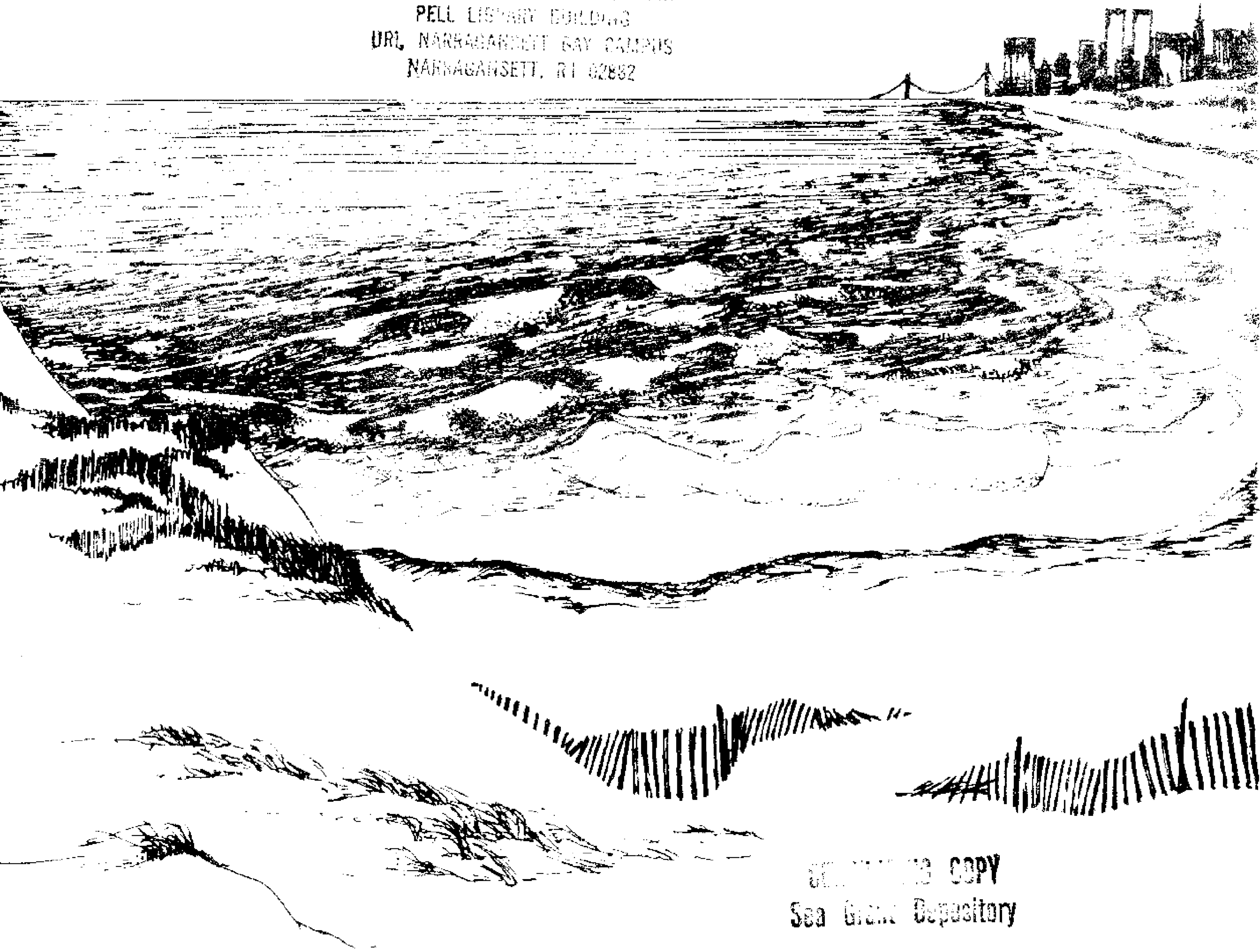
# Beach Forms and Coastal Processes

*Warren E. Yasso and Elliott M. Hartman, Jr.*







MESA NEW YORK BIGHT ATLAS MONOGRAPH **11**

The offshore water in the bend of the Atlantic coastline from Long Island on one side to New Jersey on the other is known as New York Bight. This 15,000 square miles of the Atlantic coastal ocean reaches seaward to the edge of the continental shelf, 80 to 120 miles offshore. It's the front doorstep of New York City, one of the world's most intensively used coastal areas — for recreation, shipping, fishing and shellfishing, and for dumping sewage sludge, construction rubble, and industrial wastes. Its potential is being closely eyed for resources like sand and gravel — and oil and gas.

This is one of a series of technical monographs on the Bight, summarizing what is known and identifying what is unknown. Those making critical management decisions affecting the Bight region are acutely aware that they need more data than are now available on the complex interplay among processes in the Bight, and about the human impact on those processes. The monographs provide a jumping-off place for further research.

The series is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA) and the New York Sea Grant Institute. NOAA's Marine EcoSystems Analysis (MESA) program is responsible for identifying and measuring the impact of man on the marine environment and its resources. The Sea Grant Institute (of State University of New York and Cornell University, and an affiliate of NOAA's Sea Grant program) conducts a variety of research and educational activities on the sea and Great Lakes. Together, Sea Grant and MESA are preparing an atlas of New York Bight that will supply urgently needed environmental information to policy-makers, industries, educational institutions, and to interested people. The monographs, listed inside the back cover, are being integrated into this *Environmental Atlas of New York Bight.*

**ATLAS MONOGRAPH 11 presents findings on natural and man-made beaches, dunes, shoreline structures, beach growth and erosion, and storm effects. Yasso and Hartman emphasize a fact coastal planners know well: that putting up more structures along the shore will compound the cost of storm repair, and that some expensive shore protection methods have proved futile.**


## Credits

**Cynthia Williams** editor
**Mimi Kinlon** cover and text design
**Elaine Faust, Paula Krygowski, and Dan Cole** drafting
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MESA New York Bight Project



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*and*
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New York Sea Grant Institute
Albany, New York
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Elliott M. Hartman, MA, is an associate professor in the Science Department at Westchester Community College. His publications concern beach research and innovations in science teaching at community colleges.

Both authors recently completed revision of all geology and oceanography articles for the fourth edition of the Columbia Encyclopedia.

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# Acknowledgments

We appreciate the fine efforts of many private, state, and federal agencies whose personnel kindly supplied the photographs and basic maps that add greatly to visual aspects of this presentation. Especially, we thank Jane Cotton and Marie Spivey of the US Army Corps of Engineers Waterways Experiment Station, Gilbert Nersesian of the US Army Corps of Engineers, New York District, and S. Bucolo of the US Army Corps of Engineers, Philadelphia District, for providing photographs and model study and beach survey data. We are also indebted to Lt. T. Lynch and Chiefs Abbott and Worth of the Third Coast Guard District for photographs and maps of the Montauk Point area, to R. Ott, superintendent, and Mrs. E. Kohler of the Long Island State Park Commission for phototgraphs of Jones Beach, and to Mrs. Cynthia Pepenella for photographs.

Mrs. Marcela Lorenz, who typed the manuscript from our late-night, left-handed scribblings, deserves a special vote of appreciation.

Most of all, Professor Arthur N. Strahler is remembered for his compassionate nurturing of the interests and abilities of the senior author during his early struggles with shoreline research at Sandy Hook.

Our wives and families also deserve kind mention for the endless weeks of tip-toeing required during the writing of this report.

Manuscript submitted September 1974.

# Abstract

Headlands, estuaries, a barrier spit, and barrier bars and islands separated from the mainland by shallow lagoons are the major landforms of the New York Bight coast. Bight beaches are subject to both annual and long-term changes in shape and position typical of ocean-facing shorelines.

Wave refraction causes littoral drift of beach sand in a predominantly westward direction along the south shore of Long Island. At Fire Island Inlet the westward drift rate is 366,440 $m^3$/yr (480,000 $yd^3$/yr). Northward littoral drift predominates along the New Jersey coast north of Dover Township. At Sandy Hook the northward drift rate reaches a maximum of 376,300 $m^3$/yr (493,000 $yd^3$/yr). South of Dover Township the drift is predominantly southward, reaching a maximum of 152,700 $m^3$/yr (200,000 $yd^3$/yr) at Cape May Inlet.

Jetties and groins temporarily block littoral drift; they do not stop beach erosion entirely. Jetties retard inlet migration, and groins slow erosion of updrift beaches; but in so doing, both accelerate downdrift beach erosion. Sand dredged from filled inlets is used for artificial beach nourishment, which temporarily stabilizes shorelines without adversely affecting downdrift beaches.

Coastal storms and man's encroachment onto beaches amplify the normal erosion of waves, wind, and tide. A 1960 hurricane and a major 1962 coastal storm caused extensive damage to bight beaches and shoreline structures. Many people fail to learn from those storms and from natural erosion that building on beaches and dunes should be avoided.

# Introduction

Geomorphology is the branch of geology and physical geography dealing with surficial changes in landforms. In recent years geomorphic investigations have become more quantitative than in the past as scientists sought to apply mathematical, statistical, and physical models to comprehending landform change. Through quantitative techniques we now have a good understanding of the relationship between streams and landscape changes.

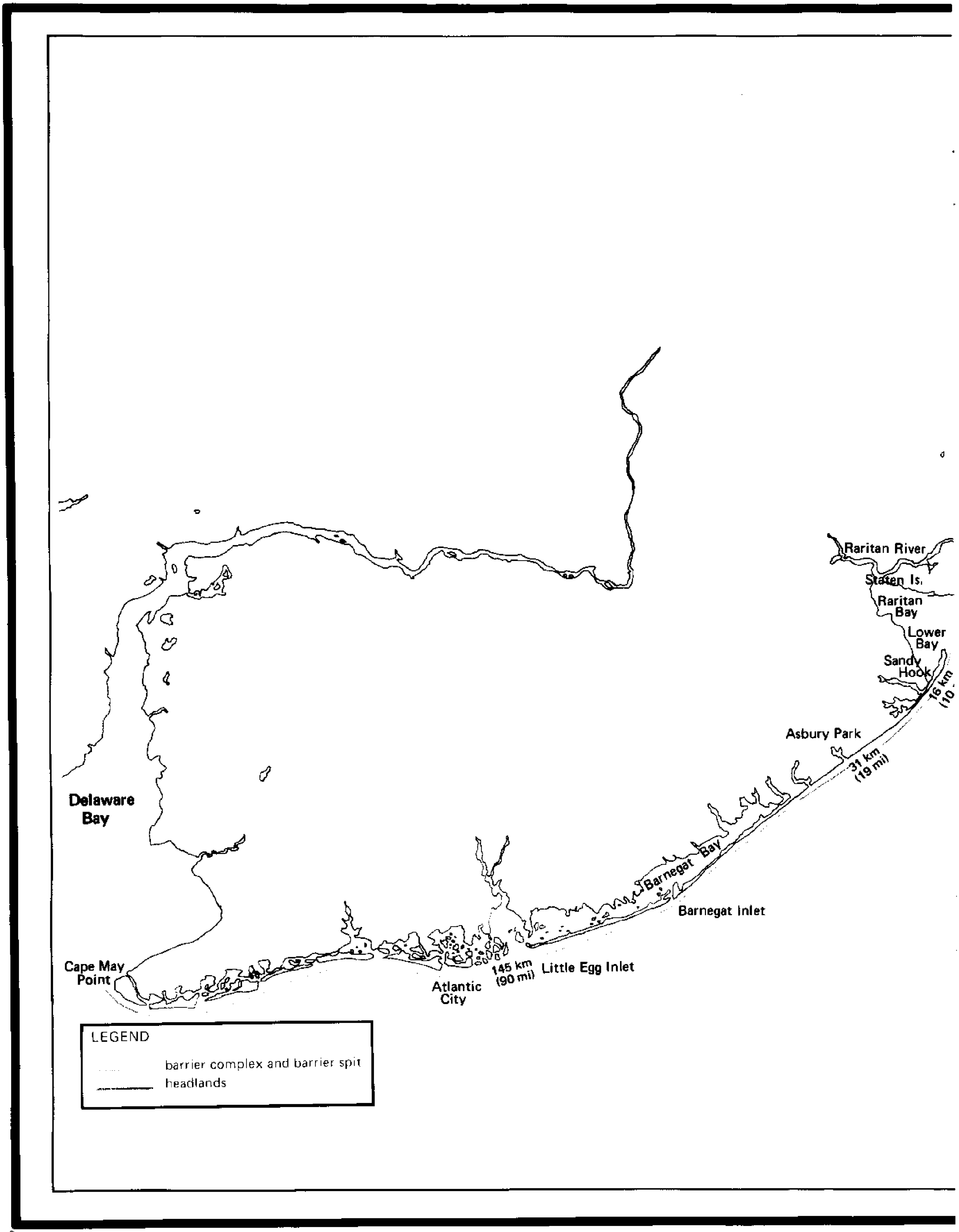
Knowledge of wave and tide relationships to beach and coastal change is not yet in such a happy state of accomplishment. Perhaps this is because the beach is the most complex physical environment on earth: it represents the remarkable interface between lithosphere, hydrosphere, and atmosphere. We still stand in helplessness when a coastal storm brings a surge of flood water and high waves deep into low-lying coastal areas. We still stand in resignation when coastal engineers use the power of bulldozers, pile drivers, and cranes to build various kinds of walls to help protect beaches. We know that interfering with one element of a system will inevitably affect other parts of the system. In most cases we know little about the short-term effects of coastal engineering structures and practically nothing about the long-term effects.

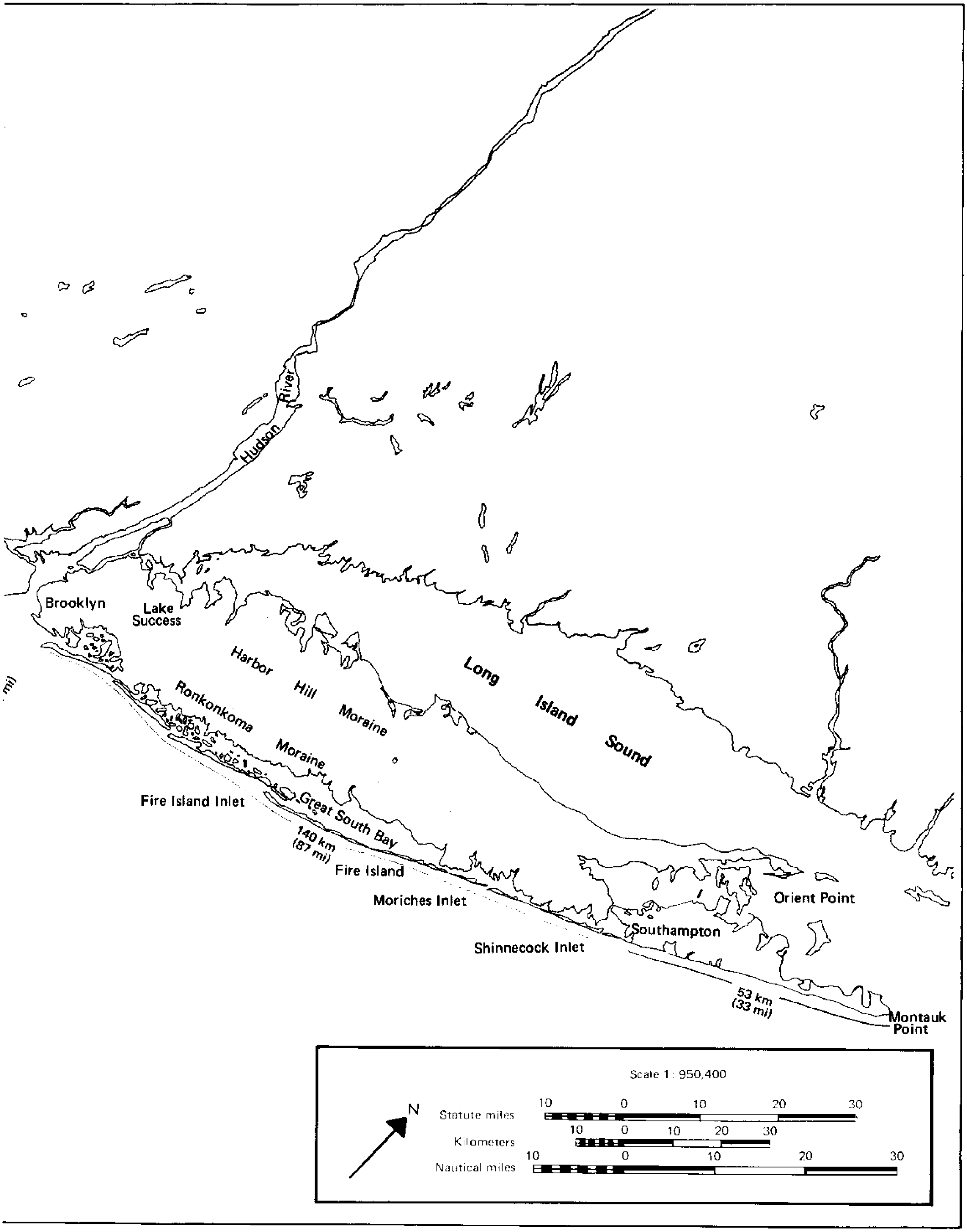
Perhaps some day coastal storms and hurricanes will be dissipated with a small quantity of silver iodide or other cloud seeding chemical. Perhaps some day a small volume of biodegradable liquid will be used to form a monolayer that prevents the development of storm waves. Perhaps some day an invisible, porous, resilient, self-healing glue will stabilize beach sand against movement by wind and waves. Such a day is not yet upon us. Meanwhile, we must seek to improve the conceptual and physical models which so far allow us only a rudimentary understanding of beach processes.

In this report we seek to describe and illustrate the types of landforms found along the New York Bight shoreline and to give examples of natural processes and man-made structures that cause change in these landforms. We must assume that the reader will not expect a complete description of water wave mechanics, sedimentology, and geomorphology. For these basics we refer the reader to standard reference works such as Johnson (1919), King (1959), Shepard (1963), and Wiegel (1964). We have attempted to give general descriptions of beach processes so the reader will have a fundamental understanding of terminology. There are many landforms and beach processes for which New York Bight is the best exemplar. However, many other coastal areas have been studied longer or are more dramatic exemplars of coastal processes and their consequences. These are described in the reference literature.

Map 1 is a general locator map for places mentioned in the text.

## Map 1. General locator




Hudson River
Brooklyn
Lake Success
Harbor Hill Moraine
Ronkonkoma Moraine
Long Island Sound
Fire Island Inlet
Great South Bay
140 km (87 mi)
Fire Island
Moriches Inlet
Shinnecock Inlet
Southampton
Orient Point
53 km (33 mi)
Montauk Point
Scale 1: 950,400
N
Statute miles
10 0 10 20 30
Kilometers
10 0 10 20 30
Nautical miles
10 0 10 20 30

# Descriptive Geomorphology

The shoreline of New York Bight extends in a discontinuous, broad, inverted V-shape, opening to the southeast. It covers approximately 390 km (245 mi) from the eastern tip of Long Island to the southern tip of New Jersey. The south shore of Long Island stretches for 193 km (120 mi) from Montauk Point on the east to Coney Island on the west. This part of the bight shoreline trends roughly northeast-southwest. Lower New York Bay separates the Long Island portion of the bight coastline from the New Jersey shore, which extends for 200 km (125 mi) southwest from Sandy Hook to Cape May at the mouth of Delaware Bay.

A *shoreline* is where land and sea meet. It is an ephemeral feature on the earth's surface because it migrates back and forth in response to the action of tides, waves, currents, changes in supply of sediment, and changes in sea level. The *shore* is a broad zone extending from the low-tide shoreline landward to the coastline. It also changes significantly with time in response to the natural forces of the coastal environment. Behind the shore is the *coast* which consists of bluffs or the landward edge of lagoons. The coastal zone gradually merges with the landforms of the interior. To the geologist, a *beach* is an accumulation of sediment along the shore kept in almost continual motion by wave, current, and wind action. Thus, the beach extends seaward from stabilized shore dunes to surf base, at depths of 9 m (30 ft) or so.

Beaches are fragile strips of sand whose existence depends upon a delicate balance of forces operating along the shore. This balance is a dynamic equilibrium affected by a changing shoreline and by man's development of beach areas. Historical records show that beaches in the bight have migrated back and forth over a wide band that often includes presently developed shore property. Many resort facilities and private residences are built practically to the high-tide line and thus are subject to long-term shoreline changes. In many cases, the development of recreational facilities accelerates beach erosion. Sand dunes, perhaps the most effective natural shore protective feature, have sometimes been bulldozed to provide a better view of the sea and access to the beach. Dune grass stabilizes the sand in dunes to prevent erosion by wind or heavy rains. But dune grass too often has been inadvertently destroyed by people and machines.

The overall form of a beach provides clues about the source of sand, rate and direction of sand movement, and whether a beach is eroding or prograding. In nature, the sand making up a beach has its origin in the weathering and erosion of continental rock masses. Where rivers provide a copious supply of sand to the shore, beaches will be broad and will tend to widen *(prograde)*. Where river-borne sediment is scarce, beaches will tend to narrow *(retrograde)*. Eventually the coast itself will be subjected to erosion by ocean waves. A general rise in sea level during the past 20,000 years has drowned the mouths of the major rivers (Hudson and Raritan) that discharge into the bight area. What little sediment these sluggish rivers now carry is predominantly silt; most of this sediment is deposited at the heads of estuaries. The rivers currently supply scant nourishment to bight beaches, indicating that the only natural source of new beach sediment is wave erosion of the headland coasts. Since the retreat of the Wisconsin glacial ice about 20,000 years ago, the Montauk headlands, which show severe erosion, have probably supplied most of the sand making up the barrier complex along the south shore of Long Island. At present there are no data to indicate the amount of beach material supplied by the erosion of these bluffed headlands, but it is reasonable to hypothesize that they do not supply an adequate quantity for stability of the barrier islands. This implies that the barrier islands partly cannibalize themselves through the littoral drift of sand.

The subdued highlands near Long Branch and Asbury Park are too low and isolated from wave action to supply much new sand to New Jersey beaches. The sand in littoral transport along the New Jersey shore is mainly a redistribution of sand from the beaches and the shallow continental shelf. Undoubtedly, as time passes, sand is progressively lost offshore by wave and wind action.

The history of the bight shores has been one of rapid erosion of the bluffed headlands accompanied by the littoral drift of sand, which forms barrier bars, spits, and islands that grow in the direction of littoral drift. Once formed, these barriers are eroded by wave action on their seaward shores. Erosion causes these barriers to become longer and narrower and to migrate toward the mainland coast.

## Coastal Plains and Glacial Sediment

Beaches of Long Island and New Jersey are similar in many respects. This is due in part to similar underlying geologic structure. The New York Bight coast is part of the coastal plain province of the eastern United States and is believed to have formed as a result of a general subsidence of this region during the Cretaceous period, beginning about 135 million years ago. Sediments derived from the eroding Appalachian Mountains accumulated offshore to form continental shelf deposits underlying the present bight shoreline. During the Tertiary period, beginning about 70 million years ago, the Appalachian region was gently upwarped; this raised and tilted the coastal plain sediments toward the southeast. Until the beginning of the Pleistocene epoch, about two million years ago, erosion of the rejuvenated Appalachian Mountains provided sediment to the growing coastal plain.

During the Pleistocene, glacial ice sheets formed in Canada, northern Europe, and Siberia. At least four progressions of these continental ice sheets are recorded in their terminal moraine deposits. The last major ice advance, called the Wisconsin glacial age, carried soil and rock material south through New England and deposited it as the Ronkonkoma moraine. This hummocky ridge, extending from Lake Success to Montauk Point, forms the backbone of Long Island. The ice retreated and then perhaps readvanced to form the Harbor Hill moraine along the north shore of Long Island to Orient Point. Both of these moraines merge to the west of Lake Success near the Nassau–Queens County border and continue southwestward through Brooklyn, across The Narrows and through Staten Island. Meltwater streams breached the older Ronkonkoma moraine in many places, and their outwash deposits created the gently southward inclined sediment layers of southern Long Island. As the ice finally began to melt, 20,000 years ago, the meltwater returned to the sea, raising sea level, flooding Long Island Sound, and subjecting the south shore to wave action. When sea level began to rise, the eastern terminus of Long Island was probably several miles to the east and has eroded to its present position at Montauk as a result of wave action.

Although the New Jersey coast was not glaciated, it was affected by sea-level changes caused by growth and melting of the ice sheets. As sea level lowered, the southeastward-flowing streams of New Jersey cut into the easily eroded coastal plain sediments, creating a series of deep valleys. When sea level rose, the divides between valleys formed seaward-facing headlands that were subsequently truncated by wave erosion, providing the raw material for New Jersey beaches.

## Types of Shore Forms

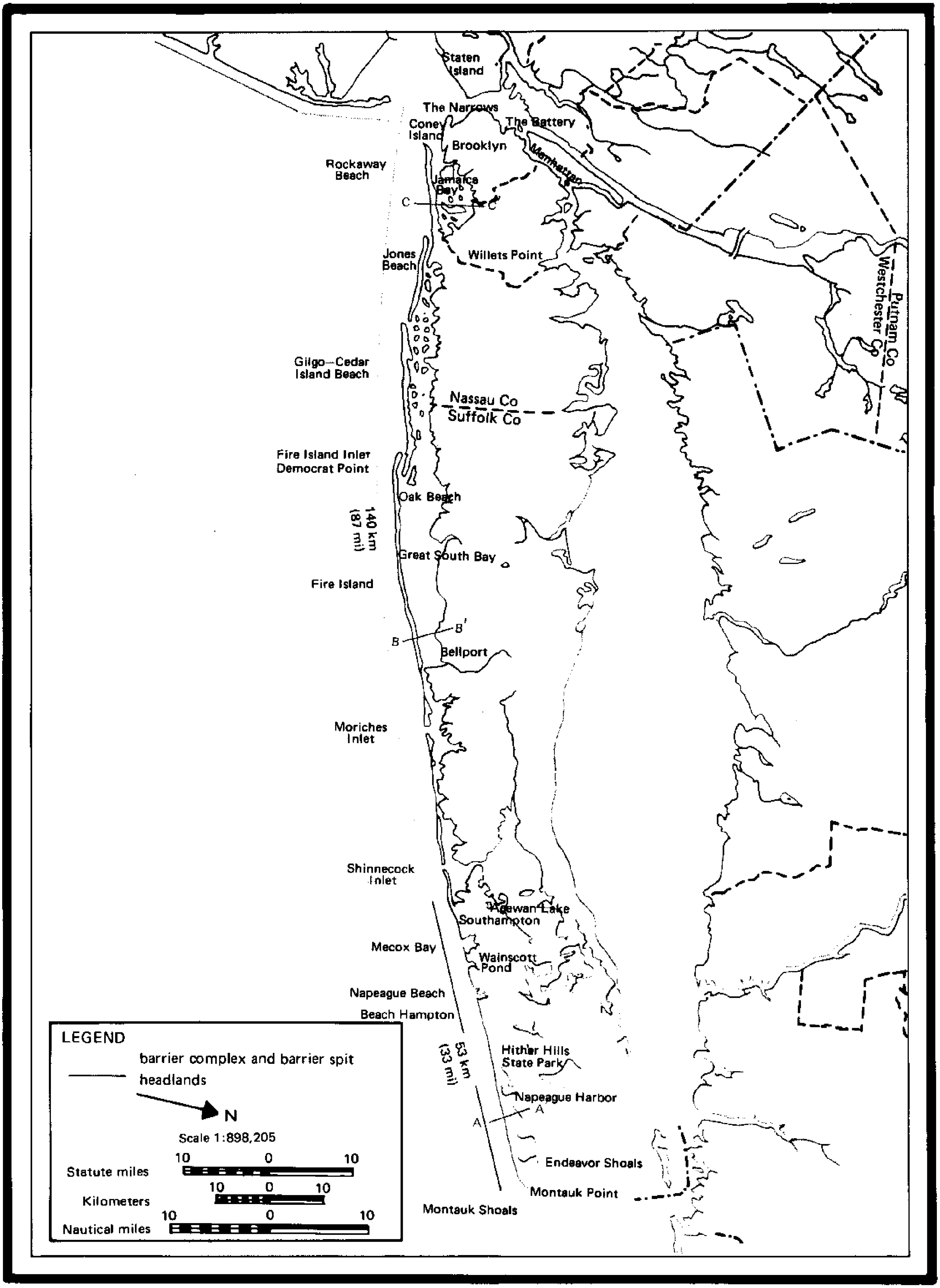
The similarity in underlying geologic structure for both shores of the bight leads one to suspect that similar types of shorelines would develop and, in general, this is true. There are only four major coastal forms: headlands, barrier complex, barrier spit, and estuaries. *Headlands*, such as those at Montauk Point, are characterized by a narrow beach at the base of a bluff or cliff; they supply sediment to the beach. Only 91 km (57 mi) of the two coasts are of this type. A *barrier complex* is formed by a sequence of long, narrow barrier islands or barrier bars and is separated from the mainland coast by a lagoon or salt marsh. The Rockaway Beach–Fire Island section of Long Island is a barrier complex. This is the most common coastal type not only of the bight but also of the entire Atlantic and Gulf coasts. About 303 km (188 mi) of the bight coast are of the barrier complex type. A *barrier spit* like Sandy Hook is formed where littoral transport has caused the projection of a sediment body into a deep bay. *Estuaries* are represented by the drowned mouths of the Hudson and Raritan rivers as well as smaller rivers emptying directly into the bight. Estuarine environments include lagoons, salt marshes and their associated inlets through the barrier islands.

## Long Island Shore Forms

Although many similarities exist between the New Jersey and Long Island shores, it is convenient and useful to consider them in more detail as separate entities. Taney (1961) gives a broad introduction to geomorphology of the south shore of Long Island as does Wicker (1951) for the New Jersey coast.

The south shore of Long Island can be divided at Southampton into an eastern headlands coast and a western barrier complex (Map 2). The headlands portion, extending 53 km (33 mi) westward from Montauk Point to Southampton, has suffered severe erosion. These headlands are characterized by truncated hills of variable height and steepness fronted by a narrow beach composed dominantly of gravels and coarse sand. The headlands of Long Island's south shore were largely formed by erosion of the Ronkonkoma moraine and are thought to have extended

## **Map 2.** Long Island



several miles to the east, perhaps as far as Montauk Shoals or Endeavor Shoals, immediately following the retreat of the Wisconsin ice sheet.

Steep bluffed headlands extend for 16 km (10 mi) from Montauk Point to the vicinity of Hither Hills State Park. A profile line across the headland at Montauk Beach is shown in Figure 1. The moraine is 3 km (2 mi) wide at this point and rises to about 56 m (185 ft) above mean sea level. A steep wave-cut cliff, 12 m (40 ft) high, borders the coast. A narrow beach and shallow submarine terrace lie at the base of the cliff. A normal erosional underwater profile begins about 150 m (500 ft) seaward of the shoreline.

The 6 km (4 mi) along Napeague Beach to Beach Hampton represent a break in the Ronkonkoma moraine. This region is marked by a low, sandy shore with continuous dunes behind the beach and is flanked on the east and west by low-lying marshes. During severe coastal storms, ocean waters frequently surge across this area into Napeague Harbor.

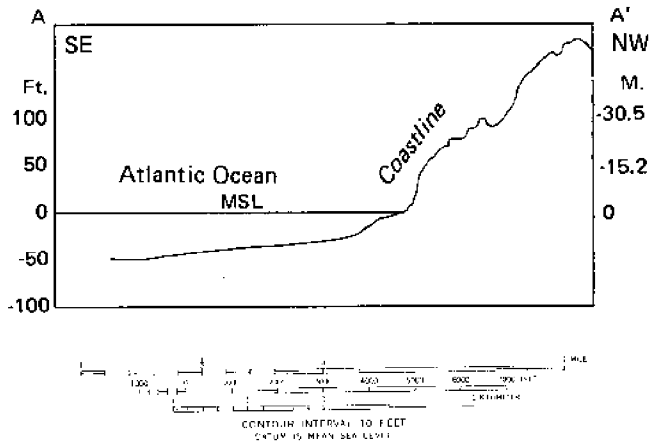



**Figure 1.** Topographic profile – Montauk Beach, NY (headland).

The western portion of the headlands extends 30 km (19 mi) to Southampton. It consists of sandy beaches fronting continous ridges of sand dunes with elevations over 6 m (20 ft). Behind the dunes is a pitted outwash plain forming a subdued, seaward-

**Figure 2.** Jones Beach State Park looking west toward Jones Inlet, Point Lookout, and Long Beach Island, 5 August 1973. (Courtesy of Long Island State Park Commission)

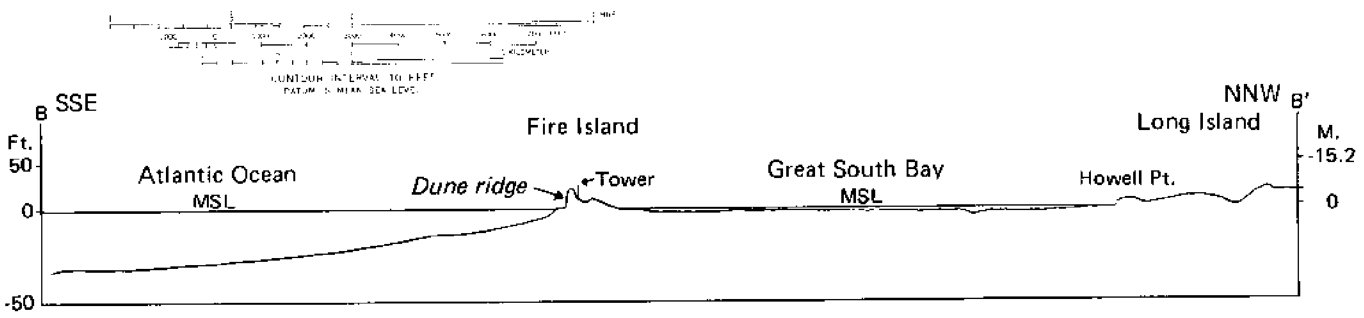



**Figure 3.** Topographic profile – Fire Island, NY (barrier complex).

sloping headland. Many meltwater streams formed deep channels in the coastal plain. Littoral drift dammed them to form freshwater lakes (e.g., Agawam Lake, Mecox Bay, Wainscott Pond).

Stretching from Southampton for 140 km (87 mi) to the end of Coney Island is the barrier complex portion of the south shore. It consists of four barrier islands: Fire Island, Jones Beach Island (Figure 2), Long Beach Island, and Coney Island (which has been connected to the mainland by artificial landfill). Also included are two barrier bars attached to the mainland at their eastern ends: Southampton Beach and Rockaway Beach. These long, narrow strips of sand vary in width from less than 0.16 km (0.1 mi) on the east to over 1.6 km (1 mi) in localized areas and are continually being remolded by waves, wind, and currents. It seems probable that they were created by the westward littoral drift of sediment from Montauk since retreat of the last glacier. Behind the shores of these barriers, a series of irregular sand dunes rise to 9 m (30 ft) in height. They display steep wind- and wave-eroded slopes on the ocean side and gentle inland slopes often stabilized by beach grass. The barriers are separated from the mainland by interconnected tidal lagoons: Shinnecock Bay, Moriches Bay, and Great South Bay. Jamaica Bay, the westernmost of these lagoons, is isolated from the others. West of Fire Island Inlet, the tidal lagoons are nearly filled with marshy islands and tidal deltas.

Figure 3 shows a profile of Fire Island at the lookout tower opposite Bellport, Long Island. Here Fire Island is 3 km (2 mi) from the mainland and only 381 m (1,250 ft) wide. It is characterized by a prominent and steep dune ridge 7 to 10 m (20 to 30 ft) high facing the ocean. Other subdued beach ridges are found behind the ocean-facing dune ridge. Great South Bay is a shallow lagoon lying between Fire Island and the mainland. Along this profile line the lagoon averages 1 m (3 ft) in depth except in dredged boat channels where the water is deeper. Few marshy islands are found in the lagoon. Offshore beyond the shallow submarine terrace, the underwater profile is an extension of the gentle seaward slope of the outwash sediments comprising the mainland.

A profile across the Rockaway Beach barrier bar is shown in Figure 4. This barrier bar is 550 m (1,800 ft) wide. Topographic relief is low, with no profile elevations exceeding 3 m (10 ft). Dune ridges are not conspicuous. Jamaica Bay, the tidal lagoon behind Rockaway Beach, is over 18 km (11 mi) wide at this point. Except for dredged channels, the bay is shallow and studded with marshy islands. The terminal moraine is 14 km (9 mi) inland from the lagoon shore.

At the present time six tidal inlets breach the barriers along the south shore of Long Island. These have formed from storm waves cutting through low points on the barriers. Natural inlets are inherently unstable and, unless maintained by dredging and jetties, tend to close or migrate in the littoral drift direction.

Coney Island is a former barrier island now connected by fill to the Brooklyn mainland. North

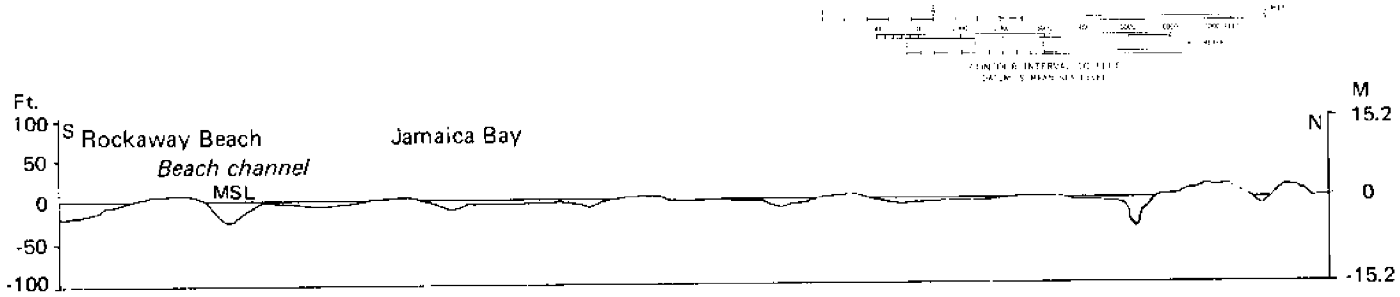



**Figure 4.** Topographic profile – Rockaway Beach, NY (barrier complex).

along the Brooklyn shoreline are morainal hills at The Narrows. Formerly marshy lowlands lie along the shoreline of Upper New York Bay. All of this shoreline has been modified by the construction of bulkheads and dock facilities. On the Staten Island side of The Narrows and southward are narrow sandy beaches protected by long groins. These beaches were formed by wave erosion of outwash from the moraine extending southwest across Staten Island.

## New Jersey Shore Forms

The coast of New Jersey trends approximately south-southwest from Highlands to Barnegat Inlet, where it turns to follow a gently curving line to the southwest toward Cape May (Map 3). A barrier complex, separated from the mainland by tidal marshes and lagoons, comprises 146 km (91 mi) of the coastline. Subdued headlands with relatively narrow beaches totaling 39 km (24 mi) are found between Monmouth Beach and Bay Head and in the vicinity of Cape May south of Cape May Inlet. A 16 km (10 mi) long barrier spit (Sandy Hook) forms the northernmost portion of the Atlantic coast of New Jersey.

From Great Kills Harbor around Raritan Bay to Sandy Hook, the shoreline tends to be low and marshy with a few well protected sand beaches. Many of these beaches were formed by pumping sand from offshore deposits. Sandy Hook is a low, complex recurved spit projecting north for 6 km (4 mi) from Monmouth Beach to Highlands and thence north and west into Raritan Bay an additional 10 km (6 mi). It cuts off the direct drainage of the Navesink and Shrewsbury rivers into the Atlantic Ocean, diverting their waters north into Raritan Bay. Sandy Hook was originally built by the northerly littoral drift of beach sand and over the years has been alternately attached and separated from the mainland at Highlands. Since 1850 it has been connected to the barrier bar ending at Monmouth Beach.

A subdued headlands section extends 31 km (19 mi) southward from Monmouth Beach through the cities of Long Branch, Asbury Park, and Point Pleasant to Bay Head. The low headlands consist of a seaward-sloping terrace with elevations of 5 to 8 m (15 to 25 ft), terminating along a low cliff line which borders a narrow beach. The beach widens progressively to 60 m (200 ft) at the southern terminus of the headlands section, and the headland elevations diminish progressively to the south along this stretch.

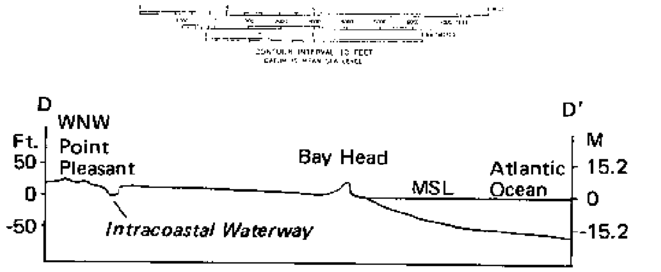



**Figure 5.** Topographic profile — Point Pleasant, NJ (headland).

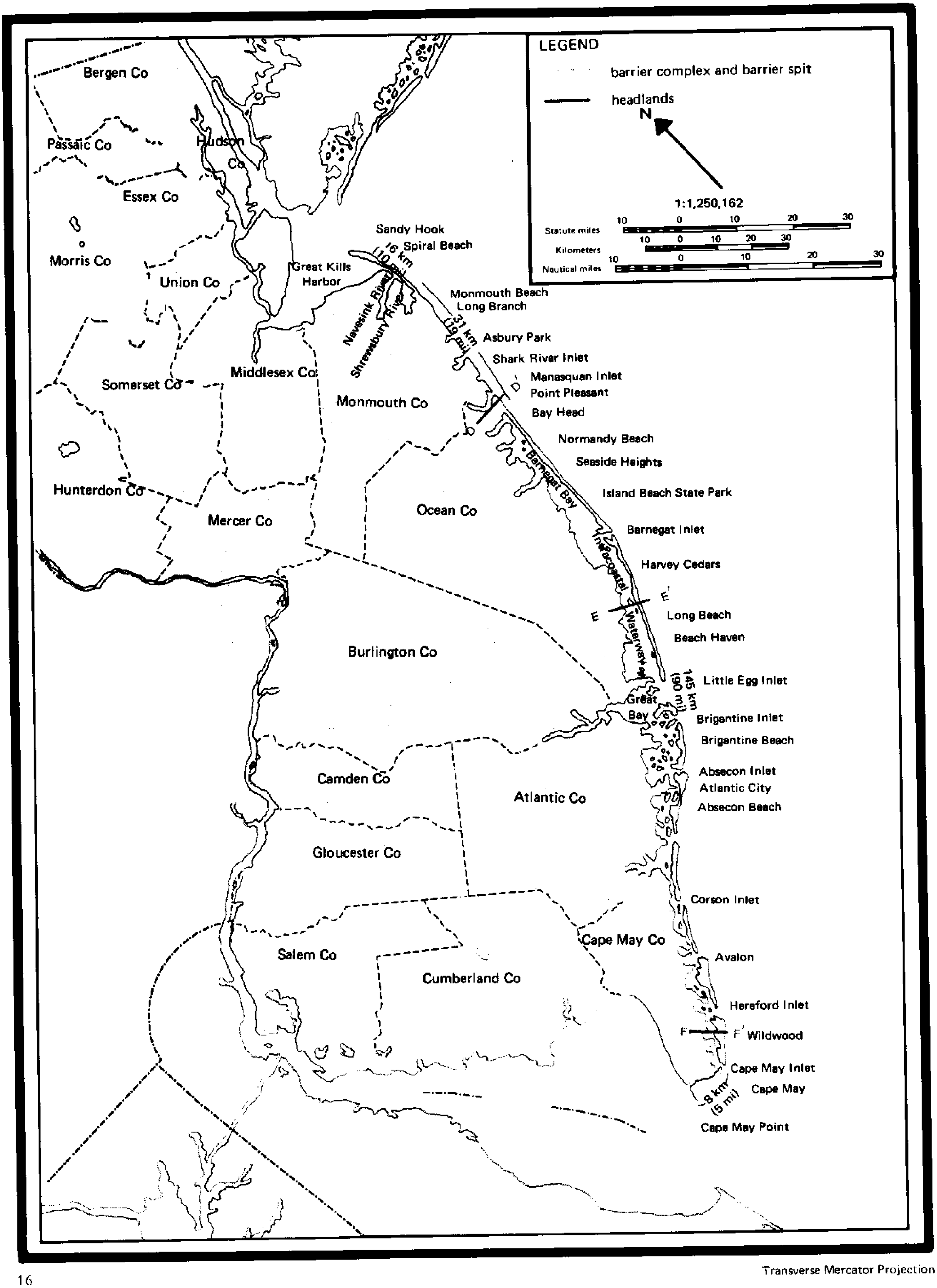
A profile at Point Pleasant is shown in Figure 5. A line of dunes 6 m (20 ft) high lies landward of the beach. Mainland elevations rise to over 3 m (10 ft) on the bank of the Intracoastal Waterway 4.8 km (3.7 mi) inland. Beyond the shallow offshore terrace is a normal erosional underwater profile. This portion of the New Jersey shore has suffered rapid erosion. The headlands are composed of unconsolidated Tertiary and Quaternary sediments which yield readily to the influences of waves and storms.

Aside from the Hudson and Delaware estuaries, only the sluggish Shark and Manasquan rivers empty directly into the Atlantic Ocean along the New Jersey coast. They drain a total area of only 315 $km^2$ (121 $mi^2$) and therefore cannot be considered significant contributers of sand to local beaches. As in the case of Long Island, small lakes formed when longshore drift dammed many streams that flowed seaward along the coastal plain.

Extending south from the mainland at Bay Head to Cape May Inlet is the extensive barrier complex of the New Jersey shore. The barrier islands lie 3 to 8 km (2 to 5 mi) from the mainland and vary in width from 0.2 km (500 ft) to 1.6 km (1 mi). The tidal lagoons behind the barrier islands are shallow. The northernmost lagoons — Barnegat Bay, Little Egg Harbor, and Great Bay — are relatively free of islands. However, southward from Brigantine Inlet the lagoons are studded with low, marshy islands. Perhaps these islands developed during Pleistocene times when high volume river flow deposited sediment in the southerly lagoons.

Figure 6 shows a profile across the New Jersey barrier complex at Harvey Cedars. Here Long Beach barrier island is about 0.35 km (0.22 mi) wide and is separated from the mainland by a shallow lagoon 2.4 km (1.5 mi) wide. The lagoon averages about 0.6 m (2 ft) deep along the profile line, except where it has been dredged to maintain the Intracoastal Waterway. On the ocean side of the barrier island is a prominent but discontinuous dune ridge about 6 m (20 ft) high. Both shores of the lagoon are marshy. On the landward shore of the lagoon the marshes extend

## Map 3. New Jersey




Transverse Mercator Projection

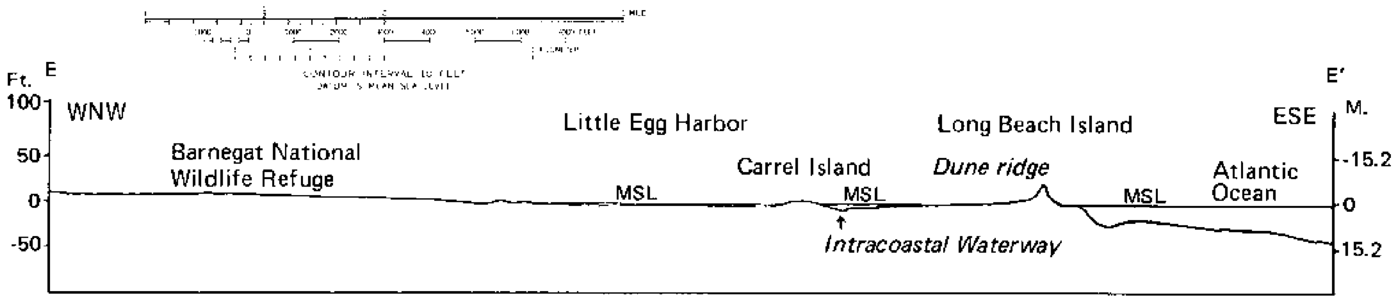



**Figure 6.** Topographic profile – Harvey Cedars, NJ (barrier complex).

about 6.3 km (3.9 mi) inland (beyond the limits of the profile), where they merge with the gently sloping headlands whose maximum height is about 30 m (100 ft) in this region.

In the Wildwood profile (Figure 7), about 6.2 km (3.8 mi) northeast of Cape May Inlet, the barrier island widens to about 2 km (1.3 mi) across. No prominent dune ridges exist along the profile line but there are low dunes ranging to 6 m (20 ft) high a short distance to the south. The lagoon behind the barrier island is about 2 km (1.2 mi) wide, very shallow, and studded with marshy islands separated by tidal channels. The marshes merge with the mainland in the vicinity of the Garden State Parkway.

Sand dunes, some ranging to 9 m (30 ft) in height, are found along the ocean shoreline of the barrier islands. Figure 8 is an aerial view of Island Beach State Park, looking south toward Barnegat Inlet. Width of the beach, low dunes, and increasingly dense vegetation toward the lagoon shore are typical of the barrier complex along the New Jersey coast. Nine inlets presently connect the Atlantic Ocean with lagoons behind the barrier islands and bars.

The bight shoreline ends on the south at a low headland. This headland section extends 8 km (5 mi) from Cape May to Cape May Point. Figure 9 is an aerial view of Cape May looking west toward Delaware Bay. The low headland begins just inland from the shorefront buildings and can be seen as open land behind (west of) the town.

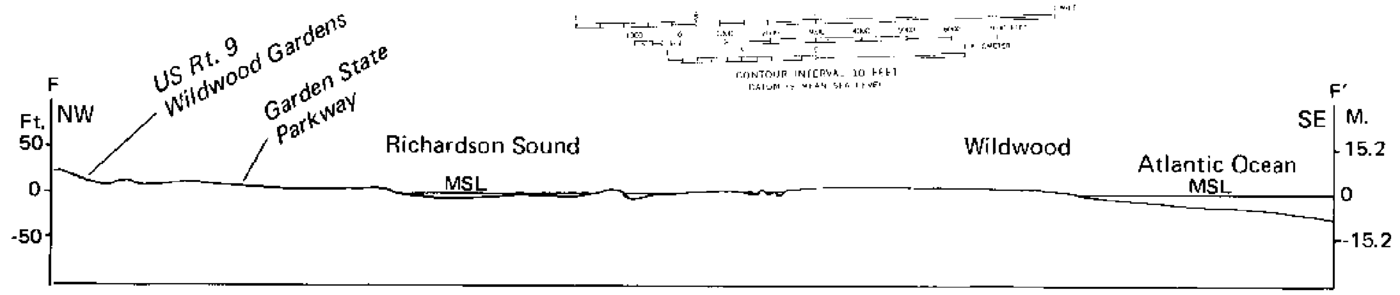



**Figure 7.** Topographic profile – Wildwood, NJ (barrier complex).

## General Trends of Beach Development

Establishing whether a beach is eroding, accreting, or maintaining positional equilibrium is fairly difficult on a short-term time frame; it is extremely difficult on a long-term time frame. This is because accurate surveys began only within the last hundred years and because of man's meddling with problem areas of the shoreline. Structures built to resolve a problem of erosion or accretion in one area set off a chain reaction up and down the coast. For the most part, the effect of a given structure on adjacent beaches isn't known in advance. Model studies help resolve some of the gross design problems, but no model study can consider all of the important variables relating to a coastal problem.

Coastal geologists and engineers have several tools to use in their search for data on behavior of shorelines. Topographic maps and charts are two prime tools. New York is one of the world's greatest natural harbors; the importance of the harbor necessitated thorough surveys at an early date. Maps were made routinely from vertical aerial photographs beginning in World War II. These added to the stock

Figure 8. View south at Island Beach State Park, NJ, with Barnegat Bay to the right. (Courtsey of New Jersey Department of Environmental Resources)

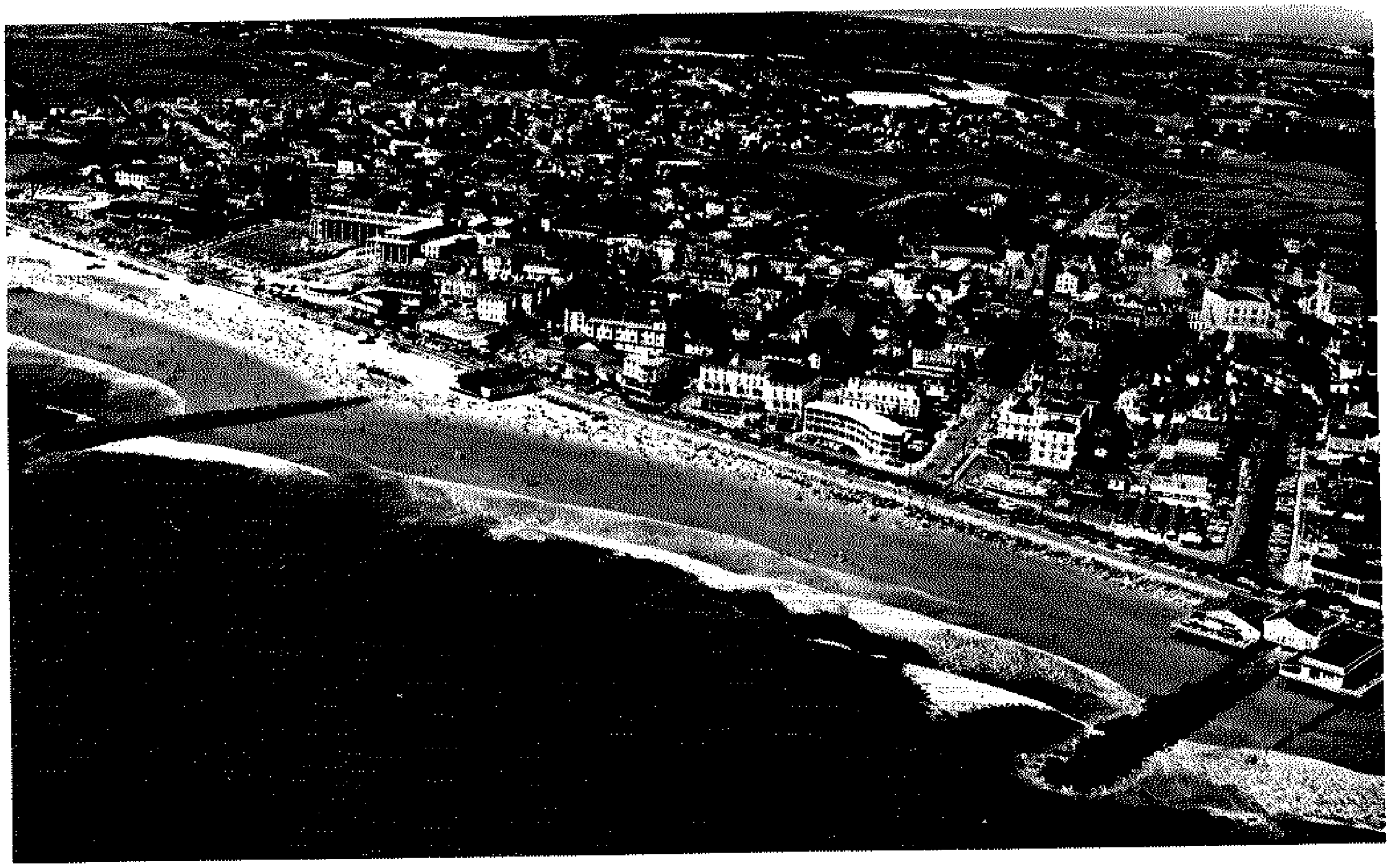


Figure 9. View west at Cape May with Delaware Bay in the background. (Courtesy of US Army Corps of Engineers, Philadelphia District)

of information pertaining to erosional or accretional trends along the New York Bight shoreline.

Sequences of ground photographs are taken over the years at the same location; topographic profiles are made across beaches from surveying points on land. These are two more useful tools for coastal investigators. Vespers and Essick (1964) illustrate the value of sequences of ground photographs in coastal studies.

Where no other information is available, a fifth tool is observation of shoreline shape and position with reference to fixed coastal engineering structures like groins, jetties, and seawalls. For example, the aerial view of Cape May Point (Figure 10) tells a great deal about the nature of this shoreline. The rock seawall in the middle foreground suggests a serious erosion problem. The four unusually long rock groins to the south (left) of the seawall around Cape May Point are another attempt to prevent erosion and build a swimming beach at the same time. Note that the sand beach has built seaward along the nearer (north) side of the groins. This indicates that sand is moving predominantly from north to south along Cape May Point. Because the beaches have not built out to the ends of the groins we can assume there is only a small supply of sand from the north.

## Headland Erosion — An Example from Montauk Point, NY

Montauk Point is exposed to storm waves from a greater range of directions than any other section of the New York Bight coast. This situation arises from the long fetch in all directions clockwise from northeast to southwest. The scenic cliffs surrounding the Montauk Point Lighthouse resulted from a combination of wave attack, rainfall, and sea-level rise. Figure 11 is a 1953 aerial view showing the cliffs of roughly stratified glacial sediment ranging in size from fine clays to large boulders. Wave attack at the base of the cliff removes support for upper portions of the cliff. To regain a stable slope angle, the upper sediment layers slump downward and accumulate at the base of the cliff (Figure 12). Rainwater washing down from the top of the slope aids in causing the downward slump. Storm waves erode these accumulations and continue cutting into the cliff. The toe revetment (in Figure 11, the large rocks at the base of the cliff) helps dissipate wave energy by preventing storm waves from breaking directly against the cliff.

Positions of the top edge of the cliff in 1868, 1944, and 1972 and topographic contours along the top surface of the Montauk Point headland are shown

**Figure 10.** View northwest at Cape May Point. (Courtesy of US Army Corps of Engineers, Philadelphia District)

**Figure 11.** View northwest at Montauk Point with Long Island Sound in the background, 1953. (Courtesy of Third US Coast Guard District, NY)

Figure 12. Edge of glacial moraine cliff at Montauk Point, about 1949. (Courtesy of Third US Coast Guard District, NY)

in Figure 13. Between 1868 and 1972 the top edge of the cliff retreated at an average rate of 21 cm/yr (0.84 ft/yr). At that rate of erosion the lighthouse structures will be jeopardized in less than a century.

## Inlet Migration and Jetty Construction – An Example from Fire Island, NY

Fire Island is a barrier island extending approximately 48 km (30 mi) from Moriches Inlet on the east to Fire Island Inlet on the west. Littoral drift is westward along the south shore of Long Island: the western end of Fire Island shows a long-term progressive migration in that direction. Similar westward extension of other south shore barriers has resulted in westward migration of inlet mouths.

Historical behavior of Fire Island's western terminus (now called Democrat Point) and Fire Island Inlet is shown in Figure 14. In 1825 the western tip of Fire Island was about 130 m (425 ft) west of the lighthouse. By 1834 the tip of the barrier island was about 1,040 m (3,425 ft) west of the lighthouse. The 1834 shoreline mapping by the US Coast and Geodetic Survey is the first reasonably accurate indication of the overall high-water shoreline position for Fire Island. Continued westward migration is shown by the high-water shorelines of 1867, 1909, 1924, and 1939.

The ocean-facing shoreline of Fire Island during these early years shows a positional change typical of all barrier bars, spits, and islands whose development is allowed to proceed naturally. Barrier island lengthening and shift in a landward direction (retrogradation) are seen by comparing the 1867 and 1909 shorelines. A small retrogradation and almost equivalent lengthening occurred in about one-third the time – between 1909 and 1924. Panuzio (1968) estimates the western tip of Fire Island grew westward at an average rate of 65 m/yr (212 ft/yr) between 1825 and 1939.

A stone jetty was built south and west from the 1939 shoreline of Democrat Point. The jetty brought an abrupt halt to the lengthening of Fire Island. Instead, beach sand was trapped by the jetty, causing a seaward movement (progradation) of the high-water shoreline as the new beach filled in. The change in development of the barrier island is well illustrated on the 1962 vertical aerial photograph shown in Figure 15. Thinly-vegetated beach ridges can be seen as light gray bands curving north (toward the top of the photo) at the thickest part of Fire Island. Such curving ridges are evidence of the westward growth of the island. Short, north-south oriented, white bars across the most seaward beach ridges are bare patches of sand.

Completed in 1941, the jetty reached its sand-impounding capacity in 1948; then littoral drift sand again began to spill over into Fire Island Inlet in large quantities. The 1955 shorelines of Fire Island and Jones Beach barrier island are shown in Figure 14. Inlet filling is suggested by the line of low sand islands stretching north from the Fire Island jetty. Northward shift of Fire Island Inlet, because of this natural filling, caused tidal currents to scour sand from Oak Beach on the north side of the inlet (Saville 1961). Between 1946 and 1959 more than 780,000 $m^3$ (1 million $yd^3$) of sand were pumped onto the Oak Beach shore in an attempt to restore those beaches.

By 1959, in a cooperative program, the Long Island State Park Commission and the US Army Corps of Engineers dredged a new inlet closer to the Fire Island jetty. Some of the pumped sand was placed as a feeder beach along the Gilgo–Cedar Island Beach shoreline. The old channel was closed by a sand-fill dike, seen in Figure 15 as a finger-like projection trending southeast from Oak Beach. Dredged sand was also placed along the Oak Beach shoreline to the east of the dike.

Sand dredging and filling have not provided a long-term solution for erosion of the Gilgo–Cedar Island Beach shoreline. Nor have they affected filling of Fire Island Inlet by littoral drift sand from the east. This inlet filling begins as a sand barrier projecting from the jetty into Fire Island Inlet (Figure 15).

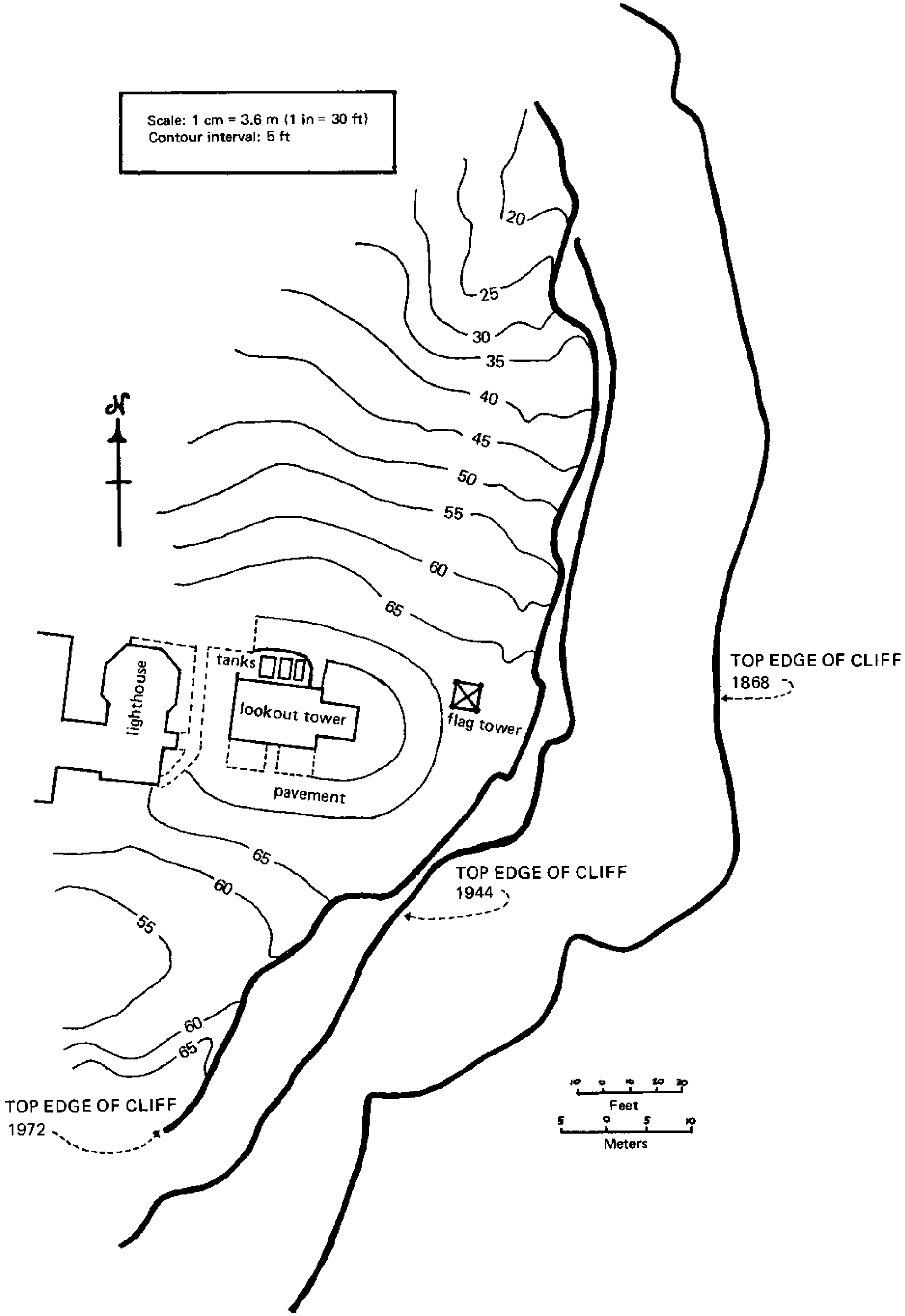



Figure 13. Changes in position of top edge of cliff at Montauk Point, 1868 to 1972. (After Third US Coast Guard District, NY)

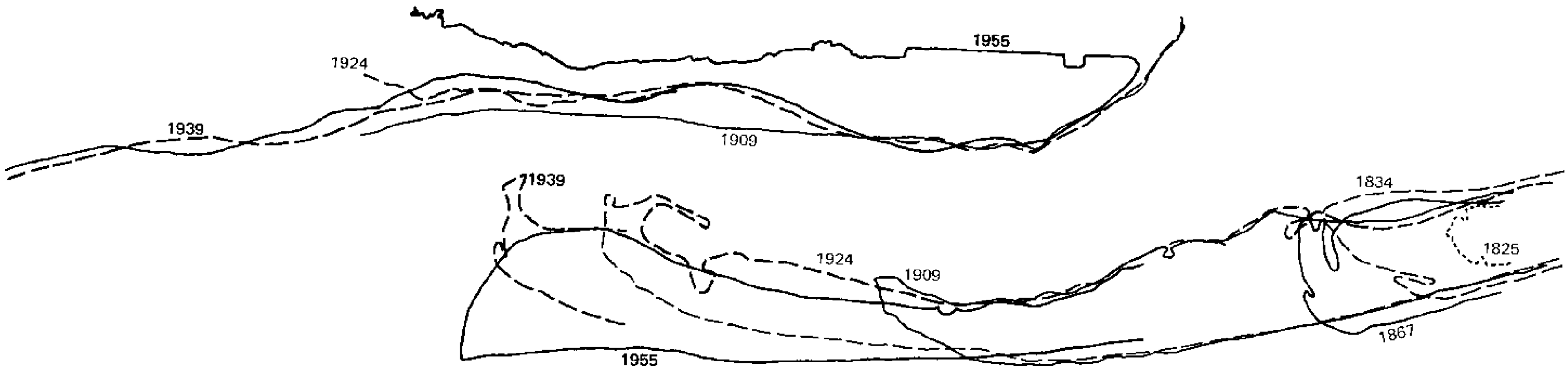



**Figure 14.** Changes in high water shoreline of beaches adjacent to Fire Island Inlet, 1825-1955. (After US Army Corps of Engineers, NY District)

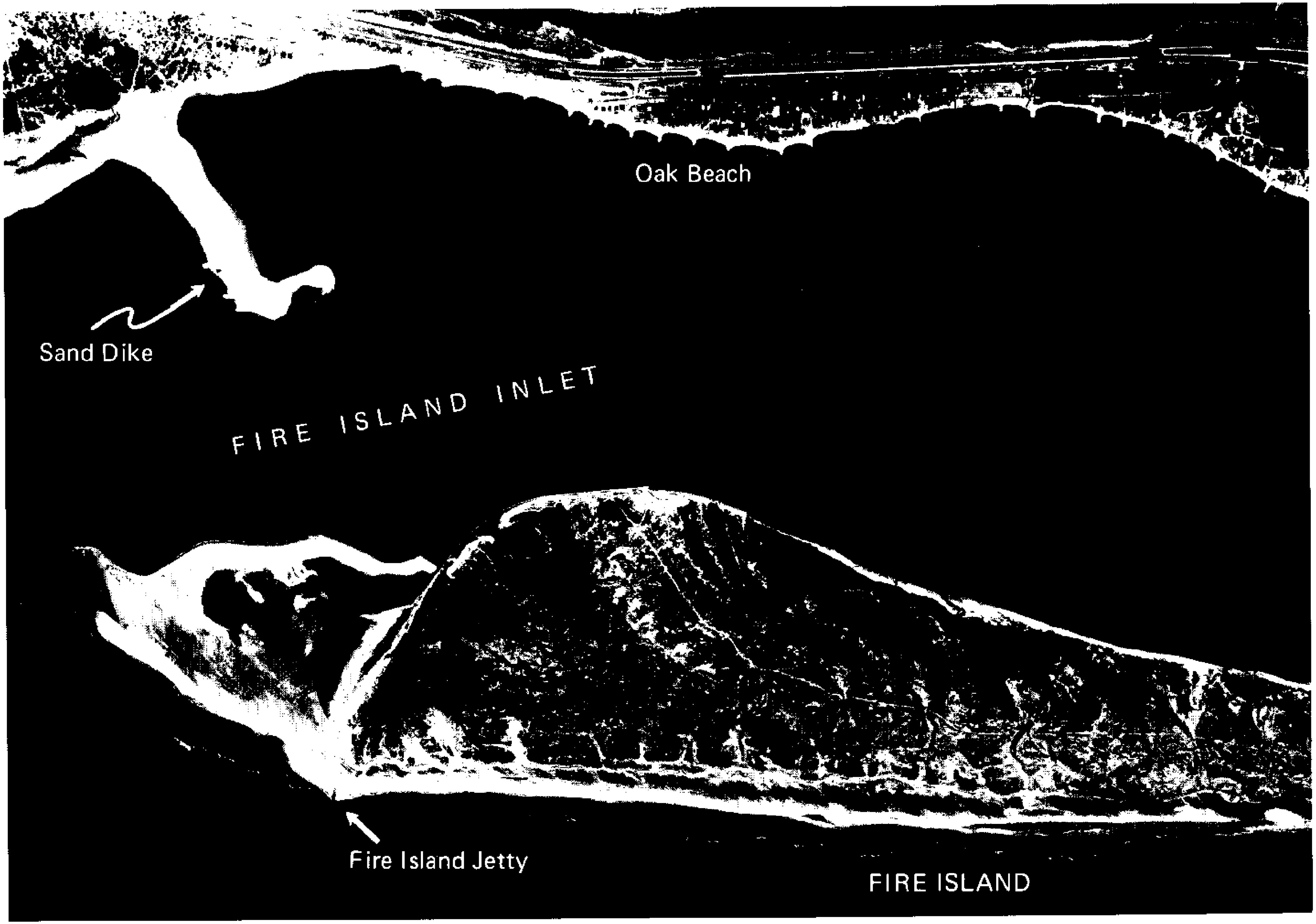



**Figure 15.** Fire Island Inlet and adjacent beaches. (US Coast and Geodetic Survey aerial photo No. S3524, 25 March 1962)

Additional measures to resolve beach problems at Fire Island were studied in a scale model constructed at the Waterways Experiment Station in Vicksburg, MS (Bobb and Boland 1969). Several proposals, including seaward extension of the jetty, were eliminated as a result of the model studies. The most cost-effective plan for resolving beach and inlet problems of the Fire Island area calls for dredging a deep littoral trap west of the jetty. This basin will be part of the new position of Fire Island Inlet. Another deep basin on the east side of the inlet channel, between Oak Beach and Fire Island, will be dredged to help control inlet erosion by reducing tidal current velocity. Periodic dredging of the littoral trap will maintain inlet position and nourish Gilgo and Cedar Island beaches on Jones Beach. Implementation of the model study results began in 1973 (Figure 16).

Although the serious beach erosion problems along the eastern portion of Fire Island were not considered in the model study discussed above, there is merit in the concept of recycling sand dredged from Fire Island Inlet by pumping it eastward to be used as fill for eroding beaches. The present plan for Fire Island Inlet merely attempts to keep the littoral stream moving to the west.

In fact, if we think of each segment of the Long Island barrier complex as a closed system, then the sand recycling idea achieves new significance. A dredge or sand pumping station at each inlet would transport sand back to the eastern terminus of a given barrier segment. This would help resolve erosion problems at the Hamptons, Fire Island, and Rockaway beaches. The eastern half of the Rockaway barrier bar has suffered locally severe erosion over the last few years. This results from a combination of inlet filling at East Rockaway Inlet and new groin construction along the eastern third of the barrier bar. Figure 17 shows a portion of the Rockaway shoreline in an area of serious erosion. The view is east from Beach 88th Street. At low tide the usable beach is very narrow; at high tide even small waves reach under sections of the boardwalk. Sand recycling

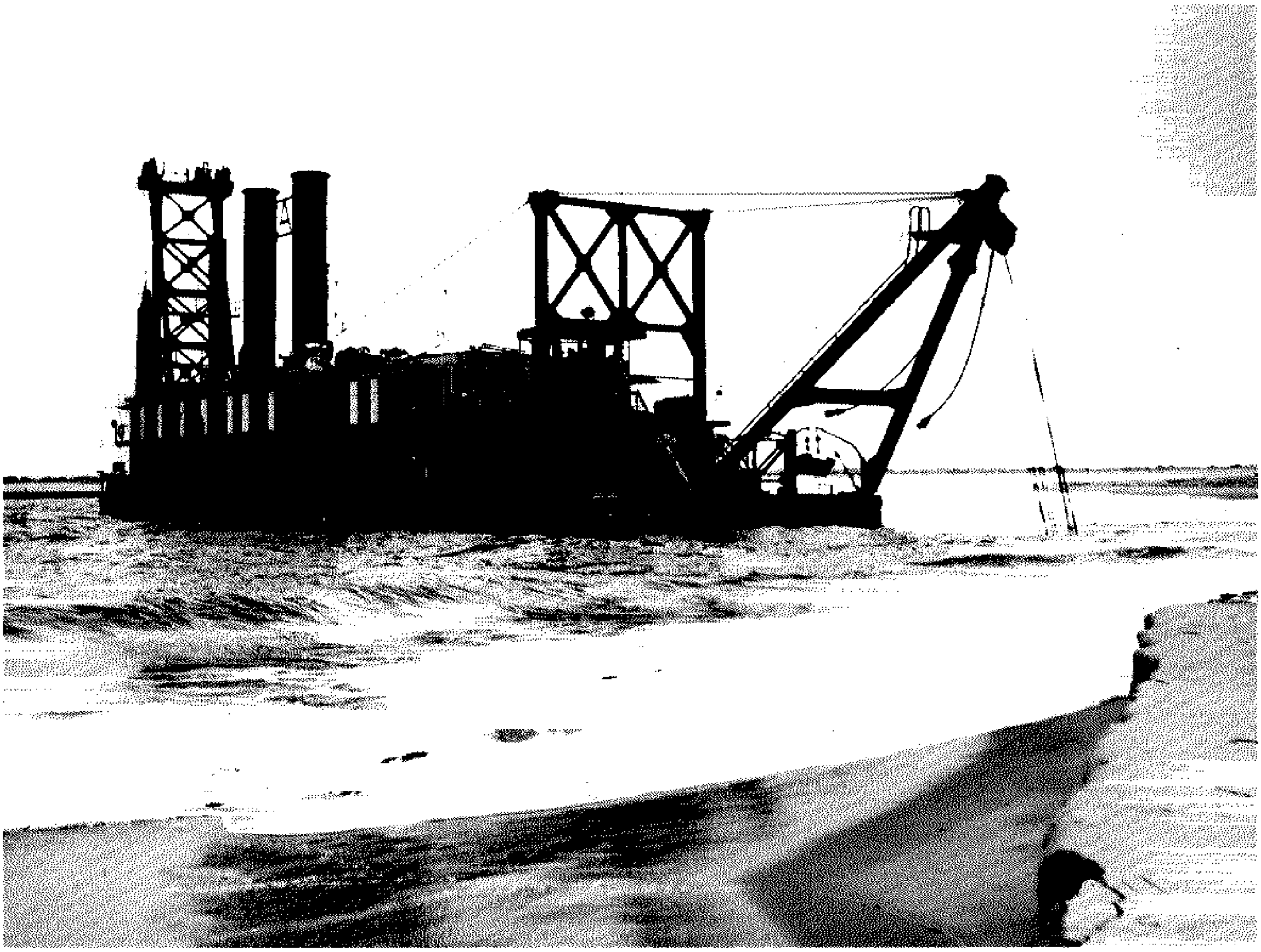


Figure 16. Inlet channel dredging near Fire Island jetty. (Photo by C. Pepenella, August 1974)

from prograding beaches at the western end of the Rockaway barrier bar is a tempting solution to this problem.

An environmentally intelligent, laissez faire answer to beach problems was advocated recently by the National Park Service at Cape Hatteras National Seashore. That is, we would surrender to natural forces by evacuating the beach except for seasonal recreational use. Only temporary structures would be built in realization of inevitable shoreline shifts. Inlets into lagoons used primarily by pleasure craft would be dredged to minimal depth and allowed to migrate freely.

Perhaps the solution to shoreline problems involves a constantly reevaluated compromise between the full protectionist and laissez faire models of behavior. Recent federal designation of national seashore areas is a useful step toward reducing future private ownership of endangered beach areas. Private owners tend to be full protectionists. Therefore, governmental ownership of beach areas removes the massive pressure to build engineering structures at public expense to protect private property and allows examination of creative solutions.

## Barrier Spit Development – An Example from Sandy Hook, NJ

Sandy Hook is a barrier spit with its landward *(proximal)* terminus attached to the mainland at Monmouth Beach. Sandy Hook Lighthouse is a 31 m (103 ft) high structure built in 1762 at what was then the northern tip of the barrier spit. Lighted on 18 June 1764, it is the oldest lighthouse in continuous service in the western hemisphere. Haupt (1905) estimates that between 1776 and 1857 the seaward *(distal)* terminus of Sandy Hook advanced northward at a rate of 20 m (65 ft) per year.

Sometime after 1855 a strong westerly recurve began to form at the northern tip of Sandy Hook. By 1926 the western end of the recurve was 1,000 m (3,300 ft) west of the western shoreline of 1855. The northern edge of dark vegetation seen on the 1962 vertical aerial photograph (Figure 18) marks the approximate position of the high-water shoreline in 1926. Light gray bands of sparsely-vegetated dune ridges, trending northwest-southeast in the triangular tip, mark stages in the post-1926 growth of Sandy Hook. A deep-dredged ship channel, oriented

**Figure 17.** Beach 88th Street two hours after high tide. (Photo by C. Pepenella, October 1973)

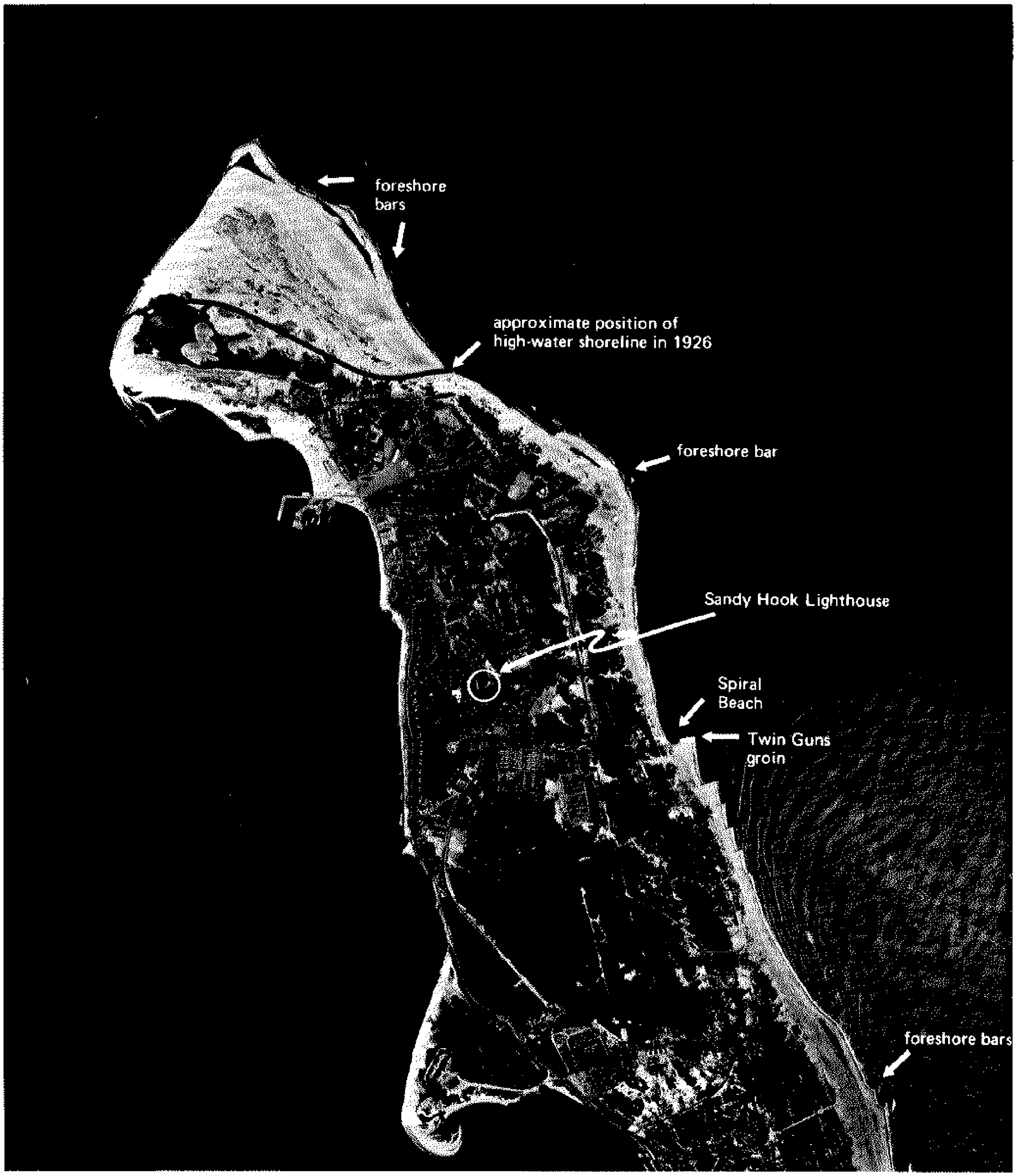



**Figure 18.** Northern portion of Sandy Hook. (US Coast and Geodetic Survey aerial photo No. W4545, 4 May 1962)

northeast-southwest, parallels the western side of the tip of Sandy Hook. This ship channel has blocked any further westward growth of the barrier. Position of the Sandy Hook Lighthouse, marking the 1762 shoreline, is at the center of the white circle on the photograph.

Long foreshore sand bars separated by dark lagoons of tidal water can be seen along the three seaward bulges of the Atlantic shoreline of Sandy Hook (Figure 18). These low embankments represent new sand deposited by waves during the great Atlantic coastal storm of 5-8 March 1962. At the same time the foreshore bars were being deposited, serious erosion was taking place along the center portion of the Atlantic shoreline of Sandy Hook. This section of the shoreline has shown a periodic shift of about 180 m (600 ft) over the years. In 1836 it reached its maximum recorded seaward position. In 1855 the shoreline was at its most landward position. Shoreline position in the 1962 aerial photograph is close to the 1855 high-water shoreline location. The latest cycle of erosion appears to have begun in the early 1950s and accelerated during the March 1962 coastal storm, causing a roughly semicircular, erosional cut behind Spiral Beach (Figure 18). Spiral Beach was named by Yasso (1964) because the beach curvature in map view is a logarithmic spiral.

A 19 July 1962 view of Spiral Beach, looking south from coastal defense fortifications, is seen in Figure 19. Arrow A points to concrete rubble used to extend the landward end of the groin, to prevent further erosion of Twin Guns Beach south of the groin. Note that the top of the beach foreshore ends against the face of a large concrete cylinder. The same cylinder is seen almost two months later in a view to the north (Figure 20). Arrow B indicates that about 12 m (40 ft) of beach erosion took place between 19 July and 13 September 1962. By September 1963, erosion at this location had doubled. But a cycle of filling began the following spring and by the early 1970s Spiral Beach had built back. By 1973 its steep foreshore was positioned at the landward end of the Twin Guns Beach groin. The concrete fortifications seen in Figure 20 are now almost completely covered by a dune ridge paralleling Spiral Beach.

It will be interesting to watch the behavior of this and other beaches over the years. At most coastal locations systematic beach observations have been made only over the last decade. There is no way of knowing whether specific beach areas have periodic episodes of major progradation and retrogradation other than the annual cycle of cut and fill. We yet may be able to confirm our suspicions about long-term periodicity of erosion and accretion, relative to some mean equilibrium position, for beaches at places like Sandy Hook and Fire Island.

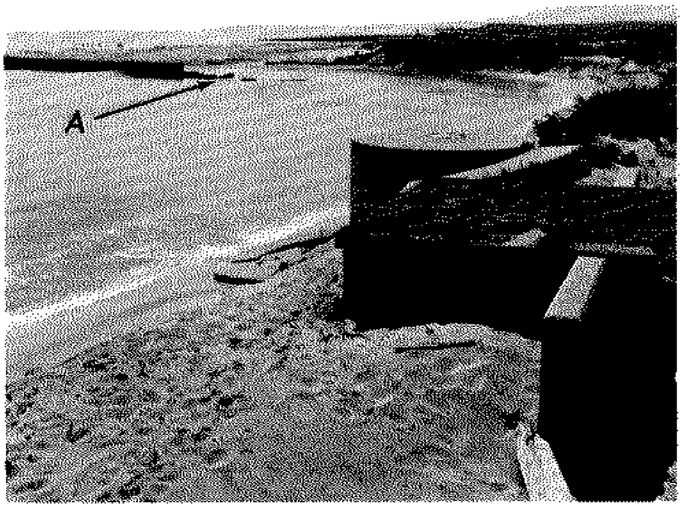



**Figure 19.** View south at Spiral Beach, Sandy Hook, at high tide, 19 July 1962. (Photo by W. Yasso)

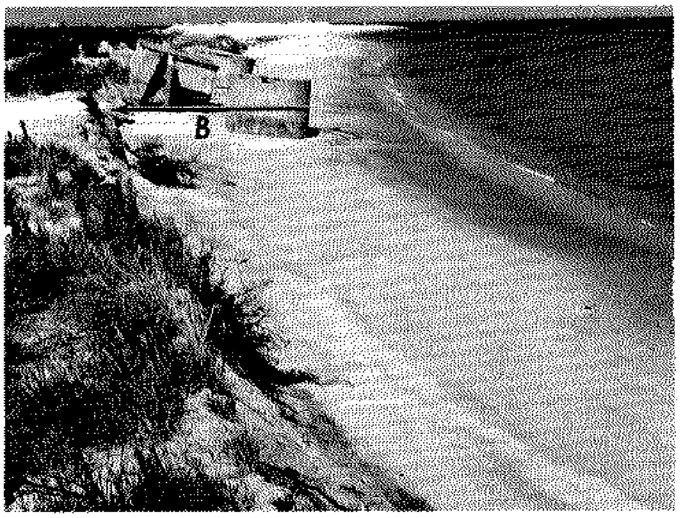



**Figure 20.** View north at Spiral Beach, Sandy Hook, at low tide, 13 September 1962. (Photo by W. Yasso)

# Coastal Processes and Shore Protection

In 1954 the US Army Coastal Engineering Research Center began a visual surf observation program (Helle 1958). Breaker period, significant wave height, breaker angle with the shore and in deep water, type of breaker, and unusual beach changes were estimated and recorded by US Coast Guard personnel. By 1968 a number of observation stations were closed, including the four New York Bight stations: Short Beach, Freeport, NY; Monmouth Beach, Toms River, and Atlantic City, NJ. Darling (1968) lists wave data collected at the Atlantic City Lifeboat Station from 1955 through 1959.

Without visual data on waves in the bight, there are, nonetheless, two methods of obtaining wave data. Data are recorded by an automatic wave gauge on Steel Pier at Atlantic City. Wave information can also be derived from hindcasting based on meteorological data for the period of interest (Salville Jr. 1954; Neumann and James 1955). *Hindcasting* is predicting waves that should have been produced by a past storm. Such hindcasts are made for deep water: wave characteristics are not affected by the ocean bottom in deep water.

Deep-water wave direction and energy are informative for comparison among large coastal segments. The percentage of deep-water wave energy from five compass directions at five locations in the bight is presented in Table 1. Geography limits significant deep-water wave directions to those between east-northeast and south-southeast. For example, 53% of deep-water wave energy approaches Fire Island Inlet from east-northeast. The least amount of deep-water wave energy, 6.2%, approaches Fire Island Inlet from south-southeast. Wave energy from the five directions at each location totals 100%. Looking across the table, we see that about the same percentage of wave energy from any one of the compass directions listed affects each coastal location. Estimates of absolute magnitude of wave energy for each direction at each location are given by Fairchild (1966).

Information on refraction is important to studies of beach behavior. *Refraction* is the retarding effect on waves as they leave deep water and enter shallowing water near the shoreline. Waves are subject to a direction-changing interaction with the seabed similar to optical refraction of light waves. Refraction of ocean waves causes wave crests to swing toward parallelism with the coastline (Figure 21); rarely is refraction complete. Some aspects of wave refraction in the bight are discussed by Pierson (1951, and in press).

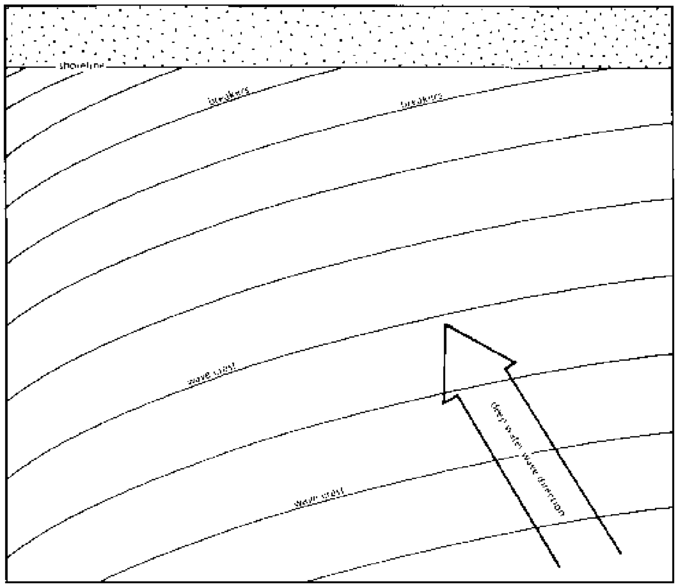



**Figure 21.** Diagram of wave refraction.

Most waves approach most shorelines at a small, but significant, angle. Part of the wave energy is directed at right angles to the shoreline and part is directed parallel to the shoreline; the latter causes beach sediment to move along the shoreline in what is

**Table 1.** Deep-water wave energy at five locations

| Deep-Water Wave Direction | Fire Island Inlet | Sandy Hook | Manasquan Inlet | Barnegat Inlet | Cape May Inlet |
|---|---|---|---|---|---|
| ENE | 52.9% | 53.2% | 53.4% | 53.9% | 55.3% |
| E | 27.4% | 27.1% | 26.7% | 25.9% | 23.5% |
| ESE | 6.7% | 6.5% | 6.7% | 6.9% | 7.8% |
| SE | 6.8% | 6.9% | 7.0% | 7.2% | 7.8% |
| SSE | 6.2% | 6.3% | 6.2% | 6.1% | 5.6% |

Source: After Fairchild 1966

termed *littoral drift.* Littoral drift of beach sediment in the breaker, or surf, zone is called *longshore drift.* Littoral drift of sediment on the beach foreshore, caused by the swash and backwash of breaking waves, is called *beach drift* (Figure 22).

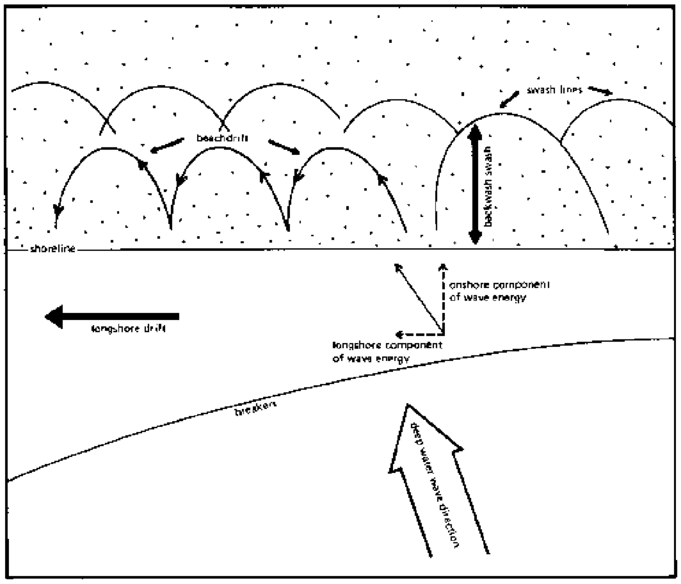



**Figure 22.** Diagram of littoral drift.

It has long been known that the general littoral drift of sediment along Long Island beaches is westward. Along the New Jersey coast beach sediment moves in opposite directions from the Dover Township shore, an area of no net littoral drift. The key to understanding these motions of beach sediment is in noting the directions of the longshore component of wave energy for bight locations.

Table 2 lists the annual percentage of longshore wave energy accounted for by waves from the five directions at five locations. For example, at Fire Island Inlet, waves from east-northeast over the year provide 11.8% of the total longshore energy. Although waves from the east provide slightly more than half of the toal wave energy of east-northeast waves (Table 1: 27.4% compared to 52.9%), they provide nearly three times the longshore energy of east-northeast waves (31.1% compared to 11.8%). Even more striking is the large percentage of net longshore wave energy provided by east-southeast and southeast waves. As listed in Table 1 these wave directions supply only one-fourth of the total deep-water wave energy of easterly waves. Yet they provide yearly longshore energy percentages almost equal to waves from the east.

Table 2 also lists the direction of longshore energy flow. For example, at Fire Island Inlet, waves from the five directions all cause a westward littoral drift; therefore, the sum of longshore energy components is reported as 100% westward at Fire Island Inlet. At Manasquan Inlet, a small southerly component of longshore energy reduces net longshore energy to 87.8% northward flow. At Barnegat Inlet, southward and northward longshore energy are almost balanced. Therefore only 2.1% of the total longshore energy remains to do long-term work; this energy is directed southward.

What is the effect of the net longshore energy? This energy transports beach sand by littoral drift mechanisms. Table 3 presents a summary of estimated littoral drift rates around the bight as given by Fairchild (1966) and Caldwell (1967). Westward littoral drift prevails along the south shore of Long Island. A drift rate of 366,400 $m^3$ (480,000 $yd^3$) of beach sediment a year has been measured at Fire Island. The jetties and inlets at Fire Island and Jones Beach trap a large quantity of this westward littoral drift. Both this trapping and the presence of extensive groin fields on beaches west of Jones Inlet suggest that littoral drift rates are lower to the west.

Sandy Hook's annual northward littoral drift rate of 376,300 $m^3$ (493,000 $yd^3$) is the highest

**Table 2.** Longshore wave energy component percentages

| Deep-Water Wave Direction | Fire Island Inlet | Sandy Hook | Manasquan Inlet | Barnegat Inlet | Cape May Inlet |
|---|---|---|---|---|---|
| ENE | 11.8% W | 2.2% N | 1.6% S | 1.5% S | 14.9% S |
| E | 31.1% W | 53.9% N | 4.5% S | 47.1% S | 58.0% S |
| ESE | 27.9% W | 19.8% N | 5.8% N | 2.4% S | 1.4% S |
| SE | 20.9% W | 9.2% N | 28.9% N | 25.5% N | 13.3% N |
| SSE | 8.3% W | 14.9% N | 59.2% N | 23.5% N | 12.4% N |
| Net Longshore Energy and Direction | 100% W | 100% N | 87.8% N | 2.1% S | 48.5% S |

Source: After Fairchild 1966

**Table 3.** Littoral drift rates

| | Net Drift and Direction | |
|---|---|---|
| | $M^3$/Yr | $Yd^3$/Yr |
| Fire Island Inlet | 366,400 W | 480,000 W |
| Sandy Hook | 376,300 N | 493,000 N |
| Manasquan Inlet | 56,500 N | 74,000 N |
| Dover Township | 0 | 0 |
| Barnegat Inlet | 38,200 S | 50,000 S |
| Atlantic City | 76,300 S | 100,000 S |
| Corson Inlet | 114,500 S | 150,000 S |
| Cape May Inlet | 152,700 S | 200,000 S |

Source: After Fairchild 1966 and Caldwell 1967

littoral drift rate in the bight. All beaches between Sandy Hook and Dover Township have a net northward littoral drift. The drift rate decreases progressively southward from Sandy Hook to Dover Township, where the net drift rate is zero between the towns of Normandy Beach and Seaside Heights. South of this area the littoral drift is southward. Rate of drift increases progressively southward, reaching a maximum of 152,700 $m^3$/yr (200,000 $yd^3$/yr) at Cape May Inlet.

A beach area of no net littoral drift, which separates opposite directions of drift away from that area, is called a *nodal point.* An interesting consequence of the nodal point at Dover Township is that beaches to the north and south do not require groin protection, although there is a groin at Point Pleasant Beach. The Manasquan Inlet jetties, 11 km (7 mi) north of Normandy Beach, and the Barnegat Inlet jetties, 18 km (12 mi) south of Seaside Heights, are the first littoral drift barriers in either direction from the nodal point. South of Barnegat Inlet there are no groins for an additional 34 km (21 mi) to the town of Beach Haven.

## Storm Effects

**Coastal Hurricanes.** Hurricanes traveling through coastal waters are especially damaging to beaches and coastal structures because of the large waves generated by the storm and wind-driven storm surges. *Storm surges* are floods of ocean water blown landward by onshore winds. Added to the storm surge is the slightly elevated sea level caused by the low atmospheric pressure at the hurricane center. The storm surge reaches a maximum in the strong counterclockwise (onshore) winds that precede the hurricane eye. The offshore winds following the hurricane eye often help remove floodwaters from coastal land. Hurricanes and coastal storms can in a few hours cause beach changes – inlet filling, bluff erosion, extensive dune destruction, for example – that usually occur only after years of normal wave action. The storm surge water races through natural or man-made dune cuts, which rapidly widen and deepen and, in extreme cases, become new inlets. Beach sand is carried into the lagoon, forming delta-like deposits called *washover fans.* Storm waves also attack shore structures ordinarily safe from wave action (US Army Corps of Engineers 1971*a*).

Hurricane Donna is the most recent large coastal hurricane to strike the New York Bight coast. Between 9 and 13 September 1960 hurricane Donna traveled across Florida, the Carolina capes, western Long Island, and New England. A complete description of hurricane Donna is given by Cry (1960). By 2 pm on 12 September, the storm center, with peak gusts up to 200 km/hr (125 mph), moved over eastern Long Island. The storm surge struck at The Battery, New York City, coincident with the time of astronomical high tide, causing a record high tide of 2.6 m (8.4 ft) above mean sea level. Water-level curve at The Battery is shown in Figure 23. Duration of the storm surge was short; tide level rose above ordinary mean high water at 10 am and returned to that level by 3:30 pm of 12 September. Therefore flood and wave damage from hurricane Donna was more limited than from a slow-moving coastal hurricane. In the area from Manasquan Inlet to the eastern end of Long Island, damage amounted to $48 million (US Army Corps of Engineers 1961).

**Extratropical Cyclones.** Extratropical cyclones are associated with weather fronts. The great Atlantic coastal storm of 5-8 March 1962 formed off the east coast of Florida in the early morning of 5 March 1962. Carrying winds of gale force and above, the storm moved slowly northward toward Cape Hatteras where it merged with a storm center from the Mississippi Valley late on 5 March. By early afternoon of 6 March the storm covered the eastern third of the United States and the western North Atlantic Ocean (O'Brien and Johnson 1963). Significant deep-water wave heights of between 6 and 9 m (20 and 30 ft) were observed (Bretschneider 1964) for this storm. *Significant wave height* is the average height of the highest one-third of the waves of a given wave group.

On 6 March the storm became almost stationary over the coast and began to move eastward into the Atlantic only on 7 March. Storm surge from the high onshore winds coincided with unusually high astronomical spring tides. The combined effect was five successive periods of coastal flooding during high tides of 6-8 March. Tide curve for The Battery is shown in Figure 23. A near-record tide of 2.2 m (7.2 ft) above mean sea level was recorded in the late evening of 6 March.

Some indication of storm severity and duration is given by the aerial view of Cape May Light Station in Figure 24. In this photograph, taken on 9 March, flooding of low-lying interior sections is clearly visible. Building destruction and beach erosion in this portion of southern New Jersey were minor compared with other sections of the East Coast. Many inlets were filled, closed, or shifted as a result of the storm. Waves and tidal currents deposited thick blankets of sand over roads on the barriers (Figure 25). As a result of the storm, 33 persons died and property damage amounted to an estimated $200 million.

## Sea-Level Effects

Most sea-level changes are long-term in nature; the effects are noted over generations and centuries. Small cumulative sea-level fluctuations caused by absolute changes in land elevation or in ocean level have resulted in broad lateral movements of the shoreline.

After the Wisconsin ice sheets withdrew water from the ocean basins 20,000 years ago, exposing continental shelf areas, sea level was an estimated 130 m (430 ft) below its present level. Submerged marine terraces and fossils of land-dwelling creatures confirm that the bight shoreline was many miles to the

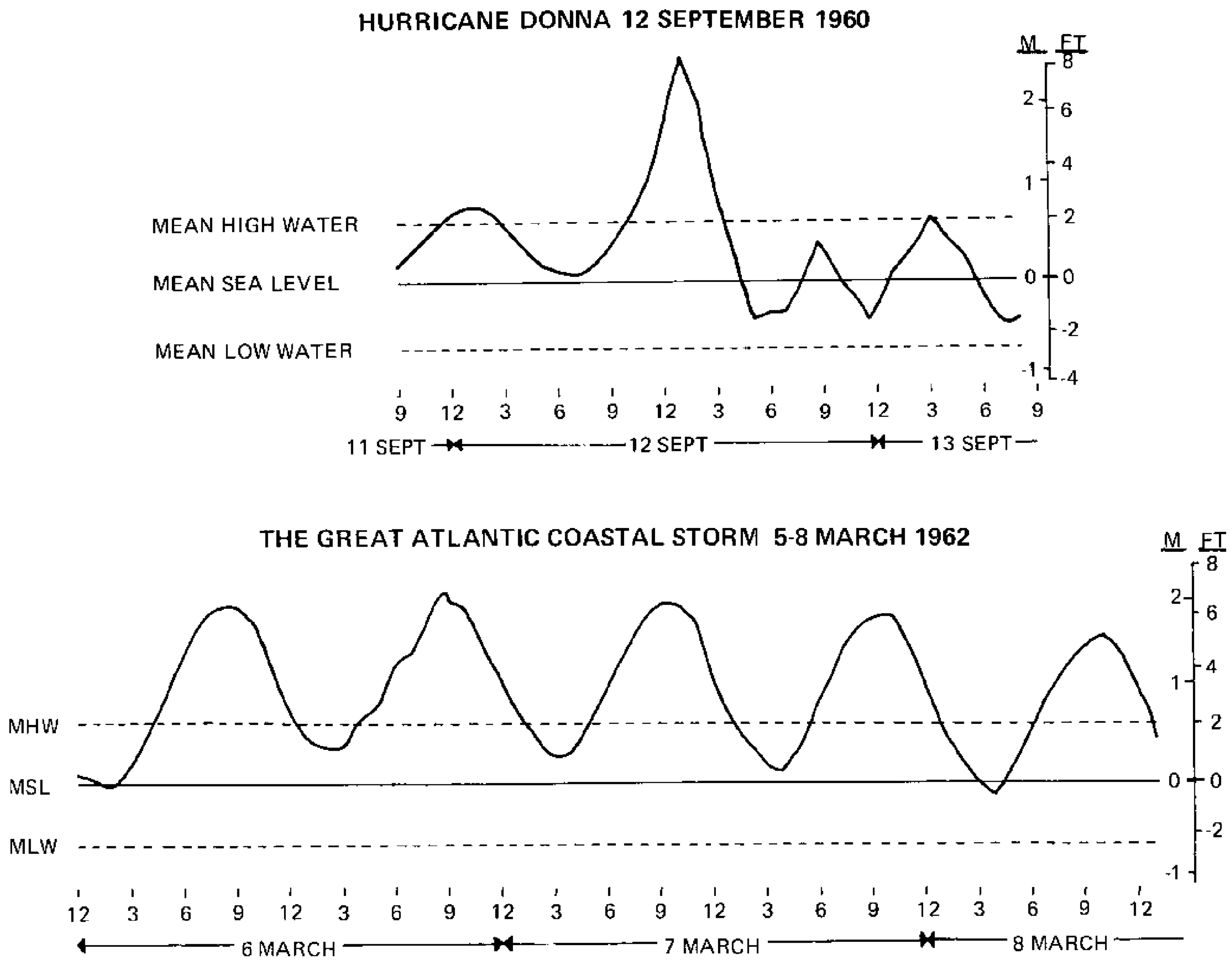



**Figure 23.** Storm surge superimposed on astronomical tides at The Battery, NY, 12 September 1960 and 5-8 March 1962. (After US Army Corps of Engineers, NY District)

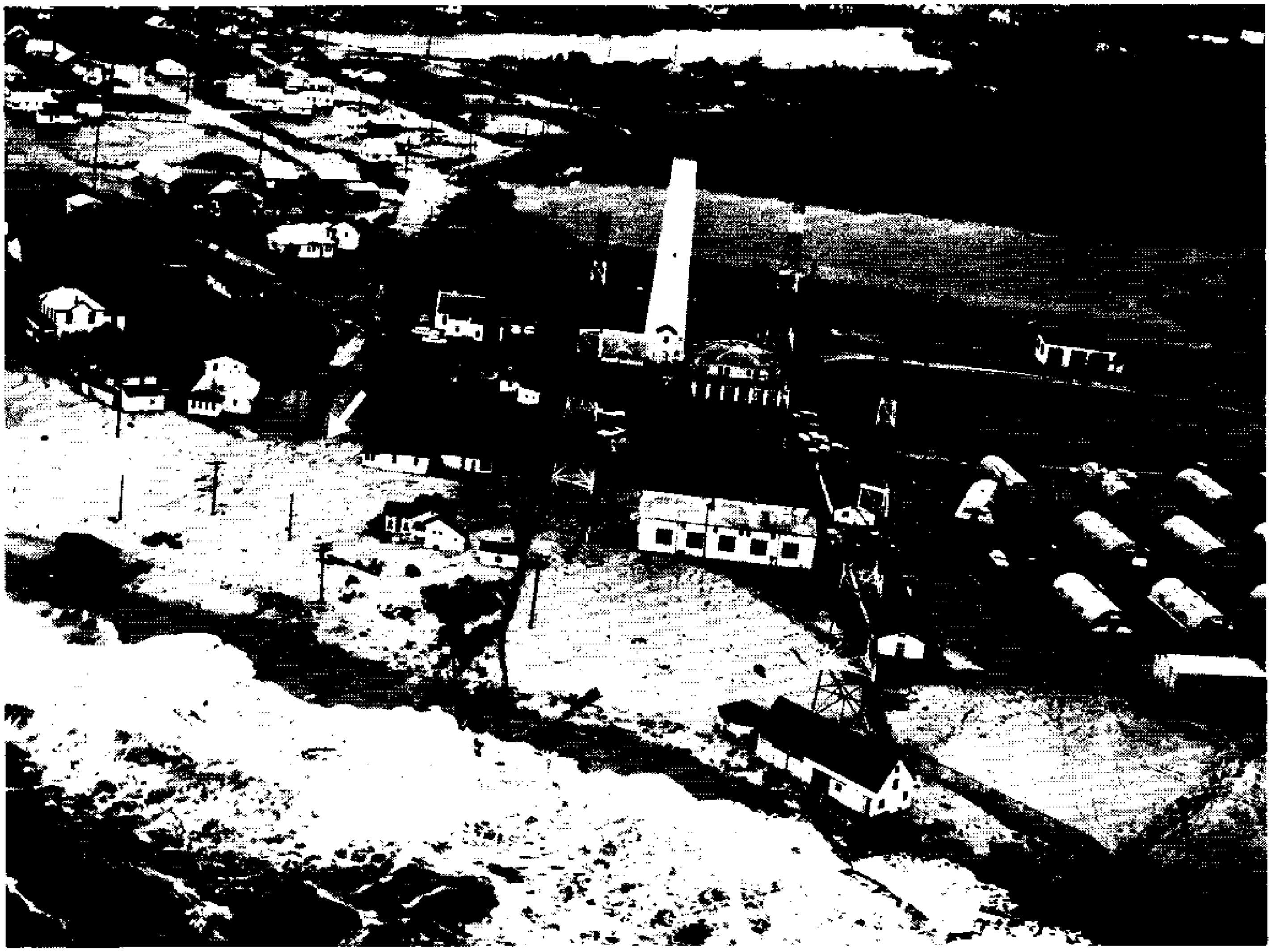


**Figure 24.** View north at Cape May Light Station, Cape May Point, 9 March 1962. The white arrow shows the line of maximum wave attack 120 m (400 ft) landward of mean high tide line. (Courtesy of US Coast Guard Headquarters, Washington, DC)

**Figure 25.** Sand deposits on Long Beach Island road one week after great Atlantic coastal storm, 16 March 1962. Note the partly destroyed house on the left. (Courtesy of NJ Department of Environmental Resources)

southeast along the edge of the continental shelf. As the glaciers melted, sea level rose rapidly until about 7,000 years ago when it was approximately 10 m (30 ft) below present level. Sea level has since risen at a worldwide average of 1 mm/yr (0.04 in/yr) (Hicks 1972). Sea-level changes induced by alterations in the volume of water stored in the ocean basins are called *eustatic*, or absolute sea-level changes.

Relative sea-level changes caused by vertical movement – related to faulting or volcanic eruptions – of coastal land masses are called *tectonic* sea-level changes. They are usually superimposed upon the glacial-eustatic rise in sea level. However, other subtle land movements are more germane to the New York Bight coast. During Pleistocene glaciation the enormous weight of the ice mass depressed the underlying continental crust to the north. Depression was greatest in the subarctic regions where the ice was thickest; it progressively lessened toward the margins of the ice sheet where the earth probably bowed upward into a marginal bulge similar to the compensating bulge created in an air mattress under a person's weight. Because the Wisconsin terminal moraine passes through Staten Island and Long Island, it seems reasonable that much of the northern New Jersey shore and all of Long Island's Atlantic shore were in this marginal bulge region. Withdrawal of masses of glacial ice leads to *isostatic unloading adjustments* (rebounding) of the earth's crust; these are continuing at the present time. Former ice-depressed areas, such as in the north-central and northeastern United States, adjust with a rapid uplift, whereas marginal bulge areas collapse by subsidence. Recent estimates indicate that land in the bight region is subsiding between 5 and 10 mm/yr (0.2 and 0.4 in/yr), resulting in a corresponding relative rise in sea level superimposed upon the glacial-eustatic sea-level rise of 1 mm/yr (0.04 in/yr).

Removal of underground resources, such as petroleum or water, also can result in shore subsidence. Atlantic City has suffered from the effects of rising sea levels caused by increased withdrawal of fresh water from artesian aquifers underlying the coastal plain.

As illustrated in Figure 26, tide gauges along the east coast of the United States show a general trend of increasing sea level since 1895 (Hicks 1972). From 1895 to 1928 sea levels generally rose 4.6 cm (1.8 in), although there were two periods (1903-08 and 1920-28) when sea levels dropped slightly. A steep rise of nearly 11.4 cm (4.5 in) occurred between 1928 and 1946, followed by a continued, but slower,

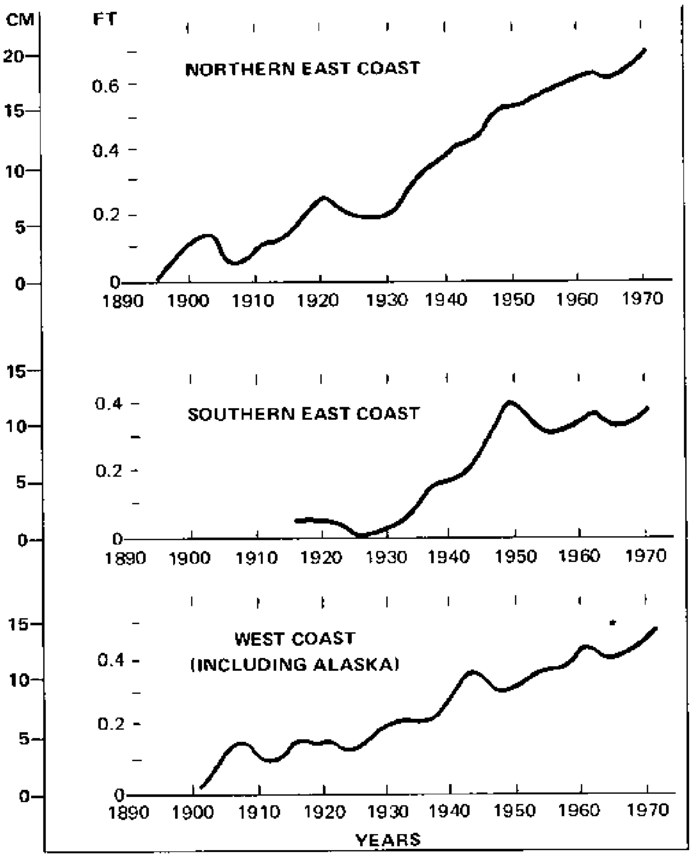



**Figure 26.** Mean sea-level changes. (After Hicks 1972)

rise of 2.4 cm (0.96 in) until 1964. From 1964 to 1970 sea levels rose an average of 7.6 cm (3 in). Similar sea-level rises along the southern east coast and the west coast of the United States are also shown in Figure 26.

Tide gauges at stations in the bight area indicate the following rise in sea level over the 30-year period beginning in 1940: Willets Point, 7.1 cm (2.8 in); New York (The Battery), 8.7 cm (3.4 in); Sandy Hook, 14.2 cm (5.6 in); and Atlantic City, 8.7 cm (3.4 in). The high relative sea-level rise for Sandy Hook may be due in part to land subsidence caused by compaction of coastal sediment. If the 30-year rate continues, sea level will rise 0.30 m (1 ft) in only 108 years. Based on the average slope of the bight shore (0°10′), such a rise in sea level would cause the shoreline to migrate landward approximately 112 m (366 ft).

Rising sea levels pose no real and immediate danger to property or human life. However, when viewed in terms of the decision-making process for long-term coastal management and shoreline protection programs, rising sea levels have a number of predictable consequences, which those responsible should consider. As sea level rises, we can expect a long-term erosion trend along oceanfront property. Structures and roads should be designed and located so they will not be endangered within their expected life span. Without man's interference, barrier islands, spits, and bars are capable of maintaining their elevation as they migrate landward during sea-level rise.

The intertidal wetlands and salt marshes along estuaries and in the quiet lagoons behind barrier complexes are now recognized to be of significant ecological importance. People care about preserving them as nesting and spawning sites for wildlife and fish. Continued rise in sea level will drown this resource even under the most careful management programs. A rise in sea level normally would cause the landward edge of lagoonal wetlands to parallel the landward migration of the barrier complex. Too often the landward edges of these wetlands are bounded by roads, railways, and developed real estate built on landfill. These block the landward migration of the wetlands – even over extended periods. Under present climatic conditions, sea level should continue to rise. Thus the lagoons and marshlands will become narrower unless provisions are made in long-range planning to set aside areas into which the wetlands can migrate.

## Shore Protection Structures

Coasts are naturally protected from wave attack first by the *berm* (low ridge built by swash at the top of the foreshore) and seaward-sloping foreshore, then by dunes on the beach backshore. The gently sloping beach face absorbs and dissipates the destructive energy of waves when they break and are deflected upward, against the force of gravity, as the swash runs up the beach. Because the beach is not rigid but is composed of sediment particles, wave energy is dissipated also in picking up and transporting these particles. Dunes absorb the energy of storm-generated waves that surge across the berm. During severe storms like hurricane Donna, the dunes undergo erosion but are substantial enough in most places to protect adjacent coastal regions. The beach area gradually rebuilds after storm erosion, although not necessarily in the same position as before the storm (US Army Corps of Engineers 1971*b*).

Man often builds into the coastal zone without considering the importance of dunes in coastal protection and without considering the natural seaward and landward migration of the shoreline. Resorts – Atlantic City, for example – have developed within the historical zone of shoreline migration. In many areas, vegetated dunes have been lowered, often with devastating results when storms severely damaged unprotected buildings. Where extensive dunes and beaches protect shore developments, and where there is abundant beach sand, protective structures may not be required. But where construction encroaches onto an eroding beach, shore protection may be necessary. Attempts to halt erosion and to trap sand along a limited stretch of beach are difficult, costly in the long run, and often ineffective. Action to preserve beaches should be undertaken only following a comprehensive plan that considers the erosion problem of the entire shoreline.

**Bulkheads and Seawalls.** Protective structures such as bulkheads and seawalls are present along some bight beaches. They are designed primarily to serve as armor against direct wave attack on the coast. *Bulkheads* are vertical walls constructed of steel or concrete sheetpiling or of timber (Figure 27) and designed to protect headlands or the inner parts of inlet channels from undermining. Where used to protect exposed headlands, bulkheads often allow extreme scour by wave attack. Eventually they can become undermined, necessitating the construction of massive seawalls in their place.

Some *seawalls* are constructed of heavy, vertical, concrete sheetpiles. Most concrete seawalls are built with a stepped or curved seaward face to dissipate wave energy gradually and inhibit undermining. In some cases a concrete apron in front of the seawall helps curb undermining. Seawalls are also constructed of large stone blocks called *rip-rap*. The rip-rap may be chinked with smaller stones or grouted with concrete.

Construction costs for bulkheads and seawalls are estimated by the US Army Corps of Engineers (1971*b*) to range from \$245/m (\$75/ft) for a low bulkhead to \$1,640/m (\$500/ft) for a massive seawall located far from rock sources.

Seawalls are found in greatest concentration along northern New Jersey shores, where rip-rap seawalls extend almost continuously from the southern part of Sandy Hook to Shark River Inlet. Figure 28 is a view of the seawall at Sandy Hook, taken in 1960 shortly after hurricane Donna. The person stands at the berm crest marking the top line of the foreshore. Vigorous wave action caused the swash to travel past the berm and carry sand to the backshore against the seawall. In this way sand eroded from the backshore by waves from the hurricane was replaced. Since the photograph was taken, the Sandy Hook seawall has been repaired, grouted, and faced with concrete.

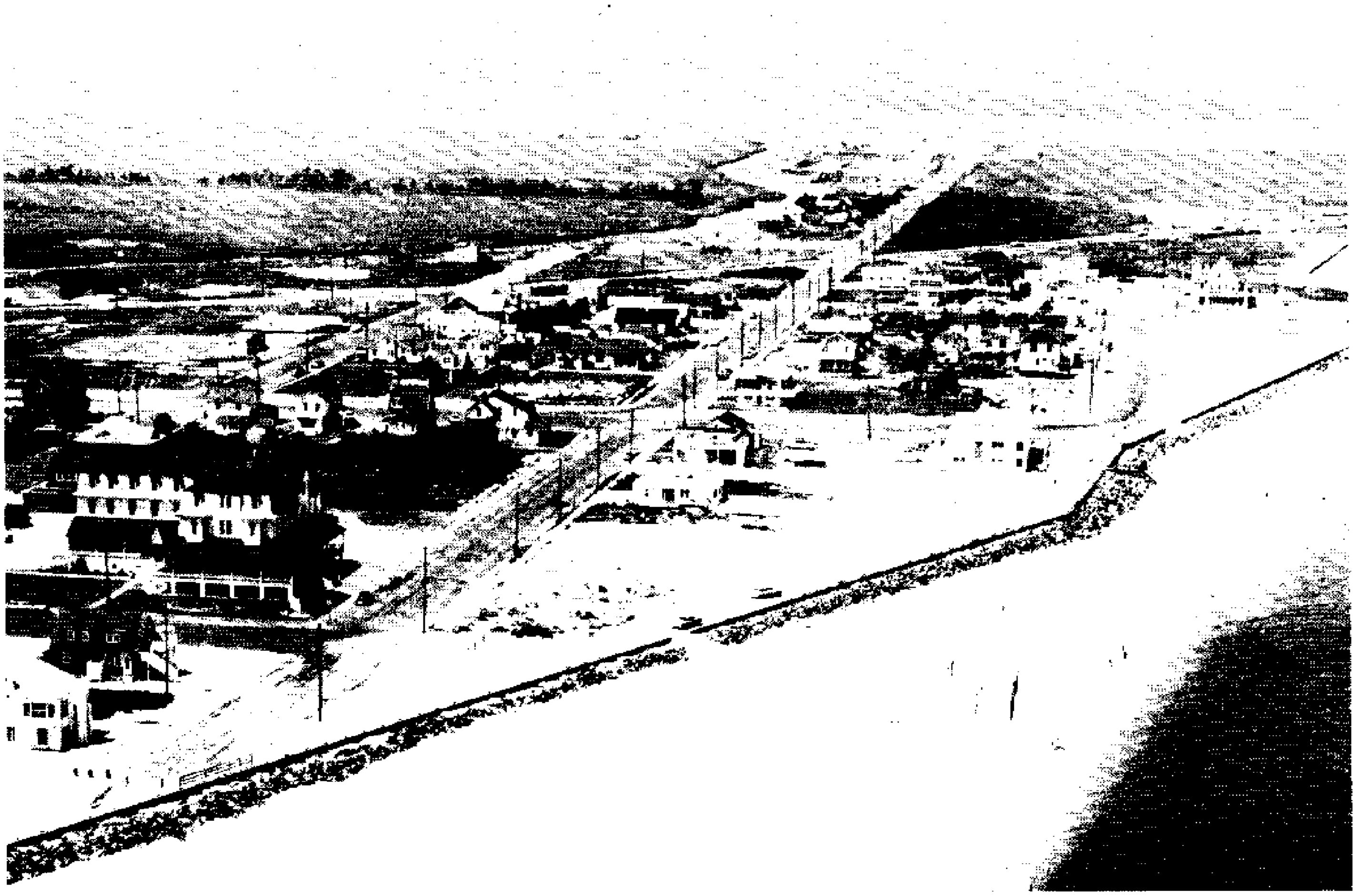


**Figure 27.** Revetment and timber bulkhead at Avalon, NJ, low tide, August 1963. (Photo by E. Miller, courtesy of mayor's office Avalon, NJ)

**Figure 28.** Rip-rap seawall, Sandy Hook, 23 September 1960. (Photo by W. Yasso)

**Revetments and Cliff Terracing.** *Revetments* are a surface armor of rip-rap or interlocking concrete blocks placed along the seaward slope of dunes or cliffs to prevent undermining by wave erosion. Only the small portion of the bight in the immediate vicinity of Montauk Point consists of a cliffed headland protected by a revetment. In Figure 11 the rip-rap toe revetment can be seen along the base of the cliffed headland immediately behind the narrow beach. Waves directly attacking the cliff face would cause the rapid recession of the cliff were it not for the protection of the toe revetment. The stones probably average 1 to 2 m (3 to 6 ft) on a side (the fence in Figure 29 is four feet high).

The men in Figure 29 are building narrow, flat *terraces* in the cliff face. Long planks are anchored to the edge of each terrace; then dirt is backfilled on the upslope side of the plank. These terraces were subsequently planted with erosion-inhibiting vegetation. This terracing reduces rain erosion and soil landsliding on the face of the cliff.

Revetments are sometimes constructed in conjunction with bulkheads where dunes or headlands are inadequate – in Avalon, for example (Figure 27). Here real estate development has progressed virtually to the edge of the beach. A timber bulkhead with a stone revetment nearly 1.6 km (1 mi) long was built in 1962 for $460/m ($140/ft). Note the proximity of the rectangular two-story building to the dark, high-tide swash line near the projection in the bulkhead at the right of the photograph. Development so near the beach endangers the homes. Several sand ramps or wooden stairs over the revetment provide access to the beach.

Figure 29. Cliff terracing, Montauk Point, 25 September 1971. (Courtesy of Third US Coast Guard District, NY)

**Groins.** A *groin* is designed to slow the littoral drift of sand and to impound sand along the shore of its updrift side. Usually constructed of concrete or steel sheetpiling, timber, or rip-rap, it extends from the backshore into the water at right angles to the shoreline.

Groins are most effective where there is ample sand. Unfortunately, groins have often been constructed without consideration of all factors relating to a particular beach problem. No man-made structure placed in the path of littoral drift can in any way increase the total amount of sand available for shoreline protection. It can only retard or arrest the movement of sand along the shore. Where there is an insufficient natural supply of sand, a groin system will be only marginally successful at best.

High groins extending through the breaker zone will initially trap most of the sand moving along the shore until their impounding capacity is reached. Sand eventually transported around the ends of such groins is often deposited in deeper water, thus removing it from the littoral drift.

Because the presence of groins accelerates erosion downdrift, building one groin may necessitate construction of a second, then a third, and so on (Inman and Brush 1973). Downdrift erosion becomes so urgent that the only choices remaining are to continue building protective structures or to replenish sand artificially on eroded beaches. In this way entire coastlines become studded with groins.

Long Branch, once known as "the resort of Presidents," has long experienced severe shoreline erosion problems (US Army Corps of Engineers 1957). Today beach erosion is undermining the boardwalk. The extensive groin system has done little to widen beaches there. Between 1838 and 1953, the entire northern portion of the New Jersey coastline was receding at the average rate of 1.5 m/yr (5 ft/yr). In attempts to widen the beaches and protect the erodable headlands, the US Army Corps of Engineers constructed hundreds of groins designed to retard the northward movement of sand. Despite these structures, there has been only an estimated 12% reduction in the volume of sand migrating toward Sandy Hook (Caldwell 1967).

Figure 30 shows repairs being made in 1960 to a timber and woodpiling groin at Sandy Hook. Seawall and groin construction and maintenance are expensive. Cost of constructing groins ranges between $300 and $1,000/m ($100 and $300/ft) (US Army Corps of Engineers 1971*b*).

Groins of any type should not be constructed unless properly designed for the specific site, with full cognizance of their impact upon downdrift shores. Berg (1967) and Balsillie and Berg (1972) discuss engineering aspects of groin design and placement. Some groins affect downdrift erosion less than others. Low groins, constructed so their top elevations approximate the desired beach profile, permit significant quantities of sand to pass over them. Other groins are constructed to be partly permeable to sand flow. Thus they provide a more continuous supply of sand to the downdrift beaches while allowing some accretion on the updrift side.

The aesthetic impact of groins on the immediate shore is also worth considering. Rock rubble groins extending out from the shore do not make a picturesque beach and they cause wave turbulence and currents that may make swimming hazardous.

**Jetties.** *Jetties,* commonly constructed in pairs, one on either side of an inlet, help stabilize the depth and location of inlets important to boating and shipping. They are long walls of rip-rap extending seaward from the shoreline for longer distances than most groins. Their great seaward length keeps inlet and estuary channels open to a safe minimum depth. That is, an inlet dredged to 10 m (30 ft) below sea level would require a jetty extending at least to a 10 m (30 ft) depth contour. Often they are made even longer to allow for progradation of the updrift beach as sand is trapped by the updrift jetty.

Inlets migrate naturally in the downdrift direction if no jetties impede this movement. When sand in littoral drift reaches an inlet, it is carried into the lagoon on the flood tide, forming an inner shoal or tidal delta. Sand carried outward on the ebb tide creates an outer shoal on the seaward side of the inlet. As the updrift barrier grows into the inlet, the channel migrates toward the downdrift side. Powerful tidal currents erode the downdrift barrier beach, causing the gradual downdrift migration of the inlet.

Inlets occasionally form during coastal storms and hurricanes, where storm surge and waves breach a barrier complex. For example, by 1838 the two natural inlets into Moriches Bay (Long Island) were closed by the westward littoral drift of sand. The bay remained landlocked until 1931 when high tides and a storm surge breached the barrier, forming the present inlet. Despite construction of a jetty in 1947, Moriches Inlet had migrated a total of 1,200 m (4,000 ft) westward by 1951. By late spring of that year littoral drift closed it once again. Local interests began building two jetties on the site of the original inlet. Before construction of the jetties was completed, a small storm reopened the inlet in 1953, and it has remained open ever since. Jetties have not successfully stabilized either Moriches Inlet or Shinnecock Inlet (US Army Corps of Engineers 1960).

Because the purpose of jetties is to prevent shoaling, they usually have been constructed high enough to totally obstruct the flow of sand into the channel. Sand is impounded on the updrift side, as exemplified by jetties at Jones Beach (Figure 31), Fire Island, Shark River, and Cape May. The supply of sand to downdrift beaches is drastically reduced, resulting in their erosion. For example, downdrift erosion rates west of Shinnecock Inlet on Long Island increased from an average rate of 0.3 m/yr (1 ft/yr) to an average rate of 2 m/yr (7 ft/yr) following construction of jetties at Shinnecock Inlet.

Beaches at Cape May were wide and firm until jetties were constructed in 1911 at Cape May Inlet. As sand accumulated north of the jetties, the beach at Cape May began to recede, leaving large areas denuded of sand. At the same time, beaches at Wildwood and Wildwood Crest in the updrift direction began to prograde. The property owners and the municipality of Cape May Point constructed bulkheads, groins, and other protective structures in an effort to arrest the erosion. In 1926 a comprehensive shore protection program began with the construction of 24 timber and steel sheetpile groins. Additional groins were constructed in 1939. Stone and rubble groins were constructed in 1946 and 1950 to replace ineffective and deteriorated structures. In 1960 massive rip-rap seawalls (Figure 10) were constructed in an attempt to stabilize shorelines, but beaches at Cape May Point continue to erode. At the time of writing, proposals are being advanced to

**Figure 30.** Strengthening timber and woodpiling groin with rip-rap, Sandy Hook, September 1960. Rip-rap was removed from seawall to build a ramp for the power shovel. After rip-rap blocks were put on both sides of the groin, stockpile sand was dumped around groin and rip-rap. (Photo by W. Yasso)

nourish these beaches with sand pumped from Hereford Inlet 8 km (5 mi) to the north.

Similar problems along beaches fronting Avon, NJ, arose from jetty construction at Shark River Inlet. The problems were partly solved by trucking sand, impounded along the southern jetty, to nourish downdrift beaches to the north. More recently, updrift jetties have been constructed with a weir, or low section; sand moves over the weir and into a dredged catch basin. Sand is pumped periodically from the catch basin to nourish downdrift beaches. Model studies showed that a weir would not be effective in the case of the Fire Island jetty.

Inlets not controlled by jetties can be affected by offshore engineering structures. For example, a nuclear power plant is proposed offshore near Little Egg Inlet, north of Atlantic City. A model study (Figure 32) currently is being conducted by the Waterways Experiment Station in Vicksburg, MS, to examine quantitatively the effects of a breakwater on the shoreline. Model measurements, with and without the breakwater, will evaluate wave heights, breaker characteristics, and shore currents over a yearly range of conditions. Any effects of the breakwater will be evaluated for beaches adjacent to Little Egg Inlet.

## Beach Nourishment

Shorelines are protected most effectively and economically when proper attention is given to the impact of the protective structures on the natural environment. Although beach erosion control structures, when properly designed and used, have a place in shoreline conservation, indiscriminate use of them can result in an ever-expanding erosion problem.

Artificial beach nourishment is gaining prominence because it is beneficial not only to the local shoreline but also to the adjacent shores. The US Army Corps of Engineers (1971*b*) estimates that the initial cost of artificial nourishment ranges from $160 to $1,000/m ($50 to $300/ft) of shore receiving sand fill. Cost depends on exposure, proximity of borrow areas, length of beach, and degree of rebuilding needed. Replacing eroded fill at one- to five-year intervals costs from $15 to $45/m ($5 to $15/ft). These figures compare favorably to the costs of building protective structures, such as groins, revetments, and seawalls. Artificial nourishment will benefit beaches downdrift for several years; it causes fewer complications than does building shore protection structures.

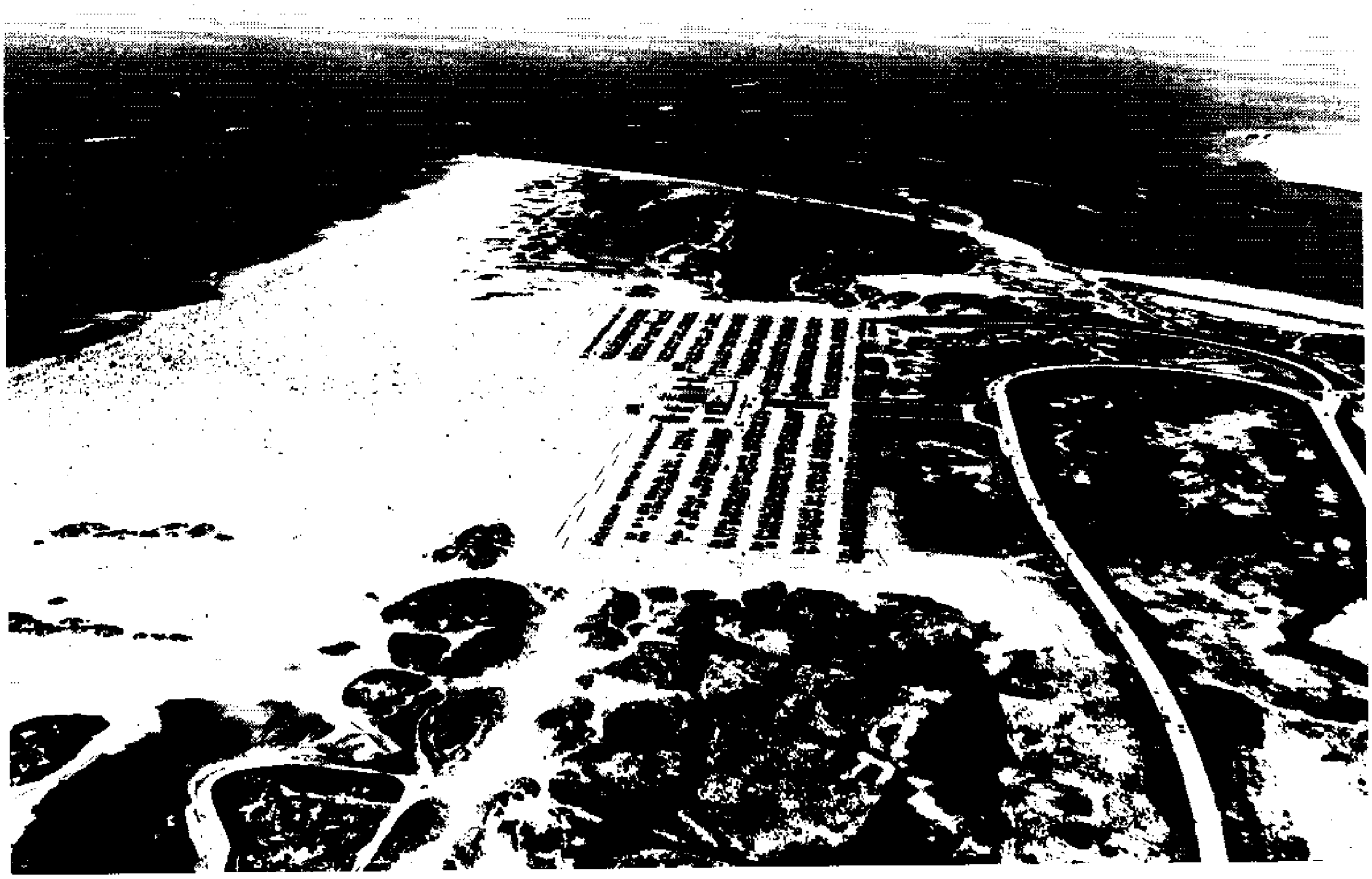


**Figure 31.** Western Jones Beach State Park and jetty at Jones Inlet, 5 August 1973. Most of the beach area was built by natural filling of sand behind the jetty. (Courtesy of Long Island State Park Commission)

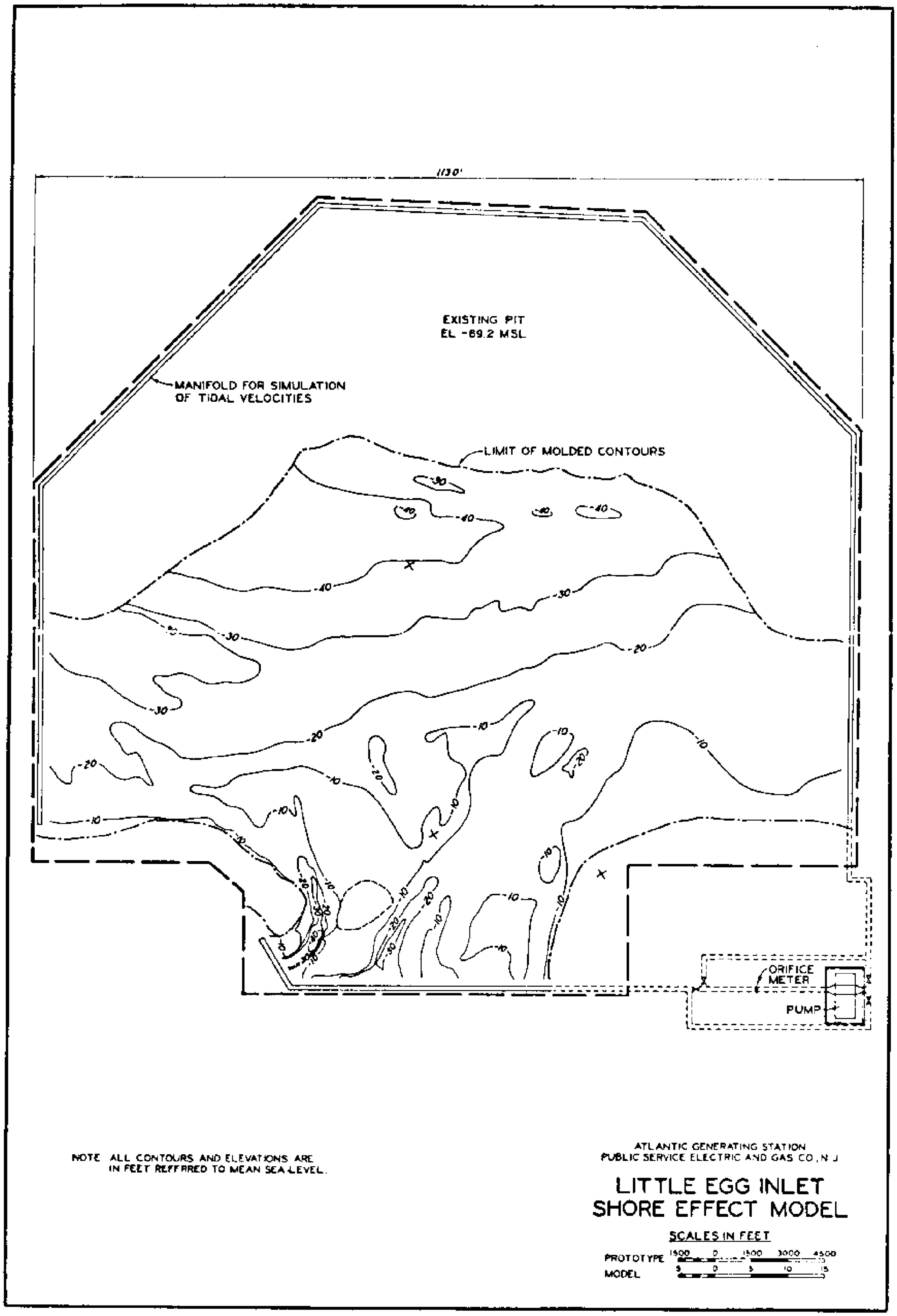



Figure 32. Bottom contours and test basin configuration for Little Egg Inlet model study. (Courtesy of US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS)

To plan artificial beach nourishment, it is necessary first to determine quantitatively the rate of loss of beach material. This is the rate at which sand must be provided merely to stabilize the beach so that no net loss occurs. In the bight region, where essentially no natural supply of additional sand exists, this loss rate will equal the littoral drift rate. The loss rate is determined by periodic profile surveys which show volumetric changes in the nearshore region and the migration of the shoreline. Periodic aerial photography can be used to estimate the volume-rate of beach sand loss where other data are lacking.

Second, the predominant direction of littoral drift must be determined. Where protective structures have been built, beach material impounded on the updrift sides of jetties, groins, or other barriers to littoral drift indicates its direction. Where these structures are not present, analysis of the past wave climate and the longshore components of wave energy can be used to estimate littoral drift direction.

Third, suitable beach material must be found in borrow areas near enough to be transported economically to the fill site. Sand of approximately the same grain-size distribution and sorting characteristics as the natural sand of the beach to be nourished is preferable. If the beach fill contains clay- or silt-size admixtures, then wave action will tend to winnow this finer material away from the beach. Coarser particles will be left behind according to the wave climate of the beach. During the sorting process, the beach slope will adjust to sand characteristics and wave conditions. Criteria for evaluation of sediment for beach nourishment are discussed by Hall (1952). Environmental impact of sand removal must also be evaluated carefully.

Last, the amount of fill must be determined. This depends in part on beach and dune dimensions needed to withstand a storm of given intensity, as well as the desired beach width and length. All these factors vary with the locality.

Examples of bight nourishment projects are discussed below. Watts (1962) gives an overview of other nourishment projects related to inlets and nearby beaches along other sections of the US coast.

**Offshore Nourishment at Long Branch, NJ.** Long Branch is located in the northern portion of the New Jersey headlands coastal region. The net littoral drift here is north. Insufficient sand supply at Long Branch results from its proximity to the nodal point and from the efforts of communities in the updrift direction to preserve their beaches by trapping littoral drift behind numerous groins. Long Branch beaches and headlands have experienced severe erosion for as long as such things have been recorded. Bulkheads and groins have been minimally effective in halting shoreline erosion.

In 1948 the US Army Corps of Engineers, in an experimental program, dredged 471,000 $m^3$ (602,000 $yd^3$) of sand from the New York channel and dumped it approximately 0.8 km (0.5 mi) offshore at Long Branch in 12 m (38 ft) of water to see if the fill material would move onshore to rejuvenate the beaches. A hopper dredge placed the material in a mound 1,147 m (3,700 ft) long, 232 m (750 ft) wide, and 2 m (7 ft) high.

Measurements over the next four years showed that the shoreline continued to erode at an average net rate of 119,340 $m^3$/yr (156,000 $yd^3$/yr). This was only slightly less than the 135,400 $m^3$/yr (177,000 $yd^3$/yr) loss prior to the experiment. Surveys of the offshore area showed that the mound remained intact although it was lower and smoother, suggesting that sand washed off the top of the mound redistributed itself into low spots. Some sand spread over a large offshore area without moving onshore. This experiment is discussed by Hall (1949) and Hall and Herron (1950). It appears that nourishment sand must be placed directly on the beach or at least in shallow water nearby (Harris 1954). Harris's follow-up study of the Long Branch offshore nourishment project confirmed findings of similar experiments conducted off Atlantic City where 2.7 million $m^3$ (3.5 million $yd^3$) of sand were dumped in 5 to 6 m (18 to 20 ft) of water between 1935 and 1943. There was no noticeable benefit to the shoreline in either case.

**Bypassing Sand from Absecon Inlet, NJ.** Many resorts – Atlantic City (Figure 33) is one example – have developed on the downdrift side of inlets, into the area of shoreline migration. Subsequent minor erosion of the shore narrows the beach and endangers buildings. Protective measures are usually taken following the construction of updrift jetties.

Several sand emplacement strategies have been employed adjacent to jettied inlets. Determining which method, or combination of methods, is to be used must be done for each problem site as conditions dictate. Sometimes shoreline erosion has reached a critical stage, exposing life and property to possible danger from winter storms of even moderate severity. In such cases direct filling of the entire eroded shoreline may be the most practical means of

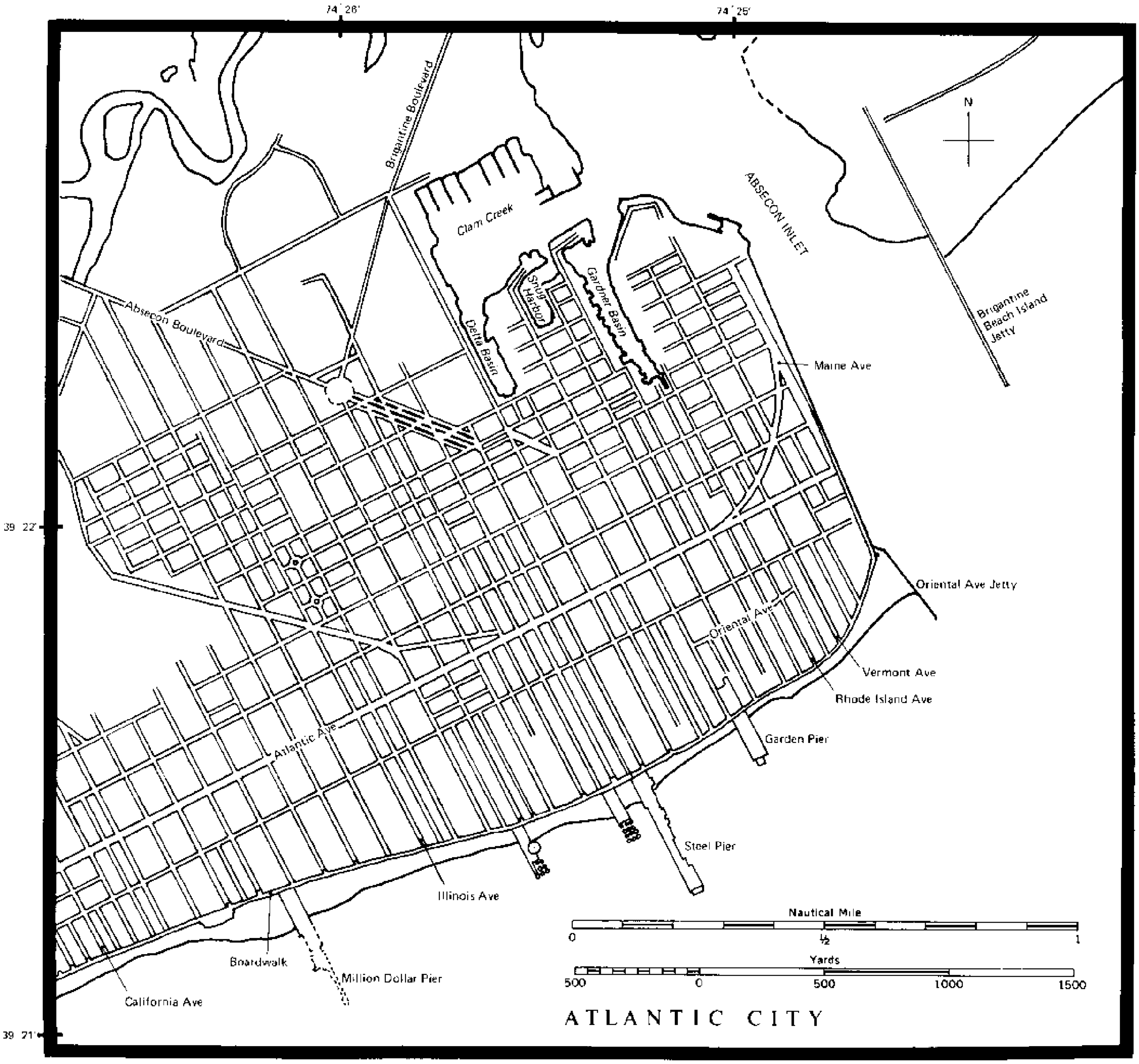



**Figure 33.** Location diagram for Atlantic City and vicinity. (From the US Coast and Geodetic Survey Chart 1217, 6 October 1973)

preservation. Once the critical phase has passed, this scheme of beach preservation may evolve into a stockpile program. The stockpiled beach is, in effect, overfilled so that it can serve as a source for nourishment and maintenance of the shoreline farther downdrift. In some cases, sand is continually pumped from inlet shoals and deposited on the downdrift beach.

A US Army Corps of Engineers bypassing program for Absecon Inlet is an example of artificial beach nourishment using sand from inlet shoals (US Army Corps of Engineers 1948, 1962). Atlantic City is located on the northern 6 km (4 mi) of Absecon Beach Island; above the inlet to the north is Brigantine Beach Island. Maintenance of the generally wide and flat ocean beach requires that sand be pumped southwestward from Brigantine Beach at an estimated rate averaging 304,000 $m^3$/yr (400,000 $yd^3$/yr).

The first reliable survey of Atlantic City in 1841 shows the ocean shoreline located over 305 m (1,000 ft) inland from the present boardwalk near Steel Pier. Atlantic City extended nearly 24 m (800 ft) into Absecon Inlet northeast of Maine Avenue. From 1841 to about 1925 there was a general shoreline progradation; at the same time Absecon Inlet migrated south toward Maine Avenue. The inlet shoreline was relatively stable until 1939 when it migrated an additional 1,830 m (6,000 ft) toward Maine Avenue. By 1948 the Maine Avenue beach was cut back to 30 m (100 ft), endangering the boardwalk and buildings. A jetty was built at that time on the south side of Absecon Inlet, at Oriental Avenue, to divert the shipping channel away from the Maine Avenue beaches. Revetments and groins were constructed, and approximately 765,000 $m^3$ (1,000,000 $yd^3$) of sand were moved by hydraulic dredge and pipeline from the south end of Brigantine Beach. This fill was deposited on the ocean beach between Oriental and Illinois avenues and along the inlet beach edging Maine Avenue. The ocean beach was widened by 122 m (400 ft) and the inlet beach by 61 m (200 ft). Studies indicated that the increased erosion after 1939 was basically due more to a greater frequency of northeast storms, and a hurricane in 1944, than to changes in the rate of littoral drift.

After the 1948 nourishment, the fill sand between Rhode Island Avenue and Steel Pier eroded rapidly. By 1960 the shoreline near Vermont and Rhode Island avenues had again eroded back toward the boardwalk. Some of this sand may have moved farther northeast to fill in behind the Oriental Avenue jetty where the shore advanced over 30 m (100 ft) between 1948 and 1955. From Steel Pier southwest to Million Dollar Pier, the beach remained stable as littoral drift replenished it with fill sand, and beyond Million Dollar Pier to the southwest the shoreline actually advanced by benefit of the beach nourishment updrift. But by 1955 this part of the shoreline also began to recede as the stockpiled sand gave out.

The March 1962 coastal storm caused additional erosion along the already heavily eroded ocean shoreline northeast of Steel Pier. The US Army Corps

Figure 34. Vermont Avenue groin (foreground) and Steel Pier (longest pier), Atlantic City, summer 1963. (Courtesy of American Airlines)

of Engineers decided to repair this portion of beach, concluding that periodic beach nourishment would be the most suitable and economic means of stabilizing Atlantic City beaches. Accordingly, in February 1963 sand was pumped from the inlet and the impounded portion of the Brigantine Beach jetty. Initially 612,000 $m^3$ (800,000 $yd^3$) of sand were dumped along the ocean beaches between the Oriental Avenue jetty and the Garden Pier vicinity (Figure 34).

The Rhode Island Avenue profiles (Figure 35) show the behavior of a stockpile beach. In February 1963, before stockpiling began, the mean position of the shoreline was a scant 15 m (50 ft) from the boardwalk support. Following stockpiling, the shoreline prograded over 91 m (300 ft). Then waves began to attack the stockpile, producing a typical berm/foreshore profile which generally receded during this period. The last profile available shows that three years after stockpiling the mean position of the shoreline was still approximately 24 m (80 ft) seaward of the original pre-stockpiling shoreline.

The California Avenue profiles (Figure 36) illustrate the beneficial effect of beach nourishment on adjacent downdrift beaches. California Avenue is located 1.6 km (1 mi) southwest of Rhode Island Avenue. A low berm abruptly appeared on the 27 February profile, growing upward and landward until September when it disappeared. The sudden appearance of this low berm during the winter season is interpreted as accretion due to the beginning of stockpiling. Its upward growth and landward migration exemplify seasonal development typical of prograding beaches during summer-wave conditions. Throughout 1964 and 1965 the California Avenue beach grew, first upward and then seaward, as sand moved south from the Rhode Island Avenue feeder beach. By late October 1965 the beach had prograded approximately 31 m (100 ft).

Coastal navigation charts show that from 1963 to 1973 the shoreline northeast of Central Pier migrated shoreward as erosion removed stockpiled sand. Southwest of Central Pier during the same period, progradational changes in the shoreline continued.

**Proposed Nourishment of Sandy Hook Beaches.** On 12 September 1974 the US Army Corps of Engineers announced a proposed shipping channel realignment project (Public Notice No. 7841) on Sandy Hook. The Corps of Engineers would remove about 207 m (680 ft) of the triangular northern tip of Sandy Hook, dredging sand to 11 m (35 ft) below mean low water datum. About 588,000 $m^3$ (700,000 $yd^3$) of this sand would be deposited along a 1,700 m (5,600 ft) stretch of Sandy Hook shoreline. Spiral Beach is near the center of this artificial nourishment area. The new channel would be redredged periodically as the northerly littoral drift filled it in. It could be argued that the dredged sand should be sent further south where it presumably originated: beaches south of Sandy Hook are in worse condition than those near Spiral Beach. However, artificial nourishment of Sandy Hook beaches would make them a more valuable resource for the Gateway National Recreation Area.

## Dune Building and Stabilization

Substantial dunes are essential to the coast for defense against waves, wind, and storm surges. They act as buffers, protecting both inland properties and the shoreline itself from erosion. Dunes are themselves highly susceptible to wind and wave erosion. The same storm activity that creates heavy waves also causes the strong winds common along the coastal zone. Even the daily effects of differential heating over land and water generate strong onshore and offshore winds. These winds can easily erode sand from beaches and cause coastal dunes to migrate inland, covering roads, trees, and even buildings, if unchecked.

A prime reason for coastal susceptibility to wind erosion is that beaches and dunes are essentially a desert environment. Rainwater sinks through the dry and highly permeable sand. Natural beach vegetation must adapt to salt spray and a lack of soil nutrients; fortunately, many species of grass and shrubs do thrive under such conditions. The considerable role these plants play in dune stabilization frequently is appreciated only after they have been destroyed by human activity.

Substantial dunes can be built behind the beach by direct sand placement. A slower but less expensive procedure is to build wind obstructions, such as picket-style sand (or snow) fences which break up the airflow and cause wind-blown particles of sand to be deposited in the "wind shadow" of the structure. Fences parallel to the beach, with spurs extending at right angles to the fence every 15 m (50 ft), trap both sand blowing inland and sand blowing along the beach (Jagschitz and Wakefield 1971).

Other wind-flow barriers used successfully are brush and discarded Christmas trees planted closely in rows parallel to the beach, and fences of cloth or wire

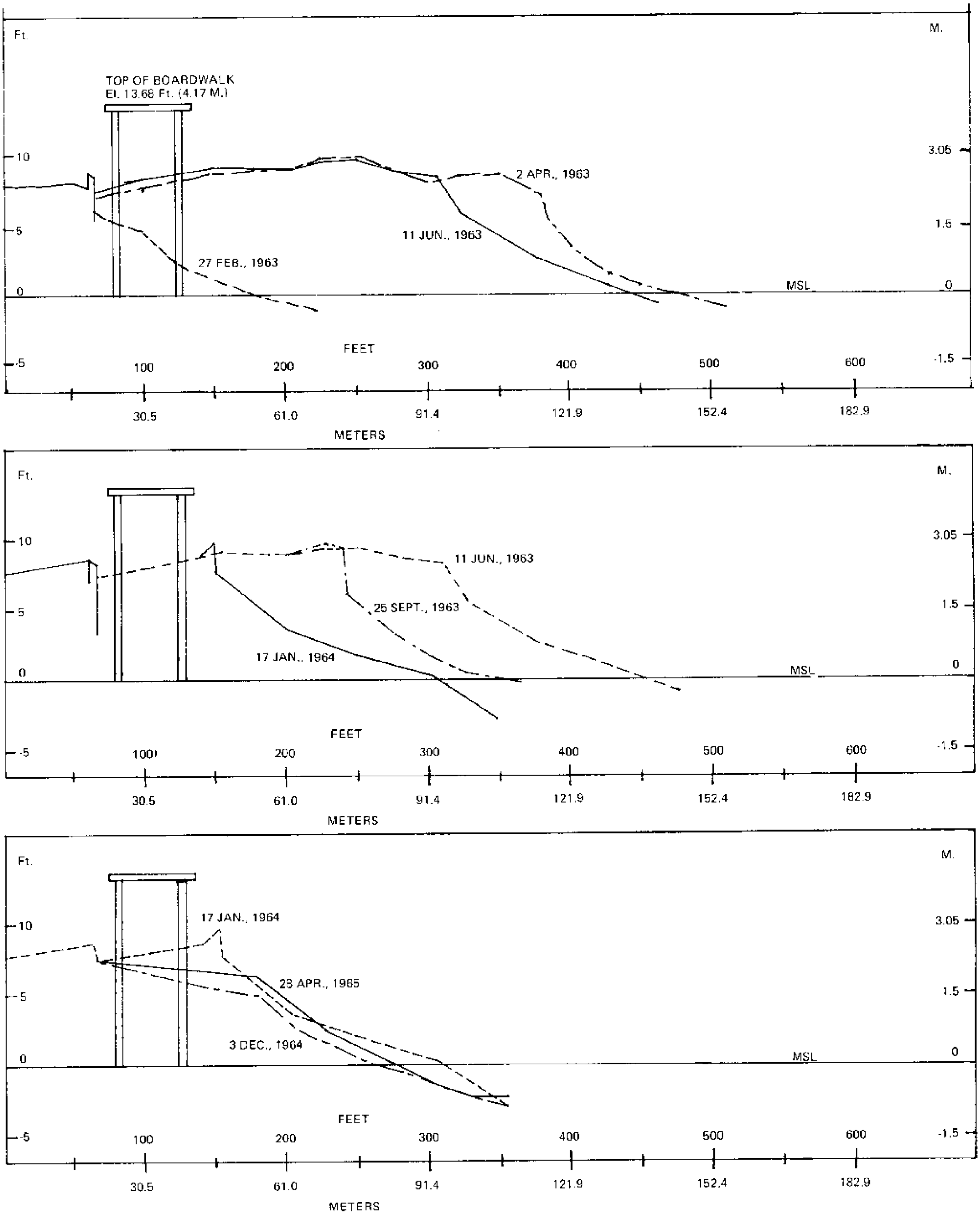



**Figure 35.** Topographic profiles – Rhode Island Avenue, Atlantic City, 27 February to 28 April 1965. (After US Army Corps of Engineers, Philadelphia District)

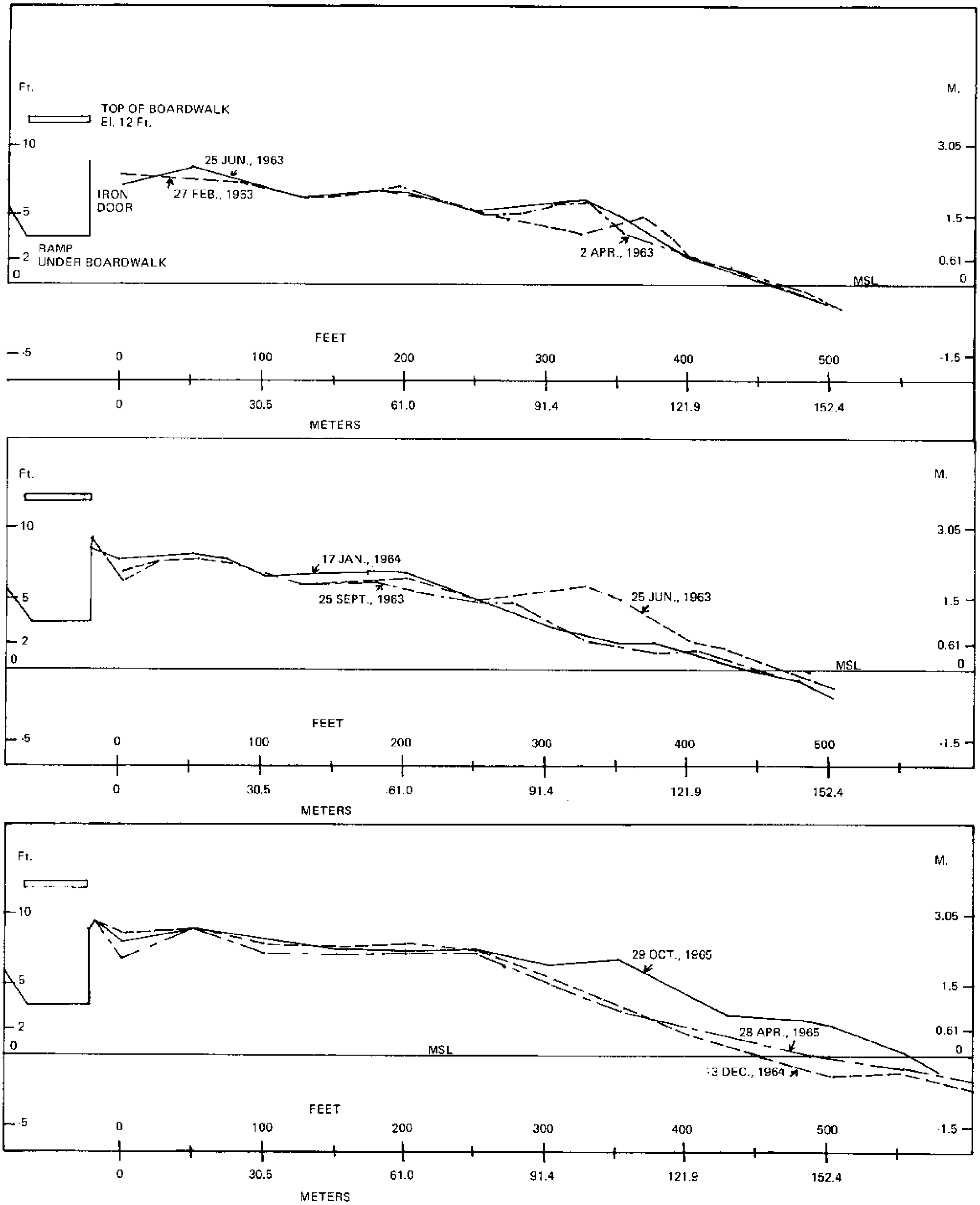



**Figure 36.** Topographic profiles – California Avenue, Atlantic City, 27 February to 29 October 1965. (After US Army Corps of Engineers, Philadelphia District)

mesh (Savage and Woodhouse 1969). As sand drifts build, the obstructions are buried. Additional obstructions can be built on top to make the dunes larger.

Even substantial dunes, whether artificially built or naturally formed over many years, can be lost to wind erosion in only a few months if steps are not taken to stabilize them and prevent erosion on their windward sides. Plants used to stabilize dunes must have long stems and roots to resist strong winds, waves, drought periods and temporary burial by drifting sand. Plots of American beach grass *(Ammophila breviligulata)* (Figure 37) and sea oats *(Uniola peniculata)* have been used successfully along Atlantic coastal regions to build and stabilize dunes (Thornton and Davis 1964). In 1959 an experimental "plantation" of a hardy Japanese sedge *(Carex kobomugi)* resembling beach grass was established on Island Beach State Park. An interesting and innovative experiment undertaken in Great Britain and other locations by a British synthetic rubber company involves spraying a latex-oil mixture over the fertilized and seeded dune area. This prevents sand and seed from blowing away before the seed can germinate and mature. In European experiments, dense growths of fescue grasses that grew up through the latex-oil surface film had well-developed root systems up to 33 cm (13 in) long. Results may prove equally successful if attempted along New York Bight.

Striking improvements in coastal aesthetics as well as in dune stability have been achieved through dune planting. Grasses and shrubs add to the attractiveness of the coast and provide a habitat for dune-dwelling animals. Dune grass, shrub, and tree planting programs at Jones Beach and Fire Island are excellent examples for emulation along other stretches of the bight shoreline.

**Figure 37.** American beach grass. Inset shows grassy beach ridges at Democrat Point, Fire Island. (Photo by C. Pepenella, August 1974)

# Conclusion

In summer, the warm waters, sandy beaches, and gentle surf along the shores of New York Bight provide recreation for the densely populated metropolitan regions of New York, New Jersey, and eastern Pennsylvania. New York State operates five state parks on the south shore of Long Island, with a total of 29.6 km (18.4 mi) of beach frontage. The National Park Service administers over 8,000 hectares (19,000 acres) of Fire Island as the Fire Island National Seashore, providing access to nearly all the south beach of Fire Island. Gateway National Recreational Area, created in 1972, will contain 11,000 hectares (26,000 acres) of recreational beach and lagoon in New York and New Jersey. New Jersey provides one state park with 14 km (9 mi) of ocean shoreline in addition to the 16 km (10 mi) along Sandy Hook that is now part of Gateway. Although the remainder of the New Jersey shore is either privately or municipally owned, about 75% of its shore is available to the public. There is no beach-use charge on about half the public access shoreline. In terms of economics, the resort business is New Jersey's leading industry, generating over $2.6 billion annually. It is significant in both cash flow and employment.

The recreational shoreline must be maintained by protective structures, nourishment, and dune stabilization procedures as described in this monograph. Storms like hurricane Donna in 1960 and the great Atlantic coastal storm in 1962 take their toll of the commercial and recreational shoreline. About $20 million was spent on shoreline repair after the March 1962 coastal storm alone. Increased shoreline use by the burgeoning population of the bight region will multiply the overall cost of repairs from future coastal storms and hurricanes. We must learn how and where to maintain the shoreline for the best use by the people.

About 13% of the Maine to Virginia shoreline is classified as critically eroding, and that includes the 390 km (245 mi) of the bight shoreline. No other large coastal region of the United States has as great a percentage of shoreline in such an endangered condition (US Army Corps of Engineers 1971*a*). Montauk Point, Fire Island, Jones Beach, Rockaway Beach, Sandy Hook, Atlantic City, and Cape May Point are well-documented examples of erosion problems. This report attempts to summarize the knowledge base that planners and citizens need to make creative shoreline management decisions.

# References


Balsillie, J.H., and Berg, D.W. 1972. State of groin design and effectiveness. *Proc. 13th Conf. Coastal Eng.*, Amer. Soc. Civ. Eng., pp. 1367-83.

Berg, D.W. 1967. Variations in groin design. *J. Waterways and Harbors Div.*, Amer. Soc. Civ. Eng. 92:79-99.

Bobb, W.H., and Boland, R.A., Jr. 1969. Channel improvement, Fire Island Inlet, New York. US Army Corps of Eng. Waterways Exp. Sta. Tech. Rep. H69-16.

Bretschneider, C.L. 1964. The Ash Wednesday east coast storm, March 5-8, 1962: A hindcast of events, causes, and effects. *Proc. 9th Conf. Coastal Eng.*, Amer. Soc. Civ. Eng., pp. 617-59.

Caldwell, J.M. 1967. Coastal processes and beach erosion. US Army Coastal Eng. Res. Cent. Reprint 1-67.

Cry, G.W. 1960. North Atlantic tropical cyclones – September 1960. *Climatological Data National Summary* 11:371-85. Asheville, NC: US Dep. Com. Weather Bur.

Darling, J.M. 1968. Surf observations along the United States coasts. US Army Coastal Eng. Res. Cent. Reprint 1-68.

Everts, C.H. 1973. Beach profile changes on western Long Island. *Coastal Geomorphology*, ed. D.R. Coates, pp. 279-301. Binghamton, NY: Publications in Geomorphology, State Univ. of New York at Binghamton.

Fairchild, J.C. 1966. Correlation of littoral transport with wave energy along shores of New York and New Jersey. US Army Coastal Eng. Res. Cent. Tech. Mem. 18.

Hall, J.V. 1949. Sand movement study at Long Branch, NJ. US Army Beach Erosion Board Bull. 3(2):1-5.

______, and Herron, W.J. 1950. Test of nourishment of the shore by offshore deposition of sand, Long Branch, New Jersey. US Army Beach Erosion Board Tech. Mem. 17.

Hall, J.V., Jr. 1952. Artificially nourished and constructed beaches. US Army Beach Erosion Board Tech. Mem. 29.

Harris, D.L. 1963. Characteristics of the hurricane storm surge. US Dep. Com. Weather Bur. Tech. Paper 48.

Harris, R.L. 1954. Restudy of test-shore nourishment by offshore deposition of sand, Long Branch, New Jersey. US Army Beach Erosion Board Tech. Mem. 62.

Haupt, L.M. 1905. A menace to the New York Harbor entrance. *Amer. Geogr. Soc. Bull.* 37:65-77.

Helle, J.R. 1958. Surf statistics for the coasts of the United States. US Army Beach Erosion Board Tech. Mem. 108.

Hicks, S.D. 1972. Vertical crustal movements from sea level measurements along the east coast of the United States. *J. Geophys. Res.* 77:5930-34.

Inman, D.L., and Brush, B.M. 1973. The coastal challenge. *Science* 181:20-32.

Jagschitz, J.A., and Wakefield, R.C. 1971. How to build and save beaches and dunes. Univ. of Rhode Island Agr. Exp. Sta. Bull. 408.

Johnson, D.W. 1919. *Shore processes and shoreline development.* New York: John Wiley.

King, C.A.M. 1959. *Beaches and coasts.* London: Edward Arnold.

McCormick, C.L. 1973. Probable causes of shoreline recession and advance on the sourth shore of eastern Long Island. *Coastal Geomorphology*, ed. D.R. Coates, pp. 61-71. Binghamton, NY: Publications in Geomorphology, State Univ. of New York at Binghamton.

Neumann, G., and James, R.W. 1955. North Atlantic coast wave statistics hindcast by the wave spectrum method. US Army Beach Erosion Board Tech. Mem. 57.

O'Brien, M.P., and Johnson, J.W. 1963. The March 1962 storm on the Atlantic coast of the United States. *Proc. 8th Conf. Coastal Eng.*, ed. J.W. Johnson, pp. 555-62. Richmond, CA: Coun. on Wave Res.

Panuzio, F.L. 1968. The Atlantic coast of Long Island. *Proc. 11th Conf. Coastal Eng.*, ed. J.W. Johnson, 1:1222-41. Richmond, CA: Coun. on Wave Res.

Pierson, W.J., Jr. 1951. The interpretation of crossed orthogonals in wave refraction phenomena. US Army Beach Erosion Board Tech. Mem. 21.

———. In press. Wave conditions. *MESA New York Bight Atlas Monograph 5.* Albany: New York Sea Grant Institute.

Ruzyla, K. 1973. Effects of erosion on barrier-island morphology, Fire Island, NY. *Coastal Geomorphology,* ed. D.R. Coates, pp. 219-37. Bingham-Geomorphology, State Univ. of New York at Binghamton.

Savage, R.P., and Woodhouse, W.W., Jr. 1969. Creation and stabilization of coastal barrier dunes. *Proc. 11th Conf. Coastal Eng.,* Amer. Soc. Civ. Eng., pp. 671-700.

Saville, T., Jr. 1954. North Atlantic coast wave statistics hindcast by Bretschneider-revised Severdrup-Munk methods. US Army Beach Erosion Board Tech. Mem. 55.

———. 1961. Sand transfer, beach control, and inlet improvements, Fire Island Inlet to Jones Beach, New York. *Proc. 7th Conf. Coastal Eng.,* ed. J.W. Johnson, pp. 785-807. Richmond, CA: Coun. on Wave Res.

Schuberth, C.J. 1971. Long Island's ocean beaches. *Sea Frontiers* 17(6):350-62.

Shepard, F.P. 1963. *Submarine geology.* New York: Harper & Row.

Taney, N.E. 1961. Geomorphology of the south shore of Long Island. US Army Beach Erosion Board Tech. Mem. 128.

Thornton, R.B., and Davis, A.G. 1964. Development and use of American beachgrass for dune stabilization. US Dep. Agr. Soil Conserv. Serv.

US Army Beach Erosion Board. 1948. Beach and channel improvement measures at Atlantic City, New Jersey. Bull. 2(3):5-12.

US Army Corps of Engineers. 1957. Beach erosion control study, shore of New Jersey from Sandy Hook to Barnegat Inlet. House Doc. 361/82/2. Washington, DC: Govt. Print. Off.

———. 1960. Beach erosion studies. *The Annu. Bull.* 14:51-53.

———, New York District. 1961. Report on hurricane of 12 September 1960 (Donna), vol. 1.

———, Philadelphia District. 1962. Review of report on cooperative beach erosion control study at Atlantic City, NJ.

———, New York District. 1963. Report on storm of 6-8 March 1962, vol. 1.

———. 1971*a*. Report on the national shoreline study.

———. 1971*b*. Shore protection guidelines.

Vesper, W.H., and Essick, M.G. 1964. Pictorial history of selected structures along the New Jersey coast. US Army Coastal Eng. Res. Cent. Misc. Paper 5-64.

Watts, G.M. 1962. Mechanical bypassing of littoral drift at inlets. *J. Waterways and Harbors Div.,* Amer. Soc. Civ. Eng. 88:83-99.

Wicker, C.G. 1951. History of the New Jersey coastline. *Proc. First Conf. Coastal Eng.,* ed. J.W. Johnson, pp. 299-319. Richmond, CA: Coun. on Wave Res.

Wiegel, R.L. 1964. *Oceanographical engineering.* New Jersey: Englewood Cliffs.

Yasso, W.E. 1964. Plan geometry of headland-bay beaches. Columbia Univ., Dep. Geol. Tech. Rep. 7. (*Also* USN Proj. NR 388-057.)

———. 1971. Forms and cycles in beach erosion and deposition. *Environmental Geomorphology,* ed. D.R. Coates, pp. 109-37. Binghamton, NY: Publications in Geomorphology, State Univ. of New York at Binghamton.

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