



Technical Report CHL-99-13  
August 1999

**US Army Corps  
of Engineers**  
Waterways Experiment  
Station

# **Monmouth Beach, New Jersey: Beach-Fill “Hot Spot” Erosion Evaluation**

## **Report 1 Physical Processes Analysis**

*by S. Jarrell Smith, Mark B. Gravens, Jane M. Smith*

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Prepared for U.S. Army Engineer District, New York

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by S. Jarrell Smith, Mark B. Gravens, Jane M. Smith

U.S. Army Corps of Engineers  
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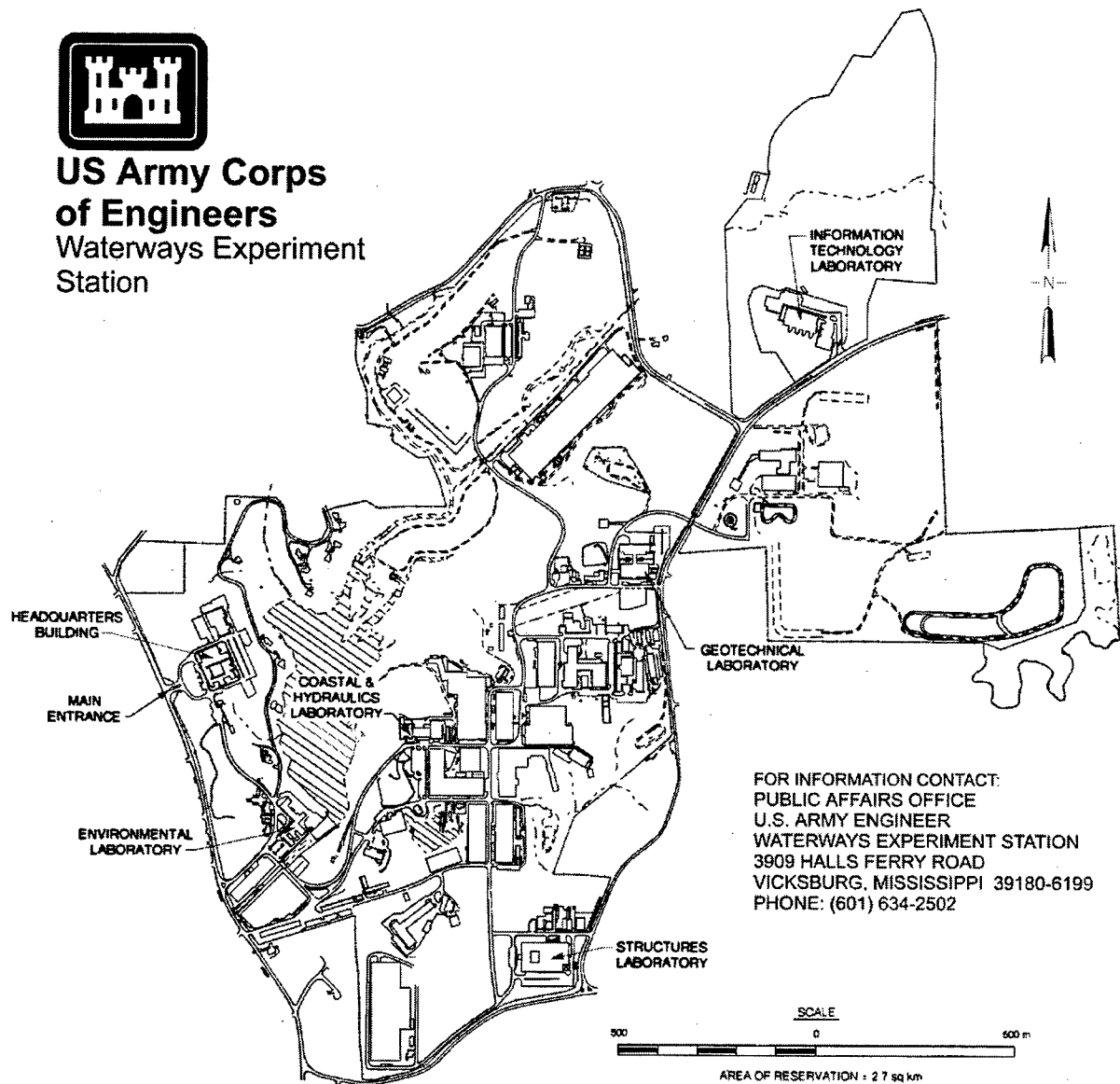
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# Preface

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In May 1996, the U.S. Army Engineer District, New York (New York District), requested the U.S. Army Engineer Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL) to evaluate coastal processes and to determine contributing factors for the accelerated erosion of a newly constructed beach fill at Monmouth Beach, New Jersey. Ms. Lynn M. Bocamazo, Engineering Division, New York District, was the project study manager. WES is a complex of five laboratories of the U.S. Army Engineer Research and Development Center (ERDC).

This report documents the subject study, which presented and evaluated hypotheses for the coastal processes contributing to the accelerated erosion at Monmouth Beach. The four hypotheses evaluated in this report are wave focusing by Shrewsbury Rocks, cross-shore beach profile adjustment, beach-fill end losses, and beach-fill planform adjustment. The study concludes by summarizing the evaluation of each hypothesis and presenting conceptual recommendations for mitigation of the high erosion rates.

The study was performed by Mr. S. Jarrell Smith, Mr. Mark Gravens, and Dr. Jane M. Smith, Coastal Processes Branch (CPB), Coastal Sediments and Engineering Division, CHL. Work was performed under the supervision of Mr. Bruce A. Ebersole, Chief, CPB, and Mr. H. Lee Butler (retired), former Chief of the former Research Division. Ms. J. Holley Messing, CPB, coordinated report preparation.

The Director and Acting Assistant Director of CHL were Dr. James R. Houston and Mr. Thomas W. Richardson, respectively.

At the time of report publication, Commander of ERDC was COL Robin R. Cababa, EN.

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# Conversion Factors, Non-SI to SI Units of Measurement

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

| Multiply             | By        | To Obtain    |
|----------------------|-----------|--------------|
| cubic yards          | 0.7645549 | cubic meters |
| feet                 | 0.3048    | meters       |
| miles (U.S. statute) | 1.609347  | kilometers   |

# 1 Background

---

The U.S. Army Engineer District, New York (New York District), is constructing Section I - Sea Bright to Ocean Township, New Jersey, of the Atlantic Coast of New Jersey-Sandy Hook to Barnegat Inlet Beach Erosion Control Project (U.S. Army Engineer District, New York 1989). Within the initial portion of this project, a zone of accelerated shoreline erosion has developed near the southern boundary of Monmouth Beach, New Jersey. This report is first in a series on the topic of accelerated erosion rates of the beach fill at Monmouth Beach, New Jersey. The objective of the present report is to identify factors contributing to the area of accelerated erosion at Monmouth Beach. The present study evaluates four hypotheses presented as possible explanations for the hot spot within the beach fill, identifies likely contributors to the accelerated erosion rates, and makes recommendations regarding concepts of mitigating the erosional hot spot. The second report extends the conceptual recommendations of this report by developing and analyzing shore-protection alternatives and estimating required stone sizes and volumes for the recommended alternatives.

## Beach-Fill Summary

The Atlantic Coast of New Jersey-Sandy Hook to Barnegat Inlet Beach Erosion Control Project (New York District 1989) was designed in three sections (Figure 1), Section 1 being Sea Bright to Ocean Township, New Jersey. Section 1 is scheduled to be constructed in four contracts (Figure 2), with the first contract, Contract 1A, ranging from the southern boundary of Monmouth Beach north to Rumson Bridge (3.1 miles<sup>1</sup> in length). The planform design for the Contract 1A beach fill begins with sta 131 near Rumson Bridge and extends south to sta 295 near the Monmouth Beach/Long Branch municipal boundary (Figure 3). Beach-fill placement for Contract 1A began in June 1994 and ended for the season on 3 January 1995 resulting in completion of the southern third of the contract. Construction of Contract 1A resumed in April 1995, proceeding northward to completion in November 1995. By late 1995, a 0.5-mile length of beach fill (between sta 253 and 277) in the southernmost portion of Contract 1A was suffering from accelerated erosion, with erosion rates decreasing between

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<sup>1</sup> A table of factors for converting non-SI units of measurement to SI units is presented on page viii.

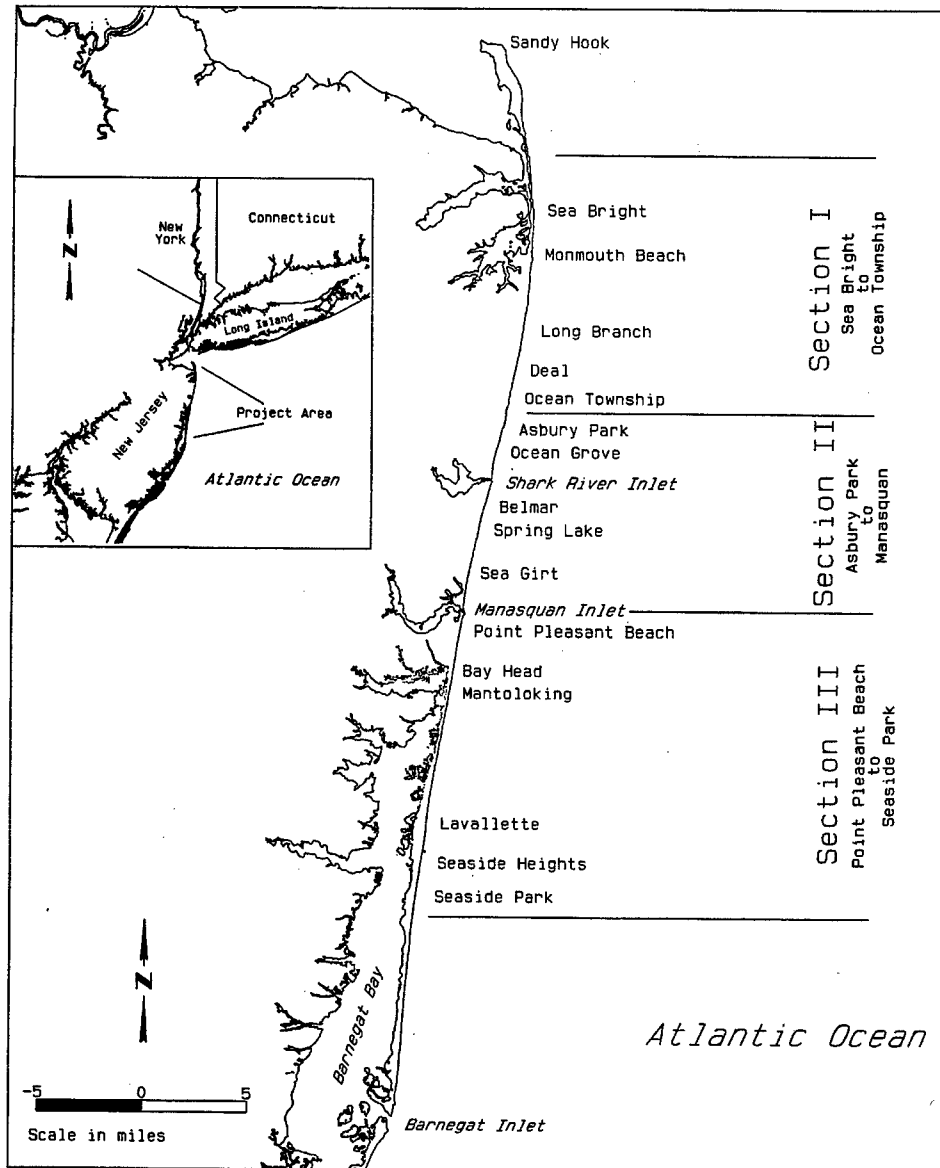


Figure 1. Atlantic Coast of New Jersey Beach Erosion Control Project

sta 277 and the southern boundary of Contract 1A. This hot spot was renourished during November 1995 with an additional placement of 230,000 cu yd of beach-fill material.

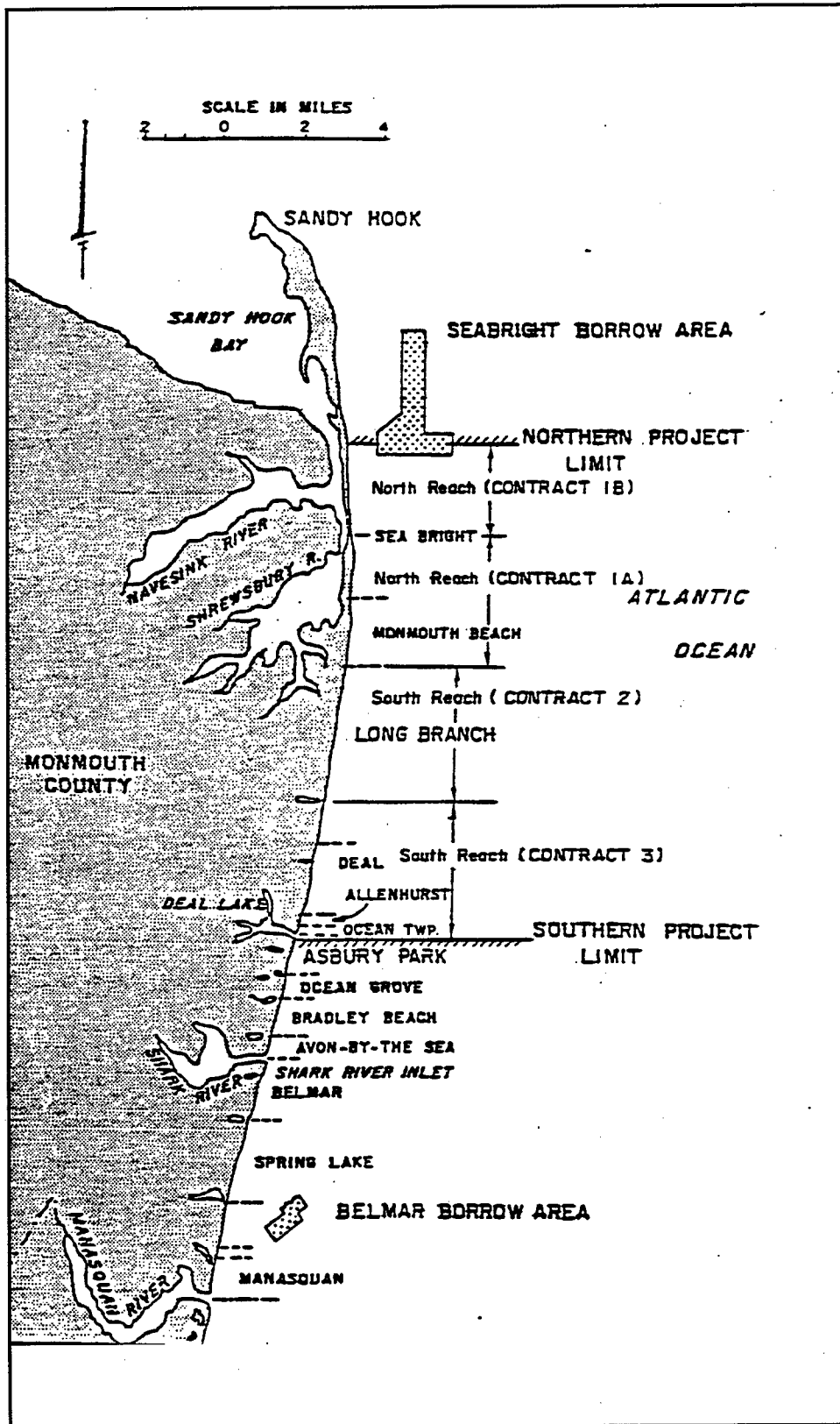


Figure 2. Section I - Sea Bright to Ocean Township, NJ (New York District 1989)

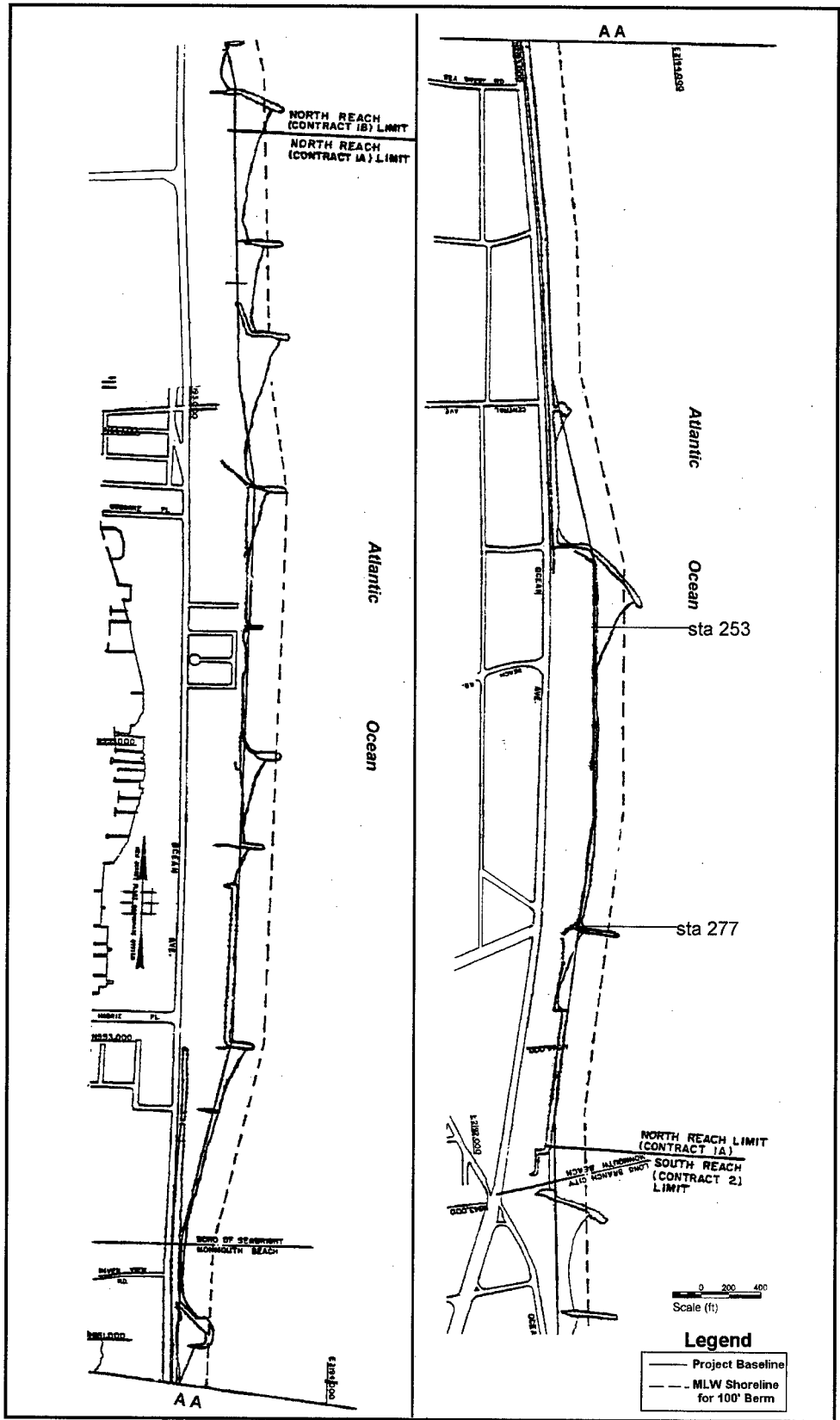


Figure 3. Beach-fill planform design (New York District 1989)

## Beach-Fill Specifications

The beach fill within Contract 1A has a design berm width of 100 ft, a design berm elevation of 10 ft mean high water, and a berm cap of 2 ft. The mean low water shoreline for the 100-ft design berm is presented by the dashed line in Figure 3. The stationing labels presented in this figure are used later to reference specific positions along the beach fill and as identifiers for beach profile surveys. The construction template has a 1V:15H slope from the berm to mean low water. Below mean low water, the construction template slope decreases to 1V:20H as shown in Figure 4.

## Scope of Study

Four hypotheses have been developed as potential causes of the hot spot found within Contract 1A: wave focusing by Shrewsbury Rocks, cross-shore adjustment, beach-fill end losses, and beach-fill planform adjustment. These hypotheses will be further examined in this report to determine the contributing factors of the accelerated erosion at the hot spot.

## Wave focusing by Shrewsbury Rocks

Shrewsbury Rocks is a rock outcropping located approximately 1.2 miles northeast of the hot spot at Monmouth Beach, New Jersey. It is hypothesized

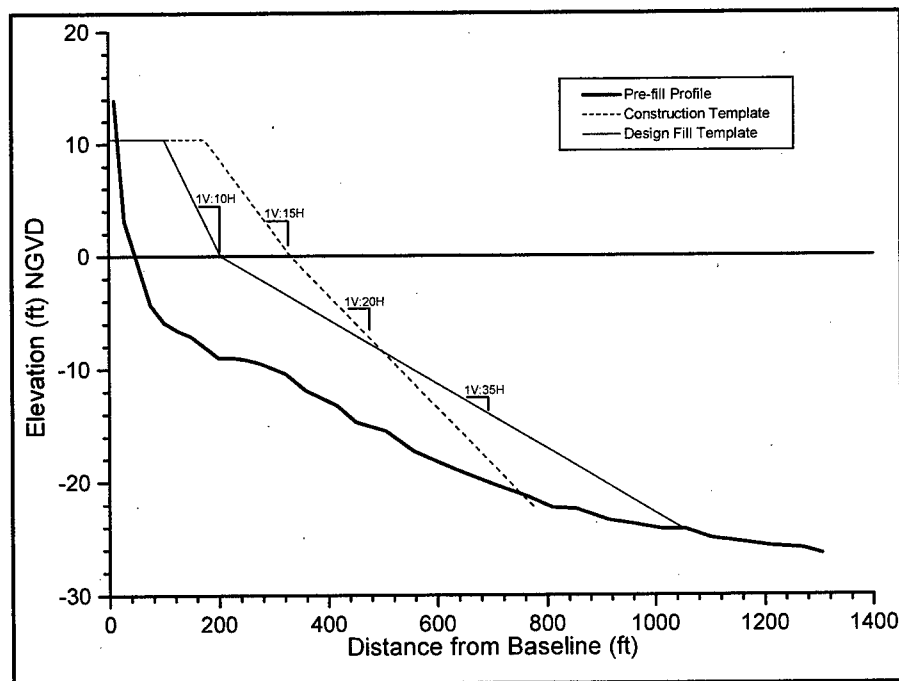


Figure 4. Design and construction template (New York District 1989)

that wave focusing by Shrewsbury Rocks may cause gradients in wave height and direction which in turn produce gradients in longshore sediment transport. Gradients in longshore sediment transport rates could then cause erosion of the shoreline. This task evaluates the potential of wave focusing by Shrewsbury Rocks to cause the Monmouth Beach hot spot. Evaluation of the offshore feature's influence on the hot spot includes statistical analysis of available wave gauge information and determination of the reaches of shoreline within the shadow zone of the rock outcropping.

### **Cross-shore adjustment**

Erosion within the hot-spot region may be due to greater than anticipated cross-shore adjustment of the construction template, resulting in decreased beach width at the hot spot. In evaluating the contribution of cross-shore profile adjustment to the development of the hot spot, an analysis of the cross-shore evolution of the beach-fill cross section is performed. The prefill, postfill, and theoretical equilibrium profile shapes are compared and an assessment made of the present state of cross-shore adjustment and the anticipation of additional cross-shore adjustment of the profiles and subsequent decreases in beach width.

### **Beach-fill end losses**

End losses are significant for beach fills constructed with short lengths. Since the beach fill in the hot-spot region at southern Monmouth Beach protrudes seaward of the beach fill placed in adjacent areas, it can be ideally treated as a short, rectangular beach fill placed upon a longer beach fill. This task examines the losses associated with a short, rectangular fill using an analytical approach and an idealized application of the GENESIS numerical model for shoreline change (Hanson and Kraus 1989).

### **Beach-fill planform adjustments**

Because the beach fill in the hot-spot area at Monmouth Beach protrudes seaward of the adjacent shorelines, the loss of beach fill from the hot-spot region may be related to the planform adjustment of the beach fill to an orientation similar to the offshore bathymetric contours. This task focuses on identifying trends in bathymetric evolution of the beach fill and the implications of these evolutionary trends in the development of the erosional hot spot.

## **Primary Objective**

The objective of this study is to evaluate coastal processes at the hot spot and identify processes that appear to contribute to the accelerated erosion rates of the beach fill. Following evaluation of the four proposed hypotheses, the major contributing factor(s) for the development of the erosional hot spot are identified. In addition, conceptual design alternatives or construction procedures are recommended for further consideration and study.

## 2 Wave Focusing by Shrewsbury Rocks

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This analysis examines the potential that the hot spot at Monmouth Beach is caused by differential longshore sand transport rates caused by wave transformation over the Shrewsbury Rocks. Hot-spot erosion at Corps of Engineers beach-fill projects at Ocean City, Maryland, and Folly Beach, South Carolina, has been linked to differential longshore sand transport caused by irregularities in the nearshore bathymetry. Consequently, there is a possibility that wave transformation over the Shrewsbury Rocks could be responsible for the observed hot spot at Monmouth Beach. This chapter examines the available wave data and determines what areas of the beach are down-wave of the rock outcropping under wave conditions observed since construction of Contract 1A.

### Wave Statistics

Wave data for the project region are available from two gauges. The gauge nearest the beach fill is located at Long Branch, New Jersey ( $40.30^{\circ}$  N,  $73.97^{\circ}$  W), in a water depth of approximately 32.8 ft (10 m). A slope array was deployed at Long Branch in 1994 and replaced with a directional wave gauge (DWG) in 1995. Wave data are available from January 1994 - March 1996. These data were collected at a rate of 1 Hz for 1,024 sec. Samples were collected each hour during expected storm conditions and once every 4 hr for low-wave-height conditions. Wave periods and directions were not recorded for wave heights less than 0.7 ft (0.2 m). Numerous gaps appear in the wave record (30 percent of the gauge deployment). The longest gap was mid-November 1994 to mid-July 1995, when the slope array failed and was replaced with the DWG. Wave directions are also missing from January to mid-March 1994. Statistics from the Long Branch gauge are given in Appendix A1. The statistics include breakdowns of the wave height, period, and direction by month; wave height and period by direction; and the mean and maximum wave heights for the duration of the gauge deployment. Statistical tables and mean heights were generated using data taken at 4-hr increments (0, 400, 800, 1200, 1600, 2000 Greenwich mean time (GMT)) to evenly weight storm and nonstorm conditions in the statistics. The statistical values have not been adjusted to account for the nonrandom gaps in the data. The maximum recorded wave height was 13.8 ft (4.2 m) on

11 November 1995. The mean wave height ranged from 2.7 ft (0.82 m) in January to 1.9 ft (0.58 m) in June. Figure 5 is a wave rose for the Long Branch gauge, showing the percent occurrence of wave conditions in sixteen 22.5-deg direction bands. The percent occurrences in the wave rose have been adjusted, by month, to reflect an even distribution of wave conditions throughout the year accounting for gaps in the record. The adjustment is made by calculating the distribution for each month, and then weighting the data for each month based on the number of days in the month.

Wave data are also available from the National Data Buoy Center (NDBC) Buoy 44025, located south of Long Island at 40.25° N, 73.17° W. The buoy is located almost directly offshore of Monmouth Beach in a water depth of 130 ft (40 m). Wave data are available from January 1994 - February 1996. Data were collected at a rate of 1 Hz for 1,024 sec, once per hour. The buoy data were examined because the record is more complete (93-percent data return as compared with Long Branch gauge's 70 percent). The only significant gap in the data record was 11 November to 4 December 1995 (note that this is the time of the maximum wave height at the Long Branch gauge). Statistics from the buoy are given in Appendix A2. The maximum recorded wave height was 24.3 ft (7.4 m) on 3 March 1996 (wave height at the Long Branch gauge was 13 ft (4 m) at that time). The wave heights at the buoy are significantly larger than measured at Long Branch. The distribution of wave periods above 10 sec is similar for the two gauges, but the buoy records more short-period wave events (periods less than 7 sec) because of local wave generation between the New Jersey coast and the buoy location. Wave directions are more broadly distributed at the buoy than at Long Branch because of the deeper water depth and longer fetch from the west. Both the buoy and Long Branch gauge have peaks in the directional distribution at 112.5-135 deg (angles are referenced clockwise from North). The buoy also has a secondary peak at 292.5 deg. Figure 6 is a wave rose for the Long Island buoy. The percent occurrences have been adjusted to account for gaps in the record. Wind speeds and directions measured at the buoy are included in the statistics given in Appendix A2. Figure 7 is a wind rose for the buoy site.

Although there are large gaps in the Long Branch data record, these data are used to look at the wave directions at Monmouth Beach for assessing the wave focusing by Shrewsbury Rocks. The proximity of the Long Branch gauge to Monmouth Beach makes it most relevant for evaluating the local wave climate, in spite of data gaps.

Figures 8-11 show seasonal wave roses for the Long Branch measurements. Note that the percentages in each plot add to 100 percent. Two dominant patterns arise. In the fall and winter (September through February), the dominant wave direction is 112.5 deg (east-southeast) (40 percent). The percent occurrence in the adjoining bands (90 and 135 deg) is 17-24 percent and 27-28 percent, respectively.

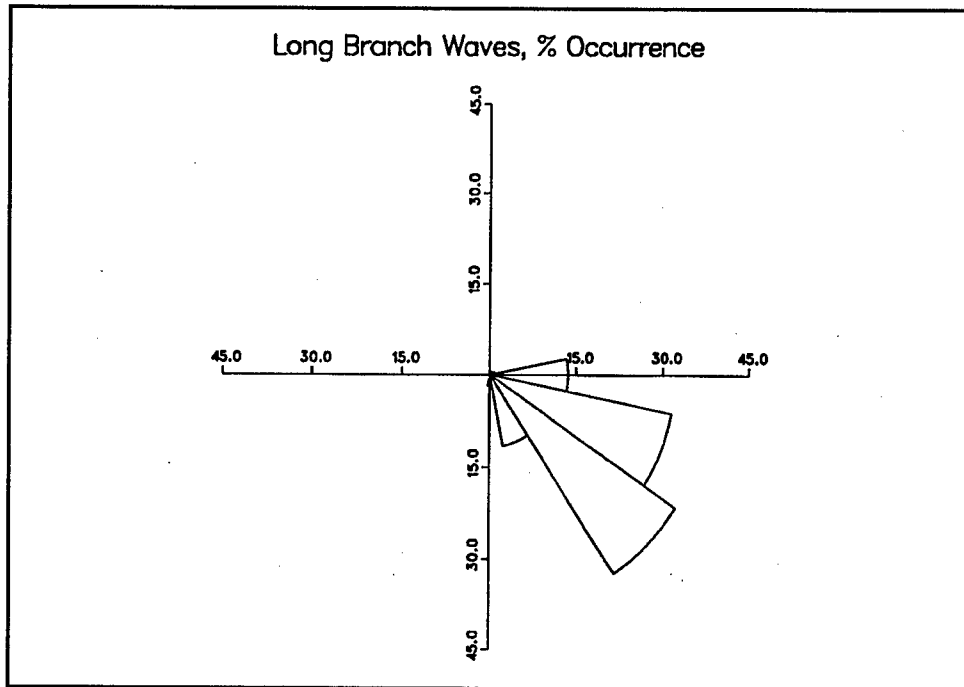


Figure 5. Long Branch wave rose

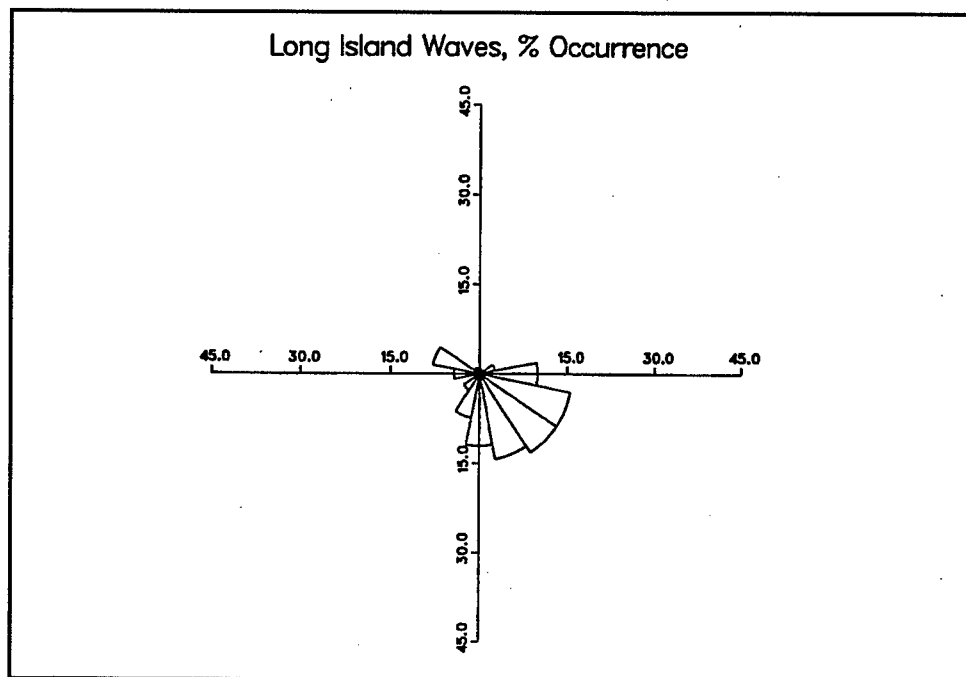


Figure 6. Long Island buoy wave rose

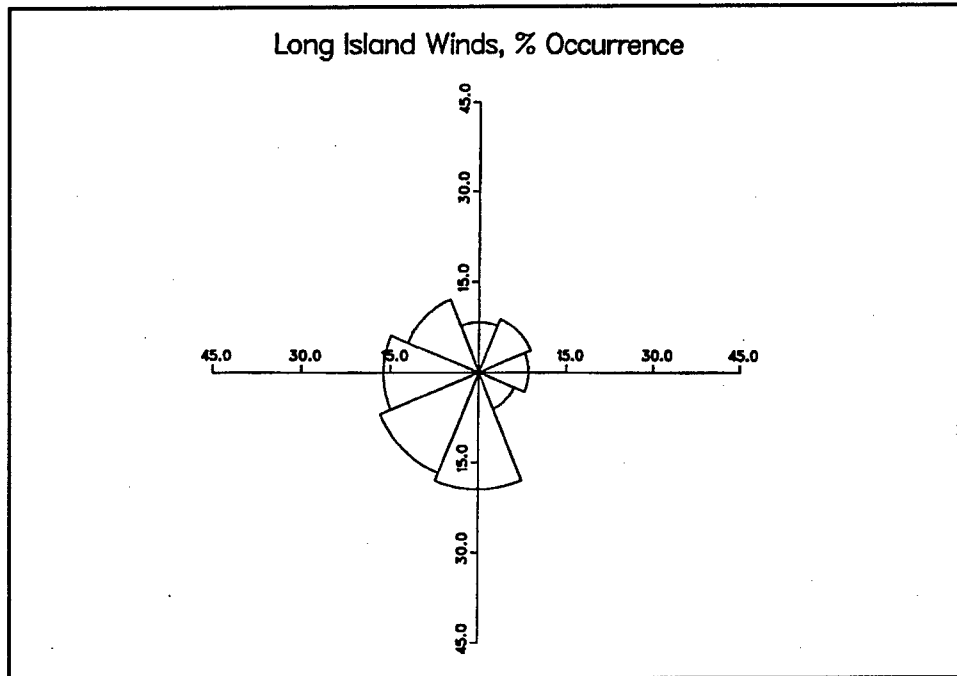


Figure 7. Long Island buoy wind rose

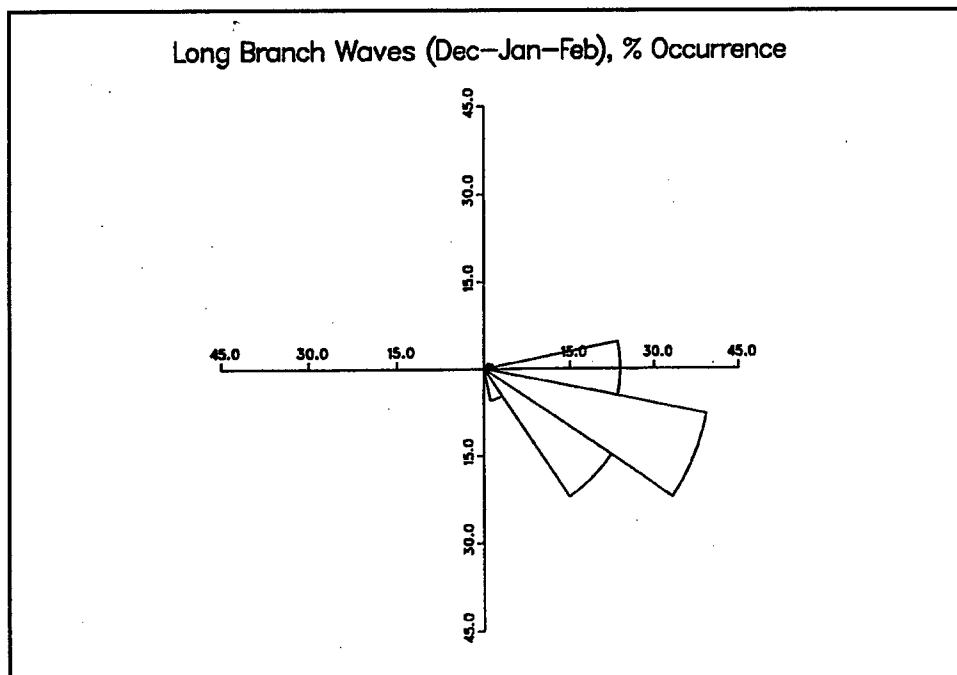


Figure 8. Long Branch wave rose (winter)

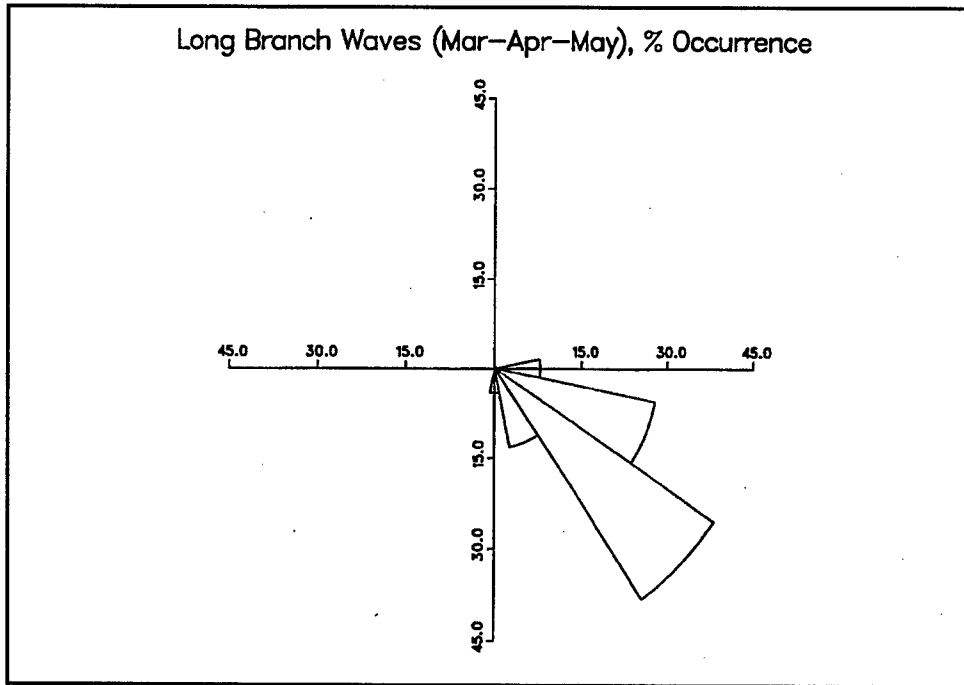


Figure 9. Long Branch wave rose (spring)

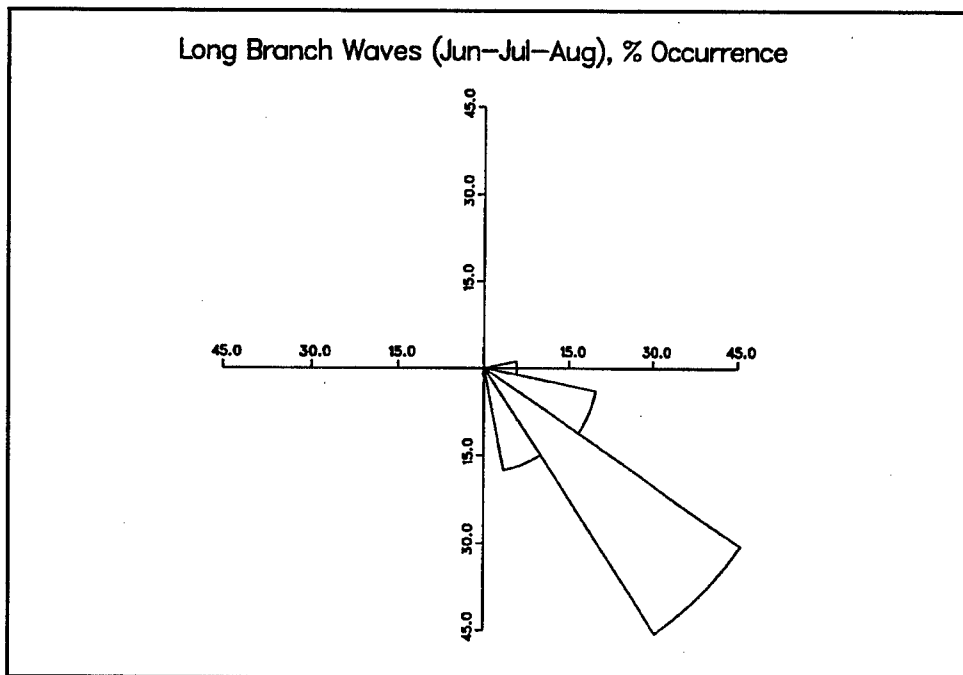


Figure 10. Long Branch wave rose (summer)

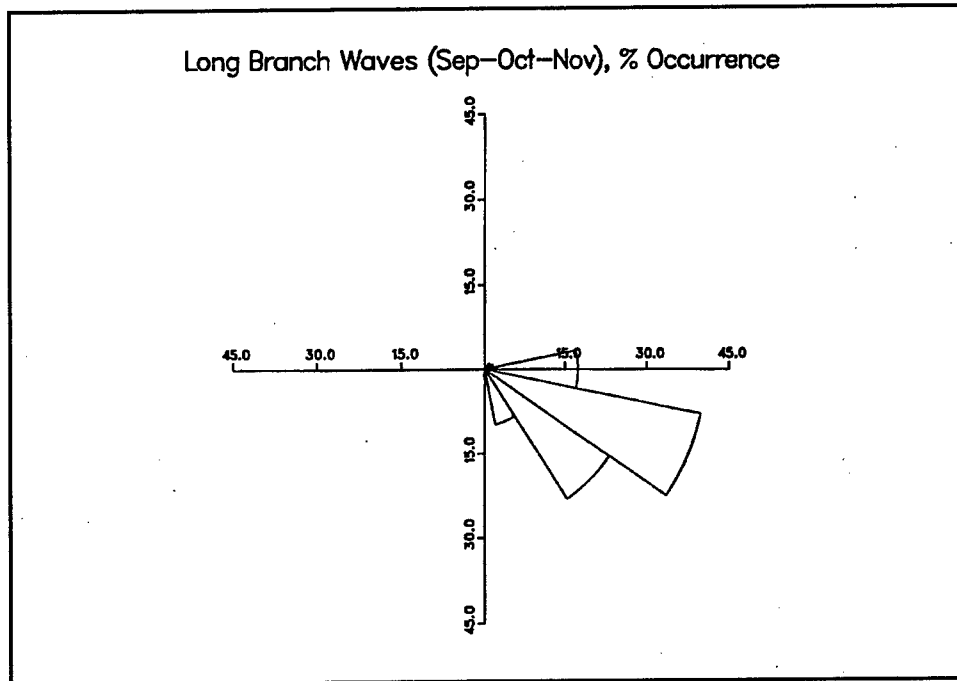


Figure 11. Long Branch wave rose (fall)

In the spring and summer, the dominant wave direction is 135 deg (southeast) (46-55 percent). The adjoining bands (112.5 and 157.5 deg) account for 20-28 percent and 13-18 percent, respectively. Occurrences of wave directions outside the range 78.8 to 168.7 deg are rare. Angles north of this range are sheltered by Long Island, and local wave generation is limited by the short fetch. Angles south of the range are nearly parallel to shore and thus would have refracted to less oblique angles seaward of the 33-ft (10-m) depth, unless the wave periods were very short. The east-southeast and southeast dominant wave directions are consistent with the northerly direction of net longshore sand transport at Monmouth Beach. Figures 12 and 13 present histograms of the wave height and period distributions for all populated wave directions. The histograms again show that the dominant wave directions are in the 112.5- and 135-deg bands. The distributions of wave heights less than 3.3 ft (1.0 m) are fairly flat, with a large drop off in heights above 3.3 ft (1.0 m). The 90-deg band has a relatively flat distribution of heights and periods. The direction bands 22.5, 45.0, 67.5, and 180.0 deg contain only short-period and low-wave-height events.

The incident wave directions illustrated in the statistical tables and figures show that the wave climate at Monmouth Beach is dominated by waves from the southeast (39 percent) and east-southeast (32 percent). Fourteen percent of the waves approach from the east, but less than 2 percent total from directions north of east, and these are short-period, small-height waves.

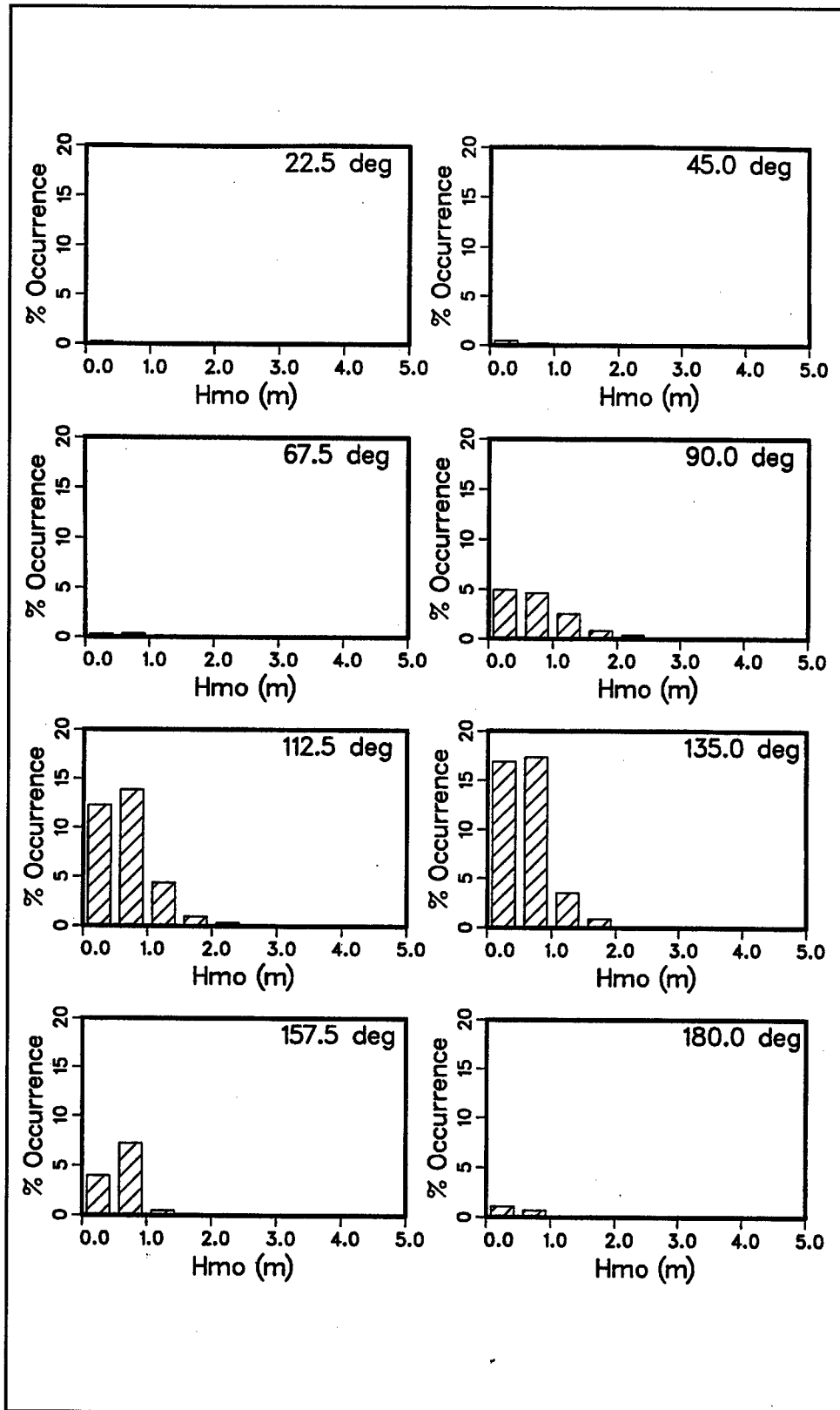


Figure 12. Histograms of wave-height distribution by direction (Long Branch gauge)

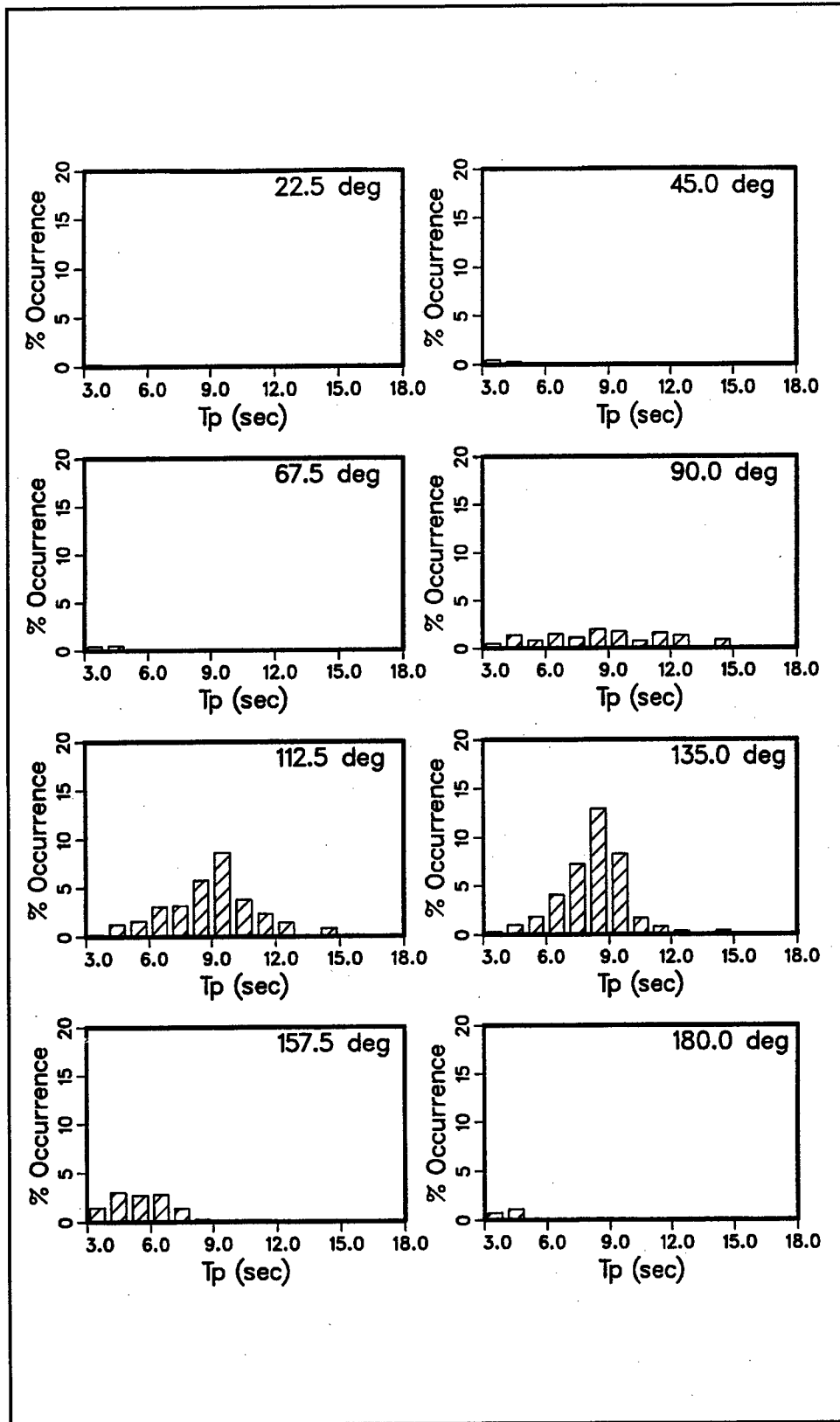


Figure 13. Histograms of wave-period distribution by direction (Long Branch gauge)

The hot spot at Monmouth Beach is approximately 0.7 miles south of Shrewsbury Rocks. Impacts of the rocks on the beach-fill project are expected directly inshore from the rocks or to the north, not to the south. The expected impact could include increased wave height and a local reversal in wave direction, producing gradients in longshore sand transport. A previous study of coastal processes in the region (Kraus et al. 1988) showed one example of wave height and angle variation along the shore from the wave transformation model RCPWAVE (Figure 14 reproduces Figure 11 from Kraus et al.). Figure 14 shows, for an incident wave angle of 101.5 deg (-7.5 deg in wave model), the wave amplification at Cell 142 is 1.7. Cell 142 is approximately directly west of Shrewsbury Rocks, near sta 218. More southerly wave directions would move the location of the wave focusing further north of the rocks.

The bathymetry contours just south of Shrewsbury Rocks angle offshore toward the rocks. This bathymetry feature could increase the breaking wave angles on the northern portion of the hot spot and contribute to a local increase in northerly sand transport. It is interesting to note that the indentation in the shoreline to the north of the hot-spot region is located in the lee of Shrewsbury Rocks. Accelerated erosion of the recently completed beach fill in the lee of Shrewsbury Rocks (centered around sta 218) may be a future concern.

## Storms

Nineteen storms with maximum wave heights exceeding 6.6 ft (2 m) were measured at the Long Branch directional wave gauge during the 27 months of data collection (approximately 19 months, excluding gauge downtime). Storm peaks are denoted as the time when the maximum wave height occurred. Table 1 summarizes peak wave conditions for each storm. The peak period and direction are the period and direction associated with the maximum wave height. Storm duration is the approximate length of time when the wave height exceeded 6.6 ft (2 m). Wave conditions exceeding 6.6 ft (2 m), sorted by storm magnitude, are listed in Appendix A3. The period of record at the Long Branch gauge is not sufficient to characterize the storm climatology, but does give examples of typical, short-return-period storm conditions. The range of peak directions for wave heights exceeding 6.6 ft (2 m) is 86 to 140 deg, with a mean direction of 109 deg. The storm wave conditions imply predominant storm transport to the north in Contract 1A. Focusing of wave energy by Shrewsbury Rocks would be manifested as a hot spot in the middle or northern half of Contract 1A (near sta 218), not the southern end. Storm wave directions are approximately shore normal (100 deg) or well south of shore normal (130 deg). Waves in the northeast quadrant are fetch limited, because of the presence of Long Island, and wave heights are limited to approximately 1.6 ft (0.5 m).

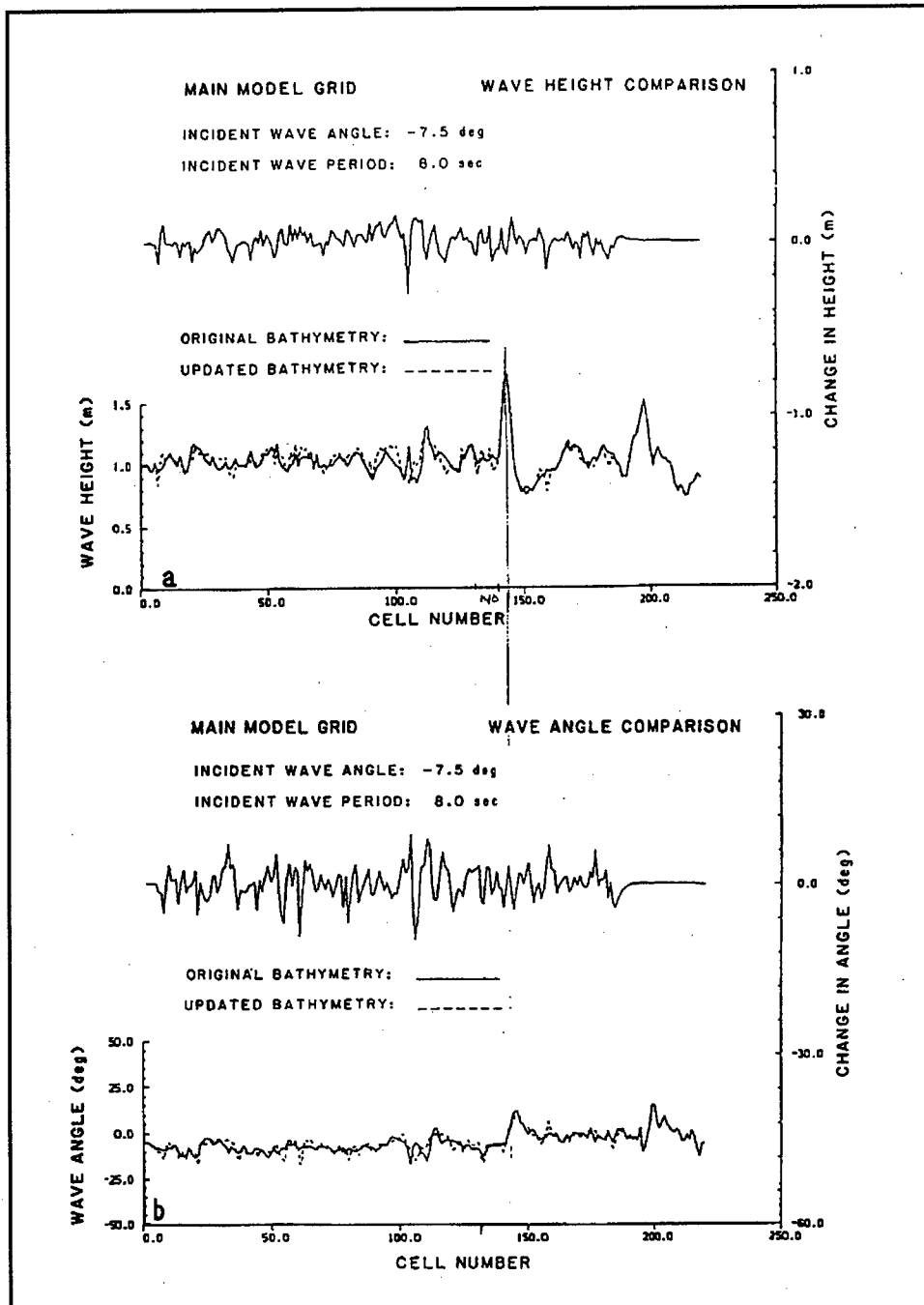


Figure 14. Wave height and angle variation near Monmouth Beach, NJ (from Kraus et al. 1988)

**Table 1  
Peak Storm Conditions at Long Branch**

| $H_{mo}$ , m | $T_p$ , sec | $\theta_p$ , deg | Duration, hr | Date     |
|--------------|-------------|------------------|--------------|----------|
| 4.22         | 10.7        | 101              | 19           | 95111501 |
| 4.08         | 9.8         | 129              | 10           | 95111205 |
| 4.07         | 11.6        | ---1             | 34           | 94030309 |
| 3.90         | 11.6        | 108              | 28           | 96010811 |
| 3.79         | 9.8         | ---              | 21           | 94010415 |
| 3.76         | 8.5         | 97               | 11           | 96032003 |
| 3.55         | 8.5         | 107              | 18           | 94092304 |
| 3.14         | 8.5         | ---              | 19           | 94022322 |
| 3.14         | 9.1         | 130              | 10           | 96011920 |
| 3.05         | 9.1         | 133              | 12           | 96012721 |
| 2.46         | 7.5         | 86               | 11           | 95122002 |
| 2.38         | 6.7         | 96               | 5            | 96011221 |
| 2.36         | 8.0         | 121              | 28           | 94111723 |
| 2.33         | 7.1         | 96               | 9            | 96032912 |
| 2.23         | 8.5         | ---              | 10           | 94021123 |
| 2.17         | 7.1         | 102              | 6            | 96010308 |
| 2.11         | 7.1         | ---              | 9            | 94012612 |
| 2.11         | 9.1         | ---              | 3            | 94012823 |
| 2.06         | 7.5         | 105              | 4            | 94101512 |

<sup>1</sup> No direction information available.

## Summary

Waves at Monmouth Beach typically approach from 90 to 157.5 deg, with a dominant direction of 135 deg. Less than 2 percent of the waves approach from north of east. These waves are fetch limited and have small heights (>1.6 ft (0.5 m)) and short periods (>5 sec). The dominant southeast and east wave directions shown in the wave statistics and the storm data indicate that wave focusing by Shrewsbury Rocks would impact the mid to north end of Contract 1A and not be a factor in the hot spot located at the south end of the project. Wave focusing would be manifest as a local amplification in wave height and local reversal or gradient in wave direction. The northeasterly angle of the bathymetry contours between the hot spot and Shrewsbury Rocks could increase the breaking wave angles on the northern portion of the hot spot and contribute to a local increase in northerly sand transport.

## 3 Beach Profile Evolution

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Beach-fill material placed along a shoreline is typically constructed in the form of a simple, predefined template in which the design berm elevation is extended some distance seaward of the prescribed berm width. Side slopes of the construction template are considerably steeper than the natural profile. This construction practice allows easier placement of the beach-fill material and facilitates the estimation of placed volume during construction. Adjustment of this oversteepened construction template towards an equilibrium beach profile is anticipated in the design of beach fills. Transport of material from the upper portions of the beach-fill construction template to the offshore portions of the beach profile is accomplished through cross-shore transport processes.

Hypothesizing that cross-shore processes could produce greater than anticipated profile adjustment, the accelerated retreat of the shoreline at the Monmouth Beach hot spot could be attributed to beach-fill sediments moving offshore along the beach profile. As part of this study, the available profile survey data are evaluated to determine if cross-shore transport is a significant contributing factor to the shoreline erosion at the hot spot. In addition, the equilibrium profiles for several locations alongshore are computed and compared with the most recent beach profile surveys to determine whether additional cross-shore adjustment should be anticipated, further reducing the beach width in the vicinity of the hot spot.

### Profile Survey Data

Data used in the beach profile analysis were collected to compute beach-fill pay quantities. These data were collected at various stages of completion of the project (between June 1994 and October 1995) at 100-ft, alongshore intervals over the particular reach of the project being surveyed. The profile surveys typically extend from the seawall or revetment approximately 1,000 ft seaward with depths ranging from 20-25 ft in the National Geodetic Vertical Datum (NGVD).

## Beach Profile Evolution

Beach profiles are compared over the period June 1994 to October 1995 to examine beach profile evolution. The alongshore locations indicated in Figure 15 were selected for evaluating the beach profile evolution within and south of the identified hot-spot region (sta 255, 265, 275, 286, and 290) as well as immediately north of the hot spot (sta 208, 224, 232, 240, and 245). These profiles are used to evaluate beach profile evolution and associated cross-shore and longshore processes present at each location.

### Hot-spot region

Within and south of the hot-spot region, beach profile evolutions of sta 255, 265, 275, 286, and 290 are examined. Available beach profile surveys at each location are used to discuss the sediment transport processes that contribute to the evolution of each profile.

Station 255 is located near the tip of Groin 44 (New York District 1989), a curved groin approximately 4,500 ft (0.85 mile) north of the southern boundary of Monmouth Beach. Figure 16 presents the profile surveys for sta 255 from June 1994 to October 1995. The evolution of the beach profile at sta 255 indicates that the groin impounded northbound beach-fill material placed to the south of sta 255 prior to construction of the design template in October 1994. After placement of beach-fill material in October 1994, the beach profile at sta 255 remains relatively stable with only a slight shoreward transition of the profile and little cross-shore profile adjustment. It is likely that the stability of this profile is due to its proximity to Groin 44.

Station 265 is located within the area considered the Monmouth Beach hot spot. The beach profile surveys shown in Figure 17 indicate dynamic changes over time at this location. Placement of the construction template is apparent in the October 1994 beach profile. After October 1994, progressive erosion of the profile is evident. The beach profile at sta 265 lost 156 cu yd/ft between October 1994 and October 1995. The net losses of material from the beach profiles at this location and lack of evidence that material is moving offshore indicate that longshore sediment transport is dominant at this location.

The beach profiles at sta 275 (Figure 18) indicate placement of the construction template between August and September of 1994, then progressive erosion of the profile until its condition approaches the prefill condition in October 1995. Similar to sta 265, the profile at sta 275 does not indicate any cross-shore profile adjustment; instead, there is a net loss of 170 cu yd/ft of beach fill between September 1994 and October 1995.

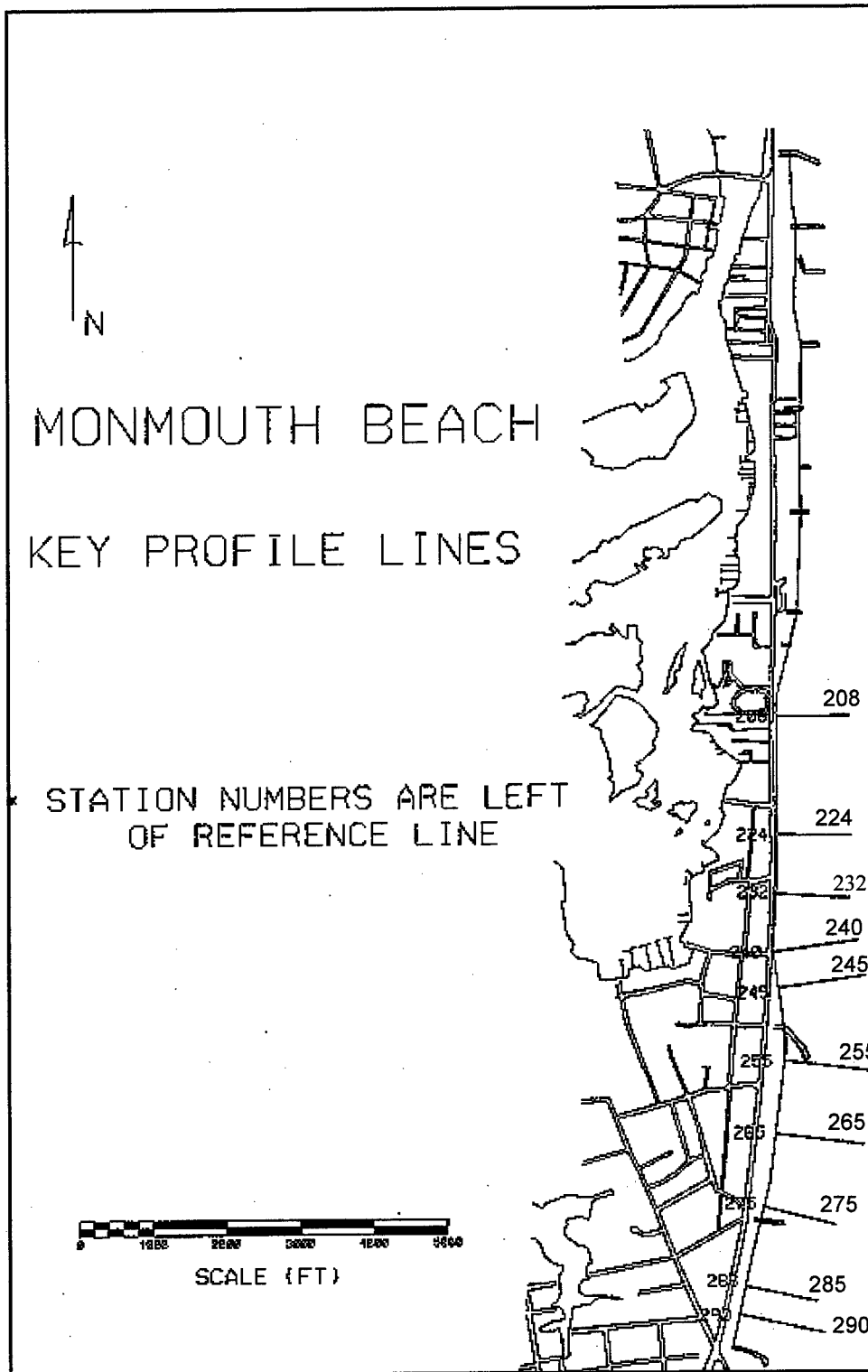


Figure 15. Beach profiles used in cross-shore analysis

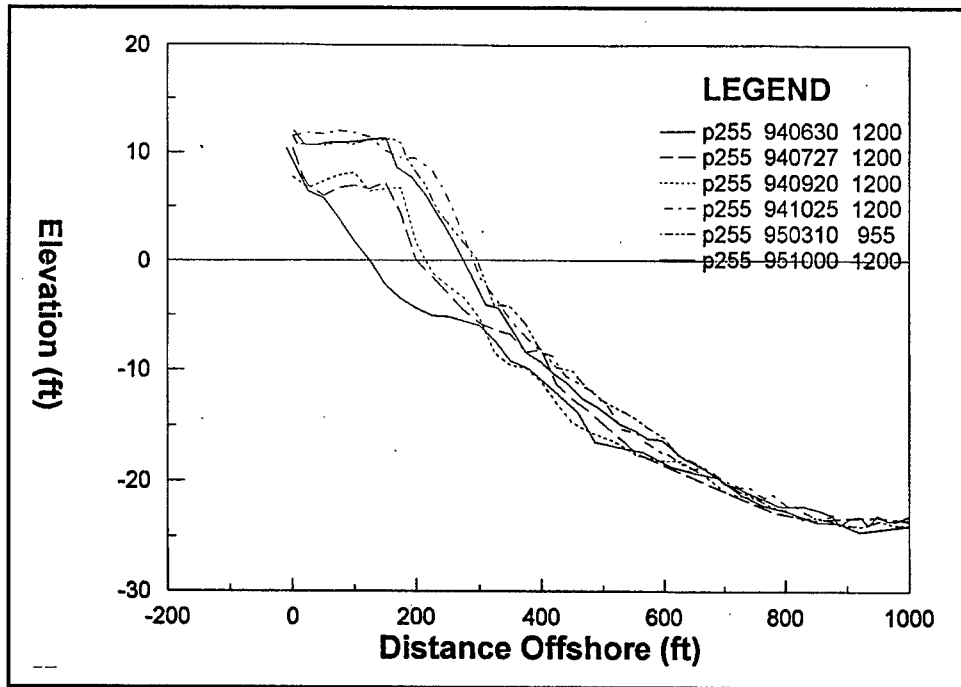


Figure 16. Beach profile evolution at sta 255

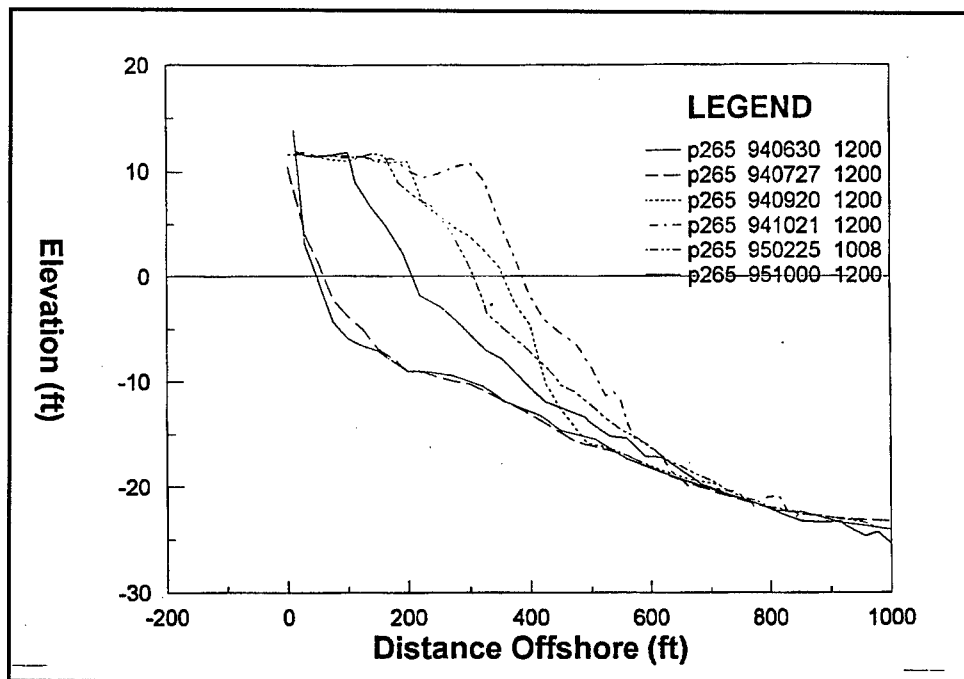


Figure 17. Beach profile evolution at sta 265

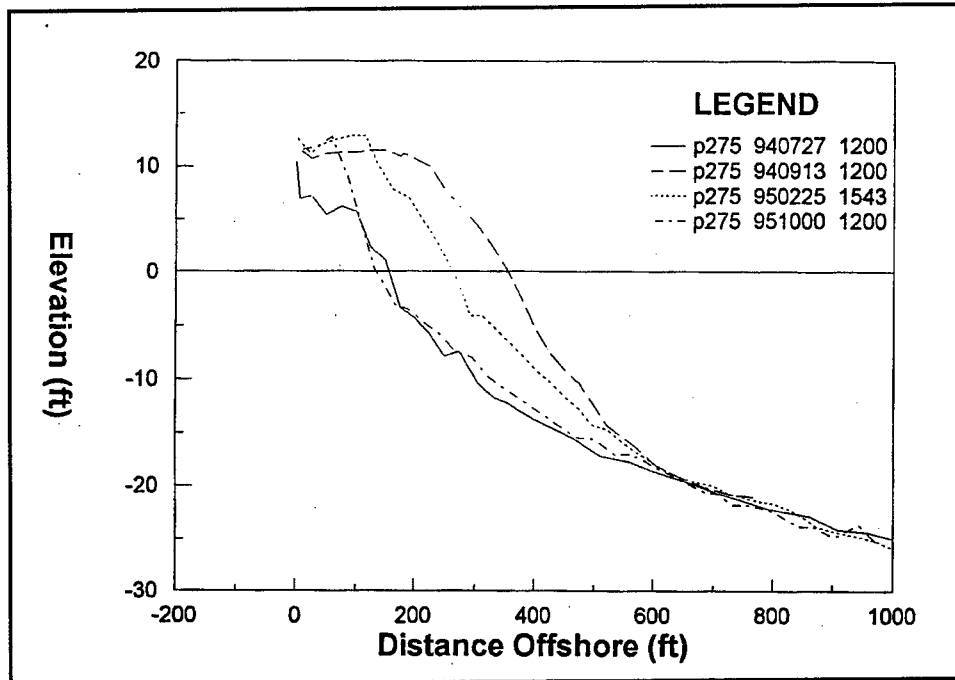


Figure 18. Beach profile evolution at sta 275

Beach profiles at sta 286, 290, and 294 indicate similar patterns of evolution as sta 265 and 275, but have net sediment losses of 70, 36, and 36 cu yd/ft, respectively (significantly smaller than the losses at sta 265 and 275). These profiles are given in Appendix B.

A consistent pattern within the general region of the hot spot is significant losses of material from the beach profiles with little or no cross-shore profile adjustment. This indicates that the loss of material from the hot-spot region is related to longshore transport processes instead of cross-shore transport processes.

### North of hot spot

No beach-fill construction was completed north of the hot-spot region before beach-fill placement ended for the season on 3 January 1995. Beach-fill construction at this time advanced only as far north as the base of Coastal Structure 44.<sup>1</sup> Before construction resumed in April 1995, all stations along the beach-fill reference line were surveyed. The March 1995 profile surveys north of Groin 44 reveal that a large volume of material accumulated between December 1994 and March 1995. This indicates that a significant amount of material lost from the hot-spot region was transported north and deposited in the adjacent region to the north. Profiles 208, 232, 240, and 245 are presented to demonstrate the effect of the evident longshore transport.

<sup>1</sup> Personal Communication, 12 August 1996, Brian Carr, New York District.

Profiles 245 and 240 are located 400 and 900 ft north of the base of Coastal Structure 44, respectively. These two profiles are located immediately downdrift of the beach fill completed on 3 January 1995. Profile 245 (Figure 19) gained 64 cu yd/ft between December 1994 and March 1995, a period during which there was no beach-fill activity. Similarly, beach profiles at sta 240 (Figure 20) indicate that a unit volume of 69 cu yd/ft was gained during November 1994 and a unit volume of 109 cu yd/ft was gained between December 1994 and March 1995.

Further north, at sta 208 and 232, beach profiles exhibit trends similar to sta 240 and 245. Beach profiles at sta 232 (Figure 21) indicate a unit volume increase of 31 cu yd/ft during November 1994 and a unit volume increase of 60 cu yd/ft between December 1994 and March 1995. The beach profiles at sta 208, one of the stations furthest north of the hot spot that was surveyed prior to the March 1995 survey, indicate a unit volume gain of 69 cu yd/ft between October 1994 and March 1995 (Figure 22). Because of the lack of December 1994 survey data north of sta 206, the northern extent of material transported from the hot-spot area is unknown. However, significant gains of material on the profiles north of the hot-spot area between October 1994 and March 1995 indicate that large volumes of beach-fill material were transported north from the hot-spot region to the profiles experiencing significant gains in unit volume.

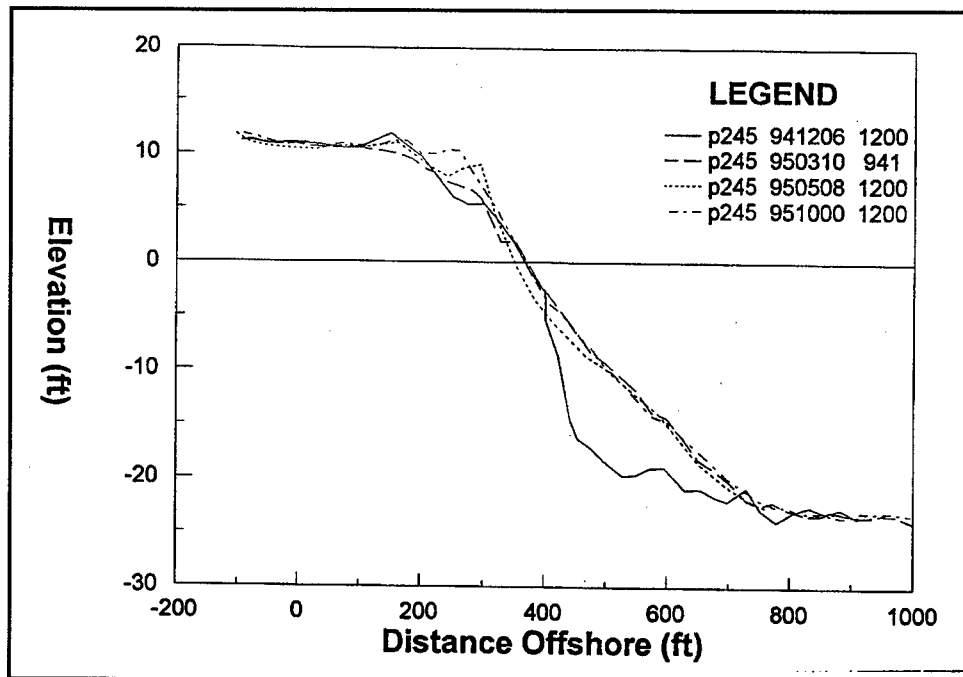


Figure 19. Beach profile evolution at sta 245

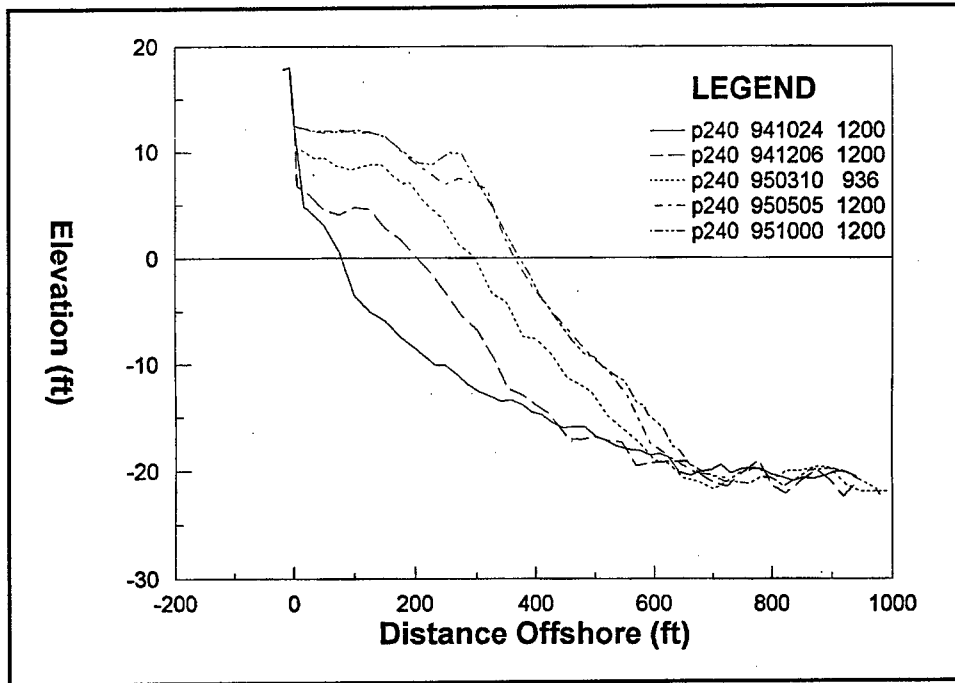


Figure 20. Beach profile evolution at sta 240

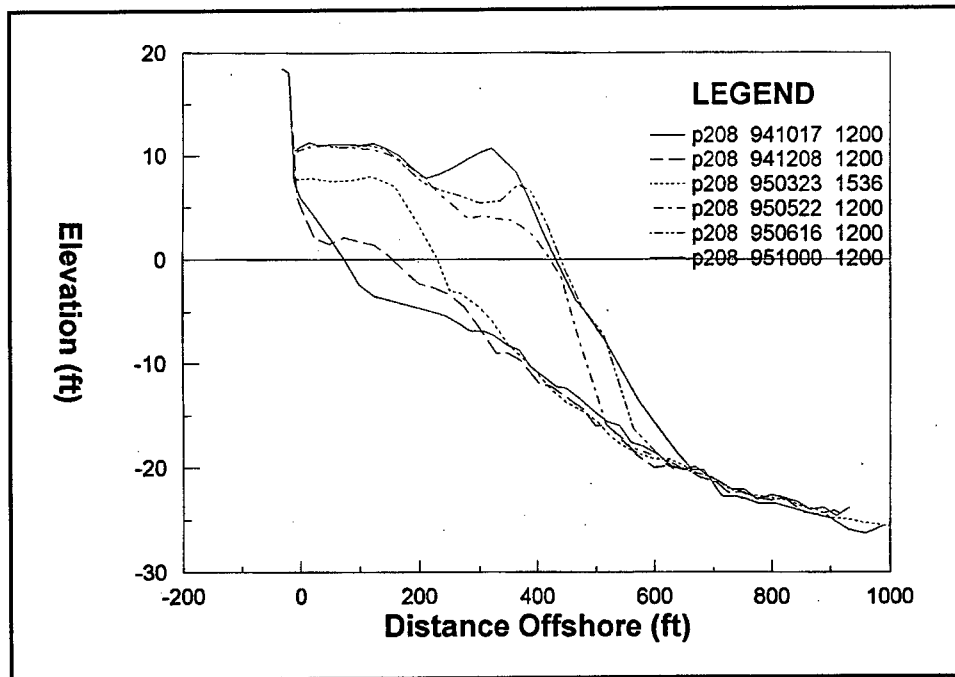


Figure 21. Beach profile evolution at sta 232

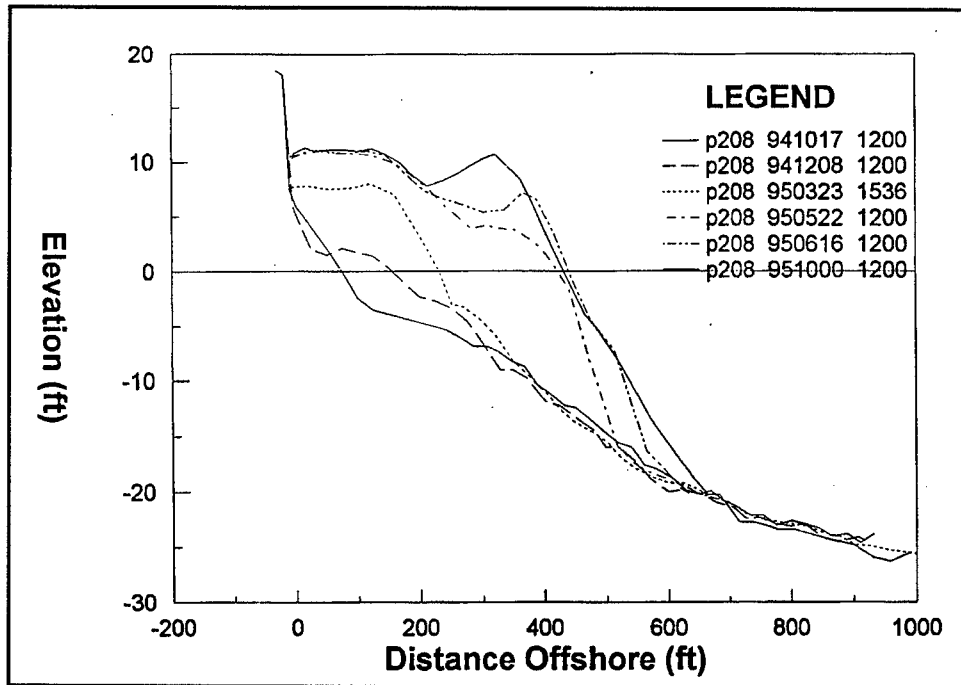


Figure 22. Beach profile evolution at sta 208

## Beach Profile Equilibrium

The shape of the beach profiles at the hot spot in comparison with the equilibrium profile is useful in assessing whether additional cross-shore adjustment and consequential shoreline retreat will occur. Dean (1977, 1991) has demonstrated that an equilibrium profile relationship,  $y = Ax^{2/3}$ , can be used to estimate the equilibrium beach profile shape, where  $y$  is water depth and  $x$  is distance seaward of the shoreline. The empirical shape factor,  $A$ , has been shown to be related to the median sediment diameter,  $d_{50}$  (Moore 1982). Using the equilibrium profile relationship and available sediment grain-size distributions, an assessment of the beach profile's approach to cross-shore equilibrium is made.

### Sediment characteristics

The median grain size diameter of the beach fill was quantified to specify an equilibrium beach profile. Sediment samples were collected between October 1994 and January 1995. Four sediment samples were collected at 200-ft alongshore intervals between sta 246 and 276 with sampling locations at the backshore beach, midberm, mean high water, and mean low water. The analysis of the sand samples indicates that grain sizes across the beach fill poorly sorted (with exception of the mean low water samples), as expected for a newly placed beach fill that has not been subjected to much wave activity.

A composite analysis of all sediment samples collected between sta 246 and 276 resulted in a  $\phi_{50}$  of 0.65 ( $d_{50} = 0.64$  mm) and a standard deviation of  $0.77\phi$ . If the typical lognormal grain-size distribution of sediments is assumed for the beach-fill material, a 95-percent confidence interval for the  $\phi_{50}$  is defined by the range of  $\phi$  units within two standard deviations of the mean. For the samples taken from the beach fill, the range of  $\phi_{50}$  defining the 95-percent confidence interval is 2.20 to -0.89, which corresponds to a range from  $d_{50}$  of 0.22 to 1.86 mm. The sieve analysis is presented in Appendix B.

### Profile comparisons

Based upon the statistical definitions from the sieve analysis, equilibrium profiles computed from the median grain size and the bounds of the 95-percent confidence interval were compared with the October 1995 profiles. The comparisons of the measured profiles with the equilibrium profiles give an indication of each profile's equilibrium status. Profiles on the steep side of the mean equilibrium profile are expected to adjust in the cross shore to come closer to equilibrium. Beach profiles that are near equilibrium are not to be expected to adjust substantially in the cross-shore direction.

In the region between sta 255 and 295, beach profiles are near their equilibrium shape. Figure 23 shows the beach profile at sta 275 with the corresponding equilibrium profiles for median grain diameters of 0.22, 0.64, and 1.86 mm. It is evident in this figure that the beach profile at sta 275 is in a similar shape as the equilibrium beach profile for the average  $d_{50}$  from the sieve analysis. Significant shoreline recession because of cross-shore adjustment of this profile is not expected.

In contrast to the profiles of the hot-spot region, the beach profiles between sta 208 and 255 do not indicate an approach to equilibrium beach profile shape. Instead, the beach profiles tend to be steeper than equilibrium, indicating that cross-shore profile adjustment and related shoreline recession is expected in this region. Figure 24 illustrates the typical relationship between measured and equilibrium beach profiles immediately north of the hot-spot region (October 1995). In this figure, the beach profile for sta 240 is shown to be considerably steeper than the 0.64-mm equilibrium beach profile. Neglecting additional longshore transport processes, this beach profile's shape will adjust to become closer to the shape of the equilibrium beach profile. As a consequence of this cross-shore adjustment, a corresponding recession of the shoreline position is expected. Shoreline recession because of cross-shore adjustment is not expected to exceed the anticipated adjustment from the project design.

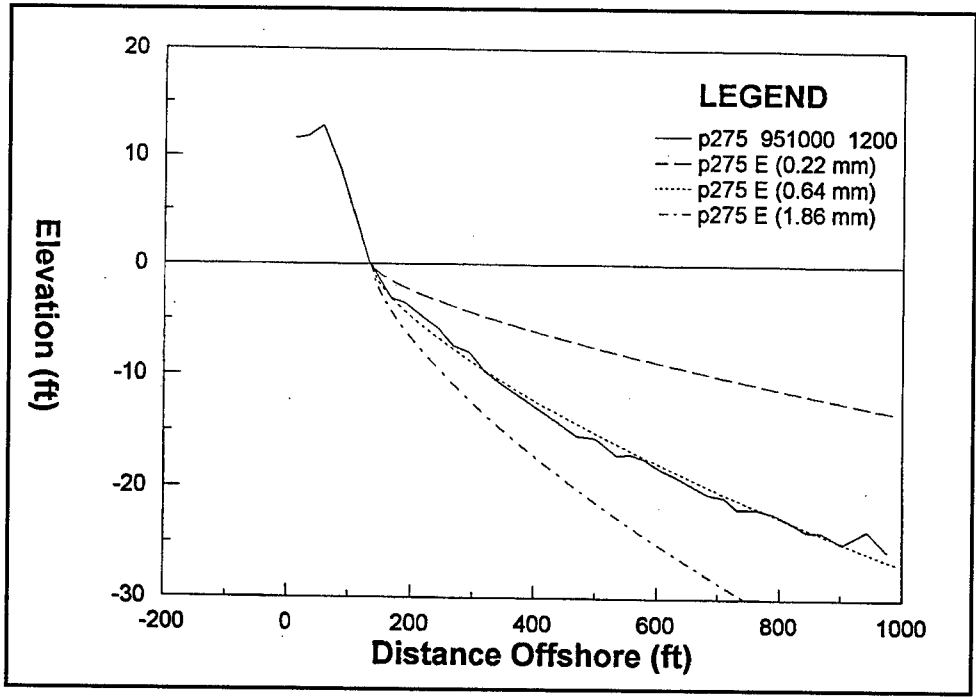


Figure 23. Beach profile and equilibrium profiles at sta 275

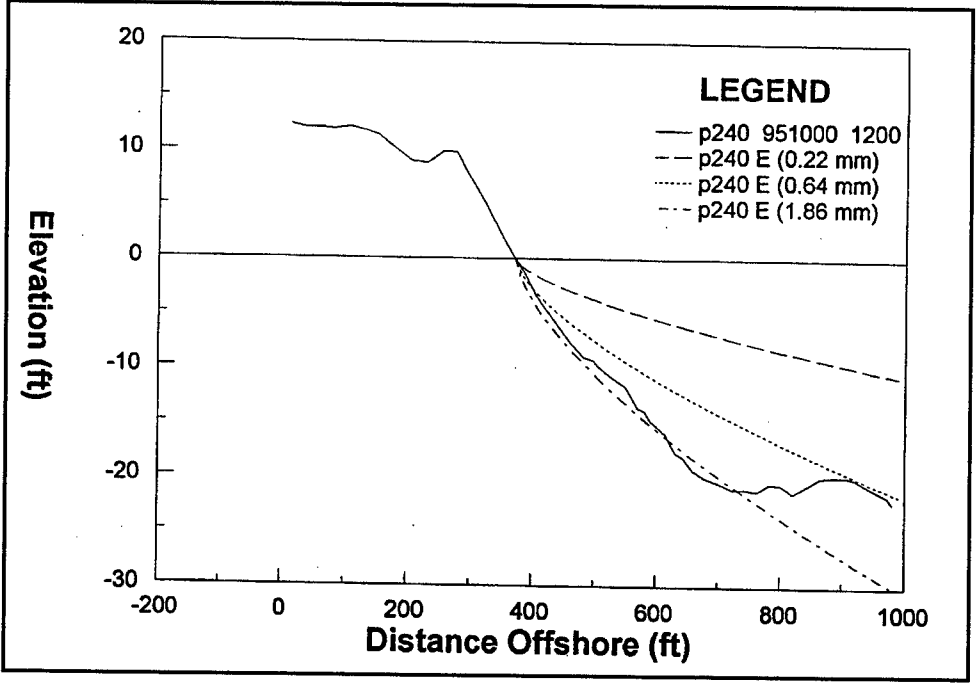


Figure 24. Beach profile and equilibrium profiles at sta 240

## Summary/Conclusions

Evolution of the beach fill between sta 255 and 275 (hot-spot region) indicates that shoreline recession at the hot spot is not a product of cross-shore sediment transport. In fact, little material was moved in the offshore direction. Net losses from these beach profiles suggest that the loss of material from the hot-spot region is due to longshore transport. Beach profiles to the north of the hot-spot region indicate significant gains of material during a period in which no beach-fill material was placed, thus support the idea of longshore losses. Additional shoreline retreat because of cross-shore sediment transport is not likely in the hot-spot region because of the beach profile's near-equilibrium shape. However, additional shoreline retreat because of longshore transport cannot be dismissed.

Beach profiles to the north of the hot spot, in the area that received material from the hot-spot region, are steeper than equilibrium and can be expected to adjust in the cross-shore sense towards the equilibrium beach profile if no additional material is deposited through longshore sediment transport.

## 4 Beach-Fill End Losses

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The placement of beach nourishment fill material within the Sea Bright to Ocean Township construction project has represented a substantial perturbation in an otherwise relatively long, straight shoreline. However, within the Monmouth Beach area, this perturbation is even more pronounced, owing to the design of a more or less uniform dry beach width along the project reach and the more seaward location of existing infrastructure within Monmouth Beach as compared with adjacent properties. The shoreline perturbation of the beach fill at the hot spot can be ideally treated as a short beach fill situated upon a longer beach fill. The shoreline perturbation resulting from the placement of beach-fill material represents a disequilibrium condition, and induced sediment transport flows can be expected. These induced sediment transport flows can occur in both cross-shore and longshore directions. Dean, Healy, and Dommerholt (1993) provided a description of three phases of observed sediment transport in the vicinity of beach nourishment projects, shown in Figure 255. The effects of cross-shore sediment flows are examined in the previous chapter, whereas this analysis focuses on longshore sediment transport flows and the associated longshore equilibration.

The intent of this analysis is to examine the Monmouth Beach hot spot (with respect to Contract 1A and shorelines to the south) to estimate the magnitude of fill material expected to be removed from the placement region because of beach-fill end losses. Two approaches are employed in the following analysis: the first involves analytical solutions of the shoreline change equations, and the second, involves application of the GENESIS shoreline change model (Hanson and Kraus 1989) in an idealized manner.

### Analytical Approach

The analysis summarized in this section is documented in *Beach Nourishment and Protection* (National Research Council 1995). Pelnard-Considère (1956) combined the linearized equation of sediment transport and the equation of continuity, considering the profiles to be displaced without change of form, to yield

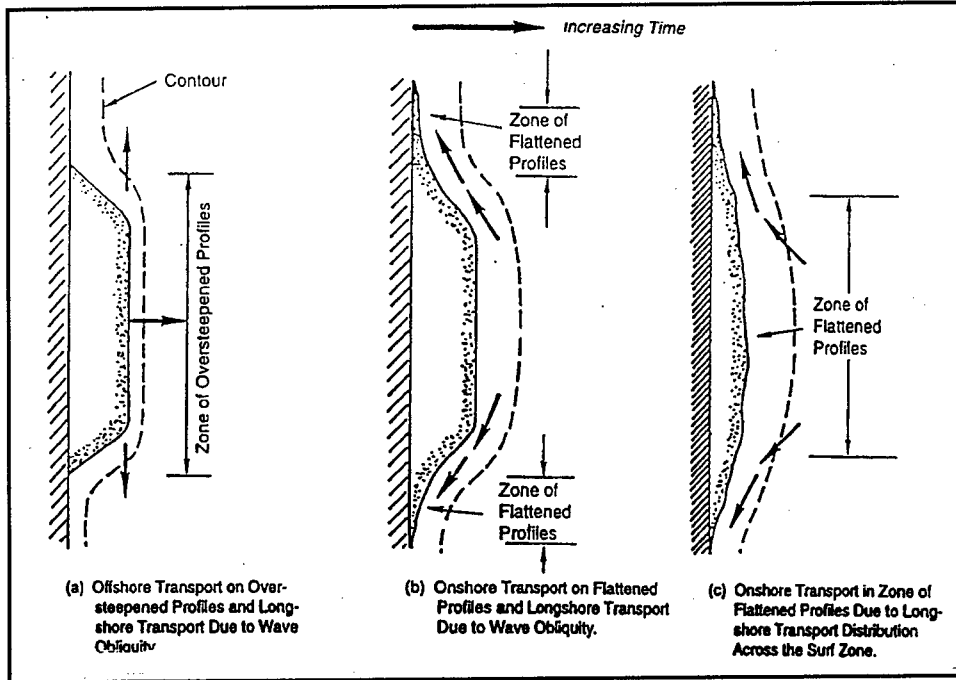


Figure 25. Three phases of observed sediment transport in vicinity of nourished projects (Note: cross-contour transport because of profile disequilibrium (from Dean et al. 1993))

$$\frac{\partial y}{\partial t} = G \frac{\partial^2 y}{\partial x^2} \quad (1)$$

in which  $t$  represents time and  $x$  and  $y$  are the longshore and cross-shore distances from the origin, respectively. The parameter  $G$  is called the alongshore diffusivity and is expressed as follows (in terms of breaking wave conditions)

$$G = \frac{K h_b^{2.5} \sqrt{g/\kappa}}{8(s-1)(1-p)(h_* + B)} \quad (\text{for breaking conditions}) \quad (2)$$

where

$K$  = a sediment transport factor usually taken as 0.77

$h_b$  = breaking wave height

$g$  = acceleration of gravity

$\kappa$  = ratio of breaking wave height to local water depth (usually taken as 0.78)

- $s$  = ratio of specific gravity of sediment to that of water in which it is immersed ( $\approx 2.65$ )
- $p$  = porosity ( $\approx 0.35$ )
- $h_s$  = depth of closure
- $B$  = berm height

It can be shown that in the absence of background erosion, the fraction of material remaining,  $M$ , in the region where fill is placed depends only on the parameter  $\sqrt{Gt}/\ell$  in which  $\ell$  is the length of the initially rectangular project and  $t$  is time (see Figure 26). For values of  $M$  between 0.5 and unity, it can be shown that an approximate expression for the relationship in Figure 26 is

$$M = 1 - \frac{2}{\sqrt{\pi}} \frac{\sqrt{Gt}}{\ell} \quad (3)$$

within a 15-percent error band in  $M$ . This equation was employed to estimate the time interval for 50 percent of the placed material to be transported from the original project limits. The standard values listed previously for  $K$ ,  $\kappa$ ,  $s$ , and  $p$  were used in all calculations. The length of the fill project, the depth of closure, and average berm height were taken as 4,100 ft (1,250 m), 29.5 ft (9.0 m), and 10.4 ft (3.17 m), respectively. In the first test,  $h_b$  was taken equal to 2.0 ft (0.6 m) (the effective wave height at the Long Branch wave gauge), resulting in  $G$  equal to 22,924 sq yd/month (19,167 sq m/month). The interval to 50 percent of placed material remaining was estimated to be 16 months. In the second test,  $h_b$  was taken equal to 3.0 ft (0.9 m) (the effective wave height at the Long Branch wave gauge shoaled to breaking conditions) to more accurately estimate breaking wave conditions. In this case,  $G$  was computed as 63,170 sq yd/month (52,818 sq m/month), and the interval to 50 percent of placed material remaining was estimated to be about 6 months.

The preceding calculations indicate that end losses from the Monmouth Beach area should be rather large, if one can consider the Monmouth Beach region as an independent beach fill because of its protrusion seaward beyond adjacent beaches. Beach profile analyses indicate that approximately 620,000 cu yd were placed between sta 264+00 and 282+00 during the period July-October 1994. Approximately 1 year later (November/December 1995), two emergency fill placements were undertaken, and approximately 230,000 cu yd were placed within this region. Assuming these emergency fills replaced fill material transported out of the placement area indicates a 37-percent loss of the initial placement volume or 63-percent retention over a 13-month interval. Both analytical predictions indicate that expected losses exceed the measured losses. The smaller magnitude of measured beach-fill losses is likely due to the fill-retaining capacity of the groins located at the ends of the Monmouth Beach hot-spot region.

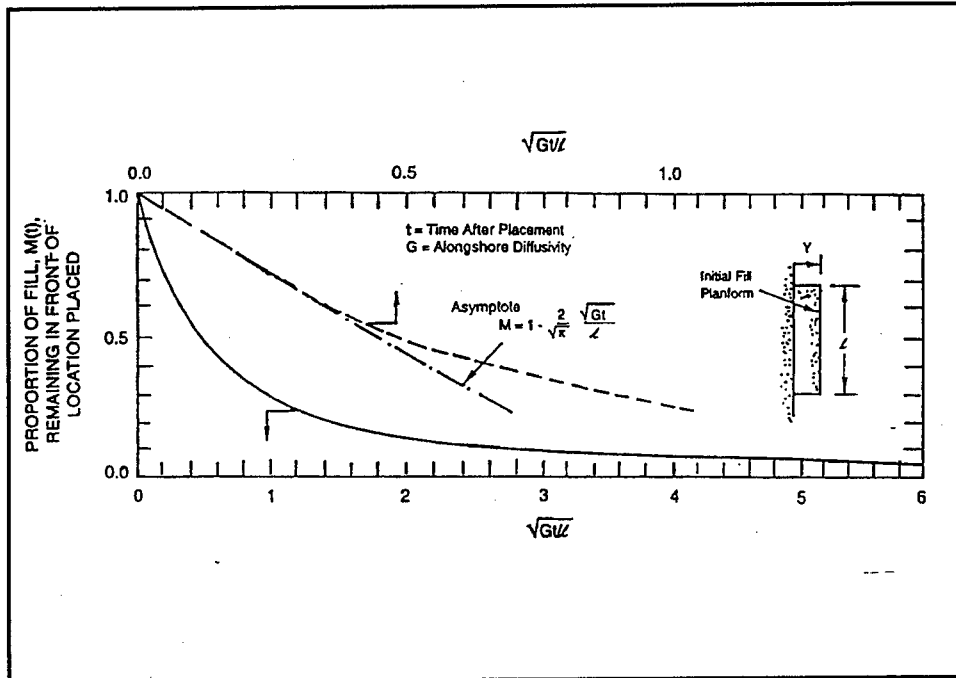


Figure 26. Proportion of material remaining,  $M$ , in region placed (from National Academy Press 1995)

## Numerical Approach

The analysis summarized in this section involves the application of the GENESIS (Hanson and Kraus 1989) shoreline evolution model to further investigate the processes that have caused the rapid loss of beach-fill material from the Monmouth Beach hot-spot area. As idealized in the previous analytical approach, the Monmouth Beach hot spot is viewed as a short beach fill superimposed upon a larger beach fill. The GENESIS model was set up with a 20,505-ft (6,250-m) model domain containing a 4,100-ft- (1,250-m) long beach fill located in the center of the model domain. The initial berm width of the beach fill was specified as being 278 ft (85 m), estimated from the initial volume of beach-fill material placed between sta 264 and 282. The GENESIS model was calibrated to the measured volume losses using the effective wave height at the Long Branch wave gauge ( $H_{eff} = 2.0$  ft (0.6 m),  $\theta = 0$  deg). With the idealized shoreline and effective wave conditions, the GENESIS model was calibrated (GENESIS calibration coefficients,  $K_1 = 0.93$  and  $K_2 = 0.5$ ) such that 37 percent of the fill material would be lost from the hot spot in the first 13 months after placement.

Having calibrated the GENESIS model to the available measurements, model simulations were performed using four different 1-year-long time series of wave conditions measured at the Long Branch directional wave gauge. These simulations resulted in a more realistic time sequence of shoreline evolution (e.g., more rapid losses during energetic wave events associated with winter

storms than during relatively calm summer wave conditions). The four different wave time series and repetitive model simulations were used to compute error bands at monthly intervals. The model predictions show that the observed losses from the Monmouth Beach region are reasonably well predicted using the GENESIS model. Following this analysis, another series of model simulations were performed to investigate the relative benefit of constructing a shore-perpendicular groin at the northern end of the beach fill. A groin with a length of 200 ft (61 m) was placed at the northern end of the hot-spot region (approximately the location of the existing Coastal Structure 44). Again, multiple simulations were performed using the four different wave time series to compute error bands around each of the predictions. The model results show that between 10 and 20 percent more material remains in the placement area if a groin is constructed at the northern end of the modeled reach.

This estimate is specific to the idealized conditions modeled. Additional model simulations are recommended to optimize the groin length based on the desired berm equilibrium width within the Monmouth Beach area and to determine long-term downdrift impacts of the proposed groin.

## **Summary and Conclusions**

Figure 27 provides a summary of the calculations performed in this task. The major conclusion of this task is that the observed losses from the Monmouth Beach region can be relatively well explained by considering the region as an independent or stand-alone beach-fill project and calculating the loss of material from the region because of longshore sand transport processes. A secondary conclusion is the finding that the construction (or extension) of a shore-perpendicular groin at the northern end of the Monmouth Beach has the potential to significantly reduce the loss of fill material from the region. In addition, the construction of the Contract 2 beach fill to the south should provide an updrift supply of sand that will reduce the severity of beach erosion within the hot-spot region.

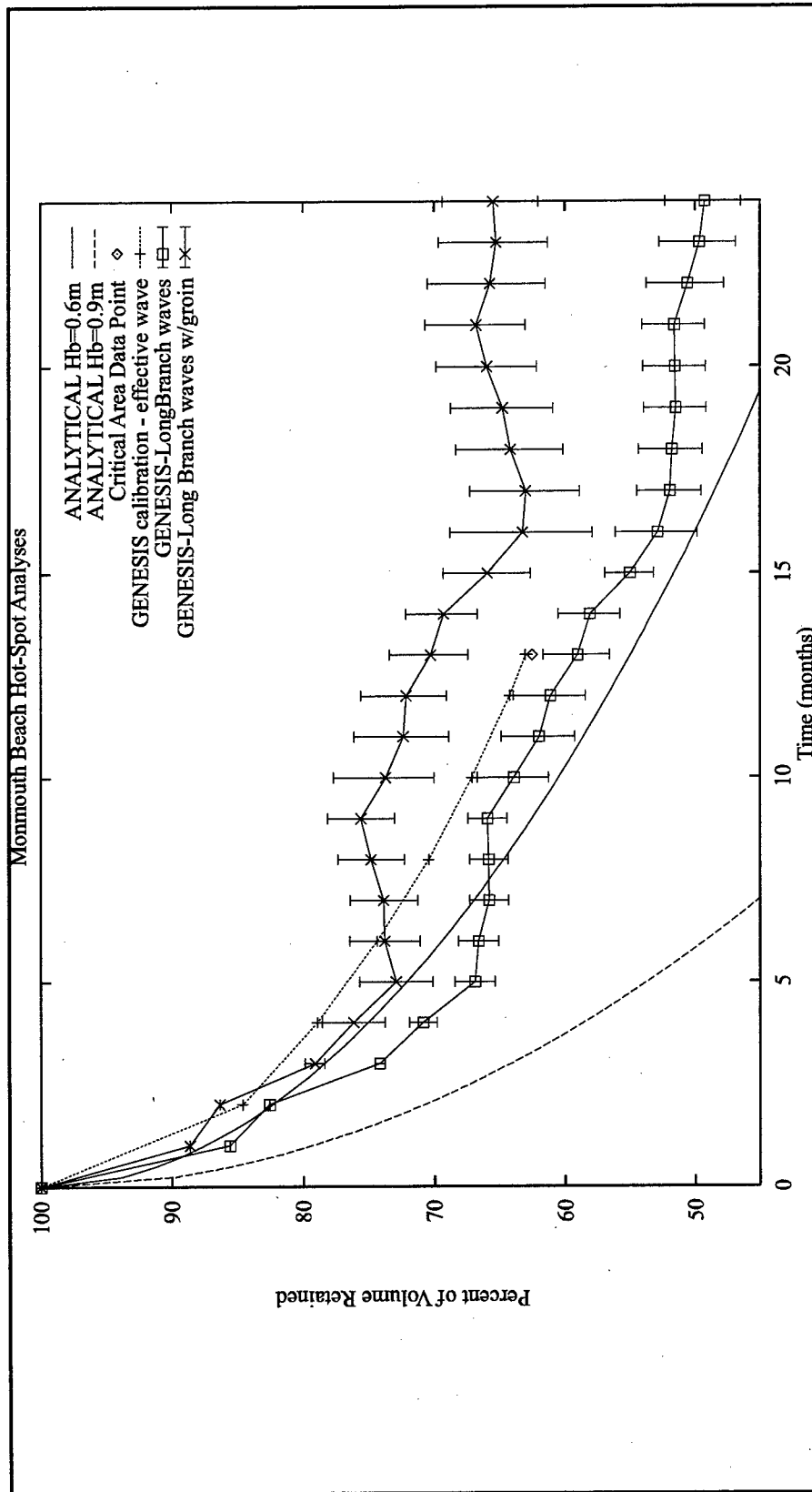


Figure 27. Estimates of percent of fill volume retained within placement area

## **5 Beach-Fill Planform Adjustment**

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The prefill shoreline at the northernmost portion of the hot-spot region protrudes significantly seaward of the adjacent shoreline because of the presence of infrastructure and the subsequent protection of this infrastructure with a seaward-protruding seawall and a curved groin (Groin 44). The planform design of the beach fill adds a 100-ft design berm to the existing shoreline, which results in the beach-fill planform protruding seaward similar to the structure-protected prefill shoreline. It is hypothesized that the severe loss of beach-fill material at the hot spot is related to this seaward protrusion of the beach-fill planform and that the beach fill will tend to adjust towards a shape and orientation similar to the offshore bathymetric contours.

As part of this analysis, three-dimensional bathymetric models were developed from beach profile surveys to evaluate the planform evolution of the shorelines and bathymetric contours. In addition, bathymetric change between sequential beach profile surveys was computed to give locations of eroded and accreted material. This analysis identifies trends in beach-fill evolution and relates these evolutionary trends to the development of the hot spot.

### **Data Source and Bathymetry Models**

Data used in the analysis of beach planform evolution were those collected for the purpose of computing beach-fill pay quantities. These beach profile surveys were measured at various stages of completion of the beach-fill project at approximately 100-ft intervals along the beach-fill reference line over the particular reach of the project being surveyed. The beach profile surveys typically extend from the beach-fill reference line (which generally follows the seawall or revetment) to approximately 1,000 ft seaward, with maximum depths ranging from 20-25 ft. In addition to the beach profile data, a set of aerial photographs taken in April 1996 were used to digitize the mean high water (mhw) shoreline for that time and landmarks (streets, coastal structures, etc.) useful in relating the bathymetric models to the physical domain.

The profile survey data were imported into the Intergraph MGE Terrain Modeler at a 500-ft alongshore density for each respective survey time period. The beach profile data were triangulated to define a surface and then incorporated into a bathymetric grid with a horizontal resolution of 25 ft. Color-shaded contours, shorelines, and plots of bathymetric change presented in this chapter were generated using the bathymetric models developed from the beach profile survey data.

## Beach-Fill Planform Evolution

The evolution of the beach-fill planform is important in understanding the transport processes that resulted in the high rates of shoreline erosion within the hot-spot region. Four plots of nearshore bathymetry are key in understanding how the beach fill evolved from prefill condition to the nourished shoreline with significant erosion at the hot-spot region. The four bathymetric models defining this evolution are given in Figures 278-31, representing the bathymetric conditions during February 1993 (prefill), October 1994, March 1995, and October 1995, respectively.

The February 1993 bathymetry (Figure 278) represents the prefill conditions along the Contract 1A reach of shoreline. Notice the sediment-starved condition of the shoreline. Only locations near groins (sta 250, 175, and 140) or where shoreline orientation decreases northbound transport potential (sta 195-205) have much dry beach. Also notice that the -20-ft contour is in general much straighter than the shoreline (which is dictated by the offsets in seawall and revetment construction as well as the presence of groins).

The October 1994 bathymetry (Figure 29) represents the constructed condition of the northern portion of the hot-spot region (to sta 255) and the adjacent, unnourished beach to the north as the beach-fill placement approached completion for the season. Note that construction did not cease until 3 January 1995,<sup>1</sup> but material was placed no further north than sta 245<sup>2</sup> at that time.

A complete profile survey of Contract 1A was performed in March 1995 to establish the condition of the beach fill before resuming construction in April. Figure 30 represents the condition of the beach fill from beach profile surveys of March 1995. During the period between October 1994 and March 1995, little beach-fill material was added to Contract 1A, and the volume that was added was placed no further north than Profile 245. Yet during this time, the region between sta 200 and 240 gained significant amounts of material, while the region

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<sup>1</sup> Personal Communication, June 1996, Lynn Bocamazo, New York District.

<sup>2</sup> Personal Communication, 12 August 1996, Brian Carr, New York District.

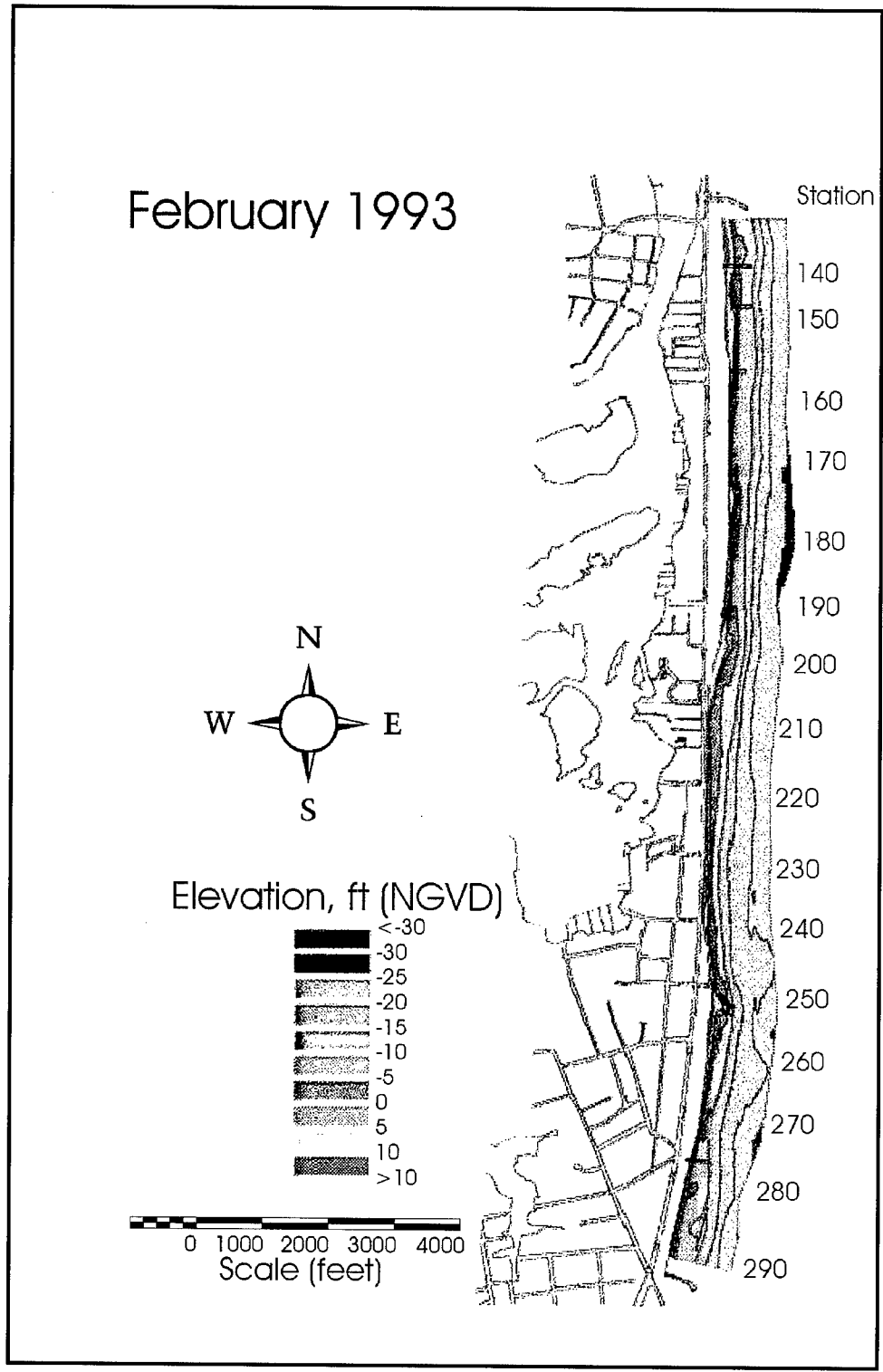


Figure 28. Nearshore bathymetry model (February 1993)

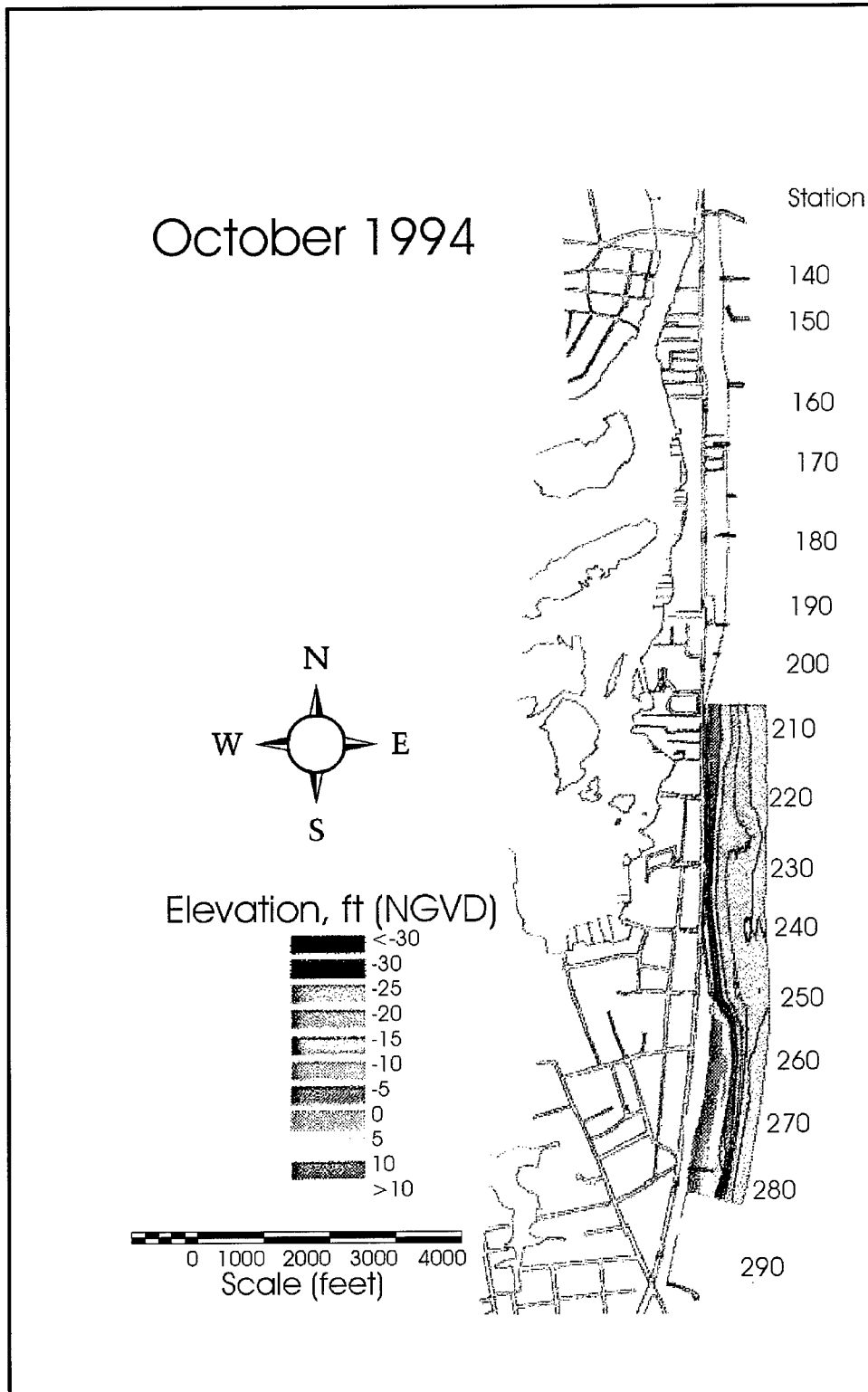


Figure 29. Nearshore bathymetry model (October 1994)

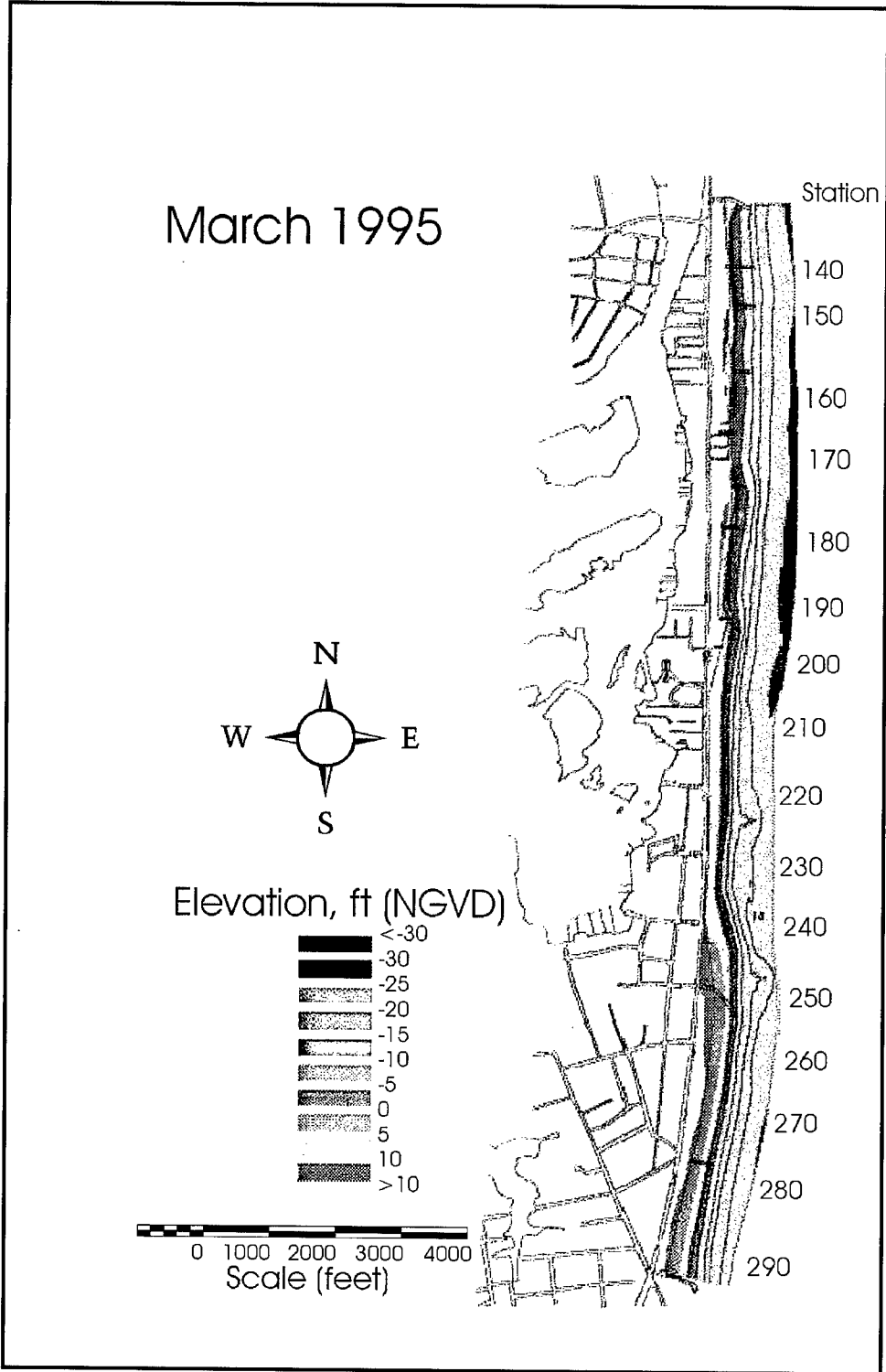


Figure 30. Nearshore bathymetry model (March 1995)

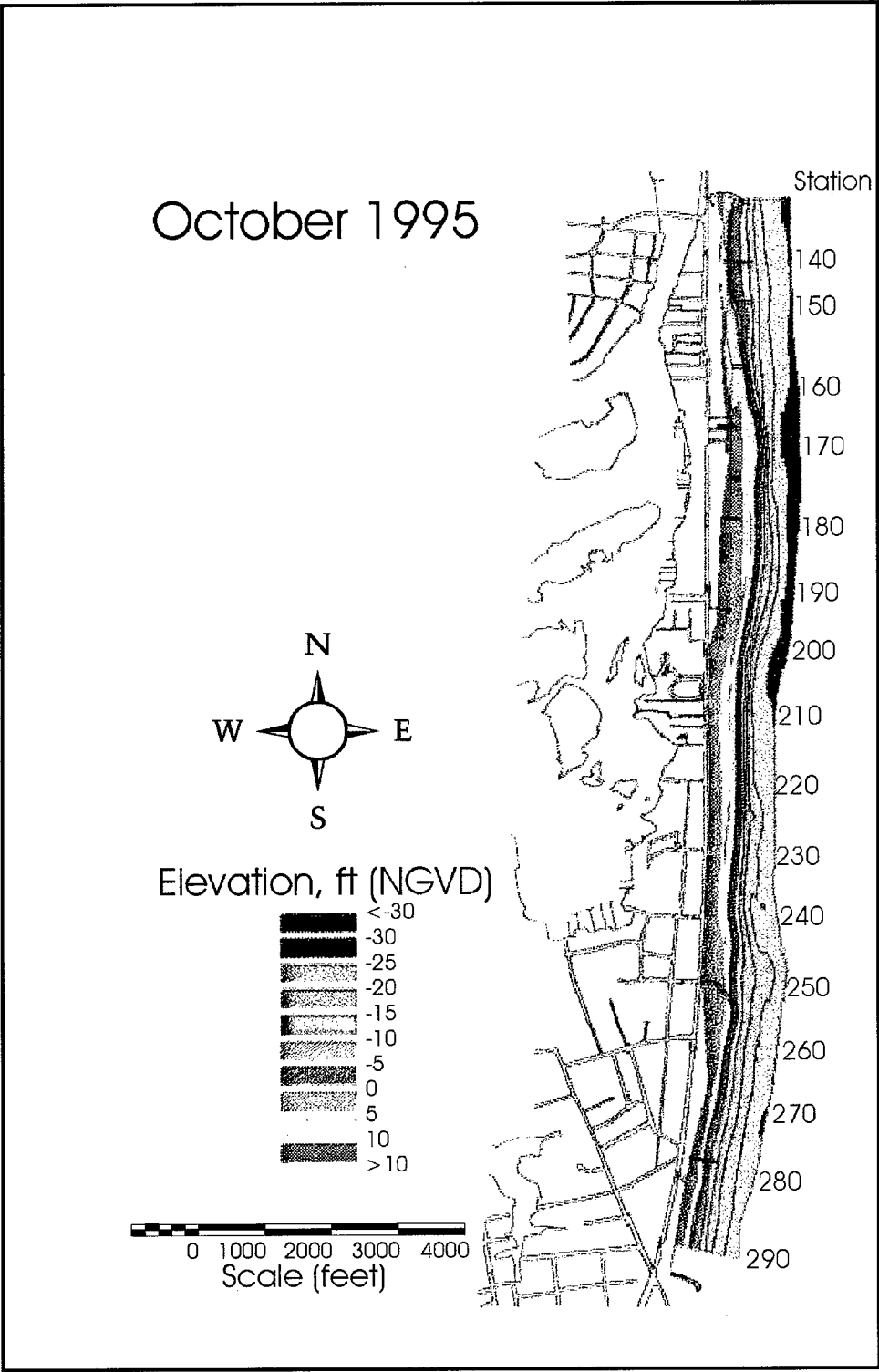


Figure 31. Nearshore bathymetry model (October 1995)

south of sta 255 lost significant volumes of material. The loss of material from the hot-spot region and the corresponding gain of material in the region to the north support the theory that beach-fill end losses play an important role in the development of the Monmouth Beach hot spot.

Proceeding in time to the October 1995 bathymetry (Figure 31), the beach fill for Contract 1A has proceeded north and is nearing completion. In the hot-spot region, additional erosion of beach-fill material has left the area with a much narrower beach and consequently less protection against storms. The erosion of the protruding beach fill has resulted in the evolution of the shoreline to a shape and orientation similar to that of the -20-ft contour of the prefill condition (Figure 278). This adjustment of the beach fill to a more "natural" configuration through the longshore transport of material apparently contributed to the development of the hot spot at Monmouth Beach. Also, from Figure 31, it appears that the most severe erosion within the hot-spot region (found at sta 275) is partially due to the downdrift effect of Coastal Structure 45 located at sta 277.

Evolution of the mhw shoreline over the construction cycle of Contract 1A illustrates the relationship between the loss of material from the hot-spot region and the gain of material downdrift. Figure 32 presents the mhw shorelines for February 1993 (prefill), October 1994, March 1995, October 1995, and April 1996 (sparse monitoring survey data are also presented for April 1996). The evolution of the mhw shoreline illustrates the smoothing effect of longshore transport on the shoreline perturbation presented in the construction of the beach-fill planform. The beach width, relative to the beach-fill reference line (or seawall), north of the hot spot has increased at the expense of the beach width within the hot-spot region.

Additional support of the beach-fill end-loss hypothesis is found in an elevation difference plot between the October 1994 and March 1995 bathymetric models (Figure 33). In this plot, the loss of material from the northern portion of the hot-spot region is evident along with material placed between October and December 1994 near sta 245. The elevation gained in the 3,200-ft alongshore region between sta 208 and 240 represents a significant volume of material—material presumably transported from the hot-spot region. Coverage of the October 1994 beach profile surveys is insufficient to determine volume lost from the hot spot versus volume gained in the adjacent region to the north.

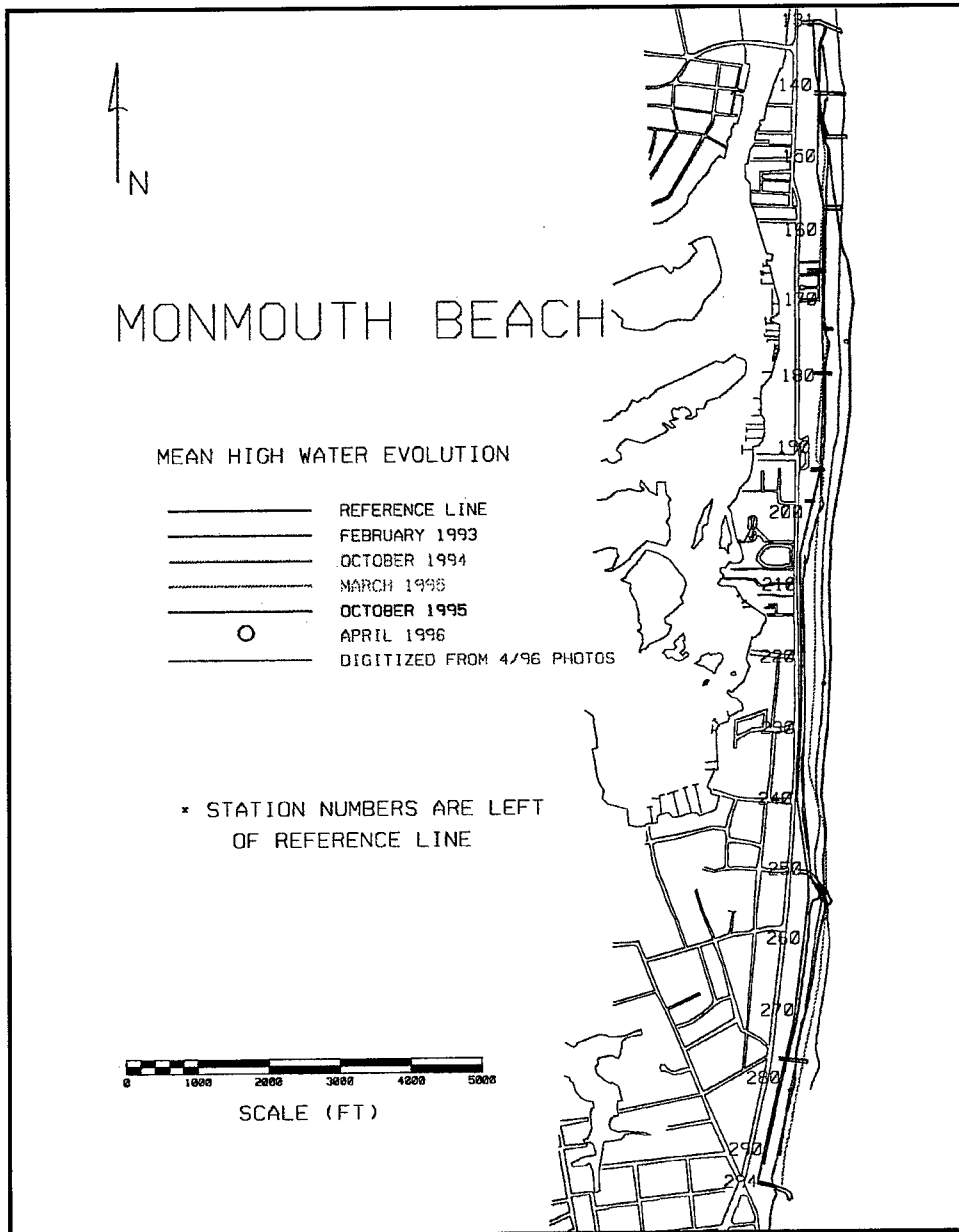


Figure 32. Evolution of mean high water shoreline

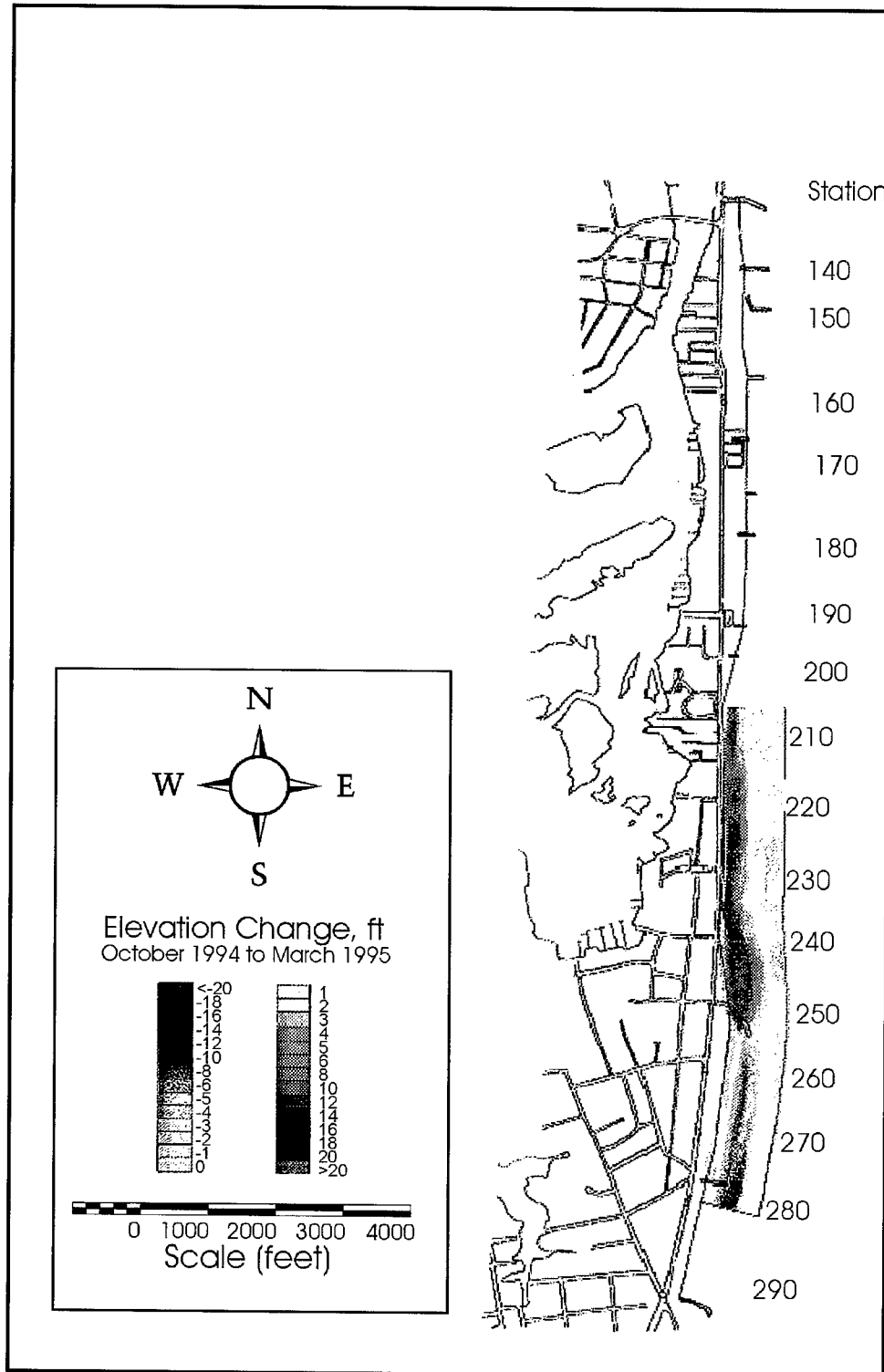


Figure 33. Elevation difference (March 1995 versus October 1994)

## Conclusions

Evaluation of the planform evolution of the beach-fill project in the vicinity of the hot spot supports the findings of the beach-fill end-loss analysis. The visualization of measured beach profile data in a three-dimensional model reveals that material lost from the hot-spot region was gained in the sediment-starved profiles to the north as indicated by elevation change between the October 1994 and March 1995 bathymetric models. Analysis of the evolution of the mhw shoreline reveals that the seaward protrusion of the beach fill in the hot-spot region adjusted to the general shape and orientation of the -20-ft prefill contour. Now that longshore beach-fill adjustment has smoothed the shoreline, erosion rates within the hot-spot region are expected to decrease.

## 6 Conclusions

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Evidence presented in the evaluation of beach-fill end losses indicates that the hot spot at Monmouth Beach is due to accelerated losses associated with the seaward protrusion of the beach fill in the region between sta 255 and 295. The remaining hypotheses either are unsupported or support the theory of beach-fill end losses as being the primary factor in the development of the hot spot. A brief summary of the results of each hypothesis is presented below relating each to the conclusions of this study.

The effect of wave focusing by Shrewsbury Rocks on the hot-spot area was evaluated by analyzing the local wave climate. Shrewsbury Rocks are located approximately 4,500 ft (0.85 mile) to the northeast of the northernmost boundary of the hot-spot region. A directional wave gauge stationed offshore of Long Branch, New Jersey, provided wave data for the time period from start of beach-fill placement (June 1994) through March 1996 (well after recognition of the hot spot). Wave statistics indicate that an insignificant number of wave events approach from north of east and those that do approach shore from that direction have low wave heights and short periods because of the sheltering by Long Island, NY. Previous work by Kraus et al. (1988) indicates that wave focusing may occur at approximately sta 218 (0.7 mile north of hot spot) and slightly northward for the wave climate evident in this study. The conclusions of this portion of the study are that Shrewsbury Rocks does not likely affect the hot spot by the focusing of wave energy, but offshore bathymetric contours angling from the hot spot towards the rocks may increase breaking wave angles and accelerate northerly longshore sediment transport.

Evaluation of cross-shore adjustment of the construction template within the hot-spot region indicates that little if any cross-shore movement of material has occurred. In fact, longshore processes dominate the evolution of the profiles within the hot-spot region. Each profile within the hot-spot region indicates net losses of material from the profile, indicative of longshore gradients in sediment transport. Further analysis of the profiles north of the hot-spot region indicates significant gains in material even during breaks in beach-fill placement. The significant net gains in beach profile volume to the north indicate that material lost from the hot-spot area was deposited in the adjacent, sediment-starved profiles to the north. In addition to the analysis of beach profile evolution, equilibrium beach profiles were superimposed upon the October 1995 beach profiles to assess the equilibrium condition of the beach profiles in the hot-spot

region. This analysis revealed that the beach profiles in the hot-spot region were near to equilibrium condition and should not adjust further by cross-shore sediment transport processes. However, the more recently constructed beach profiles to the north have profile shapes significantly steeper than the equilibrium profile and will adjust in the cross-shore sense, resulting in recession of the shoreline (neglecting any additional gains or losses because of longshore sediment transport processes).

Beach-fill end losses were established as a major contributor to the development of the Monmouth Beach hot spot through both analytical and idealized numerical evaluations. An analytical procedure to estimate the end losses from the beach fill protruding seaward of the adjacent fills and shoreline indicates that more than 50 percent of the placed volume could be expected to be lost from the region associated with beach-fill end losses. This estimate is greater than the approximately 40 percent of material actually lost, but neglects the presence of the two groins at the boundaries that serve to retard longshore sediment transport. The idealized numerical model study reasonably represents the measured losses and indicates that mitigative action in the form of groin extensions may be effective in reducing the losses from the hot-spot region. An estimated increase in beach-fill retention of 10-20 percent was estimated using the idealized model configuration, but for implementation of such a plan, detailed investigation is recommended.

Evaluation of the planform evolution of the beach-fill project in the vicinity of the hot spot supports the findings of the beach-fill end-loss analysis. The visualization of measured beach profile data in a three-dimensional model reveals that material lost from the hot-spot region was gained in the sediment-starved profiles to the north. Analysis of the evolution of specific offshore contours reveals that the seaward protrusion of the beach fill in the hot-spot region adjusted to the general shape and orientation of offshore contours.

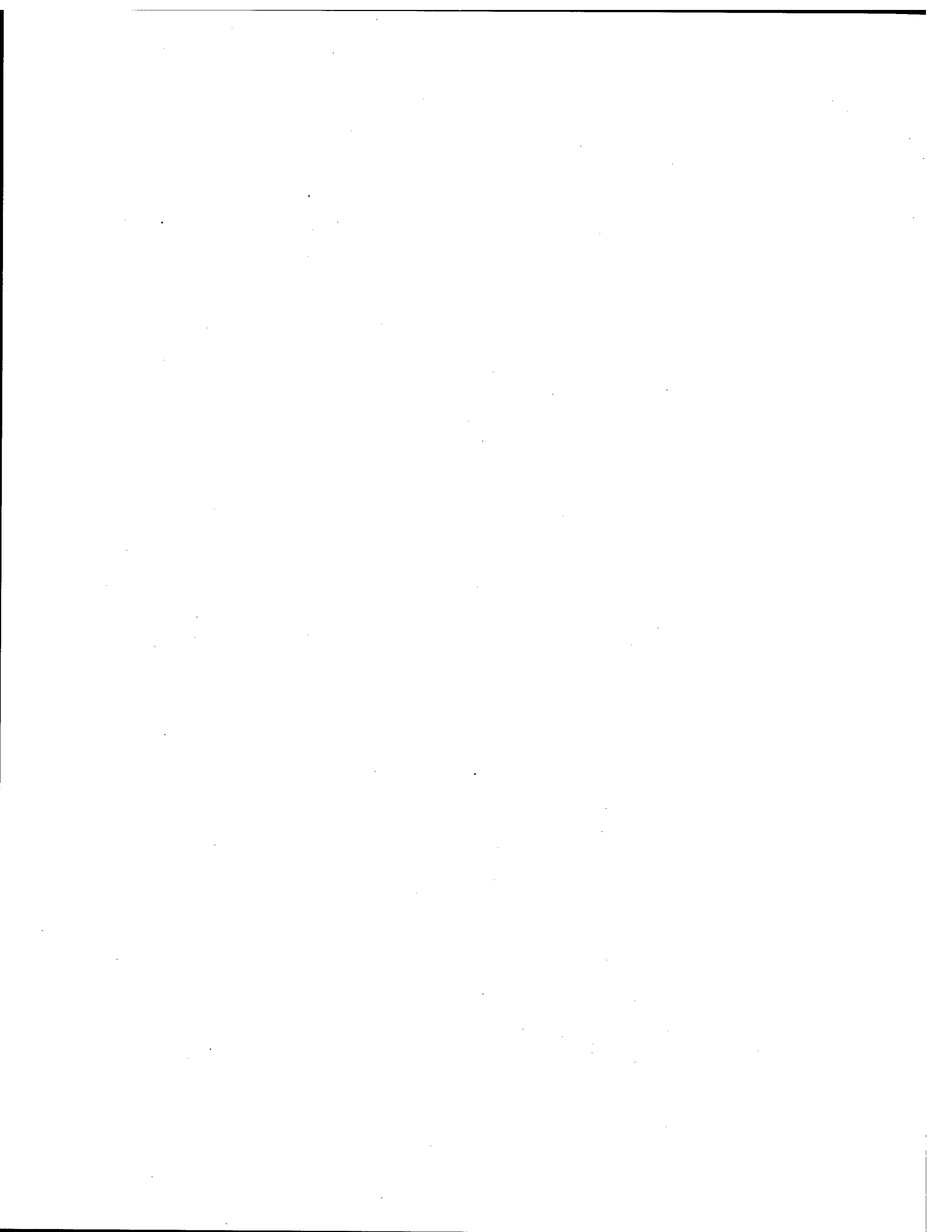
The combined theoretical beach-fill end-loss computations and supporting bathymetric data convincingly point to beach-fill end losses as the primary factor causing the hot spot at Monmouth Beach. In addition, the offshore bathymetric contours may cause an increase in northerly sediment transport within the hot spot, further contributing to the longshore sediment losses. In efforts to maintain a protective beach in the hot-spot region to protect inland structures, this study suggests the modification of existing groins as a conceptual mitigative action to protect the 100-ft design berm. A detailed analysis of the impacts of groin modifications is recommended.

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# Appendix A

## Wave Statistics

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Appendix A is composed of three sections. Appendix A1 presents tabular statistics of directional wave measurements made between January 1994 and March 1996 in 10 m water depth at Long Branch, New Jersey (gauge location: 40.30° N, 73.97° W). Appendix A2 presents statistical tables in the form of Appendix A1 for the National Data Buoy Center (NDBC) Buoy 44025, located south of Long Island at 40.25° N, 73.17° W in a water depth of 40 m. Statistics for NDBC Buoy 44025 were computed for the period January 1994 through February 1996. Appendix A3 presents time-series wave conditions (wave height, wave period, and direction) for 19 storms (defined by wave height greater than 2.0 m) from the Long Branch directional gauge.

# A1. LONG BRANCH WAVE STATISTICS

LONG BRANCH, NJ  
 LONG BRANCH, NEW JERSEY 1994 - 1996  
 LAT: 40.30 N, LONG: 73.97 W, DEPTH:-999 M  
 SUMMARY OF WAVE INFORMATION BY MONTH

| Hmo (m)       | OCCURRENCES OF WAVE HEIGHT BY MONTH FOR ALL YEARS |     |     |     |     |     |     |     |     |     |     |     | TOTAL | %     |
|---------------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|
|               | JAN   | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |       |       |
| 0.00 - 0.49   | 123   | 182 | 164 | 59  | 69  | 77  | 74  | 155 | 135 | 196 | 138 | 133 | 1505  | 30.6  |
| 0.50 - 0.99   | 147   | 96  | 125 | 109 | 99  | 92  | 171 | 137 | 136 | 132 | 100 | 31  | 1375  | 27.9  |
| 1.00 - 1.49   | 52  | 44  | 50  | 12  | 15  | 9   | 6   | 52  | 66  | 33  | 28  | 16  | 383   | 7.8   |
| 1.50 - 1.99   | 28  | 13  | 14  | .   | 3   | 1   | .   | 28  | 11  | 10  | 11  | 1   | 120   | 2.4   |
| 2.00 - 2.49   | 8   | 4   | 5   | .   | .   | .   | .   | .   | 3   | 1   | 8   | 3   | 32    | 0.7   |
| 2.50 - 2.99   | 6   | 2   | 2   | .   | .   | .   | .   | .   | .   | .   | 2   | .   | 12    | 0.2   |
| 3.00 - 3.49   | 5   | .   | 2   | .   | .   | .   | .   | .   | 1   | .   | 2   | .   | 10    | 0.2   |
| 3.50 - 3.99   | 2   | .   | 3   | .   | .   | .   | .   | .   | 1   | .   | 1   | .   | 7     | 0.1   |
| 4.00 - 4.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 4.50 - 4.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 5.00 - 5.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 5.50 - 5.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 6.00 - 6.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 6.50 - 6.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 7.00 - 7.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 7.50 - 7.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 8.00 - 8.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 8.50 - 8.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 9.00 - 9.49   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 9.50 - 9.99   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 10.00-GREATER | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| BAD DATA      | 187   | 169 | 193 | 180 | 186 | 181 | 121 | .   | 7   | .   | 70  | 188 | 1482  | 30.1  |
| TOTAL         | 558   | 510 | 558 | 360 | 372 | 360 | 372 | 372 | 360 | 372 | 360 | 372 | 4926  | 100.0 |

| Tp(sec)       | OCCURRENCES OF PEAK PERIOD BY MONTH FOR ALL YEARS |     |     |     |     |     |     |     |     |     |     |     | TOTAL | %     |
|---------------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|
|               | JAN   | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |       |       |
| 3.0 - 3.9     | 5   | 9   | 9   | 10  | 10  | 9   | .   | 9   | 11  | 35  | 16  | 8   | 131   | 2.7   |
| 4.0 - 4.9     | 26  | 23  | 12  | 17  | 21  | 25  | 21  | 18  | 24  | 22  | 32  | 10  | 251   | 5.1   |
| 5.0 - 5.9     | 23  | 18  | 16  | 28  | 9   | 10  | 22  | 16  | 29  | 17  | 17  | 14  | 219   | 4.4   |
| 6.0 - 6.9     | 31  | 24  | 23  | 20  | 23  | 20  | 53  | 85  | 31  | 24  | 20  | 13  | 367   | 7.5   |
| 7.0 - 7.9     | 26  | 35  | 40  | 28  | 23  | 43  | 50  | 68  | 32  | 30  | 35  | 6   | 416   | 8.4   |
| 8.0 - 8.9     | 38  | 70  | 52  | 49  | 60  | 55  | 51  | 95  | 46  | 72  | 44  | 20  | 652   | 13.2  |
| 9.0 - 9.9     | 94  | 94  | 112 | 27  | 29  | 13  | 37  | 40  | 49  | 105 | 47  | 28  | 675   | 13.7  |
| 10.0 - 10.9   | 55  | 27  | 36  | .   | 7   | .   | 10  | 3   | 27  | 18  | 23  | 11  | 217   | 4.4   |
| 11.0 - 11.9   | 38  | 10  | 20  | .   | 2   | 1   | 5   | 14  | 26  | 14  | 19  | 8   | 157   | 3.2   |
| 12.0 - 12.9   | 4   | 4   | 15  | .   | .   | 3   | 2   | 9   | 24  | 19  | 17  | 9   | 106   | 2.2   |
| 13.0 - 14.9   | 2   | 2   | 2   | .   | .   | .   | .   | 10  | 35  | 7   | 5   | 7   | 70    | 1.4   |
| 15.0 - 16.9   | .   | .   | .   | .   | .   | .   | .   | 5   | 8   | .   | .   | .   | 13    | 0.3   |
| 17.0 - 18.9   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 19.0 - LONGER | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| BAD DATA      | 216   | 194 | 221 | 181 | 188 | 181 | 121 | .   | 18  | 9   | 85  | 238 | 1652  | 33.5  |
| TOTAL         | 558   | 510 | 558 | 360 | 372 | 360 | 372 | 372 | 360 | 372 | 360 | 372 | 4926  | 100.0 |

OCURRENCES OF PEAK DIRECTION BY MONTH FOR ALL YEARS

| Dp(deg)<br>Direction Band & Center | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL | %     |
|------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|-------|
| 348.75 - 11.24 ( 0.0)              | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0.0   |
| 11.25 - 33.74 ( 22.5)              | .   | 2   | 1   | .   | .   | .   | .   | .   | .   | .   | 1   | 1   | 5     | 0.1   |
| 33.75 - 56.24 ( 45.0)              | 1   | 4   | 1   | .   | 1   | .   | .   | .   | 2   | 4   | 6   | 1   | 20    | 0.4   |
| 56.25 - 78.74 ( 67.5)              | 2   | 2   | 2   | .   | .   | .   | .   | 3   | 4   | 6   | 5   | 3   | 27    | 0.6   |
| 78.75 - 101.24 ( 90.0)             | 38  | 24  | 44  | 4   | 8   | 2   | 2   | 57  | 50  | 53  | 63  | 47  | 392   | 8.0   |
| 101.25 - 123.74 (112.5)            | 93  | 69  | 95  | 36  | 53  | 25  | 38  | 115 | 174 | 154 | 77  | 36  | 965   | 19.6  |
| 123.75 - 146.24 (135.0)            | 45  | 50  | 100 | 101 | 81  | 116 | 148 | 152 | 89  | 107 | 76  | 34  | 1099  | 22.3  |
| 146.25 - 168.74 (157.5)            | 2   | 14  | 22  | 32  | 26  | 33  | 60  | 42  | 20  | 34  | 41  | 10  | 336   | 6.8   |
| 168.75 - 191.24 (180.0)            | .   | .   | 2   | 6   | 15  | 3   | 3   | 3   | 1   | 5   | 6   | 2   | 46    | 0.9   |
| 191.25 - 213.74 (202.5)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 213.75 - 236.24 (225.0)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 236.25 - 258.74 (247.5)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 258.75 - 281.24 (270.0)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 281.25 - 303.74 (292.5)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 303.75 - 326.24 (315.0)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| 326.25 - 348.74 (337.5)            | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | 0     | 0     |
| BAD DATA                           | 377 | 345 | 291 | 181 | 188 | 181 | 121 | .   | 20  | 9   | 85  | 238 | 2036  | 41.3  |
| TOTAL                              | 558 | 510 | 558 | 360 | 372 | 360 | 372 | 372 | 360 | 372 | 360 | 372 | 4926  | 100.0 |

OCURRENCES OF WAVE HEIGHT AND PEAK PERIOD FOR 45-DEG DIRECTION BANDS

(337.50 - 22.49) 0.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 1           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 1     |
| 1.00 - 1.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 2.00 - 2.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 1           | 0           | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 1     |

( 22.50 - 67.49) 45.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 30          | .           | .           | .            | .             | .             | .             | .             | .             | .               | 30    |
| 1.00 - 1.99    | 3           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 3     |
| 2.00 - 2.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 33          | 0           | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 33    |

| ( 67.50 - 112.49) 90.0 DEG |             |             |             |              |               |               |               |               |               |                 |       |
|----------------------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| Tp(sec)                    |             |             |             |              |               |               |               |               |               |                 |       |
| Hmo (m)                    | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
| 0.00 - 0.99                | 80          | 63          | 119         | 176          | 140           | 33            | 1             | .             | .             | .               | 612   |
| 1.00 - 1.99                | 17          | 81          | 74          | 31           | 10            | .             | .             | .             | .             | .               | 213   |
| 2.00 - 2.99                | .           | 4           | 13          | 1            | 1             | .             | .             | .             | .             | .               | 19    |
| 3.00 - 3.99                | .           | .           | 3           | 3            | 3             | .             | .             | .             | .             | .               | 9     |
| 4.00 - 4.99                | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99                | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99                | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99                | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99                | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER             | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL                      | 97          | 148         | 209         | 211          | 154           | 33            | 1             | 0             | 0             | 0               | 853   |

| (112.50 - 157.49) 135.0 DEG |             |             |             |              |               |               |               |               |               |                 |       |
|-----------------------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| Tp(sec)                     |             |             |             |              |               |               |               |               |               |                 |       |
| Hmo (m)                     | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
| 0.00 - 0.99                 | 81          | 288         | 675         | 458          | 67            | 24            | 5             | .             | .             | .               | 1598  |
| 1.00 - 1.99                 | 4           | 46          | 75          | 46           | 15            | 13            | 7             | .             | .             | .               | 206   |
| 2.00 - 2.99                 | .           | .           | 10          | 1            | .             | .             | .             | .             | .             | .               | 11    |
| 3.00 - 3.99                 | .           | .           | .           | 2            | .             | .             | .             | .             | .             | .               | 2     |
| 4.00 - 4.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER              | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL                       | 85          | 334         | 760         | 507          | 82            | 37            | 12            | 0             | 0             | 0               | 1817  |

| (157.50 - 202.49) 180.0 DEG |             |             |             |              |               |               |               |               |               |                 |       |
|-----------------------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| Tp(sec)                     |             |             |             |              |               |               |               |               |               |                 |       |
| Hmo (m)                     | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
| 0.00 - 0.99                 | 136         | 48          | 2           | .            | .             | .             | .             | .             | .             | .               | 186   |
| 1.00 - 1.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 2.00 - 2.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99                 | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER              | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL                       | 136         | 48          | 2           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 186   |

(202.50 - 247.49) 225.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 1.00 - 1.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 2.00 - 2.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 0           | 0           | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 0     |

(247.50 - 292.49) 270.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 1.00 - 1.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 2.00 - 2.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 0           | 0           | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 0     |

(292.50 - 337.49) 315.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 1.00 - 1.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 2.00 - 2.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 3.00 - 3.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 0           | 0           | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 0     |

| Hmo (m)        | ALL DIRECTIONS<br>Tp (sec) |             |             |              |               |               |               |               |               |       | BAD<br>LONGER DATA | TOTAL |
|----------------|----------------------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-------|--------------------|-------|
|                | 3.0-<br>4.9                | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0- |                    |       |
| 0.00 - 0.99    | 357                        | 433         | 852         | 781          | 224           | 57            | 6             | .             | .             | .     | 170                | 2880  |
| 1.00 - 1.99    | 25                         | 149         | 177         | 99           | 33            | 13            | 7             | .             | .             | .     | .                  | 503   |
| 2.00 - 2.99    | .                          | 4           | 34          | 4            | 2             | .             | .             | .             | .             | .     | .                  | 44    |
| 3.00 - 3.99    | .                          | .           | 5           | 8            | 4             | .             | .             | .             | .             | .     | .                  | 17    |
| 4.00 - 4.99    | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| 5.00 - 5.99    | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| 6.00 - 6.99    | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| 7.00 - 7.99    | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| 8.00 - 8.99    | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| 9.00 - GREATER | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | .                  | 0     |
| BAD DATA       | .                          | .           | .           | .            | .             | .             | .             | .             | .             | .     | 1482               | 1482  |
| TOTAL          | 382                        | 586         | 1068        | 892          | 263           | 70            | 13            | 0             | 0             | 0     | 335                | 4926  |

SUMMARY OF MEAN Hmo(m) BY MONTH AND YEAR

| YEAR | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | MEAN |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1994 | 0.72 | 0.66 | 0.69 | 0.62 | 0.63 | 0.58 | 0.58 | 0.57 | 0.56 | 0.51 | 0.67 | 0.00 | 0.62 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.60 | 0.85 | 0.85 | 0.67 | 0.72 | 0.46 | 0.70 |
| 1996 | 0.92 | 0.61 | 0.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MEAN | 0.82 | 0.63 | 0.70 | 0.62 | 0.63 | 0.58 | 0.59 | 0.71 | 0.72 | 0.59 | 0.70 | 0.46 |      |

MAX Hmo(m)\*10 WITH ASSOCIATED Tp(sec) AND Dp(deg/10) BY MONTH AND YEAR

| YEAR | JAN    | FEB    | MAR    | APR    | MAY    | JUN    | JUL    | AUG    | SEP    | OCT    | NOV    | DEC    | MAX    |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1994 | 3810** | 31 9** | 4112** | 13 510 | 17 812 | 18 914 | 11 715 | 19 810 | 36 911 | 21 711 | 24 811 | 0 0 0  | 4112** |
| 1995 | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 10 813 | 19 710 | 18 713 | 20 912 | 421110 | 25 810 | 421110 |
| 1996 | 391210 | 17 6 6 | 38 9 9 | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 391210 |
| MAX  | 391210 | 31 9** | 4112** | 13 510 | 17 812 | 18 914 | 11 715 | 19 710 | 36 911 | 21 711 | 421110 | 25 810 |        |

\*\* bad direction data

MAX Hmo(m): 4.2    MAX Tp(sec): 11.    MAX Dp(deg): 98.    DATE(gmt): 95111501

## A2. LONG ISLAND WAVE STATISTICS

LONG ISLAND, NY  
 LONG ISLAND, NEW YORK 1994 - 1996  
 LAT: 40.25 N, LONG: 73.17 W, DEPTH:-999 M  
 SUMMARY OF WAVE INFORMATION BY MONTH

### OCCURRENCES OF WAVE HEIGHT BY MONTH FOR ALL YEARS

| Hmo (m)         | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | TOTAL | %     |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 0.00 - 0.49     | 61   | 114  | 126  | 140  | 77   | 178  | 213  | 202  | 72   | 98   | 52   | 115  | 1448  | 7.6   |
| 0.50 - 0.99     | 402  | 488  | 472  | 605  | 684  | 649  | 851  | 535  | 464  | 681  | 221  | 400  | 6452  | 34.0  |
| 1.00 - 1.49     | 626  | 514  | 468  | 383  | 415  | 399  | 220  | 314  | 448  | 347  | 248  | 322  | 4704  | 24.8  |
| 1.50 - 1.99     | 414  | 409  | 217  | 194  | 195  | 98   | 109  | 158  | 235  | 114  | 163  | 188  | 2494  | 13.2  |
| 2.00 - 2.49     | 290  | 247  | 100  | 59   | 39   | 39   | 22   | 93   | 100  | 115  | 91   | 142  | 1337  | 7.1   |
| 2.50 - 2.99     | 182  | 93   | 18   | 10   | 11   | 26   | 1    | 76   | 41   | 45   | 62   | 121  | 686   | 3.6   |
| 3.00 - 3.49     | 86   | 52   | 5    | 1    | 11   | 4    | .    | 62   | 14   | 9    | 46   | 37   | 327   | 1.7   |
| 3.50 - 3.99     | 48   | 28   | 8    | .    | .    | 1    | .    | 7    | 5    | 3    | 31   | 18   | 149   | 0.8   |
| 4.00 - 4.49     | 21   | 15   | 4    | .    | .    | .    | .    | .    | 4    | .    | 1    | 3    | 48    | 0.3   |
| 4.50 - 4.99     | 17   | 1    | 4    | .    | .    | .    | .    | .    | 2    | .    | .    | 1    | 25    | 0.1   |
| 5.00 - 5.49     | 8    | .    | 2    | .    | .    | .    | .    | .    | 1    | .    | .    | 2    | 13    | 0.1   |
| 5.50 - 5.99     | 4    | .    | 4    | .    | .    | .    | .    | .    | .    | .    | .    | 3    | 11    | 0.1   |
| 6.00 - 6.49     | 5    | .    | 3    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 8     | 0     |
| 6.50 - 6.99     | 3    | .    | 4    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 7     | 0     |
| 7.00 - 7.49     | 1    | .    | 3    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 4     | 0     |
| 7.50 - 7.99     | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 8.00 - 8.49     | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 8.50 - 8.99     | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 9.00 - 9.49     | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 9.50 - 9.99     | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 10.00 - GREATER | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| BAD DATA        | 64   | 79   | 50   | 48   | 56   | 46   | 72   | 41   | 54   | 76   | 525  | 136  | 1247  | 6.6   |
| TOTAL           | 2232 | 2040 | 1488 | 1440 | 1488 | 1440 | 1488 | 1488 | 1440 | 1488 | 1440 | 1488 | 18960 | 100.0 |

### OCCURRENCES OF PEAK PERIOD BY MONTH FOR ALL YEARS

| Tp(sec)       | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | TOTAL | %     |
|---------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 3.0 - 3.9     | 85   | 99   | 76   | 117  | 50   | 65   | 67   | 38   | 122  | 160  | 71   | 137  | 1087  | 5.7   |
| 4.0 - 4.9     | 262  | 280  | 189  | 150  | 197  | 190  | 100  | 93   | 219  | 192  | 157  | 234  | 2263  | 11.9  |
| 5.0 - 5.9     | 470  | 406  | 173  | 268  | 198  | 178  | 225  | 171  | 207  | 187  | 248  | 292  | 3023  | 15.9  |
| 6.0 - 6.9     | 205  | 218  | 84   | 171  | 130  | 177  | 297  | 246  | 106  | 69   | 104  | 123  | 1930  | 10.2  |
| 7.0 - 7.9     | 221  | 248  | 126  | 254  | 316  | 353  | 328  | 340  | 126  | 158  | 82   | 98   | 2650  | 14.0  |
| 8.0 - 8.9     | 126  | 186  | 151  | 209  | 147  | 213  | 113  | 184  | 81   | 116  | 50   | 60   | 1636  | 8.6   |
| 9.0 - 9.9     | 208  | 257  | 233  | 138  | 190  | 125  | 95   | 94   | 93   | 218  | 53   | 119  | 1823  | 9.6   |
| 10.0 - 10.9   | 307  | 206  | 219  | 23   | 75   | 55   | 86   | 52   | 80   | 169  | 55   | 108  | 1435  | 7.6   |
| 11.0 - 11.9   | 251  | 37   | 85   | 18   | 99   | 21   | 69   | 84   | 104  | 68   | 35   | 78   | 949   | 5.0   |
| 12.0 - 12.9   | 24   | 22   | 63   | 21   | 30   | 17   | 31   | 71   | 86   | 36   | 56   | 45   | 502   | 2.7   |
| 13.0 - 14.9   | 5    | 2    | 30   | 20   | .    | .    | 5    | 60   | 126  | 39   | 4    | 49   | 340   | 1.8   |
| 15.0 - 16.9   | 3    | .    | .    | 3    | .    | .    | .    | 14   | 36   | .    | .    | 3    | 59    | 0.3   |
| 17.0 - 18.9   | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 0     | 0     |
| 19.0 - LONGER | 1    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 1     | 0     |
| BAD DATA      | 64   | 79   | 59   | 48   | 56   | 46   | 72   | 41   | 54   | 76   | 525  | 142  | 1262  | 6.7   |
| TOTAL         | 2232 | 2040 | 1488 | 1440 | 1488 | 1440 | 1488 | 1488 | 1440 | 1488 | 1440 | 1488 | 18960 | 100.0 |

OCCURRENCES OF PEAK DIRECTION BY MONTH FOR ALL YEARS

| Dp(deg)<br>Direction Band & Center | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | TOTAL | %     |
|------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 348.75 - 11.24 ( 0.0)              | 13   | 26   | 10   | 8    | 7    | 3    | 5    | 21   | 20   | 31   | 11   | 18   | 173   | 0.9   |
| 11.25 - 33.74 ( 22.5)              | 14   | 16   | 12   | 11   | 1    | 3    | .    | 6    | 17   | 11   | 9    | 17   | 117   | 0.6   |
| 33.75 - 56.24 ( 45.0)              | 31   | 20   | 8    | 4    | 2    | 3    | 6    | 8    | 10   | 12   | 20   | 19   | 143   | 0.7   |
| 56.25 - 78.74 ( 67.5)              | 101  | 59   | 27   | 22   | 59   | 45   | 13   | 67   | 21   | 27   | 23   | 46   | 510   | 2.7   |
| 78.75 - 101.24 ( 90.0)             | 197  | 198  | 258  | 51   | 331  | 66   | 18   | 168  | 165  | 173  | 24   | 133  | 1782  | 9.4   |
| 101.25 - 123.74 (112.5)            | 284  | 249  | 349  | 215  | 216  | 175  | 122  | 220  | 301  | 325  | 83   | 241  | 2780  | 14.7  |
| 123.75 - 146.24 (135.0)            | 350  | 218  | 186  | 241  | 171  | 337  | 222  | 309  | 286  | 206  | 122  | 135  | 2783  | 14.7  |
| 146.25 - 168.74 (157.5)            | 359  | 187  | 216  | 274  | 139  | 338  | 352  | 244  | 144  | 130  | 101  | 98   | 2582  | 13.6  |
| 168.75 - 191.24 (180.0)            | 141  | 200  | 88   | 255  | 183  | 232  | 477  | 241  | 80   | 103  | 73   | 32   | 2105  | 11.1  |
| 191.25 - 213.74 (202.5)            | 65   | 129  | 15   | 154  | 179  | 119  | 124  | 112  | 126  | 78   | 129  | 37   | 1267  | 6.7   |
| 213.75 - 236.24 (225.0)            | 39   | 54   | 7    | 41   | 61   | 60   | 45   | 33   | 48   | 94   | 46   | 36   | 564   | 3.0   |
| 236.25 - 258.74 (247.5)            | 31   | 61   | 3    | 3    | 3    | .    | 8    | 1    | 22   | 9    | 16   | 23   | 180   | 0.9   |
| 258.75 - 281.24 (270.0)            | 200  | 219  | 78   | 13   | 26   | 1    | 6    | 5    | 62   | 60   | 87   | 93   | 850   | 4.5   |
| 281.25 - 303.74 (292.5)            | 277  | 277  | 112  | 84   | 34   | 6    | 9    | 4    | 53   | 96   | 150  | 347  | 1449  | 7.6   |
| 303.75 - 326.24 (315.0)            | 39   | 26   | 28   | 8    | 3    | 4    | 2    | .    | 16   | 27   | 9    | 47   | 209   | 1.1   |
| 326.25 - 348.74 (337.5)            | 26   | 21   | 28   | 5    | 17   | 2    | 7    | 6    | 12   | 25   | 11   | 21   | 181   | 1.0   |
| BAD DATA                           | 65   | 80   | 63   | 51   | 56   | 46   | 72   | 43   | 57   | 81   | 526  | 145  | 1285  | 6.8   |
| TOTAL                              | 2232 | 2040 | 1488 | 1440 | 1488 | 1440 | 1488 | 1488 | 1440 | 1488 | 1440 | 1488 | 18960 | 100.0 |

OCCURRENCES OF WAVE HEIGHT AND PEAK PERIOD FOR 45-DEG DIRECTION BANDS

(337.50 - 22.49) 0.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 163         | .           | .           | .            | .             | .             | .             | .             | .             | .               | 163   |
| 1.00 - 1.99    | 134         | 19          | .           | .            | .             | .             | .             | .             | .             | .               | 153   |
| 2.00 - 2.99    | .           | 2           | .           | .            | .             | .             | .             | .             | .             | .               | 2     |
| 3.00 - 3.99    | .           | 1           | .           | .            | .             | .             | .             | .             | .             | .               | 1     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 297         | 22          | 0           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 319   |

( 22.50 - 67.49) 45.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 120         | 22          | .           | .            | .             | 1             | 2             | .             | .             | .               | 145   |
| 1.00 - 1.99    | 86          | 97          | 2           | .            | .             | .             | .             | .             | .             | .               | 185   |
| 2.00 - 2.99    | .           | 26          | 6           | .            | .             | .             | .             | .             | .             | .               | 32    |
| 3.00 - 3.99    | .           | .           | 11          | .            | .             | .             | .             | .             | .             | .               | 11    |
| 4.00 - 4.99    | .           | .           | 1           | 1            | .             | .             | .             | .             | .             | .               | 2     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 206         | 145         | 20          | 1            | 0             | 1             | 2             | 0             | 0             | 0               | 375   |

|                |     | ( 67.50 - 112.49) 90.0 DEG |             |             |              |               |               |               |               |               | TOTAL           |  |
|----------------|-----|----------------------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|--|
|                |     | Tp(sec)                    |             |             |              |               |               |               |               |               |                 |  |
| Hmo (m)        |     | 3.0-<br>4.9                | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER |  |
| 0.00 - 0.99    | 190 | 221                        | 240         | 391         | 231          | 56            | 3             | .             | .             | 1             | 1333            |  |
| 1.00 - 1.99    | 77  | 444                        | 273         | 412         | 198          | 43            | .             | .             | .             | .             | 1447            |  |
| 2.00 - 2.99    | .   | 115                        | 250         | 102         | 58           | 19            | 1             | .             | .             | .             | 545             |  |
| 3.00 - 3.99    | .   | 2                          | 52          | 36          | 20           | .             | .             | .             | .             | .             | 110             |  |
| 4.00 - 4.99    | .   | .                          | 13          | 18          | 2            | .             | .             | .             | .             | .             | 33              |  |
| 5.00 - 5.99    | .   | .                          | 1           | 10          | 7            | 1             | .             | .             | .             | .             | 19              |  |
| 6.00 - 6.99    | .   | .                          | .           | 4           | 8            | .             | .             | .             | .             | .             | 12              |  |
| 7.00 - 7.99    | .   | .                          | .           | .           | 4            | .             | .             | .             | .             | .             | 4               |  |
| 8.00 - 8.99    | .   | .                          | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 9.00 - GREATER | .   | .                          | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| TOTAL          | 267 | 782                        | 829         | 973         | 528          | 119           | 4             | 0             | 0             | 1             | 3503            |  |

|                |     | (112.50 - 157.49) 135.0 DEG |             |             |              |               |               |               |               |               | TOTAL           |  |
|----------------|-----|-----------------------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|--|
|                |     | Tp(sec)                     |             |             |              |               |               |               |               |               |                 |  |
| Hmo (m)        |     | 3.0-<br>4.9                 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER |  |
| 0.00 - 0.99    | 102 | 342                         | 1288        | 1008        | 284          | 56            | 13            | .             | .             | .             | 3093            |  |
| 1.00 - 1.99    | 43  | 211                         | 458         | 587         | 254          | 59            | 6             | .             | .             | .             | 1618            |  |
| 2.00 - 2.99    | .   | 28                          | 87          | 144         | 194          | 53            | 19            | .             | .             | .             | 525             |  |
| 3.00 - 3.99    | .   | 1                           | 18          | 59          | 112          | 19            | 3             | .             | .             | .             | 212             |  |
| 4.00 - 4.99    | .   | .                           | 2           | 13          | 12           | 5             | .             | .             | .             | .             | 32              |  |
| 5.00 - 5.99    | .   | .                           | .           | 1           | 2            | 2             | .             | .             | .             | .             | 5               |  |
| 6.00 - 6.99    | .   | .                           | .           | .           | 3            | .             | .             | .             | .             | .             | 3               |  |
| 7.00 - 7.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 8.00 - 8.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 9.00 - GREATER | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| TOTAL          | 145 | 582                         | 1853        | 1812        | 861          | 194           | 41            | 0             | 0             | 0             | 5488            |  |

|                |     | (157.50 - 202.49) 180.0 DEG |             |             |              |               |               |               |               |               | TOTAL           |  |
|----------------|-----|-----------------------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|--|
|                |     | Tp(sec)                     |             |             |              |               |               |               |               |               |                 |  |
| Hmo (m)        |     | 3.0-<br>4.9                 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER |  |
| 0.00 - 0.99    | 386 | 760                         | 471         | 162         | 17           | .             | 1             | .             | .             | .             | 1797            |  |
| 1.00 - 1.99    | 103 | 653                         | 844         | 178         | 18           | 12            | .             | .             | .             | .             | 1808            |  |
| 2.00 - 2.99    | 1   | 57                          | 181         | 100         | 7            | 13            | 11            | .             | .             | .             | 370             |  |
| 3.00 - 3.99    | .   | .                           | 14          | 29          | 19           | .             | .             | .             | .             | .             | 62              |  |
| 4.00 - 4.99    | .   | .                           | 1           | 3           | 1            | .             | .             | .             | .             | .             | 5               |  |
| 5.00 - 5.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 6.00 - 6.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 7.00 - 7.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 8.00 - 8.99    | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| 9.00 - GREATER | .   | .                           | .           | .           | .            | .             | .             | .             | .             | .             | 0               |  |
| TOTAL          | 490 | 1470                        | 1511        | 472         | 62           | 25            | 12            | 0             | 0             | 0             | 4042            |  |

(202.50 - 247.49) 225.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 523         | 49          | 1           | .            | .             | 1             | .             | .             | .             | .               | 574   |
| 1.00 - 1.99    | 188         | 398         | 5           | .            | .             | .             | .             | .             | .             | .               | 591   |
| 2.00 - 2.99    | .           | 57          | 14          | .            | .             | .             | .             | .             | .             | .               | 71    |
| 3.00 - 3.99    | .           | .           | 3           | .            | .             | .             | .             | .             | .             | .               | 3     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 711         | 504         | 23          | 0            | 0             | 1             | 0             | 0             | 0             | 0               | 1239  |

(247.50 - 292.49) 270.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 507         | 5           | .           | .            | .             | .             | .             | .             | .             | .               | 512   |
| 1.00 - 1.99    | 278         | 797         | .           | .            | .             | .             | .             | .             | .             | .               | 1075  |
| 2.00 - 2.99    | .           | 417         | 10          | .            | .             | .             | .             | .             | .             | .               | 427   |
| 3.00 - 3.99    | .           | 32          | 38          | .            | .             | .             | .             | .             | .             | .               | 70    |
| 4.00 - 4.99    | .           | .           | 1           | .            | .             | .             | .             | .             | .             | .               | 1     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 785         | 1251        | 49          | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 2085  |

(292.50 - 337.49) 315.0 DEG  
Tp(sec)

| Hmo (m)        | 3.0-<br>4.9 | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | TOTAL |
|----------------|-------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------|
| 0.00 - 0.99    | 242         | 3           | .           | .            | .             | .             | .             | .             | .             | .               | 245   |
| 1.00 - 1.99    | 184         | 137         | .           | .            | .             | .             | .             | .             | .             | .               | 321   |
| 2.00 - 2.99    | .           | 51          | .           | .            | .             | .             | .             | .             | .             | .               | 51    |
| 3.00 - 3.99    | .           | 6           | 1           | .            | .             | .             | .             | .             | .             | .               | 7     |
| 4.00 - 4.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 5.00 - 5.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 6.00 - 6.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 7.00 - 7.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 8.00 - 8.99    | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| 9.00 - GREATER | .           | .           | .           | .            | .             | .             | .             | .             | .             | .               | 0     |
| TOTAL          | 426         | 197         | 1           | 0            | 0             | 0             | 0             | 0             | 0             | 0               | 624   |

| Hmo (m)        | ALL DIRECTIONS |             |             |              |               |               |               |               |               |                 |             | TOTAL |
|----------------|----------------|-------------|-------------|--------------|---------------|---------------|---------------|---------------|---------------|-----------------|-------------|-------|
|                | Tp (sec)       |             |             |              |               |               |               |               |               |                 |             |       |
|                | 3.0-<br>4.9    | 5.0-<br>6.9 | 7.0-<br>8.9 | 9.0-<br>10.9 | 11.0-<br>12.9 | 13.0-<br>14.9 | 15.0-<br>16.9 | 17.0-<br>18.9 | 19.0-<br>20.9 | 21.0-<br>LONGER | BAD<br>DATA |       |
| 0.00 - 0.99    | 2256           | 1402        | 2000        | 1561         | 532           | 114           | 19            | .             | .             | 1               | 15          | 7900  |
| 1.00 - 1.99    | 1093           | 2756        | 1582        | 1177         | 470           | 114           | 6             | .             | .             | .               | .           | 7198  |
| 2.00 - 2.99    | 1              | 753         | 548         | 346          | 259           | 85            | 31            | .             | .             | .               | .           | 2023  |
| 3.00 - 3.99    | .              | 42          | 137         | 124          | 151           | 19            | 3             | .             | .             | .               | .           | 476   |
| 4.00 - 4.99    | .              | .           | 18          | 35           | 15            | 5             | .             | .             | .             | .               | .           | 73    |
| 5.00 - 5.99    | .              | .           | 1           | 11           | 9             | 3             | .             | .             | .             | .               | .           | 24    |
| 6.00 - 6.99    | .              | .           | .           | 4            | 11            | .             | .             | .             | .             | .               | .           | 15    |
| 7.00 - 7.99    | .              | .           | .           | .            | 4             | .             | .             | .             | .             | .               | .           | 4     |
| 8.00 - 8.99    | .              | .           | .           | .            | .             | .             | .             | .             | .             | .               | .           | 0     |
| 9.00 - GREATER | .              | .           | .           | .            | .             | .             | .             | .             | .             | .               | .           | 0     |
| BAD DATA       | .              | .           | .           | .            | .             | .             | .             | .             | .             | .               | 1247        | 1247  |
| TOTAL          | 3350           | 4953        | 4286        | 3258         | 1451          | 340           | 59            | 0             | 0             | 1               | 1262        | 18960 |

OCCURRENCES OF WIND SPEED BY MONTH FOR ALL YEARS

| WS (m/sec)      | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | TOTAL | %     |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 0.00 - 2.49     | 101  | 158  | 139  | 137  | 231  | 136  | 193  | 260  | 131  | 147  | 42   | 63   | 1738  | 9.2   |
| 2.50 - 4.99     | 297  | 359  | 448  | 485  | 487  | 476  | 673  | 494  | 294  | 395  | 121  | 182  | 4711  | 24.8  |
| 5.00 - 7.49     | 533  | 438  | 399  | 431  | 411  | 503  | 392  | 358  | 534  | 445  | 200  | 311  | 4955  | 26.1  |
| 7.50 - 9.99     | 527  | 441  | 270  | 237  | 209  | 232  | 137  | 246  | 312  | 256  | 248  | 355  | 3470  | 18.3  |
| 10.00 - 12.49   | 467  | 313  | 113  | 90   | 83   | 39   | 21   | 77   | 102  | 134  | 221  | 268  | 1928  | 10.2  |
| 12.50 - 14.99   | 169  | 214  | 54   | 10   | 11   | 7    | .    | 8    | 7    | 33   | 66   | 132  | 711   | 3.8   |
| 15.00 - 17.49   | 49   | 36   | 5    | 2    | .    | 1    | .    | 3    | 6    | 2    | 17   | 38   | 159   | 0.8   |
| 17.50 - 19.99   | 19   | 2    | 9    | .    | .    | .    | .    | 1    | .    | .    | .    | 3    | 34    | 0.2   |
| 20.00 - GREATER | 6    | .    | 1    | .    | .    | .    | .    | .    | .    | .    | .    | .    | 7     | 0.0   |
| BAD DATA        | 64   | 79   | 50   | 48   | 56   | 46   | 72   | 41   | 54   | 76   | 525  | 136  | 1247  | 6.6   |
| TOTAL           | 2232 | 2040 | 1488 | 1440 | 1488 | 1440 | 1488 | 1488 | 1440 | 1488 | 1440 | 1488 | 18960 | 100.0 |

OCCURRENCES OF WIND DIRECTION BY MONTH FOR ALL YEARS

| WD(deg)<br>Direction Band & Center | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | TOTAL | %     |
|------------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|
| 337.50 - 22.49 ( 0.0)              | 219  | 207  | 136  | 92   | 100  | 81   | 46   | 119  | 167  | 138  | 54   | 166  | 1525  | 8.0   |
| 22.50 - 67.49 ( 45.0)              | 275  | 194  | 148  | 91   | 149  | 130  | 46   | 200  | 200  | 103  | 59   | 151  | 1746  | 9.2   |
| 67.50 - 112.49 ( 90.0)             | 170  | 111  | 149  | 149  | 139  | 194  | 105  | 103  | 158  | 89   | 52   | 76   | 1495  | 7.9   |
| 112.50 - 157.49 (135.0)            | 137  | 87   | 131  | 92   | 82   | 103  | 131  | 67   | 103  | 108  | 67   | 50   | 1158  | 6.1   |
| 157.50 - 202.49 (180.0)            | 205  | 199  | 204  | 399  | 354  | 463  | 481  | 354  | 232  | 248  | 153  | 47   | 3339  | 17.6  |
| 202.50 - 247.49 (225.0)            | 219  | 267  | 182  | 254  | 250  | 288  | 432  | 414  | 223  | 267  | 166  | 158  | 3120  | 16.5  |
| 247.50 - 292.49 (270.0)            | 517  | 604  | 268  | 194  | 196  | 72   | 114  | 102  | 193  | 234  | 212  | 279  | 2985  | 15.7  |
| 292.50 - 337.49 (315.0)            | 426  | 292  | 220  | 121  | 162  | 63   | 61   | 88   | 110  | 225  | 152  | 425  | 2345  | 12.4  |
| BAD DATA                           | 64   | 79   | 50   | 48   | 56   | 46   | 72   | 41   | 54   | 76   | 525  | 136  | 1247  | 6.6   |
| TOTAL                              | 2232 | 2040 | 1488 | 1440 | 1488 | 1440 | 1488 | 1488 | 1440 | 1488 | 1440 | 1488 | 18960 | 100.0 |

SUMMARY OF MEAN Hmo(m) BY MONTH AND YEAR

| YEAR | JAN  | FEB  | MAR  | APR  | MAY  | JUN  | JUL  | AUG  | SEP  | OCT  | NOV  | DEC  | MEAN |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1994 | 1.74 | 1.45 | 1.38 | 1.11 | 1.11 | 0.94 | 0.87 | 0.91 | 1.10 | 0.91 | 1.65 | 1.53 | 1.22 |
| 1995 | 1.67 | 1.56 | 1.13 | 1.00 | 1.05 | 1.01 | 0.83 | 1.54 | 1.46 | 1.33 | 1.27 | 1.34 | 1.26 |
| 1996 | 1.75 | 1.41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.59 |
| MEAN | 1.72 | 1.47 | 1.26 | 1.06 | 1.08 | 0.98 | 0.85 | 1.22 | 1.28 | 1.11 | 1.54 | 1.44 |      |

MAX Hmo(m)\*10 WITH ASSOCIATED Tp(sec) AND Dp(deg/10) BY MONTH AND YEAR

| YEAR | JAN           | FEB    | MAR    | APR    | MAY    | JUN    | JUL    | AUG    | SEP    | OCT    | NOV    | DEC    | MAX |
|------|---------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-----|
| 1994 | 5910 8 44 8 9 | 741110 | 24 818 | 341111 | 35 819 | 26 818 | 33 8 6 | 51 811 | 29 8 7 | 411012 | 5913 9 | 741110 |     |
| 1995 | 40 917 46 914 | 29 915 | 30 819 | 25 7 7 | 30 7 7 | 19 720 | 391413 | 331715 | 391111 | 31 820 | 36 8 9 | 46 914 |     |
| 1996 | 7211 8 37 631 | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 0 0 0  | 7211 8 |     |
| MAX  | 7211 8 46 914 | 741110 | 30 819 | 341111 | 35 819 | 26 818 | 391413 | 51 811 | 391111 | 411012 | 5913 9 |        |     |

MAX Hmo(m): 7.4    MAX Tp(sec): 11.    MAX Dp(deg): 97.    DATE(gmt): 94030311

MAX WIND SPEED(m/sec): 22.    MAX WIND DIRECTION(deg): 42.    DATE(gmt): 96010805

### A3. STORM DATA

| date     | Hmo (m) | Tp (sec) | dir (deg) |
|----------|---------|----------|-----------|
| 95111415 | 2.20    | 7.1      | 104       |
| 95111416 | 2.62    | 7.1      | 99        |
| 95111417 | 2.81    | 7.5      | 96        |
| 95111418 | 3.54    | 9.1      | 102       |
| 95111419 | 3.54    | 8.5      | 97        |
| 95111420 | 2.99    | 9.1      | 98        |
| 95111421 | 3.71    | 9.1      | 97        |
| 95111422 | 3.47    | 9.1      | 89        |
| 95111423 | 3.82    | 9.8      | 105       |
| 95111500 | 3.86    | 10.7     | 98        |
| 95111501 | 4.22    | 10.7     | 101*      |
| 95111502 | 3.67    | 11.6     | 107       |
| 95111503 | 3.22    | 11.6     | 101       |
| 95111504 | 3.44    | 10.7     | 104       |
| 95111505 | 2.69    | 9.8      | 104       |
| 95111506 | 2.59    | 9.1      | 104       |
| 95111507 | 2.78    | 10.7     | 102       |
| 95111508 | 2.15    | 8.5      | 109       |
| 95111509 | 2.14    | 10.7     | 108       |
| 95111120 | 2.00    | 7.1      | 137       |
| 95111121 | 2.24    | 7.1      | 133       |
| 95111122 | 2.02    | 7.5      | 139       |
| 95111200 | 2.00    | 7.1      | 140       |
| 95111201 | 2.62    | 7.5      | 132       |
| 95111202 | 3.22    | 8.0      | 133       |
| 95111203 | 3.30    | 8.0      | 136       |
| 95111204 | 3.35    | 9.8      | 128       |
| 95111205 | 4.08    | 9.8      | 129*      |
| 95111206 | 2.89    | 10.7     | 126       |
| 94030218 | 2.08    | 6.7      | -999      |
| 94030219 | 2.09    | 6.7      | -999      |
| 94030220 | 2.32    | 7.1      | -999      |
| 94030221 | 2.22    | 7.1      | -999      |
| 94030222 | 2.35    | 7.5      | -999      |
| 94030223 | 2.64    | 8.0      | -999      |
| 94030300 | 3.03    | 7.5      | -999      |
| 94030301 | 3.20    | 8.5      | -999      |
| 94030302 | 3.64    | 8.5      | -999      |
| 94030303 | 3.43    | 8.5      | -999      |
| 94030304 | 3.75    | 9.1      | -999      |
| 94030305 | 4.01    | 9.8      | -999      |
| 94030306 | 3.80    | 9.8      | -999      |
| 94030307 | 3.77    | 10.7     | -999      |
| 94030308 | 3.54    | 9.8      | -999      |
| 94030309 | 4.07    | 11.6     | -999*     |
| 94030310 | 3.94    | 10.7     | -999      |
| 94030311 | 3.94    | 11.6     | -999      |
| 94030312 | 3.79    | 11.6     | -999      |
| 94030313 | 4.00    | 12.8     | -999      |
| 94030314 | 3.57    | 12.8     | -999      |
| 94030315 | 3.53    | 12.8     | -999      |
| 94030316 | 3.48    | 10.7     | -999      |
| 94030317 | 3.23    | 12.8     | -999      |
| 94030319 | 2.56    | 11.6     | -999      |
| 94030320 | 2.36    | 12.8     | -999      |
| 94030321 | 2.14    | 11.6     | -999      |
| 94030402 | 2.01    | 11.6     | -999      |

|          |      |      |       |
|----------|------|------|-------|
| 96010719 | 2.28 | 6.4  | 95    |
| 96010720 | 2.35 | 6.7  | 86    |
| 96010721 | 2.41 | 7.5  | 99    |
| 96010722 | 2.86 | 8.0  | 92    |
| 96010723 | 3.05 | 8.0  | 93    |
| 96010800 | 3.30 | 8.5  | 98    |
| 96010801 | 3.39 | 8.5  | 99    |
| 96010802 | 3.25 | 9.1  | 102   |
| 96010803 | 3.80 | 9.1  | 96    |
| 96010804 | 3.39 | 9.8  | 102   |
| 96010805 | 3.64 | 9.8  | 97    |
| 96010806 | 3.73 | 10.7 | 103   |
| 96010807 | 3.69 | 10.7 | 105   |
| 96010808 | 3.63 | 11.6 | 103   |
| 96010809 | 3.61 | 10.7 | 103   |
| 96010810 | 3.89 | 10.7 | 104   |
| 96010811 | 3.90 | 11.6 | 108*  |
| 96010812 | 3.55 | 11.6 | 96    |
| 96010813 | 3.40 | 12.8 | 111   |
| 96010814 | 3.31 | 11.6 | 106   |
| 96010815 | 3.11 | 11.6 | 105   |
| 96010816 | 3.04 | 11.6 | 105   |
| 96010817 | 2.89 | 12.8 | 103   |
| 96010818 | 2.80 | 12.8 | 107   |
| 96010819 | 2.61 | 11.6 | 106   |
| 96010820 | 2.51 | 11.6 | 108   |
| 96010821 | 2.39 | 11.6 | 111   |
| 96010822 | 2.01 | 8.5  | 93    |
| 94010323 | 2.24 | 7.1  | -999  |
| 94010400 | 2.17 | 7.5  | -999  |
| 94010401 | 2.33 | 7.5  | -999  |
| 94010402 | 2.51 | 7.1  | -999  |
| 94010403 | 2.56 | 7.5  | -999  |
| 94010404 | 2.53 | 8.0  | -999  |
| 94010405 | 2.44 | 8.0  | -999  |
| 94010406 | 2.71 | 9.1  | -999  |
| 94010407 | 2.66 | 9.1  | -999  |
| 94010408 | 2.50 | 9.1  | -999  |
| 94010409 | 2.39 | 9.1  | -999  |
| 94010410 | 2.39 | 9.1  | -999  |
| 94010411 | 2.54 | 9.1  | -999  |
| 94010412 | 2.65 | 9.8  | -999  |
| 94010413 | 2.78 | 9.1  | -999  |
| 94010414 | 3.33 | 9.8  | -999  |
| 94010415 | 3.79 | 9.8  | -999* |
| 94010416 | 3.34 | 8.5  | -999  |
| 94010417 | 2.54 | 9.8  | -999  |
| 94010418 | 2.23 | 10.7 | -999  |
| 94010419 | 2.25 | 9.1  | -999  |
| 96031920 | 2.15 | 6.1  | 90    |
| 96031921 | 2.31 | 7.1  | 97    |
| 96031922 | 2.80 | 7.1  | 85    |
| 96031923 | 2.95 | 7.5  | 92    |
| 96032000 | 2.67 | 7.5  | 86    |
| 96032001 | 3.13 | 8.0  | 99    |
| 96032002 | 3.31 | 8.0  | 92    |
| 96032003 | 3.76 | 8.5  | 97*   |
| 96032004 | 2.81 | 8.5  | 93    |
| 96032005 | 2.31 | 9.1  | 95    |
| 96032006 | 2.05 | 8.5  | 100   |

|          |      |      |       |
|----------|------|------|-------|
| 94092219 | 2.09 | 6.7  | 109   |
| 94092220 | 2.17 | 6.7  | 99    |
| 94092221 | 2.35 | 7.1  | 110   |
| 94092222 | 2.52 | 7.5  | 107   |
| 94092223 | 3.02 | 7.5  | 106   |
| 94092300 | 3.19 | 8.0  | 109   |
| 94092301 | 3.24 | 7.5  | 103   |
| 94092302 | 3.42 | 8.5  | 113   |
| 94092303 | 3.36 | 8.5  | 108   |
| 94092304 | 3.55 | 8.5  | 107*  |
| 94092305 | 3.45 | 8.5  | 106   |
| 94092306 | 3.07 | 8.5  | 108   |
| 94092307 | 2.37 | 8.5  | 105   |
| 94092308 | 2.30 | 8.0  | 109   |
| 94092310 | 2.01 | 8.5  | 122   |
| 94092311 | 2.02 | 9.8  | 127   |
| 94092312 | 2.09 | 10.7 | 131   |
| 94022316 | 2.11 | 7.1  | -999  |
| 94022317 | 2.58 | 7.1  | -999  |
| 94022318 | 2.75 | 8.0  | -999  |
| 94022319 | 2.88 | 8.0  | -999  |
| 94022320 | 2.70 | 8.0  | -999  |
| 94022321 | 2.82 | 8.0  | -999  |
| 94022322 | 3.14 | 8.5  | -999* |
| 94022323 | 2.94 | 8.5  | -999  |
| 94022400 | 2.85 | 8.5  | -999  |
| 94022401 | 2.65 | 8.5  | -999  |
| 94022402 | 2.66 | 9.1  | -999  |
| 94022403 | 2.38 | 9.1  | -999  |
| 94022404 | 2.07 | 8.5  | -999  |
| 94022405 | 2.25 | 9.1  | -999  |
| 94022406 | 2.01 | 8.0  | -999  |
| 94022407 | 2.64 | 9.1  | -999  |
| 94022408 | 2.28 | 8.5  | -999  |
| 94022409 | 2.22 | 9.1  | -999  |
| 94022410 | 2.49 | 9.1  | -999  |
| 96011914 | 2.05 | 7.5  | 139   |
| 96011915 | 2.35 | 8.0  | 134   |
| 96011916 | 2.66 | 8.0  | 135   |
| 96011917 | 2.89 | 9.1  | 134   |
| 96011918 | 2.87 | 9.1  | 131   |
| 96011919 | 2.76 | 9.8  | 128   |
| 96011920 | 3.14 | 9.1  | 130*  |
| 96011921 | 2.71 | 9.1  | 126   |
| 96011922 | 2.64 | 9.8  | 128   |
| 96011923 | 2.08 | 9.8  | 126   |
| 96012712 | 2.07 | 7.1  | 129   |
| 96012718 | 2.27 | 7.1  | 125   |
| 96012719 | 2.45 | 7.5  | 131   |
| 96012720 | 2.98 | 8.0  | 139   |
| 96012721 | 3.05 | 9.1  | 133*  |
| 96012722 | 2.43 | 9.8  | 125   |
| 96012723 | 2.33 | 9.8  | 129   |

|          |      |      |       |
|----------|------|------|-------|
| 95121923 | 2.05 | 7.1  | 97    |
| 95122000 | 2.18 | 7.1  | 97    |
| 95122001 | 2.18 | 7.5  | 100   |
| 95122002 | 2.46 | 7.5  | 86*   |
| 95122003 | 2.18 | 8.0  | 97    |
| 95122004 | 2.35 | 8.0  | 95    |
| 95122005 | 2.44 | 8.0  | 100   |
| 95122006 | 2.29 | 8.0  | 95    |
| 95122007 | 2.39 | 8.0  | 95    |
| 95122008 | 2.26 | 8.5  | 93    |
| 95122009 | 2.15 | 8.5  | 102   |
| 96011220 | 2.24 | 6.1  | 92    |
| 96011221 | 2.38 | 6.7  | 96*   |
| 96011222 | 2.28 | 7.1  | 101   |
| 96011223 | 2.29 | 8.0  | 120   |
| 96011300 | 2.05 | 8.0  | 114   |
| 94111710 | 2.03 | 7.1  | 114   |
| 94111717 | 2.02 | 6.7  | 112   |
| 94111718 | 2.01 | 6.7  | 118   |
| 94111720 | 2.03 | 7.5  | 111   |
| 94111721 | 2.33 | 7.1  | 106   |
| 94111722 | 2.26 | 7.5  | 112   |
| 94111723 | 2.36 | 8.0  | 121*  |
| 94111800 | 2.22 | 8.0  | 117   |
| 94111801 | 2.29 | 9.1  | 121   |
| 94111802 | 2.11 | 9.8  | 114   |
| 94111803 | 2.14 | 8.0  | 118   |
| 94111804 | 2.06 | 7.5  | 117   |
| 94111805 | 2.10 | 10.7 | 122   |
| 94111806 | 2.17 | 7.1  | 116   |
| 94111807 | 2.12 | 8.0  | 122   |
| 94111808 | 2.11 | 7.5  | 117   |
| 94111809 | 2.28 | 8.5  | 124   |
| 94111810 | 2.11 | 8.5  | 125   |
| 94111811 | 2.09 | 7.1  | 116   |
| 94111812 | 2.26 | 8.5  | 120   |
| 94111813 | 2.14 | 6.4  | 118   |
| 96032911 | 2.10 | 6.7  | 88    |
| 96032912 | 2.33 | 7.1  | 96*   |
| 96032913 | 2.18 | 7.5  | 95    |
| 96032914 | 2.05 | 7.5  | 100   |
| 96032916 | 2.11 | 8.5  | 109   |
| 96032919 | 2.07 | 9.1  | 112   |
| 94021118 | 2.04 | 8.0  | -999  |
| 94021123 | 2.23 | 8.5  | -999* |
| 94021200 | 2.22 | 8.5  | -999  |
| 94021201 | 2.17 | 9.1  | -999  |
| 94021203 | 2.07 | 8.5  | -999  |
| 96010308 | 2.17 | 7.1  | 102*  |
| 96010313 | 2.06 | 8.0  | 113   |
| 94012612 | 2.11 | 7.1  | -999* |
| 94012613 | 2.10 | 8.0  | -999  |
| 94012620 | 2.05 | 8.5  | -999  |
| 94012821 | 2.01 | 8.0  | -999  |
| 94012822 | 2.05 | 9.1  | -999  |
| 94012823 | 2.11 | 9.1  | -999* |

|          |      |     |      |
|----------|------|-----|------|
| 94101512 | 2.06 | 7.5 | 105* |
| 94101513 | 2.00 | 7.5 | 108  |
| 94101514 | 2.06 | 7.1 | 100  |
| 94101515 | 2.01 | 7.5 | 105  |

\* Storm Peak, as determined from maximum wave height

# Appendix B

## Beach Profile Evolution

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Appendix B contains plots of beach profile surveys along the beach fill of Contract 1A (Monmouth Beach and Seabright, New Jersey) and a grain-size distribution analysis of sediment samples collected from the beach fill at Monmouth Beach. Figures B1 through B10 present available beach profile surveys for sta 208, 224, 232, 240, 245, 255, 265, 275, 286, and 294. Figure B11 is the sieve analysis of the beach-fill material. Figures B12 through B20 compare equilibrium beach profiles with the October 1995 beach profile surveys at sta 208, 232, 240, 245, 255, 265, 275, 286, and 294.

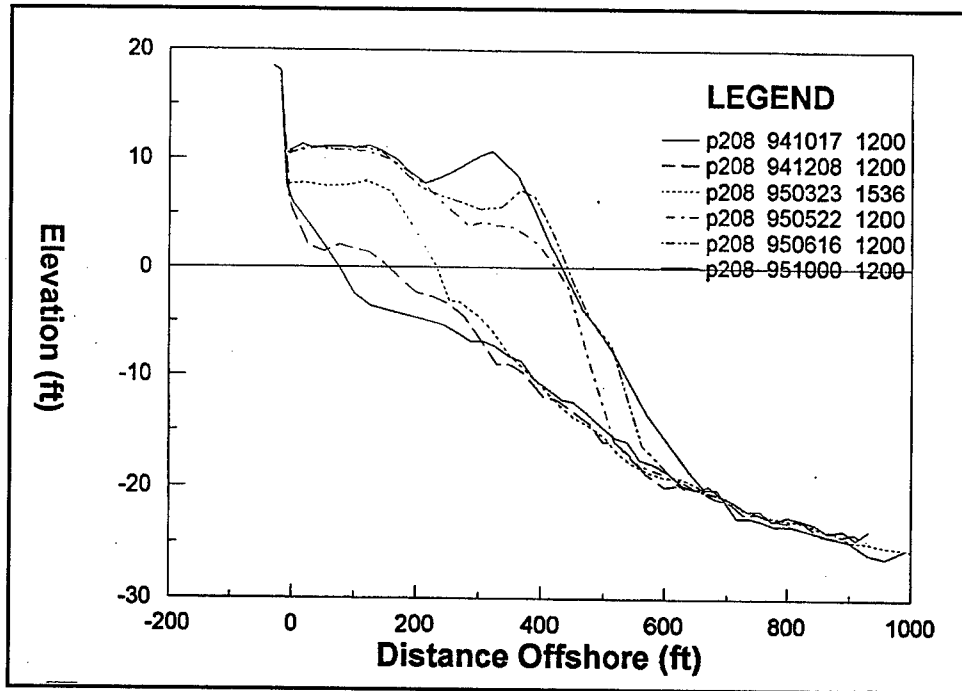


Figure B1. Beach profile evolution (sta 208)

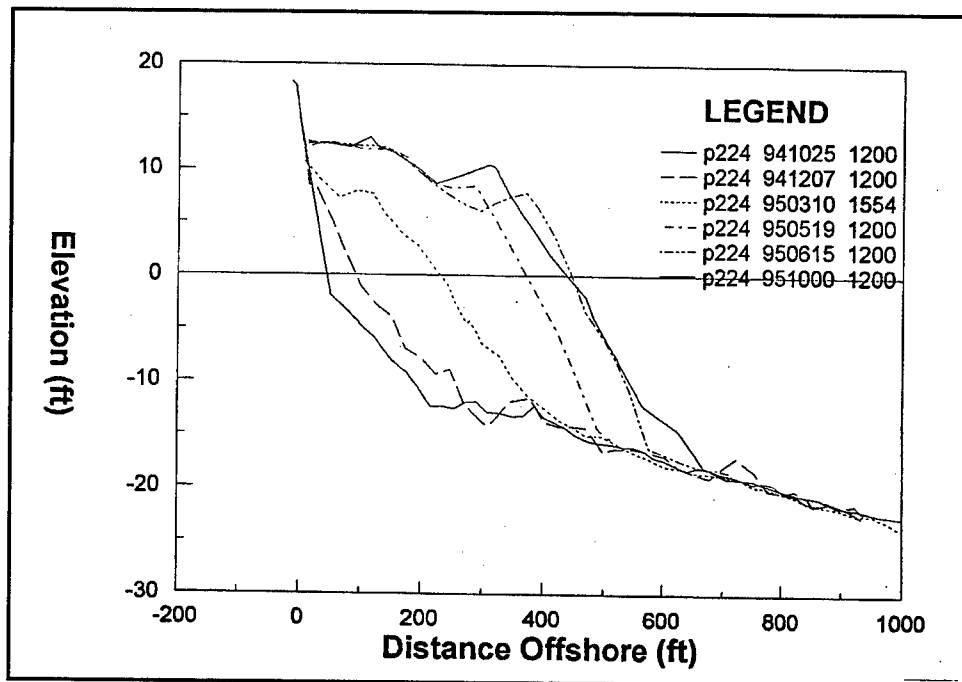


Figure B2. Beach profile evolution (sta 224)

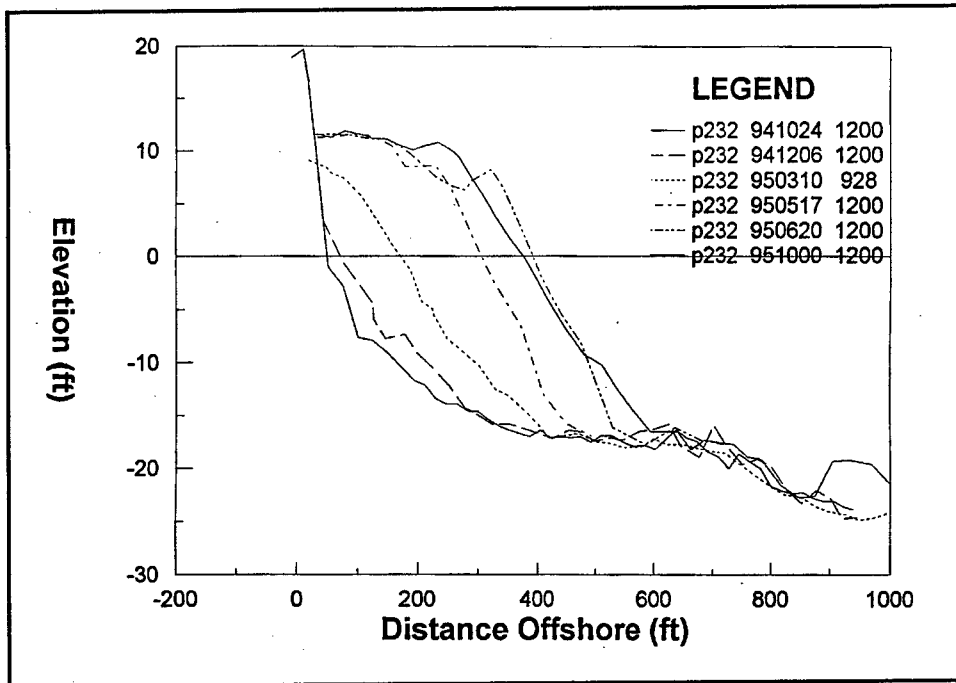


Figure B3. Beach profile evolution (sta 232)

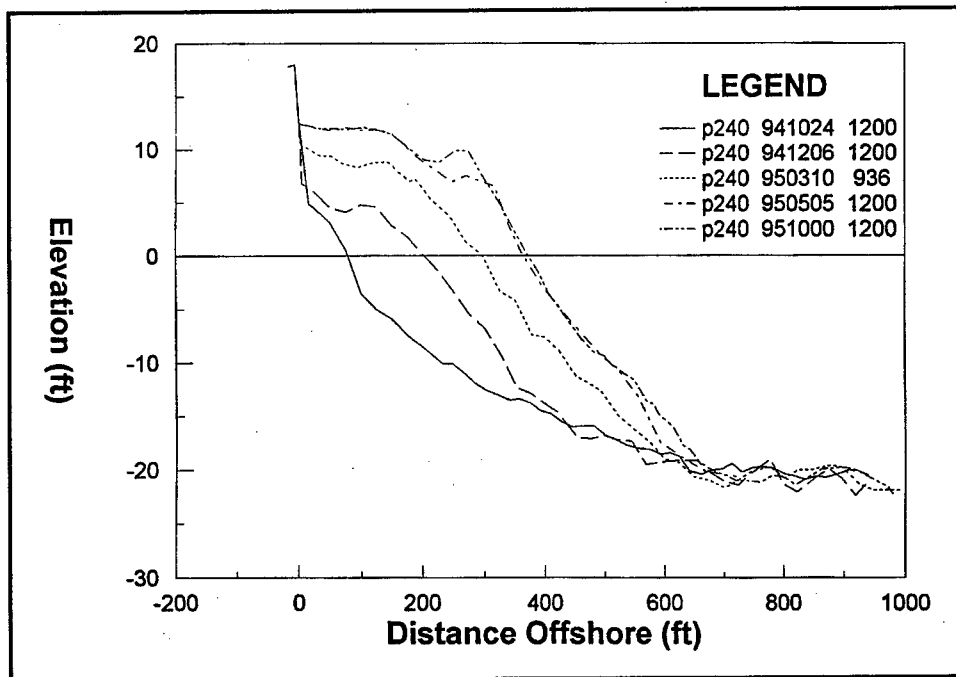


Figure B4. Beach profile evolution (sta 240)

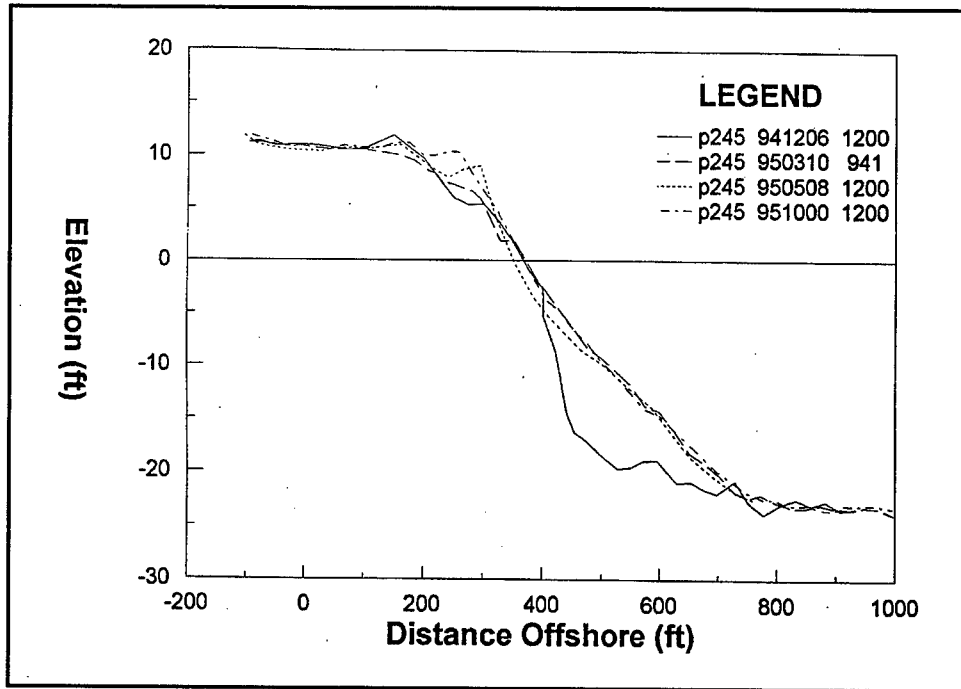


Figure B5. Beach profile evolution (sta 245)

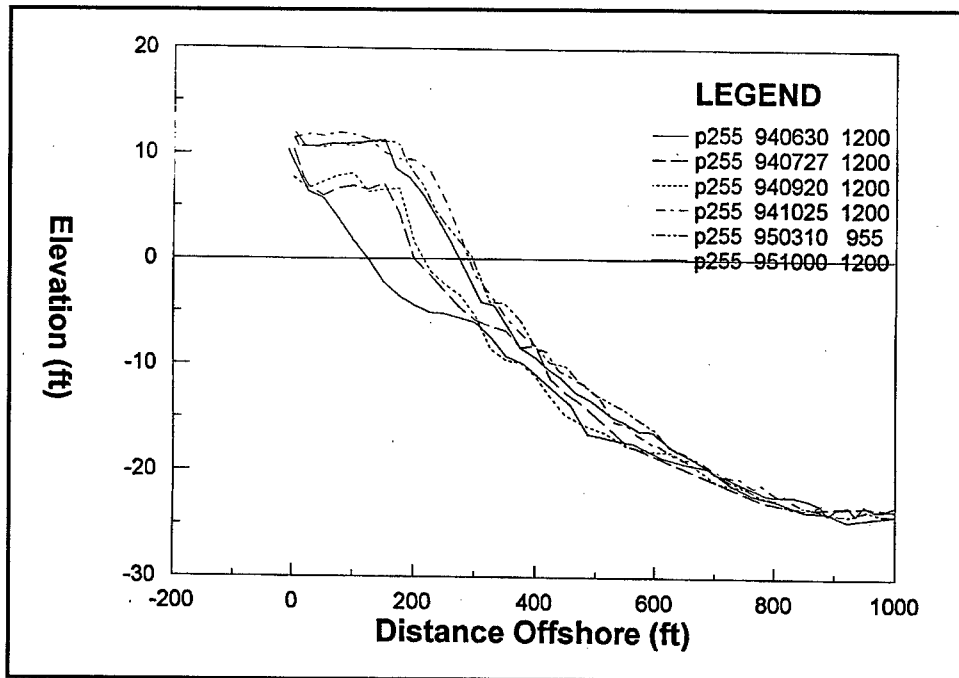


Figure B6. Beach profile evolution (sta 255)

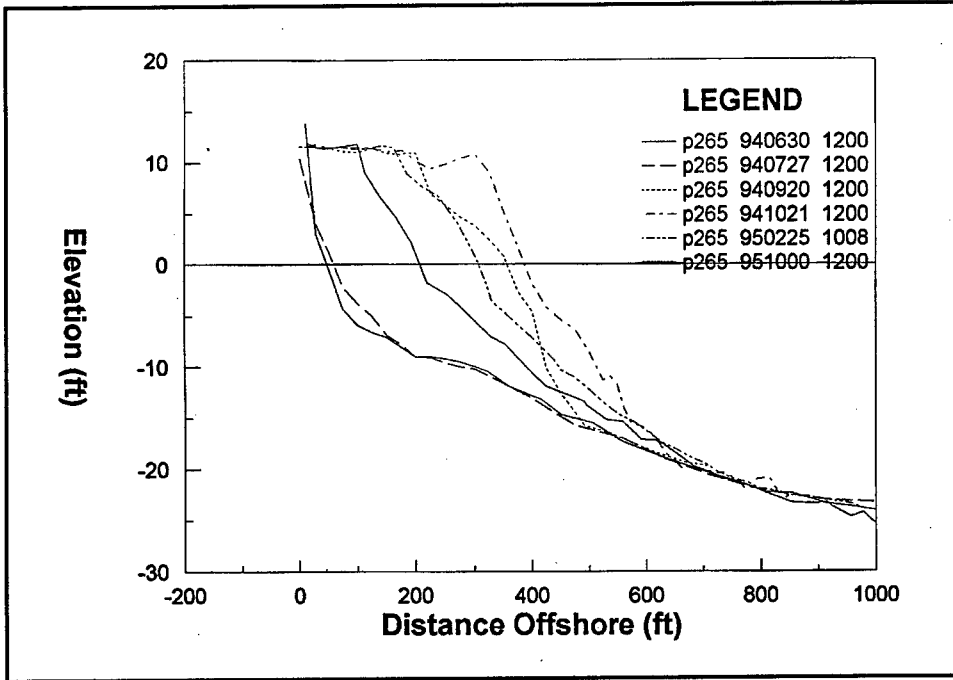


Figure B7. Beach profile evolution (sta 265)

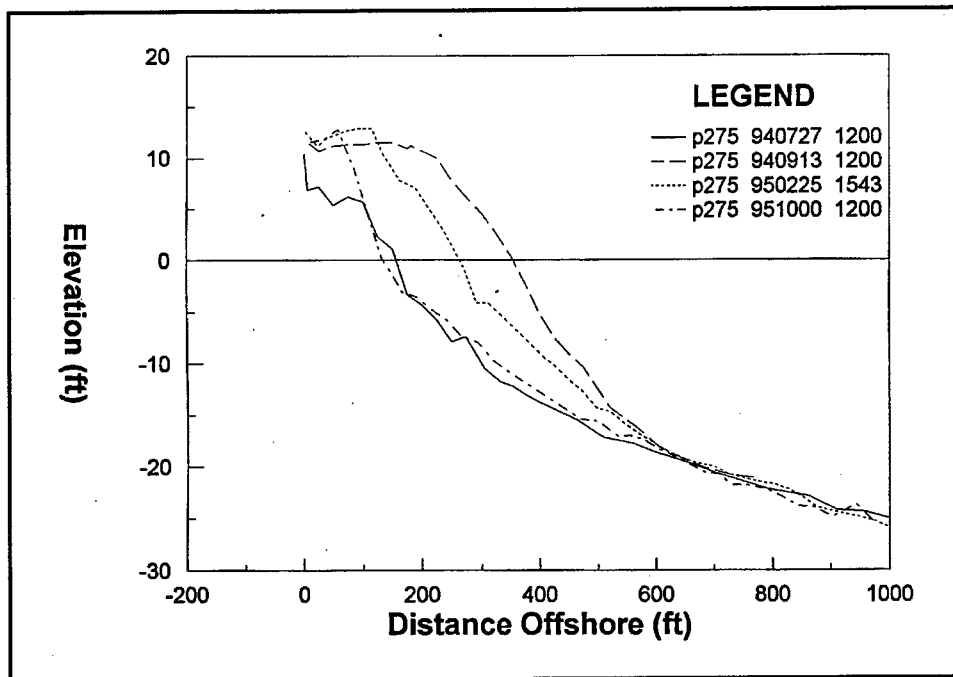


Figure B8. Beach profile evolution (sta 275)

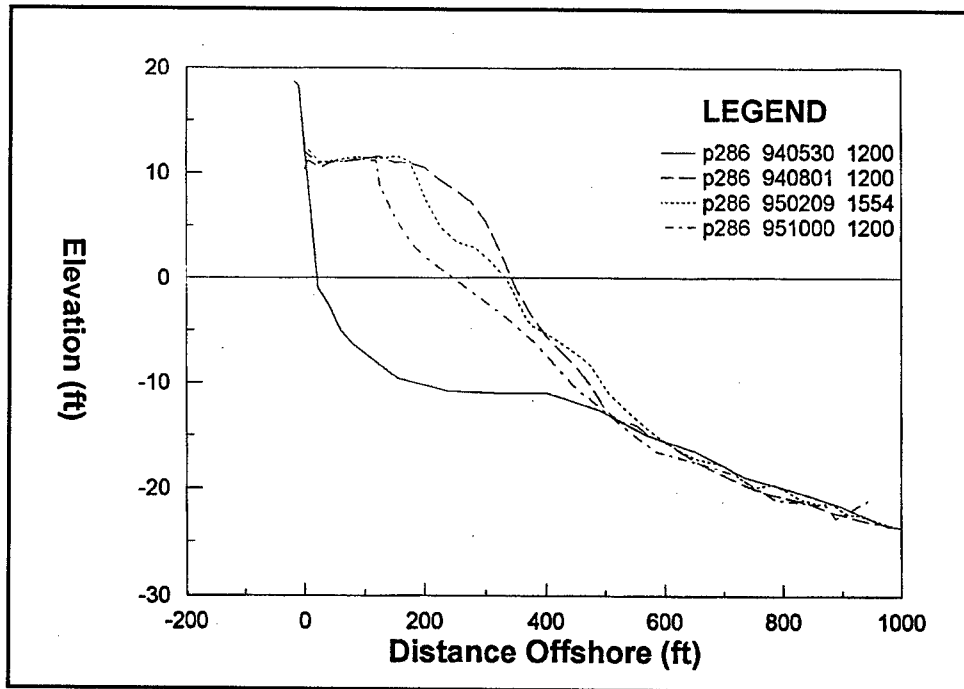


Figure B9. Beach profile evolution (sta 286)

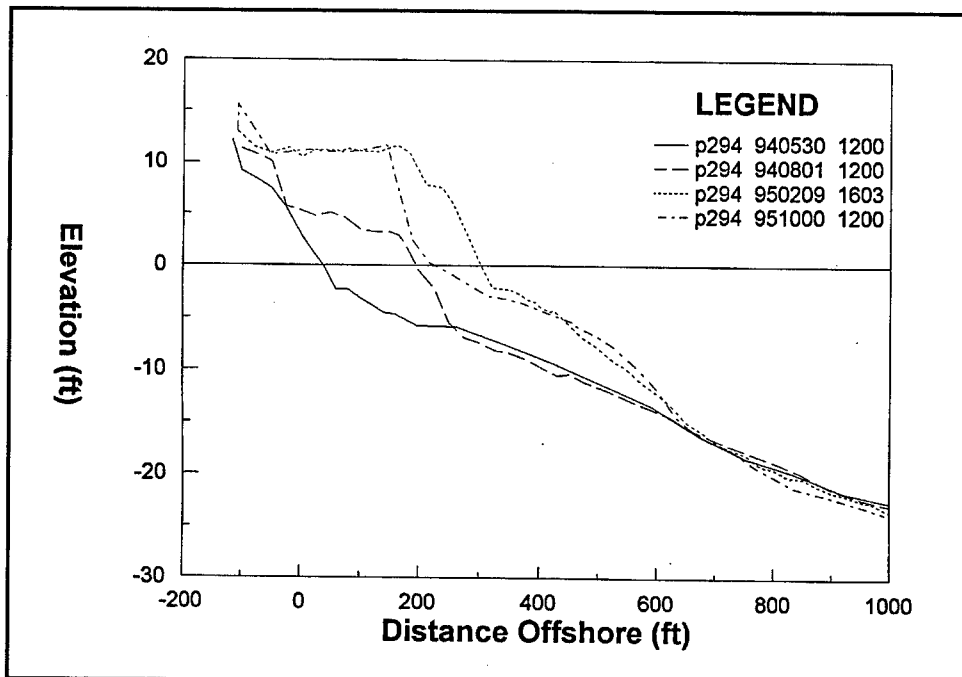


Figure B10. Beach profile evolution (sta 294)

| Backshore Beach |           |           |           |           |           |           |         |          |          | Edge of Berm |           |           |           |           |           |          |          |          |  |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|---------|----------|----------|--------------|-----------|-----------|-----------|-----------|-----------|----------|----------|----------|--|
| Profile         | d16<br>mm | d16<br>PH | d50<br>mm | d50<br>PH | d64<br>mm | d64<br>PH | mean    | st. dev. | kurtosis | d16<br>mm    | d16<br>PH | d50<br>mm | d50<br>PH | d64<br>mm | d64<br>PH | mean     | st. dev. | kurtosis |  |
| 246             | -0.4      | 32        | 1.1       | 0.47      | 2         | 0.25      | 0.900   | 1.200    | -0.167   | -1.7         | 3.25      | 0.7       | 0.82      | 1.8       | 0.29      | 0.267    | 1.750    | -0.248   |  |
| 246             | -1.7      | 3.25      | 0.3       | 0.81      | 1.6       | 0.33      | 0.067   | 1.650    | -0.141   | 0            | 1.00      | 0.8       | 0.57      | 1.9       | 0.33      | 0.900    | 0.800    | 0.000    |  |
| 250             | -0.5      | 1.41      | 0.8       | 0.57      | 1.8       | 0.29      | 0.700   | 1.150    | -0.097   | 0            | 1.00      | 0.7       | 0.62      | 1.5       | 0.35      | 0.733    | 0.750    | 0.044    |  |
| 252             | -0.8      | 1.74      | 0.9       | 0.54      | 1.8       | 0.29      | 0.633   | 1.300    | -0.205   | -0.5         | 1.41      | 1.3       | 0.41      | 2.2       | 0.22      | 1.000    | 1.350    | -0.272   |  |
| 254             | -1        | 2.00      | 1.2       | 0.44      | 2.2       | 0.22      | 0.800   | 1.600    | -0.250   | 0.1          | 0.93      | 1.4       | 0.38      | 2         | 0.25      | 1.167    | 0.950    | -0.246   |  |
| 256             | -0.7      | 1.62      | 0.8       | 0.57      | 1.7       | 0.31      | 0.600   | 1.200    | -0.167   | 0.2          | 0.87      | 1.3       | 0.41      | 1.8       | 0.29      | 1.100    | 0.800    | -0.250   |  |
| 258             | 0.1       | 0.93      | 1.3       | 0.41      | 1.8       | 0.29      | 1.067   | 0.850    | -0.275   | -0.5         | 1.41      | 0.9       | 0.54      | 1.7       | 0.31      | 0.700    | 1.100    | -0.182   |  |
| 260             | -0.5      | 1.41      | 1         | 0.50      | 1.9       | 0.27      | 0.800   | 1.200    | -0.167   | -1           | 2.00      | 0.5       | 0.71      | 2.1       | 0.23      | 0.533    | 1.550    | 0.022    |  |
| 262             | -0.3      | 1.23      | 1.2       | 0.44      | 2.1       | 0.23      | 0.787   | 1.250    | -0.027   | -1.3         | 2.46      | 0.4       | 0.76      | 1.8       | 0.29      | 0.900    | 1.450    | -0.065   |  |
| 264             | -0.5      | 1.41      | 0.8       | 0.57      | 2         | 0.25      | -0.033  | 2.150    | -0.108   | -0.7         | 1.82      | 1         | 0.50      | 1.8       | 0.29      | 0.700    | 1.250    | -0.240   |  |
| 266             | -2.3      | 4.92      | 0.2       | 0.81      | 1.7       | 0.31      | 0.933   | 0.850    | -0.198   | -2.4         | 5.28      | -0.5      | 1.41      | 1.3       | 0.41      | -0.333   | 1.850    | -0.018   |  |
| 268             | 0         | 1.00      | 1.1       | 0.47      | 1.8       | 0.29      | 0.787   | 1.150    | -0.203   | -2.3         | 4.92      | -0.3      | 0.81      | 1.4       | 0.38      | -0.400   | 1.850    | -0.054   |  |
| 270             | -0.5      | 1.41      | 1         | 0.50      | 1.8       | 0.29      | 0.800   | 1.450    | -0.207   | 0.3          | 0.81      | 1.4       | 0.38      | 2.2       | 0.22      | 1.300    | 0.850    | -0.105   |  |
| 272             | -0.8      | 1.74      | 1.1       | 0.47      | 2.1       | 0.23      | 0.800   | 1.550    | -0.194   | 0            | 1.00      | 0.9       | 0.54      | 1.7       | 0.31      | 0.867    | 0.850    | -0.039   |  |
| 274             | -1.3      | 2.46      | 0.7       | 0.62      | 1.8       | 0.29      | 0.400   | 1.550    | -0.194   | -0.3         | 1.23      | 1.5       | 0.54      | 2.3       | 0.20      | 1.167    | 0.850    | -0.039   |  |
| 276             | 0.4       | 0.76      | 1.1       | 0.47      | 1.8       | 0.29      | 1.100   | 0.700    | 0.000    | -0.3         | 1.23      | 1.5       | 0.54      | 2.3       | 0.20      | 1.167    | 0.850    | -0.039   |  |
| average         |           |           | 0.8125    | 0.53      |           |           | 0.70625 | 1.278125 | *****    |              |           | 0.79375   | 0.58      |           |           | 0.635417 | 1.25625  | *****    |  |
| st. dev.        |           |           | 0.30957   | 0.68      |           |           | 0.57442 | 0.88     |          |              |           | 0.57442   | 0.88      |           |           | 0.57442  | 0.88     |          |  |
| low             |           |           | 0.60293   | 0.43      |           |           | 0.21933 | 0.68     |          |              |           | 0.21933   | 0.68      |           |           | 0.21933  | 0.68     |          |  |
| high            |           |           | 1.22207   | 0.43      |           |           | 1.36817 | 0.39     |          |              |           | 1.36817   | 0.39      |           |           | 1.36817  | 0.39     |          |  |

| MLW      |           |           |           |           |           |           |          |          |          |
|----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|----------|
| Profile  | d16<br>mm | d16<br>PH | d50<br>mm | d50<br>PH | d64<br>mm | d64<br>PH | mean     | st. dev. | kurtosis |
| 0.5      | 0.71      | 1         | 0.50      | 1.5       | 0.35      | 1.000     | 0.500    | 0.000    | 0.2      |
| 0.5      | 0.71      | 1.1       | 0.47      | 1.6       | 0.33      | 1.067     | 0.550    | -0.061   | -1.2     |
| 0        | 1.00      | 0.8       | 0.57      | 1.5       | 0.35      | 0.787     | 0.750    | -0.044   | -1.2     |
| -0.7     | 1.62      | 0.6       | 0.86      | 1.5       | 0.35      | 0.467     | 1.100    | -0.121   | -3.4     |
| -0.5     | 1.41      | 0.8       | 0.86      | 1.6       | 0.33      | 0.567     | 1.050    | -0.032   | -2.8     |
| -1.5     | 2.83      | 0.5       | 0.71      | 1.7       | 0.31      | 0.233     | 1.600    | -0.167   | -5.4     |
| -2.2     | 4.59      | -0.8      | 1.87      | 1.7       | 0.31      | -0.467    | 1.950    | 0.222    | -3.4     |
| 0.1      | 0.93      | 1.2       | 0.44      | 2         | 0.25      | 1.100     | 0.950    | -0.105   | -0.6     |
| -0.3     | 1.23      | 0.7       | 0.62      | 1.8       | 0.29      | 0.733     | 1.050    | 0.032    | -0.7     |
| 0.4      | 0.76      | 1.8       | 0.29      | 2.1       | 0.23      | 1.433     | 0.850    | -0.031   | -0.2     |
| 0.7      | 0.62      | 1.3       | 0.41      | 1.8       | 0.29      | 1.267     | 0.550    | -0.061   | -0.1     |
| 0        | 1.00      | 1.3       | 0.41      | 2.2       | 0.22      | 1.187     | 1.100    | -0.121   | -0.4     |
| -0.7     | 1.62      | 0.8       | 0.57      | 1.8       | 0.29      | 0.633     | 1.350    | -0.133   | -2.3     |
| 1        | 0.50      | 1.5       | 0.35      | 2         | 0.25      | 1.500     | 0.500    | 0.000    | -2       |
| -0.3     | 1.23      | 1         | 0.50      | 1.5       | 0.35      | 0.733     | 0.800    | -0.298   | 0.5      |
| 0.7      | 0.62      | 1.3       | 0.41      | 1.7       | 0.31      | 1.233     | 0.300    | -0.133   | 0.7      |
| average  |           |           | 0.9125    | 0.53      |           |           | 0.839583 | 0.946875 | *****    |
| st. dev. |           |           | 0.60208   | 0.81      |           |           | 0.31042  | 0.81     |          |
| low      |           |           | 0.31042   | 0.35      |           |           | 0.070633 | 1.209375 | 0.051143 |
| high     |           |           | 1.51458   | 0.35      |           |           | 0.070633 | 1.209375 | 0.051143 |

Figure B11. Sieve analysis

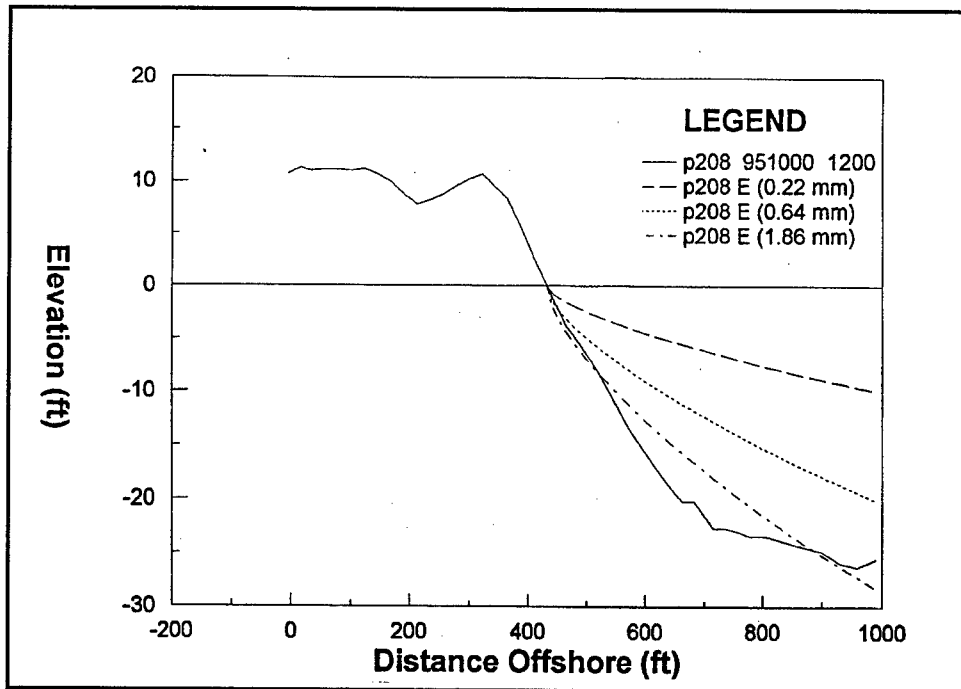


Figure B12. Beach profile equilibrium comparisons (sta 208)

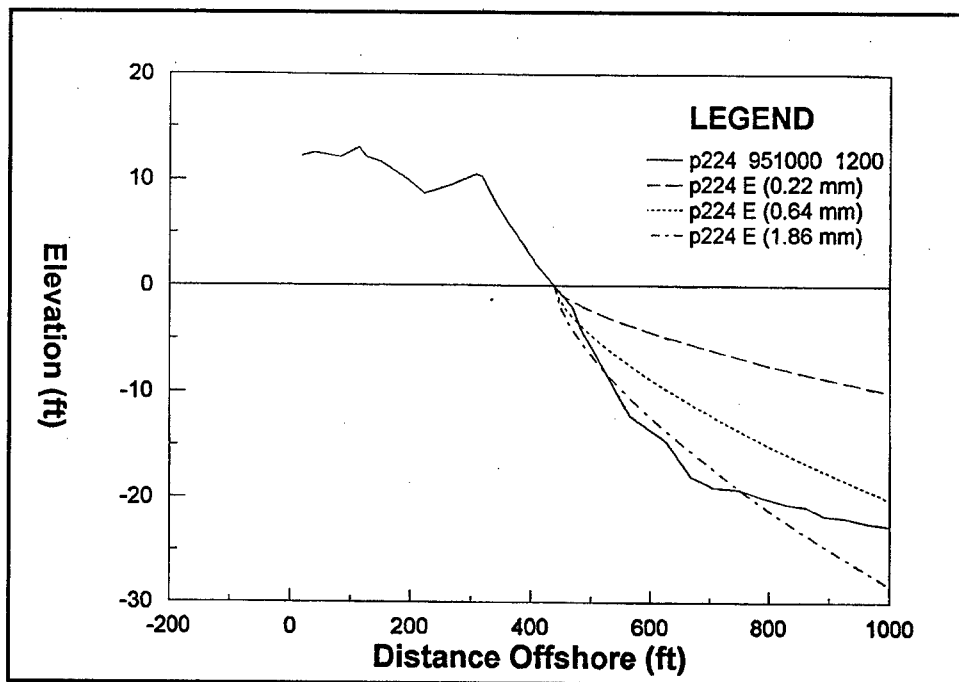


Figure B13. Beach profile equilibrium comparisons (sta 224)

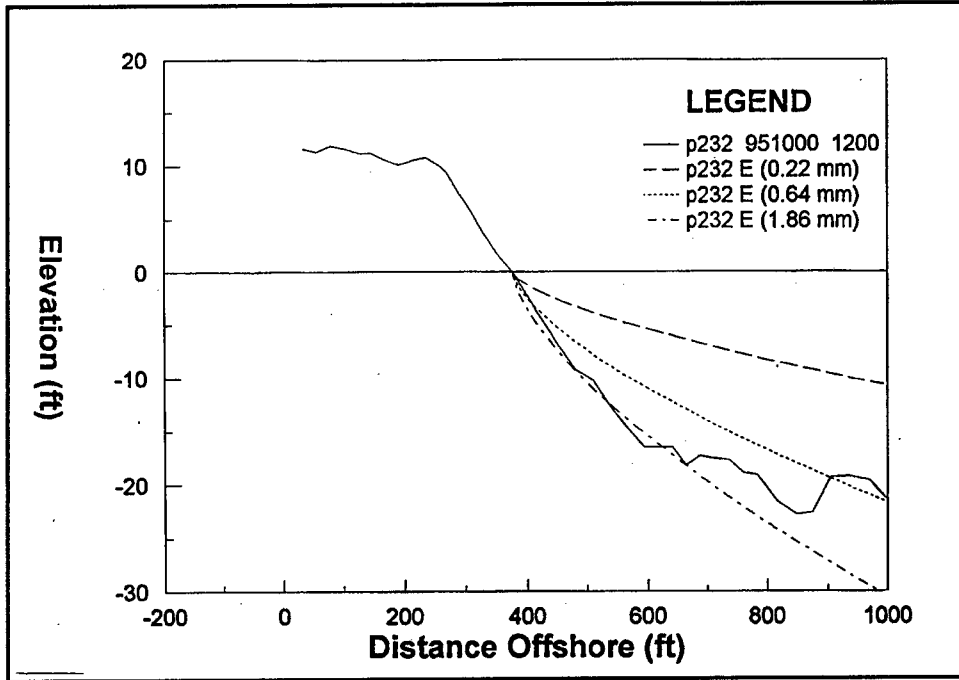


Figure B14. Beach profile equilibrium comparisons (sta 232)

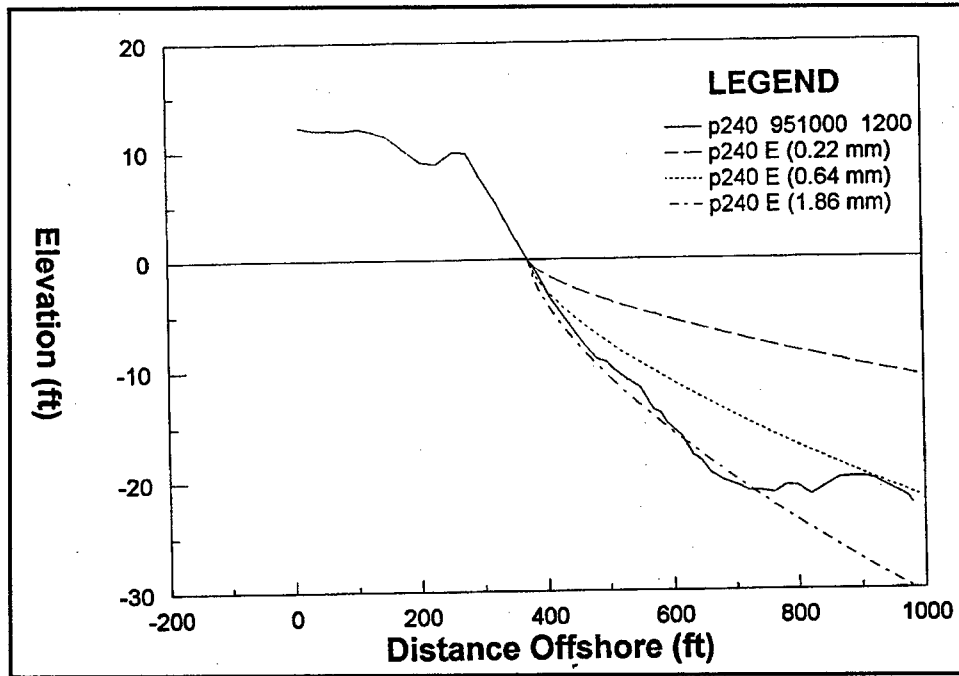


Figure B15. Beach profile equilibrium comparisons (sta 240)

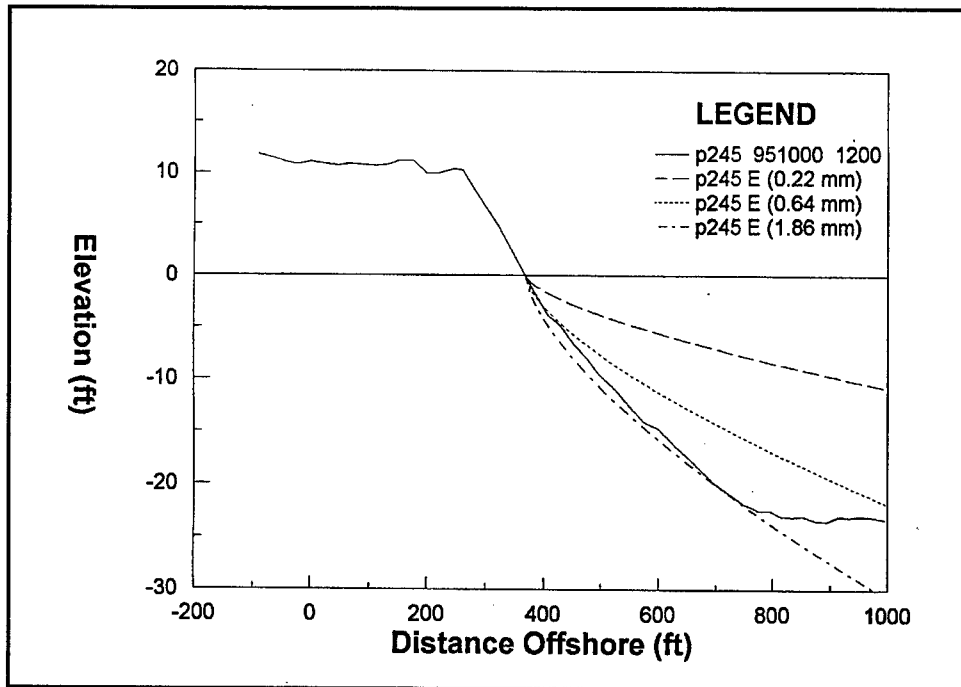


Figure B16. Beach profile equilibrium comparisons (sta 245)

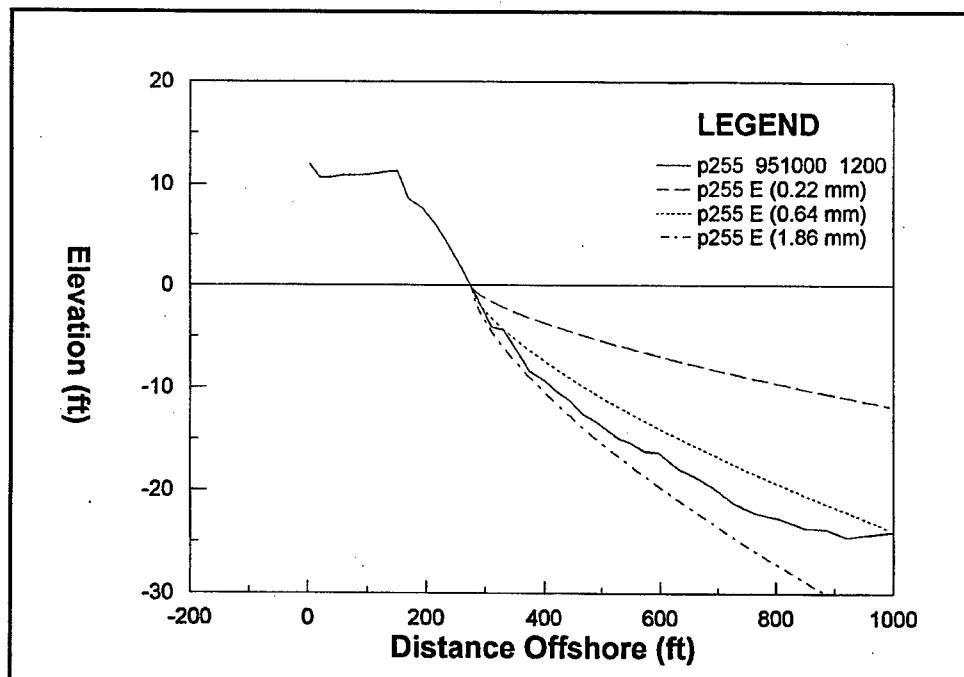


Figure B17. Beach profile equilibrium comparisons (sta 255)

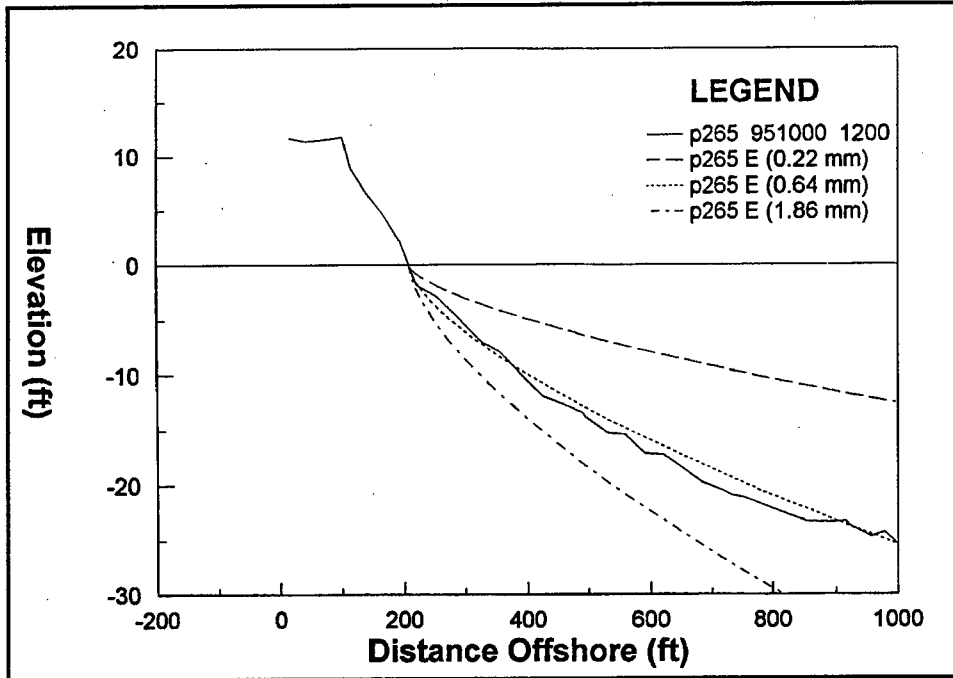


Figure B18. Beach profile equilibrium comparisons (sta 265)

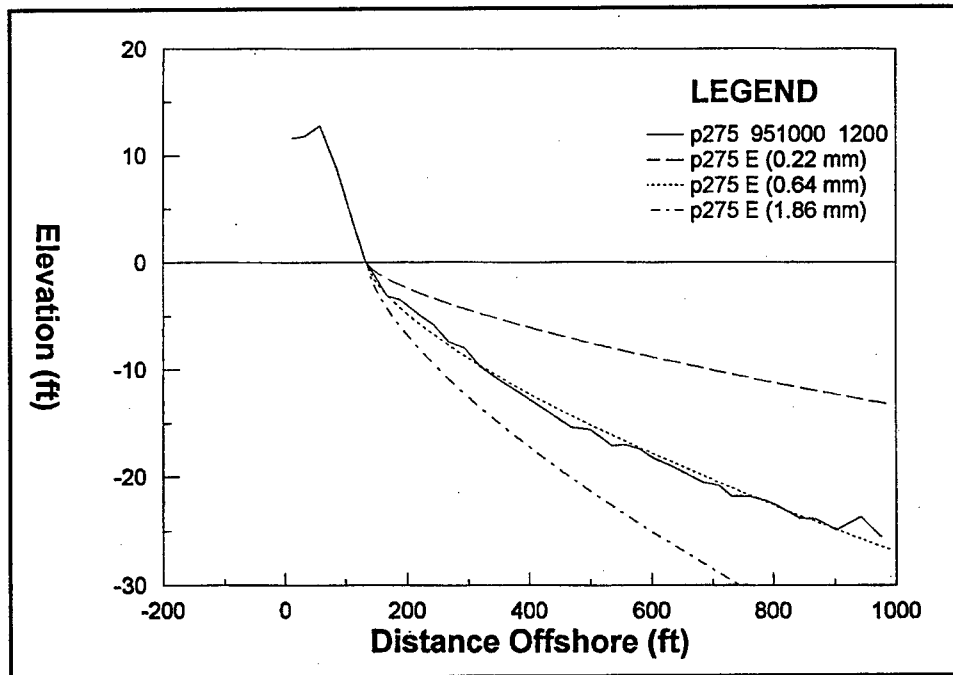


Figure B19. Beach profile equilibrium comparisons (sta 275)

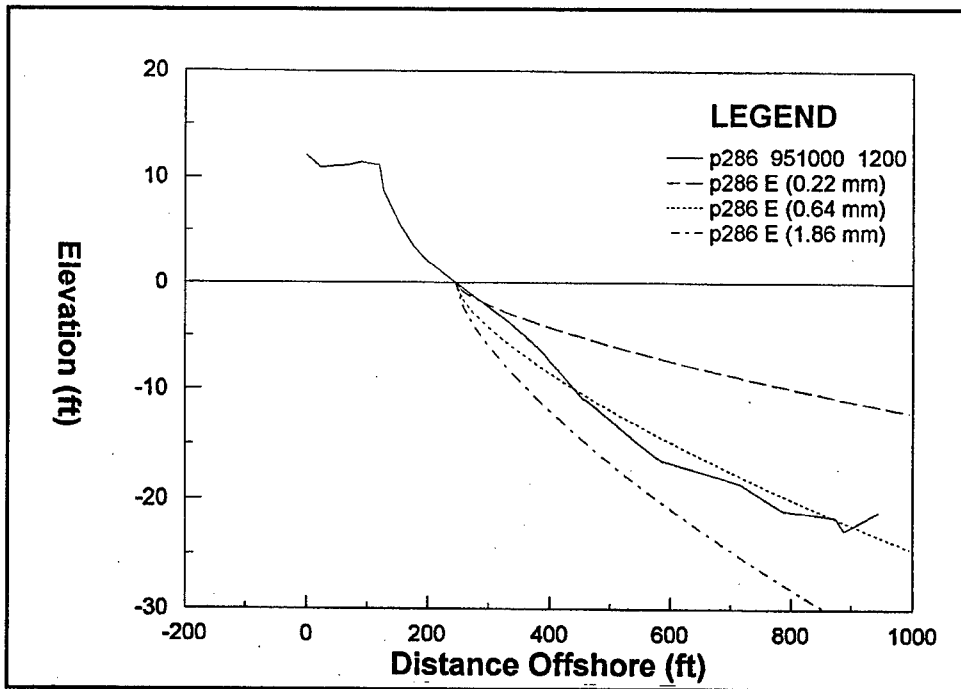


Figure B20. Beach profile equilibrium comparisons (sta 286)

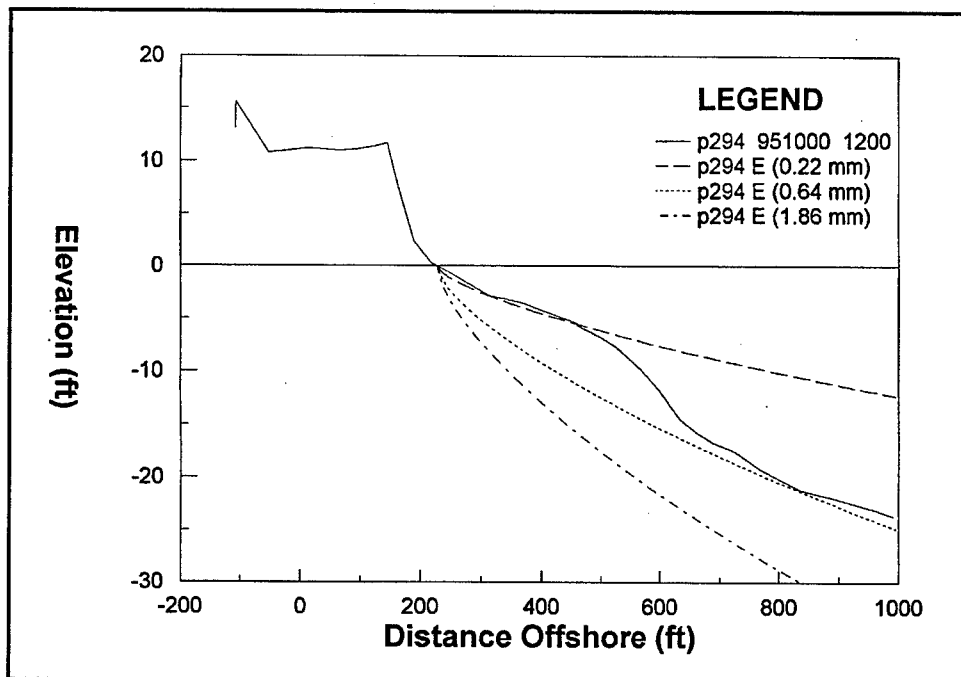


Figure B21. Beach profile equilibrium comparisons (sta 294)

# REPORT DOCUMENTATION PAGE

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