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Marine Sciences Research Center
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USE IMPAIRMENTS
OF
JAMAICA BAY

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OF

JAMAICA BAY

A Report Prepared by
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for
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This report is respectfully dedicated to

Mr. Martin Lang

who dedicated his professional career to cleaning the waters of the City of New York and who had the foresight to initiate major ecological research studies in the New York Bight, New York Harbor and Jamaica Bay.

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BACKGROUND AND HISTORY

Jamaica Bay and the surrounding uplands are located in an area of great urbanization. With the exception of a small area toward the eastern end, Jamaica Bay lies entirely within the City of New York. It is bordered by John F. Kennedy International (JFK) Airport on the eastern end and Brooklyn, New York on the northern and western sides (Figure 1). It is part of the Gateway National Recreation Area (GNRA) which, in addition to the Jamaica Bay area, includes units in Breezy Point, NY, Staten Island, NY, and Sandy Hook, NJ. The GNRA was established by Congress on October 27, 1972 to "preserve and protect for the use and enjoyment of present and future generations an area possessing outstanding natural and recreational features..." as defined in the enabling legislation (Public Law 92-592, October 27, 1972). Administered by the National Park Service, United States Department of the Interior, this area is comprised of 107 km^2 (26,500 acres) encompassing beaches, wetlands, dunes, forests and a wildlife preserve. The Jamaica Bay portion of GNRA, known as the Jamaica Bay unit, upon which this report will focus, contains 65 km^2 (16,000 acres) of which approximately 75% is water, marsh and meadowland and 25% is uplands (Table 1) (United States Department of the Interior, 1979).

The history of Jamaica Bay has been well documented in Jamaica Bay - A History (Black, 1981). Unless otherwise referenced, the historic information cited is from this survey.

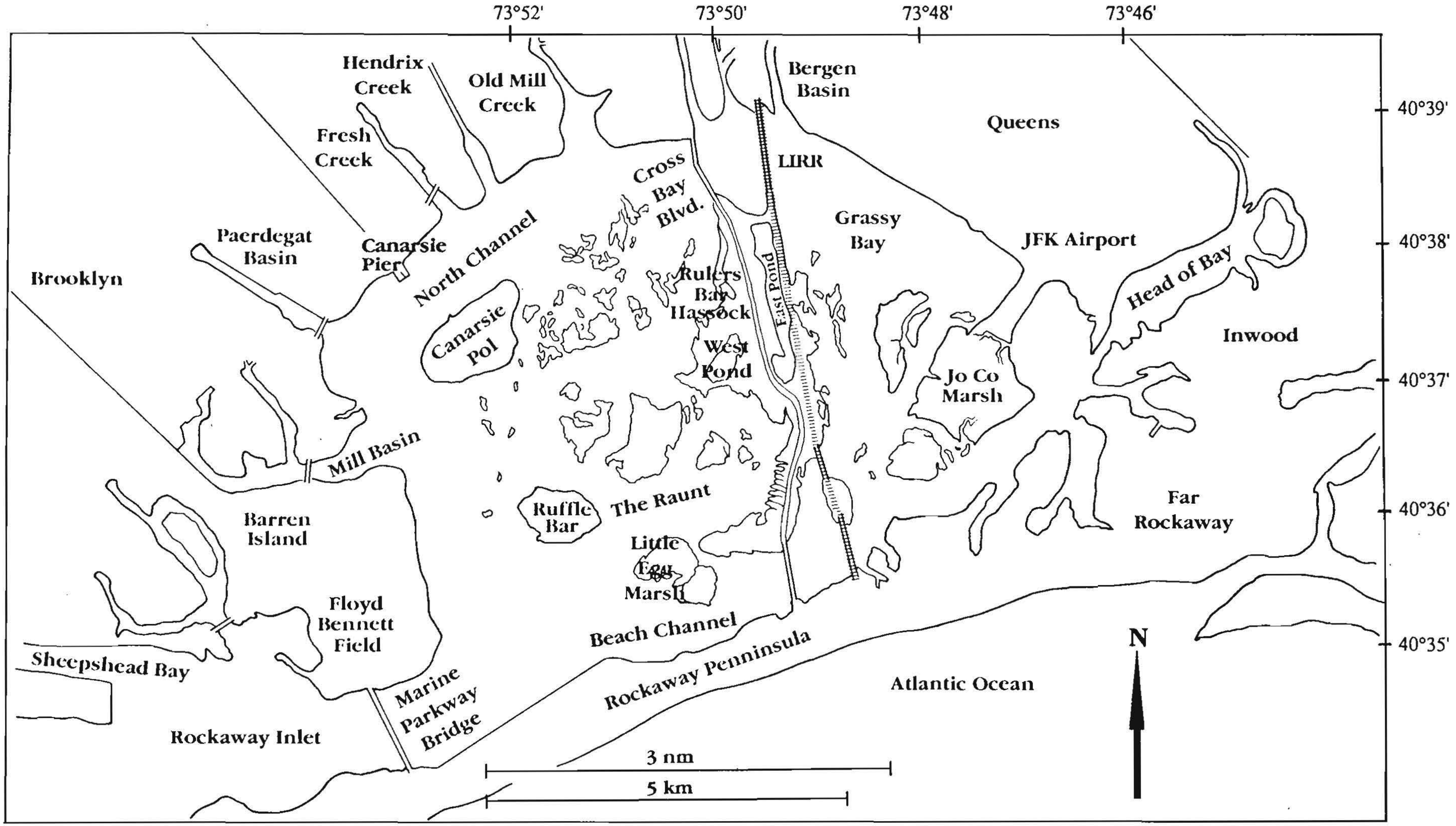

FIGURE 1. MAP OF JAMAICA BAY AND SURROUNDING AREAS.

Table 1. Areas of the various portions of Jamaica Bay (drawn or estimated from a number of sources).

Location	Area
Gateway National Recreation Area	107 km^2 (26,500 acres)
Jamaica Bay Unit (this is the area referred to in this report)	65 km^2 (16,000 acres)
Jamaica Bay historically (includes water and uplands)	101 km^2 (25,000 acres)
Jamaica Bay-area covered by water	52.5 km^2 (13,000 acres)
Jamaica Bay Wildlife Refuge	36 km^2 (9,000 acres)

Archaeological information indicates that during the late 16th and early 17th centuries Indians were settled in the area. Remains of shellfish, fish, mammals and birds as well as fish hooks, canoes, and rakes for harvesting shellfish, imply that the area's economy was based on fishing and hunting. There is no evidence that the Indians of this region negatively impacted the natural history of the Bay and the surrounding uplands. Before 1650, Dutch settlers had named this area "Rustdorp." Subsequently, the English named it "Jamaica" after the resident Jameco Indians (Water Resources Commission, 1965). Historic uses of Jamaica Bay and its surrounding uplands included residential settlement, agriculture, industry, fishing, shipping and other forms of transportation. By the 1660s, the Native Americans had, with few exceptions, been driven from the area, having relinquished their titles for Jamaica Bay shorelands to the Dutch between 1636-1667.

Prior to the 1850s, there was not much physical alteration of the lands or waters of the Jamaica Bay area other than some subsistence farming and several mills erected by the Dutch. Agriculture in the uplands of Jamaica Bay was largely for personal use with any surplus marketed. The same can be said for the fisheries of the Bay prior to 1865. Jamaica Bay was renowned for the "abundance, variety and quality" of its finfish and shellfish for almost three centuries. In the 1840s, approximately sixty men were engaged in occupations that centered on the Bay, its waters and fauna. That number continued to increase and after the Civil War fishing emerged as an important industry in Jamaica Bay.

Beginning in the late 1850s, the number of companies on Barren Island, part of what is now known as the Floyd Bennett Field area (Figure 1), began to increase. Although there were never more than seven or eight industries in operation at one time, between 1859-1934, twenty-eight companies had facilities on the island (Table 2). The principal industries of the area were menhaden fish (Brevoortia tyrannus) oil and fertilizer production and refuse deposition. Other industries were smelting (1890), asphalt production (1920s), and boat building. Several mills operated on the creeks that emptied into Jamaica Bay. A 1912 newspaper article described the three refuse disposal plants on Barren Island as among the largest in the world (Black, 1981). Refuse loads totalling between 500 and 1,000 metric tons arrived daily at Barren Island. The fish oil and fertilizer activities reached their peak in the early part of the 20th century. These fertilizer plants processed dead horses and other animals shipped from New York City. The resulting fertilizer was marketed in Europe. The impact of this industry on the flora and fauna of the area is unclear, but was likely not significant as the factories were not in operation for very long. The fish oil production plants did have a severe impact on the environment by depleting the menhaden populations; by the mid 1890s menhaden in Jamaica Bay were very scarce.

By the late 1800s, the uses of Jamaica Bay were in

Table 2. Barren Island industries from 1859 to 1934 (modified from Black, 1981).

NAME	ACTIVITY	DATE
Cornell East	Fertilizer	1859
West Factory	Fertilizer	1859-60
Smith & Company	Menhaden	1868-71
Steinfield & Company	Unknown	1869-73
Simpson	Unknown	1869
Goodkind Brothers	Menhaden	1872-77
Swift & White	Fertilizer	1870-81
Hawkins Brothers	Menhaden	1872-88
Jones & Company	Menhaden	1872-81
Valentine Koon	Menhaden	1872-74
Barren Island Manufacturing	Fertilizer	1875-88
Thomas A. Shae	Fertilizer	1875-81
E. F. Coe	Fertilizer	1878-95
Read & Company	Unknown	1879-83
Menhaden Company	Menhaden	1881-?
Barren Island Bone	Fertilizer	1884-93
P. White & Sons	Fertilizer	1884-?
Robinson	Unknown	1886-87
Barren Island Fertilizer & Oil	Fertilizer	1890-95
Andrew Wessel	Unknown	1895
Wimpfeimer	Fertilizer	?-1890
R. Recknagle	Unknown	unknown
Louis C. DeHomage	Unknown	unknown
Barren Island Oil and Bone	Fertilizer	1889-?
NY Sanitary Utilization Co.	Disposal	1905-19
Products Manufacturing	Disposal	?-1934
Vaniderstine & Sons	Hides	1910
Cove Chemical	Unknown	1911

competition with one another. The area was becoming a popular beach resort (including a substantial amusement park in Canarsie to rival nearby Coney Island), developing as a fishing area and growing as an industrial area.

Several train lines and many ferries and excursion boats crossed Jamaica Bay in the latter part of the 19th century to transport people to the Rockaway beaches. Some of the larger vessels carried as many as 3,700 people on a single trip. On a summer day in 1894, 75,000 people were reported at Rockaway beach (Figure 1), most having been transported there by the railroad that traversed Jamaica Bay. There were many hotels in the area, places to eat and several types of entertainment.

The Canarsie area (Figure 1) was the center of commercial and recreational fishing. A substantial shellfish industry, mainly oysters (Crassostrea virginica) and hard clams (Mercenaria mercenaria), was developing in the 1860s and reached a peak in the early 20th century. As early as 1904, however, contamination of Bay waters was such that shellfish populations were decreasing and many of the Canarsie oysters and clams harvested contained pathogens harmful to humans. By 1921, the shellfish industry was closed throughout the Bay by the New York City Board of Health due to high levels of sewage-related pollution. No shellfish have been legally marketed from the Bay since that time.

The 20th century also brought with it considerable physical alterations of the Bay which led to significant topographical changes. Jamaica Bay had been an almost circular embayment covering 101 km^2 (25,000 acres). It consisted mostly of low-lying islands, salt marshes and sand flats before the intervention of humans (Franz and Harris, 1985). The total Bay area covered by water has been substantially reduced by almost half to 52.5 km^2 (13,000 acres). In addition, filling and dredging caused the number of islands in Jamaica Bay to be greatly reduced, although approximately 16.2 km^2 (4,000 acres) of marshland in the central core of the Bay are largely intact (National Park Service, 1984). In the early 1940s, JFK Airport (known then as Idlewild Airport) was created on land formed from sand dredged from the bottom of the Bay, a process that destroyed 18 km^2 (4,500 acres) of marshland (Franz and Harris, 1985). Grassy Bay (Figure 1), the hole from which the sand was dredged, is now the deepest and possibly the most polluted of the open portions of the Bay (Franz and Harris, 1985).

In 1905, the Comptroller of the City of New York, E.M. Grout, proposed an "Improvement and Development of Jamaica Bay and other Waterfront Areas" program with Jamaica Bay to serve as a central point for goods manufacturing (Water Res. Comm., 1965). Through this program many areas were dredged, others filled, and some bulkheaded. Piers were also built to accommodate ferries and commercial ships and major roadways, railways and the airport now known as JFK were constructed. Some of the fill from dredging the northern and western portions of the Bay was used to create Floyd Bennett Field while fill from solid waste was used to extend the north shore of the Bay such that almost all of the original marshland of the outer zone was destroyed (Black, 1981). Industrial growth in the area was slow, yet, in 1906, industries on Barren Island produced goods (mainly fertilizer and oils) valued at over $7.5 million.

In 1910, the New York City (NYC) Department of Docks and Ferries became committed to plans for Jamaica Bay "improvement." As part of this plan, Rockaway Inlet and a shipping channel from Jamaica Bay channel to Mill Basin were dredged, Floyd Bennett Field Municipal Airport was created, and large areas of marsh were filled to produce uplands. In 1923, Cross Bay Boulevard was finished and in 1925 the first Canarsie pier was completed (Water Res. Comm., 1965). Many parts of the NYC Department of Docks' plan never came to fruition. This was due, in part, to Robert Moses arriving at the helm of Bay development in 1930. Robert Moses conceived the idea of the Bay as a park, not as an area of industrial and commercial expansion. In 1938 when the NYC Department of Sanitation proposed using Jamaica Bay as a dumpsite for solid waste by creating large artificial islands out of garbage, Robert Moses was successful in having Jamaica Bay transferred to the jurisdiction of the NYC Department of Parks and Recreation (Zeppie, 1977). Jamaica Bay remained under the sole jurisdiction of this Department until 1972 when the National Park Service took over management of the area.

In 1948, the Jamaica Bay Wildlife Refuge (JBWR) was established and managed by the NYC Parks Department. In 1951, two large freshwater ponds on either side of Cross Bay Boulevard, East and West Ponds, were created (Zeppie, 1977). On March 12, 1954 an agreement was drafted between the NYC Department of Parks and Recreation and the New York State Conservation Department wherein a basis was established for operating the wildlife preserve according to federal regulations. Since 1972 the JBWR has been managed by the National Park Service as part of the Gateway National Recreation Area. The remaining natural areas of the Jamaica Bay Wildlife Refuge have been preserved in a relatively undisturbed and natural state, in accordance with the long term management goals of the Refuge (Cardenas, 1985). Development in the Bay area is limited to expansion of educational and recreational facilities as well as improvements in mass transit to make the park more accessible (Zeppie, 1977).

Changes of management and jurisdiction of the Bay over the years were not simply titular. Different agencies' overviews on the uses and potential of Jamaica Bay have led to conflicts. The Port Authority of New York and New Jersey proposed expanding JFK Airport half-way across the Bay. This would not only have destroyed many of the Bay's natural features but would also have produced undesirable noise levels over the Rockaways and eastern Brooklyn (Newburger, 1968). In 1967, the National Recreation and Parks Association, under the auspices of the NYC Planning Commission, proposed deep-dredging Jamaica Bay waters "to permit full use by all types of recreation watercraft. The fill gained from dredging could be used to create a chain of connected islands" (Newburger, 1968). Effectively, this would have destroyed all the natural marshland, an especially attractive quality of the Bay, and created artificial islands out of context with the wildlife areas already present. The administration of the Bay since 1972, when the National Park Service assumed management of the area, has been consistent with the enabling legislation's definition of "preservation and protection."

Significant impairments to the Jamaica Bay system have occurred through a variety of means. The harvesting of shellfish has been eliminated due to the contamination of the water by sewage leading to human health concerns. Recreation has been restricted due to the need to protect the wildlife of the Refuge, although in 1987 ship traffic in Jamaica Bay, including recreational, industrial and commercial vessels, totalled 20,341 trips (United States Army Corps of Engineers, 1987). Water quality has been impaired by combined sewer overflows (CSOs), stormwater runoff, landfill leachate, topographical changes and sewage effluent. Faunal diversity has been diminished due to habitat alteration, stabilization and destruction.

Through most of its history, Jamaica Bay has served people as a source of food and a place for recreation. At the same time, the waters and wetlands have been used as an area of disposal for solid waste and sewage. By 1980, more than 1.5 million people were served by the six sewer districts that empty into Jamaica Bay (New York City Department of Environmental Protection, 1990; Nassau County Planning Commission, 1984).

These uses of the area are not compatible, as witnessed by the loss of the shellfish industry and the decline in water-contact recreational use. In spite of the changes in morphology and water quality, Jamaica Bay remains a tremendous asset to the City of New York and the New York Bight ecosystem. In order to conserve and hopefully rehabilitate Jamaica Bay, it is important to understand ecological processes in the Bay and human impacts on the marine ecosystem. Many of the stresses of excess population and industrialization as measured by pollutant loadings and ecosystem impacts can be specified in terms of use impairments - use impairments that have measurable social and economic relevance.

Broad categories of impairment attributed to pollution that are causing significant losses of ecological, economic or social values in Jamaica Bay are: limitations on swimming and other water-contact recreational activities; unsafe seafoods; losses of commercial and recreational fisheries; and impacts on marine animals and plants as well as water-dependant birds, herpetofauna and mammals. These impairments are generally caused by loss or modification of habitat, the presence of pathogens and toxicants, and excess nutrient loading. Measures of such impairments are not standardized, nor in many cases, totally quantifiable. Specific subsets of these impairments have been examined in terms of their spatial and temporal changes, when available. This report will describe the physical, biological and chemical characteristics of the Bay, discuss the uses of the area, and detail the most serious use impairments.

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PHYSICAL CHARACTERISTICS

Regional Setting

Jamaica Bay is located on the southwestern shore of Long Island and geographically is a shallow bay (Shalowitz, 1964) of the New York Bight. The New York Bight is a 39,000 km^2 (11,360 nautical miles^2) sector of the Mid-Atlantic continental shelf between Montauk Point, NY and Cape May, NJ, and is nearly 180 km (97 nautical miles) wide from the mouth of the New York-New Jersey Harbor Estuary to the edge of the continental shelf (Sindermann and Swanson, 1979). Jamaica Bay is located at the ocean entrance to one of the most urbanized waterways in the world, the New York-New Jersey Harbor Estuary.

Geology

The New York Bight is part of the eastern United States coastal plain province, derived from erosion of the Appalachian mountains since their uplift 70 million years ago (United States Department of the Interior, 1976). The Appalachians were a source of sediment to the coastal plains until the beginning of the Pleistocene epoch. Toward the end of that epoch, the last of four ice sheets created a terminal moraine forming present-day Long Island and Staten Island (US Dept. Int., 1976). After the sea level rise following the last glacial period, approximately 12,000 years ago, nearly half a million cubic meters of sand a year were being eroded from eastern Long Island shores and moved westward (National Academy of Sciences, 1971). This process of sediment transport has caused Jamaica Bay to be covered with Pleistocene deposits from the Wisconsin glaciation that lay over pre-glaciation clays and gravels. These deposits in turn overlay Cretaceous sands and clays which rest on a layer of bedrock (US Dept. Int., 1976). Most of the present surface soils in the marshlands of the Bay region are either sands or organic silts and clays. Most of this material is there as the result of human activities.

Morphology

The New York Bight is dominated by sandy shorelines and marshy embayments. Jamaica Bay is a coastal body of water, containing salt marsh islands within a tidal lagoon. It is shallow except where dredging has created channels and it is connected by Rockaway Inlet to the sea (US Dept. Int., 1976). The coastline has undergone changes resulting from anthropogenic activities as well as hydrodynamic action. In 1670, Jamaica Bay was an open embayment. Westward migration of both the Rockaway inlet and Breezy Point barrier island overlapped Barren Island around 1870. Jamaica Bay is now almost entirely enclosed, with Rockaway Inlet as its only connection to the ocean. Between 1876-1976 but mostly since 1907, alterations in the Jamaica Bay shoreline have been primarily caused by humans (US Dept. Int., 1976). Figure 2 shows the shoreline of Jamaica Bay in 1844 and

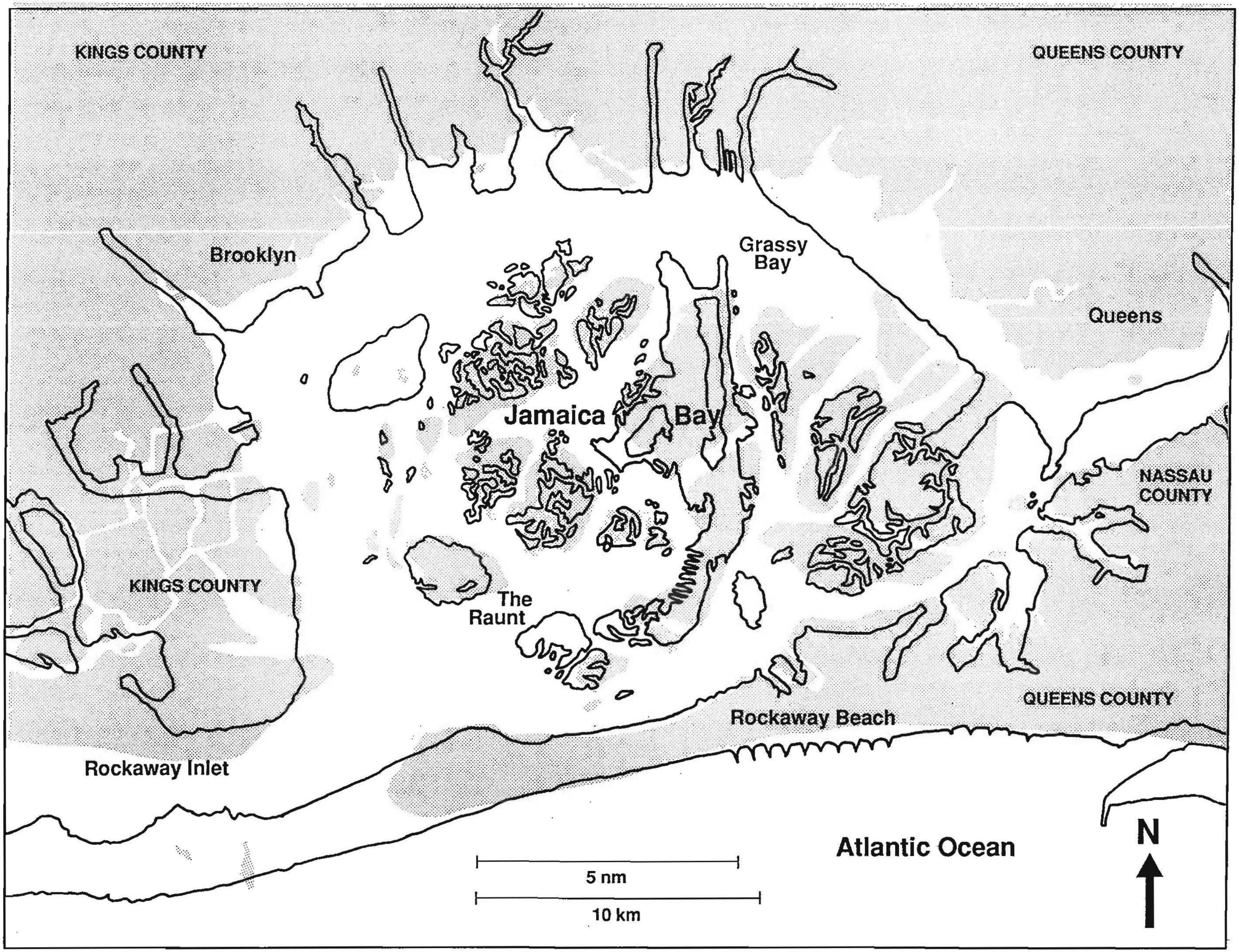

FIGURE 2. SHORELINE CHANGES - SHADED AREA DEPICTS SHORELINE IN 1844 AND SOLID LINE OUTLINES PRESENT DAY SHORELINE. (redrawn from US Dept. Int., 1976)

today (US Dept. Int., 1976). Due to its present configuration, the mean tidal range in the Bay increases from 1.50 m (4.9 ft) at its mouth (Plumb Beach Channel) to 1.65 m (5.4 ft) at its head (Head of Bay). Correspondingly, the mean tidal range inside Jamaica Bay (1.5-1.6 m [5.0-5.3 ft]) is greater than the range outside the Bay at East Rockaway Inlet (1.25 m [4.1 ft]). The depth-averaged salinity decreases from Rockaway Inlet towards the northern Bay at Bergen Basin. Maximum depth-averaged salinities of 30 parts per thousand are observed during the summer at the entrance to the Bay, and minimum depth-averaged salinities of a few parts per thousand are observed at the northern Bay after heavy rains. Depth-averaged temperature increases from Rockaway inlet to the northern coast of the Bay. Maximum depth-averaged temperatures of 24°C (75°F) occur during the summer at the northern shore and minimum temperatures of a few degrees Celsius are observed during the winter (New York City Department of Environmental Protection, 1991).

Prior to the City of New York's efforts to develop Jamaica Bay as a major seaport early in the 20th century, the Bay was a circular marshland of approximately 101 km^2 (25,000 acres). Public agencies, with the idea of developing the Bay as an industrial and commercial center, were responsible for most of the Bay's "remodeling," a great deal of which was part of the Jamaica Bay Improvement Plan (National Park Service, 1984). The development plan called for the widening and deepening of a moat between the inner and outer portions of the Bay. Some channels were dredged to 480 m (1500 ft) wide and 12 m (40 ft) deep. The dredged material was used to fill in the marsh area outside the moat for the construction of piers and docks. Further areas were filled as a consequence of solid waste disposal (Nat'l Acad. Sci., 1971). The addition of solid-waste landfills along North Channel in Brooklyn and Queens, destroyed nearly all of the 49 km^2 (12,000 acres) of marshland along the periphery of the Bay. As of 1970, only 52.5 km^2 (13,000 acres) of the Bay, with 16.2 km^2 (4,000 acres) of inner Bay area, remained essentially unaltered (Nat'l Acad. Sci., 1971). The creeks that once transected the marshes can still be seen, however the marshes that stood behind the beaches have been filled in with refuse, covered over with sand, and graded. The shores of the former creeks have been bulkheaded and many of them have become stagnant basins. Sewers have replaced the watercourses that once drained into the creeks from the open lands of Brooklyn and Queens. Large sewage-treatment plants now stand at the heads of several basins (Nat'l Acad. Sci., 1971). The Shore (Belt) Parkway, Howard Beach and Hamilton Beach housing development projects and the John F. Kennedy (JFK) International Airport are among the many constructional changes that mark the Bay area.

During the period from 1900-1970 the US Army Corps of Engineers issued an average of three dredging permits per year for Jamaica Bay (Nat'l Acad. Sci., 1971). Dredging was done to obtain fill and provide navigational routes, the maintenance of which often required re-dredging. The development of Rockaway Peninsula, Canarsie Pol, and Floyd Bennett Field, has required further dredging. A conservative estimate of the total sediment dredged in Jamaica Bay through the years is 70.9×10^6 m^3 (92.7×10^6 yd^3) (Table 3). The largest single authorized project was the dredging of 37×10^6 m^3 (48.4×10^6 yd^3) of sediment from what is now called Grassy Bay to provide fill for present-day JFK Airport. The dredging left a deep pool into which the Jamaica Sewage Treatment Plant discharges about 360×10^6 liters (95 million gallons) of secondarily treated sewage per day (Staubhtz and Wolcott, 1985).

Eighty years of dredging activities have considerably altered the bathymetry of Jamaica Bay. Only a very small portion of the Bay preserves its original depth. The earlier mean depth was nearly 1 m (3.3 ft) whereas the present mean depth is approximately 5 m (16 ft). One of the net effects of the dredging and deepening of the Bay has been an increase in the residence time (or flushing time) of the basin. Water now requires three times longer (35 days) to be flushed out of the Bay than 80 to 100 years ago (11 days) (Nat'l Acad. Sci., 1971). During the period from 1912 to the 1930s, a 300 m (1000 ft) wide and 10 m (30 ft) deep ship channel was dredged from Rockaway Inlet to Paerdegat Basin (Nat'l Park Serv., 1984). By 1940, a single contiguous stretch of land joined the previously separated islands of Goose Creek, Black Bank Marsh, Rulers Bar Hassock, Goose Pond Marsh and Big Egg Marsh (Nat'l Park Serv., 1984).

Table 3. Volume of material (in m^3) that was dredged up until 1971 (modified from Nat'l Acad. Sci., 1971).

Project	Volume
J.F. Kennedy International Airport (1938)	45.0x10^6
Easterly runway extension (1958)	3.2x10^6
Westerly (4-22L) extension (1962)	8.5x10^6
Sanitary fill along north shore (1938-1971)	7.4x10^6
Seaplane runways near Floyd Bennett Field (1942)	1.9x10^6
Fill for New York State Mental Hygiene Hospital (1969-70)	2.7x10^6
Beach Channel High School	1.5x10^6
Twin Pines Village	0.7x10^6
Total until 1971	70.9x10^6

By 1970, almost all of the marshes that once lined the shores of Jamaica Bay had either been filled or were above mean high tide levels. The eastern marshes were bisected by a rapid transit line and a roadway. In 1953, two brackish ponds, the East and the West Pond, were created from dredging for fill to repair the rapid-transit lines. Urbanization through filling of low level areas and development of related support structures has added topographical relief to Jamaica Bay where very little was originally present.

Urban development has also decreased the surface area of the Bay as a result of the filling of extensive zones for residential and service-oriented activities. As a consequence, the tidal prism, defined as the volume of water contained in an embayment between mean high water and mean low water (Ippen, 1966), has decreased to a present value of 7.1×10^7 m^3 (9.3×10^7 yd^3). The present tidal prism is about 36% of the total Bay volume at midtide (Staubhtz and Wolcott, 1985). The 1962 extension of JFK Airport (runway 4-22L), obstructed the natural counter-clockwise flow in Jamaica Bay and increased the residence time of the creeks by threefold what it was 100 years ago, when the creeks were not bulkheaded (US Dept of Int., 1976). Grassy Bay was transformed into a nearly stagnant pool in which fine-grained sediments and their associated contaminants readily precipitate (Nat'l. Acad. Sci., 1971). The deepening of certain channels, the shoaling of others, and further natural changes suggest that the Bay's configuration is normally dynamic and not stable.

Hence, any attempts to stabilize Jamaica Bay require constant dredging and filling efforts that generally cause ecological damage to the system.

The dredge/fill process has resulted in a decreasing surface to volume ratio of the Bay. In fact, it is estimated that 70% of the present Bay water volume was added as a result of dredging (Feuerstein and Maddaus, 1976). Another of the effects of the deepening of the Bay has been an increase in the tendency of the water column to become vertically stratified. The process of stratification can lead to longer residence times of pollutants and to severe dissolved oxygen depletion, generally in the summer. The Bay's surface area is still broad enough, however to allow for wind-driven turbulent vertical mixing (US Dept. Int., 1976) and the tidal currents are strong enough to generate considerable energy for vertical and lateral mixing most of the year (Staubhtz and Wolcott, 1985).

In addition to the physical alterations to Jamaica Bay, there probably has been a significant change in the structure of the water column. This has occurred gradually with the construction and use of the six sewage treatment plants that discharge all or part of their effluent into the Bay. These plants discharge approximately 1087×10^6 liters daily (287 MGD). Since the Coney Island Sewage Treatment plant outfall is located in Rockaway Channel, only about half (one tidal cycle) of its effluent influences the Bay directly. Thus, some 894×10^6 liters per day (236 MGD) of fresh water are added to the Bay via sewage effluent that can modify the water column and influence the circulation. This is a considerable amount of fresh water, equalling about 1.3% of the tidal prism. Given that the water surface of the Bay is 52.5 km^2 (13,000 acres), the input of sewage effluent is equivalent to adding a 1.7 cm (0.7 in) surface film over the entire Bay each day.

Although the quantity of fresh water that is still added to the Bay via groundwater seepage and through natural streams and rivulets is unknown, it is apparently quite small because of the manner in which parts of the Bay have been bulkheaded and its tributaries channelized by storm sewers and CSOs. Leendertse and Liu (1975) estimated that some 149 km^2 (36,700 acres) surrounding the Bay are drained by storm sewers and CSOs (an anthropogenic watershed). Zeppie (1977) estimated surface runoff to the Bay to be about 1.6x10^{11} liters per year (4.0x10^{10} gal per year) or 4.7x10^8 liters per day (1.1x10^8 gal per day). This is only approximately 50% of the effluent discharged directly into the Bay by the six sewage treatment plants (1.1x10^9 liters per day, 2.9x10^8 gal per day). Thus sewage effluent is probably the largest source of fresh water to the Bay averaged over the year.

Parts of the shore of Jamaica Bay are still lined with marsh and grasslands. Portions of the northern and western peripheral marshlands remain although they are much reduced. Constructional changes and urbanization that have taken place surrounding the Bay will not permit the inland migration of the marshlands otherwise expected under the constant sea level rise of 2.8 mm

(0.11 inches) per year recorded in the New York Harbor area since the 1890s (Swanson, 1976; Hicks et al., 1983).

The topography and water quality in some parts of the Bay have been drastically altered due to sewage disposal, dredged bottoms, and sanitary landfills. Grassy Bay is one of the deepest and most stagnant areas of the Bay; it is as deep as 15 m (50 ft) at several locations during mean low water. It has a small tidal prism, long residence time, poor circulation due to channel constrictions at the northwestern Cross Bay Boulevard end and a stagnant zone at the northeastern end at runway 4-22L (Nat'l Acad. Sci., 1971). These conditions are aggravated by several factors: (1) outfalls from the sewage treatment plant on the north shore into Grassy Bay, (2) a major storm drain that enters Bergen Basin and flows into Grassy Bay, and (3) oil residues left by barges that have passed through the Bay and spilled part of their contents. The status of Grassy Bay, exemplifies the kind of situation that dredging and filling have caused in Jamaica Bay (Nat'l Acad. Sci., 1971).

Use Impairments

There have been many changes to Jamaica Bay over geologic and historic time. The coastline has been subjected to natural and anthropogenic modifications: dredging and filling have been the major modern alterations to the Bay. Streams have been bulkheaded, disrupting drainage and flow patterns. Freshwater is added to the Bay mainly via sewage effluent. Many of the islands and land additions in the region have arisen from filling activities, particularly the construction of runway 4-22L of JFK airport.

The urbanization around the Bay hinders the inland migration of marshes expected due to sea level rise in the area. Because rising sea level covers marshes at their seaward margins, the resulting trend is one of reduced wetland acreage. Although the loss of habitat has been a big problem for most fauna of the Bay, some bird populations are thriving on the islands created with dredged material.

Nowhere else in Jamaica Bay are the effects of morphological changes more clearly demonstrated than in Grassy Bay. This area was drastically deepened by dredging and the natural counter-clockwise circulation of the entire Bay was blocked just beyond this embayment by the filling of the natural channel by runway extension 4-22L. In addition, the outfall for the Jamaica Water Pollution Control Plant empties into Grassy Bay (see Water Quality chapter), carrying nutrients and particulate material. The combination of increased depth, poor circulation and increased nutrient loading has led to stratification of the water column and low dissolved oxygen in the summer. These effects are repeated, to a somewhat lesser degree, throughout the Bay.

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TOXIC SUBSTANCES

The accumulation of contaminants in the biosphere can result in changes in the structure and function of natural ecosystems. Aquatic pollution can also be a hazard to human health when some contaminants are transferred up the food chain into organisms that are consumed by humans. Several toxicants, such as polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethane (DDT), are soluble in fats but very insoluble in water. They therefore are selectively retained in living tissue and can be concentrated by uptake both from water and through trophic transfer from food organisms. A number of elements and compounds dispersed in the marine environment are toxic, mutagenic, teratogenic or carcinogenic and are, therefore, causes of concern. The United States Environmental Protection Agency (USEPA) has identified 129 priority pollutants. Organo-metallic compounds of the following metals and metalloids as well as the free metal ions are included on this list: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag), and zinc (Zn) (National Oceanic and Atmospheric Administration, 1988a). Pesticides and herbicides comprise a second category of priority pollutants, while PCBs, polynuclear aromatic hydrocarbons (PAHs), and oil and grease make up a third, "miscellaneous" category (NOAA, 1988a). There are many more USEPA priority pollutants, especially of the volatile types, but information on the concentrations of these others in Jamaica Bay is scarce.

Pollution in the greater Jamaica Bay area has been a problem since at least the middle of the nineteenth century. Industries, municipal facilities and private citizens felt free to dispose of a wide variety of noxious substances in the waters of the Bay, including even such occasional items as dead horses (Black, 1981). By the 1920s, after channels had already been dredged along the Bay's western and northern parts, it became apparent that the Bay would not be used as a major seaport. The main channel is still used, however, by barges. Raw sewage was released directly into the Bay until the 1930s. By 1927, however, the largest and most modern sewage treatment plant in the region, at that time, was constructed on Jamaica Bay (Squires, 1981). Landfills and dumps have been located along the perimeter of the Bay since the early 1900s, some have been closed only recently. They have been used for the disposal of garbage, street dirt, commercial waste, construction waste, demolition waste, ashes, incinerator residues, waste oil, and paint pigment wastes and solvents (Gibbs and Hill, Inc., 1984). Ongoing pollution led to the assessment by Newburger (1968) of the unsuitability of the Bay for recreational uses (bathing, fishing, boating). Pollution, primarily by metals, pesticides and petroleum products, continues to be a present-day problem. A report by the United States Department of the Interior (1976) indicated that within the Gateway National Recreation Area (GNRA), Jamaica Bay and Staten Island beaches were the areas most severely impacted by raw sewage, treated municipal and industrial wastewater effluents from water pollution control plants (WPCP), combined sewer overflows (CSOs), stormwater runoff from separate sewer systems, and seepage through landfills and faulty septic tanks. Point sources of pollutant discharge are indicated on Figure 3.

The greatest problem areas are the north and east sides of the Bay where the major basins drain densely populated areas via storm and sanitary sewer systems (Newburger, 1968). Dye studies have shown that the entire northern area of Jamaica Bay is affected almost uniformly by flow from the Jamaica Water Pollution Control Plant. The Rockaway Sewage Treatment Plant affects Southern Winhole Channel, Broad Channel and Eastern Grass Hassock Channel throughout the tidal cycle and Beach Channel principally during ebb tidal flows (Ingram and Mitwally, 1966). Today, most of the Broad Channel community is still using septic tanks which leach into Jamaica Bay (Don Riepe, Jamaica Bay Wildlife Refuge, personal communication).

Impacts of increased pollution loading are exacerbated by changes to the physical structure or morphology of the Bay. Dredging and artificial obstructions have substantially increased the Bay's flushing time, such that previously well flushed, sandy

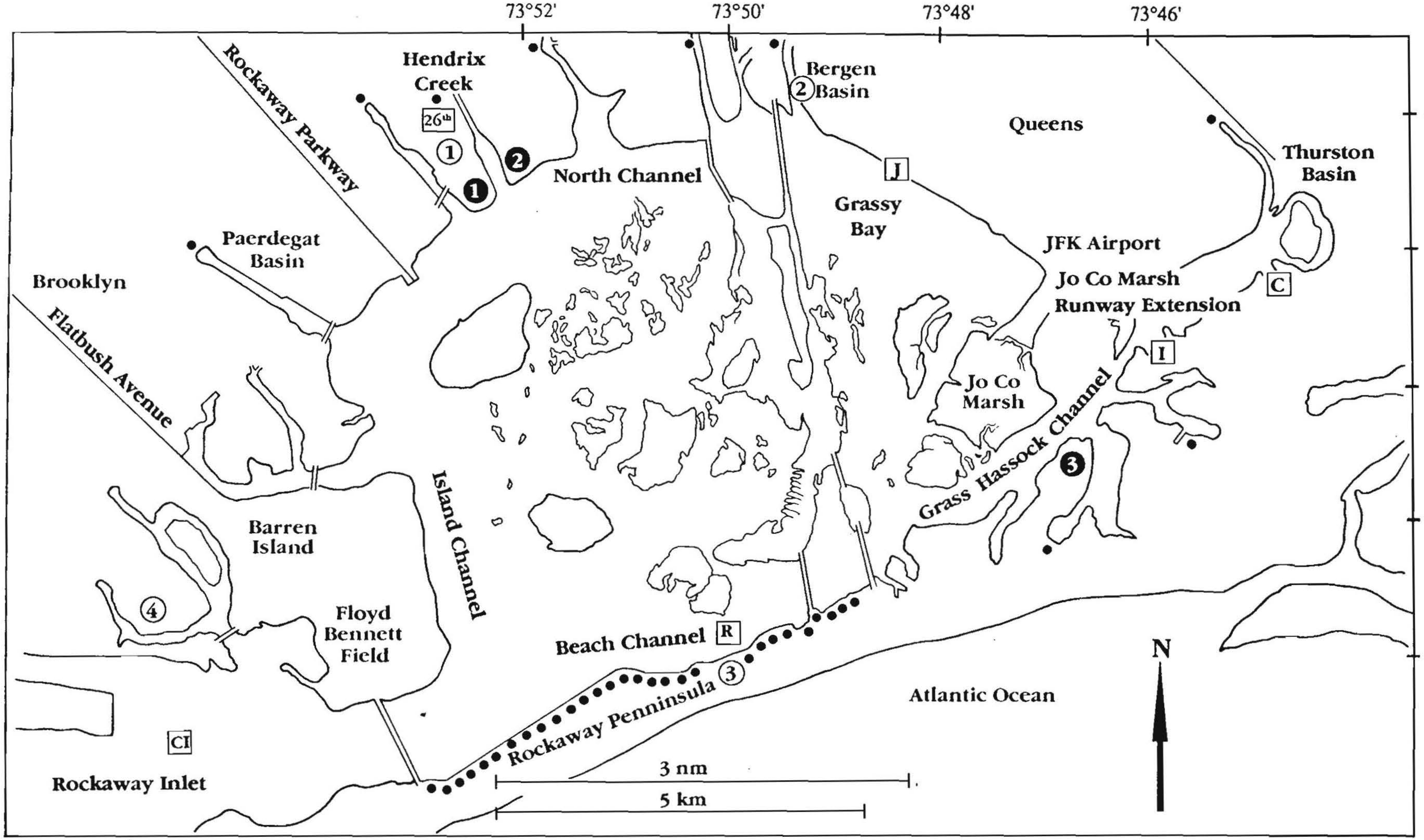


FIGURE 3. LOCATIONS OF WATER POLLUTION CONTROL PLANTS, WPCP OUTFALLS AND MAJOR CSOs IN JAMAICA BAY.

SEWAGE OUTFALLS	WPCP LEGEND	LANDFILL
I Inwood	① 26th Ward	❶ Pennsylvania Ave.
C Cedarhurst	② Jamaica	❷ Fountain Ave.
J Jamaica	③ Rockaway	❸ Edgemere
CI Coney Island	④ Coney Island	
26th 26th Ward		
R Rockaway		● Major CSOs

areas now have weak current regimes resulting in the deposition of high amounts of silt, clay and organics (Ramondetta and Harris, 1978). Increases in fine materials delivered to the system from sewage effluent also contribute to increases in deposition. Grassy Bay, at the eastern end of Jamaica Bay, is a good example of an area with increased deposition. Construction of the JoCo Marsh runway extension at JFK Airport (Figure 3) and the concurrent dredging of the basin during construction have transformed a once shallow, well flushed marsh into a deep settling pond with organic deposits containing high levels of metals and petroleum compounds (Franz and Harris, 1985). Due to the deepening through dredging, the constriction of the northwest end by Cross Bay Boulevard and blockage of the southeast end by the runway extension, Grassy Bay can nearly be considered a closed system (Ramondetta and Harris, 1978).

Metals and organic pollutants in marine systems are often associated with fine particles. Decreased flushing means that fine particles are more likely to settle out of the water column. Thus, increased deposition of muds and silts may indicate increased concentrations of pollutants in the sediments. Increased flushing times also decrease the dilution of dissolved and particulate pollutants resulting in increased residence time and concentrations of these substances in the water column.

Metals

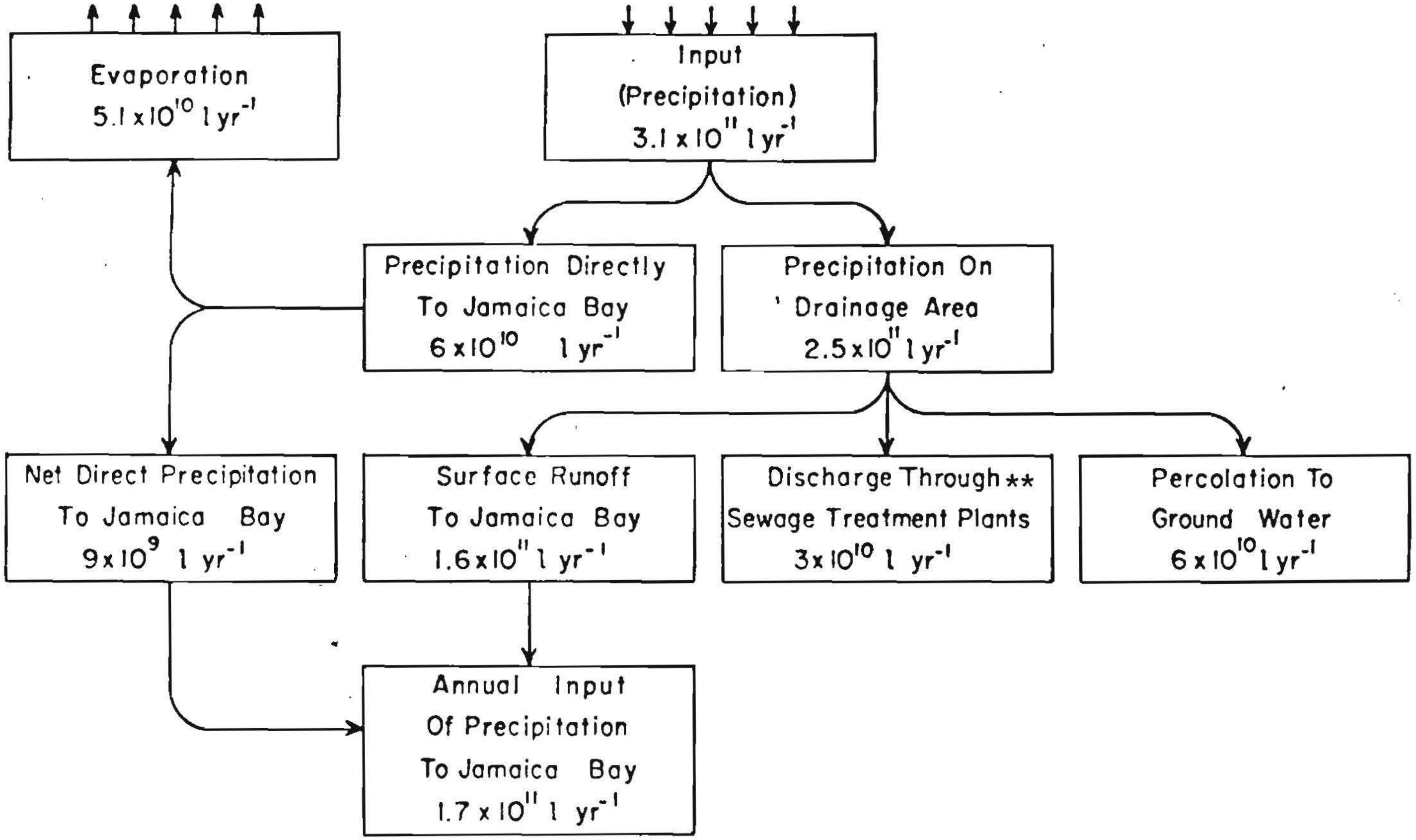
Many of the above-named priority pollutant metals and metalloids (As, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn) are found in Jamaica Bay sediments at levels well above background values (Franz and Harris, 1985; "background values" was undefined). Large volumes of sewage effluent and surface runoff from various sources carry these metals to the Bay (Table 4). There is a general decrease in sediment metal concentrations from north to south in the Bay, which is consistent with the locations of the major sources of sewage effluent and runoff in the north, but which may also be due to better flushing in the south. There are also some elevated metal levels in the sediments of Grass Hassock Channel near the Edgemere Landfill. These may be due to the fuel oil/gasoline installations on the southeast edge of the Bay (Franz and Harris, 1985). Surface runoff to the Bay is about $1.6\text{x}10^{11}$ liters per year ($4.0\text{x}10^{10}$ gal) (this does not include the domestic waste stream discharged through the sewage treatment plants) (Zeppie, 1977). A flow chart of the annual precipitation onto the Jamaica Bay drainage basin is presented in Figure 4. Natural surface water inputs are negligible, if not non-existent, since most of the basins have been bulkheaded (Zeppie, 1977).

Jamaica Bay sediments are generally enriched in total metals relative to sediments in other embayments in the United States. The greatest enrichments are for Pb, Cu, and Cd, with lesser enrichments for Ni and Cr. Between 1947 and 1977, the flux of Cu, Cd and Pb to Jamaica Bay sediments increased, whereas fluxes

Table 4. Metals in sewage effluent discharged into Jamaica Bay, NY. Loads are in kg per day. (1977 data from Zeppie, 1977; 1987 data from HydroQual, 1991).

Source	Cu		Cr		Ni		Cd		Hg
	1977	1987	1977	1987	1977	1987	1977	1987	1987
26th Ward	31.1	10.6	10.4	5.6	18.3	10.7	3.0	0.21	0.17
Jamaica	63.3	20.7	15.0	6.8	32.0	5.5	6.0	0.26	0.14
Rockaway	10.2	4.8	2.2	1.5	3.0	0.9	1.0	0.04	0.10
Coney Island	-	32.4	-	4.4	-	14.4	-	0.13	0.29
Cedarhurst and Inwood	1.1	-	0.2	-	0.3	-	0.1	-	-

Figure 4 ANNUAL PRECIPITATION FLOW CHART JAMAICA BAY DRAINAGE AREA *



* From Klein *et al.*, 1974

** Precipitation only - does not include the domestic waste stream of Cr and Ni remained fairly constant (Zeppie, 1977). Comparisons of 1971-1973 data with 1981-1983 data show a general decrease in sediment metal concentrations. The largest decrease was for Pb which may be due to the phasing-out of leaded gasoline at the end of the 1970s (Franz and Harris, 1985). These concentrations will be discussed in later sections.

Sands (< 1% organic carbon) generally contain lower concentrations of metals than muds. Metal concentrations correlate fairly well with each other and with percent total organic carbon (%TOC). Table 5 contains these correlation coefficients. Some muddy bottom sediments low in %TOC are also low in trace metals, indicating that %TOC might be the important factor regulating sediment trace metal content rather than grain size (Ramondetta and Harris, 1978).

Sediment metal concentrations are considerably greater than water column concentrations, as much as hundreds of times (Ramondetta and Harris, 1978), due to the tendency of the metals to adsorb to particles.

Concentrations of metals in ambient water throughout the metropolitan region are a subject of much discussion and research at the present time. Relatively high variability and high concentrations (above USEPA water quality criteria and New York State water quality standards) of eight metals (Cu, Hg, As, Cd, Pb, Ni, Ag, Zn) have been reported by many of the historical water column data sets, including the yearly Harbor Surveys conducted by the New York City Department of Environmental

Table 5. Correlation coefficient matrix for metals and organic material in sediments of Jamaica Bay (from Zeppie, 1977).

	Organic Matter	Ni	Cr	Pb	Cu
Organic Matter	1	0.93	0.90	0.83	0.82
Ni	0.93	1	0.94	0.89	0.88
Cr	0.90	0.94	1	0.88	0.89
Pb	0.83	0.89	0.88	1	0.99
Cu	0.82	0.88	0.89	0.99	1

Protection (NYCDEP) (1991) and in various environmental impact statements. A number of the high concentrations recorded occurred in the waters surveyed in Jamaica Bay. Relatively recent metals data collected throughout the Harbor area in 1988 by consultants for USEPA (Batelle Ocean Sciences) indicated much lower concentrations and variability. Reasons for the significant differences observed between the historical data and those of the USEPA were not immediately clear, but could include differences in collection, processing, matrix compensation (chelation extraction vs matrix modification) and form of metal analyzed (acid-soluble vs total recoverable). Therefore, a split sampling study for metals (total recoverable, acid-soluble, dissolved and particulate) in ambient Harbor waters and WPCP effluents was carried out in 1991 between Batelle and the NYCDEP. The main purpose of this split sampling was to evaluate the comparability of historical metals data derived from the traditional methods employed in the Harbor Survey Program, versus state-of-the-art collection, processing, extraction and analytical methods employed by oceanographic researchers. Two of the sites for ambient water sampling were in Jamaica Bay -- Jamaica Bay/JFK Airport (B1) and Jamaica Bay/Bridge (B2) (Marine Parkway Bridge across Rockaway Inlet). Effluents from all four of the WPCPs that discharge into the Bay were sampled -- Jamaica, Rockaway, 26th Ward and Coney Island.

The results of the split sampling study indicated that the metal concentrations in ambient water obtained by the NYCDEP were high relative to those obtained by Batelle (Batelle Ocean Sciences, 1991a & b). These results confirm the suspicion that historical estimates of metal concentrations throughout the New York-New Jersey Harbor have generally been too high. The results as they pertain to Jamaica Bay indicated that total-recoverable and acid-soluble copper concentrations exceeded the NYS standard (2 ppb) in the majority of samples collected. There were few exceedences of criteria for dissolved copper and no exceedences for any other dissolved metal. Bottom waters contained higher concentrations of metals than surface waters. Levels of metals in sewage effluents to the New York-New Jersey Harbor were below criteria; levels in effluents from the WPCPs that discharge into Jamaica Bay were about average among all 21 plant effluents tested (Batelle, 1991a).

Lead: Lead is used in gasoline, batteries, cables, paint and, in the past, plumbing. Lead is toxic to invertebrates, molluscs, crustaceans and fish, although molluscs appear to be more sensitive than fish (O'Connor and Stanford, 1979). Profiles of Pb concentrations in the Bay sediments suggest that increases in the flux of Pb are anthropogenic and closely tied to automobile combustion of leaded gasoline (Franz and Harris, 1985). Leaded gas use in cars has been phased out but it is still used in boats. The Pb reaches the Bay sediments via urban runoff considerably more so than by atmospheric deposition directly to the Bay (NOAA, 1988a). Lead was detected more than 50% of the time in CSO and runoff samples during a 1984 USEPA national CSO study done in other areas of the country. Lead was one of the more common pollutants in these flows and its concentration varied the least among drainage basins. Thus it is reasonable to expect that CSOs are a source of Pb to Jamaica Bay. In a 1975 study, an estimate of the total mass loading of Pb to the lower New York Bay was 5.8 metric tons per day, of which 41% was from urban runoff (Mueller et al., 1976). A portion of this runoff was discharged through CSOs.

Over the last fifteen years, Pb levels have decreased in Jamaica Bay sediments. Franz and Harris (1985) cite Pb as the metal showing the biggest decrease in sediment concentrations. Recent data (1986-1988) on Pb levels in the blue mussel (Mytilus edulis) from Jamaica Bay show no significant trend. The mussels were collected as a part of the NOAA National Mussel Watch Program. This program collects mussels and oysters from 177 sites around the coastal and estuarine United States and analyzes them for levels of contaminants. The average soft tissue Pb concentration for Jamaica Bay mussels was 5.5 parts per million (ppm) (NOAA, 1989). There are no United States Food and Drug Administration (USFDA) or USEPA criteria for Pb levels in shellfish.

Copper: Loadings of copper to surface sediments in Jamaica Bay are due to discharge of this metal from sewage effluent and runoff (Table 4). Klein et al. (1974) reported that residential waste water can account for 47% of the Cu in the Bay. Copper compounds are added to New York City's upstate reservoirs to control algal growth. Copper pipes carrying this water can also be a source of metal. An increase in the number of households in the Jamaica Bay area and an increase in the household use of chemicals and detergents containing Cu could account for the levels of this metal in the system. Copper is toxic to a wide array of species and causes growth inhibition and reduced photosynthesis in phytoplankton (O'Connor and Stanford, 1979).

Copper was one of the few metals to show an increase in sediment concentrations between the early 1970s and the 1980s. Franz and Harris (1985) attribute this to expansion of the Rockaway Sewage Treatment Plant. Actual concentrations in the sediment ranged from 1.4 to 186 ppm. An increase in concentration is also evident in mussel tissue analyses. The National Mussel Watch Program found a statistically significant increase for Cu in M. edulis from Jamaica Bay between 1986-1988 with average concentrations going from 10 to 13 ug/g (NOAA, 1989). There are no USFDA or USEPA criteria for Cu levels in shellfish.

Cadmium: Loadings of cadmium to surface sediments are due to the presence of this metal in sewage effluent and runoff (Table 4). Klein et al. (1974) reported that 49% of the Cd in the Bay is from residential waste water. Cadmium is leached from New York City's (NYC) galvanized iron distribution pipes to drinking water

(NOAA 1988a). Cadmium is also contributed to residential waste water from household chemicals. Another source of Cd to sewage effluent is its industrial use by the electroplating industry. The only growing use of Cd is in batteries. Incinerators and coal burning power plants as well as motor vehicles can generate aerosols containing Cd which contribute to concentrations in urban runoff from the New York-New Jersey Harbor drainage basin (NOAA, 1988a).

Cadmium is a teratogen, carcinogen, and a probable mutagen. Cadmium concentrations in bottom sediments at ten out of twenty six stations in a 1985 study exceeded the levels permitted by USEPA in sewage solids for ocean disposal (Franz and Harris, 1985). In that study, concentrations ranged from <0.005 to 5.8 ppm. No significant trend was seen in blue mussel tissue between 1986-1988 (NOAA, 1989). The average tissue concentration was 2.2 ug/g. There are no USFDA or USEPA criteria for Cd in shellfish.

Chromium: Chromium can exist in the marine environment in two different forms, trivalent and hexavalent, the latter being more toxic to organisms. Chromium reduces photosynthesis in algae and has been shown to affect egg and embryo development in some invertebrates and molluscs (O'Connor and Stanford, 1979). The flux of Cr to the sediments has been relatively constant since 1947 (Zeppie, 1977; Franz and Harris, 1985). The electroplating industry is an important source of Cr to the Bay via sanitary sewer effluent. This source accounted for 43% of the Cr entering NYC waste water in the early 1970s (Klein _et_ _al_. 1974). Since 1975, the electroplating and metal finishing industries have reduced their loads of Cr to the sanitary sewers by 95% through pretreatment (NYCDEP, 1989). Chromium was detected in greater than 50% of CSO and runoff samples in other drainage basins (USEPA, 1984). No significant trends were seen in mussel tissue levels in recent years; the average tissue concentration of 1.8 ug/g (NOAA, 1989) does not exceed the USEPA criteria of 54 ppm for hexavalent Cr. The USEPA criteria were revised and updated in 1988 by the EPA Region IV Office (USEPA, 1989). These criteria have not been formally adopted by USEPA, but in this report, where the Region IV criteria are more stringent than the formal criteria, Region IV numbers have been used.

Nickel: Nickel, at relatively high concentrations, has been shown to be toxic to a wide variety of marine organisms. The 48 hour LC_{50} values for crustacean species range from 150 to 300 ppm.

The flux of Ni to the sediments was relatively constant between 1947-1977 (Zeppie, 1977). The electroplating industry accounted for 62% of the Ni entering NYC waste water in 1974 (Klein _et_ _al_. 1974). Since 1975, the electroplating and metal-finishing industries have reduced their loads of Ni to the sanitary sewers by 93% through pretreatment (NYCDEP, 1989). Other important sources are lubricating oils and various petroleum products. Ramondetta and Harris (1978) noted the association of Ni with the asphaltene component of petroleum; they found areas with petroliferous pollution to be enriched in Ni. Sediment Ni concentrations are very site-dependent with higher levels near the Inwood and Norton Point fuel oil/gasoline facilities (Franz and Harris, 1985). The Ni concentration was found to have increased at one station in the North Channel between 1972-1982 (Franz and Harris, 1985). The levels in 1981-1982 ranged from 0.7 to 35 ppm. The Mussel Watch Program also noted a significant increase in Ni concentrations in M. edulis between 1986-1988 from 1.2 to 3.4 ug/g (NOAA, 1989), but these values are well below the USEPA (USEPA, 1989) criteria of 220 ppm.

Zinc: Zinc has been shown to affect egg and larvae development in invertebrates and molluscs and to be toxic to many marine organisms (O'Connor and Stanford, 1979).

The major source of Zn to the Bay is runoff (NOAA, 1988a). The sources of Zn to runoff are manufacturing, waste incineration and tire wear. Approximately 30% by weight of a finished tire is zinc oxide (ZnO) which is dispersed to the environment by tire wear (NOAA, 1988a). Zinc was the only metal detected in 100% of CSO samples taken from various areas of the country; the primary source to CSOs is runoff (USEPA, 1984). Zinc is also leached to the water supply from the galvanized water supply lines to NYC. Franz and Harris (1985) found a decrease in sediment levels between 1972-1982. In 1982 the range of sediment concentrations was 6 to 282 ug/g. No significant trend was seen in mussel tissue levels with the average concentration being 120 ug/g (NOAA, 1989). There are no USFDA or USEPA criteria for Zn levels in shellfish.

Mercury: The largest present use of mercury in the United States, is in batteries. Prior to 1972 it was used in fungicides and for agricultural purposes. It is also present in latex paint. Leaching of Hg from spent batteries and paint disposed of in landfills is becoming recognized as a potential problem for future toxicant control.

A human illness, Minamata Disease, is linked to consumption of Hg-contaminated seafood. The marine food chain became polluted with methyl-Hg as a consequence of industrial waste disposal in the mid-twentieth century in the waters around Minamata, Japan. Consumption of methyl-Hg-contaminated fish caused damage to the central nervous systems of many people there. This is the only documented instance of human mercury poisoning from seafood consumption. Mercury is also toxic to marine organisms (O'Connor and Stanford, 1979).

Historical data sets for Hg, especially for water concentrations, are held in little confidence due to the difficulty of Hg analysis in the marine environment (Saila and Segar, 1979). Keeping this in mind, increases in sediment Hg concentrations were seen at three stations in the Bay between 1972-1982. Franz and Harris (1985) attribute this to expansion of the Rockaway Water Pollution Control Plant. They also found that samples from five out of 26 stations had concentrations which exceeded the USEPA limits for sewage solids for ocean disposal. The yearly average concentrations of inorganic mercury ranged from 27 to 2800 ppm in 1982. No significant trends were found in mussels in recent years (NOAA, 1989). The average concentration was 0.26 ug/g, below the USFDA action limit of 1 ppm.

Metal Correlations: The levels of all metals in sediments correlate fairly well with each other but some pairings correlate particularly well (see Table 5 for correlation coefficients). Nickel and Cr is one such pair. The electroplating industry, over the past 50-60 years, discharged constant relative amounts of Ni and Cr which might account for the strong correlation in the flux of these metals to the sediments. Copper, Cd, Pb, and Zn are well correlated due to their similar patterns in anthropogenic loadings and their similar behaviors in marine sediments. Vanadium (V) and Cobalt (Co) are well correlated. Their main sources are petroleum derivatives. Their concentrations were highest in the southeastern part of the Bay near Inwood and Norton Point (Ramondetta, 1974; Ramondetta and Harris, 1978). Nickel is also correlated with V and Co and is a component of both petroleum derivatives and sewage effluent. Its presence in effluents is often a result of improperly disposed waste crankcase oils (Ramondetta, 1974; Ramondetta and Harris, 1978).

Strong hydrogen sulfide (H_2S) odors in the sediment suggest that metals may be present as insoluble metal sulfides. This is not surprising as the decomposition of the large loadings of organic material to the Bay may cause the sediments to become anoxic and reduction of sulfate occurs under these conditions. Sulfate reduction produces HS^- ions which may react with metals to form metal sulfides.

Relative concentrations of Cd, Cu, Cr, Ni, and Zn in sediments roughly correspond to their relative concentrations in New York City sewage effluent (Klein et al. 1974). Similar findings were made for New York Bight apex bottom muds (Harris and Waschitz, 1982).

Spatial Trends: Sediment metal values in 1981-1982 varied from site to site but tended to increase with larger percentages of mud, still well correlated with %TOC (Franz and Harris, 1985). The metal values are often hundreds of times greater than background concentrations (undefined by Franz and Harris, 1985), with peak values in the deep areas of Grassy Bay near the Jamaica Water Pollution Control Plant outfall, north shore outfall basins, Paerdegat Basin and Hendrix Creek (Figure 3) (Ramondetta, 1974; Ramondetta and Harris, 1978). The cleanest area is in Grass Hassock Channel between Silver Hole Marsh and Rockaway

Beach as well as at the entrance to Negro Bar Channel (Ramondetta and Harris, 1978).

The metal concentrations in sediments exceed permissible USEPA levels for ocean dumping of sewage sludge at many stations (Figure 5, stations 6, 9, 10, 12, 13, 15, 17, 18, 25, 26) which are largely along the northern edge of the Bay where there is outflow from water pollution control facilities. There are two stations, station 6 in the southeast portion and station 8 in the eastern portion that receive untreated sewage (National Park Service, 1984). All of these areas are significantly impacted by metals, but Grassy Bay (station 9) is by far the most polluted location in the Bay with much higher metal concentrations (Franz and Harris, 1985) due to its changed current structure and inputs from the Jamaica Water Pollution Control Plant and JFK Airport. The maximum concentrations seen in 1981-1982 for every metal but Hg were in Grassy Bay. The highest mercury concentration was seen just south of Ruffle Bar (Figure 5, station 25).

Squibb et al. (1991) found that average metal concentrations were higher in the Rockaway Inlet than in Jamaica Bay itself. This seems contraintuitive due to the relatively high tidal velocities, increasing dilution and hindrance to deposition of fine particles in this area. No explanations were offered for this phenomenon. The outfall from the Coney Island Water Pollution Control Facility is located in the inlet, however, and may be the source of the problem (Figure 3).

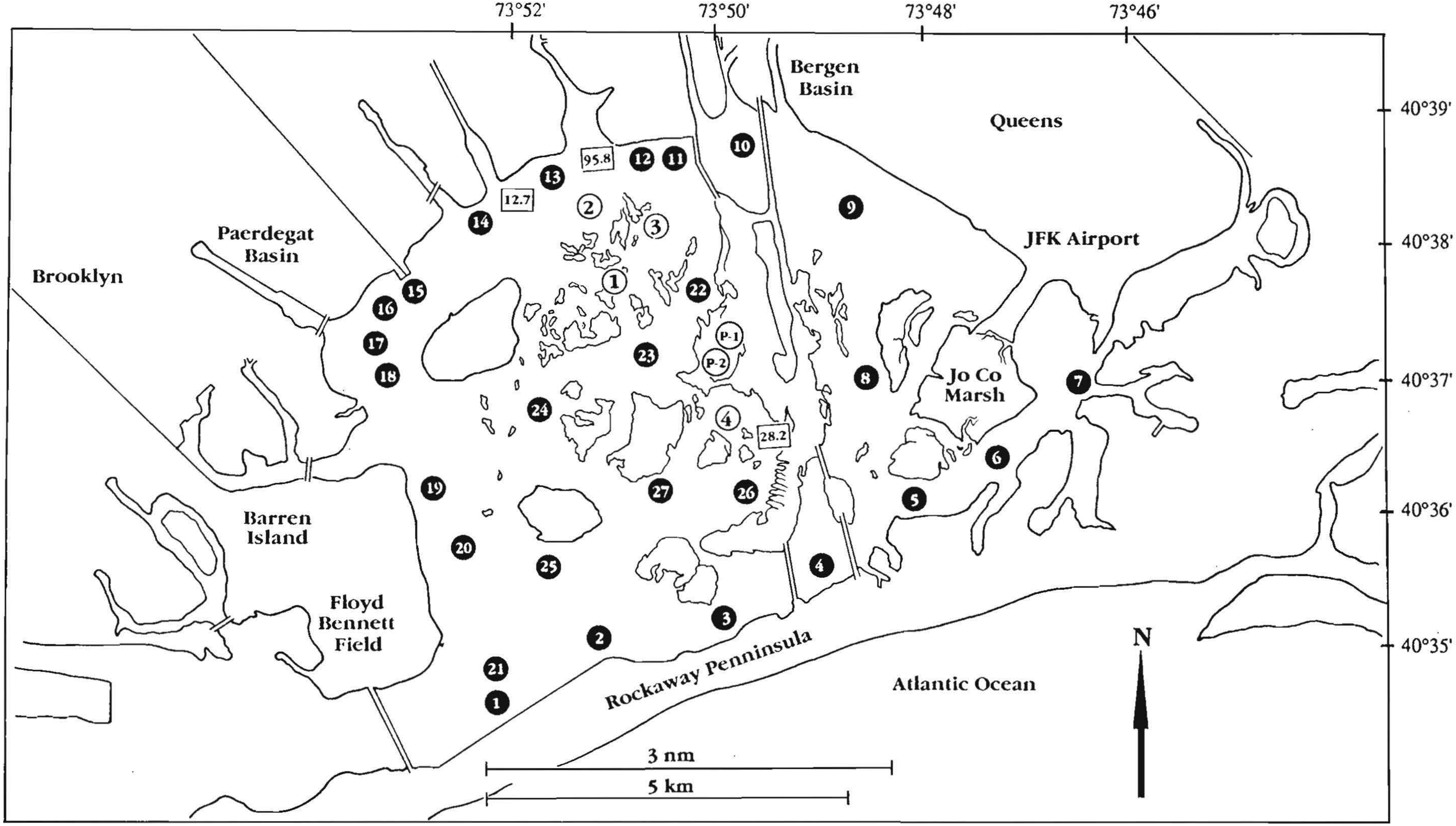


FIGURE 5. LOCATION OF SAMPLING STATIONS IN JAMAICA BAY USED IN THREE STUDIES OF METAL CONCENTRATIONS IN SEDIMENTS.

❶ - ㉗ **Franz & Harris (1985)**

① - ④, (P-1) & (P-2) **Zeppie (1977)**

12.7, 95.8, 28.2 **Ramondetta & Harris (1978)**

Pesticides:

Dichloro-diphenyl-trichloroethane (DDT) was extensively used in the New York Bight region from its introduction in the mid-1940s until its ban on eastern Long Island in 1966 and nationwide in 1972 (Howe et al. 1978). DDT, generally in low concentrations in the water column, is taken up by the plankton, whose consumers then accumulate the pollutant to an even greater degree (Howe et al. 1978). Crabs, fish and amphibians also have been found to store considerable amounts of DDT, other pesticides, and PCBs (Howe et al., 1978) due to resistance of these chemicals to degradation and their high solubilities in lipids. DDT and its metabolites DDD and DDE are carcinogenic (O'Connor and Stanford, 1979).

Average DDT concentrations in muddy sands just outside of the entrance to Jamaica Bay during 1984-1987 were 87 ng/g (NOAA, 1988b). This Jamaica Bay site was ranked tenth among the twenty most polluted areas in the United States with respect to DDT. Mussels in the Bay averaged 180 ng/g DDT tissue concentration during 1986-1988 and no significant trends in concentration were seen (NOAA, 1989). This concentration placed Jamaica Bay mussels twentieth out of the top twenty polluted areas in the nation. This concentration does not exceed the USFDA action limit of 5 ppm for fish tissue but does exceed a more protective USEPA (USEPA, 1989) criteria of 0.032 ppm.

Dieldrin, another chlorinated hydrocarbon, was present in sediments in the Bay at concentrations ranging from not detectable to 65 mg/l in 1970 (USEPA, 1976). After the USEPA concluded that it was carcinogenic, its registration was canceled in October 1974 except for a few restricted uses such as subsurface ground insertion for termite control. Dieldrin was present in mussel tissue at an average concentration of 32 ng/g dry weight in 1986 and was not detectable in 1988, a significant decrease during the period (NOAA, 1989). The USEPA (USEPA, 1989) criteria for dieldrin in mussel tissue is 0.00067 ppm.

Chlordane was used for control of pests on various agricultural products, wood, and lawns. Its use was phased out in the early 1980s and completely banned in 1988. It is still present in Jamaica Bay, however, as evidenced by average mussel concentrations of 69 ng/g dry weight during 1986-1988 (NOAA, 1989). This level exceeds the USEPA (USEPA, 1989) criteria of 0.0083 ppm. Jamaica Bay is ranked nineteenth among the top twenty areas of the nation in mussel tissue chlordane levels.

Polychlorinated Biphenyls:

Polychlorinated biphenyls (PCBs) are synthetic halogenated aromatic hydrocarbons with a variety of industrial uses. Production of PCBs in the United States ceased in 1977. Most non-electrical materials containing PCBs, such as plastics, carbonless copy paper, ink, etc, are now out of service and have been landfilled or incinerated (NOAA, 1988a).

PCBs have a wide range of acute and chronic health effects. They are accumulated in marine organisms and have been found in levels exceeding the USFDA action limit for edible tissue of 2 ppm in bluefish caught at Breezy Point and Rockaway Inlet (Bush et al. 1989). In a 1985 National Park Service study, average PCB concentrations in fish tissue were below the USFDA action limit of 2 ppm in all species tested, but above a more restrictive USEPA (Region IV) criteria of 0.0014 ppm (Tanacredi, 1987). The average concentration of PCBs in muddy sands (64% of sample grain size was less than 64 μm) just outside of the entrance to Jamaica Bay during 1984-1987 was 749 ng/g (NOAA, 1988b). This ranked it ninth out of the top 20 polluted sites in the nation. The mean mussel tissue concentration for 1986-1988 was 760 ng/g dry weight which ranked them fifteenth of the top 20 (NOAA, 1989) and exceeds the USFDA action limit.

Petroleum Hydrocarbons:

Petroleum pollutants include the oils and greases themselves and compounds such as polynuclear aromatic hydrocarbons. It does not take a major oil spill to damage water quality for wildlife and recreation. A small oil or kerosene slick on the water degrades the water for recreational purposes, and these slicks have often been observed in many parts of Jamaica Bay (Nat'l Acad. Sci., 1971). Municipal wastewater discharges to the Bay have been shown to contain high concentrations of organic carbon from waste crankcase oil (Tanacredi, 1977). Increasing demands for petroleum products and a lack of incentive to recycle waste oil may ultimately lead to greater concentrations of petroleum-derived hydrocarbons entering the marine environment (Sieger and Tanacredi, 1979).

Although continual, low-level discharges of petroleum hydrocarbons in waste water are not as dramatic as an oil spill, the consequences over an extended time period and under proper conditions could be equally devastating (Sieger and Tanacredi, 1979; National Research Council, 1985). Of the 5.28×10^9 liters (1.25 billion gallons) of new oils purchased annually by the United States auto industry, approximately 68% leave engines as waste and only about 4.23×10^8 liters (100 million gallons) is re-refined. Specifically, in the New York metropolitan area only 40% of an estimated 4×10^8 liters (94 million gallons) of automotive and industrial waste petroleum is re-processed (Sieger and Tanacredi, 1979). In 1981, the amount of petroleum hydrocarbons in wastewater effluent released into coastal waters of the world was greater than the average amount released from tanker and nontanker oil spills between 1975 and 1980 (Nat'l Res. Coun., 1985). Currently, the amount of oil and grease released by sewage treatment plants into the New York-New Jersey Harbor Estuary on a yearly basis is approximately equal to the oil released by a spill like that from the EXXON VALDEZ in Alaska in 1989 (R. L. Swanson, Waste Management Institute, SUNY Stony Brook, pers. comm.). The composition of these oils is different but the comparison is useful to emphasize the magnitude of these chronic, low-level releases.

Table 6 lists the average daily volumes of effluent entering Jamaica Bay from Water Pollution Control Plants in various years up to 1988-1989. The total amounts of effluent have not changed much over the past fifteen years (Tanacredi, 1990). The effluents contain large amounts of oil and grease, a portion of which are petroleum hydrocarbons. The National Research Council (1985) estimates that 40% of petroleum hydrocarbons are removed by secondary sewage treatment. Tanacredi (1990) estimates that 48-96% of total hydrocarbons are currently removed from sewage treatment effluent.

Polynuclear Aromatic Hydrocarbons:

Polynuclear aromatic hydrocarbons (PAHs) are generally stable, unreactive compounds containing two or more benzene rings. They can be subdivided into low and high molecular weight classes. Low molecular weight PAHs, such as naphthalene, tend to be more water-soluble, more volatile and more acutely toxic. High molecular weight PAHs, such as benzo(a)pyrene and fluoranthene, tend to bioaccumulate to a greater degree. Many PAHs are known or suspected carcinogens.

PAHs are components of fossil fuels. Crude oils consist of an average of one to three percent PAHs by weight (USEPA, 1984). The burning of fossil fuels and the transport of oil have elevated the levels of these compounds in the environment. Spills and disposal of waste oil are significant contributors of PAHs to surface water. Used motor oil may contain as much as

Table 6: Discharge from water pollution control plants in liters$\times 10^6$/day (modified from a. Mueller *et al*., 1976. b. Mueller *et al*., 1982. c. HydroQual, Inc., 1991 d. NYCDEP, 1991).

Plant:	1976[a]	1979-80[b]	1987[c]	1988-89[d]
Rockaway	72.9	87.4	102.6	95
Coney Island	376.2	372.4	395.2	387.6
Jamaica	353.4	383.8	376.2	372.4
26th Ward	250.8	342	247	228
Inwood (Nassau Co.)	5.7	6.9		
Cedarhurst (Nassau Co.)	3.5	3.5		

25.5 mg/g PAHs (USEPA, 1984). Inadvertent losses of petroleum products by barge transit to JFK Airport probably have contributed to PAH levels in the Bay. Losses and spills of lubricating oils and fuels during airport operations probably still contribute to PAH levels in the Bay. In marine systems, they are found associated with suspended solids and sediments, and become incorporated into the tissues of marine organisms, delivering a mutagenic burden to the marine ecosystem and, potentially, to humans (Ember, 1975; Payne and Martins, 1978).

Most of the bottom sediments contain PAHs and organosulfur compounds characteristically found in wastewater effluents discharged into the Bay (Sieger and Tanacredi, 1979). Substituted naphthalenes dominate the PAH compounds in the wastewater effluents delivered to the bottom sediments of Grassy Bay. These sediments are adjacent to the Jamaica Water Pollution Control Plant outfall and near Plum Beach, northeast of the sewage discharge from the Coney Island Water Pollution Control Plant (Sieger and Tanacredi, 1979).

Considerable amounts of PAHs remain suspended in near-surface waters of Jamaica Bay and have also been associated with compounds isolated from tissue extracts of marine benthic bivalves (Tanacredi, 1977). Previous studies (Payne and Martins, 1978) have shown that fish and other organisms, in areas with a history of oil contamination, contain elevated levels of mixed function oxidase enzymes that "bioactivate" complex aromatic compounds found in waste crankcase oils into mutagens. These metabolites have high molecular weight and can associate with suspended solids and sediments in marine environments.

The degradation rates of PAHs are very slow (i.e. 11 days for naphthalene and 3500 days for benzo(a)pyrene) and although there is no evidence to suggest that they bioaccumulate, they have nonetheless been found in tissues of marine organisms (Dunn and Stich, 1976; Lee and Anderson, 1977; Tanacredi, 1981). The potential adverse effects on human health are self-evident.

Analysis of wastewater effluent has revealed high concentrations of substituted naphthalenes. Surface sediments at six sites in Jamaica Bay and effluents from the Coney Island and Jamaica Water Pollution Control Plants were found to be contaminated by substituted napthalenes. Sediments near the Coney Island and 26th Ward Plants are also contaminated with naphthalene (Sieger and Tanacredi, 1979). The total yearly burden (1987) of napthalenes from wastewater to Jamaica Bay has been calculated to be greater than ten metric tons per year (Tanacredi, 1990; Table 7). Anderson <u>et</u> <u>al</u>. (1974) have suggested that napthalenes are the petroleum hydrocarbon fraction most toxic to marine organisms. Mammalian metabolism of napthalenes generates epoxides as intermediates (Sieger and Tanacredi, 1979), an activated metabolite more toxic than the parent compound.

The Mussel Watch found that levels of several PAHs figured on a dry weight basis in blue mussels exceeded the USEPA (USEPA, 1989) criteria of .00093 ppm. When converted to the wet

Table 7. Concentrations of extracted substituted naphthalenes in water pollution control plant effluents (in parts per billion) (from Tanacredi, 1990).

	1978		
Sample Effluent	April 11	June 6	June 28
26th Ward	22.9	10.9	5.7
Jamaica	24.6	11.5	6.8
Rockaway	13.7	3.0	5.5

weight basis of the criteria (approximate conversion factor of 5) they do not individually exceed the criteria but do far exceed the criteria when summed. Due to the similar chemistries of these compounds, an additive approach should be considered when judging their potential toxicities (Squibb et al., 1991).

Toluene, also a petroleum hydrocarbon, has been detected in ground water at the Edgemere landfill (Parsons and Brinkerhoff-Cosulich, 1982). Toluene has been detected in effluent from CSOs in other areas of the country greater than 50% of the time (USEPA, 1984).

John F. Kennedy International Airport

In a 1970 study (Nat'l Acad Sci., 1971), JFK Airport was listed as a major source of air pollution - carbon monoxide, hydrocarbons, nitrogen oxides and particulates - to the Jamaica Bay environs. Particulate matter and smoke from jet engines, whose fuel runs richer during takeoff; emissions of cars, buses and trucks working the airport; fuel oil spillage; and sanitary sewage from treatment plants at the northwestern section of the airport are all sources of pollution. The automobile pollution from the airport is considered to be about one-half of that from the aircraft (Nat'l Acad Sci., 1971). Unburned residues from aircraft engines are dispersed into the air via plane exhausts and much of the jet fuel is volatile and evaporates. Although some of the fuel reaches the Bay, it is not the primary pollutant (Franz and Harris, 1985). The non-volatile lubricating oils and other petroleum products used in aircraft upkeep are of greater concern. These can spill to airport pavement and be carried to the Bay in storm water through the major airport drains. About 50% of airport runoff goes into Grassy Bay, 25% into Bergen Basin and 25% into Thurston Basin.

Combined Sewer Overflows:

As previously mentioned, CSOs can contribute many pollutants to receiving water bodies. Combined sewer overflows appear to be an important source of several metals. Pesticides and acid- or base-extractable pollutants were not frequently present in CSO effluent, however (USEPA, 1984). There were significant differences among drainage basins in this 1984 study, though, and land use patterns must be evaluated in order to predict the types of pollutants that will be present in runoff and CSO effluent from a particular area. Airports, for example, may contribute more petroleum-related pollutants and metals to these flows. The generally urban areas surrounding the Bay also contribute pollutants and runoff of some metals (Zn in particular, as mentioned previously). The locations of major CSO outfalls into Jamaica Bay are indicated in Figure 3.

Currently the New York City Department of Environmental Protection (NYCDEP) is undertaking a CSO Abatement Program (see Water Quality - Floatables section, this document, for more details on this program). A portion of this program calls for 1.27×10^8 liter (30 million gallon) underground retention facilities to catch CSO and storm sewer effluent. The facility plan for Paerdegat Basin and site selection are underway. Tributary projects are to be initiated for Bergen and Thurston Basins in fiscal years 1990 and 1991. Completion of these projects may help to decrease toxic loadings to the Bay through treatment of the effluents.

Landfills:

There are three important landfills on the perimeter of Jamaica Bay. Fountain Avenue and Pennsylvania Avenue are on the north edge along Northern Channel and Edgemere is on the south along Grass Hassock Channel (Figure 3). The three landfills have been deactivated but have not been capped (John Tanacredi, GNRA, pers. comm.). The landfills are proposed end-use sites for chemically stabilized sewage sludge. The stabilized sludge will be used as part of the final cap, which is to be constructed between 1992 to 1994 for Edgemere and by 1997 for the other two (NYCDEP, 1991).

Landfills are sources of pollution to the Bay. Gibbs and Hill, Inc. (1984) modelled leachate flow from these landfills. Their studies estimate that 80%, 96%, and greater than 99% of leachate from Fountain Avenue, Edgemere, and Pennsylvania Avenue landfills respectively, flow directly into Jamaica Bay. Several metals (antimony, Cd, Cu, Pb, Ni, thorium, Zn, Fe, and manganese) were detected in leachates sampled at the shoreline. Volatile organics and volatile halogenated hydrocarbons were below detection limits except within the oil collection boom at the Pennsylvania Avenue site.

Landfills may also be contributing toxic pollutants to the ground water in the Bay area. In some areas of the landfills the buried waste is in hydraulic contact with the upper glacial aquifer due to "windows" in the tidal marsh deposits underlying the landfills. There appears to be limited interchange between the landfills and the upper glacial aquifer however. The deeper aquifers are believed to be unaffected. Within the upper glacial aquifer, the ground water flows towards Jamaica Bay (Gibbs and Hill, Inc., 1984). Thus the landfills could be contributing pollutants, especially metals, to the Bay primarily via runoff and, to limited extent, leaching into the ground water.

Comparisons With Other Areas:

In Jamaica Bay the maximum metal concentrations in sediments in 1981-1982 (Franz and Harris, 1985) were greater than values for Narragansett Bay (Eisler _et_ _al_., 1977); less than those for the extreme western part of Long Island Sound (Greig _et_ _al_., 1977); and less than those in the New York Bight disposal areas for sewage sludge (the 12-Mile Site) and dredged materials. The exception to this is Ni concentrations which were about equal to those in the New York Bight disposal area (Carmody _et_ _al_., 1974; Harris and Waschitz, 1982). The NOAA National Status and Trends Program ranked the sediments of Jamaica Bay among the twenty most polluted sites nationally for ten metals (Ag, arsenic, Cd, Cr, Cu, Hg, Pb, antimony, tin, and Zn), PAHs, PCBs, DDT, and total chlorinated pesticides. Concentrations in mussel tissue were among the top twenty for three metals (Cu, Pb, Hg), PAHs, PCBs, DDT, and Chlordane (NOAA, 1988b; NOAA, 1989). While it is difficult to interpret this kind of information, it is clear that Jamaica Bay must be considered polluted with regard to toxic metals and some organics.

Use Impairments:

There is little information about the effect these elevated levels of toxicants are having on the biota of Jamaica Bay. There are no statistically significant correlations between metal sediment loads and either richness or density of benthic species (Franz and Harris, 1985).

The USEPA water criteria are based on acute and chronic toxicity levels which could affect marine and estuarine aquatic life. New York state has established standards, which are legally enforceable, in a similar manner. Whether or not metals concentrations in ambient water are exceeding criteria depends on the outcome of the split-sampling study being coordinated between Batelle and the NYCDEP.

There are no federal USEPA criteria specifically for tissue concentrations in shellfish. The USFDA and USEPA criteria for edible fish tissue are used here for shellfish. The fish tissue criteria are designed for the protection of humans consuming seafood. The criteria are developed through the use of bioconcentration factors and correspond to a 10^{-6} incremental cancer risk for carcinogens or to a "no effect" level for non-carcinogens. The USFDA, in setting action limits, takes into account both the health risks to the consumer and the economic impacts of banning the product.

The extent to which the metals present in Jamaica Bay are biologically available is unknown. None of the metals examined at length here (Pb, Cu, Cd, Cr, Ni, Hg, Zn) exceed tissue criteria where such criteria exist. However, arsenic (As) levels in mussel tissue (8.3 ppm - NOAA, 1989) do exceed the USEPA (USEPA, 1989) criterion of .0062 ppm.

DDT and Chlordane in blue mussels do exceed USEPA (USEPA, 1989) criteria and PCBs in several species of fish exceed the FDA action limits. In summary, the possibilities of metal-related human health risks from eating seafood from Jamaica Bay are unclear, but may be significant. Chlorinated pesticides may also pose a human health risk as some of these compounds exceed their criteria and are found in fish and shellfish tissue.

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WATER QUALITY

The health of the biological community in Jamaica Bay, as well as the well-being of a variety of potential commercial and recreational uses of the Bay, depend on the quality of the Bay's water. The area surrounding Jamaica Bay is densely populated and the inputs of nutrients and other contaminants to the Bay via the sewage system therefore have a great effect on the Bay's ecology and water quality. Water quality is often assessed by measuring concentrations of dissolved oxygen, biological oxygen demand, nutrients and coliform bacteria.

Water quality varies considerably in Jamaica Bay with distance into the Bay from the mouth at Rockaway Inlet. In general, water quality is poorest along the northern edge of the Bay and in Grassy Bay which is at the northeast end, adjacent to John F. Kennedy International (JFK) Airport. This is in part due to the presence of sewage treatment plants and major combined sewage overflows (CSOs) (Figure 3), and in part to the circulation patterns in the Bay.

Dissolved Oxygen

The biological community requires minimum levels of oxygen for respiration. Many organisms show signs of stress when dissolved oxygen (DO) drops below 3 mg/l (a condition which has been termed hypoxic) and some when the level drops below 4 mg/l.

It is not possible to assure that no detrimental effects will occur if the DO level is not maintained above 5 mg/l. It is true, however, that most species have not been tested for their sensitivity to dissolved oxygen levels.

The concentration of DO in the water depends on a variety of factors. These include tidal mixing, vertical mixing of the water column by wind and waves, photosynthesis by phytoplankton, and the demand for oxygen imposed by organisms living in the water and in the sediments. Any of these factors may vary over time and space leading to differences within the system.

Records from the New York Harbor Water Quality Survey (NYHWQS) (NYCDEP, 1991) indicate little change in DO concentrations in Jamaica Bay since the survey was initiated in 1926 (Figure 6). Dissolved oxygen saturation in the Bay as a whole has averaged around 75% from 1926 to 1966 (Ludwig and Associates, 1970). It is not clear at what depth these samples were taken but they were probably the averages between near-surface (1 m below) and near-bottom (1 m above) samples (Tom Brosnan, NYCDEP, personal communication). Data from the 1991 NYHWQS covers the period from 1970 to 1990, when mean summer DO values in surface waters varied between 6-8 mg/l. Mean summer dissolved oxygen concentrations in bottom waters during this same period varied between 5-7.5 mg/l (Figure 7). Mean summer DO in the bottom waters declined in the early 1970s, followed by a period of improvement from the mid to late 1970s but by the early 1980s this trend reversed and the mean summer DO values at the

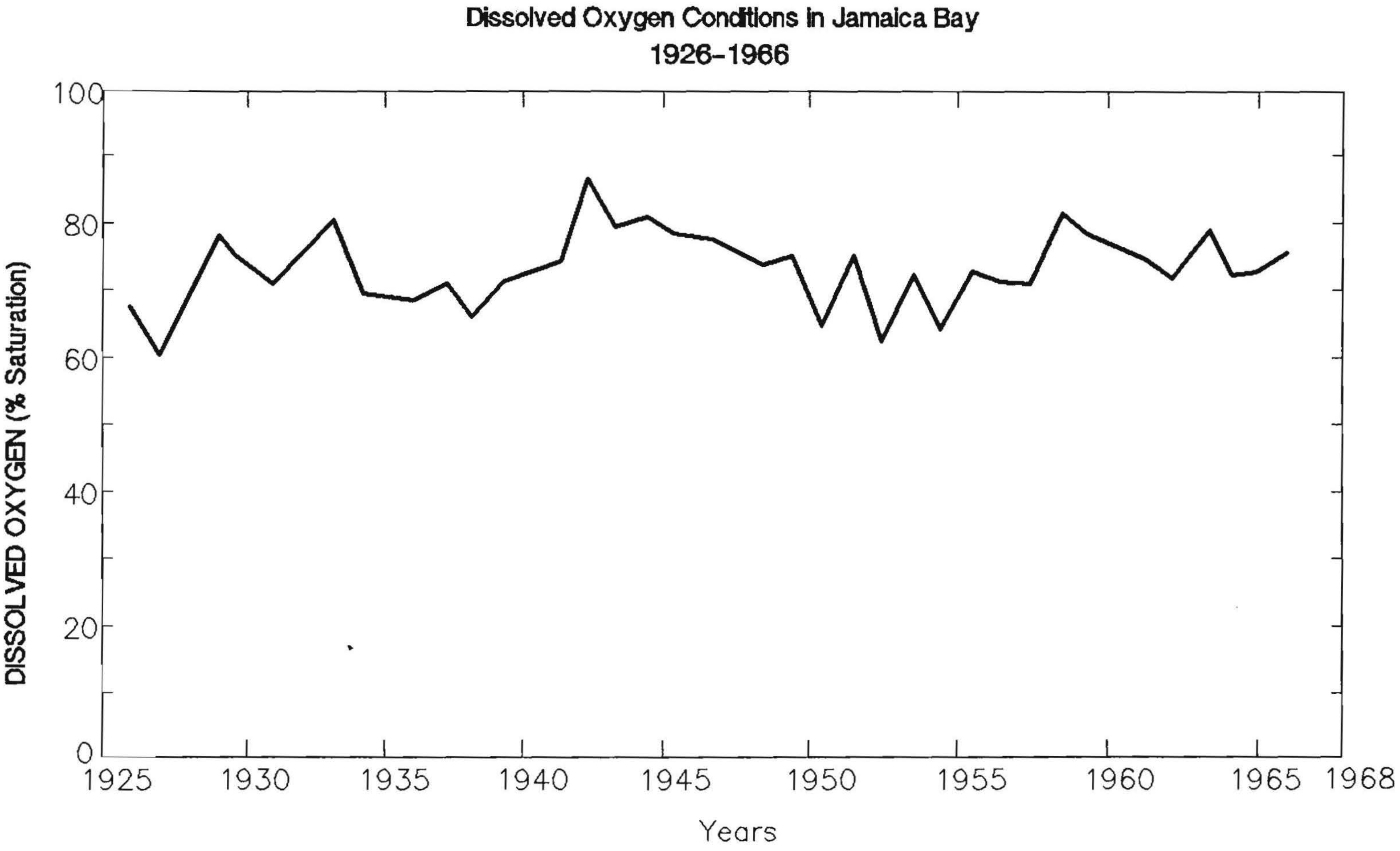

Figure 6. Levels of dissolved oxygen in Jamaica Bay subsurface waters from 1926-1966 (from Ludwig and Associates, 1970).

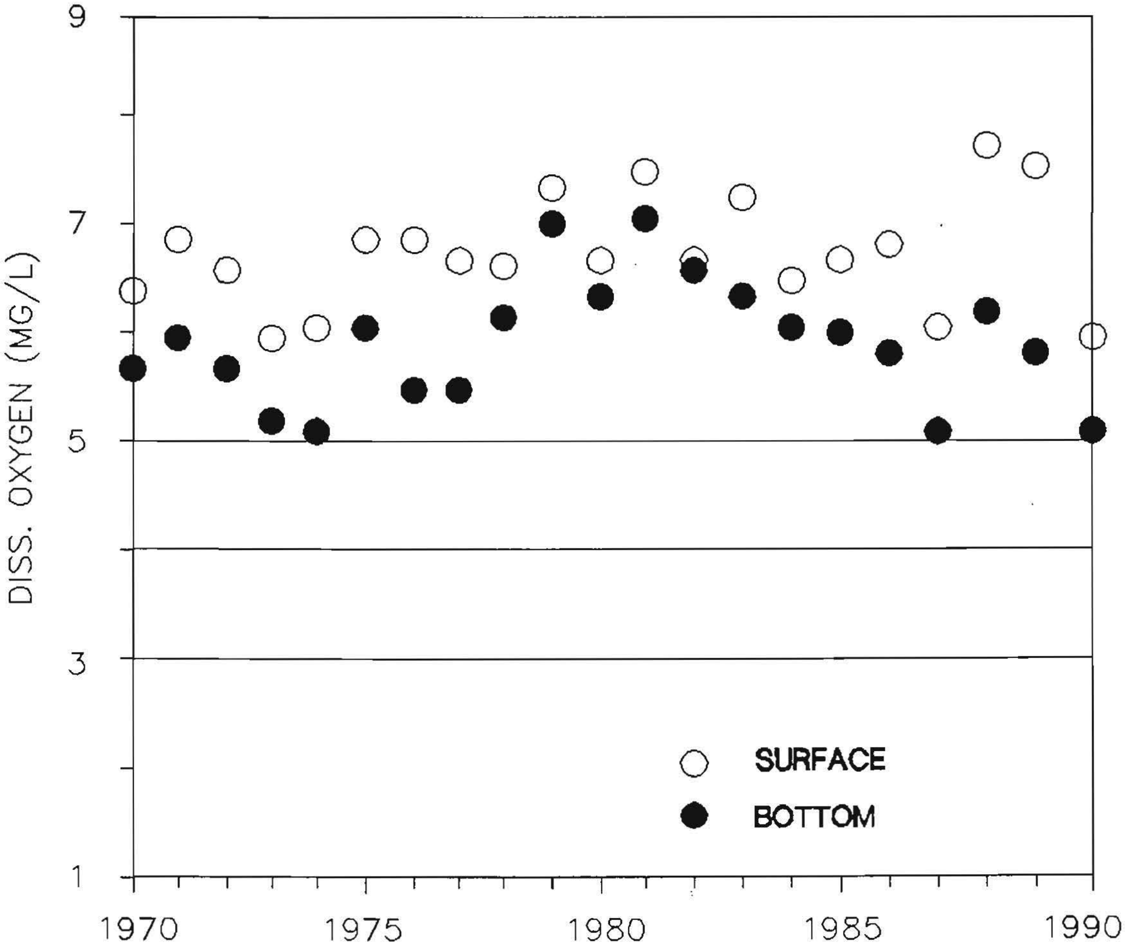

Figure 7. Levels of dissolved oxygen in Jamaica Bay surface and bottom waters from 1970-1990 (from New York City Department of Environmental Protection, 1991).

bottom have declined steadily (Keller et al., 1990). Dissolved oxygen concentrations were unusually low throughout most of the New York Harbor in 1987. This decrease may be attributable to the unusually hot, stable weather interspersed with periods of heavy rainfall which characterized the summer of 1987. This weather probably intensified stratification of the water column, minimizing mixing of the bottom and surface waters.

Concentrations of DO vary from station to station within the Bay, with the highest levels occurring near Rockaway Inlet where there is the greatest exchange of Bay and ocean waters. The lowest levels are found in Grassy Bay where circulation is limited and where the Jamaica Water Pollution Control Plant's effluent empties into the Bay (Ludwig and Assoc., 1970). In 1990, average DO concentrations from June through September were greater than 5 mg/l in surface waters where sampled. Bottom waters, averaged over the same time period, also had concentrations greater than 5 mg/l in most of the Bay, with the exception of the area near Bergen Basin and near Grassy Bay (NYCDEP, 1991, Figure 8). It should be noted, however, that much of the eastern Bay (including Grassy Bay) is not sampled by the NYCDEP and it is in this area that the lowest values of DO are likely to occur.

Distinct seasonal variations in average DO concentrations also occur in Jamaica Bay. Levels as high as 10-12 mg/l throughout the Bay in the winter may drop sharply in the summer to less than 2 mg/l. The seasonal variations in average DO

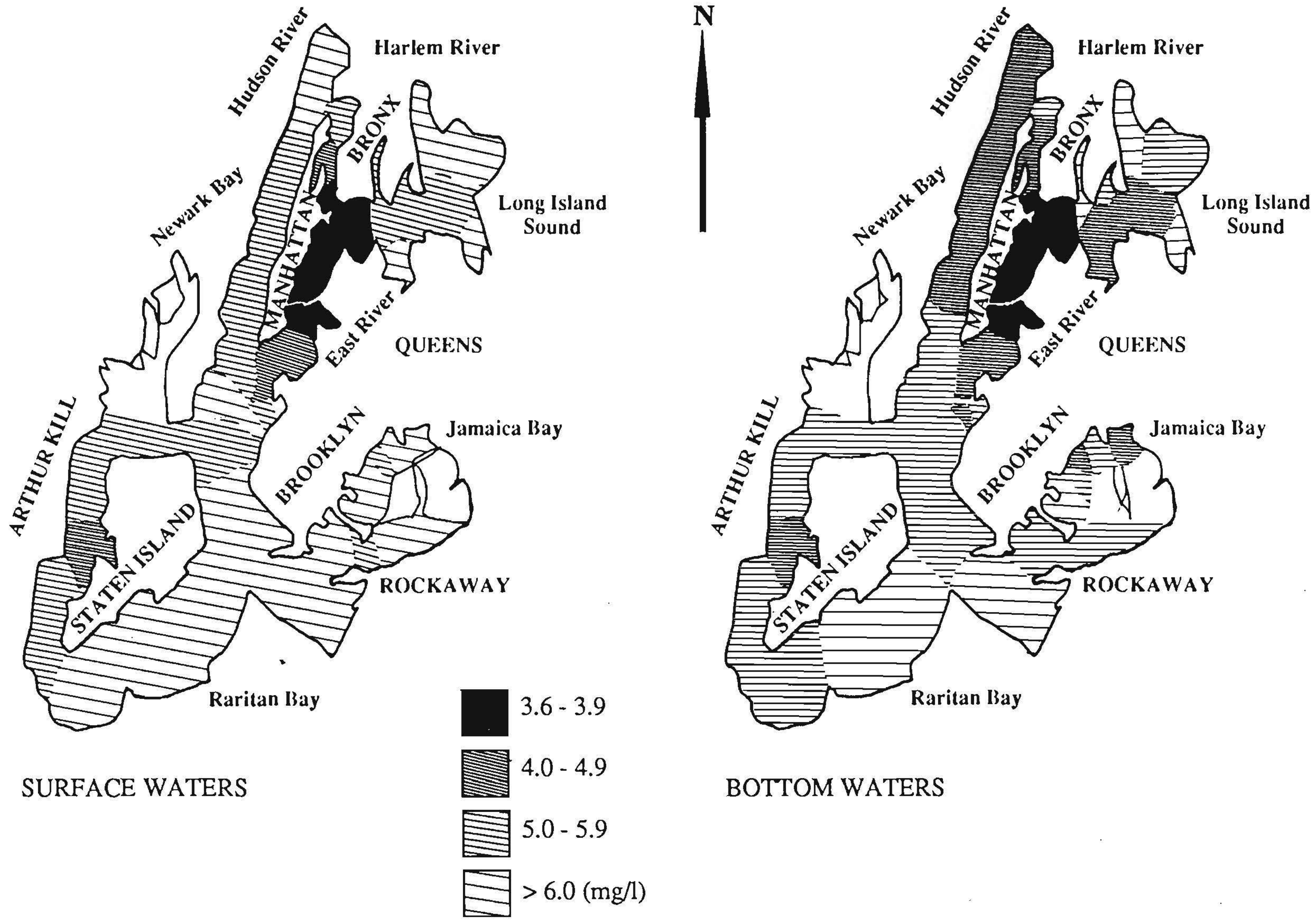

Figure 8 SUMMER 1990 DISSOLVED OXYGEN DISTRIBUTION (FROM NYC DEP, 1990)

concentrations in Jamaica Bay are due to seasonal temperature differences, which greatly affect oxygen solubility; to seasonal changes in mixing of the water column; and to seasonal differences in metabolic demand on the dissolved oxygen resources of the Bay (Feuerstein and Maddaus, 1976). In the summer, Grassy Bay becomes vertically stratified and the bottom layers can become hypoxic or anoxic (0 mg/l of dissolved oxygen). In addition, because the waters of Grassy Bay are highly eutrophic, intense algal production can result in dramatic diurnal fluctuations in DO concentrations (Feuerstein and Maddaus, 1976).

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed by microorganisms in the metabolic process of converting organic matter into stabilized end products such as CO_2 and O_2. The BOD fluctuates seasonally, reflecting the varying organic content of the waters of the Bay. For example, average BOD increased from about 1.5 mg/l in October and November, 1968 to about 5.0 mg/l in February, 1969 when phytoplankton productivity was at its peak (Ludwig and Assoc., 1970).

There is also considerable variability in the BOD of the sediments in different parts of the Bay. Levels of BOD in the sediments are essentially a reflection of the degradability of the organic matter in the sediments. The small creeks and basins off of the North Channel receive discharges from CSOs and sewage treatment plants, and consequently have sediments with the highest levels of BOD. The organic content of the sediments near the discharge sites in 1968-1969 was so high that anoxic conditions prevailed at the sediment-water interface. This was reflected in the complete absence of benthic animals in these areas (Ludwig and Assoc., 1970).

Data from the 1991 NYHWQS indicate that average BOD concentrations in 1989 ranged from 1.8 to 3.7 mg/l in the bottom layer of water and from 1.9 to 2.6 mg/l in the surface layer. From 1970 to 1987 BOD levels have decreased slightly. Concentrations of BOD decrease from the eastern side of the Bay toward Rockaway Inlet.

Nutrients

As with most marine systems, the limiting nutrients for the phytoplankton in Jamaica Bay are nitrogen and phosphorus. Excess inputs of these, however, can result in algae blooms or changes in algal community structure. The former may lead to increased BOD and, possibly, anoxic conditions; the latter may result in changes in the benthic or fish communities. Ludwig and Associates (1970) estimated nutrient levels in Jamaica Bay in 1968-1969 to be twenty times as high as those needed to sustain maximum crops of algae. Approximately 92% of the nitrogen and phosphorus entering Jamaica Bay is from the effluent of water pollution control plants, thus concentrations of these nutrients increase in Grassy Bay, site of the outfall for the Jamaica Water

Pollution Control Plant (Ludwig and Assoc., 1970). Table 6 shows the amount of effluents discharged into the Bay by each of the water pollution control plants.

Seasonally, average organic nitrogen concentrations varied only slightly, ranging from a low of 0.45 mg/l at the mouth of the Bay in the winter, to a high value of 1.2 mg/l in Broad Channel during the summer (Feuerstein and Maddaus, 1976). Concentrations of ammonia, orthophosphate and total phosphate along the northern shore of Jamaica Bay in 1986 and 1987 were among the highest recorded by the NYHWQS (Figures 9 and 10). Long-term trends suggest that nitrate and nitrite levels have dropped since 1974 in most areas of the Bay. A less distinct trend is evident, however, if data from 1974-1978 are excluded (Figures 11, 12 and 13). Three out of the four NYC sewage treatment plants were being upgraded during this period (Table 8). These operations may have had an influence on the release of nutrients to the water.

Concentrations of ammonia also increased fairly uniformly with increasing distance into the Bay from the inlet. Summertime average concentrations ranged from 0.2 - 1.2 mg/l, whereas winter averages were slightly higher, 0.4 - 1.8 mg/l. The higher ammonia levels in winter may be due to slower metabolic conversion of ammonia to other forms of nitrogen (Feuerstein and Maddaus, 1976).

Total phosphate average concentrations are approximately 1 mg/l in the back-bay areas decreasing to around 0.2 mg/l at the

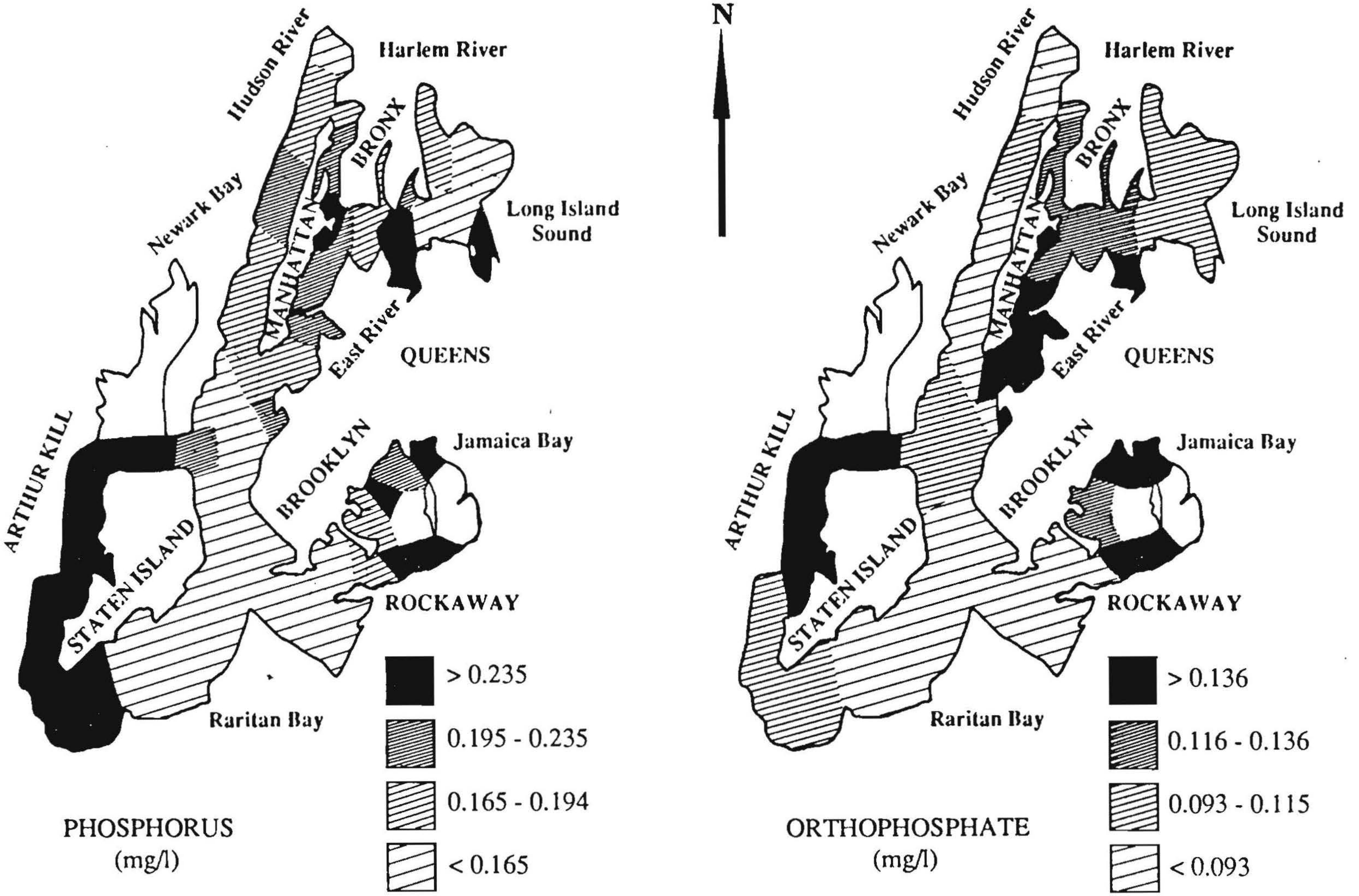

Figure 9 PHOSPHORUS CONCENTRATIONS IN NEW YORK HARBOR IN 1987.
TOTAL PHOSPHORUS AND DISSOLVED ORTHOPHOSPHATE.
(MODI[illegible] FR[illegible] NY[illegible]EP, [illegible]

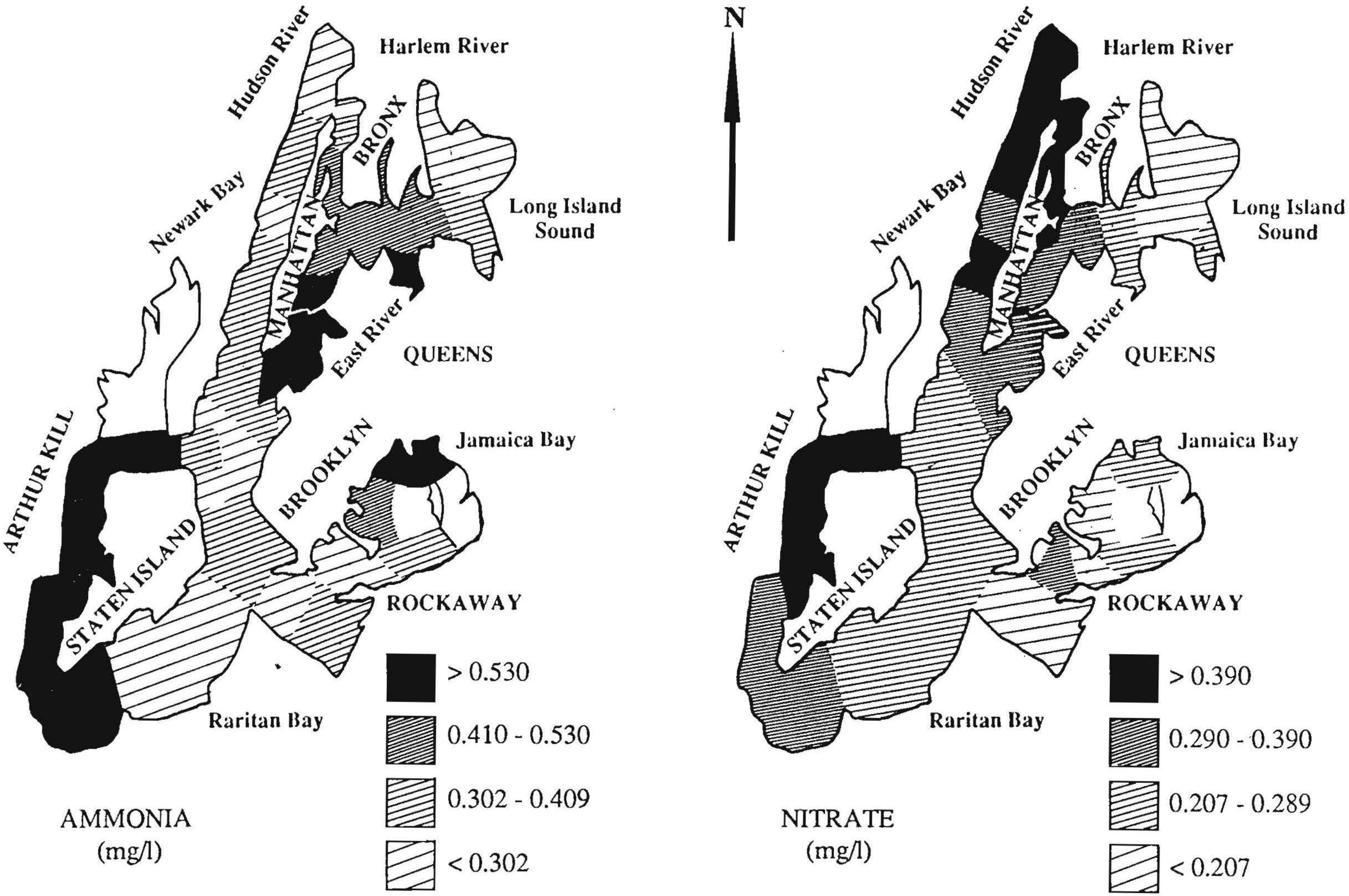

Figure 10 NITROGEN CONCENTRATIONS IN NEW YORK HARBOR IN 1987. AMMONIA AND NITRATE (MODIFIED FROM NYC DEP, 1989) (Note: "Nitrate" data are actually nitrate plus nitrite.)

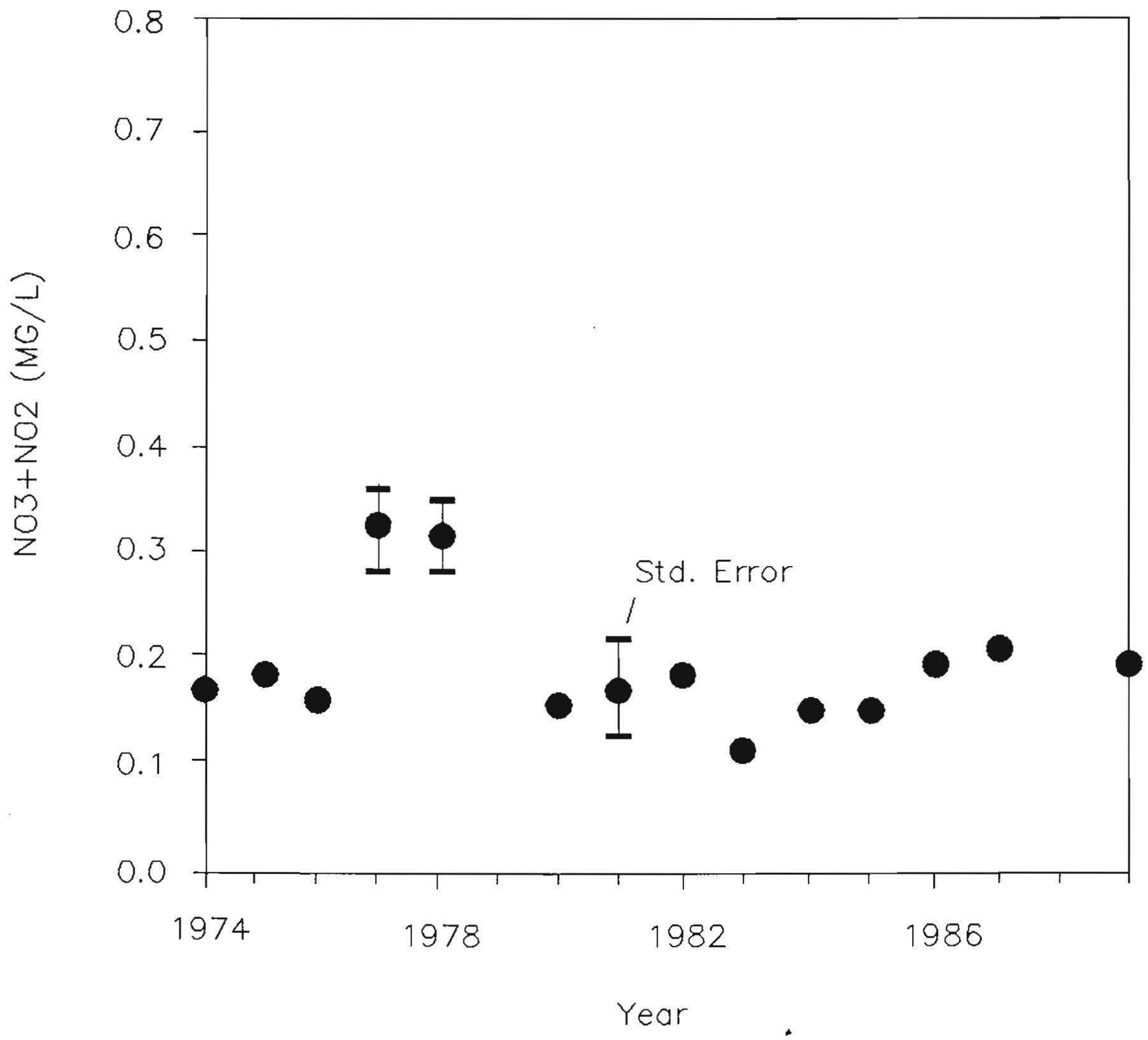

Figure 11. Levels of nitrates in Jamaica Bay surface waters from 1974-1989 (from New York City Department of Environmental Protection, 1991).

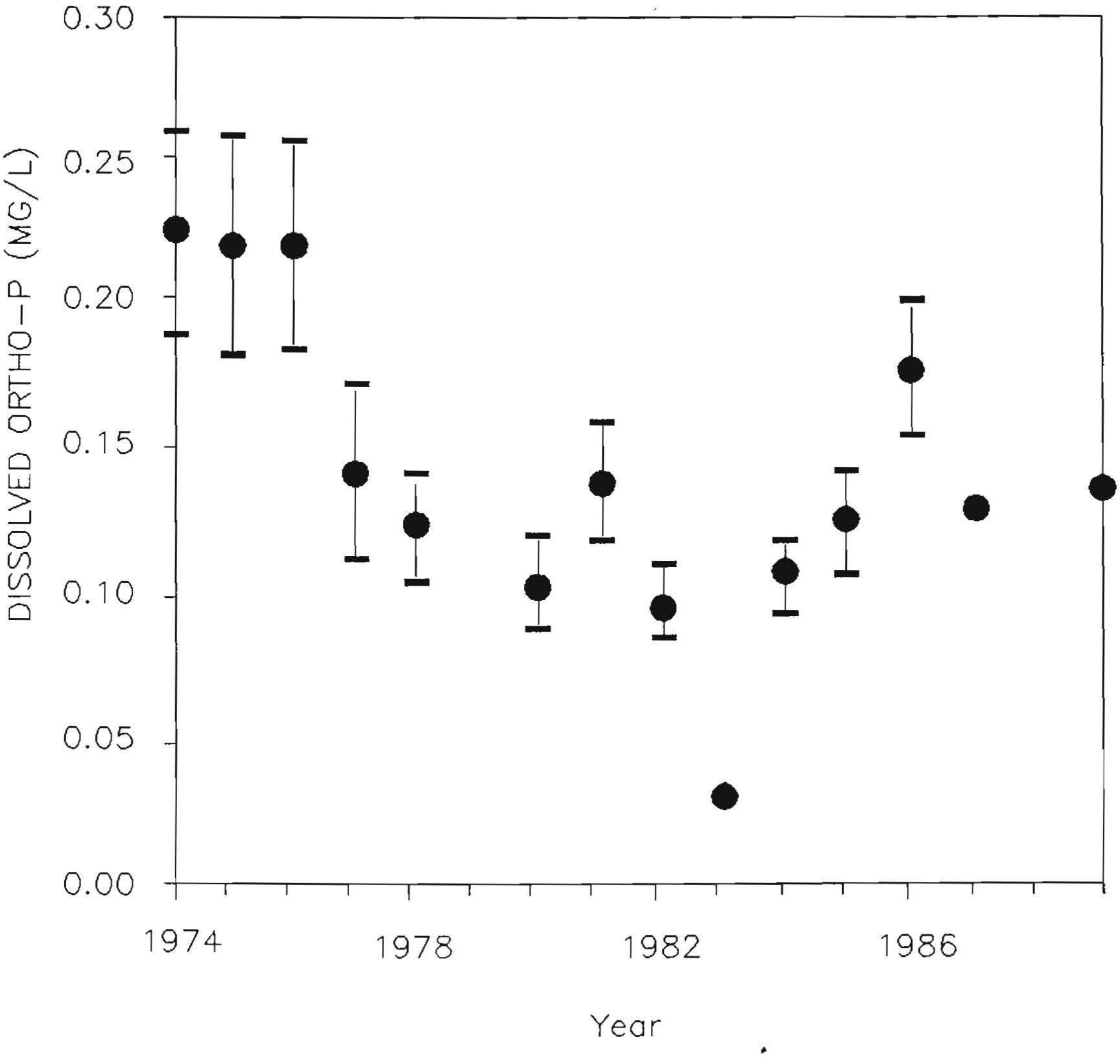

Figure 12. Levels of dissolved orthophosphate in Jamaica Bay surface waters from 1974-1989 (from New York City Department of Environmental Protection, 1991).

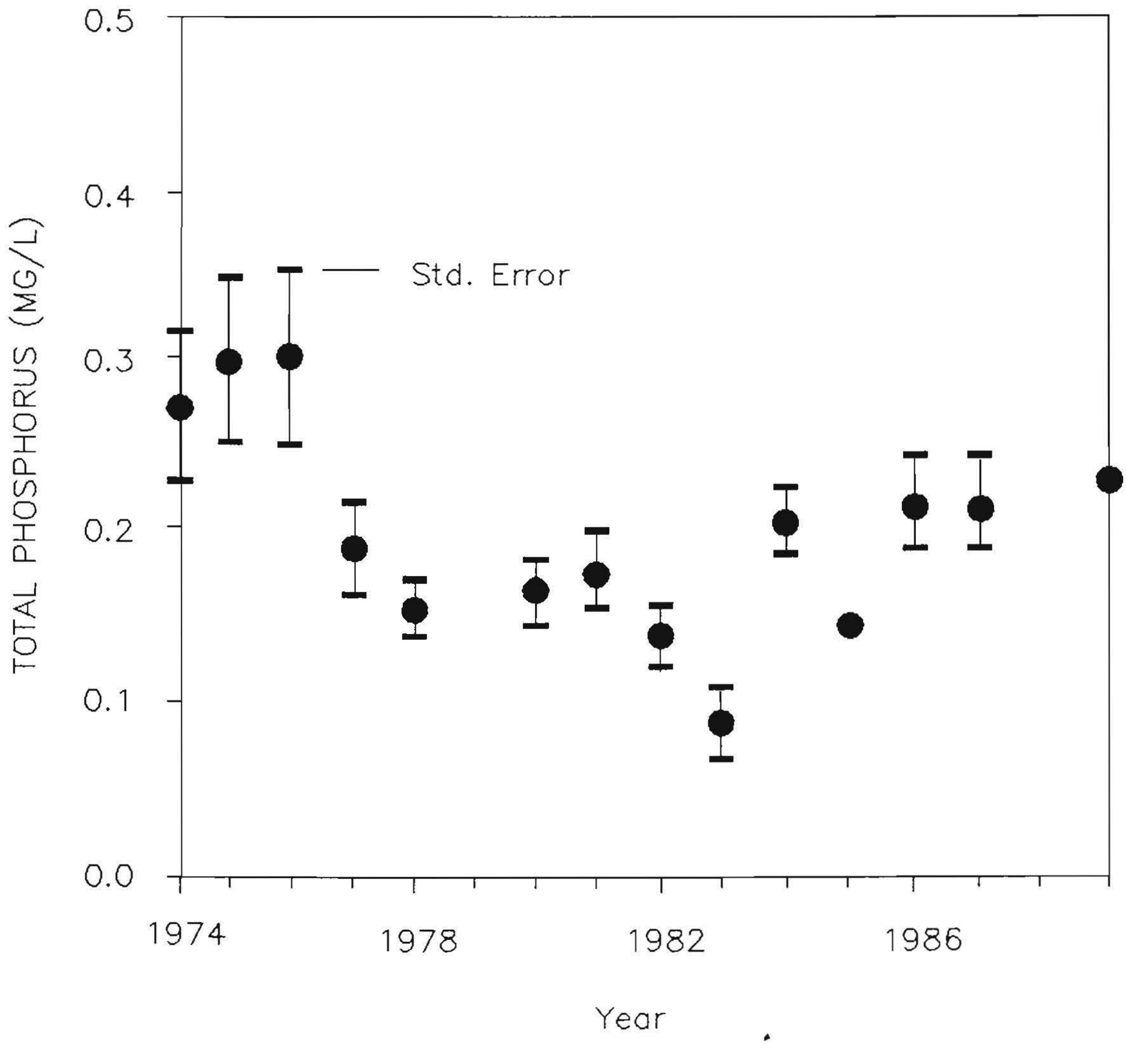

Figure 13. Levels of total phosphorus in Jamaica Bay surface waters from 1974-1989 (from New York City Department of Environmental Protection, 1991).

Table 8. Upgrading of water pollution control facilities, including treatment type, capacity and flow in 1986 and year completed (in liters$\times 10^6$/day). Modified from NYC Dept. Environm. Prot., 1987.

Plant	Treatment Type	Capacity	Flow	Year Completed
Rockaway	Full Secondary	171	83.6	1978
Coney Island	Modified Aeration	418	402.8	1994*
Jamaica	Full Secondary	380	361	1978
26th Ward	Full Secondary	323	220.4	1979

* To be completed by this date.

inlet year round. Orthophosphate is similarly distributed (Feuerstein and Maddaus, 1976).

A recent comparison of inorganic nutrient concentrations in Jamaica Bay with concentrations in nearby Sandy Hook Bay, showed higher levels of all chemical species in Jamaica Bay (Cosper et al., 1989).

Pathogens

The presumed presence of human pathogens in marine waters is estimated by determining total and fecal coliform bacteria concentrations. These serve as indicators of bacterial pathogens. Shellfishing and bathing waters are classified according to criteria based on coliform counts. In order to comply with New York State's standard for bathing water, the monthly geometric mean of the samples collected must be less than 200 fecal coliform cells/100 ml water or the monthly median must be less than 2400 total coliform cell/100 ml. To comply with the state shellfishing standard, the median in any series of water samples must not exceed 70 total coliform cells/100 ml (and no more than 10% of the samples at a station may exceed a Most Probable Number [MPN] of 330 cells/100ml) or 14 fecal coliform cells/100 ml (and no more than 10% of the samples at a station may exceed a MPN of 49 cells/100ml).

One problem with using coliform bacteria as an indicator for public health is that coliforms are poorly correlated with viruses in marine waters. Although most bacteria are effectively destroyed by the chlorination processes of most sewage treatment plants, viruses are not (New Jersey Department of Environmental Protection [NJDEP], 1990). The hepatitis virus, for example, is thought to be one of the most chlorine-resistant of the water-borne viruses. Recent estimates suggest that approximately 50% of viruses survive the disinfection process. In addition, the infective dose for viruses in humans is many times lower than for most bacteria in humans (NJDEP, 1990).

The consumption of contaminated shellfish has been associated with numerous cases of bacterial diseases such as gastroenteritis, and viral diseases such as infectious hepatitis as well as illnesses caused by enteroviruses. Between 1980 and 1983, 4200 cases of shellfish-associated illnesses were reported in the United States (NJDEP, 1990). The Bay's shellfish beds have been closed since 1921 so one would not expect such cases to occur. No cases of disease have been definitely attributed to shellfish taken from Jamaica Bay although there have been suspected cases because of illegal shellfishing (see Fauna section).

Diseases associated with swimming in waters contaminated by sewage discharges include gastroenteritis and a number of viral infections. Most of the swimming-related outbreaks of diseases in the United States are not enteric. They include a variety of skin infections associated with cuts or abrasions, as well as the conditions commonly known as "swimmer's ear" and "swimmer's itch" (NJDEP, 1990). Again, no cases from Jamaica Bay were specifically cited by this study.

Data from the NYHWQS of 1991 show a gradual decline in total coliform concentrations in most areas of the Harbor over the past twenty years, but this trend is less pronounced in Jamaica Bay (Figure 14). This reduced trend may be due to the fact that nearly 100% of the sewage effluent going in to the Bay in the last twenty years has been treated while only 80-90% of sewage effluent discharged into the Harbor between 1970 and 1989 was treated (current sewage discharges to the Harbor are almost 100% treated). It may be for this reason that coliform concentrations have been an order of magnitude lower in Jamaica Bay, in the last twenty years, than in most of the Harbor. Marginal improvements in Jamaica Bay are thus more difficult to achieve relative to the New York-New Jersey Harbor Estuary. It must also be kept in mind that waterfowl and other warm-blooded organisms that frequent the Bay and Wildlife Refuge are also a source of coliform to the water that are not treated. A duck, for example, contributes approximately 5.5 times more fecal coliform per day than a human (Metcalf and Eddy, 1991).

The City used to chlorinate the effluent from sewage treatment plants only in the summer months in order to reduce the risk to swimmers of contracting water borne diseases, but in July 1986, a regional, year-round disinfection requirement took effect (NJDEP, 1990). Since the NYHWQS only measures coliform concentrations in the Bay during the summer, there is no way of determining if there has been a reduction in coliform levels in

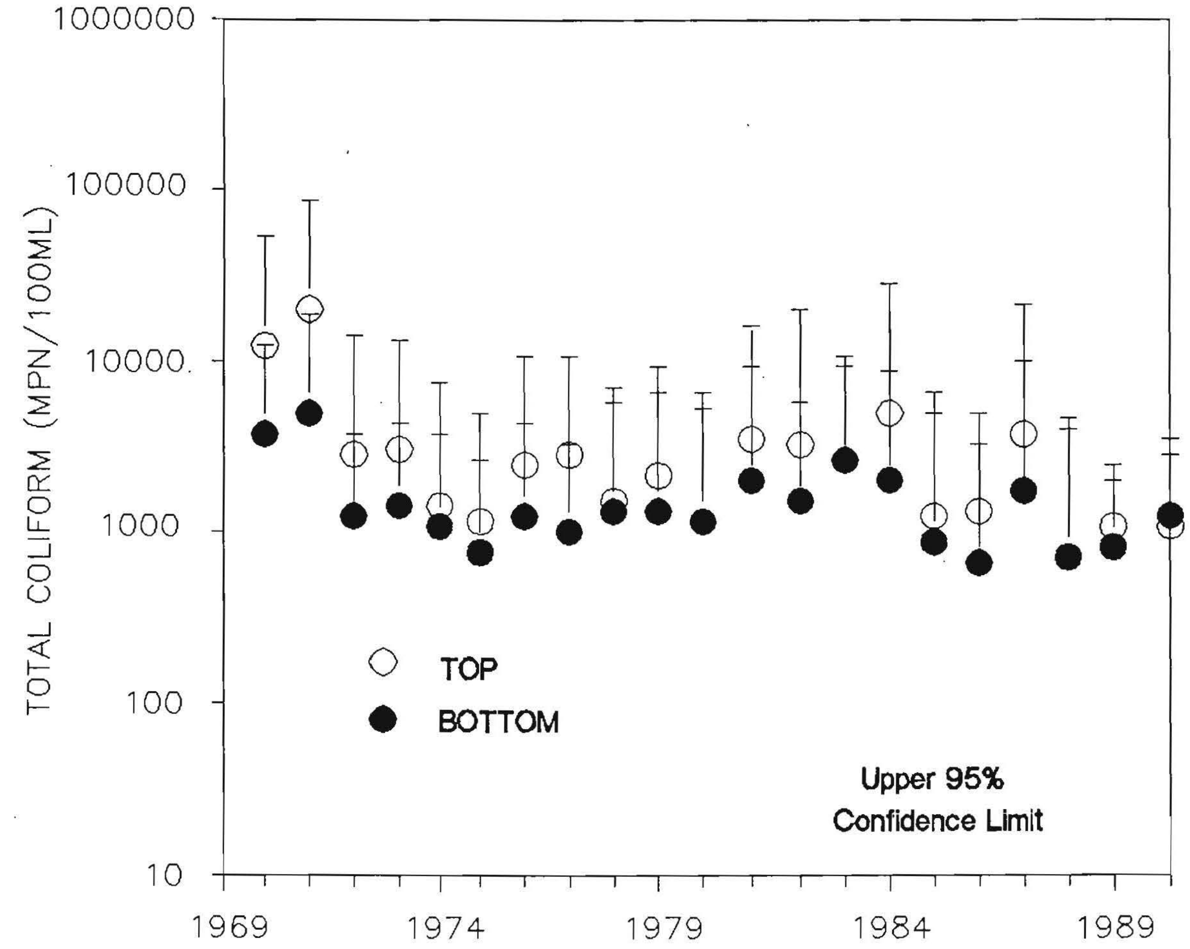

Figure 14. Levels of total coliforms in Jamaica Bay surface and bottom waters from 1969-1990 (from New York City Department of Protection, 1991).

Bay waters throughout the year. The Interstate Sanitation Commission has stated, however, that there have been noticeable reductions in coliform concentrations in other metropolitan waters since the commencement of year-round chlorination, so it is possible that Bay waters may have improved.

Sewage treatment plant effluents and bird feces are not the only sources of bacteria, however. Pathogens may also enter the system through the discharge of raw sewage from combined sewer overflows. During heavy rainfalls, or if flow regulators are not functioning properly, combined flows of some waste water and surface runoff bypass sewage treatment plants and discharge directly into the Bay. The authors of several studies have recognized that in order to comply with bathing water standards, CSOs must be disinfected (Feuerstein and Maddaus, 1976) or eliminated altogether (NJDEP, 1990).

The City has been developing a Combined Sewer Overflow Abatement Program for the last several decades. In 1972 construction was completed on a storm overflow retention facility at Spring Creek in Jamaica Bay. This facility was designed to act as a holding tank for storm and sewage waters and provide for chlorination of these overflows and the removal of settleable and floatable solids. It has a capacity of 4.7×10^3 m^3 (1.7×10^6 ft^3), which is equivalent to a five year storm (Feuerstein and Maddaus, 1976). This water is eventually diverted to the 26th Ward Water Pollution Control Plant for processing. A second facility is currently under construction at Paerdegat Basin (Interstate

Sanitation Commission, 1988). Ultimately, the City plans to have similar facilities at all of its major CSOs.

Floatables

Floating marine debris consists of a wide variety of materials, including plastic, wood, paper, glass, rubber, metal and organic waste materials that are found on the surface or suspended in the water column (Swanson and Zimmer, 1990). There are several sources of this material in the New York-New Jersey area: 1) combined sewer overflow and storm water discharges; 2) landfills and transfer stations; 3) driftwood; and 4) shoreline litter, beach use and resuspension of beach litter (Swanson and Zimmer, 1990).

Although there are several landfills on the perimeter of Jamaica Bay, all of these are now closed. In spite of these closures, these areas may remain potential sources of floating debris well into the future. For example, the action of water at the base of the Pennsylvania Avenue landfill is already eroding material out into the Bay. In addition, the rising sea level and subsequent saturation of the fill may also lead to dispersal of the material in the next few decades.

Driftwood is derived mainly from decaying structures along the shore, derelict vessels and construction debris. Compared to other portions of the New York-New Jersey Harbor, the amount of driftwood in Jamaica Bay is relatively small. In fact, in the

Floatables Action Plan prepared for the New York Bight, no portion of Jamaica Bay is included in the priority lists for driftwood clean-up, either by the US Environmental Protection Agency or the US Army Corps of Engineers. It may be included in the future when an additional collection vessel is obtained (USEPA, 1991). A related problem in the Bay which does not technically fall under the category of driftwood, however, is that of abandoned cars which are often dumped and left to rust in the peripheral shallows of the Bay. There is currently no program which addresses this problem.

Although Jamaica Bay is not immune to litter, especially that resuspended during spring tides, it is less of a problem than on the ocean beaches. Those areas are vulnerable not only to the trash left by beach users but also to material washed up from boats and ships offshore and any floatable material that escapes from New York Harbor. Very little debris from outside the Bay appears to enter through the inlet to contaminate the area (USEPA, 1991).

The primary sources of contamination for Jamaica Bay are the CSO and storm water discharges. The City of New York has developed a comprehensive CSO Abatement Program to deal with problems associated with these discharges. Phase I of the study, which has been completed, identifies and characterizes the City's CSOs, assesses their effects and analyzes regulatory requirements. Phase II, planning for abatement facilities, is being conducted in four major areas of the harbor complex.

Jamaica Bay is one of these areas. A Tributary CSO Abatement Program has been developed and planning for CSO abatement has begun in Paerdegat Basin. In addition, the 26th Ward Water Pollution Control Plant has been chosen as the site of a demonstration project for a low-cost abatement facility utilizing the Flow Balance Method. This method employs a series of floating storage curtains suspended in the receiving water body by pontoons to contain the debris from combined sewer or stormwater overflows. Although still under study, the low-cost Fresh Creek project has demonstrated that floatable debris originating from CSO discharges can be captured (USEPA, 1991).

In addition to the CSO Abatement Facility, the Floatables Action Plan has recommended that the City of New York purchase a skimmer vessel for the cleanup of floatable debris in Jamaica Bay. Such a vessel would be particularly effective in the calm, relatively shallow waters of the Bay (USEPA, 1991).

Floatables are a problem in Jamaica Bay but they do not appear to be as serious a concern as in other areas of the Harbor Estuary complex. For example, during the operation of the Floatables Action Plan in the summer of 1989, only one slick of floating garbage and trash was reported in Jamaica Bay as compared to 47 in the Upper Harbor and 40 in Newark Bay (USEPA, 1989). Other types of pollution are of greater concern to the overall health of Jamaica Bay. It is true, however, that what floatable debris does accumulate in Jamaica Bay is not likely to be easily flushed out of the system due to the poor circulation and low flows in the Bay.

Use Impairments

Impairments to uses of the Bay by humans due to poor water quality conditions include the loss of a major shellfishery; limited use of the Bay's waters for swimming and other water-contact sports; a reduction in recreational fishing; and health risks from eating more than minimal quantities of finfish and shellfish. Most of the waters of Jamaica Bay have been classified by the Interstate Sanitation Commission as suitable for swimming. The exception to this "A" level classification is the northern portion of the Bay where concentrations of total and fecal coliforms exceed state standards (Dames and Moore, 1976). In 1970, the NYC Department of Parks had plans for developing nine beaches and seven marinas along the western and northern shores of the Bay (National Academy of Sciences, 1971). However, the full recreational potential of these beaches will not be realized unless the major CSOs near these sites are treated (Feuerstein and Maddaus, 1976).

Historically, poor water quality has affected the biota of the Bay. The disappearance of the oyster populations in the Bay and the closing of hard clam beds to fishing are the most obvious losses caused by the decline in the quality of ambient water. Recent studies indicate that the diversity and abundance of plankton communities in the Bay are similar to those of bays on Long Island's south shore (Cosper, _et_ _al_., 1989). Those bays, however, are considered classic examples of highly eutrophic systems. Undoubtedly, the plankton communities in Jamaica Bay are very different from what they were prior to settlement of the area by humans.

One notable difference between the ecology of Jamaica Bay and the nearby bays of the south shore of Long Island is the complete absence of the sea grass Zostera marina in Jamaica Bay. The absence of sea grasses in the Bay may be attributable to the relatively high turbidity of the waters (Ludwig and Assoc., 1970).

The periodic hypoxic or anoxic conditions found in the bottom waters of Grassy Bay probably represent the greatest impairment to the benthic animals in the Bay. These conditions also result in a seasonal loss of feeding habitat for macrocrustaceans and fish. This means the Bay will support fewer of these species. For these reasons, it has been suggested that remedial measures should include replacing fill taken from this area in order to reduce the retention time of water in the basin (Nat'l. Acad. of Sci., 1971).

Work on hypoxia in western Long Island Sound has indicated that the timing and extent of the hypoxic zone determines how much of an impairment to the biota results. Unfortunately, details about the onset, length and frequency of the hypoxic episodes in Jamaica Bay are not known. Grassy Bay, for example, is not even included in the sampling sites of the New York Harbor Water Quality Survey.

Floatable wastes do not pose a serious impairment to the biota, but they do reduce the attractiveness of Jamaica Bay as an area of recreational activity. The sources of floatables to the area, CSOs, landfills, driftwood and shoreline litter, are not likely to be eliminated in the near future, therefore it is unlikely there will be any noticeable reduction of debris.

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FAUNA

Urban embayments like Jamaica Bay are the focus of attention and research due to the fact that many major food fisheries rely on these embayments for their survival and yet these ecosystems are extremely vulnerable to human-induced stresses and perturbations (Boesch, 1982). Jamaica Bay has been used as a source of food since settlement of the area by native Americans. Colonizing Europeans also found its waters, marshes and grasslands to be reliable sources of sustenance. During the 19th century, the Bay was the site of major commercial bivalve fisheries, as well as a major sports fishery (National Academy of Sciences, 1971). Sewage contamination of the Bay waters forced the closure of the area to shellfishing in the early 1900s, however. Valuable soup turtles were still being taken from the Bay as recently as the late 1800s to supply lavish parties thrown by such figures as Diamond Jim Brady, the financier, philanthropist and bonvivant. Over-harvesting caused that industry to die out (National Park Service, 1984). By 1967, fishing and crabbing were on the decline in the Bay (Newburger, 1968) although many species of finfish and crustaceans could still be found there (Nat'l Acad. Sci., 1971). Now, Jamaica Bay is the site of much subsistence and recreational fishing. Poor water quality, habitat destruction and overharvesting of commercial species have combined to render the Bay's commercial seafood resources almost negligible, however.

Plankton

The only studies of plankton in Jamaica Bay are quite recent (Peterson and Dam, 1987; Cosper et al., 1989). These investigations were conducted at various sites (the same ones for both studies) at different times of the year and measured such environmental variables as temperature, salinity, oxygen, nutrients and the abundance of plankton and primary productivity. Similar trends were seen in both studies. Chlorophyll a values ranged from a low of <20 µg/l to 90-110 µg/l during the spring blooms. These values are similar to those seen in other Long Island embayments (Peterson and Dam, 1987).

Size composition of the phytoplankton changed predictably through the year. Large diatoms dominated during the spring blooms and small flagellates and small diatoms (<20 µm diameter) dominated during the summer blooms. In autumn the size composition was intermediate between these two extremes. This pattern is similar to that seen in Great South Bay (Lively et al., 1983) and to that in the lower part of the New York-New Jersey Harbor Estuary and coastal waters of the New York Bight (Malone, 1976; Malone, 1977).

Taxonomic composition of the phytoplankton in the summer in the well-mixed, high salinity regime near the entrance to the Bay differed from that found in the partially-stratified, low salinity regime of the inner Bay. The first regime displayed an assemblage similar to that normally found in coastal waters and the inner Bay was characterized by cryptomonads and dinoflagellates (Peterson and Dam, 1987).

The zooplankton were numerically dominated by adult and juvenile copepods in all areas of the Bay. Larval forms, mostly of bivalves, were particularly numerous in June and July. Minimal zooplankton abundance occurred in October.

Dominant species of calanoid copepods were *Acartia tonsa*, *Acartia hudsonica* and *Paracalanus parvus*, particularly during the summer months. *Eurytemora affinis*, *Centropages typicus* and several harpacticoid species were also present at several stations on most sampling dates. A small species, *Oithona similis*, was also present year-round but appeared to be most abundant at the times and places when smaller phytoplankton forms were dominant. These species and their distributions in relation to various environmental parameters are characteristic of most embayments in the area (Peterson and Dam, 1987; Cosper *et al*., 1989).

Benthic Invertebrates

The most comprehensive survey of the benthic macrofauna in Jamaica Bay was a study in 1981-1982 by Franz and Harris (1985, 1988). Figure 5 indicates the location of their sampling stations in the Bay. This study found a considerable number of macrobenthic invertebrates in most portions of the Bay except in the most disturbed areas adjacent to John F. Kennedy International (JFK) Airport. Table 9 contains a complete faunal list as well as abundances at different times of the year. Five species accounted for 74% of all the individuals collected in all periods between 1981 and 1982. In July 1981 they accounted for 87%. These species consisted of three amphipods (*Ampelisca abdita*, *Corophium tuberculatum*, *Unciola dissimilis*) and two polychaetes (*Streblospio benedicti*, *Mediomastus ambiseta*).

Franz and Harris analyzed their population data in a variety of ways. Species richness or the number of species (Figure 15) was compared to the density of individuals within species and the dominance of particular species (i.e. the five superdominants mentioned before). In addition, these parameters were compared to environmental factors such as percent total organic carbon (%TOC); sediment grain size; percent mud, sand or gravel; and metal concentrations, including cadmium, copper, lead and mercury.

Species richness and density were positively correlated with each other and both were negatively correlated with %TOC, particularly in muddy fine sand communities when the level of TOC becomes greater than 1.0-1.25% of the dry sediment weight. The %TOC was positively correlated with trace metal concentrations but there were no statistically significant correlations between species parameters and metal concentrations. Franz and Harris compared their findings in Jamaica Bay to the benthic community data from two other bays: a relatively pristine embayment, Mullica Bay, NJ and a highly polluted system, Raritan Bay, NJ. Benthic species richness in Jamaica Bay was more similar to that

Table 9. List of benthic fauna from Jamaica Bay taken on four sampling dates - October 1981; April, July and November 1982. Numbers totalled across all sampling sites (modified from Franz and Harris, 1985).

SPECIES	OCTOBER	APRIL	JULY	NOVEMBER
Mollusca				
Crepidula fornicata	266	326	145	488
Crepidula plana	538	814	163	330
Crepidula convexa	172	130	63	157
Tellina agilis	95	190	209	12
Mercenaria mercenaria	121	161	94	40
Ilyanassa obsoleta	553	359	214	329
Mulinia lateralis	143	115	6	24
Busycon carica	1	1	0	0
Lyonsia hyalina	6	9	18	8
Ensis directus	6	29	17	2
Doridella obscura	14	10	21	3
Macoma tenta	7	1	327	15
Mya arenaria	3	11	110	7
Eupleura caudata	3	3	2	2
Gemma gemma	15	91	74	1198
Boonea bisuturalis	9	5	5	7
Urosalpinx cinerea	5	8	8	11
Mytilus edulis	7	120	1	14
Acteon punctostriatus	19	1	3	4
Petricola pholadiformis	4	6	90	3
Nassarius trivittatus	11	1	2	1
Crassostrea virginica	1	0	0	2
Busycon canaliculatum	4	0	0	0
Spisula solidissima	0	1	3	5
Cratena pilata	0	1	0	0
Tenellia fuscata	0	9	0	0
Nucula proxima	0	0	4	8
Pitar morrhuana	0	0	3	0

Table 9 (cont'd). List of benthic fauna from Jamaica Bay

SPECIES	OCTOBER	APRIL	JULY	NOVEMBER
Arthropoda				
Libinia emarginata	1	6	3	3
Unciola dissimilis	2107	892	1712	1362
Pagurus longicarpus	50	42	52	25
Neopanope texana	156	99	296	108
Ampelisca abdita	10170	14008	22346	11949
Elasmopus levis	781	205	595	593
Corophium tuberculatum	1036	618	16828	3551
Heteromysis formosa	71	13	304	132
Byblis serrata	5	0	0	0
Oxyurostylis smithi	9	112	50	43
Paraphoxus spinosus	125	110	186	323
Melita nitida	61	35	64	173
Ovalipes ocellatus	12	5	5	6
Cancer irroratus	3	3	14	4
Lysianopsis alba	133	63	103	131
Edotea riloba	2	4	9	7
Stenopleustes gracilis	1	0	0	0
Pagurus pollicaris	1	0	0	0
Palaimonetes vulgaris	4	2	11	24
Erichthonius brasiliensis	14	15	82	154
Caprella sp.	1	5	8	50
Crangon septimspinosus	1	14	59	39
Trichophoxus epistomus	0	29	11	9
Ampelisca vadorum	0	10	17	0
Gammarus laurencianus	0	14	12	3
Lembos smithi	0	2	0	0
Protohaustorius deichmannae	0	1	0	0
Leptochelia savignyi	0	17	0	0
Limulus polyphemus	0	0	0	1
Pycnogonida sp.	0	0	0	1

Table 9 (cont'd). List of benthic fauna from Jamaica Bay.

SPECIES	OCTOBER	APRIL	JULY	NOVEMBER
Polychaeta				
Glycera capitata	157	178	107	25
Streblospio benedicti	3585	5707	2096	1515
Tharyx acutus	696	551	704	328
Lepidomous squamatus	15	121	17	6
Eulalia viridis	2	0	0	0
Mediomastus ambiseta	899	1889	691	174
Sabellaria vulgaris	521	704	96	313
Sabella microphthalma	38	28	20	32
Syllid sp.	36	87	29	82
Hydroides dianthus	8	6	0	0
Dispio unciata	4	0	0	0
Nephthys bucera	28	29	26	3
Scoloplus fragilis	27	46	67	15
Glycera branchiata	3	0	0	0
Asabellides oculata	15	768	164	22
Phyllodoce arenae	12	2	1	7
Pectinaria gouldii	22	18	43	5
Nereis succinea	216	310	191	150
Aricidea jeffreysii	37	13	9	53
Polydora ligni	156	186	687	94
Capitella capitata	5	202	29	6
Nereis arenaceodonta	46	5	2	0
Hesionid sp.	1	2	0	0
Scolecolepides viridis	4	84	23	2
Eteone lactea	39	211	108	107
Eumida sanguinea	536	950	705	335
Cirratulus grandis	2	0	2	1
Phyllodoce maculata	10	0	0	0
Polydora ciliata	1	0	0	0
Syllis cornuta	18	5	0	0
Sthenelais limicola	1	0	0	0
Podarke obscura	35	7	3	3
Exogone dispar	4	10	0	5
Heteromastus filiformis	0	132	50	4
Notomastus sp.	0	5	1	0
Dodecaceria coralii	0	1	3	0
Amphitrite affinis	0	2	2	3
Amastigos caperatus	0	2	3	0
Glycera americana	0	7	0	0
Autolytus fasciatus	0	2	0	0
Polycirrus sp.	0	2	0	0
Paranaitis speciosa	0	5	0	0
Stauronereis rudolphi	0	1	1	1
Lycastopsis pontica	0	1	0	0
Apistobranchus tullbergi	0	0	1	0
Nephthys incisa	0	0	1	0
Phyllodoce groenlandica	0	0	1	0
Microphthalmus aberrans	0	0	3	0

Table 9 (cont'd). List of benthic fauna from Jamaica Bay.

SPECIES	OCTOBER	APRIL	JULY	NOVEMBER
Miscellaneous taxa				
Oligochaeta sp.	23	173	41	71
Nermertea sp.	21	37	19	10
Nematostella vectensis	2	0	0	0
Euplana gracilis	9	2	17	69
Nematoda sp.	21	110	23	89
Tubulanus sp.	0	10	3	0
Cerebratulus lacteus	0	1	0	0
Sagartia sp.	0	3	2	0
Procephalothrix spiralis	0	3	4	0

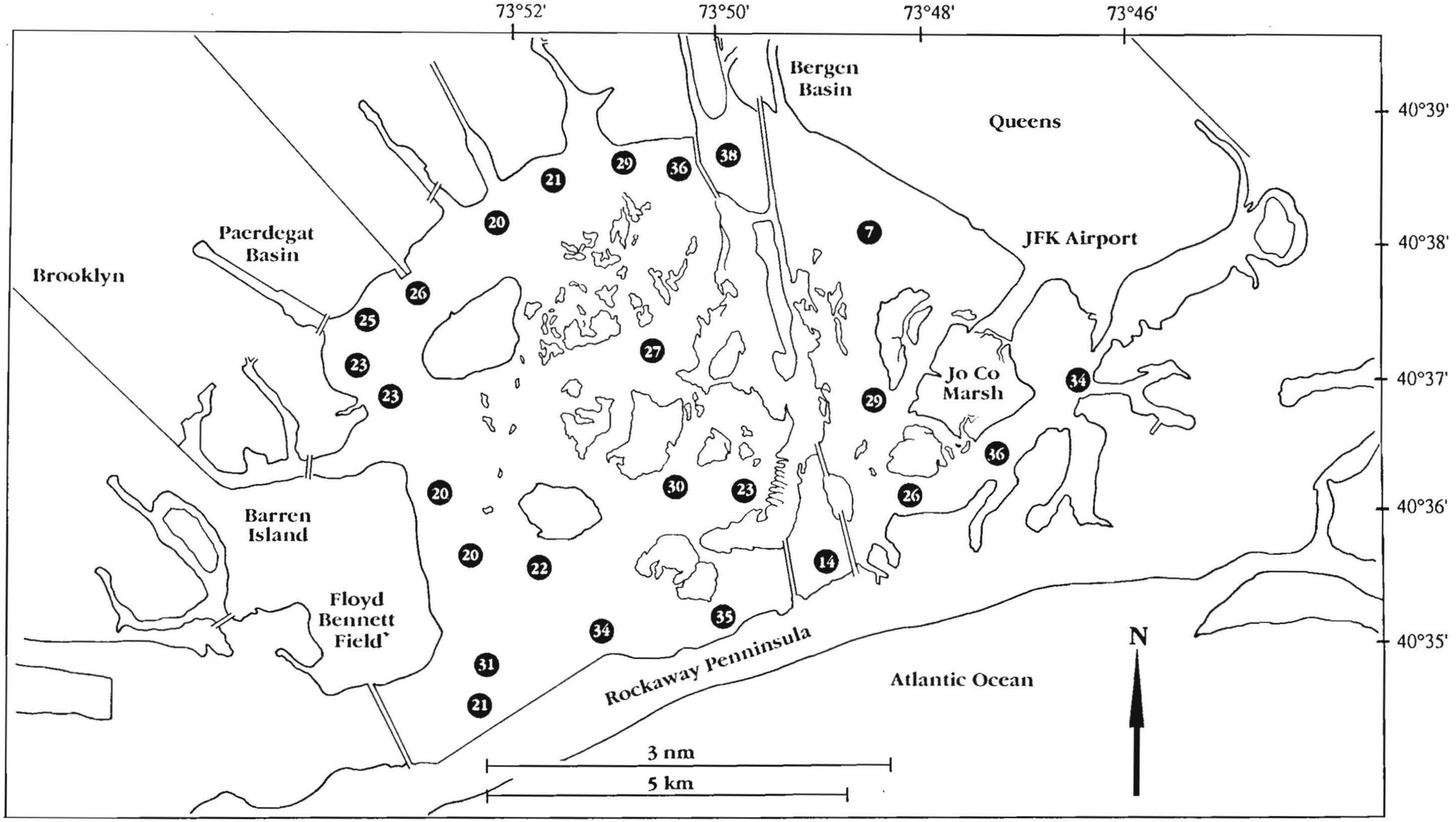

FIGURE 15. BENTHIC SPECIES RICHNESS (NO. SPECIES) AT SAMPLING LOCATIONS THROUGHOUT JAMAICA BAY IN 1982 (FROM FRANZ AND HARRIS, 1985).

of Mullica Bay than to Raritan Bay (Table 10); at most stations in Jamaica Bay, environmental conditions are sufficient to support "normal" benthic macrofaunal diversity (Franz and Harris, 1985). In addition, Table 11 shows that macrobenthic invertebrate densities for Jamaica Bay appear well within the range of values for Mullica Bay and well above those for the highly polluted Raritan Bay (Franz and Harris, 1985).

Based on their occurrence in other nearby embayments such as Great South Bay and western Long Island Sound, certain species were expected in the 1981-82 survey of Jamaica Bay benthos, but were not encountered. These included the bivalves Yoldia limatula and Macoma balthica and the gastropods Acteocina canaliculata, Cylichnella bidenta, Anachis translirata, and Mitrella lunata. In addition, another common bivalve, Nucula proxima, was very scarce in this survey. No explanation of these absences or scarcities is offered by Franz and Harris (1985).

One of the superdominant species in the muddy fine-sand community is the amphipod, Ampelisca abdita. This species is primarily responsible for the high levels of crustacean biomass seen in certain sections of the Bay (Franz and Harris; stations 6, 7, 8, 10, 26; Figure 5). Amphipods play a major role in benthic community food chains as well as in the diets of many fish species (Boesch, 1979). They are the preferred prey of certain shorebirds (Goss-Custard, 1977) and may possibly be the primary consumers in food chains supporting juvenile and adult flatfish as well as overwintering waterfowl in Jamaica Bay

Table 10. Number of species per station, number of stations sampled and species richness (%) in each category for three estuaries - Jamaica Bay, NY; Mullica River/Great Bay, NJ and Raritan Bay, NJ (modified from Franz and Harris, 1985).

	Jamaica Bay		Mullica River/ Great Bay		Raritan Bay	
No. species per station	Number of stations	%	Number of Stations	%	Number of Stations	%
1 - 10	6	5.9	0	0	12	44.4
11 - 20	26	25.5	8	33.3	6	22.2
21 - 30	39	38.9	9	37.5	2	7.4
31 - 40	22	21.6	6	25.0	3	11.1
> 40	9	8.8	1	4.1	4	14.8

Table 11. Macrobenthos density in selected Atlantic estuaries (1 mm sieve size)(modified from Franz and Harris, 1985).

LOCATION	MEAN DENSITY/M^2	SOURCE
Casco Bay/Portland Harbor (Maine)	8743	Larsen *et al.*, 1983
Mystic River (Massachusetts)	3000	Rowe *et al.*, 1972
Moriches Bay (Long Island, New York)	1300	O'Connor, 1972
Raritan Bay (New Jersey)	109	McGrath, 1974
Jamaica Bay (New York)	5085 (2134)*	Franz and Harris, 1985
Mullica River/Great Bay (New Jersey)	4000**	Durand and Nadeau, 1972
Delaware Bay (Delaware)	722	Maurer *et al.*, 1978
Chesapeake Bay (eelgrass) (Virginia)	14000	Orth, 1973
Tampa Bay (Florida)	510	Bloom *et al.*, 1972

* Mean of non-ampeliscid-dominated stations.
** Density estimated from graphical data.

(Franz and Harris, 1985). Amphipods, ampeliscid forms in particular, are often the dominant components of healthy estuarine benthic communities (Boesch, 1982; Steimle et al., 1982). They are, however, very sensitive to pollution (Blumer et al., 1970; Sanders et al., 1972). Accordingly, amphipods constitute <1% of the fauna at the former sewage sludge dumpsite (12-Mile) in the New York Bight apex in contrast to >70% of the fauna at many nearby uncontaminated sites (Franz and Harris, 1985). Ampeliscids are virtually non-existent in Raritan Bay whereas they occur in the relatively pristine Mullica River estuary, NJ in densities up to >1000 m^{-2} (Durand and Nadeau, 1972). High abundances and a wide distribution of amphipods in Jamaica Bay (Franz and Harris, 1985) are an overall indication of the relatively good health of the overall system. Excessive organic sewage materials in addition to metals and xenobiotic compounds could nevertheless destroy these communities in the more vulnerable sections of the Bay. Such a loss may be the result of a transition from sandy to black, organically rich sediments, as in Grassy Bay (Franz and Harris, 1985). The permanent loss of one or more of the superdominants coupled with further species richness decreases, could lead to unstable benthic relationships wherein short-term and random species invasions could result in a fluctuating dominance structure (Franz and Harris, 1988).

Metal contamination can lead to decreasing recruitment and survival of juvenile hard clams and mud snails, among other Bay invertebrates (Franz and Harris, 1985). Benthic organisms such as clams can concentrate metals from sediment through the filtration of resuspended material (Dow and Hurst, 1972). Mud snails (Nassarius obsoleta) are common deposit feeders in Jamaica Bay and exhibit liver enrichment in copper (396x) and zinc (102x) above the surrounding sediment levels (Ramondetta and Harris, 1978). The Grassy Bay area is highly polluted with metals, organic pesticides and petroleum hydrocarbons (Ramondetta and Harris, 1978) and is also almost devoid of benthic fauna. In addition, the water quality (as measured by dissolved oxygen, biological oxygen demand and nutrients) is very poor in this area (see Water Quality and Toxic Substances sections, this document).

Although no correlation of species diversity with metal concentrations was seen in the data of Franz and Harris, this does not mean that metals are not affecting benthic organisms (Dow and Hurst, 1972).

The overall results of Franz and Harris' sampling showed generally high density and diversity of benthic fauna, but several sites, besides Grassy Bay, were also quite depauperate. Stations 25 and 26 (Figure 5) may be a sink for organic particulates and metals as these stations have the lowest diversity and are not physically near any known point source of organic contamination. Redeposition of sediment via tidal currents, in particular, may account for this situation at Station 25 (Franz and Harris, 1985).

Heavy organic enrichment has caused a decrease of indigenous benthos in many portions of the New York Bight. In some areas with large amounts of organic loading, whole classes of organisms are virtually absent (Boesch, 1982). In portions of the Christiaensen Basin in the Bight (adjacent to the metropolitan region's former 12-Mile sewage sludge dump), however, several species not expected to occur, such as amphipods, do indeed occur (National Marine Fisheries, 1972; Botton, 1979; Reid et al., 1991). The latter situation appears to be true in Jamaica Bay as well, except in previously-mentioned sites such as Grassy Bay.

Unfortunately, it is not easy to determine whether the changes in benthic community structure in some areas of the Bay are due to organic enrichment, organic toxicants or metal contamination. Until further research is done in these areas, it will not be possible to identify the principal sources of the pollutants impacting Jamaica Bay benthic communities.

Shellfish

These organisms are treated separately from other benthic invertebrates due to their commercial importance. In this section, the term "shellfish" is used to refer only to commercially-important bivalve molluscs.

Historically, Jamaica Bay was one of the six great shellfish nurseries on the Atlantic Coast. During one peak year, 1905, over $5 million was grossed with the marketing of 10,000 bushels of hard clams (Mercenaria mercenaria). This ranked it behind only Great South Bay and Chesapeake Bay in clam production (New

York Fish and Game Commission, 1905).

In the 1860s, the development of techniques for planting seed oysters (Crassostrea virginica) combined with the absence of such bivalve predators as starfish and oyster drills resulted in a fast-growing and successful industry in Jamaica Bay which supplemented the already large natural populations of oysters (Nat'l Park Serv., 1984). Harvesting of both natural and seeded oysters combined to make Jamaica Bay one of the largest producers of this bivalve species between the years 1900 and 1920. In 1904, for example, 74 vessels were officially registered for the harvesting of natural oyster populations in the Bay. These boats employed 1500 men and their annual shellfish harvest was valued at $2 million (Nat'l Park Serv., 1984). There were also many boats operating illegally; their harvest and income is incalculable. In addition, 266 oyster boats operated out of Canarsie (Brooklyn) to work 500 to 600 seeded oyster plots in the Bay (Nat'l Acad. Sci., 1971). In the rich, protected waters of the Bay, only one season was required for oysters to be brought to a marketable size (Franz and Harris, 1985). At the peak of production, the Bay produced 700,000 bushels of oysters annually (Interstate Sanitation Commission, 1938). At this time, thousands of hectares of Jamaica Bay were devoted to oyster farming with leases available to New York State residents (one year residency requirement) for 25 cents/acre/year (Muller, 1905). In addition to oysters, a local soft clam (Mya arenaria) market was developed during this time (Nat'l Acad. Sci., 1971).

An increase in New York City's waste stream as well as an increase in the flushing time of the Bay due to dredging of channels resulted in a gradual pollution of the Bay waters during the first two decades of the 20th century (Nat'l Acad. Sci., 1971). By World War I, 190 million liters (50 million gallons) per day of raw sewage were being dumped into the Bay, contributing to the decline of the oyster industry (Nat'l Park Serv., 1984). By 1921, the New York City Department of Health had closed the Bay to shellfishing because of human health problems resulting from contamination of the bivalves by pathogens released with the sewage (Nat'l Acad. Sci., 1971; Nat'l Park Serv., 1984). Since then, no shellfish have been marketed legally from the Bay (Franz and Harris, 1985). A subsistence fishery on hard clams is maintained by a large number of local people, however, although its size can not be accurately assessed (Nat'l Acad. Sci., 1971; Franz and Harris, 1988).

The hard clam and soft clam populations in Jamaica Bay at present are apparently very healthy (John Tanacredi, Nat'l Park Serv., personal communication; also see data from Franz and Harris, 1985, Table 9). Changes in water quality and toxicant concentrations have evidently not had an adverse effect on these species. The closure of Bay waters to legal shellfishing in the 1920s followed by the designation of much of the Bay as a Wildlife Refuge has acted to encourage the growth of these populations. The presence of large numbers of clams combined with the closure of large areas in other metropolitan embayments to clamming has resulted in high levels of illegal harvesting of *Mercenaria mercenaria* from Jamaica Bay.

The waters of Jamaica Bay fall under the jurisdiction of two law enforcement agencies: the National Park Service Police and the New York State Department of Environmental Conservation (NYSDEC) Enforcement Division. These agencies cooperate with each other to prevent the harvesting and sale of hard clams from Jamaica Bay. Unfortunately, most illegal harvesting is done at night when these agencies have the fewest personnel on duty. In addition, the combination of minimal fines and an overloaded New York City court system has often resulted in the dismissal of charges or, at worst, a "slap on the wrist" financial penalty. The offenders are usually back out on the Bay within a week. More success is had if the agencies can catch these fishermen selling their clams to wholesalers in Nassau or Suffolk Counties. Recently, the NYSDEC arrested a major Suffolk County wholesaler and several fishermen (repeat offenders) for the sale of hard clams from Jamaica Bay (Chris Pappas, NPS Police, pers. comm.; David Baker, NYSDEC Reg. II, pers. comm.). The danger in the harvesting and sale of Jamaica Bay hard clams to the general public remains one of human health. A recent (September, 1990) outbreak of shellfish poisoning has been closely linked to clams from the Bay and there have been other outbreaks in the past few years which are also suspected to have resulted from the consumption of Jamaica Bay shellfish (Charles DeQuillfeldt, NYSDEC Reg. III, pers. comm.). Unfortunately, an increased demand for hard clams by the public in recent years has led to increased shellfishing in Jamaica Bay. The large amount of money that can be made for relatively little effort more than compensates the fishermen for any fines incurred if caught.

In the 1960s, the NYSDEC started a limited program of transplanting Jamaica Bay clams to cleaner waters for depuration in an effort to take advantage of the large populations there. This program lasted from 1966 until 1968. Hard clams were harvested from Jamaica Bay and placed, within 24 hours, into certified waters at various locations throughout Long Island but primarily on the north shore. After a minimum of 21 days, these clams could then be re-harvested and sold. Although the program was discontinued, the National Park Service and the NYSDEC have discussed the possibility of restarting the program (Shellfish Division, NYSDEC Reg. III, pers. comm.). Even if the two agencies agree to restart this program, there are problems with it. The 21-day depuration period is sufficient to clear a clam's system of bacteria but may not be sufficient for viruses. Most toxic substances picked up by the clams would not be released from the tissues in this period of time, either. For example, oysters (_Ostrea edulis_) from the River Fal in southwest England accumulate so much copper that they must be relaid in uncontaminated water for a year before they can be marketed (Clark, 1986).

Many problems exist which would also have to be considered before legal shellfish harvesting could be resumed in the Bay.

The problem of human pathogenic contamination of clams via sewage and CSO effluent is the major obstacle. In addition, the ability of molluscs to concentrate many pollutants, including metals, organic pesticides and petroleum hydrocarbons would require strict controls and monitoring of these compounds in Bay waters and sediments. Current information on mollusc contamination in Jamaica Bay is contained in the Toxic Substances section of this document.

Between 2,000 and 5,000 acres of Jamaica Bay bottom are potential commercial shellfish beds, but bans on dredging, sand mining, and future construction on the shoal areas must exist to ensure stable and successful cultivation (Parks, Recreation and Cultural Affairs Administration, 1970). Of lesser urgency would be refilling dredged areas like Grassy Bay in order to increase the amount of suitable Bay bottom available for cultivation.

In addition to their commercial importance, bivalves (along with the rest of the invertebrates) are important trophic links in the overall ecology of the Bay system. Rails, black duck and herons are among the many birds of the Bay feeding on these organisms (Parks Recr. Cult. Aff. Admin., 1970). Many shellfish species, in turn, are responsible for filtering large quantities of algae from the waters while other species feed on the organic material in bottom sediments. Thus, the shellfish are important in maintaining the general health of the system.

Radical changes in abundance or condition of these species would indicate the existence of severe or unusual stresses in the

Bay. An example of this is the disappearance of the American oyster (Crassostrea virginica) from Jamaica Bay. As mentioned before, this embayment was once the site of large-scale oyster farming and harvesting of natural beds. At about the same time the shellfish beds in the entire Bay were closed due to human health problems, the oyster populations were beginning to collapse (Nat'l Park Serv., 1984). It is suspected that this might have been at least partly due to increased total suspended solids (TSS) in Bay waters (Nat'l Park Serv., 1984). This increase in TSS could have been the result of the dumping of raw sewage containing high amounts of particulates into the Bay. These effluents also contained high levels of nitrogen and phosphorus which could have led to phytoplankton blooms, thus further increasing the TSS. Increased nutrient loading can also lead to a switch in the species of dominant phytoplankton. A change in the species of algae available to oysters as food to ones which could not be utilized by the bivalves may also have played a role in the decline. Other possible factors include changing salinity and disease (Robert Cerrato, SUNY Stony Brook, pers. comm.). Today there are virtually no oysters in Jamaica Bay and there is no reason to believe that the populations will ever return under the current conditions (Don Riepe, Jamaica Bay Wildlife Refuge, pers. comm.). This situation is not unique to Jamaica Bay, however. Other nearby estuaries such as the New York-New Jersey Harbor and the Great South Bay are also nearly devoid of Crassostrea virginica (Franz and Harris, 1985; Cerrato et al., 1989; Robert Cerrato, pers. comm.).

Finfish

Jamaica Bay is important as a nursery ground to many species of finfish residing in the waters of the New York Bight (Parks Recr. Cult. Aff. Admin., 1970). Two out of three Atlantic fish taken commercially depend on intertidal wetlands and shallow bays for their survival during some part of the life cycle (Clark, 1967) and Jamaica Bay provides the requisite elements for a fish nursery (Parks Recr. Cult. Aff. Admin., 1970).

Bluefish (Pomatomus saltatrix), menhaden (Brevoortia tyrannus), and silver hake (Merluccius bilinearis) are primarily oceanic but require an estuarine environment as larvae and juveniles (Parks Recr. Cult. Aff. Admin., 1970). At least as early as 1970, the number of juveniles of these species were quickly disappearing throughout the New York region (Parks Recr. Cult. Aff. Admin., 1970). There are also a number of migratory fish species such as weakfish (Cynoscion regalis), striped bass (Morone saxatilis) and white mullet (Mugil curema) that spawn in Jamaica Bay waters. As of 1970, 60 species of fish including tautog (Tautoga onitis), northern puffer (Sphoeroides maculatus), American eel (Anguilla rostrata), northern kingfish (Menticirrhus saxatilis), scup (Stenotomus chrysops), black sea bass (Centropristis striata), winter flounder (Pseudopleuronectes americanus), summer flounder (Paralichthys dentatus) and yellowtail flounder (Limanda ferruginea) as well as those mentioned above, spend a portion of their lives in the estuarine waters of Long Island, including Jamaica Bay (Parks Recr. Cult. Aff. Admin., 1970). In recent years (1986-1989), surveys carried out by the NYSDEC have confirmed the presence of these same species in Jamaica Bay during at least the summer months.

The yield in estuarine-dependent sportfishing in the mid-Atlantic states dropped considerably through the 1960s. In 1970, the catch of fluke (i.e. summer flounder) was 80% less and the catch of weakfish and scup was 25% less than in earlier years (Table 12) (Parks Recr. Cult. Aff. Admin., 1970). Whether or not these decreases are due to a loss of habitat or overfishing is not clear.

Unfortunately, an accurate assessment of changes in fish populations over time and space within Jamaica Bay can not be made. Surveys of the fish fauna in the Bay have been irregular. The New York State Conservation Department carried out limited surveys of the marine organisms in the Bay in 1938-1939. In July and August 1970, the U.S. Fish and Wildlife Service also performed a limited survey of the Bay's marine life and found substantial species diversity. The most recent finfish data have been collected by the National Park Service in 1985-1986 and 1988-1989 and by the NYSDEC in 1984-1990 as part of its striped bass survey program.

In 1938, records of fish collected in lower New York Harbor during the previous eighteen years by the New York Aquarium were scanned in order to determine when and where fishing was still

Table 12. Recorded catch in pounds of two species of fish - scup (*Stenotomus chrysops*) and fluke (summer flounder, *Paralichthys dentatus*) - in 1959 and 1969 from New York and New Jersey waters (from Parks, Recr. Cult. Aff. Admin., 1970).

		1959	1969
Scup	New Jersey coast	12.5×10^6	3.5×10^6
	New York coast	13.5×10^6	1.8×10^6
Fluke	New Jersey coast	6.2×10^6	1.2×10^6
	New York coast	2.8×10^6	0.6×10^6

carried on in the lower Harbor and whether changes were related to pollution (Breder, 1938). Just twenty miles south of the Battery, 129 species (48% of the total number of 261 listed for southern New England and New York) were recorded between 1934 and 1938. It is likely that this species list for the lower Harbor is also a fair representation of the species that could be found in Jamaica Bay during the same time period.

In the early 1970s, only about 60 species of finfish and shellfish were known to exist in the Bay, fewer than in earlier years; and their productivity was poor (Nat'l Acad. Sci., 1971). In 1987, Lane and Tanacredi listed 48 species of finfish as present at least part of the year (Table 13) but Riepe et al. (1990) listed 59 species caught in the Bay (Table 14). Differences of this sort may be due to different sampling methodologies employed (Peter Woodhead, SUNY Stony Brook, pers. comm.) and/or to the effects of environmental variables during the sampling periods. Information on sampling schedules and other factors is not available from the National Park Service. In spite of these caveats, the Park Service data do appear to indicate increasing abundance of many species over the years from 1985 to 1989.

Data from sampling done by the NYSDEC Fisheries Division for their striped bass survey in Jamaica Bay show many fewer fish species taken than in the Park Service surveys (Table 15). Total number of species taken across all sampling dates ranged from 31

Table 13. Species and quantity of finfish taken in Jamaica Bay by otter trawl, seine and gill net in 1985-1986 (Lane and Tanacredi 1987).

Species	Otter trawl	Seine	Gill net	Total
American eel	4	0	0	4
Blueback herring	7	1	61	69
Red hake	11	0	0	11
Spotted hake	64	0	0	64
Northern pipefish	42	2	6	50
Striped bass	2	0	0	2
Tautog	23	13	8	44
American sandlance	8	0	0	8
Rock gunnel	21	0	0	21
Grubby	29	0	0	29
Smallmouth flounder	22	1	0	23
Four-spot flounder	15	0	1	16
Windowpane	109	0	5	114
Winter flounder	1061	3	10	1074
Atlantic silversides	15	5461	0	5476
Fourspine stickleback	12	0	0	12
Alewife	2	0	4	6
Mummichog	3	207	0	210
Cunner	14	13	2	28
Little skate	2	0	0	2
Lined seahorse	41	11	4	55
Black sea bass	38	0	2	40
White mullet	3	6	0	9
Smooth dogfish	1	0	36	37
Atlantic menhaden	1	0	550	551
Bay anchovy	134	172	0	306
Oyster toadfish	25	0	0	25
Atlantic tomcod	46	0	0	46
White hake	2	0	0	2
Scup	228	0	5	233
Butterfish	11	1	0	12
Striped searobin	62	3	8	73
Summer flounder	93	0	15	108
Silver hake	5	0	0	5
Weakfish	115	14	1	130
Northern puffer	1	3	0	4
Yellow jack	1	0	9	10
Planehead filefish	1	0	1	2
Lookdown	1	1	1	2
Spotfin butterflyfish	3	0	0	3
Bluespotted cornetfish	1	0	0	1
Striped killifish	0	700	0	700
Bluefish	0	36	23	59
Spot	0	1	0	1
Northern kingfish	0	42	0	42
American shad	0	3	0	3
Crevalle jack	0	0	2	2

Table 14. Species and quantity of finfish taken in Jamaica Bay by otter trawl and seine in 1988-1989 (Reipe *et al.*, 1990).

Species	Otter trawl	Seine	Total
Spotted hake	27	0	27
Tautog	68	13	81
Winter flounder	2901	13	2914
Cunner	12	2	14
Porgy	215	0	215
Lined seahorse	52	2	54
Black sea bass	11	0	11
Red hake	60	0	60
Northern pipefish	57	2	59
Northern searobin	21	3	24
Spotfin butterflyfish	7	0	7
Bigeye	1	0	1
Windowpane	236	3	239
Grubby	90	1	91
Smallmouth flounder	130	12	142
Rock gunnel	5	0	5
Clearnose skate	7	0	7
Butterfish	4	0	4
Atlantic silversides	53	8771	8824
Summer flounder	62	34	96
Planehead filefish	7	0	7
Northern stargazer	17	0	17
Orange filefish	5	0	5
Striped searobin	164	1	165
Spiny dogfish	6	0	6
Northern puffer	9	0	9
American eel	6	0	6
Northern kingfish	25	35	60
Four-spot flounder	6	0	6
Goby sp.	1	0	1
Smooth dogfish	1	0	1
Scup	2	0	2
Atlantic herring	1	0	1
Inshore lizardfish	5	9	14
Weakfish	140	12	152
Blueback herring	21	0	21
Naked goby	2	0	2
White perch	4	15	19
Oyster toadfish	58	0	58
Atlantic tomcod	5	0	5
Alewife	1	0	1
Bluespotted cornetfish	5	0	5
Silver hake	1	0	1
Striped bass	2	0	2
Hogchoker	1	0	1
Four-spine stickleback	1	0	1
Spot	128	1	129

Table 14 (cont'd). Species and quantity of finfish caught in Jamaica Bay in 1988-1989.

Species	Otter trawl	Seine	Total
Bay anchovy	4	0	4
Arrow goby	2	2	4
Grey snapper	1	1	2
Striped killifish	0	1558	1558
Bluefish	0	937	937
Mummichog	0	67	67
Banded killifish	0	15	15
Atlantic needlefish	0	1	1
White mullet	0	72	72
Permit	0	83	83
Yellow jack	0	8	8
Striped burrfish	0	1	1

Table 15. Species and quantity of finfish caught in Jamaica Bay with seines in the years 1986-1989 by the New York State Department of Environmental Conservation, Division of Marine Resources.

Species	1986	1987	1988	1989
Striped bass	89	80	278	692
Killifish	5909	8081	9791	16329
Atlantic silversides	11642	42813	16724	22966
Winter flounder	300	513	628	245
Bay anchovy	1986	487	3258	808
Bluefish	329	4290	185	673
Windowpane	5	29	100	19
Blueback herring	257	100	8	4
Pipefish	330	82	311	148
American sandlance	0	1	0	2
Three-spine stickleback	0	4	8	3
Four-spine stickleback	4	1	61	17
Atlantic menhaden	6	4	1	2
Atlantic tomcod	0	2	4	4
Alewife	19	1	0	9
American eel	12	3	8	11
Summer flounder	31	3	2	30
Lined seahorse	2	7	26	4
Oyster toadfish	8	23	4	0
Northern puffer	21	12	4	7
White perch	0	69	17	16
Cunner	1	0	0	1
Spot	156	3	0	0
Atlantic herring	51	2	803	69
White mullet	35	0	13	35
Grubby sculpin	7	0	6	17
Crevalle jack	10	14	54	2

Table 15 (cont'd). Species and quantity of finfish caught in Jamaica Bay by the NYSDEC.

Species	1986	1987	1988	1989
Smallmouth flounder	0	2	17	4
Atlantic needlefish	0	7	3	1
Striped mullet	190	23	0	0
Pollack	0	0	7	1
Northern searobin	90	0	0	0
Striped searobin	0	0	2	4
Planehead filefish	0	0	0	1
Naked goby	0	1	0	7
American shad	1	0	0	0
Spotted hake	2	0	1	0
Permit	0	3	0	10
Northern kingfish	77	42	88	2
Inshore lizardfish	1	0	2	6
Grey snapper	0	4	0	0
Striped anchovy	0	0	1	0
Halfbeak	0	0	2	0
Four-spot flounder	0	0	0	1
Trunkfish	0	0	0	5
Cowfish	0	0	0	1
Bluespotted cornetfish	0	0	0	2

in 1986 to 38 in 1989. The striped bass survey relies solely on seine hauls, however, while the Park Service uses otter trawls and gill nets in addition to seines.

A survey of finfish in October 1969 indicated a standing crop of less than 1.2 kg per hectare (1.1 lbs. per acre) at all stations; in June 1970 the values ranged from no fish per hectare at Grassy Bay to 7.9 kg per hectare (7.0 lbs. per acre) in North Channel. These numbers can be compared to 88.6 kg per hectare (79 lbs. per acre) in San Francisco Bay and 243.7 kg per hectare (217 lbs. pounds per acre) in Laguna Madre, TX (Nat'l Acad. Sci., 1971).

Between 1950-1970, there was an 80-90% decrease in the commercial catch of certain species of fish in the New York Bight (Nat'l Acad. Sci., 1971). The major cause of this decline was probably overfishing but the loss of wetlands in the New York metropolitan area may also have been a factor. The only remaining nursery grounds for such fish in this region are the New York-New Jersey Harbor Estuary and Jamaica Bay (Nat'l Acad. Sci., 1971). This decrease in abundance of commercial species has led to reduced fishing effort over the years within the Bay. The decreased effort may have, ironically enough, helped preserve other species of fish in Jamaica Bay. Any further decrease in the area of the Bay and any further impairments to circulation may have deleterious effects on the remaining fish populations, however (Nat'l Acad. Sci., 1971).

A comparison of offshore, marine fish stocks to inshore, anadromous or estuarine stocks has shown that the latter have decreased at a significantly greater rate than the former in the past 100 years. As overfishing and other stresses have caused both types to decline, the greater decline in inshore species would seem to implicate pollution and poor water quality as a factor (Swanson _et_ _al_., 1991).

It has been difficult to assess the impacts of pollutants on the survival of fish. The major concern about toxic substances in fish is the impact on humans through consumption. High concentrations of PCBs in finfish led to a ban on commercial and recreational fishing for striped bass in the Hudson River by the NYSDEC. American shad (_Alosa_ _sapidissima_) and Atlantic sturgeon (_Acipenser_ _oxyrhyncus_) were excluded from this ban as they reside in the river so short a time that any exposure to PCBs would not be considered deleterious to fish or human health. There are no United States Environmental Protection Agency or United States Food and Drug Administration criteria for concentrations of other toxic substances in fish tissue.

Reptiles and Amphibians

Historic records of Long Island, NY indicate the existence of a diversity of herpetofauna (Schlaugh and Burnley, 1968). Noble (1927) indicates 39 native species while Schlaugh (1978) lists 37 as definite and 12 more as possible. Most of these could be found in the three counties peripheral to Jamaica Bay (Cook and Pinnock, 1987). In Brooklyn, New York, most herpetofauna are extinct and in Nassau County, New York, 24 of the 35 indigenous species are considered extinct or endangered (Schlaugh, 1978). The eastern hognose snake (Heterodon p. platyrhinos), the smooth green snake (Opheodrys v. vernalis) and the eastern mud turtle (Kinosternum s. subrubrum) occurred in the Rockaways in the past but are no longer found there (Ditmars, 1896; Engelhardt, 1913; Engelhardt et al., 1915; Murphy, 1916). This decrease in the herpetofauna is a typical trend accompanying urbanization (Campbell, 1974; Dove, 1985). In Jamaica Bay, the loss of habitat was also accompanied by some creation as well. The upland habitats created from dredge spoil deposition on marshes were insular, however, and, with the decline of mainland herpetofauna, these became remnant populations (Cook and Pinnock, 1987).

A 1979-1980 inventory (Cook and Pinnock, 1987) of Ruler's Bar Hassock, the Bay's main island, revealed the presence of an impoverished herpetofauna with only a portion of the native species present that were capable of being supported by the diverse habitats available on the island. Unfortunately, this is not a surprising state of affairs when one considers that the salt waters of Jamaica Bay in combination with various factors resulting from urbanization constitute formidable dispersal barriers (Campbell, 1974). Those species present included breeding populations of Fowler's toad (Bufo woodhousei fowleri), northern diamondback terrapin (Malaclemys t. terrapin) and the eastern garter snake (Thamnophis s. sirtalis) as well as individuals of the eastern box turtle (*Terrapene c. carolina*), eastern painted turtle (*Chrysemys p. picta*), red-eared slider (*Chrysemys scripta elegans*), and the snapping turtle (*Chelydra serpentina*). The diamondback terrapin is an indigenous salt marsh species; the turtles inventoried may be what remains of a native population (Cook and Pinnock, 1987). The other species observed by Cook and Pinnock are known for their urban tolerance or as popular pets, suggesting that their presence on the island is a result of unintentional introduction or purposeful release by humans (Schlaugh, 1978; Klemens, 1985).

Table 16 lists the population status of amphibians and reptiles reintroduced to the Jamaica Bay area in 1980 in an attempt to re-establish the species diversity (Cook and Pinnock, 1987). Species released include the spring peeper (*Hyla crucifer*), the smooth green snake (*Opheodrys v. vernalis*), the northern brown snake, the eastern hognose snake, the eastern milk snake (*Lampropeltis t. triangulum*), the black racer (*Coluber c. constrictum*), the snapping turtle, the eastern painted turtle and the eastern box turtle. Jamaica Bay has a history of initial abuse for which recent restoration efforts may help compensate. Although it is unreasonable to expect the complete restoration of all of the pre-urbanization fauna, efforts so far appear to have been successful at re-establishing a few (Cook and Pinnock, 1987).

It is clear, however, that almost all of the native species of snakes, turtles and amphibians are extinct from the Jamaica

Table 16. Population status of amphibians and reptiles released on Ruler's Bar Hassock Island, Jamaica Bay Wildlife Refuge, New York, NY, 1980-1986 (modified from Cook and Pinnock, 1987).

Species	Years studied	No. individuals	Established
Spring peeper	80-83	58 adult 3600 larvae	Yes
Green frog	85-86	15 adult	*
Red-backed salamander	83-86	361 juvenile 1443 adult	*
Northern brown snake	80-84	23 juvenile 49 adult	Yes
Smooth green snake	81-86	17 juvenile 64 adult	*
Eastern hognose snake	84-85	21 hatchling 4 adult	*
Eastern milk snake	84-85	13 juvenile 9 adult	*
Black racer	85-86	4 juvenile 17 adult	*
Snapping turtle	83-85	320 hatchling 11 juvenile 35 adult	*
Eastern painted turtle	82-85	28 juvenile 295 adult	*
Eastern box turtle	80-86	12 juvenile 183 adult	*

* insufficient elapsed time or data to determine.

Bay area in spite of its status as a Wildlife Refuge and this constitutes one of the most severe impacts of urbanization on the system.

Use Impairments

Two aspects of impairment must be considered for the fauna: first, impairments to use of the Bay by the fauna, and, second, limitations to human use of the Bay because of the fauna.

The fauna of Jamaica Bay have been studied aperiodically by a variety of investigators since the 1800s. There is no question that the native terrestrial communities have been radically changed by the urbanizing of the territory around Jamaica Bay. The aquatic system has also been changed and reduced but the impacts, in terms of species diversity and even density may not have been as severe. Plankton and benthic communities are possibly similar in many ways to those which existed prior to European settlement although a lack of surveys prior to the 1970s makes confirmation of this idea impossible. The fish communities, however, have undoubtedly seen major changes as a result of overharvesting in the Bay and adjacent coastal waters and destruction of spawning and nursery grounds. This situation will improve only if sufficient restrictions are put on commercial and recreational fishing. Curbs on the discharge of toxic substances into the Bay will also be necessary in order to avoid acute and chronic contamination of many species, particularly larval and juvenile forms.

Impairments of the Bay's use by man as a result of the need to protect faunal activities is a more difficult issue. The protection of the fauna so that they might be enjoyed for their own sake, while enhancing and preserving the health of the Bay, should more than compensate for the loss of some recreational freedom. That Jamaica Bay has the relatively productive and diverse aquatic communities that it does, is largely the result of its preservation as a Wildlife Refuge and National Park. Care must be taken to see that anthropogenic interference with the system is minimized. Jamaica Bay is one of the few areas within New York City able to sustain at least some herpetofauna and avifauna which is accessible to most City residents. It is one of the very few remnants of nature that many residents can ever see up close, given their economic limitations on travel. To the extent that the fauna are impaired, millions of people are deprived of ever experiencing those fragments of a natural system. The opportunity that Jamaica Bay represents to thousands of people living in an urban area that isolates them from natural ecosystems is more valuable than any loss to commercial interests in the Bay.

For these reasons and because of the designation of most of the Bay as a wildlife refuge, there are, necessarily, some restrictions on recreational activities. Other restrictions may be required in the future. Should commercial fishing for striped bass and other finfish or shellfish be resumed in Jamaica Bay waters, strict limits on the location of fishing (outside the refuge) and the amounts taken would have to be imposed. Should the waters become safe for swimming, restrictions would have to be imposed to protect the fauna from that activity. Increased boating and associated activities such as recreational fishing, waterskiing, picnicking on islands, etc. are regulated in order to protect breeding and nursery grounds for finfish, crustaceans, reptiles and amphibians; these restrictions and the enforcement of them may have to be tightened. In these ways, human use of the Bay has been "impaired" but it is more important to protect this valuable resource than it is to allow unrestricted recreation.

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BIRDS

The Atlantic Flyway, an air corridor along the east coast of North America, is an important migration route for many species of birds. Large numbers are found in this region at various times during spring and fall. The Jamaica Bay Wildlife Refuge (JBWR), part of the Gateway National Recreation Area (GNRA) of the National Park Service, is composed of an unurbanized 36 km^2 (9,155 acres) of freshwater ponds, salt marshes, shallow tidal waters and bordering uplands supporting a wide diversity of marine organisms, including at least 326 species of birds (Davis, 1976; Howe *et al.*, 1978; Burger 1983; Riepe *et al.*, 1990). Although Long Island's south coast has many tidal bays, it is more than 140 km (75 nautical miles) by air from Jamaica Bay, NY to the nearest significant coastal salt marsh in New Jersey, making the JBWR an important link in the Atlantic Flyway. The JBWR is the northern extreme in the range of a variety of birds such as the glossy ibis (*Plegadis falinellus*), the southern extreme of the breeding range of the great black - backed gull (*Larus marinus*) and a stronghold from which several species of herons, egrets and ibises have colonized other areas of New England and North America. Moreover, the JBWR serves as a resting, feeding, and breeding refuge to perhaps 25% of Long Island's wintering waterfowl as well as several species listed by the state of New York as threatened or endangered, including osprey (Pandion haliaetus), piping plover (Charadrius melodus), and common, least, and roseate terns (Sterna hirundo, S. albifrons and S. dougallii) (Parks, Recreation, and Cultural Affairs Administration, 1970; National Academy of Sciences, 1971).

A variety of factors have contributed to changes in the avifauna of the JBWR over the years. Most of these factors result from urbanization of surrounding areas; some examples include landfills, roads, marinas, industrial and residential construction, and waste disposal facilities.

Habitat

The alteration or destruction of habitat may be the single most important reason why birds nesting in the coastal zone throughout the New York Bight will never again reach their former large numbers (Howe et al., 1978). For example, the human population of the Rockaway Peninsula, adjacent to the JBWR, has doubled since 1950, now exceeding 100,000 residents. Growing needs for more roads, housing, and waste disposal have increasingly affected the ranges and abundances of a number of migratory bird species in the region, through loss of breeding, nesting, and feeding habitat. In fact, along the entire east coast of the United States, the building of cities and resorts has substantially diminished areas of choice nesting habitat. For example, herons, ospreys and fish crows (Corvus ossifragus) once nested in the forests of Seven Mile Beach, NJ while common and least terns, piping plovers and black skimmers (Rynchops niger) used the beaches (Howe et al., 1978). By 1936, few birds remained after the draining and development of marshes devastated their habitat (Stone, 1937).

Filling of marshes accounted for the loss of 7.1% (2385 km^2 or 589,000 acres) of United States estuarine habitat as of the mid 1960s (Howe et al., 1978). By 1965, dredging and filling were responsible for the loss of 81 km^2 (20,000 acres) of estuarine habitat in New York and 219 km^2 (54,000 acres) in New Jersey, the majority being destroyed between 1954-1958 (Spinner, 1969; United States Department of the Interior, 1970). In fact, the estuaries of New York and New Jersey were filled in more than those of almost any other state, with the exception of California (Howe et al., 1978).

Between 1964 and 1968, an average of $3.5x10^6$ metric tons per year ($3.9x10^6$ tons/yr) of dredge spoil were being dumped in the New York Bight; by 1975 this rate had doubled to $7.1x10^6$ metric tons per year ($7.8x10^6$ tons/yr) (Gross, 1976). Some of the spoil was deposited as small islands within the JBWR, and the creation of new habitat has had a positive effect on local bird populations (Howe et al., 1978). Habitat improvements have come about as a result of compromises made over the years in order to enhance and extend the JBWR, and to make it accessible to the public. In 1953, the New York City Department of Parks and Recreation and the New York State Department of Environmental Conservation (NYSDEC) decided to create two freshwater ponds to increase the breeding of non-marine waterfowl and to attract them during non-breeding seasons (Nat'l Acad. Sci., 1971). In return for permission to dredge sand from JBWR to use for the embankment of the newly constructed rapid transit line, the Metropolitan Transit Authority agreed to construct the dikes needed for the two ponds. However, the conversion of park lands for these ponds may have adversely affected some non-waterfowl species. There are no data to verify either an increase in freshwater wildfowl or a decrease in other species of birds as a result of the construction of the ponds, although members of the Refuge staff believe that numbers of freshwater birds have increased (Don Riepe, JBWR, pers. comm.).

For illustration of the effects of these kinds of modifications, Urner (1934) censused a Newark-Elizabeth, NJ salt marsh from 1898-1932, during which time the marsh had been heavily ditched and diked. Ditching, for draining land, began in 1916, and diking, for impounding water above sea level, began in 1921. During the study, the number of breeding species increased from 16 to 19; but the total number of individuals decreased from 467 to 306. Though abundances of some species of waterfowl increased during the survey period, abundances of most species decreased. For example, black duck (Anas rubripes) and mallard (Anas platyrhynchos) abundances increased after diking while American and least bittern (Botaurus lentigonosus and Ixobrychus exilis) abundances decreased after ditching. Clearly habitat changes do not affect all species equally.

The building of highways along beaches provides scenic views and beach access, but also impairs large stretches of habitat formerly attractive to bird species which nest on open beaches (Howe et al., 1978). Further, vehicular mortality is estimated to be responsible for 29% of man-induced bird mortality in the United States (Howe et al., 1978), and species using beaches are probably at greatest risk.

The piping plover, a bird listed as endangered, is a good example of a species whose decline has been caused by human activities. This bird nests on open beaches in the JBWR (Davis, 1976). The causative factors in plover population decline are: 1) loss of habitat; 2) human disturbance, including pets, vehicles and recreation; and 3) natural predation (Riepe, 1989). Much of the plover's Atlantic Coast habitat has already been impaired or permanently destroyed by continuing coastal development such as recreational housing and resorts (Riepe, 1989). The piping plover, essentially the only plover species to nest in the New York Bight region, was common along Bight beaches during much of the 19th century, but was nearly rendered extinct by extensive hunting for the millinery trade before the turn of the 20th century (Howe et al., 1978). By 1907, it was considered a rare summer resident of Long Island (Braislin, 1907). After the migratory bird treaty of 1913, which protects many Canadian and U.S. species, large numbers of piping plovers were again seen. Cruickshank (1942) reported them to be common by the early 1940s and Wilcox (1959) found 64 pairs of piping plovers between

Moriches and Shinnecock inlets on the south shore of eastern Long Island. For the next ten years, their numbers declined severely due to the transfer of dredged bottom sand to the beach for the construction of dunes and beachside summer homes (Howe et al., 1978). Subsequently, plover populations declined more gradually until the early 1960s (Howe et al., 1978). Between 1974 and 1977, piping plovers were widely distributed along sandy beaches on Long Island, at least as far west as Lloyd Neck, on the north shore of Long Island (Howe et al., 1978). However, by the early 1970s, they had disappeared from disturbed areas and were confined to remote sandy beaches (Howe et al., 1978).

The correlation between human presence and plover productivity in the JBWR is clear. In August 1988, at Breezy Point, as many as 1,710 disturbances of plovers (averaging one each 2.4 minutes) were observed in the form of pedestrian, off the road vehicle or "other" traffic (Riepe, 1989). In addition, the fledge rate, defined as birds reaching the age to fly, at Breezy Point in 1988 was very low (relative to that of birds in undisturbed areas outside the New York Bight) although there was a fair hatching rate (Riepe, 1989). These results confirm those seen in earlier studies done elsewhere. Cairns (1977), working in Nova Scotia, found that piping plover reproductive success was twice as great on remote beaches as on recreational beaches, and Fleming et al. (1988) found chick survival in highly active (>30 visits per week) recreational areas to be 28% of survival in low activity (0-20 visits per week) areas. In a Barnstable, MA study

(Strauss et al., 1986), the number of plover fledglings per nesting pair found in areas lightly used by pedestrians was more than two times greater than the number found in areas used heavily by off-road vehicles and pedestrians.

Data on hatching and fledging rates may be offset by other data, however. At Breezy Point in 1987, 14 nesting pairs of piping plovers were observed, and 18 pairs were observed one year later. This apparent increase in the number of plovers might be a function of either more intensive field surveys or increased available habitat due to accretion of sand (Riepe, 1989).

In addition to the data on hatching and fledging in piping plovers, there is also evidence that these rates may have decreased for many species of egrets, ibises, and other shorebirds in Jamaica Bay as a result of disturbance by humans (Burger, 1981). Ducks appear to be only moderately affected by these disturbances while gulls and terns are relatively unaffected (Burger, 1981).

The common tern is the most abundant nesting tern in the New York Bight region (Howe et al., 1978). Found in high numbers in the early 19th century, the common tern populations of the region were obliterated by feather hunters by the mid-1880s (Cruickshank, 1942). They recovered in the 1920s under the protection of federal law. Subsequently they have been forced onto small, uninhabited islands and marshes because of commercial development and recreational beach use (Howe et al., 1978). Further, in the early 1970s, three common tern colonies on Long

Island, including one at Breezy Point, were decimated by human interference or vandalism (Gochfield, 1974a; Howe et al., 1978). However, common terns, unlike piping plovers (Wilcox, 1959), often shift colony locations from year to year (Drury, 1973; Gochfield, 1974b), making it difficult to assess the effects of anthropogenic disturbances on breeding populations unless more regular surveys are made (Howe et al., 1978).

The black skimmer's history in the New York Bight is similar to that of other colonial waterfowl in that it virtually disappeared during the intensive period of bird-hunting for feathers around the turn of the 20th century (Stone, 1937; Drury, 1973). Black skimmers, like common terns, cannot breed successfully on mainland sites heavily used by man (Howe et al., 1978), and islands free from predation, human disturbance, and competition for nesting space with herring gulls (*Larus argentatus*) are rare (Howe et al., 1978).

Total number of birds is difficult to determine, but a rough estimate is more than several hundred thousand birds inhabit JBWR during the year (Don Riepe, pers. comm.).

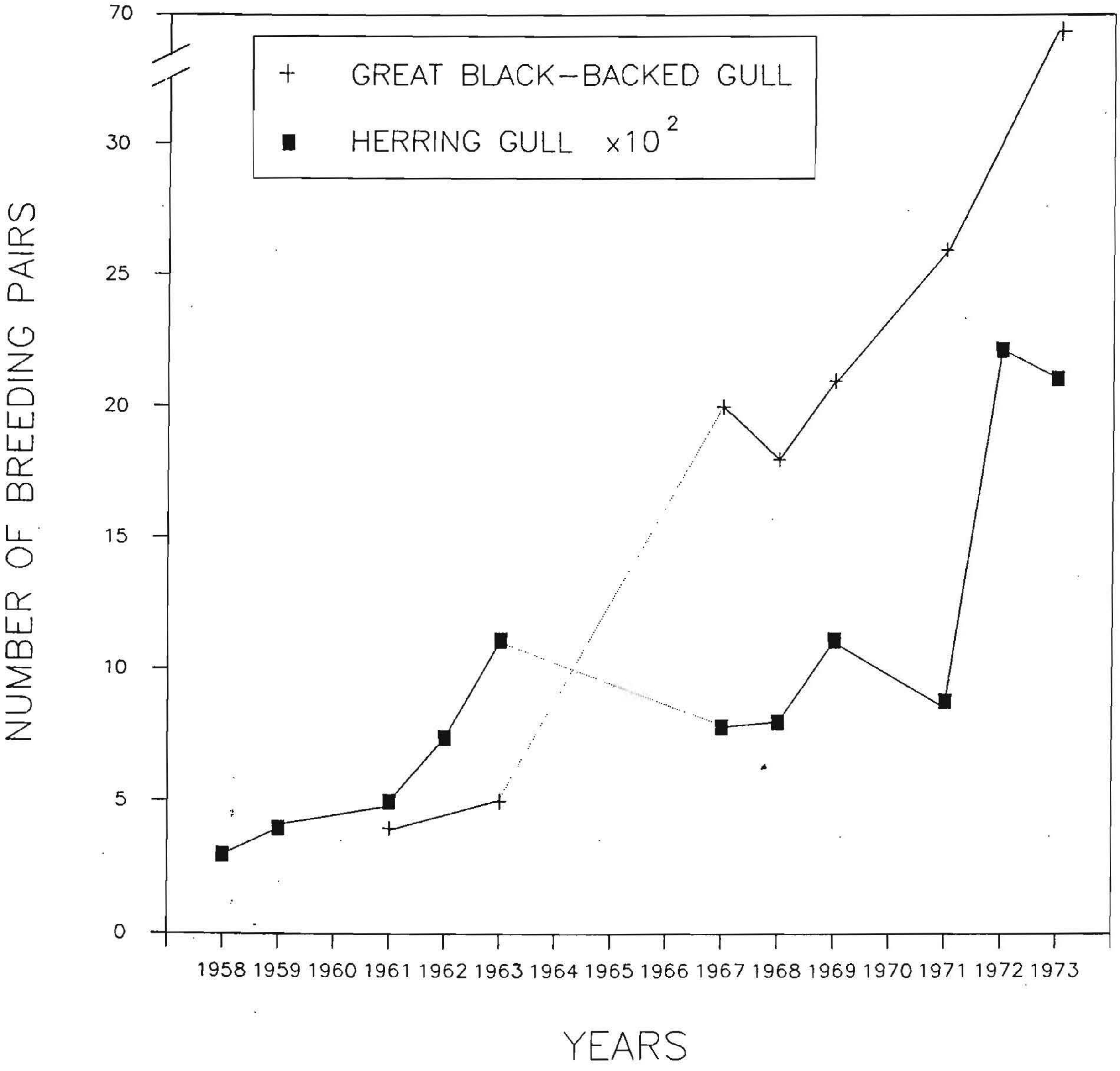
Landfills and Gulls

In assessing the Jamaica Bay environment specifically, there are lessons to be drawn indirectly from other areas. The increase in herring gulls and great black-backed gull populations in the United States Northeast has been ascribed to the proliferation of dumpsites and landfills, which parallel human population increases and offer a steady food supply to gull populations (Howe _et al_., 1978). Although JBWR attracts many species of birds due to its location along a migration route, it also attracts birds because of the Pennsylvania Avenue, Fountain Avenue, and Edgemere sanitary landfills (Figure 3). These landfills were fully operative as of 1975, and were sources of food for thousands of gulls (US Dept. Int., 1976). By 1981, the Pennsylvania Avenue site was no longer in regular use, in 1985 the Fountain Avenue site was closed, and in 1991 the Edgemere site was closed. None of the sites have been capped (Gil Burns, NYSDEC, personal communication). Herring gull flocks as large as several thousand have been common at dumpsites throughout the New York Bight region (Howe _et al_., 1978).

Data collected at Captree State Park on Long Island show populations of herring and great black-backed gulls to have tripled from 1967 to 1973 (Figure 16). Within the JBWR, 1978 maximum abundances of herring and great black-backed gulls were approximately 6000 and 700, respectively (Burger, 1983). Drury and Kadlec (1974) suggested that herring gull populations in New England were stabilizing over a twenty year period between the mid-1950s and mid-1970s, due to limitations of food or nesting. However, Nisbet (1971) reported that breeding pairs of the great black-backed gull were doubling every 9 to 10 years, faster than the doubling rate (12-15 years) reported by Kadlec and Drury (1968) for herring gulls.

The diversity and abundance of colonial waterfowl and shore

Figure 16. Herring and great black-backed gull populations at Captree State Park, NY (redrawn from Howe _et_ _al._, 1978).



birds can be adversely influenced by the herring gull population, through predation and competition (Nisbet, 1971; Howe et al., 1978). Since the landfill closures around JBWR, the gull populations have declined (Don Riepe, pers. comm.). However, no dramatic increases in tern or plover populations, those most likely to benefit from reduced gull abundances, have been noticed by park rangers (Don Riepe, pers. comm.).

Great black-backed gulls were not found breeding on Long Island until 1942 (Wilcox, 1944). As of 1977, they were nesting in at least 15 herring gull colonies and their numbers have increased significantly since then (Howe et al., 1978). As their numbers increase further, this species also could become a significant predator on the young of other bird species (Bent, 1921; Howe et al., 1978), including terns and perhaps even herring gulls (Howe et al., 1978). It is not clear if the appearance and increasing abundance of great black-backed gulls is due to the presence of landfills in the area.

On a positive note, herring gulls effectively scavenge decaying material, such as dead fish and may thus have a positive effect on water quality in some respects (Howe et al., 1978).

Birds and John F. Kennedy International (JFK) Airport

The Pennsylvania Avenue, Fountain Avenue, and Edgemere landfills are located near JFK Airport, and, until recently, they attracted many herring gulls, the birds most frequently involved in aircraft accidents (Nat'l Acad. Sci., 1971). The JFK Airport has had a serious bird problem for many years. For example, 31 bird-aircraft strikes occurred in 1975 alone. The most serious one involved the ingestion of gulls into a DC-10 engine which then exploded and separated from the aircraft (US Dept. Int., 1976). As many as a million herring gulls may overwinter in the greater New York area, and a conservative estimate of the number of gulls overwintering in the wildlife refuge is 30,000 (Nat'l. Acad. Sci., 1971). In 1990, John Tanacredi of the JBWR reported that the 3,000 laughing gulls (_Larus_ _articilla_) were a hazard due to the danger of bird-aircraft interactions. A plan to oil the 1990 gull eggs, thereby killing them, to reduce the gull populations at JBWR and alleviate the bird-aircraft problems was developed (Newsday, 1990). Experimental egg oiling of 3,000 gull nests, approximately half of those present in JBWR, was accomplished in 1990 and resulted in the mortality of most oiled eggs. Future control of the population through egg oilings will be considered (Don Riepe, pers. comm.).

It is noteworthy that the flat stretches of grassland, typical of most airports, do provide a limited habitat for some species of birds, despite noise, oil pollution, and the presence of humans. For example, in 1975, 12 breeding pairs of the upland sandpiper (_Bartramia_ _longicauda_) were discovered at JFK Airport (Howe _et_ _al_., 1978).

Pollution and Birds

There are considerable consequences for humans and birds alike as a result of the release of various waste products and by-products of human activities. Some of these include chlorinated hydrocarbons, including dichloro-diphenyl-trichloroethane (DDT) and other pesticides, and industrial compounds, like polychlorinated biphenyls (PCBs). Many coastal and estuarine salt marshes were repeatedly sprayed with DDT to reduce mosquito populations and were a major source of this compound to the New York Bight prior to the ban on its use in 1972 (Howe et al., 1978). In the high-water grass marsh where the Carman's River enters Great South Bay, Long Island, DDT residues ranged from 296 to 3656 kg per km^2 (2.6 to 32.6 lbs. per acre), with a mean of 1457 kg per km^2 (13.0 lbs. per acre) (Woodwell et al., 1967). Metabolites of DDT greatly inhibit calcium metabolism and egg shell production (Spitzer et al., 1978). Birds high up in the food web, like ospreys, can accumulate relatively high concentrations of DDT, greatly affecting their reproductive success. During the 1950s and 1960s when DDT was in common use, osprey populations declined dramatically. For example, in 1948, 300 active osprey nests were reported on Gardiners Island, NY, while only 30 were reported in 1968 (Spitzer et al., 1978). However, since use of DDT was prohibited, osprey populations have increased steadily (Spitzer et al., 1978; Poole, 1989), and in 1990 for the first time in 30 years ospreys have produced fledglings in JBWR (New York Times, 1990; Donald Riepe, pers. comm.).

It is estimated that $5x10^8$ kg ($5.5x10^5$ tons) of PCBs have been sold in the United States since their introduction for use in transformers and condensers in 1929 (Hammond et al., 1972). Marine environments receive PCBs in industrial waste and through the burning of plastics (Dustman et al., 1971; White and Stickel, 1975). They occur in the highest concentrations near industrialized, densely populated areas, such as the northern portion of the New York Bight (Howe et al., 1978). Oysters (Crassostrea virginica) exposed to 10 parts per billion (ppb) PCB can concentrate these compounds 3,000-fold (33 parts per million) (Dustman, et al., 1971). Birds feeding on prey containing high concentrations of PCBs, accumulate some of the highest concentrations observed (Howe et al., 1978). The levels of PCBs in birds of the New York Bight, as reported by Risebrough (1971), were among the highest recorded for birds anywhere. Wet weight concentrations of DDT and PCB in the fat of three representative species were 40.9 and 52.6 ppm, respectively, in sooty shearwaters (Puffinus griseus), 70.9 and 104.3 ppm, in greater shearwaters (Puffinus gravis), and 199 and 697 ppm in Wilson's storm-petrels (Oceanites oceanicus) (Risebrough, 1971).

Chlorinated hydrocarbons can also have a delayed effect on bird mortality and reproductive success. Many organic pollutants, such as dieldrin and PCBs, are stored in body fat reserves, which are often utilized when birds are exposed to stresses, like cold weather or oil spills, (Stickel, 1975). Koeman (1971) and Van Velzen et al. (1972) reported that stored chlorinated hydrocarbon residues were the cause of mortality in wild birds when fat was mobilized as a result of reduced food supply. In general, positive correlations between bird population declines and pollutant concentrations are more commonly seen than in most other taxa.

As with habitat alterations, all pollutants do not affect all species equally. Widespread reproductive failure has been linked to chlorinated hydrocarbons, which reach the birds through the food web. As mentioned previously, high concentrations found in ospreys and their eggs have been linked to population declines throughout the New York Bight and elsewhere (Howe et al., 1978; Poole, 1989). The American oystercatcher, (Haematopus palliatus), though most common in Great South Bay, NY also nests in JBWR (Howe et al., 1978), and feeds on oysters, mussels, razor clams, and hard clams (Post and Raynor, 1964). In spite of high concentrations of organic pollutants in the JBWR and the capacity of these molluscs to concentrate pollutants, there was still no evidence of oystercatcher reproductive failure, like that of ospreys during the same period (Howe et al., 1978). This may be because molluscs are lower in the food web than the fish eaten by ospreys and, thus, less pollutants are taken up by oystercatchers.

On Long Island in 1969 and the early 1970s, unusually high incidences of developmental abnormalities related to pollution residues were reported in young terns, such as loss of flight feathers, and maldeveloped limbs, mandibles, and eyes (Gochfield 1975, 1976). Positive correlations were found between residual concentrations of mercury in the body and incidence of feather loss (Gochfield, 1975, 1976). However, another study has shown a 10% increase in breeding pairs on Long Island during the same period (Buckley and Kane, 1975). Although it is likely that the roseate tern is exposed to the same environmental contaminants, the incidence of abnormalities in the roseate tern is markedly lower than that of other local tern species (Hays and Risebrough, 1972). Nonetheless, both can be sensitive biological indicators of toxic agents in the New York Bight (Howe _et al_., 1978).

Like Great South Bay and other lagoons in the Bight region, Jamaica Bay is flushed slowly, and retains pollutant residues for a considerable time. Pollutants enter Jamaica Bay through sewage treatment plant outfalls, CSOs, storm sewers, leachates from landfills and the atmosphere. Unfortunately, the effects of pollutants on the birds of the JBWR is unknown at present. Past experiences, with DDT for example, have shown the devastating effects that one substance can have; it could easily happen again as a result of inputs of other chlorinated hydrocarbons or novel man-made substances. Another concern is human health. Although hunting is prohibited within JBWR, poaching may occur. If poached game is consumed, toxic substances may be passed from JBWR bird populations to humans.

Diseases

Though humans greatly affect the health of birds, birds can transmit diseases such as eastern or western equine encephalitis

(EEE or WEE) to domestic animals and humans. These viral diseases are transmitted by mosquitoes from many types of birds, including doves, sparrows, blackbirds, herons, egrets, ducks, pheasant, partridge, and others (Howe _et_ _al_., 1978). Especially prevalent on the east coast of the United States, EEE primarily affects birds and horses. However, in 1959, 22 human fatalities were recorded in southern New Jersey. On Long Island, occasional EEE outbreaks have also been reported (Howe _et_ _al_., 1978). Most outbreaks occur in late summer, when bird populations are augmented by recruited young and migrants. In addition to these and other arboviruses, wild bird populations are occasionally responsible for the transmission of avian cholera, blood flukes, schistosomiasis, and chlamydiosis. Schistosomiasis causes a rash known as swimmers itch, outbreaks of which occur in the spring and autumn when migratory birds and ducks are present. Chlamydiosis, also known as psittacosis or ornithosis, is occasionally fatal to humans, but some cases may have been confused with primary atypical pneumonia (Howe _et_ _al_., 1978).

Use Impairments

Cases of bird-related diseases transmitted from JBWR bird populations are probably quite rare. Though water quality is adversely affected by defecation of bird populations in some areas, bird feces are probably insignificant in comparison to the 1140 million liters of human waste water and associated high concentrations of dissolved nutrients and coliform bacteria emptied into the Bay each day. Birds do not inhibit human use of the JBWR, other than through limited access to some areas. Birds enhance human use of the JBWR, since bird watching undoubtedly comprises a major portion of the recreational use of the JBWR.

Unquestionably, bird use of the region was impaired due to feather hunters in the late 19th and early 20th centuries. Since the protection of most of these species from hunting, declines in waterfowl populations have been the result mainly of habitat alteration and destruction, local urbanization, and pollution. Use by some bird species, like terns, oystercatchers, and plovers, has probably been further impaired within the JBWR since 1975 when several local landfills opened and gull populations increased. This latter impairment should diminish as local landfills are closed and capped. Changes in bird populations due to the creation of small spoil islands, dikes, and ponds are not obvious and require further study.

Discussion of bird populations in Jamaica Bay usually focusses on decreases in numbers of species and individuals (the one exception is the increased gull populations due to landfills). The number of birds counted in the January bird count in the JBWR, however, has remained fairly constant over the last ten years (Don Riepe, per. comm.). It is also possible that populations of birds in JBWR could increase in the future. If damage to coastal habitats along the eastern seaboard and particularly the New York Bight region continues, Jamaica Bay could witness an influx of a considerable number of species from these regions. The results of forcing more individuals into a smaller area may have a number of consequences. First, many species may be forced out of the Refuge due to loss of their minimal requirements for feeding and reproduction; other species may outcompete them for what may be perceived as "degraded" habitat. More individuals in a small area may also result in an increase in local predation and disease outbreaks. There are a number of possible causes for fluctuations in bird populations in the New York Bight. Frequent, reliable and standardized assessments of habitat quality and bird population abundances are necessary to monitor the JBWR in order to assess its importance to avian species in the region.

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RECREATION

Although it would be difficult to determine just what could be considered an adequate amount of outdoor recreation in any area, the opportunity for outdoor recreation is generally considered valuable and desirable. This is particularly true for an area that is within eight miles of a concentration of about eight million people, most of whom would ordinarily be unable to spend much time in an even vaguely natural recreational setting. Jamaica Bay development was affected by this need for recreation due to the popularity of the beaches of Rockaway Peninsula and the open areas for fishing and boating. Before the Civil War, travel to the beaches of the area required a train to Jamaica Bay and then an uncomfortable stage coach ride (National Park Service, 1984). Subsequently, the Brooklyn and Rockaway Beach Railroad, also known as the Canarsie Line, was built to facilitate transportation to and from the Bay area beaches, carrying over 122,000 riders in 1867 (Nat'l Park Serv., 1984). The Long Island Railroad trestle, built in the second half of the 19th century, carried over 3.5 million passengers in 1902 (Nat'l Park Serv., 1984). Although the major recreational attraction was Rockaway Beach, Jamaica Bay itself attracted recreants in the late 19th and early 20th centuries (Nat'l Park Serv., 1984). Improvement of the public transportation system gave increasing numbers of transient and permanent pleasure seekers access to the beaches and wetlands of the Jamaica Bay area. The New York City Board of Estimate designated the Jamaica Bay area as parkland in 1938; today the Bay remains the largest park area in New York City (Parks, Recreation and Cultural Affairs Administration, 1970).

A study in the 1960s addressed what Americans over 12 years of age enjoyed doing most (National Academy of Sciences, 1971). For cities of the northeastern United States with more than a million inhabitants, swimming was the preferred outdoor activity, followed by picnicking, driving, walking and fishing (Figure 17). The results of a national survey (Table 17) by the United States Department of the Interior, Bureau of Outdoor Recreation indicate similar findings (Carls, 1978). In June 1990, a study of the Gateway National Recreation Area (GNRA) found that swimming, fishing, picnicking, sunbathing and bicycling were the most common activities for visitors to the GNRA (Madison, 1991). The survey did not differentiate between the different units of GNRA; most likely sunbathing and swimming were not activities associated with Jamaica Bay, but the Sandy Hook beaches and Jacob Riis Park.

Swimming had been common in the Bay in the 1930s, but declining water quality curtailed this activity soon after (Nat'l Park Serv., 1984). In the late 1960s swimming again appeared to be a realizable goal, but non-municipal "bootleg" sewer outfalls and other inputs were still polluting the Bay (Nat'l Park Serv., 1984). Twenty years ago, people would swim from piers, from

Figure 17. Number of activity-days per person, 12 years and over, June 1, 1960-May30, 1961 (from NAS, 1971).

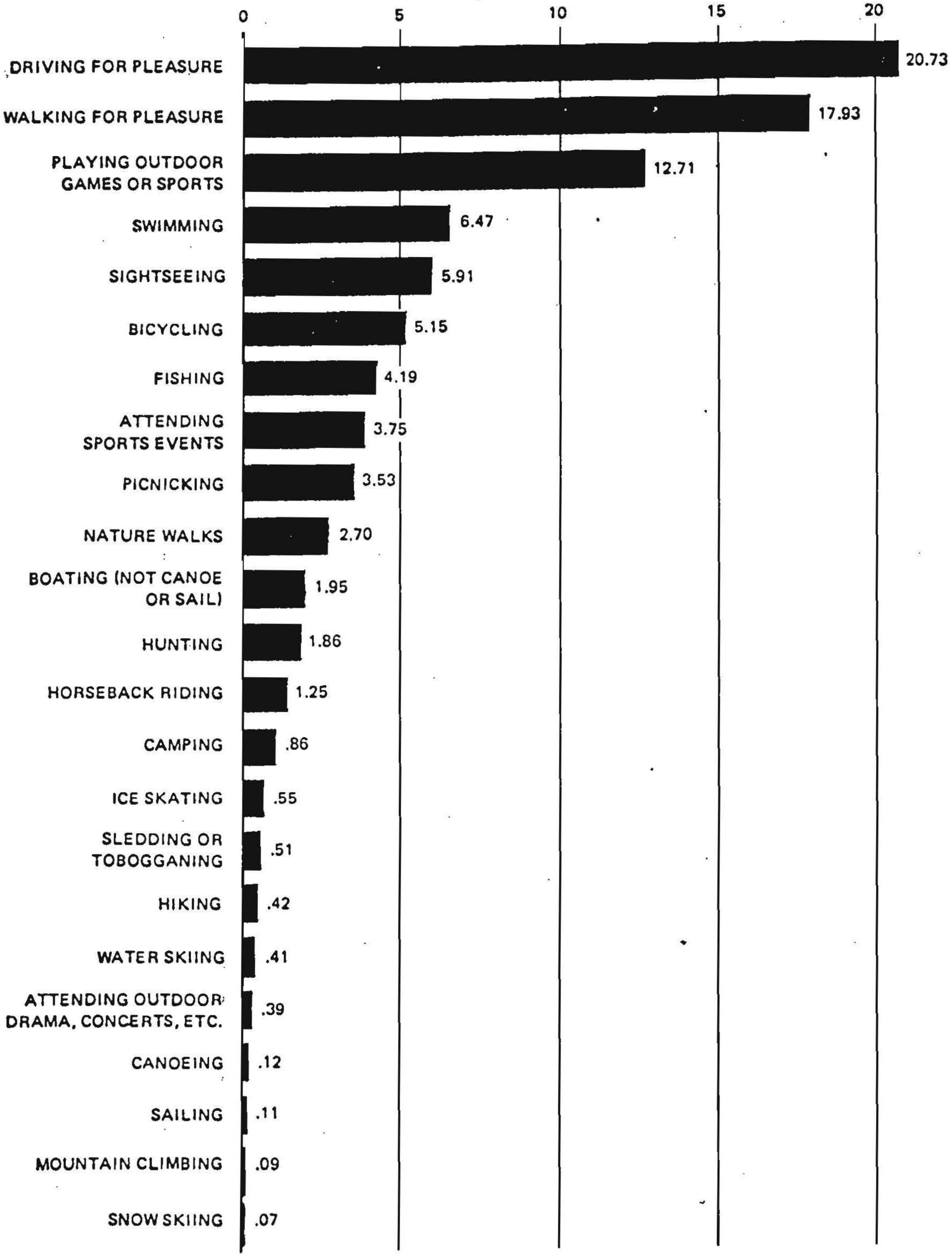

Table 17. Percent national recreation survey respondents participating in summer 1972 recreational activities (from Carls, 1978).

Activity	% Survey Respondents
Swimming	52
*Picnicking	47
*Sightseeing	37
*Driving for pleasure	34
*Walking for pleasure	34
Visiting zoos, fairs, amusement parks	24
*Other activity	24
*Fishing	24
Playing other outdoor games or sports	22
*Nature walks	17
*Other boating	15
Going to outdoor sports events	12
Camping in developed campgrounds	11
*Bicycling	10
Going to outdoor concerts, plays	7
*Horseback riding	5
Hiking with a pack/mount/rock/climb	5
Tennis	5
Waterskiing	5
Golf	5
Camping in remote or wilderness areas	5
Riding motorcycles off-the-road	5
*Bird watching	4
*Canoeing	3
*Sailing	3
Hunting	3
*Wildlife and bird photography	2
Driving 4-wheel drive vehicles off-the-road	2

*Activities available in the Jamaica Bay area boats, and near the sewage sludge tank on the Edgemere landfill site at the entrance to Bergen Basin, except after a rainfall when prohibitively foul-smelling floating wastes discouraged the practice (Nat'l Acad. Sci., 1971). As of 1970, the bathing water quality in the entire Bay was not good enough for swimming. It was hoped, however, that the contact chlorination system at the 26th Ward Sewage Treatment Plant and the construction of other wastewater treatment facilities would result in water quality high enough for swimming by 1978 (Nat'l Acad. Sci., 1971). Chlorination and even secondary treatment of sewage effluent have not resulted in the desired water quality, however (see WATER QUALITY section, this document).

As of 1970, Brooklyn contained only 0.8 recreational hectares (2 acres) per thousand people, and Queens two recreational hectares (5 acres) per thousand inhabitants, compared with Westchester's eight hectares (20 acres), and Morris County, New Jersey's 6.4 hectares (16 acres)(Nat'l Acad. Sci., 1971). On a typical hot, non-work day, the population density on Coney Island Beach was about 9900 people per hectare (2.5 acres). The National Academy of Sciences report (1971) recommends 1850 persons per hectare for comfortable beach bathing.

Jamaica Bay and its coastline have been used as a site for recreation ever since its original settlement. Clamming, crabbing, and sportfishing were major recreational activities in previous centuries (Nat'l Acad. Sci., 1971). In the 1920s, more than 400 boats were available as rentals, and bait sales were 20 times (unadjusted for inflation) what they were in 1970 (Nat'l Acad. Sci., 1971). Broad Channel residents continued renting hundreds of boats on weekends after the banning of shellfishing by the New York City Department of Health in the 1920s. The practice continued as of 1970 at Canarsie Pier, one of the more polluted areas of the Bay, where 70 rowboats and bait were still available (Nat'l Acad. Sci., 1971). Swimming, boating, and water skiing, especially near Island Channel, Beach Channel, Broad Channel and Grassy Bay, were ongoing and popular as of 1967 (Newburger, 1968). Although Jamaica Bay witnessed fewer numbers of fishermen and bathers over the years, fishermen and swimmers were still there for recreational purposes in 1970 (Nat'l Acad. Sci., 1971). Many privately owned power boats were used in the Bay for recreation.

Pollution, filling of marshlands, and commercial development have hindered the recreational use of the Bay proper, but this was not the case for the Rockaway peninsula where transportation was the main hinderance (Parks, Rec. Cult. Aff. Admin., 1970). The only two major roads providing access to the beaches, Cross Bay Boulevard and the Marine Parkway, were so congested with traffic on hot beach days that the parking lot at Jacob Riis Park at the end of the peninsula was never filled. Similarly, the single subway line, making infrequent trips, did not deposit nearly as many people at the beaches as wanted to recreate there (Nat'l Acad. Sci., 1971).

There have been many impediments to the use of the Bay areas as recreation grounds. There were potential park areas that were not utilized as of 1970 for several reasons: they were not accessible by the Shore Parkway; they were filled areas that had not been sodded; or they were currently being used as land-fill operations (Nat'l Acad. Sci., 1971). Canarsie Pier Park was the only completed and accessible park by 1970. Also, the park areas at Howard Beach and Canarsie Park were subjected to increased noise levels from the JFK Airport, thereby greatly diminishing their use (Nat'l Acad. Sci., 1971). Although technological improvements mandated by the Aviation Safety and Noise Abatement Act of 1980 have alleviated some of the volume, noise continues to have a significant impact on the area.

The potential of Jamaica Bay for recreational uses was assessed in a study by the Parks, Recreation and Cultural Affairs Administration of the City of New York (1970). The study reported that the development of beaches along the shores of the Bay would increase usable beach frontage in New York City by 60% and would serve over 13.5 million people. Boating activities such as sailing, sailboarding, canoeing and rowing could be enjoyed by one million people per year. Certain activities are restricted in some areas of Jamaica Bay. For example, power boating and water skiing have been eliminated from the wildlife area since they appear to be incompatible with the preservation of wildlife and fish in the Bay (Parks, Rec. Cult. Aff. Admin., 1970). Table 17 indicates that over half of the activities covered in the Bureau of Outdoor Recreation survey are available in the Jamaica Bay area.

Recreational activities, particularly fishing, were very popular in Jamaica Bay in 1983 (Nat'l Park Serv., 1984). The number of visitors to Jamaica Bay has continued to rise through the late 1980s (Table 18). The decrease in visitors in 1988 was attributed to the washup of some small quantities of medically-related wastes (Swanson and Zimmer, 1990) on the beaches at Breezy Point, Staten Island and Sandy Hook.

Birdwatching is a major recreational activity in the Jamaica Bay Wildlife Refuge. This is especially true during spring and fall bird migrations because the Refuge is strategically located on the Atlantic Flyway, a major migration route. A survey of visitors (Table 19) found that 84% of the visitors were birders (Nat'l Park Serv., 1976). Four school classes per day visit the Refuge, providing rare educational opportunities to New York City schoolchildren who are not often able to visit wildlife areas.

In a recent survey of 450 Bay fishermen, Riepe _et al_. (1990) reported that they fished from shores or bridges of the Bay an average of 13 times per year. A summary of additional responses is contained in Table 20.

The stresses that might be placed upon Jamaica Bay's natural ecosystem by various kinds of recreation would be relatively insignificant compared with those stresses resulting from other sources (Nat'l Acad. Sci., 1971) such as the development of the Bay as a port. In fact, upland areas that are set aside for recreational purposes may help reduce further adverse impacts on

Table 18. Visitation figures (×1000) for the Jamaica Bay regions of the Gateway National Recreation Area, 1974-1989 (modified from National Park Service records, Division of Interpretation and Recreation).

YEAR	Total Annual Visitation	Wildlife Refuge District
1974	576	
1975	1,167	
1976	1,302	
1977	1,443	
1978	853	
1979	629	
1980	699	130
1981	1,092	222
1982	1,222	240
1983	2,028	499
1984	1,868	489
1985	1,851	676
1986	2,268	1,027
1987	2,442	1,044
1988	2,250	868
1989	2,599	796

Table 19. Reported activities of visitors to Jamaica Bay Wildlife Refuge (from Nat'l Park Serv., 1976).

(A) Reports engaging in following activities (multiple response):	Number	%	Weighted % by no. of visits
Birding	673	84	86
Other nature study	485	60	63
Walking	403	50	47
Photography	317	39	41
Jogging	20	2	3
Other	69	8	9
(B) Reports following is principal activity:			
Birding	381	67	71
Other nature study	36	6	6
Walking	64	11	9
Photography	50	9	8
Jogging	2	-	-
Other	34	6	6
No principal activity	69	(not incl. in %)	
No answer	168	(not incl. in %)	

Table 20. Results of survey of 450 people fishing in Jamaica Bay (from Riepe *et al.*, 1990).

1. What is the importance of "fishing for food ?"

46	very important
86	important
206	not important
112	no response

2. Do you eat fish caught in Jamaica Bay?"

304	yes
139	no
7	no response

3. "Which species of fish do you eat?" was asked of the 304 "yes" respondents:

89	bluefish
88	winter flounder
77	summer flounder
57	porgy
22	blackfish
11	weakfish
6	striped bass
5	American eel
5	black sea bass
1	menhaden
1	herring

Jamaica Bay by precluding the further development of those areas.

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CONCLUSIONS

Jamaica Bay is one of the most heavily urbanized bays in the country, lying as it does almost entirely within the bounds of one of the largest cities in the United States. As with most other embayments on the United States Atlantic coast, Jamaica Bay has a history of use and abuse by humans. Jamaica Bay was hailed as one of the greatest shellfishing areas on the East Coast and its shores were lined with summer communities, vacation homes and various amusement spots. Thousands of people from the surrounding city converged on the Bay to take advantage of the readily-available seafood, the natural beauty and the recreational activities. And all of this was available within a few short miles of the pollution and poverty of New York City.

As Jamaica Bay was enjoying popularity as a natural setting to "get away from it all," the City of New York was discarding millions of liters of raw sewage and thousands of kilograms of solid waste into its waters and surrounding lowlands each day. Compounding these waste impacts was the effort of the New York City Department of Docks and Ferries to develop the Bay as an international port and shipping center. This latter effort led to the draining, filling and development of the peripheral marshes, the bulkheading of many of the streams plus the dredging of many of the channels. Disposal of sewage effluent and garbage into the Bay resulted in poor water quality and contamination of the shellfish with human pathogens; physical alterations destroyed the Bay's natural ability to absorb or flush contaminants; uses of the peripheral areas of the Bay resulted in habitat destruction and chemical contamination. Because many people used the resources of the Bay to help feed themselves, to build upon and to sell to others, the amenities which originally attracted people to the area, were lost. Attractiveness is a relative concept, however. The people who come to the Bay now are not concerned with its original condition; Jamaica Bay as it exists today, through partial protection and restoration, is a valuable natural resource for thousands of modern city dwellers.

Various perceptions of the Bay have led to widely differing uses, but in the end, the ecosystem itself has always suffered. One person who appreciated this abuse and attempted to provide an alternative was Robert Moses, Commissioner of the New York City Department of Parks and Recreation from 1934-1960. His vision of Jamaica Bay was as the centerpiece for a system of parks. Unfortunately, a combination of overlapping jurisdictions and politics prevented a realization of this goal. The only portions that were created were the Jamaica Bay Wildlife Refuge and the Shore Parkway. Ironically, with the increased reliance of the population on the automobile for transportation, the Shore Parkway itself has become a major source of pollution to the Bay. This idea of Jamaica Bay as a park has persisted, however, and remains the primary guiding image for management of the system today.

Overlapping jurisdictions leading to conflicting uses remains the primary problem with the management of the Jamaica Bay system today. Most of the Bay is under the control of the National Park Service but key features are maintained by other agencies. The Port Authority of New York and New Jersey operates JFK Airport and regulates commercial boat traffic; the Long Island Railroad maintains the railroad trestle; the New York City Department of Transportation is responsible for the parkways and bridges; the New York City Department of Environmental Protection maintains the sewerage system, including wastewater treatment facilities and CSOs, and, upon cessation of dumping garbage, the landfills. This means that although the actual water and remaining undeveloped lowlands of Jamaica Bay are controlled by one agency, the sources of contamination and degradation are all under the control of other agencies, most of which do not have maintenance of a healthy aquatic ecosystem as their highest priority. This results in conflicts of use.

A primary example of such a conflicting use in the second half of the 20th century is the construction of runway extension 4-22L at JFK Airport in 1962. In order to extend the runway, it was necessary to create land on which to build it. This was accomplished by the further dredging of Grassy Bay for fill material. This area had already been artificially deepened by dredging to provide fill for the construction of the rest of the airport in the early 1940s. The direction of the runway was such that the extension filled the channel east of Grassy Bay across into JoCo Marsh. These dredging and filling activities have had a profound effect on the entire Bay. The depth of Grassy Bay was increased, which also increased the residence time of the water and the accumulation of pollutants in that basin. The channel between JoCo Marsh and JFK Airport was part of the primary route taken by water circulating counter-clockwise around the Bay. The runway extension now effectively blocks this route, forcing water to flow through more tortuous routes west and south of there before reaching Beach Channel to flow out of Rockaway Inlet. This change in flow pattern has increased the flushing time of the Bay substantially. JoCo Marsh was and is part of the JBWR. The fact that the runway extension could be built out into the Refuge and in such a way as to seriously impair the circulation patterns of the entire system, is a clear indication that the Jamaica Bay system is still prey to uses that impair the ecosystem.

While physical alterations appear to have had the most dramatic impact on the ecological functioning of the Bay, the redistribution and substantial increase of fresh water input has probably had a significant impact as well. This additional "fresh" water comes from a storm sewer system that extends beyond the Bay's natural drainage basin. Very little natural percolation of storm water into the Bay occurs. Sewage effluent, which is an additional source of water not naturally added to the system, is 1.9 times that of the original annual drainage to the Bay from precipitation. This additional fresh water may have altered the natural water chemistry of the Bay, causing it to become more estuarine in character. Water column stratification may now be more intense, contributing to such problems as oxygen depletion in near-bottom waters.

Broad categories of use impairment in Jamaica Bay that are causing significant losses of ecological, economic or social values are 1) limited opportunities for swimming and other water-contact recreation, 2) unsafe seafoods, 3) losses of commercial and recreational fisheries, 4) loss or modification of habitat. Causes of these impairments include 1) human pathogens, 2) toxic substances and 3) excess nutrient loadings, in addition to the others mentioned previously. Measures of such impairments are not standardized, nor in many cases, totally quantifiable. The specific subsets of these impairments that have been examined are listed in Table 21. These impairments are overlapping throughout the Bay and may be caused by a variety of factors often acting synergistically. In addition, the causal agents may have both direct and indirect effects. For example, contaminants may, at low levels, directly jeopardize the health of finfish or shellfish by lowering reproductive capacity. They may indirectly affect human health via the consumption of those organisms.

It is clear that there are also ecologically beneficial uses of the Bay that limit other, equally positive uses (Table 22). For example, its use as a bird sanctuary obviously limits some recreational uses. Another example would be commercial

Table 21. Impaired uses and measurements of impairment.

Impairments of Use by Humans	Measures of impairment
Limited opportunities for water-contact recreation	Pathogen contamination Habitat loss and modification
Unsafe seafoods	Toxicants Human pathogens
Impairments of Ecosystem Health and Productivity	
Losses of commercial and recreational fisheries	Habitat loss and modification Distribution and abundance
Population changes in birds, mammals and turtles	Habitat loss and modification Human conflicts Toxicants

Table 22. Present and potential uses of Jamaica Bay and conflicts among these uses.

Uses	Conflicts
Wildlife refuge	Recreation (water-contact) Commercial shellfish harvesting Commercial shipping Transportation (physical alterations, pollutants Effluent dilution (water quality)
Recreation (water-contact)	Wildlife refuge Commercial shellfish harvesting Commercial shipping Effluent dilution (water quality)
Commercial shipping	Wildlife refuge Recreation (water-contact) Commercial shellfish harvesting
Commercial shellfish harvesting	Wildlife refuge Recreation (water-contact) Commercial shipping Transportation Effluent dilution
Transportation (non-water, i.e. JFK Airport, roads, bridges, trains)	Wildlife refuge Recreation (water-contact) Commercial shellfish harvesting
Effluent dilution (sewage treatment plants and CSOs)	Wildlife refuge Recreation (water-contact) Commercial shellfish harvesting

harvesting of hard clams. The depuration project once run by the New York State Department of Environmental Conservation (see Fauna section) is once again being considered. The cooperation of the National Park Service would be required in these efforts, however, and, thus far, the Park Service believes that the removal of substantial numbers of hard clams would constitute an impairment to the ecosystem. The same situation would arise should the water quality of the Bay become good enough to again permit commercial shellfishing without depuration. In these cases it is important that the conflicts are recognized so that rehabilitation and management of this irreplaceable resource can better succeed.

The overall health of the Jamaica Bay ecosystem can probably be considered marginal but certainly better than most parts of the New York-New Jersey Harbor Estuary. Phytoplankton populations are similar to those in nearby estuaries on Long Island; benthic macrofauna are similar in distribution and abundance to a relatively clean system in New Jersey; finfish, on the other hand, are certainly not as abundant as they once were. Water quality seems to be marginal-to-satisfactory and still improving. Contaminants in sediments, however, are present in alarming levels in much of the Bay and this may eventually have a negative impact on the living marine resources. As a wildlife refuge, the Bay is serving as an important and needed resource. Perhaps most importantly, while it could not be considered an outstanding recreational area in terms of swimming and beaches, it is providing, nonetheless, recreational and educational opportunities to millions of people that otherwise would have little opportunity to experience the joys and pleasures of the natural environment.

It is clear that Jamaica Bay can not serve all desired uses well. We must decide which suite of uses are, in the long term, most beneficial and plan and act accordingly. A long-term commitment to such a plan has been lacking in the past and has significantly contributed to the Bay's less-than-optimum state today.