TABLE OF CONTENTS

ACKNOWLEGEMENTS iii

Chapter 1 - Introduction 1

1.1 THE VALUE OF JAMAICA BAY 1
1.2 IS JAMAICA BAY LIKE CENTRAL PARK? 3
1.3 LOCAL LAW 71 AND INTRODUCTION 376 4
1.4 ORGANIZATION OF THIS PLAN 5

Chapter 2 - Jamaica Bay and Its Watershed: Landscape and Setting 7

2.1 JAMAICA BAY 7
2.2 HISTORICAL SETTING 8
2.3 GEOGRAPHICAL SETTING 15
2.4 CLIMATOLOGICAL SETTING 18
2.5 GEOLOGY AND SOILS 20
2.6 HYDROLOGY 23
2.7 GROUND WATER SUPPLY 25
2.8 REFERENCES 27

Chapter 3 - Water Quality 29

3.1 BACKGROUND 29
3.2 WATER QUALITY OF THE BAY 30
3.2.1 Water Quality Standards 30
3.2.2 Nitrogen 32
3.2.3 Dissolved Oxygen 32
3.2.4 Pathogens 35
3.2.5 Chlorophyll a 35
3.3 WATER QUALITY OF THE TRIBUTARIES 36
3.3.1 The Tributaries 36
3.3.2 Bergen and Thurston Basins 37
3.4 POLLUTANT SOURCES 39
3.4.1 Background 39
3.4.2 Wastewater Discharges 39
3.4.3 Combined Sewer Overflows 42
3.4.4 Storm Sewers 43
3.4.5 Landfills 43
3.4.6 Ground Water 43
3.4.7 Atmospheric Deposition 43
3.4.8 Tidal Exchange and Rockaway Inlet 44
3.5 RELATIVE CONTRIBUTION OF POLLUTANT SOURCES 44
3.6 CURRENT PROGRAMS TO ADDRESS WATER QUALITY CONCERNS IN JAMAICA BAY AND ITS TRIBUTARIES 45
3.6.1 Nitrogen Control Order on Consent/Consent Judgment 45
3.6.2.CSO Consent Order 46
3.6.3.Comprehensive Jamaica Bay Water Quality Plan 46

3.6.4 Other Water Pollution Control Plants Projects and Program 47
3.6.5 Combined Sewer Overflow Retention Projects and Programs 48
3.7 REFERENCES 50

Chapter 4 - Ecology 52

4.1 THE JAMAICA BAY ECOSYSTEM 52
4.2 AQUATIC ENVIRONMENT 53
4.3 WETLANDS 57
4.4 SEDIMENT QUALITY IN THE BAY 61
4.5 SHORELINE 65
4.6 UPLANDS 67
4.7 URBAN ECOLOGY 69
4.8 VEGETATION 70
4.9 WILDLIFE 73
4.10 CURRENT ECOLOGICAL RESTORATION EFFORTS IN JAMAICA BAY 83
4.11 REFERENCES 90

Chapter 5 - Public Access, Open Space, and Recreation 93

Chapter 6 - Land Use and Development 95

6.1 WATERSHED NEIGHBORHOODS 95
6.2 LAND USE PLANNING AND ZONING 101
6.2.1 Land Use 101
6.2.2 Zoning 105
6.3 REFERENCES 107

Chapter 7 - Watershed Stakeholders and Public Outreach Efforts 108

7.1 GOVERNMENTAL AND REGULATORY AGENCIES 108
7.2 NON-GOVERNMENTAL AND COMMUNITY ORGANIZATIONS 113
7.3 PUBLIC OUTREACH PROGRAM TO SUPPORT THIS PLAN 114

Chapter 8 - Previous and Current Planning Efforts 119

8.1 THE PAST 119
8.2 RESTORATION/CONSERVATION PLANS 119
8.3 OTHER NEW YORK CITY PLANS RELEVANT TO JAMAICA BAY 122
8.4 OTHER ENVIRONMENTAL PROGRAMS 127
8.5 REFERENCES 129

ACKNOWLEGEMENTS

Photo Credit: The photos on the cover, and many of the photos in the body of this *Draft Jamaica Bay Watershed Protection Plan* were provided by Don Riepe/American Littoral Society. Thanks, Don.

Cover Map Credit: Thank you, National Park Service.

Chapter 1 - Introduction

1.1 THE VALUE OF JAMAICA BAY

The value of Jamaica Bay is evident to all who have watched a glowing sunset while on its waters, or a flight of waterfowl coasting in for a landing. The residents who grew up fishing along its shorelines, boating around the tidal marshes, or exploring the natural areas of the estuary will attest to the value of the Bay as an important part of their lives and their identities. At the same time, the Jamaica Bay landscape has a more practical use, as a living-space, work-space, or travel corridor. These two values reflect an important aesthetic and function, but represent only a fraction of the myriad of values and roles associated with Jamaica Bay.

For thousands of years, Jamaica Bay has served as an important ecological resource for flora and fauna populations. The Bay has evolved over the last 25,000 years as an important and complex network of open water, salt marsh, grasslands, coastal woodlands, maritime shrublands, brackish and freshwater wetlands. The wildlife use of these systems is commensurate with this complex network of natural systems. These natural communities support 91 species of fish, 325 bird species (of which 62 are confirmed to breed) and are an important habitat for many species of reptiles, amphibians and small mammals. The Bay is a critical stopover area along the Eastern Flyway migration route and is one of the best bird-watching locations in the western hemisphere. The 16,000 acres of water, islands, marshes, and shorelines support seasonal or year round populations of 214 species of special concern, including state and federally listed species. Because of its geographic size and very diverse functioning natural habitats, it is no surprise that Jamaica Bay is a national and international renowned birding location.

Jamaica Bay, one of the largest coastal wetland ecosystems in New York State, is a component of the National Park Service's (NPS) Gateway National Recreation Area (GNRA). A significant portion of the Bay, approximately 9,100 acres, has also been designated as the Jamaica Wildlife Refuge and is designated by the New York State Department of State (NYSDOS) as a Significant Coastal Fish and Wildlife Habitat. The diversity of bird species and breeding habitats within the Bay were important factors in these designations. The Jamaica Bay Wildlife Refuge was also the first site to be designated by the National Audubon Society as an "Important Bird Area." It is clear that Jamaica Bay is currently functioning as a regional habitat for many different types of wildlife.

> *"To stand at the edge of sea, to sense the ebb and flow of the tides, to feel the breath of a mist moving over a great salt marsh, to watch the flight of shore birds that have swept up and down the surf lines of the continents for untold thousands of year, to see the running of the old eels and the young shad to the sea, is to have knowledge of things that are as nearly eternal as any earthly life can be."*
>
> *-Rachel Carson*

Unfortunately, the valuable resources that comprise Jamaica Bay are being lost. The Jamaica Bay estuary is only about half of its pre-colonial extent and the salt marsh wetlands that have been a defining ecological feature of the Bay are decreasing at an accelerated rate. The more estuarine habitat that is lost within the Bay's watershed and elsewhere in the Northeast and

Mid-Atlantic regions, the more valuable the remaining habitat in Jamaica Bay becomes. Jamaica Bay retains irreplaceable value for its self-sustaining ecological functions, as well as the proximity of its assets by foot, rail and car to the urban metropolis. As one critical tidal estuary in a series that extends up and down the East Coast, Jamaica Bay provides ecological values far beyond its borders. The precious assets include:

- The ecological value of the tidal estuary, locally, regionally and internationally;
- Diverse habitats including salt marsh, coastal grasslands, woodlands, maritime shrubland, and brackish and freshwater wetlands;
- The on site recreational use for bird watching, wildlife viewing and fishing, as well as for other recreational activities such as bicycling, swimming, walking, boating/canoeing and picnicking;
- The local value of the viewshed;
- Aesthetic values to adjacent landowners;
- The socioeconomic benefits to the City of having the Bay as a resource, and of the City's identification with the Bay;
- Local marine research and site of an outdoor classroom;
- The natural functions of flood control and infrastructure protection against storm surges; and
- The natural function of pollutant attenuation.

Over the last 150 years, interior wetland islands and perimeter wetlands have been permanently

FIGURE 1.1.1 Jamaica Bay Watershed, 2002; Source: NOAA

removed as a result of extensive filling operations; shorelines have been hardened and bulkheaded to stabilize and protect existing communities and infrastructure; deep channels and borrow areas have been dredged, altering bottom contours and affecting natural flows; and natural tributaries along with their important benefits of balanced fresh water and coarse sediment exchanges have essentially disappeared leaving behind deposits of silts and particulates from urban runoff. These activities have synergistically affected historic flow patterns in the Bay, eradicated natural habitat, impacted water quality, and modified the rich ecosystem that was present prior to the extensive urban development of the watershed.

It has become apparent that some ecological functions and valuable environmental resources provided by the Jamaica Bay watershed to the surrounding communities and region are at risk. Living resources and natural processes that have been self-sustaining since the last glacial epoch are in jeopardy and may need to be sustained by some type of environmental intervention in perpetuity. It is only now, when we are realizing the effects of centuries of changes within Jamaica Bay and its watershed that the true value of sustaining and maintaining our natural heritage in this ecologically productive area has become starkly evident.

1.2 IS JAMAICA BAY LIKE CENTRAL PARK?

Central Park has long been the emerald jewel of Manhattan. It is known and recognized world-wide, both visually and as a unique environmental resource of the City of New York and its people.

The reasons that Central Park has reached this status are many and varied but, largely, it is because the City took the initiative to protect and preserve the park. Community groups act as unofficial monitors and partners of the City in acknowledging the value of the park to its urban and cultural environment. The City has approached its obligation with a long-term and institutionalized dedication. This ethic has been possible because it developed over time, because Central Park has become a symbol that is cross-linked with the City's identity, and the park is totally within the control and jurisdiction of the City.

What has created and sustained Central Park is also in abundance within the Jamaica Bay watershed – committed advocates. The preservation of Jamaica Bay has engaged the efforts of federal, state and City governments and a strong and active network of community organizations and advocates. The foundation for grass roots, popular and governmental support is in place and ready for Jamaica Bay.

However, the protection of Jamaica Bay as an environmental resource presents more significant challenges. The protection of Jamaica Bay is intimately connected to its vast watershed and the uses and activities contained within it. Today, the Jamaica Bay watershed is a densely populated urban region. Highways encircle and cross the

Definitions

Conservation: Regulated, sustainable use of environmental resources for commercial and public uses.

Preservation: Limited, restricted use, or maintenance, or environmental resources to prevent exploitation and degradation.

Restoration: "…a process in which a damaged resource is renewed. Biologically. Structurally. Functionally." (John J. Berger.1987. Restoring the Earth: How Americans are Working to Renew our Damaged Environment)

Bay, as does a rail line. One of the best known international airports in the world was developed by filling in a large portion of the Bay with dredged material from other portions of the Bay; residential areas were formed by placing fill in marshes in the Bay and along its shores. Highways and other development have resulted in restricted access to the shoreline. Urban residential development at or adjacent to other shore points has brought its environmental stresses and future development still threatens vital wetlands and other open spaces that remain.

Other regions in the country such as the Great Lakes and Chesapeake Bay have faced many of the same challenges. However, watershed planning in these regions is successfully advancing the goals of improving the degraded value of their respective aquatic resources and can provide models for the Jamaica Bay watershed.

Gifford Pinchot
(August 11, 1865 – October 4, 1946)

As the first Chief of the United States Forest Service (1905-1910) and the Republican Governor of Pennsylvania (1923-1927, 1931-1935), Pinchot became famous for reforming the management and development of forests in the United States and his advocacy of scientific conservation for the planned use and renewal of the nation's forest reserves: "the art of producing from the forest whatever it can yield for the service of man." He coined the term conservation as applied to natural resources. (www.answers.com /topic/gifford-pinchot).

1.3 LOCAL LAW 71 AND INTRODUCTION 376

This *Jamaica Bay Watershed Protection Plan* (JBWPP) was put into motion by the City Council. Under Local Law 71 (LL 71), signed by Mayor Bloomberg on July 20, 2005, the New York City Department of Environmental Protection (NYCDEP) is required to "assess the technical, legal, environmental and economical feasibility" a variety of protection measures as part of the JBWPP development process. The objective of the bill, originally sponsored by the City Council Committee on Environmental Protection chaired by Council Member Gennaro, was to ensure a comprehensive watershed approach toward restoring and maintaining the water quality and ecological integrity of the Bay. The implementation of the final JBWPP is intended to provide an evaluation of the current and future threats to the Bay and ensure that environmental remediation and protection efforts are coordinated in a focused and cost-effective manner.

LL 71 also required that an advisory committee be formed to assist NYCDEP in fulfilling its responsibilities. The Jamaica Bay Watershed Protection Plan Advisory Committee (JBWPPAC) is composed of seven members: four selected by the Mayor and three selected by the Speaker of the Council. While each member was selected based on their affiliation with a specific organization, the group was also responsible, in part, for representing the broader public interest in the process. Member representation includes the NPS, Natural Resources Defense Council (NRDC), Jamaica Bay Eco Watchers, Marine Sciences Research Center at Stony Brook University, Port Authority of New York and New Jersey (PANY/NJ), U.S. Army Corps of Engineers

(USACE), and a community/ environmental activist.

LL 71 was amended (Introduction No. 376) on August 16, 2006 to extend the development of the JBWPP by one year. Under that amendment, this Draft *Jamaica Bay Watershed Protection Plan* is required to be submitted on March 1, 2007. The *Final Jamaica Bay Watershed Protection Plan* is scheduled to be completed and submitted to the City Council on October 1, 2007.

1.4 ORGANIZATION OF THIS PLAN

The *Jamaica Bay Watershed Protection Plan* is organized into two volumes as described below. Each of these volumes is designed to be stand-alone, yet work together to provide complete information about the Bay's existing conditions and future management strategies throughout its watershed.

Volume 1. Jamaica Bay Watershed Regional Profile

This volume presents a description of the context within which this *Jamaica Bay Watershed Protection Plan* has been developed, that is, the history of Jamaica Bay, the key issues currently affecting the Bay, and current management efforts. It contains:

- the current set of geographical, geophysical, water quality, and ecological data for the Bay and its watershed;
- information on the human uses of the watershed, including land use, zoning, and recreation and access; and
- a description of the stakeholder institutions, their distinctive jurisdictions and mandates, current planning efforts, and public outreach programs.

http://www.emagazine.com/images/upload/1120591803CU

Tidal Wetlands

"Intertidal marsh and coastal fresh marsh tidal wetlands are the most biologically productive of all tidal wetlands areas. Furthermore, since they receive twice-daily tidal flushing, the products of vegetative photosynthetic activity and decomposition in these zones are readily transported to adjacent waters for use in the estuarine food chain. Their intertidal location also makes them among the most effective wetland zones for flood and hurricane and storm protection. Both their intertidal location and their highly productive nature makes them among the most effective wetland zones for cleansing ecosystems and for absorbing silt and organic material. Because of these high values and their sensitive location at the land and water interface, intertidal and coastal fresh marshes must be the most stringently protected and preserved tidal wetlands zones. Even small portions of these zones are critically important resources. Consequently, only very limited types of land use and development are compatible with the values of these areas." (6 NYCRR 661.2(D)).

Volume 2. Jamaica Bay Watershed Protection Plan:

This volume provides the vision, objectives, and potential management and implementation strategies for the *Jamaica Bay Watershed Protection Plan*. There are three primary sub-sections:

- an introduction to watershed planning concepts;
- the framework for the plan including the vision, issues identification, objectives, and management strategies; and
- Objectives, Potential Management Strategies, and evaluation methods to address five categories:
    - Category 1: Water Quality Improvements
    - Category 2: Restoration Ecology
    - Category 3: Public Use and Enjoyment
    - Category 4: Sound Land Use and Development
    - Category 5: Public Education and Outreach
    - Category 6: Coordination and Implementation

Volume I, *Jamaica Bay Watershed Regional Profile*, has several purposes. It is intended to be a comprehensive reference document for Jamaica Bay. And it also provides the information needed to identify issues of concern that face the Bay, setting the stage for developing management strategies to address these issues.

Volume I provides an extensive body of existing research, studies, and data, compiled and analyzed in order to clearly understand the issues facing the Bay, current efforts to address these issues and existing gaps in protection measures that continue to adversely impact the water quality and ecological integrity of the Jamaica Bay watershed. This *Regional Profile* provides information about the diverse landscape of the Bay and its watershed, water quality of the Bay and the current status of the ecological system as a whole. It is intended to be a comprehensive but not exhaustive compilation and reference guide for existing data and information about the watershed both past and present. Key planning issues identified set the stage for actions that will need to be implemented to preserve and restore the valuable asset that is Jamaica Bay.

Although this task was not required by LL71, NYCDEP felt that it was a necessary first step given the complexities of the issues facing Jamaica Bay and the overwhelming body of research and publications about the Bay that needed to be consolidated. For this reason, Volume 1 is intended to provide useful and relevant information for decision-making while also serving as a centralized repository of existing information about the Bay.

Volume 2, the *Watershed Protection Plan*, is intended to serve as a blueprint for the future management of the Bay and its watershed to achieve a shared vision for Jamaica Bay. Therefore, Volume 2 starts with the vision for the Bay and issues that need to be overcome to achieve the vision. For each of the issues, objectives for the Bay were set and, for each objective, potential management strategies, or actions, are identified to address the objective. This *Draft Jamaica Bay Watershed Protection Plan* also documents the steps that will need to be undertaken to evaluate each management strategy before a recommendation can be made as to its feasibility and effectiveness (see sections entitled "Strategy Assessment Approach" under each Management Strategy). Where possible in these sections, potential future implementation strategies were also identified. While implementation approaches will be discussed in the *Final Jamaica Bay Watershed Protection Plan* for each of the recommended strategies, the further development of implementation steps for many of the recommended strategies will be an ongoing process after the *Final Jamaica Bay Watershed Protection Plan* is completed in October 2007.

Chapter 2 - Jamaica Bay and Its Watershed: Landscape and Setting

2.1 JAMAICA BAY

The Jamaica Bay watershed is situated at the southwestern tip of Long Island and is located primarily within the Boroughs of Brooklyn and Queens, New York City. A relatively small portion of the Bay is located in the Town of Hempstead, Nassau County, New York. The watershed is approximately 91,000 acres (142 square miles) in size. The Jamaica Bay estuary connects with Lower New York Bay to the west through Rockaway Inlet. The estuary encompasses about 25,000 acres (39 square miles), measuring approximately 10 miles at its widest point east to west and approximately 4 miles at its widest point north to south. Figure 1.1.1 shows the Jamaica Bay watershed.

Jamaica Bay has evolved from a landscape of grasslands, woodlands, freshwater streams and salt marsh wetlands teeming with birds and a diverse array of animal life to one of the most densely urbanized areas in the United States. While the ecological function of Jamaica Bay has been altered, it still serves as an invaluable natural resource for the region.

FIGURE 2.1.1 Jamaica Bay, 1889; Source: US Coast and Geodetic Survey, NYC

2.2 HISTORICAL SETTING

The changes which have occurred to the landscape of the Jamaica Bay watershed date back to the cultural history of Euro-American settlement in the New York City region. The trends and settlement patterns of these peoples influenced what Jamaica Bay is today. Much of the description of the history that follows was summarized from Black (1981) and other sources as cited herein.

The Early Years and the Settlement of Brooklyn

The area now known as Brooklyn, situated at the southwestern tip of Long Island, was originally inhabited by a group of Native Americans who called themselves the Lenape, which means "the People." They included the Nayack and the Canarsee, who planted corn and tobacco and fished in the rivers.

The Dutch, who settled in Manhattan in the early 1600s, began to buy land across the river in 1636. As a result of diseases, such as smallpox (new to America), war, land deals that were not always honorable, and other factors, by the 1680s the native people had lost all claims to the rolling, heavily forested landscape.

Canarsie Beach, Brooklyn; Source: New York Public Library

The Dutch founded five villages: Bushwick, Brooklyn, Flatbush, Flatlands, and New Utrecht. Gravesend, a sixth village, was founded in 1643 by Lady Deborah Moody, an Englishwoman who was fleeing religious persecution in England and the Massachusetts Bay Colony. The British captured the Dutch territory in 1674, and gathered the six villages into Kings County, part of the crown colony of New York.

A census taken in 1698 counted 2,017 people in Kings County. About half of these early settlers were Dutch. The others came from Germany, England, France, and Scandinavia, and included a large number of black slaves brought from Africa. Slavery was prevalent in these rich farmlands during the 18th century. By 1771, just before the Revolutionary War, slaves represented nearly one third of the population of Kings County. Slavery would not become illegal in New York State until 1827.

During the Revolution, British troops nearly destroyed George Washington's inexperienced Army at the battle of Brooklyn in 1776. The fighting ranged from Gravesend to Gowanus, and the Colonial Army narrowly escaped annihilation by slipping across the East River to Manhattan during a foggy night. The British then occupied Manhattan and Brooklyn for the duration of the war.

The village of Brooklyn, directly across the East River from Manhattan, was the funnel through which the food grown on Long Island's rich farmlands passed to New York City. As New York City flourished, so did Brooklyn, its nearest neighbor. Rowboats, sailboats, and horse-powered ferries plied the waters of the East River, and speculators and merchants began to buy land along the waterfront. The U.S. Navy opened a shipyard on Wallabout Bay in 1801, and Robert Fulton began a steam-ferry service across the East River in 1814, allowing wealthy businessmen to live in Brooklyn Heights and commute across the river.

In 1860, 40% of Brooklyn's wage earners worked in Manhattan, and ferries carried more than 32 million passengers a year. However, they could not keep up with the demand for transport. To ease

some of the congestion and link the two great cities, plans to build a bridge were proposed. The New York Bridge Company was founded in 1865 and constructed the Brooklyn Bridge, which opened in 1883. The bridge brought a new wave of people into Brooklyn, particularly immigrants seeking relief from the high rents and small apartments of New York City.

The city of Brooklyn expanded to accommodate the new population, eventually swallowing up all of Kings County, itself being annexed by New York City in 1898. The construction of bridges to Long Island contributed to an acceleration in the development and growth of Brooklyn and Queens and of the upland portions of the Jamaica Bay watershed. A review of historical maps shows that until the turn of the 20th century, the area of Brooklyn adjacent to the Jamaica Bay estuary was largely undeveloped. The shoreline, as depicted in the maps, was marshland, with the exception of limited development at Canarsie (because of local high ground extending into the marsh area). As transportation networks were developed following the turn of the 20th century, urban infrastructure expanded around the perimeter of the estuary.

Trolley on Rockaway Parkway; Source: New York Public Library

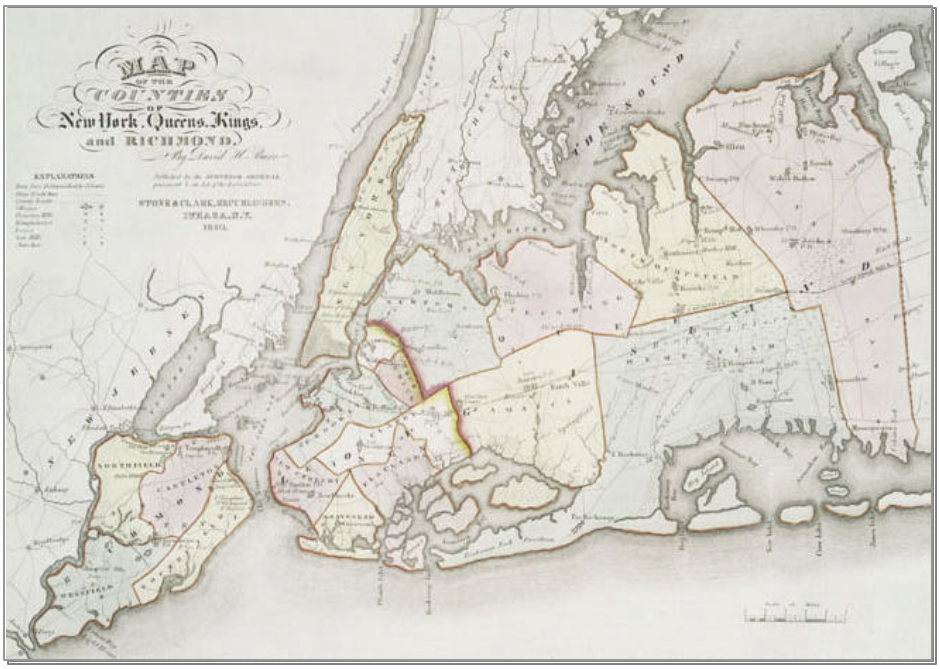
The early years of the 20th century saw a vast expansion in the population and urbanization of Brooklyn. Innovations in transportation, funded by tax dollars from New York City, brought new bridges, trolley lines, elevated railroads, and subway lines that extended farther and farther into the heart of the borough. Trolleys began to traverse the streets of Brooklyn in 1890, the Williamsburg Bridge was completed in 1903, the first subway line was cut under the East River in 1908, and the Manhattan Bridge opened in 1909. Each expansion opened new areas for settlement and development. The rural character of Brooklyn was quickly vanishing.

The Settlement of Queens

The expansion of rapid transit brought sudden transformation to the Borough of Queens as well. When the Pennsylvania Railroad purchased the Long Island Rail Road in 1900, then electrified it through Queens in 1905-1908, and opened the Penn Tunnels under the East River in 1910, it brought virtually the whole of Queens within the suburban commuting zone of Manhattan. A record number of new communities were founded at this time. Forest Hills (1906) South Ozone Park (1907) Howard Beach (1911) and Kew Gardens (1912) were some of the towns that were built.

The most momentous event in the history of Queens occurred in 1909 when the long planned Queensboro Bridge was finally opened. This opened a direct link to the county and ended the dependence on ferries. A whole new road system grew up to accommodate the traffic, and Queens Boulevard, a 200 feet wide roadway, was laid out as the main arterial highway of the new borough.

From 1915 onward, much of northern and southwestern Queens came within reach of the New York City subway system. In June 1915 the Interborough service opened to Long Island City and later to Queensboro Plaza (1916) and Astoria (1917). Another branch extended along Queens Boulevard and the newly laid out Roosevelt Avenue, reaching Corona in 1917 and Flushing in 1928. In southern Queens, the Brooklyn Rapid Transit Company built an elevated line along



Queens, 1840; Source: New York Public Library

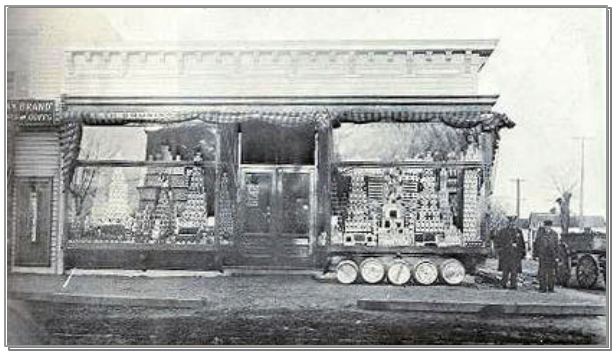
Liberty Avenue through Ozone Park and Woodhaven to Richmond Hill in 1915 and along Jamaica Avenue from the Brooklyn border through Woodhaven and Richmond Hill to Jamaica during 1917-1918. As all developers and realtors knew, these massive improvements in transportation, especially the opening of Queens to five-cent fare service, promised rapid growth. Farms and open areas began to vanish and endless rows of new streets and one family houses began to spread out all over Queens.

During the 1920s, the population of Queens more than doubled from 469,042 to 1,079,129, a growth rate of 130 percent. Although the Great Depression of the 1930s ended this boom, growth of another kind was underway, with the construction of more bridges (the Triborough Bridge in 1936 and the Bronx-Whitestone in 1939,) roadways (the Interboro Parkway in 1935 and the Grand Central Parkway in 1936) and airports (LaGuardia Airport in 1939 and Idlewild in 1948, renamed JFK Airport in 1963.

Although a part of Queens, Rockaway was settled separately and earlier than other areas around Jamaica Bay. In 1833 the Rockaway Association, a group of wealthy individuals who wanted to develop a fine oceanfront hotel in Rockaway, purchased most of the oceanfront property on the old homestead from descendants of Richard Cornell. The Marine Hotel was erected on the site of the original Cornell home.

Transportation to and from Rockaway originally consisted of horse-drawn carriages and horses. A ferry took passengers from downtown Manhattan to Brooklyn, and by the mid-1880s, the steam railroad succeeded the stagecoach, terminating at the present Far Rockaway station of the Long Island Railroad. Benjamin Mott deeded to the railroad company a seven-acre tract of land to be utilized as a railroad depot. The coming of the railroad to Far Rockaway increased land values and resulted in a boom to the businesses in the area. By 1888, the Village of Far Rockaway was large enough to apply for incorporation.

On July 1, 1897 the Village of Rockaway Park was incorporated into the City of Greater New



E. Theodore Bruning's Cash Grocery, Rockaway Parkway, 1908; Source: www.geocities.com/buddychai2/Brooklyn/canarsie.html

York. Streets were graded and sections of Rockaway Park, Belle Harbor and Neponsit began to be developed.

The completion of the Cross Bay Bridge in 1925, the further development of the beach and boardwalk in 1930, the completion of the Marine Parkway Bridge in 1937 and the improvements to the railroad services in 1941 were all factors that made Rockaway more accessible to the working class people of New York.

Development in the Jamaica Bay Estuary

In pre-European settlement times, the Lenape and their ancestors used the Jamaica Bay estuary primarily as a shellfishery, as evidenced by the shellfish middens that can still be found in excavations around the Bay. The dry land at Canarsie was the site of one of their settlements, providing direct access to the Bay. It is probable that they also hunted and fished in the shallow marshlands that extended around the perimeter of the estuary.

It was not until the early 19th century that the first European settlers began to develop the Jamaica Bay estuary. In the 1830s, John Norton made a large land purchase in the area of what is now

Historic Barren Island; Source: New York Public Library

known as Norton Basin (Rhoads *et al.*, 2001). In 1833, Norton built a large hotel known as the Marine Pavilion on marshes that had been filled using Bay sediments dredged to make access channels in the shallow waters. What seems like an interesting historical note actually is typical of the manner in which the natural marshland and Bay ecology has been managed over the last two centuries. The history of Jamaica Bay is replete with similar examples, some of which follow.

Historic Barren Island was home to fertilizer plants in the 1850s and continuing into the 1930s. Black (1981) reported that commercial statistics in

Mill Basin, Brooklyn; Source: New York Public Library

a 1906 report to Congress indicated that the island and Mill Creek were the only productive areas immediately around the Bay. Barren Island was expanded and extended with fill until it became what is now known as Floyd Bennett Field. Similarly, fill was used to expand Bergen and Mill Islands until they were joined together and to the mainland.

In the early 1900s, Mill Island was the home of a dredging contractor and dry dock operator. The present Mill Basin and East Mill Basin are the channelized remnant of the natural waterway that once surrounded the island. Bedford Creek was bulkheaded in the first quarter of the 20th century, eventually becoming today's Paerdegat Basin. Likewise, the natural form of the Canarsie shoreline underwent considerable filling in the first half of the 20th century until Sand Bay and other formations disappeared. Shell Bank Basin was created from a considerably smaller creek tributary to the larger Bay.

Although there was occasional discussion of dredging channels to allow navigation by larger vessels, Jamaica Bay has never had significant use for passenger or commodity shipping. As a

practical matter, the Bay was too shallow for the types of vessels needed to accommodate a commercial port, and the magnitude of dredging to prepare it for such use, while proposed at various times, never has taken place. A 1917 report by the City's Bureau of Public Improvements (CNY, 1917) noted the establishment of several industries on Mill Basin. Dredging of an 18 feet deep and 500 feet wide channel from the entrance of the Bay to Mill Basin had been performed in the summer of 1912. This channel, proposed by the Jamaica Bay Improvements Commission, was to extend around the Bay. The Bureau of Public Improvements predicted that Jamaica Bay would "…in time become the port of entry for a considerable amount of domestic commerce." Basins would be constructed back from the main channel in the Bay and bulkheads constructed to docking facilities. While some of the dredging moved forward, the larger vision died for practical reasons, including the growth of commercial harbor facilities elsewhere in New York Harbor.

According to Black (1981), the islands of the Bay (except for the larger Barren, Bergen, and Mill Islands and Ruffle Bar) consisted "…almost entirely of meadows and marsh with no uplands…" What is now Broad Channel Island is comprised of what were formerly Big Egg Marsh, Goose Pond Marsh, Rulers Bar Hassock and Goose Creek Marsh. Fill was used to connect and eliminate these natural marsh formations, which have been developed to the community that exists today. The residents of Broad Channel Island continue to debate further development on the island in an attempt to conserve what little remains of the natural environmental heritage.

Jamaica Bay was not conducive to a commercial fin fishing industry, but it has long supported a recreational fishery. In the 17th and 18th century, subsistence fishing occurred in small settlements around the Bay. By contrast, from the mid-1800s to the early 1900s, the Bay sustained a strong commercial shellfishing and sportfishing industry. Issues of water quality resulted in the closing of the shellfish beds in 1923. In 1917 (CNY, 1917), it was estimated that 750,000 to 1,000,000 bushels of seed oysters were planted and harvested annually, as were 300,000 bushels of hard clam seeds. Soft "steamer" clams grew naturally in the Bay, and clamming was estimated to yield about 270,000 bushels a year. Not surprisingly, the entrance to the Bay has undergone significant natural change in recent history. In 1835 Rockaway Point was located near the east boundary of Jacob Riis Park. Material from a shoal south of Rockaway Point was used to extend the point four miles to the west in the following century (CNY, 1917). The federal Board of Engineers for Rivers and Harbors in a 1964 report (Board of Engineers, 1964) studied options (never built) to reduce shore erosion in Jamaica Bay and along the Atlantic shore of the Rockaways. It proposed a series of levees along the Bay shore of Jacob Riis Park (as well as along the Atlantic shore of the Rockaways), a 4,530 foot stone hurricane barrier with a navigation inlet across the entrance to Jamaica Bay from just west of Jacob Riis Park across to what was still described as Barren Island (which is still noted as the home of the U.S. National Air Station), and shorter levees at specific locations in Mill Basin.

In its 1917 report (CNY, 1917), the Bureau of Public Improvements already noted that Jamaica Bay was "…without any inflowing fresh water feeders of consequence." The Bay is described as shallow, averaging 4.7 ft in depth at low tide, with channels reaching extreme depths of 66 ft in Big Channel east of Barren Island, 32 ft in Beach Channel south of Ruffle Bar, and 47 ft deep north of Rockaway Point. Continued dredging has modified these metrics, not necessarily to the benefit of the estuarine ecosystem. The channels and the Bay would continue to change over the next 90 years, the result of continued development in the watershed and a lack of knowledge of ecological principles with respect to resource planning of the Bay, and the impacts that these alterations would have on aquatic communities, water circulation, and dissolved oxygen and other constituents of the water column.

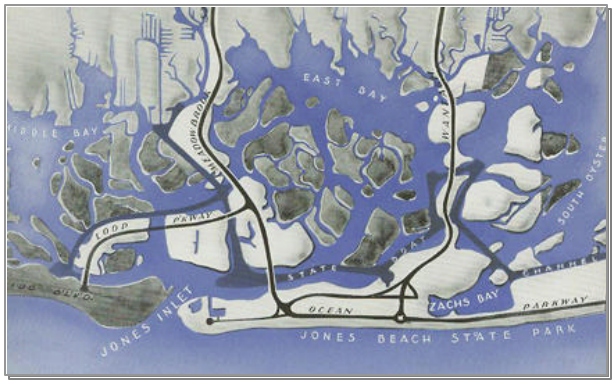
In 1938 (CNY, 1938), Robert Moses, the City's Commissioner of the Department of Parks, sent a

letter to Mayor Fiorello LaGuardia that set a new vision for Jamaica Bay. He decried the 1922 plan that proposed to turn the Bay into a major industrial port "…greater than the combined ports of Liverpool, Rotterdam and Hamburg." Instead, he promoted a residential and recreational program for the Bay, suggesting that there was other space available for industrial expansion, such as Staten Island. Moses proposed to:

- completely rezone the Bay and its surrounding area
- transfer "all islands to the Park Department for recreational use, including protection of scenery and waters"
- "encouragement of swimming, fishing, boating and preservation of wild life"
- "public use of the meadowlands adjoining Cross Bay Boulevard, including Big Egg Marsh"
- "purification of the polluted waters of the bay…"

This was a new vision for the Bay which Moses said at the time was "…the only large area in New York City whose character is undetermined, the only one which a tremendous public improvement can be insured with comparatively small expense by prompt official action." However, little was done to implement the controls that Moses suggested; the rate of development in and around the Bay continued, largely unabated until modern times.

It is important to understand the modifications that have occurred to the Bay in the last 150 years. Islands have been removed by dredging or extended to the nearby mainland by fill; shorelines have been altered by dredge and fill activities; bulkheads have been installed to stabilize and protect shorelines; channels and borrow areas have been dredged, altering bottom contours and affecting flows; and natural tributaries have essentially disappeared – their remains deposits of silts and particulates from urban runoff. These activities have conspired to affect historic flow patterns in the Bay, eradicated natural habitat, impacted water quality, and modified the rich ecosystem that still was present in the Civil War



Robert Moses Plan
(Jones Beach)

"The plan to preserve the islands in Jamaica Bay in their natural state has its parallel in the Great South Bay in Nassau and Suffolk Counties where the most important islands have been dedicated to the state for park purposes. This map shows the islands (in white) between Jones Beach State Park and the mainland which will forever be preserved in their present state." (CNY Department of Parks, 1938).

Robert Moses Plan
(Boating)

"The present channel system, inadequate for deep draft tug boats and commercial vessels, is of sufficient depth and entirely satisfactory for the average small pleasure boat, with the exception of a relatively short section in the northeastern part of the bay. By dredging the channel shown on the map 10 feet deep and 200 feet wide, at a cost of $200,000 [add year of this value], a complete circulatory channel system for motor launches will be provided. The cost of dredging alone under the industrial and commercial plan now on the city map is estimated at approximately $20,000,000." (CNY Department of Parks, 1938).

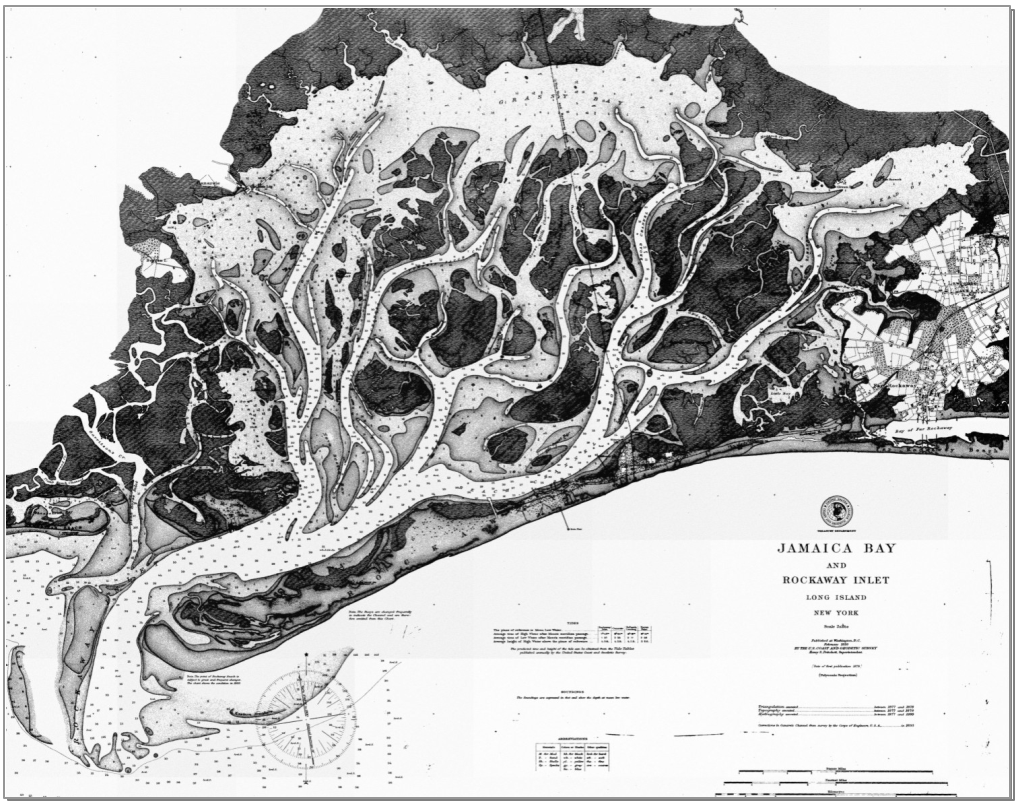


FIGURE 2.2.1 Jamaica Bay, 1899; Source: U.S. Coast and Geodetic Survey

FIGURE 2.2.2 Jamaica Bay, 2002; Source: NOAA

era of the 19th century. A comparison of conditions in the Bay in 1899 and today is presented in Figures 2.2.1 and 2.2.2.

The tributaries to the Bay, in particular, have undergone extensive physical changes over the years. Fresh water that feeds the tributaries is almost solely from combined sewer overflows (CSOs), storm sewers, and wastewater pollution control plans (WPCPs). They have been dredged and bulkheaded, and widened or narrowed; most bear little resemblance to the original water courses that passed through the original channels. For example, in the 1930s, Paerdegat Basin was dredged with a main channel depth of 16 feet below mean low water for its entire length and connected to the dredged shipping channels in Jamaica Bay; however, the navigable channel has not been maintained since its original dredging. Hendrix Creek has been greatly affected by channelization and filling; the width of the creek has been made a uniform 60 to 80 feet; and its depth (at low tide) reduced 2 to 5 feet. Spring and Ralph Creeks (which is tributary to Spring Creek) have retained some semblance of their original channel configuration; however, the system as a whole has been altered to the point where freshwater input is wholly derived from CSOs, storm sewers, and WPCPs.

2.3 GEOGRAPHICAL SETTING

The Watershed

In a natural or non-urban setting, the watershed of a body of water would be delineated by the topography of the area. Any overland flow or stormwater runoff (*i.e.*, rainfall or snow melt) within the watershed would flow down hill collecting in drainage ways, ditches, streams, creeks, and rivers until reaching the main receiving waterbody. Based strictly on the topography of the area, the Jamaica Bay watershed encompasses portions of the Boroughs of Brooklyn and Queens in New York City, and portions of the Towns of Hempstead and North Hempstead in Nassau County. Together, the land area of the watershed, based on topography alone, of the Bay is approximately 91,000 acres. Figure 2.3.1 shows the topographic watershed boundary for Jamaica Bay without regard to the collection and discharge of sanitary and stormwater sewers. Elevations within the watershed range from sea level to a maximum of approximately 250 feet, to the west of Queens and Nassau County border near the Cross Island Parkway.

Eight tributaries empty into Jamaica Bay—Sheepshead Bay, Paerdegat Basin, Fresh Creek, Hendrix Creek, Spring Creek, Shellbank Basin, Bergen Basin, and Thurston Basin. Tributaries are considered the dead ended canals located around

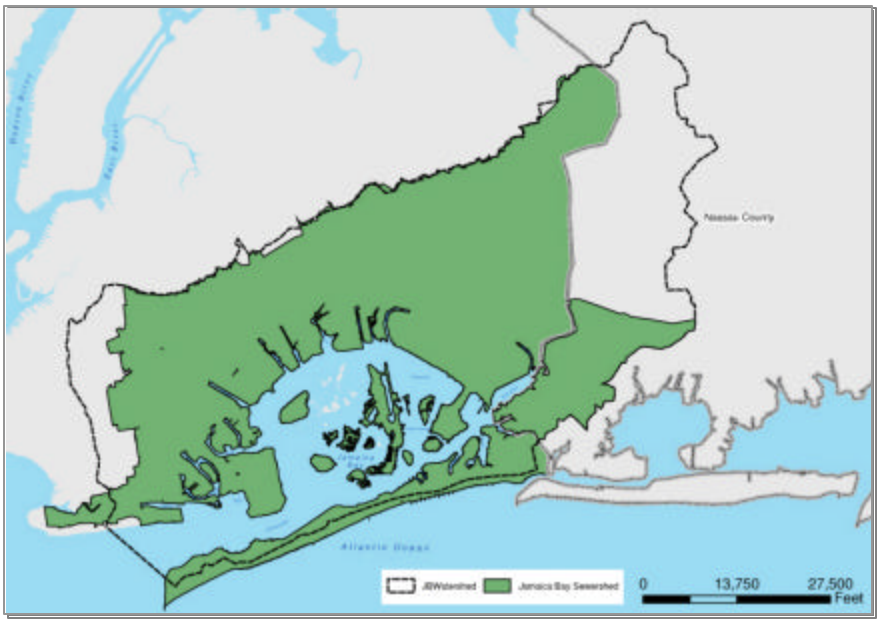


FIGURE 2.3.1 Jamaica Bay Sewershed and Watershed; Source: NYCDEP

FIGURE 2.3.2 Gateway National Recreation Area; Source: US National Park Service, 1994

the City. The term "basin" usually refers to the watershed, but in Jamaica Bay refers to the receiving water. All the Jamaica Bay tributaries have been highly altered over the years through channalization and tend to have little or no freshwater flow. They all receive CSOs from the Jamaica Bay watershed and several receive treated effluent from four NYC WPCPs and auxiliary plant (*i.e.*, Spring Creek, Bergen Basin, and Hendrix Creek).

The land area that is actually tributary to Jamaica Bay is the area served by combined and separated sewer systems, or the sewershed, that collect and convey sanitary wastewater, as well as stormwater. The collected flow is then discharged to Jamaica Bay. Therefore, portions of the area within the topographic boundary that otherwise would define the watershed, the western-most portion of the watershed in Brooklyn and the majority of the eastern-most portion in Nassau County, are not in the sewershed of the Bay. Runoff from those areas is diverted from Jamaica Bay by sewers that collect and convey both sanitary wastewater and runoff to other water bodies. In this area of Brooklyn, runoff is taken by the sewers and eventually discharged to the Lower Bay of New York. For flows in Nassau County, collected runoff is directed either to the Brosewere Bay and the Atlantic Ocean to the south or from the north side of the terminal moraine that characterizes Long Island (see Chapter 2.5), to Long Island Sound to the north. However, runoff from an area in the extreme southwest corner of Nassau County, including the Village of Cedarhurst and treated effluent from the Cedarhurst WPCP, does flow into Jamaica Bay.

The City portion of the watershed's land area is approximately 46,000 acres. Land uses in the Jamaica Bay watershed include residential, commercial and industrial lands, landfills, as well as vacant, undeveloped lands, marshes, wetlands, parks, and the John F. Kennedy International Airport. (JFK Airport) The airport, located on the eastern edge of the Bay, occupies over 4,300 acres on the eastern edge of the Bay (see Chapter 6, *Land Use and Development*, for more detail on land uses).

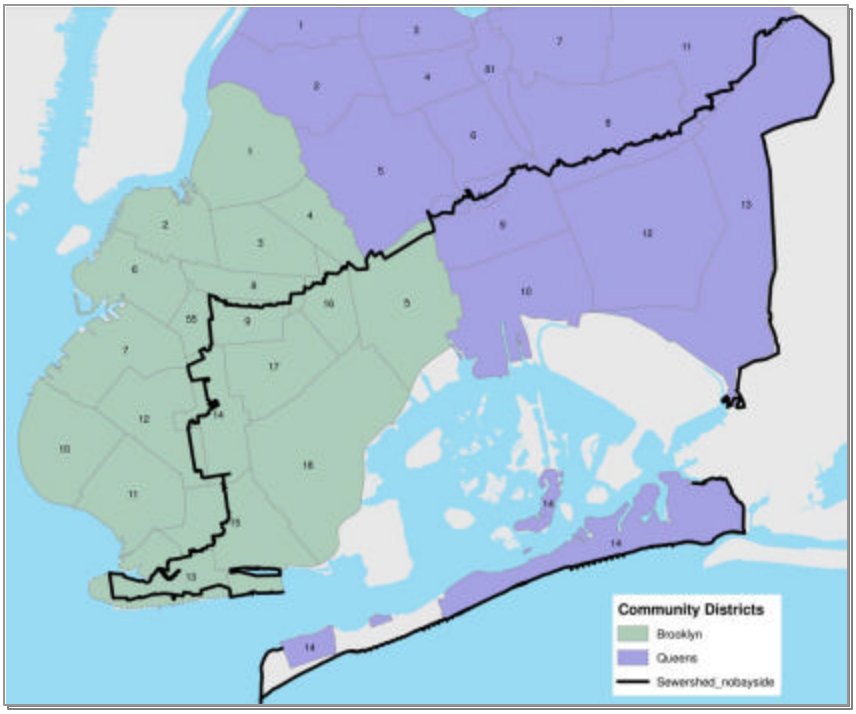


FIGURE 2.3.3 Sewershed Community Districts; Source: NYCDEP

The Bay includes areas of open water, tidal flatlands, salt marshes, and a number of islands. The largest island in the Bay is Broad Channel Island. Broad Channel Island is connected to the mainland and Rockaway by Cross Bay Boulevard. Other transportation connections across the Bay are the Marine Parkway Bridge extending from the Floyd Bennett Field area to the west end of the Rockaway peninsula and the "S" and "A" subway lines of the Metropolitan Transportation Authority (MTA) which crosses the Bay at Broad Channel Island.

The Bay has been designated by the New York State Department of Environmental Conservation (NYSDEC) as a Critical Environmental Area (CEA), the only one in New York City, and by the NYSDOS as a significant Coastal Fish and Wildlife Habitat as part of its Coastal Zone Management Program. A portion of Jamaica Bay is included in the National Park Service Gateway National Recreation Area (NPS GNRA). The GNRA also includes part of Sandy Hook across the Lower New York Harbor on the New Jersey shore.

The Bay

Jamaica Bay is the largest estuarine waterbody in the New York City metropolitan area covering an area of over 16,000 acres (approximately 13,000 acres of open water and 3,000 of islands and marshes). It is bounded on the west and northwest by Brooklyn, on the north and northeast by Queens. The northeastern and southeastern corners of the Bay are bordered by Nassau County. The northern shore of the Rockaway Peninsula, a part of Queens, forms the southern boundary. The Bay is connected to the Atlantic Ocean through the Rockaway Inlet and has a tidal range of approximately 5 to 6 feet. It measures approximately 10 miles at its widest point east to west and approximately 4 miles at its widest point north to south. The mean depth of the Bay is approximately 13 feet with maximum depths reaching 30 to 50 feet in navigation channels and borrow pit areas.

Dredging and filling of the Bay over the past century has significantly altered not only the bottom of the Bay but also its shoreline, and the number and shape of the Bay's islands and marsh

lands. The alteration has resulted in the loss of many of the Bay's tidal marshes, portions of the Bay becoming channelized, the disappearance or bulkheading of many of the Bay's tributaries, and the loss of many islands due to dredging and channelization work over the years. However, other islands have been created by dredging and filling operations.

2.4 CLIMATOLOGICAL SETTING

The New York City/Jamaica Bay region experiences a humid continental climate moderated by proximity to the Atlantic Ocean (NYSCO, 2006). Three air masses provide the dominant climatic conditions for the area. Primarily in the winter months, masses of dry, cold arctic air arrive from the northern interior of the United States and Canada. In the summer, prevailing winds from the south and southwest convey warm, humid air from the Gulf. The third great air mass flows inland from the North Atlantic Ocean, producing cool, cloudy, and damp weather conditions, moderating temperatures during the warmer months. Most storm and frontal systems moving eastward across the continent pass through or proximate to the New York City metropolitan area, while storm systems moving northward along the Atlantic coast also have a strong influence on New York City's regional weather.

An understanding of climate characteristics of the watershed, particularly rainfall and climate change effects, is important for development of the Volume 2, *Jamaica Bay Watershed Protection Plan.* The intensity of storm events influences the volume of stormwater and CSO events. Climate change affects plant growth seasons and has led to changes sea level rise and loss of wetlands. These climatological processes as they relate to Jamaica Bay are explained further below.

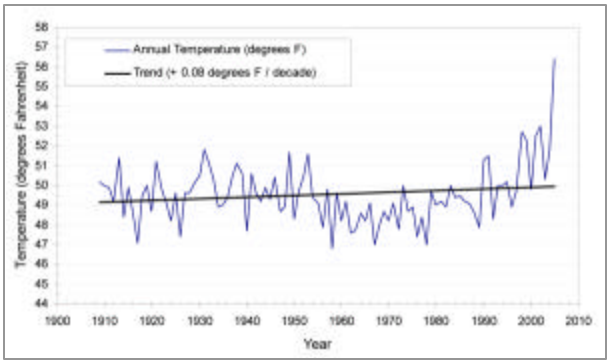


FIGURE 2.4.1 Mean Annual Temperatures for the New York Metro Region (at New York Central Park); Source: National Climatic Data Center (NCDC), 2006

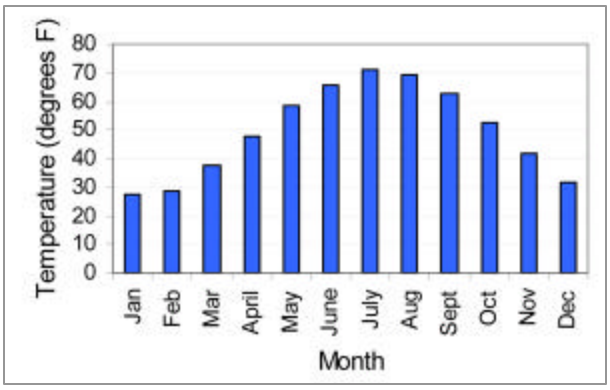


FIGURE 2.4.2 Mean Monthly Temperatures for the New York Metro Region (at New York Central Park); Source: National Climatic Data Center (NCDC), 2006

Temperature

The average annual regional temperature is about 50°F (NCDC, 2006). In the last decade, New York City has experienced its five highest mean annual temperatures to occur in the last century, a surprising and potentially concerning statistic (NCDC, 2006, Figure 2.4.1). Due to local warming from the urban heat island effect, these temperatures are likely to be elevated compared to less developed areas in the region. Large cities tend to have somewhat unique climate

characteristics, due to the prevalence of dark surfaces (generally pavement and rooftops) that absorb more heat from the sun, and less vegetation to provide shade and temperature regulation. Heat from urban areas affects plant growth seasons and plant survival while wind patterns are influenced by surface structures such as tall buildings (Sukopp, 1998).

Precipitation

Moisture for precipitation originates primarily in the Gulf of Mexico and Atlantic Ocean through atmospheric circulation patterns. There are no distinct dry or wet seasons in the New York City region (Figure 2.4.3). In the Jamaica Bay area, minimum precipitation occurs in the winter season, with an average monthly accumulation of about 3.5 inches on Long Island to average summer highs of 4 inches along the New York coastal zone. Monthly winter snow accumulations of between 3 to 10 inches occur in New York City and Long Island. Occasionally, the amounts may exceed 20 inches as a result of recurring (northeasterly) coastal storms. Annual precipitation for the New York Metro area (as measured in Central Park) is depicted in Figure 2.4.4. Average annual precipitation for the Jamaica Bay region is 45 inches, while the average snowfall is 29 inches (NCDC, 2006).

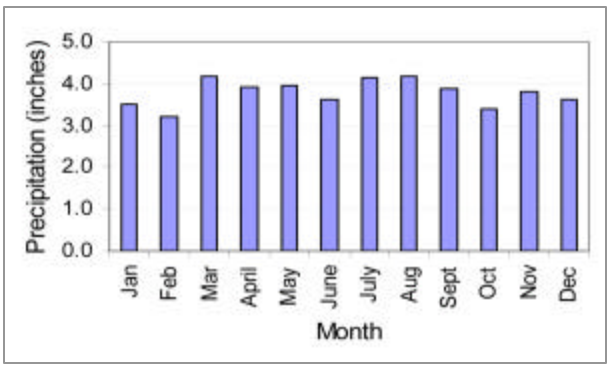


FIGURE 2.4.3 Average Monthly Precipitation for the New York Metro Region (at New York Central Park); Source: National Climatic Data Center (NCDC), 2006

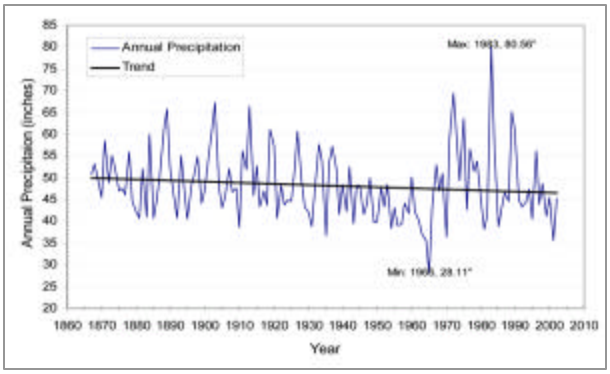


FIGURE 2.4.4 Annual Precipitation for the New York Metro Region (at New York Central Park); Source: National Climatic Data Center (NCDC), 2006

Long term rainfall statistics were evaluated for the establishment and selection of an "average year" as the design rainfall condition for all activities related to New York City's CSO and related programs; this design rainfall condition is consistent with the U.S. Environmental Protection Agency's (USEPA's) CSO Control Policy. Storm intensity and frequency were evaluated in the years 1970 – 2002 using data collected at John F. JFK Airport; this information provides a perspective on the average storm in New York City (see Table 2.4.1, following). Based on these data, 1988 was selected as representative of the average year.

TABLE 2.4.1 Long Term Statistics, JFK Airport Rainfall Record (1970-2002)

Rainfall Parameter	Long Term Median	Average Year (1988)
Total volume, inches	39.4	40.7
Intensity, inches/hr	0.057	0.068
Number of storms	112	100
Storm duration, hours	6.08	6.12

Rainfall in the region is usually sufficient during the growing season for most needs. Severe droughts are rare, but periods of low precipitation can stress available water supplies and result in moisture deficiency for upland vegetation. Tidal marshes in Jamaica Bay are not impacted by drought to the extent of freshwater wetlands and uplands, although a temporary decline in freshwater input to the Bay does result in locally

increased salinity levels, which may affect some aquatic species.

The metropolitan New York City area is subject to severe flooding of highways, streets, and low-lying ground. The replacement of the natural soil cover with cement, asphalt, and other impervious materials encourages flooding from moderately heavy rains that historically would infiltrate into the ground or run off into natural stream channels. The shorelines of Jamaica Bay are subject to tidal flooding during storm surges from winds generated by hurricanes and large coastal storms. These storm surges may drive tidal waters well inland, causing extensive property damage and shoreline erosion.

Climate Change and Sea Level Rise (SLR)

As the earth and its oceans warm, ice sheets at the poles melt and sea water thermally expands, both contributing to sea level rise (SLR) (Wigley and Raper, 1987). As the sea levels rise, Eastern coastal states are susceptible to the loss of coastal lands due to erosion and inundation. In particular, sea level rise poses a direct threat to the health of tidal wetland systems that provide essential habitat to migratory and resident fish and birds.

There are no long term tide gauges in Jamaica Bay. SLR information is derived from a tide gauge in Battery Park, Manhattan, which has been recording data since 1856 and has one of the longest known records in the United States. Information from this gauge indicates a SLR of 2.7 mm/yr in the Jamaica Bay watershed (Hartig *et al.*, 2000). If wetland surface level accretion is not sustained with the pace of SLR, there is concern that the remaining island salt marsh wetlands in Jamaica Bay will vanish in a few generations' time (USACE, 2005).

In 2000, the International Panel on Climate Change (IPCC) suggested that SLR is expected to double in the next 50-100 years even if a significant reduction in current climate warming greenhouse gases emission trends occurs (IPCC, 2002). Furthermore, the data implies that if nothing is done to our current rate of greenhouse gas production, the rate of SLR could triple in the next 50-100 years (IPCC, 2002). This means that by 2020 the mean SLR could be between 2.7-7.3 mm/yr, and by 2050 the sea level could be expected to rise between 2.7-13.7 mm/yr (Hartig *et al.*, 2000). Using these rates of sea level rise, by 2050 the mean sea level in Jamaica Bay could increase by 12 centimeters (0.4 feet) to 47 centimeters (1.5 feet) in elevation.

A direct result of SLR will include the extensive, accelerated loss of uplands and shoreline wetlands from wave driven erosion and tidal inundation. While some upland areas may not become directly inundated, salt spray, storm surges, and saltwater intrusion are likely to affect plant and animal species that do not normally have contact with higher salinity waters. Wetlands utilize natural landward migration as a means of adapting to slower rates of SLR. In Jamaica Bay, the process of landward migration is frequently arrested by hardened shorelines, leaving these wetlands areas vulnerable to becoming overwhelmed by increasing rates of SLR. The degree to which sea level rise contributes to the accelerating loss of salt marsh islands in Jamaica Bay is as yet unquantified, but is identified as a major driver in their disappearance (NPS, 2004).

2.5 GEOLOGY AND SOILS

Geology

The metamorphic bedrock formations that underlie Long Island are more than 400 million years old, while the overlying sands and clays were deposited about 70 million years ago (Mills, 1974). The bedrock, or basement formation, that lies beneath Long Island slopes to the south and east at depths ranging from 2,000 feet below the surface along the southern edge of Long Island to being near the surface, particularly in the northwestern portions of Queens and

Brooklyn (Mills, 1974). However, due to the general depth of the bedrock, there are few, if any, outcrops anywhere in the watershed area. Figure 2.5.1 shows the geology underlying Long Island.

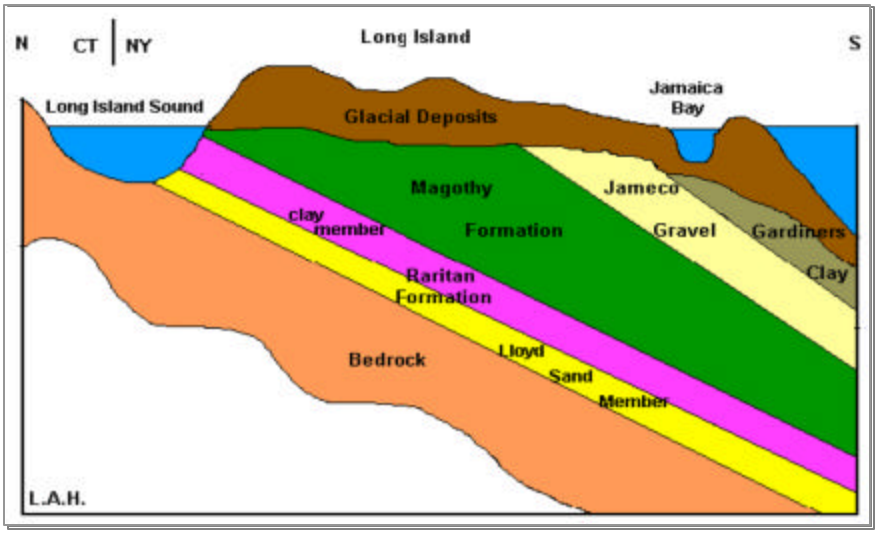


FIGURE 2.5.1 Coastal Plain Geology Underlying the Glacial Deposits of Western Long Island; Source: US Department of Agriculture, 2005a

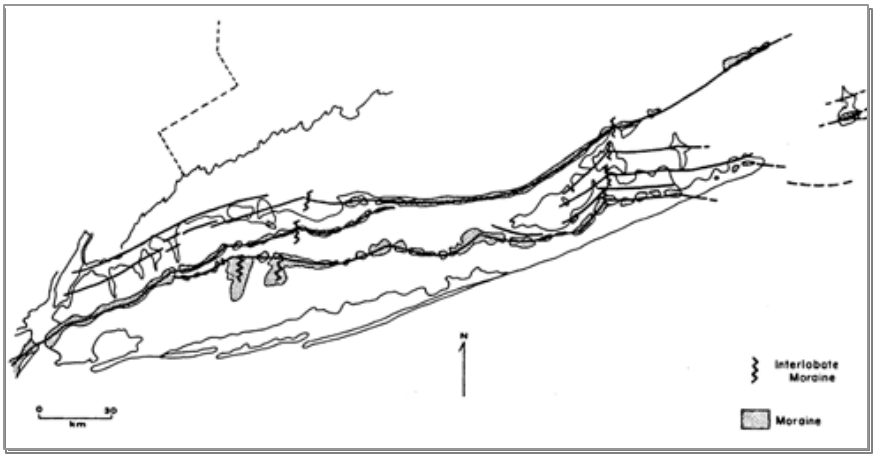


FIGURE 2.5.2 Terminal Moraine and Correlation of Recessional Moraine Segments Across Long Island; Source: Sirkin, L. Late Wisconsianan Glaciation of New England, 1982

The surface features of Long Island that form the general topography seen by the casual observer are the result of glacial advances and retreats. Moraines are elongated ridges that are formed at the edge of a glacier. Moraine formations consist of rocks, sand, and gravel that have been carried by the glacier, sometimes from distant locations (Rogers, W. B., *et al.*). Moraines deposited at the ending limit of a glacier, such as those found on Long Island, are called terminal moraines. The two terminal moraines that are found on Long Island are the Harbor Hill and Ronkonkoma (Rogers, W. B. *et al.*, nd). The outwash plain is that area beyond the margins of a glacier where meltwater deposits sand, gravel, and mud washed out from the glacier. On Long Island the outwash plain extends southward from the Harbor Hill and Ronkonkoma moraines (Figure 2.5.2).

With respect to the Jamaica Bay watershed, it is the Harbor Hill moraine and the outwash plain that has had the most influence in shaping the surface of the watershed area. The Harbor Hill moraine is a continuous ridge extending from Brooklyn on

Definitions

Moraine: A large body of drift (consisting of till, stratified drift, or both that has been shaped into a rounded ridge... At the outer margin of a glacier that has reached its maximum extent, the ice pushes up debris into a ridge whose trend follows the edge of the ice. This ridge is known as *terminal moraine.* (Sanders, J.E., *et. al.*, 1976).

Urban Land: "…Areas where at least 85 percent of the surface is covered with asphalt, concrete, or other impervious building material. These areas mostly are parking lots, shopping centers, industrial centers…" (U.S. Soil Conservation Service).

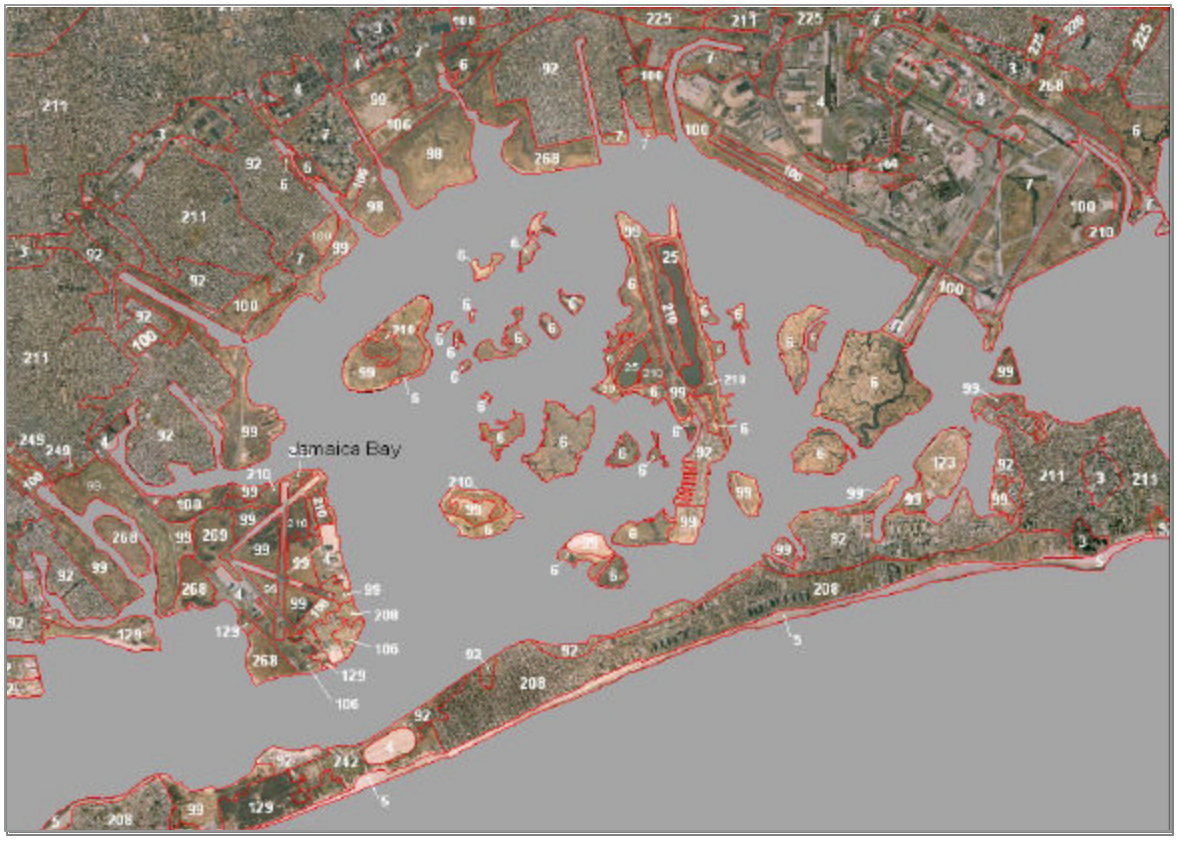


FIGURE 2.5.3 Jamaica Bay Reconnaissance Soil Survey; Source: NRCS

the west to Port Jefferson on the east. High points of the Harbor Hill moraine are found near Lloyds Neck (approximately 280 ft) and Eatons Neck (approximately 230 ft) on the north shore of Long Island, about 18 and 25 miles northeast of the Jamaica Bay watershed, respectively. The outwash plain from the Harbor Hill moraine extends southward sloping from the ridgeline to the Atlantic Ocean (Bennington, J.B., nd).

Soils

The composition of a soil in any given location depends on the geologic forces that acted on the area, the source or sources of the mineral formations that contributed to the makeup of the soil and, often of great significance, man's activities that may have altered the surface layers. In the case of Long Island, the results of repeated glacial advances and retreats of the area were the primary origin of the area's soils (USDA, 2005b). Over time, the physical structure of the surface soils has been subjected to wind, rain, and runoff. These forces serve to erode soils from one area and deposit them in another. Naturally occurring soils found in valleys and streams, on hills and sloped areas are the products of these forces.

Man made (anthropogenic) forces have influenced the surface soils that are now found in the Jamaica Bay watershed (see Figure 2.5.3). Many of the soils found along the shoreline *(i.e.*, within 1/4 mile) of the Bay have been greatly influenced by residential, commercial, and industrial development, landfilling with waste materials, and dredging operations and are non-native (not undisturbed, even if they consist of local materials). Shoreline slopes are often characterized by a gentle slope (less than 5 percent slope) along natural shoreline banks where they have not been

channelized or otherwise developed with piers, boat slips, or bulkheads to stabilize the banks. Areas away from the immediate shoreline (*i.e.* greater than 1/4 mile) of the Bay are generally characterized as "urban" soils or those areas where the soil has been covered by pavement and/or buildings. For detailed soil information see Chapter 4, Ecology.

Although the majority of the area within the topographic watershed that is within Nassau County does not contribute flow to Jamaica Bay, the soils there are also generally described as urban soils (USDA 1987).

2.6 HYDROLOGY

There are four aquifers underlying the Jamaica Bay area as shown on Figure 2.5.1 (USGS, 1999). Together these aquifers make up the Brooklyn-Queens Aquifer System:

- Lloyd Aquifer, the deepest
- Magothy Aquifer
- Jameco Aquifer
- Upper Glacial aquifer

The Lloyd Aquifer consists mainly of fine to coarse sands and interbedded gravels, silt and clay. The thickness of the Lloyd Aquifer ranges from essentially zero at its northern edge under Long Island Sound to 200 to 300 feet thick under the southern portions of Brooklyn and Queens. It is found perhaps 90 feet below sea level in northern Queens and over 800 feet below sea level under the southern portion of the Jamaica Bay watershed area (USGS, 1999).

The Magothy Aquifer consists mainly of very fine to coarse sand and silty sand with small amounts of interbedded clay and silt. As with the Lloyd Aquifer, the thickness of the Magothy Aquifer ranges from essentially zero at its northern edge under Long Island Sound but reaches a thickness of 200 to 500 feet thick under the southern portions of Brooklyn and Queens. It is found perhaps 100 to 200 feet above sea level in northern Queens and over 400 feet below sea level under the southern portion of the Jamaica Bay watershed area (USGS, 1999).

> *"More than just the substrate for creating growth, the soil is Earth's primary filter, cleansing and recycling water and decaying material; is also a major component of the earth's planet's water-storage and water-cycling processes."*
>
> *- Dr. David Suzuki*

The Jameco Aquifer consists mainly of coarse sand and gravel in its northern reaches to finer particles in the south. The thickness of the Jameco Aquifer ranges from essentially zero at its northern edge in the central part of the Jamaica Bay watershed but reaches a thickness of no more than 200 feet thick under the southern portions of Brooklyn and Queens. It is found perhaps 90 to 100 feet below sea level at its northern edge and over 200 below the sea level below the southern portion of the Jamaica Bay watershed area (USGS, 1999).

The Upper Glacial Aquifer overlies the other units and may be found at the surface throughout nearly all of Brooklyn and Queens. As such, it is characterized by the unconsolidated mixtures of clay, sand, gravel, and boulders that are common

to the outwash plain south of the Harbor Hill Moraine (USGS, 1999).
Fresh ground water from the Brooklyn-Queens Aquifer system starts as precipitation in the form of rainfall and snowmelt (USGS, 1999). This recharge process is achieved by precipitation that finds its way to the aquifer through the percolation or the slow seepage into the ground from the surface, either through porous areas such as open grass covered lawns, parks, or cemeteries, or by seepage from the bottoms of lakes, ponds, and streams.

Of course, not all of the precipitation reaches the aquifer. This process is important for Jamaica Bay: since the watershed is highly urbanized and covered by impervious surfaces, precipitation runs off buildings, roads, and other paved, concrete or constructed surfaces into sewers. This water, and the waste materials and contamination that it picks up, is then conveyed by storm sewers or CSOs directly to the Bay and its tributaries, or WPCPS and eventually to the Bay as treated discharges.

There are no significant or naturally flowing streams or other surface water features in the Brooklyn and Queens areas that, in other areas, would be expected to contribute to the recharge of the underlying aquifers. Streams and their drainage areas that once flowed through the Jamaica Bay watershed have been covered over by the expansion of streets, roads, residential housing, commercial uses, and industrial growth. There are few ponds and lakes in the area to contribute fresh water to the aquifer.

Approximately 50% of the precipitation returns directly to the atmosphere through evapotranspiration (USGS, 1999). Due to the relatively high degree of impervious surfaces (*i.e.*, paved areas) within the watershed, much of the precipitation that does not escape through evapotranspiration does not recharge the aquifer system but runs off to be collected in the combined sewer system. This collected runoff eventually is discharged to Jamaica Bay via the existing WPCPs and CSO points located around the Bay.

As noted, natural fresh water flow into Jamaica Bay is negligible in comparison to the discharge from four WPCPs and numerous outfalls into the Bay. These WPCPs, and storm sewers, are the largest source of fresh water to Jamaica Bay as natural flow has been greatly diminished due to urbanization. Inflow from the Hudson River and ground water flow also contribute fresh water to the Bay.

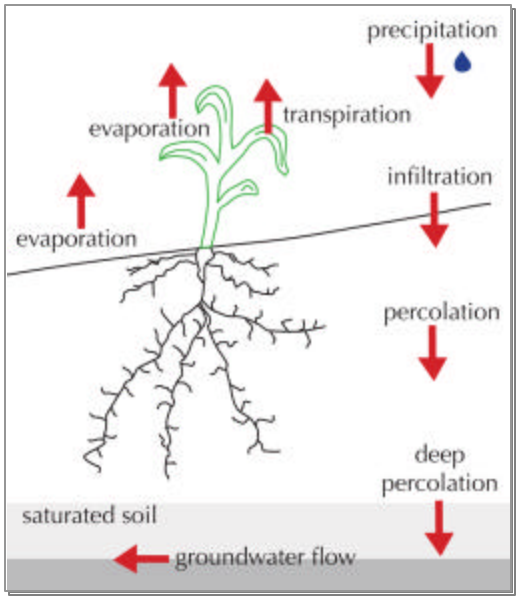


FIGURE 2.6.1 Ground Water Percolation; Source: University of Kentucky

The percentage of precipitation that is not lost through evapotranspiration or through the sewer system does make its way into the ground to recharge the aquifer where there are pervious surfaces: lawns; landscaped and vegetated areas; natural areas; and other land that is undeveloped, unpaved, or both.

Once in the aquifer system, ground water in the Upper Glacial Aquifer generally moves laterally and discharges to the surrounding salt water bodies (USGS, 1999). Ground water that is able to make its way by moving vertically to the lower aquifers also eventually discharges to the surrounding salt water bodies.

The hydrologic characteristics of Jamaica Bay have also been affected by the dredging and filling that have taken place. Prior to urbanization and

development of the watershed, the Bay had a maximum depth of approximately eleven feet. But dredging of navigational channels and the provision of about 90 million cubic yards of fill for projects such as the JFK Airport expansion, has increased the depth as much as 50 feet in certain locations (*e.g.*, Grassy Bay). Similarly, much of the Bay's shoreline has been filled with a variety of materials including dredged sediment but also municipal waste, incinerator ash, and other historic fill.

2.7 GROUND WATER SUPPLY

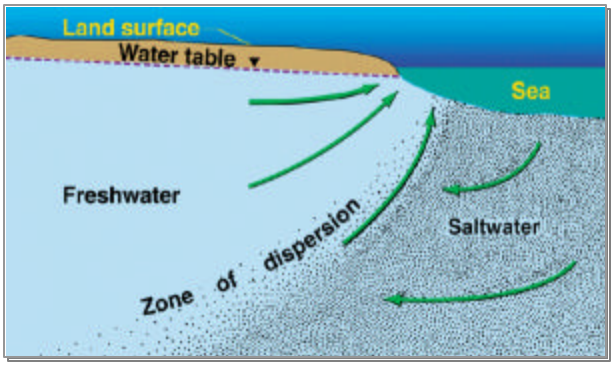
The ground water aquifer system underlying western Long Island had served as a public water supply for much of Brooklyn and Queens as well as for Nassau County beginning in the mid-1800s. Before then, private wells tapped into the shallow aquifer provided much of the water for drinking, washing, and sanitary needs of the area's population. With the swift increase in population and commerce in the area in the late 1800s and following the turn of the century the relatively ready availability of fresh water pumped from the aquifer was used to meet the demands of the expanding growth.

Historically, the aquifer system has come under pressure from:

- the *increasing demand* to supply fresh water to meet the expanding growth of the area, and
- the *decreasing ability* of the area to recharge the aquifer system due to the increased amount of impervious area associated with growth.

In the past, ground water from the Brooklyn-Queens Aquifer system was pumped out to provide drinking water for parts of southeastern Brooklyn and Queens and also for parts of Nassau County. A brief summary of the use of the Brooklyn-Queens Aquifer in Brooklyn and Queens was reported by the USGS (USGS, 1999).

- In 1904 the ground water aquifer supplied virtually all of the approximately 42 million gallons per day (MGD) for public use and approximately 14 MGD for industrial use in both Brooklyn and Queens. By 1916, public use had grown to approximately 54 MGD and industrial use to 34 MGD.
- In 1917, the City extended a water supply tunnel into the area which brought fresh water obtained from upstate. This resulted in a reduction of the ground water pumped out to meet the public water supply demand. However, both public and industrial demands on the aquifer continued to increase.



Salt Water Intrusion

Under natural conditions, the movement of fresh ground water from coastal aquifers is toward the sea, in the case of the Brooklyn and Queens area, the Atlantic Ocean. This movement prevents salt water from moving into or intruding into the aquifer system. The interface between fresh water and salt water is kept near the coast or far below land surface and is actually a zone in which fresh water and salt water mix.

Ground water pumping can reduce the rate and volume of fresh water flow toward coastal discharge areas and allow salt water to move landward. Salt water intrusion decreases the volume available for fresh water storage in the aquifer system, and, in extreme cases, can result in the abandonment of supply wells.

- In the period of 1918 to 1930 the public water supply demand grew from approximately 34 MGD to 92 MGD while the industrial demand grew from approximately 34 to 70 MGD.
- The period of 1931 to 1946 saw significant changes in the water supply system for Brooklyn and Queens. In 1936, a second water tunnel was developed for the delivery of water to the area. However, this second tunnel merely met the water demand for new growth; the ground water aquifer was still relied on to provide fresh water to prior customers. Therefore, the withdrawal from the aquifer remained relatively constant at 70 to 90 MGD. Concurrently, the use of the ground water for industrial use began to decline due to concerns over salt water intrusion (see sidebar on page 25 for more discussion of this phenomenon).
- In 1947, essentially all pumping of the ground water in Brooklyn ended, again due to concerns over salt water intrusion. Meanwhile, pumping to provide water to parts of Queens went from approximately 45 MGD in the late 1940s to nearly 70 MGD in the 1970s. After 1974, both public and industrial water supplies from the aquifer fell to less than 10 MGD as water was increasingly provided from the upstate water supply system.

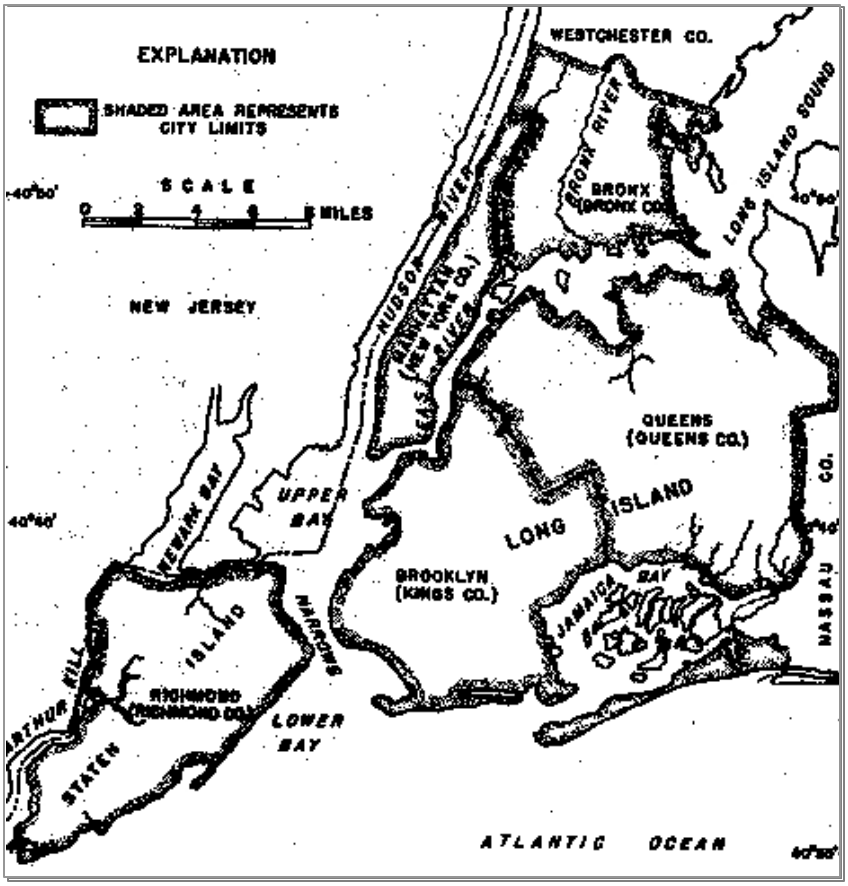


FIGURE 2.7.1 Location and Geologic Setting of Brooklyn-Queens Aquifer System; Source: U.S. Environmental Protection Agency

What aquifer supplied the ground water used for drinking water?

- In 1904 virtually all of the ground water was pumped from the Upper Glacial Aquifer, the shallowest of the four aquifers making up the Brooklyn-Queens Aquifer System. Withdrawals from this aquifer occurred through to the late 1940s in Brooklyn when use of the ground water was ceased. During that time, the Upper Glacial aquifer provided approximately 15–25 MGD for users in Brooklyn and an average of approximately 20 MGD, ranging from about a minimum of 15 MGD to a maximum of over 45 MGD for users in Queens, up until the 1970s (Figure 2.7.1).
- The Jameco Aquifer, the next lower aquifer, was used sporadically in Brooklyn up until the 1940s, and up until the 1970s in Queens.

An average of about 5 MGD was pumped from the Jameco Aquifer.

- The Magothy Aquifer was not used to provide ground water to Brooklyn users. In Queens, pumping from this aquifer was generally less than 5 MGD up until the early 1960s. From the early 1960s to the mid-1970s, the use of the Magothy aquifer increased from about 10 to 45 MGD.
- The Lloyd Aquifer was used for a short time in the early 1930s to provide ground water to Brooklyn users and, even then, at a rate of less than 4 MGD. In Queens, this aquifer was used from the early 1900s up until the 1970s providing about 2 MGD from the early 1900s through 1930 and about 5 MGD from 1930 until the 1970s.

In 1996, New York City purchased the 69 wells of the Jamaica Water Supply (JWS) company that had been operating the ground water supply wells in Queens and, through the NYCDEP, took responsibility for the provision of water to the Queens residents serviced by the JWS company.

In 2004, the wells owned by the New York City provided an average of 6.4 million gallons of water per day water to approximately to 350,000 people. In 2006, the ground water system supplied approximately 2 MGD. The area for which ground water is used covers 29 square miles in southeastern Queens and includes the following neighborhoods: Cambria Heights, Hollis, Holliswood, Jamaica, Jamaica Estates, Kew Gardens, Laurelton, Queens Village, Richmond Hill, Rosedale, St. Albans, South Jamaica, South Ozone Park, and Springfield Gardens. Only seven wells were used for this purpose and represented less than 1% of the City's total water usage.

Due to the decreasing withdrawal of ground water from the Brooklyn-Queens Aquifer System, the ground water table in portions of Brooklyn and Queens has begun to rise. The rise in the water table has led the NYCDEP to pump ground water in excess of that needed to supply the residents of the service area to the sewer system in order to avoid the flooding of basements by ground water. However, in contrast to the rise in the ground water table in portions of the Jamaica Bay watershed, the urbanization and development has increased the degree of impervious surface area that has resulted in there being less recharge of the underlying aquifers as noted above.

In addition to the general lowering of the ground water table from reduced recharge, the quality of the ground water has deteriorated due to contamination from a variety of sources. Included among the sources of contamination are salt water intrusion, percolation of surface water that contains road salt, leaking sewer lines, and spills of chemicals and petroleum products.

2.8 REFERENCES

Augustyn, R.T., and P.F. Cohen. 1997. Manhattan in Maps 1527-1995. Rizzoli International Pubs., New York, NY.

Bennington, J.B. nd. New observations of the glacial geomorphology of Long Island from a digital elevation model (DEM). http://pbisotopes.ess.sunysb.edu/lig/Conferences/abstracts-03/bennington/

Black, F.R. 1981. Jamaica Bay: A History. National Park Service, Washington, D.C.

City of New York (CNY), Bureau of Public Improvements. 1917. Report on the Main Drainage and Sewage Disposal of the Area Tributary to Jamaica Bay. New York, NY.

City of New York (CNY), Department of Parks. 1938. The Future of Jamaica Bay. New York, NY.

Hartig, K. E., F. Mushacke, D. Fallon, and A. Kolker. 2000. A Wetlands Climate Change Impact Assessment for the Metropolitan East Coast Region. Center for International Research Earth Science Information Network. Columbia Earth Institute, New York, NY.

Intergovernmental Panel on Climate Change (IPCC). 2002. Climate Change 2001: Synthesis Report. Watson, R.T. *et al.* (eds.). Cambridge University Press, Cambridge, England.

Mills, H.C. c. 1974. Garvies Point Museum and Preserve. nd, Referenced from Educational Leaflet # 16 Nassau County Museum of Natural History. http://www.garviespointmuseum.com/geology.php

National Climatic Data Center (NCDC). 2006. National Park Service (NPS). 2004. Proceedings: Jamaica Bay's Disappearing Marshes, March 3, 2004. New York Aquarium, New York, NY. http://www.ncdc.noaa.gov/oa/climate/research/cag3/city.html

National Park Service (NPS), Gatgeway National Recreation Area (GNRA), Jamaica Bay Institute. 2004. Proceedings: Jamaica Bay's Disappearing Marshes, 3 March 2004, New York Aquarium, U.S. Department of the Interior. Washington, DC.

New York City Department of Environmental Protection (NYCDEP). nd. New York City's water supply system. New York, NY. http://www.nyc.gov/html/dep/html/groundwater.html>

New York State Climate Office (NYSCO). 2006. www.sysc.eas.cornell.edu.

O'Brien & Gere Engineers, Inc. 2003. Jamaica Bay Eutrophication Project Study, NYCDEP. Syracuse, NY.

Rhoads, J.M., D.J. Yozzo, M.M. Ciancola, and R.J. Will. 2001. Norton Basin/Little Bay Restoration Project: Historical and Environmental Background Report. U.S. Army Corps of Engineers, New York District, New York, NY.

Rogers, W.B., *et al*. nd. Overview of New York geology Adapted from: Educational Leaflet 33, New York State Museum, Albany, NY. http://gretchen.geo.rpi.edu/roeker/nys/nys_edu.pamphlet.html>

Sukopp, H. 1998. Urban Ecology – Scientific and Practical Aspects. In: *Urban Ecology*. Breuste, J., H. Feldmann, and O. Uhlmann, eds. Springer. Berlin.

U.S. Army Corps of Engineers (USACE), New York District. 2005. Jamaica Bay Marsh Islands, Jamaica Bay, New York. DRAFT Integrated Ecosystem Restoration Report and Environmental Assessment. New York, NY.

U.S. Department of Agriculture (USDA). 2005a. Soil Survey of Gateway National Recreation Area, New York and New Jersey. Staten Island, New York.

U.S. Department of Agriculture (USDA). 2005b. New York City Reconnaissance Soil Survey. Staten Island, New York.

U.S. Department of Agriculture (USDA). 1987. Soil Survey of Nassau County, New York. Washington, D.C.

U.S. Environmental Protection Agency (USEPA), Region 2. nd. Brooklyn-Queens Aquifer System. New York, NY. <http://www.epa.gov/Region2/water/aqwuifer/brooklyn/brooklyn.htm>.

U.S. Geological Survey (USGS). 1999. Ground-water Resources of Kings and Queens Counties, Long Island, New York. Reston, VA.

Wigley, T.L., and S. Raper. 1987. Thermal expansion of sea water associated with global warming. Nature 330:127 – 131.

Photograph by Don Riepe, Jamaica Bay Wildlife Refuge

Chapter 3 - Water Quality

3.1 BACKGROUND

Jamaica Bay has been impacted over time by development in its watershed: dredging, filling and other significant alterations to the Bay, as well as natural processes. There are many sources of water that affect the water quality conditions within Jamaica Bay. These sources include:

- WPCPs that treat the sewage from residences, industries and other land uses in the watershed/sewershed;
- CSOs that contain a mixture of storm runoff and sewage when there is too much flow for the WPCPs to handle;
- Storm sewers that carry rainfall runoff, along with anything that may be on roofs, yards, and the streets;
- Landfill leachate;
- Ground water;
- Direct rainfall/Atmospheric deposition; and
- Tidal exchange with the Lower Harbor via the Rockaway Inlet.

In addition to the pollutant sources listed above, the water quality conditions are further exacerbated by the historical alterations to the Bay's geometry and morphology. The impacts of these sources and alterations vary throughout the Bay. The poorest water quality in the Bay can be found in Grassy Bay in the eastern portion of the Bay and the North Channel.

The open waters of Jamaica Bay, Shellbank Creek, Gerritsen Creek and Mill and East Mill Basins are classified Class SB for primary and secondary contract recreation (including bathing, fishing and fish propagation and survival) by the NYSDEC. The other tributaries are classified for secondary contact use such as fishing and boating and for fish propagation and survival (Class I).

> *"Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land."*
>
> *- Luna Leopold*

Overall attainment of coliform water quality standards is primarily influenced by conditions following wet weather events. Requirements of Class I waters are not attained for fecal coliforms in a few tributaries during months with a large number of wet weather events. Areas within the Bay's tributaries and dead end canals are prone to reduced water quality due to surface runoff and poor flushing.

Jamaica Bay has been extensively modeled. Water quality modeling is a critical component of the *Jamaica Bay Watershed Protection Plan* development process. Modeling enables the ability to test hypotheses regarding the issues and high priority problems facing the Bay. Although modeling has limitations and may not provide conclusive findings to the issues involved, the results provide valuable information that can be used to further improve the focus of the *Jamaica Bay Watershed Protection Plan*, refine potential management strategies, and develop final recommended actions.

3.2 WATER QUALITY OF THE BAY

3.2.1 Water Quality Standards

The NYSDEC assigns classifications to all of the waterbodies within its jurisdiction. These classifications are assigned such that "The discharge of sewage, industrial waste or other wastes shall not cause impairment of the best usages of the receiving water as specified by the water classifications at the location of the discharge and at other locations that may be affected by such discharge." (6NYCRR Part 701). Two of the classifications developed by NYSDEC apply to waters within Jamaica Bay: Class SB and Class I.

Class SB applies to the open waters of Jamaica Bay, Shellbank Creek, Gerritsen Creek and Mill and East Mill Basins. Class I applies to the remaining tributaries of Jamaica Bay. The best usages of Class SB waters are primary and secondary contact recreation and fishing. These waters must also be suitable for fish propagation and survival. Class I waters have best usages of secondary contact, and must be suitable for fish propagation and survival. Associated with each of these classifications are

TABLE 3.2.1

Class	Coliform Bacteria		Dissolved Oxygen
	Total	Fecal	
SB	Monthly median <2,400/100 mL	Monthly geometric mean <200/100 mL	>5.0 mg/L
	80% <5,000/100 mL		
	80% <5,000/100 mL		
1	Monthly geometric mean <10,000/100 mL	Monthly geometric mean <2000/100 mL	>4.0 mg/L

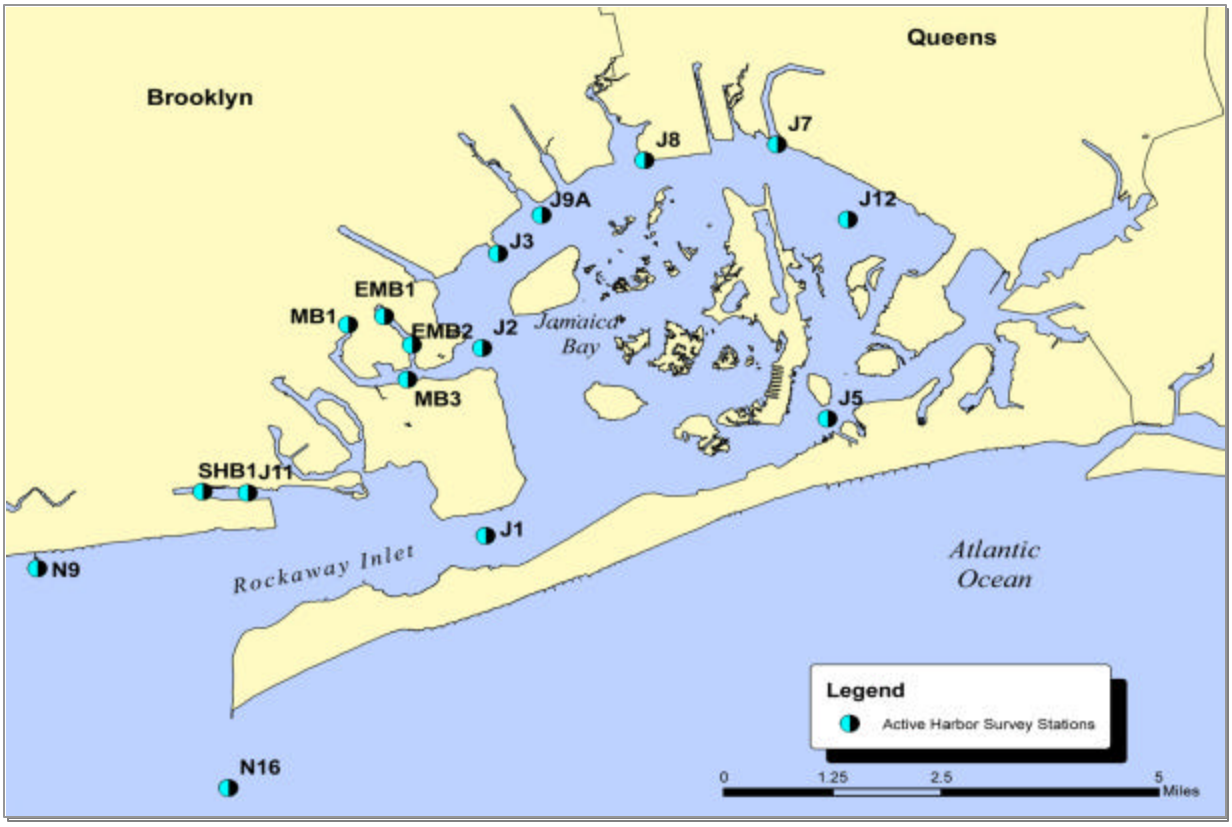


FIGURE 3.2.1 Active Harbor Survey Stations; Source: HydroQual, Inc.

water quality standards that are assigned such that each waterbody can achieve its best usage. Water quality standards for these waters specify numerical dissolved oxygen and coliform requirements and narrative standards.

As shown in Table 3.2.1 the numerical dissolved oxygen water quality standard for Class SB is a never-less-than concentration of 5.0 mg/L. The Class SB total coliform standard requires that the monthly median value not exceed 2,400 MPN/100 mL and more than 20 percent of the samples, from a minimum of 5 examinations, not exceed 5,000 MPN/100 mL. The fecal coliform standard requires that the monthly geometric mean, from a minimum of five examinations, shall not exceed 200 MPN/100 mL. The Class I water quality standards applied to tributaries and embayments of Jamaica Bay have a dissolved oxygen standard requiring a never-less-than concentration of 4.0 mg/L. The Class I total coliform standard requires that the monthly geometric mean, from a minimum of five examinations, shall not exceed 10,000 MPN/100 mL. The fecal coliform standard requires that the monthly geometric mean, from a minimum of five examinations, shall not exceed 2,000 MPN/100 mL. This is presented in tabular form in Table 3.2.1.

Ambient water quality is monitored by NYCDEP at a number of monitoring stations throughout the Bay as shown in Figure 3.2.1. Data gathered at these sites is presented below for nitrogen, dissolved oxygen, pathogens, and chlorophyll a.

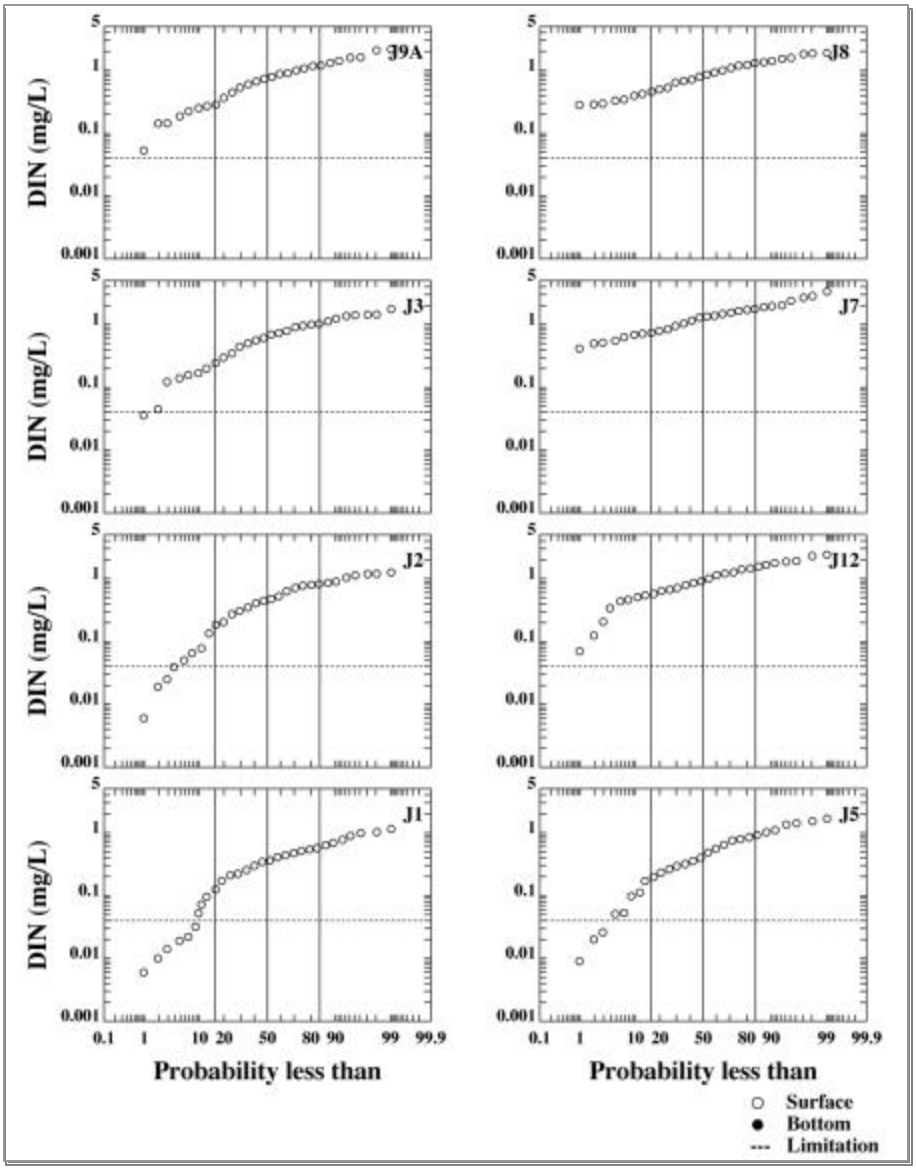


FIGURE 3.2.2 DIN mg/L in Jamaica Bay, 2001 – 2005.

3.2.2 Nitrogen

Nitrogen concentrations are a major contributor to low dissolved oxygen levels in Jamaica Bay. A primary source are the four WPCPs that discharge to the Bay.

Algae are simple plants that require nutrients, light and the appropriate temperature to grow. The macronutrients that are required for growth are nitrogen and phosphorus. If either nitrogen or phosphorus concentrations in the water column are low, algal growth becomes nutrient limited. In most estuarine systems, nitrogen is typically the limiting nutrient. This means that algae typically run out of available nitrogen before phosphorus. However, within Jamaica Bay, nitrogen and phosphorus are in excess; before these can be depleted, light required for chlorophyll production becomes the limiting growth factor.

A concentration of less than 0.04 mg/L of dissolved inorganic nitrogen (DIN) is thought to begin to limit algal growth. Jamaica Bay has levels in excess of 0.04 mg/L DIN. Nitrogen toxicity also has been implicated in limiting the survival of some aquatic plants and may contribute to marsh loss. DIN consists of ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3).

Figure 3.2.2 presents the year-round DIN data collected in Jamaica Bay from 2001 through 2005. The data show that except for rare occasions in the western and southern portions of the Bay (sampling locations J1 and J5), the DIN concentrations are well above the limiting concentration for algal growth. In some locations the median DIN concentration would have to be reduced by more than a factor of ten to approach nutrient limiting conditions. The daily average loads of nitrogen forms from the four WPCPs that discharge to the Bay are presented in Table 3.2.2

TABLE 3.2.2

WPCP	Nitrogen Form	Existing Conditions	1995-96 Conditions
Coney Island	Organic Nitrogen	2,400	3,400
	NH_4	8,200	10,800
	NO_{2+} NO_3	1,800	200
	DIN	10,100	11,100
	Total Nitrogen	12,500	14,500
26th Ward	Organic Nitrogen	1,500	4,600
	NH_4	2,500	10,400
	NO_{2+} NO_3	700	1,000
	DIN	3,200	11,400
	Total Nitrogen	4800	16,100
Rockaway	Organic Nitrogen	300	700
	NH_4	500	1,200
	NO_{2+} NO_3	1,000	400
	DIN	1,600	1,700
	Total Nitrogen	2,000	2,500
Jamaica	Organic Nitrogen	3,700	4,900
	NH_4	11,800	13,000
	NO_{2+} NO_3	1,300	300
	DIN	13,100	13,300
	Total Nitrogen	16,900	18,200
Total	Organic Nitrogen	8,100	13,700
	NH_4	23,200	35,500
	NO_{2+} NO_3	5,000	2,100
	DIN	28,200	37,700
	Total Nitrogen	36,400	51,500

3.2.3 Dissolved Oxygen

One of the more important constituents that is monitored within the bay is dissolved oxygen (DO). DO is important for aquatic life propagation and survival. Low dissolved oxygen levels can also lead to odor

problems resulting from the creation of hydrogen sulfide (H_2S) gas in the sediment.

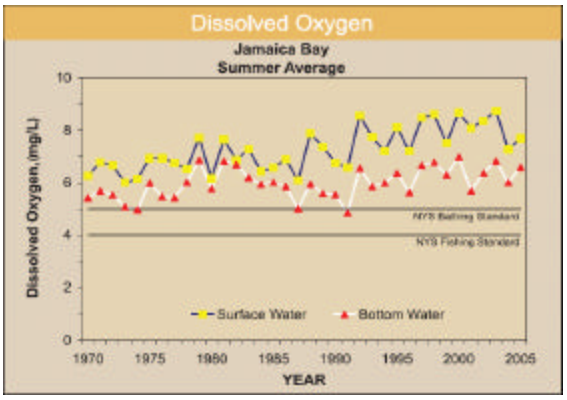


FIGURE 3.2.4 2005 Harbor Survey Program

During 2005, surface and bottom DO levels in Jamaica Bay were above NYSDEC standards. 2005 surface and bottom average summer DO levels were 7.70 mg/L and 6.59 mg/L, respectively. High variability was measured in DO levels in Jamaica Bay. Supersaturated DO levels are common due to algal blooms. These blooms result in large, sudden, and variable DO changes. During 2005 DO levels were lowest in the eastern portion of the bay at station J12 in Grassy Bay. DO levels increased moving westward from J12 to J1. This trend was particularly noticeable in the bottom waters.

Figure 3.2.3 presents probability distributions for surface and bottom DO concentrations measured by Harbor Survey at eight stations during the period of 2001 through 2005. Although average DO concentrations in Jamaica Bay meet the DO water quality standard, there are periods when DO levels decline below the standard. The areas nearest the Rockaway Inlet at station J1 attain the standard most often, while the Grassy Bay station J12 attains the standard least often.

Trends

Average DO levels were well above the 5.0 mg/L standard as early as 1970; Figure 3.2.4 from 2005 Harbor Survey Program. DO variability is high within and between years and the gap between surface and bottom waters has been increasing since the 1980s. High surface DO levels are often due to supersaturated conditions attributable to algae blooms and eutrophic waters.

A simple analysis of trends in summer time DO concentrations in Jamaica Bay was completed by HydroQual, Inc. for the DO data collected during June through September in the years 1995 through 2005 as part of the NYCDEP's Harbor Survey Program. The analysis was completed at the request of the NYCDEP and the Jamaica Bay Watershed Protection Plan Advisory Committee to determine if trends could be observed in the DO data over the

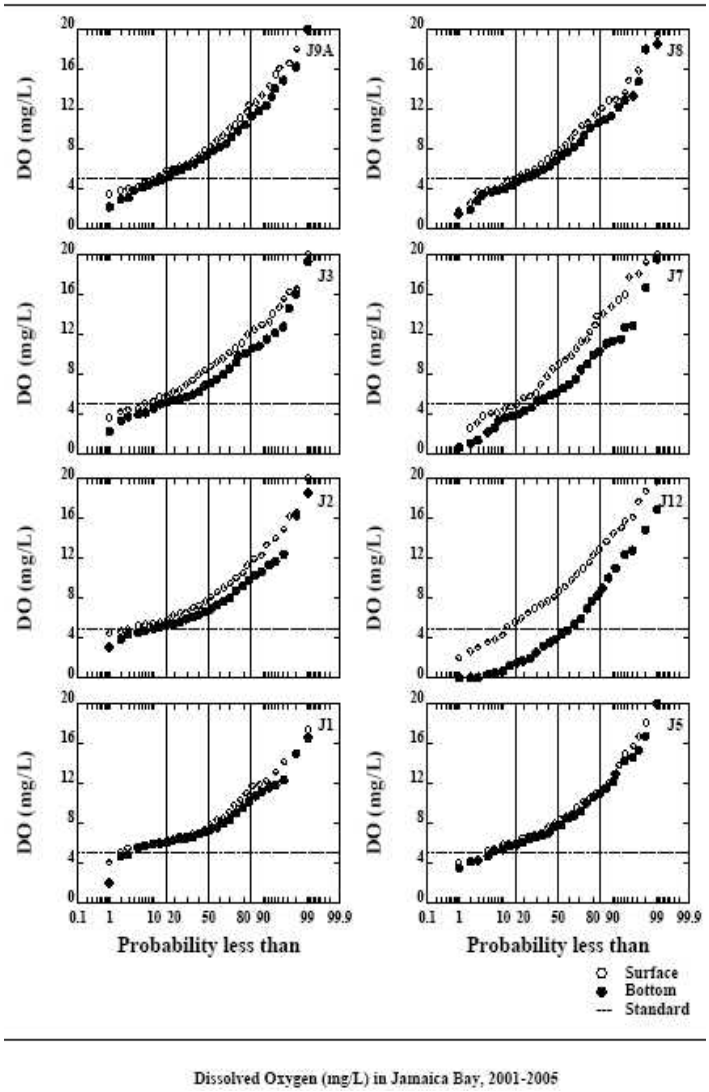


FIGURE 3.2.3 Dissolved Oxygen mg/L in Jamaica Bay 2001-2005

past ten years. Concerns were raised that water quality may have gotten worse over this time period. During the eleven year period examined, NYCDEP has reduced the nitrogen loading to Jamaica Bay from the four WPCPs from greater than 50,000 lb/day to less than 40,000 lb/day.

A visual inspection of the data does not show obvious trends due to the year-to-year variability. For a more rigorous analysis, a simple linear regression analysis was completed on the mean DO concentration for the summer data collected at each water quality monitoring station. In this analysis a line of best fit is computed for the data and a slope and correlation coefficient is calculated for the line. A positive slope corresponds to an increasing trend in DO concentrations. A higher slope corresponds to a greater change. The correlation coefficient describes how well the DO concentration is correlated to the year. A perfect straight line would have a correlation coefficient of 1.0. No correlation would have a correlation coefficient of 0.0. This analysis has limitations because the number of samples collected at each station varied from year to year from eight samples to seventeen samples. Also, the range and standard deviation of the data was not taken into account.

A few general statements can be made from this regression analysis. The first is that regression lines for stations near the mouth of Jamaica Bay (N9, N16, J1) (see Figure 3.2.1 for station locations) have very flat slopes and very low correlation coefficients. This indicates very little change in the DO concentrations over the period examined.

Secondly, only a few locations had negative slopes for the regression lines, which indicates decreasing DO levels. These stations include the surface measurements at stations J2 (Outside Mill Basin), J3 (Canarsie Pier), J11 (Sheepshead Bay), and J12 (Grassy Bay). Of these stations only stations J11 and J12 had high correlation coefficients, and station J12 has only five years of data. The declines in surface DO concentrations may correspond to reduced primary productivity by phytoplankton.

Finally, the remaining stations indicate a trend of increasing DO concentrations. Of these remaining stations, only regression lines from station J5 (Beach Channel), and the bottom regression lines from stations J7 (outside Bergen Basin), J8 (outside Bergen Basin), J12, and J9A (outside Fresh Creek) have correlation coefficients greater than 0.4. The slopes of these stations range from 0.087 mg DO/L per year to 0.155 mg DO/L per year. Over a ten year period the expected increase in DO concentrations would be 0.87 mg/L to 1.55 mg/L during the summer.

Overall, the Harbor Survey monitoring data indicate that there is a fair amount of year-to-year variability in DO concentrations. The general trends in the data indicate the DO concentrations have either stayed the same or improved slightly over the period of 1995-2005. The locations with declining DO concentrations had DO concentrations well above the DO standard. Figure 3.2.5 shows the existing quality of Jamaica Bay bottom waters. The figure is a graphical representation of model output based on 2005 loads and 1988 meteorological conditions.

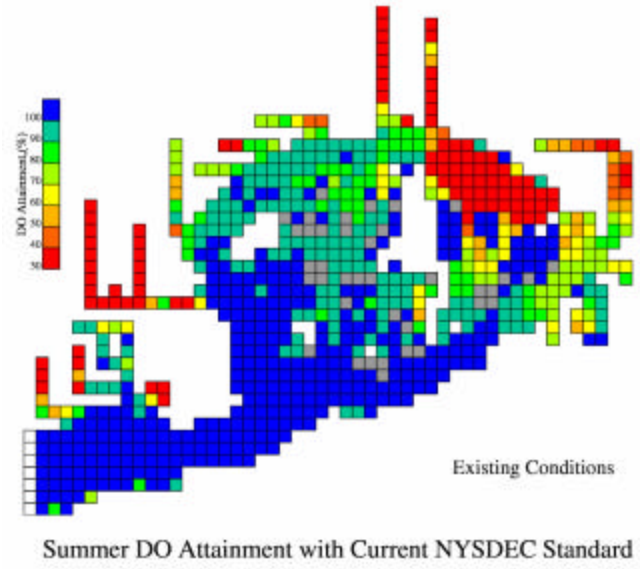


FIGURE 3.2.5. Dissolved Oxygen Bottom Waters Summertime

3.2.4 Pathogens

In 2005, sanitary water quality was superior for Jamaica Bay. Summer fecal coliform (FC) levels were well below the 200 cells/100mL SB standard for all stations. Under wet weather conditions, the Bay experiences localized degradation. At these times, spikes in FC may temporarily exceed the SB standard of 200 cells/10mL for the entire northern portion of the Bay (from Mill Basin to Bergen Basin). Mean FC levels in Jamaica Bay as a whole have been at or below the 200 cells/100mL standard for bathing over the past 20 years. FC levels peaked at 200 in 1990, and reached a low of 23 in 1998. During 2005 the FC summer geometric mean was 24 cells/100mL.

An additional NYSDEC standard for primary contact recreational waters is a maximum allowable enterococci concentration of a geometric mean of 35 cells/100 mL for a representative number of samples. This standard, although not promulgated, is now an enforceable standard in New York State since the USEPA established January 1, 2005 as the date upon which the criteria must be adopted for all coastal recreational waters. Enterococci concentrations for 2000-2005 are on average less than 10 cells 100 mL refer to Figure 3.2.6. 2005 Harbor Survey Program.

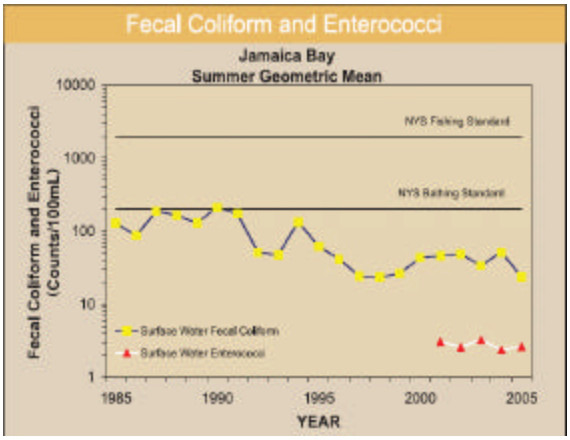


FIGURE 3.2.6 2005 Harbor Survey Program

3.2.5 Chlorophyll a

Chlorophyll a is another constituent that can be used to understand the water quality in the Bay. Algae produce chlorophyll a in order to capture light for photosynthesis. Chlorophyll a is a good indicator of the amount of algae in the water.

In most estuarine systems, nitrogen is potentially the limiting nutrient, which means that algae typically deplete nitrogen in the water before they deplete phosphorus. However, within Jamaica Bay, nitrogen and phosphorus are in excess and light for chlorophyll production becomes the limiting factor. As noted earlier, a concentration of less than 0.04 mg/L of DIN is thought to begin to limit algal growth.

High chlorophyll a concentrations in Jamaica Bay are indicative of eutrophic conditions. The slow turnover of water within the Bay allows for the development of large standing phytoplankton populations. Of the four geographic Harbor Survey regions, Jamaica Bay continues to display the widest range of individual chlorophyll a measurements. Chlorophyll a values range from a high of 171 µg/L at Station J8 (Spring Creek) to a low of 1.4 µg/L at Station J1 (Rockaway Inlet). All nine Stations have summer averages above 20 µg/L. On average, chlorophyll a concentrations for the Bay measured 39.6 µg/L. This is consistent with recent years, but well above levels that are indicative of enriched or eutrophic waters.

Trends – Chlorophyll a concentrations in Jamaica Bay have increased over the past 18 years. Yearly summer averages peaked in 1995 at 58.7 µg/L. Average concentrations from 1999 to 2004 ranged between 37 µg/L and 54 µg/L. These conditions have coincided with prolonged algae blooms in Jamaica Bay and reports of nuisance algae in the tributaries.

FIGURE 3.3.1 Jamaica Bay Tributaries; Source: HydroQual, Inc.

3.3 WATER QUALITY OF THE TRIBUTARIES

3.3.1 The Tributaries

Eight large and several smaller tributaries empty into Jamaica Bay - Sheepshead Bay, Paerdegat Basin, Fresh Creek, Hendrix Creek, Spring Creek, Shellbank Basin, Bergen Basin, and Thurston Basin (see Figure 3.3.1). In the context of Jamaica Bay, tributaries, canals, creeks and basins are generally former natural tributaries that are currently dead ended, usually with significantly modified configuration as compared to their pre-1700s condition. All the Jamaica Bay tributaries, basins creeks and canals have been highly altered over the years through channalization and tend to have little or no freshwater flow other than that conveyed by CSO and/or storm sewers. They generally have been dredged wider and deeper then their natural condition, and have CSO outfalls and sometimes storm sewer outfalls at their head end. Some tributaries and basins have natural fresh water tributaries still present. For example, streams within portions of Nassau County drain to Thurston Basin/Head of Bay. Also, Spring Creek drains to Old Mill Basin. What people generally refer to as Spring Creek is actually Old Mill Basin.

Paerdegat Basin, Fresh Creek, Hendrix St. Canal, Bergen Basin and Thurston Basin all receive CSO overflows from the Jamaica Bay watershed and Hendrix Street Canal also receives treated effluent from the 26th Ward WPCP. Spring Creek receives effluent from the Spring Creek Auxiliary WPCP, as CSO retention tank. These waterbodies also receive some amount of direct runoff of storm water and storm water discharges from storm drains, as well as direct rainfall. It is the combination of pollution inputs and lack of fresh water or tidal flushing that are the main factors that create poor water quality conditions within these tributaries.

Generally, existing water quality in Fresh Creek, Hendrix Street Canal and Spring Creek fail to attain standards at the headend for DO and bacteria. Water quality conditions in Bergen and Thurston Basins are discussed below.

3.3.2 Bergen and Thurston Basins

The receiving waters of Thurston and Bergen Basins were sampled during the summer of 1995 as part of the Jamaica Tributaries CSO Facility Planning Project (Hazen and Sawyer, 1996). Sampling occurred during wet weather and dry weather to provide information on existing water quality conditions and data for the development of a mathematical water quality model. Samples were collected from five stations along Thurston Basin, four stations along Bergen Basin, three stations along Shellbank Basin and one station in Hawtree Basin. Primary parameters were scheduled to be collected 100% of the time while secondary and tertiary parameters were collected 50% and 10% of the time, respectively. Field investigations included the following studies. On all sampling days, each station was sampled two to four times between 0800 and 1600 hours. Water samples were collected from two feet below the surface and two feet above the bottom.

As part of the Waterbody/Watershed Facility Plan for Bergen and Thurston Basins, a supplemental receiving water quality monitoring program was initiated in 2005 to update current water quality conditions and the water quality model. Three dry and two wet weather surveys were conducted. Receiving water samples were collected at approximately the same station locations sampled during the Jamaica Tributaries CSO Facility Planning Project except for Station TB5 in Head of Bay. The water quality parameters sampled in Bergen Basin replicated those collected during the original facility plan monitoring effort and included dissolved oxygen, total and fecal coliform, enterococci, chlorophyll a, biochemical oxygen demand, total suspended solids, salinity, temperature, and conductivity. Water quality samples collected in Thurston Basin consisted of temperature, salinity, and enterococci.

Dissolved Oxygen

In each basin, average DO concentrations are lowest at the head end under both dry and wet weather conditions due to accumulated organic matter from combined sewage and stormwater discharges as well as the confined nature of the basins. Average DO levels progressively increase toward the mouth as a result of tidal mixing with Jamaica Bay. Dissolved oxygen reaches supersaturation levels at several stations due to photosynthetic activity in surface waters.

In 1995, Thurston Basin attained dissolved oxygen standards only 30 to 50 percent of the time in the surface water samples and 10 to 30 percent of the time in the bottom waters. There were many factors contributing to the failure to meet standards, including dry weather sewage discharges at the head which have subsequently been abated, excessive algal growth, raw sewage discharges at the mouth in the Meadowmere/ Warnerville communities, storm and combined sewer discharges at the head, and a 1,200 foot long sediment mound at the head of the Basin. As discussed in Section 3.5 below, these conditions are being corrected.

For Bergen Basin, 1995 DO standards were not attained from 1 to 40 percent of the time for surface waters and 0 to 20 percent of the time for bottom waters. The standards were not being met for the following reasons: improper sanitary connections to the sewer system which have subsequently been abated, excessive algal growth, combined and storm

Hawtree Basin: Photograph . L. Kachalsky. O'Brien & Gere

sewer discharges, Jamaica WPCP effluent discharge, and the sediment mound at the head end of the basin. Sampling results from 2005 indicate DO has improved significantly in Bergen Basin with attainment of water quality criteria increasing to 60 to 80 percent in surface waters and 30 to 60 percent in bottom waters. Average DO concentrations in Bergen Basin in 2005 were at or above 4.0 mg/L in surface waters and slightly below 4.0 mg/L in bottom waters. These improvements in DO are attributable to the cessation of Jamaica WPCP effluent discharges to Bergen Basin and abatement of improper sanitary connections to storm sewers. Phytoplankton bloom activity is still evident at Stations BB-2 and BB-3.

The results of the 1995 and 2005 water quality monitoring programs indicate that the impact of CSOs, stormwater discharges and photosynthesis on DO concentrations is felt throughout both basins. Additionally in 1995, impacts to DO from improper sanitary connections to storm sewers and the discharge of Jamaica WPCP effluent to the head of Bergen Basin in combination with the sediment mound were more acute in the upper and middle portions of the basins while Jamaica Bay was affected to a lesser extent. In the mid 1990s, due to hydraulic issues with the Jamaica WPCP outfall to Grassy Bay, treated effluent was discharged to Bergen Basin. Also, the large diurnal fluctuations in DO levels found in the basins resulting from widespread photosynthetic activity and algal decomposition mask the impact of organic loadings from CSOs on DO concentrations under both dry and wet weather conditions.

Pathogens

In 1995, Thurston Basin showed a general decreasing trend toward the mouth for total and fecal coliforms on the surface and bottom. Stations TB1 and TB2 exceeded state standards for both total and fecal coliforms on the surface. Station TB5, in Head of Bay, met the monthly median total coliform standard of 2,400 cells/100ml, but had greater than 20% of samples greater than 5,000 cells/100ml at the surface and bottom. In 1995, the sources of coliform bacteria to Thurston Basin were dry weather discharges (50 identified homes which have subsequently been abated, and raw sewage discharge at the mouth in the Meadowmere/ Warnerville communities which is presently being abated by the NYCDEP (New York Times, 2007) and combined sewer and storm sewer discharges at the head end.

Bergen Basin displayed the most chronic coliform problem, failing to meet state standards for total and fecal coliforms for all surface water stations. However, total and fecal coliform concentrations were below NYSDEC water quality criteria in bottom waters. The concentration disparity between top and bottom is due to stratification, which is typical in confined basins of this nature.

The 1995 wet weather coliform levels in Bergen Basin were elevated due to CSO and storm water discharges. In 1995, Bergen Basin was receiving sanitary flow from improper sanitary connections to storm sewers and effluent from the Jamaica WPCP which resulted in dry weather coliform concentrations above NYSDEC water quality standards as well. Sampling results from 2005 revealed cessation of Jamaica WPCP effluent discharges to Bergen Basin and abatement of improper sanitary connections to storm sewers has led to an approximate 50 percent reduction in total coliform concentrations and a five fold decrease in fecal coliform concentrations and resulted in dry weather coliform concentrations below NYSDEC water quality standards.

3.4 POLLUTANT SOURCES

3.4.1 Background

As noted previously, there are numerous sources of pollutants that contribute to the water quality impairment of Jamaica Bay including CSOs, WPCPs, storm sewers, landfill leachate, ground water, atmospheric deposition and tidal exchanges (see Figure 3.3.1). With respect to landfill leachate, the major landfills around the Bay have been remediated (capped) and closed, so that the potential for ground water transport of contaminants in leachate to the Bay has been greatly reduced.

Each of these sources discharge different pollutants to the Bay. The contribution of each source and its affect on water quality is described below.

3.4.2 Wastewater Discharges

The NYCDEP owns and operates four major secondary treatment WPCPs that discharge into Jamaica Bay: Coney Island, 26th Ward, Jamaica and Rockaway WPCPs. These plants discharge the majority of the fresh water that enters the Bay, approximately 258 MGD. Each of the NYC plants accepts sanitary wastewater as well as CSO for treatment. The treated wastewater is then discharged to Jamaica Bay. Due to a finite hydraulic capacity, during wet-weather, CSO events do discharge to the Bay.

The Nassau County wastewater treatment plant, Cedarhurst, discharges approximately 0.9 MGD into Motts Creek at the eastern end of the Bay. Nassau County and NYC's plants combined contribute more than 90 percent of the nitrogen, phosphorus, and silica loading and more than 80 percent of the carbon/BOD loading to Jamaica Bay.

As a result of loadings, particularly nitrogen and phosphorus, from the above dischargers, Jamaica Bay is a highly enriched (eutrophic) system. The available nitrogen and phosphorus contribute to the growth of algae, which reduces water clarity. In addition, these algae eventually die and settle to the bottom sediment and the decomposition process requires a great deal of oxygen. As a result, oxygen in the overlying water becomes depleted and causes stress on the aquatic life subjected to the low dissolved oxygen levels. This can result in aquatic life mortality and/or the inability or impaired ability of aquatic organisms to propagate.

From Top Left to Bottom Right: Coney Island WPCP, Jamaica Bay WPCP, 26thWard WPCP, and Rockaway Parkway WPCP; Souce: Google TeleAtlas, 2005

The WPCPs that discharge into Jamaica Bay apply disinfection to the effluent discharge. As a consequence, WPCPs contribute on order one percent or less to the bacteria concentrations in Jamaica Bay. However, due to the chlorine used for disinfection, WPCPs are the primary source of total residual chlorine to the Bay.

The Contaminant Assessment and Reduction Project (CARP) grew out of the Hudson River Estuary (HEP) program. HEP's Comprehensive Conservation and Management Plan (CCMP) calls for 13 specific actions to reduce continuing inputs of toxic chemicals to the environment, including the reduction of municipal discharges of chemicals of concern. CARP is a cooperative effort of New York, New Jersey, USEPA, and USACE. One of its key objectives is to "Establish baseline levels of contaminants of concern in water, sediments and fish tissue" (www.carpweb.org).

Jamaica Bay WPCP Locations; Source: O'Brien & Gere

As part of its ongoing program, CARP sampled wastewater treatment plant effluents throughout the Hudson River estuary, including limited sampling of the four WPCPs in Jamaica Bay in 1999 and 2000 (Litton, 2003). The analytical results indicated the presence of a variety of CARP's chemicals of concern in the WPCP effluents. However, no specific pattern as to why certain chemicals or quantities were detected in the effluent of one WPCP and not another was attributed to the results or conclusions drawn during the study. Furthermore, the CARP study addressed effluent concentrations for individual plants and not toxic loadings. (Litton, 2003).

The New York City and Nassau County WPCPs, including one auxiliary WPCP also operated by NYCDEP, are described below:

Jamaica WPCP (NYC)

The Jamaica WPCP is permitted by the NYSDEC under State Pollutant Discharge Elimination System (SPDES) permit number NY-0026115. The facility is located at 150-20 134th Street in the Jamaica section of Queens, on a site approximately 26 acres in size adjacent to Bergen Basin. The Jamaica WPCP serves an area of approximately 26,000 acres in the southeast section of Queens.

The Jamaica WPCP has been providing full secondary treatment since 1978 including primary screening, raw sewage pumping, grit removal and primary settling, air activated sludge capable of operating in the step aeration mode, final settling, and chlorine disinfection. The Jamaica WPCP has a design dry weather flow capacity of 100 MGD, and is designed to receive a maximum flow of 200 MGD with 150 MGD receiving secondary treatment. Flows over 150 MGD receive primary treatment and disinfection. The daily average flow during 2006 was 88 MGD, with a dry weather flow average of 83 MGD.

Rockaway WPCP (NYC)

The Rockaway WPCP is permitted by the NYSDEC under SPDES permit number NY-0026221. The facility is located at 106-21 Beach Channel Drive in the Rockaway Park section of Queens, on a site approximately 12 acres in size adjacent to Jamaica Bay. The Rockaway WPCP serves an area of approximately 6,260 acres on the Rockaway Peninsula.

The Rockaway WPCP has been providing full secondary treatment since 1978 including primary screening, raw sewage pumping, grit removal and primary settling, air activated sludge capable of

operating in the step aeration mode, final settling, and chlorine disinfection. The Rockaway WPCP has a design dry weather flow capacity of 45 MGD, and is designed to receive a maximum flow of 90 MGD with 67.5 MGD receiving secondary treatment. Flows over 67.5 MGD receive primary treatment and disinfection. The daily average flow during 2006 was 23 MGD, with a dry weather flow average of 23 MGD.

26th Ward WPCP (NYC)

The 26th Ward WPCP is permitted by the NYSDEC under SPDES permit number NY-0026212. The facility is located at 122-66 Flatlands Avenue in the Spring Creek section of Brooklyn, on a site approximately 57 acres in size adjacent to the Hendrix Street Canal. The 26th Ward WPCP serves an area of approximately 5,910 acres in the eastern section of Brooklyn near Jamaica Bay including the communities of Ocean Hill, Brownsville, Broadway Junction, Highland Park, Cypress Hills.

The 26th Ward WPCP has been providing full secondary treatment since 1979 including primary screening, raw sewage pumping, grit removal and primary settling, air activated sludge capable of operating in the step aeration mode, final settling, and chlorine disinfection. The 26th Ward WPCP has a design dry weather flow capacity of 85 MGD, and is designed to receive a maximum flow of 170 MGD with 127.5 MGD receiving secondary treatment. Flows over 127.5 MGD receive primary treatment and disinfection. The daily average flow during 2006 was 58 MGD, with a dry weather flow average of 50 MGD.

Coney Island WPCP (NYC)

The Coney Island WPCP is permitted by the NYSDEC under SPDES permit number NY-0026182. The facility is located at 2591 Knapp Street in the Sheepshead Bay section of Brooklyn, on a site approximately 30 acres in size adjacent to Shell Bank Creek. The Coney Island WPCP serves an area of approximately 15,100 acres in southern/central Brooklyn.

The Coney Island WPCP has been providing full secondary treatment since 1994 including primary screening, raw sewage pumping, grit removal and primary settling, air activated sludge capable of operating in the step aeration mode, final settling, and chlorine disinfection. The Coney Island WPCP has a design dry weather flow capacity of 110 MGD, and is designed to receive a maximum flow of 220 MGD with 165 MGD receiving secondary treatment. Flows over 165 MGD receive primary treatment and disinfection. The daily average flow during 2006 was 89 MGD, with a dry weather flow average of 83 MGD.

CSO outfall at Bergen Basin. Photo: L. Kachalsky, O'Brien & Gere

Spring Creek AWPCP (NYC)

The Spring Creek Auxiliary WPCP is located at the head end of Old Mill Creek, at the confluence with Spring Creek. The facility is located in the 26th Ward WPCP drainage area; however, it also receives wet weather flow from the Jamaica drainage area. The Spring Creek A WPCP is designed to retain 10 to 12 million gallons. The design objectives for this facility are: to provide contact time for chlorine to disinfect; remove floating solids; hold overflow and remove heavy solids; and return stored volume to the 26th Ward WPCP.

Cedarhurst WPCP (Nassau County)

The Cedarhurst WPCP is permitted by the NYSDEC under SPDES permit number NY-0022462. The facility is located at on Peninsula Boulevard at Hanlon Drive, Cedarhurst. The Cedarhurst WPCP is designed to treat 1 MGD that is then discharged to Mott Creek, a tributary of Jamaica Bay. The Cedarhurst WPCP serves an area of approximately 440 acres in size. Separate stormwater sewers direct stormwater flow directly to the Bay.

Other WPCP Sources

In addition to the municipal WPCPs listed above, there are a number of industrial wastewater dischargers within the watershed for which SPDES permits have been issued. These industrial dischargers include the following:

- JFK Airport, Queens, discharges to Bergen Basin
- Lefferts Oil Terminal, Queens, discharges to Bergen Basin
- Keyspan Generation (Far Rockaway Power Station), Queens, discharges to Motts Basin
- Carbo Industries, Nassau County, discharges to Jamaica Bay

Storm sewer outfall in Fresh Creek
Photograph: L. Kachalsky. O'Brien & Gere

- Carbo-Concord Oil, Nassau County, discharges to Jamaica Bay
- ExxonMobil, Inwood, Nassau County, discharges to Head of Bay

3.4.3 Combined Sewer Overflows

Combined sewers are sewers that convey both sanitary and stormwater flow. During dry weather, all of the sanitary flow is delivered to a WPCP for treatment. During wet weather, the combined

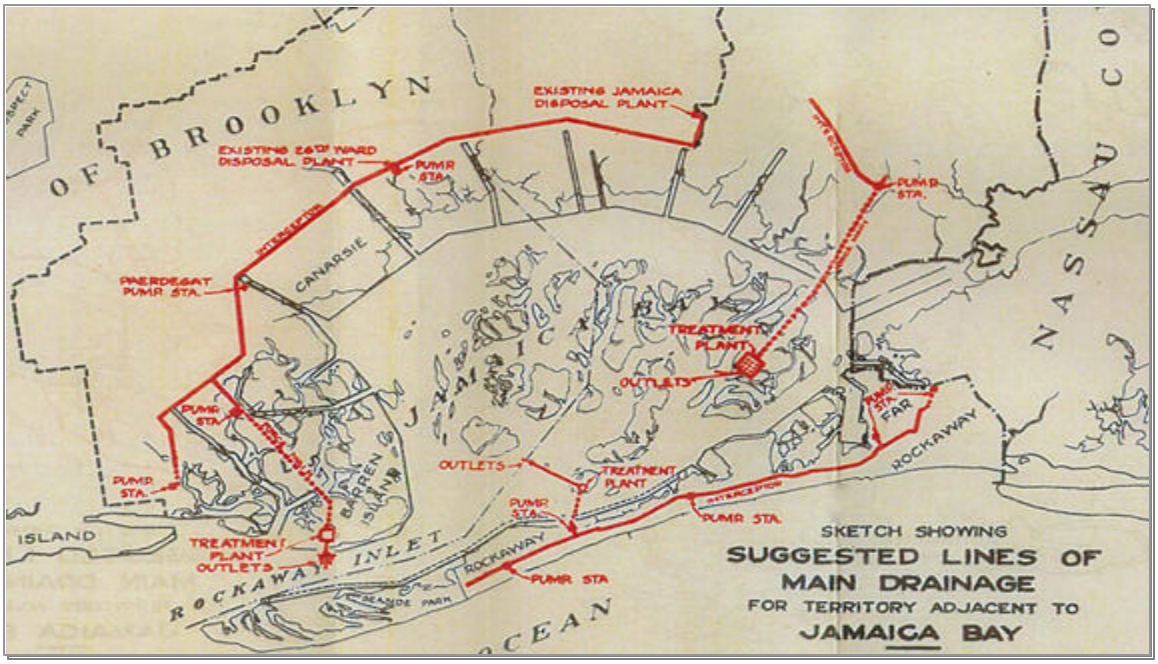


FIGURE 3.4.1 Bay Drainage Plan; Source: Secty. of the Army, 1965

volume of sanitary and stormwater flow can surpass a WPCP's ability to accept the flow. In such cases, regulators in the sewer system act as relief valves that convey some of the untreated sanitary and stormwater mixture through an outfall into a tributary or directly into the Bay.

There are six combined sewer overflow pipes that discharge to Jamaica Bay tributaries. Overflows occur intermittently during wet weather and contain diluted sanitary flow; therefore, CSOs contribute only a small portion of the carbon, nitrogen, phosphorus and silica loading to Jamaica Bay. Nutrient loadings from CSOs are less than five percent of the total nutrient load to the Bay. Carbon loadings from CSOs are approximately 15 percent of the carbon loading to the Bay. On the other hand, since the CSO volume is not disinfected, CSOs are the major contributor (85-95 percent) of bacteria to the Bay. In addition, since the CSO flow does not pass through a WPCP, solids that would have been removed by treatment settle to the bottom of the tributaries near the CSO outfall creating localized sediment mounds. While CSOs have a small impact on the Bay as a whole, they have major impacts on the water quality of the tributaries to which they discharge.

3.4.4 Storm Sewers

Storm sewers collect the rainfall that falls on neighborhoods in separately sewered areas and direct the flow into the Bay and the tributaries that surround the Bay. The runoff contains the pollutants found in rainwater and any pollutants picked up during its travel to the sewer. Storm sewers contribute less than one percent of the nutrient loadings and less than three percent of the carbon loading to Jamaica Bay. The contribution of bacteria to the Bay from storm sewers is approximately five to fifteen percent of the total loading to Jamaica Bay. Storm sewers are minor contributors to the pollutant loading to the Bay as a whole, but can have a major impact on the tributaries to which they discharge. Limited data make it difficult to assess the relative contribution of storm sewers to the toxics loads.

3.4.5 Landfills

Three landfills border Jamaica Bay: Pennsylvania Avenue, Fountain Avenue and Edgemere. All three are closed and have either been capped or are in the process of being capped. The landfills are now minor contributors of conventional pollutants to the Bay.

Based on limited data, it is estimated that landfills contribute less than one percent of the carbon, nitrogen, and phosphorus loadings to the Bay. Litton (2003) does not report loading estimates of toxics for landfills in Jamaica Bay.

3.4.6 Ground Water

Available estimates for ground water discharge to Jamaica Bay range from 10 MGD (Gibbs and Hill, 1984) to approximately 30 MGD (Misut and Voss, 2004). Misut and Voss also estimate that pre-development ground water flow to the Bay was approximately 47 MGD. Pollutant concentrations associated with this ground water are largely unknown. Based on the flow volume and contaminant concentrations, ground water could have an important impact on water quality in the Bay.

3.4.7 Atmospheric Deposition

Atmospheric deposition includes dry-fall of particles and aerosols, and wet-fall. Any deposition that occurs on land is included in the CSO and storm sewer sources. The remainder is deposition directly onto the Bay. Since the Bay's surface area is relatively small (20 sq mi), atmospheric deposition is a minor contributor of conventional pollutants to the Bay. Available estimates (see below) indicate that atmospheric deposition contributes a very small amount of phosphorus, and less than two percent of the carbon and nitrogen loading to the Bay.

3.4.8 Tidal Exchange and Rockaway Inlet

Water is tidally exchanged between the Lower Bay of New York Harbor and Jamaica Bay through the Rockaway Inlet. In general, the water quality in the Rockaway Inlet is the best in Jamaica Bay. However, there may be times when pollutants from outside of the Bay can be transported into the Bay through the Rockaway Inlet. The exchange of pollutants in this manner is difficult to quantify since much of what is imported into the Bay during flood tide is exported during ebb tide. Since the volume of the Bay can increase by as much as a third between ebb tide and flood tide, it is important to be aware of the potential impacts of Lower Bay water on Jamaica Bay.

3.5 RELATIVE CONTRIBUTION OF POLLUTANT SOURCES

Table 3.5.1 provides a summary of the estimated loads from various sources in Jamaica Bay. The WPCP estimates are based on data collected during 2002 and 2003. CSO and stormwater estimates are based on modeled flows from RAINMAN (a runoff model developed for NYC) and sanitary and stormwater concentrations collected for Jamaica Bay. The rainfall is based on 1988 conditions that have been established as a representative benchmark for the area. Atmospheric deposition is based on 1988 rainfall and deposition data collected as part of the Jamaica Bay Eutrophication Study during 1995-96. The landfill estimates, which have limited accuracy, are based on estimated leachate flows and concentrations, and are the least reliable of the estimates of contributions to the Bay. Ground water is not included because reliable estimates are not available. Dry weather overflows (DWOs) are excluded because no DWOs have been identified in the Bay. The Rockaway Inlet is also not included, as it tends to be a net exporter of pollutants.

The loadings presented in Table 3.5.1 clearly show that the WPCPs are the major contributors to the phosphorus, nitrogen, silica, and carbon loadings to Jamaica Bay. CSOs are just as clearly the major contributors to the pathogen loadings to the Bay. The pathogen loadings assume that there are currently no dry weather overflows in the Bay.

Additional modeling tools and technologies are being used to illustrate potential loading contributions in the Bay and its tributaries.

TABLE 3.5.1 Load Summary – Sources of Inputs; Source: HydroQual, Inc.

System Name	WPCP	CSO	Stormwater	Atmospheric Deposition	Landfills
Total Phosphorus (lb/day)	6,100	140	20	10	No Est.
Total Nitrogen (lbs/day)	36,600	1,040	140	630	170
Total Silica (lb/day)	17,900	700	100	No Est.	No Est.
Total Organic Carbon (lb/day)	32,800	5,600	1,050	630	320
BOD5 (lb/day)	22,500	4,900	640	No Est.	No Est.
Enterococci (org./yr)	8.37E+14	5.72E+17	1.08E+17	No Est.	No Est.
Fecal Coliform (org./yr)	1.82E+14	1.85E+18	2.58E+17	No Est.	No Est.
Total Coliform (org./yr)	7.27E+14	9.76E+18	6.93E+17	No Est.	No Est.

InfoWorks software, a GIS-compatible model system, is being used to model the sewer system including baseline and future sanitary flows. The Jamaica Bay Eutrophication Model (JEM) was developed to assess numerous water quality remediation alternatives such as relocation of existing outfalls from WPCPs, various levels of nitrogen removal at WPCPS, bathymetric recontouring of Jamaica Bay, as well as other alternatives including combinations of outfall relocation, treatment, and recontouring. JEM is an appropriate tool for assessing water quality in the Bay as a whole. The North Channel Eutrophication Model (NCEM) is a full eutrophication model with a sediment nutrient flux submodel developed specifically for Jamaica Bay tributaries.

InfoWorks software, a GIS-compatible model system, is being used to model the sewer system including baseline and future sanitary flows. The Jamaica Bay Eutrophication Model (JEM) was developed to assess numerous water quality remediation alternatives such as relocation of existing outfalls from WPCPs, various levels of nitrogen removal at WPCPS, bathymetric recontouring of Jamaica Bay, as well as other alternatives including combinations of outfall relocation, treatment, and recontouring. JEM is an appropriate tool for assessing water quality in the Bay as a whole. The North Channel Eutrophication Model (NCEM) is a full eutrophication model with a sediment nutrient flux submodel developed specifically for Jamaica Bay tributaries.

3.6 CURRENT PROGRAMS TO ADDRESS WATER QUALITY CONCERNS IN JAMAICA BAY AND ITS TRIBUTARIES

NYCDEP has completed facility plans and is implementing multi-phased programs to address the impacts of WPCPs and CSOs discharges on the open water and tributary waterbodies of Jamaica Bay. The programs focus on particular water quality parameters such as dissolved oxygen, coliform bacteria, floatables, settleable solids, oil and grease, and nuisance conditions. The NYCDEP has implemented various projects within the Jamaica Bay Watershed to improve the water quality both in the tributaries and open waters of Jamaica Bay. These projects include WPCP upgrades, CSO reduction facilities and floatables control facilities. Landfill closures and restoration projects have also mitigated a source of pollution to the Bay. These efforts are discussed in Chapter 4, *Ecology*.

Many of these projects are being undertaken pursuant to the Nitrogen Control Consent Order/ consent judgment or the CSO Consent Order as described in the following two sections.

3.6.1 Nitrogen Control Order on Consent/Consent Judgment

The NYSDEC and the Department entered into a Nitrogen Control Order on Consent (Index # CO2-20020131-7) on April 22, 2002 that updated SPDES permits of the four Jamaica Bay WPCPs in order to reduce the total nitrogen load discharged into Jamaica Bay. One of the goals of the Nitrogen Order on Consent was to control the occurrence of eutrophic conditions in Jamaica Bay by reducing the total nitrogen load discharged to the open waters of the bay, thereby improving attainment of dissolved oxygen water quality standards.

Presently, the SPDES permits of the four Jamaica Bay WPCPs establish two types of limits on permissible aggregate nitrogen discharges. These include: (a) the "Maximum Monthly Average Limit," defined as the average of the individual samples for that month; and (b) the "12-month Rolling Average Limit," defined as the average daily total nitrogen load for the current month, averaged with the eleven previous months average level. The aggregate Maximum Monthly Average Limit for the Jamaica Bay WPCPs under the current SPDES permit is 54,600 pounds per day, and the aggregate 12-month Rolling Average Limit for the Jamaica

Bay WPCPs is 45,300 pounds per day. The rolling average has recently been increased to 49,500 pounds TN during construction of Contract 12 Upgrades at 26th Ward WPCP per the nitrogen order on consent. After completion of construction activities at 26th Ward WPCP, the rolling average goes back to 45,300 pounds per day.

The Consent Order obligated the Department to undertake and submit to the NYSDEC, for review and approval, a Comprehensive Jamaica Bay Report that is to include recommendations and an implementation schedule for improving water quality in Jamaica Bay either through treatment or non-treatment.

The Order on Consent for Nitrogen was superseded on January 10, 2006 by a Consent Judgment (Index # 04-402174). The Consent

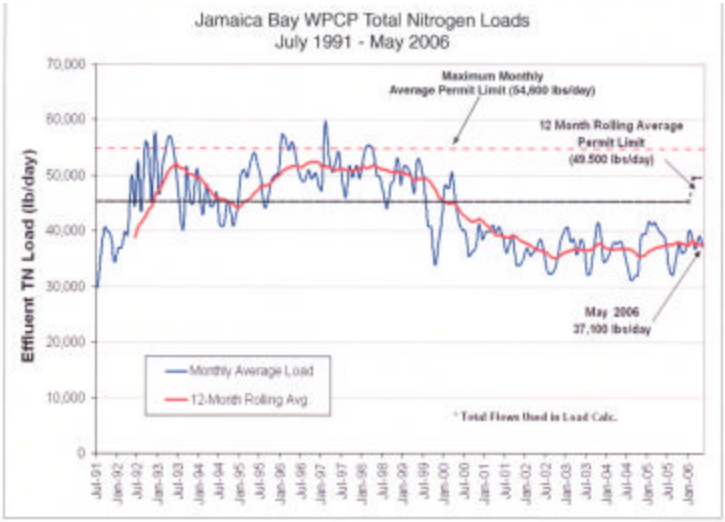


FIGURE 3.6.1 Jamaica Bay WPCP Total Nitrogen Loads, Source: NYCDEP

Judgment required that the Comprehensive Jamaica Bay Report be submitted to the NYSDEC on October 31, 2006. The Consent Judgment also requires that that construction of Phase I Plan Improvements to the 26th Ward WPCP be completed by June 30, 2008 and that said improvements to the 26th Ward WPCP result in a Combined Nitrogen Effluent Limit for the Jamaica Bay WPCPs of 45,300 pounds per day.

NYCDEP has completed a Comprehensive Jamaica Bay Water Quality Plan, and the plan was submitted to the NYSDEC on October 31, 2006.

3.6.2.CSO Consent Order

NYCDEP entered into an Administrative Consent Order with NYSDEC on June 26, 1992 to govern NYCDEP's obligations for its CSO program. It required NYCDEP to implement CSO abatement projects in nine facility planning areas divided into two tracks: those areas where dissolved oxygen and coliform standards were being contravened (Track One), and those areas for which floatables control was necessary (Track Two). The 1992 Order was modified on September 19, 1996 to add catch basin cleaning, construction, and repair programs.

NYCDEP and NYSDEC negotiated a new Consent Order that was signed January 15, 2005 that supersedes the 1992 Order and its 1996 Modifications with the intent to bring all NYCDEP CSO-related matters into compliance with the provisions of the federal Clean Water Act and New York State Environmental Conservation Law. The new Order, noticed by NYSDEC in September 2004, contains requirements to evaluate and implement CSO abatement strategies on an enforceable timetable for 18 waterbodies and, ultimately, for City wide long-term CSO control in accordance with USEPA CSO Control Policy. NYCDEP and NYSDEC also entered into a separate Memorandum of Understanding (MOU) to facilitate water quality standards reviews in accordance with the CSO Control Policy.

3.6.3.Comprehensive Jamaica Bay Water Quality Plan

As discussed above, pursuant to the Nitrogen Control Consent Judgment, NYCDEP submitted a

Comprehensive Jamaica Bay Water Quality Plan to the NYSDEC on October 31, 2006. As part of this Plan, both treatment and non-treatment alternatives were being investigated to reduce the total nitrogen load and improve water quality within the open waters of Jamaica Bay.

Treatment alternatives for nitrogen reduction that were evaluated in the Comprehensive Plan included various levels of treatment for nitrogen removal at the four WPCPs that discharge to the Bay:

- Low Level (Level 1): 12 mg/L – 16 mg/L
- Mid Level (Level 2): 9 mg/L – 13 mg/L
- High Level (Level 3): 5 mg/L – 9 mg/L
- Limit of Technology (LOT): 4.1 mg/L – 4.4 mg/L.

Conceptual designs were developed for each of the treatment options for each of the four WPCPs.

Concept level designs and associated cost estimates were developed for conveying treated effluent from the Jamaica, 26th Ward, Coney Island and Rockaway WPCPs to either the Atlantic Ocean or Rockaway Inlet via outfall tunnels. The alternatives selected for evaluation consisted of conveying:

- treated effluent via tunnels to Rockaway Inlet;
- treated effluent to the Atlantic Ocean
- Jamaica WPCP effluent only;
- Jamaica and 26th Ward WPCP effluents;
- Jamaica, 26th Ward and Rockaway WPCP effluents;
- Jamaica, 26th Ward and Coney Island WPCP effluents; and
- Jamaica, 26th Ward, Coney Island and Rockaway WPCP effluents.

Additionally, non-treatment alternatives were evaluated, including the recontouring of Grassy Bay, recontouring of Grassy Bay and North Channel, and the aeration of Grassy Bay.

The Plan is currently under review by NYSDEC.

3.6.4 Other Water Pollution Control Plants Projects and Program

26th Ward WPCP

IAt present, there are two phases of construction underway at the 26th Ward WPCP which include the following elements:

- An upgrade of the low-level pumps with some work on the high-level main sewage pumps.
- Miscellaneous Improvements, under which the plant is being further upgraded for biological nutrient removal via separate centrate treatment.

Contracts in the planning/design phase for the 26th Ward WPCP include:

- installation of new emergency generators at the facility,
- rehabilitation of the four existing preliminary settling tanks and the construction of two new preliminary settling tanks and
- construction of a new main sewage pump station and chlorine contact tank to allow the WPCP to handle an additional 50 MGD of wet weather flow.

Photograph by Don Riepe, Jamaica Bay Wildlife Refuge

Total Residual Chlorine (TRC) Program

In accordance with SPDES permit requirements, the NYCDEP is implementing a Citywide Total Residual Chlorine (TRC) Management Program, to develop strategies to bring all fourteen WPCPs into compliance with more stringent TRC effluent limits, so that discharges of treated wastewater will not

cause TRC receiving water standards to be exceeded.

Currently, all WPCP effluents are chlorinated, to meet disinfection requirements based upon the pathogen indicators total and fecal coliform. The existing permitted TRC limit for each WPCP is 2 mg/L. The NYSDEC has developed lower TRC effluent limits for each WPCP, based upon receiving water dilution modeling, and acute (fish survival) and chronic (fish propagation and survival) receiving water standards for TRC of 13 ug/l and 7.5 ug/L, respectively.

The first four compliance actions identified in the WPCP SPDES TRC Schedules of Compliance have been met including:

- preparation of a TRC scope of work,
- evaluation and verification of the proposed TRC limits,
- evaluation of treatment and non-treatment alternatives, including wastewater characterization and bench scale testing, and conclusion of the TRC limit evaluation.

In accordance with the fifth SPDES compliance action, facility plans to achieve the new, lower TRC limits at the Coney Island, Jamaica and Rockaway WPCPs have been drafted and are undergoing review. Based upon existing disinfection facilities and procedures, historical data and the bench scale results, optimization of the existing chlorination systems is being recommended to meet proposed effluent TRC limits of 0.53 mg/L and 0.59 mg/L at the Jamaica and Rockaway WPCPs, respectively. Bench scale testing, historical data and evaluation of the existing disinfection system indicates that dechlorination will be required to achieve the proposed new effluent limit of 0.64 mg/L at the Coney Island WPCP.

NYCDEP has selected the 26th Ward WPCP as the location of a full-scale disinfection demonstration facility, where chlorination/ dechlorination and UV-disinfection will be operated side-by-side in adjacent chlorine contact tanks for a period of one year. The effectiveness of the two technologies on the low ammonia effluent that will be produced by the BNR WPCPs will be evaluated, along with operability and maintenance requirements under identical conditions. The SPDES schedule of compliance requires operation of the disinfection demonstration facility to begin by April 2009.

3.6.5 Combined Sewer Overflow Retention Projects and Programs

Long-Term CSO Control Planning

NYCDEP is undertaking a Long Term Control Plan (LTCP) for controlling CSOs. The Plan will integrate all CSO Facility Planning Projects and the Comprehensive City-wide Floatables Abatement Plan, will incorporate on-going Use and Standards Attainment (USA) Project work in the remaining waterbodies, and will develop Watershed/Waterbody Facility Plan reports and the LTCP for each waterbody area. A number of the projects applicable to Jamaica Bay are described below.

Jamaica Bay CSO
The CSO Order on Consent requires a number of facility projects and upgrades for Jamaica Bay. Below are descriptions of the projects and implementation schedules.

Spring Creek AWPCP Upgrade
This entails various upgrades to the CSO retention the CSO facility. Construction Completion Due April, 2007.

A. 26th Ward Drainage Area Sewer Cleaning and Evaluation and other projects

There are particular sewers in the 26th Ward WPCP drainage area that field work has shown have significant quantities of grit/debris. Hydraulic modeling work has indicated that cleaning of those sewers could reduce the amount of CSO discharge to Fresh Creek.

The subsequent result would be an increase in CSO discharge to the Hendrix Street Canal necessitating a wet weather capacity increase of 50 MGD to the

26th Ward WPCP. Being that that sewer cleaning will take place prior to the upgrade of the 26th Ward WPCP, an interim dredging program consisting of dredging the head end of Hendrix Street Canal to a depth of 2 feet below mean low water will be undertaken to abate odors at Hendrix St. Canal.

The schedule for this element as per the CSO Order on Consent is:

1. Initiate Final Design: January, 2007 Phase I is underway.
2. Final Design Completion Including CPM Analysis: June, 2007
3. Notice to Proceed with Construction: June, 2008
4. Construction Complete: June, 2010

B. 26th Ward Wet Weather Expansion
The schedule for this element as per the CSO Order on Consent is:

1. Initiate Final Design: June 2006
2. Final Design Completion Including CPM Analysis: June 2010
3. Submit Form 2A SPDES Application: June 2009
4. Notice to Proceed with Construction: June 2011
5. Construction Complete: December 2015

C. Drainage Basin Specific Long Term Control Plans

Being reported on under the Citywide Long Term Control Plan for CSO Project

The schedule for these plans as per the CSO Order on Consent is:

1. Submit Approvable Drainage Basin Specific LTCP for Jamaica Bay: August 2012
2. Submit Approvable Drainage Basin Specific LTCP for Spring Creek: August 2012
3. Submit Approvable Drainage Basin Specific LTCP for Fresh Creek: August 2012
4. Submit Approvable Drainage Basin Specific LTCP for Hendrix Creek: August 2012

D. Paerdegat Basin CSO Retention Facility

The Paerdegat Basin CSO Retention Facility is located in southeastern Brooklyn, at the intersection of Flatlands and Ralph Avenues. The facility will receive combined sewer overflows from a drainage area of approximately 6,000 acres within the Coney Island WPCP service area. The facility is currently under construction. Upon its completion, the facility will consist of a four bay underground storage tank and operations buildings. The stored CSO (up to 20 million gallons in-tank plus 30 million gallons in-line) will be pumped back to the Coney Island WPCP for treatment after each rain event.

Jamaica Tributaries CSO

The Jamaica Tributaries project area includes the Jamaica WPCP sewershed area and the tributaries that receive wet weather discharges from the drainage area. These tributaries include Bergen, Thurston (in the southeast portion), Shellbank, and Hawtree Basins, which are located in the northeast portion of Jamaica Bay. There are several projects that are being advanced. These include:

- Meadowmere & Warnerville DWO Abatement – This project includes construction of a new pumping station, force main and sanitary sewer collection system in southeast Queens, to convey flows from the communities of Meadowmere and Warnerville to the Jamaica drainage area collection system for treatment at the Jamaica WPCP. This project will eliminate the dry weather discharges that currently occur within these two communities that are not presently connected to City's collection system.
- Expansion of Wet Weather Capacity of Jamaica WPCP – An additional 50 MGD of wet weather flow will be treated at the Jamaica WPCP to reduce CSO discharges to Bergen Basin.
- Destratification Facility – The system is designed to reduce temperature stratification during the summer season. This stratification leads to poor water quality conditions in the

basin resulting in the emission of nuisance odors. This project currently has an operating pilot facility at Shellbank Basin that has produced results over the last six summer seasons.

- Laurelton and Springfield Blvd. Drainage Plan – A drainage plan for 7,000 acres in southeast Queens is being developed to address flooding and to construct high-level storm sewers in a 1,450 acre CSO drainage area tributary to Thurston Basin. The drainage plan will identify the necessary capital sewer projects required to alleviate flooding and convert this CSO drainage area to a high level storm sewer system.
- Regulator Automation – Automation of key regulators was recommended in response to the 1988 SPDES permit requirements that called for telemetry in collection system regulators to detect dry weather overflows. The Citywide Collection Facilities Supervisory Control and Data Acquisition (SCADA) System Project will automate key collection system regulators via the installation of electro-hydraulic actuators capable of controlling flows to the sewer interceptor.

City-Wide Comprehensive CSO Floatables Plan

The NYCDEP developed a floatables abatement plan for the CSO areas of New York City in June 1997. An update of the Plan was subsequently drafted in July 2005 to reflect the completion of some proposed action elements, as well as changes to SPDES permits and modifications of regional Waterbody/Watershed Facility Plans and CSO Facility Plans. The objectives of this plan are to provide substantial reductions in floatables discharges from CSOs throughout the City.

Structural elements of the City-Wide Comprehensive CSO Floatables Plan consist of the following elements:

- Inspection of catch basins city-wide for missing hoods and the replacement of missing hoods to prevent floatables from entering the sewer system, as well as retrofitting, repairing, or reconstruction of catch basins requiring extensive repairs or reconstruction to accommodate a hood.
- Capture floatables at wet-weather CSO storage/treatment facilities
- Capture floatables at end-of-pipe and in-water facilities, including the Interim Floatables Containment Program (IFCP).

3.7 REFERENCES

Gibbs and Hill, Inc. 1984. Hydrogeologic Study Fountain Avenue, Pennsylvania Avenue and Edgemere Landfills, Part 3 Site Report. New York City Department of Sanitation, New York, NY.

Adams, D., and S. Benyi. 2003. Final Report: Sediment Quality of the NY/NJ Harbor System: A 5-Year Revisit 1993/4 – 1998. An Investigation under the Regional Monitoring and Assessment Program (REMAP) (EPA/902-R03-002). USEPA-Region 2, Division of Environmental Science and Assessment, Edison, NJ.

Adams, D.A., J.S. O'Connor and S.B. Weisberg. 1996. Draft Final Report, Sediment Quality of the NY/NJ Harbor System, An Investigation under the Regional Environmental Monitoring and Assessment Program (R-EMAP). USEPA – Region 2, Division of Environmental Science and Assessment, Edison, NJ.

Barry A. Vittor & Associates, Inc. and CAPE Environmental, Inc. 2002. Sediment Sampling and Analysis Reports, Norton Basin, Little Bay, Grass Hassock Channel, and The Raunt. Submitted to The Port Authority if New York and New Jersey and the New York State Department of Environmental Conservation. Kingston, NY.

Bopp, R.F., *et al.* 1993. Sediment-derived chronologies of persistent contaminants in Jamaica Bay, New York. Estuaries. Vol. 16 (3B): 608-616.

Feuerstein, D.R., and W.O. Maddaus. 1976. Wastewater Management Program, Jamaica Bay, New York, Volume I, Summary Report (EPA-600/2-76-222A). United States Environmental Protection Agency, Washington, D.C.

Franz, D.R., and W.H. Harris. 1985. Benthos Study Jamaica Bay Wildlife Refuge, Gateway National Recreation Area, Brooklyn, New York, Final Report. Contract CX1600-1-0031. U.S. Department of Interior, Washington, D.C.

Gibbs and Hill, Inc. 1984. Hydrogeologic Study Fountain Avenue, Pennsylvania Avenue and Edgemere Landfills, Part 3 Site Report. New York City Department of Sanitation, New York, NY.

Hazen and Sawyer. 2003. Jamaica Tributaries CSO Facility Planning Project. New York, NY.

HydroQual, Inc. 1991. New York City Phase II City-wide Combined Sewer Overflow Study of Jamaica Bay and 26th Ward Tributaries, Task 4.3.1 Computer Modeling Open Water, Jamaica Bay, and Task 4.4 Dissolved Oxygen Modeling, Jamaica Bay. Mahwah, NJ.

Hyland, J., *et al.* 2000. Summary Report: Results if initial planning meeting of the United Nations Educational, Scientific and Cultural Organization (UNESCO) Benthic Indicator Group, p.70. New York, NY.

Jamaica Bay Environmental Study Group (JBESG). 1971. Jamaica Bay and Kennedy Airport – A Multidisciplinary Environmental Study. Volume II. National Academy of Sciences, National Academy of Engineering. Washington, D.C.

Litton, S. 2003. Contaminant Assessment and Reduction Project – Water. Bureau of Water Assessment and Management, Division of Water, New York State Department of Environmental Conservation, Albany, NY.

Misut, P.E. and Voss, C.I. 2004. Simulation of subsea discharge to Jamaica Bay in New York City with a three-dimensional, variable-density, finite-element model. Proceedings of the International Conference on Finite Element Models, MODFLOW, and More: Solving Groundwater Problems, 13-16 September 2004, Karlovy Vary, Czech Republic

O'Brien & Gere Engineers, Inc. 2002. Jamaica Bay Eutrophication Study. Final Report Vols. 1 and 2. Hawthorne, NY.

Ramondetta, P.J. and W.H. Harris. 1978. Heavy Metals Distributions in Jamaica Bay Sediments. Environmental Geology , Vol. 2(3): 145-149.

Regional Planning Association. 2003. Needs and Opportunities for Environmental Restoration in the Hudson-Raritan Estuary – A Report Prepared for the US Army Corps of Engineers – Based on Recommendations of the Harbor Estuary Program Habitat Working Group and Estuary Stakeholders. USACE, New York, NY.

Sieger, T .L., and J.T. Tanacredi. 1983. Contribution of polynuclear aromatic hydrocarbons to Jamaica Bay ecosystems attributable to municipal wastewater effluent. Gateway Institute for Natural Resource Sciences. National Park Service. New York, NY.

Staubitz, W.W., and S.W. Wolcott. 1985. Hydraulic Sediment Characteristics at the North Channel Bridge, Jamaica Bay, New York. U.S. Geological Survey, Water-Resources Investigations Report 85-4085. Washington, DC.

US Department of Agriculture (USDA). 2005. New York City Reconnaissance Soil Survey. Staten Island, New York.

US Environmental Protection Agency, Region 2. 2003. Sediment quality of the NY/NJ harbor system: a 5-year revisit. Report EPA/902-R-03-002. New York, NY.

Zeppie, C.R. 1977. Vertical profiles and sedimentation rates of Cd, Cr, CU, Ni, and Pb in Jamaica Bay, New York. Masters Thesis. Marine Environmental Science Program, State University of New York at Stony Brook, NY.

US Army Corps of Engineers (USACE), New York District. 2005. Jamaica Bay Marsh Islands, Jamaica Bay, New York. DRAFT Integrated Ecosystem Restoration Report and Environmental Assessment.