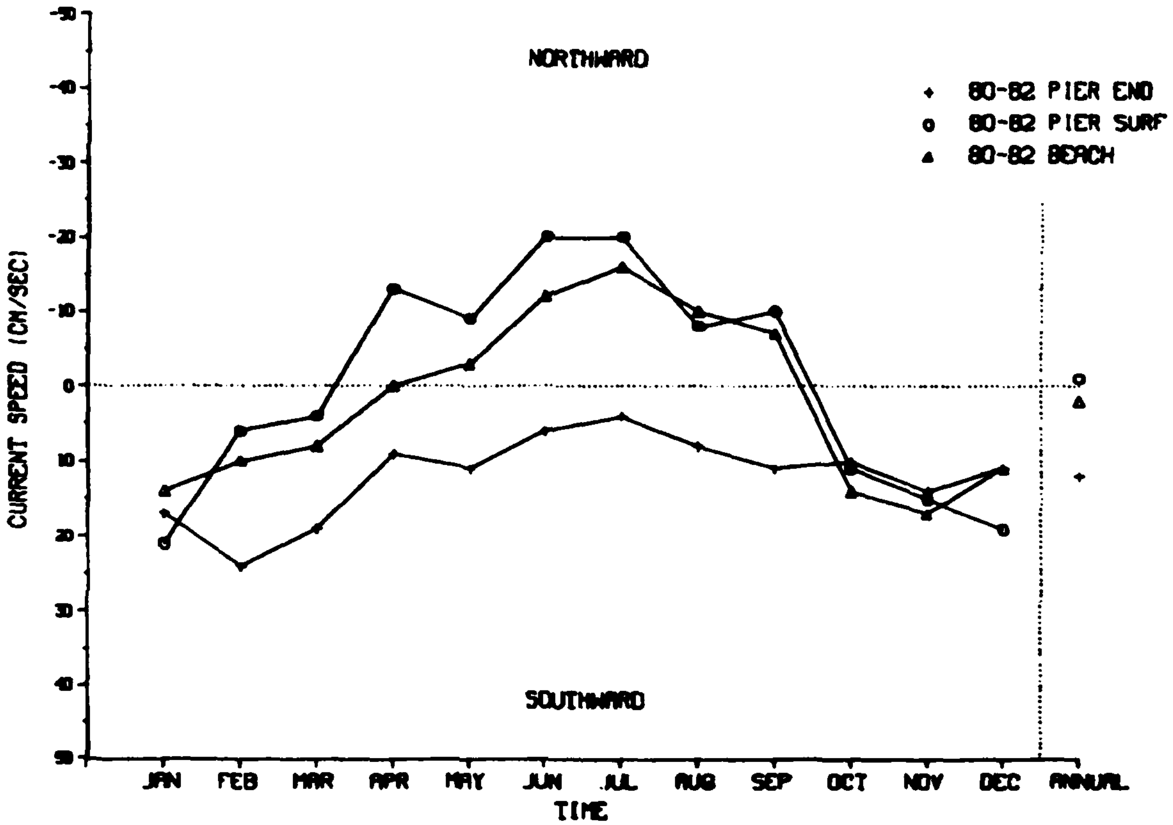

Figure 17. Monthly mean current measurements for three locations, 1980-1982

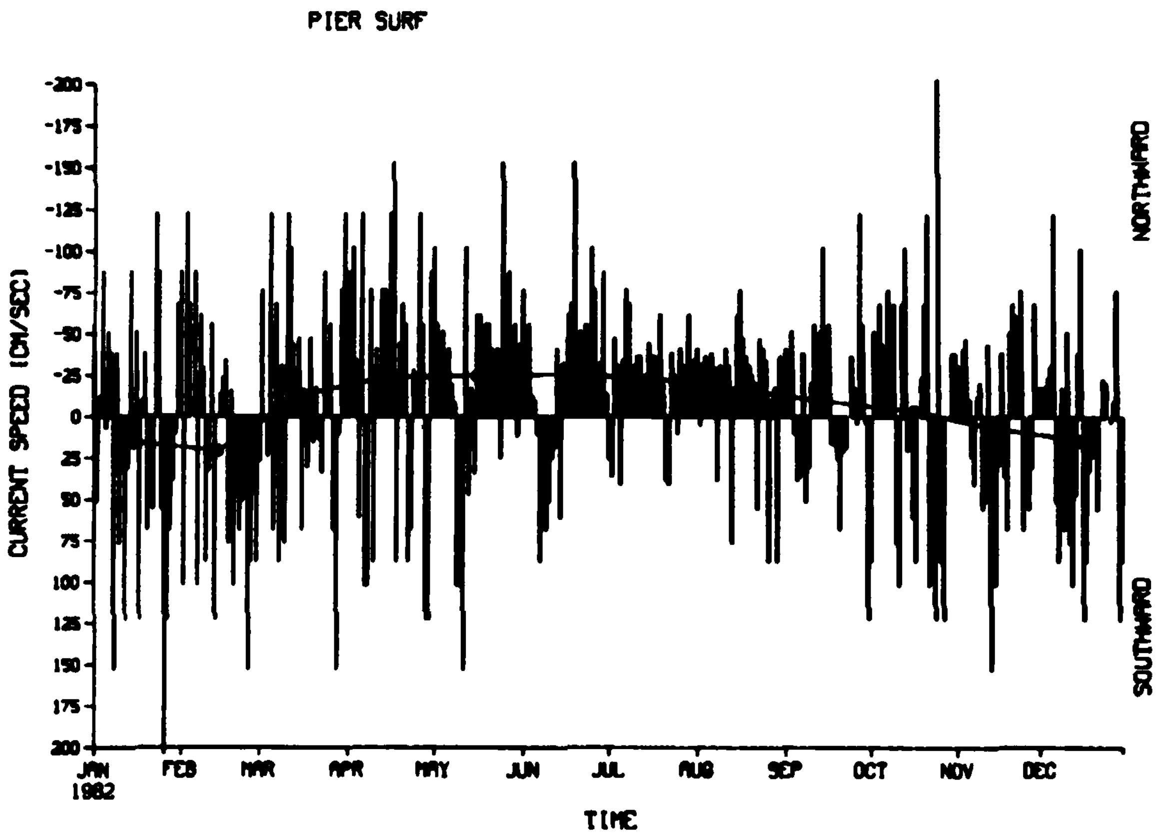

Figure 18. Daily measurements of longshore current taken from the mid-surf zone position under the FRF pier, 1982 (solid curved line connects monthly means)

Figure 19. Southward-moving edge of freshwater mass (photo taken from a point south of Corolla, N. C.)

Storms

53. The area is affected by both extratropical (northeasters) and tropical (hurricanes) cyclones. Bosserman and Dolan (1968), who examined the intensity and frequency of extraptropical storms affecting North Carolina, classified 857 storms according to the ten tracks shown in Figure 20 (note that seven of the tracks pass the FRF site). The most damaging storms follow the three widest arrows (2, 3, and 4). The severest situation occurs when the movement of a track 2 storm is slowed by a blocking high-pressure system to the north. This occurred during the Great East Coast Storm of March 1962 and resulted in strong northeasterly winds of long duration over a long fetch.

54. Storm occurrence prediction is somewhat difficult since cyclogenesis (storm formation) frequently occurs offshore of Cape Hatteras. Bosserman and Dolan (1968) found that about 19 percent of all storms affecting the Outer Banks develop in this manner. They also hindcasted wave heights for each storm studied. Storm frequencies (all tracks) by wave height and month are summarized in Table 9 and are shown in Figure 21.

55. Between 1886 and 1970, 31 hurricanes at full strength either made

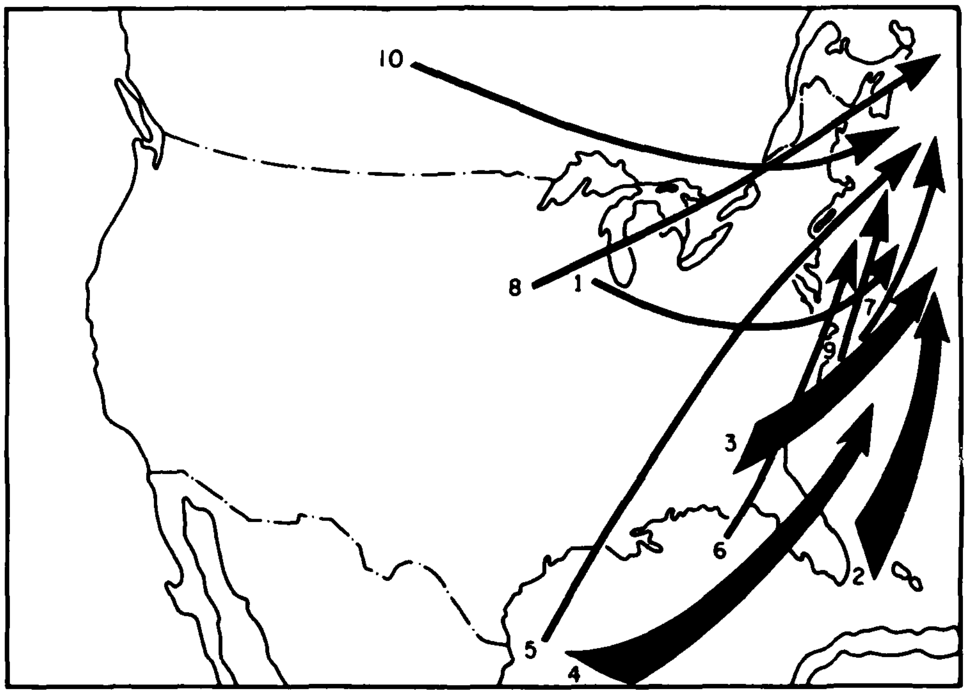

Figure 20. Storm tracks affecting the east coast
(from Bosserman and Dolan 1968)

Table 9

Summary of Storms of All Classes, 1942-1967*

	Month												Wave Height, m						
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	1.6-2.4	2.4-3.4	3.4-4.3	4.3-5.2	5.2-6.1	6.1-7.0	7 > 7.0
1966-1967	1	--	4	4	2	4	4	3	2	3	1	3	31	10	5	--	--	--	--
1965-1966	1	1	2	5	1	3	6	6	3	1	3	2	34	7	3	1	--	--	--
1964-1965	1	1	--	4	5	3	4	5	6	4	1	1	35	14	4	2	--	--	--
1963-1964	2	2	3	1	3	4	6	8	4	2	3	2	40	18	5	--	--	--	--
1962-1963	--	1	3	--	3	2	6	7	1	4	2	--	29	20	5	2	--	--	--
1961-1962	--	--	1	3	1	2	6	3	4	2	--	2	24	9	3	1	1	1	1
1960-1961	--	2	1	1	2	5	5	9	5	5	2	1	38	16	3	--	--	--	--
1959-1960	--	1	2	4	5	4	4	6	9	4	2	1	42	13	4	1	1	1	--
1958-1959	--	--	2	2	5	5	3	4	7	2	1	--	31	12	6	1	--	--	--
1957-1958	1	3	3	3	6	2	5	2	6	5	1	2	39	9	2	--	--	--	--
1956-1957	1	2	2	4	--	2	6	5	4	4	1	1	32	11	4	--	--	--	--
1955-1956	1	--	4	4	2	2	2	9	7	6	8	3	48	12	3	1	--	--	--
1954-1955	1	1	--	3	2	4	2	5	3	2	4	1	28	8	3	1	--	--	--
1953-1954	2	1	3	1	3	4	2	1	3	3	2	1	26	11	3	2	1	1	--
1952-1953	1	2	5	3	3	5	3	4	4	5	2	2	39	18	2	1	--	--	--
1951-1952	--	3	3	3	4	5	3	4	5	4	--	1	35	14	6	3	2	--	--
1950-1951	1	--	2	2	3	4	3	7	7	5	1	2	37	11	2	--	--	--	--
1949-1950	2	2	2	3	1	3	2	4	8	3	2	2	34	14	2	1	--	--	--
1948-1949	1	--	2	4	3	4	3	3	5	4	3	2	34	15	3	1	1	--	--
1947-1948	1	1	1	2	5	5	10	4	7	6	--	3	45	23	9	3	1	--	--
1946-1947	3	1	1	3	4	3	3	1	5	5	3	2	34	8	2	2	1	--	--
1945-1946	--	--	1	1	3	6	4	3	2	5	4	1	30	14	5	3	1	1	--
1944-1945	--	1	2	3	1	4	7	2	2	3	2	1	28	9	2	--	--	--	--
1943-1944	--	1	3	2	4	3	5	4	8	5	--	1	36	9	3	1	--	--	--
1942-1943	--	3	2	--	4	3	3	1	5	4	3	--	28	12	5	--	--	--	--
Totals	20	29	54	65	75	91	107	110	122	96	51	37	857	317	94	27	9	4	1
Averages	0.8	1.2	2.2	2.6	3.0	3.6	4.3	4.4	4.9	3.8	2.0	1.5	34.3	12.7	3.8	1.1	0.4	0.1	--

* From Bosserman and Dolan 1968.

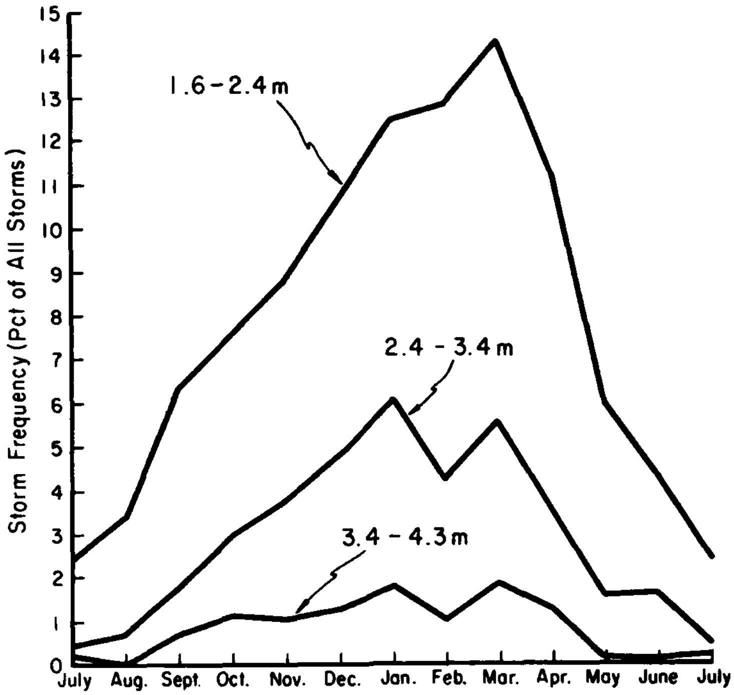

Figure 21. Monthly storm frequency and hindcasted wave height, based on a total of 857 storms (adapted from Bosserman and Dolan 1968)

landfall along coastal North Carolina or passed closely enough to affect the area (Baker 1978). The frequency of occurrence of these hurricanes varies considerably (Figure 22). The area between Cape Hatteras and Cape Lookout has the highest hurricane occurrence, while the area around the FRF has the lowest with a hurricane reaching the area once every 42 years. Tracks of historic hurricanes passing within 90 km (50 nautical miles) of the FRF are shown in Figure 23 (Ho and Tracey 1975).

56. The persistence of wave heights is shown in Table 10. This table shows the frequency of wave conditions averaged over the years 1980 through 1982. The data reveal that on 16 occasions the wave heights can be expected to exceed 2 m (6 ft) for at least 1 day or longer, and on 3 occasions, the wave heights can be expected to exceed 2 m (6 ft) for periods of 4 days.

Sediment Transport

57. The net longshore transport direction along the northern Outer Banks

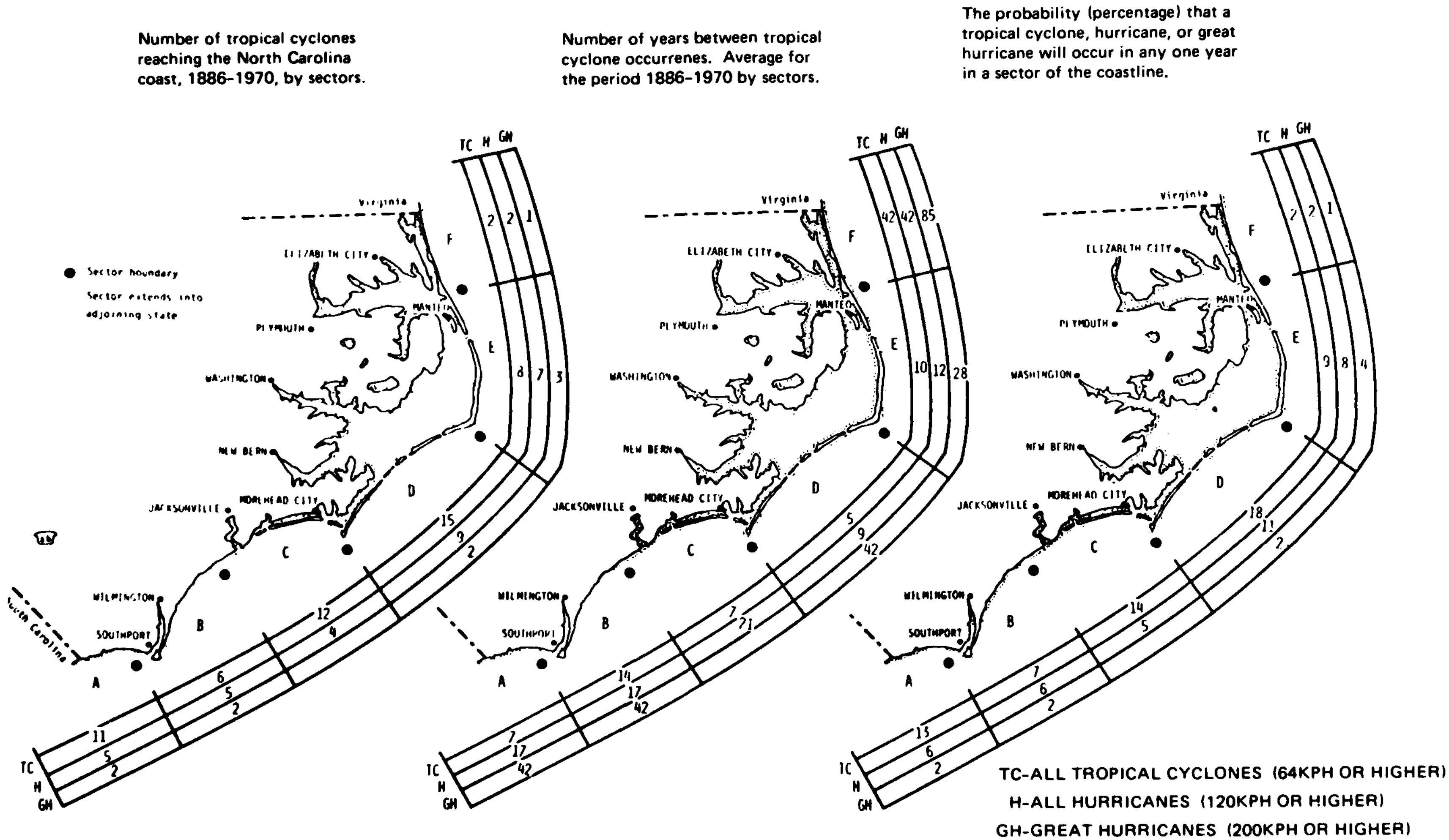

Figure 22. Hurricane statistics for North Carolina (adapted from Baker 1978)

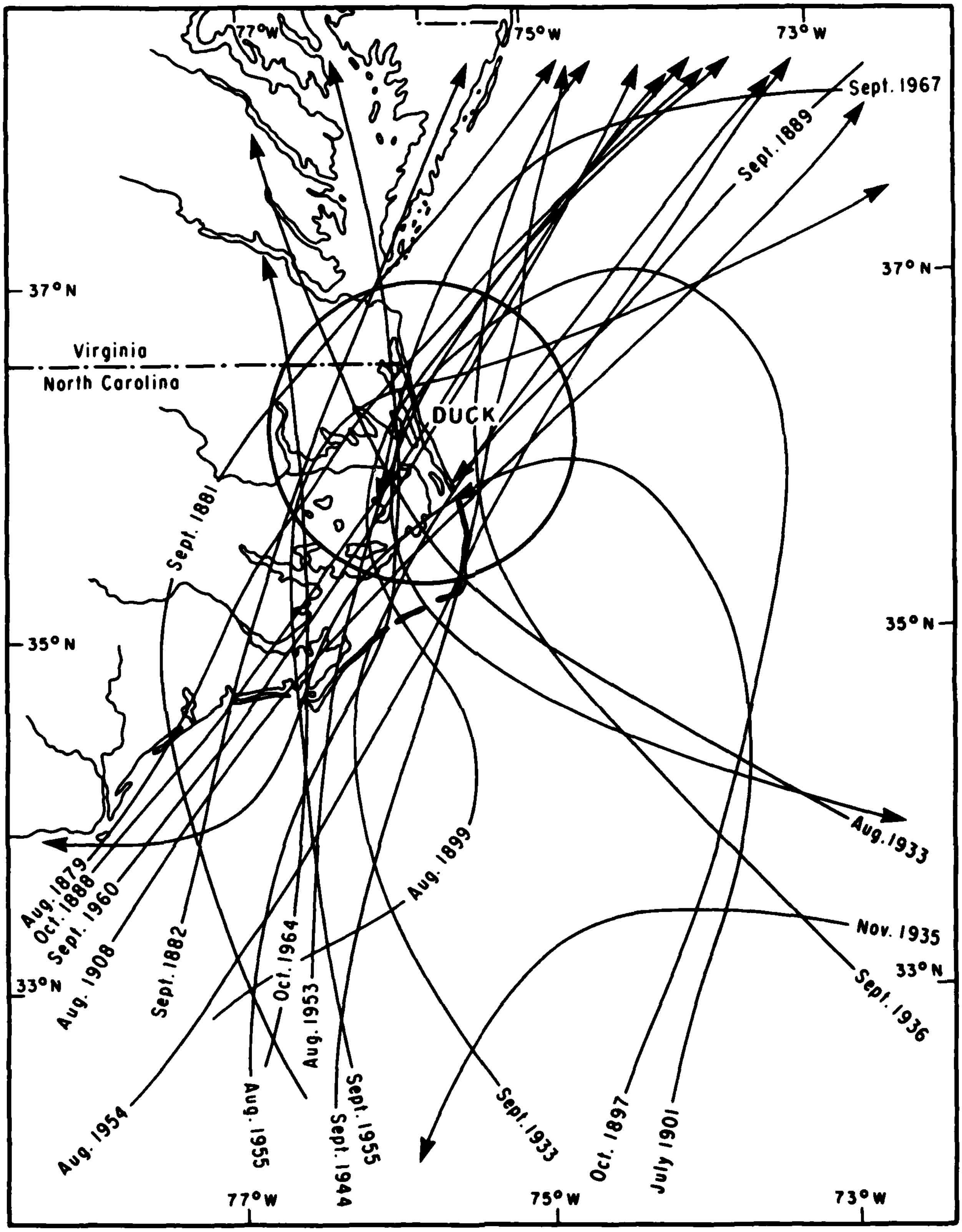

Figure 23. Major hurricanes passing within 90 km (50 nautical miles) of FRF (adapted from Ho and Tracey 1975)

Table 10

Persistence of Wave Heights at Seaward End of FRF Pier*

Height	Consecutive Day(s) or Longer											
m	1	2	3	4	5	6	7	8	9	10	11	12
1.0	46	32	23	15	10		8	6	5	3	2	1
1.5	32	17	9	6	5	3	1					
2.0	16	8	5	3	2		1					
2.5	9	4		1								
3.0	2			1								
3.5		1										

* Average annual frequency of occurrence for 1980-1982, gage 625.

has been reported as toward both the north (Langfelder, Stafford, and Amein 1968) and the south (Goldsmith, Sturm, and Thomas 1977). Jarrett (1978) determined a net southerly transport along the beaches north of Oregon Inlet.

58. Although a detailed sediment budget has not been prepared for the FRF area, the longshore sediment transport rates can be estimated using visual observations of wave height and direction collected between 1972 and 1978, at Sea Crest, N. C. (Figure 1).

59. Average monthly and annual predicted transport rates based on the method recommended in the Shore Protection Manual (SPM 1984) are given in Table 11. Note that the values use a dimensionless proportionality constant k equal to one. Generally accepted values of this constant are given at the end of the table. Annual and seasonal variations in net transport are shown in Figure 24.

60. If a proportionality value of 0.77 (Komar and Inman 1970) is used, the estimated gross transport at Sea Crest is 1,583,400 m^3 (2,071,000 yd^3) per year. The predicted net transport is to the south with a north-to-south transport ratio of 0.43. The annual net transport to the south at Sea Crest is estimated at 625,000 m^3 (822,000 yd^3) per year.

Tides and Sea Level Rise

Ocean

61. Tides at the FRF are semidiurnal with a mean range of 1 m (3 ft).

Table 11

Summary of Estimated Longshore Transport at Sea Crest, N. C.,

Based on LEO Observations

DATA FROM 39010 SEA CREST
OBSERVATION PERIOD 7/ 1/72 TO 12/28/78

MONTHS	1	2	3	4	5	6	7	8	9	10	11	12
MEAN NET ENERGY (FT-LBS/FT)	46.	71.	4.	41.	20.	21.	19.	59.	122.	147.	98.	15.
MEAN GROSS ENERGY (FT-LBS/FT)	90.	151.	145.	106.	89.	125.	69.	144.	197.	253.	164.	136.
IMMERSED WEIGHT NET(LBS)X10000	11995.	18606.	1140.	10658.	5172.	5412.	4930.	15635.	32108.	38739.	25835.	3984.
IMMERSED WEIGHT GROSS X10000	23668.	39609.	38075.	27886.	23458.	32829.	18063.	37804.	51901.	66525.	43052.	35833.
BULK VOLUME TO LEFT (CU YDS)	35777.	64379.	113214.	52809.	56050.	84039.	40256.	67952.	60671.	85168.	52775.	97625.
BULK VOLUME TO RIGHT (CU YDS)	109314.	178442.	120203.	118145.	87760.	117216.	70479.	163802.	257504.	322655.	211152.	122046.
BULK VOLUME NET (CU YDS)	73537.	114063.	6989.	65337.	31709.	33177.	30223.	95849.	196834.	237487.	158378.	24421.
BULK VOLUME GROSS (CU YDS)	145092.	242820.	233417.	170954.	143810.	201254.	110735.	231754.	318175.	407823.	263927.	219672.
NUMBER OF OBSERVATIONS	163.	121.	169.	111.	168.	152.	191.	138.	156.	202.	158.	124.

TOTAL TRANSPORT (SUM OF MONTHLY)

IMMERSED WEIGHT NET(LBS)X10000	174214.
IMMERSED WEIGHT GROSS X10000	438704.
BULK VOLUME TO LEFT (CU YDS)	810715.
BULK VOLUME TO RIGHT (CU YDS)	1878718.
BULK VOLUME NET (CU YDS)	1068004.
BULK VOLUME GROSS (CU YDS)	2689433.

NB-PROPORTIONALITY CONSTANT OF 1.00 USED IN COMPUTATIONS.
ACCEPTED VALUES ARE 0.25(INMAN AND FRAUTSCHY), 0.35(DAS), 0.77(KOMAR)

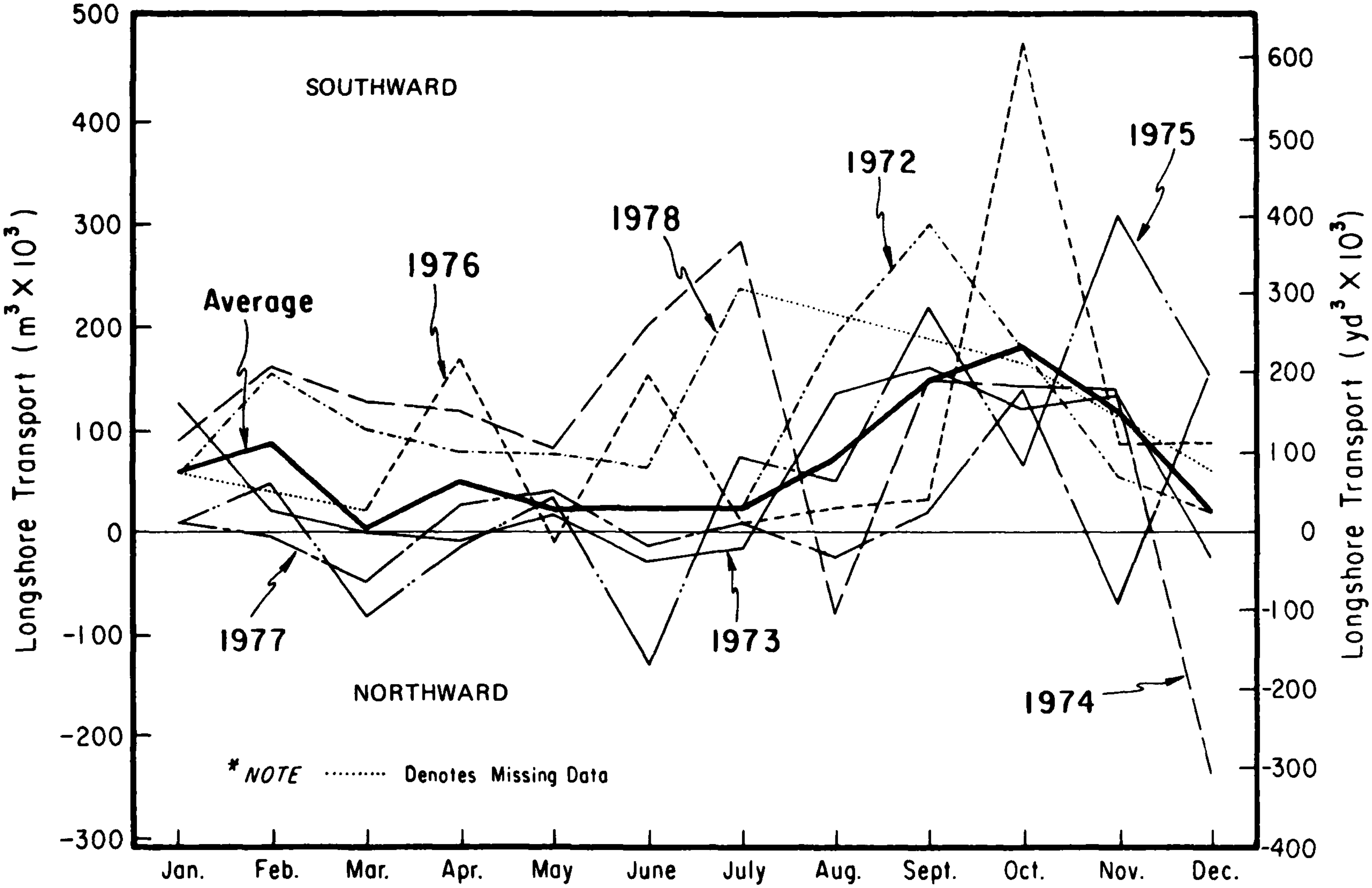

Figure 24. Monthly means of potential net transport versus time, based on visual wave observations at Sea Crest, N. C. (k = 1.0)

The local mean sea level, computed using data from 1978 to 1982, is 8 cm above the local 1929 NGVD. The variation in monthly mean sea level, along with the variation in the mean and extreme high and low water levels, is shown in Figure 25. Since 1978, the highest measured tide height, 1.49 m (4.9 ft) above NGVD, occurred during a storm on 13 November 1981. The lowest tide, -1.19 m (-3.9 ft) NGVD, was measured on 13 March 1980. The distribution of hourly tides and daily high and low tide heights for 1980 to 1982 is shown in Figure 26.

62. Ho and Tracey (1975) investigated the frequency and magnitude of storm tides for the northern North Carolina coast. Their results for 10-, 50-, 100-, and 500-year return period storms are shown in Figure 27. Note that at the Wright Monument, 23 km (14.3 miles) south of the FRF, the expected 100-year surge height is 2.77 m (9.1 ft). Tide frequencies for several classes of storm are shown in Figure 28.

63. Hicks (1981) examined the recent rate of sea level rise for a number of east, gulf, and west coast beaches. For the closest station to the FRF, Hampton Roads, Virginia (near the mouth of the Chesapeake Bay), Hicks calculated a rate of sea level rise equal to 0.4411 cm/yr (0.0144 ft/yr) based on the period 1928-1978.

Sound

64. Water levels in Currituck Sound are wind dominated: high during periods of west and southwest winds, low during northeast winds. Mean water level in the sound is about 0.27 m (0.9 ft) above NGVD (based on 1 year of data). Normal wind-induced setup is about 0.6 m (2 ft), and setdown is -0.2 m (-0.7 ft).

Water Temperature, Visibility, and Density

65. Monthly mean water characteristics for 1980 to 1982 are shown in Figure 29. There is a clear seasonal trend in both surface temperature and visibility with higher temperatures and greater visibility during the warmer summer months. Surface water density varies inversely, being greatest during the colder months. The annual average surface water temperature is 14° ± 2.2° C (57° ± 7.9° F). Water visibility averages 2 ± 1.1 m (6.6 ± 3.6 ft), and the average density is 1.0233 ± 0.0015 g/cm^3 (63.9 ± 0.094 lb/ft^3).

66. Shifting wind conditions may cause daily water characteristics to

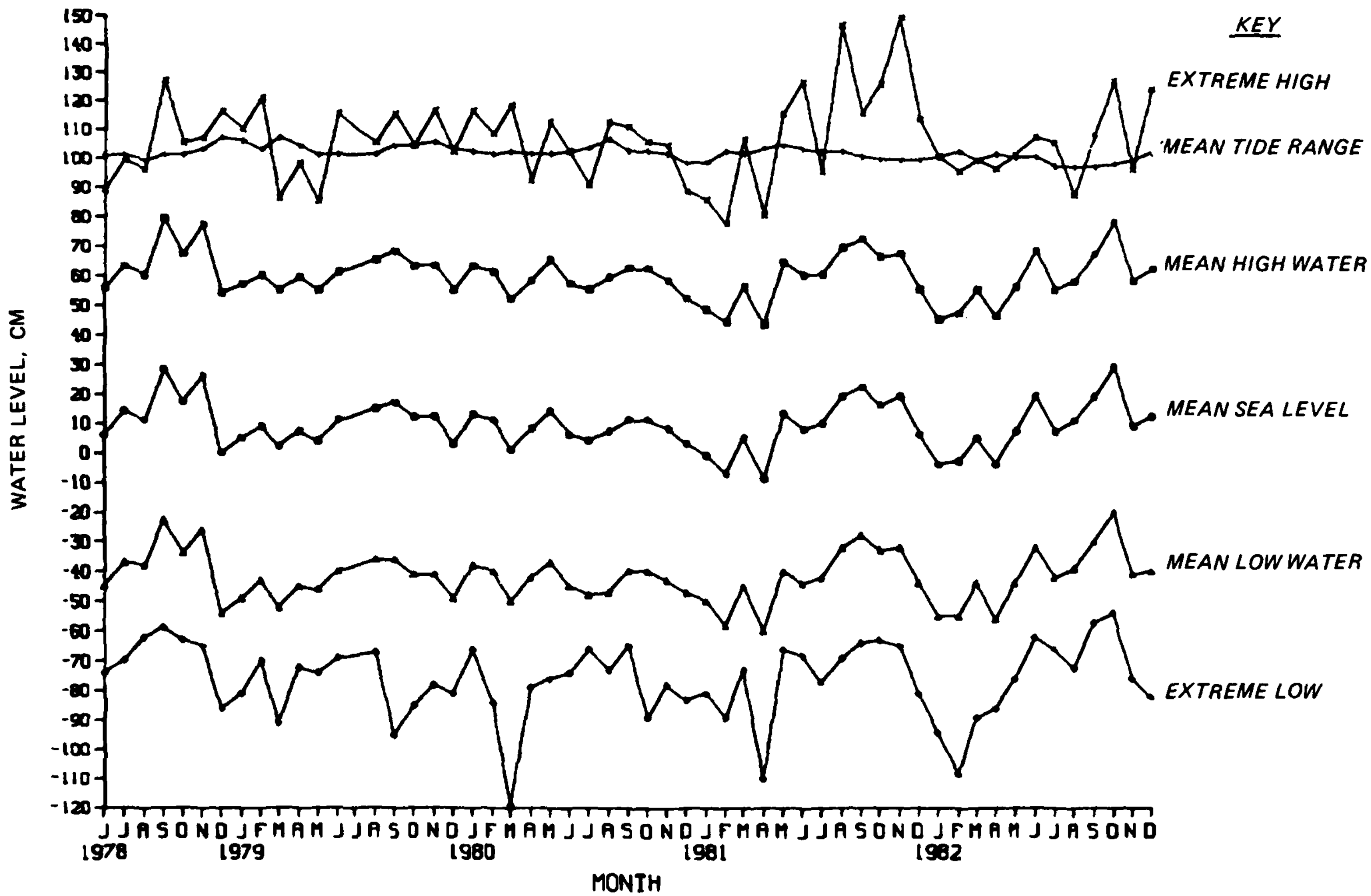

Figure 25. Monthly variation in water levels between 1978 and 1982

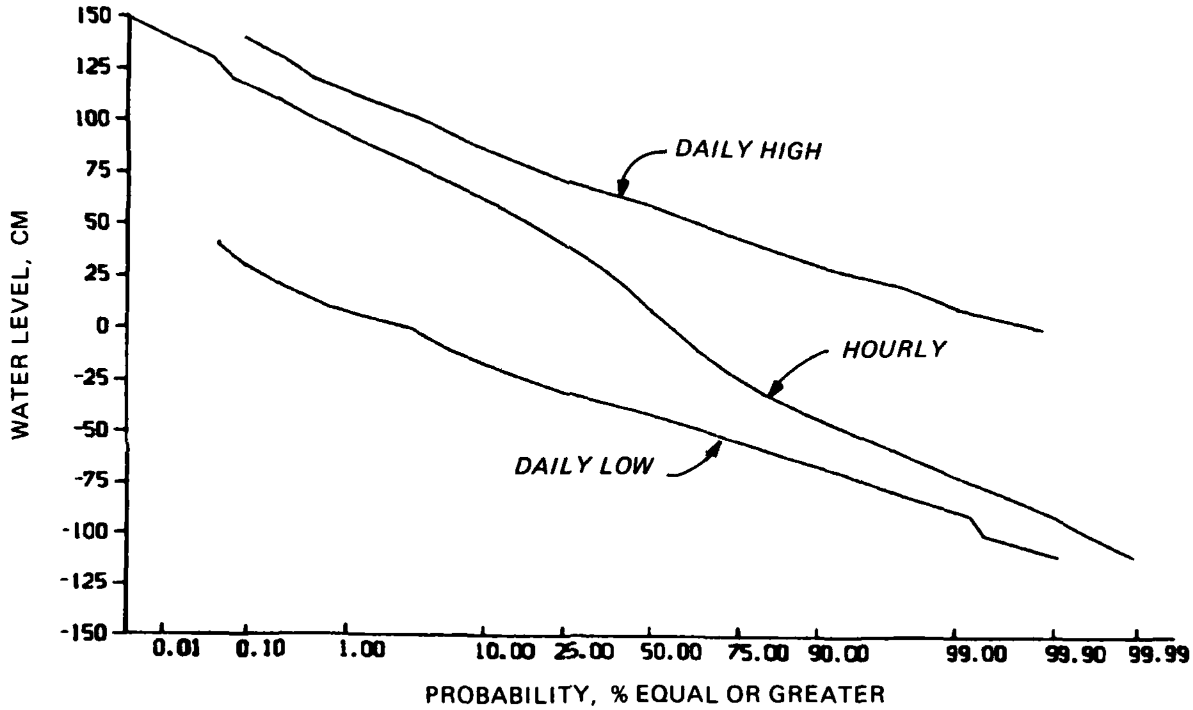

Figure 26. Cumulative distribution of water levels, 1980-1982

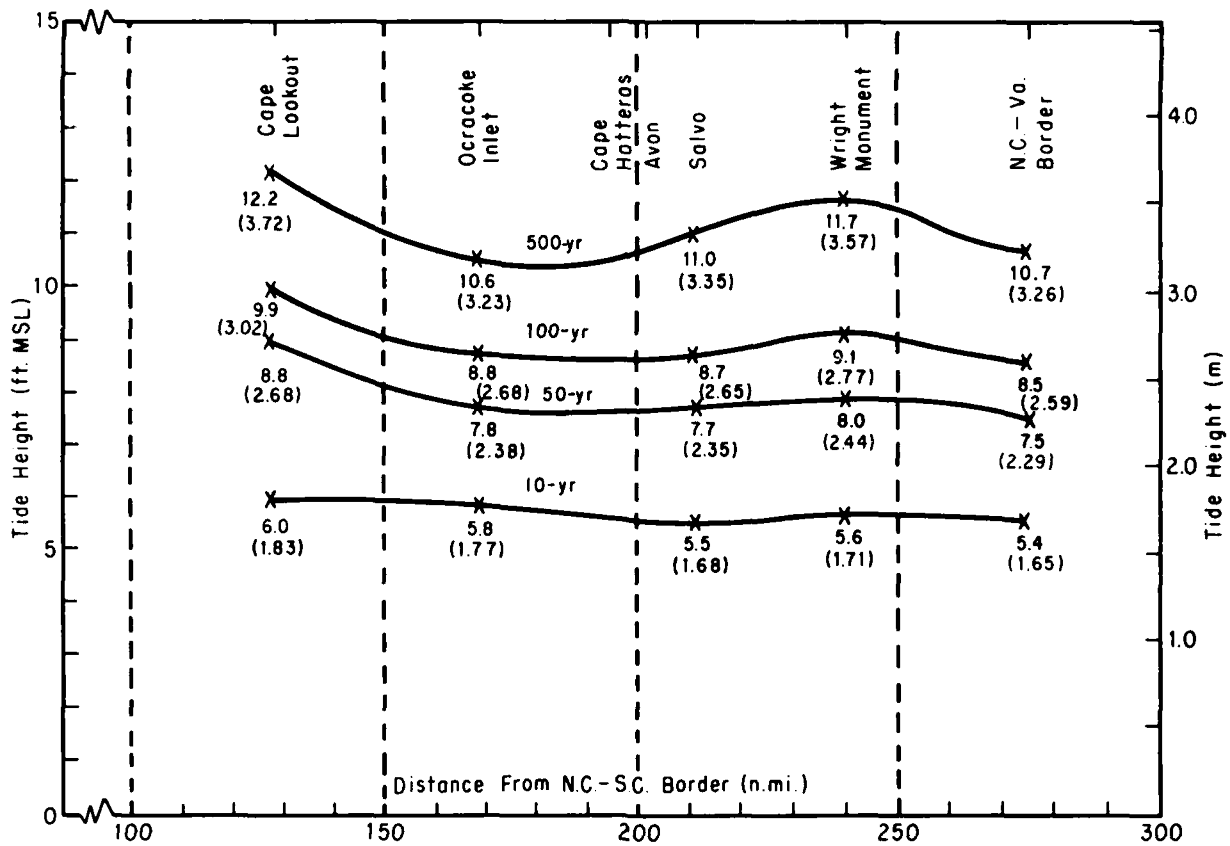

Figure 27. Coastal storm surge frequencies north of Cape Lookout, N. C. (Numbers in parentheses are values in m (*from Ho and Tracey* 1975))

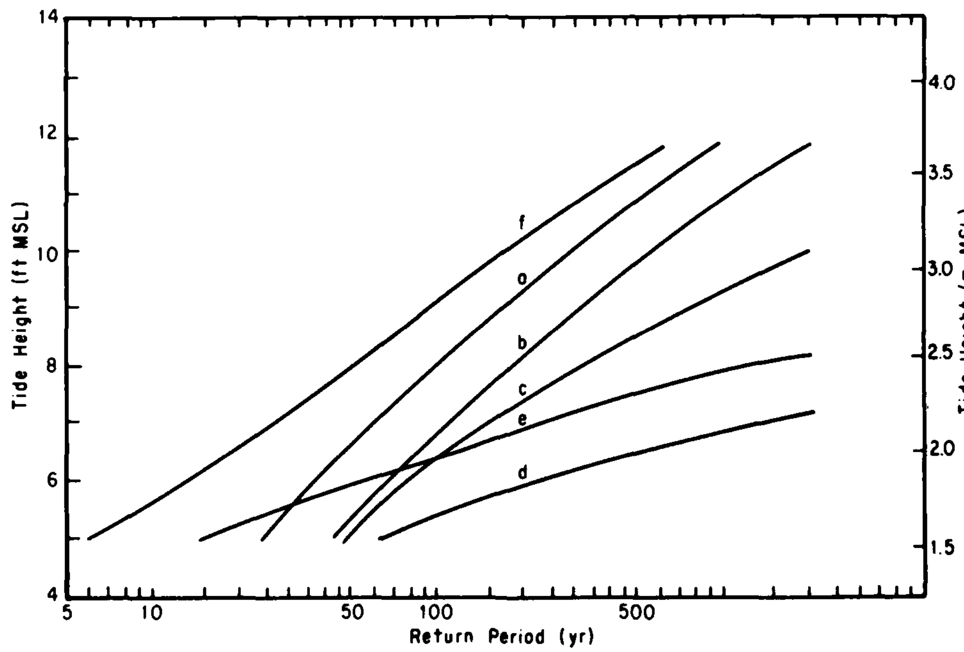

Figure 28. Tide frequencies at Wright Monument, N. C., for the following classes of storms: (a) landfalling, (b) alongshore, (c) inland, (d) exiting hurricanes and tropical storms, (e) winter storms, (f) all storms (from Ho and Tracey 1975)

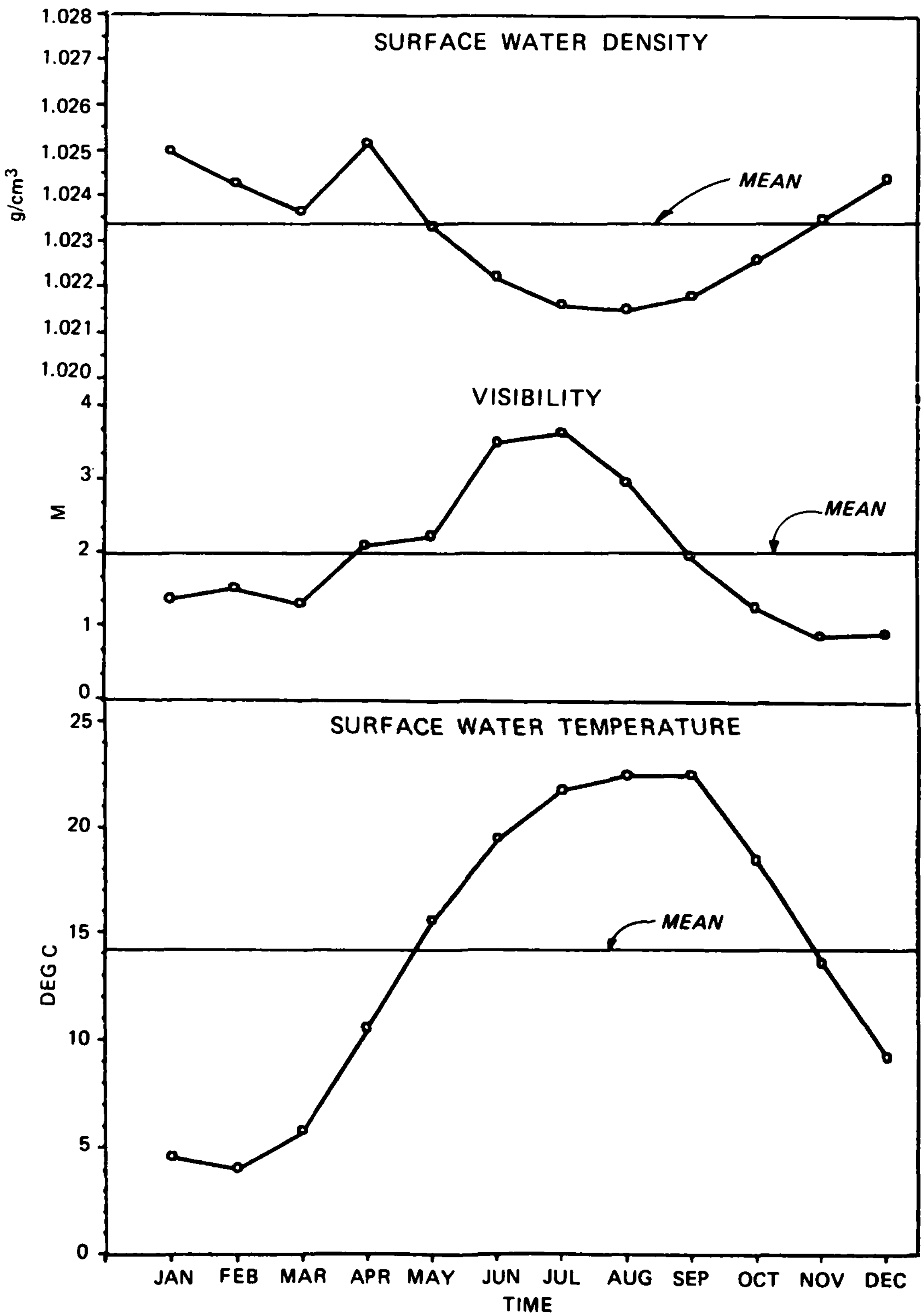

Figure 29. Variation in monthly mean water density, visibility, and temperature, 1980-1982

vary considerably, particularly during the summer. Offshore winds force warm surface water out to sea, producing upwelling of colder, and more turbid, bottom water. Onshore winds reverse the pattern, piling up warm, clear surface water near the shoreline and creating a seaward flow along the bottom.

PART V: PIER EFFECTS

67. Miller, Birkemeier, and DeWall (1983) have shown that the research pier does affect the processes controlling erosion and deposition on the adjacent bottom and shoreline. Although structural characteristics such as pile diameter, spacing, and pier length are important, waves and current conditions also contribute to the magnitude and shape of the effects.

68. Effects were identified in both the shore normal and alongshore directions. The most obvious effect is the trough which exists under much of the pier, with a scour hole near the seaward end. As shown in Figure 30,

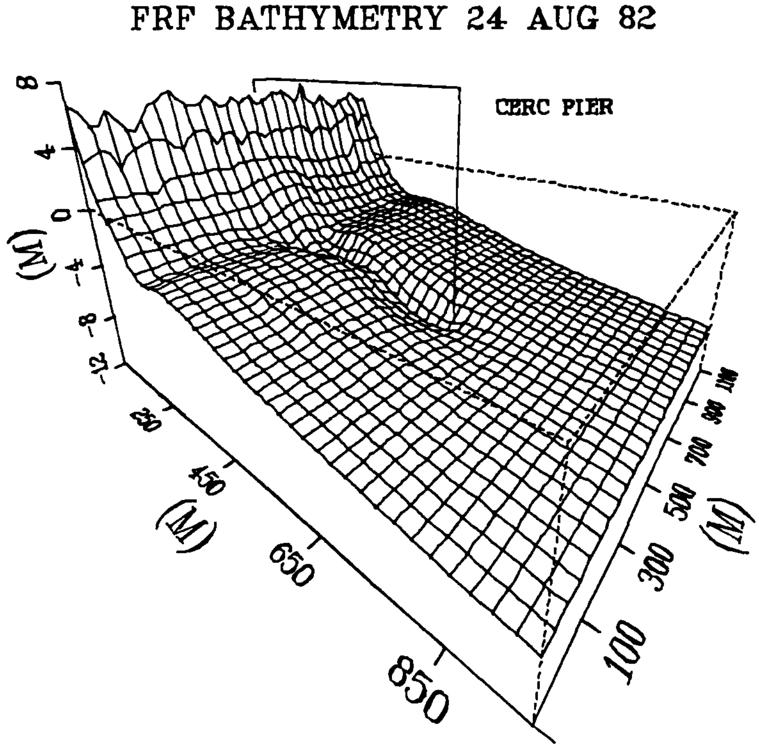

Figure 30. FRF bathymetry, 24 August 1982

the depth in this scour hole averages more than 2 m (6.6 ft) deeper than the natural nearshore contours. This trough results from the interaction of waves and currents with the piles and is a common feature under other pile structures. The depth and shape of the trough change readily under changing wave conditions. The pier also affects the normally shore parallel contours out to a distance of 300 m (1,000 ft) and to depths of -7 m (-23 ft), as shown in Figure 31.

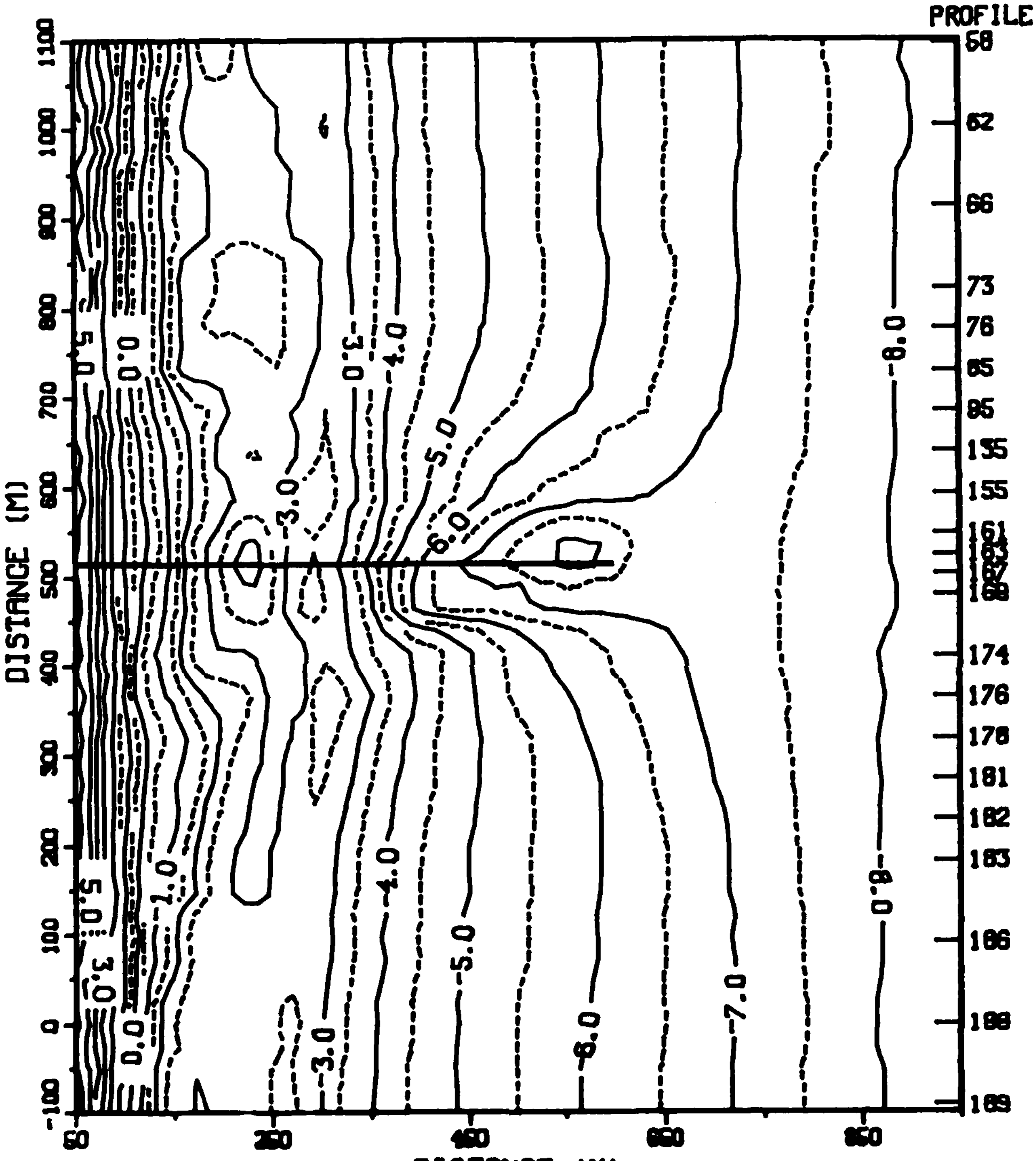

Figure 31. FRF bathymetry, 3 November 1981

69. A comparison between profile measurements along the pier to natural nearshore profiles measured at profile line 62 (see Table 4) located 489 m (1,600 ft) north of the pier showed the greater depth, steeper slope, and greater vertical variation in depth of the bottom under the pier (Figure 32).

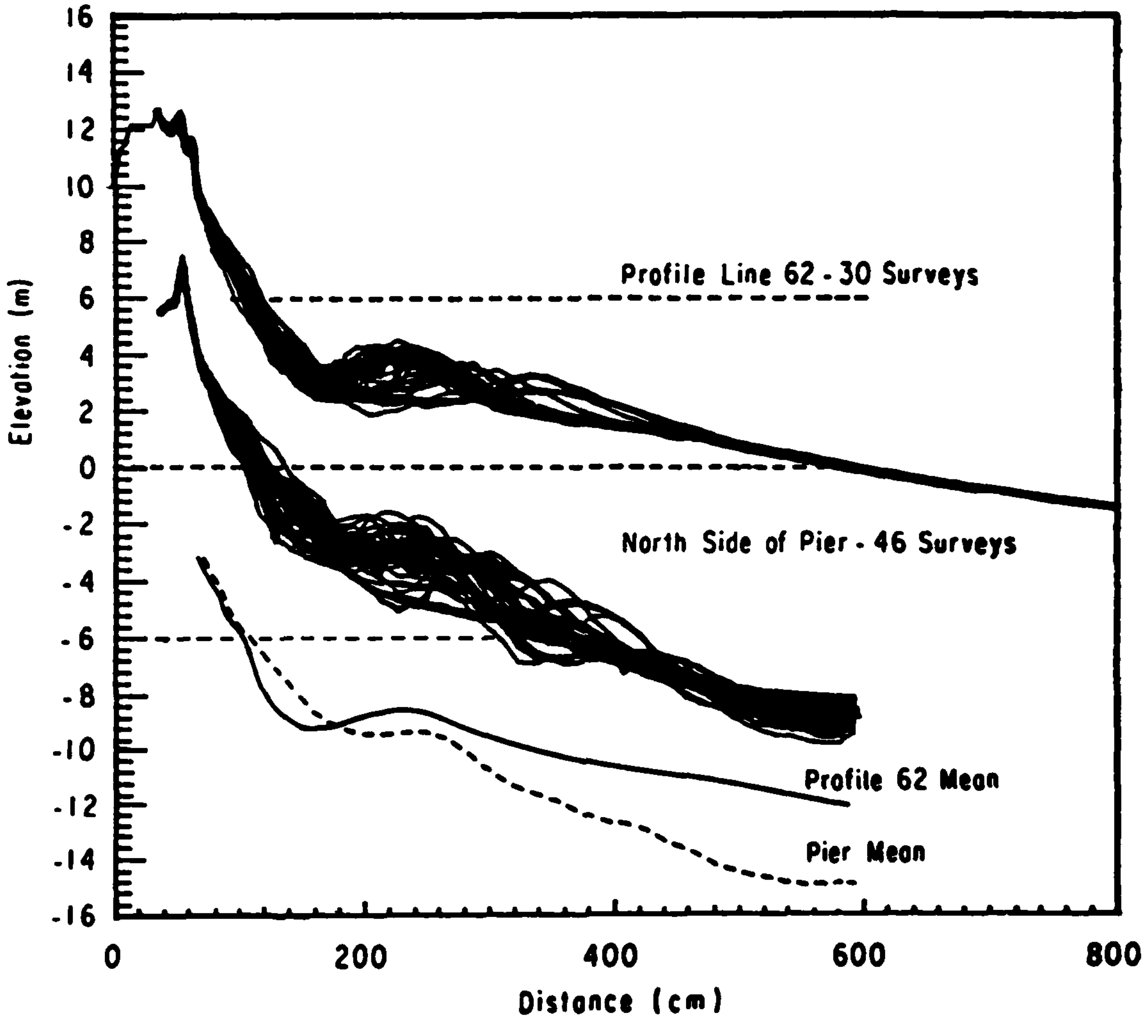

Figure 32. 1981 profile comparisons

70. During periods of unidirectional sand transport caused by low waves consistently from the southeast, the pier has had an effect similar to that of a permeable groin (Figure 33). The beach near the pier accretes to the south and erodes to the north. The effect occurred during the summers of 1978, 1979, and 1980 when waves from the southeast persisted for many days. It does not develop, or is less obvious, during summers with frequent reversals in wave direction, and it disappears completely during the winter.

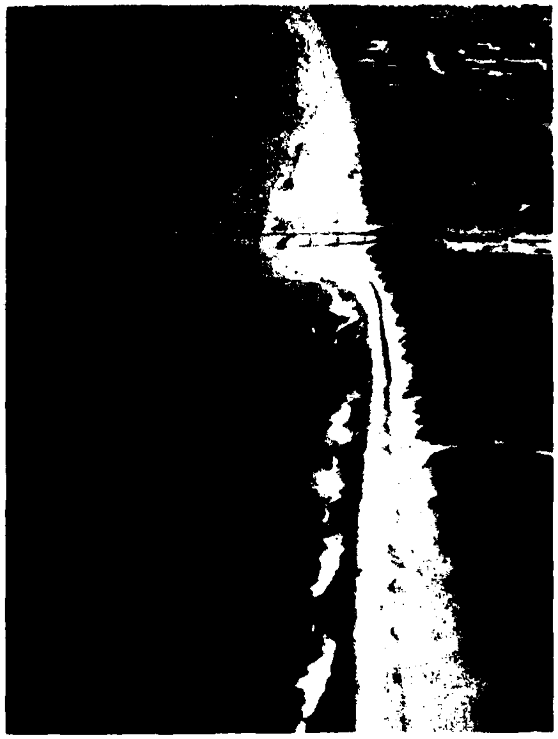

Figure 33. Aerial view of FRF shoreline, 11 June 1979, showing erosion zone north of pier

71. Figure 34 illustrates the extent of the pier's alongshore influence by plotting the net volume change along each of the surveyed profile lines for the period from July 1981 to June 1982. Net volume change is defined as the sum of all positive and negative changes along each profile line from the dune to the depth of no vertical change. A low net change indicates predominantly cross-shore movement, while a high value indicates an alongshore gain or loss of material. Areas unaffected by the pier had smaller and more consistent net changes than those of affected areas. In almost every time period, the pier and nearby areas clearly stood out as having net changes greater than the general trend. The zone influenced by the pier varied from the immediately adjacent area during calm periods to up to 350 m (1,148 ft) away during a period of storm activity (13-15 November 1981).

72. Comparison of spectral wave data and summary wave statistics between gages located under and away from the pier indicated that the scour under the pier did not seriously affect the wave data, although high waves ($H \geq 2.0$ m (6.6 ft)) were about 10 to 15 percent lower at the pier end. As waves move

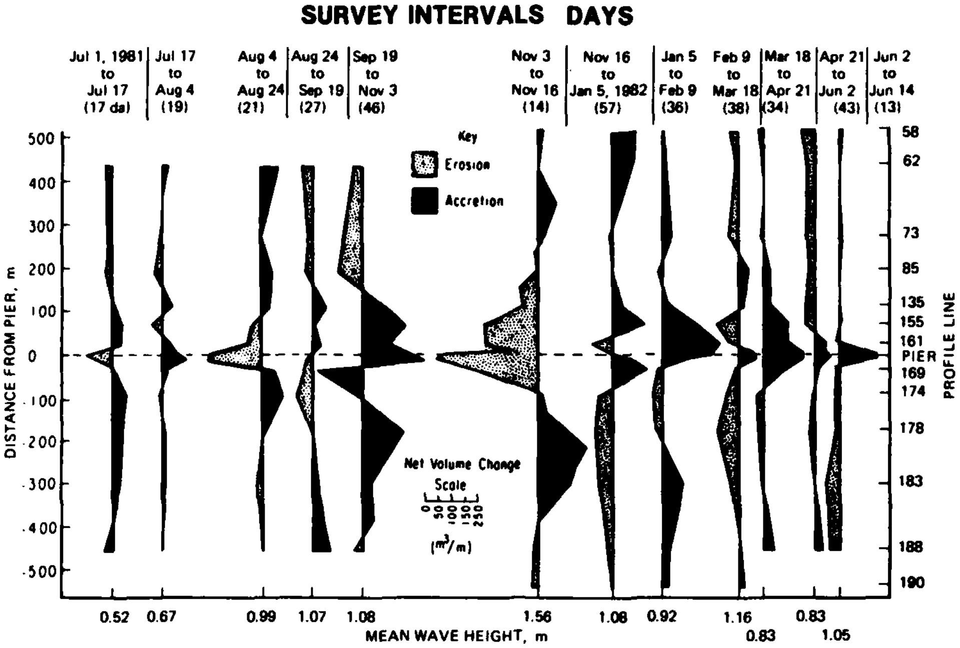

Figure 34. Net volume change versus distance from the pier, 25 July 1981-14 June 1982

along the pier they refract due to the deeper water in the trough and interact with the pier piles. This refraction results in greater differences in wave height and direction closer to shore.

PART VI: BEACHES AND GEOLOGY

73. The FRF, located along a barrier spit forming the eastern edge of the North Carolina Coastal Plain, is the northernmost part of a complex series of barrier islands which extend south to Cape Lookout. Though there are currently four inlets along this stretch (Oregon, Hatteras, Ocracoke, Drum), the area is dynamic and includes many relic inlets (Figure 35).

Origin

74. Though general consensus is that the barrier islands are comprised of recent (Holocene) sediments overlying Pleistocene deposits, their origin is both complex and slightly controversial. Judge (1980)* provides a summary of the following significant theories. De Beaumont (1845) suggested that the islands were formed by bar building. Gilbert (1885) theorized that longshore drift and spit building were the primary causes of formation. Hoyt (1967) postulated that rising sea levels (or land submergence) could flood the flats behind the dunes and form a long subaerial ridge. Hoyt and Henry (1971) noted that the capes coincided with historic river deltas which were isolated by rising sea levels. Using stratigraphic interpretation of core samples, Pierce and Colquhoun (1970, 1971) found that 39 percent of the original 200-km (124-mile) coast was primarily dune and that the islands formed by shoreline submergence. Field and Duane (1976) postulated that the barriers formed on the Continental Shelf during low sea levels and moved shoreward under the influence of sea level rise. Riggs (1978) postulated that the islands were formed by submergence and had been modified by coastal processes (waves, tides, and currents) to form their present shape and alinement.

Shoreline Changes

75. Historically, the ocean shoreline at the FRF has been relatively stable. This was documented by Wahls (1973), who found a mean annual accretion rate of 0.91 m (3 ft) per year for the period 1955 to 1971. More

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* C. W. Judge, "Geology and Physiography of the Field Research Facility at Duck, North Carolina," US Army Engineer Waterways Experiment Station, Vicksburg, Miss., unpublished, Feb. 1980.

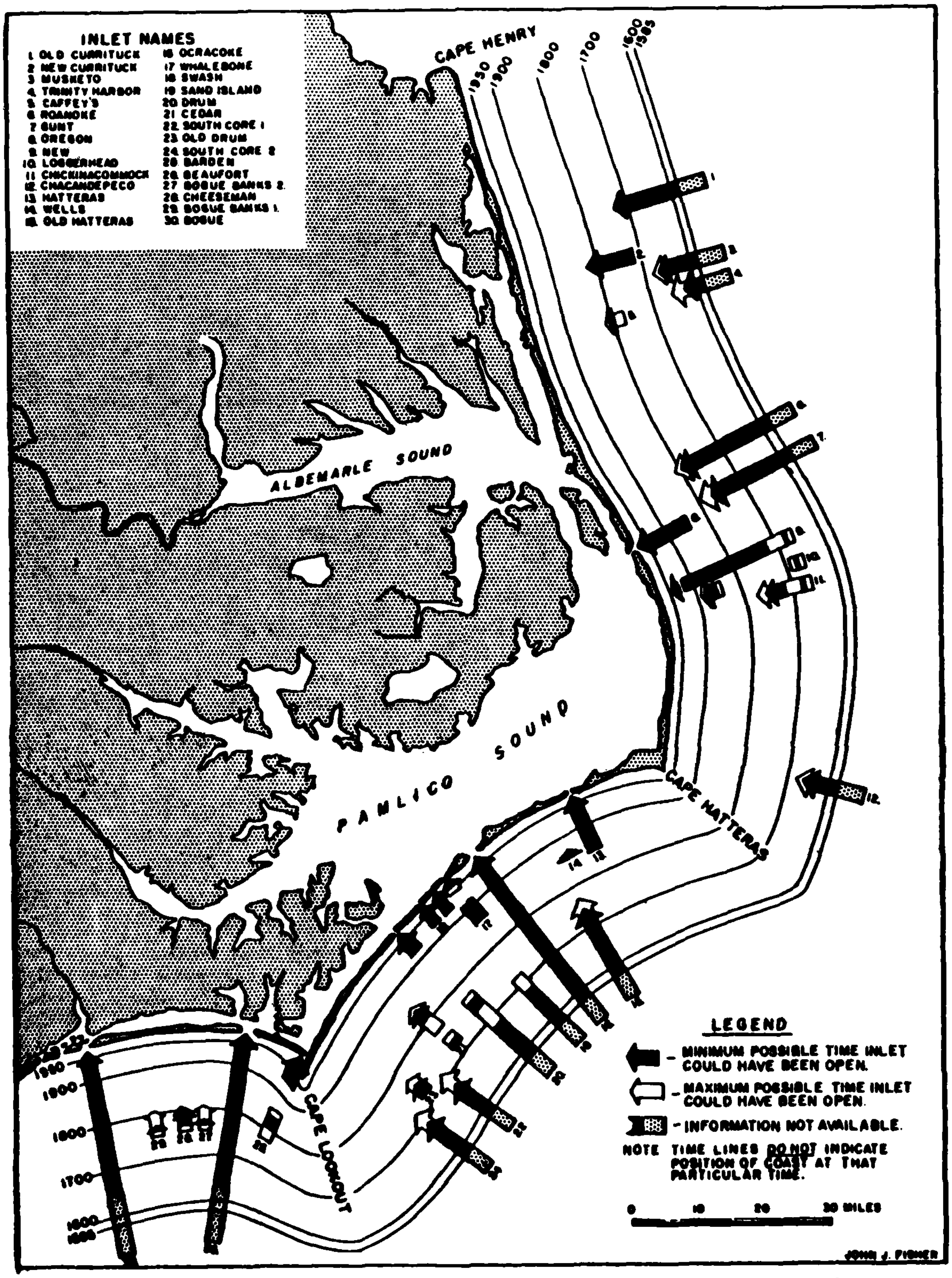

Figure 35. Temporal-spatial distribution of historic inlets along the Outer Banks coast (from John J. Fisher, "Geomorphic Expression of Former Inlets Along the Outer Banks of North Carolina," M.S. Thesis, University of North Carolina, 1962)

recently, Dolan's (1979)* analysis of shoreline changes north and south of the FRF showed long-term stability from 1940 to 1975 (Figure 36) and overall

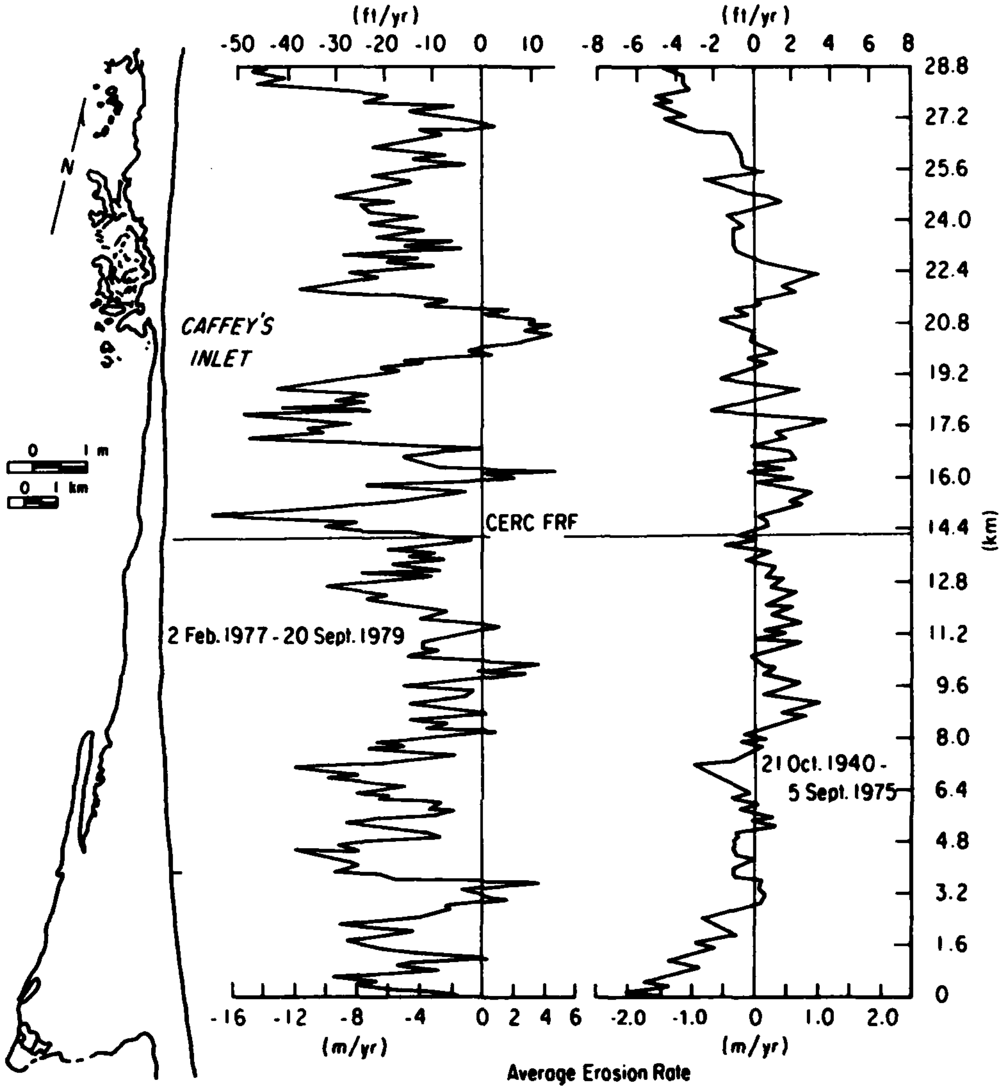

Figure 36. Average preconstruction and postconstruction erosion rates for 28 km (45 miles) of shoreline near the FRF

erosion from 1977 to 1979. These results are based on shoreline measurements from photos at 50-m (164-ft) intervals over the 28-km (45-mile) reach. Average rates of change are computed based on the rates of change for each set of successive photos. The following sets of photos were used in the analysis:

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* R. A. Dolan, "Report on Shoreline Dynamics at the CERC Field Research Facility," US Army Engineer Waterways Experiment Station, Vicksburg, Miss., unpublished, Dec. 1979.

1940-1975	1977-1979
21 October 1940	2 February 1977
29 March 1955	11 November 1977
3 May 1962	16 May 1978
5 September 1975	2 December 1978
	20 September 1979

Three rates were averaged to compute the 1940 to 1975 rates; four rates were averaged to obtain the 1977 to 1979 rates. The air photo analysis procedure is described in Dolan et al. (1979). Errors can be significant, and average rates of change less than 1.0 m (3.3 ft) per year over 40 years are difficult to measure.

76. Because long time intervals tend to smooth the data, two different horizontal scales were used in Figure 36. The 1940 to 1975 data show accretion or stability near the FRF and erosion at the northern and southern ends of the study area. Between 1977 and 1979, erosion predominated with only a few areas showing accretion. Interestingly, the area with the most noticeable accretion is located around Caffey's Inlet. The area just south of the pier appeared to be stable, while peak erosion of 17.1 m (56.1 ft) per year was found 183 m (600 ft) north of the pier.

Topography

77. A contour map of the FRF site is shown in Figure 37. The island is 680 m (2,200 ft) wide at the FRF and is bordered on the sound side by a brackish water marsh (described in Part VII). The area is typified by dunes which reach heights of more than 14 m (45.9 ft) above NGVD; the beach is backed by a dune which reaches a height of 7 m (22 ft) above NGVD. Beach width varies but averages about 40 m (130 ft). Berms, with crest elevations of 2.4 m (8 ft), and beach cusps are common. The beach tends to be wider immediately south of the pier than north of it. Foreshore slopes vary from 0.023 to 0.345, averaging 0.108.

Beach Changes

78. Beach changes which are affected by the pier have been discussed previously. This section discusses "normal" beach changes. In May 1974, before the pier was constructed, CERC began surveys to wading depth of the

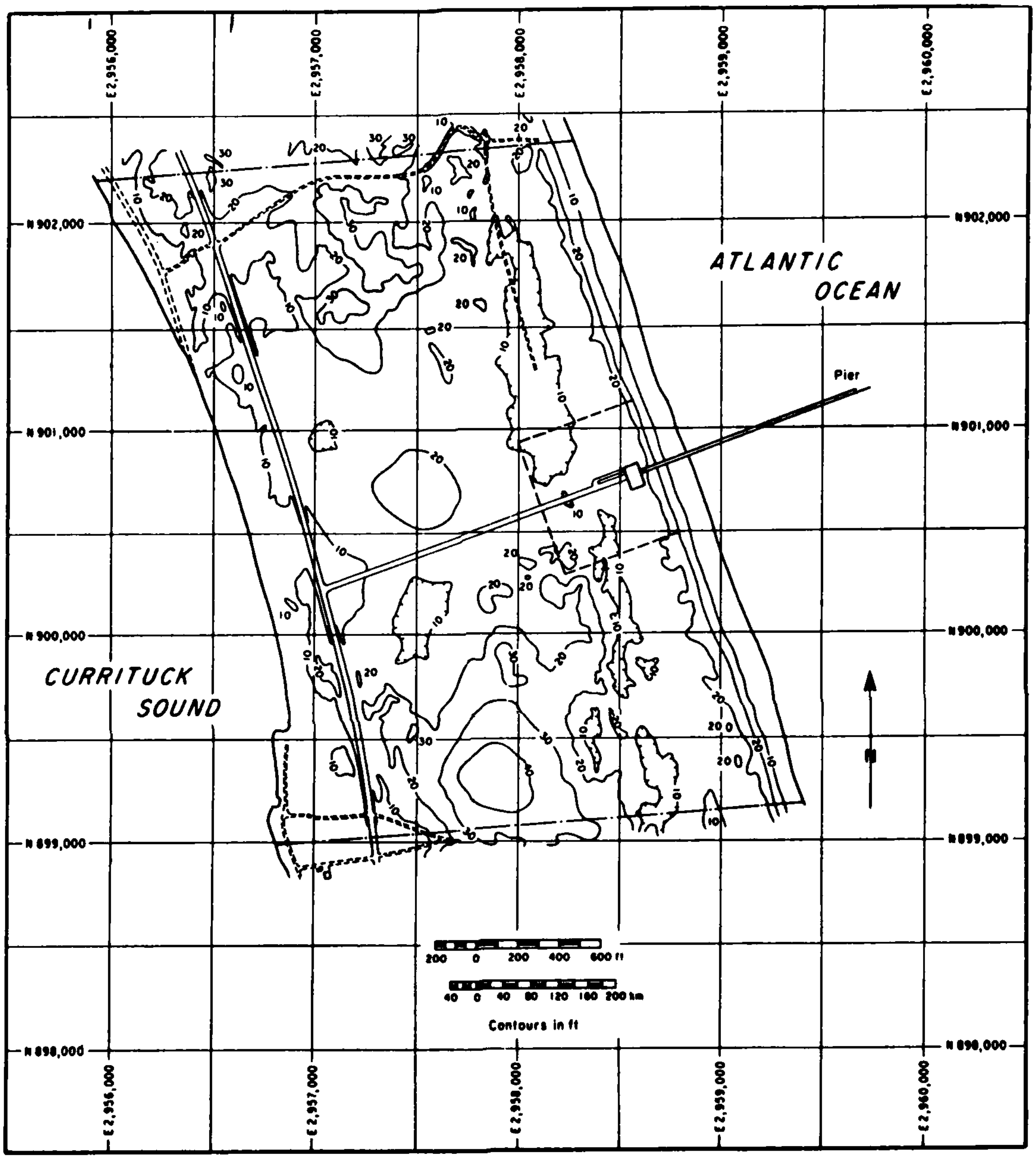

Figure 37. Contour map of the FRF site (contours in ft), North Carolina state grid system used

62 profile lines shown in Figure 12. Surveys were conducted monthly and immediately after storms. Thirty-four profile lines (4 to 20 and 45 to 61) were surveyed daily for three separate 30-day studies. The last complete survey of the 62 profile lines was conducted in January 1977.

79. Changes in unit volume and NGVD shoreline position from May 1974 to January 1977 for 15 profile lines near the pier are shown in Figures 38 and 39. Profile lines 16 and 17 are located 48 m (160 ft) north and south, respectively, of the FRF pier. Unit volume changes are referenced to the average volume above NGVD. Shoreline position is referenced to the shoreline position of the profile during the first survey. A linear regression fit to these data indicates that on the average the profile lines accreted at a rate of 3.49 m^3/m (1.39 yd^3/ft) per year, and the shoreline advanced at a rate of 1.66 m (5.4 ft) per year during this time period (Table 12). Only profile lines 2, 19, 20, and 21 underwent net erosion. With the exception of profile line 16, profile lines immediately to the north of the pier displayed a sharp erosional trend during the second phase of pier construction (March to August 1976), which reversed in September 1976. Profile lines immediately to the south of the pier and profile line 16 underwent general accretion during this period.

Table 12

Rates of Change for Profile Lines in Vicinity of the FRF, May 1974-January 1977

Profile Line No.	Distance from FRF* m	Distance from FRF* ft	NGVD Shoreline Change** m/yr	NGVD Shoreline Change** ft/yr	Above NGVD Unit Volume Change** $m^3/m/yr$	Above NGVD Unit Volume Change** $yd^3/ft/yr$
1	-5,762	-18,904	+3.36	11.0	+8.32	3.3
2	-4,755	-15,600	-3.94	-12.9	-15.87	-6.3
3	-2,677	-8,783	+1.58	+5.2	+6.47	+2.6
4	-1,667	-5,469	+4.19	+13.7	+15.10	+6.0
5	-905	-2,969	+5.31	+17.4	+14.60	+5.8
6	-524	-1,719	+3.57	+11.7	+9.88	+3.9
7	-333	-1,093	+4.22	+13.8	+7.70	+3.1
8	-238	-781	+3.42	+11.2	+3.26	+1.3
16	-48	-157	+2.58	+8.5	+7.16	+2.9
17	+48	+157	+9.59	+31.5	+11.29	+4.5

(Continued)

* Positive distance is south, negative north.
** Positive value indicates accretion, negative erosion.

Table 12 (Concluded)

Profile Line No.	Distance from FRF* m	Distance from FRF* ft	NGVD Shoreline Change** m/yr	NGVD Shoreline Change** ft/yr	Above NGVD Unit Volume Change** $m^3/m/yr$	Above NGVD Unit Volume Change** $yd^3/ft/yr$
18	+238	+781	+5.42	+17.8	+10.21	+4.1
19	+619	+2,031	+2.40	+7.9	-7.63	-3.0
20	+1,381	+4,531	-2.36	-7.7	0.00	0.0
21	+2,753	+9,032	-1.46	-4.8	-2.87	-1.1
22	+3,834	+12,579	+3.97	+13.0	+10.43	+4.2
23	+5,039	+16,532	+1.85	+6.1	+0.92	+0.4
Mean (distance-weighted)			+1.66	+5.5	+3.50	+1.4

80. Birkemeier (1979)* reported the average monthly variation in mean shoreline position and above-NGVD unit volume for the same profiles (See Figures 40 and 41) but did not include lines 7, 8, 16, and 17. These data show no clear-cut seasonal variation. The subaerial beach has the least amount of sand during March and December and the greatest amount during April and November.

Bathymetry and Nearshore Change

81. Offshore bathymetry is shown in Figure 42. Nearshore bathymetry is shown in Figure 30 and discussed in Part V. Since January 1981, profile lines 62 and 188, located away from the pier (see Figure 30), have been surveyed biweekly and after storms in order to monitor changes in the nearshore. All surveying was done with the CRAB system described in Part III. These lines were selected in order to minimize the effect of the pier's influence.

82. Profile configuration is typically single-barred with the most active zone extending from the base of the dune to about the 6-m (20-ft) water depth. This can be seen in the envelope plot of 36 surveys from January 1981 to January 1982 shown in Figure 43. Maximum vertical change during the period shown was 2.3 m (7.5 ft) and occurred just seaward of the shoreline. Only minor vertical changes occurred in water depths greater than 6 m.

83. Figure 44 illustrates the rapid offshore movement of the bar which occurred during October and November 1981. The largest and deepest changes occurred during the storm of 13-15 November 1981, which produced a maximum

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* W. A. Birkemeier, "Beach Profile Changes near the CERC Field Research Facility on the Outer Banks of North Carolina, Duck to Cape Hatteras," Assateague Shore and Shelf Field Trip Guide, unpublished, Apr. 1979.

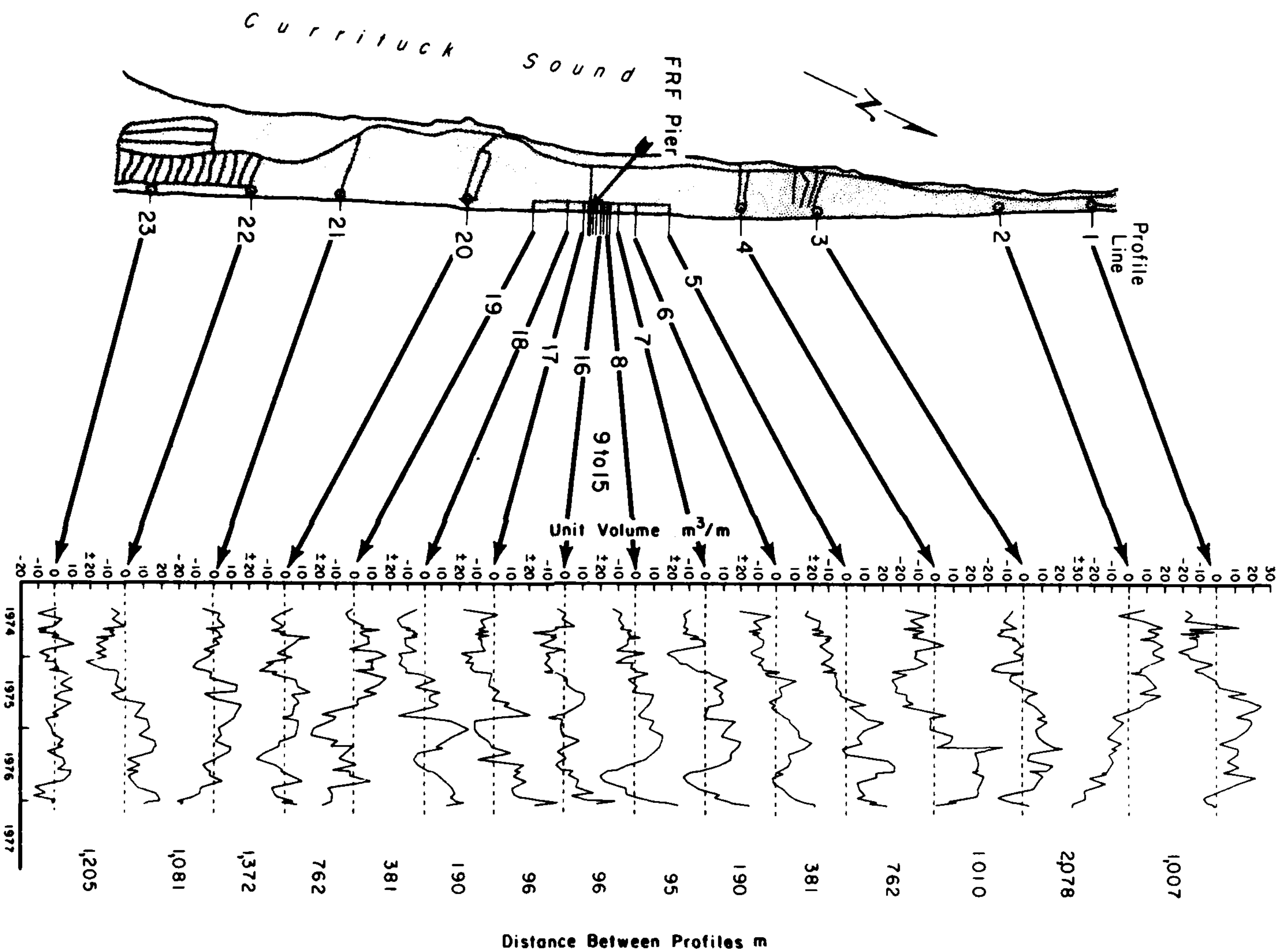

Figure 38. Variation in unit volume above NGVD on 16 profile lines near the FRF

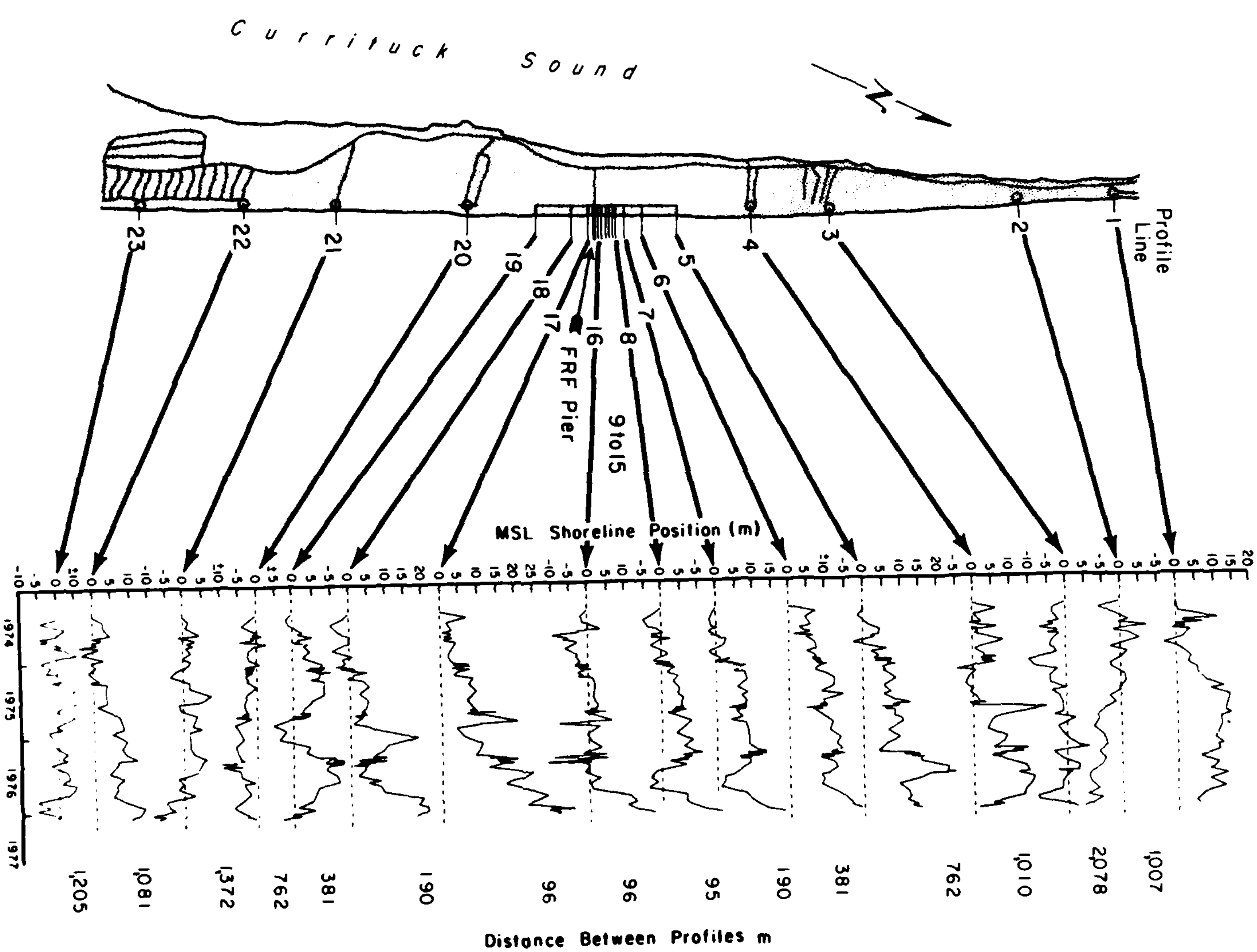

Figure 39. Variation in NGVD shoreline position on 16 profile lines near the FRF

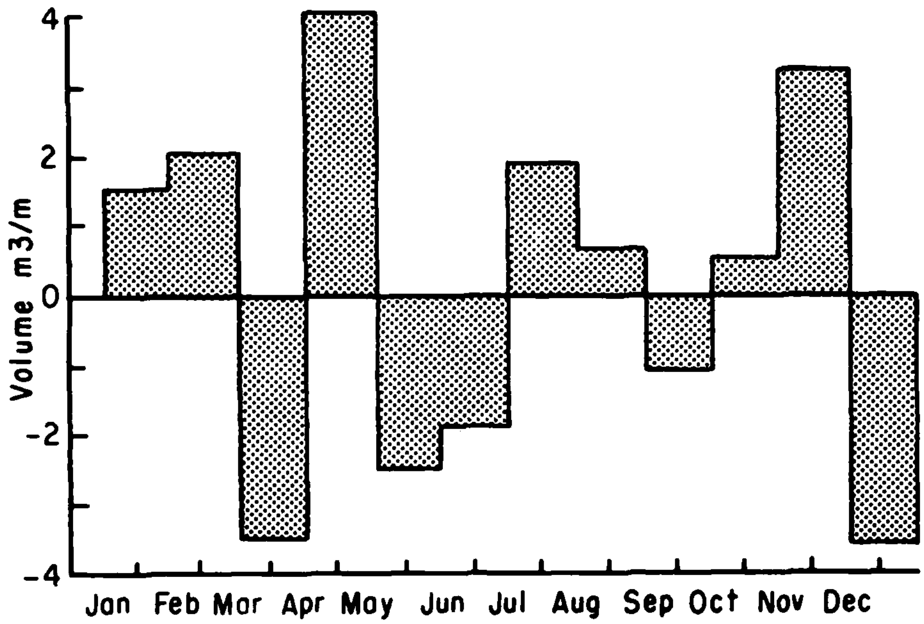

Figure 40. Monthly variations in mean profile volume (profile lines 1 to 6 and 18 to 23, from May 1974 to January 1977)

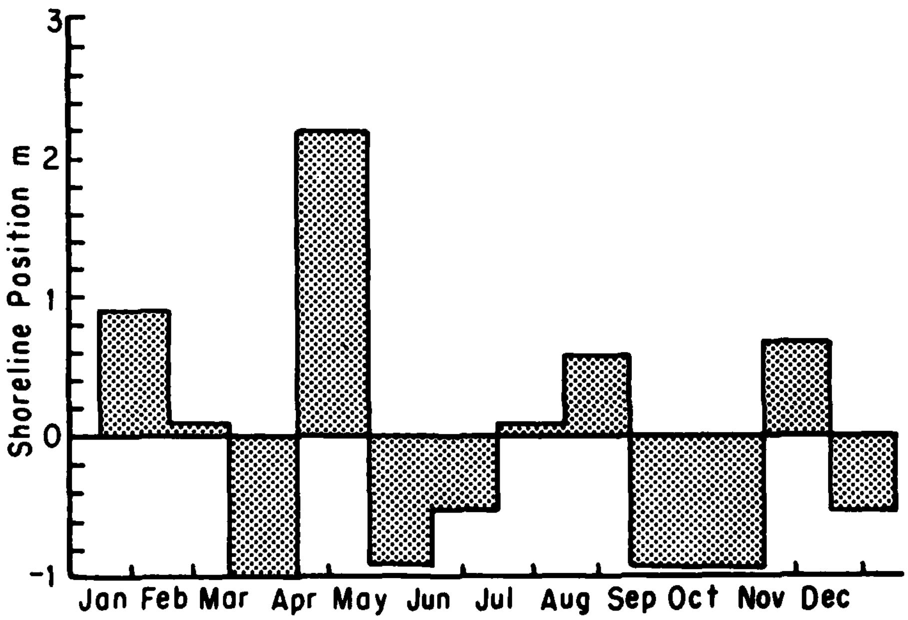

Figure 41. Monthly variations in mean shoreline position (profile lines 1 to 6 and 18 to 23 from May 1974 to January 1977)

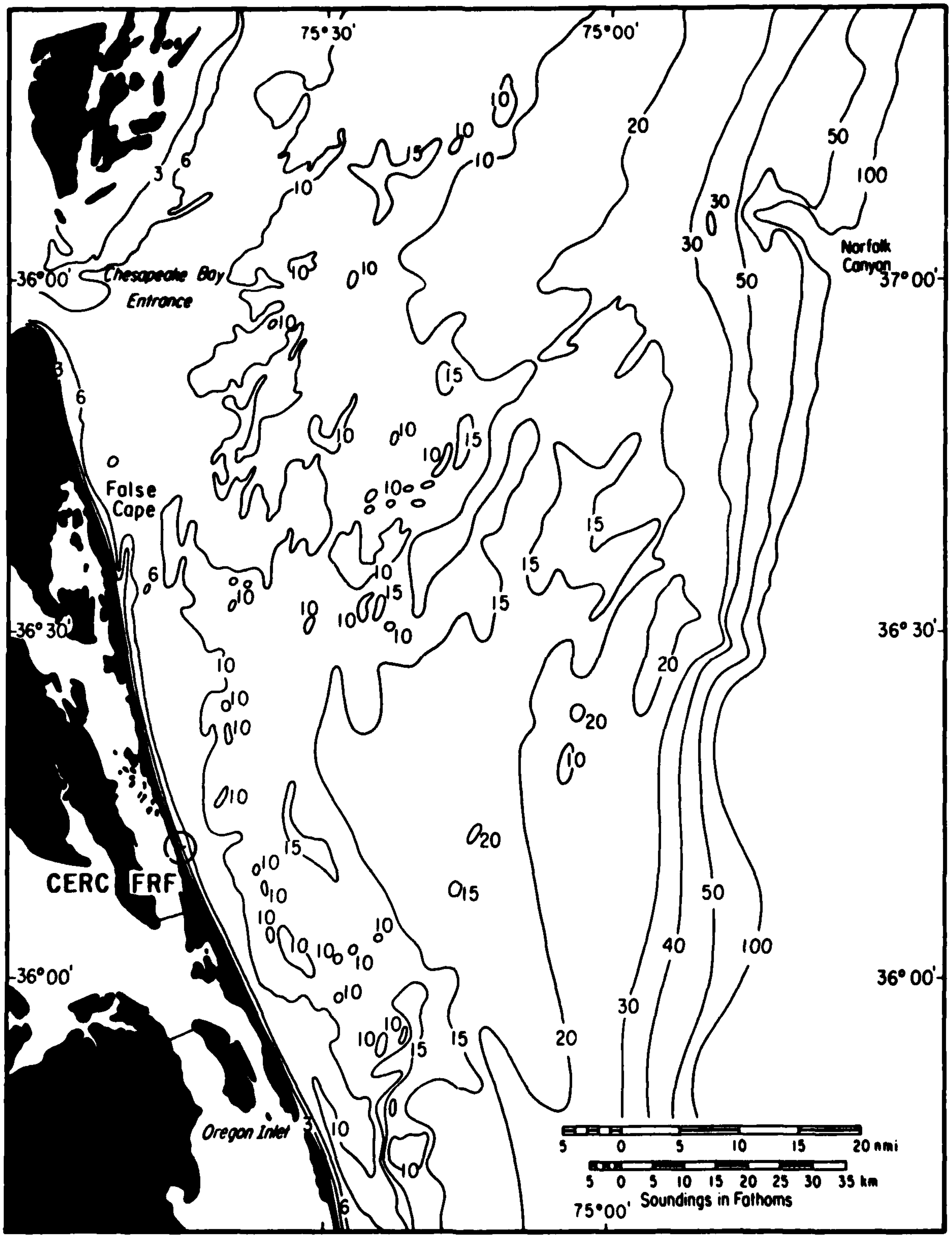

Figure 42. Deepwater contours offshore of the FRF

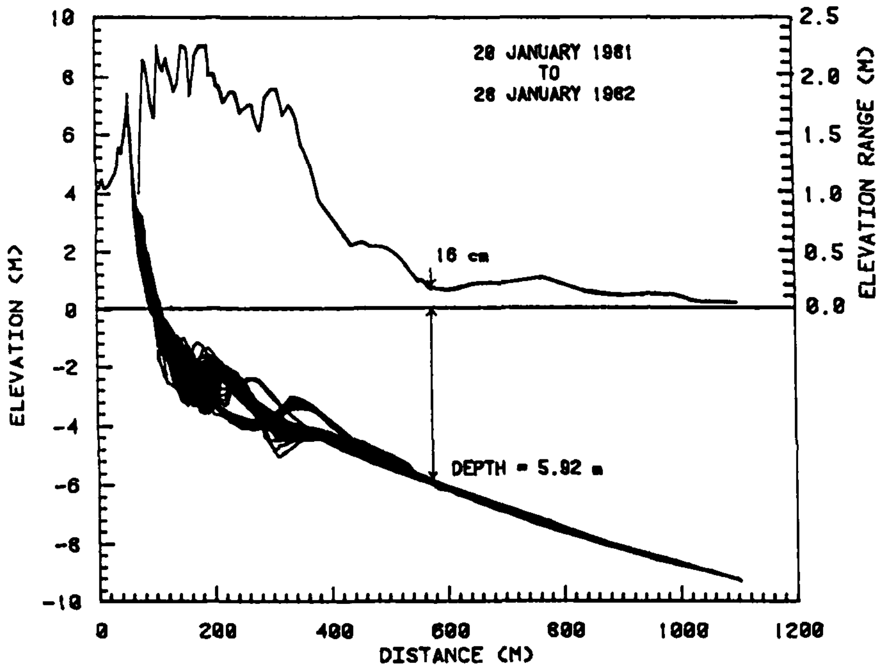

Figure 43. Envelope of 36 surveys of profile line 188

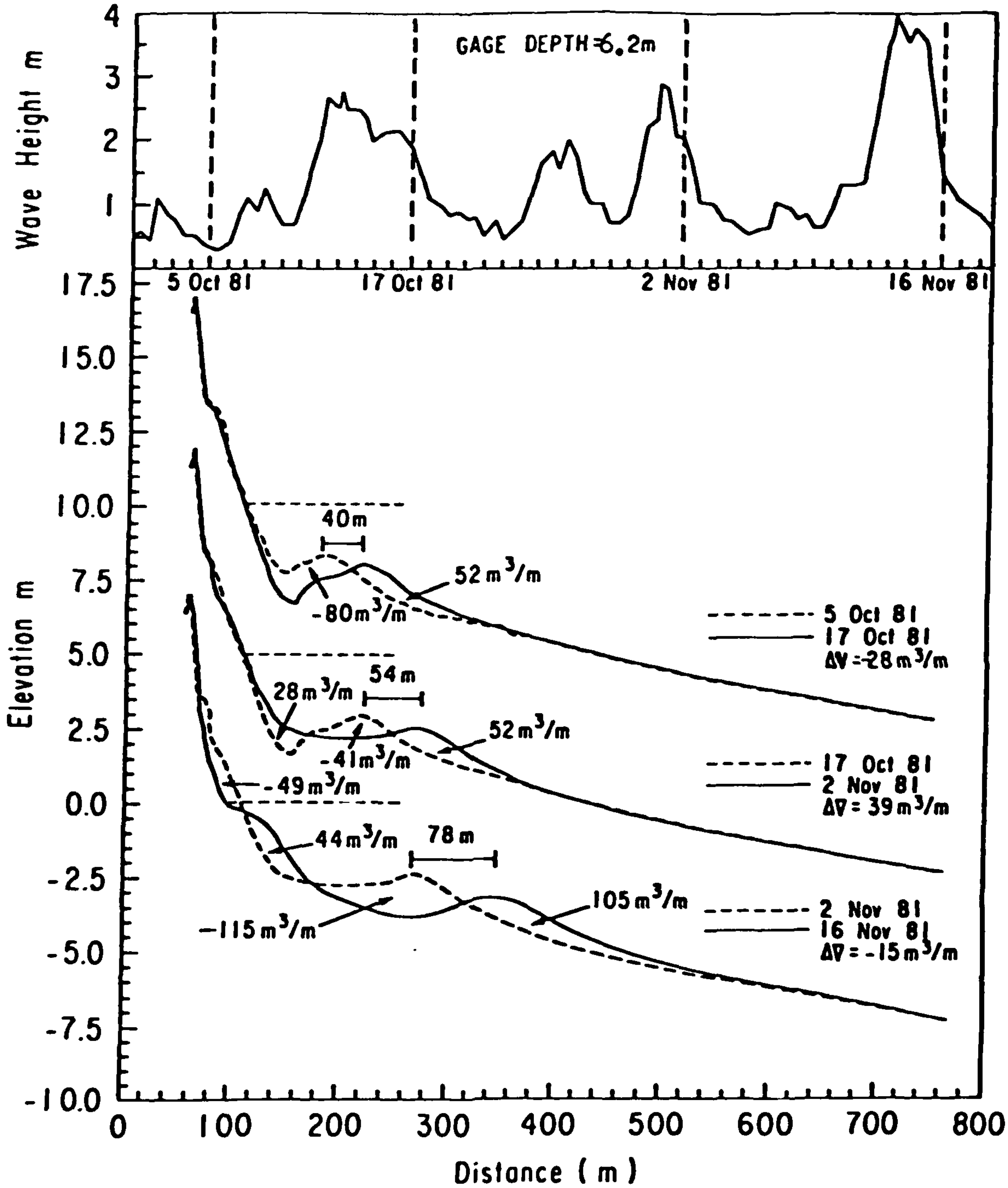

Figure 44. Bar movement and profile changes on line 188 resulting from a series of fall 1981 storms

surge 1.6 m (5.2 ft) above NGVD and significant wave heights of 4 m (13 ft). Measurable vertical change occurred to depths of 6.8 m (22.3 ft) below NGVD (Birkemeier, in preparation).

84. Changes during the period 8 February to 1 September 1982, shown in Figure 45, were dramatically different from those shown in Figure 43. They were characterized by a slow landward movement of the bar totalling 120 m (394 ft). The profile was more stable than in 1981 with a maximum variation of only 1.5 m (4.9 ft). Vertical changes in water depths greater than 6 m (20 ft) were again negligible.

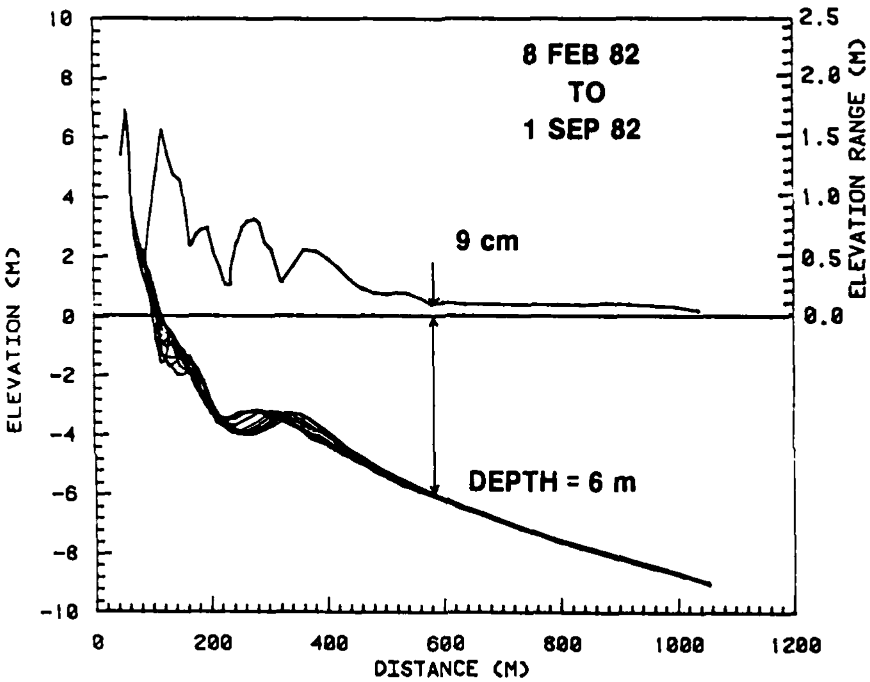

Figure 45. Envelope of 17 surveys of profile line 188

Longshore Bars

85. The nearshore profile data discussed above illustrate the barred profile configuration typical of the area. The profile lines provide only single cross sections of the large three-dimensional bar-trough pattern existing in the area. Major storms tend to reorganize the longshore bar into a deeper, well-defined linear feature. During the long recovery process as the bar moves onshore, it is molded by local processes . .o a more complex configuration.

86. Lester (1980)* examined the frequency and movement of longshore bars, using aerial photos from five overflights, and found that two different bar patterns existed. From Duck north 75 km (47 miles) to Cape Henry, there was a single, uninterrupted bar. However, from Duck south to Oregon Inlet there was a sequence of seven sandbars. These bars had a trisectional formation, in that each bar tended to propagate at an angle from the shore then continued southward parallel to shore for a considerable distance until only remanent indications of the bar remained. The trisectional bar formation is defined as (a) the proximal--the section that propagated from shore; (b) the body--the section that was parallel to shore; and (c) the distal or transitional--the section where only remanent indications of the bar remained and the proximal segment of a new bar was starting. Three bars with this configuration are shown in Figure 46.

87. These bars showed a strong indication of seasonal, shore-normal migration. During the summer and winter months, the average distance of the bar from shore was 137 m (450 ft) and 290 m (960 ft), respectively. The total length of the bars ranged between 6.4 and 9.6 km (4 and 6 miles). The average length of each proximal section was 1.2 km (0.75 mile), each body segment 7.2 km (4.5 miles), and each distal segment 1.4 km (0.9 mile). There was very little indication of shore-parallel migration. Instead, there appeared to be a very consistent location for the initiation of bar propagation from shore.

Sediment Characteristics

Beach material

88. As part of the BEP mentioned in Part III, a series of 915 sand samples was collected quarterly from 14 transects along the beach, above mean low water (mlw) between 1974 and January 1977 (Figure 47). Headland and DeWall (1979)** reported on the analysis of these samples. Each sample consisted of about 200 g (7 oz) taken by a specially constructed sampler from the top 1 cc (0.4 in.) of the beach. The location and elevation of each sample were carefully determined using tape and level techniques. Samples

* M. E. Lester, "Aerial Investigation of Longshore Bars Along the Outer Banks of North Carolina, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., unpublished, 1980.

** J. R. Headland and A. E. DeWall, "Sand Size Trends Along the Northern Outer Banks of North Carolina," Assateague Shore and Shelf Trip Guide, unpublished, Apr. 1979.

Figure 46. Aerial view looking north from Kill Devil Hills, showing three distinct longshore bars

were collected from the landward side of the dune, the dune crest, the dune toe, the berm, and the foreshore.

89. Splits of the samples were analyzed on the CERC Rapid Sediment Analyzer (RSA). Ten percent of the samples were also run at 0.5-ϕ

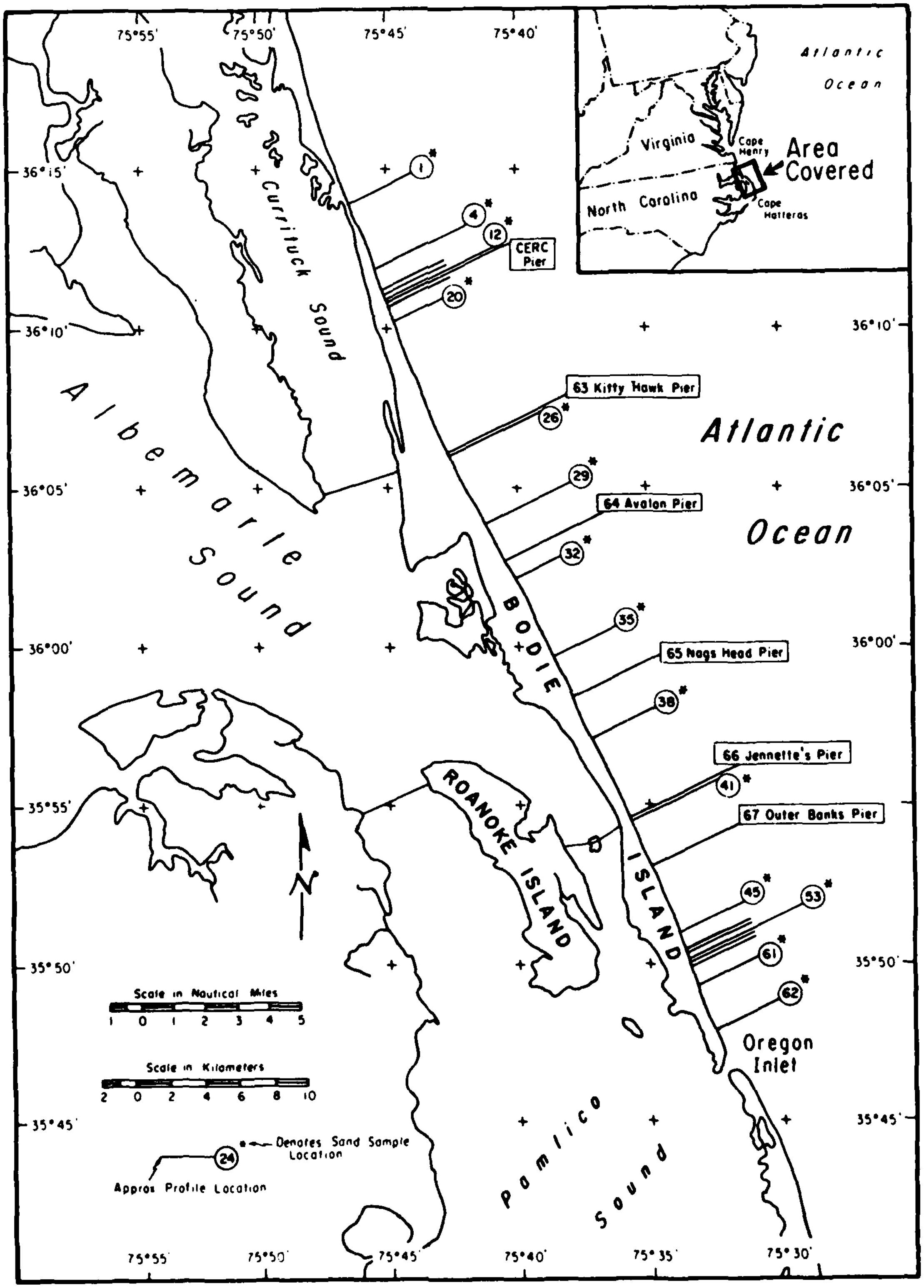

Figure 47. Location of sand sample profile lines

intervals through a standard sieve analysis for control. A subset of 60 foreshore samples collected during 1976 was analyzed for carbonate content. The results were then analyzed for variations in mean size as a function of (a) position along each profile line, (b) position along the beach, (c) season, (d) percent carbonate, and (e) foreshore slope. An average of all profile lines indicated the mean grain size decreased landward from 0.52 mm (0.9 ϕ) on the foreshore to 0.38 mm (1.4 ϕ) at the dune (Figure 48). Profile lines to the north show a much wider range of sizes than the lines in the vicinity of Oregon Inlet due to a secondary mode in the coarse fraction on the berm and foreshore (Figure 49). The mean size of the dune sand remains nearly constant and ranges between 0.3 and 0.4 mm (1.7 and 1.3 ϕ). Figure 50 shows the bimodal distribution for a sample taken from the foreshore at profile line 20 (south of the FRF).

90. Figure 51 illustrates the change in average sample mean and standard deviation alongshore and confirms a decrease in sand size from north to south. The coarsest material occurs in the vicinity of the FRF (between lines 12 and 20) where the mean sand size on the foreshore averages 0.6 to 0.8 mm (0.7 to 0.3 ϕ).

91. Figure 52 summarizes the seasonal mean sand size, averaged by position on the profile line. Sand size on the dune remains generally unchanged, while the foreshore material (mean high water (mhw) to NGVD) tends to become finer during the summer months. Sand size on the berm is coarser during the summer than during the rest of the year. Seasonal trends were not uniform from profile to profile.

92. The carbonate fraction of the foreshore samples, which consists of whole and broken shell material, ranges from 0 to 20 percent of the sample by weight (Figure 53). The highest percentages occurred during the fall survey of profile lines 35 to 41. Mean grain size was found to have a positive correlation (0.4) with percent carbonate.

93. Foreshore slope was determined at the same time each sample set was taken. Figure 54 shows the strong positive correlation coefficient ($r = 0.88$) between the average mean grain size and the average foreshore slope for each of the 15 profile lines; Figure 55 shows the decrease in average foreshore slope from north to south.

94. The north-to-south decrease in mean grain size confirms earlier findings by Swift et al. (1971) and Shideler (1973). A downdrift decrease

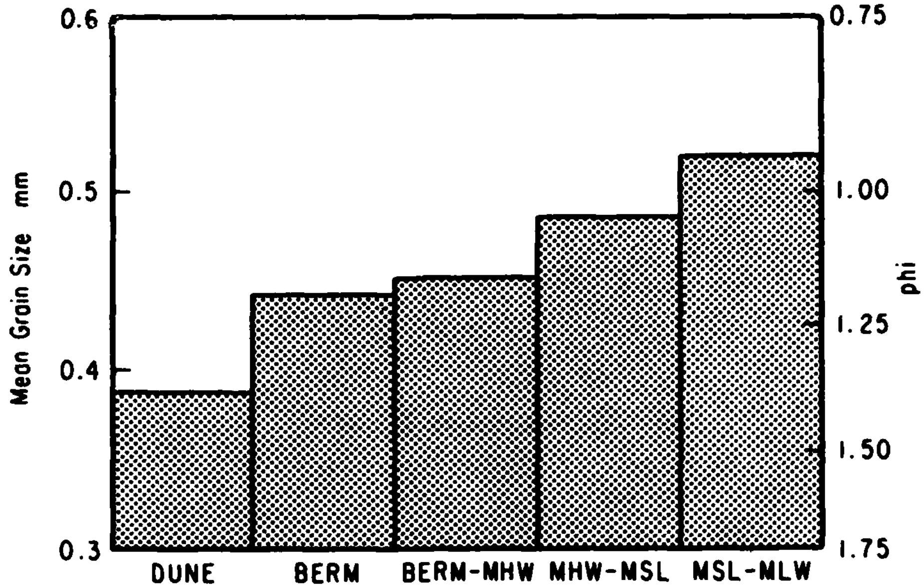

Figure 48. Average mean grain size (all samples) by profile position

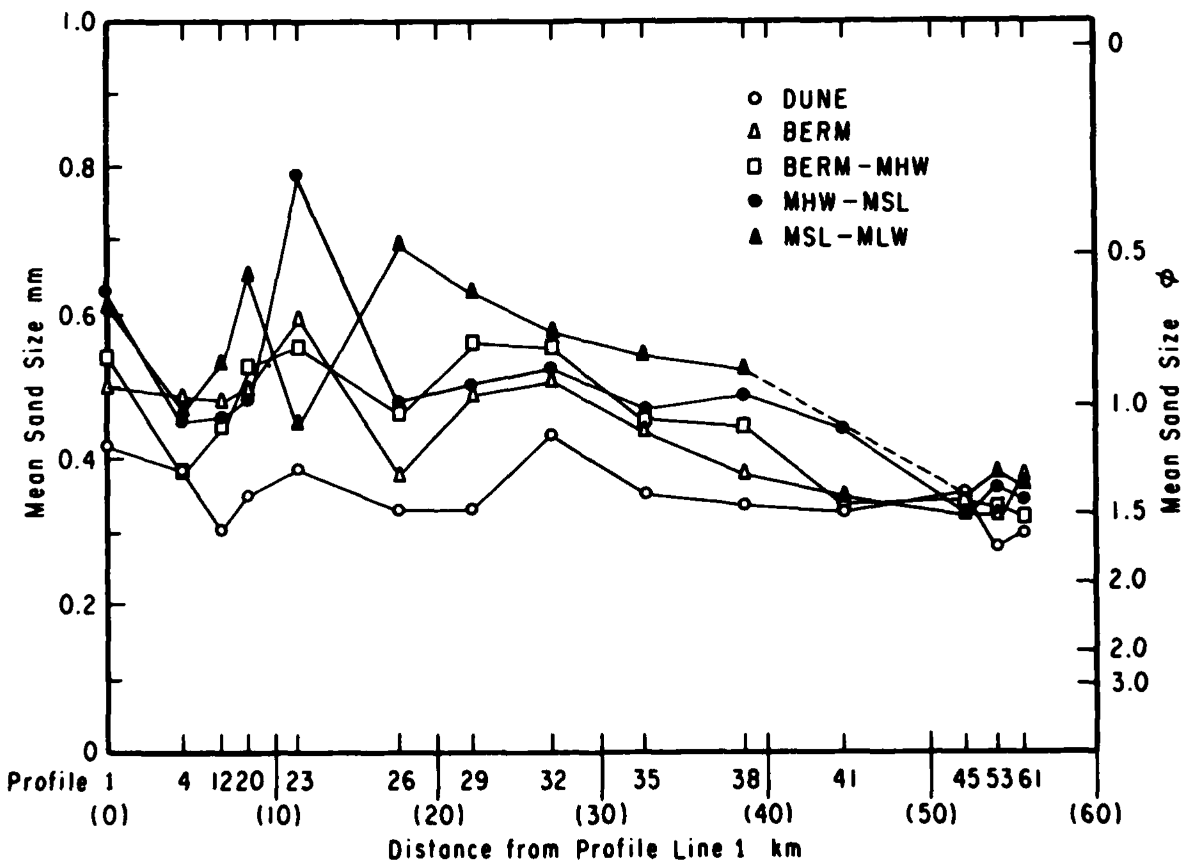

Figure 49. Alongshore variation in mean grain size by profile position

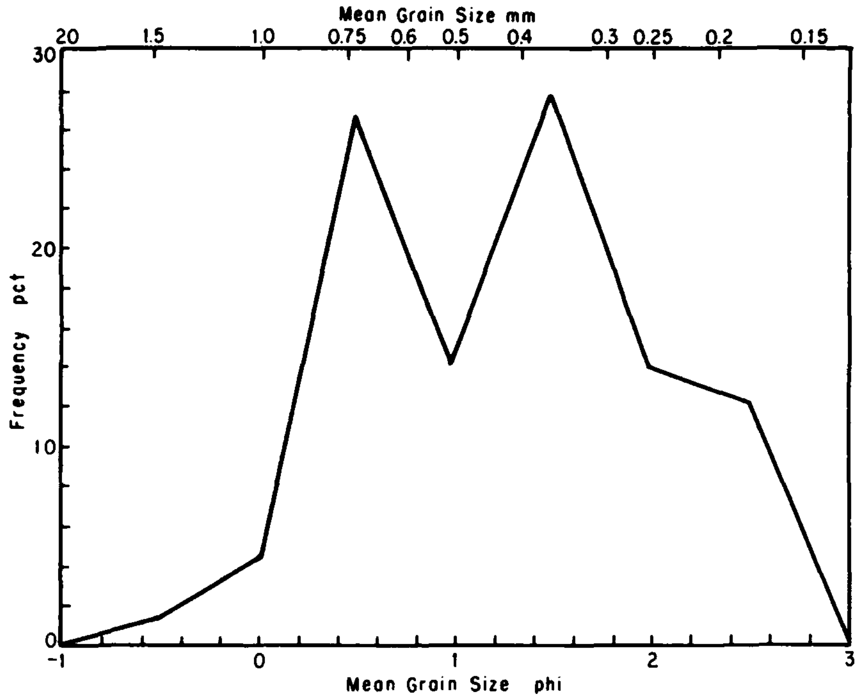

Figure 50. Example of bimodal foreshore sand-size distribution, collected at profile line 20 on 7 May 1976 (el +0.2 m (0.66 ft) NGVD)

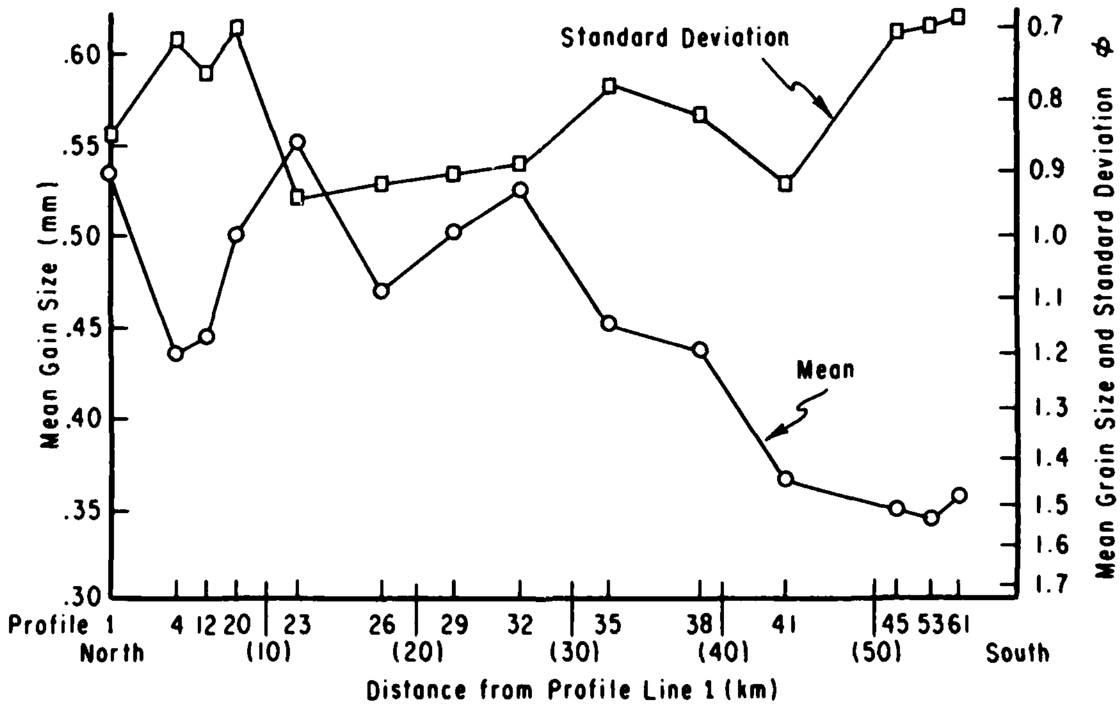

Figure 51. Alongshore variation in average mean grain size and standard deviation

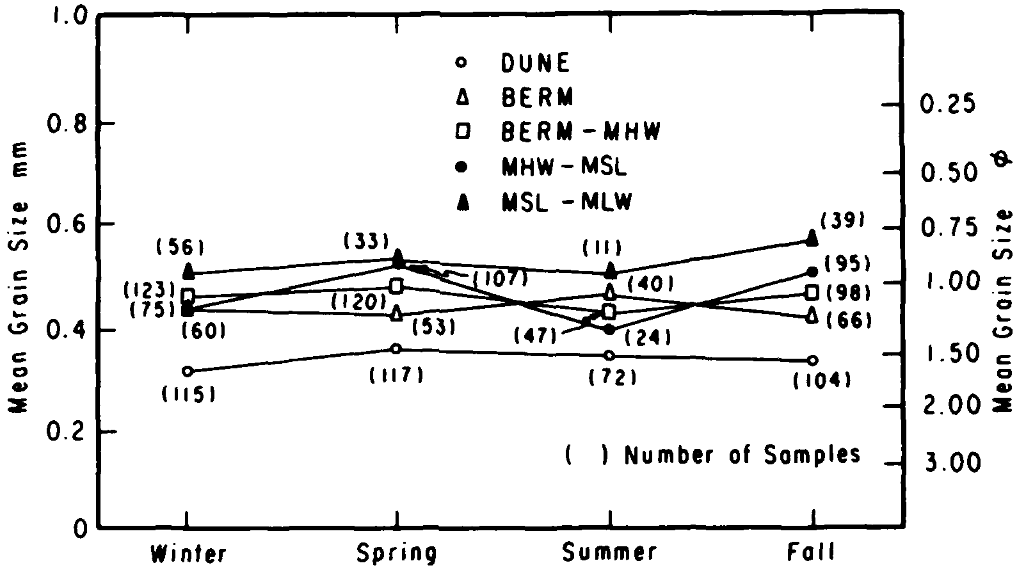

Figure 52. Mean grain size averaged by season and profile position

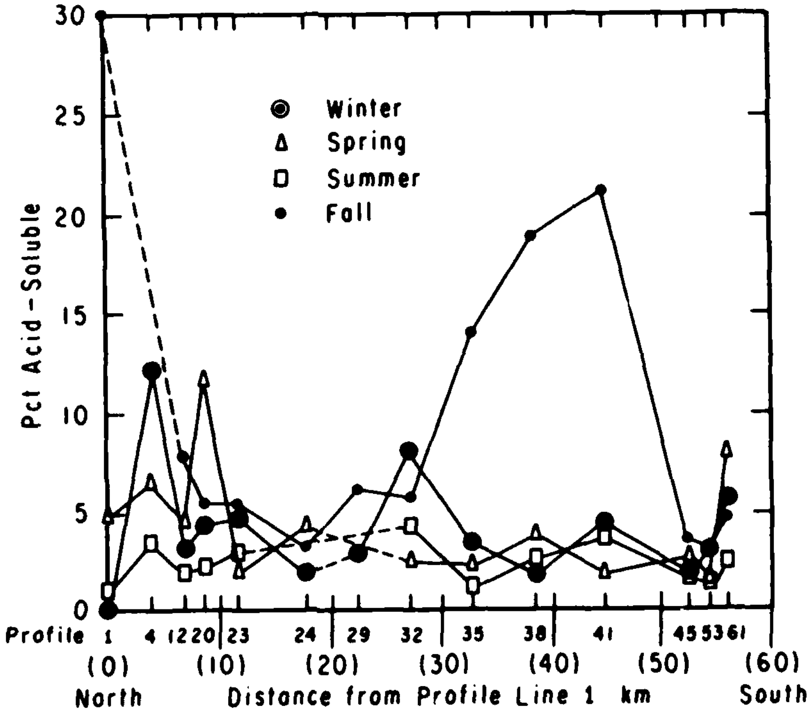

Figure 53. Carbonate percentage in foreshore samples by season

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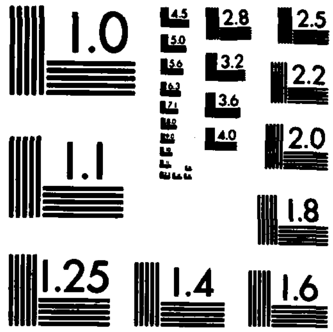

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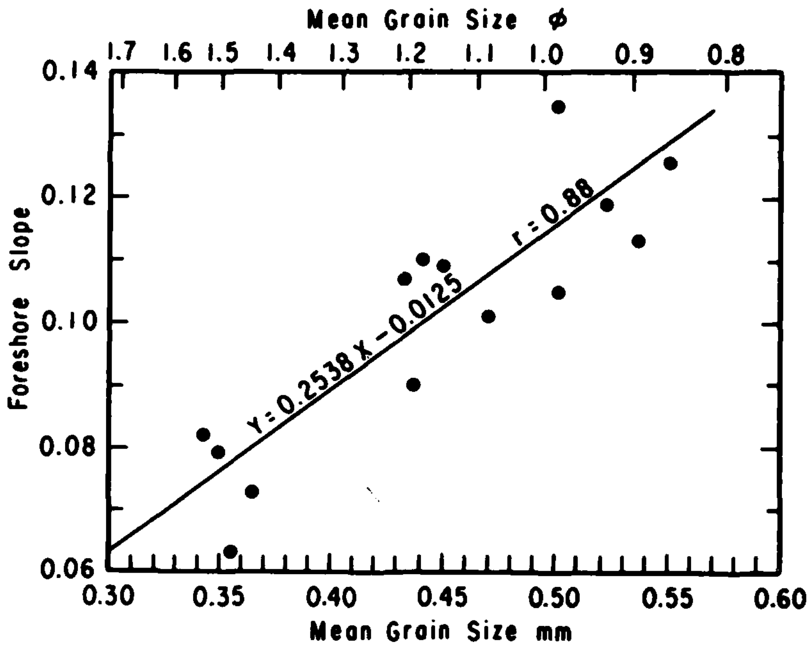

Figure 54. Average foreshore slope versus average mean grain size

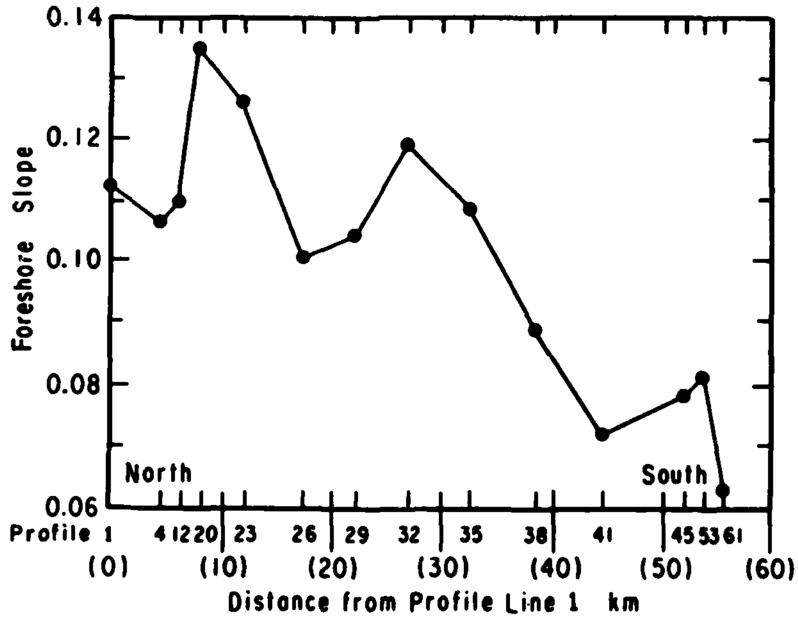

Figure 55. Alongshore variation in average foreshore slope

in sand size has been noted at other localities along the east coast (e.g., Ramsey and Galvin, 1977). The coarse sand along the northern section of the study area is characterized by a bimodal-size distribution. The northward-coarsening trend does not continue northward of the study area (Goldsmith, Sturm, and Thomas, 1977); rather, it appears to be localized between Caffey's Inlet and the vicinity of Duck. Swift et al. (1971) attributed this coarse anomaly to a local source of gravel which is excavated from the former Albemarle River channel.

Nearshore sediments

95. In August 1979 scuba divers collected a set of 35 short-core sediment samples on three shore-normal transects along the pier center line and along parallel lines 75 m (250 ft) both north and south of the pier center line. The results of the settling tube (RSA) analyses of these samples are plotted as box plots in Figure 56. Each sample is plotted relative to its distance (in m) from the FRF baseline, along the shore-normal transect. Values of the 10th, 16th, 25th, 50th (median), 75th, 84th, and 90th percentiles of the cumulative size distribution are also plotted for each sample. Sample depths, as determined by leadline soundings and corrected to NGVD elevations, are plotted for each transect. The statistics are summarized in Table 13.

96. According to Folk's (1965) classification, the bottom material is generally moderately well-sorted, medium to fine sand. Median grain size ranges from 0.28 to 0.12 mm (1.85 to 3.11 ϕ) with sorting values ranging between 0.74 and 0.40 mm (0.44 and 1.31 ϕ) (Table 13). A zone of sandy silt is encountered at 13- to 15-m (45- to 49-ft) depths. No gravel was directly observed, although one sample (Table 13, transect I,13) taken 43 m (140 ft) directly seaward of the pier end did contain a secondary mode in the 1.4- to 1.0-mm- (-0.5 to 0-ϕ-) size fraction (very coarse sand).

97. The bottom was generally observed to be rippled, except in the surf zone where ripples were wiped out by surging breakers. Ripples were generally shore-parallel with wavelengths ranging from 4 to 12 cm (1.5 to 5 in.) and heights from 1 to 4 cm (0.4 to 1.5 in.). At a 2.9-m (9.5-ft-) water depth megaripples were observed to be the primary bed form with smaller ripples superimposed. Megaripple wavelength was 2 m (6.5 ft); height was 15 cm (6 in.).

98. More recent data collected along profile line 188 from March 1982 are shown in Figure 57. Wide distributions of sediment are found from the

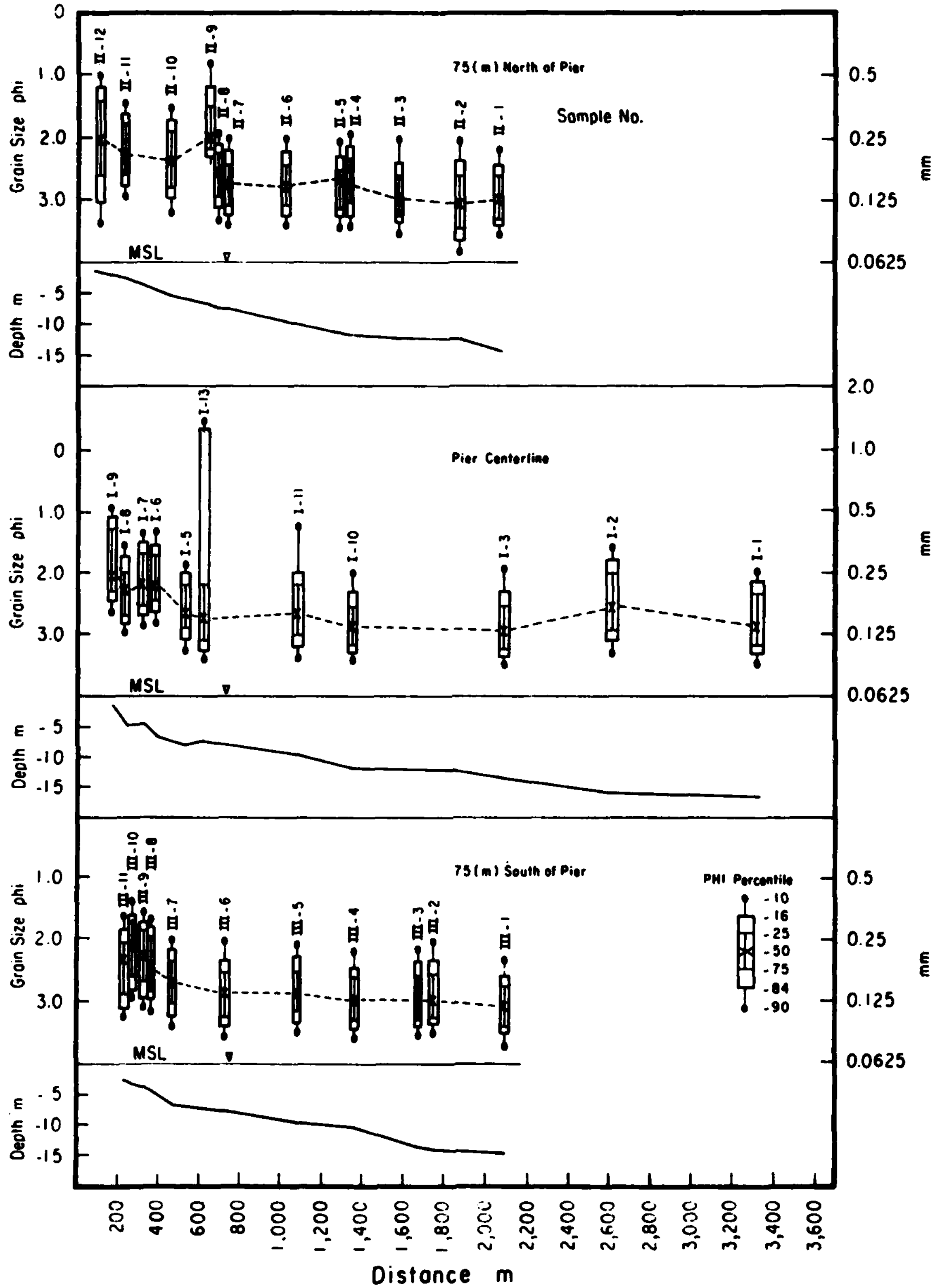

Figure 56. Size distributions of sediment cores collected along three transects near the FRF, 7 to 9 August 1979

Table 13

FRF Offshore Sand Samples, 7 to 9 August 1979

Sample No.	NGVD Depth m	Mean Grain Size ϕ	Mean Grain Size mm	Median Grain Size ϕ	Median Grain Size mm	Std Dev ϕ	Distance from Baseline m
TRANSECT I (Pier Center Line)							
1	16.4	2.76	0.15	2.86	0.14	0.51	3,341
2	15.8	2.48	0.18	2.55	0.17	0.59	2,610
3	13.7	2.83	0.14	2.95	0.13	0.56	2,085
4	11.99	*	*	*	*	*	1,838
5	8.1	2.47	0.18	2.62	0.16	0.64	550
6	6.5	2.05	0.24	2.18	0.22	0.63	410
7	4.7	2.03	0.24	2.16	0.22	0.70	350
8	4.7	2.31	0.20	2.39	0.19	0.48	250
9	1.4	1.80	0.29	1.89	0.27	0.66	210
10	11.3	2.77	0.15	2.87	0.14	0.54	1,366
11	9.40	2.47	0.18	2.67	0.16	0.83	1,093
13	7.30	2.27	0.21	2.74	0.15	1.31	640
TRANSECT II (75 m North of Center Line)							
1	14.5	2.96	0.13	3.01	0.12	0.44	2,090
2	12.7	2.97	0.13	3.08	0.12	0.70	1,890
3	12.2	2.83	0.14	2.96	0.13	0.62	1,647
4	11.7	2.64	0.16	2.75	0.15	0.58	1,361
5	11.4	2.77	0.15	2.85	0.14	0.51	1,340
6	9.8	2.71	0.15	2.79	0.14	0.55	1,085
7	7.6	2.69	0.15	2.77	0.15	0.57	787
8	7.6	2.60	0.16	2.61	0.16	0.46	736
9	6.9	1.79	0.29	1.97	0.26	0.61	704
10	5.3	2.32	0.20	2.37	0.19	0.64	497
11	2.7	2.14	0.23	2.24	0.21	0.63	283
12	1.5	2.03	0.24	2.01	0.25	0.91	159

(Continued)

* Too fine for RSA.

Table 13 (Concluded)

Sample No.	NGVD Depth m	Mean Grain Size ϕ	Mean Grain Size mm	Median Grain Size ϕ	Median Grain Size mm	Std Dev ϕ	Distance from Baseline m
TRANSECT III (75 m South of Center Line)							
1	14.7	2.99	0.13	3.11	0.12	0.62	2,090
2	14.1	2.78	0.15	2.93	0.13	0.76	1,750
3	13.6	2.89	0.13	2.98	0.13	0.58	1,675
4	10.4	2.86	0.14	2.94	0.13	0.64	1,370
5	9.6	2.80	0.14	2.86	0.14	0.47	1,088
6	7.8	2.86	0.14	2.87	0.14	0.50	743
7	6.5	2.68	0.16	2.70	0.15	0.54	491
8	4.1	2.44	0.18	2.45	0.18	0.51	379
9	3.8	2.26	0.21	2.29	0.20	0.55	343
10	3.0	2.15	0.23	2.13	0.23	0.59	275
11	2.5	2.46	0.18	2.41	0.19	0.61	251

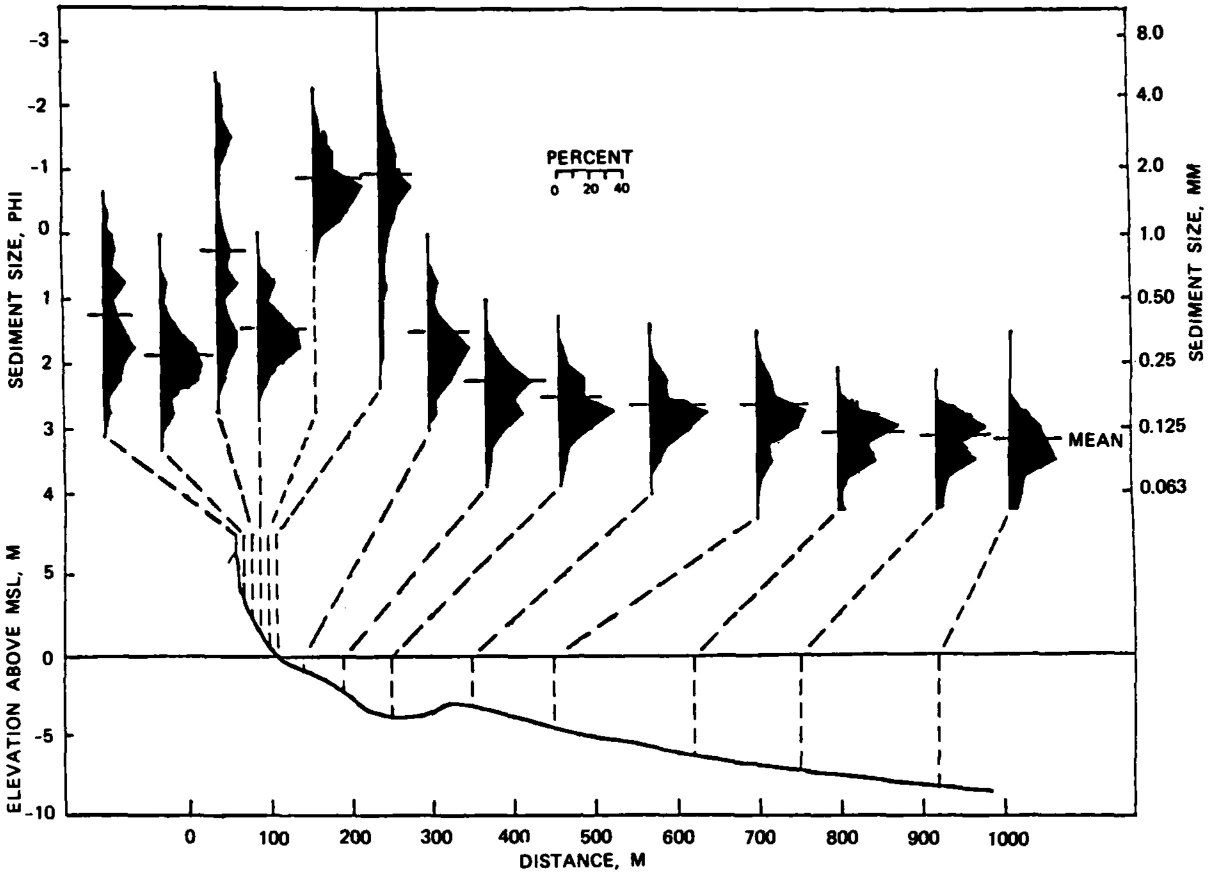

Figure 57. Distributions of sediments across profile line 188 on 17 March 1982

beach to the nearshore bar with well-sorted, finer sediments farther offshore.

Subbottom sediments

99. Field (1973)* summarized the results of a subbottom geophysical survey conducted at the site during 1972-1973. His analysis of four nearshore vibracores and five drill holes (Figures 58 and 59) show that the beach is underlain by more than 15 m (50 ft) of sand at the shoreline, thinning to about 1.5 m (5 ft) at the 12-m (40-ft) contour. Sediments vary from coarse sand with gravel layers to dense, poorly graded (well sorted), fine sand. Alternating silts, clays, and silty sands are common below this sand prism. Geophysical records show a nearly horizontal reflector (layer) at -12 m (-40 ft) NGVD nearshore that appears to intersect the bottom and become

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* M. E. Field, "Report on Analysis of Offshore Seismic and Core Logs from the Proposed CERC Field Research Facility, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., unpublished, Mar. 1973.

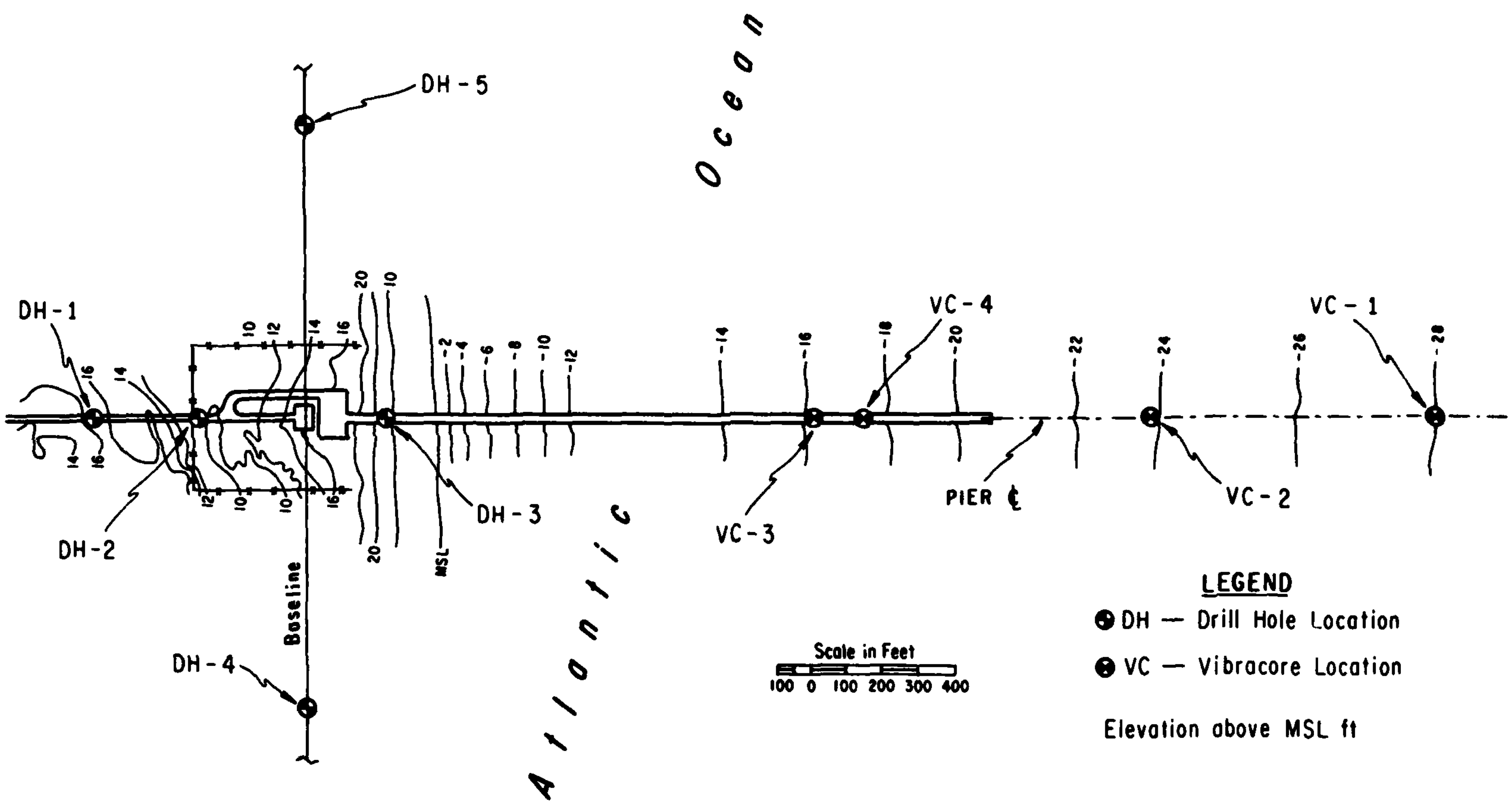

Figure 58. Location of drill holes and vibracores

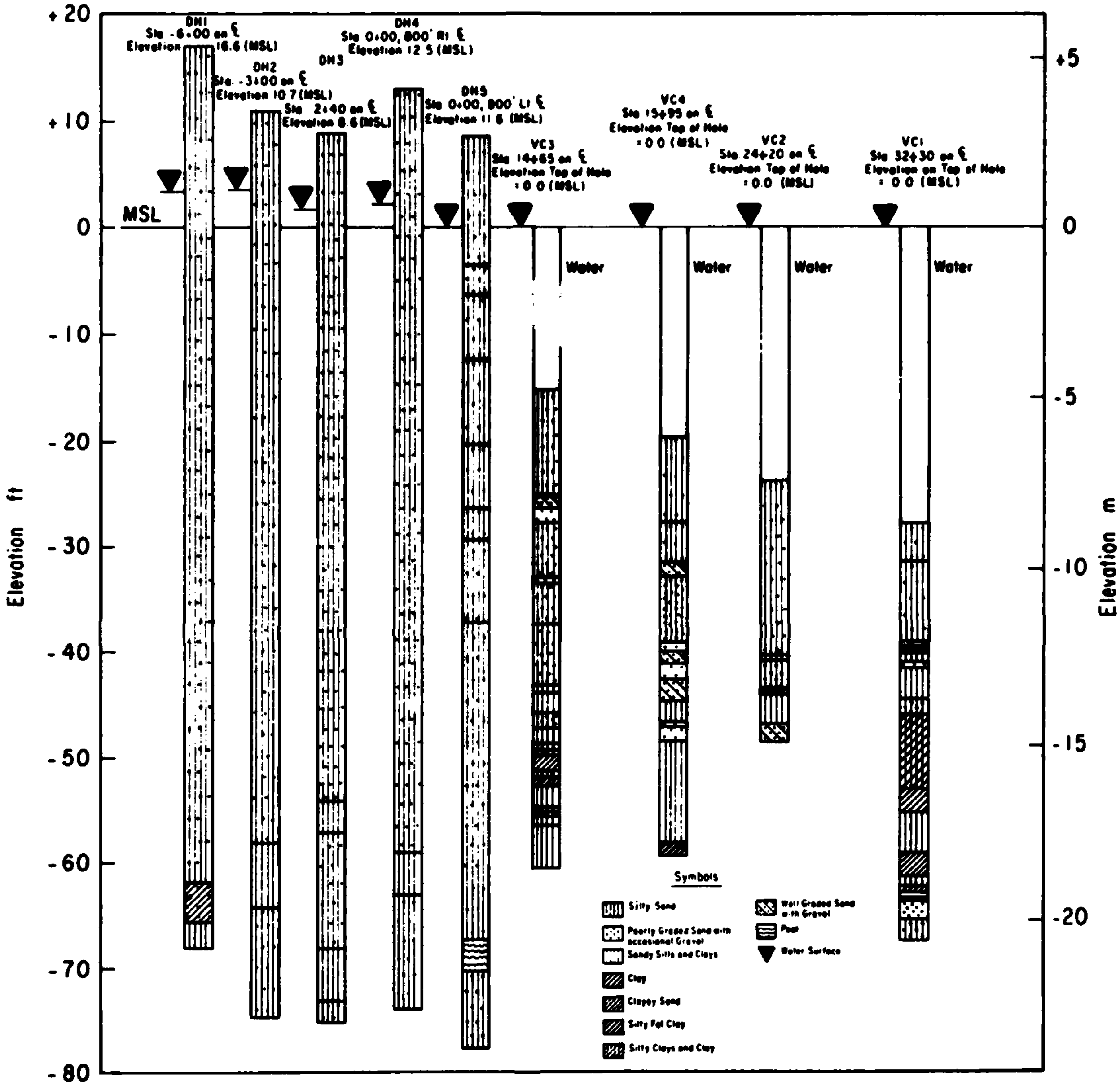

Figure 59. Summary of drill hole and vibracore logs

exposed at about -14 m (-45 ft) NGVD. The depth of this major reflector was found to correlate with the change from sand with gravel layers to silts and clays noted in the core logs (Figure 59). The surface samples and visual observations discussed above confirm an outcrop of the silt layer at -13 to -15 m (-43 to -50 ft) NGVD. Detailed core logs and geophysical records are on file at CERC.

PART VII: ECOLOGY OF THE FRF SITE

100. The mid-1600's settlement of the Outer Banks drastically changed the vegetation and topography of the region. Forests were diminished for fuel and building, and grass and shrubs were uprooted by grazing livestock which continued into the beginning of the 1900's. Once vegetation was disrupted the sandy soils became susceptible to movement by wind and storm tides. The blowouts and sand dunes seen today are results of these forces.

101. In 1935 the Works Progress Administration and the Civilian Conservation Corps began stabilizing the foredune from the Virginia border to approximately the middle of Ocracoke Island. Some of these foredunes now exceed 8 m (26 ft) in height. The ocean beach, foredunes, arborescent (tree- and shrub-dominated) and sound-side marsh zones are the most characteristic features of the Outer Banks profile (Levy 1976). The most variable zone is between the foredune and the arborescent zone. This is particularly evident at the FRF site.

102. Ecological studies relative to the flora and fauna at the FRF will now be discussed. Table 14 summarizes the available ecological data for the FRF.

Table 14

Ecological Data for FRF

Data	Survey Dates	Remarks
1. Sound-side marsh and control area profile lines	Sep 1973, Sep 1978, May 1979, Oct 1979, Apr 1980, Jul 1980, Sep 1980, May 1981-Jul 1981, Nov 1981	See Part VII, para 108, for preliminary results
2. Currituck sound profiles (nine profile lines located every 51.8 m (170 ft) along sound shore)	Jun 1979, May 1980	Lines are labeled "CS" in Figure 11
3. Herbarium specimens (collection of plant species)	Plant study (Levy 1976)	Available at CERC
4. Beach fauna reference collection	Fauna study (Matta 1977)	Available at CERC

Vegetation

103. Levy conducted a complete vegetation study of the FRF site. A vegetation map of 11 different communities in the area is shown in Figure 60. Permanent plots were located in each of the designated communities. The results of the study showed the flora to be composed of about 178 species and 132 genera representing 58 families (Appendix E). Six of the plant communities

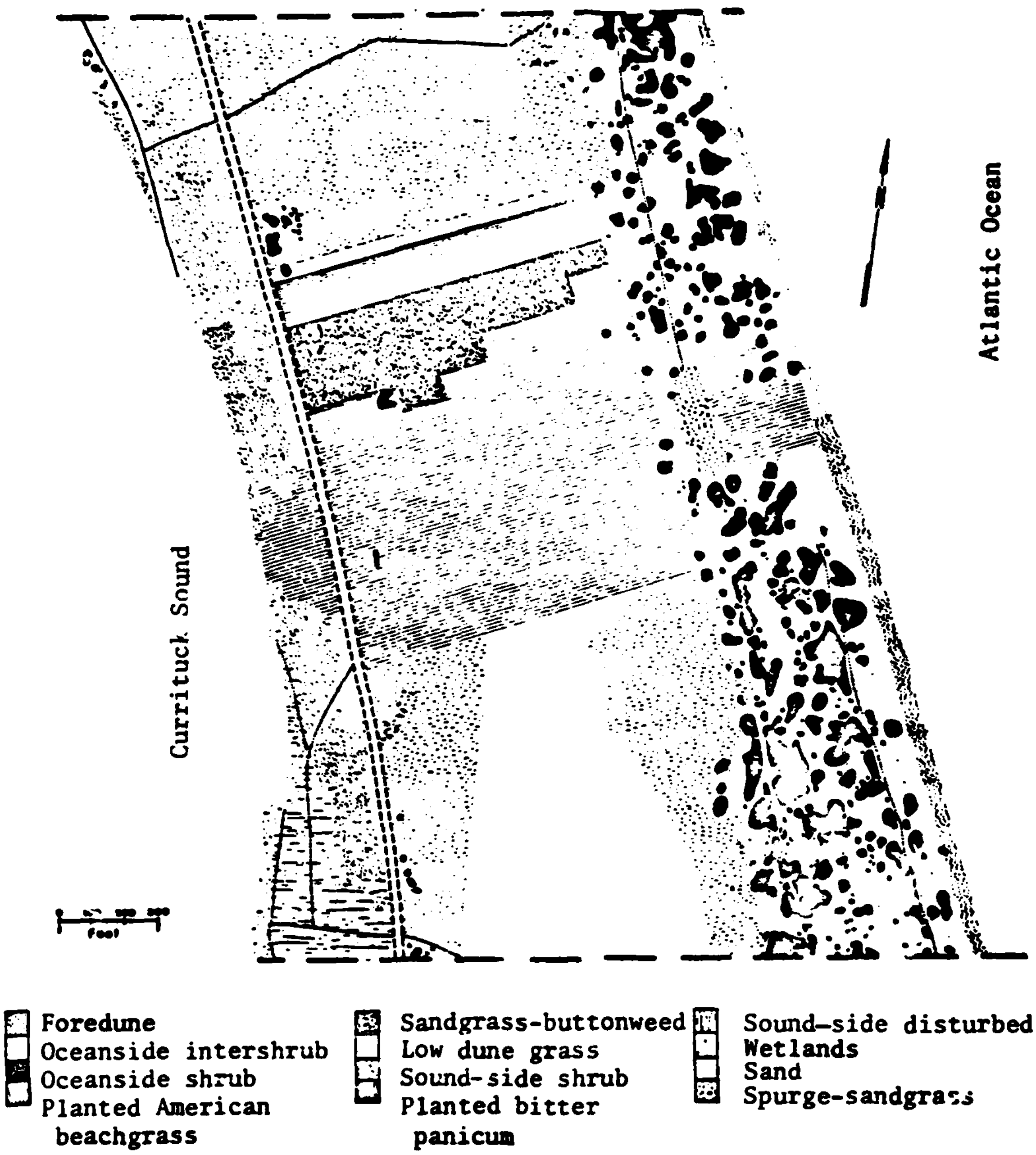

Figure 60. Vegetation map of the FRF (Levy 1976)

correlate with the communities generally common to the Outer Banks: foredunes, wetlands, oceanside shrub, sound-side shrub, low dune grass, and bare sand. The remaining five communities are relatively unique to this site: sound-side disturbed, planted American beachgrass (*Ammophila breviligulata*), planted bitter panicum (*Panicum amorulum*), sandgrass-buttonweed (*Triplasis purpurea-Diodia teres*), and spurge-sandgrass (*Euphorbia polygonifolia-Triplasis purpurea*).

104. In September 1978, CERC reestablished approximately two-thirds of the previous plots, which could be located, and added more. Plant species were collected and identified, and the vegetation was mapped for comparison with aerial photos at scales of 1:2,000 to 1:34,000. Optimum scales for identifying vegetative species, associations, communities, and zones were also determined in the comparison.

Dune vegetation

105. In April 1972, before CERC obtained the FRF site, the US Navy sprigged the area with American beachgrass. In 1973 and 1974, North Carolina State University conducted experiments on propagation, handling, processing, and planting of bitter panicum, American beachgrass, and sea oats (*Uniola paniculata*) in the northern part of the site about 300 m (1,000 ft) inland. By the fall of 1974, bitter panicum was the most successfully established. Fertilizer applications were necessary to retain the vigor of the planted stands. The results of this study were reported by Seneca, Woodhouse, and Broome (1976). Although the actual plantings are no longer clearly delineated, the general area is still identifiable from the air (see Figure 4).

Marsh vegetation

106. Experimental marsh plantings were established between April and September 1973 on the sound-side shore of the site to stabilize the eroding shore (Figure 61): a nursery area to the south and an unplanted control area to the north. Four species were planted: smooth cordgrass (*Spartina alterniflora*), black needlerush (*Junus roemerianus*), narrow- and broad-leaved cattails (*Typha* spp.), and common reed (*Phragmites australis*). Plant density and dry weight for the marsh were determined in June and October 1979. The results of this experiment show that the optimum planting time is April, May, and June. CERC, in conjunction with the Soil Conservation Service (SCS), has planted 10 species of freshwater marsh plants on the sound side to determine their erosion control potential, and 11 accessions of saltmeadow cordgrass (*Spartina*

Figure 61. Experimental marsh in Currituck Sound before planting (April 1973)

patens) in the dunes to determine those most suited for dune stabilization in the Outer Banks area.

107. Profile lines in the marsh were surveyed in 1973, 1978, and 1979. Between September 1973 and September 1978, the 1- to 1.5-m (3- to 5-ft) bank eroded at a rate of about 1.5 m (5 ft) per year. Between 1978 and 1979, 1.06 m^3/m (0.4 yd^3/ft) of sediment began to accrue in the planting area, while the unplanted area eroded -1.68 m^3/m (-0.7 yd^3/ft). The marsh is now well established (Figure 62). Many new species, mostly freshwater, have invaded

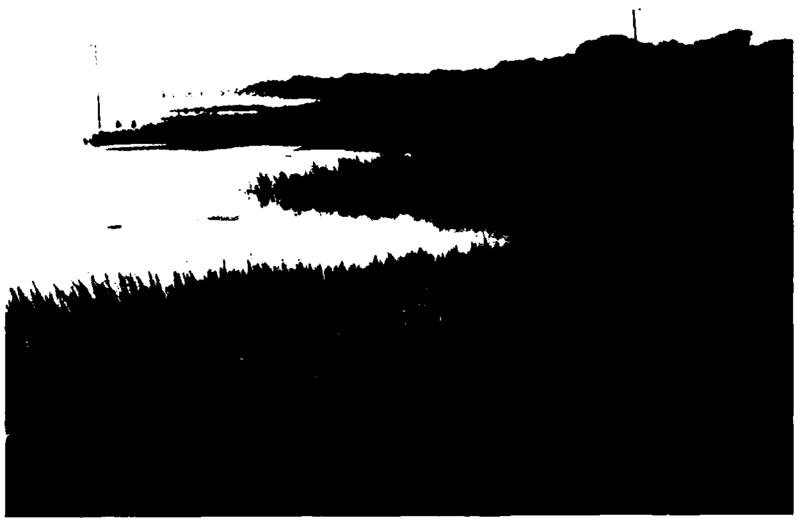

Figure 62. Experimental marsh in September 1975

the marsh, as the salinity is negligible, varying between 1 and 5 parts per thousand. Sediments in the sound are composed of medium sand.

Fauna Studies

108. Matta (1977) conducted an intensive seasonal study of the FRF ocean and sound beach fauna. On the ocean beach, 23 species of macrofauna in 5 phyla and 19 families were collected (see Appendix E); all but four of these species were polychaetes or crustaceans. Several types of meiofauna were also quantitated but were not identified to the species level. On the sound beach 23 species of macrofauna in 4 phyla and 23 families were collected (see Appendix E), with the phylum Arthropoda dominating the macrofauna, the phylum Annellida the most numerous.

109. The land fauna were surveyed over a period of a year from August 1975 to September 1976 (Gorbics and Hurme 1978)*. Identification was made on the basis of tracks, scats, visual observation, and trapping. Thirteen different species were documented; however, the study was not intensive enough to provide a complete fauna list.

110. In summary, the FRF provides a unique national resource for conducting a wide variety of research, engineering, and test and evaluation studies. To maximize the Facility's contribution to Corps and national needs, non-CERC use of this resource, as well as cooperative investigations, are encouraged.

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* C. S. Gorbics and A. K. Hurme, "Land Fauna Survey of the CERC Field Research Facility, Duck, N. C., US Army Engineer Waterways Experiment Station, Vicksburg, Miss., unpublished, Aug. 1978.

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This bibliography, compiled in 1980, contains more than 360 references discussing the Outer Banks of North Carolina, loosely defined as the area between Virginia Beach, Va., and Shackleford Banks, N. C. Although Virginia Beach is not a barrier island, it has been included because of its proximity to the FRF and because of the wealth of coastal research conducted there. The references are divided into the following broad topics:

Atlases
Beach Processes
Dunes
Ecology
Geology
Hydraulics
Inlets
Literature
Miscellaneous
Sediments
Shoreline Changes

Because some of these topics overlap (e.g., Beach Processes and Shoreline Changes) and citations are not cross referenced, the references under all pertinent topics should be checked.

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APPENDIX A: EXAMPLE OF LIABILITY RELEASE

CERC FIELD RESEARCH FACILITY

Safety and Liability Statement

I, ______________________________, representing ______________________________
(printed name) (agency/organization)

________________________________have been briefed on the safety aspects of my work at the FRF, Duck, N. C., and shall conduct my work so as not to cause undue hazards to myself, other individuals, or property. I agree that my work at the Facility is subject to the following conditions:

1) That I will make available all results and publications relating to FRF use to the Army and any other interested Government agency.

2) That any property of the United States damaged or destroyed by my actions shall be promptly repaired or replaced to the satisfaction of Chief, FRF, or in lieu of such repair or replacement, that I will pay to the United States money in an amount sufficient to compensate for the loss sustained by the United States by reason of damage to or destruction of Government property.

3) The United States shall not be responsible for damages to property or injuries to persons which may arise from or be incident to my use of the Facility, or for damages to my property or injuries to myself.

My experiment will be conducted from __________________ to __________________
(Date) (Date)

____
(Signature)

____
(Date)

APPENDIX B: DIVE PLAN

Nongovernment Diving Operations Plan

Field Research Facility

Duck, N. C.

1. Description of Mission:

a. Diving operations are scheduled to be conducted from _______________ to ______________ at the Field Research Facility (FRF), Duck, N. C.

b. The diving operation is being conducted by personnel from

____
(organization)

c. Briefly describe purpose of operation.

____
____
____

d. Describe in detail proposed underwater work.

____
____
____
____
____
____
____
____
____
____

e. Describe location of operation (if available include any coordinates, transit angles, etc.) in relation to the pier.

____
____
____

f. If equipment is to be left in place, provide a diagram on a separate page of the general layout including distances, instrumentation, handlines, pipes, buoys, etc.

g. Total expected bottom time for each diver for entire operation is ______ hours.

h. Maximum expected depth is ______ feet.

2. Description of Diving Apparatus/Equipment to be Used.

a. Open-circuit scuba, SAS, other (describe).

____

____

b. Wet suit, unisuit.

c. Tanks.

(1) Single - double.

(2) Steel - aluminum.

(3) Number being brought to FRF __________.

d. Diving craft or platform.

(1) Craft.

(a) Make ________________.

(b) Length __________________.

(c) Outboard hp _________________.

(d) Number of personnel (including divers) to accompany craft _____.

(2) If craft is not being used, briefly describe

(a) Means by which divers will enter and exit the water.

(b) Approximate distance from entry and exit point(s) to dive location.

3. Safety Requirements.

a. Diving.

(1) A standard diving flag will be displayed when diving operations are underway.

(2) All dives will be no-decompression dives.

(3) The minimum number of personnel on a scuba dive team will include: a diver, a buddy diver or standby diver (if diver is line tended), and a tender/timekeeper.

(4) Divers will maintain either visual or physical contact when submerged.

(5) A buoyancy compensator will be worn by each diver.

(6) Dives will not be made when steady currents exceed 1 knot.

(7) All dives will be accomplished in accordance with OSHA commercial Diving Regulation, Part 1910, Subpart T.

b. One diver in each dive team will be designated as the "senior diver" with the following responsibilities:

(1) Maintain a first aid kit.

(2) Notify the FRF Chief when diving operations are underway and when they are secured.

(3) Ensure that emergency support and facilities are available prior to commencement of dive.

(4) Give an operations briefing to all divers prior to the start of operations.

(5) Conduct a pre-dive check on divers prior to entering the water.

c. Diving craft.

(1) Breaking waves 4 feet or higher will preclude launching of craft through the surf zone.

(2) Normal safe boating practices will be followed.

4. Personnel.

Position	Name	Certification (type and date) divers only
Onsite supervisor (if other than senior diver)	____________	____________
Senior diver	____________	____________
Divers	____________	____________
	____________	____________
	____________	____________
Support personnel	____________	____________
	____________	____________
	____________	____________
	____________	____________

Place an asterisk (*) beside any personnel who are first aid and/or CPR qualified.

APPENDIX C: BENCH-MARK DOCUMENTATION FORM

BENCH-MARK DOCUMENTATION FORM

COUNTRY	TYPE OF MARK	STATION	
LOCALITY	STAMPING ON MARK	AGENCY (CAST IN MARKS)	ELEVATION (FT) (M)
LATITUDE	LONGITUDE	DATUM	DATUM
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	ESTABLISHED BY (AGENCY)
(NORTHING)(EASTING) (FT) (M)	(EASTING)(NORTHING) (FT) (M)	GRID AND ZONE	DATE / ORDER

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)
	° ' "	° ' "		

N

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.

APPENDIX D: SEASONAL JOINT WAVE HEIGHT-PERIOD DISTRIBUTIONS 1980-1982 (PIER END WAVE GAGE 625)

SEASONAL JAN-MAR
PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	11.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	TOTAL
0.00 - .49	.	2	1	4	7	5	11	11	11	7	14	9	.	82
.50 - .99	.	11	25	40	41	37	47	54	67	50	45	22	1	440
1.00 - 1.49	.	.	7	34	46	36	15	17	50	17	40	7	.	269
1.50 - 1.99	.	.	.	10	24	21	6	9	17	7	11	12	1	118
2.00 - 2.49	.	.	.	.	1	7	5	5	2	5	9	19	.	53
2.50 - 2.99	.	.	.	.	.	1	2	1	5	2	6	6	.	23
3.00 - 3.49	.	.	.	.	.	.	1	.	.	2	.	1	.	4
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	13	33	88	119	107	87	97	152	90	125	76	2	

SEASONAL APR-JUN
PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	11.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	TOTAL
0.00 - .49	.	2	2	7	23	25	57	46	28	8	12	17	1	228
.50 - .99	.	6	30	34	47	59	93	113	94	30	13	20	4	543
1.00 - 1.49	.	.	5	19	23	24	20	20	34	19	7	2	.	173
1.50 - 1.99	.	.	.	4	5	1	5	6	4	8	7	.	.	40
2.00 - 2.49	.	.	.	.	1	1	.	1	1	2	1	1	1	9
2.50 - 2.99	.	.	.	.	.	1	.	.	1	.	.	.	.	2
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	8	37	64	99	111	175	186	162	67	40	40	6	

SEASONAL JUL-SEP
PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	11.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	TOTAL
0.00 - .49	.	5	3	3	12	48	36	68	56	15	21	31	3	301
.50 - .99	.	4	29	32	84	71	44	64	63	29	25	20	3	468
1.00 - 1.49	.	.	3	21	44	23	15	15	16	9	12	7	.	165
1.50 - 1.99	.	.	.	7	9	7	.	3	4	1	5	4	.	40
2.00 - 2.49	.	.	.	.	1	.	.	.	.	3	9	3	.	16
2.50 - 2.99	.	.	.	.	.	.	1	1	1	.	3	.	.	6
3.00 - 3.49	.	.	.	.	.	.	.	1	.	1	.	.	.	2
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	9	35	63	150	149	96	152	140	58	75	65	6	

SEASONAL OCT-DEC
PERCENT OCCURRENCE(X10) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)													TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	11.0-10.9	11.0-11.9	12.0-13.9	14.0-16.9	17.0-LONGER	
0.00 - .49	.	.	2	.	3	7	10	12	11	8	23	15		91
.50 - .99	.	3	33	36	63	34	31	46	50	47	35	30	12	420
1.00 - 1.49	.	.	7	37	68	46	12	17	14	14	24	7	.	246
1.50 - 1.99	.	.	2	6	38	21	4	.	6	11	13	15	1	117
2.00 - 2.49	.	.	.	.	7	8	7	5	5	8	14	14	1	69
2.50 - 2.99	.	.	.	.	2	4	6	4	2	1	11	5	2	37
3.00 - 3.49	.	.	.	.	.	.	1	1	2	1	4	2	.	11
3.50 - 3.99	.	.	.	.	.	.	.	.	2	.	2	1	.	5
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	3	44	79	181	120	71	85	92	90	126	89	16	

APPENDIX E: LISTS OF FLORA AND FAUNA AT THE FRF

Table E1.

FRF Floristics List (Levy 1976)

Family and Species	Common Name
Family Aceraceae	
Acer rubrum L.	Red maple
Family Aizoaceae	
Mollugo verticillata L.	Carpet weed
Family Alismataceae	
Sagittaria graminea var. weatherbiana (Fernald) Bogin	Arrowhead
Family Amaranthaceae	
Alternanthera philoxeroides (Martins) Grisebach	Alligator weed
Family Anacardinaceae	
Rhus copallina L.	Winged sumac
R. radicans L.	Poison ivy
Family Apiaceae	
Centella asiatica (L.) Urban	
Eryngium aquaticum L.	Eryngo
Hydrocotyle umbellata L.	Marsh pennywort
Lilaeopsis carolinensis C. & R.	
Ptilimnium capillaceum (Michaux) Raf.	
Sium suave Walter	Water parsnip
Family Aquifoliaceae	
Ilex opaca Aiton	American holly
I. vomitoria Aiton	Yaupon
Family Asclepiadaceae	
Asclepias lanceolata Walter	Milkweed
Family Aspleniaceae	
Asplenium platyneuron (L.) Oakes	Ebony spleenwort
Family Asteraceae	
Achillea millefolium L.	Yarrow
Ambrosia artemisiifolia L.	Ragweed
Aster tenuifolius L.	Aster
Baccharis halimifolia L.	Groundsel tree
Bidens mitis (Michaux) Sherff	Beggar ticks
Carduus spinosissimus Walter	Yellow thistle
Crepis vesicaria ssp taraxifolia (Thuillier) Thellung	Hawk's beard
Eclipta alba (L.) Hasskar	Yerba-de-tago
Erigeron canadensis var. canadensis L.	Horseweed
E. candensis var. pusillus (Nuttall) Ahles	Horseweed
Eupatorium capillifolium var. capillifolium (Lam.) Small	Dog fennel
E. serotinum Michaux	Thoroughwort
Gaillardia pulchella Foug.	Blanket flower
Gnaphalium obtusifolium L.	Rabbit tobacco
Hieracium gronovii L.	Hawk weed
Heterotheca adenolepis (Fernald) Ahles	
H. gossypina (Michaux) Shinners	
Iva frutescens L.	Marsh elder
I. imbricata Walter	Seashore elder
Krigia virginica (L.) Willd.	Dwarf dandelion
Lactuca canadensis L.	Wild lettuce
Mikania scandens (L.) Willd.	Climbing hempweed
Pluchea foetida (L.) D.C.	Marsh fleabane
P. purpurascens (Swartz) D.C.	Salt marsh fleabane
Pyrrhopappus carolinianus var. carolinianus (Walter) D.C.	False dandelion
Solidago rugosa var. rugosa Miller	Goldenrod
S. sempervirens L.	Goldenrod
S. tenuifolia Pursh	Goldenrod
Xanthium strumarium var. strumarium L.	Cocklebur
Family Bignoniaceae	
Campsis radicans (L.) Seemann	Trumpet vine
Family Brassicaceae	
Cakile edentula (Bigelow) Hooker	Sea rocket
Lepidium virginicum L.	Peppergrass

Family and Species	Common Name
Family Cactaceae	
Opuntia compressa (Salisbury) Macbride	Prickley pear
O. drummondii Graham	Fragile prickley pear
Family Campanulaceae	
Lobelia elongata Small	Marsh lobelia
Specularia perfoliata (L.) A. D.C.	Venus' looking glass
Family Caprifoliaceae	
Lonicera japonica Thunberg	Japanese honeysuckle
L. sempervirens L.	Coral honeysuckle
Family Chenopodiaceae	
Chenopodium ambrosioides L.	Mexican tea
Family Cornaceae	
Cornus florida L.	Dogwood
Family Convolvulaceae	
Calystegia sepium (L.) R. Brown	Hedge bindweed
Family Cucurbitaceae	
Melothria pendula L.	Creeping cucumber
Family Cyperaceae	
Carex alata Torrey	Sedge
Cyperus dentatus Torrey	Sedge
C. erythrorhizos Muhl.	
C. filicinus Vahl	
C. haspan L.	
C. ovularis (Michaux) Torrey	
C. rivularis Kunth	
C. esquiflorus (Torrey) Mattfeld and Kukenthal	
C. strigosus L.	
C. surinamensis Rottboell	
Eleocharis tuberculosa (Michx.) R. & S.	Spike rush
Fimbristylis autumnalis (L.) R. & S.	Sand rush
F. dichotoma (L.) Vahl	
Fuirena squarrosa Michaux	Umbrella grass
Scirpus americanus Persoon	Chair maker's rush
Family Ebenaceae	
Diospyros virginiana L.	Persimmon
Family Euphorbiaceae	
Croton glandulosus var. septentrionalis Muell.-Arg.	Croton
C. punctatus Jacquin	Croton
Euphorbia polygonifolia L.	Beach spurge
Family Fabaceae	
Apios americana Medicus	
Cassia fasciculata Michaux	Partridge pea
Centrosema virginianum (L.) Bentham	Butterfly pea
Desmodium paniculatum (L.) D.C.	Beggar lice
D. pauciflorum (Nuttall) D.C.	Beggar lice
D. strictum (Pursh) D.C.	Beggar lice
Lespedeza capitata Michaux	Bush clover
Family Fabaceae (concl'd.)	
L. cuneata (Dumont) G. Don	
L. striata (Thunberg) H. & A.	Japanese clover
L. virginica (L.) Britton	
Strophostyles helvola (L.) Ell.	Wild bean
Family Fagaceae	
Quercus virginiana Miller	Live oak
Family Gentianaceae	
Sabatia dodecandra var. dodecandra (L.) B.S.P.	Sea pink
Family Hamamelidaceae	
Liquidambar styraciflua L.	Sweet gum
Family Hypericaceae	
Hypericum gentianoides (L.) B.S.P.	St. John's wort

(Continued)

Table E1 (Concluded)

Family and Species	Common Name
Family Juncaceae	
Juncus coriaceus Mackenzie	Rush
J. megacephalus M.A. Curtis	Rush
J. roemerianus Scheele	Black rush
Family Juncaginaceae	
Triglochin striata R. & P.	Arrow grass
Family Lamiaceae	
Monarda punctata L.	Horsemint
Salvia lyrata L.	Sage
Stachys nuttallii Shuttlew	Hedge nettle
Family Lauraceae	
Persea borbonia (L.) Spreng.	Red bay
Family Liliaceae	
Smilax bona-nox L.	Greenbrier
Yucca filamentosa L.	Bear grass
Family Linaceae	
Linum virginianum var. *medium* Planchon	Flax
Family Loganiaceae	
Polypremum procumbens L.	
Family Lycopodiaceae	
Lycopodium appressum (Chapman) Lloyd and Underwood	Club moss
Family Lythraceae	
Lythrum lineare L.	Loosestrife
Family Malvaceae	
Hibiscus moscheutos L.	Rose mallow
Kosteletzkya virginica (L.) Presl.	Sea shore mallow
Family Myricaceae	
Myrica cerifera var. *cerifera* L.	Wax myrtle
M. pensylvanica Loisel	Bayberry
Family Onagraceae	
Oenothera biennis L.	Evening primrose
O. fruticosa L.	Sundrops
O. humifusa Nuttall	Evening primrose
Family Orchidaceae	
Spiranthes cernua (L.) Richard	Nodding ladies' tresses
Family Pinaceae	
Pinus taeda L.	Loblolly pine
Family Phytolacaceae	
Phytolacca americana L.	Pokeweed
Family Plantaginaceae	
Plantago lanceolata L.	Plantain
Family Poaceae	
Andropogon elliottii Chapman	Broom straw
A. virginicus L.	Broom sedge
Ammophila breviligulata	American beachgrass
Bromus secalinus L.	Brome grass
Cenchrus tribuloides L.	Sandspurs
Cynodon dactylon (L.) Persoon	Bermuda grass
Digitaria filiformis var. *villosa* (Walter) Fernald	Crab grass
D. ischaemum (Schreber) Schreber ex Muhl.	Crab grass
D. sanguinalis (L.) Scopoli	Crab grass
Echinochloa walteri (Pursh) Heller	Walter's barnyard grass
Eleusine indica (L.) Gaertner	Goose grass
Elymus virginicus L.	Wild rye grass
Eragrostis elliottii Watson	Love grass
E. spectabilis (Pursh) Steudel	Love grass
Erianthus giganteus (Walter) Muhl.	Beard grass
Festuca sciurea Nuttall	Fescue
Leptoloma cognatum (Schultes) Chase	Witch grass
Family Poaceae (concl'd.)	
Panicum amarulum Hitchcock and Chase	Bitter panicum
P. amarum Ell.	Panic grass
P. dichotomiflorum Michaux	Fall ronieum
P. scoparium Lam.	
P. vaginatum Swartz	
P. virgatum L.	Switch grass
Polypogon monspeliensis (L.) Desf.	Rabbit foot grass
Sacciolepis striata (L.) Nash	
Setaria geniculata (Lam.) Beauvois	Fox tail grass
Sorgum halepense (L.) Persoon	Johnson grass
Spartina cynosuroides (L.) Roth	Giant cord grass
S. patens (Aiton) Muhl.	Salt meadow grass
Sphenopholis obtusata (Michaux) Scribner	Wedge grass
Triplasis purpurea (Walter) Chapman	Sand grass
Trisetum pensylvanicum (L.) Beauvois ex R. & S.	
Uniola paniculata L.	Sea oats
Zea mays L.	Corn
Family Polygonaceae	
Polygonum hydropiperoides var. *opelousanum* (Riddell ex Small) Stone	
P. pensylvanicum L.	Knot weed
P. sagittatum L.	Tear thumb
Rumex acetosella L.	Sheep sorrel
R. verticillatus L.	Swamp dock
Family Pontederiaceae	
Pontederia cordata L.	Pickerelweed
Family Primulaceae	
Samolus parviflorus Raf.	Water pimpernel
Family Ranunculaceae	
Ranunculus sardous Crantz	Buttercup
Family Rosaceae	
Amelanchier arborea var. *laevis* (Wiegand) Ahles	June berry
Prunus serotina var. *serotina* Ehrhart	Black cherry
Rubus betulifolius Small	Blackberry
Family Rubiaceae	
Diodia teres Walter	Buttonweed
D. virginiana L.	
Family Rutaceae	
Zanthoxylum clava-herculis L.	Hercules' club
Family Salicaceae	
Salix nigra Marshall	Black willow
Family Scrophulariaceae	
Agalinis purpurea (L.) Pennel	Gerardia
Linaria canadensis (L.) Dumont	Toad flax
Verbascum thapsus L.	Mullein
Family Solanaceae	
Physalis viscosa ssp *maritima* (M.A. Curtis) Waterfall	Ground cherry
Datura stramonium L.	Jimson weed
Family Urticaceae	
Boehmeria cylindrica (L.) Swartz	False nettle
Family Verbenaceae	
Callicarpa americana L.	French mulberry
Lippia nodiflora (L.) Michaux	Frogbit
Family Vitaceae	
Parthenocissus quinquefolia (L.) Planchon	Virginia creeper
Vitis aestivalis var. *aestivalis* Michaux	Summer grape
V. rotundifolia Michaux	Muscadine
Family Xyridaceae	
Xyris jupicai Richard	Yellow-eyed grass

Table E2.

Faunistic List of the Ocean Beach at the FRF (Matta 1977)

- Phylum NEMERTEA
  - *Tubulanus pellucidus*
- Phylum ANNELLIDA
  - Class Polychaeta
    - Family Spionidae
      - *Scolelepis squamata*
      - *Spiophanes bombyx*
    - Family Nephtyidae
      - *Nephtys bucera*
    - Family Megalonidae
      - *Megalona rosea*
    - Family Hesionidae
      - *Microphthalmus sczelkowii*
    - Family Opheliidae
      - *Travisia carnea*
    - Family Phyllodocidae
      - *Etcone heteropoda*
    - Family Glyceridae
      - *Glycera* sp.
- Phylum MOLLUSCA
  - Class Bivalvia
    - Order Heterodoatida
      - Family Donacidae
        - *Donax* sp. (probably *variablis*)
      - Family Solenidae
        - *Ensis* sp.
    - Order Prionodontida
      - Family Arcidae
        - *Anadara ovalis*
- Phylum ARTHROPODA
  - Class Crustacea
    - Order Amphipoda
      - Family Haustoriidae
        - *Parahaustorius longimerus*
        - *Amphiporeia virginiana*
        - *Bathyporeia quoddyensis*
      - Family Ischyroceridae
        - *Jassa falcata*
    - Order Mysidacea
      - *Metamysidopsis mexicana*
    - Order Cumacea
      - Family Leuconidae
        - *Leucon americanus*
        - *Eudorellopsis deformis*
      - Family Pseudocumidae
        - *Petalosarsia declivis*
    - Order Decapoda
      - Family Paguridae
        - *Pagurus longicarpus*
      - Family Portunidae
        - *Ovalipes ocellatus*
      - Family Hippidae
        - *Emerita talpoida*
  - Microcrustacea
    - Subclass Ostracoda
      - Order Myodacopoda
        - Species A
      - Order Podocopa
        - Species A
    - Subclass Copepoda
      - Order Harpacticoida
        - Species A
        - Species B
- Phylum CNIDARIA
  - Class Anthozoa
    - Order Actiniaria
      - Species A (immature)

Table E3.

Faunistic List of the Sound Beach at the FRF (Matta 1977)*

- Phylum NEMATODA
  - Order Dorylaimida
- Phylum ANNELLIDA
  - Class Polychaeta
    - Order Spionida
      - Family Spionidae
        - *Scolecolepides viridis*
    - Order Phyllodocida
      - Family Nereidae
        - *Laconereis culveri*
    - Order Terebellidae
      - Family Ampharetidae
        - *Lysippides grayi*
  - Class Oligochaeta
    - Order Prosopora
      - Family Lumbriculidae
        - *Lumbriculus* sp.
    - Order Plesiopora
      - Family Tubifisidae
        - *Peloscolex* sp.
- Phylum MOLLUSCA
  - Class Bivalvia
    - Family Mactridae
      - *Rangia cuneata*
  - Class Gastropoda
    - Order Pulmonata
      - Family Physidae
        - *Physa* sp.
      - Family Ancylidae
        - *Ferrissia* sp ?
- Phylum ARTHROPODA
  - Class Crustacea
    - Order Amphipoda
      - Family Haustoridae
        - *Lepidactylus dyticus*
      - Family Gammaridae
        - *Gammarus* sp.
      - Family Photidae
        - *Leptocheirus plumulosus*
      - Family Oedicerotidae
        - *Monoculodes* sp.
    - Order Isopoda
      - Family Anthuridae
        - *Cyathura polita*
      - Family Idoteidae
        - *Chiridotea* sp.
    - Order Decapoda
      - Family Cambaridae
        - *Cambarus* sp ? (immature)
      - Family Portunidae
        - *Callinectes sapidus*
  - Class Insecta
    - Order Odonata
      - Family Coenagrionidae
        - *Enallagma* sp.
    - Order Collembola
      - Species A
    - Order Coleoptera
      - Family Dytiscidae
        - *Uvarus* sp.
    - Order Diptera
      - Family Tabanidae
        - Species A (immature)
      - Family Chironomidae
        - (Immatures)
      - Family Cerotopogonidae
        - (Immatures)

* Species above 0.5 mm only

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