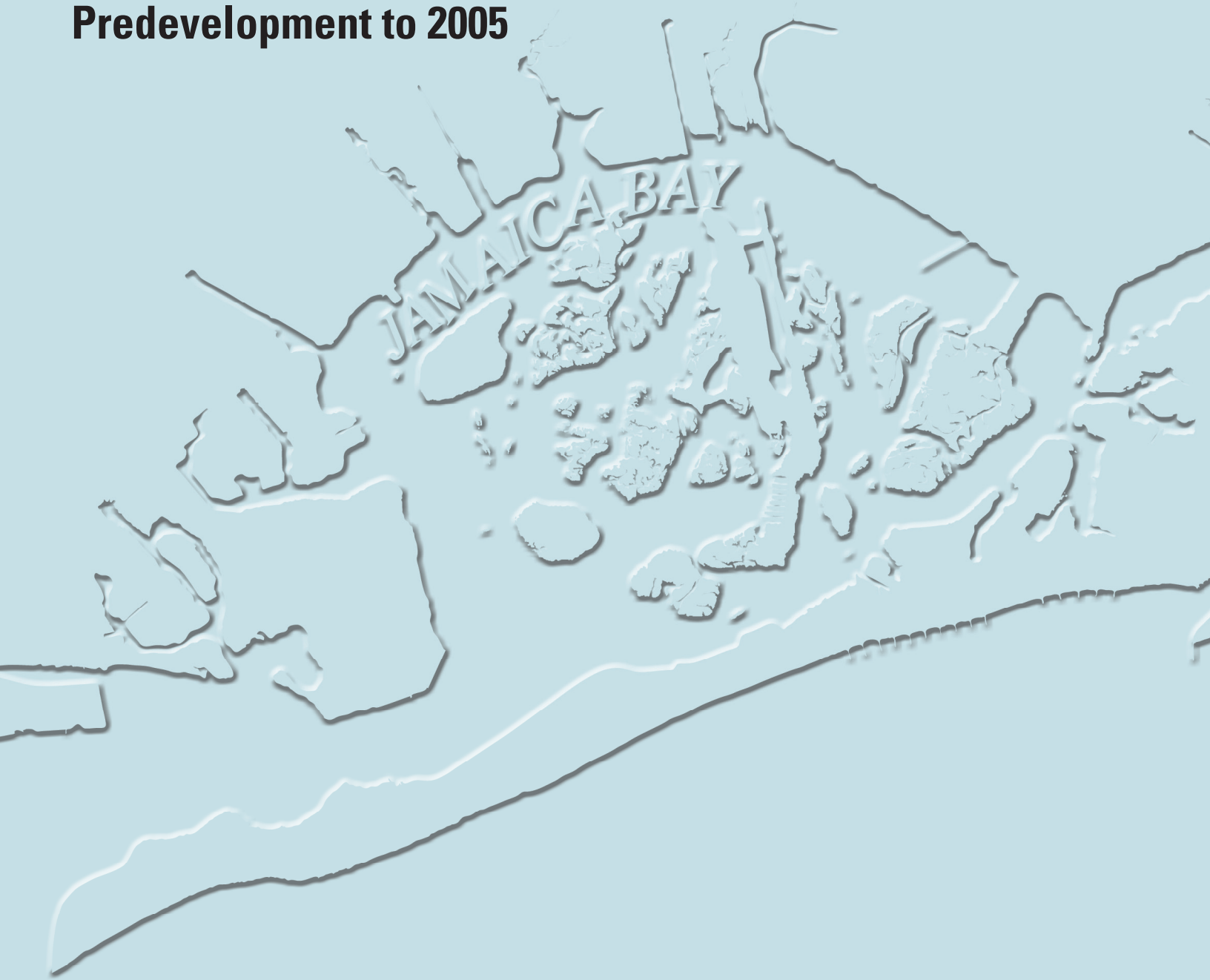


Prepared in cooperation with the National Park Service

Nitrogen Loading in Jamaica Bay, Long Island, New York: Predevelopment to 2005



Scientific Investigations Report 2007–5051

U.S. Department of the Interior
U.S. Geological Survey

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By Mark J. Benotti, Michele Abbene, and Stephen A. Terracciano

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
Area		
hectare (ha)	0.003861	square mile (mi ²)
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
liter (L)	0.2642	gallon (gal)
liter (L)	0.0000002642	million gallons (Mgal)
liter (L)	61.02	cubic inch (in ³)
Mass		
kilogram (kg)	2.205	pound avoirdupois (lb)
kilogram (kg)	0.001102	ton, short (2,000 lb)

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Acronyms

AS	Activated sludge
BOD	Biological oxygen demand
CSO	Combined sewer overflows
NPS	National Park Service
NYCDEP	New York City Department of Environmental Protection
TF	Trickling filter
TN	Total nitrogen
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	Wastewater-treatment plant

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Nitrogen Loading in Jamaica Bay, Long Island, New York: Predevelopment to 2005

By Mark J. Benotti, Michele Abbene, and Stephen A. Terracciano

Abstract

Nitrogen loading to Jamaica Bay, a highly urbanized estuary on the southern shore of western Long Island, New York, has increased from an estimated rate of 35.6 kilograms per day (kg/d) under predevelopment conditions (pre-1900), chiefly as nitrate plus nitrite from ground-water inflow, to an estimated 15,800 kilograms per day as total nitrogen in 2005. The principal point sources are wastewater-treatment plants, combined sewer overflow/stormwater discharge during heavy precipitation, and subway dewatering, which account for 92 percent of the current (2005) nitrogen load. The principal nonpoint sources are landfill leachate, ground-water flow, and atmospheric deposition, which account for 8 percent of the current nitrogen load. The largest single source of nitrogen to Jamaica Bay is wastewater-treatment plants, which account for 89 percent of the nitrogen load. The current and historic contributions of nitrogen from seawater are unknown, although at present, the ocean likely serves as a sink for nitrogen from Jamaica Bay. Currently, concentrations of nitrogen in surface water are high throughout Jamaica Bay, but some areas with relatively little mixing have concentrations that are five times higher than areas that are well mixed.

Introduction

Excessive nutrients (nitrogen in marine environments or phosphorus in freshwater environments) in enclosed aquatic systems can lead to hypoxic or anoxic conditions and eutrophication. Jamaica Bay is a 5,260 hectare (ha) estuary that includes salt-marsh islands, shallow brackish water, and dredged navigable channels. The bay is a highly urbanized estuary in the southeastern part of New York City on the southern shore of western Long Island (fig. 1). Jamaica Bay receives nitrogen in the form of nitrate (or nitric acid), nitrite, ammonia, and organic nitrogen from several point sources including wastewater-treatment plants (WWTPs), combined sewer overflows/stormwater (CSOs) during heavy precipitation, and subway dewatering practices. Nonpoint sources including leachate from landfills lining the shores,

atmospheric deposition, and subsurface discharge of ground-water flow also deliver nitrogen to the bay.

Jamaica Bay began experiencing a pronounced loss of salt-marsh islands concomitant with the urbanization of its shoreline (Hartig and others, 2002). Based on recommendations by a panel of coastal wetland experts (U.S. Department of the Interior, 2001), the National Park Service (NPS) is encouraging research in order to understand the suite of factors that may be responsible for this marsh loss in Gateway National Recreation Area, which is partially enclosed within Jamaica Bay. Some studies of marsh loss in Jamaica Bay have focused on sediment dynamics within the bay by evaluating the sources and fate of sediments and the response of the marshes to sea-level rise (Gordon and Houghton, 2004; Goodbred and others, 2004; Wilson and Flagg, 2004).

The high level of nutrients in the urban Jamaica Bay Estuary may be a contributing factor to marsh loss. High concentrations of nutrients may stimulate the growth of vigorous sea lettuce (*Ulva* sp.) smothering other marsh vegetation, including smooth cordgrass (*Spartina alterniflora*). Additionally, eutrophication in Jamaica Bay may have caused a reallocation of energy in *S. alterniflora* from roots to shoots (Wijte and Gallagher, 1996). In either case, the decreasing *S. alterniflora* biomass in the peat substrate undermines the structural integrity of the marsh, leading to marsh deterioration. Alternatively, the decomposition of peat may result from increased microbial activity in response to the increased nutrient availability; this in turn would increase the rate of consumption of sedimentary organic matter (Valiela and others, 1985) and the breakdown of peat. As an initial step in addressing these nutrient-related hypotheses, the NPS is assembling all available information on nutrient loading to the bay.

Purpose and Scope

This report describes the distributions of nitrogen concentrations in surface water Jamaica Bay; presents, where available, historical trends in nitrogen loading from each of the major point- and nonpoint-sources of nitrogen to Jamaica



Figure 1. Location of Jamaica Bay, Long Island, N.Y., and selected point and nonpoint sources of nitrogen.

Bay, and provides an estimated budget of nitrogen currently entering the bay. The U.S. Geological Survey (USGS) began a one-year study in the fall of 2005, in cooperation with NPS, assessing historic nitrogen loading to Jamaica Bay to help understand the sources and amounts of nitrogen entering the bay from predevelopment to 2005.

Study Area

Urban development in the areas bordering Jamaica Bay has extensively changed the quantity and quality of freshwater entering the bay. Much of the shore has been altered with bulkheads, hard structures, and upland filling and is now

very different than it was a century ago. The natural flow of water and sediment has been modified by channel dredging, stormwater diversion, WWTP operations, and causeway construction. Jamaica Bay decreased from approximately 10,100 ha prior to extensive development (pre-1900) to 5,260 ha in 1971, a result of filling in and bulkheading marshes that bordered the perimeter of the bay (Jamaica Bay Environmental Study Group, 1971). The bay, however, is still relatively large in relation to its mouth (Rockaway Inlet) through which tidal exchange with the New York Bight occurs. Water circulation in Jamaica Bay is largely inhibited by a series of salt-marsh islands, and mixing is generally limited to exchange through the navigable channels on the

northern and southern sides of the bay (Swanson and others, 1992). The mean depth of the bay is 5 meters (m), but some parts are as deep as 20 m as a result of dredging and sand-mining operations. Thus, the bathymetry and slow flushing of Jamaica Bay favor the accumulation of contaminants entering from point- and nonpoint-sources.

The increasing urbanization of Jamaica Bay during the 20th century has been accompanied by a pronounced loss of smooth cordgrass (*Spartina alterniflora*) marsh. About 206 ha of salt-marsh islands were lost during 1924–71 for reasons other than dredging (at a rate of 4 ha per year); another 213 ha were lost from 1974–94 at a rate of 11.5 ha per year (New York State Department of Environmental Conservation, 2006). Some salt-marsh islands have deteriorated extensively and have lost almost 80 percent of their *S. alterniflora* cover (Hartig and others, 2002), which is consistent with the concept that high nutrient levels can lead to salt-marsh loss, as is stated in some of the hypotheses previously mentioned.

Nitrogen Loading to Jamaica Bay

Nitrogen loading to Jamaica Bay has led to high concentrations of nitrate, nitrite, and ammonia throughout surface waters of the estuary. Concentrations of nitrogen, which are affected by the amounts of tidal mixing, are generally highest in the northeastern areas of the bay and lowest in the mouth. To assess surface-water concentrations of nitrogen in Jamaica Bay, a coupled hydrodynamic/water-quality simulation was used to derive a snapshot of the age of water throughout the bay (fig. 2, Richard Isleib, HydroQual, Inc., written commun., 2006). Meteorological and tidal conditions can affect this age distribution, but the model results offer a snapshot of water ages throughout the estuary and indicate the extent of mixing in different areas of the bay. The age distribution of water modeled at three representative sites is shown on the model grid in figure 2. Water ages range from 0 to 40 days; the youngest water is at the mouth, and

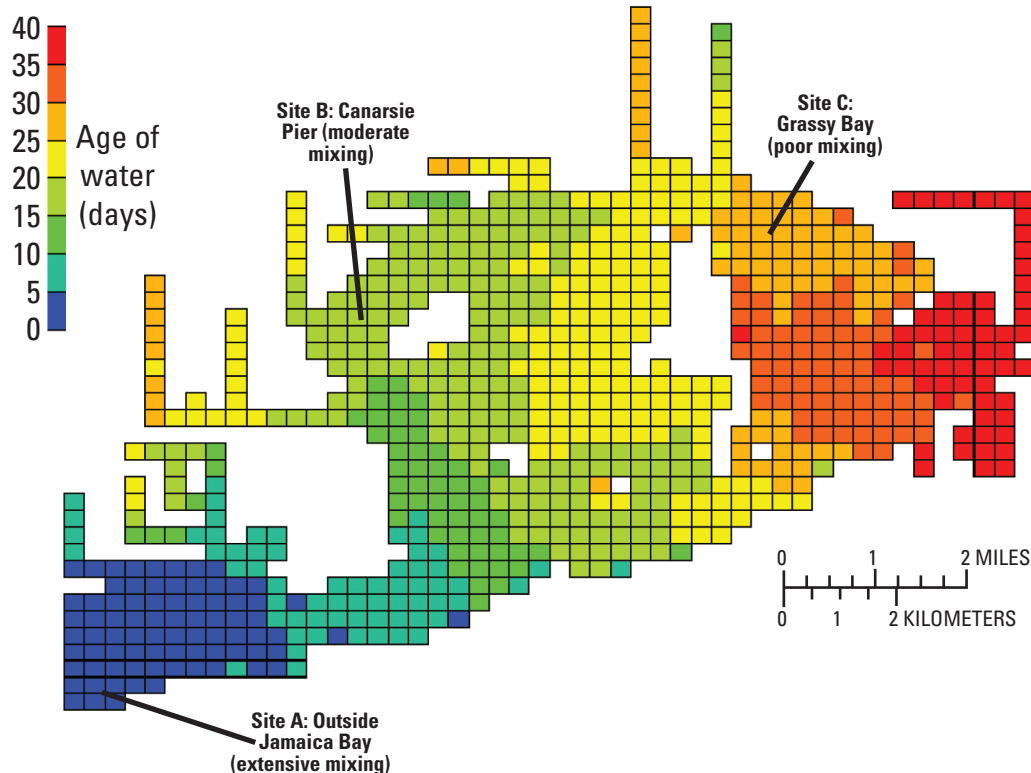


Figure 2. Age and extent of surface-water mixing at three sites on Jamaica Bay, Long Island, N.Y., as defined by a coupled hydrodynamic/water-quality model (From Richard Isleib, HydroQual, Inc., written commun., 2006).

the oldest water is in the easternmost parts. According to the simulation, water at Site A (New York Bight, outside the bay) is 0 to 5 days old and undergoes the most extensive mixing with water from outside the bay; water at Site B (Canarsie Pier) ranges from 15 to 20 days old and has undergone an intermediate amount of mixing; and water at Site C (Grassy Bay) ranges from 25 to 30 days old and has undergone the least amount of mixing. Sites in the easternmost part of the bay, where the age of the water is about 40 days, are not included in this discussion because the volume of water in this area is small in relation to that at Site C. These three representative sites are used to assess nitrogen concentrations in areas of the bay that experience varying degrees of tidal exchange.

Nitrogen concentration data at New York City Department of Environmental Protection (NYCDEP) harbor survey stations adjacent to Sites A, B, and C were downloaded from the U.S. Environmental Protection Agency's (USEPA) Storage and Retrieval database (USEPA, 2006a). In this database, the NYCDEP sampling station closest to Site A is N16; those closest to Site B are J10, J2 and J3, and that closest to Site C is J7. Historically, nitrogen concentrations at Sites A, B, and C have been elevated, with the highest concentrations at Site C, an area with the least amount of mixing. The concentrations of three species of nitrogen at these sites since measurements began in the mid-1970s are shown in figure 3. Concentrations of most nitrogen species at the three sites have generally been constant since 1980. Ammonia concentrations prior to 1980 were higher than after the WWTPs were upgraded in the late 1970s.

Point Sources

Jamaica Bay receives nitrogen from point sources, which include wastewater-treatment plants, combined sewer overflow/stormwater discharge during heavy precipitation, and subway dewatering. Point sources contribute 92 percent of the nitrogen entering Jamaica Bay. The principal point-source contributions and their historic trends in loading (where available) are described in the following sections.

Wastewater-Treatment Plants

Treated wastewater is the largest contributor of nitrogen to Jamaica Bay. NYCDEP operates four WWTPs that discharge secondary-treated wastewater to the bay: Coney Island, Jamaica, 26th Ward, and Rockaway (fig. 1). Three smaller WWTPs also discharge into the bay: Inwood and Cedarhurst, operated by Nassau County, which discharge into the easternmost areas of the bay; and one plant operated by the NPS at Floyd Bennett Field. The Inwood WWTP was decommissioned in 1999. Data on all WWTPs that discharge or have discharged to Jamaica Bay are given in table 1. The six plants now in operation (all but the Inwood WWTP) discharge approximately 970×10^6 liters per day (L/d) of biologically

treated wastewater to Jamaica Bay (Interstate Environmental Commission, 2005).

The four municipal WWTPs operated by the NYCDEP discharge 99 percent of the wastewater-effluent load to Jamaica Bay. Thus, nitrogen loading from wastewater can be largely explained by contributions from these four plants. For the purposes of this study, the three small plants, for which there are less data, are not considered. The NYCDEP monitored concentrations of nitrogen in effluent from the four large municipal WWTPs that discharged into Jamaica Bay during 1991–2005; these data were used to compile each plant's historic nitrogen loadings to Jamaica Bay (Robert DeLorenzo, O'Brien and Gere, written commun., 2005). Nitrogen concentrations prior to 1991 were not routinely monitored, but could be inferred from measurements of biological oxygen demand (BOD) at the four municipal WWTPs during 1951–90 (Robert DeLorenzo, O'Brien and Gere, written commun., 2005). Annual BOD and total nitrogen (TN) concentrations in effluent from each of the four municipal WWTPs are shown in figure 4; TN concentrations were calculated as the sum of the concentration of the four nitrogen species: nitrate, nitrite, ammonia, and organic nitrogen.

The large declines in BOD in effluent from three of WWTPs (Jamaica, 26th Ward, and Rockaway) in the late 1970s coincide with upgrades to secondary treatment (table 1). The increase in effluent TN concentrations in the early 1990s reflects changes in sludge-disposal practices at all four municipal plants; sludge was formerly disposed of in the ocean, but since 1993, has been dewatered by centrifugation and disposed of in landfills or used in agricultural land-application practices as fertilizer. The nutrient-rich centrate is returned to the influent of the WWTP, and thus increases the TN concentrations in the final effluent. The decrease in TN load in effluent in the late 1990s is due to a decrease in flow rate at the WWTPs (data not shown; Robert DeLorenzo, O'Brien and Gere, written commun., 2005). TN contributions to Jamaica Bay from the four municipal WWTPs are shown in figure 5. To create this plot, the daily loads of TN from the Jamaica, 26th Ward, and Rockaway WWTPs were summed with half the daily load from the Coney Island plant, because the latter discharges into the mouth of the bay and only half of the daily load would enter the bay (the amount that is discharged on a flood tide). The plot of TN contributions to Jamaica Bay from the four WWTPs during 1991–2005 (fig. 5) illustrates that the nitrogen load from WWTP effluent peaked in 1995 (at $20,336 \pm 1,522$ kg/d), and has been fairly stable since 2001 ($13,379 \pm 1,187$ to $14,037 \pm 1,279$ kg/d).

Combined Sewer Overflows (CSOs) and Stormwater Discharge

CSOs and stormwater also contribute nitrogen to Jamaica Bay. New York City's sewer systems, including those in Brooklyn and Queens, which were designed in the late 19th

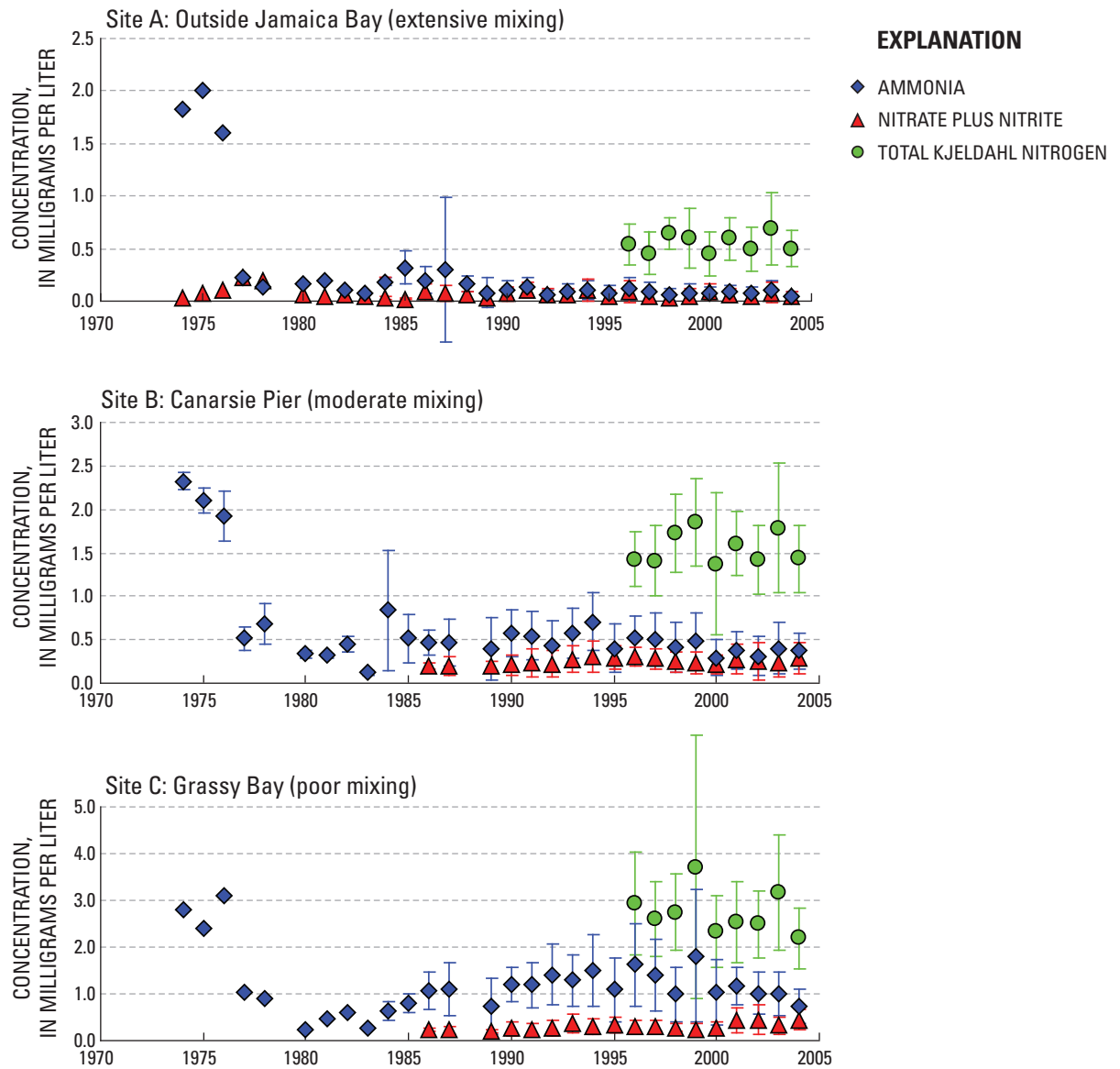


Figure 3. Average annual concentrations (\pm standard deviation) of five nitrogen species at three sites (A) outside Jamaica Bay, (B) Canarsie Pier, and (C) Grassy Bay in Jamaica Bay, Long Island, N.Y. (Site locations are shown in fig. 2. Data from USEPA, 2006.)

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Table 1. Characteristics of six wastewater-treatment plants that discharge to Jamaica Bay, Long Island, N.Y.

[The first four plant locations are shown in fig. 1; L/d, liters per day; AS, activated sludge; TF, trickling filter; --, not applicable; data from Interstate Environmental Commission, 2005]

Plant	Average flow ($\times 10^6$ L/d)	Design flow ($\times 10^6$ L/d)	Year built	Year upgraded to secondary treatment (type of plant)	Population served
Coney Island	348	416	1935	1995 (AS)	602,100
Jamaica	314	379	1943	1978 (AS)	632,150
26th Ward	223	322	1944	1979 (AS)	271,240
Rockaway	79	170	1952	1978 (AS)	94,500
Cedarhurst	3.0	3.8	1981	1981 (TF)	6,000
Inwood ¹	-	9.5	1961	1989	7,600
GATE	0.30	3.8	1942	1981 (TF)	5,000

¹Decommissioned in 1999

century, route stormwater into sanitary sewers. During heavy precipitation, the combination of stormwater and wastewater can overload the capacity of WWTPs; this phenomenon is referred to as a CSO event. Additionally, some drainage systems around Jamaica Bay collect stormwater runoff. These two systems (the combined sewer system carrying untreated wastewater and stormwater, and the stormwater system carrying urban runoff) discharge into Jamaica Bay during periods of heavy precipitation and are collectively referred to as CSO/stormwater. Other circumstances that can disrupt wastewater-treatment operations and trigger CSO events are power failures, such as the August 2003 blackout in the Northeast, which resulted in the discharge of untreated wastewater to New York Harbor and Jamaica Bay.

CSO/stormwater loads were calculated for two time periods, 1988 and 1995–96, as part of the Jamaica Bay Eutrophication Model (HydroQual, Inc., 2002). These data are presented in table 2. The load estimates are imprecise, however, because the yearly nitrogen load from CSOs is derived from isolated occasions, rather than based on a steady input. A few days of heavy precipitation, such as the rainfall of October 2005, when about 254 millimeters (mm) of rain was recorded at nearby John F. Kennedy Airport over a few days (U.S. National Oceanic and Atmospheric Administration, 2006), may account for a large fraction of the yearly nitrogen load from CSOs/stormwater. Regardless, daily averages allow better comparison with steadier inputs, like those from WWTPs or subsurface ground-water flow.

Subway Dewatering

The flooding of subterranean subway tunnels has been a problem in several parts of Brooklyn and Queens since the recovery of the water table from drawdowns that resulted from pumping during the 1930s and 1940s (Buxton and Shernoff, 1999). Ground water was a major source of public

supply for Brooklyn and Queens starting in the mid-19th century, and rapid increases in population and pumping (at times exceeding 379×10^6 L/d; Cartwright, 2002) led to severe water-table declines (to as much as 11 m below sea level), as well as saltwater intrusion along the shore. Pumping for public supply was stopped in Brooklyn in 1947 and in western Queens in 1974. In central and eastern Queens, pumping continued, but by 1996, only about 53×10^6 L/d was pumped for public supply (Cartwright, 2002). Many subway tunnels were constructed during the period of depressed water levels and became flooded as the water table recovered. Continuous dewatering in some locations is necessary, and some of the removed water is pumped into coastal waters.

In the Jamaica Bay watershed, water is pumped at Nostrand and Newkirk stations as well as at the Pitkin Avenue station and discharged into Jamaica Bay. Water removed by dewatering at the Nostrand and Newkirk stations (fig. 1) is discharged into Sheepshead Bay (Ritu Mody, FPM Engineering Group, written commun., 2005). Water removed at the Pitkin Avenue station (fig. 1) is discharged via a storm sewer into Jamaica Bay (Kevin Phillips, FPM Engineering Group, written commun., 2006). From dewatering activities, the discharge rate to Jamaica Bay is estimated to have been 29×10^6 L/d in 1991, and a proposed long-term dewatering strategy for the Nostrand and Newkirk stations would increase this withdrawal rate to about 39×10^6 L/d (Misut and Monti, 1999). The removal of water by subway dewatering is, in effect, the withdrawal and discharge of ground water to Jamaica Bay; therefore, the total contribution of nitrogen to Jamaica Bay from subway dewatering can be estimated from the average nitrogen concentration in shallow ground water in Brooklyn and Queens. Concentrations of nitrate, nitrite, and ammonia in wells in the Jamaica Bay watershed were accessed from the USEPA's STORET database (USEPA, 2006a) and the U.S. Geological Survey's National Water Information System online database (U.S. Geological Survey, 2006). Data were organized by year for which ground-water discharge

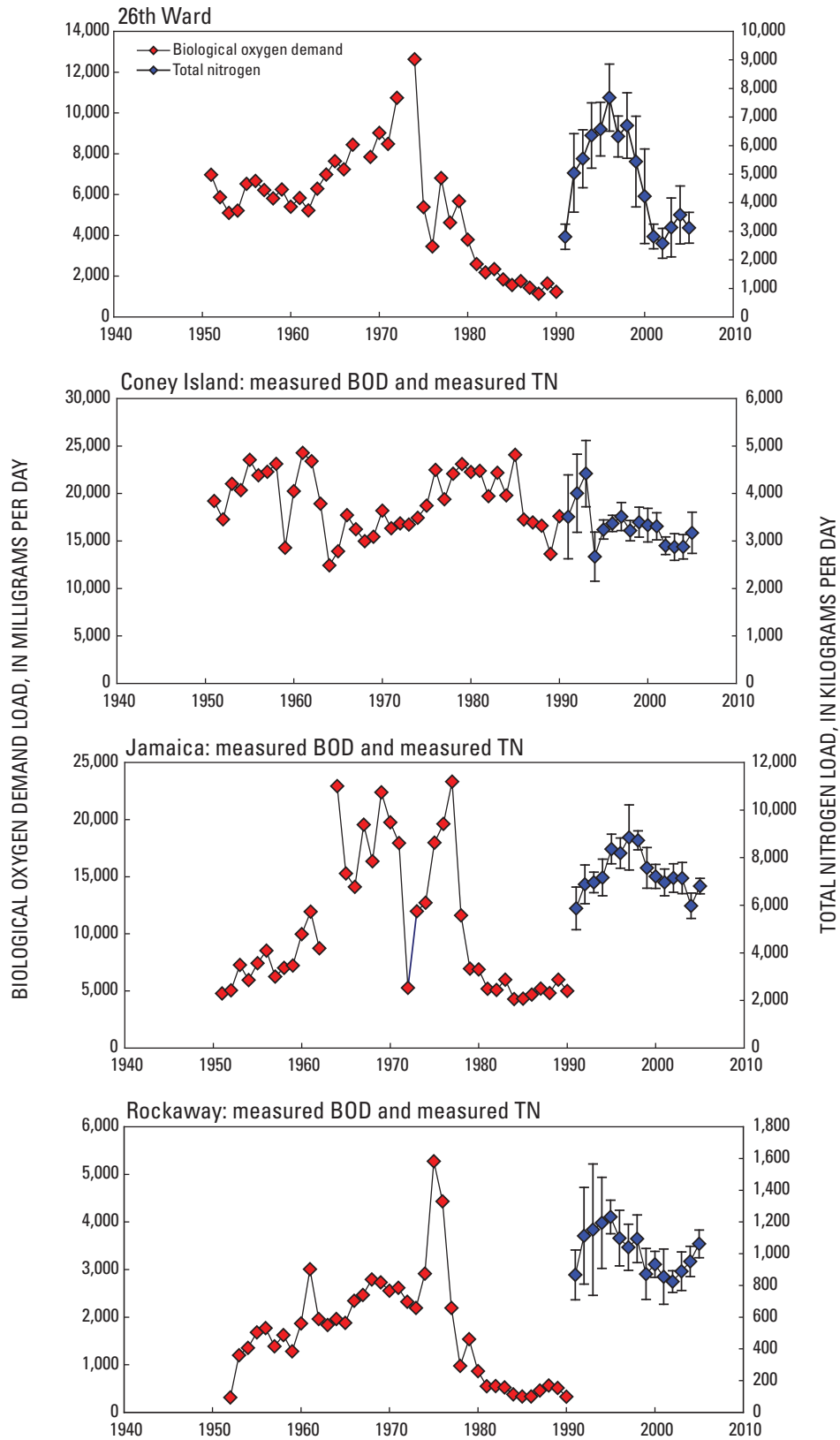


Figure 4. Daily loads of total nitrogen (TN, \pm standard deviation) and biological oxygen demand (BOD) in the effluents from four large municipal wastewater-treatment plants that discharge into Jamaica Bay, N.Y. (Plant locations are shown in fig. 1. Data From Robert DeLorenzo, O'Brien and Gere, written commun., 2005.)

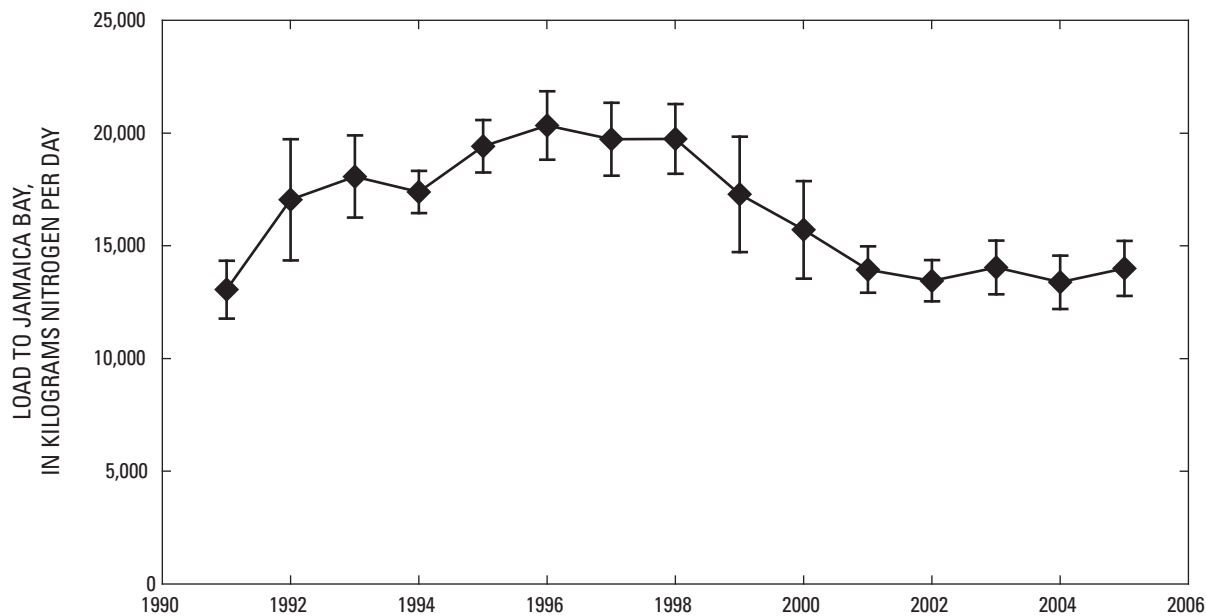


Figure 5. Summed total loads of nitrogen (\pm standard deviation) during 1991–2005 from four wastewater-treatment plants to Jamaica Bay, N.Y. (Plant locations shown in fig. 1. Data from Richard Isleib, HydroQual, Inc., written commun., 2005.)

Table 2. Combined sewer overflows/stormwater (CSO) daily average flow and daily nitrogen loads to Jamaica Bay.

[L/d, liters per day; kg/d, kilograms per day; data from HydroQual, Inc., 2002]

Inputs	1988	1995–96
CSO/stormwater daily average flow ($\times 106$ L/d)	311	242
Ammonia load (kg/d)	338.9	130.4
Nitrite plus nitrate load (kg/d)	255.3	113.9

to Jamaica Bay has been estimated. The discharges of water to Jamaica Bay from dewatering sites for 1991 and 2005 are given in table 3 with the corresponding mean concentrations (\pm standard error) and loads of nitrate, nitrite, and ammonia.

Nonpoint Sources

Jamaica Bay also receives nitrogen from nonpoint sources, which include landfill leachate, subsurface ground-water flow, and atmospheric deposition. Nonpoint sources currently contribute 8 percent of the nitrogen entering Jamaica Bay. The principal contributions of nonpoint sources and their historic trends in loading (where available) are described in the following sections. Another significant nonpoint source of nitrogen to Jamaica Bay are unsewered areas (Larry Swanson, written commun., 2006). Constraining the

nitrogen contribution from unsewered areas would be a nearly impossible task given the lack of supporting data. This study, therefore, does not take it into account, but recognizes that nitrogen from unsewered areas may be a significant nonpoint source, one which future data collection studies may want to attempt to measure.

Landfills

The shore of Jamaica Bay contains three capped municipal landfills: the Pennsylvania Avenue and Fountain Avenue Landfills on the north shore near the Brooklyn/Queens border and the Edgemere Landfill on the southeastern shore in Queens (fig. 1). The Fountain Avenue Landfill on the bay’s north shore occupies 120 ha and was operated from 1961–1985. It generally received solid waste from New York City that included garbage, rubbish, street dirt, commercial waste, construction waste, demolition waste, ash, and incinerator residue (Tagliacozzo and others, 1984). The adjacent Pennsylvania Avenue Landfill encompasses about 45 ha and was operated from 1956–1962, then was reopened in 1974 to receive construction waste and to serve as a site for drying sewage sludge. Throughout the 1970s, it also received waste oil that was used in road-dust control (Tagliacozzo and others, 1984). The Edgemere Landfill encompasses about 61 ha and was operated from 1938–1991. It received residential waste, rubbish, street dirt, ashes, construction waste, and demolition waste. During the 1970s, it also received waste oil used for road-dust control (Tagliacozzo and others, 1984).

As part of the Jamaica Bay Eutrophication Model, nitrogen loading due to landfill leaching was calculated (HydroQual, Inc., 2002). These loads are presented in table 4; however, they were calculated for the years 1995–96, before the three landfills were entirely capped. Since publication of the Jamaica Bay Eutrophication Model, capping was completed at the Edgemere (mid-1990s) and Pennsylvania Avenue Landfills (early 2006). Capping of the Fountain Avenue Landfill is in the final stages and should be completed in 2007. Loads of nitrogen may be lower once the landfill is capped because the cap is designed to be highly impermeable to precipitation. A more recent estimate of nitrogen loading that accounts for landfill capping has not been made.

Ground Water

The ground-water system of Brooklyn and Queens consists of unconsolidated postglacial deposits underlain by four aquifers and two confining units. The shallow upper glacial aquifer contributes most of the ground-water flow to Jamaica Bay, although some flow may enter from the deeper

Magothy Aquifer through erosional holes in the confining Gardiners Clay layer at Arverne and Floyd Bennett Field (fig. 1) near the south-shore barrier beaches (Buxton and Shernoff, 1999). Freshwater enters the Kings and Queens County aquifer system as precipitation that recharges the water table and as westward ground-water flow from Nassau County (fig. 1). The estimated rate of recharge from infiltration of precipitation on Long Island during the predevelopment period (pre-1900) was about 11×10^6 L/d/km², corresponding to 791×10^6 L/d for Kings and Queens Counties (Buxton and Shernoff, 1999). An additional 23×10^6 L/d of freshwater entered the aquifer system as westward ground-water flow from Nassau County. Urbanization has decreased infiltration and increased runoff. Recharge to this aquifer system in 1983 was estimated to be 405×10^6 L/d, or approximately half of that during predevelopment conditions. Westward-flowing ground water contributed another 34×10^6 L/d. An additional 265×10^6 L/d enters the aquifer system as return flow from leaky water-supply lines and other infiltration.

Ground water contains nitrogen from many point- and nonpoint-sources. It discharges to Jamaica Bay through the sea floor, along the shore, and as stream base flow. Calculation

Table 3. 1991 and 2004 discharges to Jamaica Bay, Long Island, N.Y., from subway dewatering, and average concentrations and loads of nitrogen species in ground water entering Jamaica Bay.

[L/d, liters per day; mg/L, milligrams per liter; kg/d, kilograms per day. Data from Misut and Monti, 1999; USEPA, 2006a; and U.S. Geological Survey, 2006]

	1991	Current (1991–2004)
Discharge ($\times 10^6$ L/d)	29	29 (39)*
Concentration (mg/L)		
Nitrite plus nitrate	6.74 ± 0.81	5.69 ± 0.43
Ammonia	0.41 ± 0.14	0.16 ± 0.04
Load (kg/d)		
Nitrite plus nitrate	194 ± 23	164 ± 12 (224 ± 17)*
Ammonia	11.8 ± 4.0	4.6 ± 1.2 (6.3 ± 1.6)*

*Numbers in parentheses reflect a pumping increase to 10.4 million gallons per day as part of a proposed long-term dewatering strategy. The values in this column are used in the absence of information on current dewatering practices.

Table 4. Estimated loads of nitrogen entering Jamaica Bay, Long Island, N.Y., from landfill leachate.

[kg/d, kilograms per day. Locations are shown in fig. 1. Data from HydroQual, Inc., 2002]

Landfill	Ammonia load (kg/d)	Nitrate plus nitrite load (kg/d)
Edgemere	116.0	0.3
Fountain Avenue	107.1	4.1
Pennsylvania Avenue	33.5	0.2

of the ground-water contribution of nitrogen to Jamaica Bay is difficult, however, because concentrations of nitrogen species in ground-water vary spatially and temporally in the subsurface. For example, nitrate concentrations in wells proximate to Jamaica Bay in Brooklyn and Queens and screened in the upper glacial aquifer ranged from less than 0.05 mg/L to 17 mg/L in 1996, and those in a single well screened in the upper glacial aquifer adjacent to Jamaica Bay were 22 mg/L in 1983 and below detection limit in 1996 (Cartwright 2002).

A further complication is the variation in the rate of ground-water discharge to Jamaica Bay through time. Temporal changes in the amount of water discharged to Jamaica Bay could increase or decrease the nitrogen load. To study the historic inputs of nitrogen to Jamaica Bay through ground-water discharge, a USGS saturated-unsaturated finite-element model (Voss and Provost, 2002) was used to simulate the flow of variable-density ground water driven by variations in solute mass. Details of the model application to Jamaica Bay are summarized in Misut and Voss (2004). Total ground-water discharge to Jamaica Bay from the shore, the sea floor, and base flow has been estimated to range from a maximum of about 178×10^6 L/d during the predevelopment period to less than 39×10^6 L/d during the mid-20th century, and to about 114×10^6 L/d at present (table 5). Little or no surface runoff occurred before development became extensive because the soils surrounding the bay are highly permeable, and the water table provided flow to streams along their entire length. The construction of roads, parking lots, and buildings decreased the amount of land surface available for infiltration of precipitation and thereby resulted increased runoff into streams. This also caused the rate of ground-water recharge to decrease, the water table to decline, and ground-water discharge to the Bay to decrease.

The inflow of nitrogen species (nitrate, nitrite, and ammonia) to Jamaica Bay from ground water was estimated from the concentrations of these compounds in years for which estimates of ground-water discharge were modeled. Concentrations of nitrate, nitrite, and ammonia in wells in the Jamaica Bay watershed were accessed from the USEPA's STORET database (USEPA, 2006a) and the U.S. Geological Survey's National Water Information System online database (U.S. Geological Survey, 2006). Predevelopment ground-water concentrations of nitrate were assumed to be 0.2 mg/L (Kimmel, 1972). Box plots of concentration distributions for nitrate plus nitrite and ammonia in ground water during six time periods for which model-generated estimates were available and the corresponding model-generated rates of ground-water discharge to the bay are presented in figure 6.

The model-generated discharges and the mean nutrient concentrations for ground water entering Jamaica Bay were then used to calculate the approximate loads of ammonia and nitrate plus nitrite entering Jamaica Bay; these values are given in table 6.

Atmospheric Deposition

Deposition of nitrogenous compounds from the atmosphere is a significant nonpoint source of nitrogen to Jamaica Bay. Atmospheric deposition can occur during precipitation events (referred to as wet deposition) or during dry-weather conditions (referred to as dry deposition). A strong linkage between atmospheric deposition of nitrogen and coastal eutrophication at the watershed scale has been shown by Jaworski and others (1997). Atmospheric deposition to Jamaica Bay, however, is limited only to the surface area of the bay, because most deposition on land enters the combined sewer system, which is accounted for in the CSO/stormwater and WWTP loading calculation. The USEPA maintains the Clean Air Status and Trends Network online database that includes data for wet and dry deposition of nitrogen as ammonia, nitrite, and nitric acid at stations across the United States. To assess the load of nitrogen to Jamaica Bay as a result of wet and dry deposition, available data were downloaded for the three closest monitoring stations to the bay (sites WSP144 in Washington Crossing, N.J.; CAT175 in Claryville, N.Y.; and ABT147 in Abington, Conn.; USEPA, 2006b). Average values were calculated from the three different sites (WSP144 has a wet-deposition record from 1981–2005 and a dry-deposition record from 1989–2005; CAT175 has a wet-deposition record from 1982–2005 and a dry-deposition record from 1994–2005; ABT147 has a wet-deposition record from 1999–2005 and a dry-deposition record from 1994–2005). Yearly average wet- and dry-deposition values were used to calculate the daily loads to Jamaica Bay (based on the area of the bay, 5,260 ha; fig. 7). Nitrogen concentrations in wet deposition during the predevelopment period were essentially zero (John Mak, Stony Brook University, oral commun., 2006), and no estimate of predevelopment dry deposition was found.

Current Nitrogen Loading to Jamaica Bay

A current nitrogen budget can be assembled using the most current load reported for each of the point and nonpoint sources. The most current nitrogen loads from each of the six sources and that source's contribution to the nitrogen budget are presented in table 7. The largest source of nitrogen to Jamaica Bay is WWTPs, which contribute 89 percent of nitrogen; the smallest sources of nitrogen to the bay are subway dewatering activities (1 percent), CSOs/stormwater (2 percent) and atmospheric deposition (2 percent). Point sources contribute 92 percent of the nitrogen to Jamaica Bay and nonpoint sources contribute 8 percent. A similar nitrogen budget was completed as part of the Jamaica Bay Eutrophication Model (HydroQual, Inc., 2002) using nitrogen loading values collected in 1995–96. Similar trends in loading were reported: NYC WWTPs (94.96 percent), CSO and stormwater (2.35 percent), atmospheric deposition (1 percent), Nassau WWTPs (0.36 percent), and landfills (1.26 percent),

Table 5. Ground-water discharges to Jamaica Bay, Long Island, N.Y., during predevelopment period (pre-1900) and recent periods (1974, 1983, 1991, 1996, 1999).

[L/d, liters per day; <, less than; ~, approximately; sim, model simulated. Pumping data from Cartwright, 2002. Discharge data from Misut and Voss, 2004]

Period	Description	Brooklyn industrial pumping (×106 L/d)	Queens industrial pumping (×106 L/d)	Queens water-supply pumping (×106 L/d)	Discharge to Jamaica Bay (×106 L/d)
Predevelopment		0	0	0	178 (sim)
1974	Water-supply withdrawal at maximum in southeast Queens; water-supply withdrawal in southwest Queens stopped because of saltwater intrusion. Water levels rising in Brooklyn and west Queens; falling in east Queens.	< 38	~ 15	216	~ 76
1983	Continued water-supply withdrawal in southeast Queens. Brooklyn water table at equilibrium. Water levels rising in west Queens and falling in southeast Queens and southwest Nassau County.	25	8.7	216	~ 76
1991	Reduction in Queens water-supply withdrawal. Repairs to water mains result in decreased leakage. Increased dewatering in Brooklyn. Water levels rising in southeast Queens.	83	57	91	~ 95
1996	Continued reduction in Queens's water-supply withdrawal. Increased dewatering in Queens. Water levels rising in southeast Queens.	83	57	53	~ 114
1999	Continued reduction in Queens's water-supply withdrawal. Water table stable in Brooklyn, Queens, and Nassau.	45	57	38	114 (sim)

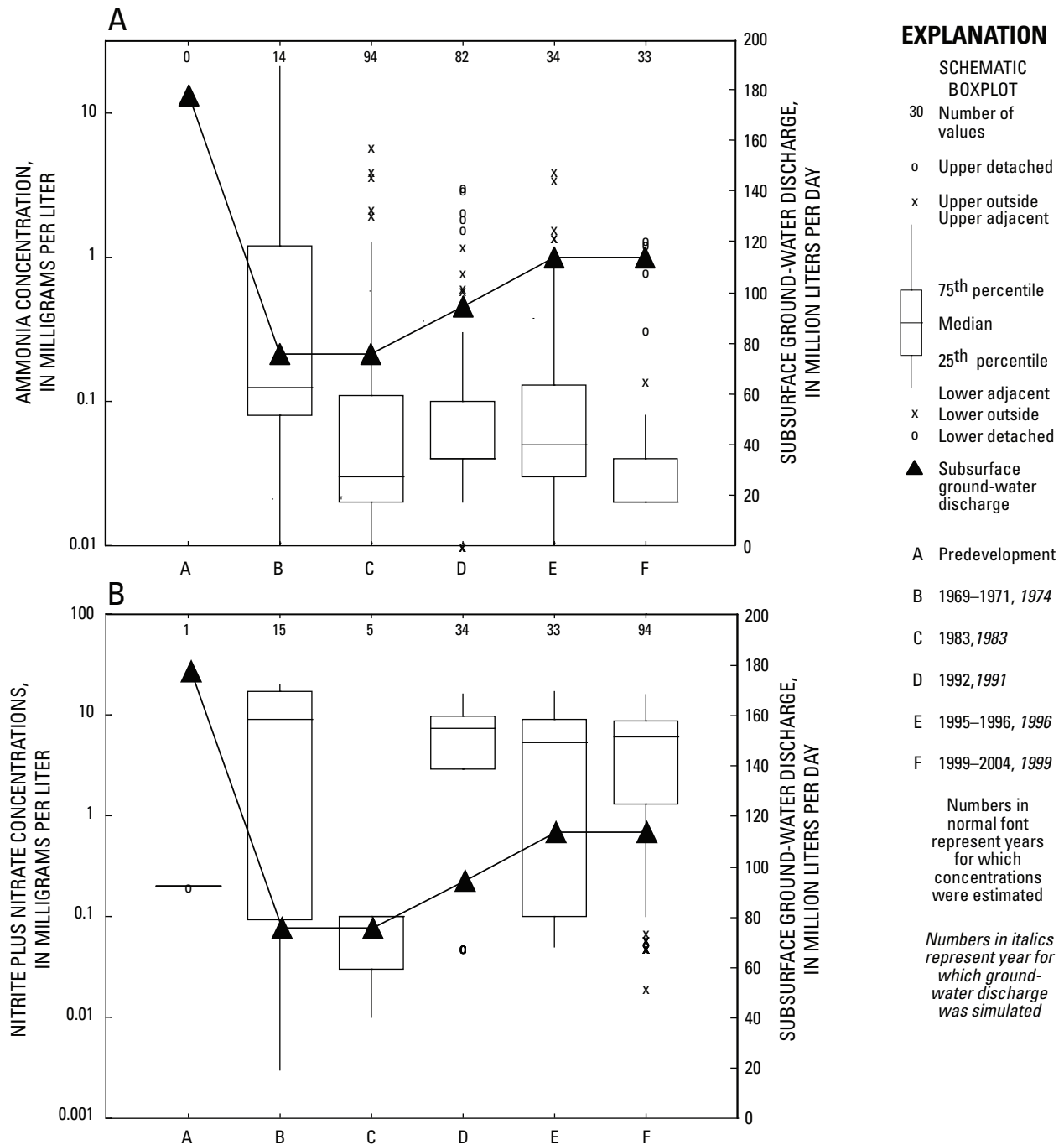


Figure 6. Concentrations of ammonia and of nitrate plus nitrite in water from wells in the Jamaica Bay watershed during six periods of Long Island development and the corresponding modeled ground-water discharges to Jamaica Bay: (A) ammonia; (B) nitrate plus nitrite. Concentrations of nitrate, nitrite, and ammonia in wells in the Jamaica Bay watershed were accessed from the USEPA's STORET database (USEPA, 2006, accessed June 29, 2006) and the U.S. Geological Survey's National Water Information System online database (U.S. Geological Survey, 2006, accessed June 29, 2006). Discharge data from Misut and Voss, 2004.

Table 6. Calculated loads of nitrogen species entering Jamaica Bay, Long Island, N.Y., through ground-water discharge during six selected time periods.

[kg/d, kilogram per day. Data calculated from mean ground-water concentrations and discharges given in table 5]

Period	Ammonia load (kg/d)	Nitrite plus nitrate load (kg/d)
Predevelopment	35.6	
1969–1971, 1974	667	153
1983, 1983	5.22	21.3
1992, 1991	638	38.5
1995–1996, 1996	632	48.6
1999–2004, 1999	647	18.6

although they included Nassau WWTPs as a point source and did not include subway dewatering practices or ground-water discharge. The reason that the HydroQual, Inc., NYC WWTP contribution is larger than the value calculated in this report is that the TN load from WWTPs was much higher in 1995–96 than it is currently (fig 5).

Nitrogen can enter Jamaica Bay from seawater via tidal mixing, but the load is difficult to estimate without a more complete and detailed understanding of mixing throughout the bay. Under predevelopment conditions, the calculated total load of nitrogen to Jamaica Bay (35.6 kg/d, table 7) may not have been sufficient to support its extensive salt marshes. Any nitrogen required beyond the load delivered through ground water would have been drawn from marine sources. Thus, the waters of New York Harbor and New York Bight may have served as a source of nitrogen to Jamaica Bay. Present distributions of nitrogen in surface water in Jamaica Bay show that nitrogen concentrations are higher in areas where the simulation shows water to be older (figs. 2 and 3), suggesting that the younger water from New York Harbor and New York Bight serves as a sink for nitrogen in Jamaica Bay.

The spatial distribution of nitrogen also illustrates the heterogeneity of the Jamaica Bay ecosystem and presents issues for further consideration. The area of Jamaica Bay experiencing minimal mixing, Grassy Bay (Site C in figs. 1 and 2), has concentrations of nitrogen that are about five times higher than concentrations at the mouth of the bay, even though the Jamaica WWTP discharges into Grassy Bay and the Coney Island WWTP discharges into the mouth of Jamaica Bay. The heterogeneity in concentrations of nitrogen in surface water in the bay suggests that some areas are not well flushed by tidal mixing, allowing concentrations of nitrogen to increase. Thus, if marsh loss is due to nutrient loading, marshes in remote and poorly mixed areas of Jamaica Bay (like Grassy Bay) may be more susceptible to loss.

Summary and Conclusions

Jamaica Bay, a highly urbanized and eutrophic estuary on the southern shore of western Long Island, receives nitrogen in the forms of nitrate (or nitric acid), nitrite, ammonia, and organic nitrogen from several point and nonpoint sources. The USGS and NPS conducted this study to describe the distributions of nitrogen concentrations in surface waters of Jamaica Bay, present (where available) historical trends in nitrogen loading from each of the major point- and nonpoint-sources of nitrogen to Jamaica Bay, and provide an estimated budget of nitrogen currently entering the bay. The current (2005) load of nitrogen to Jamaica Bay is estimated to be 15,785 kilograms per day. The principal point sources are wastewater-treatment plants, combined sewer overflow/stormwater discharge during heavy precipitation, and subway dewatering, which account for 92 percent of the current nitrogen load. The principal nonpoint sources are landfill leachate, ground-water flow, and wet deposition, which account for 8 percent of the current nitrogen load. The largest single source of nitrogen to Jamaica Bay is WWTPs, which account for 89 percent of the nitrogen load. The contribution to nitrogen loading from seawater was not evaluated due to an incomplete understanding of historical concentrations of nitrogen and physical mixing, although currently, Jamaica Bay is likely a source of nitrogen to water outside the bay. Under predevelopment conditions (pre-1900), Jamaica Bay primarily received nitrogen from subsurface ground-water flow and the load was estimated to be 35.6 kilograms per day; whether the ocean was a source or a sink for nitrogen is not known. Currently, the ocean serves as a sink for nitrogen from Jamaica Bay. At present, surface-water concentrations of nitrogen are elevated in the bay (0.29–0.45 mg/L nitrate plus nitrite, 0.37–0.74 mg/L ammonia, and 1.43–2.91 mg/L total Kjeldahl nitrogen) with the highest concentrations present in areas with relatively little mixing.

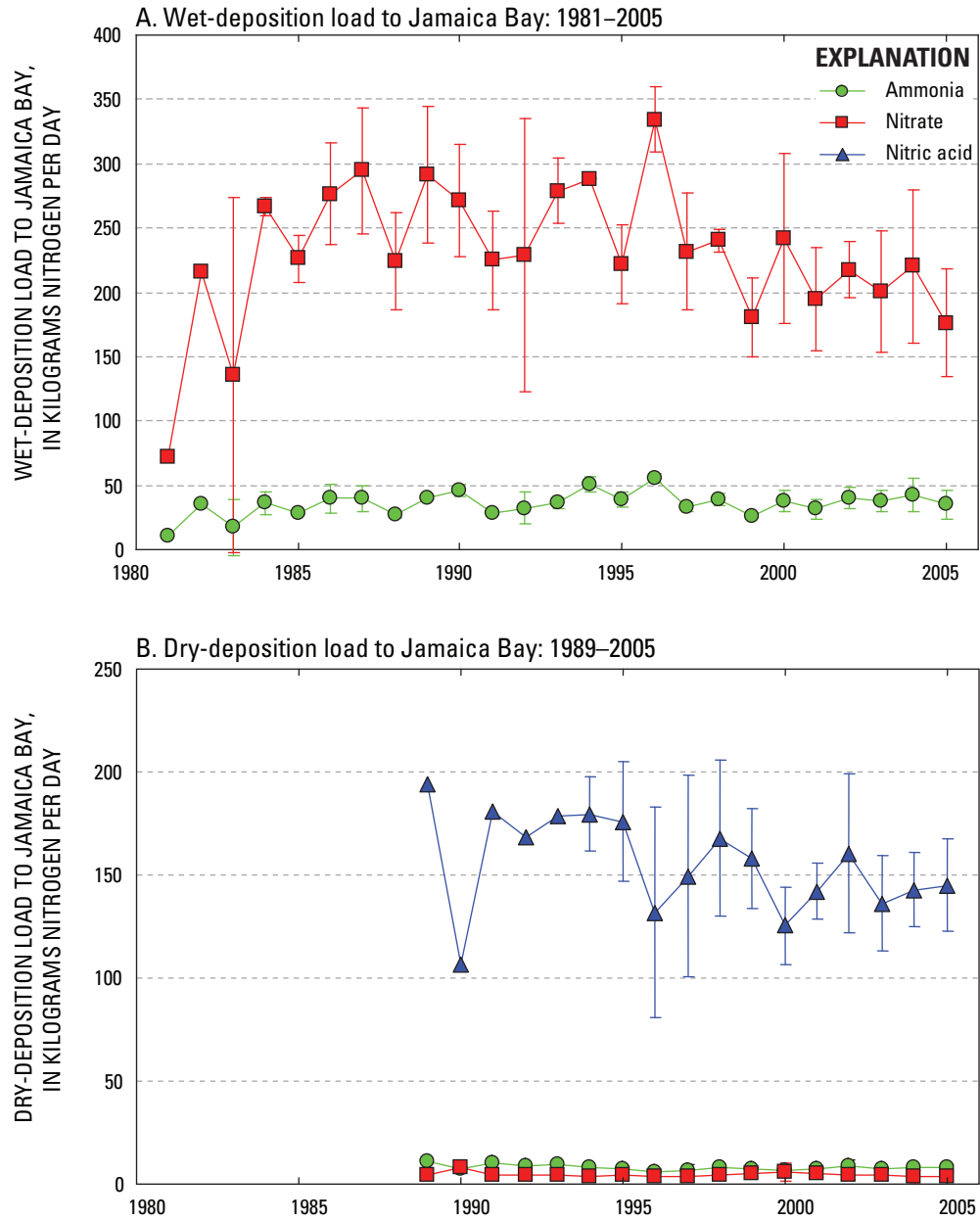


Figure 7. Atmospheric (A) wet- and (B) dry-deposition loads of nitrogen species in the Jamaica Bay area (mean \pm standard deviation) calculated from data from three Clean Air Status and Trends Network (CASTNET) sampling locations in New Jersey, New York, and Connecticut. Data from USEPA (2006b).

Table 7. Loads of nitrogen to Jamaica Bay under predevelopment and current conditions.

[kg/d, kilograms per day; na, not applicable; <, less than. Data from figs. 5 and 7, as well as tables 2, 3, 4 and 6]

Source	Predevelopment		Current conditions	
	Load (kg/d)	Percentage of total nitrogen load	Load (kg/d)	Percentage of total nitrogen load
Wastewater discharge				
Total nitrogen	na	0	13,995 ± 1218	89 ± 8
CSOs/storm-water discharge				
Nitrite plus nitrate	na	0	113.9	2
Ammonia			130.4	
Subway dewatering practices				
Nitrite plus nitrate	na	0	224 ± 17	1 ± <1
Ammonia	na		6.3 ± 1.6	
Landfill leachate				
Nitrite plus nitrate	na	0	4.6	2
Ammonia	na		256.6	
Ground-water discharge				
Nitrite plus nitrate	35.6	100	667 ± 49	4 ± <1
Ammonia	na		19 ± 4	
Atmospheric deposition (wet + dry)				
Nitrite plus nitrate plus nitric acid	0	0	368	2
Total	35.6		15,785	

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