

Estimates of Nitrogen Loads Entering Long Island Sound from Ground Water and Streams on Long Island, New York, 1985-96



U.S. Geological Survey
Water-Resources Investigations Report 00-4196

Prepared in Cooperation with
New York State Department of Environmental Conservation
and U.S. Environmental Protection Agency

Cover: The Lighthouse at Execution Rocks, designed by architect Alexander Parris, was constructed in 1849 and first lit in 1850. It stands approximately 55 feet tall and is located at the west end of Long Island Sound on a rocky reef one mile north of Sands Point. The keeper's quarters, attached to the lighthouse, was built in 1868. The name Execution Rocks is said to have been derived from a British Revolutionary War practice of chaining prisoners to the rocks and allowing them to drown when high tide came in (no one knows whether or not this is true). The lighthouse is listed in the National Register of Historic Places. Photo courtesy of Ron Busciolano (USGS)

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By Michael P. Scorca and Jack Monti, Jr.

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For additional information
write to:

U.S. Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report may be
purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Bldg. 810
Denver, CO 80225-0286

CONTENTS

Abstract	1
Introduction	2
Purpose and scope	3
Previous studies	3
Acknowledgments	4
Physiography and hydrogeology	4
Ground-water flow	6
Effects of urbanization on ground water and streamflow	7
Sanitary sewers	7
Storm sewers.....	7
Study methods and approach	8
Calculation of nitrogen loads	8
Nitrogen loads in streamflow	8
Nitrogen loads in ground-water discharge.....	9
Nitrogen loads in ground-water discharge from three land-use areas	10
Data presentation	11
Estimates of Nitrogen loads	11
Surface water	11
Geographic trends.....	11
Seasonal fluctuations	11
Long-term trends	12
Annual mean nitrogen loads	12
Ground Water.....	14
Trends in ground-water quality at selected wells	14
Discharge to Long Island Sound	17
Nitrogen load from the shallow aquifer.....	20
Nitrogen load from deep aquifers	21
Nitrogen loads from sewered, unsewered, and agricultural areas	21
Nitrogen concentration of ground water	22
Ground-water discharge.....	24
Nitrogen load	24
Previous estimates of nitrogen load for Long Island.....	25
Previous estimates of nitrogen load for Westchester County	26
Summary and conclusions	27
References cited.....	28

FIGURES

1. Map showing principal geographic features of Long Island Sound, Connecticut, and Long Island, N.Y.	2
2. Map showing locations of four selected streams that discharge to Long Island Sound from the north shore of Nassau and Suffolk Counties, N.Y.....	4
3. Generalized section showing hydrogeologic units and directions of ground-water flow on the north shore of Long Island, N.Y.	6
4. Box plots showing distribution of nitrogen concentrations in four streams on the north shore of Long Island, N.Y., 1966-96.	12
5-6 Graphs showing data on the four selected streams on the north shore of Long Island, N.Y.:	
5. Concentration of total nitrogen, 1970-96.....	13

6. A. Annual mean discharge, 1985-96, B. Annual mean nitrogen concentration, 1985-96, C. Annual mean nitrogen load, 1985-96.	15
7. Map showing locations of 15 selected wells and extent of the three selected land-use areas on the north shore of Nassau and Suffolk Counties, N.Y.	16
8-9 Graphs showing:	
8. Total nitrogen concentration in ground water on the north shore of Long Island, N.Y.:	
A. In 4 selected wells in Nassau County, 1954-96.....	17
B. In 10 selected wells in Suffolk County, 1966-88.....	18
9. Total and dissolved nitrate concentrations at well N-1298.2 in Nassau County, N.Y., 1952-84.	19
10. Map showing locations of constant-head cells in Nassau and Suffolk Counties along the north shore in the USGS Long Island regional ground-water-flow model grid.	19
11. Map showing locations of 175 monitoring wells screened in the shallow aquifer along the north shore of Long Island, N.Y.	20
12. Box plots showing distribution of nitrogen concentrations in samples from wells within one mile of the north shore of Long Island, N.Y.: A. Total nitrogen concentrations from shallow wells (less than 200 ft deep). B. Total concentration in deep wells (greater than 200 ft deep). C. Total and dissolved nitrate concentrations in deep wells screened in the Lloyd aquifer.	22
13. Map showing locations of 182 monitoring wells screened in deep aquifers and within one mile of the north shore of Long Island, N.Y.	23

TABLES

1. Generalized description of major hydrogeologic units underlying the northern part of Long Island, N.Y.	5
2. Summary statistics for discharge and water-quality data for four streams that discharge to Long Island Sound from the north shore of Long Island, N.Y.	9
3. Summary statistics for concentrations of total nitrogen in four streams that discharge to Long Island Sound from the north shore of Long Island, N.Y., 1966-96.	11
4. Estimated annual mean nitrogen loads entering Long Island Sound from four streams on the north shore of Long Island, N.Y., 1985-96.	14
5. Simulated average annual ground-water discharge to Long Island Sound from the north shore of Long Island, N.Y.	20
6. Summary statistics for concentrations of total nitrogen and total nitrate concentrations in samples from wells within one mile of the north shore of Long Island, N.Y., for which shallow- and deep ground-water data were available.	21
7. Estimates of annual nitrogen load entering Long Island Sound from shallow and deep ground water along the north shore of Long Island, N.Y., as indicated by concentrations at wells within 1 mile of north shore.	21
8. Land use in the three selected sewered, unsewered, and agricultural study areas along the north shore of Long Island, N.Y.	
9. Summary statistics for concentrations of total nitrogen in samples from selected wells in the sewered, unsewered, and agricultural areas along the north shore of Long Island, N.Y.....	23
10. Annual shallow ground-water discharge and corresponding total nitrogen loads entering Long Island Sound from the selected sewered, unsewered, and agricultural areas along the north shore of Long Island, N.Y.	24
11. Published and current estimates of annual nitrogen load entering Long Island Sound from the north shore of Long Island, N.Y.	25
12. Summary statistics for discharge and water-quality data for five streams that discharge to Long Island Sound from Westchester County, N.Y.	26

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To Obtain
<i>Length</i>		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<i>Area</i>		
acre	4,047	square meter (m ²)
square mile (mi ²)	2.59	square kilometer (km ²)
<i>Flow</i>		
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)
million gallons per year (Mgal/yr)	3,785	cubic meter per year (m ³ /yr)
<i>Load</i>		
tons per year (ton/yr)	0.9072	kilograms per year (kg/yr)
<i>Chemical Concentration</i>		
milligrams per liter (mg/L)		
<i>Other Abbreviations Used</i>		
nitrogen (N)		
less than (<)		

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Fresh ground water that discharges from the northern part of Long Island's aquifer system to Long Island Sound contains elevated concentrations of nitrogen from agricultural fertilizer, domestic waste and fertilizer, and precipitation. The nitrogen contributes to algal blooms, which consume oxygen as the algae die and decompose. The resulting low dissolved oxygen concentrations (hypoxia) adversely affect plant and animal populations in Long Island Sound.

The four major streams on the north shore of Long Island that have long-term discharge and water-quality records were selected for analysis of geographic, long-term, and seasonal trends in nitrogen concentration. Nitrogen concentrations generally decrease eastward among three Nassau County streams, then increase again at the easternmost stream, Nissequogue River in Suffolk County. A long-term (1970-96) increase in total nitrogen concentrations in the Nissequogue River also is evident. Seasonal fluctuations in nitrogen concentrations in all four streams reflect chemical reactions and microbial activity in the stream system, so total nitrogen concentrations in the three easternmost streams generally were lowest during summer and highest in winter, whereas those in the westernmost stream (Glen Cove Creek) were highest during summer and lowest in winter.

The nitrogen loads discharged to Long Island Sound from each of the four streams for each year during 1985-96 were calculated from the annual

mean total nitrogen concentration and the annual mean discharge. Nissequogue River's annual mean discharges were 3 to 6 times larger than those of Glen Cove and Mill Neck Creeks, and produced the largest annual loads of nitrogen—65 to 149 ton/yr (59,000 to 135,000 kg/yr). Cold Spring Brook had the lowest annual mean discharges and annual mean total nitrogen concentrations of the four streams; its annual mean nitrogen load ranged from 1.2 to 2.8 ton/yr (1,100 to 2,500 kg/yr).

The nitrogen load carried to Long Island Sound by shallow ground water from the north shore of Long Island was calculated from simulated shallow-aquifer discharges from Nassau and Suffolk Counties (9,200 and 21,400 Mgal/yr or 34,800,000 and 81,100,000 m³/yr, respectively) and median total nitrogen concentrations at selected wells (2.2 and 4.3 milligrams per liter as N, respectively). The resultant nitrogen load was 84 ton/yr (76,500 kg/yr) for Nassau County and 384 ton/yr (349,000 kg/yr) for Suffolk County.

The nitrogen load carried to Long Island Sound by deep ground water from the north shore was calculated from simulated deep-aquifer discharges from Nassau and Suffolk counties (13,200 and 47,300 Mgal/yr or 50,000,000 and 179,000,000 m³/yr, respectively). The median nitrogen concentrations of deep ground water for the two counties were 1.62 and 1.34 mg/L as N, respectively. The resultant nitrogen load from deep-aquifer discharge was 89 ton/yr

(81,000 kg/yr) for Nassau County and 265 ton/yr (240,000 kg/yr) for Suffolk County.

Nitrogen loads entering Long Island Sound from the shallow aquifer underlying three areas of differing land use along the north shore—a sewered residential area in Nassau County, an unsewered residential area in Suffolk County, and an agricultural area in Suffolk County—were evaluated. The agricultural area contains no major streams and, therefore, produces very little surface runoff to Long Island Sound and substantially greater shallow-aquifer discharge than in the sewered and unsewered areas. Ground water in the agricultural area also had the highest median nitrogen concentration (9.9 mg/L as N) of the three land-use areas and discharged the largest estimated nitrogen load to Long Island Sound—152 ton/yr (138,000 kg/yr), which represents about 40 percent of the estimated total nitrogen load from Suffolk County. Ground water in the sewered area had the lowest nitrogen concentration (1.9 mg/L as N) and discharged the smallest nitrogen load to Long Island Sound—7.28 ton/yr (6,600 kg/yr). The analysis

indicates that land use on the north shore of Long Island can greatly affect the nitrogen concentration of water in the shallow aquifer and the resultant nitrogen load discharged to Long Island Sound from ground water.

INTRODUCTION

Long Island Sound extends about 100 mi (160 km) eastward from New York City and lies between Connecticut and Long Island, N.Y. (fig. 1). It is used for many recreational activities, including swimming, boating, and fishing, as well as commercial harvesting of shellfish.

Freshwater entering Long Island Sound from precipitation and from streams and ground water on Long Island and Connecticut contains nitrogen in concentrations that vary seasonally and locally. Nitrogen is an essential nutrient for plant growth, but in excessive amounts it can support algal blooms that consume oxygen as the algae die and decompose (Long Island Sound Study, 1998). Dissolved oxygen concentrations can become low enough to adversely affect plant and animal populations in the Sound, a

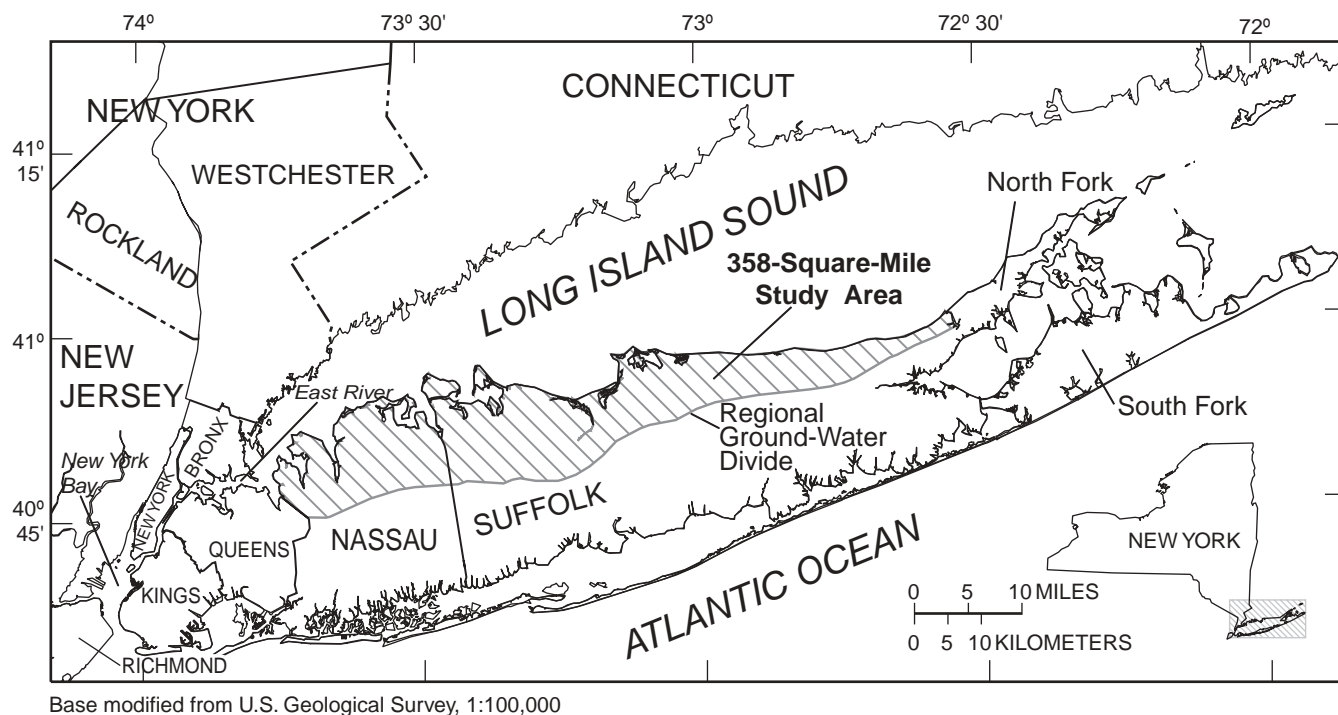


Figure 1. Principal geographic features of Long Island Sound, Connecticut, and Long Island, N.Y.

condition known as hypoxia. Nitrogen enters Long Island Sound from tributary streams, ground water, atmospheric deposition (rainfall and dryfall), and from the East River and the Atlantic Ocean (fig. 1). These sources can have elevated concentrations of nitrogen as a result of human activities and products, particularly sewage and agricultural and domestic fertilizers.

A partnership of federal, state, and local agencies sponsored by the U.S. Environmental Protection Agency (USEPA) and the States of New York and Connecticut established the Long Island Sound Study (LISS) in 1985 to research the hydrodynamic and geochemical conditions in the Sound and to support the development of management strategies to improve the water quality and the aquatic habitat for its fish and shellfish populations. As a part of this study, the U.S. Geological Survey (USGS) offices on Long Island and in East Hartford, Conn., began a 3-year investigation in 1998, in cooperation with the USEPA, the New York State Department of Environmental Conservation (NYSDEC), and the Connecticut Department of Environmental Protection, to provide estimates of nitrogen loading to Long Island Sound. The Connecticut office computed total nonpoint nitrogen loads for water years 1988-98 from watersheds draining to Long Island Sound from the north by analyzing water-quality, stream-discharge, and land-cover data. The Long Island office applied ground-water and surface-water-quality data from the USGS database to simulated ground-water-discharge values and measured stream-discharge data to obtain estimates of annual nitrogen loading from the north shore of Long Island to Long Island Sound.

The USGS study on Long Island had three major components: (1) estimation of annual mean nitrogen loads discharged by four selected streams into Long Island Sound; (2) calculation of annual nitrogen loads discharged to Long Island Sound from the shallow and deep aquifers, and (3) delineation of a sewered residential area, an unsewered residential area, and an agricultural area, for calculation of (a) nitrogen concentrations in shallow ground water in each area, and (b) annual load discharged from each area to the Sound.

Purpose and Scope

This report presents (1) geographic, seasonal, and long-term trends in nitrogen concentration in the four major north-shore streams that discharge to Long

Island Sound, (2) annual mean nitrogen concentrations in these streams, and the annual mean nitrogen loads discharged from these streams to Long Island Sound, during 1985-96, (3) nitrogen loads discharged from shallow and deep aquifers in Nassau and Suffolk Counties to the Sound, and (4) loads discharged from the shallow aquifer in three separate land-use areas, for comparison of the effects of land use on nitrogen loads entering the Sound. A brief discussion of available data and previously published load estimates from nearby Westchester County, N.Y. (fig. 1), is included.

Previous Studies

Studies that address the concentrations of nitrogen in ground water and surface water on Long Island include Perlmutter and Koch (1975), Katz and others (1980), Ragone and others (1981), and Bleifuss and others (1998). Water-quality differences between several areas of differing land use on Long Island are reported by LeaMond and others (1992), Eckhardt and others (1989), Eckhardt and Stackelberg (1995), and Pearsall (1996).

Preliminary estimates of nonpoint-source nitrogen loads entering Long Island Sound from Long Island's north shore have been developed through the use of watershed models (Karimipour, 1997). P. E. Stacey (Connecticut Department of Environmental Protection, written commun., 1999) developed estimates of nitrogen loads entering Long Island Sound from average stream discharges. Farrow and others (1986) used the National Coastal Pollutant Discharge Inventory, which was updated for base year 1984, to estimate the chemical loads entering Long Island Sound.

Several previous studies have used other comprehensive methods to compute chemical loads entering Chesapeake Bay and other coastal bays in Maryland and Virginia. Bachman and Phillips (1996) sampled the base flow of streams with differing watershed characteristics during selected seasons and estimated loads from the calculated median instantaneous yields. Phillips and others (1999) evaluated nitrate loads discharged from ground water to streams in a wide range of hydrogeomorphic regions in the Chesapeake Bay watershed and the residence time of ground water in the aquifer system before it discharges to streams. Bachman and others (1998) related ground-water discharge, base-flow nitrate yields, and hydrogeomorphic regions in the Chesapeake

Bay watershed. Dillow and Greene (1999) estimated nitrate loads entering coastal bays of Maryland.

Acknowledgments

Thanks are extended to Mark Tedesco, Director of the USEPA Long Island Sound Office, for assistance and cooperation during this project. Thanks are also extended to William McBrian of the Suffolk County Department of Public Works, Sanitation Engineering Division, and Ronald Green of the Suffolk County Planning Department, for providing maps that show the extent of sewered areas in Suffolk County, and to James Ennis of the Nassau County Department of Public Works, Division of Sanitation and Water Supply, for providing a map that shows the extent of sewered areas in Nassau County.

PHYSIOGRAPHY AND HYDROGEOLOGY

Long Island has a total area of about 1,400 mi² and is separated from the rest of New York State along its western shore by the East River and New York Bay

(fig. 1). It is bounded on the north by Long Island Sound and on the east and south by the Atlantic Ocean. The eastern part of Long Island includes two large peninsulas that are referred to as the North and South Forks, which are hydraulically separate from the main body of Long Island. A detailed physiographic description of Long Island is presented by Franke and McClymonds (1972). The 358-mi² study area extends from the regional ground-water divide to the north shore of Nassau and Suffolk Counties (fig. 1); its western boundary is the Queens County line, and its eastern boundary coincides with that of the USGS Long Island regional ground-water-flow model (Buxton and Smolensky, 1999). Kings and Queens Counties, the South Fork, and all but the western edge of the North Fork, are excluded.

The western half of Long Island's north shore is characterized by a series of necks and bays, some of which form harbors such as Port Washington and Port Jefferson (fig. 2). The eastern half of the north shore is characterized by steep sand cliffs and narrow beaches. Stream channels on the north shore generally are shorter than those on the south shore because the main topographic drainage divide is north of the

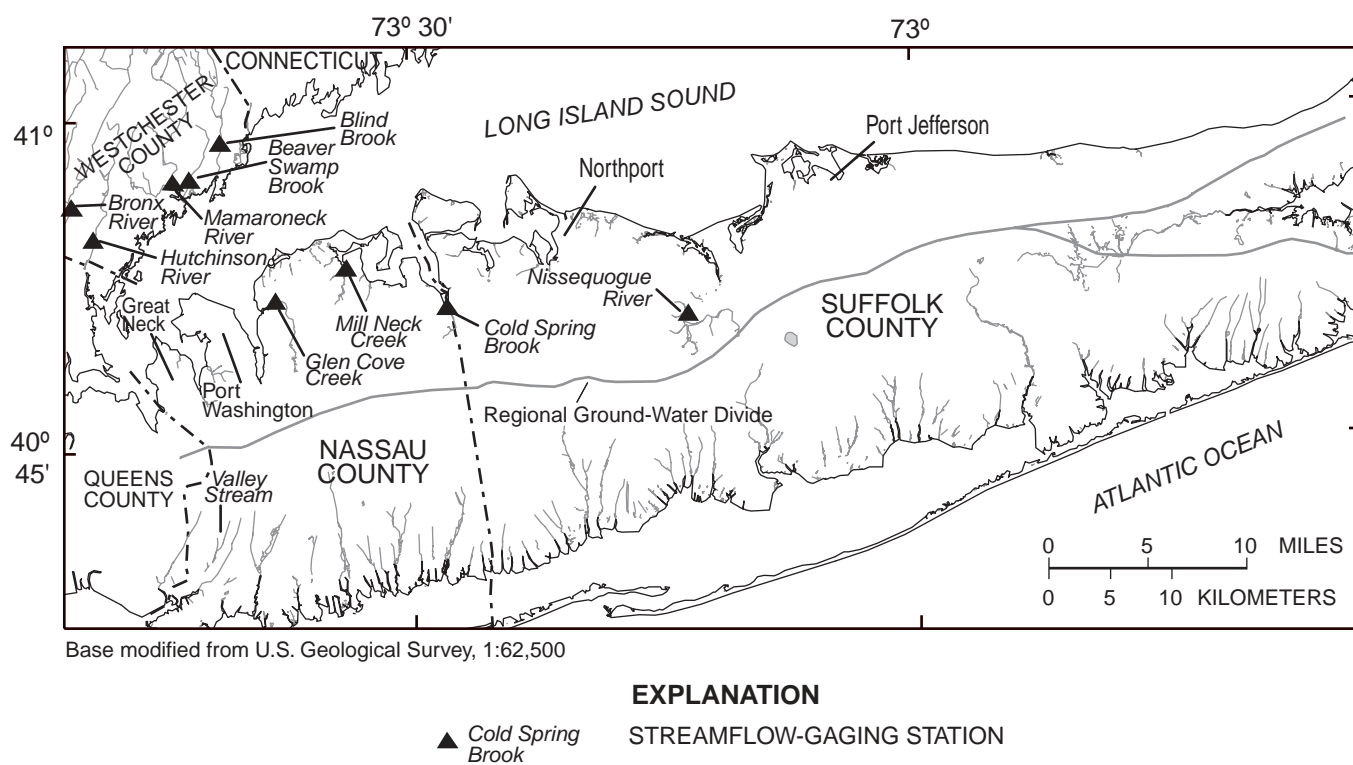


Figure 2. Locations of four selected streams that discharge to Long Island Sound from the north shore of Nassau and Suffolk Counties, N.Y.

center of the island, and the land surface in the northern half of the island generally is steeper than that of the outwash plain in the southern half. The topographic drainage area along the north shore extends from the western border of Nassau County to the eastern tip of Suffolk County and encompasses about 220 mi² (Karimipour, 1997).

Long Island is underlain by unconsolidated sediments of Late Cretaceous and Pleistocene age that were deposited on a southeastward-dipping bedrock surface. Long Island's hydrogeologic setting has been described in detail by Suter and others (1949), Jensen

and Soren (1971; 1974), and Smolensky and others (1989). A summary of the principal hydrogeologic units is given in table 1; a generalized north-south hydrogeologic section of the study area is depicted in figure 3.

The upper Pleistocene deposits, which form the uppermost major stratigraphic unit on Long Island, include moraine, till, outwash, and glaciolacustrine sediments that were deposited during the Wisconsinan glaciation of the Pleistocene Epoch. This unit consists mostly of moderately to well-sorted sand and fine gravel and is highly permeable in most places, but

Table 1. Generalized description of major hydrogeologic units underlying the northern part of Long Island, N.Y.

[Modified from Jensen and Soren (1971, table 1); Krulik and Koszalka (1983); Smolensky and others (1989, table 1), and Stumm (2001). ft, feet; ft/d, feet per day]

Series	Geologic unit	Hydrogeologic unit	Description and water-bearing character
PLEISTOCENE	Upper Pleistocene deposits	Upper glacial aquifer	Mainly brown and gray sand and gravel deposits of moderately high horizontal hydraulic conductivity (270 ft/d average for Long Island); may also include deposits of clayey till and lacustrine clay of low hydraulic conductivity. Local units are the north-shore aquifer, the north-shore confining unit, and the Smithtown clay unit. A major aquifer.
	Upper Pleistocene deposits	Smithtown clay unit ¹	Mainly brown or gray clay with some lenses of sand. Poorly permeable. Could be chronostratigraphically equivalent to the North Shore confining unit.
	Upper Pleistocene deposits	North Shore confining unit ¹	Olive-brown and olive-gray clay and silt deposits. Unit has low vertical hydraulic conductivity and confines water in underlying aquifer. Unit also contains a minor sand layer that is moderately permeable. Could be chronostratigraphically equivalent to the Smithtown clay unit.
	Upper Pleistocene deposits	North Shore aquifer ¹	Sand, silt, and gravel; brown and olive-gray, poor to moderate sorting. Moderately permeable.
UPPER CRETACEOUS	Matawan Group and Magothy Formation, undifferentiated	Magothy aquifer	Gray, white, and brownish-gray, poorly to well-sorted, fine to coarse sand of moderate horizontal hydraulic conductivity (50 ft/d). Contains much interstitial clay and silt, and lenses of clay of low hydraulic conductivity. Generally contains sand and gravel beds of low to high conductivity in basal 100 to 200 ft. A major aquifer.
	Unnamed clay member of the Raritan Formation	Raritan confining unit	Gray, black, and multicolored clay and some silt and fine sand. Unit has low vertical hydraulic conductivity (0.001 ft/d) and confines water in underlying aquifer.
	Lloyd Sand Member of the Raritan Formation	Lloyd aquifer	White and gray fine-to-coarse sand and gravel of moderate horizontal hydraulic conductivity (40 ft/d) and some clayey beds of low hydraulic conductivity.
PALEOZOIC and PRECAMBRIAN	Undifferentiated crystalline bedrock	Bedrock	Mainly metamorphic rocks of low hydraulic conductivity; considered to be the base of the ground-water flow system.

¹ Not shown in figure 3.

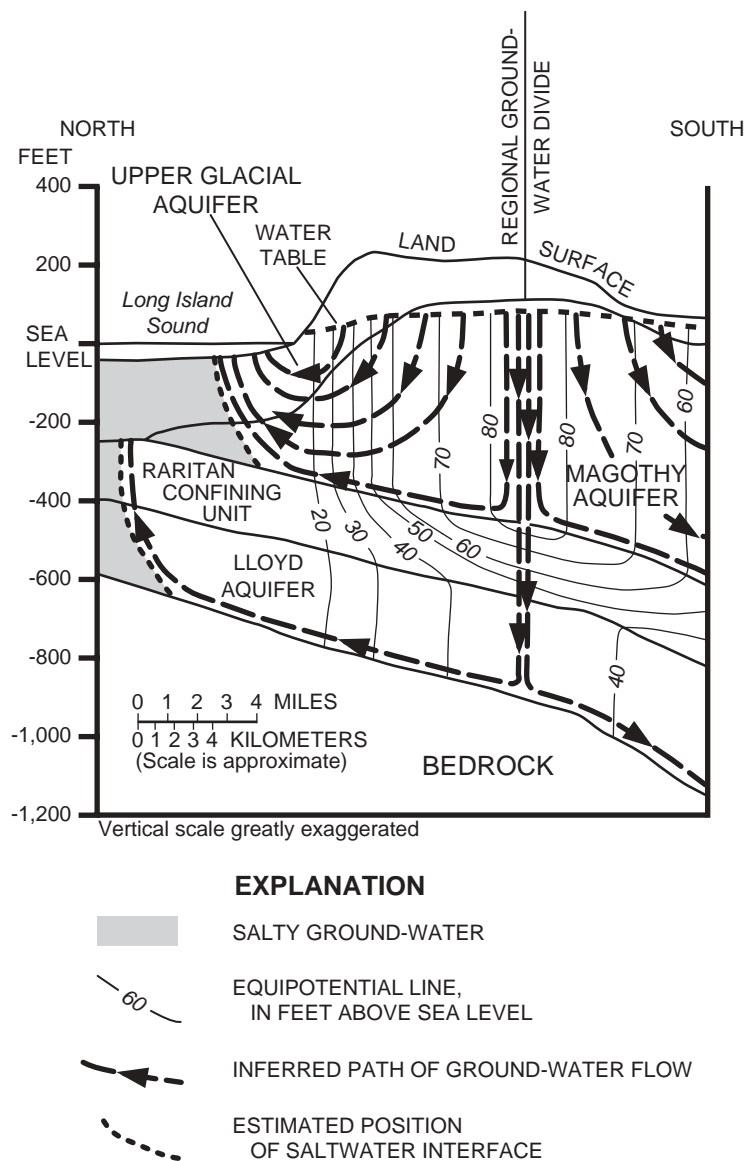


Figure 3. Generalized section showing hydrogeologic units and directions of ground-water flow on the north shore of Long Island, N.Y. (Modified from Nemickas and others, 1989, fig. 8.)

locally contains fine-grained, poorly permeable layers of silt or clay. The saturated part of the upper Pleistocene deposits forms the upper glacial aquifer, which contains the water table throughout most of Long Island and is the source of base flow to streams.

Beneath the Pleistocene deposits is a sequence of Cretaceous-aged sand, silt, and clay units overlying bedrock. The northern limits of the Cretaceous units are irregular and variable as a result of erosion by streams during the Tertiary Era and Pleistocene Epoch, and by glacial scour during the advances of the Pleistocene continental ice sheet. These units generally

do not extend far offshore beneath Long Island Sound; the terminal extent of these units is onshore in some areas (Stumm, 2001). The uppermost Cretaceous unit is the Matawan Group-Magothy Formation, undifferentiated, which forms the Magothy aquifer, the main source of water supply on Long Island. The water table is in the Magothy aquifer in parts of northern and east-central Nassau County and westernmost Suffolk County (Busciolano, 1998). Beneath the Magothy is the Raritan Formation, which consists of an unnamed clay member (the Raritan confining unit) and the Lloyd Sand Member (Lloyd aquifer), which overlies bedrock. The Raritan confining unit confines water in the underlying Lloyd aquifer.

Ground-Water Flow

The hydrologic cycle on Long Island was described at length by Franke and McClymonds (1972), who evaluated the relations among major hydrologic factors, including precipitation, evapotranspiration, direct runoff, ground-water recharge, ground-water movement, and pumpage, to develop an islandwide water budget. Precipitation is the sole source of freshwater in Nassau and Suffolk Counties. In undeveloped areas of Long Island, about 50 percent of the precipitation that falls is lost through evapotranspiration and direct runoff to streams; the other 50 percent infiltrates the soils and enters the ground-water system (Aronson and Seaburn, 1974; Franke and McClymonds, 1972).

In urbanized areas, such as parts of the north shore study area, the infiltration is considerably less, as explained further on.

The Long Island ground-water system consists of two major components—the shallow flow system, which in some places is hydraulically connected with streams, and the regional (deep) flow system. Precipitation that enters the shallow-flow system flows seaward and discharges directly to tidewater, or, if within the ground-water contributing area of a stream, it seeps into the stream channel to become base flow. Water that enters the shallow-flow system north of the regional ground-water divide (fig. 3) flows northward, and water that infiltrates south of the divide flows southward. Water that enters the deep-flow system in the area just north of the divide moves downward

through the upper glacial aquifer into the underlying Magothy and Lloyd aquifers, where it moves laterally, then vertically upward, into Long Island Sound as deep-aquifer discharge.

Franke and Cohen (1972) and Buxton and Modica (1992) estimated that ground water in the northern part of Long Island generally takes 10 to 100 years to move through the shallow flow system and subsequently discharge along the north shore. Some water that reaches the deepest parts of the system can take longer than 100 years to discharge. In some areas, water can take just a few years to travel through the system. Some water that enters the soil near the shore can take as little as a few days to discharge from the shallow aquifer.

Both studies showed that water that enters the system farther inland, near the divide, can take more than 400 years to move through the deep-flow system, although pumping can decrease this time. A study of nitrogen- and oxygen-isotope ratios, and concentrations of dissolved oxygen, indicates the age of ground water through the upper glacial and Magothy aquifers in the Northport area (fig. 2) to be less than 100 years (Bleifuss and others, 1998).

Effects of Urbanization on Ground Water and Streamflow

Continuous eastward development on Long Island throughout the 20th century has resulted in a decrease in the base flow of streams and an increase in the amount of stormflow. Factors that have contributed to this change are (1) ground-water pumping for water supply and disposal of wastewater to sanitary sewers, rather than to underground systems that return the water to the shallow aquifer; (2) construction of impervious surfaces, such as roads and parking lots, that facilitate storm runoff and prevent the infiltration of precipitation, and (3) construction of storm sewers that prevent infiltration of precipitation by routing storm runoff to streams. These practices have lowered ground-water levels substantially, even where recharge basins mitigate the loss of stormwater (Franke, 1968; Sulam, 1979).

Sanitary Sewers

The continuous discharge of cesspool and septic-tank effluent to ground water in heavily developed parts of Nassau and Suffolk Counties eventually raised

the concentrations of nitrogen and other chemicals in the upper glacial aquifer; therefore, sanitary-sewer systems that discharge to sewage-treatment plants were constructed in densely populated areas. The discharge of wastewater from the sewage-treatment plants to offshore surface-water bodies (bays, Long Island Sound, and the Atlantic Ocean) has sharply decreased aquifer contamination but removes large volumes of water from the shallow-aquifer system (Spinello and Simmons, 1992). This loss of water in several areas, particularly on the south shore of Nassau County, has resulted in water-table declines, intrusion of saltwater into aquifers, decreased base flow, and decreased shoreline and subsea discharge (Franke, 1968; Pluhowski and Spinello, 1978; Reilly and others, 1983). The effects of sewer systems on surface-water and ground-water-quality on Long Island are documented by Perlmutter and Koch (1972), Ku and Sulam (1979) and Ragone and others (1981) and on Long Island Sound by the Long Island Sound Study (1998) and P. E. Stacey (Connecticut Department of Environmental Protection, written commun., 1999).

Storm Sewers

The conversion of permeable land to impervious surfaces (such as streets, sidewalks, and parking lots) prevents the infiltration of precipitation to the water table and thereby creates large volumes of storm runoff that flow into storm-sewer systems, which discharge to nearby streams or to recharge basins. This form of stormwater disposal has three main hydrologic consequences: (1) water that flows to streams and thence to tidewater does not replenish the ground-water system, (2) peak stream discharges during individual storms typically are larger and more variable than in less developed areas (Seaburn, 1969), and (3) the ratio of surface runoff to base flow in streams that receive storm runoff increases sharply (Spinello and Simmons, 1992). Under natural (predevelopment) conditions, Long Island streams derived 95 percent of their total flow from ground water (Franke and McClymonds, 1972) and only about 5 percent from direct runoff (precipitation falling directly on a stream's surface and overland runoff flowing into the stream channel). Direct runoff represented only about 2 percent of the total precipitation (Cohen and others, 1968) because Long Island's soils and surficial sediments allow rapid infiltration.

Today, Long Island streams derive a lesser percentage of their annual flow from ground water and a greater percentage from surface runoff, primarily as a result of storm sewers and sanitary sewers. The percentages of base flow and surface runoff in selected streams on the south shore of Nassau County and southwestern Suffolk County from the 1940's to 1985 were calculated by Pluhowski and Spinello (1978), Reynolds (1982), and Spinello and Simmons (1992), and those for the four streams on the north shore of Long Island were also calculated by Reynolds (1982) for 1960-75. The most extreme example of altered relative percentages of streamflow components is Valley Stream in southwestern Nassau County, in which 100 percent of the streamflow for several years during 1976-85 was derived from storm runoff (Spinello and Simmons, 1992).

In many parts of Long Island, recharge basins are used to capture surface runoff from storm sewers and facilitate the infiltration of water to the ground-water system. Recharge to ground water in areas with recharge basins has been estimated to be about 10 percent greater than in areas without them (Ku and others, 1992).

STUDY METHODS AND APPROACH

The nitrogen data analyzed in this study were retrieved from the USGS National Water Information System (NWIS) database. In the absence of a stored value for total nitrogen, the concentrations of the four individual nitrogen components (nitrate, nitrite, ammonia, and organic nitrogen) in each sample represented in the database were summed to obtain the total nitrogen value; then the minimum, median, and maximum total nitrogen values for groups of samples were calculated. Values less than the detection limit were also ranked and included in the statistical analyses.

The total nitrogen concentration of a given sample represents the sum of (1) the combined concentrations of total nitrite and nitrate, and (2) the combined concentrations of total ammonia and organic nitrogen. These two combined values were not available for most samples, however; therefore, the concentrations of the four individual components were summed to provide total nitrogen values. This approach increased the size of the data sets because many samples have no stored value for total nitrogen. Nitrite was generally not included in the total because

its concentrations were typically 2 to 3 orders of magnitude lower than those of nitrate in most samples. Concentrations of nitrogen components that were below the detection limit were considered to be zero in this analysis. In samples for which the values of nitrogen constituents from unfiltered water were not available, concentration values from filtered water were substituted. Samples for which data on individual constituents were insufficient to provide a representative total nitrogen value were omitted from further analysis.

Calculation of Nitrogen Loads

Estimates of nitrogen loads in this report represent the average annual quantity of nitrogen discharged from streams and ground water on the north shore of Nassau and Suffolk Counties to Long Island Sound. Loads are calculated by multiplying the concentrations of total nitrogen at selected streams and groups of wells by measured or simulated average annual discharges.

Nitrogen Loads in Streamflow

Data from all four major north-shore streams were used in this study because, until recently, the streams were equipped with continuous-discharge recorders and have long records of discharge and water quality. An assessment of surface-water runoff from the drainage areas other than those of the four streams was beyond the scope of this project, but these four streams are estimated to comprise between two-thirds and three-quarters of the total surface-water discharge to Long Island Sound from Long Island (A.G. Spinello, U.S. Geological Survey, oral commun., 2000) because (1) the north shore has only a few other defined stream channels, (2) the low discharge of these other minor streams have relatively small discharges, and (3) the surficial sediments of Long Island allow rapid infiltration of precipitation and produce little direct runoff, except in urbanized areas with storm sewers that route storm runoff to streams. The network of culverts that discharge runoff directly to the Sound has not yet been fully assessed.

The largest of these streams is the Nissequogue River (fig. 2), which has a topographic drainage area of about 27 mi² and an average discharge of 42.5 ft³/s for its period of record (1944-96). The two next-largest streams—Glen Cove Creek and Mill Neck Creek—each have a drainage area of about 11 mi²;

their average discharges are 7.28 and 8.97 ft³/s, respectively, for their periods of record (1939-96 and 1937-96). The smallest stream, Cold Spring Brook, has a drainage area of 7.3 mi² and an average discharge of 2.65 ft³/s for its period of record (1950-96). USGS sample collection at the three streams in Nassau County ceased after 1996, and sample collection at Nissequogue River ceased after 1997. No samples were collected at Cold Spring Brook during 1977-91.

Geographic, seasonal, and long-term trends in nitrogen concentrations in each stream were evaluated from graphs of chemical concentrations plotted over time and in box plots (graphical representations of the statistical distributions of grouped values; Chambers and others, 1983). Examination of discharge-related trends in surface water was beyond the scope of this study because stormflow water-quality data were unavailable. In addition, the base-flow and direct-runoff components of total streamflow were quantified only for 1960-75 (Reynolds, 1982). Although most samples on which the analyses were based probably were collected at base flow, some could reflect effects of storm runoff.

Annual mean nitrogen loads for the four streams during 1985-96 were calculated as the mean stream discharge for each calendar year multiplied by the mean nitrogen concentration for that year. This method provides only an approximation of the annual load because it does not fully account for seasonal fluctuations, discharge-related effects, or stormflows. For example, Brown and others (1997) and Stockar (1994) observed changes in concentrations of constituents during storms at the headwaters of East

Meadow Brook, a stream in an urbanized setting in the southern part of Nassau County. The general pattern seen was an increase in concentrations at the beginning of storms and decreasing concentrations as the storm progressed. The decreases in concentrations (mass per volume) during stormflows generally result from dilution, although an increase in discharge generally results in an increase in load (mass per time unit).

Nitrogen Loads in Ground-Water Discharge

Preliminary estimates of the nitrogen load entering Long Island Sound from shallow and deep ground water discharge on Long Island's north shore were calculated from simulated ground-water discharges multiplied by the median total nitrogen concentrations in water from selected shallow and deep wells north of Long Island's regional ground-water divide in Nassau and Suffolk Counties. Discharges from shallow and deep aquifers were generated by the USGS Long Island regional ground-water flow model as calibrated for a steady-state simulation of 1983 (average long-term) hydrologic conditions (Buxton and Smolensky, 1999).

Wells representing shallow ground water in this analysis were less than 200 ft deep, and those representing deep ground water were more than 200 ft deep. Shallow ground water is more likely than deep water to reflect the effects of land use and the chemical concentrations of ground water that discharges to Long Island Sound. The wells selected initially were in the USGS water-quality-monitoring network, which was maintained until 1996. These wells were few and unevenly distributed, however; therefore, two additional sets of wells from the USGS database were

Table 2. Summary statistics for discharge and water-quality data for four streams that discharge to Long Island Sound from the north shore of Long Island, N.Y.

[mi², square miles; ft³/s, cubic feet per second. Discharge data from Spinello and others (1997). Locations are shown in fig. 2]

Gaging-station name	Gaging-station number	Drainage area upgradient from gaging station (mi ²)	Period of discharge record	Mean discharge (ft ³ /s)	Number of samples	Sampling date (mo/d/yr)	
						First	Last
Glen Cove Creek at Glen Cove	01302500	11	1939-96	7.28	100	5/6/66	2/12/96
Mill Neck Creek at Mill Neck	01303000	11.5	1937-96	8.97	154	5/6/66	5/22/96
Cold Spring Brook at Cold Spring Harbor	01303500	7.3	1950-96	2.65	54	5/6/66	2/12/96
Nissequogue River near Smithtown	01304000	27	1944-96	42.5	285	2/13/67	6/16/97

selected through a Geographic Information System (GIS)—those that were within 1 mi and those that were within 4 mi of the north shore. The statistical distributions of water-quality data for the 1-mi group were similar to those of the 4-mi group; therefore, the 1-mi group (175 shallow wells, 182 deep wells) was selected to represent the water quality of ground-water discharge to the Sound.

Nitrogen loads in shallow ground water were calculated as the product of (1) the median concentrations of total nitrogen for the entire period of record at the selected shallow wells, and (2) the shallow ground-water discharges generated by the regional ground-water-flow model (Buxton and Smolensky, 1999). A three-dimensional finite-difference model code (McDonald and Harbaugh, 1988) was used to construct the regional model during the 1980's. This model was developed as a tool for regional assessment of the aquifer system and to estimate effects of proposed water-supply strategies. Four model layers represent the three major aquifers; the intervening confining units are represented implicitly. The grid extends as far east as the ground-water-flow systems of the North and South Forks, which are separate from the flow system on the main body of Long Island.

Each cell in the regional flow-model grid has six faces and is square in plan view (4,000 ft on a side). The thicknesses of the cells vary, depending on the stratigraphic units. Shallow-aquifer discharge equals horizontal flow into constant-head cells, which receive no inflow (recharge) along their top face, and represents about one third of the total ground-water discharge from the north shore to Long Island Sound. Deep-aquifer discharge equals vertical flow that enters along the bottom face from the deep model layers that represent the Magothy and Lloyd aquifers and represents about two-thirds of the ground-water flow to Long Island Sound. The simulated discharges along the shoreline cell faces were cumulated (1) for Nassau and Suffolk Counties, and (2) for selected land-use areas, then multiplied by the calculated nitrogen concentrations to obtain the load discharged from the north shore as far east as the western part of the North Fork.

Total nitrogen concentrations were not calculated for samples from the deep wells because nitrate represented almost all of the total nitrogen in most samples; that is, the concentrations of ammonia, organic nitrogen, and nitrite were so low that nitrate

could be substituted for total nitrogen concentration in the load calculations. Thus, nitrogen loads for deep ground water were calculated as the product of the median concentrations of total or dissolved nitrate at the deep wells and the deep-aquifer discharges generated by the model.

Nitrogen Loads in Ground-Water Discharge from Three Land-Use Areas

The three land-use areas along the north shore that were compared in this study correspond to those used in a previous study (LeaMond and others, 1992) or were delineated from maps provided by municipalities showing the extent of sewerage areas. The objective was to indicate the effects of sanitary sewers and agriculture on the concentration of nitrogen in shallow ground water and the resultant nitrogen loads discharged to Long Island Sound by ground water. The sewerage area is in Great Neck in Nassau County (fig. 7) and is the farthest west and smallest of the three areas; about 80 percent of its area is residential and commercial land. The unsewered area is near the Nissequogue River in west-central Suffolk County; about 64 percent of this area is residential and commercial land. The agricultural area is in eastern Suffolk County and encompasses most of the western edge of the North Fork and extends as far south as the ground-water divide. The land use in the area is about 68 percent agricultural land (cropland and pasture). All three land-use areas are within the area represented by the USGS regional ground-water-flow model.

The primary source of land-use data was an USEPA land-cover data set (U.S. Environmental Protection Agency Region II digital land-cover data set, written commun. 1997), which contained (1) Landsat Thematic Mapping (TM) data for 1988-89 and 1991-93; (2) population-density and housing-density data; (3) USGS Land-Use and Land-Cover data (LUDA); and (4) National Wetland Inventory (NWI) data. The land-cover data are categorized into 15 land-use classes.

Water-quality data for wells in the three land-use areas were used to reevaluate nitrogen concentrations in the shallow (upper glacial) aquifer. The median nitrogen concentration that was calculated for the selected wells in each land-use area for the entire period of record was then multiplied by the corresponding simulated ground-water discharge from

that area to obtain the annual nitrogen load entering Long Island Sound as shallow-aquifer discharge.

Data Presentation

The annual values presented herein for discharges and nitrogen concentrations in streams represent calendar years rather than water years¹. The term “total” nitrogen concentration refers to the stored value for nitrogen concentration or the summed concentrations of the nitrogen components in each sample. The term “total” concentration of nitrate, nitrite, ammonia, and organic nitrogen refers to the concentrations of the components in unfiltered water.

ESTIMATES OF NITROGEN LOADS

Nitrogen enters Long Island Sound from precipitation, streams, ground water, the East River, and the Atlantic Ocean. Some of the nitrogen is derived from natural sources, but additional and varying amounts are contributed by human activities and disposal practices.

Nitrate is the major component of total nitrogen in streams on Long Island; therefore, the trends in total nitrogen concentration are similar to trends in nitrate concentration. Ammonia generally occurs at concentrations less than 0.2 mg/L as N. Concentrations of nitrite, the smallest component of total nitrogen, are 2 to 3 orders of magnitude lower than those of nitrate in most samples.

Surface Water

The NWIS database contains water-quality data for 54 samples from Cold Spring Brook, 154 samples from Mill Neck Creek, and 100 samples from Glen Cove Creek, from 1966 through 1996 and 285 samples collected from the Nissequogue River from 1967 through 1997 (table 3).

Geographic Trends

Concentrations of nitrogen in the four streams generally decrease eastward in Nassau County (from

¹A water year extends from October 1 of the preceding year through September 30 of the named year.

Table 3. Summary statistics for concentration of total nitrogen in four streams that discharge to Long Island Sound from the north shore of Long Island, N.Y., 1966-96.

[Concentrations are in milligrams per liter. Stream locations are shown in fig. 2]

Statistic	Glen Cove Creek	Mill Neck Creek	Cold Spring Brook	Nissequogue River
Number of samples	82	117	35	204
minimum	2.66	0.58	0.48	0.13
median	4.1	1.6	0.99	2
maximum	6.9	3.88	2.07	4.87

Glen Cove Creek to Cold Spring Brook), then increase at Nissequogue River in Suffolk County (fig. 4). The lowest minimum, median, and maximum concentrations of total nitrogen were at Cold Spring Brook, and the highest minimum, median, and maximum concentrations of total nitrogen were at Glen Cove Creek (table 3), whose median total nitrogen concentration (4.13 mg/L as N) for 1966-96 was about twice as high as that at Nissequogue River (2 mg/L as N). Glen Cove Creek is in the most urbanized setting of the four major streams and could be affected more than the others by products of human activity, such as lawn fertilizers and animal waste in street runoff. It also probably receives the largest volume of storm runoff from storm-sewer systems that drain local streets.

Seasonal Fluctuations

Concentrations of total nitrogen, in water samples from the four streams during 1970-96 are plotted in figure 5. Seasonal fluctuations in nitrogen concentrations reflect chemical reactions and biological activity in the streams. Although most samples probably were taken at base flow, some samples could show effects of storm runoff, which can contain nitrogen from fertilizers or animal wastes (Brown and others, 1997).

Total nitrogen concentrations in the three easternmost streams generally display similar patterns over time; their lowest values occur during summer, and their highest values occur in winter. The westernmost stream, Glen Cove Creek, shows the opposite trend. Total nitrogen concentrations in Glen Cove Creek and Mill Neck Creek fluctuated about 3 mg/L as N within each year of the early 1980's, but this range decreased to about 1 mg/L as N during

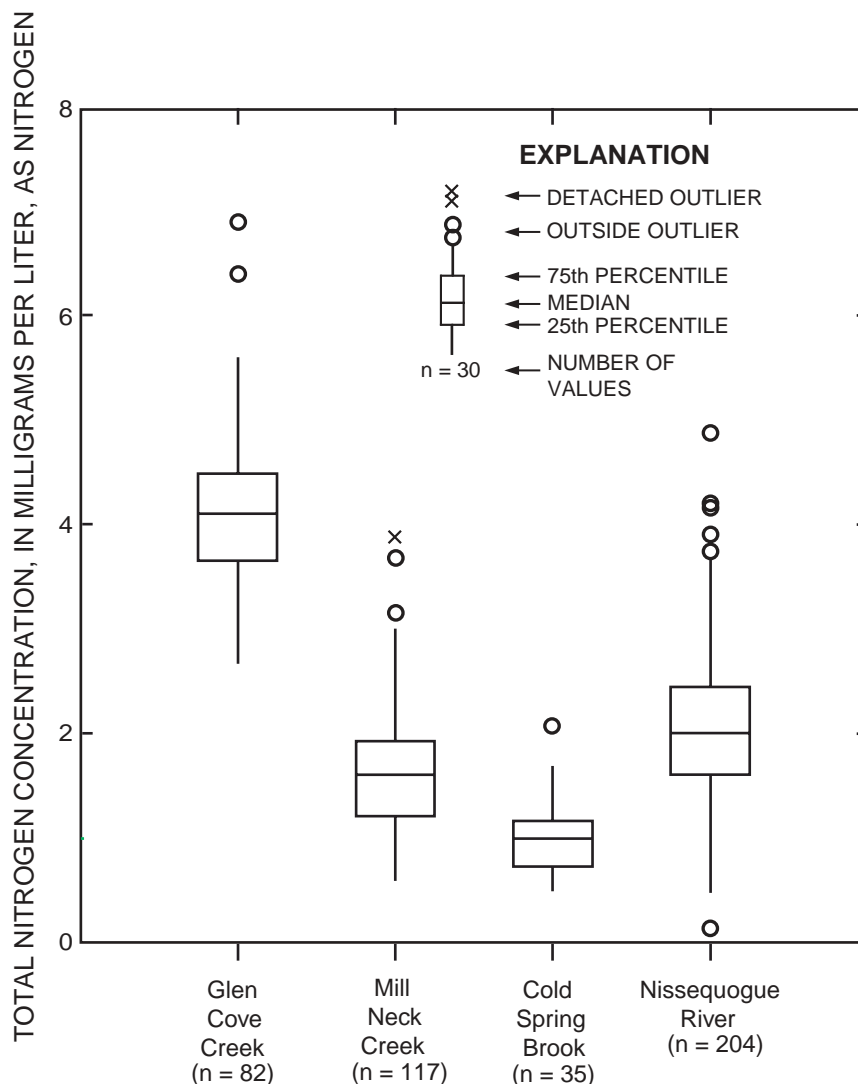


Figure 4. Distribution of nitrogen concentrations in four streams on the north shore of Long Island, N.Y., 1966-96. (Locations are shown in fig. 2.)

1990-96. Cold Spring Brook's yearly range was less than 1 mg/L as N during the 1970's, except 1973, and was about 1 mg/L as N in the 1990's. The yearly range in total nitrogen concentration in the Nissequogue River increased over time—the annual range was about 1 mg/L as N in the 1970's and about 2 mg/L as N in the 1990's.

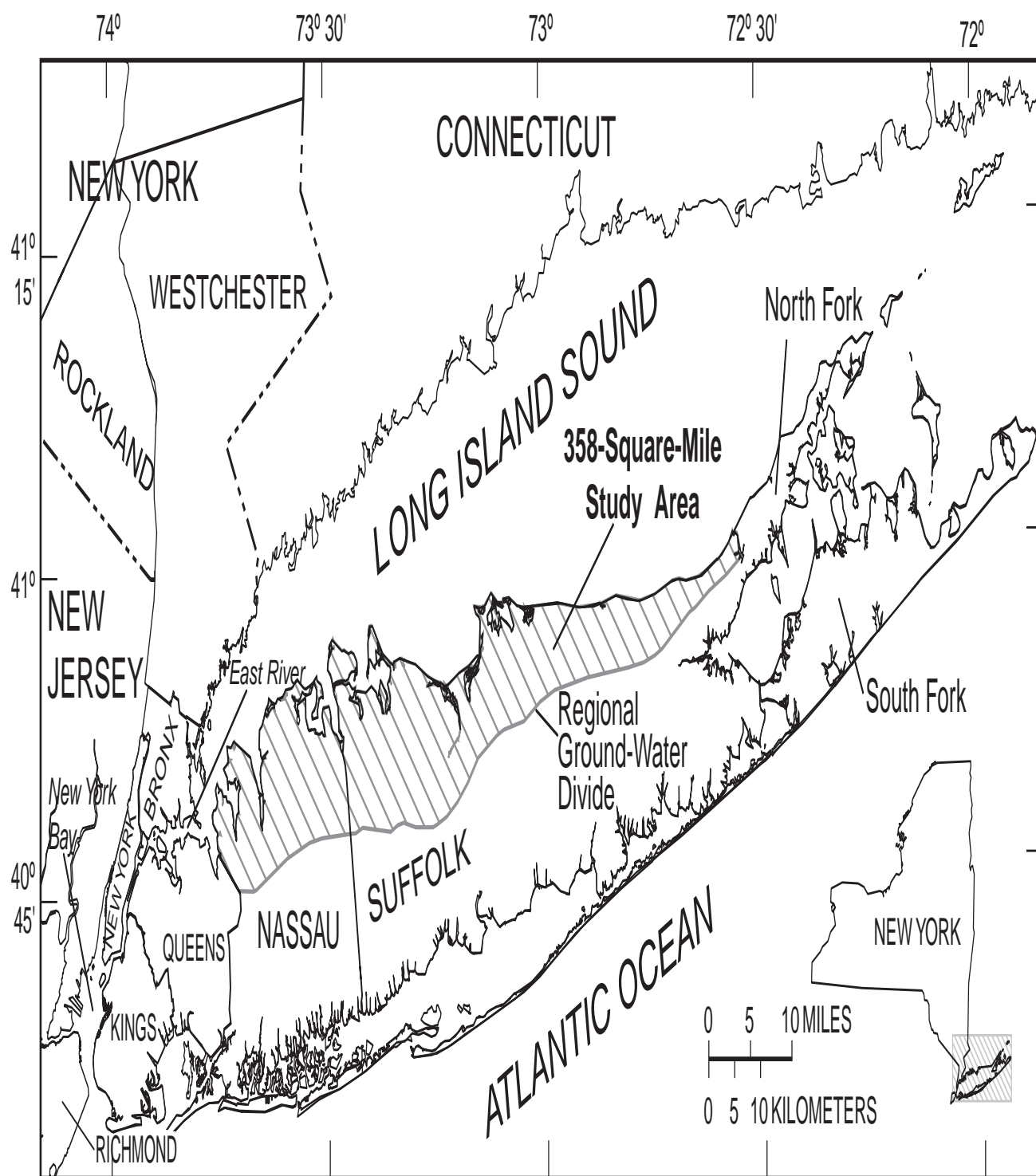
Long-Term Trends

Only the long-term record for the easternmost stream (Nissequogue River) shows a clear trend—an increase in total nitrogen concentration—which probably results from increasing urbanization. Before 1978, the concentration of total nitrogen rarely exceeded 2 mg/L as N, but during the 1980's and

1990's, the annual maximum concentrations often exceeded 3 mg/L as N, and annual minimum concentrations were often about 2 mg/L as N.

Annual Mean Nitrogen Loads

Nissequogue River produces larger annual nitrogen loads than the other three streams (65 to 149 ton/yr; 59,000 to 135,000 kg/yr) because its annual mean discharges are greater (table 4). The annual mean discharges of Glen Cove Creek and Mill Neck Creek are similar to each other (fig. 6A and table 2), but Glen Cove Creek has a higher nitrogen concentration than Mill Neck Creek and, therefore, larger annual loads (figs. 6B and 6C). Cold Spring Brook was sampled during only 4 years in the 1990's;



Base modified from U.S. Geological Survey, 1:100,000

Figure 5. Concentration of total nitrogen in four streams on the north shore of Long Island, N.Y., 1970-96. (Locations are shown in fig. 2.)

this stream has the lowest annual mean discharges and the lowest annual mean nitrogen concentrations of the four streams. Annual mean nitrogen concentrations for this stream ranged from 0.9 to 1 mg/L as N, and the annual mean nitrogen load ranged from 1.2 to 2.8 ton/yr (1,100 to 2,500 kg/yr).

Estimated annual nitrogen loads for the four streams combined ranged from 98 to 216 ton/yr (89,000 to 196,000 kg/yr). Nissequogue River contributed 60 to 75 percent of the annual loads, and Cold Spring Brook, during the 4 years in which it was sampled, represented only 1 to 2 percent of the annual loads.

Ground Water

The USGS collected water samples from selected north-shore wells for several decades before 1996, but few data are available for use in estimating nitrogen loading from shallow and deep aquifers after 1989. Despite the paucity of data from individual wells, plots of nitrogen concentrations over time at several wells for which long-term data are available (locations shown in fig. 7) are presented in figure 8.

Trends in Ground-Water Quality at Selected Wells

Nitrogen concentrations in samples of ground water from all of the selected wells ranged widely over time, but long-term and geographic trends could be observed in the data from some of the wells. The nitrogen concentrations in the large majority of samples from the four wells in Nassau County were

generally less than 5 mg/L as N. In the western half of Suffolk County, the maximum nitrogen concentrations in samples from most wells during their periods of record were about 5 mg/L as N, but it exceeded 10 mg/L as N at some wells. Several samples from the two wells in the agricultural land-use area in the eastern half of Suffolk County contained nitrogen concentrations above 10 mg/L as N.

Nitrogen concentrations at well N-4388, on the western border of the sewered area (discussed later on) in southern Great Neck (fig. 8A), show a generally increasing trend during 1954-84 and ranged from about 1.5 to 4.5 mg/L as N. Nitrogen concentrations at well N-6087, in Port Washington, increased from about 1 mg/L as N during the 1960's to about 4 mg/L as N in the 1970's and remained above 3 mg/L as N during the 1980's. Nitrogen concentrations at well N-1176, in Old Westbury near the ground-water divide in central Nassau County, generally were about 2 mg/L as N, but the concentrations fluctuated widely during 1977-85.

Total nitrogen concentrations at well N-8877, on the eastern border of the sewered area in southern Great Neck (fig. 7), fluctuated widely during the 1970's and early 1980's, and thereafter remained generally consistent. Review of the nitrogen-component concentrations in the samples indicated that nitrate concentrations at this well were lower (mostly less than 0.5 mg/L as N) than those at the other three Nassau County wells. Organic nitrogen concentration sometimes was relatively high at N-8877 and, at these times, was the major component of total nitrogen concentration; total nitrogen

Table 4. Estimated annual mean nitrogen loads entering Long Island Sound from four streams on north shore of Long Island, N.Y., 1985-96

[ton/yr, tons per year; kg/yr, kilograms per year. Dashes indicate no samples collected. Locations are shown in fig. 2]

Year	Glen Cove Creek		Mill Neck Creek		Cold Spring Brook		Nissequogue River	
	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr
1985	35	32,000	13	12,000	--	--	87	79,000
1986	36	33,000	14	13,000	--	--	99	89,000
1987	36	32,000	15	14,000	--	--	96	87,000
1988	28	25,000	16	15,000	--	--	65	59,000
1989	38	34,000	22	20,000	--	--	110	100,000
1990	33	30,000	19	17,000	--	--	149	135,000
1991	32	29,000	14	12,000	--	--	140	127,000
1992	25	22,000	12	11,000	3	2,400	107	97,000
1993	24	22,000	11	10,000	2	1,600	103	93,000
1994	27	25,000	14	13,000	2	1,600	92	83,000
1995	20	18,000	10	8,800	1	1,100	67	61,000
1996	31	28,000	14	13,000	--	--	86	78,000

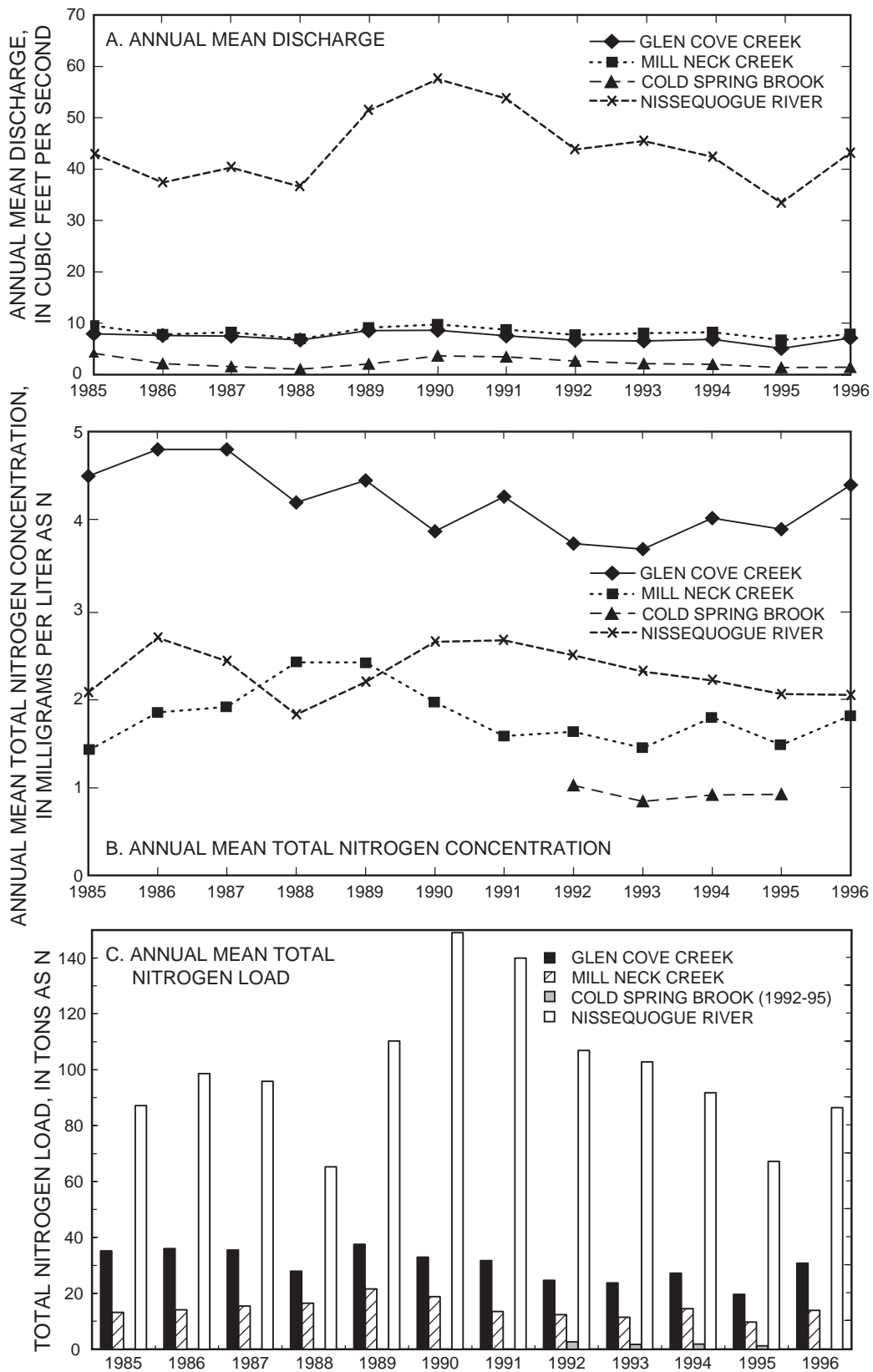
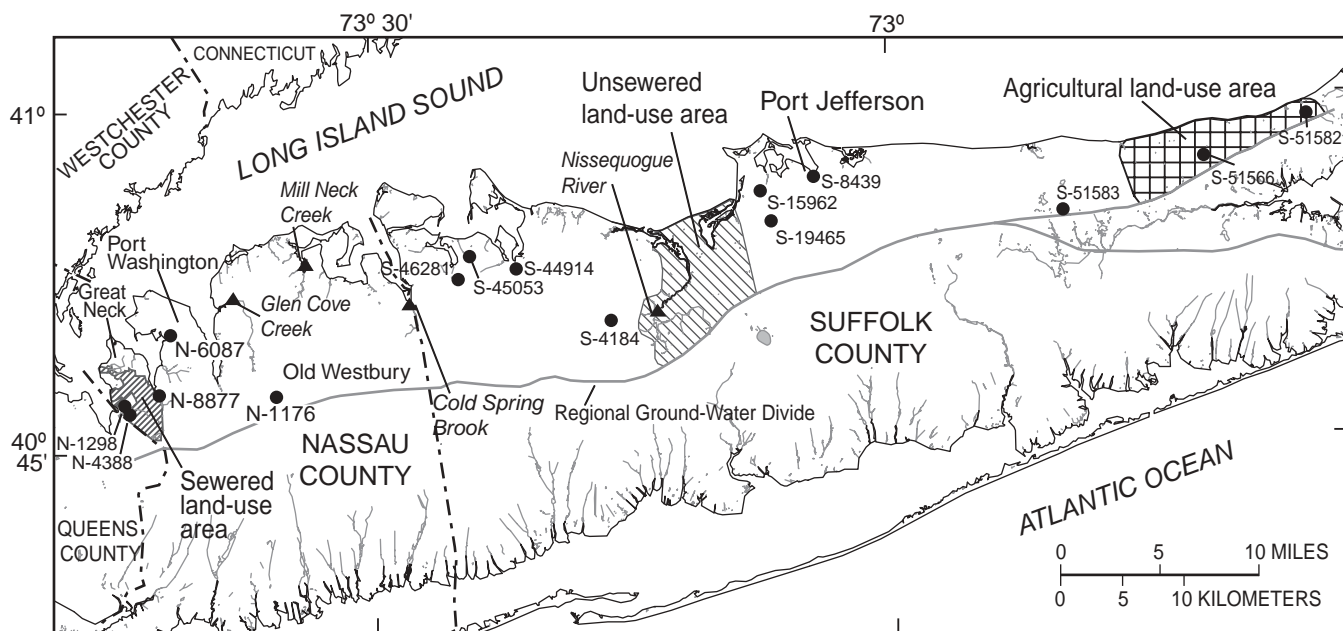


Figure 6. Data for the four selected streams on the north shore of Long Island, N.Y., 1985-96. (Locations are shown in fig. 2): A. Annual mean discharge, B. Annual mean nitrogen concentration, 1985-96, C. Annual mean nitrogen load, 1985-96.



Base modified from U.S. Geological Survey, 1:62,500

EXPLANATION

- S-4184 MONITORING WELL -- Number assigned by New York State Department of Environmental Conservation.
- ▲ Cold Spring Brook STREAMFLOW-GAGING STATION

Figure 7. Locations of 15 selected wells and extent of the three selected land-use areas on the north shore of Nassau and Suffolk Counties, N.Y.

concentrations at these times exceeded 1 mg/L as N. Ammonia concentrations at this well sometimes were relatively high also (> 0.5 mg/L as N). The relatively high concentrations of organic nitrogen and ammonia could indicate anoxic conditions in ground water in this area.

Total nitrogen concentrations in two of three wells (S-44914 and S-45053) in northwestern Suffolk County (fig. 7) varied widely during the 1970's and 1980's (fig. 8B). Those at well S-46281 were the highest of the three and, from the late 1970's to 1985 (fig. 8B), showed an increasing trend to about 10 mg/L as N.

Nitrogen concentrations at well S-4184, west of the Nissequogue River and near the unsewered area (discussed further on), were variable and generally above 8 mg/L as N. Total nitrogen concentrations at the three wells (S-8439, S-15962, and S-19465) in the northern part of central Suffolk County, just east of the unsewered area show differing patterns. Those at S-8439 display a clearly increasing trend over time, but the concentrations did not exceed 1.3 mg/L as N. Nitrogen concentrations at well S-15962 declined

from about 6 mg/L as N in the early 1970's to less than 2 mg/L as N in the early 1980's but also were highly variable; during 1981-85 they increased to more than 5 mg/L as N. Nitrogen concentrations at well S-19465 increased from less than 0.5 mg/L as N in the early 1970's to 5 mg/L as N in 1980, then declined to about 3 mg/L as N during 1980-82, and increased to about 4 mg/L as N from 1983 through 1986. The fluctuations in nitrogen concentration in these wells could result from changes in residential development over the past 3 decades and from the effects of local sanitary-sewer systems.

The lowest total nitrogen concentrations detected in this study were at well S-51583, which is downgradient from a forested area of central Suffolk County to the west of the agricultural study area (fig. 7). Total nitrogen concentrations at this well generally were less than 1 mg/L as N, except in a few samples in which the organic nitrogen concentration exceeded 1 mg/L as N.

The highest total nitrogen concentrations detected in this study were at wells S-51566 and S-51582, in the agricultural study area in eastern Suffolk County.

Total nitrogen concentrations in several samples from well S-51566 exceeded 15 mg/L as N, and those at well S-51582 exceeded 10 mg/L as N in several samples, but decreased after the early 1980's (fig. 8B).

Discharge to Long Island Sound

Ground water north of the regional ground-water divide discharges to Long Island Sound unless it is withdrawn from the aquifers by pumping wells. Ground-water flowpaths and travel times in the aquifer system are affected by the hydraulic properties of the hydrogeologic units and by stresses imposed by urbanization, such as pumping. Under natural (predevelopment) conditions, water that discharges from the deep (Magothy and Lloyd) aquifers to the Sound can be in the ground-water system for more than 400 years (Franke and Cohen, 1972) and probably has not been affected chemically by human activities. Water in the Lloyd aquifer contains less nitrogen than water in the other aquifers; the median nitrate concentration in samples from wells screened in the Lloyd aquifer in Nassau County within 1 mi of the coast was 0.44 mg/L as N. Median nitrate concentrations in samples from the Magothy aquifer in 1989 in undeveloped areas were less than 0.3 mg/L as N (Pearsall, 1996). In some developed areas, however, pumping has drawn contaminated water from the upper part of the aquifer system into the deep aquifers (Eckhardt and Pearsall, 1989), where it affects water quality. An example is in northwestern Nassau County at well N-1298.2 (fig. 9), which is screened in the Lloyd aquifer. Nitrate concentrations in samples from this well generally increased from less than 0.5 mg/L as N during the 1960's to greater than 1 mg/L as N after 1976, but remained less than 2 mg/L as N through 1984 (fig. 9). Median nitrate concentrations in samples from deep wells in long-term sewered, recently sewered, and unsewered areas near the ground-water divide were found to be 3.55, 2.36, and 0.60 mg/L as N, respectively (Stackelberg, 1995). The elevated concentrations in the two sewered areas are the result of past human activities.

Discharge to Long Island Sound is represented in the USGS Long Island regional flow model (Buxton and Smolensky, 1999) by flow into constant-head cells along the north shore of Nassau and Suffolk Counties (fig. 10). Shallow discharge is from the uppermost model layer and is considered to represent only shallow ground water, which generally is younger and more likely to be affected by human activities than

deep ground water. Simulated shallow aquifer discharge (horizontal flow into the constant-head cells) totaled 9,200 Mgal/yr (34,800,000 m³/yr) from Nassau County and 21,400 Mgal/yr (81,100,000 m³/yr) from Suffolk County (table 5). Deep-aquifer discharge is represented by the vertical flow into constant-head cells and represents the combined

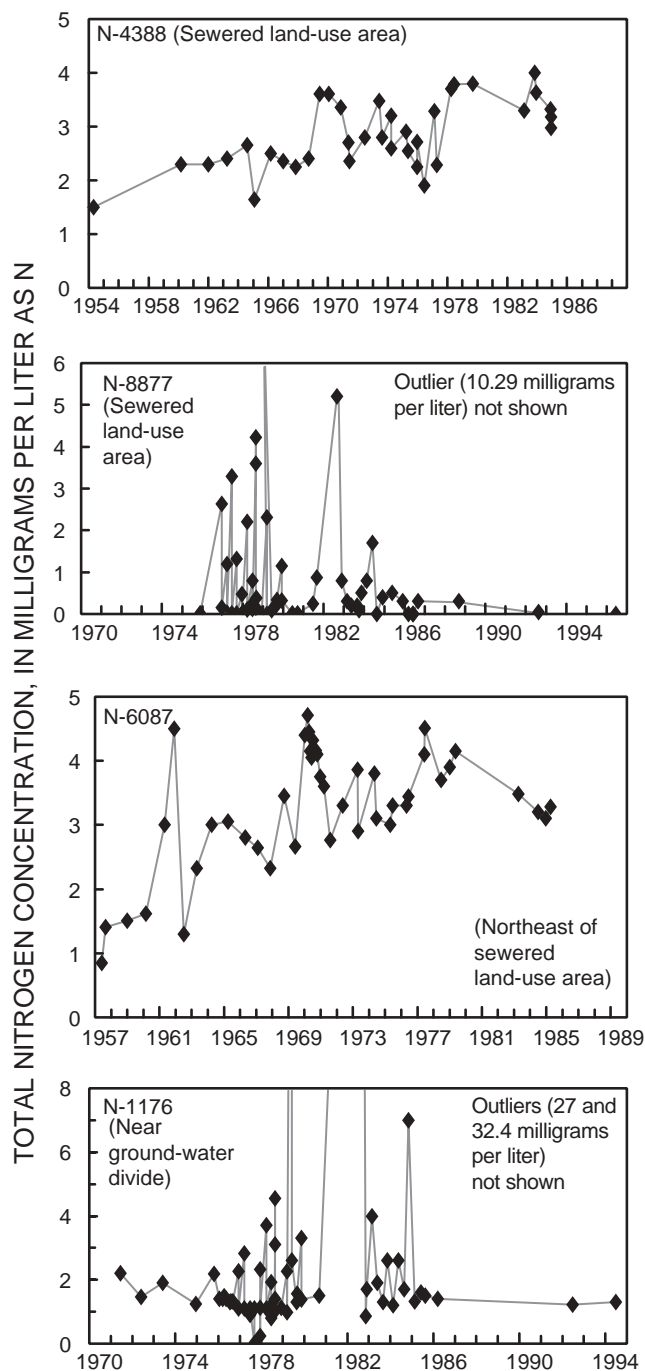


Figure 8A. Total nitrogen concentration in four selected north-shore wells in Nassau County, N.Y., 1954-96. (Well locations are shown in figure 7.)

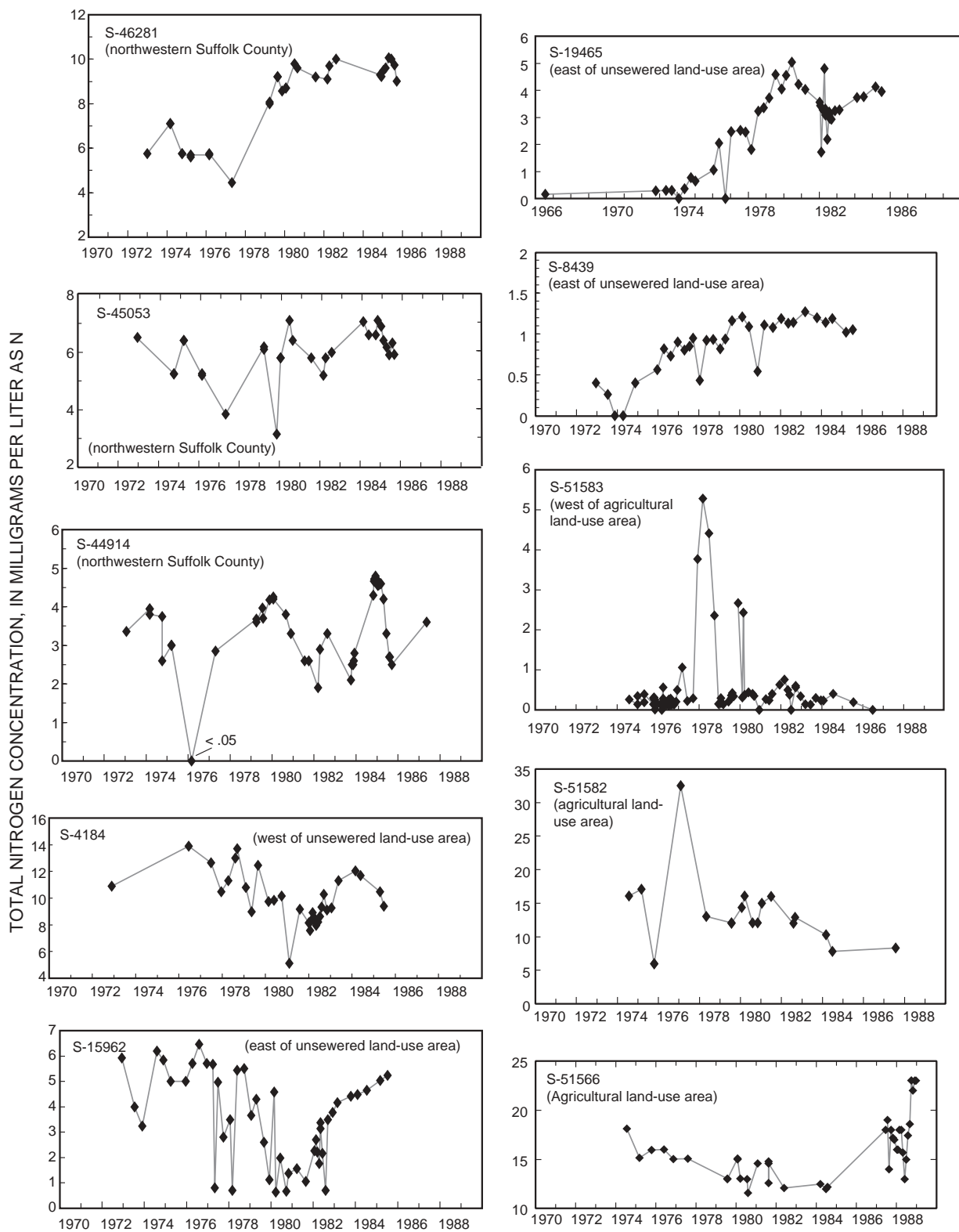


Figure 8B. Total nitrogen concentration in 10 selected north-shore wells in Suffolk County, N.Y., 1966-88. (Well locations are shown in figure 7.)

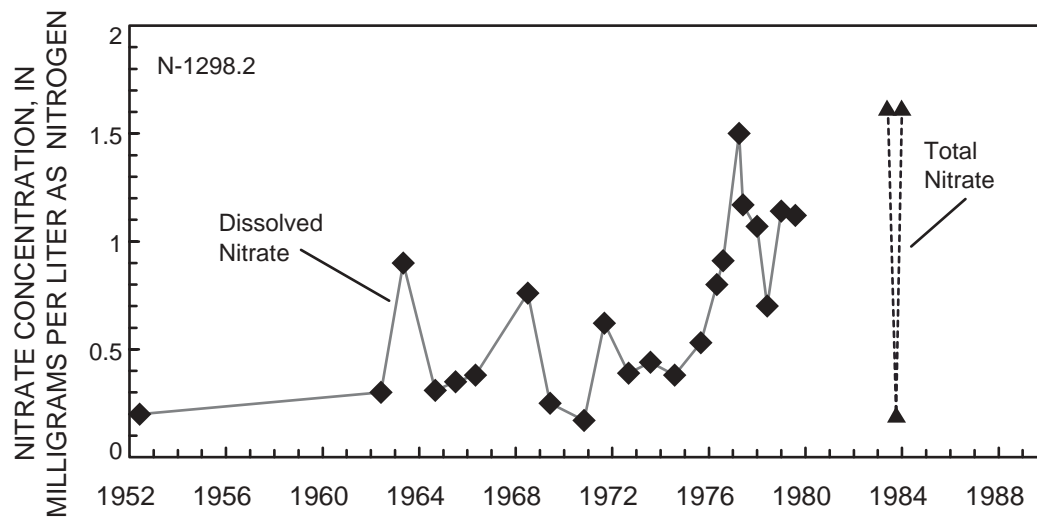
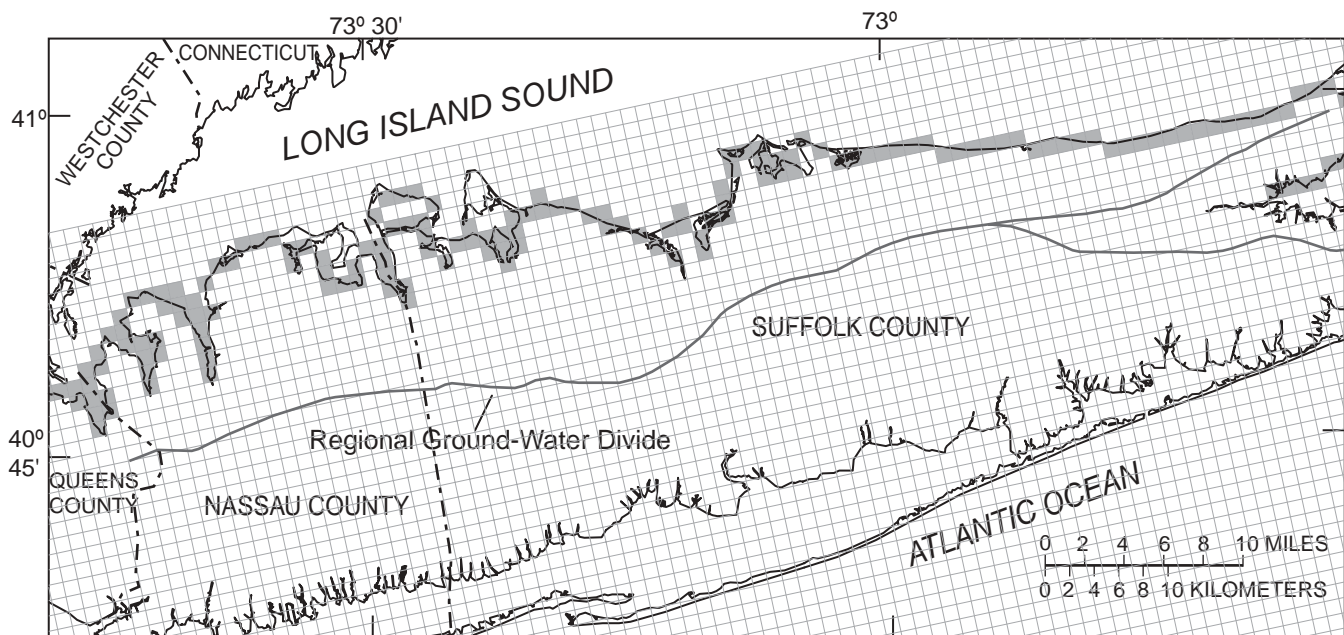


Figure 9. Total and dissolved nitrate concentrations at well N-1298.2 in Nassau County, N.Y., 1952-84 (Location is shown in fig. 7).



EXPLANATION

- MODEL GRID CELL
- CONSTANT-HEAD CELL

Figure 10. Locations of constant-head cells in Nassau and Suffolk Counties along the north shore in the USGS Long Island regional ground-water-flow model grid (Modified from Buxton and Smolensky, 1999, fig. 3B).

discharges from model layers that represent the Magothy and Lloyd aquifers. Simulated deep aquifer discharges totaled 13,200 Mgal/yr (50,000,000 m³/yr) from Nassau County and 47,300 Mgal/yr (179,000,000 m³/yr) from Suffolk County (table 5). Deep-aquifer discharge represents about two-thirds of the ground water discharged from Long Island's north shore to Long Island Sound. The age of water in the deep aquifers was not evaluated as part of this study because particle-tracking analysis was beyond the scope of the project.

Nitrogen Load from the Shallow Aquifer

Water-quality data for at least one sample from each of 175 shallow wells (<200 ft deep) within 1 mi of the coast are available in the USGS-NWIS database. (Well locations are shown in fig. 11.) These wells provided 1,648 samples, 1,380 of which had sufficient information to provide values for total nitrogen concentration (table 6). The median concentration of total nitrogen for the period of record

Table 5. Simulated average annual ground-water discharge to Long Island Sound from the north shore of Long Island, N.Y.

[Mgal/yr, million gallons per year; m³/yr, cubic meters per year]

County	Shallow-aquifer discharge		Deep-aquifer discharge	
	Mgal/yr	m ³ /yr	Mgal/yr	m ³ /yr
Nassau	9,200	34,800,000	13,200	50,000,000
Suffolk	21,400	81,100,000	47,300	179,000,000
Total	30,600	115,900,000	60,500	229,000,000

(1946-96) for those samples in Nassau County was 2.2 mg/L as N; values ranged from below detection limit (<0.05 mg/L as N) to 17.2 mg/L as N. The median concentration for the 1-mi group in Suffolk County was 4.3 mg/L as N; the values ranged from below the detection limit (<0.5 mg/L as N) to 32.5 mg/L as N. Multiplying the simulated discharges from the shallow aquifer by the respective median nitrogen concentrations of 2.2 and 4.3 mg/L as N for Nassau

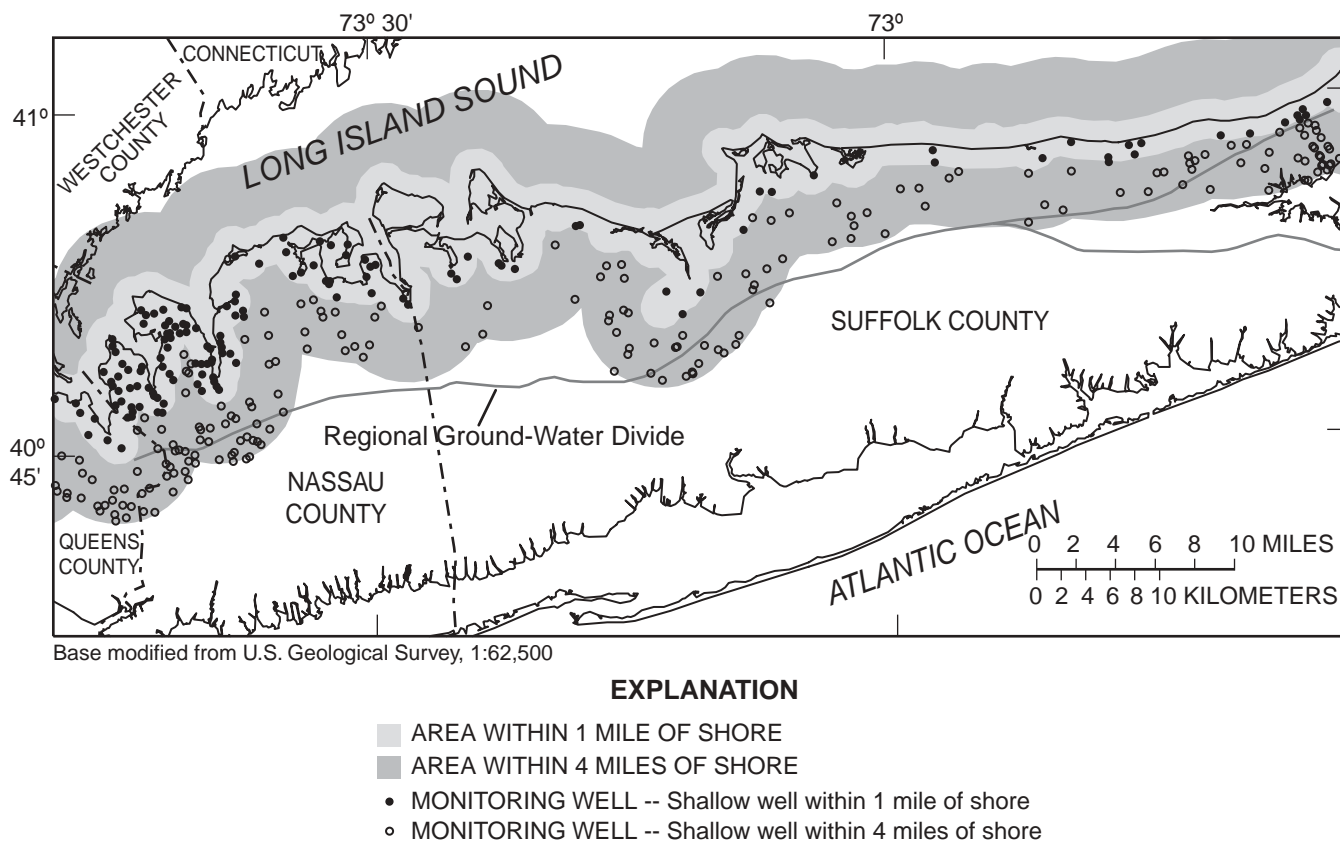


Figure 11. Locations of 175 monitoring wells screened in the shallow aquifer along the north shore of Long Island, N.Y.

Table 6. Summary statistics for concentrations of total nitrogen and total nitrate concentrations in samples from wells within one mile of the north shore of Long Island, N.Y., for which shallow- and deep ground-water data were available

[Concentrations are in milligrams per liter as N]

Statistic	Shallow ground water			Deep ground water		
	Nassau	Suffolk	Total	Nassau	Suffolk	Total
Number of wells and samples						
Wells with water-quality data	135	40	175	137	45	182
Samples with water-quality data	1,056	592	1,648	1,656	875	2,531
Samples with nitrate concentration	155	448	603	201	826	1,027
Samples used to calculate total nitrogen load	815	565	1,380	--	--	--
Concentrations						
	Total nitrogen			Total nitrate		
Minimum	<0.05	<0.05		0.01	<0.01	
Median	2.2	4.3		1.62	1.34	
Maximum	17.2	32.5		20	13.6	

and Suffolk Counties gave nitrogen loads of 84 and 384 ton/yr (76,500 and 349,000 kg/yr), respectively (table 7). The statistical distribution of total nitrogen concentrations in samples from these wells is depicted in a box plot in figure 12.

Nitrogen Load from Deep Aquifers

Water-quality data for at least one sample from each of 182 deep wells within 1 mi of the shore are available in the USGS-NWIS database. (Well locations are shown in fig. 13). These wells provided 2,531 samples, 1,027 of which included total nitrate concentration (table 6). Box plots showing the statistical distributions of total nitrogen and nitrate concentrations at these wells are included in figure 12. The median concentration of total nitrate in the 1-mi group in Nassau County was 1.62 mg/L as N; values ranged from 0.01 mg/L as N to 20 mg/L as N. The median concentration for Suffolk County was 1.34 mg/L as N; the values ranged from less than 0.01 mg/L as N to 13.6 mg/L as N. Multiplying the simulated deep-aquifer discharges by the respective median

nitrogen concentrations of 1.62 and 1.34 mg/L as N for Nassau and Suffolk Counties, respectively, gave total nitrate loads of 89 and 265 ton/yr (81,000 and 240,000 kg/yr) (table 7).

Nitrogen Loads From Sewered, Unsewered, and Agricultural Areas

Long Island's population density generally decreases eastward with increasing distance from New York City. The western part of Long Island typically has little or no agriculture and contains mostly medium- to high-density suburban residential communities (Long Island Regional Planning Board, 1982) that contain 5 to 20 persons per acre (U.S. Bureau of the Census, written commun., 1987).

Nassau and Suffolk Counties became increasingly urbanized throughout the 20th century, and water-management projects, such as the construction of sanitary-sewer systems and recharge basins, have been undertaken since the 1920's. Eleven sewage-treatment plants on the north coast of Long Island discharge

Table 7. Estimates of annual nitrogen load entering Long Island Sound from shallow and deep ground water along the north shore of Long Island, N.Y., as indicated by concentrations at wells within 1 mile of north shore

[mg/l, milligrams per liter; ton/yr, tons per year; kg/yr, kilograms per year]

County	Shallow ground water			Deep ground water		
	Median total nitrogen concentration (mg/L as N)	Annual total nitrogen load		Median total nitrate concentration (mg/L as N)	Annual total nitrate load	
		ton/yr	kg/yr		ton/yr	kg/yr
Nassau	2.2	84	76,500	1.62	89	81,000
Suffolk	4.3	384	349,000	1.34	265	240,000
Total		468	425,000		354	321,000

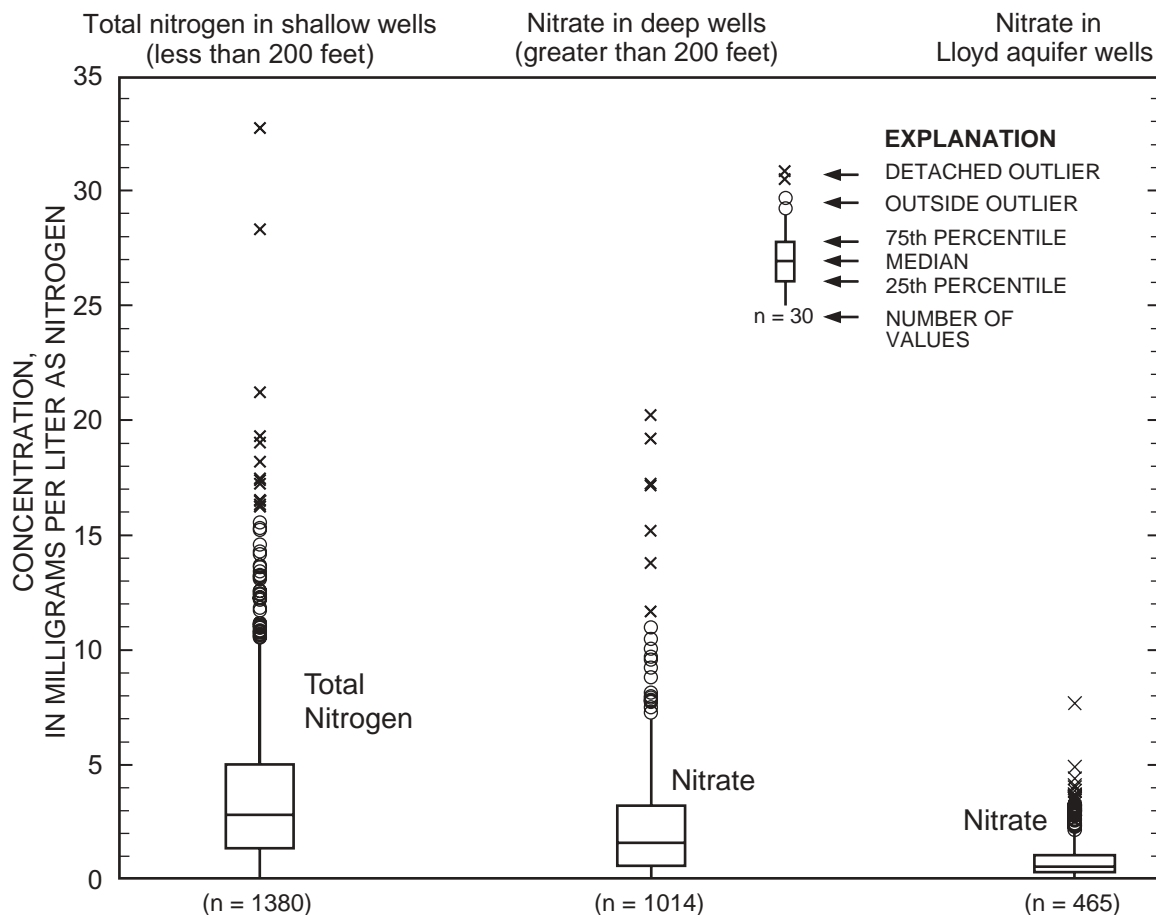


Figure 12. Distribution of nitrogen concentrations in samples from wells within 1 mile of the north shore of Long Island, N.Y.: A. Total nitrogen concentrations in shallow wells (less than 200 feet deep). B. Total nitrate concentrations in deep wells (greater than 200 feet deep). C. Total and dissolved nitrate concentrations in deep wells screened in the Lloyd aquifer.

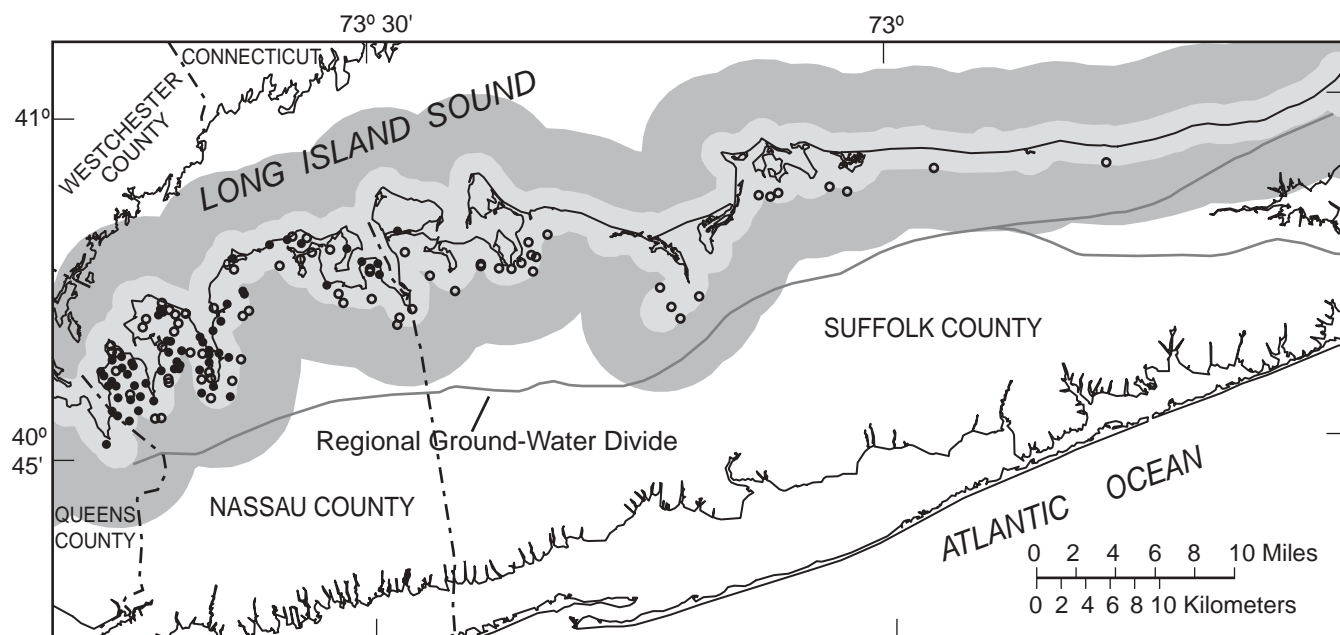
treated water to bays and to Long Island Sound, but their service areas extend over less than 10 percent of the north shore area. In Suffolk County, some suburban areas are serviced by local sewage-treatment plants that discharge treated water through infiltration basins, but most of the county is unsewered.

The total area, and the percentage, of land occupied by each of 15 land-use classes within the three selected land-use areas described previously are given in table 8. The predominant land use in the sewered area is residential, which accounts for 76 percent of the total area. A little more than half of the unsewered area is low-density residential (1 to 4 dwellings per acre), and an additional 7.5 percent is high-density residential. The agricultural area is less than 3 percent residential and about 68 percent agricultural (cropland and pasture). Forested land

represents about a quarter of the unsewered and agricultural areas (26 and 23 percent, respectively), but only about 11 percent of the sewered area.

Nitrogen Concentration of Ground Water

The lowest median nitrogen concentration for the three study areas was in the sewered area (1.9 mg/L as N, table 9); this is lower than the median for the 1-mi group of wells in Nassau County (2.2 mg/L as N, table 9). The median nitrogen concentration for the unsewered area was 3.7 mg/L as N—higher than that for the sewered area but lower than that of the 1-mi group in Suffolk County (4.3 mg/L as N, table 7). The agricultural area had the highest median nitrogen concentration (9.9 mg/L as N)—about twice as high as the median for the 1-mi group in Suffolk County.



Base modified from U.S. Geological Survey, 1:62,500

EXPLANATION

- AREA WITHIN 1 MILE OF SHORE
- AREA WITHIN 4 MILES OF SHORE
- MONITORING WELL -- Deep well within 1 mile of shore
- MONITORING WELL -- Deep well within 1 mile of shore and screened in Lloyd aquifer

Figure 13. Locations of 182 monitoring wells screened in deep aquifers and within 1 mile of the north shore of Long Island, N.Y.

Table 8. Land use in the three selected land-use areas (sewered, unsewered, and agricultural) along the north shore of Long Island, N.Y.

[Data from U.S. Environmental Protection Agency Region II digital land-cover data set, written commun. 1997; mi², square miles. Locations are shown in fig. 7]

Land-Use Class	Sewered area		Unsewered area		Agricultural area	
	Percentage of total area	Area (mi ²)	Percentage of total area	Area (mi ²)	Percentage of total area	Area (mi ²)
Open water	0.99	0.05	1.66	0.45	0.18	0.04
Low-density residential	44.49	2.32	51.86	14.09	2.42	.52
High-density residential	31.90	1.66	7.5	2.04	.22	.05
Commercial/industrial	4.04	.21	4.27	1.16	1.35	.29
Pasture/hay	0	0	2.04	.55	34.42	7.46
Row crop	.34	.02	1.50	.41	33.46	7.25
Other grasses	6.04	.31	4.06	1.10	1.6	.35
Forest, evergreen	.97	.05	6.25	1.70	1.65	.36
Forest, mixed	7.84	.41	15.25	4.14	18.19	3.94
Forest, deciduous	2.55	.13	1.86	.51	5.85	1.27
Wetland, woody	.62	.03	.72	.20	.09	.02
Wetland, emergent growth	.22	.01	2.09	.57	.09	.02
Quarry/strip mine/gravel pit	0	0	.03	.01	.32	.07
Bare rock/sand	0	0	.91	.25	.16	.04
Transitional barren	0	0	0	0	0	0
Total	100	5.20	100	27.18	100	21.68

Ground-Water Discharge

Discharges of shallow ground water simulated by the regional flow model (Buxton and Smolensky, 1999) were summed for each of the three land-use areas (table 9). Because the sewered area encompasses most of the Great Neck peninsula (fig. 7), the simulated shallow-aquifer-discharge from the entire neck (930 Mgal/yr; 3,500,000 m³/yr) was used to represent the discharge from the sewered area. Ground-water discharge from the unsewered area totaled 660 Mgal/yr (2,500,000 m³/yr), and that from the agricultural area totaled 3,710 Mgal/yr (14,060,000 m³/yr). Some shallow ground water in the sewered and unsewered areas discharges to local streams as base flow, but no major streams are present in the agricultural area; therefore, shallow aquifer discharge along the shore of the agricultural area is substantially greater than that in the sewered and unsewered areas.

In the regional flow model, ground water discharges into constant-head cells that parallel the north shore (fig. 10). The discharge through the constant-head-cell faces is dependent on model-cell thickness, the hydraulic conductivity value assigned to the aquifer, and head differences. In the current analysis, simulated discharge through the modeled length of coastline (cumulated lengths of model's shoreline constant-head-cell faces), and the nitrogen concentrations in the land-use areas, had a greater effect on total loads than the size of the land-use areas. The modeled lengths of shoreline were 9.85 mi for the

Table 9. Summary statistics for concentrations of total nitrogen in samples from selected wells in the sewered, unsewered, and agricultural areas along the north shore of Long Island, N.Y.

[Concentrations are in milligrams per liter. Locations are shown in fig. 7]

Statistic	Land-Use Area		
	Sewered	Unsewered	Agricultural
Number of wells and samples			
Wells with water-quality data	31	11	24
Samples with water-quality data	305	152	270
Samples used to calculate total nitrogen load	240	146	235
Concentrations			
	Total nitrogen concentration		
Minimum	0.02	0.03	0.06
Median	1.9	3.7	9.9
Maximum	13.0	31.1	32.5

sewered area and 11.4 mi each for the agricultural and unsewered areas.

Nitrogen Load

The sewered area discharged the smallest nitrogen load to Long Island Sound—7.28 ton/yr (6,600 kg/yr; table 10). The unsewered area discharged 10.1 ton/yr (9,200 kg/yr) as shallow-aquifer discharge, but the Nissequogue River, which drains the unsewered area, also discharges the largest nitrogen load from streamflow to Long Island Sound.

The agricultural area, which had the highest nitrogen concentration and the largest shallow-aquifer discharge, produced the largest load—152 ton/yr (138,000 kg/yr)—about 40 percent of the total estimated shallow-aquifer discharge from Suffolk County (table 7). This analysis indicates that land use greatly affects the nitrogen concentration in ground water and the resultant nitrogen load discharged to Long Island Sound from shallow aquifers.

Table 10. Annual shallow ground-water discharge and corresponding total nitrogen loads entering Long Island Sound from the sewered, unsewered, and agricultural areas along the north shore of Long Island, N.Y.

[Mgal/yr, million gallons per year; m³/yr, cubic meters per year; mg/L, milligrams per liter; ton/yr, tons per year; kg/yr, kilograms per year. Locations are shown in fig. 7]

Land-use area	Shallow ground-water discharge		Median total nitrogen concentration at selected wells mg/L as N	Annual total nitrogen load from shallow ground water	
	Mgal/yr	m ³ /yr		ton/yr	kg/yr
Sewered	930	3,500,000	1.9	7.28	6,620
Unsewered	660	2,500,000	3.7	10.1	9,180
Agricultural	3,710	14,060,000	9.9	152	138,600

Previous Estimates of Nitrogen Load for Long Island

Previous investigators developed estimates of nitrogen load from the watershed area that drains to Long Island Sound from Nassau and Suffolk Counties—that is the area north of Long Island's topographic drainage divide—that are based on different methods (Farrow and others, 1986; Karimipour, 1997; and P. E. Stacey, Connecticut Department of Environmental Protection, written commun., 1999). Farrow and others (1986), using data from the National Coastal Pollutant Discharge Inventory, estimated the nitrogen load from a 255-mi² area in Nassau and Suffolk Counties that produces urban and nonurban runoff to total 634 ton/yr (575,000 kg/yr). Karimipour (1997), using four watershed models, estimated nitrogen loads from Nassau and Suffolk Counties to range from 496 to 728 ton/yr (450,000 to 660,000 kg/yr). P. E. Stacey (Connecticut Department of Environmental Protection, written commun., 1999) used average stream-discharge values and estimated nitrogen inputs from nonpoint and atmospheric sources to develop export coefficients for several types of land cover. Multiplying these coefficients by the corresponding land-surface areas within each watershed resulted in an estimated load of 702 ton/yr (636,000 kg/yr) from Nassau and Suffolk Counties.

The previous estimates used techniques that either explicitly or implicitly estimate surface-water loads. However, these methods were developed and tested for the mainland (continental United States) where virtually all ground water eventually becomes surface water. Thus, these methods are really estimates of the sum of surface- and ground-water components. The present study evaluates the load

from ground water separately from that of surface water. Therefore, the surface-water loads developed in previous studies should be compared to the sum of the surface- and ground-water loads developed in this present study.

In this study, the estimated combined annual nitrogen loads for the four major streams on the north shore during 1985-96 averaged 148 ton/yr (134,000 kg/yr) and ranged from 98 to 216 ton/yr (89,000 to 196,000 kg/yr). As discussed in a previous section, these four streams are assumed to contribute most of the surface-water discharge from Long Island to the Sound (A.G. Spinello, U.S. Geological Survey, oral commun., 2000).

This study also evaluated the shallow-aquifer loads and the deep-aquifer loads separately. The nitrogen load from shallow-aquifer discharge totaled 468 ton/yr (425,000 kg/yr), and that from deep-aquifer discharge totaled 354 ton/yr (321,000 kg/yr; table 7); together these give a total of 822 ton/yr (746,000 kg/yr).

The estimated load from shallow-aquifer discharge and the four streams totaled 617 ton/yr, which is similar to the estimates obtained by the previous investigators (table 11). An additional 354 ton/yr from deep-aquifer discharge results in a combined average load from surface- and ground-water discharges of 970 ton/yr (880,000 kg/yr).

Some of the possible reasons that the estimate developed in this report is larger than those published in previous reports are that 1) storm flow usually has lower average concentrations than base flow, and applying base flow concentrations to storm flows could overestimate loads, and 2) the estimate in this report includes a deep-aquifer component that is probably not adequately accounted for by the previous estimates, particularly because the regional ground-

Table 11. Published and current estimates of annual nitrogen load entering Long Island Sound from the north shore of Long Island, N.Y. [mi², square miles; kg, kilograms]

	Farrow and others (1986)	Karimipour (1997)	Stacey (1999) ¹	USGS (this study)			
				Surface water ²	Shallow aquifer	Deep aquifers	Combined surface and ground water
Watershed area, mi ²	255	220	235	57	358	358	358
Annual load	634 tons 575,000 kg	496 to 728 tons 450,000 to 660,000 kg	702 tons 636,000 kg	148 tons 134,000 kg	468 tons 425,000 kg	354 tons 321,000 kg	970 tons 880,000 kg

¹ Connecticut Department of Environmental Protection, written commun.
² Data represent the four north-shore streams described herein.

water divide is south of, rather than coincident with, the topographic drainage divide that was used to develop surface-water watershed areas.

Previous Estimates of Nitrogen Load for Westchester County

Historical discharge records for five streams in Westchester County (fig. 2) that discharge to Long Island Sound are available in the USGS-NWIS database. These streams—Blind Brook, Beaver Swamp Brook, Mamaroneck River, Hutchinson River, and Bronx River—were equipped with continuous-stage recorders and were operated during 1945-89 (table 12). The Hutchinson and Bronx Rivers pass through Bronx County before discharging into the East River and Long Island Sound. The Bronx River has the largest drainage area and the largest average discharge of the five streams (26.5 mi² and 42.7 ft³/s), and Beaver Swamp Brook has the smallest (4.59 mi² and 6.51 ft³/s).

The NWIS database contains historical water-quality data for samples collected from the five streams during the 1970's (table 12). Blind Brook was sampled the most frequently (8 samples), and Hutchinson River was sampled the least frequently (1 sample). The Department of Environmental Engineering at Manhattan College has collected water-quality and discharge data at Blind Brook and the Mamaroneck River since 1997. Streamflow samples are collected weekly and during stormflows and analyzed for nitrogen, bacteria, and phosphate concentrations, and for physical properties.

The loads of selected constituents entering Long Island Sound from a 101.5-mi² area in Westchester County were estimated by Farrow and others (1986). The estimated total nitrogen loads from urban runoff totaled 222 ton/yr (201,000 kg/yr), and those from nonurban runoff totaled 9.1 ton/yr (8,250 kg/yr).

Two estimates of nitrogen loads discharged from Westchester County to Long Island Sound were developed by P. E. Stacey (Connecticut Department of Environmental Protection, written commun., 1999) from average stream discharge. These are (1) a “natural” nitrogen load—the average load that would have been derived from atmospheric deposition and nonpoint-source runoff from a mostly forested drainage area (the probable condition of the land during the precolonial period), and (2) an “enriched” nitrogen load—the average load currently produced as a result of human contributions from point-, nonpoint-, and atmospheric sources. The estimated current nitrogen load derived from Westchester County (1,010 ton/yr; 914,000 kg/yr) represents the estimated “natural” nitrogen load of 43 ton/yr (39,000 kg/yr) and the “enriched” nitrogen load of 965 ton/yr (875,000 kg/yr). The same investigator (P. E. Stacey, Connecticut Department of Environmental Protection, written commun., 1999) also estimated a 52.5-mi² area in Westchester County that drains to Long Island Sound to be 91 percent urban (medium- and high-density residential and commercial land) and 9 percent forest (including wetland, marsh, soil, and water bodies); the total nitrogen load estimated for urban areas totaled 184 ton/yr (167,000 kg/yr), and that for the forested areas totaled 5.46 ton/yr (4,950 kg/yr).

Table 12. Summary statistics for discharge and water-quality data for five streams that discharge to Long Island Sound from Westchester County, N.Y.

[mi², square miles; ft³/s, cubic feet per second. Discharge data from Firda and others (1990). Locations are shown in fig. 2]

Gaging-station name	Gaging-station number	Drainage area upgradient from gaging station (mi ²)	Period of discharge record	Average discharge (ft ³ /s)	Total number of samples	Period of water-quality record
Blind Brook at Rye	01300000	9.20	1945-89	15.7	8	1971-76
Beaver Swamp Brook at Mamaroneck	01300500	4.59	1945-89	6.51	5	1971-72
Mamaroneck River at Mamaroneck	01301000	23.1	1945-52 1955-89	35.9	5	1971-72
Hutchinson River at Pelham	01301500	5.76	1945-89	7.17	1	1972
Bronx River at Bronxville	01302000	26.5	1945-89	42.7	5	1970-76

SUMMARY AND CONCLUSIONS

Fresh ground water that discharges from the northern part of Long Island to Long Island Sound contains nitrogen from human activities, as well as from natural sources. Nitrogen is an essential nutrient for plant growth and, in excessive amounts, can contribute to algal blooms that consume oxygen as the algae die and decompose. The resulting condition, known as hypoxia, adversely affects plant and animal populations in Long Island Sound.

Four streams on the north shore of Long Island that discharge to Long Island Sound and for which long-term discharge and water-quality data are available (Glen Cove Creek, Mill Neck Creek, Cold Spring Brook, and Nissequogue River) were selected for analysis of geographic, seasonal, and long-term trends in total nitrogen concentrations. Nitrate is the major component of total nitrogen in streams on Long Island; therefore, trends in total nitrogen concentration are similar to trends in total nitrate concentration.

The four streams indicate an eastward decrease in nitrogen concentrations within northern Nassau County, but an increase from Nassau County to the Nissequogue River in Suffolk County, the easternmost of the four streams. The Nissequogue River data indicate a long-term (1970-96) increase in total nitrogen concentrations.

Chemical reactions and microbial activity within the stream systems cause seasonal fluctuations in nitrogen concentrations in the streams. Total nitrogen concentrations in the three easternmost streams generally display a seasonal pattern similar to that of nitrate—the lowest concentrations generally occur during summer, and the highest are in winter. The opposite trend is seen in the westernmost stream (Glen Cove Creek).

The estimated annual nitrogen load discharged to Long Island Sound from each stream for 1985-96 was calculated as the product of annual mean total nitrogen concentration for the stream and the annual mean discharge. Nissequogue River produced the greatest annual loads (65 to 149 ton/yr; 59,000 to 135,000 kg/yr) because its annual mean discharges are greater than those of the other streams. Cold Spring Brook has the lowest annual mean discharges and the lowest annual mean nitrogen concentrations of the four streams. The annual mean total nitrogen load was 1.2 to 2.8 ton/yr (1,100 to 2,500 kg/yr).

The nitrogen load entering Long Island Sound from shallow-aquifer discharge was calculated as the horizontal ground-water discharges generated by the USGS Long Island regional-flow model, multiplied by the annual median total nitrogen concentrations in samples from 175 selected wells. Simulated shallow-aquifer discharge from Nassau County totaled 9,200 Mgal/yr (34,800,000 m³/yr), and that from Suffolk County totaled 21,400 Mgal/yr (81,100,000 m³/yr); the median nitrogen concentrations for the two counties were 2.2 and 4.3 mg/L, respectively. The resultant nitrogen load from shallow-aquifer discharge in Nassau County was 84 ton/yr (76,500 kg/yr), and that from Suffolk County was 384 ton/yr (349,000 kg/yr).

Simulated deep-aquifer discharge from Nassau County totaled 13,200 Mgal/yr (50,000,000 m³/yr), and that from Suffolk County totaled 47,300 Mgal/yr (179,000,000 m³/yr); the median nitrogen concentrations in deep ground water for the two counties were 1.62 and 1.34 mg/L, respectively. The resultant nitrogen load from deep-aquifer discharge in Nassau County was 89 ton/yr (81,000 kg/yr), and that from Suffolk County was 265 ton/yr (240,000 kg/yr).

Three areas along the north shore of Long Island and north of the Island's regional ground-water divide—a sewered area, an unsewered area, and an agricultural area—were selected to evaluate the effect of these land uses on nitrogen loads entering the Sound. The sewered area had the lowest nitrogen concentration (1.9 mg/L as N) and discharged the smallest nitrogen load (7.28 ton/yr; 6,600 kg/yr). The unsewered area discharged 10.1 ton/yr (9,200 kg/yr) as shallow-aquifer discharge, but the Nissequogue River, which drains the unsewered area, substantially increases the combined surface- and ground-water load from the area. No major streams are present in the agricultural area, so that it produces very little surface-water runoff to Long Island Sound; therefore, shallow-aquifer discharge along the shore is substantially greater than that in the sewered and unsewered areas. The agricultural area had the highest nitrogen concentration (9.9 mg/L as N) and produced the largest estimated nitrogen load—152 ton/yr (138,000 kg/yr), which represents about 40 percent of the estimated total nitrogen load from Suffolk County. The analysis indicates that differing land use on the north shore of Long Island can strongly affect the nitrogen concentration of ground water and the

resultant nitrogen load discharged to Long Island Sound from shallow-aquifer discharge.

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