

Prepared in cooperation with New York State Department of State

## **Trends in Nitrogen Concentration and Nitrogen Loads Entering the South Shore Estuary Reserve from Streams and Ground-Water Discharge in Nassau and Suffolk Counties, Long Island, New York, 1952-97**



Water-Resources Investigations Report 02-4255

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

Cover photograph: Narrow stretch of water in the South Shore Estuary Reserve where you can see across to the other side. The photo was taken from Smith Point Marina just west of Smith Point bridge. (Photograph by Jack Monti, Jr.; USGS)

# Trends in Nitrogen Concentration and Nitrogen Loads Entering the South Shore Estuary Reserve from Streams and Ground-Water Discharge in Nassau and Suffolk Counties, Long Island, New York, 1952-97

By Jack Monti, Jr. and Michael P. Scorca

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4255

Prepared in cooperation with  
NEW YORK STATE DEPARTMENT OF STATE



Coram, New York  
2003

U.S. DEPARTMENT OF THE INTERIOR  
GALE A. NORTON, Secretary

U.S. Geological Survey  
Charles G. Groat, Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

---

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 . . . . . 4
  - Acknowledgments . . . . . 4
- Physiography and hydrogeology . . . . . 4
  - Streams . . . . . 8
  - Ground-water system . . . . . 8
  - Effects of urbanization on streamflow and ground water . . . . . 8
    - Historic changes in base flow . . . . . 9
    - Effects of sanitary sewers, storm sewers, and recharge basins . . . . . 9
- Method and approach . . . . . 9
  - Stream data . . . . . 10
    - Discharge data . . . . . 10
    - Nitrogen-concentration data . . . . . 11
    - Estimation of annual stream loads . . . . . 11
  - Ground-water data . . . . . 12
    - Discharge data . . . . . 12
    - Nitrogen-concentration data . . . . . 13
    - Estimation of ground-water loads . . . . . 15
  - Factors affecting load calculations . . . . . 15
- Nitrogen concentrations in streams and ground water . . . . . 16
  - Streams . . . . . 16
    - Geographic trends . . . . . 17
      - Nassau County . . . . . 17
      - Suffolk County . . . . . 18
    - Seasonal trends . . . . . 18
    - Long-term trends . . . . . 18
  - Ground water . . . . . 21
    - Geographic trends . . . . . 21
    - Temporal trends . . . . . 21
    - Trends with depth . . . . . 26
- Nitrogen loads entering the South Shore Estuary Reserve . . . . . 26
  - Annual stream loads . . . . . 27
    - Geographic trends . . . . . 27
    - Temporal trends . . . . . 27
  - Ground-water loads . . . . . 27
    - Shallow-ground-water system . . . . . 32
    - Deep-ground-water system . . . . . 32
  - Total nitrogen load . . . . . 32
- Summary . . . . . 33
- References cited . . . . . 34

## FIGURES

- 1. Map showing location of study area and South Shore Estuary Reserve, Long Island, N.Y. . . . . 3
- 2. Map showing locations of 13 selected streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y. . . . . 5

3. Generalized section showing hydrogeologic units and generalized directions of ground-water flow on the north and south shores of Long Island, N.Y. (Modified from Nemickas and others, 1989, fig. 8). . . . .	6
4. Map showing partial model grid and locations of upper layer (layer 1) constant-head cells representing the South Shore Estuary Reserve in the U.S. Geological Survey Long Island regional ground-water flow model . . . . .	13
5. Vertical section showing model hydrogeologic geometry along column 50, constant-head cells in layer 1, and simulated shallow- and deep-ground-water discharge entering the South Shore Estuary Reserve (SSER) . . . . .	14
6. Map showing locations of 192 wells on the south shore of Nassau and Suffolk Counties, N.Y. for which at least one sample was available with a calculated total nitrogen value during 1952-97. . . . .	15
7. Map showing location of the 1-mile-wide zone along the south shore of Nassau and Suffolk Counties, N.Y., and the five geographic areas into which it was divided for comparison of geographic trends in total nitrogen and nitrate concentrations. . . . .	16
8. Boxplots showing distribution of total nitrogen concentration in 13 selected streams on the south shore of Nassau and Suffolk Counties, N. Y., 1971-97.. . . .	17
9. Boxplots showing distribution of nitrogen concentration for summer (April through September) and winter (October through March) during 1971-97 at 13 south shore streams in Nassau and Suffolk Counties, N.Y. . . . .	19
10. Graphs showing total nitrogen concentrations of 13 selected streams on the south shore of Nassau and Suffolk Counties, N.Y., 1971-97. . . . .	20
11. Boxplots showing distribution of nitrogen concentration in streams on the south shore of Nassau and Suffolk Counties, N.Y. during selected time periods: A. In the nine streams in sewered areas. B. In the four streams in unsewered areas. . . . .	22
12. Boxplots showing distribution of total nitrogen concentrations in samples from streams and shallow wells, and nitrate concentrations in samples from deep wells in the five geographic areas within 1 mile of the south shore of Nassau and Suffolk Counties, N.Y., 1952-97 . . . . .	24
13. Boxplots showing distribution of nitrogen concentrations in samples from shallow wells in Areas A through E along south shore of Nassau and Suffolk Counties, N. Y., for four selected time periods . . . . .	25
14. Graphs showing annual mean discharge, mean nitrogen concentration, and mean nitrogen load calculated for 11 selected south-shore streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y., 1972-97 . . . . .	29
15. Boxplots showing distribution of nitrogen load calculated in 11 selected streams on the south shore of Nassau and Suffolk Counties, N.Y. 1972-97. . . . .	31
16. Bar chart showing combined nitrogen load from four streams in Nassau County and seven in Suffolk County, N.Y. that discharge to the South Shore Estuary Reserve during 1972-97. . . . .	32

Tables

1. Generalized description of principal hydrogeologic units underlying Long Island, N.Y. . . . .	7
2. Drainage area, period of record, mean discharge, and water-sampling data for the 13 selected streams that discharge to the South Shore Estuary Reserve, Long Island, N.Y. . . . .	11
3. Maximum, median, and minimum total nitrogen concentrations for the 13 selected streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y. . . . .	12
4. Simulated annual mean discharge from shallow and deep ground water to South Shore Estuary Reserve, Nassau and Suffolk Counties, N.Y., based on 1983 steady-state hydrologic conditions . . . . .	13
5. Time periods used in temporal-trend analysis of nitrogen concentrations in streams of Nassau and Suffolk Counties, N.Y., 1952-97 . . . . .	21
6. Number of samples collected from selected shallow and deep wells within 1 mile of the south shore of Nassau and Suffolk Counties, N.Y., and maximum, median, and minimum concentrations of nitrogen at shallow wells and of nitrate at deep wells, 1952-97. . . . .	23
7. Minimum, maximum, and median total nitrogen concentrations in shallow and deep ground water in Areas A through E of South Shore Estuary Reserve, Nassau and Suffolk Counties, N.Y., 1952-97. . . . .	23
8. Geographic grouping of the 13 selected streams that discharge to the South Shore Estuary Reserve, Long Island, N.Y. . . . .	26
9. Estimated annual nitrogen loads entering the South Shore Estuary Reserve from 11 streams on the south shore of Long Island, N.Y., 1972-97 . . . . .	28

10. Median concentration and annual load of nitrogen entering the South Shore Estuary Reserve from shallow and deep ground water in Nassau and Suffolk Counties, N.Y., as calculated from concentrations at wells within 1 mile of the shore, 1952-97. . . . .	31
11. Total annual nitrogen load entering the South Shore Estuary Reserve from streams and ground water on the south shore of Long Island, N.Y., 1972-97 . . . . .	33

---

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

---

Multiply	By	To Obtain
<i>Length</i>		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
<i>Area</i>		
acre	4,047	square meter (m <sup>2</sup> )
square mile (mi <sup>2</sup> )	2.59	square kilometer (km <sup>2</sup> )
<i>Flow</i>		
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
<i>Mass</i>		
ton	907.2	kilogram (kg)
<i>Chemical Concentration</i>		
milligrams per liter (mg/L)		
<i>Other Abbreviations Used</i>		
nitrogen (N)		
kilograms per year (kg/yr)		
million gallons per year (Mgal/yr)		
cubic meters per year (m <sup>3</sup> /yr)		
year (yr)		
second (s)		
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.

**This page has been left blank intentionally.**

# Trends in Nitrogen Concentration and Nitrogen Loads Entering the South Shore Estuary Reserve from Streams and Ground-Water Discharge in Nassau and Suffolk Counties, Long Island, New York, 1952-97

*By Jack Monti, Jr. and Michael P. Scorca*

## ABSTRACT

The 13 major south-shore streams in Nassau and Suffolk Counties, Long Island, New York with adequate long-term (1971-97) water-quality records, and 192 south-shore wells with sufficient water-quality data, were selected for analysis of geographic, seasonal, and long-term trends in nitrogen concentration. Annual total nitrogen loads transported to the South Shore Estuary Reserve (SSER) from 11 of these streams were calculated using long-term discharge records. Nitrogen loads from shallow and deep ground water also were calculated using simulated ground-water discharge of 1968-83 hydrologic conditions.

Long-term declines in stream discharge occurred in East Meadow Brook, Bellmore Creek and Massapequa Creek in response to extensive sewerage in Nassau County. The smallest long-term annual discharge to the SSER was from the westernmost stream, Pines Brook, which is in an area in which the water table has been lowered by sewers since 1952. The three largest average annual discharges to the SSER were from the Connetquot River, Carlls River, and Carmans River in Suffolk County; the discharges from each of these streams were at least twice those of the other streams considered in this study.

Total nitrogen concentrations in streams show a geographic trend with a general eastward

increase in median total nitrogen concentration in Nassau County and a decreasing trend from Massapequa Creek eastward into Suffolk County. Total nitrogen concentrations in streams generally are lowest during summer and highest in winter as a result of seasonal fluctuations in chemical reactions and biological activity. The greatest seasonal difference in median total nitrogen concentration was at Carlls River with values of 3.4 and 4.2 mg/L (milligrams per liter) as N during summer (April through September) and winter (October through March), respectively. Streams affected by the completion of sewer districts show long-term (1971-97) trends of decreasing total nitrogen concentration and streams showing an increase in total nitrogen concentration are in unsewered areas with increased urbanization.

Discharges from shallow ground water (upper glacial aquifer) and deep ground water (upper part of Magothy aquifer) were simulated from a ground-water-flow model calibrated to steady-state (1968-83) conditions. Simulated discharges from shallow-ground-water system in Nassau County were 10,700 Mgal/yr (million gallons per year) or 40,500,000 m<sup>3</sup>/yr (cubic meters per year), and those from Suffolk County were 52,300 Mgal/yr or 198,000,000 m<sup>3</sup>/yr. Discharges from deep-ground-water system in Nassau County were 4,900 Mgal/yr or 18,500,000 m<sup>3</sup>/yr, and

those in Suffolk County were 12,700 Mgal/yr or 48,200,000 m<sup>3</sup>/yr.

Ground-water concentrations of nitrogen decrease with depth and from west to east. The shallow ground water median nitrogen concentration for each county was determined using 1,155 samples collected at 167 shallow wells (125 feet deep or less) within 1 mile of the shore. The deep ground water median nitrate concentration (nitrate represented almost all of the total nitrogen) for each county was determined using 112 samples collected at 25 deep wells (greater than 125 feet deep) within 1 mile of the shore. The median nitrogen concentration for the shallow and median nitrate concentration for the deep ground water in Nassau County were 3.85 and 0.15 mg/L as N, during 1952-97; the corresponding concentrations for Suffolk County were 1.74 and <0.10 (less than 0.10) mg/L as N, during 1952-97.

Nitrogen loads discharged from streams to the SSER for each year during 1972-97 were calculated as the annual total nitrogen concentration multiplied by the annual discharge. These values were calculated only for the seven streams for which sufficient data were available. The largest long-term (1972-97) average annual nitrogen load from Carlls River was 104 ton/yr or 94,300 kg/yr—about twice that of Connetquot River (54 ton/yr or 48,900 kg/yr) and over three times that of Carmans River (33 ton/yr or 29,900 kg/yr). The smallest annual mean nitrogen load was from Pines Brook, which has the lowest annual mean discharge of all streams analyzed.

The nitrogen load carried to the SSER by ground-water discharge in shallow-ground-water system in Nassau and Suffolk Counties was calculated as the simulated discharge for each county multiplied by the respective median nitrogen concentration, and loads from deep-ground-water system were calculated as the simulated discharge for each county multiplied by the respective median nitrate concentration. All discharges were obtained from the U.S. Geological Survey's Long Island ground-water-flow model. The resultant nitrogen loads discharged to the SSER from shallow ground

water were 172 ton/yr (156,000 kg/yr) from Nassau County and 380 ton/yr (345,000 kg/yr) from Suffolk County; equaling 552 ton/yr entering the SSER. Those from deep ground water were 3 ton/yr (2,700 kg/yr) from Nassau County and <0.5 ton/yr (480 kg/yr) from Suffolk County; equaling about 3.5 ton/yr entering the SSER.

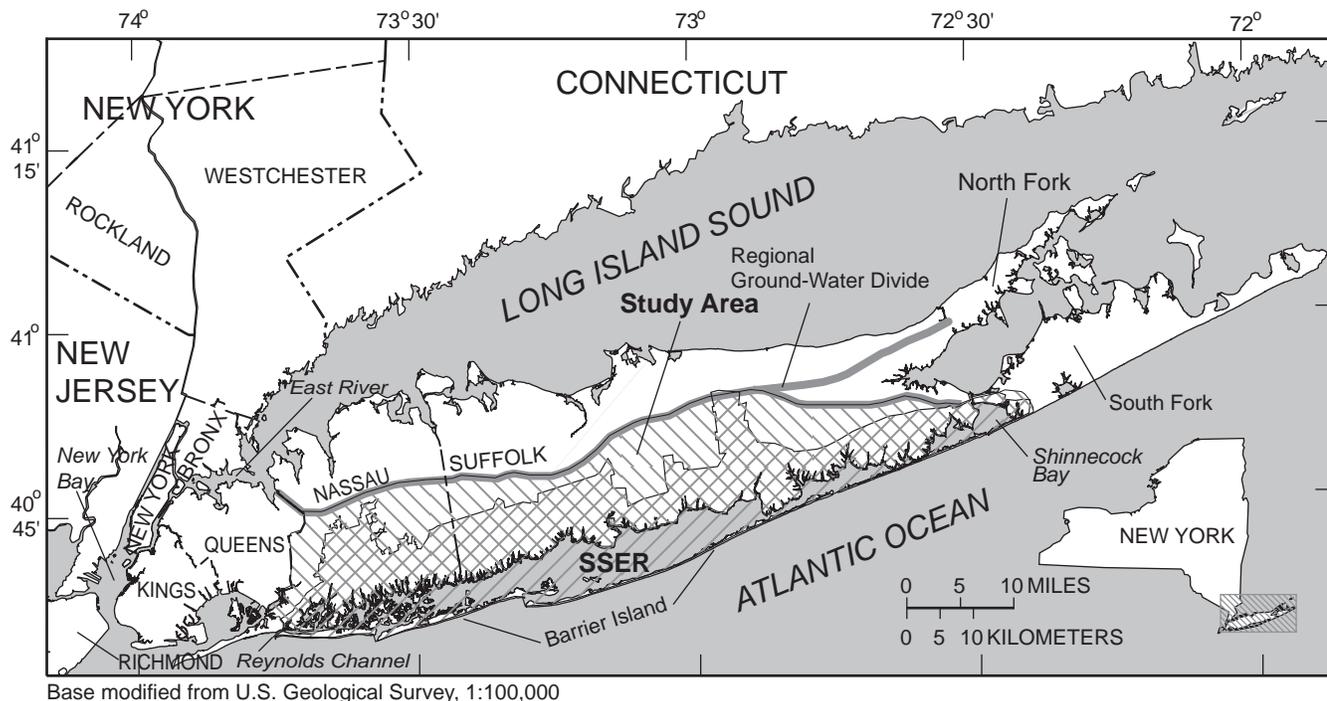
The sum of both stream loads and ground-water loads results in the total load to the SSER. The largest calculated total nitrogen load entering the SSER from both streams and ground water occurred in 1979 with a total load of 1,260 ton/yr (1,140,000 kg/yr). The smallest calculated nitrogen load entering the SSER occurred in 1995 with a total load of 725 ton/yr (658,000 kg/yr).

## INTRODUCTION

The South Shore Estuary Reserve (SSER) of Long Island, N.Y. is a series of shallow tidal bays enclosed by barrier islands and connected to the Atlantic Ocean by various inlets. The SSER extends about 80 mi (129 km) eastward from the Reynolds Channel in Nassau County to the eastern end of Shinnecock Bay in Suffolk County (fig. 1). The SSER's shoals, mudflats, aquatic vegetation, and wetlands (tidal and freshwater) provide a rich habitat for fish and wildlife. The SSER is used for recreational activities such as swimming, boating, and fishing, as well as for commercial harvesting of shellfish.

Freshwater entering the SSER from precipitation, streams, and ground water contains nitrogen in concentrations that vary temporally and spatially. Nitrogen is an essential nutrient for plant growth, but in excessive amounts it can give rise to algal blooms that consume oxygen when the algae die and decompose (Long Island Sound Study, 1998). The resulting low dissolved oxygen concentrations, known as hypoxia, can affect plant and animal populations adversely and is a growing concern in the SSER. Nitrogen enters the SSER from streams, ground water, atmospheric deposition (wetfall and dryfall), and the Atlantic Ocean. These sources can have elevated concentrations (above background levels) as a result of human activities and products, particularly sewage, and agricultural and domestic fertilizers.

In 1993, the Long Island South Shore Estuary Reserve Act established the SSER and called for the Reserve's protection and prudent management. The



#### EXPLANATION

-  SOUTH SHORE ESTUARY RESERVE
-  STUDY AREA
-  REGIONAL GROUND -WATER DIVIDE

**Figure 1.** Location of study area and South Shore Estuary Reserve, Long Island, N. Y.

Act created a 23-member Council and charged it with preparation of a comprehensive management plan for the Reserve. The Council adopted the completed comprehensive management plan in April 2001. The plan identifies actions necessary to improve the Reserve's water and living resources, public access, and the estuary-related economy.

As a part of the SSER study, the U.S. Geological Survey (USGS) began an investigation in 1998, in cooperation with the New York State Department of State (NYS DOS), to refine estimates of nitrogen loading (mass per year) to the SSER. The USGS combined ground- and surface-water-quality data from the USGS National Water Information System (NWIS) database with simulated ground-water discharge and with measured stream-discharge data to

obtain estimates of nitrogen loading (mass per year) from the south shore streams and ground water to the SSER. Except for concentrations, data are presented in both English and metric units for the ease of use among the public and scientific readers.

#### Purpose and Scope

This report (1) describes the physiography and hydrogeology of the SSER study area and the methods of data compilation, (2) presents geographic, seasonal, and long-term (1971-97) trends of total nitrogen concentrations in the 13 major south-shore streams that discharge to the SSER, in Nassau and Suffolk Counties and geographic, temporal, and depth trends in shallow and deep ground water that discharge to the

south shore of these counties, and (3) presents the estimated annual mean nitrogen loads discharged from 11 of these streams during 1972-97, and the estimated nitrogen loads discharged to the SSER from aquifers, as represented by data from 192 wells. The report also discusses the effects of urbanization and sewerage on nitrogen loads entering the SSER.

Total nitrogen loads from stream- and ground-water discharge were calculated if both discharge and water-quality data were available. The SSER contains two areas for which nitrogen loads could not be calculated because discharge data were unavailable—the barrier islands and the South Fork. Discharge and nitrogen loads from these locations could be estimated through ground-water modeling but this was beyond the scope of the study.

## Previous Studies

Various studies 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), Bleifuss and others, (1998), and Scorca and Monti (2001). Water-quality differences between areas representing selected land uses on Long Island are reported by LeaMond and others (1992), Eckhardt and others (1989), Eckhardt and Stackelberg (1995), and Pearsall (1996).

The Long Island Regional Planning Board (1978) gave preliminary estimates of nonpoint-source nitrogen loading from Long Island's south shore to the SSER and provided a description of water-quality conditions in the SSER, indicating the amounts of contaminants from differing sources. Scorca and Monti (2001) calculated estimates of nitrogen loads entering the Long Island Sound from North-Shore-stream and ground-water discharge, and compared nitrogen loads from areas characterized by differing land uses north of the regional ground-water divide.

Various studies have used other methods to compute loading to Chesapeake Bay and other coastal bays in Maryland and Virginia. Bachman and Phillips (1996) sampled base flow of streams from basins with differing characteristics on a seasonal basis and estimated the loads from calculated median instantaneous yields. Phillips and others (1999) evaluated nitrate loads from ground water in differing hydrogeomorphic regions and the residence time of ground water within the Chesapeake Bay

watershed before it discharges to streams. Bachman and others (1998) related base-flow nitrate loads to hydrogeomorphic regions. Dillow and Greene (1999) estimated the nitrate loading to coastal bays of Maryland.

## Acknowledgments

Thanks are extended to Rodney McNeil, John Herring and Dennis Mildner of the NYSDOS for their assistance and cooperation during this project. Thanks also are extended to William McBrien of the Suffolk County Department of Public Works, Sanitation Engineering Division, and Ronald Green of the Suffolk County Management Information Services for providing maps that show the extent of sewerage 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 sewerage areas in Nassau County.

## PHYSIOGRAPHY AND HYDROGEOLOGY

Long Island is bounded along its western shore by the East River and New York Bay, on the north by Long Island Sound, and on the east and south by the Atlantic Ocean (fig. 1). The eastern part of Long Island includes two large peninsulas that are referred to as the North and South Forks, which are poorly connected and have no effect on its shallow and deep ground water from the main body of Long Island. A detailed physiographic description of Long Island is presented by Franke and McClymonds (1972).

The SSER study area (550 mi<sup>2</sup>) extends from the regional ground-water divide to the south shore of Nassau and Suffolk Counties (fig. 1); its western boundary is the Queens-Nassau County border, 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 and the North and South Forks are excluded from analysis because either stream- or ground-water discharge enters a different estuary or, as is the case for the South Fork, the discharge data were not available.

The south shore of Long Island is characterized by marshes and bays (fig. 2). Stream channels on the south shore generally are longer than those on the north shore because the main topographic drainage

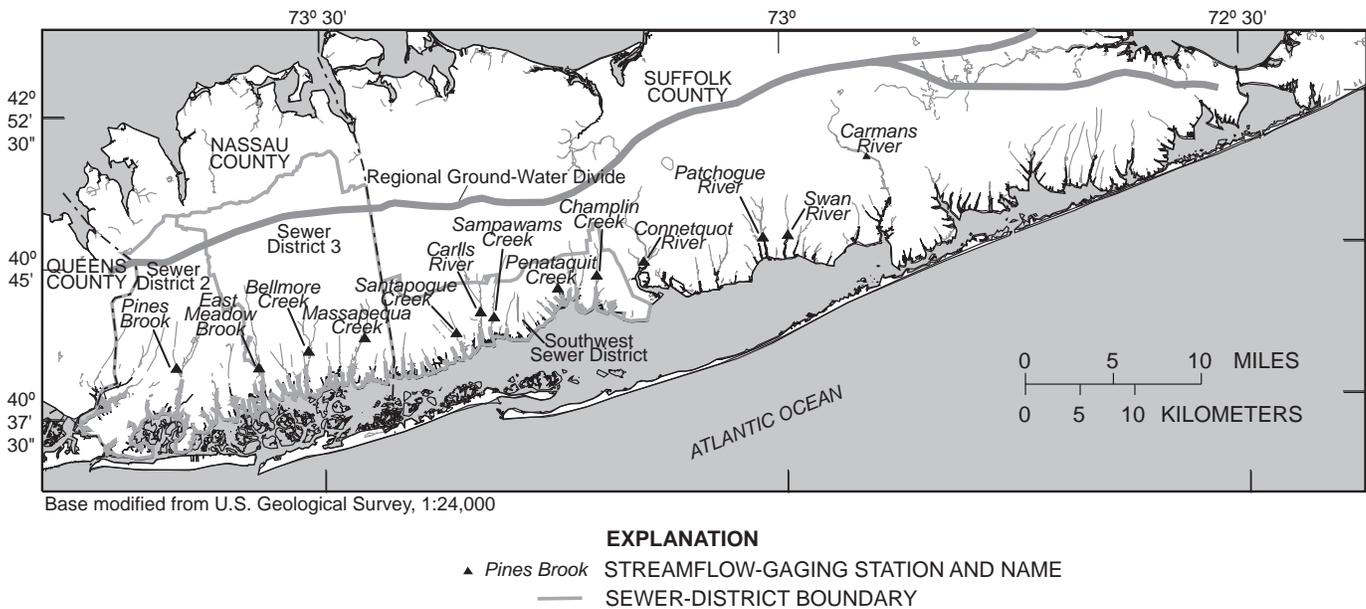
divide is north of the center of the island. The north shore consists of steep cliffs and narrow beaches; the southern part of the island is a gently sloping outwash plain.

Long Island is underlain by unconsolidated sediments of Late Cretaceous and Pleistocene age that were deposited on a southeastward-dipping bedrock surface. The hydrogeologic setting of Long Island 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 underlying the study area is given in table 1; a generalized north-south hydrogeologic section of the study area is given in figure 3.

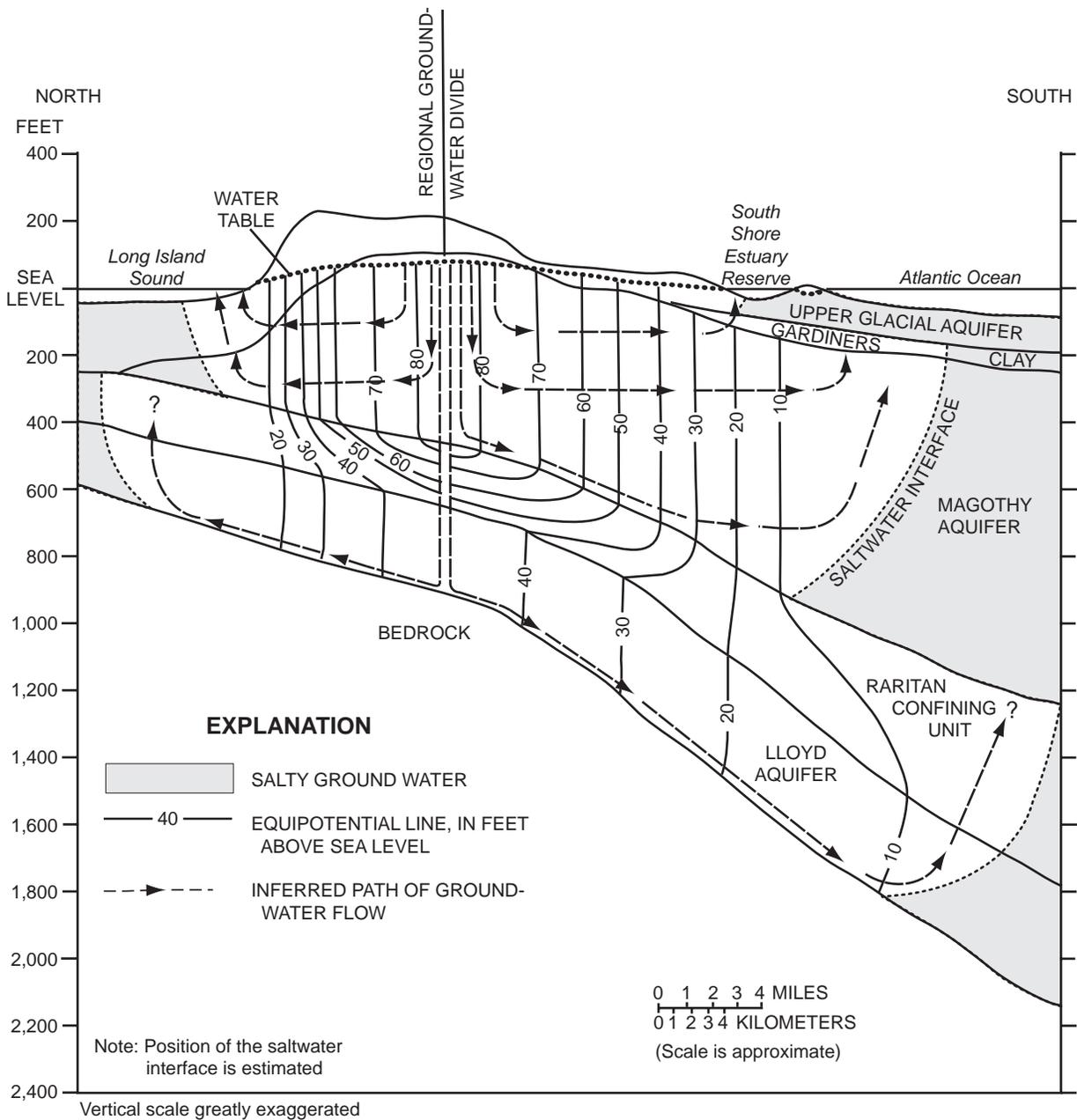
The upper Pleistocene deposits, which form the uppermost principal geologic unit on Long Island, include glacial morainal sediments, till, outwash, and glaciolacustrine sediments that were deposited during the Wisconsinan glaciation of the Pleistocene series. This unit consists mostly of moderately to well-sorted sand and fine gravel, which is highly permeable in most places but 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. The effects of eustatic sea-level changes

during the Pleistocene are shown by various lagoonal and shallow-bay clays along southern Long Island; the most prominent of these is the Gardiners Clay (Smolensky and others, 1989).

Beneath the Pleistocene deposits is a sequence of Cretaceous-aged units overlying bedrock. The northern limits of the Cretaceous units are irregular and variable as a result of erosion by streams during the Tertiary period and Pleistocene series, and by glacial scour during the advances of the Pleistocene continental ice sheets; and the northern extent of these is onshore in some areas (Stumm, 2001). The southern extent of these units generally extend far offshore beneath the SSER and Atlantic Ocean. The Monmouth Group (Monmouth greensand) unconformably overlies the Matawan Group and Magothy Formation. The clay and silty sand material that forms the Monmouth Group was deposited by a transgressing sea. The Matawan Group and Magothy Formation, which forms the Magothy aquifer, is undifferentiated and is the main source of drinking-water supply on Long Island. Beneath the Magothy Formation 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.



**Figure 2.** Locations of 13 selected streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y.



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

**Table 1.** Generalized description of principal hydrogeologic units underlying Long Island, N. Y.

[Modified from Jensen and Soren, 1971, table 1; Smolensky and others, 1989, table 1; and Scorca and others, 1995. ft, feet; ft/d, feet per day]

System	Series	Geologic unit	Hydrogeologic unit	Description and water-bearing character
QUATERNARY	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 south-shore aquifer and confining unit, and the Smithtown clay unit. A major aquifer.
		Upper Pleistocene deposits	20 - foot clay <sup>1</sup>	Grayish-green clay, silt, and sand; generally underlain and overlain by outwash deposits. Unit has lower hydraulic conductivity than outwash deposits and tends to confine water in the underlying aquifer.
		Gardiners Clay	Gardiners Clay	Green and gray clay, silt, clayey and silty sand, and some interbedded clayey and silty gravel. Unit has low vertical hydraulic conductivity (0.001 ft/d) and tends to confine water in the underlying aquifer.
CRETACEOUS	UPPER CRETACEOUS	Monmouth Group	Monmouth greensand <sup>1</sup>	Interbedded marine deposits of dark gray, olive-green, dark greenish-gray and greenish-black glauconitic and lignitic clay, silt and clayey and silty sand. Unit has low vertical hydraulic conductivity and tends to confine water in the underlying aquifer.
		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 the 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.

<sup>1</sup>Not shown in figure 3.

## Streams

Streams in the highly permeable glacial outwash deposits on the south shore of Nassau and Suffolk Counties are broad, straight, and shallow and generally follow the courses established by meltwater channels during glacial retreat (fig. 2). More than 100 stream channels, typically less than 5 mi long, flow to the tide water that surrounds Long Island (Buxton and Smolensky, 1999). Stream discharge consists of two distinct components—base flow and stormflow or direct runoff. Base flow is the discharge from ground water that intercepts the stream channel; stormflow is the discharge caused by precipitation that falls on the stream or is redirected to the stream through storm runoff drains. Streams on Long Island function as ground-water drains; small changes in ground-water levels may cause large changes in stream discharge (Spinello and Simmons, 1992). Water that enters the ground-water system on Long Island either discharges to stream channels, is pumped by wells, or discharges to the tidal waters as ground-water discharge.

## Ground-Water System

Precipitation is the sole source of freshwater recharge to 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 urban areas the infiltration is decreased considerably by paved surfaces, as explained later. The hydrologic cycle on Long Island is discussed at length in Franke and McClymonds (1972), which includes an islandwide water budget.

The Long Island ground-water system consists of two major components—the shallow-flow or shallow-ground-water system, which is associated with streams, and the regional-flow or deep-ground-water system. Precipitation entering the shallow-flow system (mainly the upper glacial aquifer) flows seaward and discharges directly to tidewater as shallow-ground-water discharge, or, if it falls within the 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 flows northward, and water that infiltrates south of the

divide flows southward (fig. 3). Ground water that enters the flow system in the area just south of the regional ground-water divide moves downward through the upper glacial aquifer into the underlying Magothy and Lloyd aquifers, where it moves laterally southward, then upward to the SSER and Atlantic Ocean as deep-ground-water discharge; unless it is withdrawn from the aquifers by pumping wells. The flowpaths that ground water follows through the aquifer system, and the traveltime, also are affected by the hydraulic properties of the hydrogeologic units and by stresses, as well as those imposed by urbanization such as pumping.

Franke and Cohen (1972) and Buxton and Modica (1992) used cross-sectional (2-dimensional) ground-water-flow models to estimate the ground-water age. They estimated that ground water in the southern part of Long Island takes less than 100 years to move through most of the shallow-flow system and discharge along the south shore, although water that reaches the deepest parts of the shallow-flow system can take more than 400 years to reach the south shore. Human activities, such as pumping, can decrease this time, however. The ground-water age was not evaluated as part of this study because it would have required particle-tracking analysis, which was beyond the scope of the study.

## Effects of Urbanization on Streamflow and Ground Water

Continuous eastward development on Long Island throughout the 20th century has decreased the base flow of streams and increased the amount of stormflow. Factors that have contributed to this change are (1) ground-water pumping for water supply, (2) disposal of wastewater to sanitary sewers rather than to underground septic systems that return the water to the upper glacial aquifer, (3) construction of impervious surfaces, such as roads and parking lots, that produce storm runoff and prevent the infiltration of precipitation, and (4) construction of storm sewers that route storm runoff to streams. These practices have lowered ground-water levels substantially, even where artificial recharge basins mitigate the loss of stormwater (Franke, 1968; Sulam, 1979).

## Historic Changes in Base Flow

Ground water as base flow provided the main component of streamflow in Long Island streams under natural (pre-development) conditions. Base flow accounted for about 95 percent of annual streamflow (Franke and McClymonds, 1972); only about 5 percent was derived from direct runoff, which consisted of precipitation falling directly on stream surfaces and overland runoff flowing into stream channels. Stream channels in some urban areas have been modified from their natural condition by culverts and storm sewers, which divert runoff from impervious surfaces to the stream and, thereby, increase the runoff component of total streamflow and decrease the base-flow component.

## Effect of Sanitary Sewers, Storm Sewers, and Recharge Basins

The continuous discharge of cesspool and septic-tank effluent to ground water in heavily developed parts of Nassau and Suffolk Counties eventually contaminated the upper glacial aquifer with nitrogen and other constituents. To prevent further aquifer contamination, sanitary-sewer and sewage-treatment systems were constructed to discharge treated wastewater to south-shore bays within the SSER and the Atlantic Ocean. The discharge of treated wastewater from sewage-treatment plants to offshore surface-water bodies rather than to the ground-water system has improved the ground-water quality but results in the removal of a large volume of water from the ground-water system (Spinello and Simmons, 1992). This loss of water in sewered areas, particularly along the south shore of Nassau County, has caused water-table declines, decreased the base flow of streams, and decreased the rates of 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 have been documented by Perlmutter and Koch (1972), Ku and Sulam (1979), Katz and others (1980) and Ragone and others (1981).

The conversion of land underlain by permeable soils to impervious surfaces (such as streets, sidewalks, and parking lots) that prevent infiltration of precipitation to the water table creates large volumes of street runoff, which flows into storm-sewer systems that discharge to nearby streams and tidewater or to artificial-recharge basins. Stormwater disposal through storm sewers that flow to streams and

tidewater have three main hydrologic consequences: (1) stormwater does not replenish the ground-water system, (2) peak stream discharges during individual storms are larger and more variable than in undeveloped areas (Seaburn, 1969), and (3) the ratio of surface runoff to base flow in streams that receive street runoff has increased sharply (Spinello and Simmons, 1992). Storm runoff in many parts of Long Island is directed to artificial-recharge basins, which facilitate the infiltration of water to the ground-water system and mitigate undesirable changes in streamflow patterns. Ku and others (1992) estimated that ground-water recharge in areas with artificial-recharge basins is about 10 percent greater than in areas without them, which helps to maintain ground-water levels and stream base flow.

Previous investigators (Pluhowski and Spinello, 1978; Spinello and Simmons, 1992) quantified the ratios of streamflow components (base flow and storm runoff) in selected streams on the south shore of Nassau County and southwestern Suffolk County. These ratios have been altered substantially in some locations by the diversion of stormwater to streams and by the reduction in base flow that has resulted from sanitary sewerage. Results of hydrograph separation show that during 1976-85 the annual base flow of streams in heavily urbanized Nassau County averaged from 14 percent in western Nassau County to 79 percent in eastern Nassau County; and from 88 percent in western Suffolk County to 96 percent in an unsewered area of Suffolk County (Spinello and Simmons, 1992). These results indicate that the installation of sanitary sewers is one of the major causes of base-flow declines. The most extreme example is at Valley Stream, in southwestern Nassau County (fig. 2), in which all of the streamflow was derived from storm runoff, and none from base flow, for most of the time during 1976-85 (Spinello and Simmons, 1992).

## METHOD AND APPROACH

The methods described in this report are similar to those used in a previous estimation of nitrogen loads entering Long Island Sound (Scorca and Monti, 2001). The data consisted of stream discharges and nitrogen concentrations, and ground-water discharges from shallow- and deep-flow system and nitrogen concentrations. Stream-discharge data were obtained from stage-recording devices and ground-water

discharges were obtained from the Long Island regional flow model (Buxton and Smolensky, 1999). Stream and ground-water nitrogen-concentration data were obtained from the NWIS database. The nitrogen-concentration data were grouped temporally and spatially for trends analyses.

Many samples represented in this data base have no stored value for total nitrogen. In the absence of a total nitrogen value, the concentrations of the four individual N components (nitrate, nitrite, ammonia, and organic nitrogen) were summed to obtain a total nitrogen value. The individual N-components concentrations (in mg/L as N) can represent either filtered or unfiltered methods. Unfiltered individual N values represent unfiltered raw samples, and filtered individual N values represent filtered samples. In the absence of an unfiltered N value for a given component, the filtered N value was used, if available. The minimum, median, and maximum total nitrogen values for groups of samples were calculated (table 3 and table 6). Samples for which individual N-components values were insufficient to provide a total nitrogen value were omitted from further analysis.

Nitrogen loads from streams were calculated as the annual discharge multiplied by the annual nitrogen concentration. Nitrogen loads from shallow and deep ground-water systems were calculated as the median nitrogen and nitrate concentrations, respectively, multiplied by the simulated ground-water discharge from the respective county and aquifer.

The SSER contains two areas for which entering nitrogen loads could not be calculated because discharge data were unavailable—the barrier islands and the South Fork. Discharge and nitrogen loads from these locations could be estimated through ground-water modeling but this was beyond the scope of the study.

## Stream Data

Thirteen major streams along the south shore were selected for the study. The stream-discharge data used in this study were collected at stage-recording stations; stream nitrogen-concentration data collected at these stations were obtained from the NWIS database.

The streams were, from west to east, Pines Brook, East Meadow Brook, Bellmore Creek, Massapequa Creek, Santapogue Creek, Carlls River, Sampawams Creek, Penataquit Creek, Champlin Creek,

Connetquot River, Patchogue River, Swan River, and Carmans River (fig. 2). The first four streams are in Nassau County; the other nine are in western or central Suffolk County. All 13 streams originally were equipped with stage-recording devices, referred herein as continuous-recording stations; but by 2002, only five stations remain active—Carlls River, Sampawams Creek, Connetquot River, Swan River, and Carmans River. Continuous-recording stations generally have long records of discharge with concurrent water-quality data, allowing the calculation of loads for that time period. Two of the 13 streams—Santapogue Creek and Champlin Creek—do not have concurrent discharge and water-quality records; therefore, loads for these streams could not be calculated.

## Discharge Data

Summary statistics of the discharge data and water-quality samples for the 13 streams are given in table 2. Connetquot River has two continuous-recording stations, herein referred to as Connetquot River base station and Connetquot River supplementary station. The discharge data from the two stations are summed in table 2; water-quality sample data are presented separately (table 2).

The discharge indicate that Connetquot River provided the largest discharge to the SSER (38.5 ft<sup>3</sup>/s for water years<sup>1</sup> 1944-2000) even though Carmans River has the largest drainage area to its continuous-recording station on the south shore (71 mi<sup>2</sup>). The recorded discharge increases appreciably along a stream's course because the streams contributing area increases moving downstream—the closer the location of measurement is to the stream's mouth, the greater the discharge. The continuous-recording station at Carmans River is farther from the mouth than at Connetquot River and Carlls River; thus, the Carmans River discharge at that location is less than that of Connetquot River and Carlls River (fig. 2). Partial-record discharge sites are points along a stream channel at which instantaneous measurements are taken. Data collected over 2.5 mi downstream from the continuous-recording station at a partial-record site on Carmans River (gaging-station number 01305040) indicate that this stream provides the largest discharge of all streams to the SSER (63 ft<sup>3</sup>/s for water years

---

<sup>1</sup>A water year extends from October 1 of the preceding year through September 30 of the named year.

**Table 2.** Drainage area, period of record, mean discharge, and water-sampling data for the 13 selected streams that discharge to the South Shore Estuary Reserve, Long Island, N.Y.

[Discharge data from Spinello and others (1997, 1998, 2001). mi<sup>2</sup>, square miles; ft<sup>3</sup>/s, cubic feet per second. Locations are shown in fig. 2.]

Station name	Station number	Drainage area (mi <sup>2</sup> )	Discharge records		Water-quality records		
			Period of record	Mean discharge (ft <sup>3</sup> /s)	Total number of samples	Date of first sample	Date of last sample
Pines Brook at Malverne	01311000	10.0	1937-1999	3.45	81	5/5/66	2/27/96
East Meadow Brook at Freeport	01310500	31.0	1937-2000	12.70	157	4/22/66	8/26/96
Bellmore Creek at Bellmore	01310000	17.0	1937-2000	8.78	102	4/22/66	5/22/96
Massapequa Creek at Massapequa	01309500	38.0	1937-2000	9.77	156	5/11/66	6/16/97
Santapogue Creek at Lindenhurst	01309000	7.0	1945-1969	4.16	120	5/4/66	1/30/97
Carlls River at Babylon	01308500	35.0	1945-2000	26.00	134	5/4/66	6/17/97
Sampawams Creek at Babylon	01308000	23.0	1945-2000	9.68	125	5/4/66	6/17/97
Penataquit Creek at Bay Shore	01307500	5.0	1945-1976	6.31	122	5/6/66	8/19/96
Champlin Creek at Islip	01307000	6.5	1945-1969	7.05	116	10/17/65	8/19/96
Connetquot River near Oakdale	01306500	24.0	1944-2000	38.50 <sup>1</sup>	127 <sup>2</sup> 70 <sup>3</sup>	5/6/66 2/14/67	8/19/96 6/17/97
Patchogue River at Patchogue	01306000	13.5	1948-1969, 1974-1976	20.40	109	5/6/66	8/12/96
Swan River at East Patchogue	01305500	8.6	1947-2000	12.30	114	5/11/66	6/18/96
Carmans River at Yaphank	01305000	71.0	1942-2000	24.00	311	5/11/66	6/18/97

<sup>1</sup>Base-station data and supplementary-station data combined for mean discharge value

<sup>2</sup>Samples collected at base station

<sup>3</sup>Samples collected at supplementary station

1972-98). The discharge rate at the partial-record station on Carmans River is 2.6 times greater than the discharge at the continuous-recording station. If nitrogen concentrations were assumed to be equal at both stations then the load could be extrapolated to be 2.6 times greater than those calculated for Carmans River. Water-quality data were not obtained at this partial-record-discharge station, however; therefore, no nitrogen load could be calculated.

### Nitrogen-Concentration Data

The NWIS database contains water-quality data for samples collected from the 13 selected streams during 1966-97 (table 3); but only samples collected after 1971 contain sufficient nitrogen information for calculation of a total nitrogen value; hence, the concentrations given in table 3 represent only 1971-97. The following sections describe the overall geographic, seasonal and long-term trends of total nitrogen concentration observed in south-shore streams.

Geographical, seasonal, and long-term (1971-97) trends in total nitrogen concentrations in each stream were evaluated from graphs of chemical concentrations in water samples plotted as a function of time and in boxplots (Chambers and others, 1983). Examination of discharge-related trends in base flow and storm runoff was beyond the scope of this study because stormflow water-quality data were unavailable. It is assumed that most samples were collected under base-flow conditions, although some samples reflect effects of storm runoff.

### Estimation of Annual Stream Loads

Annual nitrogen loads for the 13 selected streams for 1972-97 were calculated as the mean stream discharge for each calendar year multiplied by the mean total nitrogen concentration for that year; thus, the annual values presented herein for discharges and total nitrogen concentrations in streams represent calendar years rather than water years. Annual values were calculated for both stations on the Connetquot River. This method of computation does not fully

**Table 3.** Maximum, median, and minimum total nitrogen concentrations for the 13 selected streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y.

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

Station name	Number of samples	Total nitrogen concentration <sup>1</sup>		
		Maximum	Median	Minimum
Pines Brook at Malverne	68	6.58	3.01	.4
East Meadow Brook at Freeport	120	15.9	3.92	.63
Bellmore Creek at Bellmore	83	21.5	5.7	.69
Massapequa Creek at Massapequa	123	16.1	7.4	.71
Santapogue Creek at Lindenhurst	99	15.3	4.4	.71
Carlls River at Babylon	113	6.51	3.83	1.01
Sampawams Creek at Babylon	102	9.6	4.36	.36
Penataquit Creek at Bay Shore	101	6.55	4.33	1.08
Champlin Creek at Islip	97	9.92	3.32	1.68
Connetquot River near Oakdale (Base)	108	2.9	1.82	.84
Connetquot River near Oakdale (Supplementary)	52	4.3	2.18	.89
Patchogue River at Patchogue	97	4.23	2.83	1.33
Swan River at East Patchogue	97	3.91	1.92	1.05
Carmans River at Yaphank	241	8.3	1.25	.53

<sup>1</sup>Values reported as less than the detection limit were included in the statistical analyses as half the detection limit.

account for effects of seasonal fluctuations, data-collection location, or discharge-related effects and, therefore, provides only a general estimate of annual streamflow load that may be lower than the actual load. For example, concentrations typically decrease during a storm through dilution, even though the increasing discharge might result in an increased load. Brown and others (1997) and Stockar (1994) observed changes in the concentrations of selected constituents during storms at the headwaters of East Meadow Brook (fig. 2) and often found the concentrations to be lower than those in base flow.

## Ground-Water Data

Simulated ground-water discharges and nitrogen concentrations were used to calculate loads discharged to the SSER from the shallow and deep ground water in Nassau and Suffolk Counties. Wells less than 125 ft deep were used to characterize shallow ground water; wells from 126 to 300 ft deep were used to characterize deep ground water.

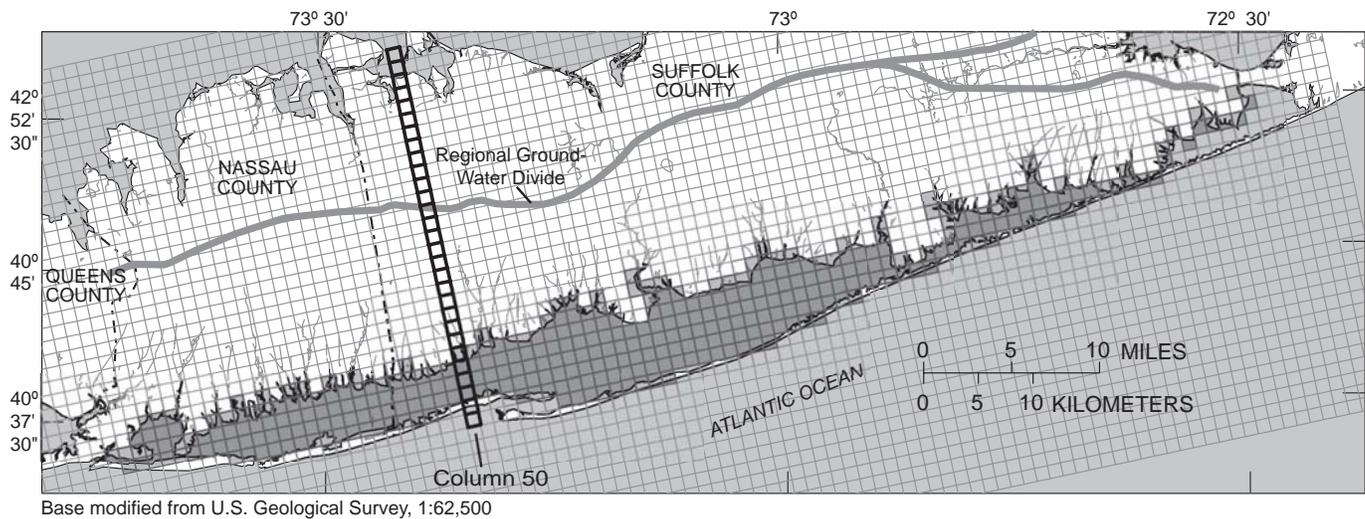
## Discharge Data

Shallow- and deep-ground-water discharges were calculated separately because shallow ground water is

more likely than deep ground water to reflect the effects of land use and the chemical concentrations of ground water that discharges to the SSER. The discharges from both depths were generated by the USGS Long Island regional ground-water-flow model for a steady-state simulation of 1968-83 (Buxton and Smolensky, 1999).

The Long Island regional model was developed during the 1980's using MODFLOW, a three-dimensional finite-difference model (McDonald and Harbaugh, 1988) that was designed for assessment of the Long Island aquifer system and estimation of the effects of proposed water-management strategies. Four model layers were used to represent three major aquifers; the intervening confining units are represented implicitly. The model grid extends as far east as the ground-water-flow systems of the North and South Forks. The effects of the North and South Fork ground-water-flow systems on ground water in the main body of Long Island are negligible.

Discharge to the SSER from the shallow and deep ground water used in this study is represented in the model by flow into constant-head cells in the uppermost model layer along the south shore of Nassau and Suffolk Counties (fig. 4). Horizontal discharge into constant-head cells in the uppermost layer represents shallow ground water, that is younger



**EXPLANATION**

- MODEL CELLS
- CONSTANT-HEAD CELLS

**Figure 4.** Partial model grid and locations of upper layer (layer 1) constant-head cells representing the South Shore Estuary Reserve in the U.S. Geological Survey Long Island regional ground-water flow model. (Vertical section of column 50 is shown in fig. 5.)

and more likely to be affected by contamination from human activities than deep ground water. Deep-ground-water discharge is simulated by vertical flow into constant-head cells in the uppermost model layer representing the discharge from the upper part of the Magothy aquifer (layer 2) into the SSER (fig. 5).

Simulated discharges that flow horizontally (shallow-ground-water discharge) into selected constant-head cells from Nassau County totaled 10,700 Mgal/yr (40,500,000 m<sup>3</sup>/yr), and those from Suffolk County totaled 52,300 Mgal/yr (198,000,000 m<sup>3</sup>/yr) (table 4). The shallow-ground-water discharge represents about 78 percent of the ground water discharged from the south shore to the SSER. Simulated deep-ground-water discharges totaled

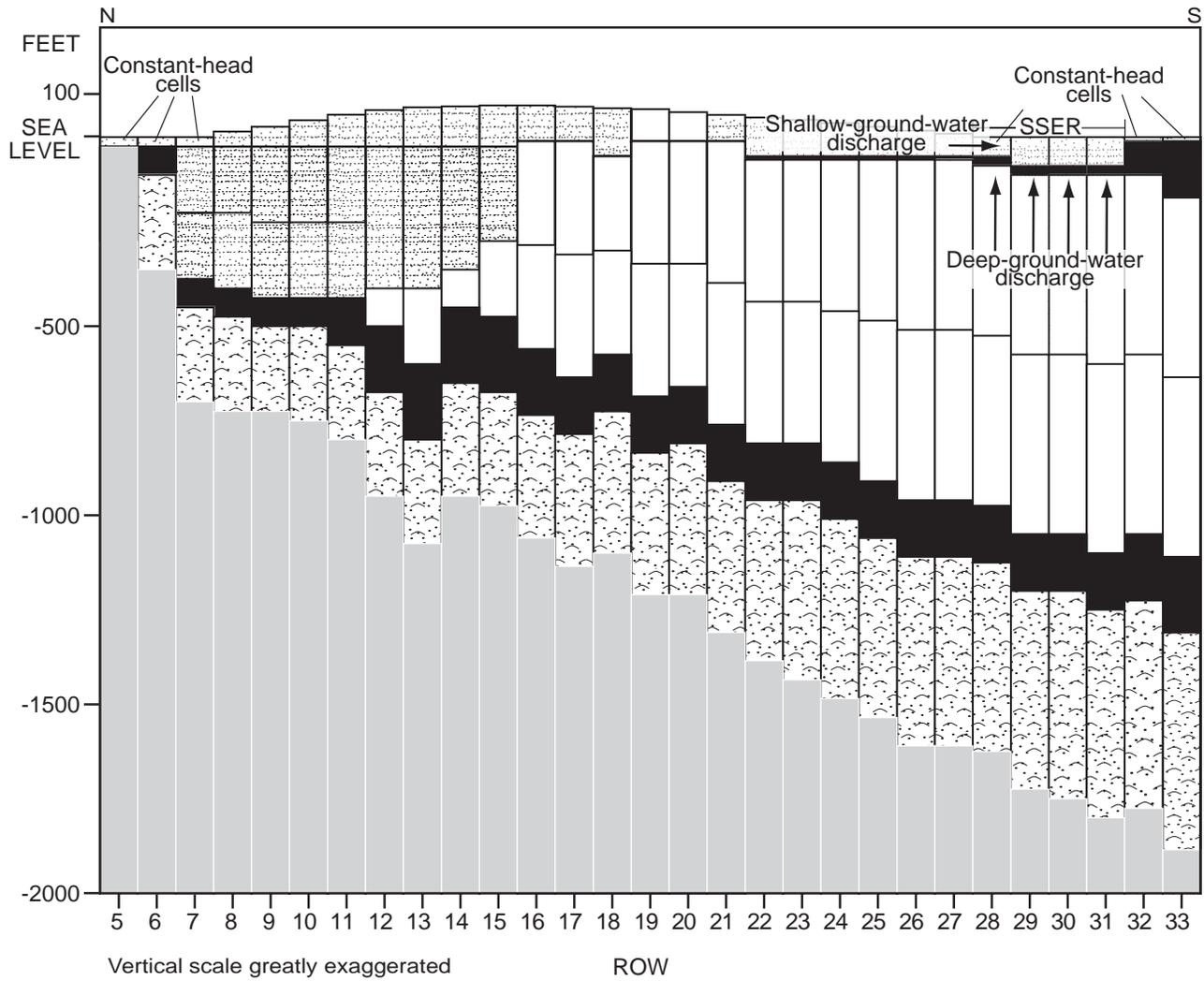
4,900 Mgal/yr (18,500,000 m<sup>3</sup>/yr) from Nassau County and 12,700 Mgal/yr (48,200,000 m<sup>3</sup>/yr) from Suffolk County (table 4). Deep-ground-water discharge represents about 22 percent of the ground water discharged from the south shore to the SSER.

**Nitrogen-Concentration Data**

The NWIS database contains water-quality data for 192 wells within a 1-mi-wide zone along the southern coastline of the study area; 121 wells are in Nassau County, and 71 in Suffolk County (fig. 6). The data analysis included 1,267 samples collected during 1952-97—1,155 from 167 shallow wells (0-125 ft in depth) and 112 from 25 deep wells (126-300 ft in depth). The shallow-well data were used to determine

**Table 4.** Simulated annual mean discharge from shallow and deep ground water to South Shore Estuary Reserve, Nassau and Suffolk Counties, N.Y., based on 1983 steady-state hydrologic conditions [Mgal/yr, million gallons per year; m<sup>3</sup>/yr, cubic meters per year]

County	Shallow-ground-water discharge			Deep-ground-water discharge		
	Mgal/yr	m <sup>3</sup> /yr	Percent of total	Mgal/yr	m <sup>3</sup> /yr	Percent of total
Nassau	10,700	40,500,000	13	4,900	18,500,000	6
Suffolk	52,300	198,000,000	65	12,700	48,200,000	16
<b>Total</b>	<b>63,000</b>	<b>238,500,000</b>	<b>78</b>	<b>17,600</b>	<b>66,700,000</b>	<b>22</b>



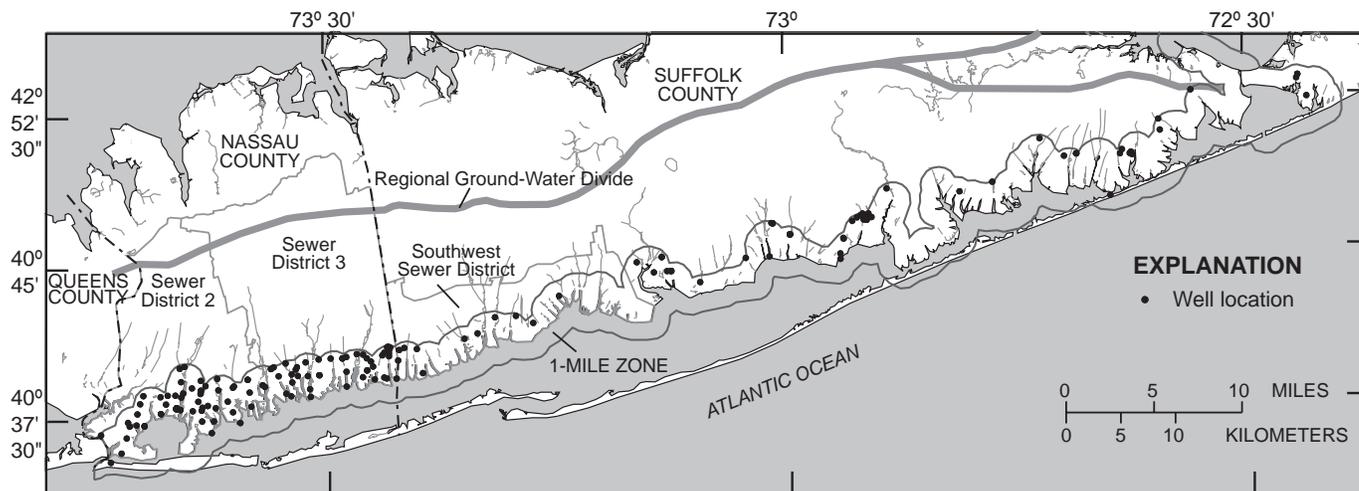
**EXPLANATION**

-  UPPER GLACIAL AQUIFER
-  MAGOTHY AQUIFER
-  LLOYD AQUIFER
-  CONFINING UNIT- Gardiners Clay and Raritan confining unit

**MODEL LAYERS AT REPRESENTATIVE ROW**

-  Layer 1
-  Layer 2
-  Layer 3
-  Confining unit
-  Layer 4
-  Bottom of model

**Figure 5.** Vertical section showing model hydrogeologic geometry along column 50, constant-head cells in layer 1, and simulated shallow- and deep-ground-water discharge entering the South Shore Estuary Reserve (SSER). (Location of column 50 is shown in fig. 4.)



**Figure 6.** Locations of 192 wells on the south shore of Nassau and Suffolk Counties, N. Y., for which at least one sample was available with a calculated total nitrogen value during 1952-97.

the median total nitrogen concentrations in the upper glacial aquifer, and the deep-well samples were used to determine median nitrate concentration (rather than as total nitrogen concentrations because the ammonia, organic-nitrogen, and nitrite components in the great majority of samples were so small that nitrate represented almost all of the total nitrogen) in the deep ground water (upper part of the Magothy aquifer) for Nassau and Suffolk Counties.

A geographic information system (GIS) was used to delineate the 1-mi-wide zone along the south shore (fig. 7). Ground water within this zone includes that which discharges directly into the SSER by horizontal and vertical flow. Median total nitrogen concentrations for each county were calculated from water-quality data collected (during 1952-97) at 192 wells selected within the 1-mi-wide zone. Five geographic areas within this zone also were delineated by a GIS and were used to spatially group wells and sample data (fig. 7). Three of the geographic areas (A,B, and C) are in sewered areas and two (D and E) are in unsewered areas. The geographic, temporal, and depth trends in total nitrogen concentrations in each geographic area are depicted in boxplots, as discussed later in the report.

### Estimation of Ground-Water Loads

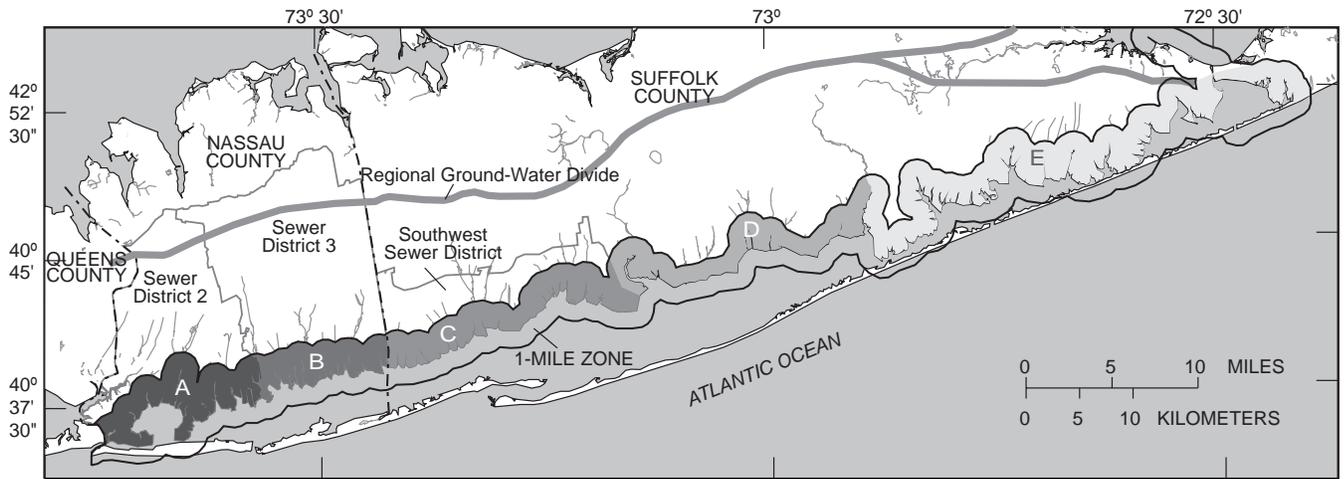
Nitrogen loads entering the SSER from ground water on Long Island's south shore were calculated as

groundwater discharges from each county (generated by the model) multiplied by the median total nitrogen concentration for that county. The loads from shallow ground water were calculated as the median total nitrogen concentrations for Nassau and Suffolk Counties, multiplied by the shallow-ground-water discharges for each county; the loads from the deep ground water were calculated as the median nitrate concentrations—rather than as total nitrogen concentrations—multiplied by the deep-ground-water discharges for each county.

### Factors Affecting Load Calculations

The nitrogen loads to the SSER from both ground-water and stream discharge that are calculated in this report will assist with estuary budget calculations. As with any data analysis, the data quality and approach that are used in this analysis to estimate loads are affected by various factors.

Although the nitrogen data represents all available data in the USGS database over the last 50 years, they reflect changes in data collection, and sampling and analytical techniques that have occurred over that time. The historical data were collected for purposes other than this study and were obtained at sites not related to this investigation. Wells have been installed and abandoned over time for many different



**Figure 7.** Location of the 1-mile-wide zone along the south shore of Nassau and Suffolk Counties, N.Y., and the five geographic areas (A-E) into which it was divided for comparison of geographic trends in total nitrogen and nitrate concentrations.

reasons, which could include water-quality or -quantity problems, damage to the well, changes in data-collections network, changes in ownership. In addition, sampling frequency differs widely from site to site and through time.

Generally, on Long Island, stream discharge increases with distance downstream; therefore, if the concentration of nitrogen in the stream were to remain the same along the length of the stream channel, then the load that would reach the SSER should be greater than the load calculated at upstream sites. The continuous-gaging stations at most streams were installed at the furthest downstream non-tidal site, but could be further upstream as a result of access limitations. Thus, the load of a stream at its mouth, where it reaches the SSER, could be larger than the calculated values presented in this report.

Although over 100 streams discharge to the SSER, stream loads were calculated for 11 major streams with continuous-record discharge stations and water-quality records. The large majority of the approximately 90 remaining streams are smaller and have lower discharges than the gaged streams, but the loads from these streams are not accounted for in this study.

The Long Island regional model was developed for a different purpose than the objective of this study. The simulated ground-water discharges used in the model were based on 1968-83 hydrologic conditions, which was a period of long-term average and relatively stable hydrologic conditions as compared to other periods. In order to simulate changes in hydrologic

conditions, the inputs to the regional model could be changed and the resulting changes in the simulated ground-water discharges could be determined.

In addition, only 20 streams that discharge to the SSER were represented in the Long Island regional model. The discharge from the other (approximately 80) south-shore streams, which were not quantified in the model, were included effectively in the simulated shallow-ground-water discharge.

## NITROGEN CONCENTRATIONS IN STREAMS AND GROUND WATER

Estimating nitrogen loads to the SSER requires both a flux and a concentration to calculate a load. The changes that have occurred along the south shore of Long Island such as waste management and urban growth have certain effects on the inputs used to calculate load. This section describes the trends in nitrogen concentrations in streams and ground water with focus on changes in waste management and urban development.

### Streams

Trends in nitrogen concentrations (geographic, seasonal and long-term (1971-97)) are discussed in the following sections. They are presented here to give the reader an understanding of how concentrations varied under different flow conditions.

## Geographic Trends

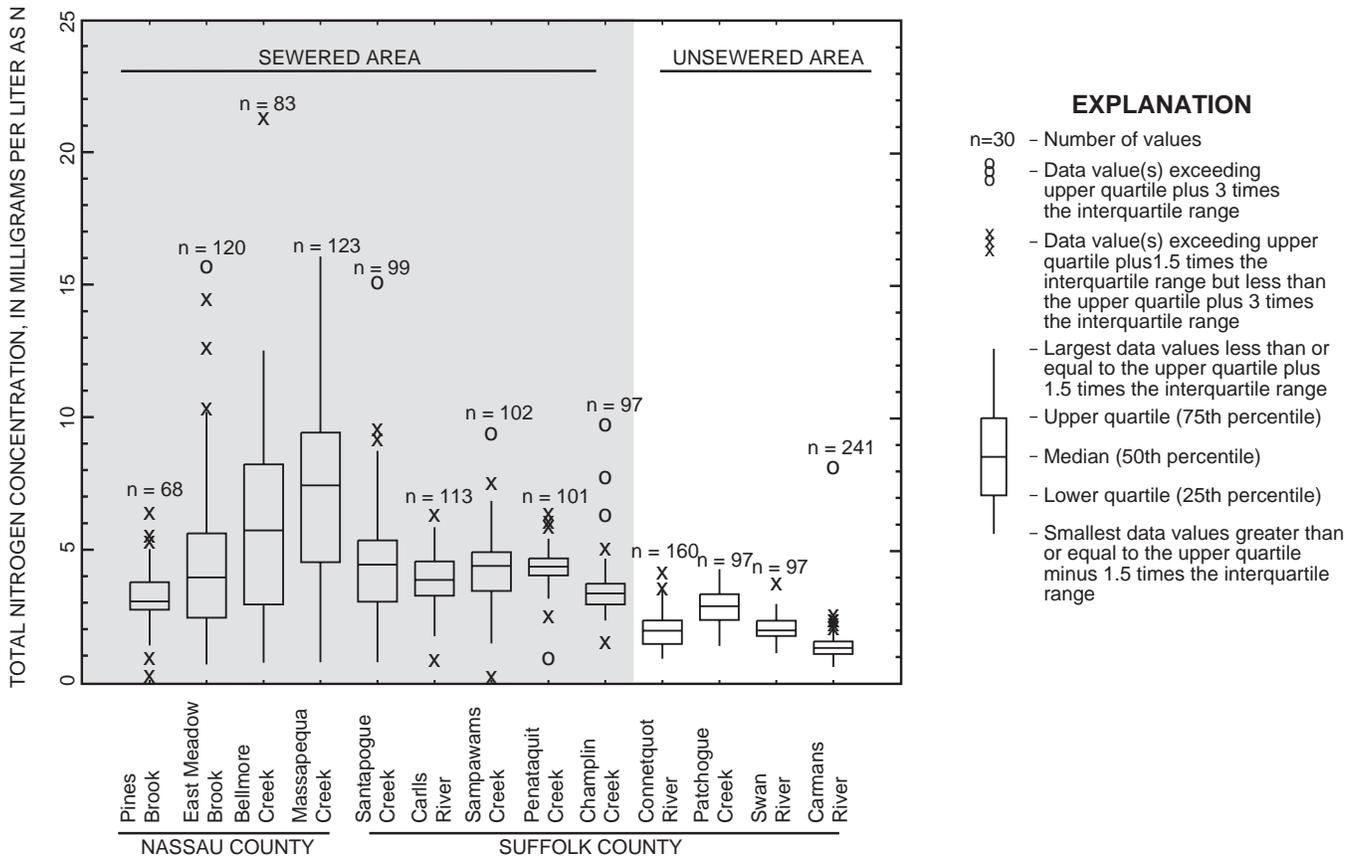
The geographic distribution of total nitrogen data collected during 1971-97 is presented in boxplots (fig. 8). Nitrogen data for both stations at Connetquot River were combined. The boxplots indicate a general eastward increase in median total nitrogen concentration in Nassau County streams, and a decreasing trend from Massapequa Creek eastward into Suffolk County. Patchogue River, in Suffolk County deviated slightly from this decreasing trend.

### Nassau County

The trend in Nassau County is due primarily to the effects of sewer systems. Nassau County generally was a rural community with a population of 400,000 before World War II but grew into a highly suburbanized community with a population of 1,400,000 by 1970 (Sulam and Ku, 1977). Sewering of residential communities, Sewer District 2 (SD2) in

southwestern Nassau County (fig. 2) began in 1952, and sewer hookups continued until the 70-mi<sup>2</sup> system was completed in 1964. Sewering of residential communities, Sewer District 3 (SD3) in southeastern Nassau County (fig. 2) began in 1974 and sewer hookups continued until the 105-mi<sup>2</sup> system was completed in 1988. Both systems took 12 to 14 years to complete, but the start of wastewater treatment in SD2 preceded that in SD3 by 20 years. The stream data analyzed in this investigation start in 1971, which is about 20 years after SD2 started treating wastewater and just before SD3 began treatment.

The ground-water-contributing area to Pines Brook, the westernmost stream, is within SD2; that of East Meadow Brook is within both sewer districts, and those of Bellmore and Massapequa Creeks are within SD3. As expected, the boxplots (fig. 8) show less variability in the total nitrogen distribution at Pines Brook than at East Meadow Brook, Bellmore Creek or Massapequa Creek because the only change in



**Figure 8.** Distribution of total nitrogen concentration in 13 selected streams on the south shore of Nassau and Suffolk Counties, N.Y., 1971-97.

sewering in Nassau County during the period represented (1971-97) was in SD3 (fig. 8). Many of the early samples from East Meadow Brook, Bellmore Creek, and Massapequa Creek had high total nitrogen concentrations; these most likely are a reflection of background conditions before sewerage. The median total calculated nitrogen concentration for Pines Brook, East Meadow Brook, Bellmore Creek and Massapequa Creek during 1971-97 are 3.0, 3.9, 5.7, and 7.4 mg/L as N, respectively; this eastward increase reflects the later completion of sewerage in SD3.

### Suffolk County

The trend in Suffolk County is most likely related to the pattern of eastward urban growth on Long Island. The sewer district in southwestern Suffolk County, locally called the Southwest Sewer District (SWSD), started treating wastewater in residential communities in 1982 (fig. 2) and was completed in 1989. This service area contains five streams—Santapogue Creek, Carlls River, Sampawams Creek, Penataquit Creek and Champlin Creek. The northern part of drainage areas of Carlls River and Sampawams Creek (35 and 23 mi<sup>2</sup>, respectively) probably are outside the SWSD service area and intercept water from unsewered areas. The median total nitrogen concentration of these five streams (Santapogue Creek, Carlls River, Sampawams Creek, Penataquit Creek, and Champlin Creek) during 1971-97 are similar— 4.4, 3.8, 4.4, 4.3, and 3.3 mg/L as N, respectively (fig. 8).

The village of Patchogue, east of SWSD, provides sewage treatment for some of its residents, but all other parts of Suffolk County beyond SWSD are served by residential septic systems. Ground water beneath densely populated areas in eastern Suffolk, as in Nassau and western Suffolk Counties, is characterized by elevated (above background levels) total nitrogen concentrations. The streams that drain these unsewered areas are Connetquot, Patchogue, Swan, and Carmans Rivers. The median (1971-97) total nitrogen concentrations for the two Connetquot River stations and Swan River is about 2 mg/L as N. Patchogue River, has the highest median total nitrogen concentration of the four streams is 2.8 mg/L as N; the probable cause for the higher concentration is the community was developed by the 1950's and urban growth continued within the stream's drainage area. Carmans River had the lowest median total nitrogen

concentration of all 13 streams analyzed (1.25 mg/L as N, during 1971-97).

### Seasonal Trends

Concentrations of total nitrogen in streamwater samples during 1971-97 were divided into two groups—summer and winter—for each stream. The summer group included samples collected from April through September, and the winter group consisted of samples collected from October through March. Data collected at the two Connetquot River stations were grouped as one site. The seasonal differences in nitrogen concentration in each stream are depicted in boxplots (fig. 9).

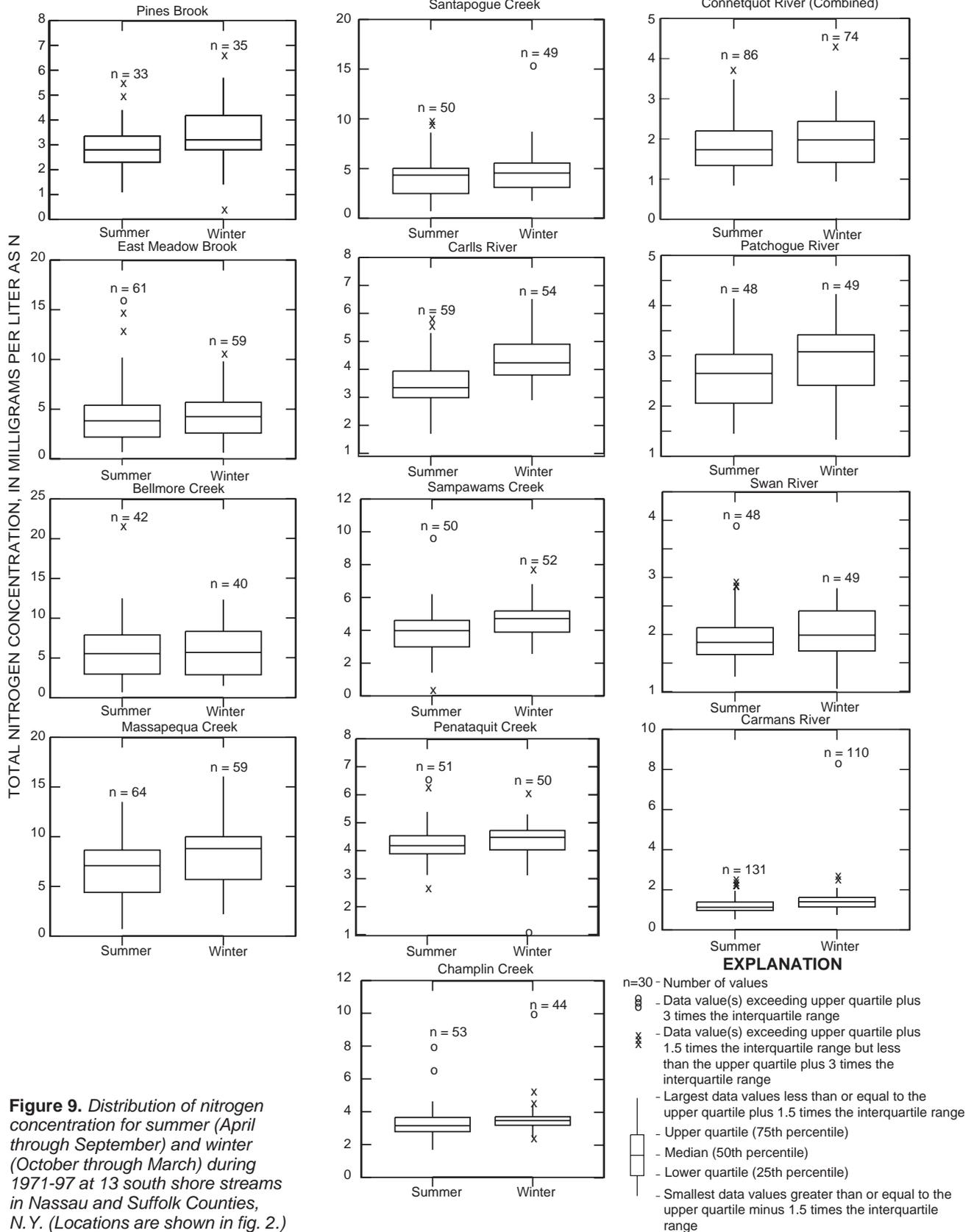
Seasonal fluctuations in total nitrogen concentrations are caused by chemical reactions and biological activity in the streams. Summer values are lower than winter values as a result of biological uptake of N during the growing season. Although most samples probably were collected during normal flow conditions, some samples might show effects of storm runoff, which can contain nitrogen from fertilizers or animal wastes (Brown and others, 1997). The median concentrations for winter are higher than those for summer in all streams, but the difference is small and is difficult to discern in some of the boxplots (fig. 9). The greatest seasonal difference in median total nitrogen concentration was at Carlls River with values of 3.4 and 4.2 mg/L as N during summer (April through September) and winter (October through March), respectively.

### Long-Term Trends

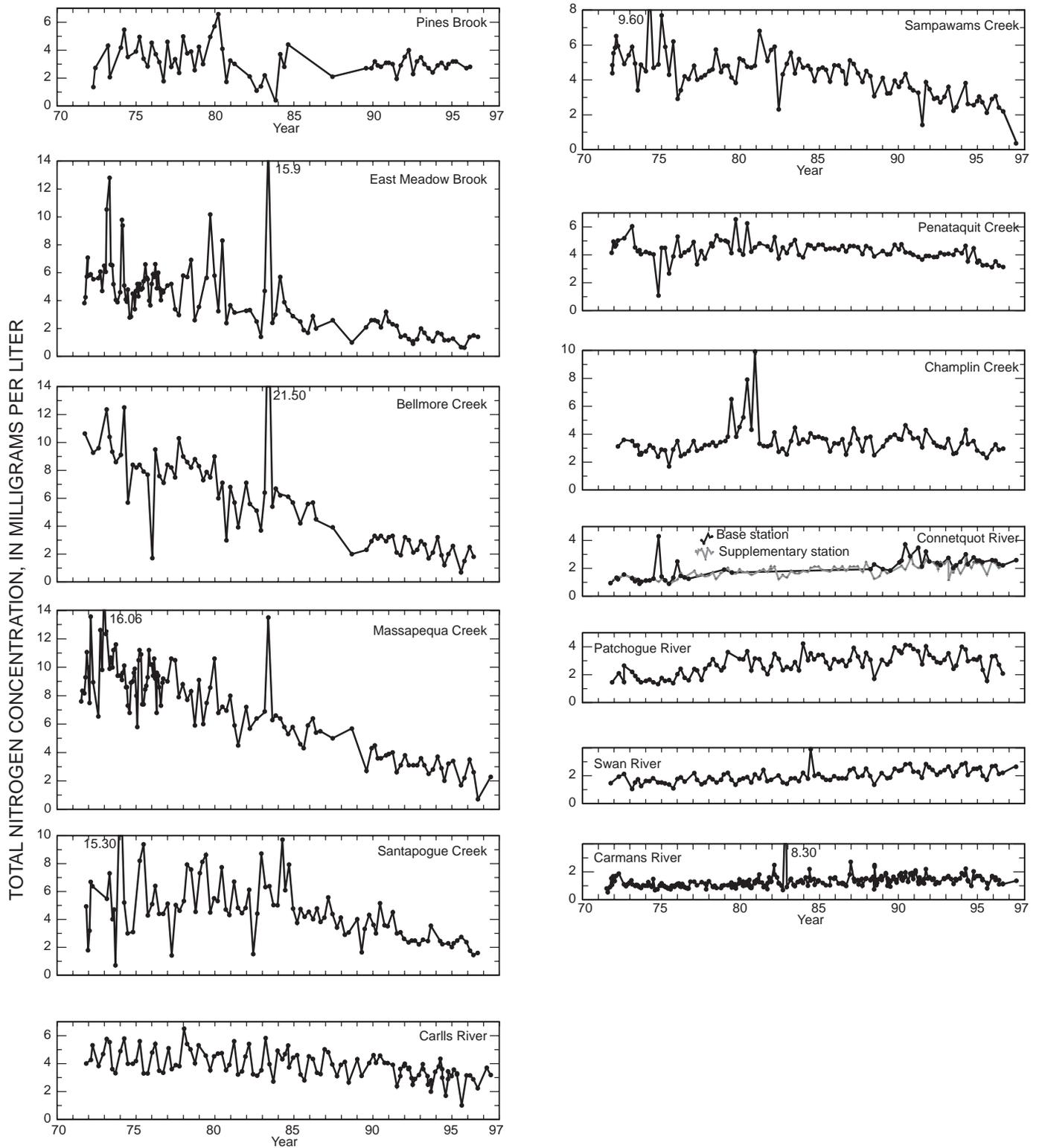
The eight streams whose total nitrogen concentration have been lowered by the completion of sewer districts (Pines Brook, East Meadow Brook, Bellmore Creek, Massapequa Creek, Santapogue Creek, Carlls River, Sampawams Creek and Penataquit Creek) show clear long-term trends of decreasing total nitrogen concentration since 1971 (fig. 10). A quantitative comparison with pre-sewer conditions was not possible because no data from before 1972 were available, but Sulam and Ku (1977) analyzed nitrate trends during 1910-75 using two abandoned infiltration galleries—one near Massapequa Creek, and the other near Bellmore Creek. The results indicate that nitrate concentrations increased during 1910-40 and 1941-60, but decreased during 1961-75. The decreasing trend may reflect the

NASSAU COUNTY STREAMS

SUFFOLK COUNTY STREAMS



**Figure 9.** Distribution of nitrogen concentration for summer (April through September) and winter (October through March) during 1971-97 at 13 south shore streams in Nassau and Suffolk Counties, N. Y. (Locations are shown in fig. 2.)



**Figure 10.** Total nitrogen concentrations of 13 selected streams on the south shore of Nassau and Suffolk Counties, N.Y., 1971-97. (Locations are shown in fig. 2.)

decreasing rate of population growth or the effect of increased recharge after the drought of 1962-66. Four of the streams that were unaffected by sewers—Connetquot River, Patchogue River, Swan River, and Carmans River— show an increase in total nitrogen concentration since 1972, probably as a result of eastward urbanization over time. The Champlin Creek data show no discernible long-term trends, even though the station is in SWSD.

The change that probably had the greatest effect on nitrogen concentrations in Long Island ground water was the installation of sewers. This period of change was divided into six phases, described in table 5. The stream data were grouped accordingly for comparison of nitrogen concentration in streams in the sewered areas with those in the unsewered areas. The first two time periods were omitted because only the stream data collected after 1971 contain sufficient nitrogen information for calculation of a total nitrogen concentration. The distribution of nitrogen in each time period for streams in sewered and unsewered areas is depicted in boxplots of figure 11.

## Ground Water

The 167 shallow wells within 1 mi of the south shore provided 1,662 samples, of which 1,155 had sufficient information for calculation of total nitrogen concentration (table 6A). The 25 deep wells within 1 mi of the shore provided 193 samples, of which 112 had values of total nitrate concentration.

The median total nitrogen concentration for 408 samples collected at 104 shallow wells in Nassau County (during 1952-97) was 3.85 mg/L as N; values ranged from 0.008 mg/L to 40.1 mg/L as N; the median total nitrogen concentration for 747 samples collected at 63 shallow wells in Suffolk County (during 1952-97) was 1.74 mg/L as N; the values ranged from <0.01 mg/L as N to 21.6 mg/L as N (table 6B).

The median nitrate concentration for 58 samples collected at 17 deep wells in Nassau County (during 1952-97) was 0.15 mg/L as N; values ranged from <0.01 mg/L to 12.61 mg/L as N; the corresponding concentration for Suffolk County was <0.10 mg/L as N; values ranged from <0.01 mg/L to 4.93 mg/L as N (table 6B). The nitrogen concentrations, although based on sparse data, were sufficient for a rough computation of spatial, temporal, and depth trends.

**Table 5.** Time periods used in temporal-trend analysis of nitrogen concentrations in streams of Nassau and Suffolk Counties, N.Y., 1952-97.

[SD2, SD3, Nassau County Sewer Districts 2 and 3, respectively; SWSD, Southwest Sewer District. Locations are shown in fig. 2.]

Time period	Calendar years	Description
1	pre-1952	Most of Nassau County and all of Suffolk County unsewered
2	1952-64	SD2 began treating wastewater; final sewer hookups completed in 1964
3	1965-73	Pre-SD3 period; SD2 in operation
4	1974-81	Pre-SSD period. SSD began treating wastewater; final sewer hookups completed in 1988.
5	1982-88	SSD began treating wastewater; SD33 completed in 1988.
6	1988-97	All three sewer districts completed

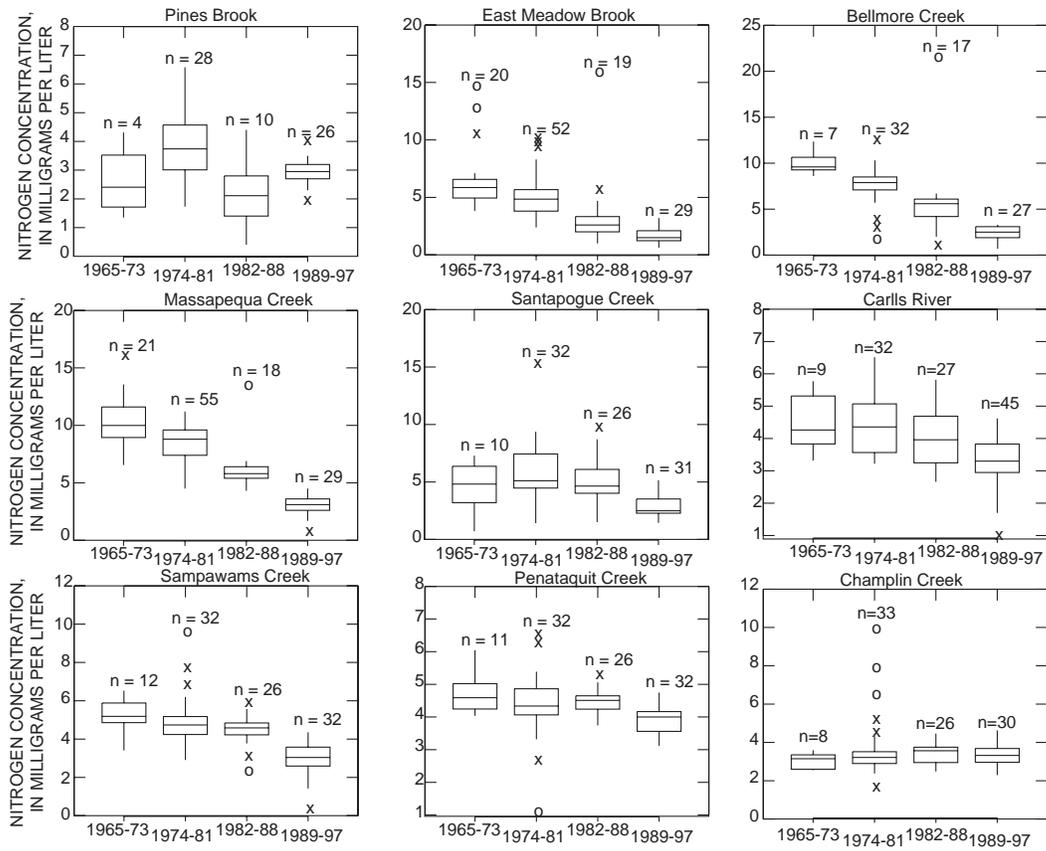
## Geographic Trends

The water-quality data from the 192 wells were grouped into five geographic areas (fig. 7). Area A is SD2, area B is SD3, area C is SWSD, area D is east of SWSD and west of Carmans River, and area E is east of Carmans River. Summary statistics for shallow and deep wells within the five areas are given in table 7. The distribution of total nitrogen data collected from streams, shallow wells and deep wells during 1952-97 are presented in boxplots (fig. 12). The boxplots indicate an eastward increase in median total nitrogen concentrations in shallow-wells in Nassau County (from Area A to Area B), and a decreasing trend eastward into Suffolk County (from Area C through Area E), similar to the geographic trends observed in the stream data. The deep-well data in figure 12 indicate uniformly low concentrations except in the easternmost area (Area E), where the median nitrate concentration exceeded 3 mg/L as N. Eleven of the 16 samples with nitrate concentrations greater than 3 mg/L as N were from a single well in Area E and, thus, probably are not a true representation of the deep ground water within that area, but rather a site-specific occurrence. More data collection would be needed to confirm this conclusion, however.

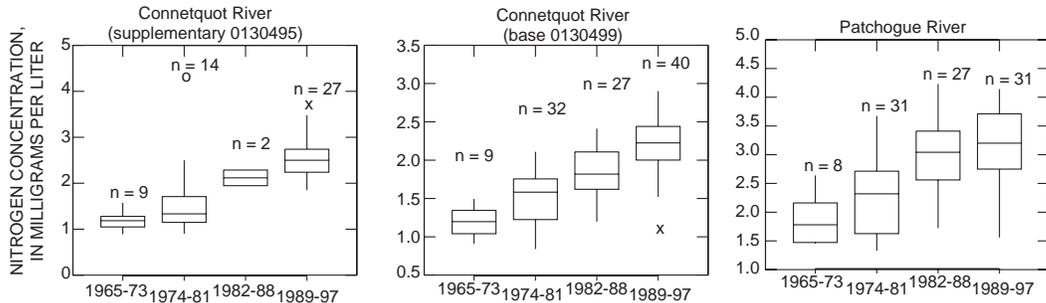
## Temporal Trends

The shallow-well data that were grouped into geographic areas A through E were regrouped to

**A. STREAMS IN SEWERED AREAS**



**B. STREAMS IN UNSEWERED AREAS**



**EXPLANATION**

- n=30 - Number of values
- o - Data value(s) exceeding upper quartile plus 3 times the interquartile range
- x - Data value(s) exceeding upper quartile plus 1.5 times the interquartile range but less than the upper quartile plus 3 times the interquartile range
- Largest data values less than or equal to the upper quartile plus 1.5 times the interquartile range
- Upper quartile (75th percentile)
- Median (50th percentile)
- Lower quartile (25th percentile)
- Smallest data values greater than or equal to the upper quartile minus 1.5 times the interquartile range

**Figure 11.** Distribution of nitrogen concentration in streams on the south shore of Nassau and Suffolk Counties, N.Y. during selected time periods: A. In the nine streams in sewered areas. B. In the four streams in unsewered areas. (Time periods are defined in table 5; locations are shown in fig. 2.)

**Table 6.** Number of samples collected from selected shallow and deep wells within 1 mile of the south shore of Nassau and Suffolk Counties, N.Y., and maximum, median, and minimum concentrations of nitrogen at shallow wells and of nitrate at deep wells, 1952-97.

[Shallow-well depth 0-125 feet; deep-well depth 126–300 feet; mg/L as N, milligrams per liter as nitrogen; <, less than; Min, minimum; Med., median; Max., maximum]

	Shallow ground water			Deep ground water		
	Nassau	Suffolk	Total	Nassau	Suffolk	Total
Number of wells with water-quality data	104	63	167	17	8	25
Number of samples used to calculate total nitrogen load	408	747*	1155	58	54	112

	Total Nitrogen			Total Nitrate		
	Min.	Med.	Max.	Min.	Med.	Max.
Nassau County	.008	3.85	40.1	<.01	.15	12.61
Suffolk County	<.01	1.74	21.6	<.01	<.01	4.93

\* Most samples do not have values for organic nitrogen

represent changes that have occurred over time. The factor that seems to have the greatest effect on ground-water quality along the south shore, as in the long-term trend analysis for the streams, was the implementation of sewerage. Initially, the six time periods listed in table 5 were chosen but two periods—pre-1952 and 1989-97—lacked data. Therefore, the pre-1952 period was omitted and the data for 1989-97 were merged with data collected during 1982-88; thus, the last time period was 1982-97. The results are presented in boxplots (fig. 13).

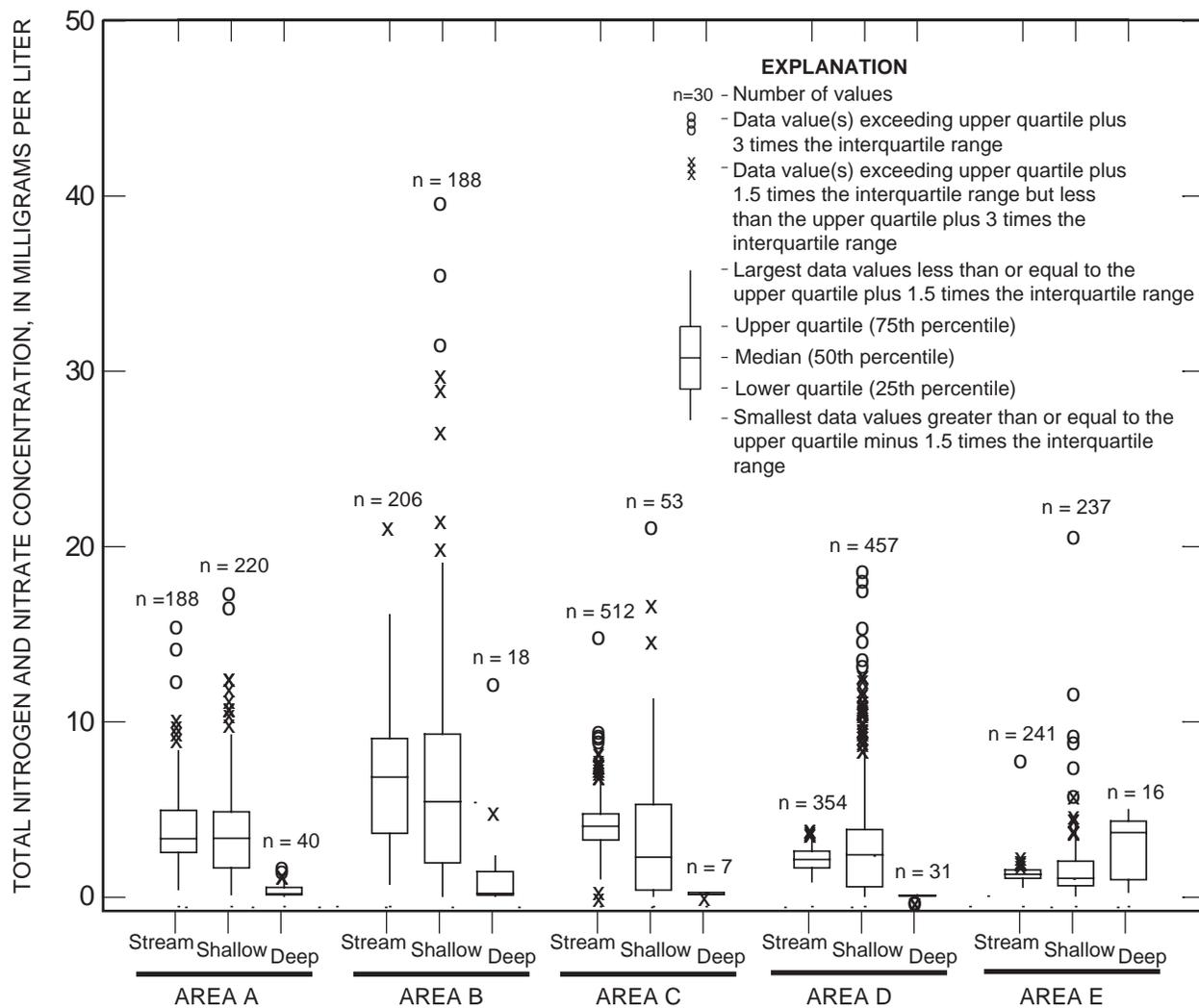
The boxplots for Area A (SD2) show little change in median nitrogen concentration over time probably because this area has been sewered since 1952, and most of the data were collected after 1965 (fig. 13). The median nitrogen concentrations for periods 1 through 4 are 2.70, 3.60, 3.02, and 3.95 mg/L as N, respectively. Note that only four samples were used to calculate the median nitrogen concentration in time period 1; therefore, the boxplot is not comparable with the others.

The boxplots for Area B (SD3) indicate no change in median nitrogen concentrations from period 1 to period 2 (median values are 1.26 and 1.55 mg/L as N,

**Table 7.** Minimum, maximum, and median total nitrogen concentrations in shallow and deep ground water in Areas A through E of South Shore Estuary Reserve, Nassau and Suffolk Counties, N.Y., 1952-97.

[Concentrations are in milligrams per liter; <, less than. Locations are shown in fig. 2]

Geo-graphic area	Total nitrogen concentration			Number of samples	Number of wells
	Min	Median	Max		
<b>Shallow wells (depth 0-125 feet)</b>					
A	.102	3.31	17.81	220	57
B	.008	5.40	40.1	188	47
C	<.01	2.25	21.60	53	10
D	<.01	2.36	19.06	457	33
E	.022	1.03	21.04	237	20
<b>Deep wells (depth 126-300 feet)</b>					
A	<.01	.14	2.14	40	10
B	<.01	.17	12.61	18	7
C	.10	.10	.40	7	1
D	<.01	<.05	.20	31	4
E	.24	3.63	4.93	16	3

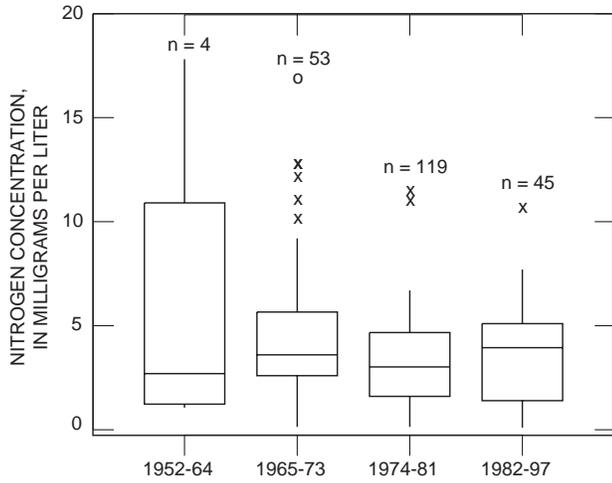


**Figure 12.** Distribution of total nitrogen concentrations in samples from streams and shallow wells, and nitrate concentrations in samples from deep wells in the five geographic areas within 1 mile of the south shore of Nassau and Suffolk Counties, N.Y., 1952-97. (Locations are shown in figs. 6 and 7.)

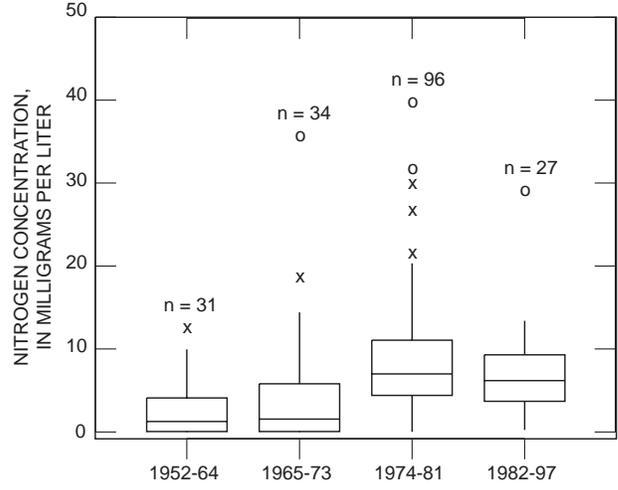
respectively) (fig. 13). An increase is indicated in period 3 (median nitrogen concentration of 7.00 mg/L as N) and a small decrease in period 4 (median nitrogen concentration of 6.20 mg/L as N). Wastewater has been treated in Area B since 1974, but this increase occurs in 1974-81, probably because water with high nitrogen concentrations north of the 1-mi-wide zone was entering the zone at this time. Katz and others (1980) mapped the areal distribution of median nitrate-N concentrations in the upper glacial aquifer during 1972-76, and Perlmutter and Koch (1972) mapped the nitrate concentration in the upper glacial aquifer in Nassau County during 1966-70; both investigations indicate higher concentrations of nitrate

north of the 1-mi-wide zone. Buxton and Modica (1992) estimated that velocities range from less than 1 ft/d to 2 ft/d, under steady-state conditions, in the upper glacial aquifer; thus, water moving at the faster rate of 2 ft/d would take more than 7 years to travel 1 mile. Therefore, the water north of the 1-mi zone, with high nitrate values, probably was entering the 1-mi zone during period 3 causing the increase from period 2 to period 3. Another reason for the high nitrate concentrations may be increased fertilizer use; Porter (1980) indicated two principal sources of nitrogen are human waste and fertilized turf. Sewering removes the human wastewater contribution, but the N contribution from fertilizers remains. This contribution

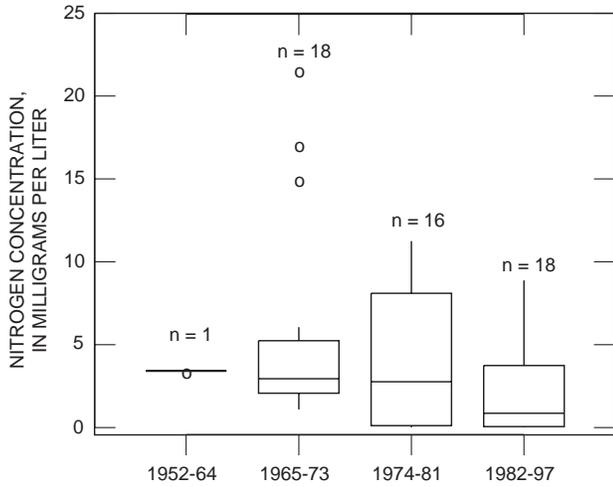
Area A (Sewer District 2)



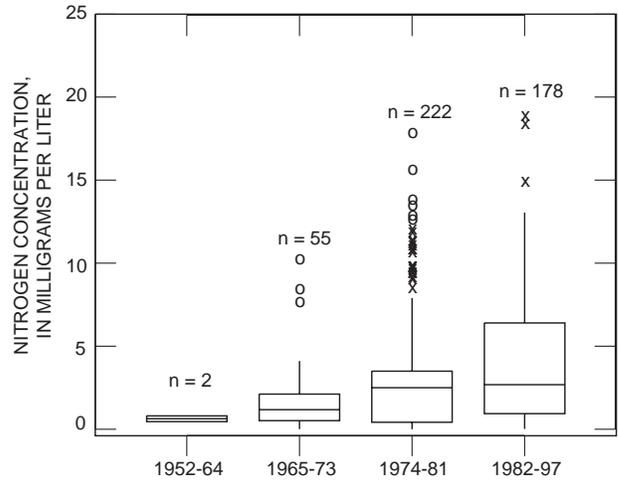
Area B (Sewer District 3)



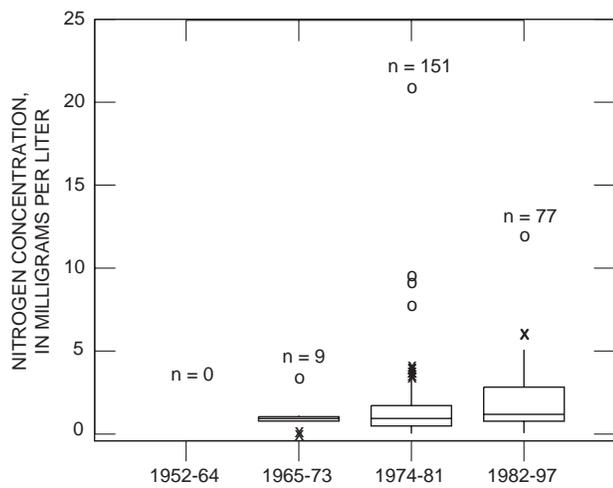
Area C (Southwest Sewer District)



Area D (Unsewered West of Carmans River)



Area E (Unsewered area East of Carmans River)



**EXPLANATION**

- n=30 - Number of values
- ⊠ - Data value(s) exceeding upper quartile plus 3 times the interquartile range
- \*\* - Data value(s) exceeding upper quartile plus 1.5 times the interquartile range but less than the upper quartile plus 3 times the interquartile range
- Largest data values less than or equal to the upper quartile plus 1.5 times the interquartile range
- Upper quartile (75th percentile)
- Median (50th percentile)
- Lower quartile (25th percentile)
- Smallest data values greater than or equal to the upper quartile minus 1.5 times the interquartile range

**Figure 13.** Distribution of nitrogen concentrations in samples from shallow wells in Areas A through E along south shore of Nassau and Suffolk Counties, N.Y., for four selected time periods. (Locations are shown in figs. 6 and 7.)

may account for the observed increase from period 2 to period 3. Solute-transport modeling might be used to investigate the occurrence of high nitrogen water. This modeling is beyond the scope of this study.

The boxplots for Area C (SWSD) show little change in median nitrogen concentration from periods 1 through 3 (median values are 3.40, 2.95, and 2.76 mg/L as N, respectively) (Note that period 1 only has one sample). The median nitrogen concentration decreased to 0.86 mg/L as N in period 4, possibly in response to sewerage, which started in 1982.

The boxplots for Areas D and E show increasing median nitrogen concentrations over time (fig. 13). The median nitrogen concentrations in Area D from periods 1 through 4 are 0.64, 1.18, 2.50, and 2.69 mg/L as N, respectively (Note that period 1 only has one sample). In Area E, no samples were available for period 1 but median nitrogen concentrations for periods 2 through 4 are 0.93, 0.94, and 1.19 mg/L as N, respectively. This small increasing trend probably is the result of urban growth; the Long Island regional planning board recorded a population increase in Suffolk County from around 276,000 in 1950 to 1.3 million in 1990.

### Trends with Depth

Nitrogen concentrations generally decrease with depth below land surface, and water in the upper part of the Magothy aquifer contains less nitrogen than the overlying upper glacial aquifer. Median nitrate concentrations in samples taken in 1989 from parts of the Magothy aquifer that were unaffected by human activities were less than 0.3 mg/L as N (Pearsall, 1996). Pumping in some developed areas can draw high nitrogen waters from the shallow part of the ground-water system into deeper parts (Eckhardt and Pearsall, 1989). Median nitrate concentrations in samples from deep wells (depth was based on travel time more than 100 years along a vertical flow path) in selected areas near the regional ground-water divide from June 1987 through September 1988 were 3.55 mg/L as N in SD2, 2.36 mg/L as N in SD3, and 0.60 mg/L in unsewered areas (Stackelberg, 1995). These elevated concentrations in the deep ground water of sewerage areas are attributed to the drawdown of shallow ground water that has been affected by human activities.

The geographic areas that were used to group the well data also were applied to the stream water-quality data for comparison with the corresponding shallow-

and deep-well data to discern trends with depth (fig. 12). The streams whose data were used for each area are listed in table 8.

The boxplots indicate that the median nitrogen concentration decreases with depth, except in Area E, as explained earlier. Stream median nitrogen

**Table 8.** Geographic grouping of the 13 selected streams that discharge to the South Shore Estuary Reserve, Long Island, N.Y.

[Stream locations are shown in fig. 2; geographic-area locations are shown in fig. 7.]

Geographic area	Streams
A	Pines Brook, East Meadow Brook
B	Bellmore Creek, Massapequa Creek
C	Santapogue Creek, Carlls River, Sampawams Creek, Penataquit Creek, and Champlin Creek
D	Connetquot River, Patchogue River, and Swan River
E	Carmans River

concentration also are similar or slightly higher than, the shallow-well median nitrogen concentration for each geographic area (fig. 12). The plots also show a wider variability in shallow-well data than in stream data, although this might be attributed to differences in periods of records of water-quality samples.

### NITROGEN LOADS ENTERING THE SOUTH SHORE ESTUARY RESERVE

The nitrogen loads discharged from streams to the SSER for each year during 1972-97 were calculated as the annual mean total nitrogen concentration multiplied by the annual mean discharge. These values were calculated only for the seven streams for which sufficient data were available (East Meadow Brook, Bellmore Creek, Massapequa Creek, Carlls River, Sampawams River, Swan River, and Carmans River). Discharge data collection on Santapogue and Champlin Creeks was discontinued in water year 1969; therefore, these streams were omitted from the 1972-97 load calculations.

The nitrogen load carried to the SSER by the shallow-ground-water system (upper glacial aquifer) was calculated as the model-generated discharge multiplied by the median total nitrogen concentrations for Nassau and Suffolk Counties at 167 shallow wells (125 ft deep or less) within 1 mi of the shore. The

nitrogen load from the deep-ground-water system (upper part of Magothy aquifer) to the SSER were calculated as the simulated discharge multiplied by the median nitrate concentrations (nitrate represented almost all of the total nitrogen) for Nassau and Suffolk Counties at 25 deep wells (greater than 125 feet deep) within 1 mi of the shore.

## Annual Stream Loads

The nitrogen loads discharging to the SSER from streams during 1972-97 varied with fluctuations in total nitrogen concentrations and stream discharge (fig. 14). The large variations mainly are a result of the implementation of sewer systems, fluctuations in recharge from precipitation and urban growth. The nitrogen loads entering the SSER from streams are summarized in table 9.

## Geographic Trends

The three westernmost streams except Pines Brook (East Meadow Brook, Bellmore Creek, and Massapequa Creek) show a wide variation in annual nitrogen load throughout 1972-97 (table 9) and is visible in the boxplots shown in figure 15. The loads for all four streams ranged from 1.65 to 184 ton/yr (1,500 to 165,000 kg/yr). The smallest loads for these four streams occurred in 1995, a year characterized by low annual precipitation and low stream discharge. Pines Brook (the westernmost stream) had the smallest range in annual nitrogen load (1.97 - 15.8 ton/yr; 1780 - 14,300 kg/yr), and had the lowest discharge of all streams, it also had the smallest annual mean nitrogen load. Carlls River had the largest long-term (1972-97) average annual mean nitrogen load (104 ton/yr; 94,300 kg/yr), with a range of 36.3 to 184 ton/yr (32,900 to 167,000 kg/yr) (fig. 15). The annual mean nitrogen load from Carlls River was over three times that of Carmans River (33 ton/yr or 30,000 kg/yr) and twice that of Connetquot River (54 ton/yr or 49,000 kg/yr); however, from 1972 to 1987 only a portion of the load from Connetquot River was calculated (table 9).

## Temporal Trends

Nitrogen loads from streams entering the SSER were evaluated for two periods—1972-84 and 1985-97. A median load for each stream was calculated for each period from the 1972-97 load calculations in

table 9; Penataquit Creek and Patchogue Creek were omitted because no loads were calculated for 1985-97. The results indicate that the sewered residential areas in Nassau County had a large reduction in estimated nitrogen loads. The four streams in this area (Pines Brook, East Meadow Brook, Bellmore Creek, and Massapequa Creek) produced about 220 ton/year (200,000 kg/yr) before 1985 and 43 ton/year (39,000 kg/yr) after 1985—an 80 percent decrease in nitrogen load. The two streams in the SWSD (Carlls River, and Sampawams Creek) together produced about 175 ton/yr (159,000 kg/yr) before 1985 and 98 ton/yr (88,900 kg/yr) after 1985—a 40-percent decrease. The streams in the unsewered areas in Suffolk County (Connetquot River, Swan River, and Carmans River) produced about 129 ton/yr (117,000 kg/yr) during 1972-84 and 139 ton/yr (126,000 kg/yr) during 1985-97—a long-term increase of about 7 percent.

The stream nitrogen loads discharged to the SSER in each year from 1972 through 1997 (from table 9) were summed for each county and graphed in figure 16 to show each counties annual stream load. The loads from both stations at Connetquot River were combined, however, from 1972 through 1987 the combined value is missing a calculated load from one or both stations, also Penataquit Creek and Patchogue River only have 4 and 2 years of calculated load, respectively; therefore, the loads calculated in Suffolk County streams is smaller than the actual load. The combined stream load discharged to the SSER from 11 streams ranged from 169 ton/yr (153,000 kg/yr) in 1995 to 705 ton/yr (640,000 kg/yr) in 1979; however, note that values for the Penataquit and Patchogue Rivers are missing for both years, and the value for Connetquot base station in 1979 is missing (fig. 16). This range in stream loads is in addition to the loads transported by ground-water discharge

## Ground-Water Loads

The nitrogen load entering the SSER from aquifers was calculated as simulated ground-water discharges multiplied by the median total nitrogen concentrations calculated from data from the selected wells represented in the NWIS database. The numbers of shallow and deep wells, and samples are summarized by well depth and county in table 6; the concentrations and loads are summarized by county and depth in table 10.

**Table 9. Estimated annual nitrogen loads entering the South Shore Estuary Reserve from 11 streams on the south shore of Long Island, N.Y., 1972-97.**

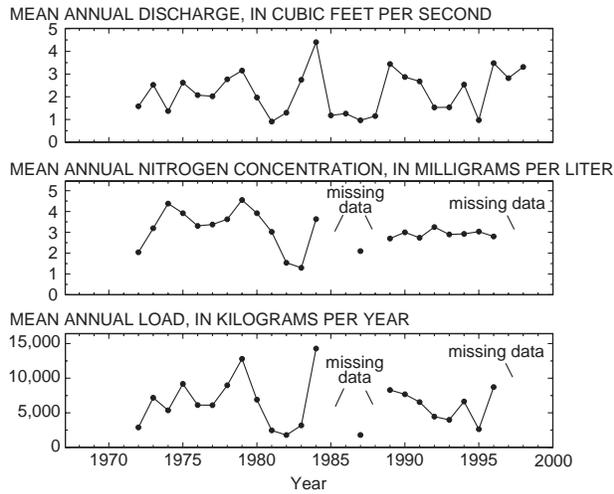
[Discharge measurement on Santapogue and Champlin Creeks ceased in 1969; therefore, these streams are omitted. ton/yr, tons per year; kg/yr, kilograms per year. Dashes indicate no samples collected. Locations are shown in fig. 2.]

Year	Pines Brook		East Meadow Brook		Bellmore Creek		Massapequa Creek		Carlls River		Sampawams River	
	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr
1972	3.18	2,880	57.6	52,300	--	--	119	108,000	111	101,000	55.8	50,600
1973	7.93	7,190	93.9	85,200	83.8	76,000	182	165,000	134	122,000	52.2	47,400
1974	5.91	5,360	40.0	36,300	58.0	52,600	74.1	67,200	110	99,800	55.4	50,300
1975	10.1	9,170	76.0	68,900	65.6	59,500	123	112,000	121	110,000	87.2	79,100
1976	6.74	6,120	71.3	64,700	38.2	34,700	89.5	81,200	116	105,000	33.6	30,500
1977	6.72	6,090	47.5	43,000	62.2	56,400	101	92,000	114	103,000	32.9	29,800
1978	9.89	8,970	85.6	77,700	69.8	63,300	118	107,000	184	167,000	56.1	50,900
1979	14.1	12,800	150	136,000	65.6	59,500	155	141,000	156	142,000	63.4	57,500
1980	7.59	6,890	57.3	52,000	34.9	31,700	83.4	75,700	119	108,000	47.5	43,100
1981	2.70	2,450	16.6	15,100	16.2	14,700	34.6	31,400	91.4	82,900	41.2	37,400
1982	1.97	1,780	18.0	16,300	13.8	12,500	45.9	41,600	92.4	83,800	39.4	35,700
1983	3.51	3,180	82.6	74,900	44.2	40,100	85.2	77,300	129	117,000	55.2	50,100
1984	15.7	14,200	76.2	69,100	41.9	38,000	92.9	84,300	161	146,000	69.9	63,500
1985	--	--	12.8	11,600	13.2	12,000	23.6	21,400	78.9	71,600	37.4	33,900
1986	--	--	10.5	9,560	9.34	8,470	20.0	18,100	74.1	67,200	31.2	28,300
1987	1.99	1,800	13.6	12,300	8.22	7,460	20.9	19,000	80.7	73,200	35.9	32,600
1988	--	--	3.79	3,440	4.27	3,870	22.7	20,600	62.7	56,900	21.1	19,100
1989	9.14	8,300	30.5	27,700	12.4	11,200	33.5	30,400	131	119,000	56.5	51,300
1990	8.48	7,690	34.6	31,400	16.8	15,200	38.9	35,300	154	140,000	55.6	50,400
1991	7.22	6,550	16.7	15,100	11.0	9,940	26.4	23,900	98.8	89,600	33.4	30,300
1992	4.90	4,440	5.07	4,600	6.73	6,100	14.1	12,800	74.0	67,100	22.9	20,800
1993	4.39	3,990	6.97	6,320	5.69	5,160	15.3	13,900	69.0	62,600	24.9	22,600
1994	7.32	6,640	6.36	5,770	4.60	4,170	12.2	11,100	65.0	59,000	24.0	21,800
1995	2.90	2,630	1.66	1,500	2.00	1,810	5.25	4,760	36.2	32,800	13.2	12,000
1996	9.60	8,710	7.62	6,910	5.82	5,280	10.4	9,410	60.9	55,200	24.1	21,900
1997	--	--	--	--	--	--	10.1	9,130	72.2	65,500	2.45	2,220

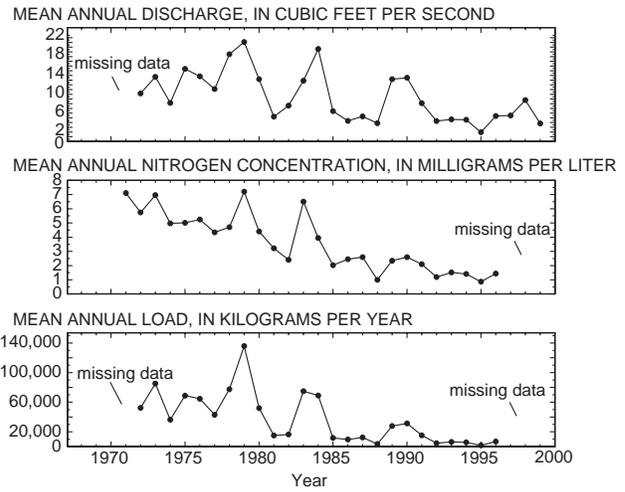
  

Year	Penataquit Creek		Connetquot River stations				Patchogue River		Swan River		Carmans River	
	ton/yr	kg/yr	Base	kg/yr	Supplementary	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr	ton/yr	kg/yr
1972	33.9	30,800	--	--	10.9	9,900	--	--	23.4	21,200	27.1	24,600
1973	38.9	35,300	--	--	17.3	15,700	29.9	27,100	20.9	19,000	32.3	29,300
1974	19.4	17,600	--	--	26.2	23,800	32.1	29,100	20.1	18,200	27.5	24,900
1975	29.2	26,500	--	--	24.8	22,500	--	--	17.8	16,100	24.3	22,000
1976	--	--	--	--	27.3	24,800	--	--	22.4	20,300	26.3	23,900
1977	--	--	--	--	--	--	--	--	19.6	17,800	25.9	23,500
1978	--	--	--	--	26.9	24,400	--	--	27.1	24,600	31.1	28,200
1979	--	--	--	--	27.6	25,000	--	--	30.3	27,500	43.3	39,300
1980	--	--	53.4	48,400	--	--	--	--	23.2	21,000	32.6	29,600
1981	--	--	38.7	35,100	--	--	--	--	17.5	15,900	22.3	20,200
1982	--	--	32.8	29,800	--	--	--	--	20.7	18,800	47.7	43,300
1983	--	--	49.1	44,500	--	--	--	--	27.3	24,800	35.7	32,400
1984	--	--	60.4	54,800	--	--	--	--	45.3	41,100	55.2	50,100
1985	--	--	40.3	36,600	--	--	--	--	20.5	18,600	33.2	30,100
1986	--	--	37.8	34,300	--	--	--	--	19.7	17,900	25.9	23,500
1987	--	--	42.8	38,800	--	--	--	--	22.2	20,100	27.7	25,100
1988	--	--	26.0	23,600	21.7	19,700	--	--	16.8	15,200	25.0	22,700
1989	--	--	42.8	38,800	40.5	36,700	--	--	27.6	25,000	39.4	35,700
1990	--	--	60.2	54,600	73.8	67,000	--	--	33.8	30,700	52.2	47,400
1991	--	--	49.0	44,500	61.5	55,800	--	--	29.7	26,900	44.3	40,200
1992	--	--	45.3	41,100	39.9	36,200	--	--	23.8	21,600	28.0	25,400
1993	--	--	39.1	35,500	40.8	37,000	--	--	24.9	22,600	33.8	30,700
1994	--	--	45.4	41,200	43.9	39,800	--	--	25.0	22,700	34.8	31,600
1995	--	--	33.5	30,400	34.0	30,800	--	--	19.2	17,400	20.8	18,900
1996	--	--	36.8	33,400	47.1	42,700	--	--	25.6	23,200	24.7	22,400
1997	--	--	--	--	53.2	48,300	--	--	29.7	26,900	31.1	28,200

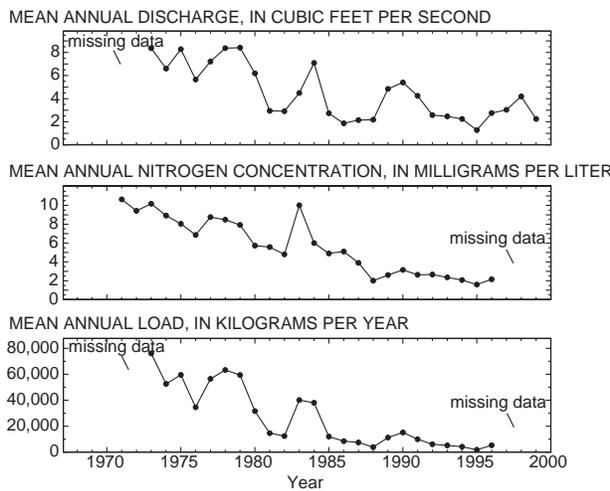
### Pines Brook



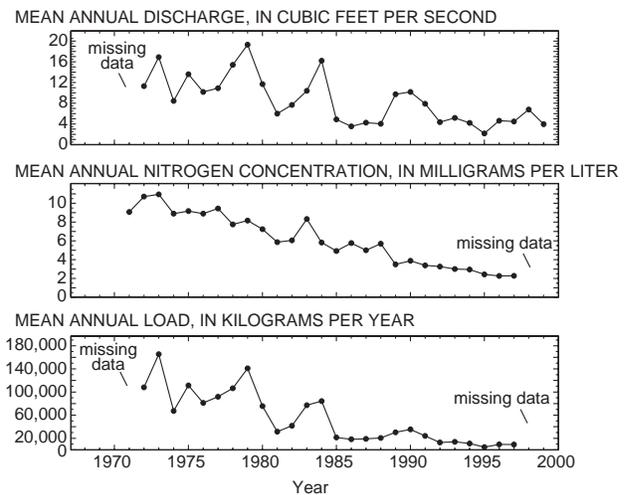
### East Meadow Brook



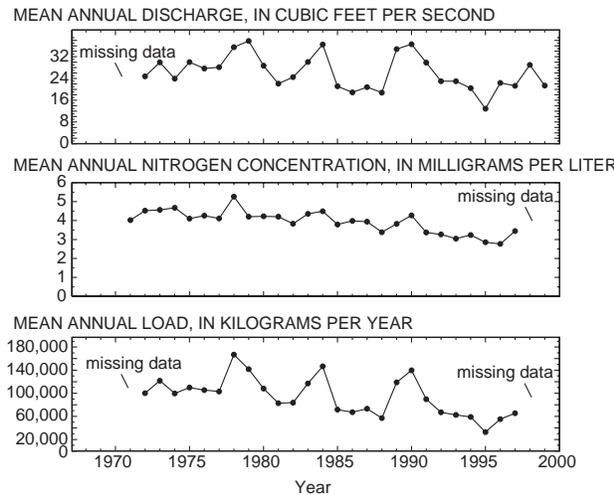
### Bellmore Creek



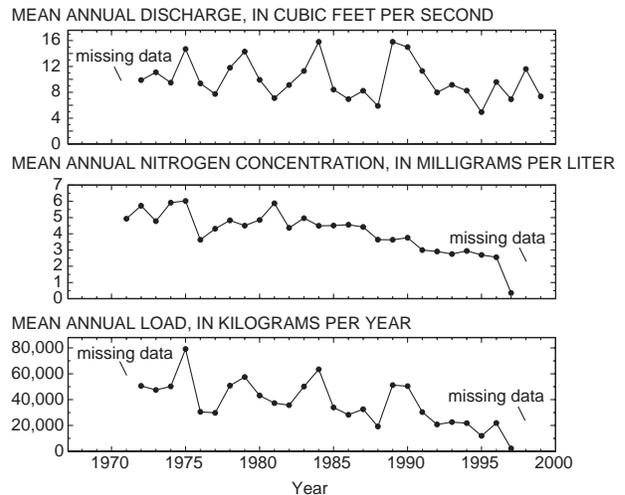
### Massapequa Creek



### Carlis River

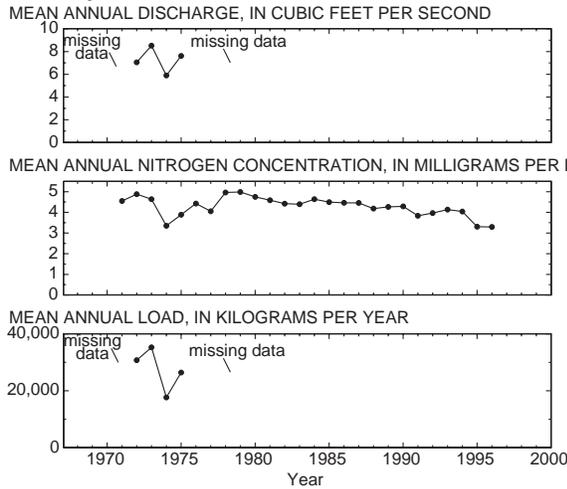


### Sampawams River

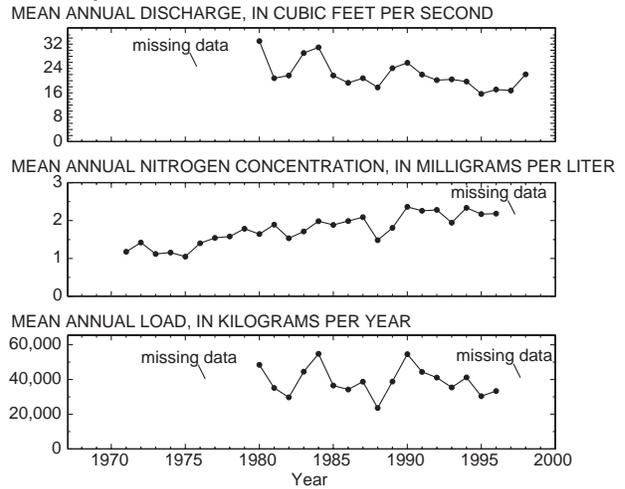


**Figure 14.** Annual mean discharge, mean nitrogen concentration, and mean nitrogen load calculated for 11 selected south-shore streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y., 1972-97. (Locations are shown in fig. 2.)

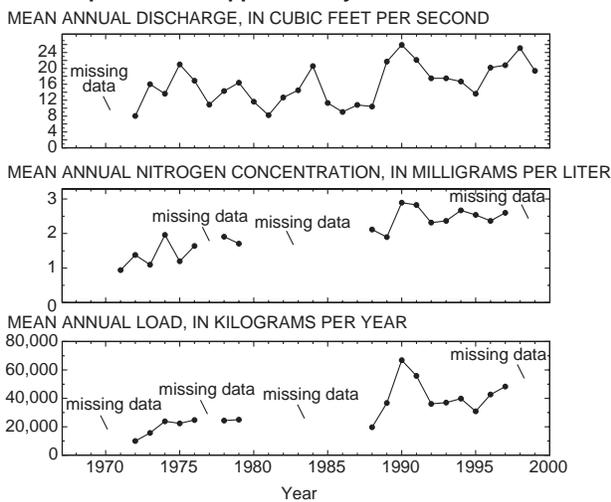
### Penataquit Creek



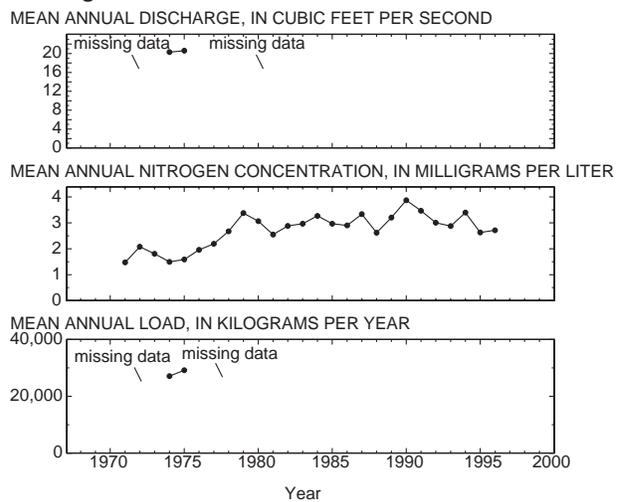
### Connetquot River- Base Station



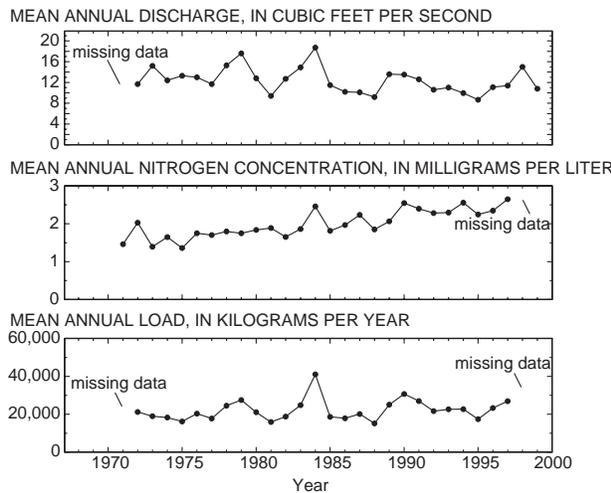
### Connetquot River- Supplementary Station



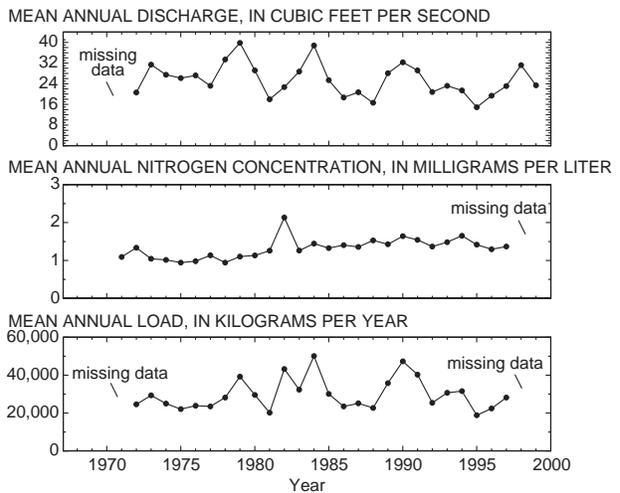
### Patchogue River



### Swan River



### Carmans River

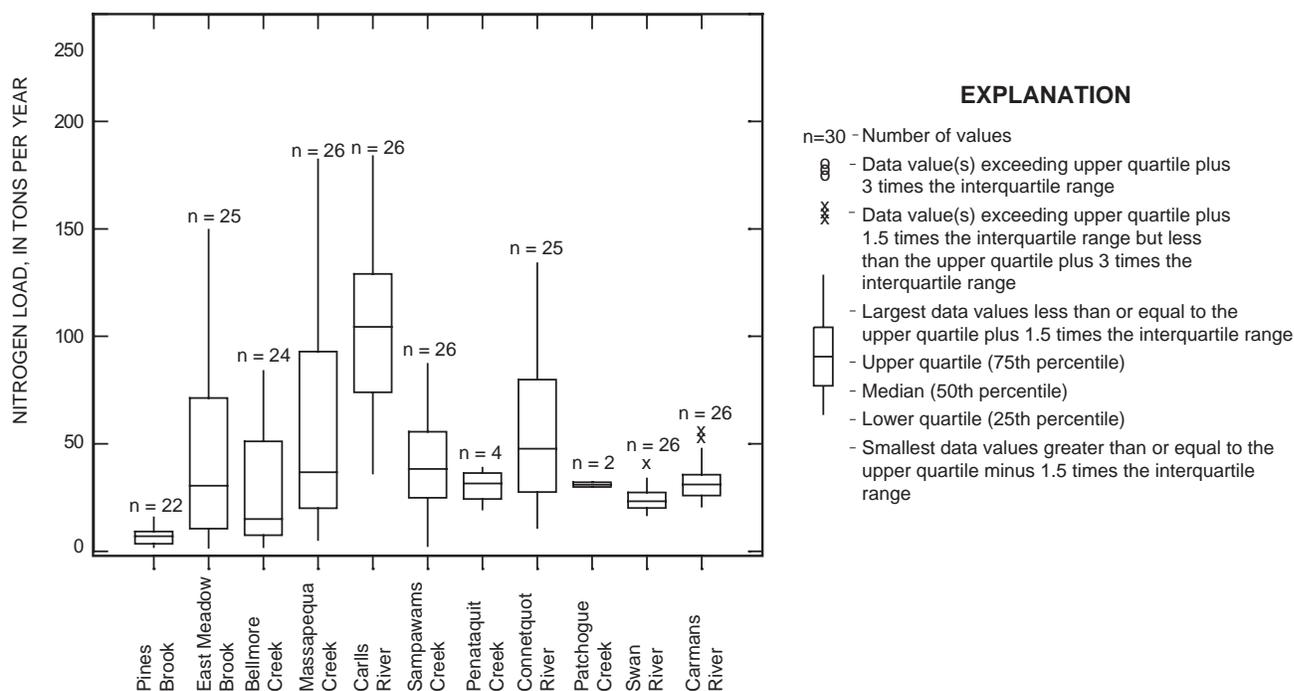


**Figure 14.** (continued) Annual mean discharge, mean nitrogen concentration and mean nitrogen load calculated for 11 selected south-shore streams that discharge to the South Shore Estuary Reserve from Nassau and Suffolk Counties, N.Y., 1972-97. (Locations are shown in fig. 2.)

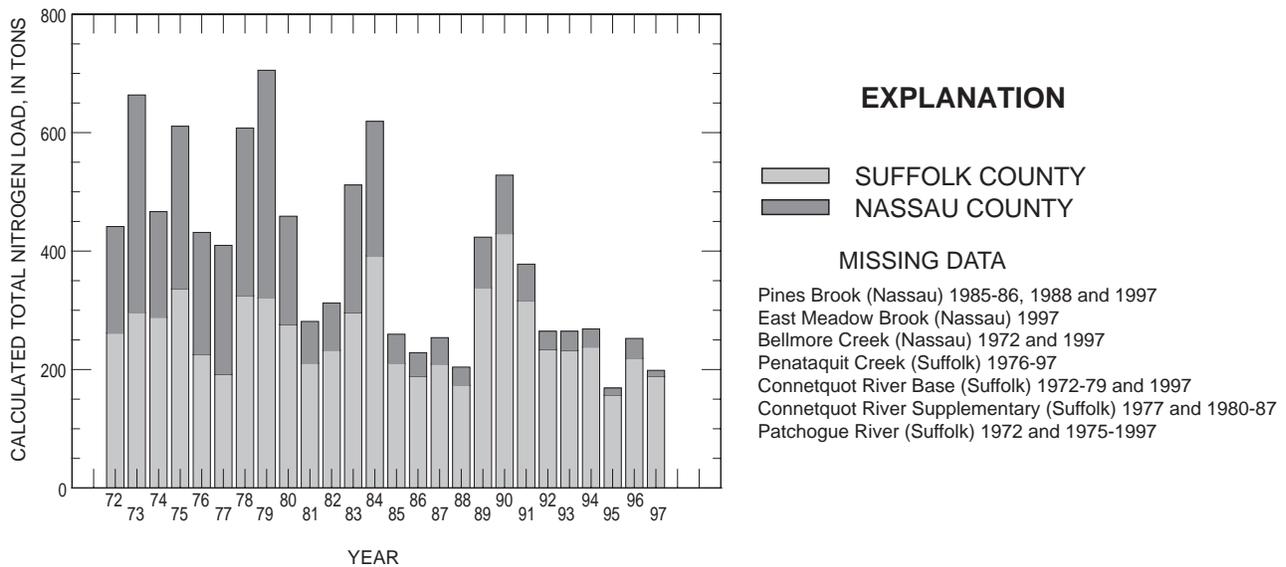
**Table 10.** Median concentration and annual load of nitrogen entering the South Shore Estuary Reserve from shallow and deep ground water in Nassau and Suffolk Counties, N.Y., as calculated from concentrations at wells within 1 mile of the shore, 1952-97.

[Based on simulated discharge of 1983 steady-state conditions. mg/L, milligrams per liter; ton/yr, tons per year; kg/yr, kilograms per year; <, less than.]

	Shallow ground water (as total nitrogen)			Deep ground water (as total nitrate)		
	Median concentration for wells (mg/L as N)	Annual load from ground water		Median concentration for wells (mg/L as N)	Annual load from ground water	
		ton/yr	kg/yr		ton/yr	kg/yr
Nassau County	3.85	172	156,000	0.15	3.0	2,700
Suffolk County	1.74	380	345,000	<0.01	<0.5	<480
<b>Total</b>		<b>552</b>	<b>501,000</b>		<b>&lt;3.5</b>	<b>&lt;3,180</b>



**Figure 15.** Distribution of nitrogen load calculated in 11 selected streams on the south shore of Nassau and Suffolk Counties, N.Y., 1972-97. (Locations are shown in fig.2.)



**Figure 16.** Combined nitrogen load from four streams in Nassau County and seven in Suffolk County, N.Y. that discharge to the South Shore Estuary Reserve during 1972-97.

### Shallow-Ground-Water System

The median nitrogen concentration for samples from the 104 shallow wells in Nassau County was 3.85 mg/L as N; values ranged from 0.008 mg/L to 40.1 mg/L as N, during 1952-97 (table 6). The median concentration for the 63 shallow wells in Suffolk County was 1.74 mg/L as N; the values ranged from <0.1 mg/L as N to 21.6 mg/L as N, during 1952-97. Multiplying the simulated shallow-ground-water discharges by the shallow well median total nitrogen concentrations of 3.85 and 1.74 mg/L as N for Nassau and Suffolk Counties, respectively, gave nitrogen loads of 172 and 380 ton/yr or 156,000 and 345,000 kg/yr; equaling 552 ton/yr (501,000 kg/yr) entering the SSER from the shallow-ground-water system (table 10).

### Deep-Ground-Water System

The median nitrate concentration for the 17 deep wells in Nassau County was 0.15 mg/L as N, and the range was from <0.01 to 12.61 mg/L as N, during 1952-97. The median concentration for the eight deep wells in Suffolk County was <0.01 mg/L as N, and the range was from <0.01 to 4.93 mg/L as N, during 1952-97. Multiplying the simulated deep-ground-water discharges by the respective median total nitrogen

concentrations of 0.15 and <0.01 mg/L as N for Nassau and Suffolk Counties, respectively, gave total nitrate loads of 3.0 and <0.5 ton/yr or 2,700 and 480 kg/yr; equaling about 3.5 ton/yr (3,180 kg/yr) entering the SSER from the deep-ground-water system (table 10).

### Total Nitrogen Load

The total nitrogen loads entering the SSER is the sum of both the stream loads and ground-water loads. It only was possible to calculate annual loads from 11 selected streams with the available data. These loads varied geographically, and temporally. The ground-water loads calculated are annual loads; however, the load is a constant value (556 ton/yr; 504,000 kg/yr) because water-quality data were sparse and discharge data were simulated under steady-state hydrologic conditions. The ground-water load is the sum of the shallow-ground-water system nitrogen load (552 ton/yr; 501,000 kg/yr) and deep-ground-water system nitrate load (3.5 ton/yr; 3,180 kg/yr). The surface-water load and the total load to the SSER (surface-water plus ground-water load) for each year (1972-97) is summarized in table 11.

The largest calculated total nitrogen load entering the SSER occurred in 1979 with a total load of 1,260 ton/yr (1,140,000 kg/yr). The smallest

**Table 11.** Total annual nitrogen load entering the South Shore Estuary Reserve from streams and ground water on the south shore of Long Island, N.Y., 1972-97.

[Total load is the sum of combined stream load and ground water load; missing stream loads explained in fig. 16; bar graph of combined stream load shown in fig. 16. ton/yr, tons per year; kg/yr, kilograms per year.]

Year	Combined Stream Load		Total Load	
	ton/yr	kg/yr	ton/yr	kg/yr
1972	442	401,000	998	905,000
1973	664	602,000	1,220	1,110,000
1974	467	424,000	1,023	928,000
1975	611	554,000	1,170	1,060,000
1976	431	391,000	987	895,000
1977	410	372,000	966	876,000
1978	608	552,000	1,160	1,050,000
1979	705	640,000	1,260	1,140,000
1980	459	416,000	1,020	925,000
1981	281	255,000	837	759,000
1982	312	283,000	868	787,000
1983	512	464,000	1,070	971,000
1984	619	562,000	1,180	1,070,000
1985	260	236,000	816	740,000
1986	229	208,000	785	712,000
1987	254	230,000	810	735,000
1988	204	185,000	760	689,000
1989	424	385,000	980	889,000
1990	528	479,000	1,080	980,000
1991	378	343,000	934	847,000
1992	265	240,000	821	745,000
1993	265	240,000	821	745,000
1994	269	244,000	825	748,000
1995	169	153,000	725	658,000
1996	253	230,000	809	734,000
1997	199	181,000	755	685,000

calculated nitrogen load entering the SSER occurred in 1995 with a total load of 725 ton/yr (658,000 kg/yr). This range in load is an estimate based on the available data; the actual load to the SSER is higher because of various factors discussed in previous sections. These factors should be considered when calculating the SSER nitrogen load budget.

## SUMMARY

The South Shore Estuary Reserve (SSER) of Long Island, N.Y. is a series of shallow tidal bays that provide a rich habitat for fish and wildlife. High nitrogen concentrations and resulting low dissolved oxygen concentrations (hypoxia) is a concern in the SSER. The U.S. Geological Survey, in cooperation with the New York State Department of State

(NYS DOS), began an investigation in 1998 to refine estimates of nitrogen loading to the SSER.

Analyses of total nitrogen concentrations in the 13 streams that discharge from Nassau and Suffolk Counties, N.Y. from the SSER indicate a general eastward increase from Pines Brook (the westernmost stream) to Massapequa Creek in Nassau County, and a decrease from Massapequa Creek to Carmans River (the easternmost stream) in Suffolk County. Patchogue River deviated slightly from this decreasing trend. Eight of the streams (Pines Brook, East Meadow Brook, Bellmore Creek, Massapequa Creek, Santapogue Creek, Carlls River, Sampawams Creek, and Penataquit Creek) showed apparent decreasing trends in total nitrogen concentration during 1971-97, whereas four streams (Connetquot River, Patchogue River, Swan River, and Carmans River) showed long-term (1971-97) increasing trends. No long-term trends were discernible from Champlin Creek data.

Seasonal fluctuations in total nitrogen concentrations in the streams result from chemical reactions and biological activity within the stream systems. In all 13 selected streams, the median nitrogen concentration in winter (October through March) were higher than in summer (April through September) during 1971-97; but the difference is small. Carlls River had the largest difference in median nitrogen concentration between winter and summer.

The estimated annual nitrogen load discharged to the SSER from 11 of the 13 streams (Santapogue and Champlin Creeks were omitted because discharge data were not available during 1972-97) for 1972-97 was calculated as the annual mean total nitrogen concentration for each stream multiplied by its annual mean discharge. The combined annual nitrogen load from these 11 streams during 1972-97 ranged from 169 ton/yr (153,000 kg/yr) in 1995 to 705 ton/yr (640,000 kg/yr) in 1979. Carlls River had the highest mean annual nitrogen load (104 ton/yr; 94,300 kg/yr) during this period and a wide range of values (36.3 to 184 ton/yr; 32,900 to 167,000 kg/yr). Pines Brook had the smallest range in annual nitrogen load (1.97 to 15.8 ton/yr; 1,780 to 14,300 kg/yr) and coincides with the lowest discharge of all selected streams.

Geographic trends of total nitrogen concentrations in shallow wells (0-125 ft deep) grouped into five geographic areas within 1 mi of the south shore were similar to that of the stream nitrogen concentration—a

general eastward increase in Nassau County followed by a eastward decrease in Suffolk County. The streams and the shallow wells within each geographic area had similar median nitrogen concentrations. Total nitrogen concentrations in ground water generally decrease with depth. Water in the upper part of the Magothy aquifer have a lower median nitrate value than the median nitrogen value of the overlying upper glacial aquifer.

The nitrogen load entering the SSER from shallow-ground-water and deep-ground-water system was calculated as the horizontal and vertical ground-water discharges generated by the USGS Long Island regional-ground-water-flow model multiplied by the median total nitrogen concentrations calculated from data from selected wells represented in the USGS NWIS database. Simulated shallow-ground-water discharge from Nassau County totaled 10,700 Mgal/yr (40,500,000 m<sup>3</sup>/yr), and that from Suffolk County totaled 52,300 Mgal/yr (198,000,000 m<sup>3</sup>/yr). Median total nitrogen concentrations for the two counties were 3.85 and 1.74 mg/L as N, respectively. The resultant nitrogen load from shallow-ground-water discharge was 172 ton/yr (156,000 kg/yr) in Nassau County, and 380 ton/yr (345,000 kg/yr) from Suffolk County; equaling 552 ton/yr entering the SSER.

Simulated deep-ground-water discharge to the SSER from Nassau County totaled 4,900 Mgal/yr (18,500,000 m<sup>3</sup>/yr), and that from Suffolk County totaled 12,700 Mgal/yr (48,200,000 m<sup>3</sup>/yr). The median nitrate concentrations for the two counties were 0.15 and <0.01 mg/L as N, respectively. The resultant nitrogen load from deep-ground-water discharge was 3 ton/yr (2,700 kg/yr) in Nassau County, and <0.5 ton/yr (480 kg/yr) in Suffolk County; equaling about 3.5 ton/yr entering the SSER.

The sum of both stream loads and ground-water loads results in the total load to the SSER. The largest calculated total nitrogen load entering the SSER from both streams and ground water occurred in 1979 with a total load of 1,260 ton/yr (1,140,000 kg/yr). The smallest calculated nitrogen load entering the SSER occurred in 1995 with a total load of 725 ton/yr (658,000 kg/yr).

## REFERENCES CITED

- Aronson, D.A., and Seaburn, G.E., 1974, Appraisal of the operating efficiency recharge basins on Long Island, N.Y., in 1969: U.S. Geological Survey Water-Supply Paper 2001-D, 22 p.
- Bachman, L.J., and Phillips, P.J., 1996, Hydrologic landscapes on the Delmarva Peninsula, Part 2— estimates of base-flow nitrogen load to Chesapeake Bay: *Water Resources Bulletin*, v. 32, no. 4, p. 779-791.
- Bachman, L.J., Lindsey, B., Brakebill, J., and Powars, D.S., 1998, Ground-water discharge and base-flow nitrate loads of nontidal streams, and their relation to a hydrogeomorphic classification of the Chesapeake Bay watershed, middle Atlantic coast: U.S. Geological Survey Water-Resources Investigations Report 98-4059, 71 p.
- Bleifuss, P.S., Hanson, G.H., and Schoonen, M.A.A., 1998, A geochemical study of nitrate contamination in the Long Island aquifer system, *in* *Geology of Long Island and Metropolitan New York*, April 18, 1998, Abstracts: Stony Brook, N.Y., Long Island Geologists, p. 12-23.
- Brown, C.J., Scorca, M.P., Stockar, G.G., Stumm, Frederick, and Ku, H.F.H., 1997, Urbanization and recharge in the vicinity of East Meadow Brook, Nassau County, New York, Part 4—water quality in the headwaters area, 1988-93: U.S. Geological Survey Water-Resources Investigations Report 96-4289, 37 p.
- Buxton, H.T., and Modica, Edward, 1992, Patterns and rates of ground-water flow on Long Island, New York: *Ground Water*, v. 30, no. 6, p. 857-866.
- Buxton and Smolensky, 1999, Simulation of the effects of development of the ground-water flow system of Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 98-4069, 57 p.
- Chambers, J.M., Cleveland, W.S., Kleiner, B., and Tukey, P.A., 1983, *Graphical methods for data analysis*: Murray Hill, N.J., Bell Laboratories, 395 p.
- Dillow, J.J.A., and Greene, E.A., 1999, Ground-water discharge and nitrate loadings to the coastal bays of Maryland: U.S. Geological Survey Water-Resources Investigations Report 99-4167, 8 p.
- Eckhardt, D.A.V., Flipse, W.J., Jr., and Oaksford, E.T., 1989, Relation between land use and ground-water quality in the upper glacial aquifer in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 86-4142, 35 p.
- Eckhardt, D.A.V., and Pearsall, K.A., 1989, Chlorinated organic compounds in ground water at Roosevelt Field, Nassau County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 86-4333, 62 p.
- Eckhardt, D.A.V., and Stackelberg, P.E., 1995, Relation of ground-water quality to land use on Long Island, New York: *Ground Water*, v. 33, no. 6, p. 1019-1033.
- Franke, O.L., 1968, Double-mass curve analysis of the effects of sewerage on ground-water levels on Long

- Island, N.Y., *in* Geological Survey Research 1968: U.S. Geological Survey Professional Paper 600-B, p. B205-B209.
- Franke, O.L., and Cohen, Philip, 1972, Regional rates of ground-water movement on Long Island, New York, *in* Geological Survey Research 1972: U.S. Geological Survey Professional Paper 800-C, p. C271-277.
- Franke, O.L., and McClymonds, N.E., 1972, Summary of the hydrologic situation on Long Island, New York, as a guide to water-management alternatives: U.S. Geological Survey Professional Paper 627-F, 59 p.
- Jensen, H.M., and Soren, Julian, 1971, Hydrogeologic data from selected wells and test holes in Suffolk County, Long Island, New York: Suffolk County Department of Environmental Control, Long Island Water Resources Bulletin 3, 35 p.
- \_\_\_\_\_, 1974, Hydrogeology of Suffolk County, Long Island, New York: U.S. Geological Survey Hydrologic Investigation Atlas HA-501, 2 sheets, scale 1:250,000.
- Katz, B.G., Lindner, J.B., and Ragone, S.E., 1980, A comparison of nitrogen in shallow ground water from sewered and unsewered areas, Nassau County, New York, from 1952 through 1976: *Ground Water*, v. 18, no. 6, p. 607-616.
- Ku, H.F.H., Hagelin, N.W., and Buxton, H.T., 1992, Effects of urban storm-runoff control on ground-water recharge in Nassau County, New York: *Ground Water*, v. 30, no. 4, p. 507-514.
- Ku, H.F.H., and Sulam, D.J., 1979, Hydrologic and water-quality appraisal of southeast Nassau County, Long Island, New York: Nassau County Department of Public Works, Long Island Water Resources Bulletin 13, 129 p.
- LeaMond, C.E., Haefner, R.J., Cauller, S.J., and Stackelberg, P.E., 1992, Ground-water quality in five areas of differing land use in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Open-File Report 91-180, 67 p.
- Long Island Sound Study, 1998, Phase III Actions for Hypoxia Management: EPA 902-R-98-002, 25 p.
- Long Island Regional Planning Board, 1978, Long Island Comprehensive Waste Treatment Management Plan, Volume I: Summary Plan, Hauppauge, N.Y., p. 32-33.
- McDonald, M.G. and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chapter A1, 586 p.
- Nemickas, Bronius, Mallard, G.E., and Reilly, T.E., 1989, Availability and historical development of ground-water resources of Long Island, New York—an introduction: U.S. Geological Survey Water-Resources Investigations Report 88-4113, 43 p.
- Pearsall, K.A., 1996, Comparison of native ground-water quality with water quality in agricultural and residential areas of Long Island, New York: U.S. Geological Survey Open-File Report 95-401, 11 p.
- Perlmutter, N.M., and Koch, Ellis, 1972, Preliminary hydrogeologic appraisal of nitrate in ground water and streams, southern Nassau County, Long Island, New York, *in* Geological Survey Research 1972: U.S. Geological Survey Professional Paper 800-B, p. B225-B235.
- \_\_\_\_\_, 1975, Hydrogeochemical data from investigation of water quality in sewered and unsewered areas, southern Nassau County, Long Island, New York: Nassau County Department of Public Works, Long Island Water Resources Bulletin 4, 37 p.
- Phillips, S.W., Focazio, M.J., and Bachman, L.J., 1999, Discharge, nitrate load, and residence time of ground water in the Chesapeake Bay watershed: U.S. Geological Survey Fact Sheet FS-150-99, 6 p.
- Porter, K., 1980, An evaluation of sources of nitrogen as causes of ground-water contamination in Nassau County, Long Island: *Ground Water*, v. 18, no. 6, p. 617-625.
- Pluhowski, E.J., and Spinello, A.G., 1978, Impact of sewerage systems on stream base flow and ground-water recharge on Long Island, New York: U.S. Geological Survey Journal of Research, v. 6, no. 2, p. 263-271.
- Ragone, S.E., Katz, B.G., Kimmel, G.E., and Lindner, J.B., 1981, Nitrogen in ground water and surface water from sewered and unsewered areas, Nassau County, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 80-21, 64 p.
- Reilly, T.E., Buxton, H.T., Franke, O.L., and Wait, R.L., 1983, Effects of sanitary sewers on ground-water levels and streams in Nassau and Suffolk Counties, New York—Part 1, Geohydrology, modeling strategy, and regional evaluation: U.S. Geological Survey Water-Resources Investigations Report 82-4045, 45 p.
- Scorca, M.P., Reilly, T.E., and Franke, O.L., 1995, Selected hydrogeologic and water quality data from Jones Beach Island, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 92-4171, 21 p.
- Scorca, M.P., and Monti, Jack, Jr., 2001, 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, 29 p.
- Seaburn, G.E., 1969, Effects of urban development on direct runoff to East Meadow Brook, Nassau County, Long Island, N.Y.: U.S. Geological Survey Professional Paper 627-B, 14 p.
- Smolensky, D.A., Buxton, H.T., and Shernoff, P.K., 1989, Hydrologic framework of Long Island, New York: U.S. Geological Survey Hydrologic Investigations Atlas HA-709, 3 sheets, scale 1:250,000.

- Spinello, A.G., and Simmons, D.L., 1992, Base flow of 10 south-shore streams, Long Island, New York, 1976-85, and the effects of urbanization on base flow and flow duration: U.S. Geological Survey Water-Resources Investigations Report 90-4205, 34 p.
- Spinello, A.G., Busciolano, Ronald, Winowitch, R.B., and Eagen, V.K., 1997, Water Resources Data, New York, Water year 1996, volume 2—Long Island: U.S. Geological Survey Water Data Report NY-96-2 (published annually), 231 p.
- Spinello, A.G., Pena-Cruz, Gilberto, Winowitch, R.B., and Eagen, V.K., 1998, Water Resources Data, New York, Water year 1997, volume 2—Long Island: U.S. Geological Survey Water Data Report NY-97-2 (published annually), 223 p.
- Spinello, A.G., Pena-Cruz, Gilberto, and Winowitch, R.B., 2001, Water Resources Data, New York, Water year 2000, volume 2—Long Island: U.S. Geological Survey Water Data Report NY-00-2 (published annually), 223 p.
- Stackelberg, P.E., 1995, Relation between land use and quality of shallow, intermediate, and deep ground water in Nassau and Suffolk Counties, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 94-4080, 82 p.
- Stockar, G.G., 1994, Sources and fate of nitrogen and chloride in urban runoff at East Meadow Brook, Nassau County, Long Island: Stony Brook, N.Y., unpublished Master's thesis, State University of New York at Stony Brook, 135 p.
- Stumm, Frederick, 2001, Hydrogeology and extent of saltwater intrusion of the Great Neck peninsula, Great Neck, Long Island, New York: U.S. Geological Survey Water-Resources Investigations Report 99-4280, 41 p.
- Sulam, D.J., 1979, Analysis of changes in ground-water levels in a sewerred and an unsewerred area of Nassau County, Long Island, New York: Ground Water, v. 17, no. 5, p. 446-455.
- Sulam, D.J. and Ku, H.F.H., 1977, Trends of selected ground-water constituents from infiltration galleries, southeast Nassau County, New York: Ground Water, v. 15, no. 6, p. 439-445.
- Suter, Russell, de Laguna, Wallace, and Perlmutter, N.M., 1949, Mapping of geologic formations and aquifers of Long Island, New York: New York State Water Power and Control Commission Bulletin GW-18, 212 p.