Technical Report CERC-93-13
August 1993

US Army Corps of Engineers
Waterways Experiment Station

Coastal Research Program

Beach Nourishment Project Response and Design Evaluation: Ocean City, Maryland

Report 1
1988-1992

by *Donald K. Stauble, Andrew W. Garcia, Nicholas C. Kraus*
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Prepared for Headquarters, U.S. Army Corps of Engineers

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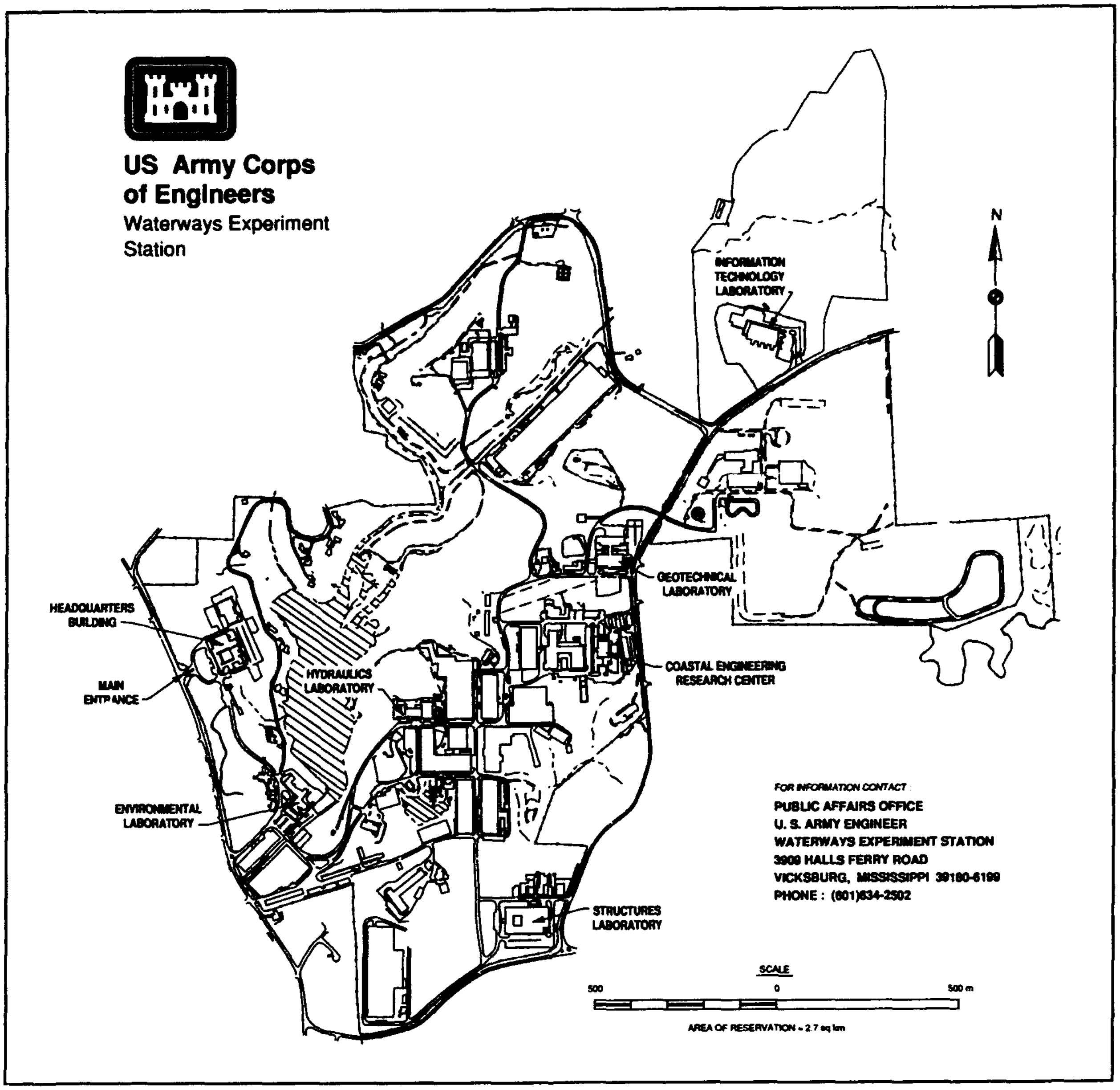

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Preface

The work described herein was authorized as a part of the Civil Works Research and Development Program by Headquarters, U.S. Army Corps of Engineers (HQUSACE). Work was performed under the Episodic Events Work Unit 12112 of the Coastal Field Data Collection Program and under the Beach Fill Engineering Work Unit 32801 of the Shore Protection and Restoration Program at the Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station (WES). Messrs. John H. Lockhart, Jr., John G. Housley, Barry W. Holliday, and David A. Roellig were HQUSACE Technical Monitors. Ms. Carolyn M. Holmes, CERC, was Program Manager of the Coastal Research Program and Field Data Collection Program.

This report was written over the period 1 January through 30 June 1992 by Dr. Donald K. Stauble, Team Leader, Coastal Geology Unit, Coastal Structures and Evaluation Branch (CSEB), Engineering Division (ED), CERC; Dr. Andrew W. Garcia, Prototype Measurement and Analysis Branch (PMAB), ED, CERC; Dr. Nicholas C. Kraus, Senior Scientist, CERC; Mr. William G. Grosskopf, Principal, Offshore Coastal Technologies, Inc., East Coast; and Mr. Gregory P. Bass, Engineering Division, US Army Engineer District, Baltimore (USAED Baltimore). Mr. Robert Lindner, Planning Division, and Mr. Alfred E. Robinson, Engineering Division, USAED Baltimore, provided background documentation and review of this report. Mr. James P. McKinney, mathematician, PMAB, prepared the plates containing wave data; Ms. Claire R. Livingston and Mr. Brian Williams, Contract Students, CSEB, respectively assisted in reducing and compiling the grain-size and beach-profile data and in preparing computer graphics; Ms. Karen Pitchford, Technician, CSEB, assisted in data reduction and generation of three-dimensional graphs; Mr. John M. Mason, ASCI Corporation and Coastal Processes Branch (CPB), Research Division (RD), CERC, provided computer services support for reduction and analysis of the profile survey data; and Ms. Allison Abbe, Science and Engineering Aide, CPB, RD, CERC, assisted in formatting of this report. Mr. Mark Hansen, former member of CSEB, CERC, coordinated monitoring of the Phase I portion of the project. This study was performed under the administrative supervision of Dr. James R. Houston, Director, CERC; Mr. Charles C. Calhoun, Jr., Assistant Director, CERC; Mr. Thomas W. Richardson, Chief, ED, Ms. Joan Pope, Chief, CSEB, and Mr. William L. Preslan, Chief, PMAB. Dr. Garcia was the Principal Investigator, Episodic Events Work Unit 12112, and Dr. Kraus was Principal Investigator, Beach Fill Engineering Work Unit 32801. This report was edited by Ms. Janean Shirley, Information Technology Laboratory, WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic yards	0.7646	cubic meters
degrees	0.01745	radians
feet	0.3048	meters
inches	25.4	millimeters
knots	0.5148	meters/second
miles (US statute)	1.6093	kilometers
nautical miles	1.8532	kilometers
yards	0.9144	meters

1 Introduction

Beach nourishment, the artificial placement of material on the beach, is becoming a preferred method of shore protection on eroding coastlines. Shore-protection works are aimed at preserving life and permanent resources located in the backshore against inundation, wave attack, and erosion that accompany hurricanes and severe storms. As one of several possible shore-protection alternatives, beach nourishment is often the least expensive, and it has the advantage of providing a natural seaside environment for residents and visitors, as well as habitat for animals and vegetation.

Similar to all engineered structures, a beach nourishment project must undergo periodic inspection and maintenance, and it also has a certain assigned longevity. Engineering parameters entering beach nourishment design include required volume of material, maintenance volume and schedule, and the profile configuration that will optimally provide the desired level of protection against a storm of certain frequency or characteristics. These parameters are determined through physical-process and economic models that incorporate beach and upland inventories of resources, by observation of the response of natural beaches and nourishment projects in the area to storms, and by calculations with numerical models that simulate storm-induced beach erosion. Quantitative estimates of the adjustment of the material after it is placed on the beach and long-term evolution under wave action, currents, and changes in water level are also part of the beach nourishment design.

Owing to the great expense and risk of nearshore data collection, measurements of long-term evolution and short-term response to storms of both natural and nourished beaches are scarce. Research work units of the Coastal Program of the U.S. Army Corps of Engineers that are conducted at the U.S. Army Engineer Waterways Experiment Stations's (WES's) Coastal Engineering Research Center (CERC) actively seek opportunities to collect data on beach fill performance and the associated oceanographic and meteorologic forces to assess and improve beach fill design and monitoring procedures.

Through the cooperation and combined resources of the State of Maryland, the U.S. Army Engineer District, Baltimore (USAED, Baltimore), and research elements of CERC, an extensive and unprecedented level of monitoring is taking place at a beach nourishment project located along the coast of Ocean City, Maryland. This project was divided into two phases, with the State of Maryland placing fill on the beach during the summer of 1988 (herein called the State fill) and the Corps of Engineers placing fill along the Ocean City shoreline during the summer of 1990 and finishing during the summer of 1991 (herein called the Federal fill). The project as a whole is formally called the "Atlantic Coast of Maryland (Ocean City) Shoreline Protection Project," as stated in an errata sheet dated 25 January 1990 that accompanies the final *General*

Design Memorandum (GDM) (USAED Baltimore 1989). The database contains pre-project sediment sampling and high-accuracy beach profile surveys, approximately quarterly surveys of the beach profile from 1988 to the present, and nearshore wave and water-level measurements from the summer of 1988 to the present. Additional beach profile surveys have been made to capture the response of the nourished beach to several major storms, and the joint monitoring program is expected to continue for 5 years subsequent to the official completion of initial construction, September 1988.

The data set for the Ocean City beach nourishment project will become a valuable resource for understanding the behavior of beach nourishment projects, and the objectives of this report are to document the project from its inception to the present and to provide first-order analyses and interpretation of the data. Future publications on the Ocean City project will continue in compiling the data; also, additional analysis will be performed, including numerical modeling of longshore and cross-shore sand transport and the resultant beach planform and profile change, and quantification of the changes, if any, of the sediment grain size along and across the shore. Regional processes in relation to the nourishment project will also be considered.

Project Setting

Ocean City, Maryland, is located on Fenwick Island, a north-south oriented barrier island of the central Delaware-Maryland-Virginia (Delmarva) coast (Figure 1). The Delmarva Peninsula is located in the mid-Atlantic Bight between the latitudes of approximately 37 and 39 deg, terminating at Cape Henlopen, Delaware, on the north and, on the south, at Cape Charles at the entrance to Chesapeake Bay, Virginia. The orientation in trend of the coast along the peninsula changes from west of north at Cape Henlopen to west of south at Fishing Point, Virginia, and continuing similarly to Cape Charles.

The Delmarva coastline has undergone steady landward transgression during recent geologic history, attributed to relative sea-level rise (for example, estimated by Lyles, Hickman, and Debaugh (1988) to be 3.2 mm/year at Baltimore, Maryland, from the record of a tidal gauge fully operating from the years 1903 to 1986), loss of sediment on its lateral ends, and barrier washover. Anders and Hansen (1990) summarize the geological history of the area, and Halsey (1979) discusses the paleontology and stratigraphy of the Delmarva Peninsula and the transgressive movement of its barriers.

Fenwick Island is a sandy barrier spit extending between Indian River Inlet, Delaware, to the north and Ocean City Inlet to the south, and it is backed by Isle of Wight and Assawoman Bays (Figure 2). To the north, before reaching Indian River Inlet, Fenwick Island joins the mainland at a headland located in the vicinity of Bethany Beach, Delaware. The length of coast between Indian River Inlet and Ocean City Inlet is about 20 miles[1], and island width ranges between approximately 2,000 ft along Isle of Wight Bay to 1,500 ft along Assawoman Bay, exclusive of substantial back-bay wetlands and commercial development such as marinas. The elevation along a central axis of Fenwick Island is approximately 5 ft National Geodetic Vertical Datum (NGVD) and intermittent coastal dunes can vary in height, with 10- to 15-ft-high (NGVD) dunes being typical (US Geological Survey Quadrangle Maps: Ocean City Quadrangle

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page xii.

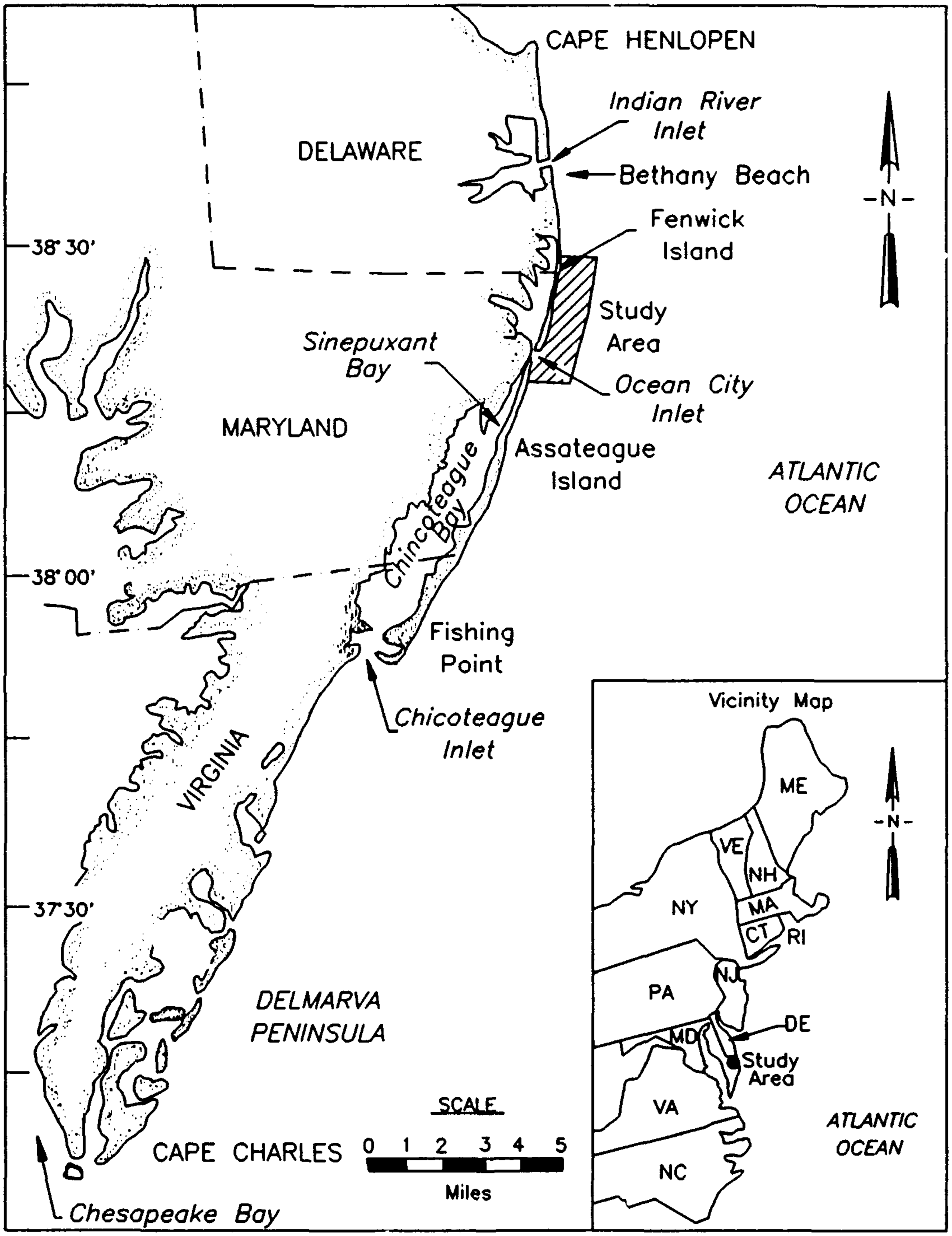

Figure 1. Location map for the project site (Delmarva Peninsula)

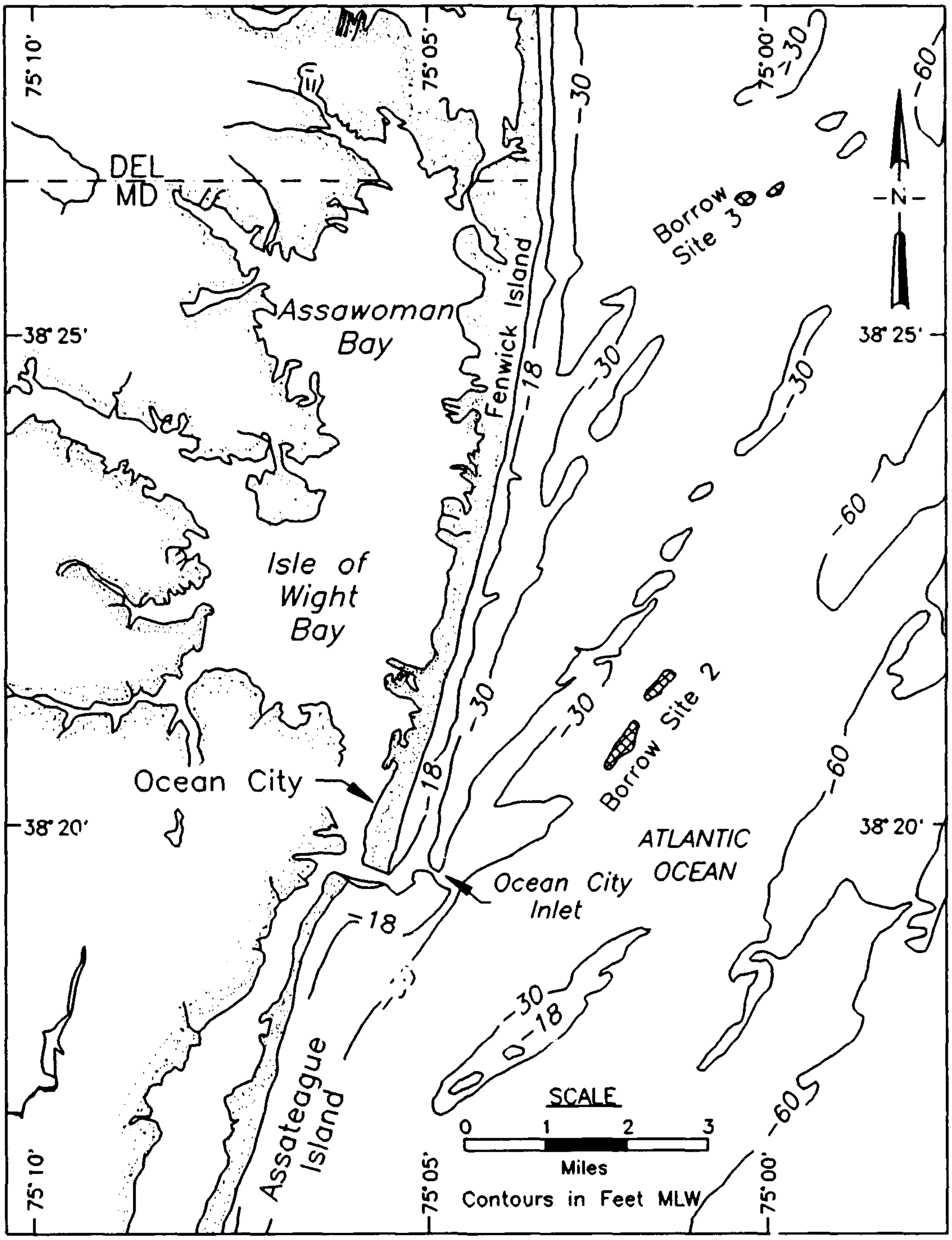

Figure 2. Fenwick Island and nearshore

M3815-W7500/7.5 (1964; photorevised 1972) and Assawoman Bay, MD.-Del. Quadrangle 38075-DI-TF-024 (1967; photorevised 1981). The foreshore slope along Ocean City averages about 1:10 down to 2 ft below NGVD. From -2 ft to -10 ft NGVD, the profile slope averages 1:40. A longshore bar is typically located at about the 5-ft depth. Deeper than 10 ft, the profile becomes more gentle. The 30-ft depth contour is located about 1 nm offshore, and the 60-ft depth contour lies about 3 nm offshore. Grain-size analysis of the extensive beach samples taken in April 1986 (Anders and Hansen 1990) gave a composite median grain size of 0.37 mm after eliminating small quantities of gravel from the analysis(USAED Baltimore 1989).

The Ocean City nourishment project terminates at the Delaware State line. The State of Delaware, in conjunction with the State of Maryland project in 1988, placed approximately 333,500 cu yd of fill along 1 mile of beach just north of the State line in the Town of Fenwick Island (Figure 3). The fill placed at Fenwick Island, Delaware, was the southern portion of a 1988-1989 State of Delaware beach restoration project that also included fill placement in the Bethany Beach/South Bethany Beach area (Skrabal, Ramsey and Henry 1990). A tapered transition beach was extended 1,600 ft along Fenwick Island, Delaware during the Federal fill placed during 1991 to preserve the integrity of the project from flanking and end loss. To the south, the project ends 3,500 ft north of the north jetty of Ocean City Inlet. Maryland's beaches are contiguous with the sandy beach/dune system of the Delaware coast that includes the Town of Fenwick Island, which continues north to Fenwick Island State Park, the towns of South Bethany Beach and Bethany Beach, and on to Indian River Inlet.

Assateague Island lies to the south of Ocean City Inlet as the next barrier in the Delmarva chain. This 37-mile-long sandy barrier island is backed by Sinepuxent Bay to the north and by Chincoteague Bay to the south, terminating to the south at Chincoteague Inlet, Virginia. Assateague Island is undeveloped, with Assateague Island National Seashore operated by the National Park Service (NPS) on the northern portion located in the State of Maryland, together with a State Park operated by the Maryland Department of Natural Resources, and on the southern portion as Chincoteague National Wildlife Refuge located in the State of Virginia.

Fenwick and Assateague Islands were separated on 23 August 1933 by an intense hurricane that opened what is now Ocean City Inlet. Truitt (1968) describes the periodic openings by storms of inlets on Fenwick and Assateague Islands that have occurred since the late 17th century. He states that along the Maryland coast, historically, "five natural inlets supported sea-going vessels." Although the inlet opened in 1933 would probably have closed as have others, the entrance was made permanent by construction of jetties by the Federal Government, and the Corps of Engineers (CE) maintains the inlet for navigation. Placement of jetties and development of a large ebb tidal shoal off the inlet have severely reduced the supply of sediment that would reach Assateague Island in the littoral drift that has a net from the north. Dean and Perlin (1977) discuss shoreline-related impacts of jetty construction for both Fenwick and Assateague Islands. The geologic, demographic, and engineering history of Fenwick Island has been summarized by Dolan, Lins, and Stewart (1980), including many aerial photographs.

Project History

The Committee on Public Works of the House of Representatives, at the request of local interests made through their representative in Congress, adopted a resolution on 19 June 1963 directing the Secretary of the Army to direct the Chief of Engineers to make a study of the shores of the Atlantic Ocean in Maryland. The CE was to ascertain the need for beach erosion control, hurricane protection, and related purposes. By a resolution dated 13 February 1967, the Committee expanded the study to include the Virginia portion of Assateague Island.

In response to the 1963 authorization, the USAED Baltimore undertook a study of storm protection for Ocean City, Maryland, and Assateague Island. Those efforts resulted in a completed draft report in May 1970.[1] This report was not made final because the city of Ocean City withdrew project support until the mid-1970's. The draft report recommended that a Federal project for beach erosion control and hurricane protection at Ocean City be adopted. It also presented a plan to solve erosion and storm damage on Assateague Island. During the next 6 years, the plan was revised and updated in order to obtain support of local interests. In March 1978, local support was provided by the Maryland Department of Natural Resources.[2] A feasibility and environmental impact study was initiated, resulting in an August 1980 report entitled, "Atlantic Coast of Maryland and Assateague Island, VA, Feasibility Report and Final Environmental Impact Statement" (USAED, Baltimore 1980).

The feasibility report recommended the construction of a beach and dune system along approximately 33,500 ft of shoreline between 27th Street and the Maryland-Delaware state line. A map of the project layout is given in Figure 3. A sheet-pile bulkhead was recommended to be placed from 27th Street south to North Division Street (located south of 1st Street). The design height of the berm was +8.7 ft, the total beach width was recommended to be 200 ft, and the dune/bulkhead crest was recommended to be +16.0 ft. All topographic elevations and water depths given in this report, unless otherwise stated, refer to the National Geodetic Vertical Datum (NGVD) established in 1929. A storm warning plan and periodic sand replenishment every 3 years were also recommended in the report.

The Chief of Engineers submitted the report on the recommended Storm Protection Project on 29 September 1981 to the Assistant Secretary for Civil Works. The Assistant Secretary, on 27 May 1983, requested that the Office of Management and Budget (OMB) review the Chief of Engineers' report. At that time OMB opposed authorization of the project because recreational benefits were a large part of the total benefits of the project.

On 2 May 1984, the Governor of Maryland, after being notified of OMB's decision, expressed concern about the decision and indicated the need for protection from storms and for erosion control.[3] The Baltimore District Engineer responded that the project was recreation

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[1] Draft Summary Report for Atlantic Coast of Maryland and Assateague Island, Virginia; Beach Erosion Control and Hurricane Protection Planning, USAED Baltimore, Maryland, May, 1970.

[2] Letter from Mr. James B. Coulter, Secretary, Maryland Department of Natural Resources, to Baltimore District Engineer Withers, dated 29 March 1978.

[3] Letter from Maryland Governor Harry Hughes to Baltimore District Engineer Brown, dated 2 May 1984.

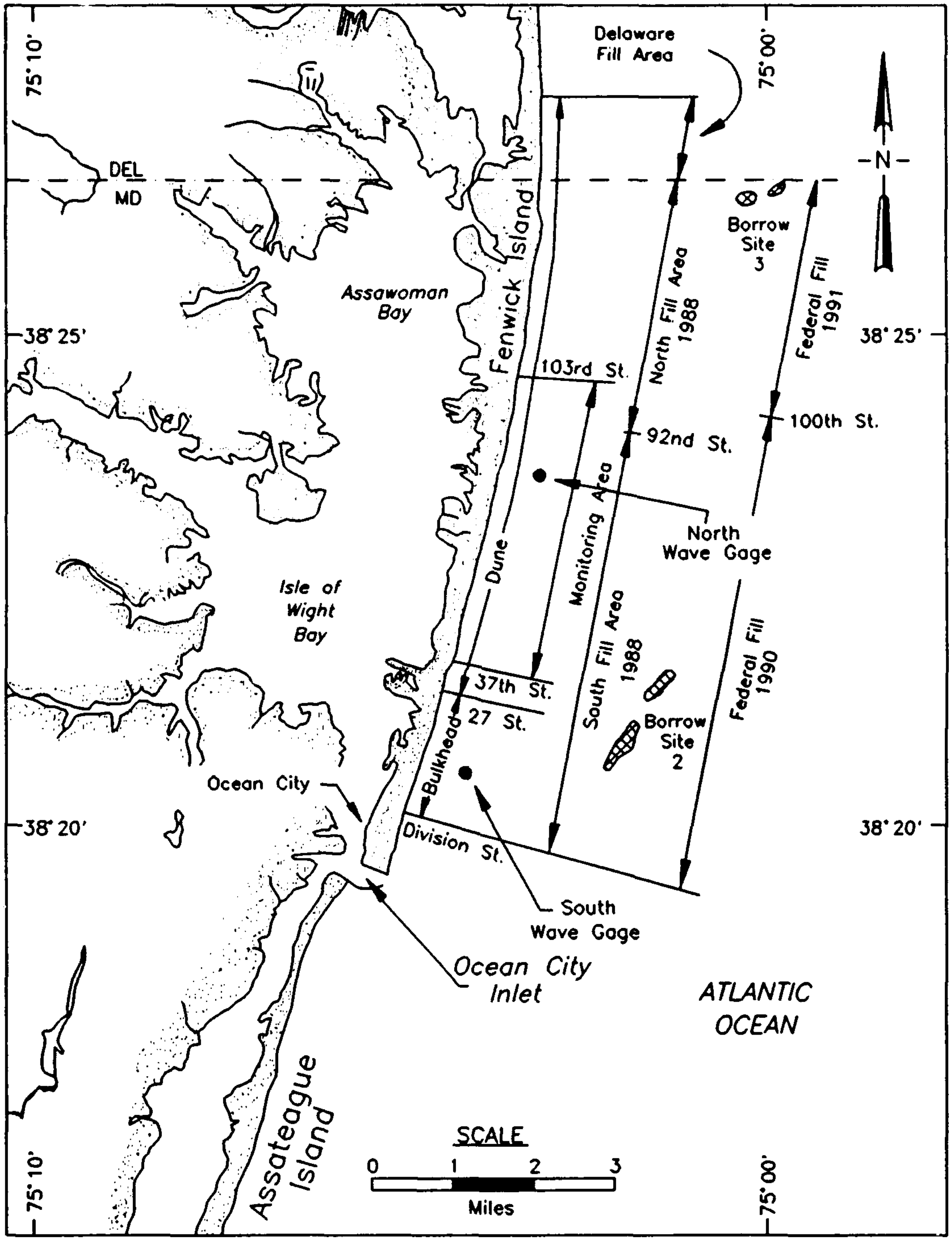

Figure 3. Beach nourishment project monitoring area

oriented and that State and local governments or the private sector should provide for recreational opportunities. In April 1985, the Governor[1] outlined the State of Maryland's ongoing efforts to stabilize the beach at Ocean City and requested that the District consider providing only the hurricane protection portion of the CE 1981 plan. The Governor indicated that the State would provide a series of groins and a 24-ft-wide beach, which would eliminate the need for the recreational component of the CE plan that OMB found unacceptable. The CE was requested to consider providing the additional storm protection on its own merit.

In 1985, the State of Maryland noted that an enhanced recreational beach could be maintained at a much lower cost using periodic beach nourishment as originally proposed by the CE instead of continuing to construct stone groins. During that same year, the CE found that the State's plan would provide 10-year protection from storms and that the benefit-cost ratio on storm-protection benefits only, above the 10-year level, was estimated at 1.3 to 1. In August 1985, the USAED, Baltimore, furnished the Governor a letter stating that the storm protection plan was economically justified if the State beach replenishment plan was in place.[2] The State then agreed to abandon its plan to build stone groins, to construct the first component of the project, and to cost-share the storm-protection plan. Congress subsequently directed the CE in the Conference Report on the FY 1986 Appropriations Bill on Energy and Water Development (October 1985) to continue engineering studies for the storm protection project.

The Atlantic Coast of Maryland (Ocean City) Shoreline Protection Project was authorized for construction by Section 501(a) of the Water Resources Development Act of 1986 (Public Law 99-662) which states in part:

> The following works of improvement for the benefit of shoreline protection are adopted and authorized to be prosecuted by the Secretary substantially in accordance with the plans and subject to the conditions recommended in the respective reports designated in this subsection, except as otherwise provided in this subsection. Construction of the projects authorized in this title shall be subject to determinations of the Secretary, after consultation with the Secretary of the Interior, that the construction will be in compliance with the Coastal Barrier Resources Act (Public Law 97-348)...
>
> The project for shoreline protection, Atlantic Coast of Maryland and Assateague Island, Virginia: Report of the Chief of Engineers, dated September 29, 1981, at a total cost of $58,200,000, with an estimated first-Federal cost of $26,700,000 and an estimated first non-Federal cost of $31,500,000.

The purpose of the authorized project, according to the GDM (USAED, Baltimore 1989), "...is to provide beach erosion control and to protect the Town of Ocean City from a 100-year storm on the Atlantic Ocean." The State of Maryland, in December 1985, agreed to "construct a beach profile which exceeds minimum requirements essential for erosion control...".[3]

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[1] Letter from Maryland Governor Harry Hughes to Baltimore District Engineer Walsh, dated 6 April 1985.

[2] Letter from Baltimore District Engineer Walsh to Maryland Governor Hughes, dated 13 August 1985.

[3] Letter from the Maryland Director for the Department of Natural Resources Administration to the Assistant Secretary of the Army (Civil Works), dated 12 December 1985.

Implementation of this agreement meant that the State would build, in 1988, and at its own expense, a beach consisting of 2.4 million cu yd of material. The Federal project, to be built by the CE in addition to the State of Maryland's beach, would then provide protection against extreme storms. In March 1988, the State of Maryland awarded a contract for beach replenishment. The State fill construction was completed in September 1988 after placement of 2.4 million cu yd of sand at a total cost of $14,200,000. That fill served as the first component of the shore-protection project.

During the years 1987-1989, planning and engineering studies were performed and completed for the CE portion of the project, i.e., the storm-protection beach fill. Construction of the Federal project extended over two summer seasons, with approximately 70 percent constructed during summer 1990 and the remainder during summer 1991.

Physical Processes

The change in orientation of the Delmarva coast that occurs along Fenwick Island may have consequence for longshore sand transport direction. Evidence from impoundment at the south jetty and erosion at the north jetty at Indian River Inlet, Delaware, indicates a net longshore sand transport on the order of 100,000 cu yd/year to the north (Clausner et al. 1991). Impoundment at the north jetty of Ocean City Inlet and shoreline recession on Assateague Island adjacent to the south jetty indicate transport to the south at the south end of Fenwick Island. There is, therefore, a divergent nodal point in transport along Fenwick Island that is nominally placed in the vicinity of Bethany Beach, Delaware, although long-term trends in waves and wind imply great spatial and temporal variability in the location of the nodal point (Dean and Perlin 1977). The reversal in transport along Fenwick Island is probably dominated by change in shoreline orientation, although year-to-year variations in waves and irregular offshore bathymetry will also exert some control. The conclusion is clear, however, that over a long time interval, Fenwick Island is losing sand by longshore transport across its two lateral borders. The average shoreline recession rate for Fenwick Island from the Maryland state line to Ocean City Inlet between 1849 and 1980 was -2 ft/year, ranging between 0 and -4 ft/year (Byrnes, in preparation)

The north jetty, constructed in 1934, has reached its capacity for trapping sand. Dean and Perlin (1977) examined aerial photographs and found that shoreline position adjacent to the north jetty had reached a dynamic equilibrium position by at least 1955. Limited availability of earlier photographs makes determination of the exact approach to equilibrium uncertain. The 3,500 ft of beach adjacent to the north jetty is wide in comparison to the more northern beach (Figure 4). Sand that passed through or over the north jetty in the past contributed to the formation of the flood tidal shoal that is located in Isle of Wight Bay. Sand entering the navigation channel that is dredged is placed by pipeline along the northern end of Assateague Island. Sand that bypasses the north jetty is also jetted offshore or carried in the ebb-tidal current to settle on the ebb tidal shoal. Loss of sand from the littoral system into the ebb-tidal shoal has been a primary cause for rapid shoreline retreat along northern Assateague Island (Leatherman et al. 1987).

Northern Assateague Island, shown in Figure 5, has exhibited a decrease in shoreline recession since the late 1960's, corresponding to the slower rate of shoal growth since 1967. This decrease is evident on the shoreline change maps produced by the National Ocean Service (NOS) and CERC for the Delmarva coast (Byrnes, in preparation). Prior to 1933, Assateague

Figure 4. Oblique aerial photograph showing southern end of Fenwick Island

Spit, in the vicinity of what is now northern Assateague Island, was eroding at approximately 3 ft/year). Shortly after the hurricane breached Assateague Spit in 1933, the CE stabilized the inlet with two jetties. The jetties and the new inlet interrupted pre-inlet longshore sediment movement patterns. The result was accumulation of sand on the Ocean City beaches north of the north jetty, development of an offshore ebb-tidal shoal and a flood-tidal shoal in the adjacent bay, and severe downdrift shoreline recession of northern Assateague Island.

Because the northern jetty and emerging ebb shoal trapped littoral material, shoreline recession rates along northern Assateague Island initially exceeded 40 ft/year. Although the zone north of the north jetty filled, the ebb-shoal continued to act as a sink for sediment, contributing to the high rate of shoreline recession. During this time, the shoreline and dunes of northern Assateague Island eroded landward until overwash penetrated across the full width of the barrier. Since that time, barrier width has remained dynamically constant as the entire island form migrates landward. Consequently, the width of Sinepuxent Bay has decreased in this area. Storms have created a sheet flow overwash area devoid of vegetation to the south of the inlet. Further to the south, as the erosion reached into the dunes, the dunes were lowered and frequent

Figure 5. Oblique aerial photograph of northern Assateague Island

overwash channels and fans developed at low points in the primary dune line (Fisher and Stauble 1977, Leatherman 1979). These morphologic changes have modified the island's ecological characteristics as well, because of the transport of sand inland through the overwash channels. The resulting overwash fan deposits covered existing island vegetation. With time, vegetation has grown through this new sand deposit.

Observations and data recently acquired by CERC suggest that the Ocean City Inlet ebb shoal growth may be slowing, allowing bypassing of littoral materials to northern Assateague, which would eventually reduce future shoreline recession and island migration. Wave refraction over the Ocean City Inlet ebb shoal probably produces localized northerly littoral drift along the northern tip of Assateague Island. Movement of littoral materials into the inlet throat and subsequent shoaling of the ship channel were substantially reduced by sand tightening of the south jetty in 1985, originally recommended by Dean and Perlin (1977). An initial effect of sand tightening has been rapid beach accretion immediately south of the south jetty (Bass, Fulford, and Underwood, in preparation). To the present writing, the navigation channel has been dredged only once (over September to November, 1990).

Ebb-tidal shoal

Anders and Hansen (1990) identified nine potential borrow sites for the Ocean City beach nourishment project, including the ebb shoal. This ebb shoal, which began forming when the inlet opened in August 1933, extends approximately 0.6 mile offshore, and is approximately 2 miles wide. Nine vibracores and limited seismic data were collected over the shoal. Preliminary comparison of bathymetric surveys (Underwood and Anders 1989) indicates that ebb shoal sediment volume increased steadily from 1935 to the mid 1970's at a rate of approximately 350,000 cu yd/year. Since this time, sediment accumulation on the shoal has been irregular, with an overall average rate of 39,000 cu yd/year. This irregular behavior may indicate an approach to a dynamic equilibrium condition where the ebb shoal, which previously acted as a sediment sink, is now allowing sediment to bypass to northern Assateague Island. Detailed re-examination of these data sets, together with acquisition of new data sets, is in progress at CERC to accurately portray the time sequence of ebb shoal growth to the present and its impacts on the downdrift shoreline of Assateague Island.

Waves

Nearshore wave measurements made at the site by CERC from August 1988 through January 1992 are discussed in Chapter 2, with summaries of wave statistics given in Appendix A. This measurement program has already provided rare and valuable wave- and water-level data for assessing the impacts of storms on a beach-fill project (discussed in Chapter 3). The present section reviews general properties of the waves as derived from a comprehensive hindcast. Water level information is also discussed.

Wave statistics for the Atlantic coast of the United States for the 20-year period 1956 to 1975 are available from a hindcast performed by CERC's Wave Information Study (WIS). The WIS provides wave height, period, and direction for both sea (locally generated waves) and swell (waves generated far from the site) at 3-hr intervals at stations spaced at approximately 10-nm intervals along the Atlantic coast (and other coasts) of the United States. The hindcast thus provides 58,440 sets of values of the 20-year period at each station. In the hindcast, waves are generated and propagated to nearshore by numerical simulation models. The basic input for the hindcast are pressure and wind measurements, and bottom bathymetry.

The original WIS hindcast for the Atlantic coast (Jensen 1983) has recently been revised (Hubertz et al. 1993) and is called the WIS Revised Atlantic Level 2 (RAL2). The revised hindcast incorporates advances in understanding of the physical processes and in numerical modeling technology. The original WIS hindcast station pertaining to Ocean City, WIS Phase III Station 67, was located at the 33-ft (10-m) depth contour off Fenwick Island at coordinates 38.46° N, 75.05° W. Information from this station was summarized in a CERC report on the beach and borrow-site investigation for the Ocean City beach nourishment project (Anders and Hansen 1990). The nearest station in the revised hindcast is RAL2 Station 65, located at coordinates 38.50° N, 75.00° W off Bethany Beach, Delaware on the 60-ft (18-m) contour. One distinction between the original and revised hindcasts is that the RAL2 methodology reports wave information for all points on the compass, as opposed to the original WIS Phase III stations, which did not include offshore-directed waves.

The wave rose for WIS RAL2 Station 65 is shown in Figure 6. Numbers in triangles on the perimeter of the wave stacks give frequency of occurrence for the particular direction. Waves incident from the west have limited influence on coastal processes along the beach at Ocean City, whereas waves incident from the east move sand along the beach and alter both the shape of the shoreline and the beach profile. Waves out of the southeast quadrant occur more frequently than do waves from the northeast (25 versus 4 percent), but the waves from the northeast tend to be higher. Waves incident from due east at the 60-ft contour have the potential to move sediment alongshore on Fenwick Island because of the concave shape of the coast. The hindcast gave a mean energy-based significant wave height (H_{mo}; see Chapter 2) of 1.0 m with lowest monthly mean significant wave heights of 0.6 m in July and August and maximum mean significant wave height of 1.2 m in December, January, and February. The most common wave period for waves less than 0.9 m high was 4 sec; for waves between 0.9 and 1.8 m high, 6 sec; and for waves greater than 0.9 m high, the most common periods were between 6 and 8 sec. The highest wave, 7.7 m, in the hindcast occurred during the March 1962 northeaster, and its spectral peak period was 15 sec, with a direction of 79° from True North.

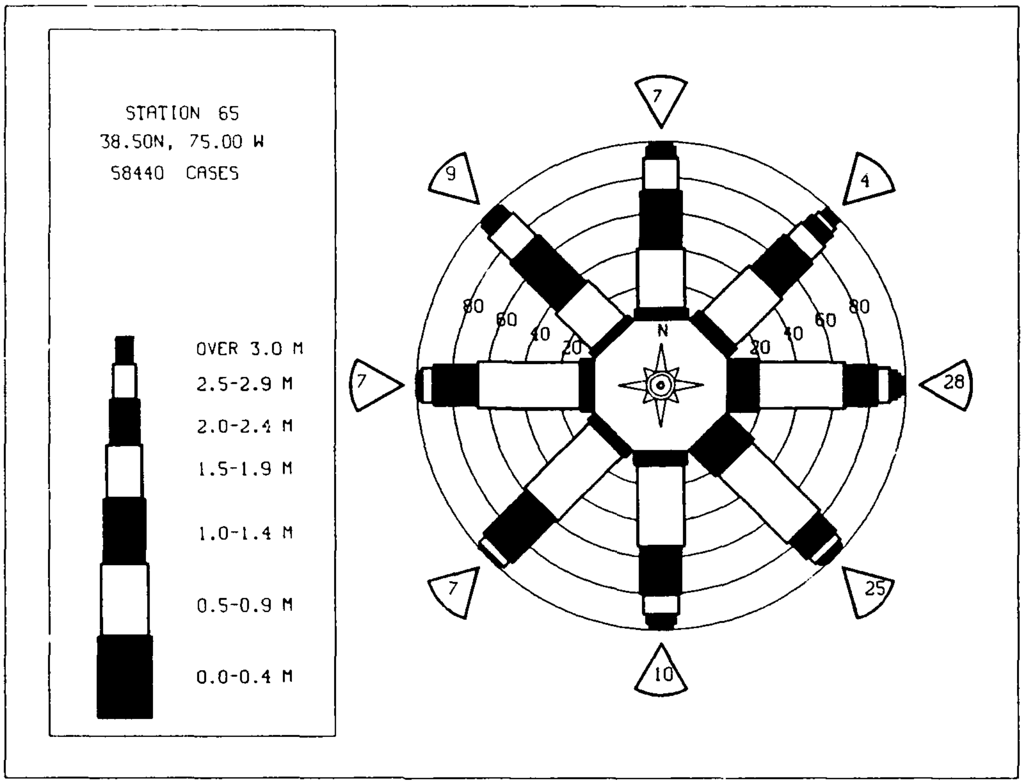

Figure 6. Wave rose for WIS revised Atlantic Station 65 (60-ft depth)

Water level

The tide at Ocean City is semidiurnal, meaning that it goes through two low and two high waters each day. The tide prediction for Ocean City (National Oceanic and Atmospheric Administration (NOAA) 1984) lists a mean neap range of 3.4 ft and a mean spring range of 4.1 ft for the ocean and 2.2 and 2.7 ft, respectively, in Isle of Wight Bay. The tidal range can be greater than these means. For example, on 6 August 1976, Dean and Perlin (1977) report that the ocean tidal range was 6.65 ft.

Records supplied for this study by National Ocean Service for the tidal datums at the Ocean City Fishing Pier for the tidal epoch 1960-1978 indicate that mean high water (mhw) lies 1.81 ft above NGVD; mean low water (mlw) lies 1.61 ft below NGVD; and mean sea level is 0.12 ft above NGVD. The mlw and mhw datums are, respectively, the arithmetic means of the low- and high-water heights for the 19-year epoch.

Storms

Storms are a major consideration in design of most beach fill projects, and this is the case for the Ocean City nourishment project, which has as its purpose storm protection. Ocean City is impacted by extratropical cyclones and, to a lesser extent, tropical cyclones. A cyclone is "any closed circulation, in which the winds rotate counterclockwise in the northern hemisphere..." (Neumann et al. 1987). Extratropical cyclones, or northeasters, typically originate in northern latitudes and derive their energy from large-scale differences in temperature and moisture between cold and warm air masses. Northeasters, which occur frequently on the Atlantic coast in autumn and winter, are relatively large in extent and may persist over more than one tidal cycle. Tropical cyclones develop over tropical waters and are typically smaller in extent than extratropical storms, but with much greater wind speeds and storm surge than are typical of northeasters. The more intense tropical cyclones are classified as tropical storms if the sustained (1-min average) wind speed is in the range of 39 to less than 74 mph; if the sustained wind speed is greater than 74 mph, the tropical cyclone is a hurricane. Tropical cyclones tend to arrive at the Atlantic coast between early August and late October.

During the past 60 years, the Ocean City storm climatology has been dominated by northeasters. A review of the historic storm population between 1933 and 1988 was performed for the design formulation phase of the storm-protection project.[1] For the present report, this historic storm compilation was supplemented with post-1988 storm information. The original review identified 18 major storms, listed in Table 1, of which 14 were northeasters and four were hurricanes. Two major northeasters, the "Halloween" storm of 30 October 1991 and the 4 January 1992 storm, have impacted the project since then. These two recent major storms and additional minor northeasters, such as four storms in February and March 1989 and on 11 November 1991, are described in Chapter 2. The Halloween and 4 January 1992 storms, although severe, did not cause appreciable damage to Ocean City because of the presence of the beach fill, which prevented damage by erosion and by flooding. The functioning of the fill during these storms is discussed in Chapter 3.

The north-south orientation of the shorelines of Delaware and Maryland (Figure 1) makes the area more exposed to northeasterly waves than are neighboring coastlines in New Jersey and Virginia, which have a more northeast-southwest orientation. Conversely, the turning of the shoreline orientation into the mouth of the Delaware Bay at Cape Henlopen places the Ocean City and Delaware coastlines farther west of the preferred path of most coastal hurricanes and tropical

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[1] Grosskopf, W. G., and Resio, D. T. 1988. Storm hindcast for Ocean City, Maryland. Draft report submitted to the USAED, Baltimore, by Offshore Coastal Technologies, Inc.

Table 1
Damaging Storms at Ocean City, 1933-1992

Year	Hurricane	Northeaster
1933	September	
1944	September	
1956		March
1956		April
1956		September
1960	September (Donna)	
1962		March
1962		November
1964		January
1971		April
1971		November
1974		December
1975		March
1976		April
1978		February
1981		November
1983		February
1985	September (Gloria)	
1991		October ("Halloween")
1992		January

storms than are neighboring beaches. Hurricanes normally move north from the tropics and, if not having made landfall to the south, normally follow the general mid-Atlantic northeast-southwest orientation of the coast and Gulf Stream. Ocean City's location within the Delaware Bay entrance area is farther from the historical path than are New Jersey beaches 30 miles to the north and Virginia beaches 50 miles to the south. Finally, Ocean City is located in an area where hurricane frequency and intensity decrease rapidly with northerly latitude.

Most severe hurricanes in the mid-Atlantic states occurred prior to this century and many of the recent storms were not of sufficient magnitude or proximity to Ocean City to cause notable damage. The most extreme hurricane of record at Ocean City occurred in September 1933. This was a very intense storm that moved toward the northeast about 100 miles to the east of the Delmarva Peninsula. The storm generated the highest coastal storm surge recorded to that date, +5.8 ft NGVD (USAED, Baltimore 1980) in the area and, as mentioned previously, opened Ocean City Inlet between the present Fenwick and Assateague Islands.

The most extreme storm of record in terms of highest offshore waves, greatest surge, and longest duration, was a northeaster that occurred on 6-8 March 1962, also commonly referred to as the "Ash Wednesday" or the "Five High" storm. The storm intensified as it moved directly offshore of the Ocean City area and then became stationary, generating persistent onshore winds exceeding 60 mph for five high tides (thus the name "Five High"). The persistent winds generated a nearshore storm surge that exceeded the previous record from the 1933 storm at Ocean City by 1.5 ft. The high water levels, resultant island inundation, and record-high waves battered the city for over 60 hr.

Economic damage resulting from four of the most extreme storms that occurred prior to 1980 are listed in Table 2 and indicate the potential impact of storms for Ocean City. This comparison illustrates the devastating effect of the long-duration 1962 northeaster as compared to previous shorter-duration hurricanes. Note, however, that the city was much less developed in 1933 and 1944. More recent storms, of March 1989, October 1991, November 1991, and January 1992, that impacted the Ocean City nourishment project and were recorded by the associated monitoring, are described in Chapter 2.

Table 2
Damage Associated with Major Storms

Storm	Storm Type	Damage (1980 dollars)
September 1933	Hurricane	$ 500,000
September 1944	Hurricane	$ 250,000
September 1960	Hurricane	$ 350,000
March 1962	Northeaster	$11,300,000

Project Overview

As previously mentioned, two separate beach fill projects have been performed at Ocean City, Maryland. In 1988, the State of Maryland placed a recreational beach fill between 3rd Street and the Maryland-Delaware State line. In 1990 and 1991, the CE placed a storm-protection beach fill which included a dune, seawall, and wider beach and berm than the State fill.

Both projects were constructed from beach-quality material taken from Borrow Areas 2 and 3 (Figures 2 and 3; also, see GDM (USAED, Baltimore 1989), Book 1, Figure 1). The representative grain size from Borrow Area 2, to the south, directly off Ocean City beaches, is 0.25 mm; the representative grain size diameter for Borrow Area 3, located at the Delaware-Maryland border, is 0.35 mm. Two dredging contractors worked simultaneously on the State of Maryland fill project, whereas a single contractor placed the material for the Federal project. Material was pumped onto the shoreline where it was redistributed to form the construction template by bulldozers and other vehicular machinery. Following the construction of the beach and dune in the Federal project, sand fencing was manually emplaced followed by planting of dune grasses. The Federal project was constructed over two seasons: from June to September 1990, the area between 3rd Street and 100th Street was completed; and from June to August 1991, the area from 100th Street to the Delaware State line was completed.

The fill constructed by the State of Maryland consisted of approximately 2.7 million cu yd of material placed along the entire project area. The State project construction template consisted of a flat berm at elevation +8.5 ft NGVD extending 90 ft from the construction baseline, then sloping at a 1:20 slope seaward down to -1.5 ft NGVD and then at a 1:12 slope down to the existing bottom. At equilibrium, this quantity of material was estimated to provide about 60 ft of additional beach width above mhw.

The Federal project design profile was derived through the iterative use of a beach and dune storm-erosion numerical simulation model published by Kriebel and Dean (1985) (Book 2, GDM). A hindcast of 18 storms produced time series of winds, waves, and water levels that served as input to the erosion model at each of 37 longshore locations spaced nearly equally along the project shoreline. Several beach-fill design alternatives or configurations were developed by varying the design beach width and dune dimensions. The storm-induced erosion of the configurations was simulated using the beach and dune erosion model through each of the 18 storms. The model produced a time series of beach profile changes throughout each storm at the 37 longshore beach profile locations, including the landward migration of specified elevation contours and the integrity of the dune crest. Design level (100-year) wave overtopping rates and eroded contour locations (at +3, +6, and +10 ft NGVD) were estimated using a best-fit Fisher-Tippett Type III distribution through the storm results for each profile. These results were used to calculate inland property damage for each design configuration. The alternative that maximized the benefit-cost ratio was selected for final design and construction.

The selected Federal project design beach profile consisted of a seaward translation of the pre-project profile such that a 165-ft-wide beach with a 100-ft-wide berm at +8.5 ft NGVD is provided between the construction line and the mhw shoreline in the boardwalk area (from 3rd Street to 27th Street). A concrete-capped steel sheet-pile bulkhead was also built along the seaward edge of the boardwalk in this area with a crest at +14.5 ft NGVD. A sand dune and beach complex was constructed extending north from 27th Street to the Delaware State line. The dune cross section is trapezoidal, with a 25-ft-wide crest at elevation +14.5 ft NGVD and 1V:5H side slopes. The seaward toe of the dune is located 95 ft from the construction baseline at elevation +8.5 ft NGVD. A total beach width of 100 ft was established seaward of the dune, with a 35-ft-wide berm at elevation +8.5 ft NGVD.

Construction templates were developed for 11 reaches within the project, with representative cross sections shown in Figure 7. The upper drawing shows a typical section with a bulkhead, and the lower drawing shows a typical section with a dune. The construction berm for each reach included the total needed for the design profile plus 4 years of advanced nourishment and 15 percent overfill. Each construction template had a dune, as described above, and a berm at +8.5 ft NGVD, with varied width and from which the fill was sloped at 1:20 down to -1.5 ft NGVD and at 1:12 down to the intersection with the existing bottom. The berm width was varied to accommodate the needed beach fill volume. The total amount of material placed in the Federal project was 3.8 million cu yd.

Expected annual longshore losses over the project area were estimated by reviewing historic shoreline change data derived by Leatherman (1984), longshore sand transport rates developed from WIS data, a longshore transport study by Douglas (1985), and sand impoundment studies at the jetty located at Ocean City Inlet (Dean 1978). Excluding unusual events, these studies indicated that annual net longshore transport rates varied between 150,000 and 300,000 cu yd to the south. The field-oriented studies indicated that the rate is likely in the lower end of this range, and thus a rate of 175,000 cu yd/year was adopted for use in estimating future annual renourishment needs.

Replenishment is planned every 4 years, with annual beach profile surveys used for decisions to augment the plan as necessary to maintain design-level protection. The annual surveys and subsequent analysis of the data are to be performed to assess whether the design-level protection is likely to be compromised within 1 year from the survey.

Scope of This Report

This report documents the background of the "Atlantic Coast of Maryland (Ocean City) Shoreline Protection Project," a beach nourishment project that was constructed over the period 1988 to 1991. The report contains data and analysis results for associated monitoring of waves, water level, beach profile, and sediments. The report draws upon monitoring data available for the period January 1988 through January 1992 for main quantitative analysis of the beach fill performance and understanding of coastal processes at the study site.

Chapter 1 provides an overview of both the regional and local area of the study site, including background on the project authorization, general physical processes, and discussion of previous studies for the area. Chapter 2 describes the wave and water level conditions at the site obtained from the monitoring program. Chapter 3 describes the short- and long-term behavior of the beach fill, including analysis of beach profile data and sediment samples. Chapter 4 gives an evaluation of the design and performance of the fill, including discussion of the accuracy of the beach profile survey system, upon which much of the beach profile analysis rests. Chapter 5 gives a summary and conclusions of the study.

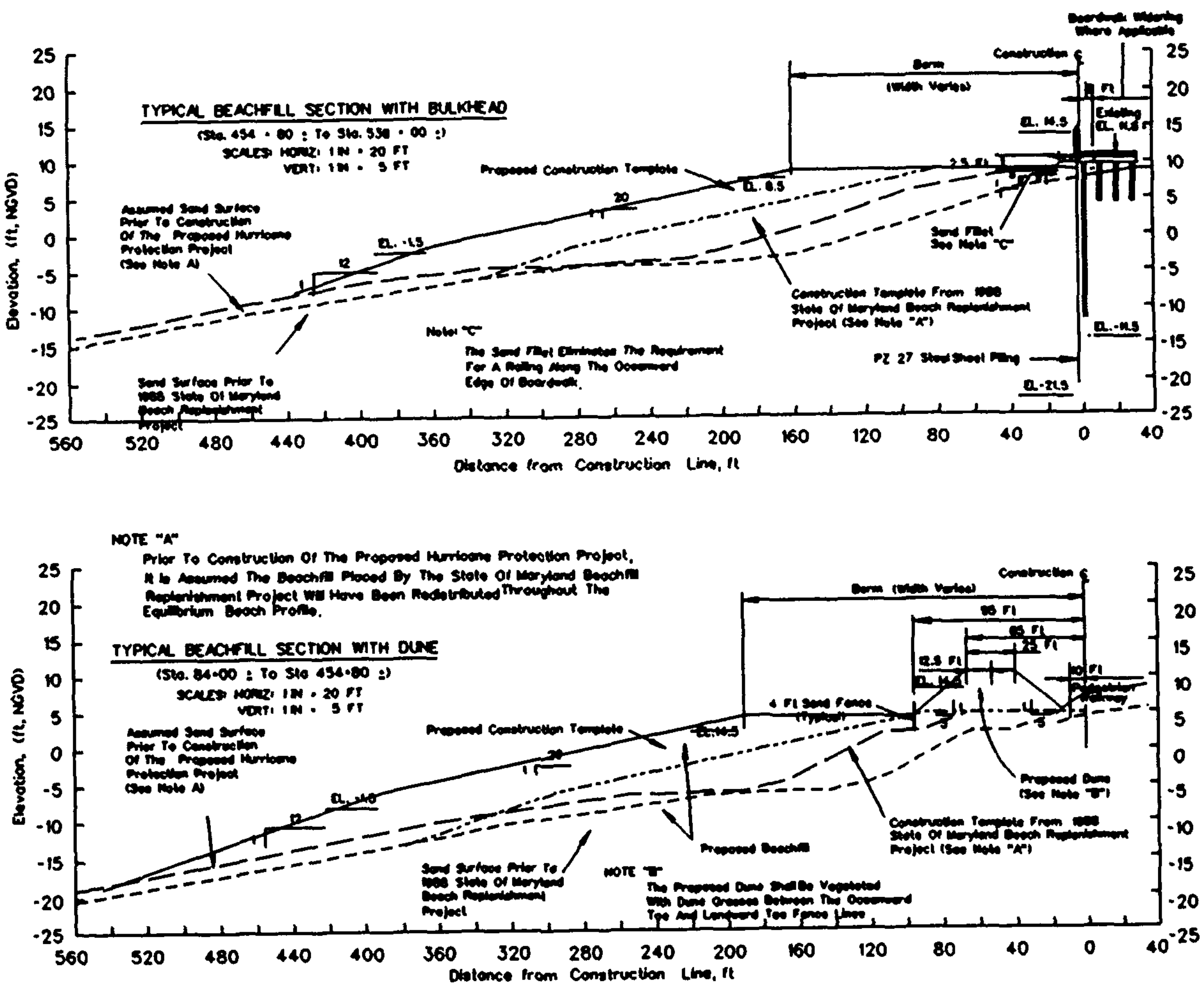


Figure 7. Representative fill cross section

This report also includes three appendices that provide access to much of the processed data for independent analysis. Appendix A gives plots of the profile survey data by street for visual inspection, and it also contains a listing of the data. Appendix B contains summaries of the grain size data, and Appendix C gives plots of wave and water level data. Notation used in this report is listed in Appendix D.

2 Nearshore Waves and Tide

Rationale and Description of Wave and Tide Measurements

An essential element of a successful beach response determination program is a complete suite of wave and water level data. These data define the conditions during which major changes of the beach morphology occur. Wave data are used as input to sediment transport models to aid in determining both storm-induced changes and long-term shoreline evolution. Water level data are necessary to separate the effects of waves and tides and to specify the mean shoreline position at any particular time.

Acquisition of wave data as part of the Coastal Field Data Collection Program conducted by CERC was initiated in the summer of 1988 to address four specific needs:

a. To provide wave data during tropical and extratropical storms at an exposed Atlantic coast location.

b. To provide a continuous wave data record in support of the beach nourishment monitoring project at Ocean City.

c. To develop a data set for verification of regional coastal processes simulation models.

d. To provide wave and current data for verification of shoreline evolution and longshore current simulation models.

Initial wave data acquisition was accomplished using internal recording, non-directional instruments placed at two locations as shown in Figure 3 in approximately the 32.8-ft water depth. Geographic coordinates of the gauge locations are latitude 38° 23.87' N, longitude 75° 2.44' W for the north site, and latitude 38° 20.22' N, and longitude 75° 3.72' W for the south site. The north and south gauges are located offshore of 80th and 10th streets, respectively, and separated by a distance of approximately 22,965 ft. Both gauges are located approximately 3,280 ft offshore. Plans called for operation of the non-directional gauges through the fall of 1988 and winter of 1989 with conversion to directional wave gauges and addition of current meters to occur in the spring of 1989. However, the deployment was delayed by the process of obtaining permission from the local authorities for cable access across the beach.

Acquired data at both Ocean City locations are presented in Appendix C. Annual time series plots, (plates C1 through C8) show the result of significant wave height H_{mo}, peak period T_p, and direction θ_p for 1988 through 1991. For both gauges, Plate C9 is a percentage exceedance histogram based upon combined wave data from both north and south gauge locations for the data collection period from August 1988 through January 1992. Plate C10 is a percentage exceedance histogram for the fall and winter (October through February), spring (March through May), and summer (June through September) seasons.

The rationale for operating gauges at two locations relatively close together is based upon consideration of the complex nearshore bathymetry and the fact that the beach-nourishment material was obtained from two offshore borrow areas having distinct sediment characteristics (Borrow Areas "2" and "3" shown in Figure 2). The nearshore bathymetry is characterized by a series of elongated shoals oriented approximately in the northeast-southwest plane at about 30 to 45 deg to the local shoreline. These shoals may result in different wave climates at the two nourishment areas. There is also the possibility that the different sediment characteristics will cause the beach profile to evolve differently even under identical wave conditions. The two gauge locations were therefore selected to aid in separating the effects of wave climate from those of beach-fill characteristics when evaluating the beach response.

Tide data also are useful for the verification of both regional coastal and shoreline evolution models, as well as for assessing the effectiveness of the beach nourishment project. The NOS operated a tide station on the Ocean City fishing pier beginning in May 1975. A storm in February 1989 caused extensive damage to the gauge and repairs were not completed until late March 1989. Moreover, the storm of 2-4 January 1992 destroyed the fishing pier where the gauge was located. The future of this station is uncertain because of existing logistical problems. The pier was privately owned, and the owner has effectively refused NOS permission to re-establish the tide gauge. If a need arises for tidal elevation information during periods when the NOS station was not operating, tide level estimates may be obtained by further processing of CERC's wave gauge data. However, because the CERC-operated wave measurement systems are located distant from the shore and use bottom-mounted pressure transducers, it is impractical to establish an NGVD relationship for the CERC tide data. An approximate elevation relation may be determined by comparing concurrent CERC and NOS tide data series. It should also be noted that the CERC tide data are not controlled to NOS standards.

Non-directional wave measurements (August 1988 - May 1990)

This section summarizes wave and tide data for the period August 1988 to May 1990. The wave gauges acquired 1,024 pressure samples at a 1-Hz rate every 3 hr. The data were spectrally analyzed via a fast Fourier transform (FFT) algorithm and corrected for attenuation of the pressure signal with depth using linear theory. Quality checks were limited to visual inspection of the data. The data acquired at both Ocean City locations are presented in Appendix C. Plates C11 through C43 show the results of significant wave height and peak period from August 1988 to May 1990.

Following the unaltered spectrally based significant wave height H_{mo} and peak spectral period T_p plots (Plates C11 through C43) are similar plots to which 3-day block (Plates C44 through C47) and running (Plates C48 through C51) averages have been applied. The block and running averages have been applied to emphasize periods when the wave climate was being affected by storms and as an aid to users desiring to isolate extended periods of high wave activity. The 3-day averages were selected as being representative of the typical duration of both tropical and extratropical storms that might be expected to affect a small reach of coastline.

Predicted and observed tide data are displayed in Plates C52 through C69 (both provided by NOS). The NOS tide gauge was damaged in late April 1989. No explanation was given by NOS for terminating the predicted data on 10 April 1989.

Directional wave measurements

Directional wave gauges were installed by CERC in February 1990 at the same sites as the non-directional gauges.

Data acquisition system. Measurements for directional waves were obtained using pressure (P), orthogonal (u), and horizontal (v) velocity component (PUV) type gauges located in approximately the 32-ft depth. The gauges measure near-bottom water particle velocity components with a cross-axis Marsh-McBirney electromagnetic current meter and hydrodynamic pressure with a Paroscientific pressure sensor. Each data acquisition system consists of two different data collection units: a serial analog unit (SAU) and a remote transmitter unit (RTU). The SAU, which resides underwater with the sensors, converts the analog signals from the pressure sensor and the two current meter sensors into digital signals using an analog-to-digital converter, and transmits them through an armored cable to an RTU located on the beach. Each system is equipped with an uninterruptable power supply which automatically supplies battery power for up to 3 days when the local power fails. The digitized signals, in the form of hourly files, are temporarily stored in an RTU and then transmitted daily to a computer at CERC via commercial phone line.

System accuracy. Estimates of the absolute accuracy of the PUV-type directional wave gauge depend upon knowledge of both the accuracies of individual sensors used in the wave gauge and the degree to which the actual wave field conforms to the analysis model used to compute the wave parameters. Because absolute knowledge of the properties of the wave field cannot be determined by realizable measurements, the degree of conformity between the actual wave field and the analysis model cannot be determined. However, relative overall estimates of the accuracy of the PUV-type gauge have been made by intercomparing a PUV-type gauge and a 10-element linear pressure array. The intercomparisons were conducted at the CERC Field Research Facility at Duck, North Carolina. The 10-element linear array is generally acknowledged as a state-of-the-art operational wave gauge in terms of accuracy and resolution of wave direction. Table 3, based upon the work of Holme and Birkemeier (1992)[1] shows the correlation coefficients and differences in the 95 percent prediction interval for H_{mo}, T_p, and peak frequency θ_p for the two gauge types. Peak frequency determination is discussed in the next section. Based upon this comparison, if one accepts results of the linear array gauge as

[1] Holme, S. J., and W. A. Birkemeier, "Intercomparison of Directional Wave Gages," CERC Memorandum for Record, July 1992.

definitive, measurements made with PUV-type gauges can be expected to agree to within approximately 0.1 m for H_{mo}, 1.2 sec for T_p, and 8 deg for θ_p.

Table 3
Comparison of PUV and Linear Array Wave Gauges

Parameter	H_{mo}	T_p	θ_p
Correlation coefficient	0.98	0.96	0.96
95 percent prediction interval difference	*0.1 m*	*1.2 sec*	*8 deg*

Collection. The directional wave data collection started during March 1990 and has continued to the present, except for periods when the gauges experienced mechanical problems. Availability of the data also depends upon its quality, addressed below. The two velocity components and pressure are simultaneously sampled at 1 Hz for 1,024 sec. A data collection period begins every hour, but the decision for storing data into the RTU is programmed by the computer. That is, a typical data file contains the data collected every 4 hr beginning at 0000, 0400, 0800, 1200, 1600, and 2000 hr Universal Coordinated Time (UTC, subtract 5 hr to convert to Eastern Standard Time), but during periods when the significant wave height exceeds approximately 1 meter, as is typical during storms, data may be stored every hour, i.e., to 0000, 0100, etc., or every 2 hr, i.e., at 0000, 0200, etc.

Data type and storage. The raw data transmitted to the analysis computer at CERC in Vicksburg, Mississippi, are in binary format, with each file containing 512-byte fixed-length records multiplexed with three channels. The data are stored in the project database at CERC.

Analysis. A preliminary examination of the raw data determines whether the data are of quality acceptable for further processing. The acceptance criterion is that 90 percent or more of the data in each of these individual channels are judged as "good." Before performing the subsequent analysis step, the measured time series are corrected by removing spikes. Linear interpolation is then used to complete the time series.

The data are then further examined for trends (non-stationarity), most likely caused by tidal fluctuations. In general, if a trend exists in the time series and it is linear, the data are adjusted by subtracting the trend components. A diagnostic test that determines the statistical significance of trend removals is also carried out prior to the data adjustment. Any data showing trends of higher order than linear are rejected.

An FFT routine is used for computing power spectra and cross-power spectra. To reduce the undesirable effect of side lobes and leakages of energy, a 10-percent cosine-bell window is applied to the time series. The variances of frequency spectra are reduced by segmenting the time series into eight equal bands and computing the ensemble average of the spectra. The frequency resolution is thus 0.0078 Hz. The significant wave height is computed using the formula $H_{mo} = 4 (\int S(f)df)^{1/2}$ where the sea-surface spectrum $S(f)$ is also low-pass filtered with a high-frequency cutoff of approximately 0.33 Hz.

Wave direction is estimated using the CERC standard procedure for analyzing directional wave data. The procedure is based on the method for single location measurements first used by Longuet-Higgins, Cartwright, and Smith (1963) for data obtained from a heave-tilt-roll buoy.

The directional spectrum $S(f,\theta)$ is defined by $S(f,\theta) = S(f)D(f,\theta)$ where $S(f)$ is the sea-surface spectrum and $D(f,\theta)$ is a directional spreading function, normally expressed as a function of frequency only. The directional spreading function $D(f,\theta)$ is then written as a Fourier series with the cross-power spectra of PUV data using the relationship (linear transfer functions) between the directional spectrum and the cross-power spectra.

A convenient way to present the directional information, as alternative to presenting $D(f,\theta)$ over the entire frequency range, is to display the mean direction θ defined as $\tan^{-1}(b_l/a_l)$, where $a_l = \int D(\theta)\cos(\theta)d\theta$ and $b_l = \int D(\theta)\sin(\theta)d\theta$. Physically, θ may be interpreted as the direction of the average vector (a_l,b_l). The mean direction reported here is for the frequency $f_p = 1/T_p$, at which the sea surface power spectrum has the maximum value.

Monthly results are displayed in Plates C70 through C75. For certain time intervals (March 1990 for the north gauge, part of March 1990 for the south gauge, August 1990 for the north gauge, and July to December for the south gauge), no wave data are available or usable because of gauge malfunctions or human error.

Recent Storm History at Ocean City

The evolution of the beach at Ocean City has been well-documented since the beginning of this century, as discussed in Chapter 1. However, the present beach condition can be considered to have evolved subsequent to the northeaster storm of March 1962. This storm caused extensive damage and beach change along much of the northeast Atlantic Coast of the United States and is considered one of the most destructive in recent history. A maximum water level of +7.7 ft NGVD was reported at Ocean City during this storm. However, it appears not to be based upon a tide gauge record. No documentation could be located which indicates a tide gauge operating in the Ocean City vicinity during 1962. However, Harris and Lindsay (1957) report a high-water indicator being installed by CE in August, 1956. If the +7.7-ft level was based upon measurements obtained from this high water indicator, it should be considered an instantaneous value and therefore not directly comparable with measurements obtained by tide gauges for which wave effects are attenuated to some degree.

The next major meteorological event that significantly affected Ocean City was Hurricane Gloria in 1985. Gloria passed Cape Hatteras, North Carolina, on 26 September 1985 and made landfall on western Long Island, New York, on 27 September 1985 (Neumann et al. 1987). The maximum water elevation at Ocean City observed during Gloria was +5.8 ft NGVD (Gill and Deitemyer 1992) and contributed to substantial beach erosion. The erosion caused by Gloria was severe enough to undermine the foundations of many beachfront structures, necessitating prompt remedial action, and left Ocean City with a narrow beach inadequate for hurricane and storm protection and of limited recreational value.

The inundation and erosion produced by Gloria at Ocean City are noteworthy because the coastline between Norfolk, VA, and Atlantic City, NJ, experiences the second lowest frequency of landfalling tropical storms and hurricanes of any along the Atlantic and Gulf of Mexico Coasts (Neumann et al. 1987). Although Ocean City is located within a reach of coastline that has a low frequency of landfalling tropical storms and hurricanes, it is near the prime genesis area for Atlantic coastal winter storms (Colucci 1976). A perspective of the peak water levels may be gained by noting that the highest water level recorded at Ocean City during the period 1973 through 1991, when the NOS tide gauge was operating, was +5.8 ft NGVD (for Hurricane Gloria, 1985).

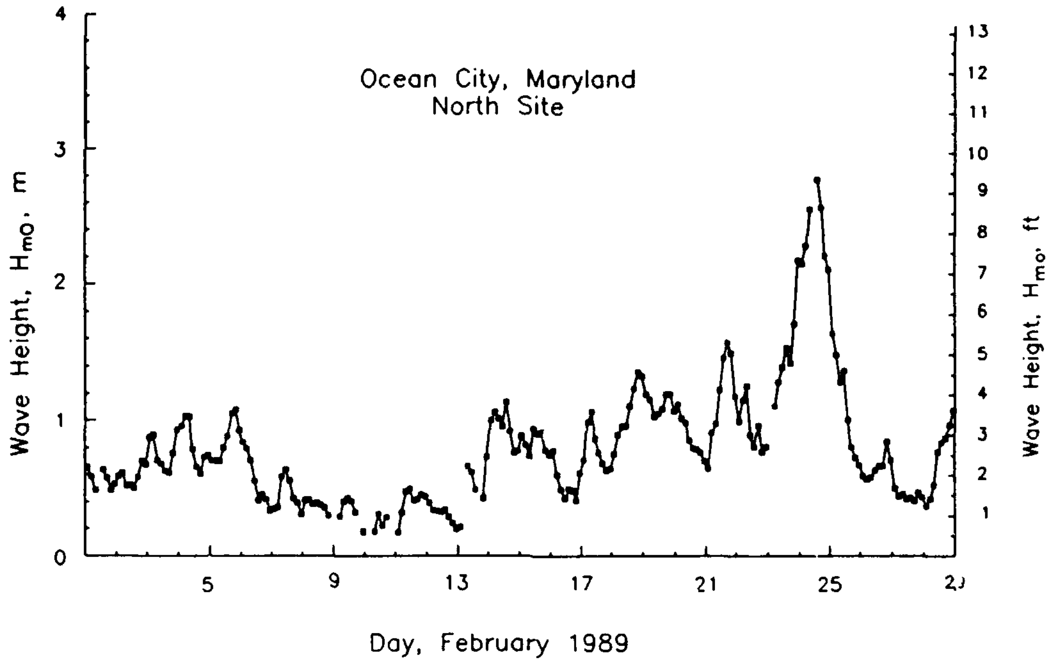
Storms of February - March 1989

The first significant storms observed following deployment of the non-directional wave gauges occurred between 23 February and 25 March 1989. Four storms were observed which generated H_{mo} wave heights in excess of 2.25 m; two of these events produced H_{mo} wave heights close to 3.0 m. Figure 8 shows H_{mo} and T_p for February 1989 and Figure 9 for March 1989. The storm of 23-26 February damaged the NOS tide gauge. The gauge was not repaired until 24 March 1989; consequently no water level data are available during this period. Summaries of the following events are based upon information contained in NOAA daily weather maps.

The storm of 23-26 February, 1989, formed on 23 February as a closed low pressure system located about 200 miles due east of Cape Hatteras. By 24 February the system had moved slightly north of due west bringing it to about 100 miles east of Cape Hatteras; the low had intensified with minimum surface pressures decreasing from about 1008 mb to 999 mb with winds of 30 to 35 knots. At Ocean City, the wind directions were predominantly from the northeast to north-northeast. During the next 24 hr (25 February 1989), the system moved rapidly to the northeast, deepened slightly to 992 mb, and was located about 400 miles east of Long Island. By 26 February, the storm had moved northeast of Nova Scotia and no longer affected the United States.

The storm of 3-4 March 1989 was of shorter duration and lower intensity than the storm of 23-26 February 1989. This storm formed as a closed low about 250 miles due east of the Chesapeake Bay with a minimum surface pressure of about 1015 mb and winds of approximately 20 knots. At Ocean City, the wind directions were predominantly from the northeast. By 5 March 1989 the system had dissipated.

The storm of 7-12 March 1989 was the result of a low which formed on 7 March about 100 miles due east of Cape Hatteras combined with a strong high pressure system which moved over eastern Canada at about the same time. The extreme surface pressures of these systems were approximately 1007 mb and 1046 mb, respectively. This intense pressure gradient generated a region of strong northeast flow (25 to 30 knots) extending from Cape Hatteras to Cape Cod. Over the next three days (8-10 March 1992), a second high moved off the southeast Atlantic coast gradually pushing the low to the east. The region of strong pressure gradient was thus moved eastward into the open Atlantic Ocean. The slow shifting of position of these systems to the east is reflected in the gradual reduction in wave height and increase in peak period illustrated in Figure 9. By 12 March 1989, Ocean City was outside the influence of these systems.



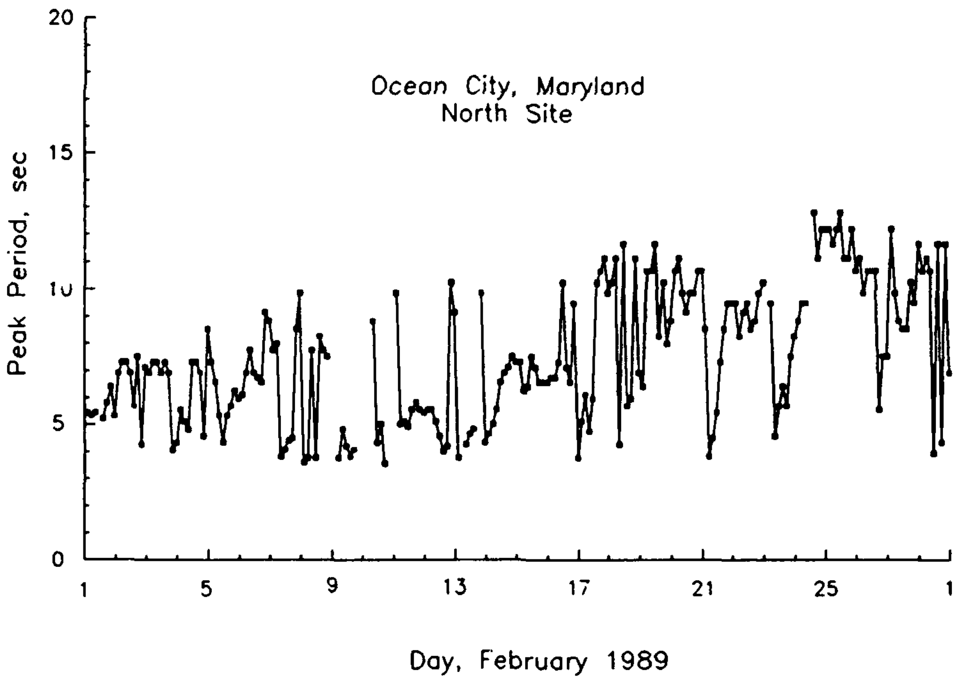
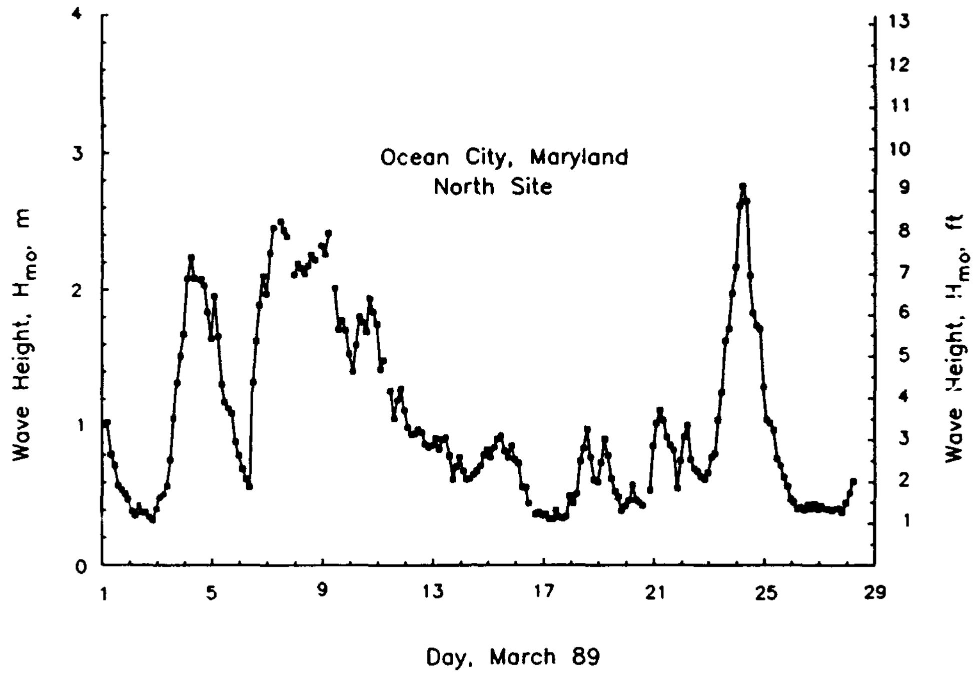


Figure 8. Wave height H_{mo} and peak period T_p for February 1989 as measured at Ocean City north gauge site



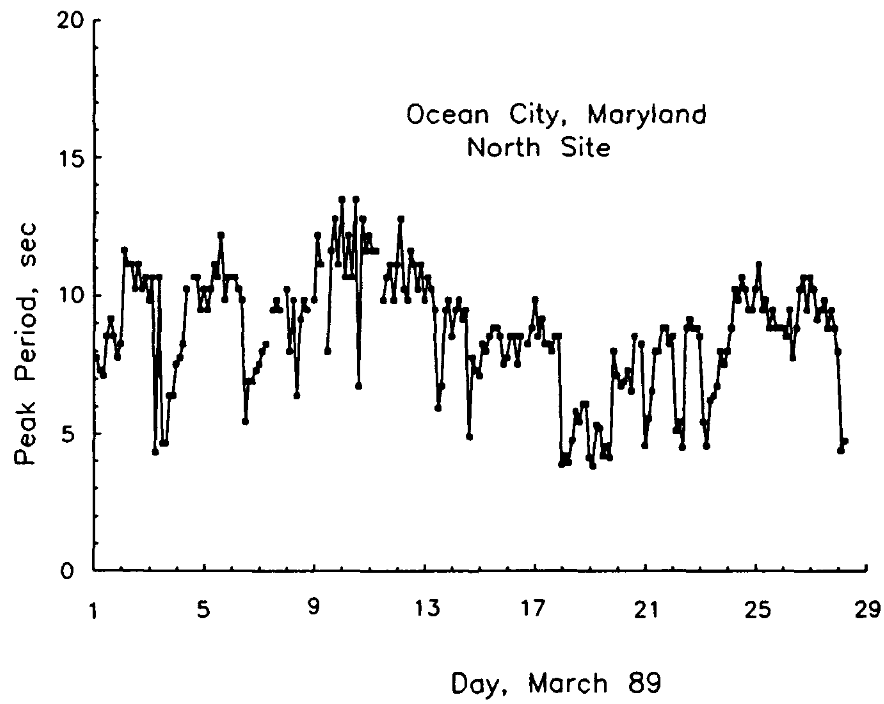


Figure 9. Wave height H_{mo} and peak period T_p for March 1989 as measured at Ocean City north gauge site

The storm of 23-24 March 1989 was the result of a small, fast-moving low which originated in the Gulf of Mexico and moved northeast across the continental United States. The low moved into the Atlantic Ocean near Cape Hatteras on 23 March 1989 and intensified rapidly with the minimum surface pressure dropping from 1014 mb to 1004 mb between 23 and 24 March. The north-northeast track of the low brought it to within about 50 miles of Ocean City late on 24 March 1989. Maximum marine wind speeds reported were approximately 25 knots but the tighter pressure gradient in the vicinity of Ocean City may have resulted in local wind speeds of slightly more than 30 knots. By 25 March 1989, the system had moved northward and was centered about 50 miles east of Cape Cod.

Storm of 29 October - 2 November 1991

The northeast storm of 29 October - 2 November 1991 (the "Halloween Storm") generated prolonged elevated water levels along much of the United States northern Atlantic coastline. Wind gusts greater than 50 knots for more than 15 hr and a peak gust of 68 knots were reported at the Chatham, Massachusetts, Weather Service Office. The strong, sustained winds were the consequence of a large maritime cyclone east of Cape Cod and a very strong high pressure area centered north of New England. The surface pressure differential between these two systems reached an extraordinary 67 mb the morning of 30 October.[1] On the basis of observed wave heights, Dolan and Davis (1992) characterize this storm as the most powerful northeaster to affect the Atlantic coast in the past 42 years, surpassing even the March 1962 storm. Moreover, the 114-hr duration of the storm is the sixth longest in the 42-year record.

Figure 10 shows plots of wind speed, direction, and surface barometric pressure at National Data Buoy Center (NDBC) buoys 44009 and 44012, located approximately 22 statute miles NNE and 42 statute miles NE of Ocean City, respectively. At Ocean City, peak water levels of +5.4 and +5.3 ft NGVD were recorded at the NOS tide gauge (Gill and Deitemyer 1992) and the CERC wave measurement system, respectively. The prolonged duration of this storm is illustrated in Figure 11 and emphasized by the fact that the observed water levels at the NOS gauge exceeded the predicted by 1.5 ft or more for approximately 66 hr (Gill and Deitemyer 1992).

The usual wave measurement parameters of zero moment wave height H_{mo}, peak wave period T_p, and dominant wave direction θ_p recorded at Ocean City during the Halloween storm are shown in Figure 12. The maximum H_{mo} observed at Ocean City during the storm was 3.1 m at 0400 hr UTC 31 October with a corresponding T_p of 19.7 sec. At buoy location 44009, a maximum H_{mo} of 4.7 m and T_p of 16.7 sec were reported at 0500 hr UTC 31 October. Buoy location 44012 reported a maximum H_{mo} of 4.7 m and T_p of 25 sec at 0200 hr UTC, also on 31 October. Dominant periods of 20 to 25 sec as reported at Ocean City and buoy location 44012 are extraordinarily long in the context of the Ocean City wave climatology (see Table 4). Percent occurrence of wave height and period by direction for data collected from both gauges from April 1990 through January 1992 are provided in Table C1 in Appendix C.

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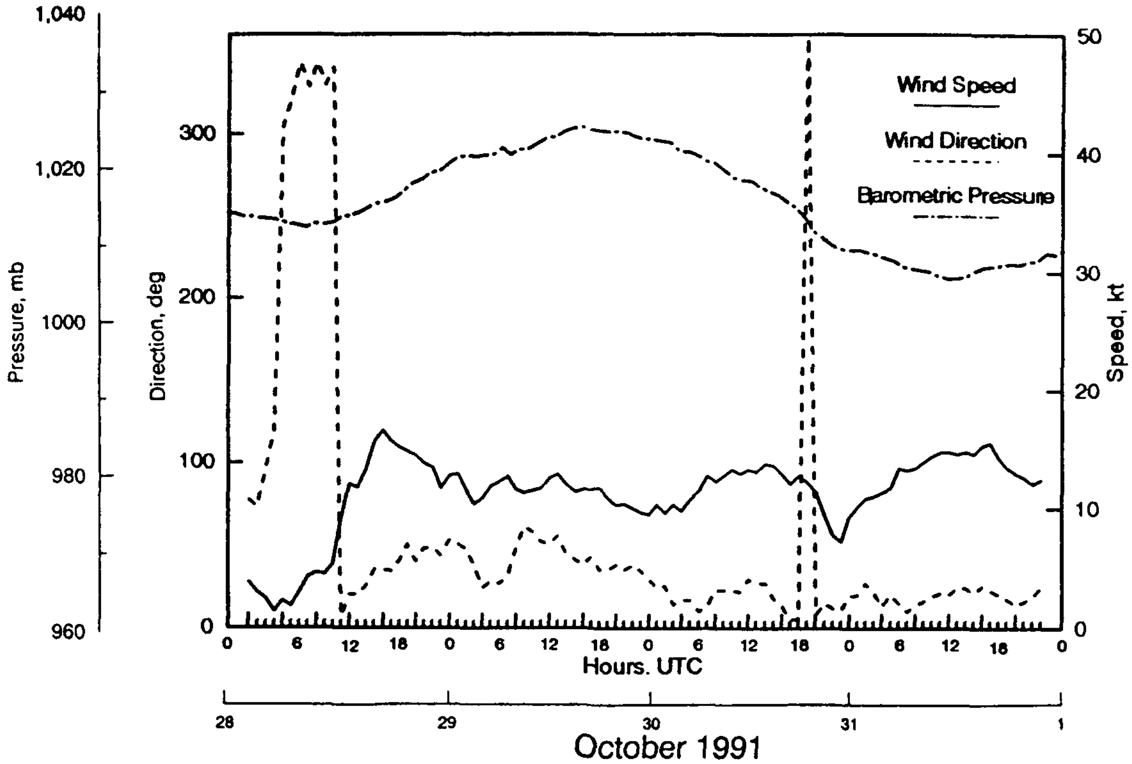
[1] Thompson, R.B., Meteorologist in Charge, Southern New England Area, NWS, 1991. "The Back-Door Coastal Storm of October 1991," unpublished manuscript.



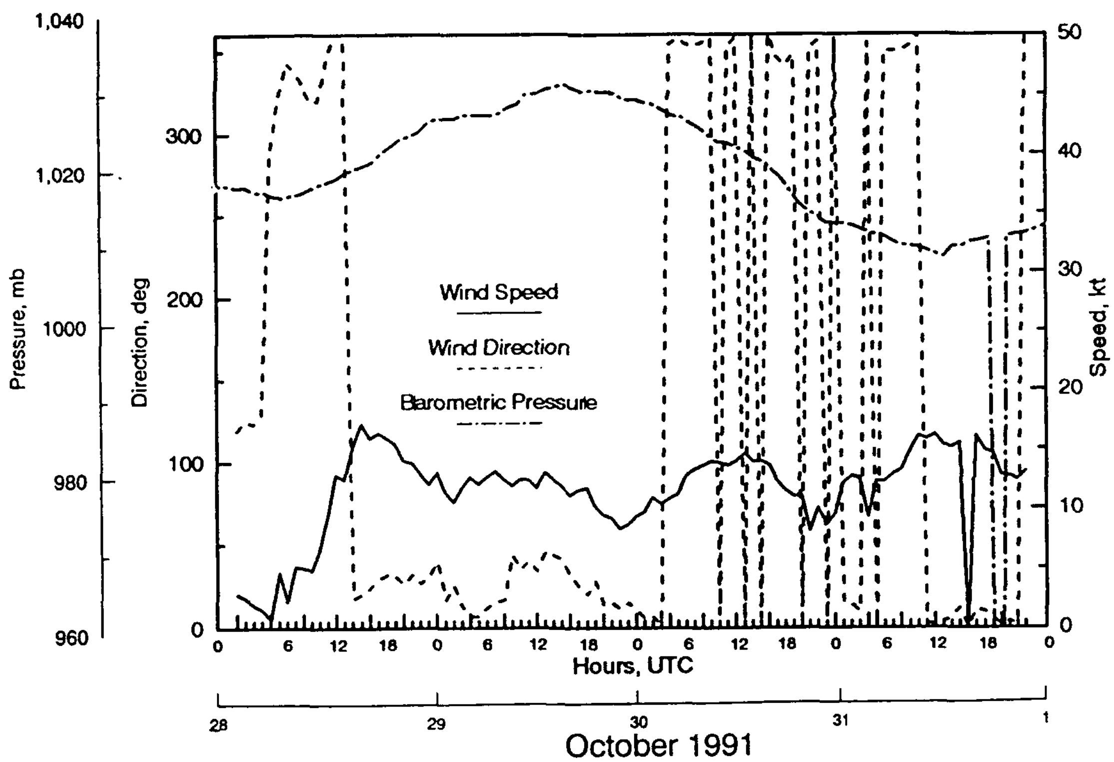


Figure 10. Wind speed, wind direction, and barometric pressure measured during the storm of 28-31 October 1991 (Halloween Storm) at NDBC buoys 44009 and 44012

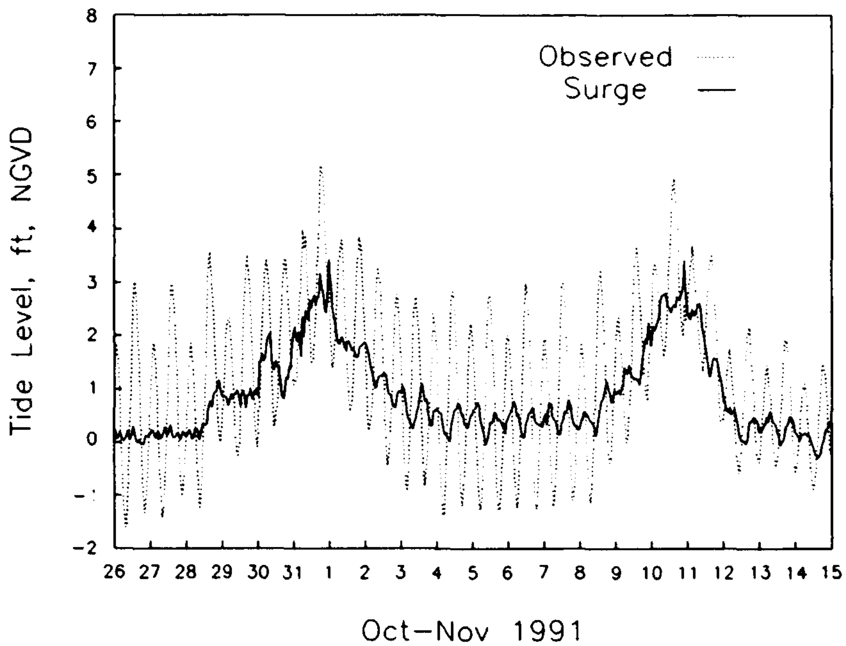


Figure 11. Hydrograph of observed water level and computed surge measured at NOS tide gauge for storms of 28-31 October and 9-11 November 1991

Storm of 2-4 January 1992

The meteorological characteristics of the 4 January 1992 storm contrast significantly with those of the Halloween Storm. Whereas the Halloween Storm was a very large, slow-moving, well-forecast (Thompson 1991) maritime winter cyclone, the 2-4 January storm was a small, rapidly developing, fast-moving, event.[1] Because of the small size of the storm, it was not well-depicted by the synoptic analysis products and, therefore, not well-forecast. The rapid intensification and short duration of this storm are illustrated by the barograph, wind speed, and direction plots in Figure 13 acquired at NDBC buoys 44009 and 44012, respectively.

The barograph at buoy location 44009 shows the pressure tendency increasing from about -1 mb/6 hr at 0600 hr UTC to -1 mb/2 hr at 1200 hr UTC on 3 January. At 0700 hr UTC on 4 January, an extraordinary pressure tendency of -3 mb/hr was recorded at buoy 44009. Approximately 3 hr later, at 1000 hr UTC, a minimum surface pressure of 993 mb and maximum sustained wind speed of approximately 40 knots were recorded at this location. Six hours later (1600 hr UTC), the surface pressure had increased to 1002 mb, and sustained wind speed had dropped to about 15 knots. The period of sustained winds of 15 knots or greater lasted from 0700 hr UTC 3 January to 1700 hr UTC 4 January, for a duration of 34 hr. The minimum surface pressure reported at buoy location 44012 was 997 mb at 1100 hr UTC on 4 January. The maximum sustained wind speed reported at location 44012 was approximately 40 knots, comparable to the speed reported at location 44009.

[1] J. Belville, Meteorologist in Charge, Washington, D.C. Forecast Office, National Weather Service, personal communication.

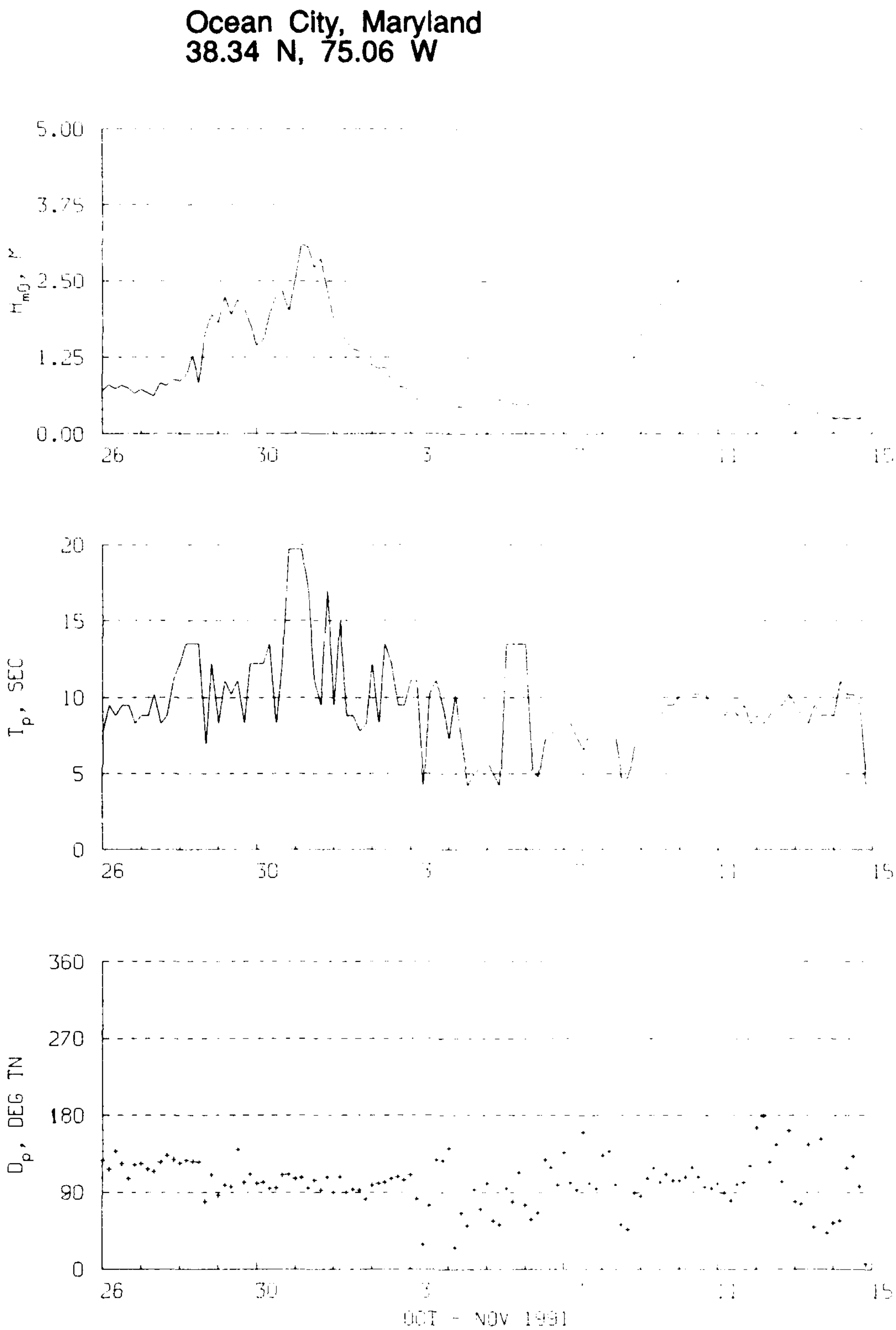


Figure 12. Wave height H_{mo}, peak period T_p, and dominant direction θ_p measured at Ocean City south gauge site for storms of 28-31 October and 9-11 November 1991

At buoy location 44009 the peak of the storm (wind speeds at or near 40 knots) occurred between 0800 and 1400 hr UTC 4 January. Wind directions during this period were within a 50-deg sector of approximately 50 to 100 deg relative to true north. The dominant wave directions at Ocean City during this period (which included the maximum H_{m0}) were between 106 and 133 deg. The shoreline orientation at Ocean City is approximately 20 deg east of north; thus waves approaching at a shore-normal direction would be from 110 deg.

Figure 14 is an anemometer record obtained at an NPS remote meteorological station located on Assateague Island approximately 18 miles south of Ocean City. At approximately 0300 hr Eastern Standard Time (EST) on 4 January 1992, sustained winds began to increase rapidly, peaking at approximately 0700 hr EST at over 40 mph, with gusts exceeding 55 mph. The wind speed then rapidly decreased, dropping to less than 10 mph by 1200 hr EST. Just as significant, the wind direction during the height of the storm was between 30 and 120 deg and at the peak of the storm was approximately 100 deg, or almost directly onshore. The close proximity of this storm to Ocean City and the predominantly onshore winds undoubtedly were significant contributors to the substantial damage which occurred.

Table 4
Percent Occurrence (x1000) of Wave Height and Period

North (38.40 N 75.04 W) - South (38.34 N 75.06 W) for August 1988-January 1992

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
0.0-0.4	3592	2884	6446	14715	2790	1973	1666	966	424	94	35550
0.5-0.9	4441	6964	15038	15957	3254	2531	2028	872	361	70	51516
1.0-1.4	204	1069	3254	3474	691	377	220	141	86	-	9516
4.9-6.2	23	94	951	746	165	157	86	39	7	-	2268
2.0-2.4	-	-	172	463	86	70	7	7	7	15	827
2.5-2.9	-	-	7	149	15	-	31	7	-	15	224
3.0-3.4	-	-	-	7	7	-	-	23	7	7	51
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	7	-	-	7	-	14
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**8260**	**11011**	**25868**	**35511**	**7008**	**5115**	**4038**	**2055**	**899**	**201**	**99966**

Mean HmO(m) = 0.7; Largest HmO(m) = 4.4; Mean TP(sec) = 8.3; NO. OF CASES = 12721.

The wave parameters of zeroth moment wave height, peak wave period, and dominant wave direction recorded at Ocean City during the 2-4 January storm are shown in Figure 15. Measurements are usually taken at 4-hr intervals and are denoted as individual points on the respective plots. Beginning at 1500 hr UTC on 3 January, measurements were taken at 1-hr intervals;

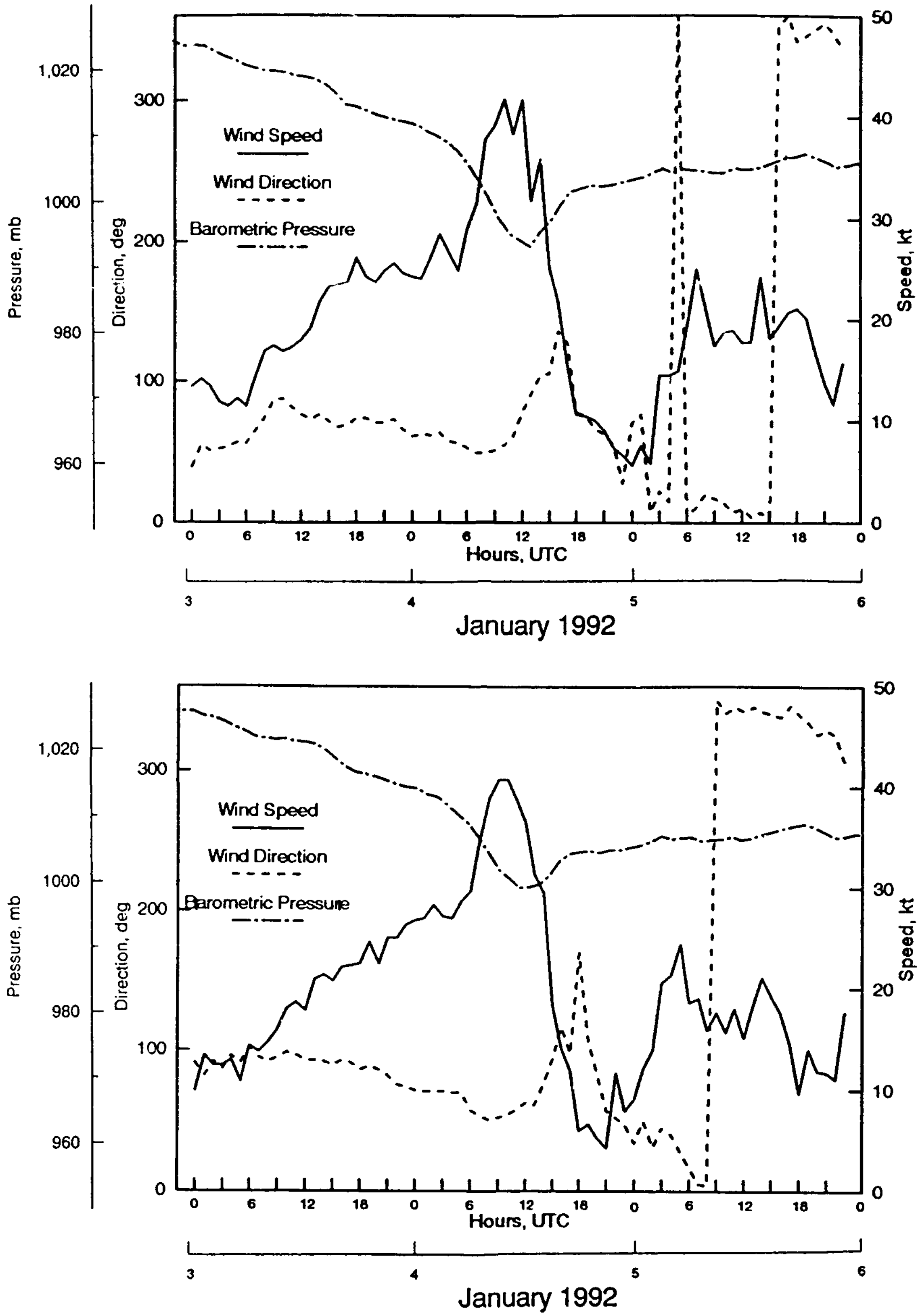


Figure 13. Wind speed, wind direction, and barometric pressure measured during the storm of 2-5 January 1992 at NDBC buoys 44009 and 44012

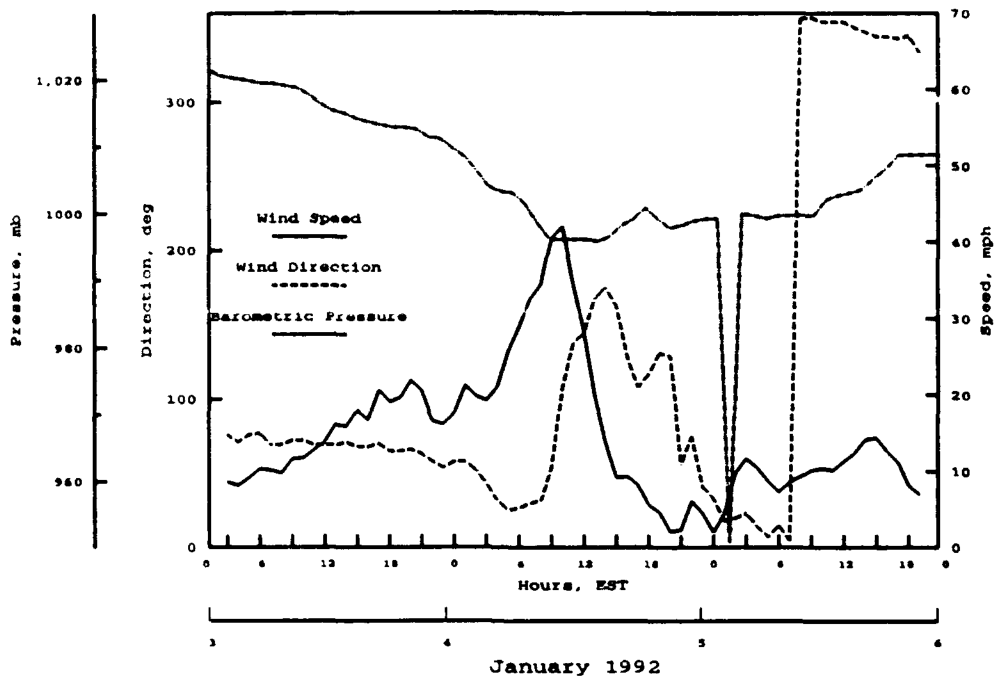


Figure 14. Wind speed, wind direction, and barometric pressure measured during the storm of 2-5 January 1992 at Assateague Island meteorological station

these portions of the plot are indicated by solid lines for the H_{mo} and T_p parameters. The maximum H_{mo} observed at Ocean City during the storm was 4.4 m at 1200 and 1300 hr UTC on 4 January. The corresponding T_p were 12.2 and 15.1 sec, respectively. At buoy location 44009, H_{mo} of 7.6 and 7.2 m and corresponding T_p of 14.3 sec were reported at these times, respectively. Buoy location 44012 reported H_{mo} of 7.3, 8.2, and 8.5 m at 1200, 1300, and T_p of 12.5. 14.3, and 14.3 sec. The significant differences in H_{mo} at the three locations, while maintaining a similarity in T_p, are probably due to the differences in water depth at the three locations. The water depth at the Ocean City gauge sites is approximately 36 ft. Water depths at buoy locations 44009 and 44012 are approximately 79 and 82 ft, respectively.

The pier on which the Ocean City NOS tide gauge was located was destroyed by high waves late on 3 January 1991, prior to the peak of the storm. An estimate of the surge level was obtained from the CERC wave measurement system by averaging the water level for each hourly wave-measurement interval. A datum estimate for the CERC measurement system was obtained by matching the high and low water levels to the NOS gauge measurements for three tide cycles prior to the failure of the pier supporting the NOS tide gauge. Figure 16 shows the hydrograph of observed and observed minus predicted tide (surge). A maximum water level of +6.6 ft NGVD was observed at 1200 hr UTC on 4 January. This level is approximately 4.6 ft above the predicted high tide of +2.0 ft NGVD at 1148 hr UTC.

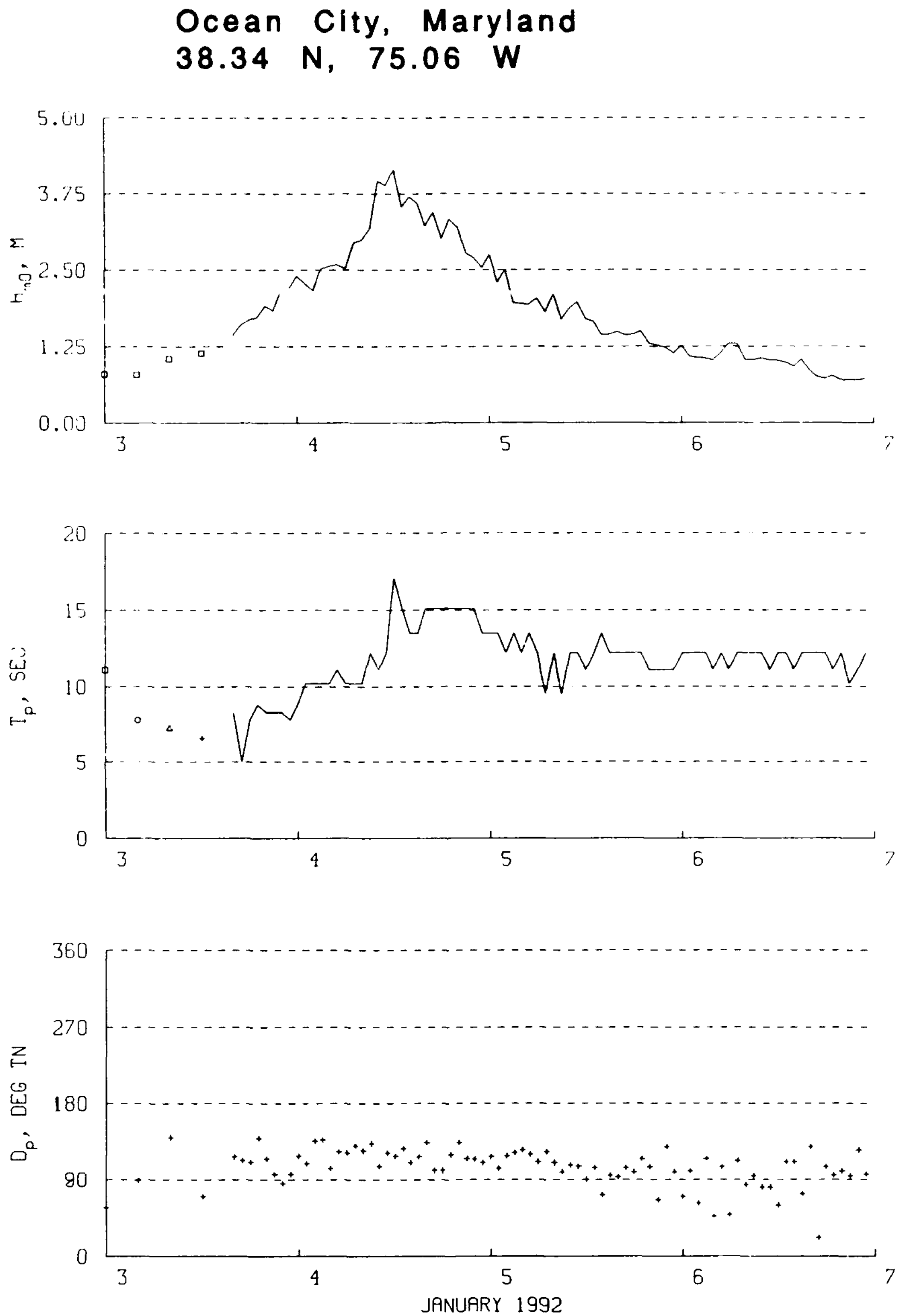


Figure 15. Wave height H_{mo}, peak period T_p, and dominant direction θ_p measured at Ocean City south gauge site for the storm of 2-5 January 1992

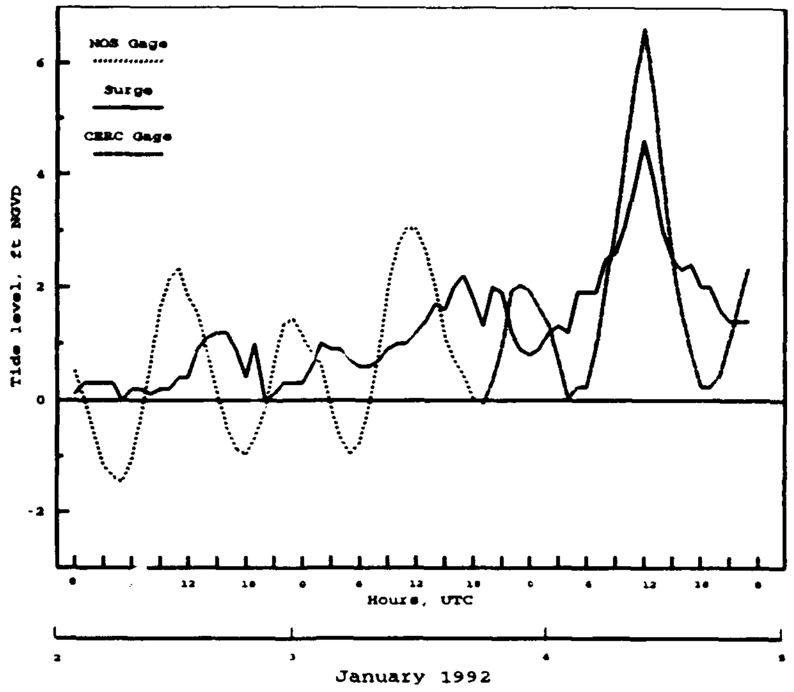


Figure 16. Hydrograph of observed water level and computed surge measured at NOS and CERC tide gauges for the storm of 2-5 January 1992

3 Fill Performance Monitoring

Pre-Project Beach

Design criteria for the 1988 State fill were developed from a survey of 36 beach profile lines in April 1986 (Anders and Hansen 1990). These lines extended seaward from benchmarks established near the street ends, with supplementary benchmarks located one block landward from the beach. The surveys extended to wading depth using a standard total station and rod. From wading depth to the seaward limit of the survey (usually around 1,000 to 2,000 ft seaward from the street end), a sled with attached survey rod was towed behind a boat. The elevations were read from the same survey instrument, providing a continuous profile from the baseline to the seaward extent of the survey. Sediment samples were also collected at 11 locations along each profile line (Anders, Underwood, and Kimball 1987). Subaerial sediment samples of approximately 100 g were collected by hand and placed in marked bags. The subaqueous samples were collected by ponar grab sampler from the boat, and a subsample was placed in bags for size analysis. Characterization of the active beach profile envelope and sediment grain size distribution is needed to define required fill volume, the design template, and the suitability of the borrow material (Stauble 1991b). Details of the beach fill design for the State and Federal fill can be found in USAED, Baltimore (1989).

Project monitoring starts before fill is placed on the beach. Baseline data of pre-project conditions are collected to evaluate the characteristics of the native beach. Pre-project monitoring establishes a database to provide design parameters and to evaluate the performance of the project after placement. Guidelines for establishing the components of a beach fill monitoring program that were used in this project can be found in Stauble (1991a). Monitoring of the response of the State beach fill began one month before fill placement with a set of profile surveys and sediment samples. Pre-project monitoring took place during June 1988 to document the native beach conditions before fill placement. Twelve profile line locations were chosen within the central portion of the project limits extending from 37th Street on the south to 103rd Street on the north (Figure 17). This area covered the central 3.5 miles of the project. The pre-project monitoring was limited to the central portion of the project to provide essential data on project performance under initial budget and time constraints.

The southern limit of the project was located at 4th Street. South of 4th Street the beach width increases to a maximum width at the north jetty of Ocean City Inlet. The shoreline from the inlet to 27th Street is fronted by a concrete bulkhead and boardwalk. North of 27th Street, a dune of varying height was present on the native beach and, during the Federal fill (1990-1991), a storm dune was constructed at a +15-ft elevation to the northern terminus of the project

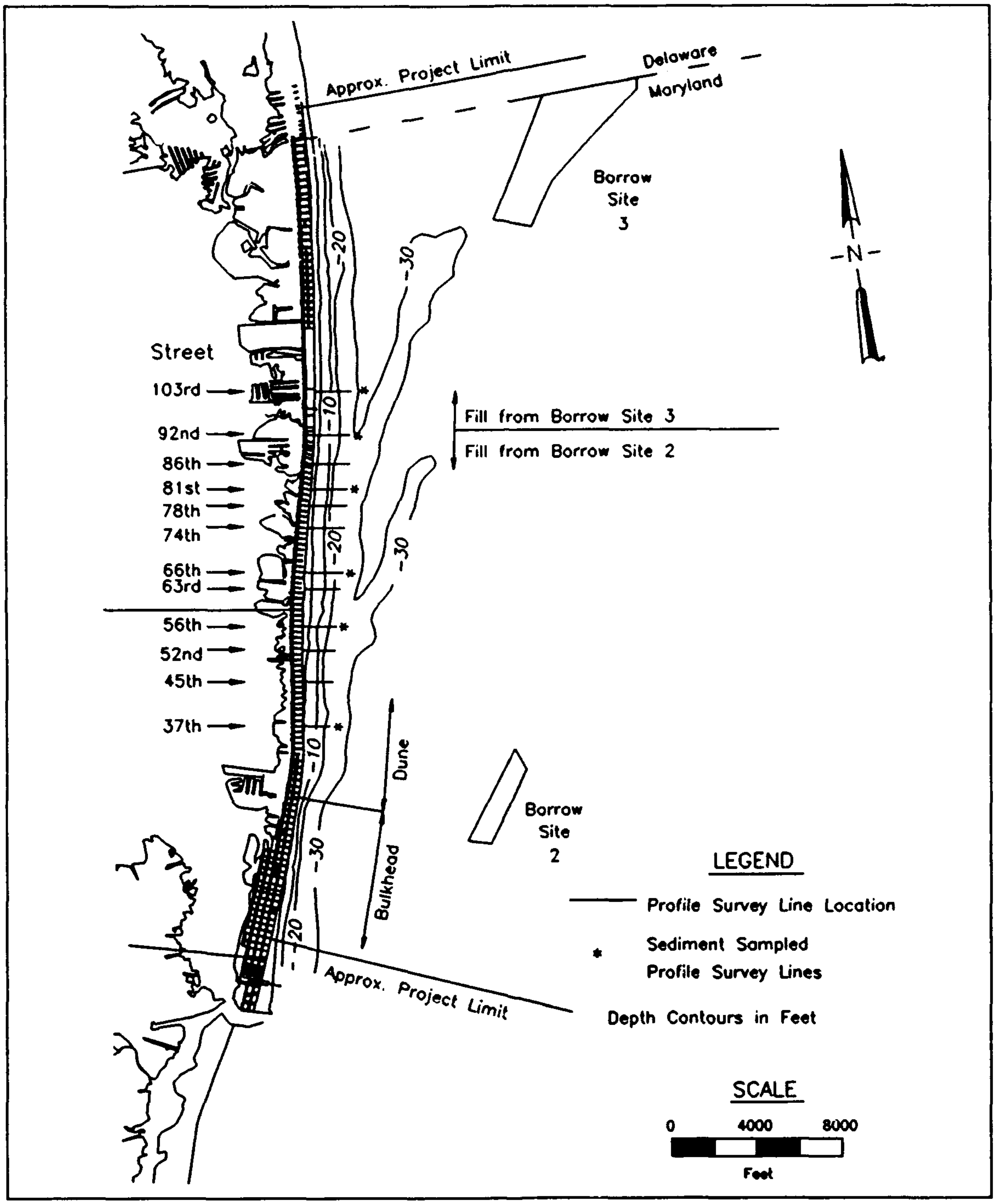


Figure 17. Survey line and sediment sample locations used in report for monitoring fill behavior and their relative positions to the shoreface-attached shoals

1600 ft north of the Maryland State line between North and South Carolina Avenues in the town of Fenwick Island, Delaware. The nearshore (defined in this report as the area below NGVD) is characterized as having several shoals that trend 45 deg from the orientation of the shoreline (Figure 2). The borrow areas were located on two of these offshore features. Two shoals are present within the study area that attach to the shoreline and are shown by the 30-ft contour on Figure 17. The southern shoal attaches to the shoreline between 50th and 60th Streets and the northern shoal attaches to the shoreline between 75th and 90th Streets. The Delmarva shelf has the largest number and highest density of shoreface-attached and detached sand ridges of any US east coast shoreline (McBride and Moslow 1991).

Profile Survey Components and Procedure

Material in this section is adapted from a draft manual[1] prepared for USAED Baltimore for monitoring and maintaining the shore-protection integrity of the project.

Survey system components

Most beach profile surveys made at Ocean City were conducted by Offshore and Coastal Technologies, Inc., East Coast (OCTI-E) under contract with USAED, Baltimore (Table 5). The OCTI-E beach profile surveying system consists of a towable sled and a total survey station. The sled is designed for surveys to water depths of 33 ft (-30 ft NGVD at high tide). The sled is towed by a boat outfitted with multiple motors, appropriate propellers, and towing apparatus. The sled runners and structure are constructed of steel, and the mast is made of aluminum (Figure 18). An array of glass surveying reflectors (prisms) is fixed atop the sled mast, with a lower single reflector located 3 ft below the main reflector array. The upper array used at Ocean City consists of three reflectors and is the primary target used in surveying beach profiles. The lower reflector provides additional data for correcting elevations surveyed on steeply sloping bottoms, where the sled may tilt.

The shore-based portion of the survey system consists of a Leitz Set2 total station and a Sokkisha SDR33 data collector. This laser-based system has a range of 7,700 ft with an accuracy greater than 0.01 ft in distance and in elevation at ranges surveyed at Ocean City. Elevation resolution in typical Ocean City beach profile ranges is estimated to be about 0.04 ft at maximum range.

Profile survey procedure

The surveying procedure consists of setting up the shore-based instruments on the beach profile (or adjacent to it) and surveying both the front and rear permanent monuments to obtain vertical and horizontal references. The beach profile lines are parallel to the street alignment,

[1] Offshore & Coastal Technologies, Inc. - East Coast, 19 Feb 1992, "Beachfill Maintenance Manual, Atlantic Coast Storm Protection Project, Ocean City, MD," draft report prepared for USAED, Baltimore.

Table 5
Profile Survey Descriptions

Year	Month	Purpose	Surveyor	Length	Remarks
1986	Apr	State Fill Design	FRF	Long	Not Used
1988	Jun	Pre-State Fill	Contractor	Short	Not Used
	Jun/Jul	Pre-State Fill	Triangle Surv	Long	For CERC
	Sep	Post-State Fill	Contractor	Short	Not Used
	Sep	Post-State Fill	Triangle Surv	Long	For CERC
1989	Jan	4 Months	OCTI-E	Long	For CERC
	Apr	8 Months	OCTI-E	Long	For CERC
	Jun	11 Months	OCTI-E	Long	For CERC
	Sep/Oct	14 Months	OCTI-E	Long	For USAEDB
1990	Jun	Pre-Federal Fill	OCTI-E	Long	For USAEDB
	Jul/Sep/ Oct	Post-Federal Fill	OCTI-E	Long	For USAEDB
	Dec	3 Months	OCTI-F	Long	For USAEDB
1991	Mar/Apr	6 Months	OCTI-E	Long	For USAEDB
	Jun	9 Months	OCTI-E	Long	For USAEDB
	Nov	Post-Halloween Storm	OCTI-E	Long	For CERC 12 Profile Lines
1992	Jan	Post-Dec Storm	OCTI-E	Long	For USAEDB

so that rows of street-parallel power poles or the curbing can be used to align the profile line if the monumentation has been disturbed. Once the instrument is referenced to monumentation, a manual survey of the subaerial beach is performed using a standard survey rod. The rod has a 0.6-sq-ft plate attached to its base to prevent penetration of the sand surface with the rod.

Measurements are made every 20 ft along the subaerial profile, or at a shorter interval to define major morphologic features, starting at the front monument and proceeding seaward to about -4 ft NGVD. The sled is then towed by boat out into the water from about +5 ft to beyond -25 ft NGVD. The boat is navigated by correcting position based upon a continuous report of sled coordinates from the shore station. The sled is kept to within 5 to 10 ft of the profile line approximately 95 percent of the time. Measurements of the position of the sled reflectors are made at approximately 40-ft intervals along the profile line, except in depths of less than 8 ft where measurements are made at shorter intervals to resolve bar/trough features. The

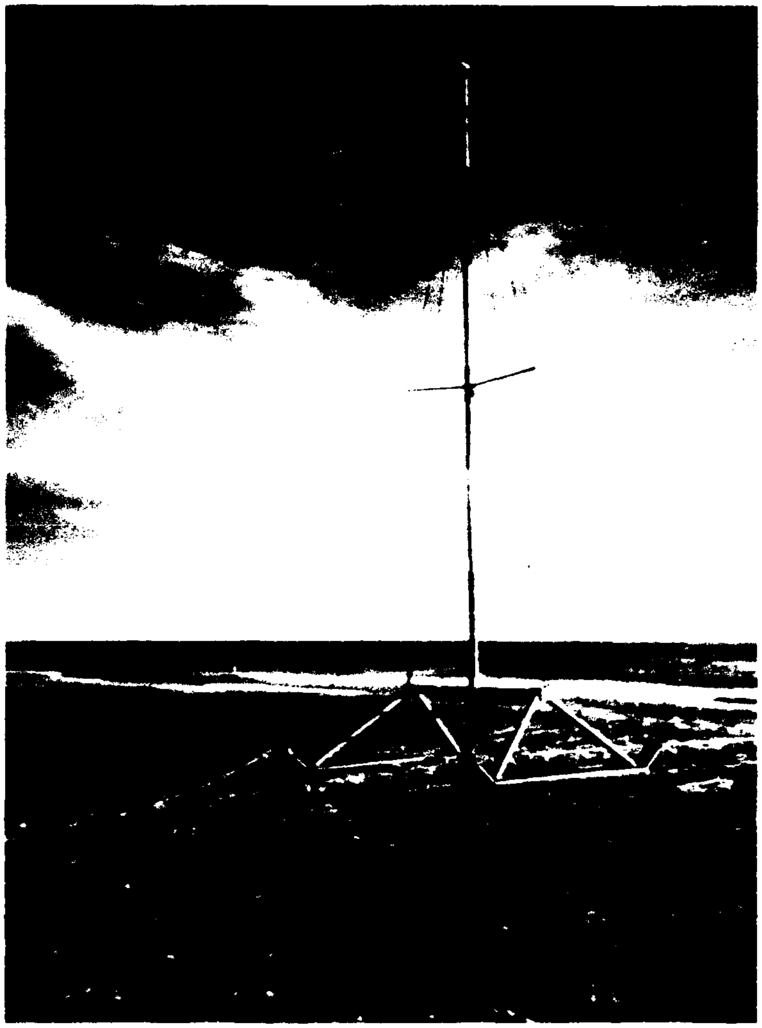


Figure 18. Photograph of the sled used in nearshore profile line surveys

measurements are recorded by the data collector and copied to a computer for processing or editing at the end of each survey day.

Survey accuracy

Errors associated with beach profile surveys can arise from several possible sources.

Instrument error. Inaccuracies of the electronic surveying instruments used by OCTI-E are considered to be small (less than 0.05 ft in horizontal and vertical distances). This is a random error, as opposed to a bias or systematic error. OCTI-E utilized the highest quality total station equipment available.

Operation error. Measurement inaccuracies can arise through errors associated with instrument set up (leveling) and data-collection techniques (ability to aim the laser at the center of the target). The same instrument operator obtains the measurements at the Ocean City nourishment so that systematic errors will be consistent from one survey to the next, thereby minimizing possible errors in volumetric change calculation. It is estimated that the operator systematic error on any survey is less that 0.05 ft (one quarter of the target prism diameter).

Bias due to beach properties. The height of the sled mast above the beach depends upon the depth to which the sled runners penetrate the sand surface. On firm, wet bottoms the sled runners normally penetrate about 0.5 cm. This number has been determined by comparing survey data collected by both sled and rod of the overlapping section of each beach profile and by field testing of the sled under various saturated beach face conditions. Post-survey analysis includes inspection of these comparison measurements to assure that the sled was not penetrating abnormally into the bottom. Abnormal penetration can be corrected in post-processing by using the overlapping data. This correction procedure has only been required in areas of very fine material in recently nourished fill areas.

Monumentation errors. Beach profile line azimuths at Ocean City are established by using the line defined by two permanent control monuments established on each profile. Occasionally, one or both monuments will have been disturbed, requiring that a beach profile azimuth be established using the street alignment (curb or telephone poles). Originally, all beach azimuths were established to be parallel to street alignments. An error of 2 to 3 deg in profile azimuth is possible, resulting in horizontal distance maximum error along a profile line of about 1 ft, making elevation error negligible. Monuments can also be disturbed by natural or societal causes, producing a systematic error in elevation. Periodic control re-surveys by the USAED, Baltimore, are performed to avoid this problem. Monumentation bias usually produces obvious offsets in a beach profile survey relative to previous surveys.

The maximum error associated with OCTI-E beach profile procedures is judged to be approximately 0.05 ft for conditions at Ocean City (good monumentation, relatively short beach profile lengths to reach closure depth). This error would produce a maximum potential error of about 1.4 cu yd/ft in a given beach profile if the error were systematic throughout the profile. The actual mean error is considered to be less.

Coverage error. In addition to equipment and procedure limitations, calculation accuracy of large-scale volume change depends on the number of beach profile survey lines covering the fill area. Sensitivity analysis has indicated that optimal profile line spacing (cost versus accuracy) is on the order of 1,000 ft (44 profiles lines from the Maryland-Delaware State line to the Ocean City Inlet). As the spacing increases, variations in beach platform create uncertainties in volume change. Two 44-line profile surveys taken in October 1989 and June 1990 were used to calculate volume changes over the entire Ocean City area. The calculations were supplemented by 22-line profile surveys taken in December 1990, March/April 1991, and June/July 1991. Volume changes were calculated using the entire data set, every other profile line, and every fourth profile line. As the number of profile lines decreased, the standard deviation of the volume change from line to line increased, leading to greater uncertainty in the total volume change estimate. For a typical survey it was found that the 90 percent confidence limits range from 3.3 cu yd/ft for a 22-line survey, to 2.0 cu yd/ft for a 44-line survey. The 44-profile line survey value of 2.0 cu yd/ft is equivalent to a 0.05-ft uncertainty in elevation over a profile line 1,000 ft long, comparable with the estimated accuracy of the sled surveys. The two recent beach fill projects at Ocean City were exposed to Atlantic Ocean conditions, which cause pronounced longshore features of various scales. To account for such features, a spacing of 500 ft would be optimal. This would reduce the uncertainty due to coverage errors below the errors associated with survey techniques. However, the improvement in volume change estimation would be small relative to the total volume of fill placed (about 45,000 cu yd in the Federal fill or 0.1 percent). Thus smaller spacing between survey locations would only be appropriate for studies of localized areas of the project.

The surveys began at the benchmark and proceeded seaward to a depth of approximately 25 to 36 ft, located between 1,500 and 3,500 ft seaward of the baseline. A construction baseline was established as the 0 distance at the landward end of the fill placement area. This baseline extended as a roughly straight line alongshore seaward of the building limit line and benchmark locations and is used as a fixed reference for comparing profile survey data collected over the project monitoring period. The locations of the beach profile survey lines were established initially in 1986 at street ends, starting with Profile Line 1 at the inlet and progressing northward to Profile Line 37 at the border between Maryland and Delaware. This numbering scheme omitted Line 12. Profile spacing was irregular along the island but covered approximately every fifth street to give a nominal 1,200-ft spacing. Additional profile survey locations were established at selected street ends between the original 36 lines during the pre-fill survey of the State fill in 1988. These additional profiles were designated with a 500-series numbering scheme starting with 504 at Caroline Street and extending northward to 586 at 144th Street. This dual numbering of profiles became awkward, and the survey lines were renumbered in March of 1989 before placement of the Federal fill. The new numbers start at the inlet at Profile 1 and progress northward in ascending order to Profile 44 at the Maryland/Delaware state line. The new profile locations for the most part were on the same street end, but a new monument system was used that moved the benchmark from the center line of the street to the curb. In most cases this offset was within 25 ft. Table 6 provides a conversion from the old to new profile numbers and their corresponding street locations.

The profile monitoring plan was modified for the Federal fill, with an increase in the number of profile lines to be monitored. The locations of the survey lines were also changed, but most of the original 12 lines monitored for the State fill were continued. This report describes the changes in these 12 profiles over both the State and Federal fill monitoring up until January 1992. Twenty-two of the forty-four profiles under the new numbering scheme are now included in the monitoring program of Federal fill. Essentially every other profile line is now being monitored, which provides greater alongshore coverage of the entire project. The only two lines that were dropped between the State and Federal fill monitoring were Line 21 located at 66th Street and Line 522/26 located at 78th Street. Analysis of elevation and volume change along the entire 22-line Federal fill profile survey set will be included in a future report. Tables 7 and 8 provide a list of the profile lines and the dates surveys were taken and identify the profiles where sediment samples are collected.

Table 5 summarizes available profile surveys that have been made for design, placement volume calculations, and project monitoring. Some of the surveys made to document volume of fill placed only reached to wading depth and were not used in this study due to their short length. (The data have been reduced and are available for analysis.) Long sled surveys were made within a few weeks of these short surveys and provided a more complete history of beach change. The April 1986 design profile survey and sediment set were collected by the survey crew from CERC's Field Research Facility (FRF) located at Duck, North Carolina, and included Line 1 through Line 37 on the old numbering system. This profile survey set was modified with the addition of a proposed design storm berm or dune by USAED, Baltimore. These data sets were not used in this report due to absence of original data sets and the 2-year time span between the survey and actual project construction.

Table 6
Beach Profile Line Locations, Numbering Schemes, and Profile/Sediment Data Used in Project Monitoring

Street No.	Old Profile Line No.	New Profile Line No.	Profile Line Used in this Study	Sediment Collected
South First	1	1		
Dorchester	2	2		
1st	3	3		
3rd	4	4		
7th	5	5		
10th	6	6		
13th	7	7		
15th	8	8		
20th	9	9		
25th	10	10		
27th	11	11		
32nd	13	12		
37th	14	13	✓	✓
41st	15	14		
45th	16	15	✓	
48th	17	16		
52nd	18	17	✓	
56th	19	18	✓	✓
61st	20	19		
63rd	544	20	✓	
66th	21	21	✓	✓
69th	546	22		
71st	22	23		
74th	550	24	✓	
76th	23	25		
78th	552	26	✓	
81st	24	27	✓	✓

(Continued)

Table 6 (Concluded)				
Street No.	**Old Profile Line No.**	**New Profile Line No.**	**Profile Line Used in this Study**	**Sediment Collected**
84th	556	28		
86th	25	29	✓	
92nd	26	30	✓	✓
99th	27	31		
103rd In the vicinity of Old Landing Rd.	28	32	✓	✓
Old Wharf Rd.	568	33		
112th	29	34		
Between Fountainhead and Sea Watch condominiums	30	35		
120th	31	36		
122nd	574	37		
124th	32	38		
129th	33	39		
132nd	578	40		
134th	34	41		
138th	35	42		
142nd	36	43		
146th	37	44		

A sled survey was conducted during June 1988, immediately before fill placement, to accurately characterize the pre-fill beach at the 12 profile locations identified in Figure 17. Profile lines were surveyed to wading depth by the dredging contractor at each survey location from Line 5 (the southernmost profile within the fill placement area) to Line 37 at the State line, including some of the 500-series profiles (for a total of 44 survey lines) immediately before fill placement in June 1988 to measure the subaerial pre-project beach condition. The State project was constructed during the summer of 1988. "As-built" short surveys were made immediately after fill placement by the dredging contractor at each profile location to determine the volume of fill pl. d on the subaerial beach. These survey lines averaged approximately 200 ft in length and did not include any of the nearshore bar/trough or shelf area. Due to their short length, they were not used in the present analysis.

Table 7
Survey Dates and Sediment Sample Collections, State Fill

Profile Number Old/New	Phase I (State Fill) Dates									
	1986	1988				1989				1990
	Apr	Jun[1]	Jun/ Jul[1] PRE	Sep[1]	Sep[1] POST	Jan	Apr	Jun[2]	Sep/ Oct	Jun PRE
1/1	X •									
2/2	X •						•		X	
3/3	X •						•		X	
4/4	X •								X	
5/5	X •	X		X			•	X	X	X
6/6	X •	X		X				X	X	X
7/7	X •	X		X			•	X	X	X
8/8	X •	X		X			•	X	X	X
9/9	X •	X		X				X	X	X
10/10	X •	X		X			•	X	X	X
11/11	X •	X		X				X	X	X
13/12[3]	X •	X		X		X	X	X	X	X
14/13	X •	X	X •	X	X •	X •	X •	X •	X	X
15/14	X •	X		X		X	X	X	X	X
16/15	X •	X	X	X	X •	X •	X	X	X	X
17/16	X •	X		X		X	X	X	X	X
18/17	X •	X	X	X	X •	X •	X	X	X	X
19/18	X •	X	X •	X	X •	X •	•	X	X	X
20/19	X •	X		X		X	X	X	X	X
544/20		X	X	X	X •	X •	X	X	X	X
21/21	X •	X	X •	X	X •	X •	X •	X	X	X
456/22		X		X					X	X
22/23	X •	X		X				X	X	X
550/24		X	X	X	X •	X •	X	X	X	X
23/25	X •	X		X				X	X	X
552/26		X	X	X	X •	X •	X	X	X	X

(Continued)

Table 7 (Concluded)

Profile Number Old/New	Phase I (State Fill) Dates									
	1986	1988				1989				1990
	Apr	Jun[1]	Jun/ Jul[1] PRE	Sep[1]	Sep[1] POST	Jan	Apr	Jun[2]	Sep/ Oct	Jun PRE
24/27	X *	X	X *	X	X *	X *	X *	X *	X	X
554/28		X		X					X	X
25/29	X *	X	X	X	X *	X *	X	X	X	X
26/30	X *	X	X *	X	X *	X *	X *	X *	X	X
27/31	X *	X		X		X	X	X	X	X
28/32	X *	X	X *	X	X *	X *	X *	X *	X	X
568/33		X		X					X	X
29/34	X *	X		X		X	X	X	X	X
30/35[4]	X *	X		X		X	X	X	X	X
31/36	X *	X		X				X	X	X
574/37		X		X					X	X
32/38	X *	X		X		X	X	X	X	X
33/39	X *	X		X				X	X	X
578/40		X		X					X	X
34/41	X *	X		X				X	X	X
35/42	X *	X		X				X	X	X
36/43	X *	X		X				X	X	X
37/44	X *	X		X				X	X	X

X = Profile surveyed.
* = Sediment sample taken.
12 Shaded profile numbers used in monitoring of Phase I (State fill).
[1] Using new profile numbering scheme.
[2] New profile numbering scheme surveyed March 89 - first used June 89.
[3] No profile monument #12 in original (old) profile numbering scheme.
[4] Old profile monument #30 offset 150 ft to the north from new profile monument #35 (all other old profile monuments within 25 ft of new profile monuments).

Post-fill project monitoring began with a set of long sled surveys made on the 12 designated profiles during September and October of 1988, soon after the project was completed. A quarterly sampling schedule of long sled profiles specifically for project monitoring was initiated three months later in January 1989. During February and March of 1989 a series of extratropical storms impacted the project area. The April profile survey set provided an opportunity to evaluate the fill behavior after these storms.

Monitoring of the State project extended for 1 year to September/October 1989. The new profile numbering scheme was first used for the June 1989 survey. A 7-month hiatus in monitoring occurred after the September/October profile survey until June 1990. In preparation for the Federal fill placement, a set of long sled surveys from Line 5 to Line 44 was obtained to assess the condition of the beach and State fill after almost 2 years and as a pre-fill survey for the Federal fill. The Federal fill was placed during the summer of 1990, and post-fill profile surveys were made as the fill was being placed from July to September 1990 on 16 survey lines within the project (Table 7). A more systematic monitoring program, consisting of 22 profile survey lines and covering the entire length of the project, was initiated with the 3-month survey in December 1990. These lines were surveyed to a depth of 25 ft, extending from 1,000 to 2,000 ft from the baseline. Monitoring of the profile and sediment change continued on the 22 lines with a 6-month March/April and a 9-month June 1991 data set.

A strong extratropical storm impacted the project on 31 October 1991 and became known as the Halloween Storm. The regularly scheduled September survey was delayed, but a limited post-storm survey was made in November at 12 locations throughout the project. Another extratropical storm impacted the area on 4 January 1992. The regularly scheduled survey of 22 lines was made about a week after this storm and allowed a measure of the response of the project to these two major storms. The project is continuing to be monitored, and future profile surveys and sediment sample collection will be made. These profile surveys and sediment analysis will be reported on in the next in this series of reports. All of these storms (March 1989, October 1991, January 1992) are described in Chapter 2.

Profile data were recorded in field notebooks and processed in the laboratory. The profiles were plotted and compared using the Interactive Survey Reduction Program of Birkemeier (1984). The program allows the plotting of profiles at various scales and vertical exaggerations from field data sets of distance from baseline (x) and elevation (y). An unlimited number of profiles can be plotted on a single axis to compare profile change and determine profile envelopes and closure areas. Profiles of successive dates were compared and volume changes were calculated with the program.

The 12 profile lines located between 37th Street and 103rd Street in the central 3.5 miles of the project were monitored throughout the State and Federal project. The southern portion of the project from 3rd Street north to 91st Street used Borrow Area 2 (see Figure 17 for location). From 92nd Street to the northern limit of the Project at the State line, the fill material came from Borrow Area 3. The southern shoreface-attached shoal met the shoreline on a 45-deg angle in the vicinity of 50th Street to 60th Street and was surveyed on Lines 18/17 and 19/18. The northern shoreface-attached shoal merged with the shoreline between 75th Street and 92nd Street and was measured in surveys on Lines 552/26 and 26/30.

Table 8
Survey Dates and Sediment Sample Collections, Federal Fill

Profile Numbers[1] Old/New	Phase II (Federal Fill) Dates							
	1990			1991			1992	
	Jun PRE	Jul/Sep POST	Dec	Mar/Apr	Jun	Nov	Jan	Mar
1/1								
2/2			X	X *	X *		X *	
3/3								
4/4			X	X *	X *	X *	X *	
5/5	X							
6/6	X	X	X	X *	X *		X *	
7/7	X							
8/8	X	X	X	X *	X *	X *	X *	
9/9	X							
10/10	X	X	X	X *	X *	X *	X *	
11/11	X							
13/12[2]	X	X	X	X *	X *		X *	
14/13	X	X	X	X *	X *	X *	X *	
15/14	X							
16/15	X	X	X	X *	X *	X *	X *	
17/16	X							
18/17	X	X	X	X *	X *		X *	
19/18	X	X	X	X *	X *	X *	X *	
20/19	X							
544/20	X	X	X	X *	X *	X *	X *	
21/21	X							
456/22	X			X				
22/23	X							
550/24	X	X	X	X *	X *	X *	X *	
23/25	X							
552/26	X			X				

(Continued)

Table 8 (Concluded)								
Profile Numbers[1] Old/New	Phase II (Federal Fill) Dates							
	1990			1991			1992	
	Jun PRE	Jul/Sep POST	Dec	Mar/Apr	Jun	Nov	Jan	Mar
24/27	X	X	X	X *	X *		X *	
554/28	X							
25/29	X	X	X	X *	X *		X *	
26/30	X	X	X	X *	X *		X *	
27/31	X							
28/32	X	X	X	X *	X *	X *	X *	
568/33	X							
29/34	X		X	X *	X *		X *	
30/35[3]	X							
31/36	X		X	X *	X *		X *	
574/37	X							
32/38	X	X	X	X *	X *	X *	X *	
33/39	X							
578/40	X		X	X *	X *		X *	
34/41	X							
35/42	X	X	X	X *	X *	X *	X *	
36/43	X							
37/44	X		X	X *	X *		X *	

X = Profile line surveyed.
* = Sediment sample taken.
12 Shaded profile line numbers used in monitoring of Phase I (State fill).
[1] Using new profile numbering scheme.
[2] No profile monument #12 in original (old) profile numbering scheme.
[3] Old profile monument #30 offset 150 ft to the north from new profile monument #35 (all other old profile monuments within 25 ft of new profile monuments).

Depth of Closure

Review of concepts

Changes in sand volume and profile shape are central factors in the evaluation of beach fill performance. Such analysis is performed for the profile extending from the landward side of the dune to a point offshore where no notable change in bottom elevation occurs. This seaward limit of profile change is called the depth of closure, the minimum water depth at which no measurable or significant change in bottom elevation occurs. The Ocean City beach nourishment project has provided accurate sled-survey data for evaluating beach fill performance and for conducting basic studies on profile change and the depth of closure.

In engineering studies, it is standard practice to assume that waves are the main hydrodynamic force responsible for profile change on open-ocean beaches. Movement of sediment on the profile and resultant change in bottom elevation are a function of the wave properties and sediment grain size. The depth of closure is, therefore, a time-dependent quantity that may be interpreted statistically. For example, Hallermeier (1978, 1981) introduced a seaward limit of extreme surf-related sediment movement leading to erosion (or offshore sediment transport). He developed a simple predictive equation for the depth of the seaward limit expressed in terms of the average of the nearshore storm wave height (and the associated wave period) that is exceeded only 12 hr per year. Birkemeier (1985) validated the form and predictions of the Hallermeier equation with profile survey data obtained at CERC's Field Research Facility, located at Duck, North Carolina, on a sandy barrier beach facing the Atlantic Ocean. Birkemeier (1985) used measured wave conditions that existed between profile surveys that exhibited offshore sand movement. The depth of closure concept and statistical values for its use in beach fill design are discussed by Kraus and Larson (1993).

For Ocean City, sufficient numbers of profile surveys of high quality are available to determine empirically the depth of closure for the 3-1/2 years encompassed by the data set. The depth of closure determined in this manner contains the influence of higher wave energy events as well as typical waves that mold the profile into dynamic equilibrium. This relatively long time period is appropriate for evaluation of beach fill project performance. In the analysis, the depth of closure is identified as the minimum depth where the standard deviation in depth change decreases markedly to a near-constant value (Kraus and Harikai 1983). In this view, the landward region of larger standard deviation in depth change is interpreted to be the active profile dominated by short-period waves and by changes in water level accompanying storms, whereas the region of smaller and nearly constant standard deviation is interpreted to be a region predominantly influenced by lower-frequency and weaker sediment-transporting processes such as by the large-scale shelf and oceanic circulation. The smaller standard-deviation values also fall within the limit of measurement accuracy and denote the operational limit of specifying a closure depth unambiguously.

Observed depth of closure

The data set from which the depth of closure analysis proceeds is summarized in Table 9. Surveys extending less than approximately 900 ft from the baseline were excluded, and the analysis covers the 12 lines for which seven or more long surveys were available. Many of these surveys extend to the 30-ft depth.

Table 9
Dates of Surveys Used to Determine Profile Depth of Closure

37th St.	45th St.	52nd St.	56th St.	63rd St.	66th St.
6-16-88	6-28-88	6-28-88	6-29-88	6-29-88	7-1-88
9-22-88	9-22-88	9-22-88	9-21-88	9-22-88	9-19-88
1-17-89	1-19-89	1-19-89	1-19-89	1-19-89	1-19-89
4-20-89	4-12-89	4-12-89	4-12-89	4-12-89	4-14-89
6-20-89	6-20-89	6-20-89	6-19-89	6-19-89	6-19-89
10-1-89	9-28-89	9-28-89	9-28-89	9-28-89	10-1-89
6-1-90	6-1-90	6-1-90	6-1-90	6-1-90	6-1-90
8-14-90	9-6-90	9-1-90	9-7-90	9-11-90	
12-1-90	12-1-90	12-1-90	12-1-90	12-2-90	
3-26-91	3-26-91	3-26-91	3-26-91	3-26-91	
6-26-91	6-26-91	6-26-91	6-26-91	6-26-91	
11-3-91	11-3-91	1-11-92	11-3-91	11-2-91	
1-11-92	1-11-92		1-11-92	1-11-92	

74th St.	78th St.	81st St.	86th St.	92nd St	103rd St.
7-1-88	6-30-88	6-30-88	6-22-88	6-22-88	6-22-88
9-19-88	9-15-88	9-13-88	9-8-88	9-7-88	10-26-88
11-9-89	1-19-89	1-19-89	1-20-89	1-20-89	1-20-89
4-14-89	4-14-89	4-14-89	4-20-89	4-20-89	4-20-89
6-19-89	6-19-89	6-19-89	6-19-89	6-19-89	6-19-89
9-28-89	9-28-89	9-28-89	9-28-89	9-29-89	10-1-89
6-1-90	6-1-90	6-1-90	6-1-90	6-1-90	6-1-90
10-11-90		9-28-90	8-28-90	9-8-90	7-17-90
12-2-90		12-2-90	12-2-90	12-2-90	12-2-90
3-26-90	3-26-91	4-2-91	4-2-91	4-2-91	4-2-91
6-26-91		6-27-91	6-27-91	6-27-91	6-27-91
11-2-91		1-11-92	1-11-92	1-11-92	11-2-91
1-11-92					1-10-92

Figures 19 to 22 plot the profile survey data and standard deviation in elevation derived from the surveys for the northernmost line (103rd Street), two mid-project lines (74th and 52nd Streets), and the southernmost line (37th Street). The shape of the northern profiles tends to be steep, with bars absent. The sand-rich nearshore profile at 37th Street, which has a prominent nearshore bar and gentle slope offshore, may be a result of the presence of the shore-attached shoal and sand impoundment at the jetty, located approximately 3 miles to the south. The profile surveys at 52nd Street reveal a shoal located about 2,000 ft from the baseline. Other properties of the profile shape and evolution are discussed in the sections of this chapter which follow.

Figures 19 to 22 show a clear reduction in the standard deviation in the range of the 18- to 20-ft depth. Seaward of this depth, the lower and relatively constant standard deviation of about 3 to 4 in. is in the range of measurement error of the sled survey method described previously in this chapter; the area of near-constant deviation may also reflect the working of less energetic and longer time-scale sediment movement processes than wave action. Above the approximately 20-ft depth contour, the profile exhibits large variability, indicative of the active area of littoral transport. Large changes above the datum are associated with beach fill placement, major erosive storms, and the action of ordinary waves reworking the profile.

To further examine spatial variability in the profile and determine the depth of closure for the nourishment project, the mean profile and envelopes of maximum and minimum elevation determined in all surveys were calculated for each line. The envelopes thus contain extreme values in any survey and the greatest error in measurement. An abrupt change in an envelope curve and standard deviation usually indicate the end of one of the profile surveys in the data set for the particular line. The mean and envelope profiles for the 12 surveys listed in Table 7 are displayed in Figures 23 to 34, which are discussed in order in the following paragraphs.

The mean profile for 103rd Street decreases monotonically to the 30-ft depth. The standard deviation in elevation change becomes small and relatively constant about 1,200 ft from the baseline, in about the 23- to 24-ft depth. Near to shore there are two peaks in the deviation of about 3 ft, one located at the dune and the other along the foreshore, representing placement of the beach nourishment and storm erosion. A third peak in deviation is centered about 1,000 ft from shore and indicates movement of fill to this area of the profile at approximately the 22-ft depth. The next survey line, 92nd Street, shows three smaller peaks in deviation, located on the dune, berm, and foreshore, and there is no peak in the offshore. The profile at this survey line evidently did not require as great sediment movement to the offshore as did the profile at 103rd Street; a steep reduction in standard deviation in elevation change occurs about 700 ft offshore, indicating a closure depth of 18 ft. The shoal, located 2,000 ft from the baseline and beyond on the 92nd Street line, which appears stable for the available surveys, may protect the landward profile and beach by breaking storm waves and by supplying sand during accretionary wave conditions.

The elevation envelopes and standard deviations for the profile lines at 86th and 81st Streets are similar above NGVD, reaching deviations of 4 ft in broad peaks. The envelopes for 86th Street pinch off about 700 ft offshore, giving a closure depth of 18 ft. The standard deviation increases from a minimum amount as the landward side of the shoal is approached, indicating some movement of the shoal and exchange of material with the shore. Near and seaward of the crest of the shoal, the deviation again decreases. Movement of material on the shoal may be indicative of longshore as well as cross-shore transport and be related to wave convergence and wave-induced currents. The closure depth of the 81st Street line is about 22 to 23 ft, and there

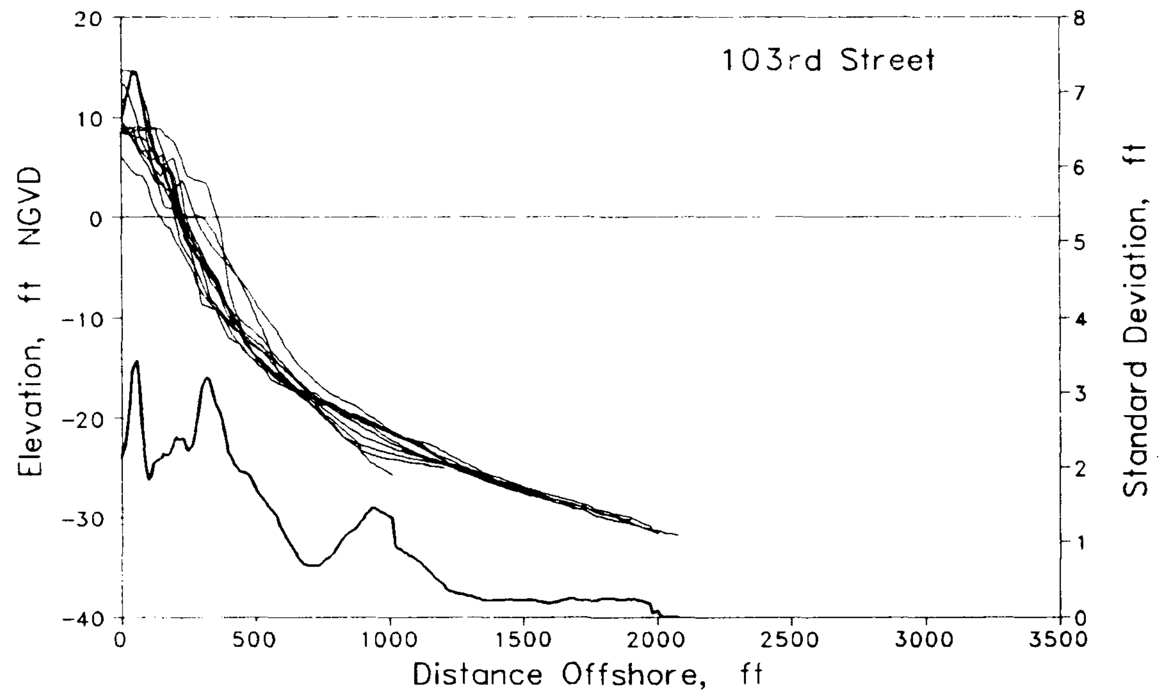


Figure 19. Profile surveys and standard deviation in elevation, 103rd St.

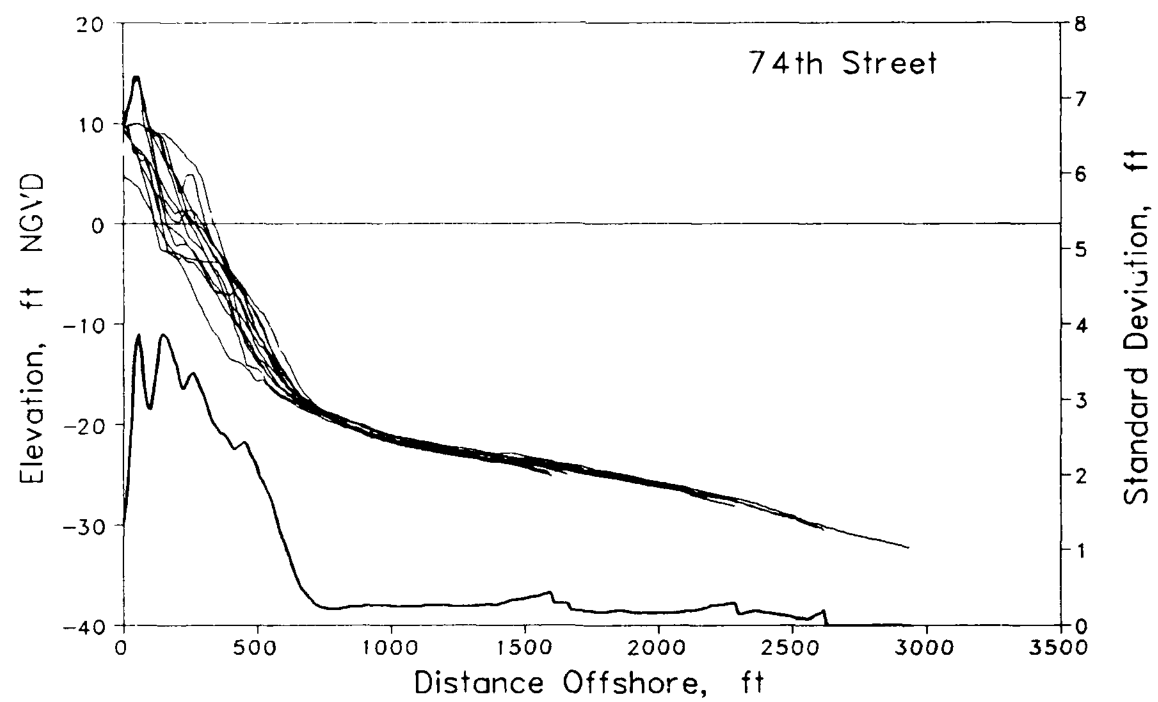


Figure 20. Profile surveys and standard deviation in elevation, 74th St.

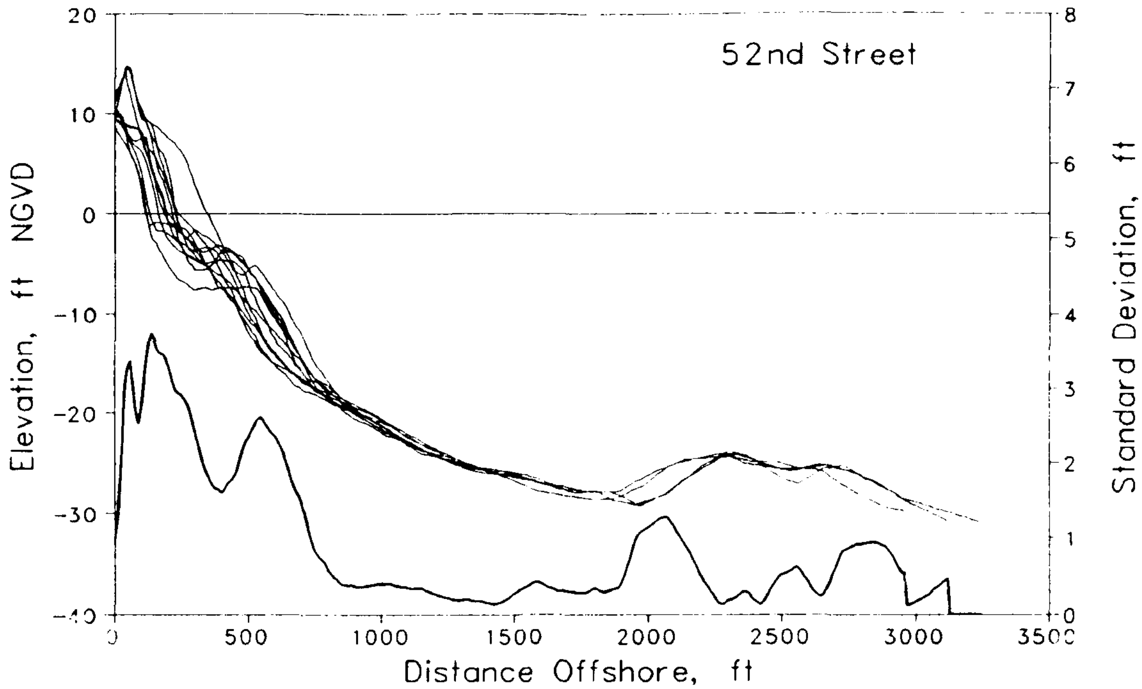


Figure 21. Profile surveys and standard deviation in elevation, 52nd St.

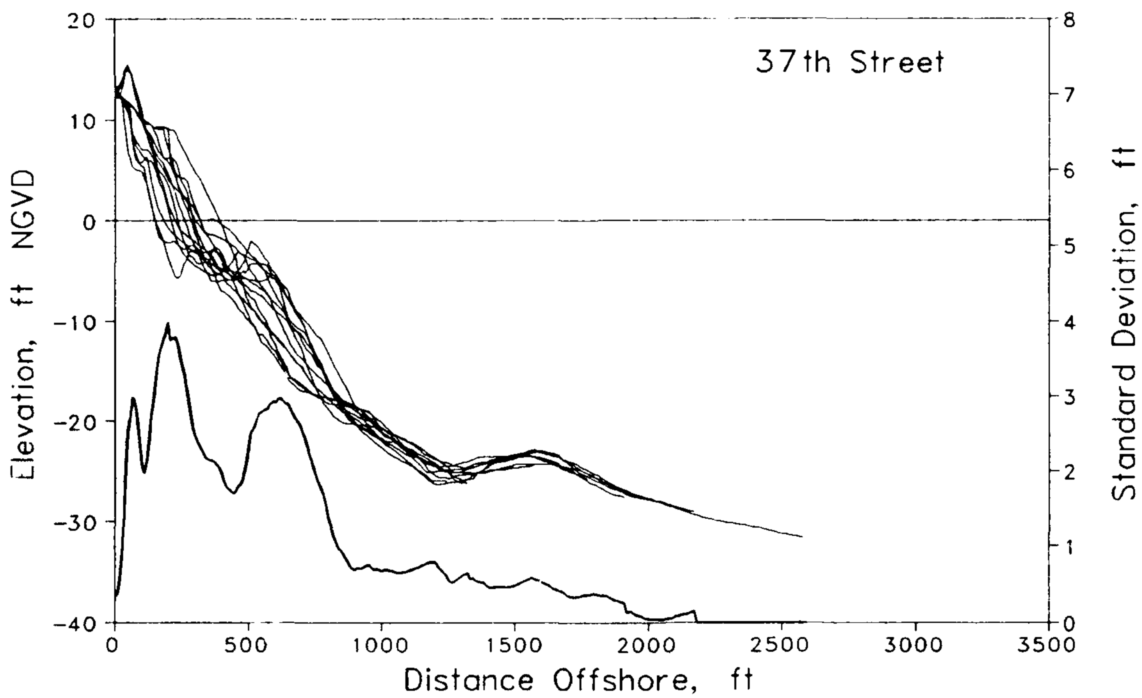


Figure 22. Profile surveys and standard deviation in elevation, 37th St.

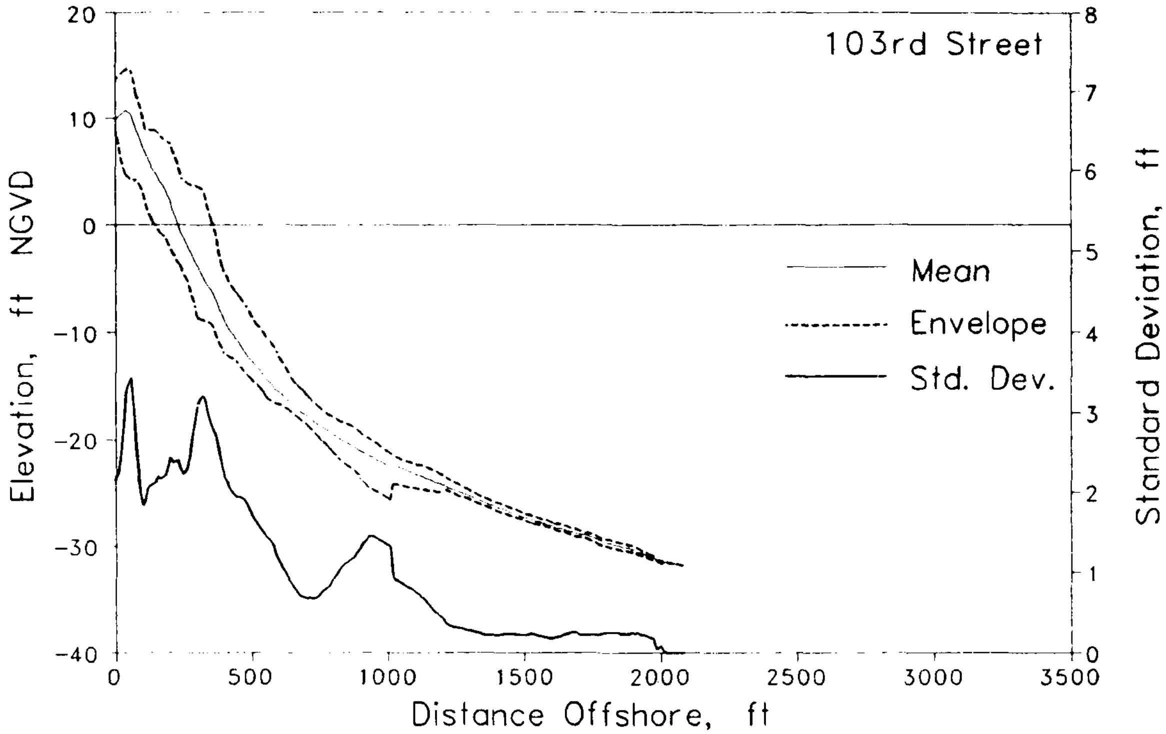


Figure 23. Profile envelopes and standard deviation in elevation, 103rd St.

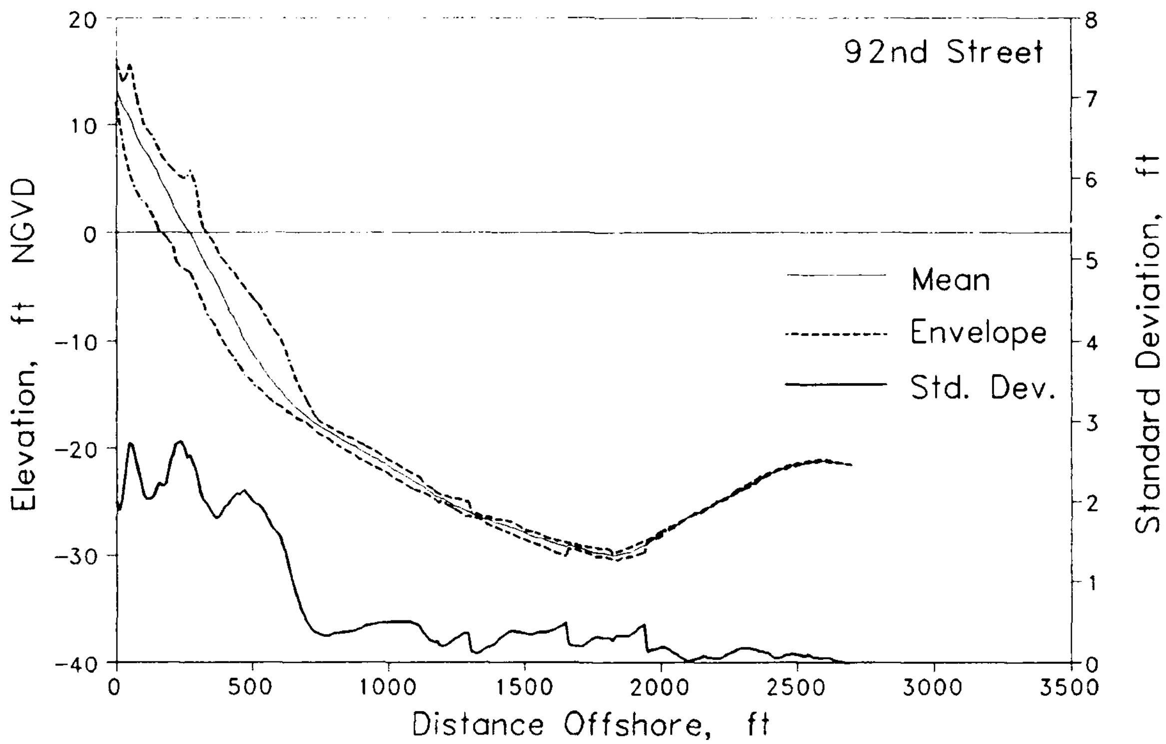


Figure 24. Profile envelopes and standard deviation in elevation, 92nd St.

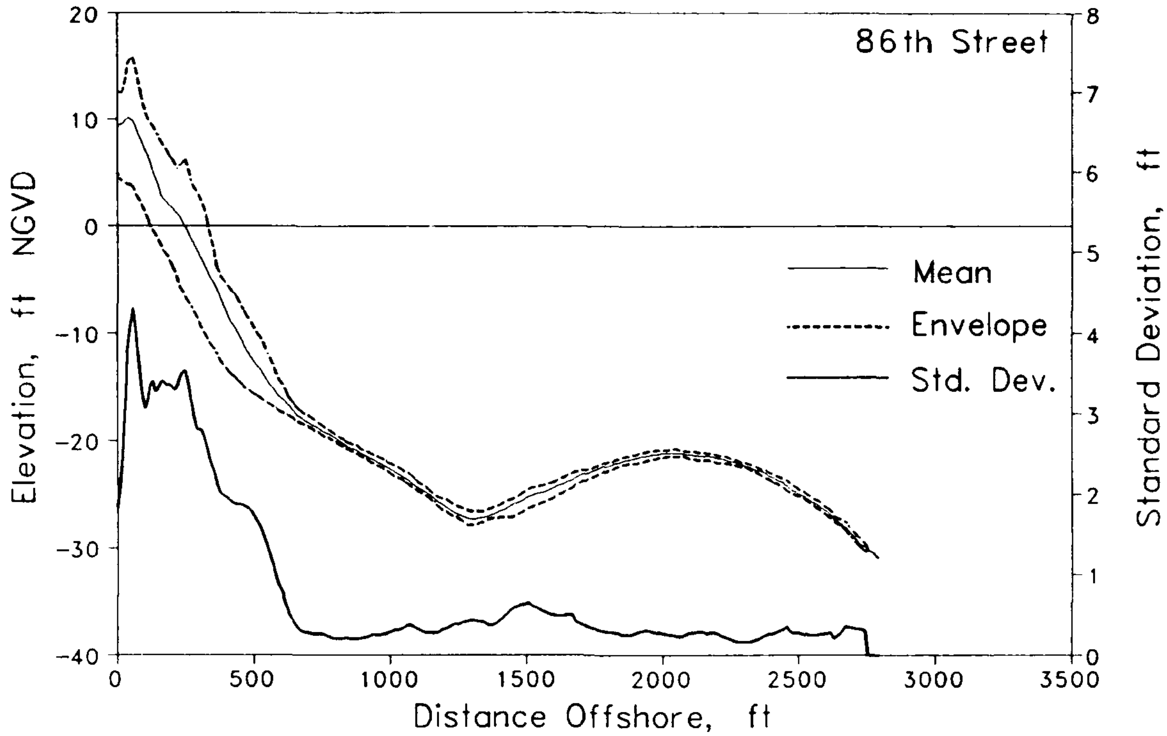


Figure 25. Profile envelopes and standard deviation in elevation, 86th St.

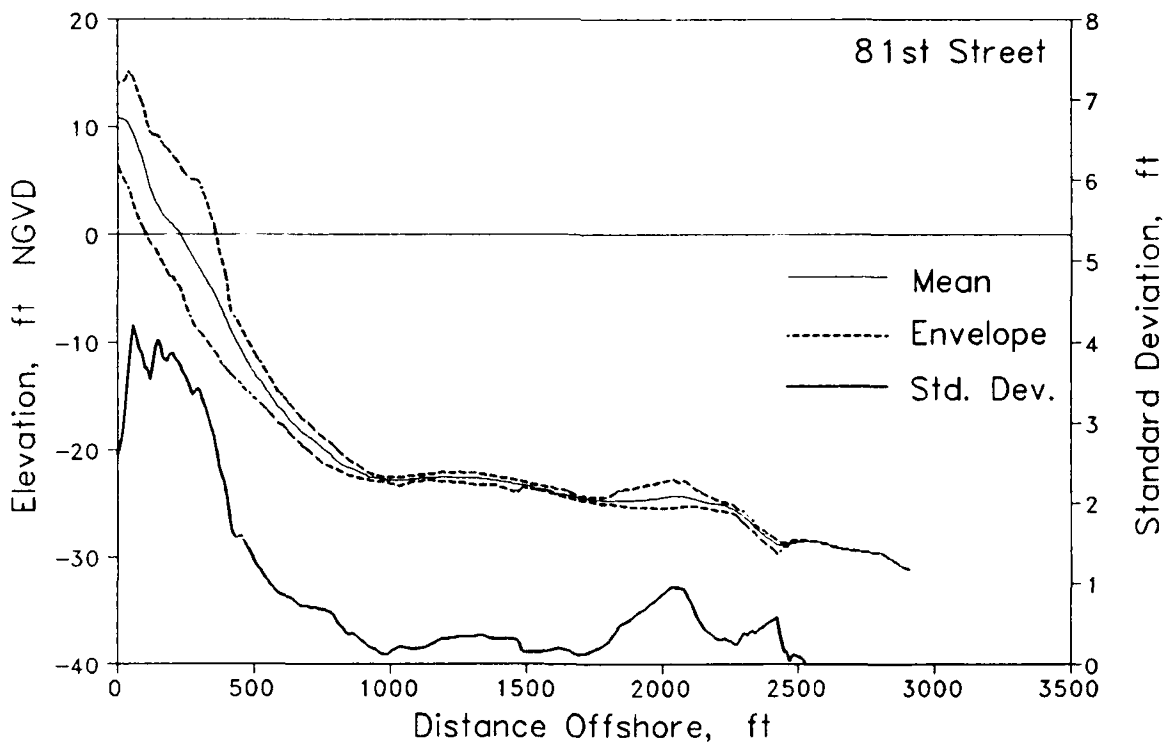


Figure 26. Profile envelopes and standard deviation in elevation, 81st St.

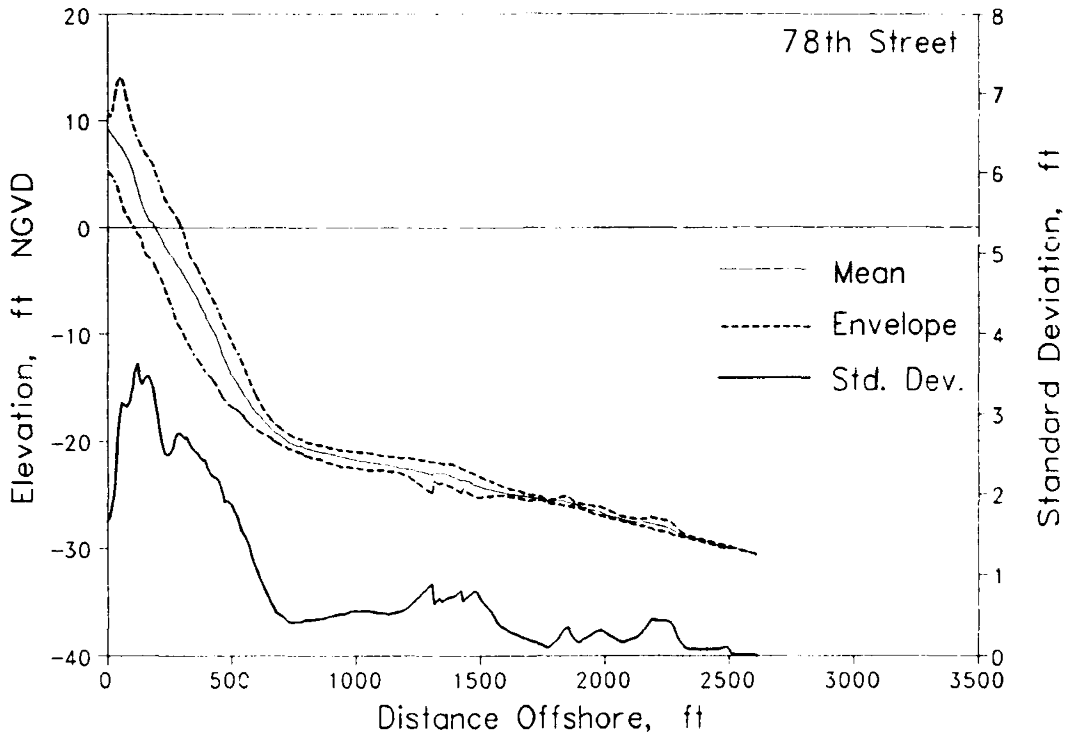


Figure 27. Profile envelopes and standard deviation in elevation, 78th St.

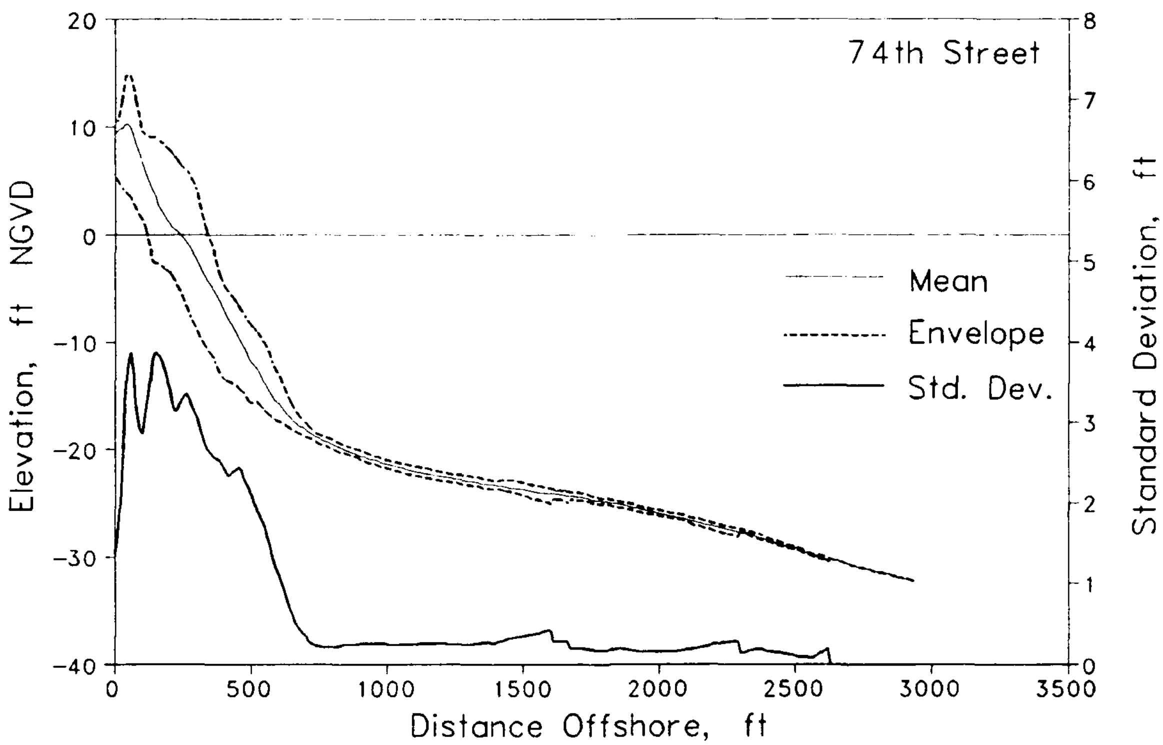


Figure 28. Profile envelopes and standard deviation in elevation, 74th St.

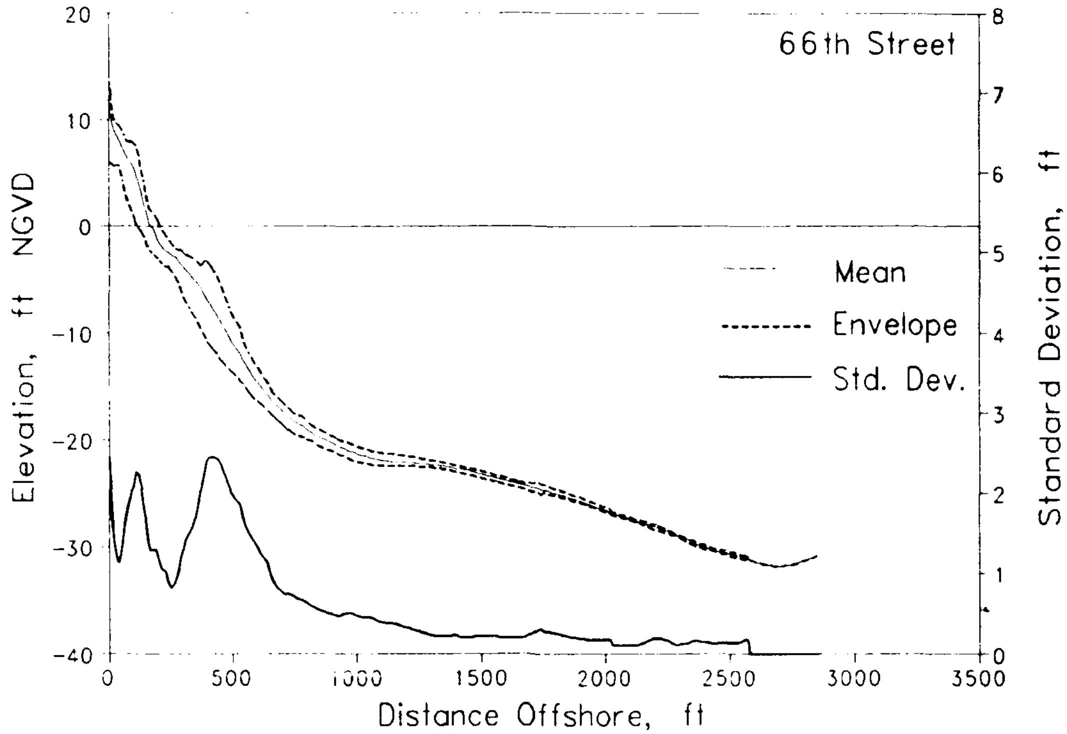


Figure 29. Profile envelopes and standard deviation in elevation, 66th St.

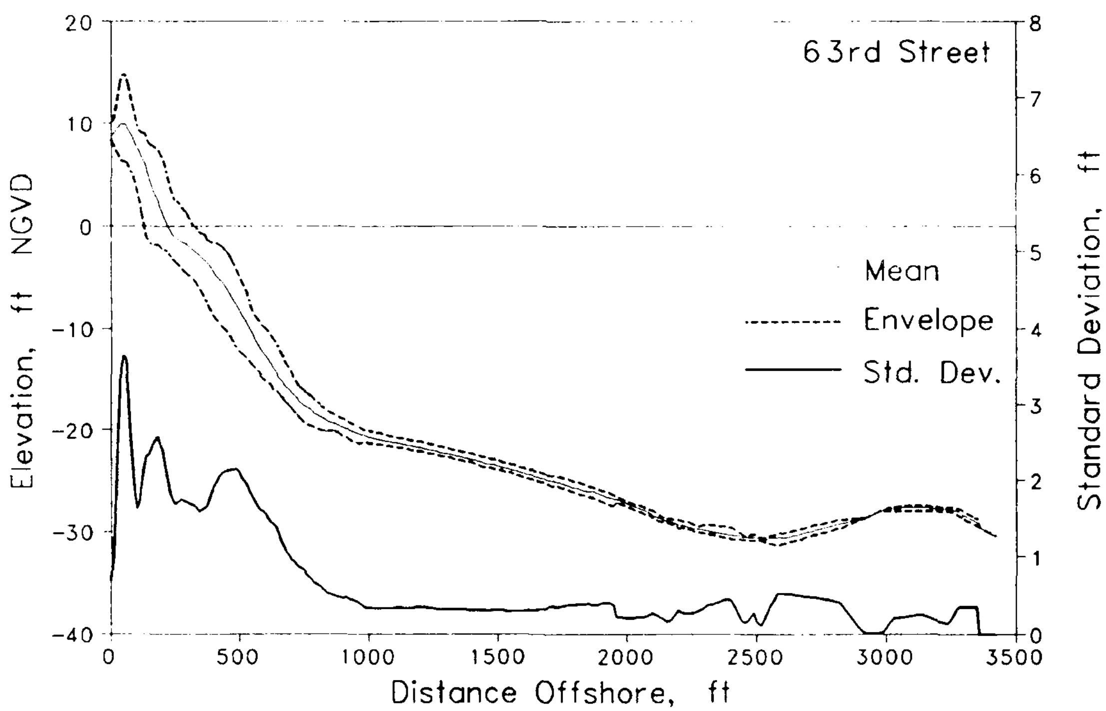


Figure 30. Profile envelopes and standard deviation in elevation, 63rd St.

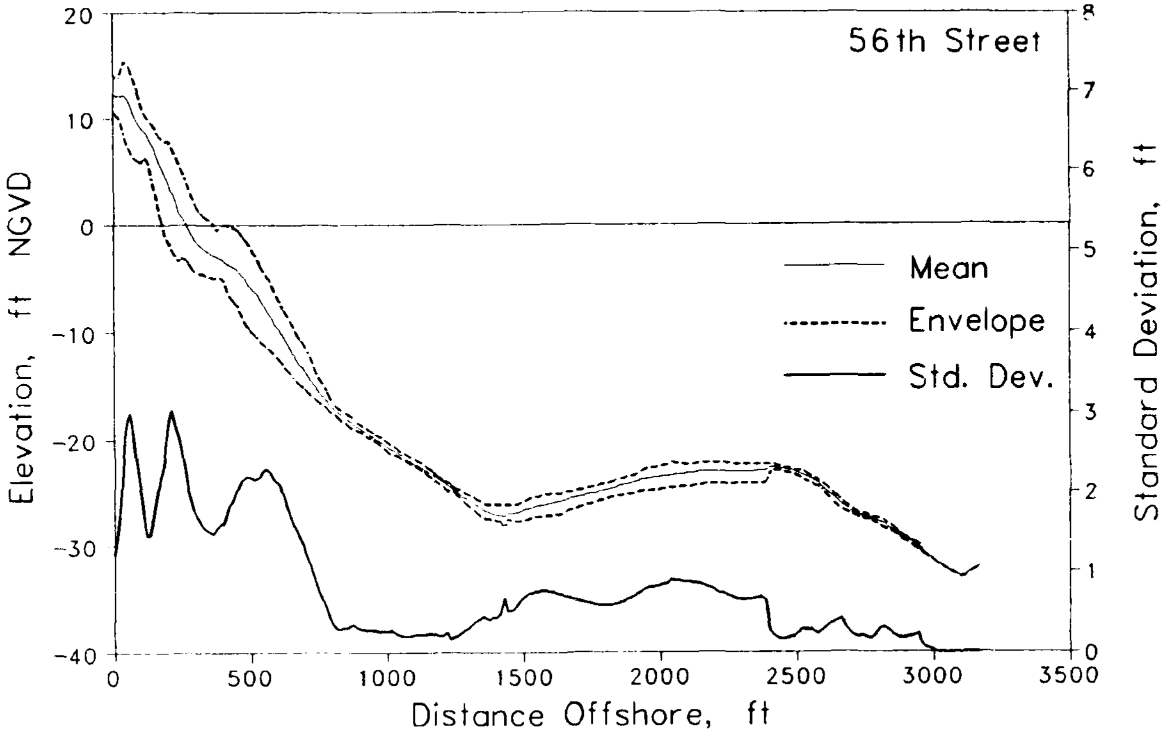


Figure 31. Profile envelopes and standard deviation in elevation, 56th St.

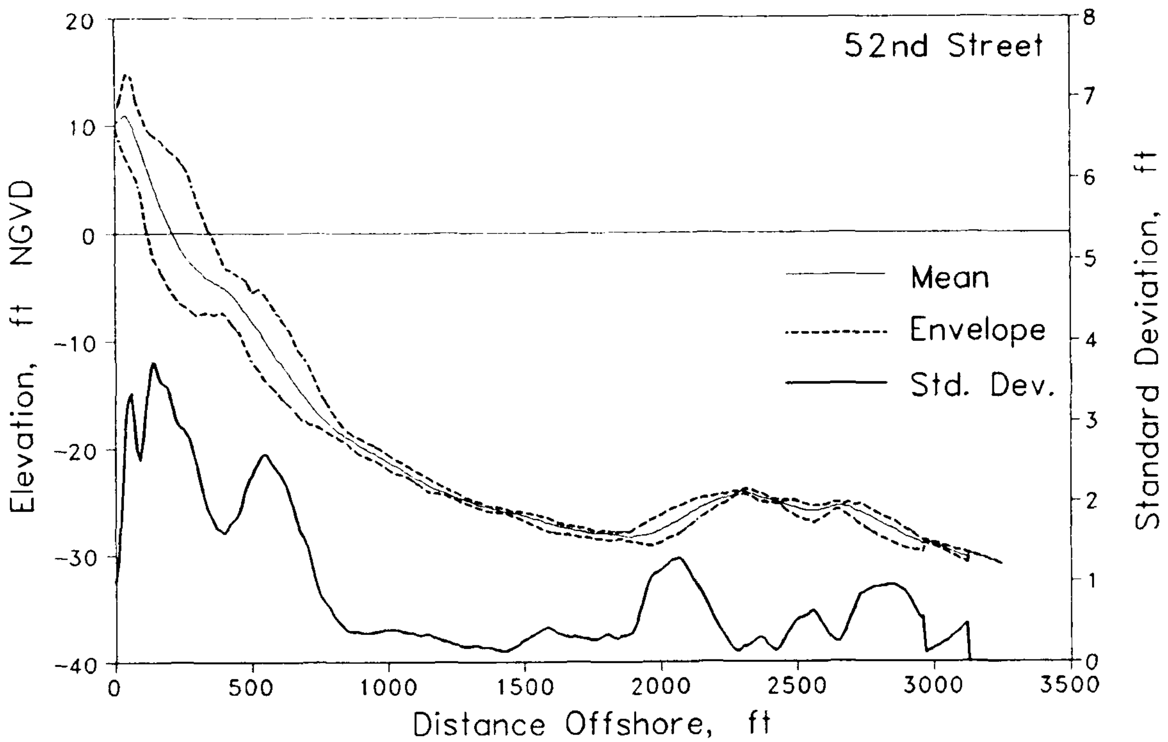


Figure 32. Profile envelopes and standard deviation in elevation, 52nd St.

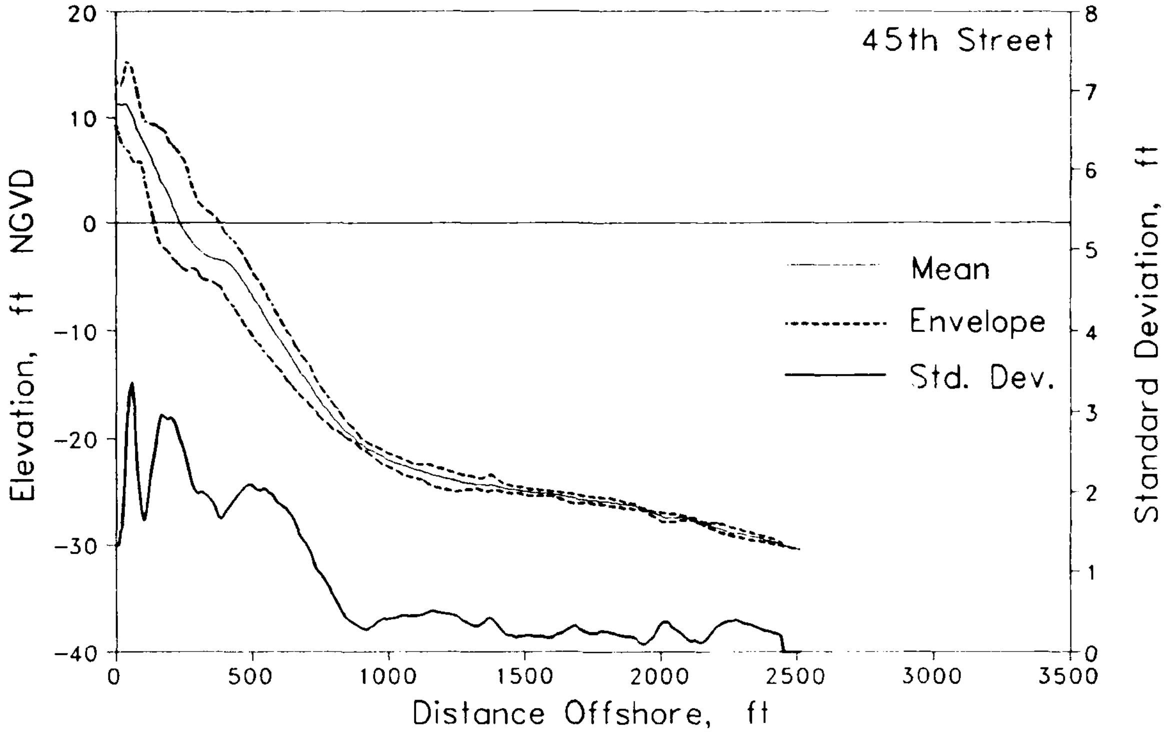


Figure 33. Profile envelopes and standard deviation in elevation, 45th St.

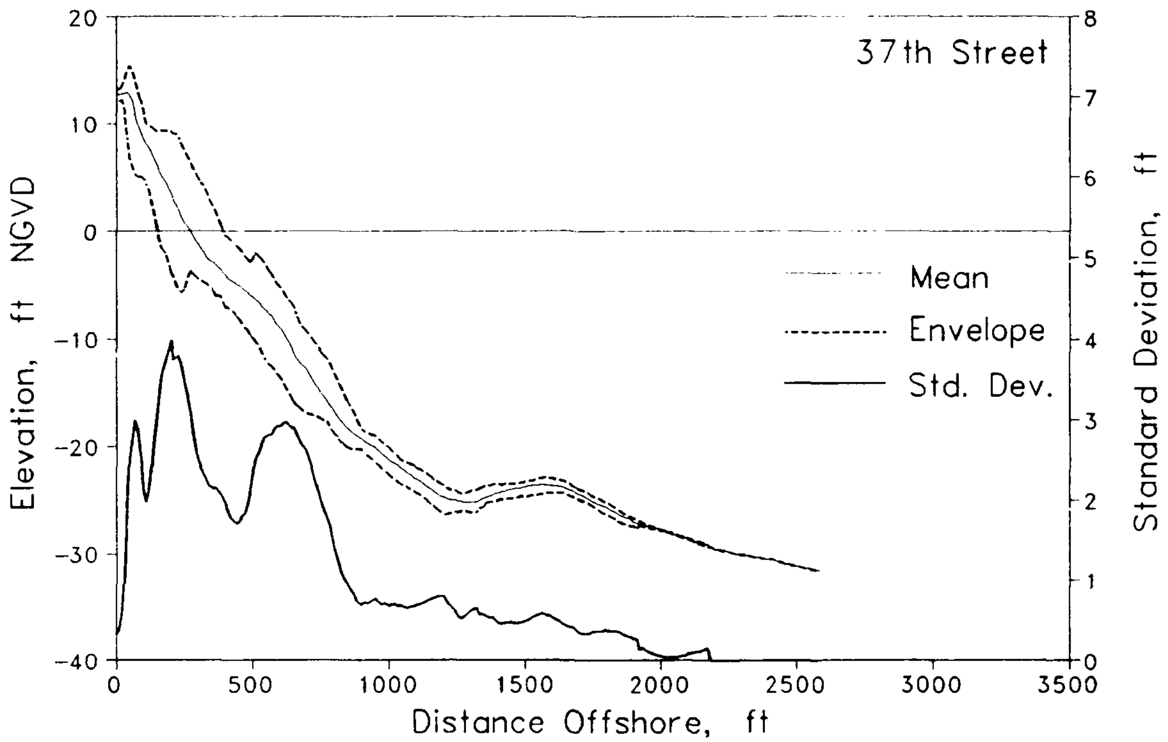


Figure 34. Profile envelopes and standard deviation in elevation, 37th St.

is some profile change on the end of a plateau and small shoal located 2,000 ft from the baseline.

The elevation envelope and deviation for the 78th Street survey line are interesting in showing one area of minimal elevation change at about the 20-ft depth and another at about the 25-ft depth, indicating some active movement and filling of the profile between these two depths. A conservative depth of closure for this survey line would therefore be 25 ft. In contrast, the survey line at 74th Street shows clear closure about 770 ft from the baseline, at the 23-ft depth.

The behavior of the elevation envelope and deviation for the 66th Street survey line is interesting in showing a steep decline on the seaward side of the deviation peak centered 500 ft from the baseline. A separation in frequent and less frequent events is therefore indicated at about 700 ft at the 18-ft depth. The existence of a gradual reduction in deviation about 1,300 ft offshore at the 22-ft depth indicates some slower scale movement of sediments in that area. A conservative estimate for the depth of closure for the 66th Street survey line would be 22 ft. The closure depth of the 63rd Street survey line is at 20 ft. The shoal located 2,500 ft offshore and beyond on the 63rd Street line exhibited moderate change in depth. Overall, the profile lines at 66th and 63rd Streets showed relatively small deviation in elevation in comparison to the other lines.

The deviations in elevation for the 56th and 52nd Street survey lines show multiple peaks nearshore and offshore. The depth of closure for both profiles is estimated at 16 ft and 18 ft, respectively, and is located about 1,800 ft from the baseline. The deviation then rises somewhat due to sediment movement on broad shoals. For beach fill design, it appears reasonable to consider the shoal and beach only weakly coupled because of the relatively small variation in depth change over the 500 to 700 ft separating these regions of more active depth change.

The deviation in elevation for the 45th Street survey line drops steeply at the 20-ft depth, going from more than 3 ft to about 0.5 ft. The deviation for the 37th Street line shows a similar sharp decrease at about the 19-ft depth, but then continues to decrease to about the 27-ft depth. Small changes in profile elevation between the 19- and 27-ft depths may be due, in part, to nearshore shoal activity and longshore transport and impoundment of southward-moving material by the jetty.

Depth of closure scatter plots

Results of the closure depth analysis are summarized in Figures 35 and 36, which plot the standard deviation in profile elevation as a function of mean elevation. In these figures, the mean elevation runs from deeper water on the left side of the horizontal axis to land and the dune on the right side. The plots were separated into two groups of six survey lines each on the north and on the south. These figures indicate that the depth of closure for Ocean City lies in the range of 16 to 22 ft, with 20 ft NGVD being a representative value. The dip in deviation at about the 3-ft depth for the southern group of profiles indicates relative stability of the inshore. The southern profiles also tend to have less movement in elevation above NGVD, which may indicate a more stable profile shape of the southern beach to storm waves or that less erosive wave forces act on the southern end of the project as compared to the northern end of Ocean City. A reduction in wave energy can be produced by sheltering from the jetty and by divergence of waves away from the area.

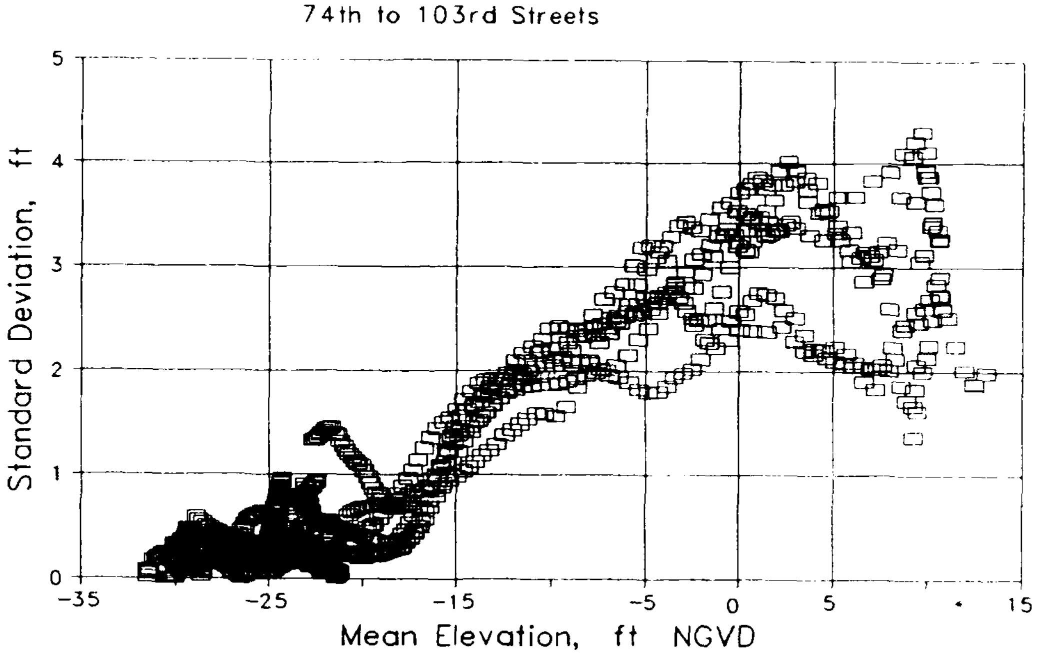


Figure 35. Standard deviation in elevation versus mean elevation, northern beaches

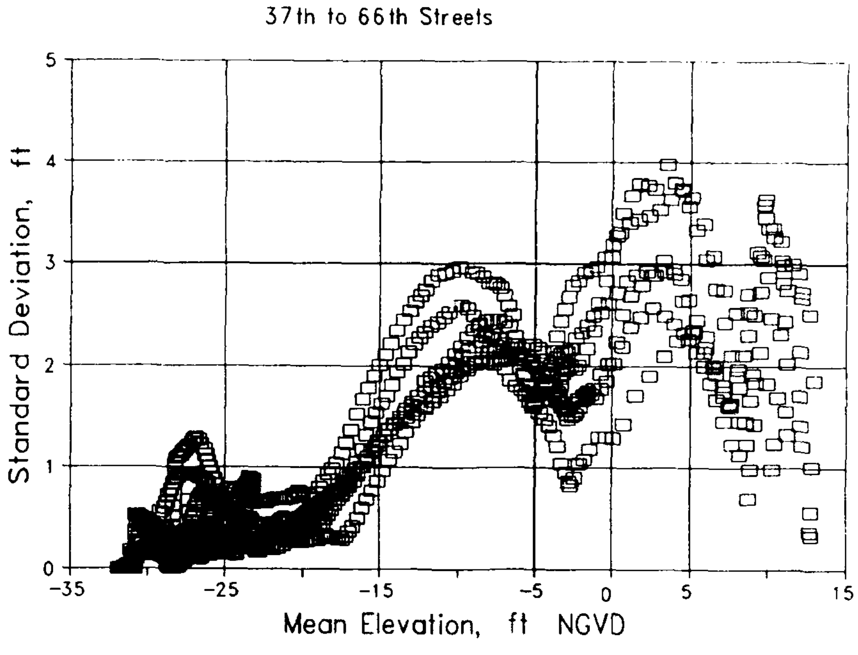


Figure 36. Standard deviation in elevation versus mean elevation, southern beaches

Beach Change

The following analysis examines the variability in the cross-shore patterns in profile elevation and volume change along each profile line and the alongshore variability in profile response of both the State and Federal fills. Table 10 provides a summary of shoreline position and volume change of the 12 profile lines over the study period. A complete description of the profile change history is given for the 37th Street profile location. The basic pattern of change was found on all of the profile lines, and a short description of the variations measured at the other 11 profile locations is supplied.

All depths are referenced to NGVD, with mean high water (MHW) at +1.81 ft and mean low water (MLW) at -1.61 ft, mean sea level at 0.12 ft, and mean tide level at 0.05 ft. All horizontal distances are measured from the baseline position (0 ft). Volume change calculations were made from the baseline to 900 ft offshore to normalize volume change between survey dates. The sled surveys extended from 650 ft to 2,500 ft offshore. Only a few profile lines over the study period were less than 900 ft long, and these surveys were extended to the 900-ft length by appending data from the previous survey to the existing survey. The shortest profile was 650 ft long, with the remainder of the shorter surveys extending to approximately 800 ft. All surveys that required appending by this procedure showed little elevation change between the previous and next survey sampled at the connection depth. It was therefore judged that the extension of 12 short profile lines of 141 lines analyzed over the entire study period did not bias the volume calculations and allowed the bulk of the surveys to be analyzed to their maximum length.

The assumption will be made as a first approximation that most of the sand transport within the 3-dimensional (3D) area covered by the study profiles was in the cross-shore direction. Profile response in nature is a 3D process with sand movement both alongshore and across shore. There is most likely a natural seasonal drift to the north in the summer months when the prevailing wave incidence is from the east and south, with low mean wave height. During the winter months, with increased extratropical storm activity, the transport is to the south. The yearly net transport is to the south with the frequency and intensity of storms affecting the actual value of sediment volume transported. The influence of the shoreface-attached shoals complicates this basic longshore drift pattern, with localized wave refraction and focusing of wave energy at specific locations. Recognizing the possible 3D transport, analysis of the profile data was examined in both the cross shore and alongshore. The change in sand volume across shore was conserved on most of the profile lines. Analysis of the cross-shore sand transport patterns will be presented here in Chapter 3, and the alongshore change in sand transport patterns will be presented in Chapter 4.

37th Street

The southernmost profile that was regularly surveyed was located at 37th Street. This profile line was originally designated as Line 14 and renumbered as Line 13. It is located approximately 3,200 ft north of the bulkhead/boardwalk area. A low "dune" more in the shape of a mound was located in the vicinity of the baseline in the pre-fill native profile of June 1988. A small bar was located around 300 ft seaward of the baseline with a crest elevation at -2 ft. A second low bar was located at around 700 ft seaward with an 18-ft depth. A third bar was located in 23 ft of water some 1,500 ft offshore. Around 71 cu yd/ft of beach fill were placed during the State fill.

Table 10
Profile Change Summary

Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
Pre / Post-State Fill From June 1988 to September 1988									
880922	37	148.7	46.6	24.4	71.0	148.7	71.0	46.6	24.4
" "	45	138.4	32.3	30.7	63.0	138.4	63.0	32.3	30.7
" "	52	121.4	30.2	24.4	54.5	121.4	54.5	30.2	24.4
880921	56	88.9	19.9	14.5	34.5	88.9	34.5	19.9	14.5
880922	63	102.1	27.9	19.1	47.0	102.1	47.0	27.9	19.1
880919	66	90.1	26.8	18.4	45.2	90.1	45.2	26.8	18.4
" "	74	127.3	51.4	56.5	107.9	127.3	107.9	51.4	56.5
880915	78	191.3	55.6	74.2	129.8	191.3	129.8	55.6	74.2
880913	81	153.1	51.2	57.0	108.2	153.1	108.2	51.2	57.0
880908	86	145.8	55.5	60.6	116.1	145.8	116.1	55.5	60.6
880907	92	109.4	37.9	31.2	69.1	109.4	69.1	37.9	31.2
881026	103	64.0	37.8	1.1	38.9	64.0	38.9	37.8	1.1
Post-State Fill / 4-Month (Pre-Storm) From September 1988 to January 1989									
890117	37	-63.9	-12.9	1.5	-11.4	84.8	59.7	33.7	25.9
890119	45	-53.1	-11.3	4.6	-6.7	85.3	56.3	21.1	35.2
" "	52	-50.3	-8.5	3.3	-5.3	71.1	49.3	21.7	27.6
" "	56	-0.2	18.3	16.2	34.4	88.6	68.9	38.2	30.7
" "	63	-21.0	-6.4	20.4	14.0	81.1	61.0	21.4	39.5
" "	66	-13.7	2.5	30.9	33.4	76.4	78.6	29.3	49.3
" "	74	-21.2	-12.4	14.1	1.7	106.2	109.5	38.4	70.6
" "	78	-75.2	-12.7	0.0	-12.7	116.1	117.1	42.9	74.2
" "	81	-35.0	-11.4	0.4	-11.1	118.1	97.1	39.8	57.4
890120	86	-38.7	-13.4	2.0	-11.4	107.1	104.7	42.1	62.6
" "	92	-10.2	2.7	11.1	13.8	99.2	82.9	40.7	42.2
" "	103	8.9	-4.2	10.4	6.2	72.9	45.1	33.6	11.5

(Sheet 1 of 6)

Street Number = Street numbers that coincide with profiles surveyed. See Table 6.
Shl Chg = Shoreline change from previous date. Example: 148.7 ft is the change of the shoreline on 37th street between the dates of June 1988 and September 1988.
Above NGVD Vol Chg = The change in volume measured above the NGVD line to baseline from the previous date.
Below NGVD Vol Chg = The change in volume measured below the NGVD line to 900 ft from baseline from the previous date.
Net Prof Vol Chg = Net Profile Volume Change. The sum of the above and below NGVD volume changes.
Cumulative changes = The cumulative sums of each parameter for individual profiles.

Table 10 (Continued)									
Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
4-Month (Pre-Storm) / 6-Month (Post-Storm) From January 1989 to April 1989									
890420	37	-84.9	-26.9	36.3	9.4	-0.1	69.1	6.8	62.3
890412	45	-42.6	-8.4	39.9	31.6	42.7	87.8	12.7	75.2
" "	52	-73.7	-19.5	-8.3	-27.8	-2.6	21.5	2.2	19.3
" "	56	-73.0	-28.7	25.3	-3.4	15.7	65.5	9.5	56.0
" "	63	-24.0	-7.7	47.4	39.7	57.1	100.6	13.7	86.9
890414	66	-51.6	-13.2	24.4	11.1	24.8	89.8	16.1	73.7
" "	74	-112.0	-27.5	-5.3	-32.8	-5.8	76.7	11.4	65.3
" "	78	-99.2	-29.0	11.7	-17.3	16.8	99.8	13.9	85.9
" "	81	-94.1	-23.4	20.2	-3.2	24.0	93.9	16.4	77.5
890420	86	-65.8	-29.1	18.5	-10.6	41.3	94.1	13.0	81.1
" "	92	-76.1	-24.3	9.5	-14.8	23.1	68.1	16.4	51.8
" "	103	-8.5	-14.0	25.2	11.2	64.4	56.3	19.6	36.7
6-Month (Post-Storm) / 9-Month From April 1989 to June 1989									
890620	37	30.1	5.1	-3.7	1.3	29.9	70.4	11.9	58.6
" "	45	6.6	2.0	-19.1	-17.1	49.3	70.7	14.7	56.1
" "	52	15.0	3.8	13.3	17.0	12.5	38.5	5.9	32.6
890619	56	25.5	5.4	-24.5	-19.2	41.2	46.3	14.9	31.4
" "	63	-15.0	-0.2	-32.8	-33.0	42.1	67.7	13.5	54.1
" "	66	34.5	7.9	-9.8	-1.9	59.3	87.9	24.0	63.9
" "	74	48.3	10.3	6.7	17.0	42.5	93.7	21.7	72.0
" "	78	29.4	7.4	-6.4	1.0	46.3	100.8	21.2	79.5
" "	81	18.5	1.6	-12.8	-11.3	42.5	82.6	17.9	64.7
" "	86	-2.9	7.8	-16.0	-8.2	38.4	85.9	20.8	65.1
" "	92	31.4	10.9	-14.2	-3.3	54.5	64.8	27.2	37.6
" "	103	-11.7	4.8	-16.8	-11.9	52.7	44.4	24.5	20.0
									(Sheet 2 of 6)

Table 10 (Continued)									
Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
9-Month / 12-Month From June 1989 to October 1989									
891001	37	27.8	6.8	-3.4	3.4	57.7	73.8	18.7	55.1
890928	45	10.3	5.3	0.5	5.8	59.5	76.5	20.0	56.6
" "	52	33.3	7.7	10.8	18.5	45.8	57.0	13.6	43.4
" "	56	6.8	2.4	5.8	8.1	47.9	54.4	17.2	37.2
" "	63	21.2	2.6	8.0	10.6	63.3	78.2	16.2	62.1
891001	66	-1.7	1.1	16.3	17.4	57.6	105.3	25.1	80.2
890928	74	-19.7	-3.3	2.0	-1.3	22.8	92.4	18.4	74.0
" "	78	-20.1	-2.3	4.5	2.2	26.2	103.0	18.9	84.0
890929	81	-10.4	1.1	1.5	2.6	32.1	85.2	19.0	66.2
" "	86	-10.1	0.1	10.8	10.8	28.3	96.7	20.8	75.9
" "	92	-14.4	4.6	13.1	17.8	40.1	82.6	31.9	50.7
891001	103	12.3	-3.8	21.9	18.1	65.0	62.5	20.7	41.8
12-Month / 22-Month (Pre-Federal Fill) From October 1989 to June 1990									
900601	37	16.2	3.5	-24.6	-21.1	73.9	52.7	22.1	30.5
" "	45	39.9	8.5	-24.3	-15.8	99.5	60.7	28.5	32.2
" "	52	19.8	6.6	-25.3	18.7	65.5	38.4	20.2	18.1
" "	56	29.8	5.4	-11.1	5.7	77.7	48.7	22.6	26.1
" "	63	42.5	6.7	-12.8	6.1	105.8	72.1	22.8	49.3
" "	66	34.2	4.4	-8.6	-4.3	91.8	101.0	29.4	71.6
" "	74	8.5	-0.5	-20.7	-21.2	31.3	71.2	17.9	53.3
" "	78	51.8	-3.0	-19.0	-22.0	77.9	80.9	15.9	65.0
" "	81	25.4	-1.1	-14.6	-15.7	57.6	69.5	17.9	51.6
" "	86	43.4	-2.5	-16.9	-19.4	71.7	77.3	18.3	59.0
" "	92	44.4	-5.8	-5.9	-11.8	84.5	70.8	26.0	44.8
" "	103	14.2	6.9	-37.3	-30.5	79.2	32.0	27.4	4.6
									(Sheet 3 of 6)

Table 10 (Continued)									
Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
22-Month (Pre-Federal Fill) / Post-Federal Fill From June 1990 to September 1990									
900814	37	164.6	61.4	25.9	87.3	238.5	140.0	83.5	56.5
900906	45	138.5	47.7	33.7	81.4	238.0	142.2	76.2	65.9
900901	52	160.0	56.8	34.7	91.5	225.5	129.9	77.0	52.9
900907	56	107.1	38.4	23.1	61.6	184.8	110.3	61.1	49.2
900911	63	87.8	38.6	16.3	54.9	193.6	127.0	61.4	65.6
" "	66								
901011	74	185.5	72.4	3[illegible].5	104.0	216.8	175.2	90.3	84.8
" "	78								
900928	81	196.7	75.9	37.8	113.7	254.2	183.2	93.8	89.4
900828	86	140.2	66.4	21.6	88.0	211.9	165.3	84.7	80.6
900908	92	51.4	41.1	2.7	43.8	135.9	114.6	67.2	47.5
900717	103	129.5	52.4	52.1	104.5	208.7	136.5	79.9	56.7
Post-Federal Fill / 4-Month From September 1990 to December 1990									
901201	37	-70.5	-18.1	28.8	10.7	167.9	150.7	65.4	85.3
" "	45	-115.8	-20.7	16.2	-4.5	122.2	137.7	55.6	82.1
" "	52	-117.1	-25.7	15.6	-10.1	108.4	119.8	51.3	68.5
" "	56	-86.5	-12.0	9.4	-2.6	98.3	107.7	49.1	58.7
901202	63	-75.0	-19.6	8.6	-11.0	118.6	116.1	41.9	74.2
" "	66								
" "	74	-30.7	-17.4	21.0	3.6	186.1	178.8	72.9	105.8
" "	78								
" "	81	-75.1	-15.5	-3.9	-19.4	179.1	163.8	78.3	85.5
" "	86	-39.4	-7.2	8.0	0.8	172.5	166.1	77.5	88.6
" "	92	26.6	1.7	18.4	20.1	162.5	134.7	68.8	65.9
" "	103	-111.6	-24.6	-30.8	-55.3	97.1	81.2	55.3	25.9
									(Sheet 4 of 6)

Table 10 (Continued)									
Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
4-Month / 8-Month From December 1990 to April 1991									
910326	37	-37.2	-7.4	0.4	-7.0	130.7	143.8	58.1	85.7
" "	45	-24.4	-8.3	-0.5	-8.8	97.8	128.9	47.3	81.6
" "	52	-12.3	-5.9	-5.3	-11.2	96.1	108.6	45.4	63.2
" "	56	-2.0	3.6	11.1	14.8	96.3	122.5	52.7	69.8
" "	63	-30.0	5.8	0.5	6.3	88.6	122.3	47.6	74.7
" "	66								
" "	74	-42.1	-12.6	4.0	-8.7	144.1	170.1	60.3	109.8
" "	78	76.3	42.2	52.6	94.8	154.3	175.8	58.1	117.6
910402	81	-33.7	-18.1	1.0	-17.1	145.4	146.7	60.2	86.4
" "	86	-21.0	-15.1	3.2	-11.9	151.5	154.2	62.5	91.7
" "	92	-0.3	-9.7	4.1	-5.6	162.2	129.1	59.2	70.0
" "	103	-13.1	-11.8	7.6	-4.2	84.0	76.9	43.5	33.4
8-Month / 10-Month (Pre-Storm) From April 1991 to June 1991									
910626	37	8.5	0.1	3.3	3.4	139.2	147.2	58.2	89.0
" "	45	11.1	3.5	-7.5	-4.1	109.0	124.9	50.8	74.1
" "	52	16.8	7.0	7.0	14.0	112.9	122.6	52.4	70.2
" "	56	36.0	5.1	18.3	23.4	132.3	145.9	57.8	88.1
" "	63	21.3	1.3	-6.0	-4.8	109.9	117.6	48.9	68.7
" "	66								
" "	74	5.0	4.7	-13.9	-9.2	149.1	160.9	65.0	95.9
" "	78								
910627	81	8.7	5.0	-7.7	-2.7	154.1	143.9	65.2	78.7
" "	86	2.8	6.7	-5.9	0.9	154.2	155.1	69.2	85.9
" "	92	-42.6	-5.0	-24.2	-29.2	119.6	99.9	54.1	45.8
" "	103	2.9	2.5	-7.1	-4.6	86.9	72.4	46.0	26.4
(Sheet 5 of 6)									

Table 10 (Concluded)									
Date Sampled yr/mo/dy	Street Number	Shl Chg ft	Above NGVD Vol Chg cu yd/ft	Below NGVD Vol Chg cu yd/ft	Net Prof Vol Chg cu yd/ft	Cum Shl Chg ft	Cum Net Vol Chg cu yd/ft	Cum Above NGVD Vol Chg cu yd/ft	Cum Below NGVD Vol Chg cu yd/ft
10-Month (Pre-Storm) / Post-Halloween From June 1991 to November 1991									
911103	37	-31.4	-12.3	1.4	-11.0	107.8	136.2	45.9	90.3
" "	45	-56.1	-23.6	-1.7	-25.3	52.9	99.6	27.2	72.4
" "	52								
" "	56	-33.0	-15.8	-0.1	-15.9	99.3	130.0	42.0	88.0
911102	63	-10.0	-16.2	9.8	-6.4	99.9	111.2	32.6	78.5
" "	66								
" "	74	22.3	-21.1	6.5	-14.6	171.3	146.4	43.9	102.5
" "	78								
" "	81								
" "	86								
" "	92								
" "	103	63.4	0.9	49.3	50.2	150.3	122.6	46.9	75.7
Post-Halloween / Post-4 Jan Northeaster From November 1991 to January 1992									
920111	37	118.0	2.5	42.9	45.4	225.8	181.6	48.4	133.2
" "	45	129.7	-4.5	15.8	11.3	182.6	110.9	22.7	88.2
" "	52	-40.0	-20.8	28.8	8.1	72.9	130.7	31.7	99.0
" "	56	34.0	-2.4	-6.0	-8.4	133.3	121.7	39.6	82.0
" "	63	90.8	-11.1	5.8	-5.2	190.7	105.9	21.6	84.4
" "	66								
" "	74	-28.7	-20.2	15.9	-4.3	142.6	142.0	23.7	118.4
" "	78								
" "	81	-19.2	-34.0	26.6	-7.3	135.0	136.6	31.3	105.3
" "	86	-11.3	-29.7	17.6	-12.1	142.9	143.0	39.5	103.5
" "	92	53.9	-12.7	65.7	53.0	173.6	152.9	41.4	111.5
920110	103	-20.8	-9.0	28.4	19.5	129.5	142.0	37.9	104.1
									(Sheet 6 of 6)

which moved the shoreline (0 NGVD) seaward 148.9 ft. On the post-fill survey of 22 September 1988, the fill material reached to a depth of 10 ft at 500 ft offshore (Figure 37). Initial fill readjustment at 37th Street showed that some subaerial fill material had moved into the nearshore by January 1989, with the formation of a nearshore bar crest at the 3-ft depth, some 400 ft offshore. The shoreline moved landward 64 ft with a loss of 12.9 cu yd/ft above NGVD and a gain of 1.51 cu yd/ft below NGVD out to 900 ft offshore. This readjustment occurred because the fill beach was constructed out of equilibrium with the prevailing hydrodynamic processes. The waves re-sort the sand and create a foreshore slope and nearshore profile that tends toward an equilibrium shape for the particular grain size.

Rapid removal of fill material from the subaerial beach and deposition in the nearshore after placement has been reported on several beach nourishment projects. The construction beach face is almost always steeper than the native beach face and scarping commonly occurred within hours of fill placement as the waves rearrange the fill material. In some projects sand moved offshore within hours of fill placement and within 3 months the profile had reached a more natural equilibrium shape (Stauble and Hoel 1986). Other projects reported times of 1.5 to 2 years for fill profiles to form an equilibrium shape of the subaerial beach (Winton et al. 1981).

A series of extratropical storms occurring in rapid succession in February and March 1989 impacted the fill 6 months after placement. Waves with significant height greater than 6 ft accompanied by elevated water levels around 3.3 to 4.9 ft above NGVD were recorded on the northern nearshore wave gauge (see Figure 3 for gauge location) over the periods 24-25 February and 4-6, 8-11, and 23-25 March 1989. The maximum significant wave height reached 9.2 ft on 24 February and 9 ft on 24 March. The storms eroded the subaerial beach, with a large accretional zone appearing in the nearshore region between 500 and 1,000 ft from the baseline

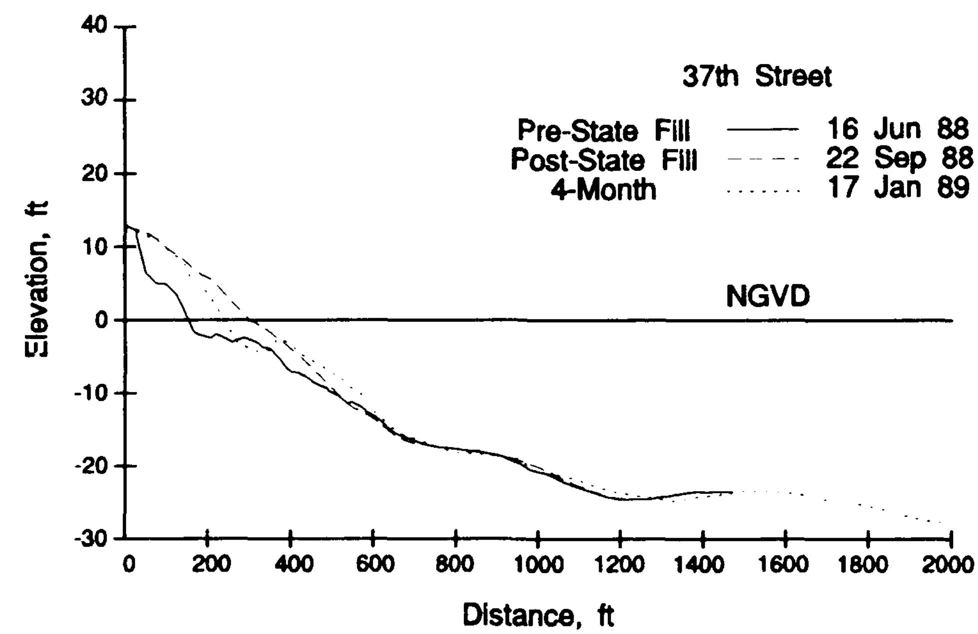


Figure 37. Pre- and post-State fill profile at 37th St. and initial 3-month fill readjustment

(Figure 38). The shoreline position moved 84.9 ft landward with removal of 26.9 cu yd/ft above NGVD and deposition of 36.3 cu yd/ft out to 900 ft offshore. The pattern of erosion and accretion indicated that a large portion of the fill was removed from the subaerial portion of the profile and was deposited in the immediate nearshore with a net loss of only 1.9 cu yd/ft from the profile. All total profile volume measurements were standardized to a distance of 900 ft from the baseline. Additional movement of a thin layer of material may have occurred seaward of the 900 ft. However, the main closure depth on this profile is located between 800 and 1,500 ft from the baseline. The location of this point changes with time, depending on the wave energy, moving seaward with higher waves and landward under smaller waves. For the most part, a closure depth could be identified on each set of profiles landward of the seaward limits of the survey, as discussed in a previous section.

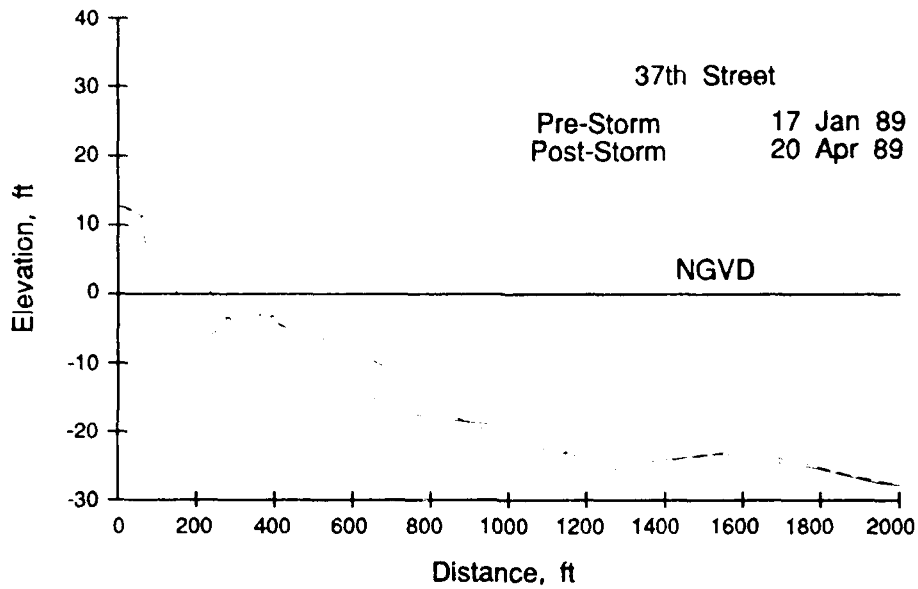


Figure 38. Pre- and post- March 89 storms profile readjustment at 37th St.

During the remainder of the State fill monitoring, no other significant storms occurred, and the pattern of slow movement of sediment onto the foreshore from the nearshore can be seen in Figure 39. A seasonal pattern can be seen with an eroded foreshore during October 1989 with a well-pronounced nearshore bar located around 500 ft offshore. The June 1989 and 1990 profile surveys show a more planar shape with accretion of the foreshore and a less well-defined nearshore bar. Shoreline position progressively moved seaward, and the volume of sand increased on the foreshore as material was transported landward and onto the foreshore. A corresponding decrease in volume in the nearshore occurred below NGVD. The shoreline position moved seaward 74 ft from the April 1989 post-storm survey to June 1990.

The Federal fill placed an additional 87.3 cu yd/ft of sand on the beach at this location. The Federal fill design included a storm berm or dune to be constructed at the backberm location (Figure 7). The post-Federal fill survey of August 1990 (Figure 40) showed the volume of

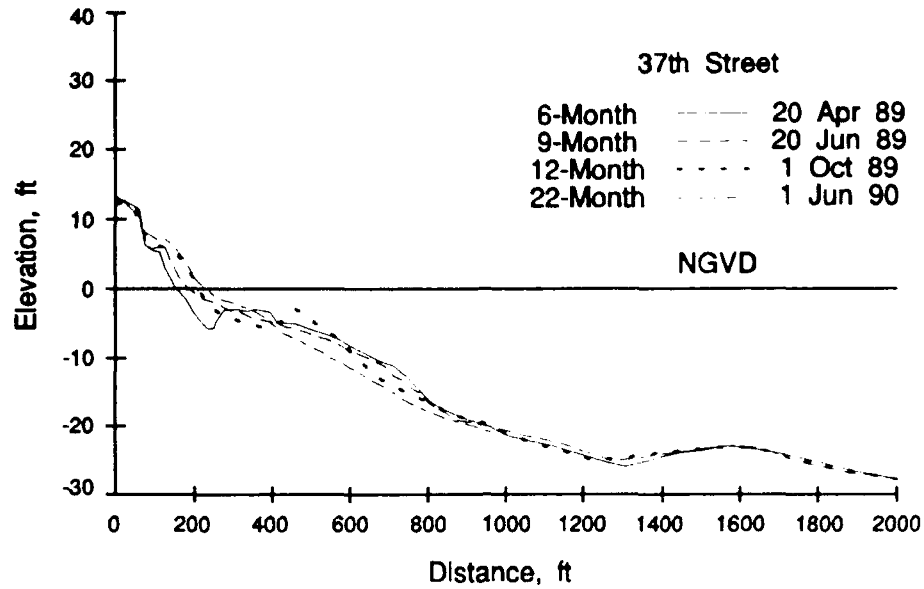


Figure 39. Six- to twenty-two-month performance of State fill at 37th St.

Federal fill placed on top of the remaining State fill of the pre-Federal fill June 1990 survey. The shoreline position also moved seaward 164.6 ft. After 4 months, the December 1990 survey showed the erosion of the Federal fill with a volume of 18.1 cu yd/ft removed above NGVD. Accretion of 28.8 cu yd/ft occurred below NGVD on the nearshore to a distance of 900 ft. This volume adjustment occurred as the new fill readjusted to a more natural slope for the prevailing wave climate. The shoreline moved landward 70.5 ft as the foreshore slope flattened. A net gain of 10.7 cu yd/ft over the profile indicated some material was deposited on this profile from external sources, most likely from the updrift beach and not by cross-shore transport.

The period from December 1990 to June 1991 showed the seasonal influence on the fill profile readjustment (Figure 41). No significant storms occurred during the first winter season. The foreshore continued to erode from December 1990 to March 1991 with a loss of 7.4 cu yd/ft above NGVD and shoreline recession of 37.2 ft. A trough and bar developed at a depth of 5 ft as sand shifted offshore, with only a small net gain of 0.4 cu yd/ft below NGVD. By June 1991 the bar had migrated around 150 ft landward, and the shoreline had moved seaward slightly, with a gain of a thin layer of sand on the foreshore. The berm crest had at the same time moved landward around 50 ft. The basic pattern of cross-shore sediment transport was found to be seaward movement (causing erosion of the foreshore and deposition in the nearshore) after high wave events and landward movement (causing deposition on the foreshore and erosion of the nearshore) after a period of low waves.

After the summer of 1991, two large extratropical storms impacted the Ocean City area. The first storm occurred from 29 October to 2 November and was named the Halloween Storm. Wave gauge records at Ocean City indicated that significant wave height reached more than 6 ft from 29 to 31 October, 1991. A maximum H_{mo} of 10.2 ft was recorded on 31 October and

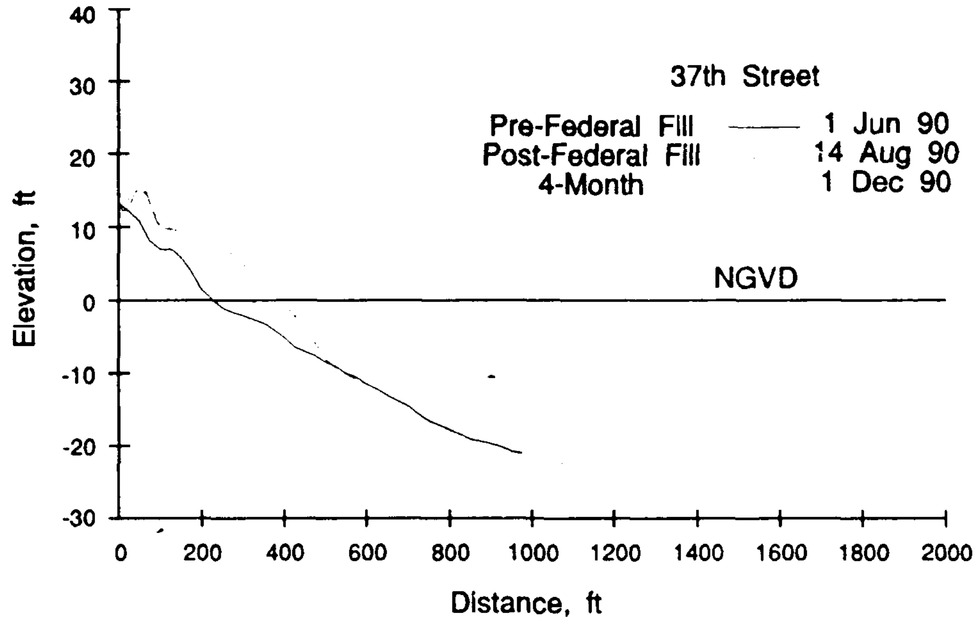


Figure 40. Pre- and post-Federal fill profile at 37th St. and initial 4-month fill readjustment

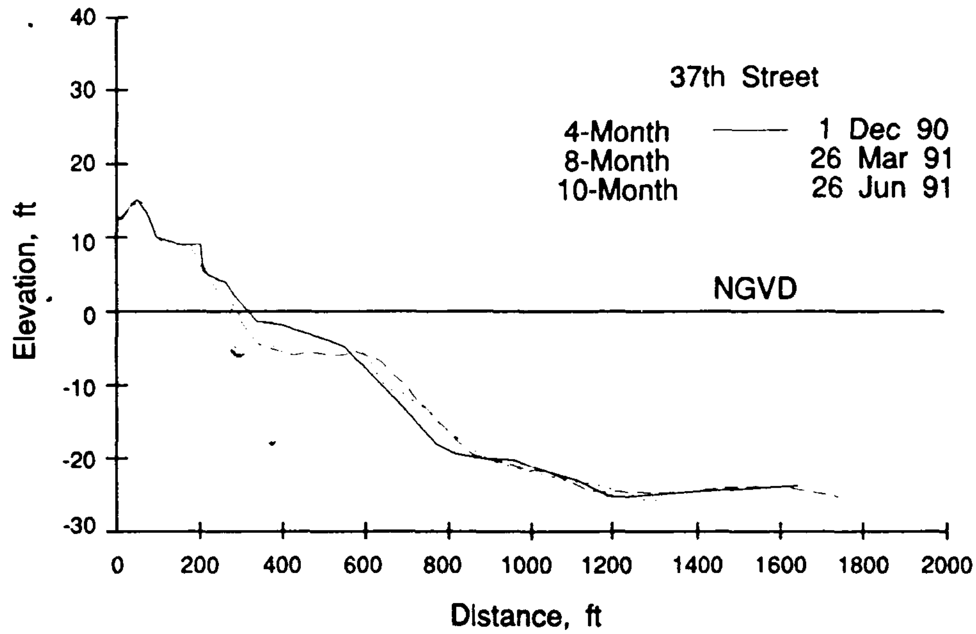


Figure 41. Four- to ten-month Federal fill readjustment at 37th St.

maximum water levels measured 5.4 ft above NGVD. The duration of the storm with elevated water levels extended 66 hr. A special limited post-storm profile survey was made at seven of the twelve profile locations within a week after the storm to document its impact to the fill, 14 months after fill placement. The pre-storm profile set was made during June 1991, 4 months prior to the storm. There was no immediate pre-storm survey, but this early summer profile is expected to be representative of the accretional profiles common during the low wave energy summer months and should be representative of the profiles at the time the storm arrived. Figure 42 shows the storm-induced changes at 37th Street where the foreshore eroded with a removal of 12.3 cu yd/ft of sand, and the shoreline position moved landward 31 ft. The storm berm at the backshore remained intact and no notable erosion was measured on the dune. The nearshore trough deepened and a shallow bar cresting at the 2.5-ft depth, 500 ft offshore, was formed.

A second large extratropical storm impacted the area on 4 January 1992. This fast-moving storm had an H_{mo} of 14.4 ft and a maximum surge level of 6.6 ft above NGVD as measured at the CERC wave gauges (both wave gauges recorded about the same wave heights and periods). The profile at 37th Street surveyed about a week later exhibited a more planar shape, filling in the bar/trough region and forming a swash bar that was beginning to migrate up the lower foreshore. Recovery processes advanced the shoreline 118 ft seaward, while depositing a small volume (2.5 cu yd/ft) on the foreshore and 42.9 cu yd/ft in the former trough and between 700 and 900 ft offshore. On the profile as a whole (baseline to 900 ft offshore) there was a net gain of 42.9 cu yd/ft.

Figure 43 summarizes the volume changes calculated at 37th Street over the monitoring of State and Federal fills until January 1992. Placement of fill material initially moved the shoreline seaward and placed sand on the subaerial beach during both fill placement events. The storms in March 1989, only 6 months after fill placement, provided a mechanism to readjust the convex fill profile to a more nearly equilibrium concave bar/trough profile shape. Through monitoring of the profile past wading depth into the nearshore, it was found that most of the sand removed from the subaerial beach above NGVD was deposited in the nearshore within 900 ft of the baseline. Material taken from the foreshore by wave action during times of storm-induced high water levels was deposited in the nearshore with little or no net loss to the active profile of the volume of fill placed. The March 1989 storms removed all but 14.6 percent of the fill sand on the subaerial beach, but 97.3 percent of the fill could be accounted for on the profile.

Almost 2-year monitoring of the State fill showed that 47.5 percent of the fill remained on the subaerial beach as waves moved material back onto the foreshore. The total active profile contained 74.1 percent of the State fill sand placed on this beach, with the bulk remaining in the nearshore zone. The Federal fill project placed additional sand on top of the State fill placement and included the storm berm (dune) construction. During the Federal fill monitoring there was a more gradual removal of sand from the subaerial beach. The two large storms occurring just over a year after placement of the Federal fill had less impact than the March storms that occurred just 6 months after placement of the State fill. After the Halloween Storm, 55 percent of the fill remained above NGVD. Only 2.7 percent was removed from the profile out to 900 ft, with most of the fill residing in the nearshore. A gain in sand volume in the nearshore after the 4 January 1992 storm accounted for 129 percent of the volume of sand that was placed during the Federal fill on the 900-ft standardized length of the profile. Above NGVD, the beach contained 57.9 percent of the Federal fill volume as post-storm landward transport onto the

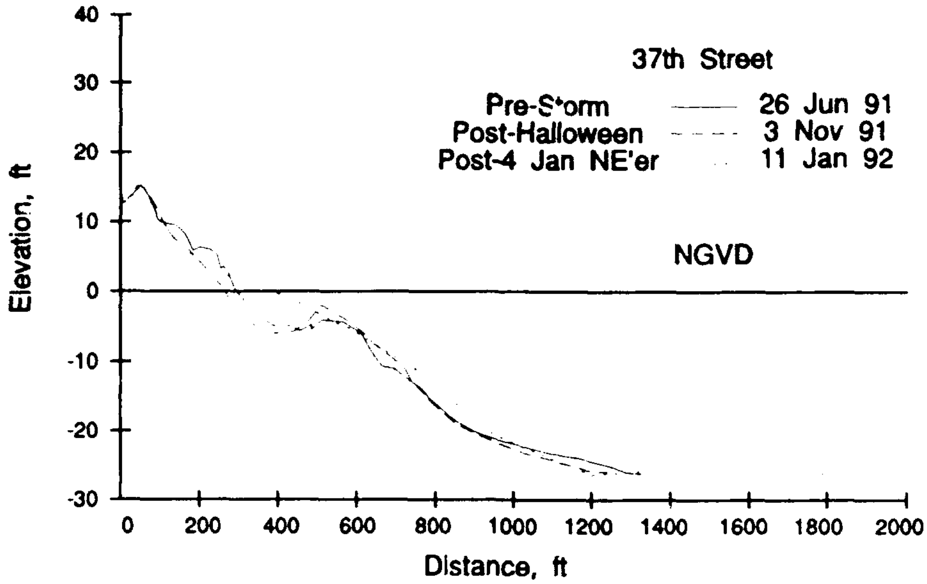
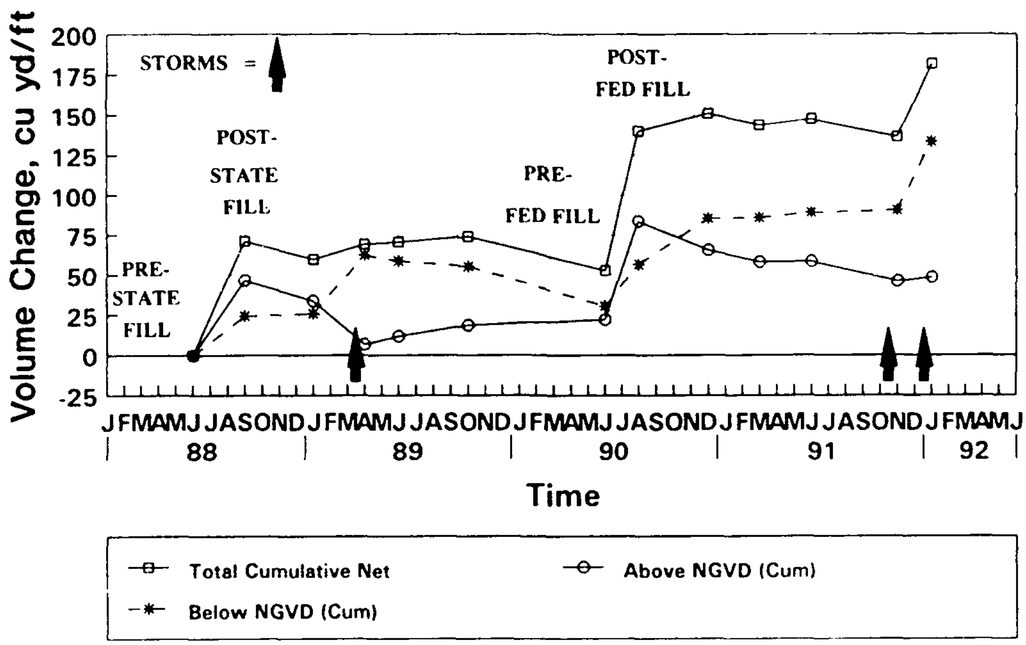


Figure 42. Pre- and post-storms profile readjustment at 37th St.



CUM. VOL FROM 0-900 FT FROM BASELINE

Figure 43. Profile volume change at 37th St.

foreshore had already begun. This new material presumably came from neighboring beach areas. As of January 1992, 103.8 percent of the State fill volume remained above NGVD, and 225 percent of the original fill volume remained on the active profile of Survey Line 13/14. At this location, both the State and Federal fill volumes were retained in the immediate area, and additional sand was deposited as the prevailing waves and currents readjusted the nourished profile.

45th Street

The next profile survey site to the north is located at 45th Street and was numbered as Line 16 in the old numbering system and as Line 15 after March 1989. The native profile contained a low dune or mound at the baseline and a better-developed trough and nearshore bar at 300 ft seaward of the baseline than on the 37th Street profile. This profile did not have evidence of additional bars in the nearshore. The fill material was placed to the 10-ft depth around 500 ft seaward of the baseline (Figure 44). The shoreline was moved 138.4 ft seaward, filling in the bar and trough, with 63 cu yd/ft of sand added to the profile. By January 1989, the foreshore had eroded with sand deposited as a bar and trough around 400 ft seaward of the baseline. The storms in March produced a similar erosion pattern on the subaerial beach as observed at the 37th Street survey line, but a ridge and runnel were formed at the berm crest, and accretion in the nearshore filled in the nearshore trough. A net loss of 6.7 cu yd/ft was calculated along the profile (Figure 45).

Profile recovery patterns (Figure 46) showed deposition of sand on the subaerial portion of the profile as of June 1989, but 19.1 cu yd/ft were removed from the nearshore, presumably moved alongshore. Over the summer months, foreshore accretion and the formation of a new nearshore bar accounted for the gain of 6.0 cu yd/ft as of September 1989. Almost 1 year later, in June 1990, the profile had gained additional sand across the entire foreshore with the formation of pronounced berm crest and infilling of the previous bar/trough. A reduction of 15.8 cu yd/ft of sand was calculated across the standardized profile length to 900 ft on 45th Street with flatting of the nearshore slope.

The Federal fill with the new +15-ft storm protection dune added 81.4 cu yd/ft of sand and advanced the shoreline 138.5 ft seaward (Figure 47). The fill extended to around 500 ft from the baseline and to the 12-ft depth contour. Initial fill readjustment through December 1990 shows the typical pattern of erosion on the subaerial beach and deposition on the nearshore, between 500 and 800 ft offshore in the 5- to 15-ft depth range. Erosion of the foreshore and formation of the nearshore trough and bar around 400 ft occurred over the winter months (Figure 48). A slight gain on the upper foreshore was calculated by June 1991, with seaward movement of the bar and net removal of 4.1 cu yd/ft from the standardized length of the profile.

The impact of the Halloween storm was more severe at this location than at 37th Street and eroded the dune face and berm, as well as moving the bar seaward for a profile length net 25.3 cu yd/ft of erosion (Figure 49). The shoreline receded 56.1 ft. The 4 January storm removed almost all of the design storm dune. The trough was, however, filled in and the nearshore bar migrated landward as a swash bar. An almost immediate storm recovery of 11.3 cu yd/ft of accretion was calculated to 900 ft from the 11 January survey, 5 days after the storm.

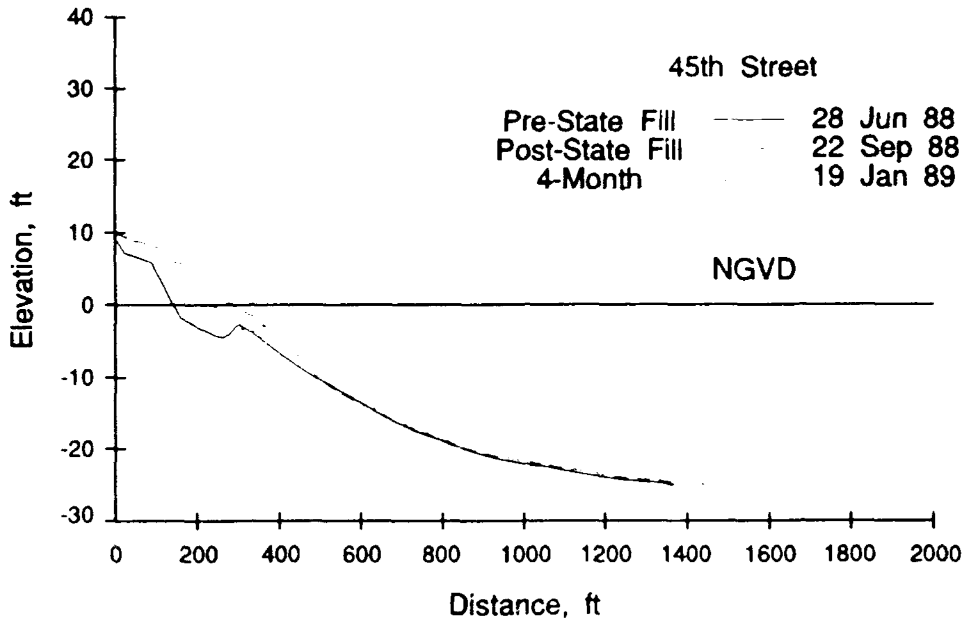


Figure 44. Pre- and post-State fill profile at 45th St. and initial 4-month fill readjustment

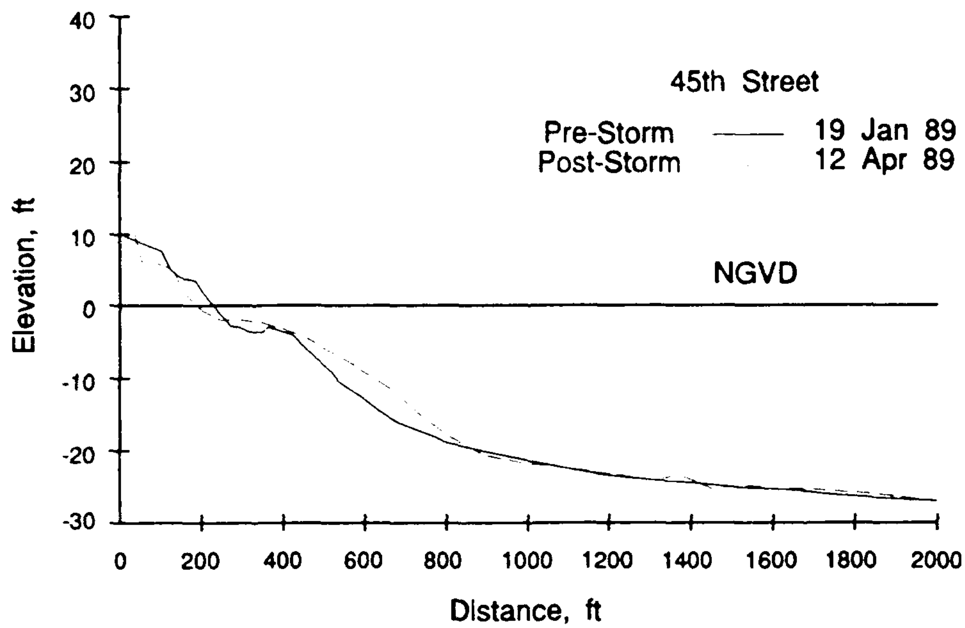


Figure 45. Pre- and post- March 89 storms profile readjustment at 45th St.

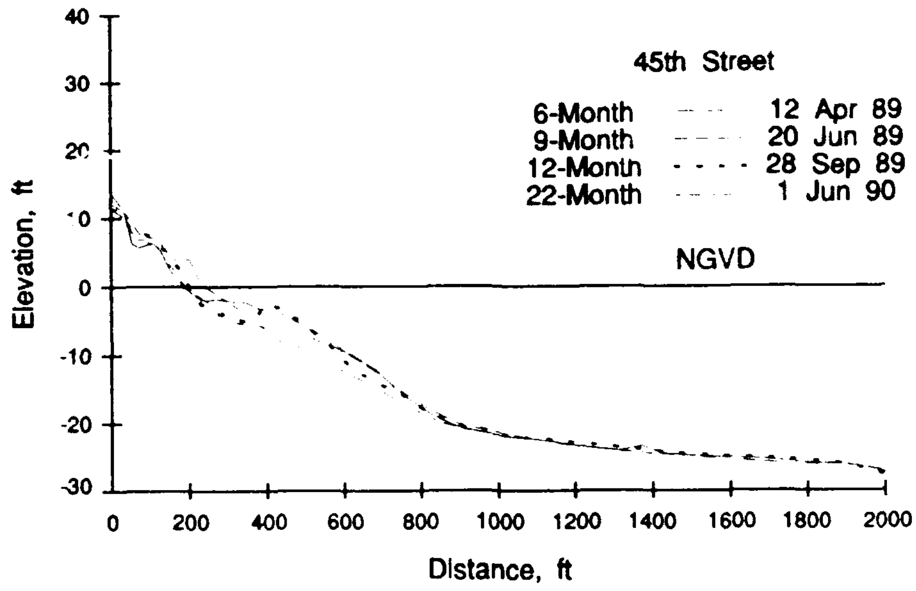


Figure 46. Six- to twenty-two-month performance of State fill at 45th St.

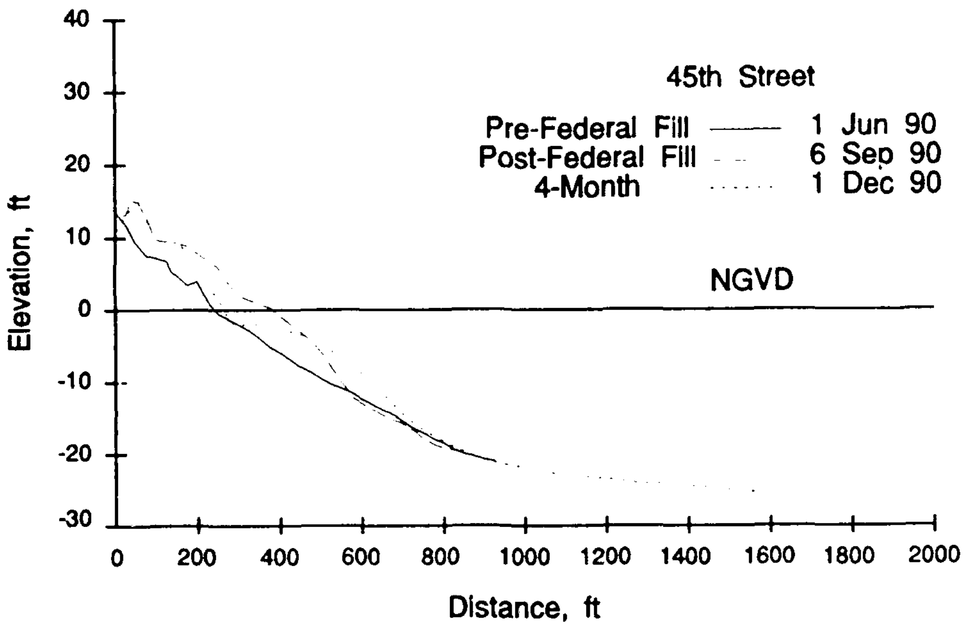


Figure 47. Pre- and post-Federal fill profile at 45th St. and initial 4-month fill readjustment

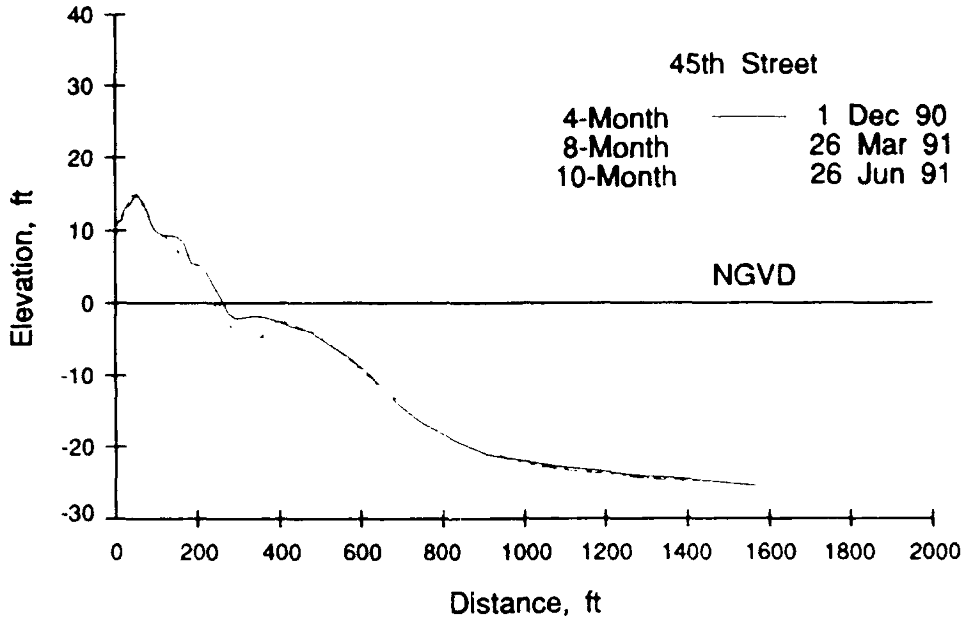


Figure 48. Four- to ten-month Federal fill readjustment at 45th St.

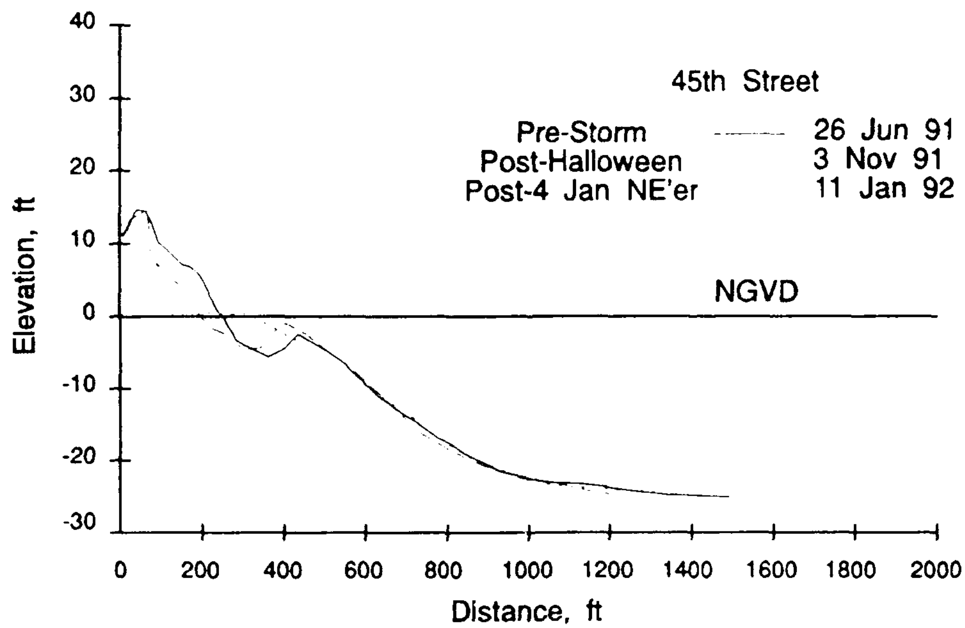


Figure 49. Pre- and post-storms profile readjustment at 45th St.

The cross-shore volume change summary for this profile (Figure 50) has a basic pattern of accretion at times of fill placement and gradual erosion of the foreshore as the fills readjust. Sand removed from the foreshore was deposited in the nearshore. A larger amount of material was deposited in the nearshore after the March 1989 storms, with 39.2 percent remaining on the foreshore and 139 percent of the original fill volume accounted for on the profile. Over the State fill monitoring period, accretion at the foreshore accounted for 88.1 percent of the original fill volume remaining above NGVD. A slight loss of volume from the nearshore below NGVD accounted for 96.4 percent of the fill remaining on the profile in June 1990. After Federal fill placement, steady erosion of the foreshore and accretion in the nearshore occurred. The Halloween and January 1992 storms impacted 45th Street by removing 70.3 percent of the above NGVD Federal fill volume, and depositing material in the nearshore, with a net retention of 80 percent of the Federal fill volume along the 900-ft profile length as of January 1992. Long-term response indicated that 70.1 percent of the above NGVD fill from the State fill placement volume was retained as of January 1992. The profile to 900 ft retained 175 percent of the original State fill placement, indicating that the fill sand was retained in the nearshore region below NGVD.

52nd Street

The native beach profile located at 52nd Street, originally designated as Line 18 and renumbered as Line 17, contained a pronounced berm crest and more of a low tide terrace and swash bar than the nearshore bar and trough configuration found at 45th Street. This profile survey line is located at the southern end of one of the shoreface-attached shoals. Figure 51 contains the comparison of the pre- and post-fill surveys showing the pattern of fill placed on the subaerial beach that moved the shoreline 121 ft seaward and added 54.5 cu yd/ft of sand to a

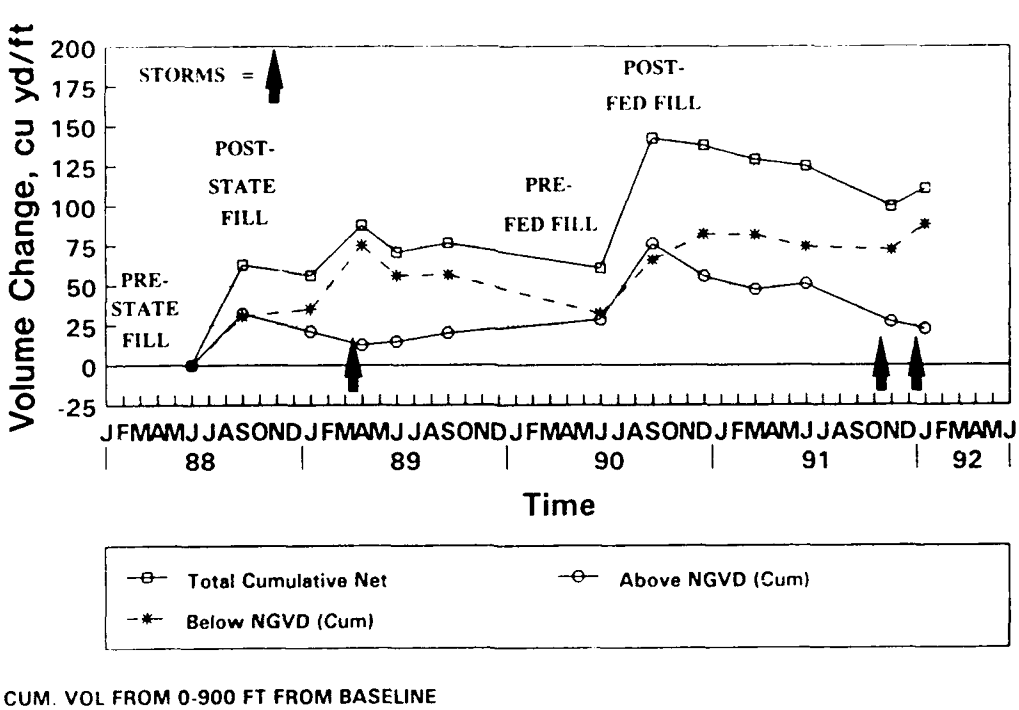


Figure 50. Profile volume change at 45th St.

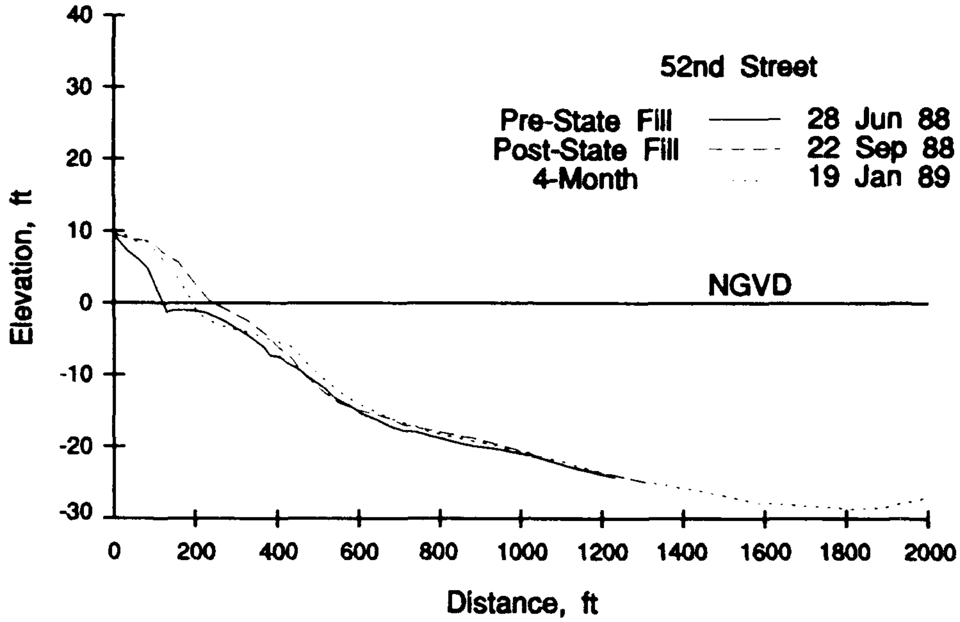


Figure 51. Pre- and post-State fill profile at 52nd St. and initial 3-month fill readjustment

depth of 10 ft. Additional accretion was measured on the nearshore slope from the 15- to 20-ft depth. The initial readjustment as of January 1989 showed erosion of the foreshore and the formation of a bar located approximately 400 ft seaward of the baseline, and accretion on the nearshore slope. There was an almost equal balance of erosion with accretion for a net total profile loss of 5.3 cu yd/ft. The March 1989 storms moved the shoreline landward 73.7 ft, with net erosion of 27.8 cu yd/ft over the total profile length to 900 ft (Figure 52). The bar moved around 100 ft seaward, and its crest lowered from 4 ft to 7 ft below NGVD. Accretion occurred on the seaward slope of the nearshore bar. The increase in erosion from these storms may be caused by the close proximity of this profile location to the shoreface-attached shoal, which bisects this profile 2,000 ft from the baseline. The shoal crest moved seaward from approximately 2,200 ft to 2,400 ft as the nearshore trough filled between 1,400 ft and 1,800 ft offshore.

The initial storm recovery measured on the June 1989 survey occurred entirely below NGVD, with the flatting of the bar and infilling of the trough to form a planar profile (Figure 53). By September 1989, a thin sand layer of 7.7 cu yd/ft volume deposited on the foreshore, and a nearshore bar formed above the planar slope accounting for an additional 10.8 cu yd/ft of accretion. The shoreface-attached shoal also migrated toward shore and filled in the leeward side of the shoal flank. Eight months later, in June 1990, a berm was present on the upper foreshore and deposition on the rest of the foreshore accounted for additional accretion volume of 6.6 cu yd/ft above NGVD. The bar apparent the previous fall was not present, and the nearshore slope had filled the trough for a net loss of 18.7 cu yd/ft across the profile.

A total of 91.5 cu yd/ft of fill material was placed in a storm dune and on the profile out to

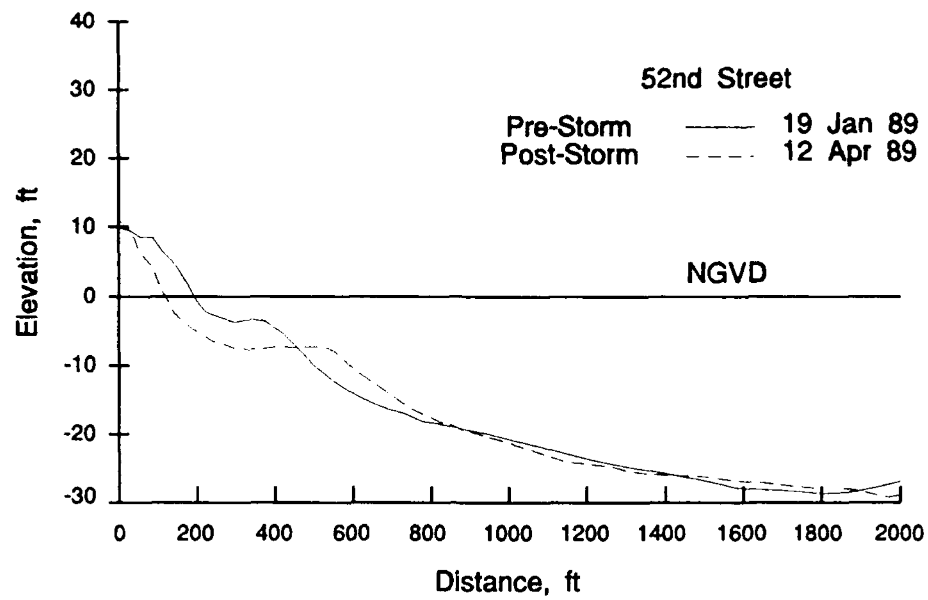


Figure 52. Pre- and post- March 89 storms profile readjustment at 52nd St.

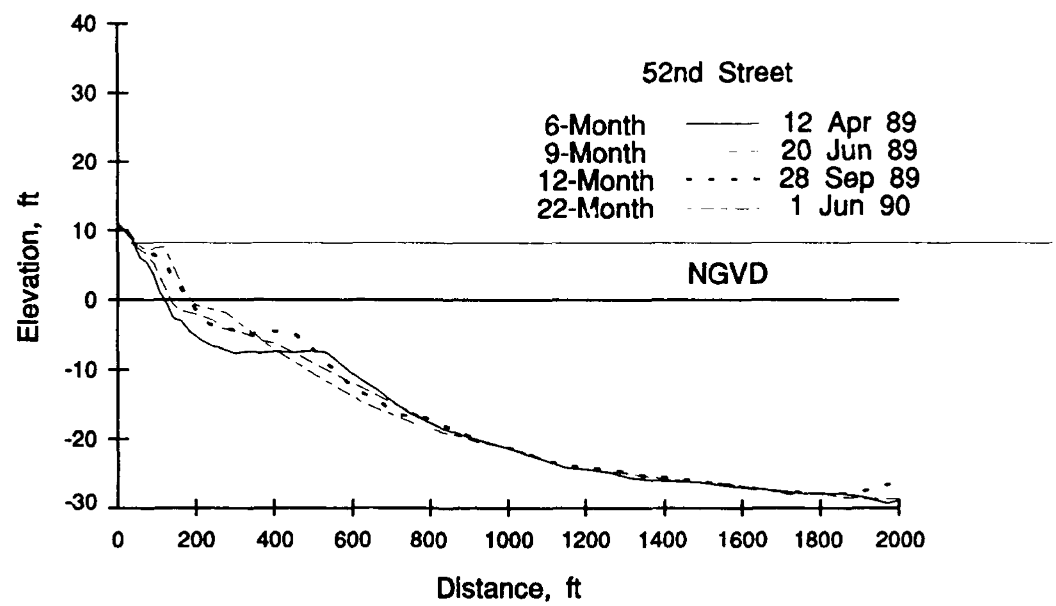


Figure 53. Six- to twenty-two-month performance of State fill at 52nd St.

the 10-ft depth contour during the Federal fill operation, which extended the shoreline 160 ft seaward (Figure 54). The typical pattern of initial readjustment of the Federal fill occurred with erosion of the subaerial beach of 25.7 cu yd/ft and accretion of 15.6 cu yd/ft on the nearshore bar's seaward slope. During the winter months, an additional 11.2 cu yd/ft eroded from both the foreshore and trough (Figure 55). By June 1991, the foreshore experienced some accretion, and the trough filled slightly, for a total profile gain of 14 cu yd/ft. The bar remained in its same position. No profile survey was made at this site after the Halloween storm, but a survey was made after the 4 January storm. A comparison of the June 1991 and January 1992 surveys in Figure 56 shows the combined effects of both storms. Erosion from the dune face, berm, and foreshore resulted in 20.8 cu yd/ft of sand removed, but the storm dune remained intact. The nearshore had two bars, a swash bar located 280 ft seaward of the baseline at the 2-ft depth contour that filled the nearshore trough of the June 1990 survey and a nearshore bar 525 ft seaward of the baseline at the 5-ft depth contour. Sand was also deposited on the seaward slope of the nearshore bar to a depth of 20 ft.

The time series of volume change in Figure 57 showed a loss in volume at this location after the March 1989 storms with a gradual recovery by the summer of 1989. Storm impact resulted in only 7.2 percent of the fill remaining on the dry beach at this location, whereas 39.4 percent of the original fill material was present on the profile out to 900 ft. By the end of the State fill monitoring study, the above NGVD beach was recovering, with 67.1 percent of the original fill volume remaining. The total profile volume retained 70.4 percent of the original fill material. After the Federal fill, progressive erosion was measured until March 1991, when the profile gained sand volume. The Halloween and 4 January storm resulted in erosion of the foreshore and a large gain in the nearshore. Above NGVD, 41.1 percent of the Federal fill was retained by January 1992, and 100.6 percent of the placed volume could be accounted for along the 900-ft profile length. The long-term response at 52nd Street indicated that 104.9 percent of the State fill volume was retained above NGVD as of January 1992 and 239.6 percent of the original State fill volume was retained over the profile to 900 ft. The nearshore is therefore acting as a repository for both State and Federal fill volumes. The proximity to the shoreface-attached shoal may account for the high storm-induced erosion rates above NGVD and a depositional sink in the nearshore in the lee of the shoal.

56th Street

The profile survey location at 56th Street was originally numbered as Line 19 and later renumbered as Line 18. The pre-fill native beach contained a pronounced berm crest and a shallow nearshore trough and bar form. This survey line is located at the center of the southern shoreface-attached shoal. The landward trough of this shoal is 1,400 ft from the baseline at the 27-ft depth, and the shoal appears to crest at the seaward limit of the profile surveys at 2,500 ft with a crest depth of 23 ft. Initial fill placement during the State project was only 34.4 cu yd/ft, which extended out 400 ft from the baseline to a depth of 7 ft (as compared with other surveys where the fill extended to the 10-ft depth). The shoreline was advanced seaward only 88 ft (Figure 58). The readjustment moved fill material into the nearshore from 400 to 600 ft seaward of the baseline, and additional fill material was placed on the dry beach for a cumulative gain of 68.9 cu yd/ft by January 1989. The nearshore portion of the January survey was similar in form to the pre-fill native survey of June 1988 except that the profile was translated seaward by 100 ft. The response to the March 1989 storms (Figure 59) was erosion of 28.9 cu yd/ft of the subaerial beach and deposition of most of the material in the nearshore with a net loss of only 3.5 cu yd/ft

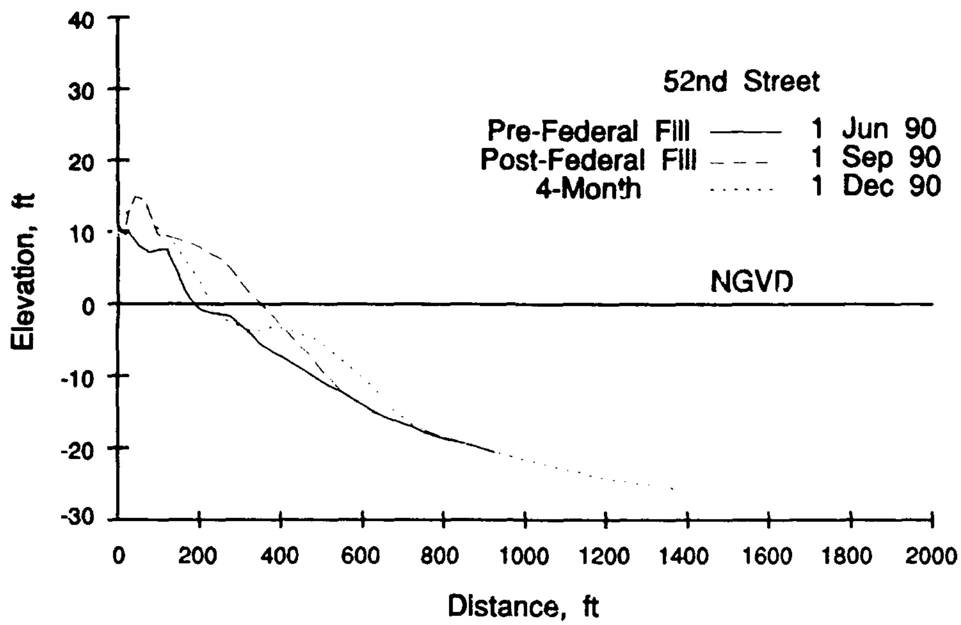


Figure 54. Pre- and post-Federal fill profile at 52nd St. and initial 4-month fill readjustment

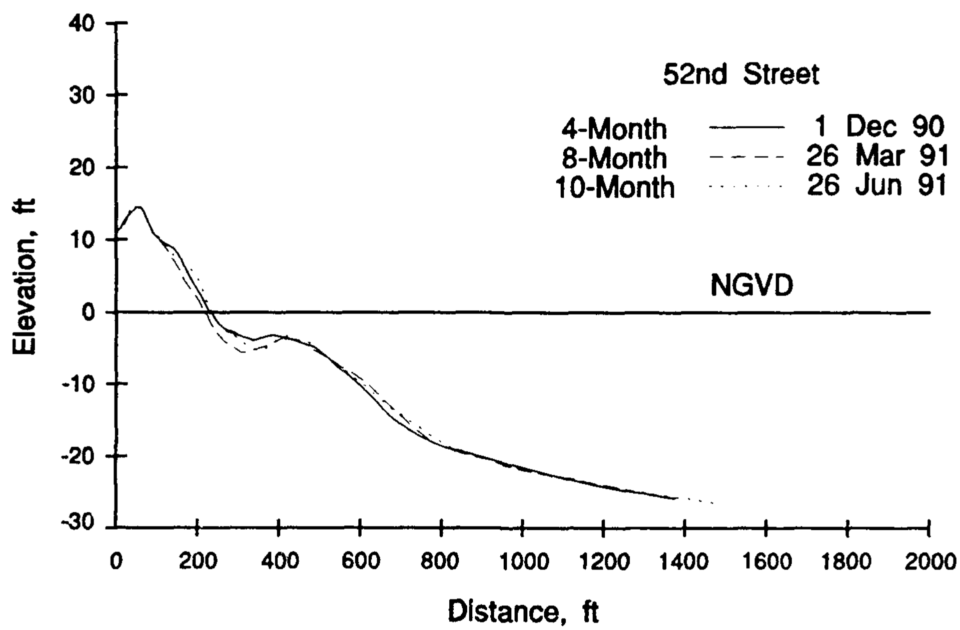


Figure 55. Four- to ten-month Federal fill readjustment at 52nd St.

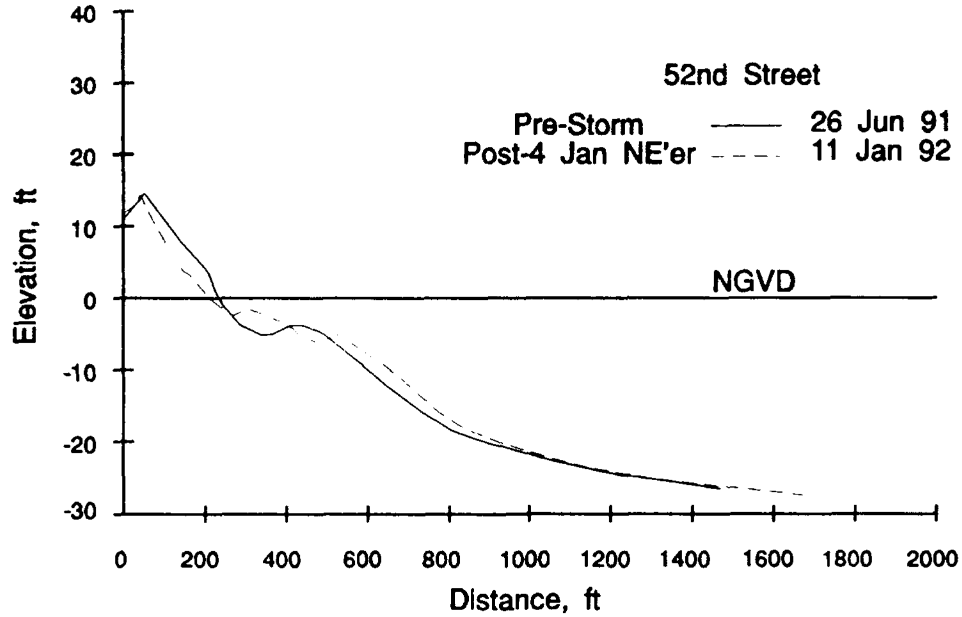


Figure 56. Pre- and post-storms profile readjustment at 52nd St.

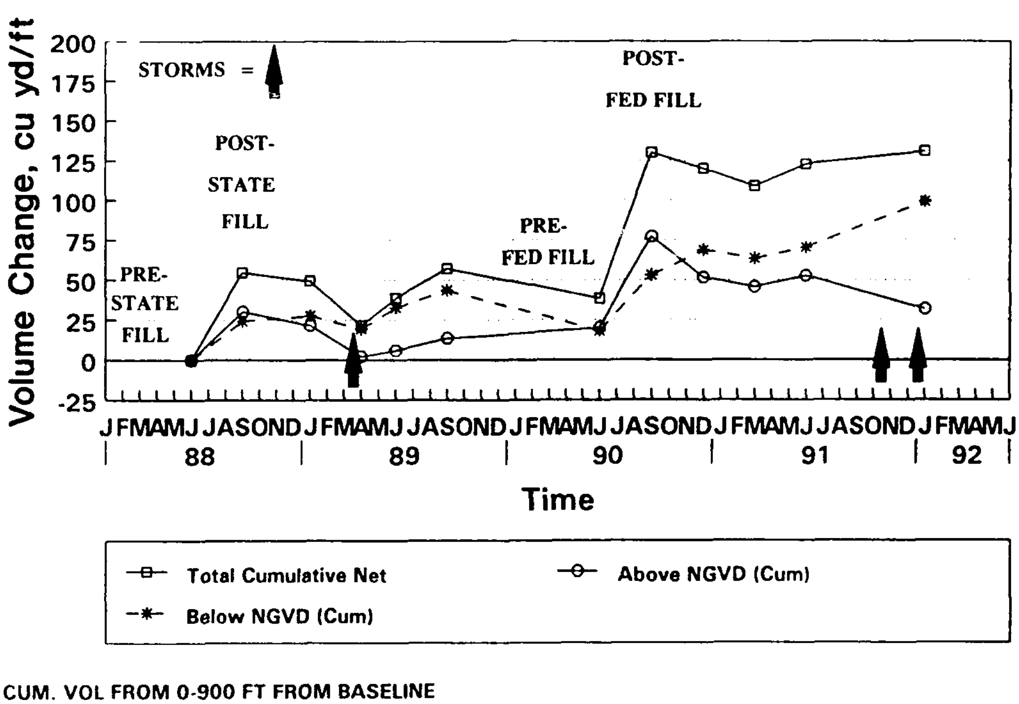


Figure 57. Profile volume change at 52nd St.

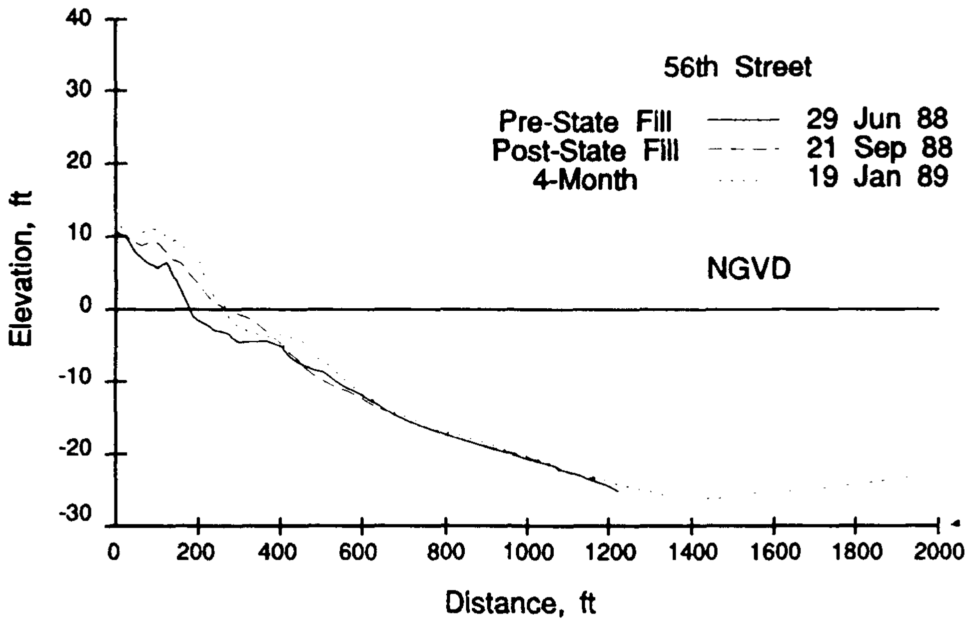


Figure 58. Pre- and post-State fill profile at 56th St. and initial 4-month fill readjustment

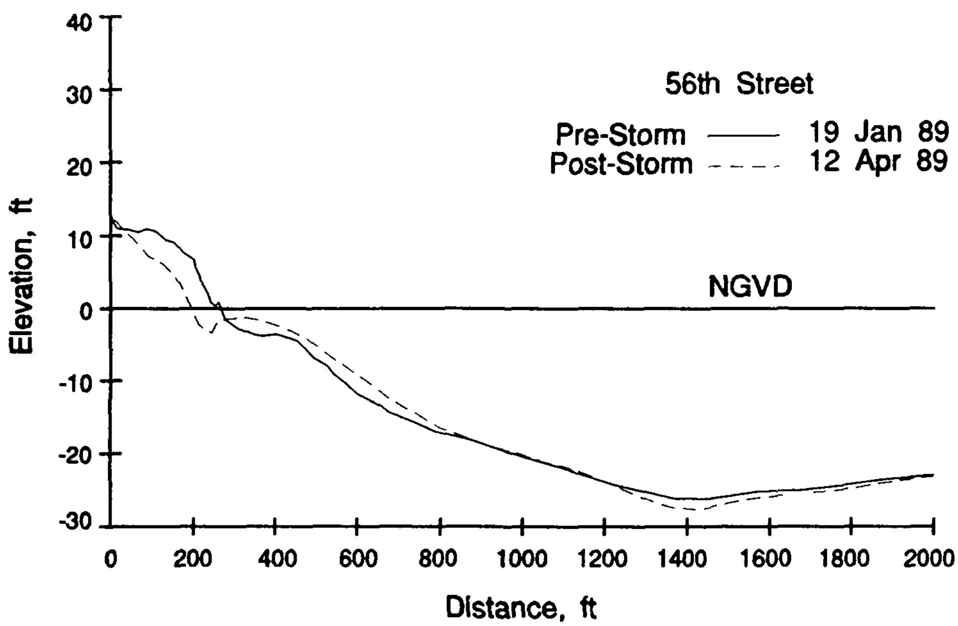


Figure 59. Pre- and post- March 89 storms profile readjustment at 56th St.

out to 900 ft on the profile. Erosion occurred in the trough and landward face of the shoreface-attached shoal between 1,500 and 2,500 ft offshore.

Recovery of the State fill at this profile survey location was characterized by steady accretion onto the foreshore with the formation of a pronounced berm crest between April 1989 and June 1990 (Figure 60). No bar was found during the surveys performed in June of 1989 and June of 1990, but a bar was present in the September 1989 survey. Slight accretion was also measured on the landward flank of the shoreface-attached shoal.

The Federal portion of the project placed 110.3 cu yd/ft of fill on the constructed dune, berm, and nearshore slope to a depth of 10 ft reaching to 500 ft seaward of the baseline (Figure 61). Fill placed seaward of the pre-fill berm crest was eroded into the nearshore by December 1990. The sand created more of a low tide terrace type deposit rather than a typical nearshore bar. A loss of only 2.6 cu yd/ft was calculated over the profile out to 900 ft seaward of the baseline. Further adjustments to this survey location over the 8- and 10-month survey periods showed the growth of the berm on the foreshore and the landward migration of the nearshore bar (Figure 62). This resulted in growth of sediment volume across the entire profile above the original fill placement. The response to the Halloween storm was removal of a large portion of the subaerial berm and foreshore, and movement of the sand into a nearshore bar with a net profile loss of 15.9 cu yd/ft (Figure 63). Little change in profile elevation on the subaerial beach was observed after the storm on 4 January 1992, with the storm berm eroding its seaward face but remaining intact. The nearshore bar rapidly moved onshore and into the lower swash zone as part of the beach recovery after the storm.

Volume change at the 56th Street profile survey site differed from the survey lines previously discussed in that a small volume of fill was placed during the initial construction and additional fill was added before January 1989 for the State fill. Erosion after the March storms resulted in 47.6 percent of the fill remaining on the above NGVD beach, but a large (189.9) percent of the State fill volume remained on the 900-ft length of the profile. Erosion of the profile volume as seen in Figure 64 occurred in June 1989 as the foreshore accreted and the nearshore bar migrated onshore. By the end of the State fill monitoring in June 1990, 113 percent of the initial placed fill remained on the subaerial beach. Because additional fill was placed on this profile prior to January 1989, the volume of fill remaining from all placed fill equaled 59 percent above NGVD and 70.7 percent for the total profile. The Federal fill increased the volume of sand on this profile and the total volume increased until the two storms in late 1991 and early 1992. The foreshore volumes tended to remain relatively constant with a gain in the offshore, resulting in almost 110 percent of the Federal fill volume on the total profile even after the two storms. Above NGVD, 64.9 percent of the Federal fill remained after the January 1992 survey. The visible subaerial beach in January 1992 contained 103.8 percent of the total fill placed before January 1989 (during State fill and supplemental placement). The total profile fill volume calculated since the State fill at 56th Street was 177 percent of the original fills placed. This additional sand volume may be associated with possible deposition at the vicinity of the point of attachment of the shoreface-attached shoal.

63rd Street

The profile survey location at 63rd Street was one of the 500 series surveys added in June 1988 to monitor the State fill. It was originally numbered as Line 544 and renumbered as Line

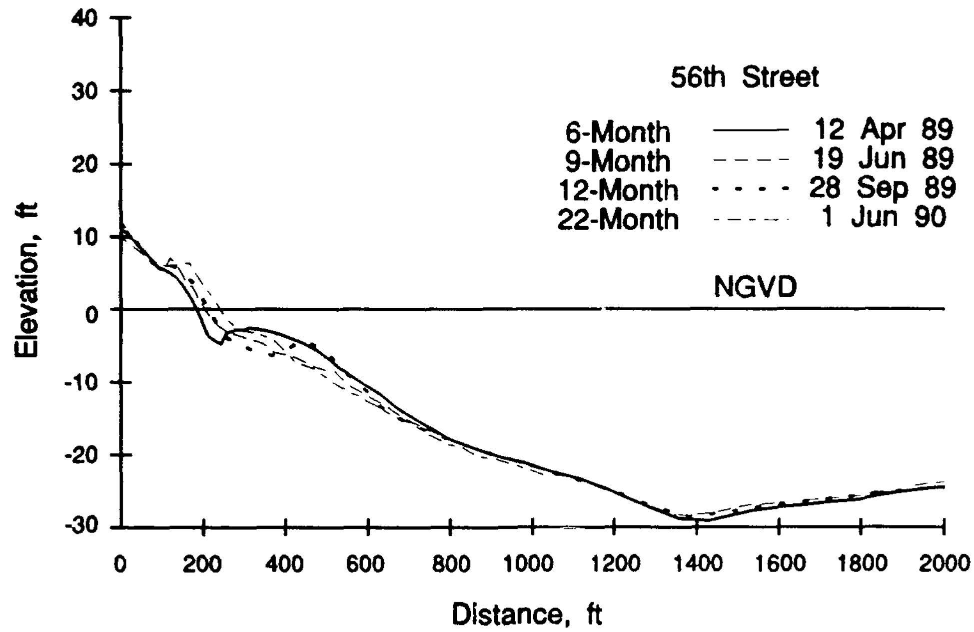


Figure 60. Six- to twenty-two-month performance of State fill at 56th St.

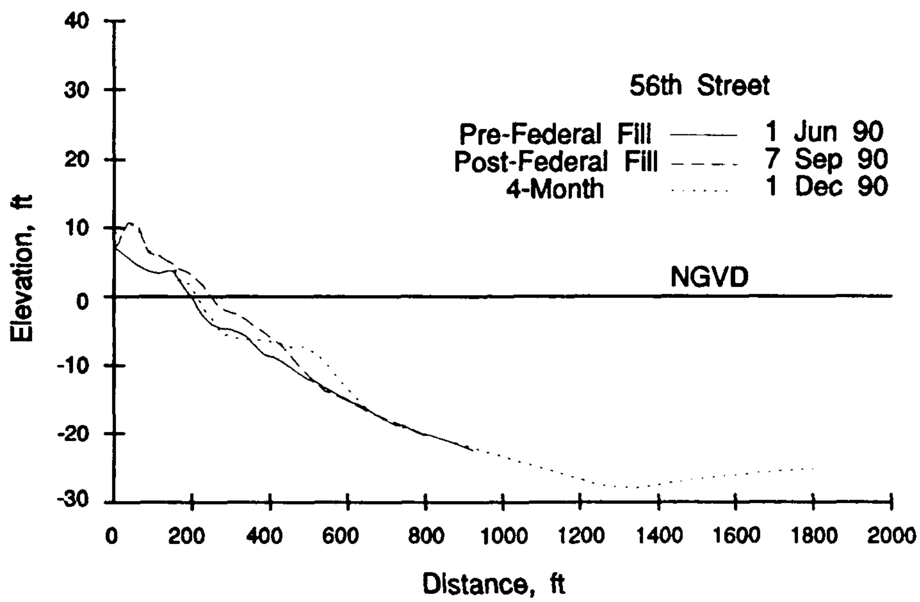


Figure 61. Pre- and post-Federal fill profile at 56th St. and initial 4-month fill readjustment

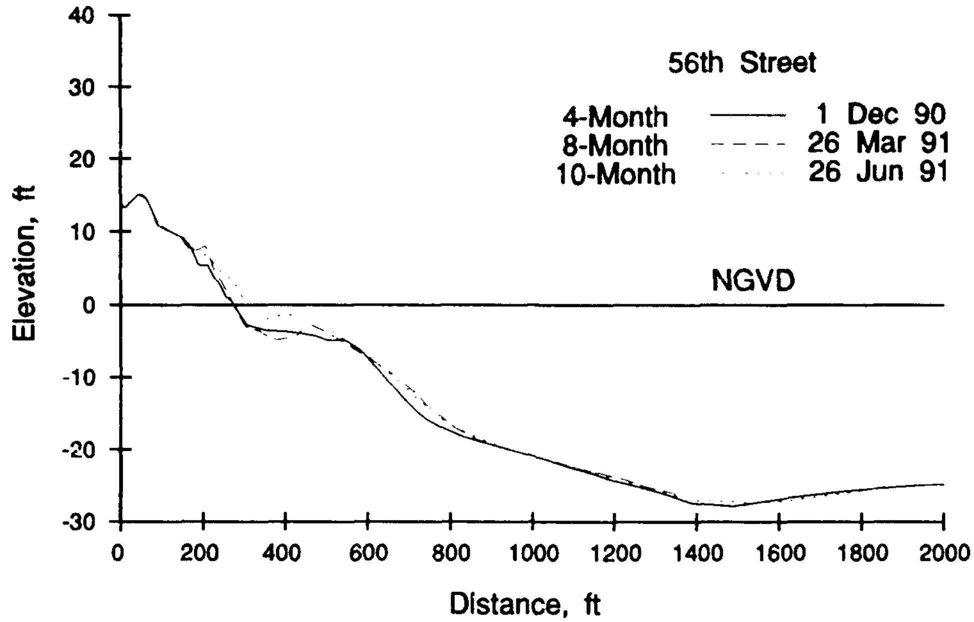


Figure 62. Long-term Federal fill readjustment at 56th St.

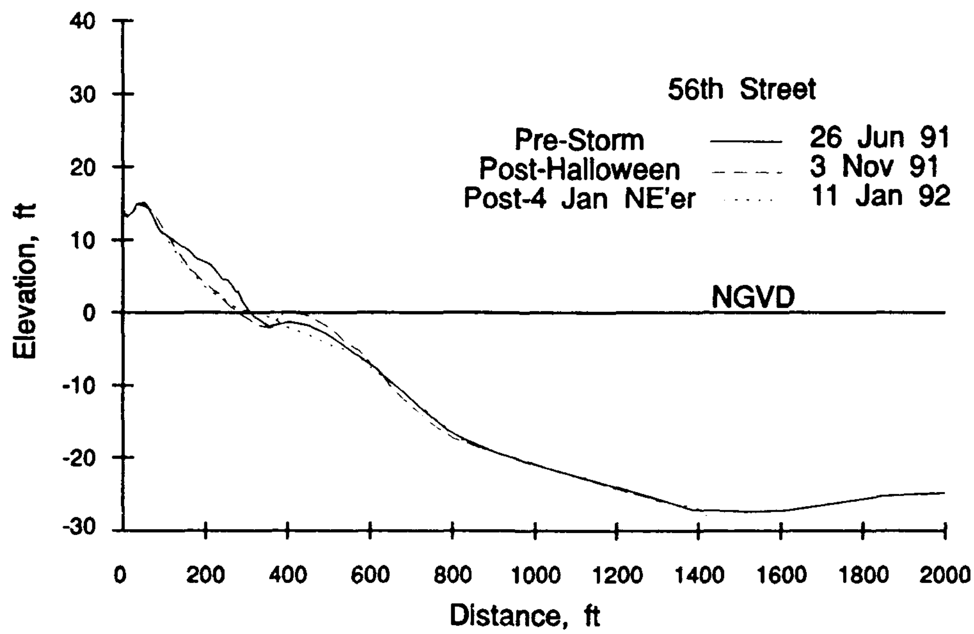
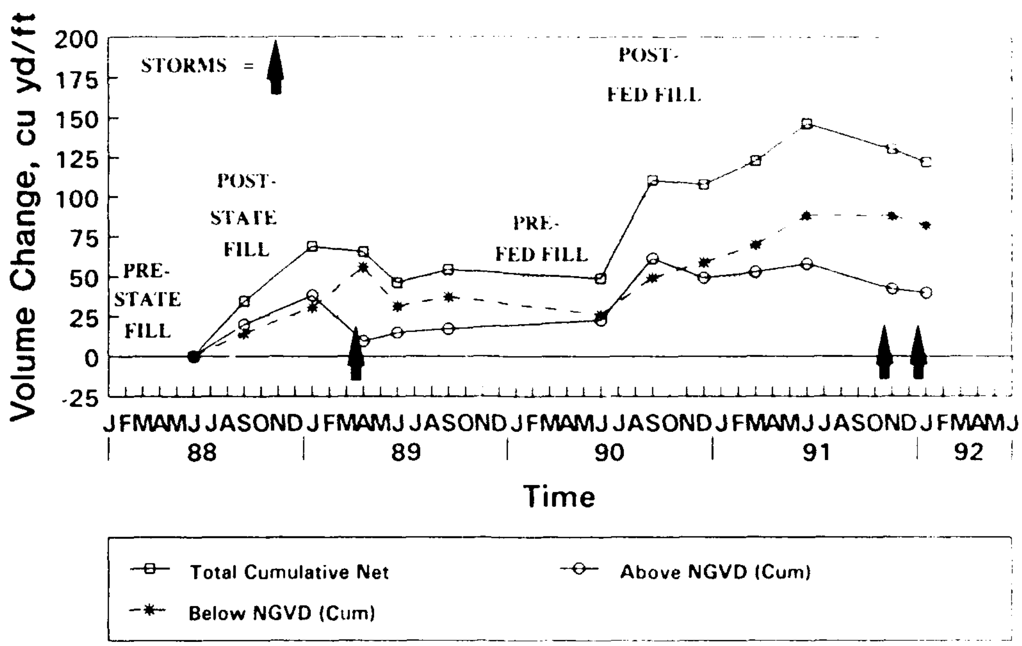


Figure 63. Pre- and post-storms profile readjustment at 56th St.



CUM. VOL FROM 0-900 FT FROM BASELINE

Figure 64. Profile volume change at 56th St.

20 in June 1989. This line is located in the lee of the shoreface-attached shoal. Morphology of the native beach included a mound of sand at the street end, with a berm crest at the +6-ft elevation above NGVD. A sloping foreshore flattened to a low tide terrace just below NGVD without evidence of a nearshore trough or bar. The State fill extended from the backbeach at an elevation of +9 ft to the 10-ft depth contour located 450 ft seaward of the baseline (Figure 65). The shoreline was advanced seaward 102.1 ft with the addition of almost 47 cu yd/ft. Initial readjustment of the profile shape within the first 4 months resulted in erosion of 6.4 cu yd/ft from the subaerial beach and deposition of 20.4 cu yd/ft on the nearshore out to the 15-ft depth contour, 500 ft seaward of the baseline. The planform of the fill evolved with erosion of the berm and lower foreshore into the form of a shallow trough and low bar-like feature with deposition in the nearshore between the 5- and 15-ft depths, located between 400 and 500 ft offshore.

The storm response of this profile was to depc ·it more sand from the berm and foreshore on the nearshore to the 20-ft depth contour, located 900 ft offshore, for a net gain over the profile out to 900 ft of 39.7 cu yd/ft (Figure 66). Although material from the visible portion of the beach was removed by profile readjustment and storm erosion, the nearshore accreted with addition of sand from outside the immediate profile area. Storm recovery between April and June 1989 deposited sand on the berm crest, and a thin layer of sand was eroded from the nearshore portion of the profile extending from the lower foreshore to the 20-ft depth contour. The first significant nearshore trough/bar form was measured in September 1989 (Figure 67). The foreshore also experienced deposition for a total profile gain of 10.6 cu yd/ft. Comparison of volume change that occurred over the next winter from September 1989 to June 1990 showed landward transport of the bar and deposition on the lower foreshore and berm crest. This

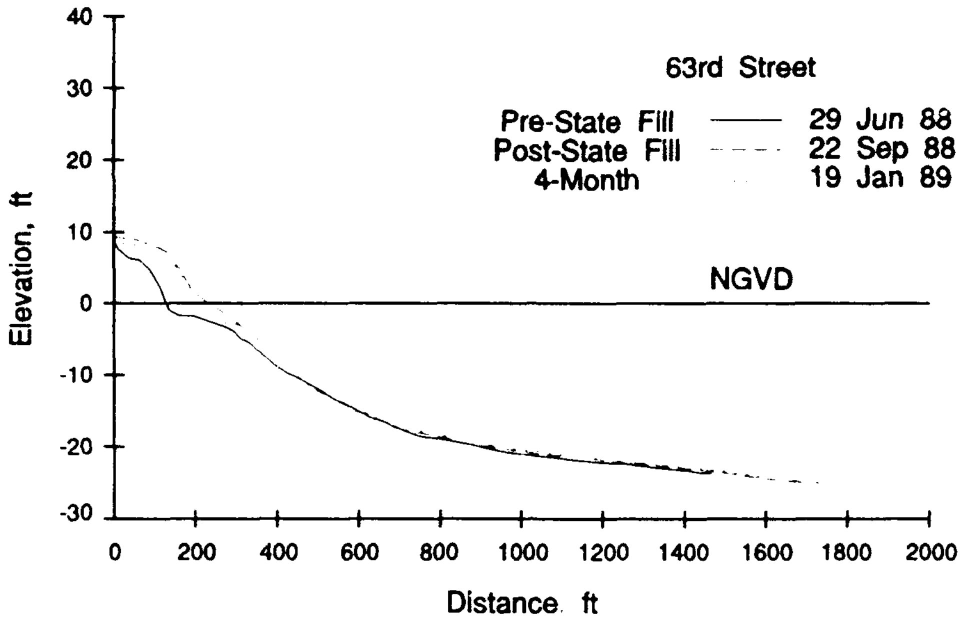


Figure 65. Pre- and post-State fill profile at 63rd St. and initial 4-month fill readjustment

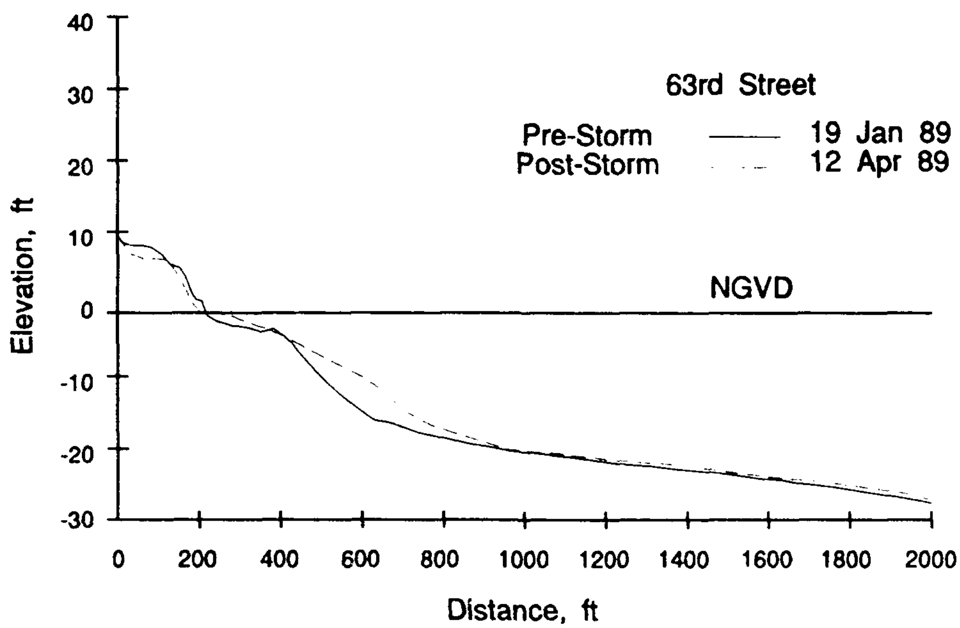


Figure 66. Pre- and post- March 89 storms profile readjustment at 63rd St.

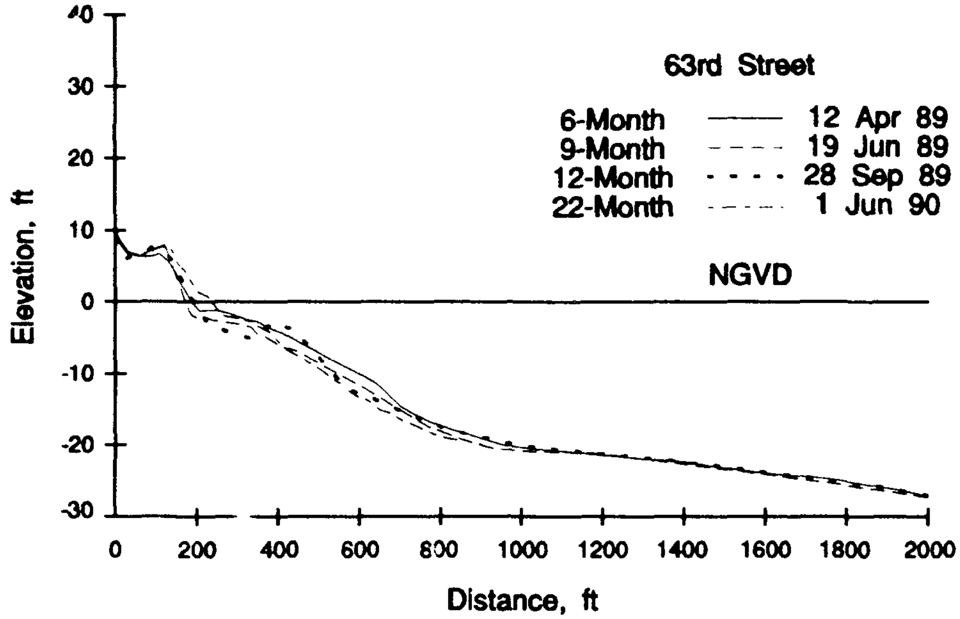


Figure 67. Six- to twenty-two-month performance of State fill at 63rd St.

accretion most likely occurred during the spring of 1990. With the erosion in the nearshore, the profile experienced a slight net volume loss over the entire 900-ft length of 6.1 cu yd/ft over this time period, September 1989 to June 1990.

The Federal fill placement supplied 54.9 cu yd/ft of sand on this profile (Figure 68). The fill material encompassed construction of a storm-protection dune and moved the shoreline seaward 87.8 ft, placing fill out to a depth of 10 ft. Natural readjustment moved 19.6 cu yd/ft from the dune base to the lower foreshore and deposited 8.6 cu yd/ft on the nearshore for a net loss on this profile of 11 cu yd/ft. In contrast to the readjustment of the State fill, the nearshore was not a depository for the Federal fill. Adjustment was continuing up to March 1991, with deposition of sand on the upper berm and in a thin layer in the nearshore. Again the bar/trough morphology was not common at this profile location, with a low tide terrace being more common (Figure 69). A slight gain in profile volume was calculated at 6.3 cu yd/ft. Minimal profile adjustment occurred during the spring, with nearshore bar formation at the base of the lower foreshore at the 2-ft depth and a thin layer of sand accreting on the foreshore.

After the Halloween storm the constructed dune remained intact, with erosion of the subaerial beach in front of the dune, and removal of 16.2 cu yd/ft. Below NGVD, deposition of 9.8 cu yd/ft occurred as a shallow low-tide terrace and fill on the nearshore slope to around 500 ft seaward of the baseline. An area of erosion occurred at the base of this slope to 1,000 ft from the baseline at a depth of 20 ft with a net removal of 6.4 cu yd/ft over the profile to 900 ft (Figure 70). The survey made after the January 1992 storm indicated that the storm berm was removed with some overwash deposition landward of the baseline. This survey was taken 7 days after the storm and an accretional swash bar had already formed on the lower foreshore,

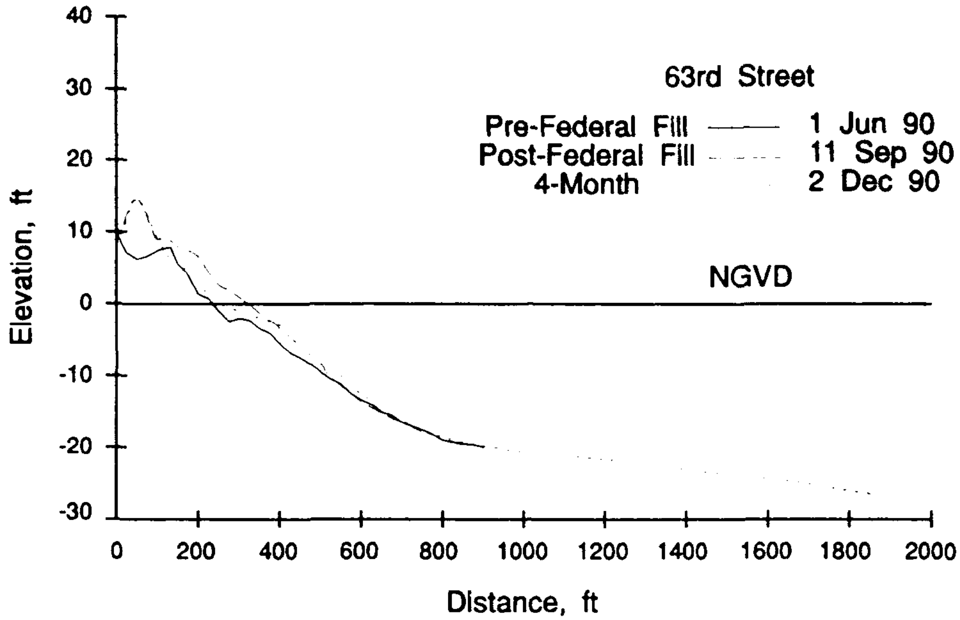


Figure 68. Pre- and post-Federal fill profile at 63rd St. and initial 4-month fill readjustment

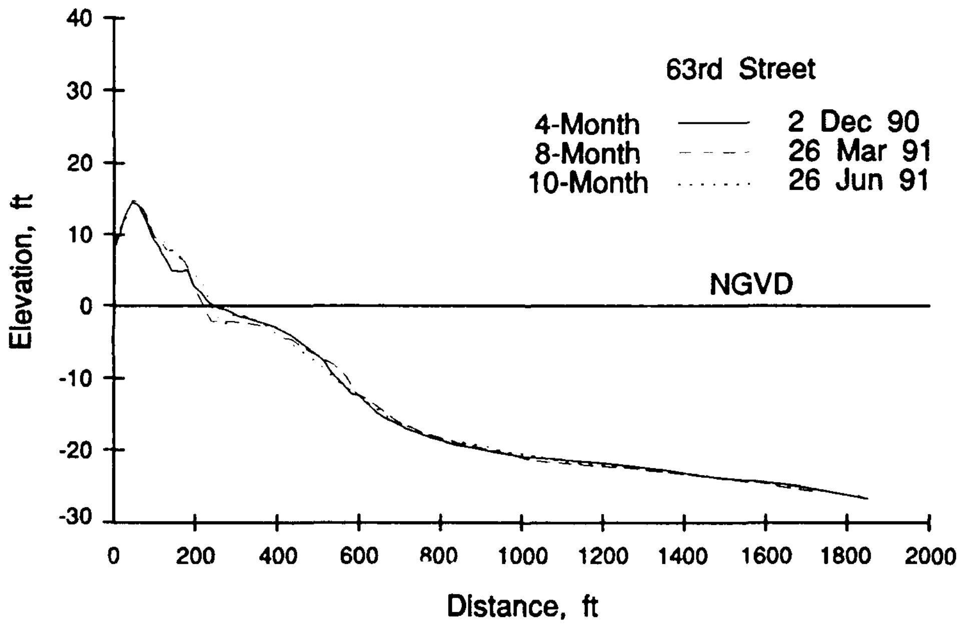


Figure 69. Four- to ten-month Federal fill readjustment at 63rd St.

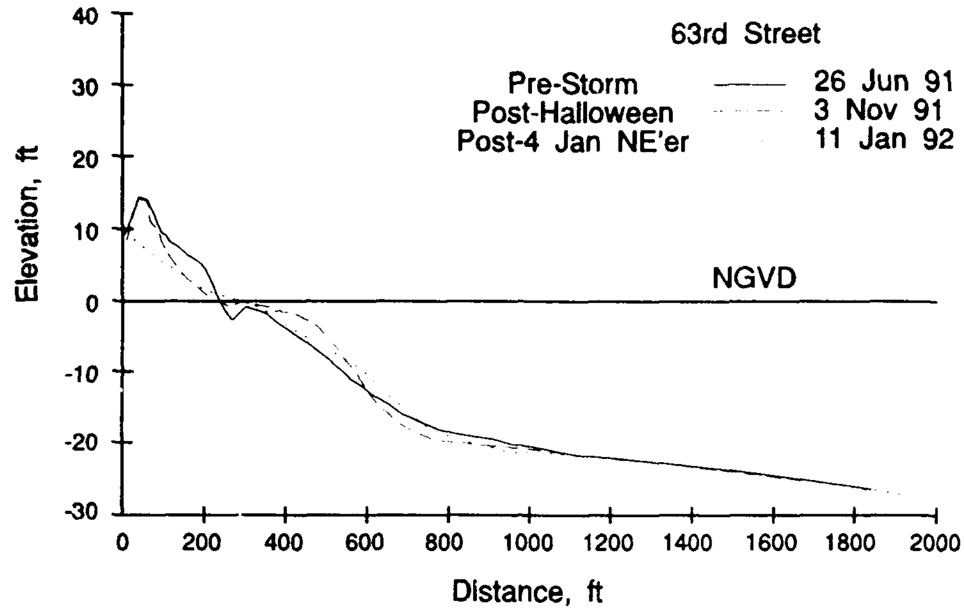


Figure 70. Pre- and post-storms profile readjustment at 63rd St.

indicating the initiation of recovery. This sand presumably had moved landward from the nearshore area located between 300 and 500 ft offshore. Additional deposition occurred below the 10-ft depth out to around 800 ft. There was a net removal of 5.2 cu yd/ft from this profile.

The sand volume change time history from 63rd Street showed a steady gain over the profile from State fill placement, with a large gain after the March 1989 storms. The pattern of removal of sand from the subaerial beach and deposition in the nearshore was evident along this survey line. Almost half of the sand placed on the subaerial beach was removed (49.2 percent remained) as a result of the three storms. A gain of 214.2 percent of sand on the profile resulted from the large accretion in the nearshore. Sand began to return to the foreshore with a gain above NGVD and slight loss below NGVD up until June 1990 (Figure 71). Eighty-two percent of the placed fill volume returned above NGVD, and the profile retained 153.5 percent of the fill volume.

The Federal fill placement provided additional material mostly on the berm and foreshore. Steady adjustment of sediment into the nearshore followed initial placement. Removal of the berm increased with the Halloween storm and the January 1992 storm, which removed almost the entire constructed dune. The actions of these storms resulted in a decrease in dry beach volume, but a gain in the nearshore. Only 35.6 percent of the Federal fill remained on the visible beach after the two storms, with 83.4 percent of the placed fill remaining on the profile out to 900 ft. The long-term volume change behavior at this location was that 77.4 percent of the State fill remained on the subaerial beach as of January 1992. A gain below NGVD resulted in a net profile volume change of 225.8 percent over the State and Federal monitoring period, with most of the fill material residing in the nearshore within 900 ft of the baseline. The profile

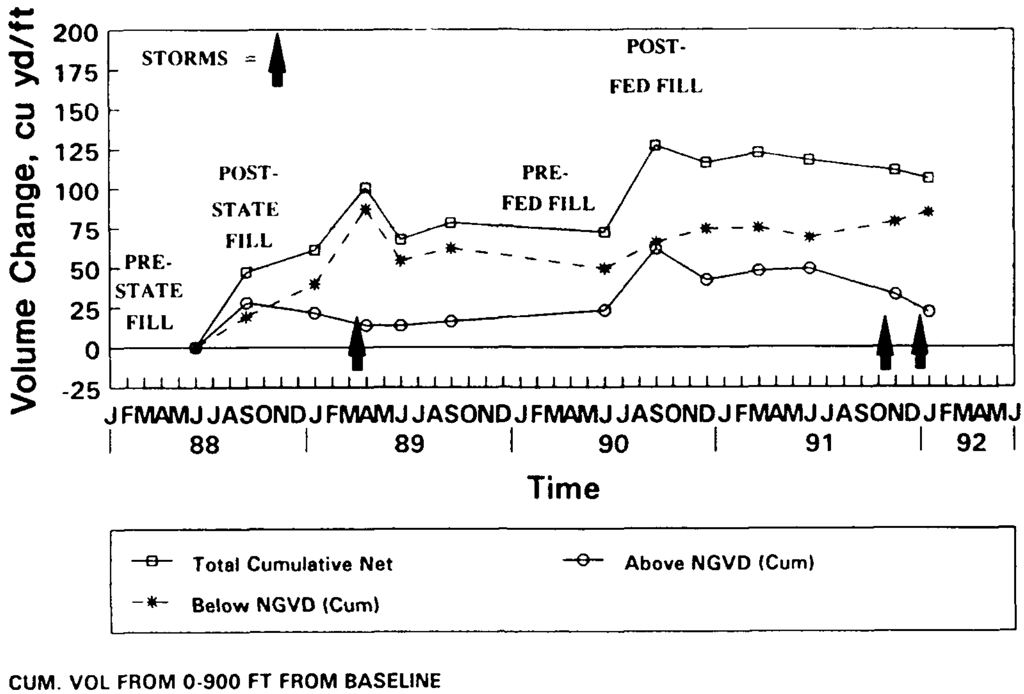


Figure 71. Profile volume change at 63rd St.

survey location in the lee of the shoal, which crested approximately 3,000 ft offshore, may have affected profile response to the storms.

66th Street

Survey Line 21 in both the old and new numbering scheme was located at 66th Street. This profile was only surveyed during the State fill monitoring portion of the study and was dropped from the survey schedule during the Federal fill monitoring. This line contained a native dune with a crest elevation of +18 ft, located 70 ft landward of the baseline. A berm crest was present at +5.5 ft, with a gradually sloping foreshore and nearshore. No bar/trough was observed on this July 1988 survey. The State fill was placed from the dune face at about +15 ft and extended to the 14-ft depth contour located 450 ft seaward of the baseline (Figure 72). The shoreline was moved seaward 90.1 ft, with a total volume of 45.2 cu ft/yd of fill material placed. The initial fill readjustment 4 months after fill placement at this location showed a slight gain in volume of 2.5 cu yd/ft on the upper foreshore with formation of a berm crest. An additional volume gain of 30.9 cu yd/ft was calculated in the nearshore with the formation of a low tide terrace and fill extending from the 2- to 20-ft depth contours. The only loss of material from the profile was found just below NGVD, as the profile changed from the planar fill shape to the concave foreshore/convex nearshore shape.

The profile responded to the March 1989 storms with erosion along the entire subaerial beach face and deposition in the nearshore, including formation of a nearshore trough and bar. Removal of 13.2 cu yd/ft occurred in an area extending from the dune base to the nearshore

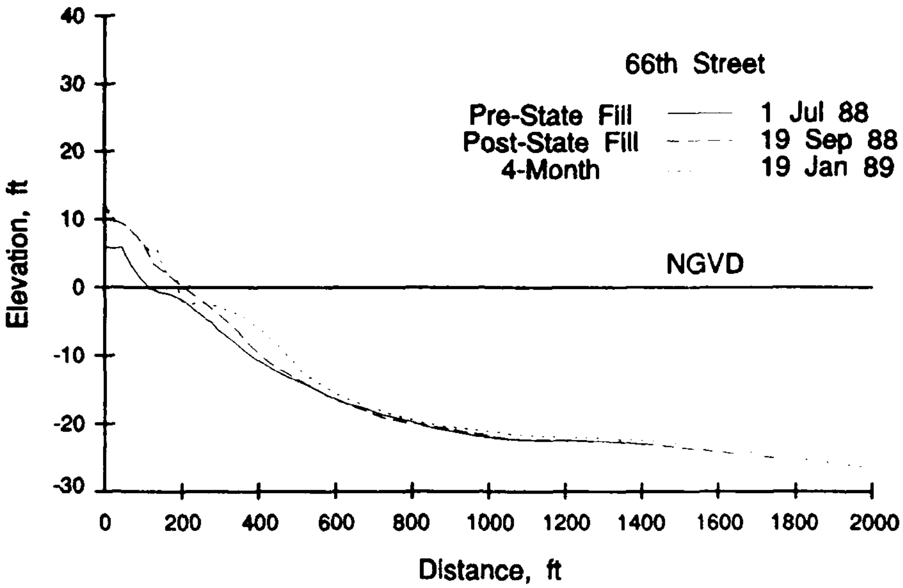


Figure 72. Pre- and post-State fill profile at 66th St. and initial 4-month fill readjustment

trough. Deposition in the nearshore of 24.4 cu yd/ft resulted, extending from the bar crest at the 3-ft depth contour to the 20-ft depth contour, a distance of approximately 700 ft (Figure 73). The net result was a gain of 11.14 cu yd/ft of sand over the profile out to 900 ft. Spring storm recovery resulted in landward transport of sand from the nearshore with deposition on the foreshore and the reformation of the berm crest (Figure 74). A net loss of only 1.9 cu yd/ft occurred over the profile as the sand was redistributed landward and the bar was smoothed into a more planar slope. Over the summer, the profile continued to gain sand. By October 1989, there was little change in the subaerial beach, but a new bar/trough formed in the nearshore with a net profile gain of 17.4 cu yd/ft. The last survey at 66th Street in June 1990 provided a 22-month-long record of the State fill behavior. Additional accretion at the berm crest and on the lower foreshore was observed, as the bar migrated landward again and the above NGVD portion of the profile gained 4.4 cu yd/ft. Overall, the net volume change on the profile was a loss of 4.3 cu yd/ft, mostly from the nearshore.

State fill monitoring of the volume change at 66th Street is summarized in Figure 75 and shows a steady increase in the net profile volume out to 900 ft seaward of the baseline. The subaerial beach maintained a reasonably constant volume after fill placement, except for the erosion after the March storms. After the storms in March 1989, 60 percent of the fill was on the visible beach, and 198.7 percent of the State fill volume at initial placement was on the 900-ft length of the profile in April 1989. The gain was mostly due to deposition in the nearshore. A net volume gain of 109.7 percent of original fill volume was calculated on the subaerial beach at the end of the State fill monitoring period in June 1990. Although over 100 percent of the fill volume was in place on the visible beach, the main accretion of sand occurred below NGVD in the nearshore. The net increase in sand volume was 223.5 percent of the initial fill along the 900-ft length of the profile as of June 1990. The source of the sediment along the profile is

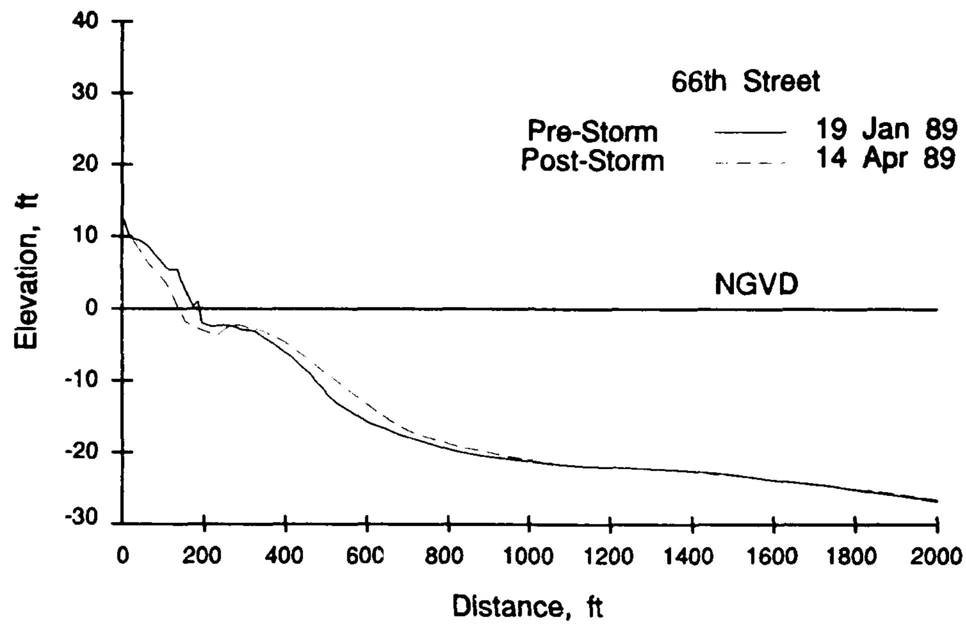


Figure 73. Pre- and post- March 89 storms profile readjustment at 66th St.

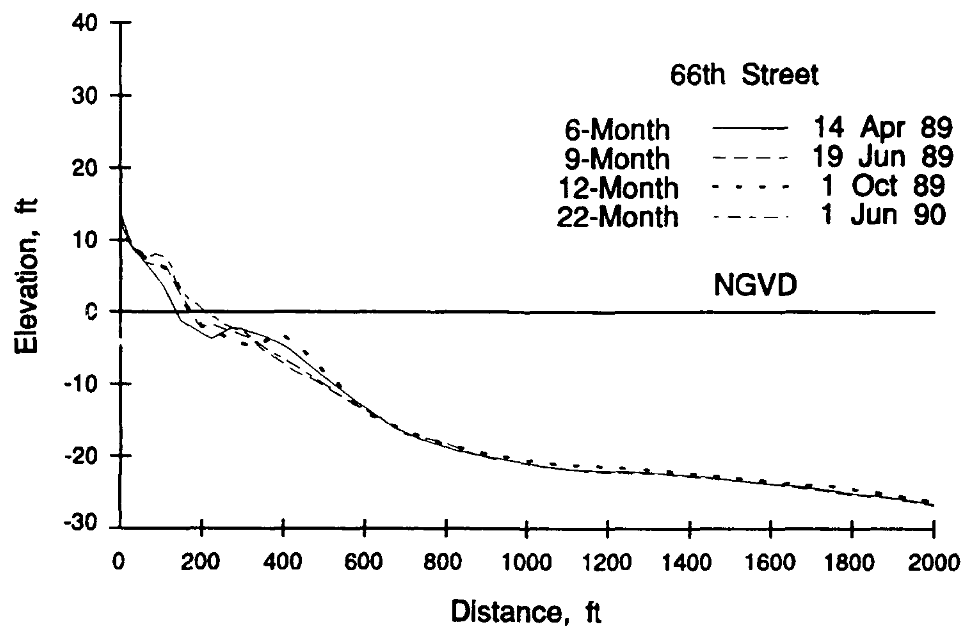


Figure 74. Six- to twenty-two-month performance of State fill at 66th St.

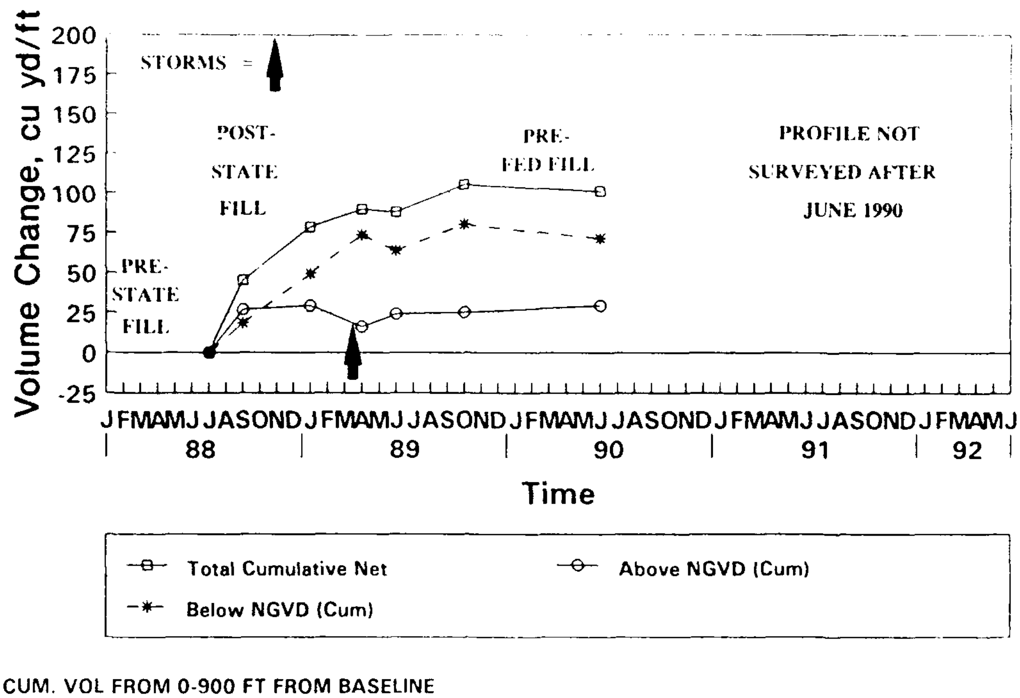


Figure 75. Profile volume change at 66th St.

presumably from longshore movement of fill material into this area. The location of the 66th Street profile survey line in the lee of the shoreface-attached shoal may account for the large gain in volume.

74th Street

The 74th Street survey location was designated as Line 550 under the old numbering system and as Line 24 in the new numbering system. Starting with 74th Street and extending to 86th Street, the native profiles had a steeper foreshore with a planar shape than both the southern native profiles (37th and 45th Streets, which had a bar/trough native configuration) and the central native profiles (52nd to 66th Streets, which had a convex low-tide terrace configuration). The four profiles between 74th and 86th Streets are also located where the large northern shoreface-attached shoal connects with the beach (Figure 17). The native profile at 74th Street had a backshore mound with a maximum elevation of +11 ft, 25 ft landward of the baseline and a small berm crest at the +4-ft elevation. The State fill placed 107.9 cu yd/ft that advanced the shoreline 127.3 ft seaward (Figure 76). This large volume placed on a steeper native profile can be contrasted with 71 cu yd/ft placed at 37th Street, which advanced a flatter native profile shoreline 148.7 ft seaward. The fill extended from just below the crest of the backshore mound seaward to around the 15-ft depth contour that was located only 500 ft from the baseline. The fill extended the same distance seaward at 37th Street but only reached a depth of around 10 ft. Initial response in the first three months showed the typical erosion of the foreshore from the berm crest to the lower foreshore of -12.4 cu yd/ft. Accretion occurred at the base of the planar nearshore slope at the depth of 15 ft and a thin layer of sand extended to the end of the measured

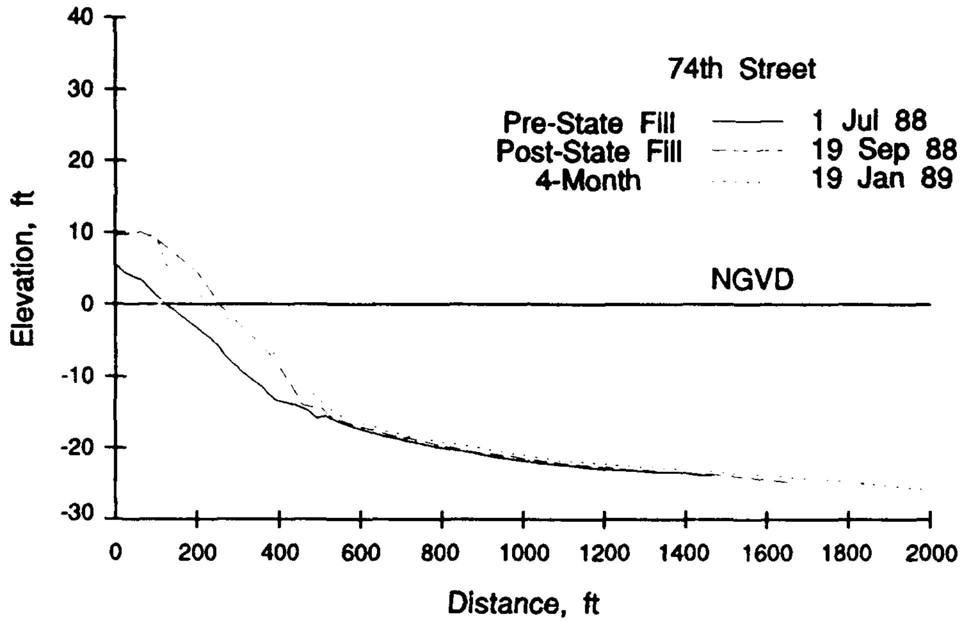


Figure 76. Pre- and post-State fill profile at 74th St. and initial 4-month fill readjustment

survey at 1,650 ft from the baseline. A slight net gain of 1.7 cu yd/ft was measured over the profile length out to 900 ft.

Impact of the extratropical storms in March 1989 resulted in erosion of 27.5 cu yd/ft from the berm and foreshore, with continued erosion of the lower foreshore. A shallow trough and nearshore bar formed 450 ft from the baseline with a bar crest at the 5.5-ft depth (Figure 77). Deposition occurred on the bar out to a depth of 18 ft. A net loss of 32.8 cu yd/ft occurred out to 900 ft, with a shoreline recession of 112 ft. Of the 12 study profiles after these storms, this location recorded the highest volume loss and the largest landward movement distance of the shoreline. Initial recovery in the spring months up until June 1989 produced a landward movement of sand with deposition on the foreshore from the berm crest to the base of the low tide terrace. The bar migrated landward and disappeared into the low tide area of the profile (Figure 78). A net gain of 17 cu yd/ft resulted along the 900-ft length of the profile. Over the summer months of 1989, the foreshore again eroded slightly with a loss of 3.3 cu yd/ft. At the same time the low-tide terrace expanded toward the offshore with a gain of 2.0 cu yd/ft, for a net loss of only 1.3 cu yd/ft over the 900-ft study length of the profile. During the remainder of the State fill monitoring period, the beach became planar with almost no change in the foreshore and landward migration of the low tide terrace. A net profile volume loss of 21.2 cu yd/ft resulted mainly from lowering of the nearshore elevation.

Federal fill placement of 104 cu yd/ft, in the storm dune and on the berm/foreshore, moved the shoreline seaward 185.5 ft (Figure 79). This large quantity of new fill was placed to a depth of 11 ft approximately 400 ft offshore. Three months after placement of this new fill, the profile readjusted by eroding the berm and foreshore, forming a ridge and runnel on the foreshore. Sand

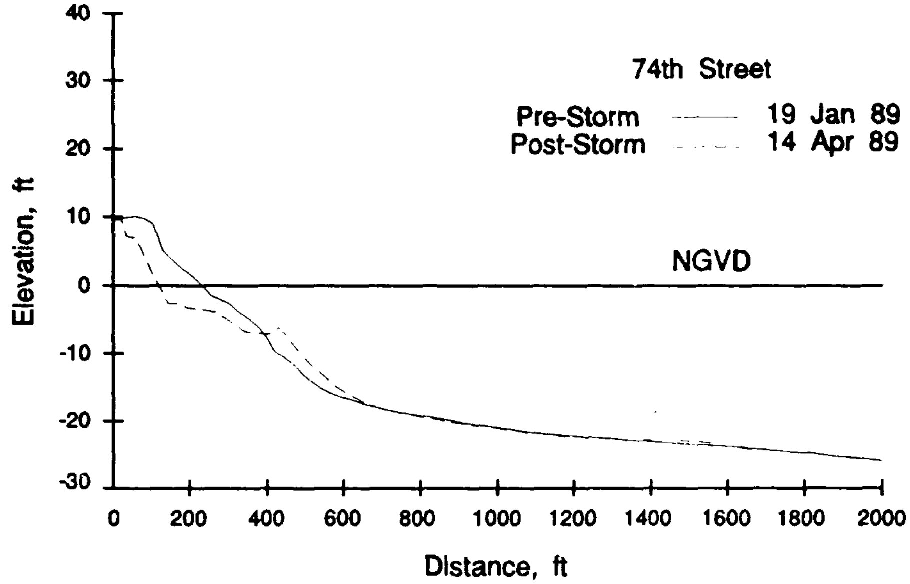


Figure 77. Pre- and post- March 89 storms profile readjustment at 74th St.

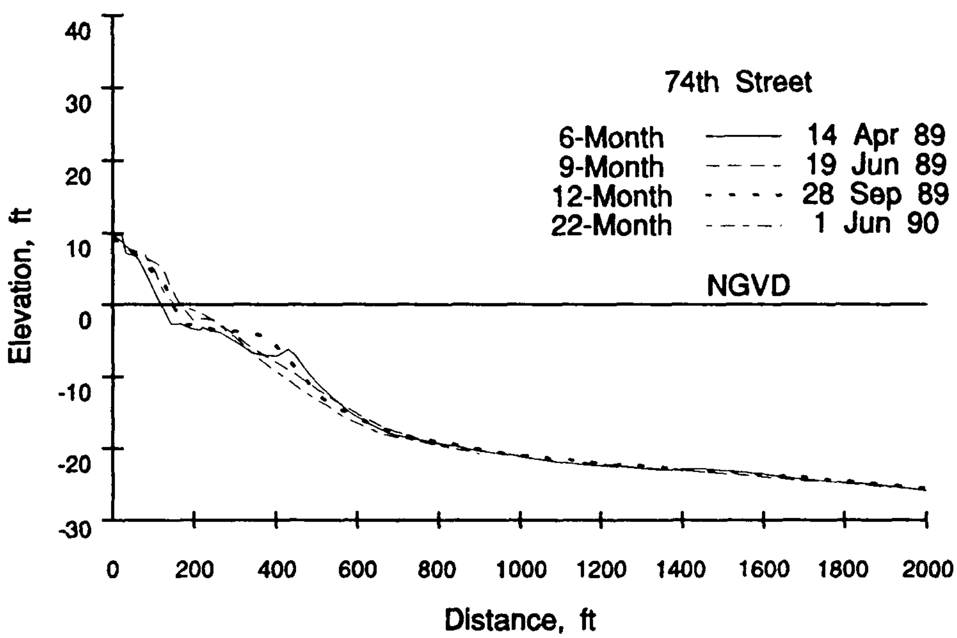


Figure 78. Six- to twenty-two-month performance of State fill at 74th St.

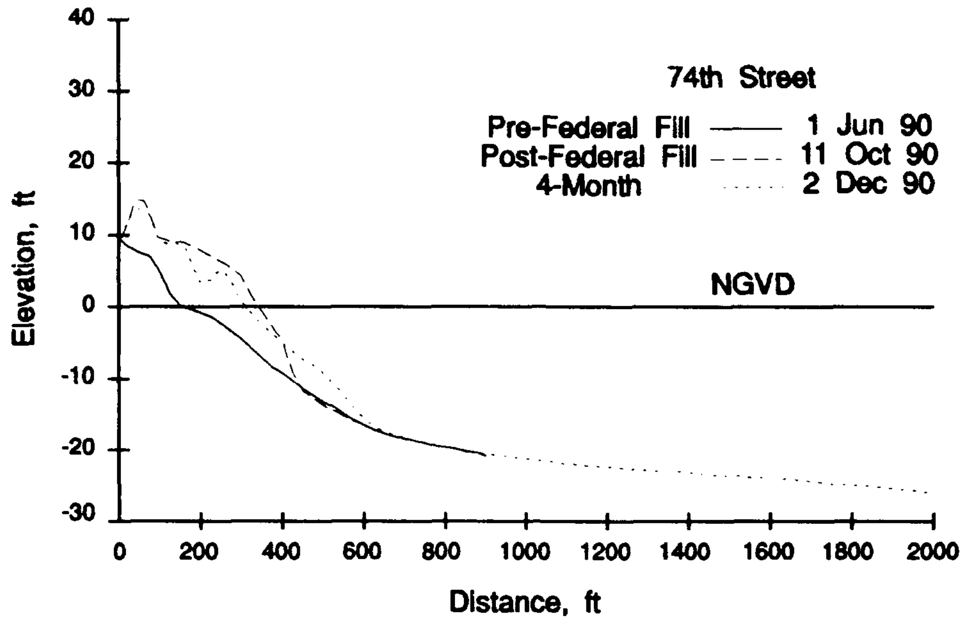


Figure 79. Pre- and post-Federal fill profile at 74th St. and initial 4-month fill readjustment

was deposited in the lower nearshore in an almost equal volume resulting in a net gain in profile volume of 3.6 cu yd/ft out to 900 ft. The longer term readjustment during the first year after placement began with the removal of the ridge and runnel on an otherwise basically stable planar profile from December 1990 to March 1991 (Figure 80). Spring volume changes resulted in a deposition of 4.7 cu yd/ft of sand on the foreshore and erosion of 13.9 cu yd/ft was measured on the nearshore with a net removal of 9.2 cu yd/ft along the profile length to 900 ft. The general trend over these first nine months was a decline in total profile volume (-14.3 cu yd/ft).

The Halloween storm caused erosion of the subaerial beach at 74th Street from the base of the dune to a swash bar at NGVD (Figure 81). A volume loss of 21.1 cu yd/ft on the foreshore was offset by a small amount of deposition of 6.5 cu yd/ft in the nearshore between NGVD and the 13-ft depth. The net volume change along the profile was a loss of 14.6 cu yd/ft. Additional storm impact from the 4 January northeaster resulted in the removal of the storm dune and most of the berm that remained from the Halloween storm. A large quantity of this sand was deposited in the nearshore zone with a net loss of only 4.3 cu yd/ft over the profile to 900 ft. A low-tide terrace just above NGVD was present when this profile was surveyed one week after the storm, so recovery was just beginning to return sand to the foreshore.

A summary of the volume change at 74th Street is presented in Figure 82. Volume changes above NGVD for both the State and Federal fills show removal of material from the subaerial beach after each fill. The March storms removed sand from the visible beach, leaving 22.3 percent of the State fill volume still in place on the beach. The 900-ft length of profile retained 71.1 percent of the placed fill. Over the 21 months of monitoring the State fill, 34.9 percent remained on the beach above NGVD. Most of the original fill material went into

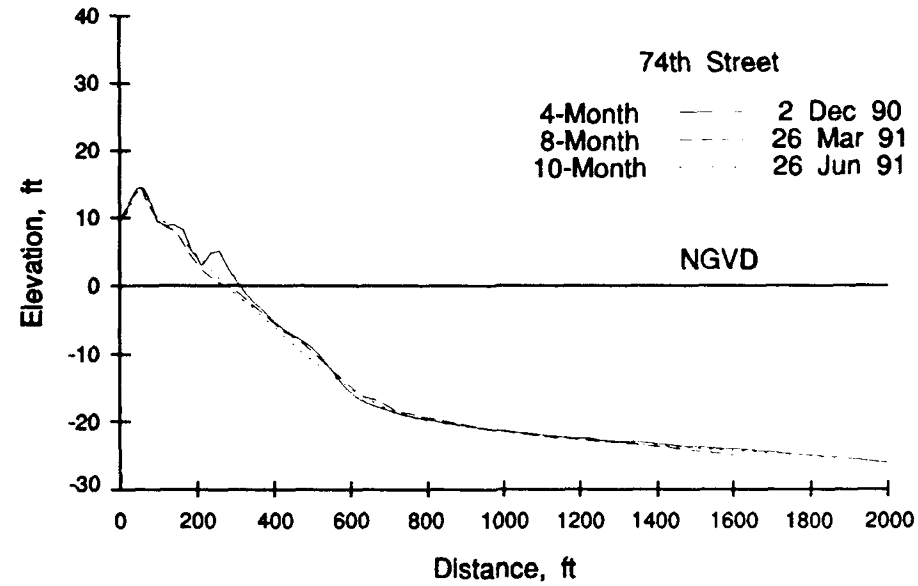


Figure 80. Four- to ten-month Federal fill readjustment at 74th St.

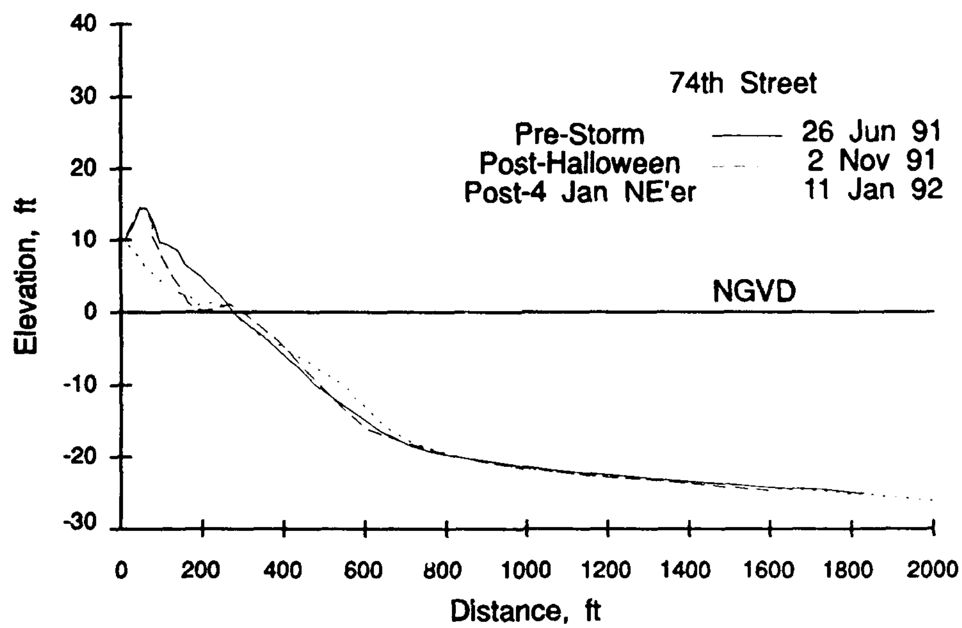


Figure 81. Pre- and post-storms profile readjustment at 74th St.

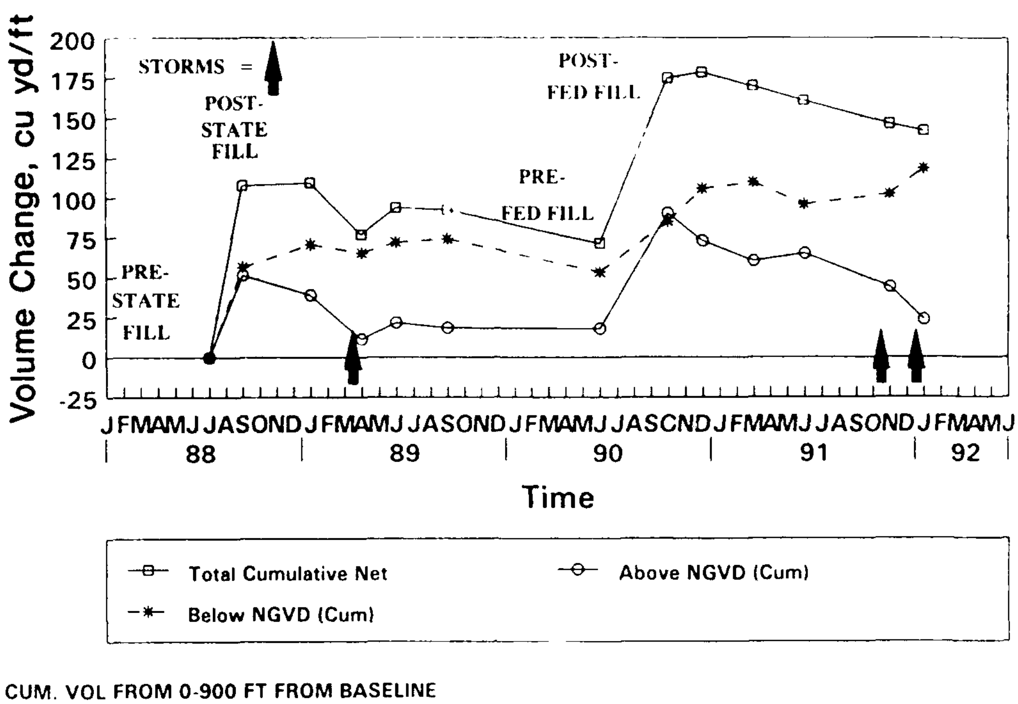


Figure 82. Profile volume change at 74th St.

the nearshore with a total profile volume retention of 66 percent. The addition of Federal fill in 1990 provided more material that progressively eroded from the subaerial beach with 26.2 percent remaining after 15 months of Federal fill monitoring. Much of this material also went into the nearshore with a total retention of 81.1 percent of the Federal fill retained over the profile to 900 ft. This profile survey location only retained 46.1 percent of volume placed on the State fill on the beach above NGVD as of January 1992. The bulk of the fill was deposited in the nearshore. The volume retention along the 900-ft profile length was 131.7 percent of the volume placed on the State fill. This survey location retained the lowest percentage of fill placed over both projects (131.7 percent) and had the shortest active profile envelope (approximately 700 ft).

78th Street

The survey location at 78th Street was numbered as Line 552 in the original designation and renumbered as Line 26 in the new scheme. This survey location was the second of four profile lines located in the area of the shoreface-attached shoal. The native beach contained a dune, with a crest elevation of approximately +14 ft. The survey in June 1988 revealed a steeply sloping planar profile to a depth of 20 ft at a horizontal distance of 600 ft where the profile had a flatter, featureless nearshore slope. The State fill placed 129.8 cu yd/ft of sand at this location from the +10-ft elevation on the dune face extending to the 20-ft depth contour offshore. This was the most fill placed per foot of beach along the study reach and advanced the shoreline seaward 191.3 ft (Figure 83). The fill profile retained a planar shape with no bar/trough formation. Initial fill readjustment of the State fill consisted of erosion of the foreshore, with the formation

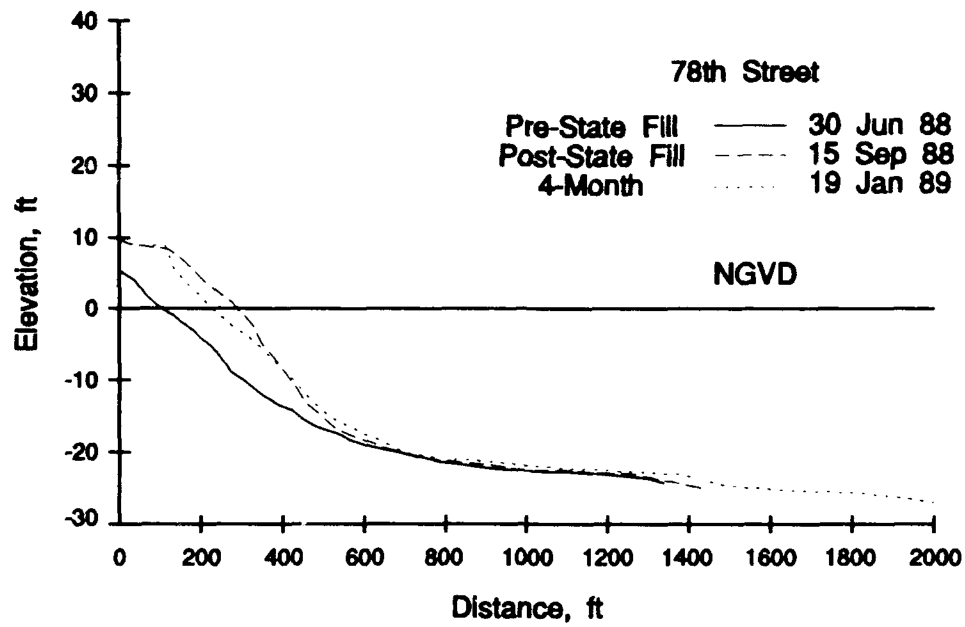


Figure 83. Pre- and post-State fill profile at 78th St. and initial 4-month fill readjustment

of a berm crest at +9 ft. This material was not deposited in the nearshore as at the other profile survey locations to the south, but was transported out of the immediate vicinity. Removal of 12.7 cu yd/ft of sand was measured, all of which occurred above NGVD. No change was detected below NGVD.

The storms during March 1989 removed 29.0 cu yd/ft of sand from the area at the base of the dune to NGVD, and additional material was eroded from the lower foreshore (Figure 84). The sand was deposited in an area below the 5- to 20-ft depth and in a relatively thin 1-ft-thick layer across the nearshore to the 25-ft depth contour, located some 1,700 ft offshore. This deposition was anomalous compared to most of the other survey locations, where the deposition was confined to a distance of 800-1,000 ft offshore within a 2-ft or thicker deposit. This portion of the nearshore, located seaward of 700 ft, is part of the landward component of the shoreface-attached shoal, and may explain the active sand elevation changes as part of the shoal-related response to waves and longshore currents.

In the spring, a recovery of some of the sand occurred as deposition on the foreshore and landward transport of the nearshore storm sand deposit forming a swash bar at MLW or -2 ft (Figure 85). Sand volume deposited on the foreshore almost equally balanced within 1 cu yd/ft the sand transported from the nearshore area landward of the 22-ft depth contour located 900 ft offshore. Some of the thin layer of sand located seaward of 800 ft was also eroded, but could not be tracked as to its final deposition area. By September 1989, the foreshore had eroded slightly. Deposition occurred in the nearshore as the swash bar moved seaward to form a low-tide terrace. A slight gain in the nearshore of 2.2 cu yd/ft occurred over the profile out to 900 ft. Sand was also deposited between 900 and 1,500 ft offshore in the shoreface-attached shoal region.

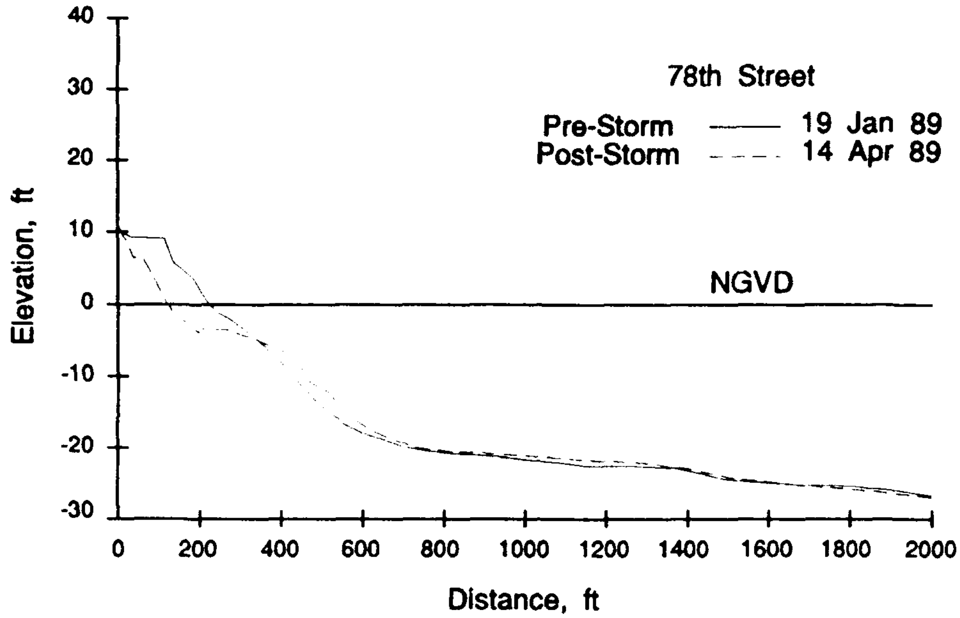


Figure 84. Pre- and post- March 89 storms profile readjustment at 78th St.

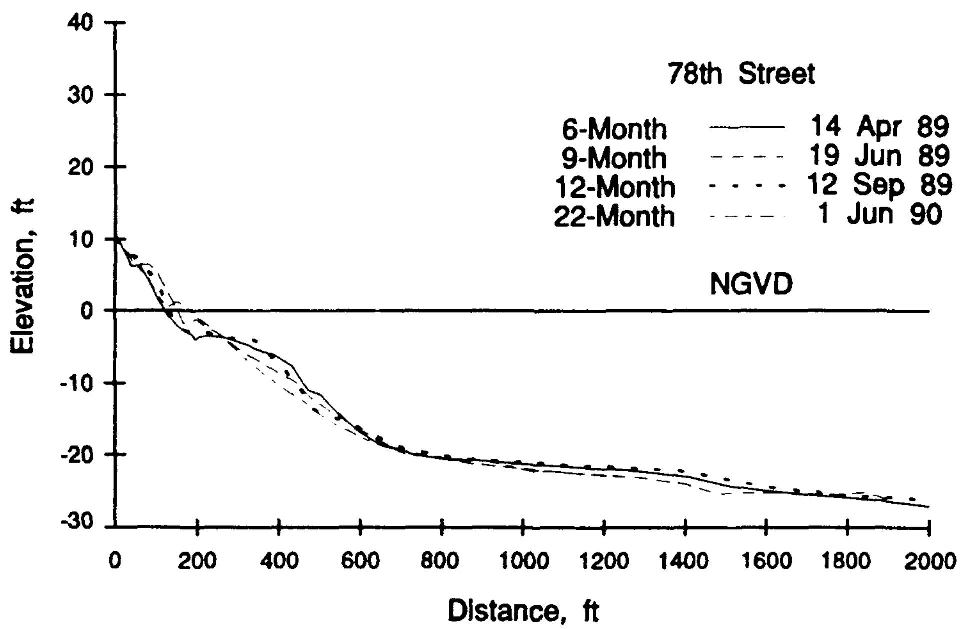


Figure 85. Six- to twenty-two-month performance of State fill at 78th St.

The source of this sand may be from the shoal or alongshore transport of beach sand. By June 1990 the cycle repeated with landward transport and deposition on the lower foreshore as a swash bar at NGVD. The June 1990 survey had less sand on the foreshore and subsequent erosion of the nearshore area (from 200 to 600 ft offshore) than the September 1989 survey, for a net decrease in volume of 22 cu yd/ft.

Only selected profile locations were surveyed with the sled after the placement of the Federal fill, and 78th Street was not surveyed. The next survey was taken in March 1991, seven months after Federal fill placement. Figure 86 shows the storm berm dune and volume of sand remaining after this time period. A fill volume of 94.8 cu yd/ft remained on the profile at this date, which extended offshore to a depth of 20 ft, 700 ft from the baseline. Presumably, more fill was placed at this location, but because the post-fill (September 1990) and the 3-month (December 1990) surveys were not made at this location, an accurate estimate of the actual volume of fill placed cannot be made. No further surveys have been made at this location.

The time history of the volume change during the State fill monitoring at 78th Street showed an initial increase as the fill was placed, with a gradual removal of fill from the subaerial beach and deposition in the nearshore (Figure 87). A retention of only 25 percent of fill occurred on the subaerial beach after the March storms, and 77 percent of the placed sand could be accounted for with the accretion in the nearshore portion of the profile. An accretion of sand onto the foreshore resulted in a slight gain in sand in the months after the storms with a relatively constant sand volume remaining until the June 1990 survey. A total of 28.6 percent of sand remained on the subaerial beach, and a total of 62.4 percent remained on the profile to 900 ft, 21 months after State fill placement. The close proximity of this survey location with the shoreface-attached shoal connection to the shoreline resulted in a longer length (1,600 ft) of active profile than most of the study locations.

81st Street

The survey line located at 81st Street was also in close proximity to the shoreface-attached shoal. The native beach had a natural dune with a crest height of +13 ft, located 50 ft landward of the baseline. The profile shape was planar to a depth of 20 ft, at 800 ft seaward of the baseline. A low-relief bar was located 1,300 ft seaward of the baseline and was most likely associated with the shoal. A total of 108.2 cu yd/ft of fill material was placed at this location, which was the third largest amount measured in the study area. This fill extended from an elevation of +7 ft against the front face of the dune to the 15-ft depth contour, 500 ft seaward of the baseline (Figure 88). The shoreline was extended 153 ft seaward. A small bar had developed in the vicinity of 1,100 ft offshore with a crest elevation at the 20-ft depth. Four months after fill placement, the fill had begun to rearrange with removal of 11.4 cu yd/ft of material from the foreshore to a depth of 7 ft. There was virtually no change in profile shape in the nearshore with only slight deposition between the 10- and 22-ft depths. The bar form at 1,100 ft was removed with a layer of sand deposited seaward of 1,200 ft. The active profile envelope was much further seaward at this location than on profiles to the south and more sand was deposited seaward of 900 ft.

Storm-induced erosion occurred on the entire subaerial beach from the dune base seaward to the 4.5-ft depth, with the formation of a trough and bar 250 ft seaward of the baseline (Figure 89). Out to 900 ft there was almost an even exchange of volume, with 23.4 cu yd/ft eroded from

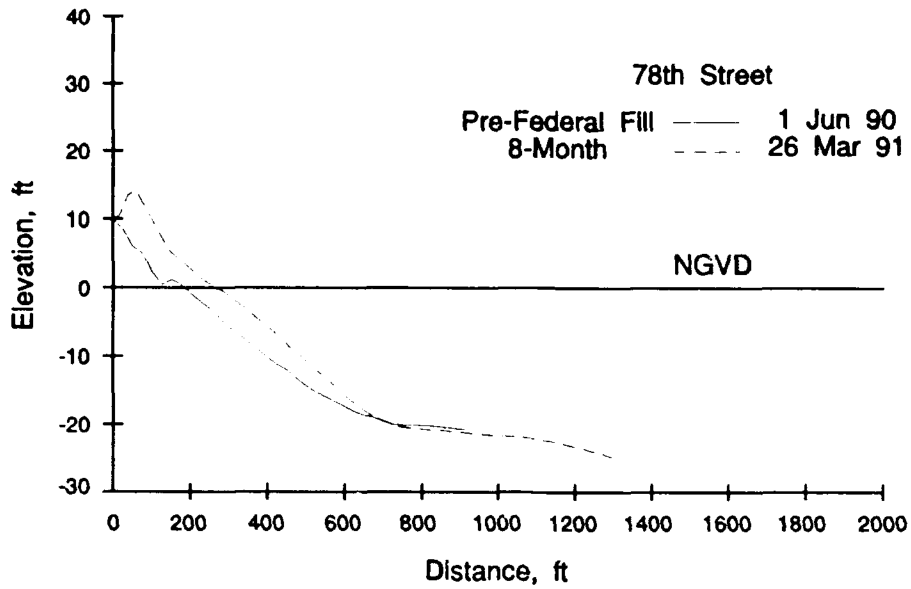


Figure 86. Pre-Federal fill profile at 78th St. and initial 4-month fill readjustment

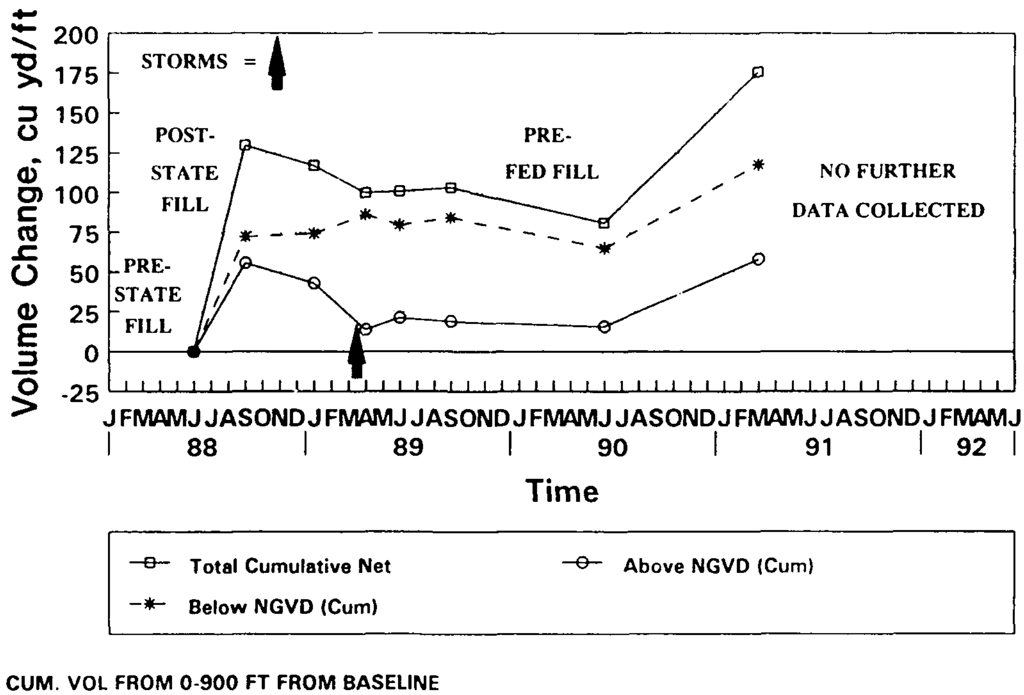


Figure 87. Profile volume change at 78th St.

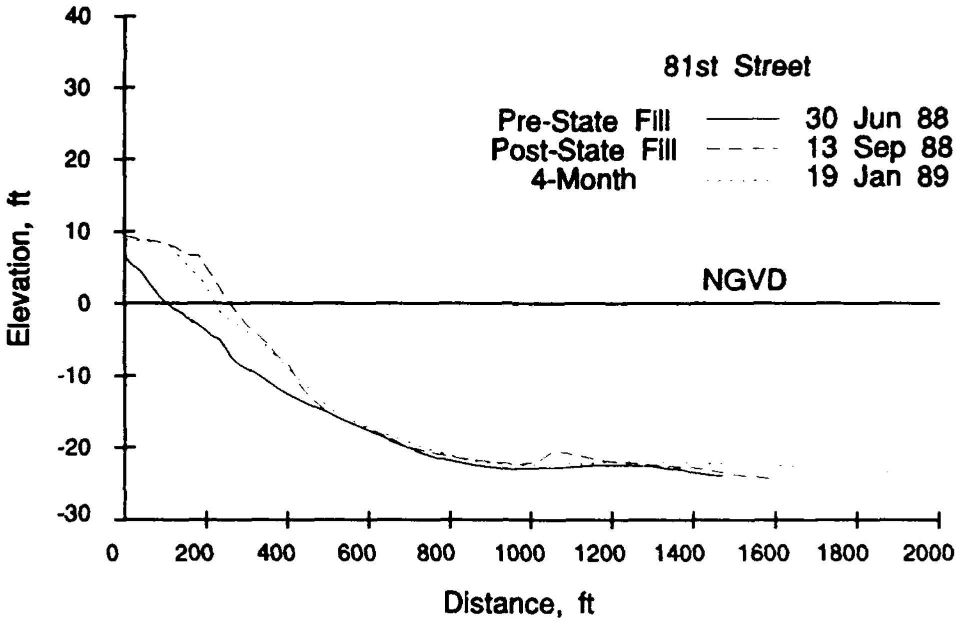


Figure 88. Pre- and post-State fill profile at 81st St. and initial 4-month fill readjustment

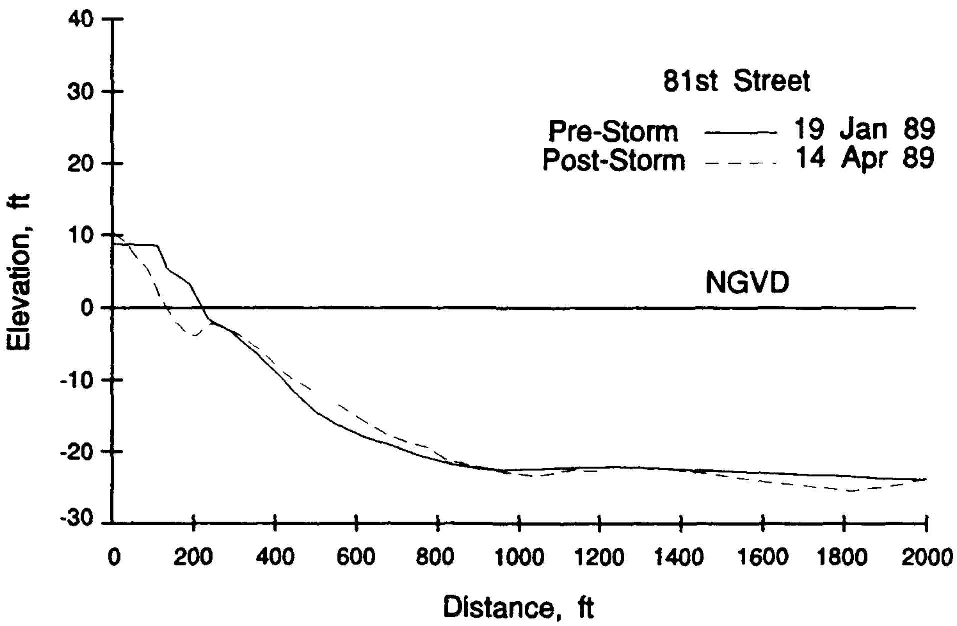


Figure 89. Pre- and post- March 89 storms profile readjustment at 81st St.

the foreshore and 20.2 cu yd/ft deposited on the nearshore. The lowest point in the trough was at the same elevation as the pre-fill planar survey elevation. The level of sand in the outer extent of the survey between 1,000 and 2,000 ft also showed lowering. Between March and June of 1989, the bar migrated landward, filling the trough and forming a more typical planar profile. However, only 1.6 cu yd/ft of sand was deposited above NGVD (Figure 90). The nearshore experienced continued erosion for a net profile deficit of 11.3 cu yd/ft out to 900 ft. Additional infilling of the profile at the outer limits of the survey between 1,800 and 2,000 ft occurred, but volumes were not calculated seaward of 900 ft. This area was located just landward of the shoreface-attached shoal, in 24 ft of water. Over the summer months, the profile changed little with only a small (2.6 cu yd/ft) gain almost evenly across the foreshore and nearshore. The nearshore low-tide terrace re-formed with erosion just below NGVD and just seaward of the low tide terrace. Between September 1989 and June 1990, the profile became planar again, with a net removal of 15.7 cu yd/ft, most of which occurred in the nearshore. The foreshore had little change in shape or elevation. The June 1990 survey only reached to around 900 ft and did not cover the seaward shoreface-attached shoal.

The Federal fill placed 113.7 cu yd/ft during the summer of 1990, which was the largest volume placed on any location for this second fill. The shoreline was also advanced the greatest distance seaward at 196.7 ft (Figure 91). The constructed storm berm was to the design height of 15 ft and was placed 50 ft seaward of the baseline. The fill profile by September 1990 had developed a berm at the +5-ft elevation and had a convex shape to the base of the fill at the 11-ft depth. The survey was steepened and extended out only 400 ft from the baseline. The fill material was reshaped by waves and currents within the first four months, eroding the foreshore and forming a berm at +5 ft landward of the fill berm. The only deposition was measured in the nearshore from the 7- to 15-ft contour at the base of the nearshore slope. The volume of material removed across the profile to 900 ft was 19.4 cu yd/ft.

The more long-term readjustment over the winter months between December 1990 and April 1991 removed the berm crest and portions of the upper berm, forming a planar beach shape again (Figure 92). Little change was observed in the nearshore and shoreface-attached shoal located 2,000 ft offshore. The volume eroded on the subaerial beach was not conserved, and there was a net deficit of 17.1 cu yd/ft along the profile measured to 900 ft. During the spring of 1991 there was little change along the profile, with slight accretion on the foreshore and erosion in the nearshore, for a net loss of 2.7 cu yd/ft.

The 81st Street location was not surveyed during the limited profile collection after the Halloween storm but the profile was surveyed after the 4 January 1992 northeaster. The combined effects of both storms resulted in the erosion of the storm berm and most of the subaerial beach (Figure 93). A ridge and runnel formed on the lower foreshore resulting in the lower foreshore remaining at about the same slope and elevation as before the storm. The deposition of sand occurred evenly across the nearshore out to a depth of 24 ft. The remainder of the nearshore had little change in elevation. More sand was eroded from the berm than deposited in the nearshore, resulting in a net loss of 7.3 cu yd/ft across the profile to 900 ft.

The 81st Street profile survey line was in a very dynamic location. Large amounts of fill material were placed on this area in both the State and Federal projects (Figure 94). However, much of the volume of material placed was eroded from the subaerial beach, as the beach moved toward equilibrium with the prevailing processes. Not all of the sand could be accounted for in the nearshore deposition at this location. Sand removed from this profile location is assumed to

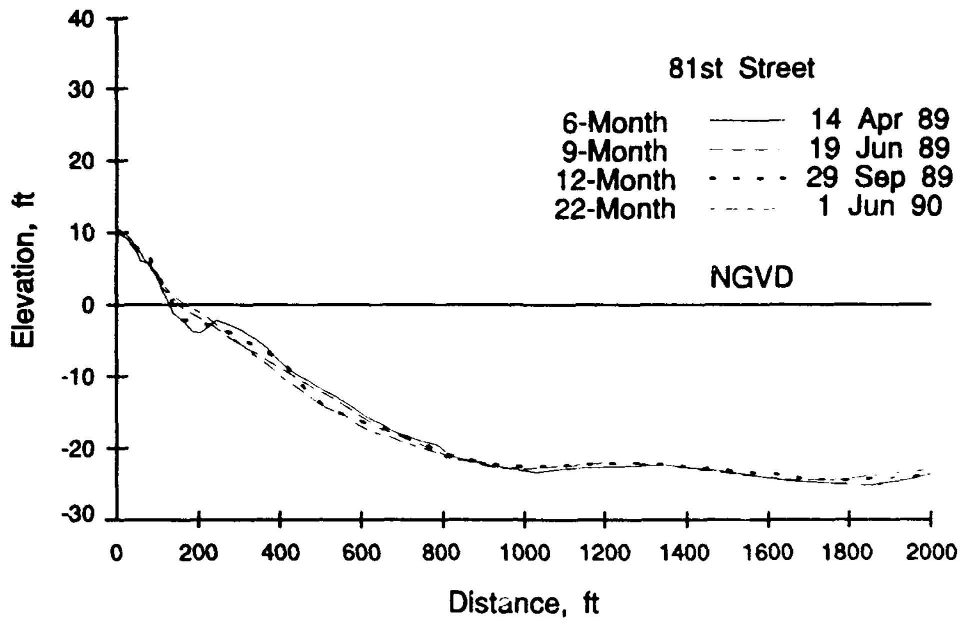


Figure 90. Six- to twenty-two-month performance of State fill at 81st St.

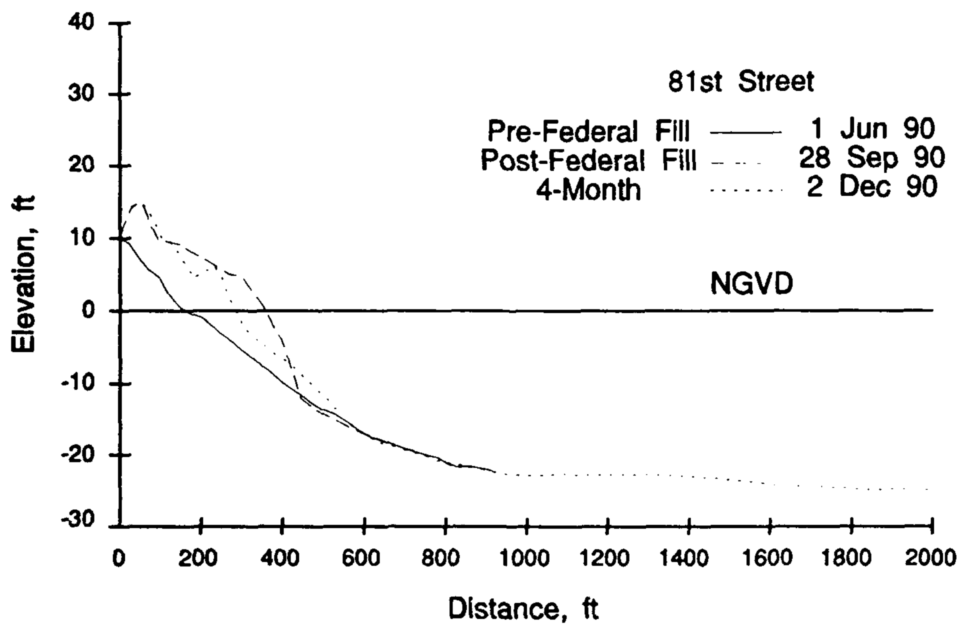


Figure 91. Pre- and post-Federal fill profile at 81st St. and initial 4-month fill readjustment

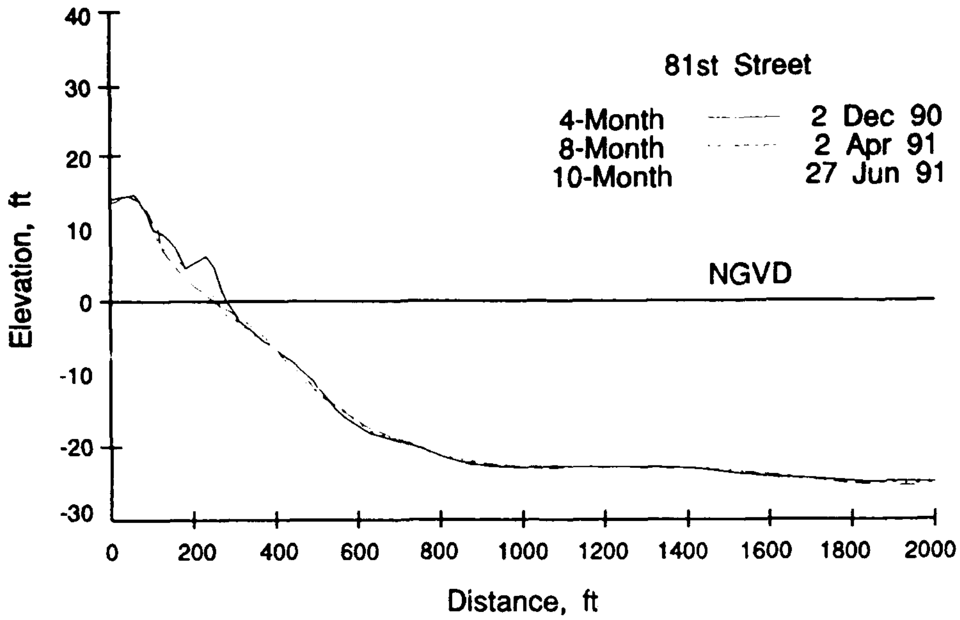


Figure 92. Four- to ten-month Federal fill readjustment at 81st St.

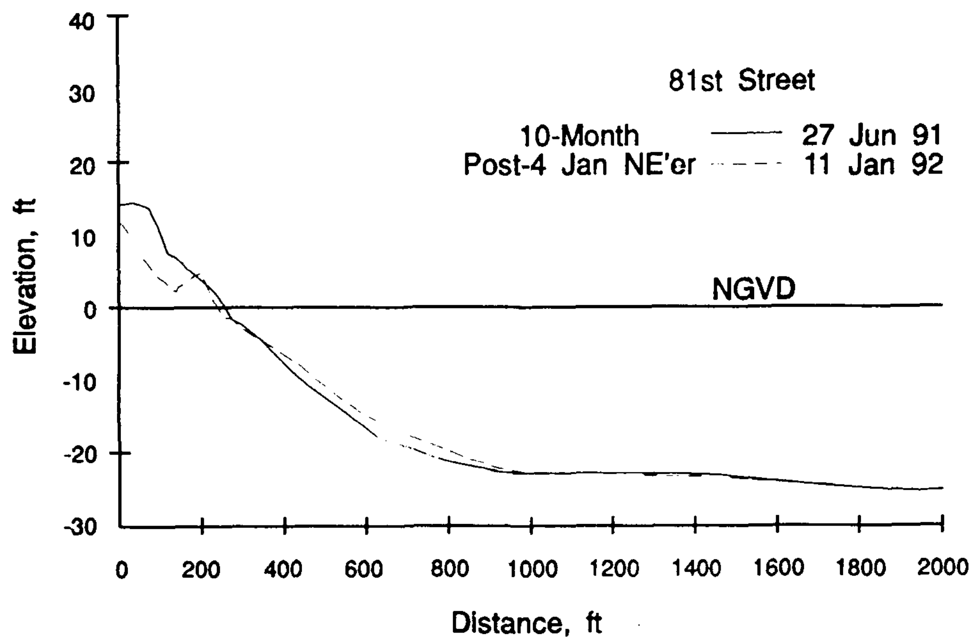


Figure 93. Pre- and post-storms profile readjustment at 81st St.

have moved alongshore to supply other reaches of the beach. The nearshore extending to the shoreface-attached shoal was actively changing volume during the State project. Volume measurements, standardized to 900 ft seaward of the baseline, indicated that 86.8 percent of the fill remained after the March 1989 storms, but only 32 percent was retained on the subaerial beach. Some recovery of sand was measured over the 21-month State fill monitoring period, with a total of 35 percent remaining on the subaerial beach as of June 1990. The profile out to 900 ft retained 64.3 percent of the fill over the monitoring period. The Federal fill monitoring period saw erosion of the new fill material from the subaerial beach with 33.3 percent of that fill retained after the Halloween and January storms (a 16-month monitoring period). The total profile retained 74.6 percent of the Federal fill. This site was prone to erosion, with only 61.1 percent of the State fill volume retained above NGVD as of January 1992. Material eroded off the foreshore was deposited in the nearshore and 126.3 percent of the volume placed during the State fill along the profile was retained as of January 1992.

86th Street

The profile survey location at 86th Street was five blocks north of 81st Street situated behind the shoreface-attached shoal as it trends at 45 deg from the shore. The native beach in this location had a low mound at the street end with an elevation of approximately +13 ft. The pre-fill beach of June 1988 was planar except for a small berm at +4 ft. The fill in the State project was placed against the backshore at elevation +10 ft and extended to a depth of 16 ft, at 500 ft offshore. The large amount of fill placed at this location extended the shoreline 145.8 ft seaward and added 116.1 cu yd/ft of sand to the profile. The post-fill survey had a small berm at +6 ft and a steeper slope to the foreshore (Figure 95). Within the first 4-month period, the foreshore

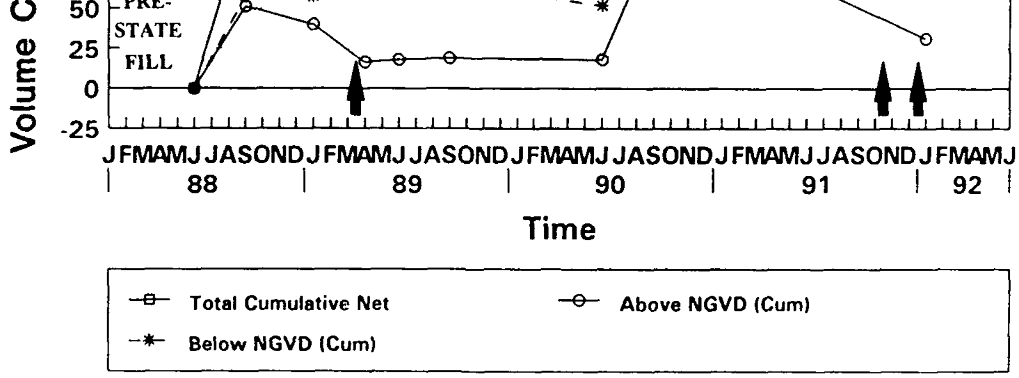


Figure 94. Profile volume change at 81st St.

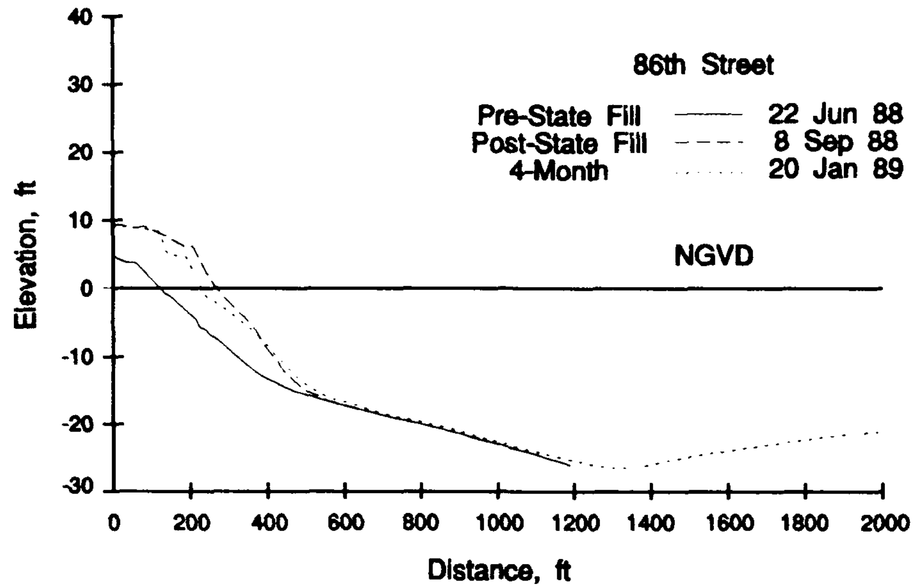


Figure 95. Pre- and post-State fill profile at 86th St. and initial 4-month fill readjustment

eroded, forming a new berm crest at +9 ft and a new secondary berm with a crest at +5 ft, the elevation of the native beach berm crest. Sand was removed down to the 5-ft depth. Only a small area of deposition at the nearshore break in slope was measured at the 15-ft depth contour (located between 400 and 500 ft offshore). The net profile volume eroded by 11.4 cu yd/ft out to 900 ft.

The crest of the shoal was located 2,000 ft offshore with a crest depth of 20 ft. A trough with a depth of 25 ft, located 1,300 ft offshore, separated the shoreface from the shoreface-attached shoal as it trended offshore.

The profile survey response to the March 1989 storms resulted in 29.1 cu yd/ft of the subaerial beach being removed from the base of the backshore to MLW at the 2-ft depth. Accretion occurred in the nearshore between the 7- and 18-ft contours, between 400 and 700 ft offshore. Out to 900 ft, there was a net loss of sand volume of 10.6 cu yd/ft. Lowering of the trough in front of the shoreface-attached shoal was also observed (Figure 96). No appreciable change occurred in the shoal crest. During the spring, accretion was measured on the foreshore with the formation of a berm that had a crest elevation of +6 ft (Figure 97). The nearshore from the 5- to 15-ft depth contour was lowered with the formation of a swash bar at the 2-ft depth contour. A net deficit of 8.2 cu yd/ft was measured to 900 ft. The trough also filled in landward of the shoal, again with little change in crest elevation. Over the summer, sand was deposited on the upper berm and the low tide terrace expanded for a net accretion of 10.8 cu yd/ft over the landward 900 ft of the profile. The trough area 1,300 ft seaward of the baseline also received additional sand. Longer term monitoring over the next 9 months recorded a change in the profile shape from a berm/low tide terrace configuration in September 1989 to a planar profile with no morphologic features in June 1990. The cut and fill of the berm and low-tide terrace resulted

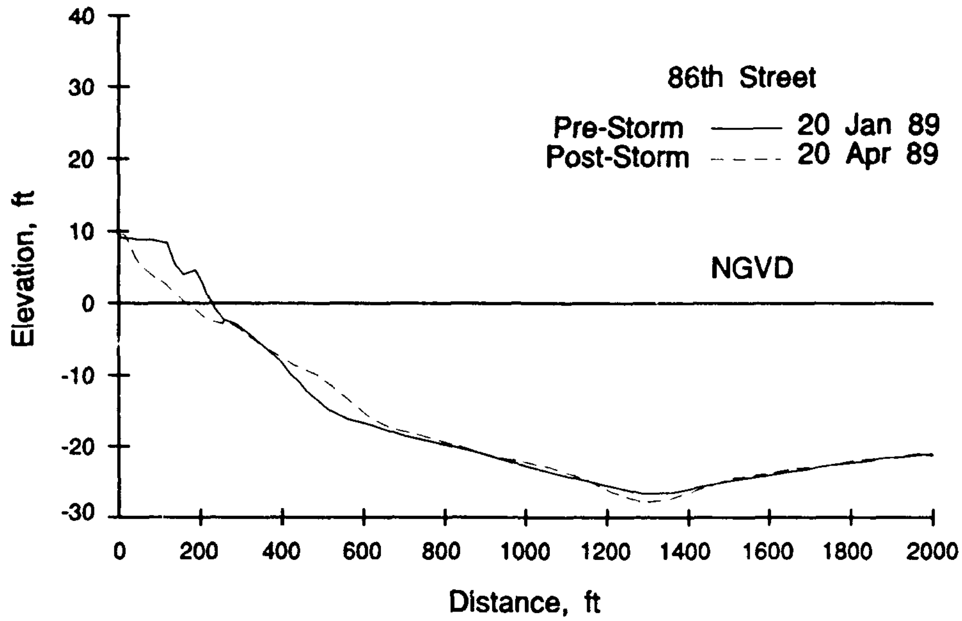


Figure 96. Pre- and post- March 89 storms profile readjustment at 86th St.

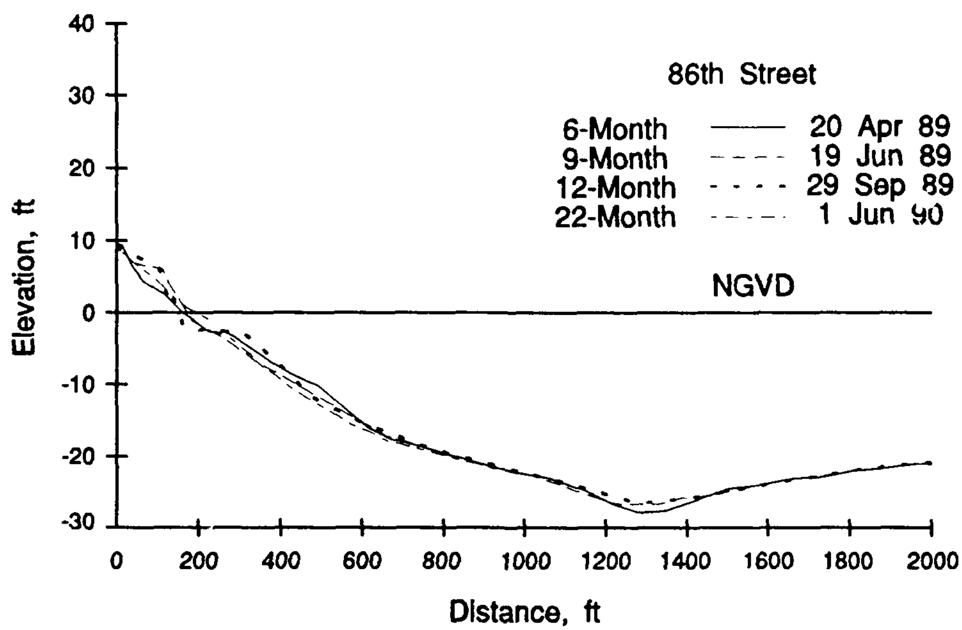


Figure 97. Six- to twenty-two-month performance of State fill at 86th St.

in -2.5 cu yd/ft change above NGVD and -16.9 cu yd/ft below NGVD out to 900 ft. The June 1990 survey did not extend to the shoal.

The Federal fill placed 88.0 cu yd/ft of sand over the June 1990 pre-Federal fill survey. A storm berm was constructed to a height over +15 ft. The convex profile of fill material extended to a depth of 11 ft and extended 400 ft seaward (Figure 98). Initial reshaping of the fill profile within the first 4 months removed sand from the upper berm and foreshore, while forming a berm crest at +5 ft around 300 ft from the baseline. An almost equal volume of fill material was deposited in the nearshore between 400 and 500 ft at a depth of 6 to 15 ft, resulting in a net gain of 0.8 cu yd/ft over the standardized 900-ft profile length. Over the winter months of the first year of the Federal fill, the berm was removed and a more planar beach was produced with slight accretion in the nearshore for a net removal of 11.9 cu yd/ft of sand (Figure 99). These surveys extended over the shoreface-attached shoal and showed a constant elevation of the lower shoreface and trough area. A slight seaward shift occurred over the shoal that extended past the seaward limit of the survey. During the spring a gain of only 0.9 cu yd/ft took place along the 900-ft length of the profile with a slight accretion of sand on the foreshore and an almost equal erosion to the nearshore. Negligible change was measured seaward of 500 ft, with the trough and shoal retaining a constant elevation. The next survey collected at 86th Street was on 11 January 1992. Changes in volume are a result of both the Halloween storm and 4 January 1992 northeaster (Figure 100). The storm berm (dune) was removed with landward transport as overwash. The berm was also eroded down to a ridge and runnel in the lower foreshore between +1 and +4.5 ft in elevation. Deposition occurred in the nearshore from a depth of 2 to 17 ft extending to 500 ft offshore. A net loss of 12.1 cu yd/ft out to 900 ft was measured. Little change was observed in the trough and only a slight erosion can be seen on the shoal landward flank.

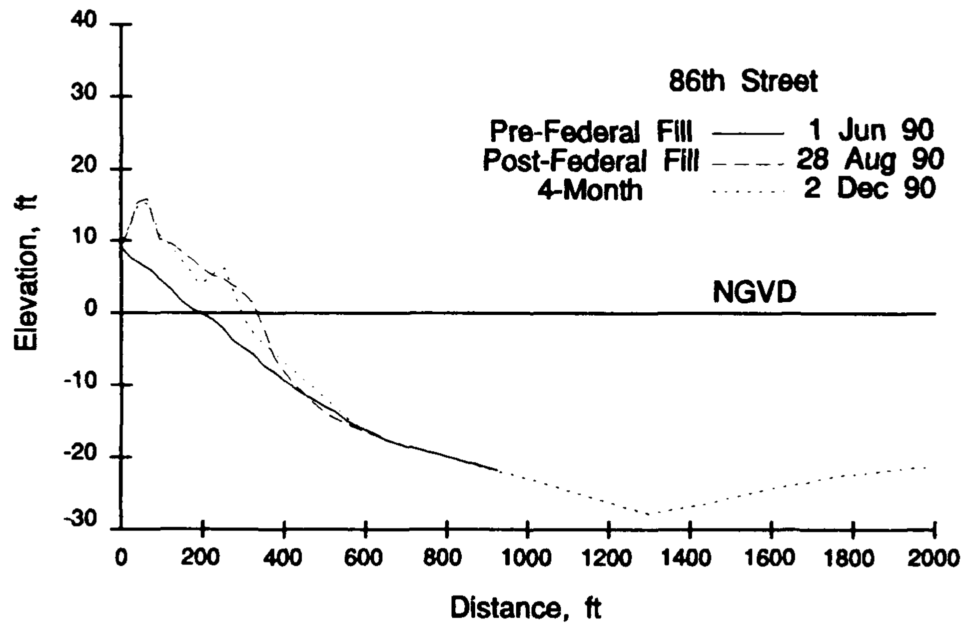


Figure 98. Pre- and post-Federal fill profile at 86th St. and initial 4-month fill readjustment

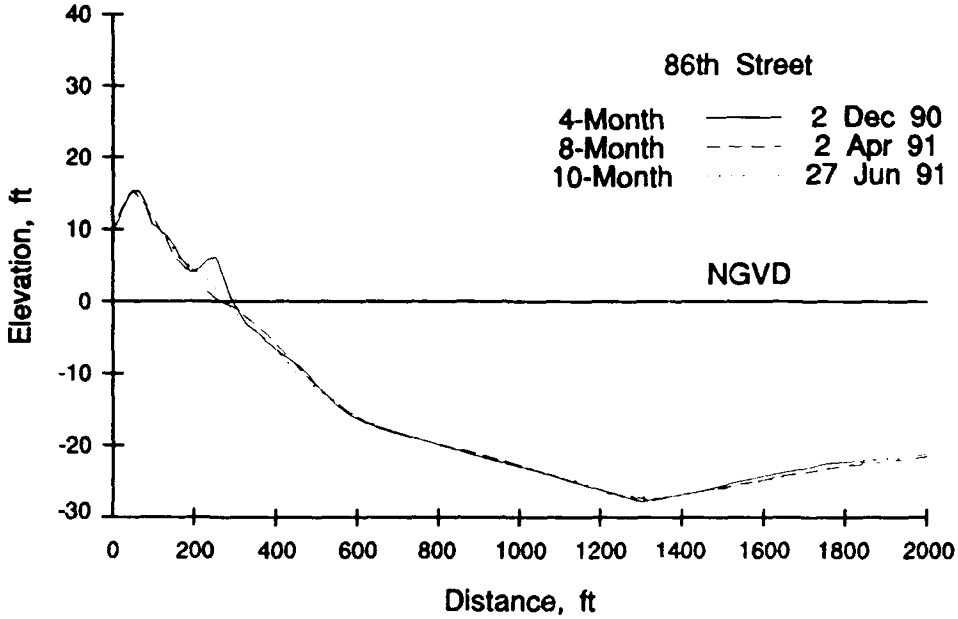


Figure 99. Four- to ten-month Federal fill readjustment at 86th St.

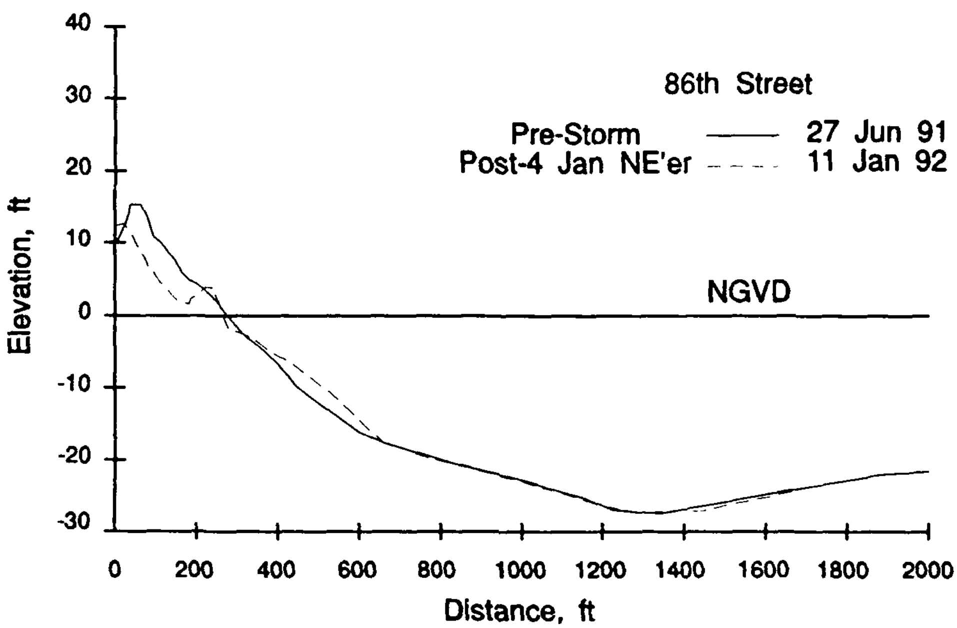


Figure 100. Pre- and Post-storms profile readjustment at 86th St.

At 86th Street, the pattern of erosion above NGVD and deposition below NGVD (Figure 101) indicated that much of both the State and Federal fill material moved into the nearshore. A net deficit of sand across the profile meant that fill material was transported from the vicinity of this survey location. Only 23.4 percent of the fill remained on the subaerial beach after the March 1989 storms, whereas 81 percent of the fill remained on the profile out to 900 ft. At the end of the State fill monitoring, some sand returned to the subaerial beach, with 32.9 percent of the fill volume remaining above NGVD and 66.6 percent of the fill being retained over the profile. The effect of the Halloween and January storms on the Federal fill indicated that the same pattern of subaerial erosion and nearshore accretion occurred. Above NGVD, 46.6 percent of the Federal fill remained after the 17 months of project monitoring, and the total profile to 900 ft contained 86.5 percent of the Federal fill sand. The remaining 13.5 percent of the fill was transported off the profile, presumably alongshore. From the long profiles that extended over the shoreface, through the trough, and onto the shoreface-attached shoal, there was little evidence of major change in elevation or position of these features over the monitoring period. Long-term monitoring indicated that 71.2 percent of the State fill volume was retained above NGVD as of January 1992. The profile to 900 ft retained 123.1 percent of the volume placed on the State fill.

92nd Street

The survey line located at 92nd Street was at the northern end of the shoreface-attached shoal. The crest of the shoal trended away from the shore at this point and extended past the seaward limit of this profile survey. The shoal crest was located around 2,000 ft seaward of the baseline on the 86th Street location, while the profile was still rising at 92nd Street at 2,500 ft. The trough was located at about 1,800 ft as compared with 86th Street, where the trough was about 1,400 ft seaward of the baseline. The original numbering scheme designated this as Line 26,

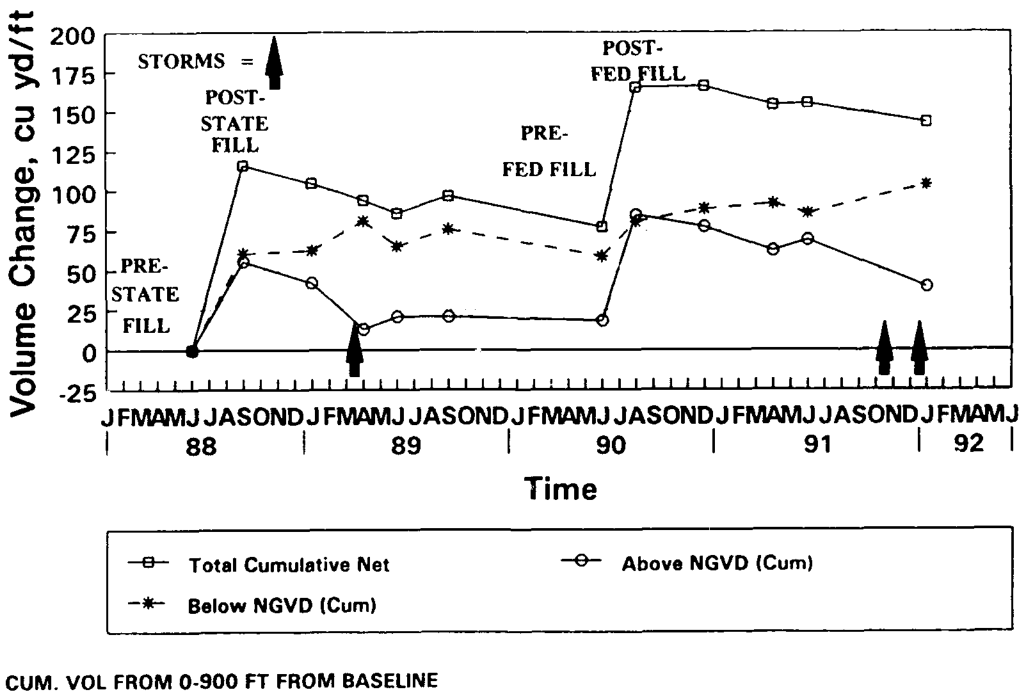


Figure 101. Profile volume change at 86th St.

which was renumbered as Line 30. The native profile surveyed in June 1988 contained a dune with a crest elevation of +15 ft, which was located 25 ft landward of the baseline. The survey showed a planar shape with no nearshore bar or trough. The State fill placed 69.1 cu yd/ft of sand between the dune base at +8 ft and the nearshore at the 14-ft depth (Figure 102). The fill profile had a convex shape and advanced the shoreline 109.4 ft seaward. Only minor changes in volume were measured during the initial readjustment of the profile as of January 1989, with a gain of 13.8 cu yd/ft on the entire profile out to 900 ft. The subaerial beach and nearshore both had areas of deposition, indicating that the fill was not out of equilibrium with the prevailing processes. A slight berm was created at +5 ft.

The March 1989 storms eroded most of the berm and foreshore, with some minor deposition occurring at the base of the dune (Figure 103). The convex pre-storm profile was replaced by a more planar foreshore profile shape with a small berm at the +5-ft elevation. Erosion volume of 24.3 cu yd/ft was measured above NGVD, with a deposition of only 9.5 cu yd/ft in the nearshore between the 5- and 15-ft depth contours. Little change was seen in the survey seaward of the 20-ft depth contour before and after the storms within the trough and shoreface-attached shoal's landward flank.

Spring recovery consisted of landward migration of the nearshore sand to form a new berm with a crest elevation at +6 ft by June 1989 (Figure 104). The above-NGVD accretion totaled 10.86 cu yd/ft. The nearshore eroded from the swash zone around NGVD to the 10-ft depth (500 ft offshore), with a below-NGVD volume loss of 14.2 cu yd/ft to 900 ft. A small swash bar was observed in the 2-ft depth or MLW area, with a net profile volume loss of 3.3 cu yd/ft. The September 1989 survey measured summer changes of a small (4.6 cu yd/ft) additional accretion on the subaerial beach and a shift of the swash bar into a low tide terrace. An additional 13.2 cu yd/ft of sand accreted in the nearshore. Little change was measured on the

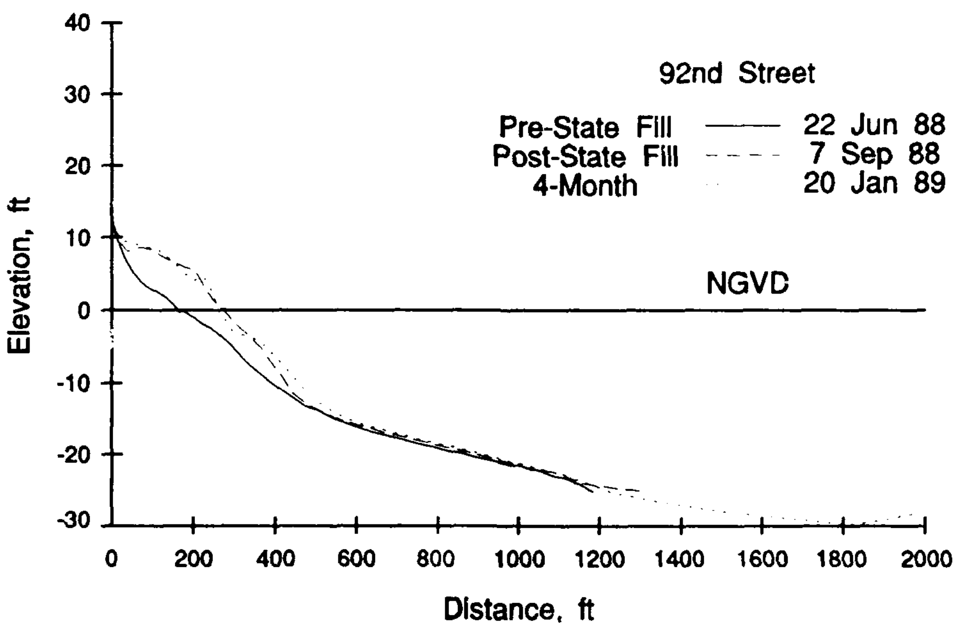


Figure 102. Pre- and post-State fill profile at 92nd St. and initial 4-month fill readjustment

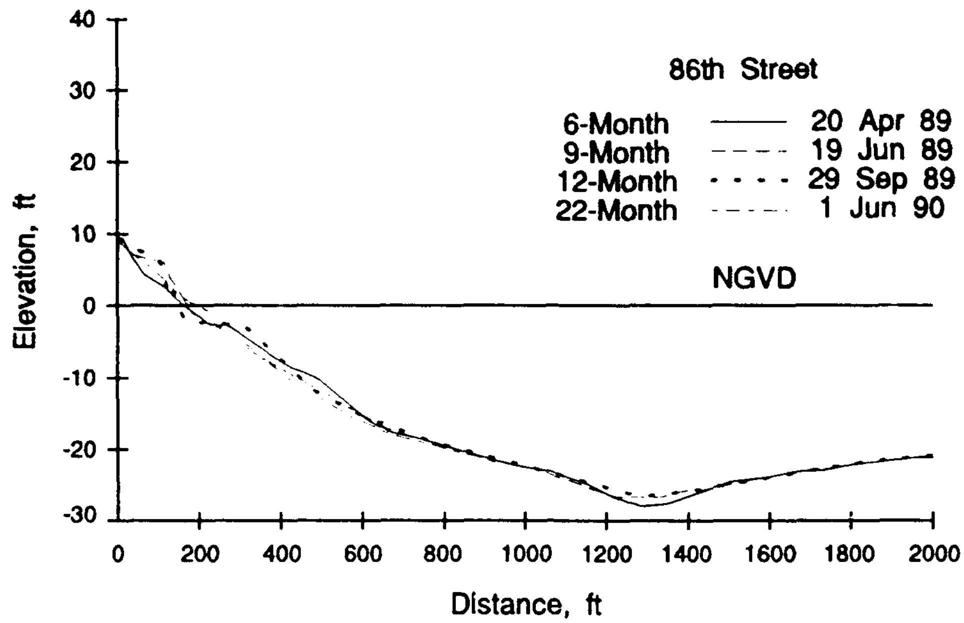


Figure 103. Pre- and post- March 89 storms profile readjustment at 92nd St.

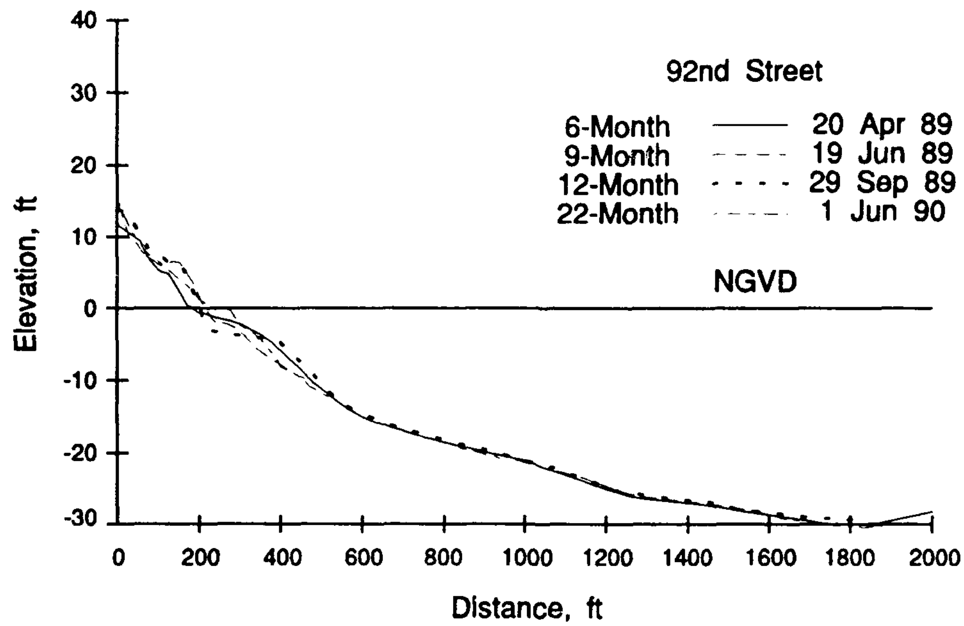


Figure 104. Six- to twenty-two-month performance of State fill at 92nd St.

lower nearshore shoreface, trough, or landward side of the shoal. The longer-term response to June 1990 indicated that the profile returned to a planar shape, smoothing out the berm and low tide terrace of the previous September. An equal net loss of sand volume was measured both above and below NGVD, for a net loss of 11.8 cu yd/ft of beach. No assessment of the offshore shoal could be made since the June 1990 survey only reached seaward 1,000 ft.

Only a minimum amount of fill was added at 92nd Street during the Federal fill, totaling 43.8 cu yd/ft over the profile to 900 ft. A small storm berm (dune) was constructed 50 ft seaward of the baseline, with an elevation of +15 ft, which was the same elevation as the native dune. A fill volume of 41.1 cu yd/ft was placed on the subaerial portion of the profile. Little fill material was placed in the nearshore and only extended to a depth of 5 ft at 400 ft from the baseline (Figure 105). Over the first 4 months of the Federal fill monitoring, this profile gained an additional 20.1 cu yd/ft of sand, adding volume on a berm crest that formed at the +5-ft elevation, 350 ft seaward of the baseline. Additional accretion extended across the foreshore into the nearshore to a depth of 15 ft, ending 500 ft offshore. The December 1990 survey was too short to assess any change on the shoal flank.

Continued monitoring over the winter months indicated that there was little change in profile volume from December 1990 to April 1991. The berm on the December survey was removed by April with a loss of 9.7 cu yd/ft (Figure 106). The profile became planar with slight accretion along the nearshore portion of the profile of 4.1 cu yd/ft. Spring changes resulted in removal of a thin layer of sand from the storm berm base to the 15-ft depth for a total of 29.2 cu yd/ft removed over the profile to 900 ft by June 1991. Ninety-second Street was not surveyed after the Halloween storm, but was monitored after the 4 January 1992 storm. Figure 107 shows the pattern of erosion of the front face of the storm berm dune, berm and upper foreshore. The protective storm berm was not completely eroded at this location as was the case at many of the profile survey locations. A total of 12.7 cu yd/ft was eroded above NGVD. A swash bar was present on the 11 January 1992 survey, indicating landward transport of sand had begun. A large volume of sand was deposited in the nearshore, totaling 65.7 cu yd/ft. This large volume of sand in the vicinity of 92nd Street suggests that the nearshore is a depository of sediment transport from other areas. Little change in profile elevation or volume was measured seaward of the 20-ft depth contour, located at 900 ft from the baseline. These pre- and post-storm surveys did not reach the offshore shoal flank, so no assessment of change can be made seaward of the survey limits.

The summary of volume change at 92nd Street indicated that only a small amount of sand was placed on this profile in both the State and Federal portions of the project (Figure 108), as compared with other survey locations. After the March 1989 storms, 43.1 percent of the fill material remained on the above NGVD portion of the profile. In measuring the volume change over the 900 ft of comparable profile length after the storms, 98.5 percent of the fill could be accounted for. For the entire State fill monitoring, ending in June 1990, 68.7 percent of the fill volume was above-NGVD, indicating return of sand to the subaerial beach. The nearshore apparently was a sink for sand from surrounding areas since 102.5 percent of the fill volume was found comparing the volume along the 900-ft profile length. Similar retention of the Federal fill was also observed. After the 4 January 1992 storm, 61.7 percent of the new fill volume was still above NGVD, and a surprising 133.4 percent of the Federal fill volume was found on the 900-ft profile length, again located mostly in the nearshore below NGVD. Long-term monitoring indicated that this profile was a depositional site with 109.3 percent of the State fill volume retained above NGVD. The large volume of nearshore deposition resulted in 221.3 percent of

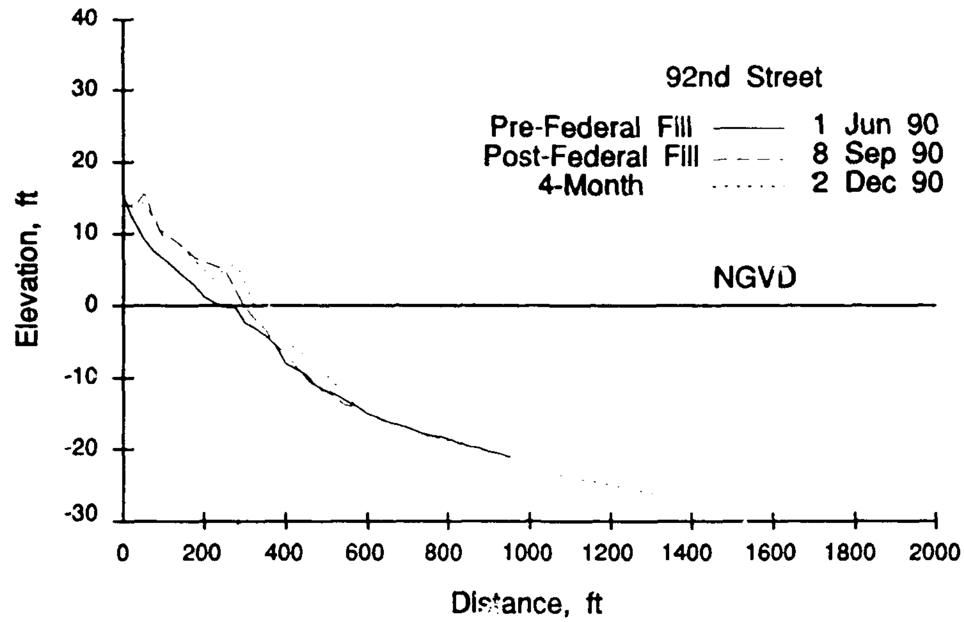


Figure 105. Pre- and post-Federal fill profile at 92nd St. and initial 4-month fill readjustment

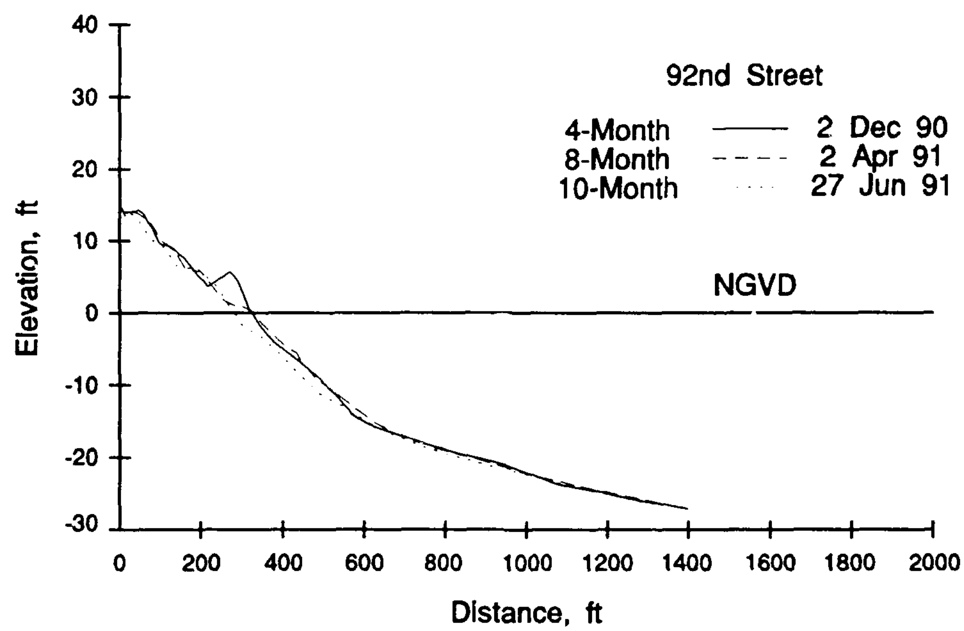


Figure 106. Four- to ten-month Federal fill readjustment at 92nd St.

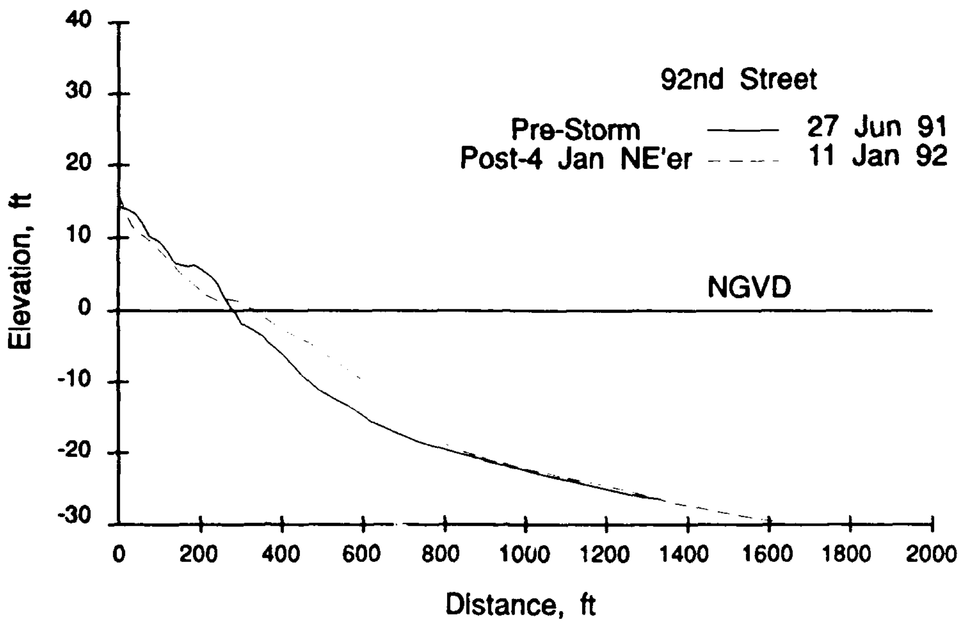
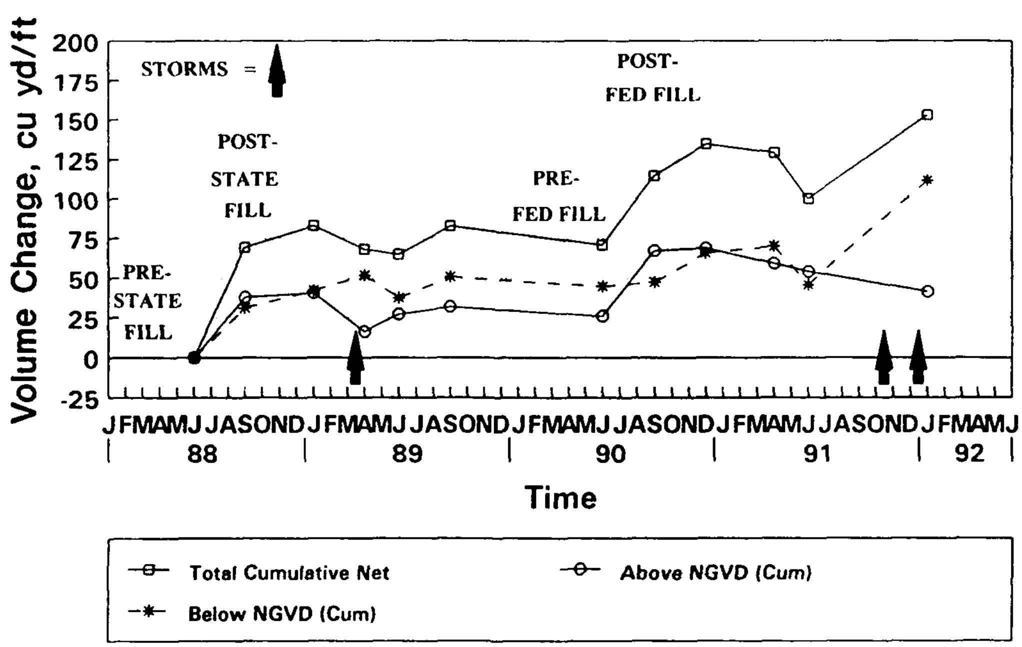


Figure 107. Pre- and post-storms profile readjustment at 92nd St.



CUM. VOL FROM 0-900 FT FROM BASELINE

Figure 108. Profile volume change at 92nd St.

the original State fill volume placed along this profile being retained along the profile out to 900 ft.

103rd Street

The most northward survey line location in the monitoring program is located within a stretch of beach backed by large condominiums and hotels. The street ends were replaced by narrow public access walkways with no street numbers. Line 28 is located in the approximate vicinity of where 103rd Street would be if the streets were continuous. This location was renumbered as Line 32 in the new numbering scheme. The shoreface-attached shoal is located around 3,000 ft offshore, well beyond the seaward limit of the surveys at this location. The native beach had a dune height of +14 ft, with the dune crest located 20 ft landward of the baseline. This pre-fill survey was planar except for a small berm crest at +4.5 ft, located 100 ft seaward of the baseline. The State fill was placed from an elevation of +9 ft on the front face of the dune to the 9-ft depth contour (Figure 109). This post fill survey showed that the shoreline extended only 64 ft seaward, and the nearshore portion of the fill was only 350 ft seaward of the baseline. This was the second smallest volume placed on a profile line during the State fill at 38.9 cu yd/ft. After 4 months had elapsed, a small amount of the berm (4.2 cu yd/ft) eroded, forming a new berm crest at the same elevation as on the native beach. A small area of accretion was located between the 5- and 15-ft depths in the nearshore and gained 10.4 cu yd/ft, for a net 900-ft-length gain of 6.2 cu yd/ft.

After the March storms, the berm crest was cut back 60 ft with a loss of 14 cu yd/ft of sand above NGVD (Figure 110). The area between NGVD and the 9-ft depth contour remained at the same elevation as the pre-storm survey. Accretion occurred on the lower nearshore from a depth of 10 to 23 ft, for a net profile gain out to 900 ft of 11.2 cu yd/ft. Little elevation change was noted in the area from 1,000 to 2,000 ft offshore. Again, additional sand had been deposited in the nearshore. Post-storm recovery during the spring, up until June 1989, was observed with the formation of a berm. This berm had a crest at +6 ft and gained 4.8 cu yd/ft above NGVD (Figure 111). Part of the storm accretion in the nearshore was removed between NGVD and the 15-ft depth, for a net profile loss of 11.9 cu yd/ft. There was some gain in sand on the lower nearshore between the 16- and 25-ft depth contours, 700 to 1,200 ft from the baseline. By October 1989, the berm was reduced by 3.8 cu yd/ft and moved up the profile to a new crest elevation of +8.5 ft. Some of the sand was moved into the nearshore just below NGVD and extended to the 10-ft depth contour. A second accretionary area was located on the lower nearshore between the 20- and 25-ft depth contours. Out to the limit of 900 ft, the profile gained 18.1 cu yd/ft. The long-term volume change between October 1989 and June 1990 was a loss of 30.5 cu yd/ft along the 900-ft length. A new berm had formed further down the dry beach with the crest at the +5-ft elevation extending to NGVD with a gain of 6.8 cu yd/ft. The nearshore between NGVD and the 20-ft depth eroded, resulting in a loss of 37.5 cu yd/ft.

The post-Federal fill survey showed the construction of the storm berm dune at the +15-ft elevation 50 ft seaward of the baseline. The convex-shaped profile had a berm crest at +4 ft and fill material extending 400 ft seaward to a depth of 15 ft (Figure 112). In contrast to the minimal fill volume placed during the State fill, the second largest volume of fill placed during the Federal fill was located at 103rd Street, extending the shoreline seaward 129.5 ft with a volume of 104.6 cu yd/ft. The initial readjustment at this location during the first 4 months after the Federal fill placement was dramatic with about half of the fill volume (55.3 cu yd/ft) removed

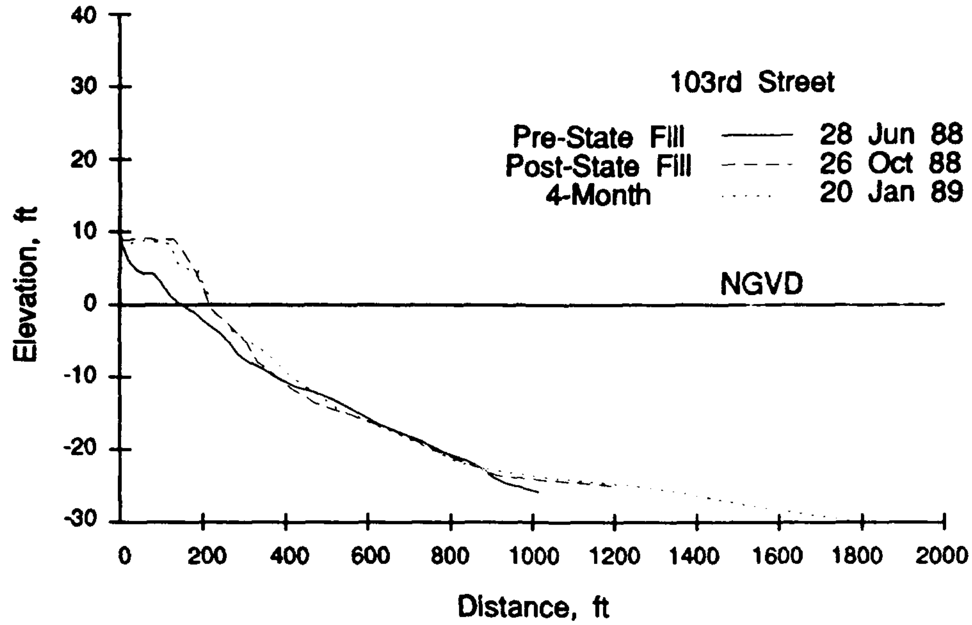


Figure 109. Pre- and post-State fill profile at 103rd St. and initial 4-month fill readjustment

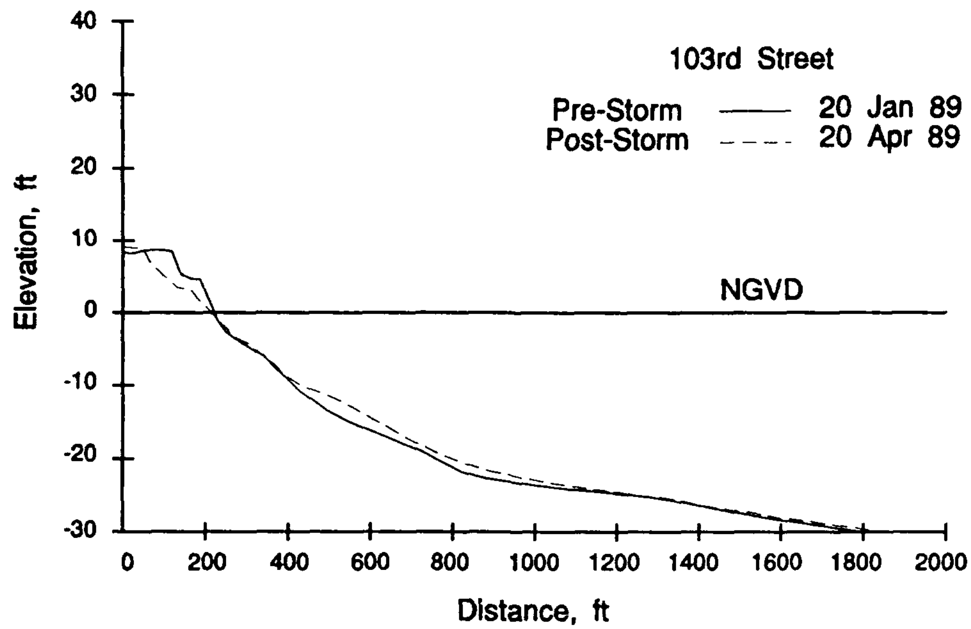


Figure 110. Pre- and post- March 89 storms profile readjustment at 103rd St.

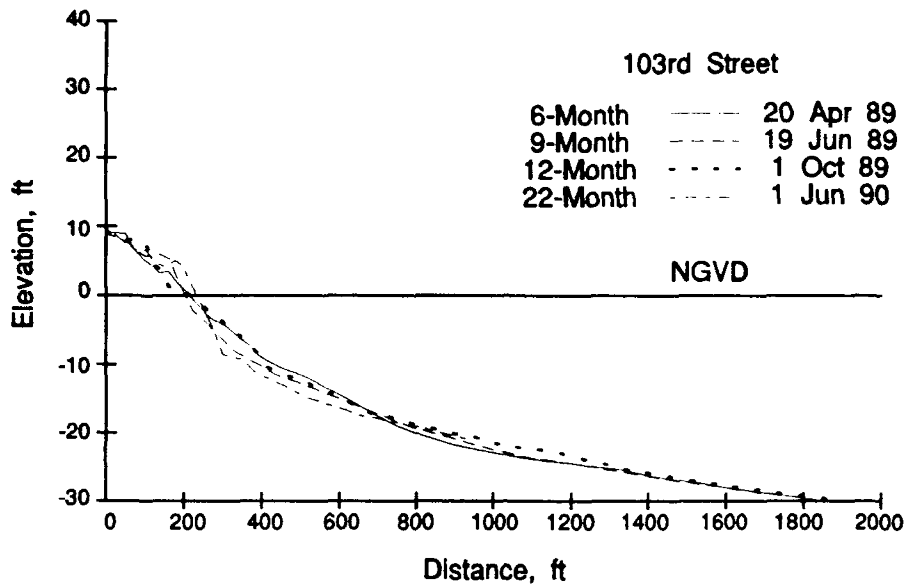


Figure 111. Six- to twenty-two-month performance of State fill at 103rd St.

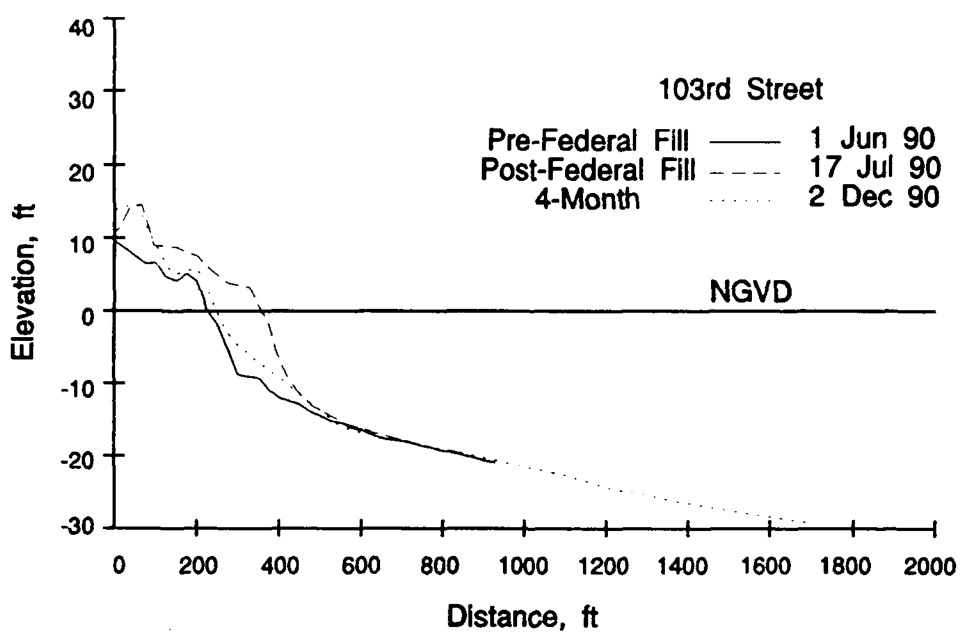


Figure 112. Pre- and post-Federal fill profile at 103rd St. and initial 4-month fill readjustment

from the profile. Erosion was measured from the dune base to the 10-ft depth contour. The foreshore was almost back to the pre-fill June 1990 profile elevation. A berm was formed at the +6-ft elevation, but there was no deposition in the nearshore zone. The sand removed from the foreshore was transported out of the vicinity of the profile.

After the initial post-fill profile adjustment, minimal changes were measured. Over the winter months the berm was removed causing a volume change of -11.8 cu yd/ft above NGVD by the April 1991 survey (Figure 113). Deposition of 7.6 cu yd/ft occurred over a thin layer across the nearshore from NGVD to the 20-ft depth, but the net profile lost 4.3 cu yd/ft. As of June 1991, 2.5 cu yd/ft was deposited back on the foreshore, but a net loss of 4.6 cu yd/ft was measured across the 900-ft length of the profile.

A survey was taken at this location after the Halloween storm and showed accretion at the dune base and erosion on the remainder of the above-NGVD survey, for almost no net change (only +0.9 cu yd/ft). A low-tide terrace was formed at NGVD, and a large volume of accretion (49.3 cu yd/ft) appeared out to the 17-ft depth contour, 600 ft from the baseline (Figure 114). The excess sand deposited on the nearshore gave a total of 50.2 cu yd/ft deposited to 900 ft. As at 92nd Street, this sand was presumably transported onto the profile from alongshore sources. The impact of the 4 January 1992 storm was recorded by a profile survey made on 11 January 1992. The storm berm dune was partially removed in this location, and was moved toward the street end by landward sand transport. The berm was eroded by 9 cu yd/ft down to a ridge and runnel on the foreshore at the +4-ft elevation. Deposition of 28.4 cu yd/ft occurred on the lower foreshore and nearshore, but the main deposition was more seaward than from the Halloween storm. The profile gained 19.5 cu yd/ft, with in excess of 28.4 cu yd/ft of sand being deposited in the nearshore to a depth of 25 ft, some 1,500 ft offshore.

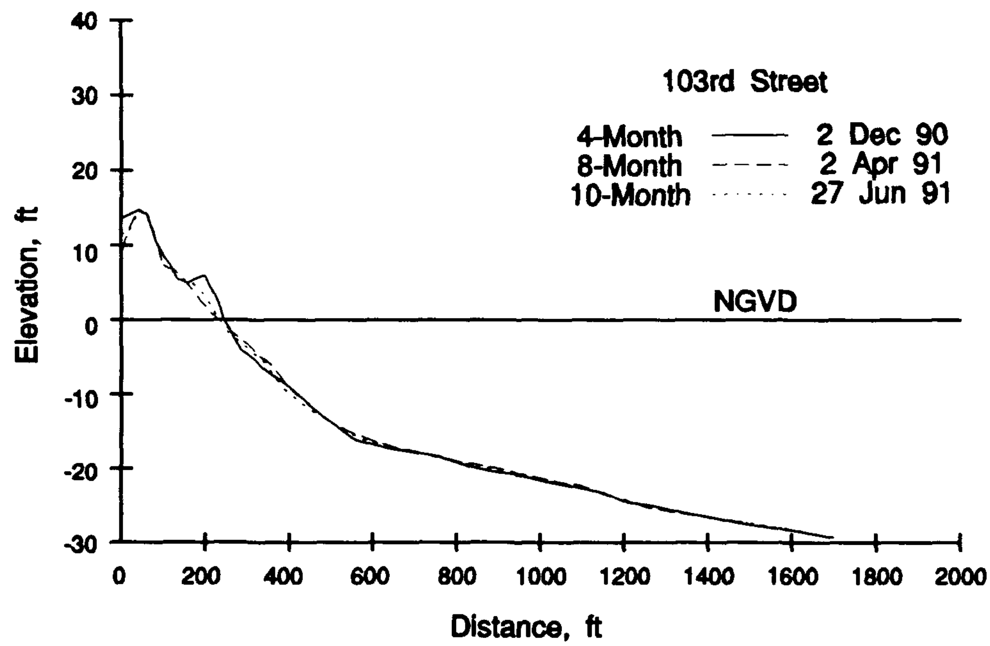


Figure 113. Four- to ten-month Federal fill readjustment at 103rd St.

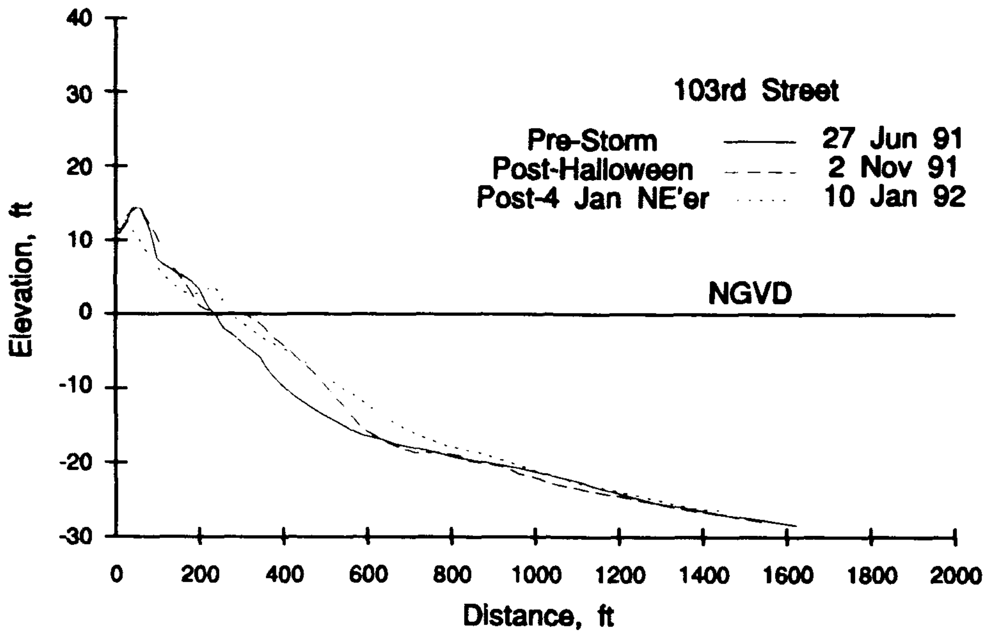


Figure 114. Pre- and post-storms profile readjustment at 103rd St.

The volume change at 103rd Street during the State fill monitoring period reflects the small amount of fill volume placed on this beach. In spite of the small fill, the profile shape gained sand over the first 4 months (Figure 115). As the above-NGVD fill volumes decreased, the nearshore steadily gained sand as a result of fill readjustment and the impacts of the storms in March 1989. Fifty-two percent of the fill remained on the subaerial beach after the storms, and 144.8 percent of the fill volume was found along the profile out to 900 ft. The source of this sand deposited in the nearshore came from a small amount of fill placed below NGVD, but most of the new volume on the survey after the storms was deposited onto the profile line by longshore transport. At the end of the State fill monitoring period, 72.6 percent of the fill volume was retained as sand returned to the subaerial beach. During the same time period, the nearshore lost volume but over the 900-ft profile length, 82.3 percent of the fill volume was still present. In contrast to the State fill, the third largest volume of fill placed along the 12 study locations was placed at the 103rd Street location during the Federal fill. Monitoring after the two storms as of January 1992, indicated that 47.5 percent of the new fill remained above NGVD. Over the length of 900 ft, 104 percent of the fill volume could be accounted for, reflecting the influx of sand into the nearshore portion of the profile in response to fill readjustment and more directly due to storm-induced deposition. Again some of this excess volume most likely came from alongshore sources outside the immediate survey area. Over the entire study period, the 103rd Street profile retained 100.3 percent of the State fill volume above NGVD. With the influx of excess sand in the nearshore as of January 1992, 365.1 percent of the State fill volume was measured along the 900-ft length at this site.

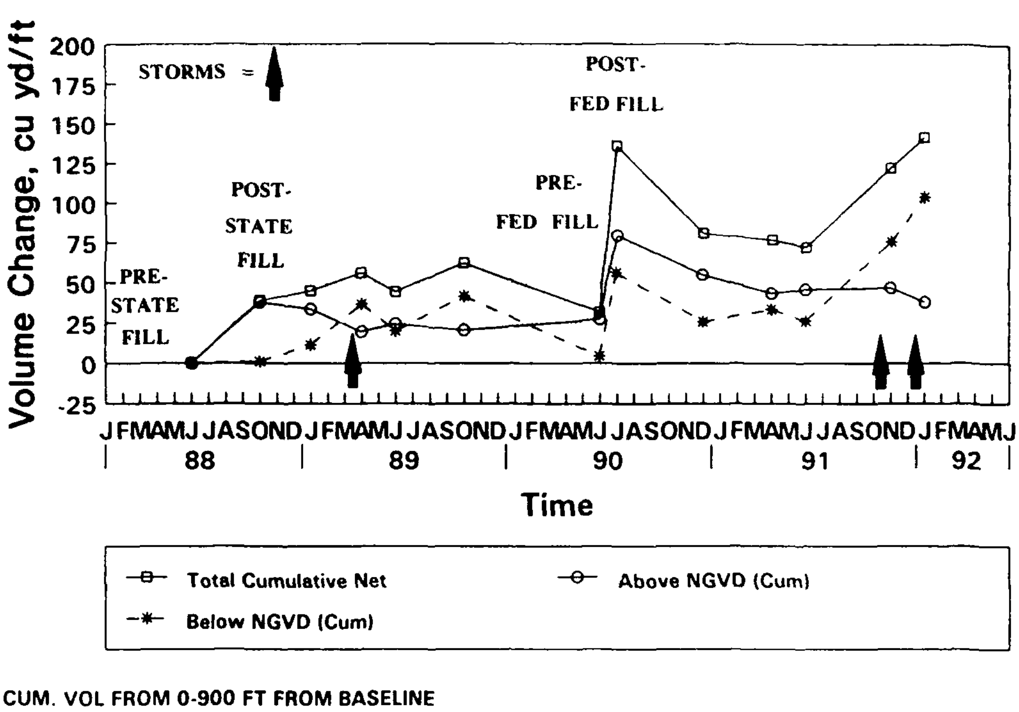


Figure 115. Profile volume change at 103rd St.

Grain Size Change

Six profile survey lines located at 37th, 56th, 66th, 81st, 92nd, and 103rd Streets, were designated sediment sampling sites for this report. Sediment grab samples were collected during the beach profile survey at these locations for the June 1988 pre-State fill and September 1988 post-State fill surveys and the first three State fill monitoring surveys of January, April, and June 1989 (Table 6). Sediment samples were collected at various other profile sites during the State fill monitoring, but collection was not on a regular basis and the number of samples collected during any given survey was not consistent. The data for the six lines listed above were complete, and the analysis for this report will focus on these lines, which adequately cover the 3.7 miles of the study area.

Figures 116 through 121 show the sediment sample locations on the six profiles through the State fill monitoring time period. During the pre-fill survey of June 1988, surface grab samples were collected at 12 to 17 locations along each profile survey line at the dune face, dune base, berm, foreshore, step, nearshore trough, nearshore bar, and at the 5-, 10-, 15-, 20-, and 25-ft depths referenced to NGVD. The subaqueous samples were collected with an Ekman clamshell sampler. Between 9 and 11 samples were collected during the post-fill surveys of September 1988 and covered the dune, berm, foreshore, and nearshore area. Beginning with the January 1989 sample collection, the sediment sample set was standardized at 11 surface grab sample locations collected at the: dune base, berm crest, mid-tide, swash, nearshore trough, bar crest, and 5-, 10-, 15-, 20-, and 25-ft depth contours. State fill sediment sample monitoring also included the post-storm April 1989 survey and the 9-month June 1989 survey. Samples collected for the June 1989 survey were not analyzed on Lines 19/18 and 21. Sediment collection was

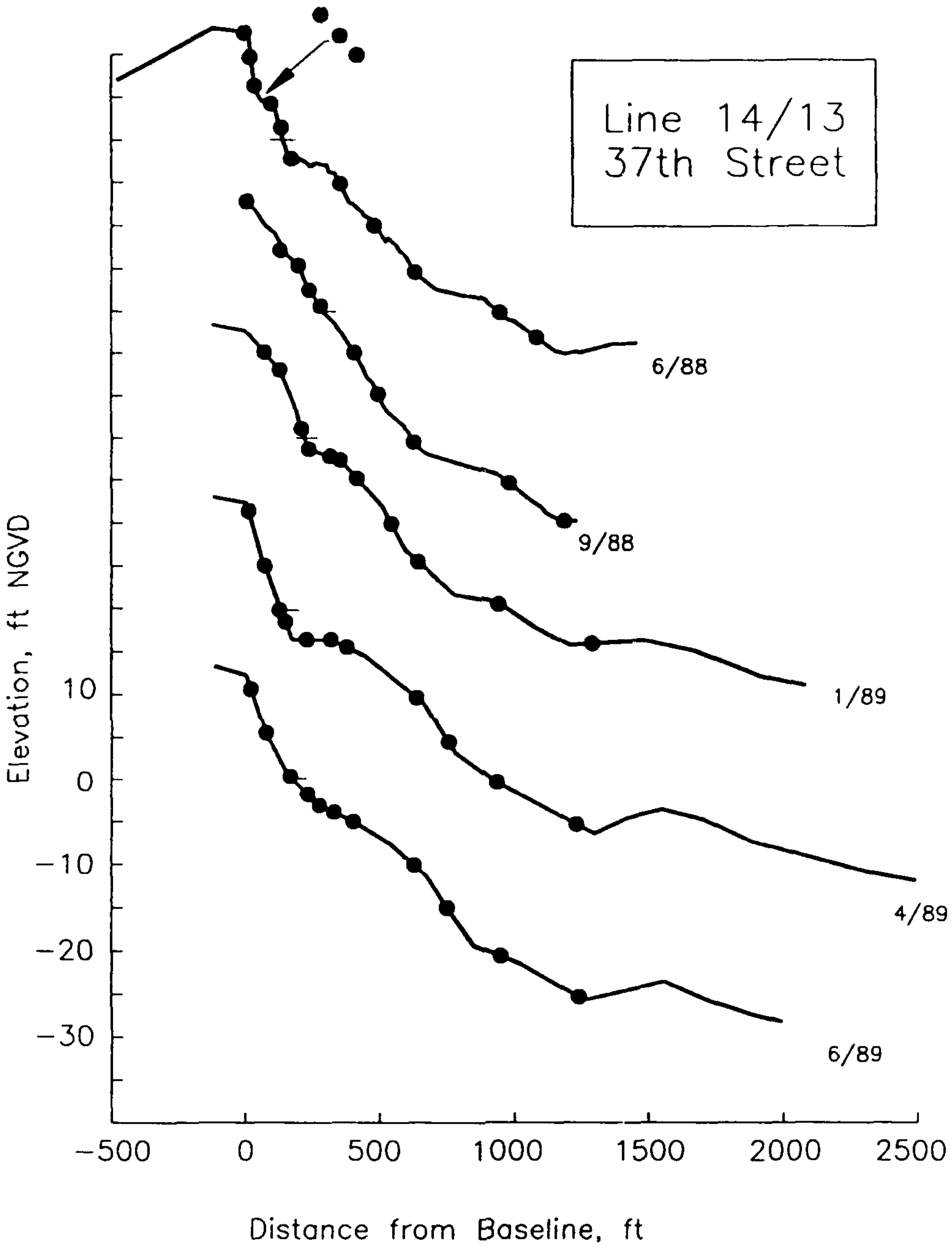


Figure 116. Sediment sample locations on profile line at 37th St. collected during State fill monitoring

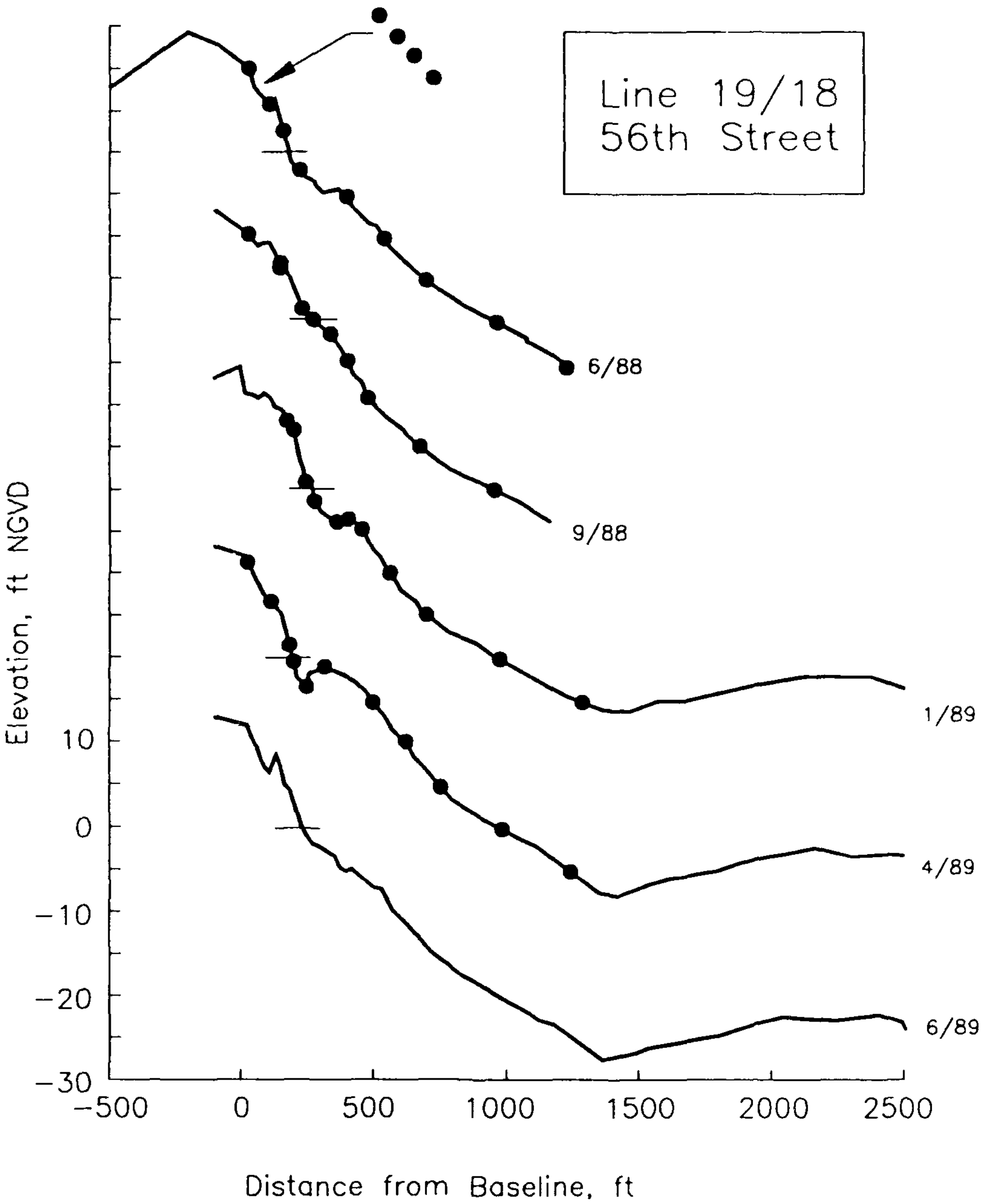


Figure 117. Sediment sample locations on profile line at 56th St. collected during State fill monitoring

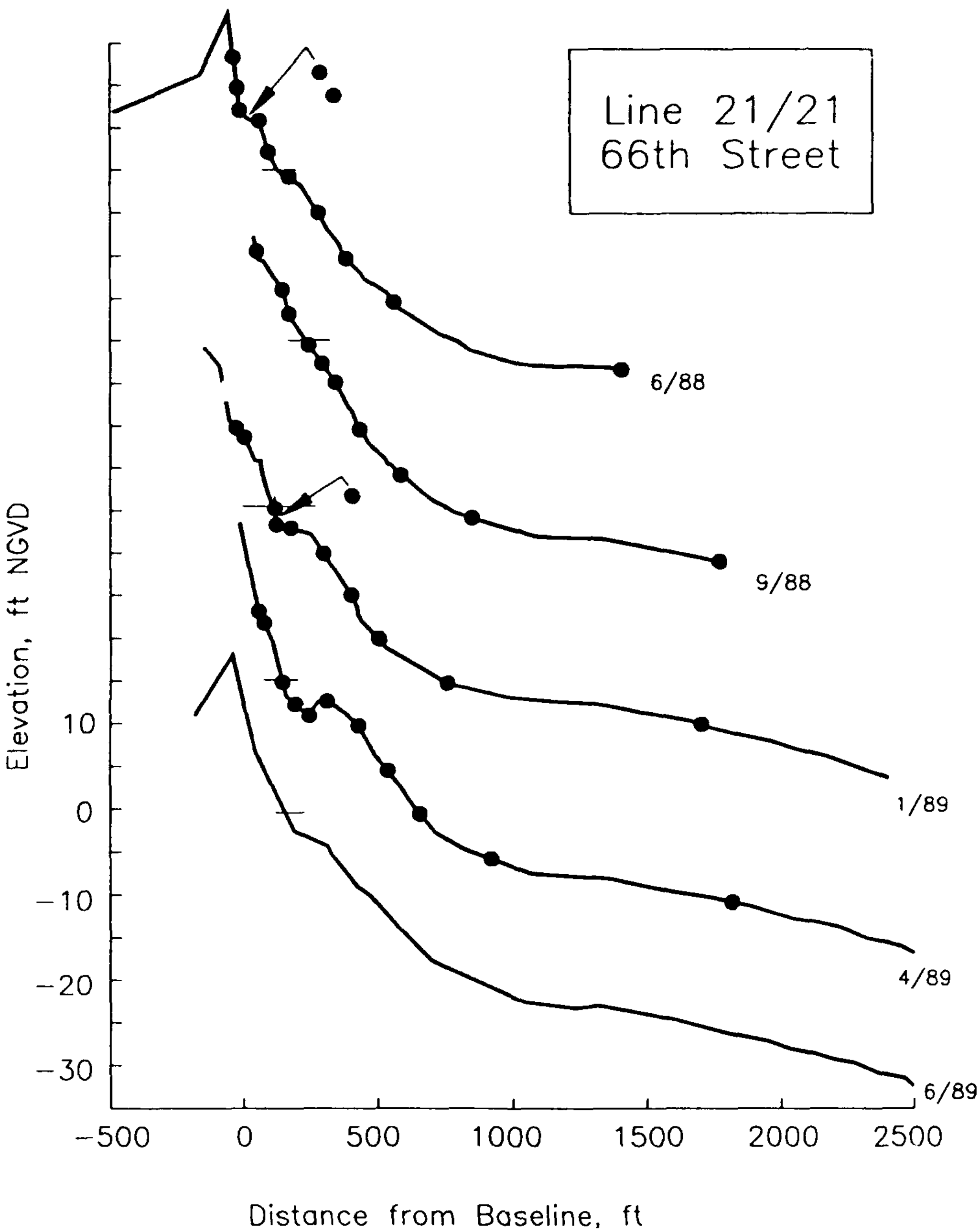


Figure 118. Sediment sample locations on profile line at 66th St. collected during State fill monitoring

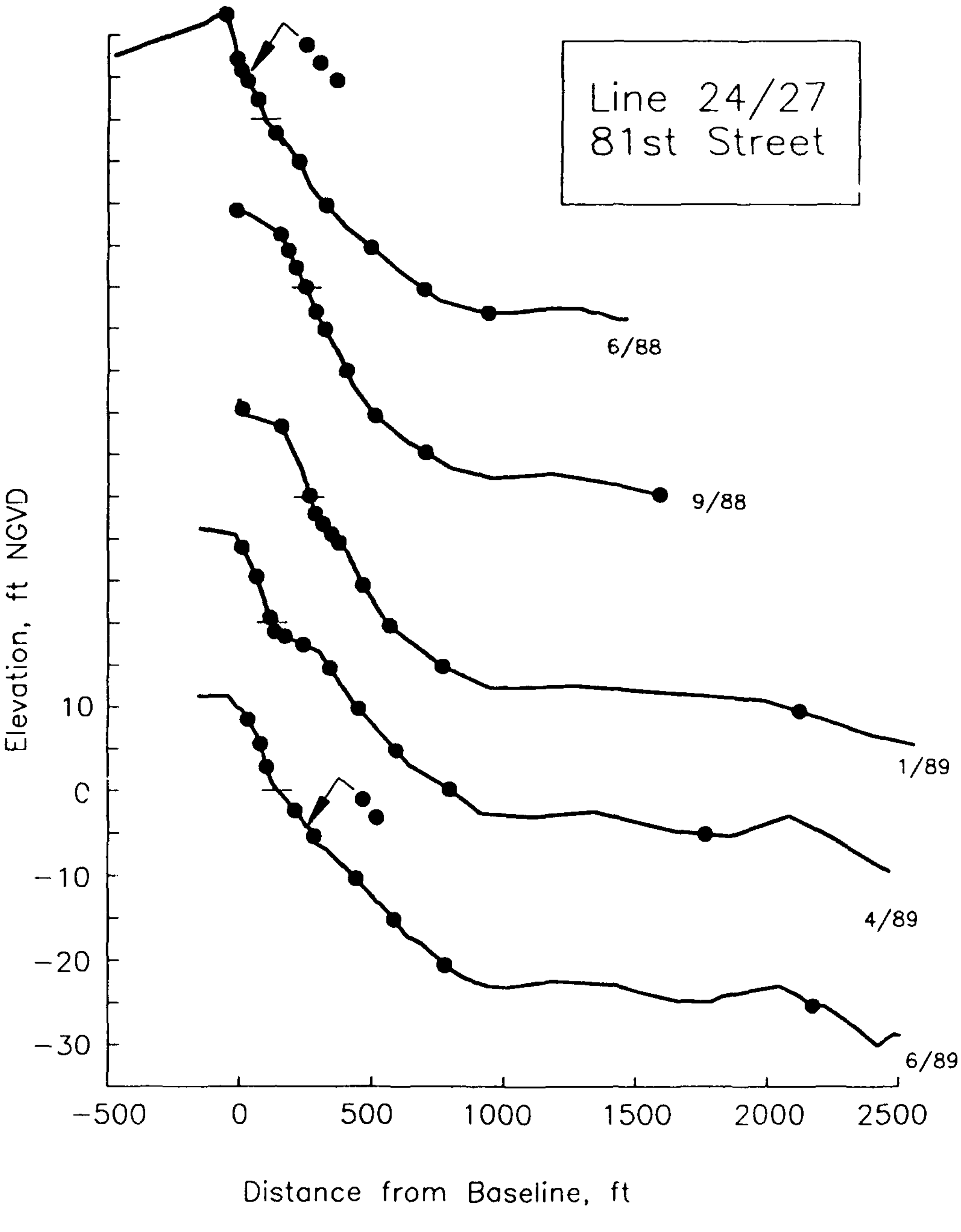


Figure 119. Sediment sample locations on profile line at 81st St. collected during State fill monitoring

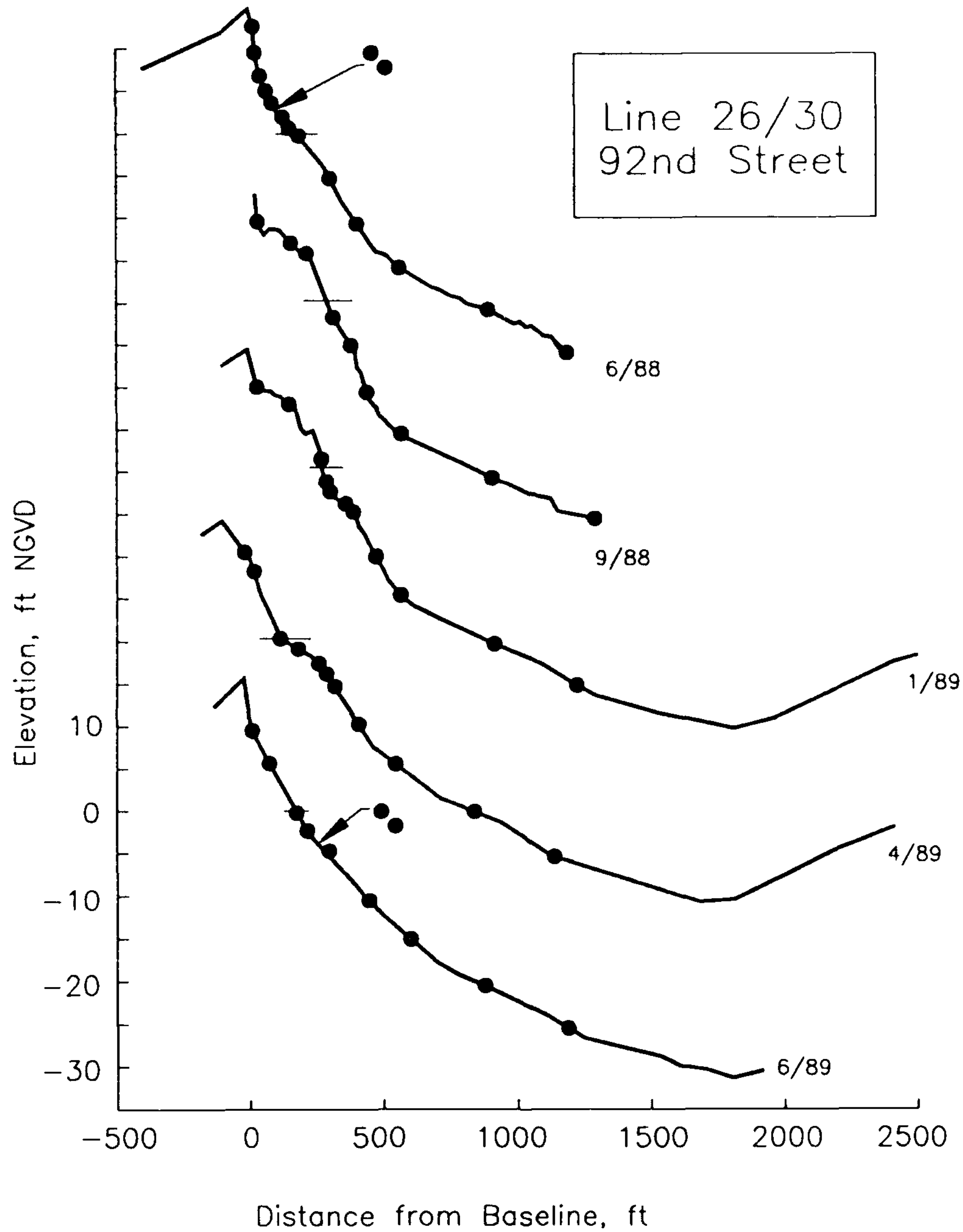


Figure 120. Sediment sample locations on profile line at 92nd St. collected during State fill monitoring

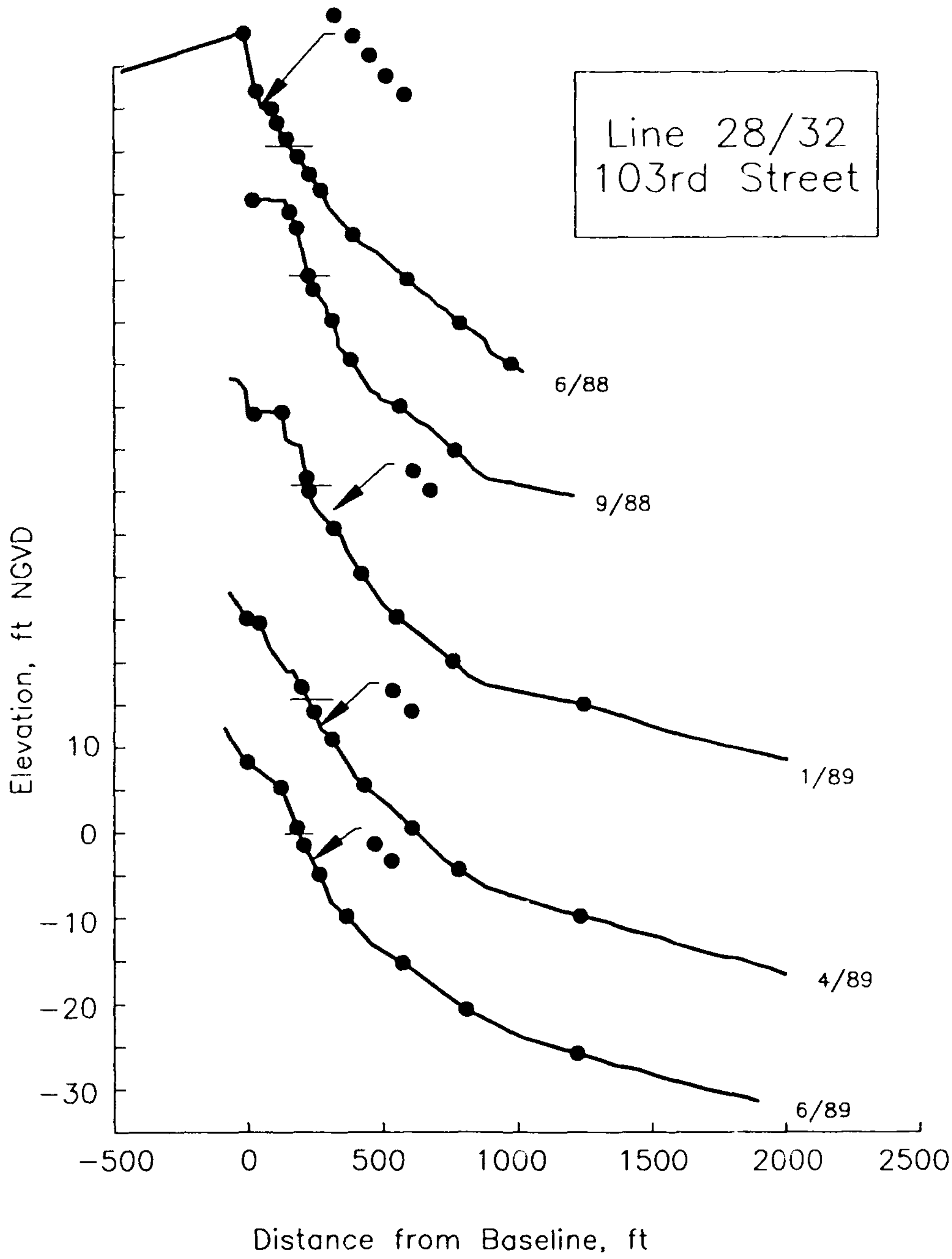


Figure 121. Sediment sample locations on profile line at 103rd St. collected during State fill monitoring

suspended until Federal fill sediment sample monitoring was initiated on 22 survey lines in March/April 1991. This most recent Federal fill project sediment data will be analyzed and reported on at a later date. The present report focuses on the evaluation of the sediment grain size distribution changes after placement of the State fill.

Analysis of all State fill sediment samples was done at CERC's sediment analysis laboratory. Samples were washed with demineralized water over a 230-mesh sieve to separate mud from sand Because all samples collected during monitoring of the State fill had less than a 5-percent mud size fraction (0.063 mm or 4 ϕ) no fine-grain analysis was done. The samples were dried in an oven and split to approximately 20 to 30 g. Grain-size analysis was performed using 24 quarter-phi interval sieves ranging from 4.00 mm to 0.063 mm (-2 ϕ to 4.0 ϕ) as outlined in Folk (1980). The sieving technique used a sonic sifter as described in Underwood (1988). An electronic balance connected to a desktop microcomputer using Interactive Sediment Analysis Package (ISAP) software provided almost complete automation of the grain-size distribution analysis and statistical calculation. Mean grain size and sorting were calculated using the method of moments and the median was calculated using graphical techniques. Plotting routines provided frequency curves. Skewness and kurtosis were calculated using both the method of moments and graphic techniques. Plots of cumulative frequency curves and probability plots are available at CERC, but are not reproduced in this report. Table 11 presents a comparison of the standard sieve mesh numbers, in millimeters and phi units, along with the Unified Soils and Wentworth Classifications to aid in the interpretation of the sediment data. Table 12 provides a description of the sorting values used in this report based on Friedman (1962) and Folk (1980).

Beach sands are a mixture of a range of sizes whose distribution varies across shore and, to a lesser extent, alongshore. The variability in size distribution is a function of the mechanism of deposition. In sampling a beach, the location of the sample is important for characterizing the sediment. The largest sand particles are commonly found at the plunge point just seaward of the backwash, the point of maximum turbulence of the incoming transalatory surf bore with the preceding backwash. This area is often characterized by a coarse sediment deposit that abruptly ends in the form of a step located at the base of the foreshore in the seaward direction. In proceeding offshore, one will step down off this coarse material and onto the usually finer, more solidly packed sand of the trough region. A secondary coarse sand distribution can also be found at the berm crest where the runup deposited all grain sizes in transport during the uprush as the swash momentarily stops and the sediment settles out before the backwash starts. Dune sand distribution is usually the finest of the subaerial beach, where the main mechanism of transport and deposition is limited by the ability of the wind to entrain and move sand. Sand distributions characteristically become finer in the offshore direction as the waves transition from the highly turbulent breaker zone to the oscillatory motions in deeper water. Bascom (1959) characterized this grain size distribution on several U.S. Pacific coast beaches and Stauble (1992) found this model to generally fit at the FRF located in Duck, North Carolina.

Beaches composed of finer grain sizes have less variability than beaches with coarser distributions. Anders and Hansen (1990) present a technique to determine the numbers of samples that are needed to characterize the beach, based on the native beach grain size distributions collected in April, 1986 at Ocean City. The coarser grain size distributions were found at the area of the lower foreshore, between the beach step and the 2-ft depth contour and required a larger number of samples to accurately represent this area. Areas with more uniform grain size distributions, such as the mid-berm, required fewer samples to characterize that area of the beach. Most sediment movement occurred between the berm crest and the nearshore bar

Table 11
Sediment Grain Size Classification

Unified Soils Classification		ASTM MESH	MM Size	PHI Size	Wentworth Classification	
Cobble			4096.00	-12.0	Boulder	GRAVEL
			1024.00	-10.0		
			256.00	-8.0	Cobble	
			128.00	-7.0		
			107.00	-6.75		
			90.51	-6.5		
			76.00	-6.25		
Coarse Gravel			64.00	-6.0		
			58.82	-5.75	Pebble	
			45.26	-5.5		
			38.00	-5.25		
			32.00	-5.0		
			26.91	-4.75		
			22.63	-4.5		
			19.00	-4.25		
Fine Gravel			16.00	-4.0		
			13.45	-3.75		
			11.31	-3.50		
			9.51	-3.25		
		2.5	8.00	-3.0		
		3.0	6.73	-2.75		
		3.5	5.66	-2.5		
		4	4.76	-2.25		
SAND	Coarse	5	4.00	-2.0		
		6	3.36	-1.75	Granule	
		7	2.85	-1.5		
		8	2.35	-1.25		
		10	2.00	-1.0		
	Medium	12	1.68	-0.75	Very Coarse	SAND
		14	1.41	-0.5		
		16	1.19	-0.25		
		18	1.00	0.0		
		20	0.84	0.25	Coarse	
		25	0.71	0.5		
		30	0.59	0.75		
		35	0.50	1.0		
		40	0.42	1.25	Medium	
	Fine	45	0.35	1.5		
		50	0.30	1.75		
		60	0.25	2.0		
		70	0.210	2.25	Fine	
		80	0.177	2.5		
		100	0.149	2.75		
		120	0.125	3.0		
		140	0.105	3.25	Very Fine	
		170	0.088	3.5		
		200	0.074	3.75		
Silt		230	0.0625	4.0		
		270	0.053	4.25	Silt	MUD
		325	0.044	4.5		
		400	0.037	4.75		
			0.031	5.0		
			0.0156	6.0		
			0.0078	7.0		
			0.0039	8.0		
Clay			0.0020	9.0	Clay	
			0.00098	10.0		
			0.00049	11.0		
			0.00024	12.0		
			0.00012	13.0	Colloid	
			0.00006	14.0		

Table 12
Sorting Classification of Sands[1]

Ranges of Values of Standard Deviation, phi	Sorting Class	Typical Environments of Sands
< 0.35	Very well sorted	Coastal- and lake dunes; many beaches (foreshore); common on shallow marine shelf
0.35-0.50	Well sorted	Most beaches (foreshore); shallow marine shelf; many inland dunes
0.50-0.71	Moderately well sorted	Most inland dunes; most rivers; most lagoons; distal marine shelf
0.71-1.00	Moderately sorted	Many glacio-fluvial settings; many rivers; some lagoons; some distal marine shelf
1.00-2.00	Poorly sorted	Many glacio-fluvial settings
2.00-4.00	Very poorly sorted	Many glacio-fluvial settings
> 4.00	Extremely poorly sorted	Some glacio-fluvial settings

[1] After Friedman (1962) and Folk (1980)

on a natural beach (Anders and Hansen 1990). Examination of the profile envelopes from the 12 study survey lines indicates that this also holds true for beach fill placement and readjustment.

Sediment sample statistics were used to characterize the sediment grain size distributions across shore and alongshore. The main statistical descriptions used to characterize the sediment are the first moment (mean grain size), second moment (standard deviation representing the degree of sorting), and the median grain size. These statistical data are listed in Appendix B for all sediment samples. An examination of the six survey lines with sediment data over the pre- and post-State fill and the three monitoring surveys of January, April, and June 1989 showed a variability in the cross-shore sediment distribution between survey lines. Sediment samples were collected at different positions during the pre- and post-fill surveys as compared to the three monitoring surveys. In order to cross-compare the spatial and temporal grain size data, 11 designated beach morphology zones were identified on the profiles. The subaerial beach zones included the dune base, berm crest, mid-foreshore, and swash or step at the base of the foreshore. The subaqueous samples included the nearshore trough and bar (which were not present on all profiles) and the 5-, 10-, 15-, 20-, and 25-ft depth contours. The sediment samples that were collected closest to these 11 morphology zones were used in the calculations. The extra cross-shore samples (collected during the pre-fill survey) were not included in this analysis. Most of these extra samples were collected along the berm, between the dune base and the berm crest, and were very similar in distribution to the berm crest sample. An average value was computed for the mean grain size and horizontal position within each of the 11 morphologic zones (Table 13). The range around the mean was also calculated to identify the variability that occurred over time in each beach zone.

Table 13
Sediment Sample Locations, Average Mean Grain Size, and Standard Deviation of Means

Sample Location	Average Distance ft	6/88-6/89 Average Mean Grain Size, phi	Average Mean Grain Size, mm	Standard Deviation of Mean Grain Size, phi
37th Street				
DB	20	1.52	0.35	0.19
BEC	150	1.78	0.29	0.23
MT	200	1.66	0.32	0.42
STEP	230	1.55	0.34	0.19
NST	240	1.71	0.31	0.32
BAC	340	1.77	0.29	0.26
-5	400	1.77	0.29	0.68
-10	580	2.24	0.21	0.60
-15	700	2.31	0.20	0.21
-20	970	1.79	0.29	0.47
-25	1250	1.56	0.34	0.59
56th Street				
DB	30	1.61	0.33	0.03
BEC	140	1.56	0.34	0.27
MT	180	1.87	0.27	0.36
STEP	270	1.18	0.44	0.70
NST	300	1.39	0.38	
BAC	360	1.11	0.46	
-5	450	2.27	0.21	0.29
-10	620	2.21	0.22	0.23
-15	710	2.06	0.24	0.93
-20	980	2.88	0.14	0.69
-25	1250	2.99	0.13	0.73

(Sheet 1 of 3)

Table 13 (Continued)				
		6/88-6/89		
Sample Location	Average Distance ft	Average Mean Grain Size, phi	Average Mean Grain Size, mm	Standard Deviation of Mean Grain Size, phi
66th Street				
DB	20	1.28	0.41	0.09
BEC	80	1.47	0.36	0.10
MT	130	1.89	0.27	0.37
STEP	220	1.07	0.48	0.49
NST	220	1.02	0.49	
BAC	260	1.22	0.43	
-5	360	1.82	0.28	0.57
-10	460	2.21	0.22	0.59
-15	610	2.38	0.19	0.90
-20	860	2.67	0.16	1.06
-25	1620	3.22	0.11	0.06
81st Street				
DB	0	1.39	0.38	0.12
BEC	120	1.54	0.34	0.15
MT	140	1.72	0.30	0.36
STEP	220	1.07	0.48	0.69
NST	260	1.13	0.46	0.52
BAC	270	1.02	0.49	0.37
-5	310	1.52	0.35	0.70
-10	400	2.24	0.21	0.07
-15	570	2.13	0.23	0.40
-20	750	1.39	0.38	0.67
-25	1900	2.11	0.23	0.40

(Sheet 2 of 3)

Table 13 (Concluded)				
		6/88-6/89		
Sample Location	Average Distance ft	Average Mean Grain Size, phi	Average Mean Grain Size, mm	Standard Deviation of Mean Grain Size, phi
92nd Street				
DB	30	1.49	0.36	0.17
BEC	140	1.27	0.42	0.11
MT	210	1.41	0.38	0.30
STEP	250	1.05	0.48	0.83
NST	310	1.35	0.39	0.08
BAC	330	1.55	0.34	0.42
-5	340	1.86	0.28	0.76
-10	440	2.28	0.21	0.68
-15	580	3.08	0.12	0.27
-20	900	2.97	0.13	0.30
-25	1250	2.41	0.19	0.88
103rd Street				
DB	10	1.17	0.44	0.23
BEC	120	1.41	0.38	0.43
MT	180	1.40	0.38	0.38
STEP	210	1.36	0.39	0.39
NST	240	0.31	0.81	0.47
BAC	270	1.56	0.34	1.16
-5	290	2.10	0.23	0.47
-10	400	2.28	0.21	0.19
-15	580	2.25	0.21	0.13
-20	790	2.54	0.17	0.48
-25	1110	2.65	0.16	0.60
				(Sheet 3 of 3)

Composite analysis

The high degree of variability, both on a spatial and temporal scale, in the grain size data of the individual surface sediment samples made it difficult to identify the interrelationship between sediment compositional changes and profile response. In order to eliminate some variability and provide a clearer picture of sediment distribution on the study beaches, composite samples were mathematically constructed from the cross-shore samples on a given survey. Hobson (1977) describes techniques to calculate composite sediment grain size distributions. Composite grain size distributions have been used in the past to average several grain size distributions into one representative sample for comparison with another individual or composite group of samples (e.g., Stauble, Hansen, and Blake 1984). In this manner, variability and complex relationships can be simplified. Composite samples can be used for further analysis in the same manner as individual grain size distributions.

A foreshore composite was constructed mathematically using the three samples in the intertidal zone (berm crest, mid-tide and swash/step). A nearshore composite was constructed from the five samples in the nearshore zone (5-, 10-, 15-, 20- and 25-ft depths). The dune base sample was not used because most of the time (except after the storms) the dune base was not under the influence of wave action and any grain size change was a result of the fill placement and eolian processes. The bar and trough samples were also not used because a bar/trough configuration was not present on several of the profiles and samples collected in the area between the step and 5-ft depth had mixed grain size distribution characteristics of the high-energy swash/step and the lower energy conditions of the nearshore, depending on the survey date they were collected. The pre- and post-fill surveys did not include a trough or bar sample. A profile composite was also calculated using all of the sediment data in the cross-shore from the dune base to the 25-ft depth sample for each survey location. This composite mathematically combined all of the samples collected on the survey line on that day.

The foreshore composite contained sediment deposited by wave action ranging from the limit of runup around MHW (berm crest) to the area of the lower foreshore where the breakers interact with the backwash (swash/step). These sediment data from the foreshore area of the beach present information on the active intertidal portion of the profile with the prevailing wave conditions and represent most of the active profile envelope where the fill was placed. The nearshore composite covered the area of the profile that was just seaward of the breaker zone (5-ft depth sample on most survey dates) to the offshore area of sediment transport by waves (25-ft depth). On most survey dates, the 25-ft sample was collected at or near the closure depth. Most of the fill was placed on the landward end of this composite zone (landward of the 15-ft sediment sample depth) and this composite represented the change in sediment as the fill material was re-sorted and deposited in the nearshore with time.

A compilation of the individual cross-shore sediment data using the mean grain size of each individual sample showed the wide pattern of variability of the native beach and changes due to fill placement, as well as the redistribution of the fill material over the 9 months of project monitoring. This period includes the sediment response to the storms in March 1989. Further analysis of the sediment data included construction of a time history of frequency curves of the foreshore and nearshore composites. Sediment surveys on the southern portion of the project (37th, 56th, 66th, and 81st Streets) received fill material from Borrow Area 2 and the surveys of the northern portion of the project (92nd and 103rd Streets) received fill material from Borrow Area 3. With some of the individual sample variability removed by the composite method, a general trend in sediment change emerged. The use of the composite frequency curves allowed for examination of the entire range of grain sizes in the sediment distributions, and not just a single mean value. A summary of the sediment change was compiled by plotting the mean grain size and sorting characteristics of the foreshore and nearshore composites. These values were compared on each of the six profiles to reveal the re-sorting and change in means as the fill readjusted under the prevailing wave conditions.

37th Street sediment monitoring

Initial sediment analysis used the average mean grain size value for the location of each beach zone across shore at the southern end of the monitoring area at 37th Street. The means are plotted over the active envelope of the profile, which includes the native beach, post-fill beach, and the 9-month monitoring profile (Figure 122). The means were averaged from these three sampling times as well as for the 4-month survey and the pre-and post-storm samples. Over the sediment study period (June 1988 to June 1989) the average coarsest material was found at the dune base and the swash/step located around MLW. The largest range in mean size was found at the 5-ft depth. Thus, the most active sediment change occurred in the area around the breaker and surf/swash interaction zones. An anomalous increase in mean grain size was observed in the offshore and reflects the presence of coarse sands and fine gravel size material found in the 20- and 25-ft depth samples. The coarser material was present at this location on the pre-fill native survey and continued to be coarser than the 5- to 15-ft contour samples even after fill placement. These nearshore samples had a wide range in mean values through the study, indicating a persistent fluctuation in grain size distribution. The coarse material appears to be natural in origin, unrelated to the beach fill, and may be from lag deposits of coarse material in the nearshore area, possibly from outcrops of relict layers of coarse Pleistocene stream beds.

The fill material sampled during the post-fill survey was finer than the native beach as indicated by the mean grain size values of the samples from the berm crest, mid-tide, and step/swash areas (Figure 123). The September 1988 nearshore samples collected soon after fill placement had a grain size distribution similar to the native beach, except for the 10-, 15- and 25-ft contour samples, which were coarser than the native sample at that depth. Four months after fill placement, the mixing of the fill material with the native sediments produced a trend toward the coarser native material on the foreshore, bar/trough, and at the 5-ft depth.

After the storms of March 1989, the foreshore samples had a coarser mean, with the step, 5-, and 10-ft contour samples becoming the coarsest (Figure 124). The more seaward samples became finer than the pre-storm nearshore samples. This pattern indicated that the turbulence was high in the shallow swash zone and at the 5- to 10-ft depth where wave breaking, surf, and runup deposited only the coarser material and transported the finer grain size material offshore to the 20- and 25-ft depths. The fines covered the naturally occurring coarser sands. The final samples collected during the June 1989 survey showed a trend to finer grain sizes being transported back onto the foreshore, bar/trough and shallow nearshore, which corresponded to the observed profile accretion. This survey line contained the series of nearshore bars and is not directly associated with the shoreface-attached shoals.

To reduce some of the variability and identify the process/response of the sediment, the foreshore and nearshore composites were calculated. Because beach sand is composed of a range

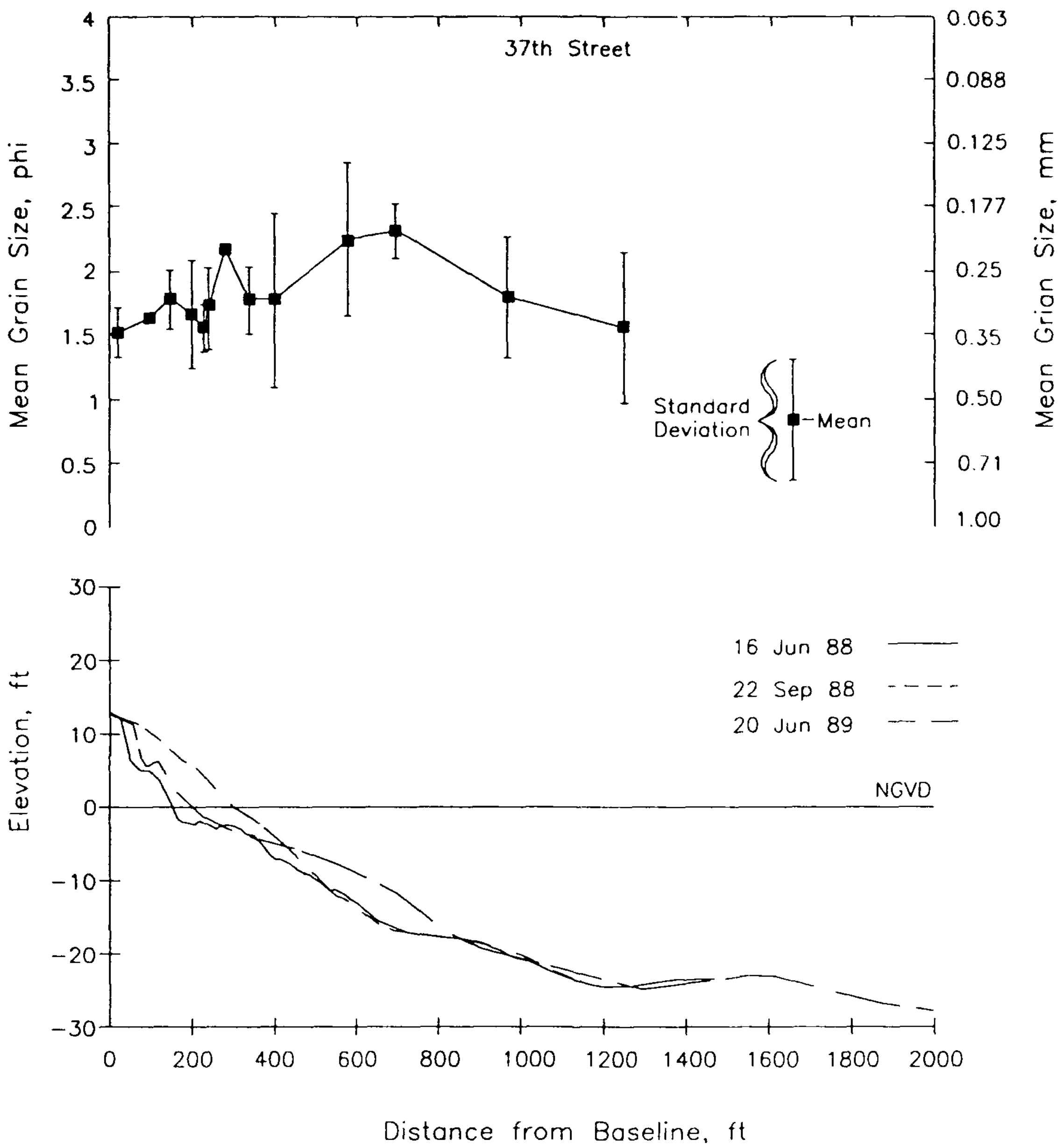


Figure 122. Cross-shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 37th St.

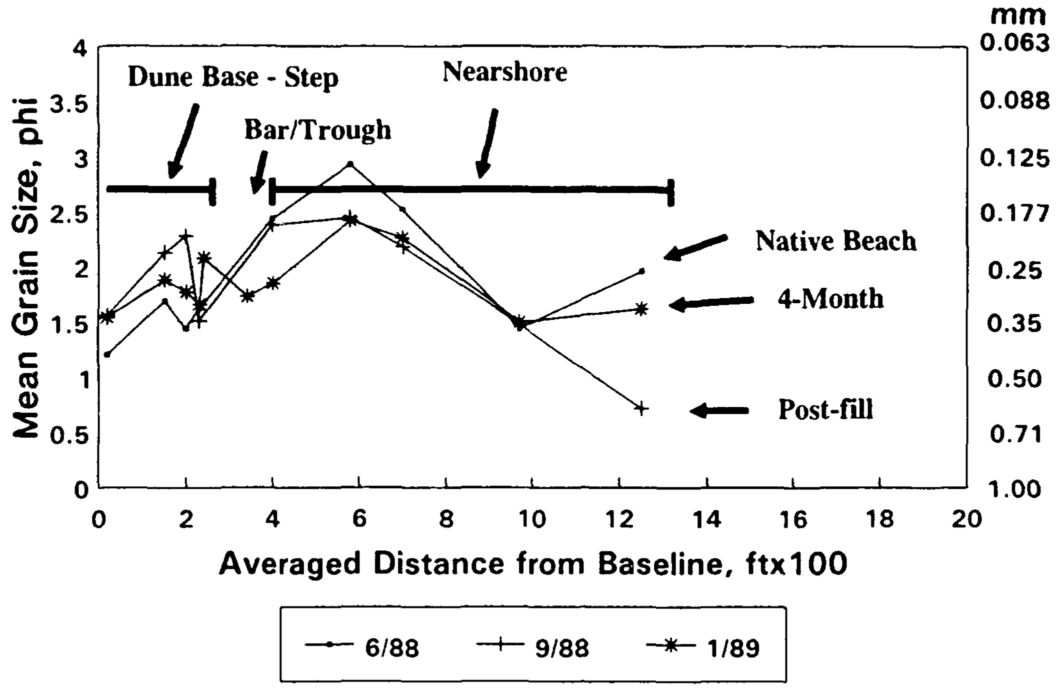


Figure 123. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month fill monitoring

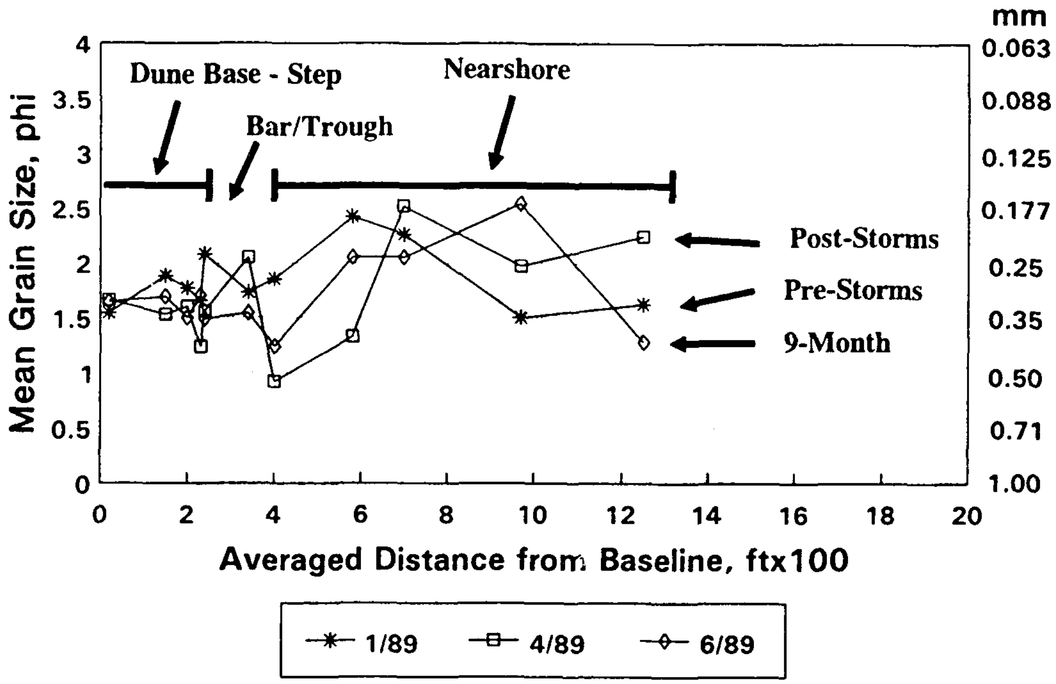


Figure 124. Cross-shore distribution of mean grain size for pre- and post- March 89 storms and 9-month monitoring at 37th St.

of many individual grain sizes, frequency curves are used to depict the entire distribution from coarse to fine material and their occurrence. A time history of the foreshore composite at 37th Street shows the shift to the finer grain distribution that occurs in the transition from the native composite frequency distribution curve to the post-fill curve (Figure 125). The grain size distribution remained moderately well sorted in both composites. These curves represent the composite of the berm crest, mid-tide and step samples, and the curves show the shift to a finer borrow material after fill placement within the intertidal area. With 4 months of normal wave action on the foreshore, the January 1988 composite sample showed a shift back toward the coarser native distribution with a loss of the finer fraction. This composite also became better sorted, with removal of the coarser and finer sizes. The impact of the March 1989 storms was evident on the post-storms foreshore composite, where a coarse fraction of gravel and coarse sand was found. The sample was only moderately sorted. This increase in the coarse fraction corresponds to erosion of the intertidal area at 37th Street. With the return of lower waves, the 9-month monitoring foreshore composite grain size distribution shifted to a finer distribution as the foreshore accreted. The absence of coarse storm lag material also improved the sorting.

The nearshore sample composite composed of the 5- to 25-ft depth samples provided information on the change in sediment size distribution in the offshore. The native beach nearshore composite predominately contained fine sand sizes, common of the lower energy environment seaward of the normal breaker zone. This native composite was only moderately sorted due to a wide range of grain sizes in the nearshore. The post-fill nearshore composite had evidence of coarse material, which may have been naturally occurring in this nearshore area. The 4-month nearshore composite had no coarse material, which may have been covered by fill being deposited in the nearshore. The finer fraction also contained a smaller weight percent, creating a finer, better-sorted sample. After the March storms, the coarse fraction was again present in the composite distribution, along with an increased weight percent in the 0.25- to 0.125-mm (2.0- to 3.0-ϕ) fine sand fraction. This region gained sand volume as the foreshore eroded and appeared to receive a selectively sorted finer material. The anomalous coarse fraction may have been due to exposure of an outcropping of coarse material at the 5- to 10-ft depths. As the nearshore sand was transported back onto the foreshore over the spring months, the 9-month nearshore composite grain size distribution again showed no coarse material and a gain of material in the 0.5- to 0.177-mm (1.0- to 2.5-ϕ) medium to fine sand range.

The temporal distribution in the 37th Street composite samples of the foreshore and nearshore is summarized in Figure 126, which compares the composite mean with the sorting values. The nearshore samples were always finer and more poorly sorted than the foreshore samples, but the range in both mean grain size and sorting of the foreshore and nearshore samples was narrow through time. The post-fill foreshore composite became finer and slightly more poorly sorted than the native foreshore composite. Within 4 months, the foreshore became coarser and better sorted. The storms in March further coarsened the foreshore, with a decrease in sorting. By the 9-month monitoring survey, the mean grain size remained the same, but sorting had improved. After fill placement, the nearshore composite mean retained the same mean but became more poorly sorted. After 4 months, the nearshore returned to a mean and sorting that were similar to the native nearshore. The storms created a coarser and more poorly sorted nearshore. The 9-month sample became finer and returned to a sorting similar to the native nearshore composite. The 9-month monitoring of sediment distribution at 37th Street indicates a trend toward re-sorting of the finer fill material back to the native distribution on both the foreshore and nearshore.

37th Street

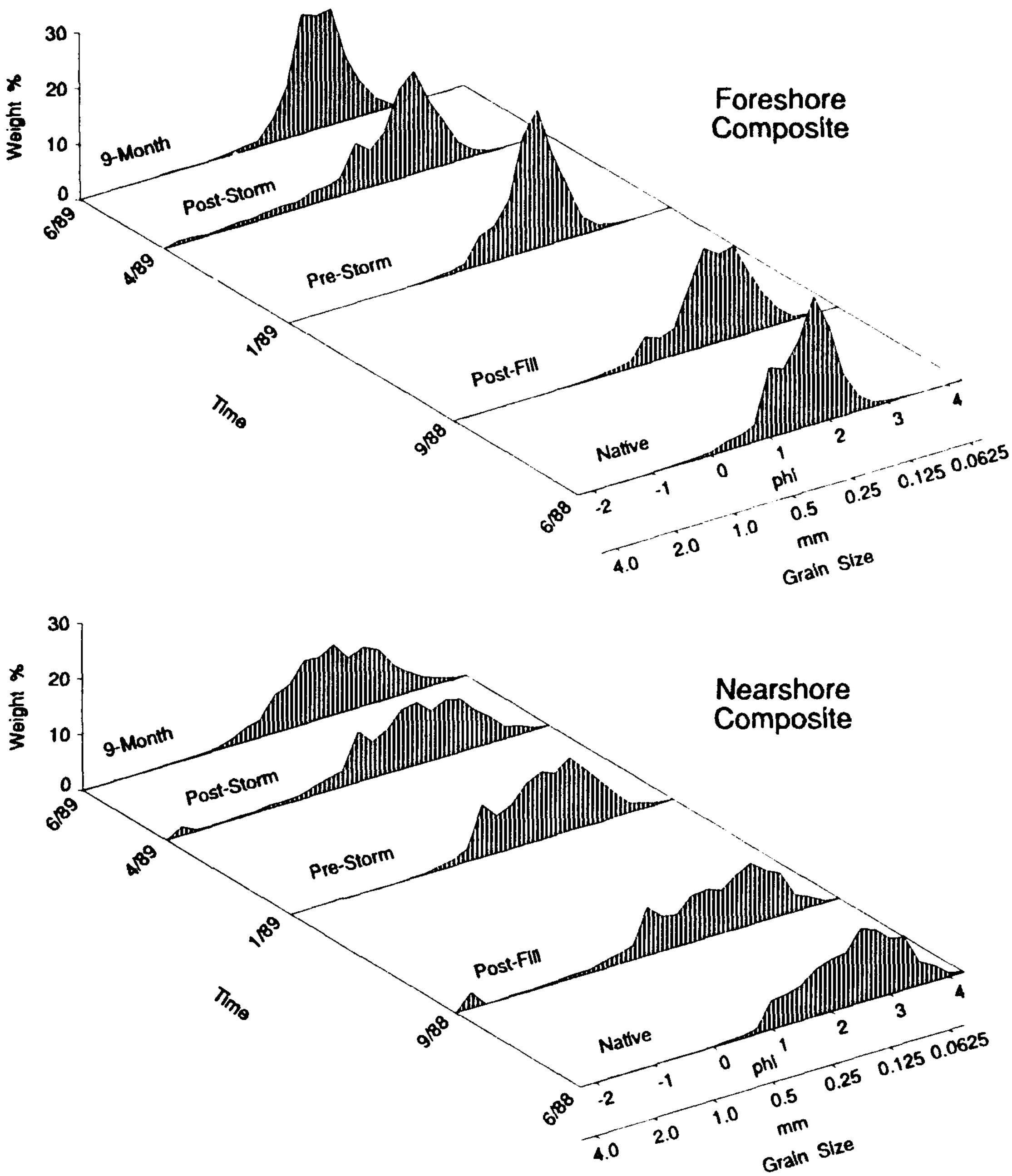


Figure 125. Time history of foreshore and nearshore sediment composite frequency curves at 37th St.

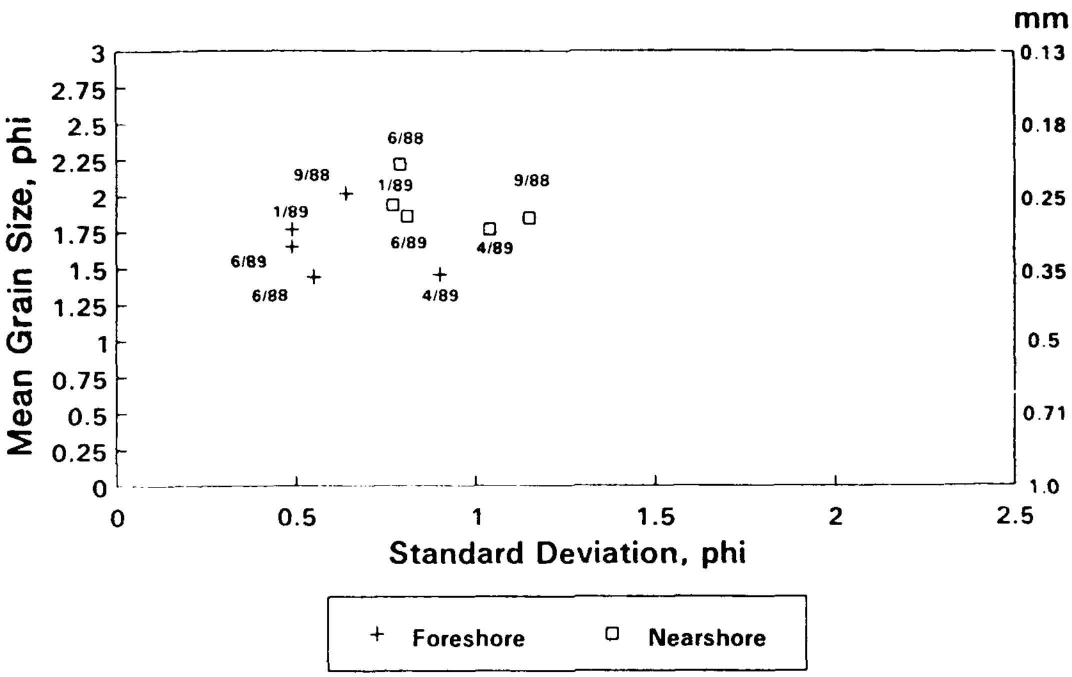


Figure 126. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 37th St.

56th Street sediment monitoring

A more common cross-shore-averaged mean sediment distribution was observed at the survey line at 56th Street. The coarsest average grain size means were found on the lower foreshore and the bar/trough region, with a progressive fining in the offshore direction (Figure 127). High variability through time was observed in the means at the step and in the 15-, 20- and 25-ft depths. The 5- and 10-ft means were somewhat coarser than the common trend. These samples were located in the 600- to 800-ft distances offshore from the baseline and were a depositional area for fill material. The seaward movement of the fill could explain the observed pattern. This survey was located landward of the southern shoreface-attached shoal.

The native beach contained coarse material at the berm crest, step, and 15-ft depth. At these locations, coarse sand and fine gravel material were present (Figure 128). The anomalous coarse material in the nearshore at the 15-ft depth may be from a lag deposit of relict coarse material. The fill material placed at this location was finer than the native beach at all cross-shore locations. The post-fill berm crest, mid-tide, and step means exhibited the significant shift to fine material, which was from the southern Borrow Area 2. The post-fill 15-ft depth sample did not exhibit an anomalous coarsening of the mean, but followed the more typical beach sediment distribution pattern of progressive fining in the offshore direction. Since the fill reached to about the 10-ft depth, this fining of the nearshore area may be a result of early deposition of re-sorting of the finer components of the fill. Within the first 4 months, the sediment means began to trend back toward the means of the native beach. Mixing of the fill material with the native beach sand as the profile reshaped into a more equilibrious slope by waves and currents resulted in this shift

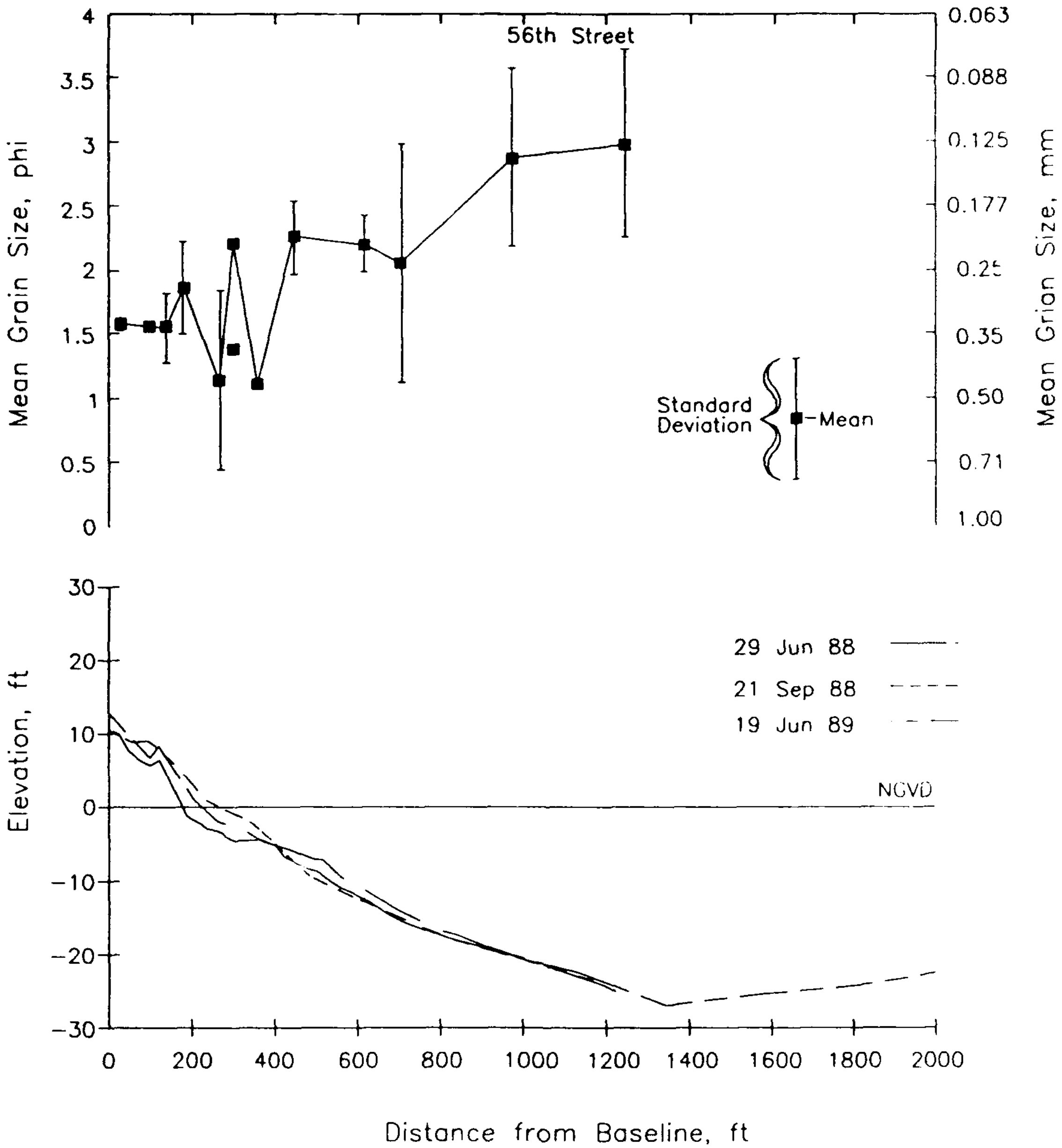


Figure 127. Cross-shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 56th St.

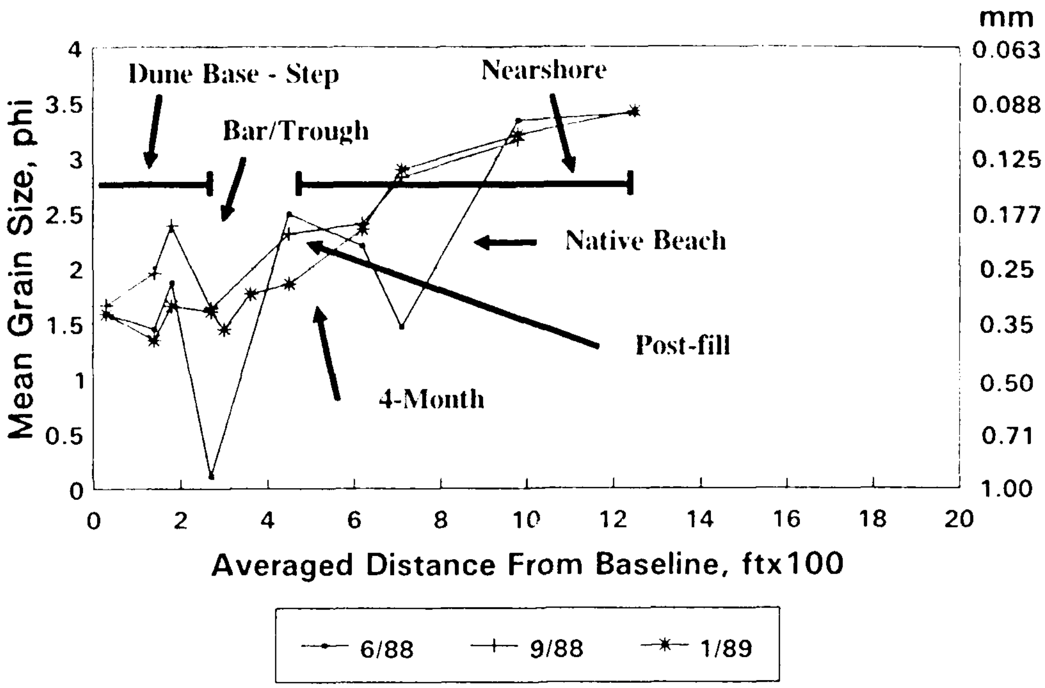


Figure 128. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month monitoring at 56th St.

in the mean sediment values. The pattern of progressive fining in the offshore direction continued in this 4-month survey as fill material was transported into the nearshore.

With the presence of high waves during the storms in March 1989, the beach sediment responded by becoming coarser at most cross-shore sampling positions (Figure 129). On the subaerial beach, the mean grain sizes of the post-storms samples were close to the pre-storms samples, with the berm crest becoming slightly finer. The greatest change to a coarser mean grain size occurred on the bar crest and at the 15-, 20-, and 25-ft depths. The 5-ft sample mean was the only nearshore sample that became finer than the pre-storms sample. Sediment eroded from the subaerial beach was deposited in the area between the 2- and 15-ft contour (Figure 59) and appeared to be selectively sorted to finer material in the shallower nearshore seaward flank of the bar (5-ft sample) and coarser material in the 15- to 25-ft depth range. This coarse material may have its source in naturally occurring coarse lag material already present in the native nearshore area. A 9-month sediment sample was not analyzed at this survey line.

Examination of the composite grain size distributions at 56th Street found a coarse, moderately sorted foreshore and a fine, moderately well-sorted nearshore native grain size distribution (Figure 130). The post-fill foreshore composite contained a large fraction of fine material and no coarse sands or gravel component and was moderately well-sorted. This foreshore distribution was almost identical to the 37th Street distribution indicating that similar fill material was placed at 56th Street. The initial 4-month re-sorting of the fill material winnowed out the fine fill material and returned the foreshore composite to a distribution similar to the native beach, without the coarse fraction. The composite became well-sorted. The storms in March 1989 had little effect on the foreshore composite at this location, with the pre- and post-storms composite having a very similar distribution.

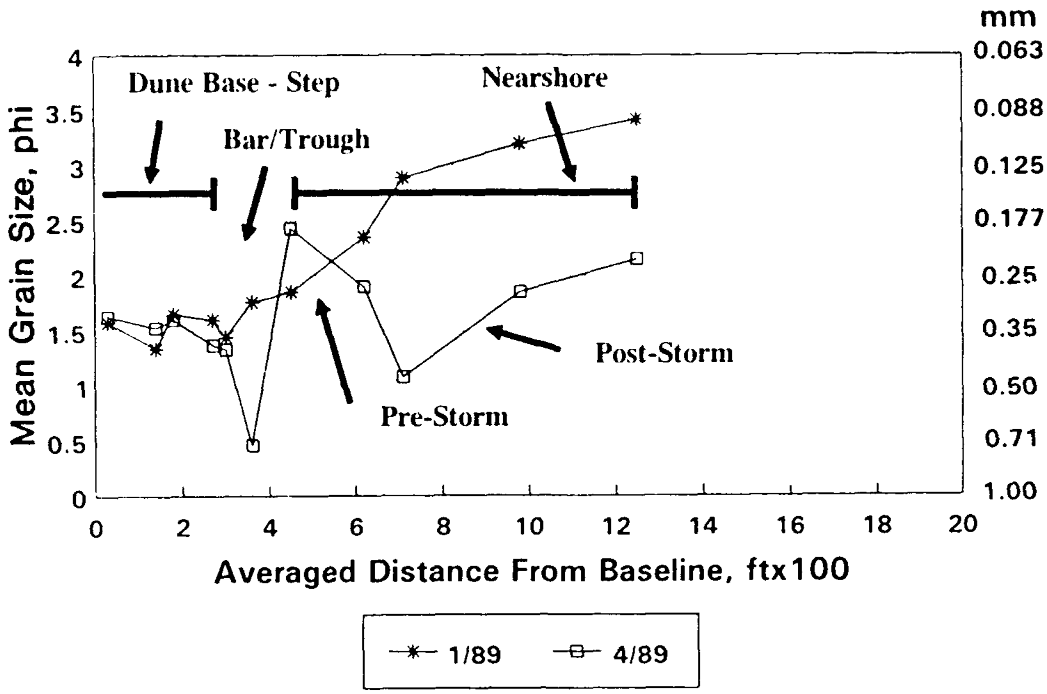


Figure 129. Cross-shore distribution of mean grain size for pre- and post- March 1989 storms at 56th St.

The post-fill nearshore composite at 56th Street became better sorted and slightly finer with the removal of both the coarser and finer end of the distribution. A peak formed in the frequency curve around the 0.11-mm (3.25-ϕ) fine sand class. The 4-month monitoring nearshore composite changed little, with the slight addition of material at the very fine sand end of the distribution. The storms formed a coarse, poorly sorted distribution in the nearshore, with the addition of a small percentage of gravel, and a larger percentage of coarse and medium sand. The fine sand component was removed from the distribution.

A summary of the temporal variation in the composite grain size distribution at 56th street showed that there was a greater variation in the mean and sorting values between the nearshore and the foreshore (Figure 131) than at 37th Street. The fill material placed on the foreshore was finer and better sorted than the native material. The re-sorting over the first 4 months produced a coarser, better-sorted sediment distribution on the foreshore, which surprisingly changed little after the storms. The nearshore composite mean and sorting values were very similar for the native, post-fill, and 4-month nearshore distributions. This indicated little change in the nearshore sediment distribution. After the storms, coarse material located in the nearshore contributed to produce a coarser, more poorly sorted distribution.

66th Street sediment monitoring

The averaged mean grain size distribution in the cross-shore at 66th Street also had a common pattern of coarse material in the swash and bar/trough area of highest wave-induced turbulence

56th Street

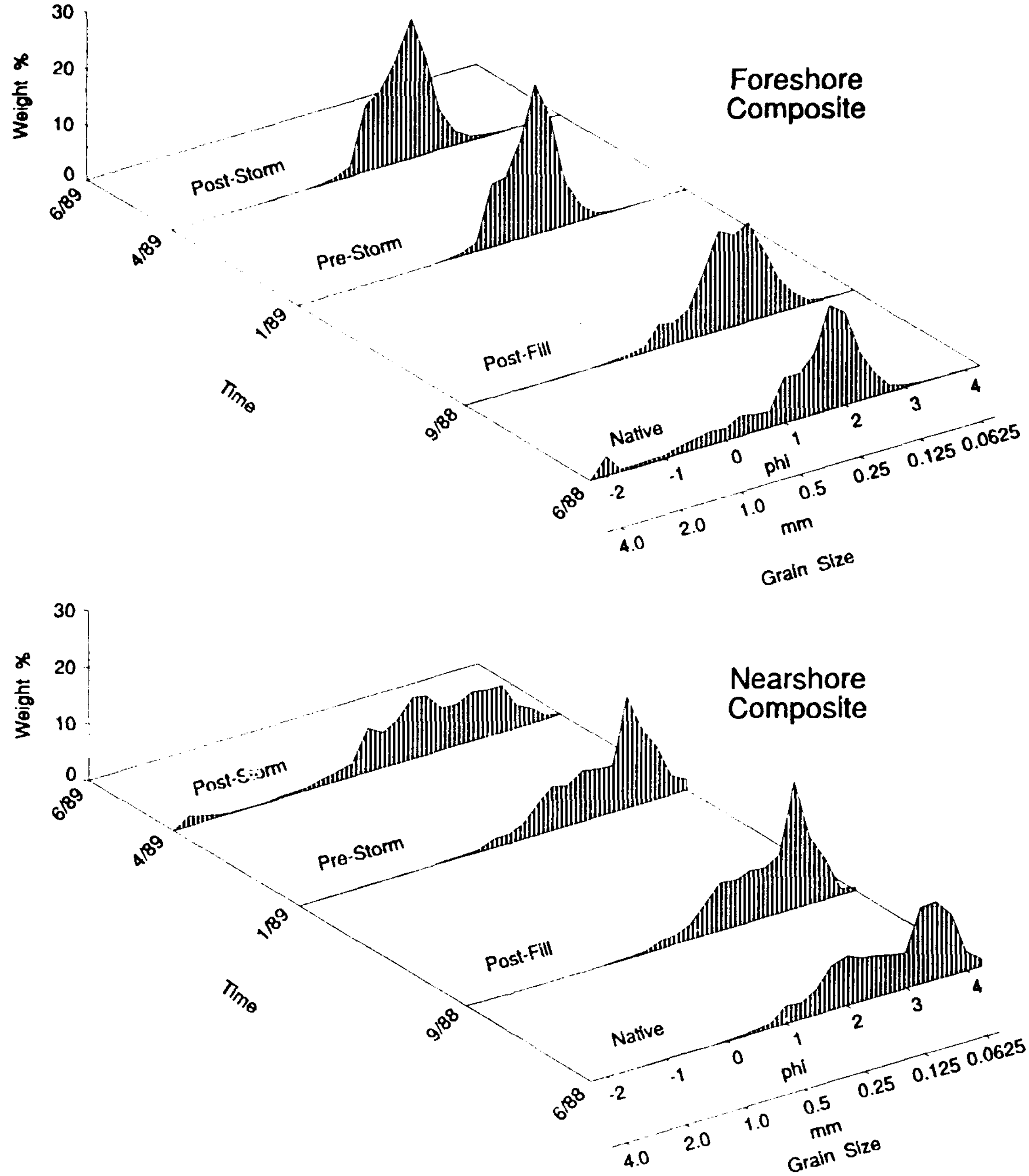


Figure 130. Time history of foreshore and nearshore sediment composite frequency curves at 56th St.

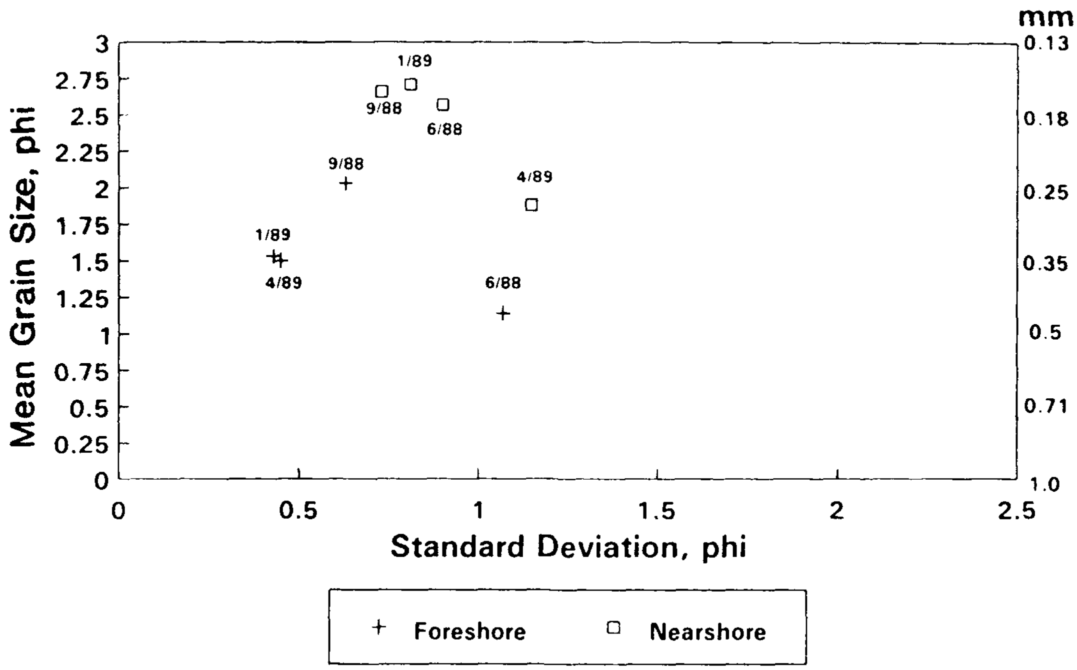


Figure 131. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 56th St.

(Figure 132). The finest mean on the subaerial beach was the mid-tide sample. The nearshore samples became progressively finer in the offshore direction. Standard deviations about the mean for the mid-tide, step, 5-, 10-, 15-, and 20-ft depth samples were high and corresponded to the active envelope of the beach profile. The dune base, berm crest, and the 25-ft depth sample means had low variability and were in areas of the profile envelope that were relatively stable over the sampling period. Because of the shallow offshore slope at 66th Street, the 25-ft depth sample was collected at an averaged 1,600 ft offshore and exhibited a temporal uniformity in grain size distribution due to its distance offshore.

Eight samples were used in the analysis of the native beach cross-shore mean distribution. No sample was collected at the 20-ft depth, and no bar/trough was present. The coarsest mean was located at the step as expected (Figure 133). The 20-ft depth sample also contained coarse native sediment and is suspected to be a coarse lag deposit, similar to the 15-ft depth sample at 56th Street and the 25-ft depth sample at 37th Street. Except for the 5-ft contour, the post-fill sediment means were finer than the native beach. This borrow material was from the southern borrow area. The post-fill sample located at the 15-ft depth still exhibited a coarser mean than the adjacent samples. The fill material placement area was just landward of this area and mixing of the native sand with the fill material would include a high percentage of the coarse native material. Within 4 months, most of the cross-shore sand became coarser, with the coarsest mean found at the 5- and 20-ft depths as the fill material was re-sorted and moved into the nearshore. The nearshore had a wider range of change than the subaerial beach.

After the passage of the storms in March 1989, the subaerial beach and bar/trough samples became coarser and the nearshore samples became finer than the pre-storms samples

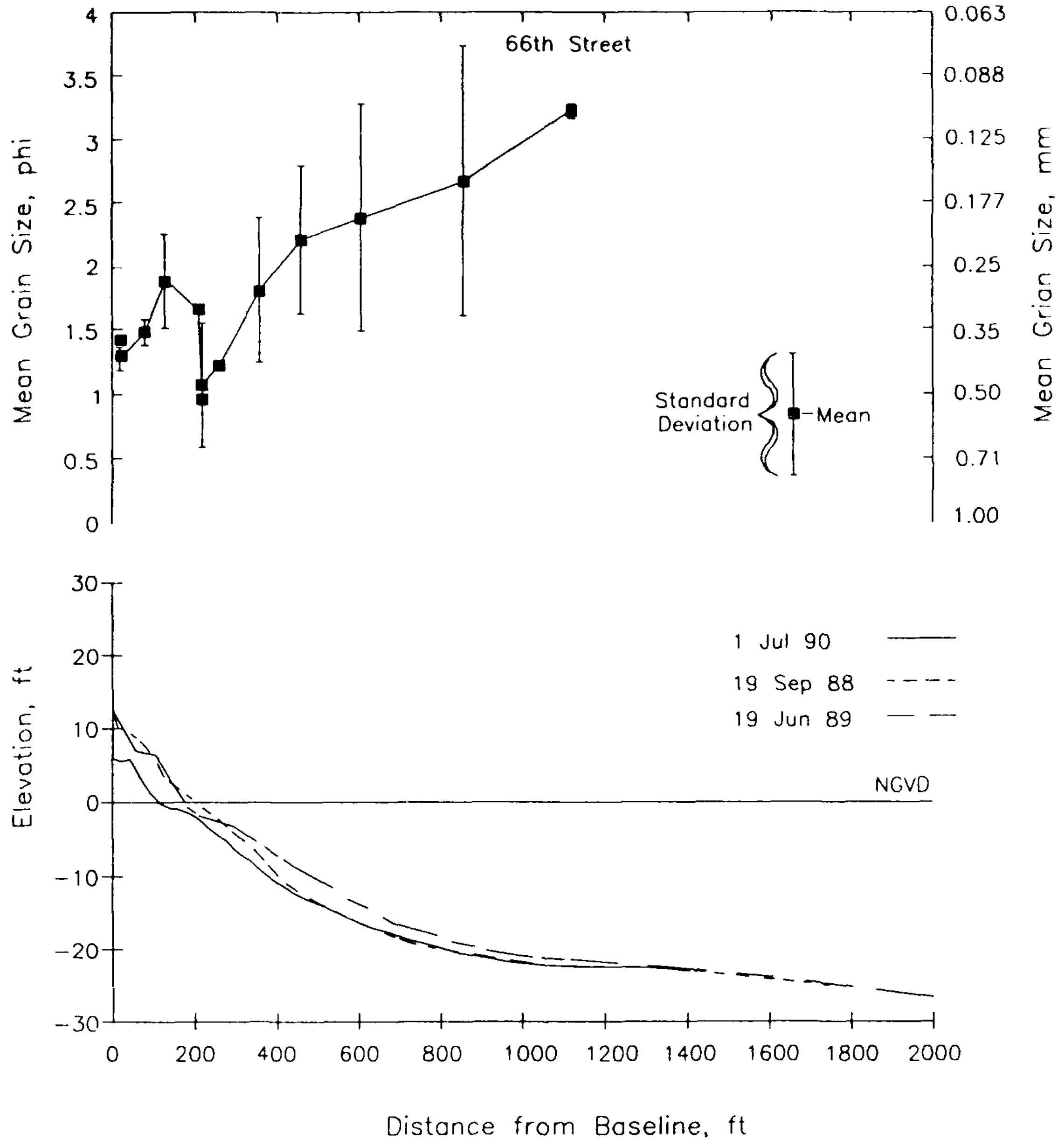


Figure 132. Cross shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 66th St.

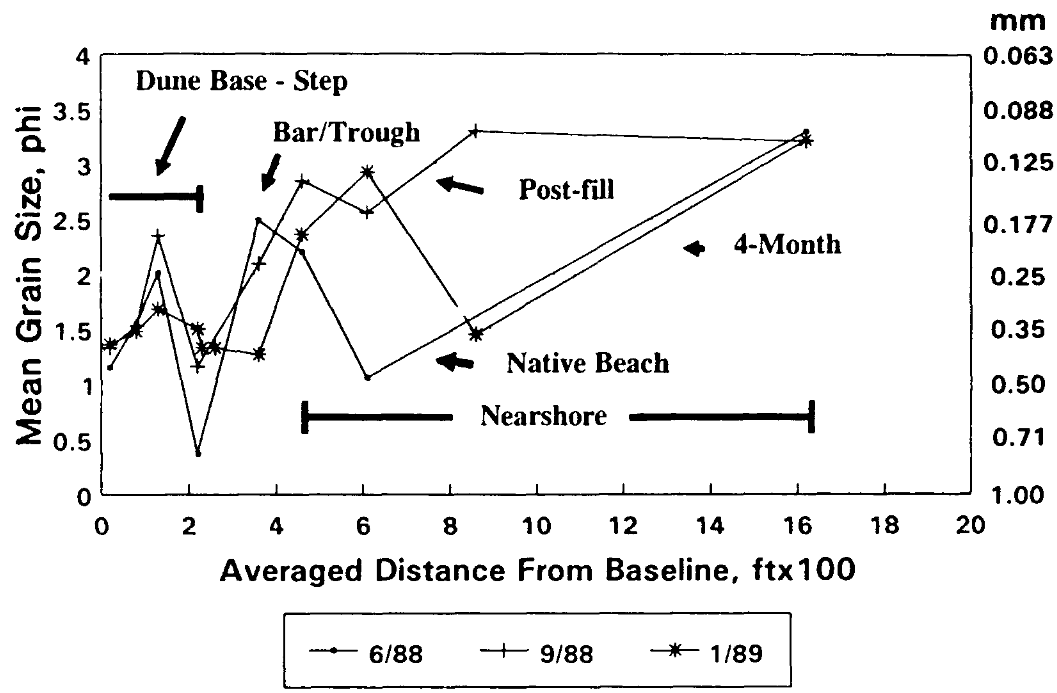


Figure 133. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month monitoring at 66th St.

(Figure 134). The finer material was removed with the erosion of the subaerial beach and deposited in the lower energy area of the nearshore out to 1,000 ft offshore. The coarsest mean was located at the trough and bar crest in the high wave energy portion of the profile. No 9-month survey sediment samples were analyzed.

The composite grain size distribution of the foreshore and nearshore at 66th Street provided a time history of the change in the active sediment zones (Figure 135). The native beach foreshore composite contained a wide range of grain size classes from the coarse material in the gravel and coarse sand fraction to the fine sand range, and was only moderately sorted. The bulk of the coarse material was located in the step sample. The post-fill composite distribution retained the wide range in grain sizes found on the native beach, with the addition of a fine fraction from the fill material. The sorting was the poorest of the post-fill foreshore composites. The post-fill step sample again contained the bulk of the coarse fraction, with the berm crest and mid-tide samples containing the predominately fine, well-sorted fill material. Within the first 4 months of re-sorting, the foreshore composite distribution became moderately well-sorted, losing both the fine sand fraction of the fill material and the coarse gravel component. This "loss" of the coarse and fine end size classes may be a result of either burial of the coarser fill material under a reworked layer of recent sediment or removal from the foreshore (most likely for the fine sizes) by wave processes. The storms caused a slight coarsening of the distribution of the foreshore composite with an increase in the percent of material around 0.5 mm (1.0 ϕ) and a reduction in the percent of material around 0.25 mm (2.0 ϕ). As with the storm-induced change of the foreshore composite at 56th Street, little change occurred in the overall grain size distribution.

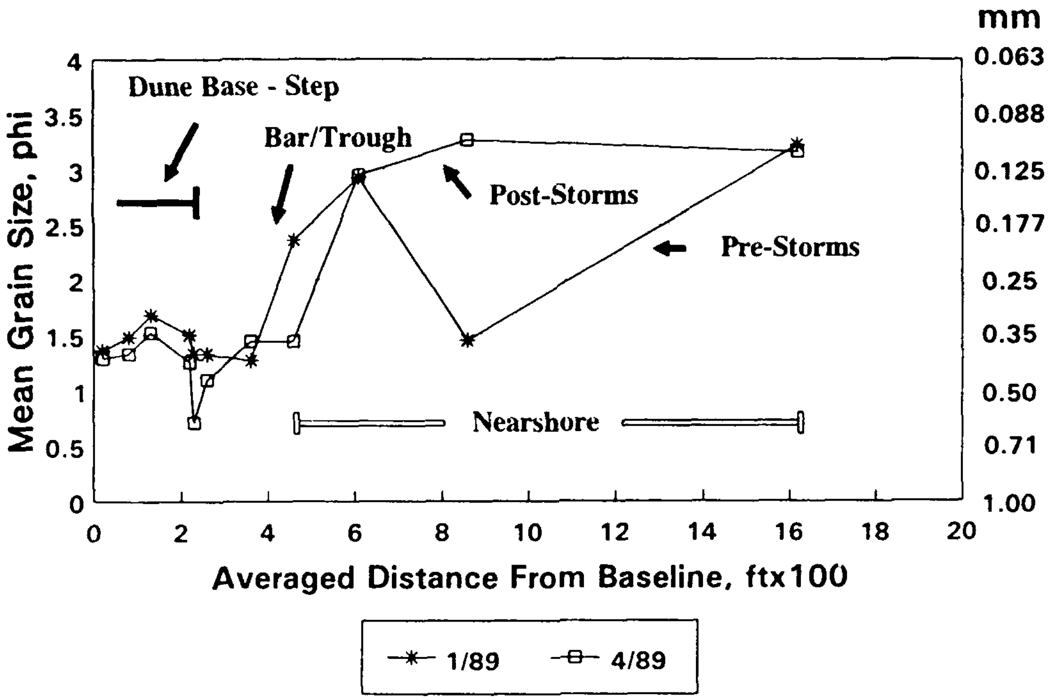


Figure 134. Cross-shore distribution of mean grain size for pre- and post-March 89 storms at 66th St.

The native beach nearshore composite was almost bimodal, with a main peak in the fine sand percentage around 0.05 mm (3.25 ϕ), and a secondary coarse sand peak around 0.5 mm (1.0 ϕ), which was the result of coarse material in the 20-ft depth sample. A shift to a finer unimodal post-fill nearshore composite was found as the native coarse material was covered by the fine material making its way onto the nearshore as waves re-sorted the fill, rapidly winnowing out the fines and depositing them in the lower energy nearshore. As the waves and currents continued to re-sort the fill material, the 4-month composite shifted back to a bimodal distribution with similar percentage peaks in the original 0.05-mm (3.25-ϕ) size class and a new peak at the 0.3-mm (1.75-ϕ) size class. As sediment was eroded off the subaerial beach by the wave activity, a higher percentage of the coarser material was deposited in the nearshore. The predominant 0.05-mm (3.25-ϕ) peak was present after the March 1989 storms and gained in magnitude as the composite distribution returned to a frequency curve similar to that of the native nearshore. Gravel size material was also found in the composite, owing to the coarse material in the 5- and 10-ft depth samples. The eroding coarse material from the lower foreshore was deposited in the shallow nearshore.

The grain size distributions of the foreshore and nearshore were more distinctly separated at 66th Street. A summary of the composite mean and sorting values showed that the nearshore composites had a narrow range of mean grain sizes and sorting over the study period (Figure 136) indicating that the depositional environment and/or available sediment distributions of the nearshore were limited to a narrow range of conditions. The foreshore composites had two distinct groupings: pre- and post-fill and pre- and post-storm, with a narrow range in mean grain size and a distinct split in sorting values. The foreshore composite native beach and post-fill beaches were more poorly sorted than the 4-month and post-storm composites. The improved sorting of the foreshore composite 4 months after the fill indicated that the foreshore sediment

66th Street

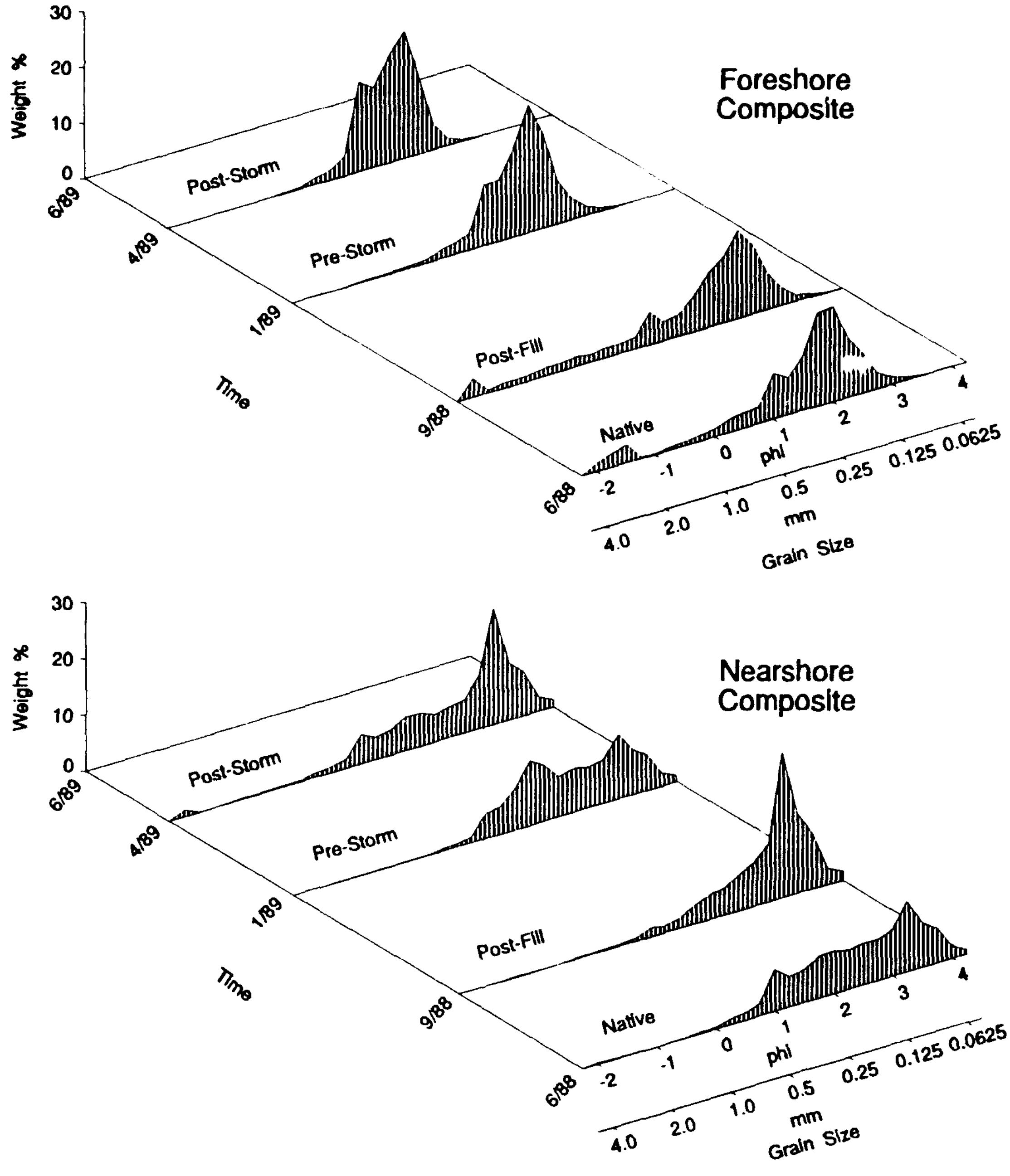


Figure 135. Time history of foreshore and nearshore sediment composite frequency curves at 66th St.

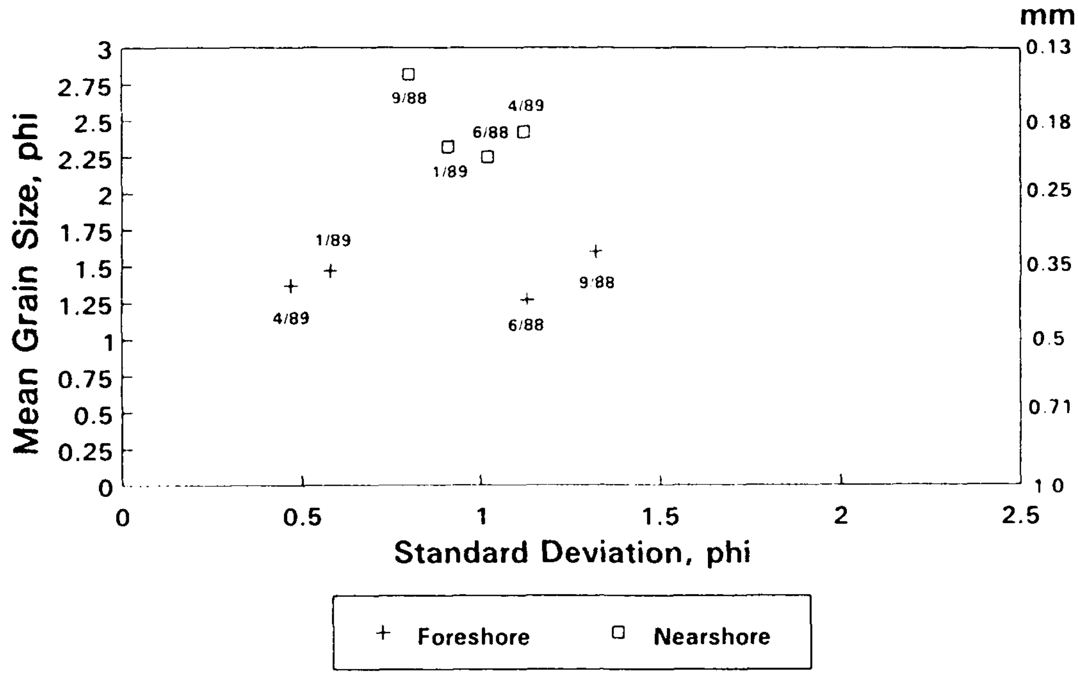


Figure 136. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 66th St.

distribution had an opportunity to re-sort the post-fill distribution. Storm-induced wave conditions improved the foreshore sorting. The improved sorting narrowed the range of grain sizes found on the foreshore to the central sand sizes, as both coarse and fine grain sizes were missing from these final two sample dates.

In contrast to the 37th Street samples, in which the foreshore and nearshore mean and sorting values were grouped close together throughout the study, the 66th Street samples had a distinct finer mean in the nearshore, which separated these composites from those on the foreshore area. The nearshore became finer and sorting improved after fill placement. A shift back to near native mean and sorting values was observed in the 4-month sample, and little change was observed after the storms in the nearshore composite statistical distribution.

81st Street sediment monitoring

The average cross-shore sediment mean distribution at 81st Street exhibited an anomalous distribution in the nearshore with a trend to coarse sand in the nearshore at a depth of 15 ft. The coarsest average means were located at the samples collected at the step and bar/trough (Figure 137). This survey location exhibited a bar/trough form only after the March 1989 storms. The rest of the surveys collected the so-called bar/trough samples on a concave shoreface slope between the step and the 5-ft depth. The standard deviation about the means had a wide range on all sample locations from the mid-tide sample seaward to the 25-ft depth, except for the 10-ft depth sample, which had the finest averaged mean and a narrow range of the means over the

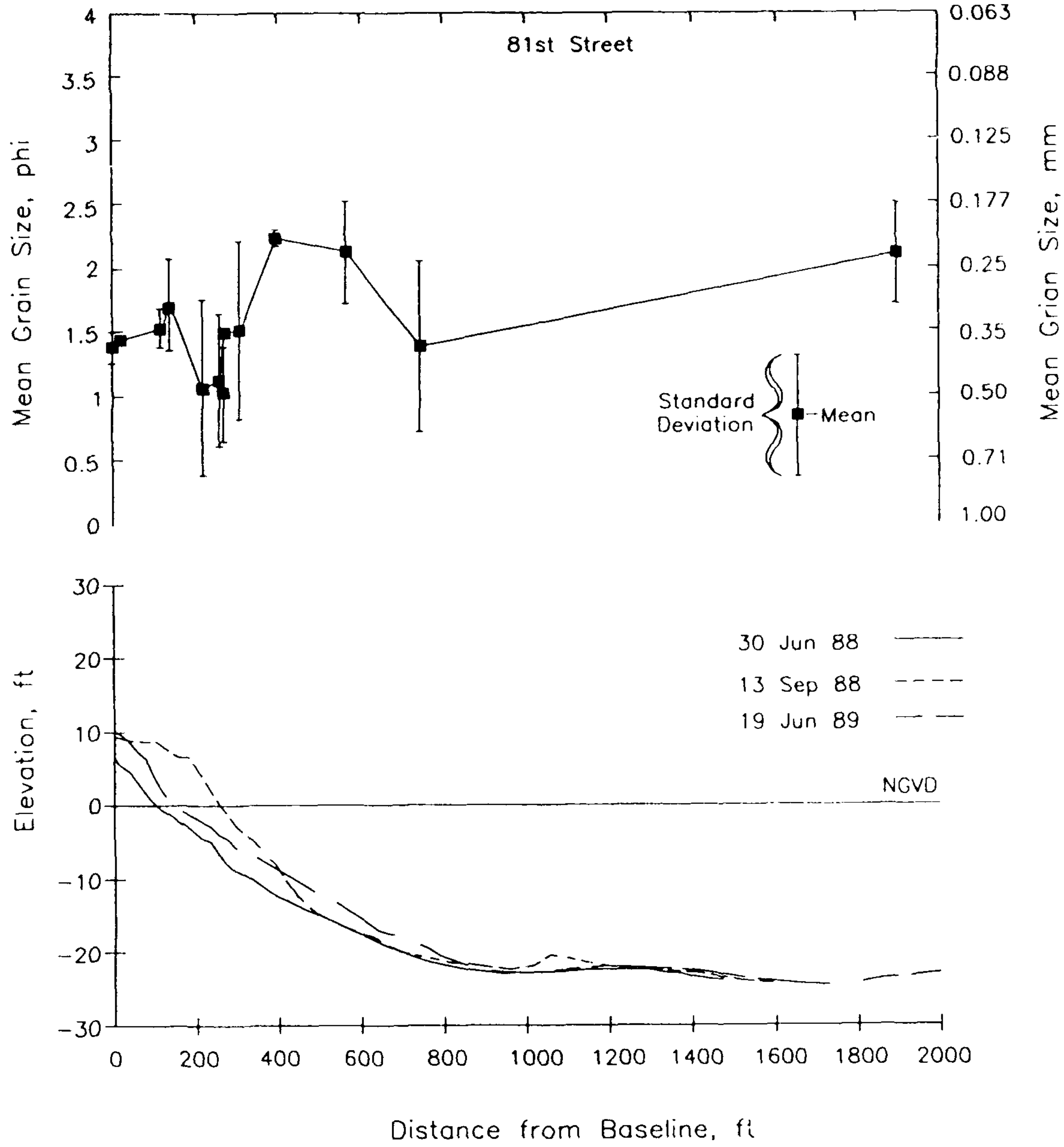


Figure 137. Cross-shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 81st St.

study period. The 81st Street survey location is in the lee of the southern shoreface-attached shoal. The flat shoreface slope, with an average 25-ft depth sample collected 1,900 ft from the baseline, was the profile with the most seaward active profile envelope.

The finest native beach foreshore sediment grain size distributions of the project study area were found at 81st Street. Of these samples, the coarsest native beach mean in the cross-shore sediment distribution was located at the step, as expected. In contrast, the coarsest means were found on the native nearshore area. The finest mean at this survey location was found at the 15-ft depth (Figure 138). Coarser means were found at the 20- and 25-ft depths. This coarsening in the offshore direction may be due to exposure in the nearshore of coarse natural gravel material in the flatter sloping offshore, seaward of the 15-ft depth. The post-fill sediment at this survey site was identified as having coarser means than the native material from the dune base to the step on the subaerial beach and at the 10-, 15-, and 25-ft nearshore depths. Even though the borrow material was from the finer southern borrow area, it was coarser than the native sand at this location. In the nearshore, the post-fill 5-ft depth sample had a mean similar to the pre-fill native mean and the only sample location that had a finer post-fill mean was at the 20-ft depth. After 4 months, there was little change in the mean grain size on the subaerial beach, except at the step, where the 4-month monitoring sample was finer than both the native beach and post-fill beach. The nearshore area had a mixed change in mean grain size. The 5- and 15-ft samples were coarser, and the 10-, 15- and 25-ft samples were finer than the post-fill samples. This initial re-sorting indicated that finer material was deposited in the nearshore except for the shallow 5-ft depth (located under the influence of breaking waves) and the 15-ft sample, where coarser native material may have mixed with the fill.

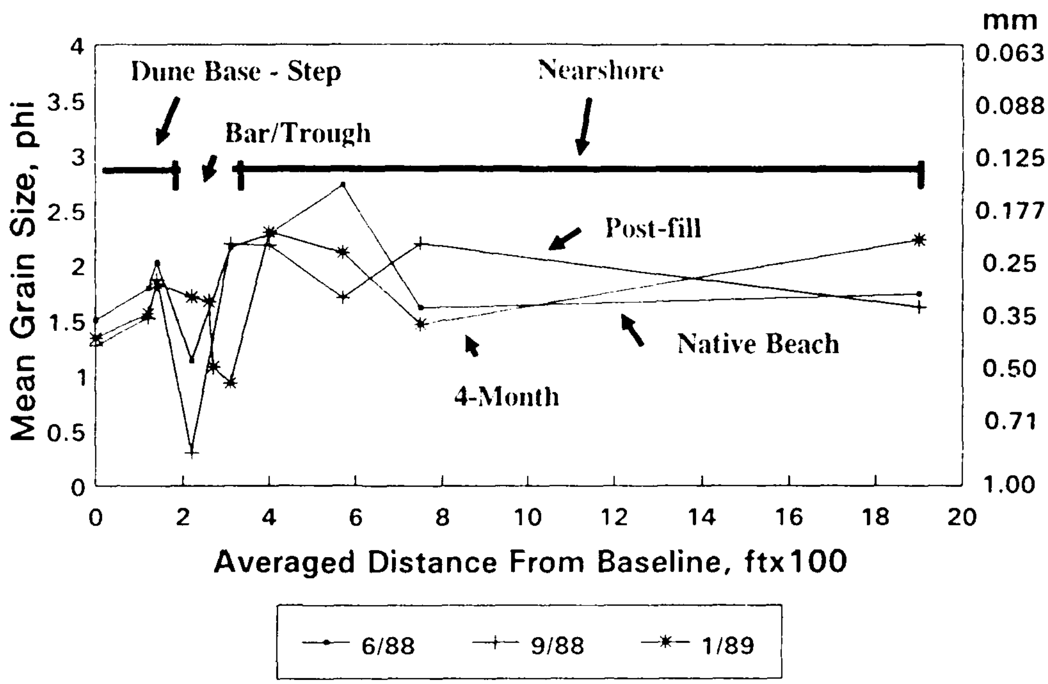


Figure 138. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month monitoring at 81st St.

After the storms, the 81st Street location exhibited a general coarsening in the cross-shore mean grain size distribution. The step and 20-ft-depth sample means were the coarsest. The only post-storm means that were finer than the pre-storm means were the dune base, bar crest, 5-ft and 25-ft depth samples (Figure 139). By June 1989, the 9-month monitoring mean grain sizes along the profile had returned to a distribution similar to the 4-month January 1989 means. The largest change occurred at the bar crest and 5-ft depth samples, where the coarsest means were found in the 9-month survey samples. The bar/trough feature filled in and returned to a more concave slope, with wave-induced turbulence probably controlling the coarseness of the means of these samples.

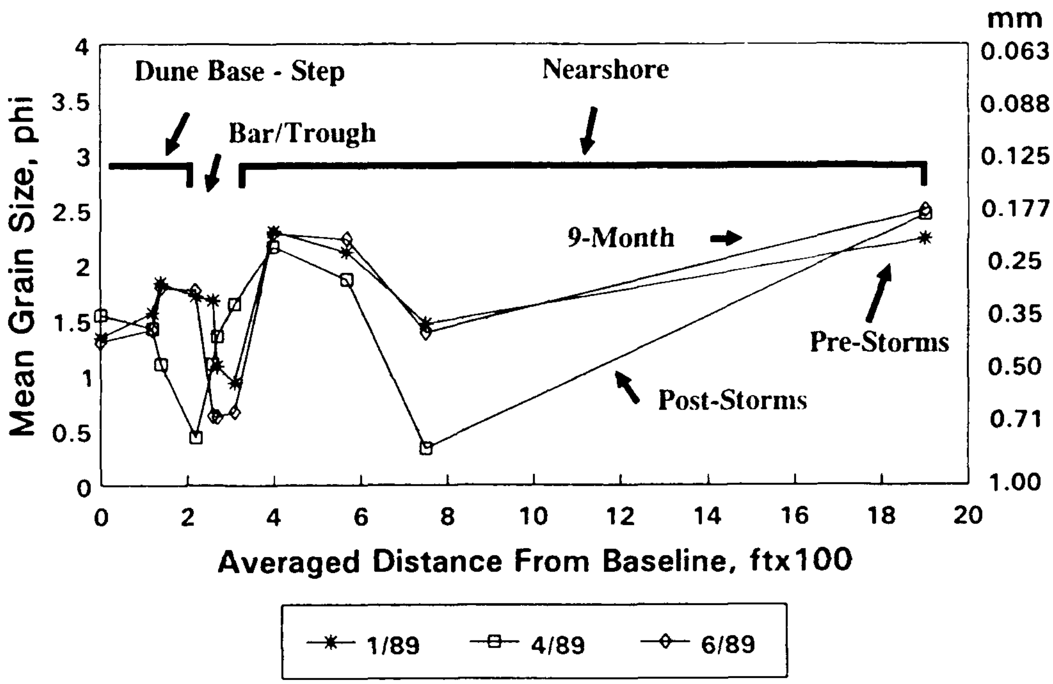


Figure 139. Cross-shore distribution of mean grain size for pre- and post-March 1989 storms and 9-month monitoring at 81st St.

The analysis of the composite grain size distribution for the foreshore and nearshore reduced the variability in individual samples and provided a mechanism for evaluating the time history of sediment change at 81st Street. The native beach foreshore composite contained a small percentage of gravel size material, with the bulk of the sediment occurring in the coarse to fine sand size range (Figure 140). This composite could be considered bimodal with the main percentage of material around 0.25 mm (2.0 ϕ) and a secondary peak around 0.5 mm (1.0 ϕ). After fill placement, the foreshore composite became coarser with the addition of coarse sands and gravel. Most of this material was found in the step sample on the September 1988 post-fill sampling. The only sediment survey location where the fill material had a coarser distribution than the native beach was 81st Street, due mainly to the coarser material centered at the high wave energy zone of the step. Because these samples were collected soon after the fill was placed and the fill extended to the 15-ft depth, this coarse material most likely came from the borrow material placed at 81st Street. Since mixing of the native and borrow material starts almost immediately after fill placement within the intertidal zone and particularly at the step, some of this coarse material may also be from the native beach. Over the first 4 months, as the

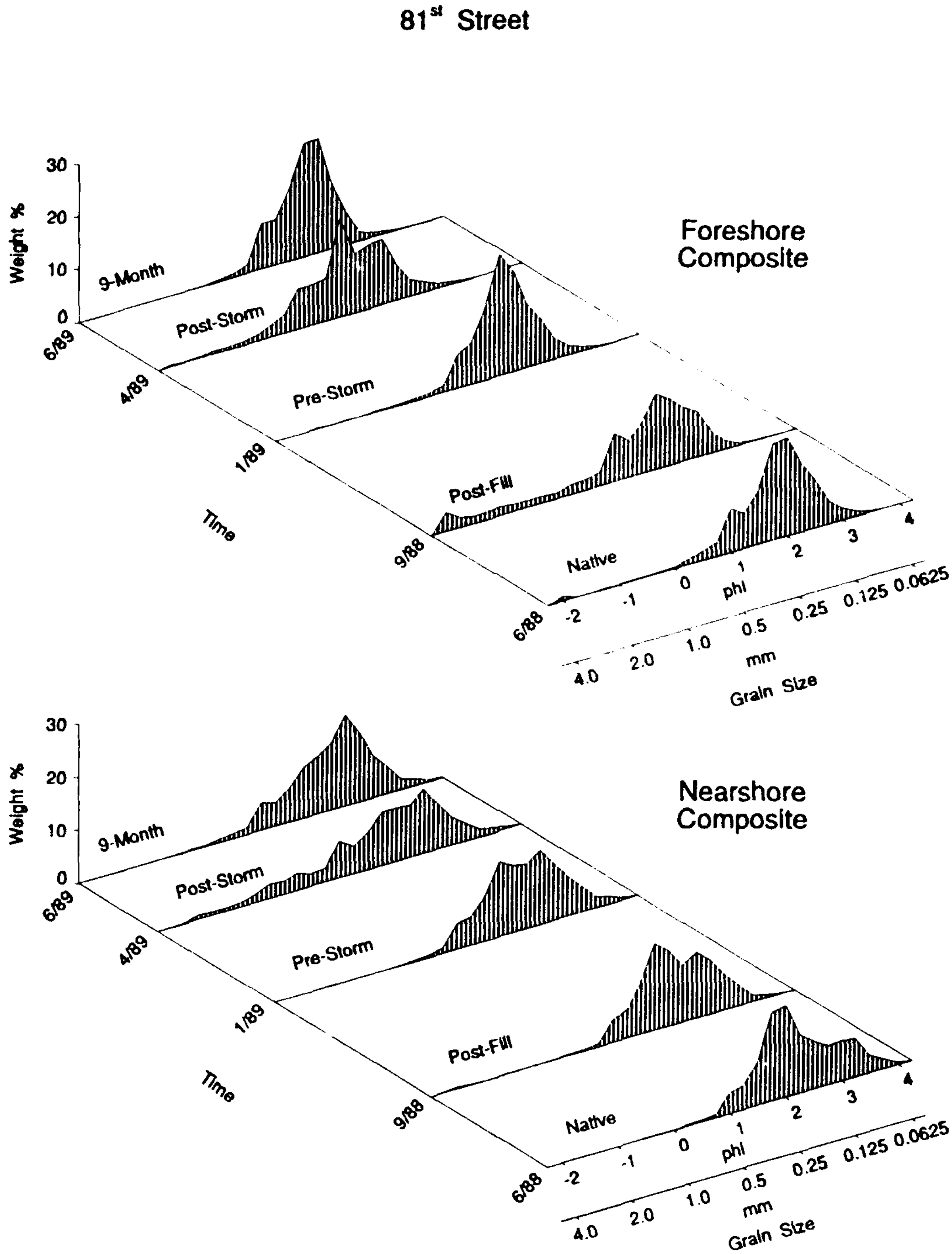


Figure 140. Time history of foreshore and nearshore sediment composite frequency curves at 81st St.

fill readjusted its profile shape, the foreshore sediment distribution returned to a distribution similar to the native beach composite. The coarse fraction was not present and may have been buried under the redistributed fill profile. No change in percent of occurrence was observed in the fine portion of the distribution from the native to the 4-month intertidal composite. The foreshore composite sediment distribution shifted to a coarser distribution after the passage of the storms in March 1989. The peak in the distribution shifted from 0.5 mm (2.0 ϕ) to 1.0 mm (1.0 ϕ), and a small percentage of gravel and coarse sand was present again. The shift to the coarse end of the distribution represents the increase in coarser sand deposition due to the higher energy of the storm. The fine material was eroded from the foreshore, leaving the coarser lag deposit. After deposition of sand back onto the foreshore over the spring months, the foreshore composite returned to a distribution very similar to the native foreshore. The means were identical and the 9-month sample was better sorted, with lower percentages of both coarse and fine material.

The native nearshore sediment composite at 81st Street contained mostly medium sand size material and was the coarsest native nearshore composite of the six sediment survey locations. No gravel or coarse sand was present in the area between the 5- and 25-ft depth at this survey location. The post-fill nearshore composite shifted slightly to a coarser distribution with the addition of material in the 0.177-mm (2.5-ϕ) size range and less fine material. This fine sand material was deposited between the 5- and 15-ft depth area where fill material was placed. Over the first 4 months of fill redistribution, the nearshore composite distribution changed little, indicating that the sediment size distribution of this area was stable even though fill sand was being deposited in this area. Storm impact to the nearshore composite distribution was to increase the percent of the coarse material as sand was deposited onto the nearshore from the foreshore. The 9-month composite of the nearshore sediment distribution showed a shift to the finer sizes and a return to a distribution slightly finer than the native nearshore composite. The coarse material present after the storm was either transported back to the foreshore or alongshore. There was only a small volume of sand recovery to the foreshore from the nearshore measured on the profile at 81st Street in June 1989.

A summary of the composite means and sorting of the foreshore and nearshore at 81st Street showed that there was more variability in the foreshore composites than in the nearshore (Figure 141). The foreshore composite became coarser and more poorly sorted after fill placement. At the same time, there was little change in the nearshore mean and sorting. With fill re-sorting in the first 4 months, the foreshore composite returned to a slightly finer mean, with better sorting. The nearshore again changed little. The impact of the storms on the foreshore composite was to increase the mean to the coarsest found at 81st Street during the project monitoring period with the addition of a coarse sediment lag that was moderately well sorted. The nearshore composite also became coarser and more poorly sorted after the storm, as fill was transported from the foreshore to the nearshore. With the return of fair weather wave conditions, the 9-month nearshore composite showed a return to a similar mean and sorting of the native nearshore composite. The 9-month foreshore composite showed a return to a mean value that was similar to the 4-month sample statistics, and it was the best-sorted sample of the 81st Street foreshore composites.

92nd Street sediment monitoring

The general trend in the cross-shore grain size means at 92nd Street exhibited a relatively

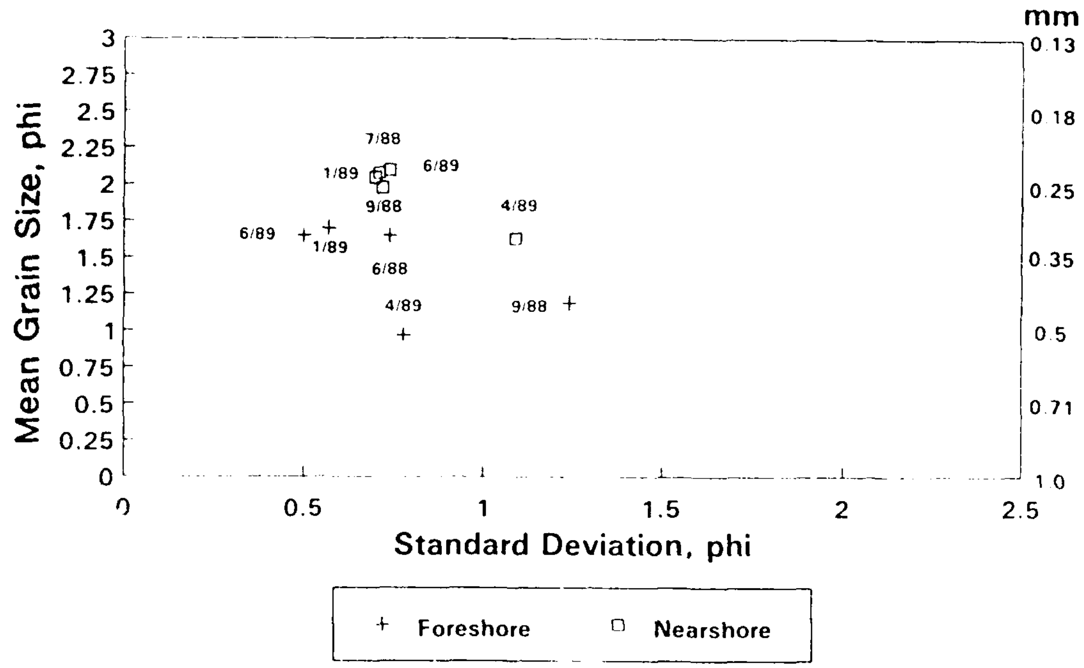


Figure 141. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 81st St.

coarse foreshore mean, with a fining in the offshore direction up until the 15-ft contour. The 20- and 25-ft depth sample means became coarser (Figure 142). Ninety-first Street was the transition location between the finer fill from Borrow Area 2 to the south and the coarser fill from Borrow Area 3 to the north. The coarser fill was the predominant component at this survey location. The coarsest average mean was found at the step and the finest average mean was located at the 15-ft depth sample. The 15- and 20-ft average means were the finest along the study area. The widest range in means was found at the step, and at the 5-, 10-, and 25-ft depth samples.

The native beach mean distribution in the cross-shore had a wide range in values, with the coarsest mean value of the monitoring study located at the step (1.27 mm or -0.35 ϕ) and the finest native mean at 92nd Street found at the 25-ft depth (0.12 mm or 3.09 ϕ). This native distribution had a common pattern of means found on the typical beach, with the fining in the offshore direction. The only variation on the distribution was the lack of a secondary coarse mean at the berm crest. The native subaerial cross-shore pattern was a progressive increase in mean grain size from the dune base to the step (Figure 143). The post-fill sediment mean distribution was coarser on the subaerial beach, except at the step, which was finer than the native beach, but was still the coarsest material on the post-fill beach. The means became progressively finer in the offshore direction out to the 15- and 20-ft depth, where the finest means of the post-fill study area were found at 0.09 mm (3.49 ϕ). The 25-ft depth sample was coarser than the native beach. The fill material was placed out to the 15-ft depth, but a thin layer of sediment accretion was measured out to the seaward extent of the profile at the 25-ft depth. After 4 months of wave sorting, the means from the dune base to the step became finer than either the native beach or post-fill mean. At the same time, the nearshore means became coarser than

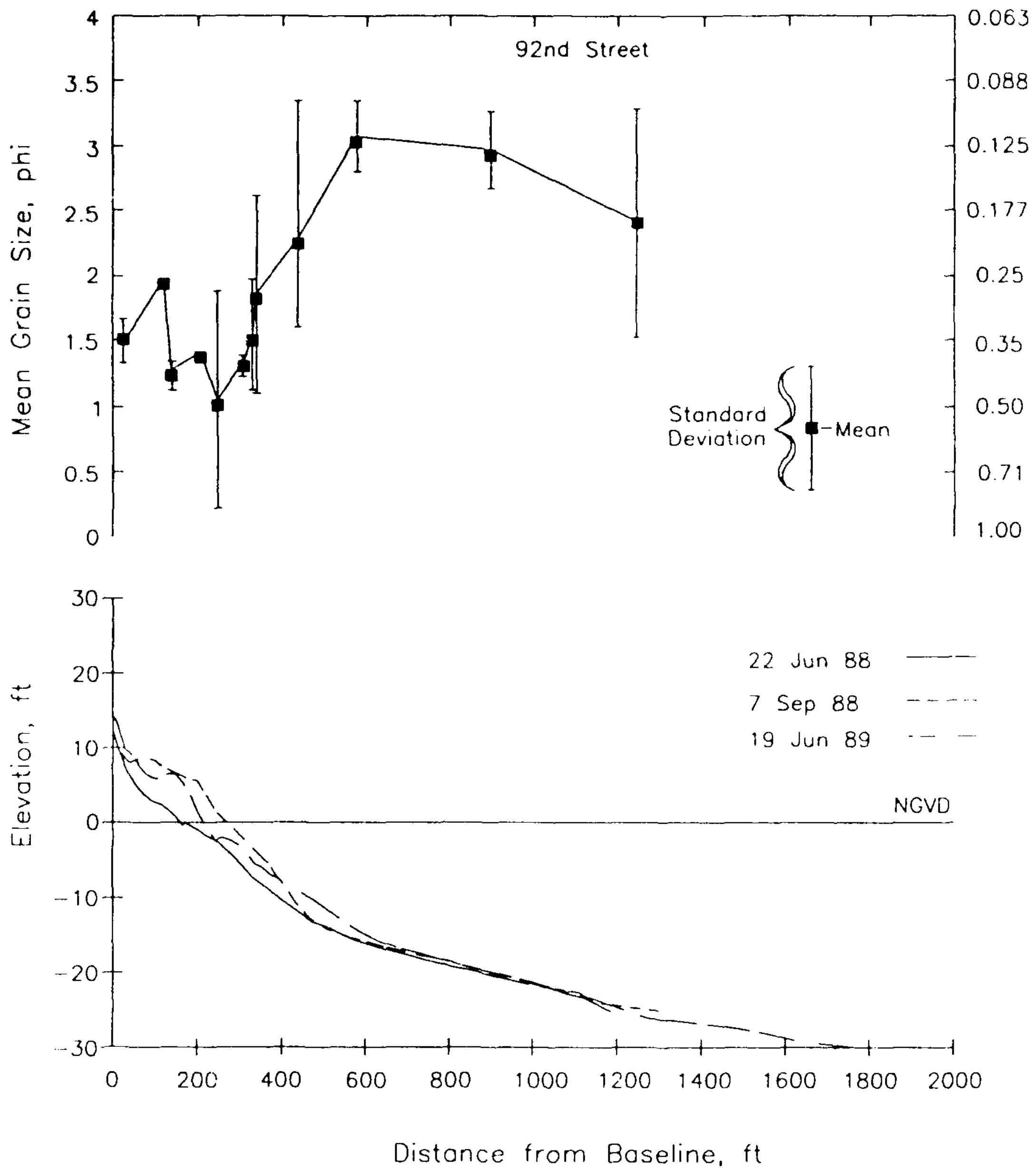


Figure 142. Cross-shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 92nd St.

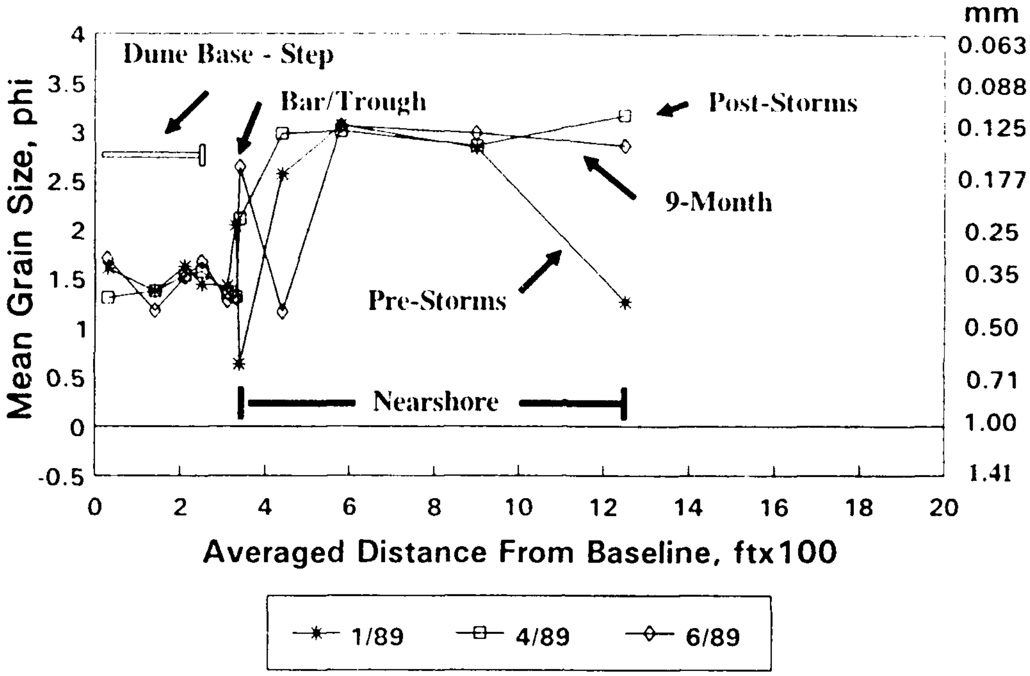


Figure 143. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month monitoring at 92nd St.

the post-fill means, with the coarsest nearshore mean value at the 25-ft depth. The coarse mean at the 25-ft depth was similar to the coarse post-fill mean.

After the March 1989 storms, the cross-shore change in mean grain size had a complex pattern (Figure 144). The dune base sample mean became the coarsest dune base sample over the study period at 92nd Street. The foreshore samples, which included the berm crest, mid-tide and step, remained close to the same mean values as before the storms. The nearshore sample means became finer at the 5- and 10-ft sample depths, remained the same at the 15- and 20-ft sample depths, and became much finer at the 25-ft depth sample, returning to a mean slightly finer than the native mean. In general terms, this deposition of fine material in the nearshore came from winnowing the finer material from the foreshore, but the fine grain size material most likely did not come from the subaerial beach at 92nd Street, since these beach samples did not become significantly coarser. The volume of material lost from the subaerial beach was not deposited in the offshore along this profile, because little elevation change was measured in the nearshore. A thin layer of fine material was deposited in this nearshore region after the storm. The 9-month sediment sample means showed little change from the post-storm samples. The dune base sample had the finest mean of the study period, probably owing to the wind transport of finer material to the dune base over the spring months. The berm crest became coarser, the mid-tide remained the same, and the step became slightly finer than the post-storm samples. The nearshore samples had more variability, particularly in the shallow areas. The 5-ft depth sample mean became finer than the post-storms sample as this area of the profile experienced some minimal accretion as the sand returned to the foreshore from the offshore. The 10-ft sample mean became the most coarse of the 9-month survey and was significantly more coarse than the

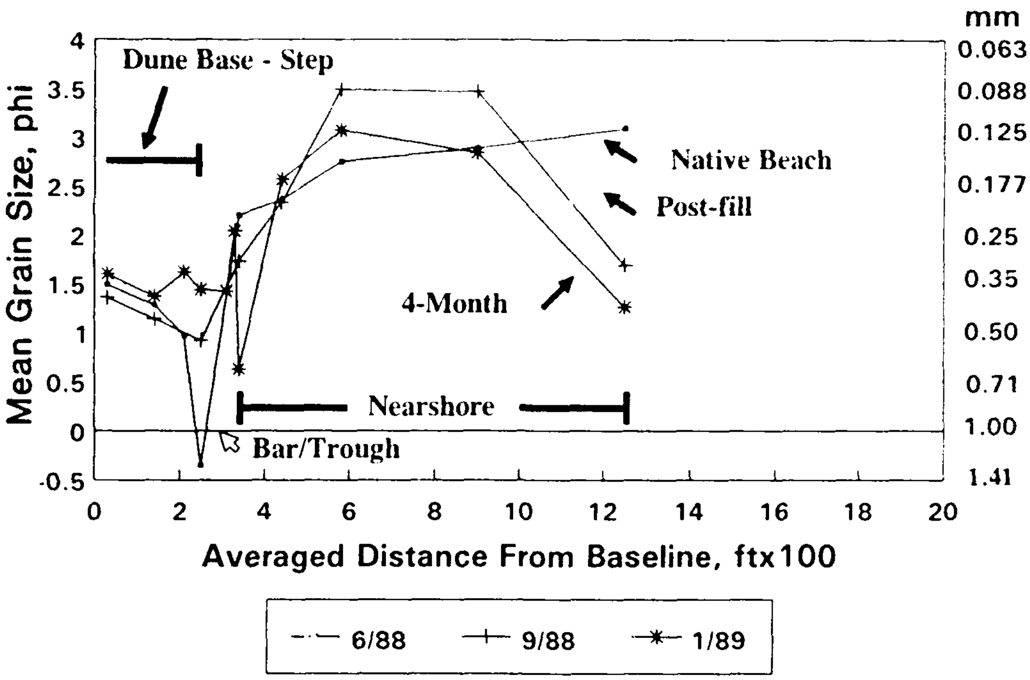


Figure 144. Cross-shore distribution of mean grain size for pre- and post-March 1989 storms and 9-month monitoring at 92nd St.

post-storms sample at that location. The 15-, 20-, and 25-ft depth samples remained very similar to the post-storm means. The 15-ft sample showed little change in the mean since the 4-month sample of January 1989. The 20-ft sample mean was slightly finer and the 25-ft sample mean was slightly coarser than the post-storms samples.

With this somewhat complex pattern in individual sample change across the profile, the creation of the foreshore and nearshore composites was necessary to reduce the variability. Even with the composite analysis, this location had a dynamic change in sediment grain size distribution. The native foreshore composite showed a poorly sorted sample with a wide range of grain sizes, from gravel to fine sand, present (Figure 145). This site had the coarsest native foreshore composite distribution of the study. Even though the fill material placed at 92nd Street came from the coarser Borrow Area 3, the native beach foreshore composite was coarser than the post-fill composite. The post-fill foreshore had a wide range of grain sizes, indicating poor sorting, but contained less coarse material and more fine material than the native foreshore, making the post-fill composite finer relative to the native. After the first 4 months, the fill material had re-sorted to produce a moderately well-sorted foreshore composite, containing no gravel or coarse sands. The fine fraction was also winnowed away, to produce a more typical ocean beach foreshore composite, as found at other sites in the study. The response of the foreshore composite to the storms resulted in very little change in the grain size distribution. The post-storms sample became even better sorted with the loss of a portion of the coarser and finer ends of the distribution. No coarse material was exposed even though sand was eroded from the foreshore. Even after 9 months, the foreshore composite grain size distribution was basically the same as the 4-month and post-storm distribution. With little volume change or accretion

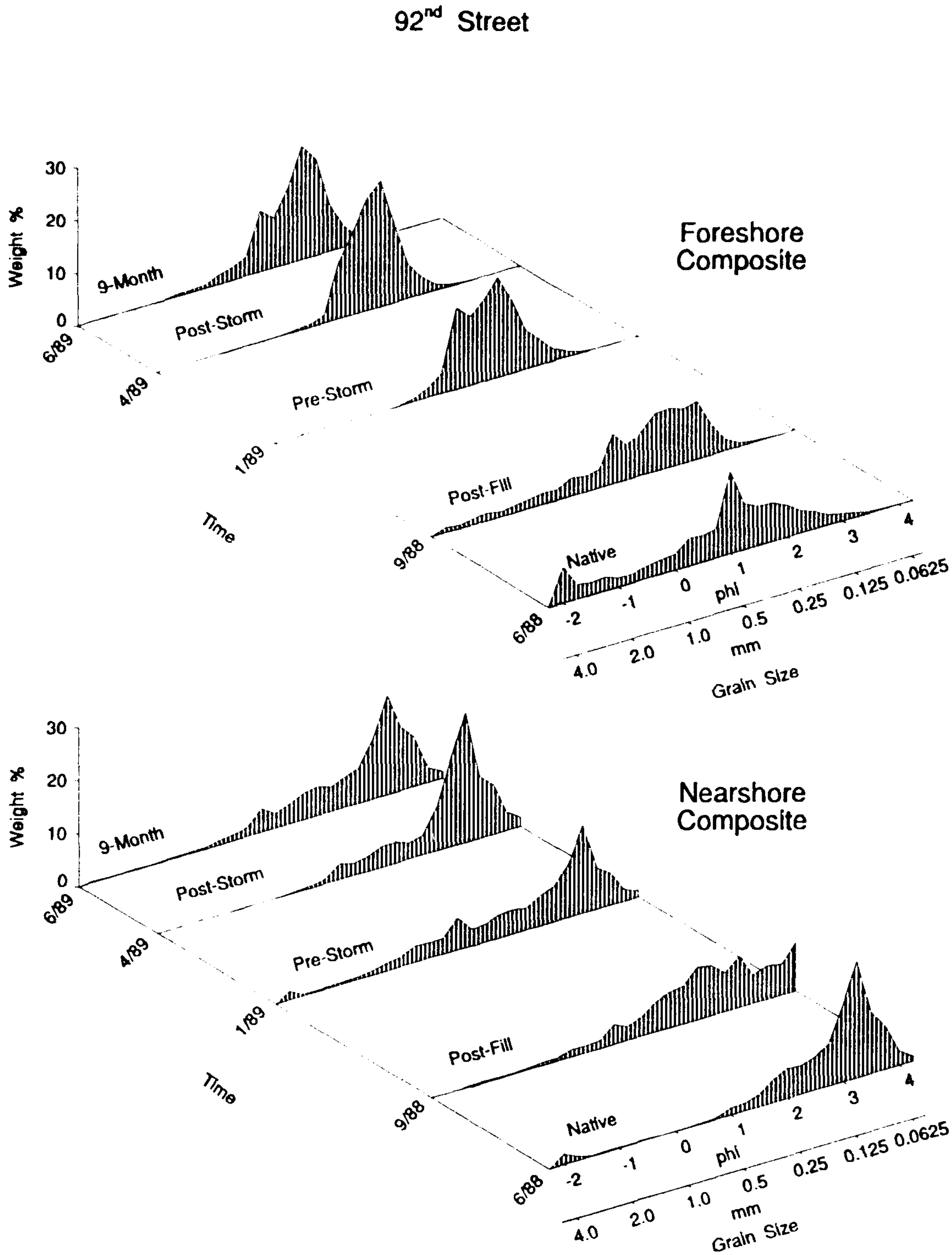


Figure 145. Time history of foreshore and nearshore sediment sample composite frequency curves at 92nd St.

measured on the foreshore at 92nd Street after the 9-month monitoring, only a slight shift to coarser grain sizes was found, with a slight decrease in sorting.

The nearshore composites at 92nd Street exhibited a distinct finer grain size distribution than the foreshore composite. The native nearshore composite contained about a 2-percent coarse gravel component and a predominant fine sand component, with a pronounced peak around 0.125 mm (3.0 ϕ). The gravel was found in the 5-ft depth sample. The post-fill nearshore composite contained a more poorly sorted sample than the native, with an increase in the coarse gravel component, and more coarse sand size material. A very fine sand size component was also present. Four months after fill placement, the nearshore composite still contained a coarse component and was more poorly sorted than the post-fill sample, with a gain in the 4.0-mm (-2.0-ϕ) gravel component and coarse sand size fractions. The frequency curve peak returned at around 0.125 mm (3.0 ϕ), similar to the native nearshore distribution. The very fine sand fraction was also winnowed out. The March 1989 storms produced a more well-sorted, finer nearshore distribution with no coarse material and a gain in percent composition of the fine sand size frequency curve peak. Within the 9-month monitoring period, the nearshore composite shifted back to a slightly coarser distribution with an increase in the coarse to medium size sand component.

Ninety-second Street sediment samples contained a wide range of grain sizes, with a large coarse component in both the foreshore and nearshore, which produced poorer sorting values. There was a wide range in the mean grain size of the foreshore and nearshore (Figure 146). The coarsest, most poorly sorted native beach foreshore composite sample was found here. The post-fill nearshore composite was finer and slightly better sorted. The evolution of the nearshore

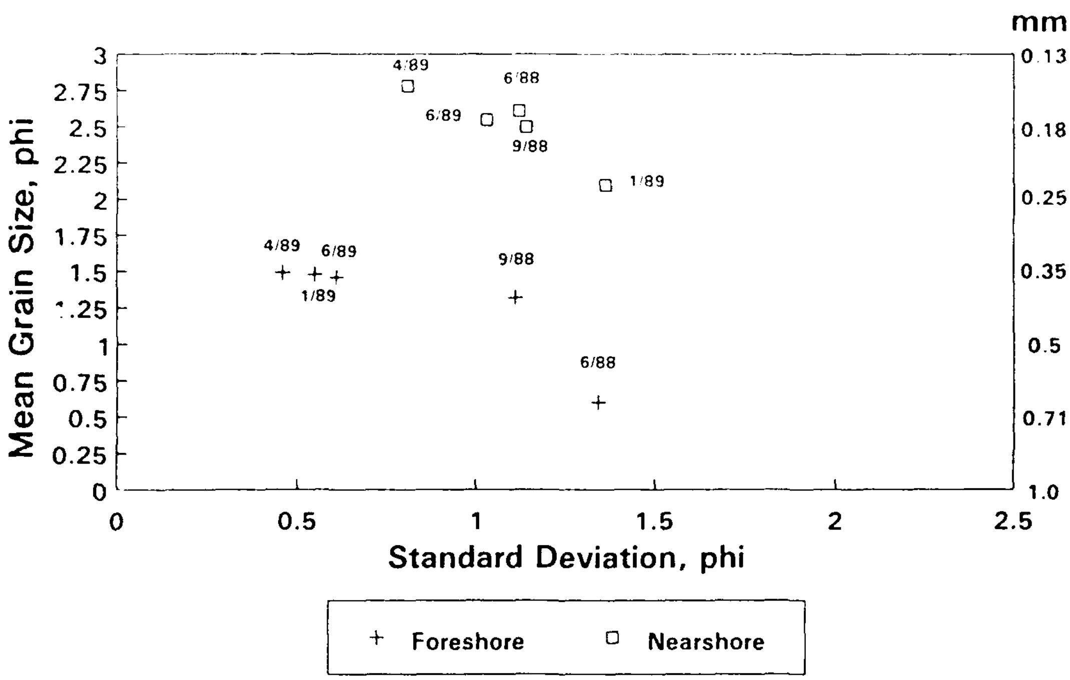


Figure 146. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 92nd St.

composites over the monitoring period showed that the means were practically constant, with little change in sorting values over the 9-month study. The coarse material located in the shallow nearshore produced more poorly sorted nearshore composites, with fine sand size means. The coarsest mean with the poorest sorting occurred at the 4-month nearshore composite sample. The finest, best-sorted sample occurred after the storms. The mean and sorting values of the native nearshore were similar to the post-fill samples and returned to similar values by the 9-month sample.

103rd Street sediment monitoring

At the northern end of the study area, at 103rd Street, the cross-shore pattern in average grain size means shows a progressive fining in the offshore direction from the dune base, except for the step sample average mean. The averaged mean of the trough was the coarsest mean on this survey line (Figure 147). There was no significant bar/trough configuration on this profile, and the trough and bar samples were collected between the step and the 5-ft depth contour along the concave profile planform. The averaged mean of the trough represents the area on the profile where the breakers were most likely to be located and the highest turbulence was present, thus controlling the deposition of coarser material. Beginning with the 5-ft depth sample and progressing to the 25-ft depth sample, the averaged means became finer than 0.25 mm (2.0 ϕ) indicating in general a lower energy environment of deposition in the offshore. The averaged means of the subaerial beach area were relatively uniform in grain size, and the coarsest material on the dry beach was found at the dune base. This anomalous distribution of the coarsest averaged mean was due in part to the native beach grain size distribution and also to the beach fill disruption of this native distribution. The highest range in mean values was found at the so-called bar sample and also at the 25-ft depth sample. The most uniform range in means was found at the 10- and 15-ft depth samples.

The distribution of the native beach grain size means exhibited a typical cross-shore beach pattern, with the coarsest mean found at the step. No secondary coarse sand was found at the berm, but the dune base was the second-coarsest mean on the native profile (Figure 148). The finest native mean was found at the 20-ft depth, with a secondary fine mean at the 5-ft depth. A non-typical increase in coarseness was found at the 25-ft depth sample, a possible relict coarse sediment deposit. The post-fill mean grain size cross-shore pattern had an increase of the dune base sample, no change of the berm crest sample, and a decrease in the step sample relative to the native beach. No post-fill mid-tide samples were collected. The nearshore sample means were relatively uniform and slightly coarser than the native nearshore means. No post-fill 25-ft depth sample was collected. A redistribution of sand in the first 4 months of the State fill project monitoring had only minor changes in the cross-shore means. The dune base returned to a mean similar to the native beach. The berm crest sample mean became coarser than both the native beach and the post-fill mean. The 4-month monitoring mid-tide sample was finer than the native beach and the step sample was between the coarse native beach and fine post-fill sample means. The 5-ft depth nearshore sample mean continued its trend to a coarser mean from the native sample mean as the fill material was deposited in that area. The 10-ft sample mean remained basically unchanged throughout the initial phases of monitoring. A finer mean was found at the 10-ft depth and the 15-ft sample mean returned to the native mean. The 4-month sample was much finer than the native sample mean in the 25-ft depth.

The impact of the storms on the mean sediment pattern in the cross-shore at 103rd Street was

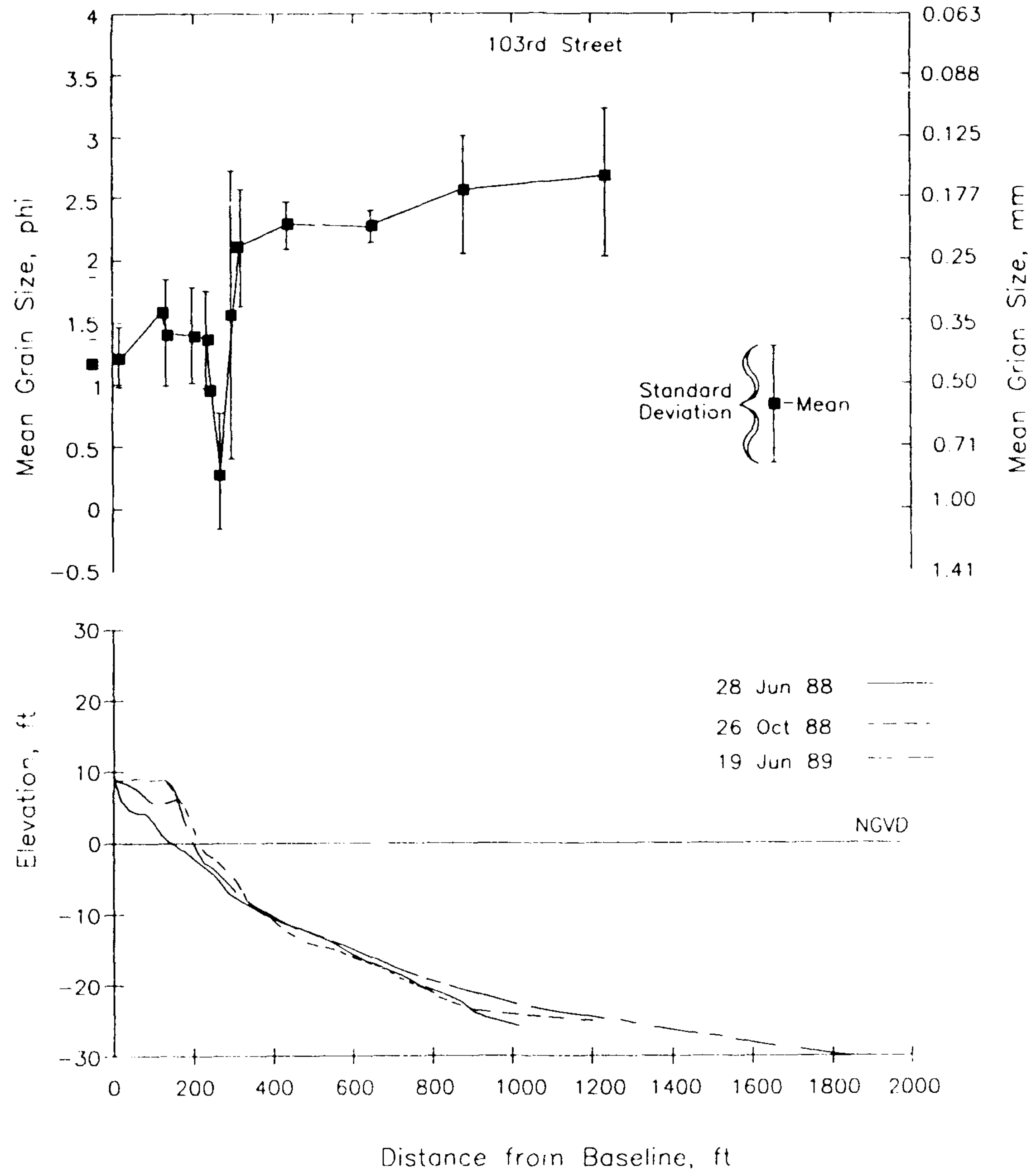


Figure 147. Cross-shore distribution of averaged mean grain size and range of standard deviation compared with profile envelope at 103rd St.

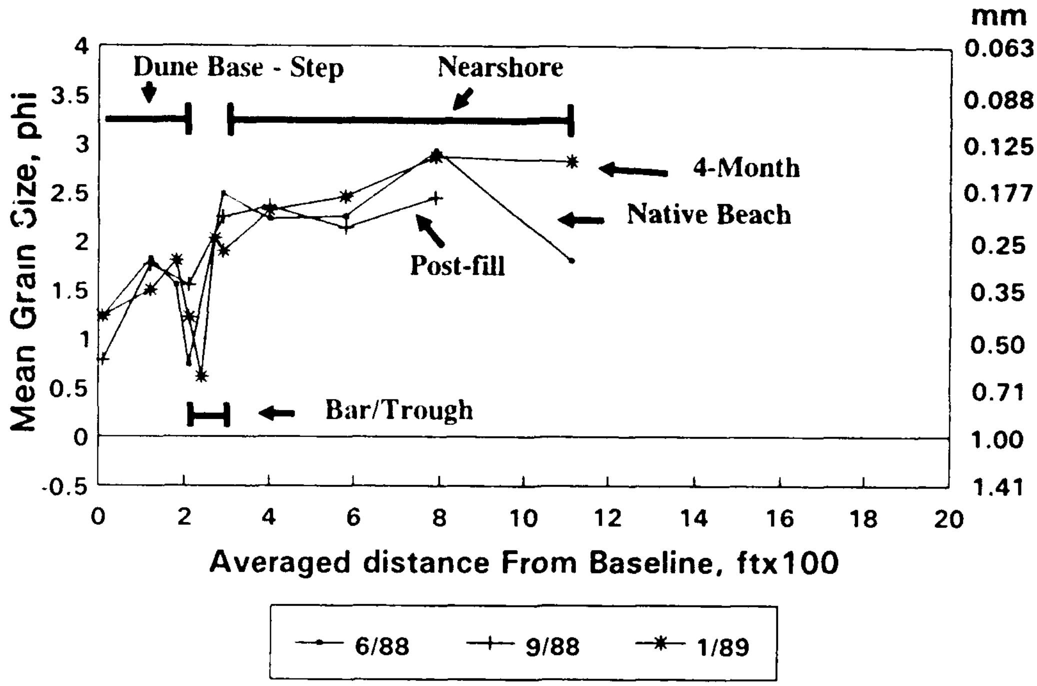


Figure 148. Cross-shore distribution of mean grain size for pre- and post-State fill and 4-month monitoring at 103rd St.

one of general coarsening. While the dune base became finer, the berm crest and mid-tide samples became coarser as the beach eroded (Figure 149). This post-storm step mean was finer than the pre-storms step sample, with the coarsest mean found in the trough/bar samples. The nearshore 5-, 15-, and 20-ft depth sample means were coarser than the pre-storms means and the 10- and 25-ft depth sample means became finer. Over the 9-month monitoring period, the recovery of the beach from the storms presented a mixed cross-shore pattern in sediment sample mean change. The dune base sample mean returned to its original native mean and the berm crest mean became finer than the post-storms mean as the berm accreted. The 9-month monitoring mid-tide mean became coarser than the post-storm mean and the step became slightly coarser than the post-storm step mean. The coarsest mean was still found at the "trough" sample, which probably was located more in the high energy breaker zone. The bar and 5-ft sample means became finer than the post-storms samples as this part of the profile gained sand. The rest of the nearshore sample means became coarser than the post-storms means as this part of the profile lost sand volume.

The 103rd Street survey location was also nourished with the coarser Borrow Area 3 sand. The construction of composite sediment samples aided in reducing the variability of this complex individual sediment distribution fluctuation. The native foreshore composite at 103rd Street was similar to that at 92nd Street, and was poorly sorted with a size range from gravel (4.0 mm or -2.0 ϕ) to very fine sand (0.088 mm or 3.5 ϕ). The sample was bimodal (Figure 150) with peaks at 0.5 mm (1.0 ϕ) and 0.30 mm (1.75 ϕ), and with a small peak at 4.0 mm (-2.0 ϕ). Just as at 92nd Street, the post-fill foreshore composite was finer than the native, with a lack of gravel size and an excess of fine sand as compared with the native distribution. The post-fill sample exhibited the same bimodal distribution, except the finer peak shifted to around 0.25 mm (2.0 ϕ). As the fill material was re-sorted, the 4-month foreshore composite shifted slightly to a finer

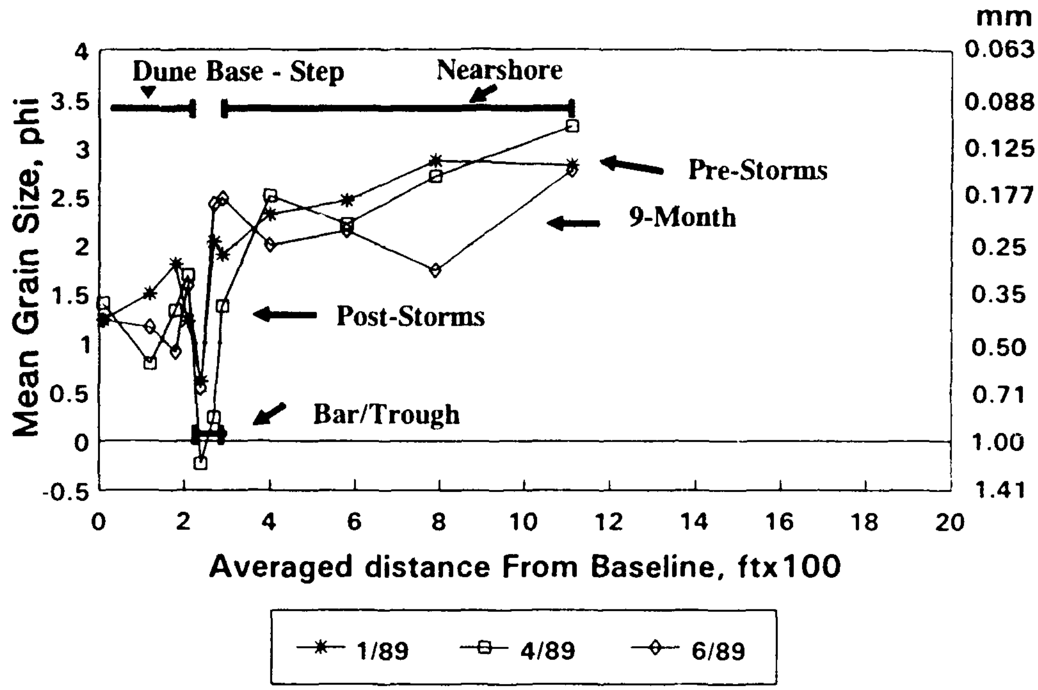


Figure 149. Cross-shore distribution of mean grain size for pre- and post-March 1989 storms and 9-month monitoring at 103rd St.

grain size with a loss on the coarse end and a gain on the finer end of the distribution. The bimodal distribution was preserved, with a shift of the fine peak back to the native 0.30 mm (1.75 ϕ). While the bimodal peaks were preserved, a gravel fraction was again found after the March 1989 storms. The higher energy storm waves also winnowed out the fine sand from the foreshore composite. Very little change was observed in the foreshore composite distribution of the 9-month monitoring, with a slight increase in the percentage of material in the coarse sand size fraction, as the foreshore regained sand volume.

The nearshore composite was again much finer than the foreshore composite at 103rd Street. The native nearshore composite had a nearly bell-shaped unimodal distribution with a peak around 0.177 mm (2.5 ϕ). No gravel or coarse sand were present at this location in the native nearshore grain size distribution. The post-fill nearshore sediment distribution was almost identical to the pre-fill native beach with only a slight shift to finer grain sizes. The State fill material was placed mainly on the subaerial beach and did not reach far into the nearshore. After 4 months, the nearshore composite had shifted to a finer size distribution as the fill re-sorted itself. A small percentage of gravel and coarse sand size material was also found in the distribution. The medium sand was replaced with fine to very fine sand. The March 1989 storms caused a slight shift to coarser sand sizes with an increase in the percent of gravel and coarse sand. A small percentage of the very fine sand material was winnowed out. The bulk of the nearshore sand was still composed of fine sand. By the 9-month survey, the nearshore composite had shifted back to a coarser distribution, with the removal of the fine portion of the distribution and the gain of medium sand size material. Some coarser sand material was also removed from the distribution.

103rd Street

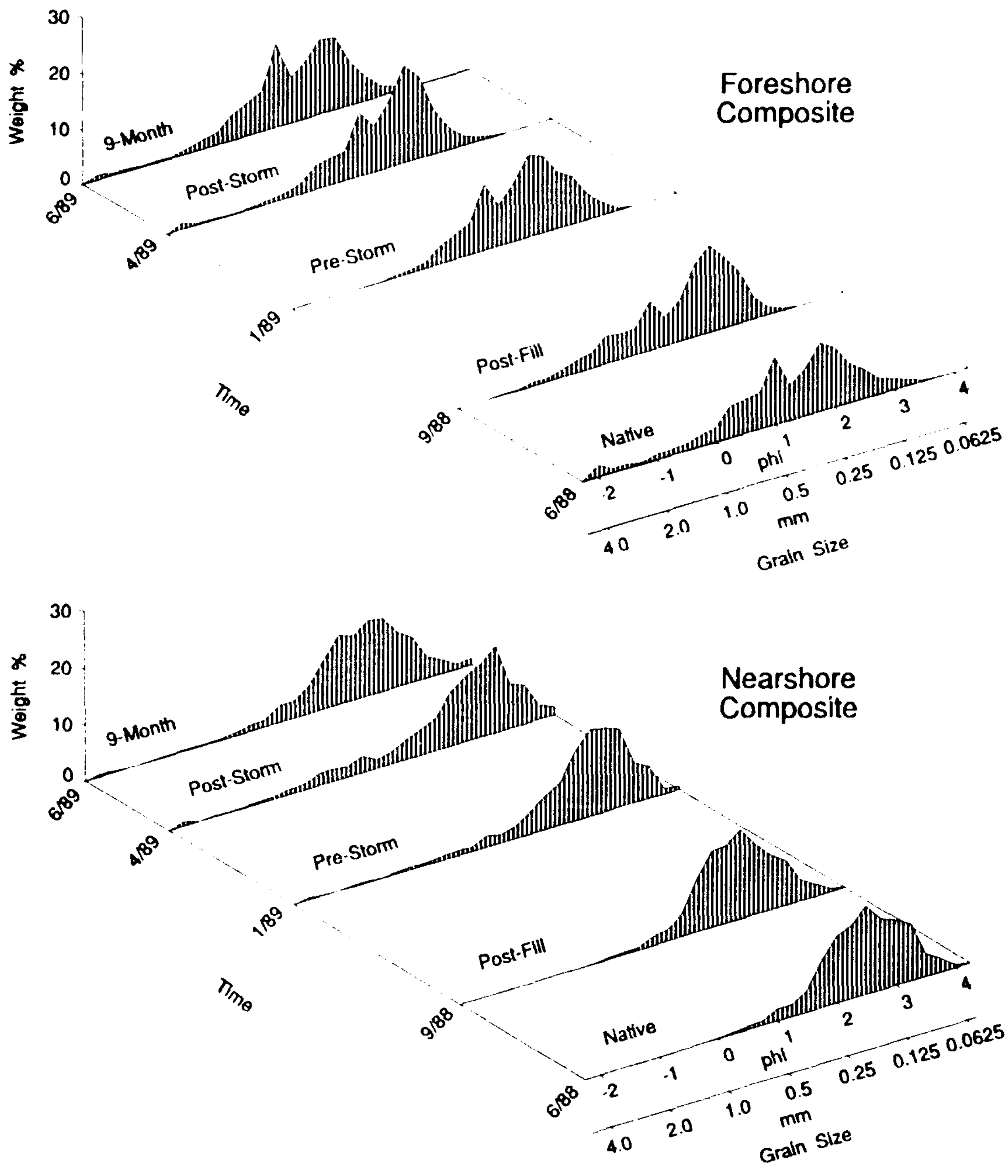


Figure 150. Time history of foreshore and nearshore sediment composite frequency curves at 103rd St.

To summarize the grain size distribution at 103rd Street, Figure 151 shows the distribution of the foreshore and nearshore composite mean and sorting values over the monitoring period. The coarsest and most poorly sorted material was present on the foreshore of the native beach. The fill material was finer and better sorted than the native foreshore. The 4-month samples became finer and better sorted in the foreshore distribution. The impact of the storm on the 103rd Street profile resulted in a shift to a coarser mean grain size and more poorly sorted distribution similar to the post-fill sample. After 9 months, the nearshore distribution became coarser and more poorly sorted and trended back to the native foreshore composite. The nearshore native beach was fine-grained and well-sorted. After fill placement, the composite distribution of the nearshore showed little change. By the 4-month sampling, the nearshore had the finest composite mean, but poorer sorting with the inclusion of some coarser material. The storms produced the poorest sorting of the nearshore composite, but retained a basically fine size distribution. After 9 months, the nearshore composite became coarser and better sorted.

Alongshore sediment distribution patterns

Each of the sediment sample survey locations had a unique sediment distribution history through the monitoring period. The nearshore had characteristically finer material than the foreshore. In the 4-month composite,the coarsest native foreshore material was located at 92nd and 103rd Streets and the coarsest nearshore native sand was found at 81st and 37th Streets (Figure 152). The finest native nearshore material was found at 92nd Street, giving this site the widest range in foreshore-to-nearshore grain size variations. Both 81st and 37th Streets had the finest and best-sorted foreshore material and had the smallest grain size range between the native

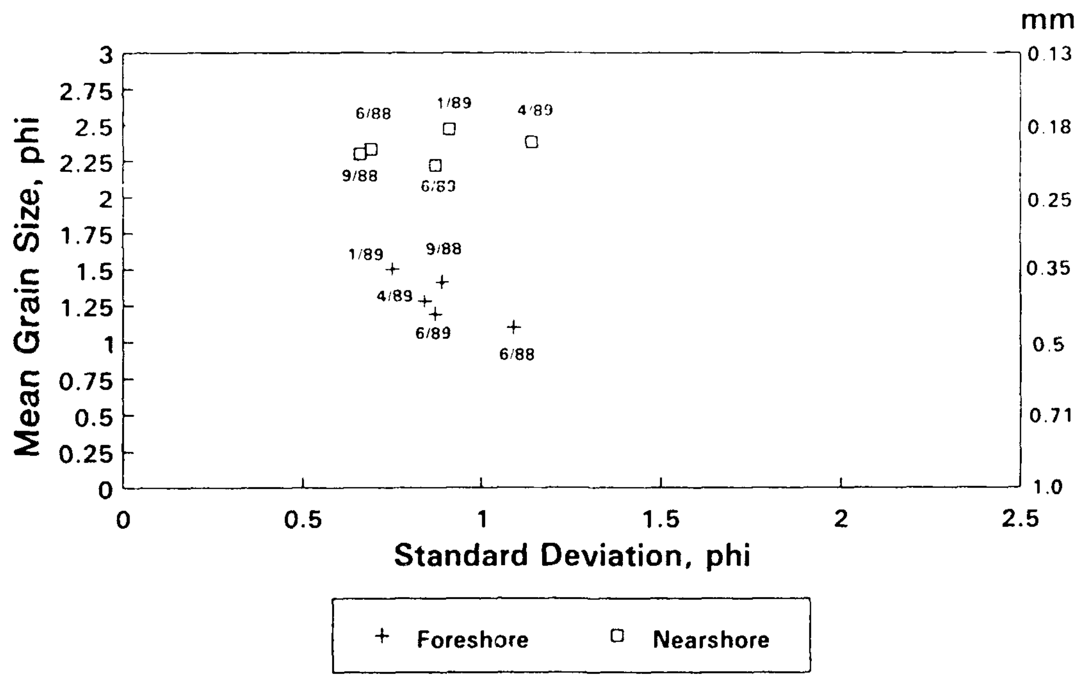


Figure 151. Time history of foreshore and nearshore sediment composite mean grain size and sorting at 103rd St.

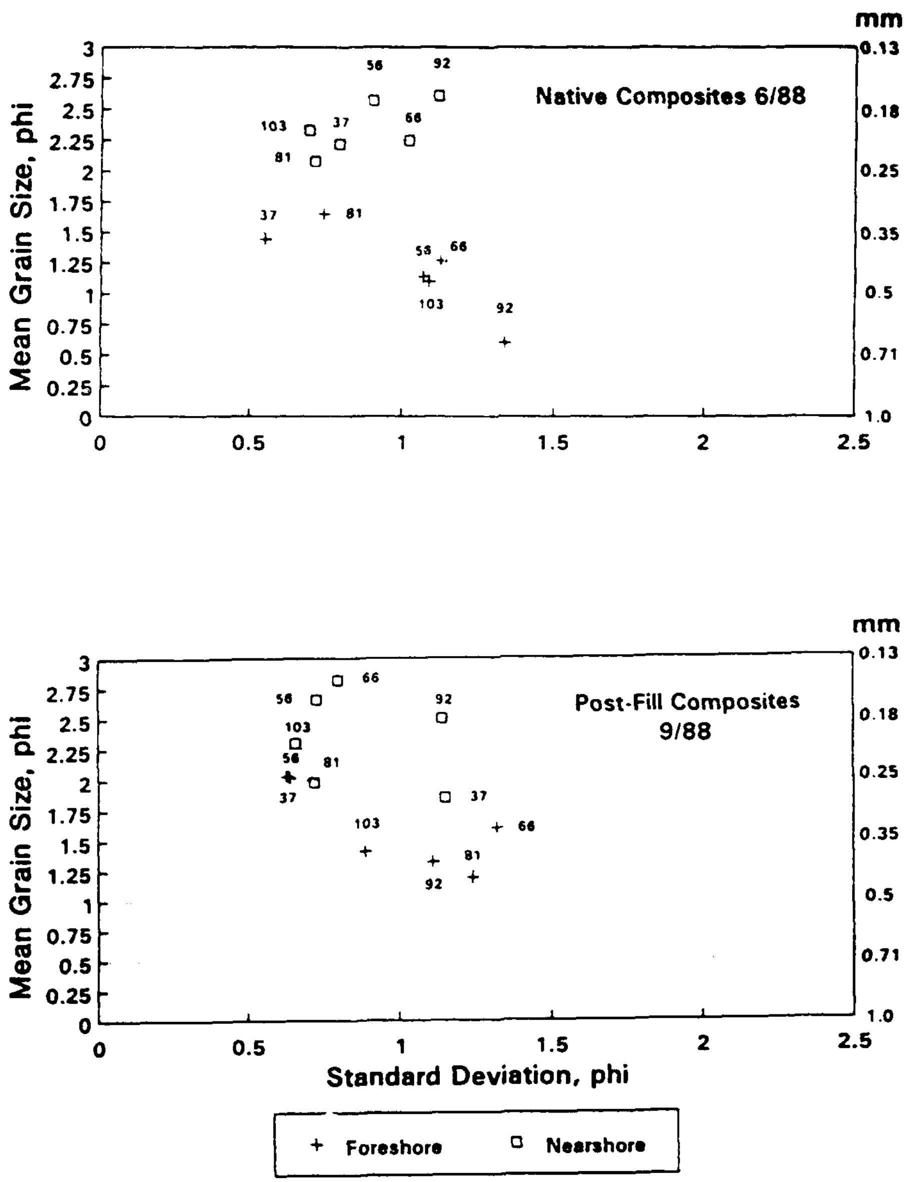


Figure 152. Comparison of the composite grain size and sorting of the foreshore and nearshore native and post-fill sediment of the six sediment monitoring survey lines

foreshore and nearshore. The general trend was for the finest native foreshore composites to have the best sorting, as would be expected. The opposite trend was found in the nearshore, with the coarsest nearshore native composites having the best sorting and the finest composite means having the poorest sorting.

The fill material had a finer foreshore distribution than the native beach at all locations except 81st Street, even though the fill material came from two different borrow areas. The finer Borrow Area 2 material in the south was placed on the beach starting from the south and moving north to around 91st Street. The coarser fill material was placed north of 91st Street, but the native beach was also coarser on the north end of the project. In the 6-month composite, the coarsest foreshore fill material was found in the northern end of the project at 81st and 92nd Streets, and the finest foreshore fill material was found to the south at 37th and 56th Streets (Figure 153). In general the finer grain sizes had the better sorting, except for 66th Street, which had the poorest sorting of the post-fill foreshore composites. The coarsest post-fill nearshore material was found at 37th and 81st Streets, where the fill was placed further into the nearshore. This nearshore material was coarser than the foreshore composite at 37th Street. The finest nearshore composites were found at 66th and 56th Streets. The trend in sorting somewhat followed the trend of finer grain sizes having the better sorting, even though the fill was on the nearshore for only a short time.

A complex pattern of grain size change was observed over the monitoring period. In general over the study period, the coarsest nearshore material was found in the southern end of the project at 37th and 81st Streets (Figure 153). The finest nearshore material was found at the northern end of the project at 92nd Street. Four months after fill placement, the foreshore composites of all beaches had the smallest range in composite mean and sorting values, with the coarsest material at 66th and 92nd Streets and the finest at 37th and 81st Streets. The finest nearshore material was found at 56th and 103rd Streets, and the coarsest nearshore material was located at 37th and 81st Streets. No trend in sorting could be found as the sediment interacted with the waves to re-sort the fill. After the storms in March, the coarsest foreshore material was found at 81st Street. The finest foreshore material was found at 56th, 92nd, and 37th Streets. The coarsest nearshore material was also found at 81st and at 37th Streets. This made for a narrow range in means and sorting between the foreshore and nearshore at 37th Street. The finest nearshore material was found at 92nd Street. Due to the high energy of the storms, the composite sediment sorting on either the foreshore or nearshore had no significant trend.

The final sediment monitoring samples were collected 9 months after fill placement. Because 56th and 81st Streets did not have samples analyzed at this time, only four sediment survey locations were evaluated. The coarsest foreshore composite sediment was located at 103rd and 92nd Streets and the finest was at 81st and 37th Streets. The coarsest nearshore composite was located at 37th Street, and the finest was located at 92nd Street. The foreshore composites showed a trend toward finer sizes having better sorting. Again the opposite trend was present in the nearshore composites. The composite statistics of the 9-month monitoring were close to the native composite statistics of the four survey locations evaluated, indicating that the fill material was taking on the characteristics of the pre-fill native beach.

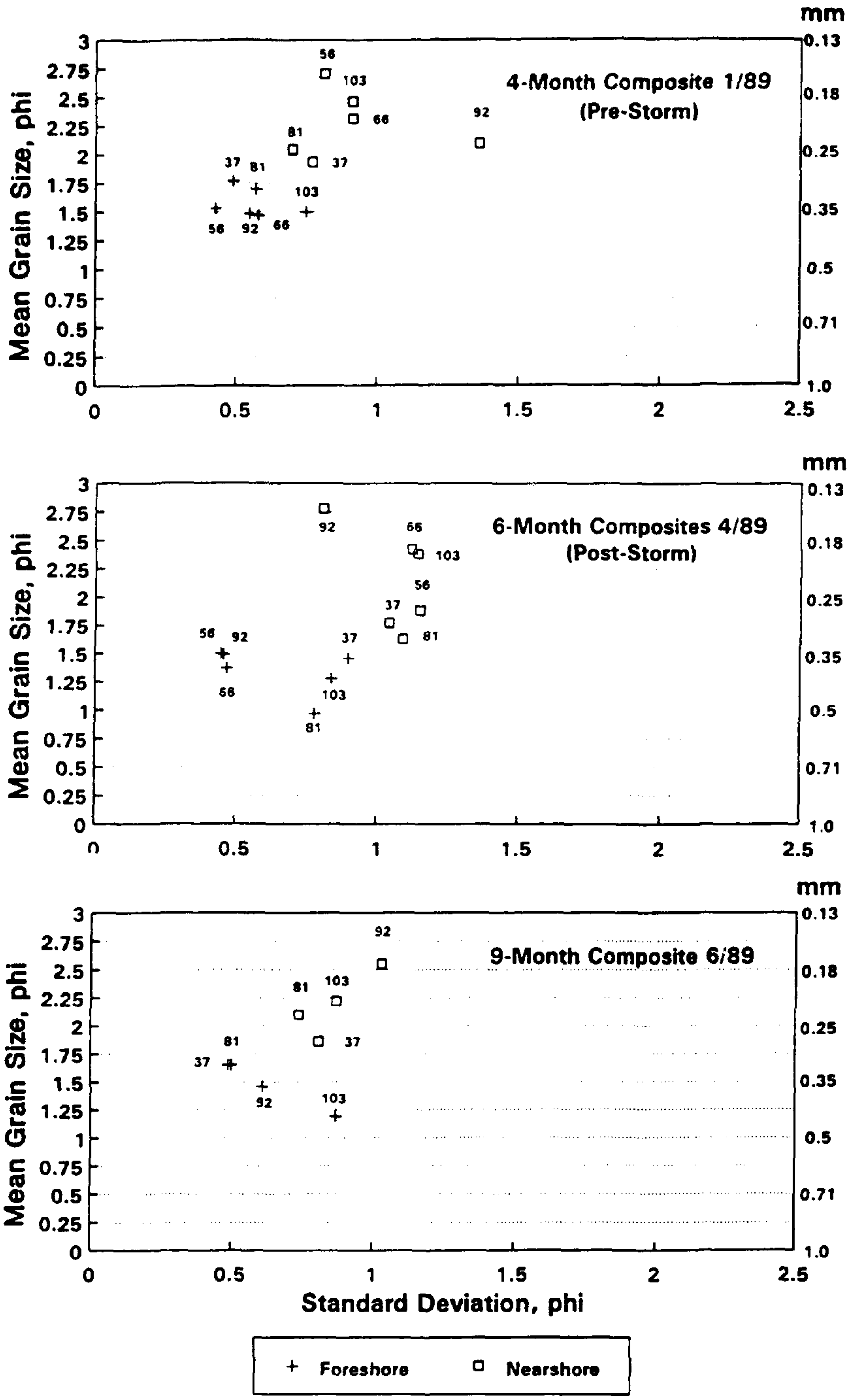


Figure 153. Comparision of the composite mean grain size and sorting of the six foreshore and nearshore 4-month, 6-month, and 9-month survey sediment monitoring lines

4 Project Evaluation

Profile Response

3D Analysis

In order to evaluate the initial and longer-term readjustment of the beach nourishment projects and the impacts storms had on fill behavior, both the cross-shore and alongshore characteristics of the observed profile and sediment change were examined. This 3D approach to analyzing the 12 study profile survey lines describes the variability in cross-shore response from one profile location to the next. In this chapter a series of 3D plots is presented to illustrate the alongshore distribution of the volume added between the pre- and post-fill beach surveys of both the State and Federal projects. The response of the projects to the series of storms that impacted the State fill in March 1989 and the Federal fill after the Halloween 1991 and January 1992 storms was also plotted.

The alongshore variability in the amount of sand placed for the State fill is shown in Figure 154 through the superposition of the pre-fill and post-fill surveys. This plot compresses the alongshore coordinate by a factor of 5 to provide a scale to make prominent profile change. The fill material was placed from the base of the existing back beach mound to the toe of fill that extended into the nearshore, from the baseline to a minimum of around 400 ft at the northern end of the project to a maximum of around 600 ft at the southern end of the project. Pre-fill bars were present in the southern portion of the project, and concave to planar profile shapes were present toward the northern end of the project. The bulk of the fill material was placed between 74th Street and 92nd Street, where a pronounced berm crest was present on the fill envelope.

The profile surveys that bracketed the March 1989 storms (performed in January and April, 1989) were among the longest and extended seaward some 3,000 ft to the shoreface-attached shoals (Figure 155). The storm-induced erosion pattern was to remove sand from the subaerial beach and deposit it in the nearshore just seaward of the bar that was found at the southern end of the study area and at the seaward edge of a low tide terrace that formed at the northern portion of the study area. The seaward limit of the accretion was located at the base of the shoreface slope. The shallow portions of the shoreface-attached shoal also showed elevation changes, with a general trend in scour of the landward side of the shoal and deposition on the seaward side. The shoals were located at the seaward limit of the surveys and a complete description of shoal changes could not be obtained. The deepest portion of the surveys between the nearshore accretionary deposit and the shoreface-attached shoals showed little change in elevation over these two surveys. Hot spots or areas of greatest erosion of the foreshore were associated with

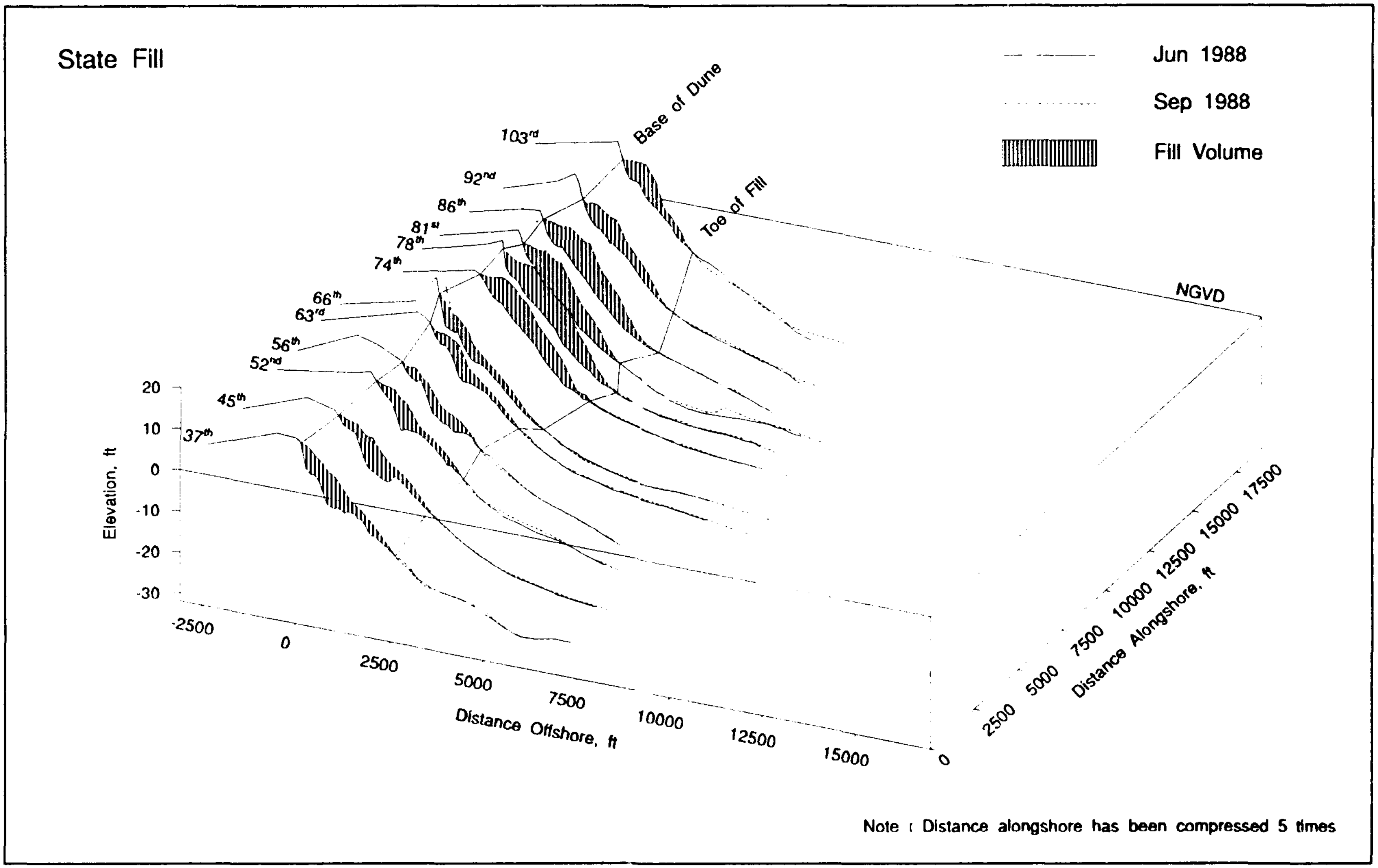


Figure 154. Three-dimensional plot of pre- and post-State fill beach profiles

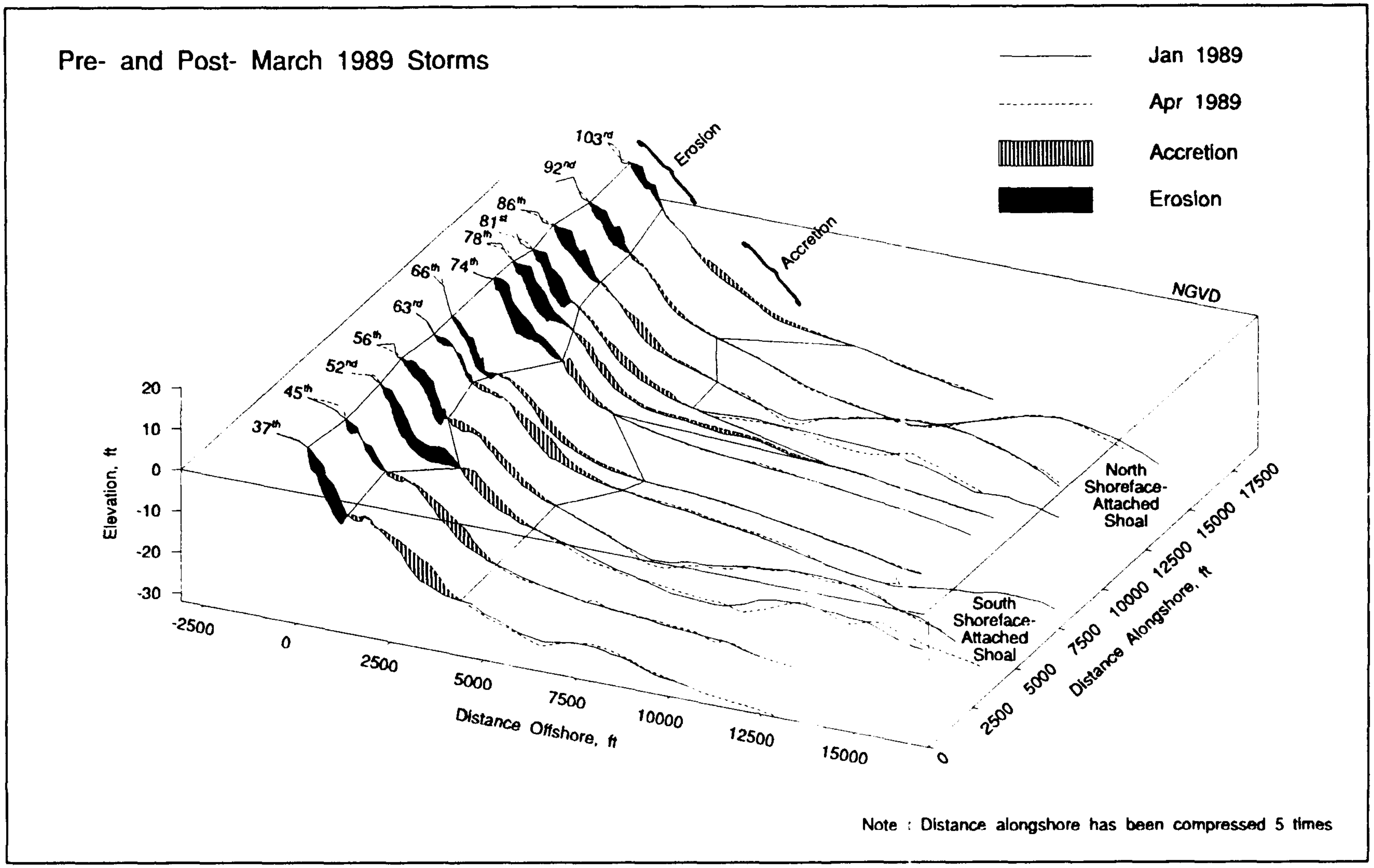


Figure 155. Three-dimensional plot of State fill pre- and post-storm beach profiles

the profiles located in the area where the shoals attached to the shoreface. The largest depositional prisms were found at the flatter nearshore profiles at the southern end of the study area.

The alongshore distribution of the Federal fill placement referenced to the June 1990 pre-fill surveys is shown in Figure 156. The fill placement included construction of the storm dune at the backshore, seaward of the baseline. The toe of the fill extended into the nearshore to between 500 and 600 ft from the baseline in the south and to between 400 and 500 ft in the north. The fill was again placed mainly on the subaerial beach, with largest volumes placed on the area between 74th and 103rd Streets.

The rapid-response evaluation of the Halloween storm of October 1991 on the Federal fill was documented by a limited set of surveys. The profile change pattern showed erosion on the subaerial beach, but the storm dune remained intact at most locations, with scarping of its face. A smaller storm occurred on 11 November 1991, but no surveys were made after this event. The largest of the storms occurred on 4 January 1992. A week after this storm, a full set of surveys was made. This storm caused complete erosion of the storm dune and overwash at several locations along the monitoring area, with erosion of the subaerial beach.

The survey set made in June 1991 was the closest survey set, prior to the storms, to the post-storm January 1992 set. Comparision of these survey sets shows the profile change pattern covering the period of both the Halloween and 4 January storms (Figure 157). The subaerial beach eroded from the dune to an area just below NGVD. Sand was deposited within the trough found in the June 1991 survey on the southern part of the study and in an area seaward of the nearshore bar to the base of the shoreface. The northern profiles had no bar prior to the storms and sand was deposited along the nearshore platform. The largest volume of sand was deposited in the vicinity of 92nd and 103rd Streets. Again, the largest erosion of the subaerial beach or hot spot was found in the area where the most fill was placed, between 74th and 86th Streets. This zone was expanded to the south and included 45th and 63rd Streets. The largest accretionary prisms were found in the nearshore at the southern end of the study area (37th Street) and at the northern end (92nd and 103rd Streets). Although the erosion pattern was expanded, the area of main loss of material from the dry beach was located on the profile lines that were in the vicinity of the shoreface-attached shoals. The nearshore deposition zones were located on profile survey lines somewhat protected behind the nearshore bar (37th Street) or the shoreface-attached shoal (92nd and 103rd Streets). Although the predominant longshore drift is to the south along this beach, the erosion and deposition patterns suggest a more complex shoal-controlled circulation and deposition pattern.

Much of the variability in profile response along the study beach may be due to the variability in the nearshore bathymetry. Two shoreface-attached shoals bisect the beach at locations between 52nd and 56th Streets and between 74th and 92nd Streets. Three nearshore bars are located on the profile at 37th Street. The profiles at the southern end of the study area are characterized by flatter foreshore and nearshore slopes. A nearshore bar/trough was common over the study period at depths between 2 and 5 ft at 37th, 45th, 52nd, 56th, and 66th Streets. The steepest foreshore slopes with no bar/trough and commonly a low tide terrace were found at 74th, 78th, 81st, and 86th Streets. The northern profiles at 92nd and 103rd Streets were more commonly narrow, with a concave shape. These northern profiles had no bar/trough and only an occasional low-tide terrace.

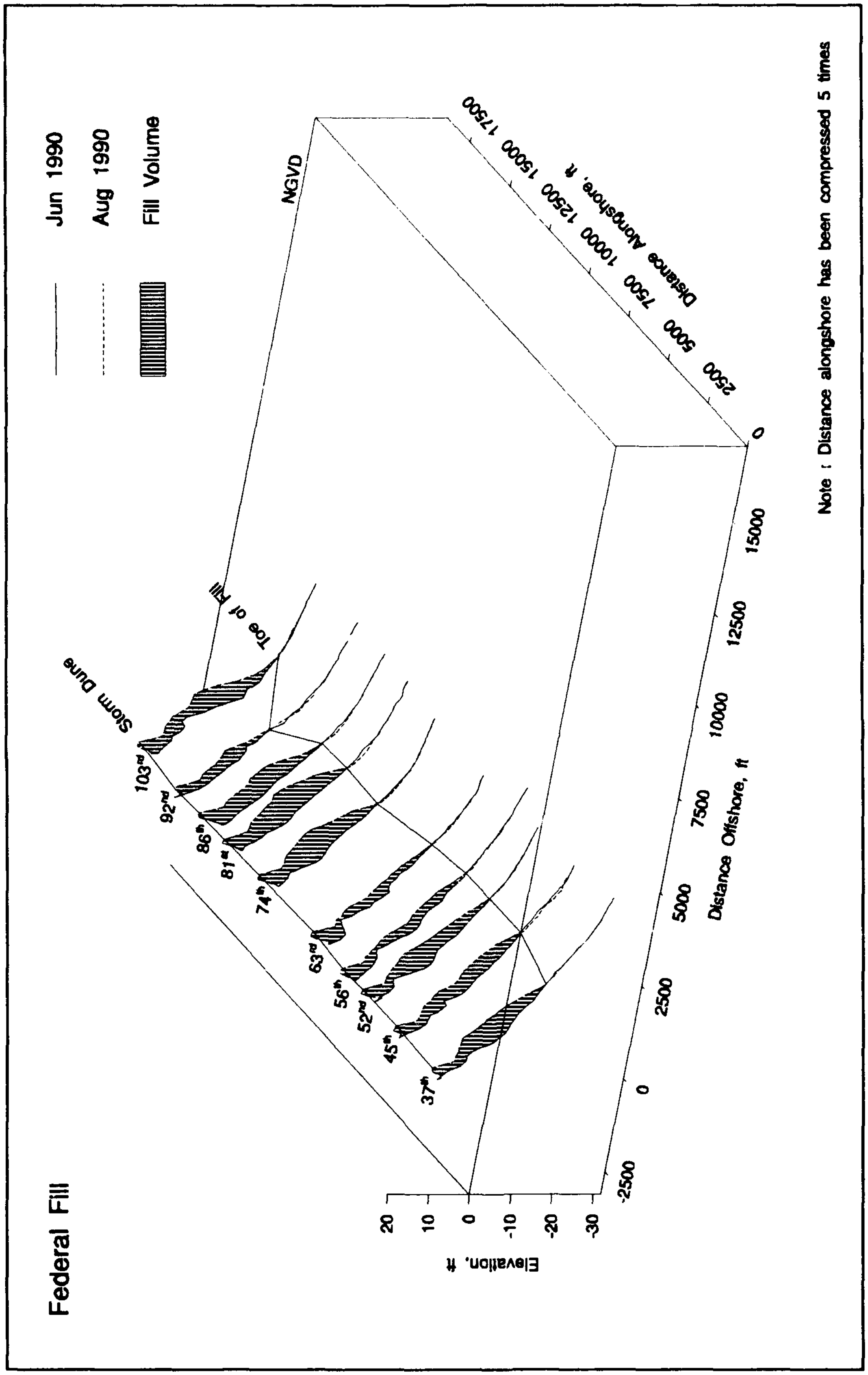


Figure 156. Three-dimensional plot of State-fill pre- and post-Federal fill beach profiles

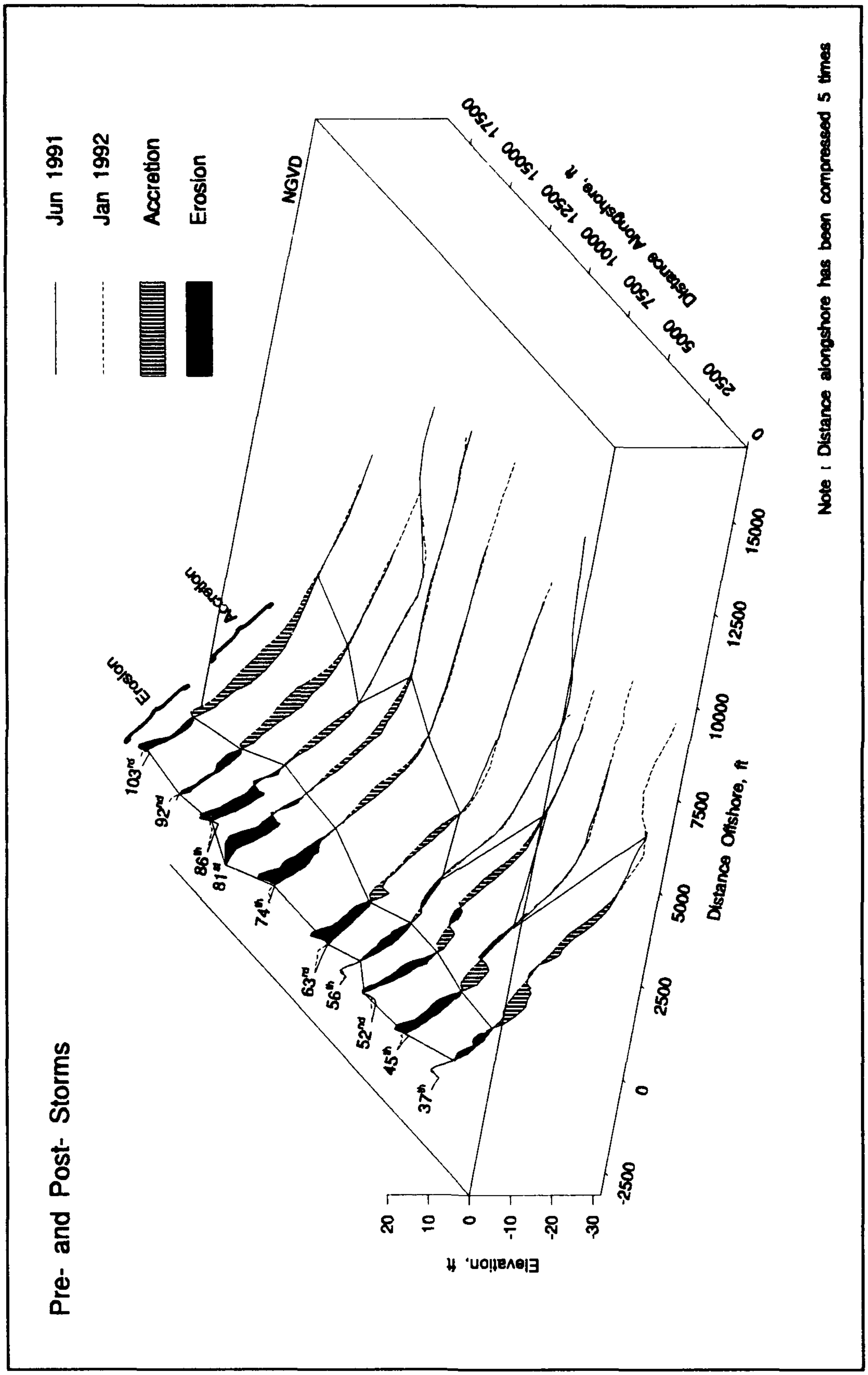


Figure 157. Three-dimensional plot of Federal fill pre- and post-storm beach profiles

Volume change

Because of the differing morphologies and beach width of the native profiles, fill placement dimension varied with location. For the State fill, sand extended 600 ft into the offshore on the flatter southern profiles and only 500 ft seaward on the steeper northern profiles. Hot spots with highest erosion volumes and greatest landward movement of the shoreline after the extratropical storms in March 1989 were observed at 52nd and 74th Streets, both located behind the intersection of the shoreface-attached shoals with the beach. Fill placement for the Federal project also had different dimensions, with material extending 500 to 600 ft seaward on the southern end and only 400 ft seaward on the northern steeper profiles. Response to the Halloween storm in 1991 and the 4 January 1992 storm indicated that the greatest erosion volumes and shoreline landward movement distances were measured at 52nd to 56th Streets and 74th to 86th Streets. Again, the hot spots of erosion were situated near the attachment of the shoal with the shoreline.

An average of the cumulative volume change that occurred along each of the 12 monitoring profile lines was calculated for the portion of the subaerial beach above NGVD, the nearshore below NGVD, and as total volume change of the common 900-ft calculation length of the profile. These average cumulative volume changes are used as an indication for summarizing the project volume change over the central portion of the fill placement from 37th Street to 103rd Street. Even though there was variability in volume placed along the project and variability in movement of the fill over the monitoring period of both the State and Federal projects at each location, the calculated average gives a general trend in project response of initial fill and storm response. Figure 158 shows the increase in volume after each fill and the general pattern of erosion on the subaerial beach above NGVD and deposition on the nearshore below NGVD as the fill material responded to the normal coastal processes and extreme events. On average, 32 percent of the fill remained on the subaerial beach after the three northeasters in March 1989. Over the 900 ft of the calculated profile length, 104 percent of the fill remained after the storms. The excess volume above that placed within the study area may be sand transported into the study area from the northern and southern ends of the fill outside the monitoring area as well as reflect measurement limitations. Approximate conservation of sand volume indicates that all of the fill material was retained on the active profile envelope and that none was lost from the littoral system after the storms. The State fill 2-year monitoring volume averages indicate that a substantial amount of sand returned to the subaerial beach by June 1989. An average of 58.6 percent or over half of the fill placed was retained on the subaerial beach. The overall profile average State fill retention was 87.8 percent within the 3.7-mile central portion of the fill limits. The 12.2 percent of fill volume removed from the study area can be surmised to have been deposited in a thin layer seaward of 900 ft, in the trough and flanks of the shoreface-attached shoals, and alongshore outside of the study area.

The Federal fill was placed on top of the remaining State fill and showed the same pattern of gradual removal of the fill from above NGVD and deposition on the nearshore as the profiles readjusted to waves and currents. The two major storms that impacted the project occurred about a year and a half after the Federal fill was in place. As of January 1992, after the two storms, 43.6 percent of the Federal fill remained on the subaerial beach and 96 percent of the fill was retained on the active profile within the study area. Examination of the total State and Federal project volumes showed that 85.9 percent of the fill placed on the subaerial beach on both projects was still on the visible beach. Including the nearshore accretion, the profile out to 900 ft contains 185.7 percent of the volume placed in the State fill. The excess volume of sand

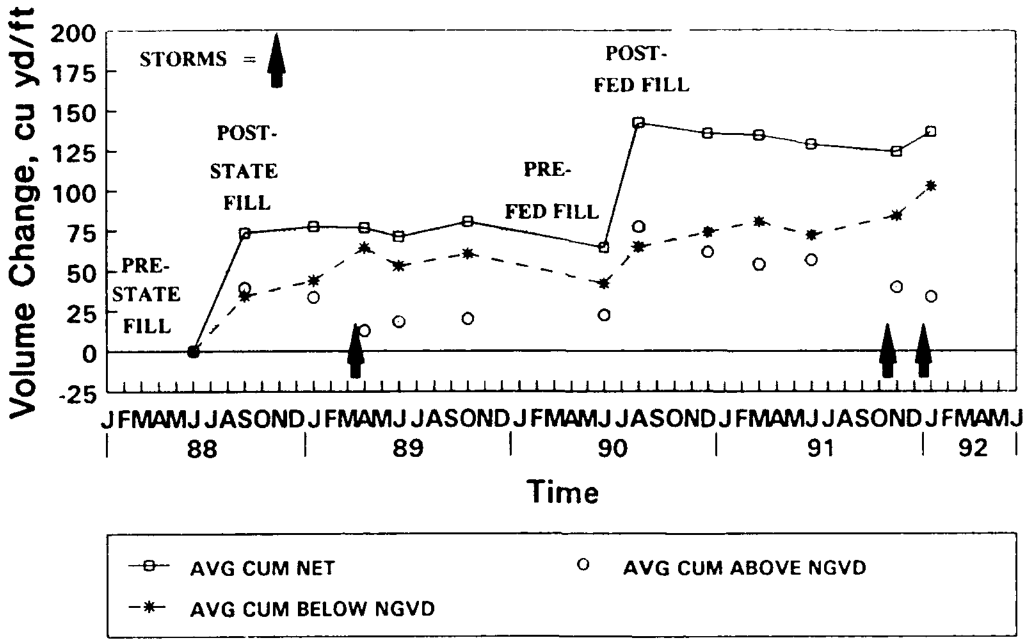


Figure 158. Average cumulative volume change for all 12 monitoring profiles

deposited in the 3.7-mile longshore study limits may have come from sand transported offshore from the subaerial beach and alongshore from outside the project study limits. Although there were changes in profile elevation seaward of the 900 ft associated with the shoreface-attached shoals, the majority of surveys were too short to assess an interchange of sand from the trough and shoal flanks. A zone of minimum elevation change existed at all profile survey sites between the active beach profile envelope and the shoreface-attached shoal/trough morphology.

The shoreline defined as the point where the profile crosses NGVD was used as an indicator of fill behavior response. Average cumulative shoreline movement for the 12 study profiles was plotted over the observation period from June 1988 to January 1992 and indicated that the shoreline was moved seaward on average 123.4 ft after placement of the State fill (Figure 159). As the profile readjusted after each fill, the shoreline moved landward as sand was transported by wave and currents into the nearshore. Initial readjustment as of January 1989 moved the shoreline landward to an average position 92.3 ft seaward of the pre-fill conditions. The most landward shoreline positions occurred after the storms in March 1989, when the shoreline moved onshore an average of 98.3 ft. The shoreline was located only 25.1 ft seaward of the pre-fill position. Monitoring of the storm recovery period for the State fill between April 1989 and June 1990 indicated an average seaward movement of 51.2 ft. At the end of the State fill monitoring, the shoreline was located 76.4 ft seaward of the pre-fill position.

The shoreline was located 210.8 ft seaward of the pre-State fill position after placement of the Federal fill. Initial readjustment of the profile after this second fill moved the shoreline landward to 141.3 ft. The average project shoreline stabilized around 125 ft until the Halloween storm of October 1991. The shoreline position then moved landward an average of 97.2 ft from the post-Federal fill position after this storm. Five of the profiles had landward movement of the shoreline, while five profiles had formation of a ridge and runnel at or near NGVD after the

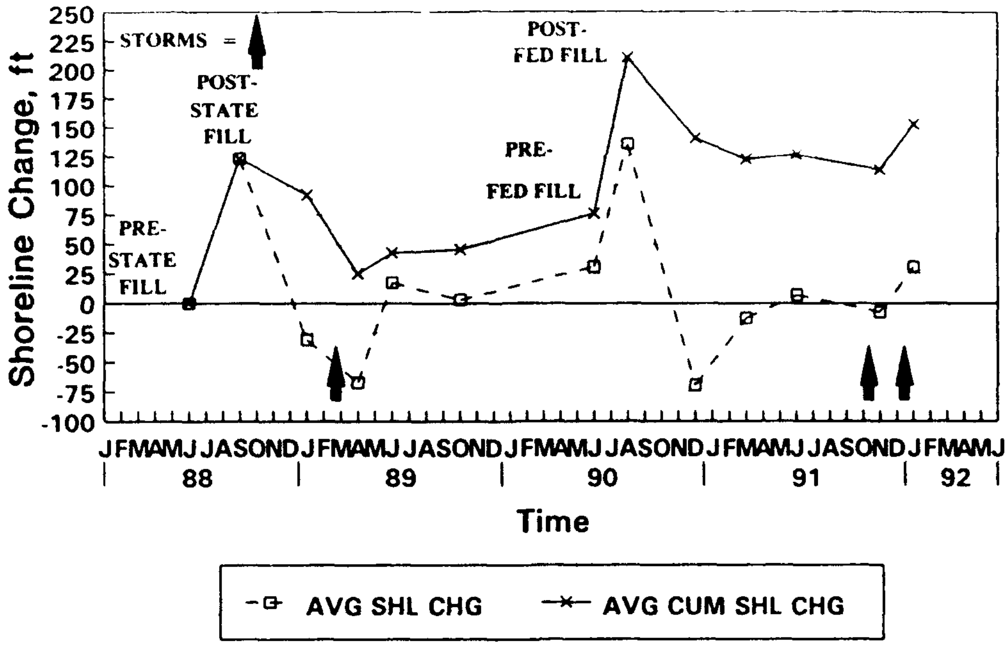


Figure 159. Average shoreline positions for all 12 monitoring profiles, where zero is NGVD

January 1992 storm. The shoreline on average advanced seaward 39.3 ft with this ridge accretion. The shoreline averaged 152.9 ft seaward of the June 1988 native beach average shoreline position. As of January 1992, the average shoreline was located 29.5 ft seaward of the September 1988 post-State fill average NGVD, indicating that sand placed by the two fill projects is still controlling the shoreline position.

The active envelope (defined as the area between the lowest and highest profile elevations) of a representative profile location of the northern erosion area using the 81st Street profile extended some 700 ft offshore and did not contain a bar/trough form. The shore-attached shoal area located around 2,000 ft offshore also had an active envelope that was detached from the beach (see Figure 26). In contrast, the active envelope of the 37th Street profile, representing the southern portion of the study area, away from the direct association of the shoreface-attached shoal, was over 1,000 ft offshore, and contained an active nearshore bar/trough configuration attached to the beach profile (see Figure 22). Both profile configurations converge to a closure point on their seaward end. The profiles that have a bar/trough or low tide terrace have a more seaward closure point. The profiles that have only a foreshore and nearshore concave shape have a closure point located more landward.

The alongshore distribution in the active envelope indicated that the profiles associated with the area where the two shoreface-attached shoals merge to the beach face have longer active profile lengths. The narrower active profiles were associated with the survey lines in the vicinity of where the shoals first attach to the beach face (Figure 160). The choice of criteria where the profile envelope closed was determined on the long active envelope profile locations where the standard deviation in elevation was less than 0.3 ft. Most of the profile locations exhibited a distinct depth where the change in nearshore elevation became relatively constant. However,

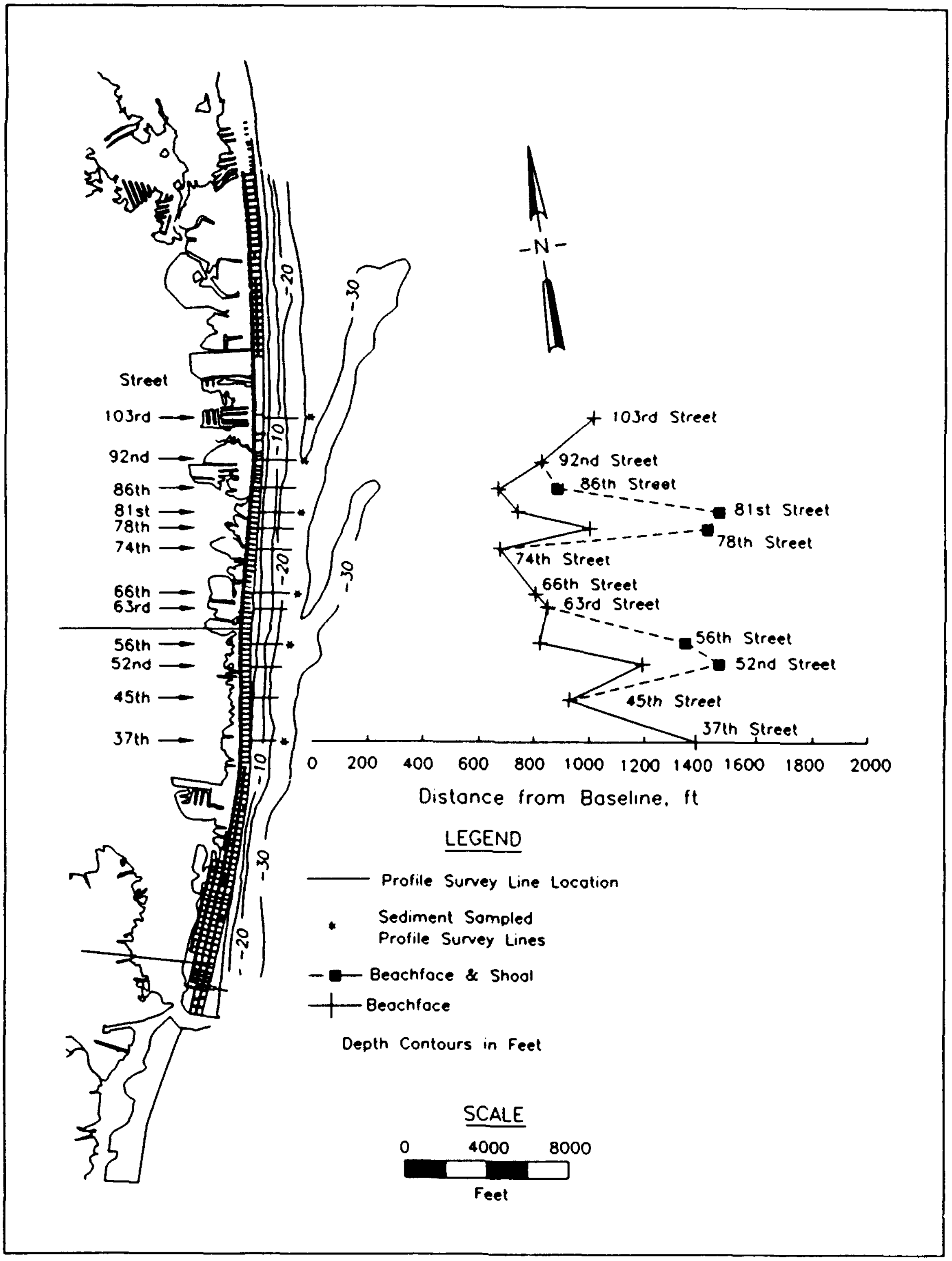


Figure 160. Alongshore variability in seaward distance of active profile envelope relative to the two shoreface-attached shoals

some exhibited a wide range in the seaward extent of the active profile envelope. The profile lines located at 45th, 52nd, and 56th Streets (southern shoal attachment area) and at 78th, 81st, 86th, and 92nd Streets (northern shoal attachment area) had a closure depth on the beach face during low wave conditions (solid line on Figure 160), but the active profile envelope extended seaward near the shoreface-attached shoal after storms (dotted line on Figure 160). Sometimes the shoal area had an active envelope to the seaward extent of the profile surveyed out to 2,500 ft). The longest active envelope of the shoreface-attached shoal (not including the shoal) was located at 52nd Street (south shoal attachment) and 78th Street (north shoal attachment). The other long active envelopes associated with the attachment of the shoals to the beach face were at 45th and 56th Streets (southern shoal) and 78th and 86th Streets (northern shoal). The profile at 37th Street, in the area of the multiple shore parallel nearshore bars, also exhibited a long active envelope of elevation change encompassing the nearshore bar. The shortest active envelope was located at 74th Street (in the lee of the southern shoal) and 86th Street (at the attachment point of the northern shoal) where the profile was concave and the nearshore change in elevation extended less than 700 ft seaward of the baseline, even after storms. The other short active profile envelopes, located in the lee of the shoreface-attached shoals, were found at 63rd and 66th Streets (lee of southern shoal), and 86th and 92nd Streets (apex and lee of northern shoal).

3D volume change

Three-dimensional plots of the cumulative volume changes along the study area were constructed to assess the time history of the profile volume readjustment to the two nourishment projects. The volume changes were combined for all of the individual subaerial beach above NGVD, which represents the visible portion of the project. The nearshore from NGVD to 900 ft offshore was also examined to assess the amount of sand moving into and out of this area. A total profile volume change from the baseline out to 900 ft was plotted to give the time history of the net change in volume along the study area over the study period. Figure 161 shows the 3D perspective of volume change from the baseline to NGVD depicting the cumulative volume change for profiles over the State and Federal fill monitoring periods. The alongshore variability in volume placed during the State fill shows that a larger volume of the sand was placed in the area between 74th Street and 86th Street. A major portion of the fill material was placed above NGVD. An initial loss of material from the subaerial beach can be seen at all profile locations except 56th Street, where additional fill was placed at the dune base between September 1988 and January 1989. The storms in late February and March 1989 eroded the volume to its lowest level during the monitoring period almost uniformly along the study area. The highest cumulative erosion of the subaerial beach was located at the southern end of the study area with the minimum volume at 56th Street. The largest volume still above NGVD was located at 103rd Street. A gradual recovery in sand volume was measured along all of the profiles for the period after the storms until the end of the State fill monitoring period in June 1990. More sand volume was returned to the beach at 45th and 66th Streets at the southern end and at the northern end at 92nd and 103rd Streets. The lowest cumulative volumes returned to the above NGVD portion of the beach were found at 52nd Street and the area between 74th Street and 86th Street (the area of highest initial fill volumes).

Again, a larger volume of fill was placed along the area between 74th Street and 86th Street during Federal fill placement, to compensate for the higher volume loss above NGVD in this area. A gradual reduction in the above-NGVD volume was measured over the rest of the monitoring period at all profile survey locations. Initial response by December 1990 found that

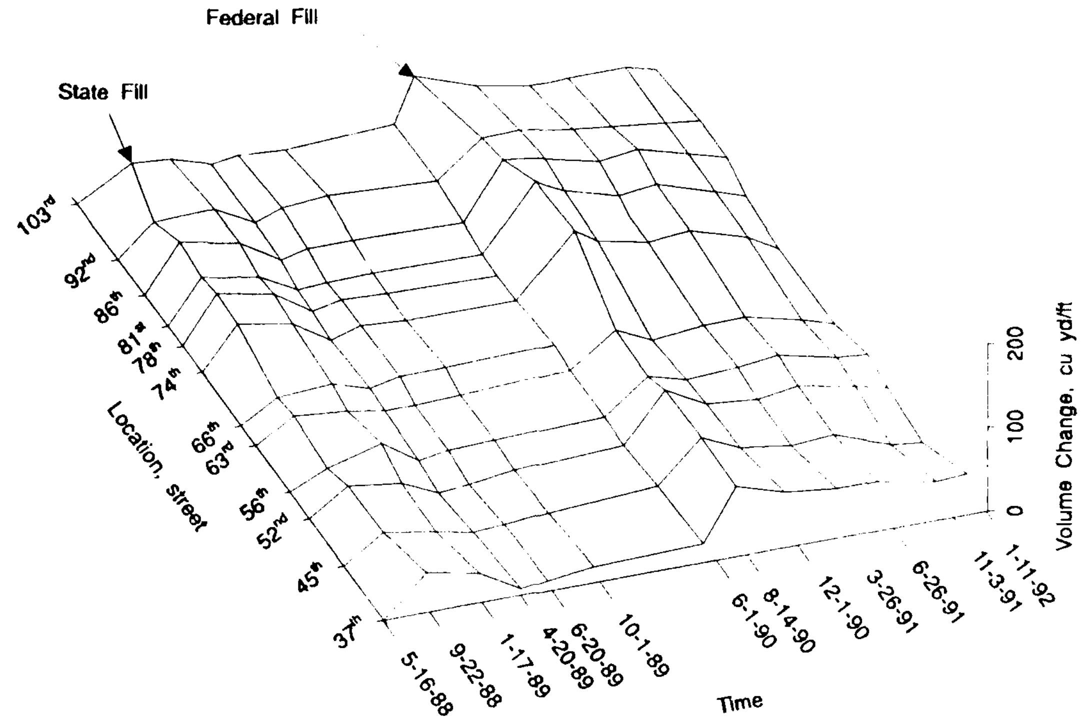


Figure 161. Above-NGVD cumulative volume change for profiles over study period

the lowest cumulative volume was measured at 63rd Street, whereas the largest volume retained was in the area of highest fill placement between 74th and 86th Streets. The limited sample survey set made after the Halloween profile limited analysis of storm response to a combined response of both the Halloween and 4 January 1992 storms. The profile locations with the least volume of sand retained above NGVD as of January 1992 were at 45th Street and between 63rd and 74th Streets.

Although sand was being removed from above NGVD by storms, it was deposited in the nearshore. The standardized distance of 900 ft was used as the seaward limit in the analysis. Figure 162 depicts the 3D pattern in cumulative volume change below NGVD for the study profiles over the study period. Here, the trend was for gradual gain in sand volume over time. The initial volume change in the nearshore reflected fill volume that was placed seaward of NGVD on the profiles, with the most subaqueous fill being placed between 74th and 86th Streets. The smallest amount of fill placed in the nearshore was at 103rd Street, with small amounts also placed between 56th and 66th Streets. Initial response along the study area was for fill to move from the subaerial beach into the nearshore, which was reflected in the gain in volume at all locations as of January 1989. The largest cumulative positive change in volume was measured at 74th and 78th Streets, whereas only minimal gains were measured at the project ends at 37th and 103rd Streets. After the March 1989 storms, large gains in volume were measured along the entire study area as fill was deposited in the nearshore. Only 52nd and 74th Streets experienced a decrease in volume in the nearshore. The largest gain in cumulative volume occurred at 63rd and 78th Streets. As sand returned to the subaerial beach from April 1989 to June 1990, the cumulative volumes in the nearshore decreased. By June 1990, the cumulative volume at 103rd and 52nd Streets was the lowest, with the largest volume at 66th Street.

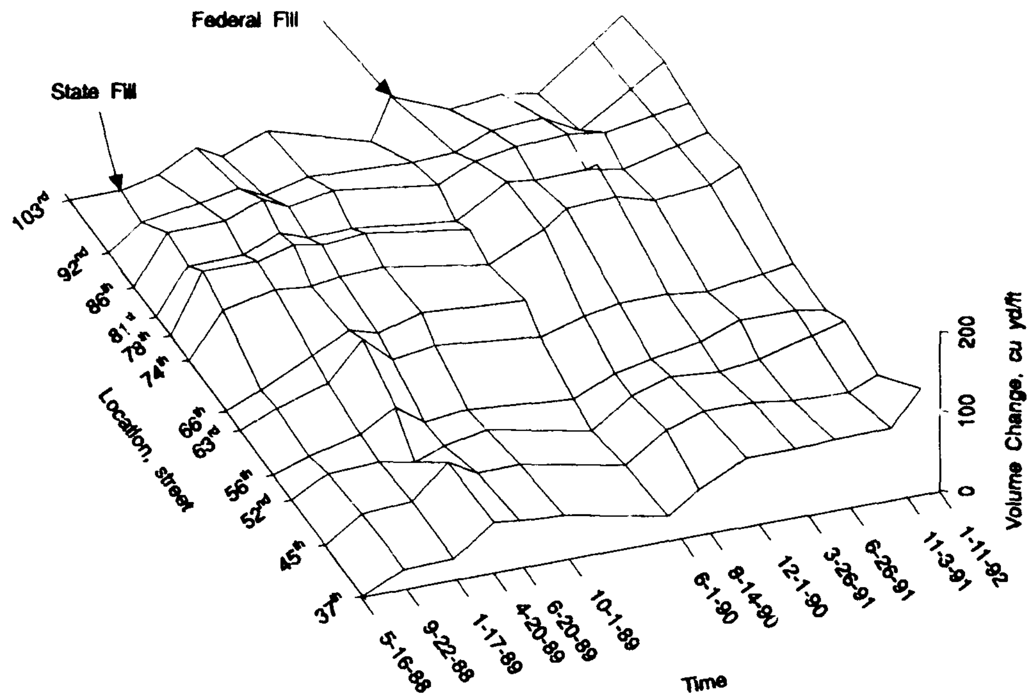


Figure 162. Below-NGVD cumulative volume change for profiles over study period

Placement of fill during the Federal portion of the project resulted in a gain in volume in the nearshore at all locations as fill was placed out into the nearshore below NGVD. The largest gains in volume were recorded between 74th and 86th Streets. The least amount of Federal fill volume was placed in the nearshore at 92nd and 56th Streets. As the Federal fill readjusted, a general trend was to gain sand in the nearshore, but the rate of change was variable depending on profile location. The response to the Halloween and January 1992 storms indicates that again large amounts of sand were deposited into the nearshore region within the monitoring area. As of late January 1992, the largest gains in nearshore volume occurred at 37th Street in the south and the area between 74th and 103rd Streets in the north. The area with the least amount of sand gained in the nearshore was located between 45th and 63rd Streets, but these gains were still above 82 cu yd/ft.

The combined gains and losses of the above- and below-NGVD volumes along the study area provide a measure of the net volume change from the baseline to 900 ft offshore. Figure 163 gives a 3D plot of the net profile cumulative volume change for study profiles over the entire State and Federal fill monitoring period. The general trend was one of accretion along the profile length at all profiles. Patterns of alongshore cumulative volume change varied between the State and Federal projects as fill was placed on the beach and was readjusted by storm and normal hydrodynamic processes. In general, the losses from the subaerial beach were balanced by gains in the nearshore, so the net volume change on the 900-ft-long profile was mainly one of increase in time after the fill placement periods. Larger volumes of fill material were placed on the profiles between 74th and 86th Streets. The State project monitoring indicated that net volumes decreased at these sites, as well as between 37th and 52nd Streets, as the fill readjusted over the first 3-month monitoring period. The profiles between 56th and 74th Streets and between 92nd and 103rd Streets measured net increases in profile sand volumes. After the storms in March

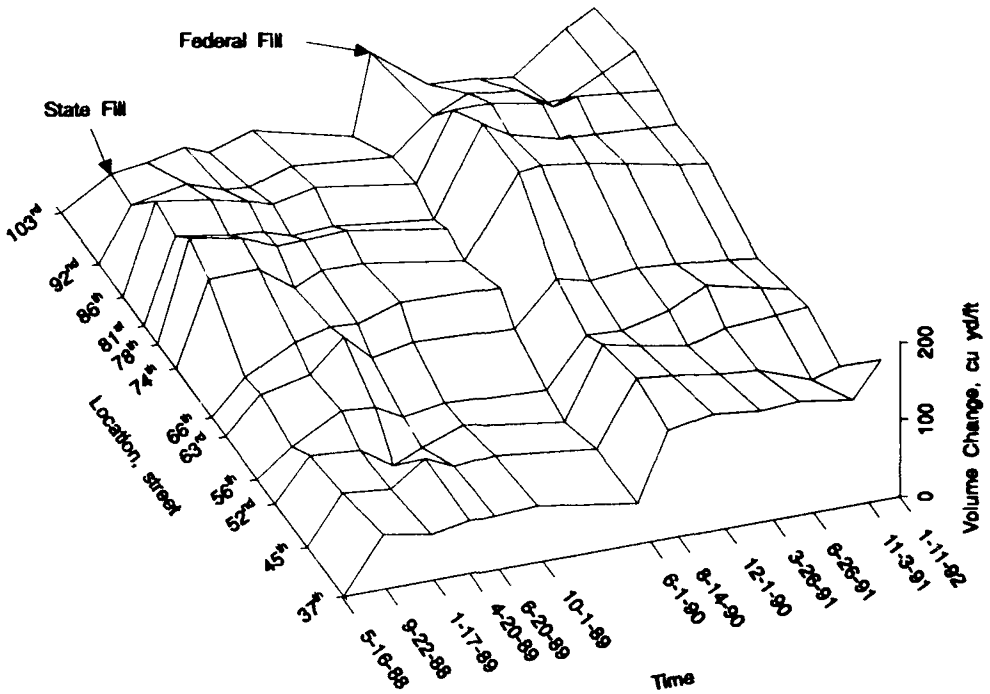


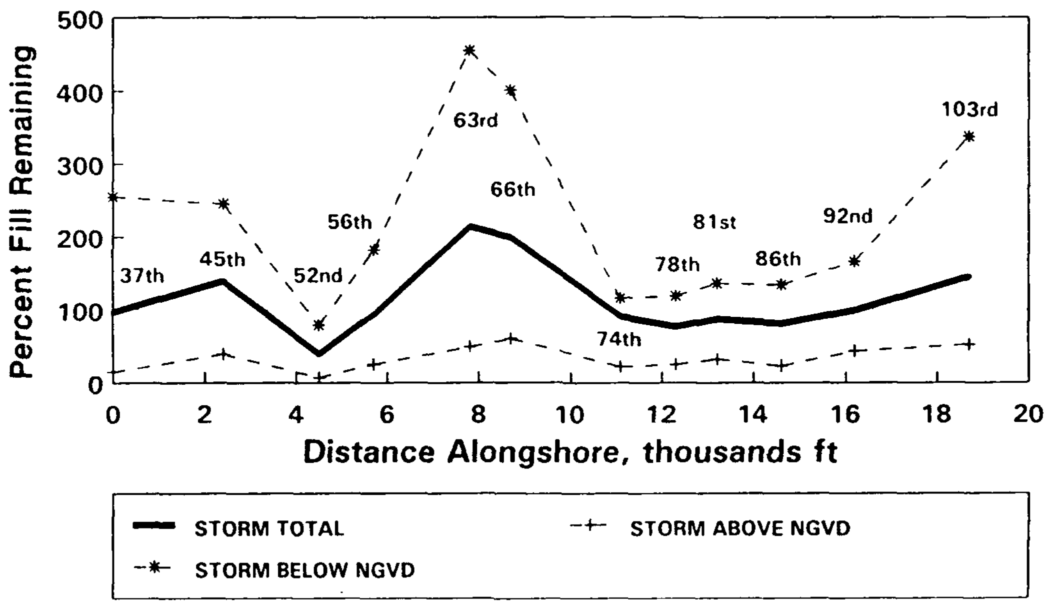
Figure 163. Net profile cumulative volume change for study profiles over study period

1989, the pattern was one of net accretion along the profiles between 37th and 45th Streets, net erosion between 52nd and 56th Streets, net accretion between 63rd and 66th Streets, and net erosion between 74th and 92nd streets, with net accretion at 103rd Street. At the end of the State project monitoring in June 1990, there was a net erosion between 37th and 52nd Streets, net accretion between 56th and 66th Streets, net erosion between 74th and 103rd Streets, with no change at 92nd Street.

After the Federal fill placement, all of the study profile locations gained sand across the 900 ft of standardized profile length, with the largest gains in net volume measured between 74th and 86th Streets. The pattern of readjustment varied alongshore as the fill volume was redistributed across the profile. Before the impact of the Halloween storm, the fill was readjusting with a slight gain in net volume at 37th Street, a loss of fill between 45th and 52nd Streets, a gain at 56th Street, and a net loss from 63rd through 103rd Streets. The impact of the Halloween and January 1992 storms caused varying volume changes alongshore. A gain in net volume was measured at 37th, 52nd, 56th, 92nd, and 103rd Streets. A net loss of the Federal fill sand occurred at the other locations. The total project performance of both the State and Federal fills indicated that there was over 105 cu yd/ft of sand above the pre-State fill volume on the profile out to 900 ft at all locations monitored as of January 1992. As can be seen, most of this material is located in the nearshore, below NGVD.

Percent fill remaining

Comparison of volume changes between surveys provides a means to assess the behavior of the fill material as it responded to the storm and fair-weather hydrodynamics. Analysis of the percent of fill remaining on each profile survey location in the longshore direction was done to provide a 3D picture of fill performance. The percent of fill remaining is based on a comparison of the volume of fill placed with the volume change at each survey date. The State project monitoring profile volumes were compared with the volume of fill placed during the summer of 1988 and the Federal project monitoring profile volumes were compared with the volume of fill placed during the summer of 1990. Figure 164 gives the longshore values of percent of fill remaining above NGVD on the visible beach, below NGVD in the nearshore, and the total profile (baseline to 900 ft) length measured on each survey location calculated after the storms in March 1989. The largest percent of volume retained on the total profile was found at 63rd and 66th Streets. A second high percentage of fill volume was retained at 103rd Street. These two areas were in the lee of the shoreface-attached shoal. Less than 100 percent of the fill volume placed during the State project remained on the total profile at the 52nd Street location and between 74th Street and 86th Street. Both of these areas were located where the shoal attached to the shoreline. Less than 50 percent of the fill material remained on the above-NGVD portion of the beach at all locations after the storm, except at 66th and 103rd Streets.



Total = 0 to 900 ft Across Shore

Figure 164. Percent of fill remaining above NGVD, below NGVD, and over the total profile length after the March 1989 storms as measured from September 1988 to April 1989

For the 21-month monitoring period of the State project, a similar pattern of percent fill remaining was calculated in the longshore direction. The highest percentage of sand remaining on the total profile was at the survey locations between 63rd and 66th Streets (Figure 165). One hundred percent of the fill placed could be found at 45th and 92nd Streets. The locations at 37th, 52nd to 56th, 74th to 86th, and 103rd Streets all had less than 100 percent of the volume of fill remaining on the profile out to 900 ft. In most cases, except for sites at 52nd and 56th Streets, an equal or higher percentage of sand volume remained in the nearshore than the volume placed as fill in September 1988. The return of sand to the above-NGVD portion of the beach was calculated, with all sites retaining greater than 50 percent of the volume of fill placed (except the area between 74th and 86th Streets).

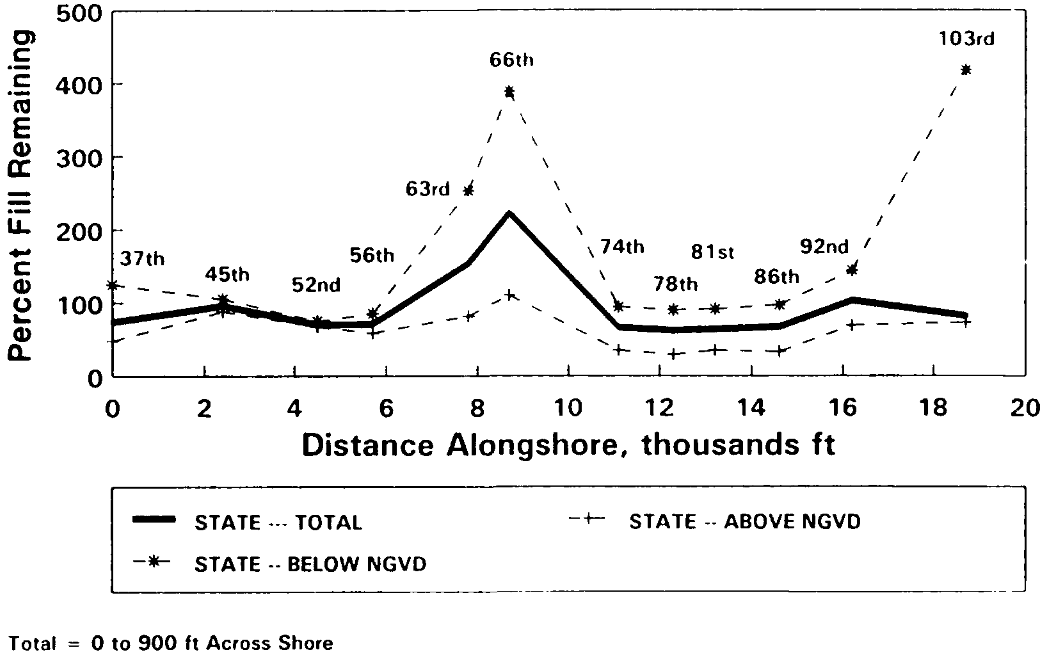
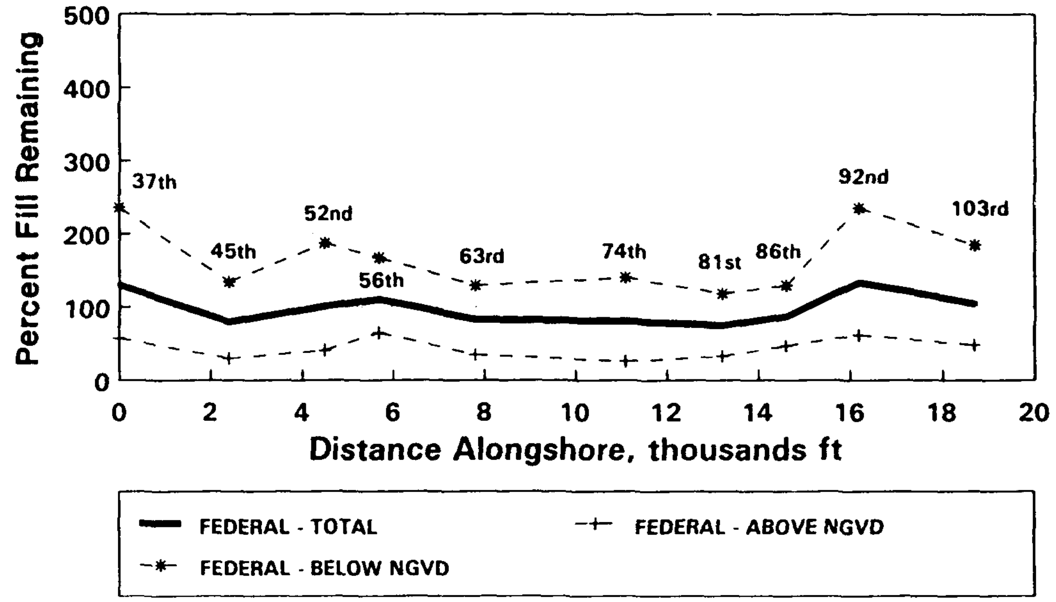


Figure 165. Percent of fill remaining above NGVD, below NGVD, and over total profile length after the 21-month State fill monitoring as measured from September 1988 to June 1990

The Federal fill exhibited a different pattern in the percent of fill volume retained in the longshore direction. The 16-month monitoring included the effects of Federal fill volume retained on the profile (Figure 166). The profile survey sites that retained less than 100 percent of the fill volume were located at 45th Street, and between 63rd and 86th Streets. Surveys were not taken at 66th and 78th Streets during the Federal fill monitoring. The highest percent of fill retention was calculated at 37th and 92nd Streets, with near 100-percent retention between 52nd and 56th Streets, and at 103rd Street. The survey lines that had greater than 100 percent volume retention corresponded with the profiles that had little dune erosion after the January 1992 storm. The sites that had near 100-percent retention corresponded to the profiles that had partial dune face erosion and the sites with less than 100 percent retention corresponded to the profiles that had complete dune removal after the January 1992 storm.

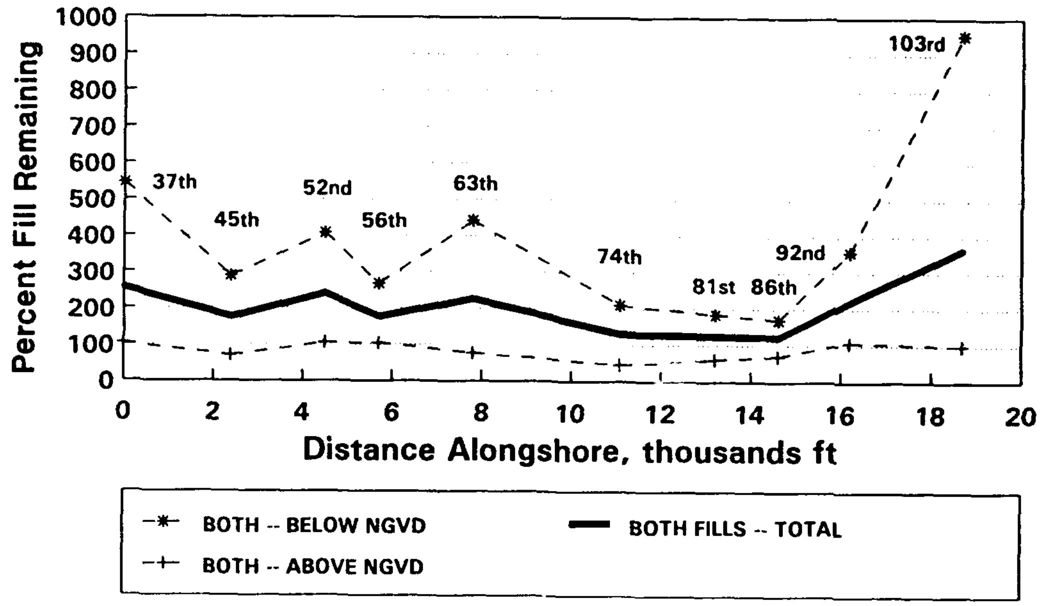
Summary of volume change

A comparison of the percent of fill volume remaining after the 28-month monitoring of both projects in the longshore direction showed a pattern of long-term behavior. All of the survey sites had greater than 100 percent of the fill volume remaining on the total profile at the end of the monitoring period (Figure 167). Areas with less than 200 percent of fill volume remaining on the total profile were found on the survey lines at 45th and 56th Streets and between 74th and 86th Streets. The highest volume retained was found at 103rd Street and was due to the large gain in the nearshore. Other sites with greater than 200 percent of the fill volume remaining on the profile were at 37th, 52nd, 63rd, and 92nd Streets. The general trends in percent of volume remaining above NGVD, below NGVD, and over the total profile support the premise that the areas of erosion and loss of fill volume are located where the profiles were steepest and



Total = 0 to 900 ft Across Shore

Figure 166. Percent of fill remaining above NGVD, below NGVD, and over total profile length after the Halloween and January 1992 storms and 16-month Federal fill monitoring as measured from September 1990 to January 1992



Total = 0 to 900 ft Across Shore

Figure 167. Percent of fill remaining above NGVD, below NGVD, and over total profile length after the 28-month State and Federal fill monitoring as measured from September 1988 to January 1992

located near the point of connection of the shoreface-attached shoal with the shoreline. The survey lines that retained the most volume of fill were profiles that had a bar/trough configuration or were located in the lee of the shoreface-attached shoal.

Sediment Response

Few data exist on the behavior of fill material once it is placed on a project beach. Overfill ratio calculations predict the amount of borrow material to be placed on the project to provide a stable nourished beach. The renourishment factor predicts how often fill will need to be placed to maintain the required fill volume. Both of these calculations are based on the grain size statistics of the native beach and the borrow area. Few studies exist that examine how well these methods predict the behavior of the fill because of a lack of monitoring data. The large amount of sediment data collected on the monitoring of the Ocean City project allowed for analysis of the sediment response for a period of one year after placement of the State fill. Additional sediment analysis of the Federal fill portion of the project will be presented in future reports.

The sediment sampling plan called for collection of surface samples from all zones on the active profile at six survey locations along the 3.5 miles of the central portion of the project, including the dune base, berm crest (MHW), mid-tide, swash/step (MLW), nearshore trough and bar, and at the 5-, 10-, 15-, 20-, and 25-ft depths. The initial grain size analysis of the individual samples presented a complex array of both spatial and temporal variability in the native and post-fill sediment. The various types of sediment-transport mechanisms across the beach, the changing energy conditions of the transport mechanisms, the complex nearshore bathymetry with two shoreface-attached shoals, and the placement of fill material from two different borrow sources over native material all played a role in producing this high variability. The passage of several storms during the first six months of the monitoring period also allowed investigation into the change in sediment grain size by storm processes on a newly placed fill.

To reduce variability in the individual samples, composites were constructed of the most active part of the beach environment. The foreshore composite mathematically combined the intertidal samples of the berm crest, mid-tide location, and step. The nearshore composite combined the 5- to 25-ft depth samples, which extended offshore from the breaker zone. The choice of these two composites was based on the available sample locations across shore and on past work (Stauble and Hoel 1986). The foreshore composite represented the area of the beach where the main volume of fill was placed, producing the greatest disequilibrium in the profile platform, and the area of the profile where breaker, surf, and swash/backwash processes were most active. The nearshore composite represented the portion of the beach profile seaward of the breakers, where the wave energy was less intense and the profile slope flattened. These composites provided a better picture of sediment redistribution. By using the entire frequency curve, a picture of what grain size classes were present and how the weight percentage of each class size changed provided an understanding of how the depositional environment changed. The foreshore was chacteristically coarser and in most instances more poorly sorted than the nearshore. This reflected the higher energy of the active wave environment of the foreshore that placed the finer grain sizes in transport and winnowed them out of the samples, particularly during the storm events. The finer material was deposited seaward of the active wave environment and deposited in the less energetic nearshore. The exception to this generalization was found where coarse material was present on the nearshore that is suspected to be a relict deposit of material outcropping in the nearshore.

Sediment data collected in 1986 were used to calculate the native beach and borrow area statistics. Analysis of the native beach sediments collected in June 1988 was used to characterize the immediate pre-fill beach sediment distribution. These data showed an alongshore variability of the native beach as evident by the finer sands found at 37th and 81st Streets and naturally occurring coarse sand at the northern portion of the study at 92nd and 103rd Streets. Beach fill material from Borrow Area 2 was placed along the southern portion of the project and included survey lines from 37th to 81st Streets. The 1986 borrow area composites indicated that this source was finer than material from Borrow Area 3, which was placed on the northern portion of the project that included survey lines at 92nd and 103rd Streets (USAED, Baltimore 1989).

To examine the native to borrow area sediment distribution, a set of foreshore composites was mathematically constructed that included sample data from the southern portion of the study area (37th, 56th, 66th, and 81st Streets). A southern nearshore composite was also constructed from the nearshore samples at the four streets. The first set of composites constructed included the native beach material collected in June 1988. This set was compared with the composites constructed from the post-fill survey collected in September 1988 just after the fill was placed on the beach. This post-fill southern composite represented the grain size distribution of the Borrow Area 2 material that formed the beach fill. Because the samples were collected soon after placement and there were no high-energy wave conditions, the bulk of the fill material was not greatly re-sorted from the time it was placed on the beach. The post-fill foreshore composite consisted entirely of fill material placed on the intertidal area. The post-fill nearshore composite was a mix of the fill material that was placed in the shallow end of the profile and the deeper native material seaward of the fill placement.

The change in the grain size distribution of the southern foreshore composite showed a shift to finer material in the post-fill sample, indicating that the fill material was finer than the native foreshore (Figure 168). The grain size distribution of the gravel and coarse sand component was similar between the native and post-fill sands, but there was a deficiency in the coarse to medium sand sized in the post-fill sample (between 1.0 mm and 0.25 mm or 0.0 to 2.0 ϕ). The excess post-fill fine material ranged from 0.25 to 0.63 mm (2.0 to 4.0 ϕ).

The nearshore composite grain size distribution comparison between the native pre-fill and post-fill showed more similar distribution curves. The post-fill composite contained a higher percentage of fine sand material and a small percentage of gravel material not present in the native nearshore (Figure 169). The fill only extended seaward to about the 15-ft contour. The nearly identical distributions were a result of mixing the fill samples from the 5- to 15-ft depth samples with the 20- and 25-ft depth samples of mainly native material in the post-fill sample.

A composite was constructed of the two northern sediment survey lines (92nd and 103rd Streets) to examine the change in grain size distributions of the northern Borrow Area 3 fill as it was placed on the beach. The native beach had a coarser distribution than the southern native beach with almost 5 percent of the distribution containing gravel-size material. The post-fill northern composite was also coarser than the southern post-fill composite distribution, indicating that the fill material from Borrow area 3 was indeed coarser than from Borrow area 2. Both the native and post-fill northern samples were coarser than their southern counterparts. The post-fill northern composite was still finer than the native material (Figure 170). The post-fill distribution

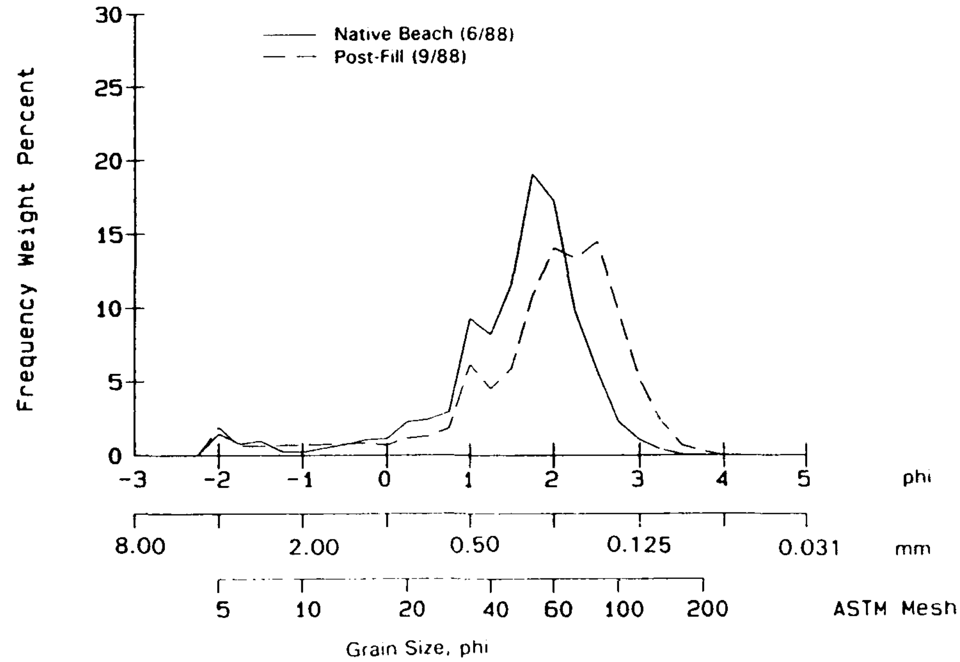


Figure 168. Comparison of southern composite foreshore, native versus post-fill

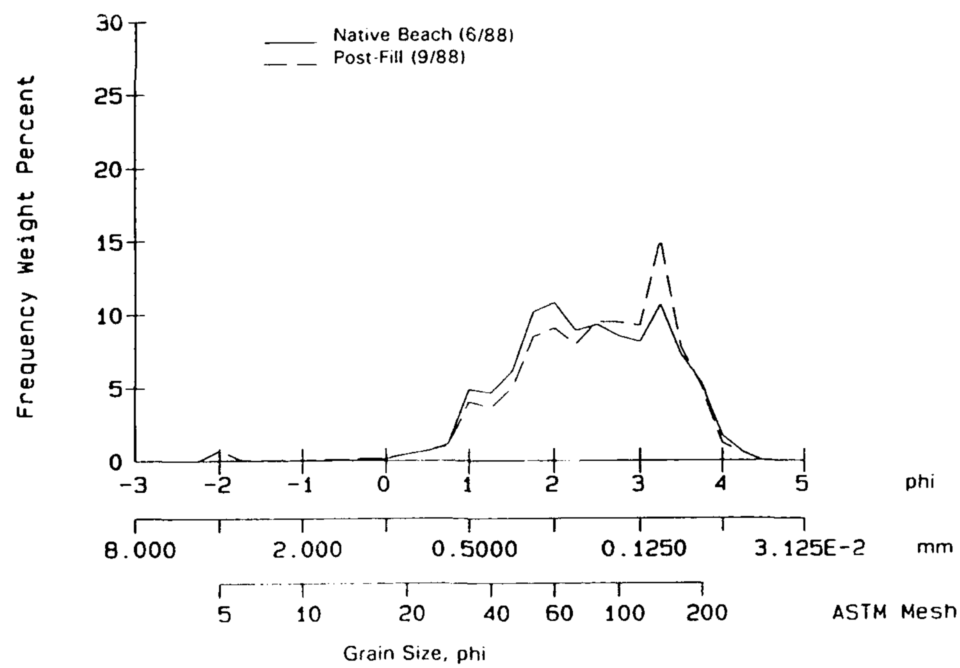


Figure 169. Comparison of southern composite nearshore, native versus post-fill

did not contain the high percentage of gravel material and had an excess of medium to fine sand in the 0.25- to 0.125-mm (2.0- to 3.0-ϕ) range. These northern samples were bimodal with a dominant peak at 0.5 mm (1.0 ϕ) and a secondary peak at 0.25 mm (2.0 ϕ) on the native beach distribution, which reversed in rel. .:ve size on the post-fill beach.

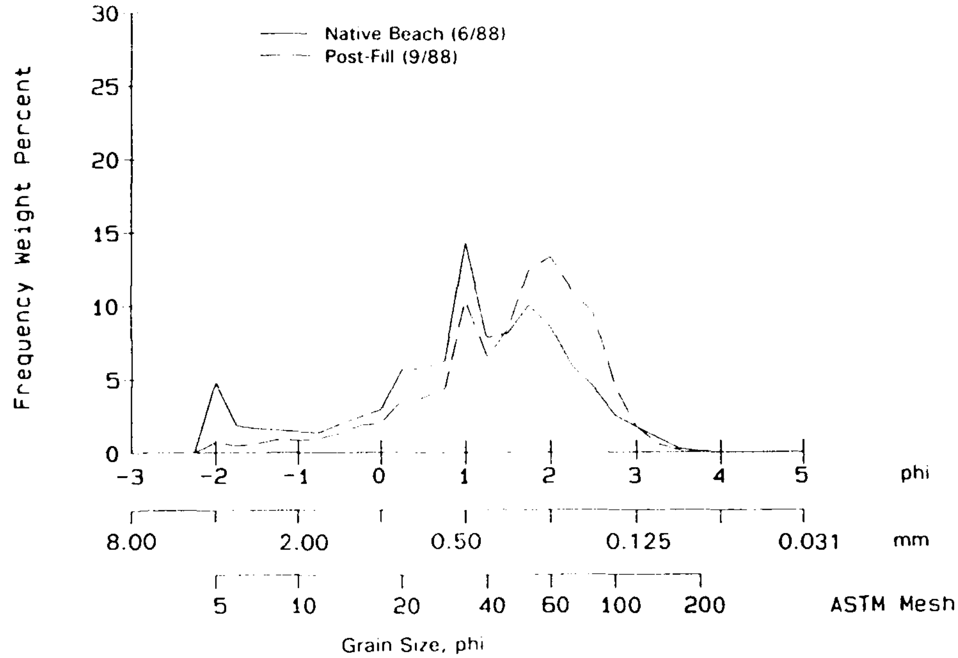


Figure 170. Comparison of northern composite foreshore, native versus post-fill

The northern native nearshore composite contained a small percentage of gravel, with the bulk of the sample in the medium to very fine sand range (Figure 171). The post-fill sample contained excess coarse sand material between 1.0 and 0.5 mm (0.0 and 1.0 ϕ) and excess very fine sand between 0.63 and 0.44 mm (4.0 and 4.5 ϕ). The fill only extended to a depth of 10 ft on the northern profile survey lines by the post-fill sample survey, with the rest of the nearshore composed of native sand. The post-fill composite was deficient in fine sand size material between 0.13 and 0.63 mm (3.0 to 4.0 ϕ).

Within the first four months, the fill material became better sorted on the foreshore composite of both the northern and southern composites. Wave re-sorting winnowed out the finest sizes and the gravel material was most likely covered. Analysis of the storm impact on the composite size distribution of the foreshore of the southern composites showed that the distribution shifted even further to the coarse fractions. The high wave energy associated with the four storms winnowed even more of the finer size fraction of the foreshore (Figure 172). A lag deposit of the coarser sand and minimal gravel size material was present after the storms, as the curve became bimodal, with a main peak at around 0.25 mm (2.0 ϕ) and a secondary peak at 0.5 mm (1.0 ϕ).

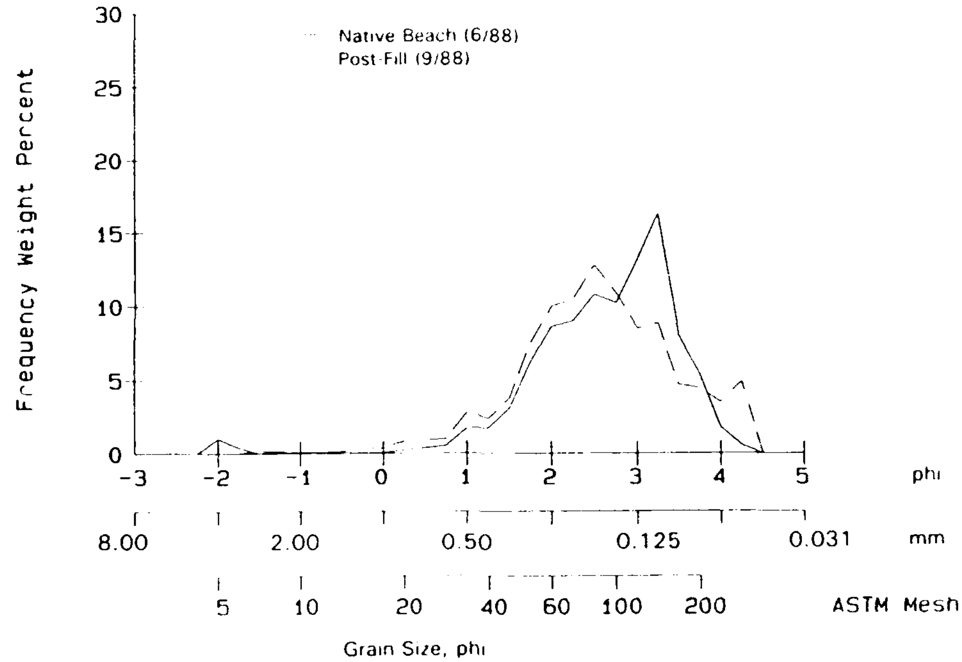


Figure 171. Comparison of northern composite nearshore, native versus post-fill

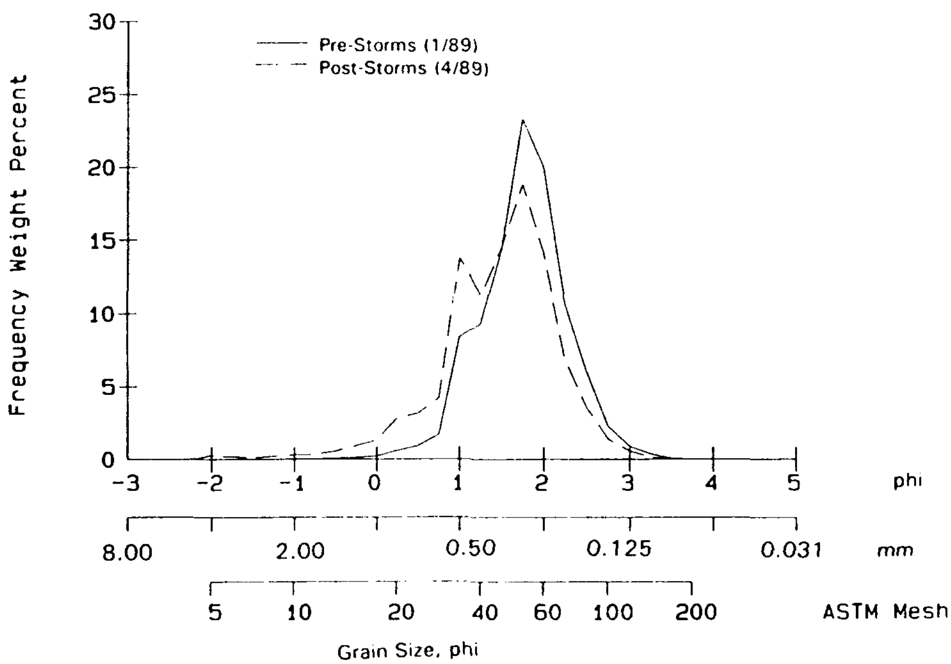


Figure 172. Comparison of southern composite foreshore, pre- versus post-storms

The nearshore area on most of the survey lines gained sand that was eroded off the subaerial beach. The southern nearshore sediment composite also shifted to a coarser distribution with the presence of around 1 percent gravel size material and an addition of the coarse sand size material (Figure 173). A small amount of the finest pre-storm distribution was winnowed out of the distribution. The nearshore composites were not as well sorted at the foreshore, owing to the different sediment transport regimes of the two regions.

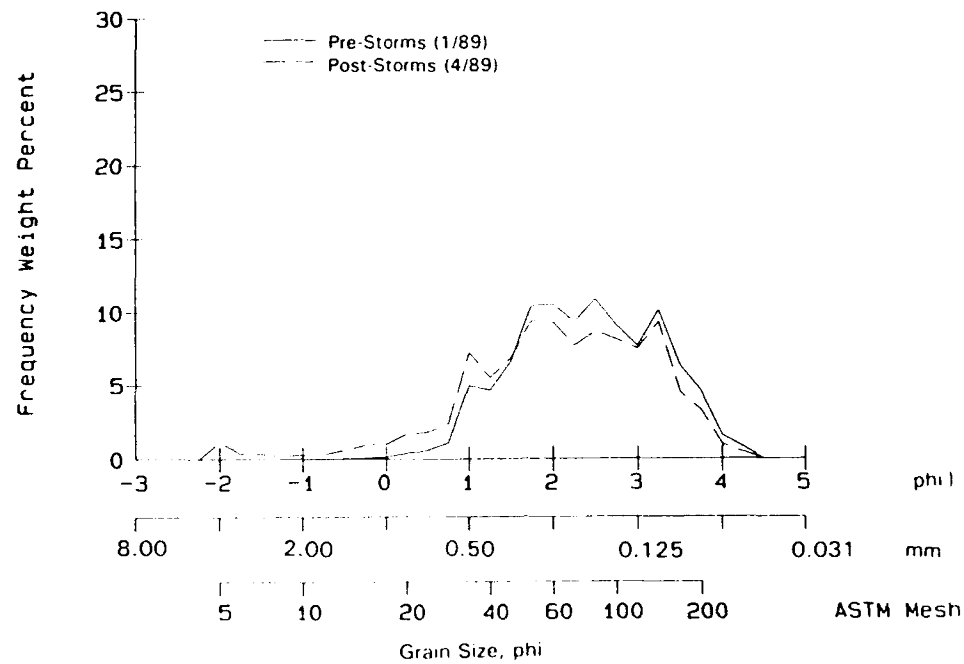


Figure 173. Comparison of southern composite nearshore, pre- versus post-storms

Even though two different borrow sources were used to provide material for the project, the 4-month foreshore composite of the northern study area was almost identical to the 4-month foreshore composite of the southern area. Similar wave conditions sorted the sediment of both borrow sources to a well-sorted medium sand. The main difference was the more bimodal distribution of the northern foreshore composite after 4 months of fill placement. The storm impact to the northern foreshore composite also had a winnowing out of a portion of the fine sand material (Figure 174). Less coarse sand and gravel size material was present in the post-storm sample, with an addition of more material in the 0.5 to 0.25 mm (1.0 to 2.0 ϕ) medium sand size range. The post-storm composite was more unimodal with the loss of the 0.5-mm (1.0-ϕ) peak, but retained the main peak at 0.3 mm (1.75 ϕ).

The 4-month northern nearshore composite had a different distribution than the southern nearshore samples, with more well-sorted distribution containing finer material and a dominant peak at 0.125 mm (3.0 ϕ) in the fine to very fine sand range (Figure 175). The deposition of sand in this nearshore region after the March 1989 storms created a slightly finer and better sorted distribution with a removal (potentially buried) of the coarser material, and the addition of more fine and very fine sand material. This fine material may have been winnowed off the foreshore and deposited in the lower energy nearshore area after storm passage.

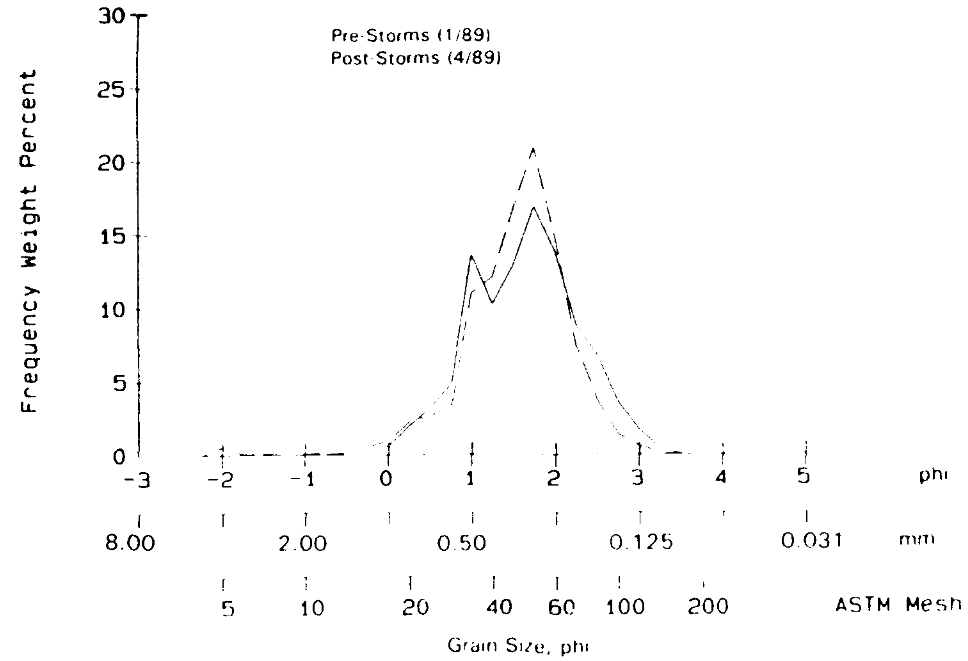


Figure 174. Comparison of northern composite foreshore, pre- versus post-storms

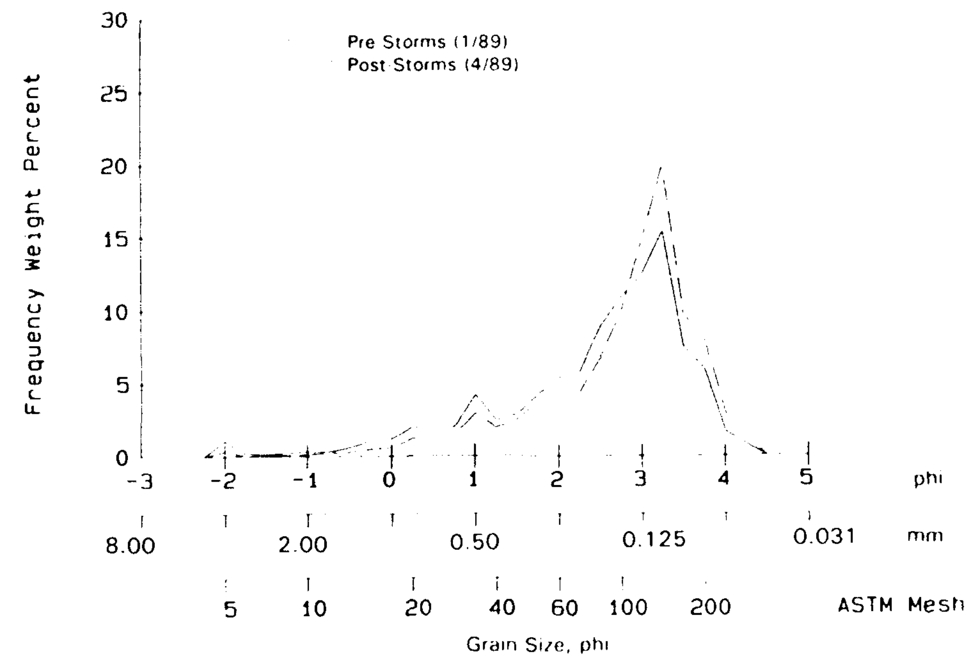


Figure 175. Comparison of northern composite nearshore, pre- versus post-storms

To understand the sediment re-sorting that occurred over the 9 months since fill was placed on the beach, a comparison of the 9-month sediment sample composite grain size distribution was made with the pre-fill native distribution. The southern foreshore composite of the 9-month sampling was composed of the 37th and 81st Street samples because the 56th and 66th Street samples were not analyzed from the 9-month sampling. A new native composite was computed using only the 37th and 81st Street samples to make the comparison of the native southern composite to the 9-month composite more uniform. The native foreshore southern composite using the two street locations differed from the four-sample composite by having slightly less percent by weight of the coarse sand fraction. The foreshore composite curve retained its basic shape. The change between the native and the 9-month samples in the two-street foreshore southern composite is shown in Figure 176. The re-sorting of the fill material by the storms and local waves produced a slightly finer 9-month foreshore composite, but overall the composite returned to the native composite distribution of grain sizes. There was an absence of coarse sand between the 1.0- and 0.5-mm (0.0- and 1.0-ϕ) size classes and additional material in the medium and fine sand between the 0.5- and 0.2-mm (1.0- and 2.25-ϕ) size classes.

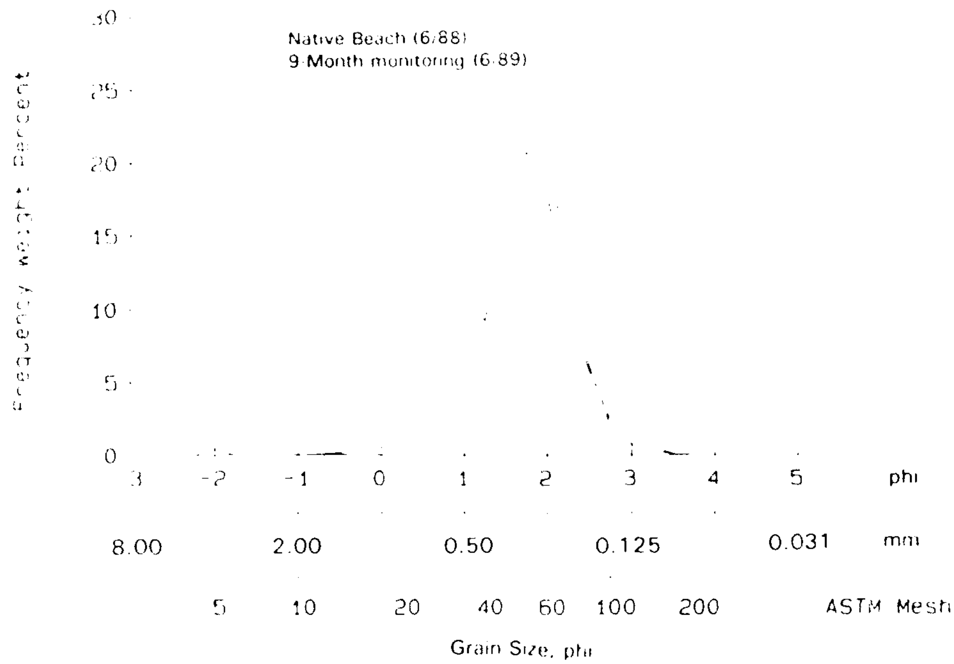


Figure 176. Comparison of southern composite foreshore, native versus 9-month

The nearshore composite of the southern native beach that included 37th and 81st Streets showed more of a difference than the four-street native composite. The two-street composite contained more coarse material with a main peak around 0.25 mm (2.0 ϕ) and a lack of a fine peak around 0.11 mm (3.25 ϕ) due to the coarser nearshore composite at 81st Street. The nearshore composites at 56th and 66th Streets contained finer material that tended to shift the composite to the finer distribution. Nine months after fill placement, the southern nearshore composite of the two streets had a slightly coarser distribution relative to the two-street native nearshore composite (Figure 177). There was a slightly higher percentage of material in the coarse sand size classes between 1.0 and 0.5 mm (0.0 to 1.0 ϕ). Less percentage of very fine sand between 0.125 and 0.074 mm (3.0 and 3.75 ϕ) was present in the 9-month composite. An increase in fine sand size material was found as the peak of the curve shifted from medium sand at 0.3 mm (1.75 ϕ) in the native nearshore composite to fine sand at 0.177 mm (2.5 ϕ) in the 9-month composite. The selective sorting of the fill by wave and currents over the 9 months had transported slightly coarser material into the nearshore area. The nearshore distribution also had an increase in fine sand sizes with a decrease in medium and very fine sand material, as the fill material from Borrow Area 2 was mixed with native nearshore sediments.

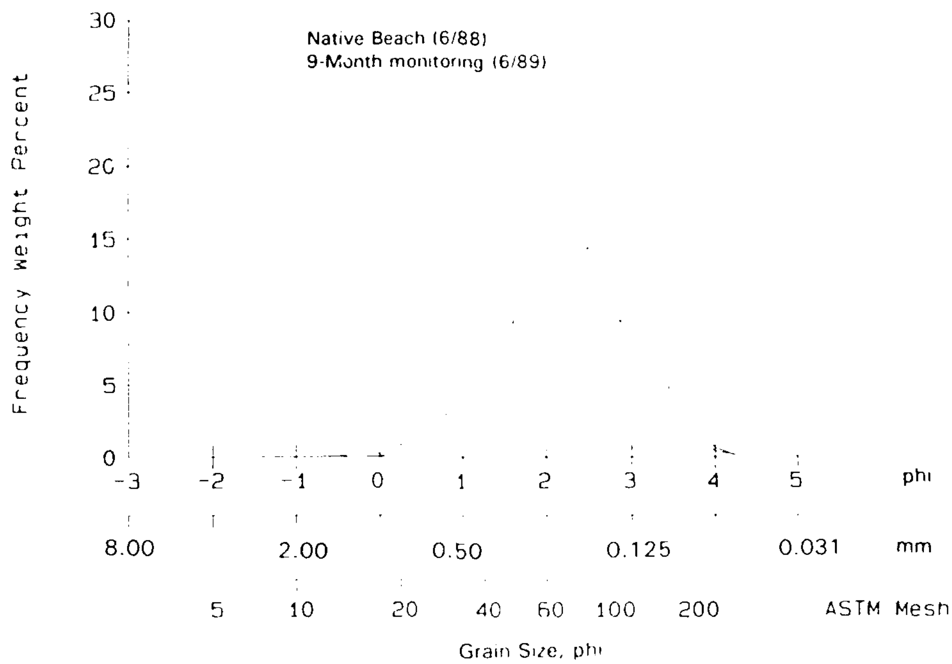


Figure 177. Comparison of southern composite nearshore, native versus 9-month

The northern composite sediment distribution for both the native beach and the 9-month monitoring was composed of samples collected at the 92nd and 103rd Street locations. Fill placed in this area was taken from Borrow Area 3. Nine months after fill placement, the northern foreshore composite had lost the gravel component and most of the very coarse sand with a grain size greater than 1.0 mm (0.0 ϕ) relative to the native nearshore (Figure 178). A percentage of the coarse sand was also not present in the 9-month foreshore composite. Storm recovery had occurred, with deposition on the foreshore between the April and June surveys. The native beach had peaks at 0.5 mm (1.0 ϕ) and at 0.3 mm (1.75 ϕ). The dominant peak on the native northern foreshore composite was at 0.5 mm (1.0 ϕ) and switched to the secondary peak in the 9-month composite, indicating that the coarse-to-medium sands of this size class were retained on the foreshore throughout the re-sorting process.

After 9 months, the northern nearshore composite had retained a frequency distribution of grain size similar to the native sands (Figure 179). This nearshore area did not receive much fill immediately after placement, because the fill was placed close to shore on these steeper northern profiles. The re-sorting of the subaerial beach and the rearrangement of the profile resulted in a slight shift to coarser material after 9 months. This new sediment distribution reflected the

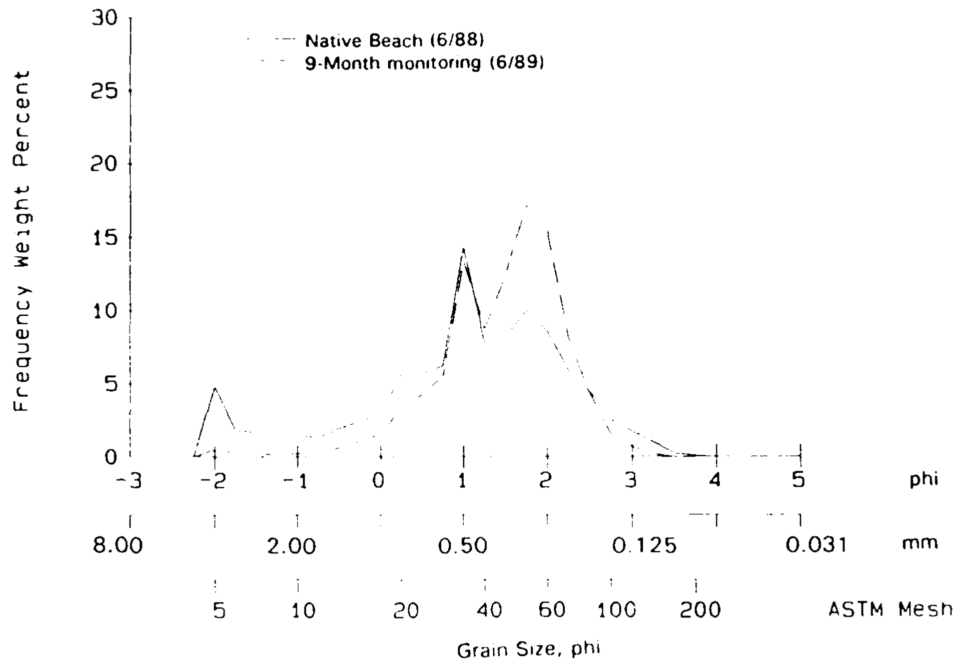


Figure 178. Comparison of northern composite foreshore, native versus 9-month

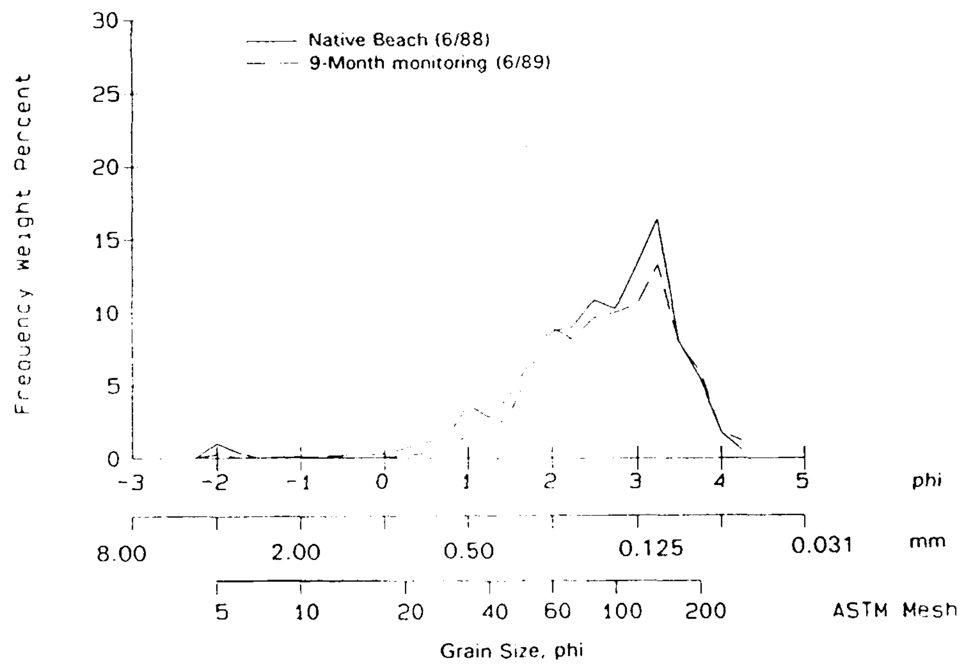


Figure 179. Comparison of northern sediment composite nearshore, native versus 9-month (92nd and 103rd Streets)

movement of sediment back onto the dry beach as the beach profile responded to fair weather waves in the spring of 1989. A small percentage of additional lag of very coarse and coarse sand ranging between 1.0 and 0.35 mm (0.0 and 1.5 ϕ) remained in the nearshore. A smaller percentage of the fine and very fine sands ranging between 0.25 and 0.105 mm (2.0 and 3.25 ϕ) was present as the sorting process removed these sizes from the 5- to 25-ft depth zone in the northern nearshore.

State Fill Performance Evaluation

The question of how important grain size is to the stability and performance of a beach fill is a subject of great interest. To approach this subject, an analysis of the grain size data with the performance of the beach fill change was undertaken. Grain size change was represented by the difference in mean grain size between the composite samples at each monitoring survey. The means of the foreshore composites were compared and either became coarser or finer between each sample interval. Fill performance was represented by the change in volume measured between samples. The step sample was usually slightly below NGVD (2-ft depth maximum or around MLW), but the foreshore composite as a whole reflected the grain size distribution on the active portion of subaerial beach from the berm crest to the step. By comparing the volume change measured on the subaerial beach with the foreshore sediment composite mean change, a relationship of profile readjustment with sediment re-sorting could be obtained. Figure 180 presents the change in grain size of the foreshore composite means at each survey line with the change in fill volume as measured on the subaerial beach above NGVD.

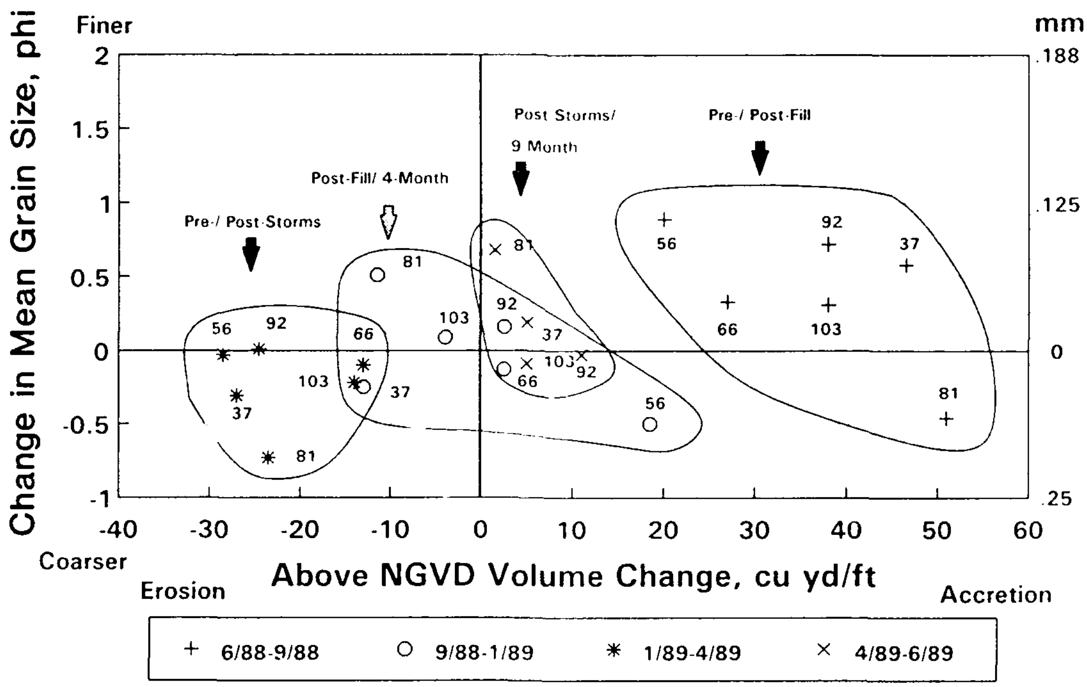


Figure 180. Change in foreshore composite mean grain size with above-NGVD volume change between surveys

State fill placement advanced the shoreline seaward and added volume to the active profile. The fill profile was, however, not in equilibrium with the prevailing wave conditions, having a high berm. Even though the composite grain size distribution of the northern borrow area was coarser than the southern borrow area, the fill material placed on the beach from both borrow areas was finer than the native beach sediment distribution at each respective survey location. A coarsening was found in the foreshore composites on the northern portion of the native beach. The borrow material was similar to the native beach. The overfill ratio for Borrow Area 2 was calculated using the Reduced State Contract Area Revised -28- to -50-ft core depth sample composites (USAED, Baltimore 1989). The R_a = 1.02 indicated that the borrow area grain size distribution based on the composite mean and sorting values was close to the native beach values. The overfill ratio for Borrow Area 3 was calculated using Area I+II Revised -28- to -50-ft core depth sample composites. The R_a = 1.0 indicated that the northern borrow area composite mean and sorting were very close to the native beach values.

The post-fill foreshore sediment composite means became finer within less than one phi unit of the native foreshore composites. The largest fill difference in the fine grain size direction was measured at 56th Street, indicating that the fill was 0.8 phi units finer than the native mean. The one exception to this pattern was found at 81st Street, where the fill had a -0.45 phi difference, indicating that the native foreshore had a finer sediment distribution than the fill placed at that site and the composite mean became coarser after fill placement. The position of the points within the grouping of the pre- to post-fill samples on the accretional side of Figure 180 reflects the variability in the volume of fill placed above NGVD at each profile/sediment survey location. This variability is a function of the construction, where the largest volume of sand was placed in the vicinity of 81st Street. The least amount of fill was placed in the vicinity of 56th Street.

Within the first 4 months, waves and currents acted on the foreshore area, reshaping the profile and re-sorting the fill material. There were no high wave energy events during this initial monitoring period. The post-fill to 4-month monitoring change indicated that the foreshore means of the three southern survey locations at 37th, 56th, and 66th Streets became coarser by less than a ½ phi unit (Figure 180). The northern three survey locations became finer by less than ½ phi unit. The subareal beach at 37th and 81st Streets lost approximately 12 cu yd/ft, while 56th Street gained approximately 19 cu yd/ft. The survey locations at 66th and 92nd Streets gained less than 5 cu yd/ft and 103rd Street lost less than 5 cu yd/ft. All of these survey locations were clustered around the zero change in profile volume and mean grain size. All of the 4-month foreshore composites became better sorted than the fill material as the finer material was winnowed out and the coarser material was covered.

The high wave energy of the four storms that occurred just 5 months after State fill placement, before the fill had completely come to equilibrium, resulted in erosion of the foreshore. Erosion volumes between 10 and 30 cu yd/ft were measured at all locations (Figure 180). The foreshore composite mean remained virtually unchanged at 56th and 92nd Streets and became coarser by less than ½ phi unit at 37th, 66th, and 103rd Streets. The highest change in mean grain size was measured at 81st Street, where mean grain size became coarser by 0.75 phi unit. All of the profile/sediment locations experienced erosion on the foreshore and all of the sediment shifted to a coarser mean after the storms, but no specific trend was evident in grain size versus foreshore volume change.

During the spring months of 1989, the foreshore experienced accretion on most of the profiles as the fair weather waves returned sand from the nearshore back onto the foreshore. The foreshore at 92nd Street received the most volume of the four profile/sediment survey locations where data were analyzed. The least gain in sand volume was found at 81st Street. The largest change in composite mean was also found at 81st Street, where the mean became 0.68 phi unit finer as sand returned to the foreshore. The two northern survey locations at 92nd and 103rd Streets experienced a slight coarsening in the mean grain size, and the two southern survey locations experienced a fining of the foreshore.

The nearshore composite mean difference was also calculated and compared with the volume change measured between survey data below NGVD. The profiles almost immediately began to be reshaped, removing material from the subaerial placement area and transporting material onto the nearshore and alongshore. The change in volume after fill placement was one of accretion at all profile/sediment survey locations, as some of the fill was placed on the shallow nearshore area. The largest volume of fill in the nearshore was placed at 81st Street and the least fill volume was at 103rd Street. The fill material was finer than the native foreshore but was slightly coarser than the native nearshore sands at four of the six locations (Figure 181). The addition of the fill produced a 0.57-phi unit change to finer material in the nearshore at 66th Street and a slight fining at 56th Street. The largest coarse change of 0.37 phi unit was found at 37th Street where the fill extended further seaward, with only slight coarsening found at 103rd Street where the fill extended only a short distance into the nearshore.

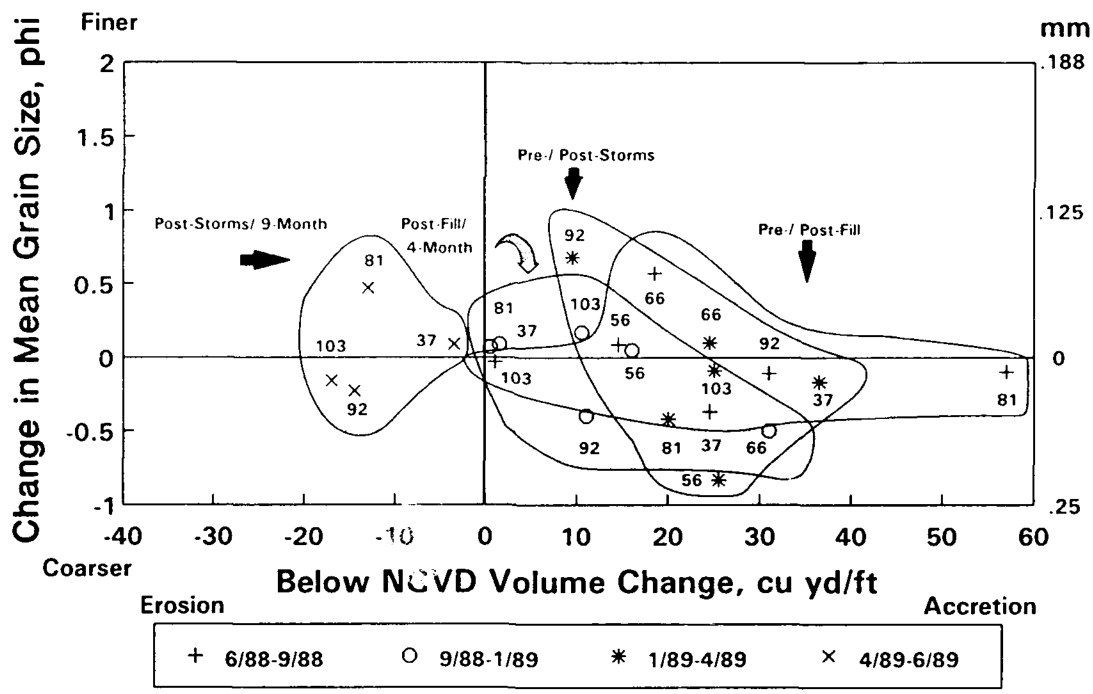


Figure 181. Change in nearshore composite mean grain size with below-NGVD volume change between surveys

As the fill was readjusted along the profiles within the first 4 months, the nearshore continued to receive sand from the foreshore. The volume changes comparing the post-fill to the 4-month survey were all positive, with deposition continuing on the nearshore (Figure 181). The largest deposition was measured at 66th Street (31 cu yd/ft). The smallest volume addition to the nearshore was measured at 37th and 81st Streets, where less than 2 cu yd/ft of sand was deposited. Comparing the nearshore composite means from January 1988 with those from the September 1988 composites indicated that four of the survey sites became slightly finer as the fill moved into the nearshore. All changes in the mean were less than 0.2 phi unit finer than the post-fill. A shift to coarser means was measured at 66th and 92 Streets, with the largest shift at 0.5 phi at 66th Street. A general trend of a shift to coarser means accompanied the greatest accretion in the nearshore over this initial monitoring period.

The impact of the storms on the nearshore included additional accretion on all study sites as more sand volume was removed from the subaerial beach and deposited in the nearshore. Thirty-seventh Street experienced the most accretion of the profile/sediment study sites, with a gain of around 37 cu yd/ft of sand (Figure 181). The smallest accretion of 9.5 cu yd/ft was measured at 92nd Street. Four of the profile/sediment survey site nearshore composite means became coarser as sand was deposited, with the maximum difference value of 0.83 phi unit found at 56th Street. The largest shift to a finer composite mean was found at 92nd Street, with a change of just over 0.5 phi unit. A general trend in coarser nearshore composite means after the storms was associated with the higher accretion volume measurements. The smallest gain in nearshore volume was associated with a shift to a finer mean grain size.

Only erosion was found in the comparison of the below-NGVD volume changes between the post-storm and 9-month profile/sediment surveys. The source of sand that moved back onto the foreshore by fair weather wave processes during the spring of 1989 came from this nearshore region. The northern profiles (92nd and 103rd Streets) lost the most sand volume from the nearshore. A shift of less than a 0.25 phi unit to coarser means was also observed (Figure 181). The smallest volume loss of 3.7 cu yd/ft from the nearshore was measured at 37th Street, with a minimal change to a finer composite mean. The largest shift of 0.5 phi unit to a finer mean was measured at 81st Street. A weak reverse trend of higher erosion accompanying a shift to coarser means was found, but only four sample sites were analyzed.

In the calculation of the overfill ratio and the renourishment factors, the phi mean difference is compared to the ratio of the sorting (*Shore Protection Manual* 1984). The analysis compares the mean and the sorting values of the native beach with the borrow area. The overfill ratios that were calculated from Borrow Area 2 ($R_a = 1.02$) and Borrow Area 3 ($R_a = 1.00$) using the 1986 native beach grain size data indicated that an equal volume of borrow material would be required to produce a unit volume of usable fill material with the same grain size distribution as the native material. For a detailed discussion of the overfill model see Stauble and Hoel (1986).

To assess the performance of the fill and the fill suitability based on the overfill ratio, an analysis of the amount of fill that remained on the beach and nearshore as of the 9-month profile/sediment survey was performed. The phi mean difference was calculated using the formula

$$\frac{\mu_b - \mu_n}{\sigma_n}$$

where μ_b = composite mean of the borrow, μ_n = composite mean of the native, and σ_n = composite sorting of the native sample. The phi mean difference indicates whether the borrow is finer or coarser than the native. A phi mean difference was calculated for the 9-month monitoring sampling periods by substituting the 9-month composite values (June 1989) for the borrow values using

$$\frac{\mu_{6/89} - \mu_n}{\sigma_n}$$

where $\mu_{6/89}$ is the composite mean grain size for the June 1989 survey. These values were calculated for the foreshore composites, nearshore composites, and a profile composite (that included all samples from the dune base to the 25-ft depth). Phi mean differences were compared to the percent of fill remaining. The percent of fill remaining was calculated from the cumulative volume data calculated from ISRP for the above-NGVD, below-NGVD, and the entire profile out to 900 ft between the pre-fill (native beach of June 1988) and the 9-month monitoring (June 1989) dates. The values for foreshore sediment phi difference were paired with the above-NGVD percent of fill remaining (Figure 182).

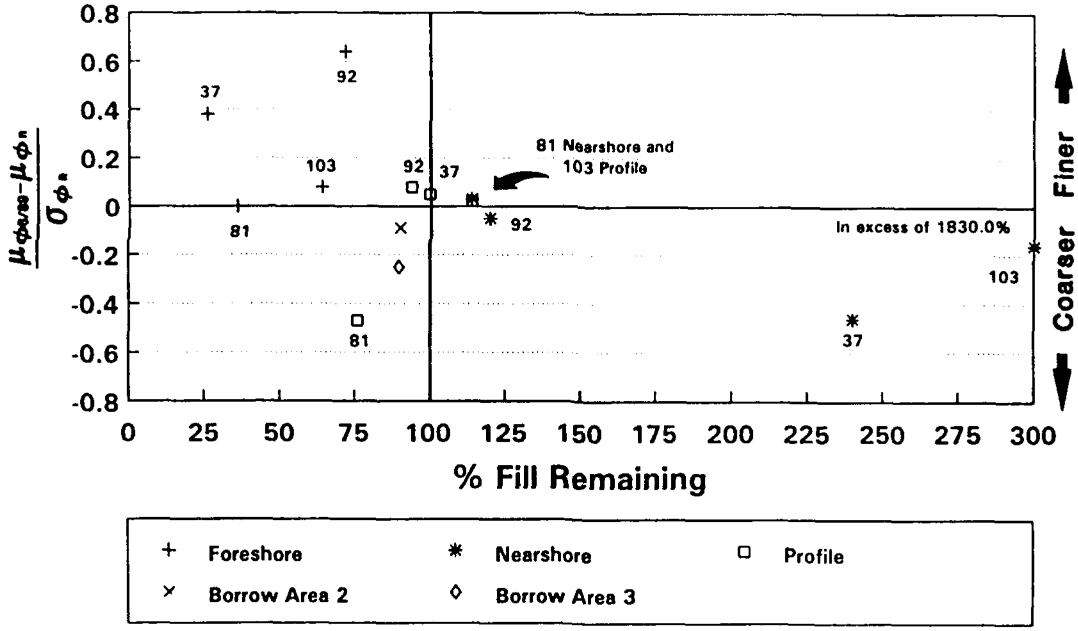


Figure 182. Comparison of the phi-mean difference of the native beach to 9-month monitoring sample with the percent of fill remaining at four sediment survey lines

The nearshore sediment values were paired with the below-NGVD percent of fill and the profile sediment data were paired with the total profile percent of fill remaining. As the fill profile was reshaped by the fair weather and storm-generated waves, the foreshore lost material. Of the four profile/sediment survey locations, the 37th Street location had the least amount of fill remaining above NGVD after the first 9 months of monitoring of the State fill. Ninety-second Street had the best retention of fill on the subaerial beach, with 75 percent by volume of fill remaining. The native beach/9-month monitoring foreshore composite phi mean difference indicated that the foreshore means were either the same (81st Street) or finer than the native (37th, 92nd, and 103rd Streets). The nearshore gained sand over the study period and all of the below-NGVD volumes were greater than 100 percent of the volume of fill placed at each profile/sediment survey site. The 103rd Street location gained the most sand in the nearshore as of June 1989, possibly due to material moving south alongshore from the northern portions of the fill. Eighty-first Street gained the least amount of fill. It is suspected that the location of this survey site in close proximity to the attachment point of the northern shoreface-attached shoal resulted in a focusing of waves on this street and enhanced the erosion of the fill. Except for a slight fining of the 81st Street site, all of the nearshore sediment composites became coarser than the native nearshore as the fill was redistributed.

The profile composite values averaged the changes in sediment statistics of the foreshore and nearshore, plus included the dune base and the bar and trough samples (when collected). The volume of fill removed from the subaerial beach was also balanced by the deposition in the foreshore to give an average fill volume retained at each site. Over the 900-ft standardized cross-shore length, the 81st Street location had the least percentage of fill retained of the four survey sites; 76 percent. The best retention of fill was found at 103rd street, where 120 percent of the fill occupied the standard profile length. Three of the four sites had a slightly finer mean than the native beach as averaged across the entire profile composite. Eighty-first Street experienced a coarsening of the fill as compared with the native composite data. A comparison of the predicted overfill ratio values of the phi difference with an assumed 90-percent retention are plotted to compare the predicted with the actual mean grain size change and percent of fill remaining after 9 months. The 90-percent retention is based on the average annual erosion of approximately 5 cu yd/ft, calculated from a pre-fill erosion rate of somewhere between 2 and 5 ft per year listed in Anders and Hansen (1990) and USAED, Baltimore (1989). The overfill ratio method predicts the profile composite retention percentages fairly well, but overpredicts the foreshore retention and grain size change and underpredicts the actual nearshore retention and sediment composite mean change.

5 Summary and Conclusions

Beach nourishment for the "Atlantic Coast of Maryland (Ocean City) Shoreline Protection Project" was provided in two separate phases. A recreational beach was placed by the State of Maryland between 3rd Street and the Maryland-Delaware State line in the summer of 1988. Material was pumped from two offshore borrow sites, Site 2 located off the southern end of the Town of Ocean City, and Site 3 off the northern end of the project near the State line (Figure 3). Using two dredges, fill material from the southern borrow site was placed between 3rd Street to around 92nd Street, simultaneously with fill material from the northern borrow site placed between 92nd Street and the State line. Approximately 2.7 million cu yd of fill material were placed during this first State fill phase, and at the same time, additional fill material was placed along a 1-mile length of beach in Delaware by the State of Delaware.

During the summer of 1990, second-phase construction was begun by the CE to provide storm protection to upland property. Construction included a dune, seawall, and a wider beach placed on the existing State fill. Material for this second phase was pumped from Borrow Area 3 at the north. From 3rd Street to 27th Street, in the area of the boardwalk, a seawall was constructed with a crest at 14 ft. North of 27th Street a sand dune was included in the construction template with a crest elevation of 14.5 ft. The Federal fill part of the project was constructed as far north as 100th Street from June to September 1990, and the section from 100th Street to the State line was completed from June to August 1991. A 1,600-ft-long transition zone was constructed into Delaware to taper the fill shoreline into the existing shoreline. Approximately 3.8 million cu yd were placed during the Federal fill.

The beach profile and sediment monitoring area extended from 37th Street on the south to the vicinity of 103rd Street on the north. This area encompasses roughly the center one third of the project. Twelve profile lines were surveyed during the State fill monitoring period from the pre-State fill June 1988 survey to the pre-Federal fill June 1990 survey. Profile surveys were not made at 66th and 78th Streets during monitoring of the Federal fill.

Two non-directional wave gauges were placed approximately 1.6 miles offshore of the project in 30 ft of water to record wave height and period just before the beginning of the State fill. The south wave gauge was located off 10th Street, and the north gauge was located off 80th Street. Two gauges were used to provide a redundancy backup and to account for the complex offshore bathymetry, including the shoreface-attached shoals that conceivably could cause different wave propagation between the northern and southern ends of the project. These gauges were replaced with directional wave gauges in February 1990. Spectrally based significant wave height H_{mo}, peak spectral period T_p, and dominant direction Θ_p (after March 1990) were recorded. The use of two wave gauges allowed for almost complete coverage during the monitoring period. Except for a few time periods, at least one gauge was always in operation. Analysis of the wave records showed that the nearshore bathymetric variations did not cause strong variations in H_{mo}, T_p, or Θ_p, with both gauges recording similar values.

The 20-year hindcast wave climate available for the Ocean City area showed an H_{mo} of 1.0 m at Station 65 in 18 m (60 ft) of water. A seasonal variation in wave height occurred, with the lowest waves (H_{mo} of 0.6 m) occurring during the summer months of July and August and the highest waves (H_{mo} of 1.2 m) occurring during the winter months of December, January, and February. The predominant wave approach directions are from the east and southeast, with 28 and 25 percent of all hindcast waves approaching respectively from these directions. Only 4 percent of the waves approached from the northeast, but they tended to be higher. The lower waves had shorter periods. The summary of the actual wave gauge records located in 10 m (30 ft) of water showed a seasonal trend. Wave heights exceeded 1 m around 20 percent of the time in the winter months from January 1988 to March 1992. For the summer months from July 1988 to September 1991, wave heights exceeded the 1-m H_{mo} only around 5 percent of the time. The actual wave record showed a pattern of wave approach direction similar to the hindcast data, with the predominant wave approach direction from the east and southeast, with 28.9 and 32.5 percent of all recorded waves approaching respectively from these directions. An overall mean from all gauge records over the August 1988 to January 1992 period was an H_{mo} of 0.7 m, with the largest H_{mo} being 4.4 m. The mean T_p was 8.3 sec.

Within five months of the placement of the State fill, four extratropical storms impacted the project. Between 23 February and 25 March 1989 the first significant storms were observed, with all four storms producing waves with heights exceeding 2.25 m at the gauges. On 24 February and 21 March, waves were close to 3.0 m in height. Peak periods ranged between 10 and 12 sec during the highest wave events.

The Halloween Storm of 1991 (29 October - 2 November 1991) impacted the Federal fill some two months after the completion of the northern part of the project and 14 months after the completion of the southern part. This extratropical storm had a duration of 66 hr, with a surge of around 4.5 ft NGVD. The maximum H_{mo} of 3.1 m was measured at the wave gauge sites on 31 October 1991, with a T_p of 19.7 sec, an unusually long wave period for the mid-Atlantic Ocean coast.

Another extratropical storm impacted the project two months later, between 4 and 5 January 1992. The beach had little time to recover from the Halloween Storm and from a smaller extratropical storm that impacted the project area over 9-12 November 1991. In contrast to the large, slow-moving, and long- duration Halloween Storm, this northeaster was small, rapidly developing, and fast moving. The maximum H_{mo} of 4.4 m was measured at the wave gauge sites on 4 January 1992, with a T_p between 12.2 and 15.1 sec. The NOS tide gauge on the Ocean City pier was destroyed during the storm, but an estimate of the storm surge was made from the wave gauge water level records at +6.6 ft.

Beach profile surveys were made on 16 dates for the monitoring of this project, starting with the pre-State fill native beach in June 1988 and ending with the post-storm profile set of the Federal fill in January 1992 at the time of preparation of this report. The profile surveys extended seaward to as much as the 30-ft depth using a sled. These highly accurate surveys provided long profiles that start from the baseline landward of the dune and extend seaward as much as 2,000 ft. Sufficient numbers of profile surveys exist to determine the depth of closure for this 3-1/2-year data set. At least three periods of high-wave events were covered. Depth of closure is identified here as the minimum depth where the standard deviation in depth change on the survey decreases markedly to a near constant depth (typically much less than 0.5 ft). The active envelope of profile change is located landward of this area and indicated the region of the profile that is dominated by short-period wave activity and storm-induced water level changes. Changes seaward of this region exhibit smaller and near constant standard deviation, which is the region influenced by lower-frequency and weaker sediment-transport processes controlled by large-scale shelf circulation.

The profile lines located at the southern end of the monitoring area (37th to 45th Streets) characteristically are flatter and show a depth of closure between the 19- and 20-ft depth some 1,800 ft offshore. The area where the southern shoreface-attached shoal intersects the shoreline (52nd to 63rd Streets) showed a depth of closure around the 16- to 20-ft depth around 1,800 ft offshore. These lines showed the smallest deviation relative to all other profiles and may be protected by the shoal. The middle of the monitoring area, (66th to 78th Streets) had an area of closure around the 22- to 25-ft depth which was located between 770 and 1,300 ft offshore. The northern shoreface-attached shoal intersects the shoreline in the vicinity of the 81st to 92nd Streets area. Here closure is at the 22-ft depth at 81st Street around 1,000 ft offshore and decreases to the 18-ft depth at 86th and 92nd Streets around 700 ft offshore. The northern area (103rd Street) has a steeper profile and reaches closure at the 24-ft depth around 1,200 ft offshore. Depth changes occur on the ocean side and the lee side of the two shoreface-attached shoals, but the trough area between the active profile and the shoal showed little change, indicating that the shoals may be decoupled from the beach face closure depth. On average, closure depth can be considered at the 20-ft (6-m) depth NGVD for the Ocean City area.

Analysis of the 12 individual profile surveys over the monitoring period showed cross-shore patterns in erosion and accretion between profiles and provided volume changes. Volume changes were computed between the dune and NGVD (the above-NGVD volume), between NGVD and 900 ft seaward of the baseline (the below-NGVD volume), and as the total volume change both above and below NGVD (the total profile volume). The 900-ft depth was chosen to represent the seaward limit of profile activity because this was on average the shortest profile length in the data sets. Pre- and post-State fill profile surveys showed the placement area of the fill material and the volumes placed at each location. Approximately 2.7 million cu yd of fill were placed on the beach during the State fill. Initial 4-month readjustment of the fill profile into a more natural profile shape by the fair-weather coastal processes removed some of the fill from the dry beach and deposited it in the nearshore. The four extratropical storms occurring in February and March 1989 eroded material from the foreshore, which was deposited in the nearshore area between NGVD and closure depth. A post-storm project average erosion of 21.1 cu yd/ft above NGVD area was balanced by deposition of 20.3 cu yd/ft of material in the nearshore to 900 ft. Storm recovery was documented with 6-month (immediate post-storm profile), 9-month, 12-month, and 22-month surveys. By June 1990, 22 months after the State fill placement, the above-NGVD beach had accreted 10 cu yd/ft or about 54 percent of the fill volume on the beach before the storm had returned above NGVD. The total volume of sand on the profile was 64.6 cu yd/ft, or 87.8 percent of the State fill placed.

The June 1990 profile became the pre-Federal fill survey and was compared with the post-Federal fill survey of August 1990. Approximately 3.8 million cu yd of fill were placed on the beach during the two summers of the Federal fill. This portion of the project included new dune construction for storm protection with a crest elevation of +14.5 ft. Around 70 percent of the project was constructed during the summer of 1990, and the remaining 30 percent (north of 100th Street) was finished during the summer of 1991. A 4-month post-fill survey documented the initial readjustment of the fill material with removal of material from the berm and deposition in the nearshore. Eight-month and ten-month monitoring surveys showed little change to most of the profiles with a slight loss in the above-NGVD portion of the profiles and accretion in the below-NGVD portion. The June 1991 profile survey was the last profile made before the Halloween Storm of 1991 and became the pre-storm profile condition. A partial set of surveys (6 of the 12 profile line locations) was taken in November just after the Halloween Storm to document the storm impact. The Halloween Storm eroded a large portion of the subaerial beach but the dune was only scarped at its base at most locations. An average of 17 cu yd/ft were eroded from above NGVD, and 12.4 cu yd/ft of sand were accounted for in the nearshore to closure (20-ft depth contour). Before any additional profiles could be taken, the 4 January 1992 northeaster impacted the project. An additional 6 cu yd/ft of material were eroded from above NGVD, and 18.4 cu yd/ft of sand were deposited in the nearshore area to closure. An average total profile volume of 136.7 cu yd/ft remained within the monitoring area, or around 96 percent of the Federal fill placed. The subaerial beach volume as of January 1992 was, on average, 33.8 cu yd/ft above NGVD, which is 86 percent of the State fill volume even after the two storm events. Most of the fill material remained in the nearshore with an average of 103 cu yd/ft, which is close to 300 percent of the volume placed in the monitoring area for the State fill.

Analysis of sediment characteristics of samples collected during the State fill project showed the influence of the fill material on the native beach and the change in sorting after the passage of four storms. Fill material had a finer foreshore distribution than the native beach on all six sediment sampling locations except 81st Street, even though the fill material came from two different borrow areas. Finer fill material from Borrow Area 2 was placed on the beach from the south terminus of the project to 91st Street. A coarser fill material from Borrow Area 3 was placed north of 91st Street, but the native beach was coarser than this fill material. Composites were constructed of the foreshore and nearshore samples to remove some of the variability in grain size distribution in the cross-shore direction. The coarsest foreshore composite fill material was found in the northern end of the project, and the finest foresnore fill material was found to the south. In general, the sediment distributions with finer means had better sorting. The coarsest post-fill nearshore material was found at 37th and 81st Streets, where the fill was placed further into the nearshore.

A complex pattern of grain size change was observed over the monitoring period. In general, the coarsest nearshore material was found along the southern end of the project. The finest nearshore material was found at the northern end of the project at 92nd Street. Four months after fill placement, the foreshore composites of all beaches had the smallest range in composite mean and sorting values. No apparent trend in sorting could be found as the sediment was interacting with the wave conditions to re-sort the fill. After four storms impacted the project in March 1989, the coarsest foreshore material was found at 81st Street, an area of high erosion volume. The finest foreshore material was found at 56th, 92nd, and 37th Streets in areas protected by the shore-attached shoals and nearshore bar. The coarsest nearshore material was also found at 81st and at 37th Streets. The finest nearshore material was found at 92nd Street. Due to the high energy of the storms, the composite sediment sorting showed little trend on either the foreshore or nearshore. The final sediment monitoring samples were collected 9 months after State fill placement. Because 56th and 66th Streets did not have samples analyzed at the time of preparation of this report, only four sediment survey locations were evaluated. The coarsest foreshore composite sediment was located at 103rd and 92nd Streets and the finest was at 81st and 37th Streets. The coarsest nearshore composite was located at 37th Street, and the finest was located at 92nd Street. The foreshore composites showed a trend toward finer sizes having better sorting. The opposite trend was present in the nearshore composites. The composite statistics of the 9-month monitoring were close to the native composite statistics of the four survey locations evaluated, indicating that the fill material was taking on the characteristics of the pre-fill native beach.

Much of the variability in profile response along the study beach may be due to the variability in the nearshore bathymetry. Two shoreface-attached shoals bisect the beach at locations between 52nd and 56th Streets and between 74th and 92nd Streets. At the southern end of the project, a shore-parallel longshore bar/trough profile is common. Three nearshore bars are located on the profile at 37th Street. The profiles at the southern end of the study area are characterized by flatter foreshore and nearshore slopes. A nearshore bar/trough was common over the study period at depths between 2 and 5 ft at 37th, 45th, 52nd, 56th, and 66th Streets. The steepest foreshore slopes with no bar/trough and more commonly a low tide terrace were found at 74th, 78th, 81st, and 86th Streets. The northern profiles at 92nd and

103rd Streets were more commonly narrow, with a concave shape. These northern profile lines had no bar/trough and only an occasional low-tide terrace.

Comparison of the percent of State fill volume remaining alongshore after the 28-month monitoring of both projects summarizes the pattern of long-term project behavior. All of the survey sites had greater than 100 percent of the State fill volume remaining on the profile at the end of the monitoring period. Most of the fill material was located in the subaerial portion of the profile. Sites with less than 200 percent of the State fill volume remaining on the profile were found at 45th and 56th Streets and between 74th and 86th Streets. The highest volume retained was found at 103rd Street due to the large gain in the nearshore. Other sites with greater than 200 percent of the State fill volume remaining on the profile were at 37th, 52nd, 63rd, and 92nd Streets. The general trends in percent of volume remaining on the above-NGVD, below-NGVD, and total profile support the premise that "hot spots" or areas of greater erosion and loss of fill volume are located where the profiles were steepest and near the point of connection of the shoreface-attached shoal with the shoreline. The profile survey lines that retained the most fill volume had a bar/trough configuration or were located in the lee of the shoreface-attached shoal.

In conclusion, the beach nourishment project performed well in protecting the beachfront infrastructure of Ocean City from storm damage. The fill material was eroded from the foreshore after the major storms of 1989 and 1991/92, but could be accounted for in the nearshore between NGVD and closure. An average of 57 percent of the State fill was on the above-NGVD profile at the end of 14 months after fill placement. Much of that material was deposited in the nearshore, and on the profile to the 900-ft distance, 87.8 percent of the fill was accounted for. The addition of the Federal fill with the dune above the remaining State fill added additional protection to the project. After the Halloween and 4 January northeasters, an average of 43.6 percent of the Federal fill remained above NGVD. The eroded material was again deposited in the nearshore region, and 96 percent of the fill material was still within the nearshore area of the 3.7-mile-long fill monitoring area of the 7-mile-long project.

Localized "hot spots" of erosion were found on the State fill at 52nd to 56th Streets and 74th to 86th Streets after the 1989 storm series. Increased erosion of the subaerial beach and breaching of the protective dune occurred on the Federal fill at 45th, 63rd, and 74th to 86th Streets after the Halloween and 4 January northeasters. These profile locations correspond with the areas where shoals attach to the shoreface. The erosion pattern was probably produced by wave convergence and divergence over these shoal features. The slight differences between the storms' impact on the state fill and Federal fill are attributed to the strong easterly component of the winds from the 4 January storm that resulted in producing higher wave heights and elevated water levels. The Halloween storm and the northeasters in 1989 had more of a northeasterly component, which would create different wave refraction patterns over the shoals and focus wave energy on slightly different parts of the beach.

As a rule, monitoring data on beach fill performance have been difficult to obtain, and assessment of project performance and improvement of design concepts have been limited. The use of the survey sled on the Ocean City, Maryland project has allowed for a highly accurate and long profile survey that covers the entire area of the active profile envelope. The long period of monitoring has provided both initial fill readjustment and assessment of longer term behavior. The collection of sediment samples allows for assessment of grain size readjustment and comparison of the native to fill grain size distributions. Wave and water level gauge data provide a unique data set to assess the physical forces acting on the beach fill. Monitoring of both pre- and post-storm processes has allowed for assessment of project impacts from extreme events. Comprehensive monitoring of this beach fill project has provided excellent data for evaluating fill performance and level of protection, as well as for research on beach fill behavior and improving predictive engineering design technology.

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Appendix A
Beach Profile Survey Data

Appendix A contains two parts, a listing of the survey data file and plots of the beach profiles used in this report.

The data file lists the entire length of each survey by street and chronologic order. Table A1 lists the explanation of the data format. Some surveys started landward of the baseline and have negative horizontal coordinates for points landward of the baseline. Some surveys started seaward of the baseline and highlighted coordinates (e.g., 0 130) were added from the previous survey to provide a common starting point for all surveys at the baseline (0 ft). The standardized profile length was determined to be 900 ft in length from the baseline. Highlighted coordinates (e.g., 900 -198) at the seaward end of some surveys represent data added to short surveys from the previous survey to extend all surveys to at least 900 ft. This standardized length provided a reasonable horizontal distance over which to calculate volume change between survey dates.

The plots are by Survey Line number and listed by street location. The plots produced in ISRP Volume 2.0 compare each survey to the previous survey in the file. The surveys extend from the baseline (0 ft) to 1,000 ft, covering the standardized 900-ft profile length. The pre-State fill survey was made in June 1988 and the post-State fill survey was made in September 1988. The pre-storm profile during the State fill project monitoring was made in January 1989 and the post-storm survey was made in April 1989. The pre-Federal fill survey was made in June 1990 and the post-Federal fill survey was made in September 1990. A post-Halloween storm survey was collected at seven of the survey lines in November 1990. The post-4 January 1992 storm survey was made in January 1992.

Table A1
Explanation of Profile Survey Data Format

Position	Description of Entry
	First Data Line in Each Record
1-5	Profile Location Number
6-10	Blank
11-16	Date of survey (year, month, day)
17-22	Time of Survey (e.g., 1750 = 17:50)
23-26	Number of coordinate pairs in the survey
27-32	Minimum elevation in the survey (e.g., -258 ft = -25.8 ft)
33-46	Blank
47-94	First four distance-elevation pairs Elevation values need to be decreased by a factor of 10. (e.g., *80 42 = Horizontal Distance 80 ft, Elevation 4.2 ft*)
	Following Data Lines in Each Record
1-10	Same as first data line
11-94	Seven distance-elevation pairs

37th Street (Line 14/13)

OC 37	880616	0	75	-246			-475	73	-108	134	0	130	26	122
OC 37	51	64	76	50	97	50	122	36	134	23	137	19	146	9
OC 37	166	-16	177	-20	189	-21	205	-24	218	-19	228	-22	240	-24
OC 37	258	-30	267	-26	272	-27	281	-24	300	-26	318	-30	330	-37
OC 37	348	-38	370	-52	377	-57	388	-65	400	-71	413	-71	437	-78
OC 37	453	-84	453	-85	472	-90	487	-93	491	-97	492	-97	513	-104
OC 37	538	-115	545	-112	570	-119	581	-124	581	-125	606	-133	622	-141
OC 37	651	-155	722	-171	753	-174	780	-176	802	-177	829	-179	853	-180
OC 37	908	-186	930	-192	951	-196	973	-203	992	-207	1016	-210	1040	-216
OC 37	1061	-222	1097	-230	1130	-236	1168	-243	1201	-246	1233	-245	1266	-245
OC 37	1301	-242	1322	-240	1358	-237	1381	-235	1406	-236	1428	-235	1451	-235
OC 37	1468	-235												
OC 37	880922	0	56	-246			0	130	9	127	39	120	59	116
OC 37	79	110	98	99	118	91	139	83	159	72	179	63	199	58
OC 37	210	54	263	21	299	1	348	-16	423	-51	432	-56	441	-61
OC 37	451	-66	459	-72	469	-76	476	-81	486	-86	495	-91	502	-95
OC 37	508	-99	520	-106	529	-111	539	-116	551	-122	569	-125	582	-130
OC 37	598	-135	607	-139	618	-145	633	-151	643	-155	655	-160	679	-166
OC 37	691	-169	769	-175	846	-181	894	-186	943	-191	970	-196	1000	-202
OC 37	1015	-206	1034	-211	1052	-216	1073	-222	1088	-226	1112	-231	1133	-236
OC 37	1159	-241	1196	-246	1242	-245								
OC 37	890117	700	59	-286			-108	134	14	125	29	121	44	117
OC 37	59	113	74	111	89	102	104	95	117	89	129	85	144	76
OC 37	159	54	178	45	197	38	217	21	238	0	258	-21	274	-34
OC 37	291	-37	310	-43	331	-43	351	-41	365	-26	386	-29	403	-34
OC 37	412	-43	438	-52	465	-61	523	-81	543	-92	568	-100	584	-115
OC 37	595	-122	614	-133	638	-145	660	-156	722	-168	790	-182	847	-184
OC 37	947	-190	998	-208	1087	-218	1148	-231	1203	-239	1254	-243	1318	-248
OC 37	1386	-243	1447	-239	1494	-235	1558	-235	1601	-237	1643	-241	1684	-246
OC 37	1731	-248	1794	-255	1858	-264	1930	-275	2017	-280	2092	-286		
OC 37	890420	1100	54	-317			-108	134	21	126	39	120	58	114
OC 37	75	62	95	54	110	53	126	28	150	2	176	-15	198	-37
OC 37	233	-58	249	-57	254	-49	276	-31	307	-30	336	-33	347	-31
OC 37	356	-30	394	-34	412	-50	457	-51	505	-61	559	-70	613	-86
OC 37	675	-105	710	-111	744	-127	805	-164	834	-174	893	-189	948	-199
OC 37	1011	-215	1065	-223	1119	-230	1179	-239	1249	-252	1306	-260	1375	-249
OC 37	1440	-240	1504	-236	1560	-230	1623	-233	1706	-241	1793	-252	1889	-267
OC 37	1978	-276	2088	-286	2172	-294	2249	-299	2328	-303	2410	-306	2492	-312
OC 37	2586	-317												
OC 37	890620	630	53	-278			-108	134	-1	127	18	124	38	120
OC 37	56	113	69	77	90	56	107	59	122	63	141	36	161	15
OC 37	181	1	200	-8	220	-14	241	-18	259	-22	281	-29	299	-32
OC 37	320	-35	339	-42	361	-44	383	-47	405	-48	435	-56	440	-56
OC 37	444	-57	446	-56	492	-65	510	-70	556	-76	593	-88	640	-99
OC 37	664	-105	689	-113	713	-127	738	-133	763	-146	785	-153	801	-166
OC 37	825	-175	846	-181	867	-191	973	-203	1055	-215	1135	-225	1275	-252
OC 37	1399	-241	1483	-235	1567	-229	1655	-233	1735	-251	1871	-268	1998	-278
OC 37	891001	813	60	-291			-483	79	-224	98	11	122	22	121
OC 37	32	120	49	112	51	109	51	105	63	100	74	75	86	71
OC 37	96	66	107	62	118	59	130	58	142	58	154	51	165	41
OC 37	184	27	202	9	210	1	216	-6	223	-12	231	-19	253	-31
OC 37	268	-37	289	-43	372	-56	421	-48	456	-30	486	-37	499	-45
OC 37	513	-52	528	-59	581	-76	604	-93	631	-108	659	-123	683	-133
OC 37	712	-141	742	-150	802	-166	867	-185	943	-196	1010	-213	1083	-229
OC 37	1148	-237	1216	-249	1295	-248	1363	-242	1435	-237	1506	-233	1589	-231
OC 37	1667	-237	1746	-249	1832	-261	1929	-272	2001	-278	2078	-284	2170	-291
OC 37	900601	0	40	-211			0	133	25	121	50	107	75	81
OC 37	100	69	125	70	150	59	175	40	200	14	225	1	250	-11
OC 37	275	-17	300	-21	325	-27	350	-32	375	-41	400	-52	425	-65
OC 37	450	-71	475	-77	500	-85	525	-91	550	-101	575	-106	600	-115
OC 37	625	-122	650	-131	675	-139	700	-146	725	-157	750	-166	775	-172
OC 37	800	-179	825	-184	850	-191	875	-194	900	-198	925	-202	950	-208
OC 37	975	-211												

OC 37	900814	1200	42	-198			0	133	10	121	25	126	40	148
OC 37	50	149	65	149	75	133	95	102	100	97	125	97	150	92
OC 37	175	94	200	90	210	90	225	90	250	74	275	60	300	48
OC 37	325	40	350	23	375	10	400	-5	425	-24	450	-39	475	-61
OC 37	500	-81	525	-94	550	-102	575	-109	600	-116	625	-124	650	-131
OC 37	675	-140	700	-147	725	-156	750	-166	775	-172	800	-178	825	-184
OC 37	850	-191	875	-194	900	-198								
OC 37	901201	1500	66	-257			-56	140	-25	134	2	126	15	132
OC 37	27	140	39	147	50	154	65	143	79	129	97	102	110	99
OC 37	123	97	138	95	151	92	166	92	179	92	193	92	206	92
OC 37	210	55	224	50	237	44	252	43	266	41	278	32	290	20
OC 37	304	12	318	2	343	-14	372	-15	410	-19	432	-24	465	-32
OC 37	501	-37	522	-40	560	-49	582	-63	606	-76	632	-88	652	-103
OC 37	676	-115	701	-128	717	-143	736	-155	756	-168	780	-183	824	-196
OC 37	854	-202	888	-203	924	-204	972	-206	1017	-214	1081	-226	1130	-234
OC 37	1184	-251	1203	-256	1248	-257	1290	-254	1335	-253	1371	-251	1401	-249
OC 37	1441	-249	1486	-247	1532	-246	1574	-244	1625	-244	1669	-242		
OC 37	910326	1115	65	-258			-56	140	-27	133	0	125	14	127
OC 37	28	138	38	150	51	152	64	148	81	125	98	102	114	95
OC 37	131	96	150	92	168	90	183	92	186	82	203	70	213	61
OC 37	223	51	240	34	257	18	268	12	279	4	295	-9	305	-15
OC 37	328	-32	345	-44	355	-47	373	-51	400	-55	431	-60	470	-57
OC 37	484	-57	506	-59	527	-60	550	-60	566	-59	581	-55	649	-69
OC 37	667	-82	688	-93	710	-105	727	-118	747	-129	768	-140	782	-151
OC 37	799	-159	816	-169	833	-180	852	-189	872	-199	900	-203	938	-208
OC 37	982	-215	1021	-221	1052	-221	1102	-233	1144	-245	1172	-251	1216	-250
OC 37	1271	-251	1378	-252	1496	-244	1642	-244	1771	-258				
OC 37	910626	600	60	-262			-56	140	-22	134	10	127	29	139
OC 37	41	145	52	152	66	142	79	128	97	101	117	96	129	95
OC 37	141	94	152	88	162	82	173	71	183	58	202	62	213	61
OC 37	224	60	234	56	244	52	254	31	254	31	261	35	277	20
OC 37	291	1	304	-8	318	-17	333	-26	370	-43	388	-50	429	-50
OC 37	457	-57	485	-48	485	-55	511	-42	567	-44	614	-62	629	-79
OC 37	645	-93	663	-108	696	-112	716	-121	739	-129	762	-138	784	-153
OC 37	809	-165	835	-179	858	-188	884	-196	911	-205	961	-214	1019	-222
OC 37	1078	-231	1092	-233	1119	-236	1163	-239	1244	-251	1287	-261	1326	-262
OC 37	911103	1000	58	-260			-56	140	-28	134	-2	127	11	127
OC 37	26	137	42	150	59	148	75	135	94	115	112	95	132	77
OC 37	142	69	142	69	150	69	170	61	186	54	205	42	217	35
OC 37	228	26	238	19	248	10	251	10	261	0	272	-9	284	-19
OC 37	286	-18	298	-25	310	-31	323	-39	337	-46	352	-56	352	-56
OC 37	361	-61	419	-59	438	-59	476	-44	483	-40	508	-20	540	-29
OC 37	554	-35	569	-40	618	-60	641	-74	667	-86	694	-98	718	-110
OC 37	735	-125	755	-138	776	-150	798	-165	824	-177	850	-189	905	-205
OC 37	953	-217	1034	-234	1126	-247	1189	-259	1241	-260				
OC 37	920111	1500	65	-277			-56	140	-21	136	10	131	29	137
OC 37	43	151	60	147	71	135	82	119	93	109	104	96	124	83
OC 37	142	67	177	53	209	36	221	34	231	31	242	28	252	26
OC 37	263	23	273	20	298	11	322	0	341	0	361	2	379	0
OC 37	398	-4	419	-8	436	-13	464	-20	474	-24	507	-34	541	-44
OC 37	582	-54	616	-64	652	-79	693	-93	736	-107	779	-122	813	-140
OC 37	846	-157	880	-176	921	-195	942	-203	965	-210	990	-217	1021	-225
OC 37	1058	-232	1095	-240	1124	-248	1158	-255	1193	-262	1198	-264	1238	-262
OC 37	1284	-260	1340	-257	1398	-244	1448	-241	1547	-234	1593	-239	1653	-243
OC 37	1705	-248	1746	-256	1793	-263	1842	-270	1914	-277				

45th Street (Line 16/15)

OC 45	880628	100	54	-250			-520	64	-167	122	-23	105	0	92
OC 45	24	72	45	68	69	63	89	58	113	32	137	4	161	-19
OC 45	175	-24	190	-27	202	-32	216	-35	244	-43	261	-45	281	-40
OC 45	301	-27	319	-33	341	-42	355	-46	357	-48	371	-54	391	-64
OC 45	407	-70	424	-76	441	-83	469	-94	487	-100	527	-111	541	-117
OC 45	570	-126	584	-130	606	-137	634	-147	663	-157	696	-166	730	-175
OC 45	762	-182	793	-188	821	-195	855	-201	893	-208	924	-212	939	-215
OC 45	993	-220	1060	-226	1121	-233	1171	-238	1258	-244	1314	-247	1365	-250
OC 45	1368	-250												

OC 45	880922	100	54	-252			0	92	7	98	41	88	60	87
OC 45	80	84	101	80	120	69	140	59	153	56	182	55	233	23
OC 45	273	2	355	-23	409	-50	417	-56	426	-61	435	-65	443	-70
OC 45	451	-75	461	-81	468	-86	473	-91	482	-96	492	-101	502	-106
OC 45	515	-111	531	-116	546	-121	564	-126	579	-131	595	-136	610	-141
OC 45	625	-146	642	-151	661	-156	681	-161	695	-165	712	-169	739	-175
OC 45	767	-181	789	-186	814	-192	830	-195	860	-201	894	-206	915	-209
OC 45	973	-215	1012	-219	1071	-225	1098	-228	1178	-235	1257	-242	1359	-247
OC 45	1458	-252												
OC 45	890119	809	56	-293			-167	123	-45	112	-18	107	-2	104
OC 45	14	97	35	92	79	81	103	76	123	50	135	44	150	38
OC 45	169	36	184	34	199	21	213	9	246	-13	270	-28	291	-30
OC 45	314	-36	350	-37	362	-30	382	-34	422	-41	455	-60	473	-70
OC 45	495	-81	519	-92	536	-105	553	-112	592	-126	630	-143	654	-152
OC 45	684	-162	722	-170	785	-184	793	-188	895	-201	967	-210	1036	-218
OC 45	1101	-225	1182	-233	1246	-237	1324	-242	1401	-244	1472	-249	1526	-251
OC 45	1595	-253	1655	-255	1730	-260	1795	-263	1879	-266	1944	-268	2017	-270
OC 45	2086	-273	2165	-283	2266	-293								
OC 45	890412	1200	57	-305			-167	123	-23	122	-6	120	14	118
OC 45	35	108	53	62	71	56	91	60	109	62	129	50	147	27
OC 45	165	12	187	-2	205	-9	229	-18	246	-21	262	-19	278	-19
OC 45	319	-23	344	-23	378	-32	407	-34	451	-44	496	-59	555	-77
OC 45	611	-99	619	-99	649	-111	685	-124	735	-152	832	-191	891	-206
OC 45	946	-213	1020	-221	1079	-223	1147	-228	1235	-236	1311	-241	1372	-234
OC 45	1430	-246	1495	-249	1556	-251	1614	-252	1684	-254	1742	-257	1802	-260
OC 45	1898	-262	1966	-269	2018	-279	2070	-273	2127	-275	2182	-284	2240	-291
OC 45	2299	-294	2364	-297	2458	-302	2515	-305						
OC 45	890620	1015	48	-273			-167	123	-21	117	-6	115	11	109
OC 45	29	103	47	85	64	68	83	67	100	63	119	57	137	41
OC 45	148	35	172	16	187	2	199	-5	218	-14	239	-20	263	-28
OC 45	286	-34	311	-45	337	-54	370	-58	417	-59	417	-59	451	-62
OC 45	501	-72	535	-80	565	-87	636	-108	659	-119	682	-126	709	-132
OC 45	733	-148	750	-152	776	-163	802	-176	825	-183	866	-195	908	-205
OC 45	1078	-223	1192	-233	1373	-245	1471	-248	1583	-254	1668	-258	1775	-262
OC 45	1886	-262	2024	-273										
OC 45	890928	958	73	-297			-167	123	-73	118	12	112	31	98
OC 45	43	90	53	80	65	78	75	76	87	76	97	74	108	70
OC 45	119	65	130	59	140	51	151	43	162	34	181	21	188	13
OC 45	195	5	203	-2	221	-20	243	-32	266	-40	285	-43	306	-47
OC 45	331	-50	351	-52	371	-47	394	-26	421	-29	447	-37	468	-44
OC 45	483	-51	496	-56	513	-64	528	-70	548	-79	561	-86	575	-94
OC 45	592	-104	606	-112	627	-124	654	-131	657	-132	665	-134	684	-141
OC 45	706	-148	729	-155	754	-161	783	-170	797	-178	813	-184	830	-190
OC 45	879	-199	921	-209	950	-209	952	-209	994	-216	1072	-224	1150	-225
OC 45	1224	-231	1287	-235	1358	-239	1438	-244	1531	-248	1609	-250	1683	-253
OC 45	1818	-257	1903	-262	2003	-279	2096	-277	2206	-280	2442	-297		
OC 45	900601	100	39	-211			0	135	25	118	50	92	75	75
OC 45	100	71	125	67	138	52	150	47	175	34	200	40	225	10
OC 45	250	-6	275	-14	300	-21	325	-29	350	-40	375	-52	400	-60
OC 45	425	-70	450	-80	475	-87	500	-96	525	-104	550	-110	575	-116
OC 45	600	-124	625	-132	650	-139	675	-145	700	-155	725	-165	750	-171
OC 45	775	-180	800	-185	825	-195	850	-200	875	-204	900	-208	925	-211
OC 45	900906	1200	42	-208			0	135	10	131	25	130	40	152
OC 45	50	149	65	148	75	127	95	99	100	96	125	94	150	92
OC 45	175	88	180	86	200	74	225	69	250	59	275	36	300	20
OC 45	325	13	350	8	375	2	400	-10	425	-19	450	-32	475	-44
OC 45	500	-58	525	-81	550	-102	575	-122	600	-130	625	-138	650	-147
OC 45	675	-152	700	-158	725	-167	750	-180	775	-187	800	-193	825	-194
OC 45	850	-197	875	-204	900	-208								
OC 45	901201	1600	47	-255			-69	131	-33	122	0	109	9	112
OC 45	24	130	39	139	52	150	66	138	78	122	94	100	112	94
OC 45	131	93	150	91	168	82	185	54	204	52	222	41	238	25
OC 45	254	10	270	-7	275	-15	296	-22	338	-18	362	-19	401	-26
OC 45	435	-33	476	-40	517	-56	544	-65	574	-76	600	-89	623	-101
OC 45	646	-114	667	-126	689	-141	732	-161	750	-168	772	-175	794	-182
OC 45	828	-192	867	-202	908	-211	1076	-228	1181	-234	1273	-241	1382	-244
OC 45	1567	-255												

OC 45	910326	1150	44	-249			-69	131	-35	121	-3	109	12	111
OC 45	28	131	38	147	51	151	65	139	79	118	96	100	113	92
OC 45	131	91	135	80	151	68	169	60	186	48	204	35	220	20
OC 45	234	5	240	-1	247	-8	254	-14	273	-29	289	-37	314	-54
OC 45	352	-51	395	-25	428	-27	461	-37	511	-54	539	-65	571	-78
OC 45	596	-89	640	-106	665	-117	687	-126	765	-159	855	-187	948	-215
OC 45	1077	-232	1163	-237	1245	-242	1362	-249	1460	-248				
OC 45	910626	900	51	-251			-69	131	-29	121	8	110	26	126
OC 45	42	147	54	145	65	144	80	125	94	101	113	93	132	82
OC 45	150	72	161	70	171	68	182	63	193	57	209	42	225	23
OC 45	233	13	243	5	253	-2	262	-13	273	-23	283	-33	306	-41
OC 45	332	-48	359	-56	398	-45	433	-25	468	-36	507	-49	548	-66
OC 45	561	-75	576	-82	592	-90	628	-109	670	-127	688	-135	709	-142
OC 45	731	-150	775	-169	804	-176	842	-191	886	-203	932	-215	1045	-230
OC 45	1125	-232	1178	-236	1245	-242	1341	-248	1494	251				
OC 45	911103	830	50	-250			-69	131	-46	127	-24	122	8	110
OC 45	20	122	30	136	42	145	59	145	70	134	72	93	86	76
OC 45	103	62	119	56	136	47	153	37	167	22	183	9	199	-4
OC 45	205	-9	227	-18	249	-23	275	-37	300	-46	344	-44	365	-27
OC 45	403	-9	447	-23	479	-36	504	-48	533	-59	568	-76	606	-94
OC 45	629	-106	643	-116	660	-124	677	-133	695	-144	715	-154	737	-164
OC 45	759	-173	785	-180	812	-188	882	-206	978	-225	1054	-230	1160	-245
OC 45	1241	-250	1315	-247	1365	-243	1435	-246						
OC 45	920111	1400	57	-265			-69	131	-46	129	-25	126	-10	125
OC 45	3	124	9	129	25	114	41	103	57	89	70	83	82	75
OC 45	106	62	127	46	152	36	175	24	200	15	223	3	245	0
OC 45	257	1	267	2	277	4	287	6	298	5	308	3	329	-1
OC 45	367	-13	381	-18	391	-22	423	-32	473	-50	504	-60	521	-68
OC 45	540	-75	561	-82	605	-98	657	-115	676	-126	698	-135	721	-144
OC 45	741	-155	765	-164	790	-174	822	-186	859	-197	898	-207	974	-222
OC 45	1055	-235	1149	-239	1227	-243	1342	-244	1422	-249	1512	-254	1595	-254
OC 45	1681	-262	1773	-257	1866	-262	1922	-265						

52nd Street (Line 18/17)

OC 52	880628	0	52	-242			-529	76	-127	104	-28	114	-7	102
OC 52	14	86	36	71	61	60	84	48	106	20	131	-13	132	-12
OC 52	150	-9	169	-9	191	-10	205	-11	227	-14	244	-18	264	-24
OC 52	276	-27	293	-33	304	-37	324	-44	334	-49	367	-62	383	-74
OC 52	406	-75	428	-86	451	-92	476	-104	495	-111	521	-122	524	-124
OC 52	545	-135	581	-145	607	-155	642	-162	676	-172	710	-178	748	-181
OC 52	778	-186	808	-190	861	-197	892	-200	920	-202	968	-206	1001	-210
OC 52	1035	-214	1079	-221	1116	-227	1149	-232	1194	-238	1230	-242		
OC 52	880922	0	51	-250			-7	102	8	94	39	89	59	87
OC 52	79	86	99	82	119	70	132	63	157	57	202	24	236	2
OC 52	337	-29	383	-51	390	-55	398	-60	408	-65	420	-71	427	-74
OC 52	439	-81	443	-84	449	-89	456	-94	463	-99	472	-104	481	-109
OC 52	490	-114	500	-119	515	-126	548	-139	572	-144	596	-150	630	-155
OC 52	666	-160	687	-164	703	-169	749	-175	794	-180	839	-185	884	-190
OC 52	919	-195	963	-201	993	-205	1024	-211	1046	-215	1073	-220	1098	-225
OC 52	1115	-228	1169	-234	1215	-239	1275	-246	1312	-250				
OC 52	890119	932	66	-300			-34	109	-14	106	8	98	29	94
OC 52	57	84	67	86	89	84	105	71	119	60	135	51	148	42
OC 52	161	30	173	20	199	-7	210	-15	224	-24	273	-34	296	-38
OC 52	318	-35	341	-34	355	-35	374	-36	396	-45	418	-53	440	-65
OC 52	459	-76	479	-89	498	-100	517	-109	546	-122	584	-137	611	-145
OC 52	647	-155	688	-164	728	-170	779	-182	815	-185	886	-194	944	-200
OC 52	1000	-208	1067	-217	1136	-227	1210	-238	1302	-249	1379	-256	1448	-263
OC 52	1503	-269	1583	-279	1722	-284	1805	-287	1883	-285	1985	-272	2077	-253
OC 52	2145	-247	2222	-245	2309	-244	2383	-249	2491	-250	2556	-256	2640	-257
OC 52	2704	-268	2763	-278	2827	-287	2895	-295	2951	-297	2966	-300		

OC 52	890412	1400	65	-310			-127	104	-18	108	-10	111	8	106
OC 52	25	97	41	83	56	61	73	55	89	40	107	11	127	-8
OC 52	142	-26	162	-30	184	-46	212	-57	238	-65	266	-70	296	-76
OC 52	341	-74	358	-76	405	-74	446	-75	493	-73	533	-75	561	-88
OC 52	592	-103	628	-117	663	-129	694	-143	745	-163	819	-182	836	-186
OC 52	874	-193	874	-193	908	-199	956	-207	998	-213	1045	-222	1095	-231
OC 52	1145	-241	1201	-244	1260	-248	1312	-256	1372	-260	1484	-262	1580	-269
OC 52	1636	-272	1700	-275	1757	-279	1852	-279	1910	-285	1967	-293	2061	-281
OC 52	2141	-265	2203	-253	2298	-239	2378	-244	2493	-265	2557	-271	2654	-256
OC 52	2730	-253	2805	-265	2858	-270	2954	-286	3256	-310				
OC 52	890620	900	55	-292			-127	104	-32	108	-12	111	5	106
OC 52	25	94	46	77	62	70	75	65	95	47	116	20	138	-5
OC 52	160	-17	179	-17	201	-21	223	-25	244	-29	263	-40	288	-45
OC 52	313	-46	345	-52	374	-60	405	-63	464	-80	466	-81	506	-93
OC 52	539	-102	572	-112	591	-117	654	-135	694	-146	727	-158	803	-179
OC 52	838	-187	880	-196	987	-211	1066	-224	1151	-237	1230	-246	1341	-252
OC 52	1415	-259	1490	-260	1570	-265	1645	-273	1723	-281	1799	-278	1873	-288
OC 52	1949	-292	2061	-282	2138	-266	2218	-253	2290	-242	2361	-251	2433	-253
OC 52	2529	-258	2693	-252										
OC 52	890928	1126	71	-310			-121	107	-68	108	-19	108	-1	109
OC 52	18	95	37	83	56	75	76	68	95	63	106	59	116	54
OC 52	127	46	137	35	148	25	158	12	162	7	166	1	177	-11
OC 52	187	-20	194	-23	206	-28	224	-33	238	-36	268	-41	294	-44
OC 52	314	-49	342	-50	387	-46	437	-47	489	-59	500	-70	513	-79
OC 52	527	-89	570	-109	581	-116	593	-123	606	-130	665	-145	683	-153
OC 52	704	-160	726	-167	785	-170	858	-187	935	-205	1028	-217	1094	-232
OC 52	1159	-239	1273	-246	1345	-254	1405	-256	1493	-262	1585	-269	1658	-276
OC 52	1805	-280	1889	-279	1959	-268	2041	-257	2126	-249	2202	-245	2278	-241
OC 52	2344	-243	2414	-249	2494	-257	2584	-255	2641	-252	2719	-256	2793	-262
OC 52	2897	-277	2974	-290	3051	-299	3129	-310						
OC 52	900601	0	40	-205			-1	109	18	95	25	100	50	80
OC 52	75	71	100	75	120	76	125	68	150	37	175	7	200	-8
OC 52	225	-12	250	-14	275	-18	300	-29	325	-41	350	-56	375	-65
OC 52	400	-72	425	-81	450	-89	475	-98	500	-107	525	-115	550	-122
OC 52	575	-131	600	-139	625	-148	650	-155	675	-160	700	-166	725	-170
OC 52	750	-177	775	-182	800	-186	825	-190	850	-193	875	-197	900	-201
OC 52	925	-205												
OC 52	900901	1200	42	-201			-1	109	18	95	25	125	40	147
OC 52	50	146	65	144	75	128	95	97	100	94	125	93	150	88
OC 52	175	84	180	81	200	75	225	70	250	63	275	48	300	29
OC 52	325	13	350	-2	375	-16	400	-30	425	-43	450	-60	475	-73
OC 52	500	-92	525	-106	550	-122	575	-131	600	-140	625	-150	650	-156
OC 52	675	-161	700	-169	725	-171	750	-177	775	-180	800	-186	825	-190
OC 52	850	-193	875	-197	900	-201								
OC 52	901201	1700	52	-258			-120	107	-62	108	-10	110	1	112
OC 52	11	115	27	134	44	147	62	144	75	127	91	107	102	102
OC 52	112	96	131	92	147	86	164	65	178	50	184	44	205	26
OC 52	224	5	234	-4	246	-13	258	-22	284	-28	318	-36	335	-39
OC 52	385	-31	484	-48	512	-60	540	-73	555	-81	573	-89	590	-97
OC 52	604	-105	619	-112	635	-120	645	-129	657	-136	670	-144	686	-153
OC 52	705	-160	725	-168	786	-184	839	-193	890	-199	940	-208	995	-216
OC 52	1090	-229	1152	-237	1207	-244	1262	-249	1317	-253	1373	-258		
OC 52	910326	1215	54	-257			-120	107	-68	106	-21	105	-2	109
OC 52	18	119	29	134	41	146	60	144	71	132	83	115	96	104
OC 52	115	94	134	83	152	59	166	43	181	32	196	20	212	7
OC 52	218	-1	225	-9	232	-17	243	-28	257	-35	272	-48	292	-53
OC 52	302	-57	346	-56	357	-52	414	-33	439	-38	465	-46	494	-54
OC 52	526	-66	573	-83	589	-91	607	-98	625	-105	641	-115	660	-124
OC 52	679	-133	694	-143	711	-152	729	-162	746	-170	765	-177	785	-184
OC 52	834	-193	885	-205	942	-211	1025	-224	1110	-230	1185	-242	1282	-252
OC 52	1339	-257												

OC 52	910626	1150	52	-265			-120	107	-68	106	-21	105	-9	107
OC 52	2	110	18	122	34	141	52	145	71	132	88	111	99	105
OC 52	110	98	121	91	131	83	142	78	153	71	164	67	174	62
OC 52	192	53	210	33	226	8	236	-2	244	-11	253	-18	262	-26
OC 52	272	-34	316	-46	346	-54	366	-51	393	-39	428	-37	478	-44
OC 52	499	-55	524	-65	549	-75	569	-86	591	-95	614	-105	640	-119
OC 52	669	-132	700	-145	733	-159	770	-172	817	-188	869	-197	977	-214
OC 52	1077	-229	1163	-239	1234	-247	1303	-251	1397	-259	1469	-265		
OC 52	920111	1300	53	-275			-120	107	-65	111	-16	117	-1	117
OC 52	12	116	27	128	41	143	50	128	75	106	97	78	123	60
OC 52	147	37	160	32	172	25	183	14	194	0	213	-3	234	-12
OC 52	267	-25	303	-16	340	-23	371	-29	416	-43	440	-57	477	-62
OC 52	524	-51	557	-62	590	-74	608	-82	629	-89	650	-97	666	-107
OC 52	686	-115	705	-124	736	-141	752	-150	770	-157	789	-165	807	-172
OC 52	827	-178	849	-185	937	-204	1002	-214	1076	-227	1150	-237	1241	-247
OC 52	1307	-252	1404	-259	1499	-265	1539	-267	1585	-270	1634	-273	1674	-275

56th Street (Line 19/18)

OC 56	880629	100	52	-251			-536	76	-209	142	-105	129	24	100
OC 56	48	77	76	63	100	57	123	64	147	37	176	2	187	-11
OC 56	196	-15	225	-23	237	-29	261	-32	276	-35	282	-40	294	-44
OC 56	303	-46	303	-46	366	-44	366	-44	402	-52	423	-67	437	-72
OC 56	479	-84	504	-87	535	-100	559	-109	586	-115	625	-128	656	-139
OC 56	675	-146	712	-156	740	-162	755	-165	822	-178	850	-182	887	-188
OC 56	916	-193	931	-195	969	-201	996	-206	1020	-210	1073	-218	1073	-221
OC 56	1090	-223	1133	-231	1142	-233	1184	-241	1198	-244	1223	-251		
OC 56	880921	100	50	-235			-105	129	24	100	35	95	60	87
OC 56	79	90	100	90	119	79	140	67	158	62	231	11	273	-2
OC 56	336	-17	405	-50	411	-56	423	-62	431	-66	443	-71	451	-76
OC 56	459	-81	468	-86	478	-91	493	-96	507	-101	528	-107	547	-111
OC 56	570	-116	587	-121	605	-126	621	-131	637	-136	655	-141	671	-145
OC 56	688	-150	714	-157	730	-161	757	-166	781	-171	806	-176	832	-180
OC 56	869	-185	907	-191	934	-195	972	-201	1011	-207	1026	-210	1053	-215
OC 56	1078	-220	1101	-225	1134	-230	1167	-235						
OC 56	890119	1048	59	-317			-105	129	-54	135	-7	141	5	120
OC 56	15	110	42	109	64	105	86	110	109	106	130	95	153	91
OC 56	176	76	202	67	205	56	214	45	221	34	235	20	241	9
OC 56	254	2	261	8	277	-16	308	-29	330	-33	348	-36	364	-39
OC 56	403	-36	451	-45	471	-56	492	-69	524	-80	542	-92	573	-105
OC 56	598	-118	626	-126	658	-134	676	-143	732	-156	784	-169	877	-182
OC 56	947	-195	1022	-208	1124	-225	1217	-242	1367	-262	1462	-262	1569	-252
OC 56	1674	-250	1780	-243	1889	-235	2006	-229	2124	-223	2237	-223	2373	-224
OC 56	2497	-235	2609	-250	2719	-269	2819	-277	2922	-297	3010	-317		
OC 56	890412	1600	56	-301			-105	129	11	120	50	97	71	85
OC 56	89	72	107	67	127	60	148	48	168	31	188	7	211	-23
OC 56	226	-30	244	-35	258	-19	280	-15	300	-15	312	-12	361	-17
OC 56	391	-22	436	-32	475	-43	524	-64	589	-89	632	-105	671	-123
OC 56	797	-165	918	-190	981	-199	1045	-211	1115	-221	1184	-235	1285	-260
OC 56	1354	-275	1428	-278	1535	-264	1605	-259	1663	-256	1730	-252	1791	-249
OC 56	1853	-242	1912	-237	1974	-233	2040	-230	2094	-226	2162	-224	2232	-227
OC 56	2306	-232	2384	-231	2453	-229	2520	-230	2623	-248	2699	-269	2768	-276
OC 56	2828	-286	2896	-293	2958	-301								
OC 56	890619	1930	55	-272			-105	129	16	120	33	105	55	92
OC 56	75	78	92	68	104	66	120	83	140	69	158	50	174	43
OC 56	195	20	214	3	235	-10	256	-18	279	-22	299	-26	322	-30
OC 56	346	-35	371	-47	389	-50	402	-49	438	-58	473	-67	490	-71
OC 56	516	-71	554	-91	561	-95	609	-110	648	-122	681	-135	718	-145
OC 56	802	-168	848	-175	907	-188	983	-202	1064	-216	1161	-229	1253	-252
OC 56	1354	-272	1433	-268	1522	-257	1615	-253	1712	-248	1797	-244	1875	-237
OC 56	1950	-228	2033	-224	2037	-222	2214	-227	2313	-226	2397	-223	2482	-229
OC 56	2571	-240	3754	-268										

OC 56	890928	1238	82	-331			-31	146	-31	146	-31	146	0	131
OC 56	29	112	47	98	64	84	75	79	84	72	96	73	106	73
OC 56	118	72	129	71	141	67	152	61	165	55	178	47	189	36
OC 56	200	24	214	7	220	7	228	-3	237	-12	247	-22	268	-31
OC 56	284	-36	312	-42	339	-48	366	-51	391	-48	416	-38	445	-30
OC 56	475	-39	507	-51	533	-65	556	-80	582	-89	591	-97	601	-103
OC 56	611	-110	627	-120	649	-128	668	-135	682	-139	685	-140	712	-147
OC 56	769	-161	792	-166	853	-178	942	-193	1030	-209	1073	-218	1123	-225
OC 56	1174	-233	1252	-251	1291	-259	1335	-266	1381	-273	1474	-267	1571	-258
OC 56	1684	-251	1805	-243	1920	-236	1997	-233	2127	-230	2206	-229	2288	-229
OC 56	2362	-224	2464	-228	2562	-237	2590	-248	2624	-257	2658	-267	2743	-276
OC 56	2810	-278	2857	-289	2912	-299	2969	-309	3010	-317	3057	-324	3107	-331
OC 56	3179	-318												
OC 56	900601	100	43	-216			0	112	25	101	50	90	75	80
OC 56	100	74	125	71	150	75	167	75	175	66	200	46	225	27
OC 56	250	3	275	-11	300	-17	325	-19	350	-25	375	-32	400	-47
OC 56	425	-61	450	-65	475	-71	500	-81	525	-91	550	-101	575	-106
OC 56	600	-11[illegible]	625	-122	650	-130	675	-138	700	-142	725	-151	750	-161
OC 56	775	-168	800	-175	825	-176	850	-185	875	-191	900	-192	925	-197
OC 56	950	-201	975	-206	1000	-211	1025	-216						
OC 56	900907	1200	42	-192			0	112	10	119	25	137	40	153
OC 56	50	151	65	150	75	134	95	104	100	100	125	100	150	90
OC 56	170	83	175	80	200	75	225	66	250	52	275	32	300	16
OC 56	325	8	350	4	375	-4	400	-15	425	-25	450	-36	475	-46
OC 56	500	-61	525	-79	550	-93	575	-107	600	-120	625	-126	650	-131
OC 56	675	-139	700	-146	725	-154	750	-160	775	-166	800	-171	825	-178
OC 56	850	-183	875	-191	900	-192								
OC 56	901201	1800	65	-278			-31	146	-8	140	12	133	28	142
OC 56	43	151	62	147	76	132	92	108	104	105	114	102	134	97
OC 56	153	91	171	79	191	54	203	54	214	55	226	40	241	28
OC 56	255	12	265	7	275	1	285	-9	297	-19	308	-28	335	-33
OC 56	361	-36	398	-37	439	-39	473	-43	504	-49	544	-48	565	-56
OC 56	590	-67	611	-80	630	-94	651	-107	672	-120	694	-133	718	-147
OC 56	741	-158	788	-172	792	-173	793	-173	833	-182	881	-190	930	-198
OC 56	982	-206	1033	-214	1085	-223	1146	-233	1203	-243	1263	-252	1318	-261
OC 56	1386	-274	1488	-278	1569	-271	1630	-266	1685	-262	1745	-258	1805	-255
OC 56	1853	-253	1930	-249	1989	-247	2165	-260	2395	-241				
OC 56	910326	1240	53	-263			-31	146	-14	140	1	132	17	134
OC 56	28	142	41	150	52	151	65	144	76	129	95	110	106	106
OC 56	116	101	135	96	151	89	167	74	187	74	206	80	216	66
OC 56	226	50	237	39	248	29	258	18	274	0	291	-18	304	-31
OC 56	322	-35	335	-36	346	-40	378	-49	425	-45	455	-26	485	-34
OC 56	514	-43	548	-54	579	-66	609	-76	650	-92	680	-106	720	-124
OC 56	742	-138	768	-150	794	-163	816	-172	841	-179	867	-187	947	-201
OC 56	1047	-216	1101	-225	1164	-233	1228	-242	1266	-250	1310	-256	1356	-263
OC 56	910626	1430	54	-274			-31	146	-7	140	15	134	26	141
OC 56	35	150	53	152	64	143	74	132	89	114	108	105	121	101
OC 56	140	93	159	85	177	75	195	71	212	66	231	53	242	45
OC 56	252	45	263	38	274	28	278	29	289	16	303	5	317	-5
OC 56	355	-19	403	-13	448	-18	489	-28	520	-39	547	-50	575	-61
OC 56	609	-75	644	-92	684	-111	716	-128	754	-147	783	-160	821	-172
OC 56	864	-183	910	-194	946	-200	1005	-210	1080	-221	1209	-241	1300	-256
OC 56	1386	-271	1521	-274	1625	-271	1849	-252	1975	-248	2093	-244	2288	-238
OC 56	2390	-236												
OC 56	911103	700	52	-260			-31	146	-9	139	11	131	26	139
OC 56	39	149	54	146	67	142	82	131	96	117	116	100	133	84
OC 56	151	69	160	60	175	53	188	45	204	38	220	30	231	26
OC 56	242	21	253	12	267	5	281	-2	300	-8	315	-14	327	-18
OC 56	362	-22	373	-10	390	-2	399	-1	413	0	456	-6	506	-23
OC 56	536	-40	573	-53	588	-62	603	-72	618	-78	647	-100	681	-119
OC 56	717	-138	742	-151	771	-162	801	-173	870	-187	906	-194	947	-201
OC 56	990	-207	1028	-215	1071	-221	1117	-228	1214	-245	1306	-260		

OC 56	920111	1200	49	-285			-31	146	-6	142	17	137	32	143
OC 56	51	151	68	139	87	115	117	94	144	68	169	54	192	37
OC 56	206	32	218	26	233	21	246	15	258	12	269	8	288	3
OC 56	300	2	311	0	333	-2	355	-7	374	-12	393	-19	408	-24
OC 56	440	-29	482	-40	519	-49	553	-52	592	-73	637	-91	683	-110
OC 56	700	-120	720	-129	741	-138	768	-151	783	-160	802	-168	821	-176
OC 56	892	-192	981	-205	1020	-213	1066	-220	1114	-226	1184	-238	1234	-245
OC 56	1302	-259	1397	-269	1431	-285								

63rd Street (Line 544/20)

OC 63	880629	100	48	-237			-605	62	-84	129	-44	119	-18	108
OC 63	11	76	38	63	63	61	87	48	112	24	136	-10	159	-18
OC 63	192	-18	274	-33	294	-40	312	-50	325	-53	340	-59	342	-61
OC 63	395	-87	426	-98	449	-104	463	-108	514	-124	535	-133	572	-143
OC 63	608	-153	630	-160	659	-165	683	-172	750	-186	792	-189	831	-193
OC 63	875	-197	908	-202	958	-208	1027	-212	1095	-216	1098	-217	1177	-221
OC 63	1252	-224	1304	-228	1339	-230	1345	-230	1368	-232	1407	-233	1415	-235
OC 63	1438	-236	1465	-237										
OC 63	880922	100	53	-251			-18	108	7	92	19	90	40	90
OC 63	59	89	80	85	99	80	120	75	138	69	192	16	231	0
OC 63	290	-22	353	-51	361	-56	372	-61	381	-66	391	-71	400	-76
OC 63	411	-81	420	-86	427	-91	436	-95	444	-100	455	-105	461	-108
OC 63	475	-115	487	-120	506	-125	527	-131	547	-136	566	-140	581	-145
OC 63	593	-151	616	-155	639	-160	662	-166	686	-171	702	-175	717	-178
OC 63	776	-185	818	-190	870	-197	919	-201	981	-206	1039	-211	1122	-215
OC 63	1206	-220	1298	-225	1389	-230	1461	-235	1509	-238	1613	-246	1693	-251
OC 63	890119	1133	72	-309			-84	129	-25	114	-6	98	16	84
OC 63	39	81	61	82	83	79	107	70	128	55	154	50	166	38
OC 63	176	25	183	15	194	6	207	5	219	-15	242	-23	266	-27
OC 63	285	-30	299	-30	326	-33	356	-38	383	-34	413	-46	428	-54
OC 63	439	-63	469	-82	495	-98	518	-111	544	-124	570	-135	593	-146
OC 63	617	-155	632	-161	666	-163	706	-171	741	-178	780	-183	820	-188
OC 63	863	-193	905	-197	963	-203	1019	-206	1078	-210	1126	-213	1171	-216
OC 63	1255	-222	1307	-224	1369	-228	1422	-231	1475	-234	1532	-238	1585	-242
OC 63	1627	-243	1677	-248	1751	-253	1832	-260	1922	-268	2013	-278	2090	-285
OC 63	2162	-292	2259	-300	2374	-306	2489	-309	2731	-294	2818	-289	2913	-287
OC 63	3027	-276	3142	-275	3212	-277	3276	-278	3355	-289				
OC 63	890412	1800	56	-308			-84	129	-25	114	-7	101	12	84
OC 63	32	69	50	66	69	62	89	63	108	66	129	56	149	39
OC 63	168	18	187	-1	205	-13	224	-12	245	-12	265	-15	283	-17
OC 63	301	-21	322	-25	346	-28	380	-38	416	-46	446	-56	483	-67
OC 63	515	-76	551	-87	603	-102	640	-115	672	-131	700	-146	730	-157
OC 63	730	-157	774	-168	825	-179	954	-201	1030	-206	1114	-210	1197	-215
OC 63	1304	-220	1392	-224	1478	-231	1611	-241	1757	-248	1934	-263	2091	-285
OC 63	2127	-291	2180	-293	2241	-299	2308	-303	2411	-308	2497	-302	2495	-287
OC 63	2521	-307	2530	-307	2598	-301								
OC 63	890619	1800	59	-314			-84	129	-31	115	-13	102	8	83
OC 63	29	67	46	64	65	65	83	70	103	74	124	75	144	35
OC 63	164	9	185	-18	204	-24	221	-22	242	-26	262	-28	280	-30
OC 63	304	-31	332	-35	347	-45	364	-48	410	-63	451	-71	488	-82
OC 63	527	-95	567	-107	589	-114	616	-127	653	-134	682	-145	709	-153
OC 63	737	-162	766	-174	807	-183	882	-202	962	-207	1071	-209	1135	-212
OC 63	1196	-212	1318	-222	1381	-226	1454	-232	1543	-237	1608	-242	1686	-247
OC 63	1805	-257	1882	-262	1981	-272	2039	-276	2114	-287	2201	-289	2374	-304
OC 63	2467	-305	2580	-314	2820	-297	2983	-280	3240	-280	3429	-306		
OC 63	890928	1332	55	-310			-158	115	-79	106	-8	94	4	85
OC 63	15	74	28	69	40	63	53	65	65	67	78	71	89	75
OC 63	101	72	112	69	131	62	145	51	157	37	171	23	183	6
OC 63	203	-7	209	-16	221	-26	242	-32	270	-41	294	-47	327	-51
OC 63	356	-42	391	-28	444	-42	458	-52	474	-61	491	-70	514	-89
OC 63	541	-105	570	-122	649	-140	730	-160	811	-179	883	-188	978	-200
OC 63	1052	-205	1142	-210	1220	-214	1305	-219	1406	-226	1498	-231	1616	-240
OC 63	1701	-246	1805	-254	1890	-260	1998	-271	2101	-280	2198	-297	2307	-294
OC 63	2395	-296	2488	-310										

OC 63	900601	100	38	-200			0	98	25	71	50	62	75	66
OC 63	100	74	125	79	133	78	150	54	175	40	200	13	225	7
OC 63	250	-11	275	-25	300	-21	325	-23	350	-35	375	-41	400	-56
OC 63	425	-69	450	-76	475	-85	500	-95	525	-105	550	-112	575	-126
OC 63	600	-134	625	-140	650	-151	675	-156	700	-165	725	-170	750	-176
OC 63	775	-182	800	-190	825	-193	850	-195	875	-196	900	-200		

OC 63	900911	1200	42	-200			0	98	10	96	25	125	40	144
OC 63	50	144	65	142	75	120	95	91	100	89	125	90	130	90
OC 63	150	78	175	76	200	65	225	43	250	25	275	18	300	9
OC 63	325	-1	350	-15	375	-22	400	-35	425	-45	450	-60	475	-75
OC 63	500	-88	525	-102	550	-117	575	-125	600	-137	625	-145	650	-152
OC 63	675	-160	700	-165	725	-171	750	-179	775	-182	800	-190	825	-193
OC 63	850	-195	875	-196	900	-200								

OC 63	901202	700	57	-266			-158	115	-103	118	-53	122	-24	104
OC 63	2	82	15	101	27	126	45	145	59	142	70	131	80	118
OC 63	96	94	108	85	118	73	130	62	141	49	152	49	162	48
OC 63	179	51	194	28	213	18	230	6	244	1	258	-3	277	-6
OC 63	307	-14	324	-16	352	-21	395	-28	433	-40	476	-58	513	-75
OC 63	534	-92	558	-107	582	-122	601	-124	614	-132	628	-140	643	-147
OC 63	665	-155	690	-162	715	-169	779	-183	836	-192	885	-197	940	-203
OC 63	1000	-208	1067	-211	1135	-214	1197	-217	1267	-222	1351	-227	1464	-236
OC 63	1581	-243	1681	-250	1762	-258	1850	-266						

OC 63	910326	1315	51	-257			-158	115	-82	111	-13	105	3	94
OC 63	15	109	34	136	45	148	60	146	75	131	86	116	96	98
OC 63	115	89	131	77	146	78	159	72	175	59	189	37	207	14
OC 63	219	-2	238	-21	253	-22	273	-21	289	-21	311	-24	336	-25
OC 63	357	-27	371	-27	405	-43	434	-46	490	-56	505	-65	521	-73
OC 63	538	-81	567	-97	597	-114	607	-122	618	-128	629	-135	669	-151
OC 63	705	-164	758	-176	832	-189	938	-201	1020	-213	1066	-216	1106	-217
OC 63	1148	-219	1272	-225	1382	-232	1615	-247	1714	-257				

OC 63	910626	1710	53	-264			-158	115	-71	106	8	95	26	117
OC 63	42	144	61	141	79	121	95	96	106	90	116	82	128	78
OC 63	139	74	159	64	170	61	180	57	192	52	202	46	221	25
OC 63	237	2	246	-8	256	-17	267	-26	273	-24	302	-8	350	-17
OC 63	378	-31	412	-43	446	-56	482	-72	509	-84	524	-93	541	-101
OC 63	559	-110	591	-122	609	-131	629	-138	650	-145	686	-160	731	-170
OC 63	778	-182	826	-188	868	-192	912	-195	955	-202	1003	-205	1116	-218
OC 63	1206	-221	1340	-229	1478	-237	1592	-245	1693	-252	1798	-261	1843	-264

OC 63	911102	700	59	-260			-158	115	-71	100	9	81	24	121
OC 63	42	141	61	140	78	120	96	82	115	62	129	52	132	49
OC 63	146	39	161	28	180	19	198	7	216	4	232	-1	249	-5
OC 63	263	-8	279	-5	295	-1	310	-5	327	-1	341	-6	358	-9
OC 63	361	-8	374	-16	386	-14	390	-16	404	-16	429	-20	464	-31
OC 63	499	-49	517	-60	542	-80	566	-97	573	-104	582	-111	591	-118
OC 63	600	-126	609	-133	619	-140	629	-148	640	-155	651	-162	670	-170
OC 63	710	-183	752	-194	815	-201	887	-203	943	-205	1002	-210	1106	-217
OC 63	1274	-226	1373	-231	1441	-235	1579	-246	1715	-255	1778	-260		

OC 63	920111	1100	65	-276			-158	115	5	116	-40	117	-19	106
OC 63	0	93	24	86	45	77	68	68	89	58	109	50	133	42
OC 63	155	32	167	28	178	24	190	20	201	15	211	13	221	11
OC 63	240	17	252	18	263	20	277	17	289	14	302	9	313	3
OC 63	335	-7	350	-14	367	-20	375	-23	398	-34	421	-42	452	-51
OC 63	482	-61	537	-81	568	-92	605	-107	644	-127	654	-135	665	-141
OC 63	677	-148	691	-157	707	-165	724	-173	761	-184	848	-200	947	-213
OC 63	959	-214	984	-213	1030	-215	1139	-219	1196	-221	1227	-224	1272	-226
OC 63	1355	-231	1386	-232	1425	-236	1543	-243	1603	-248	1664	-252	1699	-254
OC 63	1755	-258	1828	-265	1872	-268	1907	-272	1955	-276				

66th Street (Line 21/21)

OC 66	880701	0	48	-231			-599	67	-179	112	-71	180	-48	127
OC 66	-23	67	-1	60	22	56	44	58	68	32	93	12	117	-2
OC 66	142	-8	161	-9	185	-15	197	-18	207	-22	226	-31	238	-37
OC 66	247	-40	262	-47	277	-52	294	-63	307	-69	330	-78	346	-85
OC 66	363	-94	383	-102	398	-108	425	-117	444	-124	470	-131	511	-140
OC 66	549	-151	574	-158	631	-171	682	-179	719	-187	780	-195	844	-206
OC 66	916	-213	973	-219	1053	-223	1139	-225	1222	-225	1285	-226	1337	-227
OC 66	1405	-231	1399	-231										

OC 66	880919	0	50	-251			-19	164	1	126	11	104	21	97
OC 66	42	94	61	86	81	75	104	60	126	34	206	-1	262	-25
OC 66	313	-49	325	-55	337	-61	347	66	352	-70	361	-75	372	-81
OC 66	380	-86	390	-92	398	-96	405	-101	416	-106	425	-111	439	-116
OC 66	453	-121	472	-127	489	-133	503	-137	517	-141	536	-146	554	-152
OC 66	569	-156	586	-162	605	-166	629	-171	652	-176	675	-181	697	-186
OC 66	720	-191	748	-195	778	-198	864	-206	1051	-223	1304	-226	1420	-231
OC 66	1500	-236	1581	-241	1665	-246	1745	-251						
OC 66	890119	1252	57	-309			-75	185	-19	164	1	126	11	112
OC 66	21	98	44	94	67	85	91	69	114	54	136	54	142	41
OC 66	150	33	156	25	162	18	176	3	187	10	196	-20	220	-25
OC 66	244	-23	270	-24	292	-29	325	-31	365	-46	391	-57	416	-68
OC 66	436	-79	459	-90	477	-103	496	-113	504	-121	525	-131	607	-159
OC 66	645	-167	680	-175	778	-192	825	-199	882	-205	935	-208	1059	-216
OC 66	1139	-219	1207	-220	1278	-222	1351	-224	1423	-226	1494	-230	1585	-237
OC 66	1656	-241	1736	-246	1829	-254	1926	-261	2012	-268	2095	-274	2185	-280
OC 66	2263	-287	2350	-296	2454	-305	2552	-309						
OC 66	890414	800	51	-309			-30	182	-21	165	-3	137	18	101
OC 66	37	84	56	72	72	57	91	49	107	35	124	18	136	3
OC 66	152	-17	173	-25	198	-31	231	-39	265	-23	291	-23	314	-28
OC 66	333	-29	369	-37	399	-47	447	-67	488	-86	526	-101	582	-126
OC 66	653	-155	705	-171	773	-184	821	-192	889	-199	972	-208	1023	-213
OC 66	1060	-216	1121	-219	1169	-220	1238	-221	1301	-223	1371	-225	1441	-229
OC 66	1513	-233	1582	-237	1655	-241	1800	-251	1897	-257	1977	-264	2093	-272
OC 66	2177	-278	2248	-284	2330	-293	2441	-302	2572	-309				
OC 66	890619	1545	53	-319			-179	112	-38	181	-19	161	2	123
OC 66	21	96	41	80	59	69	78	65	95	66	112	63	132	40
OC 66	152	20	170	3	189	-17	207	-20	215	-21	227	-19	260	-25
OC 66	318	-37	334	-47	347	-53	372	-62	400	-72	428	33	472	-94
OC 66	512	-107	561	-124	597	-135	633	-147	699	-170	782	-180	871	-198
OC 66	965	-207	1048	-216	1137	-221	1225	-223	1323	-224	1422	-229	1526	-234
OC 66	1624	-240	1773	-251	1858	-256	1940	-262	2029	-270	2117	-276	2204	-285
OC 66	2279	-290	2354	-299	2457	-306	2581	-313	2678	-319	2765	-316	2859	-307
OC 66	891001	1437	58	-265			-141	123	-85	149	-35	181	-23	167
OC 66	-12	151	1	132	12	107	25	96	36	82	49	79	60	75
OC 66	73	71	84	66	97	63	109	61	122	54	133	46	144	33
OC 66	155	16	162	8	170	1	178	-6	202	-22	230	-30	256	-35
OC 66	288	-44	319	-48	340	-45	392	-31	421	-42	441	-51	472	-68
OC 66	504	-86	530	-96	538	-104	546	-110	555	-116	573	-127	611	-143
OC 66	631	-147	654	-155	680	-161	707	-168	788	-183	861	-193	927	-200
OC 66	1006	-207	1082	-212	1163	-214	1262	-218	1335	-221	1430	-226	1556	-233
OC 66	1606	-236	1662	-240	1739	-241	1918	-256	2023	-265				
OC 66	900601	0	41	-208			-38	183	-13	153	12	109	37	84
OC 66	62	74	87	80	112	75	124	64	137	38	162	13	187	11
OC 66	212	-4	237	-11	262	-20	287	-25	312	-31	337	-44	362	-54
OC 66	387	-62	412	-70	437	-78	462	-87	487	-95	512	-104	537	-115
OC 66	562	-123	587	-131	612	-140	637	-145	662	-157	687	-165	712	-171
OC 66	737	-177	762	-182	787	-185	812	-190	837	-195	862	-197	887	-200
OC 66	912	-203	937	-208										

74th Street (Line 550/24)

OC 74	880701	100	53	-238			-478	65	-89	104	-60	99	-35	83
OC 74	-9	61	15	47	38	40	62	35	87	20	131	-4	143	-8
OC 74	157	-15	171	-21	183	-26	198	-32	213	-40	226	-45	235	-48
OC 74	246	-56	255	-62	263	-69	264	-70	285	-82	299	-88	305	-92
OC 74	326	-102	341	-108	357	-115	376	-126	394	-134	433	-139	473	-148
OC 74	495	-158	518	-156	547	-164	585	-172	618	-177	654	-183	709	-190
OC 74	751	-195	779	-198	838	-204	878	-207	922	-212	968	-216	1055	-222
OC 74	1112	-225	1206	-230	1270	-232	1338	-235	1390	-235	1432	-238	1465	-238

OC 74	880919	100	54	-250			-38	96	-19	95	2	95	21	97
OC 74	42	99	61	100	82	96	102	90	121	82	142	72	159	62
OC 74	201	44	251	0	345	-50	353	-55	362	-61	369	-66	377	-70
OC 74	383	-75	390	-79	395	-84	402	-89	407	-95	413	-100	419	-105
OC 74	425	-110	431	-115	437	-120	442	-126	452	-133	459	-141	485	-144
OC 74	507	-145	515	-150	525	-155	537	-160	563	-165	590	-171	624	-176
OC 74	658	-181	689	-185	721	-189	771	-195	819	-200	864	-205	908	-210
OC 74	991	-215	1072	-221	1153	-225	1235	-230	1354	-234	1510	-240	1573	-243
OC 74	1667	-250												

OC 74	890119	1337	65	-303			-83	100	-14	95	14	95	36	99
OC 74	60	100	84	96	105	88	116	69	128	50	141	43	177	24
OC 74	196	18	226	3	240	-8	253	-16	298	-26	325	-39	348	-47
OC 74	373	-59	387	-69	400	-78	411	-91	422	-100	445	-107	472	-118
OC 74	498	-134	518	-143	537	-151	558	-157	578	-162	596	-166	603	-167
OC 74	612	-168	665	-178	717	-185	778	-191	848	-197	915	-204	974	-209
OC 74	1036	-214	1103	-219	1174	-222	1230	-225	1288	-227	1342	-229	1399	-231
OC 74	1465	-234	1535	-237	1609	-239	1661	-242	1712	-244	1765	-247	1820	-249
OC 74	1880	-253	1939	-256	2001	-260	2071	-264	2130	-268	2205	-272	2264	-275
OC 74	2315	-279	2394	-285	2455	-291	2520	-295	2596	-303				

OC 74	890414	1200	53	-264			-89	104	-41	95	-21	95	4	96
OC 74	22	97	34	71	42	69	55	69	73	52	91	30	108	11
OC 74	142	-27	164	-27	192	-34	215	-36	219	-32	238	-37	262	-39
OC 74	285	-46	306	-54	323	-61	338	-67	362	-70	402	-72	430	-62
OC 74	450	-73	468	-88	483	-98	505	-112	534	-127	549	-134	578	-149
OC 74	614	-162	644	-171	675	-179	713	-185	741	-188	784	-192	810	-195
OC 74	823	-196	899	-204	976	-210	1076	-218	1166	-223	1252	-226	1346	-230
OC 74	1451	-229	1593	-236	1681	-243	1774	-247	1856	-250	1938	-256	2063	-264

OC 74	890619	1400	56	-323			-89	104	-47	94	-29	93	-11	94
OC 74	7	94	25	87	46	72	66	61	85	63	104	59	124	47
OC 74	143	22	165	1	179	-11	195	-23	217	-20	244	-21	265	-29
OC 74	285	-37	306	-45	332	-57	361	-68	388	-77	427	-90	468	-105
OC 74	481	-110	504	-119	590	-149	661	-171	745	-187	762	-191	864	-200
OC 74	962	-209	1037	-215	1123	-219	1187	-222	1281	-227	1359	-230	1470	-234
OC 74	1558	-238	1674	-245	1753	-247	1849	-252	1922	-255	1993	-259	2100	-265
OC 74	2194	-271	2272	-275	2347	-282	2439	-289	2506	-293	2551	-297	2592	-299
OC 74	2648	-304	2729	-310	2943	-323								

OC 74	890928	1548	66	-306			-90	107	-49	100	-12	93	1	91
OC 74	13	88	26	83	38	77	51	73	62	69	75	68	86	68
OC 74	98	54	109	37	120	31	130	24	136	13	143	4	150	-4
OC 74	166	-23	170	-28	179	-29	196	-29	214	-32	230	-33	252	-35
OC 74	273	-36	305	-38	326	-38	358	-39	397	-55	414	-67	435	-80
OC 74	445	-87	456	-94	468	-100	484	-113	495	-122	518	-133	538	-141
OC 74	561	-147	585	-154	644	-170	717	-183	788	-191	931	-205	1006	-211
OC 74	1085	-215	1154	-219	1233	-223	1326	-226	1395	-230	1468	-233	1541	-235
OC 74	1632	-239	1702	-241	1770	-245	1862	-249	1951	-255	2020	-258	2090	-262
OC 74	2182	-268	2275	-273	2366	-279	2448	-287	2534	-294	2624	-306		

OC 74	900601	100	36	-209			0	94	25	83	50	75	75	71
OC 74	100	49	125	17	150	1	175	-4	200	-9	225	-14	250	-24
OC 74	275	-35	300	-46	325	-59	350	-72	375	-85	400	-93	425	-103
OC 74	450	-114	500	-133	525	-140	550	-150	575	-159	600	-166	625	-172
OC 74	650	-178	675	-182	700	-185	725	-188	750	-191	775	-195	800	-197
OC 74	825	-199	850	-203	875	-204	900	-209						

OC 74	901011	1200	42	-209			0	94	10	99	25	121	40	147
OC 74	50	147	65	146	75	128	95	96	100	95	125	89	150	90
OC 74	155	90	175	85	200	78	225	70	250	63	275	55	300	41
OC 74	325	13	350	-8	375	-29	400	-49	425	-91	450	-118	475	-128
OC 74	500	-138	525	-146	550	-154	575	-160	600	-167	625	-174	650	-177
OC 74	675	-182	700	-187	725	-188	750	-191	775	-195	800	-197	825	-199
OC 74	850	-203	875	-204	900	-209								

OC 74	901202	800	72	-272			-90	107	-45	101	-3	95	12	104
OC 74	29	128	45	143	63	142	80	119	96	93	106	90	116	87
OC 74	128	88	138	89	151	85	163	81	174	67	185	50	199	41
OC 74	211	29	225	37	237	47	248	49	258	51	273	35	289	15
OC 74	293	15	304	4	317	-5	330	-15	348	-25	367	-35	402	-54
OC 74	425	-64	451	-74	475	-82	497	-91	520	-104	543	-119	562	-133
OC 74	586	-149	610	-162	641	-173	670	-179	735	-190	766	-194	804	-198
OC 74	834	-201	883	-205	916	-208	970	-212	1019	-216	1056	-217	1093	-220
OC 74	1137	-222	1177	-224	1220	-225	1256	-228	1305	-230	1351	-230	1432	-235
OC 74	1475	-237	1510	-237	1560	-240	1607	-240	1662	-243	1747	-249	1798	-250
OC 74	1849	-253	1908	-256	1960	-259	2027	-263	2181	-272				
OC 74	910326	1415	45	-251			-90	106	-90	107	-53	100	-20	91
OC 74	-4	92	9	97	20	116	40	143	51	147	65	141	81	117
OC 74	96	96	113	89	129	90	143	86	152	79	170	55	184	42
OC 74	200	29	214	17	222	13	232	9	242	5	278	-2	297	-5
OC 74	314	-12	332	-20	354	-28	377	-35	395	-45	416	-53	438	-61
OC 74	459	-75	483	-86	508	-99	536	-117	568	-133	602	-149	639	-164
OC 74	682	-176	726	-189	871	-205	1128	-224	1382	-235	1605	-251		
OC 74	910626	1830	42	-252			-90	107	-37	104	11	101	29	121
OC 74	45	145	62	144	80	123	96	96	111	93	124	90	140	84
OC 74	157	65	175	57	195	48	213	38	232	28	252	16	271	1
OC 74	283	-6	298	-12	313	-19	341	-31	379	-50	406	-64	435	-78
OC 74	472	-98	502	-111	543	-129	587	-145	634	-164	704	-184	756	-193
OC 74	839	-202	981	-213	1076	-220	1237	-227	1337	-232	1493	-239	1567	-242
OC 74	1651	-245	1723	-246	1829	-252								
OC 74	911102	900	53	-248			-90	107	-52	102	-18	95	-5	97
OC 74	6	100	23	120	33	130	43	143	60	145	76	123	77	106
OC 74	94	83	110	64	126	51	144	33	161	13	179	5	186	3
OC 74	197	2	213	0	227	11	241	13	259	13	269	9	278	6
OC 74	295	0	311	-6	327	-15	360	-30	388	-42	414	-55	438	-68
OC 74	467	-84	490	-102	516	-116	546	-135	576	-151	609	-163	670	-176
OC 74	741	-188	814	-199	921	-211	995	-217	1045	-220	1110	-224	1163	-227
OC 74	1223	-229	1310	-233	1365	-237	1417	-238	1491	-241	1534	-244	1598	-248
OC 74	920111	1000	59	-282			-90	104	-89	107	-75	107	-62	107
OC 74	-48	110	-36	114	-18	110	-1	106	10	99	20	91	42	78
OC 74	61	62	83	51	103	37	115	33	125	28	145	25	164	22
OC 74	175	17	184	10	198	11	209	12	219	13	232	11	244	10
OC 74	264	1	296	-13	311	-19	325	-23	342	-35	382	-45	424	-59
OC 74	456	-68	493	-83	523	-92	559	-107	578	-121	601	-133	624	-145
OC 74	646	-157	667	-166	715	-181	803	-197	862	-205	929	-210	983	-216
OC 74	1077	-222	1143	-226	1226	-229	1320	-233	1409	-237	1536	-241	1654	-246
OC 74	1778	-251	1862	-255	1989	-262	2066	-265	2169	-274	2291	-282		

78th Street (Line 552/26)

OC 78	880630	100	54	-242			-481	75	-122	120	-47	135	-30	69
OC 78	-6	53	14	49	39	39	63	19	91	4	93	5	102	1
OC 78	113	-3	121	-7	134	-10	141	-14	151	-19	164	-24	172	-28
OC 78	181	-31	194	-39	202	-43	212	-47	227	-54	238	-61	249	-69
OC 78	261	-78	272	-88	289	-94	304	-100	314	-105	347	-120	364	-126
OC 78	376	-129	389	-135	419	-141	451	-155	481	-165	506	-169	540	-175
OC 78	564	-183	617	-193	689	-201	757	-209	791	-214	853	-218	931	-224
OC 78	1004	-226	1051	-228	1102	-228	1144	-229	1192	-231	1247	-234	1298	-236
OC 78	1338	-242												
OC 78	880915	100	55	-250			-27	109	0	98	20	91	39	89
OC 78	60	88	79	86	100	86	119	84	140	74	159	67	173	63
OC 78	227	28	296	0	320	-15	350	-51	357	-56	364	-61	371	-66
OC 78	380	-71	389	-76	395	-81	401	-86	406	-91	412	-96	417	-99
OC 78	427	-104	432	-111	437	-116	443	-121	448	-126	454	-131	459	-134
OC 78	474	-141	480	-146	485	-149	499	-156	509	-160	519	-165	535	-170
OC 78	551	-175	568	-180	592	-185	626	-190	648	-195	670	-200	699	-205
OC 78	763	-210	837	-215	940	-220	983	-225	1253	-230	1307	-235	1345	-240
OC 78	1397	-245	1428	-250										

OC 78	890119	1429	65	-306			-122	123	-45	129	-26	110	-11	104
OC 78	2	97	19	93	31	90	36	89	59	89	85	88	113	88
OC 78	134	55	156	45	170	39	183	33	194	24	204	14	217	3
OC 78	231	-8	245	-15	269	-22	299	-34	325	-45	357	-60	377	-72
OC 78	402	-85	421	-98	438	-108	453	-120	469	-128	490	-140	513	-150
OC 78	530	-158	553	-169	601	-182	706	-202	758	-207	807	-210	855	-212
OC 78	900	-214	948	-216	989	-219	1041	-221	1094	-224	1154	-228	1199	-228
OC 78	1251	-228	1303	-229	1369	-231	1426	-238	1481	-246	1541	-250	1607	-252
OC 78	1692	-256	1749	-256	1808	-257	1863	-260	1915	-263	1998	-270	2110	-277
OC 78	2242	-284	2340	-290	2449	-297	2531	-301	2607	-306				
OC 78	890414	1500	48	-301			-122	121	-9	116	9	99	23	82
OC 78	38	63	60	63	82	41	108	13	131	-9	156	-24	187	-33
OC 78	195	-40	205	-35	237	-35	268	-36	326	-47	339	-52	387	-60
OC 78	434	-76	450	-90	472	-110	503	-116	537	-137	588	-164	634	-180
OC 78	678	-190	731	-200	818	-206	879	-207	957	-210	1030	-213	1106	-215
OC 78	1172	-218	1250	-220	1328	-224	1412	-231	1511	-243	1586	-248	1712	-255
OC 78	1802	-259	1876	-262	1947	-266	2033	-273	2134	-279	2213	-284	2314	-290
OC 78	2422	-296	2506	-301										
OC 78	890619	1200	53	-301			-122	121	-32	123	-13	113	7	94
OC 78	26	83	44	73	63	64	81	64	100	56	121	27	139	8
OC 78	157	-4	166	-18	173	-17	197	-12	241	-30	263	-34	301	-53
OC 78	328	-61	356	-71	392	-85	438	-96	454	-107	478	-120	522	-137
OC 78	603	-167	640	-175	679	-190	780	-204	859	-210	934	-215	1037	-221
OC 78	1117	-225	1221	-229	1299	-231	1401	-240	1475	-253	1548	-252	1554	-250
OC 78	1604	-252	1667	-252	1722	-254	1779	-255	1847	-251	1908	-264	1977	-270
OC 78	2037	-272	2112	-277	2180	-271	2263	-276	2327	-290	2425	-295	2492	-301
OC 78	890928	1633	57	-307			-99	129	-63	123	-31	115	-18	111
OC 78	-7	105	6	97	19	87	30	83	41	77	53	72	64	66
OC 78	76	63	86	59	100	40	107	33	115	21	126	6	135	-5
OC 78	144	-16	154	-26	179	-29	209	-28	238	-31	264	-38	301	-38
OC 78	331	-39	357	-46	379	-61	397	-73	417	-81	439	-98	459	-114
OC 78	474	-128	488	-138	552	-152	595	-163	647	-177	686	-187	715	-193
OC 78	818	-203	913	-208	1025	-211	1129	-215	1225	-217	1379	-222	1484	-232
OC 78	1587	-243	1689	-250	1786	-256	1883	-258	1981	-262	2070	-271	2187	-275
OC 78	2320	-288	2387	-292	2475	-297	2619	-307						
OC 78	900601	100	32	-208			0	99	25	84	50	60	75	51
OC 78	100	23	125	4	150	12	175	4	200	-9	225	-20	250	-31
OC 78	275	-44	300	-57	325	-69	350	-80	375	-92	400	-103	425	-113
OC 78	450	-121	475	-133	500	-144	525	-153	550	-161	575	-168	600	-175
OC 78	625	-182	650	-187	675	-191	700	-196	725	-201	818	-203	913	-208
OC 78	910326	1450	43	-249			-100	129	-58	117	-20	102	-1	100
OC 78	17	105	28	121	38	135	50	139	61	139	78	120	94	100
OC 78	107	92	117	90	122	79	136	63	149	52	167	43	184	37
OC 78	198	29	215	20	234	11	252	2	266	-2	283	-4	304	-16
OC 78	332	-27	356	-37	392	-53	430	-72	462	-90	490	-103	526	-121
OC 78	562	-138	581	-148	597	-158	615	-166	634	-175	681	-191	744	-205
OC 78	982	-217	1077	-220	1199	-233	1301	-249						

81st Street (Line 24/27)

OC 81	880630	0	48	-239			-472	75	-146	113	-49	126	-25	97
OC 81	-9	71	15	54	38	45	63	26	88	8	114	-6	140	-14
OC 81	165	-27	165	-24	180	-30	200	-39	215	-46	232	-50	264	-76
OC 81	282	-86	313	-94	333	-101	374	-117	399	-126	412	-129	413	-129
OC 81	451	-140	493	-150	536	-161	578	-172	615	-181	650	-190	689	-199
OC 81	713	-204	714	-205	760	-214	802	-219	857	-225	939	-230	1089	-228
OC 81	1155	-225	1196	-225	1297	-226	1340	-230	1364	-230	1401	-235	1416	-236
OC 81	1446	-239	1472	-239										
OC 81	880913	0	54	-244			-15	95	20	91	40	88	60	87
OC 81	80	86	101	87	120	79	141	71	156	66	181	66	200	49
OC 81	231	22	256	0	295	-28	338	-50	356	-60	369	-70	390	-80
OC 81	411	-100	418	-105	426	-112	433	-115	440	-120	444	-125	450	-127
OC 81	462	-135	472	-140	484	-145	496	-150	515	-155	532	-160	547	-165
OC 81	573	-170	599	-175	627	-180	643	-185	659	-190	675	-195	692	-200
OC 81	721	-204	770	-210	810	-215	889	-220	961	-225	1017	-220	1057	-205
OC 81	1100	-210	1145	-215	1186	-220	1298	-225	1409	-230	1463	-235	1517	-240
OC 81	1591	-244												

OC 81	890119	1506	62	-315			-48	119	-24	97	-9	93	4	88
OC 81	36	87	63	86	90	86	112	85	121	74	129	63	137	52
OC 81	163	43	189	32	195	26	203	18	210	11	215	6	226	-5
OC 81	237	-16	253	-22	272	-27	298	-37	323	-49	350	-61	376	-76
OC 81	401	-89	422	-101	443	-114	458	-123	483	-136	505	-147	527	-154
OC 81	548	-161	569	-166	586	-171	593	-172	615	-178	684	-191	759	-207
OC 81	830	-217	901	-223	973	-225	1041	-224	1107	-222	1185	-221	1248	-220
OC 81	1840	-234	1926	-238	1998	-238	2062	-249	2139	-254	2204	-262	2273	-271
OC 81	2342	-281	2418	-294	2552	-290	2606	-291	2670	-297	2744	-300	2807	-309
OC 81	2863	-315	2872	-315										

OC 81	890414	1700	51	-291			-146	113	-14	106	13	99	32	90
OC 81	47	77	58	60	81	57	104	31	114	17	136	-12	166	-25
OC 81	186	-39	205	-40	210	-37	244	-22	277	-29	305	-36	341	-50
OC 81	368	-61	399	-79	422	-91	444	-100	472	-108	506	-120	542	-131
OC 81	580	-144	614	-157	649	-167	675	-177	735	-189	786	-196	819	-212
OC 81	919	-225	1029	-234	1096	-229	1161	-227	1228	-226	1345	-223	1463	-230
OC 81	1533	-236	1645	-245	1712	-248	1775	-251	1850	-252	1933	-246	1999	-237
OC 81	2080	-229	2147	-241	2243	-252	2342	-271	2462	-291				

OC 81	890619	1030	60	-313			-146	113	-37	114	-19	106	19	95
OC 81	36	86	50	77	66	68	77	63	93	42	111	24	129	10
OC 81	147	-1	163	-7	181	-13	201	-19	219	-25	235	-30	255	-41
OC 81	273	-46	294	-58	305	-64	343	-71	384	-84	426	-98	467	-112
OC 81	516	-129	533	-132	602	-157	639	-171	699	-181	757	-195	788	-206
OC 81	859	-220	932	-228	1004	-229	1190	-221	1266	-222	1341	-224	1416	-227
OC 81	1493	-234	1588	-241	1658	-245	1724	-246	1787	-245	1838	-239	1983	-231
OC 81	2038	-228	2109	-237	2167	-252	2216	-253	2269	-261	2323	-275	2367	-285
OC 81	2420	-297	2479	-284	2571	-286	2659	-293	2807	-297	2858	-306	2916	-313

OC 81	890929	700	61	-287			-80	132	-29	116	18	95	30	90
OC 81	41	83	52	76	63	66	74	69	83	62	86	57	105	37
OC 81	124	17	130	11	135	0	142	-8	149	-18	161	-22	185	-23
OC 81	205	-25	224	-30	244	-35	263	-38	282	-39	308	-40	342	-47
OC 81	369	-56	400	-76	426	-94	447	-109	471	-123	496	-136	520	-147
OC 81	572	-156	604	-164	642	-171	680	-178	735	-190	793	-207	860	-216
OC 81	913	-222	971	-226	1024	-226	1072	-225	1133	-223	1185	-222	1249	-221
OC 81	1314	-222	1381	-225	1465	-229	1547	-234	1622	-237	1697	-244	1776	-245
OC 81	1882	-242	1960	-240	2062	-236	2144	-243	2228	-249	2331	-269	2429	-287
OC 81	2521	-286												

OC 81	900601	0	36	-222			-5	100	20	94	45	74	70	57
OC 81	95	47	120	23	146	5	172	-4	198	-9	221	-18	245	-30
OC 81	271	-41	294	-52	321	-64	345	-75	369	-84	395	-98	419	-108
OC 81	446	-118	468	-127	494	-136	524	-142	545	-149	570	-159	593	-169
OC 81	618	-176	642	-180	665	-184	690	-190	719	-195	746	-200	779	-204
OC 81	801	-212	827	-217	860	-216	913	-222						

OC 81	900928	1200	41	-222			-5	100	5	111	20	125	35	151
OC 81	45	151	60	146	70	127	90	102	95	96	120	93	145	92
OC 81	150	91	170	83	195	74	220	67	245	56	270	50	295	50
OC 81	320	34	345	15	370	-16	395	-36	420	-80	445	-124	470	-135
OC 81	495	-144	520	-152	545	-159	570	-163	595	-170	620	-174	645	-180
OC 81	670	-185	695	-192	719	-195	746	-200	779	-204	801	-212	827	-217
OC 81	860	-216	913	-222										

OC 81	901202	900	60	-258			-85	132	-62	133	-41	134	-10	138
OC 81	18	142	39	144	58	146	71	137	88	120	104	98	117	95
OC 81	129	91	143	84	155	75	167	61	179	45	191	49	202	53
OC 81	217	57	231	62	250	46	269	15	282	0	296	-13	311	-27
OC 81	332	-37	368	-55	398	-66	442	-84	457	-93	474	-102	491	-110
OC 81	501	-118	513	-125	525	-133	545	-147	567	-159	612	-175	627	-181
OC 81	699	-193	740	-200	804	-214	864	-224	924	-227	995	-229	1076	-227
OC 81	1149	-228	1226	-228	1295	-228	1362	-229	1430	-231	1495	-235	1622	-243
OC 81	1698	-244	1837	-249	1921	-248	1988	-249	2122	-248	2230	-254	2304	-258

OC 81	910402	615	52	-267			-85	132	-85	132	-44	133	-6	134
OC 81	6	135	17	137	34	146	53	142	70	137	88	124	104	107
OC 81	116	97	120	73	137	61	153	48	169	37	184	29	200	21
OC 81	214	15	227	9	253	-2	284	-13	316	-24	345	-38	372	-50
OC 81	397	-66	417	-79	445	-93	467	-103	493	-120	513	-132	561	-148
OC 81	577	-156	596	-163	615	-171	679	-187	746	-201	818	-219	896	-224
OC 81	978	-228	1042	-231	1136	-229	1250	-230	1387	-231	1503	-234	1649	-243
OC 81	1770	-250	1888	-254	1998	-255	2104	-253	2253	-251	2339	-267		

OC 81	910627	800	46	-260			-85	132	-23	138	34	144	54	141
OC 81	72	137	97	109	120	74	132	70	144	65	155	60	165	53
OC 81	176	48	186	43	206	33	218	28	229	21	243	12	256	1
OC 81	275	-18	297	-24	319	-34	346	-46	372	-62	402	-79	431	-96
OC 81	456	-107	480	-116	518	-132	544	-143	585	-160	628	-179	699	-192
OC 81	751	-205	798	-213	921	-226	967	-228	1098	-228	1230	-228	1364	-229
OC 81	1460	-231	1601	-239	1705	-245	1840	-250	1956	-252	2056	-250	2264	-260
OC 81	920111	900	55	-253			-85	132	-35	124	10	113	21	104
OC 81	32	92	50	74	71	60	90	43	109	35	127	24	139	20
OC 81	143	27	162	33	179	41	197	47	216	25	227	10	240	-2
OC 81	254	-15	269	-15	284	-23	292	-27	309	-34	339	-46	368	-55
OC 81	401	-67	437	-80	475	-99	497	-108	526	-121	561	-135	585	-145
OC 81	613	-153	676	-171	732	-184	792	-197	843	-209	921	-222	1005	-230
OC 81	1143	-229	1250	-231	1321	-233	1463	-234	1537	-238	1645	-243	1768	-246
OC 81	1824	-250	1872	-251	1908	-253	1951	-252	2001	-252	2046	-252	2102	-253
OC 81	2165	-252	2238	-249										

86st Street (Line 25/29)

OC 86	880622	0	55	-262			-449	80	-159	112	-66	117	-46	96
OC 86	-27	66	-6	52	14	42	35	38	57	38	118	2	126	-3
OC 86	135	-8	146	-11	160	-18	165	-21	182	-29	196	-37	214	-45
OC 86	227	-58	237	-60	252	-69	271	-76	290	-85	306	-94	328	-104
OC 86	351	-115	380	-127	407	-136	427	-141	469	-152	485	-154	531	-163
OC 86	567	-168	607	-175	651	-181	689	-186	735	-192	771	-197	809	-202
OC 86	848	-208	901	-215	917	-218	948	-223	986	-228	1015	-233	1036	-236
OC 86	1056	-239	1088	-244	1123	-251	1135	-252	1164	-257	1170	-258	1185	-261
OC 86	1186	-262	1186	-262										
OC 86	880908	0	55	-249			-43	98	19	93	40	89	59	89
OC 86	80	91	99	89	120	83	140	75	160	68	180	62	207	61
OC 86	248	17	267	0	340	-43	356	-50	362	-56	368	-60	374	-65
OC 86	380	-72	384	-75	389	-79	395	-85	400	-91	406	-95	412	-101
OC 86	427	-105	431	-111	436	-117	442	-121	448	-127	458	-131	467	-136
OC 86	477	-141	486	-146	498	-150	509	-154	534	-160	554	-165	590	-171
OC 86	629	-177	653	-181	695	-187	727	-192	766	-196	810	-201	836	-207
OC 86	866	-211	901	-216	936	-220	999	-225	1009	-230	1030	-234	1052	-238
OC 86	1085	-244	1116	-249										
OC 86	890120	738	70	-305			-159	112	-65	115	-38	91	-25	91
OC 86	-11	91	-7	91	17	90	30	90	44	88	72	88	98	86
OC 86	118	84	138	53	158	40	173	43	188	46	203	30	213	17
OC 86	224	5	236	-9	246	-15	257	-23	288	-29	304	-36	325	-46
OC 86	344	-54	363	-63	378	-72	398	-83	417	-97	441	-109	461	-123
OC 86	487	-136	514	-149	560	-162	612	-169	658	-178	704	-186	769	-194
OC 86	869	-207	956	-221	1081	-240	1188	-254	1288	-266	1359	-265	1429	-257
OC 86	1484	-250	1538	-245	1592	-241	1639	-236	1686	-232	1734	-227	1788	-224
OC 86	1833	-221	1878	-217	1927	-215	1974	-212	2017	-213	2065	-213	2168	-214
OC 86	2220	-217	2272	-221	2316	-227	2365	-233	2414	-240	2462	-245	2519	-253
OC 86	2582	-266	2656	-280	2746	-305								
OC 86	890420	730	52	-297			-159	113	-53	105	-34	100	-13	95
OC 86	14	94	40	64	66	43	91	34	114	26	140	12	160	1
OC 86	193	-12	221	-25	250	-28	255	-29	257	-24	289	-34	318	-46
OC 86	360	-62	377	-69	427	-86	465	-95	493	-102	524	-117	568	-138
OC 86	616	-161	674	-177	744	-186	921	-215	989	-224	1059	-230	1145	-247
OC 86	1211	-265	1285	-279	1347	-276	1502	-245	1594	-239	1659	-231	1730	-229
OC 86	1812	-220	1887	-216	1956	-211	2034	-211	2105	-210	2192	-213	2269	-221
OC 86	2352	-230	2427	-238	2501	-252	2593	-265	2669	-276	2744	-297		
OC 86	890619	845	53	-310			-159	113	-56	108	-36	97	-18	93
OC 86	0	90	22	80	42	67	61	63	81	64	99	62	114	60
OC 86	131	33	151	9	174	-15	191	-22	210	-18	229	-22	250	-29
OC 86	267	-42	292	-49	309	-66	327	-66	354	-71	390	-83	463	-106
OC 86	547	-135	631	-165	705	-184	782	-193	865	-207	945	-217	1025	-228
OC 86	1105	-242	1189	-265	1267	-274	1363	-267	1431	-257	1512	-246	1595	-240
OC 86	1679	-229	1760	-225	1841	-217	1922	-212	2012	-209	2099	-210	2201	-213
OC 86	2290	-221	2379	-231	2469	-249	2547	-256	2631	-274	2723	-297	2797	-310

OC 86	890929	820	73	-269			-142	118	-82	111	-27	102	-9	95
OC 86	10	89	79	79	48	76	59	75	70	74	82	72	92	69
OC 86	103	61	113	50	119	29	127	11	134	17	135	21	145	9
OC 86	150	-1	157	-11	163	-21	171	-22	182	-24	192	-26	192	-26
OC 86	225	-23	226	-22	254	-26	285	-28	313	-30	333	-39	354	-51
OC 86	376	-63	398	-73	422	-85	443	-97	451	-104	460	-110	470	-117
OC 86	472	-119	476	-121	537	-137	570	-146	594	-150	616	-158	642	-165
OC 86	668	-172	749	-186	795	-195	847	-202	902	-209	998	-221	1081	-233
OC 86	1114	-242	1154	-249	1194	-257	1304	-269	1497	-249	1609	-239	1713	-228
OC 86	1798	-220	1942	-210	2042	-208	2123	-212	2205	-216	2277	-219	2378	-228
OC 86	2463	-240	2533	-250	2621	-266	2621	-267	2621	-266	2621	-268		

OC 86	900601	100	38	-218			0	92	25	76	50	67	75	58
OC 86	100	43	125	30	150	15	175	5	200	-2	225	-10	250	-22
OC 86	275	-39	300	-48	325	-58	350	-73	375	-82	400	-93	425	-105
OC 86	450	-114	475	-122	500	-131	525	-138	550	-149	575	-157	600	-162
OC 86	625	-168	650	-176	675	-181	700	-185	725	-188	750	-192	775	-195
OC 86	800	-199	825	-203	850	-207	875	-210	900	-214	925	-218		

OC 86	900828	1200	42	-214			0	92	10	103	25	126	40	153
OC 86	50	156	65	158	75	137	95	102	100	100	125	96	140	89
OC 86	150	84	175	73	200	60	225	51	250	49	275	37	300	27
OC 86	325	11	350	-23	375	-62	400	-82	425	-101	450	-114	475	-128
OC 86	500	-139	525	-146	550	-154	575	-159	600	-165	625	-169	650	-176
OC 86	675	-181	700	-186	725	-188	750	-192	775	-195	800	-199	825	-203
OC 86	850	-207	875	-210	900	-214								

OC 86	901202	1000	74	-298			-142	118	-86	110	-34	100	-12	102
OC 86	8	104	18	117	28	133	46	153	63	152	80	133	95	107
OC 86	108	102	120	96	132	90	142	83	154	73	165	61	177	51
OC 86	188	40	199	42	209	45	220	50	231	57	242	59	252	62
OC 86	271	34	290	4	302	-9	315	-21	329	-33	336	-36	364	-48
OC 86	375	-56	389	-62	402	-69	423	-77	459	-91	483	-105	495	-114
OC 86	508	-122	521	-129	549	-145	587	-160	649	-176	690	-183	751	-192
OC 86	825	-204	876	-212	935	-221	994	-229	1048	-237	1103	-247	1178	-259
OC 86	1233	-268	1297	-278	1357	-272	1437	-265	1514	-254	1598	-243	1691	-234
OC 86	1754	-226	1842	-221	1896	-217	1958	-214	2035	-212	2098	-217	2156	-219
OC 86	2214	-221	2325	-236	2427	-252	2475	-264	2531	-274	2589	-285	2643	-298

OC 86	910402	650	63	-279			-142	118	-84	109	-30	98	-16	97
OC 86	-3	97	9	106	20	118	39	148	50	151	60	155	77	133
OC 86	97	109	113	98	125	95	133	82	145	66	148	63	167	46
OC 86	187	34	207	24	217	20	227	14	246	6	286	-3	308	-13
OC 86	330	-25	359	-39	377	-47	400	-59	410	-67	421	-73	432	-80
OC 86	455	-95	480	-110	507	-124	543	-140	587	-158	640	-173	665	-178
OC 86	752	-192	813	-201	898	-212	968	-223	1039	-235	1122	-249	1217	-265
OC 86	1305	-279	1433	-265	1496	-260	1558	-253	1617	-246	1715	-237	1777	-230
OC 86	1847	-223	1920	-220	1967	-217	2029	-215	2084	-215	2156	-218	2221	-221
OC 86	2262	-223	2379	-229	2465	-238								

OC 86	910627	1050	51	-274			-142	118	-64	112	8	104	25	126
OC 86	40	153	53	153	64	153	80	133	95	108	112	100	127	89
OC 86	146	76	163	59	182	48	202	42	220	35	239	26	256	15
OC 86	266	6	277	-1	289	-9	312	-24	339	-36	371	-51	402	-68
OC 86	411	-76	422	-82	433	-89	445	-97	459	-104	474	-111	513	-127
OC 86	551	-143	600	-162	661	-177	770	-195	822	-204	883	-212	945	-220
OC 86	1024	-232	1062	-239	1105	-246	1151	-252	1229	-270	1343	-274	1486	-260
OC 86	1610	-247	1747	-233	1878	-220	2057	-214	2257	-222				

OC 86	920111	800	57	-273			-142	118	-98	118	-58	117	-37	117
OC 86	-18	118	1	124	21	126	41	111	60	89	71	79	80	67
OC 86	93	59	104	49	124	36	141	27	152	20	162	10	172	7
OC 86	185	22	205	29	222	38	239	39	255	16	262	3	269	-7
OC 86	277	-18	309	-20	327	-27	352	-37	368	-45	388	-52	427	-64
OC 86	461	-79	492	-91	530	-108	543	-116	558	-124	574	-132	585	-140
OC 86	599	-146	613	-153	626	-161	641	-168	657	-176	698	-184	751	-195
OC 86	837	-207	956	-224	1061	-240	1126	-251	1205	-265	1278	-273	1447	-271
OC 86	1540	-259	1598	-253	1634	-248	1670	-244						

92nd Street (Line 26/30)

OC 92	880622	0	52	-252			-413	80	-119	122	-23	148	-3	127
OC 92	15	96	34	69	54	51	73	38	93	29	113	25	132	16
OC 92	151	7	166	-4	170	0	204	-11	215	-16	244	-25	271	-38
OC 92	290	-48	333	-74	361	-86	391	-100	422	-113	473	-133	503	-138
OC 92	542	-150	570	-156	611	-164	632	-167	674	-174	693	-176	732	-182
OC 92	749	-185	787	-189	807	-193	844	-197	856	-198	890	-203	896	-204
OC 92	935	-209	986	-216	997	-215	1030	-221	1043	-221	1076	-228	1085	-230
OC 92	1121	-234	1143	-241	1143	-240	1167	-247	1167	-247	1184	-252		
OC 92	880907	0	49	-251			-3	127	15	96	19	93	39	80
OC 92	59	86	79	86	99	84	119	75	139	69	179	58	200	56
OC 92	245	14	302	-18	350	-45	359	-50	370	-55	376	-60	381	-66
OC 92	390	-73	400	-80	408	-85	424	-100	435	-110	444	-116	455	-121
OC 92	471	-130	479	-131	492	-137	519	-145	548	-150	557	-153	602	-159
OC 92	631	-164	680	-171	714	-176	754	-180	798	-185	820	-189	866	-195
OC 92	891	-200	909	-204	949	-207	995	-214	1030	-220	1109	-227	1131	-235
OC 92	1146	-240	1194	-244	1299	-251								
OC 92	890120	849	74	-299			-119	122	-20	142	5	115	24	95
OC 92	51	91	66	90	76	88	92	86	104	84	130	78	151	76
OC 92	164	63	176	50	197	40	223	46	237	33	250	20	254	4
OC 92	277	-12	297	-30	307	-32	355	-41	385	-55	398	-65	415	-73
OC 92	430	-83	443	-92	471	-110	494	-123	520	-134	542	-141	566	-148
OC 92	591	-154	614	-158	636	-162	648	-164	657	-165	707	-173	761	-181
OC 92	830	-190	899	-199	949	-206	1026	-217	1084	-225	1144	-236	1226	-252
OC 92	1290	-261	1374	-269	1449	-276	1521	-282	1610	-287	1695	-292	1806	-299
OC 92	1877	-294	1948	-286	2024	-275	2085	-267	2151	-259	2210	-250	2286	-241
OC 92	2354	-231	2415	-222	2477	-218	2533	-214	2593	-212	2646	-214	2703	-216
OC 92	2762	-222	2825	-229	2881	-233	2928	-240	2988	-252	3033	-257	3132	-278
OC 92	890420	849	59	-302			-119	122	-20	142	5	115	34	104
OC 92	58	93	78	67	101	52	124	48	139	35	157	17	172	3
OC 92	178	3	193	-5	215	-7	226	-9	250	-14	275	-17	305	-22
OC 92	325	-28	355	-37	379	-48	419	-69	444	-81	472	-99	497	-110
OC 92	531	-125	563	-138	603	-151	615	-154	615	-154	620	-155	626	-156
OC 92	757	-179	916	-201	1002	-211	1068	-225	1143	-239	1172	-245	1197	-250
OC 92	1276	-263	1362	-268	1451	-273	1540	-282	1660	-292	1762	-302	1882	-297
OC 92	2009	-281	2106	-264	2203	-250	2309	-234	2393	-223	2476	-216	2541	-212
OC 92	2605	-211	2667	-215	2728	-222	2796	-232	2850	-244	2945	-258		
OC 92	890619	645	50	-305			-119	122	-7	153	10	134	29	98
OC 92	48	90	66	74	83	63	101	59	117	61	133	65	149	64
OC 92	166	53	184	36	202	13	220	-5	241	-24	257	-20	275	-23
OC 92	294	-29	314	-39	337	-56	355	-61	355	-61	372	-69	402	-79
OC 92	436	-92	473	-102	501	-113	527	-124	532	-126	547	-132	593	-148
OC 92	634	-159	670	-166	736	-176	798	-186	861	-195	928	-203	996	-213
OC 92	1072	-225	1136	-234	1205	-248	1276	-261	1357	-266	1440	-271	1554	-281
OC 92	1642	-294	1723	-297	1831	-305	1940	-298						
OC 92	890929	951	55	-295			-70	146	-22	141	22	134	33	126
OC 92	43	115	55	105	65	93	85	75	96	73	106	72	119	66
OC 92	131	59	143	58	155	58	166	49	177	37	185	25	200	1
OC 92	207	-10	215	-20	223	-30	256	-35	289	-37	333	-42	389	-42
OC 92	405	-52	422	-60	441	-69	452	-77	465	-84	479	-91	490	-100
OC 92	503	-107	517	-115	545	-131	585	-144	625	-153	660	-160	693	-167
OC 92	724	-171	766	-178	829	-187	906	-197	1006	-212	1090	-224	1134	-235
OC 92	1185	-245	1237	-255	1308	-261	1381	-266	1451	-269	1525	-280	1612	-286
OC 92	1703	-292	1815	-295										
OC 92	900601	0	39	-211			0	151	25	119	50	93	75	76
OC 92	100	65	125	52	150	40	175	29	200	12	225	4	250	-1
OC 92	275	-2	300	-23	325	-32	350	-42	375	-56	400	-81	425	-88
OC 92	450	-96	475	-111	500	-119	525	-125	550	-134	575	-141	600	-151
OC 92	625	-156	650	-162	675	-166	700	-171	725	-176	750	-181	775	-182
OC 92	800	-186	825	-191	850	-196	875	-198	900	-203	925	-206	950	-211
OC 92	900908	1200	42	-203			0	151	10	141	25	134	40	147
OC 92	50	156	65	145	75	121	95	97	100	96	125	92	130	90
OC 92	150	81	175	67	200	60	225	53	250	50	275	24	300	-4
OC 92	325	-19	350	-34	375	-57	400	-68	425	-85	450	-101	475	-117
OC 92	500	-120	525	-132	550	-141	575	-140	600	-152	625	-158	650	-164
OC 92	675	-166	700	-171	725	-176	750	-181	775	-182	800	-186	825	-191
OC 92	850	-196	875	-198	900	-203								

OC 92	901202	1100	55	-271			0	151	10	140	10	140	10	140
OC 92	30	141	46	143	58	137	68	128	84	114	98	95	110	94
OC 92	120	93	133	88	144	82	157	76	169	68	181	60	193	51
OC 92	206	44	217	36	231	41	243	47	257	51	270	57	281	51
OC 92	291	43	311	15	316	7	323	0	330	-6	344	-18	361	-30
OC 92	379	-42	413	-56	454	-73	491	-91	503	-99	516	-106	530	-113
OC 92	552	-128	578	-144	622	-157	706	-173	763	-184	859	-198	900	-204
OC 92	948	-211	1009	-223	1078	-237	1133	-243	1177	-247	1228	-254	1283	-260
OC 92	1330	-264	1397	-271										
OC 92	910402	725	50	-265			-418	84	-201	116	-4	156	12	134
OC 92	31	142	52	135	72	127	87	115	100	100	111	96	122	92
OC 92	141	79	161	61	180	58	200	57	218	42	237	28	257	16
OC 92	268	13	278	10	289	9	300	9	311	5	321	1	340	-10
OC 92	362	-24	379	-33	406	-47	435	-57	445	-66	456	-73	468	-80
OC 92	479	-90	513	-104	547	-119	586	-136	623	-151	665	-165	714	-177
OC 92	759	-185	807	-193	867	-201	920	-210	962	-217	1019	-226	1083	-234
OC 92	1142	-242	1192	-248	1269	-257	1344	-265						
OC 92	910627	1230	47	-265			-439	85	-214	111	-10	144	17	140
OC 92	41	134	59	119	76	101	88	98	98	95	109	89	119	82
OC 92	138	65	152	63	165	61	184	63	203	55	214	51	224	47
OC 92	235	41	245	33	258	18	272	6	287	-5	302	-19	352	-36
OC 92	367	-45	384	-53	402	-62	430	-79	448	-91	469	-101	490	-112
OC 92	524	-123	566	-135	582	-142	601	-149	620	-156	689	-174	735	-185
OC 92	833	-201	940	-217	994	-223	1037	-231	1088	-237	1140	-244	1284	-262
OC 92	1333	-265												
OC 92	920111	700	48	-302			-20	160	-5	157	8	153	22	136
OC 92	34	114	54	107	72	97	93	87	113	75	133	64	151	50
OC 92	171	41	190	30	200	27	210	22	229	13	246	9	268	12
OC 92	288	16	337	-1	360	-12	383	-23	404	-29	420	-34	446	-44
OC 92	499	-60	534	-72	570	-87	597	-96	610	-104	625	-112	641	-125
OC 92	660	-136	680	-147	693	-154	730	-170	796	-189	830	-197	866	-203
OC 92	910	-211	961	-218	1014	-225	1143	-241	1243	-253	1363	-271	1502	-286
OC 92	1646	-301	1651	-302										

103rd Street (Profile 28/32)

OC103	880628	100	41	-258			-470	86	-72	124	-27	130	20	60
OC103	40	46	59	42	80	42	100	30	120	12	140	2	154	-2
OC103	159	-5	171	-9	176	-9	200	-22	223	-32	243	-40	261	-51
OC103	286	-70	313	-80	345	-89	375	-100	424	-113	470	-121	508	-130
OC103	550	-141	590	-154	628	-165	665	-173	698	-181	725	-187	737	-191
OC103	766	-200	789	-205	816	-210	873	-224	900	-237	931	-246	967	-251
OC103	1015	-258	1015	-258										
OC103	881026	0	54	-251			-27	130	4	88	24	88	44	89
OC103	53	90	73	90	83	88	103	88	128	89	148	74	168	59
OC103	176	53	187	38	199	23	211	0	232	-15	248	-20	257	-25
OC103	275	-35	284	-40	296	-46	302	-50	308	-55	313	-60	319	-65
OC103	325	-70	331	-80	357	-90	371	-96	389	-105	417	-118	433	-125
OC103	448	-130	466	-135	487	-141	552	-150	571	-155	596	-160	619	-165
OC103	644	-170	667	-175	686	-180	700	-185	715	-190	736	-195	754	-200
OC103	779	-205	796	-210	813	-215	828	-220	874	-230	902	-235	967	-240
OC103	1203	-251												
OC103	890120	952	54	-315			-72	124	-41	123	-26	116	-11	110
OC103	2	84	14	83	27	83	40	85	53	87	73	87	95	87
OC103	117	85	128	70	139	54	167	47	186	47	193	37	201	25
OC103	210	13	217	5	224	-7	232	-14	250	-28	286	-42	317	-52
OC103	341	-60	363	-74	395	-90	410	-98	424	-106	440	-113	467	-124
OC103	493	-135	539	-148	582	-159	639	-171	683	-181	728	-192	768	-204
OC103	823	-219	875	-227	918	-230	1001	-236	1054	-240	1175	-246	1273	-252
OC103	1327	-256	1493	-274	1555	-280	1629	-286	1704	-292	1801	-301	1887	-306
OC103	2010	-315												
OC103	890420	1030	45	-316			-72	124	2	90	21	90	48	89
OC103	71	65	93	54	116	43	136	32	159	34	178	20	205	4
OC103	229	-11	254	-25	257	-29	274	-36	298	-42	341	-62	368	-73
OC103	392	-87	423	-98	449	-105	484	-112	528	-123	608	-148	687	-173
OC103	746	-190	817	-205	889	-218	955	-225	1009	-231	1069	-236	1138	-242
OC103	1199	-246	1268	-251	1332	-255	1404	-264	1465	-269	1528	-274	1591	-281
OC103	1667	-286	1728	-291	1783	-295	1844	-300	1913	-307	2001	-316		

OC103	890619	530	44	-303			-85	124	-13	90	10	87	28	84
OC103	45	79	63	73	79	65	97	57	113	57	131	57	146	60
OC103	160	62	175	34	193	8	209	-11	225	-27	241	-32	259	-42
OC103	272	-49	290	-59	314	-74	329	-81	357	-90	410	-107	463	-123
OC103	521	-133	576	-144	643	-160	658	-163	708	-176	785	-192	860	-204
OC103	939	-216	1018	-228	1107	-238	1200	-245	1279	-253	1358	-260	1439	-267
OC103	1528	-275	1618	-283	1711	-290	1802	-297	1900	-303				
OC103	891001	1040	66	-319			-59	124	-23	108	11	87	22	86
OC103	32	84	44	82	55	80	67	80	78	80	89	78	100	75
OC103	112	61	124	44	134	38	144	30	161	11	171	9	182	9
OC103	192	8	212	0	234	-9	247	-16	271	-27	297	-38	325	-51
OC103	346	-58	367	-72	388	-83	396	-91	405	-97	415	-105	443	-111
OC103	470	-118	518	-127	528	-131	530	-131	566	-139	594	-149	626	-157
OC103	659	-166	693	-175	695	-175	719	-175	753	-183	787	-187	811	-191
OC103	899	-203	948	-207	1002	-216	1064	-222	1124	-225	1177	-231	1230	-239
OC103	1290	-247	1352	-256	1426	-262	1490	-269	1537	-273	1593	-278	1651	-282
OC103	1705	-286	1770	-292	1893	-300	1972	-309	1980	-313	2085	-319		
OC103	900601	0	38	-209			0	95	25	86	50	75	75	65
OC103	100	66	125	47	150	41	175	51	200	40	225	1	250	-20
OC103	275	-52	300	-87	325	-90	350	-92	375	-108	400	-120	425	-124
OC103	450	-129	475	-138	500	-144	525	-151	550	-154	575	-161	600	-164
OC103	625	-170	650	-175	675	-177	700	-179	725	-183	750	-186	775	-189
OC103	800	-193	825	-194	850	-199	875	-202	900	-206	925	-209		
OC103	900717	1200	37	-206			0	109	10	111	40	145	65	145
OC103	95	89	125	88	150	88	175	80	200	75	225	60	250	41
OC103	275	37	300	35	325	33	350	5	375	-17	400	-69	425	-95
OC103	450	-116	475	-129	500	-138	525	-147	550	-153	575	-159	600	-163
OC103	625	-167	650	-171	675	-173	700	-179	725	-181	750	-186	775	-189
OC103	800	-193	825	-194	850	-199	875	-202	900	-206				
OC103	901202	1200	51	-293			-59	124	-8	134	39	146	51	145
OC103	62	143	73	126	83	105	94	95	104	83	119	71	133	55
OC103	146	52	157	49	177	56	188	58	198	60	217	39	230	22
OC103	243	1	259	-14	267	-24	276	-32	285	-41	302	-48	317	-54
OC103	336	-65	355	-73	375	-80	403	-91	427	-103	451	-116	476	-129
OC103	512	-143	548	-159	563	-163	636	-173	758	-184	829	-197	881	-203
OC103	938	-208	1010	-217	1077	-224	1148	-233	1209	-246	1270	-250	1341	-260
OC103	1403	-266	1477	-274	1533	-279	1605	-284	1699	-293				
OC103	910402	805	52	-275			-59	124	-27	111	3	95	22	124
OC103	42	148	54	144	65	139	76	121	86	100	99	74	112	68
OC103	124	67	129	65	144	55	160	46	173	37	188	24	199	18
OC103	209	10	231	0	247	-9	266	-18	288	-28	309	-39	324	-48
OC103	341	-55	359	-63	379	-78	401	-92	414	-100	428	-107	442	-114
OC103	467	-126	486	-134	508	-141	530	-148	595	-162	657	-173	710	-179
OC103	747	-184	794	-190	852	-196	911	-202	973	-210	1036	-218	1095	-223
OC103	1156	-236	1253	-253	1314	-259	1370	-264	1439	-270	1495	-275		
OC103	910627	1400	44	-285			-59	124	-21	119	13	113	27	126
OC103	39	143	50	143	60	142	80	112	98	75	109	68	128	62
OC103	145	55	163	50	179	44	198	33	210	20	223	8	238	-3
OC103	259	-22	280	-29	313	-46	343	-59	357	-72	373	-83	389	-94
OC103	425	-111	464	-127	492	-136	551	-155	586	-163	626	-169	668	-176
OC103	745	-185	807	-193	965	-209	1104	-227	1140	-234	1181	-240	1224	-247
OC103	1287	-255	1360	-262	1436	-270	1531	-277	1622	-285				
OC103	911102	1230	48	-280			-59	124	-28	117	0	108	10	109
OC103	25	132	42	144	61	143	80	121	94	107	110	87	127	69
OC103	146	56	164	43	180	28	198	11	215	5	251	0	270	1
OC103	288	3	290	1	312	-2	336	-11	345	-15	356	-20	359	-23
OC103	377	-33	406	-46	434	-62	467	-77	496	-95	523	-113	555	-132
OC103	564	-140	575	-148	586	-155	646	-174	712	-189	756	-187	814	-191
OC103	843	-199	924	-207	963	-216	1008	-223	1055	-231	1177	-244	1249	-252
OC103	1359	-264	1542	-280										

OC103	920110	1500	48	-267			-471	86	-228	106	-7	132	5	132
OC103	16	132	35	115	52	103	68	87	85	73	105	58	122	48
OC103	132	43	142	37	152	33	162	29	175	27	187	26	211	31
OC103	233	37	245	28	255	17	266	6	280	-2	294	-11	315	-18
OC103	346	-32	411	-51	428	-59	448	-65	469	-72	495	-83	520	-94
OC103	549	-104	580	-113	597	-123	616	-131	637	-139	663	-148	693	-156
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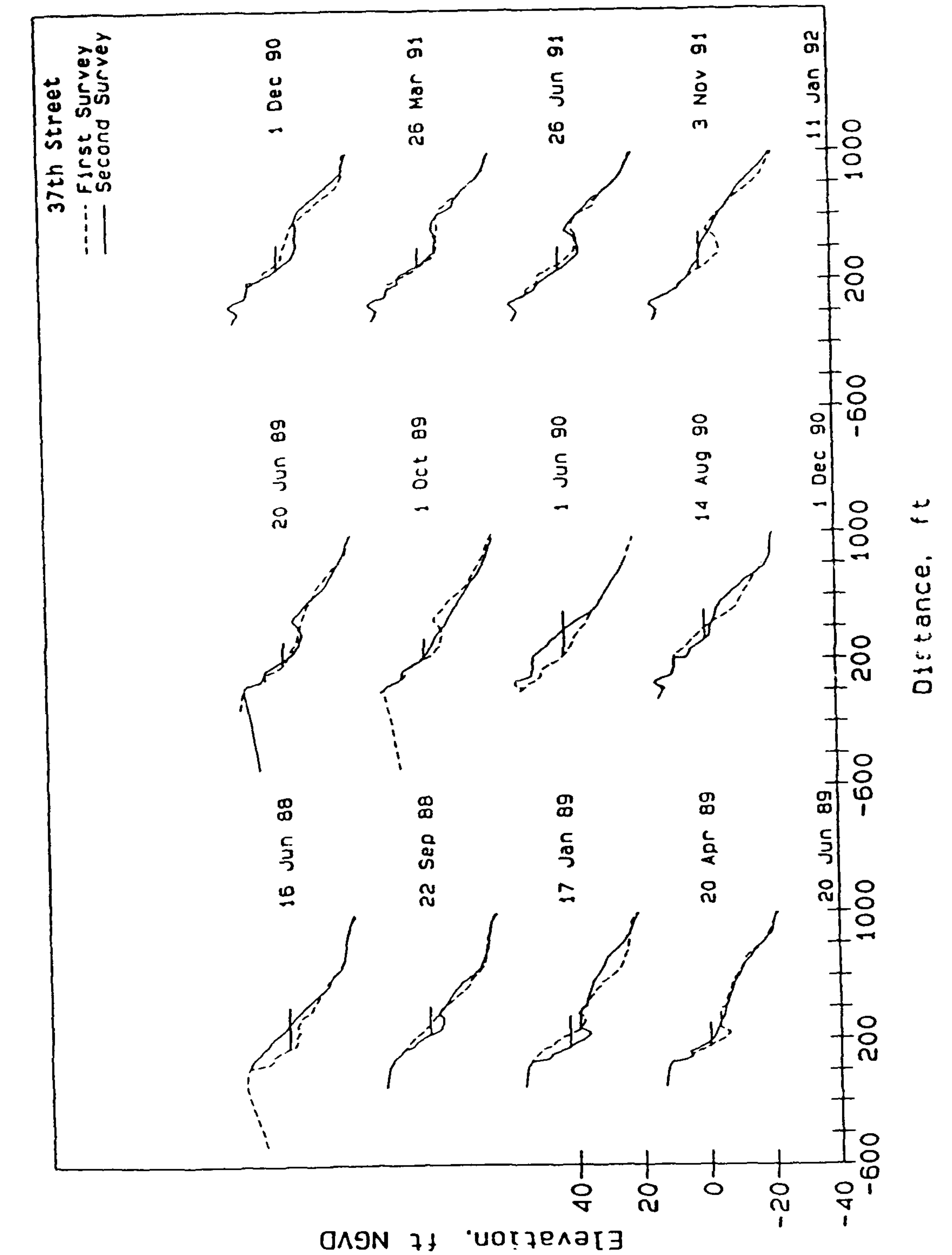
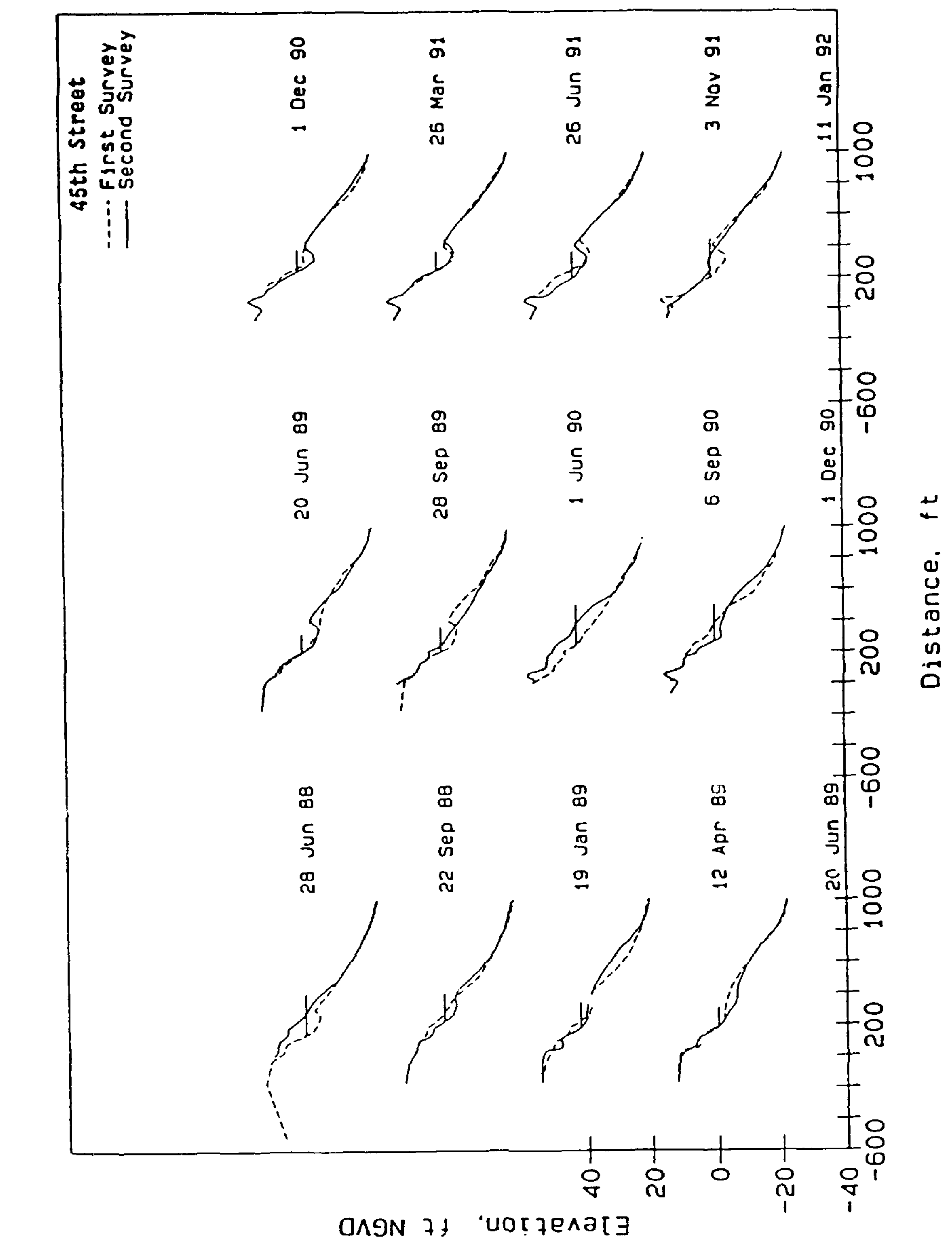
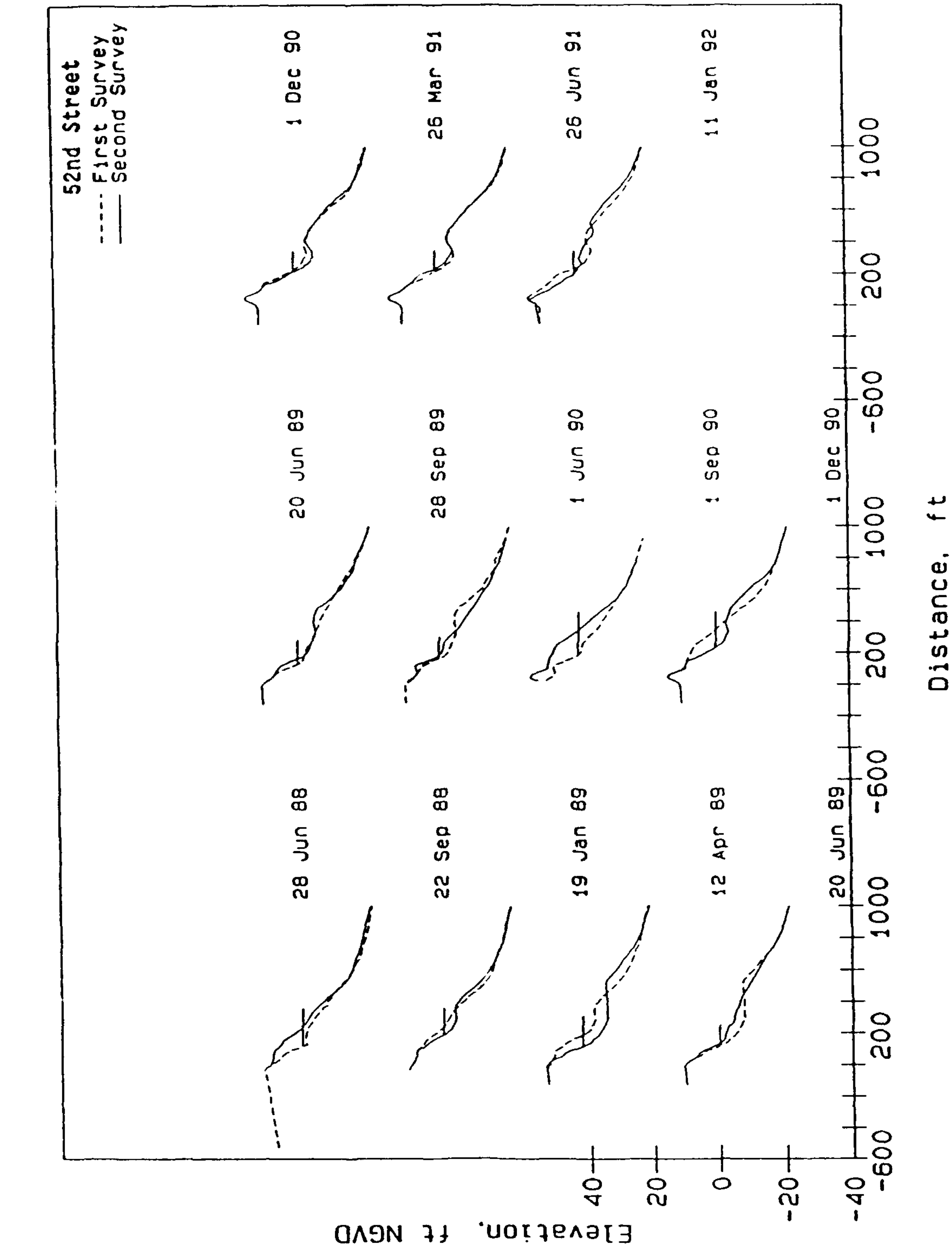
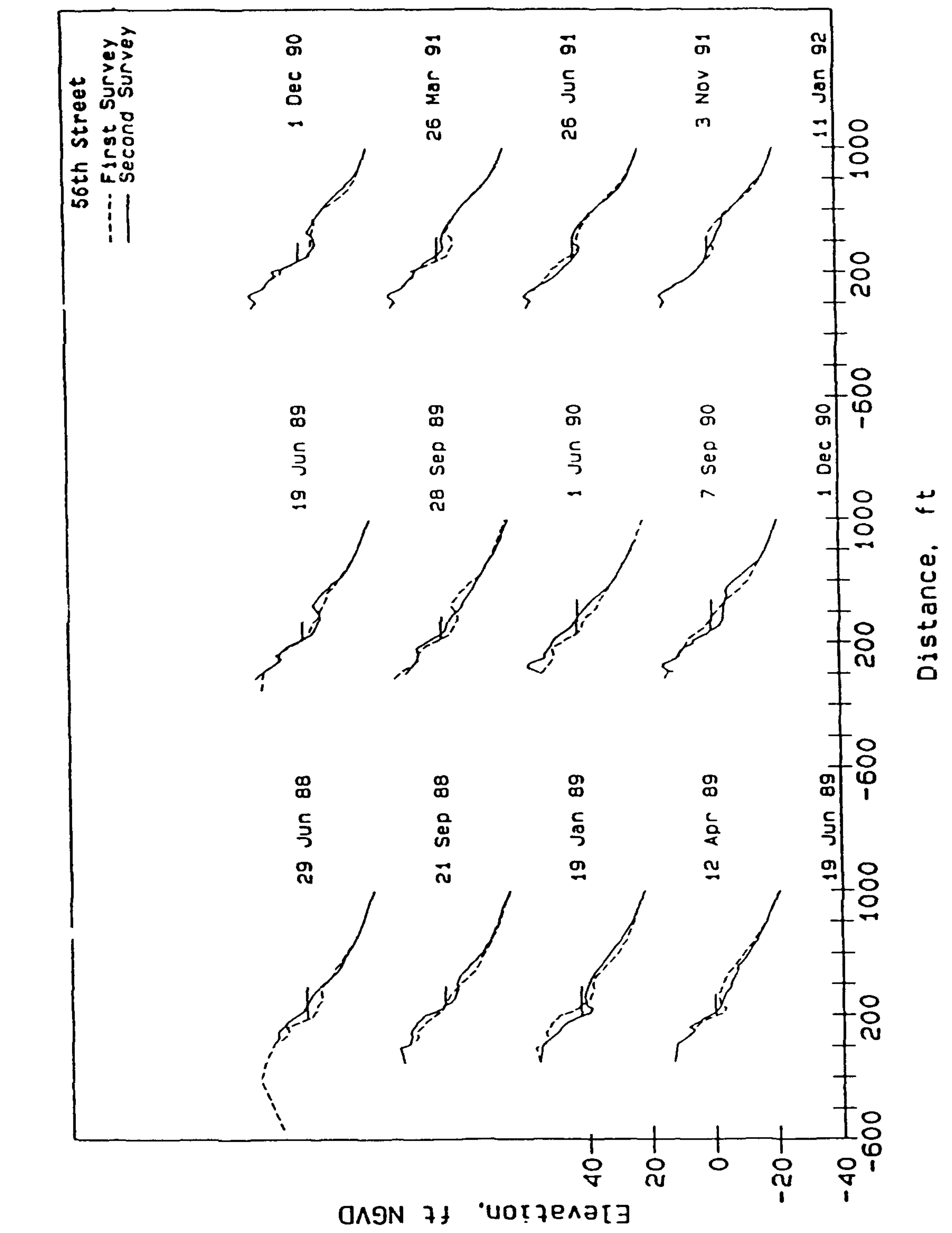
OC103	1371	-262	1461	-267										

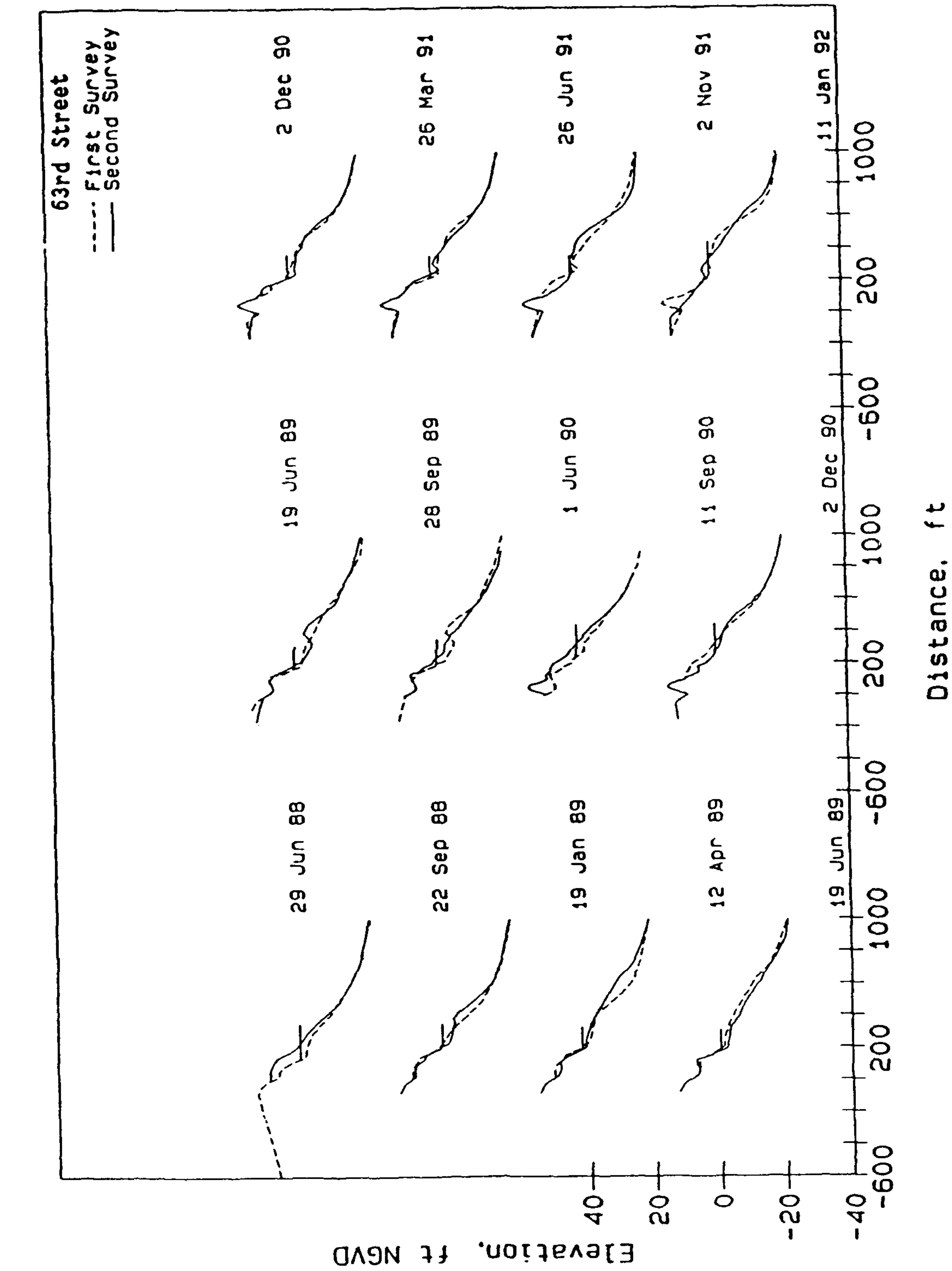

37th Street
First Survey
Second Survey
16 Jun 88
22 Sep 88
17 Jan 89
20 Apr 89
20 Jun 89
1 Oct 89
1 Jun 90
14 Aug 90
1 Dec 90
26 Mar 91
26 Jun 91
3 Nov 91
11 Jan 92
Distance, ft
Elevation, ft NGVD
40
20
0
-20
-40
-600
200
1000

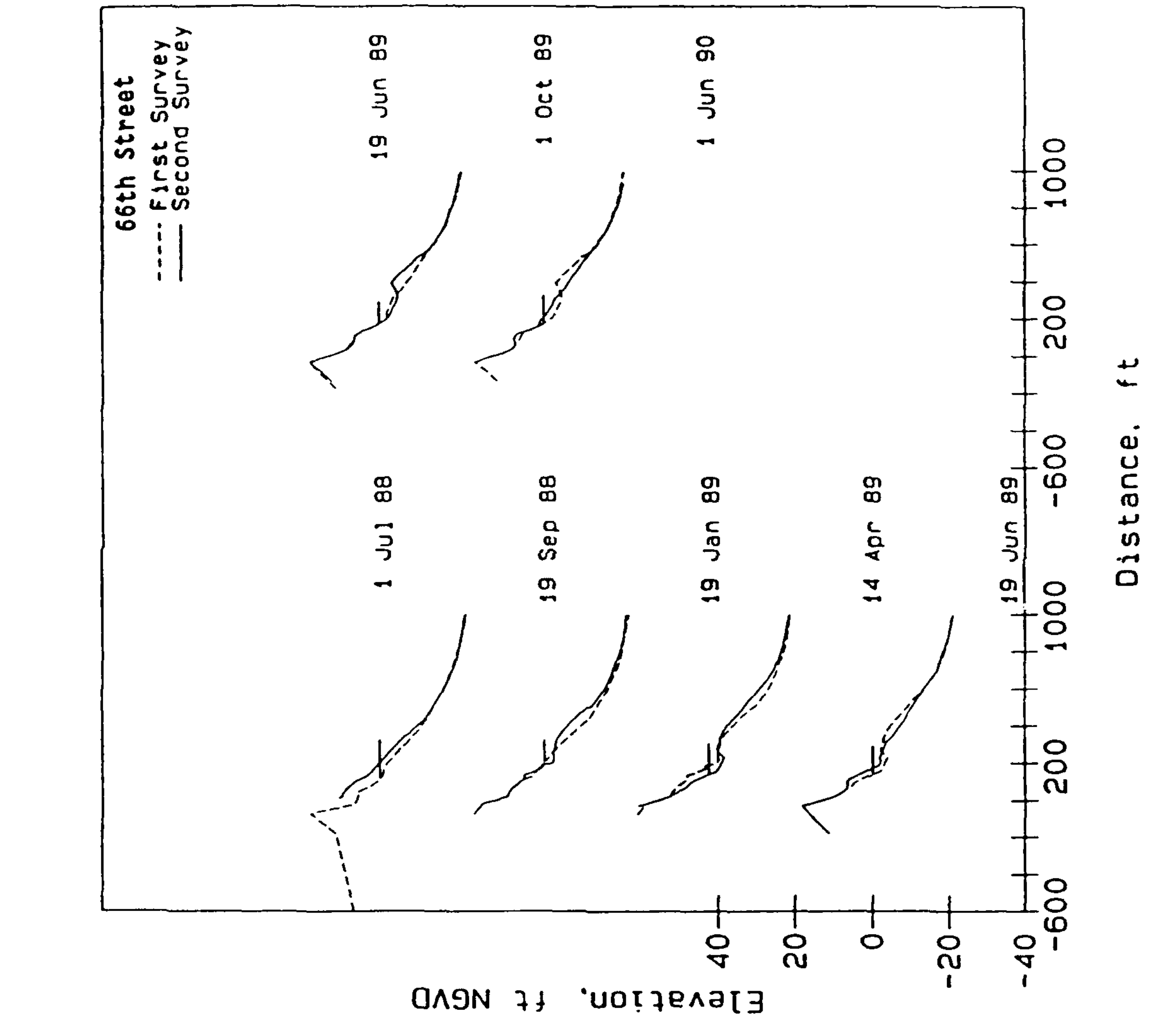

45th Street
First Survey
Second Survey
28 Jun 88
22 Sep 88
19 Jan 89
12 Apr 89
20 Jun 89
20 Jun 89
28 Sep 89
1 Jun 90
6 Sep 90
1 Dec 90
1 Dec 90
26 Mar 91
26 Jun 91
3 Nov 91
11 Jan 92
Distance, ft
Elevation, ft NGVD
-600
200
1000
-600
200
1000
-600
200
1000
40
20
0
-20
-40

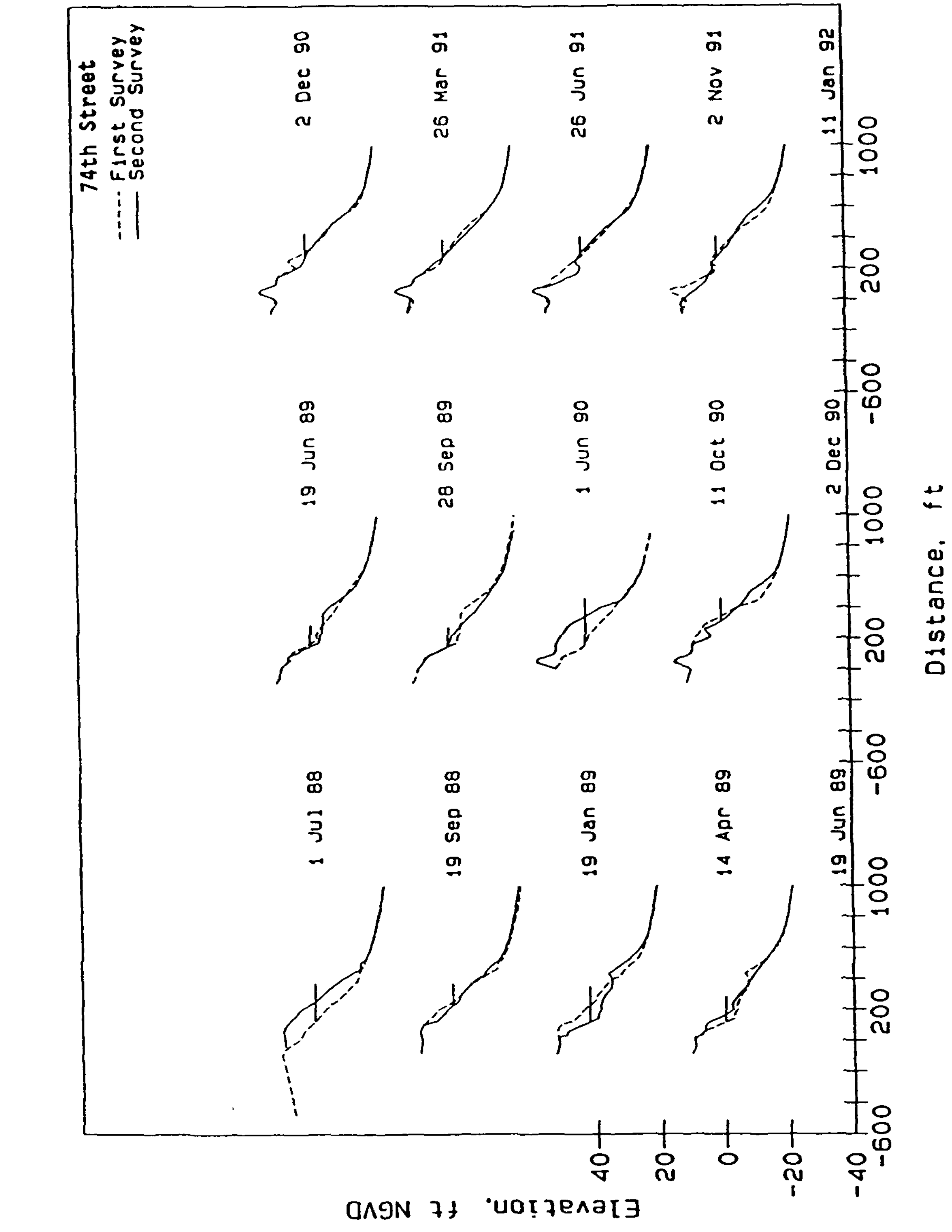

52nd Street
First Survey
Second Survey
28 Jun 88
22 Sep 88
19 Jan 89
12 Apr 89
20 Jun 89
28 Sep 89
1 Jun 90
1 Sep 90
1 Dec 90
26 Mar 91
26 Jun 91
11 Jan 92
Distance, ft
Elevation, ft NGVD

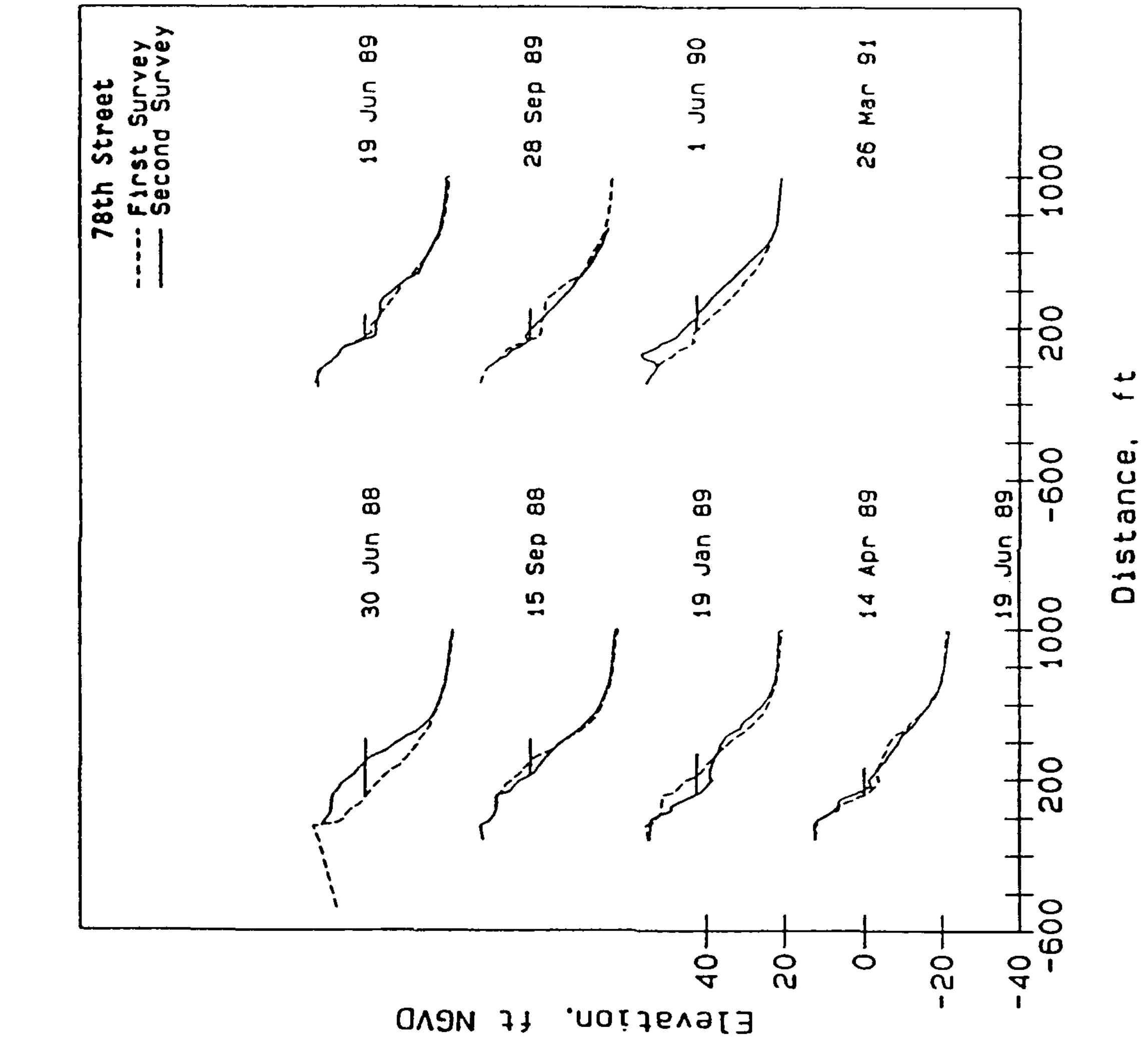


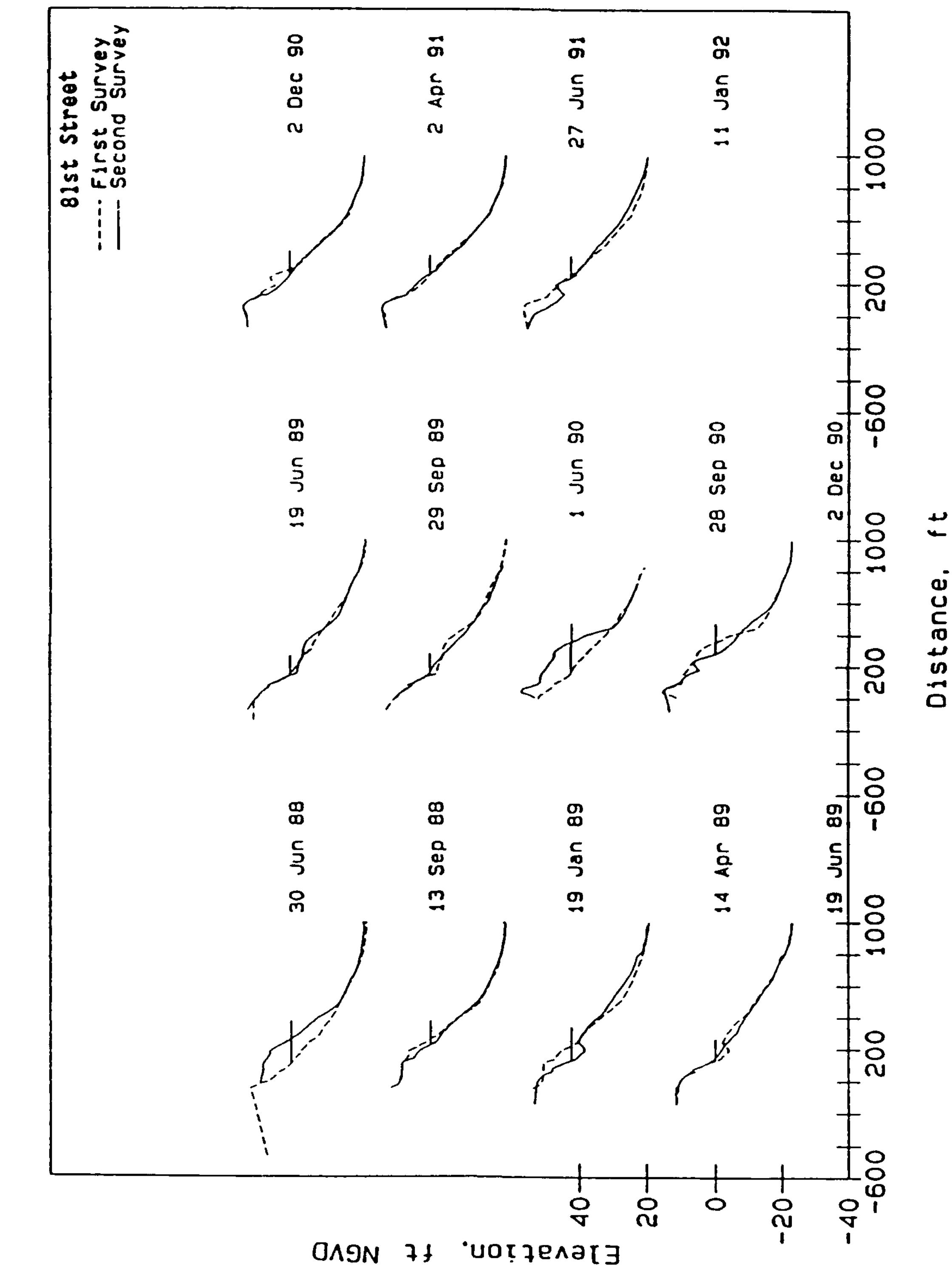
56th Street
First Survey
Second Survey
29 Jun 88
21 Sep 88
19 Jan 89
12 Apr 89
19 Jun 89
28 Sep 89
1 Jun 90
7 Sep 90
1 Dec 90
26 Mar 91
26 Jun 91
3 Nov 91
11 Jan 92
Distance, ft
Elevation, ft NGVD
-600
200
1000
-40
-20
0
20
40

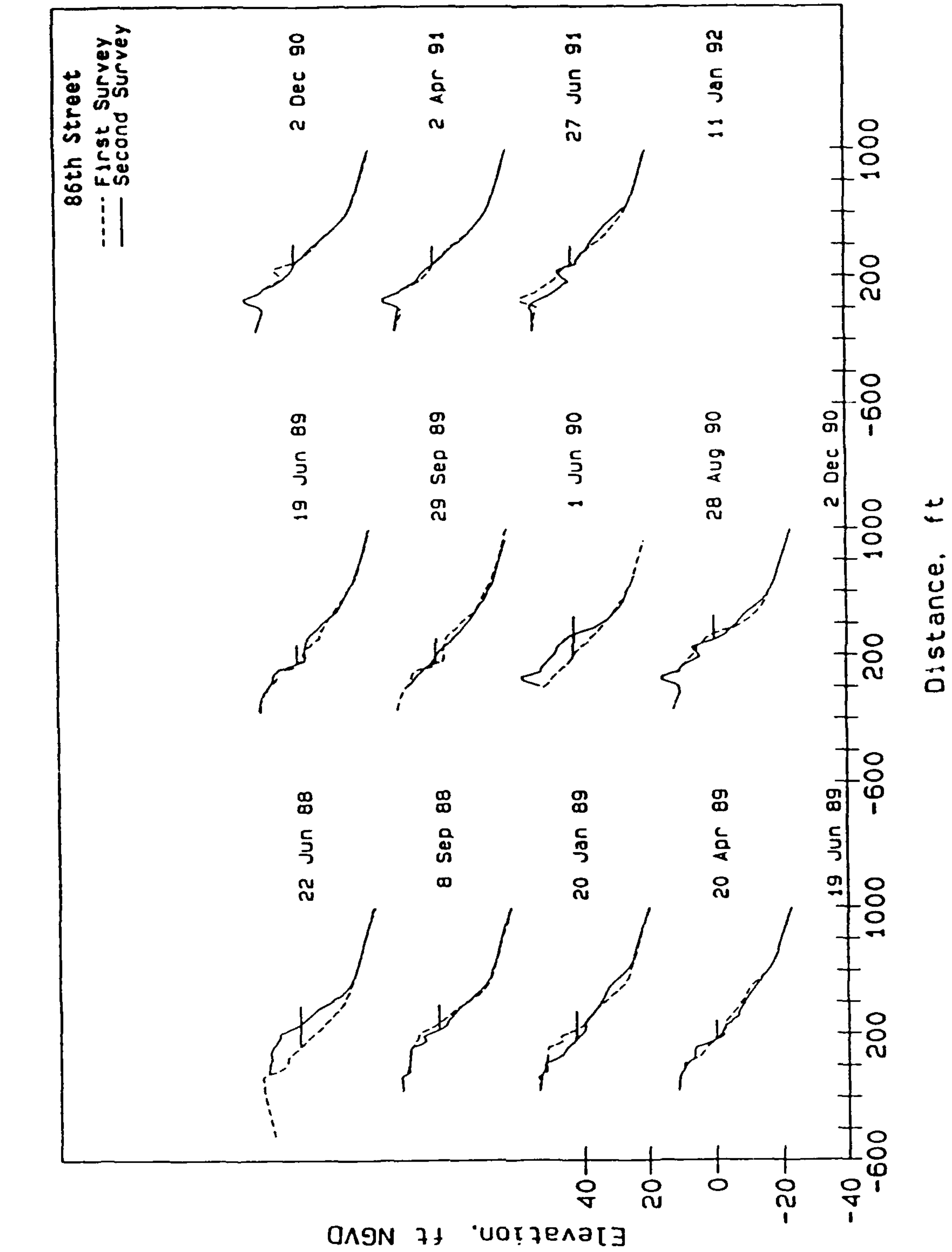

63rd Street
First Survey
Second Survey
29 Jun 88
22 Sep 88
19 Jan 89
12 Apr 89
19 Jun 89
28 Sep 89
1 Jun 90
11 Sep 90
2 Dec 90
26 Mar 91
26 Jun 91
2 Nov 91
11 Jan 92
Distance, ft
Elevation, ft NGVD


66th Street
First Survey
Second Survey
1 Jul 88
19 Sep 88
19 Jan 89
14 Apr 89
19 Jun 89
19 Jun 89
1 Oct 89
1 Jun 90
Elevation, ft NGVD
Distance, ft

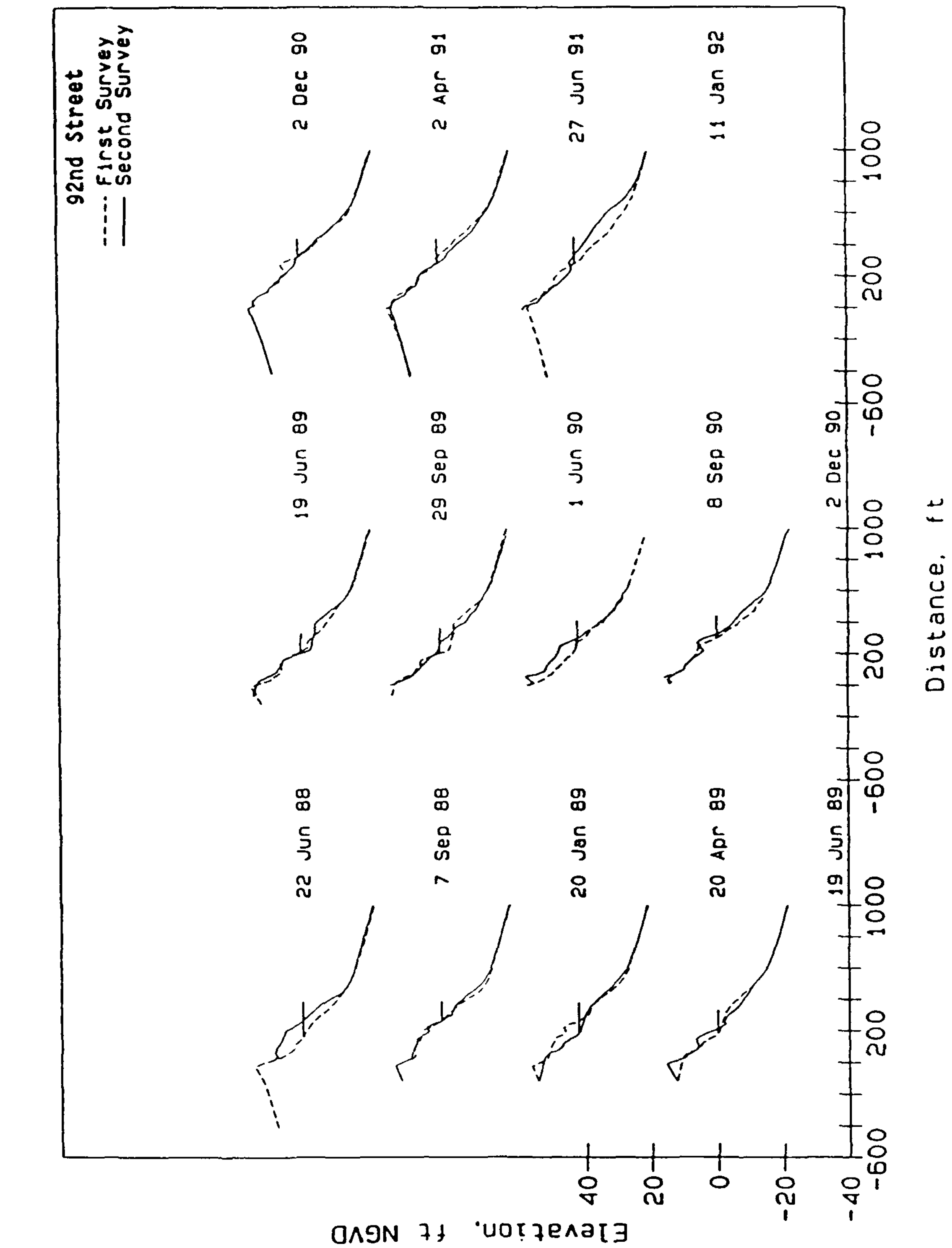

74th Street
First Survey
Second Survey
1 Jul 88
19 Sep 88
19 Jan 89
14 Apr 89
19 Jun 89
19 Jun 89
28 Sep 89
1 Jun 90
11 Oct 90
2 Dec 90
2 Dec 90
26 Mar 91
26 Jun 91
2 Nov 91
11 Jan 92
Elevation, ft NGVD
Distance, ft

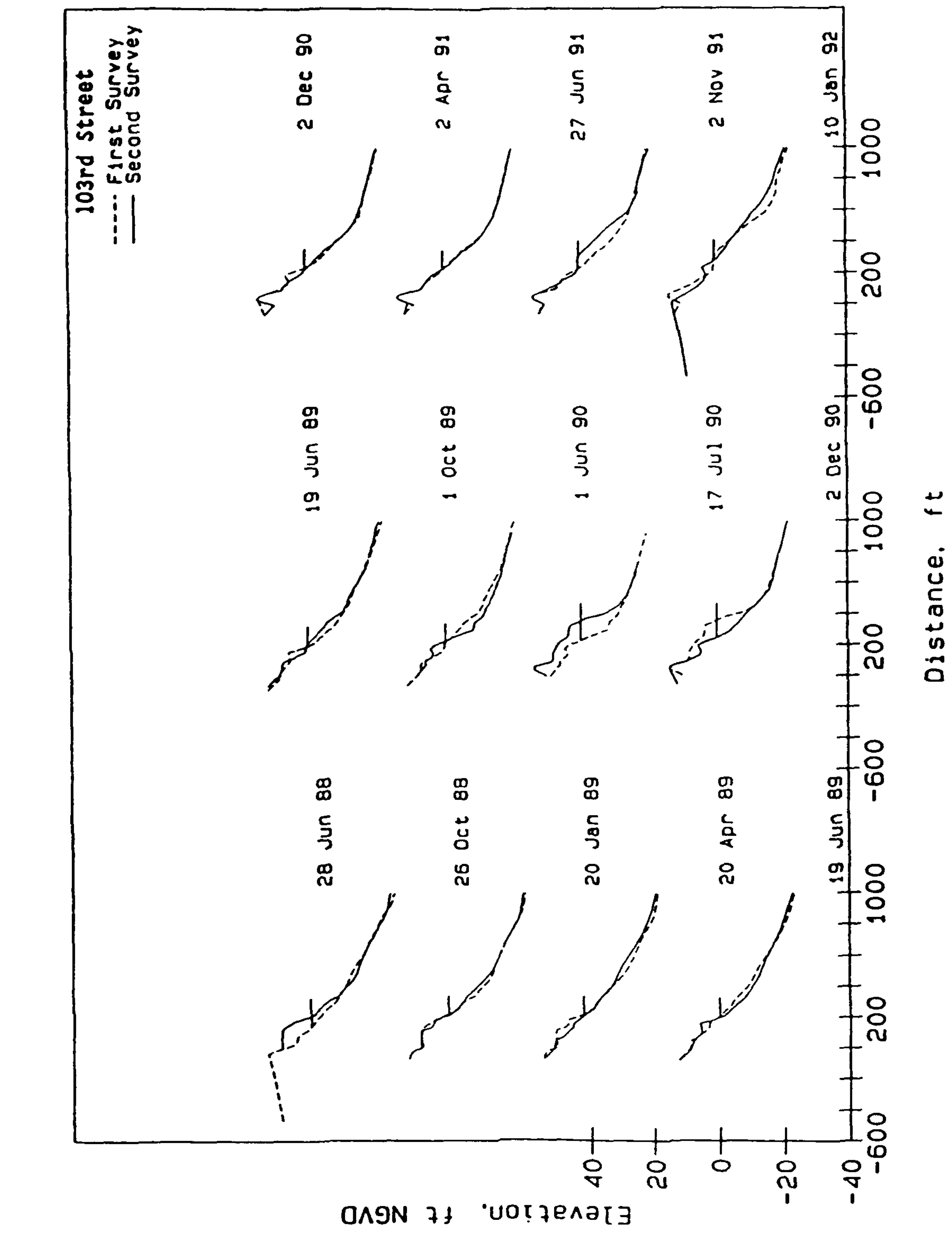

78th Street
First Survey
Second Survey
30 Jun 88
15 Sep 88
19 Jan 89
14 Apr 89
19 Jun 89
19 Jun 89
28 Sep 89
1 Jun 90
26 Mar 91
Elevation, ft NGVD
40
20
0
-20
-40
-600
200
1000
-600
200
1000
Distance, ft


81st Street
First Survey
Second Survey
30 Jun 88
13 Sep 88
19 Jan 89
14 Apr 89
19 Jun 89
19 Jun 89
29 Sep 89
1 Jun 90
28 Sep 90
2 Dec 90
2 Dec 90
2 Apr 91
27 Jun 91
11 Jan 92
Distance, ft
Elevation, ft NGVD
40
20
0
-20
-40
-600
200
1000



86th Street
First Survey
Second Survey
22 Jun 88
8 Sep 88
20 Jan 89
20 Apr 89
19 Jun 89
19 Jun 89
29 Sep 89
1 Jun 90
28 Aug 90
2 Dec 90
2 Dec 90
2 Apr 91
27 Jun 91
11 Jan 92
-600
200
1000
Distance, ft
40
20
0
-20
-40
Elevation, ft NGVD


92nd Street
First Survey
Second Survey
22 Jun 88
7 Sep 88
20 Jan 89
20 Apr 89
19 Jun 89
29 Sep 89
1 Jun 90
8 Sep 90
2 Dec 90
2 Apr 91
27 Jun 91
11 Jan 92
Distance, ft
Elevation, ft NGVD


103rd Street
First Survey
Second Survey
28 Jun 88
26 Oct 88
20 Jan 89
20 Apr 89
19 Jun 89
19 Jun 89
1 Oct 89
1 Jun 90
17 Jul 90
2 Dec 90
2 Dec 90
2 Apr 91
27 Jun 91
2 Nov 91
10 Jan 92
Elevation, ft NGVD
Distance, ft

Appendix B
Grain Size Data

Table B1 lists the sediment grain size data for each sediment sample collected for this study. Surface grab samples were collected at various locations along the profile line. Sediment sampling was not standardized until the January 1989 sampling, which resulted in several sample location codes. An explanation of the sample location code follows.

	TS	Top of dune
	MS	Mid-dune
*	DB	Base of dune
	UB	Upper berm
	MB(MB2,3)	Mid-berm (additional berm samples)
	LMBC	Lower mid-berm crest
	LB	Lower berm
	LBC	Lower berm near crest
	BTS	Top of berm scarp
*	BEC	Berm crest
*	MT	Mid-tide
	MFS	Mid-foreshore
	SWASH	Swash (low tide terrace)
*	STEP	Step
*	NST	Nearshore trough
*	BAC	Bar crest
*	-5	5-ft depth
*	-10	10-ft depth
*	-15	15-ft depth
*	-20	20-ft depth
*	-25	25-ft depth

* Main sample locations used in grain size analysis and composite analysis.

Other data include the distance and elevation at which the sample was collected on the survey; grain size statistics, including MGS (mean grain size) in millimeters and phi units; grain sorting in phi units; median, in millimeters and phi units; Skewness in phi units; and Kurtosis in phi units .

Table B2 lists the composite grain size data used in this report. The foreshore composite contains data from the following locations:

Berm crest
Mid-tide
Step

The nearshore composite contains sample data from the following depths

5 ft
10 ft
15 ft
20 ft
25 ft

The bar/trough composite contains data from the following locations:

Nearshore trough
Bar crest

The profile composite contains data from the following locations and depths:

Dune base
Berm crest
Mid-tide
Step
Nearshore trough
Bar crest
5 ft
10 ft
15 ft
20 ft
25 ft

Composite grain size statistics listed are the same as those in Table B1.

Table B1
Sediment Sample Locations and Statistics

Sample Location	Distance from Baseline, ft	Elev ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 14 (37th Street)									
June/July 1988									
TS	10	13.0	1.57	0.34	0.51	1.62	0.33	-0.42	4.32
MS	26	12.2	1.06	0.48	0.87	1.23	0.43	-1.87	7.35
DB	51	6.4	1.20	0.44	0.56	1.27	0.41	-0.90	5.02
UB	65	5.8	1.37	0.39	0.49	1.44	0.37	-1.07	6.94
MB	76	5.0	1.63	0.32	0.45	1.65	0.32	0.02	3.57
BTS	85	5.0	1.14	0.45	0.58	1.19	0.44	-0.68	3.62
BEC	97	5.0	1.69	0.31	0.34	1.69	0.31	0.00	4.17
MT	122	3.6	1.14	0.45	0.59	1.18	0.44	-1.26	6.90
STEP	165	-1.5	1.62	0.33	0.59	1.64	0.32	-0.25	3.47
-5	367	-5.0	2.44	0.18	0.54	2.49	0.18	-0.55	4.50
-10	501	-10.0	2.93	0.13	0.51	2.98	0.13	-1.13	6.94
-15	641	-15.0	2.52	0.17	0.64	2.49	0.18	-0.37	3.51
-20	964	-20.0	1.44	0.37	0.60	1.40	0.38	0.08	6.10
-23	1097	-23.0	1.96	0.26	0.69	2.04	0.24	-0.71	5.04
September 1988									
DB	9	12.7	1.56	0.34	0.53	1.61	0.33	-0.43	4.49
BEC	210	5.4	2.13	0.23	0.45	2.10	0.23	0.32	3.72
MT	263	2.1	2.28	0.21	0.44	2.29	0.20	0.14	2.70
SWASH	299	0.1	2.16	0.22	0.50	2.14	0.23	0.07	2.80
STEP	347	-1.6	1.51	0.35	0.77	1.45	0.37	-0.11	3.45
-5	423	-5.1	2.38	0.19	0.96	2.64	0.16	-1.73	6.02
-10	508	-9.9	2.45	0.18	0.68	2.54	0.17	-1.42	8.42
-15	633	-15.1	2.18	0.22	0.91	2.26	0.21	-1.57	7.93
-20	999	-20.2	1.48	0.36	0.69	1.44	0.37	0.06	4.74
-25	1242	-25.1	0.72	0.61	1.34	0.94	0.52	-0.85	3.57

(Sheet 1 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 14 (37th Street)									
January 1989									
DB	105	10.0	1.54	0.34	0.63	1.62	0.33	-0.87	5.44
BEC	145	7.6	1.88	0.27	0.50	1.91	0.27	-0.68	5.47
MT	239	1.0	1.77	0.29	0.45	1.78	0.29	-0.15	5.01
STEP	259	-1.5	1.66	0.32	0.49	1.72	0.30	-0.42	2.99
NST	318	-4.2	2.08	0.24	0.55	2.12	0.23	-0.57	3.89
BAC	366	-5.1	1.73	0.30	0.55	1.75	0.30	-0.76	7.76
-5	439	-5.0	1.85	0.28	0.70	1.91	0.27	-0.65	4.03
-10	569	-10.0	2.42	0.19	0.57	2.46	0.18	-0.78	5.31
-15	649	-15.2	2.26	0.21	0.65	2.30	0.20	-0.35	3.35
-20	968	-19.5	1.50	0.35	0.83	1.30	0.41	0.73	3.21
-25	1313	-25.0	1.62	0.33	0.61	1.62	0.33	0.05	3.58
April 1989									
DB	76	11.6	1.66	0.32	0.55	1.68	0.31	0.40	4.49
BEC	111	5.3	1.53	0.35	1.02	1.78	0.29	-1.61	5.98
MT	153	0.5	1.60	0.33	0.68	1.70	0.31	-1.38	7.74
STEP	183	-1.1	1.24	0.42	0.92	1.51	0.35	-1.15	4.13
NST	273	-6.0	1.56	0.34	0.45	1.61	0.33	-0.41	3.55
BAC	343	-3.5	2.05	0.24	0.44	2.06	0.24	-0.69	6.55
-5	413	-4.0	0.92	0.53	0.96	1.00	0.50	-1.38	5.43
-10	663	-10.0	1.33	0.40	1.06	1.56	0.34	-1.51	5.70
-15	783	-15.0	2.52	0.17	0.59	2.58	0.17	-1.21	7.45
-20	[illegible]	-20.0	1.97	0.26	0.78	1.95	0.26	-0.30	3.68
-25	1233	-25.1	2.24	0.21	0.77	2.26	0.21	-0.15	2.84
June 1989									
DB	70	10.8	1.64	0.32	0.70	1.70	0.31	-0.97	6.53
BEC	123	6.6	1.69	0.31	0.57	1.70	0.31	-0.92	6.63
MT	182	0.5	1.50	0.35	0.41	1.51	0.35	-0.14	3.86
STEP	248	-0.2	1.70	0.31	0.42	1.70	0.31	-0.69	8.60
NST	283	-3.2	1.49	0.36	0.52	1.52	0.35	-0.61	5.52
BAC	343	-4.0	1.54	0.34	0.58	1.56	0.34	-0.53	4.53
-5	413	-5.0	1.24	0.42	0.64	1.26	0.42	-0.24	4.00
-10	643	-10.0	2.05	0.24	0.60	2.04	0.24	-0.25	4.05
-15	773	-14.7	2.05	0.24	0.63	2.05	0.24	-0.32	3.86
-20	963	-20.1	1.28	0.41	0.66	1.26	0.42	0.27	5.44
-25	1273	-25.0	1.58	0.33	0.51	1.60	0.33	0.01	4.11

(Sheet 2 of 12)

Table B1 (Continued)									
Sample Location	**Distance from Baseline, ft**	**Elev. ft**	**Mean Grain Size, phi**	**Mean Grain Size, mm**	**Sorting phi**	**Median phi**	**Median mm**	**Skewness phi**	**Kurtosis phi**
Profile Survey Line 19 (56th Street)									
June/July 1988									
TS	24	10.0	1.58	0.33	0.51	1.60	0.33	0.01	4.11
MS	35	9.1	1.64	0.32	0.52	1.63	0.32	0.15	4.03
DB	48	7.7	1.58	0.33	0.48	1.59	0.33	0.20	3.70
UB	70	6.8	1.40	0.38	0.54	1.47	0.36	-0.66	5.60
MB	101	6.0	1.35	0.39	0.42	1.37	0.39	-0.13	2.97
BEC	123	6.4	1.44	0.37	0.40	1.48	0.36	-0.20	3.28
MT	154	2.8	1.86	0.28	0.41	1.86	0.28	-0.21	4.48
STEP	230	-2.5	0.11	0.93	1.20	0.20	0.87	-0.31	2.41
-5	393	-5.0	2.49	0.18	0.63	2.54	0.17	-0.65	4.25
-10	535	-10.0	2.20	0.22	0.61	2.16	0.22	-0.17	4.47
-15	689	-15.0	1.46	0.36	0.60	1.52	0.35	-0.53	5.30
-20	963	-20.0	3.33	0.10	0.42	3.36	0.10	-2.43	16.30
-25	1255	-24.8	3.40	0.09	0.42	3.43	0.09	-2.47	15.96
September 1988									
DB	38	9.5	1.66	0.32	0.63	1.69	0.31	-0.70	5.11
MB	140	6.7	1.78	0.29	0.59	1.79	0.29	-0.76	6.15
BEC	157	6.2	1.95	0.26	0.55	1.93	0.26	-0.82	8.62
MT	231	1.1	2.38	0.19	0.38	2.38	0.19	-0.38	7.70
SWASH	272	-0.2	2.22	0.21	0.62	2.25	0.21	-2.54	19.01
STEP	335	-1.7	1.63	0.32	0.66	1.61	0.33	0.13	3.09
-5	404	-5.0	2.31	0.20	0.72	2.40	0.19	-0.75	4.02
-10	506	-10.1	2.40	0.19	0.69	2.35	0.20	-0.02	2.57
-15	687	15.0	2.82	0.14	0.69	3.03	0.12	-0.53	2.48
-20	970	-20.1	3.15	0.11	0.41	3.18	0.11	-3.41	24.19
									(Sheet 3 of 12)

Table B1 (Continued)									
Sample Location	**Distance from Baseline, ft**	**Elev. ft**	**Mean Grain Size, phi**	**Mean Grain Size, mm**	**Sorting phi**	**Median phi**	**Median mm**	**Skewness phi**	**Kurtosis phi**
Profile Survey Line 19 (56th Street) (Cont.)									
January 1989									
DB	176	7.8	1.58	0.33	0.64	1.63	0.32	-0.60	4.93
BEC	202	7.0	1.34	0.40	0.42	1.34	0.40	-0.02	3.54
MT	267	1.0	1.65	0.32	0.40	1.67	0.31	-0.22	4.53
STEP	285	1.5	1.60	0.33	0.39	1.62	0.33	-0.15	3.16
NST	364	-4.0	1.44	0.37	0.80	1.60	0.33	-1.54	6.93
BAC	405	-3.6	1.76	0.30	0.63	1.82	0.28	-0.71	4.44
-5	460	-5.0	1.85	0.28	0.65	1.91	0.27	-1.05	5.55
-10	561	-10.0	2.35	0.20	0.66	2.39	0.19	-1.15	8.69
-15	705	-15.0	2.89	0.13	0.58	3.02	0.12	-1.00	5.47
-20	980	-20.0	3.20	0.11	0.47	3.20	0.11	-1.88	10.54
-25	1296	-25.0	3.42	0.09	0.40	3.43	0.09	-2.38	23.53
April 1989									
DB	50	11.3	1.63	0.32	0.44	1.63	0.32	0.21	3.82
BEC	127	6.6	1.53	0.35	0.53	1.55	0.34	-0.08	3.88
MT	190	1.4	1.60	0.33	0.39	1.64	0.32	-0.25	3.30
STEP	210	-0.5	1.37	0.39	0.37	1.39	0.38	-0.04	2.79
NST	244	-3.5	1.33	0.40	0.72	1.37	0.39	-0.28	3.55
BAC	315	-1.4	0.46	0.73	1.56	0.38	0.77	0.33	2.96
-5	505	-5.2	2.43	0.19	0.94	2.65	0.16	-0.27	1.92
-10	615	-10.0	1.90	0.27	0.73	1.92	0.26	-0.45	4.01
-15	750	-15.0	1.08	0.47	0.72	1.07	0.48	-0.58	4.86
-20	990	-20.0	1.85	0.28	0.59	1.87	0.27	-0.25	3.47
25	1245	-25.0	2.15	0.23	1.79	2.80	0.14	-1.75	4.36
									(Sheet 4 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 544 (63rd Street)									
September 1988									
DB	40	9.2	1.83	0.28	0.73	1.88	0.27	-0.72	4.28
BEC	137	6.9	2.01	0.25	0.56	2.01	0.25	-0.44	4.77
MT	192	1.6	2.31	0.20	0.38	2.29	0.20	0.43	3.01
SWASH	230	0.0	0.87	0.55	0.98	0.86	0.55	-0.31	3.91
STEP	289	-2.2	1.17	0.44	1.37	1.56	0.34	-0.69	2.63
-5	352	-5.1	2.32	0.20	0.79	2.39	0.19	-2.14	12.96
-10	444	-10.0	2.22	0.21	0.61	2.27	0.21	-0.28	3.19
-15	592	15.1	1.45	0.37	0.89	1.42	0.37	-0.47	6.61
-20	915	-20.1	2.05	0.24	0.64	2.05	0.24	-0.23	4.83
Profile Survey Line 21 (66th Street)									
June/July 1988									
TS	-45	12.7	1.80	0.29	0.49	1.78	0.29	0.14	4.94
MS	-32	9.6	1.30	0.41	0.64	1.33	0.40	-0.46	4.41
DB	-21	6.7	1.15	0.45	0.90	1.30	0.41	-1.56	6.49
UB	8	5.8	1.56	0.34	0.43	1.59	0.33	-0.38	5.03
MB	5	5.6	1.40	0.38	0.59	1.48	0.36	-0.42	3.51
BEC	50	5.9	1.55	0.34	0.44	1.58	0.33	-0.14	3.20
MT	88	2.4	2.01	0.25	0.40	1.97	0.26	0.40	3.47
STEP	150	1.0	0.37	0.77	1.38	0.67	0.63	-0.38	2.12
-5	278	5.0	2.49	0.18	0.68	2.59	0.17	-0.78	3.80
10	381	10.0	2.20	0.22	0.86	2.22	0.21	-1.90	11.10
15	557	15.0	1.06	0.48	0.51	1.05	0.48	-0.30	3.82
23	1398	23.0	3.30	0.10	0.48	3.32	0.10	-2.53	19.41
September 1988									
DB	5	10.4	1.33	0.40	0.78	1.40	0.38	-1.10	6.36
BEC	97	6.0	1.53	0.35	0.80	1.58	0.33	0.98	6.24
MT	122	3.4	2.35	0.20	0.36	2.35	0.20	0.10	3.73
SWASH	195	0.1	1.66	0.32	0.95	1.75	0.30	0.76	3.90
STEP	258	2.5	1.16	0.45	1.59	1.67	0.31	-0.71	2.36
-5	305	4.9	2.09	0.23	0.87	2.27	0.21	-1.35	5.82
10	398	10.1	2.85	0.14	0.51	2.92	0.13	-0.60	4.00
-15	549	15.2	2.56	0.17	0.91	2.87	0.14	-0.79	3.11
20	815	20.3	3.30	0.10	0.38	3.25	0.11	-4.35	59.23
25	1735	25.1	3.21	0.11	0.55	3.22	0.11	2.62	20.24

(Sheet 5 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 21 (66th Street)									
January 1989									
DB	47	9.0	1.36	0.39	0.71	1.40	0.38	-0.95	5.91
BEC	70	7.9	1.48	0.36	0.71	1.53	0.35	-0.62	4.50
MT	194	0.0	1.68	0.31	0.44	1.65	0.32	0.75	4.69
STEP	199	-2.0	1.60	0.33	0.38	1.62	0.33	-0.31	3.70
NST	223	-2.4	1.33	0.40	0.58	1.39	0.38	-0.54	3.36
BAC	249	-2.3	1.33	0.40	0.76	1.47	0.36	-0.86	4.21
-5	376	-5.0	1.27	0.41	0.83	1.40	0.38	-0.72	3.50
-10	474	-10.0	2.36	0.19	0.57	2.38	0.19	-0.63	5.72
-15	579	-15.0	2.93	0.13	0.55	3.02	0.12	-1.25	7.25
-20	834	-20.0	1.45	0.37	0.73	1.44	0.37	0.10	5.12
-25	1770	-25.0	3.22	0.11	0.61	3.30	0.10	-2.12	11.21
April 1989									
DB	40	7.6	1.29	0.41	0.49	1.27	0.41	-0.31	4.51
BEC	59	6.7	1.33	0.40	0.48	1.36	0.39	-0.37	4.50
MT	144	0.0	1.52	0.35	0.37	1.54	0.34	0.03	3.02
STEP	174	-2.7	1.26	0.42	0.51	1.30	0.41	-0.37	3.11
NST	234	-3.8	0.71	0.61	0.79	0.64	0.64	0.44	4.17
BAC	284	-2.5	1.10	0.47	0.85	1.16	0.45	-1.35	6.44
-5	414	-5.0	1.44	0.37	1.13	1.67	0.31	-1.74	6.39
-10	524	-10.0	1.44	0.37	0.84	1.46	0.36	-0.51	4.32
-15	638	-15.0	2.95	0.13	0.53	3.02	0.12	-1.35	7.83
-20	899	-20.0	3.27	0.10	0.31	3.21	0.11	0.36	4.76
-25	1794	-25.0	3.16	0.11	0.57	3.21	0.11	0.57	10.07
Profile Survey Line 552 (78th Street)									
September 1988									
DB	0	10.9	0.45	0.73	1.15	0.69	0.62	-0.38	2.54
BEC	174	6.3	1.88	0.27	0.58	1.89	0.27	0.04	2.97
MT	227	2.8	1.84	0.28	0.51	1.86	0.28	-0.31	3.46
SWASH	296	0.0	0.82	0.57	0.97	0.88	0.54	-0.40	2.95
STEP	320	-1.5	0.86	0.55	1.27	0.98	0.51	-0.29	2.03
-5	350	-5.1	2.55	0.17	0.57	2.58	0.17	-2.08	14.07
-10	418	-10.0	1.68	0.31	1.00	1.84	0.28	-0.51	2.88
-15	486	-15.0	1.42	0.37	1.14	1.58	0.33	-1.04	4.36
-20	674	-20.1	2.54	0.17	0.87	2.22	0.21	0.46	2.16
									(Sheet 6 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 24 (81st Street)									
June/July 1988									
TS	-45	12.4	1.67	0.31	0.50	1.67	0.31	0.07	3.71
MS	-10	7.2	1.46	0.36	0.65	1.52	0.35	-0.44	4.23
DB	12	5.5	1.50	0.35	0.84	1.61	0.33	-2.31	11.36
UB	19	5.2	1.77	0.29	0.38	1.74	0.30	0.34	3.76
MB	28	4.8	1.85	0.28	0.42	1.82	0.28	0.34	3.61
BEC	37	4.5	1.79	0.29	0.46	1.76	0.30	0.38	3.40
MT	66	2.4	2.02	0.25	0.42	1.97	0.26	0.40	3.34
STEP	138	-1.4	1.13	0.46	0.90	1.13	0.46	-1.13	6.15
-5	231	-5.0	2.16	0.22	0.68	2.21	0.22	-0.59	3.79
-10	329	-10.0	2.28	0.21	0.66	2.27	0.21	0.07	2.65
-15	492	-15.0	2.73	0.15	0.67	2.85	0.14	-1.06	5.37
-20	693	-20.0	1.61	0.33	0.56	1.58	0.33	0.82	5.95
-24	945	-23.0	1.74	0.30	0.39	1.78	0.29	-0.10	7.64
September 1988									
DB	0	9.5	1.27	0.41	0.84	1.34	0.40	-0.73	4.60
MB	154	6.6	1.23	0.43	1.01	1.31	0.40	-0.96	4.81
BEC	199	4.9	1.52	0.35	0.54	1.53	0.35	0.08	2.98
MT	230	2.2	1.87	0.27	0.48	1.88	0.27	-0.13	3.42
SWASH	255	0.0	1.50	0.35	0.63	1.56	0.34	-0.20	2.89
STEP	294	-2.8	0.30	0.81	1.76	0.22	0.86	-0.02	1.42
-5	337	-5.0	2.19	0.22	0.82	2.35	0.20	-2.94	14.71
-10	410	10.0	2.18	0.22	0.66	2.28	0.21	-0.79	5.66
-15	495	-15.0	1.70	0.31	0.68	1.60	0.33	0.04	5.72
-20	690	-20.0	2.19	0.22	0.68	2.12	0.23	0.18	2.15
-25	1590	-25.0	1.62	0.33	0.45	1.69	0.31	-0.93	7.70
									(Sheet 7 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 24 (81st Street) (Cont.)									
January 1989									
DB	25	8.7	1.34	0.40	0.74	1.45	0.37	0.73	4.31
BEC	111	8.4	1.56	0.34	0.73	1.60	0.33	0.62	4.68
MT	218	0.0	1.83	0.28	0.47	1.80	0.29	0.25	3.92
STEP	238	-1.6	1.71	0.31	0.45	1.69	0.31	0.27	3.32
NST	278	-3.0	1.67	0.31	0.62	1.65	0.32	0.14	2.01
BAC	303	-4.0	1.08	0.47	1.09	1.12	0.46	0.49	2.91
-5	325	-5.1	0.93	0.52	1.19	1.10	0.47	-0.89	3.51
-10	418	-10.1	2.30	0.20	0.63	2.35	0.20	0.30	3.36
-15	515	-15.1	2.11	0.23	0.68	2.02	0.25	0.22	2.40
-20	723	-20.0	1.46	0.36	0.58	1.47	0.36	0.72	4.97
-25	2073	-25.0	2.23	0.21	0.59	2.25	0.21	0.74	7.75
April 1989									
DB	31	9.1	1.54	0.34	0.56	1.53	0.35	0.21	3.65
BEC	80	5.6	1.42	0.37	0.55	1.43	0.37	0.06	3.72
MT	123	0.7	1.10	0.47	0.61	1.03	0.49	0.03	3.53
STEP	163	-2.3	0.43	0.74	0.78	0.45	0.73	-0.57	4.00
NST	204	-3.7	1.10	0.47	0.79	1.08	0.47	-0.56	4.32
BAC	243	-2.3	1.35	0.39	0.60	1.37	0.39	-0.47	4.60
-5	340	-5.2	1.64	0.32	0.77	1.67	0.31	0.57	4.46
10	443	-10.1	2.16	0.22	0.61	2.22	0.21	0.41	3.50
-15	595	-15.0	1.86	0.28	0.65	1.86	0.28	0.00	3.05
-20	793	-20.0	0.33	0.80	0.99	0.23	0.85	0.04	2.71
-25	1753	-25.1	2.45	0.18	0.75	2.48	0.18	1.16	6.47
June 1989									
DB	35	8.2	1.30	0.41	0.69	1.38	0.38	-0.86	5.10
BEC	76	5.6	1.41	0.38	0.52	1.44	0.37	-0.09	3.23
MT	143	0.6	1.79	0.29	0.45	1.78	0.29	0.62	5.30
STEP	203	-2.4	0.63	0.65	0.44	1.77	0.29	0.12	3.62
NST	234	-3.0	0.63	0.65	1.33	0.66	0.63	-0.15	1.90
BAC	253	-4.5	0.62	0.65	1.55	0.80	0.57	-0.30	1.83
-5	278	-5.1	0.67	0.63	1.49	0.72	0.61	-0.20	1.88
-10	428	-10.1	2.28	0.21	0.56	2.30	0.20	-0.38	4.23
15	573	-15.1	2.23	0.21	0.65	2.30	0.20	-1.14	7.08
-20	773	-20.1	1.38	0.38	0.59	1.40	0.38	0.22	4.45
25	2153	-25.1	2.49	0.18	0.65	2.48	0.18	-1.52	10.54

(Sheet 8 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 26 (92nd Street)									
June/July 1988									
TS	0	12.7	1.57	0.34	0.62	1.61	0.33	-0.89	6.74
MS	15	9.7	1.00	0.50	0.84	1.11	0.46	-0.98	4.43
DB	33	7.1	1.49	0.36	0.71	1.56	0.34	-1.08	7.40
UB	55	5.1	2.02	0.25	0.41	1.99	0.25	-0.24	5.86
MB	72	3.8	2.11	0.23	0.55	2.13	0.23	-0.72	5.41
LB	95	2.8	2.07	0.24	0.39	1.98	0.25	0.85	3.78
LBC	106	2.7	1.83	0.28	0.42	1.74	0.30	0.99	4.35
BEC	112	2.6	1.28	0.41	0.55	1.17	0.44	0.55	4.14
MT	142	1.3	0.97	0.51	0.82	0.88	0.54	0.22	2.78
STEP	171	-0.2	0.35	1.27	1.65	-0.79	1.73	0.66	2.13
-5	293	5.0	2.20	0.22	0.86	2.32	0.20	-1.22	5.80
-10	391	-10.0	2.56	0.17	0.65	2.68	0.16	-0.69	3.43
-15	542	-15.0	2.75	0.15	1.30	3.06	0.12	-3.00	11.30
-20	870	-20.0	2.99	0.13	0.60	3.09	0.12	-1.10	4.56
-25	1195	-25.0	3.09	0.12	0.70	3.26	0.10	-1.38	4.37
September 1988									
DB	79	9.3	1.35	0.39	0.84	1.46	0.36	1.13	5.92
MB	141	6.9	1.82	0.28	0.69	1.88	0.27	-1.17	7.24
BEC	200	5.4	1.14	0.45	0.93	1.17	0.44	-0.69	4.02
STEP	302	1.8	0.92	0.53	1.42	1.16	0.45	-0.45	2.03
5	360	5.0	1.73	0.30	1.06	2.01	0.25	-1.19	4.20
10	424	-10.0	2.33	0.20	0.61	2.41	0.19	-1.45	8.68
-15	549	-15.0	3.49	0.09	0.59	3.57	0.08	-1.83	12.57
-20	895	-20.0	3.47	0.09	0.57	3.53	0.09	-1.19	7.28
-25	1290	-25.1	1.69	0.31	1.06	1.64	0.32	0.12	3.10
									(Sheet 9 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 26 (92nd Street)									
January 1989									
DB	24	9.2	1.60	0.33	0.64	1.62	0.33	-0.26	5.49
BEC	151	7.4	1.37	0.39	0.55	1.31	0.40	0.62	3.36
MT	256	1.3	1.62	0.33	0.47	1.61	0.33	0.19	3.46
STEP	286	-1.5	1.44	0.37	0.60	1.45	0.37	0.06	2.61
NST	297	-2.5	1.42	0.37	0.74	1.46	0.36	-0.31	3.11
BAC	351	-3.7	2.04	0.24	0.87	2.27	0.21	-1.34	5.57
-5	380	-5.0	0.63	0.65	1.01	0.65	0.64	-0.25	3.32
-10	458	-10.0	2.57	0.17	0.68	2.63	0.16	2.46	16.79
-15	575	-15.0	3.07	0.12	0.56	3.12	0.12	2.01	12.84
-20	906	-20.0	2.84	0.14	0.81	3.07	0.12	1.04	3.80
-25	1216	-25.0	1.26	0.42	1.57	1.15	0.45	-0.33	2.76
April 1989									
DB	58	9.8	1.30	0.41	0.66	1.36	0.39	-0.22	2.90
BEC	71	7.5	1.37	0.39	0.53	1.39	0.38	-0.41	5.08
MT	181	0.4	1.53	0.35	0.43	1.53	0.35	0.30	2.91
STEP	251	-1.2	1.57	0.34	0.38	1.55	0.34	0.45	3.23
NST	331	-2.7	1.35	0.39	0.54	1.40	0.38	-0.58	4.62
BAC	361	-3.6	1.31	0.40	0.74	1.35	0.39	-0.98	6.25
-5	386	-5.0	2.11	0.23	1.01	2.05	0.24	-0.15	2.01
10	476	-10.0	2.98	0.13	0.45	3.00	0.13	1.02	8.73
-15	596	-15.0	3.01	0.12	0.56	3.04	0.12	1.54	11.83
-20	906	-20.1	2.68	0.16	0.84	2.95	0.13	-0.52	2.28
-25	1201	-25.2	3.17	0.11	0.58	3.19	0.11	2.38	12.50
June 1989									
DB	48	9.3	1.70	0.31	0.76	1.72	0.30	-0.57	6.59
BEC	149	6.4	1.17	0.44	0.70	1.18	0.44	-0.23	3.28
MT	211	1.0	1.51	0.35	0.44	1.54	0.34	-0.13	4.37
STEP	257	-2.3	1.67	0.31	0.55	1.72	0.30	-2.21	13.83
NST	296	-2.8	1.27	0.41	1.02	1.44	0.37	-0.50	2.66
BAC	316	3.9	1.30	0.41	0.86	1.39	0.38	-0.49	3.03
-5	331	-5.0	2.64	0.16	0.64	2.71	0.15	-1.14	7.16
-10	466	-10.0	1.16	0.45	0.82	1.20	0.44	-0.84	5.01
-15	606	-15.0	3.06	0.12	0.50	3.09	0.12	-2.15	17.62
-20	906	-20.0	2.99	0.13	0.71	3.16	0.11	-3.52	8.33
-25	1221	-25.0	2.86	0.14	1.00	3.15	0.11	-1.75	6.79
									(Sheet 10 of 12)

Table B1 (Continued)									
Sample Location	Distance from Baseline, ft	Elev. ft	Mean Grain Size, phi	Mean Grain Size, mm	Sorting phi	Median phi	Median mm	Skewness phi	Kurtosis phi
Profile Survey Line 28 (103rd Street)									
June/July 1988									
TS	-30	12.8	1.46	0.36	0.60	1.52	0.35	-0.53	5.30
DB	20	6.1	1.22	0.43	1.09	1.52	0.35	-1.65	5.65
MB	23	6.0	1.73	0.30	0.58	1.73	0.30	-0.07	3.84
MB2	30	5.2	1.95	0.26	0.42	1.92	0.26	-0.04	5.33
MB3	40	4.8	1.41	0.38	0.45	1.39	0.38	0.47	3.09
LMBC	50	4.7	1.72	0.30	0.42	1.70	0.31	0.22	3.43
LB	60	4.5	1.82	0.28	0.40	1.80	0.29	0.37	3.61
BEC	78	4.2	1.82	0.28	0.51	1.77	0.29	0.37	3.21
MT	110	2.2	1.55	0.34	0.69	1.57	0.34	0.21	2.40
MFS	120	1.2	0.91	0.53	0.88	0.82	0.57	0.08	3.40
SWASH	172	-0.8	0.65	0.64	0.98	0.78	0.58	-0.71	3.83
STEP	205	-2.5	0.74	0.60	1.49	0.98	0.51	-0.45	2.18
-5	260	-5.0	2.49	0.18	0.52	2.51	0.18	-0.77	6.57
-10	376	-10.0	2.23	0.21	0.59	2.24	0.21	-0.33	3.89
-15	579	-15.0	2.26	0.21	0.66	2.29	0.20	-0.60	4.55
-20	767	-20.0	2.93	0.13	0.51	2.98	0.13	-1.13	6.94
-25	930	-24.7	1.80	0.29	0.62	1.84	0.28	-0.31	3.54
October 1988									
DB	0	9.0	0.78	0.58	0.97	0.86	0.55	-0.79	3.86
MB	149	7.4	1.48	0.36	0.60	1.55	0.34	-0.23	2.74
BEC	177	5.3	1.76	0.30	0.57	1.82	0.28	-0.58	3.76
SWASH	212	0.0	0.99	0.50	0.90	0.95	0.52	-0.16	2.39
STEP	233	-1.5	1.55	0.34	0.91	1.80	0.29	-1.04	3.65
-5	303	-5.0	2.25	0.21	0.67	2.27	0.21	-0.68	5.60
-10	372	-9.6	2.36	0.19	0.58	2.35	0.20	-0.09	3.25
-15	553	-15.0	2.14	0.23	0.70	2.09	0.23	0.06	3.28
-20	755	-20.0	2.45	0.18	0.67	2.47	0.18	-0.34	3.45
									(Sheet 11 of 12)

Table B1 (Concluded)									
Sample Location	**Distance from Baseline, ft**	**Elev. ft**	**Mean Grain Size, phi**	**Mean Grain Size, mm**	**Sorting phi**	**Median phi**	**Median mm**	**Skewness phi**	**Kurtosis phi**
Profile Survey Line 28 (103rd Street)									
January 1989									
DB	2	8.4	1.23	0.43	0.88	1.39	0.38	-1.54	6.80
BEC	117	8.3	1.50	0.35	0.74	1.57	0.34	-0.24	2.82
MT	218	-0.2	1.80	0.29	0.69	1.85	0.28	-1.42	7.82
STEP	238	-2.3	1.22	0.43	0.70	1.16	0.45	0.01	2.46
NST	253	-3.0	0.61	0.66	1.28	0.70	0.62	-0.43	2.50
BAC	273	-3.6	2.03	0.24	0.83	2.26	0.21	-1.26	4.71
-5	308	-5.0	1.90	0.27	1.17	2.28	0.21	-1.47	4.95
-10	414	-10.0	2.32	0.20	0.77	2.43	0.19	-1.02	4.84
-15	548	-15.0	2.46	0.18	0.72	2.52	0.17	-0.69	3.98
-20	753	-20.0	2.87	0.14	0.61	2.87	0.14	-1.89	14.54
-25	1238	-25.0	2.82	0.14	0.90	3.06	0.12	-2.56	11.12
April 1989									
DB	2	9.2	1.40	0.38	0.54	1.40	0.38	0.03	4.25
BEC	48	8.9	0.79	0.58	0.92	0.80	0.57	-0.52	3.96
MT	208	1.5	1.33	0.40	0.84	1.44	0.37	-1.69	8.37
STEP	248	-1.6	1.69	0.31	0.43	1.70	0.31	0.03	3.21
NST	258	-2.7	-0.23	1.17	1.12	-0.14	1.10	0.00	2.53
BAC	298	-4.0	0.24	0.85	1.00	0.26	0.84	0.34	3.02
-5	316	-5.0	1.37	0.39	1.53	1.44	0.37	0.36	2.24
-10	428	-10.0	2.51	0.18	0.91	2.69	0.15	-1.25	4.61
-15	618	-15.0	2.22	0.21	0.74	2.26	0.21	-0.46	4.04
-20	792	-20.0	2.71	0.15	0.77	2.84	0.14	-1.29	5.36
-25	1258	-25.0	3.22	0.11	0.49	3.20	0.11	-2.20	20.44
June 1989									
DB	23	8.5	1.23	0.43	0.91	1.36	0.39	-1.05	5.14
BEC	173	6.1	1.16	0.45	1.07	1.35	0.39	-1.16	4.56
MT	213	0.1	0.91	0.53	0.71	0.87	0.55	0.06	2.88
STEP	228	-2.3	1.58	0.33	0.56	1.64	0.32	-0.48	3.89
NST	248	-3.0	0.54	0.69	1.65	0.96	0.51	-0.39	1.68
BAC	263	-3.4	2.42	0.19	0.63	2.52	0.17	-3.97	25.93
-5	288	-5.5	2.48	0.18	0.55	2.55	0.17	-1.61	9.30
-10	398	-10.1	2.00	0.25	0.58	1.96	0.26	-0.01	3.71
-15	613	-15.4	2.15	0.23	0.62	2.17	0.22	-0.37	3.48
-20	848	-20.4	1.74	0.30	0.73	1.81	0.29	-0.30	2.75
-25	1263	-25.2	2.77	0.15	1.35	3.11	0.12	-2.26	7.64
									(Sheet 12 of 12)

Table B2
Sediment Sample Grain Size of Composites

Date	Foreshore Grain Size, phi	Foreshore Grain Size, mm	Offshore Grain Size, phi	Offshore Grain Size, mm	Profile Grain Size, phi	Profile Grain Size, mm
Profile Survey Line 14 (37th Street)						
7-88	1.44	0.37	2.22	0.21	1.68	0.31
9-88	2.02	0.25	1.85	0.28	1.89	0.27
1-89	1.77	0.29	1.94	0.26	1.85	0.28
4-89	1.46	0.36	1.77	0.29	1.67	0.31
6-89	1.65	0.32	1.86	0.28	1.72	0.30
Profile Survey Line 19 (56th Street)						
6-88	1.14	0.45	2.57	0.17	1.83	0.28
9-88	2.03	0.24	2.66	0.16	2.21	0.22
1-89	1.53	0.35	2.71	0.15	2.09	0.23
4-89	1.50	0.35	1.88	0.27	1.58	0.33
Profile Survey Line 21 (66th Street)						
7-88	1.27	0.41	2.25	0.21	1.68	0.31
9-88	1.60	0.33	2.82	0.14	2.14	0.23
1-89	1.47	0.36	2.32	0.20	1.81	0.29
4-89	1.37	0.39	2.42	0.19	1.81	0.29
Profile Survey Line 24 (81st Street)						
7-88	1.65	0.32	2.08	0.24	1.85	0.28
9-88	1.19	0.44	1.98	0.25	1.53	0.35
1-89	1.70	0.31	2.05	0.24	1.68	0.31
4-89	0.97	0.51	1.63	0.32	1.36	0.39
6-89	1.65	0.32	2.10	0.23	1.51	0.35
Profile Survey Line 26 (92nd Street)						
6-88	0.60	0.66	2.61	0.16	1.83	0.28
9-88	1.32	0.40	2.50	0.18	1.97	0.26
1-89	1.48	0.36	2.10	0.23	1.83	0.28
4-89	1.49	0.36	2.78	0.15	2.02	0.25
6-89	1.46	0.36	2.55	0.17	1.94	0.26
Profile Survey Line 28 (103rd Street)						
7-88	1.10	0.47	2.33	0.20	1.65	0.32
9-88	1.41	0.38	2.30	0.20	1.70	0.31
1-89	1.50	0.35	2.47	0.18	1.86	0.28
4-89	1.28	0.41	2.38	0.19	1.67	0.31
6-89	1.19	0.44	2.22	0.21	1.67	0.31

Appendix C
Wave and Tide Data

Appendix C contains Table C1, which lists the combined percent occurrence of wave height and period by direction recorded by the north and south directional wave gauges in operation from April 1990 to January 1992 of the project monitoring. Before April 1990, a non-directional gauge was in operation at both sites. Plates C1 through C4 provide a time series presentation of the wave height and period recorded on the northern non-directional wave gauge over the period of August 1988 to March 1990, and the wave height, period, and direction of wave approach recorded on the replacement directional wave gauge over the period April 1990 to January 1992. Plates C5 through C8 provide a time series presentation of the wave height and direction recorded on the southern non-directional wave gauge over the period August 1988 to March 1990, and wave height, period, and direction of wave approach recorded on the replacement directional gauge over the period April 1990 to January 1992. Plate C9 is a histogram of the percentage exceedance of the wave height over the entire study period from August 1988 to January 1992 from both gauges. Plate C10 is a seasonal cumulative frequency curve of wave height percentage exceedance over the period of 1988 to 1992 of the fall/winter (October to February), spring (March to May), and summer (June to September). Plates 11 through 43 provide a record of spectrally based significant wave height and peak spectral period over the period that the directional wave gauges were in operation (August 1988 to May 1990). Plates C44 through C47 provide a 3-day average of the wave data to represent the typical duration of both tropical and extratropical storms. Plates C48 through C51 are running averages of the directional wave data. Theses plates emphasize periods when the wave climate was being affected by storms. Predicted and observed NOS tide data from the Ocean City tide gauge are displayed in plates C52 through C69 over the period that they were operating during the study period. Plates C70 through C75 are monthly results of significant wave height, peak period, and peak direction when data were available over the period April 1990 to December 1990.

Table C1
Ocean City, Maryland North (38.40 N 75.04 W) - South (38.34 N 75.06 W) Percent Occurrence (x1000) of Height and Period by Direction, April 1990-January 1992

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 0.0											
0.0-0.4			30								30
0.5-0.9											0
1.0-1.4											0
1.5-1.9											0
2.0-2.4											0
2.5-2.9											0
3.0-3.4											0
3.5-3.9											0
4.0-4.4											0
4.5-4.9											0
5.0+											0
TOTAL	**0**	**0**	**30**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**30**
Mean HmO(m) 0.3; Largest HmO(m) 0.3; Mean TP(sec) - 7.8; NO OF CASES 1.											
Azimuth (deg) 22.5											
0.0-0.4	120	60	30	30		60	60				360
0.5-0.9	120		30	30							180
1.0-1.4											0
1.5-1.9											0
2.0-2.4											0
2.5-2.9											0
3.0-3.4											0
3.5-3.9											0
4.0-4.4											0
4.5-4.9											0
5.0+											0
TOTAL	**240**	**60**	**60**	**60**	**0**	**60**	**60**	**0**	**0**	**0**	**540**
Mean HmO(m) 0.5; Largest HmO(m) 0.8; Mean TP(sec) 7.0; NO. OF CASES = 18.											

(Sheet 1 of 8)

Table C1 (Continued)

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg = 45.0											
0.0-0.4	300	30	-	90	30	30	150	-	-	-	630
0.5-0.9	480	450	60	30	90	30	-	-	-	-	1140
1.0-1.4	30	60	30	30	30	-		-	-	-	180
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**810**	**540**	**90**	**150**	**150**	**60**	**150**	**0**	**0**	**0**	**1950**
Mean HmO(m) = 0.6; Largest HmO(m) = 1.4; Mean TP(sec) = 6.4; NO. OF CASES = 65.											
Azimuth (deg) = 67.5											
0.0-0.4	60	120	120	631	90	180	120	-	-	-	1321
0.5-0.9	631	1081	871	661	210	150	60	60	-	-	3724
1.0-1.4	30	270	480	180	30	-	-	-	-	-	990
1.5-1.9	-	60	240	-	-	-	-	-	-	-	300
2.0-2.4	-	-	30	-	-	-	-	-	-	-	30
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**721**	**1531**	**1741**	**1472**	**330**	**330**	**180**	**60**	**0**	**0**	**6365**
Mean HmO(m) = 0.8; Largest HmO(m) = 2.1; Mean TP(sec) = 7.4; NO. OF CASES = 212											

(Sheet 2 of 8)

Table C1 (Continued)

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 90.0											
0.0-0.4	210	150	480	3635	901	661	510	150	90	-	6787
0.5-0.9	420	1322	3125	6099	1893	1592	1141	150	60	-	15802
1.0-1.4	-	450	1412	1953	540	180	90	60	-	-	4685
1.5-1.9	-	30	631	420	-	90	30	-	-	-	1201
2.0-2.4	-	-	150	270	-	-	-	-	-	-	420
2.5-2.9	-	-	-	30	-	-	-	-	-	-	30
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-		-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**630**	**1952**	**5798**	**12407**	**3334**	**2523**	**1771**	**360**	**150**	**0**	**28925**
Mean HmO(m) = 0.8; Largest HmO(m) = 2.5; Mean TP(sec) = 9.3; NO. OF CASES = 963.											
Azimuth (deg) = 112.5											
0.0-0.4	90	90	811	6370	871	901	961	120	-	-	10214
0.5-0.9	270	811	2824	9555	2554	1111	1081	420	210	-	18836
1.0-1.4	-	210	661	1322	390	120	90	-	-	-	2793
1.5-1.9	-	30	180	240	90	-	30	-	-	-	570
2.0-2.4	-	-	30	90	-	-	-	-	-	-	120
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**360**	**1141**	**4506**	**17577**	**3905**	**2132**	**2162**	**540**	**210**	**0**	**32533**
Mean HmO(m) = 0.7; Largest HmO(m) = 2.4; Mean TP(sec) = 9.6; NO. OF CASES = 1083											

(Sheet 3 of 8)

Table C1 (Continued)

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 135.0											
0.0-0.4	150	150	2493	3395	240	60	90	60	-	-	6638
0.5-0.9	360	841	4116	3816	300	180	150	150	-	-	9913
1.0-1.4	-	60	570	1201	30	-	-	-	-	-	1861
1.5-1.9	-	-	120	60	30	-	-	-	-	-	210
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-		-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**510**	**1051**	**7299**	**8472**	**600**	**240**	**240**	**210**	**0**	**0**	**18622**
Mean HmO(m) = 0.6; Largest HmO(m) = 1.8; Mean TP(sec) = 8.1; NO. OF CASES = 620.											
Azimuth (deg) = 157.5											
0.0-0.4	90	240	1201	240	30	-	60	-	-	-	1861
0.5-0.9	631	1562	3004	240	-	30	-	30	-	-	5497
1.0-1.4	-	90	540	90	-	-	-	-	-	-	720
1.5-1.9	-	-	90	60	-	-	-	-	-	-	150
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**721**	**1892**	**4835**	**630**	**30**	**30**	**60**	**30**	**0**	**0**	**8228**
Mean HmO(m) = 0.7; Largest HmO(m) = 1.9; Mean TP(sec) = 6.3; NO. OF CASES = 274											

(Sheet 4 of 8)

Table C1 (Continued)

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3 +	
Azimuth (deg) = 180.0											
0.0-0.4	150	330	240	90	-	30	-	-	-	-	840
0.5-0.9	480	871	480	30	-	-	-	-	-	-	1861
1.0-1.4	30	-	-	-	-	-	-	-	-	-	30
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	30	-	-	-	-	-	-	-	30
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0 +	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**660**	**1201**	**750**	**120**	**0**	**30**	**0**	**0**	**0**	**0**	**2761**
Mean Hm0(m) = 0.6; Largest Hm0(m) = 2.2; Mean TP(sec) = 5.4; NO. OF CASES = 92											
Azimuth (deg) = 202.5											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0 +	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0											

(Sheet 5 of 8)

Table C1 (Continued)

H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 225.0											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0.											
Azimuth (deg) = 247.5											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0											

(Sheet 6 of 8)

Table C1 (Continued)

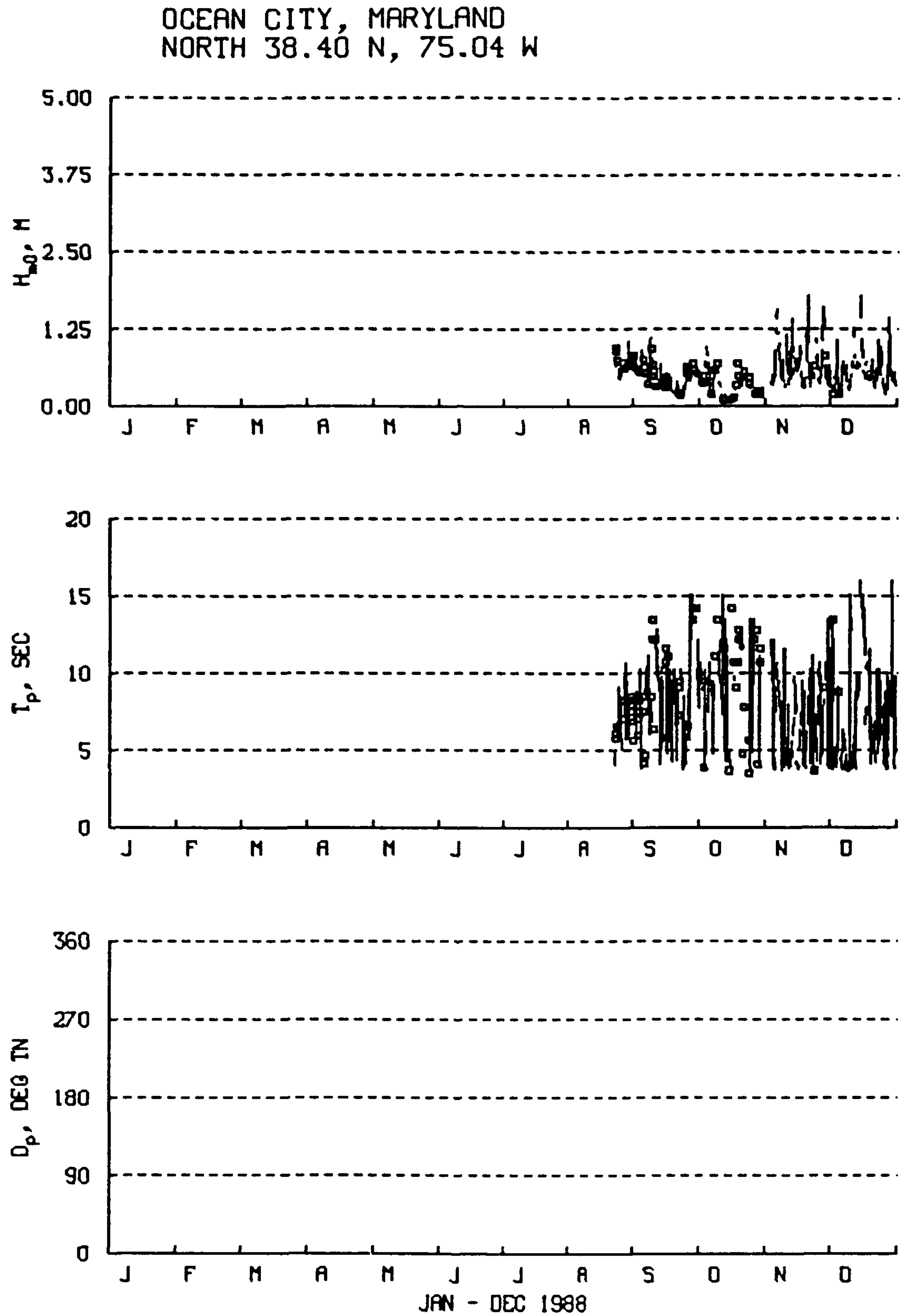
H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 270.0											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	0	-	-	-	-	-	-	-	-	-	0
TOTAL	-	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0.											
Azimuth (deg) = 292.5											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0											

(Sheet 7 of 8)

Table C1 (Concluded)

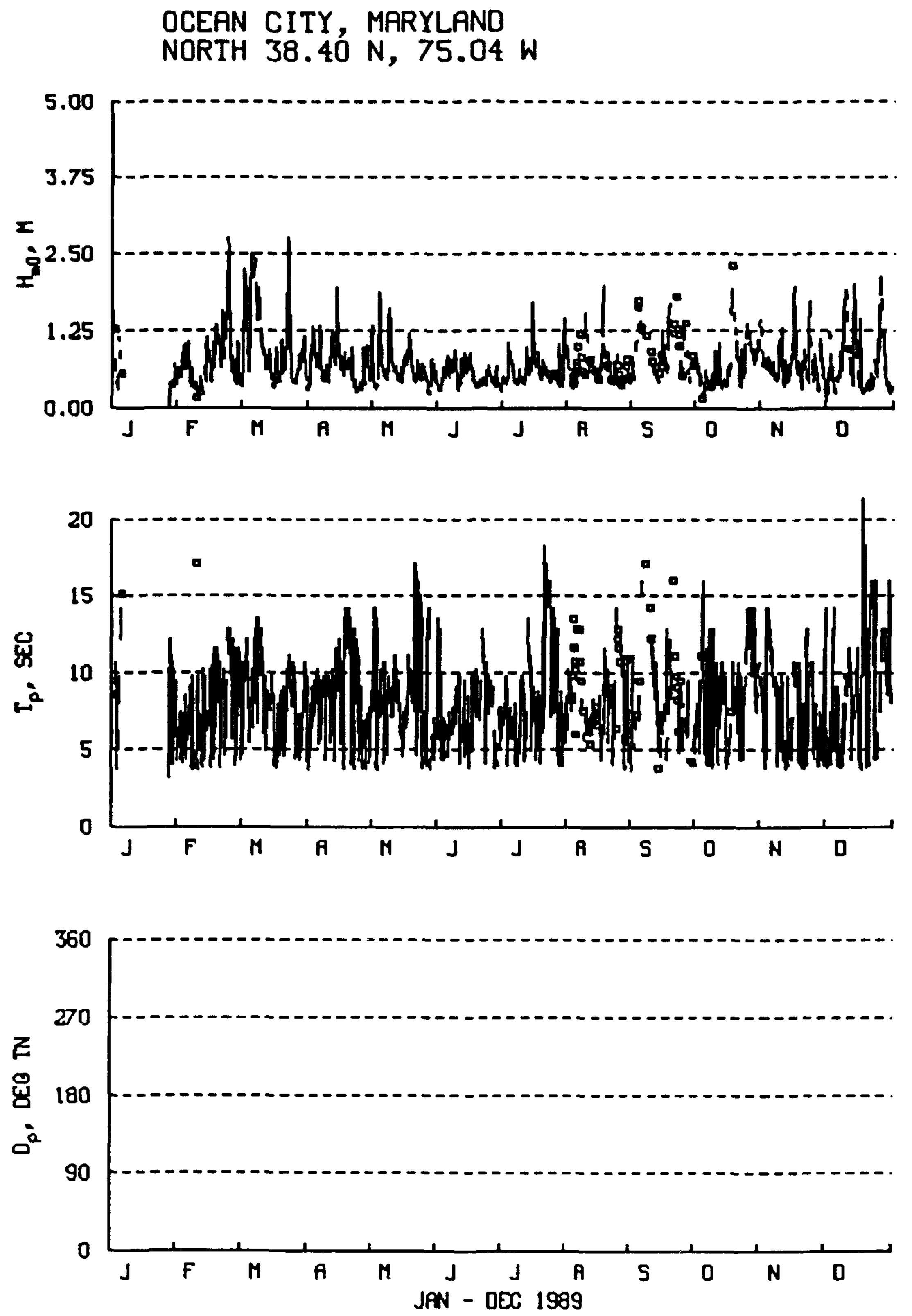
H(m)	Peak Period (sec)										Total
	-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3+	
Azimuth (deg) = 315.0											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-		-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0.											
Azimuth (deg) = 337.5											
0.0-0.4	-	-	-	-	-	-	-	-	-	-	0
0.5-0.9	-	-	-	-	-	-	-	-	-	-	0
1.0-1.4	-	-	-	-	-	-	-	-	-	-	0
1.5-1.9	-	-	-	-	-	-	-	-	-	-	0
2.0-2.4	-	-	-	-	-	-	-	-	-	-	0
2.5-2.9	-	-	-	-	-	-	-	-	-	-	0
3.0-3.4	-	-	-	-	-	-	-	-	-	-	0
3.5-3.9	-	-	-	-	-	-	-	-	-	-	0
4.0-4.4	-	-	-	-	-	-	-	-	-	-	0
4.5-4.9	-	-	-	-	-	-	-	-	-	-	0
5.0+	-	-	-	-	-	-	-	-	-	-	0
TOTAL		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mean Hm0(m) = 0.0; Largest Hm0(m) = 0.0; Mean TP(sec) = 0.0; NO. OF CASES = 0											

(Sheet 8 of 8)



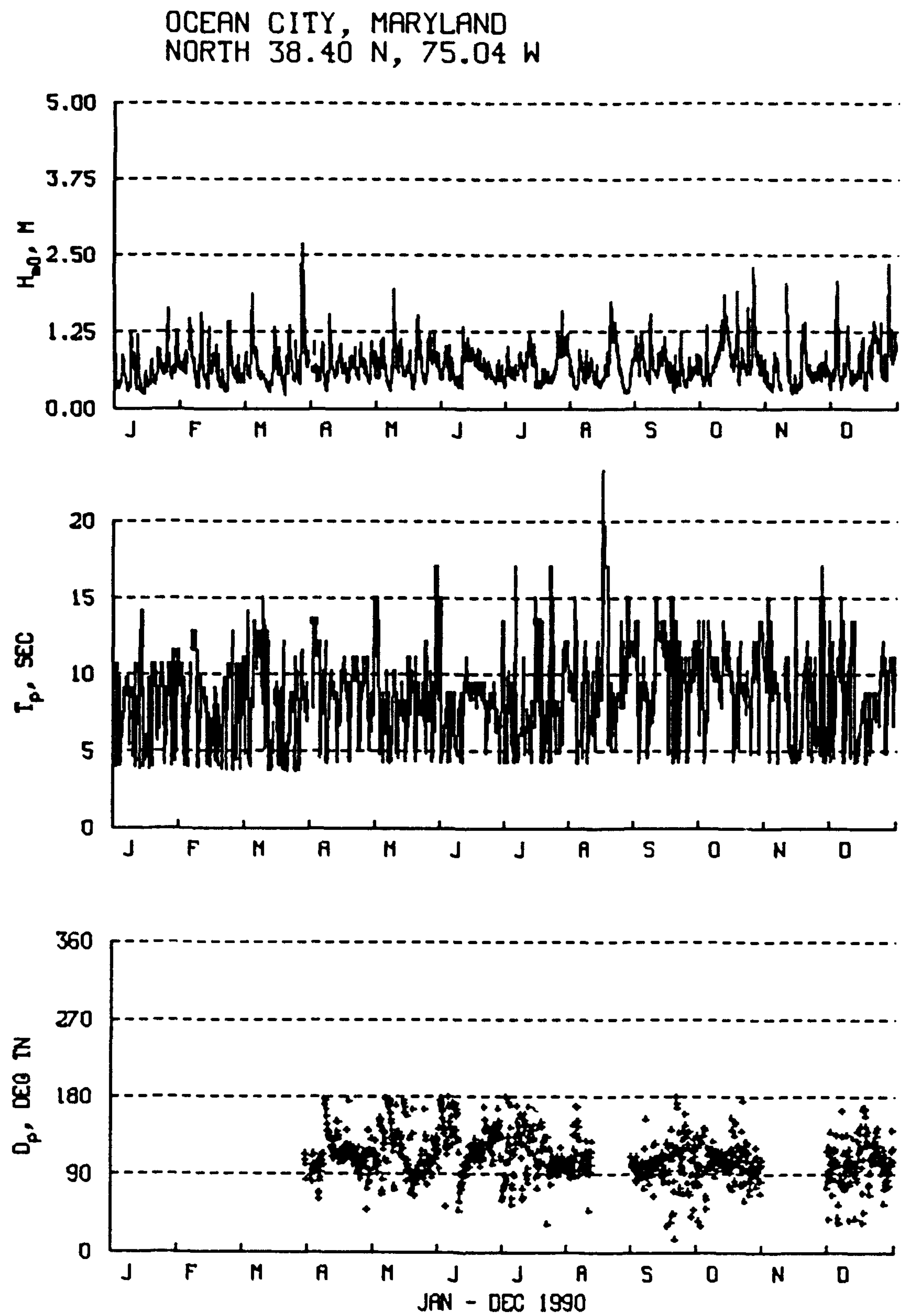
Annual Significant Wave Height, Peak Period, and Wave Direction, North Site (Jan 88 - Dec 88)

PLATE C1



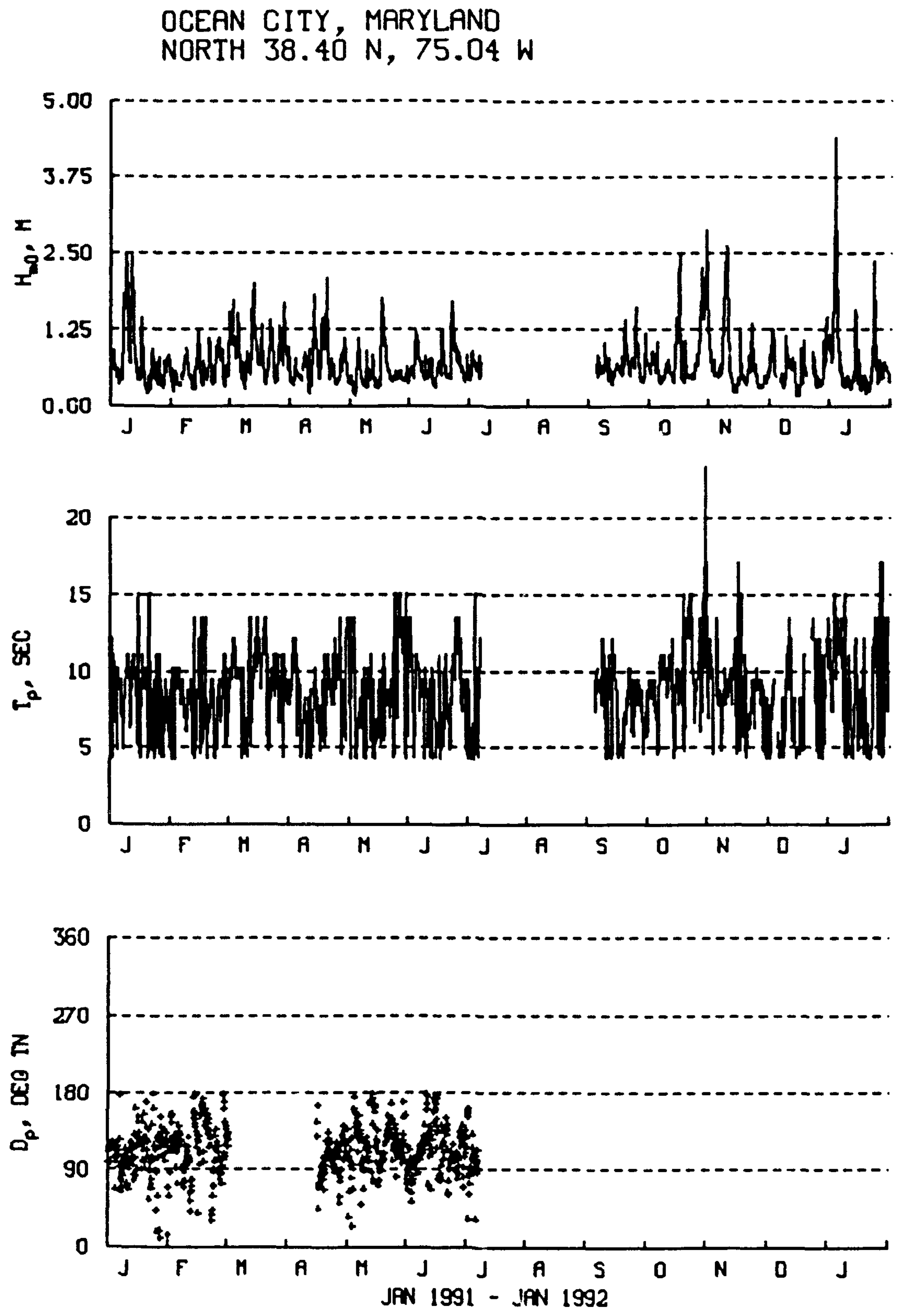
Annual Significant Wave Height, Peak Peroid, and Wave Direction, North Site (Jan 89 - Dec 89)

PLATE C2



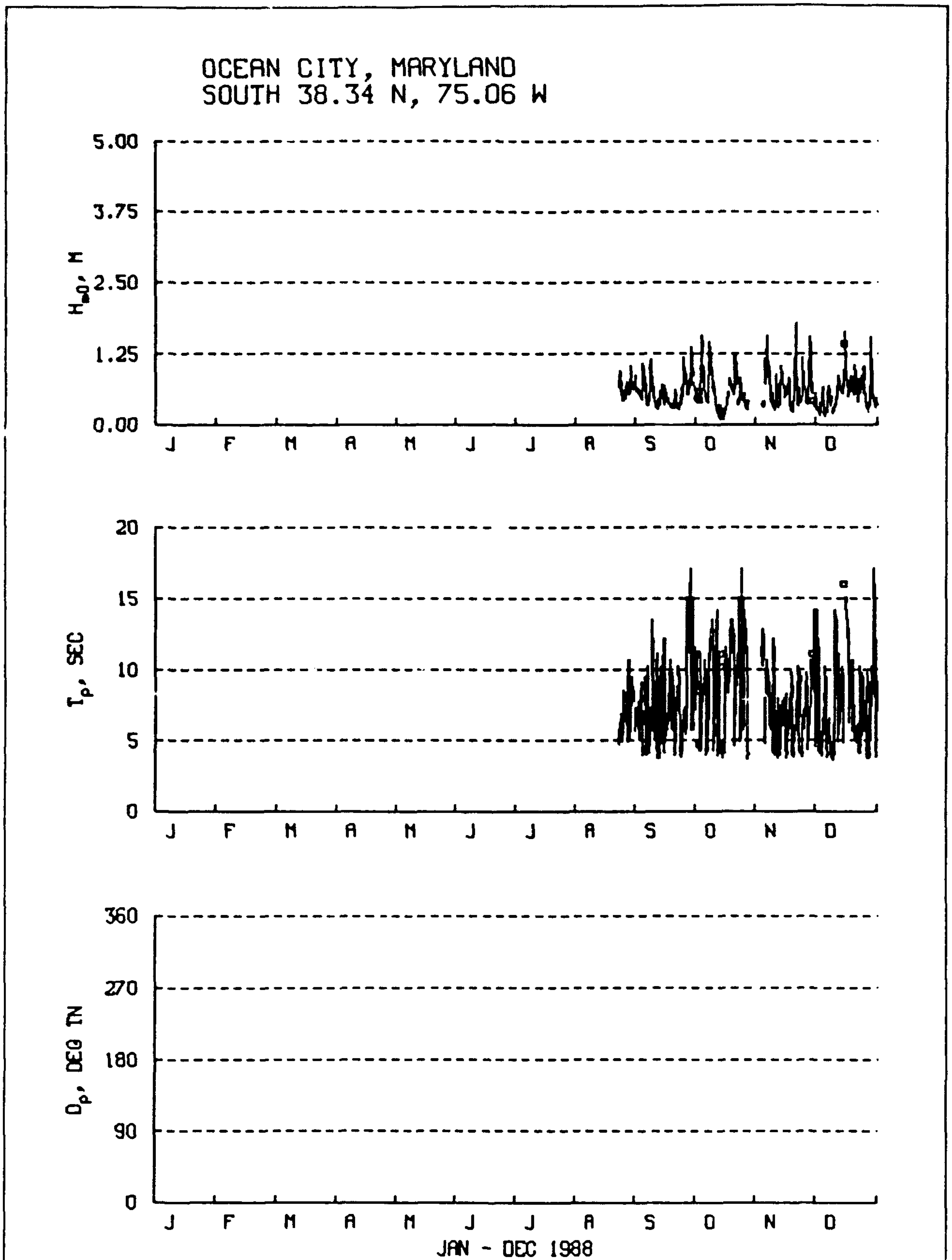
Annual Significant Wave Height, Peak Period, and Wave Direction, North Site (Jan 90 - Dec 90)

PLATE C3



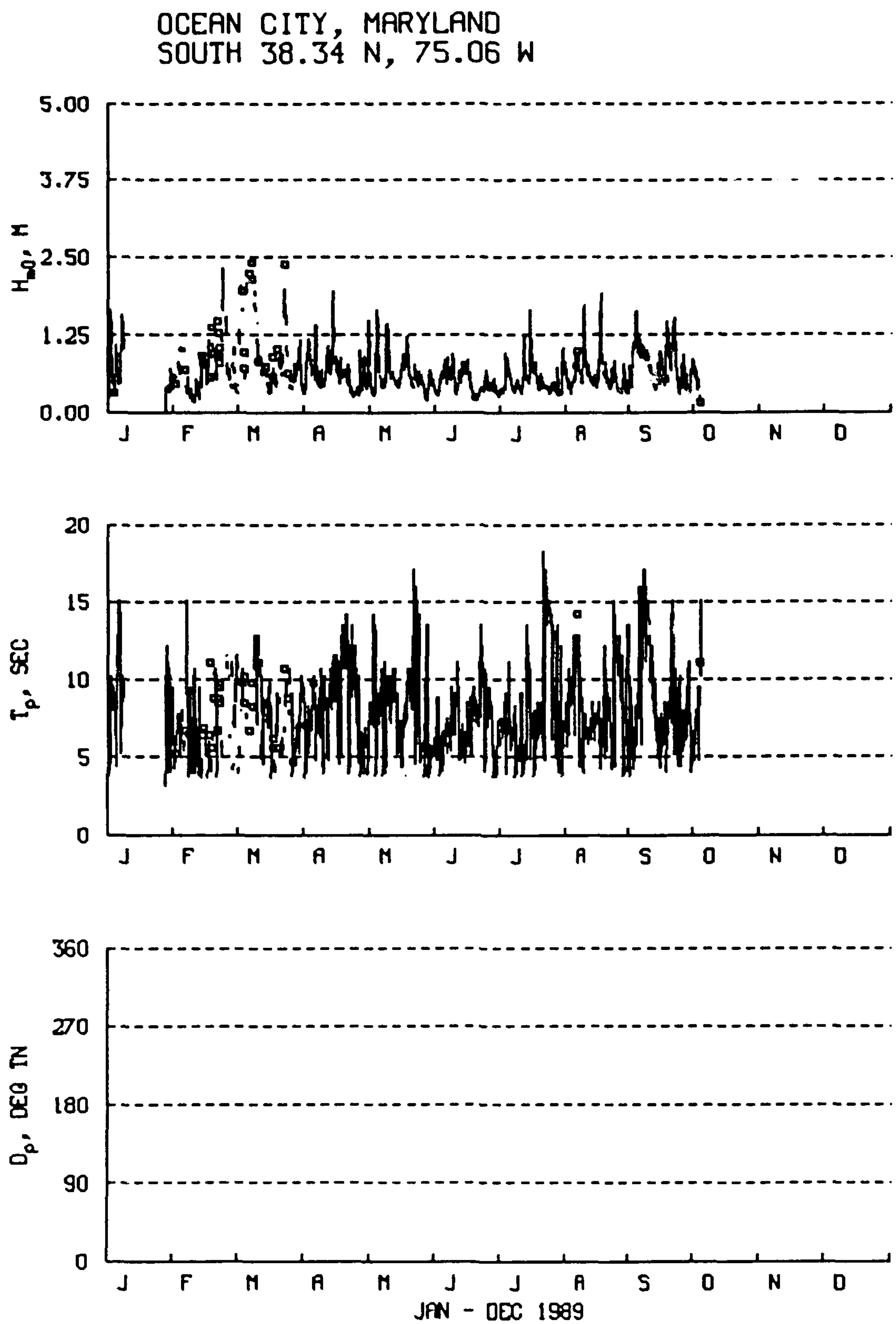
Annual Significant Wave Height, Peak Period, and Wave Direction, North Site (Jan 91 - Jan 92)

PLATE C4



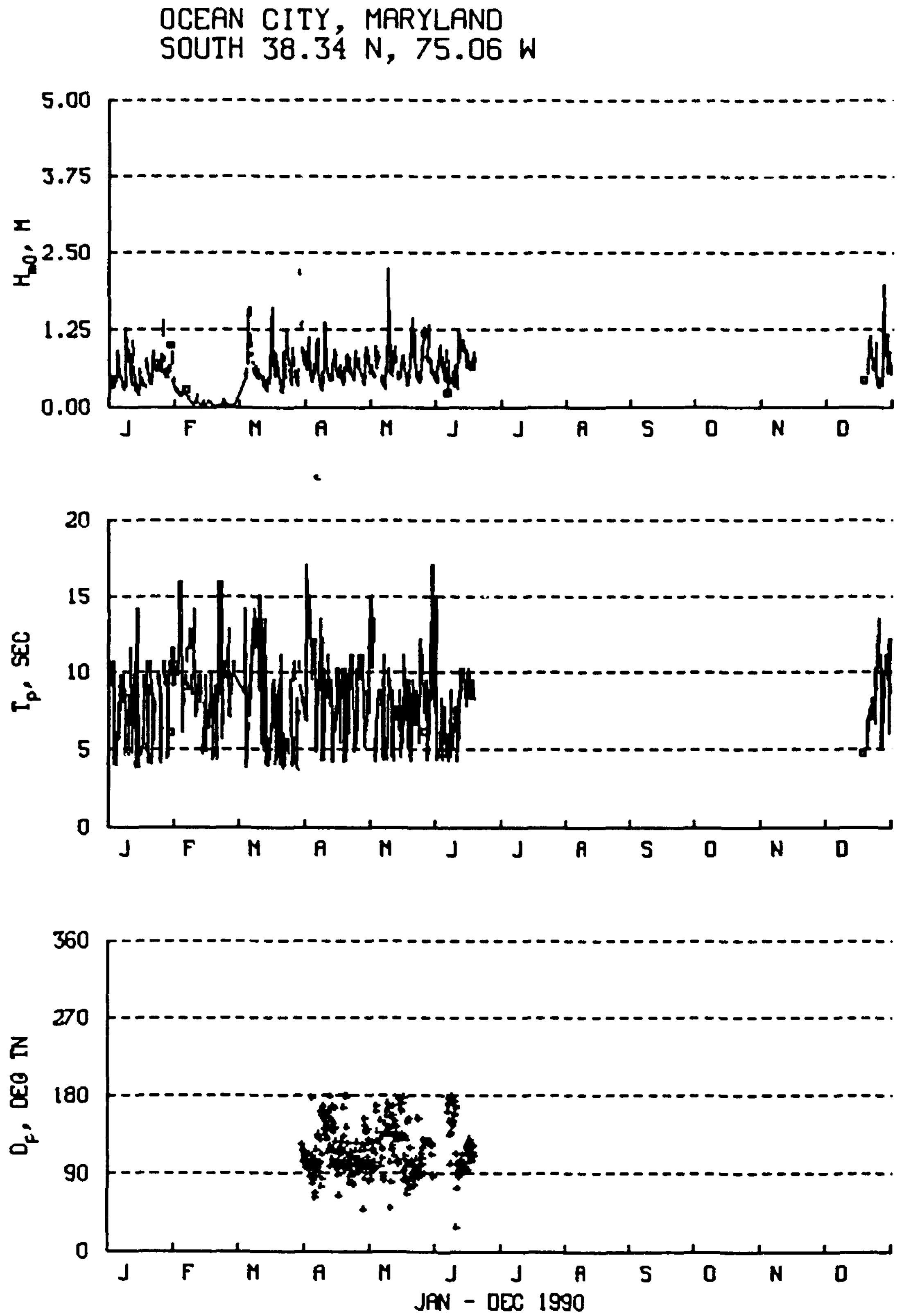
Annual Significant Wave Height, Peak Period, and Wave Direction, South Site (Jan 88 - Dec 88)

PLATE C5



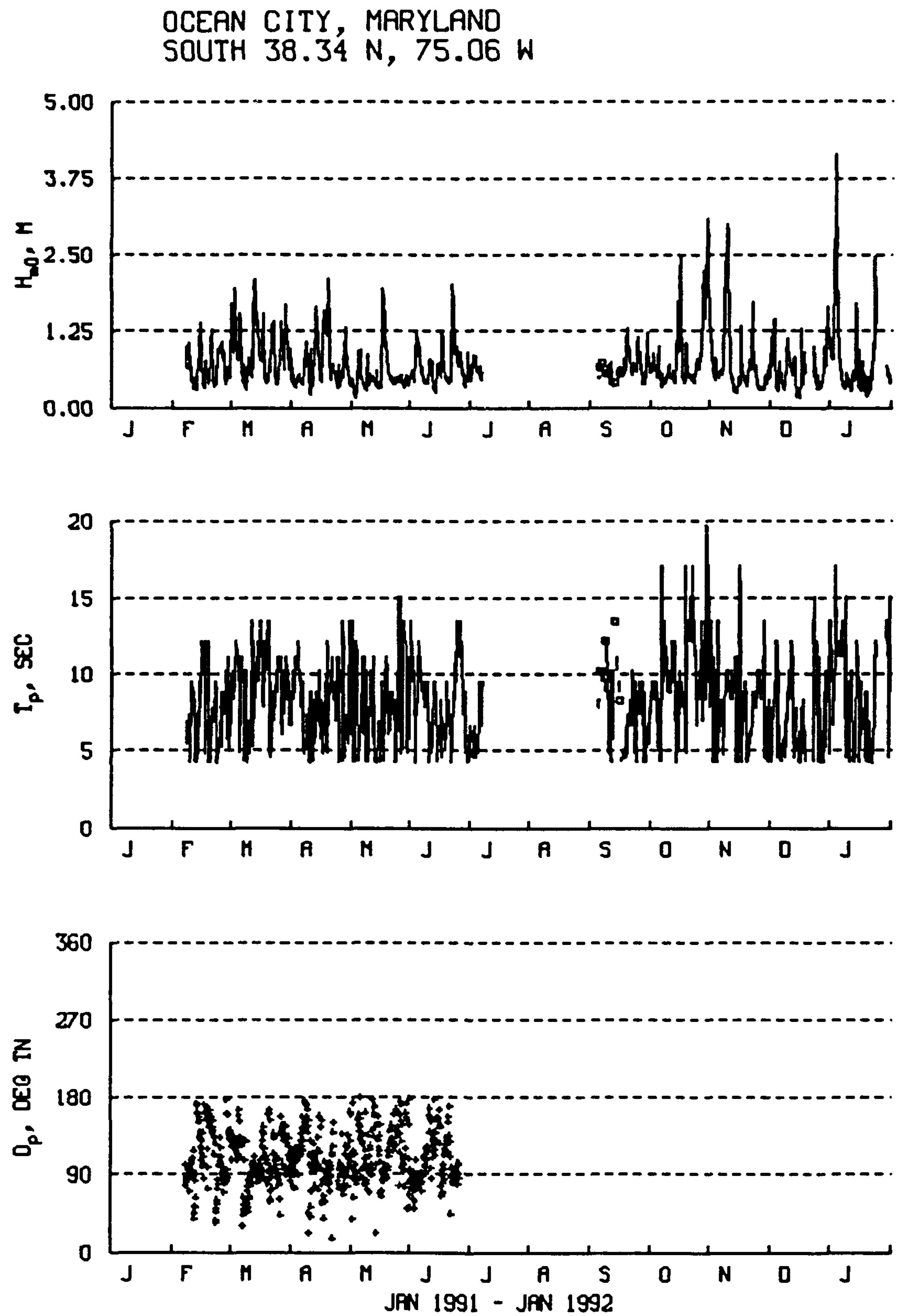
Annual Significant Wave Height, Peak Period, and Wave Direction, South Site (Jan 89 - Dec 89)

PLATE C6



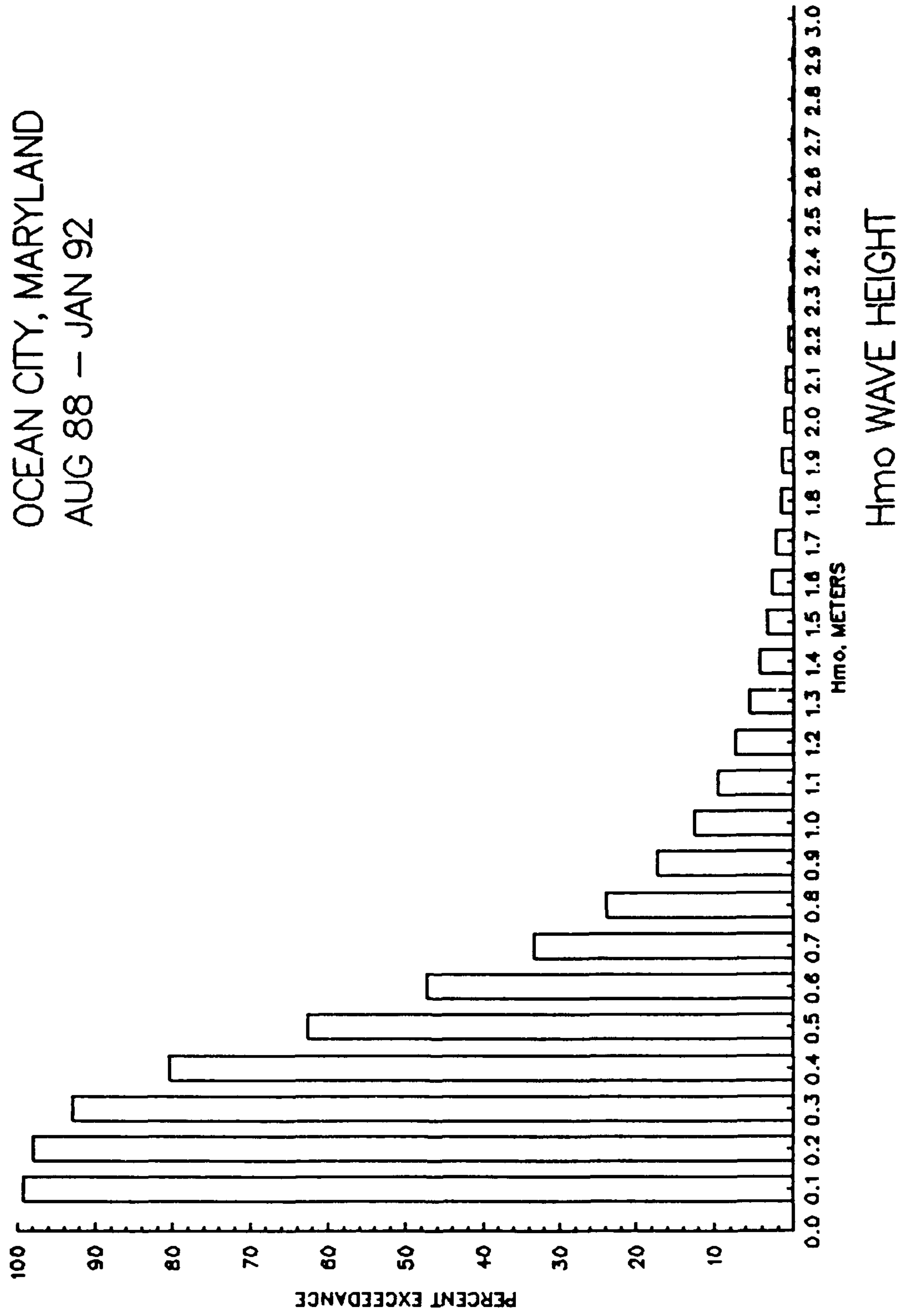
Annual Significant Wave Height, Peak Period, and Wave Direction, South Site (Jan 90 - Dec 90)

PLATE C7



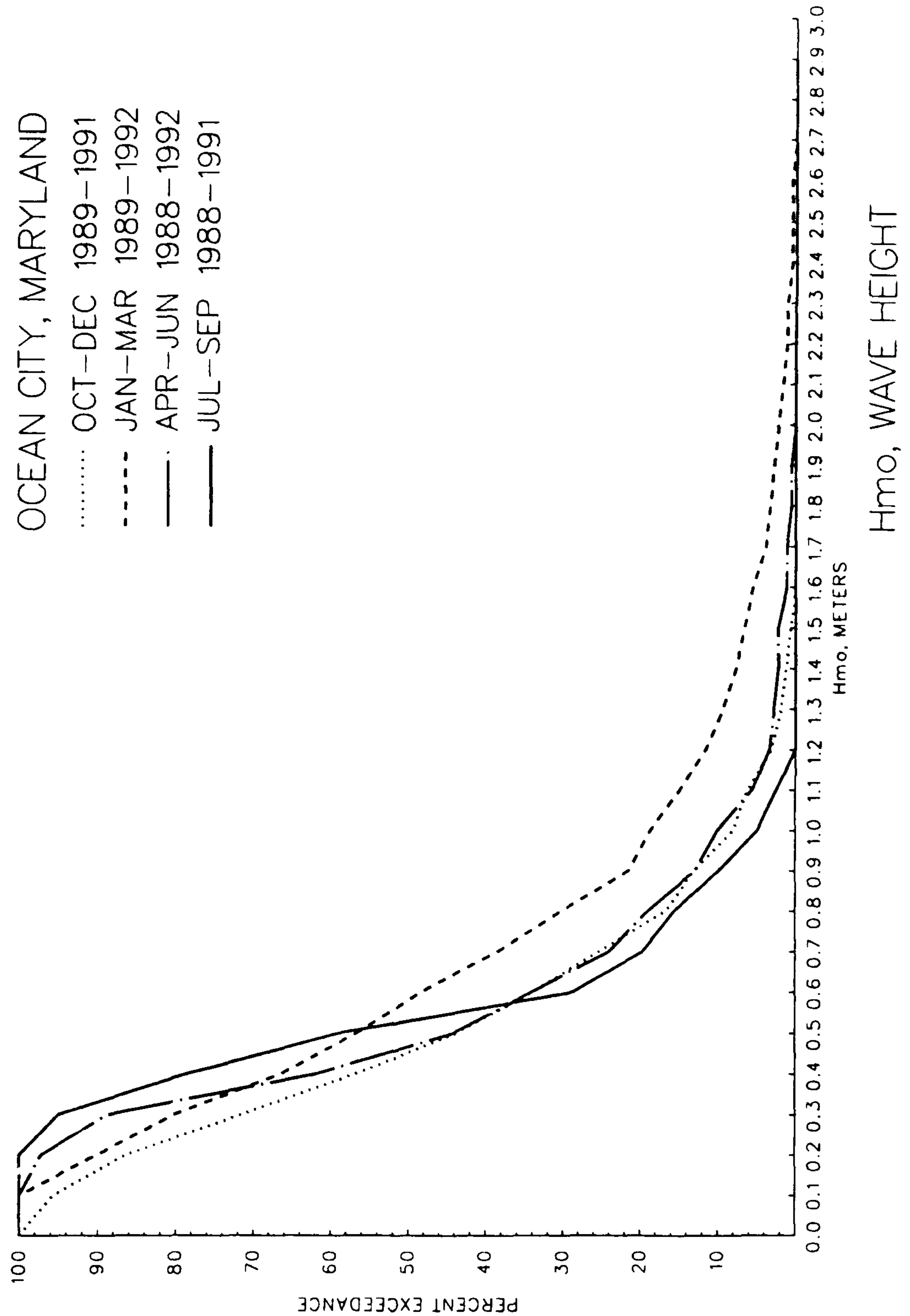
Annual Significant Wave Height, Peak Period, and Wave Direction, South Site (Jan 91 - Jan 92)

PLATE C8



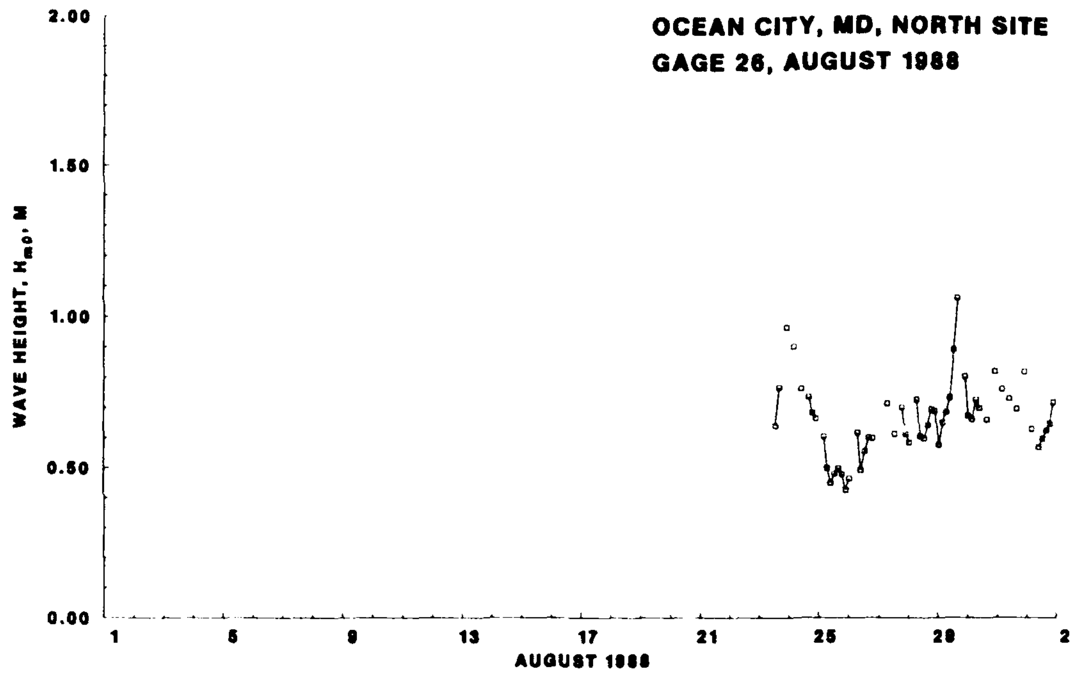
Percentage Exceedance Histogram

PLATE C9

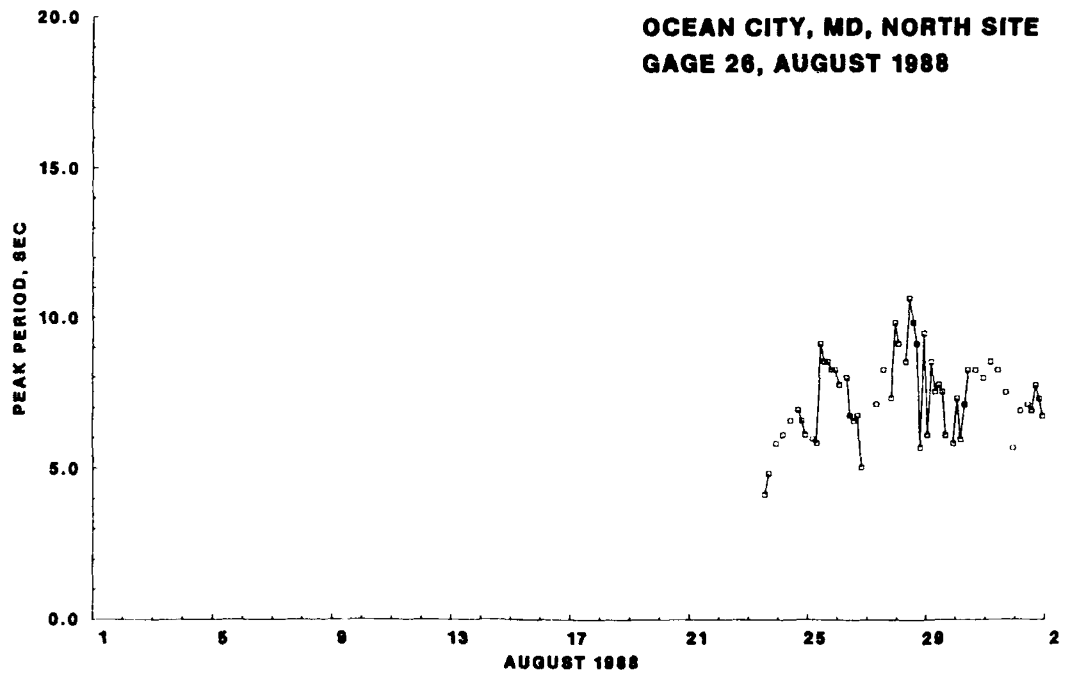


Percentage Exceedance Histogram by Seasons

PLATE C10



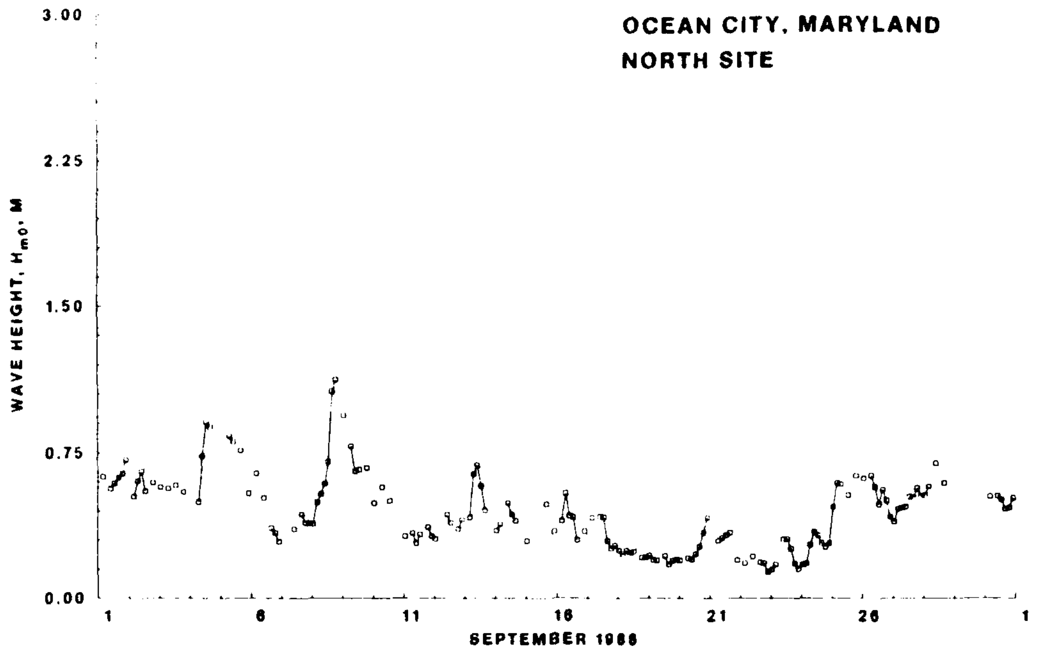
WAVE HEIGHT TIME SERIES



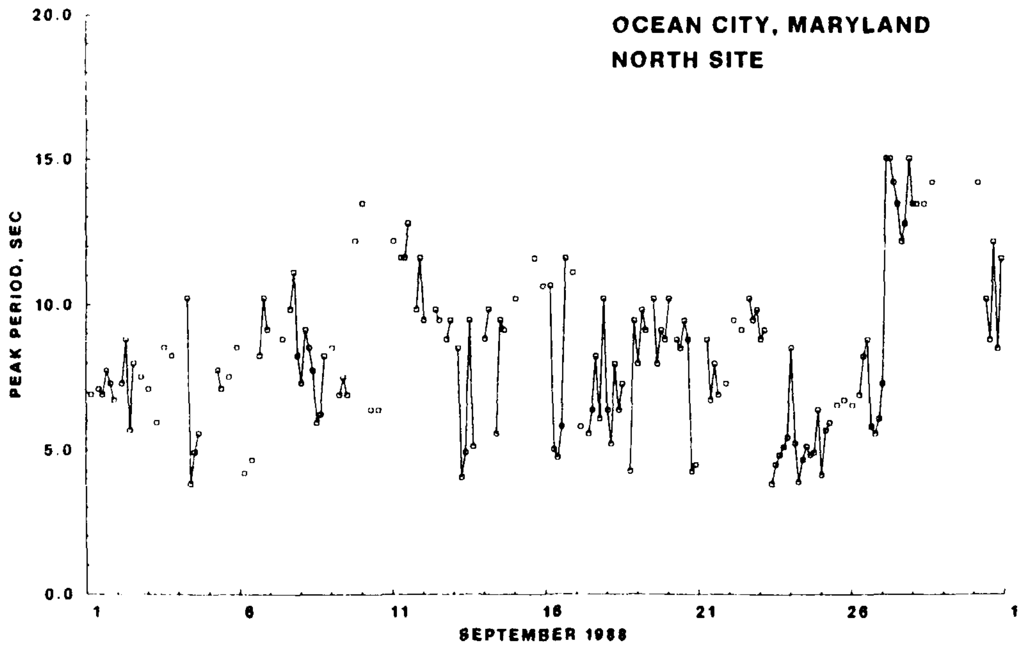
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, August 1988

PLATE C11



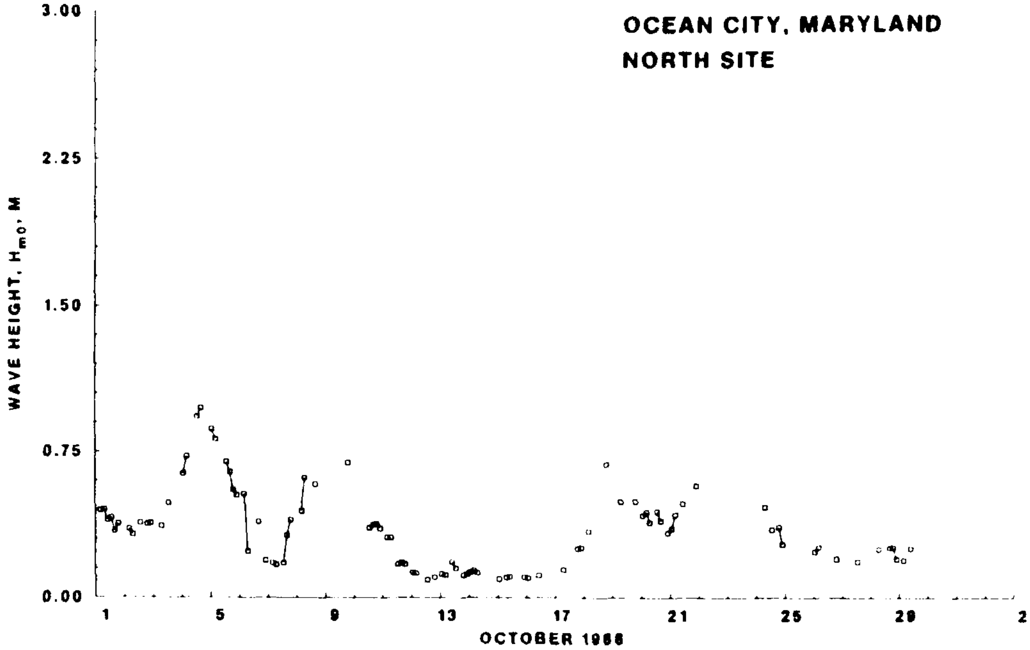
WAVE HEIGHT, H_{m0}



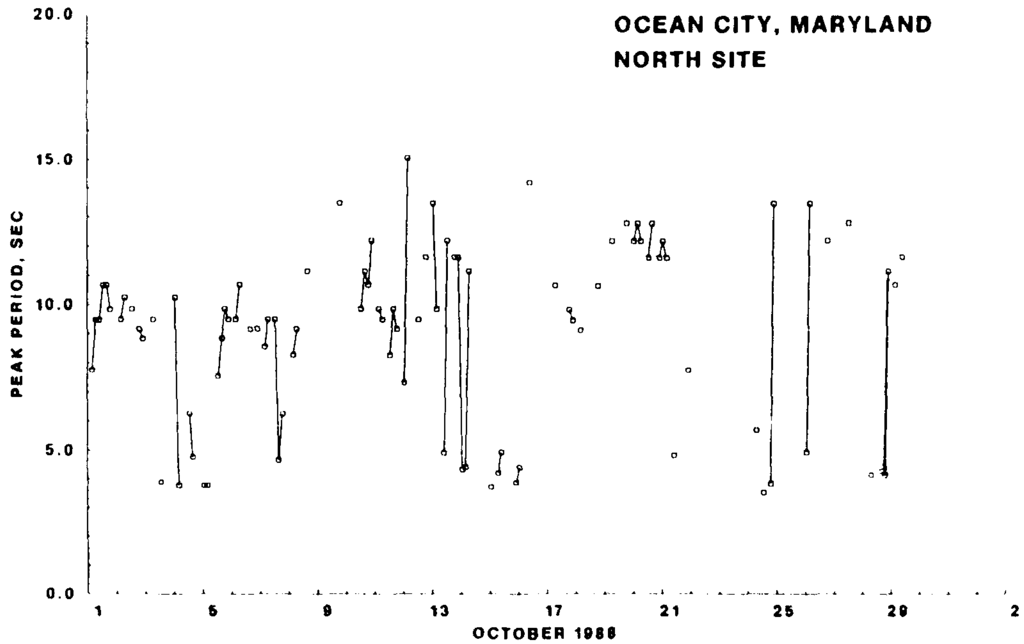
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, September 1988

PLATE C12



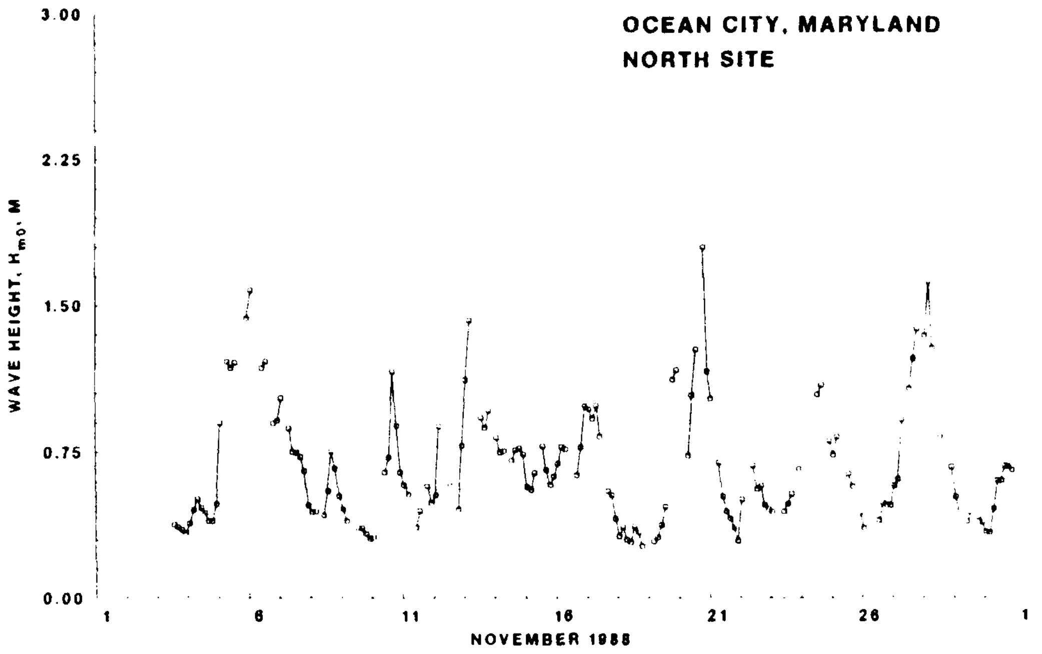
WAVE HEIGHT, H_{m0}



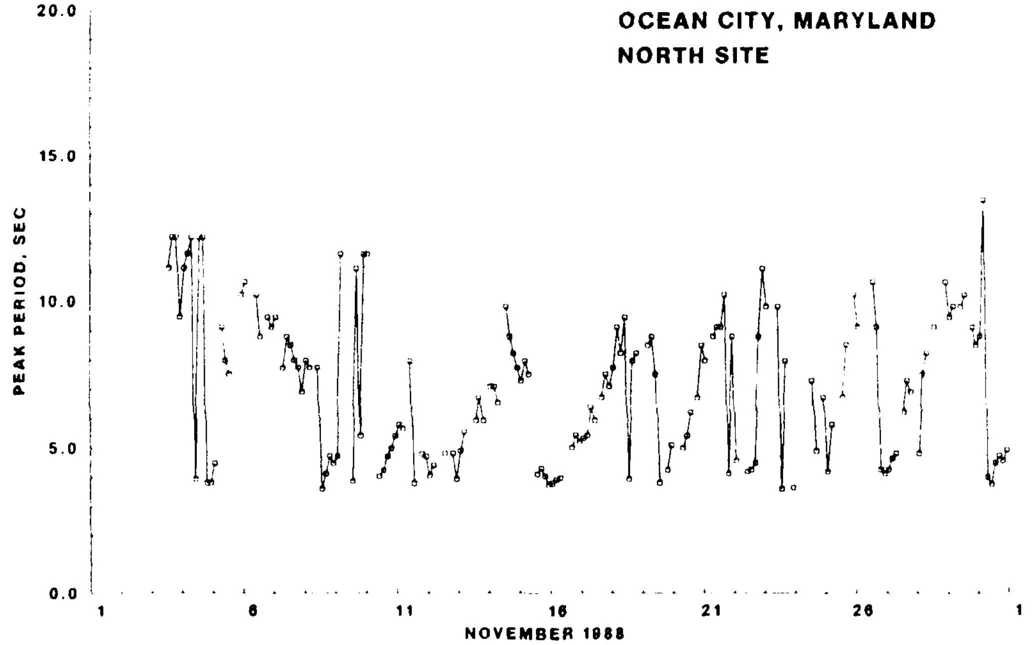
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, October 1988

PLATE C13

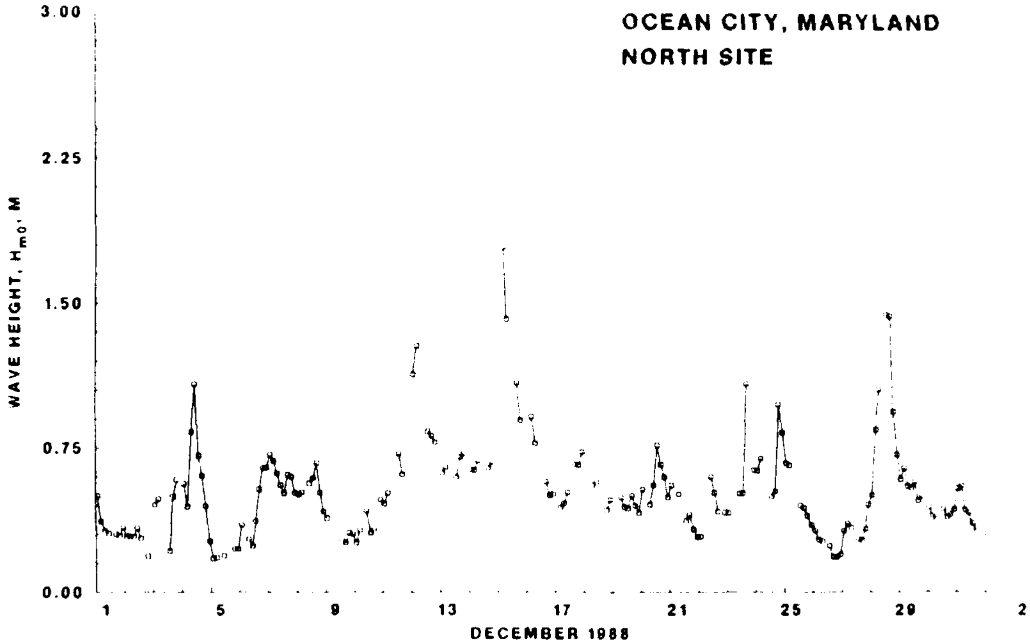


WAVE HEIGHT, H_{m0}

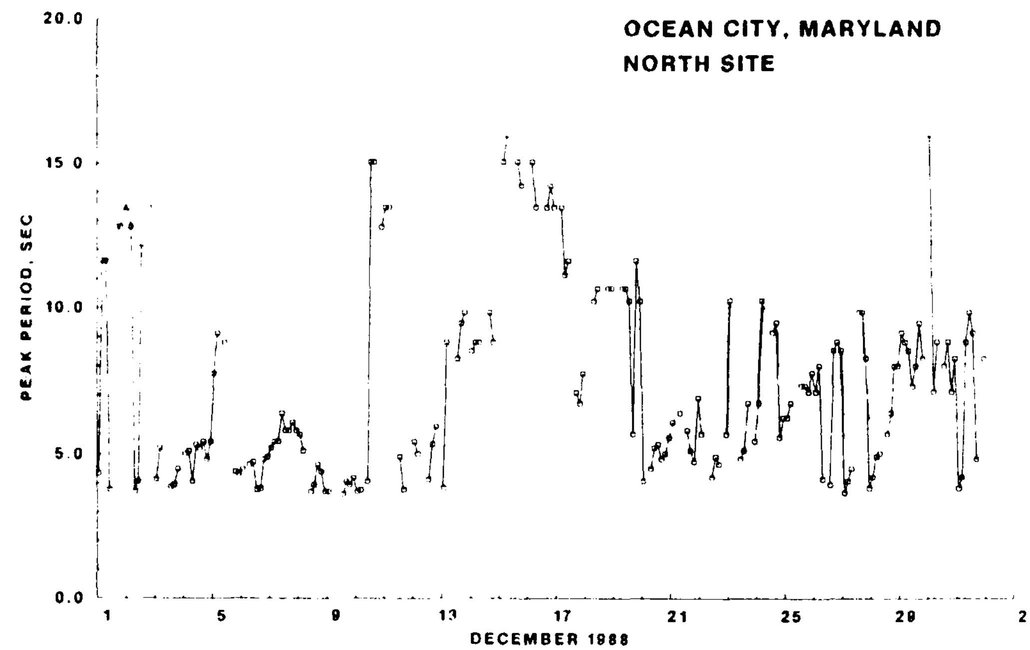


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, November 1988



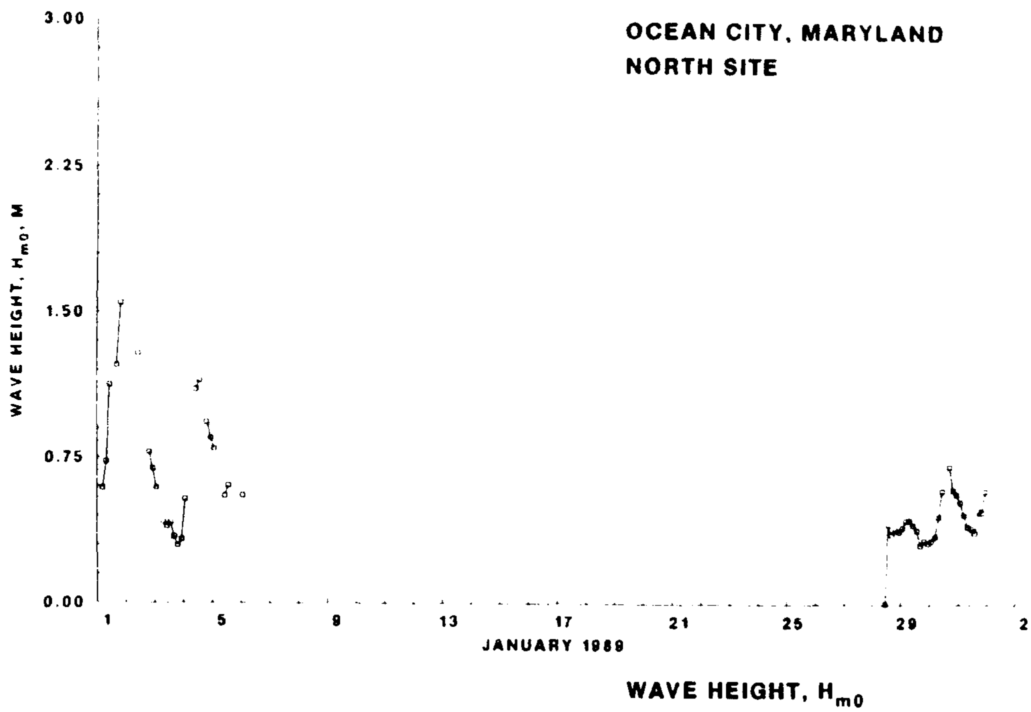
WAVE HEIGHT, H_{m0}

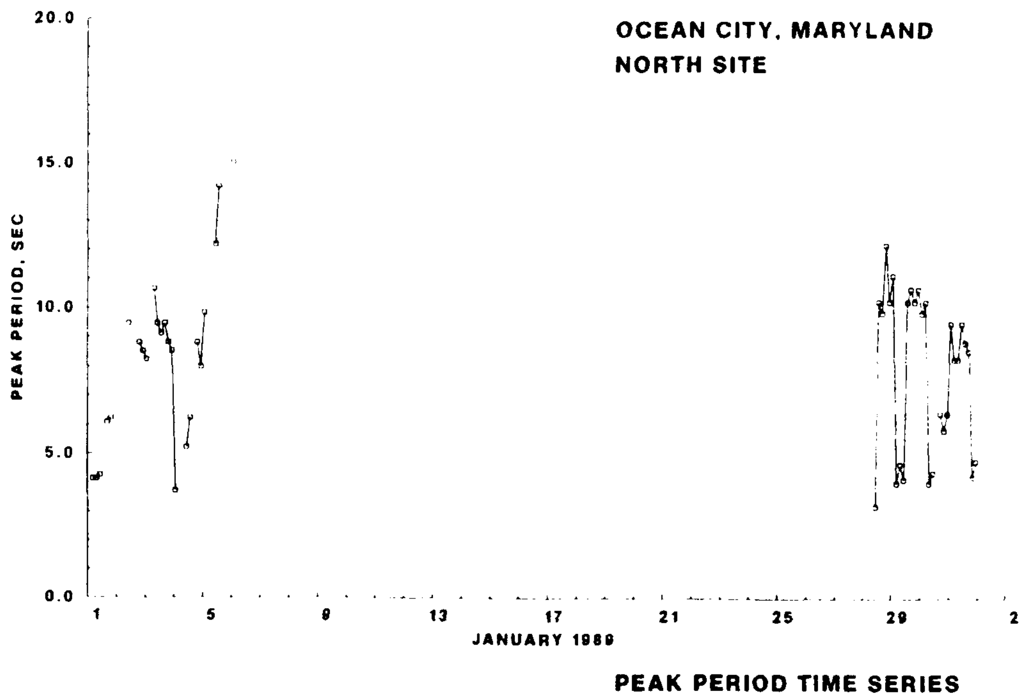


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, December 1988

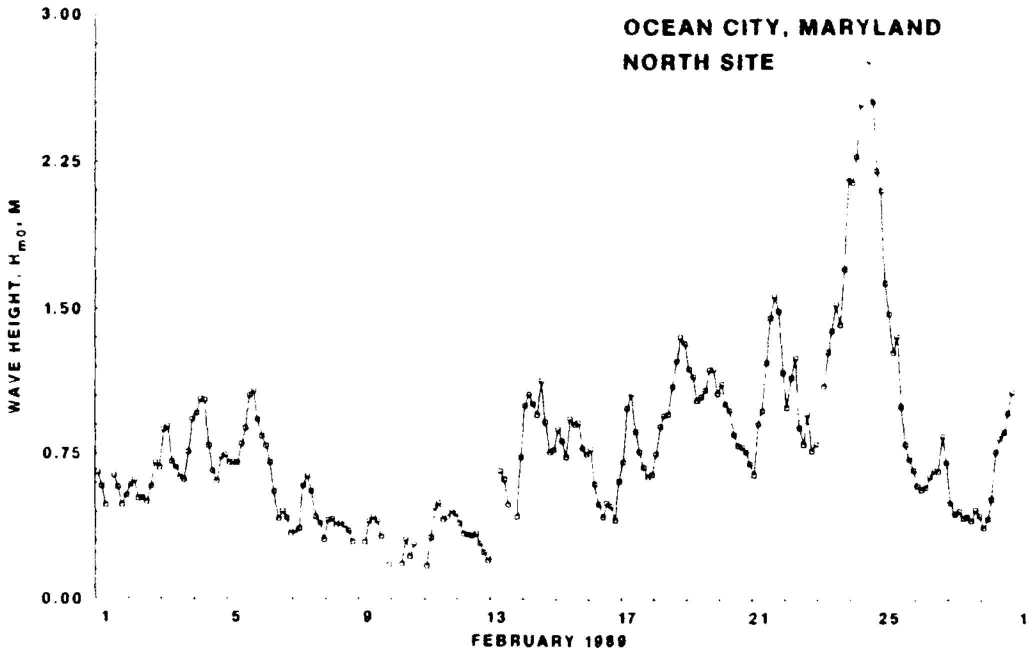
PLATE C15



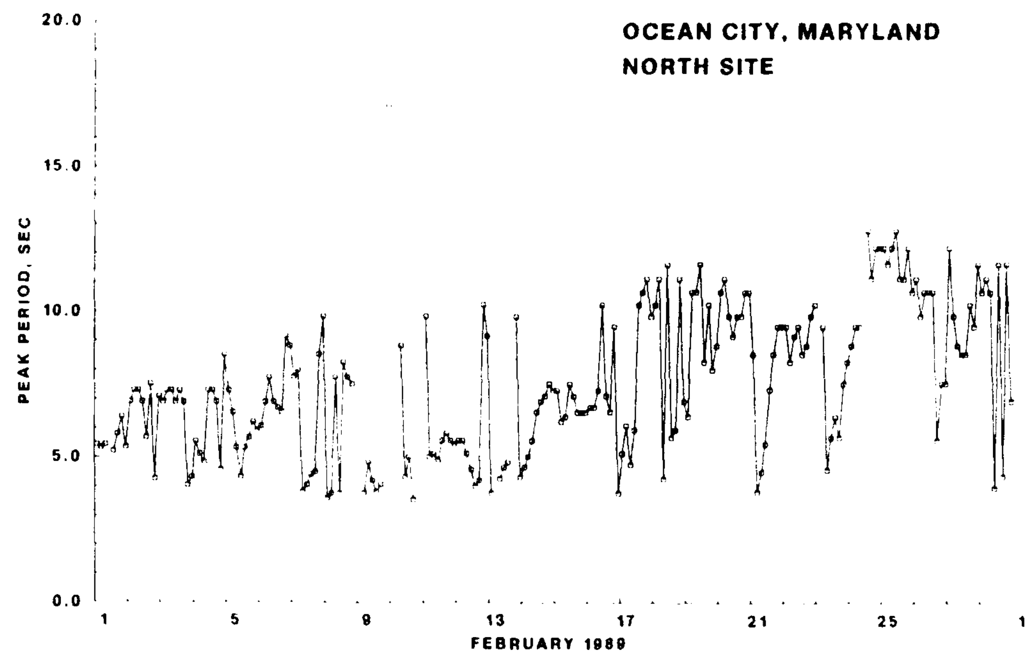


Significant Wave Height and Peak Period, North Site, January 1989

PLATE C16



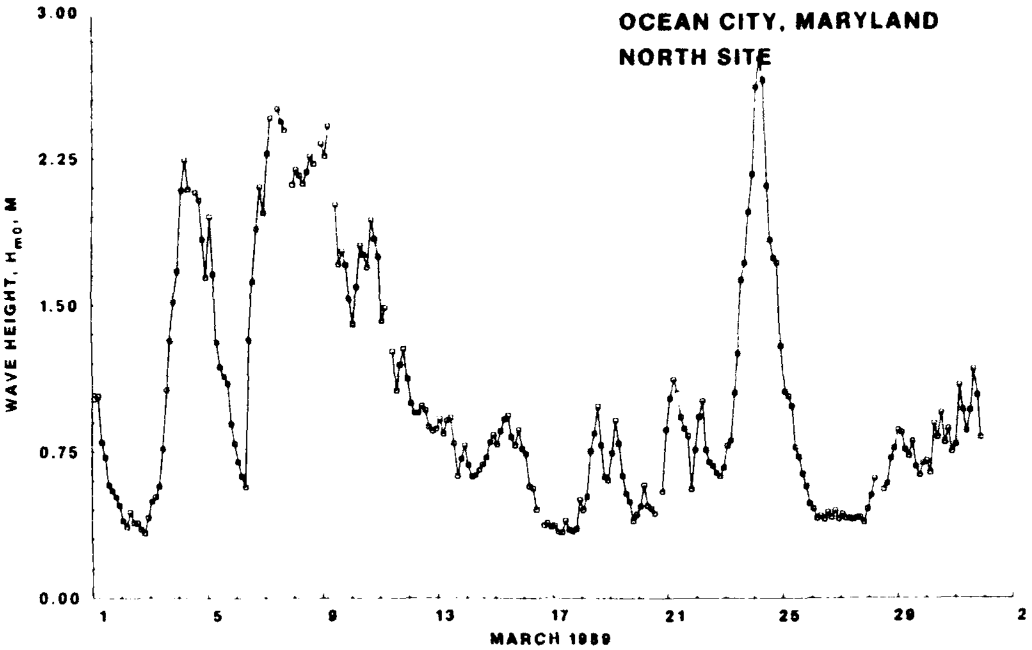
WAVE HEIGHT, H_{m0}



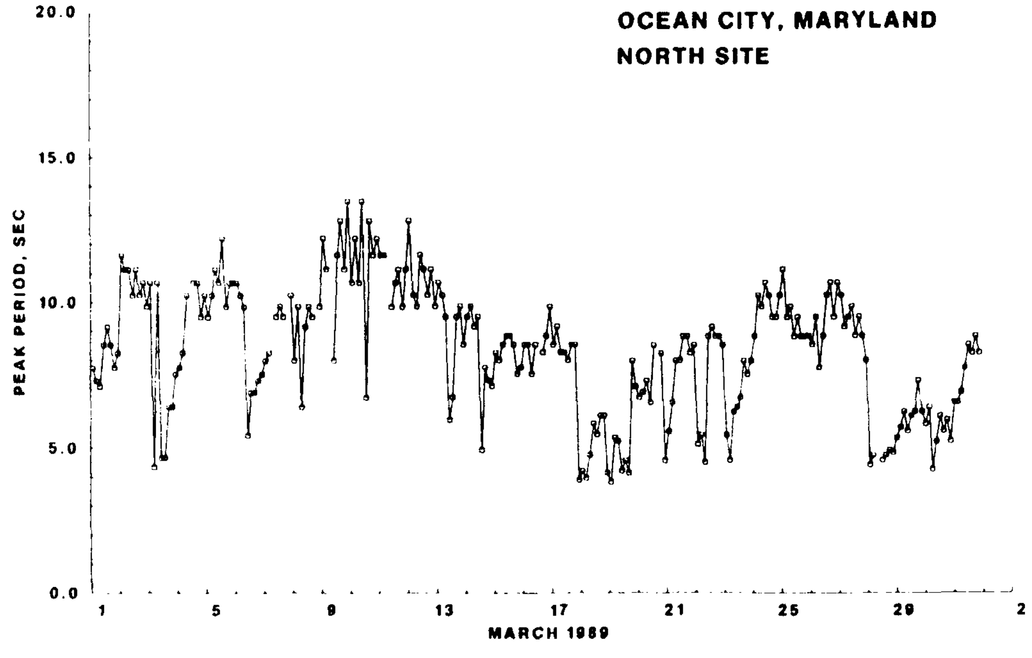
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, February 1989

PLATE C17

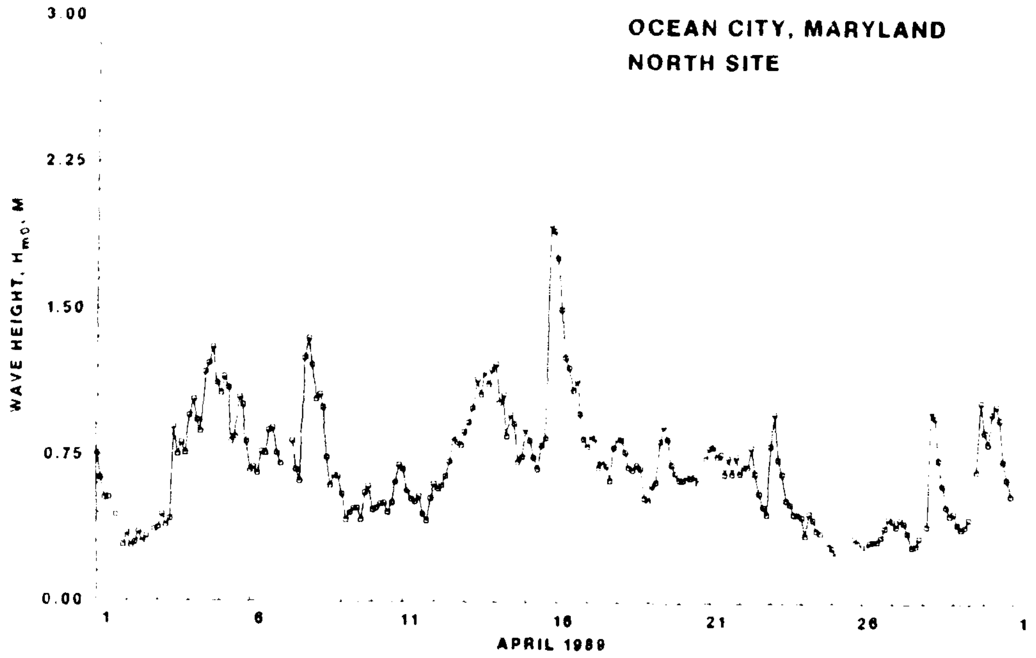


WAVE HEIGHT, H_{m0}

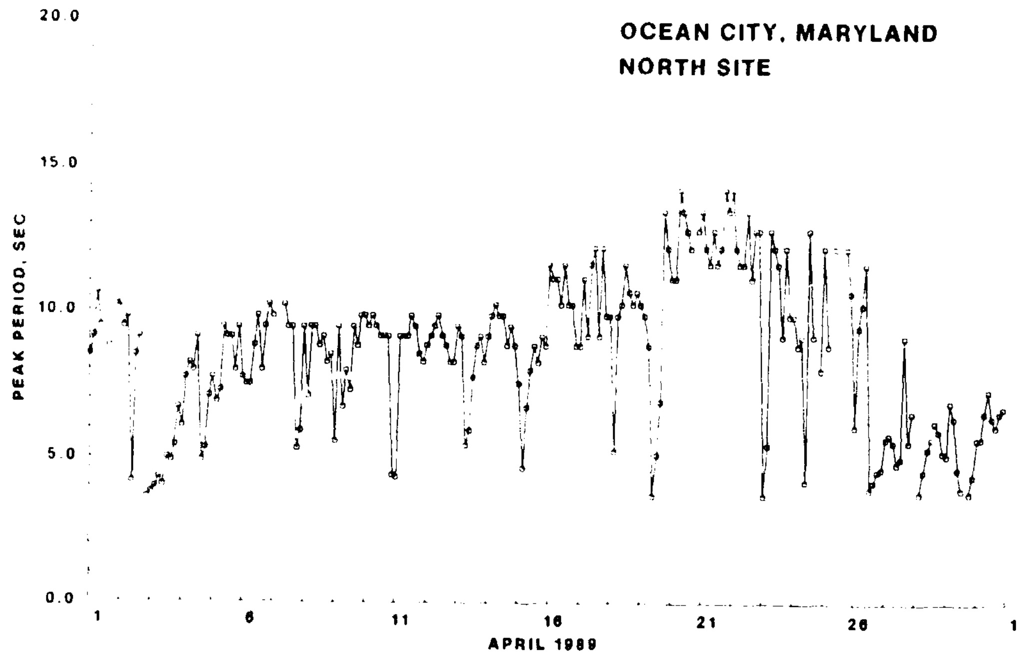


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, March 1989



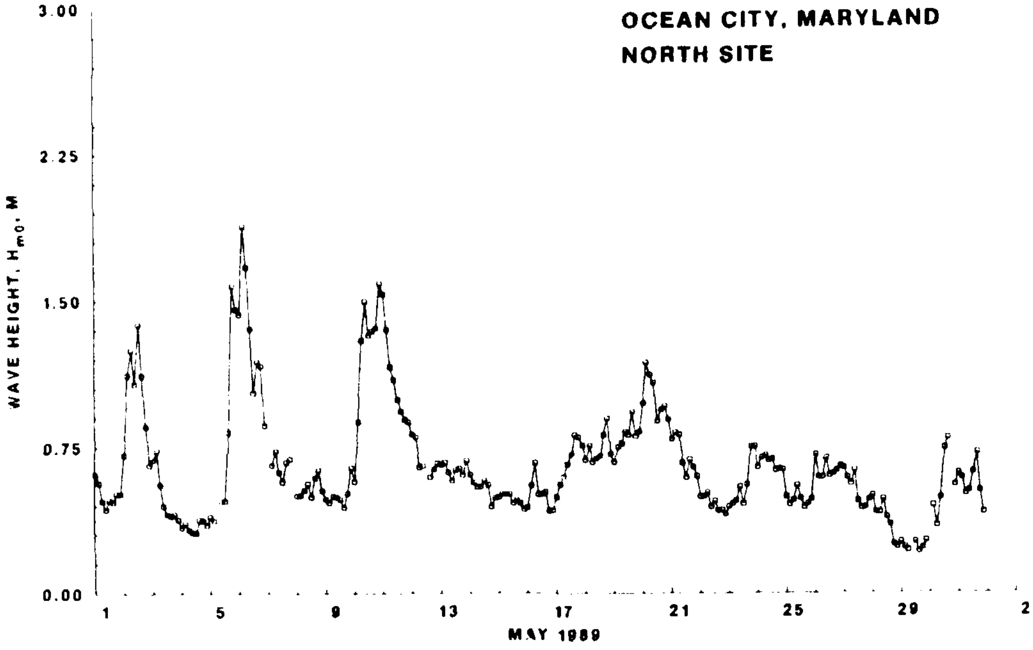
WAVE HEIGHT, H_{m0}



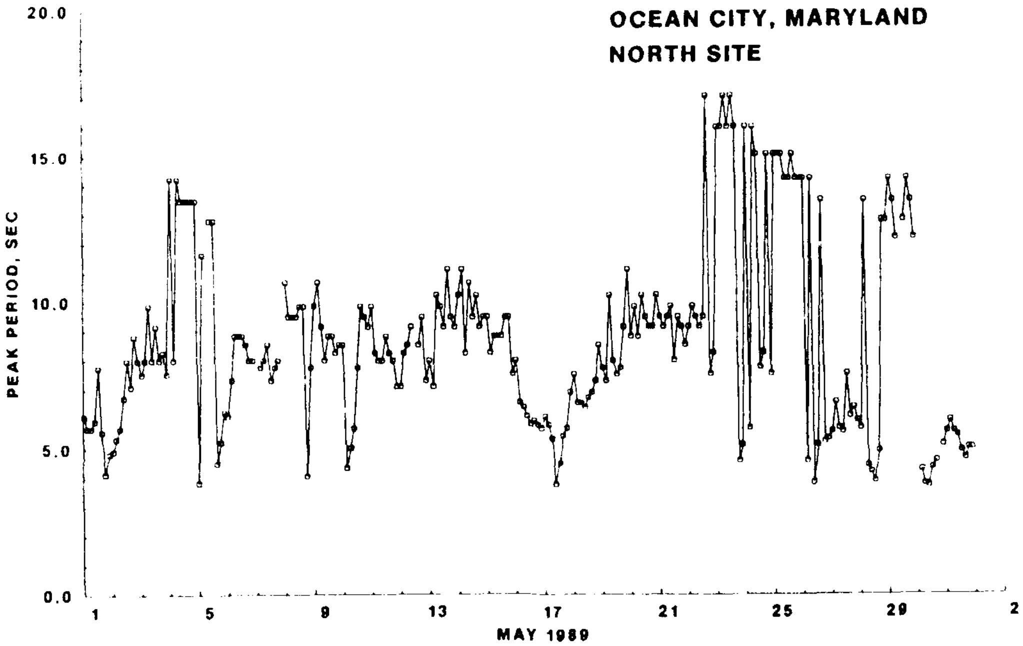
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, April 1989

PLATE C19



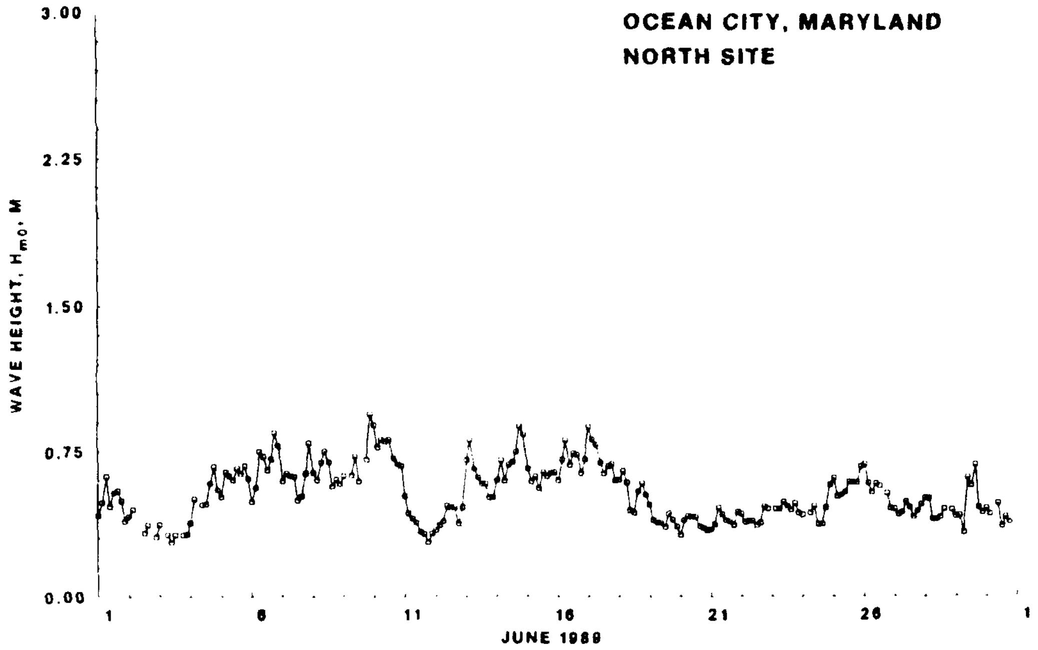
WAVE HEIGHT, H_{m0}



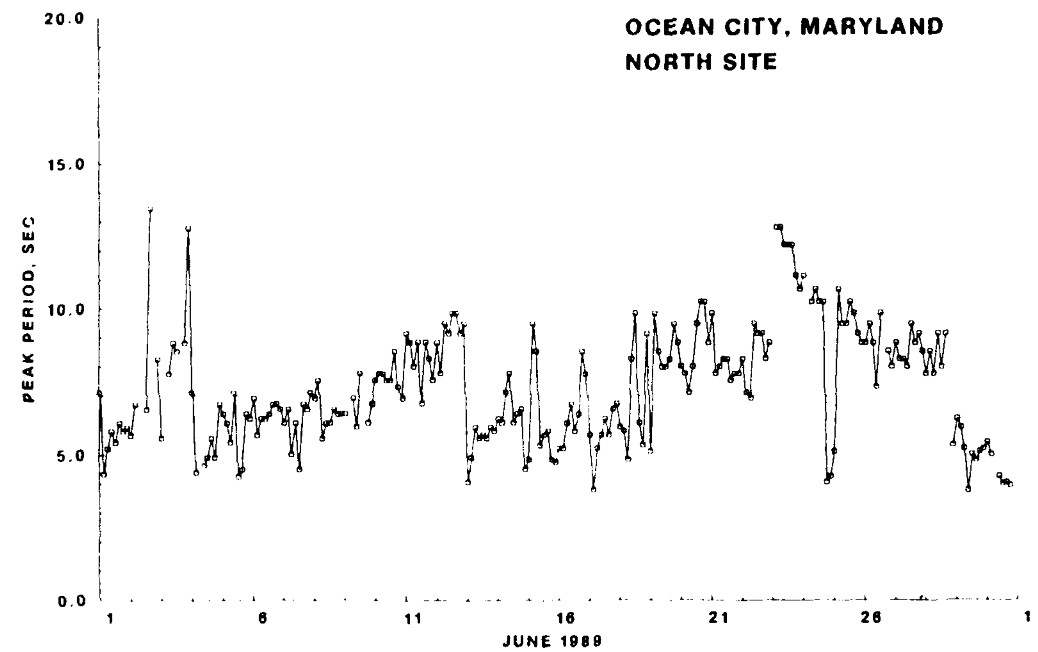
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, May 1989

PLATE C20

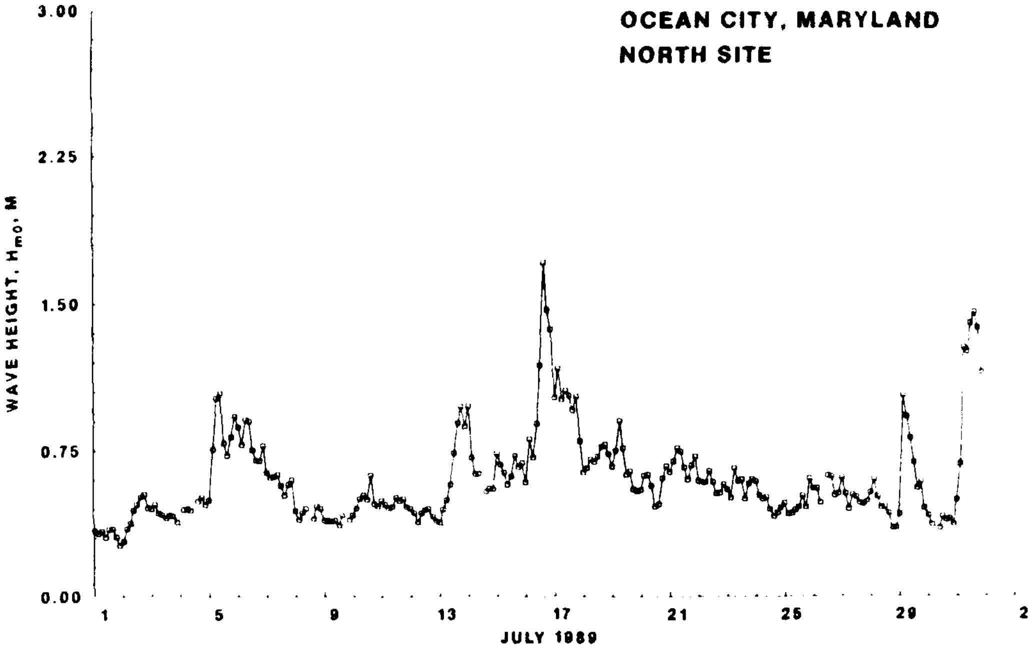


WAVE HEIGHT, H_{m0}

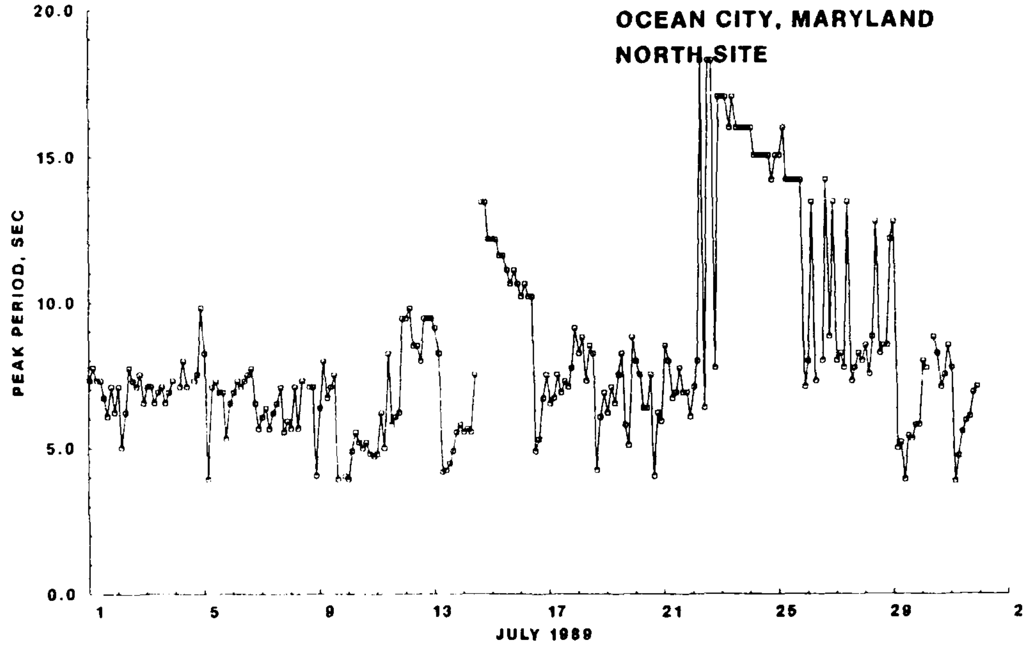


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, June 1989



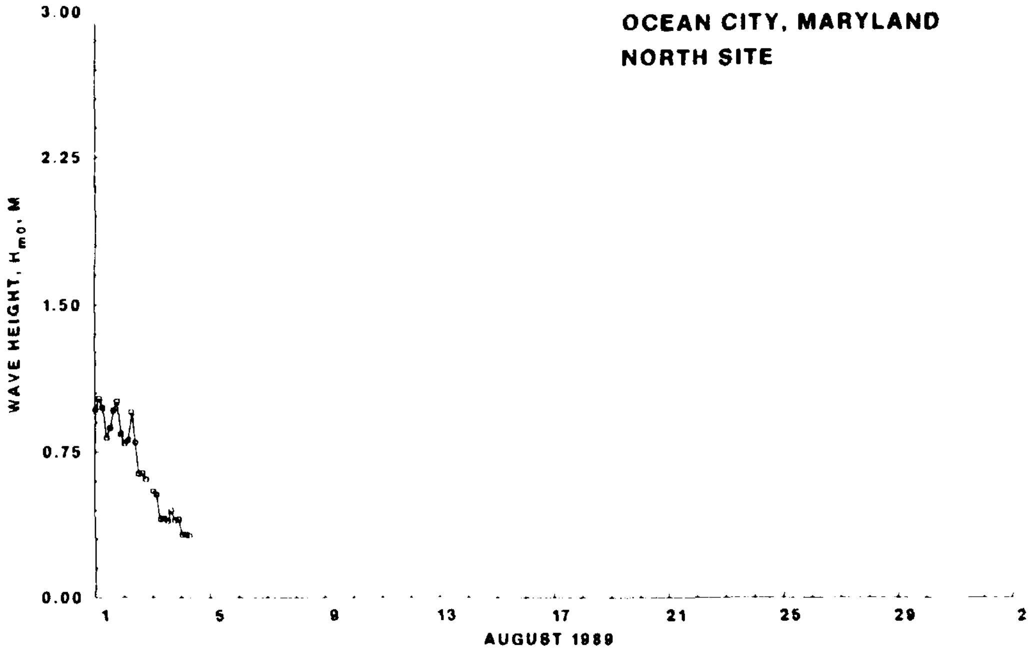
WAVE HEIGHT, H_{m0}



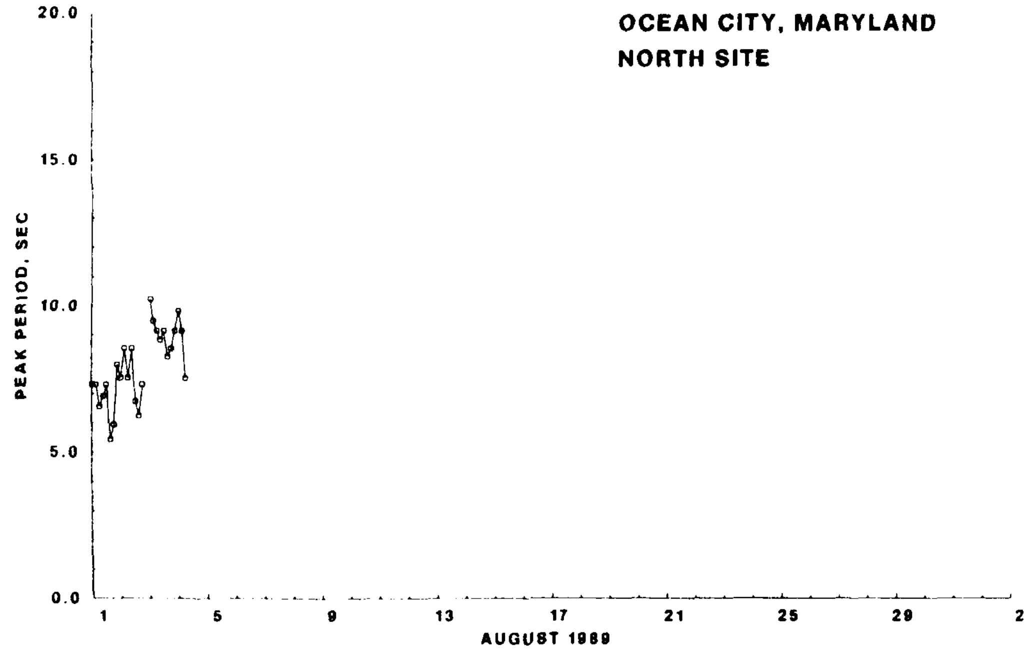
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, July 1989

PLATE C22



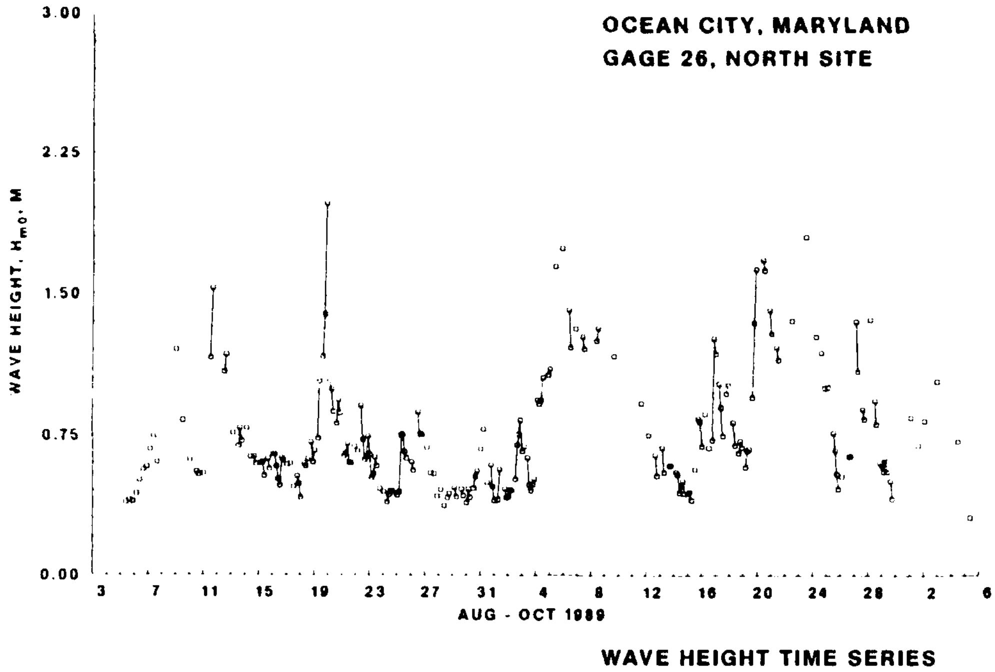
WAVE HEIGHT, H_{m0}

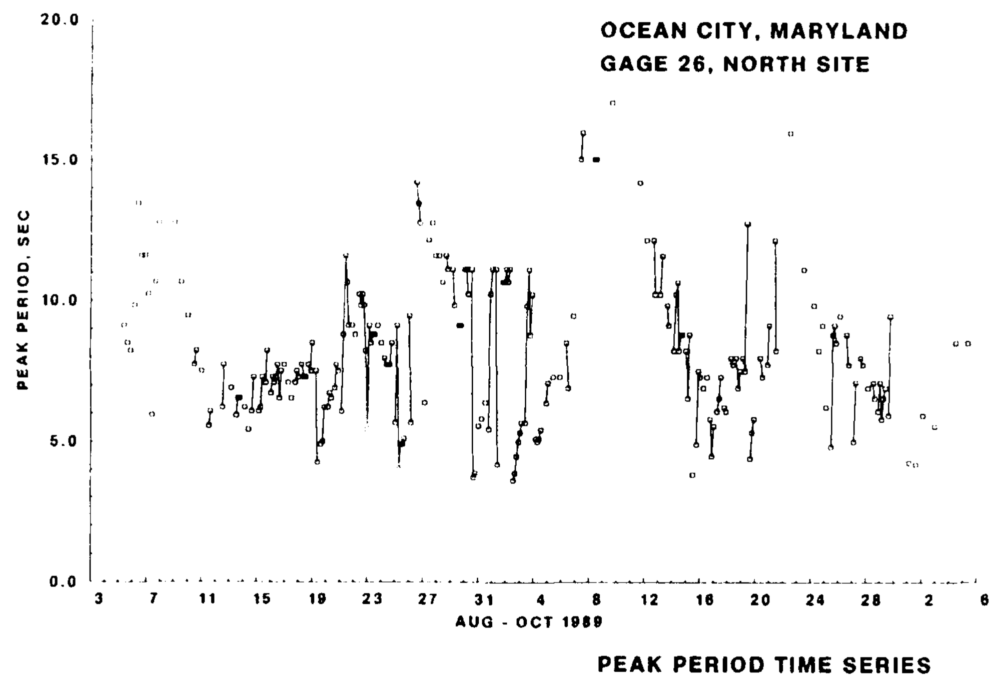


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, August 1989

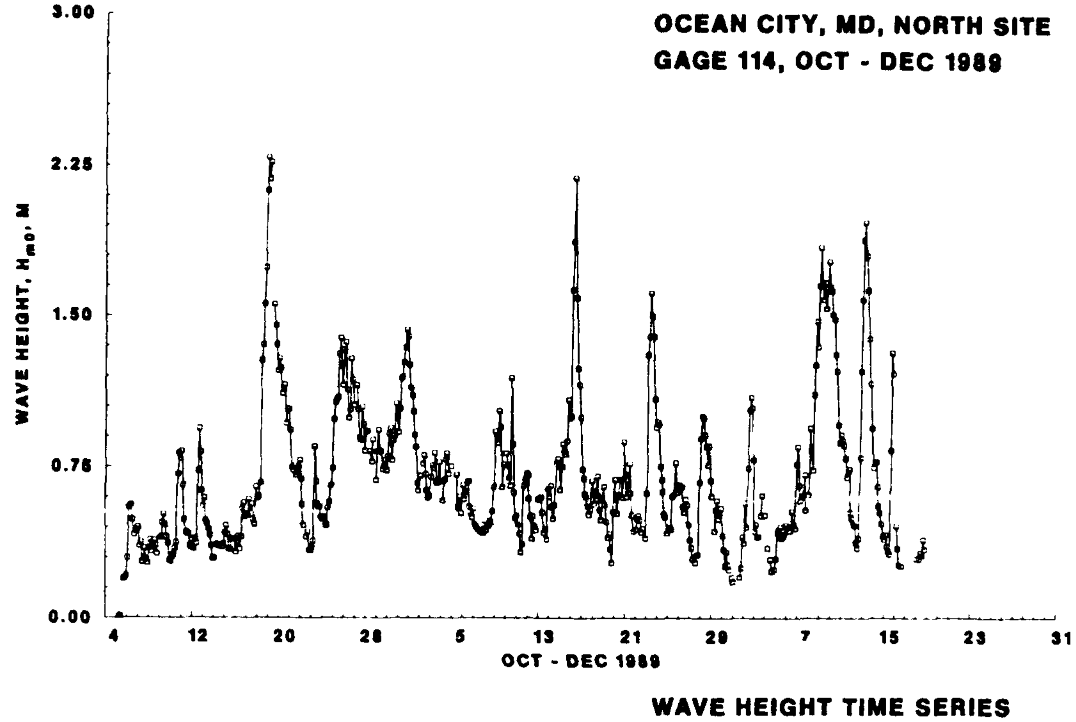
PLATE C23

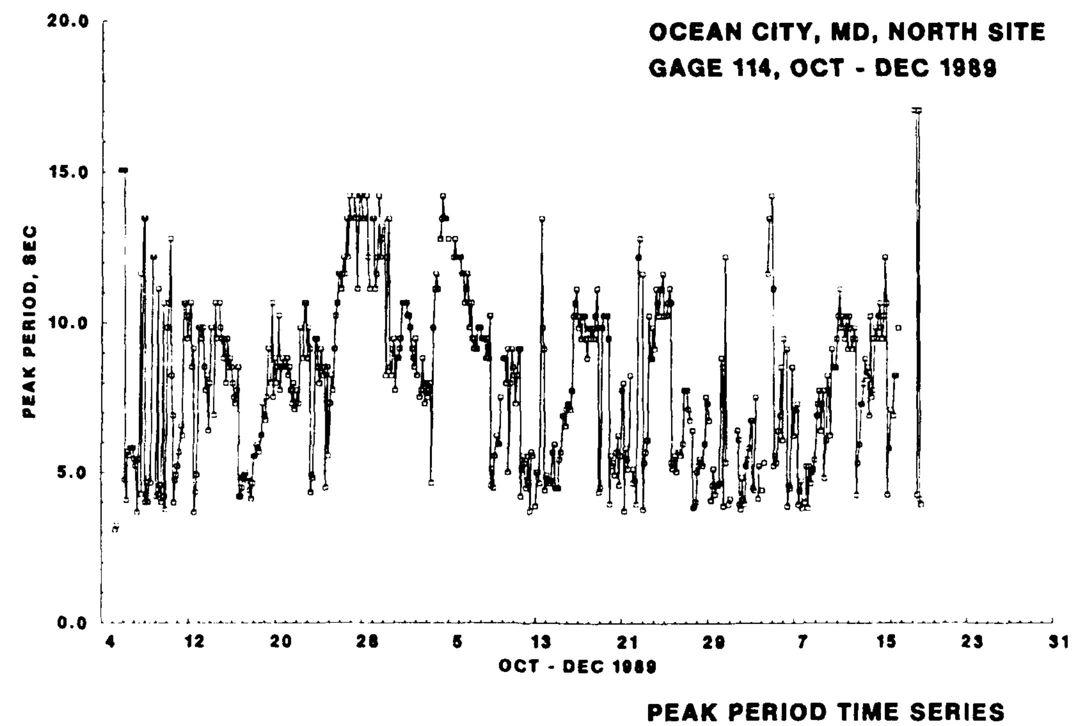




Significant Wave Height and Peak Period, North Site, August - October 1989

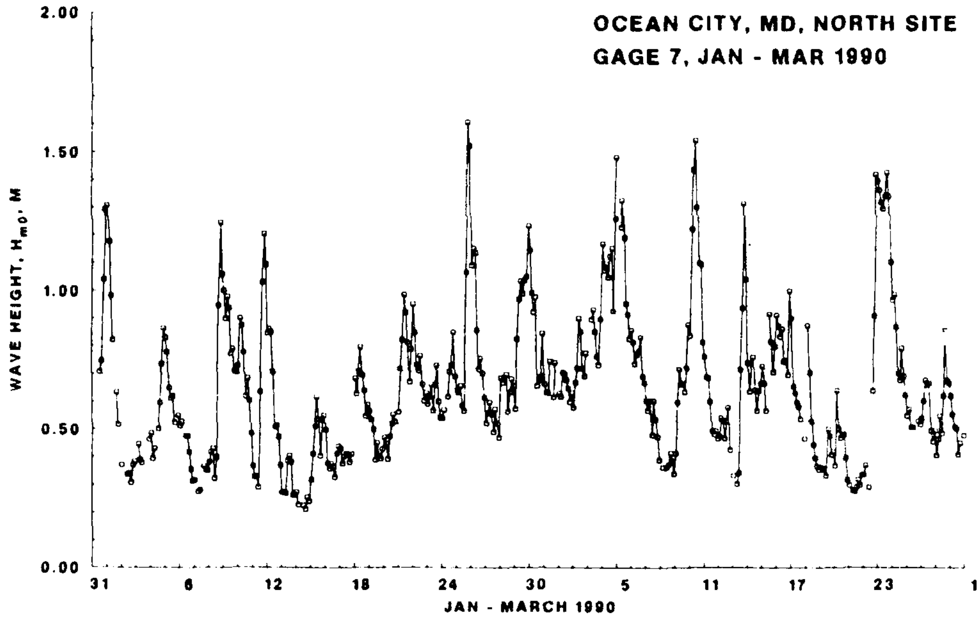
PLATE C24



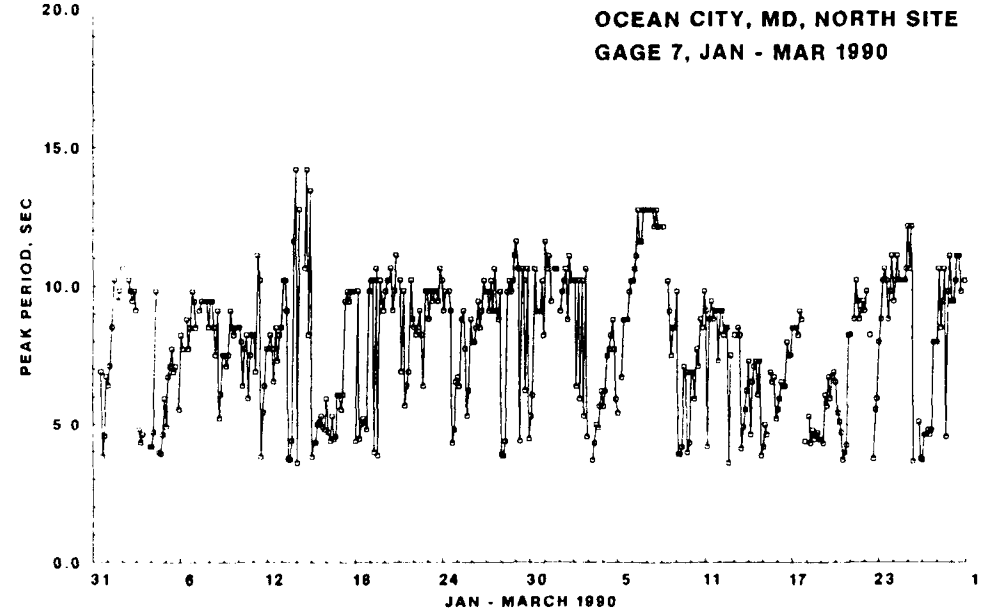


Significant Wave Height and Peak Period, North Site, October - December 1989

PLATE C25



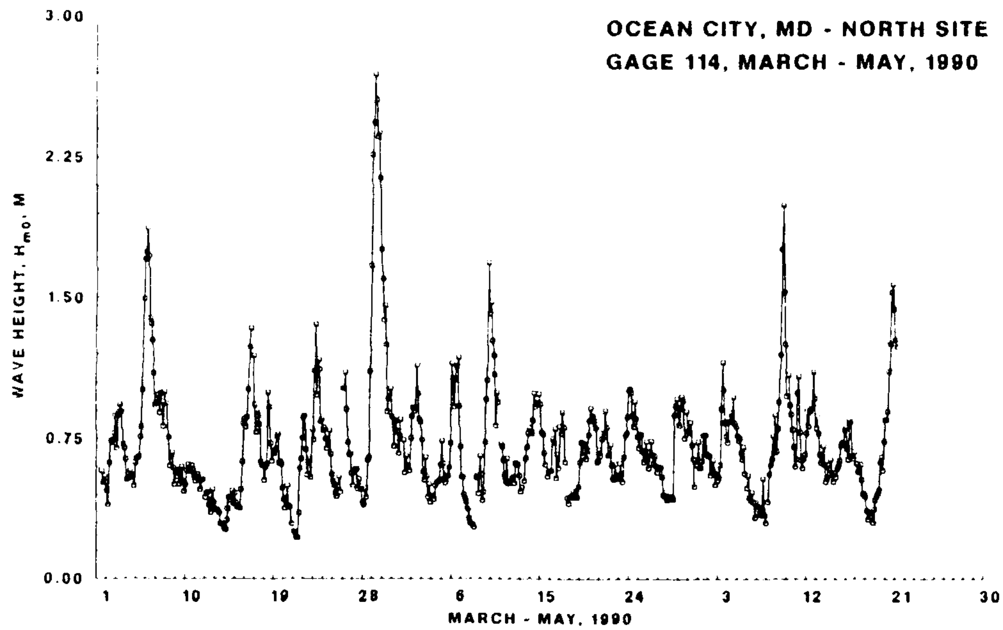
WAVE HEIGHT TIME SERIES



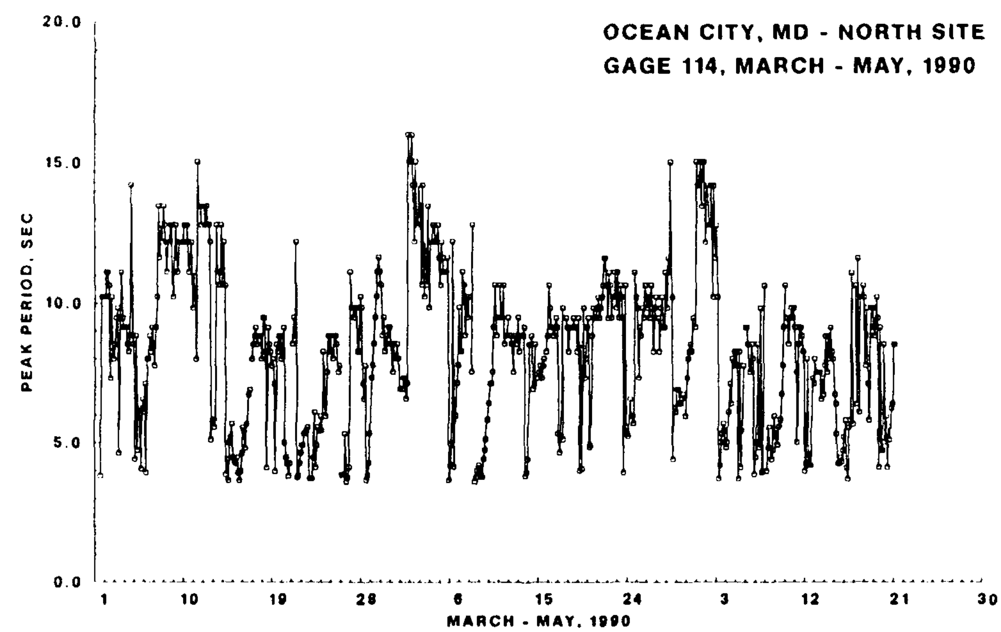
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, January - March 1990

PLATE C26



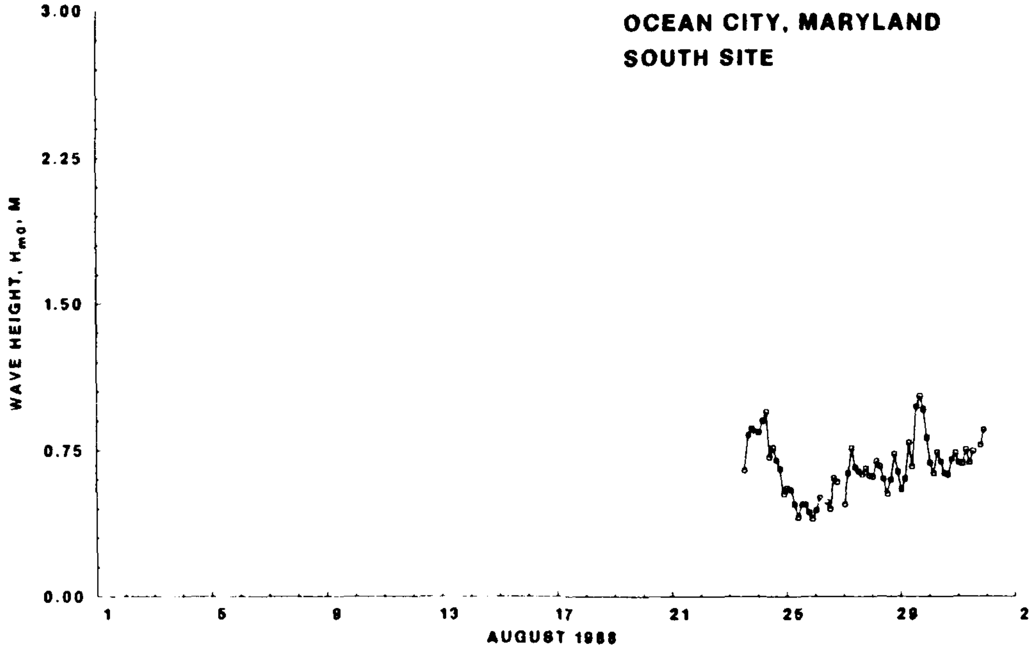
WAVE HEIGHT TIME SERIES



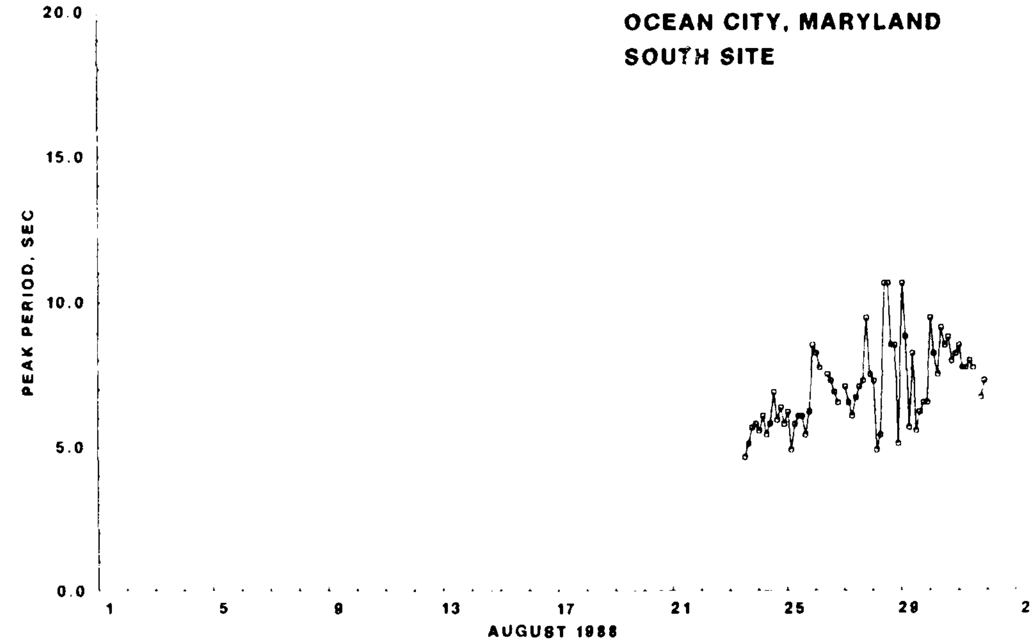
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, North Site, March - May 1990

PLATE C27



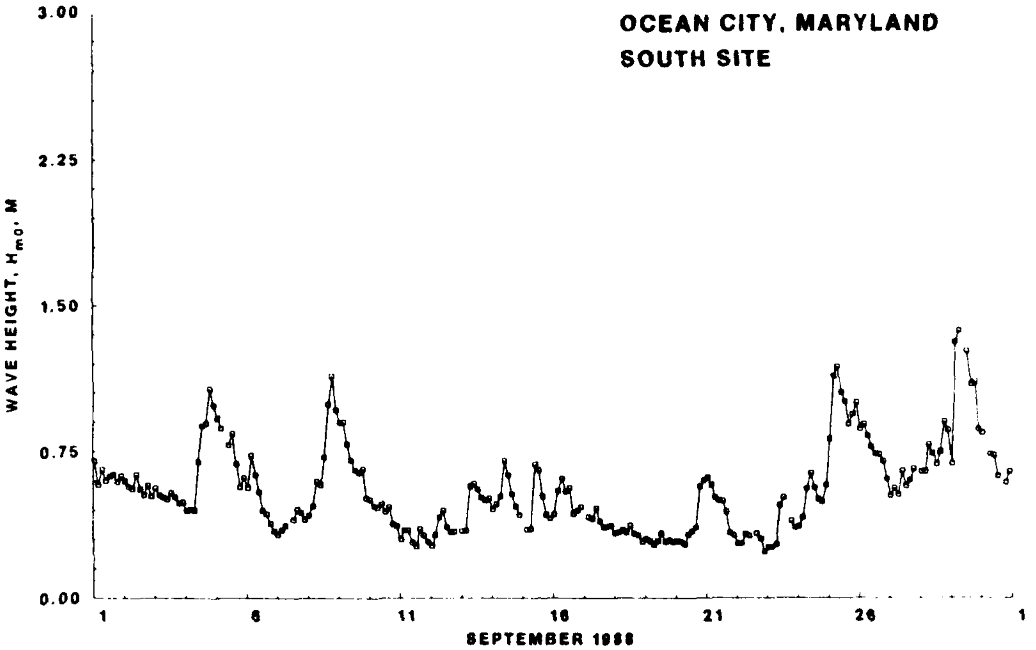
WAVE HEIGHT, H_{m0}



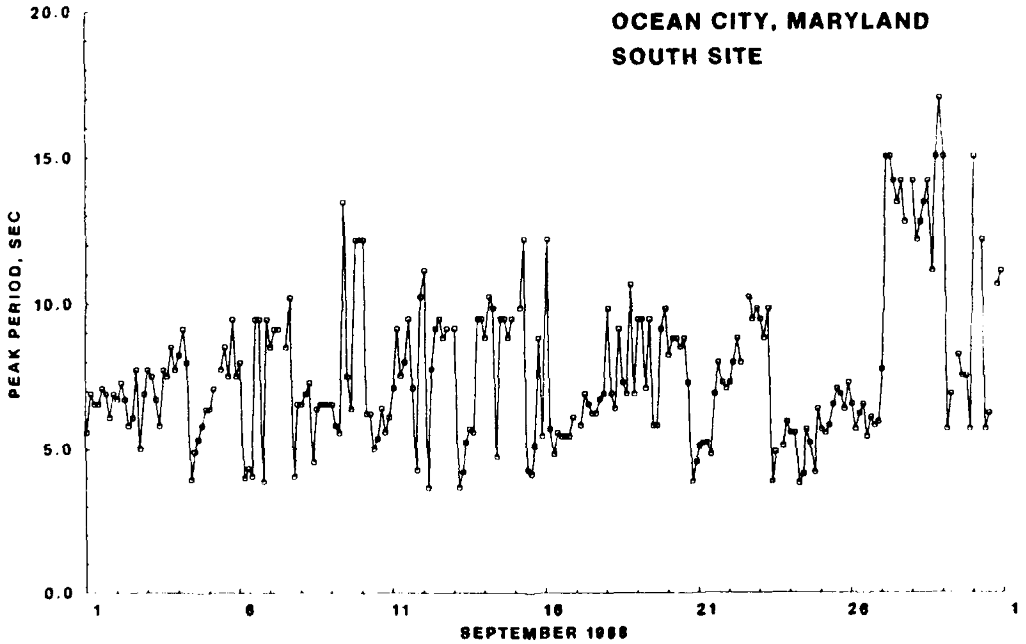
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, August 1988

PLATE C28



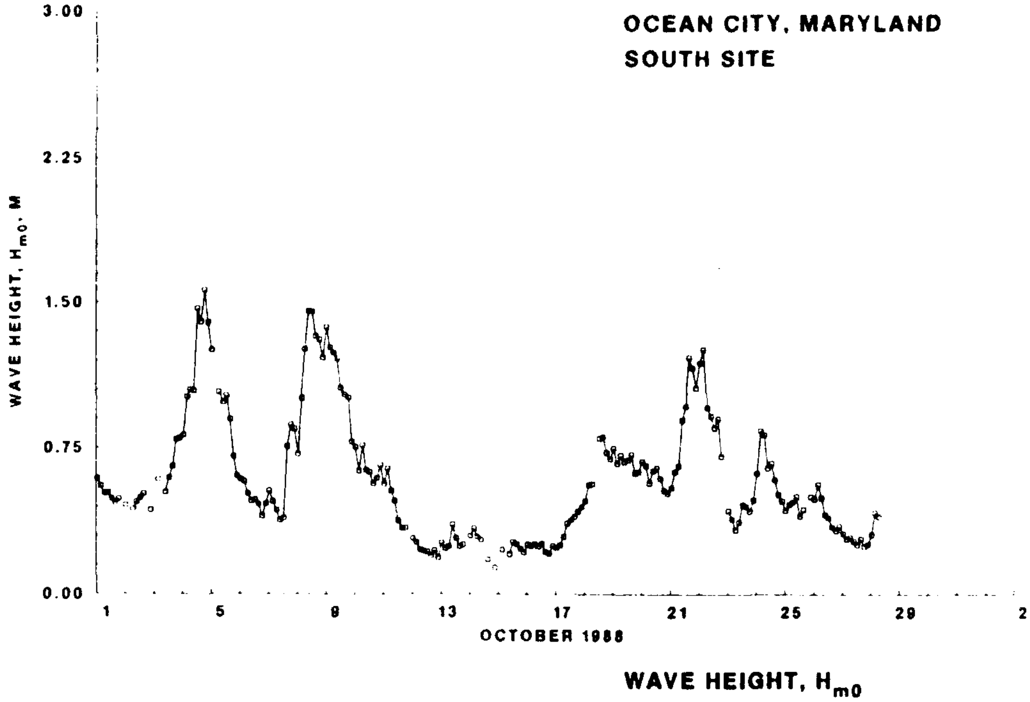
WAVE HEIGHT, H_{m0}

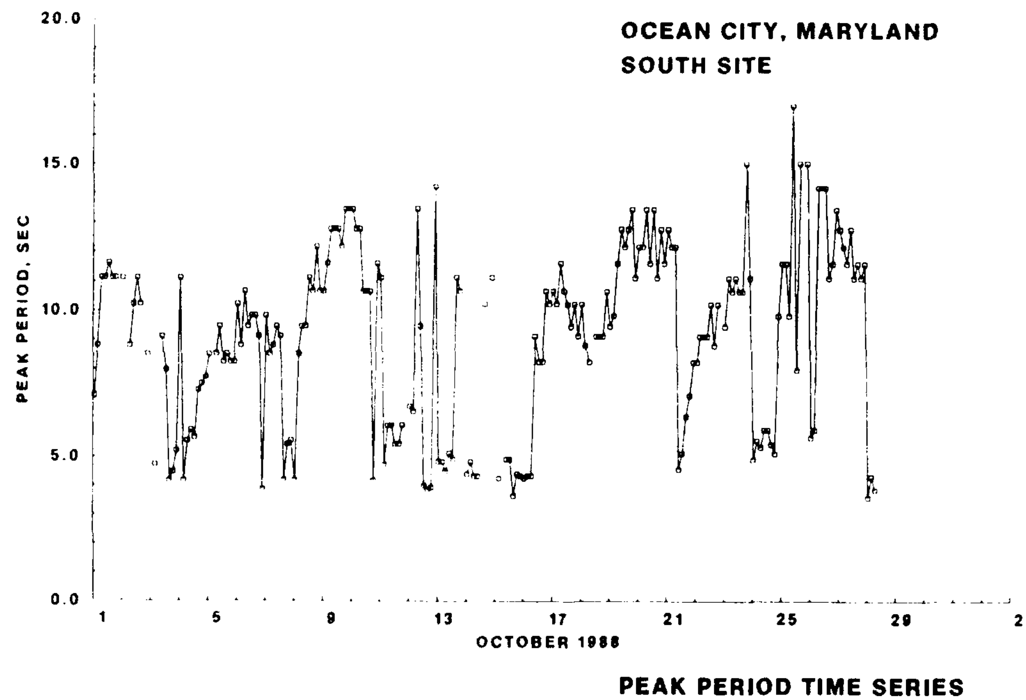


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, September 1988

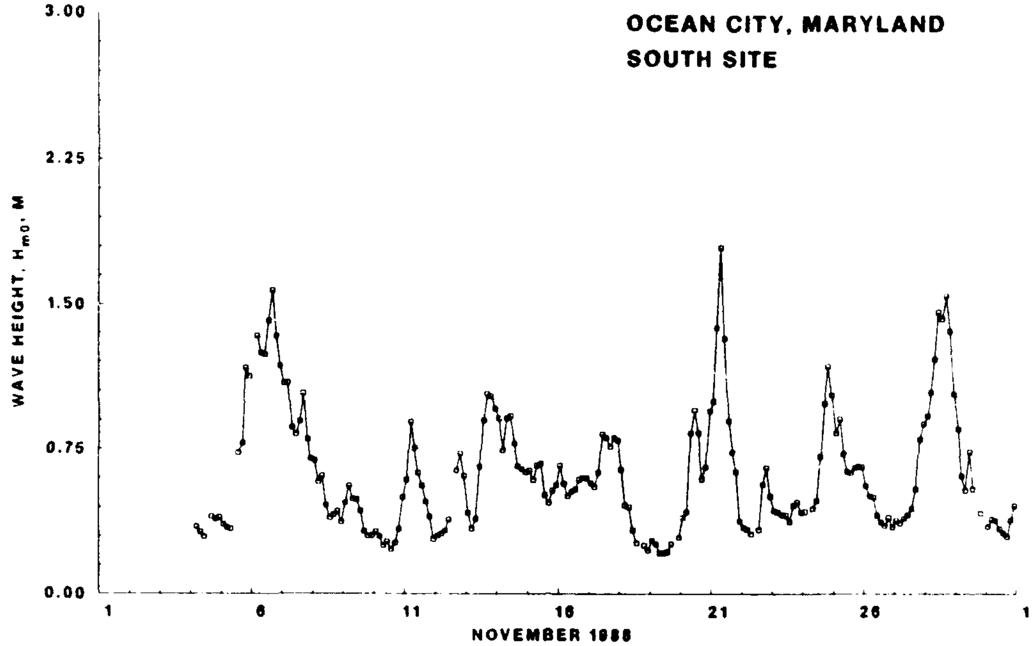
PLATE C29



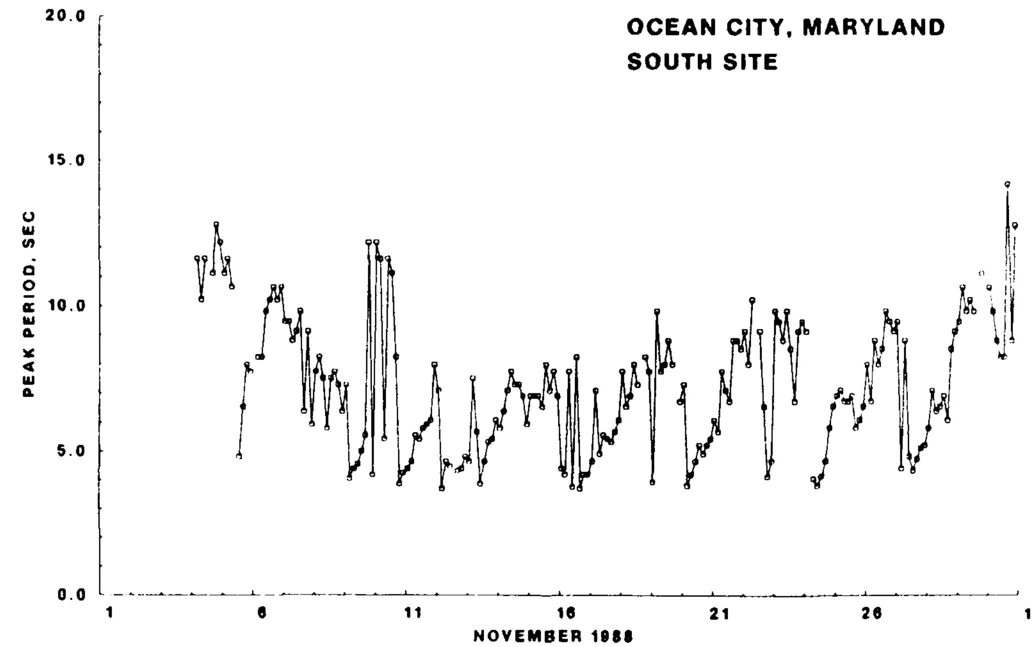


Significant Wave Height and Peak Period, South Site, October 1988

PLATE C30



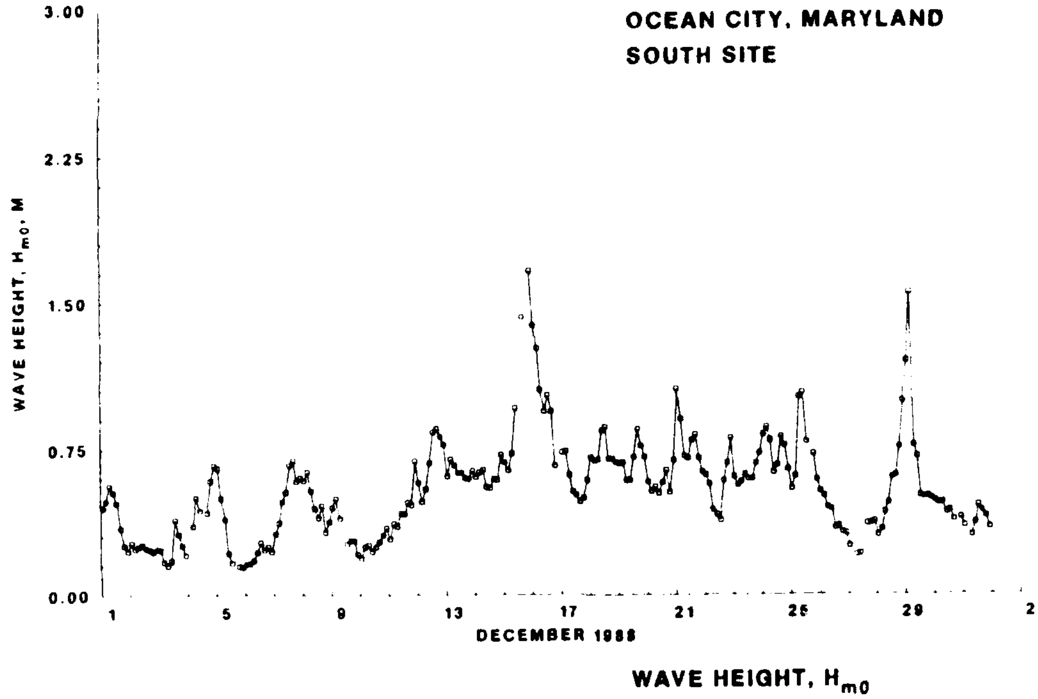
WAVE HEIGHT, H_{m0}



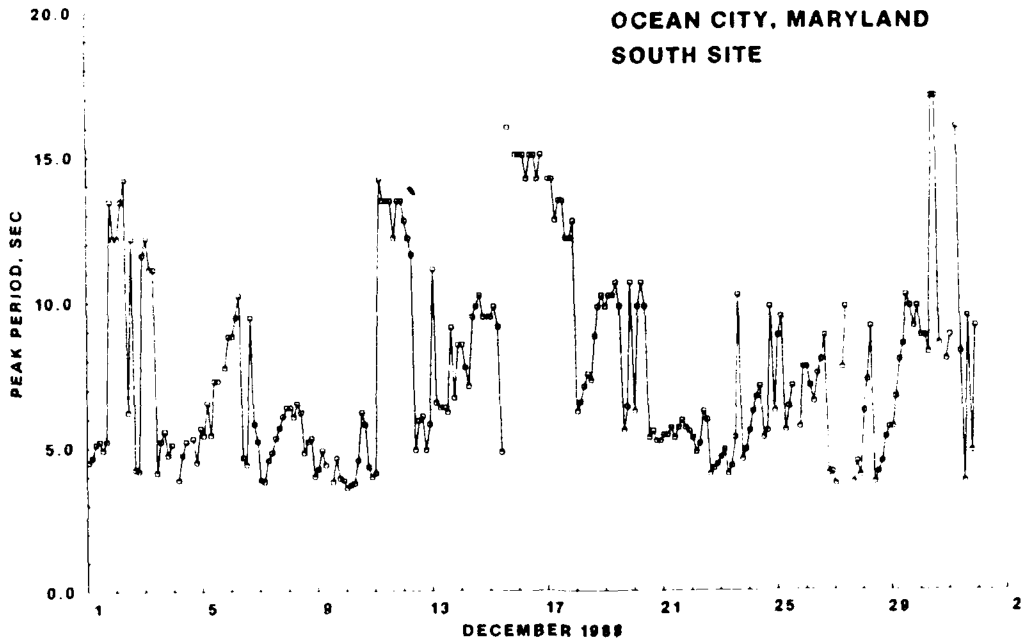
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, November 1988

PLATE C31



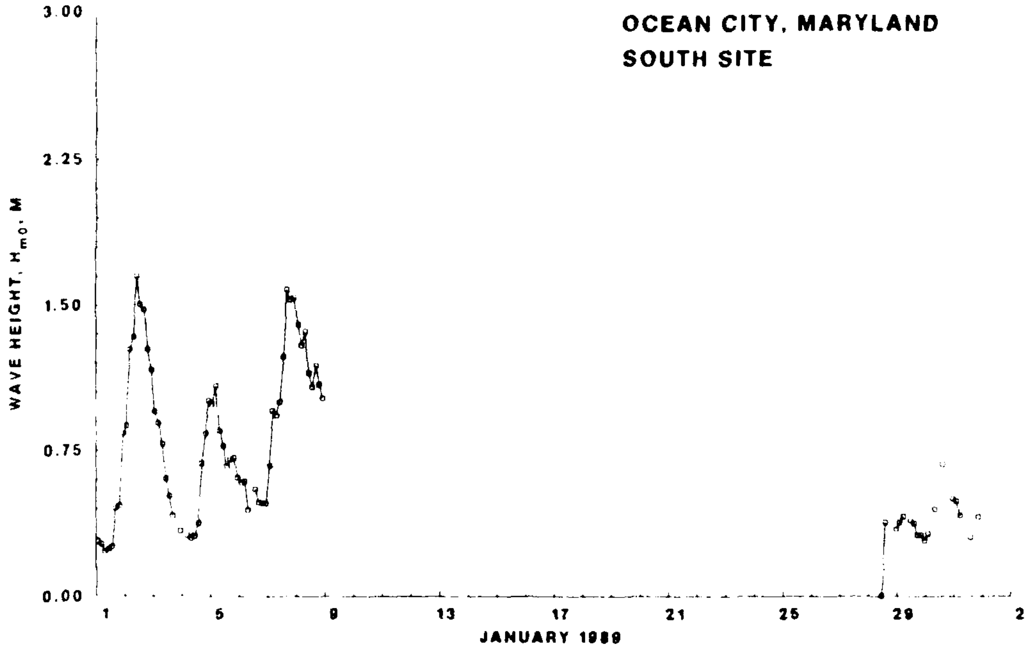
WAVE HEIGHT, H_{m0}



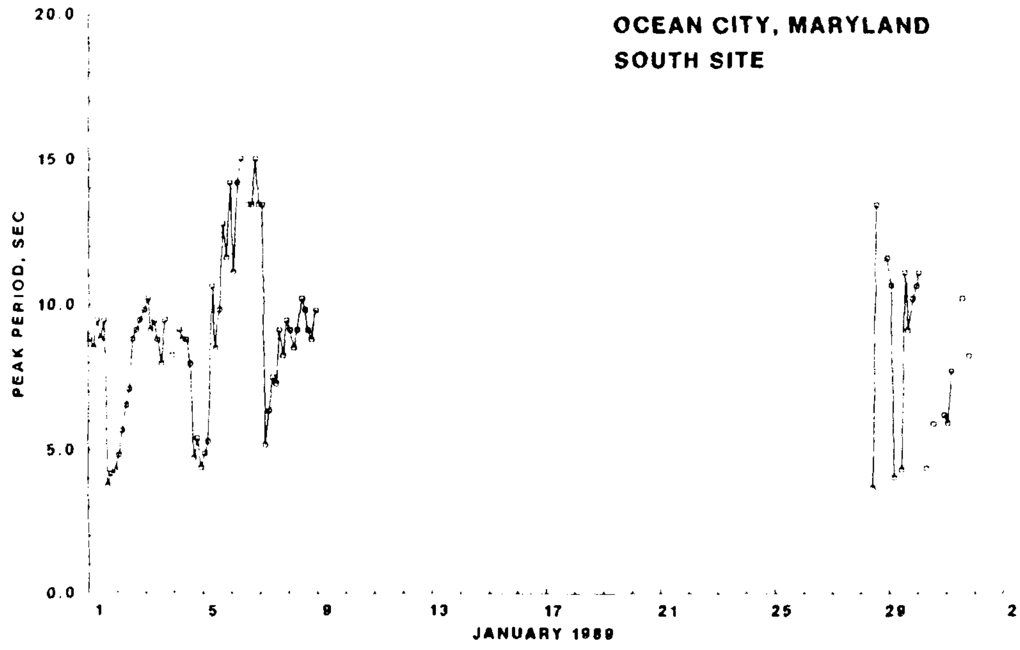
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, December 1988

PLATE C32



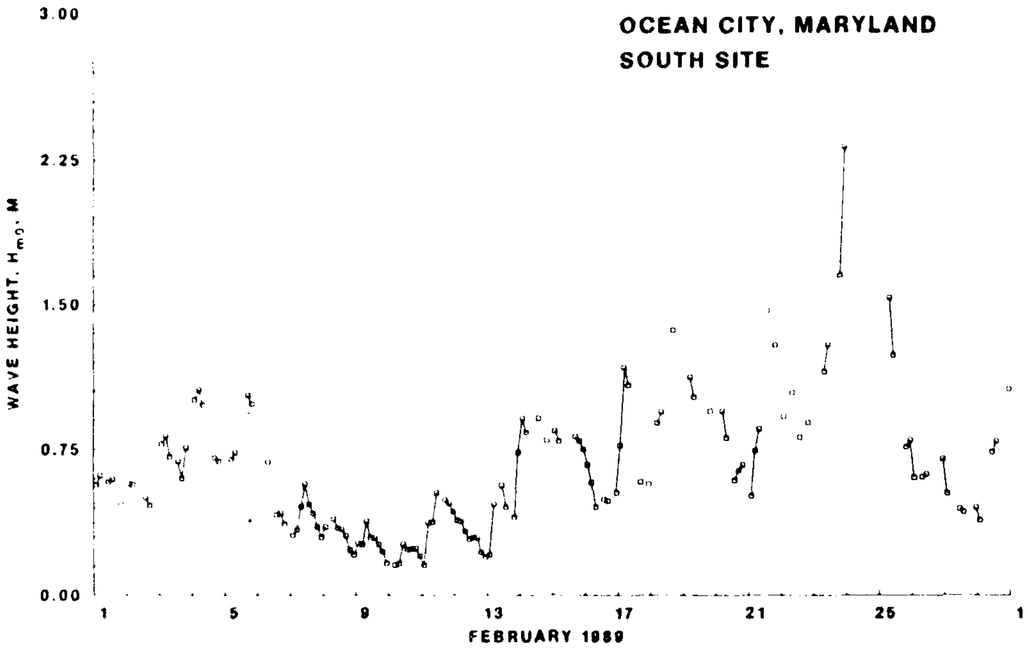
WAVE HEIGHT, H_{m0}



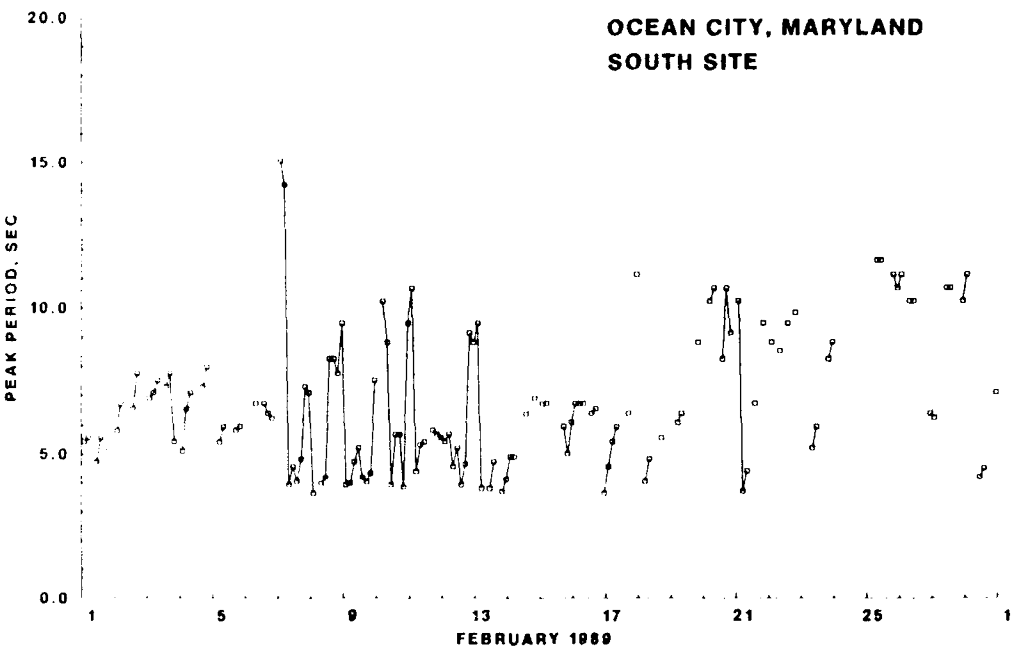
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, January 1989

PLATE C33



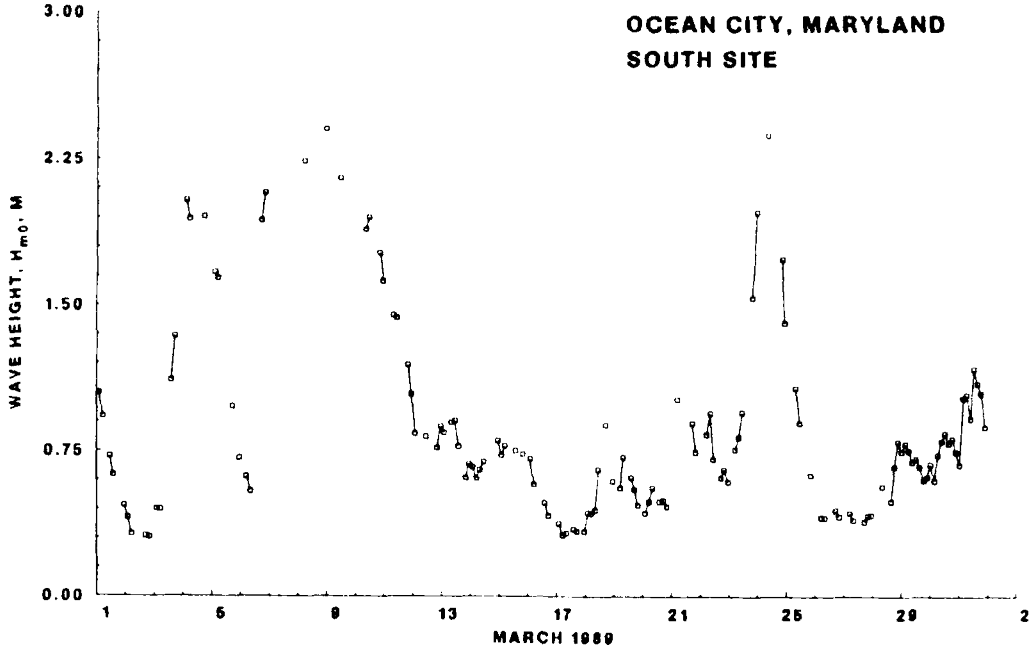
WAVE HEIGHT, H_{m0}



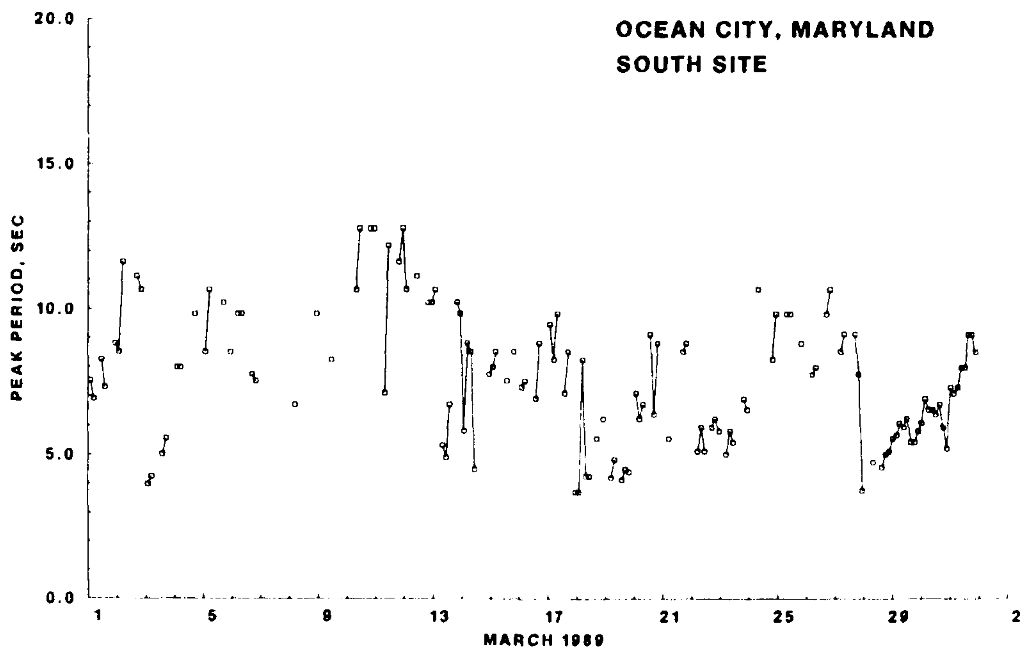
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, February 1989

PLATE C34



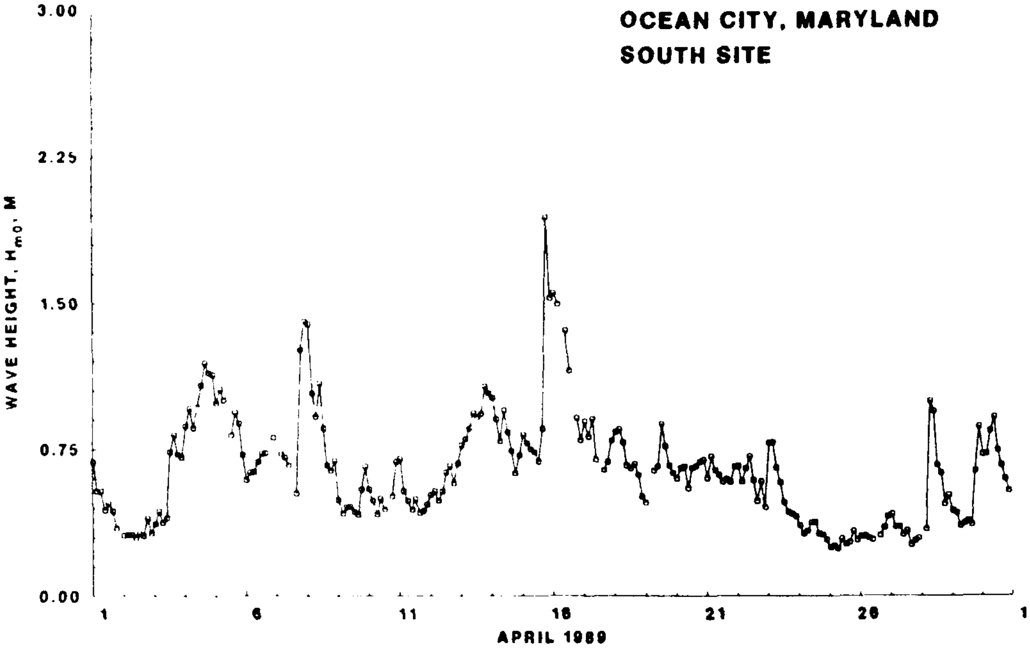
WAVE HEIGHT, H_{m0}



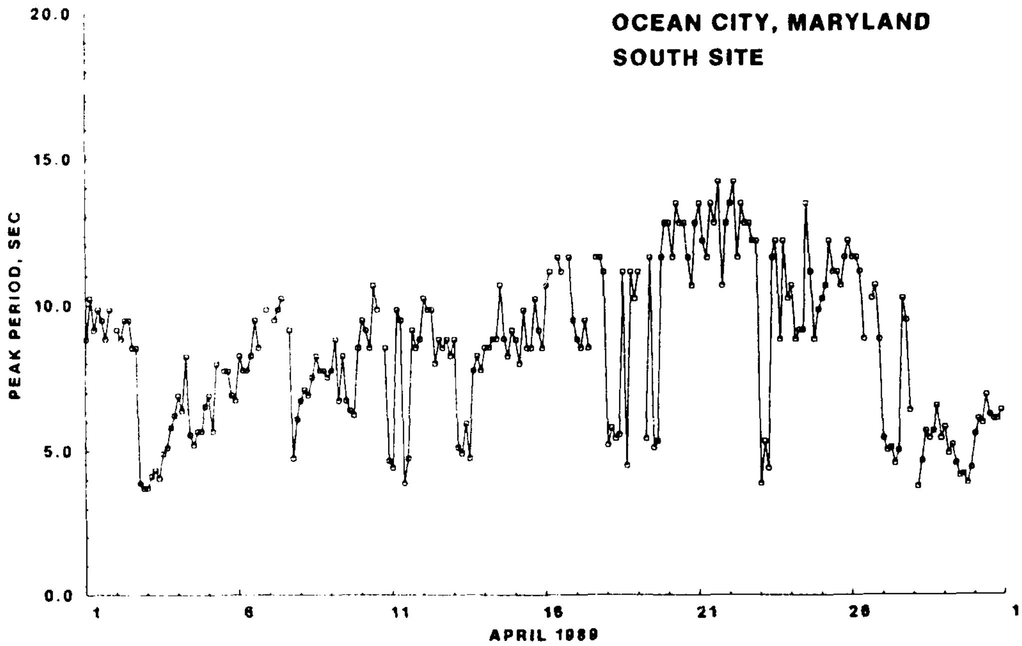
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, March 1989

PLATE C35



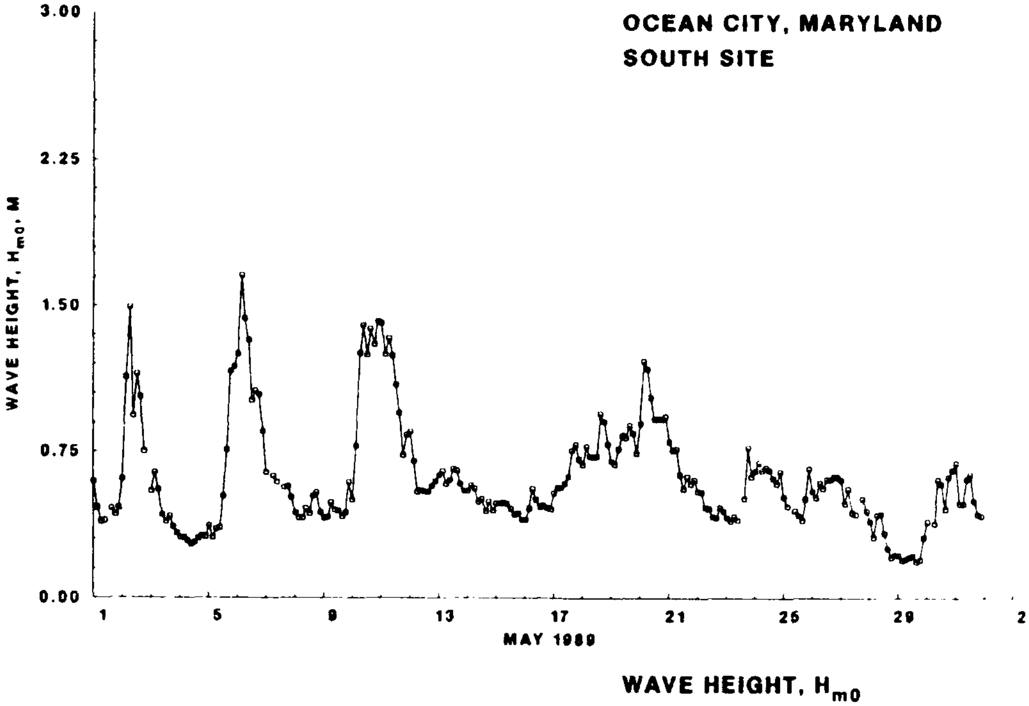
WAVE HEIGHT, H_{m0}

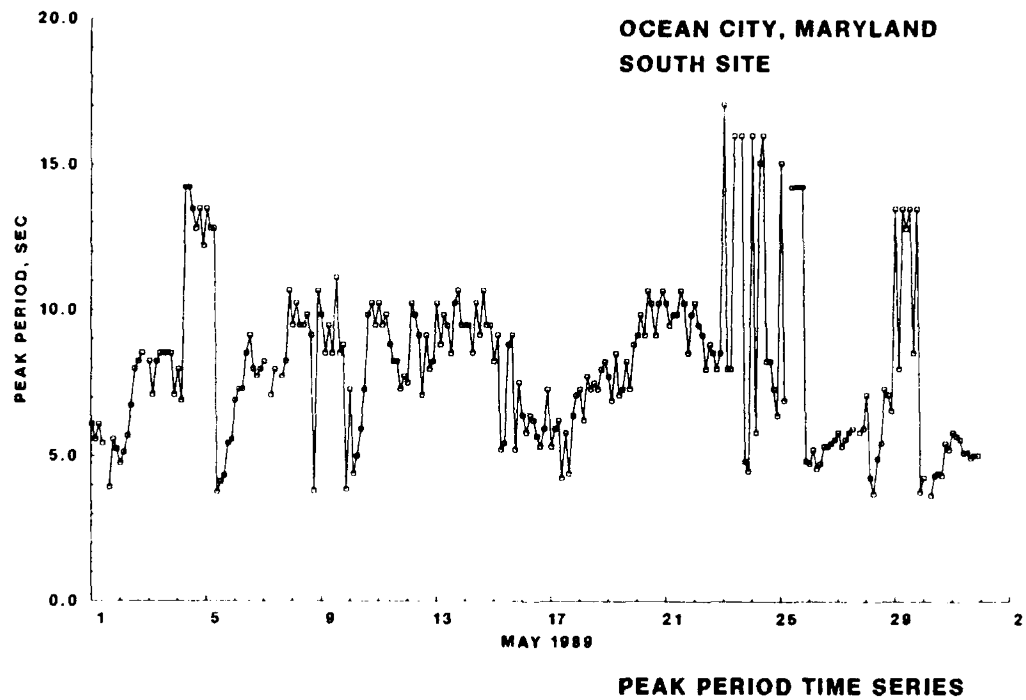


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, April 1989

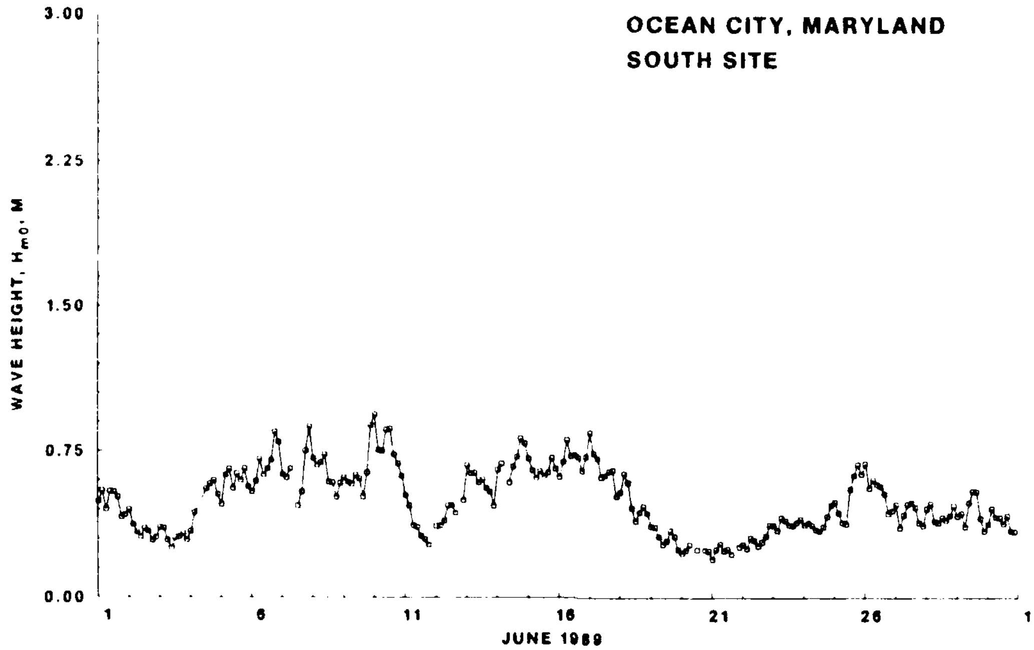
PLATE C36



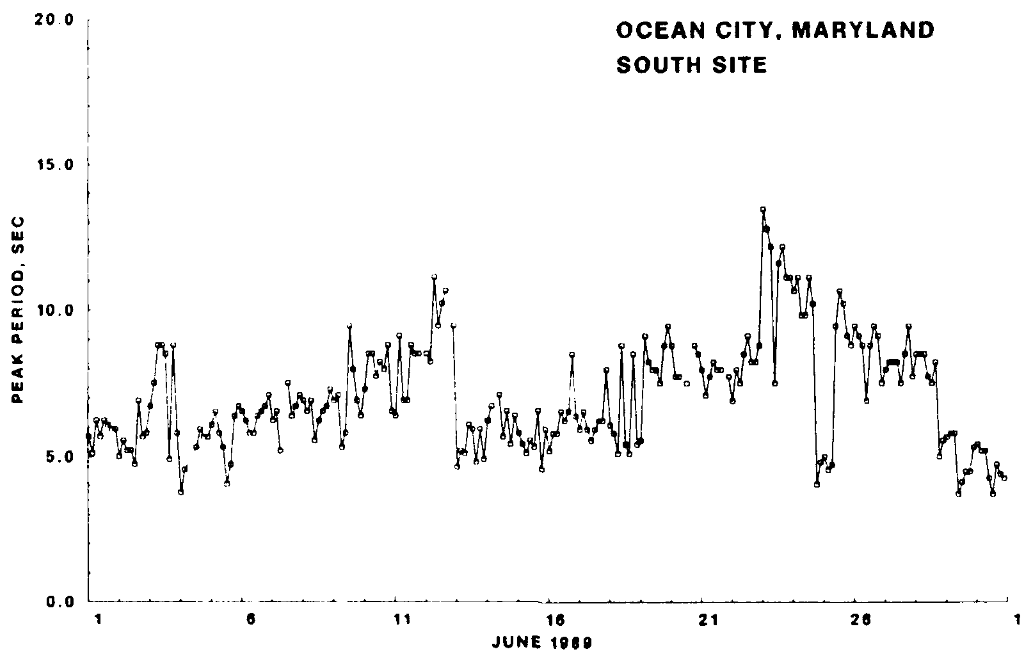


Significant Wave Height and Peak Period, South Site, May 1989

PLATE C37



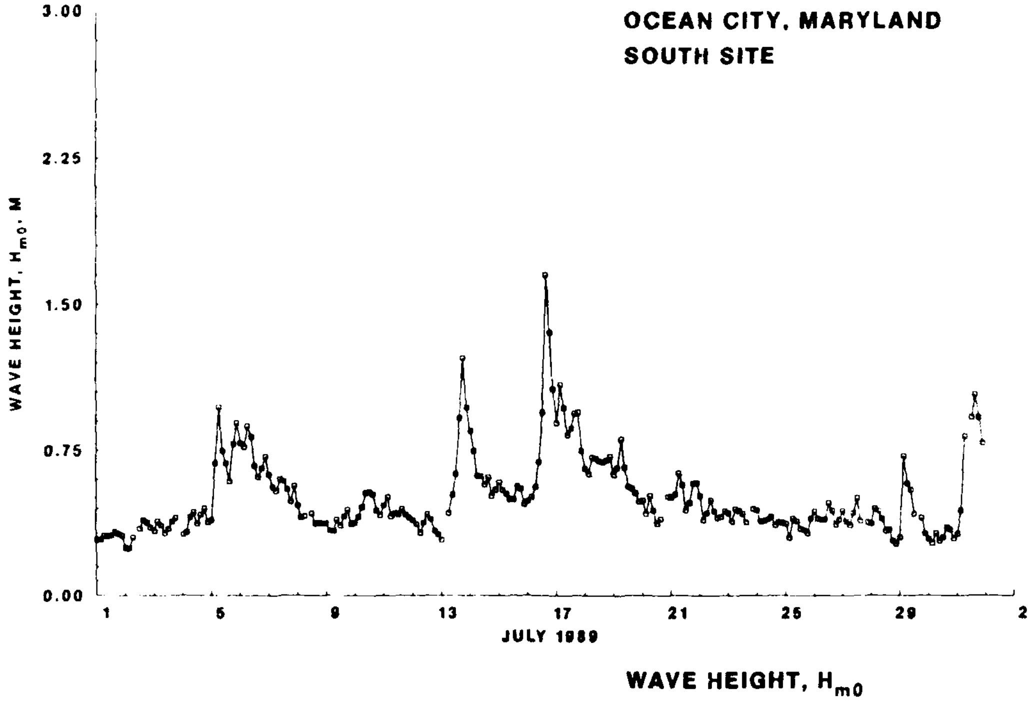
WAVE HEIGHT, H_{m0}

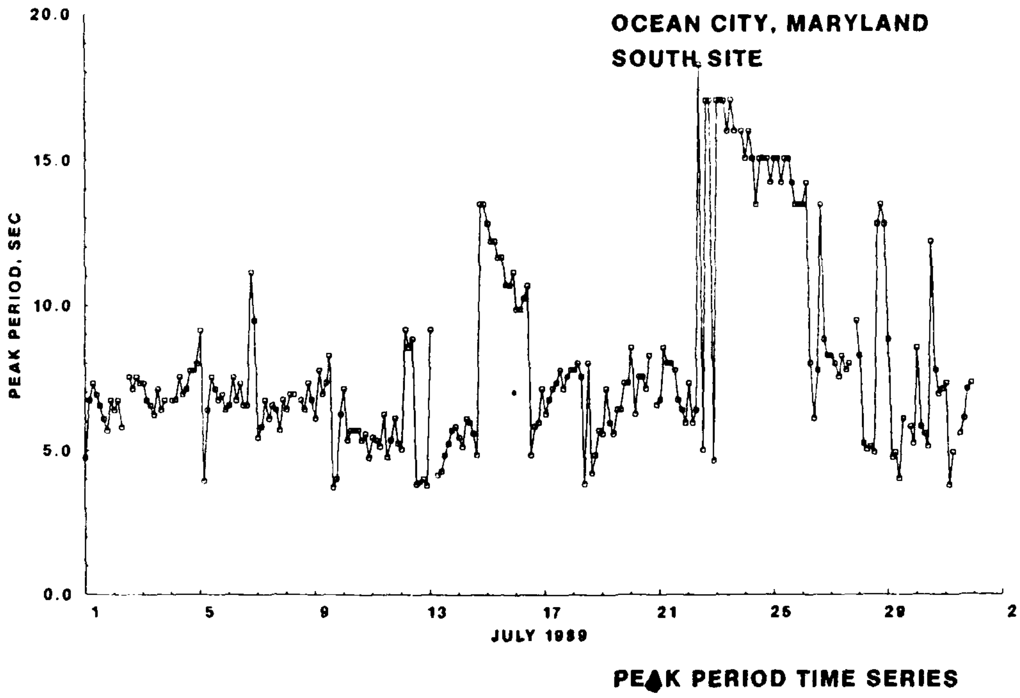


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, June 1989

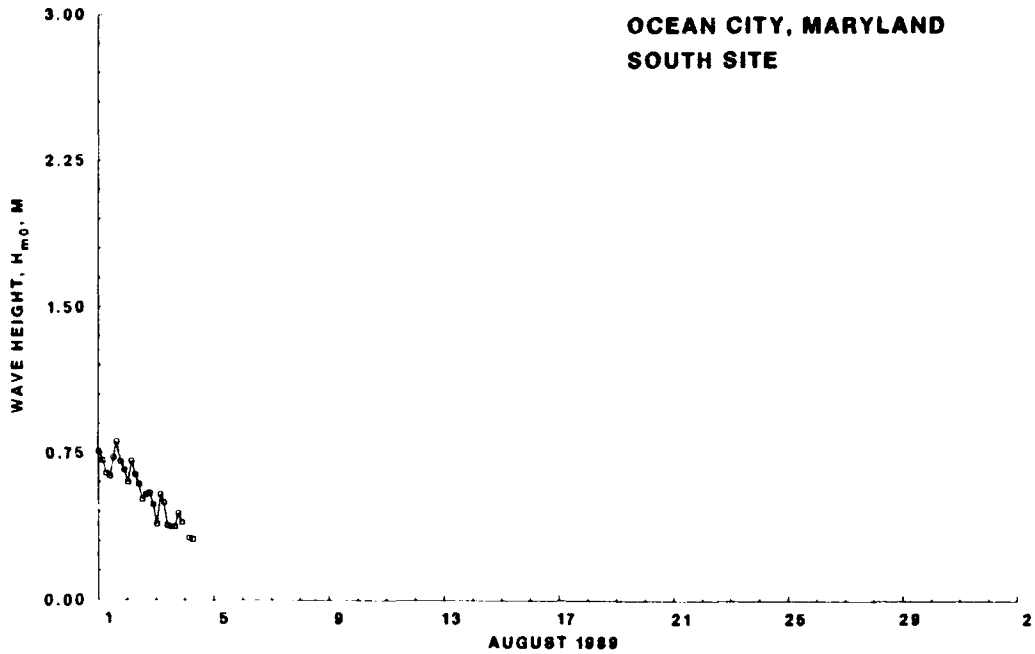
PLATE C38



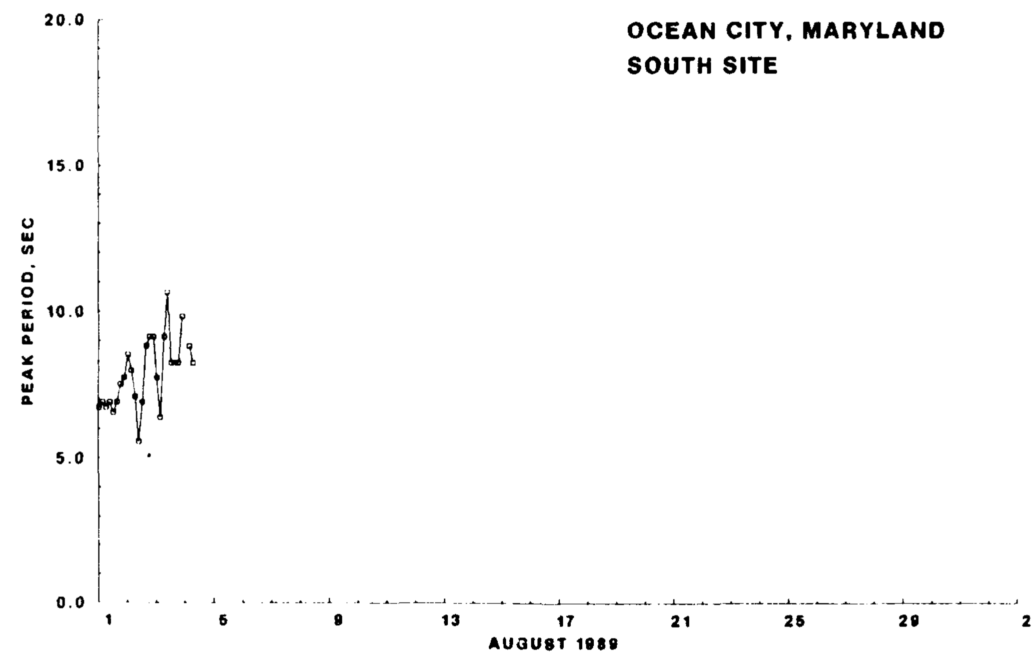


Significant Wave Height and Peak Period, South Site, July 1989

PLATE C39



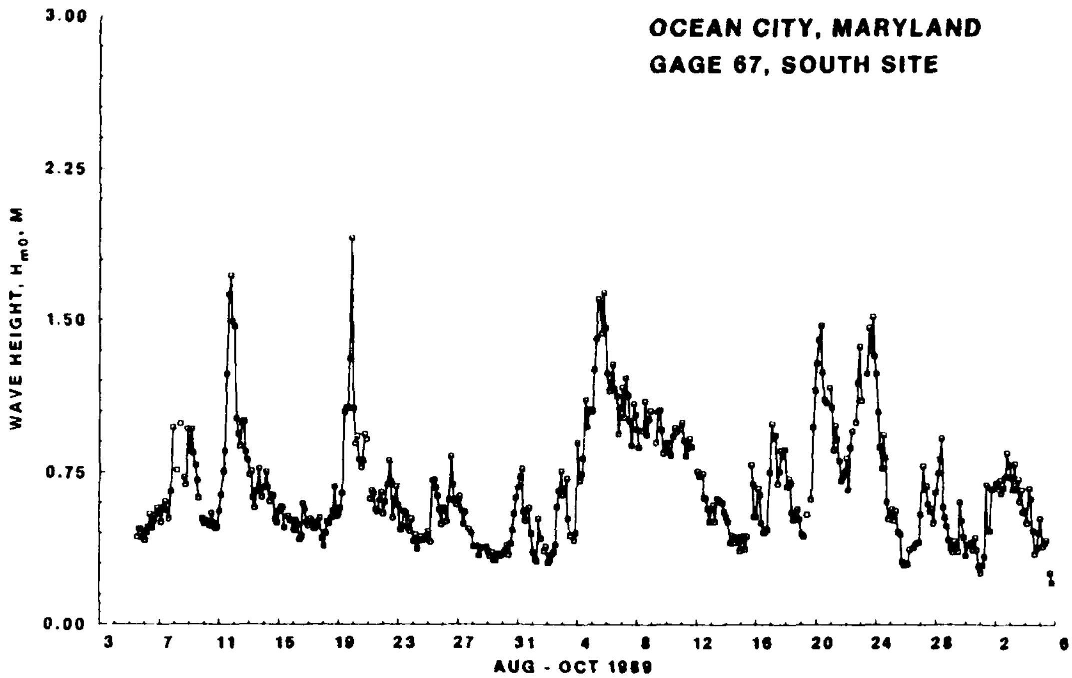
WAVE HEIGHT, H_{m0}



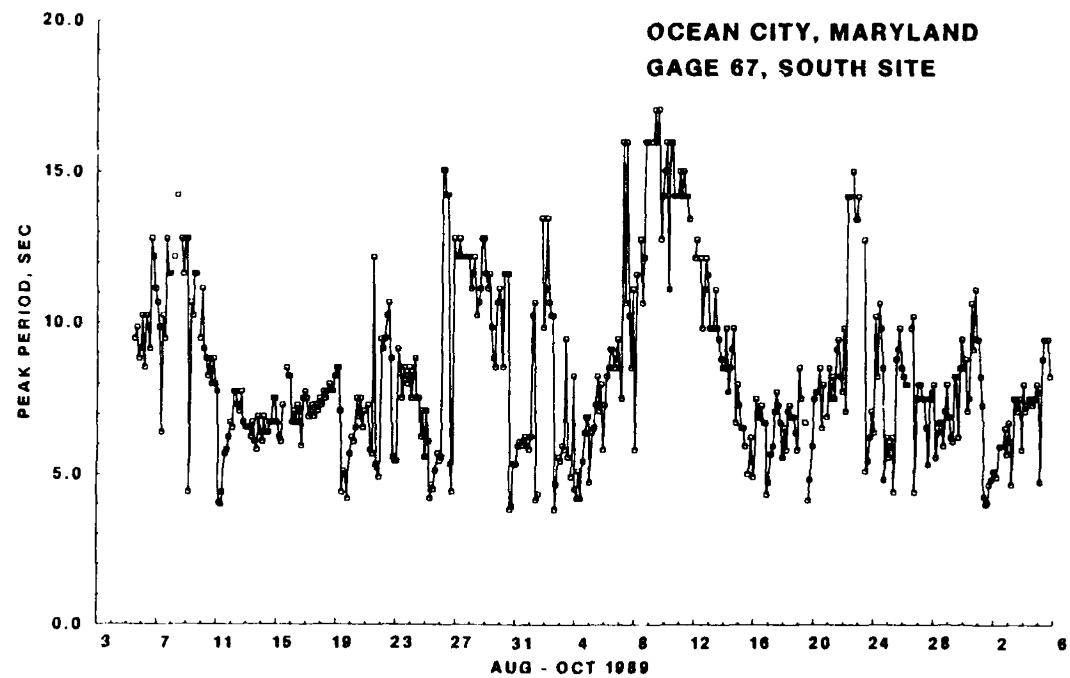
PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, August 1989

PLATE C40



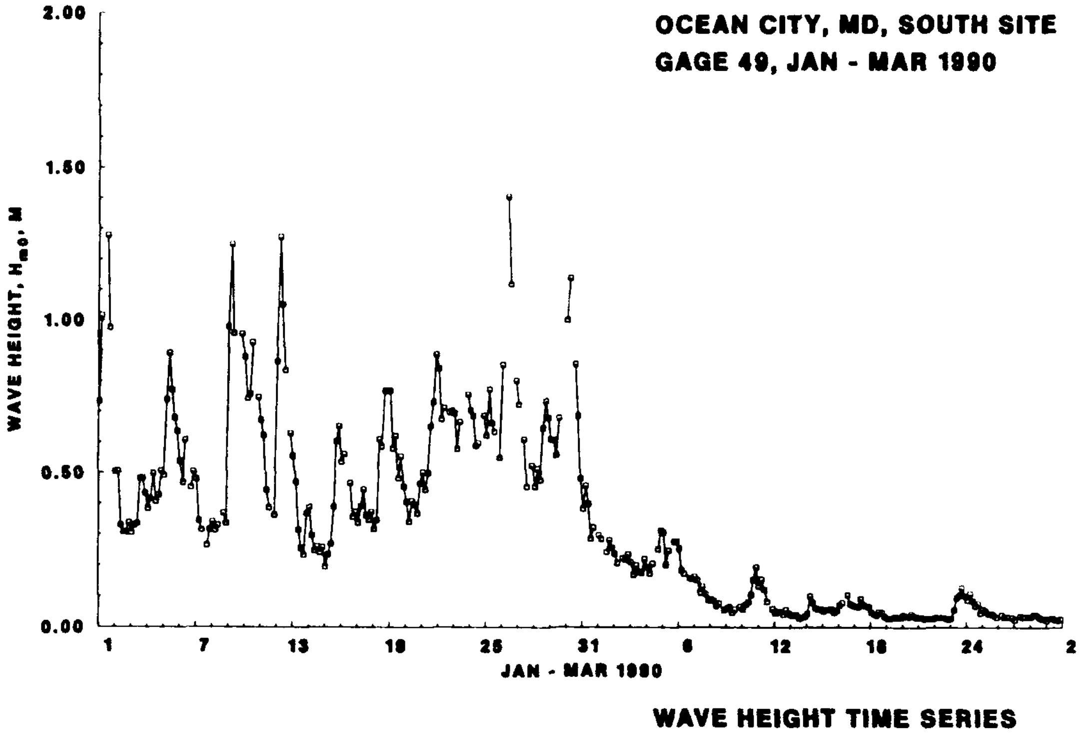
WAVE HEIGHT TIME SERIES

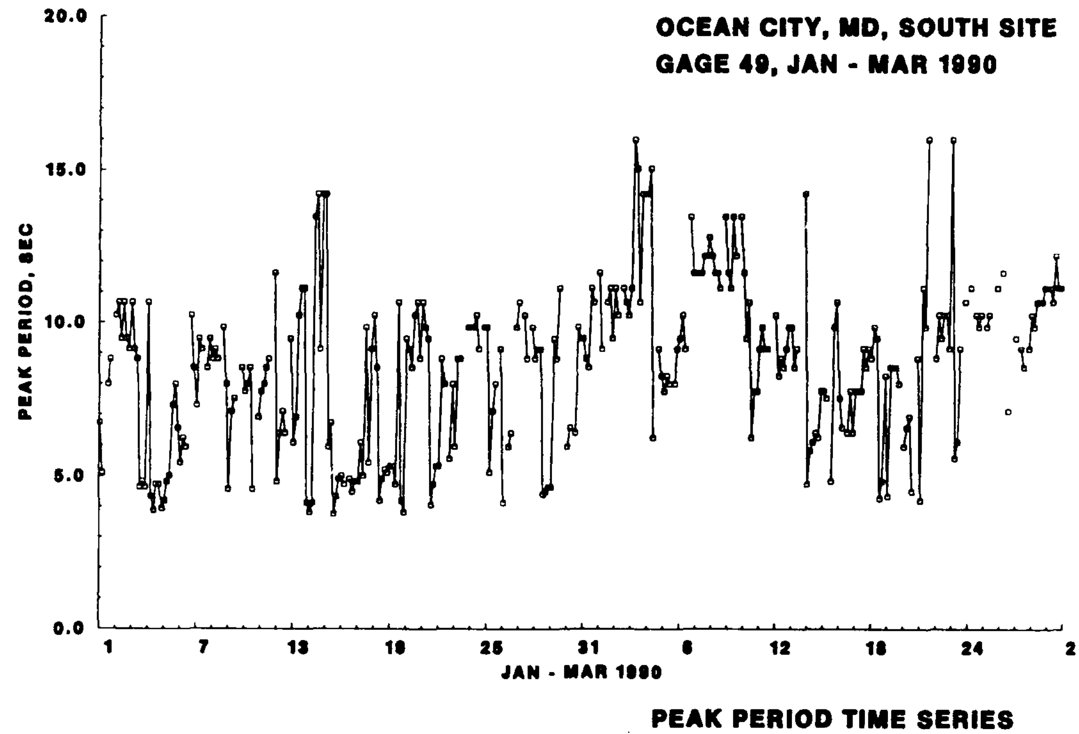


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, August - October 1989

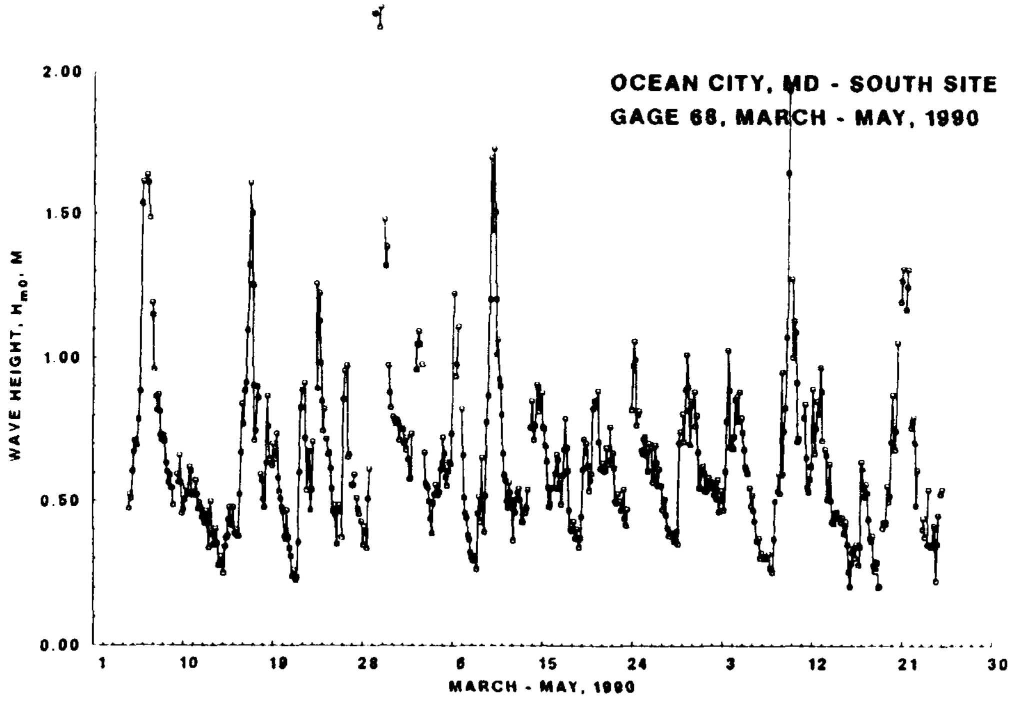
PLATE C41



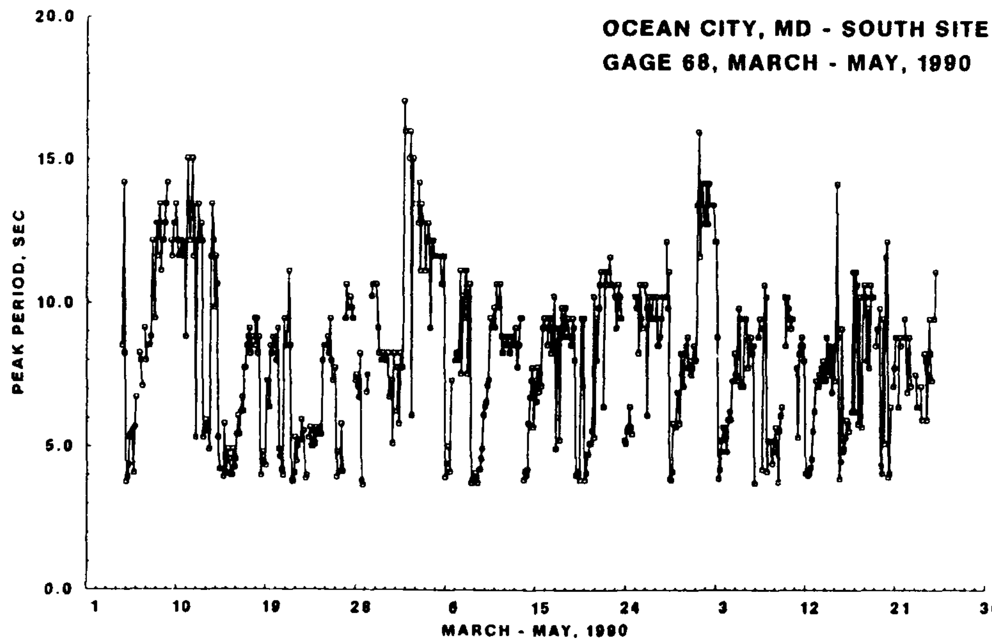


Significant Wave Height and Peak Period, South Site, January - March 1990

PLATE C42



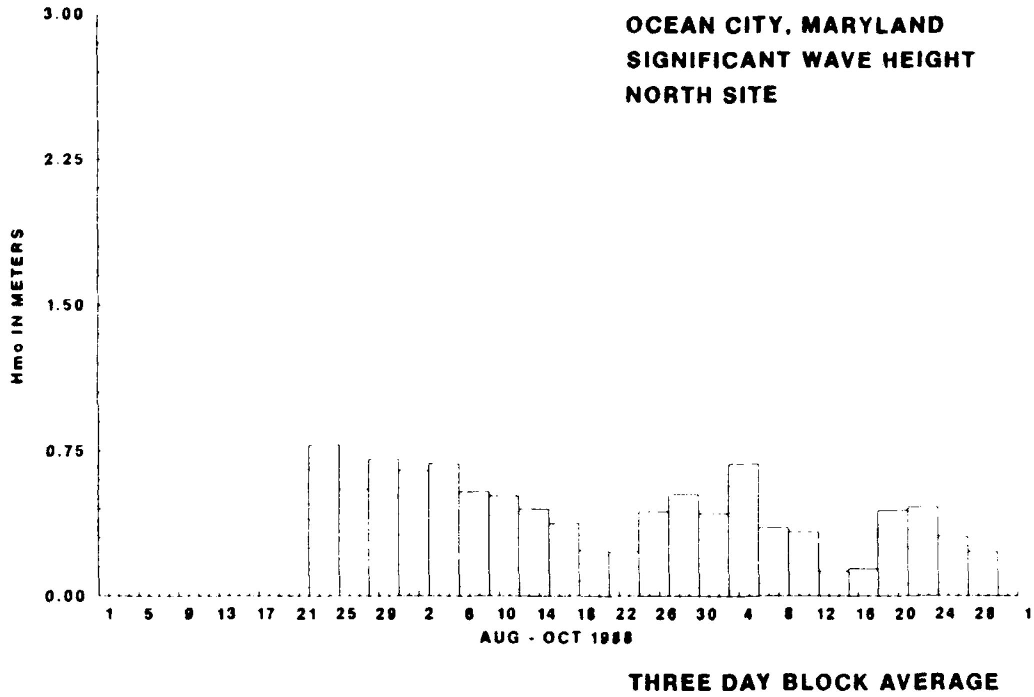
WAVE HEIGHT TIME SERIES

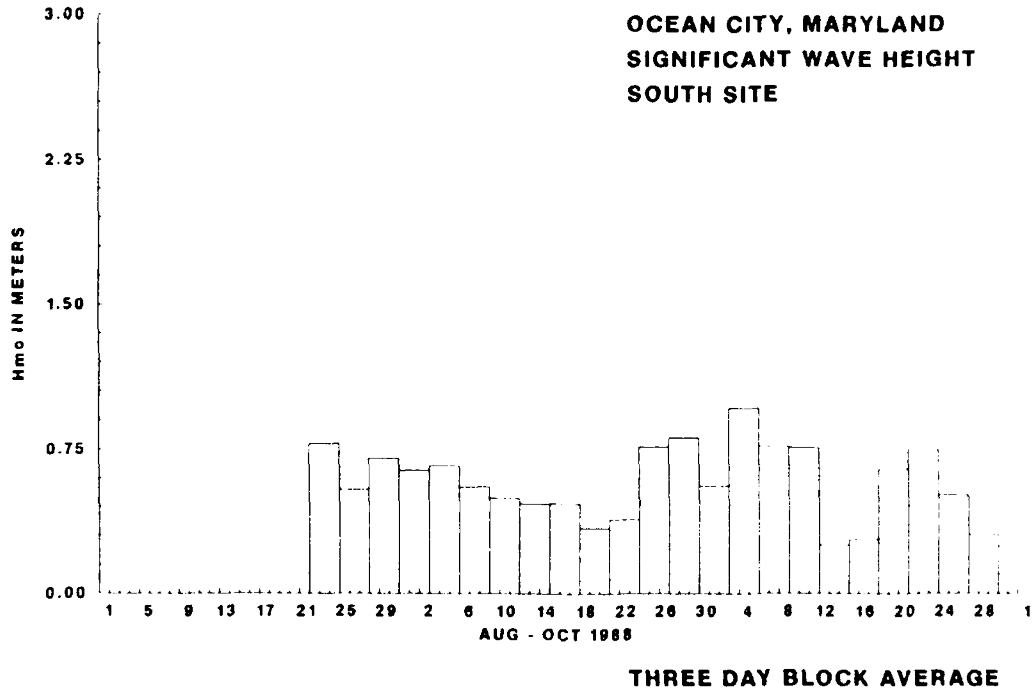


PEAK PERIOD TIME SERIES

Significant Wave Height and Peak Period, South Site, March - May 1990

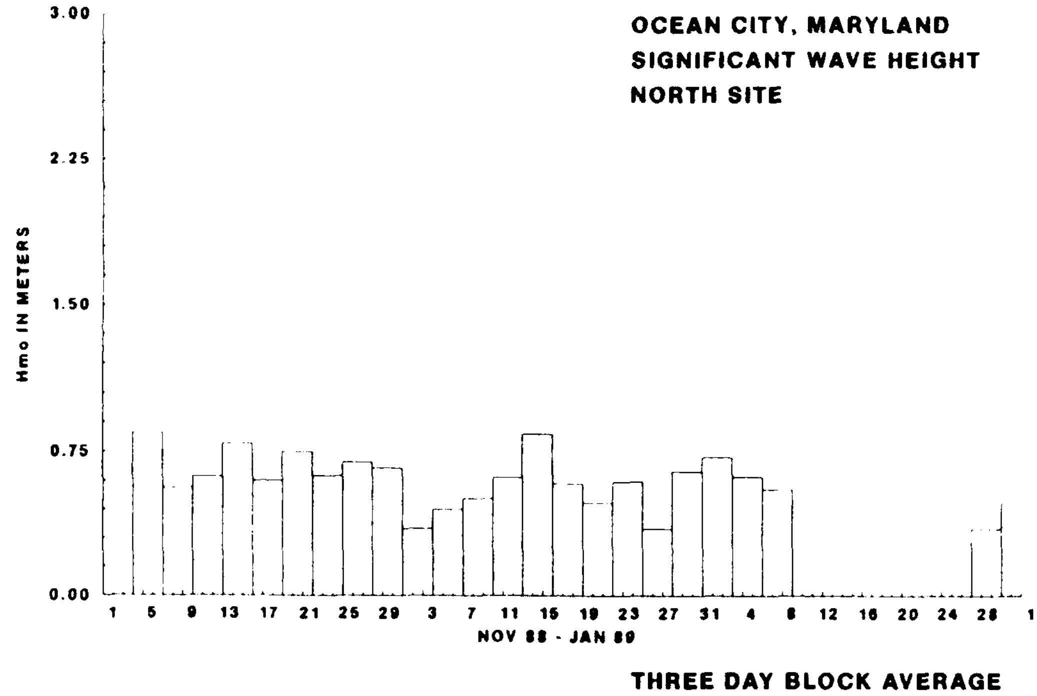
PLATE C43

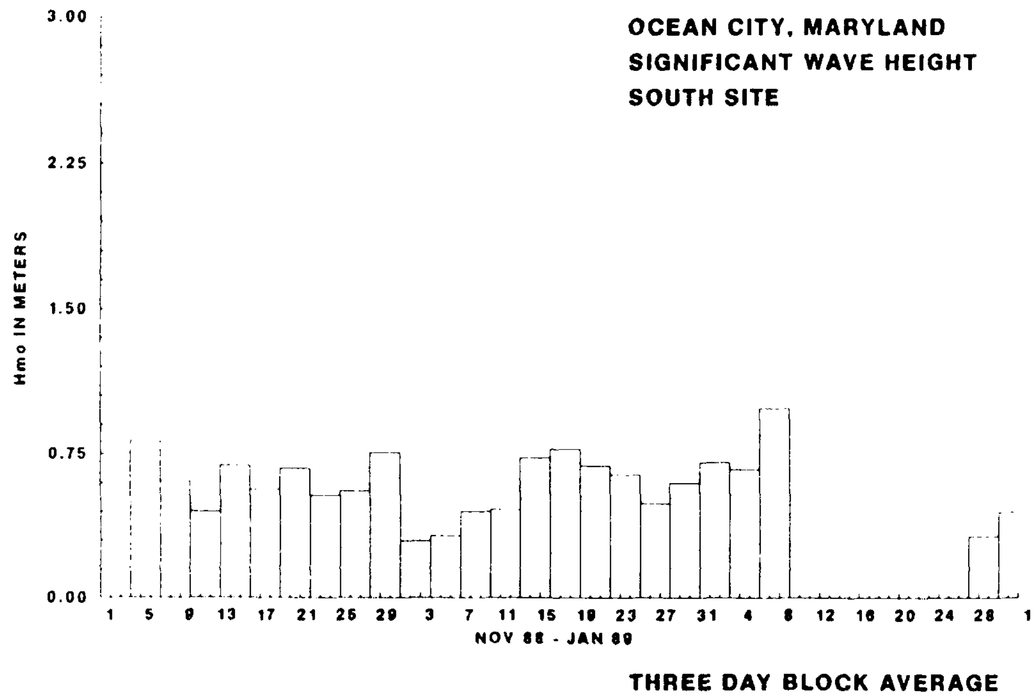




Three Day Block Averages of Significant Wave Height, North and South Sites

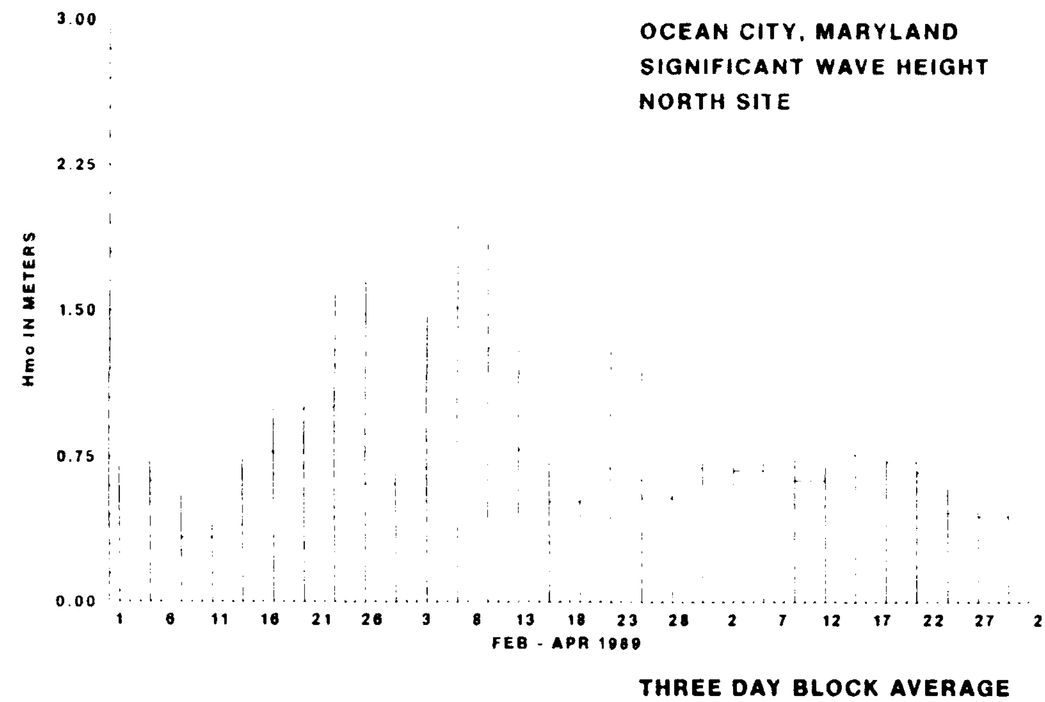
PLATE C44

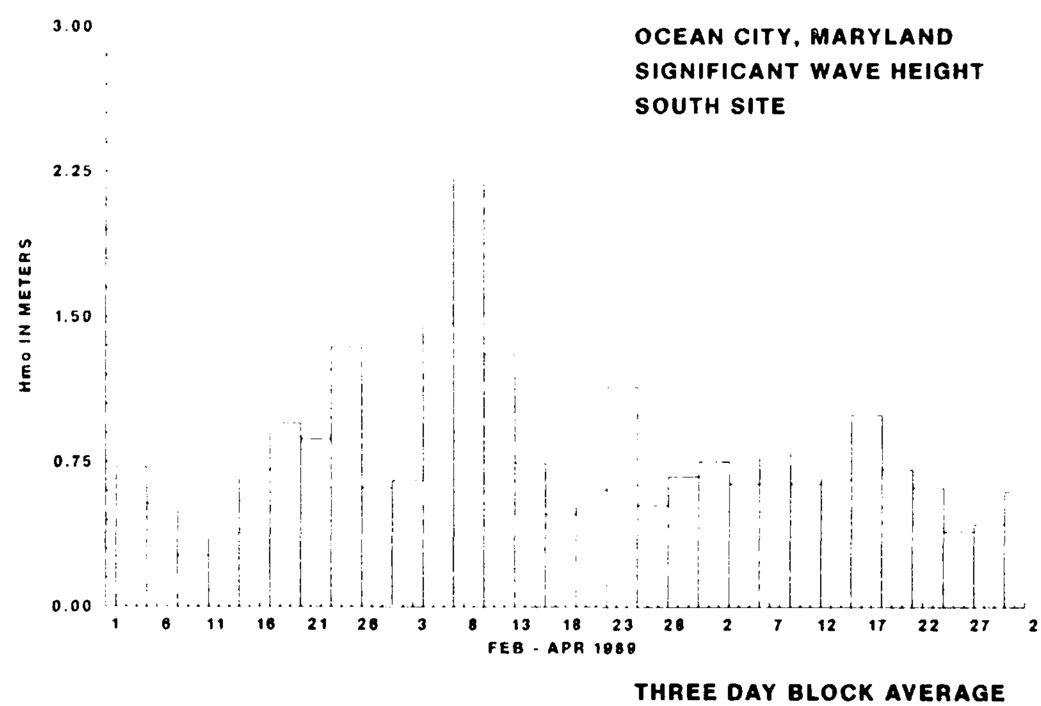




Three Day Block Averages of Significant Wave Height, North and South Sites

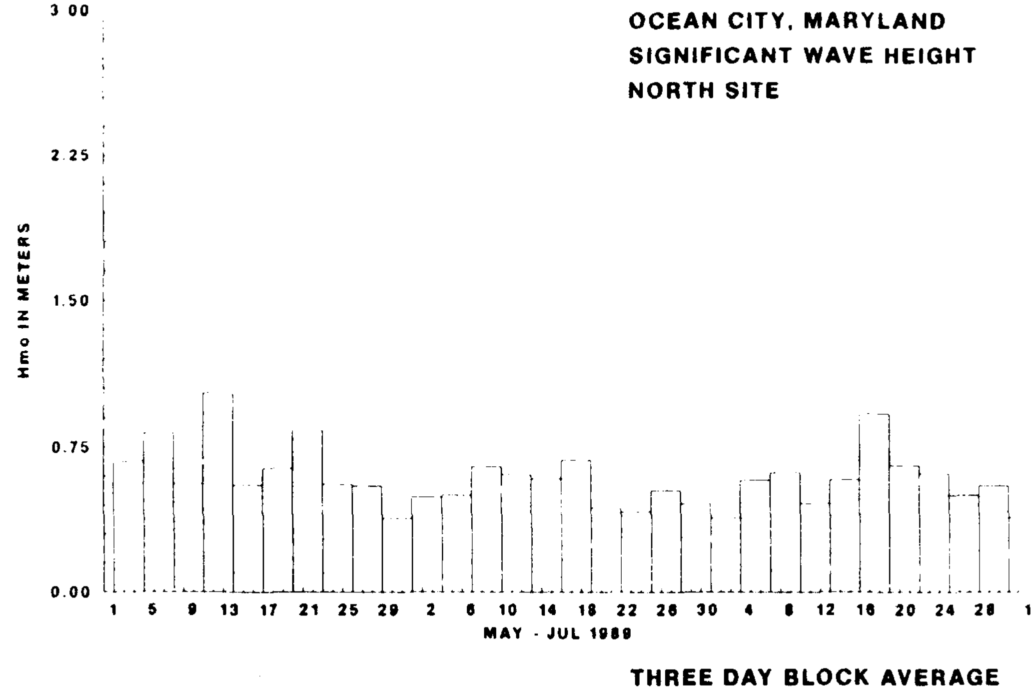
PLATE C45

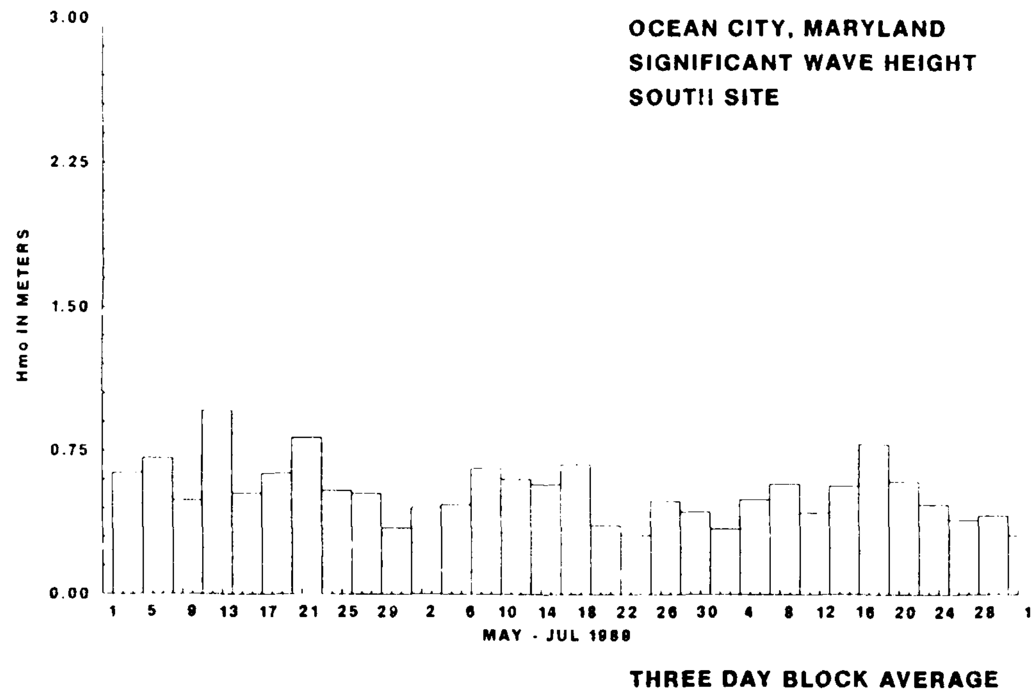




Three Day Block Averages of Significant Wave Height, North and South Sites

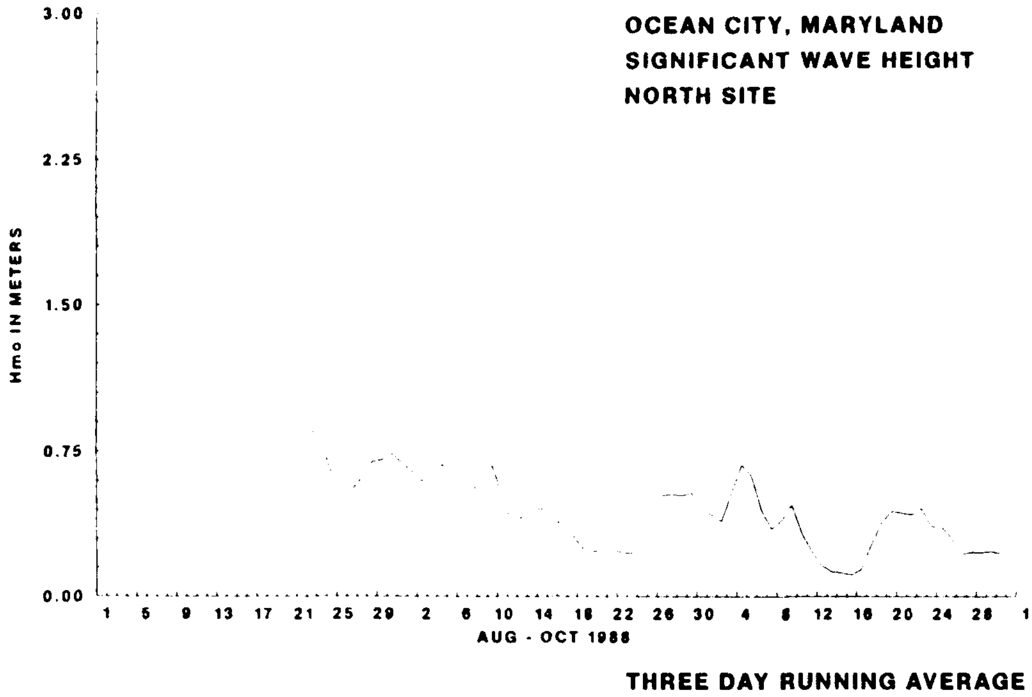
PLATE C46

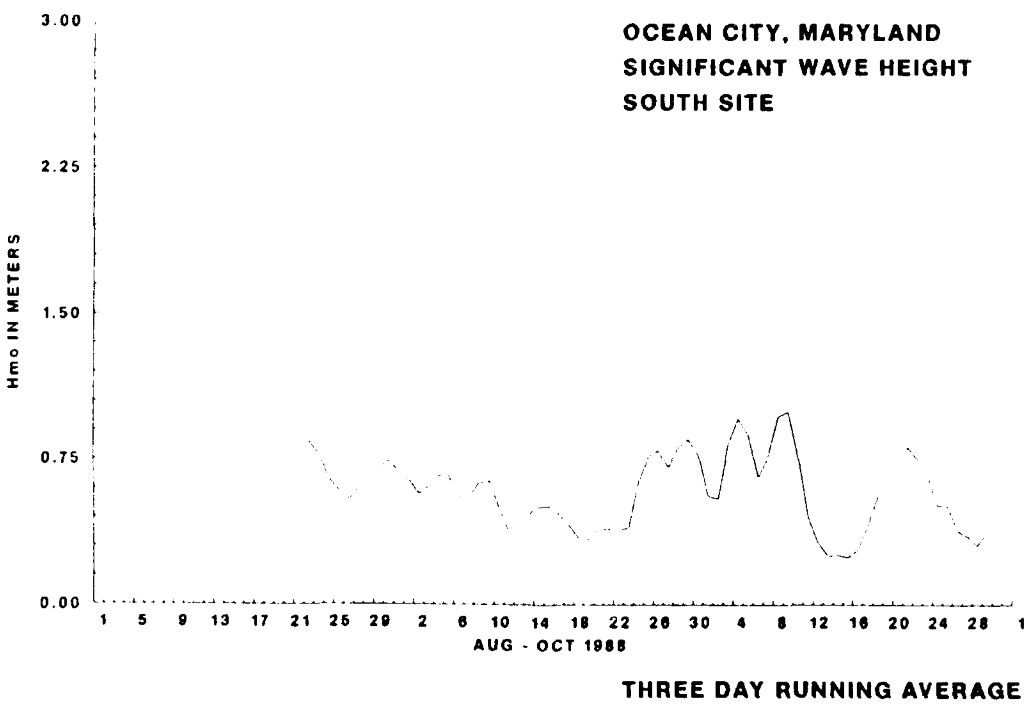




Three Day Block Averages of Significant Wave Height, North and South Sites

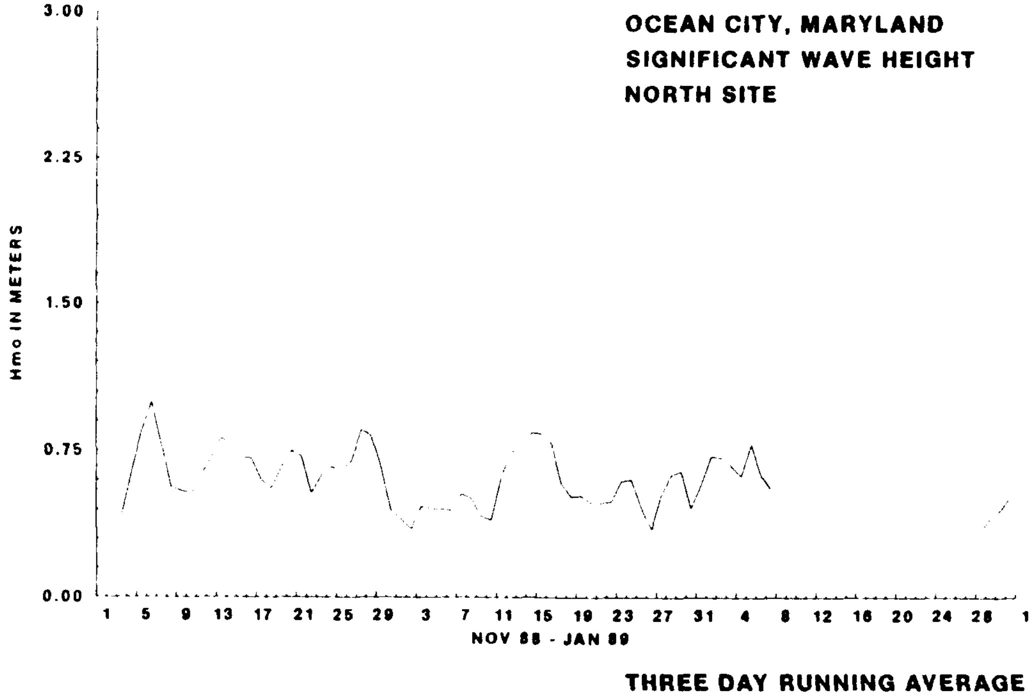
PLATE C47

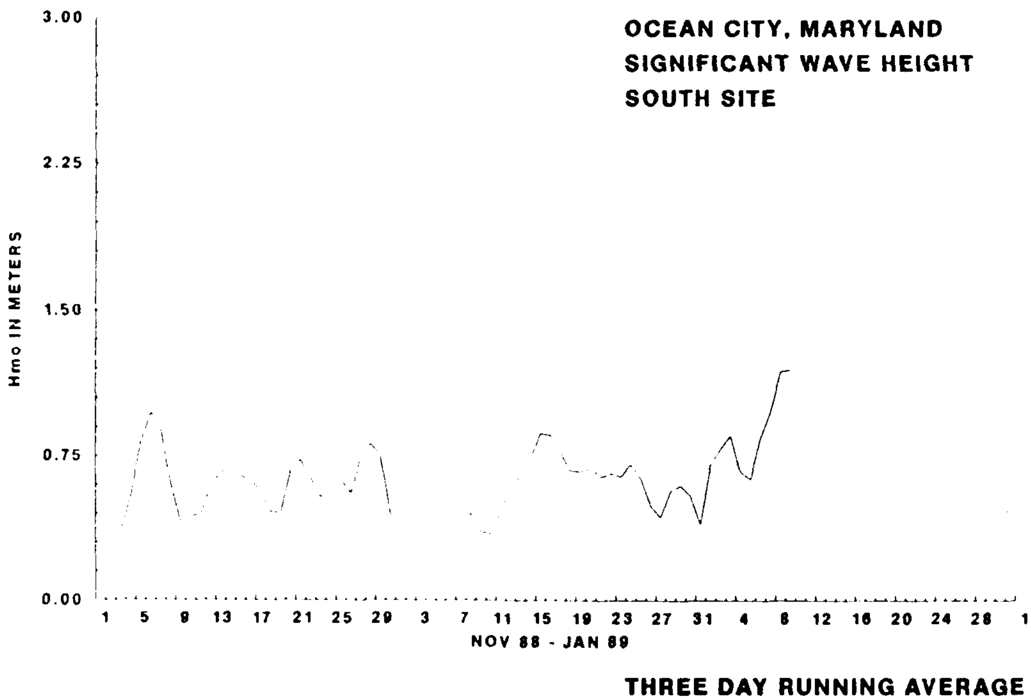




Three Day Running Averages of Significant Wave Height, North and South Sites

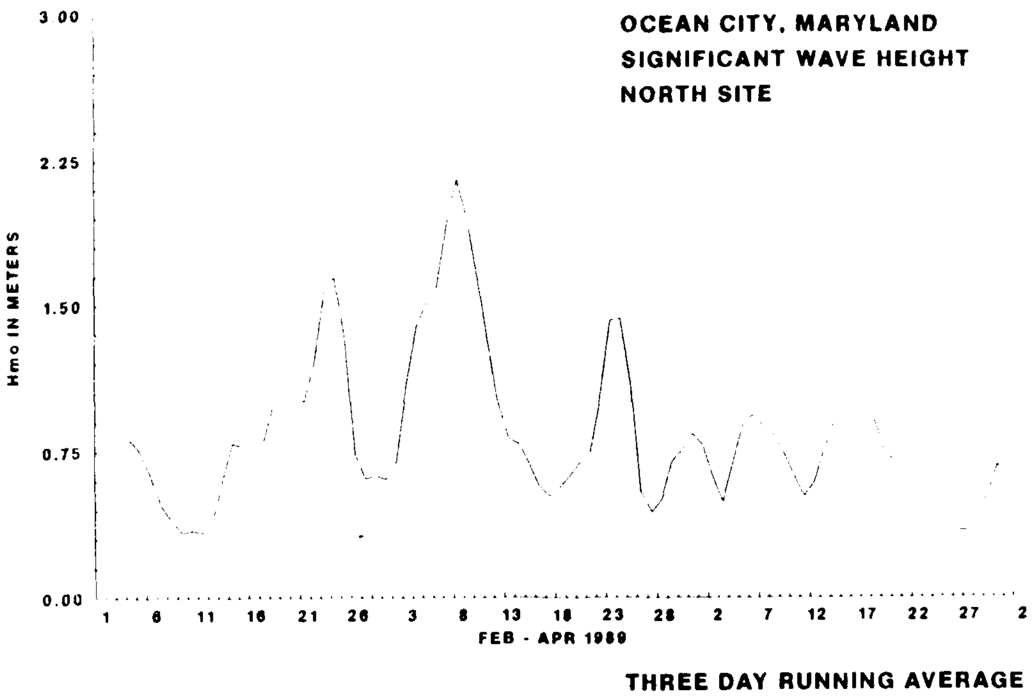
PLATE C48

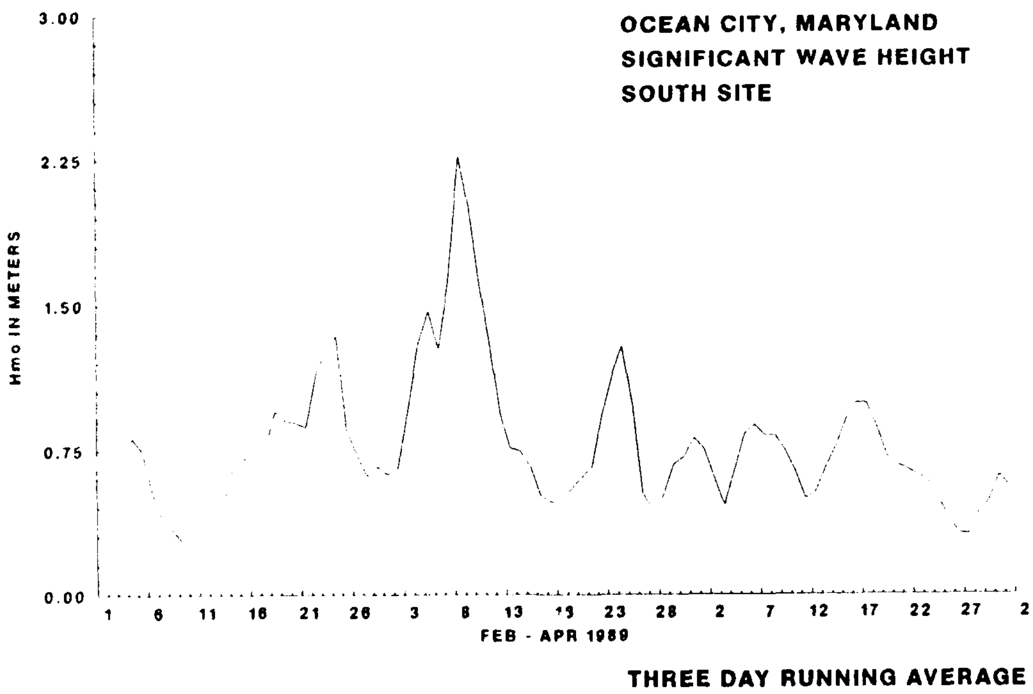




Three Day Running Averages of Significant Wave Height, North and South Sites

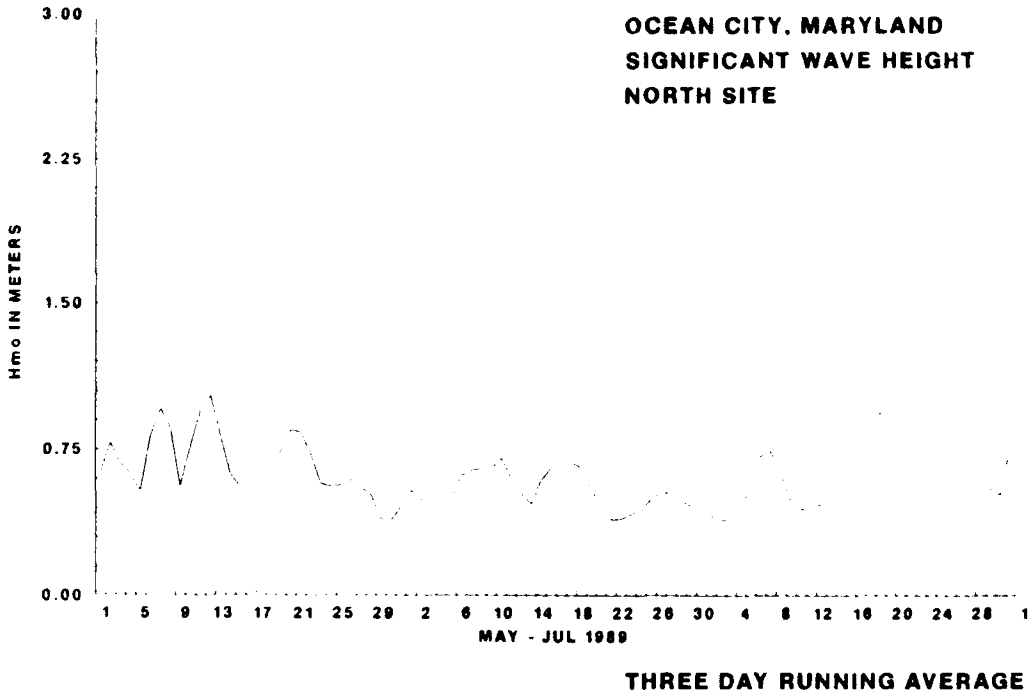
PLATE C49

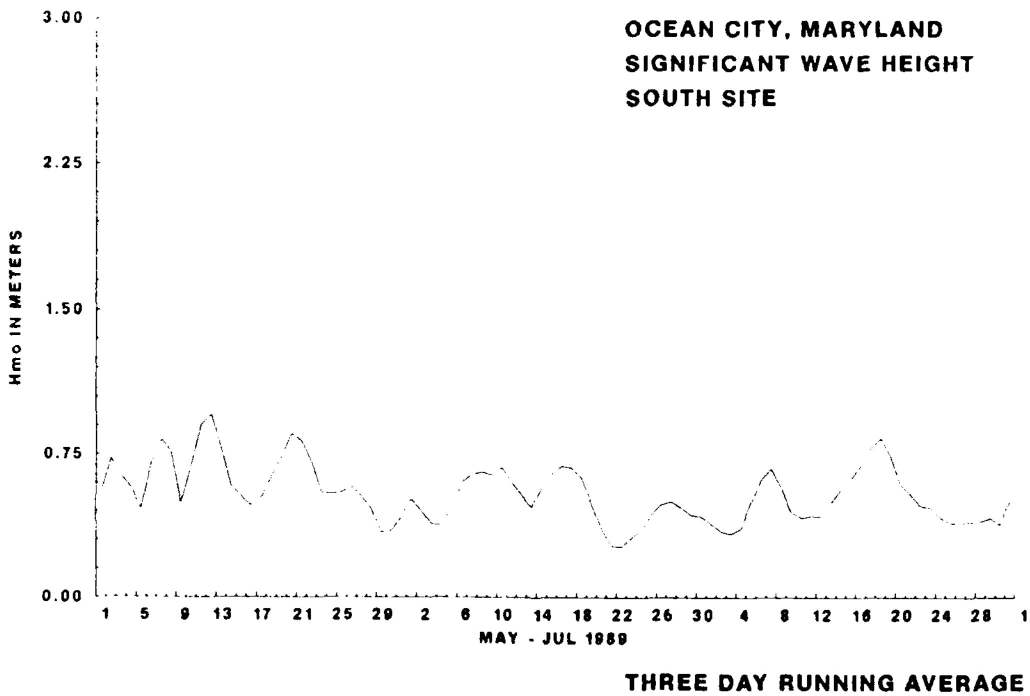




Three Day Running Averages of Significant Wave Height, North and South Sites

PLATE C50

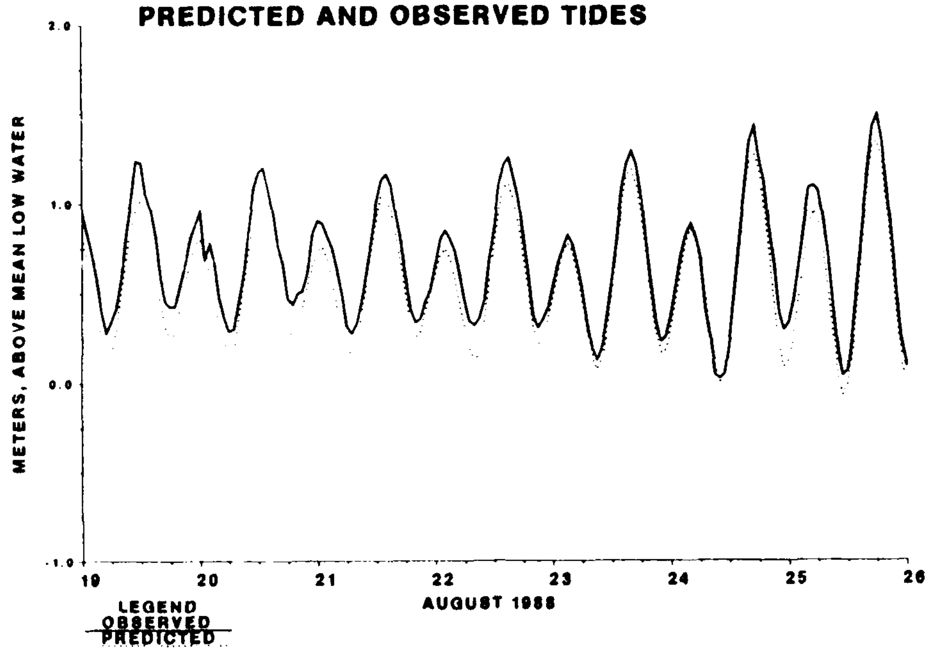




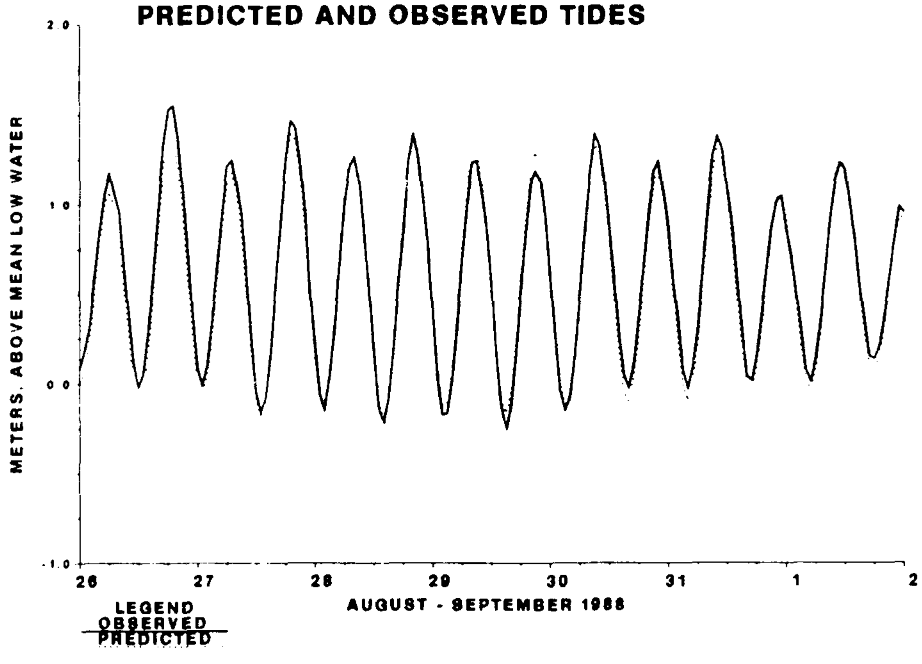
Three Day Running Averages of Significant Wave Height, North and South Sites

PLATE C51

NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES

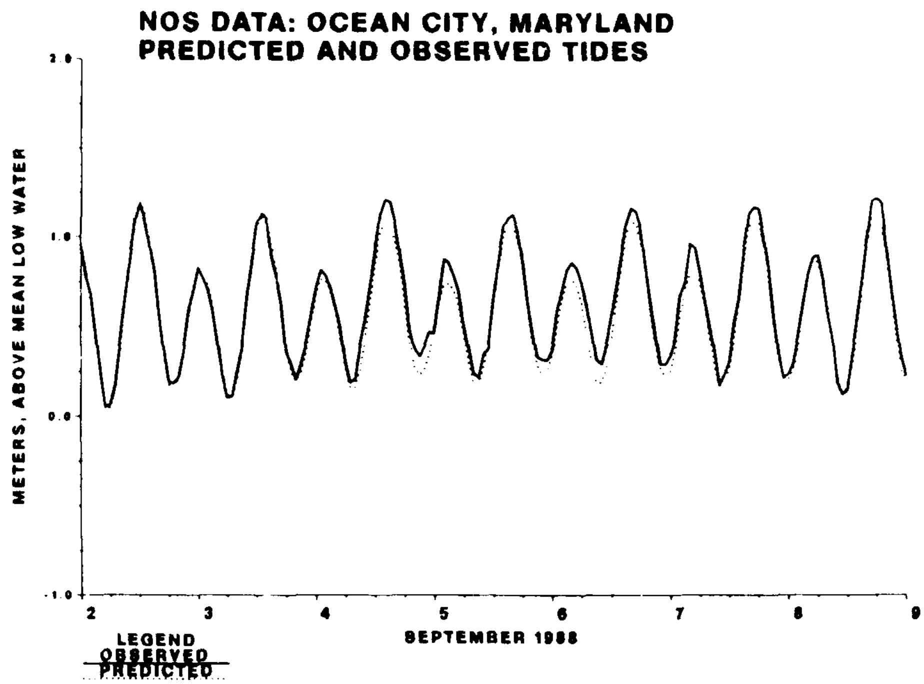


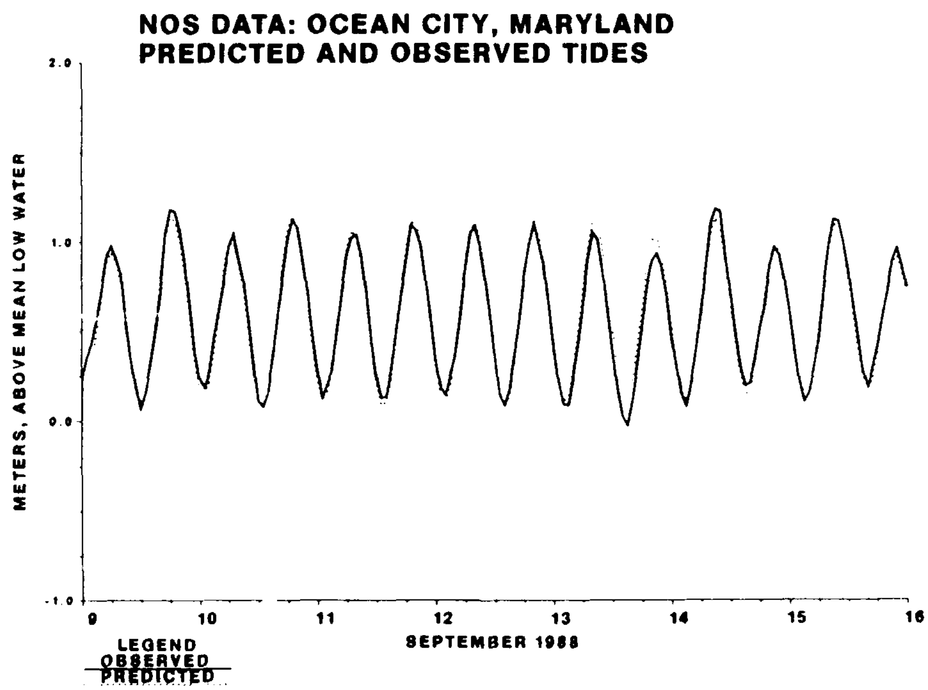
NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES



National Oceanic Service Observed and Predicted Tide Elevations, by Month

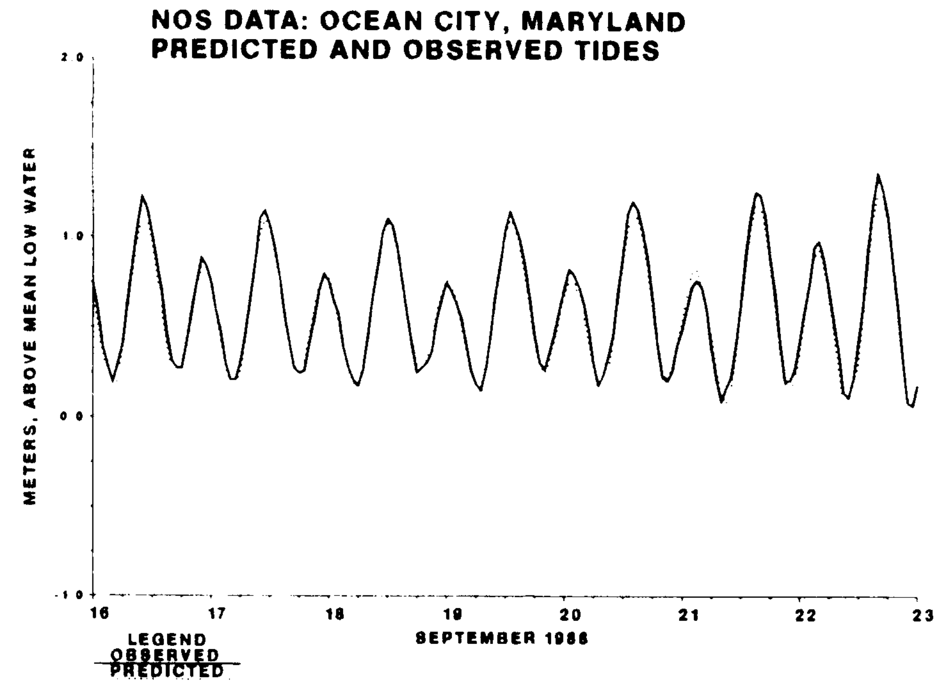
PLATE C52

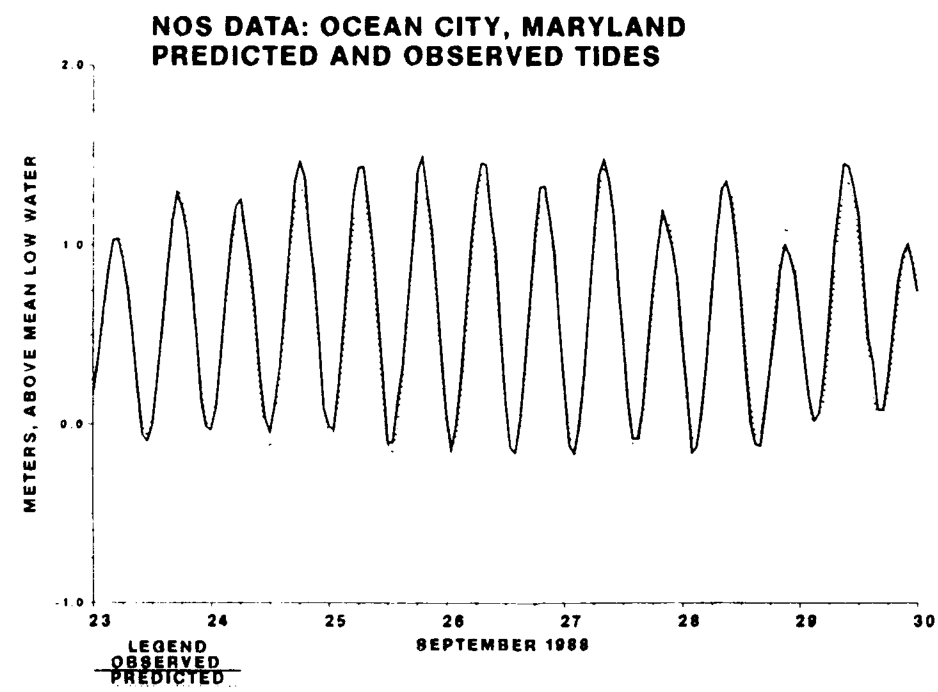




National Oceanic Service Observed and Predicted Tide Elevations, by Month

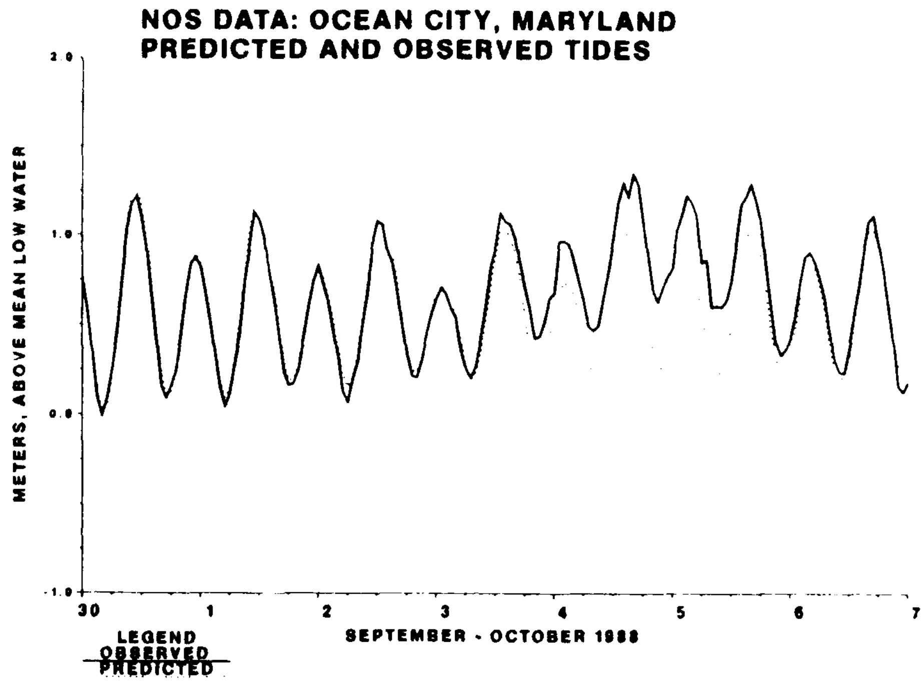
PLATE C53

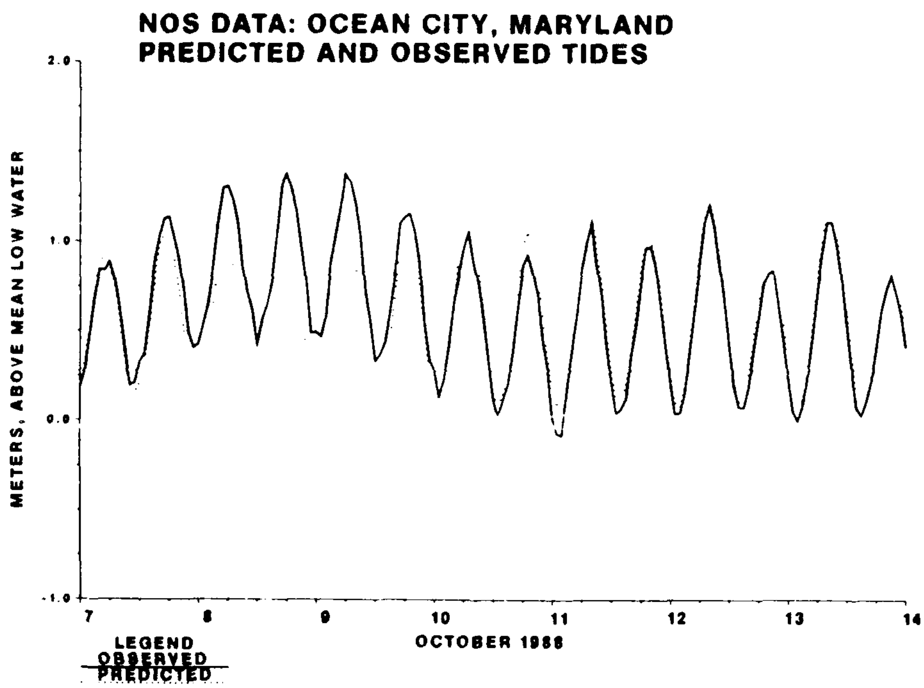




National Oceanic Service Observed and Predicted Tide Elevations, by Month

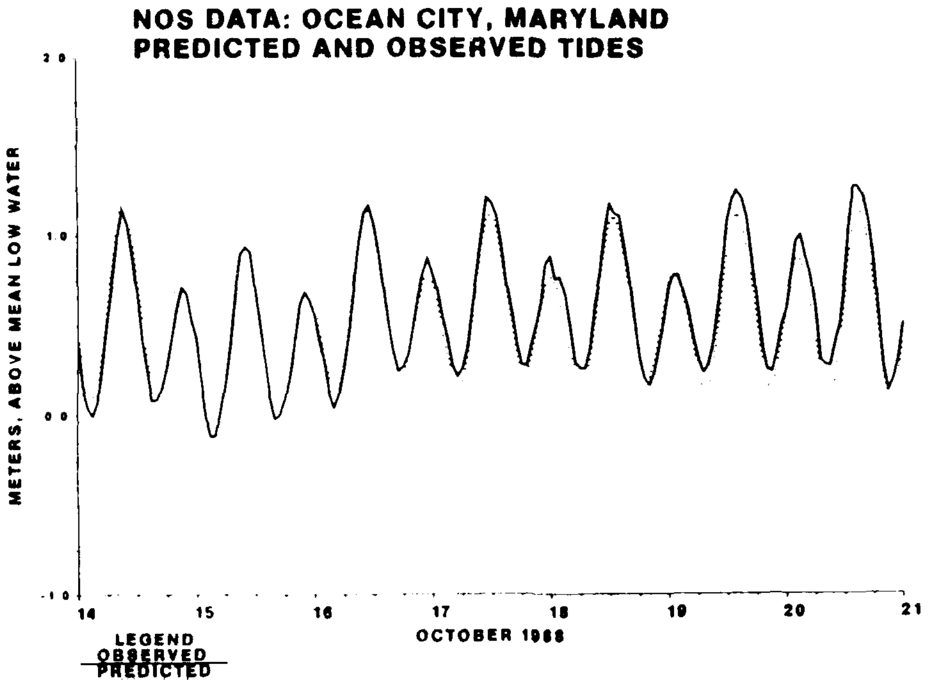
PLATE C54

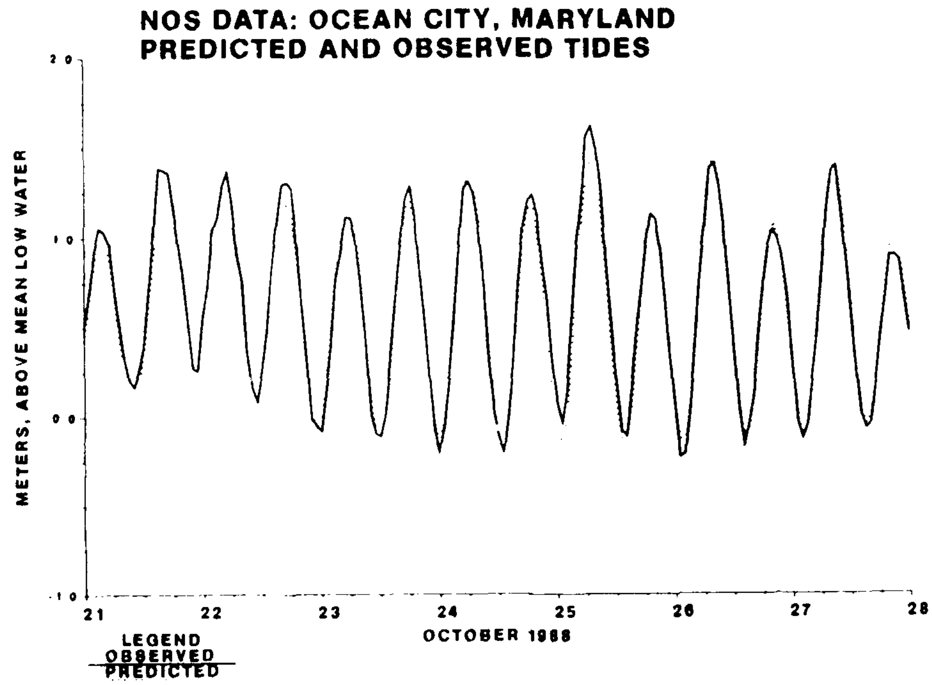




National Oceanic Service Observed and Predicted Tide Elevations, by Month

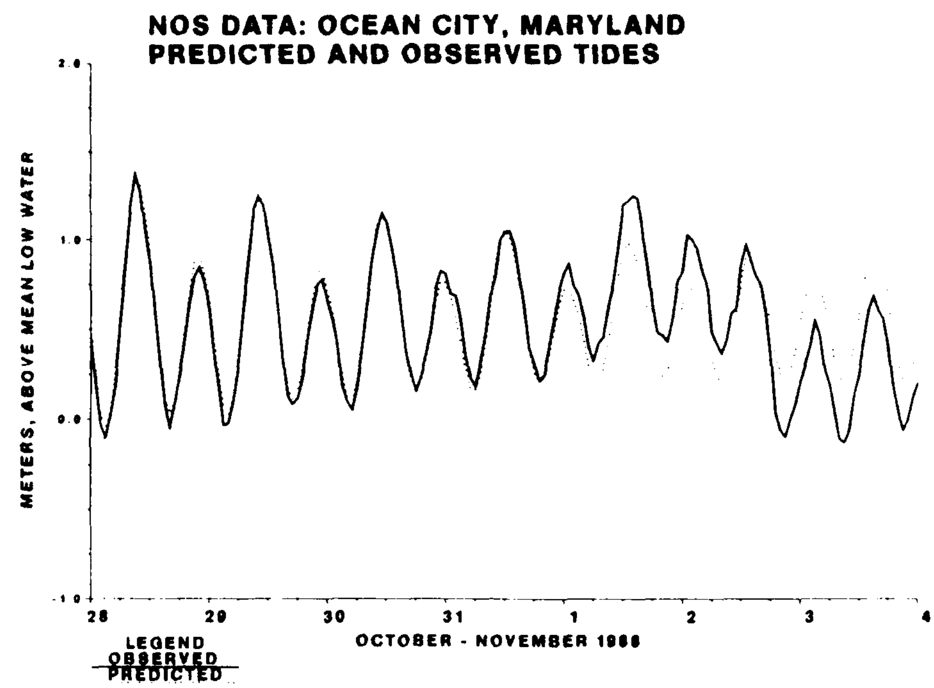
PLATE C55

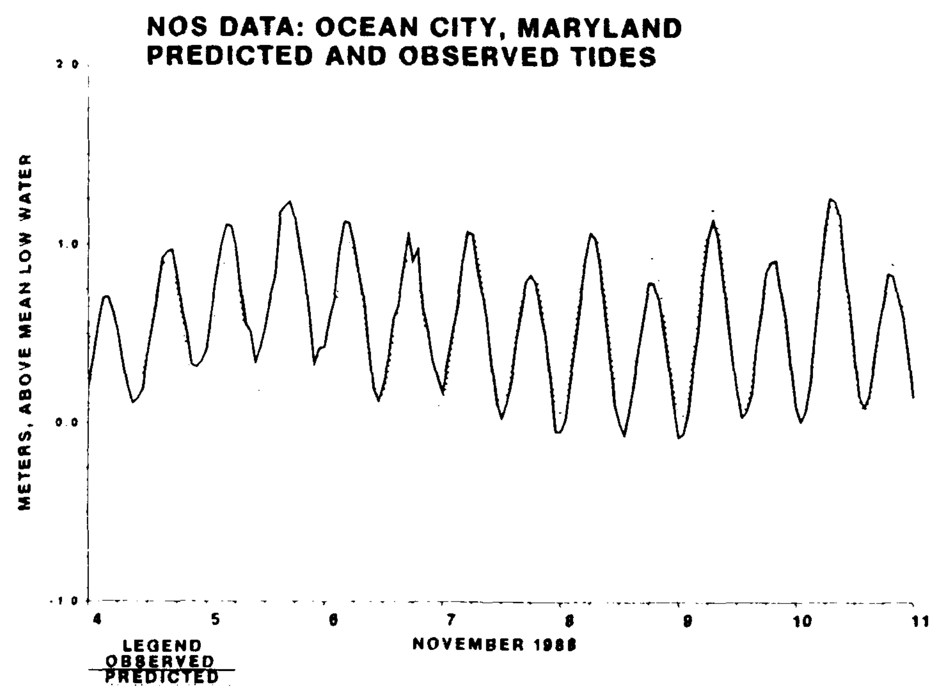




National Oceanic Service Observed and Predicted Tide Elevations, by Month

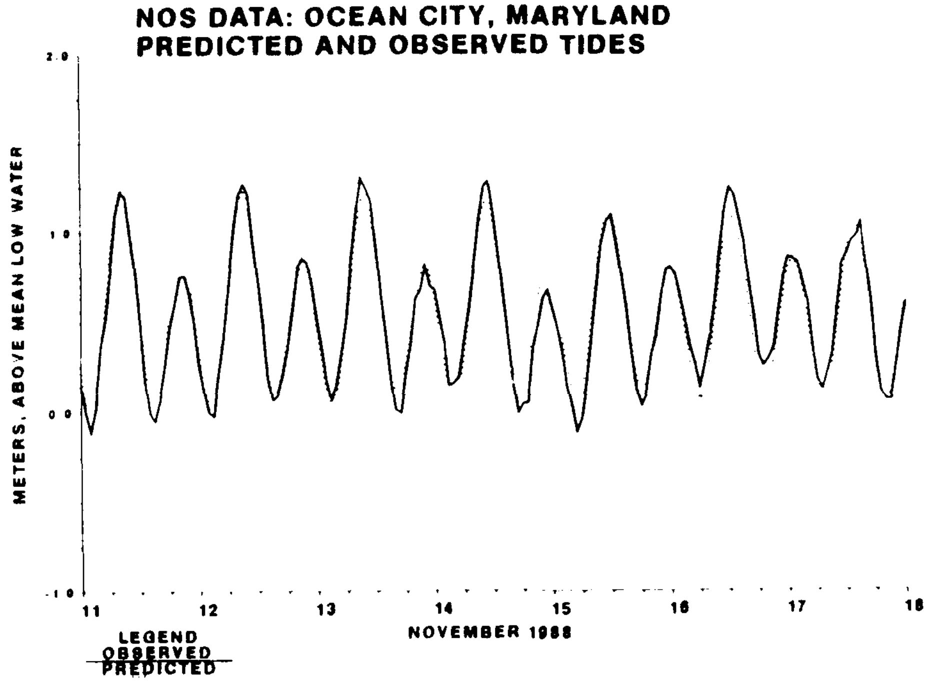
PLATE C56

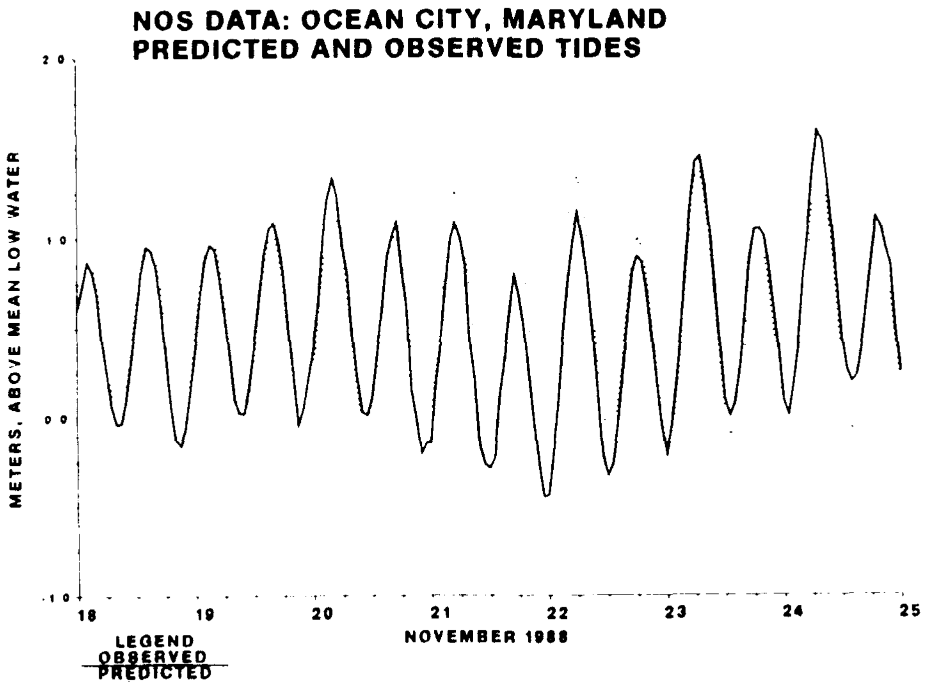




National Oceanic Service Observed and Predicted Tide Elevations, by Month

PLATE C57

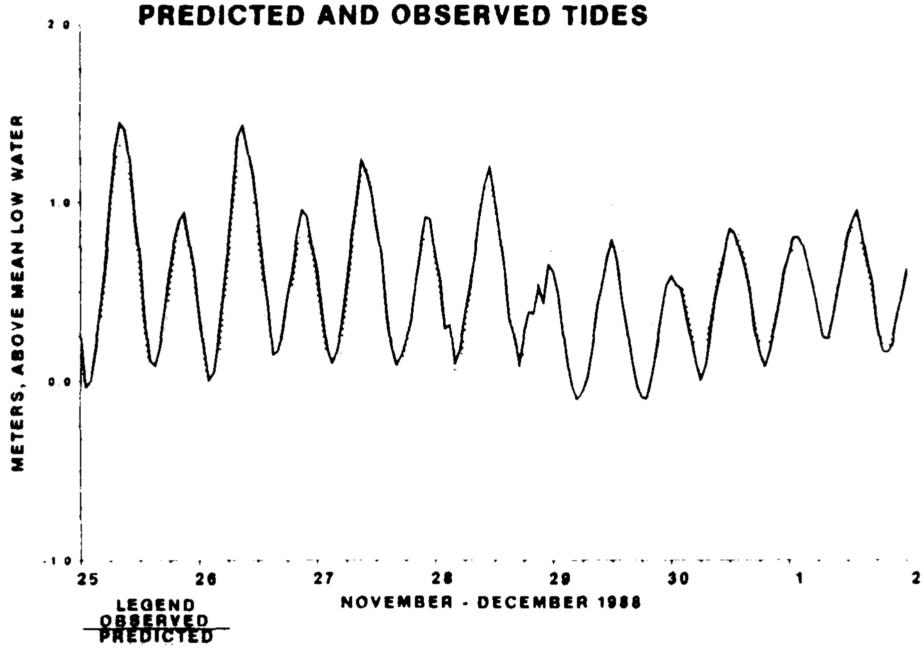




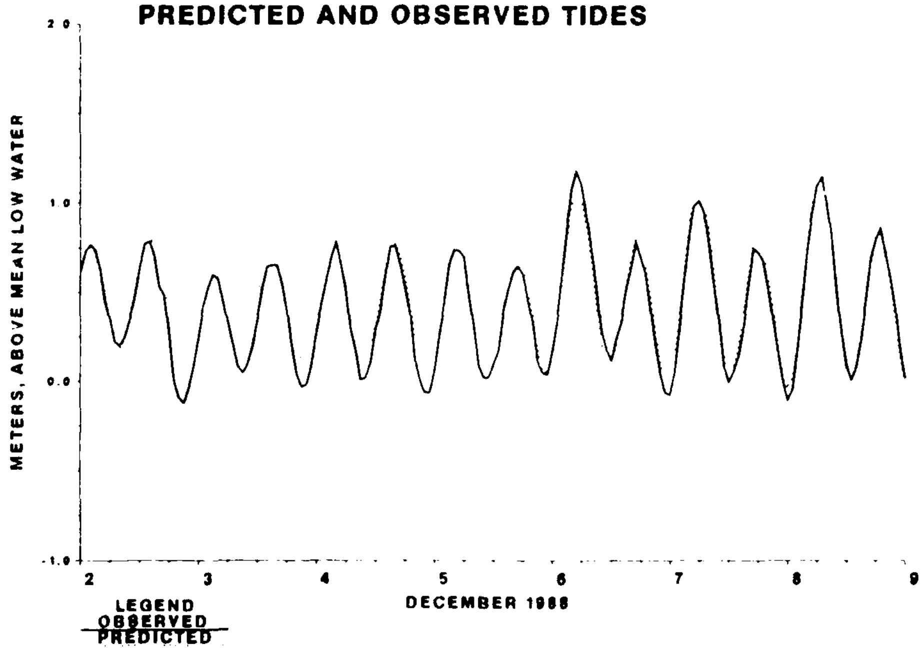
National Oceanic Service Observed and Predicted Tide Elevations, by Month

PLATE C58

NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES

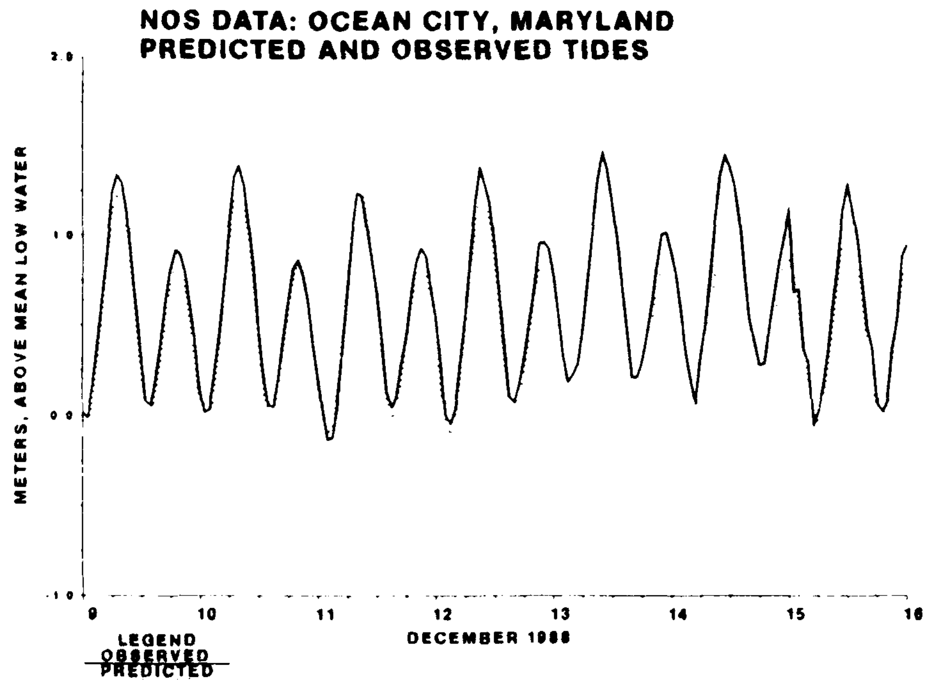


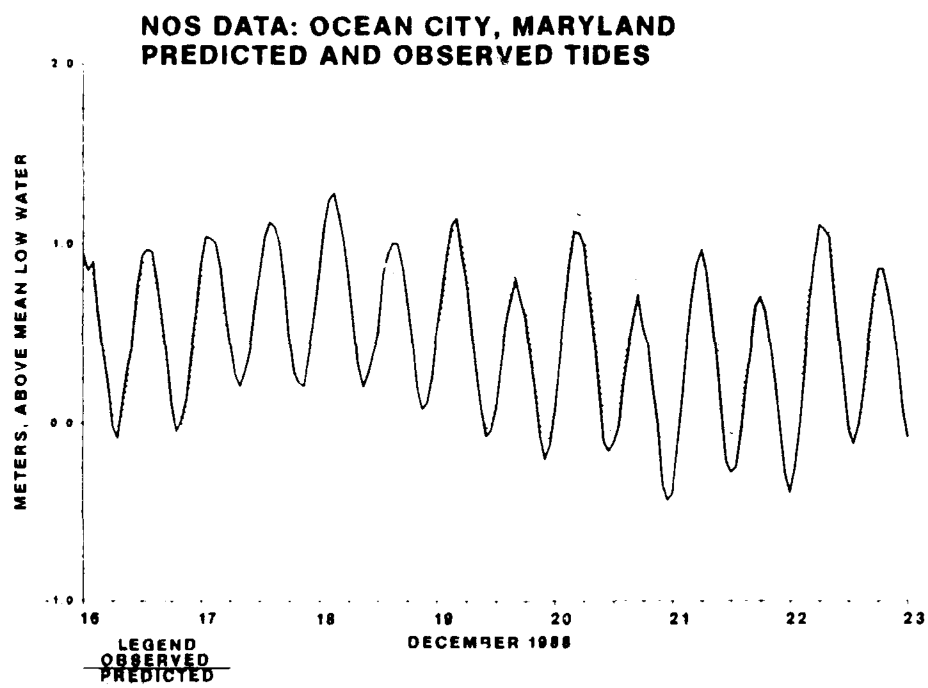
NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES



National Oceanic Service Observed and Predicted Tide Elevations, by Month

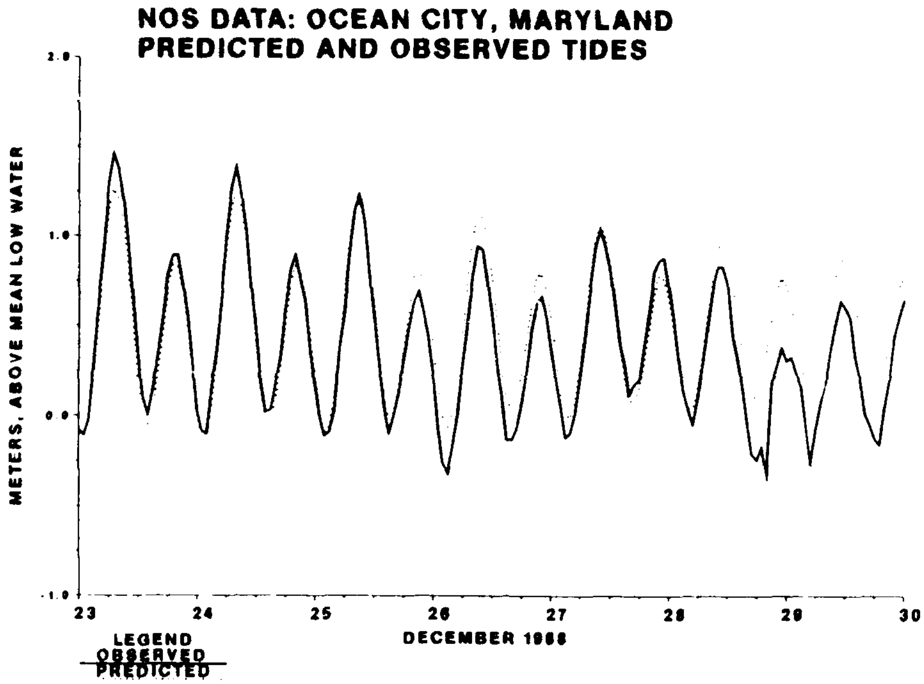
PLATE C59

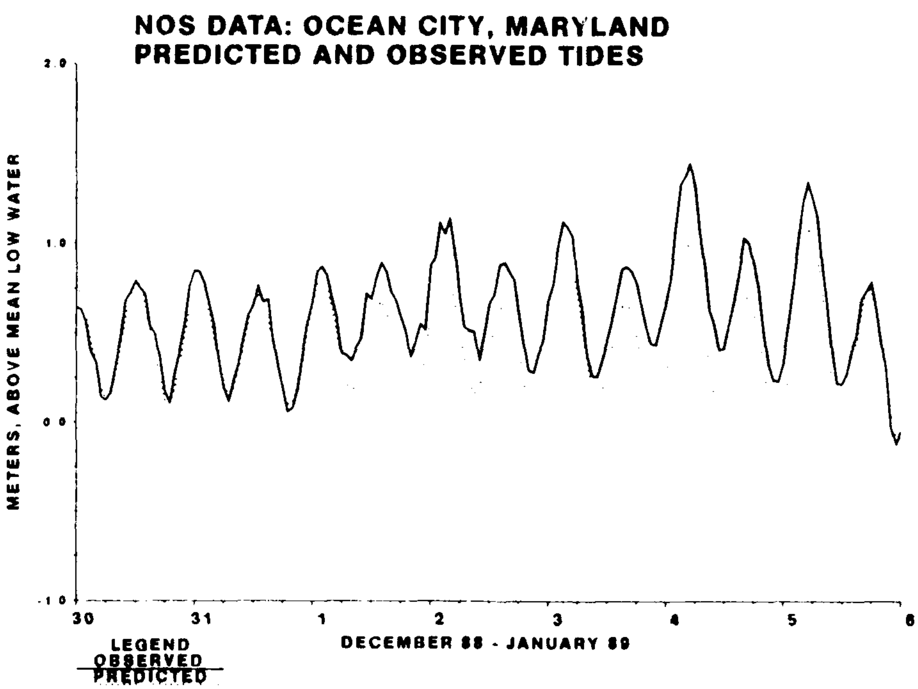




National Oceanic Service Observed and Predicted Tide Elevations, by Month

PLATE C60

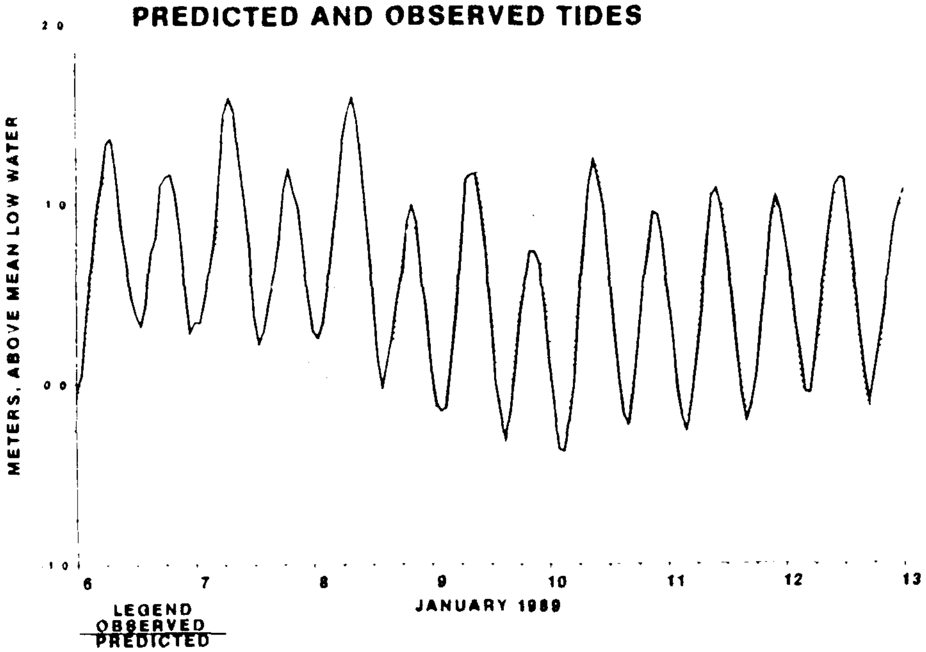




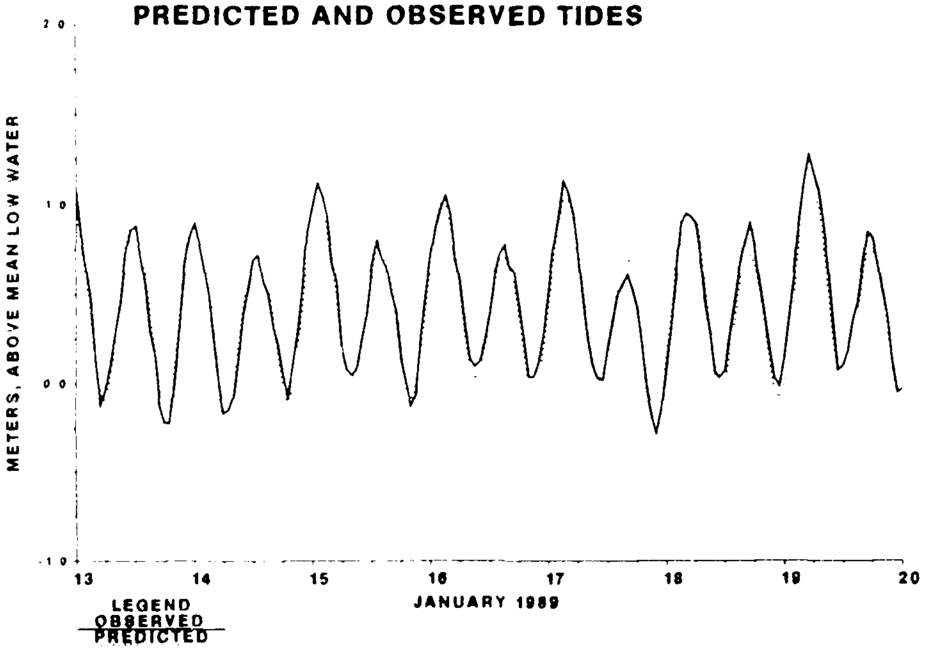
National Oceanic Service Observed and Predicted Tide Elevations, by Month

PLATE C61

NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES

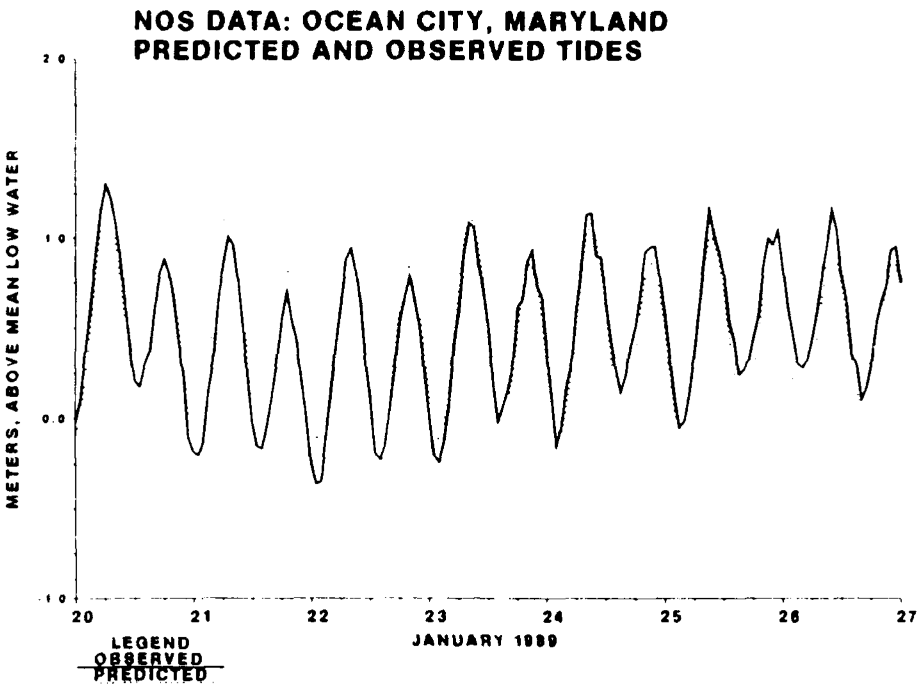


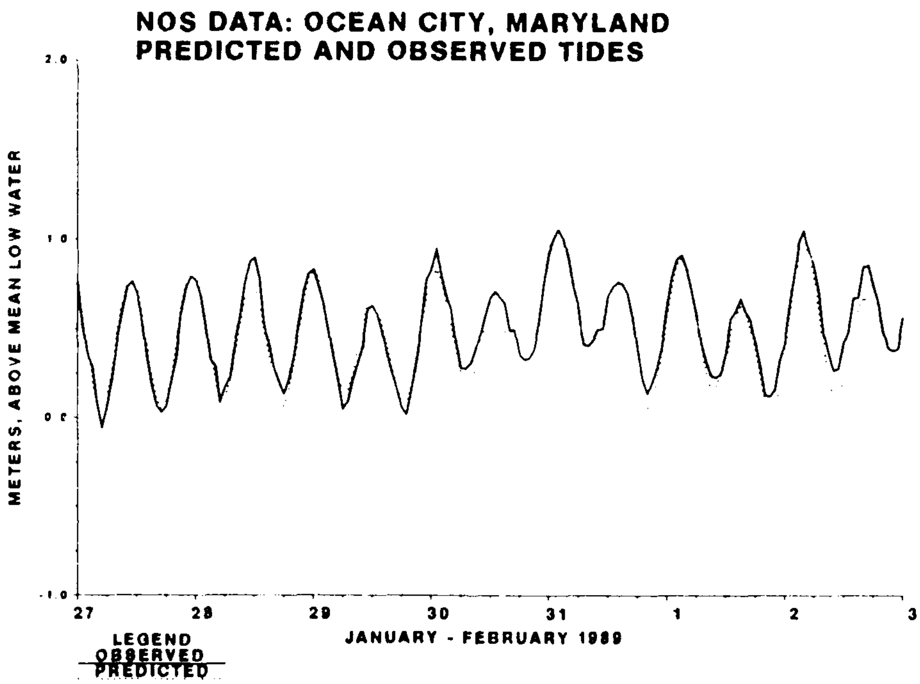
NOS DATA: OCEAN CITY, MARYLAND
PREDICTED AND OBSERVED TIDES



National Oceanic Service Observed and Predicted Tide Elevations, by Month

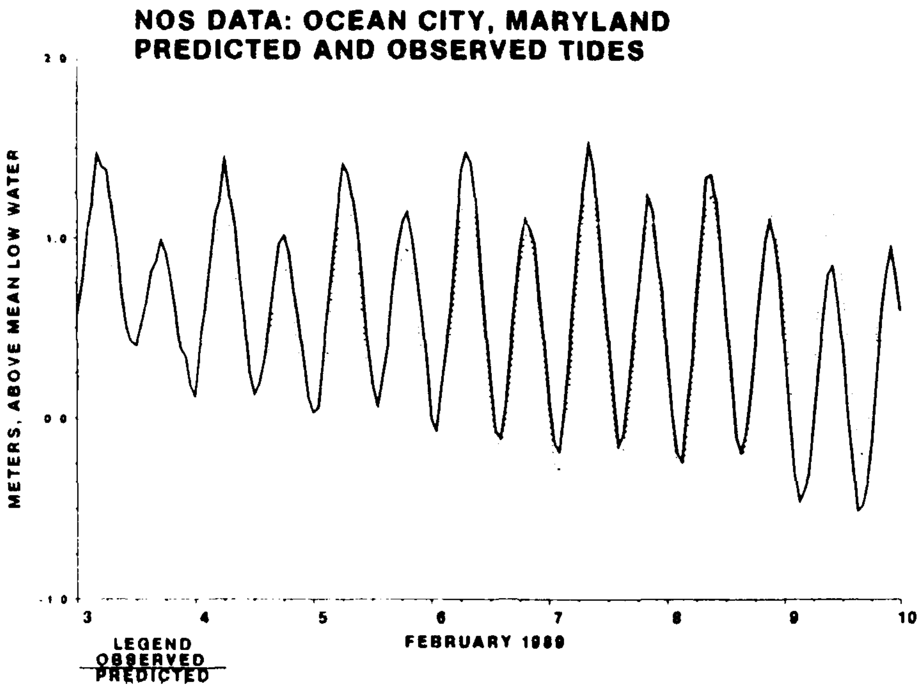
PLATE C62

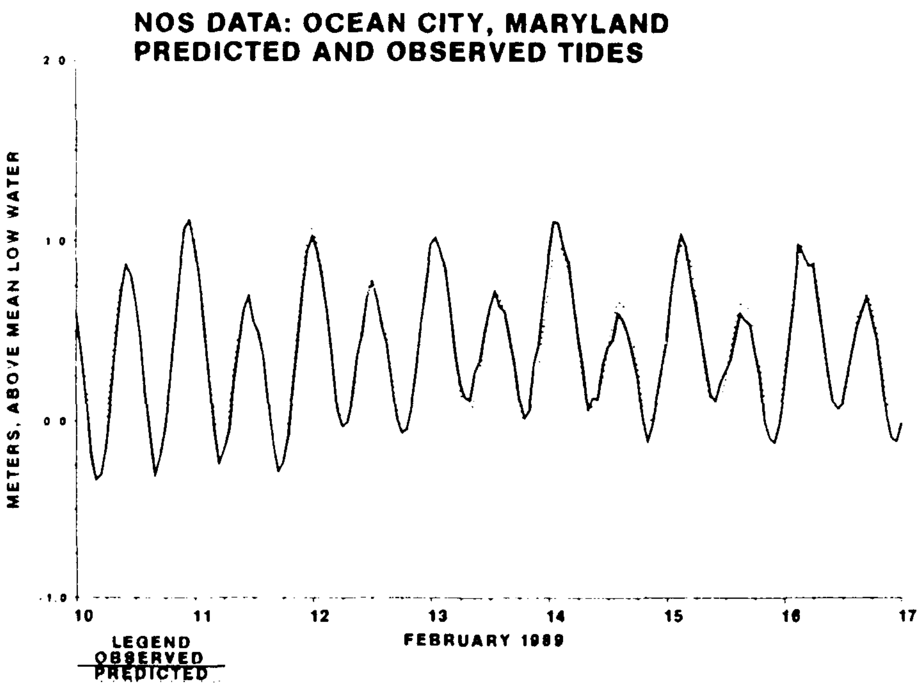




National Oceanic Service Observed and Predicted Tide Elevations, by Month

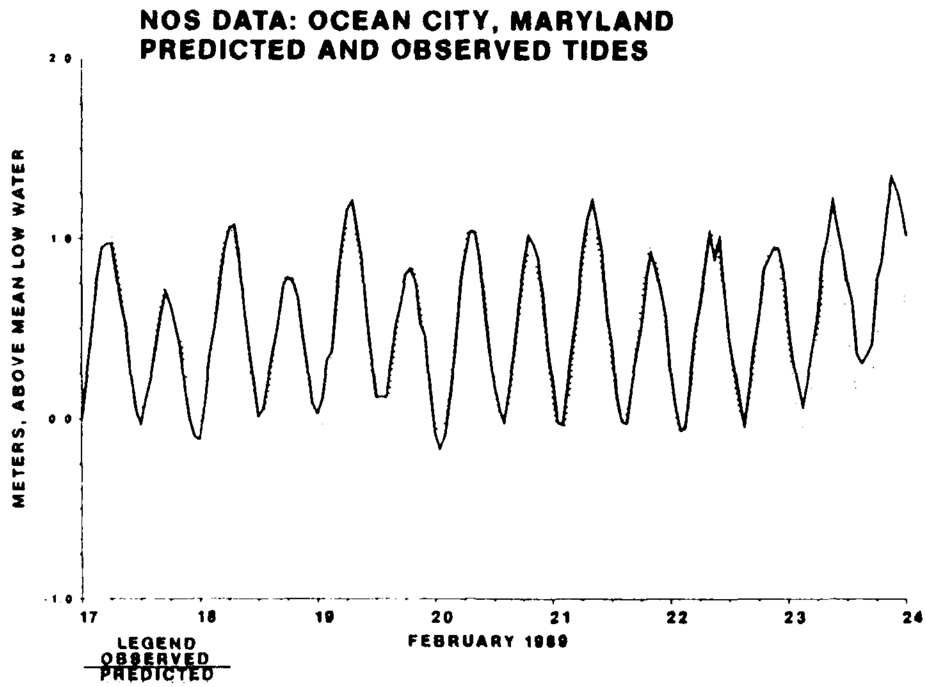
PLATE C63

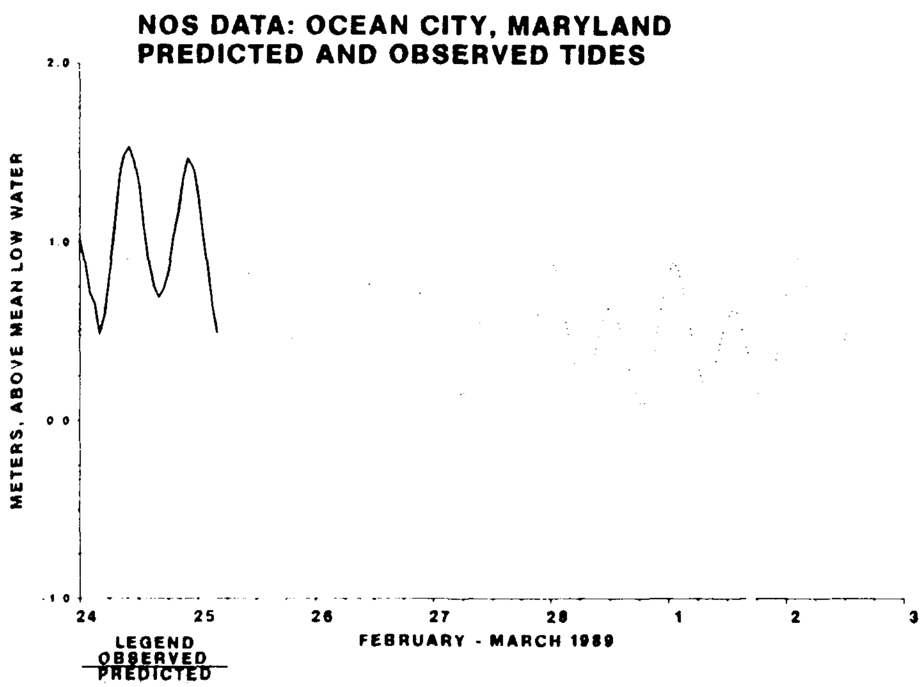




National Oceanic Service Observed and Predicted Tide Elevations, by Month

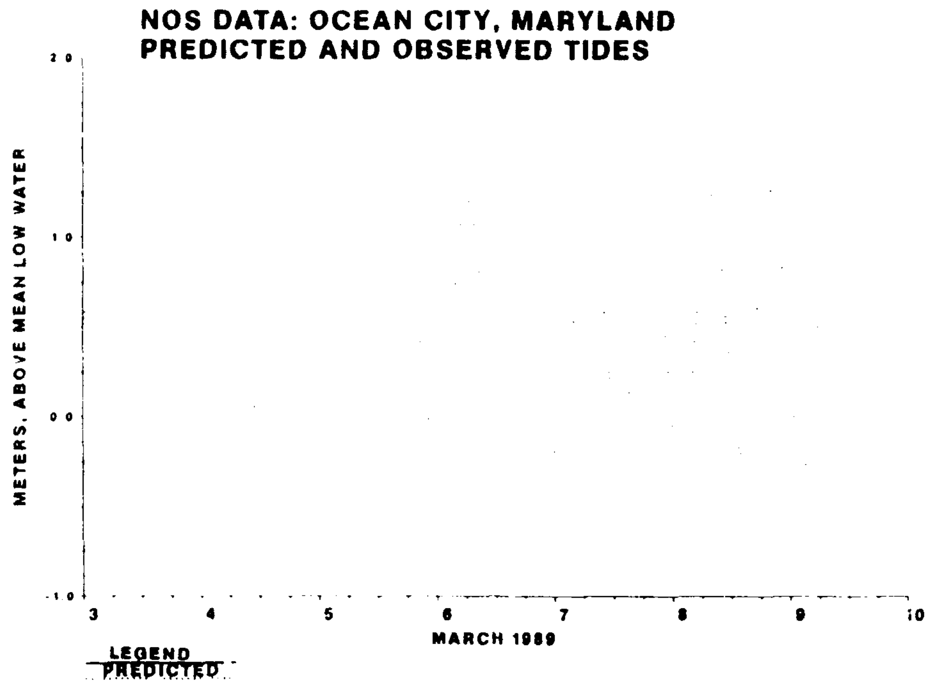
PLATE C64

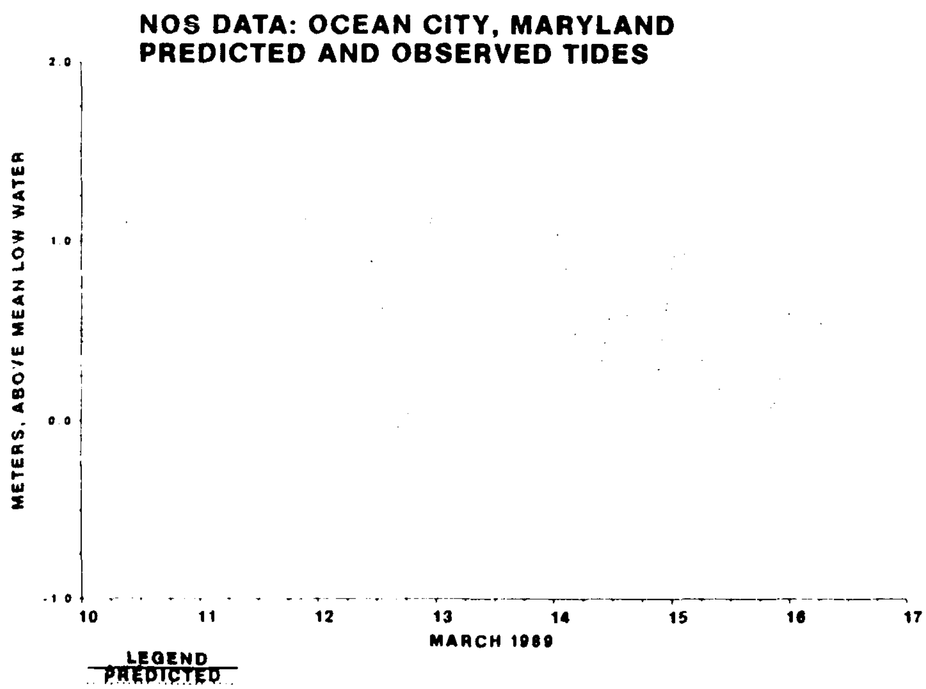




National Oceanic Service Observed and Predicted Tide Elevations, by Month

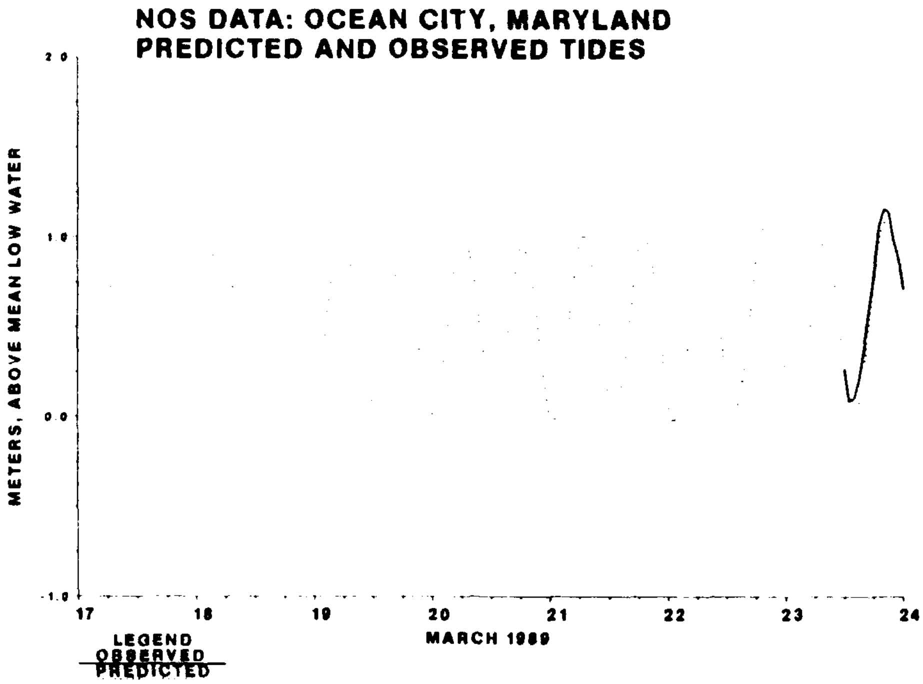
PLATE C65

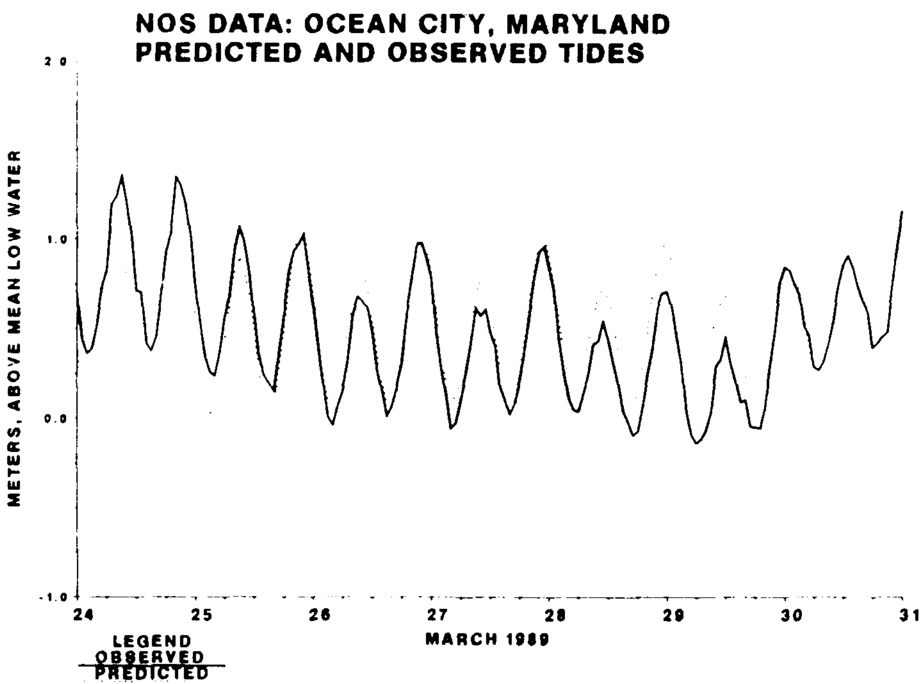




National Oceanic Service Observed and Predicted Tide Elevations, by Month

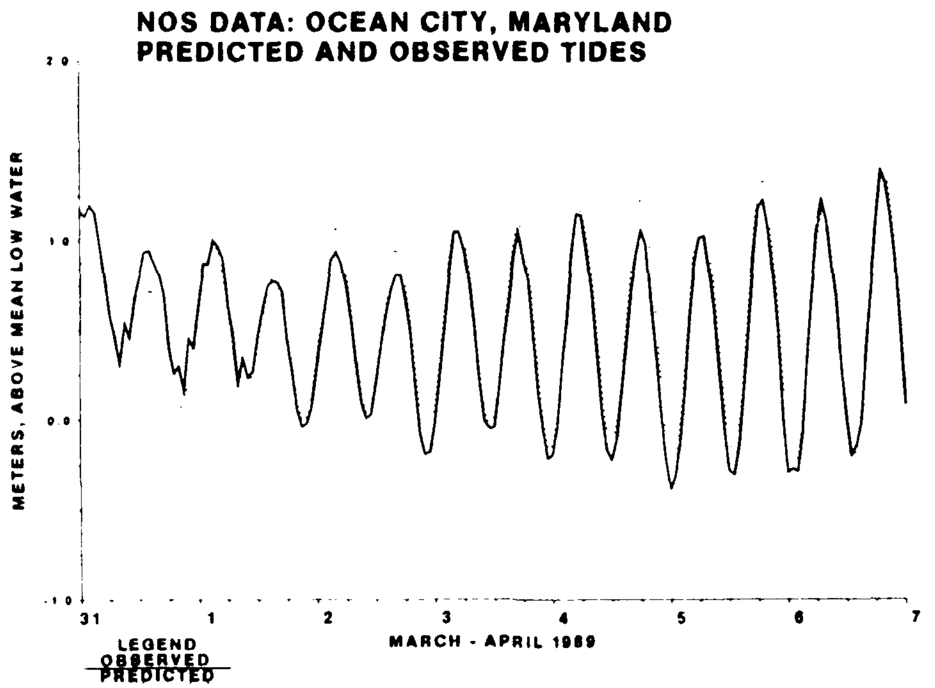
PLATE C66

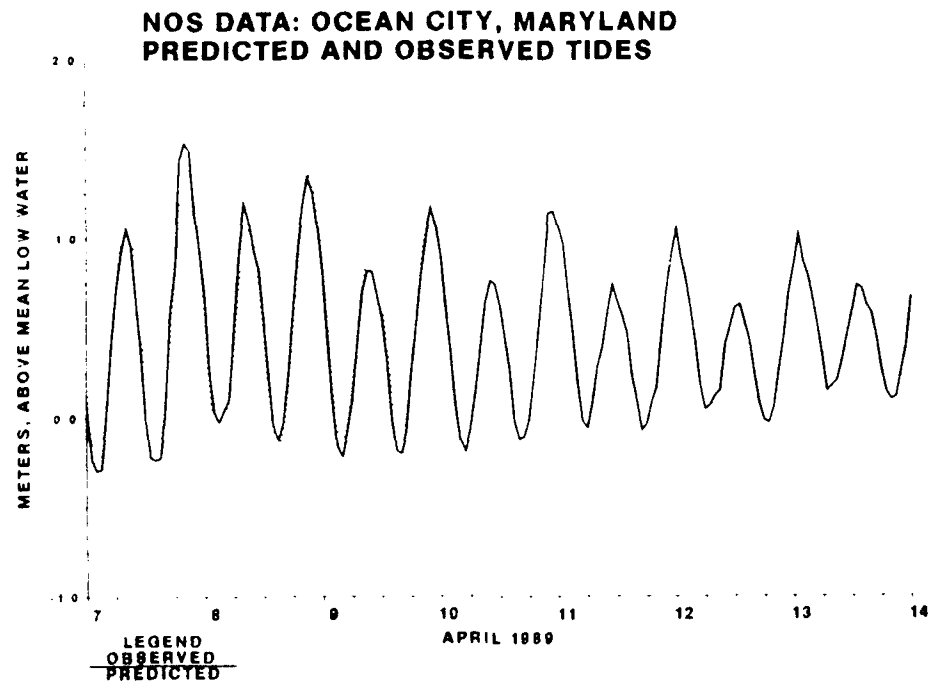




National Oceanic Service Observed and Predicted Tide Elevations, by Month

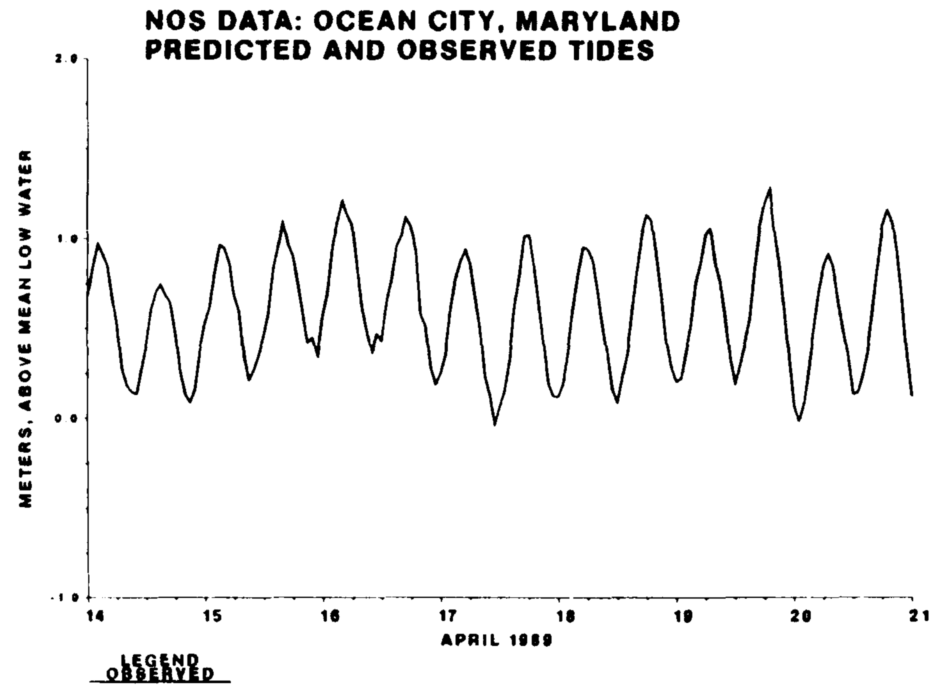
PLATE C67

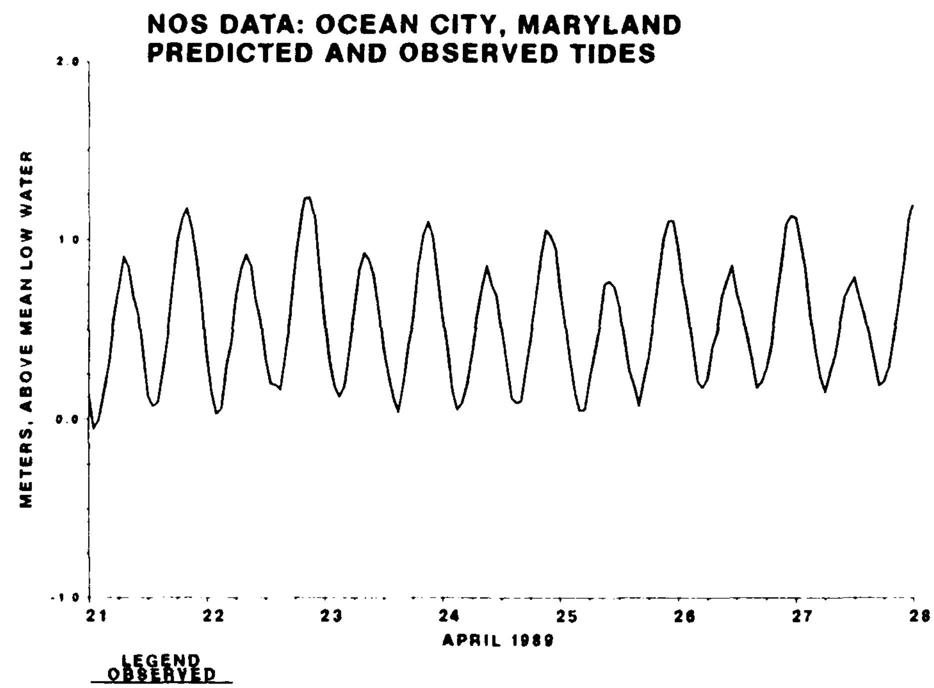




National Oceanic Service Observed and Predicted Tide Elevations, by Month

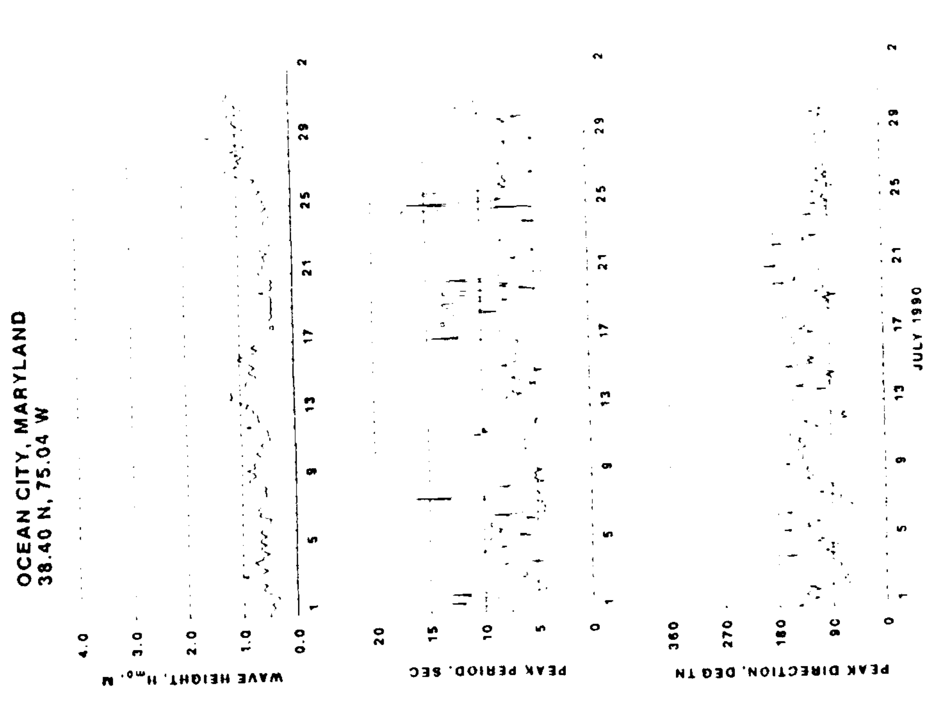
PLATE C68

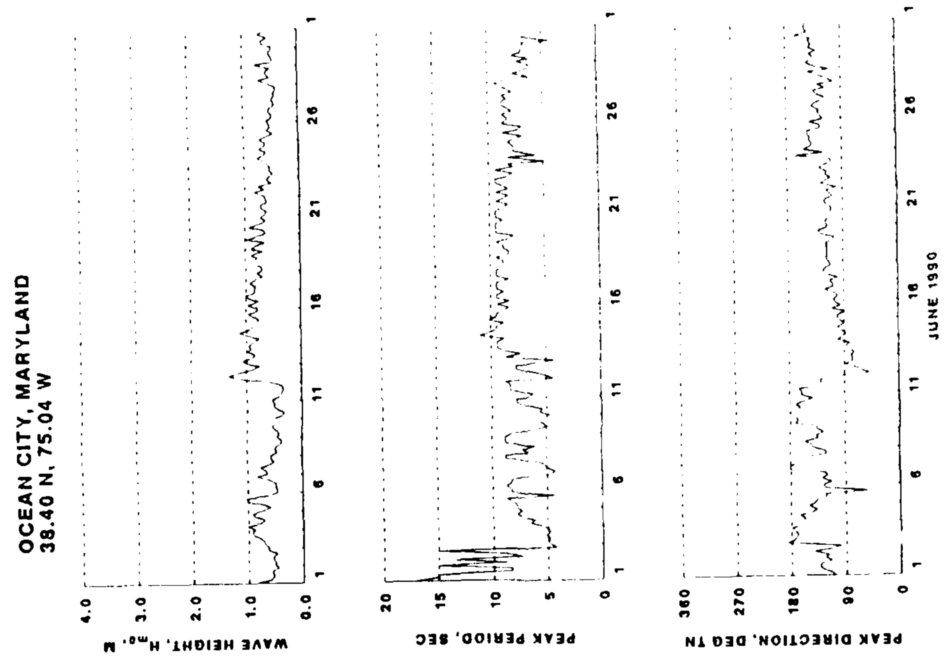




National Oceanic Service Observed and Predicted Tide Elevations, by Month

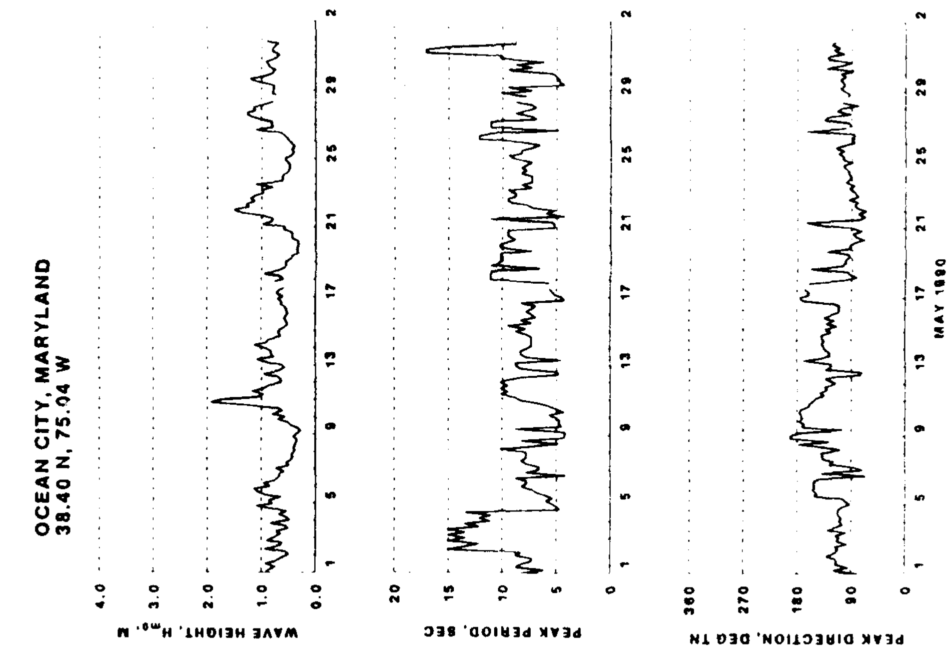
PLATE C69

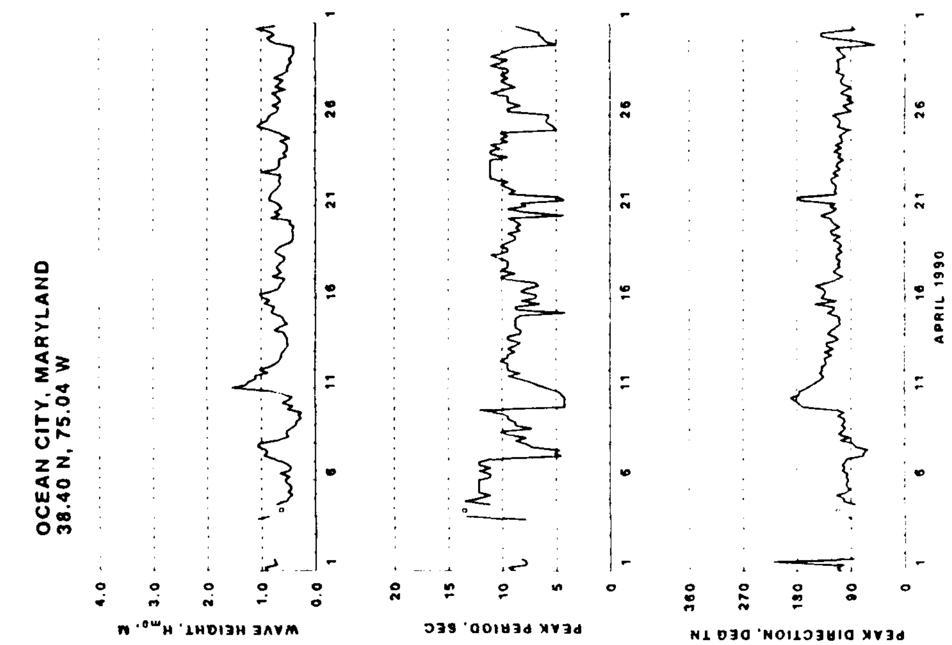




Significant Wave Height, Peak Period, and Wave Direction by Month, North Site

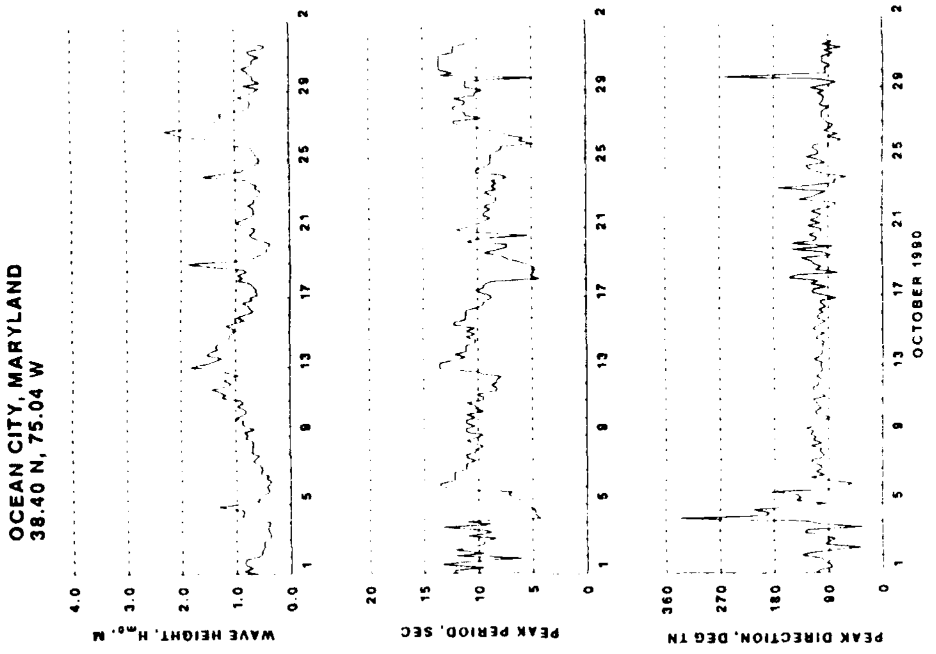
PLATE C70

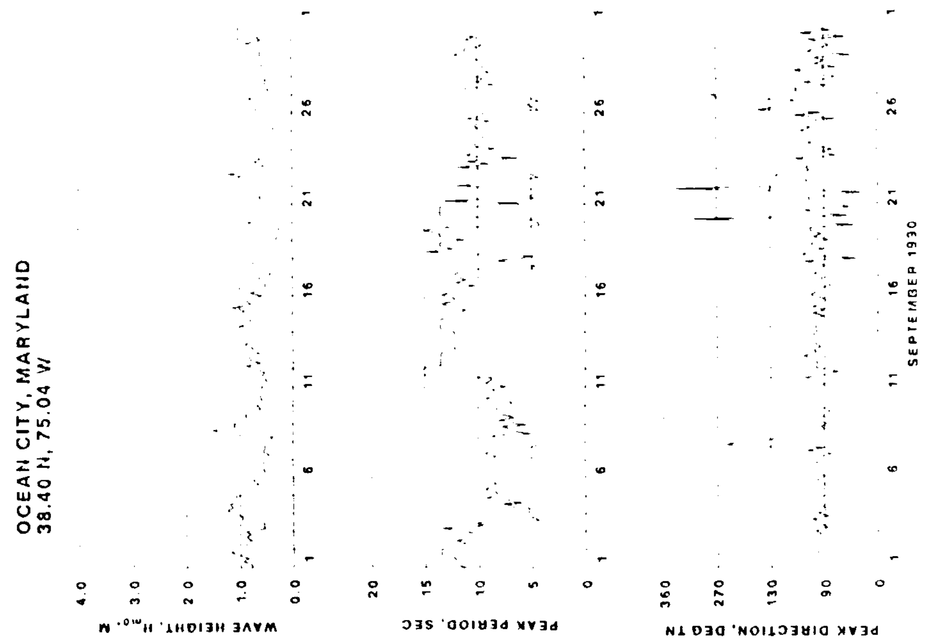




Significant Wave Height, Peak Period, and Wave Direction by Month, North Site

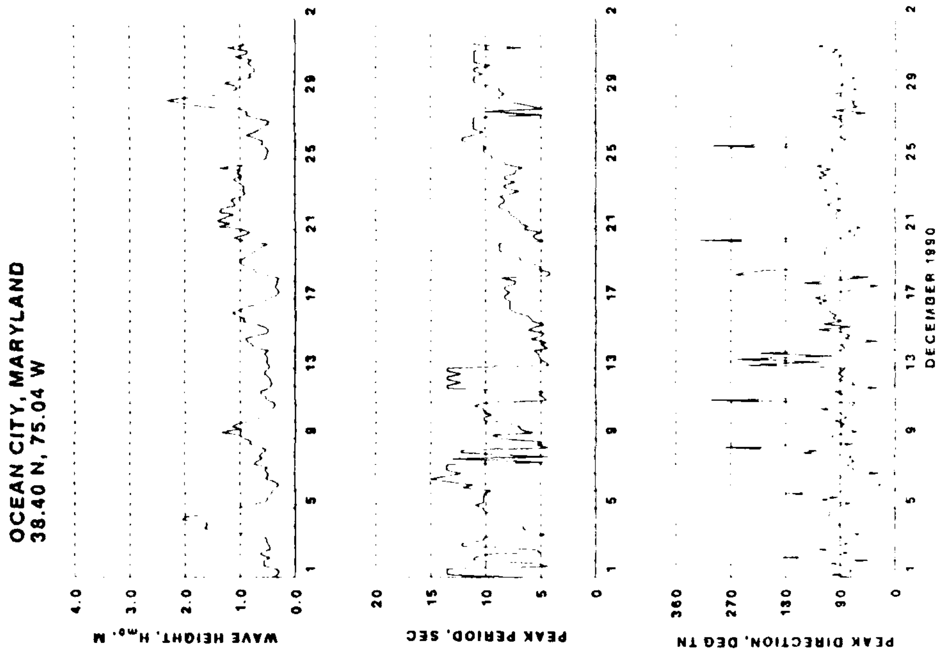
PLATE C71

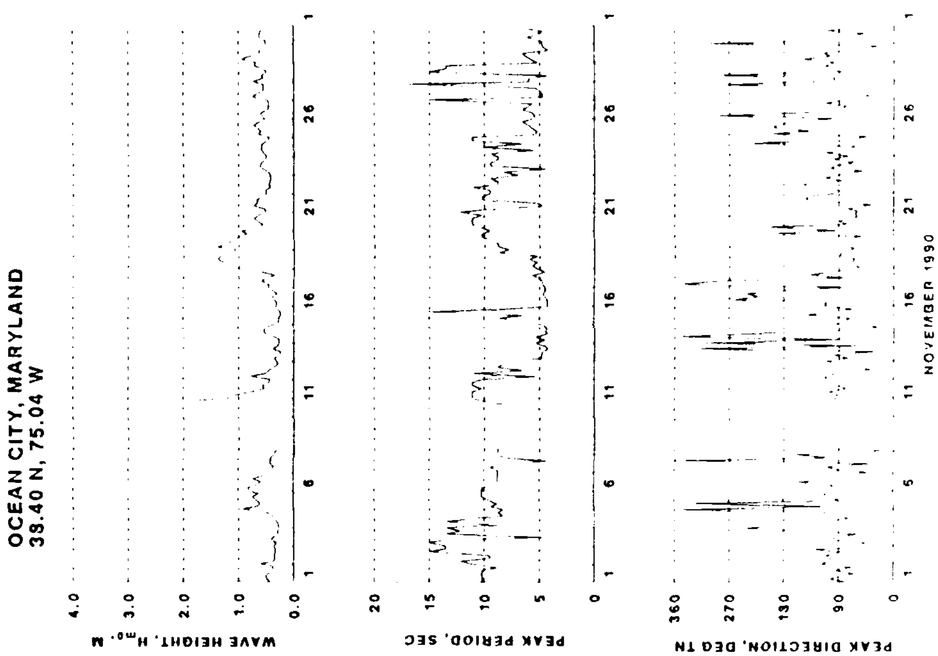




Significant Wave Height, Peak Period, and Wave Direction by Month, North Site

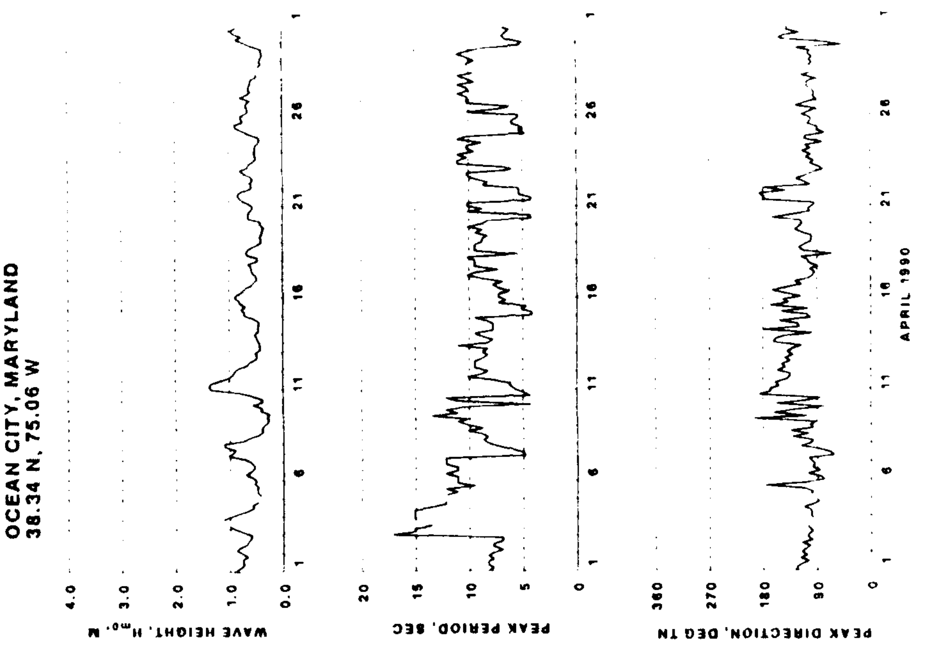
PLATE C72

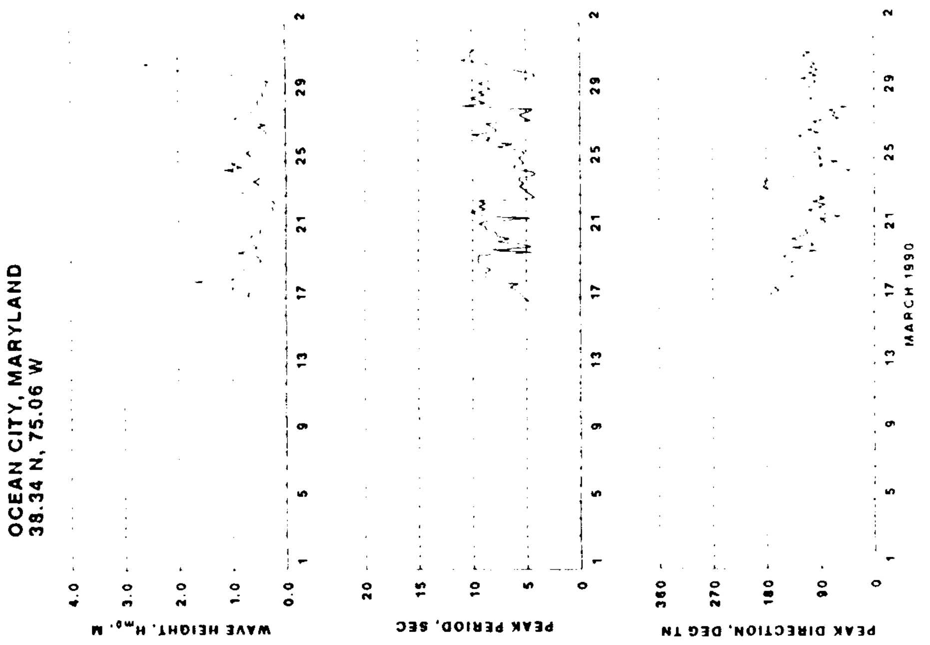




Significant Wave Height, Peak Period, and Wave Direction by Month, North Site

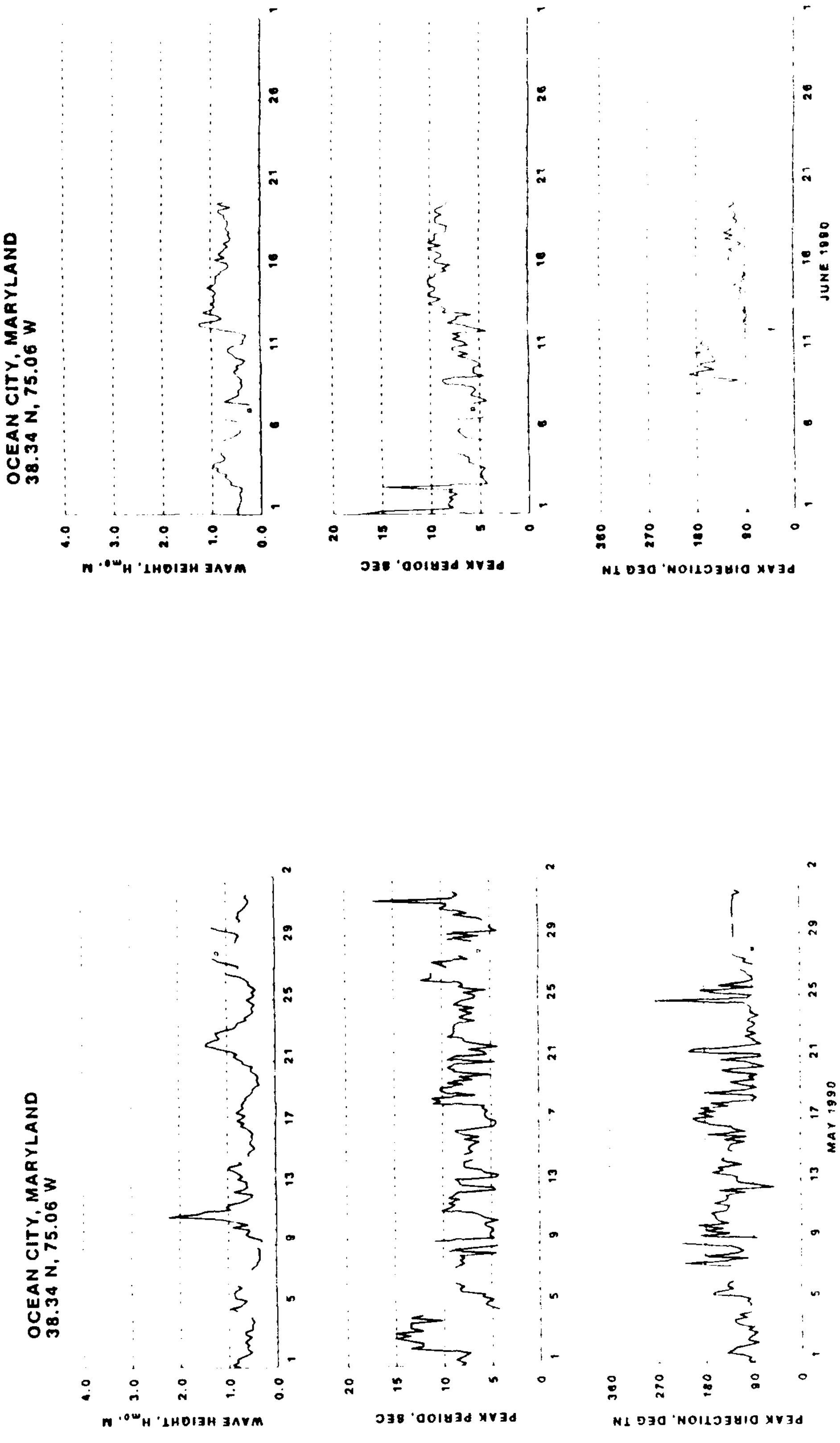
PLATE C73





Significant Wave Height, Peak Period, and Wave Direction by Month, South Site

PLATE C74



Significant Wave Height, Peak Period, and Wave Direction by Month, South Site

PLATE C75

Appendix D
Notation

$D(f,\theta)$	Directional spreading function
f_p	Peak wave frequency, sec^{-1}
H_{mo}	Spectrally determined significant wave height, m
R_a	Overfill ratio
$S(f)$	Sea surface spectrum
$S(f,\theta)$	Directional spectrum
T_p	Peak wave period, sec
θ_p	Peak frequency of wave direction, deg
μ_b	Composite mean grain size of borrow material, phi units
μ_n	Composite mean grain size of native beach, phi units
$\mu_{6/89}$	Composite mean grain size of the June, 1989 beach material, phi units
σ_n	Composite sorting coefficient of the native beach, phi units

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13. ABSTRACT *(Maximum 200 words)*

Detailed monitoring of the performance of a two-phase beach nourishment project has provided valuable information on beach fill behavior and long-term response of a beach fill to prevailing coastal processes. The Atlantic Coast of Maryland (Ocean City) Shoreline Protection Project began with placement of a recreational beach by the State of Maryland during the summer of 1988. Within three months of placement, four storms impacted the area. Recovery was monitored for an additional two years. In the summers of 1990 and 1991, additional fill material including a storm protection dune was placed by the U.S. Army Corps of Engineers as a second phase for the purpose of storm protection. Within a year of the first placement, two large storms impacted the project. Initial recovery was also documented. Project monitoring included 12 profile survey lines, sediment collection, and placement of two dedicated wave gauges. The beach nourishment project performed well in protecting the beachfront infrastructure of Ocean City from storm damage. The fill material was eroded from the foreshore after the major storms of 1989 and 1991/92, but could be accounted for in the nearshore between the shoreline and closure. Representative profile survey locations show the differential behavior of the fill controlled by nearshore bathymetric variability along the project length. The 37th Street location represents the flatter, bar/trough type profile typical of the southern portion of the fill. Localized "hot spots" of erosion occurred in areas where a shoal

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system attaches to the shoreface, as shown at 81st Street. The erosion pattern associated with these shoals was probably produced by wave convergence and divergence over these features. Analysis of sediment characteristics of samples collected during the State fill project showed the influence of the fill material on the native beach and the change in sorting after the passage of four storms. Composites were constructed of the foreshore and nearshore samples to account for cross-shore variability in grain size distribution. The coarsest foreshore and finest nearshore composite fill material was found in the northern end of the project, with the opposite found to the south. Storm impact placed coarse foreshore lag material at the erosional 81st Street location and finer material at the more stable 37th Street location. After 9 months, the fill material was taking on the characteristics of the pre-fill native beach.

14. Continued.

Beach fill monitoring
Beach nourishment
Beach profiles
Depth of closure
Ocean City, Maryland
Sediment sample analysis
Wave gauge analysis