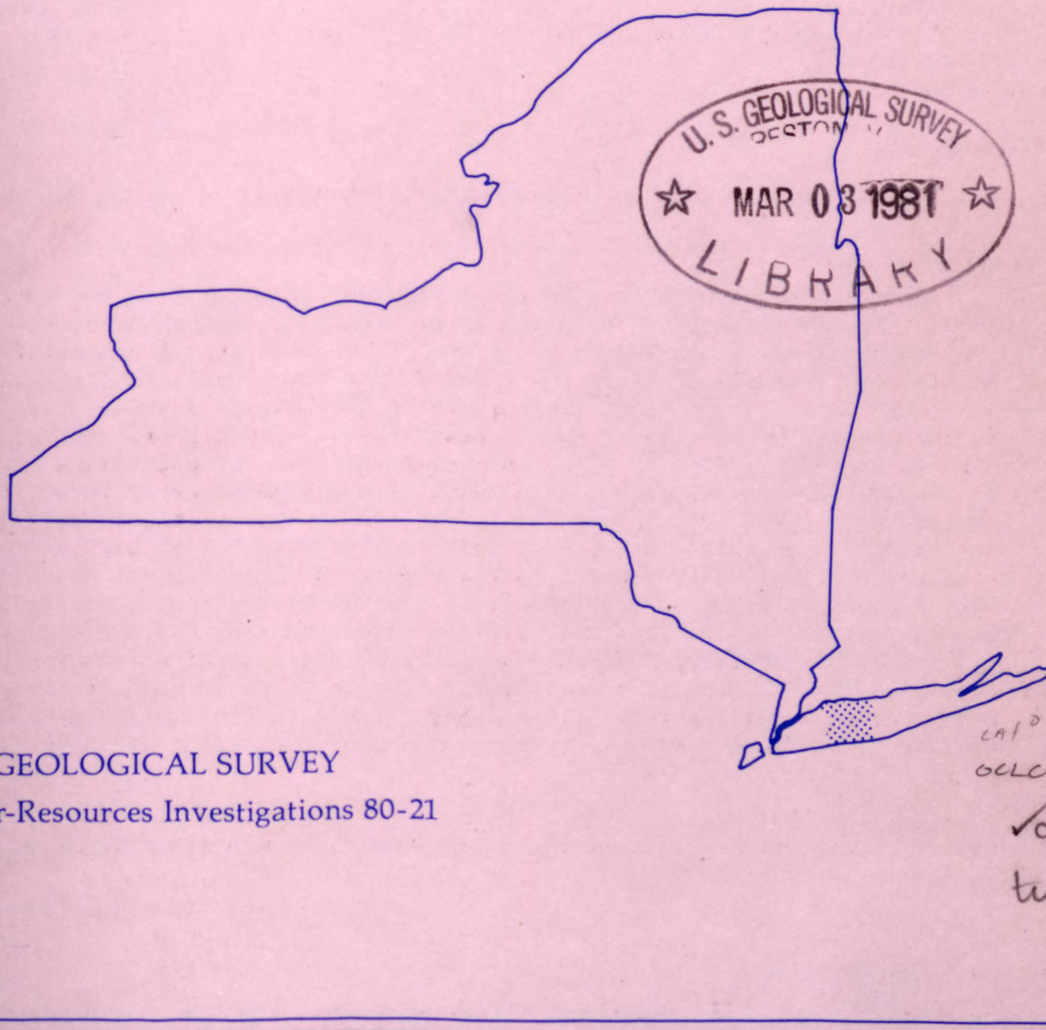
Nitrogen in Ground Water and Surface Water From Sewered and Unsewered Areas, Nassau County, Long Island, New York



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Nassau County Department of Public Works

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Analyses of more than 1,400 water samples collected from the upper glacial aquifer from 1952-76 indicate the median concentration of nitrate in the sewered area of the County to be similar to that in the unsewered area. In contrast, streams draining the sewered area have significantly lower total nitrogen concentrations than those draining the unsewered area; 8 of 10 wells in the upper glacial aquifer in the sewered area show significant decreasing nitrate concentration with time, and median nitrate concentrations in the upper 3 meters of the upper glacial aquifer are significantly lower in the sewered area. This difference may reflect (1) a bias in the data base; (2) the slow rate at which the upper glacial aquifer can "flush out" domestic nitrates that were introduced before sewering or agricultural nitrates that were introduced before urbanization; or (3) the presence of nitrogen from modern sources such as lawn fertilizers, which may mask the decreases resulting from sewerage. Nitrate analyses of water samples from the Magothy aquifer collected from 1952-76 indicate nitrate to be present at all depths but to decrease with depth. All Magothy wells at which significant changes in nitrate concentration with time were noted show increasing nitrate trends.

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NITROGEN IN GROUND WATER AND SURFACE WATER FROM SEWERED AND UNSEWERED AREAS, NASSAU COUNTY, LONG ISLAND, NEW YORK

By Stephen E. Ragone, Brian G. Katz, Grant E. Kimmel, and Juli B. Lindner

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ILLUSTRATIONS (continued)

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply metric (SI)[1/] units	By	To obtain inch-pound units
meter (m)	3.281	foot (ft)
kilometer (km)	0.621	mile (mi)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/day)
square hectometer (hm^2)	2.471	acre
metric ton per day (t/d)	2205	pound per day (lb/d)
metric ton per year (t/yr)	2205	pound per year (lb/yr)
square kilometer (km^2)	247.1	acre
liter per second (L/s)	22.83×10^{-3}	million gallons per day (Mgal/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter per kilometer (m/km)	5.279	foot per mile

1/ International System of units

NITROGEN IN GROUND WATER AND SURFACE WATER FROM SEWERED AND UNSEWERED AREAS, NASSAU COUNTY, LONG ISLAND, NEW YORK

By

Stephen E. Ragone, Brian G. Katz,
Grant E. Kimmel, and Juli B. Lindner

ABSTRACT

Nitrogen data for ground water and surface water in the sewered and unsewered parts of Nassau County south of the regional ground-water divide were analyzed to evaluate the principal sources of nitrogen and to determine what factors significantly affect its concentration in the upper glacial aquifer and the underlying Magothy aquifer. The sewered and unsewered areas are similar in size and hydrogeologic character, and many data are available on past and present water quality and land use.

Nitrate data for water samples collected during 1952-76 show that:

1. Median nitrate concentration of water in the sewered part of the entire thickness of the upper glacial aquifer is not significantly different (at the 0.95 confidence limit, N = 1,400) from that in the unsewered area.

2. Median nitrate concentrations in the upper 3 meters of the upper glacial aquifer are significantly lower (at the 0.90 confidence limit, N = 15) in the sewered area than in the unsewered area.

3. In the sewered area, water from 8 of 10 wells in the upper glacial aquifer show significantly decreasing nitrate concentration with time.

4. Total nitrogen concentrations in streams draining the sewered area are significantly lower than in those draining the unsewered area (stream quality reflects ground-water quality because 95 percent of the base flow is derived from the shallow part of the upper glacial aquifer).

5. From more than 2,000 nitrate analyses of water in the Magothy aquifer collected from 1952-76, it was found that nitrate is present at all depths but that nitrate concentrations decrease with depth.

6. Although water from most Magothy wells having long-term nitrate records show no significant changes in nitrate concentration with time, where the change is significant, nitrate is increasing.

The results described in item (1) above indicate that, on the basis of nitrogen as an indicator constituent, water quality in the sewered part is not significantly different from that in the unsewered part of the upper glacial aquifer. The results described in items (2) to (4) above suggest that water quality in the sewered area is improved or improving as compared with that in the unsewered area. The apparently contradictory findings as to the similarity of water quality in the sewered and unsewered areas may reflect a bias in the data base, as the wells from which data were collected were emplaced for purpose other than those of this study. Differences in well characteristics and pumping regimens may affect flow patterns in the zone where water is drawn and, consequently, affect water quality. Also, sample-collection and analytical techniques probably changed over the period of study. However, the data may reflect: (1) the slow rate at which the upper glacial aquifer can "flush out" domestic nitrate that was introduced before sewering or from pre-1940 agricultural sources, and(or) (2) that other present-day sources of nitrogen may mask the decreases in nitrogen that have resulted from sewerage. For example, 3,500 to 4,000 metric tons of nitrogen per year is estimated to originate from nonpoint sources, predominantly lawn fertilizers.

INTRODUCTION

Ground water is the sole source of fresh water for more than 1.4 million residents of Nassau County, N.Y. (Nassau-Suffolk Regional Planning Board, 1976). Nitrate in ground water is a matter of concern for local planners and water managers because it poses a potential health hazard to infants (Vigil and others, 1965) and because chronic toxicity and possible development of cancer from the formation of nitrosamines may result from the ingestion of water containing high concentrations of nitrate (U.S. Environmental Protection Agency, 1976; Safe Drinking Water Committee, 1977). Thus, knowledge of the factors that affect nitrate concentrations in ground water and surface waters is of great importance in developing water-management programs to protect Long Island's water supply.

The purpose of this report is to correlate areal and temporal distributions of nitrogen in ground water in southern and central Nassau County with natural and man-induced factors. These factors include hydrogeologic conditions, methods of sewage disposal, pumpage rate for public-water supply, and the types and relative importance of point and nonpoint sources of nitrate entering the ground water.

The area discussed in this report is limited to the sewered and unsewered areas of Nassau County south of the regional ground-water divide (fig. 1). The location of the ground-water divide was determined from 1974 water levels (Koszalka, 1975). Because this boundary forms a zone, rather than a line, its northernmost limit was used as the northern boundary of the study area. The sewered and unsewered sections of the area encompass 207 km^2 and 242 km^2, respectively.

A large amount of water-quality data pertaining to the study area is available, and the regional hydrologic system is relatively simple and uniform within the sewered and unsewered areas. Both ground-water withdrawals and the nitrogen load from nonpoint sources can be estimated from available data.

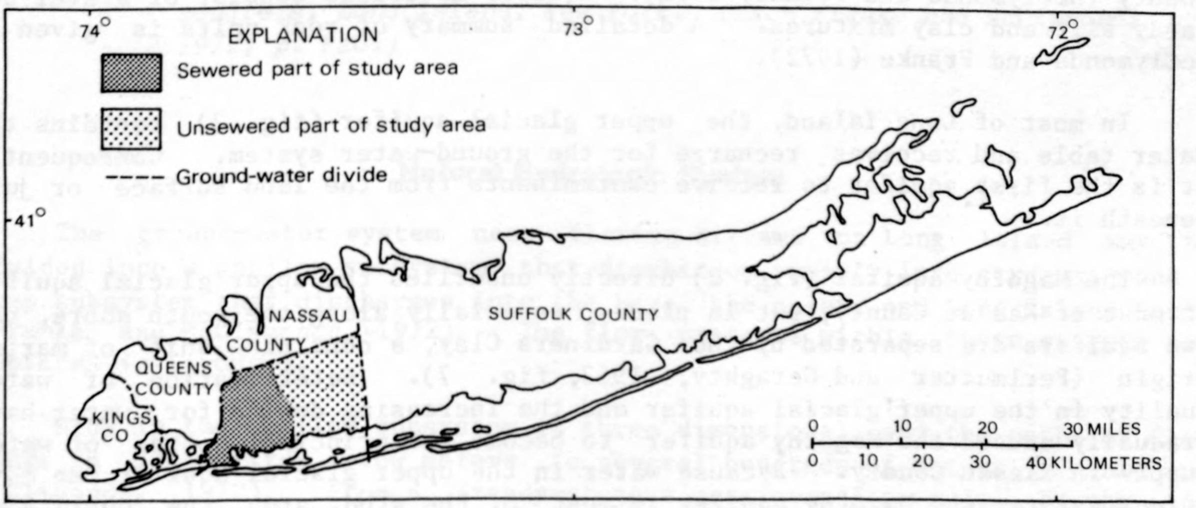

Figure 1.--Location of study area, Nassau County, Long Island, New York.

Previous Studies

Several studies have described nitrate concentrations in ground water in Nassau County (Katz and others, 1977; Ku and Sulam, 1976; Perlmutter and Koch, 1972; and Smith and Baier, 1969). Recently, nitrogen isotopes were used to help characterize sources of nitrate in ground water and indicated that several sources, such as domestic sewage and fertilizer, may be contributing nitrogen to the ground-water reservoir (Kreitler and others, 1978). In another study, the U.S. Geological Survey, in cooperation with the Nassau-Suffolk Regional Planning Board, prepared an extensive compilation of nitrate, chloride, and sulfate data from Nassau and Suffolk Counties and defined the distribution of nitrate by aquifer, depth, and time from 1952-76--virtually the entire period from which water-quality data were available (Ragone and others, 1976a).

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HYDROGEOLOGIC SETTING

Aquifers on Long Island

The Long Island ground-water reservoir consists of a southward-dipping wedge of unconsolidated glacial deposits of Pleistocene age and underlying fluvial and deltaic deposits of Cretaceous age (fig. 2). Bedrock, which is at or near land surface in northwestern Long Island, dips to the southeast at an average slope of 12.4 m/km to a depth of about 610 m in south-central Suffolk County (McClymonds and Franke, 1972). Aquifer materials consist of gravel and sandy silt and clay mixtures. A detailed summary of rock units is given in McClymonds and Franke (1972).

In most of Long Island, the upper glacial aquifer (fig. 2) contains the water table and receives recharge for the ground-water system. Consequently it is the first aquifer to receive contaminants from the land surface or just beneath it.

The Magothy aquifer (fig. 2) directly underlies the upper glacial aquifer in most of Nassau County, but in places, especially along the south shore, the two aquifers are separated by the Gardiners Clay, a confining unit of marine origin (Perlmutter and Geraghty, 1963, fig. 7). Deterioration of water quality in the upper glacial aquifer and the increasing demand for water have gradually caused the Magothy aquifer to become the principal source of water supply in Nassau County. Because water in the upper glacial aquifer can move directly into the Magothy aquifer in most of the study area, the quality of water in parts of the Magothy has begun to reflect the water-quality characteristics of the upper glacial aquifer (Perlmutter and Koch, 1972; and Ku and Sulam, 1976).

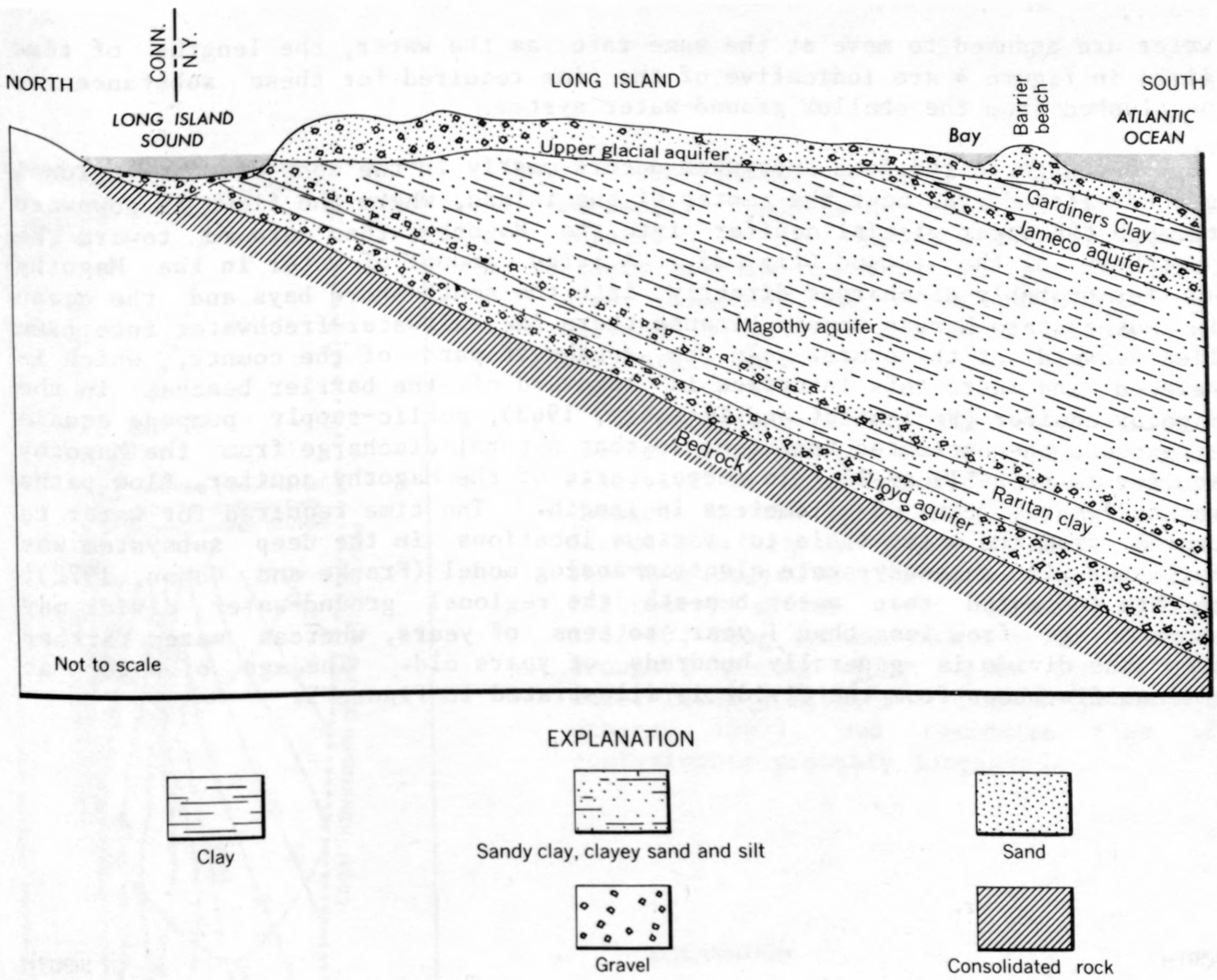


Figure 2.--Generalized geologic section showing relative positions of major aquifers, Long Island, New York. (From Franke and McClymonds, 1972, p. F10.)

Natural Hydrologic System

The ground-water system near flowing streams on Long Island may be divided into a shallow subsystem that discharges mainly into streams, and a deep subsystem that discharges into the bays, the ocean, and Long Island Sound (Franke and McClymonds, 1972). The flow patterns within these systems are depicted in figure 3.

Flow in the shallow subsystem is three dimensional, and the paths of flow range in length from a few meters to several hundreds of meters (Franke and McClymonds, 1972). From a steady-state electric-analog model, Franke and Cohen (1972) calculated that it would take a maximum of 30 years for water to drain from one of the shallow ground-water subsystems into East Meadow Brook in south-central Nassau County (fig. 4). If dissolved substances in the water are assumed to move at the same rate as the water, the lengths of time given in figure 4 are indicative of the time required for these substances to be flushed from the shallow ground-water system.

Recharge to the deep subsystem occurs mostly in the zone of the regional ground-water divide near the center of the island, where the flow is downward through the upper glacial aquifer into the Magothy, then outward toward the periphery of the island (fig. 3). A large amount of water in the Magothy aquifer probably discharges directly into the south-shore bays and the ocean in southeastern Nassau County because there the saltwater-freshwater interface lies seaward of the shore. In the southwest part of the county, which is sewered and where this interface is landward of the barrier beaches in the Magothy aquifer (Perlmutter and Geraghty, 1963), public-supply pumpage equals or exceeds the estimated recharge, so that natural discharge from the Magothy aquifer is probably small. In deeper parts of the Magothy aquifer, flow paths may be several tens of kilometers in length. The time required for water to travel from the water table to various locations in the deep subsystem was estimated with a steady-state electric-analog model (Franke and Cohen, 1972); results indicated that water beneath the regional ground-water divide may range in age from less than 1 year to tens of years, whereas water farther from the divide is generally hundreds of years old. The age of water at various distances from the divide is illustrated in figure 5.

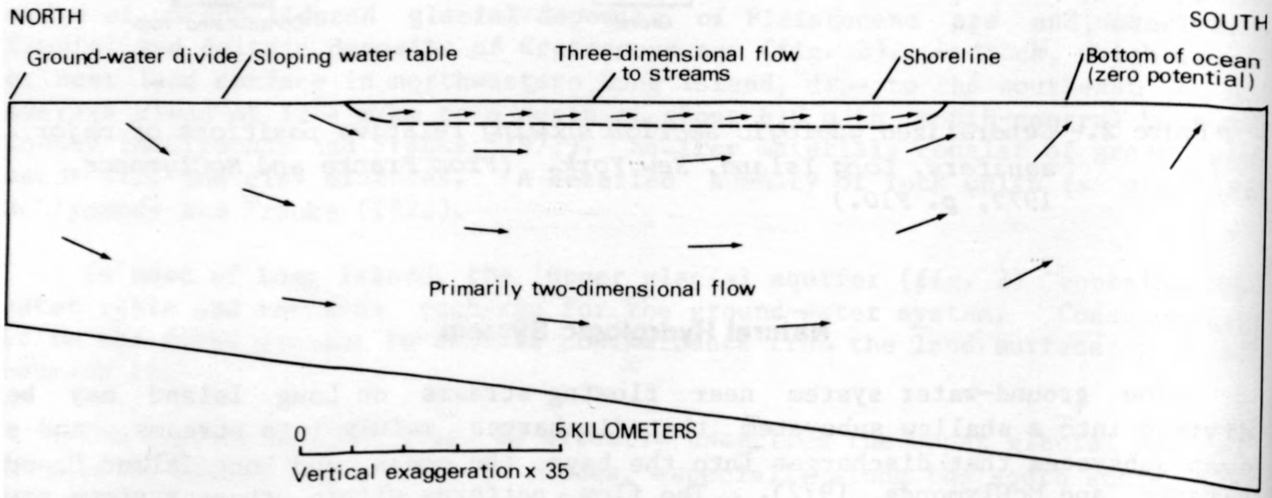


Figure 3.--Cross section of southern half of ground-water reservoir showing area with primarily two-dimensional flow and area with three-dimensional flow to streams. (From Franke and McClymonds, 1972, p. F24.)

The unsewered area (fig. 6) is currently undergoing construction of sewers. A few small sewage-treatment plants are now operating in the unsewered area; however, they serve hospitals and various industries, and their effluent is discharged into the ground.

Precipitation is the only natural source of recharge to the ground-water reservoir on Long Island. Consequently, changes in the amount of precipitation directly affect the volume of water within the hydrologic system and, in turn, may indirectly affect water quality. From 1962-66, Long Island experienced a severe drought, during which water levels and water-level gradients decreased (Cohen and others, 1969), and residence time of contaminants probably increased.

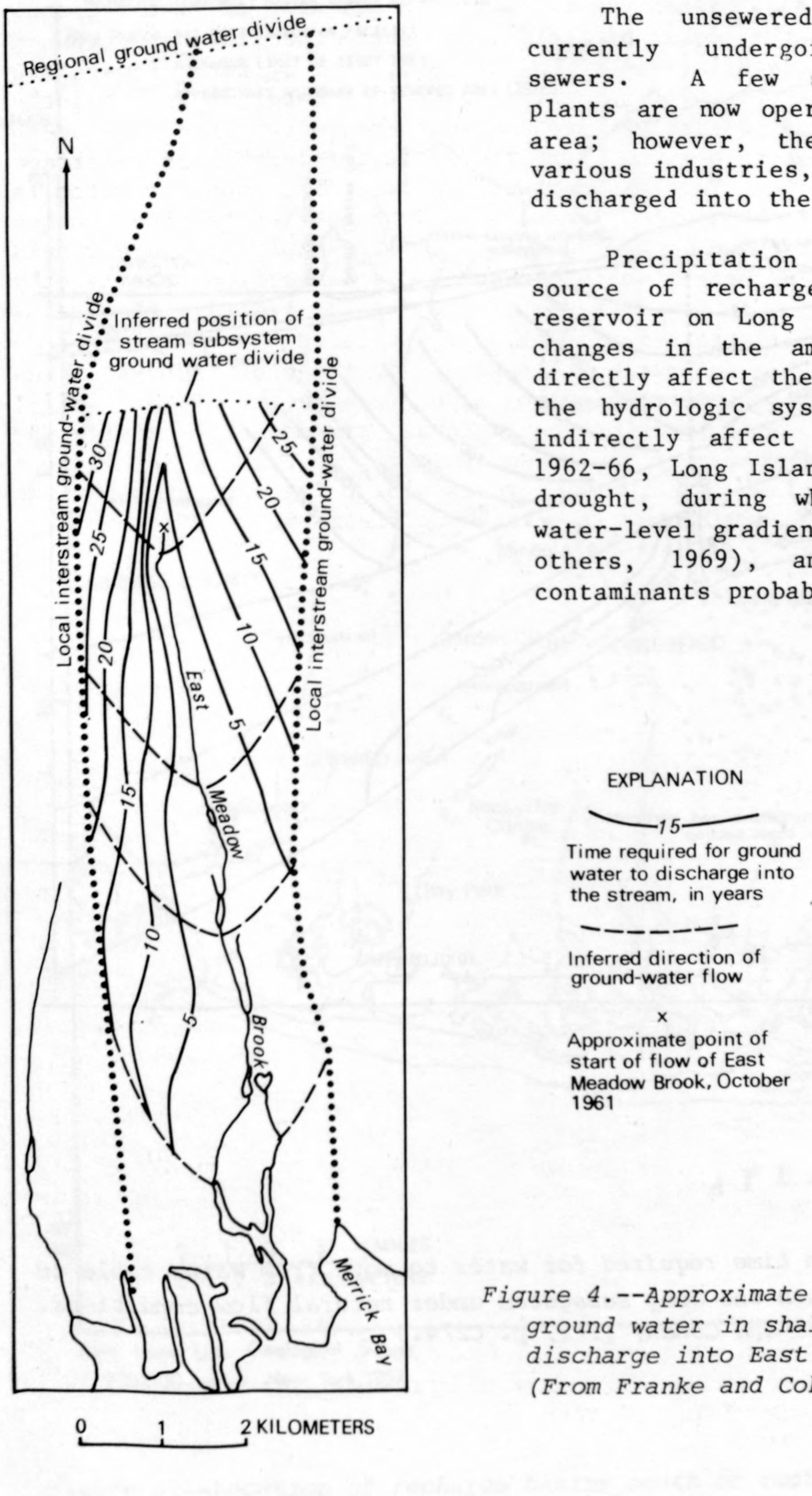


Figure 4.--Approximate time required for ground water in shallow subsystem to discharge into East Meadow Brook. (From Franke and Cohen, 1972, p. C276.)

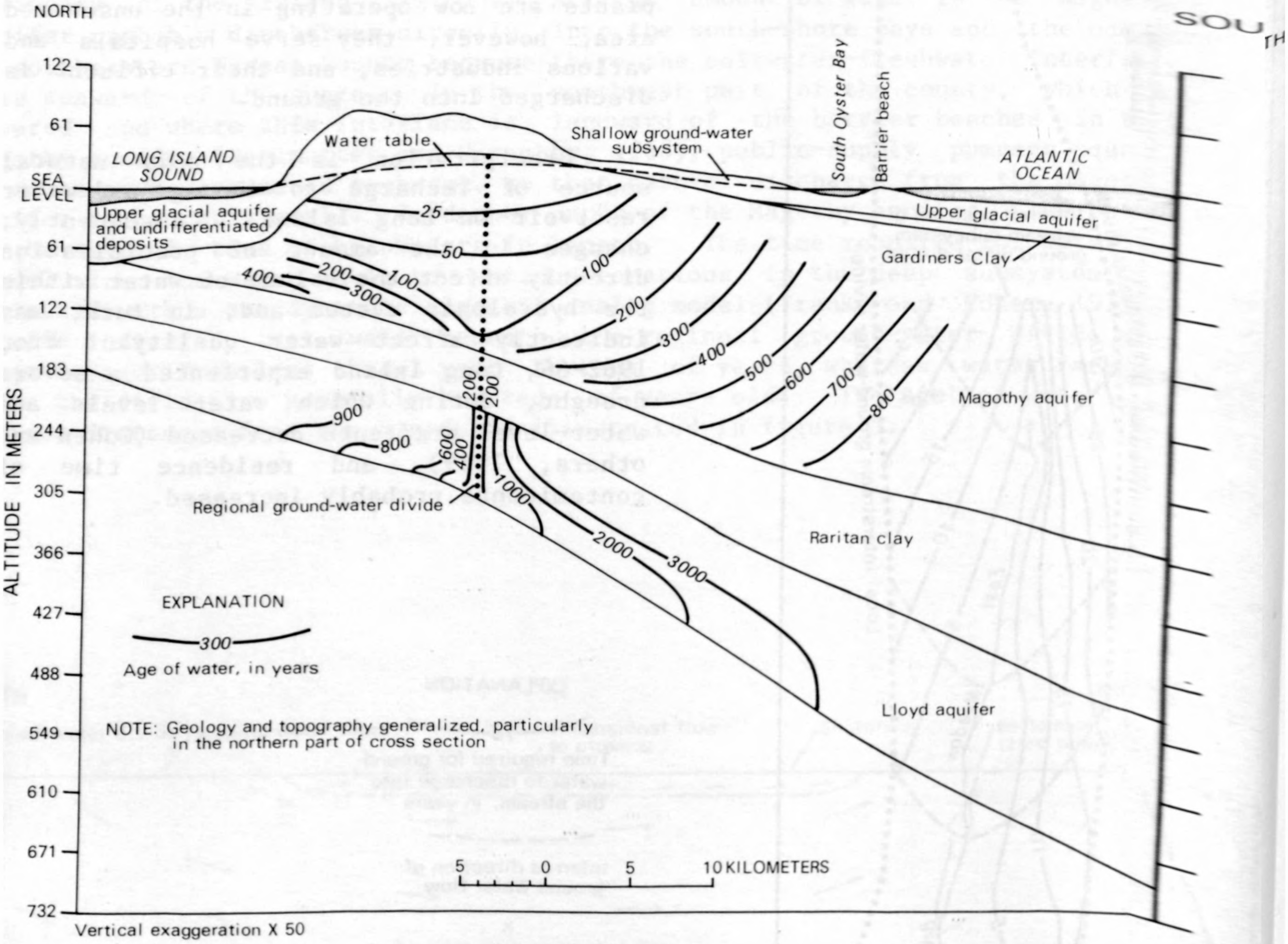
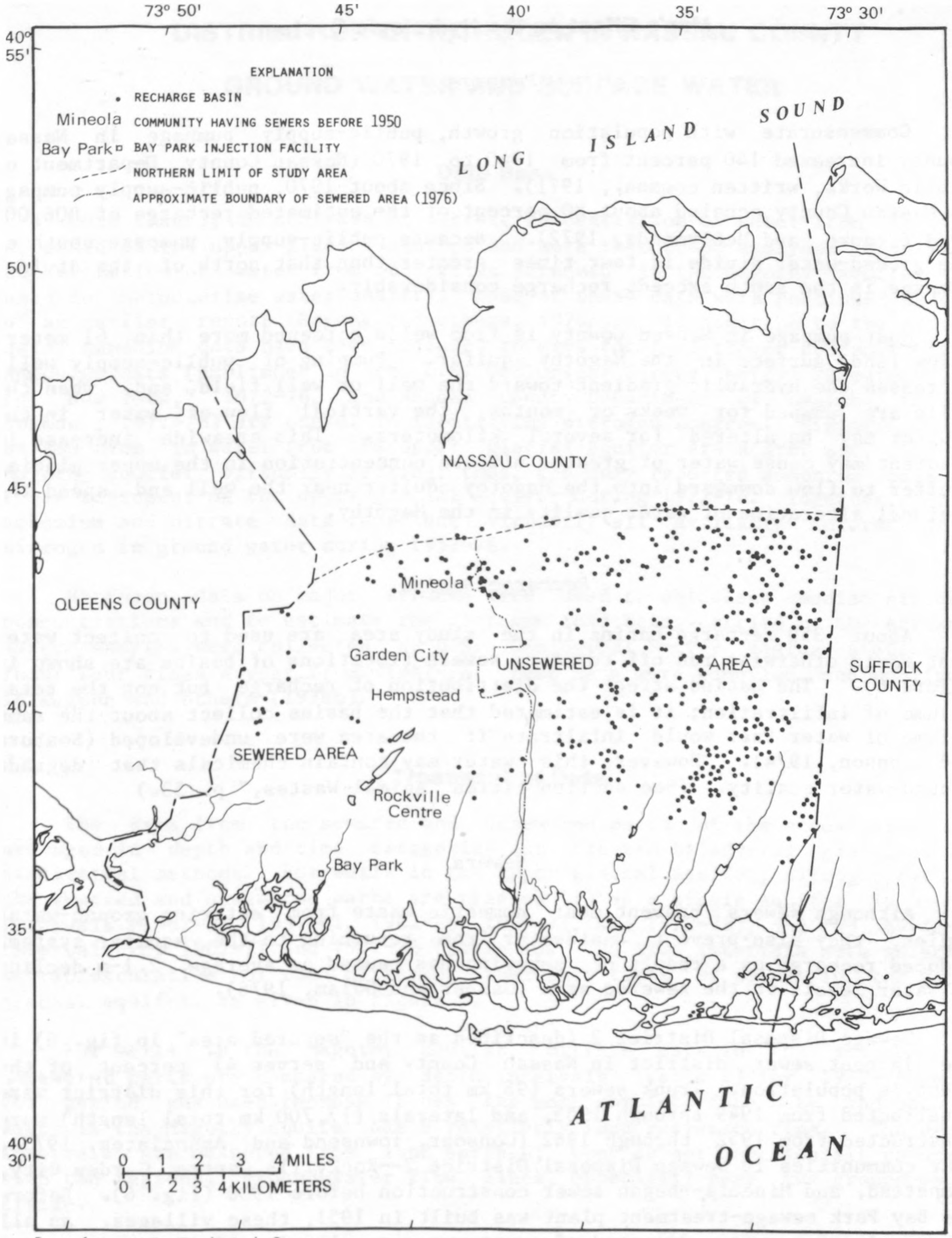


Figure 5.--Approximate time required for water to move from water table to points within the deep subsystem under natural flow conditions. (From Franke and Cohen, 1972, p. C274.)



Base from U.S. Geological Survey
1:250,000 series; New York, 1957.

Figure 6.--Location of recharge basins south of regional ground-water divide.

Man's Effect on the Hydrologic System

Pumpage

Commensurate with population growth, public-supply pumpage in Nassau County increased 140 percent from 1940 to 1970 (Nassau County Department of Public Works, written commun., 1971). Since about 1970, public-supply pumpage in Nassau County equaled about 80 percent of the estimated recharge of 806,000 m^3/d (Franke and McClymonds, 1972). Because public-supply pumpage south of the ground-water divide is four times greater than that north of the divide, pumpage in the south exceeds recharge considerably.

Most pumpage in Nassau County is from wells screened more than 61 meters below land surface in the Magothy aquifer. Pumping of public-supply wells increases the hydraulic gradient toward the well or well field, and, when the wells are pumped for weeks or months, the vertical flow of water in the aquifer may be altered for several kilometers. This areawide increase in gradient may cause water of greater nitrate concentration in the upper glacial aquifer to flow downward into the Magothy aquifer near the well and speed the regional alteration of water quality in the Magothy.

Recharge Basins

About 350 recharge basins in the study area are used to collect water that would otherwise run off to storm sewers (locations of basins are shown in figure 6). The basins affect the distribution of recharge but not the total volume of infiltration; it is estimated that the basins collect about the same volume of water that would infiltrate if the area were undeveloped (Seaburn and Aronson, 1974). However, this water may contain chemicals that degrade ground-water quality. (See section titled "Animal Wastes," p. 53.)

Sewers

Although sewers prevent most domestic waste from entering ground-water bodies, they also prevent wastewater from returning to the aquifer system. Reduced recharge as a result of sewering has caused an average 2.1-m decline in water levels in the sewered area (Garber and Sulam, 1976).

Sewage Disposal District 2 (described as the "sewered area" in fig. 6) is the largest sewer district in Nassau County and serves 41 percent of the county's population. Trunk sewers (98 km total length) for this district were constructed from 1949 through 1955, and laterals (17,700 km total length) were constructed from 1952 through 1962 (Consoer, Townsend and Associates, 1975). Four communities in Sewage Disposal District 2--Rockville Centre, Garden City, Hempstead, and Mineola--began sewer construction before 1930 (fig. 6). Before the Bay Park sewage-treatment plant was built in 1951, these villages, as all others in the county, disposed of wastewater to local surface waters or to ground-water bodies through septic tanks and cesspools.

DISTRIBUTION OF NITROGEN IN NASSAU COUNTY GROUND WATER AND SURFACE WATER

Data Base

More than 1,400 analyses of nitrate concentration of water from 316 wells screened in the upper glacial aquifer and more than 2,000 analyses of nitrate concentration of water from 383 wells screened in the Magothy aquifer were used to characterize water quality. Most of these data were published as part of an earlier report (Ragone and others, 1976a). In addition to the nitrate data, ammonium data have been included to give total nitrogen concentrations. Ammonium data (published in the U.S. Geological Survey "Water Resources Data for New York," 1972-76, and Nassau County Department of Health, written commun., 1977-78) are useful in identifying nitrogen sources. Historical data on ammonium in water from the upper glacial aquifer are scarce and, for the Magothy aquifer, virtually lacking; thus, the only reported ammonium data are those representing the upper glacial aquifer during 1972-76. Together, the ammonium and nitrate data represent virtually all available information on nitrogen in ground water during 1952-76.

Nitrogen data on major streams were used to calculate median nitrogen concentrations and to estimate the nitrogen load being carried by the streams. Water samples were collected at U.S. Geological Survey gaging stations at least four times a year from 1967-76; these data were compiled and published in Ragone and others (1976b).

Treatment of Data

The data from the sewered and unsewered parts of the study area were arranged in depth and time categories and treated by several graphical and statistical methods. For wells in the upper glacial aquifer, nitrogen data in the sewered and unsewered parts are treated (1) as a single aquifer in 5-year intervals (1952-56, 1957-61, 1962-66, 1967-71, and 1972-76), and (2) by depth intervals for 1967-71 and 1972-76 (table 1). The time intervals were selected as representative of the different residence times of water in the upper glacial aquifer, as given in figure 5.

For wells in the Magothy aquifer, nitrate data in the sewered and unsewered parts are compared by depth intervals (table 1) for 1972-76 only. This period was used because it has the most complete data base and because water in the Magothy aquifer has a relatively long residence time. The depth intervals are measured from land surface; they do not necessarily coincide with the regional ground-water flow lines, especially near the ground-water divide.

Although the data base contains virtually all nitrogen data from the last 25 years, it is subject to bias for any of the following reasons:

1. Ground-water data are obtained from wells that were installed for purposes other than those of this study. Some wells are used for public supply, have high flow capacities, and are pumped continuously, for all practical purposes, whereas other wells--those used to monitor water levels or to collect samples to measure ground-water quality--are of low capacity and are pumped intermittently. These differences in well characteristics and pumping regimens affect flow patterns in the zone from which water is being drawn and, consequently, may affect the water quality within that zone.

2. Wells may be installed or replaced at any time as a result of water-quality or quantity problems.

3. Sampling frequency has varied widely from well to well and through time.

4. Early sampling and analytical techniques were probably not uniform. However, the large number of analyses, together with the variety of statistical methods used to interpret the data in the following sections, should help to minimize the effects of these inconsistencies.

Table 1.--Distribution of wells in study area, by aquifer and depth below land surface.

Aquifer and depth interval	Number of wells: Sewered area	Number of wells: Unsewered area
Upper glacial (all depths)	166	150
Upper glacial (depth below water table)1/		
Less than 3 meters	15	29
3.1 to 6.1 meters	39	47
6.2 to 10.7 meters	30	20
10.8 to 11.3 meters	34	15
Greater than 11.3 meters	23	8
Magothy (depth below land surface)		
Less than 61 meters	11	66
61 to 122 meters	31	72
123 to 183 meters	86	78
greater than 183 meters	9	30

1/ Only wells in which depth to screen was known were used in depth-interval breakdown.

Upper Glacial Aquifer

Areal and Temporal Distribution of Nitrogen

Maps showing median nitrate concentrations (as N) of water in the upper glacial aquifer during 5-year intervals from 1952-76 and for the entire 25-year period of record are published in Ragone and others (1976a). In the present study, four ranges of median nitrate concentration (as N) in individual wells are used to characterize ground-water quality:

1. Less than or equal to 0.20 mg/L (predevelopment quality). (Perlmutter and Koch, (1972) suggest that the predevelopment concentration of nitrogen in ground water is less than 0.20 mg/L.)

2. From 0.21 to 3.0 mg/L.

3. From 3.1 to 10 mg/L.

4. Greater than 10 mg/L (this group exceeds U.S. Environmental Protection Agency interim standards [1975] for drinking water).

Median nitrate concentrations have exceeded the Environmental Protection Agency interim standard for drinking water (10 mg/L for nitrate as N) in several areas in both the sewered and unsewered parts of the study area during all time intervals since 1952 (median values are given in fig. 7). Nitrate data since 1962 are sufficient to permit designation of the four ranges of median concentration for 1962-66, 1967-71, and 1972-76 (figs. 7C to 7E). In the 1962-66 map (fig. 7C), two broad bands of water in the 0.21-to 3.0-mg/L range and the 3.1-to 10-mg/L range occur across the sewered and unsewered areas. Many smaller areas containing water in the highest and lowest concentration ranges are found within the 3.1-to 10-mg/L band.

In the 1967-71 and 1972-76 intervals (figs. 7D and 7E), the 3.1- to 10-mg/L band is less well defined because of the presence of other large areas of higher and lower median nitrate concentrations.

A map showing median ammonium concentrations (as N) during 1972-76 is given in figure 8. Ammonium, produced mainly by the deamination of organic nitrogen compounds and by the hydrolysis of urea (American Public Health Association and others, 1975), is an indicator of cesspool or septic-tank wastes. Median ammonium concentrations are generally less than 1 mg/L (as N) throughout the sewered part of the study area and in the northern half of the unsewered area. In the southern half of the unsewered area, median ammonium concentrations exceed 1 mg/L (as N). The relatively high ammonium concentrations in the southern half of the unsewered area may indicate that hydrogeologic conditions (particularly the high water table) prevent nitrification of reduced nitrogen species to nitrates.

A map showing the areal distribution of median total nitrogen concentrations during 1972-76 is given in figure 9. Total nitrogen concentration is the sum of nitrate and ammonium concentrations (as N). Organic nitrogen concentrations, which are normally included in total nitrogen, were not included because the data were insufficient. However, where organic nitrogen was included in the analyses, it constituted only a relatively small percentage of the total nitrogen concentration. Generally, the distribution of median total nitrogen concentrations in 1972-76 was similar to that of median nitrate concentrations (fig. 7E).

In most of the study area, median total nitrogen concentrations were in the 3.1- to 10-mg/L range, although they exceeded 10 mg/L in some areas in the unsewered area. Several parts of both the sewered and unsewered areas had median total nitrogen values in the 0.21- to 3.0-mg/L range.

Histograms of median nitrate concentrations were constructed for 1962-66, 1967-71, and 1972-76 for both the sewered and unsewered areas (fig. 10). Insufficient data prevented construction of histograms for 1952-56 and 1957-61. All but the 1967-71 period in the sewered area show a similar skewed distribution.

Unlike the nitrate distribution, the ammonium distribution differed between the sewered and unsewered areas during 1972-76 (the only period of sufficient data). Whereas 80 percent of the ammonium analyses from the sewered area showed less than 0.2 mg/L, and 7 percent exceeded 1.0 mg/L, only 38 percent of the ammonium analyses in the unsewered area showed less than 0.2 mg/L, and 51 percent exceeded 1.0 mg/L (table 2). Also, the median ammonium concentration was much lower in the sewered area (0.01 mg/L) than in the unsewered area (1.1 mg/L).

Median total nitrogen (nitrate plus ammonium) concentrations show a similar distribution within the sewered and unsewered areas in the three lower concentration ranges (table 3), among which the largest percentage of values from both areas is within the 3.1- to 10-mg/L range. However, 28 percent of all samples in the unsewered area had median total nitrogen concentrations in excess of 10 mg/L, whereas only 3 percent of all samples in the sewered area had median total nitrogen concentrations greater than 10 mg/L.

"Median of median nitrate concentrations" was calculated for the selected time periods in the sewered and unsewered areas (table 4). Use of these values, rather than "median" data, eliminates bias resulting from the different frequencies of sampling. To calculate these values, a median nitrate concentration was determined for water from wells that had had more than one analysis during the pertinent 5-year interval, and a median of these median values ("median of medians") was then determined. These values were compared statistically by median test (Conover, 1971) to determine statistical differences between median values of the sewered and unsewered areas or between the time intervals. No difference in median values between sewered and unsewered areas was found at a confidence level of 0.95. The only significant differences were between (a) the 1957-61 and 1962-66 intervals in the sewered area, (b) the 1962-66 and 1967-71 intervals in the sewered area, and (c) the 1957-61 and 1962-66 intervals in the unsewered area.

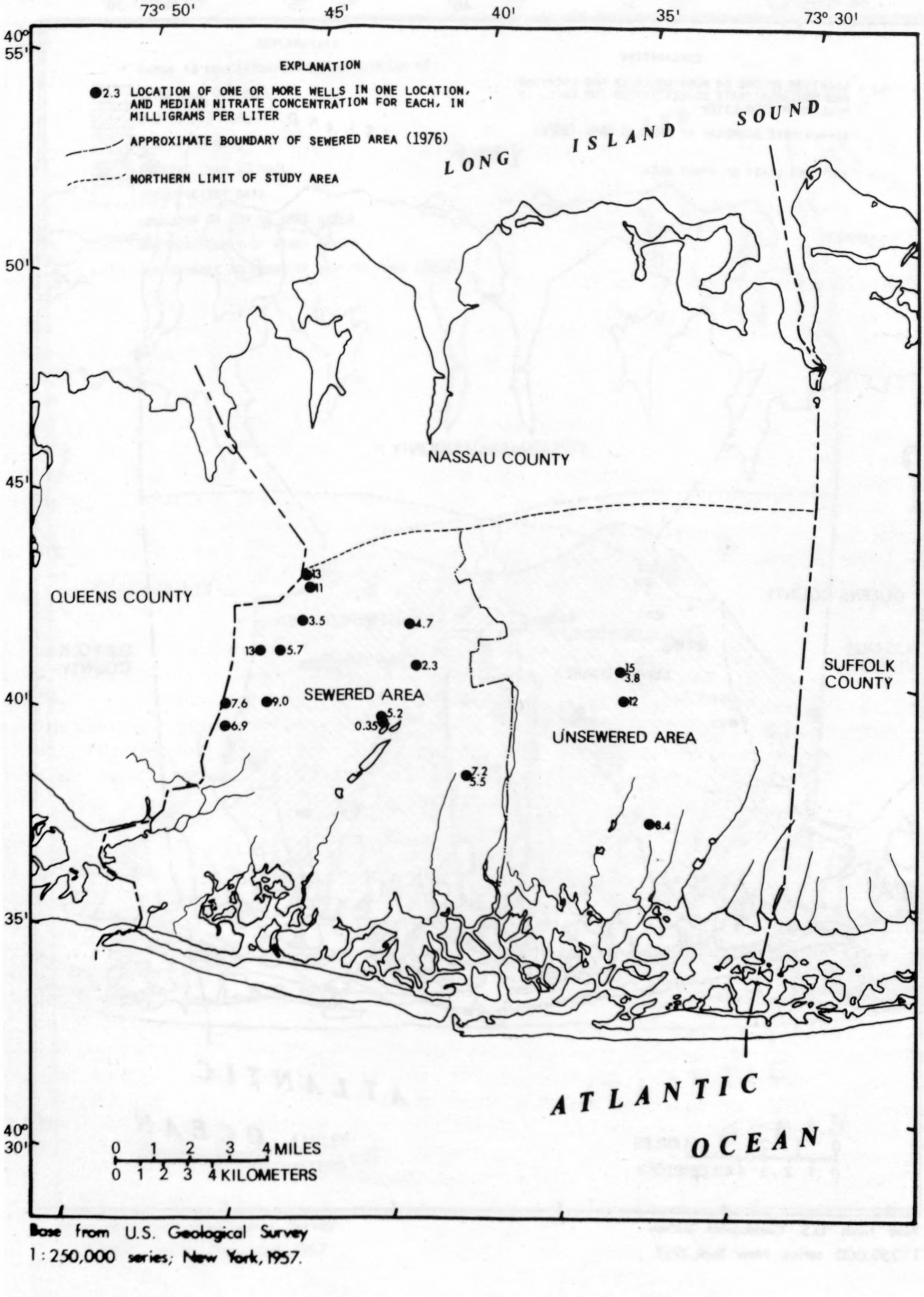


Figure 7A.--Distribution of median nitrate concentration (as N) of water from upper glacial aquifer, 1952-56.

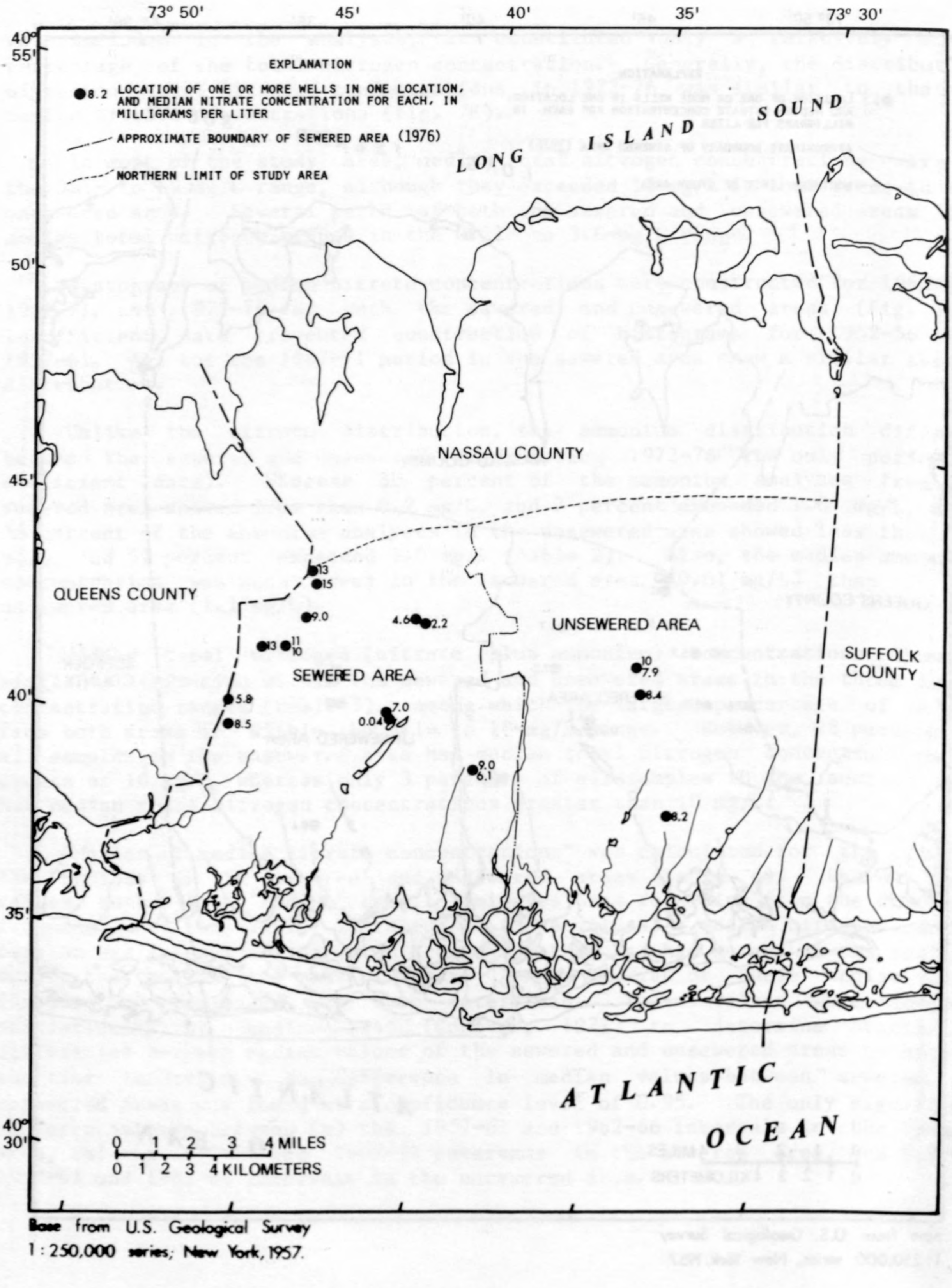


Figure 7B.--Distribution of median nitrate concentration (as N) of water from upper glacial aquifer, 1957-61.

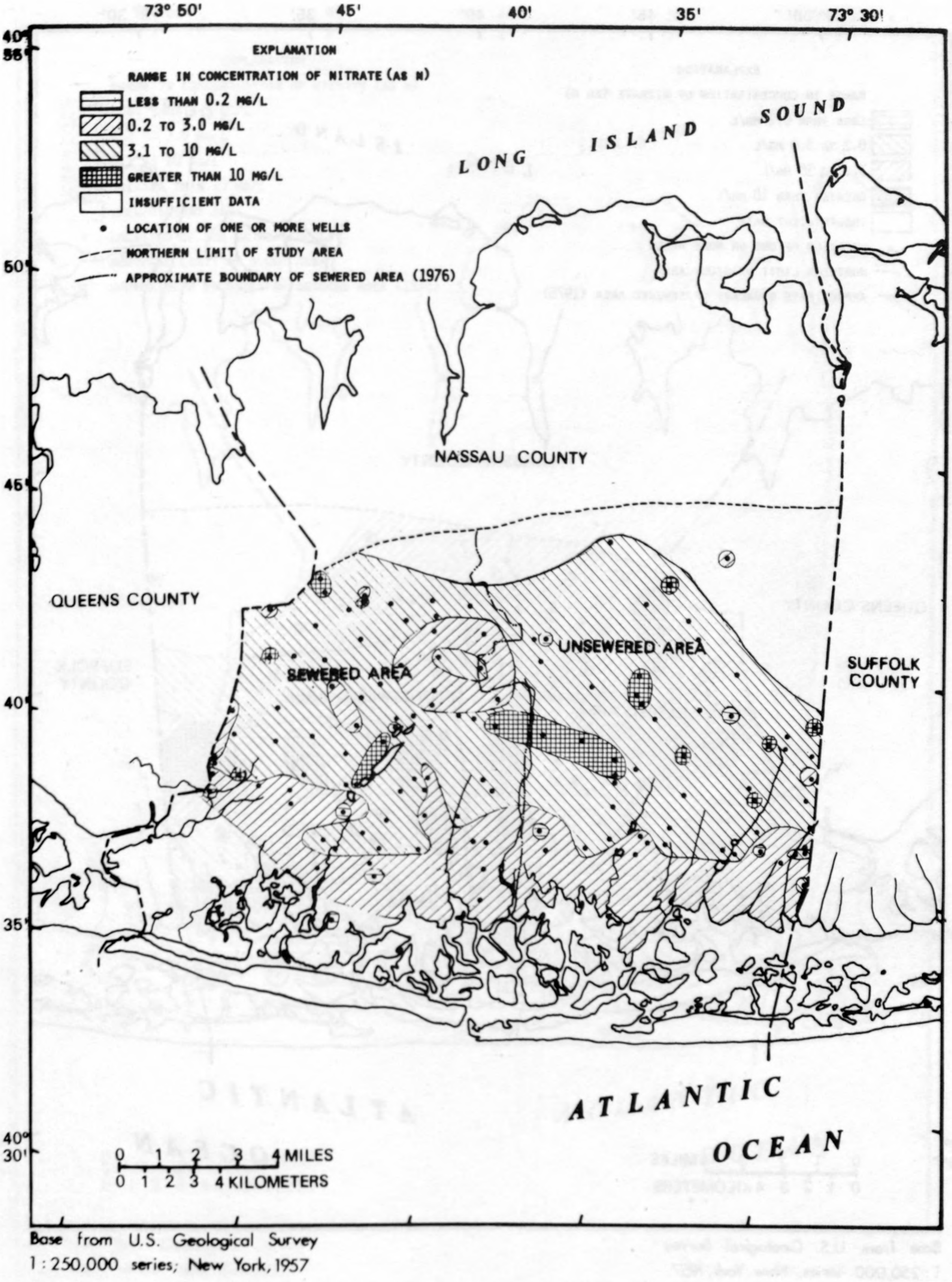


Figure 7C.--Distribution of median nitrate concentration (as N) of water from upper glacial aquifer, 1962-66.

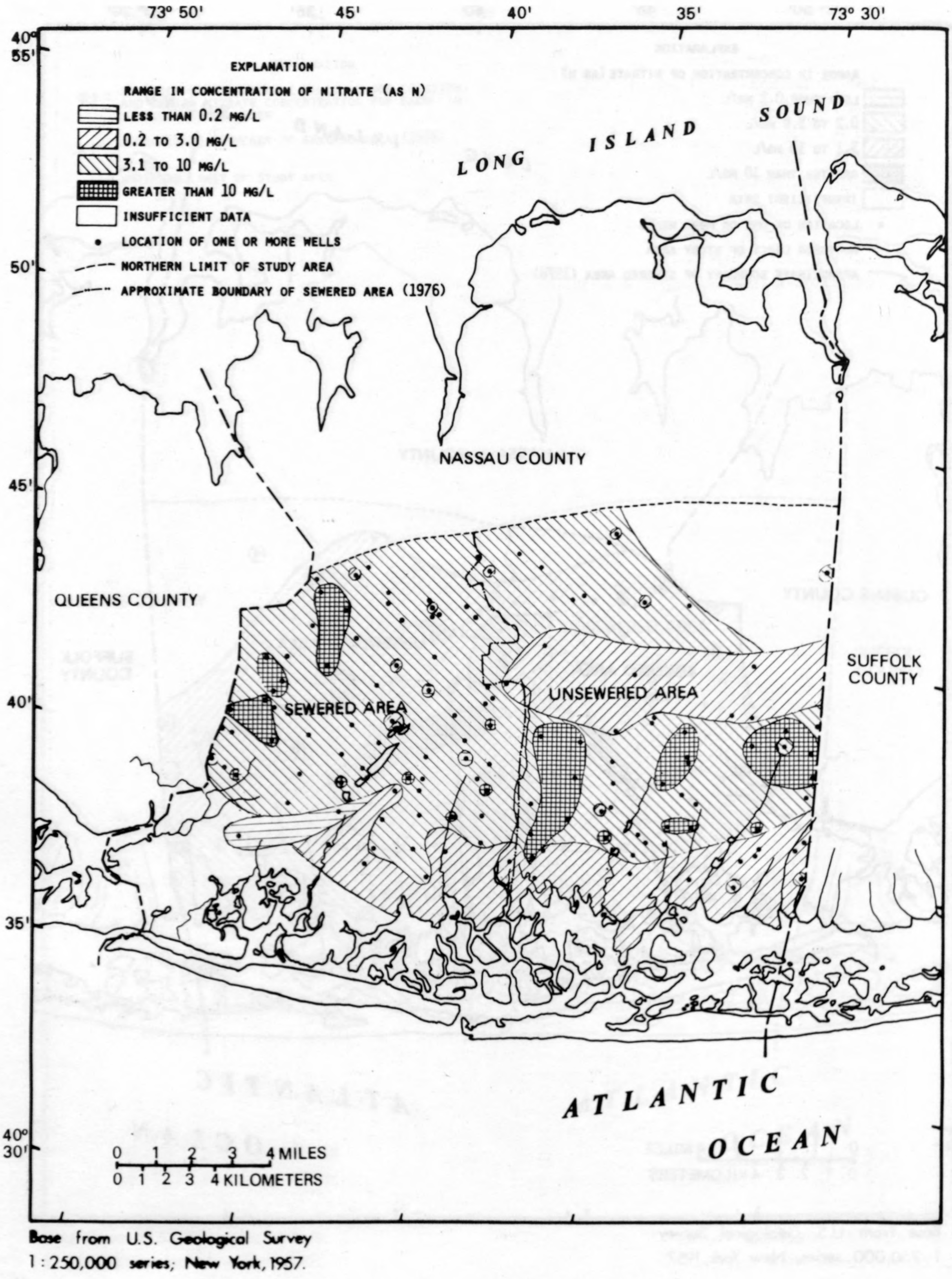


Figure 7D.--Distribution of median nitrate concentration (as N) of water from upper glacial aquifer, 1967-71.

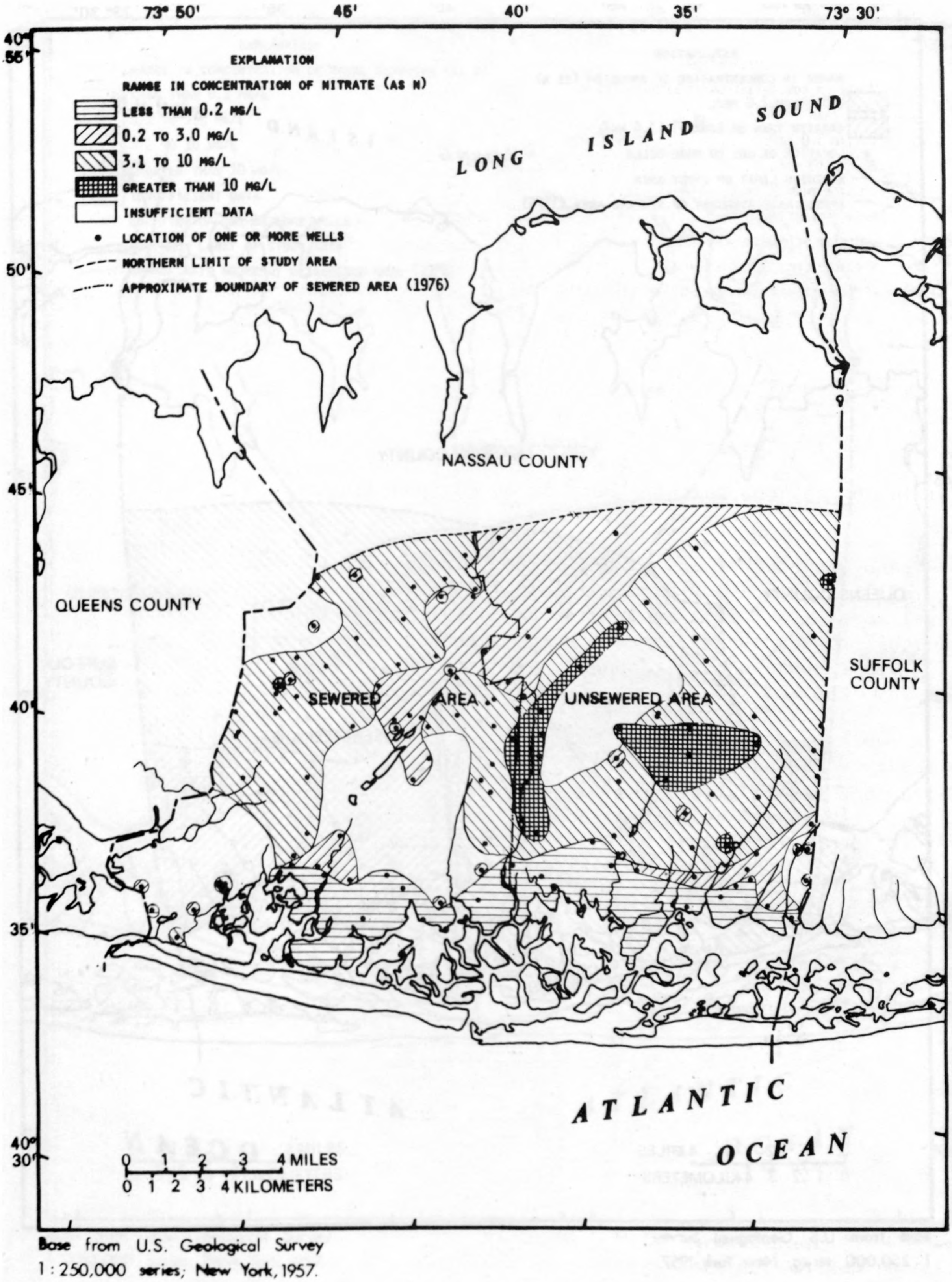


Figure 7E.--Distribution of median nitrate concentration (as N) of water from upper glacial aquifer, 1972-76.

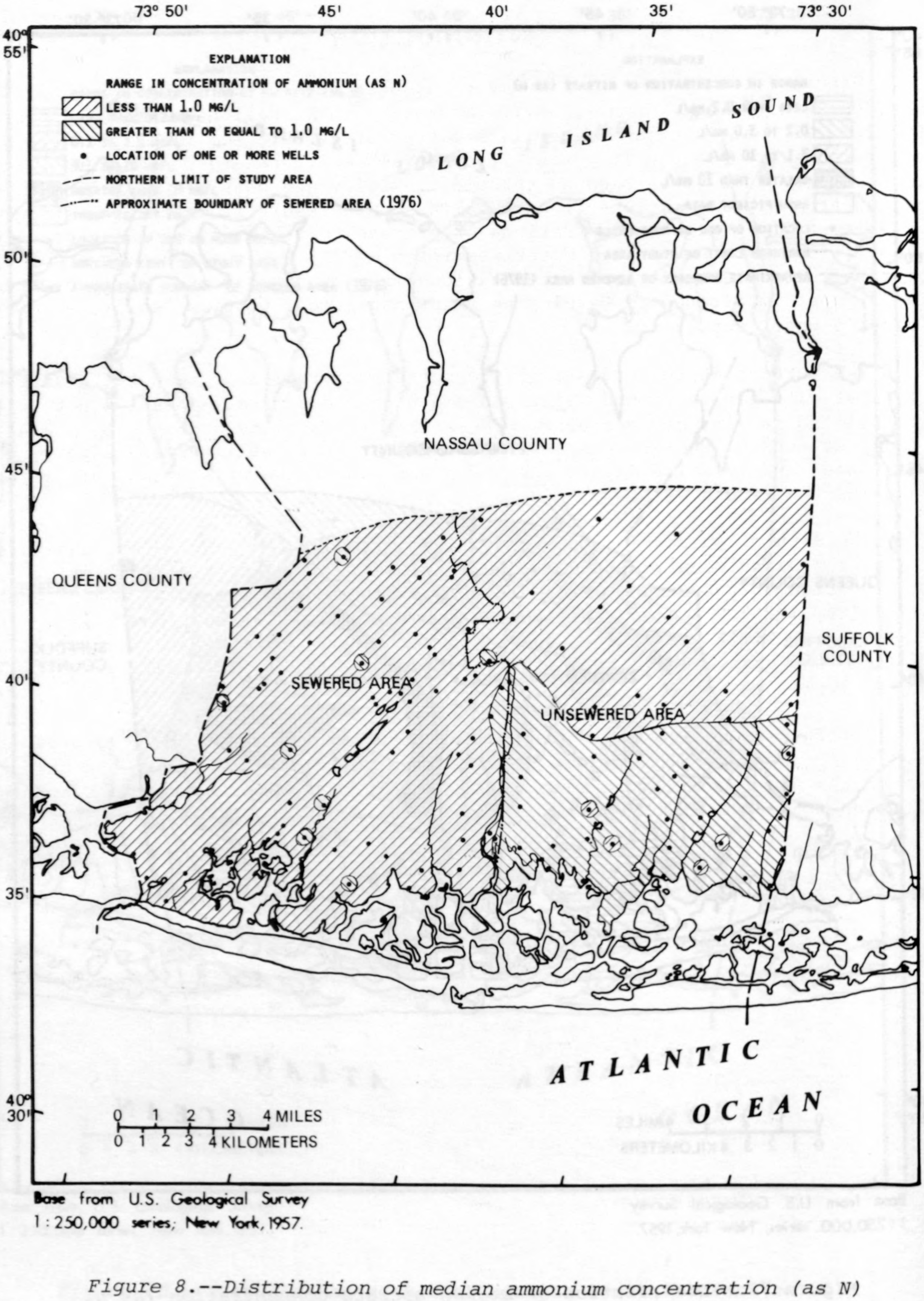


Figure 8.--Distribution of median ammonium concentration (as N) of water from upper glacial aquifer, 1952-76.

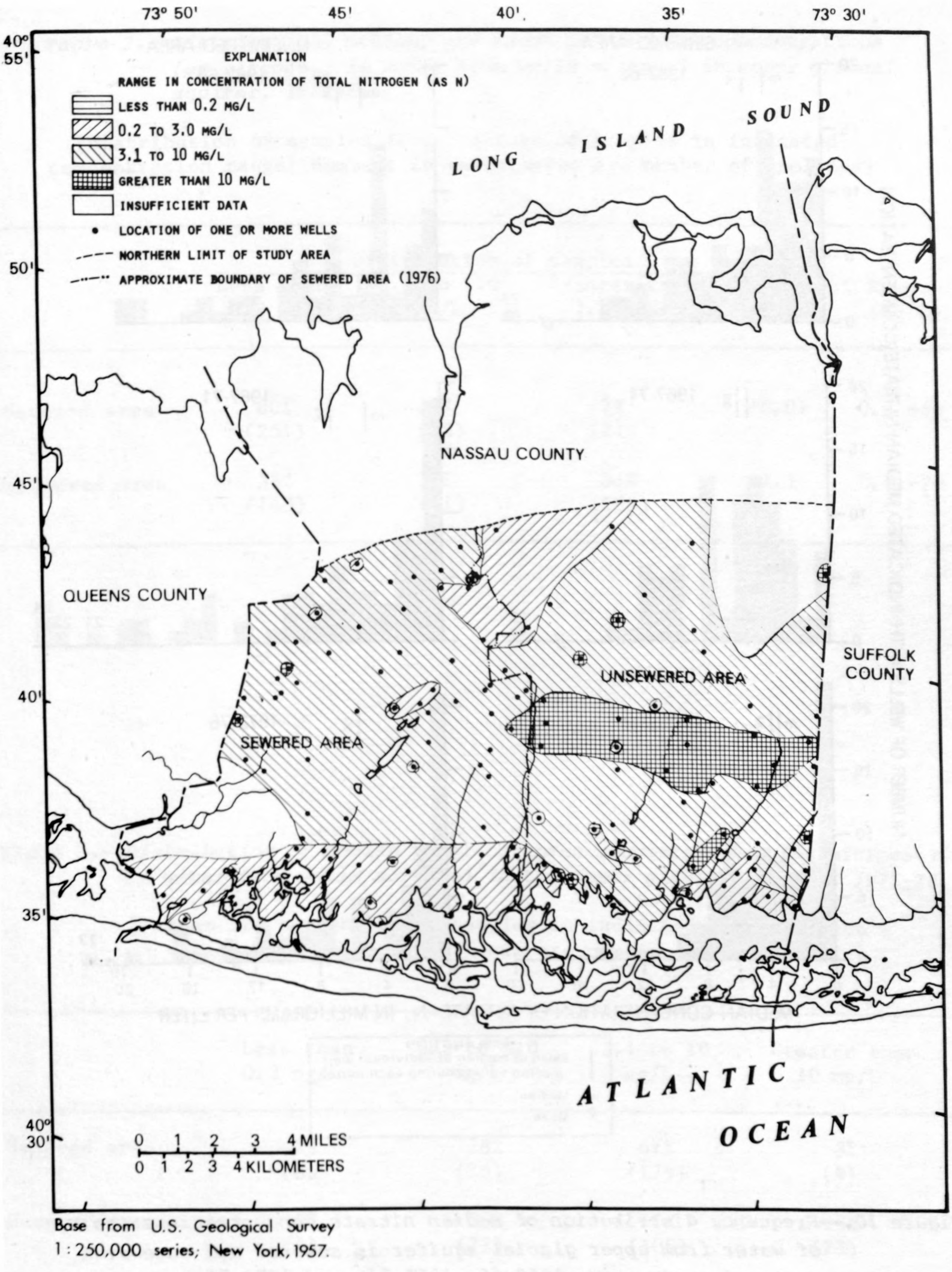


Figure 9.--Distribution of median total nitrogen concentration (as N) in water from upper glacial aquifer, 1972-76.

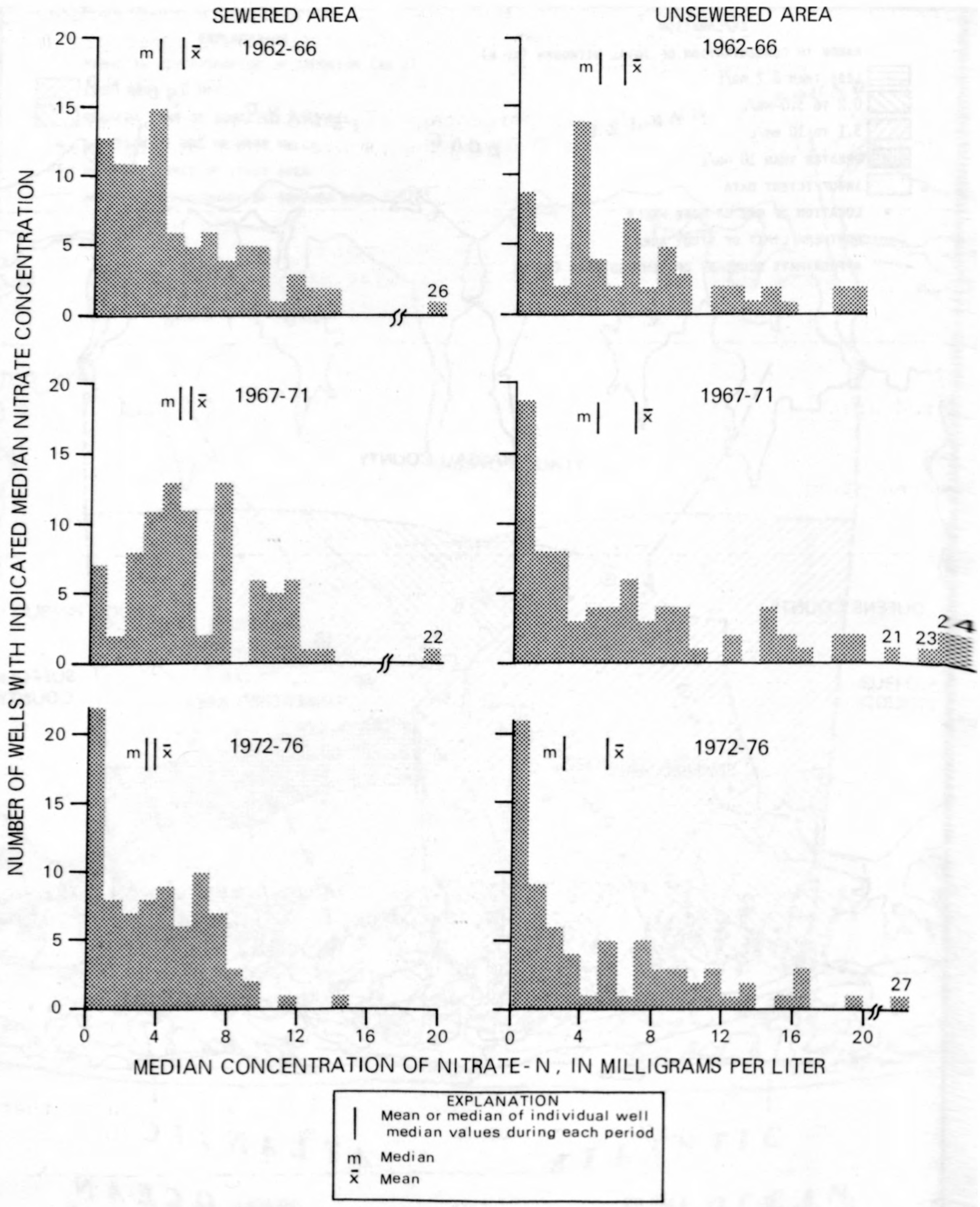


Figure 10.--Frequency distribution of median nitrate concentrations (as N) of water from upper glacial aquifer in sewered and unsewered parts of study area, 1962-66, 1967-71, and 1972-76.

Table 2.--Distribution, median, and range of ammonium concentrations (as nitrogen) in water from wells screened in upper glacial aquifer, 1972-76.

[Distribution of samples is percentage of samples in indicated concentration range; numbers in parentheses are number of analyses]

	Distribution of samples				
	Less than 0.2 mg/L	0.2 to 1.0 mg/L	Greater than 1.0 mg/L	Median (mg/L)	Range (mg/L)
Sewered area	80% (251)	13% (42)	7% (21)	0.01	0.0 -66
Unsewered area	38% (143)	11% (41)	51% (188)	1.1	0.0 -20

Table 3.--Distribution of median total nitrogen concentrations (as nitrogen) in water from wells screened in the upper glacial aquifer, 1972-76.

[Values are percentage of samples in indicated concentration range; numbers in parentheses are number of analyses.]

	Less than 0.2 mg/L	0.2 to 3.0 mg/L	3.1 to 10 mg/L	Greater than 10 mg/L
Sewered area	2% (6)	28% (75)	67% (179)	3% (9)
Unsewered area	2% (6)	30% (77)	40% (105)	28% (73)

Table 4.--Medians of individual median-nitrate concentrations of water from wells screened in the upper glacial aquifer in sewered and unsewered areas

[Significant difference, at 0.95 confidence level between any two medians is denoted by "S"; no significant difference indicated by "N"; numbers of wells are in parentheses.]

Time interval	Sewered area: Median of medians (mg/L)	Significance between areas	Unsewered area: Median of medians (mg/L)
1952-56	6.3 (14)	N	5.4 (6)
Significance between time intervals	N		N
1957-61	8.7 (14)	N	8.3 (14)
Significance between time intervals	S		S
1962-66	3.6 (90)	N	4.6 (66)
Significance between time intervals	S		N
1967-71	4.9 (92)	N	4.8 (31)
Significance between time intervals	N		N
1972-76	3.4 (84)	N	3.0 (73)

For comparison of nitrogen concentrations at different depths, the upper glacial aquifer was divided vertically into five sections. Median nitrate concentrations in the 0- to 3-meter interval below the water table were significantly lower (at the 0.90 confidence level) in the sewered area than in the unsewered area in 1972-76 (fig. 11). At depths greater than 3.1 m below the water table, median nitrate concentrations in the sewered area during the same time period were not significantly different (at the 0.90 confidence level) from those in the unsewered area.

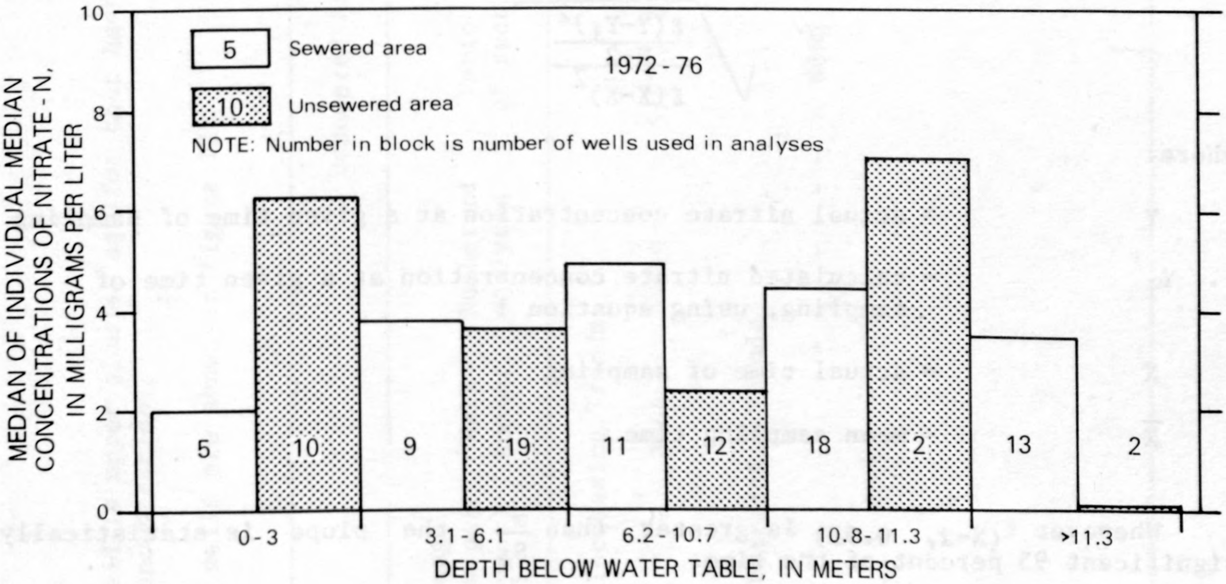


Figure 11.--Vertical distribution of median nitrate concentration (as N) in upper glacial aquifer, 1972-76.

Long-Term Trends in Concentration of Nitrate

Plots of nitrate concentration with time for individual wells are useful in determining long-term trends. However, short-term cyclic fluctuations such as those reported by Katz and others (1978), Schmidt (1977), and Pettijohn (1976), as well as erroneous data, may cause incorrect interpretations. To obtain a first approximation as to whether the changes in the concentration of nitrate with time represent statistically significant trends, a linear-trend line of the general form

$$y = mx + b \qquad (1)$$

was fitted to the nitrate data for each well by a least-squares approximation. The significance of the calculated slope (m) was tested from a null hypothesis. To do this, the following equation was used:

$$t_{(N-2,\ 0.95)} = \frac{m}{S_m}$$

where:

$t_{(N-2,\ 0.95)}$ = Student-t distribution having N-2 degrees of freedom (N equals number of measurements of nitrate concentration for each well) and a 95-percent confidence level. This value is obtained from Student-t tables.

m = calculated slope of the least-squares fitted line

S_m = standard deviation of the slope. This was calculated from

$$\sqrt{\frac{\frac{\Sigma(Y-Y_i)^2}{N-2}}{\Sigma(X-\overline{X})^2}}$$

where:

Y = actual nitrate concentration at a given time of sampling

Y_i = calculated nitrate concentration at a given time of sampling, using equation 1

X = actual time of sampling

$\overline{X}$ = mean sampling time

Whenever $t_{(N-2,\ 0.95)}$ is greater than $\frac{m}{S_m}$, the slope is statistically significant 95 percent of the time.

There is no reason to expect that the trend in the concentration of nitrate, or of any other constituent, will be linear through time. In fact, some evidence suggests that the data could be better described by a nonlinear equation (Phillips, 1973). However, linear analysis is useful as a first approximation in correlating temporal changes in the concentration of a given constituent. Also, because linear analysis is only an approximation of the trend, it is incorrect to use the equation for the least-squares fitted line to estimate constituent concentrations in the future. Thus, the calculated equation of the fitted line is valid only for the period covered by the data and should not be used to make further extrapolations.

Analyses of water from wells with 15 years or more of nitrate data were used for long-term interpretations; water from 14 of the 316 wells in the upper glacial aquifer had sufficient data for trend analyses (table 5). In the sewered area, water from 8 wells had decreasing nitrate trends, and 2 wells had a significant increasing trend. In the unsewered area, water from one well had a significant increasing trend. A median decreasing nitrate trend of 0.21 mg/L per year was found in the sewered area--the only area where data were sufficient for determining a median value. The locations of wells with increasing and decreasing trends in the sewered and unsewered areas are plotted on figure 12. These wells ranged in depth from 21 to 56 meters below the water table, with average depth below land surface ranging from 9 to 47 meters.

Table 5.--Data on wells screened in upper glacial aquifer that have significant trends in nitrate concentration.

[Locations of wells are shown in figure 12]

Sewered Area				Unsewered Area			
Well Number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)	Well number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)
			Increasing Trends				
2578	23	5/52 - 8/75	0.14	3564	19	5/52 - 8/71	0.31
3832	27	6/52 - 7/76	.06				
			Decreasing Trends				
14	25	7/52 - 8/76	.27		- - - - - - -	NONE	- - - - - - -
15	22	7/52 - 8/76	.22				
75	26	5/52 - 4/76	.22				
693	44	3/52 - 8/76	.20				
2115	19	7/52 - 8/76	.23				
2414	23	3/52 - 8/76	.08				
3722	22	6/52 - 7/76	.16				
4077	26	4/54 - 8/76	.16				
		Median value	.21				

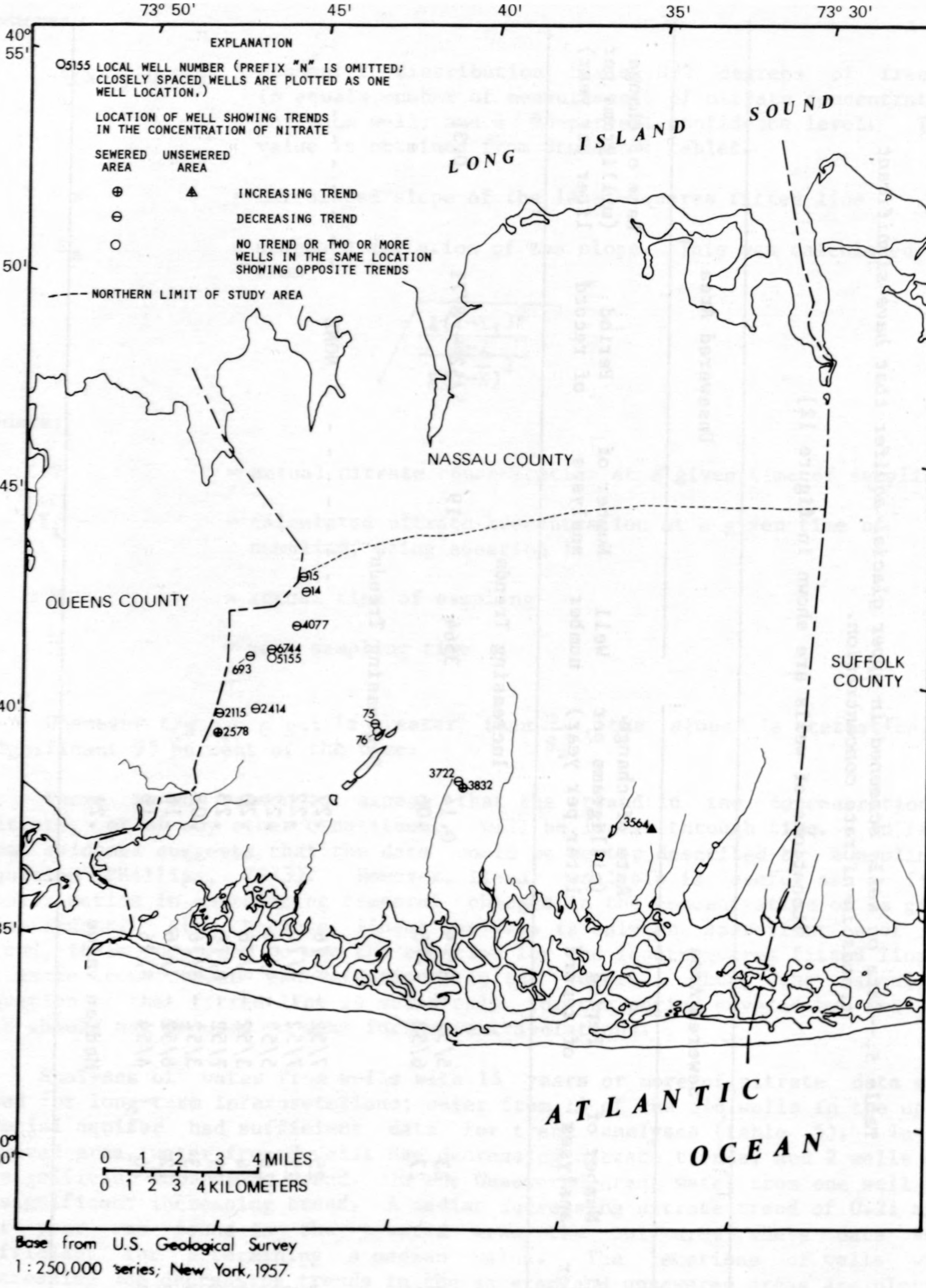


Figure 12.--Locations of wells screened in upper glacial aquifer that have long-term records of nitrate concentrations.

Stream Loads

Approximately 95 percent of streamflow on Long Island is derived from the shallow subsystem of the upper glacial aquifer (Pluhowski and Kantrowitz, 1964; Cohen and others, 1978). Consequently, the concentration of total nitrogen [1] in stream water during periods of base flow is indicative of the concentration of total nitrogen in the part of the aquifer that discharges into the streams.

Water-quality data from 1966-76 on major streams in Nassau County south of the regional ground-water divide are published in Ragone and others (1976b); locations of these streams are given in figure 13. Nitrogen loads for each stream (table 6) were calculated from median nitrogen concentrations in stream water during both time intervals (1967-71 and 1972-76) from volumes of flow equivalent to 95 percent of the average discharge for the two 5-year intervals.

As indicated in table 6, streams in the unsewered area transport more nitrogen from the shallow ground-water subsystem to tidewater than streams in the sewered area. The lower base flows from the sewered area, caused mainly by sewerage and pumping in western Nassau County and adjacent Queens County (Garber and Sulam, 1976), account in part for the large differences in load. However, the larger total nitrogen concentrations of streams in the unsewered area are also responsible for the higher load values of nitrogen in the unsewered area. Approximately half of East Meadow Brook's drainage area is in the sewered area; the other half is in the unsewered area (fig. 13). Total nitrogen concentrations of water from East Meadow Brook during 1967-71 and 1972-76 were lower than those of streams in the unsewered area but higher than those from the stream in the sewered area.

Magothy Aquifer

Areal, Temporal, and Vertical Distribution of Nitrate

The presence of nitrate in the Magothy aquifer may result from the downward movement of nitrate-enriched water near the regional ground-water divide along regional ground-water flow lines, and (or) from localized downward movement of water from the upper glacial aquifer along pumping-induced flow lines. Perlmutter and Koch (1972) described a "nitrate front" in the Magothy aquifer and defined it as the boundary between nitrate concentration (as N) of 0.2 mg/L or less and higher nitrate concentrations. The areal distribution of water within selected ranges of median nitrate concentrations in the Magothy aquifer is presented by depth intervals in figures 14 through 17. The area in which ground water contains 0.2 mg/L or less increases with depths in the Magothy aquifer. Similarly, areas containing water in the higher ranges (3.1 to 10 mg/L and greater than 10 mg/L) decrease with depth.

Median nitrate concentrations of water have generally decreased with depth in both the sewered and unsewered areas during 1972-76 (table 7).

1/ Total nitrogen (as N) is equal to the sum of organic nitrogen (as N), nitrate (as N), ammonium (as N), and nitrite (as N). Organic nitrogen was included in this section because these data were generally available.

Table 6.--Mean total nitrogen loads (as nitrogen) in water from selected streams in study area, 1967-71 and 1972-76.

[All values are in metric tons per year; median total nitrogen (as N) concentrations are in parentheses.]

Stream	1967-71	1972-76
SEWERED AREA		
Pines Brook	1.8 (1.4)	5.9 (3.5)
Maximum extrapolated load for sewered area 1/	77	114
UNSEWERED AREA		
Massapequa Creek	46 (7.7)	102 (9.4)
Bellmore Creek	49 (7.5)	98 (10)
East Meadow Brook	42 (4.5)	57 (5.2)
TOTAL	137	257
Maximum extrapolated load for unsewered area 2/	580	580

1/ Calculated by multiplying load values for Pines Brook by a factor obtained by dividing the 1971 estimated average yearly total stream discharge of 0.85 m^3/s (Katz and others, 1977) for the sewered area by the average discharge of Pines Brook for the two time intervals (U.S. Geological Survey, Water Resources Data for New York, published annually.)

2/ Calculated by multiplying the sum of loads by a factor obtained by dividing the 1967-75 mean discharge values of 2.5 m^3/s (A. W. Harbaugh, written commun., 1977) by the sum of the average discharges of the three continuously gaged streams in the unsewered area. The 1967-71 factor is larger than the 1972-76 factor because stream discharges were lower after the drought in the mid-1960's.

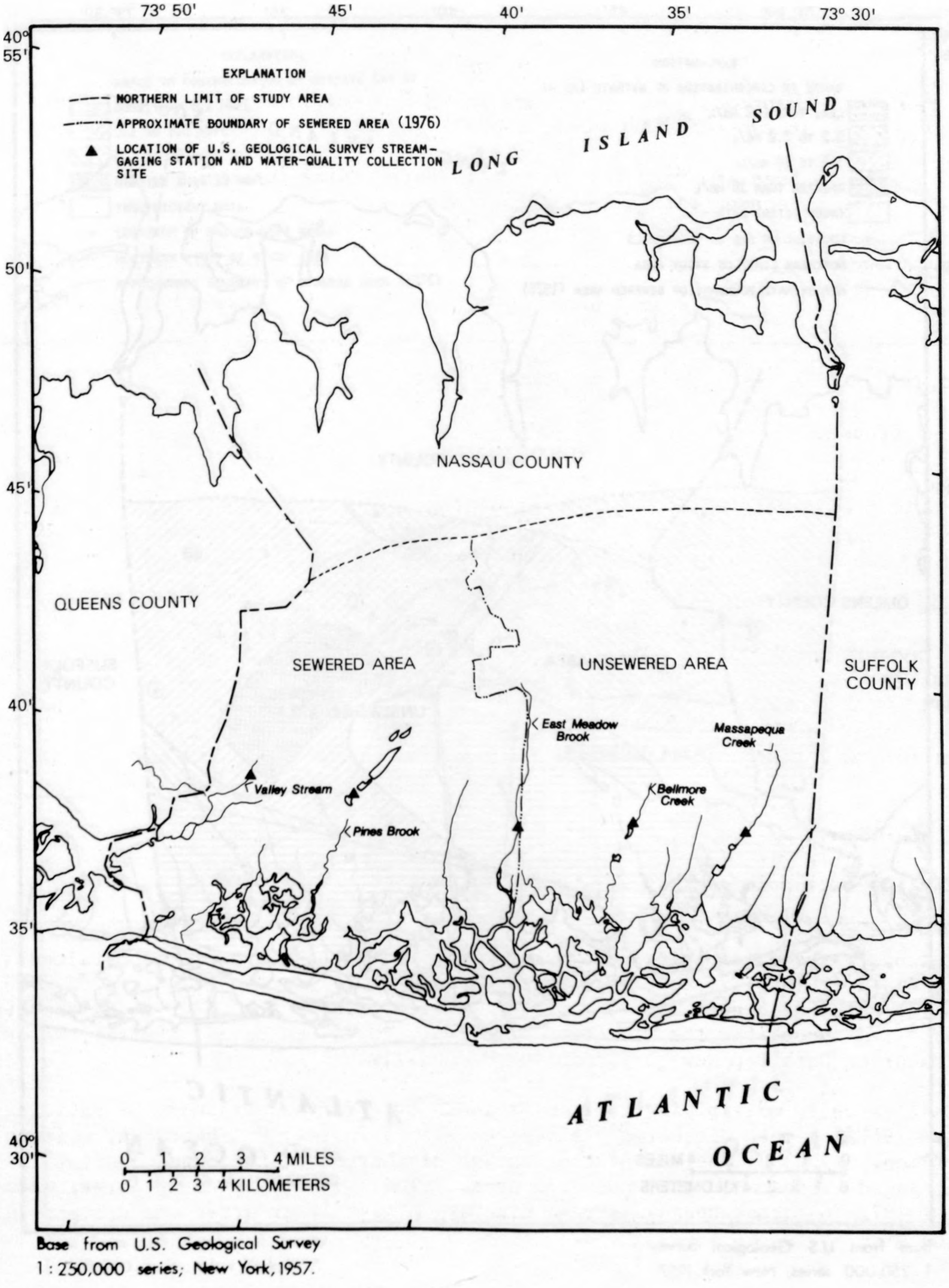


Figure 13.--Location of major streams in Nassau County south of regional ground-water divide.

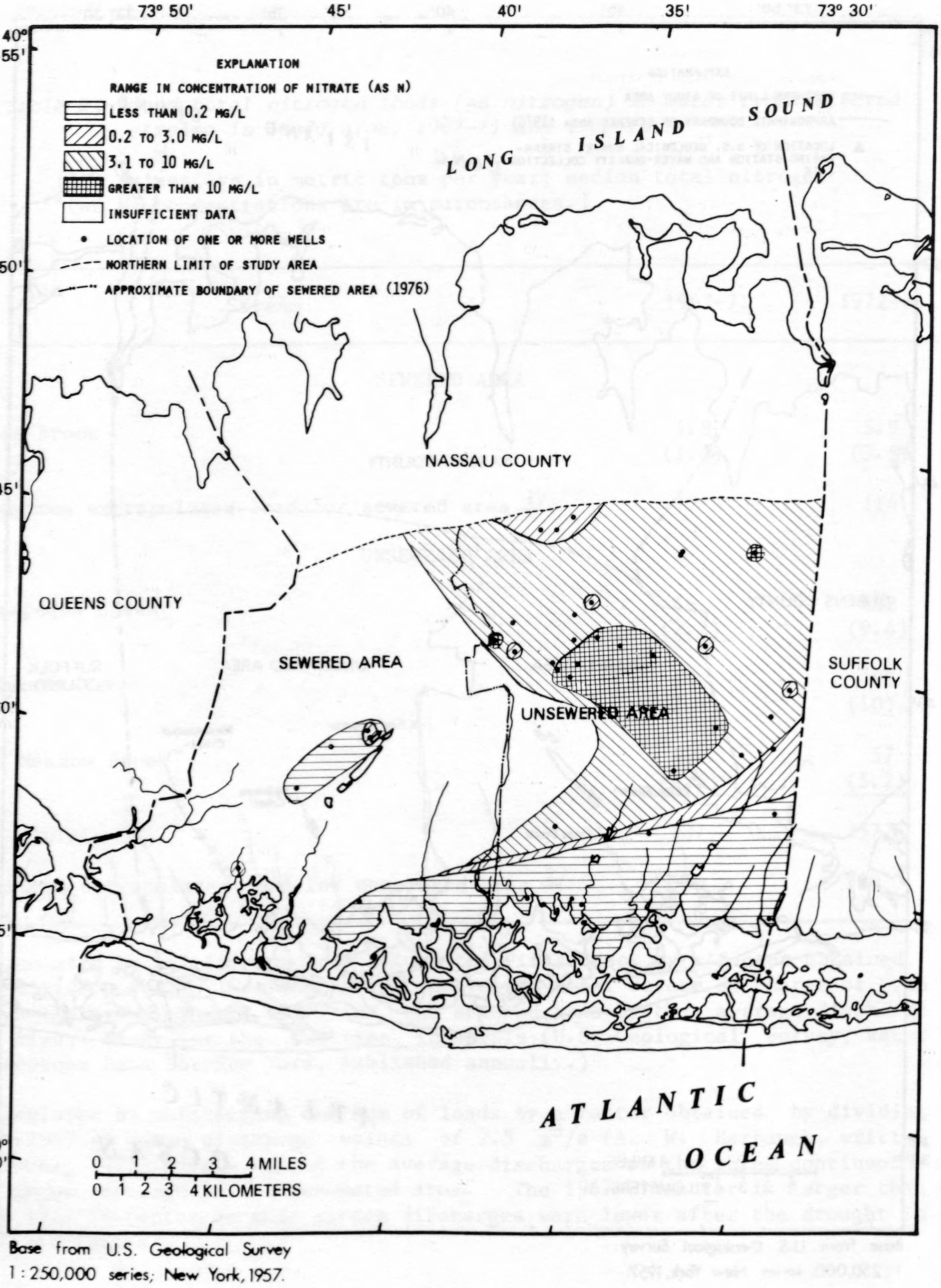


Figure 14.--Distribution of median nitrate concentrations (as N) of water in Magothy aquifer from depths less than 61 meters below land surface, 1972-76.

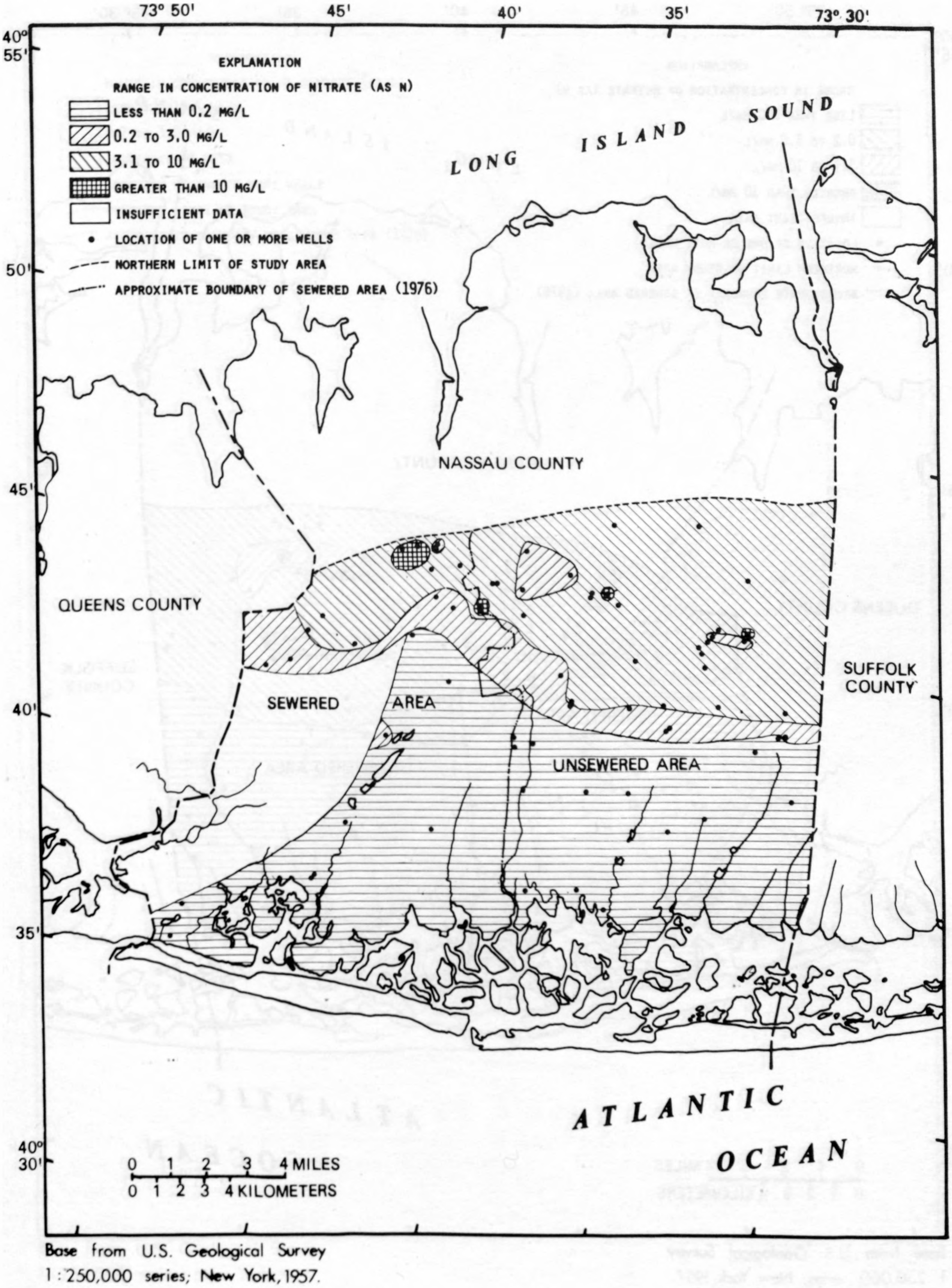


Figure 15.--Distribution of median nitrate concentrations (as N) of water in Magothy aquifer from depths of 61 to 122 meters below land surface, 1972-76.

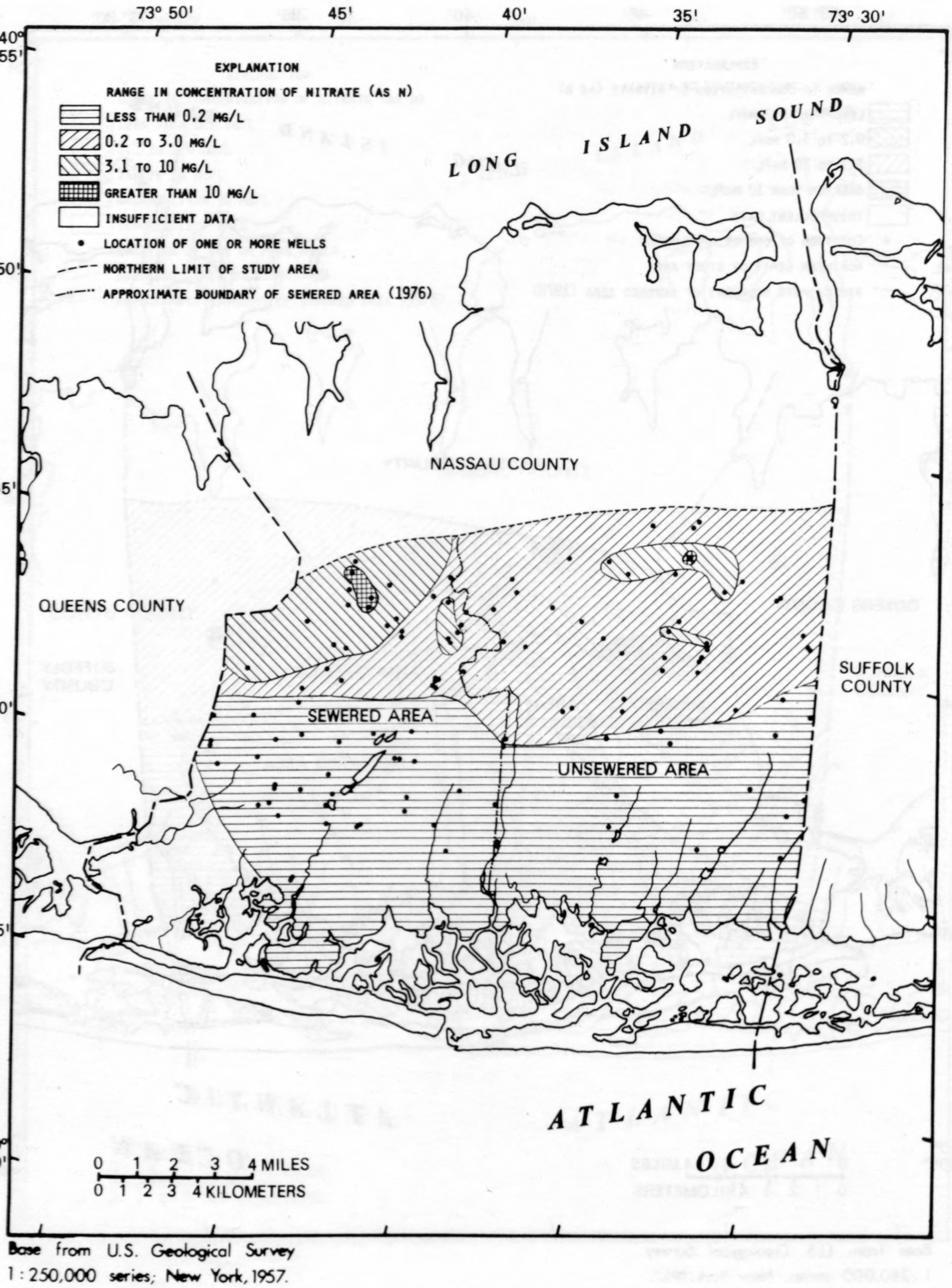


Figure 16.--Distribution of median nitrate concentrations (as N) of water in Magothy aquifer from depths of 123 to 183 meters below land surface, 1972-76.

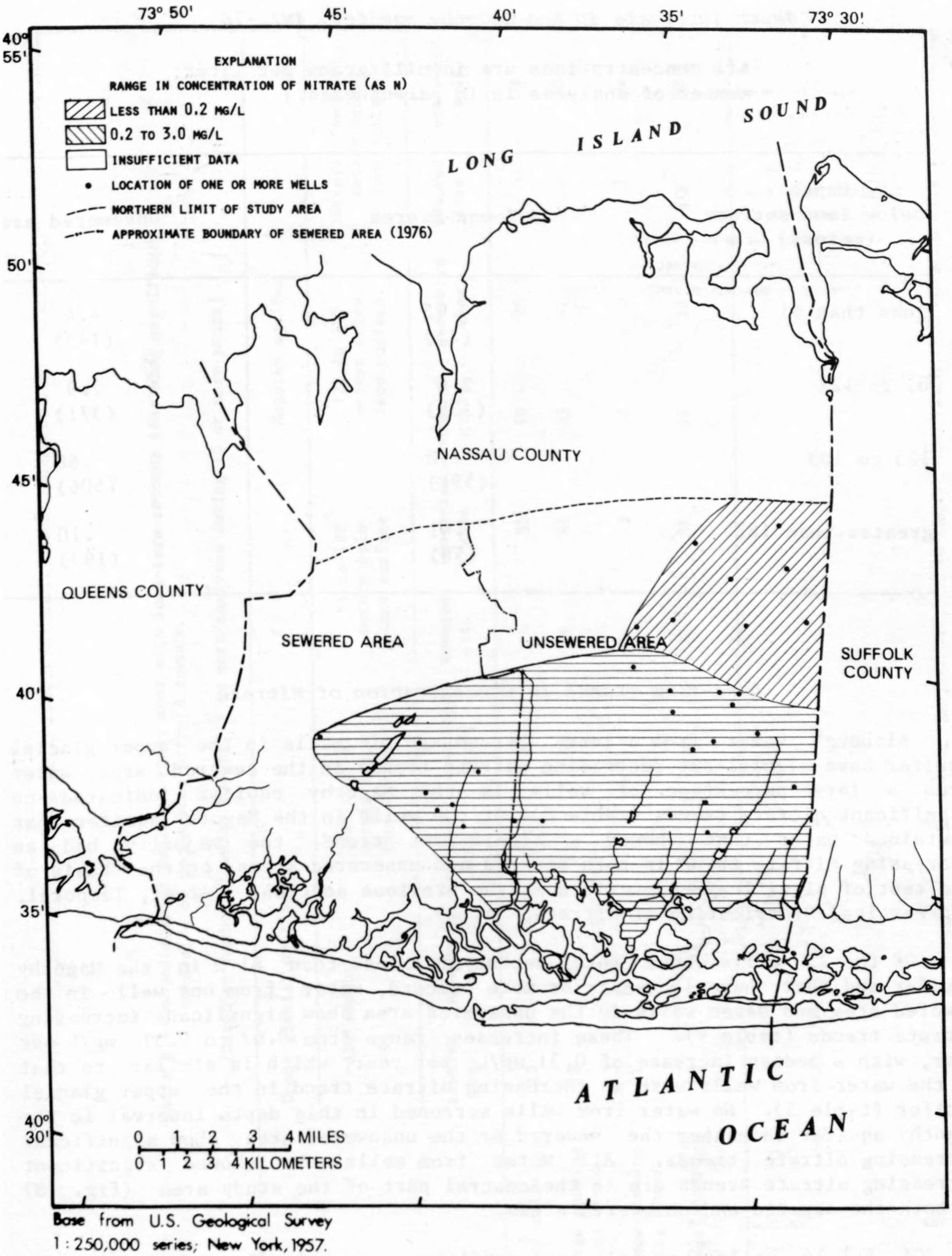


Figure 17.--Distribution of median nitrate concentrations (as N) of water in Magothy aquifer from depths of greater than 183 meters below land surface, 1972-76.

Table 7.--Median nitrate concentrations (as nitrogen) of water from different depth intervals in the Magothy aquifer, 1972-76

[All concentrations are in milligrams per liter; number of analyses is in parentheses.]

Depth below land surface (meters)	Sewered area	Unsewered area
less than 61	0.25 (21)	4.4 (143)
61 to 122	2.6 (138)	2.9 (371)
123 to 183	.10 (591)	.68 (506)
greater than 183	.01 (58)	.10 (193)

Long-Term Trends in Concentration of Nitrate

Although water from a large percentage of wells in the upper glacial aquifer have significant decreasing nitrate trends in the sewered area, water from a large percentage of wells in the Magothy aquifer indicated no significant nitrate trends (table 8). Of the wells in the Magothy aquifer that contained water that showed a significant trend, the majority had an increasing nitrate trend in both sewered and unsewered areas, on the basis of the test of significance described in the previous section, "Areal, Temporal, and Vertical Distribution of Nitrate," p. 29.

Of the 13 wells whose total depths are less than 61 m in the Magothy aquifer and that have 15 years or more record, water from one well in the sewered area and seven wells in the unsewered area show significant increasing nitrate trends (table 9). These increases range from 0.07 to 0.51 mg/L per year, with a median increase of 0.31 mg/L per year, which is similar to that of the water from wells with an increasing nitrate trend in the upper glacial aquifer (table 5). No water from wells screened in this depth interval in the Magothy aquifer in either the sewered or the unsewered area show significant decreasing nitrate trends. All water from wells that showed significant increasing nitrate trends are in the central part of the study area (fig. 18) in both the sewered and unsewered areas.

Of the 14 wells that (a) have sufficient periods of record, (b) are screened from 61 to 122 m in the Magothy aquifer, and (c) are in the sewered area, waters from five show significant increasing trends and four show

Table 8.--Percentages of wells in study area with long-term records that show significant increasing or decreasing nitrate trends.

[Based on number of wells having 15 or more analyses during 15 or more years]

	Upper glacial aquifer		Magothy aquifer							
	All depths		Less than 61 meters below land surface		61 to 122 meters below land surface		123 to 183 meters below land surface		Greater than 183 meters below land surface	
	sewered area	unsewered area	sewered area	unsewered area	sewered area	unsewered area	sewered area	unsewered area	sewered area	unsewered area
Number of wells	13	1	3	10	14	35	49	26	3	8
Percentage showing increasing trend	15	100	33	70	36	46	33	42	0	38
Percentage showing decreasing trend	69	0	0	0	28	3	8	0	0	0
Percentage showing no trend	15	0	67	30	36	51	59	58	100	62

Table 9.--Data on wells screened at depths less than 61 meters below land surface in the Magothy aquifer that have significant trends in nitrate concentration.

Sewered area				Unsewered area			
Well Number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)	Well number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)
			Increasing Trends				
4394	14	7/54 - 8/75	0.01	1937	30	10/52 - 10/76	0.07
				3488	24	1/52 - 10/76	.51
				3552	21	1/52 - 9/72	.30
				3553	20	1/52 - 5/76	.34
				3780[1]	26	6/52 - 8/76	.24
				3893[1]	32	5/52 - 8/76	.31
				4042	28	10/53 - 5/76	.38
						median value	.31
			Decreasing Trends				
	- - - - - NONE - - - - -					- - - - - NONE - - - - -	

[1]Large decrease observed in nitrate concentration in last several years

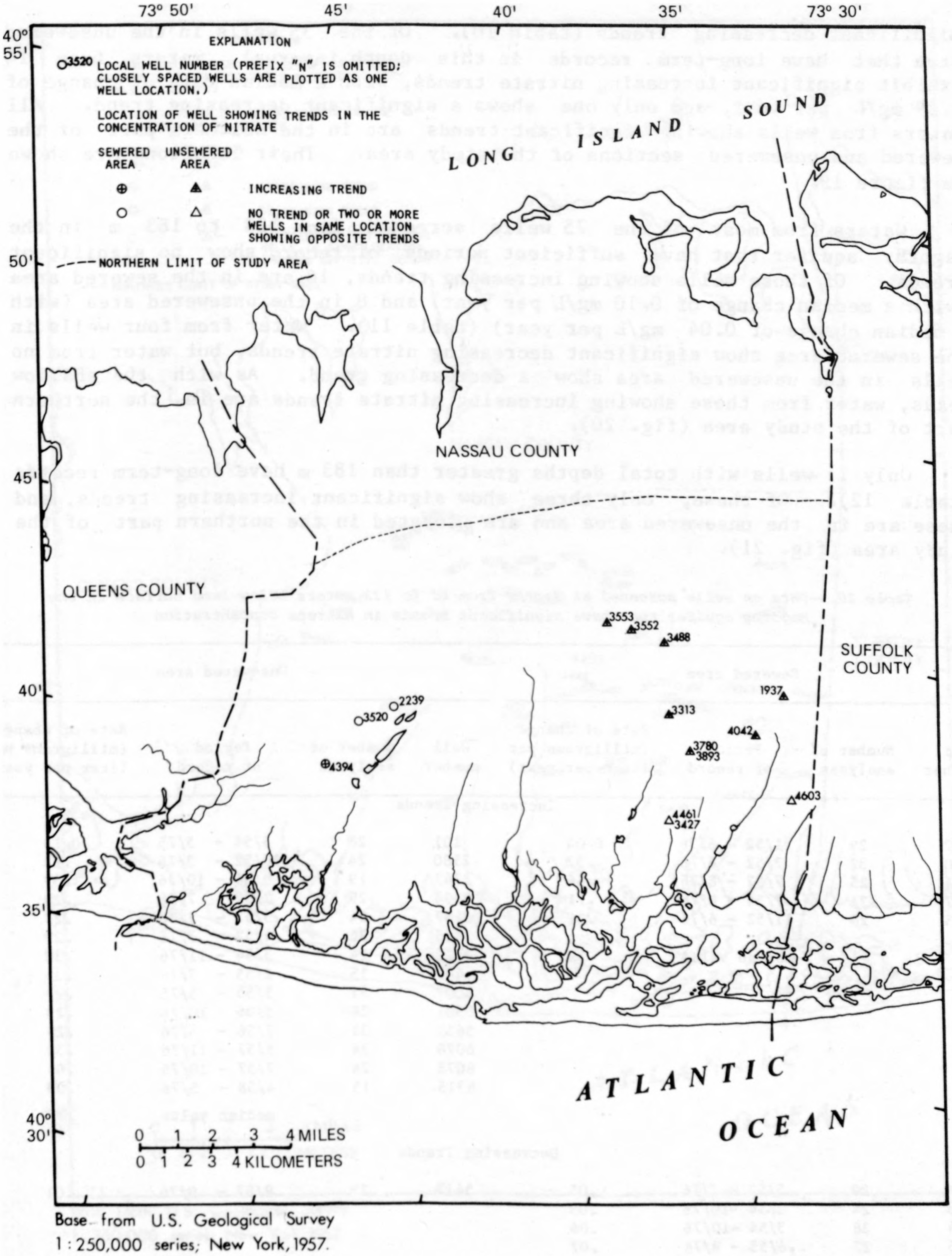


Figure 18.--Locations of wells screened at depths less than 61 meters below land surface in the Magothy aquifer that have long-term records of nitrate concentration.

significant decreasing trends (table 10). Of the 35 wells in the unsewered area that have long-term records in this depth interval, waters from 14 exhibit significant increasing nitrate trends, with a median rate of change of 0.29 mg/L per year, and only one shows a significant decreasing trend. All waters from wells showing significant trends are in the northern part of the sewered and unsewered sections of the study area. Their locations are shown in figure 19.

Waters from most of the 75 wells screened from 123 to 183 m in the Magothy aquifer that have sufficient periods of record show no significant trends. Of those wells showing increasing trends, 16 are in the sewered area (with a median change of 0.10 mg/L per year) and 8 in the unsewered area (with a median change of 0.04 mg/L per year) (table 11). Water from four wells in the sewered area show significant decreasing nitrate trends, but water from no wells in the unsewered area show a decreasing trend. As with the shallow wells, water from those showing increasing nitrate trends are in the northern part of the study area (fig. 20).

Only 11 wells with total depths greater than 183 m have long-term records (table 12). Of these, only three show significant increasing trends, and these are in the unsewered area and are located in the northern part of the study area (fig. 21).

Table 10.--Data on wells screened at depths from 61 to 122 meters below land surface in the Magothy aquifer that have significant trends in nitrate concentration

Sewered area				Unsewered area			
Well Number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)	Well number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)
			Increasing Trends				
97	29	1/52 - 6/76	0.04	101	28	5/54 - 5/75	0.13
650	32	7/52 - 8/76	.32	2580	24	10/52 - 3/76	.13
651	25	7/52 - 8/76	.66	2747	19	9/54 - 10/76	.39
2487	31	7/54 - 8/76	.71	3194	29	2/52 - 7/76	.29
4425	28	11/52 - 6/76	.01	3457	24	3/52 - 7/76	.23
				3465	26	4/52 - 7/76	.29
		median value	.32	3876	24	3/54 - 11/76	.30
				4447	15	2/55 - 7/76	.35
				5007	31	5/55 - 5/75	.27
				5301	28	5/56 - 10/76	.29
				5655	31	7/56 - 5/76	.29
				6076	24	8/57 - 11/76	.30
				6078	24	7/57 - 10/76	.64
				6315	15	4/58 - 5/76	.09
						median value	.29
			Decreasing Trends				
94	20	5/52 - 7/76	.05	5417	23	9/57 - 9/76	.01
103	24	3/54 -10/76	.03				
104	26	3/54 -10/76	.06				
5156	22	6/55 - 8/76	.07				
		median value	.06				

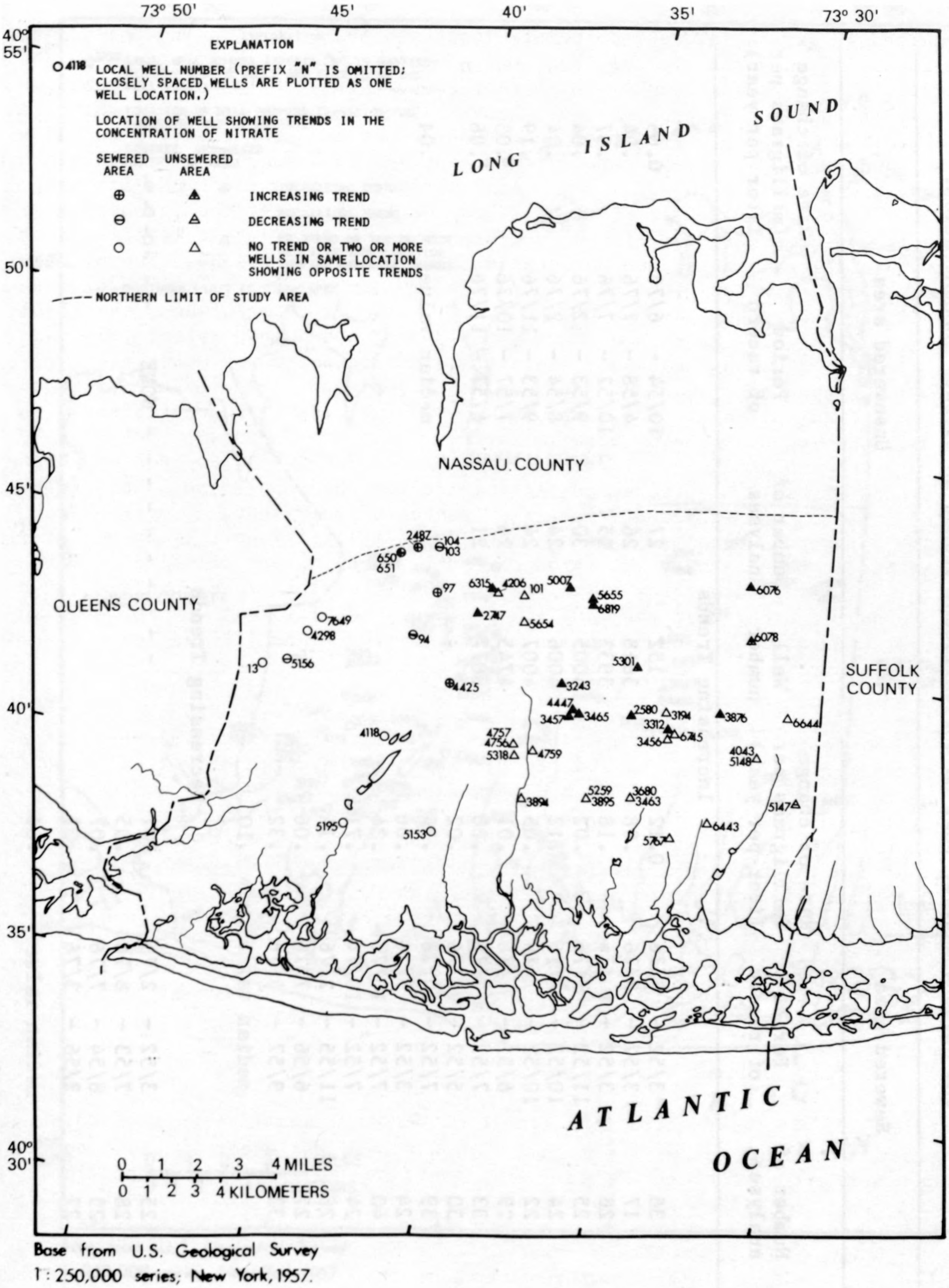


Figure 19.--Locations of wells screened at depths between 61 and 122 meters below land surface in the Magothy aquifer that have long-term records of nitrate concentration.

Table 11.--Data on wells screened at depths from 123 to 183 meters below land surface in the Magothy aquifer that have significant trends in nitrate concentration.

Sewered area				Unsewered area			
Well Number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)	Well number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)
			Increasing Trends				
11	36	3/52 - 3/76	0.12	152	27	10/54 - 6/76	0.05
12	17	3/52 - 8/76	.08	3618	26	4/58 - 7/76	.04
17	28	3/52 - 10/76	.18	3933	25	10/52 - 7/76	.07
80	25	11/52 - 7/76	.02	4005	30	9/53 - 2/76	.04
82	24	10/52 - 7/76	.12	4006	24	8/54 - 2/76	.04
83	22	10/52 - 7/76	.05	4007	24	9/53 - 11/76	.19
95	29	6/52 - 1/76	.01	4745	26	7/57 - 10/76	.03
578	33	7/52 - 7/76	.20	6077	21	6/57 - 11/76	.06
1697	30	5/52 - 2/76	.02				
2565	39	7/52 - 10/76	.36			median value	.04
3603	24	3/52 - 7/76	.06				
3672	40	7/52 - 10/76	.34				
3673	24	7/52 - 10/74	.71				
5163	26	11/55 - 2/76	.14				
5596	27	6/56 - 7/76	.06				
5603	33	9/57 - 4/76	.32				
		median value	.10				
			Decreasing Trends				
3605	25	3/52 - 2/75	.01	- - - - - - - - - - - - NONE - - - - - - - - -			
3935	28	7/53 - 8/76	.05				
4082	25	8/54 - 7/76	.07				
5260	27	2/56 - 3/76	.02				
		median value	.04				

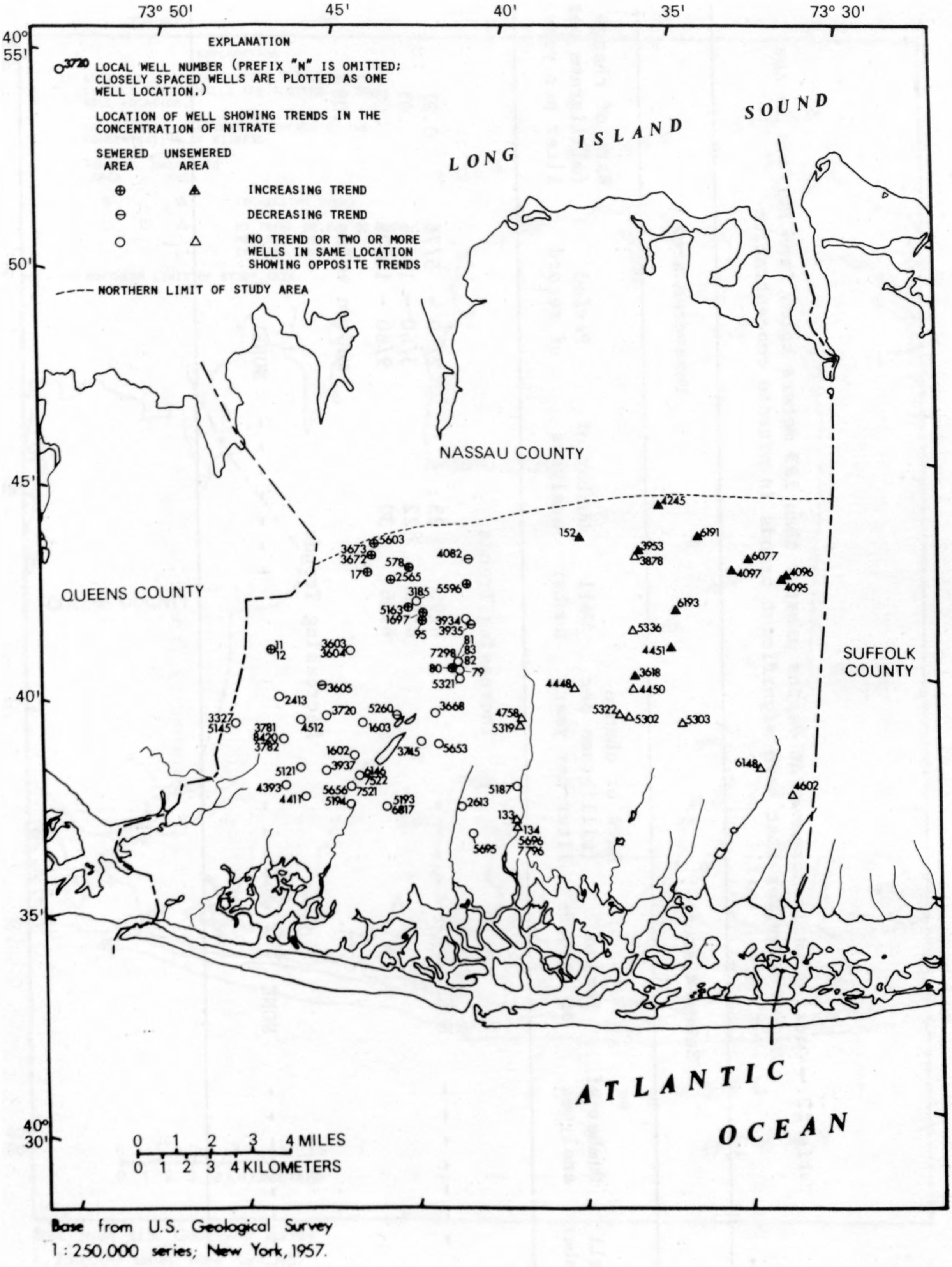


Figure 20.--Locations of wells screened at depths between 123 and 183 meters below land surface in the Magothy aquifer that have long-term records of nitrate concentration.

Table 12.--Data on wells screened at depths greater than 183 meters below land surface in the Magothy aquifer that have significant trends in nitrate concentration

Sewered area				Unsewered area			
Well Number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)	Well number	Number of analyses	Period of record	Rate of change (milligrams per liter per year)
			Increasing Trends				
- - - - - - -	NONE	- - - - - - -		6190	23	2/60 - 5/76	0.21
				6580	22	3/60 - 11/76	.01
				6956	30	9/60 - 11/76	.09
						median value	.09
			Decreasing Trends				
- - - - - - -	NONE	- - - - - - -		- - - - - - -	NONE	- - - - - - -	

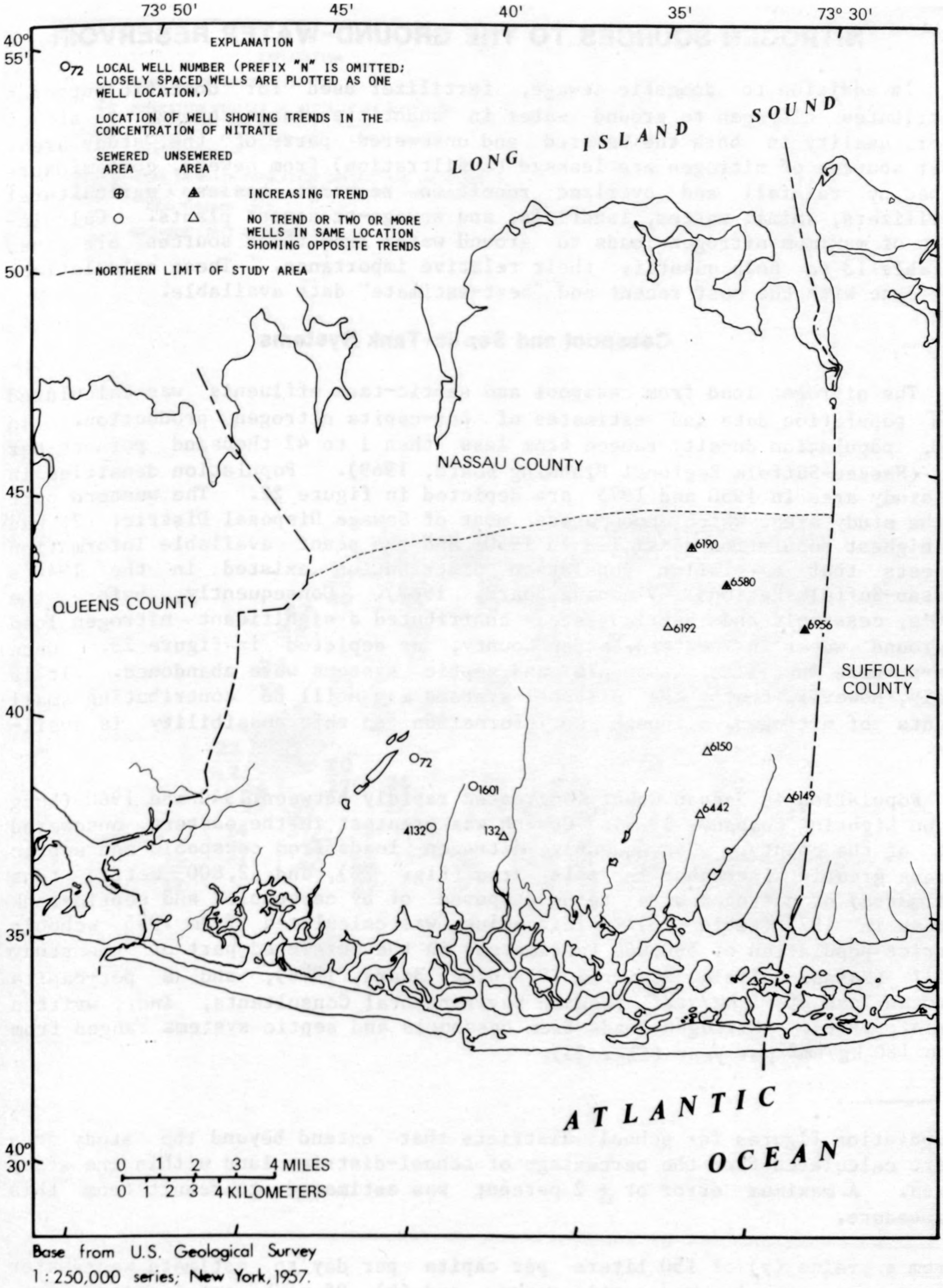


Figure 21.--Locations of wells screened at total depths greater than 183 meters below land surface in the Magothy aquifer that have long-term records of nitrate concentration.

NITROGEN SOURCES TO THE GROUND-WATER RESERVOIR

In addition to domestic sewage, fertilizer used for domestic purposes contributes nitrogen to ground water in quantities large enough to affect water quality in both the sewered and unsewered parts of the study area. Other sources of nitrogen are leakage (exfiltration) from sewers, contaminants washed by rainfall and overland runoff to recharge basins, agricultural fertilizers, animal wastes, landfills, and sewage-treatment plants. Calculations of maximum nitrogen loads to ground water from these sources are given in table 13 to help quantify their relative importance. These calculations were done with the most recent and "best-estimate" data available.

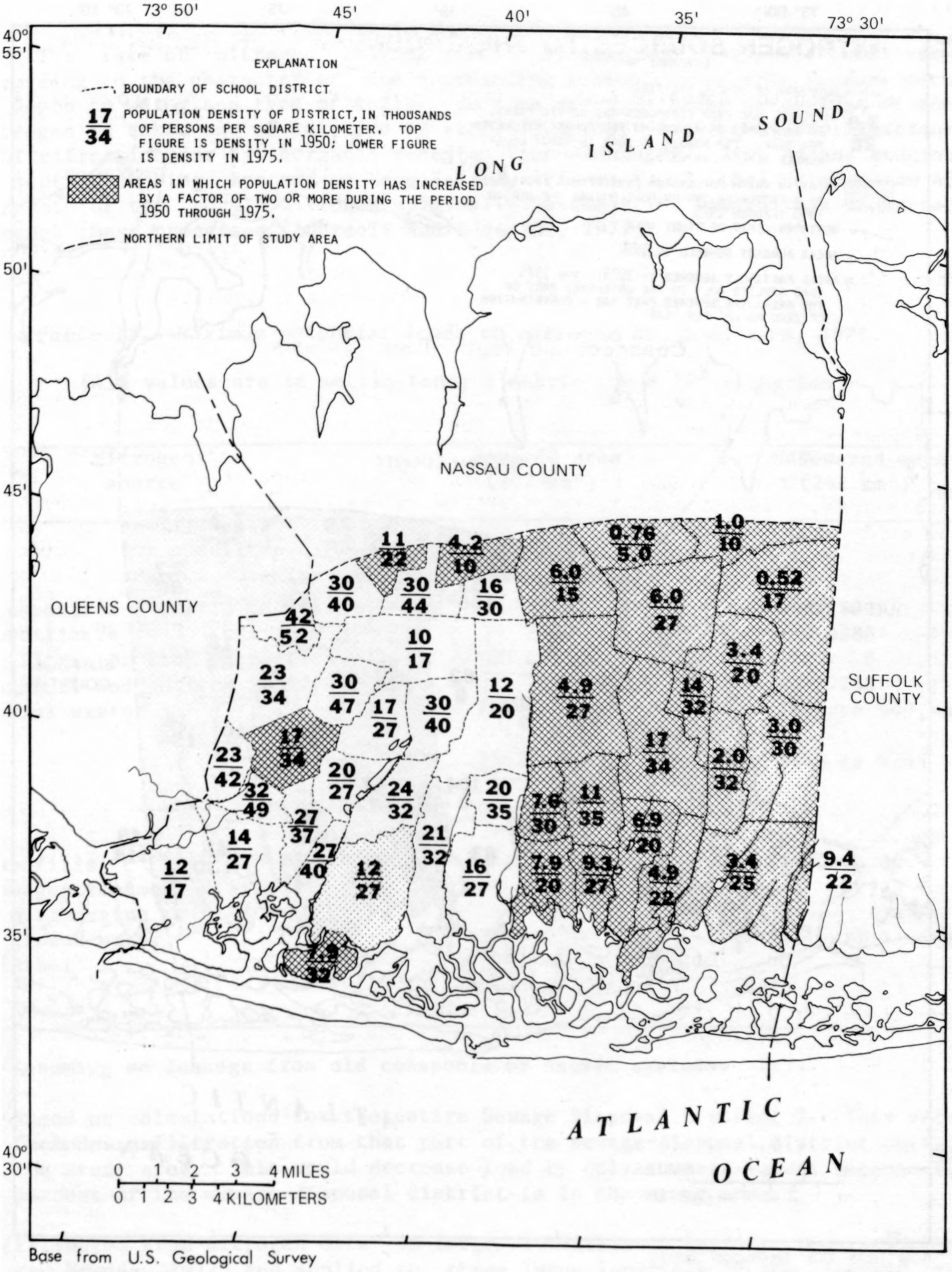
Cesspool and Septic-Tank Systems

The nitrogen load from cesspool and septic-tank effluents was calculated from population data and estimates of per-capita nitrogen production. In 1950, population density ranged from less than 1 to 42 thousand persons per km^2 (Nassau-Suffolk Regional Planning Board, 1969). Population densities in the study area in 1950 and 1975 are depicted in figure 22. The western part of the study area, which encompasses most of Sewage Disposal District 2, had the highest population densities in 1950, and the scant available information suggests that a similar population distribution existed in the 1940's (Nassau-Suffolk Regional Planning Board, 1969). Consequently, before the 1950's, cesspools and septic systems contributed a significant nitrogen load to ground water in western Nassau County, as depicted in figure 23. Once sewers were installed, cesspools and septic systems were abandoned. It is likely, however, that these disposal systems may still be contributing small amounts of nitrogen, although no information on this possibility is available.

Population in Nassau County increased rapidly between 1940 and 1960 (Long Island Lighting Company, 1977). Growth was greatest in the eastern, unsewered part of the county. Consequently, nitrogen loads from cesspools and septic systems greatly increased in this area (fig. 23), and 2,800 metric tons (estimated) of nitrogen were being disposed of by cesspools and septic-tank systems in 1975 (table 13). This value was calculated from 1975 school-district population of 560,000 (estimated) in the unsewered part of the study area[1/] (Nassau-Suffolk Regional Planning Board, 1976), and a per-capita nitrogen load of 5 kg/yr[2/] (Weston Environmental Consultants, Inc., written commun., 1976). Nitrogen loads from cesspools and septic systems ranged from 25 to 180 kg/hm^2 per year (fig. 23).

[1/] Population figures for school districts that extend beyond the study area were calculated from the percentage of school-district land within the study area. A maximum error of ± 2 percent was estimated to result from this procedure.

[2/] From a value (a) of 150 liters per capita per day to estimate wastewater flows to cesspools and septic tanks, and (b) 95 mg/L total nitrogen to estimate loadings to the ground, a loading figure of 5.2 kg total nitrogen per person per year was obtained. This figure was rounded to 5 kg total nitrogen per capita per year.



Base from U.S. Geological Survey 1:250,000 series; New York, 1957.

Figure 22.--Distribution of population densities by school districts in Nassau County in 1950 and 1975.

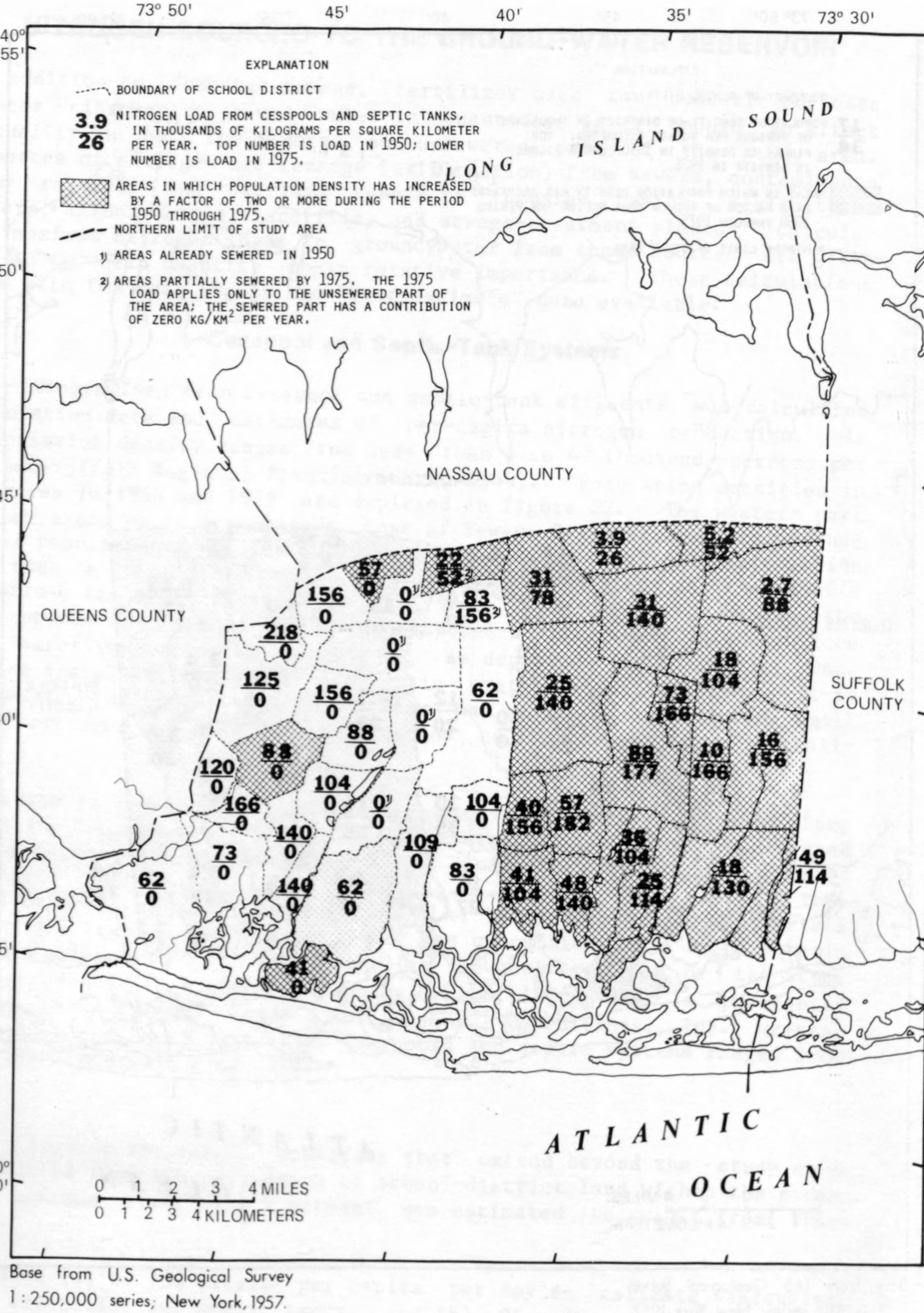


Figure 23.--Distribution of nitrogen loads from septic systems and cesspool sources in Nassau County in 1950 and 1975.

The fate of nitrogen leaving septic systems and cesspools will vary according to the character of the surrounding geologic unit and factors such as depth to water and type of soils. In some areas, a large percentage of the nitrogen is taken out of solution by microbiological processes (nitrification-denitrification) or by inorganic reaction (ion exchange). From recent studies of septic leaching systems on Long Island, it was found that as much as 45 percent of the total nitrogen originally present in sewage was converted through these processes (Andreoli and Reynolds, 1977).

Table 13.--Maximum potential loads of nitrogen to study area, 1975.

[All values are in metric tons; 1 metric ton = 10^3 kilograms]

Nitrogen source	Sewered area ($207\ km^2$)	Unsewered area ($242\ km^2$)
NONPOINT SOURCES		
Cesspools and septic tanks	1/0.0	2800
Fertilizers	2380	2780
Exfiltration from sewers	2/200 to 300	0
Rainfall and surface runoff	242	268
Animal wastes	740 to 1040	670 to 940
Total	3562 to 3962	6518 to 6788
POINT SOURCES		
Landfills	3/60 to 120	40 to 80
Sewage-treatment plants discharging to ground water	0	22
4/Other	--	--

1/Assuming no leakage from old cesspools or septic systems.

2/Based on calculations for the entire Sewage Disposal District 2. This value includes exfiltration from that part of the sewage-disposal district outside the study area. This would decrease load by only a small amount because 94 percent of the sewage-disposal district is in the study area.

3/Estimated from nitrogen data on large landfills in Suffolk County (Kimmel and Braids, 1977) and applied to three large landfills in the sewered area and two in the unsewered area that are inland from water bodies surrounding Long Island.

4/Data on industrial discharge of nitrogen to ground water are unavailable.

Fertilizers

Before the 1950's, agriculture was one of the major industries in Nassau County. Although Nassau County's farming area had already decreased through the rapid development of suburban communities during the 1930's, the estimated amount of land still used for farming in 1950 was 8,500 hm^2 (Dodson, 1950).

Although historic and current data on the rate of fertilizer application to these fields in Nassau County are not available, it can be assumed that significant amounts were and are applied for the production of potatoes and other vegetables.

In 1975, lawn fertilizers were estimated to contribute 2,380 metric tons of nitrogen to the sewered area and 2,780 metric tons to the unsewered area (table 13). This value is based on a field survey made by the Cooperative Extension Service of Cornell University. Approximately 60 percent of the nitrogen from this source is estimated to reach ground-water bodies (K. S. Porter, Suffolk County Cooperative Extension Service, oral commun., 1977).

Rainfall and Surface Runoff

Rainfall and surface runoff together contributed 510 metric tons (estimated) of nitrogen to the study area in 1975 (table 13). Of this total, rainfall contributed 490 metric tons. The value for rainfall was determined from a total nitrogen concentration of 1 mg/L in rainfall (Frizzola and Baier, 1975) and a precipitation rate of 110 cm/yr (1937-76 average at the Valley Stream and Mineola precipitation stations). It is not certain what percentage of this load reaches ground-water bodies. Although some precipitation runs off to streams, it is probably only a small amount. Nitrogen in precipitation that falls on vegetated areas may be (1) consumed as a nutrient source in biological and microbiological processes, (2) fixed in the unsaturated zone, and (or) (3) concentrated during evaporation. The extent to which processes occur varies with season.

Twenty metric tons of nitrogen enters ground water yearly by surface runoff to recharge basins. This value was calculated from volume and concentration estimates of nitrogen in water entering recharge basins. An average total nitrogen (as N) value of 5.0 mg/L (V. Minei, Suffolk County Department Environmental Control, written commun., 1976) was used, although total nitrogen concentrations (as N) have been found to be as high as 15 mg/L. The volume of water entering the recharge basins was calculated from (1) 110 cm/yr precipitation, (2) the drainage areas for each basin, as given in Seaburn and Aronson (1973), and (3) the less conservative runoff factors[1/] from Seaburn and Aronson (1974).

[1/] Two sets of runoff factors are given in Seaburn and Aronson (1974). The larger factors reflect conservative engineering estimates; the smaller factors reflect realistic values (D. A. Aronson, oral commun., 1977).

Exfiltration from Sewer Lines

Both infiltration into sewer lines and exfiltration from them occur in Sewage Disposal District 2; however, exfiltration probably exceeds infiltration. Consoer, Townsend, and Associates (1975) estimates that most of the sewage inflow and infiltration in Sewage Disposal District 2 occurs in the southern part of the sewer district, where sewer lines are below the water table (fig. 24). Exfiltration can occur whenever sewer lines are above the water table--predominantly in the northern part of the sewer district.

Exfiltration from sewer lines contributed 200 to 300 metric tons of nitrogen (estimated) in Sewage Disposal District 2 in 1975 (table 13). This value is the difference between the estimated load of nitrogen added to the sewer system in sewage and the load of nitrogen received at the Bay Park sewage-treatment plant (table 14), but includes nitrogen lost through exfiltration from the part of the sewer district that is outside the study area. Inclusion of data for the whole Sewage Disposal District 2 would only slightly increase the load value for the study area because 94 percent of the sewer-district population is within the study area. Input load was calculated from a per-capita value of 5 kg/yr and an estimated population of 586,000 to 603,000 for the entire sewer district for 1975. Influent load to the sewage-treatment plant was calculated from an average total nitrogen concentration of 30 mg/L in the influent (S. A. Fangman, Nassau County Department of Public Works, written commun., 1976) and an influent flow rate of 2.85 m^3/s (Consoer, Townsend and Associates, 1975).

Table 14.--Estimated nitrogen loads of influent to Bay Park sewage-treatment plant.

[All values are in metric tons per year]

Source of data	Load to sewer system	Load to sewage-treatment plant	Difference
This study	1/2900 to 3000	2700	200 to 300
Weston, 1976	2/2900 to 3000	2200	700 to 800

1/Based on minimum and maximum population estimates of 586,000 and 603,000, respectively.

2/Value from this study.

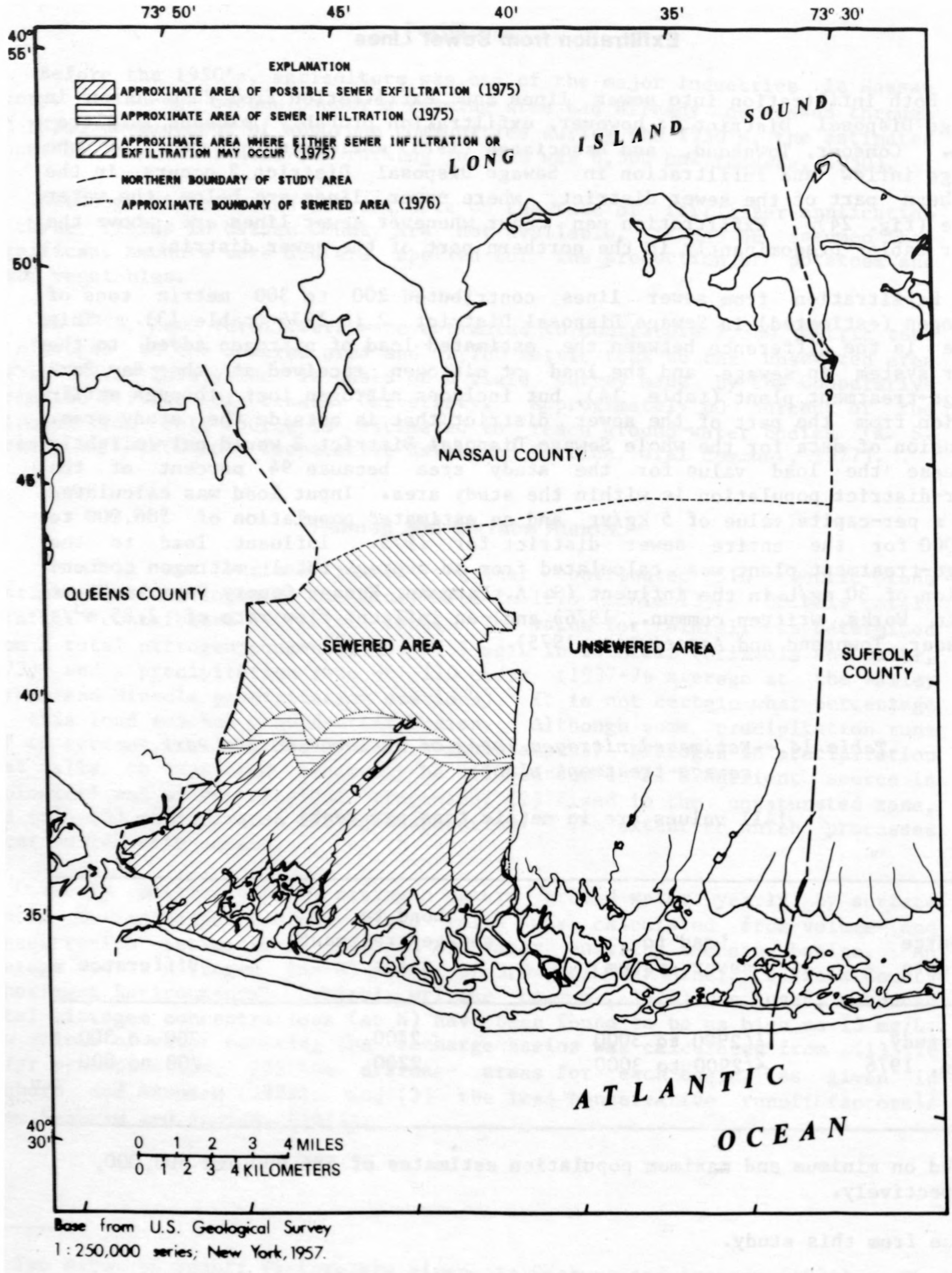


Figure 24.--Approximate areas of sewage infiltration and exfiltration, Sewage Disposal District 2, Nassau County, New York. (Modified from Consoer, Townsend and Associates, 1975.)

The nitrogen-load estimate for exfiltrating sewage is sensitive to differences in the values for flow and nitrogen concentration. Weston Environmental Consultants, Inc. (written commun., 1976) estimates an input load of 2,200 metric tons to Bay Park sewage-treatment plant in 1975. This value is based on an inflow rate of 2.78 m^3/s and, apparently, a total nitrogen concentration of 25 mg/L. The difference between Weston's value and the input load estimated in this report (2,900 to 3,000 metric tons per year) is 700 to 800 metric tons per year, or a 30-percent difference (table 14).

Animal Wastes

Animal wastes, particularly dog wastes, are another source that may contribute nitrogen to ground water (table 13). Ratios of human population to dog population in urban areas (7:1) and in suburban areas (5:1) were used to estimate dog populations in the sewered and unsewered sections of the study area (Beck, 1973). Results indicate there are 89,000 to 124,000 dogs in the sewered area and 80,000 to 112,000 dogs in the unsewered area. An average of 0.27 kg of feces and 0.8 L of urine per dog is produced daily (Suffolk County Soil and Water Conservation District, 1977, p. 9). The average nitrogen content of feces is estimated to be 5.4 percent, and 1.5 percent of urine (Alma Williams, Baker Institute Veterinary Science, Cornell University, oral commun., 1977). Estimated values of nitrogen load from each area, calculated by multiplying dog population by daily waste production and by average nitrogen content of waste, ranged from 740 to 1,040 metric tons of nitrogen per year in the sewered area and 670 to 940 metric tons nitrogen per year in the unsewered area (table 13). Significant nitrogen losses from dog wastes, perhaps as high as 70 percent, may result from volatilization (Porter, 1975).

Nitrogen from dog wastes may enter the ground by way of storm runoff to recharge basins or by direct infiltration. Concentrations of total nitrogen in water entering recharge basins have been found to be as high as 15 mg/L (V. Minei, Suffolk County Department Environmental Control, written commun., 1976), but nitrogen in these waters represents a very small part (about 20 metric tons in table 13) of the total nitrogen load, as described in section "Rainfall and Surface Runoff."

Sewage-Treatment Plants, Incinerators, and Landfills

Sewage-treatment plants, incinerators, and landfills contribute a significant amount of nitrogen to ground water. Locations of major sites in this category are shown in figure 25. The contribution from landfills was estimated (table 13) from data gathered at two landfills, each of about 10 hm^2, that receive general municipal refuse (Kimmel and Braids). The inorganic load from these sites is estimated to be 20 to 40 metric tons /yr. Under anaerobic conditions, which are predominant in most landfills, most of the nitrogen is in the form of ammonium. Ammonium nitrogen may be converted to nitrate downgradient from the site, where the ground-water environment becomes aerobic. Organic nitrogen was found to form only about 1 percent of the total nitrogen load at the test landfills.

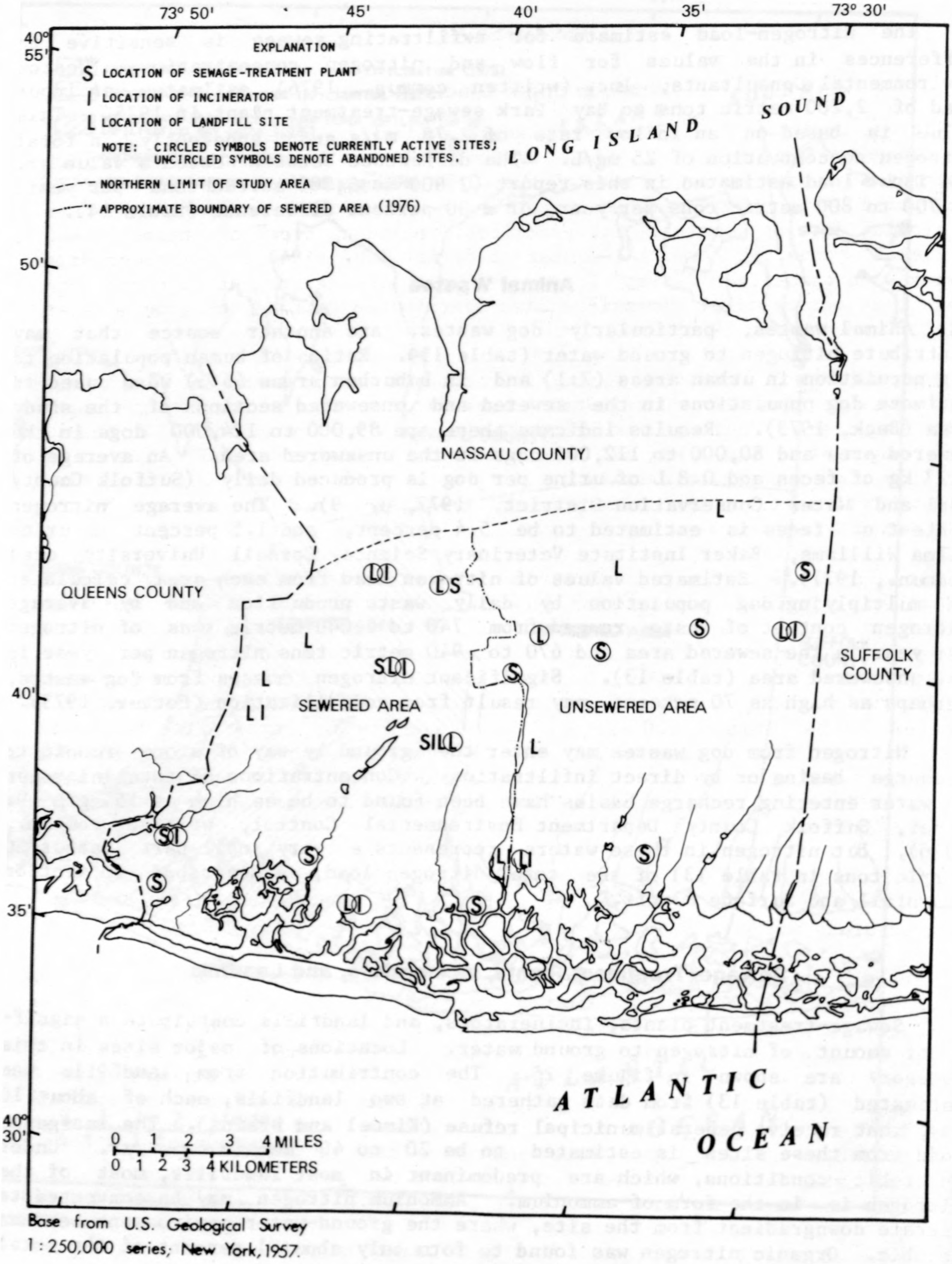


Figure 25.--Location of sewage-treatment plants, incinerators, and landfill sites in study area in 1975.

DISCUSSION

Nitrate in Upper Glacial Aquifer

Nitrate enrichment of the upper glacial aquifer has been taking place for many decades. Before 1950, when agriculture was one of the principal industries in Nassau County, much of the land along the ground-water divide was occupied by farms and small communities. Historical records from 1875 to 1945 provide data on agricultural practices, including types of crops grown, crop yields, acres per farm, and number of farms (Bond, 1947). Although data on types and quantity of fertilizers used are lacking, recent isotope data suggest that agricultural practices have contributed nitrate to ground water (Kreitler and others, 1978).

High volumes of domestic waste discharged to septic tanks and cesspools before sewerage have also contributed large amounts of nitrate to the upper glacial aquifer. Although the first large growth in population in Nassau County began after World War II and continued through the 1960's, areas of relatively high population density of 20 to 40 persons per hm^2 were scattered in the western part of the study area in the 1940's and were common by the 1950's, when sewer installation began.

Although installation of sewers has prevented a relatively large amount of nitrogen in domestic sewage from entering ground water, nitrogen continues to enter from numerous other sources (table 13). Approximately 5,160 metric tons (estimated) of fertilizer nitrogen were used for domestic purposes in the study area in 1975, and other sources, including exfiltration from sewers, rainfall and surface runoff, and animal wastes, contributed an additional load estimated to be from 2,120 to 2,790 metric tons. Landfills may also contribute significant amounts of nitrogen to the upper glacial aquifer because isolated areas having high ammonium concentrations in the sewered area coincide with the locations of landfills and sewage-treatment plants. (Compare figs. 8 and 25.)

The fact that median values of nitrate concentration throughout the upper glacial aquifer do not differ significantly between the sewered and the unsewered areas may result from a variety of causes:

(1) Nitrogen from agricultural fertilizer, or from domestic sewage through cesspools and septic tanks before the advent of sewers, may still be present in ground water throughout the study area. Although the residence time of water in the upper glacial aquifer is estimated to be 25 or 30 years in the shallow subsystem that discharges mainly into streams, it may be much longer in the deep subsystem. Nitrate data on water in shallow wells (less than 3 m below the water table) do, in fact, support this interpretation (fig. 11). Also, nitrogen data on streams indicate that ground water feeding streams in the sewered area is of better quality than that in the unsewered area.

(2) Present additions of nitrogen to ground water from nonsewage origins may mask the effectiveness of sewerage in preventing nitrogen in domestic wastes from entering ground water. These relatively large sources, coupled with imbalances in the hydrologic regimen resulting from the

1962-66 drought and from heavy pumping, probably interfered with the movement of nitrogen through the aquifer and hindered its natural flushing.

(3) The data base may be biased. Data supporting the suggested improvement in water in the shallow part of the upper glacial aquifer do not form a complete record. Before any statistically valid conclusion can be drawn to identify the predominant factors affecting the water quality, more sampling of shallow wells in both the sewered and unsewered areas and streams is necessary. The resulting data should help to establish whether the significant decreasing nitrate trends in ground water in the sewered area will continue and whether water in the shallow part of the sewered area is improving relative to that in the unsewered area. New wells would need to be installed if the present wells are not distributed properly to monitor changes in water quality as a result of sewering.

Nitrate in the Magothy Aquifer

Distribution of areas where the ground water contains more than 0.2 mg/L, 3.0 mg/L, and 10 mg/L of nitrate (as N) within the 123-to 183-m depth interval suggest widespread alteration of water quality near the bottom of the Magothy aquifer (fig. 16). However, these areas may not be as extensive as indicated because most of the data were obtained from public-supply wells that are pumped at about 60 m^3/s for extended periods and may, therefore, produce hydraulic gradients from the water table to beneath the well screen. Few data are available on water in the deeper parts of the Magothy aquifer, which is pumped but little, if at all. Nevertheless, data from a few wells support the assumption that regional water quality has been altered measurably.

Data in figures 14 through 17 suggest that nitrate from man's activities has penetrated the entire thickness of the Magothy aquifer in the area from the ground-water divide halfway to the south shore. Water from the observation wells with significant increasing trends in nitrate concentration form an east-west-trending zone along the center of Nassau County, which suggests a nitrate source from early development and farming near the ground-water divide, where the natural ground-water gradients are downward into the Magothy aquifer. Pumping from deep within the Magothy aquifer has undoubtedly accelerated nitrate enrichment. A cluster of wells having water with unusually high nitrate concentrations near the ground-water divide at the Queens County boundary will be discussed later in this section.

Additionally, chemical data from some wells indicate isolated pockets of anomalously high nitrate concentration, as shown in figures 14 through 16, which suggests vertical movement of nitrate-rich water beyond the ground-water divide area. The slopes of the trend lines in the 61- to 122-m and 123- to 183-m depth intervals of the Magothy aquifer support this observation (figs. 19 and 20). Wells tapping these depth intervals, where slopes of the trends are relatively large--greater than 0.5 mg/L per year in some cases, are clustered generally in the northern part of the study area (figs. 19 and 20).

A good hydraulic connection between the water-table (upper glacial) aquifer and the Magothy aquifer in the central part of the island has been confirmed by water-level data (Kimmel, 1972). Thus, when Magothy wells in this area are pumped, hydraulic gradients are established between the upper glacial aquifer and the well screen. Flow to a well screened in middle depths of the Magothy aquifer under idealized, anisotropic conditions is illustrated in figure 26, in which the ratio of vertical to horizontal hydraulic conductivity is 1:100. Each area (three dimensional) between flow lines leading to the well screen delivers an equal volume of water to the screen; thus, flow in the smaller areas is faster. Substances introduced at the water table within a 610- to 1,220-m radius from the wellhead reach the well screen most rapidly. Although the degree of anisotropy, depth of well screen, and pumping rate significantly affect the time of travel of water from the surface, they do not greatly affect the flowline configuration (Getzen, 1975, figs. 9 and 10).

Regional estimates of traveltime indicate that in the vicinity of the ground-water divide, 50 to 100 years would be required for water to move from the water table to the base of the Magothy aquifer under prepumping conditions (fig. 5). However, the relatively steep hydraulic gradients created around pumping wells would induce a much more rapid movement of surface contaminants, and the 30 years or so that have passed since urbanization began in this region have probably been sufficient to allow water from the water table to move to the base of the Magothy aquifer.

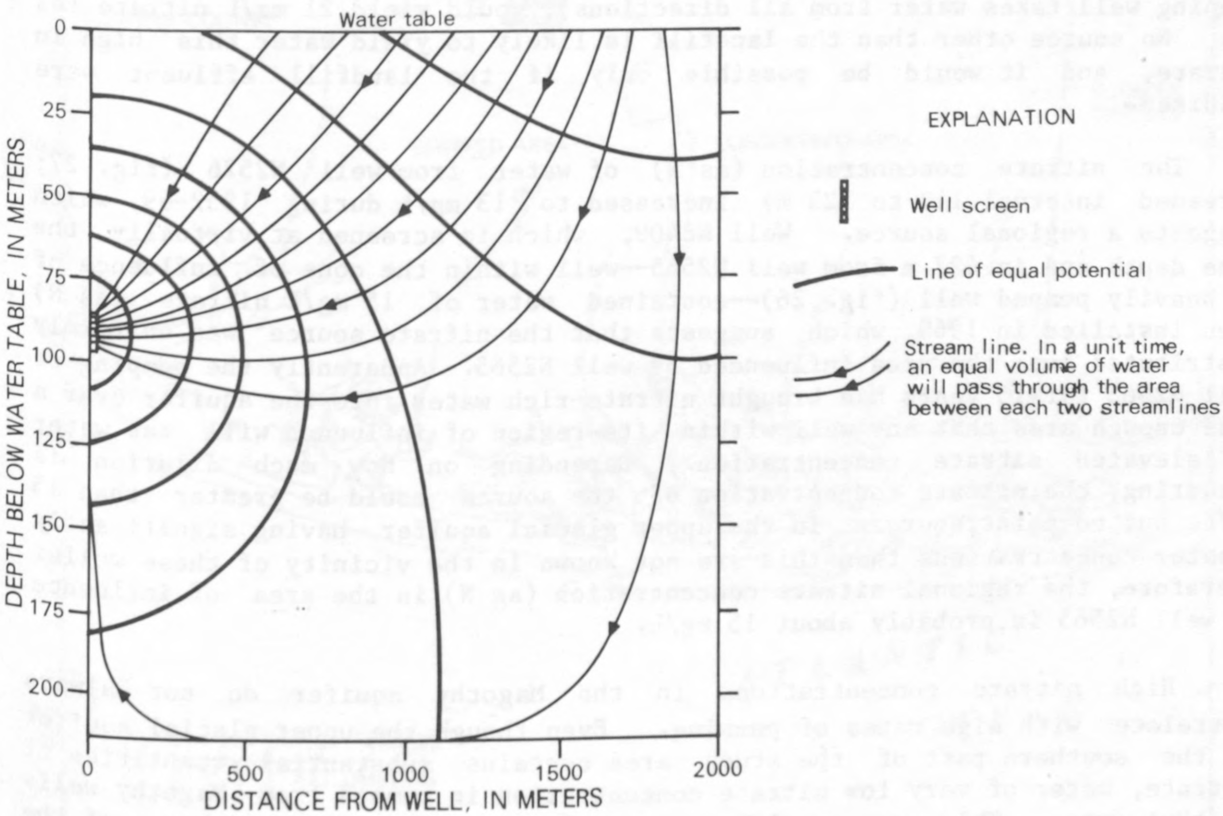
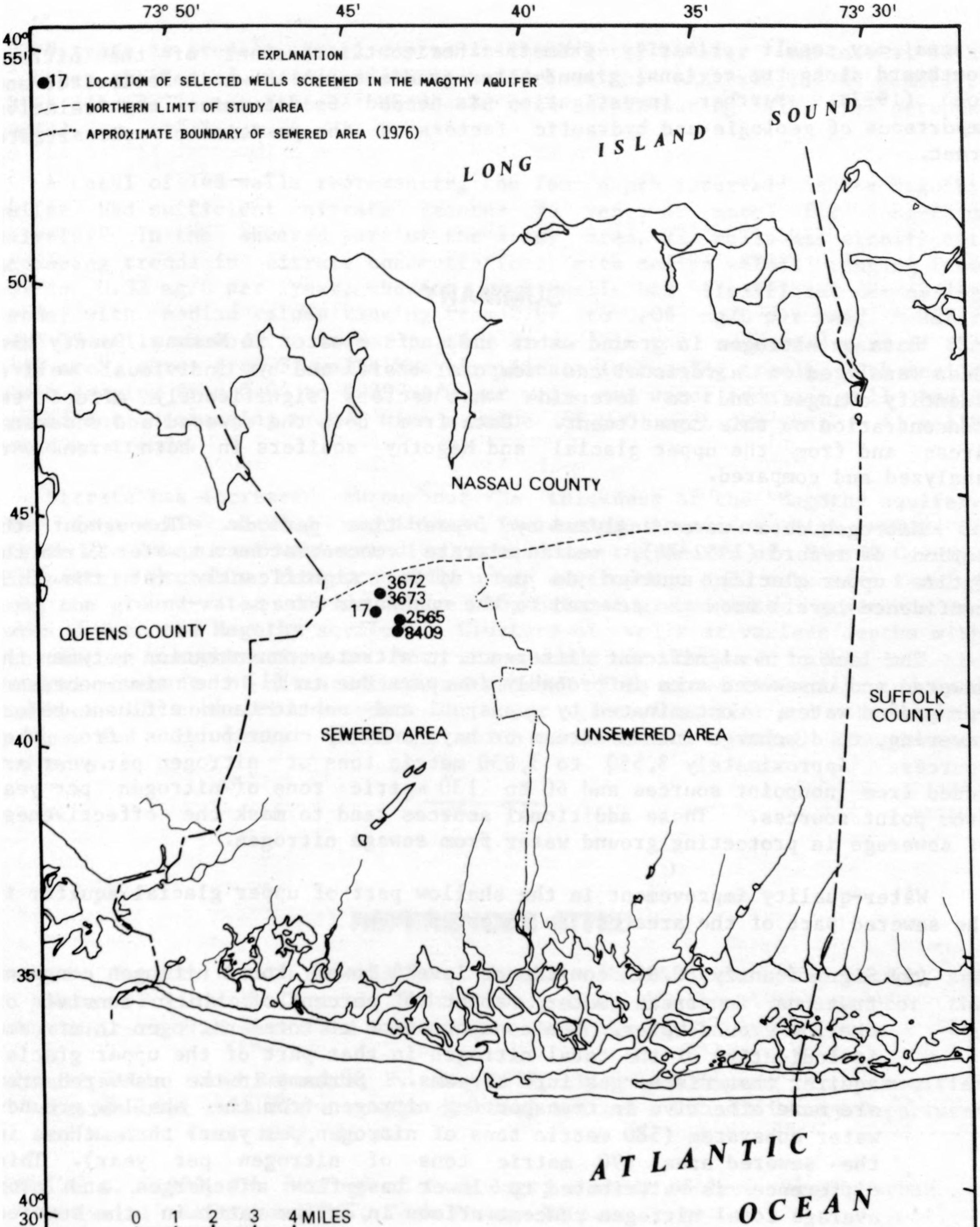


Figure 26.--Steady-state radial flow toward a well screened between 85 and 98 meters below top of an aquifer 210 meters thick. Vertical hydraulic conductivity is 0.2 meters per day; horizontal conductivity is 20 meters per day; pumping rate is 11,000 cubic meters per day. (Modified from Getzen, 1975, fig. 8b).

Although median nitrate concentrations (as N) as high as 24 mg/L have been found in the upper glacial aquifer, concentrations in this range do not seem to be widespread. However, nitrate concentrations in water from some deep wells do suggest a source unusually high in nitrate. Nitrate concentration (as N) of water from wells N3673 (screened interval 119 to 131 m below land surface) increased to 21 mg/L during 1952-70, and at well N2565 (screened interval 113 to 133 m below land surface), nitrate (as N) increased to 13 mg/L during 1952-69. Both of these wells are near the ground-water divide in the sewered area (fig. 27). Water from 10 other wells in this depth interval in the same area does not exceed 9 mg/L nitrate (as N). The nitrate concentration of water from well N3672, 60 m southeast of well N3673 and screened at about the same depth interval, was only 9 mg/L when that from N3673 was 21 mg/L. Even though well N3673 was not pumped after 1970 and pumpage from N3672 was increased, the nitrate concentration of water from well N3672 had stayed the same or decreased slightly by 1975. This pattern suggests a local nitrate source of unusually high nitrate concentration. A landfill about 600 m south of well N3673 could be a source, but it is difficult to explain why water from well N3672 did not also contain high nitrate and why well N17, screened slightly deeper than N3672 and N3673 (fig. 27) and adjacent to the landfill, yields water of only about 7 mg/L nitrate (as N). Nitrogen concentrations of hundreds of milligrams per liter near the surface would be necessary to produce water that, after dilution (as the pumping well takes water from all directions), would yield 21 mg/L nitrate (as N). No source other than the landfill is likely to yield water this high in nitrate, and it would be possible only if the landfill effluent were oxidized.

The nitrate concentration (as N) of water from well N2526 (fig. 27; screened interval 113 to 123 m) increased to 13 mg/L during 1952-69, which suggests a regional source. Well N8409, which is screened at virtually the same depth and is 427 m from well N2565--well within the cone of influence of a heavily pumped well (fig. 26)--contained water of 15 mg/L nitrate (as N) when installed in 1969, which suggests that the nitrate source was uniformly distributed over the area influenced by well N2565. Apparently the pumping of well N2565 for 15 years had brought nitrate-rich water into the aquifer over a wide enough area that any well within its region of influence will tap water of elevated nitrate concentration. Depending on how much dilution is occurring, the nitrate concentration of the source could be greater than 15 mg/L, but nonpoint sources in the upper glacial aquifer having significantly greater concentrations than this are not known in the vicinity of these wells. Therefore, the regional nitrate concentration (as N) in the area of influence of well N2565 is probably about 15 mg/L.

High nitrate concentrations in the Magothy aquifer do not always correlate with high rates of pumping. Even though the upper glacial aquifer in the southern part of the study area contains substantial quantities of nitrate, water of very low nitrate concentration is pumped from Magothy wells in that area. This may result, in part, from the relative thickness of the Magothy aquifer in the southern part of the county, but geologic controls, such as clayey beds, in the southern part of the county may retard downward movement of nitrate-enriched water from the upper glacial aquifer. Thus, nitrate enrichment of the Magothy aquifer in the southern part of the aquifer



Base from U.S. Geological Survey 1:250,000 series; New York, 1957.

Figure 27.--Location of selected wells screened in Magothy aquifer.

system may result primarily from the horizontal movement of the nitrate southward along the regional ground-water gradient, as shown in Perlmutter and Koch (1972). Further investigation is needed to determine the relative importance of geologic and hydraulic factors on the position of the nitrate front.

SUMMARY

Data on nitrogen in ground water and surface water in Nassau County have been analyzed on a regional and temporal basis and by individual well to identify changes and to determine what factors significantly affect the concentration of this constituent. Data from both the sewered and unsewered areas and from the upper glacial and Magothy aquifers in both areas were analyzed and compared.

Nitrogen data were analyzed by 5-year time periods. Throughout the period of record (1952-76), median nitrate concentratons in water from the entire upper glacial aquifer do not differ significantly (at the 0.95 confidence level) from the sewered to the unsewered areas.

The lack of a significant difference in nitrate concentration between the sewered and unsewered area is probably in part due to (1) the time necessary for ground water, contaminated by cesspool and septic-tank effluent before sewering, to discharge into a stream or bay, and (2) contributions from other sources. Approximately 3,550 to 3,850 metric tons of nitrogen per year are added from nonpoint sources and 60 to 130 metric tons of nitrogen per year from point sources. These additional sources tend to mask the effectiveness of sewerage in protecting ground water from sewage nitrogen.

Water-quality improvement in the shallow part of upper glacial aquifer in the sewered part of the area can be inferred from:

(1) Significantly (0.99 confidence level) lower total nitrogen concentrations in stream water, about 95 percent of which consists of shallow ground water. The concentration of total nitrogen in streams is indicative of the total nitrogen in that part of the upper glacial aquifer that discharges into streams. Streams in the unsewered area are more effective in transporting nitrogen from the shallow ground-water subsystem (580 metric tons of nitrogen per year) than those in the sewered area (90 metric tons of nitrogen per year). This difference is attributed to lower base-flow discharges and lower average total nitrogen concentrations in stream water in the sewered area.

(2) Significant long-term decreasing nitrate trends are indicated in 8 of 13 wells with a sufficient period of record.

(3) Near the water table, a small number of wells in the sewered area had significantly lower median nitrate concentrations than in the unsewered area.

Nitrate is present at all depths in the Magothy aquifer (historical data on other species of nitrogen are insufficient for analysis). In general, median nitrate concentration decreased with depth during all time periods studied.

A total of 148 wells representing the four depth intervals in the Magothy aquifer had sufficient nitrate records (15 years or more) for long-term analysis. In the sewered part of the study area, 22 wells had significant increasing trends in nitrate concentrations, with median values ranging from 0.01 to 0.32 mg/L per year, whereas eight wells had significant decreasing trends, with median values ranging from 0.04 to 0.06 mg/L per year. Water from 39 wells showed no trend in this area. In the unsewered part of the study area, water from 37 wells had significant increasing trends, with median values ranging from 0.04 to 0.39 mg/L per year, and water from one well had a significant decreasing trend, with a value of 0.01 mg/L per year. 41 wells showed no trends.

Nitrate has increased throughout the thickness of the Magothy aquifer. Water from wells showing significant increasing trends or high values of nitrate lie in an east-west-trending zone near the center of Nassau County. This pattern probably reflects early urban development and extensive farming along the ground-water divide, where the natural ground-water gradients are downward into the Magothy aquifer. Clusters of wells at various depths with high nitrate concentrations in both the sewered and unsewered areas indicate vertical movement of nitrate-enriched water. This flow is facilitated by a good hydraulic connection between the upper glacial aquifer and the Magothy aquifer and by heavy pumping, which increases vertical ground-water gradients.

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