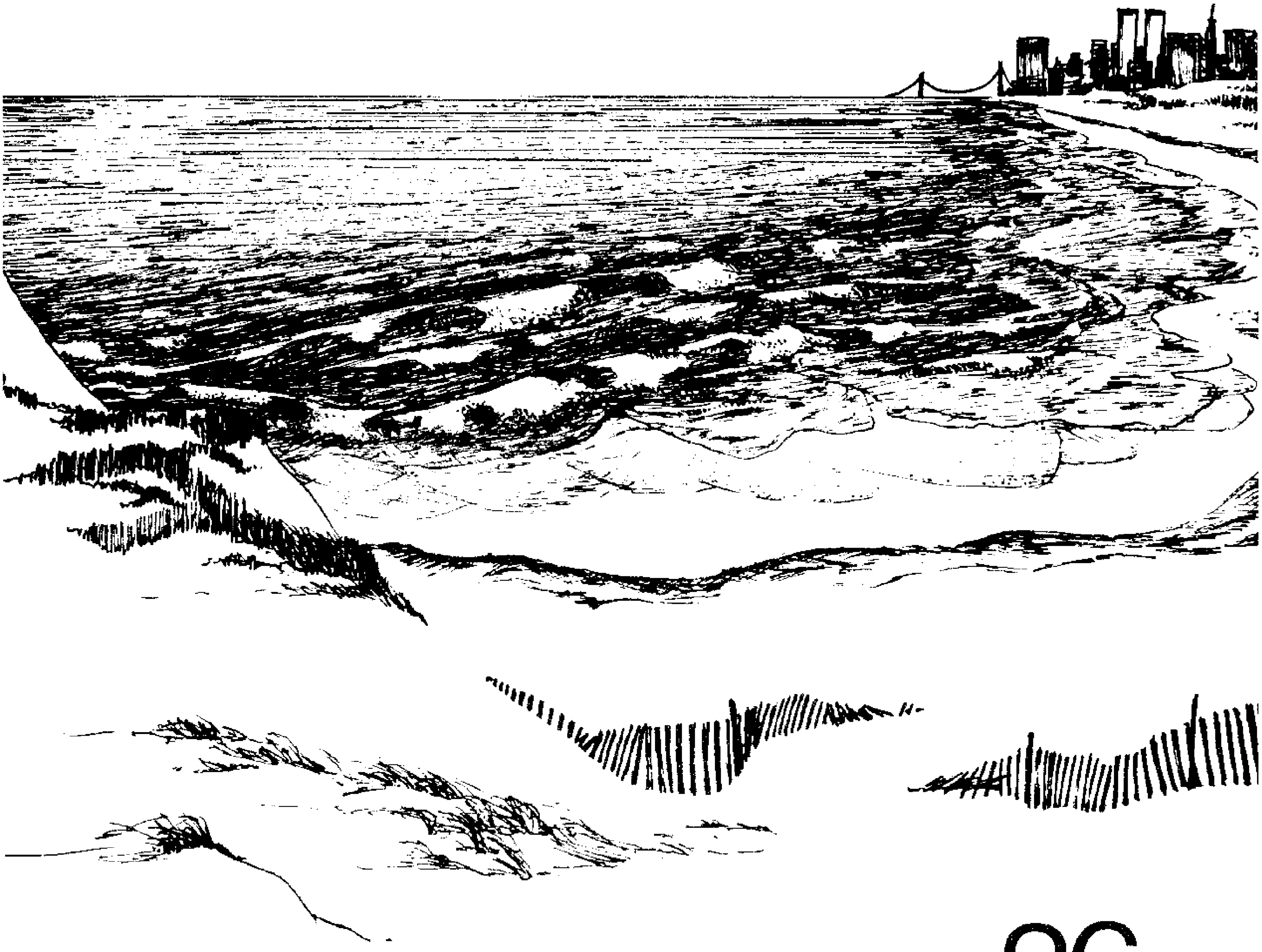
Waste Disposal

M. Grant Gross



MESA NEW YORK BIGHT ATLAS MONOGRAPH 26

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

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

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

MONOGRAPH 26 discusses wastes dumped in the major disposal sites in New York Bight. Much more waste solid, says Gross, comes from dredge spoil and rubble than from industrial sludges and sewage sludge; the entire sediment load from littoral drift and river discharge mixes with wastes and must be handled as dredge spoil. Accumulations of waste deposits not only create hills on the ocean bottom but also affect bottom-dwelling marine life, pointing to finrot in flounder and shell erosion in lobster and crab. So little is known about the effects of ocean-dumped materials, even from recent studies, that the situation demands continued extensive research. Meanwhile, dumping in the Bight goes on because it is cheaper and there is more room than on land.

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MESA NEW YORK BIGHT ATLAS MONOGRAPH **26**

New York Sea Grant Institute
Albany, New York
July 1976

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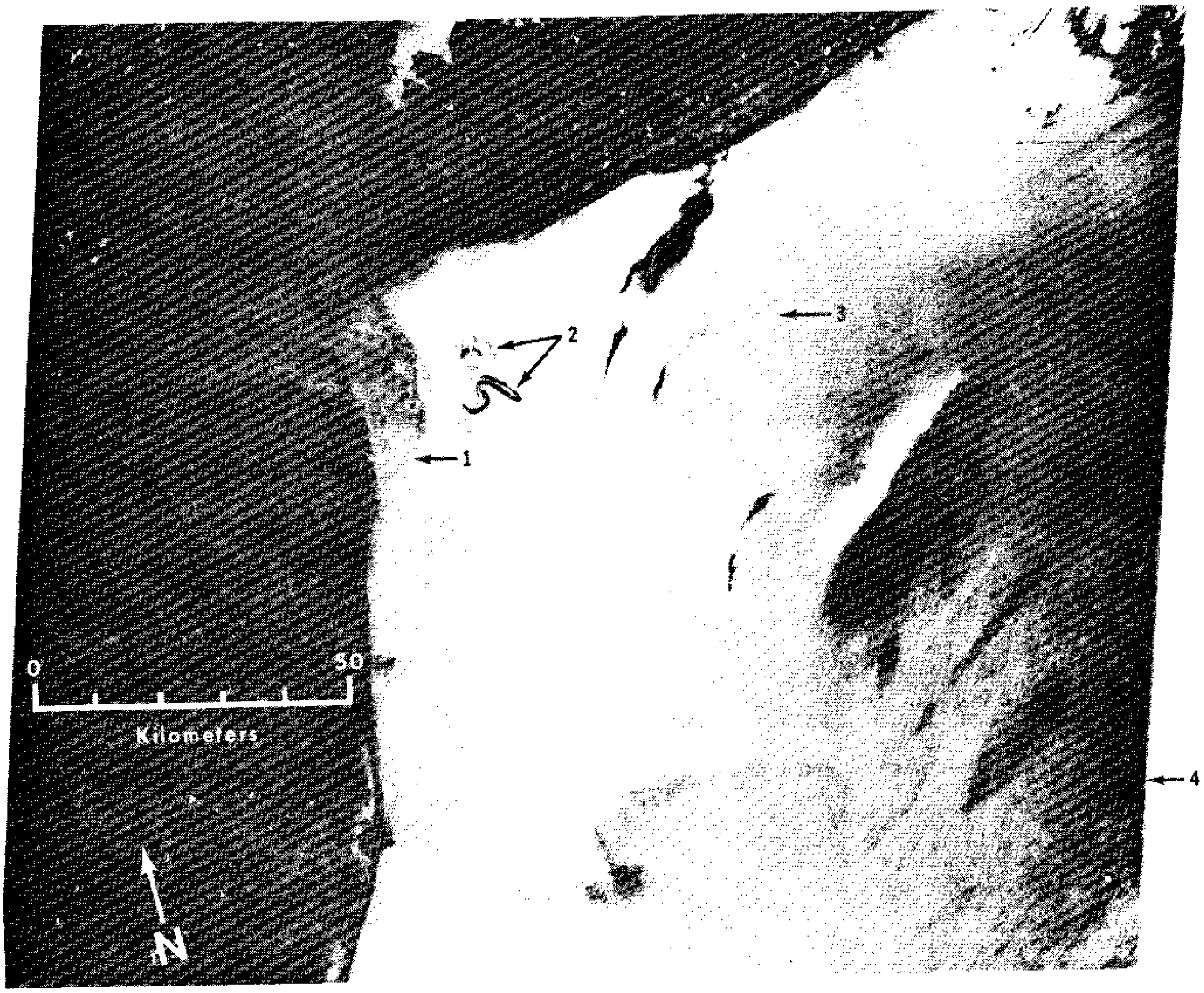
Acknowledgments

Research reported here was supported by the Public Health Service, Environmental Protection Agency, Coastal Engineering Research Center of the US Army Corps of Engineers, and the National Science Foundation.

Manuscript accepted March 1975; revised April 1976.



Frontispiece. New York Bight as seen by ERTS-1 satellite, 16 August 1972. Turbid discharge plume (1) of Hudson River can be seen near New Jersey shoreline. Distinct wavy line (2) is discolored water from waste acid disposal; less distinct lines to north may be discolored water from earlier disposal operations, perhaps of sewage sludge. Some of relatively sharp lines (3) are naturally occurring water mass boundaries unrelated to waste disposal. Surface slicks probably due to internal waves are seen at lower right (4). (Photo from NOAA's Atlantic Oceanographic and Meteorological Laboratory, courtesy of R.L. Charnell)

Abstract

Waste solids (dredge spoil, rubble, sewage sludge, and industrial sludge) are dumped at six major disposal sites in New York Bight. Waste disposal has been regulated since about 1890. Discharges of waste solids into the Bight in 1975 were: dredge spoil, 5 million metric tons; rubble, 1.2 million metric tons; industrial sludges, 0.3 million metric tons; and sewage sludge, 0.3 million metric tons. Amounts of waste solids discharged increased between 1968 and 1975 although the number of individual disposal operations declined.

At the various disposal sites, wastes can be detected by their black color, human artifacts, high carbon content (greater than 2% total carbon), and metal content (high in silver, copper, chromium, and lead). In the axis of Hudson Channel, waste deposits locally are over 15 m (50 ft) thick and cover more than 150 km^2 (60 mi^2). The head of Hudson Channel has been filled by waste deposits. This physical alteration of the bottom has caused obvious changes in abundance and distribution of bottom-dwelling organisms. Accumulations of sewage sludges on the ocean bottom are associated with diseases in crustacea and fin erosion in certain bottom-dwelling fishes. Low dissolved oxygen concentrations occur in the disposal areas during late summer.

Introduction

Waste disposal in the New York region is by no means a new problem. In March 1683, when New York City was only 60 years old, its Common Council found it necessary to decree "that none doe cast any dung, draught, dyrte or any other thing to fill up or annoy the mould or Dock or the neighborhood near the same, under the penalty of twenty shill" (New York City Common Council 1905). Nearly 300 years later the region is still struggling with waste disposal in its waterways.

Instead of scattered villages and Indian encampments, New York Bight is now bordered by cities and suburbs, the central part of a near-continuous belt of development from New Hampshire to northern Virginia—called megalopolis by Gottman (1961). As coastal lands are urbanized, there is much less room for traditional waste disposal by burial or burning near the city limits. Waste solids from the metropolitan region have been dumped in the Bight and in Long Island Sound for many decades, but only since 1970 has ocean disposal of solid wastes received so much attention.

Although the problem is an old one, there is still a serious lack of information about volumes and types of wastes going into the ocean around New York and little basis for predicting their effects. This monograph examines what we do know about waste disposal in the Bight apex. Particular attention is given to disposal of waste solids, such as sewage sludge, dredge spoil, and construction-demolition debris (called *cellar dirt*). While use of the Bight for extensive marine waste disposal is atypically large, it provides a case from which to study trends in marine disposal of waste solids in other US coastal cities (Smith and Brown 1971).

Regional Setting

New York Bight is generally shallow and covered by sand deposits up to 10 m (33 ft) thick (Freeland and Swift, in press). Water depths exceed 55 m (180 ft) only in Hudson Channel, a seafloor valley extending from near the New York Harbor entrance to the edge of the continental shelf (Veatch and Smith 1939; Williams and Duane 1974).

As the deepest section of the Bight, Hudson Channel has been used extensively for waste disposal since 1900 (Map 1), especially dredge spoil, rubble, and wrecks (Williams and Duane 1974). Long Island Sound is another disposal area for wastes from the New York metropolitan region and from cities and towns along the Connecticut and Long Island shores. Even the Hudson River has had waste disposal operations (Map 1): during World War II waste solids—type of waste is unknown—were dumped in New York Harbor (Gross 1974).

History of Waste Disposal Regulations

Procedures for controlling ocean disposal of waste solids from the New York metropolitan region have long been in effect (Smith and Brown 1971). After 1888, disposal operations were conducted under permits issued by the Supervisor of New York Harbor, Corps of Engineers. This system provided records of active disposal operations, listing the volume of wastes dumped by each operation and indicating waste disposal locations. The permits were authorized by an act of Congress (33 USC-441) approved 29 June 1888, with later amendments. Most disposal areas are described in the Code of Federal Regulations, Title 33, Navigation and Navigable Waters. Since 1973 ocean dumping has been regulated under the Marine Protection, Research and Sanctuaries Act of 1972 (PL 92-532). Because of these regulations, records of permits issued include the volume and type of waste dumped in various disposal areas since 1880. Records are unclear, however, on the exact types of waste dumped into the pre-1888 and 1888 sites on Map 1. Since 1974, NOAA has reported annually on research and monitoring of ocean dumping and related activities; the Environmental Protection Agency (EPA) also reports on its regulation of ocean disposal activities.

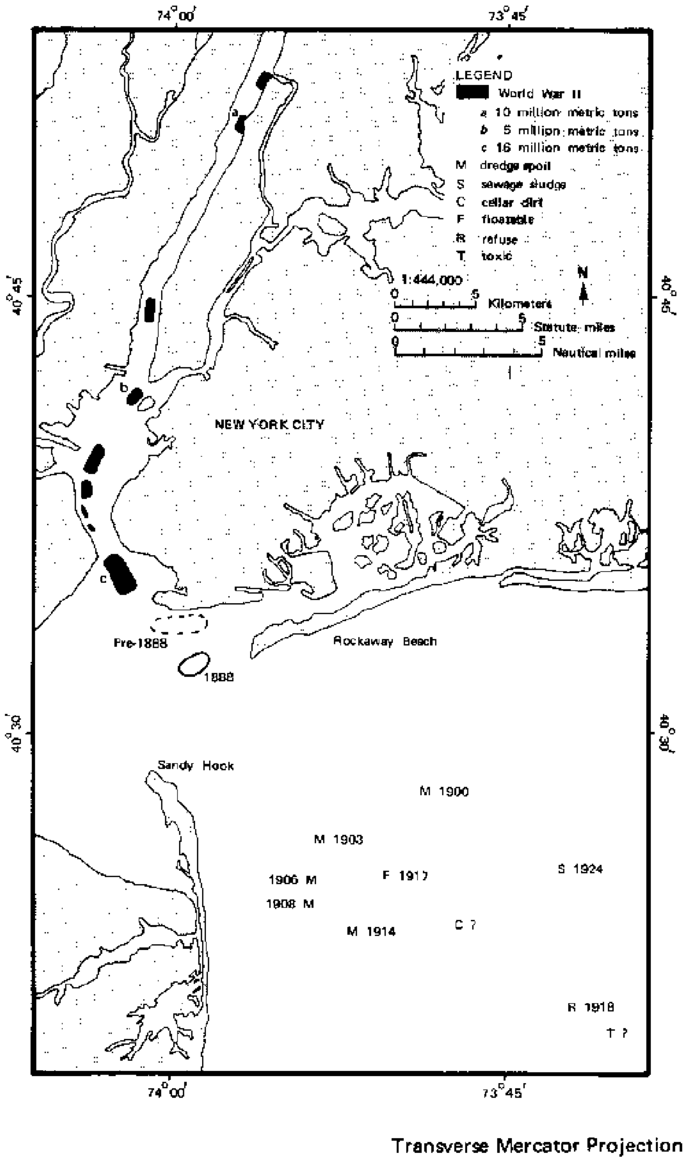
In the past, New York's street sweepings, garbage, and refuse were dumped at sea. These floatable materials were carried by surface currents and frequently washed up on Long Island and New Jersey beaches. In 1917 a separate floatable waste site was established (Map 1) and later an elaborate scheme of seasonally variable disposal sites was set up in attempts to minimize the amount of floatable refuse and garbage that washed up on the beaches (Table 1). These efforts were unsuccessful and on 18 May 1931, after long litigation, the Supreme Court forbade further discharge at sea; the last refuse was barged to sea on 28 June 1934 (Supervisor of New York Harbor 1935). After 1934, refuse, garbage, and floatable wastes were either incinerated or buried in landfill sites.

The disposal site for dredge spoil (mud) was moved frequently between 1890 and 1914 (Map 1), when it was finally established in the Hudson Channel area. These changes were apparently necessitated by shoaling in the disposal areas because of the large volumes of wastes from active channel dredging and from subway construction in New York City.

In the early 1970s there were six major waste disposal sites in the Bight (Map 2, Table 2). The toxic waste site is about 228 km (120 nmi) from the New York Harbor entrance, beyond the edge of the continental shelf, and therefore does not show on Map 2. Two heavily used sites (cellar dirt and dredge spoil) are within 19 km (10 nmi) of the New Jersey coast. The Hudson Channel site designated for disposal of ships and other wrecks seems to have been little used in the 1960s.

Effective 23 April 1973, the Ocean Dumping Act (PL 92-532) authorized EPA to issue ocean dumping permits and to establish and apply criteria for reviewing and evaluating permit applications. The Corps of Engineers issues permits or regulations for

Map 1. Early waste disposal sites



Transverse Mercator Projection

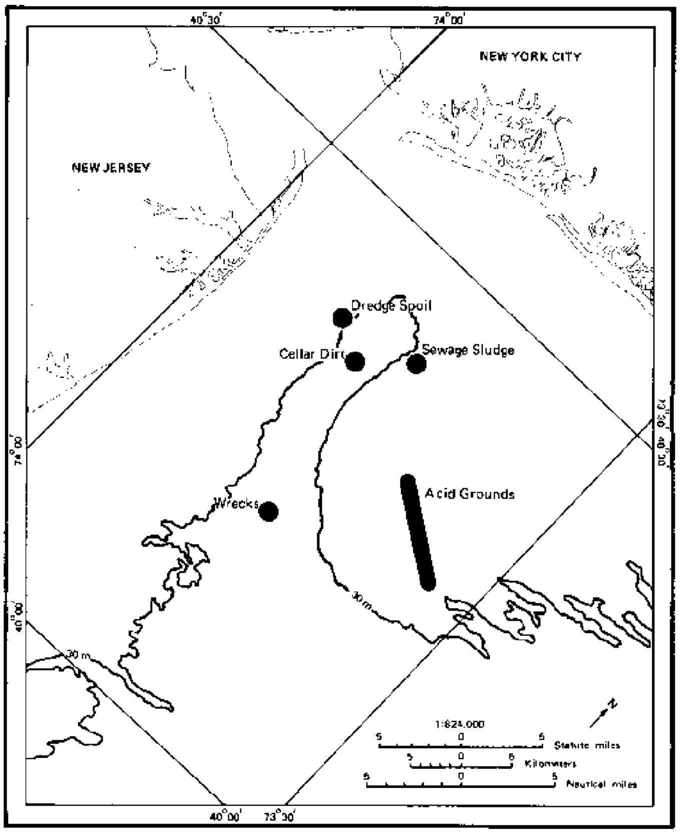
Table 1. Disposal sites for floatable wastes, 1888-1932

1888	Mud buoy, 2.5 mi (4 km) south of Coney Island for deposit of all refuse, including garbage and city refuse
1 September 1900	Point 0.5 mi (0.8 km) south and east of Sandy Hook Lightship (40°28.3'N, 73°50.1'W)
1 December 1902	Point 1.5 mi* (2.4 km) east of Scotland Lightship (40°26.8'N, 73°55.3'W) in 12 fm (72 ft or 22 m) of water
1 January 1906	Point 2 mi* (3.2 km) southeast of Scotland Lightship in 14 fm (84 ft or 25 m) of water
17 April 1908	For cellar dirt and floatable material, a point 3 mi* (4.8 km) southeast of Scotland Lightship
1 September 1913	Set water depths for waste deposits at 15 fm (90 ft or 27 m) or greater
1 May 1914	For material containing floatable matter, not less than 4 nmi (4.6 mi or 7.4 km) east-southeast of Scotland Lightship in not less than 17 fm (102 ft or 31 m) of water
1928	Garbage and street sweepings: winter (October-April) 12 nmi (18 mi or 29 km) southeast by east magnetic from Scotland Lightship; summer (April-October) 20 nmi (30 mi or 49 km) southeast by east magnetic from Scotland Lightship
1931-1932	Garbage and street sweepings: southeast by east magnetic from Scotland Lightship April-July: 20 nmi (30 mi or 49 km) July-October: 25 nmi (38 mi or 61 km) November 1931-January 1932: 12 nmi (18 mi or 29 km) January 1932-March 1932: 8 nmi (12 mi or 19 km) March 1932-April 1932: 25 nmi (38 mi or 61 km) Dumping of garbage permitted 12 nmi (18 mi or 29 km) southeast by east when gentle breezes blew from north, northwest, and west

*Presumably nautical miles but not specified in reports

Source: Data from annual reports of Chief of Engineers, US Army, 1914, 1928, 1933

Map 2. Waste disposal sites, 1974



Transverse Mercator Projection

Table 2. Major waste disposal sites

	Lat (N)	Long (W)	Distance from NY Harbor Entrance mi	km	Depth ft	m
Dredge spoil *(mud grounds)*	40°24'	73°51'	12	19	90	27
Construction debris *(cellar dirt)*	40°23'	73°49'	12	19	102	31
Sewage sludge	40°25'	73°45'	14	22	72	22
Wrecks	40°13'	73°46'	13	20	216	66
Chemicals, nontoxic *(acid grounds)*	40°20'	73°40'	17	28	13	24
Chemicals, toxic	38°45'	72°15'	181	292	7,440	2,270

Source: Smith and Brown 1971

federal ocean dumping of dredged materials with the concurrence of EPA to ensure that applicable criteria have been complied with. Under this act, the US Coast Guard is authorized to conduct surveillance and enforcement activities to prevent unlawful dumping. EPA can designate recommended disposal sites and times for dumping, protect critical areas and specify sites and times within which certain materials may not be dumped. Interim permits for dumping were issued for sites in use at the time the legislation became effective. Final regulations were issued in 1974, based upon comments made about the interim regulations and information collected while they were in effect.

Although disposal data from the oldest records do not seem to be rigorously accurate, they do provide a usable estimate of the volume of wastes dumped in the ocean. With certain assumptions about the probable bulk density of these wastes, it is possible to estimate the tons of solids involved. Detailed records cover the years after 1960; from these we can assess some trends in marine waste disposal in the New York region.

Between 1890 and 1971, the total amount of waste solids dumped in New York waters (Table 3) was about 1.4 billion m^3 (1.9 billion yd^3). This is about 50 times the amount of material removed during the construction of the Panama Canal. Spread uniformly over Manhattan Island, these wastes would form a deposit 20 m (65 ft) high, roughly equivalent to a six-story building. This amount also exceeded the suspended sediment discharge of all the Atlantic coast rivers (Gross 1970*c*; Curtis, Culbertson, and Chase 1973).

Wastes placed behind bulkheads around the New York Harbor margins have enlarged the land areas of the metropolitan region. In 1956, about 20% of New York City was on landfill; about half that area is on former sanitary landfill sites used for disposal of garbage, refuse, and other solid wastes.

Large volumes of wastes going into the Bight are not a recent development (Figure 1). Waste volumes have remained between 8 and 23 million m^3 (10 and 30 million yd^3) per year since 1895. Peak discharges of waste solids occurred in 1945 and 1946 when wastes were removed from the harbor, apparently dredging projects deferred by World War II. During wartime, wastes were dumped within New York Harbor because the threat of German submarines made it unsafe for barges and dredges to venture very far.

There is no obvious correlation between the volume of wastes discharged and the population in the metropolitan region (Pushkarev 1969) (Figure 1). Except in sewage sludges, which tend to increase with the population and with effluent treatment level, detailed analysis of the disposal records for the 1960s has shown no discernible patterns in the waste solids discharged (E. Beltrami, SUNY at Stony Brook, personal communication).

Sewage sludges and waste chemicals are primarily liquid wastes. Sewage sludges are only about 5% solid on a dry weight basis. I estimated that about 10% of the waste chemical discharge is solid (Gross 1970*b*). The major liquid components of these two wastes mix with seawater and do not add to the accumulation of solids in the Bight; but they do add significantly to the total waste volume, as shown in Table 4.

It is important to keep solid and liquid wastes separate. Liquid wastes cause immediate and primarily short-term problems when released but are removed fairly quickly from the area by currents and by dilution with nearby water masses. Waste solids,

Table 3. Placement of waste solids from New York metropolitan region, 1890-1971

	Volume (millions) m^3	Volume (millions) yd^3	Percent
New York Bight	846	1,123	59.0
Long Island Sound	97	128	6.7
New York Harbor			
Bulkhead disposal areas	467	615	32.3
Hudson River	30	40	2.0
Total	1,440	1,910	100.0

Source: Data from files of Supervisor of New York Harbor, US Army Corps of Engineers, New York District

Table 4. Waste volumes discharged, 1964-68 and 1975

Disposal Site	Volume (million m^3/yr) 1964-68 (average)	Volume (million m^3/yr) 1975	Solids (million metric tons/yr) 1964-68 (average)	Solids (million metric tons/yr) 1975
Dredge spoil	5.7	10.3	3.5	7.1
Cellar dirt	0.5	0.2	0.6	0.2
Sewage sludge	3.4	4.0	0.2	0.2
Waste acid (nontoxic)	3.5	2.0	0.3	0.2
Total	13.1	16.5	4.6	7.7

Sources: Gross 1974; EPA 1976; Hansler 1976

Figure 1. Waste discharges into New York Bight and Long Island Sound, 1890-1960

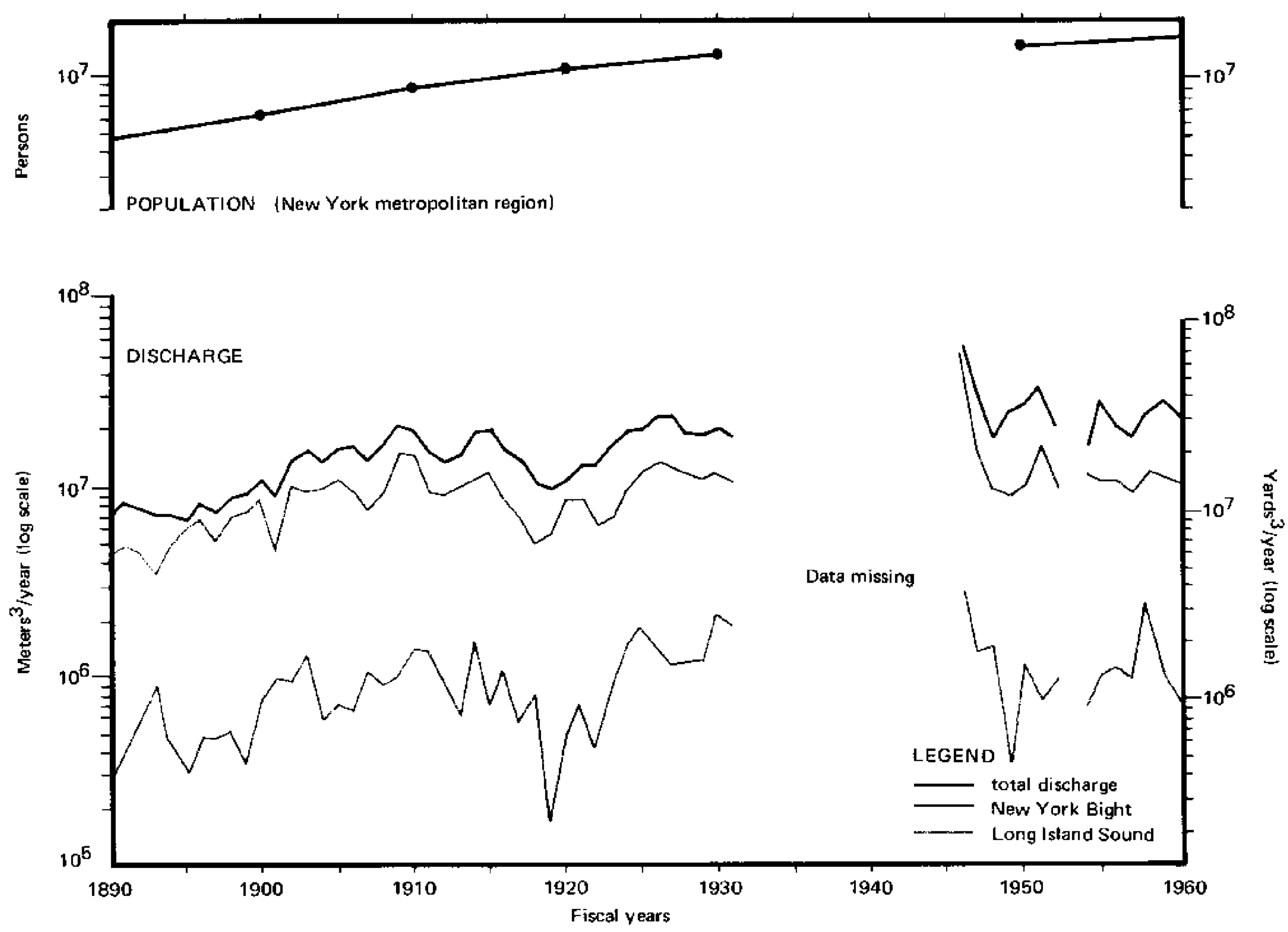
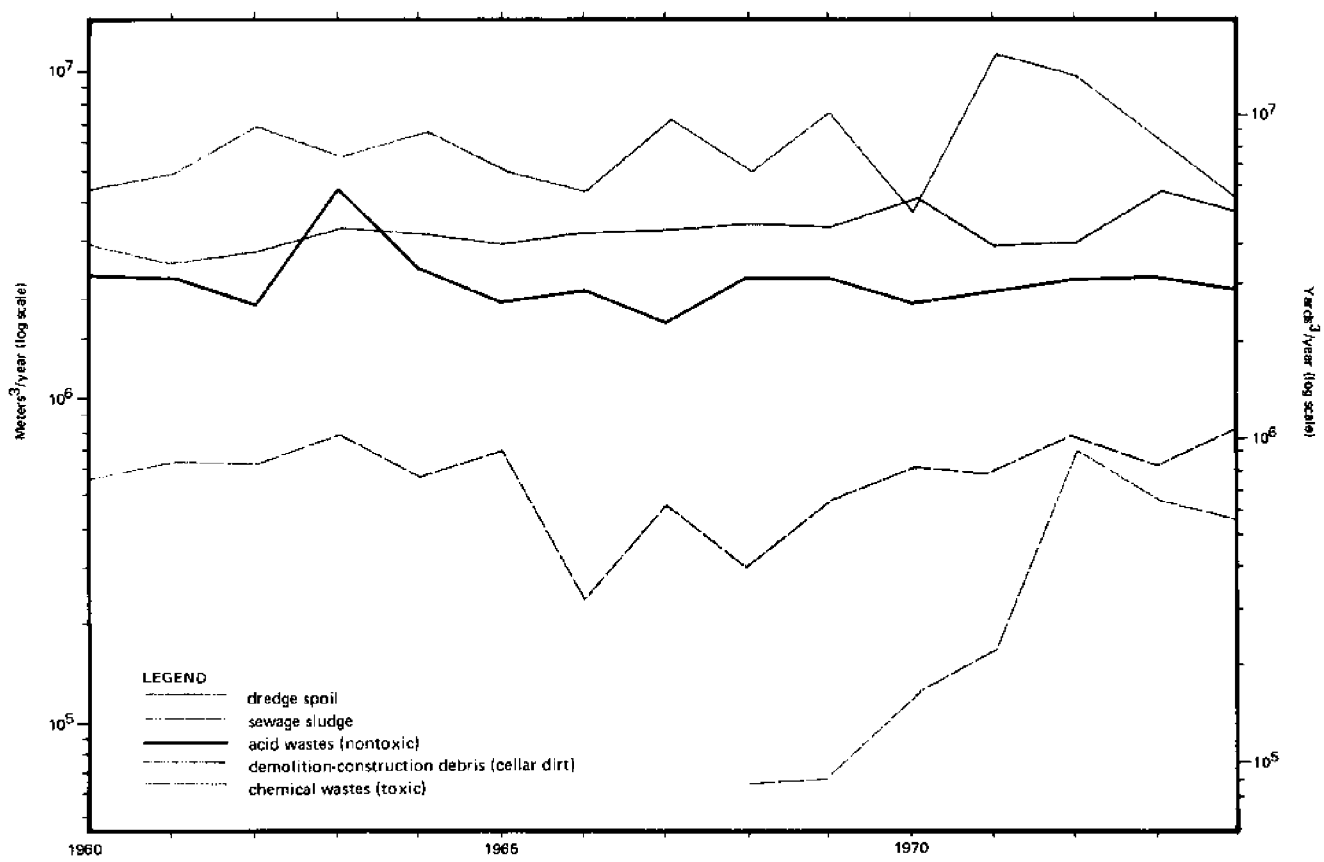


Figure 2. Waste discharges into Bight, 1960-1974



on the other hand, pose long-term problems. They settle out, burying bottom-dwelling organisms, changing physical properties of the bottom, and causing shoaling. They may also interact with the overlying waters, using dissolved oxygen and perhaps releasing substances that can affect the growth and development of marine organisms.

Large increases in the amounts of toxic wastes and dredge spoil disposed at sea occurred between 1968 and 1973. For instance, the volume of toxic waste chemicals dumped in the North Atlantic 292 km (120 nmi) southeast of New York City nearly doubled each year between 1968 and 1971 and then leveled off (Figure 2). Permit records available from the Corps of Engineers provided no details about composition or characteristics of these wastes.

After 1973 EPA Region II began phasing out all ocean disposal activities. The number of permits for industrial waste disposal dropped from 84 in 1973 to 38 in 1975. All waste disposal except dredge spoil and cellar dirt is scheduled to stop in 1981. Volumes of acid wastes decreased from about 2.8 million short tons (wet) in 1973 to 2 million short tons (wet) in 1975 (Hansler 1976). Most of the acid wastes dumped in the ocean in 1975 were from titanium dioxide production.

Sources of Waste Solids

Before going further, it will be useful to define some terms to indicate the types of wastes we are considering. The limits for each type are broad; indeed, one problem discussed later is characterization of the various kinds of wastes.

Dredge spoils are waste solids removed from waterways, generally to improve navigation, and typically consist of sand, silt, or clay mixed with wastes discharged by industrial plants or municipal sewage treatment facilities. Dry solid content ranges from 500 to 750 kg/m^3 (31 to 47 lb/ft^3) of waste.

Sewage sludges are slurries of solids removed from sewage during wastewater treatment (see Table 5), usually containing mixtures of solids from human wastes, street runoff, and industrial wastes. Dry solid content is typically 60 kg/m^3 (4 lb/ft^3) of waste.

Table 5. Municipal wastewater treatment

Primary treatment level
- Particulate matter settles out from raw sewage through sedimentation
- Removes half to two-thirds of suspended solids

Secondary treatment level
- Aerobic biological process takes organic matter from primary effluents
- Removes about 90% of suspended solids and oxygen-demanding substances

Tertiary treatment level
- Physical or chemical treatment of secondary effluents removes residual organics, nutrients (nitrogen, phosphorus), chlorine, colors
- Typical processes include: lime addition to remove phosphorus; filtering to remove solids; activated charcoal treatment to remove organic matter; disinfection

Source: American Chemical Society 1969

Industrial wastes (nontoxic chemicals and acids) are in various mill and industrial process wastes, such as titanium dioxide production. Dry solid content is assumed to be 100 kg/m^3 (6 lb/ft^3) of waste.

Construction and demolition wastes (*cellar dirt*) consist of excavation dirt, masonry, tile, stone, plumbing, glass, tar, plaster, and other debris of the construction and demolition industry. Solid content is assumed to be 1.1 metric tons/m^3 (1,824 lb/ft^3) of waste.

Chemical wastes (toxic) are mostly liquid wastes known or suspected to be toxic to organisms or humans. These include chemical manufacturing wastes and residues from petroleum refining and petrochemical processing.

A modern, industrial city produces a wide variety of wastes (Table 6), which enter rivers, waterways, and eventually the coastal ocean. Although airborne wastes do enter Bight waters, we will not consider them in any detail. Prevailing winds in the New York region are primarily from the west; thus, airborne particles from the land, including the metropolitan region, are likely to be carried out over the ocean. The amount and mode of deposition is not known. Efforts to control regional air pollution have probably reduced the amount of airborne wastes entering the Bight, but the problem requires far more study than it has received to date.

Table 6. Common urban wastes: sources and composition

Wastes	Sources	Major Constituents	Minor Constituents
Municipal refuse	domestic, industrial	paper, wood (50%) food wastes (12%) plastics & misc. (20%)	glass, stones (10%) metals (8%)
Dredge spoil	harbor, channel construction, maintenance	sand, shell, gravel river sediment	sewage solids industrial wastes
Rubble	construction, demolition	stone, concrete, steel	
Sewage solids	municipal sewage systems and treatment plants	organic matter (50%) alumino-silicates (50%)	industrial wastes
Coal ash	coal combustion, primarily power generation	quartz, mullite	
Agricultural wastes	soil erosion, manure	sand, organic matter	
Fermentation wastes	breweries, distilleries, pharmaceutical industry	organic matter	
Acids	metal and pigment processing		
Alkali	petrochemical industry		

Source: After Gross 1972

Municipal Sewage and Industrial Wastes

Municipal sewage and industrial wastes are major sources of waste solids. Untreated sewage discharge has been the common practice for centuries; as recently as the early 1970s untreated sewage contributed an estimated 140,000 metric tons of solids* each year to the total waste load carried by the region's rivers (Gross 1974). In 1969, of sewage from approximately 8.3 million persons discharged into the lower Hudson River and New York Harbor (Federal Water Pollution Control Administration 1969), about 16% received no treatment; 27% had only primary treatment. In the mid-1970s, untreated sewage from a population of nearly four million people is discharged each day (an estimated 600 million gallons) into the Hudson and tributary rivers, pending completion of planned sewage treatment facilities (US Department of Health, Education and Welfare 1965). New sewage treatment systems on Long Island are being constructed to discharge secondary-treated wastes by pipeline one to two miles at sea.

Sewage treatment plants themselves discharge large amounts of waste–sludges and liquid effluents –into New York Harbor. They treat sewage, they do not make it disappear. The treated effluents contain some solids, typically 50 parts per million (ppm), and contribute about 60,000 metric tons of solids (Gross 1974) to the harbor each year (Table 7). In addition, the nutrients (nitrogen compounds, phosphates) in the sewage discharges stimulate the growth of phytoplankton. When these minute plants die, they contribute an unknown amount to the sediment deposits accumulating in the harbor and adjacent waterways.

During wet weather, sewage treatment plants cannot handle the suddenly increased flow from combined storm and municipal waste systems (Federal Water Pollution Control Administration 1969). Thus, even areas served by sewers and sewage treatment plants intermittently discharge large volumes of untreated sewage directly into nearby waters. These overflows account for an estimated 80,000 metric tons of solids annually (Table 7).

Sewage treatment plants' other product is *sewage sludges,* thick semiliquid slurries removed from sewage before the plant effluents are discharged to the receiving waters. Sewage sludges constitute only a small part (about 200,000 metric tons annually) of the total waste load from the metropolitan region but they have been investigated intensively because of their significance for both man and marine resources (Gross 1970*a*). New York City and Long Island newspapers have repeatedly carried major stories on the effects of sludge deposits offshore. These effects include alteration of communities of bottom-dwelling organisms–and with it concern about the "dead sea" in the Bight–and the formation of sludge-contaminated deposits that may move seasonally on the continental shelf.

*Discharge figures are calculated on the basis of dry solids.

In the New York area, barges take sewage sludges and the various industrial wastes from plants and dump them in designated disposal sites in the Bight (Map 2). Specially built, rubber-lined, towed barges are used to dispose of waste acids from titanium dioxide manufacturing, for example. While the barge is underway, the acid is pumped through discharge pipes at the keel level to promote faster dilution in the turbulent wake. Processing waste is dumped at the same time.

Self-propelled barges are used to dispose of dredged wastes. Seagoing hopper dredges, resembling tankers, have deck equipment for pumping wastes into tanks or hoppers; at the disposal site the load is dumped through doors in the hopper bottom (Mauriello and Caccese 1965).

New York City has similar vessels for hauling treated sewage sludges to sea for disposal. Valves in the bottom of the tanks are opened, dumping the sludge while the vessel is underway. Probable physical behavior of the waste loads was reviewed by Clark et al (1971) and Callaway et al (in press).

Dust and soot particles discharged into the atmosphere by incinerators, automobiles, and power generating plants constitute a particularly noticeable part of the waste solid load of the region. Although these discharges were estimated at about 25,000 metric tons in the mid-1960s, I have not included them in the estimate of the waste solid discharge to the sea. Probably some of this material is deposited in the ocean as part of sewage sludges from storm sewers.

Table 7. Sources and estimated tonnages of waterborne solids deposited in New York Harbor

	Hudson River Upper Bay Newark Bay (thousand metric tons/yr)	Lower Bay Raritan Bay (thousand metric tons/yr)	Reference
Sewage discharge			
Combined sewer overflows	76	?	FWPCA 1969
Untreated sewage	140	?	USHEW 1965
Solids in sewage plant effluents (50 ppm in effluent)	60	23	USHEW 1965
Subtotal	276	23	
Riverborne sediment[a]			
Hudson River	800		Panuzio 1965
Raritan River		70	Dole and Stabler 1909
Passaic River[b]	95		
Subtotal	895	70	
Littoral drift			
Long Island		500+	Taney 1961
New Jersey		600+	Caldwell 1966
Subtotal		1,100+	
Total	1,200	1,200	

[a] Excludes approximately 700,000 metric tons of solids dumped in Hudson River each year

[b] Estimated sediment yield 100 metric tons/mi^2 (Anderson and McCall 1968) from drainage basin of 941 mi^2 (2,428 km^2)

Source: After Gross 1974

Urban Stormwater Runoff

Precipitation in urbanized areas commonly drains into sewage systems together with domestic sewage, rather than sinking into the ground or flowing straight into a nearby river or ocean. A large portion of urban land is covered by streets and buildings, reducing rain and snow infiltration into the soil. From 40% to 80% of the precipitation flows through sewers to local waterways (Federal Water Pollution Control Administration 1969).

When a storm occurs, the water runoff combined with domestic sewage generally exceeds the capacity of local sewage treatment plants; the mixture of runoff and sewage flows untreated into the nearest waterway. Analysis of water quality data on a national scale has shown that such dispersed sources cause deterioration in environmental quality during high discharge periods following storms (Council on Environmental Quality 1972). It is therefore appropriate to include urban runoff in our assessment of waste discharges into the Bight.

The New York region receives about 106 cm (42 in) of rain or snow each year; the most severe storms normally occur in August and September. Although rainwater is initially rather pure (Table 8), it picks up pollutants from the city atmosphere and streets before it is discharged. Among the many sources of these contaminants are: vehicular wastes, including oil and grease; atmospheric fallout; combustion wastes—incinerator fly ash; animal wastes; sewage deposits from collection systems; and plant debris. No data are available for the New York region on the amount or composition of these sources nor on their contribution to urban runoff, but studies in other cities show that street runoff is far from clean (Weibel 1969; Southern California Water Research Project 1973).

Using data on estimated sewage overflows in the Hudson River area (Federal Water Pollution Control Administration 1969) and on typical urban runoff from low-density areas, we can estimate that the sewage overflow from the sewered portion (3,000 km^2 or 1,200 mi^2) of the entire New York urban region discharges into the Bight at an average rate of 390 m^3/sec or 9,000 million gallons/day. While this is only a crude estimate, it suggests that urban stormwater runoff in the region exceeds the sewage system's dry weather flow of 114 m^3/sec or 2,500 million gallons/day (Tri-State Regional Planning Commission, unpublished data). Using the composition of the urban stormwater runoff (Weibel 1969), we can calculate that the solids discharged with the stormwaters could be as much as 18 million metric tons per year. In general these runoff waters are discharged into local waterways, and whether any significant fraction of these solids reach the Bight in an average year—except through dredging of navigation channels—is questionable. During major storms and floods, however, deposits of wastes in the Hudson and other rivers and in navigation channels can be eroded and carried to the ocean.

Table 8. Runoff constituents and concentrations

Constituent	Average Concentrations (mg/l)			
	Rainfall[a]	Untreated Sewage[b]	Urban Stormwater Runoff[c]	Rural Land Runoff[d]
Suspended solids	13	200	227	310
Chemical oxygen demand	16	350	111	–
Total nitrogen, as N[e]	1.3	40	3.1	9
Inorganic nitrogen, as N[f]	0.7	30	1.0	5
Total phosphate[g]	0.08	10	0.4	0.6

[a]Measured in Cincinnati, OH, August and December 1963 (Weibel 1969)
[b]Generalized composition of domestic sewage (Weibel 1969)
[c]Residential-light commercial section of Cincinnati, 27 acres (11 hectares) (Weibel 1969)
[d]After Biggar and Corey 1969
[e]Total of four forms of nitrogen
[f]Total of ammonia, nitrite, and nitrate
[g]Total acid-hydrolyzable phosphate

Sources: Weibel 1969; Biggar and Corey 1969

Riverborne Sediment and Littoral Drift

A major contributor—often ignored—to the urban waste load is the natural sediment transport process, both in rivers and along beaches. Part of this sediment load is polluted because of waste discharges from upstream cities or runoff from livestock feedlots. Some sediment, such as beach sand, is relatively clean but mixes with other wastes when deposited in New York Harbor or in navigation channels. Such sediments are eventually incorporated into the urban waste stream and must be disposed of.

Around 1900 the sediment load of the Hudson River was estimated at about 400,000 metric tons per year, and the load of the Raritan River at about 70,000 metric tons per year (Dole and Stabler 1909). Sediment yield per unit area of river drainage basin has apparently risen owing to continued urbanization of the region (Anderson and McCall 1968). Increased erosion is possibly a major cause in the greater sediment load of the Hudson River, estimated at about 800,000 metric tons per year in the early 1960s (Panuzio 1965).

In addition to their natural sediment load, the rivers of the New York metropolitan region carry a large but poorly known waste load. About 700,000 metric tons per year of various wastes were dumped into the Hudson River between 1964 and 1968 (Gross 1974). In 1969, the Hudson River north of the New Jersey state line received the sewage of approximately 590,000 persons (Federal Water Pollution Control Administration 1969). Of these discharges, 25.2% were untreated; the remainder received primary treatment. Some of these wastes may be transported into the ocean during floods.

Another natural source of solids is littoral drift—northeast along northern New Jersey and west along Long Island beaches—estimated at 600,000 and 500,000 metric tons per year respectively in the two areas (Table 7). Human activities have changed these natural sediment movements. Littoral drift along New Jersey beaches may have been reduced slightly by seawalls and jetties (Caldwell 1966; Yasso and Hartman 1975), and littoral drift along the south shore of Long Island (Taney 1961) may have decreased because of dredging and removal of sand deposited in inlets. In the 1960s a volume of sand equivalent to nearly half the total littoral drift along Long Island's south coast was dredged each year from Fire Island, Jones, and Rockaway inlets and dumped offshore.

From these data it appears that natural river sediment load and littoral drift account for about 2 million metric tons annually. From 1930-1970 the river sediment load and littoral drift apparently contributed about 85% of the amount dredged annually—1.9 out of 2.2 million metric tons.

Construction and Demolition Debris

Wastes from construction of new buildings and tearing down of old ones have been dumped in the Bight when no other disposal sites were available. These wastes are placed in a separate ocean disposal site (cellar dirt) near the head of Hudson Channel (Map 2). When large landfill projects are underway, these wastes are often used as fill materials (Figure 3).

The diverse origins and heterogeneous composition of the wastes make it impossible to know with confidence what is dumped in the cellar dirt site. The available data (Pararas-Carayannis 1973) indicate that the wastes are principally excavated earth and rock, broken concrete, rubble, and other nonfloatable debris.

The cellar dirt site received 2.8 million m^3 (3.7 million yd^3) or about 5% of the total volume of wastes discharged from 1965 through 1970 (Pararas-Carayannis 1973). This amounted to 5.3 million metric tons or about 1 million metric tons per year.

Major public works generate large volumes of wastes requiring disposal. One well-documented ex-

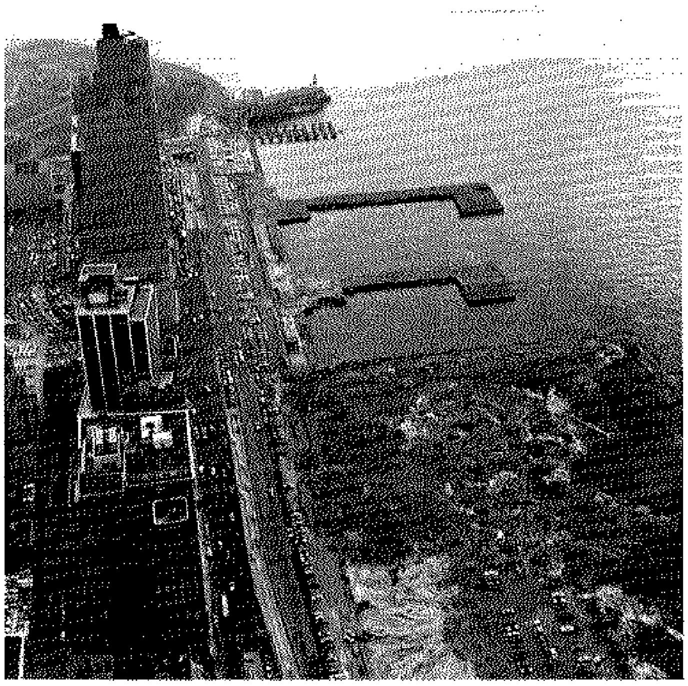


Figure 3a. 100-acre site for Battery Park City filled by material excavated during construction; above photo shows site in December 1971 before work began (Courtesy of Battery Park City Authority)

Table 9. Underground track completed and estimated waste volume generated, New York City

Years	Underground Track Completed km	Underground Track Completed mi	Waste Removed (millions) m^3	Waste Removed (millions) metric tons
1904	66.7	41.7	2.67	5.3
1905-1909	24.3	15.2	0.97	1.9
1910-1914	6.4	4.0	0.26	0.5
1915-1919	146.1	91.3	5.84	11.7
1920-1924	59.2	37.0	2.37	4.7
1925-1929	11.5	7.2	0.46	0.9
1930-1934	161.8	101.1	6.47	12.9
1935-1939	98.9	61.8	3.96	7.9
1940-1944	13.4	8.4	0.54	1.0
1945-1949	15.4	9.6	0.62	1.2
1950	3.2	2.0	0.12	0.3
Total	606.9	379.3	24.28	48.3

Source: Rinke 1954

ample is the construction of the New York City subway system between 1900 and 1950, when workers excavated for about 607 km (379 mi) of underground track. Based on a cross section of 40 m^2 (360 yd^2) for each track, about 24 million m^3 (31 million yd^3) of material were removed; this did not include underground stations and other tunnels. If we assume that the rocks dug out had an in-place density of 2 g/cm^3 (125 lb/ft^3), this amounts to 48 million metric tons (Table 9). If we include underground stations, then at least 50 million metric tons of material were removed during subway construction.

Not all this waste went into the Bight. A great deal of it was used to enlarge Governors Island (Figure 4), restoring about 100 acres (40 hectares)

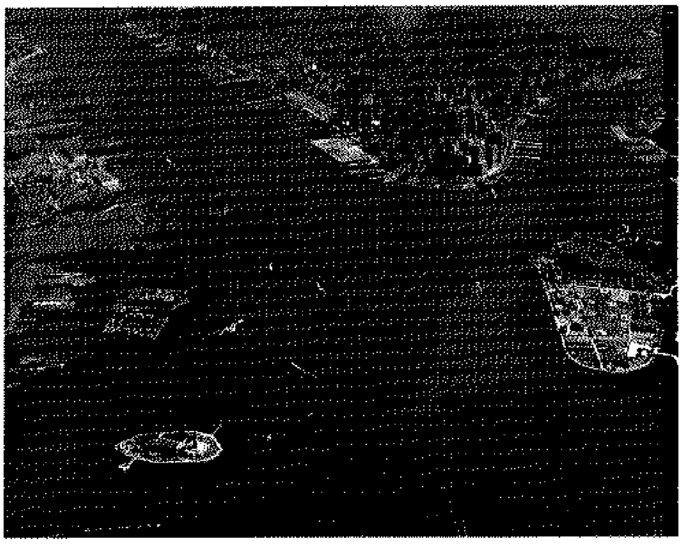


Figure 4. Ellis Island and Bedloe's Island (State of Liberty) in lower left landfilled; Governors Island (lower right) extended with debris excavated during NYC subway construction in 1900-1910 (Courtesy of Port Authority of New York and New Jersey)

Figure 3b. September 1973—completed bulkhead before sand pumping started

Figure 3c. Three weeks later—area entirely filled by sand and excavated material

that had eroded away between 1625 and 1900. Smaller amounts were used to enlarge Ellis Island in New York Harbor and Riker's Island in the East River. Between 1905 and 1914, 11.3 million m^3 (14.7 million yd^3) or about 12 million metric tons were used as landfill for constructing terminal facilities for railways at New York Harbor, Greenville's Port Liberty, and Newark Bay.

Garbage, Rubbish, and Ash

Ocean disposal of garbage and rubbish, the largest single category of waste solids generated in the Bight region, is prohibited, but we mention them here because they are used to fill wetlands around New York Harbor. In 1965 the New York metropolitan region generated 17.3 million metric tons of these solid wastes (Bower et al 1968). Of this, 11.5 million metric tons went into sanitary landfills; 4.5 million metric tons were incinerated, with the ash going to landfills. The remainder was handled by on-site burning or by salvage and reclamation.

Although disposal of refuse, garbage, or other floatable wastes at sea is no longer permitted, it occasionally occurs as a result of improper loading of refuse-hauling barges—some material falls over the side—or by illegal combining of garbage with other wastes dumped by ships or pleasure craft operating in the ocean.

The region faces a continuing garbage and refuse disposal problem. Presently used landfill sites were estimated to have sufficient capacity to accommodate New York City's refuse and other solid wastes until the mid-1970s. As these land sites are filled and no new ones become available, ocean disposal may be considered an attractive alternative in some quarters.

An alternative to ocean disposal is incineration. This merely lessens the disposal problem by dehydrating the wastes and reducing their volume through partial combustion; it does not solve it. With present technology, the ash remaining after incineration is usually 15% of the original amount (Bowerman 1969). Thus, even if all refuse from the region were burned, there would still be a disposal problem for at least 1 to 2 million metric tons per year, excluding dust and smoke released to the atmosphere.

Another source of waste solids in previous years was ash from the coal-fired power and steam generating plants as well as from ships operating in New York waters. Available permit records do not identify all sources of such ash but if we assume that the major sources—mostly public utilities—have been included, the available data indicate that coal ash disposal in the Bight averaged about 110,000 metric tons per year in the late 1960s. The amount of ash produced diminished sharply in the late 1960s and early 1970s as less coal was burned in the region because of air pollution abatement legislation. Furthermore, new uses are being developed for coal ash. But growing dependence on coal in the future may bring substantial increases in coal ash production.

Waste Deposits

Several aspects of waste deposits will be considered here.

1. How can waste deposits be recognized; what characteristics are most distinctive?
2. How widespread are the deposits in New York Bight and New York Harbor?
3. Which criteria are most helpful in recognizing and measuring the nature and magnitude of environmental problems posed by waste solid deposits?

The recognition problem has been approached through two main routes. The simplest way to identify sewage, for example, is to use diagnostic indicators, such as tomato seeds or watermelon seeds, which pass through sewage treatment plants little altered. Human artifacts, such as cigarette filters, bandages, sanitary napkins, and prophylactics are removed at the treatment plant but remain in the sludge dumped at the sewage sludge disposal site, thus accumulating in those deposits. Using these "tracers" to identify waste deposits does not require sophisticated chemical analyses.

The second way is to compare the chemical composition of dredged sediment and sewage sludges with that of natural substances likely to accumulate in New York Harbor or on the continental shelf. Such analyses indicate that physical properties, such as grain size, and the abundance of certain chemical constituents from industrial wastes, such as carbon and metals like lead and silver, are useful tags for the major waste types (Gross 1970*a,b*; Carmody, Pearce, and Yasso 1973).

The chemical characteristics aid in mapping waste deposits in New York Harbor and the Bight. They have less application in Long Island Sound where the sediment deposits that naturally cover the bottom are similar in carbon content and physical properties to many wastes. In the Bight, the carbon-rich, metal-rich wastes are distinctly different from the coarse-grained, relatively clean sands naturally occurring there (Map 3).

Sewage solids, widely dispersed throughout the New York region's waterways, are usually mixed with various other wastes. The untreated sewage discharged from most of Manhattan and large areas of Brooklyn and from many poorly operated and overloaded sewage treatment plants in the region bring large volumes of sewage solids into New York Harbor. There the solids mix with other wastes and riverborne sediments, forming large deposits that are usually dredged and taken to sea for disposal. The presence of sewage solids is also a useful indicator of waste deposits, regardless of how they were treated and transported to the ocean disposal ground.

With these criteria to map waste accumulation, it is easy to show that deposits of carbon-rich, metal-rich wastes are widespread in New York Harbor. In fact, the highest concentrations of carbon, lead, and silver (the most reliable indicators) occur in deposits in lower New York Harbor.

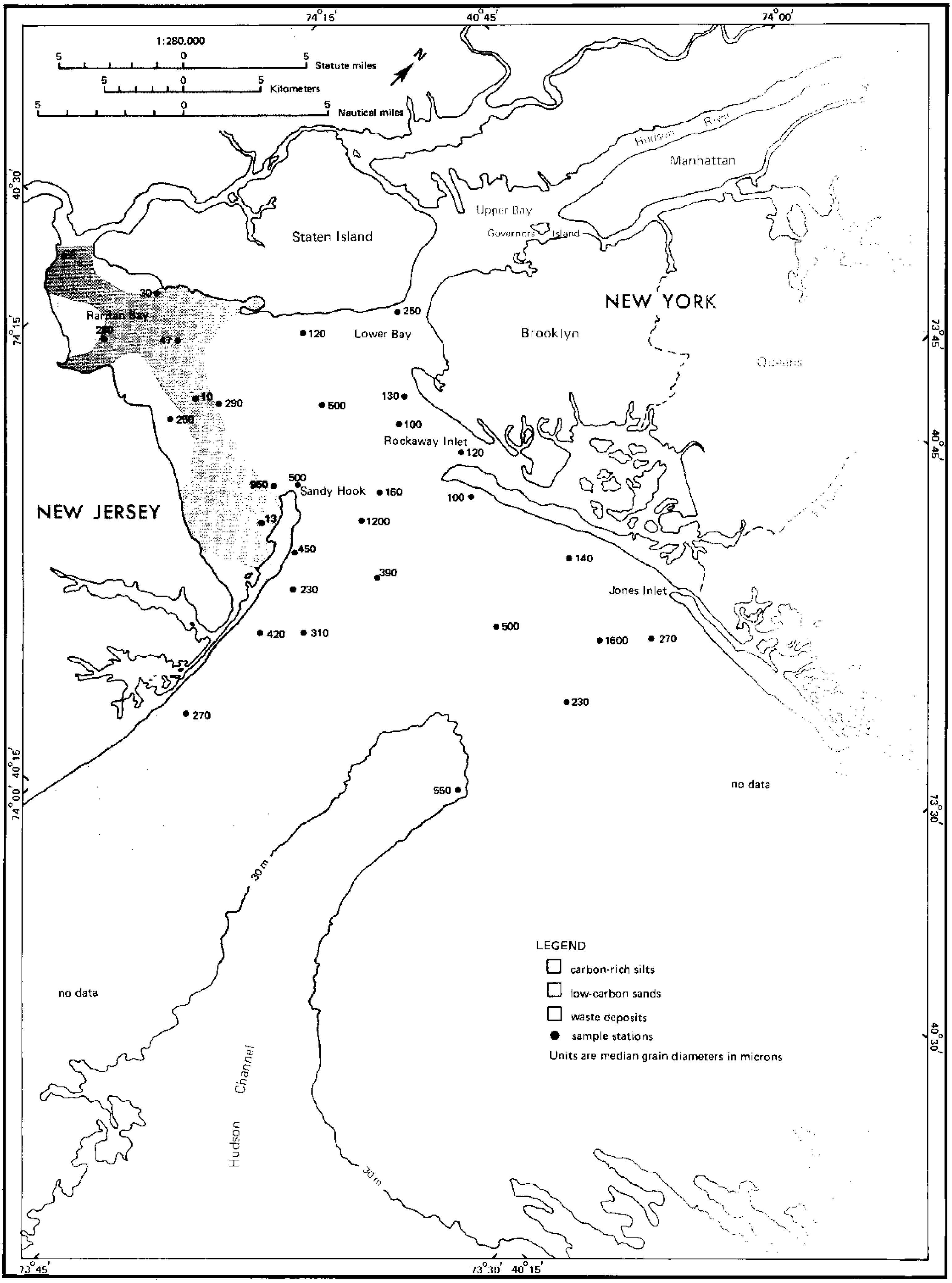
In the Bight, waste deposits are most common near the head of Hudson Channel (Gross, Lin, and Liang 1971; Carmody et al 1973)—over 15 m (50 ft) deep in the axis (Williams and Duane 1974)—where waste disposal has been carried out since the late nineteenth century (Map 4). Considering that no buoys mark the exact location of the disposal sites, that the sites have been shifted many times to avoid excessive shoaling, and that policing the waste disposal operations has been a problem, the relation between the apparent waste deposits and the designated disposal areas is remarkably good. These data suggest that most of the region's waste disposal activities take place close to the designated site. Scattered occurrences of high-carbon deposits (Map 5) near New York Harbor may result from illegal ("short") dumping.

What about subsequent physical movements of the solids after deposition? Movements of wastes toward Long Island and New Jersey beaches, especially during the summer when they are used most, would pose potential health hazards. Despite a series of newspaper articles in 1973 and 1974, based on one set of findings (US Senate 1974), the bulk of available data on sediment deposits and water quality at bathing beaches provides no convincing evidence that large masses of sludge solids move long distances across the continental shelf onto either the Long Island or New Jersey beaches. Data collected in studies made at the Marine Sciences Research Center at Stony Brook (Gross et al 1971) and at the Sandy Hook Marine Laboratory (Pearce 1969; Carmody et al 1973) are too scattered to provide strong evidence that movements of waste solids take place in any direction on a scale large enough to leave a trace on the ocean bottom. It appears, however, that wastes are moved by currents south-southeast, down Hudson Channel (Carmody et al 1973). Deposits from the deep parts of the channel south of the disposal sites include carbon-rich, metal-rich sediments. More detailed sampling than has been done to date and a close investigation of materials suspended in near-bottom waters are needed to determine the magnitude and direction of fine-sediment movements in the Bight (Harris, in press).

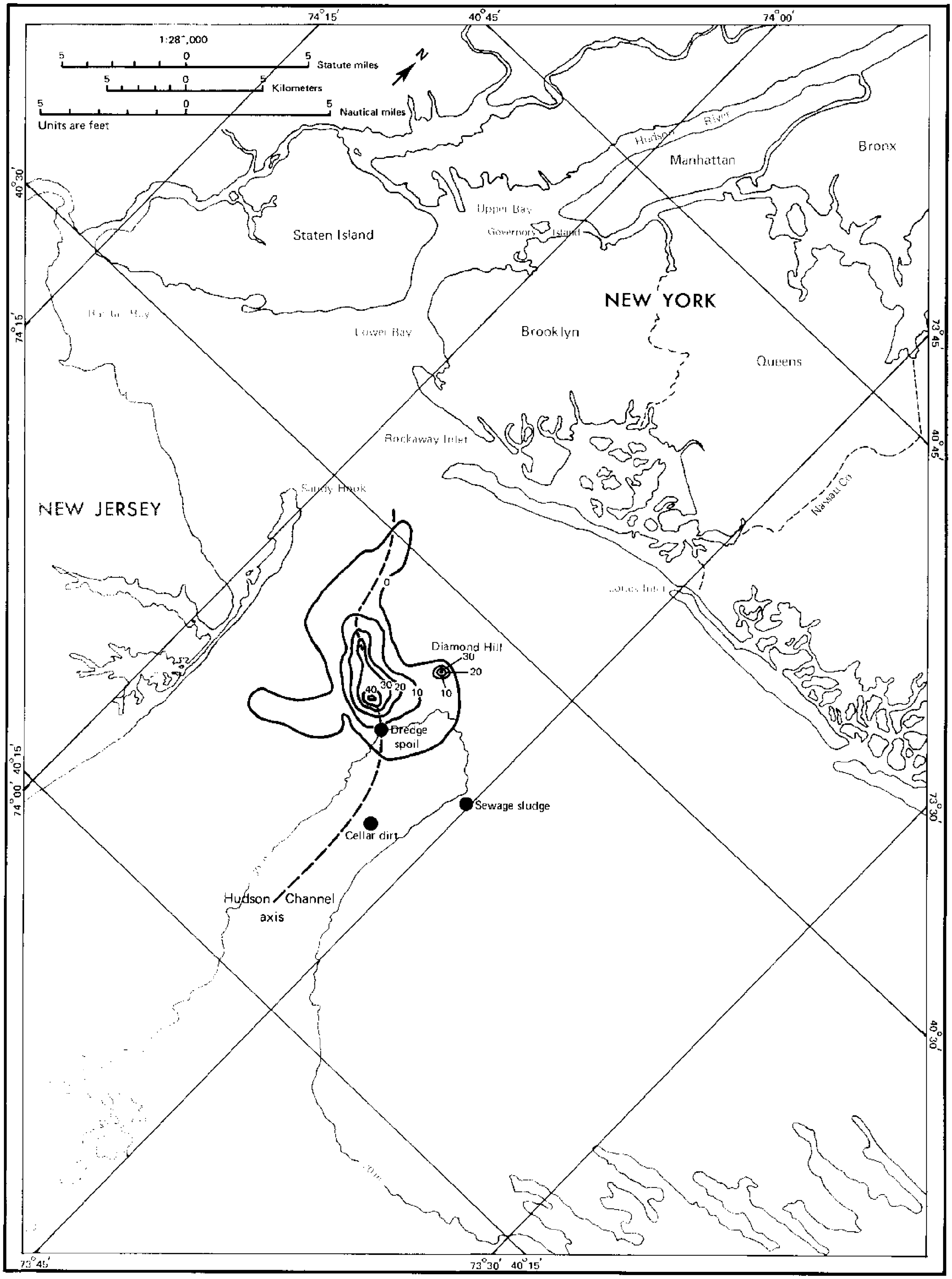
Carbon data samples collected in the 1971 study, combined with data from earlier years, are plotted on Map 5. The abundance of carbon was selected as the most reliable single criterion for samples on the continental shelf. Total carbon concentrations in the deposits indicated that carbon-rich waste deposits moved southward down the channel. Because of this previously undetected southerly extension of the waste disposal area, the size of the waste-affected area in the Bight was revised from the previous estimate of about 50 km^2 (19 mi^2) to about 150 km^2 (60 mi^2), based on the area enclosed by the 2% total-carbon contour (the darker of the two shaded areas in Map 5).

Concentrations of lead (Map 6) and silver (Map 7) in surficial deposits—rare in natural shelf sediments but abundant in urban wastes—were also determined. Because lead and silver were found in the same area as carbon, these metals are good indicators of the distribution of carbon-rich, metal-rich deposits typical in New York Harbor (Gross et al 1971) and in sewage sludge from the metropolitan region (Gross 1970*a*).

Map 3. Distribution of surficial deposits

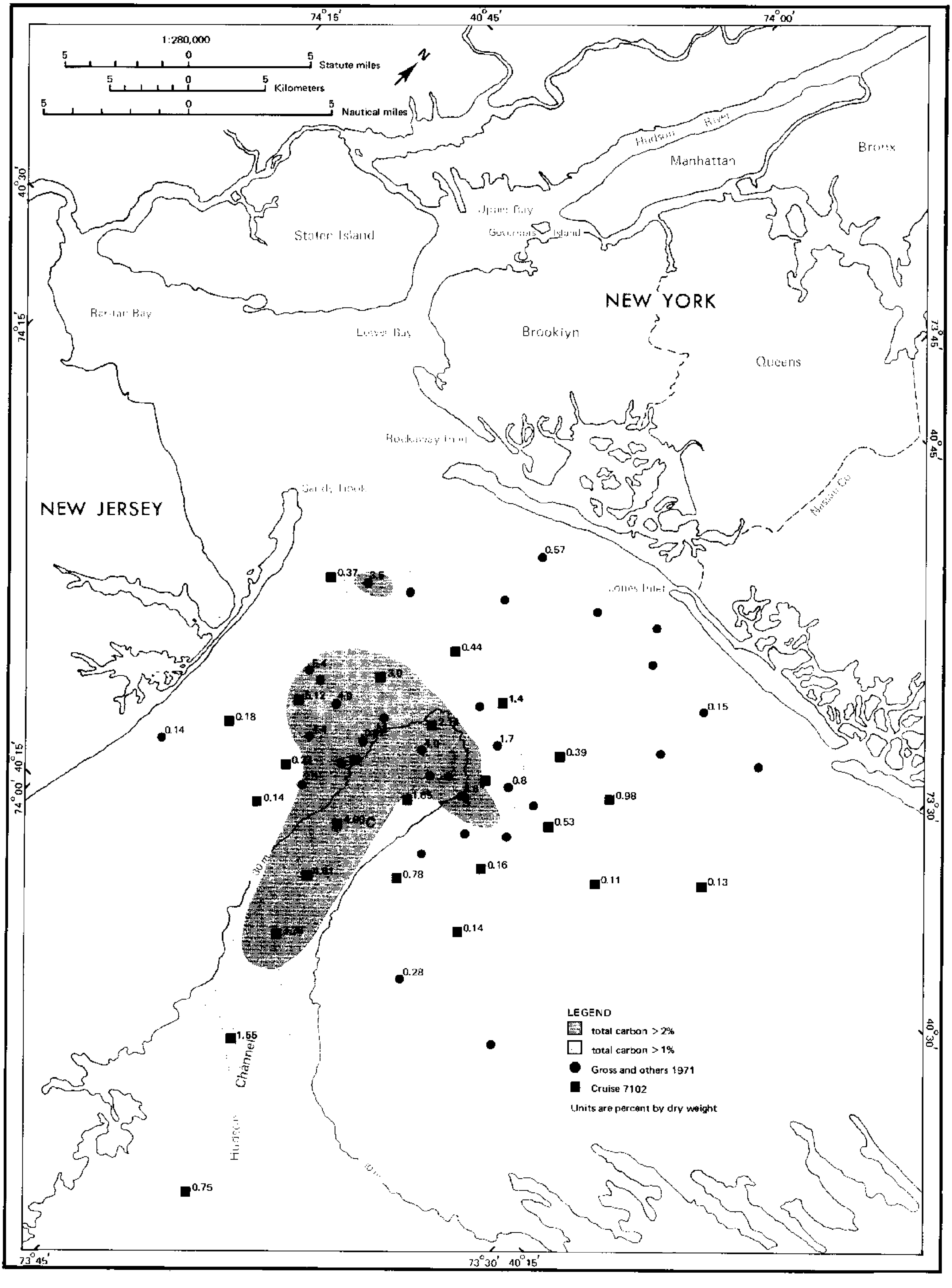


Map 4. Thickness of waste deposits



Transverse Mercator Projection

Map 5. Total carbon concentrations in surficial deposits



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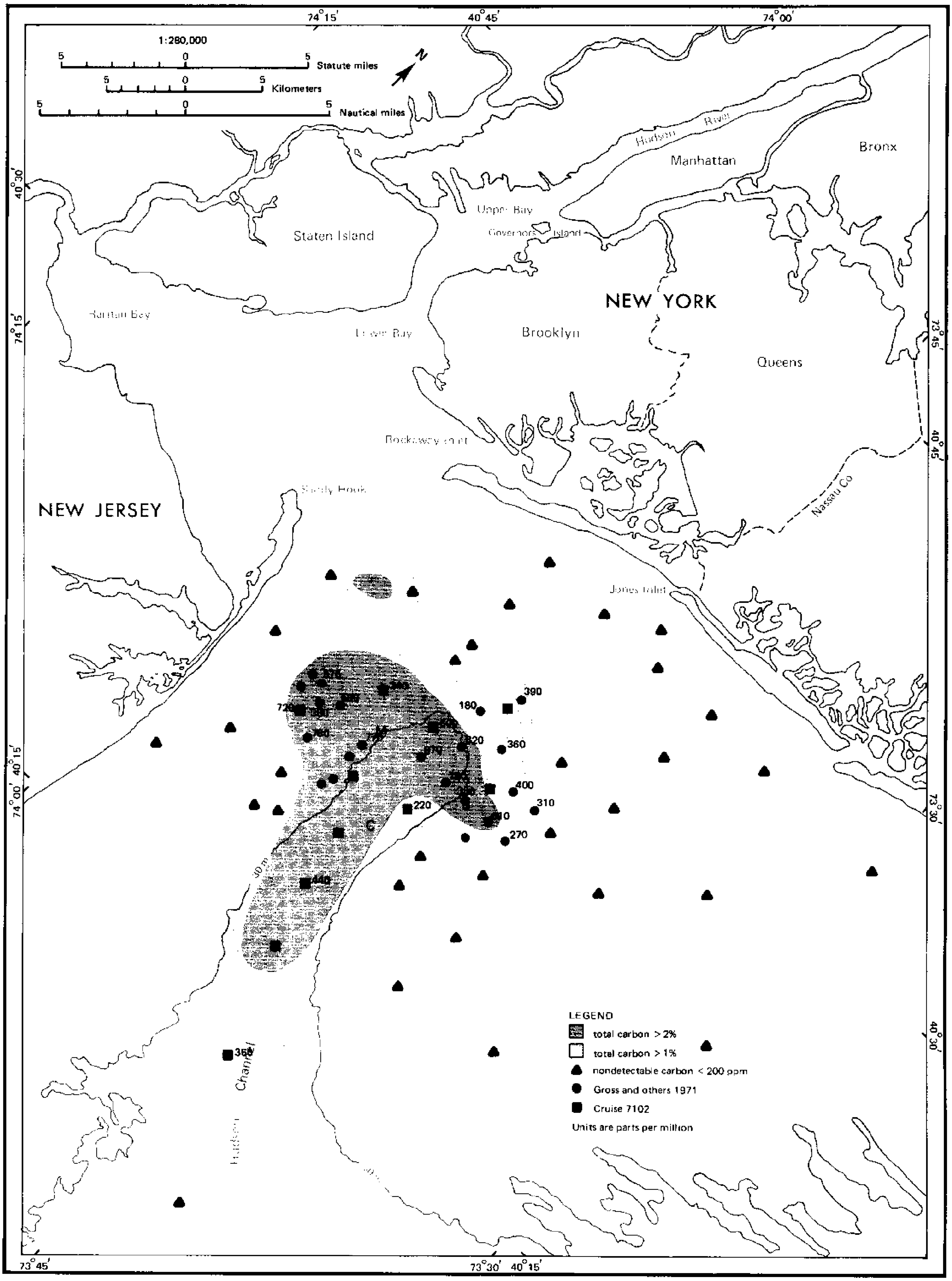
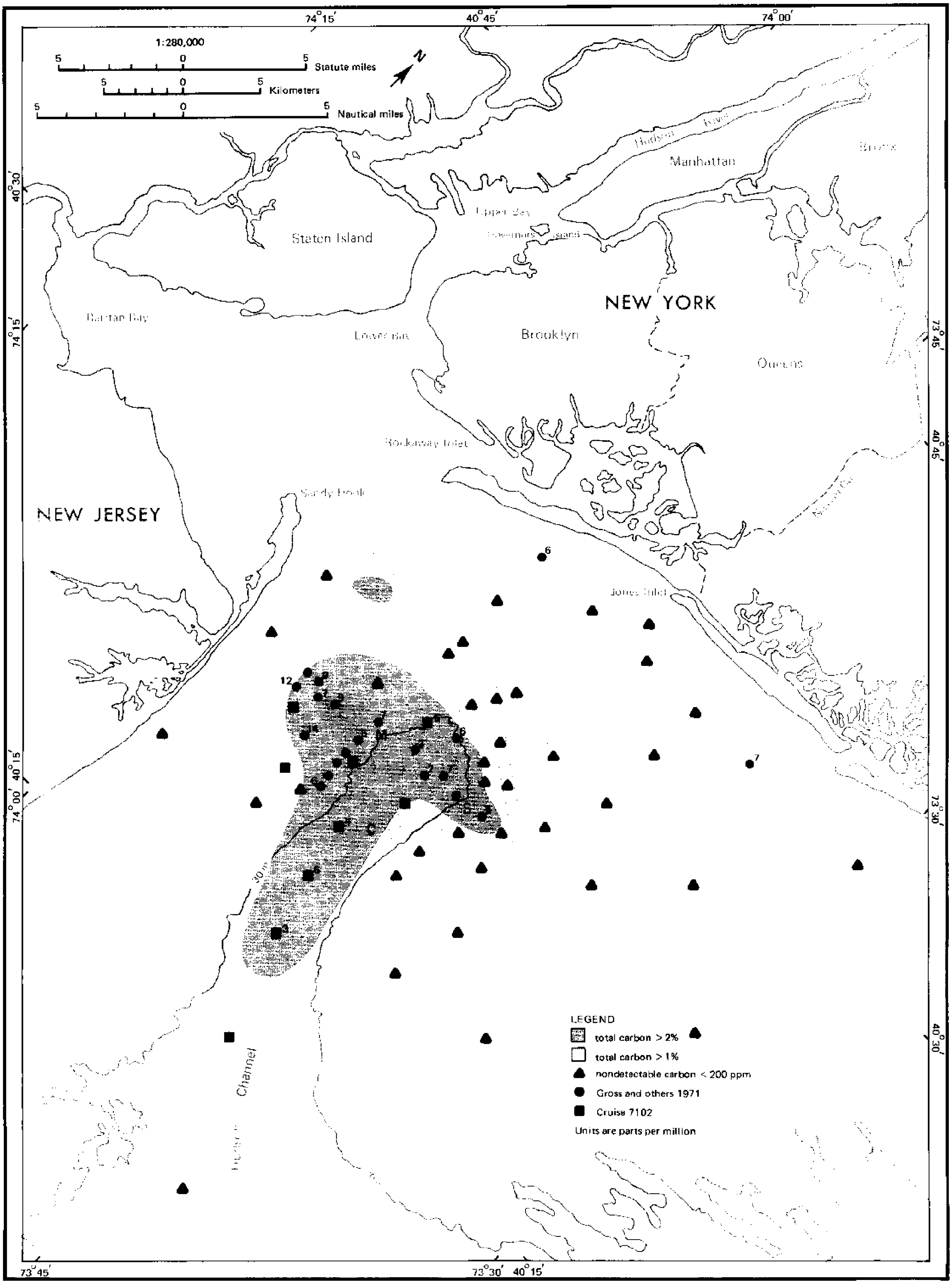
Map 6. Total lead concentrations in surficial deposits



Transverse Mercator Projection

Map 7. Total silver concentrations in surficial deposits



Transverse Mercator Projection

Environmental Impact of Waste Solid Disposal

Unfortunately we cannot say with certainty which of the several diagnostic criteria discussed above is the most reliable measure of the probable impact of the waste deposits on the marine environment. We know little about interactions between the deposits and the water above them or the animals living in or on them. Only limited field studies have been carried out to date.

The impact of waste solid disposal on the continental shelf can be appreciated only when we realize that scant riverborne sediment enters the Atlantic Ocean near New York. Nearly all sediment transported by east coast rivers is trapped and normally deposited in the estuaries, bays, and harbors (Emery 1965; Meade 1969). Consequently, the New York metropolitan region is not only supplying a large quantity of waste solids but is dumping them on the continental shelf where little other sediment is being deposited to dilute or bury the wastes (Gross 1970*c*).

Waste dumping operations are localized and usually involve releasing several thousand tons of solids whenever a barge or dredge is emptied. Thus, the ocean bottom in the disposal area may receive a relatively thick layer of waste almost instantaneously. The designated disposal grounds are small (a few square kilometers), although it is probable that dumping actually occurs over much larger areas owing to navigational errors, adverse weather conditions, and illegal dumping.

Studies of the behavior of sewage sludges discharged in the Bight have pinpointed some of the probable effects of sludge disposal in coastal ocean waters (NOAA 1975, 1976). Because sludge particles are fine grained and low density, they remain suspended in water. When sewage sludges are discharged in near-surface waters, visible plumes of discolored water move with the regional surface currents (see frontispiece). Slicks of surface-active materials and accumulations of floatable substances also form in disposal areas, causing not only aesthetic problems but also possible public health hazards associated with atmospheric transport of materials from the air-sea interface. Wave action and currents scouring the ocean bottom can resuspend and move sludge deposits in near-bottom waters (Harris, in press; Swift et al, in press). These processes are known to be important but their frequency and duration are not known.

Sludge deposits are often rich in organic carbon and metal content (Segar and Cantillo, in press; Thomas et al, in press), but the effect of metal enrichment on the marine ecosystem is poorly understood. There is evidence that metals build up in bottom-dwelling organisms and that metals such as copper may be transmitted to fish. The public health implications of such metal transfers through seafood to man have not been widely studied (Verber, in press) nor is their effect on marine ecosystems known.

In areas where large volumes of sludges have been dumped for a long time, bottom-dwelling communities have been transformed substantially (Pearce 1972). Observed changes could have been caused by altered physical properties of the bottom, by toxic metals and hydrocarbons associated with sludge solids, and by reduction in dissolved oxygen concentrations of near-bottom waters. Sewage sludge deposits have also been strongly implicated in the occurrence of diseases in marine organisms, such as finrot—the erosion of fishes' fin tissue (Murchelano and Ziskowski, in press)—and shell erosion in crabs, lobsters, and other crustacea (Rosenfield, in press).

The presence of human pathogens (disease-causing agents) in sewage sludges makes the ocean bottom unsuitable for shellfish production for human consumption (Verber, in press) and less attractive for recreational fishing. Some bacteria in sludge deposits are also known to resist antibiotics, thus possibly complicating treatment of diseases from these pathogens.

Effects of waste solid disposal on the continental shelf are difficult to evaluate. We know little about the distribution and characteristics of the waste deposits or about the ocean bottom off the New York Harbor entrance. Furthermore, comparable data on conditions before waste disposal operations began here do not exist.

Present waste disposal programs assume that wastes remain in the area where initially discharged. As long as no identifiable wastes wash up on beaches or interfere with recreation or commercial fishing, there is likely to be little immediate complaint. Although waste solids dumped in the ocean remain out of sight for a time, this does not necessarily mean that they do not pose problems for future generations.

Table 10. Some results of waste solid disposal in marine waters

Physical effects

- Changed bottom topography
  - Changed circulation: shoaling; elimination of small stagnant basins; restriction of lateral and vertical water circulation in New York Harbor
- Changed bottom type
  - Changed substrate for benthic organisms: large solid blocks—rock, rubble—attachments for benthic organisms; movable bottom materials (sand and silts, for example) undesirable for attached organisms; burying undesirable deposits
- Increased turbidity
  - Reduction of photosynthesis due to decreased light penetration

Chemical effects

- Leaching from deposits
  - Addition of nutrients or undesirable substances to water
- Reactions with suspended particles
  - Removal of materials from water by sorption onto particles
  - Possible depletion of dissolved oxygen

Biological effects

- New habitats created
  - Aquaculture: oyster bottom rehabilitated; artificial fishing reefs; lobster reefs; covering previous benthic communities
- Disease
  - Finrot on flounder
  - Closed shellfish grounds

Ocean areas now used for waste disposal may be valuable in the future as sources of sand and gravel, petroleum, or as navigational channels for new generations of deep-draft vessels. Hence, out of sight does not mean out of mind.

Then, too, some solid wastes disposed in the coastal ocean do not pollute. They may have neutral or even desirable effects. For example, waste solids have been used for construction of artificial fishing reefs in many coastal areas (Jensen 1975). Waste solids may be useful for rehabilitating parts of the coastal ocean as well as for covering over badly polluted bottom areas (Table 10).

One of the early field tests on the effects of ocean dumping on water quality in New York Bight was undertaken during a cruise in August 1971. Because of the seasonal variability in the Bight, conditions then may have been markedly atypical. Periodic surveys of the present and proposed disposal areas have been made to document environmental effects resulting from ocean disposal of waste solids (NOAA 1975, 1976).

Water Quality and Circulation in Waste Disposal Areas, August 1971

The 1971 survey of oceanographic conditions in the Bight waste disposal areas and adjoining waters was undertaken to (1) determine water quality near waste disposal sites during late summer, the season of highest water temperatures, lowest dissolved oxygen levels, and most sluggish water circulation; (2) determine effects of waste solid disposal on water quality in the disposal sites; and (3) investigate water exchanges between the disposal sites and New York Harbor. Sediment and water samples were collected from 8 to 21 August 1971 aboard R/V *Undaunted* operated by Cape Fear Technical Institute of Wilmington, NC; the institute is funded in part by the Sea Grant Program. Of 74 stations occupied during the two-week cruise, 48 were near the Bight waste disposal areas. Sampling and analytical techniques as well as shipboard instrumentation are discussed by Gross et al (1971).

Emphasis was on observing temperature, salinity, and dissolved oxygen as well as nutrient concentrations, with particular attention to substances such an ammonia, common in urban wastes but relatively rare in unpolluted seawater. The relationships between movements of waters and solids and their relationship to the waste deposit distribution and disposal operations are discussed in Gross et al (1971). Bowman and Weyl (1972) presented origins of movements of water masses on the continental shelf during 1971, and Bowman and

Wunderlich (in press) have summarized hydrographic properties of Bight waters.

During August 1971 surface water salinities (Map 8) were generally highest south of the continental shelf edge, where shelf waters mix with the Gulf Stream, and lowest in New York Harbor. The low salinities are caused by the discharge of the Hudson and other rivers as well as by the outflow from sewage treatment plants.

Surface water temperatures (Map 9) were lowest in Block Island Sound; the lowest temperature measured there was 18.3°C (64.9°F). Temperatures lower than 22°C (72°F) were rare except in New York Harbor, probably a result of mixing cold subsurface waters and of their subsequent entrainment into the surface layers. Over most of the region, surface water temperatures exceeded 23°C (73°F); in offshore waters closest to the Gulf Stream, surface temperatures were over 25°C (77°F). Both the temperature and salinity data are in general agreement with those reported by Redfield and Walford (1951).

The observed distribution of salinity with depth (Figure 5) in the harbor and in Hudson Channel is typical of the well-developed stratification of Bight water in late summer (Ketchum, Redfield, and Ayers 1951). If river discharge with salinity zero parts per thousand (S = 0 ‰) mixes with bottom waters of salinity 32 ‰, surface water salinity in the lower Hudson (24.7 ‰) indicates that about 4.5 volumes of subsurface seawater mixed with each volume of river water.

Temperature distributions (Figure 6) show the influence of surface warming and extensive mixing near the harbor entrance. Warming by the sun caused surface water temperatures to be highest (up to 23.3°C or 73.9°F) offshore. The coldest (below 6°C or 43°F) subsurface waters occurred in Hudson Channel. Mixing of surface and subsurface waters (and possibly some wind-induced upwelling in the waste disposal area) brought surface temperatures as low as 17°C (63°F).

These distributions of temperature and salinity are typical of an estuarine circulation system, in which low-salinity waters at the surface move generally seaward, mixing with the underlying, more saline and denser subsurface waters. Deep waters rise to mix with the upper layers, and then to move seaward. A counterflow of subsurface waters toward the harbor mouth resupplies these deep waters. Thus, subsurface waters in the Bight should move generally toward the harbor.

This estuarine circulation can move materials dissolved or suspended in the waters from the waste disposal sites toward the harbor. The distribution of ammonia is an example (Figure 7). Ammonia concentrations in offshore surface seawaters were low, usually less than 0.2 microgram-atoms of ammonia-nitrogen per liter of seawater (mg-at NH^3-N/liter). Around the waste disposal sites, near-bottom waters had ammonia concentrations exceeding 1 mg-at NH^3-N/liter; these bottom waters seemed to move toward the harbor entrance. Ammonia concentrations in harbor waters were much higher, reaching values of 18.3 mg-at NH^3 N/liter in the upper harbor. Through estuarine circulation, nutrients removed from the harbor and disposed of at sea may move with subsurface waters back into the harbor. In other

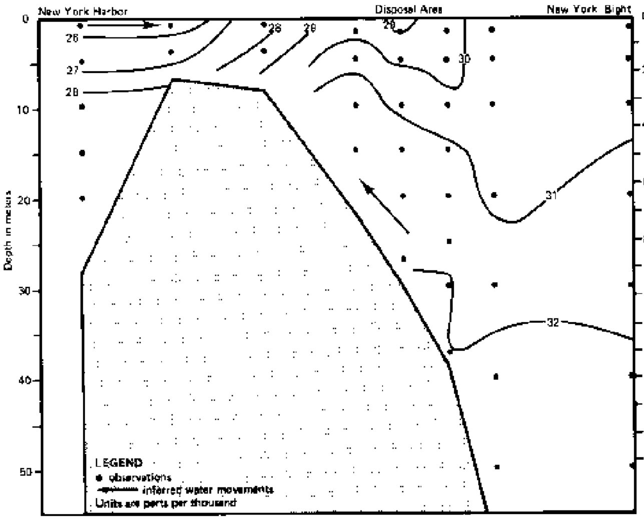


Figure 5. Salinity: vertical distribution, August 1971

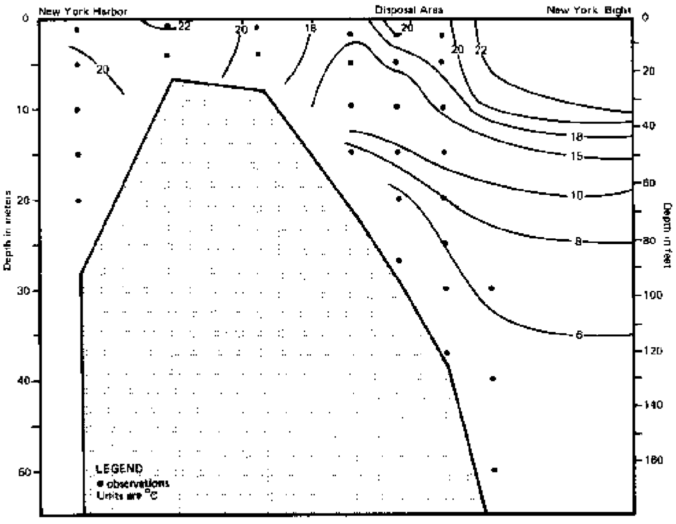
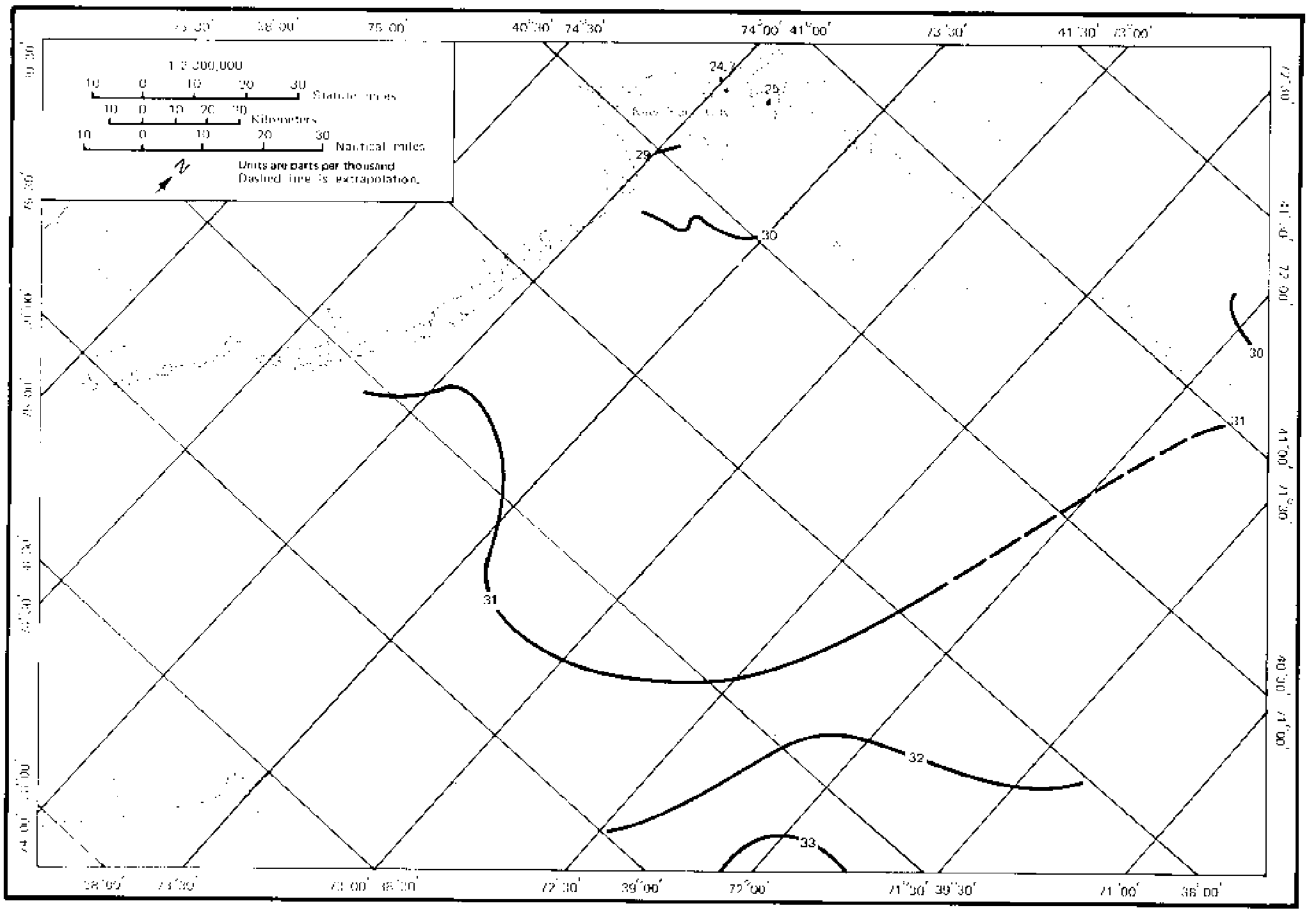


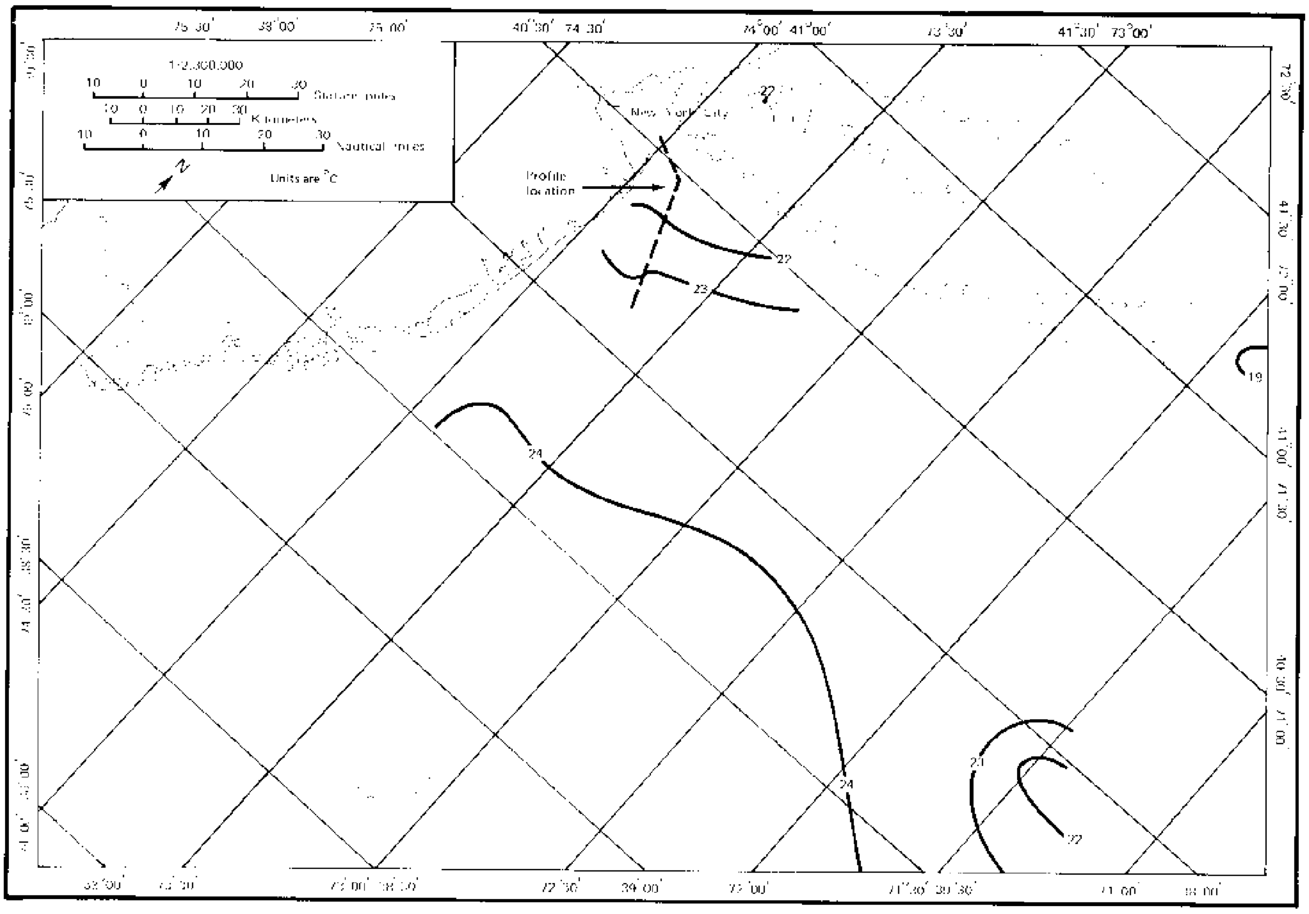
Figure 6. Temperature: vertical distribution, August 1971

Map 8. Surface water salinity, August 1971



Transverse Mercator Projection

Map 9. Surface water temperature, August 1971



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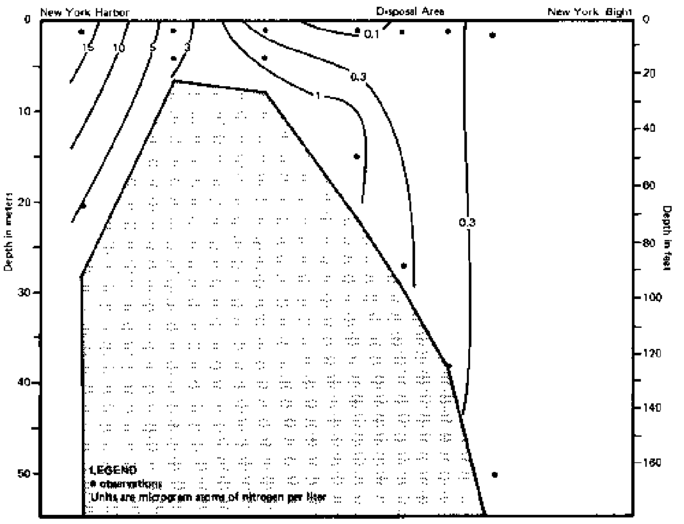

Figure 7. Ammonia-nitrogen: vertical distribution, August 1971

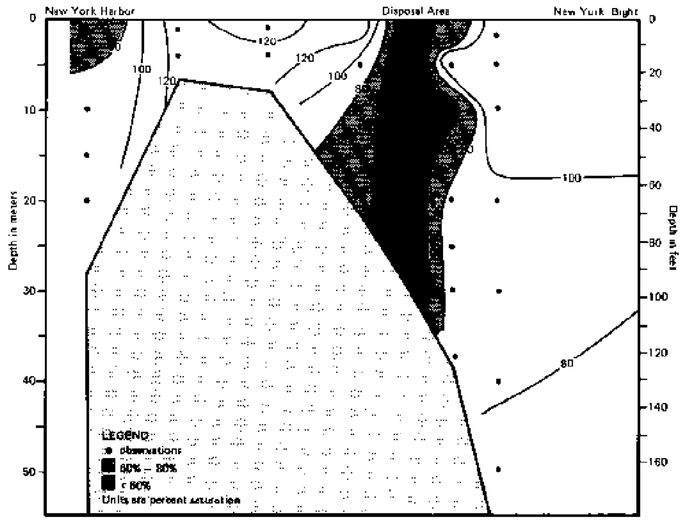

Figure 8. Dissolved oxygen: vertical distribution, August 1971

words, disposal of waste solids on the continental shelf near the harbor entrance may influence the quality of ocean water entering the harbor.

Depletion of dissolved oxygen concentrations in the disposal sites is striking but apparently localized (Figure 8). Surface and near-surface waters throughout the Bight are commonly saturated or supersaturated with dissolved oxygen owing to photosynthesis of phytoplankton. In Upper New York Bay and in the waste disposal areas, surface waters were unsaturated. Near the waste disposal sites, dissolved oxygen concentrations were well below saturation; levels as low as 35% were observed. The movement of these low-oxygen waters and their relationship to disposal operations could not be determined from the few stations sampled. But the effect of these waste disposal operations is apparently enough to depress dissolved oxygen levels locally.

Either the mixing of surface and subsurface waters or photosynthetic activity is sufficient to cause the waters moving across the harbor entrance to be resupplied with dissolved oxygen. In other words, there is no evidence from these data that low oxygen levels in waters near the disposal operations were affecting New York Harbor during August 1971.

The data on nutrient distributions show clearly that the estuarine circulation prevailing in New York Bight can return to New York Harbor substances released by waste disposal and waste deposits. To avoid these effects or to minimize the amount of nutrients returned to the harbor, more information about near-bottom circulation is needed.

Summary

Wastes from the New York metropolitan region have been dumped in New York Harbor and in New York Bight for centuries. As a result, shorelines have been built out, hills on the ocean bottom up to 10 m (30 ft) high have formed, and the head of Hudson Channel has been filled.

The waste solids come primarily from rivers (1 million metric tons/yr) and littoral drift of beach sands (1.1 million metric tons/yr), which mix with waste solids discharged by sewers (0.3 million metric tons/yr) and industrial wastes. This material settles in navigation channels where it must be removed by dredging; the material is then dumped in the Bight. Other sources of wastes placed in the Bight include demolition and construction rubble (0.6 million metric tons/yr), industrial sludges (0.4 million metric tons/yr), and sewage sludges from waste treatment plants (0.2 million metric tons/yr). Because of the mixing of riverborne sediments or beach sands with other wastes, the entire sediment load entering New York Bight from the land must be dredged and handled as a waste.

Ocean disposal is an attractive, relatively low cost disposal method for financially pressed coastal urban areas. In the New York region, it is difficult to imagine alternative disposal techniques or dumping areas that could accommodate the volume and variety of waste solids now dumped in New York Bight.

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