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Environmental Effects of Sand Mining in the Lower Bay of New York Harbor

Phase 1

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MARINE SCIENCES RESEARCH CENTER
STATE UNIVERSITY OF NEW YORK
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ENVIRONMENTAL EFFECTS OF SAND MINING IN THE LOWER BAY OF NEW YORK HARBOR

Phase I: A description of the environment, an assessment of the extent and quality of the resource based on existing data, and an annotated bibliography of pertinent literature.

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with a section on Circulation by
Robert E. Wilson

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JR Schubel
J.R. Schubel, Director

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

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INTRODUCTION

For a number of years, the Lower Bay of New York Harbor has been a major source of sand and gravel for construction aggregate and for fill. It has provided much of the aggregate and fill required for construction in metropolitan New York and New Jersey, and is undoubtedly one of the nation's largest "open-pit" sand and gravel mines. Since 1967, the rate of removal has averaged about 4.2×10^6 m^3/yr (5.5×10^6 yds^3/yr). Present allocations of dredging sectors are limited to the east bank of Ambrose Channel and to the Chapel Hill North Channel. At the present time mining is largely restricted by the New York Department of Environmental Conservation to the area in and around Ambrose Channel--the main channel for ships entering New York Harbor. While material from this area is too fine-grained for aggregate material, it is an important source of fill.

Imposition of restrictions on the location of dredge areas was prompted by a number of assumptions: (1) that dredging in other regions of Lower Bay of New York Harbor might have a greater impact on water quality and adversely affect productive shellfish and finfish areas west of Ambrose Channel, (2) that dredging in other regions might accelerate shore erosion of Staten Island, (3) that the sand deposits of the Ambrose Channel area and the region to the east are renewed by littoral drift along the south shore of Long Island, and therefore provide a renewable resource that can sustain some yield without being depleted, and (4) that since material is continuously being supplied to the designated area, the mining provides a necessary and useful service--maintenance dredging of the shipping channel. None of these assumptions has been tested by appropriate field and laboratory investigations. In view of the shortage of good quality aggregate material, and the uncertainty of the validity of these assumptions, a study of the sand and gravel resources of the Lower New York Harbor was initiated through the New York Sea Grant Institute.

The pervasive goals of this study are to: (1) develop a predictive capability for assessing the environmental impacts that would result from a variety of sand and gravel mining activities--different techniques of mining, different rates and patterns of removal; and (2) to use this information to develop appropriate plans for management of this resource. The strategies must be consistent with the natural prevailing processes and with the uses of the Harbor perceived by the public to be most important. This requires that the "appropriate" strategies for management of the sand and gravel resource must be consistent with management of the Harbor's other resources.

To attain these goals a large number of objectives must be met. This report serves as an introduction to our continuing investigation of the sand and gravel resources of Lower New York Harbor and contains the results of Phase I. This report consists of:

1. An annotated bibliography and and critical review of all literature pertinent to the assessment of the quantity and character of the sand and gravel resource of Lower New York Harbor, and of the processes that act to renew and distribute this resource.
2. A collection and interpretation of all pertinent existing data (including dissertations and other unpublished reports) in light of the stated goals.
3. Textural data for new sediment samples collected from East Bank and adjacent areas east of

Ambrose Channel, and a limited number of samples from West Bank.

4. Results of a preliminary geophysical survey of Lower New York Harbor with a high resolution seismic profiling system to assess the value of this technique in mapping (in three-dimensions) the distribution of sand and gravel, and other sediment types.

GEOLOGICAL AND PHYSICAL PERSPECTIVES

Geographical Setting

The Lower Bay of New York Harbor is located at the apex of the New York Bight at the junction of the Atlantic Ocean coasts of Long Island and New Jersey, Fig. 1. The shape of this water body is roughly rhombohedral with its northern apex located at the Narrows--the constricted section of the Hudson River between Brooklyn and Staten Island. The western apex is the mouth of the Raritan River and the southern apex is located at the base of Sandy Hook; East Rockaway Inlet represents the eastern apex. The Lower Bay is bounded on the northwest by the southern shore of Staten Island, and on the south by the northern shore of New Jersey. The eastern boundary is open to the Atlantic Ocean through the 10 km (5.5 mi) wide gap between the northern tip of Sandy Hook, New Jersey, and Rockaway Point, Long Island, Fig. 1.

The Lower Bay of New York Harbor is sub-divided into several bays. Raritan Bay, Sandy Hook Bay, and the western portion of Lower Bay comprise the Raritan Estuary. The drowned valley of the Raritan River forms the western extremity of this estuary. Raritan Bay consists of that portion of the Raritan Estuary located west of a line joining Point Comfort, New Jersey and Crookes Point, Staten Island. Sandy Hook Bay represents the area south of a line joining Point Comfort with the northern tip of Sandy Hook. Arthur Kill, a narrow channel of water separating Staten Island from New Jersey, enters the west end of Raritan Bay from the north.

The seaward portion of the drowned Hudson River estuary south of the Narrows constitutes most of the Lower Bay. Gravesend Bay is a small embayment located north of Coney Island. Rockaway Inlet enters Lower Bay from the east providing a tidal connection to Jamaica Bay. A portion of the inner continental shelf located northwest of a line joining the base of Sandy Hook and the entrance to East Rockaway Inlet, Long Island, is included in this study.

The boundary between New York and New Jersey passes approximately from east to west through the center of the Raritan Estuary. The study area includes portions of Queens, Kings, and Richmond Counties, New York, and Monmouth and Middlesex Counties, New Jersey.

General Geology

The Lower Bay of New York Harbor lies within the Coastal Plain physiographic province of northeastern United States Fig. 2. The Coastal Plain is bounded on the west by the Piedmont Province, and on the east includes the continental shelf--the submerged portion of the Coastal Plain. At the latitude of New York Harbor the sub-aerial part of the Coastal Plain has a maximum width of 44 km (24 mi) between New Brunswick and Sandy Hook, New Jersey, and the continental shelf a width of approximately 185 km (100 mi). The inland boundary of the Coastal Plain follows a line between New Brunswick and Metuchen, New Jersey, includes most of Staten Island, crosses the Hudson River just north of The Narrows, and continues eastward along the north shore of Long Island.

Coastal Plain

The sub-aerial portion of the Coastal Plain is, in general, a dissected plain that rises gradually from sea level at the

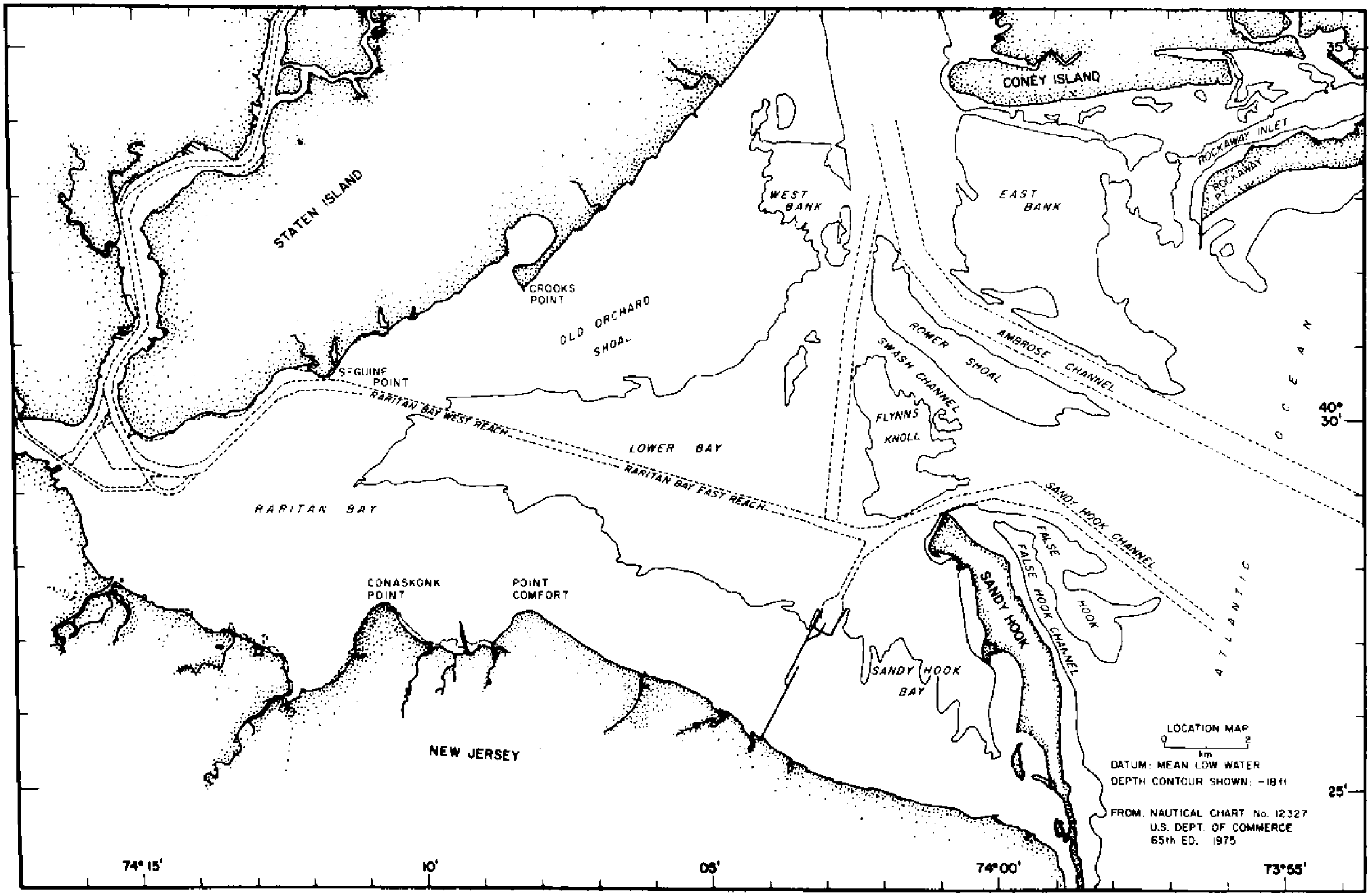

Fig. 1. Location Map

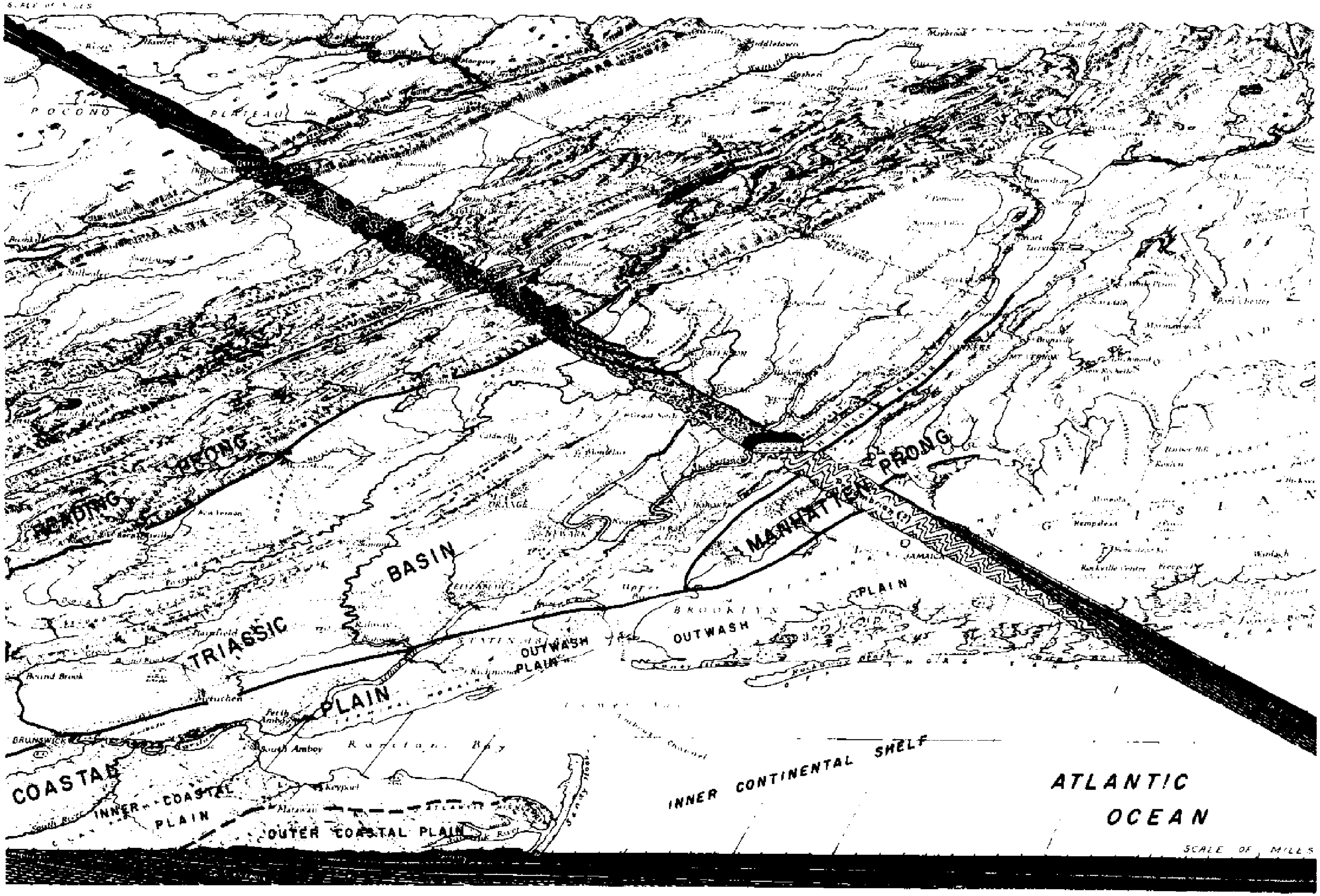

Fig. 2. Physiographic Diagram of the New York Region. Drawn by Erwin J. Raisz. Map courtesy of Hammond, Inc.

coast to elevations of 90 m (300 ft). Along its inner margin it declines in elevation to a broad shallow depression less than 30 m (100 ft) above sea level that is formed on a belt of clay and marl sediments. East of the depression is a ridge with elevations in excess of 90 m (300 ft) that is formed of resistant sand and marl sediments. The ridge has a steep western slope, and a very gentle eastern slope corresponding to the dip slope of the underlying sedimentary formations. This geologic feature, called a cuesta, forms the Outer Coastal Plain and the broad depression to the west, the Inner Coastal Plain. Geologically these two parts of the Coastal Plain are not very different. Unconsolidated clays, sands, marls, and gravels underlie both areas, but there is a greater proportion of clays in the sediments of the Inner Coastal Plain.

Triassic Basin

Bordering the Coastal Plain to the west is the Triassic Basin of the Piedmont Province of northern New Jersey. It is chiefly a lowland with gently rounded hills separated by wide valleys which slopes gently from about 120 m (400 ft) above sea level at its northwestern margin to sea level at Staten Island. Several northerly trending ridges rise several hundred feet above its surface. Underlying this basin are reddish shales, sandstones and conglomerates of Triassic age dipping to the northwest with interbedded lava flows of basalt and intrusive sills of diabase. Along its eastern border this sedimentary sequence is concealed beneath the overlapping sediments of the Coastal Plain, and underlie much of Staten Island and the western end of the Raritan Estuary.

Manhattan Prong and Reading Prong

These two areas and parts of the Piedmont Province are underlain by highly metamorphosed rocks of Precambrian and early Paleozoic age. The rocks are mainly gneisses and schists complexly folded and faulted. Outcrops of these rocks are exposed at the eastern end of Staten Island, northwestern Brooklyn and throughout Manhattan. Their only importance to this study is that both the Hudson and Raritan rivers flow through these regions, and derive some of their sediment loads from the erosion products of these rocks.

Topography

Much of the topography and bathymetry within the study area is the product of glacio-fluvial processes modified by subsequent wave and current action. Approximately 11,000 years ago, continental glaciers covered most of northeastern North America. The maximum southerly extent of this ice sheet is marked by a terminal moraine, that, within the study area, extends from the southwestern end of Staten Island to The Narrows, continues through Brooklyn, and eastward along the length of Long Island. At the time of maximum glaciation, sea level was more than 100 m (325 ft) lower than at present and the Lower Bay of New York Harbor was exposed to sub-aerial erosion. Later, as the climate moderated and the ice retreated, melt water streams flowed across the area cutting-channels and depositing sediment. With the rise in sea level, marshes formed, sites of sediment deposition and channel erosion shifted, and shoreline features migrated landward. The lower portion of the valleys of the Hudson and Raritan rivers were drowned creating estuaries, and the previously formed glacio-fluvial features were subjected to modification by the action of waves and currents. The interaction of these processes created an area of diverse and rapidly changing topography that is being further modified by the activities of man.

The topography of the northern part of Staten Island is irregular with elevations reaching 90 m (300 ft), or more, above sea level in several locations. Todt Hill the highest point at an elevation of 120 m (400 ft) is formed of outcroping serpentine bedrock. The dominant topographic feature along the south coast is the terminal moraine that roughly parallels the shore. The surface of this moraine is irregular with randomly spaced knobs and depressions. Elevations along the length of this feature vary between 15-30 m (50-100 ft). South of the moraine is a glacial outwash plain averaging 2 km (1 mi) or less in width, and having a maximum elevation of 12 m (40 ft). The outwash plain has a gentle seaward slope and merges into tidal marshes and beaches. No streams of any consequence have developed along this shore.

The south shore of the Raritan estuary extends from the mouth of the Raritan River on the west to the Atlantic Highlands on the east. The Atlantic Highlands are high bluffs rising from the shore to elevations in excess of 60 m (200 ft). These are the seaward end of the cuesta which trends south-southwest from the Highlands becoming progressively farther inland. The cuesta consists of a series of short ridges and hills which, in places, rise to elevations greater than 90 m (300 ft). West of the Highlands the coast is mostly low and flat, with much of the area covered by tidal marshes; a number of short creeks rise on the northwest slope of the cuesta and flow into the estuary. All are tidal in their lower courses, and all are bordered by swamps and marshes.

Sandy Hook is a sand spit that has gradually grown northward as the headlands, formerly projecting beyond what are now Long Branch and Asbury Park, were eroded by waves and the resulting sand transported northwards by longshore currents. The north end of the spit is reported to have advanced approximately 2 km (1 mi) in 200 years, and nearly 1 km (0.5 mi) since 1865. The surface of Sandy Hook is covered with low sand dunes interspersed with low sandy beach ridges.

To the east, both Brooklyn and Queens consist of two physiographically different areas: the terminal moraine forming the northern half, and a glacial outwash plain forming the southern part. The terminal moraine is a conspicuous hummocky ridge extending from northeastern Queens southwesterly across Brooklyn to The Narrows. The highest elevation, 85 m (280 ft), is located on the terminal moraine in northeastern Queens. North of the moraine the land surface consists of dissected, low rolling hills with an overall slope towards East River and Long Island Sound. To the south of the moraine the surface is flat with a gentle slope towards the Atlantic Ocean merging into tidal marshes, shallow bays, and beaches. Along the shore the natural physiography has been greatly altered by the construction of many structures and extensive development. Coney Island is a former barrier beach which has been joined to the larger land body of the main island by fill. Rockaway Beach is a narrow peninsula attached to the main island at its east end. It formed by the western elongation of a sand spit resulting from the rapid accumulation of littorally drifted sediment. Prior to stabilization by a jetty, the westward growth of the spit averaged 68 m (222 ft) per year over approximately the past 100 years. Jamaica Bay, located on the north side of Rockaway Beach, is a shallow embayment with numerous small marshy islands, and bordered by extensive tidal marshes. Rockaway Inlet, with an east-west alignment, enters Lower Bay between Coney Island and the west end of Rockaway Beach. It provides a tidal connection between Jamaica Bay and the ocean. East Rockaway Inlet forms the eastern terminus of Rockaway Beach separating it from the barrier beach system farther east.

Stratigraphy

A succession of Coastal Plain sedimentary formations of Late Cretaceous and Tertiary ages with an aggregate thickness of approximately 150 m (500 ft) outcrop along the south shore of the Raritan Estuary, Fig. 3. These sediments consist mainly of marine clay, silt, and gravelly sand, which for the most part are unconsolidated. Locally, beds within the formations have been cemented by iron oxide and iron carbonate, forming resistant layers. According to Minard (1969) these formations strike N 50-70° E, and dip to the southeast about 20 m/km (40 ft/mi). Overlying the Tertiary formations are unconsolidated sediments of Quaternary age. These range in composition from clay to gravel and are of both marine and alluvial origin derived from erosion of older formations. Borings taken along the length of Sandy Hook and at the end of the shorter of the U.S. Navy piers indicate the Upper Cretaceous and Tertiary formations are truncated by an erosion surface which deepens northward into Lower New York Harbor (Minard, 1969). Quaternary sediments up to 60 m (200 ft) thick overlie this erosion surface.

Bordering the Staten and Long Island shores of Lower New York Harbor are unconsolidated sediments of Pleistocene and Recent geologic age. The terminal moraine which extends as a narrow band across Brooklyn and Staten Island consists of a heterogeneous mixture of sand, gravel, boulders, and clay. Glacial outwash of sand mixed with some gravel forms a surface layer of variable thickness between the terminal moraine and the shoreline, and continues seaward comprising the upper sediments of the continental shelf. Along the shoreline are beach sands, and intermittent tidal marshes.

Red shales and sandstones of Triassic age underlie parts of Staten Island and the west end of Raritan Bay, and may extend under Lower New York Harbor at a depth of approximately 100 m (328 ft).

Bathymetry

The Lower Bay

The Lower Bay of New York Harbor encompasses the drowned lower valleys of the ancestral Hudson and Raritan rivers. The bathymetric features of this area are the product of several geological processes. Subaerial erosion occurred during periods of lowered sea level associated with the Pleistocene ice ages. Deposition and erosion formed banks and channels as melt water streams from the retreating continental glacier flowed across the area. As sea level rose, the area was gradually submerged, and the bottom was further shaped by the action of waves, currents and other littoral processes. Finally, man has altered the natural bathymetry by dredging channels through the area, filling some areas with his solid wastes, and deepening other localized areas that were mined for sand and gravel. Modification is continuing in response to natural processes and the activities of man. There is local advance and retreat of the shoreline along Lower New York Harbor. Sandy Hook is advancing northward as new littoral material is deposited, and within the bays there is some minor shifting of depths. However, with the exception of areas subject to dredging or artificial filling, there are no major or rapid changes occurring in the bathymetry of the Lower Bay of New York Harbor. The bathymetry of the region is shown in Fig. 4.

The portion of the continental shelf bounded by the south shore of Long Island and the New Jersey shore is known as the New York Bight. At the apex of this bight is the entrance to the Lower Bay of New York Harbor. The shelf in the vicinity of the apex is a relatively flat sandy plain sloping gently to the southeast at about 1 m/km (6 ft/mi). The surface topography

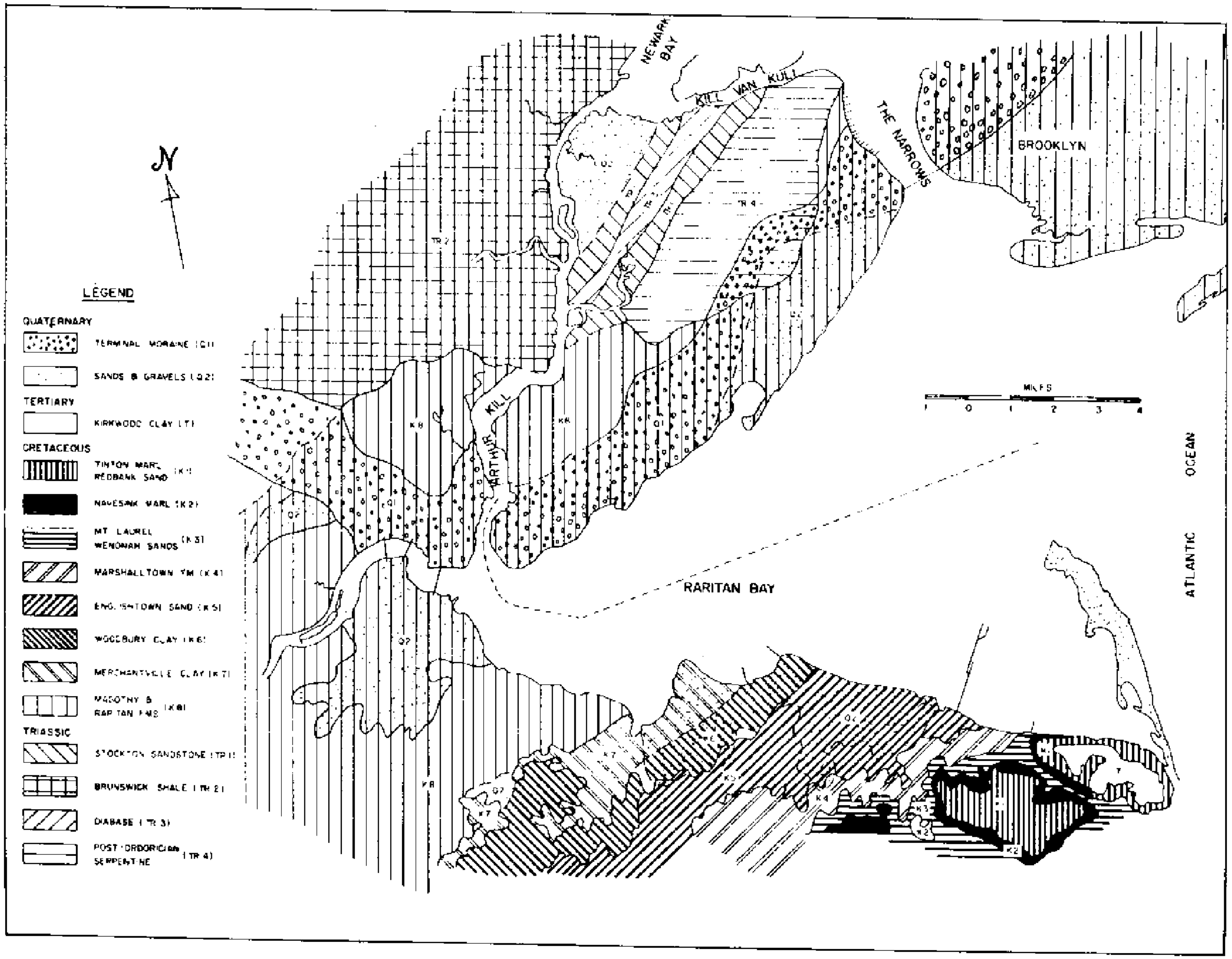

Fig. 3. Geologic Map. After Nagle (1967), modified.

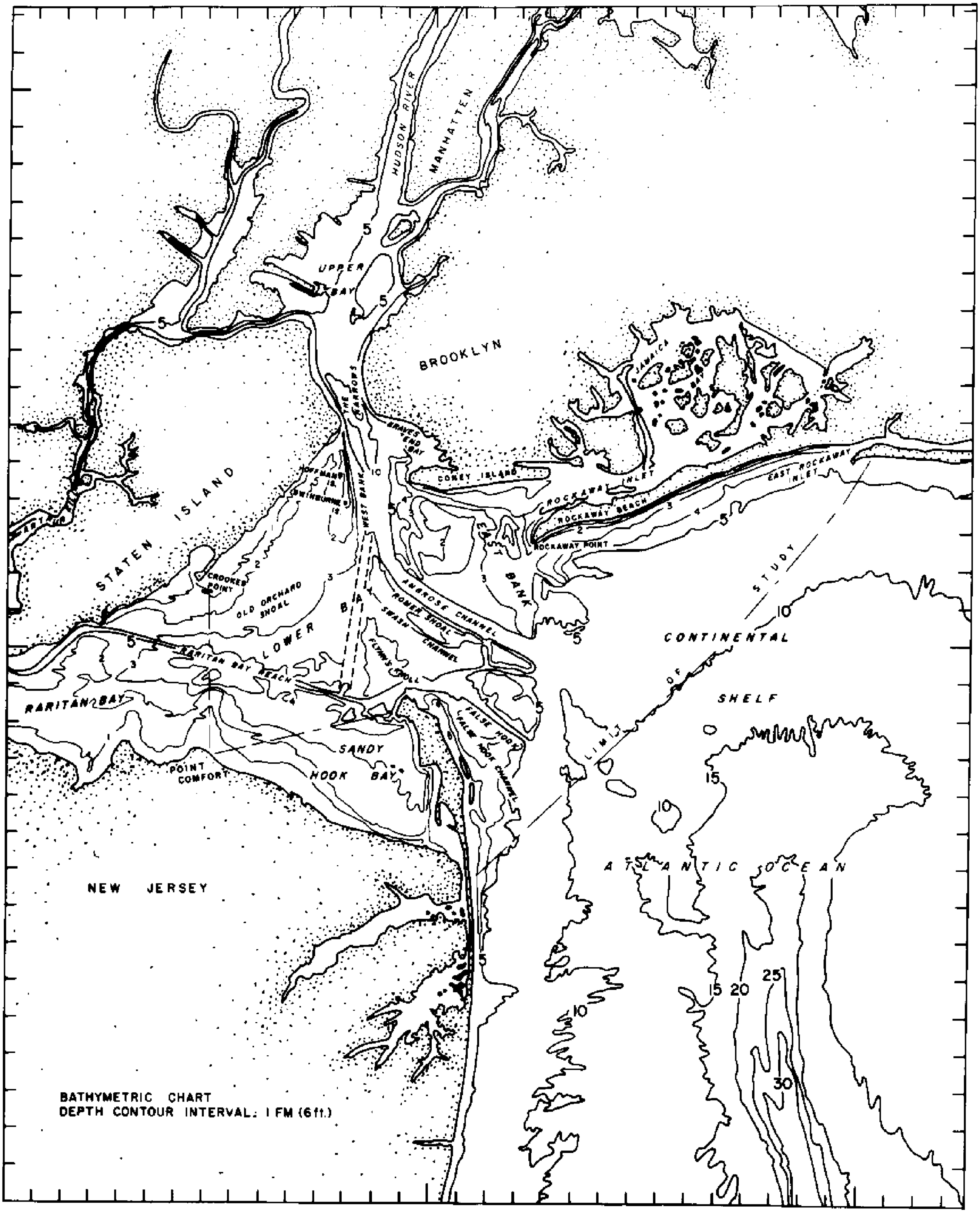

Fig. 4. Bathymetric Chart

consists of broad swells and shallow depressions that are oriented approximately parallel to the present shoreline. Sand waves and ripples are superimposed on this general topography. The submerged channel of the Hudson River trends north-south in this part of the continental shelf, is 5-6 km (3-4 mi) wide and cut 10-30 m (30 to 100 ft) into the general surface of the continental shelf, and approaches to within a few kilometers of the coast.

The seaward entrance to the Lower Bay of New York Harbor is located between the northern tip of Sandy Hook, New Jersey, and Rockaway Point, Long Island, and is approximately 10 km (5.5 mi) in width. Ambrose Channel, which has been dredged to a control depth of 14 m (45 ft), extends through this entrance from the 15 m (48 ft) depth contour on the continental shelf to the submerged gorge of the Hudson River at The Narrows. Maximum depths within The Narrows exceed 27 m (90 ft). Except for water depths within the shipping channels, water depths within Lower New York Harbor are generally less than 10 m (30 ft). Within Lower Bay several extensive shoal areas rise above the general level of the bottom. East of Ambrose Channel a large shoal known as East Bank has formed between the channel and Rockaway Point. Extensive portions of this shoal have depths of less than 3 m (9 ft) at mean low water.

Located southwest of Ambrose Channel and north of Sandy Hook are two shoals separated by a natural channel. Romer Shoal is long and narrow with a northwest-southeast orientation that parallels Ambrose Channel. Water depths of less than 2 m (6 ft) are common near its southeast end. Flynn's Knoll is elongate in a northerly direction, and rises to within about 3 m (10 ft) of the water surface. It is located directly north of the tip of Sandy Hook. Swash Channel is a natural passage between Romer Shoal and Flynn's Knoll. Water depths within this channel vary between 5-9 m (18-29 ft) at mean low water.

West Bank is an elongate shoal with a north-south orientation which borders the western edge of Ambrose Channel from The Narrows south for approximately 5 km (3 mi). In the past, extensive portions of West Bank have been dredged for fill material. However, much of this area is still very shallow with water depths ranging from 0.3-5 m (1-17 ft). Swinburne Island and Hoffman Island are small artificial islands constructed on West Bank. A narrow dredged channel with depths of 2-3 m (6-11 ft) extends south from The Narrows to these islands.

Raritan Estuary

Raritan Estuary is that portion of the Lower Bay of New York Harbor west of a line joining the northern tip of Sandy Hook and the western shoreline of the Narrows Fig. 1. Along its eastern boundary it extends for 19 km (12 mi) in a north-south direction, and along its center line in an east-west direction measures 19 km (12 mi). The total areal extent of the estuary is approximately 197 km (72 mi). As previously mentioned, the Raritan Estuary has been subdivided into three bays, Sandy Hook Bay comprising that portion south of a line drawn between the northern tip of Sandy Hook and Point Comfort on the New Jersey shore, Raritan Bay comprising the area west of a line drawn between Point Comfort and Crookes Point on Staten Island, and the northeastern part which is included in Lower Bay.

Raritan Estuary is a shallow embayment with water depths less than 10 m (30 ft) except for two very small areas near the center line of the estuary, a deep area immediately offshore of the northwest tip of Sandy Hook, and within the dredged channels. Bathymetric depth contours generally parallel the shoreline configuration. The 6 m (18 ft) depth contour, with the exception of the western shore of

Sandy Hook, is located more than 1.6 km (1 mi) offshore. Bottom gradients are generally less than 1:200, and in places are as flat as 1:2000.

Sandy Hook Bay has water depths in excess of 9 m (30 ft) immediately off the northern tip of Sandy Hook, but shoals gradually southwards to a depth of 2 m (6 ft), 0.3-1.3 km (0.2-0.8 mi) offshore. Off Point Comfort, where there is extensive shoaling, the 2 m (6 ft) depth contour is located more than 1.6 km (1 mi) offshore.

Raritan Bay is very shallow, and except for a small area at the eastern end of the bay and the dredged channels, water depths are less than 6 m (18 ft). Old Orchard shoal located directly south of Crookes Point has water depths of less than 1.5 m (5 ft) over it.

A number of dredged channels have been cut through the estuary to provide access for shipping. Sandy Hook Channel with a project depth of 11 m (35 ft), provides a route from the sea to deep water in Lower Bay. It connects with Raritan Bay Channel to the west, Chapel Hill Channel to the north, and Terminal Channel to the south. Chapel Hill Channel has a project depth of 9 m (30 ft). Terminal Channel provides access to the U.S. Navy ammunition piers at Leonardo. The controlling depth in this channel is 9.1 m (30 ft). Raritan Bay Channel extends westward through Lower Bay and the northern part of Raritan Bay to connect with Arthur Kill and the Raritan River. This channel has a project depth of 10.7 m (35 ft). Several short channels interconnect the Raritan River, Arthur Kill, and Raritan Bay Channel at the west end of Raritan Bay. An extensive turning basin has been dredged to depths of 11.3 m (37 ft) at the junction of these channels.

Several additional minor dredged channels that provide access to small boat harbors interrupt the configuration at the bottom. A channel with a controlling depth of 2.7 m (9 ft) extends from Great Kills Harbor out into Lower Bay to the 3 m (10 ft) contour. Off the entrance to Cheesequake Creek, a channel 1.5 m (5 ft) deep and 23-30 m (75-100 ft) wide extends from the 1.5 m (5 ft) depth contour in Raritan Bay to the mouth of the creek, a distance of about 0.5 km (1600 ft). A channel about 1.6 km (1 mi) in length, 2.4 m (8 ft) deep and 61 m (200 ft) wide extends from the steamboat dock at Keyport out into Raritan Bay. At Shoal Harbor and Compton Creek a 3.7 m (12 ft) deep channel, 46 m (150 ft) wide and 2.1 km (1.3 mi) long extends into Sandy Hook Bay to the 3.7 m (12 ft) depth contour. An entrance channel, 2.4 m (8 ft) deep, 45.7 m (150 ft) wide, and about 760 m (2500 ft) long leads from the 2.4 m (8 ft) depth contour in Sandy Hook Bay to a small boat harbor at Leonardo. At Atlantic Highlands the area in the lee of the breakwater has been dredged to a depth of 2.4 m (8 ft).

Circulation in the Lower Bay

This brief description of circulation in Lower New York Harbor is presented to aid in understanding sediment transport within the Harbor. Duedall et al.(1978) have presented an informative synthesis of existing knowledge on circulation in the Lower Bay which includes a useful bibliography.

Water movements in the Lower Bay are dominated by tidal currents of semi-diurnal period. The Bay is relatively wide and shallow with several open boundaries, and it exhibits complex channel topography and shoreline geometry. There are also a number of sources of fresh water to the Bay including the Hudson and Raritan Rivers. These factors combine to produce patterns of tidal flow which are both vertically and horizontally complex.

Tidal currents in the Lower Bay

can exceed 150 cm/s (3 knots) with maximum currents occurring within The Narrows and the Sandy Hook-Rockaway Point Transect. Within the western part of the Bay, tidal currents are generally less than 50 cm/s (1 knot) except within the Raritan River.

Figures 5a-5c show current vectors at a number of stations in the eastern and central parts of the Bay on maximum ebb and maximum flood. These vectors show the asymmetry in both current magnitude and direction which can occur between flood and ebb. These asymmetries, produced by the combination of factors mentioned earlier, maintain the nontidal circulation patterns which contribute to the net nontidal transport of sediment within the Lower Bay. Present knowledge of these nontidal circulation patterns is, however, sketchy and based on current observations from a number of older National Ocean Survey studies. A more detailed picture of this circulation must await a comprehensive modern survey.

Nontidal flow patterns in the Bay are somewhat characteristic of those for an estuary. In a typical estuary horizontal density gradients are established by the freshwater input at the head of the estuary. Gravitational forces associated with these gradients maintain a net nontidal circulation in which water in the surface layers moves seaward and water at depth moves up the estuary. The vertical section of nontidal currents at the Narrows in Fig. 6 illustrates the seaward flow in the surface layers and the upstream flow at depth. Because of Coriolis acceleration the boundary between inflowing and outflowing waters has a lateral slope; it is deeper on the right side of the estuary (looking down stream) than on the left.

Figures 6 and 7a-7c also illustrate the structure of nontidal flow within the Sandy Hook-Rockaway Point transect where inflow occurs at depth within the Sandy Hook and Ambrose channels and at all depths on the Rockaway Point side of the transect. Doyle and Wilson (1978) have shown that this structure is well described by a lateral momentum balance between Coriolis acceleration due to the nontidal flow, centripetal acceleration associated with tidal currents within the transect, and the lateral pressure gradient due to the lateral variations in density. Because of bottom topography and channel configurations, the seawater flowing in through Ambrose Channel proceeds upstream through The Narrows, and much of the inflow through the Sandy Hook Channel proceeds into Raritan Bay (Figs. 7a-7c). Waters flowing inward on the Rockaway Point side of the transect move northward and mix laterally with the seaward flow from the Narrows.

Raritan Bay constitutes another estuarine system which interacts with the system just described. Fresh water discharge from the Raritan River produces east-west density gradients which drive an estuarine circulation. This circulation involves a modest flow of saline water westward at depth. This water enters Lower Bay through Sandy Hook Channel (Fig. 8a) and remains confined to the channel or it flows westward. Some of this water may flow northward through Chapel Hill and Swash Channels to eventually pass through The Narrows. In addition to this westward flow into Raritan Bay, there is a seaward drift of fresher water which is confined to the south side of Raritan Bay; it is seperated horizontally from the westward flow of slightly more saline water (Figs. 7a-7c). This structure is characteristic of many wide estuaries and is associated with Coriolis accelerations.

Figure 8b represents an idealized picture of the nontidal circulation patterns within the Lower Bay. It shows that south of Old Orchard Shoal the outflow from The Narrows is deflected to the right by Coriolis acceleration into the north central part of Raritan Bay. Some of this water penetrates into Raritan Bay where it mixes and becomes part of the

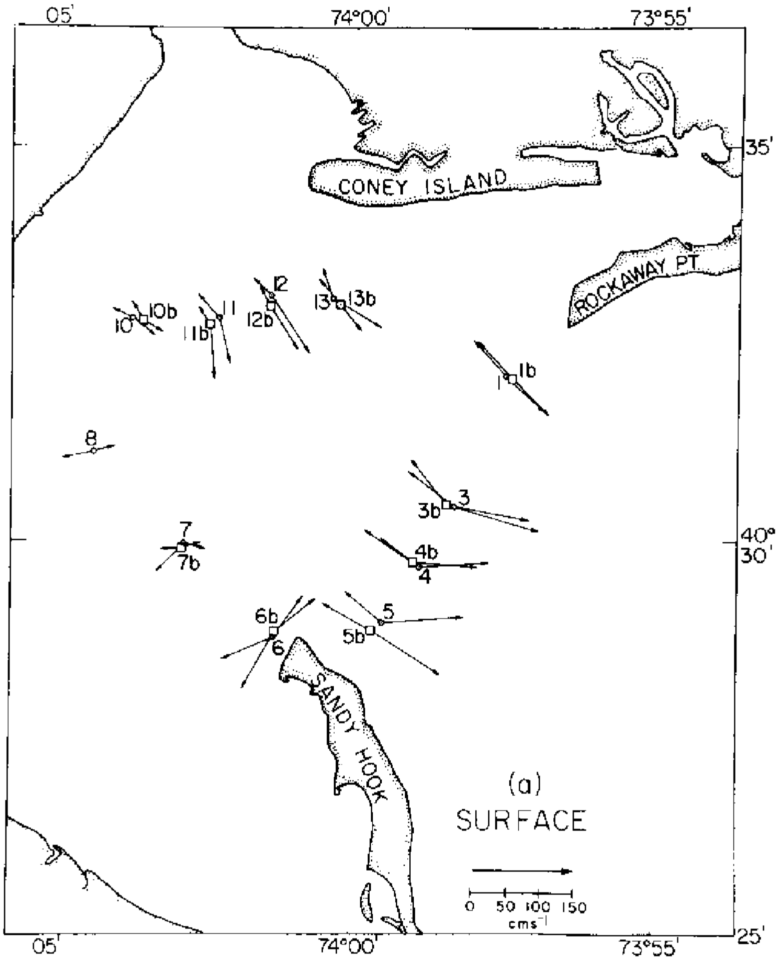

Fig. 5a. Surface current vectors for maximum flood and maximum ebb at the 1958-1959 U.S. Coast and Geodetic Survey stations. From Doyle and Wilson (1978).

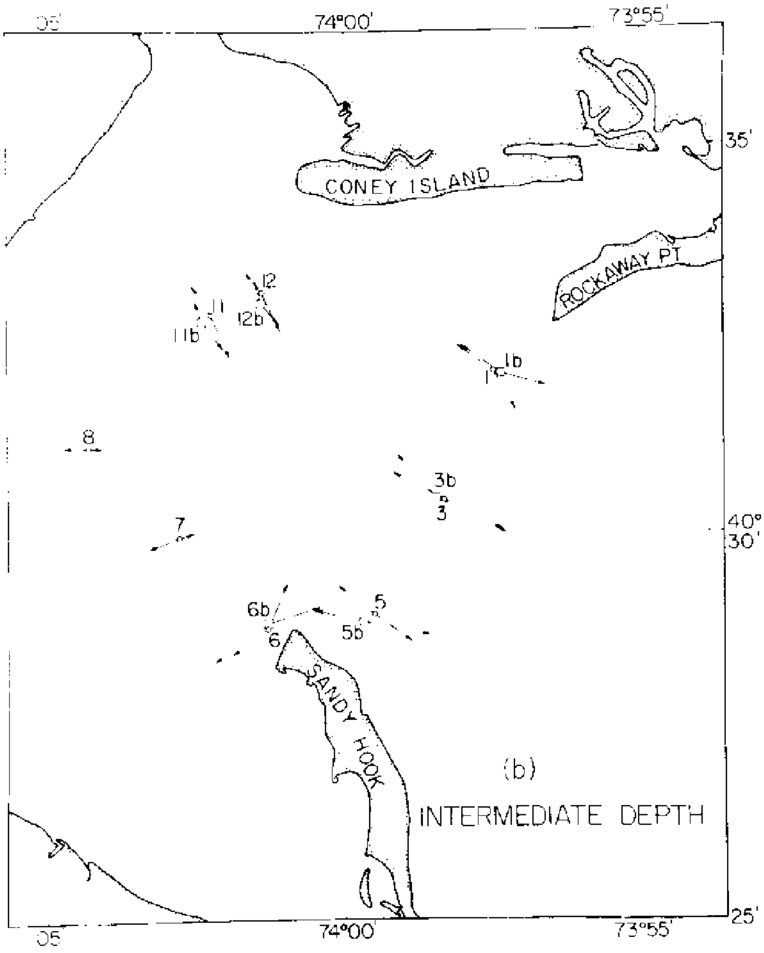

Fig. 5b. Intermediate depth current vectors for maximum flood and maximum ebb at the 1958-1959 U.S. Coast and Geodetic Survey stations. From Doyle and Wilson (1978).

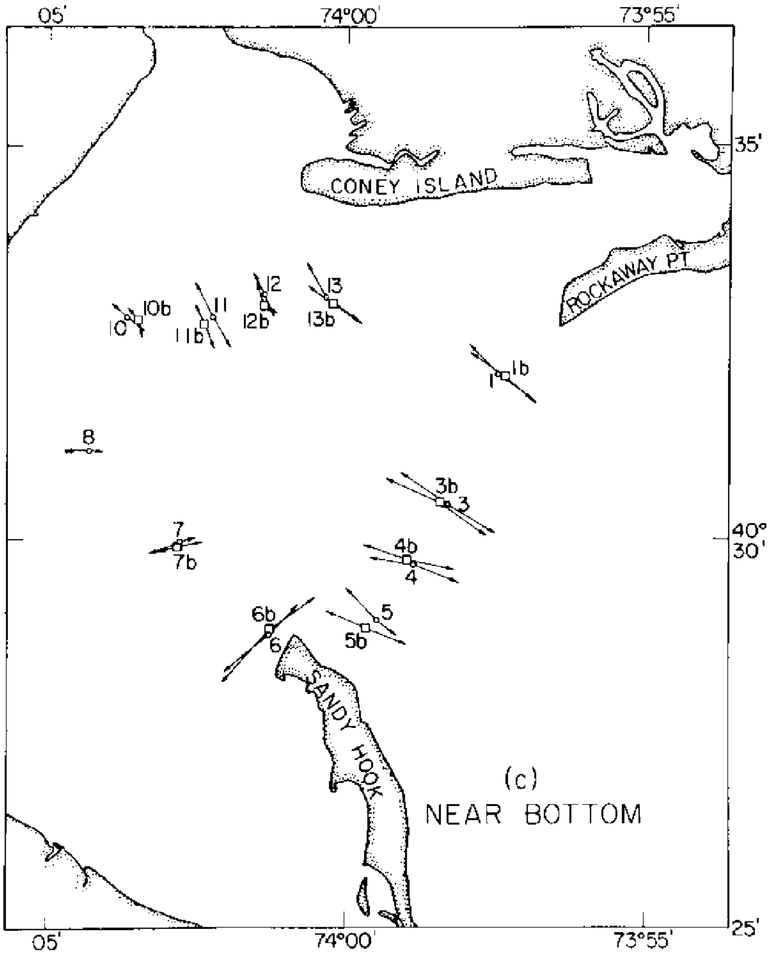

Fig. 5c. Near bottom current vectors for maximum flood and maximum ebb at the 1958-1959 U.S. Coast and Geodetic Survey stations. From Doyle and Wilson (1978).

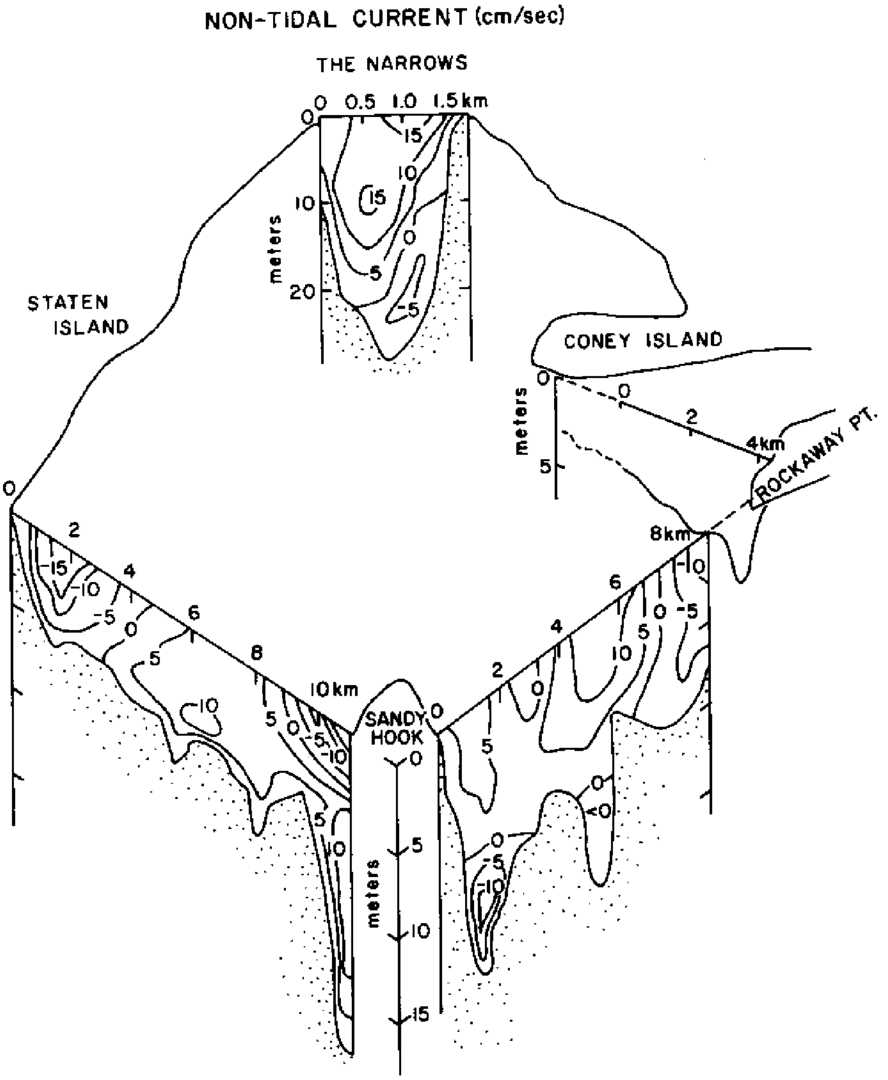

Fig. 6. Nontidal flow at sections in Lower Bay. Positive velocity is out of page. From Duedall et al. (1978).

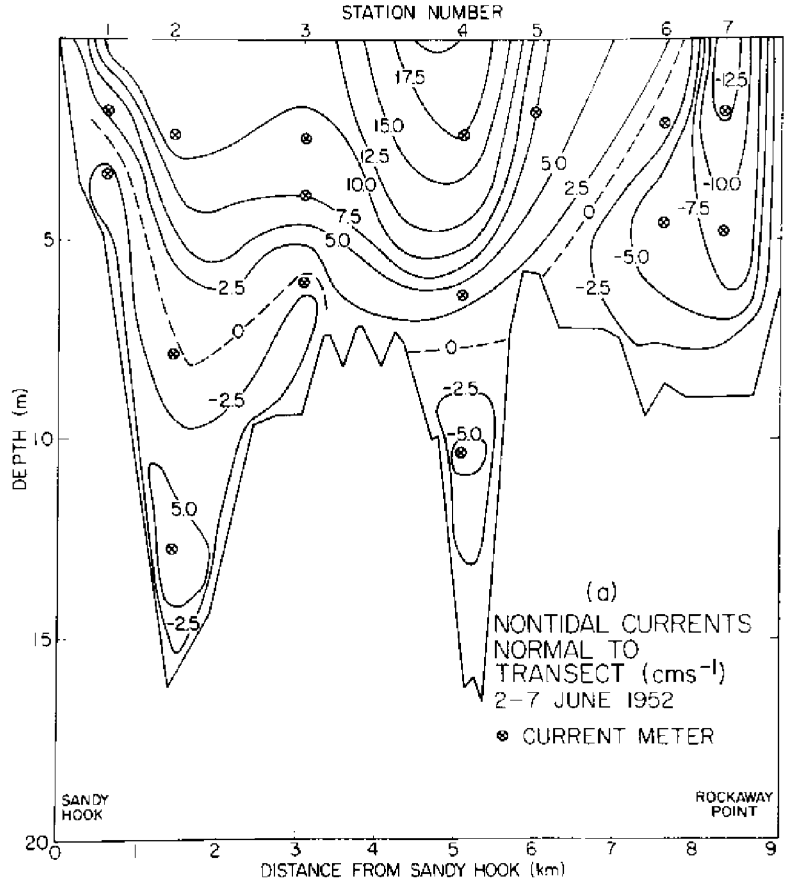

Fig. 7a. Nontidal currents normal to the Sandy Hook to Rockaway Point Transect computed for 2-7 June 1952. Positive flow is seaward. From Doyle and Wilson (1978).

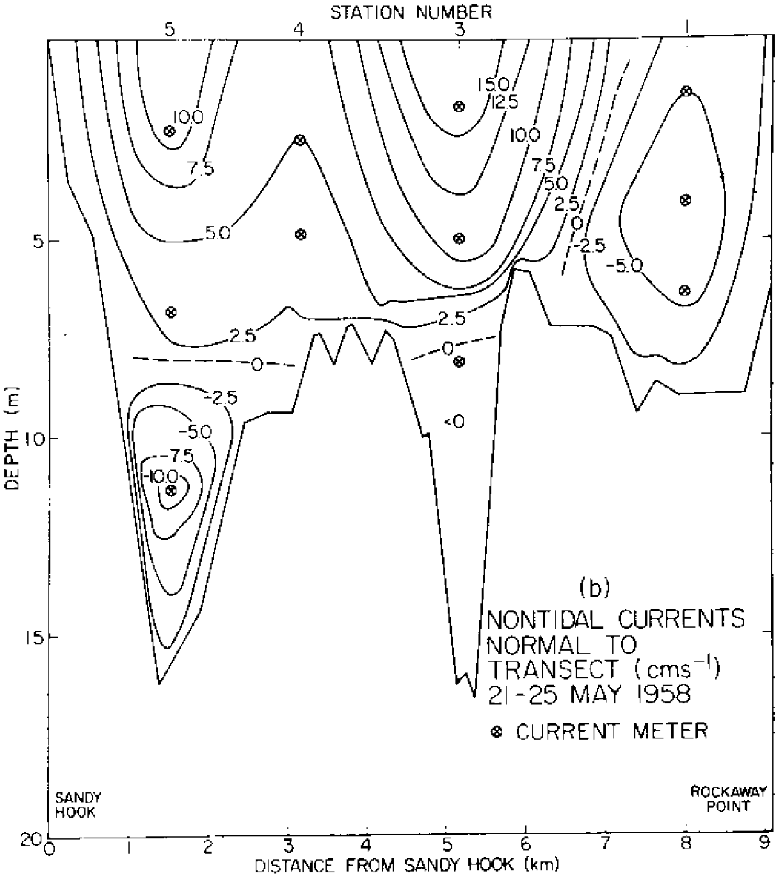

Fig. 7b. Nontidal currents normal to the Sandy Hook to Rockaway Point Transect computed for 21-25 May 1958. Positive flow is seaward. From Doyle and Wilson (1978).

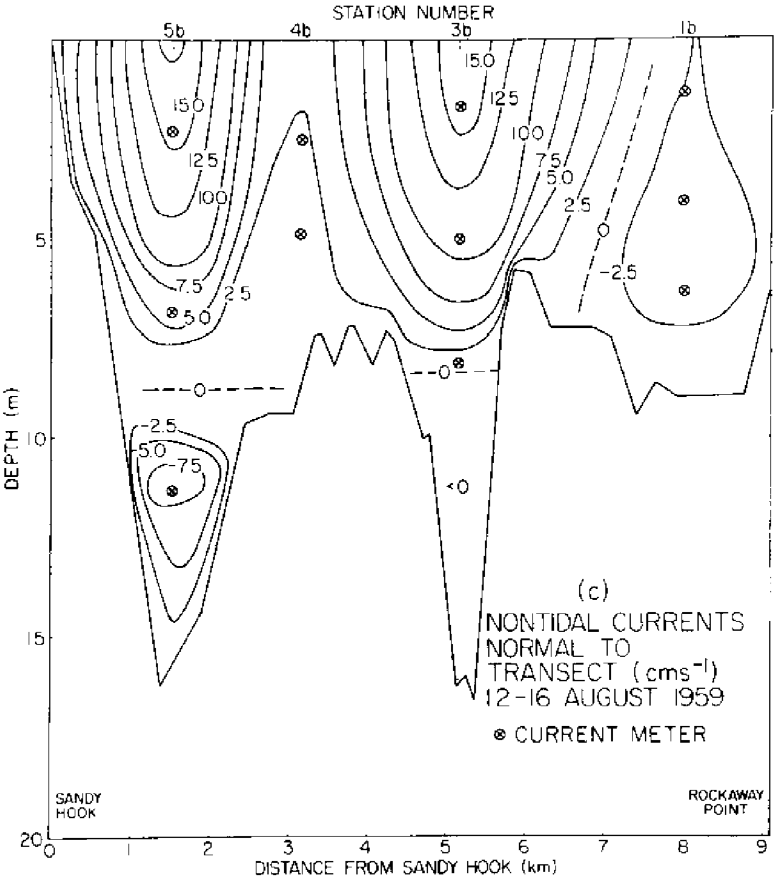

Fig. 7c. Nontidal currents normal to the Sandy Hook to Rockaway Point Transect computed for 12-16 August 1959. Positive flow is seaward. From Doyle and Wilson (1978).

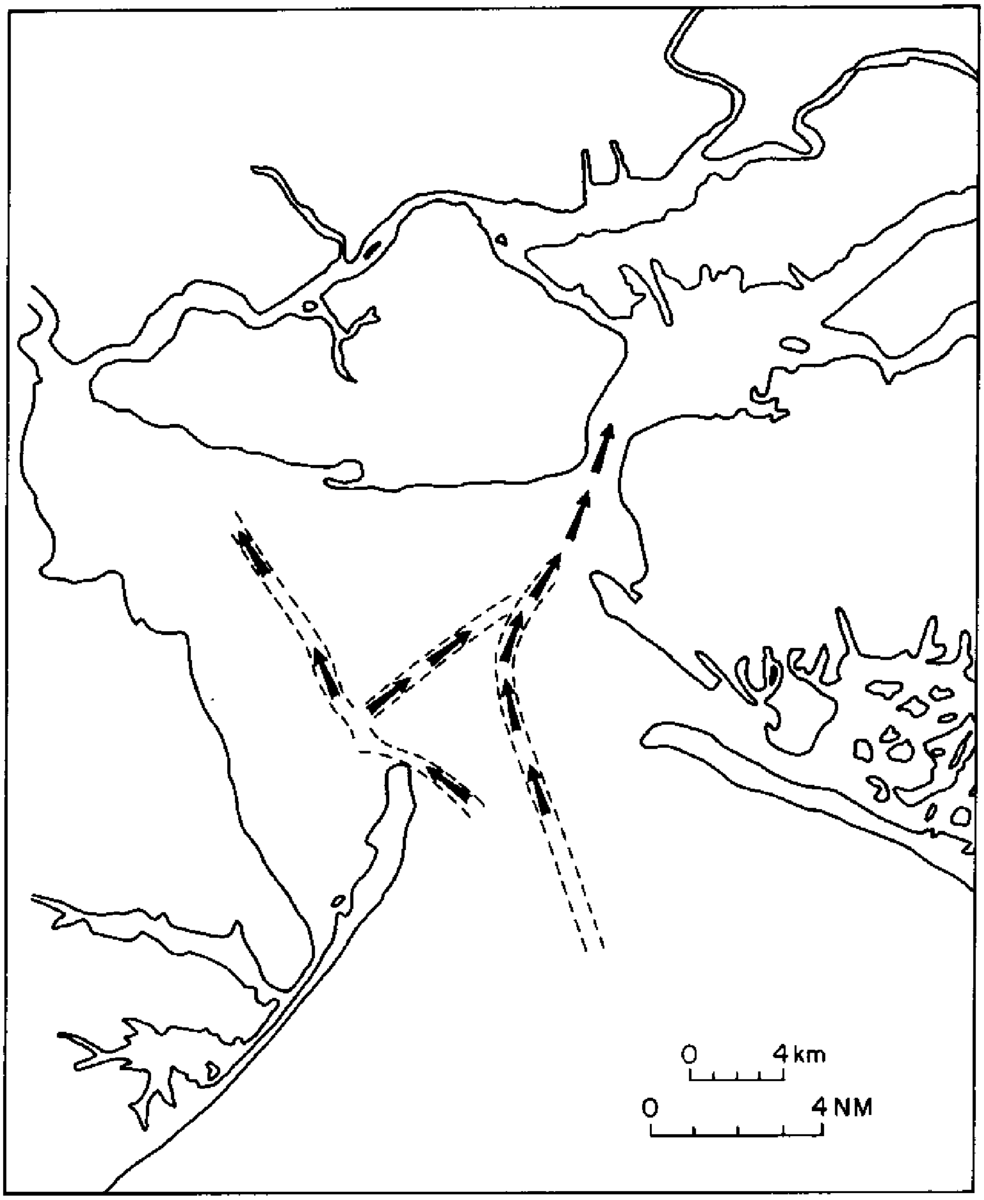

Fig. 8a. Inflow at depth associated with estuarine circulation.

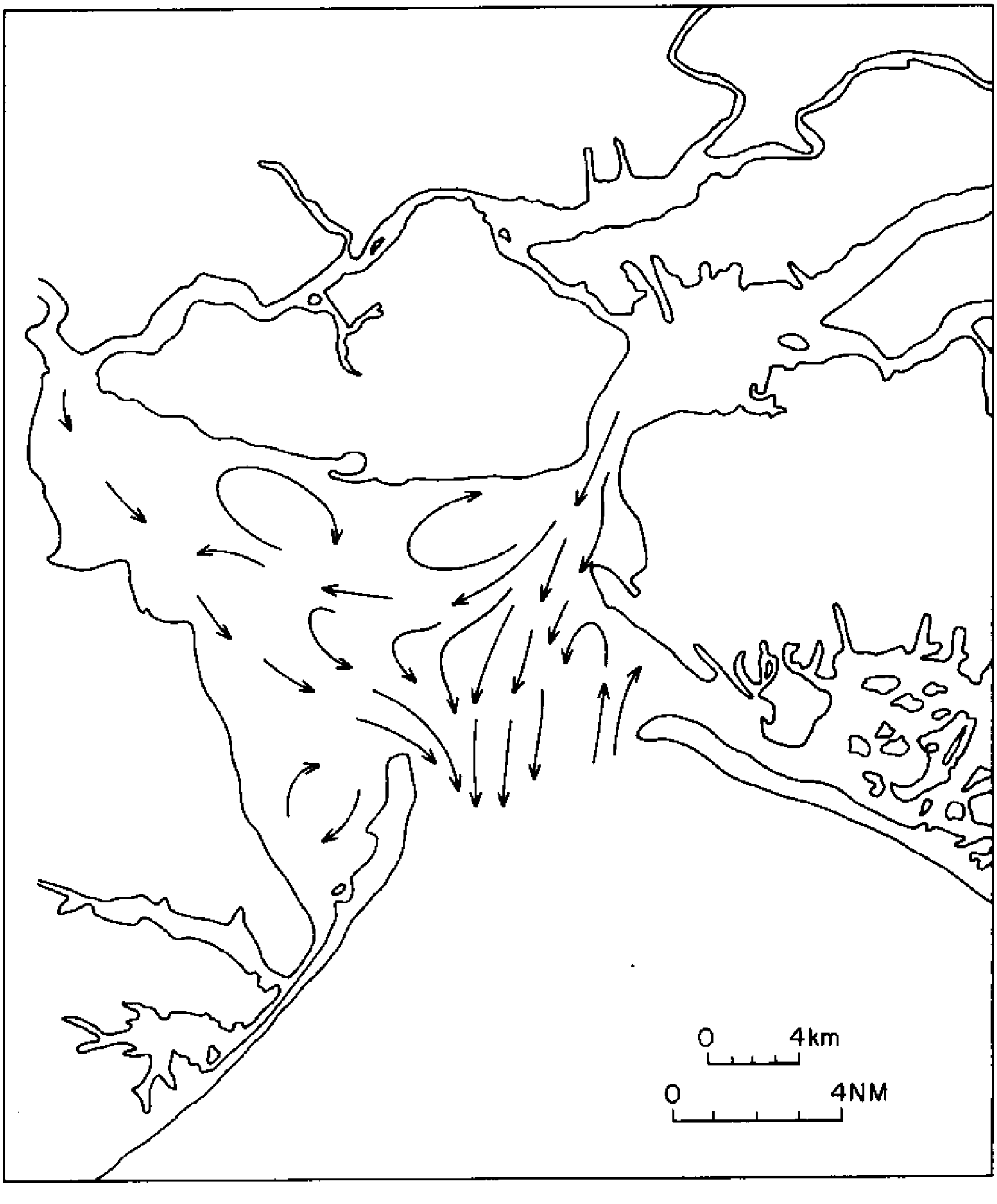

Fig. 8b. Nontidal circulation patterns.

westward drift. There is also some evidence that Old Orchard Shoal produces a blocking effect to water from the Narrows and causes flow to the northwest along Staten Island (Figs. 7a-7c). The deep estuarine flow is confined primarily to the deep channels (Fig. 8a).

BIOLOGICAL PERSPECTIVE

Introduction

The purpose of this section is to briefly review the available information on benthic communities which might be disturbed by dredging in the Lower Bay of New York Harbor. No attempt has been made to provide a detailed analysis of benthic populations or their distributions. The reader should consult the original articles listed in the annotated bibliography for more detailed information.

Between 1957 and 1960 Rutgers University repeatedly sampled the macrobenthos at more than 100 stations in Raritan Bay and Lower Bay using Peterson and Van Veen grab samplers (Dean, 1975). The location of these stations are shown in Figs. 9a,b and 10a,b.

Based on samples taken monthly from February 1966 to January 1967, the Sandy Hook Laboratory, Middle Atlantic Coastal Fisheries Center, compiled a census of the benthic fauna off the southwest coast of Long Island. One transect of six stations between Rockaway Point and Sandy Hook is located within the limits of this study. These station locations are shown in Fig. 11. The results of this survey are reported by Steimle and Stone, 1973.

In 1973 an ambitious survey of the macrobenthos was begun by Sandy Hook Marine Laboratory at 78 stations in the area between Ambrose Channel and the mouth of the Raritan River. Preliminary results are reported in McGrath, 1974. The station locations are shown in Fig. 12.

In 1975, the New York District, U.S. Army Corps of Engineers, examined an area on the East Bank of Ambrose Channel, which was to be used as a sand borrow area (Woodward and Clyde, 1975). Shipek, otter trawl and clam-dredge sampling were conducted both before and after dredging operations. The "pre-dredging" part of the study was actually conducted after some dredging activity had begun, so an undisturbed community may not have been obtained. Station locations are shown in Fig. 13.

A report prepared by the Sandy Hook Laboratory (Walford, 1971) includes an appendix on "Benthic Communities and Shellfish Populations in Lower and Raritan Bay." Dredge hauls and Smith and McIntyre grab samples throughout Lower Bay, Raritan Bay and Sandy Hook Bay were taken at 15 of the stations which the Federal Water Pollution Control Administration (now the Environmental Protection Agency) uses to monitor microbial contamination of commercial shellfish. Unfortunately, the dates and frequency of sampling are not given, nor is a species list included.

Table 1 is a master species list, combining the results of all of the above surveys. We have made no effort to compare the number of individuals, or number of species, at different stations. The wide variations in collecting devices, sampling frequency, and sediment type; the paucity of stations; and the extreme temporal and spatial patchiness of benthos, make such a comparison of little value.

Lower Bay and Raritan Bay

Walford (1971) indicated that the benthic macrofaunal densities of the Lower Bay-Raritan Bay complex are "impoverished in both number of species and number of individuals, relative to similar type estuaries and to the coastal waters of the New York Bight." Walford found a total of 31 taxa with 19 taxa at his most diverse

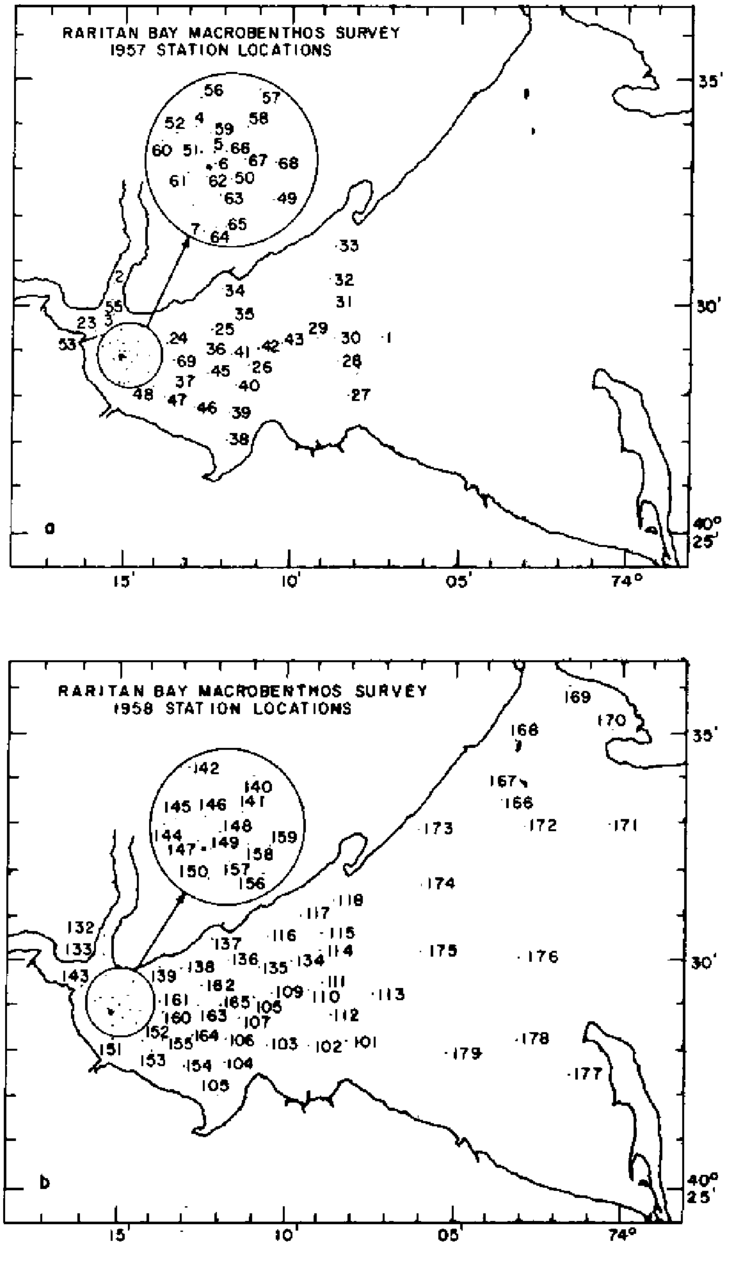

Fig. 9a,b. Raritan Bay macrobenthos survey, 1957, 1958 station locations. From Dean (1975).

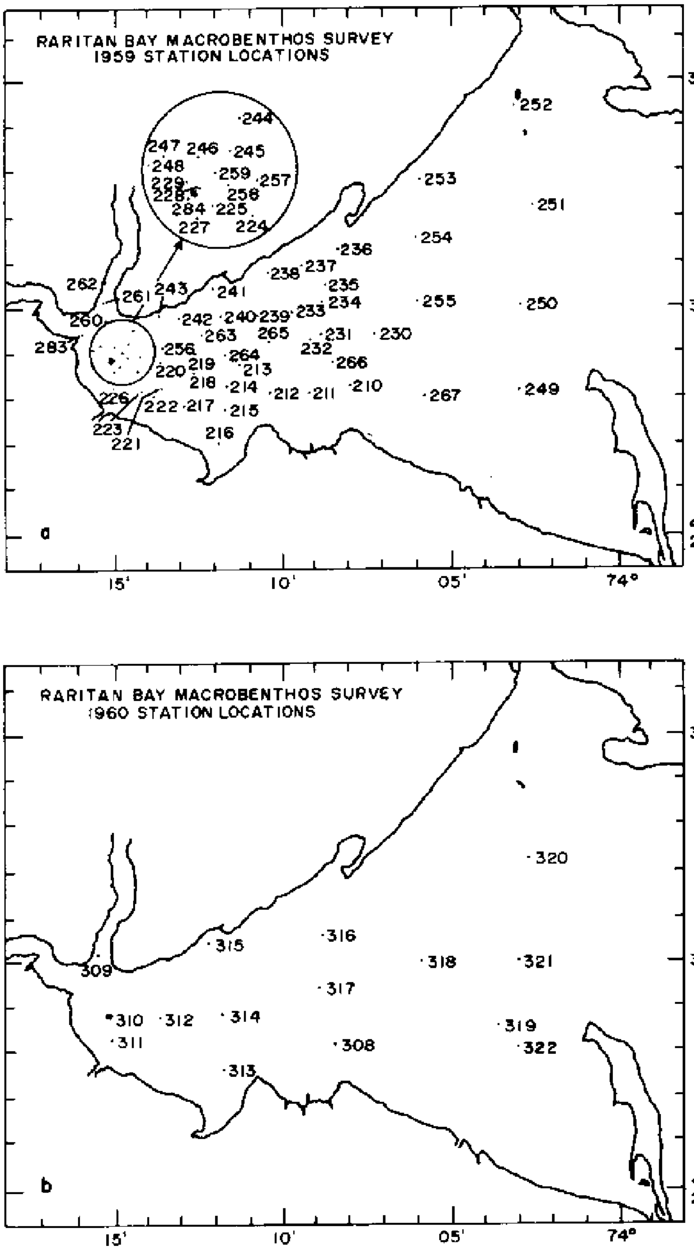

Fig. 10a,b. Raritan Bay macrobenthos survey, 1959, 1960 station locations. From Dean (1975).

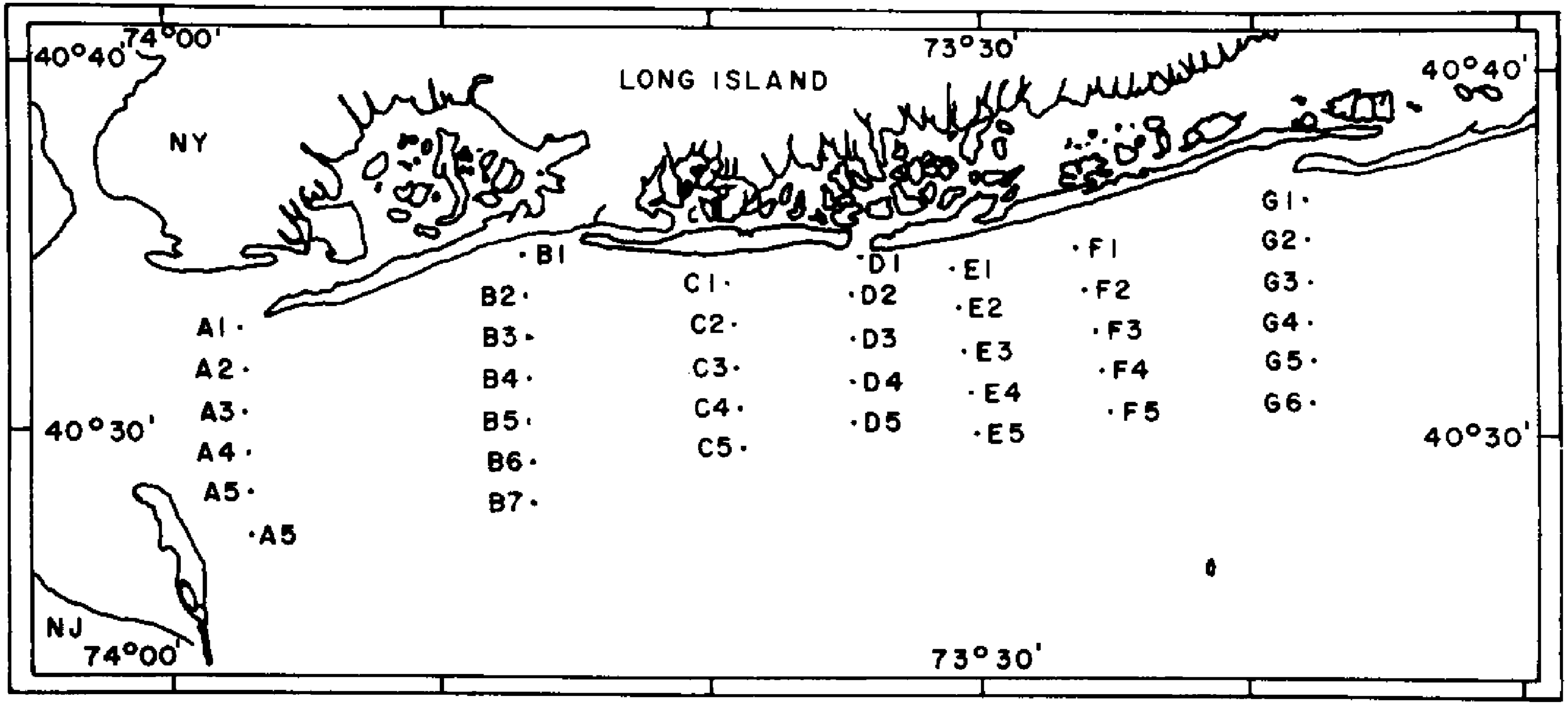

Fig. 11. Station locations, R/V CHALLENGER survey, 1966-67. From Steimle and Stone (1973).

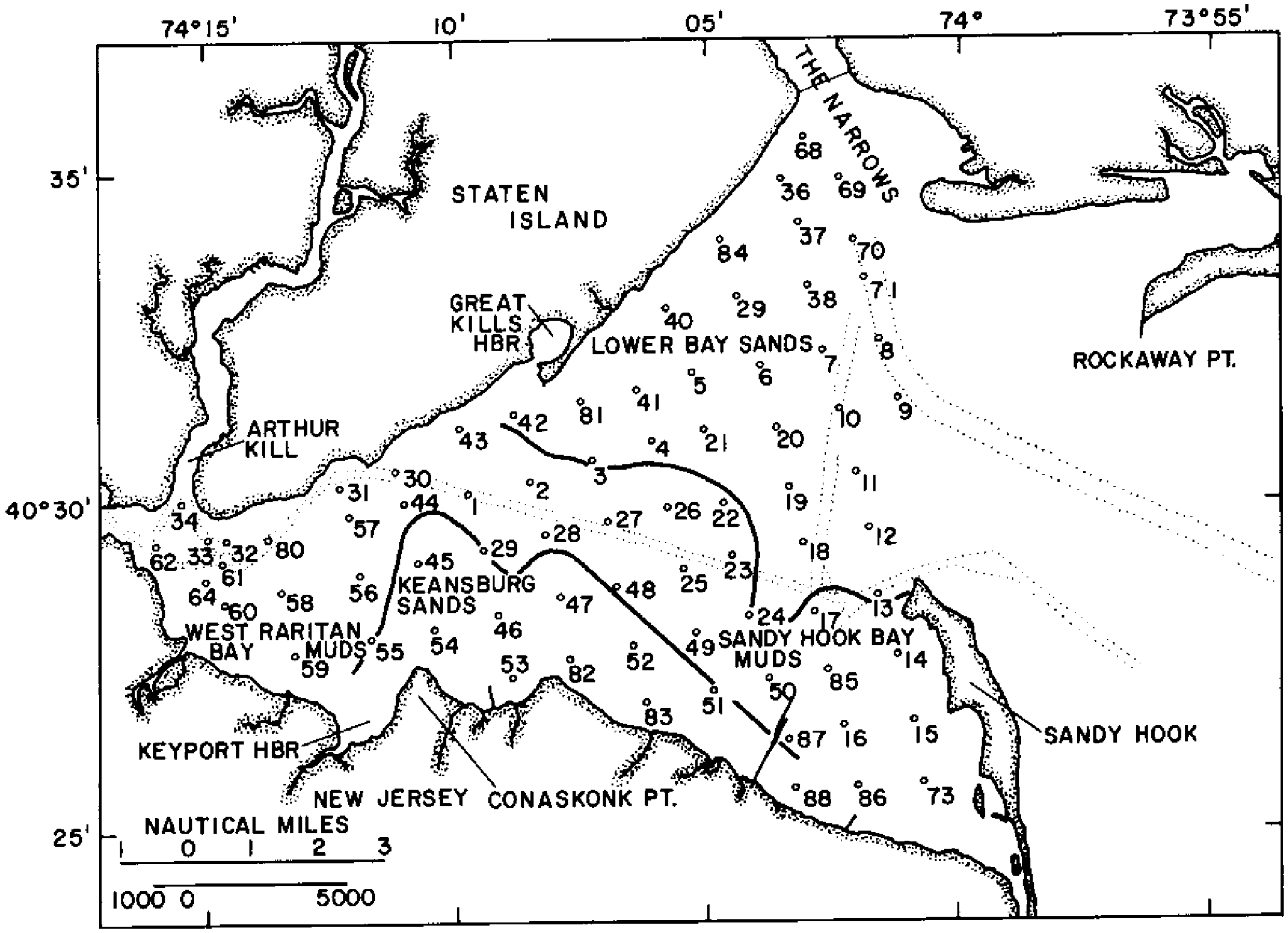

Fig. 12. Stations locations, benthic microfaunal census of Raritan Bay. From McGrath (1974).

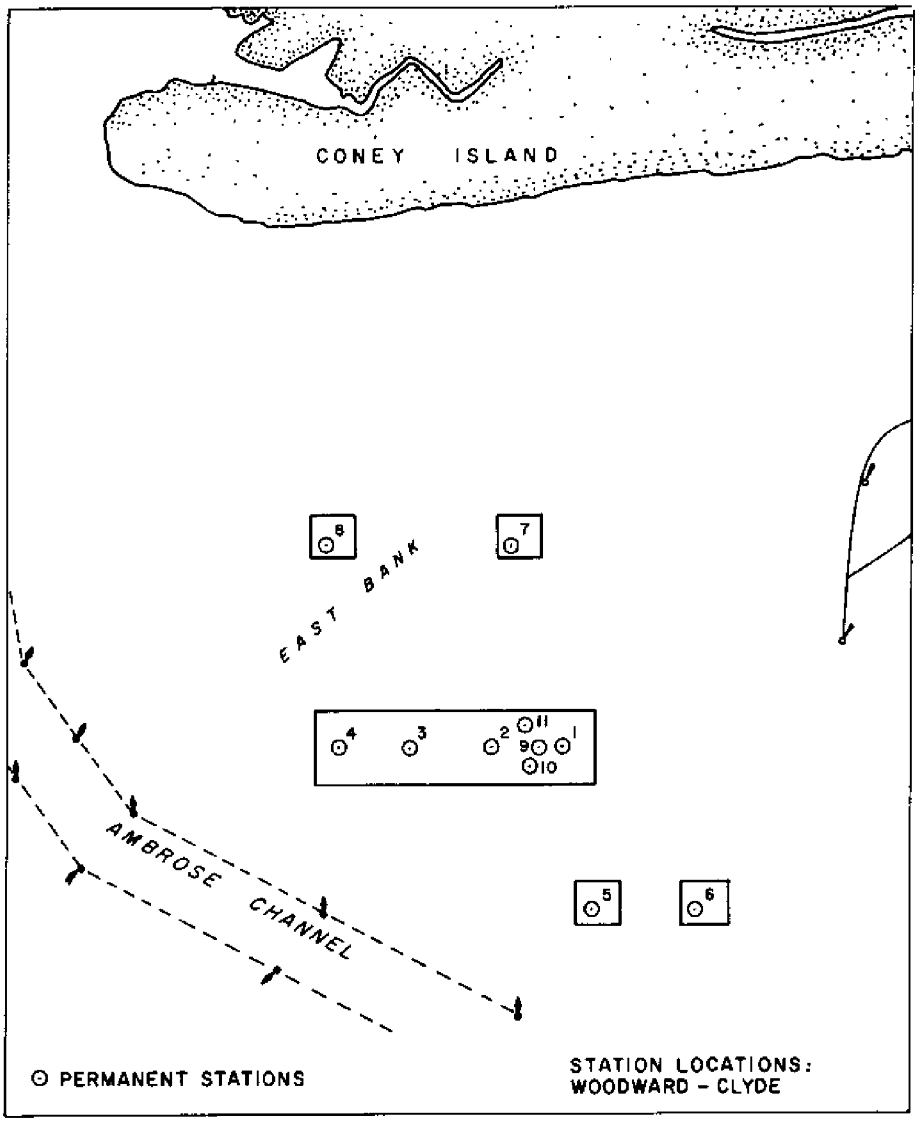

Fig. 13. Station locations, Rockaway Beach erosion control project, dredge materials research program, offshore borrow area. From Woodward-Clyde (1975).

TABLE 1

MASTER SPECIES LIST

Taxon	(**Woodward-Clyde, 1975)			McGrath, 1975	Walford, 1971	Dean, 1975	Steimle, 1967
	Trawl	Shipek	Dredge				
Annelida (Segmented worms)							
Oligochaeta (Aquatic earthworms)		x					
Polychaeta (Bristle worms)							
Ampharetidae		x					
Asabellides oculata		x					
Capitella capitata		x					
Goniadella gracilis		6					
Lumbrineris fragilis			x				
Magelona obockensis		x					
Magelona sp.		x					
Microphthalmus sp.		x					
Nephtyidae		x					
Nephtys bucera			S,M				
Nephtys picta		x	M			x	
Nephtys sp.		x	x				
Nereidae		x					
Nereis acuminata		x					
Nereis sp. (Clam worm)		x					
Phyllodocidae		x					
Pisione remota							
Sabellaria vulgaris				x	x		
Spio setosa				S			x
Spionidae		x					
Spiophanes bombyx		5		x		x	
Tharys acutus		10					
Cirriatulidae		8					
Aricidea suecica				x			
Cirratulis grandis				x			
Eumida sanguinea		x		x			
Glycera dibranchiata				S	x		
Malanidea sp.				x			
Nepthys caeca				M			
Nepthys incisa				S,M	x		
Nereis pelagica				x			x
Pectinaria gouldii				M	x		
Pherusa affinis		x		x			
Polydora ligni		x		S			
Scolecolepides viridis				S			
Spio filicornis		x		x			
Harmothoe extenuata		x					x
Harmothoe imbricata							x
Lepidonotus squamatus							x
Scolepedis squamata							x
Phyllodoce mucosa							x
Autolytus cornutus		x					
Nereis succinea						x	x
Eulalia viridis						x	

TABLE 1 (continued)

MASTER SPECIES LIST

Taxon	(Woodward-Clyde, 1975) Trawl	Shipek	Dredge	McGrath, 1975	Walford, 1971	Dean, 1975	Steimle, 1967
Ampharetidae (Cont'd.)							
Phyllodoce groenlandica						x	
Diopatra cuprea		x				x	
Lumbineris tenuis						x	
Dodecaceria corallii						x	
Hydroides dianthus						x	
Streblospio benedicti				S			
Anthropoda							
Amphipoda (Amphipods)							
Acanthohaustorius millsi		x		S			
Bathypoleia quoddyensis		x					
Elasmopus laevis		x				x	
Haustoriidae		x				x	
Parahaustorius holmesi							x
Parahaustorius longimerus		x					
Paraphoxus spinosus		9				x	
Protohaustorius deichmannae		x		S			x
Protohaustorius wigleyi		x					
Stenothoe minuta						x	
Trichophoxus epistomus		x					x
Listrella sp.		x					
Unciola serrata		x		x	x		x
Microdentopus gryllopotalpa						x	
Ischyrocerus angvipes							x
Jassa Falcata				x		x	
Paraphoxus epistomus				S			
Gammarus annulatus							
Tanaidacea		x					
Leptochelia sp.		x		M			
Decapods							
Caridea (Shrimp)							
Crangon septemspinosa (Sand Shrimp)	x			x			x
Brachyura (Crabs)							
Callinectes sapidus (Blue crab)	x						
Cancer irroratus (Rock crab)	x		x			x	
Libinia emarginata (Spider crab)	x					x	

TABLE 1 (continued)

MASTER SPECIES LIST

Taxon	(**Woodward-Clyde, 1975) Trawl	Shipek	Dredge	McGrath, 1975	Walford, 1971	Dean, 1975	Steimle, 1967
Brachyura (Cont'd.)							
Neopanope texana (Mud crab)							x
Ovalipes ocellatus (Lady crab)	3	x	x				
Anomura (Crabs)							
Pagurus pollicarus (Hermit crab)	2					x	
Cirripedia							
Balanus crenatus						x	
Balanus improvisus				x	x		
Isopoda							
Cyathura polita							
Edotea montosa				S			
Cumacea							
Leptocuma minor		x					
Diastylis sculpta				x			
Oxyurostylis smithi				x			
Ectoprocta							
Alcyonidium polycum						x	
Electra hastingsae						x	
Membranipora tenuis						x	
Schizoporella unicornis						x	
Pices							
Ammodytes americanus (American sand lance)	x						
Etropus microstomus (Smallmouth flounder)	x						
Centropristis striata (Black Sea Bass)	x						
Chilomycterus schoepfi (Striped burrfish)	x						
Hippocampus erectus (Lined seahorse)	x						
Merluccius bilinearis (Silver hake)	x						
Paralichthys dentatus (Summer flounder)	x						
Peprilus triacanthus (Butterfish)	x						

TABLE 1 (continued)

MASTER SPECIES LIST

Taxon	(**Woodward-Clyde, 1975)			McGrath, 1975	Walford, 1971	Dean, 1975	Steimle, 1967
	Trawl	Shipek	Dredge				
Mollusca							
Gastropoda (Snails)							
Busycon canaliculatum (Channelled whelk)	x						
Nassarius trivittatus				S,M*	x		
Polinices duplicatus						x	
Mitrella lunata						x	
Adalaria proxima						x	
Lunatia heros (Moon snail)	x		x	x			
Bivalvia (Clams)							
Mytilus edulis (Blue mussel)	1	1†				x	
Mulinea lateralis (Little surf clam)				S,M			x
Nucula proxima (Near nut shell)		x					
Spisula solidissima (Surf clam)		4	4	S	x	x	
Tellina agilis (Dwarf tellin)		7		S	x	x	x
Astarte borealis				M			
Mercenaria mercenaria (Hard clam)				M	x		
Mya arenaria (Soft clam)				x	x		
Yoldia limatula						x	
Anomia simplex					x		
Cephalopoda (Squid)							
Echinodermata							
Asterias forbesii (Starfish)	x		x			x	
Arbacia punctulata	x		x			x	
Nemertea (Ribbon worms)		x		S			
Nematoda (Round worms)		x		x			

TABLE 1 (continued)

MASTER SPECIES LIST

Taxon	(**Woodward-Clyde, 1975) (Trawl	Shipek	Dredge	McGrath, 1975	Walford, 1971	Dean, 1975	Steimle, 1967
Pices (Cont'd.)							
Prionotus carolinus (Northern searobin)	x						
Pseudopleuronectes americanus (Winter flounder)	x						
Scophthalmus aquosus (Windowpane)	x						
Stenotomus chrysops (Scup)	x						
Cnidaria (Coelenterata)							
Metridium senile				x			
Hydrozoa sp.				x			

*S - species is a major component of McGrath's (1974) sand community.
M - species is a major component of McGrath's mud community.
+ - numbers indicate importance of this species in East Bank community. Number 1 contributed greatest biomass to Woodward-Clyde (1975) samples, etc.

**Woodward-Clyde, 1975:
8 stations on East Bank of Ambrose Channel, each sampled once in June, 1975 (predredging). At each station: a shipek grab sample, a 10 minute clam dredge haul, and a 10 minute otter trawl for epibenthic macroinvertebrates.

Dean, 1975:
Total of 193 stations sampled during summers of 1957-1960. Stations were in Raritan Bay and on West Bank of Ambrose Channel. Peterson or Van Veen grab samples.

Steimle, 1973:
One station at 40°32.5'N 73°58.1'W, sampled monthly for 1 year in 1966-67. Peterson grab samples.

Walford, 1971:
8 stations in Raritan, and Lower Bays. Dates not given. Smith-McIntyre grab samples and shell dredge samples.

McGrath, 1974:
78 stations, sampled once each between 15 January and 2 February, 1973. Stations were the same as those used by the EPA for water quality monitoring in Raritan Bay. Smith-McIntyre grab samples.

station, which was about 400 m (112 ft) northeast of Swineburne Island. At a station immediately east of Chapel Hill Channel, he found only 3 living individuals. McGrath (1974) also noted very low diversity and density in Raritan Bay, which he attributed to pollution from the many waste water sources, aggravated by a sluggish flushing pattern.

McGrath (1974) recognized two distinct biological communities. The communities are segregated by sediment type and each is dominated by a bivalve and a polychaete. The first is found in Raritan Bay associated with a muddy bottom. This community is very low in both density and diversity. Only 4 species are seen regularly, and a total of only 10 species has been reported (Table 1). This community is dominated by the bivalve *Mulinia lateralis*, and the polychaete *Nephtys incisa*. The second community is associated with a sandy bottom in the area roughly northeast of a line from Sandy Hook to Great Kills. It is dominated by the deposit-feeding bivalve *Telina agilis* and the polychaete worm *Streblospio benedicti*, Table 1. The species lists for these two communities are quite distinct; the mud snail *Nassarius trivittatus*, is the only species found in large numbers in both communities.

Walford (1971) used a shell dredge to collect larger benthic organisms, including commercially valuable clams. Extensive beds of empty valves of the soft shelled clam, *Mya arenaria*, were found, but only one live individual. In contrast, in the 1957-1960 survey (Dean, 1975) *Mya arenaria* was one of the most abundant species observed. Oysters and bay scallops, once apparently common, have become virtually extinct. Hard shell clams *Mercenaria mercenaria* are fairly common, although varying widely in abundance. In 5 m (16 ft) of water, midway between West Bank and Old Orchard Shoal lights, Walford found one clam per 16 m^2 (170 ft^2). Virtually no juvenile individuals were found in New York State waters of Lower Bay. Walford suggested that normal reproduction and recruitment probably not occurring in the heavily polluted waters off Staten Island, although adult clams survive there.

A report prepared by Jacobson and Gharrett for the Conference on Pollution of Raritan Bay and Adjacent Interstate Waters, Third Session, Federal Water Pollution Control Administration (1967) substantiates Walford's conclusions. They report that the harvest of shellfish in Raritan Bay and adjacent waters reached a peak in the late 1880's and maintained that level until about 1945 when the harvest began a gradual decline to the present low level. Oyster production was once a major activity. According to Cumming (1917) about 81 km^2 (20,000 acres) on the New York side of the estuary contained oysters, 32 km^2 (8,000 acres) of which were under cultivation by private industry. In the early part of the century, shellfish growing and shipping was asserted to be one of the most important industries in the state with an annual oyster catch alone valued at from two to four million dollars. At present the oyster has virtually disappeared, presumably because of destruction of seed beds, increased salinity due to channel dredging, and increased pollution levels.

According to Jacobson and Gharrett (1964), a recent study by the U.S. Public Health Service revealed a standing population of nearly 1.8×10^5 m^3 (5×10^6 bushels) of hard clams in the Raritan estuary. However, the history of the hard clam industry is one of steadily decreasing harvests as the spread of pollutants closed the hard clam beds to exploitation. At the present time there is a limited area open to clamming in Sandy Hook Bay. In their report, Jacobson and Gharrett indicate that under optimum water quality conditions the potential harvest of hard clams could amount to about 1.9×10^4 m^3

(5.5×10^5 bushels) annually.

In the past, soft clams were taken along the New Jersey coast from Conaskonk Point to the northern tip of Sandy Hook, and along the entire south shore of Staten Island. Deteriorating habitat conditions have resulted in a decline of the harvest. Commercial harvest data indicate that in 1948 about 0.6×10^4 m^3 (1.8×10^5 bushels) of soft clams were taken. At the present time there is no significant commercial harvest. Under optimum conditions, the soft clam beds can produce a sustained average annual yield of 2.6×10^7 m^3/km^2 (300 bushels per acre) of habitat. It is estimated that about 162 km^2 (40,000 acres) of the Raritan estuary are soft clam habitat. Formerly, the entire estuary was considered blue crab habitat.

The Woodward and Clyde report to the U.S. Army Corps of Engineers (1975) indicates that the densities of benthic invertebrates of the East Bank are "comparable" to those found in other Atlantic coast estuaries, and are far from "depauperate." Woodward and Clyde reports 475 to 113,500 benthic macrofaunal organisms per square meter, 4 to 25 taxa per Shipek sample, 1 to 5 species per trawl, and 0 to 3 species per clam dredge haul.

The samples taken on the East Bank represent a third community. The species occurring in the largest numbers were *Mytilus edulis*, a bivalve, and *Pagarus*, the hermit crab. Of the ten species contributing the bulk of the biomass, two are suspension feeders (*Mytilus edulis*, and *Spisula solidissima*); one is a scavenger (*Pagarus*); two are predators (*Ovalipes ocellatus* and *Goniadella gracilis*) and the remaining five are apparently microherbivores (*Spiophanes bombyx, Tellina agilis, Cirratulidae, Paraphoxus*, and *Tharyx acutus*).

Of the commercially valuable species, Woodward and Clyde report large beds of blue mussel (*Mytilus edulis*) are very common. Neither soft shelled clams (*Mya arenaria*), or hard shelled clams (*Mercenaria mercenaria*) were found. Blue crabs (*Callinectes sapidus*) were caught in otter trawls.

The otter trawl brought up several commercially and/or recreationally valuable species of fish: summer flounder (*Paralichythys denatus*), sand flounder (*Scopthalmus arquesus*), squirrel hake (*Urophycis chuss*), and white hake (*Urophycis tenuis*). The otter trawl also caught a large number of the following fish: sand lance (*Ammodytes americanus*); common sea robin (*Prionotus carolinius*); winter flounder (*Pseudopleuronectes americanus*); scup (*Stenotomus chrysops*); tautog (*Tautoga onitis*); and cunner (*Tautogolabrus adspersus*). These fish spend much of their time near bottom feeding upon annelids, crustacea and bivalves. In turn they are probably major food sources for larger fish including commercially and recreationally important species.

SAND AND GRAVEL RESOURCES

Surficial Sediments

Introduction

Although not always a reliable indicator of what lies beneath, the top 10-15 cm (4-6 in) of sediment is the most easily and most frequently sampled. Fray (1969) compiled data from a large number of samples taken west of Ambrose Channel by Rutgers University (Dean and Haskins (1964), the Federal Water Pollution Control Administration (Nagle (1967), the U.S. Army Corps of Engineers, and McMaster (1954). East of Ambrose Channel, samples have been taken by the U.S. Army Corps of Engineers (Taney, 1961), Woodward and Clyde (1975) for the New York District U.S. Army Corps of Engineers. All of the above were grab samples taken along the shoreline or from the bottom of Lower New York Harbor. Appendix B of this report lists all of these samples giving their locations, and describing their size characteristics as reported in the literature. Figure 14 shows the location of the grab samples taken from the bottom of Lower New York Harbor. The period of sampling extends from 1929 to 1975, with the majority of the samples taken between 1958 to 1975.

MSRC Samples

As part of the present study, the Marine Sciences Research Center took 48 samples on March 25, 1976 with a Shipek grab sampler. Most of these samples were taken on East Bank, and a few were taken on West Bank. The latitude and longitude of the samples are given in Table 2, and are shown on Fig. 14. The location of the sampling stations were selected to fill gaps in existing data, and to provide size data for the area directly east of the present active dredging area which is being considered as the next active dredging site (James Marotta, personal communication). Station positions were obtained by horizontal sextant angles to prominent shoreline features and navigational aids that were indicated on the nautical chart. Radar ranging was used to supplement and check position locations obtained with the sextant.

At each station, approximately one liter of sediment was saved for analysis. In most cases the first drop of the sampler brought up sufficient sediment, but in a few cases 2 or 3 drops in rapid succession were required to obtain a one liter composite sample.

The samples were wet-sieved through a 62 μm sieve to separate the silt/clay fraction from the coarser sand and gravel. Both splits were dried and weighed to obtain the total weight of the sample. The coarse fraction was then sieved through a 2 mm sieve to separate the gravel and sand fractions, and the weight of each were obtained.

The sand fraction was passed through a splitter repeatedly until a representative sand sample of 45-60 g was obtained. The grain size distribution of the sand-size fraction was obtained by shaking the representative sample through a series of sieves using a Ro-Tap Shaker. The size interval between sieves was one-quarter phi. Samples were shaken for 10 minutes during each run of the Ro-Tap Shaker.

The sand retained on each sieve was weighed and expressed as a percentage by mass of the split and of the total sample. The size distribution for all samples, expressed as cumulative percent coarser than by mass, are tabulated in Table 3. Replicate analysis were run on samples 26 and 33. The reproductibility obtained for both samples was excellent.

Several samples consisted predominantly of clay and silt. No size analysis was run on these samples, and their composition is indicated as "mud." One sample, which was almost entirely mussel shells, was also set aside.

A number of statistical parameters were calculated for each sample. The values for these parameters are given in Table 4. An explanation of the various statistical parameters and method of calculation are presented in Appendix A.

The average grain size for each sample is expressed both as the median (Md), and as Folk's Graphic Mean (Mz). Although the use of the median size is not as accurate as the graphic mean, we have been forced to use it as it is the only average grain size value determined by previous investigators. The median has been used to compare the average grain size of the surficial sediment throughout Lower New York Harbor.

As a measure of the uniformity of the grain size we have determined Trask's coefficient of sorting (S_O), the graphic standard deviation σ_G, and Folk's inclusive graphic standard deviation σ_I. A measure of the asymmetry or skewness of the grain size distribution is provided by

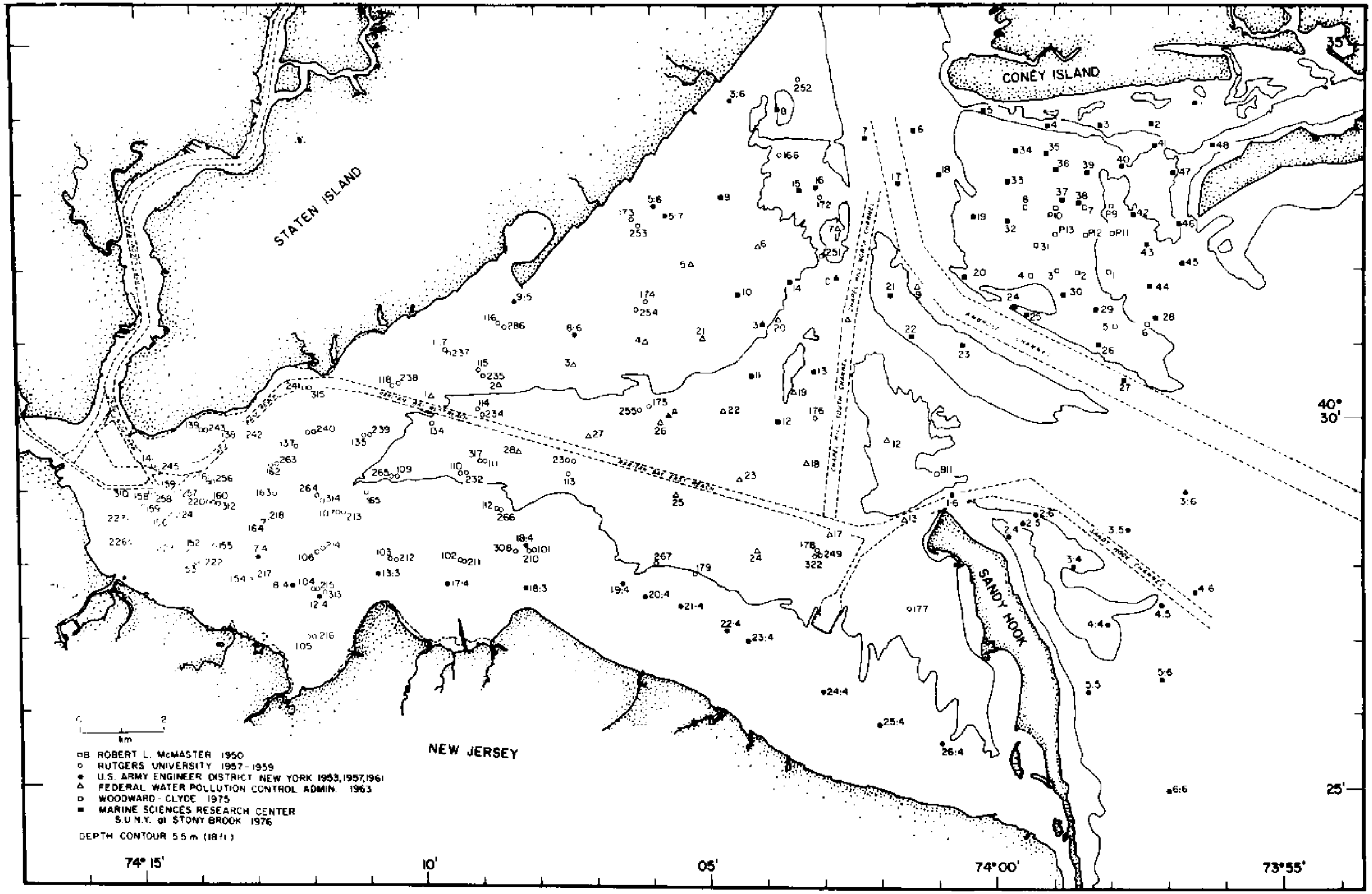

Fig. 14. Location of surface sediment grab samples.

Table 2. Station Locations.

Marine Sciences Research Center
Shipek Grab Samples
25 March 1976

Sample No.	Longitude	Latitude
1	73°56'29"	40°34'13"
2	73°57'16"	40°33'56"
3	73°58'07"	40°33'56"
4	73°59'03"	40°33'52"
5	74°00'08"	40°34'07"
6	74°01'15"	40°34'02"
7	74°02'14"	40°33'45"
8	74°03'43"	40°34'07"
9	74°04'42"	40°32'58"
10	74°04'25"	40°31'40"
11	74°04'14"	40°30'35"
12	74°03'46"	40°29'57"
13	74°03'07"	40°3 '37"
14	74°03'32"	40°31'50"
15	74°03'22"	40°33'03"
16	74°03'05"	40°33'03"
17	74°01'38"	40°33'08"
18	74°00'55"	40°33'17"
19	74°00'17"	40°32'40"
20	74°00'30"	40°31'53"
21	74°01'47"	40°31'40"
22	74°01'25"	40°31'07"
23	74°00'31"	40°30'58"
24	73°59'37"	40°31'31"
25	73°59'27"	40°31'27"
26	73°58'10"	40°30'58"
27	73°57'44"	40°30'31"
28	73°57'13"	40°31'19"
29	73°58'12"	40°31'27"
30	73°58'47"	40°31'38"
31	73°59"15"	40°32'19"
32	73°59'44"	40°32'38"
33	73°59"42"	40°33'10"
34	73°59'36"	40°33'33"
35	73°59'06"	40°33'32"
36	73°58'54"	40°33'20"
37	73°58'47"	40°32'54"
38	73°58'30"	40°32'53"
39	73°58'22"	40°33'17"
40	73°57'46"	40°33'22"
41	73°57'13"	40°33'35"
42	73°57'33"	40°32'43"
43	73°57'19"	40°32'19"
44	73°57'17"	40°31'45"
45	73°56'43"	40°32'05"
46	73°56'43"	40°32'36"
47	73°56'41"	40°33'17"
48	73°56'10"	40°33'38"

T A B L E 3

MARINE SCIENCES RESEARCH CENTER

Shipek Grab Samples
Sieve Analysis

Weight % coarser than:

Sample #	-1.0ϕ 2 mm	-0.5ϕ 1.41 mm	0.0ϕ 1.0 mm	.25ϕ 850μ	.50ϕ 710μ	.75ϕ 590μ	1.00ϕ 500μ	1.25ϕ 420μ	1.50ϕ 354μ
1	Shells and silt/clay: not sieved								
2	7.24	7.39	7.54	7.65	7.75	7.85	8.04	8.15	8.36
3	0.43	0.48	0.51	0.54	0.60	0.68	0.79	0.90	1.05
4	17.14	17.58	18.47	19.11	19.74	20.31	20.83	21.23	21.81
5	0.3	0.51	1.00	1.65	2.82	5.29	9.15	17.28	32.91
6	Malodorous muck: not sieved								
7	0	0.05	0.09	0.10	0.14	0.24	0.33	0.42	0.61
8	Predominantly silt/clay: not sieved								
9	2.58	3.42	10.36	15.95	23.78	34.28	45.35	59.88	72.53
10	1.87	2.09	2.53	3.15	4.58	8.30	14.82	27.94	45.07
11	1.19	1.33	2.19	3.42	5.62	9.90	15.82	26.21	40.09
12	Predominantly silt/clay: not sieved								
13	1.53	1.72	1.99	2.14	2.31	2.56	2.85	3.25	3.86
14	Predominantly silt/clay: not sieved								
15	Malodorous muck: not sieved								
16	Malodorous " " "								
17	0.31	0.43	0.53	0.58	0.68	0.84	1.09	1.51	2.40
18	Predominantly silt/clay: not sieved								
19	1.12	1.23	1.32	1.50	1.85	2.96	6.08	13.90	31.97
20	0.04	0.51	0.65	0.83	1.21	2.59	6.41	20.51	47.24
21	8	8.61	9.80	10.83	12.55	15.07	18.33	24.05	34.64
22	0.76	0.87	1.17	1.85	3.18	6.03	10.92	18.86	36.18
23	1.75	2.00	2.65	3.57	5.30	9.04	14.60	25.19	41.79
24	0.00	0.00	0.00	0.11	0.15	0.26	0.42	0.62	1.04
25	0.00	0.00	0.29	0.45	0.72	1.20	1.94	3.69	9.08
26a	1.78	2.12	2.60	3.13	3.80	4.55	5.50	7.35	11.32
26b	1.80	2.09	2.81	3.41	4.20	5.07	6.08	8.15	12.16

T A B L E 3

(continued)

Sample #	Weight % coarser than: 1.75φ 300μ	2.0φ 250μ	2.25φ 210μ	2.50φ 177μ	2.75φ 149μ	3.00φ 125μ	3.25φ 105μ	3.50φ 88μ	3.75φ 74μ	4.00φ 62μ
1	Shells and silt/clay: not sieved									
2	8.73	9.44	11.27	19.68	49.46	77.67	92.62	97.61	98.93	99.23
3	1.29	2.03	5.25	16.97	44.73	69.42	88.81	97.41	99.12	99.52
4	22.49	23.63	25.81	31.32	44.43	60.13	80.25	92.98	96.44	97.15
5	52.76	73.26	86.44	93.82	97.57	98.37	98.95	99.40	99.59	99.67
6	Malodorous muck: not sieved									
7	1.08	3.20	11.65	29.93	53.86	74.89	90.91	96.57	97.91	98.29
8	Predominantly silt/clay: not sieved									
9	80.29	84.61	86.96	88.06	88.93	89.76	91.18	93.43	94.85	95.11
10	60.76	76.17	86.69	91.73	93.40	94.19	95.19	96.69	97.64	98.11
11	53.72	68.05	83.17	93.41	97.11	97.94	98.75	99.11	99.24	99.30
12	Predominantly silt/clay: not sieved									
13	4.72	7.16	16.67	44.63	79.37	92.26	96.53	97.85	98.29	98.38
14	Predominantly silt/clay: not sieved									
15	Malodorous muck: not sieved									
16	Malodorous muck: not sieved									
17	4.10	7.34	13.30	26.70	54.57	79.51	94.82	98.36	98.96	99.16
18	Predominantly silt/clay: not sieved									
19	57.31	80.40	91.07	96.28	98.77	99.39	99.68	99.79	99.87	99.92
20	73.73	91.79	98.08	99.51	99.71	99.75	99.78	99.80	99.80	99.80
21	54.71	76.40	91.29	97.07	98.53	99.38	99.62	99.66	99.66	99.66
22	56.60	77.60	92.31	98.12	99.56	99.80	99.89	99.92	99.92	99.92
23	59.28	77.55	91.65	97.59	99.19	99.59	99.79	99.88	99.91	99.91
24	2.17	6.69	19.44	45.73	74.90	90.08	96.49	98.06	98.43	98.44
25	21.00	42.08	73.58	91.18	97.58	99.13	99.69	99.83	99.88	99.88
26a	17.49	30.57	62.14	90.21	97.94	99.29	99.77	99.89	99.89	99.89
26b	18.57	30.83	62.16	89.60	98.00	99.36	99.76	99.88	99.88	99.88

T A B L E 3

(continued)

Weight % coarser than:

Sample #	-1.0ϕ 2 mm	-0.5ϕ 1.41 mm	0.0ϕ 1.0 mm	.25ϕ 850μ	.50ϕ 710μ	.75ϕ 590μ	1.00ϕ 500μ	1.25ϕ 420μ	1.50ϕ 354μ
27	45.69	50.42	55.86	58.67	62.31	67.00	71.21	73.94	75.92
28	2.80	10.13	36.57	52.27	67.42	79.50	87.51	93.97	97.40
29	25.30	31.68	38.87	43.68	48.93	55.95	63.30	72.68	81.01
30	0.00	0.00	0.25	0.39	0.60	0.83	1.25	2.52	6.50
31	6.70	7.14	7.97	9.30	12.22	18.67	27.81	43.65	60.24
32	25.00	26.03	28.97	31.65	35.08	39.85	45.96	56.21	70.67
33a	0.00	0.00	0.02	0.03	0.05	0.14	0.38	1.52	6.32
33b	0.00	0.00	0.00	0.09	0.13	0.21	0.47	1.72	6.65
34	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.18	1.25
35	0.00	0.00	0.00	0.07	0.10	0.15	0.28	0.77	2.39
36	0.00	0.00	0.00	0.08	0.19	0.38	0.75	1.68	4.48
37	1.05	1.13	1.48	1.81	2.54	4.07	6.63	10.82	21.79
38	1.80	2.00	2.87	4.10	6.06	9.30	13.51	20.12	29.92
39	0.80	0.90	1.09	1.21	1.47	1.90	2.63	4.17	7.17
40	13.60	13.60	14.58	14.97	15.38	15.88	16.38	17.12	18.23
41	3.30	3.57	3.99	4.23	4.60	5.50	5.98	8.24	13.48
42	11.30	11.85	13.13	13.91	14.70	15.48	16.28	17.40	19.10
43	47.30	51.36	55.92	58.25	60.73	63.50	66.00	68.43	70.74
44	54.56	60.09	69.69	74.24	78.78	83.21	86.37	88.92	90.30
45	Entirely Shell: not sieved								
46	10.40	11.66	13.68	15.08	17.28	21.16	26.32	35.83	50.26
47	29.32	30.75	34.19	35.83	37.68	40.09	43.11	49.14	60.73
48	3.70	4.08	5.04	6.13	8.26	13.11	22.09	40.17	64.71

TABLE 3

(continued)

Weight % coarser than:

Sample #	1.75ϕ 300μ	2.0ϕ 250μ	2.25ϕ 210μ	2.50ϕ 177μ	2.75ϕ 149μ	3.00ϕ 125μ	3.25ϕ 105μ	3.50ϕ 88μ	3.75ϕ 74μ	4.00ϕ 62μ
27	77.92	82.63	89.68	95.21	97.98	98.60	98.97	99.12	99.21	99.30
28	98.52	98.95	99.58	99.79	99.84	99.86	99.88	99.90	99.90	99.90
29	85.96	88.97	92.19	96.50	99.11	99.63	99.82	99.89	99.90	99.90
30	15.03	30.28	60.43	85.02	96.84	99.11	99.68	99.85	99.88	99.90
31	73.69	84.34	91.83	97.28	99.42	99.78	99.95	99.98	100.00	100.00
32	82.47	91.50	96.47	98.55	99.48	99.74	99.86	99.89	99.90	99.90
33a	14.34	25.29	51.72	83.34	94.95	98.44	99.40	99.81	99.88	99.90
33b	15.05	26.78	53.44	84.59	96.40	98.71	99.50	99.82	99.88	99.90
34	7.31	31.02	79.93	94.62	97.95	98.82	99.30	99.60	99.69	99.70
35	8.06	22.40	52.36	78.83	92.71	97.71	99.39	99.89	99.98	100.00
36	11.46	29.63	61.74	85.54	96.21	99.18	99.81	99.96	100.00	100.00
37	39.16	63.13	83.37	93.49	98.22	99.37	99.75	99.85	99.86	99.88
38	41.64	57.43	76.43	89.84	97.09	98.93	99.56	99.75	99.80	99.80
39	12.26	24.29	40.35	77.44	91.44	96.89	98.80	99.49	99.70	99.80
40	19.97	23.94	40.75	71.88	89.90	95.13	97.64	98.80	99.18	99.21
41	22.11	35.06	54.60	76.08	87.05	90.09	91.62	92.21	92.37	92.39
42	22.75	33.78	63.63	90.12	96.64	98.56	99.32	99.61	99.69	99.80
43	73.69	78.45	85.46	91.17	95.10	96.74	98.21	98.94	99.18	99.23
44	90.94	91.33	91.80	92.48	93.58	94.74	96.39	97.63	98.11	98.25
45	Entirely Shell: not sieved									
46	68.05	84.59	95.10	98.22	99.23	99.57	99.81	99.89	99.90	99.90
47	73.27	83.87	89.56	91.96	94.52	96.34	97.86	98.52	98.70	98.73
48	82.31	92.01	96.47	97.91	98.52	98.89	99.30	99.51	99.58	99.60

Table 4. Statistical Parameters.

Marine Sciences Research Center
Shipek Grab Samples

	Central Tendency		Uniformity			Skewness or Assymetry			Kurtosis
Sample No.	Median Md (mm)	Graphic Mean Mz	Trask Sorting S_O (mm)	Graphic Standard Deviation	Inclusive Graphic Standard Deviation	Trask Skewness Sk	Graphic Skewness Sk_G	Inclusive Graphic Skewness Sk_I	Kurtosis K_G
1	shell and silt/clay								
2	.149	2.77	1.17	.33	*	0.97	+.08	**	*
3	.144	2.82	1.17	.33	.34	0.97	+.08	+.06	1.05
4	.139		1.41			1.23			
5	.308	1.75	1.24	.48	.51	0.95	+.16	+.05	1.17
6	muck								
7	.154	2.70	1.21	.40	.40	0.97	0.0	+.04	.97
8	muck								
9	.467	1.12	1.41	.88	1.08	1.07	+.03	+.17	1.74
10	.342	1.58	1.31	.55	.68	0.95	+.09	+.18	1.44
11	.314	1.64	1.35	.63	.63	1.01	-.07	-.11	1.00
12	muck								
13	.173	2.53	1.13	.28	.34	1.01	-.02	-.06	1.55
14	muck								
15	muck								
16	muck								
17	.154	2.68	1.18	.38	.40	0.99	-.07	-.14	1.20
18	muck								
19	.319	1.67	1.21	.38	.41	0.97	+.07	+.05	1.08
20	.346	1.53	1.18	.34	.34	0.99	+.01	-.01	.98
21	.308	1.53	1.27	*	.65	1.07	-.38	*	*
22	.319	1.63	1.21	.48	.49	.97	+.05	-.13	1.23
23	.319	1.58	1.27	.50	.54	1.07	-.20	-.23	1.11
24	.171	2.53	1.17	.33	.34	1.04	-.08	-.04	1.09
25	.241	2.03	1.17	.37	.37	1.04	-.10	-.11	1.14
26a	.218	2.12	1.17	.38	.45	1.11	-.33	-.43	1.55
26b	.218	2.08	1.17	.38	.47	1.11	-.47	-.51	1.70
27	.146	*	*	*	*	*	*	*	*
28	.871	0.22	1.34	.63	.63	.97	+.04	+.04	1.01
29	.707	*	2.22	*	*	1.62	*	*	*
30	.225	2.12	1.16	.36	.37	1.02	-.11	-.12	1.19
31	.392	1.35	1.34	.65	*	.97	0.0	*	*
32	.547	*	2.26	*	*	2.62	*	*	*
33a	.210	2.18	1.15	.35	.37	1.07	-.29	-.26	1.33
33b	.213	2.17	1.18	.37	.37	1.06	-.26	-.25	1.09
34	.233	2.10	1.10	.20	.23	1.02	0.0	+.03	1.29
35	.213	2.23	1.15	.33	.34	0.97	-.02	-.01	1.18
36	.225	2.16	1.17	.31	.33	0.97	-.03	-.01	1.07
37	.277	1.83	1.23	.43	.47	1.00	-.06	-.12	1.16
38	.268	1.80	1.35	.65	.67	1.15	-.23	-.29	1.10
39	.210	2.23	1.19	.38	.42	1.00	-.07	-.13	1.25
40	.203	1.90	1.20	.95	*	1.01	-.63	*	*
41	.218	2.15	1.25	.53	*	1.04	-.14	*	*
42	.218	4.55	1.21	-3.28	*	1.11	-1.08	*	*
43	1.275	*	*	*	*	*	*	*	*
44	*	*	*	*	*	*	*	*	*
45	shell								
46	.354	1.28	1.37	.83	*	1.15	-.39	*	*
47	.420	*	*	*	*	*	*	*	*
48	.392	1.33	1.21	.48	.56	1.04	-.05	-.15	1.59

*The distribution is too open to calculate this parameter.

Trask's skewness coefficient (Sk) and Inman's graphic skewness (Sk_I). For a number of samples there was insufficient data to calculate the inclusive graphic sorting or skewness. In order to compare the size characteristics of the samples obtained by other investigators, again it has been necessary to use Trask's coefficient of sorting and skewness coefficient. The peakedness of the grain size distribution, or kurtosis, is indicated by Folk's graphic kurtosis (K_G).

Finally, we calculated two special parameters used in evaluating the acceptability of sand as filtration sand: the "effective grain size," and the "uniformity coefficient." The values for these two parameters are given in Table 5.

Texture

The characteristics of the surface sediment are summarized in a series of charts, Figs. 15 to 19, which incorporate the results of our sampling and that of previous investigators.

Figure 15 illustrates the size distribution of the sediment as indicated by the median diameter in millimeters of each sample. This chart has been contoured to show the areal distribution of the various size classes of sediment. The Marine Sciences Research Center samples and the U.S. Army Corps of Engineers samples which contained over 50 percent silt and clay were not analyzed and are identified by the letter "M" for mud.

A broad swath of mud runs from the mouth of the Raritan River through the length of Raritan Bay to Sandy Hook Bay, where it is the dominant sediment type. Mud characterizes the sediment off the mouth of Cheesequake Creek, and also in Keyport Harbor at the mouth of Matawan Creek. Within the dredged areas to the west of West Bank, mud comprises the surface sediment. A patch of mud occurs between Ambrose Channel and the northwest flank of East Bank just south of the western tip of Coney Island.

Along the New Jersey shore of Raritan Bay and the western edge of Sandy Hook Bay are two fairly extensive areas of medium sand. The shape and location of these sand areas suggest they are of local derivation.

At the southwestern tip of Staten Island there is a relatively small area of medium sand. Farther to the east there is a large area of medium to coarse sand which borders Staten Island from just west of Crookes Point to The Narrows. Old Orchard Shoal is included within this area of medium to coarse sand.

Separating the band of mud through Raritan Bay from the large area of medium sand to the north is a belt of fine sand. This area of fine sand is shaped like an inverted "T", extending from the northern tip of Sandy Hook to the shore of Staten Island to the west of Crookes Point, and northward through the center of Lower Bay towards The Narrows. West Bank is included in this area of fine sand.

Most of the surface of East Bank consists of fine sand with a medium grain size of 0.20 to 0.28 mm. A large area of medium to coarse sand occurs along the western side of East Bank, and to the southwest between East Bank and the northern tip of Sandy Hook. Most of Romer Shoal and Flynn's Knoll have surficial sediments of medium to coarse sand.

Many stations within Raritan Bay, Sandy Hook Bay, and western Lower Bay have been sampled repeatedly over a period of years. There appears to have been little change in the type of sediment at these stations over the period of years represented.

Figure 16 shows the percent of each sample which is silt/clay (finer than 0.062 mm). In general, this chart reflects the pattern illustrated by the distribution of median diameter. Contours representing the 15 and 50 percentiles have been drawn, but in many areas because of lack of closely spaced samples, their

Table 5. Marine Sciences Research Center Shipek Grab Samples.

Sample No.	Effective grain size (mm)	Uniformity Coefficient
1	shell	
2	.233	.660
3	.189	.812
4	*	*
5	.483	.707
6	mud	
7	.210	.785
8	mud	
9	1.035	.536
10	.574	.660
11	.595	.595
12	muck	
13	.233	.774
14	mud	
15	mud	
16	mud	
17	.225	.732
18	mud	
19	0.451	.758
20	.467	.801
21	.993	.332
22	.507	.674
23	.590	.607
24	.233	.785
25	.342	.758
26a	.366	.637
26b	.379	.616
27	*	*
28	1.464	.660
29	*	*
30	.330	.732
31	.812	.536
32	*	*
33a	.330	.683
33b	.330	.683
34	.287	.841
35	.287	.785
36	.308	.758
37	.435	.683
38	.574	.637
39	.319	.707
40	*	*
41	.392	.595
42	*	*
43	*	*
44	*	*
45	shell	
46	1.682	.233
47	*	*
48	.660	.637

* The distribution is too open to calculate this parameter.

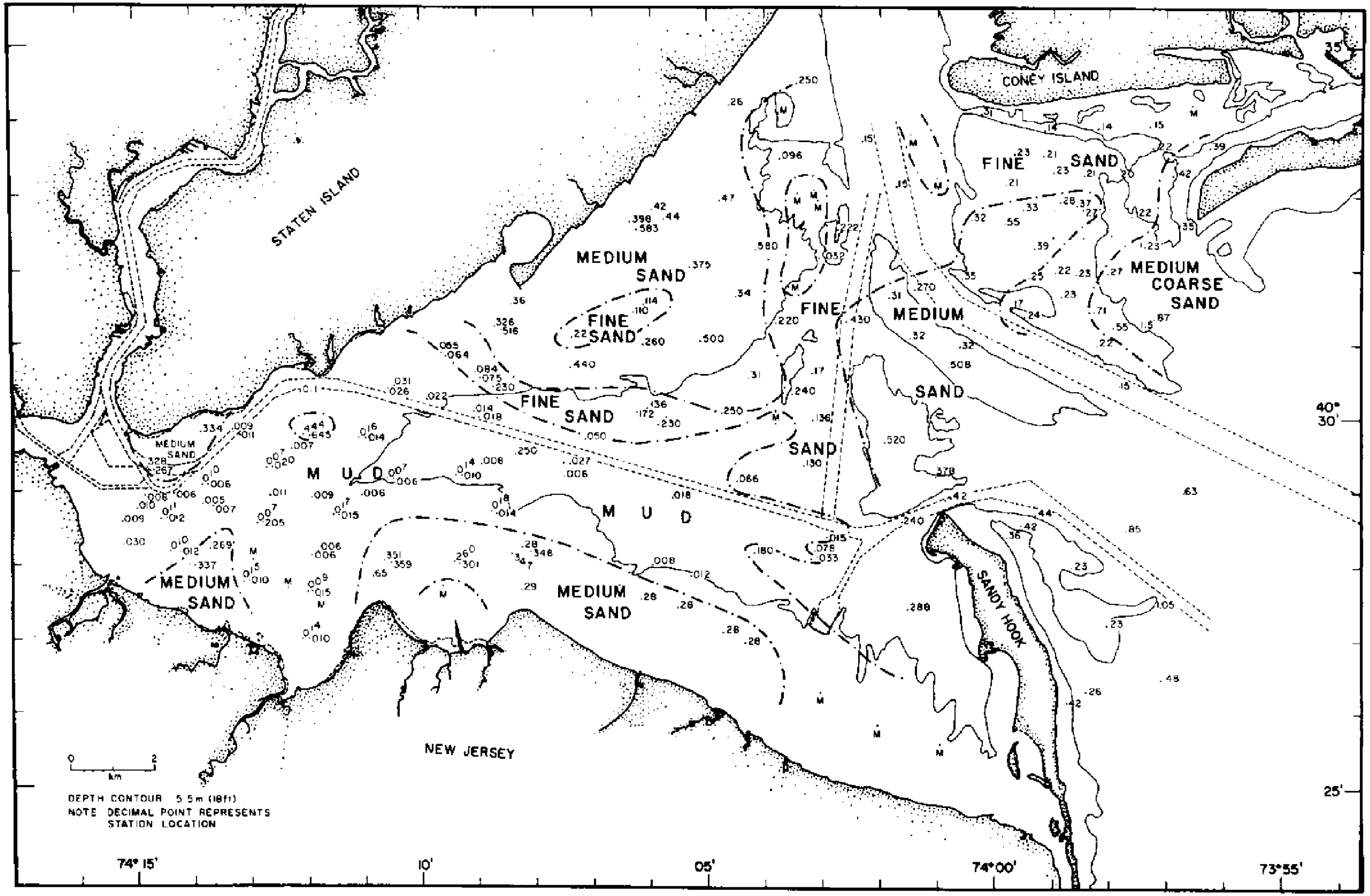

Fig. 15. Median diameter (mm), surface sediment samples.

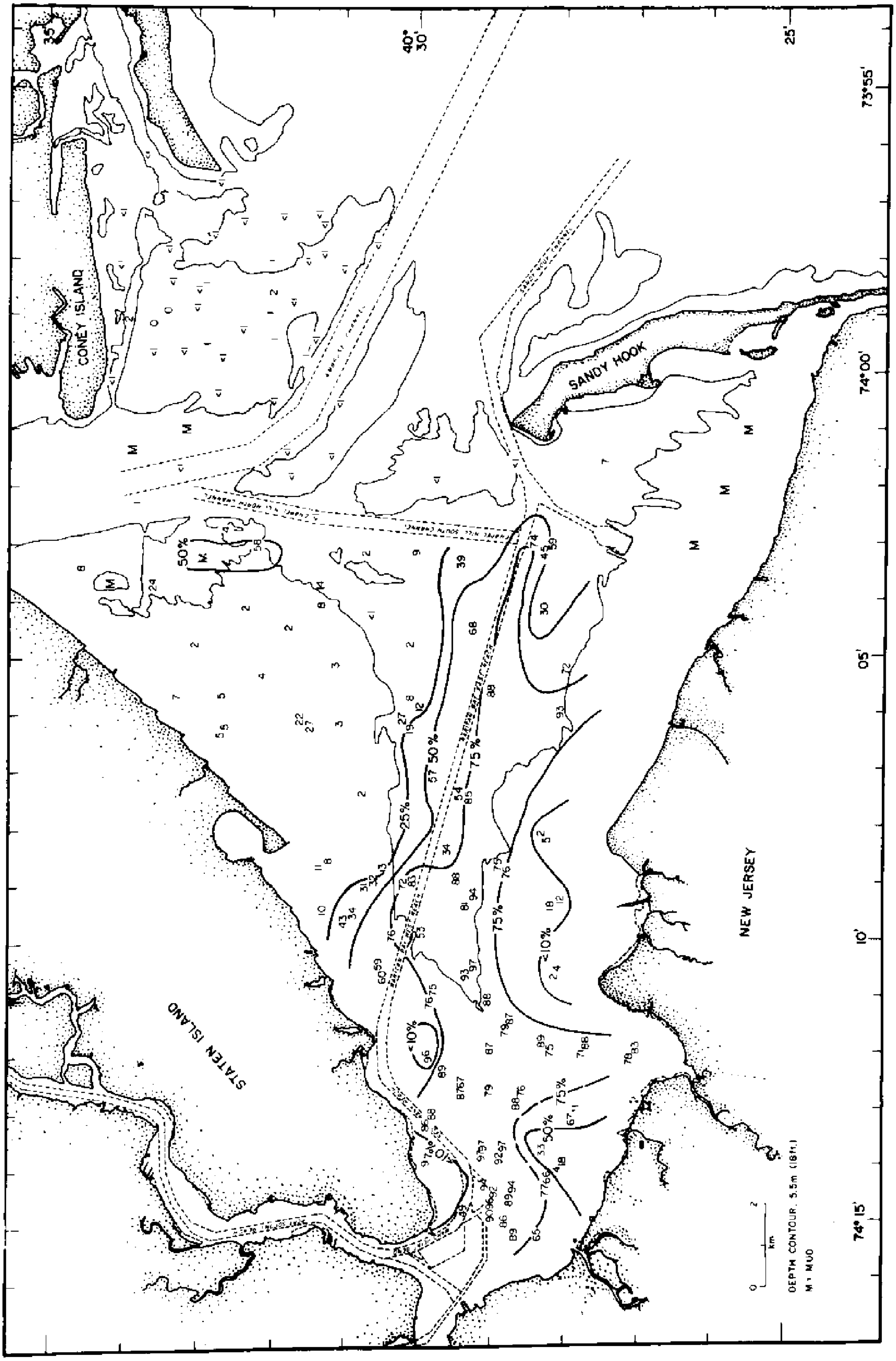

Fig. 16. Percent silt/clay, surface sediment samples.

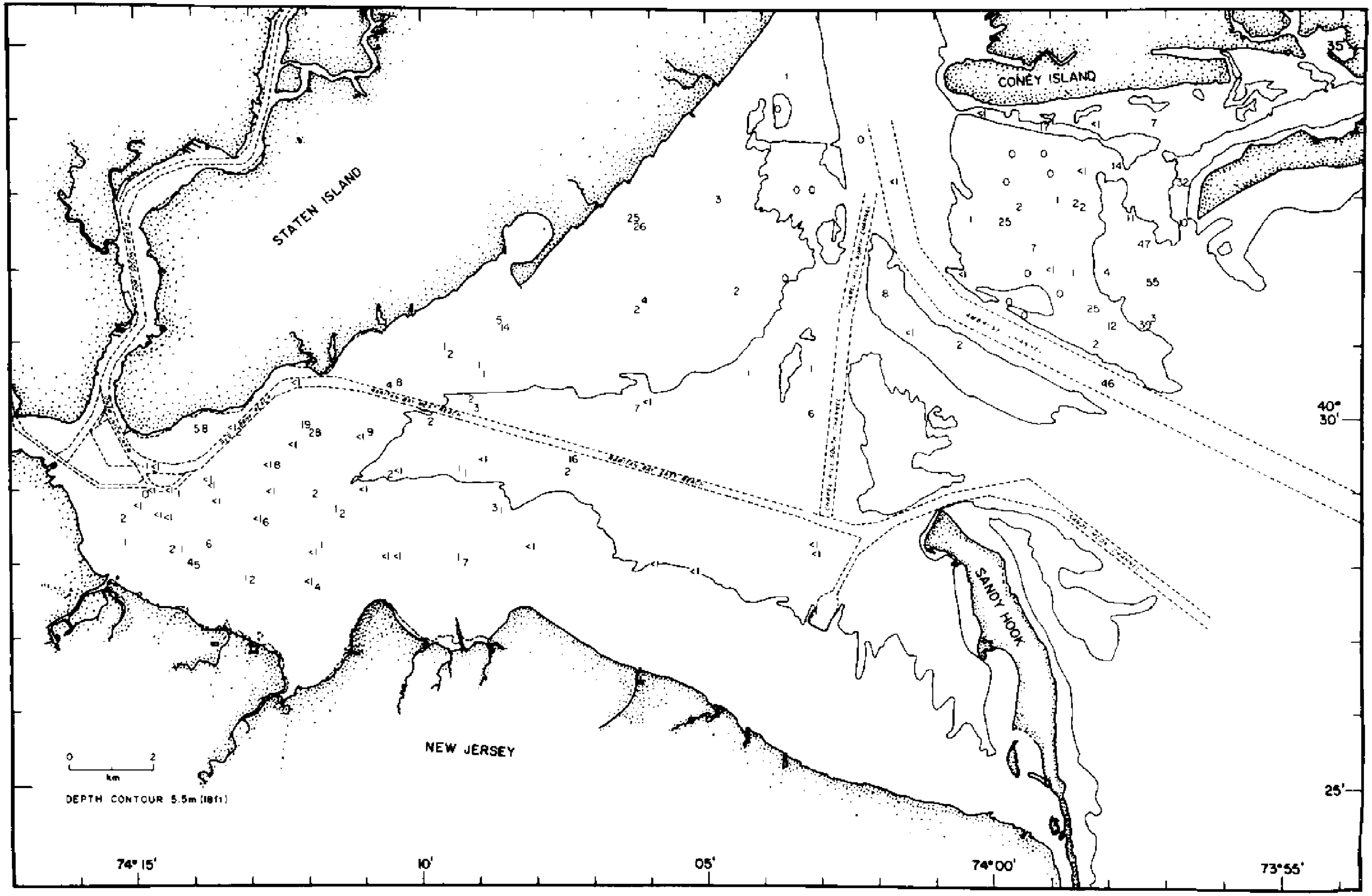

Fig. 17. Percent coarser than 2.00 mm, surface sediment samples.

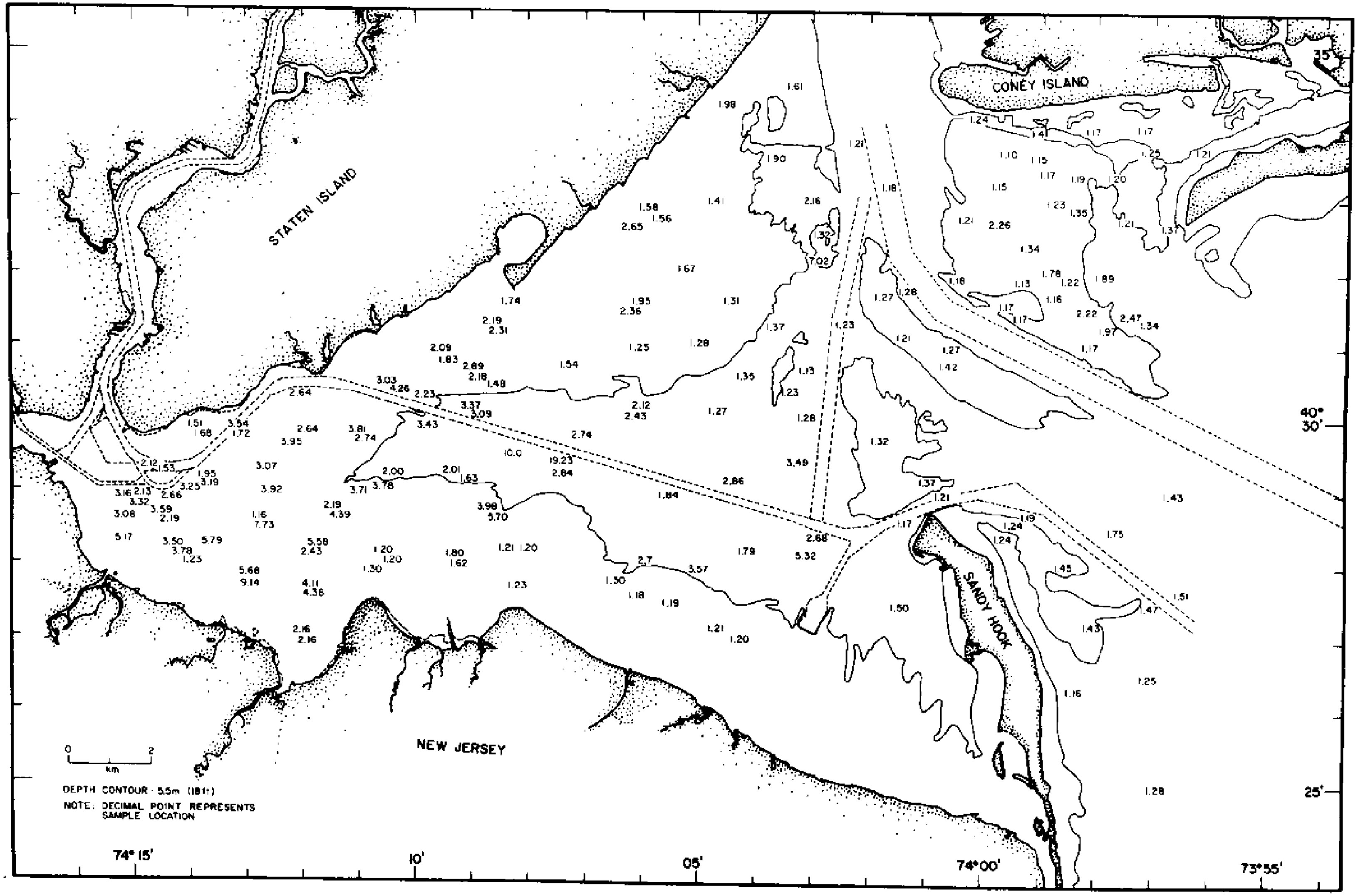

Fig. 18. Trask's coefficient of sorting, surface sediment samples.

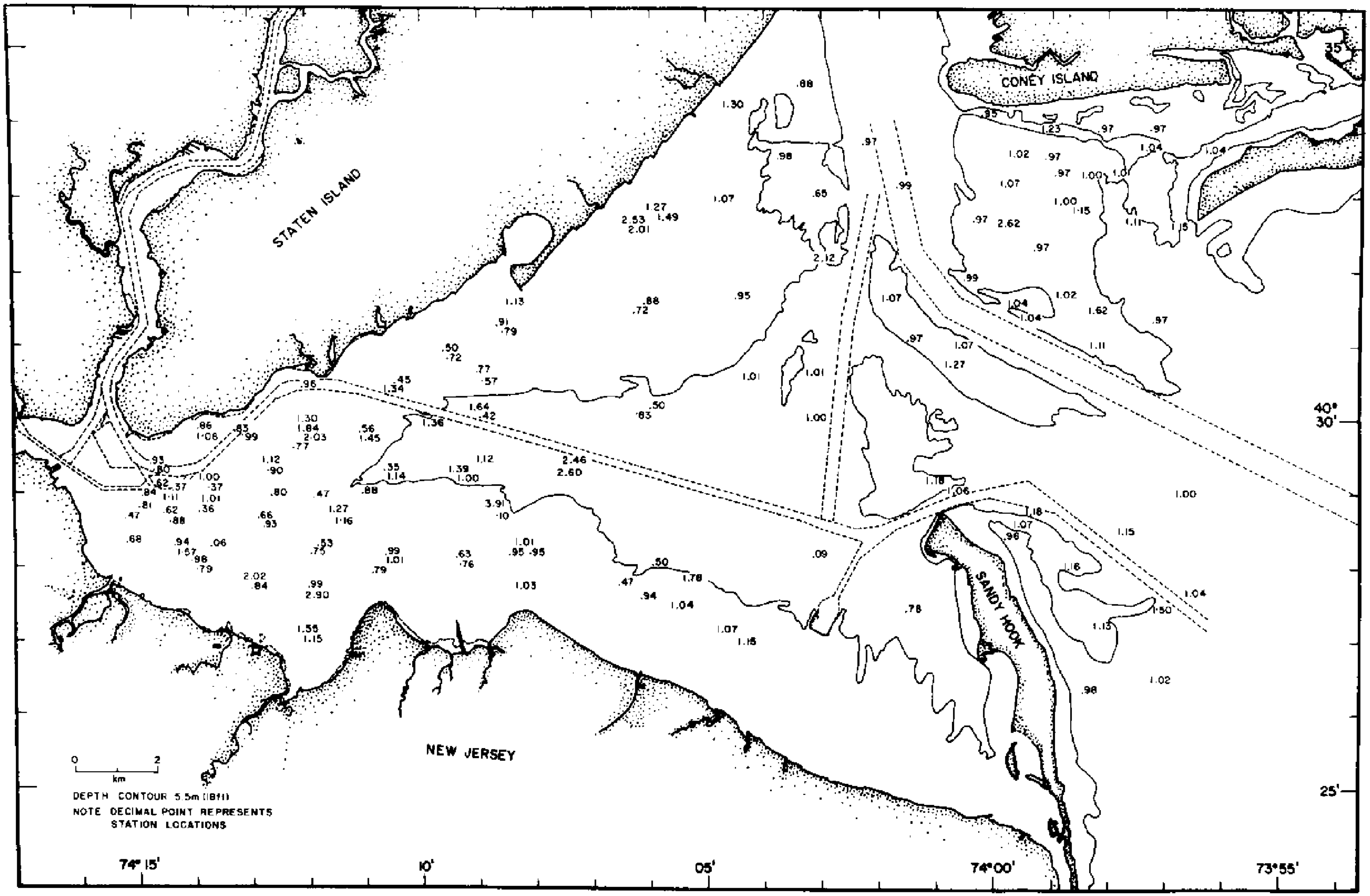

Fig. 19. Trask's coefficient of skewness, surface sediment samples.

location is approximate at best. However, they do show that there is a fairly sharp transition from mud to sand through Raritan and Sandy Hook Bays. The data also indicate that most of the area east of Chapel Hill Channel is virtually free of the silt/clay fraction. Off Staten Island between The Narrows and just southwest of Crookes Point, the surface sediment contains several percent silt/clay. One small patch within this area contains over 25 percent silt/clay. Limited data within the dredged area west of West Bank indicates some of the sediment is more than 50 percent silt/clay.

The mass percent of material coarser than 2 mm in diameter contained in the surface sediment samples is shown on Fig. 17. This material may consist of gravel, large shell fragments, or a combination of the two. For most samples there is no indication of the type of material comprising the coarse fraction. In many of the samples taken by the Marine Sciences Research Center, the greater than 2 mm size fraction consisted of large shell fragments. This was particularly true of samples collected in the vicinity of Rockaway Inlet. In any case, the data indicate that if some of the greater than 2 mm material is gravel, it is of very limited extent.

Trask's coefficient of sorting (S_o) and coefficient of skewness (Sk) distribution are shown on Figs. 18 and 19 respectively. The transition between well sorted and poorly sorted regions is quite abrupt, generally passing from $S_o > 2.5$ (which is poorly sorted) to $S_o < 1.5$ over less than one mile. Relatively strong skewness is associated with the poorly sorted sediments. In general, the size distribution in the poorly sorted area is skewed such that there is a tail at the fine end ($Sk < 1$).

The poorly sorted/well sorted boundary coincides fairly well with the 50 percentile clay/silt contours as shown on Fig. 16. However, it should be noted that Trask's coefficient of sorting is not independent of grain size, and that muds are typically less well-sorted than fine sands. The area of poorly sorted sediment may not represent an area in which the sediments are not in adjustment with the environment. Rather it may define an area in which muds are being deposited.

Within the well sorted region, the sediments of the East Bank area have extraordinarily low sorting coefficients, within or lower than the typical 1.3-1.5 range of beach sand, which is the environment in which the best-sorted natural sediments are expected. Folk's inclusive graphic standard deviations for the East Bank fall in the "very well sorted" and "well sorted" brackets, which the inclusive graphic skewness is "nearly symmetrical." East Bank sand is in adjustment with its environment.

The few samples from Romer Shoal are well sorted, but the inclusive graphic skewness indicates they are negatively skewed. This indicates the presence of a significant coarse fraction, and supports the idea that Romer Shoal is a relict glacial deposit.

Sediment from the West Bank and the area adjacent to Staten Island is not as well sorted, and is inclined to be coarsely skewed.

Sources of Sediment

Introduction

Any assessment of the sand and gravel resources of The Lower Bay of New York Harbor must consider the flux of sediment into the area. Five sources are potential contributors of sediment to Lower Bay and Raritan Bay. These include: (1) littoral drift moving westward along the south shore of Long Island, and northwards along the ocean shore of New Jersey, (2) shoreline erosion along the periphery of Lower New York Harbor, (3) the Hudson and Raritan rivers, (4) sediment derived from the adjacent continental shelf, and (5) solids from sewage treatment plant effulents.

Littoral Drift

South Shore of Long Island: The existence and direction of long shore transport along the south shore of Long Island was deduced long ago from the westward migration of inlets and spits, and the accumulation of sand on the east side of groins and jetties. Measurements made between 1835 and 1934 indicate a westward growth of Rockaway Point at an average rate of 67 m (222 ft) per year (Taney, 1961). In 1934, a long stabilizing jetty was completed at Rockaway Point, in part to stem the westward growth of the point. Periodic comparative surveys during the period 1933 to 1961 indicated the jetty trapped an average of 3.4 x 10^5 m^3 (4.5 x 10^5 yds^3) of sand annually (Taney, 1961). This figure has been used widely as a measure of the rate of littoral drift along the western reaches of the south shore of Long Island. Since the 1961 survey, sand accumulation east of the jetty has continued to grow as indicated by aerial photographs on file at the New York District, U.S. Army Corps of Engineers. The Rockaway jetty is approaching its impoundment capacity. When this occurs the volume of sand by-passing the jetty and entering Lower Bay will increase significantly.

Ocean shore of New Jersey: Sand, in transit northward along the ocean shore of northern New Jersey as littoral drift, is entering both Lower Bay and Raritan Bay. In an experiment on the rate of littoral drift at Sandy Hook, Yasso (1965) coated sand grains with fluorescent dye and placed them at the mid-swash line two hours before high tide. The grains were recovered downdrift at a distance and time after release which indicated an average maximum transport velocity of between 2.0 cm/sec and 2.8 cm/sec. This represents a rapid rate of northerly transport. At this rate, individual grains, even though temporarily trapped in deep water or on the berm, could travel considerable distance northward during the course of the year. An inverse relation exists between grain size and transport velocity (Yasso, 1965). Yasso (1975) claims that the rate of littoral transport along the ocean shore of Sandy Hook is the highest of any littoral transport within the New York Bight.

From surveys and aerial photographs, J. M. Caldwell (1966) estimated that between 1885 and 1934, the accretion of sediment at Sandy Hook amounted to 3.76 x 10^5 m^3/yr (4.93 x 10^5 yds^3/yr). Sandy Hook lighthouse, built in 1762 at what was then the northern tip of the spit, today is located about 4 km (2.5 mi) south of the tip of the spit due to the northward accretion of sand. This northward growth of the spit has forced the U.S. Army Corps of Engineers to relocate the dredged Sandy Hook Channel 455 m (1500 ft) farther north during the last 40 years (Dennis Suskowski, N.Y. District, U.S. Army Corps of Engineers, personal communication).

Shoreline Erosion

Staten Island: Between 1836 and 1885, before an extensive program of groin and bulkhead construction, the shoreline between The Narrows and Crooke's Point receded an average of 1.8 m (6 ft) per year. Fray (1969) estimated that this represents an annual erosion of about 10 m^3 per linear meter (4 yds^3 per linear ft) of shore, or about 9.6 x 10^4 m^3 (1.26 x 10^5 yds^3) total. After the construction of numerous shore protection structures, the rate of shoreline recession apparently decreased, although quantitative measurements are not available.

Most of the sediment derived from erosion prior to the construction of protective structures was transported southwestward as littoral drift. This material contributed to the growth of Crooke's Point, and to the patch of sandy bottom sediment off the southwestern corner of Staten Island. Today, few of the jetties which interrupt the southwestward littoral drift have reached their impoundment capacity. Residents and officials of Staten Island reported an increase in erosion during and after the dredging of shipping channels and commercial aggregate off Staten Island (statement to the New York State Department of Environmental Conservation from the Civic Congress of Staten Island, April 12, 1974).

Raritan Bay shore of New Jersey: Several shoreline areas appear to be supplying a small amount of sediment to the estuary at the present time. Fray (1969) reported erosion of the Raritan-Mogothy formation at Cliffwood Beach, the Woodbury Clay and Englishtown formations at Point Comfort, and the Red Bank and Tinton formations in the bluffs immediately to the west of the Atlantic Highlands. A few marshy areas, around Matawan Creek, Flat Creek and Way Point Creek are accreting. Between 1836 and 1886, most of the shore either gained or lost less than 2.5 m^3 per linear meter (1.1 yds^3 per linear ft) of shore per year. The only exception was Point Comfort which lost annually 5.0 m^3 per linear meter (2.0 yds^3 per linear ft) of shore. Numerous points, shoreline indentations, and creek mouths, as well as several groin fields interrupt the flow of littoral drift. Consequently, sediment derived from shoreline erosion is rarely transported far before redeposition.

Coney Island: The Coney Island beach was repeatedly surveyed along two ranges between 9 m (30 ft) below MLW and 1.8 or 3.6 m (6 or 12 ft) below MLW (Taney, 1961). No information was recorded regarding changes above the mean low water line. Comparison of the surveys indicate erosion amounting to approximately 819 m^3 per linear meter (325 yds^3 per linear ft) of beach between 1927 and 1932, followed by the erosion of 3250 m^3 per linear meter (1290 yds^3 per linear ft between 1932 and 1934). Since the surveys did not continue onto the beach, it is possible that some of the loss and gain of sand reflect seasonal onshore-offshore movement of sediment. Any sand eroded from the eastern section is probably carried eastward into Rockaway Inlet. West of the nodal point located near the center of Coney Island beach, sand eroded from the beach and near shore zone is probably transported into Lower Bay farther to the west (Taney, 1961).

Rivers

Raritan Estuary: Drainage into Raritan Estuary includes the Raritan River and Navesink River drainage basins, plus several small creeks. The waters from the Arthur Kill-Newark Bay drainage system flow mainly into the Hudson River north of Staten Island.

The Navesink River rises east of Freehold, flows 27 km (17 mi) northeast and enters Sandy Hook Bay. The lower 11 km (7 mi) from Red Bank to the Bay is an estuary 1.2 km (0.8 mi) wide cut-off from the ocean by Sandy Hook Spit. The drainage area of 245 km^2 (95 mi^2) lies in the marl region.

Several short creeks flow into the estuary along its south shore. The upper and middle courses of these creeks are swampy, their lower courses drowned, and they flow through tidal marshes to reach the estuary. These creeks, as well as the Navesink River, are a negligible source of sediment with respect to the estuary.

The Raritan River enters the estuary at the extreme western end of the Raritan Bay. With a drainage area of 1240 km^2 (485 mi^2) it is the largest intrastate system in New Jersey. There is a gradual transition from the rapid-flowing streams of its headwaters to the slow-moving river in the lower Raritan valley. In its last 11 km (7 mi) it meanders through a tidal marsh. The river is subject to tidal effects for about 24 km (15 mi) above its mouth, but the penetration of saline water does not extend more than 14.5 km (9 mi) above its mouth even under extreme drought conditions.

The Raritan River and its tributaries flow through an area of varied geology. Sediments entering the drainage system include mineral grains and rock fragments derived from the crystalline rocks of the New Jersey Highlands; the red sandstones and shales of the Triassic Basin; and unconsolidated sands, silts and clays of the Coastal Plain.

Dean and Haskin (1964) sampled the bottom sediments of the Raritan River at 19 stations between New Brunswick and the river mouth, a distance of 20 km (32 mi). The river is tidal throughout the entire distance sampled. They report that the sediments tend to decrease in mean particle size from New Brunswick to the river mouth. Seaward from the Washington Canal, the sediments grade from sand to silty sand to clayey silt. Near the river mouth, the particle size increases again through silt to sand-silt-clay or silty sand. All samples showed a wide distribution of sizes represented, and the sediment is poorly sorted.

Gross (1974) estimated that the Raritan River delivers 70,000 tons of sediment annually into the estuary. Most of this sediment consists of fine-grained silt and clay. Comparison of the probable circulation pattern and the distribution of sediment suggest that a portion of this fine sediment is transported into Sandy Hook Bay and is deposited. In addition, there is a band of silt and clay along the length of Raritan Bay suggesting that some silt and clay is being deposited during transit through the bay.

Hudson River: Naturally occurring sediments carried into lower New York Harbor by the Hudson River are predominantly silts and clays since the coarser sizes settle out in the basins located north of The Narrows. Panuzio (1965) estimated that the Hudson River sediment load at approximately 800,000 tons per year. In addition, there is a considerable amount of riverborne wastes introduced by the cities bordering the river. Most of this fine sediment is probably carried through Lower New York Harbor, however, there is good evidence that some silt and clay is being deposited in the vicinity of Swinburne and Hoffman Islands as a result of a small clockwise eddy current developed in this area.

Continental Shelf

There is very little information regarding the transport of sediment from the adjacent continental shelf into Lower Bay. What information is available suggest that little, if any, sediment is derived from this source.

Conclusions

Gross (1974) came to the following conclusion as to the sediment flux into the Lower New York Harbor:

> "...littoral drift is the largest contributor of sediment to the Estuary, depositing about 1.1 million tons of dry solids per year. The Hudson, Raritan, and other rivers contribute about 1 million tons per year. Sewage solids amount to nearly 0.3 million tons per year. To these should be added an unknown quantity of waste solids that are discharged directly to the estuary. In sum, the annual contributions of sediment from all sources (natural and man-controlled) to the Hudson Estuary are about 2.4 million metric tons of solids, on a dry weight basis."

Of the 1.1 million tons of dry solids contributed by littoral drift, approximately 600,000 tons are derived from the northern New Jersey littoral, and the remainder from westward moving littoral drift along the south shore of Long Island.

Gross reported that data from the Corps of Engineers indicate that an average of 2.2 million metric tons of solids were removed from the Lower New York Harbor each year since 1946. This indicates a remarkably close balance between the sources of sediment and that removed. Study of bathymetric surveys conducted over a period in excess of 100 years indicate minor shifting about of depth contours, but no major changes in the water depths with the exception of channels that were dredged (Fray, 1969). Thus, the sum of sediment removed naturally, plus that removed by annual dredging appears to balance the sediment inputs.

Sub-bottom Exploration

Introduction

Continuous seismic reflection profiling is a widely used geophysical technique for delineating sub-bottom geologic structures and bedding surfaces in water-covered areas. The principle of the technique is the same as that of the precision depth recorder, but since the frequency of the sound is lower and the energy higher, a significant fraction of energy incident on the sea floor is transmitted into the sea bed. Reflections occur at the sea floor and at surfaces below the sea floor where there is a sufficient change in the acoustic impedance of the material. In general, such changes are produced by variations in composition, texture, and other physical properties (e.g. porosity, water content, density, etc.).

A significant part of the present study was to assess the value of seismic reflection profiling in mapping the sand and gravel resources. To this end a seismic reflection survey of limited extent was conducted. Approximately 170 km (92 mi) of seismic reflection survey lines were run on 18-20 November 1975, and an additional 130 km (70 mi) were run on 16-17 March 1976. The location of these lines is shown on Figs. 20 and 21.

Method of Survey

The energy source used was an E.G. and G. Uniboom--a displacement type sound source. The source utilizes stored electrical energy to displace a submerged plate and the surrounding water, thus generating a pressure pulse. The sound source, towed on a specially designed catamaran, can be adjusted for a peak energy of 100, 200, or 300 joules.

In each case the energy is concentrated at a frequency of about 5000 Hz. For most of the survey a peak energy of 200 joules was used. The reflected signals were received with an eight-element hydrophone array, filtered through a band-pass filter, and recorded with a Gifft model 4000T precision 19" wet-paper recorder. A pulse rate of 0.5 second, and sweep times of 0.25 second, and 0.125 second were used. The system is capable of resolving layers less than 0.5 m in thickness.

Frequent navigation fixes along the tracks of the seismic reflection survey were obtained by sextant angles to shoreline features and navigational aids located on the hydrographic chart. Each navigational fix was keyed to the record by an event marker, and numbered. Radar ranging to known objects provided a secondary method of navigation, and served as a check on positions obtained by sextant angles.

Interpretation

Interpretation of the records is based on the shape and character of the echo of the reflecting layers, supplemented by the data from borings and other geologic data where available. Correlation of reflectors between survey lines, was possible in some instances. The records were adjusted for variation in ship speed to the same horizontal scale and a vertical profile was constructed showing the reflecting horizons along each survey line. A sound velocity of 1500 m per second was used in determining the

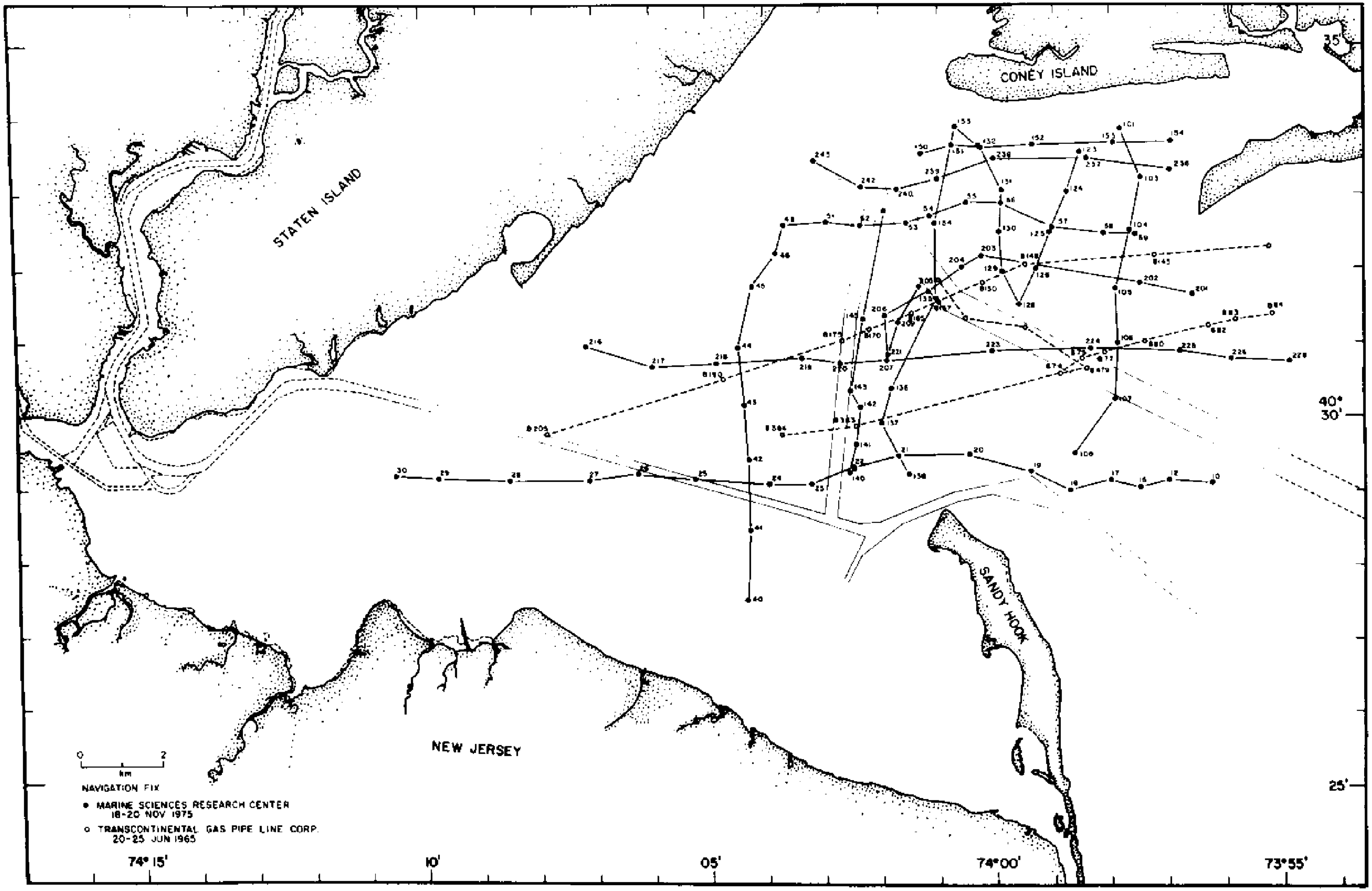

Fig. 20. Location of Marine Sciences Research Center, seismic reflection survey tracks, 18-20 November 1975.

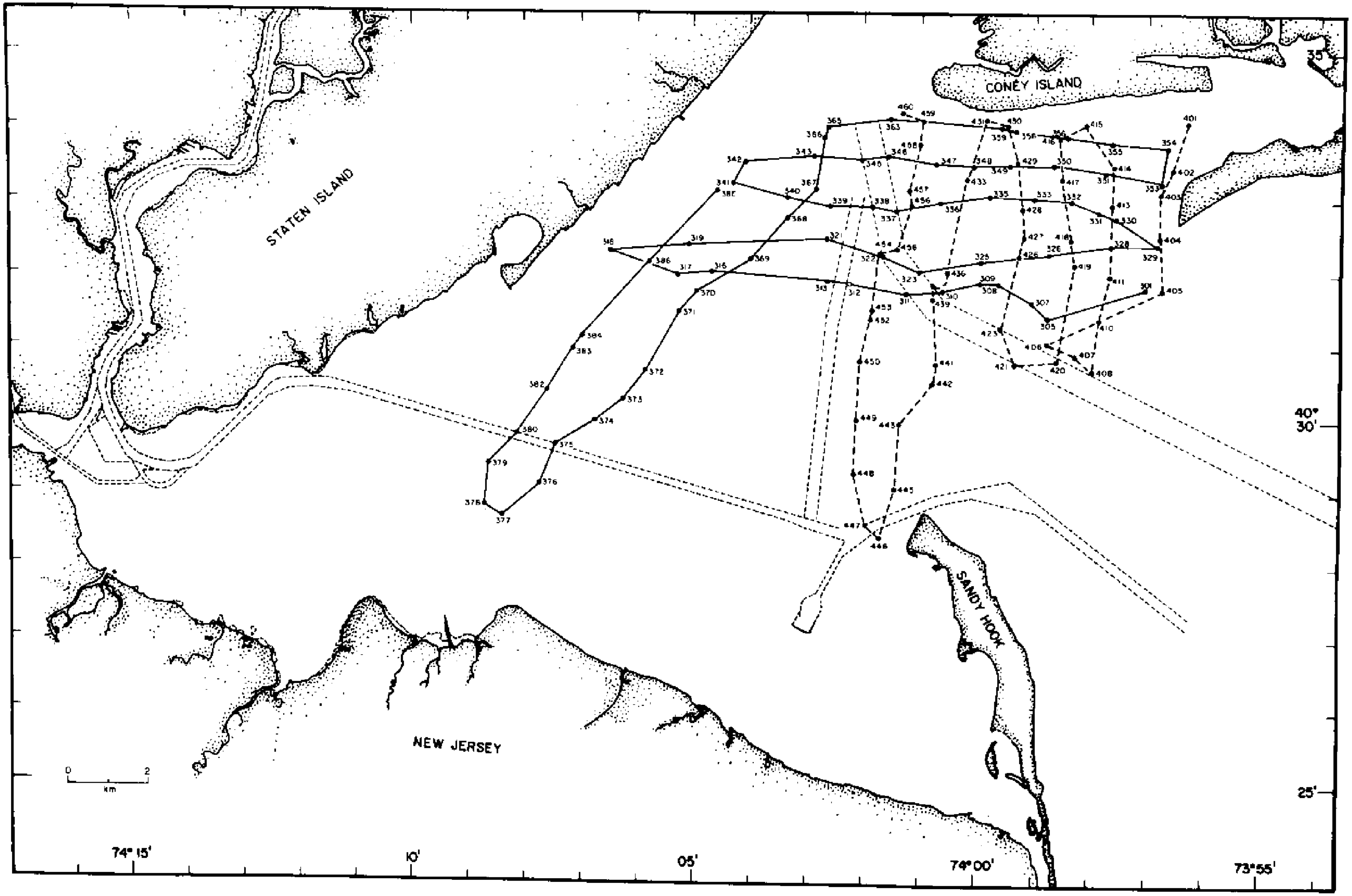

Fig. 21. Location of Marine Sciences Research Center, seismic reflection survey tracks, 16-17 March 1976.

depth to each reflector.

The results of the seismic reflection survey are presented as a series of north-south and east-west oriented profiles, Figs. 22 to 25. Included with the Marine Sciences Research Center profiles, are three profiles from a seismic reflection survey conducted by Edgerton, Germeshausen and Grier, Inc. for Transcontinental Gas Pipe Line Corporation in 1965. The location of the tracks of this survey are shown on Fig. 20.

The top horizontal line on all profiles represents the water surface. All vertical distances are measured from the water surface, and are shown in meters below mean sea level. The continuous line below that representing the water surface is the profile of the bottom. All lines at depths greater than the bottom represent reflecting horizons as identified in the records.

Discussion of Results

Examination of the profiles indicate that the number of reflectors, the horizontal extent of individual reflectors, and the depth to specific reflectors vary from profile to profile. Many reflectors terminate abruptly, while others appear intermittently. Some reflectors are essentially horizontal, while others are highly irregular. The thickness of the layers bounded by the reflecting horizons varies considerably over short distances.

This variability in the reflecting horizons along profiles and between profiles indicates that the sub-bottom sediment characteristics and areal distribution pattern is complex. It suggests that the types of sediment comprising the sub-bottom changes over short distances, and also varies rapidly with depth.

Since the primary objective of this survey was to test the seismic reflection method of mapping the sub-bottom characteristics, the survey tracks were relatively widely spaced. The results of the survey indicate that the characteristics of the sub-bottom change over distances less than that of the spacing between tracks. Consequently, it is not possible to correlate reflectors between adjacent parallel profiles except for one or two prominent reflectors. Where two tracks intersect, reflectors can be correlated on both profiles in the vicinity of the intersection.

The deepest reflector that we were able to identify consistently is located at a depth of 40-42 m (130-138 ft) below mean sea level. It is characterized by being nearly horizontal with few irregularities. This reflector has been labeled A on the profiles. It has been identified only in the area beneath East Bank. The location of the survey lines along which this reflector has been identified is shown on Fig. 26.

A second reflector which appears consistently in the records varies in depth between 20 m (65 ft) and 30 m (100 ft) below mean sea level. On the profiles, this reflector has been identified by the B. This reflector apparently is more extensive than is reflector A. Figure 27 shows the survey lines on which reflector B appears. In the area of Swash Channel, it occurs as a strong reflector at a depth of 25-30 m (85-100 ft). Beneathe East Bank it is identified at a depth of approximately 20 m (65 ft) of, and under the present location of Ambrose Channel, reflector B appears to define a broad valley, Figs. 28 and 29.

A number of sedimentary and geologic structures can be identified in the records. These include: cross-bedding, channel fill, erosion surfaces, and possible slump structure. The irregular surface shape of a number of the reflectors do not appear to be due to crustal deformation, but rather were produced by sedimentary and geomorphic processes.

Identification of sediment type on the basis of the echo characteristics of

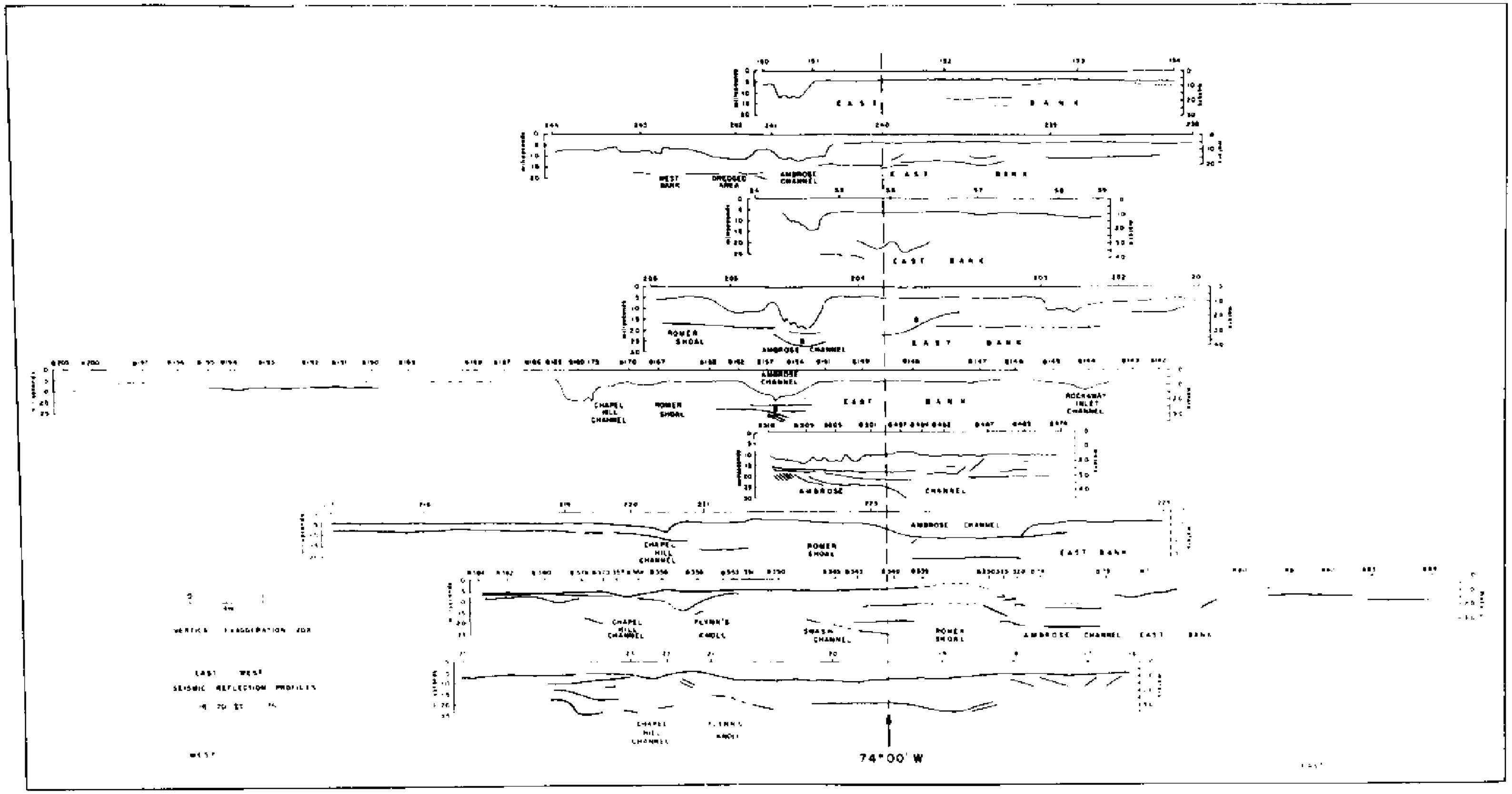

Figure 22 East-West Seismic Reflection Profiles, 18-20 November 1975.

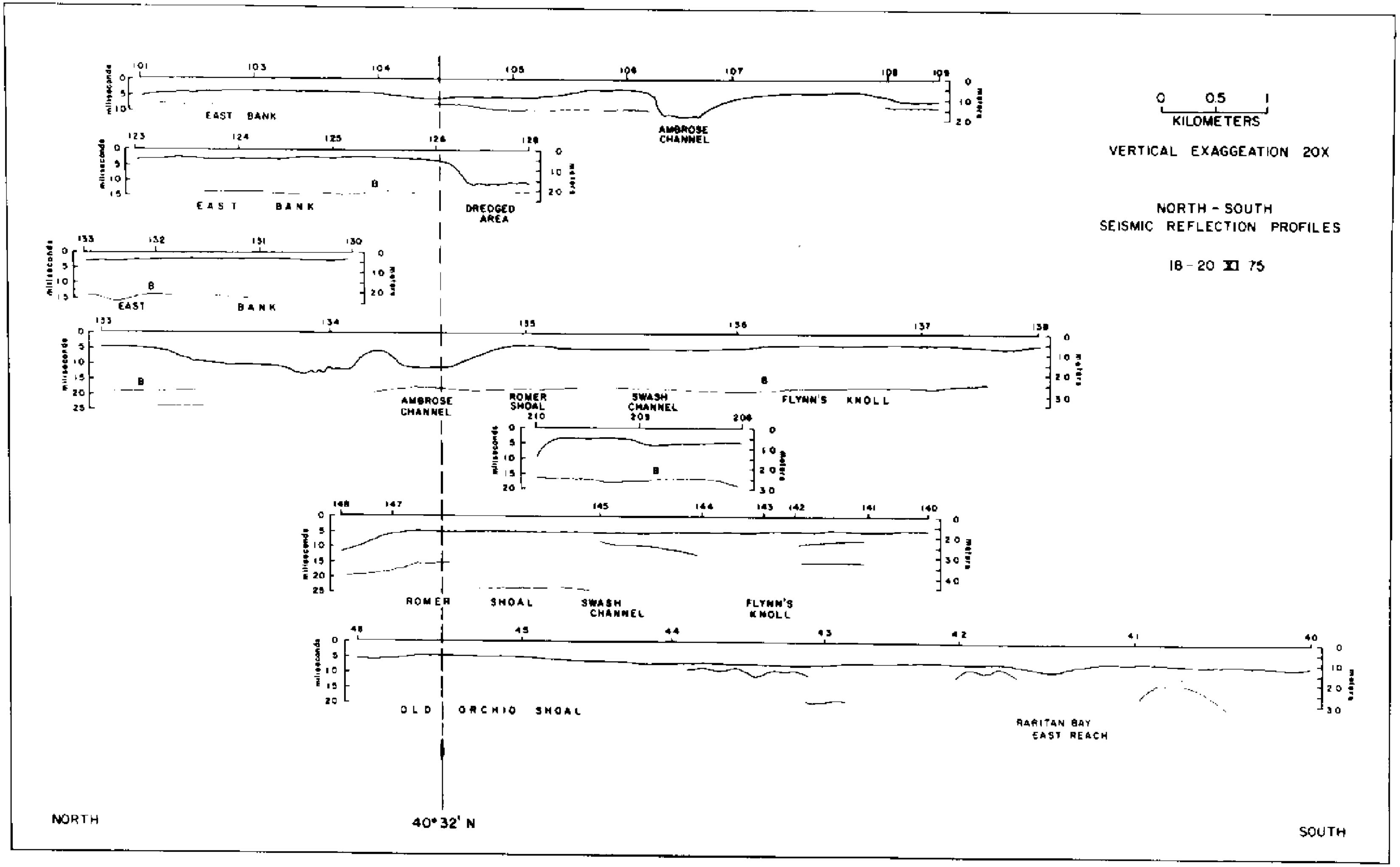

Fig. 23. North-south seismic reflection profiles, 18-20 November 1975.

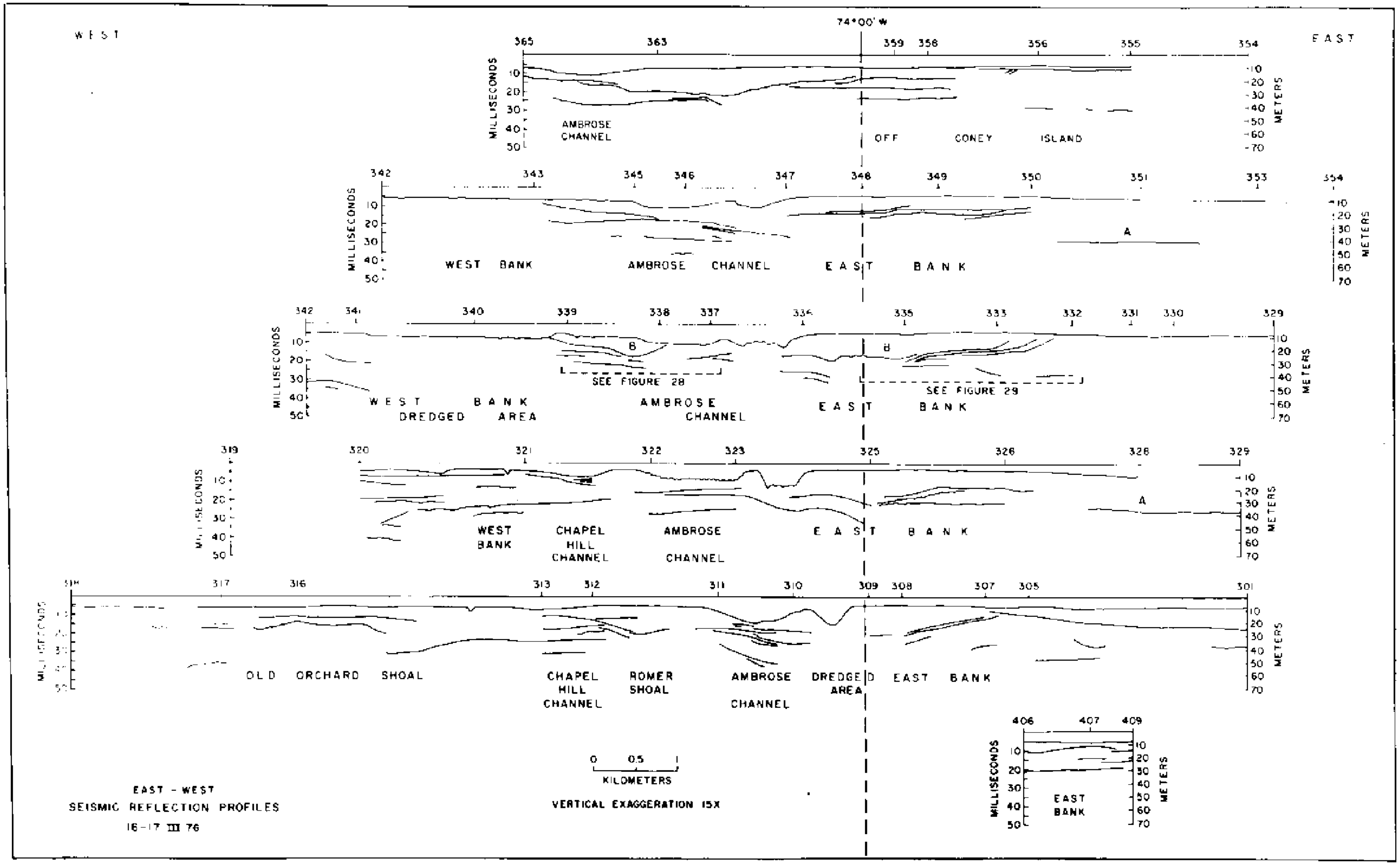

Fig. 24. East-west seismic reflection profiles, 16-17 March 1976.

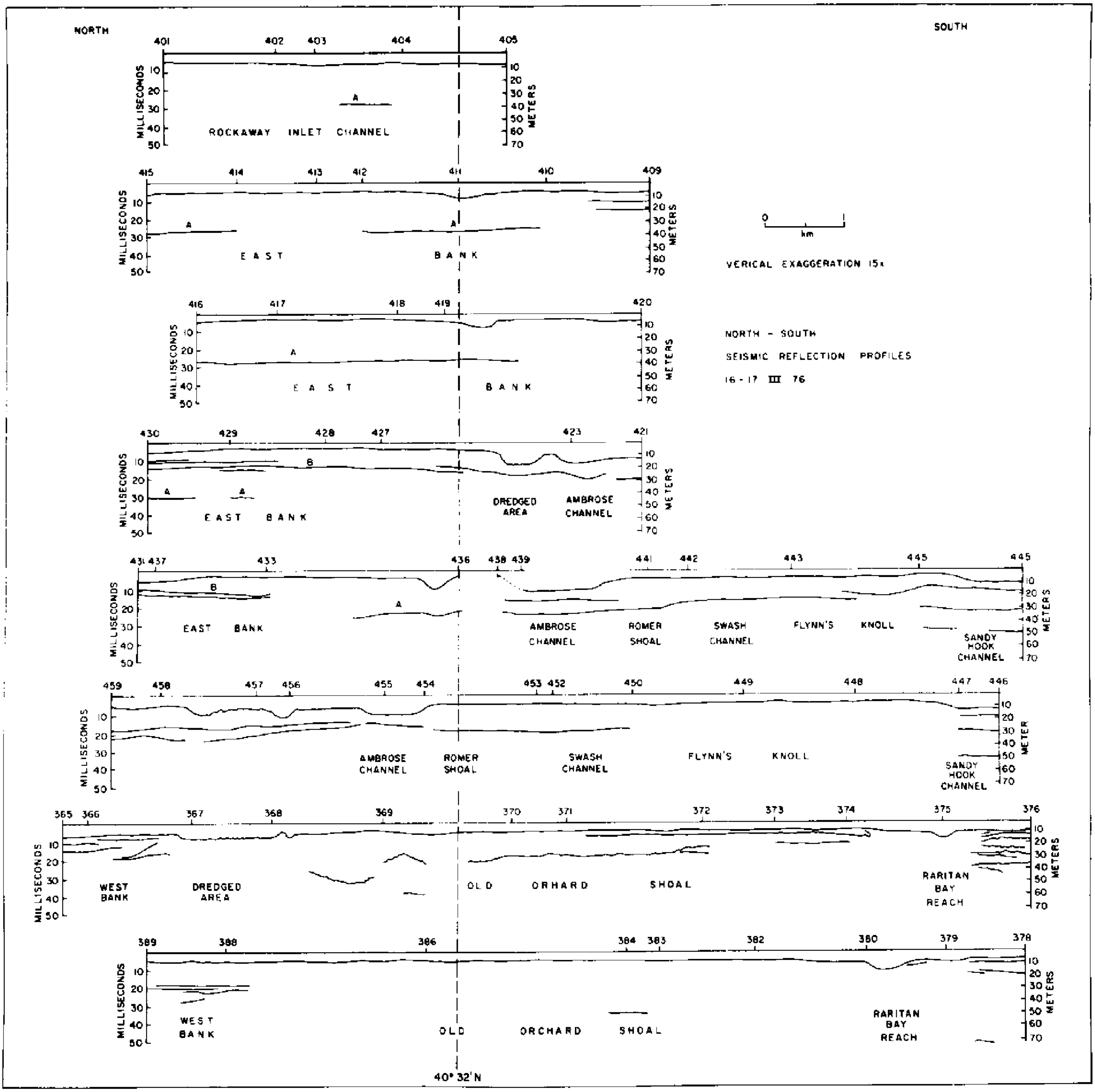

Fig. 25. North-south seismic reflection profiles, 16-17 March 1976.

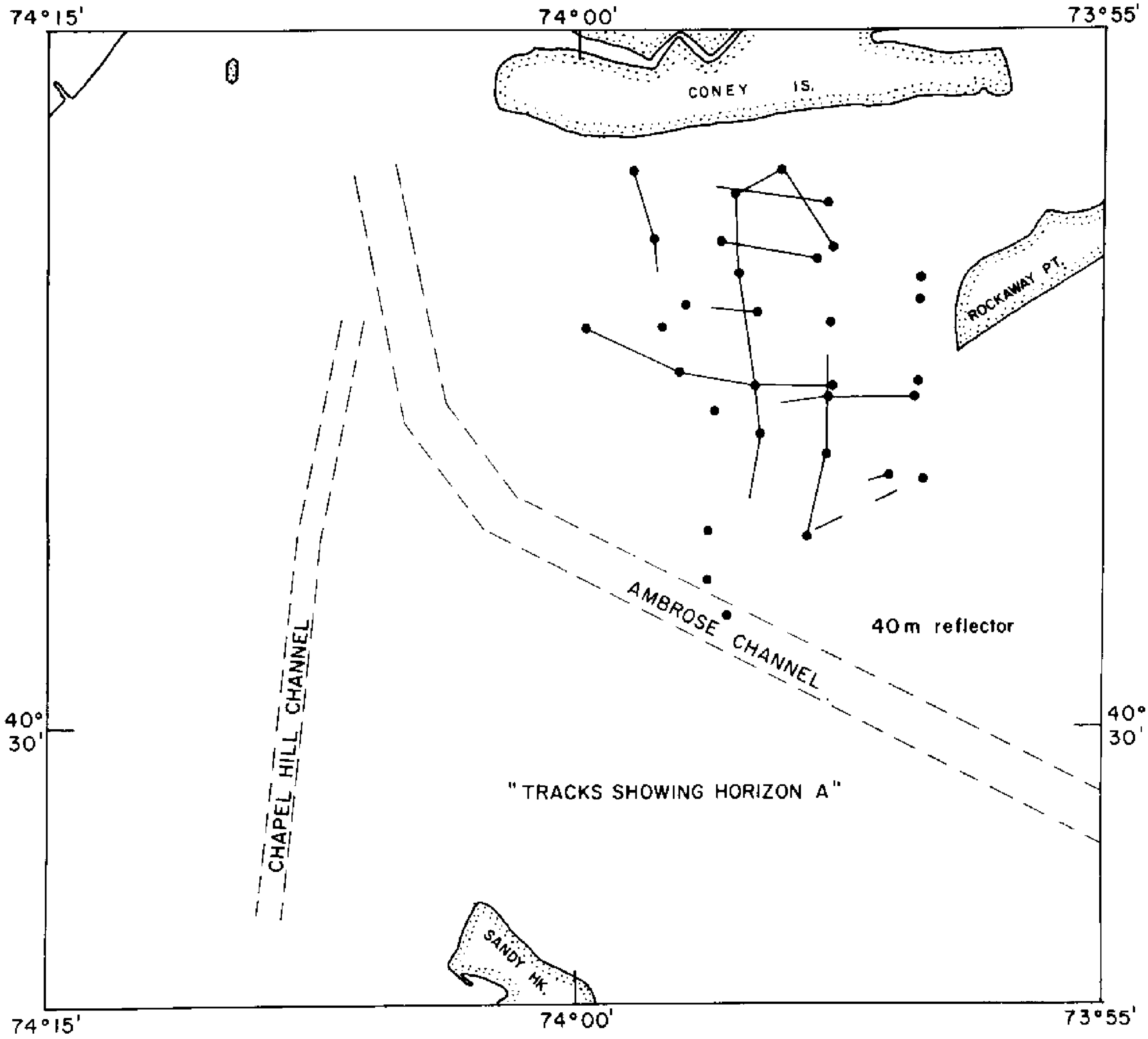

Fig. 26. Location of seismic reflection survey tracks along which reflector A has been identified.

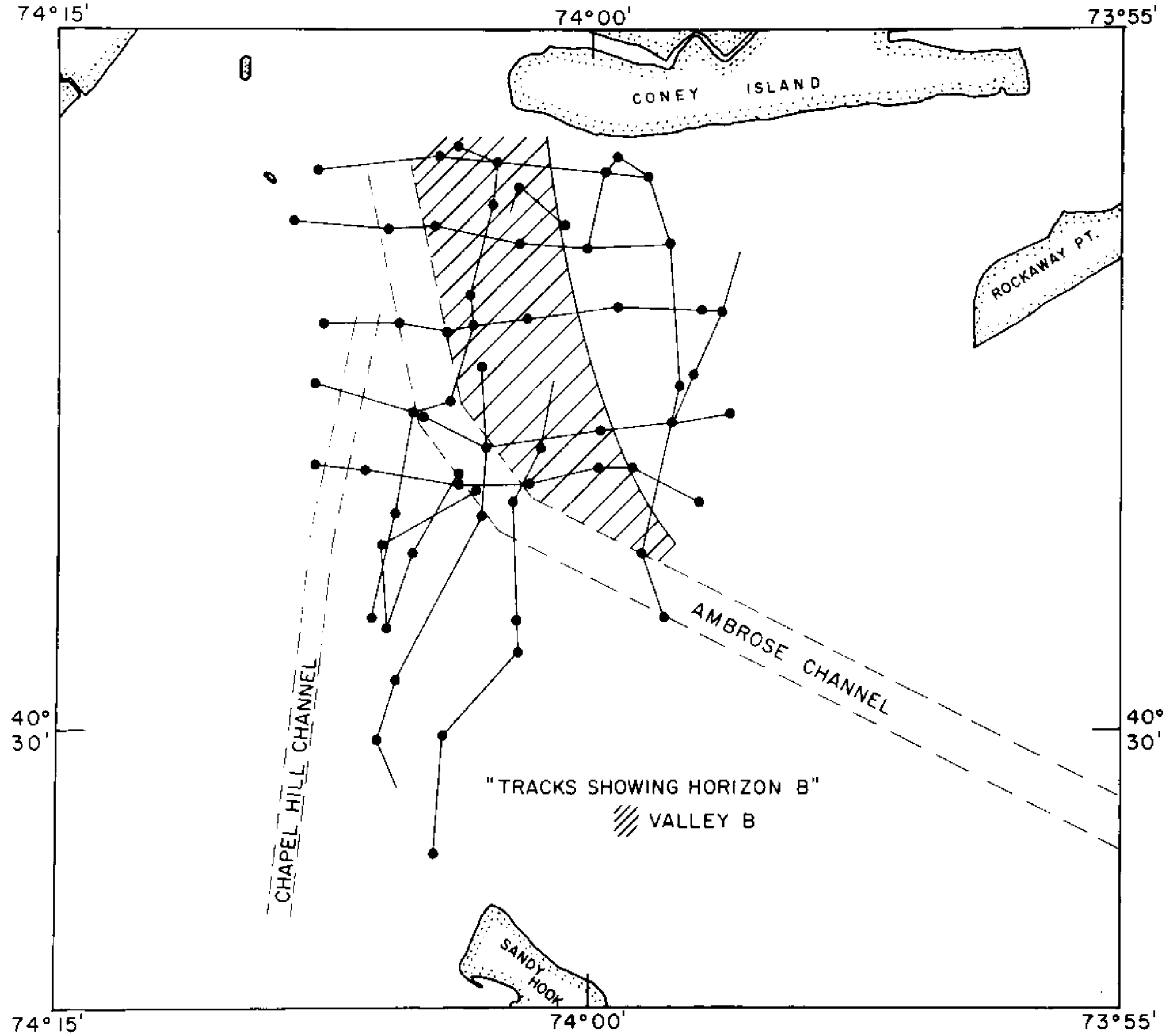

Fig. 27. Location of seismic reflection survey tracks along which reflector B has been identified.

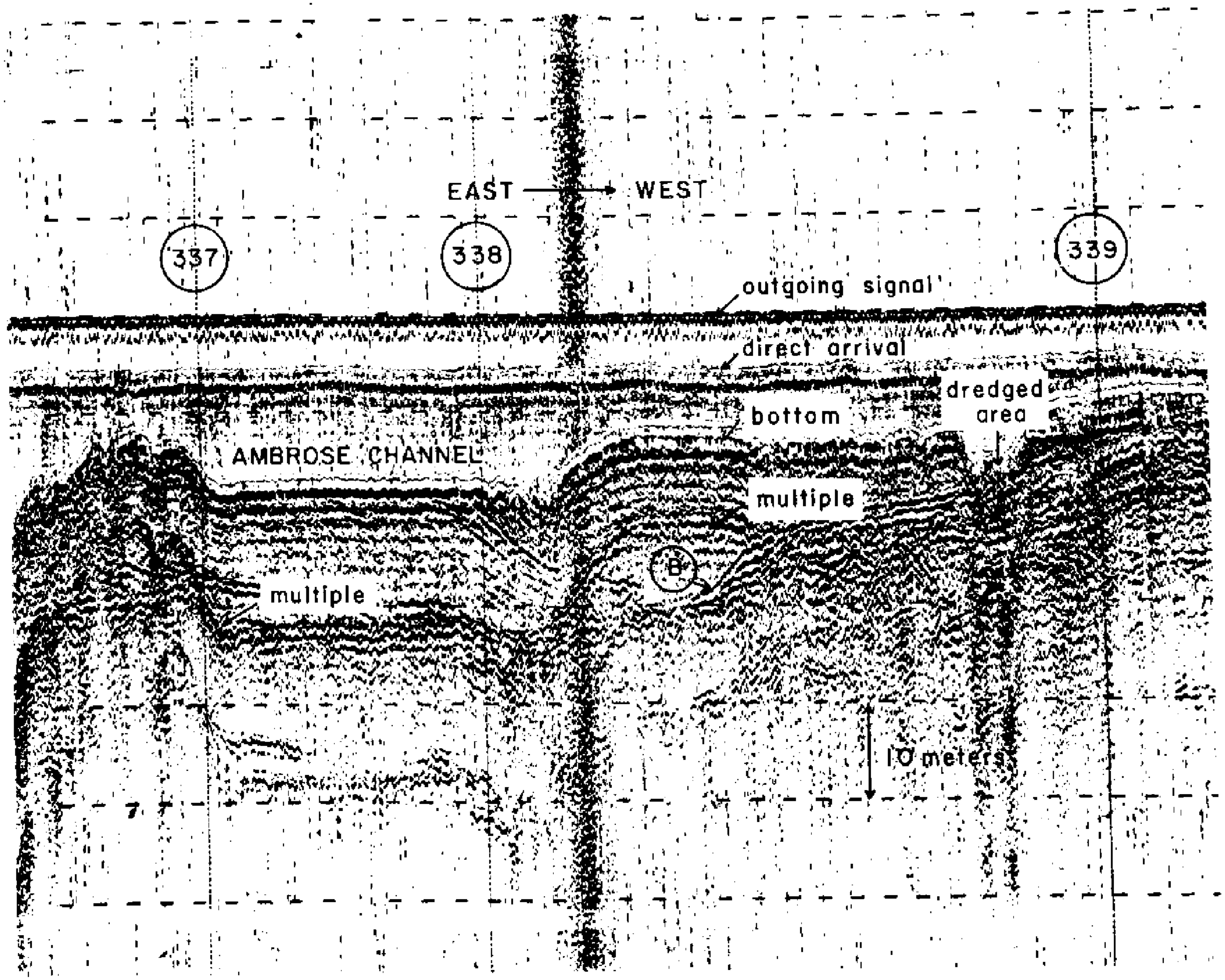

Fig. 28. Section of seismic reflection record showing reflector B in area of Ambrose Channel.

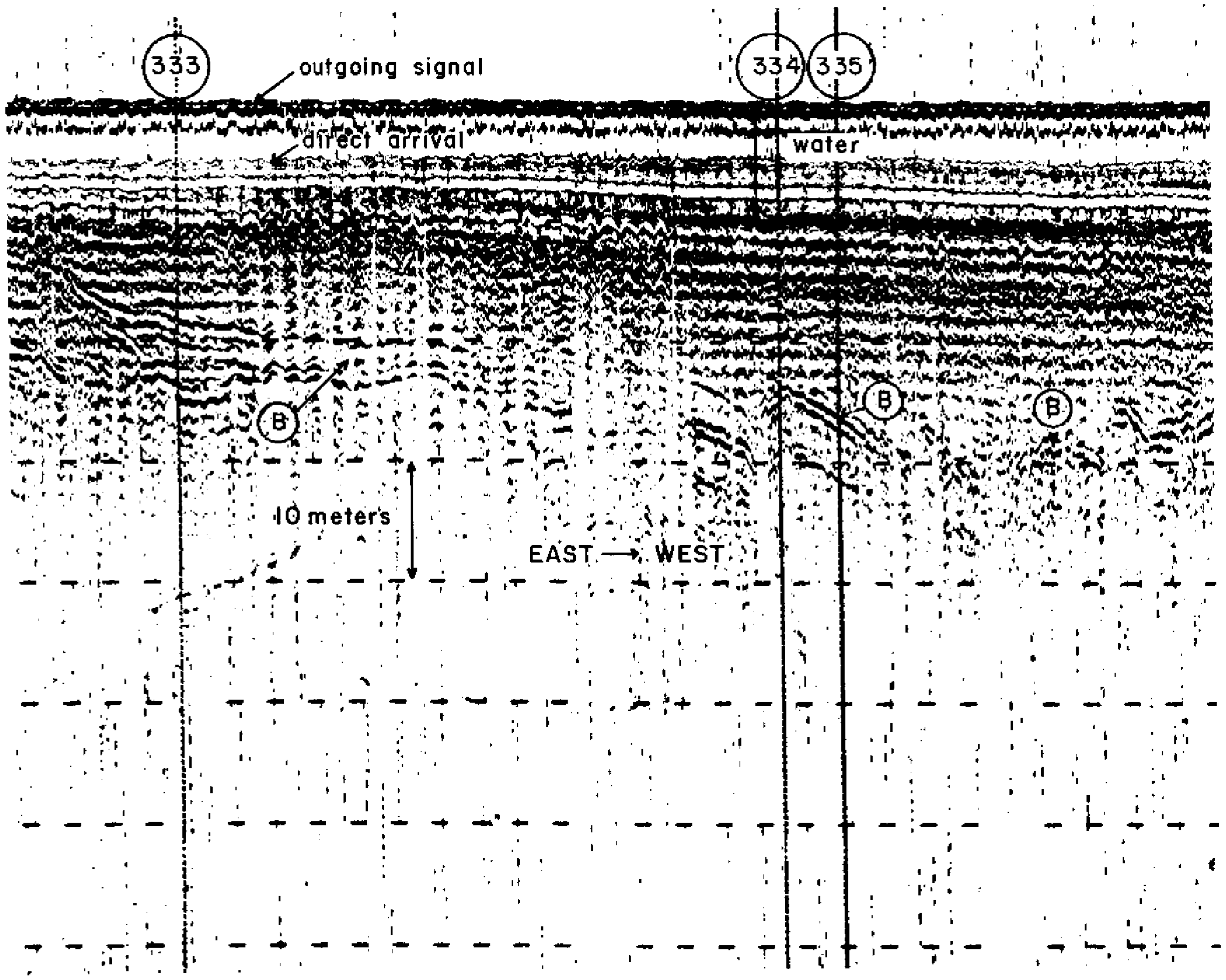

Fig. 29. Section of seismic reflection record showing reflector B under East Bank.

a reflector is very difficult. In a few instances, a tentative identification of sediment type can be made based upon the echo characteristic and correlation with data from a nearby boring. Fine-grained sediment with a high organic content, such as a buried marsh, appear to occur in some areas. These areas are characterized by very fuzzy echos, and frequently mark the sudden termination of strong reflectors. A possible explanation of this feature is a sand-filled channel within a buried marsh. Sand and gravel normally produce strong echos. Based on the limited amount of data available from this seismic reflection survey, and without correlative data from borings, identifying a layer as sand or gravel is tentative. However, the results of the survey indicate that with adequate control provided by existing boring data located both within Lower New York Harbor and along the shore, it would be possible to identify sediment types in many instances. To do this requires that survey tracks cross the boring sites.

Conclusions

The records indicate that the sediment characteristics are highly variable both horizontally and vertically. Discrete reflectors rarely can be traced for more than 2 km (1 mi) along any seismic reflection profile. Sediment layers defined by the reflecting horizons thicken and thin, or pinch out over very short distances. Assuming that similar appearing reflectors on adjacent profiles are the same is not warranted. A variety of sedimentary structures and geomorphic features appear in the records.

The evidence from the seismic reflection survey coupled with data from boring logs indicate that a variety of sediment types; including organic muds, silt and clay, sand, gravel, and various combinations of these underlie the bottom of Lower New York Harbor. A variety of sediment sources plus several geomorphic processes have operated within these areas, and are responsible for the variable sediment types present and their distribution.

The preliminary seismic reflection survey of a portion of Lower New York Harbor conducted by the Marine Sciences Research Center has demonstrated the value of this geophysical method in assessing the sand and gravel resources of the area. Interpretation of the seismic reflection records has shown that there are numerous and rapid changes in the lithology of the sub-bottom, both horizontally and vertically. To adequately determine the extent of the sand and gravel resources will require detailed mapping of sub-bottom characteristics of Lower New York Harbor.

Recommendations

Based upon the results obtained to date, and examination of seismic reflection records made available to us from other sources, the following recommendations are made:

1. A detailed seismic reflection survey of Lower New York Harbor offers the only practical and economical method of mapping the sub-bottom sediment areal distribution and vertical extent of sand and gravel deposits.
2. The seismic reflection survey should consist of an intersecting grid of closely spaced lines. The orientation of the survey lines should be approximately northeast-southeast corresponding to the strike of the geologic formations, and southeast-northwest which roughly corresponds to the regional southeast dip of the geologic structure.
3. Selection and operation of seismic reflection instrumentation should be designed to

provide the maximum amount of sub-surface information from the bottom to a depth of approximately 30 m (100 ft)--the maximum depth to which dredges can operate.

4. A few limited seismic reflections surveys have been conducted by other organizations over the past years. The quality and extent of these surveys vary, however, they do provide considerable information that should be correlated with and incorporated in the recommended survey. The survey should be designed to intersect all previous survey tracks. Records from some of the previous surveys have been obtained already by the Marine Sciences Research Center.
5. A considerable number of borings have been taken over the years for various purposes within the Lower New York Harbor and along the adjacent shore. The seismic reflection survey tracks should be designed to intersect all offshore boring sites, and tie-in with onshore boring sites as closely as possible. Interpretation of the seismic reflection records should be correlated with the boring data.
6. A number of regional and local geological reports include geologic maps and vertical profiles of the geologic structure and lithology. The seismic reflection survey should be designed to take full advantage of this data, and tie-in with it wherever possible.
7. Any comprehensive program of borings should be undertaken only after the completion of a detailed seismic reflection survey. This would enable the drilling sites to be located where they would provide a maximum of information.
8. To carry out a seismic reflection survey as recommended will require precision navigation. It is suggested that an electronic navigation system be used.

Lower New York Harbor as a Source of Sand and Gravel

Dredging Operations

Removal of bottom sediments by dredging has occurred at many areas within Lower New York Harbor. The purpose of this dredging is to provide and maintain shipping channels, to provide access channels to local harbors, to supply artificial fill to form beaches and provide shore protection, and as a source of construction material.

At the present time dredging activity is closely controlled. Commercial dredgers must obtain a permit and a water quality certificate from the Department of Environmental Conservation, a permit from the U.S. Army Corps of Engineers, and a license to remove material from state owned lands, from the New York State Office of General Services.

Before 1966 commercial dredgers worked in whatever parts of the Bay yielded suitable material. In 1966 the New York State Conservation Department issued a "Recommendation for a Preferred Dredging Area in Lower New York Bay" which permitted mining in a large area of the West Bank of Ambrose Channel (Fig. 30). In the late sixties, dredging was approved in a restricted area of the East Bank, at the bend of Ambrose Channel. The West Bank was closed to dredging in 1973.

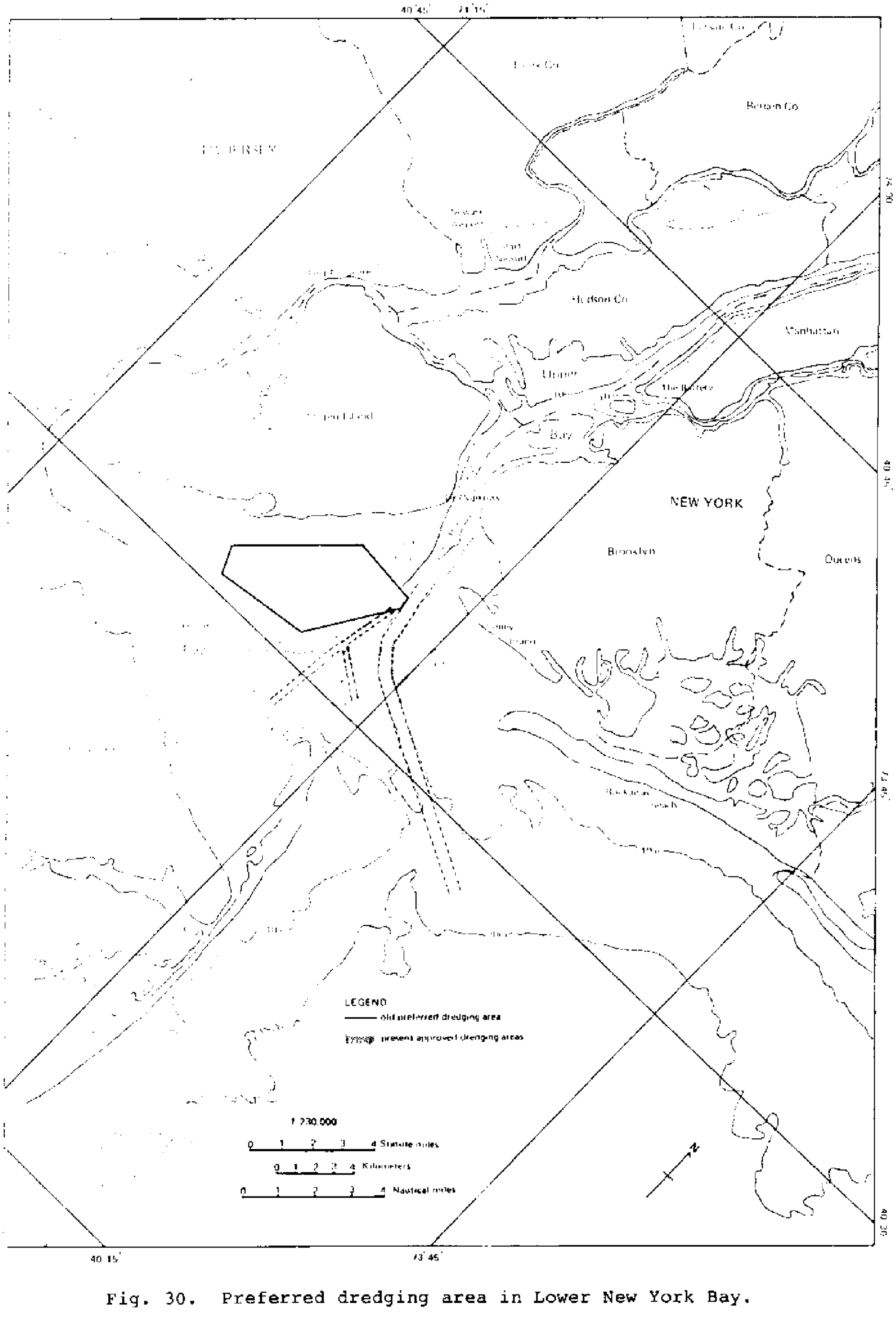

Fig. 30. Preferred dredging area in Lower New York Bay.

Currently permits are granted for private commercial dredging both on the East Bank and in portions of Chapel Hill and Swash Channels, but 90% of the actual dredging activity takes place on the East Bank area. Dredging for public works has generally been under the same areal constraints as private dredging. An exception is the 2.8×10^6 m^3 (3.7×10^6 yds^3) Rockaway beach restoration project, for which the D.E.C. approved a special borrow area west of Rockaway Point. Since 1933, the New York State Office of General Services has collected royalties on dredged materials destined for private, semi-public, or out-of-state projects. On the other hand, those dredging operations conducted for public works projects in New York City have been carelessly regulated. Records of quantity and location of mining for public works projects are buried in a labyrinth of city agencies, or nonexistant.

The best available estimates of the volume of sediment dredged is given in Tables 6 and 7. The figures for private commercial dredging between 1950 and 1966 (Schlee and Sanko, 1975) represent minimum quantities; those from 1966 to 1975 (James Marotta, Office of General Services, personal communication) are more accurate. Public works dredging, Table 6, includes fill for Newark and LaGuardia airports, Port Newark, the Brooklyn and Elizabeth Piers, and the Rocka-Rockaway Beach restoration project. This list is probably not complete.

Since 1950, commercial operators have removed at least 41×10^6 m^3 (54×10^6 yds^3) of material upon which royalties have been paid, and at least an additional 26×10^6 m^3 (35×10^6 yds^3) for public works projects. The total volume removed for channel maintenance plus aggregate mining is over 72×10^6 m^3 (94×10^6 yds^3). This volume of recorded dredging in the Lower Bay is equivalent to lowering the bottom by more than one yard within the area of the quadrangle whose vertices are Coney Island, Rockaway Point, Sandy Hook, and Great Kill Point.

The largest volume of sediment removed within the Raritan Estuary was during the construction of the New York-New Jersey Channel connecting Sandy Hook Channel with Arthur Kill and the Raritan River. The first major project to dredge the Raritan River-Arthur Kill Cut-off Channel, New York-New Jersey Channels, and Perth Amboy Anchorage was authorized in 1902. Deepening of the New York-New Jersey Channel to a project depth of 35 feet was authorized in 1935, and dredging operations commenced shortly thereafter. Enlargement of the Perth Amboy Anchorage was carried out during 1952-1954. Continual maintenance dredging has been performed to maintain project depths. Figures available on the volume of sediment removed and the median grain size of the sediment are tabulated in Table 7.

Commercial and maintenance dredging operations will continue to remove large volumes of sediment in the foreseeable future. On the basis of planned and proposed beach replenishment and highway construction projects, Peter Sanko predicts that the demand for sand throughout the remainder of the 1970's will probably exceed 6.5×10^6 m^3/yr (8.5×10^6 yds^3/yr) Schlee and Sanko (1975).

Sand Resources

Figure 31 shows potential sand borrow areas, and estimates of the thickness of useable sand. These depths have not been limited by current technological and legal limitations, but only by our observations of sediment type. Where possible, we have determined the thickness of the surface sediment layer, either from seismic reflection records or boring data. Elsewhere, the numbers represent the thickness of sediment about which we have sufficient information to make an educated guess. These numbers

Table 6. Estimates of Volume of Sediment Dredged from New York Harbor[1]

Year	Commercial Mining*, ** (Royalties (Paid) Volume, m^3	(yds^3)	Public Works Mining*,** (No Royalties) Volume, m^3	(yds^3)	Project	Location of Mining†	Maintenance Dredging†† Ambrose and Chapel Hill Volume, m^3	(yds^3)			Year
1950	764,600	(1,000,000)	2,610,310	(3,414,157)	Newark Airport						1950
1951	764,600	(1,000,000)									1951
1952	764,600	(1,000,000)									1952
1953	229,400	(300,000)									1953
1954	229,400	(300,000)									1954
1955	229,400	(300,000)									1955
1956	229,400	(300,000)									1956
1957	229,400	(300,000)	206,300	(269,800)	Brooklyn Piers						1957
1958	841,000	(1,100,000)	837,900	(1,095,900)	LaGuardia/Brooklyn Piers						1958
1959	841,000	(1,100,000	143,000	(187,000)	Port Newark						1959
1960	841,000	(1,100,000)									1960
1961	841,000	(1,100,000)	6,115,100	(7,998,200)	Elizabeth Piers		454,600	(594,600)			1961
1962	841,000	(1,100,000)					115,400	(151,000)			1962
1963	3,440,500	(4,500,000)	11,125,600	(14,551,800)	Newark Airport		240,800	(315,000)			1963
1964	3,440,500	(4,500,000)									1964
1965	261,100	(341,500)			Rte. 78, N.J.						1965
1966	1,778,000	(2,325,500)			Rte. 78, N.J.		675,900	(884,050)	636,400	(832,400)	1966
1967	3,757,400	(4,914,400			N.J. Turnpike						1967
1968	2,592,700	(3,391,100)			Elizabeth Piers		167,100	(218,500)			1968
1969	3,402,300	(4,450,000)			Amer. Export Ind. N.J. Turnpike						1969
1970	727,400	(951,400)	1,662,900	(2,175,000)	Port Elizabeth N.J. Turnpike Amer. Export Ind.						1970
1971	3,284,100	(4,295,400	764,600	(1,000,000)	Newark, N.J., P.O.						1971
1972	(1,540,600)	(2,015,000)	4,086,200	(5,344,400)	Port Elizabeth Newark, N.J. Airport Battery Park City Hartz Mt. Ind. Pk	90% East Bank 10% Chapel Hill North	1,167,300	(1,526,779)	463,170	(605,810)	1972
1973	(3,321,900)	(4,344,800)	1,895,200	(2,478,800	Port of N.J. Port of Newark Battery Park City Bowery Bay Poll Plt.	92% East Bank 6% West Bank 2% Unknown					1973

Table 6. (continued)

Year	Commercial Mining*, ** (Royalties Paid) Volume, m^3	(yds^3)	Public Works Mining*, ** (No Royalties) Volume, m^3	(yds^3)	Project	Location of Mining[†]	Maintenance Dredging[††] Ambrose and Chapel Hill Volume, m^3	(yds^3)			Year
1974	2,305,200	(3,015,100)			N.J. Turnpike Battery Pk. City Port of N.J. Bowery Bay Poll.Plant	90% East Bank 8% Chapel Hill North 2% Great Kill 90% East Bank 10% Chapel Hill North	470,670	(615,619)			1974
1975	3,821,800	(4,998,600)			N.J. Sports Complex Port of N.J. Bayonne Military Transport N.J. Turnpike Battery Park City						1975
TOTALS:	41,319,300[∞]	(54,042,800)	26,836,800[∞]	(35,100,900)			3,292,207[∞]	(4,306,048)	1,092,508[∞]	(1,429,210)	

---

[1] Reported values for volumes of sand dredged before 1965 may be too highly a factor of 2X, or more.

* From Peter Sanko for period 1350-1966

** From James Marotta for period 1966-1975

[†] From James Marotta

[††] From John Zammit

[∞] Metric equivalents were calculated from the basic data which were reported in yds^3. The discrepancies result from rounding off.

Table 7. Summary of maintenance dredging in Raritan Bay Channels and in Sandy Hook Channel: dates, volumes removed, and median grain size of dredged material.

RARITAN ESTUARY

Channel	Dates	Volume		Median Diameter (mm)
South Amboy Reach Great Beds Reach	Nov.-Dec. 1963	106,800 m^3	139,700 yds^3	
New York-New Jersey Channels sections 6,7,8,9,11,12	May-Aug. 1964	517,150 m^3	676,400 yds^3	0.043
New York-New Jersey Channels Perth Amboy Anchorage	Sept. 1964	389,600 m^3	509,600 yds^3	0.035
New York-New Jersey Channels Perth Amboy Anchorage	Oct.-Nov. 1965	354,000 m^3	463,000 yds^3	0.035
South Amboy Reach Great Beds Reach	April-May 1967	279,800 m^3	366,000 yds^3	0.008
New York-New Jersey Channels sections 9,10,11,12	July-Aug. 1967	483,200 m^3	632,000 yds^3	0.031
New York-New Jersey Channels Perth Amboy Anchorage	July-Aug. 1968	441,500 m^3	577,500 yds^3	0.035
	TOTAL	2,572,005 m^3	3,364,200 yds^3	

Average annual rate for 5-year period 514,400 m^3 (672,800 yds^3)

SANDY HOOK CHANNEL

Channel Section	Dates	Volume		Median Diameter (mm)
Sandy Hook Point	July-Aug. 1965	165,450 m^3	216,400 yds^3	0.270
Sandy Hook Channel Main and east sections	April-May 1965	267,450 m^3	349,800 yds^3	0.248
Sandy Hook Channel East section	Mar.-Apr. 1968	381,800 m^3	499,400 yds^3	0.220

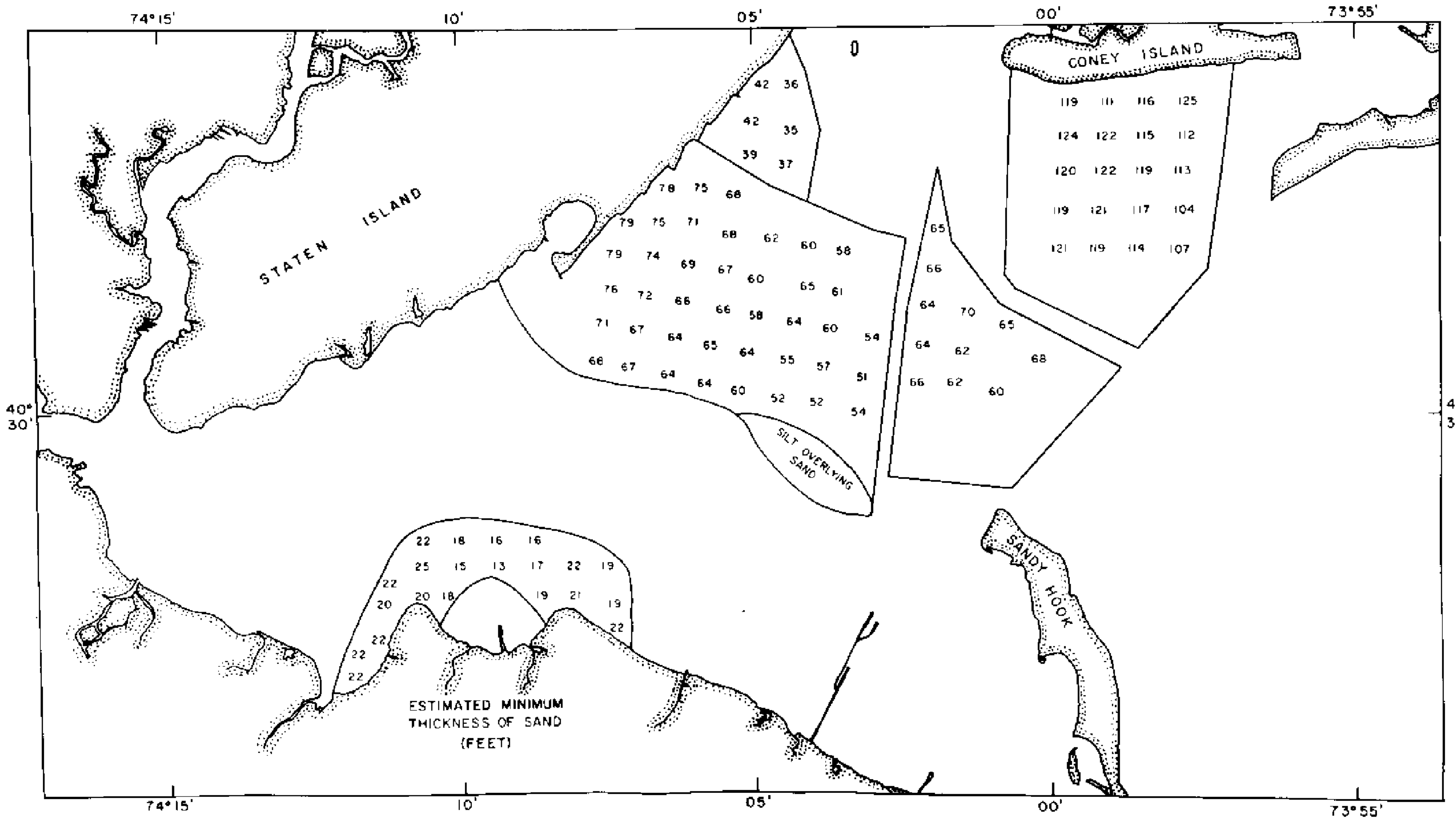

Fig. 31. Potential sand borrow areas, and estimates of thickness of useable sand.

are based on very limited information, and should be used only as a very tentative estimate of the sand that is available. In most cases there is no information on the sediment characteristics with depth.

The small patches of sand near the New Jersey and Staten Island shore of Raritan Bay may be of commercially useful grade, although we have only vague grain size analyses. Cores show that the sand north of Comnaskonk Point and Point Comfort reaches at least 7 m (24 ft) below sea level. The area of this patch is about 13 x 10^6 m^2 (15 x 10^6 yds^3); the volume of potentially mineable material is about 230 x 10^6 m^3 (300 x 10^6 yds^3). However, aggregate mining close to the New Jersey or Staten Island shore would aggravate already severe shore erosion problems.

Aggregate mined from the large area west of Chapel Hill Channel and north of Raritan Bay Channel would probably have a broad and rather unpredictable grain size distribution. Discrete layers can not be followed for any distance on either core logs or the seismic reflection profiles.

A very large volume of sand is available in this area. Near Swineburne Island, cores show clay below -15 m (-50 ft) MLW. Dredging operations in the nearby West Bank commercial dredging area uncovered "mud" at about the same depth (James Marotta, personal communication). Therefore, for the area west of the former West Bank dredging area, we have estimated the volume of sand based on -15 m (-50 ft) as the maximum depth. Further south, we feel that the sediment to the depth of consistent penetration of the seismic reflection profiles (-25 m, -82 ft) is outwash sand and gravel superficially reworked by marine processes. Most outwash sands are acceptable for commercial use. Except for previously mentioned areas around Swineburne Island, the cores in this potential borrow area show various combinations of sand, sand with gravel, and gravel, throughout their depth. Since the water on the West Bank is shallow, the thickness of sand ranges from 15-24 m (50-79 ft).

Material mined from the area bounded by Ambrose Channel, Chapel Hill Channel, and Raritan Bay Channel will have a coarser grain size distribution with more gravel than the sand now being mined. We feel that everything shallower than Horizon B (∿-25 m, -82 ft) is useable sand.

In the area north east of Ambrose Channel, we assumed that the entire thickness of sediment overlying Horizon A (-40 m, -131 ft) is useable sand. Cores indicate grain size generally coarsens with depth, although there are occasional deep lenses of silt.

<u>Potential Uses</u>

Thus far, the only uses which have been made of Lower Bay sand are for landfill and for beach restoration (James Marotta, personal communication). As Fig. 32 shows, the surficial sand is suitable for fill over many square miles of Lower Bay since the only requirement is low silt/clay content.

Beach restoration is a rather special case since an attempt is usually made to closely match the grain size distribution of the natural beach. We hope that the grain size data included in Appendix B will prove useful in choosing borrow areas for future restoration projects.

In addition, sand from parts of Lower Bay may be acceptable for other uses. In Appendix C we have presented the N. Y. State Department of Transportation specifications for mortar sand, grout sand, cushion sand, concrete sand, mineral filler, blasting sand; and the American Water Works Association requirement for filter sand. Table 8 lists those MSRC

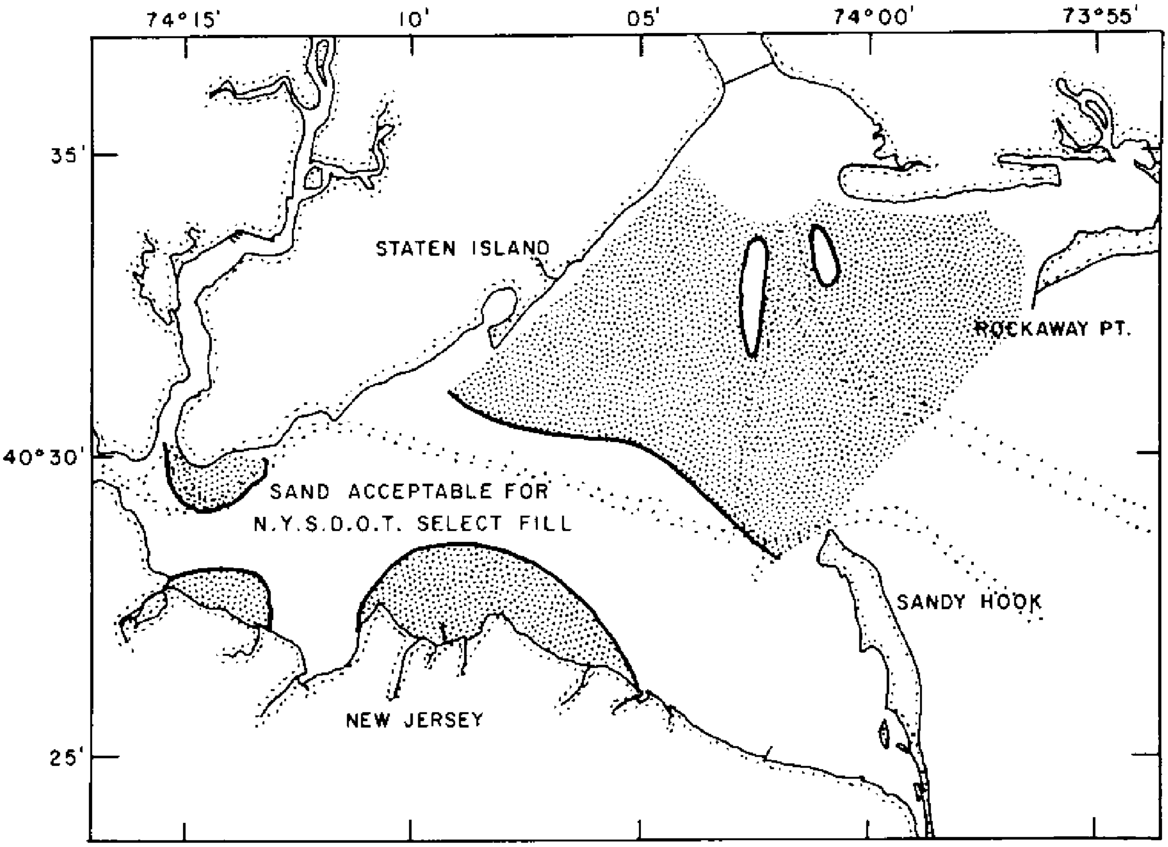

Fig. 32. Potential sources of sand for select fill.

Table 8. Marine Sciences Research Center, Shipek Grab Samples, Acceptability of Sediment for various New York State Department of Transportation Specification.

Sample No.	NYSDOT Mortar Sand	NYSDOT Grout Sand	NYSDOT Cushion Sand	NYSDOT Concrete Sand	NYSDOT Mineral Filter	Blasting G_1	Sand G_2	NYSDOT Select Sub-grade	NYSDOT Select Fill for Under-Water Placmnt.	NYSDOT Select Fill for Above-water Placmnt.	Filter Sand
1	F	F	F			F	F	OK	F	F	
2	F	C	F	F	C	F	F	OK	OK	OK	C
3	F	OK	F	F	C	F	F	OK	OK	OK	OK
4	F	C	F	F	C	F	F	OK	OK	OK	C
5	F	C	F	F	C	F	F	OK	OK	OK	OK
6	F	F	F	F		F	F	OK	F	F	
7	F	F	F	F	C	F	F	OK	OK	OK	OK
8	F	F	F	F		F	F	OK	F	F	
9	OK	C	F*	F	C	F	F	OK	OK	OK	C
10	OK	C*	F	F	C	F	F	OK	OK	OK	OK
11	F	C*	F	F	C	F	F	OK		OK	OK
12	F		F	F		F	F	OK	F	F	
13	F	C	F	F	C	F	F	OK	OK	OK	OK
14	F	F	F	F		F	F	OK	F	F	
15	F	F	F	F		F	F	OK	F	F	
16	F	F	F	F		F	F	OK	F	F	
17	F	F	F	F	C	F	F	OK	OK	OK	OK
18	F	F	F	F		F	F	OK	F	F	
19	F*	C	F	F	C	F	F	OK	OK	OK	OK
20	OK	OK	OK	F	C	F	F	OK	OK	OK	OK
21	F*	C	F	F	C	F	F	OK	OK	OK	F
22	F*	C*	F	F	C	F	F	OK	OK	OK	OK
23	F*	C*	F	F	C	F	F	OK	OK	OK	OK
24	F	F	F	F	C	F	F	OK	OK	OK	OK
25	F	OK	F	F	C	F	F	OK	OK	OK	OK
26	F	C*	F	F	C	F	F	OK	OK	OK	OK
27	OK	C	OK	C	C	F	F	OK	OK	OK	C
28	C	C	OK	C	C	C	F	OK	OK	OK	C*
29	OK	C	OK	C*	C	F	F	OK	OK	OK	C
30	F	OK	F	F	C	F	F	OK	OK	OK	OK
31	OK	C	OK	F	C	F	F	OK	OK	OK	C
32	F	C	F	F*,C*	C	F	F	OK	OK	OK	C
33	F	OK	F	F	C	F	F	OK	OK	OK	OK
34	F	OK	F	F	C	F	F	OK	OK	OK	OK
35	F	OK	F	F	C	F	F	OK	OK	OK	OK
36	F	OK	F	F	C	F	F	OK	OK	OK	OK
37	F	C*	F	F	C	F	F	OK	OK	OK	OK
38	F	C*	F	F	C	F	F	OK	OK	OK	OK
39	F	C*	F	F	C	F	F	OK	OK	OK	OK
40	F	C	F	F	C	F	F	OK	OK	OK	C¶
41	F	C	F	F	C	F	F	OK	OK	OK	C
42	F	C	F	F	C	F	F	OK	OK	OK	C
43	OK†	C	OK†	C	C	F	F	OK	OK	OK	C
44	OK†	C	OK†	C	C	F	F	OK	OK	OK	C
45	shell							OK			
46	OK†	C	OK†	F	C	F	F	OK	OK	OK	C
47	OK†	C	OK†	C	C	F	F	OK	OK	OK	C
48	OK†	C	OK†	F	C	F	F	OK	OK	OK	C*

OK	acceptable
F	too fine on one or more sieves
C	too coarse on one or more sieves
*	within ±2% on one sieve of being acceptable
†	much of coarse fraction is shell rather than gravel

Lower Bay Surficial samples which pass each test.

Potential sources of mortar sand (Fig. 33) include an area near the Staten Island shore, the Romer Shoal area, and the Rockaway Inlet Channel. Samples from this last area contain a high shell content which may make them unacceptable, and in any case biased the grain size distribution towards the coarse.

As Fig. 34 shows, the northern half of the East Bank, up to the Coney Island Shore, may have sand suitable for grout sand. Romer Shoal and the area to the east of it are another potential source.

Much of the area east of Ambrose Channel (but not the East Bank Shoal) has sand acceptable for cushion sand (Fig. 35). The warning about the shell content of Rockaway Inlet Channel sands applies here as well.

Figure 36 shows the area with sand which meets the basic gradation requirement for filtration sand for sewage. Filtration sand must pass additional uniformity requirements which vary from plant to plant. Table 5 lists the uniformity coefficient and effective grain size of each MSRC sample. These parameters determine the acceptability of sand for use in individual treatment plants.

The sieve sizes we used were not appropriate for testing for foundry sand. However, N.Y. State Department of Public Works (1973) tested 3 samples dredged from the permitted dredging areas on the East and West Bank and found them acceptable for foundry sand.

None of our samples met the requirements for concrete sand, mineral filler, or blasting sand.

Often sand quarried on land must be screened, or mixed to meet specifications (Mr. Peterac, N.Y. State Department of Transportation, personal communication). Such processing could enlarge the areas of acceptable sand. The well sorted grain size distribution of East Bank sand would seem desirable for the production of mixed sands, since the contribution to the mixture would be uniform.

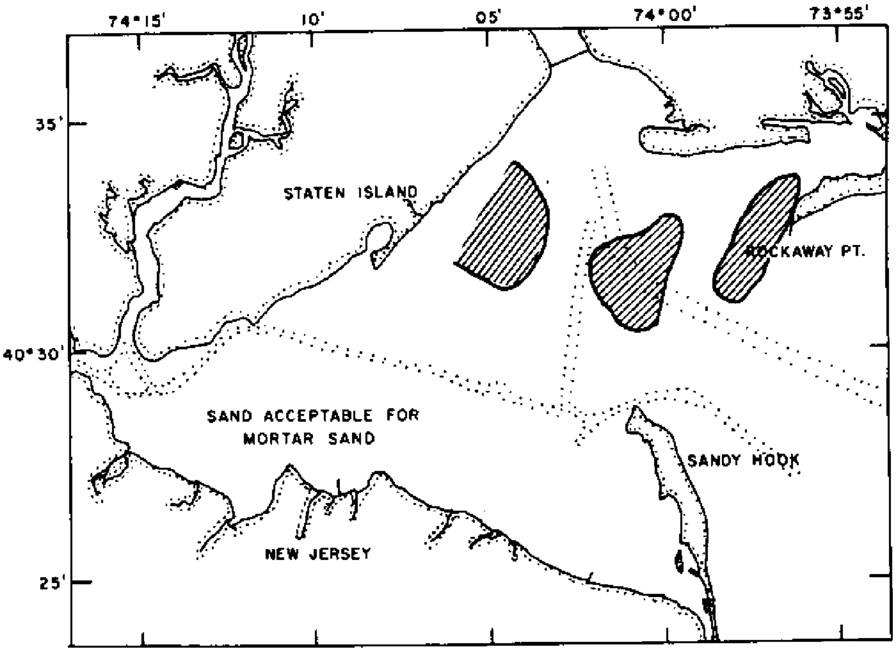

Fig. 33. Potential sources of mortar sand.

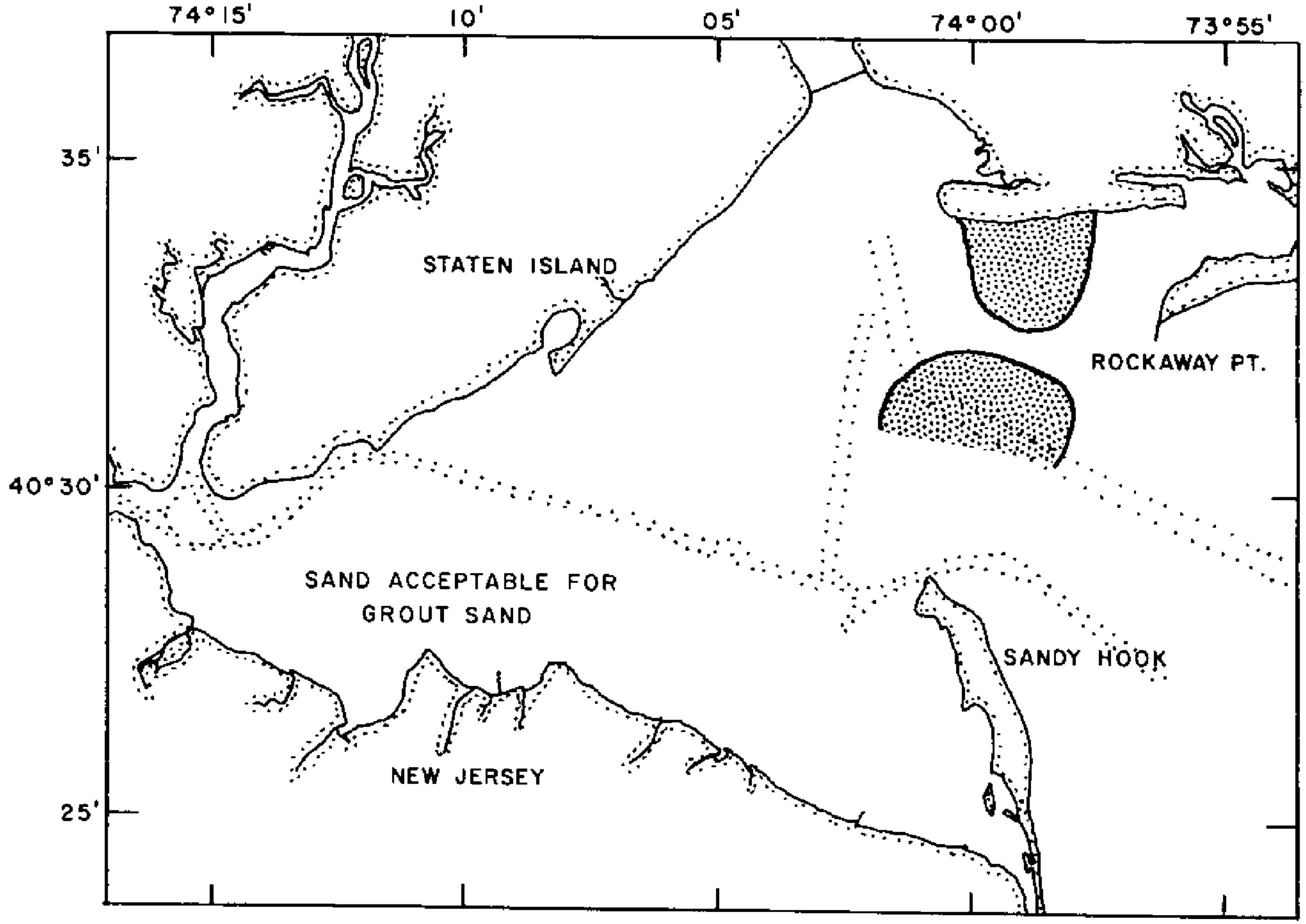

Fig. 34. Potential sources of grout sand.

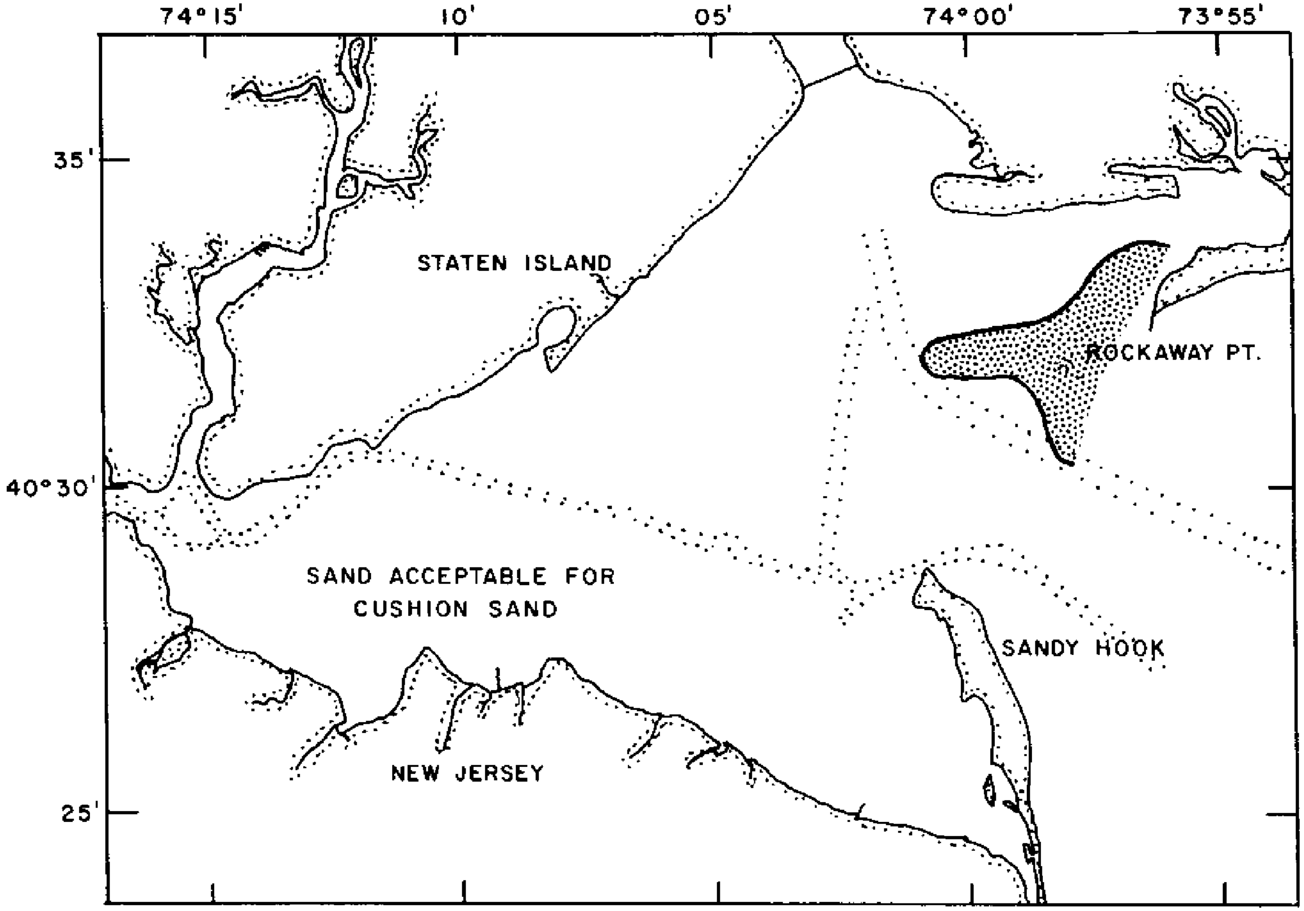

Fig. 35. Potential sources of cushion sand.

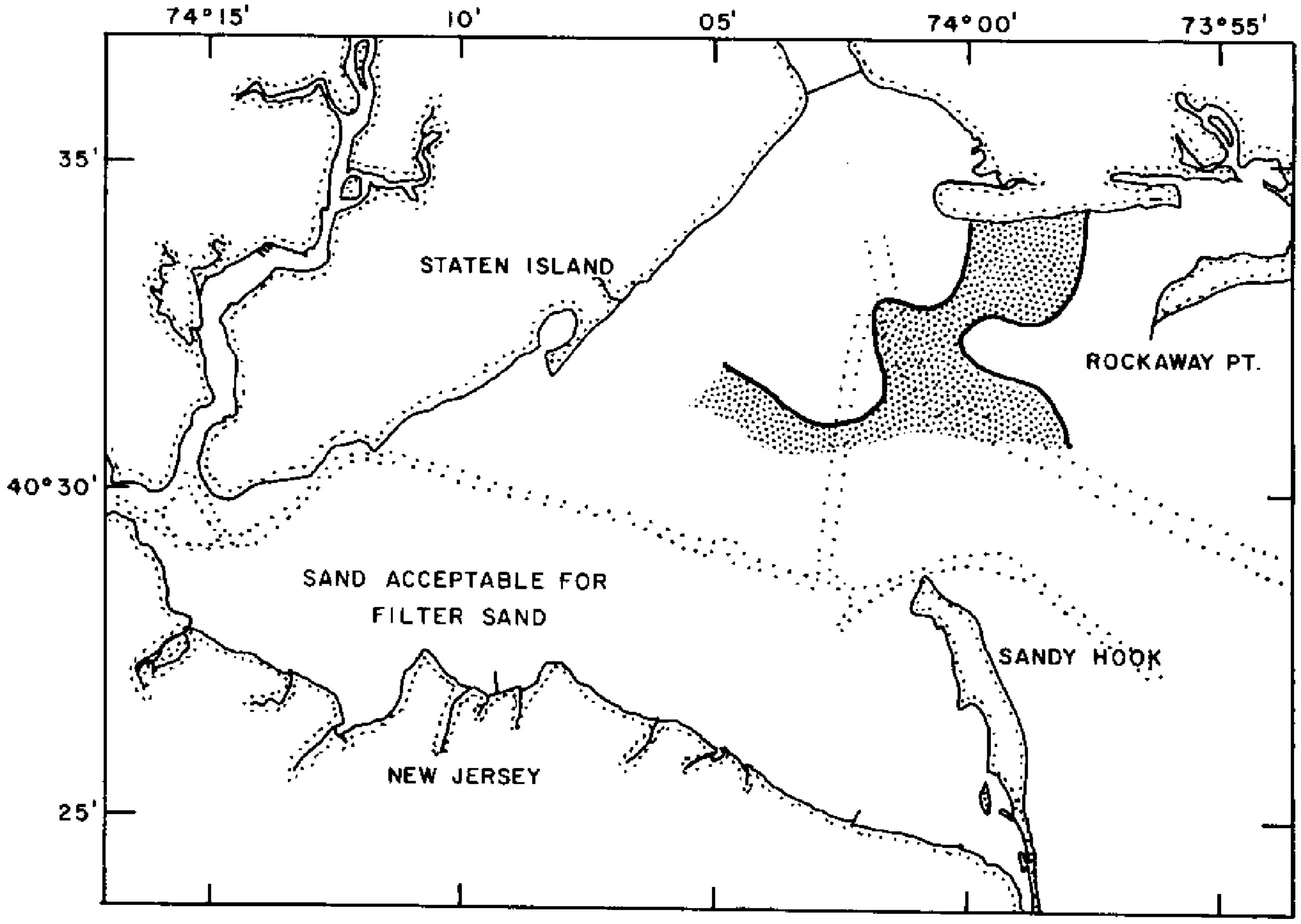

Fig. 36. Potential sources of filter sand.

REFERENCES

Caldwell, J.H. 1966. Coastal processes and beach erosion. J. of the Boston Society of Civil Engineers 53:2, 142-157.

Cumming, H.S. 1917. Investigation of the pollution of certain tidal-waters at New Jersey, New York, and Delaware. U.S. Public Health Service, Publ. Health Bull. 86.

Dean, David. 1975. Raritan Bay macrobenthos survey, 1957-1960. National Marine Fisheries Service Data Report 199.

____, and H.H. Haskin. 1964. Benthic repopulation of the Raritan River estuary following pollution abatement. Limnology and Oceanography 9:4, 551-563.

Doyle, B.E., and R.E. Wilson. 1978. Laterial dynamic balance in the Sandy Hook to Rockaway Point Transect. Estuarine and Coastal Marine Science 6, 165-174.

Duedall, I.W., H.B. O'Connors, R.E. Wilson and J.H. Parker. 1978. The lower bay complex. MESA New York Bight Atlas Monograph 29. New York York Sea Grant Institute, Albany, New York.

Folk, R.L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas.

Fray, C.T. 1969. Final report, Raritan Estuary sedimentation study. Prepared for Federal Water Pollution Control Administration, Department of the Interior, Alpine Geophysical Associates, Inc., Oak Street, Norwood, New Jersey.

Gross, M. Grant. 1970. Analyses of dredged wastes, fly ash, and waste chemicals, New York Metropolitan Region. Marine Sciences Research Center, State University of New York at Stony Brook, Tech. Rept. No. 7.

____. 1974. Sediment and waste deposition in New York Harbor. *In* Hudson River Colloquium. Edited by O.A. Roels. Annals N.Y. Academy of Sciences, Vol. 250.

Inman, D.L. 1952. Measurements for describing the size of sediments. J. Sedimentary Petrology 22, 125-145.

Inman, D.L. 1952. Measurements for describing the size of sediments. J. Sedimentary Petrology 22, 125-145.

Jacobson, F.L., and J.T. Gharreh. 1964. Fish and Wild-life Raritan Bay. *In* report for the conference on pollution of Raritan Bay and adjacent interstate waters, third session, Vol. III-appendices. Federal Water Pollution Control Administration, 1967.

McGrath, R.A. 1973. Benthic marcofaunal census of Raritan Bay--Preliminary results, benthos of Raritan Bay. *In* Proceedings, third symposium on Hudson River Ecology, Paper No. 24, March 22-23, 1974. Bear Mountain, New York Hudson River Environmental Society.

McMaster, Robert L. 1954. Petrography and genesis of the New Jersey beach sands. State of New Jersey Department of Conservation and Economic Development, Bull. 63, Geologic Series.

Minard, James P. 1969. Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey. U.S. Geological Survey Bull. 1276.

Nagle, J. Stewart. 1967. Geology of Raritan Bay. *In* report for the Conference on Pollution of Raritan Bay and adjacent interstate waters. third session, Vol. III-appendices. Federal Water Pollution Control Administration.

New York State Department of Transportation, Design and Construction Division. January 2, 1973. Standard Specifications Construction and Materials.

Panuzio, F.L. 1965. Lower Hudson River siltation. *In* Proceedings of the Federal Inter Agency Sedimentation Conference 1963, 512-550. Miscellaneous Publication No. 970, Agriculture Research Service.

Schlee, John and Peter Sanko. 1975. Sand and Gravel. MESA New York Bight Atlas, Monograph 21.

Steimle, Frank and Richard B. Stone. 1973. Abundance and distribution of inshore benthic fauna off southwestern Long Island, N.Y. NOAA Technical Report NMFS SSRF-673.

Taney, N.E. 1961. Geomorphology of the south shore of Long Island, New York. Beach Erosion Board, Corps of Engineers, Tech. Memo. 128.

Taney, N.E. 1961. Littoral materials of the South Shore of Long Island, New York. Tech. Memo. 129, Beach Erosion Board, U.S. Army Corps of Engineers.

U.S. Army Engineer District, New York, Corps of Engineers. 1953. Cooperative beach erosion study, Atlantic Coast of New Jersey-Sandy Hook to Barnegat Inlet.

_____. 1962. Cooperative beach erosion control and interim hurricane study (survey) Staten Island, New York, Fort Wadsworth to Arthur Kill.

_____. 1965. Beach erosion control report on cooperative study (survey) of Perth Amboy, New Jersey.

Walford, L.A. 1971. Review of aquatic resources and hydrographic characteristics of Raritan, Lower, and Sandy Hook Bays. Report prepared for the Battelle Institute by the staff of Sandy Hook Sport Fisheries Marine Laboratory.

Woodward-Clyde Consultants. 1975. Rockaway beach erosion control project. Dredge Material Research Program, Offshore Borrow Area. Results of Phase I-Predredging studies. Prepared for the Department of the Army, New York District, Corps of Engineers.

_____. 1975. Rockaway beach erosion control project. Dredge Material Research Program, offshore borrow area. Results of Phase II-Dredging Studies. Prepared for the Department of the Army, New York District, Corps of Engineers.

Yasso, W.E. 1965. Flourescent tracer particle determination of the size-velocity rotation for foreshore sediment transport, Sandy Hook, New Jersey. J. Sedimentary Petrology 35:4, 989-993.

_____, and Elliott M. Hartman, Jr. 1975. Beach forms and coastal processes. MESA New York Bight Atlas, Monograph 11.

APPENDIX A

STATISTICAL PARAMETERS FOR MSRC SHIPEK GRABS, AND A BRIEF EXPLANATION OF THEM.

Phi Scale

The phi (φ) scale is used to describe particle grain size. Phi diameter is defined:

$$\phi = -\log_2 (D)$$

where D is the diameter in millimeters.

Figure A-1 gives a conversion chart for diameters in phi units and millimeters. Notice that a larger φ indicates smaller diameter. Zero φ units equal one mm. Adding 1 φ corresponds to halving the diameter in mm.: 0φ = 1 mm, 1φ = ½ mm, 2φ = ¼ mm. Subtracting 1φ doubles the diameter in mm.: 0φ = 1 mm, -1φ = 2 mm, -2φ = 4 mm.

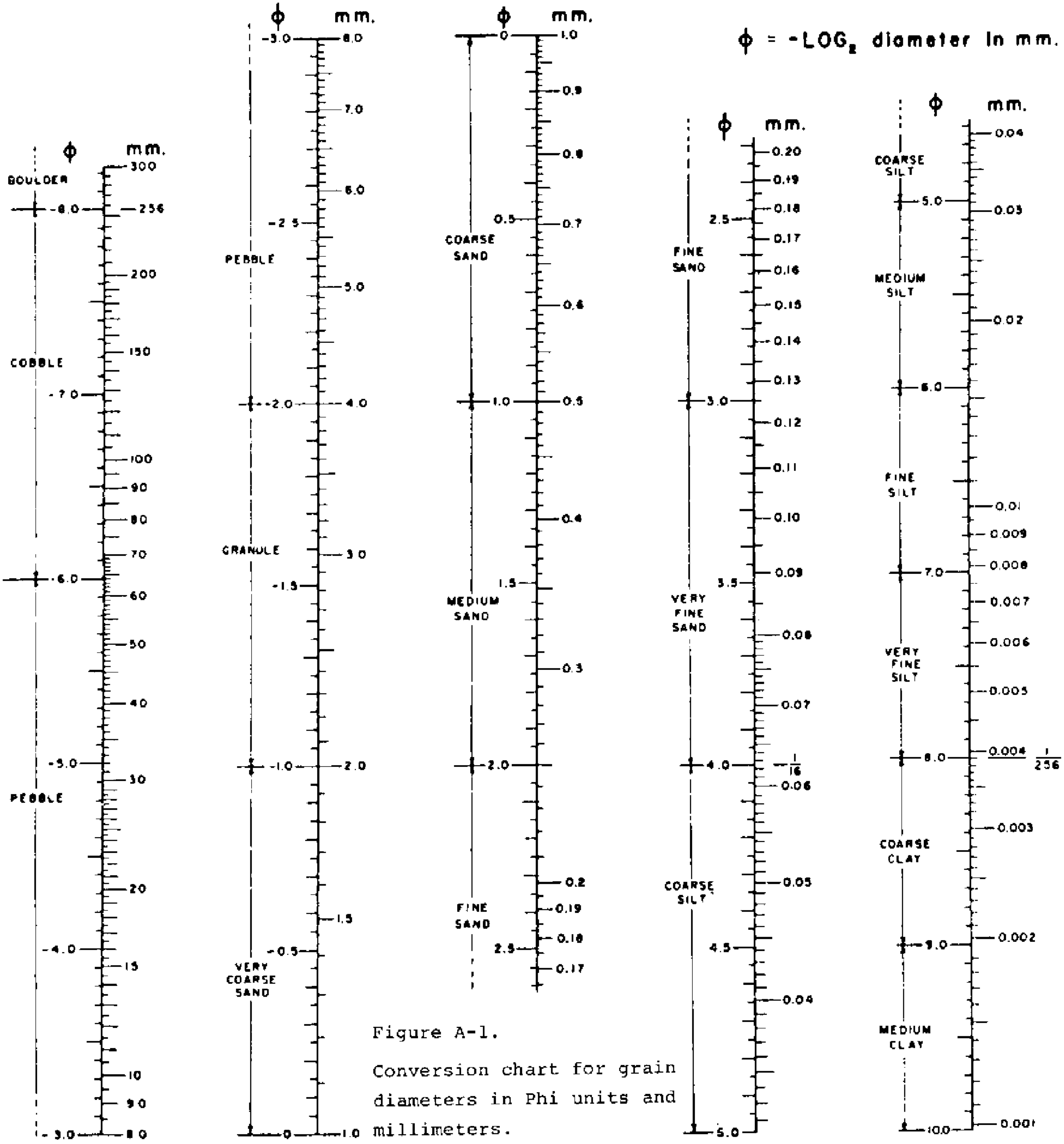

Figure A-1.

Conversion chart for grain diameters in Phi units and millimeters.

Statistical Parameters

All descriptive measures of sediment are based on a comparison with the measured sediment distribution with a "normal" or Gaussian distribution. The normal distribution is one in which there is one size class into which a large number of particles fall, and the frequency of occurrence of particles on either side of this peak decreases symmetrically and in such a fashion that the phi diameter vs. weight-percent graph forms a "bell shaped" curve.

Central Tendency

It is desirable to have one number for each sample, which can be compared with that of other samples, to state definitively that one is coarser than the other. Measures of central tendency are designed to fill this need. The median is that diameter whereby 50% by mass of the sample is coarser and 50% finer. If the size distribution by mass percent is plotted cumulatively as "% coarser than" vs. ϕ diameter, the ϕ diameter corresponding to the 50th percentile on the size distribution curve is the median:

$$Md = \phi_{50}$$

Median can also be expressed in millimeters:

$$Md = Mm_{50}.$$

The mean particle diameter is physically the x-coordinate of the center of gravity of the area under the frequency distribution curve. It can be estimated graphically from the cumulative distribution curve by taking the average of the diameters at the 16th, 50th, and 84th percentiles.

$$M = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

Mean and median grain size are functions of (1) the size range of the materials from which the sediment is derived, and (2) the amount of energy available to transport the sediment. In general, sediments become finer in the direction of transport, downstream in rivers, and down drift on beaches, spits, and bars.

Sorting or Uniformity

Measure of sorting describe the spread or range of the size distribution curve.

Trasks sorting coefficient is given by:

$$S_o = \sqrt{\frac{Mm_{25}}{Mm_{75}}}$$

The closer S_o approaches one, the more uniform is the sample. Beach samples commonly have $S_o = 1.3$ to 1.5.

Inman's graphic standard deviation is given by:

$$\sigma_G = \frac{(\phi 84 - \phi 16)}{2}$$

Folk's inclusive graphic standard deviation is:

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

These measures of standard deviation are similar in concept, but the inclusive measure incorporates a larger part of the size distribution curve, and better indicates sorting in the tails of the distribution, where large departures from the normal curve are likely to appear. However, frequently, the size distribution at one or the other extreme is unknown and Inman's statistics cannot be calculated. In both cases, the closer the standard deviation approaches zero, the better sorted the sample is. For σ_I the following descriptions have been proposed:

<0.35	very well sorted
0.35-0.50	well sorted
0.50-1.00	moderately sorted
1.00-2.00	poorly sorted
2.00-4.00	very poorly sorted
>4.00	extremely poorly sorted

Sorting depends on at least 3 factors: (1) size range of the materials from which the sediment is derived, (2) current velocity -- constant velocity sorts better than fluctuating velocity; and medium velocity better than either very weak or very strong currents, and (3) rate of supply of detritus -- any sorting agent does a more thorough job if the rate of input of new sediment is low. Finally, observation indicates that sorting is dependent on grain size. Fine sand (2ϕ to 3ϕ) is frequently well sorted, as are clays (10ϕ) and gravels (-3ϕ to -5ϕ); but sediments whose mean grain size is 0ϕ to -1ϕ or 6ϕ to 8ϕ are generally poorly sorted.

Skewness

In a normal distribution, the median equals the mean. In fact, this is rarely the case, and skewness is a measure of the discrepancy between mean and median. For example, a sample is said to be skewed toward the fine if its median grain size is smaller (median ϕ diameter is larger) than its mean grain size. Trasks skewness coefficient is given as:

$$Sk = \frac{Mm_{25} \times Mm_{75}}{Md^2}$$

If Sk = 1, the point of maximum sorting is at the median grain diameter. When Sk > 1 the size distribution curve of the sample has a tail of excess material at the coarse end. When Sk < 1, the excess material is at the fine end.

Inman's graphic skewness is given by:

$$Sk_G = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{(\phi_{84} - \phi_{16})}$$

Folk's inclusive graphic skewness is given by:

$$Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2\ (\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2\ (\phi_{95} - \phi_5)}$$

Again, the two graphic measures of skewness are analogous in concept, but Folk's skewness incorporates more of the size distribution curve. A sample with Sk_G or Sk_I equal to zero is perfectly symmetrical. If Sk_G or Sk_I is negative, the sample is coarse-skewed; positive values indicate fine-skewing.

The following verbal limits apply to Sk_I

-1.00 to -0.30	very coarse skewed
-0.30 to -0.10	moderately coarse skewed
-0.10 to +0.10	nearly symmetrical
0.10 to 0.30	moderately fine skewed
0.30 to 1.00	very fine skewed.

Kurtosis

Kurtosis indicates the relative lengths of the tails of the distribution to the central portion. Kurtosis can be visualized as a measure of the peakedness of the distribution relative to the normal "bell shaped" distribution.

Folk's graphic kurtosis is given by:

$$K_G = \frac{\phi 95 - \phi 5}{2.44\ (\phi 75 - \phi 25)}$$

The skewness and kurtosis of single source sediments, such as beach sands, tend to be quite low. Sediments from multiple sources such as mixtures of beach sands with lagoonal clays show pronounced skewness and kurtosis.

REFERENCES

Folk, Robert L. 1964. Petrology of Sedimentary Rocks, The University of Texas lab manual, Hemphills, Austin, Texas.

Inman, D. L. 1952. Measures for describing the size of sediments. Jour. Sedimentary Petrology. V. 22, pp. 125-145.

Krumbein, W. C. 1936. Application of logarithmic moments to size frequency distribution of sediments. Jour. Sedimentary Petrology. V. 6, pp. 35-47.

Shepard, Francis P. 1973. Ch. 4, "Ocean Sediments and Sedimentation," *in* Submarine Geology, Third Edition, Harper & Row.

APPENDIX B

TABLES OF SIZE CHARACTERISTICS OF SEDIMENT SAMPLES

Table B-1. Size Analyses Beach Samples-Raritan Estuary
Staten Island, New York-U.S. Army Engineer District, New York
Sampling Date: January-March 1961, also May 1962 as noted

Range No.	Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
		Sample Location: Backshore					
3	S1	Graham Beach	40°34.4'	74°05.0'	0.34	1.41	1.08
8	S1	Great Kills Park	40°31.8'	74°08.3'	0.42	1.59	1.20
9	S1	Eltingville Beach	40°32.1'	74°08.9'	0.38	1.86	1.63
11	S1	Arbutus Lake	40°31.2'	74°11.8'	0.57	1.55	0.95
13	S1	Mount Loretto	40°30.1'	74°13.5'	0.28	2.40	5.30
15	S1	Tottenville Beach	40°29.8'	74°15.1'	0.50	1.56	1.19
16	S1	Tottenville Beach	40°29.8'	74°15.1'	0.36	1.20	0.86
		Sample Location: Mean High Water					
1	S2	Fort Wadsworth	40°35.8'	74°03.4'	0.41	1.61	1.12
3	S2	Graham Beach	40°34.4'	74°05.0'	0.41	1.20	1.11
5	S2	Oakwood Beach	40°33.2'	74°06.5'	0.33	1.25	1.04
8	S2	Great Kills Park	40°31.8'	74°08.3'	0.37	1.27	1.00
11	S2	Arbutus Lake	40°31.2'	74°11.8'	0.42	1.45	1.16
13	S2	Mount Loretto	40°30.1'	74°13.5'	1.10	1.66	3.64
15	S2	Tottenville Beach	40°29.9'	74°15.1'	0.74	1.82	1.12
16	S2	Tottenville Beach	40°29.8'	74°15.1'	0.36	1.28	1.07
		Sample Location: Mean Tide Level					
1	S3	Fort Wadsworth	40°35.8'	74°03.4'	0.20	1.16	1.08
3	S3	Graham Beach	40°34.4'	74°05.0'	0.34	1.30	1.07
5	S3	Oakwood Beach	40°33.2'	74°06.5'	0.21	1.09	1.19
8	S3	Great Kills Park	40°31.8'	74°08.3'	0.40	1.21	0.99
9	S3	Eltingville Park	40°32.1'	74°08.9'	1.50	1.81	1.76
11	S3	Arbutus Lake	40°31.2'	74°11.8'	0.43	1.29	1.30
13	S3	Mount Loretto	40°30.1'	74°13.5'	0.94	2.97	2.50
15	S3	Tottenville Beach	40°29.8'	74°15.1'	0.18	1.81	1.22
16	S3	Tottenville Beach	40°29.8'	74°15.1'	0.40	1.49	1.26

Table B-1. (continued)

Range No.	Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
Sample Location: Mean Tide Level, May 1962							
1	S3	Fort Wadsworth	40°35.8'	74°03.4'	0.21	1.53	1.71
3	S3	Graham Beach	40°34.4'	74°05.0'	0.28	1.52	1.17
5	S3	Oakwood Beach	40°33.2'	74°06.5'	0.80	1.44	3.78
8	S3	Great Kills Park	40°31.8'	74°08.3'	0.26	1.22	1.16
9	S3	Eltingville Beach	40°32.1'	74°08.9'	1.20	2.96	1.98
11	S3	Arbutus Lake	40°31.2'	74°11.8'	0.33	1.26	1.07
13	S3	Mount Loretto	40°30.1'	74°13.5'	0.26	2.99	4.78
15	S3	Tottenville Beach	40°29.8'	74°15.1'	0.46	1.37	1.42
16	S3	Tottenville Beach	40°29.8'	74°15.1'	0.44	1.35	1.16
Sample Location: Mean Low Water							
1	S4	Fort Wadsworth	40°35.8'	74°03.4'	0.20	1.13	1.04
3	S4	Graham Beach	40°34.4'	74°05.0'	1.20	1.96	1.17
8	S4	Great Kills Park	40°31.8'	74°08.3'	0.28	1.17	1.00
9	S4	Eltingville Beach	40°32.1'	74°08.9'	1.10	1.00	1.07
11	S4	Arbutus Lake	40°31.2'	74°11.8'	0.58	1.50	1.06
13	S4	Mount Loretto	40°30.1'	74°13.5'	0.65	2.83	2.31
15	S4	Tottenville Beach	40°29.8'	74°15.1'	1.10	9.02	4.90
16	S4	Tottenville Beach	40°29.8'	74°15.1'	0.80	2.12	0.63

Table B-2. Size Analyses Beach Samples-Raritan Estuary

Perth Amboy, New Jersey-U.S. Army Engineer District, New York

Sampling Date: January-February 1962

Range No.	Sample No.	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
Sample Location: Backshore						
1	S1	40°30.0'	74°16.7'	0.58	2.40	1.16
2	S1	40°30.0'	74°16.5'	1.00	2.19	1.57
3	S1	40°30.0'	74°16.3'	1.50	2.15	1.32
4	S1	40°30.0'	74°16.2'	0.50	1.49	1.02
5	S1	40°30.0'	74°16.2'	0.60	1.70	1.16
6	S1	40°30.0'	74°16.1'	0.32	1.22	1.05
7	S1	40°30.0'	74°16.1'	0.35	1.20	0.86
9	S1	40°30.0'	74°16.0'	1.75	4.35	0.85
Sample Location: Mean High Water						
1	S2	40°30.0'	74°16.7'	0.60	1.66	1.22
2	S2	40°30.0'	74°16.5'	10.15	2.76	0.46
3	S2	40°30.0'	74°16.3'	0.60	1.54	1.17
4	S2	40°30.0'	74°16.2'	0.94	4.76	14.43
5	S2	40°30.0'	74°16.2'	0.67	2.21	1.65
6	S2	40°30.0'	74°16.1'	1.00	2.39	1.48
7	S2	40°30.0'	74°16.1'	0.36	1.38	1.23
Sample Location: Mean Tide Level						
1	S3	40°30.0'	74°16.7'	0.34	1.29	1.05
2	S3	40°30.0'	74°16.5'	8.60	3.41	0.40
3	S3	40°30.0'	74°16.3'	0.81	4.32	7.38
4	S3	40°30.0'	74°16.2'	3.35	1.98	1.07
5	S3	40°30.0'	74°16.2'	1.65	2.44	1.07
6	S3	40°30.0'	74°16.1'	4.95	2.21	1.01
7	S3	40°30.0'	74°16.1'	0.45	1.52	1.02
Sample Location: Mean Low Water						
1	S4	40°30.0'	74°16.7'	0.65	1.89	1.29
2	S4	40°30.0'	74°16.5'	10.00	4.47	0.24
3	S4	40°30.0'	74°16.3'	1.90	1.77	1.35
4	S4	40°30.0'	74°16.2'	1.85	3.81	0.93
5	S4	40°30.0'	74°16.2'	1.60	5.23	3.22
6	S4	40°30.0'	74°16.1'	1.20	3.39	2.41
7	S4	40°30.0'	74°16.1'	0.38	2.81	3.16
9	S4	40°30.1'	74°16.0'	6.00	7.24	0.26

Table B-3. Size Analyses Beach Samples-Raritan Estuary

Raritan Bay and Sandy Hook Bay, New Jersey

U.S. Army Engineer District, New York

Sampling Date: 1957

Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
Sample Location: Mean High Water						
1-	City of South Amboy					
2-S1	Borough of Sayreville	40°28.6'	74°16.0'	0.26	1.28	1.06
3-S1	Borough of Sayreville	40°27.9'	74°15.6'	0.58	3.28	2.16
4-S1	Laurence Harbor	40°27.8'	74°15.5'	0.64	3.54	3.13
5-S1	Laurence Harbor	40°27.6'	74°15.0'	0.90	5.09	2.33
6-S1	Laurence Harbor in Madison Township	40°27.5'	74°14.4'	0.34	8.40	29.60
7-S1	Cliffwood Beach in Matawan Township	40°27.1'	74°13.4'	1.50	5.73	1.22
8-S1	Cliffwood Beach in Matawan Township	40°26.9'	74°12.8'	0.53	5.16	9.68
9-S1	Borough of Keyport	40°26.3'	74°12.1'	0.40	1.40	1.11
10-S1	Borough of Keyport	40°26.6'	74°11.6'	0.44	2.35	2.40
11-S1	Borough of Union Beach	40°27.1'	74°11.2'	0.33	1.31	1.10
12-S1	Borough of Union Beach	40°27.4'	74°11.0'	0.39	1.30	1.06
13-S1	Borough of Union Beach	40°27.5'	74°10.8'	0.38	1.34	1.06
14-S1	Borough of Union Beach	40°27.3'	74°10.5'	0.32	1.27	0.98
15-S1	Borough of Union Beach	40°27.0'	74°10.0'	0.50	1.61	1.12
16-S1	Borough of Union Beach	40°27.0'	74°09.4'	brick fragments		
17-S1	Borough of Keansburg	40°27.1'	74°08.5'	0.28	1.24	1.03
18-S1	Borough of Keansburg	40°27.3'	74°08.1'	0.29	1.17	1.01
19-S1	Borough of Keansburg	40°27.1'	74°07.8'	0.28	1.21	1.07
20-S1	East Keansburg	40°26.7'	74°06.7'	0.28	1.21	1.07
21-S1	Port Monmouth	40°26.5'	74°06.2'	0.31	1.34	0.98
22-S1	Belford	40°26.2'	74°05.2'	0.30	1.36	1.18
23-S1	Belford	40°26.1'	74°04.8'	0.30	1.27	1.11
24-S1	Leonardo	40°25.3'	74°03.4'	0.28	1.10	0.96

Table B-3. (continued)

Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
25-S1	Borough of Atlantic Highlands	40°25.0'	74°02.4'	0.50	5.00	10.20
26-S1	Borough of Atlantic Highlands	40°24.8'	74°01.1'	0.27	1.16	0.98
27-S1	Borough of Highlands	40°24.7'	74°00.1'	0.43	1.28	1.08
27-S5	Borough of Highlands	40°25.2'	73°59.7'	1.05	2.44	2.43
28-S5	Borough of Highlands	40°24.3'	73°58.8'	1.02	1.31	1.03
28-S7	Borough of Highlands	40°24.3'	73°58.7'	0.70	1.30	1.04
29-S5	Borough of Highlands	40°23.8'	73°58.7'	0.38	1.15	1.06
	Sample Location: Mean Low Water					
1-S2	City of South Amboy					
2-S2	Borough of Sayreville	40°28.6'	74°15.6'		Mud*	
3-S2	Borough of Sayreville	40°27.9'	74°15.6'		Mud	
4-S2	Laurence Harbor	40°27.8'	74°15.4'		Mud	
5-S2	Laurence Harbor	40°27.6'	74°15.0'	0.24	1.37	0.84
6-S2	Laurence Harbor in Madison Township	40°27.5'	74°14.4'		Mud	
7-S2	Clifford Beach in Matawan Township	40°27.2'	74°13.3'	0.33	3.52	7.68
8-S2	Clifford Beach in Matawan Township	40°26.9'	74°12.8'	0.28	3.02	5.60
9-S2	Borough of Keyport	40°26.3'	74°12.1'	0.45	3.87	4.27
10-S2	Borough of Keyport	40°26.6'	74°11.6'		Mud	
11-S2	Borough of Union Beach	40°27.1'	74°11.3'	0.27	1.28	1.09
12-S2	Borough of Union Beach	40°27.4'	74°11.0'	0.49	1.56	1.24
13-S2	Borough of Union Beach	40°27.5'	74°10.8'	0.44	3.30	5.77
14-S2	Borough of Union Beach	40°27.3'	74°10.4'	0.22	1.19	1.06
15-S2	Borough of Union Beach	40°27.0'	74°10.0'		Mud	
16-S2	Borough of Union Beach	40°27.1'	74°09.4'	0.28	1.20	0.97
17-S2	Borough of Keansburg	40°27.1'	74°08.5'	0.50	1.36	1.06
18-S2	Borough of Keansburg	40°27.3'	74°08.1'	0.29	1.29	1.14
19-S2	Borough of Keansburg	40°27.1'	74°07.8'	0.23	1.25	1.17
20-S2	East Keansburg	40°26.7'	74°06.7'	0.44	1.46	1.13

Table B-3. (continued)

Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
21-S2	Port Monmouth	40°26.5'	74°06.2'	0.75	1.63	1.32
22-S2	Belford	40°26.2'	74°05.2'	1.15	1.38	1.16
23-S2	Belford	40°26.1'	74°04.8'	0.26	1.21	1.04
24-S2	Leonardo	40°25.4'	74°03.4'	0.60	1.78	1.07
25-S2	Borough of Atlantic Highlands	40°25.0'	74°02.4'	0.95	3.74	2.86
26-S2	Borough of Atlantic Highlands	40°24.8'	74°01.1'	0.30	1.36	1.07
27-S2	Borough of Highlands	40°24.7'	74°00.1'	0.25	1.22	1.04
27-S4	Borough of Highlands	40°25.2'	73°59.8'	1.15	1.68	1.30
28-S4	Borough of Highlands	40°24.3'	73°58.8'	1.75	2.34	1.61
28-S6	Borough of Highlands	40°24.3'	73°58.7'	0.74	1.57	1.07
29-S4	Borough of Highlands	40°23.8'	73°58.7'	0.48	1.26	0.93

*Sediment predominantly finer than sand; not analyzed.

Table B-4. Size Analyses Offshore Samples-Raritan Estuary

Staten Island, New York

U.S. Army Engineer District, New York

Sampling Date: January-March 1961

Range No.	Sample No.	Geographic Location	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	S_o	S_k
1	S5	Fort Wadsworth	40°35.7'	74°03.3'	2.3	0.26	1.49	1.18
1	S6	Fort Wadsworth	40°35.6'	74°03.2'	4.1	0.25	1.38	1.34
3	S5	Graham Beach	40°34.4'	74°04.9'	2.3	0.40	2.03	1.37
3	S6	Graham Beach	40°34.2'	74°04.6'	3.7	0.26	1.48	1.30
5	S5	Oakwood Beach	40°32.9'	74°06.1'	1.6	0.36	1.58	1.30
5	S6	Oakwood Beach	40°32.8'	74°05.9'	2.9	0.42	1.58	1.27
5	S7	Oakwood Beach	40°32.7'	74°05.7'	3.8	0.44	1.56	1.49
8	S6	Great Kills Park	40°31.1'	74°07.3'	3.7	0.22	1.55	1.80
9	S5	Eltingville Beach	40°31.5'	74°08.4'	2.0	0.36	1.74	1.13
11	S5	Arbutus Lake	40°31.0'	74°10.6'	2.1	0.15	1.32	1.12
15	S5	Tottenville Beach	40°29.5'	74°14.8'	1.1	0.30	1.74	1.79
15	S6	Tottenville Beach	40°29.4'	74°14.7'	4.3	0.54	2.52	1.95

Table B-5. Size Analyses Offshore Samples-Raritan Estuary
Perth Amboy, New Jersey
U.S. Army Engineer District, New York
Sampling Date: January-February 1962

Range No.	Sample No.	Latitude (N)	Longitude (W)	Distance Offshore, (m)	S_o
1	S6	40°29.9'	74°16.7'	305	M*
1	S7	40°29.7'	74°16.7'	610	M
2	S6	40°29.8'	74°16.5'	305	M
2	S7	40°29.7'	74°16.5'	610	M
4	S6	40°29.8'	74°16.3'	305	M
4	S7	40°29.6'	74°16.4'	610	M
7	S5	40°29.9'	74°16.1'	152	M
7	S6	40°29.8'	74°16.1'	305	M
8	S5	40°29.9'	74°15.9'	152	M
8	S6	40°29.8'	74°15.9'	305	M
9	S5	40°30.0'	74°15.9'	152	M
9	S6	40°29.9'	74°15.8'	305	M
10	S5	40°30.2'	74°15.7'	152	M
10	S6	40°30.1'	74°15.6'	305	M
11	S5	40°30.3'	74°15.6'	152	M
11	S6	40°30.3'	74°15.5'	305	M
12	S5	40°30.5'	74°15.6'	152	M
12	S6	40°30.5'	74°15.5'	305	M

*Predominantly silt material, not analyzed.

Table B-6. Size Analyses Offshore Samples-Raritan Estuary

Raritan Bay and Sandy Hook Bay, New Jersey

U.S. Army Engineer District, New York

Sampling Date: 1957

Range No.	Sample No.	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	S_o	S_k
2	S3	40°28.7'	74°15.6'	1.1		Mud*	
2	S4	40°29.1'	74°14.8'	4.6		Mud	
3	S3	40°28.2'	74°15.4'	1.8		Mud	
3	S4	40°28.7'	74°15.1'	2.2		Mud	
4	S3	40°28.2'	74°15.2'	1.8		Mud	
4	S4	40°28.6'	74°14.9'	2.3		Mud	
5	S3	40°28.0'	74°14.8'	2.0		Mud	
5	S4	40°28.5'	74°14.5'	2.4		Mud	
6	S3	40°27.8'	74°14.2'	1.1	0.46	3.59	1.19
6	S4	40°28.4'	74°13.9'	2.6		Mud	
7	S3	40°27.5'	74°13.2'	2.4	0.26	1.25	1.03
7	S4	40°28.1'	74°12.9'	2.9		Mud	
8	S3	40°27.3'	74°12.6'	1.2	0.24	1.26	0.99
8	S4	40°27.7'	74°12.3'	2.9		Mud	
9	S3	40°26.7'	74°12.1'	1.6		Mud	
9	S4	40°27.2'	74°12.1'	2.5		Mud	
10	S3	40°26.9'	74°11.8'	1.8		Mud	
10	S4	40°27.2'	74°12.1'	2.5		Mud	
11	S3	40°27.2'	74°11.6'	1.8		Mud	
11	S4	40°27.2'	74°12.1'	2.5		Mud	
12	S3	40°27.5'	74°11.4'	2.3		Mud	
12	S4	40°27.6'	74°11.8'	3.1		Mud	
13	S3	40°27.9'	74°10.8'	1.7	0.65	1.30	0.77
13	S4	40°28.6'	74°10.8'	3.7	0.27	1.14	1.02
14	S3	40°27.5'	74°10.1'	2.1		Mud	
14	S4	40°27.8'	74°09.6'	2.9		Mud	
15	S3	40°27.3'	74°09.9'	2.4		Mud	
15	S4	40°27.8'	74°09.6'	2.9		Mud	
16	S3	40°27.2'	74°09.5'	2.4		Mud	
16	S4	40°27.8'	74°09.6'	2.9		Mud	
17	S3	40°27.4'	74°09.0'	2.4		Mud	
17	S4	40°27.8'	74°09.6'	2.9		Mud	
18	S3	40°27.7'	74°08.2'	0.8	0.29	1.23	1.03
18	S4	40°28.3'	74°08.2'	2.4	0.29	1.17	1.01
19	S3	40°27.4'	74°07.4'	1.3	0.26	1.24	1.00
19	S4	40°27.8'	74°07.1'	2.7	0.25	1.30	0.97
20	S3	40°27.0'	74°06.5'	1.2	0.24	1.23	1.04
20	S4	40°27.6'	74°06.1'	4.3	0.28	1.18	0.94

Table B-6. (continued)

Range No.	Sample No.	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	S_o	S_k
21	S3	40°26.9'	74°05.9'	1.3	0.25	1.23	0.96
21	S4	40°27.5'	74°05.5'	3.7	0.28	1.19	1.04
22	S3	40°26.6'	74°05.0'	1.2	0.32	1.36	1.22
22	S4	40°27.1'	74°04.7'	3.9	0.28	1.21	1.07
23	S3	40°26.4'	74°04.6'	1.4	0.30	1.24	1.06
23	S4	40°27.0'	74°04.3'	3.4	0.28	1.20	1.15
24	S3	40°25.7'	74°03.2'	2.7		Mud	
24	S4	40°26.3'	74°03.0'	4.8		Mud	
25	S3	40°25.4'	74°02.2'	3.8		Mud	
25	S4	40°25.9'	74°02.0'	5.1		Mud	
26	S3	40°25.2'	74°01.1'	4.9		Mud	
26	S4	40°25.6'	74°00.9'	5.5		Mud	
27	S3	40°24.9'	73°59.9'	0.3	0.81	1.32	1.11
28	S3	40°24.2'	73°59.0'	5.5	0.52	1.31	1.06
29	S3	40°23.8'	73°58.8'	3.9	0.30	1.16	1.01

*Sediment predominantly finer than sand; not analyzed.

Table B-7. Size Analyses Offshore Samples-Raritan Estuary

Petersen Grab Samples

Oyster Research Laboratory, Rutgers University

Sampling Date: 21 July-6 August 1958

Station No.	Latitude 40°N	Longitude 74°W	Depth (m)	Md (mm)	S_o	S_k	Percent			
							Gravel	Sand	Silt	Clay
101	28' 11"	08' 07"	2.1	.348	1.20	0.98	0.1	97.7	0.6	1.6
102	28' 06"	09' 22"	3.7	.260	1.80	0.63	0.6	81.4	11.6	6.4
103	28' 05"	10' 35"	2.3	.351	1.20	0.99	0.6	97.6	0.6	1.4
104	27' 41"	11' 52"	4.0	.009	4.11	0.90	0.7	18.6	56.0	24.7
105	26' 59"	12' 00"	3.5	.014	2.16	1.55	0.8	21.2	73.6	4.4
106	28' 15"	11' 47"	4.7	.006	2.43	0.75	0.4	5.2	69.9	24.8
107	28' 40"	11' 23"	6.1	.017	2.19	1.27	1.1	20.3	74.0	4.6
108	29' 08"	10' 57"	7.0	.012	2.05	1.25	0.5	18.4	77.1	4.0
109	29' 11"	10' 27"	7.3	.006	2.00	1.14	0.2	3.2	83.5	13.1
110	29' 18"	09' 20"	7.5	.014	2.01	1.39	0.8	19.0	74.3	5.9
111	29' 27"	08' 57"	7.9	.008	2.62	1.12	0.5	11.5	73.8	14.2
112	28' 46"	08' 39"	6.4	.018	3.98	3.91	2.9	28.0	69.9	6.2
113	29' 17"	07' 25"	11.0	.006	2.84	2.60	2.1	12.9	76.5	8.5
114	30' 10"	09' 00"	7.8	.014	3.37	1.64	1.7	26.3	66.9	5.1
115	30' 33"	08' 59"	5.5	.084	2.89	0.77	0.8	67.8	24.6	6.8
116	31' 20"	08' 37"	3.0	.326	2.19	0.91	5.5	83.6	7.8	3.1
117	30' 57"	09' 37"	4.4	.055	2.09	0.50	0.5	56.7	35.4	7.4
118	30' 28"	10' 36"	5.0	.026	3.03	1.34	4.3	35.6	56.3	3.8
130	29' 44"	16' 43"	6.4	.088	1.98	1.07	0.1	7.0	86.4	6.5
131	29' 46"	16' 29"	2.7	.032	6.90	0.35	2.1	44.6	31.2	22.1
132	30' 30"	15' 30"	>9.1	.020	5.50	0.12	0.2	7.3	64.3	28.2
133	30' 07"	15' 32"	>9.1	.006	2.46	1.34	1.0	11.7	72.7	14.6
134	29' 54"	09' 53"	7.9	.014	3.43	1.36	3.2	24.2	68.6	4.0
135	29' 48"	10' 53"	6.6	.016	3.81	0.56	0.4	23.2	57.2	19.1
136	29' 45"	11' 57"	7.0	.444	1.84	1.30	14.0	77.0	4.9	4.1
137	30' 23"	12' 14"	5.9	.007	3.75	0.77	0.2	11.1	62.1	26.6
138	29' 48"	13' 06"	5.8	.009	3.54	0.83	0.7	13.5	63.7	22.1
139	29' 48"	13' 45"	5.0	.334	1.51	0.86	5.1	85.9	5.1	3.9
140	29' 31"	14' 35"	2.7	.218	2.12	2.02	12.1	80.1	3.6	4.2
141	29' 13"	14' 43"	7.0	.328	1.43	0.93	1.2	94.8	1.3	2.7
142	29' 38"	15' 23"	14.0	.176	4.89	0.22	9.6	60.0	19.2	11.2
143	29' 25"	16' 06"	4.3	.005	3.87	0.55	0.5	11.6	56.5	31.4
144	29' 05"	15' 46"	4.5	.008	4.74	0.96	0.1	20.9	52.5	26.5
145	29' 10"	15' 37"	3.5	.006	2.13	0.92	0.0	2.7	79.1	18.2
146	29' 10"	15' 10"	4.6	.085	7.79	0.33	5.4	51.8	26.6	16.2
147	28' 57"	15' 18"	3.0	.009	1.95	0.97	0.8	5.8	83.6	9.8
148	29' 00"	15' 01"	3.0	.006	2.89	0.45	0.8	4.1	66.7	28.4

Table B-7. (continued)

Station No.	Latitude 40°N	Longitude 74°W	Depth (m)	Md (mm)	S_o	S_k	Percent			
							Gravel	Sand	Silt	Clay
149	28' 51"	15' 09"	5.0	.006	2.54	1.09	0.6	7.4	72.6	19.4
150	28' 33"	15' 10"	3.0	.004	5.00	0.59	1.7	8.2	51.7	34.4
151	28' 16"	15' 10"	2.0	.025	6.92	0.51	0.9	34.5	43.0	21.6
152	28' 11"	14' 15"	3.0	.012	9.73	1.57	1.1	33.1	38.8	27.0
153	27' 58"	13' 56"	2.4	.347	1.23	0.98	3.6	92.1	1.6	2.7
154	27' 46"	13' 00"	2.7	.015	5.68	2.02	1.1	32.0	57.3	9.6
155	28' 14"	13' 40"	2.7	.269	5.79	0.06	6.2	60.9	24.7	8.2
156	28' 35"	14' 26"	2.7	.011	3.59	0.62	0.4	15.4	61.7	22.5
157	28' 43"	14' 55"	2.7	.010	3.32	0.81	0.2	14.0	65.1	20.7
158	28' 53"	14' 46"	3.2	.008	3.16	0.84	0.0	10.0	66.8	23.2
159	28' 53"	14' 22"	4.0	.007	2.66	1.11	0.1	7.8	73.8	18.3
160	28' 50"	13' 38"	4.0	.007	1.94	1.01	0.1	3.0	86.2	10.7
161	29' 06"	13' 46"	5.5	.010	1.95	1.00	0.1	7.6	84.6	7.7
162	29' 23"	12' 31"	4.6	.007	3.07	0.90	0.6	12.8	62.6	24.0
163	28' 57"	12' 36"	5.0	.011	3.92	0.80	0.4	20.6	57.8	21.2
164	28' 34"	12' 44"	---	.007	4.16	0.66	0.3	11.4	59.8	28.5
165	28' 59"	11' 59"	---	.006	3.71	0.88	0.2	11.9	60.8	27.1
166	33' 30"	03' 42"	5.0	.096	1.90	0.98	1.0	74.8	22.2	2.0
172	32' 54"	03' 02"	7.0	.065	2.16	0.65	1.0	62.5	29.8	6.7
173	32' 50"	06' 11"	3.5	.399	2.97	2.53	24.6	69.9	5.3	0.2
174	31' 37"	06' 02"	5.9	.114	1.95	0.88	4.1	73.9	17.0	5.0
175	30' 06"	06' 02"	7.5	.136	2.12	0.50	0.1	73.1	24.5	2.3
176	30' 00"	03' 06"	7.5	.186	1.28	1.00	1.0	95.1	3.6	0.3
177	27' 25"	01' 30"	6.6	.288	1.50	0.78	0.4	4.7	1.6	3.3
178	28' 12"	03' 08"	8.5	.078	5.52	0.09	0.5	56.4	28.0	15.1
179	27' 55"	05' 12"	5.0	.012	3.57	1.78	0.3	27.4	68.3	4.0

Table B-8. Size Analyses Offshore Samples-Raritan Estuary

Petersen Grab Samples

Oyster Research Laboratory, Rutgers University

Sampling Date: 3-30 July 1959

Station No.	Latitude 40°N	Longitude 74°W	Depth (m)	Md (mm)	S_o	S_k	Percent			
							Gravel	Sand	Silt	Clay
210	28' 15"	08' 06"	1.8	.337	1.21	0.95	0.0	95.4	1.0	3.6
211	28' 05"	09' 20"	3.7	.301	1.62	0.76	6.7	81.1	4.0	8.2
212	28' 05"	10' 29"	2.7	.359	1.20	1.01	0.4	95.8	0.5	3.3
213	28' 43"	11' 25"	4.0	.005	4.39	1.16	1.8	11.3	57.1	29.8
214	28' 15"	11' 45"	3.4	.006	5.58	0.53	1.1	10.2	55.6	33.1
215	27' 41"	11' 52"	3.0	.015	4.38	2.90	4.4	27.4	52.9	15.3
216	27' 00"	12' 00"	2.4	.010	2.16	1.10	0.6	16.0	63.5	19.9
217	27' 48"	13' 02"	2.7	.010	9.14	0.84	2.1	26.2	40.8	30.9
218	28' 35"	12' 46"	3.4	.005	7.73	0.93	5.6	17.9	39.9	36.6
219	28' 59"	12' 41"	3.7	.009	4.89	0.50	4.8	13.4	53.7	28.1
220	28' 48"	13' 45"	3.7	.005	4.68	0.36	2.2	5.8	55.0	37.0
221	28' 13"	13' 42"	2.7	.283	1.95	0.48	1.9	76.0	11.8	10.3
222	28' 02"	13' 57"	3.2	.337	1.54	0.79	5.4	76.9	8.2	9.5
223	28' 10"	14' 22"	4.0	.010	3.50	0.94	2.2	20.2	54.7	22.9
224	28' 35"	14' 29"	4.3	.012	2.19	0.88	0.2	5.6	75.6	18.6
225	28' 43"	14' 58"	4.0	.010	2.68	0.87	0.6	14.3	65.4	19.7
226	28' 14"	15' 09"	3.7	.030	5.17	0.68	1.1	33.8	47.1	18.0
227	28' 34"	15' 10"	4.0	.009	3.08	0.47	1.6	9.6	63.6	25.2
228	28' 52"	15' 08"	4.3	.010	1.69	1.00	0.2	6.6	79.1	14.1
229	28' 56"	15' 18"	4.3	.007	2.40	0.53	0.2	3.4	72.4	24.0
230	29' 23"	08' 25"	9.5	.027	19.23	2.46	16.3	29.7	30.2	23.8
231	29' 23"	09' 01"	7.6	.011	1.71	0.99	2.1	4.4	80.1	13.4
232	29' 15"	09' 18"	7.0	.010	1.63	1.00	1.4	4.9	79.9	13.8
233	29' 51"	09' 55"	7.0	.010	3.18	0.56	0.6	4.7	70.9	23.8
234	30' 07"	08' 59"	7.6	.018	3.08	0.42	2.5	13.4	65.5	18.6
235	30' 32"	08' 54"	6.1	.075	2.18	0.57	1.0	66.6	20.1	12.3
236	31' 17"	08' 33"	3.8	.516	2.31	0.79	13.6	78.4	4.1	3.9
237	30' 55"	09' 38"	4.4	.064	1.83	0.72	1.7	63.8	23.6	10.9
238	30' 28"	10' 33"	5.5	.031	4.26	0.45	8.4	32.2	39.5	19.9
239	29' 48"	10' 57"	4.9	.014	2.74	1.45	9.1	15.5	61.3	14.1
240	29' 48"	11' 58"	3.7	.645	2.64	2.03	27.5	66.6	1.9	4.0
241	30' 23"	12' 14"	4.3	.011	2.64	0.96	0.3	15.8	64.7	19.2
242	29' 45"	13' 13"	4.0	.011	1.72	0.99	1.7	10.4	75.8	12.1
243	29' 49"	13' 48"	2.35	.387	1.62	1.18	8.2	85.3	2.4	4.1
244	29' 30"	14' 36"	1.2	.238	3.69	6.20	25.6	69.4	1.3	3.7
245	29' 13"	14' 43"	4.9	.267	1.52	0.80	0.6	90.8	3.5	5.1
246	29' 10"	15' 10"	2.7	.008	3.54	0.55	0.2	10.7	63.0	26.1

Table B-8. (continued)

Station	Latitude	Longitude	Depth	Md			Percent			
No.	40°N	74°W	(m)	(mm)	S_o	S_k	Gravel	Sand	Silt	Clay
247	29' 10"	15' 37"	1.8	.010	1.78	1.00	1.8	6.8	75.4	16.0
248	29' 04"	15' 49"	1.7	.007	4.41	0.37	0.2	8.0	60.0	31.8
249	28' 10"	03' 07"	8.2	.033	4.96	0.48	0.1	40.2	42.3	17.4
250	30' 00"	03' 08"	7.0	.179	1.34	0.99	5.7	86.4	2.6	5.3
251	32' 16"	02' 49"	6.7	.032	7.02	2.12	17.6	24.1	42.5	15.8
252	34' 25"	03' 22"	4.0	.250	1.61	0.88	0.7	91.7	3.4	4.2
253	32' 47"	06' 08"	2.1	.583	2.65	2.01	26.2	69.0	1.1	3.7
254	31' 32"	06' 13"	5.8	.110	2.36	0.72	2.0	70.5	18.2	9.3
255	30' 05"	06' 11"	7.9	.172	2.43	0.83	6.8	73.6	11.7	7.9
256	29' 05"	13' 42"	5.5	.006	3.19	0.37	0.2	2.6	68.1	29.1
257	28' 55"	14' 21"	4.9	.006	3.85	0.38	0.4	5.8	62.7	31.1
258	28' 54"	14' 46"	4.1	.008	2.18	0.62	0.4	3.3	73.7	22.6
259	29' 00"	14' 58"	4.3	.006	5.73	0.44	0.8	14.2	49.0	36.0
260	29' 41"	15' 25"	12.2	.107	9.32	0.19	5.3	47.9	27.9	18.9
261	30' 06"	15' 33"	11.3	.005	5.41	0.61	0.2	16.1	49.7	34.0
262	30' 34"	15' 29"	11.9	.003	6.40	0.95	4.4	14.9	39.8	40.9
263	29' 23"	12' 34"	4.0	.020	4.30	1.12	7.7	25.3	45.6	21.4
264	28' 57"	11' 51"	6.4	.009	3.35	0.47	1.7	10.9	61.9	25.5
265	29' 14"	10' 34"	7.0	.007	3.78	0.35	1.6	5.5	62.6	30.3
266	28' 45"	08' 40"	5.8	.014	5.70	0.40	1.4	24.1	47.6	26.9
267	28' 02"	05' 55"	7.9	.008	2.76	0.51	0.6	5.3	69.3	24.8
268	29' 46"	16' 29"	3.0	.096	4.24	0.24	10.3	47.9	31.1	10.7
282	29' 44"	16' 43"	4.3	.005	4.43	0.31	0.4	5.9	57.5	36.2
283	29' 25"	16' 06"	3.0	.008	3.72	0.41	0.3	8.0	63.7	28.0
284	28' 45"	15' 17"	3.4	.004	4.43	0.41	0.6	3.4	56.6	39.4

Table B-9. Size Analyses Offshore Samples-Raritan Estuary

Petersen Grab Samples

Federal Water Pollution Control Administration

Sampling Date: July-August 1963

Station No.	Latitude 40°N	Longitude 74°W	Md (mm)	S_O	Percent Gravel	Sand	Silt	Clay
1	30' 14"	09' 52"	.022	2.23	5.5	18.6	75.6	0.5
2	30' 27"	08' 38"	.230	1.48	6.2	80.5	11.4	1.2
3	30' 41"	07' 21"	.440	1.54	4.0	93.8	2.2*	
4	30' 54"	06' 06"	.260	1.25	4.2	92.3	2.4	0.2
5	32' 03"	05' 17"	.375	1.67	9.2	86.9	3.9	
6	32' 17"	04' 05"	.580	1.20	1.8	95.9	2.3	--
7	32' 30"	02' 43"	.220	1.32	3.4	92.2	4.2	0.3
9	31' 45"	01' 13"	.270	1.28	0.1	99.9	0.2	
10	21' 32"	02' 27"	.430	1.23	--	100.1	0.8	
12	29' 37"	01' 52"	.520	1.32	0.1	99.7	0.2	
13	28' 39"	01' 34"	.240	1.17	12.3	87.4	0.2	
14	27' 42"	01' 17"	.012	4.31	6.8	23.4	66.3	3.5
15	26' 44"	00' 59"	.013	2.09	4.5	10.2	84.6	0.9
16	26' 30"	02' 19"	.009	1.45	2.4	8.5	79.2	12.1
17	28' 25"	02' 54"	.015	2.68	5.6	19.9	73.2	1.1
18	29' 23"	03' 11"	.130	3.49	19.8	41.5	38.5	0.2
19	30' 20"	03' 28"	.240	1.23	8.2	90.8	1.0	
20	31' 18"	03' 45"	.220	1.37	9.9	76.0	14.0	0.1
21	31' 04"	05' 02"	.500	1.28	4.4	92.5	3.4	
22	30' 07"	04' 44"	.250	1.27	6.3	92.2	2.1	
23	29' 10"	04' 27"	.066	2.86	11.7	19.9	64.2	4.3
24	28' 12"	04' 10"	.180	1.79	17.5	52.7	29.5	0.2
25	28' 58"	05' 32"	.013	1.84	1.0	6.5	86.5	1.1
26	29' 56"	05' 49"	.230	1.96	14.2	74.2	11.2	0.5
27	29' 44"	07' 05"	.050	2.74	11.7	30.9	55.8	1.4
28	29' 31"	08' 20"	.250	10.00	28.9	37.1	33.7	0.4
29	29' 18"	09' 36"	.010	3.43	4.3	21.8	72.8	1.9
30	30' 32"	11' 18"	.011	1.70	0.5	8.4	89.8	1.3
32	29' 28"	14' 45"	.027	--	1.1	40.7	58.0	
33	29' 29"	15' 02"	.620	2.18	19.5	67.7	12.8	
39	33' 14"	04' 20"	.680	1.58	4.0	90.8	5.0	
44	30' 02"	11' 10"	.640	1.76	15.4	73.8	10.4	0.4
45	29' 05"	10' 53"	1.500	1.62	6.8	90.6	2.7	
46	28' 21"	09' 20"	.290	2.49	6.0	80.9	13.1	
47	28' 34"	08' 04"	.500	1.40	7.7	90.5	1.8	
48	28' 45"	06' 54"	.011	1.74	6.8	12.3	79.8	0.5
49	28' 02"	05' 14"	.013	3.10	5.0	20.7	70.8	3.6

Table B-9. (continued)

Station	Latitude	Longitude	Md		Percent			
No.	40°N	74°W	(mm)	S_o	Gravel	Sand	Silt	Clay
51	27' 05"	04' 56"	.260	1.18	2.7	93.3	3.9	0.2
52	27' 49"	06' 30"	.350	1.29	3.2	95.4	2.3	0.2
53	27' 25"	09' 03"	.340	1.54	0.6	94.8	3.6	
54	28' 07"	10' 35"	.360	1.83	9.3	72.6	18.3	0.1
55	27' 57"	11' 45"	.110	28.40	31.3	26.8	40.4	1.5
56	28' 54"	12' 00"	.047	5.50	22.9	16.2	60.1	
57	29' 52"	12' 16"	.038	2.32	14.2	12.3	74.0	1.1
58	28' 38"	13' 30"	.030	---	7.0	18.0	75.0	
59	27' 41"	13' 11"	.086	---	12.6	46.6	40.8	
60	28' 27"	14' 46"	.068	---	16.7	35.5	47.8	
61	29' 07"	14' 55"	---	---	0.3	10.9	88.9	
62	29' 23"	16' 10"	---	---	0.1	4.4	95.7	
463	29' 49"	16' 59"	.220	5.50	18.5	18.1	63.2	

Note:		
	Gravel	> 4.000 mm
	Sand	4.000 - 0.062 mm
	Silt	0.062 - 0.004 mm
	Clay	< 0.004 mm

*Percent silt and clay

Table B-10. Size Distribution in Percent by Mass

Petersen Grab Samples

Oyster Research Laboratory, Rutgers University

Sampling Date: 21 July-6 August 1958

Percent By Mass

	GRAVEL	SAND						SILT		CLAY
Size in mm	>2	1-2	.5-1	.25-.5	.25-.1	.05-.1	.02-.05	.005-.02	.005-.002	<.002
Station										
101	0.1	0.1	7.9	79.5	8.8	1.4	0.4	0.1	0.1	1.6
102	0.6	0.7	5.2	46.1	25.8	3.6	2.8	4.2	4.6	6.4
103	0.6	0.5	8.2	79.4	8.6	0.9	0.2	0.1	0.3	1.4
104	0.7	0.9	1.0	2.0	5.6	9.1	16.7	24.3	15.0	24.7
105	0.8	1.4	1.0	2.4	8.2	8.2	12.0	56.1	5.5	4.4
106	0.4	0.6	0.9	0.9	2.1	0.7	7.1	41.5	21.0	24.8
107	1.1	1.4	1.2	1.4	6.8	9.5	21.3	46.2	6.5	4.6
108	0.5	0.7	2.2	5.8	4.8	4.9	10.1	54.8	12.2	4.0
109	0.2	0.4	0.3	0.4	0.7	1.4	9.4	40.8	33.3	13.1
110	0.8	2.5	1.8	1.5	5.1	8.1	14.2	57.0	3.1	5.9
111	0.5	1.9	1.0	0.8	2.6	5.2	15.0	35.1	23.7	14.2
112	2.9	6.4	2.8	6.7	10.5	1.6	15.1	43.2	4.6	6.2
113	2.1	3.0	2.0	2.0	3.3	2.6	15.2	22.0	39.3	8.5
114	1.7	3.9	3.7	2.9	7.4	8.4	13.0	36.1	17.8	5.1
115	0.8	1.6	6.3	13.0	22.3	24.6	8.7	9.3	6.6	6.8
116	5.5	9.5	18.4	26.8	22.4	6.5	4.1	2.4	1.3	3.1
117	0.5	0.3	0.5	0.6	13.9	41.4	17.3	9.5	8.6	7.4
118	4.3	4.3	5.1	3.3	6.5	16.4	14.7	34.9	6.7	3.8
122	4.5	6.8	23.6	49.1	6.0	0.6	1.2	2.0	1.5	4.7
123	0.3	0.4	1.4	13.1	29.3	4.5	5.7	30.3	10.7	4.3
126	0.1	0.5	0.6	0.8	4.5	5.5	12.2	27.8	20.9	27.1
127	0.2	0.2	0.4	1.5	6.6	5.8	9.8	33.2	23.7	18.6
128	3.1	2.2	2.9	6.5	23.3	13.1	9.1	15.8	9.3	14.7
129	0.4	0.6	0.7	0.9	3.4	6.6	14.3	28.6	22.3	22.2
130	0.1	0.2	0.3	0.6	4.8	1.1	11.0	47.1	28.3	6.5
131	2.1	1.2	1.6	4.4	26.6	10.8	7.2	16.1	7.9	22.1
132	0.2	0.1	0.1	0.2	2.1	4.8	11.4	31.5	21.4	28.2
133	1.0	1.2	0.6	0.9	4.4	4.6	9.8	32.9	30.0	14.6
134	3.2	3.7	2.5	1.4	4.9	11.7	14.1	31.6	22.9	4.0
135	0.4	1.6	1.0	0.7	6.1	13.9	22.8	22.2	12.2	19.1
136	14.0	9.1	20.8	35.5	11.0	0.6	1.1	2.4	1.4	4.1
137	0.2	0.3	0.4	0.9	2.9	6.6	16.6	29.1	16.4	26.6
138	0.7	1.1	0.7	0.6	3.7	7.4	21.7	25.2	16.8	22.1
139	5.1	2.5	14.0	48.5	18.7	2.2	2.4	1.4	1.3	3.9
140	12.1	6.8	10.2	11.9	49.6	1.6	0.8	1.6	1.2	4.2

Table B-10. (continued)

	GRAVEL	SAND						SILT		CLAY
Size in mm	>2	1-2	.5 1	.25-.5	.25-.1	.05-.1	.02-.05	.005-.02	.005-.002	<.002
Station										
141	1.2	4.6	13.4	50.2	26.3	0.3	0.1	0.3	0.9	2.7
142	9.6	1.8	7.6	21.0	25.8	3.8	4.4	8.1	6.7	11.2
143	0.5	1.1	1.8	5.9	2.3	0.5	6.9	31.1	18.5	31.5
144	0.1	0.4	0.8	4.0	6.7	9.0	13.5	23.3	15.7	26.5
145	0.0	0.2	0.2	0.3	0.9	1.1	9.7	43.6	25.8	18.2
146	5.4	6.3	7.1	17.0	12.2	9.2	10.9	8.3	7.4	16.2
147	0.8	0.2	0.2	0.3	1.6	3.5	14.5	52.1	17.0	9.8
148	0.8	0.3	0.3	0.4	1.1	2.0	5.2	44.4	17.1	28.4
149	0.6	0.4	0.4	0.7	1.8	4.1	12.9	34.9	24.8	19.4
150	1.7	0.5	1.0	2.2	2.6	1.9	10.4	25.0	16.3	34.4
151	0.9	1.2	2.5	8.1	18.1	4.6	20.4	11.3	113.	21.6
152	1.1	2.8	5.5	8.9	12.0	3.9	9.3	17.4	12.1	27.0
153	3.6	2.4	5.0	73.6	10.8	0.3	0.2	0.6	0.8	3.7
154	1.1	2.3	4.5	8.4	11.2	5.6	17.8	18.9	25.6	9.6
155	6.2	1.3	3.1	44.1	12.3	0.1	3.4	10.8	10.5	8.2
156	0.4	0.5	0.7	0.8	3.3	10.1	22.5	28.7	10.5	22.5
157	0.2	0.3	0.5	0.4	3.6	9.2	20.8	29.1	15.2	20.7
158	0.0	0.1	0.2	0.2	2.1	7.4	17.7	32.8	16.3	23.2
159	0.1	0.1	0.1	0.2	1.6	5.8	16.1	33.8	23.9	18.3
160	0.1	0.2	0.2	0.2	0.9	1.5	10.2	47.6	28.4	10.7
161	0.1	0.4	0.4	0.3	1.9	4.6	15.9	51.5	17.2	7.7
162	0.6	1.7	2.9	2.5	4.0	1.7	11.5	32.8	18.3	24.0
163	0.4	1.1	1.7	1.8	6.2	9.8	19.0	24.1	14.7	21.2
164	0.3	0.6	1.0	1.0	3.0	5.8	15.8	28.6	15.4	28.5
165	0.2	0.6	1.0	1.1	3.2	6.0	13.8	28.1	18.9	27.1
166	1.0	1.8	4.9	7.8	33.1	27.2	18.4	1.2	2.6	2.0
172	1.0	1.1	1.4	2.2	24.7	33.1	14.5	9.4	5.9	6.7
173	24.6	4.7	10.2	32.4	15.5	7.1	2.1	2.3	0.9	0.2
174	4.1	2.0	3.7	9.5	36.8	21.9	8.2	4.8	4.0	5.0
175	0.1	0.9	2.8	12.2	53.4	3.8	17.8	3.9	2.8	2.3
176	1.0	0.5	0.5	19.6	73.6	0.9	0.6	2.2	0.8	0.3

Table B-10. (continued)

	GRAVEL	SAND						SILT		CLAY
Size in mm	>2	1-2	.5-1	.25-.5	.25-.1	.05-.1	.02-.05	.005-.02	.005-.002	<.002
Station										
177	0.4	0.5	5.2	55.3	27.3	6.4	0.4	0.3	0.9	3.3
178	0.5	0.4	0.4	0.8	44.3	10.5	2.8	13.1	12.1	15.1
179	0.3	0.9	1.2	1.5	12.3	11.5	10.2	32.1	26.0	4.0

Table B-11. Size Distribution in Percent by Mass

Petersen Grab Samples

Oyster Research Laboratory, Rutgers University

Sampling Date: 3-20 July 1959

	GRAVEL	SAND						SILT		CLAY
Size in mm	>2	1-2	.5-1	.25-.5	.25-.1	.05-.1	.02-.05	.005-.02	.005-.002	<.002
Station										
210	0.0	0.6	5.4	76.1	12.7	0.6	0.0	0.6	0.4	3.6
211	6.7	1.2	7.8	46.8	23.5	1.8	0.3	2.6	1.1	8.2
212	0.4	1.3	10.4	79.8	3.5	0.8	0.3	0.2	0.0	3.3
213	1.8	0.6	0.4	0.8	3.0	6.5	13.4	21.4	22.3	29.8
214	1.1	1.8	1.3	1.3	1.7	4.1	21.8	20.9	12.9	33.1
215	4.4	2.7	2.7	5.0	11.8	5.2	9.9	36.6	6.4	15.3
216	0.6	0.3	0.1	0.9	5.3	9.4	10.6	48.1	4.8	19.9
217	2.1	2.8	3.8	6.4	8.9	4.3	13.1	17.4	10.3	30.9
218	5.6	3.7	4.3	4.2	5.5	0.2	6.3	21.1	12.5	36.6
219	4.8	1.3	1.3	1.3	3.0	6.5	16.1	28.8	8.8	28.1
220	2.2	0.2	0.2	0.2	1.1	4.1	10.4	31.7	12.9	37.0
221	1.9	1.9	3.2	52.5	15.7	2.7	3.6	5.2	3.0	10.3
222	5.4	3.0	11.8	52.1	9.4	0.6	0.6	4.0	3.6	9.5
223	2.2	1.1	2.0	4.5	9.0	3.6	6.6	42.2	5.9	22.9
224	0.2	0.4	0.4	0.4	1.1	3.3	28.0	41.7	5.9	18.6
225	0.6	0.5	0.6	1.1	4.1	8.0	15.1	41.9	8.4	19.7
226	1.1	0.5	1.6	6.9	22.2	2.6	27.2	12.5	7.4	18.0
227	1.6	0.3	0.3	0.5	4.3	4.2	11.5	46.3	5.8	25.2
228	0.2	1.0	1.0	0.5	0.7	3.4	11.8	62.7	4.6	14.1
229	0.2	0.2	0.2	0.2	1.1	1.7	8.1	56.2	8.1	24.0
230	16.3	6.7	7.4	6.7	5.3	3.6	6.2	14.5	9.5	13.4
231	1.4	1.2	0.9	0.7	1.2	0.9	10.4	66.1	3.4	13.8
232	1.4	1.2	0.9	0.7	1.2	0.9	10.4	66.1	3.4	13.8
233	0.6	0.3	0.3	0.3	1.0	2.8	25.5	36.5	8.9	23.8
234	2.5	1.4	1.7	1.3	2.2	6.8	32.1	24.0	9.4	18.6
235	1.0	0.4	0.6	1.3	34.4	29.9	10.2	5.9	4.0	12.3
236	13.6	12.6	25.0	18.6	17.6	4.6	0.7	2.2	1.2	3.9
237	1.7	0.5	0.5	0.8	21.7	40.3	16.0	5.1	2.5	10.9
238	8.4	3.0	2.4	1.6	7.0	18.2	18.1	16.2	5.2	19.9
239	9.1	1.6	1.5	1.1	3.6	7.7	14.2	41.7	5.4	14.1
240	27.5	9.5	20.5	32.8	3.8	0.0	0.0	1.2	0.7	4.0
241	0.3	0.4	0.6	1.4	4.9	8.5	17.4	40.2	7.1	19.2
242	1.7	0.8	0.9	0.8	2.8	5.1	10.0	60.9	4.9	12.1
243	8.2	5.6	20.7	42.3	15.9	0.8	0.5	0.5	1.4	4.1
244	25.6	4.9	5.4	10.7	46.6	1.8	0.1	0.8	0.4	3.7

Table B-11. (continued)

	GRAVEL	SAND						SILT		CLAY
Size in mm	>2	1-2	.5-1	.25-.5	.25-.1	.05-.1	.02-.05	.005-.02	.005-.002	<.002
Station										
245	0.6	0.5	2.3	51.8	33.6	2.6	0.3	1.9	1.3	5.1
246	0.2	0.2	0.2	0.8	3.6	5.9	15.8	36.9	10.3	26.1
247	1.8	0.7	1.1	1.1	1.3	2.6	11.1	58.0	6.3	16.0
248	0.2	0.2	0.2	0.2	2.4	5.0	14.8	35.1	10.1	31.8
249	0.1	0.1	0.3	0.8	33.9	5.1	22.4	11.7	8.2	17.4
250	5.7	1.2	1.0	14.3	69.1	0.8	0.0	0.9	1.7	5.3
251	17.6	3.9	2.5	2.1	13.5	2.1	18.2	18.9	5.4	15.8
252	0.7	1.9	8.0	39.4	37.6	4.8	2.0	0.9	0.5	4.2
253	26.2	9.8	18.0	30.0	10.8	0.4	0.1	0.5	0.5	3.7
254	2.0	1.7	5.6	12.3	32.4	18.5	10.0	4.5	3.7	9.3
255	6.8	2.5	7.4	22.7	26.0	15.0	5.6	3.6	2.5	7.9
256	0.2	0.2	0.2	0.2	0.2	1.8	9.6	47.0	11.5	29.1
257	0.4	0.2	0.2	0.2	1.0	4.2	11.9	38.4	12.4	31.1
258	0.4	0.2	0.2	0.2	0.7	2.0	9.0	58.4	6.3	22.6
259	0.8	0.4	0.7	2.6	5.6	4.9	11.8	26.5	10.7	36.0
260	5.3	4.2	12.4	19.2	9.7	2.4	5.9	16.2	5.8	18.9
261	0.2	0.6	0.6	1.1	6.5	7.3	10.6	24.8	14.3	34.0
262	4.4	0.6	1.6	6.7	4.3	1.7	6.0	17.7	16.1	40.9
263	7.7	2.7	3.4	3.4	6.5	9.3	16.7	25.2	3.7	21.4
264	1.7	1.1	1.2	1.1	2.8	4.7	13.1	42.9	5.9	25.5
265	1.6	0.7	0.5	0.5	1.8	2.0	11.5	41.8	9.3	30.3
266	1.4	0.5	1.8	1.1	10.1	10.6	16.4	30.4	0.8	26.9
267	0.6	0.6	0.4	0.6	1.1	2.6	11.8	49.6	7.9	24.8
268	10.3	2.1	2.7	4.0	30.4	8.7	5.8	22.9	2.4	10.7
271	22.6	9.7	10.6	8.7	2.9	9.1	14.2	8.0	3.6	10.6
272	8.1	0.4	0.4	0.6	2.3	0.8	7.4	30.4	14.7	34.9
273	2.5	6.0	16.3	31.2	6.2	3.4	3.7	8.0	6.1	16.6
274	92.0	3.1	1.1	1.0	0.0	0.0	0.0	0.0	0.2	2.6
276	0.2	0.3	6.5	56.8	24.7	1.5	1.1	3.5	0.9	4.5
277	3.6	4.6	21.0	58.2	7.4	0.2	0.2	0.5	1.0	3.3
278	0.5	0.1	0.5	29.4	54.5	1.6	1.1	2.8	2.9	6.6
279	0.2	0.2	0.2	0.2	1.2	2.0	9.8	33.3	16.0	36.9
280	1.6	0.7	2.1	12.7	16.9	0.2	5.9	51.0	0.5	8.4
281	3.6	0.3	0.5	0.8	3.8	5.0	26.2	26.9	8.8	24.1
282	0.4	0.2	0.4	0.4	2.2	2.7	10.2	35.5	11.8	36.2
283	0.3	0.3	0.5	0.6	2.0	4.6	15.5	40.2	8.0	28.0
284	0.6	0.1	0.1	0.1	1.1	2.0	9.4	32.1	15.1	39.4

Table B-12. Size Distribution in Percent by Mass

Petersen Grab Samples

Federal Water Pollution Control Administration

Sampling Date: July-August 1963

	GRAVEL	SAND				SILT		CLAY
Station No.	Wt % >4.000	Wt % 4.000-.840	Wt % .840-.420	Wt % .420-.149	Wt % .149-.062	Wt % .062-.016	Wt % .016-.004	Wt % <.004
1	5.5	2.5	0.9	3.1	12.1	35.2	40.4	0.5
2	6.2	3.4	0.4	57.8	9.9	10.8	0.6	1.2
3	4.0	5.8	43.2	43.8	1.0	2.2	<0.062	
4	4.2	1.9	10.3	77.8	2.3	1.9	0.5	0.2
5	9.2	9.2	26.2	44.8	6.7	3.9	<0.062	
6	1.8	6.2	73.5	13.7	2.5	1.9	0.4	---
7	3.4	1.4	0.6	74.6	15.6	3.7	0.5	0.3
9	0.1	0.5	7.1	92.2	0.1	---	---	---
10	---	0.7	56.6	42.8	---	---	---	---
12	0.1	1.4	70.5	27.7	0.1	---	---	---
13	12.3	1.1	1.4	84.8	0.1	---	---	---
14	6.8	1.2	0.7	13.4	8.1	13.9	52.4	3.5
15	4.5	2.6	1.2	3.8	2.6	28.7	55.9	0.9
16	2.4	1.8	1.7	4.1	0.9	12.0	77.2	12.1
17	5.6	2.2	0.8	10.8	6.1	21.2	52.0	1.1
18	19.8	4.6	1.4	20.6	14.9	32.8	5.7	0.2
19	8.2	1.6	0.7	87.7	0.8	1.0	<0.062	
20	9.9	4.6	2.5	62.2	6.7	13.2	0.8	0.1
21	4.4	3.3	64.1	22.8	2.3	3.4	<0.062	
22	6.3	1.9	3.4	78.9	8.0	2.1	<0.062	
23	11.7	2.3	1.2	12.7	3.7	49.6	14.6	4.3
24	17.5	1.6	1.3	41.5	8.3	29.0	0.5	0.2
25	1.0	1.3	0.4	2.1	2.7	34.7	51.8	1.1
26	14.2	6.3	8.3	45.4	14.2	10.4	0.8	0.5
27	11.7	4.1	2.5	9.7	14.6	53.8	2.0	1.4
28	28.9	6.7	13.0	15.3	2.1	32.5	1.2	0.4
29	4.3	1.5	1.6	7.9	10.8	10.9	61.9	1.9
30	0.5	0.2	0.2	1.8	6.2	20.1	69.7	1.3
32	1.1	4.0	15.0	*	21.7	58.3	<0.062	
33	19.5	14.5	38.9	*	14.3	12.8	<0.062	
39	4.0	32.7	46.8	8.8	2.5	5.0	<0.062	
44	15.4	18.1	41.2	10.8	3.7	9.9	0.5	0.4
45	6.8	74.9	12.7	*	3.0	2.7	<0.062	
46	6.0	7.6	26.6	*	46.7	13.1	<0.062	
47	7.7	4.8	54.2	30.8	0.7	1.8	<0.062	

Table B-12. (continued)

Station No.	GRAVEL	SAND				SILT		CLAY
								Wt %
	>4.000	4.000-.840	.840-.420	.420-.149	.149-.062	.062-.016	.016-.004	≤.004
48	6.8	4.5	1.0	2.9	3.9	13.2	67.6	0.5
49	5.0	1.8	1.0	13.8	4.1	15.6	55.2	3.6
51	2.7	2.4	8.6	81.5	0.8	2.9	1.0	0.2
52	3.2	4.8	25.7	64.8	0.1	1.5	0.8	0.2
53	0.6	1.0	47.6	40.5	5.7	3.6	<0.062	
54	9.3	5.9	27.1	35.1	4.5	17.7	0.6	0.1
55	31.3	5.9	3.2	6.2	11.5	9.9	30.5	1.5
56	22.9	2.4	1.3	*	12.5	60.1	<0.062	
57	14.2	4.8	1.5	1.5	4.5	7.8	66.2	1.1
58	7.0	4.7	2.4	*	11.0	75.0	<0.062	
59	12.6	8.7	6.4	*	31.5	40.8	<0.062	
60	16.7	3.6	2.8	*	29.1	47.8	<0.062	
61	0.3	1.7	3.7	*	5.5	88.9	<0.062	
62	0.1	0.3	0.4	*	3.7	95.7	<0.062	
AH Spec	9.0	1.7	7.9	41.4	4.2	6.9	28.1	0.7
463	18.5	4.8	3.1	*	10.2	63.2	<0.062	

*420 - 62 μ range measured together

Table B-13. Size Analyses Beach Samples-Sandy Hook

Beach Erosion Board, U.S. Army, Corps of Engineers

Sample No.	Latitude (N)	Longitude (W)	Md (mm)	Remarks
9	40°28.5'	74°01.1'	0.37	Sampled: June - August 1929
13	40°28.4'	74°00.7'	2.08	Sample location: between high water and low water from beach surface to depth of 1 - 2 feet.
15	40°28.1'	73°59.9'	0.45	
31	40°27.8'	73°59.8'	0.48	Sampled: August 1932
32	40°27.3'	73°59.5'	0.54	Sample location: high water to low water zone from beach surface to depth of 2 inches.
33	40°25.7'	73°58.9'	0.38	
1	40°28.6'	74°01.0'	0.66	Sampled: June - July 1935
2	40°28.4'	74°00.6'	1.41	Sample location: mid-tide zone from beach surface to depth of 2 - 3 inches.
4	40°27.7'	73°59.7'	2.72	
5	40°27.4'	73°59.5'	2.78	
6	40°27.0'	73°59.3'	0.32	
7	40°26.4'	73°58.9'	0.49	
8	40°26.0'	73°58.9'	1.33	
10	40°25.1'	63°58.8'	4.05	
11	40°24.6'	73°58.8'	2.16	
12	40°24.2'	73°58.7'	0.82	

Table B-14. Size Analyses Beach Samples-Sandy Hook

Robert L. McMaster

Sampling Date: *June 1950

Sampling location: see note

Sample No.	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
5	40°28.6'	74°00.0'	0.47	1.31	1.00
6	40°28.4'	74°00.6'	0.38	1.21	1.03
7	49°28.2'	74°00.0'	0.46	1.28	1.09
8	40°27.4'	73°59.5'	0.30	1.23	0.99
9	40°26.6'	73°59.1'	0.33	1.28	0.97
10	40°25.7'	73°58.9'	0.44	1.32	1.00
11	40°24.8'	73°58.9'	0.30	1.32	1.04
12	40°24.0'	73°58.6'	0.29	1.24	1.12

Note: Samples collected from most recent high water line from beach surface to a depth of 6 inches after approximately one-half of surface material scraped away. At each sampling site 4 samples were taken 15 feet apart along the high water line and made into a composite sample.

*Sample No. 12 collected October 1950.

Table B-15. Size Analyses Beach Samples-Sandy Hook

U.S. Army Engineer District-New York

Sampling Date: June-August 1953

[Sample: beach surface to approximate depth of 8 cm (3 in)]

Range No.	Sample No.	Latitude (N)	Longitude (W)	Md (mm)	S_o	S_k
		Sample Location: High Water Line				
1	S1	40°28.7'	74°00.8'	0.42	1.21	0.96
2	S1	40°28.2'	74°00.0'	0.44	1.25	1.04
3	S1	40°27.6'	73°59.6'	0.24	1.12	1.07
4	S1	40°26.9'	73°59.1'	0.30	1.28	1.07
5	S1	40°26.3'	73°58.9'	0.46	1.10	1.06
6	S1	40°25.6'	73°58.9'	0.32	1.22	1.06
7	S1	40°24.8'	73°58.8'	0.25	1.16	1.06
		Sample Location: Low Water Line				
1	S2	40°28.7'	74°00.8'	0.75	1.54	0.81
2	S2	40°28.2'	73°59.9'	0.66	1.49	0.94
3	S2	40°27.6'	73°59.6'	0.63	2.32	1.37
4	S2	40°26.9'	73°59.1'	0.65	1.72	0.92
5	S2	40°26.3'	73°58.8'	0.30	1.25	1.01
6	S2	40°25.6'	73°58.9'	0.53	1.45	0.96
7	S2	40°24.8'	73°58.7'	0.35	1.35	1.00

Table B-16. Size Analyses Offshore Samples-Sandy Hook

Beach Erosion Board, U.S. Army Corps of Engineers

Sampling Date: June 1929

Sample No.	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	Distance Offshore (m)
27	40°28.5'	74°01.5'	1.8	0.70	--
28	40°28.6'	74°01.2'	6.1	0.36	46
29	40°28.7'	74°00.9'	6.1	0.42	15
30	40°28.5'	74°00.6'	3.0	0.46	46
31	40°27.3'	73°59.3'	1.8	0.41	61

Table B-17. Size Analyses Offshore Samples-Sandy Hook

Robert L. McMaster

Sampling Date: 1950

Sample No.	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	S_o	S_k
B-11	40°29.3'	74°01.0'	7.0	0.378	1.37	1.18
B-13	40°30.8'	74°00.8'	3.7	0.508	1.42	1.27
B-21	40°28.5'	73°58.9'	6.1	0.347	1.23	1.10
B-23	40°29.0'	73°55.8'	13.7	0.389	1.17	1.01

Description of samples

B-11	Dark yellow brown quartz sand with varying amounts of shell, glauconite, and rock fragments; grains oil stained.
B-13	Same as for B-11.
B-21	Yellowish gray quartz sand with varying amounts of shell and glauconite; grains oil stained.
B-23	Dark yellow brown quartz sand with abundant glauconite; grains oil stained.

Table B-18. Size Analyses Offshore Samples-Sandy Hook
U.S. Army Engineer District, New York
Sampling Date: Summer 1953

Range No.	Sample No.	Latitude (N)	Longitude (W)	Depth (m)	Md (mm)	S_o	S_k
1	S3	40°28.7'	74°00.8'	2.2	0.37	1.22	0.86
1	S4	40°28.7'	74°00.7'	10.9	0.44	1.14	1.01
1	S5	40°28.9'	74°00.7'	14.7	0.40	1.11	0.89
1	S6	40°29.0'	74°00.6'	15.2	0.42	1.21	1.06
2	S3	40°28.3'	73°59.9'	0.9	0.28	1.15	0.98
2	S4	40°28.4'	73°59.8'	8.6	0.36	1.24	0.93
2	S5	40°28.5'	73°59.5'	3.7	0.42	1.24	1.07
2	S6	40°28.7'	73°59.3'	9.1	0.44	1.19	1.18
3	S3	40°27.6'	73°59.5'	1.8	0.20	1.28	0.94
3	S4	40°28.0'	73°58.7'	6.4	0.23	1.45	1.16
3	S5	40°28.5'	73°57.7'	6.9	0.85	1.75	1.15
3	S6	40°29.0'	73°56.7'	8.4	0.63	1.43	1.00
4	S3	40°26.9'	73°59.0'	1.8	0.20	1.27	1.04
4	S4	40°27.2'	73°58.0'	6.0	0.23	1.43	1.13
4	S5	40°27.5'	73°57.1'	6.4	1.04	1.47	1.50
4	S6	40°27.7'	73°56.5'	8.8	0.75	1.41	1.04
5	S3	40°26.3'	73°58.8'	1.8	0.42	1.41	1.09
5	S4	40°26.3'	73°58.4'	8.5	0.23	1.11	1.03
5	S5	40°26.4'	73°57.7'	6.7	0.26	1.16	0.98
5	S6	40°26.5'	73°57.1'	9.0	0.42	1.25	1.02
6	S3	40°25.0'	73°58.8'	1.8	0.36	1.41	1.10
6	S4	40°25.0'	73°58.5'	7.7	0.22	1.12	1.03
6	S5	40°25.0'	73°57.5'	6.7	0.25	1.12	0.99
6	S6	40°25.0'	73°57.0'	9.1	0.42	1.28	0.96
7	S3	40°24.0'	73°58.7'	1.7	0.24	1.47	1.22
7	S4	40°24.0'	73°58.7'	3.4	0.22	1.12	1.03
7	S5	40°24.0'	73°58.4'	5.5	0.42	1.24	1.12
7	S6	40°24.0'	73°57.1'	9.1	0.46	1.24	0.94

Table B-19. Size Analyses Beach Samples-Rockaway Beach

Beach Erosion Board, U.S. Army, Corps of Engineers

Sampling Date: as indicated

Range	Year	Md (mm)	S_o	S_k	Location
			Mid-Tide		
492 A	1935	0.28	1.37	1.15	Jacob Riis Park
493 A	1935	0.30	1.48	0.91	Jacob Riss Park
494 A	1935	0.32	1.31	0.95	Jacob Riis Park
496	1935	0.32	1.31	0.96	Jacob Riis Park
497	1935	0.25	1.22	1.00	Jacob Riis Park
497 A	1935	0.30	1.27	1.09	Jacob Riis Park
500 A	1935	0.32	1.29	1.03	Jacob Riis Park
501 A	1935	0.35	1.41	1.05	Jacob Riis Park
506 A	1932	0.35	1.25	1.27	Midway between Jacob Riis Park and Rockaway Point
506 B	1932	0.32	1.20	0.98	
510 A	1932	0.30	1.25	0.99	Rockaway Point
512 A	1932	0.36	1.70	0.95	Rockaway Point
516 A	1932	0.33	1.21	0.95	Rockaway Point
			Mean High Water		
506 A	1932	0.32	1.07	0.91	Midway between Jacob Riis Park and Rockaway Point
506 B	1932	0.28	1.22	0.95	
510 A	1932	0.28	1.11	0.87	Rockaway Point
512 A	1932	0.26	1.33	1.00	Rockaway Point
516 A	1932	0.27	1.20	0.99	Rockaway Point

Table B-20. Size Analyses Bottom Samples-East Bank

Shipek Grab Samples

Woodward-Clyde Consultants for

U.S. Army Corps of Engineers, New York District

Station No.	Md (mm)	S_o	19-4.9 (mm)	4.9-2.0 (mm)	2.0-0.43 (mm)	0.43-0.076 (mm)	<0.076 (mm)
1	0.20	1.13	10.3	5.1	11.6	71.5	1.5
2	0.19	1.66	0.0	0.0	2.1	96.0	1.9
3	0.24	1.12	0.0	0.2	7.5	90.0	2.3
4	0.18	1.05	0.0	0.0	0.4	97.7	1.9
5	0.70	1.86	8.6	11.5	53.7	25.2	1.0
6	0.80	1.47	3.3	4.3	83.4	8.0	1.0
7	0.32	1.38	1.6	0.8	25.0	70.6	1.4
8	0.37	1.34	2.8	0.5	27.1	67.3	2.3
9	0.22	1.20	0.0	0.5	6.8	89.7	3.0
10	0.15	1.34	0.0	0.0	0.8	83.0	16.2
11	0.17	1.29	0.0	0.0	0.4	93.9	5.7

Table B-21. Size Analyses Bottom Samples-Raritan River

Petersen Grab Samples

Oyster Research Laboratory, Rutgers University

Station No.	Latitude 40°N	Longitude 74°W	Depth (m)	Md (mm)	S_o	S_k	Percent Gravel	Percent Sand	Percent Silt	Percent Clay
						Sampling Date: July - August 1958				
122	29' 05"	20' 38"	5.0	.403	1.51	1.18	4.5	86.1	4.7	4.7
123	29' 32"	19' 41"	5.8	.042	4.49	0.84	0.3	48.7	46.7	4.3
126	30' 34"	18' 19"	3.5	.005	3.54	0.96	0.1	11.9	60.9	27.1
127	30' 31"	17' 48"	2.3	.007	2.71	1.12	0.2	14.5	66.7	18.6
128	30' 30"	17' 20"	7.9	.052	5.35	0.31	3.1	48.0	34.2	14.7
129	29' 54"	17' 11"	3.2	.006	3.12	1.20	0.4	12.2	65.2	22.2
						Sampling Date: July 1959				
271	29' 14"	25' 20"	5.2	.284	8.33	0.50	22.6	41.0	25.8	10.6
272	29' 33"	24' 51"	4.9	.005	4.53	0.43	8.1	4.5	52.5	34.9
273	29' 08"	23' 35"	6.4	.285	8.11	0.04	2.5	63.1	17.8	16.6
274	28' 42"	22' 40"	3.4	--	--	--	92.0	5.2	0.2	2.6
276	28' 38"	21' 26"	4.9	.296	1.48	0.78	0.2	89.8	5.5	4.5
277	29' 04"	20' 43"	6.1	.389	1.38	1.11	3.6	91.4	1.7	3.3
278	29' 31"	19' 43"	4.6	.184	1.50	1.01	0.5	86.1	6.8	6.6
280	30' 28"	17' 20"	8.5	.016	4.18	5.42	1.6	32.6	57.4	8.4
281	29' 54"	17' 11"	2.7	.012	3.80	0.47	3.6	10.4	61.9	24.1

APPENDIX C

CRITERIA FOR ACCEPTABILITY OF NEW YORK HARBOR SANDS

Mortar Sand

N.Y. State Department of Transportation Specification 703-03 states:

When dry, mortar sand shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#4 16.00 mm	100
#8 2.83 mm	95-100
#50 .30 mm	10-40
#100 .149 mm	0-15

In addition, aggregate must meet standards for organic impurities.

Grout Sand

N.Y. State Department of Transportation Specification 703-04 states:

When dry, grout sand shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#16 1.19 mm	100
#100 .149 mm	0-10
#230 .062 mm	0-6

Since we did not use a #16 sieve, in the following table sand is considered acceptable if greater than 99% passes the #18 (1 mm) sieve. In addition, aggregate must meet standards for organic impurities.

Cushion Sand

N.Y. State Department of Transportation Specification 703-06 states:

Material for cushion sand used for concrete block slope paving shall, when dry, meet the following gradation requirements:

Sieve Size	% Passing by Mass	
	Minimum	Maximum
3/8 inch	100	
#4	90	100
#8	75	100
#16	50	85
#30	25	60
#50	10	30
#100	1	10
#200	3	3

Concrete sand must also meet requirements for organic impurities.

Mineral Filler

N.Y. State Department of Transportation Specification 703-08 states:

Mineral filler used in bituminous concrete mixtures shall meet the following gradation requirements:

Sieve Size	% Passing by Mass
#30 .59 mm	100
#80 .177 mm	85-100
#200 .074 mm	65-100

Blasting Sand

There are 2 types of blasting sand: G-1 is fast cutting, while G-2 is slower on the first pass. Gradation requirements are as follows:

Sieve Size	% Retained by Mass	
	G-1	G-2
#12 1.68 mm	0	60-85
#16 1.19 mm	15-30	20-35
#20 .84 mm	20-30	0-10
#30 .59 mm	25-35	
#40 .42 mm	10-20	
pan	0-10	

Reference: Analysis of Ambrose Channel Sands by the N.Y. State Department of Public Works, Bureau of Materials. This report was furnished by J. Marotta of the N.Y. State Office of General Services.

Fill Sand for Roadways

A. Select Subgrade: N.Y. State Department of Transportation Specification 203-2.01 states:

Select subgrade shall consist of any suitable material having no particles greater than 6 inches in diameter.

B. Select Borrow and Select Fill

1. For underwater placement:

Sieve Size	% Passing
#200 .074 mm	10

2. For above water placement:

Sieve Size	% Passing
6 inches	100
#200 .074 mm	15

Filter Sand

American Water Works Association Standard B100 for Filtering Materials states:

> "Filter Sand shall consist of hard durable grains of material less than 2.4 mm in greatest diameter."

Since we did not use a 2.4 mm sieve in our analysis, in the following table sand is marked acceptable for filter sand if less than 2% was retained on the 2 mm (#10) sieve. For determining the acceptability and uniformity of filtration sand, "effective grain size" and "uniformity" coefficients are used. The effective grain size is the 10th percentile measured in mm:

$$\text{Effective Grain Size} = M_{m_{10}}$$

The uniformity coefficient is the 40th percentile divided by the effective grain size:

$$U = \frac{Mm_{40}}{Mm_{10}}$$

APPENDIX D

ANNOTATED BIBLIOGRAPHY

The annotated bibliography is presented in alphabetical order under each of the following headings: Regional Geology, Hydrology, Biology, Sediment Sources, Sediment Characteristics, and Bibliographies. An attempt has been made to include all publications that are most pertinent to an evaluation of the sand and gravel resources of New York Harbor. There are many additional publications, that have not been included, which provide background information on this area. The titles of most of these are contained in the bibliographies listed in this report.

Items in quotations are taken directly from the abstract, introduction, or summary of the paper or book. Other items are our summaries of relevant portions of the article, or our comments on its scope, accuracy, and usefulness.

Regional Geology

LeGrand, H. E. 1961. Summary of geology of Atlantic Coastal Plain. Bull. American Association of Petroleum Geologists, Vol. 45, No. 9, pp. 1557-1571.

"The emerged part of the Atlantic Coastal Plain is underlain chiefly by Cretaceous and Tertiary sediments. In aggregate the sediments thicken as a wedge toward the coast...Predominantly marine sand and clay characterize the entire sedimentary sequence... Common tendencies include: (1) downdip change in many formations from coarse clastic to fine clastic to carbonate facies (2) downdip thickening of beds, (3) downdip increase in number of beds, and (4) decreasing porosity and permeability with depth in coastal areas."

This is a useful general reference for those who wish to know more about the coastal plain sediments which underlie Lower Bay.

Minard, James P. 1969. Geology of the Sandy Hook Quadrangle in Monmouth County, New Jersey. United States Geological Survey Bulletin 1276.

"The Sandy Hook area contains the thickest and most complete section of Upper Cretaceous deposits in the Coastal Plain in New Jersey...in ascending order the units are the Englishtown, Marshalltown, and Wenonah Formations, Mount Laurel Sand, Navesink Formation, Red Bank Sand, and Tinton Sand...The Upper Cretaceous ...units consist chiefly of quartz, glauconite, montmorillonite, mixed-layer clay, kalonite, muscovite, chlorite, lignite, and pyrite...The Cretaceous units strike generally northeast...beds dip between 20 and 40 feet per mile southeast...Sandy Hook is a classic illustration of an active compound recurved spit, which has lengthened about 1,000 feet in the past quarter century."

The excellent discussion of Cretaceous sediments includes mineralogy and grain-size distribution of each formation. Of even greater value are the description of the deep anger borings taken along the length of Sandy Hook. Based on these borings, the geological structure and stratigraphy has been determined along a north-south profile to a depth of 200 feet. This information represents some of the most accurate data available on which to base interpretation of seismic reflection survey data.

The paper also includes a brief discussion of the growth of Sandy Hook supported by aerial photographs from 1940 and 1961.

Oliver, Jack E., and Charles L. Drake. 1951. Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain. Part VI: The Long Island Area, GSA Bull., Vol. 62, pp. 1287-1296.

The paper describes results of a seismic survey in the Long Island area consisting of 12 reversed refraction profiles. A 200-foot interval contour map of the crystalline rock surface is presented. This surface is approximated by a plane dipping gently south to southeast. Extrapolation of the contours indicates that bedrock surface is approximately 1000 feet below sea level near Sandy Hook. The mean sound velocity in the basement rocks is 18,400 feet/sec (5.6 km/sec). The authors identified two other seismic horizons; one termed unconsolidated sediments having a mean velocity of 5400 ft/sec (1.65 km/sec) and a second termed semi-consolidated sediments with a mean velocity of 6500 ft/sec (2.0 km/sec). The latter was found only to the south and southeast of Long Island.

Perlmutter, Nathaniel M., and Theodore Arnow. 1953. Ground water in Bronx, New York, and Richmond Counties with summary data on Kings and Queens Counties, New York City, New York. Bull. GW-32, State of New York Department of Conservation, Water Power and Control Commission.

This report contains much geological information about Staten Island and the Brooklyn area adjacent to Lower New York Harbor. Included are geological structure and stratigraphic profiles, plus a compilation of many well log descriptions. The data contained in this report are very useful in interpreting seismic reflection survey data, and correlating the sub-bottom stratigraphy and structure in Lower New York Harbor.

Sanders, John E. 1974. Geomorphology of the Hudson Estuary. *In* Hudson River Colloquium (ed. O.A. Roels), Annals N.Y. Academy of Sciences, Vol. 250.

"From just north of Bear Mountain to the Narrows, the Hudson Estuary flows in, across or along six major regional morphological provinces of features. From north to south these are: (1) the Great Valley of the Appalachians, (2) the New Jersey-Hudson Highlands, (3) the Manhattan Prong of the New England Upland, (4) the Newark Lowland (which is rimmed at its northeast end by the Palisades Ridge), (5) the Atlantic Coastal Plain, and (6) the Harbor Hill Terminal Moraine."

Schuberth, Christopher J. 1968. The Geology of New York City and Environs. The Natural History Press, Garden City, N. Y.

"This book attempts to summarize the knowledge that geologists have gained and to tell the fascinating story of the Metropolitan New York region. We will examine its changing aspect through time, back to its decipherable beginning. ...the plain of this book is first to describe the terrain as it appears today, within a radius of about one hundred miles from midtown Manhattan. This is followed by a consideration of the structural framework of our northeastern continent in terms of its primordial beginning. Then, we will follow in chronological order the sequence of events that molded and modified the landscape into its present configuration."

Spangler, Walter B., and John J. Peterson. 1950. Geology of Atlantic Coastal Plain in New Jersey, Delaware, Maryland, and Virginia. Bulletin, Americal Association Petroleum Geologists, Vol. 34, No. 1, January, pp. 1-99.

"This paper presents a detailed study of the Cretaceous and Tertiary stratigraphy of the Atlantic Coastal Plain in New Jersey, Delaware, Maryland, and Virginia. Detailed lithographic descriptions, based on field examination of all important outcrops in the area, reveal an orderly solution to the correlation problems that have persisted in previous lithologic and paleontologic studies of this area.

Diagrammatic cross sections and profiles are included to contrast the relationships of bids based on past age assignments and the relationships of beds based on the writers' age assignments and interpretations. Isopack and structure maps have been prepared from well-log data for the major formational divisions."

Widner, Kemble. 1964. The Geology and Geography of New Jersey. The New Jersey Historical Series, Vol. 19, D. Van Nostrand Company, Inc., Princeton, N. J., 193 pp.

A semi-popular, yet authoritative and comprehensive account of the geology of New Jersey. There are chapters on the geology of the Coastal Plain, and the effects of the Pleistocene glaciation on the region. A good place to start to obtain a broad view of the geology of the area. The author was State Geologist and Chief of the Bureau of Geology and Topography in the Department of Conservation and Economic Development, New Jersey.

Hydrology

Abood, K. A. 1974. Circulation in the Hudson Estuary. *In* Hudson River Colloquim (ed. O.A. Roels), Annals N.Y. Academy of Sciences, Vol. 250(1).

"This paper describes the hydrodynamic characteristics of partially stratified water bodies, as typified by the Hudson River, and presents a number of methods of establishing a quantitative relationship of density-induced velocity and circulation to salinity levels, freshwater runoff, and tidal characteristics. These methods utilize known or measurable physical and hydraulic parameters to determine the density-induced circulation (DIC) and mixing characteristic of estuaries."

Jeffries, Harry P. 1962. Environmental Characteristics of Raritan Bay, A Polluted Estuary. Limnology and Oceanography, Vol. 7, No. 1, pp. 21-31.

"Temperature, salinity, dissolved O_2, PO_4-P, and NO_3-N in Raritan Bay, N.J. were determined over a 16-month period. Each reflects the circulation pattern in which sea water floods along the northern shore, enters a region of mixing with river discharge in the head of the bay, and then ebbs out along the southern shore."

"At the mouth of the bay, salinity was higher on the northern than on the southern side. The mean annual monthly difference at the surface was 1.27%; departures from the mean were related to river flow."

"Surface and bottom dissolved O_2 content were minimal in August and highest during winter. Low concentrations occurred in the Raritan River, especially during the summer proceding operation of a trunk sewer."

"The primary source of NO_2-N was outflow from the Raritan River. Prior to operation of a trunk sewer, the river may have discharged significant quantities of PO_4-P into the bay."

"Throughout spring and summer, PO_4 concentrations rose and NO_3 decreased. It is postulated that the resultant low N:P ratio was partially due to an efficient nutrient regeneration mechanism that favored the rate of P renewal."

"A combination of rich nutrient supplies arising from natural and domestic sources, plus a sluggish circulation, efficient nutrient regeneration mechanism, and scarcity of macroscopic algae combine to form an estuarine environment capable of supporting extremely dense plankton populations."

Kao, Alan Z. H. 1975. Current Structure in the Sandy Hook to Rockaway Point Transect. Unpublished Masters Thesis, Marine Environmental Studies, State University of New York at Stony Brook.

"The structure of tidal and nontidal currents within the Sandy Hook to Rockaway Point Transect has been investigated in light of USC&GS current meter data. The data are from surveys conducted in

New York Harbor in 1952, 1958, and 1959. The vertical and horizontal variation over the Transect of tidal current amplitude and phase is discussed, as well as the variation of nontidal current velocity. The tidal and nontidal volume transport of water has been calculated. The complicated spatial structure of tidal and nontidal currents appears to have important effects on the transport of dissolved and suspended materials through the Transect."

Tidal currents are dominated by the semi-diurnal tide. Strongest ebb velocities are confined to the surface layers and to the Sandy Hook side of the transect. Flood velocities are stronger at depth than ebb velocities.

The nontidal current structure is a two-layer system with seaward flow in the surface layer and upstream flow at depth.

Ketchum, B. H. 1951. The exchange of fresh and salt water in a tidal estuary. J. Mar. Research, Vol. 10, pp. 18-38.

"An empirical theory is presented which describes the exchanges between various parts of an estuary as a result of tidal oscillation, and which permits the calculation of the average distribution of fresh and salt water within the estuary. The characteristics of the estuary used in the calculations are the mean range of tides, the river flow, and the topography, all readily available for most estuaries."

"The calculations are shown to produce results which are similar to distributions observed in three very different estuaries. The theory will permit calculations of the changes in distribution of salinity and fresh water in any given estuary to be expected as a result of variation of river flow."

Raritan River and Raritan Bay is one of the natural estuary systems used as an example. The total volume of the tidal prism is about 9,200 million cubic feet, which is almost 300 times greater than the volume introduced by the river during a tidal cycle.

Laevastu, T., M. Clancy, and A. Stroud. 1974. Computation of Tides, Currents, and Dispersal of Pollutants in Lower Bay and Approaches to New York with fine and medium grid size hydrodynamical-numerical models. Environmental Prediction Research Facility, Naval Post-graduate School, Monterey, Calif. Prepared for the Environmental Protection Agency, Pacific Northwest Environmental Research Laboratory, Corvallis, Oregon.

"The report summarizes the results of two different HN model applications with different grid sizes: one with a small grid size for the Lower Bay of New York; and the second with a larger grid size for the Approaches to New York, which includes part of the New York Bight outside the Ambrose Channel."

"(1) The numerical model reproduces well the currents as known from earlier empirical studies, but presents many more details and makes it possible to compute other current-dependent processes, such as transport and diffusion."

"(2) The flushing of the Lower Bay NE of the line between The Narrows and Sandy Hook is considerably more rapid than in the area SW of this line towards Raritan Bay."

"(3) There is a weaker outflow from the Lower Bay between the Ambrose Channel and Coney Island (off the Long Island coast), and the main outflow is between Ambrose Channel and Sandy Hook, and turns toward the south along the New Jersey coast."

Marmer, H. A. 1935. Tides and Currents in New York Harbor. Special Publication, No. 111, U.S. Department of Commerce, Coast and Geodetic Survey, 198 pp.

This is a compilation of data on direction, maximum velocity, and duration of ebb and flood currents at many stations in New York Harbor.

Surface current observations were made with a current pole; observations at various depths with current meters of unspecified type. In Lower Bay, the period of observation ranged from one to nine days. Although made without sophisticated instruments and over relatively short periods of time, Marmer's results are still fairly widely quoted because of his large number of stations.

O'Connor, Donald J. 1962. Organic Pollution of New York Harbor-Theoretical Considerations. Journal Water Pollution Control Federation, pp. 905-918.

This paper presents a theoretical development defining the relationship between biological oxygen demand and dissolved oxygen in the Upper Bay of New York Harbor. The combined contribution of organic wastes from the Hudson and East Rivers, Kill von Kull, Gowanus Creek and waste water treatment plants, produces an significant concentration of oxygen demanding wastes in the harbor waters and reduction of dissolved oxygen.

Pritchard, D. W., Akira Okubo, and Emanuel Mehr. 1962. A study of the movement and diffusion of an introduced contaminant in New York Harbor waters. Chesapeake Bay Institute Technical Report 31.

"This report presents the results to date of a study of the movement and diffusion of an introduced contaminant in New York Harbor waters, carried out under support from the Atomic Energy Commission. While the results of the study may with suitable modification have wide application to problems associated with the introduction of waste materials of various kinds into the Harbor waters, the purpose of this project has been the prediction of the spread of any radioactive material which might be introduced into these waters, with particular reference to nuclear-powered shipping."

"This report is divided into four sections. The first section presents a description of the processes of advection and diffusion which lead to the movement and spread of any introduced water-borne material in a tidal waterway such as the Hudson-East River complex, together with a discussion of various theoretical treatments of turbulent diffusion."

"The second section presents the results of a numerical solution, using an IBM 704 and later an IBM 7090, of the two-dimensional transient advection-diffusion. In this numerical computation an initial distribution of contaminant released in the vicinity of the Battery was assumed, and the subsequent distribution of contaminant in space and time was computed through 40 tidal cycles."

"The third section deals with direct observations of the movement and diffusion of a simulated contaminant in the hydraulic model of New York Harbor located at the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. In this report, emphasis is placed on the particular study in the hydraulic model which most nearly duplicates the treatment using the mathematical model discussed in section II."

"The fourth section of this report discusses the differences between the results obtained from the mathematical model and the hydraulic model. Theoretical considerations are presented which explain these differences and suggest the most probable correct results."

Stewart, H. B., Jr. 1958. Upstream bottom currents in New York Harbor. Science, Vol. 127, pp. 1113-1115.

"Analysis of data obtained during the 1952 current surveys in New York Harbor by the Coast and Geodetic Survey reveal the net upstream movement of large volumes of water near the bottom." Half hourly observations were made with a Roberts radio current meter, for at least 100 hours. Across the transect from Sandy Hook to Rockaway Point downstream movement was concentrated in the upper central portions of the stream; near bottom, the current flowed upstream."

U.S. Department of the Interior, Federal Water Pollution Control Administration, Northeast Region. 1967. Summary Report for the Conference on Pollution of Raritan Bay and Adjacent Interstate Waters, Third Session.

> "Raritan Bay receives 40,000 lbs/day of suspended solids and 185,000 lbs/day of BOD from municipal and industrial wastes. Shellfish from the bay have high bacteria counts and contain Salmonella organisms, and thus are a health hazard if eaten raw or undercooked. Shellfish meat tainted by phenols and mineral oils is common, and is unacceptable for market."
>
> This report lists sources of pollution, type of treatment and volume of waste discharged. It does not include field data on bacteria or heavy metal count in Shellfish.

Biology

Cambell, Robert. 1964. A report on the shellfish resources of Raritan Bay, New Jersey. *In* report for the conference on pollution of Raritan Bay and adjacent interstate waters, third session, vol. II-appendices. Federal Water Pollution Control Administration, 1967.

> This report summarizes in a series of maps and accompanying text the distribution and density of the Soft Shell Clam, *Mya arenaria*, and the Northern Quahang, *Mercenaria mercenaria* within Raritan Estuary from the confluence of the Raritan River and Arthur Kill to a line drawn from the tip of Sandy Hook to the west bank of The Narrows. A total of 745 stations were sampled during the period July 17-August 23, 1963.

Dean, David. 1975. Raritan Bay macrobenthos survey. 1957-1960. National Marine Fisheries Service Data Report 99.

> "This paper describes a quantitative census of benthic macrofauna from Raritan Bay and Lower Bay during the summers of 1957 to 1960, prior to and following the operation of a sewage outfall at the head of Raritan Bay. A total of 193 stations were sampled, yielding 127 taxa that were identified to genus or species." No conclusive change in number of species was observed after the opening of the sewage outfall.
>
> Species lists for each station are given, which is good baseline data against which subsequent benthic surveys can be compared.
>
> In addition, grab samples from each station were sieved to determine grain size distribution.

Jacobson, Fred L., and John T. Gharrett. 1964. Fish and Wildlife-Raritan Bay. *In* report for the conference on pollution of Raritan Bay and adjacent interstate waters, third session, vol. III-appendices. Federal Water Pollution Control Administration, 1967.

> "This report provides information on the fish and wildlife resources of the Raritan, Lower New York, and Sandy Hook Bays, located in Richmond County, New York and Monmouth and Middlesex Counties, New Jersey,...." Contained in this report are summations of data on past harvests, present harvests, economics, and potential for the following: commercial shellfishery, hard clams, soft clams, blue crabs, commercial finfishing, marine sport fishery, recreational shellfishery, and wildlife.

McGrath, Richard A. 1973. Benthic macrofaunal census of Raritan Bay--Preliminary Results, Benthos of Raritan Bay. *In* Proceedings, Third Symposium on Hudson River Ecology, paper no. 24, March 22-23, 1974. Bear Mountain, New York Hudson River Environmental Society.

> "A seasonal benthic census of the Raritan Bay estuary has been initiated during 1973. Preliminary results indicate greatly depressed macrofaunal densities in comparison with other areas... A multiplicity of water waste sources and a sluggish flushing pattern combine to make the Raritan Bay system a grossly polluted water body. Present knowledge is inadequate to assess the effects of known pollutants on the fauna of the bay."

This paper is the most recent source of quantitative data on benthic communities in Raritan Bay, Sandy Hook Bay, and Lower Bay. Commercially important species are not discussed however.

Steimle, Frank, and Richard B. Stone. 1973. Abundance and Distribution of Inshore Benthic Fauna off Southwestern Long Island, New York. NOAA Technical Report NMFS SSRF-673.

> "This paper describes a qualitative and quantitative census of the inshore benthic fauna off southwest Long Island over the period February 1966 through January 1967, prior to construction of an ocean sewer outfall in the general vicinity. Preliminary analyses of data indicate the presence of three distinct communities: 1) an inshore medium to coarse grain sand community dominated by the bivalve, *Tellina agilis*, the amphipod, *Protohaustorius deichmannae*, and the echinoderm, *Echinaracinius parma*: 2) an offshore silty fine sand community dominated by the bivalve, *Nucula proxima* and the polychaete, *Nephtys incisa*; and 3) a community dominated by the blue mussel, *Mytilus edulis*."

Commercially important species are not discussed.

Walford, Lionel A. 1971. Review of Aquatic Resources and Hydrographic Characteristics of Raritan, Lower, and Sandy Hook Bays. Report prepared for the Battelle Institute by the staff of Sandy Hook Sport Fisheries Marine Laboratory.

This paper includes as an appendix a "Report on Benthic Communities and Shellfish Populations in the Lower and Raritan Bay." Samples were taken with Smith-McIntyre bottom grab and shell dredge at 8 stations. Each station was sampled on only one occasion. No attempt was made to monitor seasonal or long term changes. The author considers that the standing crop and species diversity in this area are very impoverished relative to comparable estuarine environments and the coastal waters of the New York Bight. The total number of taxa found was only 31, while the most diverse sample, collected northeast of Swineburn Island contained 19 taxa. The sample with fewest live individuals (3) was collected immediately east of Chapel Hill North Channel; the author attributes the low biomass to dredging activities.

The only commercially important species discussed is the hard clam, *Mercenaria mercenaria*. The distribution of this species is uneven, ranging from one clam per 7 ft^2 to one clam per 150 ft^2.

Woodward-Clyde Consultants. 1975. Rockaway Beach Erosion Control Project, Dredge Material Research Program, Offshore Borrow Area, Results of Phase I-Predredging Studies. Prepared for the Department of the Army, New York District, Corps of Engineers.

This is the first report of a project to assess the environmental impact of removing sand from an off-shore borrow area between Ambrose Channel and Rockaway Point. "The overall objectives of these studies are to evaluate: (1) the effects of dredging on the benthic macroinvertebrates of the borrow area, (2) the effects of dredging on some water and sediment characteristics within and outside the borrow area,

(3) the nature and extent of repopulation within the borrow area by benthos, and (4) the rate of shoaling in the borrow area after dredging has been completed."

"Four tasks were completed during the predredging period between March and June, 1975: (1) survey of existing literature on the benthic fauna and water chemistry in the borrow area, (2) sampling and analysis of benthic fauna in the borrow and reference areas, (3) assessment of water quality, and (4) identification of characteristics of the borrow area sediments."

The water quality parameters measured were temperature, dissolved oxygen, chlorinity, pH, conductivity, and transparency; all fell within range of values reported by previous workers. No temperature or salinity stratification was noted, which is unusual. Shipek sediment samples contained 94% by weight fine to medium sand. Sediment was well sorted. A total of 51 species of benthic invertebrates were identified in samples from Shipek, trawl and clam dredges. Blue (*Spisula Solidissima*) dominated the live assemblage at all stations. Most individuals were very small.

Woodward-Clyde Consultants. 1975. Rockaway Beach Erosion Control Project, Dredge Material Research Program, Offshore Borrow Area, Results of Phase II-Dredging Studies. Prepared for the Department of the Army, New York District, Corps of Engineers.

This is a continuation of a study to indicate the environmental impact of removing sand from an offshore borrow area within Lower New York Harbor. Sampling was carried out in October 1975, after dredging had ceased.

Within the dredged area dissolved oxygen was low, temperature, conductivity, and pH were high, and chlorinity and transparency were low at the surface and high at depth relative to measurements outside the dredged area. The Shipek sediment samples from the dredged borrow area contained fewer species, lower biomass, and fewer individuals. Nephtyidae are more common within the dredged area than outside; amphipods are less common. Individuals from the dredged area were smaller than elsewhere.

This report contains the only data on benthic fauna in any dredged area of Lower Bay. It is particularly valuable because this data can be compared with predredging baseline data, reported in Phase I of the study.

Sediment Sources

Note: The extensive literature on prediction of wave energy incident on a beach, longshore current velocity, and littoral drift is not included here. The reader is referred instead to the excellent bibliography following Chapter 4 of the U.S. Army Coastal Engineering Research Center's Shore Protection Manual.

Caldwell, J. M. 1966. Coastal processes and beach erosion. Journal of the Boston Society of Civil Engineers, Vol. 53, No. 2, pp. 142-157.

This paper contains a general discussion of wave action on a beach, with examples drawn from the New Jersey coast. Caldwell describes a method of calculating the alongshore component of wave energy from observational data: wave period, wave height, wave length, direction and water depth. This is an empirical relationship based on laboratory tests and a few field observations. The littoral drift can then be estimated from the alongshore component of wave energy.

The paper presents no observational data on waves; predictions of wave energy incident on the New Jersey coast are based on a series of wave hindcasts made by the Beach Erosion Board from North Atlantic weather maps. Drift rate measurements for Sandy Hook and Cold Springs Harbor Inlet are based on repeated Corps of Engineer surveys over 100 years.

The theoretical and observational sections of this paper are not connected well. Caldwell does not compare the drift rate at Sandy Hook predicted from his empirical formula with that measured in surveys.

Charnell, Robert L. (editor). 1975. Assessment of offshore dumping in the New York Bight Technical Background: Physical Oceanography, Geological Oceanography, Chemical Oceanography. NOAA Technical Report ERL 332-MESA 3.

The geological section of this report..."summarizes relevant data acquired by the geological oceanography program of the MESA New York Bight Project. The program has been concerned with (1) the physical nature of the substrate of the Bight apex; its topography, surficial sediment distribution, and distribution of sediment with depth, and (2) the dynamic system of sediment erosion transport, and deposition within the Bight apex." This report includes much new information on sedimentation at the apex of the New York Bight between Sandy Hook and Rockaway Beach.

Colony, R. J. 1932. Source of the sands on the south shore of Long Island and the coast of New Jersey. Journal of Sedimentary Petrology, Vol. 2, No. 3, pp. 150-159.

This paper reports on a study to ascertain the source of sands forming Long Island and New Jersey beaches. Sixty-nine samples were collected between high and low water lines, and mineralogy of pebbles and sand determined. Kyanite, green mica, blue spinel, lilac-blue tourmaline, and magnetite were found only in Long Island sands, and glauconite, cordierite, chloritoid, muscovite, and green-brown and mahogany-colored tourmaline only in New Jersey sands. Thus Colony concludes that no transport takes place between the two shores.

Colony's list of mineral occurrences is basic to any study of sediment whose source is thought to be littoral material from the south shore of Long Island or the north shore of New Jersey.

Fairchild, John C. 1966. Correlation of littoral transport with wave energy along shores of New York and New Jersey. U.S. Army Coastal Engineering Research Center, Technical Memo. No. 18.

"The purpose of this report is to show the results of a study which correlates certain field measurements of net littoral transport with the average net alongshore component of wave energy...by applying wave refraction analysis aided by interpolation techniques to waves hindcast from synoptic weather charts. The littoral transport rates were obtained from beach erosion control and other applicable reports of the study area...the correlation should be reliable within the limits of the data scatter."

This paper is based on littoral transport rates from five stations, and all of those rates are estimates. The data scatter is rather large; for a given alongshore energy, the littoral transport rate varies by a factor of three. Fairchild's results do not agree with those of Caldwell (1961).

Fray, Charles T. 1969. Final Report, Raritan Estuary Sedimentation Study. Prepared for Federal Water Pollution Control Administration, Department of the Interior, by Alpine Geophysical Associates, Inc., Oak Street, Norwood, New Jersey.

Although no new data was included, here is summarized in one place general geology, historic changes in bathymetry and shoreline, littoral forces, core data, surficial sediment data, and sources and magnitude of sediment in-flow. A second section discusses the effects of sedimentation on users of Raritan Bay, and reviews attempts to control sedimentation.

Nagle, J. Stewart. 1967. Geology of Raritan Bay. In report for the Conference on pollution of Raritan Bay and adjacent interstate waters, third session, vol. III-appendices. Federal Water Pollution Control Administration, 1967.

"The study included a review of available chloride data, as well as sampling and analyses of the bay sediment. Sediment samples were subjected to size analyses and determinations of water, organic matter and carbonate content. The distribution of these readily identifiable sediment particles, the mineral muscovite, the shell of the small clam *Mulinia lateralis*, and detrital coal, was studied to determine net movement of such particles in the bay.

Major conclusions from this investigation include the following:

1) The shoreline of the Raritan estuary has reached early maturity in the geomorphic cycle of shoreline development.

2) Movement of high chlorinity water is centered in the northerly portion of the bay, while fresher water moves through the southern portion.

3) The bay floor is made up of four major sediment bodies, referred to as the Lower Bay and Keansburg Sands, and the Sandy Hook Bay and West Raritan Bay muds.

4) The high organic carbon content found in West Raritan Bay is due to small particles of organic matter, probably the result of organic matter introduced through pollution.

5) Sediment particles originating at various locations in the bay are moved progressively toward the area bounded by Sequine Point, Great Kills, Keyport and Keansburg."

Panuzio, F. L. 1968. The Atlantic coast of Long Island. *In* Proceedings of the 11th Conference on Coastal Engineering, (ed. J.W. Johnson) Richmond, Calif., Council on Wave Research, Vol. 1, pp. 1222-1241.

"The south shore of Long Island, located on the northeast coast of the United States, consists of 120 miles of headlands and barrier beach which is breached by inlets that interconnect the coastal bays with the Atlantic Ocean. The shore is subject to severe changes due to constant attack of the ocean, rising level of the ocean and severe storms. The predominant, east to west littoral drift moves from 300,000 to 600,000 cubic yards of sand along the shore annually. The affected area encompasses a million people and is valued at $2.5 billions. Improvements have been authorized for 110 miles of shore, and involve sand-fill, feeder beaches, groins, jetties, sand bypassing, and inlet barriers. The estimated cost for the entire shore improvement is $188 million. The annual charges are about $10 million. The annual benefits are $16 million. The implementation of the authorized work includes the design and model testing of several sections and the completed work in several sections, such as sandfill, feeder beaches, and groins. The completed work shows considerable effect on shore processes. Overall evaluation must await completion of the total improvement in an integral section of the shore."

Taney, Norman E. 1961. Geomorphology of the south shore of Long Island, New York. Beach Erosion Board, Corps of Engineers, Technical Memo. No. 128.

"The purpose of this report is to depict the geologic and geomorphic factors...which have influenced the present form of [the south shore of Long Island]." The south shore of Long Island is divided into two sections: an eastern eroding headlands section, and a western barrier beach section. The barrier beach is at present broken by six inlets. Examination of historic maps and charts and surveys along 525 ranges show that the shore has changed continually over the last 150 years. Inlets have opened and closed. Spits have grown, and inlets have migrated westward. The net littoral drift is westward, and is estimated at 300,000 cubic yards per year at Moriches Inlet, 450,000 cubic yards per year at Fire Island Inlet, and 450,000 cubic yards per year at Rockaway Inlet. Many protective structures (listed in the paper) have been built to alter or stop the shifting sands.

This paper is an excellent source of information on littoral drift along Long Island. Unfortunately the charts showing shoreline changes are reproduced so small as to be almost indecipherable.

U.S. Army Coastal Engineering Research Center. 1973. Shore Protection Manual, 3 volumes, Available from Superintendent of Documents, U.S. Govt. Printing Office, Washington, D.C., 20402, $14.75.

This 3 volume set contains a wealth of information on the state of the art of dealing with the coastal zone.

"Volume I describes the physical environment in the coastal zone starting with an introduction to coastal engineering, continuing with discussions of mechanics of wave motion, wave and water level predictions, and finally littoral processess. Volume II translates the interaction of the physical environment and coastal structures into design parameters for use in the solution of coastal engineering problems. It discusses planning, analysis, structural features, and structural design as related to physical factors, and shows an example of a coastal engineering problem which utilizes the technical content of material presented in all 3 volumes."

Volume III contains four appendices including a glossary of coastal engineering terms, a list of symbols, tables and plates, and a subject index." An extensive bibliography follows each chapter.

The emphasis is practical rather than theoretical. Formulae are generally presented without background or derivation. Many empirical methods are outlined in step-by-step form, such as a technique to predict wave diffraction from an elaborate set of template overlays.

Of particular interest to this study are the discussion and comparison of various models for estimating longshore current velocity, and littoral drift.

U.S. Army Engineer District, New York Corps of Engineers. 1964. Cooperative Beach Erosion Control and Interim Hurricane Study (Survey). Staten Island, New York, Fort Wadsworth to Arthur Kill.

This is a detailed study of the shoreline of Staten Island to determine the best means of preventing further erosion of the shore. The sections on the history of the shoreline, sediment analysis, and nearshore profile are pertinent to any investigation of Lower New York Harbor.

U.S. Army Engineer District, New York Corps of Engineers. 1962. Cooperative Beach Erosion Control and Interim Hurricane Study (Survey) of Raritan Bay and Sandy Hook Bay, New Jersey.

This study presents data on the littoral material, including grain-size characteristics, and vertical profiles of the beaches and nearshore bottom as determined from surveys conducted by the Corps of Engineers. The direction of transport and the volume of littoral drift are analyzed.

U.S. Army Engineer District, New York, Corps of Engineers. 1953. Cooperative Beach Erosion Study. Atlantic Coast of New Jersey-Sandy Hook to Barnegat Inlet.

This study contains considerable data on the grain size characteristics of the littoral material moving northward along Sandy Hook, as well as the volume of littoral drift.

Yasso, Warren E. 1965. Flourescent tracer particle determination of the size-velocity relation for foreshore sediment transport, Sandy Hook, New Jersey. Journal Sed. Petrology, Vol. 35, No. 4, pp. 989-993.

"Each of four size classes of foreshore sand from Sandy Hook, was color coded with daylight and ultraviolet flourescent coating material. These tracer particles were introduced at mid-swash line on the foreshore surface at Kingmill Beach, two hours prior to high tide. ...samples were obtained by channel sampling on the foreshore along a sampling line, transverse to the foreshore, that was established 30.5 meters downdrift from the point of introduction of tracerparticles. ...particles in the smallest size class ($0.701 > d > 0.589$ mm) [had] equivalent to 2.8 cm/sec average maximum transport velocity. A maximum number of marked particles in both size classes was found in a sample taken 42.3 minutes after introduction. ...for these two size classes both first arrival and converted peak arrival data indicate an inverse size-velocity relationship prevails in beach drift transport."

This paper represents early work in dye tracer studies, and as the author points out, closer time spacing of samples, greater length of sampling time, and a collection technique which allowed sampling of the entire backwash-to-swash distance, would have been desirable.

Yasso, Warren E., and Elliott M. Hartman, Jr. 1975. Beach forms and coastal processes MESA New York Bight Atlas, Monograph 11.

"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 152,000 m^3/yr (200,000 yd^3/yr) at Cape Inlet."

Yasso's explanation of the mechanism of longshore transport is an excellent introduction for the non-scientist. This paper also includes the best available discussion of the growth of Sandy Hook.

Sediment Characteristics

Duke, C. M. 1961. Shoaling of the Lower Hudson River. Waterways and Harbors Division Journal, Am. Soc. of Civil Engineers Proceedings, Vol. 87, No. WW1, pp. 29-45.

This paper is concerned with shoaling in the Hudson estuary between the Battery and the George Washington Bridge. Seventy-six percent of the sediment in these shoals is derived from the watershed area--the remainder from eroding stream banks, wastes and sewage, and the ocean. The bulk of the sediment is silt and clay. Flocullation is alleged to play a major role in deposition in the area where fresh water contacts salty water; sand content of shoaling materials is only about 7% to 16% by mass. On the basis of the hydraulic model of New York Harbor developed by the

Waterways Experiment Station at Vicksburg, Mississippi, the author suggests measures to lessen shoaling including sedimentation basins, the enlargement of the river channel near the George Washington Bridge, and the provision of a wing dike to constrict the channel south of the George Washington Bridge. Although these suggestions involve removal of sediment, it seems that no commercially useful sand or gravel would be produced.

Emery, K. O. 1966. Atlantic Continental Shelf and Slope of the United States. U.S. Geological Survey Professional Paper 529-A.

"This report is the first of a series that describes the geological, biological, and hydrological characteristics and the geological history of the continental shelf, slope, and rise off the Atlantic coast of the United States."

"Topographic charts constructed during the program reveal deep irregular topography in the Gulf of Maine and off Nova Scotia produced by glacial erosion and deposition. On the continental shelf most irregularities, such as terraces and sand waves, are formed by marine processes. In deeper water submarine canyons, aprons superimposed upon the continental rise, and broad flat abyssal plains are caused or influenced by turbidity currents. Structural deformation is shown on the topographic charts by prominant bends of the continental slope.

A suite of well distributed large bottom samples discloses a broad belt of coarse-grained relict sediment deposited during the transgression of the ocean across the shelf during post-glacial time. These sediments were contributed to the ocean by streams that carried glacial melt water in the north, or drained areas of weathered rock in the central and southern parts of the region. Modern coarse-grained detrital sediments are restricted to the nearshore zone.

"Dredge and other samples from the ocean bottom show that the unconsolidated Pleistocene and Recent sediments overlie strata of Pliocene and Miocene age on most of the continental shelf. In areas of deeper water are discontinuous outcrops of rocks that are as old as middle Cretaceous on the continental slope and as old as Paleozoic in the Gulf of Maine."

"Continuous seismic profiles reveal that the Pleistocene and Recent sediments are 10-60 meters thick throughout most of the shelf and that they uncomformably overlie the older strata. Several reflecting horizons within the sediments indicate interruptions in deposition, possibly during times of glacially lowered sea level. The profiles also show local downwarping of Pliocene and Miocene strata at the top of the continental slope, a possible result of downwarping. Earlier and greater tectonic activity is indicated by structural trenches in the vicinity of the continental slope, those at the north being filled to overflowing with Createaceous and later sedimentary strata and at the south being completely filled."

Folk, Robert L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Co., Austin, Texas.

A manual that describes in detail the analyses and interpretation of sediments.

Fray, C. T. 1954. Physical Characteristics, Composition, and Source of Littoral Material Along the New Jersey Coast. Manuscript on file Coastal Engineering Research Center, Fort Belvoir, Virginia, 150 pp.

This publication contains a summary of the characteristics of the littoral material along the Atlantic Ocean shore of New Jersey as determined from all samples taken up to the time of publication.

Fray, C. T., and John Ewing. 1961. Project 555-Monmouth County Offshore Borings. State of New Jersey Department of Conservation and Development, Report no. 1.

This report provides sub-surface data on sediment size characteristics and geologic structure along a line between Shrewsburg Rocks and Asbury Park along a line paralleling the shoreline approximately one mile offshore. Twenty cores, generally one meter or less in length, were obtained and the size characteristics of the sediment determined. Two seismic reflection profiles were run, one just shoreward of the line of cores and the other immediately to seaward. Coastal plain formations represented in the cores were identified on the basis of the physical characteristics of the sediment and fossil content where diagnostic.

Gross, M. Grant. 1974. Sediment and Waste Deposition in New York Harbor. *In* Hudson River Colloquium (ed. O.A. Roels); Annals N.Y. Academy of Sciences, Vol. 250.

"In this paper the physical alterations (by man) of the Hudson River estuary are discussed. Particular attention is paid to the sediments and waste deposits that covered much of the harbor bottom and large areas of the New York Bight."

The paper includes sections on maintenance dredging, sand and gravel mining, plus quantitative data on flux of sediment into N.Y. outer harbor.

Gross, M. Grant. 1970. Analyses of Dredged Wastes, Fly Ash, and Waste Chemicals. New York Metropolitan Region, Marine Sciences Research Center, State University of New York at Stony Brook, Technical Report no. 7.

"Chemical and physical properties were determined on wastes commonly transported by barge for disposal in coastal waters offshore from New York Harbor. Dredged wastes were studied by analysis of harbor sediment and wastes in the designated 'Mud Disposal Area.'"

Harbor samples were removed from ships and channels along the lower Hudson River and East River. This sediment is primarily silt, rather than sand and gravel.

Concentrations of major elements most closely resemble shale, although Ca and Mg are somewhat less abundant in harbor sediment than in shale, while Na and K are substantially more abundant.

Carbon concentration is higher than that of unpolluted sediments on the adjacent continental shelf, probably from sewage solids.

McKinney, Thomas F., and Gerald M. Friedman. 1970. Continental Shelf Sediments of Long Island, New York. Journal of Sedimentary Petrology, Vol. 40, No. 1, pp. 213-248.

Sampling for this study was conducted along NW-SE transects from the Long Island shore in the region of Fire Island to the 100 fathom contour.

"The detailed nature of relict sediments resulting from and related to the Holocene transgression has been revealed through a sedimentological study of a densely sampled segment of the Long Island, New York, continental shelf. Bathymetry of the Long Island shelf reflects the relict patterns of subaerial coastal-plain fluvial drainage systems from lower stands of sea level."

"The shelf sediments can be divided into an inner (0 to 25 fathoms) and middle (25 to 35 fathoms) shelf clean sand facies and an outer (> 35 fathoms) shelf muddy sand facies. Locally on the middle shelf, the outer muddy sand facies is preserved as erosional remnants and also within the interiors of shells that are buried in the clean sand. This evidence supports the view that the outer muddy sediments is relict (Garrison and McMaster, 1966); the sharp "mud line" at about 35 fathoms results not from modern deposition but from the winnowing of the formerly more extensive muddy sediment."

"The grain size distribution were plotted on log-phi scale and distinct populations were separated. In the distributions of the inner and middle shelf sands, three populations (A, B, and C) were recognized which (it is supposed) resulted from saltation (A), interstitial entrapment and/or suspension (B), and sliding and rolling (C).

The absence of the B population indicates deposition in the surf zone where intense winnowing occurs. The presence of the C population also suggests deposition in the surf zone. Deposition from currents is indicated by the presence of the B population.

Very few of the shelf sands have the size characteristics of beach swash zone deposits. Most are, however, relict of shallow nearshore environments. Most of the inner shelf sands appear to have been modified by currents, whereas many of the middle shelf sands are relict of deposition in the surf zone.

The outer shelf sands are bimodal and by graphical dissection of the size distribution, a distinct fine sand mode can be traced as a separate sedimentation unit. When the sea was about 35 fathoms, the fine sand was swept by currents (B population is present) from shoal areas to the northeast of the study area into an embayment area. This relict fine sand deposit spread to the southwest and mixed with the coarser basal sands of the transgression.

Short cores on the inner shelf indicate that fine winnowed sand on the inner shelf probably represents the reworking of a backbarrier facies by the transgressive sea.

The inner shelf sands are mineralogically more mature (orthoquartzose) but more angular (mean roundness (rho) for medium quartz grains) than the middle and outer shelf sands (subarkosic)."

McMaster, Robert L. 1954. Petrography and Genesis of the New Jersey Beach Sands. State of New Jersey Department of Conservation and Economic Development Bulletin 63, Geologic Series.

This is a painstaking study of the grain-size distribution and mineralogy of numerous sediment samples from New Jersey Beaches and nearshore bottom. McMaster's list of mineral occurrences is basic to any determinations of provenance of New York Harbor sands. Minerals found along beaches of Northern New Jersey include: actinolite, augite, andalusite, chloritoid, collophane, diopside, epidote, various feldspars, garnet, glauconite, hornblende, hypersthene, leucoxene, monazite, quartz, rutile, sillimanite, staurolite, sphene, tourmaline, zircon.

New York State Department of Transportation. 1973. Standard Specifications: Construction and Materials.

This reference manual contains the gradation requirements for mortar sand, grout sand, concrete sand, and fill, which were used in this study to evaluate various uses for Lower Bay sands.

New York State Department of Public Works. 1974. Analysis of Ambrose Channel Sands. Unpublished report submitted to James Marotta, New York State Office of General Services.

Two samples dredged from the west bank of Ambrose Channel and collected on N.J. Route 95, were analyzed for grain size distribution and mineralogy. The sand composition was 94% quartz, 4% mica and chlorite, 1% shell, and 1% other, which is acceptable for most uses. The Ambrose Channel Sands met gradation requirements for grout sand, filter sand for sewage, and moulding sand for foundry castings.

Schlee, J., and R. M. Pratt. 1970. Atlantic Continental Shelf and Slope of the U.S.-Gravels of the Northeastern part. USGS Prof. Paper 529 H.

"Gravel is concentrated mainly on the glaciated part of the continental margin--the Gulf of Maine, Scotian Shelf, and northern part of Georges Bank."

"Scattered occurrences of gravel are found on the continental slope as far south as Hudson Canyon. The gravel fraction on the slope is a minor part of the sediment (most is silt and clay) and shows a wide range in size and roundness. On the non-glaciated shelf south of New England and Long Island gravel is distributed sporadically: largest concentrations are associated with the drowned Hudson Channel east of New Jersey. The gravel is moderately sorted quartzose, and commonly in a bimodal grain-size distribution with sand."

"Most of the shelf off New England, Long Island, and New Jersey is mantled by sand and less amounts of gravel in amounts probably sufficient to constitute an economic asset. A drowned river-terrace on the shelf southeast of New York City and isolated glacial gravelly sands offshore from Boston are promising deposits meriting further detailed study. Other deposits are off Rhode Island, Cape Cod, and Long Island. A few shallow drill holes on the shelf indicate that sand is as much as several meters thick. Shallow continuous seismic profiles show that uppermost layers on the inner shelf are fairly continuous over much of the shelf, though layers are variable in thickness."

Schlee, John and Peter Sanko. 1975. Sand and Gravel. MESA New York Bight Atlas, Monography 21.

"The purpose of this paper is to point out the areal distribution of sand and gravel in New York Bight, to indicate where data are lacking and to discuss some potential problems in exploitation."

The boundaries of Schlee's study are Delaware Bay, Block Island Sound, the 200 m isobath, and a line from Sandy Hook to Rockaway Point.

The section by Peter Sanko on "Sand Mining in New York Harbor" is a good historical summary of dredging in the Lower Bay. Production statistics for 1950-1974 are included, as well as indication of use to which sand was put.

Sieck, H. 1965. Lower New York Bay Geophysical Investigation report. Prepared for Transcontinental Gas Pipe Line Corporation, Houston, Texas, by EG&G Inc.

This report describes a detailed geophysical investigation of 33 miles of a proposed pipe line route from Morgan, New Jersey through Raritan and Lower Bays, along the south shore of Long Island, to the Long Beach, New York. The acoustic sound source was an EG&G High Resolution Boomer Tranducer. "The primary objectives of the investigation were: (1) to determine the presence or absence of consolidated sediments, bedrock, or gravel in the upper 20 feet of the sub-bottom in the survey area, (2) to obtain bathymetric data for the area, and (3) to determine if soil borings would be used to effectively correlate the sub-bottom profile."

In the triangle bounded by Ambrose Channel, Sandy Hook Channel and Chapel Hill Channel, this investigator found mostly sandy bottom, with several sub-bottom reflectors which he interprets as gravel layers. We feel that more and deeper boreholes are needed before these reflections can be unambiguously attributed to gravel.

Taney, N. E. 1961. Littoral Materials of the South Shore of Long Island, New York. Technical Memo. No. 129, Beach Erosion Board, U.S. Army Corps of Engineers.

This report provides much information on the characteristics of the littoral material moving west along the South Shore of Long Island. This material may be the main sediment source supplying East Bank.

Trumbull, James A. 1972. Atlantic Continental Shelf and Slope of U.S.-Sand Sized Fraction of Bottom Sediments, New Jersey to Nova Scotia. U.S. Geological Survey Professional Paper 529-K.

"Examination of the sand-size fraction of surface sediments divide the continental shelf off the Northeastern United States into three distinctive areas. These are the glaciated Gulf of Maine and Nova Scotia shelf, the shallow high-energy Georges Bank-Nantucket Shoals area, and the more normal continental shelf south to New England and Long Island and east of New Jersey."

"Sand covers most of the continental shelf south of New England and Long Island and east of northern New Jersey. Most of the sand is well sorted and moderately well rounded. The sand was deposited primarily as glacial and fluvial outwash during glacial-stage lowering of sea level and was slightly reworked during the following transgression. It is therefore relict in origin. Silt on the middle and outer shelf south of Martha's Vineyard apparently postdates the transgression. River-derived gravel blankets a large area on the inner half of the shelf off the sandy beaches of New Jersey and Long Island. Narragansett Bay, Long Island Sound, and other protected inshore areas are floored primarily with Holocene micaceous silts sediment."

"Over all the continental shelf the primary components of the sand-size fraction are quartz and feldspar. Locally, very high concentrations of glauconite are found in the bight between New Jersey and Long Island and south of Long Island."

This paper is excellent background material, placing N.Y. Harbor sediments in larger temporal and spatial framework.

Uchupi, Elazor. 1963. Sediments on the Continental Margin off Eastern United States, USGS Prof. Paper 475-C, Art. 94, pp. C132-C137.

"Relicit glacial sediments blanket most of the continental shelf north of Hudson Canyon, and relict fluvial or nearshore quartzose sands occur throughout most of the shelf from Hudson Canyon to Cape Hatteras. Calcareous organic and authigenic sediments are the dominant sediment types on the continental margin farther south. Present-day detrital sediments are restricted to a narrow zone near shore, to the outer edge of the shelf off Long Island, and to the continental slope north of Cape Hatteras. The predominance of relict and calcareous sediments indicates that present rate of deposition of detritus derived from land is very low over most of the continental shelf. The report and accompanying sediment map were compiled from published and unpublished reports."

This is the preliminary study for the survey reported in Trumbell, James A., USGS Prof. Paper 529-K and contains no further information.

Williams, S. Jeffress, and Michael E. Field. 1971. Sediments and shallow structures of the inner continental shelf off Sandy Hook, New Jersey. Geological Society of America, Abstracts, Vol. 3, No. 1, 62 p.

"As a part of the Inner Continental Shelf Program (ICONS) being conducted by CERC 225 miles of high resolution seismic profiles were run over a 100 square mile area off Sandy Hook. Ten cores averaging 10 feet in length were also obtained. Profiles indicate that the region is underlain by regular regionally southeastward dipping strata (Cretaceous or Tertiary? Age). East of the spit an area of extremely complex cross stratifed (Pleistocene? Age) sand and gravel measuring 6 miles in a north-south direction by 2 1/2 miles east-west. Mean sediment thickness is 45 feet. The cross-bedded sequence lies disconformably on the flat lying substrate and grade laterally into flat bedded strata. Large scale ridge and trough depositional structures are present along with intricate cross bedding. Flat layers of sand 20 feet thick (Holocene Age) locally overlie the cross-bedded facies."

"Our data analysis indicates that this area has been a complex, atypical environment of deposition with different directions and modes of sediment transport and several source areas. Marked differences exist in mineral distribution and particle characteristics, indicating an admixture in varying proportions of New Jersey coastal plain sediments and moraine derivatives. These suggest that prior to Holocene transgression the region was mantled with glacio fluvial deposits. Only with sea level rise further reworking took place with significant additions of New Jersey Coastal Plain sands transported by northerly longshore drift become a dominant process."

Williams, S. Jeffress. 1973. The Geologic Framework of the New York Bight-its influence on positioning offshore engineering structures. Geological Society of America, Abstracts, Vol. 5, No. 2, 239 p.

"Results of an ICONS program reveal this region straddles two distinct physiographic provinces which are underlain by gently SE dipping Coastal Plain strata which have been differentially eroded and covered with variable thicknesses of Pleistocene-Holocene stratified sand and gravel. Shrewsbury Rocks extend offshore from Long Branch, N.J. in a NE direction and form a sea floor cuesta marking the physiographic boundary between the deeply eroded and subsequently filled sub-bottom to the north and the nearly outcropping truncated edges of Coastal Plain strata to the south. The buried submarine Hudson Channel has been traced on geophysical records from The Narrows to its shelf head (a natural deep channel) south of Sandy Hook, N.J. Other buried channels which drained the terminal moraine to the north are evident south of Rockaway Beach. Holocene transgression has served to rework existing sea floor sediments to yield the present distribution and to supply littoral currents with material for the northward growth of Sandy Hook Spit and westward growth of Rockaway Beach."

Williams, S. Jeffress and David B. Duane. 1974. Geomorphology and sediments of the Inner N.Y. Bight Continental Shelf. U.S. Army Corps of Engineers, Tech. Memo No. 45.

"Approximately 445 miles of continuous seismic reflection profiles and 61 vibrating cores were obtained from the Inner New York Bight which encompasses about 250 square miles of the offshore from northern New Jersey and western Long Island. The major physiographic features include Sandy Hook and Rockaway Beach, both prograding barrier islands, Shrewsbury Rocks and the Hudson (submarine) Channel. Shrewsbury Rocks mark the demarcation between two distinct geomorphic provinces. The area north of Shrewsbury Rocks is underlain by Coastal Plain strata which have been deeply eroded by Pleistocene glacial processes and covered by sand and gravel outwash. South of Shrewsbury Rocks, Coastal Plain strata have been evenly truncated and covered by a veneer of residual material. Three primary types of bedding have been observed on the seismic records. Coastal Plain strata exhibit a monoclinal regional southeast dip; steeply inclined crossbeds are restricted to an elongate basin east of Sandy Hook, considered to be of fluvial origins. The third type is Pleistocene-Holocene stratified fluvial sands and gravels which are regionally discontinuous and exhibit gentle seaward dip. Cores reveal that fine to medium sand is the predominant sediment type on the inner shelf. Isolated patches of coarse sand rounded sea gravels are present off Long Island where fluviant materials are exposed. Course sediment off New Jersey is judged to be residual from sea floor outcrops of Coastal Plain strata. Very fine sand, silt and muds comprise the sea floor at the head of the Hudson Channel and along the body."

"Sand suitable for beach nourishment projects is found in abundance throughout the shallow shelf parts of the Inner New York Bight. Sea floor topography is fairly flat and sand occurs as blanket deposits. It is estimated that over 2 billion cubic yards of clean sand is available for retrieval by present dredging techniques."

Williams, S. Jeffress. 1976. Geomorphology, shallow sub-bottom structure, and sediments of the Atlantic Inner Continental Shelf Off Long Island. Coastal Engineering Research Center Technical paper No. 76-2.

"About 800 square miles of the Atlantic Inner Continental Shelf off Long Island, New York, were studied by CERC to obtain information on the sea floor morphology, sediment distribution, and shallow sub-bottom stratigraphy and structure. This information is used for delineating sand and gravel resources and deciphering shelf geologic history. Basic survey data by CERC consist of 735 miles of high-resolution continuous seismic profiles and 70 vibratory cores; additional data were available from 82 sediment cores and 225 miles of seismic records. Data coverage extends from Atlantic Beach east to Montauk and in Gardiners Bay; and from the shoreface seaward about 10 miles to water depths of 105 feet."

"Three primary acoustic horizons are evident on the seismic profiles and have been identified by correlation with cores, land borings, and surface exposures of the reflectors. Granitic bedrock is the oldest and deepest horizon underlying Long Island, but its recognition on the seismic records, due to limited sub-bottom penetration, is confined to northern Gardiners Bay. The bedrock surface slopes southeast and exhibits considerable relief where glacial ice has enlarged pre-Pleistocene drainage channels. Upper Cretaceous and Tertiary semiconsolidated clastic sediments overlie the bedrock and dip and thicken to the southeast. The surfaces of these strata, which are present throughout the study area and project north under Long Island, and the second major horizon."

"The third seismic horizon is Pleistocene erosion surface cut by fluvial and glacial agents into the older rock units. Depth of this surface varies from -50 to -300 feet MSL off the western and eastern Long Island shelf to sea floor outcropping in parts of the central Long Island inner shelf. Pleistocene detritus consists primarily of blanketlike deposits of outwash sand and gravel; however, radiocarbon dates show that Holocene-age barrier-lagoonal sequences and estuarine sediments cover parts of the Long Island shelf."

"Much of the surficial sand on the inner shelf is suitable as fill for beach restoration, except for that of the shoreface region (0 to -30 feet MSL) which contains fine sand and that of major parts of Gardiners Bay which contain organic-rich silt and clay. Topographic highs on the sea floor in the form of linear shoals, and broad deltalike platforms in eastern Long Island appear most suitable for sand recovery. The sea floor in most potential borrow areas is flat and sand occurs as blanket deposits. Potential sand reserves within about 12 feet of the sea floor in the region are estimated to be more than 8 billion cubic yards."

BIBLIOGRAPHIES

Ali, S. A., C. D. Hardy, E. R. Baylor, and M. G. Gross. 1973. A Keyword Indexed Bibliography of the marine environment in the New York Bight and Adjacent Estuaries. Marine Sciences Research Center, SUNY at Stony Brook, N.Y.

Bohlen, Walter F., and J. Devine. 1973. Bibliography on the disposal of dredged spoils in coastal waters. Prepared for the U.S. Army Corps of Engineers, Marine Science Institute, University of Conn., 73 pp.

Herbich, John B., R. H. Snider, and I. Rosella Cooper. 1970. Bibliography on dredging (2nd edition). Center for Dredging Studies, Texas A&M University, Report No. 112-A-CDS, 88 p.

Marine Ecosystems Analysis Program. 1974. Bibliography of the New York Bight, Part I-Citations; Part II-Indexes. U.S. Dept. of Commerce, Rockville, Md., 184 pp. and 493 pp.

Morton, James W. 1973. A selected bibliography on dredging and the disposal of dredge spoils. Cornell University, Ithaca, N.Y. (unpublished).

National Marine Fisheries Service Sandy Hook Laboratory. 1972. The effects of waste disposal in the New York Bight. Final Report, Sect. 9: Bibliography, Highlands, N.J., 43 pp.

National Technical Information Service. 1975. Environmental and Ecological Effects of Dredging. A Bibliography with Abstracts. U.S. Dept of Commerce, Springfield, Virginia, 22161.

Pearce, Jack B., Elsie Waldhauer, and Mabel Trafford. 1971. Bibliography to Studies in the New York Bight: Including References to Effects of Sewage Sludge. U.S. Dept of Commerce, NOAA, National Marine Fisheries Service, Sandy Hook Laboratory, Highlands, New Jersey. (unpublished).

Sherk, J. Albert Jr., and L. Eugene Cronin. 1970. The effects of suspended and deposited sediment on estuarine organisms: An annotated bibliography of selected references. N.R.I. Ref. No. 70-19, Natural Resources Inst. of the University of Maryland, Chesapeake Biological Laboratory, Solomons, Md.

Slotta, Larry. 1973. Compilation of studies in dredging, dredge spoil usage and disposal. Office of Extension Oceanographer, Oregon State University, Corvallis, Oregon. (unpublished).

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