Geology and Hydrology of Northeastern Nassau County Long Island, New York

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1825

Prepared in cooperation with the Nassau County Department of Public Works and the New York State Water Resources Commission

Geology and Hydrology of Northeastern Nassau County Long Island, New York

By JOHN ISBISTER

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1825

Prepared in cooperation with the Nassau County Department of Public Works and the New York State Water Resources Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 66-241

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D. C. 20402 - Price $2.00 (paper cover)

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GLOSSARY

Coefficient of storage of an aquifer is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface (Ferris, 1962, p. 74).

Coefficient of transmissibility is the product of the field coefficient of permeability and the thickness of the saturated part of the aquifer (Wenzel, 1942, p. 7).

Effluent stream is one which receives water from the zone of saturation (Meinzer, 1923, p. 56).

Field coefficient of permeability is the number of gallons of water per day that percolates under prevailing conditions through each mile of water-bearing bed (measured at right angles to the direction of flow) for each foot per mile of hydraulic gradient (Wenzel, 1942, p. 7).

Influent stream is one which contributes water to the zone of saturation (Meinzer, 1923, p. 56).

Specific capacity is the number of gallons pumped per foot of drawdown in the well.

GEOLOGY AND HYDROLOGY OF NORTHEASTERN NASSAU COUNTY, LONG ISLAND, NEW YORK

By JOHN ISBISTER

ABSTRACT

The ground-water reservoir of Long Island consists of saturated unconsolidated coastal-plain deposits of Cretaceous, Tertiary, and Quaternary ages overlying Precambrian crystalline bedrock. Northeastern Nassau County includes a wedge-shaped part of the reservoir about 112 square miles in extent and ranging from about 400 to 1,300 feet in thickness. The ground water is replenished by precipitation at an estimated rate of 1 million gallons per day per square mile, which is equivalent to about 50 percent of the mean annual precipitation of 45 inches. Losses due mainly to evapotranspiration and, to a small extent, direct runoff account for the remainder of the precipitation.

The ground-water reservoir consists of two major water-bearing units: a principal aquifer that is tapped by a majority of wells in the study area and an underlying deep confined aquifer. The two aquifers are separated by an extensive confining unit of low permeability. The principal aquifer consists of all beds, regardless of geologic age, which occur between the water table and the top of the clay member of the Raritan Formation (Upper Cretaceous). Most of the beds belong to the Magothy(?) Formation (Upper Cretaceous), but locally the aquifer consists in part of Pleistocene deposits which occur as a relatively thin cover or as channel-fill deposits in buried valleys on the Cretaceous surface. Water in the upper part of the aquifer is unconfined (nonartesian); however, in the lower part it is highly confined (artesian). The degree of confinement in the principal aquifer generally increases with depth because of stratification and numerous discontinuous lenses of silt and clay in the unconsolidated deposits.

The deep confined aquifer is composed chiefly of the Lloyd Sand Member of the Raritan Formation (Upper Cretaceous), but locally it consists partly of the Jameco Gravel (Pleistocene). The deep confined aquifer is overlain by the clay member of the Raritan Formation and, locally, by the Gardiners Clay (Pleistocene); it is underlain by impermeable bedrock (Precambrian). The deep confined aquifer is recharged by slow downward leakage through the overlying beds. It is the only source of water for public or domestic supply along parts of the north shore.

The gross withdrawal of about 43 million gallons per day in 1960 was chiefly from the principal aquifer. About two-thirds of the withdrawal was pumped for public supply, and most of the remainder was for industrial use. Agricultural withdrawal was negligible. Most of the pumped water was returned to the ground through recharge basins, diffusion wells, and cesspools, but about 4 million gallons per day was discharged to Long Island Sound as sewage effluent. During the summer and fall, part of the water pumped for public supply is used for domestic lawn sprinkling. Evapotranspiration loss from lawn sprinkling is assumed to be as little as 5 percent of the water pumped or about 2 million gallons per day.

The chemical quality of the ground water is good to excellent, except for some locally high concentrations of nitrate, chloride, and iron.

The ground-water resources of northeastern Nassau County are not fully developed, and withdrawals under present recharge conditions can be increased appreciably, provided that net withdrawals are not increased substantially in adjoining areas. New wells should be constructed mainly in the central and southeastern parts of the area to minimize the danger of salt-water encroachment.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The population and industrial growth of northeastern Nassau County (fig. 1) since 1947, has been accompanied by a substantial increase in the use of ground water. The danger of contamination from domestic and industrial wastes has increased also. The purpose of this report is to describe the hydrologic and geologic characteristics of the ground-water reservoir and to appraise existing or potential ground-water problems. This study is part of a cooperative program to investigate the water resources of Nassau County. The program is sponsored jointly by the U.S. Geological Survey, the New York State Water Resources Commission (formerly New York State Water Power and Control Comm.), and the Nassau County Department of Public Works.

METHODS OF INVESTIGATION

Preliminary phases of the investigation which were begun in 1958 included a review of published and unpublished geologic and hydrologic reports, and an evaluation of basic data in the files of the Geological Survey and cooperating agencies. Fieldwork consisted chiefly of an inventory of new wells, periodic measurement of water levels in selected wells, collection of drillers' logs and samples from new wells, and examination of outcrops in and near the report area. During the spring of 1959, six water-table observation wells were driven in areas where data were not available. In April 1960, 14 test holes were drilled with a power auger to better define the contact between the Cretaceous and Pleistocene rocks and to determine the altitude of the water table. Permanent observation wells were installed in nine of the augered holes. In 1961, a deep test hole was drilled to bedrock at Bayville. Two observation wells were installed in the hole and two additional wells in a second test hole a few feet away (pl. 1). Chemical analyses of water samples from wells were made by the Branch of Quality of Water, U.S. Geological Survey.

PREVIOUS INVESTIGATIONS

The geology and ground-water resources of Long Island have been described in reports by Burr, Hering, and Freeman (1904), Veatch,

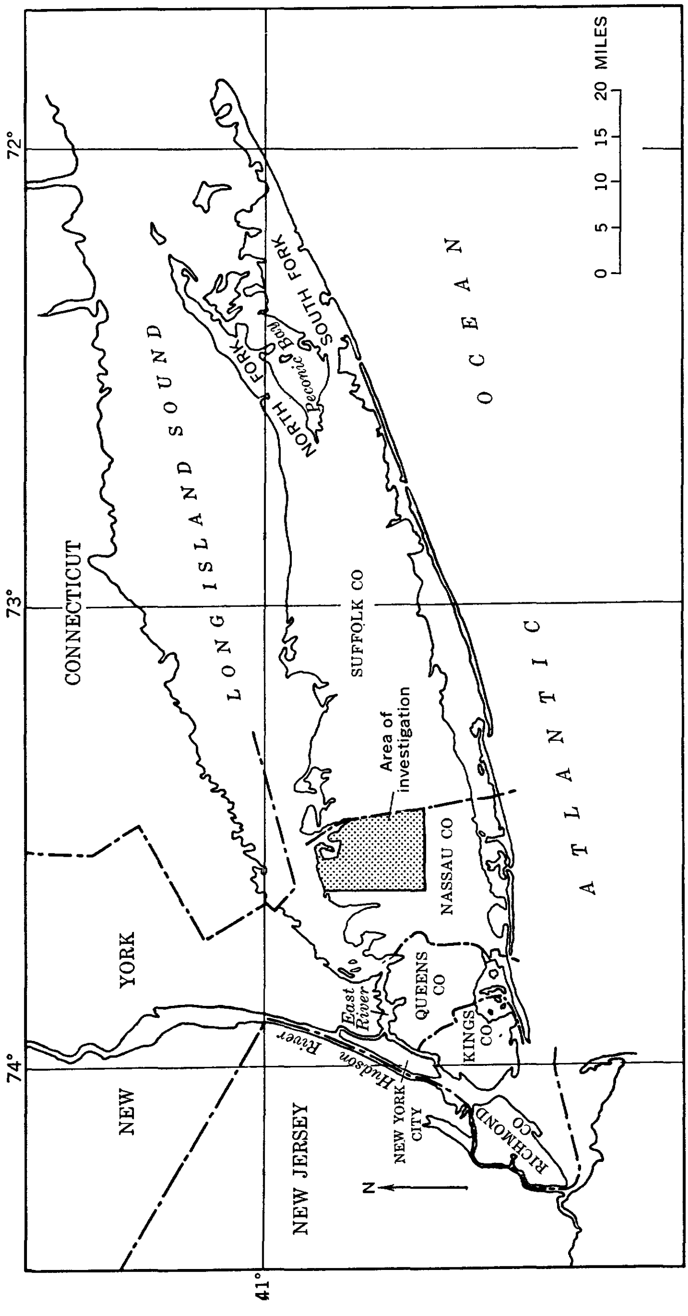

FIGURE 1.—Area of investigation.

Slichter, Bowman, Crosby, and Horton (1906), Crosby (1910), Spear (1912), Fuller (1914), and Suter, de Laguna, and Perlmutter (1949). These reports, although mostly islandwide in scope, contain information pertinent to the report area. Maps of the water table in Long Island (Jacob, 1945a; Lusczynski, 1951) show conditions in the report area in earlier years. Contour maps of the piezometric surface of the Lloyd Sand Member of the Raritan Formation in western Long Island were compiled by Lusczynski (1949a, 1952).

The bedrock surface has been mapped by de Laguna and Brashears (1948) and by Suter, de Laguna, and Perlmutter (1949). Records of wells, geologic correlation tables, and data on ground-water withdrawal are given in bulletins of the New York State Water Resources Commission, formerly the New York State Water Power and Control Commission (see "References cited"). Detailed areal studies in northwestern Nassau County by Swarzenski (1963), in southern Nassau County by Perlmutter and Geraghty (1963), and in northwestern Suffolk County by Lubke (1964) provide hydrologic and geologic information on adjoining areas. DeLuca, Hoffman, and Lubke (1965) compiled records of chloride concentrations and temperatures of water in wells in Nassau County; and reports by Wistoft, Barnell, and Crandell (1958), Isbister (1959), and Barnell and DeLuca (1961) contain water-level records and related hydrologic data. Additional basic data on northeastern Nassau County are given in an open-file report (Isbister, 1963).

ACKNOWLEDGMENTS

The author expresses his appreciation for the generous assistance and the data received from many individuals and public agencies. Records of wells and test borings, water levels, and precipitation data were made available by the Nassau County Department of Public Works. Records of chemical analyses were furnished by the Nassau County Department of Health. The author is particularly indebted to Eugene F. Gibbons, Commissioner, W. Fred Welsch, former Senior Engineer, and Henry L. Frauenthal, Hydraulic Engineer, Nassau County Department of Public Works, and to Arthur H. Johnson, Associate Hydraulic Engineer, New York State Water Resources Commission, for their cooperation and support, C. W. Lauman & Co., Layne-New York Co., Mathies Well and Pump Co., and Eastern Well and Equipment Co., and other drillers made available well logs, cores, drill cuttings, and water-level data. Many water districts made their wells available for measurements of water levels and ground-water temperature. Climatological and streamflow data were supplied by the Branch of Surface Water, U.S. Geological Survey.

Fieldwork was begun under the supervision of George C. Taylor, Jr., former district geologist. The report was prepared under the immediate supervision of Nathaniel M. Perlmutter, geologist-in-charge, Mineola subdistrict, and under the general direction of Ralph C. Heath, district geologist, New York District.

WELL-NUMBERING AND LOCATION SYSTEM

Wells on Long Island are numbered serially by county. The number is prefixed by the first letter of the county name; for example, well N6294 in Nassau County. A well number followed by the letter T indicates a test hole, which was neither permanently cased nor screened. A permanent well completed at the site of a test hole has the same number as that of the test hole, but the letter T is omitted from the number. A few test wells drilled prior to the adoption of this numbering system in 1938 have been assigned numbers without the T. Numbers are assigned in sequence by the New York Water Resources Commission as permits to drill are issued and have no relation to the location of the wells within the county.

Most of the wells in this report are shown on the well-location map (pl. 1). The map is divided into 2½-minute quadrangles, each of which is identified by a number and letter, which appear along the margin. Data for wells shown on figure 2, which are not given in this report, are in an open-file report (Isbister, 1963) or are in the files of the U.S. Geological Survey office in Mineola and the New York State Water Resources Commission office in Westbury.

GEOGRAPHY

SIZE AND LOCATION OF AREA

The report area (fig. 1) occupies about 112 square miles in the northeastern third of Nassau County and is about 9 miles wide and 13 miles long. It is bounded on the north by Long Island Sound, on the east by the Nassau County-Suffolk County boundary line, on the south by lat 40°43′30″ N., and on the west by long 73°37′30″ W.

TOPOGRAPHY AND DRAINAGE

The report area is divided into six morphologic units: (1) the headlands, (2) the Harbor Hill end moraine, (3) the intermorainal pitted outwash plain, (4) the Ronkonkoma terminal moraine, (5) the Wheatley and Mannetto Hills, and (6) the glacial outwash plain. All these units, except the headlands, coincide with geologic units shown on plate 2.

The headlands generally originate in steep bluffs, which rise abruptly from Long Island Sound to a maximum altitude of about 100 feet above sea level. The land surface becomes increasingly irregular in a southerly direction and rises to about 200 feet above sea level near the center of the area. The Harbor Hill end moraine, which consists of an irregular northeast-trending ridge of hills, reaches an altitude of about 300 feet above sea level in the vicinity of Westbury and Wheatley. Near the Suffolk County line the land surface is slightly lower, and the surface of the end moraine is more subdued. Extending south from the Harbor Hill end moraine to the Ronkonkoma terminal moraine is the intermorainal pitted outwash plain. This plain contains numerous small kames and kettle holes, and its rolling surface rises as high as 250 feet above sea level. The Wheatley and Mannetto Hills are treated as a separate unit primarily owing to their different origin. These hills, which rise about 300 feet above sea level, may be erosional remnants of a formerly extensive stream-terrace deposit. A remarkably featureless glacial outwash plain slopes gently from 140 to 160 feet above sea level at the south edge of the Ronkonkoma terminal moraine to about 80 feet above sea level along the south boundary of the report area.

Northeastern Nassau County is drained by north- and south-flowing streams (pl. 1) whose valleys originate in the topographically high area formed by the Ronkonkoma and Harbor Hill moraines and the Wheatley and Mannetto Hills (pl. 2). The streams are generally small in relation to the valleys they occupy. The stream valleys were probably formed under conditions which existed following the retreat of the Harbor Hill ice sheet, and the present streams are a result of the valleys rather than the chief agent which produced them.

The relatively permeable nature of most of the deposits lying at the surface of the report area, permits infiltration of most of the precipitation, with the result that very little runs over the surface. Therefore, the streams are fed almost entirely by ground water, and perennial flow is confined to their lower reaches.

The largest north-flowing streams originate in the Harbor Hill end moraine, except for Cold Spring Brook whose valley and headwaters extend south to the Ronkonkoma terminal moraine. Flow near the head of the valley is intermittent and consists of direct runoff and seepage from perched water bodies. In their lower reaches the stream valleys intersect the water table, and the flow increases toward the mouth.

The south-flowing streams also originate in the morainal area where their flow is intermittent. These streams generally disappear where they flow on the glacial outwash plain (pl. 2). However, in the southern part of Nassau County, beyond the report area, these streams resume flow where their channels intersect the water table.

CLIMATE

Long Island possesses a modified continental climate, which results from the combined influence of prevailing westerly winds and the proximity of the Atlantic Ocean. The major controlling factor is the westerly winds, which cause most weather conditions to approach from the continental land mass to the west. The climate is relatively humid, and temperature extremes are modified by the Atlantic Ocean and to a lesser extent by Long Island Sound.

Strahler's climate classification (1951, p. 344), which is based on air temperature, places Long Island in the temperate climate group. No data on air temperature were available from stations in northeastern Nassau County, but records were obtained from a station at the Rockaway recharge basin in Garden City, about 1 mile west of the report area (fig. 3). Graphs of air temperature in Garden City are shown on figure 2. According to the records at Garden City, the lowest mean monthly temperature is 31.4° F in January, and the highest is 74.9° F in July. Although air temperatures in Garden City are probably characteristic of the central and southern parts of northeastern Nassau County, Long Island Sound probably slightly modifies the air temperature along the north shore.

Mean annual precipitation in northeastern Nassau County is about 45 inches, according to data from four precipitation stations (fig. 3). Blair's (1942, p. 120) system of climate classification designates this amount of precipitation as heavy and the corresponding climate type as humid. An examination of precipitation records from the Garden City station (fig. 3) indicates that precipitation is heaviest in March, July, and August; lightest in January, February, June, and October, and about equal to the monthly average during the remainder of the year. Wet or dry periods may occur at any time. The relation of precipitation to water supply is described in more detail in the section on "Hydrology."

Although local winds resulting from cyclonic and anticyclonic disturbances may blow from any direction, the prevailing winds are from a westerly quadrant. However, along the north shore during the summer, a weak northerly breeze from Long Island Sound may result during the day from a convective circulation caused by rising air over the heated land mass and a southerly breeze in the evening by rising air over Long Island Sound. With the exception of the Great Lakes region, thunderstorms are more frequent in the Hudson Valley and over Long Island than in other parts of New York State. They number from 20 to 30 annually, and usually several are accompanied by hail (Mordoff, 1949, p. 29).

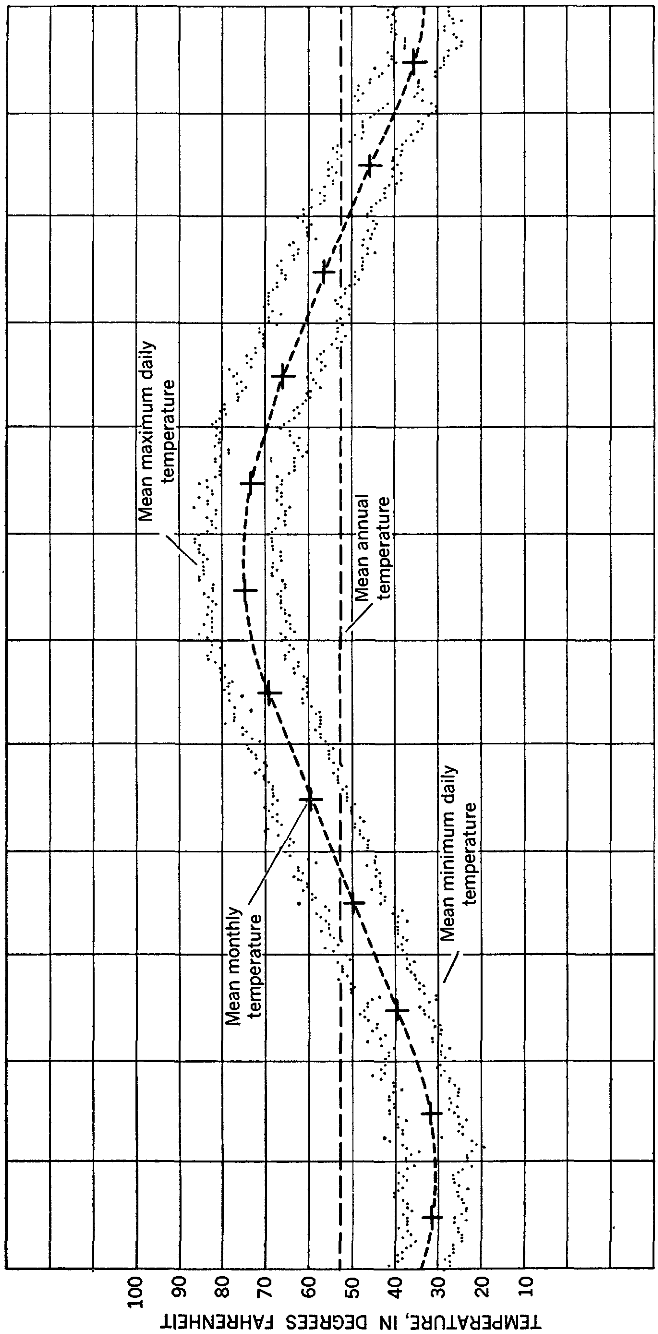

FIGURE 2.—Mean daily maximum and minimum, monthly, and annual air temperature in Garden City, 1938–59.

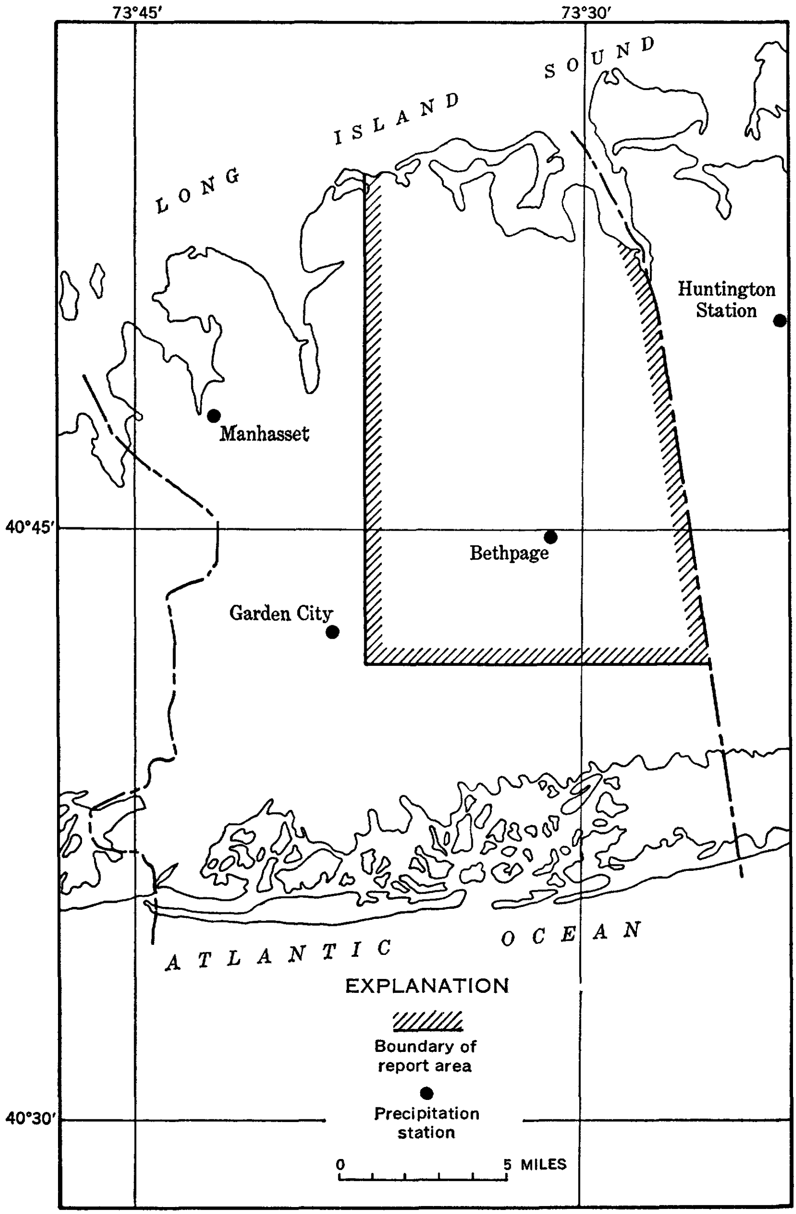

Figure 3.—Selected precipitation stations.

SOILS AND VEGETATION

The soils of northeastern Nassau County are generally sandy or silty loams developed primarily from glacial deposits. Lounsbury and others (1928, p. 13) described and mapped 16 soil types in the report area.

According to their map the Haven Loam and the Sassafrass Loam predominate north of and on the surface of the Ronkonkoma and Harbor Hill moraines (pl. 2). These soils are light brown to brown and consist generally of a surface layer of light loam, 8 inches thick, which is underlain by 22 to 30 inches of heavy loam. Beneath the heavy loam the soil is coarse and gravelly. These soils differ only in occurrence; the Haven Loam occurs on ground that is rolling or has high relief, and the Sassafrass Loam occurs on flatter plain areas.

The Hempstead Loam occurs as one continuous body south of the Ronkonkoma terminal moraine in western Long Island and is the only known area of well-drained dark-colored soil in the United States east of the Appalachian Mountains (Lounsbury, 1928, p. 21). Dark-brown to almost black silty loam, 10 inches thick, constitutes the surface layer of this soil. This rests upon 8 inches of brown to yellowish-brown fine-grained moderately heavy loam and 6 inches of light silty, clayey loam, all of which is underlain by yellow sand and gravel which merges with the underlying outwash deposits. Locally, black sand, peat beds, marsh deposits, and other organic-rich soils occur, but these are of minor importance because of their small areal extent.

The drainage and moisture-retaining properties of a soil depend upon the content of silt and clay and in turn control the type of vegetation that the soil supports. Deciduous forests, small trees, and brush grow abundantly in the till-covered area between the Ronkonkoma terminal moraine and Long Island Sound. South of the Ronkonkoma terminal moraine good drainage from the Hempstead Loam to the underlying permeable outwash deposits results in drier soils, which favor the growth of grass rather than trees and brush.

POPULATION AND INDUSTRY

Since its formation in 1899, Nassau County has experienced a rapid and continuing growth of population. An increasing need for water, especially in densely populated areas and in industrial centers, has accompanied this growth.

Prior to the early 1930's Nassau County was principally either farmland or woodland, and its population was chiefly rural. Population growth up to that time was due to a slow migration of settlers into the area. During the 1930's man's desire to live in the suburbs was made practical by improved transit facilities and roads, and the population began to shift eastward from New York City into Nassau County. Since World War II this population shift, augmented by an influx of industry and large-scale development of low-priced housing, has made Nassau County the fastest growing county in the United States. The population of Nassau County increased nearly twentyfold, from 55,448 in 1900 to 1,300,171 in 1960. School-district reports showed nearly a threefold increase in population in the northeastern part of the county, from 94,438 in 1950 to 250,960 in 1958 (Nassau County Planning Comm., 1959, pl. F). By 1960 the population in that part of the county increased to 275,770 (Nassau County Planning Comm., 1961, table B, pl. 1).

Concentration of population has been generally limited to the areas bordering the route of the Long Island Railroad (pl. 1), especially along the south branch where the relatively flat surface of the outwash plain lends itself more readily to home building and industrial development. Additional as well as improved roads and ease of travel have resulted in some lateral spread of population from the heavily populated areas bordering the railroad; but even in 1960 the north-central and northeastern parts of the report area were largely residential, and population density was much less in these parts. Projected population trends based upon the amount of land available for subdivision, existing zoning requirements, and an assumed average size family of 3.74 persons suggest that by 1975 the population of Nassau County may total about 1½ million persons (Nassau County Planning Comm., 1959, pl. L). The projected population of the report area by 1975 is about 380,000.

Numerous small light manufacturing industries are concentrated mainly as follows: (1) a belt from Mineola to Farmingdale, (2) Glen Cove, (3) Hicksville, (4) Oyster Bay, and (5) Syosset. The Grumman Aircraft Engineering Corp. in eastern Hicksville has the largest industrial plant in the area and employs several thousand workers.

GEOLOGY

SUMMARY OF STRATIGRAPHY

Northeastern Nassau County is underlain by unconsolidated coastal-plain deposits of Cretaceous, Tertiary, and Quaternary age, which overlie igneous and metamorphic rocks of Precambrian age (table 1).

The Cretaceous deposits are composed of interbedded lenses of gravel, sand, silt, and clay, which rest unconformably upon the bed-

209-982—66——2

TABLE 1.—*Summary of stratigraphy and water-bearing properties of the deposits underlying northeastern Nassau County, N.Y.*

System	Series		Geologic unit	Approximate thickness (feet)	Depth from land surface to top (feet)	Character of deposits	Water-bearing properties
Quaternary	Recent		Recent deposits: Artificial fill, salt-marsh deposits, stream alluvium, and shoreline deposits.	0–50	0	Sand, gravel, silt, and clay; organic mud, peat, loam, and shells. Colors are gray, green, black, and brown.	Generally permeable deposits near shoreline and stream-channel deposits may yield small quantities of fresh or brackish water at shallow depths. Clay and silt beneath Long Island Sound and its harbors retard salt-water encroachment and confine water in underlying aquifers.
	Pleistocene	Upper Pleistocene deposits	Harbor Hill drift	0–200	0–50	Glacial till, composed of unassorted clay, sand, and boulders. In Harbor Hill terminal moraine and ground moraine to north. Glacial outwash deposits of stratified brown sand and gravel.	Glacial till, generally low permeability. Causes perched water locally and impedes downward percolation of water to underlying beds. Highly permeable outwash deposits of sand and gravel forms upper part of principal aquifer. Wells screened in outwash deposits yield as much as 1,100 gpm and have specific capacities ranging from 1 to 68 gpm per foot of drawdown. Water is generally unconfined and is of good quality.
			Ronkonkoma drift	0–200	0–200	Glacial till, composed of unassorted clay, sand, and boulders. In Ronkonkoma terminal moraine and buried till sheet. Glacial outwash deposits of stratified brown sand and gravel.	
			Unconformity				
			Gardiners Clay	0–320	100–390	Clay and silt, grayish-green and brown. Some lenses of sand and gravel. Contains scattered shells, Foraminifera, and lignite. Interglacial deposit.	Relatively low permeability. Confines water in underlying Jameco Gravel.
			Unconformity				
			Jameco Gravel	0–185	380–550	Sand, fine to coarse, brown and gravel. May contain boulders, and layers of clay and silt. Probably early glacial outwash deposit. Undifferentiated Pleistocene valley fill consists of sand, gravel, and clay. May be equivalent in part to Jameco Gravel.	Moderately to highly permeable. Wells yield as much as 1,500 gpm. Specific capacities range from 19 to 25 gpm per foot of drawdown. Water is under artesian pressure. Some wells flow. Water usually of good quality but may have high iron content. Forms part of deep confined aquifer.
			Unconformity				

Tertiary(?)	Pliocene(?)	Mannetto Gravel		0–220	0–120	Gravel, fine to coarse, white and brown. Lenses of medium to coarse yellow to brown sand are common.	Highly permeable. Occurs almost entirely above zone of saturation.
		Unconformity					
Cretaceous	Upper Cretaceous	Magothy(?) Formation		0–800	0–350	Sand, fine to medium, clayey, white, gray, pink, and yellow. Interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel common in basal 50 to 100 ft of formation. Lignite, pyrite, and iron concretions are common.	Contains relatively impermeable to highly permeable zones. Wells screened in basal zone yield as much as 1,400 gpm. Specific capacities of wells commonly range from 15 to 30 gpm per foot of drawdown but may be as low as 1 or as high as 83. Principal source for public supply. Water is generally of excellent quality. Degree of confinement increases with depth. Forms most of principal aquifer.
		Unconformity					
		Raritan Formation	Clay Member	0–220	70–900	Clay and silt, gray, red, white, and variegated. Contains few scattered lenses and layers of sand and gravel. Lignite and pyrite are common.	Low permeability. Retards but does not prevent movement of water between the Magothy(?) Formation and the Lloyd Sand Member.
			Lloyd Sand Member	0–270	200–1, 000	Sand, fine to coarse, yellow, white, and gray, and gravel, commonly in clayey matrix. Contains lenses and layers of clay and silt.	Moderately permeable. Wells yield as much as 1,300 gpm. Specific capacities of wells range from 3 to 25 gpm per foot of drawdown. Water is confined under artesian pressure by overlying clay member. Some wells flow. Water is usually of excellent quality but may have high iron content locally. Forms most of deep confined aquifer.
		Unconformity					
Precambrian		Bedrock		?	400–1, 300	Crystalline metamorphic and igneous rocks; *muscovite-biotite schist*, gneiss, and granite. Overlain by a weathered zone of undetermined thickness.	Low permeability. Contains some water in joints and fractures but is impractical to develop. Forms lower boundary of ground-water reservoir.

rock. Two formations of Late Cretaceous age underlie the area. The oldest is the Raritan Formation. The overlying post-Raritan deposits of Cretaceous age have been assigned tentatively to the Magothy Formation but may include some younger formations which have not yet been differentiated in the report area (Perlmutter and Crandell, 1959, p. 1066). Deposits of Tertiary age are represented by the Mannetto Gravel, which the Geological Survey considers to be of Pliocene(?) age (Suter and others, 1949, p. 9). Pleistocene deposits of pre-Wisconsin age are represented by the Jameco Gravel and the Gardiners Clay. Two advances of the ice during the Wisconsin Glaciation account for the till and outwash deposits, which comprise the upper Pleistocene deposits.

Shoreline, marsh, and alluvial deposits of Recent age occur locally along the beaches and in some valleys.

Sections *AA′–CC′* (pl. 3) show the large variations in depth, thickness, and lithology of the geologic units in the report area.

The lithology and correlation of the formations penetrated by a deep well at Plainview are given in table 2. This well was drilled

TABLE 2.—*Log of well N3355 at Plainview, Nassau County*

[Adapted from Perlmutter and Lusczynski (1951).]

U.S. Geol. Survey, Round Swamp Road (map coordinates; 2E, 1.5N, 1.3W). Observation well drilled 1951 by C. W. Lauman and Co. Screen depth 1,070 to 1,090 ft. Altitude of land surface about 180 ft. Geologist's log based upon examination of core samples, electrical log, and driller's log.

	Thickness (feet)	Depth (feet)
Recent deposits:		
Topsoil, loam and gravel (from driller's log)	3	3
Upper Pleistocene deposits:		
Sand, medium to very coarse, brown, and gravel	70	73
Upper Pleistocene deposits and Mannetto Gravel. Pliocene(?):		
Sand, fine to coarse, light-brown, and small amount of gravel	45	118
Sand, medium to very coarse, brown, and gravel; trace of yellow clay at 135 ft	35	153
Magothy(?) Formation:		
Sand, medium to coarse, brown; traces of yellow clay and lignite	11	164
Sand, medium, gray; sandy clay and gray clay in thin layers and lignite particles	22	186
Sand, fine to very fine, clayey, gray and brown with thin layers of gray sandy and solid clay and lignite particles	18	204
Clay, fine to very fine, sandy, gray	21	225
Sand, fine to medium, clayey, gray to brown and some lignite	27	252
Clay, solid, gray	11	263
Sand, medium to coarse, clayey, gray to brown; some thin layers of clay and iron oxide concretions	16	279
Sand, medium, light brown and gray; some fine and coarse sand layers and a few thin sandy clay layers	71	350
Clay, solid, gray	12	362
Sand, medium to coarse, gray; some fine sand; thin layers of gray clay; clayey sand and lignite	51	413

TABLE 2.—*Log of well N3355 at Plainview, Nassau County*—Continued

	Thickness (feet)	Depth (feet)
Clay, solid, gray	9	422
Sand, medium, gray; some lignite and gray clay	16	438
Clay, dark gray; some pyrite	29	467
Sand, medium to coarse, grayish-brown; some fine gravel and a few thin clay layers	9	476
Clay, gray	14	490
Clay, silty, gray, with some fine sand in thin lignitic layers	14	504
Sand, very fine to fine, clayey, gray, and some thin layers of solid gray clay and sandy clay	50	554
Sand, fine to medium; some silt and thin layers of solid clay	31	585
Sand, medium to coarse, gray	44	629
Sand, fine to medium, gray and pink; yellow and white clay	12	641
Sand, fine to coarse, white; fine to medium gravel and some white clay	18	659
Sand, fine to medium, clayey; layers of solid and sandy clay and some layers of coarse sand and gravel	65	724
Sand, medium to coarse, gray; fine to medium gravel and some white sandy clay	14	738
Sand, fine to medium, clayey, gray; some layers of sandy clay	12	750
Sand, medium to coarse, gray and brown, mixed with some gray clay and thin layers of solid clay	35	785
Raritan Formation:		
Clay Member:		
Clay, solid, silty, light- and dark-gray; some thin layers of fine sand, lignite, and pyrite	82	867
Clay, silty, sandy, and solid, gray; some lignite and pyrite	16	883
Clay, solid, gray, red, and brown, layers of lignite and pyrite	70	953
Lloyd Sand Member:		
Sand, fine to medium, clayey, gray, and gray sandy clay	14	967
Sand, medium, clayey, gray and brown	20	987
Sand, medium to coarse and gray; some fine gravel and white sandy and solid clay	23	1,010
Sand, solid, gray and tan, thin layers of medium to coarse clayey, gray and brown sand and fine gravel	8	1,018
Sand, fine, clayey, gray, and gray clayey sand	17	1,035
Sand, medium to coarse, gray; some white and gray clay and fine to medium gravel	22	1,057
Sand, fine, clayey, gray; some thin brown streaks of medium, clayey sand	11	1,068
Sand, medium to coarse, gray and brown; some fine to medium gravel; thin layers of solid gray clay and fine to medium clayey sand	28	1,096
Clay, sandy	6	1,102
Sand, medium to coarse, clayey, white; some gravel and gray sandy clay in layers	26	1,128
Sand, fine, clayey	4	1,132
Sand, medium to coarse, white; some gravel and thin gray clay layers	6	1,138
Clay, sandy	4	1,142
Sand, fine to medium, clayey, gray, white and brown; some gravel and sandy clay in thin layers	74	1,216
Precambrian:		
Weathered bedrock (top of weathered zone uncertain)	30	1,246

to a depth of 1,246 feet through deposits of Pleistocene, Tertiary, and Cretaceous ages and partly into weathered bedrock of Precambrian age.

BEDROCK

Bedrock of Precambrian age underlies the unconsolidated sediments. A map of the bedrock surface based chiefly on scattered records of wells is given in Suter, de Laguna, and Perlmutter (1949, pl. 8). Logs are available for wells N119 and N120 in Locust Valley, N3355 in Plainview, and N7152 in Bayville which penetrate bedrock in the report area.

The upper part of the bedrock is decomposed or chemically altered, except possibly in some of the buried valleys along the north shore where the weathered zone may have been completely eroded during Pliocene or Pleistocene time. The weathered zone ranges in thickness from 5 feet to more than 100 feet, and a gradual transition from decomposed to fresh rock has been observed in core samples from a few wells in Nassau County. Well N7152 at Bayville (pl. 1) penetrated 17 feet of weathered bedrock without entering fresh rock; well S21119T, at West Neck in northwestern Suffolk County, about 1 mile east of the study area, penetrated 51 feet of weathered rock. The rock at both wells is weathered biotite schist. The weathered bedrock is composed chiefly of angular quartz and weathered biotite, chlorite, feldspar, and fragments of partly decomposed rock in a clay matrix.

The altitude and configuration of the bedrock surface are shown on figure 4 by contours that are controlled partly by data at four wells in the report area and partly by extrapolation of data from adjoining areas. The highest altitude of the bedrock surface is about 400 feet below sea level at the north shore near Lattingtown and Bayville; the lowest is about 1,200 feet below sea level in the extreme southeastern part of the report area near Farmingdale. The bedrock surface dips about 80 feet per mile to the southeast.

The displacement in the −500-foot contour near Bayville represents a north-trending buried valley, the presence of which is inferred chiefly from data on buried channels in the overlying deposits. If the valley trends north as the data imply, then it must also deepen to the north. Because the bedrock surface rises to the northwest, it follows that the bedrock surface and the valley must at some place intersect. Similar valleys are eroded into the bedrock in northwestern Nassau County and in northwestern Suffolk County. Existing information is generally too scanty to delineate all the erosional features and minor irregularities which undoubtedly exist on the surface of the bedrock.

The bedrock is not a source of water but forms the virtually impermeable base of the ground-water reservoir. The porosity of the rock, including joints and fractures, is probably less than 1 percent.

UPPER CRETACEOUS SERIES

The Upper Cretaceous Series consists of unconsolidated interbedded sand, gravel, silt, and clay that rest unconformably upon the bedrock.

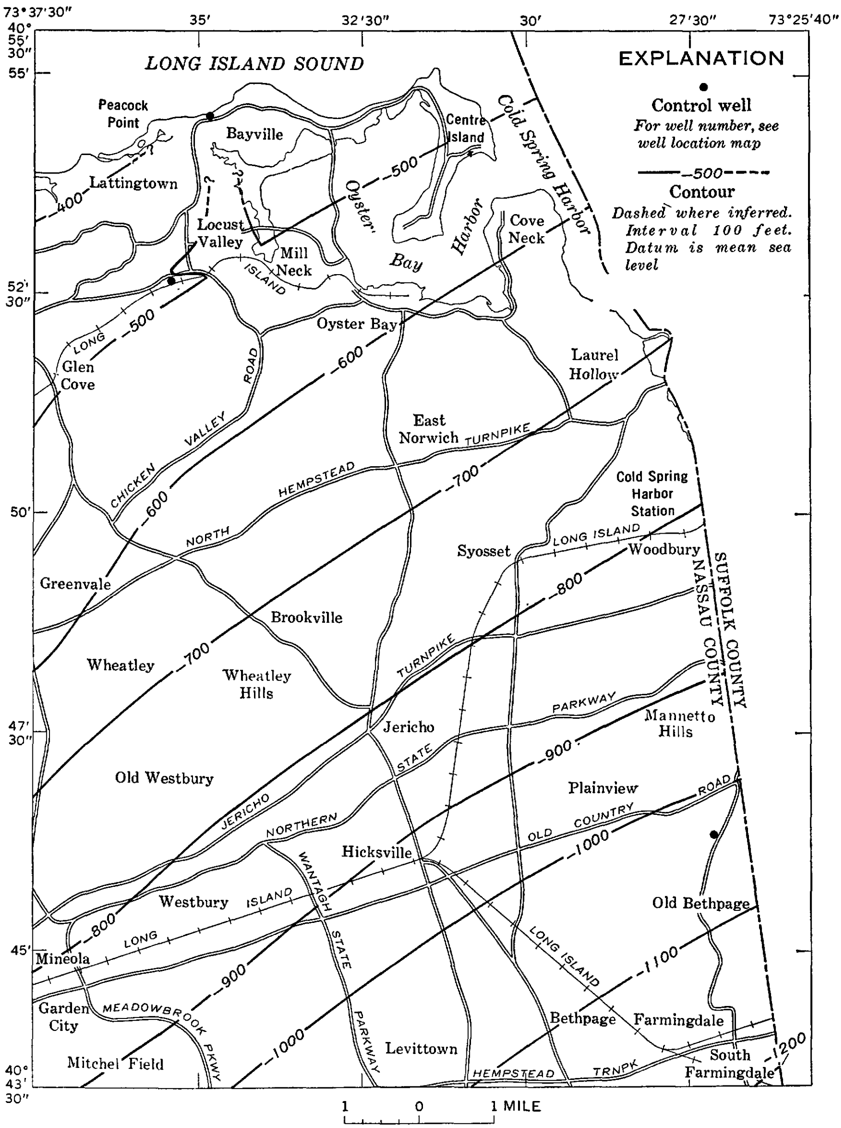

FIGURE 4.—Contours on the bedrock surface.

The lithology of these deposits commonly varies within a short distance both horizontally and vertically; however, two formations of continental origin have been identified: (1) the Raritan Formation, which is divided into the Lloyd Sand Member and an unnamed clay member, and (2) the Magothy(?) Formation.

RARITAN FORMATION

LLOYD SAND MEMBER

The Lloyd Sand Member rests unconformably upon the weathered bedrock and is overlain in most of the area by the clay member of the Raritan Formation. The Lloyd Sand Member extends to the north an unknown distance beneath Long Island Sound, where it is covered either by the clay member or by deposits of Pleistocene and Recent age.

The Lloyd was removed by stream erosion in post-Cretaceous time in some deep buried valleys near the north shore, as at Locust Valley and Cove Neck (fig. 5). However, the data are too scanty to define the configuration of these valleys accurately. The upper surface of the Lloyd ranges from about 200 feet below sea level at Peacock Point in Lattingtown to 900 feet below sea level at South Farmingdale. The Lloyd dips about 60 feet per mile to the southeast and ranges from about 200 to 250 feet in thickness in most of the area.

The Lloyd Sand Member is a stratified deposit, comprising discontinuous layers of sand, gravel, sandy clay, silt, and clay. The sand and gravel beds are composed of yellow, white, and gray quartz, with a few percent of chert and other stable minerals. The quartz grains are angular to subrounded and the beds at some places contain varying amounts of interstitial clay. Lenses of white, gray, and buff silt and clay are common. Lignite occurs as scattered particles in beds of sand and clay and in thin layers.

Despite its relatively high clay content, the Lloyd Sand Member is a productive aquifer in Nassau County. On the basis of data from a pumping test in southern Queens County, Jacob (1941, p. 783–787) reported a coefficient of transmissibility of 190,000 gpd per ft (gallons per day per foot), a field coefficient of permeability of 900 gpd per sq ft, and a coefficient of storage of 0.0003. A reevaluation of the original pumping-test data by N. J. Lusczynski (oral commun., 1962), using the leaky-aquifer equation (Jacob, 1946), suggests that the transmissibility and permeability may be about 100,000 gpd per ft and 500 gpd per sq ft, respectively. A coefficient of permeability of about 500 gpd per sq ft was computed from data obtained from a brief pumping test in southern Nassau County (N. J. Lusczynski and W. V. Swarzenski, written commun., 1962). Because of generally similiar lithology in the Lloyd throughout Nassau County, these coefficients are assumed to apply to the Lloyd in the report area. Table 3 gives field coefficients of permeability for the Lloyd Sand Member based on approximate coefficients of transmissibility estimated from specific capacities (Bentall, 1963, p. 331–340) of five public-supply wells and an assumed storage coefficient of 0.0003. Transmissibilities obtained

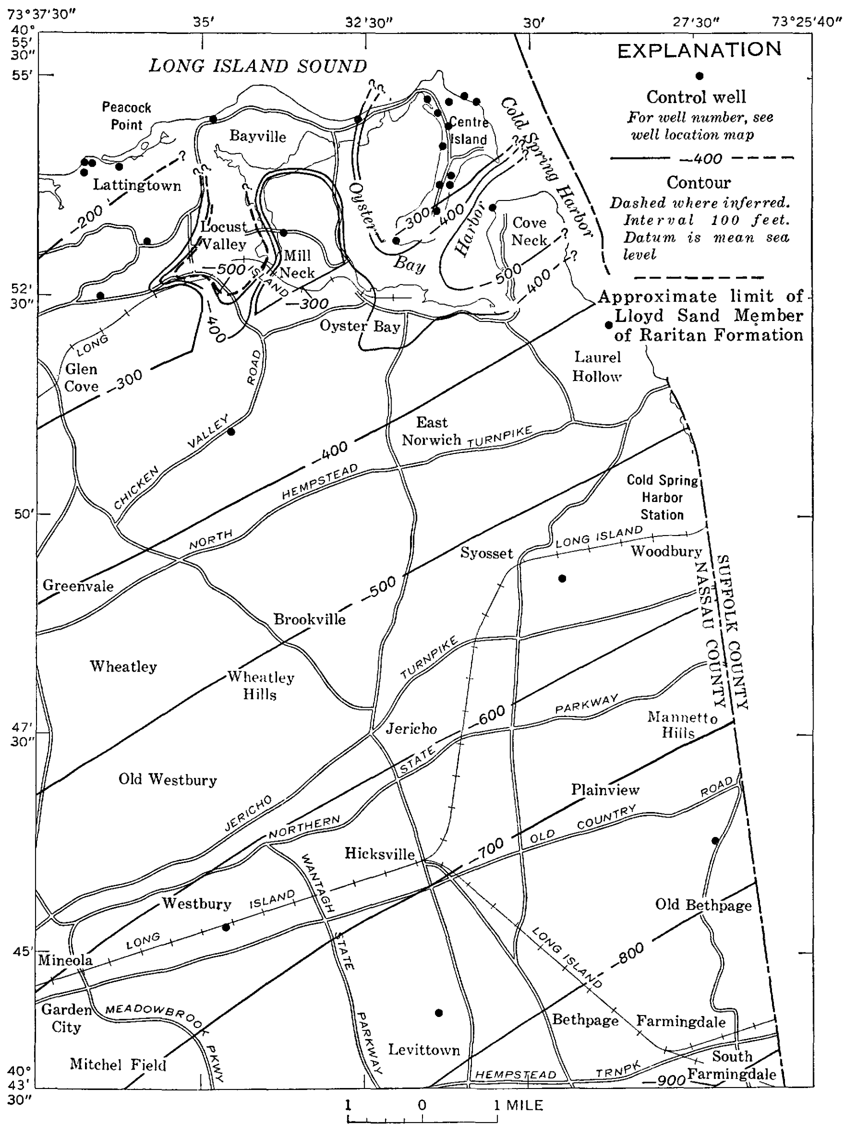

FIGURE 5.—Contours on the upper surface of the Lloyd Sand Member of the Raritan Formation.

by this method are probably lower than actual values because of the combined effects of partial penetration of the aquifer, possible head loss in the annular space, head loss due to turbulent flow in the aquifer near the screen, screen entrance loss, and other frictional losses inside the casing. It is possible that the permeability values in table 3 for wells N2602 and N5152 are low because the effective aquifer thickness may be less than the total formation thickness. However, available data are insufficient to substantiate this assumption.

TABLE 3.—*Hydraulic coefficients of the Lloyd Sand Member of the Raritan Formation in northern Nassau County*

Well	Screen depth (feet below land surface)	Specific capacity (gpm per ft)	Coefficient of transmissibility (gpd per ft)	Estimated thickness of aquifer (feet)	Field coefficient of permeability (gpd per sq ft)
N109 [1]	432-442, 464-524	20	50,000	128	400
1651	385-465	24	60,000	210	300
2602	760-800	11	20,000	230	100
5152	305-355	11	20,000	220	100
5201 [1]	434-504	27	60,000	126	500

[1] Well in northwestern Nassau County (Swarzenski, 1963, pl. 1).

An appraisal of the scanty data on the Lloyd in and near the report area suggests that the average horizontal permeability of the formation is about 400 gpd per sq ft.

Most of the wells screened in the Lloyd in the report area are used to supply estates and small homes and have a relatively low yield and capacity. The wells are at and near the north shore and on Centre Island where an adequate supply of good-quality water is generally unobtainable from shallower beds.

CLAY MEMBER

The clay member of the Raritan Formation rests on the Lloyd Sand Member. It is overlain nearly everywhere by the Magothy(?) Formation and locally by the Gardiners Clay and undifferentiated deposits of Pleistocene age (pl. 3). The clay member underlies most of the project area and extends an unknown distance to the north beneath Long Island Sound (fig. 11). It is missing in some deep buried valleys near the north shore (pl. 3) and probably beneath parts of Long Island Sound due to post-Cretaceous erosion.

The top of the clay member is generally parallel to the underlying Lloyd Sand Member and dips about 60 feet per mile to the southeast. The upper surface of the clay member (fig. 6) is thought to have low relief, except in the vicinities of Oyster Bay and Locust Valley, where it has been eroded and is entirely removed locally. At Lattingtown in the northwestern part of the project area, the top of the clay member

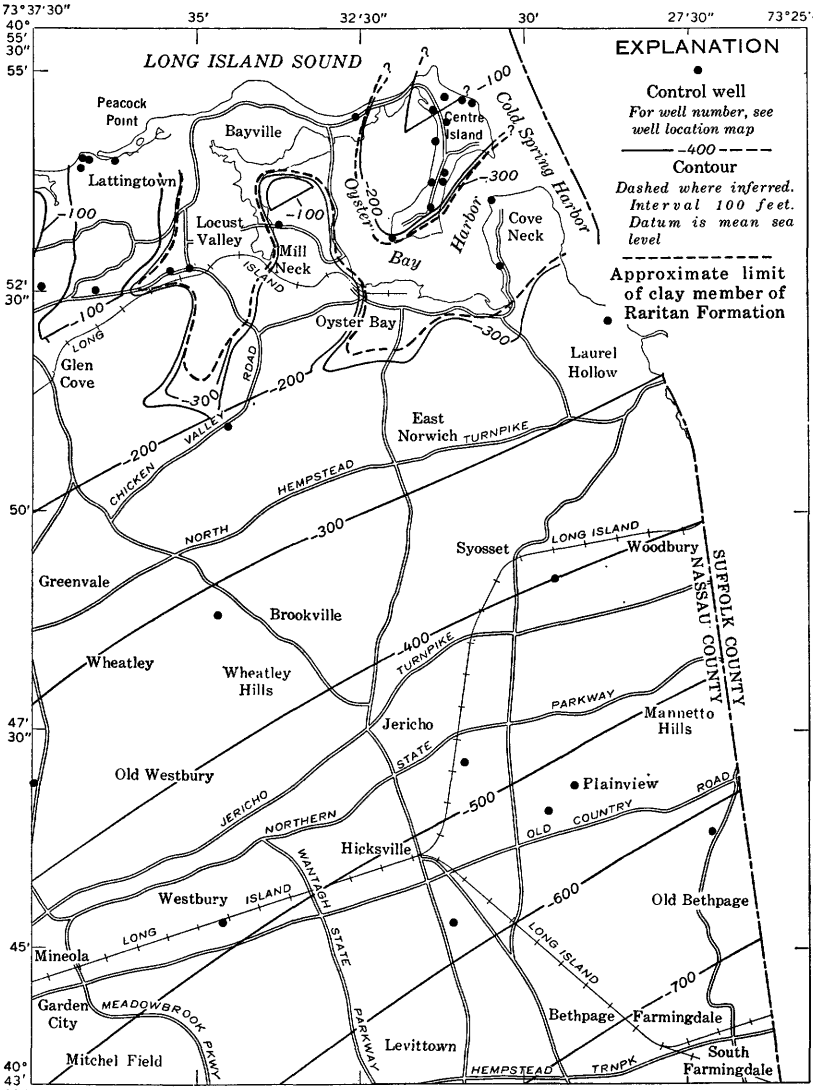

Figure 6.—Contours on the upper surface of the clay member of the Raritan Formation.

is only about 70 feet below sea level; and in South Farmingdale to the southeast, it is more than 700 feet below sea level. The thickness of the clay member in the report area ranges from 0 to about 200 feet and averages about 150 feet.

The clay member is composed chiefly of gray, red, white, and blue clay and silty clay and lenses of sand and gravel. Lignite and pyrite are common. The permeability of beds of clayey silt may be as low as 0.0002 gpd per sq ft (Wenzel, 1942, p. 11). Because of its extent and relatively low permeability, the clay member constitutes an effective confining unit for most of the Lloyd Sand Member.

MAGOTHY(?) FORMATION

The Magothy(?) Formation rests unconformably upon the Raritan Formation. The Magothy(?) underlies most of the area, but has been completely removed by erosion locally in the northern part (pls. 3–4). The formation is overlain by the Mannetto Gravel of Pliocene(?) age and deposits of Pleistocene age and is underlain by the clay member of the Raritan Formation.

The upper surface of the Magothy(?) ranges from about 100 feet below sea level to more than 200 feet above sea level. The highest altitudes occur on a northeast-trending buried ridge (pl. 4), which approximately underlies the Ronkonkoma terminal moraine. The formation crops out in a few places along the north shore, in scattered building excavations, highway and railroad cuts, and in the clay pits at Bethpage. The upper surface of the Magothy(?) has been extensively eroded and has as much as 300 feet of relief. Deep buried valleys are cut completely through the Magothy(?) Formation in the northern part of the area. Similar deep buried valleys were reported in northwestern Nassau County (Swarzenski, 1963) and in northwestern Suffolk County (Lubke, 1964). Probably a modified rectangular drainage pattern developed originally on the Magothy(?) surface. Subsequent streams eroded valleys parallel to the strike of the formation in less resistant beds, and the more resistant beds remained as ridges or cuestas. The present-day harbors of the north shore were probably cut largely by north-flowing streams and later were modified by glacial ice.

The Magothy(?) Formation in northeastern Nassau County ranges in thickness from 0 to 800 feet. The stratigraphic relations and variations in lithology and thickness of the Magothy(?) Formation are indicated on the geologic sections (pl. 3).

The lithology of the Magothy(?) is known almost entirely from well logs and samples of the formation collected during the drilling of wells inasmuch as the formation crops out only in a few places. The formation consists chiefly of interbedded gray, buff, and white fine sand and clayey sand and black, gray, white, buff, and some red clay. Gravelly zones are common near the bottom of the formation but are rare in the upper part. Angular to subangular quartz is the chief mineral in the sandy beds and is accompanied by varying amounts of clay minerals, chert, muscovite, and a small percentage of dark heavy minerals. Lignite and pyrite have been observed in many samples, and cemented concretionary layers of quartz and iron oxide are common.

The productive water-bearing zones in the Magothy(?) Formation consist of thin zones of sand and gravel, which occur at various depths as scattered, discontinuous lenses in the predominantly fine-grained material, and a thicker more extensive coarse-grained zone near the base of the formation. The basal coarse-grained zone is extensively distributed in the southern part of the area, but it is apparently not as extensive in the northern part. The basal zone is composed of coarse quartz sand and gravel, varying amounts of interstitial clay, and some layers of clay and sandy clay. The basal zone is usually less than 100 feet thick, and in some places it is very thin or entirely absent. Some wells, which tap the basal zone, yield as much as 1,400 gpm. Specific capacities of these wells generally range from about 15 to 45 gpm (gallons per minute) per foot of drawdown and in places are as high as 67 gpm per foot of drawdown.

Laboratory determinations of the porosity and permeability of six samples of sand from the Magothy(?) Formation obtained from wells drilled in the village of Hempstead, about 3 miles south of the project area, were made in 1938 by the hydrologic laboratory of the U.S. Geological Survey in Washington, D.C. The porosity ranged from 32 to 41 percent and averaged 38 percent; the permeability ranged from 500 to 1,450 gpd per sq ft and averaged 950 gpd per sq ft. The tests were made on disturbed, and in some cases washed samples, so these values are probably somewhat higher than those of the material in place. N. J. Lusczynski (written commun., 1962) reported permeabilities of 200 to 1,100 gpd per ft from pumping tests in wells screened in permeable zones of the Magothy(?) Formation in southern Nassau County and suggested that the permeability of some beds may be as high as 2,000 gpd per sq ft.

Field coefficients of permeability based on estimated thicknesses of water-bearing zones in the Magothy(?) Formation and computed from specific capacities of selected wells in the report area (table 4), type curves developed by A. F. Meyer (in Bentall, 1963, fig. 100), and an assumed coefficient of storage of 0.0005 range from about 600 to 1,200 gpd per sq ft and average about 1,000 gpd per sq ft. These values are considered low because field conditions depart from the ideal assumptions of Meyer's method. An average permeability value for the entire formation thickness would be considerably lower because the supply wells for which specific capacities are known are open only to the more permeable zones of the Magothy(?) Formation. The thicknesses of the water-bearing zones in table 4 were estimated from an appraisal of electric logs, drillers' logs, and logs based on core descriptions.

TABLE 4.—*Hydraulic coefficients of selected zones in the Magothy(?) Formation in northeastern Nassau County*

Well	Screen depth (feet below land surface)	Specific capacity (gpm per ft)	Coefficient of transmissibility (gpd per ft)	Estimated thickness of water-bearing zone (feet)	Field coefficient of permeability (gpd per sq ft)
N198	567–617	36	80,000	70	1,200
3474	452–512	31	70,000	70	1,000
4246	403–453	32	70,000	100	700
6076	296–358	41	90,000	70	1,200
6092	561–631	49	120,000	110	1,100
6191	390–489	36	80,000	130	600
6651	560–610	27	60,000	60	1,100
6915	422–475	45	100,000	90	1,100
6956	514–545, 566–597	42	90,000	110	800

Perlmutter and Geraghty (1963) used an average porosity of 25 percent and an average permeability of 500 gpd per sq ft in computing the velocity of ground water in the Magothy(?) Formation in southern Nassau County. On the basis of data from laboratory and field tests and a general appraisal of the thickness and lithology of the Magothy(?), it is estimated that the average permeability of the entire Magothy(?) Formation in the report area is about 500 gpd per sq ft.

PLIOCENE SERIES

The only formation in the report area which has been tentatively assigned to the Pliocene Series of the Tertiary Period is the Mannetto Gravel. Some nonmarine deposits, which occur as valley fillings in the northern part of the area, may also be of Pliocene age, but the data are inconclusive. All these deposits of doubtful age have been designated undifferentiated deposits of Pleistocene age.

MANNETTO GRAVEL

The Mannetto Gravel of Pliocene(?) age (Suter and others, 1949, p. 9) is believed to be a stream-terrace deposit, which caps the Wheatley and Mannetto Hills (pl. 2). The strata are composed of undisturbed nearly horizontal beds of sand and gravel. The chief distinguishing features of the beds are their stratigraphic position, altitude, pronounced crossbedding, certain superficial features of the gravel, and the degree of weathering of the gravel and boulders. The Mannetto rests unconformably on the Magothy(?) Formation, forming a plateaulike surface, which slopes gently to the south. The Mannetto Gravel of the Wheatley Hills area has a thin discontinuous cover of ground moraine, but the formation in the Mannetto Hills was apparently never covered by glacial ice.

The surface of the Mannetto Gravel ranges from about 160 feet to more than 300 feet above sea level and is considerably higher than the bordering Pleistocene outwash deposits. The thickness of the formation ranges from a few feet to about 220 feet (pl. 3). The beds are chiefly composed of well-rounded, usually deeply weathered, pitted iron-stained quartz gravel mixed with yellow to brown quartz sand. The gravel commonly ranges in diameter from ¼ to 1 inch. In addition to the quartz the gravelly strata contains a few highly weathered pebbles and boulders of igneous and metamorphic rock in places. Layers of medium to coarse yellow to brown quartz sand and brown clayey silt are also interbedded with the gravelly zones.

Previous investigators (Fuller, 1914, p. 80–85; Veatch and others, 1906, p. 33–34; and Fleming, 1935, p. 219) considered the Mannetto Gravel to be of early Pleistocene age because locally it contains some crystalline rock fragments and minerals, which are rare to absent in the Cretaceous deposits. However, the predominance of quartz distinguishes the Mannetto from surrounding younger glacial deposits in which granite, gneiss, and other rock particles are usually much more abundant. The author agrees with Cooke, Gardiner, and Woodring (1943, chart 12), Crosby (1910), and MacClintock and Richards (1936, p. 320), who suggested that the Mannetto is probably older than Pleistocene. The Mannetto is possibly equivalent in age to the Beacon Hill Gravel (Pliocene?) which was deposited under similar conditions in Monmouth County, N.J. (Lewis and Kümmel, 1915, p. 72–73).

The Mannetto Gravel occurs almost entirely above the water table and is of no importance as a source of water. Owing to the high permeability of the formation, water percolates downward relatively freely to the underlying Magothy(?) Formation.

PLEISTOCENE SERIES

Most of the surficial deposits in the report area are of Pleistocene age (pl. 2). The deposits are referred to two glaciations which were separated by an interglacial stade. The Jameco Gravel, a product of pre-Wisconsin glaciation, occurs locally along the north shore and possibly under Long Island Sound. The Gardiners Clay, also of pre-Wisconsin age, is an interglacial marine formation that rests unconformably on the Jameco Gravel. The remainder of the Pleistocene deposits is of Wisconsin age and is referred to collectively as the upper Pleistocene deposits. The upper Pleistocene deposits include two sequences of till and outwash which comprise the Ronkonkoma and Harbor Hill Drifts. Because of their wide range in permeability, thickness, and extent, the deposits of Pleistocene age have great influence on the occurrence and movement of ground water. The deposits of clay and till impede infiltration and downward percolation of water, creating perched-water conditions locally, whereas the highly permeable beds of sand and gravel offer little resistance to the movement of water.

JAMECO GRAVEL

The Jameco Gravel is an early Pleistocene outwash deposit, which was deposited by melt-water streams that flowed from a stagnating ice front north of present day Long Island (Veatch and others, 1906, p. 34). Because these streams had different sources, the composition of the sediments they transported varied widely. Beds of unconsolidated sand, gravel, and silt—which may be part of the Jameco Gravel—occur in some buried valleys in northeastern Nassau County. Unlike the characteristically dark heterogeneous Jameco Gravel beneath Kings and southern Queens Counties (Suter and others, 1949, p. 40–41), these beds vary locally in lithology. In some places the beds consist almost entirely of quartz and contain only a small percentage of igneous rock pebbles, but elsewhere, as at well N6675 on Cove Neck, granitic pebbles and cobbles constitute a major part of the beds.

The Jameco Gravel is overlain by the Gardiners Clay or beds of undifferentiated Pleistocene deposits. It is underlain either by deposits of Cretaceous age or by bedrock.

The driller's log of well N6675 (table 5) gives a representative

TABLE 5.—*Log of well N6675 at Cove Neck, Nassau County*

A. A. Salkain, Cove Neck Road (map coordinates; 5C, 1.2N, 0.5W). Cable-tool well drilled in 1959 by Mathies Well and Pump Co. Screen depth 456 to 461 ft. Altitude of land surface about 5 ft. Driller's log. Geologic correlation by John Isbister.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Recent deposits:			Gardiners Clay(?):		
Fill	2	2	Sand, coarse, brown; and gravel; and lumps of green clay	5	240
Upper Pleistocene deposits:			Sand, coarse, brown; and heavy gravel	21	261
Sand, gray	9	11	Sand, coarse, brown	9	270
Sand, brown, and gravel; large stones	12	23	Sand, coarse, gray; and heavy gravel	31	301
Clay, soft, dark gray	6	29	Sand, medium, gray; mica	10	311
Clay, hard, dark gray	3	32	Sand, coarse, gray; and small gravel	13	324
Sand, brown, and gravel; heavy stones	11	43	Gardiner's Clay:		
Clay, sandy, brown	12	55	Clay, hard, gray	2	326
Sand, fine, brown; small gravel and stones	3	58	Sand, gray, and gravel	3	329
Sand, fine, brown; pea gravel	12	70	Clay, hard, gray; gravel and shells	11	340
Clay, soft, brown; brown sand	4	74	Clay, hard, greenish-blue	10	350
Sand, medium, brown, and gravel (salt water)	12	86	Clay, hard, brown	3	353
Sand, medium, brown; heavy gravel; lumps of clay	6	92	Clay, hard, blue	8	361
Sand, medium, brown	3	95	Clay, sandy, brown; and gravel	7	368
Sand, medium, brown; large stones	7	102	Clay, sandy, gray	16	384
Sand, medium, brown; and small gravel	13	115	Clay, hard, gray	16	400
Sand, medium, brown; and heavy gravel	55	170	Clay, soft, gray	13	413
Sand, medium, brown	23	193	Clay, hard, brown	2	415
Sand, coarse, brown; and heavy gravel	17	210	Clay, silty, gray	2	417
Sand, fine, gray	20	230	Clay, hard, brown	4	421
Sand, medium, gray; with black wood	5	235	Clay, hard, gray	17	438
			Jameco Gravel:		
			Sand, brown, small gravel	2	440
			Sand, brown; gravel and large stones	16	456
			Sand, coarse, brown; and gravel	5	461
			Sand, fine, muddy	8	469

description of the Jameco in a deep buried valley in the report area. The Jameco Gravel in this well is composed mostly of granitic sand, pebbles, and cobbles. A large piece of black limestone, bearing brachiopod fossils, was recovered from a depth of about 445 feet below sea level. The Jameco at the site of this well is overlain by Gardiners Clay, which is nearly 100 feet thick.

Deposits of undifferentiated valley fill of probable Pleistocene age which are found in some buried valleys may be equivalent, in part, to the Jameco Gravel. However, where the overlying Gardiners Clay is absent, a precise correlation cannot be made.

The Jameco Gravel and undifferentiated deposits of Pleistocene age are tapped by a few wells on the north shore. Hydraulic interconnection between the Jameco Gravel and the Lloyd Sand Member (pl. 3) is discussed in a later section.

Table 6 gives estimated coefficients of permeability of the Jameco Gravel at two wells in northwestern Nassau County (Swarzenski, 1963, pl. 1) and one well in the report area. These coefficients, which range from 100 to 800 gpd per sq ft were computed from transmissibilities determined from the specific capacities of the wells, an assumed storage coefficient of 0.0004, and an estimated thickness for the part of the aquifer tested. The permeabilities in table 6 may be either higher or lower than actual values because the thickness of the water-bearing zone cannot be readily determined and because of other limitations of the method.

TABLE 6.—*Hydraulic coefficients of the Jameco Gravel*

Well	Screen depth (feet below land surface)	Specific capacity (gpm per ft)	Coefficient of transmissibility (gpd per ft)	Estimated thickness of water-bearing zone (feet)	Field coefficient of permeability (gpd per sq ft)
N38 [1]	382–396	5	10,000	41	200
119	497–571	25	60,000	80	800
675 [1]	269–286	7	15,000	104	100

[1] Well in northwestern Nassau County (Swarzenski, 1963, pl. 1).

GARDINERS CLAY

The Gardiners Clay is an interglacial marine formation, which occurs mainly as a fringing deposit along the north shore and at an unknown distance inland in some buried valleys. The Gardiners is underlain either by the Jameco Gravel (pl. 3) or by the Raritan Formation and is overlain by the upper Pleistocene deposits. The areal extent of the Gardiners is unknown in the report area because of scanty well data.

209-982—66——3

The top of the clay is normally 50 to 100 feet below sea level, but at one location (well N6675 pl. 1, 3) it is 230 feet below sea level. The Gardiners commonly ranges in thickness from 100 to 200 feet.

The Gardiners Clay is composed of brown to greenish-brown to gray clay and silt, interbedded with layers and lenses of sand and gravel. Quartz pebbles are dispersed in some clay beds; and peat, oyster and clam shells, Foraminifera, and diatoms are common.

Some water moves through the Gardiners Clay, but the formation generally acts as a confining unit for the underlying deposits and the rate of movement through it is probably low. Its effectiveness as a confining unit beneath Long Island Sound is unknown.

UPPER PLEISTOCENE DEPOSITS

The upper Pleistocene deposits include all the glacial deposits younger than the Gardiners Clay. Two bodies of drift, the Ronkonkoma and Harbor Hill, composed of till and related outwash deposits of Wisconsin age, were identified in northeastern Nassau County. Except on the Ronkonkoma terminal moraine, the Wheatley Hills, and possibly in an area southwest of the Mannetto Hills, the older Ronkonkoma Drift is either buried beneath the younger Harbor Hill Drift or else cannot be differentiated from it. Although the configuration of the underlying Cretaceous surface (pl. 4) exerts a strong influence in many places, the relief of the present land surface is mainly due to the deposits of the Harbor Hill Drift.

The wide range in the lithology of the upper Pleistocene deposits has considerable influence on the occurrence and movement of ground water in the report area. In areas underlain by till of relatively low permeability, the downward movement of water from precipitation is retarded; and perched and semiperched water occurs in many places. In areas underlain by permeable outwash, such as in Levittown, shallow wells, 80 to 125 feet deep, yield as much as 1,100 gpm and have specific capacities as high as 47 gpm per foot of drawdown. North of Glen Cove, deep wells screened in the upper Pleistocene deposits, yield as much as 1,100 gpm and have specific capacities as high as 44 gpm per foot of drawdown.

Laboratory analyses of several hundred samples of outwash from southern Long Island (Veatch and others, 1906, p. 354–360) indicate that the porosity of the glacial outwash probably ranges from 30 to 40 percent. Permeabilities of the outwash ranging from 1,000 to 1,600 gpd per sq ft and average 1,300 gpd per sq ft have been computed from pumping tests at Brookhaven National Laboratory in central Suffolk County (M. A. Warren and N. J. Lusczynski, written commun., 1955). The outwash in the report area south of the Ronkonkoma terminal moraine and in some of the buried valleys near Long Island Sound is lithologically similar to that of Suffolk County and probably has similar hydraulic characteristics. A pumping test (Lusczynski, 1949b) made in shallow wells in Hicksville, a short distance south of the report area, shows hydraulic interconnection between the outwash deposits and underlying permeable beds in the upper part of the Magothy(?) Formation. A coefficient of permeability of about 2,500 gpd per sq ft was computed from the test data on the basis of an assumed thickness of 100 feet for the zone tested. The average permeability of the outwash deposits in the report area is estimated to be 1,000 gpd per sq ft.

The outwash deposits are a minor source of water in most of northeastern Nassau County. However, in the village of Oyster Bay, where the Cretaceous formations have been deeply eroded and the outwash deposits are thick, the deposits constitute the primary source of water.

RONKONKOMA DRIFT

The Ronkonkoma ice sheet deposited a mantle of glacial drift on the Cretaceous and early Pleistocene deposits. The drift ranges from unstratified till to stratified outwash (pl. 2) and mainly occurs in three topographic forms: a ground moraine, a terminal moraine, and an outwash plain.

The basal beds of the drift are composed of stratified outwash deposited chiefly by melt-water streams emanating from the ice front as it moved slowly southward. These advance outwash deposits are predominantly sand and gravel and range in thickness from a few feet to about 100 feet. The deposits do not crop out and are not differentiated on the geologic map or sections in this report.

The ice gradually overrode its advance outwash deposits and moved to a maximum southward position indicated by the Ronkonkoma terminal moraine. The terminal moraine is a discontinuous line of hills trending generally northeast from Old Westbury to Woodbury (pl. 2). The hills are subdued in the southwest, where the summits are as high as 180 feet above sea level, but to the northeast the hills are steeper and are as high as 300 feet. The terminal moraine is composed of a series of coalescing alluvial fans and kames of stratified sand and gravel with subordinate amounts of till. Exposures in roadcuts and building excavations reveal slumping and crossbedding characteristic of ice-contact deposition. The total thickness of the terminal moraine deposits is as much as 200 feet.

South of the Ronkonkoma terminal moraine is a relatively flat outwash plain, which extends beyond the south limit of the report area to the south shore of Long Island. The outwash plain is underlain by stratified sand and gravel deposits ranging from 80 to 100 feet in thickness. These deposits are lithologically similar to the advance outwash and to some parts of the terminal moraine but generally cannot be differentiated from the younger Harbor Hill outwash. Hence, the outwash deposits shown on plate 2 south of the Ronkonkoma terminal moraine are designated as undifferentiated outwash deposits.

Fuller (1914, pl. 1) mapped one small area south and west of the Mannetto Hills as outwash from the Ronkonkoma ice sheet. His mapping may be correct as a few exposures in this area, observed in building excavations, indicated a much greater ratio of dark rock fragments to quartz pebbles than is commonly observed in the outwash elsewhere. Melt-water streams flowing from the Harbor Hill ice were possibly diverted from the area by the Mannetto Hills and a lobe of the Ronkonkoma terminal moraine. However, it is impossible to map the lateral limits of this deposit of Ronkonkoma outwash as the area is now extensively developed.

The Ronkonkoma ice sheet overrode its terminal moraine at least for a short distance and then retreated to the north, depositing a mantle of ground moraine in its wake. Till crops out on the summits of the terminal moraine and the Wheatley Hills but is covered by younger Harbor Hill outwash deposits everywhere else. The till is more deeply buried to the north and is identified in only a few well logs. The till ranges in thickness from about 5 to 20 feet and generally consists of the compact clayey or sandy-boulder type. Cobbles, and boulders as large as several feet in diameter, are commonly found in the till. The ground moraine contains small discontinuous lenses of clay and silty clay which indicate the bottoms of small temporary glacial lakes and kettles.

The sand and gravel deposits are predominantly quartz with a large percentage of fresh to weathered rock fragments and dark minerals. Biotite, hornblende, and augite are especially common. The quartz grains are subangular to subrounded and are frequently iron stained. The clayey parts of the till are generally brown to gray. The washed residue usually contains a large percentage of biotite and chlorite.

HARBOR HILL DRIFT

The Harbor Hill Drift comprises the uppermost beds almost everywhere beneath the land surface of northeastern Nassau County and is only overlain locally by Recent deposits. The drift consists of outwash and till.

Advance outwash deposits from the Harbor Hill ice sheet thinly mantle the Ronkonkoma ground moraine north of the Ronkonkoma terminal moraine. The deposits consist chiefly of sand and gravel and rarely exceed 50 feet in thickness.

The Harbor Hill end moraine (pl. 2) is an irregular ridge of hills about ½ to ¾ mile north of, and generally parallel to, the Ronkonkoma terminal moraine. The Harbor Hill moraine was formed at the terminus of the ice sheet, but is classified as an end moraine because it does not mark the maximum advance of the ice sheet. The hills rise as high as 340 feet above sea level to the southwest, but descend eastward gradually until they scarcely rise above the surrounding thick outwash deposits near Cold Spring Harbor. The beds are steeply inclined in many places and consist of poorly stratified sand and gravel containing some boulders and patches of till. The end moraine is composed mainly of a series of coalescing kames. Its upper surface is irregular and is marked by numerous kettles and depressions. The end-moraine deposits have a maximum thickness of about 200 feet.

The outwash plain which extends south from the end moraine to the Ronkonkoma terminal moraine ranges in thickness from a few feet to about 100 feet. Its surface is irregular and includes numerous kettles, depressions, and small hills which are probably kames. This feature is termed a pitted outwash plain (pl. 2). South of the Ronkonkoma terminal moraine the outwash is generally indistinguishable from the older Ronkonkoma outwash deposits because the two outwash sequences are not separated by a layer of till, and the source of the detritus, mode of deposition, and character of the bedding are similar. Presumably, some outwash from the Harbor Hill ice was deposited, perhaps in fans or deltas, by streams which breached the Ronkonkoma terminal moraine, but this has not been positively determined either in the field or from well logs and samples.

The ground moraine comprises the surficial deposits nearly everywhere in the report area north of the terminal moraine. The deposits commonly range from about 5 to 20 feet in thickness and contain numerous cobbles and large boulders in a clayey or sandy, clayey matrix.

The sand and gravel beds consist mostly of quartz mixed with large amounts of metamorphic and igneous rock fragments. The individual grains are subangular to subrounded and are commonly iron stained. Dark minerals including biotite, hornblende, and augite are common.

Beds and lenses of clay are commonly brown, gray, and black and usually contain large quantities of biotite.

RECENT SERIES

The Recent Series consists of sand, gravel, silt, and clay deposited sporadically in valleys, swamps, marshes, beaches, and sandbars and beneath Long Island Sound and nearby bays (pl. 2). Locally, these beds are composed of reworked Cretaceous and Pleistocene deposits.

Recent deposits are not used as a source of fresh water because they generally either occur above the water table, contain salt water, or are so close to salt water that pumping from them would induce rapid intrusion of salty water. The beds of silt and clay, which are presently accumulating in Long Island Sound and its harbors, form an important seal that retards both leakage of fresh water from underlying strata and encroachment of salt water into them.

HYDROLOGY

HYDROLOGIC CYCLE

The hydrologic cycle denotes the circulation of water from the sea, through the atmosphere, to the land, and back to the sea by overland and subsurface routes, and in part by way of the atmosphere. Some of the water which falls on the study area as precipitation moves overland to the sea, a part returns to the atmosphere through the process of evaporation, a part moves into the roots of growing plants and returns to the atmosphere by transpiration; the remainder moves downward to the zone of saturation, and eventually reaches the sea either by discharge into effluent streams, by submarine discharge in Long Island Sound and adjoining bays, or as sewage effluent. The amount of replenishment, or the process by which water moves into the zone of saturation, is defined as recharge. Evaluation of the ground-water resources of an area involves an appraisal of the recharge-discharge relation. If withdrawals exceed recharge, water is removed from storage, water levels decline, and, in an area such as Long Island, sea water begins to move landward into previously fresh-water aquifers.

Recharge on Long Island is derived entirely from precipitation. Early theories that considered Connecticut as the source of Long Island's ground water have been disproved (Veatch and others, 1906, p. 67–68; Lusczynski, 1950). There is no connection between the aquifers of Long Island and those of Connecticut, and a study of water levels on Long Island has shown that the regional direction of ground-water movement is generally north and south from the area of the main ground-water divide near the center of the island.

PRECIPITATION

Records of precipitation are available for four stations in and near the report area (fig. 3). The stations at Manhasset and Huntington Station are indicative of precipitation in the northern part of the area, and those at Bethpage and Garden City, in the southern part.

A simple and adequate method of estimating areal rainfall is to compute the arithmetic mean of the recorded values at all stations, provided that the variation in rainfall is relatively small (Rouse, 1950, p. 276). During the period 1955–61 the mean annual precipitation for the four stations ranged from 37.04 to 56.33 inches and averaged 46.21 inches (table 7). Inspection of annual data from the four stations indicates that Garden City, which has the longest precipitation record and is centrally located, adequately represents conditions in the report area.

A summary of the record at Garden City shows the mean annual precipitation (table 8).

Although the 1955–61 mean is about 4 percent higher than that for the 1939–54 period, the long-term record 1939–61 is considered more representative. Mean annual precipitation in the report area is therefore estimated to be about 45 inches, or 2 mgd per sq mi (million gallons per day per square mile).

TABLE 7.—*Annual precipitation, in inches, in and near northeastern Nassau County, 1955–61*

[Data for Manhasset from Nassau County Dept. Public Works]

Year	Precipitation station				Arithmetic mean
	Bethpage	Huntington Station	Manhasset	Garden City	
1955	47.22	48.31	43.41	46.75	46.42
1956	45.65	44.63	39.10	43.23	43.15
1957	37.66	39.43	34.72	36.35	37.04
1958	52.47	60.66	55.29	56.88	56.33
1959	42.59	44.16	39.67	39.60	41.51
1960	51.81	55.69	48.70	49.61	51.45
1961	52.48	45.09	45.07	47.66	47.58
Mean	47.13	48.28	43.71	45.73	46.21

TABLE 8.—*Precipitation at Garden City, Nassau County*

Period	*Mean annual precipitation (inches)*
1939–54	44.08
1955–61	45.73
1939–61	44.58

EVAPOTRANSPIRATION

Evapotranspiration is the phase of the hydrologic cycle which accounts for that part of precipitation that is returned to the atmosphere by evaporation of moisture and transpiration by plants. Evaporation is the process by which water changes from the liquid state into the gaseous state, and transpiration is the process by which plants utilize water and discharge it to the atmosphere.

The evaporation rate varies with the temperature of the air and water, relative humidity, and wind velocity. Water evaporates almost continually from streams, ponds, and marshes in the report area. Water is evaporated intermittently from recharge basins and from rooftops and paved areas following precipitation. Vegetation tends to reduce evaporation of soil moisture by shading the ground, but also increases the opportunity for evaporation by intercepting precipitation on its leaves and branches.

The transpiration rate varies with air temperature, amount of soil moisture, duration and intensity of insolation, soil chemistry, amount of vegetation, and plant type. Transpiration in the report area is greatest from May to November, which is the main growing season on Long Island.

There are no available data pertaining to evapotranspiration rates in northeastern Nassau County, and a detailed study is beyond the scope of this report. However, a reasonable estimate can be made by using an indirect method developed by Meyer (1944, p. 445–57) and by considering previous work done in similar nearby areas.

Meyer developed two graphs showing evaporation and transpiration with respect to monthly mean temperature. Values obtained from these curves must be modified by using coefficients applicable to the report area. Meyer's method suggests annual evapotranspiration ranging from about 22 to 26 inches.

Evapotranspiration (evaporation plus transpiration) in the Upton area of central Suffolk County ranges from about 15 inches per year in areas where vegetation is scanty to about 30 inches per year near streams and swampy areas; the average is 22 inches per year (M. A. Warren and N. J. Lusczynski, 1958, written commun.). Because the water table in northeastern Nassau County is below the root zone in all but a small area near the shore, and ponds and marshes are few, evapotranspiration is probably less than 30 inches. Total water losses along the coastal plain of New Jersey, which is climatically comparable to Long Island, range from about 15 to 30 inches (Hely and others, 1961, pl. 3).

From the foregoing it is estimated that the mean annual evapotranspiration for northeastern Nassau County ranges between 19 and 26 inches and that the mean is about 22 inches.

SURFACE WATER

GENERAL CHARACTERISTICS

The surface waters of northeastern Nassau County include several small streams, numerous small ponds and marshes, and salt water in Long Island Sound and its embayments.

Surface water is classed as perched if it is held up by a zone of relatively impermeable material and separated from the main zone of saturation by a zone of aeration (after Meinzer 1923, p. 57). Nonperched surface water is in direct hydraulic connection with the main zone of saturation.

Numerous small perched ponds and marshes occur in clay- and till-bottomed kettles and other depressions on, between, and north of the terminal and end moraines (pl. 2). In the Bethpage and Woodbury areas, perched water is held up by beds of Cretaceous silt and clay. Reported and probable locations of perched water in northeastern Nassau are shown on figure 7. Some of the ponds at lower altitudes near the stream valleys and the north shore are not perched and are fed by water from the zone of saturation.

The highlands composed of the Ronkonkoma terminal moraine, the Harbor Hill end moraine, and the Wheatley and Mannetto Hills (pl. 2) contain the headwaters of several small streams that drain the report area. The stream valleys are well formed and were probably created under conditions that existed at the close of the Wisconsin Glaciation. It is unlikely that the small present-day streams could have eroded the valleys that they now occupy.

Baseflow in the upper reaches of the streams is generally intermittent and is sustained by seepage of perched water. During periods of prolonged or heavy precipitation, flow is supplemented by direct runoff. As the streams descend from the highlands, flow is influent and at places ceases entirely.

The south-flowing streams descend abruptly from the Ronkonkoma terminal moraine to the flat outwash plain (pl. 2), and surface flow disappears within a short distance as the water infiltrates into the highly permeable sand and gravel deposits. These streams do not reappear in the report area.

Influent flow in the north-flowing streams also diminishes downstream but at a somewhat slower rate because the surficial deposits north of the moraines are generally less permeable than those underlying the outwash plain. About 1 mile from the north shore the stream valleys intersect the zone of saturation, and the flow becomes both effluent and perennial. Effluent flow increases downstream, probably some distance seaward of tidal flooding. Base flow in the northern streams is almost entirely ground water, and the rate of flow depends upon the ground-water contributing area rather than the topographic drainage area. The ground-water contributing area is three dimensional, and an accurate appraisal must consider ground water moving upward from the principal aquifer as well as ground water flowing laterally. For example, base flow of Mill River at Oyster Bay (pl. 1) increased 2.8 cfs (cubic feet per second), or 1.8 mgd, in about 3,000 feet on November 6, 1959. Most of this pickup was from upward-moving ground water. The flow of three streams in the report area is gaged continuously: Cold Spring Brook at Cold Spring Harbor, Mill Neck Creek at Mill Neck, and Cedar Swamp Creek at Glen Cove (table 9). Island Swamp Brook at Lattingtown is gaged intermittently, and occasional streamflow measurements have been made at two tributaries of Frost Creek at Lattingtown, Little Meadow Brook at Locust Valley, Spring Lake Creek at Mill Neck, Mill River at Oyster Bay, and Cove Neck Creek at Oyster Bay. All these streams flow generally north and drain into either Long Island Sound or its harbors.

The headwaters of Cold Spring Brook at Cold Spring Harbor (pl. 1) are about 220 feet above sea level in the Ronkonkoma terminal moraine near Woodbury (pl. 2). About 2.6 square miles of the watershed are in Suffolk County. The stream is perched and flows intermittently in the upper 1.5 miles but becomes continuous in the lower reaches where baseflow is sustained by ground water seepage. Cold Spring Brook ranks seventh in size among the streams in Nassau County.

The permanent gage on Cedar Swamp Creek at Glen Cove is outside the report area; however, about 9.5 square miles of the surface drainage area is in the report area. Flow originates in a series of ponds on the north side of the Harbor Hill end moraine, and the stream is perched for about 1.5 miles, draining a large perched ground-water body. The stream becomes effluent just south of the city of Glen Cove. Storm sewers in the city of Glen Cove discharge into Cedar Swamp Creek and cause abrupt increases in flow during rainstorms. Cedar Swamp Creek is the sixth largest Nassau County stream.

Frost Creek at Lattingtown (pl. 1) is estuarine. The water is salty, and the amount and direction of flow vary with the stage of the tide in Long Island Sound. The flow at low tide measured on April 5, 1961, was 11.8 cfs (7.6 mgd), and the combined flow of the two tributaries on the same day was about 2 cfs (1.3 mgd.). Undoubtedly, considerable fresh ground water discharges into Frost Creek channel in addition to that from the tributaries, or the flow at low tide would be much less. The chloride concentration in the water of Frost Creek on April 5 at high tide was about 15,000 ppm and at low tide about 700 ppm.

A summary of data for the 10 principal streams in the report area is presented in table 9.

Surface water is not utilized for supply in northeastern Nassau County, primarily because large quantities of good-quality ground water are readily available. Stream-fed reservoirs would have to be located close to the north shore where suitable land would be difficult

TABLE 9.—*Summary of streamflow in northeastern Nassau County*

[Streams shown on plate 1; measurements at low tide]

Stream	Location	Approximate drainage area (sq mi)		Daily discharge									Remarks
				Maximum			Minimum			Mean			
		Topographic	Ground water	Cfs	Mgd	Date	Cfs	Mgd	Date	Cfs	Mgd	Date	
Cold Spring Brook.	Cold Spring Harbor.	[1] 7	[2] 12.9	34	22	Aug. 12, 1955	2.6	1.7	Sept. 23, 1955	4.8	3.1	1951–59	
Mill Neck Creek.	Mill Neck	12	9.7	105	67.9	do.	5.6	3.6	Nov. 13, 1950	9.7	6.3	1938–59	
Cedar Swamp Creek.	Glen Cove	[3] 11	[4] 7.7	259	167	do.	4.2	2.7	July 16, 20–22; Aug. 8–10 1957.	7.4	4.8	do.	
Island Swamp Brook.	Lattingtown	1	1.3							[5] 0.8	.5		
Frost Creek	do.												Estuarine; 11.8 cfs (7.6 mgd) discharge Apr. 5, 1961.
Frost Creek Tributary No. 1.	do.	1	1.1							[6] 1.5	1.0		1.9 cfs (1.2 mgd) discharge Apr. 25, 1961.
Frost Creek Tributary No. 2.	do.	.2	.2							[6] .2	.1		0.2 cfs (0.1 mgd) discharge Apr. 25, 1961.
Little Meadow Brook.	Locust Valley	.5	.4							[6] .9	.6		1 cfs (0.6 mgd) discharge Apr. 5, 1961.
Spring Lane Creek.	Mill Neck	.7	.2							[6] .4	.3		0.4 cfs (0.3 mgd) discharge Apr. 5, 1961.
Mill River	Oyster Bay	1.4	2							[6] 4.4	2.8		3.6 cfs (2.3 mgd) discharge Nov. 6, 1959.
Cove Neck Creek.	do.	2.6	.8							[6] .7	.5		0.6 cfs (0.4 mgd) discharge Nov. 6, 1959.

[1] 2.5 sq mi in Suffolk County.
[2] 6.7 sq mi in Suffolk County.
[3] 2.6 sq mi outside report area.
[4] 2 sq mi outside report area.
[5] Estimated by correlation with Cedar Swamp Creek.
[6] Estimated by correlation with Mill Neck Creek.

to acquire. Also the high cost of constructing and maintaining dams and reservoirs and pumping the water from reservoirs to the higher inland areas is not warranted.

DIRECT RUNOFF

Direct runoff is runoff which enters stream channels promptly after rainfall or snowmelt (after Langbein and Iseri, 1960, p. 7). It consists chiefly of water that moves over the land surface and never infiltrates.

Direct runoff varies inversely with infiltration, which depends upon soil permeability and soil moisture. Generally, where the soils are predominantly clayey and silty, infiltration is retarded and direct runoff is greater. Conversely, sandy soils are more permeable and water infiltrates more readily. All soils are permeable to some extent; however, when precipitation is intense, water accumulates faster than it can infiltrate and direct runoff occurs.

The largest stream valleys originate in the topographically high areas of the terminal and end moraines (pl. 2). The surface of the moraines is largely covered with till of relatively low permeability, which retards infiltration of precipitation and induces direct runoff into the valleys. Flow in the valleys is influent, especially where the till is eroded and the valley is underlain by deposits of high permeability, and some water undoubtedly infiltrates as it flows down the valley.

The land surface north of the Harbor Hill end moraine (pl. 2) is almost completely covered by either till or soil derived from till and is locally underlain by beds of silt and clay. Infiltration of precipitation is retarded by these deposits and direct runoff is augmented. Some direct runoff probably infiltrates upstream where the stream is influent. Below this point streamflow is supplemented by ground water.

The soil on the glacial outwash plain (pl. 2) is generally sandy loam underlain by as much as 100 feet of highly permeable outwash deposits. Both in stream valleys and on the slopes, direct runoff, which originates in the hilly area of the terminal moraines where the soil is relatively impermeable, loses velocity quickly and infiltrates into the soil when it reaches the flat permeable outwash plain. Therefore, direct runoff south of the Ronkonkoma terminal moraine is assumed to be negligible under normal conditions of precipitation.

Rooftops and pavements in developed areas tend to concentrate the water and increase direct runoff, but this water is nearly all collected and diverted into artificial storm-water recharge basins where most of it infiltrates into the ground.

With the exception of Cedar Swamp Creek, all the north-flowing streams of the area drain watersheds which are under virtually natural conditions. An estimate of the amount of direct runoff to the north can be obtained by analysis of the daily-discharge hydrographs of the gaged streams. The hydrograph for Mill Neck Creek at Mill Neck is representative of flow under natural conditions because its watershed includes mostly large estates, which have few buildings and paved areas. Direct runoff varies according to the amount and intensity of the precipitation and ranges from about 1 to 9 percent of the total annual discharge. The mean annual direct runoff is estimated to be 4 percent of the annual discharge of Mill Neck Creek.

Cedar Swamp Creek at Glen Cove drains an area extensively developed by man. Storm sewers in the city of Glen Cove empty into the lower reaches of this stream. The discharge is very flashy and responds to precipitation more quickly and with greater magnitude than does the discharge of Mill Neck Creek. Estimated direct runoff ranges from 2 to 16 percent of the annual discharge. The estimated mean annual rate of direct runoff is 7 percent of the annual total discharge of Cedar Swamp Creek.

The combined topographic drainage area of 10 north-flowing streams which were gaged or measured (table 9) is about 37 square miles. The combined average discharge includes about 0.8 mgd of direct runoff, or about 0.02 mgd per sq mi. A 9-square-mile area, which was not gaged, is assumed to possess characteristics of infiltration similar to those of the gaged area. Therefore, direct runoff in the 46-square-mile area of northeastern Nassau County drained by north-flowing streams averages about 1 mgd during a normal year. (See table 11.)

GROUND WATER

GENERAL PRINCIPLES

The unconsolidated deposits contain a zone of aeration and an underlying zone of saturation. The zone of aeration is the unsaturated zone between the land surface and the water table. The water table is the upper limit of the unconfined ground water. The zone of aeration contains some soil water, intermediate vadose water, and capillary fringe water (Meinzer, 1923, p. 29–39), none of which is available to wells. The zone of aeration also contains water moving down to the water table by gravity. Soil water is discharged by evaporation and plant use; intermediate vadose water is held between the belt of soil water and the capillary fringe by molecular attraction. Water in the capillary fringe is drawn upward from the zone of saturation or is held against the pull of gravity just above that zone by capillary action. Intergranular spaces in the zone of aeration are saturated only intermittently as water moves downward through it to replenish the ground water. Intergranular spaces in the deposits in the zone of saturation are continuously saturated with ground water.

The ground-water reservoir in northeastern Nassau County is composed of saturated beds of unconsolidated sediments. Igneous and metamorphic basement rocks, which have a relatively low permeability, form the lower boundary of the reservoir. Perched water is held temporarily in zones of saturation above the main water table in deposits underlain by clay and till north of the Ronkonkoma terminal moraine and by Cretaceous silts and clays elsewhere.

The entire ground-water reservoir is a single hydraulic system in which the more permeable zones, which yield usable amounts of water to wells or springs are termed aquifers, and the less permeable zones, which retard the movement of ground water, are termed aquicludes. The boundaries of hydraulic units may coincide with geologic contacts or may cut across them so that an aquifer or aquiclude may be composed of a part of a geologic formation, an entire formation, several formations, or parts of several formations.

The ground-water reservoir of northeastern Nassau County contains two main aquifers. The principal aquifer is the shallower of the two and includes all the permeable deposits between the water table and the top of the clay member of the Raritan Formation, except that locally the upper surface of the Gardiners Clay constitutes the lower limit of the principal aquifer. The deep confined aquifer occurs between the lower surface of the Raritan clay member or Gardiners Clay and the bedrock.

Ground water moves from points of higher head towards points of lower head at rates which vary directly with the hydraulic gradient and the permeability of the deposits.

PERCHED WATER

Perched ground water occurs in northeastern Nassau County in temporary zones of saturation above and separated from the main zone of saturation. These perched water bodies are generally discontinuous and of small areal extent. North of and in the Ronkonkoma terminal moraine, perched ground water is found at varying depths underlain by beds and lenses of till and clay. In the Bethpage and Woodbury areas perched water occurs above beds of Cretaceous clay and silt. Locations of perched surface and ground water, including those reported by Veatch (1906, pl. 12), are shown on figure 7.

An example of perched water is shown by the data for observation wells N6665 and N6666, approximately 2,700 feet north of North

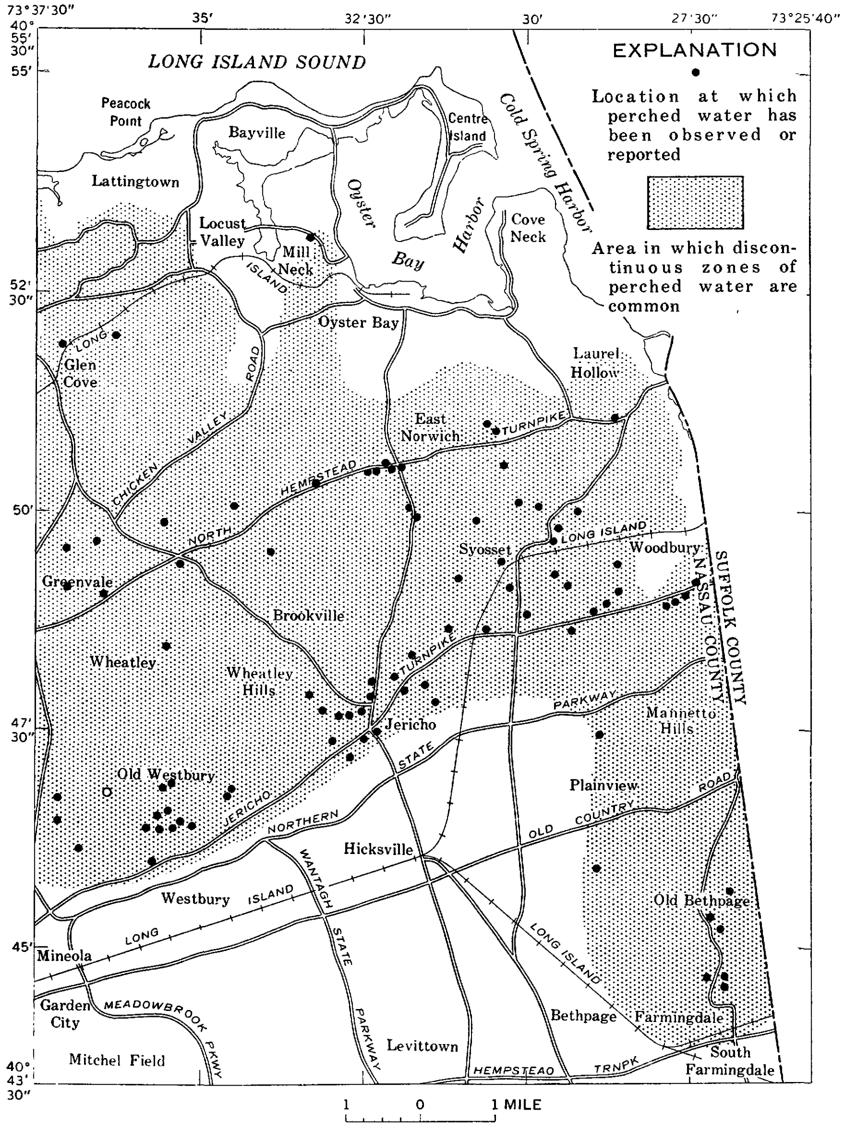

Figure 7.—Areal extent of perched water zones.

Hempstead Turnpike and 10 feet west of Cedar Swamp Creek, Greenvale (pl. 1). Well N6665 was driven to a depth of 28.6 feet below the land surface on March 17, 1959. A perched zone of saturation was penetrated about 8 feet below land surface at an altitude of 89 feet above mean sea level, which is the approximate altitude of the water surface of nearby Cedar Swamp Creek. The well driving was more difficult between depths of 12 to 16 feet below land surface, which suggests the presence of a harder and less permeable zone. Beneath the zone of hard driving, all the water ran out of the well into an unsaturated zone. Water entered the well again when the screen was at a depth of about 20 feet below the land surface. The water level eventually stabilized on March 19 at a depth of 21 feet below land surface or 76 feet above sea level, which was the altitude of the main water table at that time. Well N6666, 1 foot east of well N6665, was driven to a depth of 12.3 feet below the land surface and was terminated in the perched water body. The water level in this well ranged from 89 to 92 feet above mean sea level between March 1959 and January 1961.

Perched water bodies are not used for supply in the report area because the water is especially susceptible to surface contamination, and more reliable and adequate supplies are available at greater depth from the main ground-water reservoir. Dewatering of perched water bodies is commonly necessary during road building and the excavation of large foundations in many parts of the area.

PRINCIPAL AQUIFER

The principal aquifer includes beds of Late Cretaceous and Pleistocene age. The upper limit of the aquifer is the water table, and the clay member of the Raritan Formation forms the relatively impermeable lower boundary in most of the area. The Gardiners and other Pleistocene clays constitute the lower boundary in some deep buried valleys near the north shore. Water occurs in the aquifer both under confined (artesian) conditions and unconfined (water-table) conditions. The upper part of the aquifer contains water under unconfined conditions. The degree of confinement increases with depth and results from stratification and the presence of numerous discontinuous lenses of silt and clay primarily in the Magothy (?) Formation. Individually these lenses do not constitute distinct confining units, but their combined influence through a considerable thickness of formation significantly impedes the vertical movement of ground water.

Although individual wells are screened at nearly all depths in the principal aquifer, two zones are generally more productive than others because of their relatively high permeability. The upper zone is the saturated part of the upper Pleistocene deposits. It ranges in thickness from a few feet to about 200 feet in some of the buried valleys (pl. 3). Some wells screened in the upper Pleistocene deposits yield more than 1,000 gpm and have specific capacities up to 68 gpm per foot of drawdown. The lower zone is the basal 100 to 150 feet of the Magothy (?) Formation. Wells in the basal zone yield water at rates as high as 1,400 gpm, and have specific capacities of 15 to 30 gpm per foot of drawdown.

Wells screened in locally permeable zones in the upper part of the Magothy(?) Formation rarely yield more than 500 gpm, and specific capacities are generally less than 15 gpm per foot of drawdown.

RECHARGE

NATURAL RECHARGE BY PRECIPITATION

The principal aquifer is recharged by precipitation, which moves downward through the zone of aeration under the pull of gravity until it reaches the water table. Precipitation on the report area averages about 45 inches a year, but as shown in an earlier section about half of it is lost by evapotranspiration and direct runoff. The remaining half replenishes the ground-water reservoir at an average rate of about 1 mgd per sq mi. The effective area of infiltration in northeastern Nassau County is about 109 square miles, so the estimated total natural recharge to the shallow unconfined aquifer is about 109 mgd plus what may be added by influent streams.

Infiltration rates are relatively high in the area of the outwash plain where the loamy soil is underlain by permeable sand and gravel deposits. On and north of the Ronkonkoma terminal moraine infiltration is impeded by extensive deposits of clay and clayey till at and near land surface. The permeability of the till varies owing to differences in lithology. It may range from as low as 0.0002 gpd per sq ft where the till is chiefly clay and silt to as much as several hundred gallons per day per square foot where the till is sandier. These values are estimates based on values determined in the hydrologic laboratory of the U.S. Geological Survey (Wenzel and Fischel, 1942, p. 11).

Infiltration and recharge also vary considerably according to the season. Although precipitation is relatively evenly distributed throughout the year, net recharge is highest during the winter and early spring when plant activity is at a minimum. During the summer and fall, growing plants utilize most of the precipitation and little if any recharge occurs. Direct runoff is probably higher also during the winter in the relatively brief periods when the ground is frozen.

STORM-WATER RECHARGE BASINS

In densely populated and industrialized areas, disposal of storm water is a problem because the opportunity for natural infiltration is greatly reduced by the works of man. In 1936, as part of a long-range program for storm-water conservation and disposal, the Nassau County Board of Supervisors authorized a plan for the construction of recharge basins. These basins were designed to be 1 acre or more in size and were intended to encourage the recharge of water that might other-

209-982—66——4

wise be lost to the sea through storm sewers (Welsch, 1960, p. 1494–1498). The seepage rates from different basins vary considerably depending primarily upon the permeability of the underlying sedimentary deposits. Tests conducted in a small experimental recharge basin, excavated in highly permeable glacial outwash deposits in Garden City, indicate infiltration rates ranging from 20 to 400 gpd per sq ft (Brice and others, 1959, p. 32).

In May 1961, about 460 storm-water recharge basins were in operation in Nassau County. Most of these are county owned, but a small number are privately owned. Based on an average seepage rate of 24 gpd per sq ft (1 mgd per acre), it is estimated that approximately 40 mgd of storm runoff replenishes the ground-water reservoir in Nassau County (Welsch, 1960, p. 1497). Of this total, about 22 mgd is returned in the report area through 255 basins, most of which are in the south half of the report area.

Most of the water pumped for industrial use is returned to the ground either through diffusion wells or more commonly through recharge basins. During 1960 about 10.3 mgd of water pumped for industrial use was returned to the principal aquifer in the report area.

SANITARY SYSTEMS

Except for the sewered parts of the city of Glen Cove and the village of Oyster Bay, most sewage in the report area is disposed of by means of domestic sanitary systems. In 1960, almost 30 mgd was returned to the ground through cesspools, septic tanks, and tile drains. Most of this water seeped down to the water table in the areas of greatest concentration of population.

STORAGE

About 2 trillion gallons of ground water is in storage in the principal aquifer of northeastern Nassau County between the water table and the top of the clay member of the Raritan Formation. This is a conservative estimate, based on an average porosity of only 25 percent, and the amount may be considerably greater. Only part of this storage, probably less than 50 percent, would be available to wells, even by systematic mining of fresh water and by allowing sea water to encroach the aquifer.

Water is also temporarily stored in the zone of aeration, in the soil zone, perched water bodies, and the capillary zone. The amount of storage in the zone of aeration cannot be readily estimated. The amount of water in the soil and capillary zones is small, and although widespread in occurrence, perched water is small in quantity. Downward movement of water in the zone of aeration due to gravity is very slow, and recharge may be in transit for nearly a year where the depth to the water table is 100 feet or more. At a minimum there is probably at least 1 years' recharge, or about 40,000 million gallons of water, in transit in the zone of aeration.

WATER TABLE

The main water table is the upper surface of the main zone of saturation and the upper limit of the principal aquifer. The water table is in the Magothy(?) Formation in about one third of the report area (shaded section on pl. 4) and in the upper Pleistocene deposits in the remainder. Plate 4 also shows contours on the water table at the end of April 1960, and plate 3 shows the water table along selected geologic sections for the same time. Water-table altitudes range from sea level near the shore of Long Island Sound and its harbors to as high as 100 feet above sea level in East Norwich. In the southern part of the area, where the water table is in permeable sand and gravel deposits of the outwash plain (pl. 2), the surface is relatively smooth and the hydraulic gradient is about 10 feet per mile to the south and southeast. North of the Ronkonkoma terminal moraine (pl. 2) the higher relief of the land surface and the more complex character of the surficial and subsurface deposits cause the water table to have a more irregular configuration. Locally, the hydraulic gradient is as much as 50 feet per mile.

The altitude and gradient of the water table vary directly with the permeability of the saturated beds and with the amount and rate of recharge and discharge. Abrupt changes in either of these parameters will create small isolated high and low areas locally on the main water table. The configuration of these irregularities varies, depending upon the extent and shape of the beds of low permeability and the amount of recharge or discharge. In the absence of adequate control the highs on plate 4 are assumed to be moundshaped. The cause of the mound at Locust Valley is not known. This mound may represent a locality of below-average vertical permeability, perhaps with abnormally good infiltration capabilities at land surface. However, as is mentioned subsequently, this mound in the water table apparently coincides with local mounds in the piezometric surfaces of the principal and deep confined aquifers. The mound at East Norwich, however, is in heterogeneous beds of Cretaceous age which have relatively low permeability and which decrease in altitude to the east. The change in gradient on the east side of the mound probably coincides with the contact between the Cretaceous deposits and nearby outwash deposits of much higher permeability, creating a steep slope on the water table on the east side of the mound. Mounds of this type are probably common in areas underlain by till and beds of Cretaceous age, which are predominantly clayey. Closer spacing of observation wells would probably reveal additional mounds in the report area.

The water table fluctuates in response to changes in storage in the principal aquifer. Generally, a short-term increase in recharge causes a temporary increase in storage, which is indicated by a rise in the water table. Because of the resulting increase in the hydraulic gradient, natural discharge is increased, causing a reduction in storage and an accompanying decline in the water table.

Small fluctuations of the water table are due to transpiration by plants whose roots reach the water table. The working depth of root systems seldom exceeds 6 feet and is usually less than 3 feet. Diurnal fluctuations of the water table due to plant activity are thought to be negligible or nonexistent in most of the report area, except in a narrow belt along the north shore and along parts of the channels of some streams.

Under average conditions, the water table may fluctuate annually from about half a foot or less near the shore to as much as 4 feet in inland areas in response to variations in precipitation, evaporation from the soil and ground-water fed ponds and marshes, the interception and utilization of water by vegetation during the growing season, natural discharge, and pumpage.

The hydrograph showing the average water level of 14 wells in Nassau and Suffolk Counties (fig. 8) reflects approximately natural conditions of recharge and discharge. It is based mostly on measurements in wells in which the depth of water is relatively shallow, averaging about 22 feet. During years of average precipitation, the water level rises gradually, reaching a peak in April or May, and then declines irregularly until about October or November, when it again begins to rise. Variations in the amount and intensity of precipitation tend to modify the normal pattern slightly. Figure 8 also shows three water-table hydrographs compared with the hydrograph of the 14 wells. The fluctuations shown on the graphs reflect a general response to seasonal variations in precipitation.

As stated previously, water levels in wells where the depth to water is small generally fluctuate seasonally in response to changes in the recharge-discharge relationship. In contrast, hydrographs of wells in which the depth to water is great show that water levels fluctuate secularly, over a period of 1 to several years. According to Meinzer (1949, p. 408), where the water table is deep, the water from the surface may arrive at the water table at a relatively continuous rate, being offset in part by percolation out of the area. This phenomenon probably accounts in part for the dampening of seasonal fluctuations

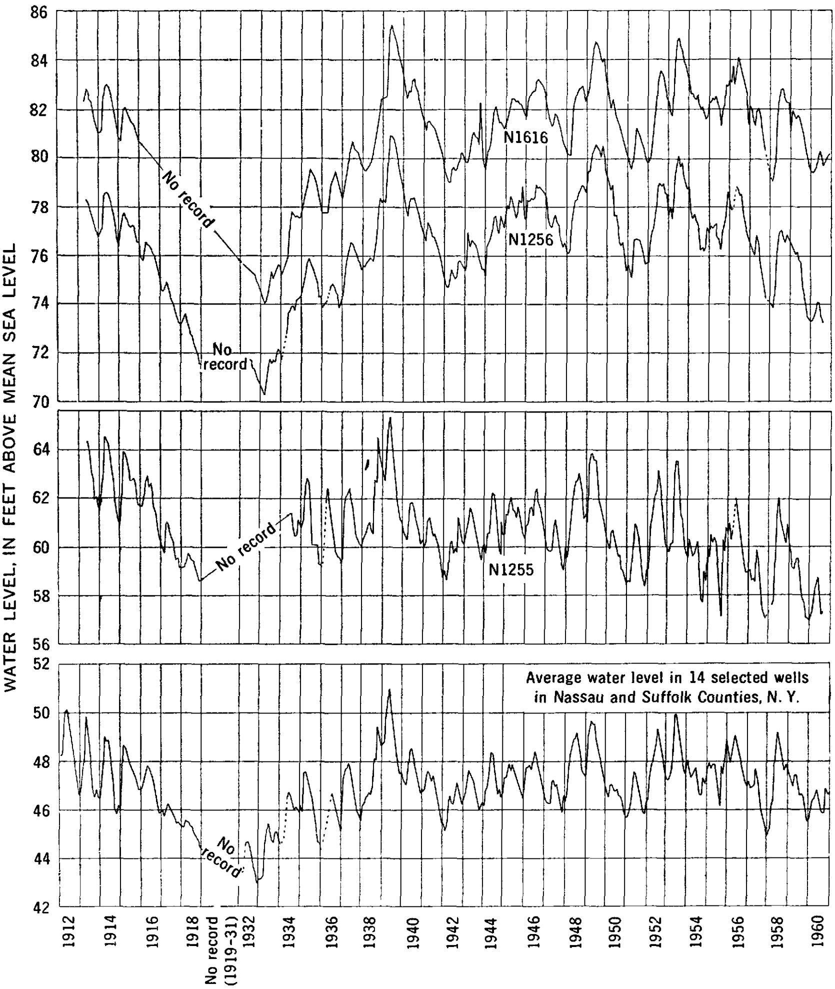

Figure 8.—Hydrographs of three water-table wells in northeastern Nassau County compared with the average water level in 14 selected wells in Nassau and Suffolk Counties, 1912–60.

shown in the hydrographs of deep water-table wells (fig. 9). The hydrographs show fluctuations of the water table at depths ranging from about 10 to 184 feet below the land surface. The diminution in the magnitude of fluctuation of the water table and the increased time lag, as the depth to water increases, can be seen by comparison of the cross-hatched parts of the hydrographs in 1951 (fig. 9, point A). The hydrographs of the deep wells also show fluctuations which correspond to variations in precipitation over a period of several or more months and are roughly comparable to graphs of the cumulative departure from normal precipitation.

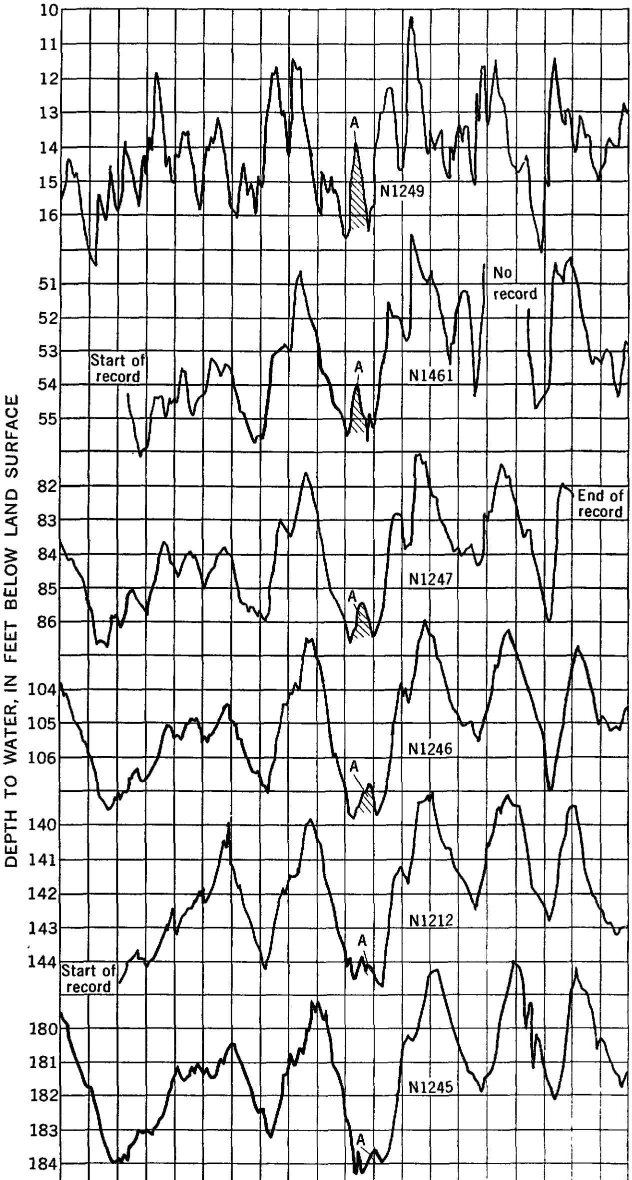

FIGURE 9.—Hydrographs of six water-table wells having different depths to water, 1941–60. Crosshatched areas marked "A" indicate the same peaks on each hydrograph.

The water table near the north shore fluctuates in response to tidal changes in Long Island Sound, which cause movement of sea water into and out of the shallow part of the principal aquifer. The tidal range in the Sound is about 7 to 9 feet. Corresponding fluctuations having a range of about 1 foot have been observed in well N1187 in Bayville, about 700 feet from the Sound. The influence of the tide on fluctuations of the water table diminishes rapidly with increasing distance from the shore and is a function of the permeability of the beds and the magnitude of the tidal variations.

The movement of recharge from the land surface to the water table is a relatively slow process. Although the entire force of gravity acts on the water, the movement of water is affected by such factors as the presence of gases in the intergranular spaces and perhaps by lateral deflection due to stratification of the deposits and lenses of silt and clay. Thus these factors account for a time lag between infiltration at the land surface and the arrival of recharge at the water table.

Water levels in wells in northeastern Nassau County in which the depth to water is about 180 feet generally reflect changes in recharge about 9 months after levels in wells where the depth to water is only 20 feet. The average time lag estimated from the hydrographs of selected wells chiefly in the till-covered part of the report area is summarized in table 10. The lag varies with time, even at the same site, because of various factors. When soil moisture is deficient, infiltrating water will replenish the soil moisture first before it moves down to the water table. In well N1245 (pl. 2 and fig. 9) the depth to water is about 180 feet, and for eight inflections the lag ranged from as little as 5 months to as much as 16 months. In contrast, the depth to water in well N1255 (pl. 2 and fig. 8) is only 20 feet, and the lag ranged from 1 to 2 months for the same eight inflections in the hydrograph. In wells N1461 and N844 (pl. 1), on the glacial outwash plain in Hicksville, the lag appears to be from 1 to 2 months less than in wells having similar depths to water but which are in areas covered by till. Wells having the same depth to water, and similar topographic

TABLE 10.—*Relation of depth to the water table and average time lag in response to recharge in till-covered areas of northeastern Nassau County*

Depth to water table (feet)	Average time lag (months)	Depth to water table (feet)	Average time lag (months)
0–10	0–1	80–100	5–6
10–25	1–2	100–120	6–7
25–40	2–3	120–140	7–8
40–60	3–4	140–160	8–9
60–80	4–5	160–180	9–10

and geologic environments, but at different sites, tend to have similar water-level fluctuations. Therefore, the average permeability for a considerable thickness of the same formations may be similar although the permeability of individual beds may be different.

PIEZOMETRIC SURFACE AT THE MIDDLE OF THE PRINCIPAL AQUIFER

The piezometric surface of a confined aquifer is an imaginary surface that coincides with the static water level in wells tapping the aquifer. The surface can be represented on a map by contours based on the altitudes of water levels in observation wells. The configuration of the contours provides information on recharge areas and the direction of movement of the water. The spacing of the contours indicates the relative permeability of the beds where an aquifer has uniform thickness. Water in the middle and lower parts of the principal aquifer is confined due to stratification and the presence of lenses and beds of clay in the overlying deposits. Most of the observation wells in which water levels were obtained are screened in about the middle of the Magothy(?) Formation, hence, the contours on figure 10 represent the piezometric surface of the middle of the principal aquifer. The piezometric surface of the lower part of the aquifer probably has about the same configuration as that shown on figure 10, but the altitude of the water levels would be slightly different. The contours are only approximate as the control is sparse and the pattern of withdrawals and relatively close spacing of pumping wells undoubtedly affect the water levels, because simultaneous shutdowns could not be obtained at all wells.

The piezometric surface in the report area generally resembles the water table (pl. 4), although it is somewhat lower and more subdued. The main water-table high at Jericho coincides with the high area on the piezometric surface, as apparently does the smaller mound at Locus Valley. However, the mound at East Norwich is apparently not expressed on the piezometric surface. The water-table contour map (pl. 4) represents conditions at the end of April 1960 (a year before preparation of the piezometric map on figure 10). However, a comparison of the general contour configuration on the two maps is possible as the water table usually fluctuates annually only 1 or 2 feet at most. The water table was generally higher in the spring of 1961 than in 1960. Heads on figure 11, which were used to depict ground-water movement in the vertical dimension, were adjusted to the end of March 1961. The altitude of the piezometric surface of the principal aquifer ranges from about 10 feet or less above sea level near the north limit of the aquifer at and near Long Island Sound to nearly 90 feet above sea level beneath parts of Brookville, Hicksville, and Jericho.

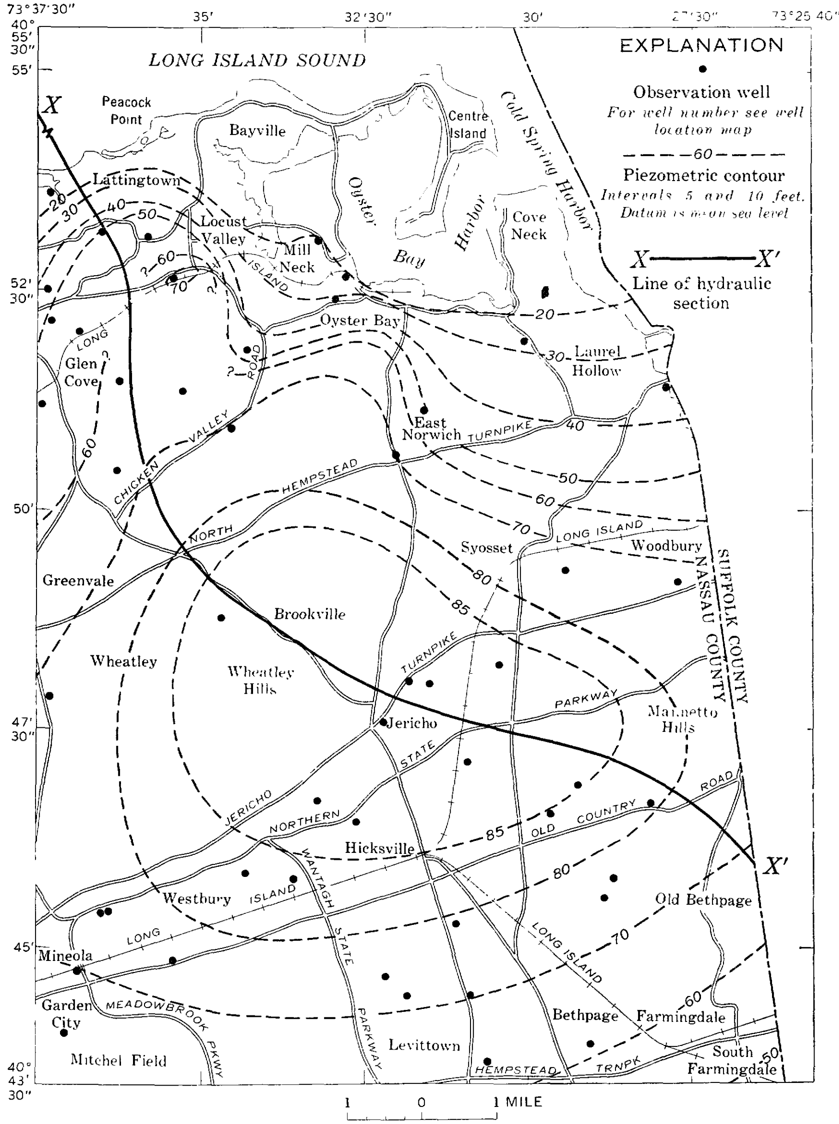

Figure 10.—Piezometric surface at the middle of the principal aquifer in March 1961. (Section X–X' shown on fig. 11.)

MOVEMENT

Water in the zone of saturation moves from points of higher head toward points of lower head. The rate of flow varies directly with the hydraulic gradient and permeability of the beds, and inversely with the porosity. Because horizontal permeability is generally greater than vertical permeability, the water moves faster in the horizontal direction. Slow vertical movement, however, is the only means of recharging the middle and basal parts of the principal aquifer and the deep confined aquifer.

The direction of movement in the principal aquifer can be approximated from the contour maps (pl. 4 and fig. 10) and the generalized section shown on figure 11.

The regional pattern of lateral movement in the principal aquifer is radially outward from a central high on the piezometric surface near Jericho and is normal to the contours on plate 4 and figure 10. Small mounds on the water table in Locust Valley, Greenvale, and East Norwich cause local departures from the regional pattern of movement.

Water in the middle and basal zones of the principal aquifer also moves radially outward from the central high on the piezometric surface (fig. 10). The contours suggest that most of the water in the aquifer moves northward to discharge areas at and near the shore, and southward and westward beyond the limits of the report area.

The vertical component of movement in the principal aquifer under natural conditions is shown by arrows on figure 11. The direction of flow is influenced chiefly by gravity, differences in permeability, and the distribution of heads in the aquifer. Water at the water table moves not only laterally, but also downward. Recharge to the pumped aquifer occurs everywhere and not only in the area of the highest water-table altitudes, although this is where the vertical component is greatest. Some water in the principal aquifer moves parallel to the upper surface of the clay member and then upward to discharge into Long Island Sound to the north, or else moves out of the report area, mostly to the south and west. Some water, however, moves downward through the clay member to recharge the underlying deep confined aquifer. North of the shore line in part of the report area (fig. 11), water moves upward from the deep confined aquifer to the principal aquifer.

The velocity of ground-water movement may be computed by the following equation based on Darcy's law:

$$v=\frac{PI}{7.48p}$$

where

v=velocity, in feet per day,
P=permeability of the deposits in the direction of flow, in gpd per sq ft,
I=hydraulic gradient, in feet per foot, and
p=porosity, which is dimensionless.

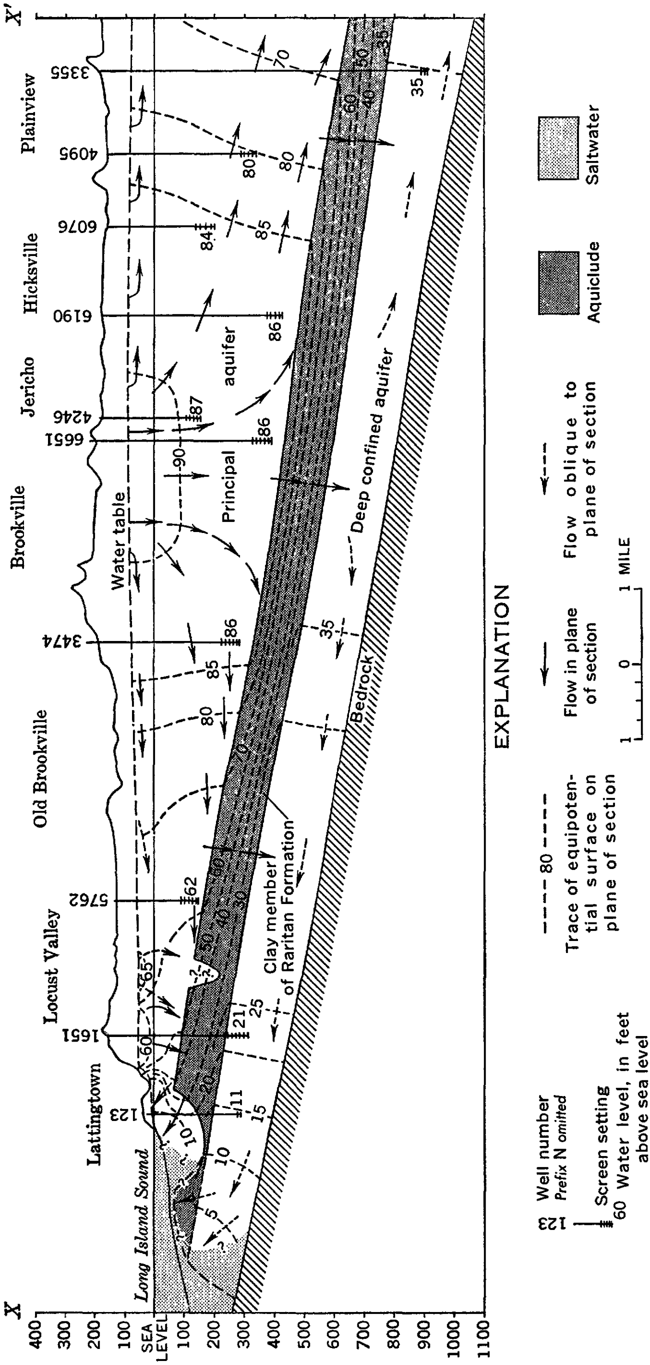

FIGURE 11.—Hydraulic section *X–X'* through the ground-water reservoir from Lattingtown to Plainview.

If the horizontal permeability of the principal aquifier ranges from about 500 to 2,500 gpd per sq ft, the porosity averages 30 percent, and the average hydraulic gradient is 10 feet per mile, the velocity of the water in different parts of the aquifier would vary according to permeability, as follows:

Permeability (gpd per sq ft)	*Approximate velocity (feet per day)*
500	0.4
1,000	.8
1,500	1.2
2,500	2

If the average horizontal permeability of the outwash deposits in the upper part of the principal aquifier is about 1,000 gpd per sq ft and the gradient is 10 feet per mile, the velocity of lateral movement in these beds would probably average about 1 foot per day. In parts of the aquifier in the northern part of the area, which are composed of glacial till and other clayey bodies of low permeability, the velocity is much lower. For example, the permeability of silty clay may be 0.0002 to 0.2 gpd per sq ft (Wenzel, 1942, p. 13). Hence, under a gradient of 10 feet per mile and an assumed porosity of 30 percent, the rate of movement in clayey beds might be 0.0000001 to 0.0001 foot per day.

DISCHARGE

Ground water discharges from the principal aquifer by seepage into streams and at springs, by evapotranspiration, by ground-water outflow, and by withdrawals from wells. The first two methods have been discussed in previous sections. Ground-water outflow as here defined consists of submarine discharge into Long Island Sound to the north and underflow to the south and west beyond the report area. Some water moves downward through the confining beds into the deep confined aquifer, and some is discharged from wells.

STREAMS AND SPRINGS

The base runoff (total discharge minus direct runoff) of all streams in the area constitutes part of the ground-water discharge from the principal aquifer. Streamflow in the upper reaches of the larger streams is largely intermittent. It consists almost entirely of direct runoff during and immediately following precipitation and of some water discharged from perched water bodies. A summary of the base runoff of three continuously gaged, and seven intermittently measured streams is given in table 11. The combined discharge of these streams is about 20 mgd, of which approximately 19 mgd is ground-water discharge and 1 mgd is direct runoff. An estimated 2 mgd was discharged from numerous springs along the shoreline of Long Island

TABLE 11.—*Ground-water discharge to streams from the principal aquifer, 1960*

Stream	Location	Topographic-drainage area (sq mi)	Mean daily discharge (mgd)	Direct runoff (mgd)	Ground-water discharge [1] (mgd)
Cold Spring Brook	At Cold Spring Harbor	7	3.1	0.2	[2] 2.9
Mill Neck Creek	At Mill Neck	12	6.3	.3	6.0
Cedar Swamp Creek	At Glen Cove	11	4.8	.2	4.6
Island Swamp Brook	Near Lattingtown	1	.5	0	.5
Frost Creek tributary 1	At Lattingtown	1	1.0	0	[3] 1.0
Frost Creek tributary 2	At Lattingtown	.2	.1	0	[3] .1
Little Meadow Brook	At Locust Valley	.5	.6	0	[3] .6
Spring Lake Creek	At Mill Neck	.7	.3	0	[3] .3
Mill River	At Oyster Bay	1.4	2.8	.1	[3] 2.7
Cove Neck Creek	Near Oyster Bay	2.6	.5	0	[3] .5
Total		37.4	20.0	.8	19.2

[1] Base flow of stream at point of gaging.
[2] Total discharge at gaging station; about 4.4 sq mi of total drainage area is in Nassau County, the remainder is in Suffolk County.
[3] Adjusted from miscellaneous measurement.

Sound and its harbors in 1960. Hence, ground-water discharged into streams and from springs totaled about 21 mgd in 1960.

GROUND-WATER OUTFLOW

Ground water discharges naturally from the principal aquifer in all directions. Northeastern Nassau County is not a hydrologic unit. The only natural hydrologic boundary is Long Island Sound to the north. The boundaries to the east, west, and south are arbitrary, and discharge in these directions consists of flow across the boundaries of the study area.

The flow of water through the zone of saturation is directly proportional to the permeability of the beds, the hydraulic gradient, and the cross sectional area through which the water moves. Outflow from the principal aquifer is probably greater to the north where gradients are steepest and to the south where the aquifer is thickest. Little if any outflow occurs to the east where flow is largely parallel to the Nassau County–Suffolk County line, the east limit of the area.

Ground-water outflow cannot be measured directly. However, it may be estimated by considering all other parameters in the hydrologic budget. On the basis of an average recharge from precipitation of about 109 mgd, total outflow from the principal aquifer is estimated at about 71 mgd. (See subsection on "Hydrologic budget.")

DEEP CONFINED AQUIFER

The deep confined aquifer is the lowermost aquifer in the report area. It consists mainly of the Lloyd Sand Member but in some places includes the Jameco Gravel and younger Pleistocene deposits that are hydraulically connected with the Lloyd Sand Member. The clay member of the Raritan Formation confines the Lloyd in most of the area, but in a few places confinement is provided by both the clay member of the Raritan Formation and by the Gardiners Clay (pl. 3). Bedrock forms the lower boundary of the deep confined aquifer.

RECHARGE

The deep confined aquifer is recharged entirely by water which moves downward from the principal aquifer through the confining beds (fig. 11). Comparison of the contours on the piezometric surfaces of the principal aquifer (fig. 10) and the deep confined aquifer (fig. 12) suggests that the deep confined aquifer receives some recharge nearly everywhere in the report area except in a narrow strip along part of the north shore where heads in the deep confined aquifer are higher than those in the basal part of the principal aquifer, and the movement of water is reversed. (See table 12 for vertical-head relations at Bayville.) The heads decrease upward along this strip showing that the vertical component of head is upward through the confining beds. No water moves into the deep confined aquifer of northeastern Nassau County from adjoining areas.

Because of scanty data, it is difficult to estimate recharge to the deep confined aquifer. The recharge probably averages between 0.1 and 0.2 mgd per sq mi; but owing to the wide range in vertical permeabilities of the clay member and in hydraulic gradients, recharge from some parts of the principal aquifer to the deep confined aquifer locally may be several times higher or lower than the average.

TABLE 12.—*Vertical head relations at Bayville on November 7, 1961*

Well	Screened depth (feet below land surface)	Water-bearing unit	Water level (feet above sea level)
N7193	15–18	Principal aquifer	2.72
7192	37–40	do	[1] 2.63
7191	139–142	(2)	10.88
7152	360–370	Deep confined aquifer	12.84

[1] Well screened in water having a chloride content as high as 5,400 p.p.m.
[2] Well screened in sandy zone in clay member of Raritan Formation.

PIEZOMETRIC SURFACE

The piezometric surface of the deep confined aquifer reflects artesian pressure in the aquifer. Changes in artesian pressure are in part compensated by the elasticity of the aquifer and to a lesser degree by water moving into and out of storage in the overlying beds of clay and silt.

Figure 12 shows approximate contours on the piezometric surface of the deep confined aquifer in March 1961. Measurements were made in observation and other wells which were shut down for periods ranging from an hour to several months. The map is generalized because the control points are mostly concentrated in the northern part of the report area, and the measurements could not be made simultaneously in all wells. Heads range from an estimated 40 feet above sea level in the east-central part of the area to 5 or 10 feet above sea level at the north shore. The hydraulic gradient is about 10 feet per mile in the northern and western parts and decreases to about 3 feet per mile in the southern and southwestern parts of the area. The main divide on the piezometric surface trends eastward through the center of the area (Brookville, Syosset, and Cold Spring Harbor Station). The slope of the piezometric surface near the north shore is relatively uniform, and heads may reach sea level about to 1 to 1½ miles offshore.

Figure 12 suggests a mound on the piezometric surface of the deep confined aquifer at Locust Valley which apparently coincides approximately with the mounds noted on the water table (pl. 4) and on the piezometric surface of the principal aquifer (fig. 10). The geologic and hydraulic factors responsible for these mounds are not fully known. Whether or not the vertical permeability of the confining beds is relatively higher at Locust Valley than elsewhere is uncertain. However, logs of wells in this area indicate considerable clay in the section, so it seems unlikely that the vertical permeability is much higher than elsewhere.

Water levels in wells tapping the deep confined aquifer generally fluctuate in a manner similar to those in the basal part of the principal aquifer. Short-term cyclical fluctuations caused by ocean-tidal loading, changes in atmospheric pressure, and pumping occur at about the same time as those in the confined part of the principal aquifer but are generally of equal or greater magnitude.

Figure 13 shows the comparison between water levels in well N3355 (pl. 1), screened in the Lloyd Sand Member at Plainview, and atmospheric pressure at Garden City. The magnitude of the fluctuations suggests that the well has a barometric efficiency approaching 100 percent, which indicates a very high degree of confinement.

Water levels in wells screened in the deep confined aquifer near Long Island Sound fluctuate with changes in ocean tide level because of the changing load on the aquifer transmitted through the overlying confining beds. The loading effect produced by a rise in ocean tides produces an increase in artesian pressure and a corresponding rise in water levels in wells, whereas a decline in tide has the opposite effect. Water-level fluctuations caused by tidal loading in well N7152

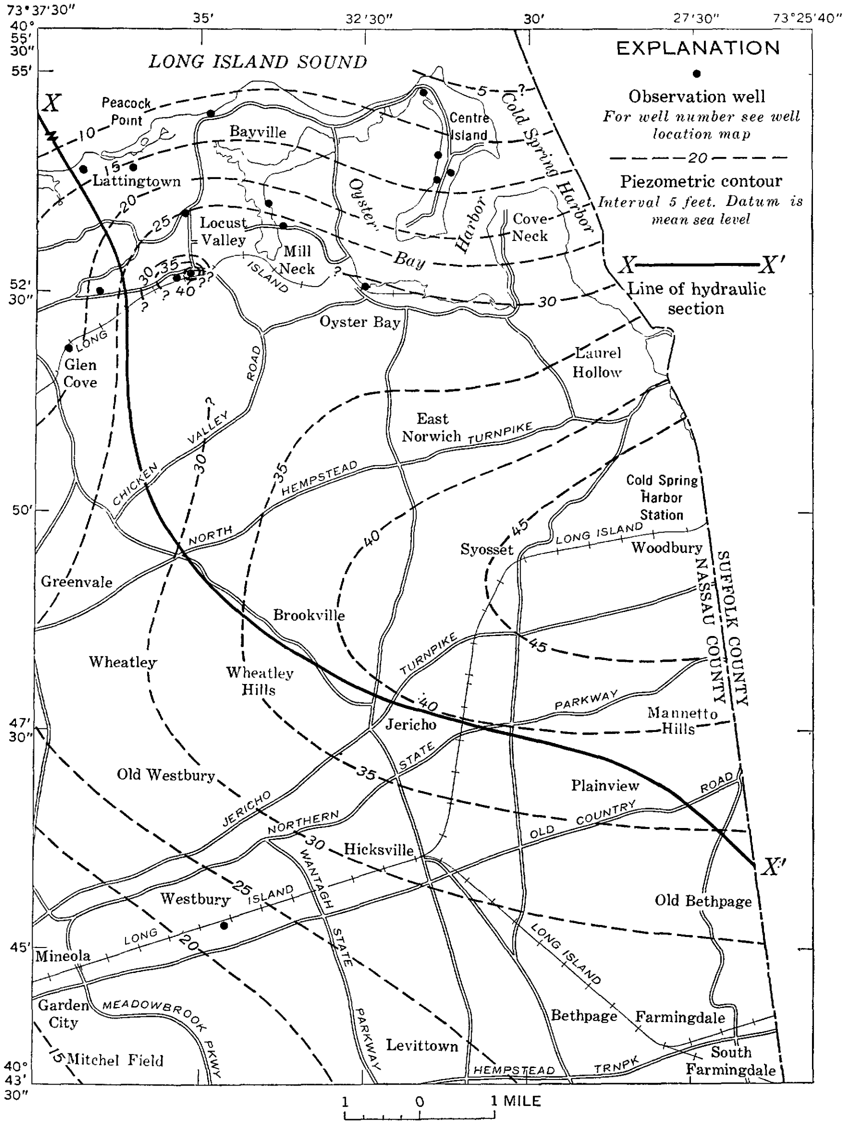

FIGURE 12.—Piezometric surface of the deep confined aquifer in March 1961. (Section *X–X'* shown on fig. 11.)

(pl. 1) in Bayville range from about 1.5 to 3 feet, and average about 2 feet.

Figure 14 shows hydrographs of wells N511 on Mill Neck and N3355 at Plainview (pl. 1) both of which are screened in the deep aquifer. Well N511 is less than 1 mile from supply well N5152 (pl. 1), also screened in the deep confined aquifer near the shoreline. Well N3355 is nearly 7 miles from the nearest pumped well screened

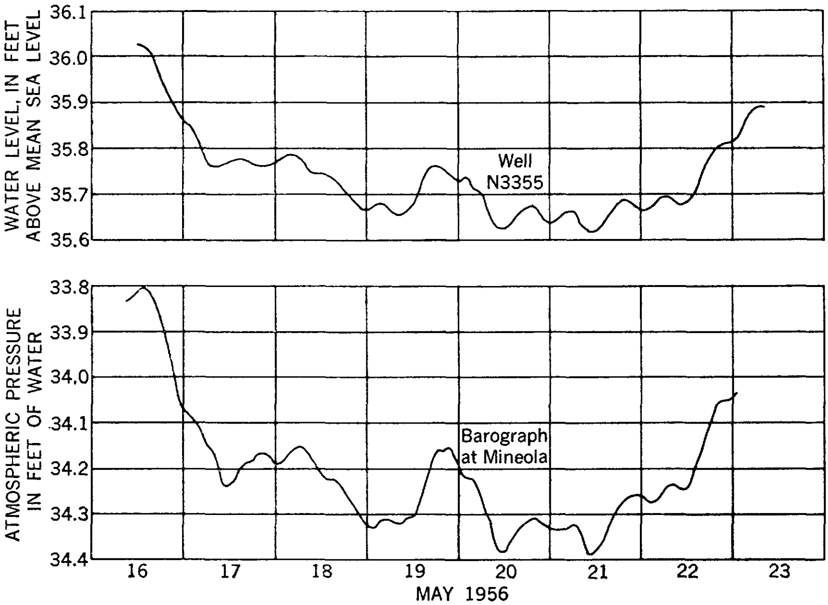

FIGURE 13.—Hydrograph of well N3355 showing water-level fluctuations caused by changes in atmospheric pressure.

in the deep confined aquifer (N2602, pl. 1) and more than 7 miles from Long Island Sound. The hydrograph of N511 is based on month-end measurements made during high tide in Long Island Sound; therefore, diurnal tidal influences are not represented in the hydrograph. Well N3355 is far enough from the shore to be free of ocean tidal influence.

The fluctuations of the water levels in wells N511 and N3355 are a result of a complex combination of pumpage and natural discharge and recharge. In an area remote from pumping wells in central Suffolk County, water levels in wells screened in the basal part of the principal aquifer have seasonal fluctuations similar to those of the water table but with only about two-thirds of the amplitude. The fluctuations in the deep confined aquifer are also similar but have only about one half the amplitude of the water-table fluctuations. No apparent time lag exists between the peaks and troughs shown on the three hydrographs (not shown) of the wells in Suffolk County. The hydrograph of N3355 is neither similar to the hydrograph of nearby water-table well N1246 (pl. 1) nor to a graph of pumpage from the deep confined aquifer in Nassau County. However, when the water-table hydrograph and the pumpage graph are superimposed, a composite curve is obtained which resembles the hydrograph

209-982—66——5

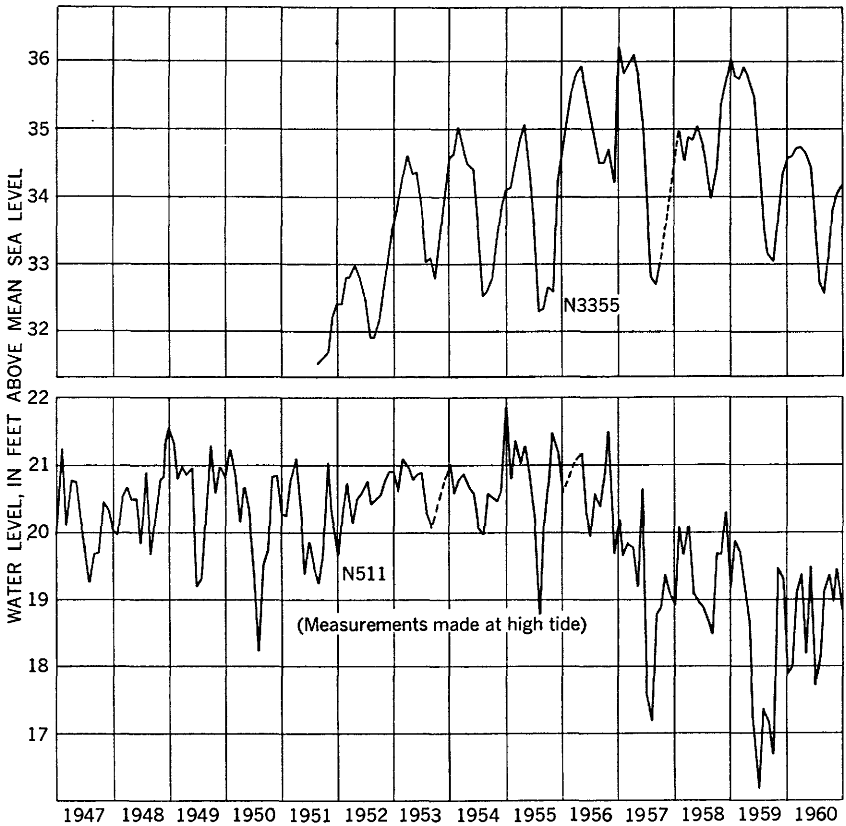

Figure 14.—Hydrographs of observation wells screened in the deep confined aquifer at Mill Neck and Plainview, 1947–60.

of well N3355. Therefore, the chief causes of seasonal water-level fluctuations in the deep confined aquifer in the report area are probably withdrawals from wells screened in the same aquifer, combined with natural effects of recharge to and discharge from the ground-water reservoir. The hydrograph of N511 is more irregular than that of N3355 owing to local pumping effects from N5152 at Locust Valley; however, the overall trend is generally similar.

MOVEMENT

Water in the deep confined aquifer moves from areas of higher head to areas of lower head. The horizontal component of movement is normal to the piezometric contours (fig. 12) and in the direction of the arrows on figure 11. Generally the water moves radially outward from the central high area (Syosset, Cold Spring Harbor Station).

Some water moves radially away from the local mound in Locust Valley. Most of the water moves to the north, south, and west, and apparently none moves to the east. For an average horizontal permeability of the beds of 400 gpd per sq ft, a porosity of 0.25, and a hydraulic gradient of 5 feet per mile, the velocity of the water horizontally would be about 0.2 foot per day. In the vicinity of pumping wells, hydraulic gradients are steeper and the rate of movement may be greater.

Data are inadequate to show any vertical movement within the deep confined aquifer. However, the water-bearing beds are stratified and the vertical permeability is lower than the horizontal permeability, which would result in less movement vertically than horizontally.

DISCHARGE

Water discharges from the deep confined aquifer by outflow across the boundaries of the area and by naturally flowing and pumped wells.

The writer estimates total outflow at about 10 mgd. Outflow is about 4 mgd to the north into Long Island Sound, about 2 mgd to the south, and about 4 mgd to the west.

About 30 wells screened in the deep confined aquifer near the north shore flow to waste at least part of the time at rates ranging from 1 to 50 gpm. The total estimated flow is 1 mgd. About 2 mgd is pumped from the deep confined aquifer. Virtually all this is returned to the principal aquifer by cesspools.

PUMPAGE

Gross pumpage from wells in the report area averaged about 43 mgd in 1960. The withdrawals are summarized according to major use:

Supply	*Mgd*
Public	32.6
Industrial	10.3
Agricultural	.08
Total (rounded)	43

Pumpage for public and industrial supply is increasing slowly in northeastern Nassau County, but agricultural pumpage is declining.

PUBLIC SUPPLY

Table 13 lists 110 public-supply wells that were in use in 1962 in northeastern Nassau County and the geologic formations and aquifer designation of the producing zones. Public-supply pumpage is shown by graphs on figure 15. The general upward trend is indicated by the increase in total pumpage from 6.2 mgd in 1944 to 32.6 mgd in 1960; a record high of 33.7 mgd was reported in 1957.

TABLE 13.—*Summary of public-supply wells in northeastern Nassau County, 1962*

[All wells are in principal aquifer except well N115, which is in both the principal aquifer and the deep confined aquifer, and wells N118, N119, N1651, N5152, and N2602, which are only in the deep confined aquifer]

Well No. State	Well No. Owner	Geologic unit
Long Island State Park Comm., Bethpage State Park		
N189	--------	Magothy(?) Formation
617	--------	Do.
Bethpage Water District		
N3876	6	Magothy(?) Formation
4063	7	Do.
4146	8	Do.
6078	9	Do.
6915	10	Do.
6916	11	Do.
Carle Place Water District		
N2747	1	Magothy(?) Formation
2748	2	Do.
4206	3	Do.
6315	4	Do.
Farmingdale, Village of		
N706	1-2	Magothy(?) Formation
1937	2-1	Do.
6644	2-2	Do.
Garden City, Village of		
N3934	10	Magothy(?) Formation
3935	11	Do.
Hicksville Water District		
N2072	4	Magothy(?) Formation
3488	5	Do.
3552	6	Do.
3553	7	Do.
3878	9	Do.
3953	8	Do.
5336	10	Do.
6190	11	Do.
6191	12	Do.
6192	13	Do.
6193	14	Do.
Jericho Water District		
N198	3	Magothy(?) Formation
199	4	Do.
570	5	Do.
3474	6	Do.
3475	7	Do.
4133	8	Do.
4245	9	Do.
4246	10	Do.
6092	12	Do.
6093	13	Do.
6651	14	Do.
7030	15	Do.
Levittown Water District		
N2402	1	Magothy(?) Formation
2403	2	Upper Pleistocene deposits
3194	6	Magothy(?) Formation
4451	10	Do.
5301	11	Do.
7076	5A	Do.
Locust Valley Water District		
N115	1	Upper Pleistocene deposits, Jameco Gravel
118	4	Jameco Gravel
119	5	Do.
1651	6	Lloyd Sand Member
5152	7	Do.
Mineola Water District		
N5596	6	Magothy(?) Formation
Mitchell Field		
N1696	5	Magothy(?) Formation
3695	1	Do.
3696	2	Do.
3697	3	Do.
3698	4	Do.
New York Water Service Div. of Utilities and Industries Corp.		
N802-4	2-4	Magothy(?) Formation
808-13	8-13	Upper Pleistocene deposits
815-18	15-18	Magothy(?) Formation
3466	20	Do.
3892	Seaman Rd 1	Upper Pleistocene deposits, Magothy(?) Formation
5261	Seaman Rd 2	Upper Pleistocene deposits
5762	Roxbury 1	Magothy(?) Formation
Old Westbury, Village of		
N105	2	Magothy(?) Formation
107	3	Do.
152	1	Do.
Oyster Bay Water District		
N585	6	Upper Pleistocene deposits
734	3	Do.
735	4	Do.
736	5	Do.
3486	1	Do.
3561	2	Do.
4400	7	Do.

TABLE 13.—*Summary of public-supply wells in northeastern Nassau County, 1962*—Continued

Well No. State	Well No. Owner	Geologic unit
Piping Rock Water Company		
N166	1	Magothy(?) Formation
167	2	Do.
613	3	Do.
614	4	Do.
Plainview Water District		
N4095	1-1	Magothy(?) Formation
4096	1-2	Do.
4097	3-1	Do.
6076	4-1	Do.
6077	4-2	Do.
6580	3-2	Do.
6956	5-1	Do.
Roslyn Water District		
N4265	3	Magothy(?) Formation
7104	6	Do.
Westbury Water District		
N101	6	Magothy(?) Formation
750	2	Do.
827	3	Do.
828	4	Do.
829	5	Do.
1667	7	Do.
2236	8	Do.
2602	9	Lloyd Sand Member
5007	10	Magothy(?) Formation
5654	11	Do.
5655	12	Do.
6819	12A	Do.
7353	14	Do.

Public-supply pumpage from the deep confined aquifer increased from an average of about 0.7 mgd in 1944 to 1.4 mgd in 1954, but conservation policies by both the water companies and the New York State Water Resources Commission helped maintain the average withdrawal slightly below 2 mgd from 1954 to 1960. Pumpage from the part of the principal aquifer composed of the Magothy(?) Formation increased from an average of 2.7 mgd in 1948 to 29.6 mgd in 1959. This increase was due in part to the construction of new public-supply wells tapping mainly the middle and basal zones of the Magothy(?) Formation and increased withdrawal from existing wells. Average pumpage for public supply from the upper Pleistocene deposits in the upper part of the principal aquifer increased from 1.6 mgd in 1945 to 4.8 mgd in 1938, but it was about 2.5 mgd during the period 1949–60. The decrease in upper Pleistocene pumpage is a result of the replacement of some shallow wells by deeper wells.

Plate 5 shows the areal distribution and average daily pumpage for public supply by geologic source in northeastern Nassau County in 1960. About 90 percent of the pumpage was from wells tapping the part of the principal aquifer composed of the Magothy(?) Formation, mostly in the south half of the report area.

INDUSTRIAL USE

Industrial pumpage in northeastern Nassau County increased 83 percent between 1948 and 1960. The average daily withdrawal ranged from a low of about 1.7 mgd in 1948 to a high of 11.3 mgd in 1959. By

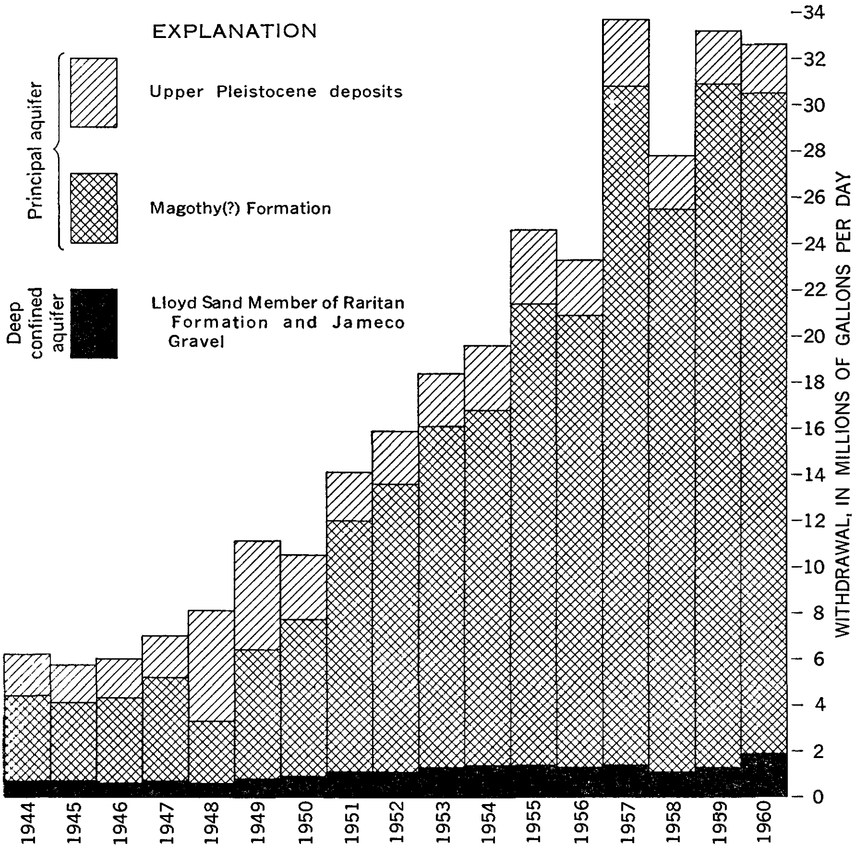

FIGURE 15.—Total annual withdrawal for public supply, by geologic source and aquifer, 1944–60.

comparison, total industrial pumpage in Nassau County for the same period increased about 75 percent—from an average of 7 mgd in 1948 to 27.1 mgd in 1959—and the total industrial pumpage for Long Island increased 35 percent—from 61 mgd in 1949 to 95 mgd in 1959. Industrial pumpage in the report area was 42 percent of the total pumpage for industrial use in Nassau County and 11 percent of the total industrial pumpage in Long Island during 1959. During 1960, an average of about 10.3 mgd was pumped for industrial use in the report area, of which almost all was pumped from the principal aquifer (1.5 mgd from the upper Pleistocene deposits and 8.8 mgd from the Magothy (?) Formation), and less than 0.1 mgd was pumped from the deep confined aquifer. Except on private estates and golf courses in the northern part of the area where a few wells used mainly for sprinkling are classified as industrial, no industrial wells tap the deep confined aquifer. However, about 1 mgd is pumped from the deep confined aquifer at industrial sites in Glenwood Landing and Glen Cove, about 1 mile west of the report area.

AGRICULTURAL USE

In 1960, 0.1 mgd was pumped for irrigation from about 23 wells at 19 farms in Nassau County. Seven of these wells are in the report area and had a combined average pumpage of about 0.08 mgd. The entire withdrawal for agricultural use was from the principal aquifer and consisted of about 0.02 mgd pumped from the upper Pleistocene deposits and 0.06 mgd pumped from the Magothy (?) Formation.

EFFLUENT FROM SEWAGE-TREATMENT PLANTS

Nearly all the water pumped in the report area is returned to the ground-water reservoir except in small sewered areas along the north shore where two sewage treatment plants discharge approximately 4 mgd of effluent into Long Island Sound. The larger installation, Glen Cove Sewage Treatment Plant, serves the city of Glen Cove, part of which extends beyond the west limit of the project area. However, all the water used for public supply in the city of Glen Cove is pumped from wells in the report area, which are owned by the New York Water Service Division, Utilities and Industries Corporation. During 1960, the Glen Cove Sewage Treatment Plant processed an average of 2.7 mgd of effluent (table 14). The plant capacity is about 3 mgd. The second and smaller plant, owned by the Oyster Bay Sewer District, serves part of the village of Oyster Bay and nearby unincorporated areas in the town of Oyster Bay. During 1959, the Oyster Bay Sewer District processed about 1.1 mgd of effluent; the average daily sewage flow was 0.53 mgd and the average daily infiltration (leakage of ground water into sewer system) was 0.60 mgd.

Effluent from the Glen Cove plant receives secondary treatment and discharges into Hempstead Harbor; effluent from the Oyster Bay plant receives primary treatment and discharges into Oyster Bay Harbor.

TABLE 14.—*Metered effluent from the Glen Cove Sewage Treatment Plant in 1960*

[Data from records of Glen Cove Sewage Treatment Plant]

Month	*Effluent (million gallons)*	*Month*	*Effluent (million gallons)*
January	78.8	September	82.8
February	75.5	October	84.1
March	81.8	November	84.7
April	81.7	December	83.1
May	81.5		
June	83.1	Total	990
July	84.2		
August	88.7	Daily average	2.7

The combined average discharge of sewage effluent is about 4 mgd and represents a net loss to the ground-water reservoir.

HYDROLOGIC BUDGET

A hydrologic budget is an accounting of the inflow to, the outflow from, and the changes in storage in a hydrologic unit such as a drainage basin, aquifer, or system of aquifers such as the ground-water reservoir of Long Island. Because northeastern Nassau County is not a hydrologic unit and available data are not adequate, a precise quantitative evaluation of all the variables in the hydrologic budget cannot be made. However, approximations have been made of the various parameters from known or estimated geologic and hydrologic data described in the previous sections or extrapolated from nearby areas.

The general relation of recharge to discharge and change in storage for any given period is expressed by the equation

$$GWR = GWD \pm \Delta GWS,$$

where

GWR=total ground-water recharge,
GWD=total ground-water discharge, and
ΔGWS=change in ground-water storage.

An approximate hydrologic budget, based on this equation, is shown schematically on figure 16. Most of the figures are estimates and should not be considered as absolute. On the basis of a mean annual rainfall of 45 inches (2 mgd per sq mi) and an infiltration area of about 109 square miles, it is estimated that about 220 mgd falls on the report area. Subtraction of evapotranspiration losses of about 110 mgd and direct runoff of 1 mgd yields an average net natural ground-water recharge of about 109 mgd.

The following table summarizes the balance between natural ground-water recharge and discharge; the change in storage is considered to be negligible.

Of the 109 mgd of natural recharge that percolates down to the principal aquifer, about 21 mgd is discharged from streams and springs and about 1 mgd from flowing wells; about 41 mgd is pumped from wells, but owing to return of water (including about 2 mgd pumped from the deep confined aquifer) through cesspools, recharge basins, and diffusion wells, the net withdrawal is only 6 mgd; about 13 mgd moves down to recharge the deep confined aquifer; and about 71 mgd is discharged from the area as outflow. It is estimated that about 30 to 40 mgd of the total outflow from the principal aquifer moves to discharge areas at or beyond the north shore where it helps to maintain the position of the salt-water interface and the remainder of the outflow moves to adjoining areas.

Average daily ground-water budget, in millions of gallons per day, of northeastern Nassau County in 1960

Recharge	
Precipitation	109
Discharge	
Streams	19
Springs and flowing wells	3
Net withdrawal (sewage wasted to sea and evapotranspiration loss from lawn sprinkling)	6
Ground-water outflow	81
	109

Of the 13 mgd which percolates down into the deep confined aquifer, 3 mgd is discharged through pumped and flowing wells and 10 mgd moves out of the area as outflow. Probably about 4 mgd of the outflow moves north to discharge beneath Long Island Sound, where it

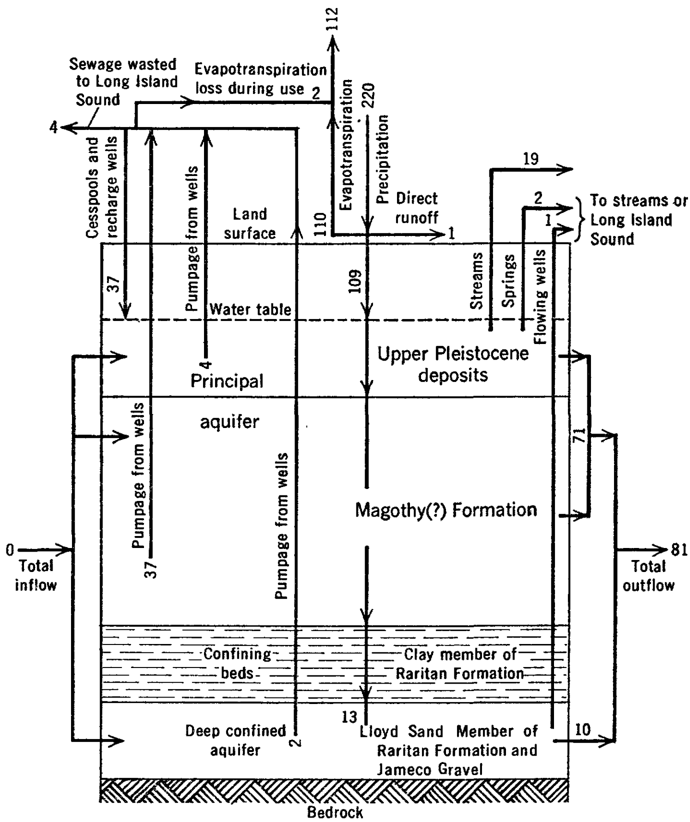

FIGURE 16.—Hydrologic budget, in millions of gallons per day.

helps to maintain the position of the salt-water front; the remainder moves to adjoining areas.

In summary, under present recharge conditions and the rate of withdrawal in and near the report area, about 81 mgd is lost as outflow and 22 mgd is lost through streams, springs, and flowing wells. Of the total outflow, about 30 to 40 mgd probably flows north to Long Island Sound, and the remainder moves to adjoining areas mainly to the south and west.

Under these conditions, an increase in the present pumping rate of one to two times would probably not seriously affect ground-water conditions in the northeastern part of the county, provided that (1) additional production wells are spaced far enough from existing wells and from each other to prevent undue interference (mutual drawdown of water levels during pumping), (2) the additional wells are located far enough inland to minimize sea-water encroachment into the aquifers, and (3) a large percentage of the water pumped continues to be returned to the principal aquifer either through cesspools, injection wells, or recharge basins.

QUALITY OF WATER

TEMPERATURE

The increasing influx of industry and population in the report area has placed additional demands on the ground-water supply for use in refrigeration and air conditioning. Ground water is commonly utilized for these purposes because of its relatively low and constant temperature. Water in streams, lakes, bays, and Long Island Sound is generally not used for cooling because of its wide annual range in temperature. The maximum desirable water temperature for use in air-conditioning systems where the water comes in direct contact with the cooling coils is about 57°F, whereas other systems may use water having temperatures up to about 70°F. Use of water having a temperature above these limits decreases the efficiency and economy of the equipment considerably.

Natural ground-water temperatures in Nassau County commonly range from about 45°F to 70°F, depending mainly on the depth of the aquifer and seasonal factors. Normally, ground-water temperatures fluctuate over a greater annual range in shallow wells than in deep wells, primarily due to the influence of air temperature.

Miscellaneous measurements of ground-water temperature (table 15), made mostly between 1960 and 1962 in the report area, ranged from about 50°F in the upper Pleistocene deposits (principal aquifer) to about 60°F in the Lloyd Sand Member (deep confined aquifer).

TABLE 15.—*Ground-water temperatures in northeastern Nassau County*

[Pa, principal aquifer; Dca, deep confined aquifer]

Well	Depth (feet below land surface)	Geologic unit	Aquifer	Date	Temperature (degrees Fahrenheit)
N115	409	Upper Pleistocene deposits, Jameco Gravel.	Pa, Dca	Feb. 21, 1962	52.6
188	72	Magothy(?) Formation	Pa	do	49.8
198	617	do	Pa	Aug. 15, 1960	52.0
199	600	do	Pa	Feb. 21, 1962	52.3
511	326	Lloyd Sand Member	Dca	Jan. 11, 1961	55.5
1243	22	Upper Pleistocene deposits	Pa	Dec. 5, 1960	56.8
1651	465	Lloyd Sand Member	Dca	Aug. 15, 1960	58.9
1937	146	Magothy(?) Formation	Pa	Feb. 21, 1962	51.4
2602	800	Lloyd Sand Member	Dca	Mar. 26, 1957	59.0
				Feb. 21, 1962	59.6
3355	1,092	do	Dca	Mar. 21, 1962	57.9
3474	512	Magothy(?) Formation	Pa	July 23, 1962	52.8
3475	482	do	Pa	Feb. 21, 1962	54.5
3488	168	do	Pa	do	54.0
3552	169	do	Pa	do	54.4
4133	450	do	Pa	do	53.0
4245	605	do	Pa	do	53.1
4400	252	Upper Pleistocene deposits	Pa	do	51.1
5301	377	Magothy(?) Formation	Pa	do	52.4
5655	255	do	Pa	Mar. 26, 1957	51.0
				Feb. 21, 1962	51.2
5762	280	do	Pa	Aug. 15, 1960	50.4
6092	631	do	Pa	Feb. 21, 1962	52.8
6191	489	do	Pa	do	52.5
6675	460	Jameco Gravel	Dca	Dec. 5, 1960	56.8

Water temperatures at various depths in observation well N3355 in Plainview are given in table 16. The static water level was 148.4 feet in March 1962. The temperatures were obtained with a direct-reading electric thermometer. The thermistor probe was lowered to the bottom of the well and measurements were made at 50-foot intervals as the probe was raised. The temperatures measured in well N3355 are similar to those obtained from pumped wells at comparable depths in the report area.

According to the data in table 17, the temperature gradient between depths of 400 and 1,000 feet is about 1°F in 80 feet. The cause of the apparent inversion in temperature in the upper part of the well is uncertain but may be due in part to the influence of the 150-foot air column above the water surface in the well.

TABLE 16.—*Temperature, in degrees Fahrenheit, of water at selected depths, in feet below land surface, in well N3355, March 1962*

Depth	Temperature	Depth	Temperature
150	50.0	650	52.2
200	49.8	700	52.5
250	49.3	750	53.0
300	49.5	800	54.0
350	49.5	850	55.0
400	49.8	900	55.8
450	50.2	950	56.8
500	50.8	1,000	57.0
550	51.2	1,050	57.8
600	51.8		

Conditions imposed by the New York State Water Resources Commission require that all water pumped from wells for air conditioning or cooling be used in a closed system and be returned to the same aquifer from which it is pumped by means of a diffusion well or some other equivalent structure. Recharge of warm water from cooling systems has resulted in local warming of the water in the principal aquifer in a few parts of the report area. However, existing data do not indicate any widespread significant changes in temperature of the natural ground water. Commercial and industrial areas in parts of Garden City, Westbury, Hicksville, and Plainview, where large amounts of warm water are returned after use for cooling, should be monitored to detect any rise in ground-water temperature in the future.

CHEMICAL QUALITY

All ground water contains certain chemical elements in solution because water is a solvent for practically all minerals. The ability of water to dissolve minerals is greatly enhanced by the presence of dissolved carbon dioxide, which combines with water to form a weak solution of carbonic acid. Some carbon dioxide is dissolved directly from the atmosphere by rainwater; a greater amount is derived from the decomposition of organic matter in the soil.

Chemical analyses of water samples from wells in Nassau County are made by the Nassau County Department of Health and the U.S. Geological Survey not only to ascertain the general chemical quality but also to detect changes in the quality which might be related to sea-water encroachment, contamination, and pollution. Table 17 gives representative chemical analyses of water, and table 18 summarizes the concentrations and properties of the principal chemical constituents.

Nearly all the ground water in the project area is suitable for most domestic and industrial uses.

The dissolved-solids concentrations in fresh water in both the principal and deep confined aquifers are usually less than 100 ppm (parts per million). The highest content recorded was 247 ppm in 1952 in water from well N2403 screened in the upper part of the principal aquifer in Levittown. This unusually high concentration was due to local contamination, probably from a combination of fertilizer and cesspool effluent. However, it is still considerably less than the maximum of 500 ppm recommended by the U.S. Public Health Service (1962).

No exact relationship exists between the dissolved-solids content and the specific conductance of water (Hem, 1959, p. 39–40), although the specific conductance is dependent upon the concentration and type of dissolved ions and temperature. The specific conductance of the

TABLE 17.—*Chemical analyses of ground water in northeastern Nassau County*

[Chemical constituents in parts per million unless otherwise noted]

Well	Map coordinates	Depth of well below land surface (feet)	Geologic unit	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na and K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$ (calcium, magnesium)	Alkalinity as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH	Remarks: Sodium (Na)	Remarks: Potassium (K)
N152	2B, 1.7N, 1.6W	476	Magothy(?) Formation	Feb. 26, 1935	11	0.40	3.4	1.1	4.5	16	2.3	4.5	0.0	0.3	34	13	13	----	----	3.9	0.6
174	5C, 0.7N, 1.7W	220	Lloyd Sand Member of Raritan Formation.	May 1, 1934	10	----	3.2	1.6	5.7	20	2.6	4.5	.1	.2	38	15	16	----	----	4.8	.9
198	3D, 2.0N, 1.7W	617	Magothy(?) Formation	Aug. 15, 1960	7.1	.02	1.0	.4	3.2	6	.3	3.0	.0	2.9	19	4	5	29	6.0	3.0	.2
511	5B, 1.2N, 1.3W	356	Lloyd Sand Member of Raritan Formation.	Jan. 11, 1961	11	2.3	2.9	.9	4.4	18	.5	3.2	.0	1.4	31	11	15	42	6.4	3.7	.7
1243	4E, 0.5N, 1.5W	25	Upper Pleistocene deposits.	Dec. 5, 1960	5.4	3.3	4.0	1.0	4.2	11	6.9	3.9	.0	1.9	35	14	9	56	6.1	3.0	1.2
1651	5A, 0.0N, 1.4W	465	Lloyd Sand Member of Raritan Formation.	Aug. 15, 1960	12	.02	5.1	1.6	6.4	18	.9	7.5	.1	9.3	60	19	15	77	6.4	5.7	.7
1696	1A, 0.7N, 0.6W	468	Magothy(?) Formation	Feb. 2, 1960	9.2	----	3.5	1.2	6.4	10	.7	5.8	.1	13	54	14	8	66	6.0		
2402	1C, 0.6N, 1.6W	211	do	Jan. 21, 1952	7.8	----	----	----	6.5	4	2	12	----	16	----	21	3	95	5.5		
2403	1C, 0.6N, 1.5W	84	Upper Pleistocene deposits.	Jan. 21, 1952	9.9	----	----	7.3	9.8	10	90	22	.0	34	247	139	8	396	5.8		
2602	2B, 0.3N, 1.8W	800	Lloyd Sand Member of Raritan Formation.	Mar. 26, 1957	8.3	.35	1.1	.6	3.5	8	.8	3.8	.2	.1	27	5	7	31	6.1	2.8	.7
3194	1C, 0.2N, 0.6W	320	Magothy(?) Formation	Jan. 21, 1952	7.3	----	----	----	3.9	6	2	8	----	4.0	----	13	5	62	5.8		
3474	3B, 1.5N, 1.9W	512	do	Aug. 15, 1960	7.9	.05	2.1	1.0	4.1	9	.5	4.1	.1	3.5	29	9	7	40	6.0	3.7	.4
3695	1A, 0.3N, 1.1W	500	do	Feb. 11, 1960	7.2	.05	1.7	.8	5.1	7	1.2	3.8	.0	7.9	36	8	6	44	6.9		
3696	1A, 0.4N, 1.0W	444	do	Feb. 2, 1960	7.9	.01	2.6	1.5	5.8	9	2.0	5.6	.0	9.0	44	13	7	52	6.3		
3697	1A, 0.4N, 1.0W	432	do	Feb. 2, 1960	7.2	.00	1.8	1.0	5.5	6	2.4	4.5	.0	8.3	37	9	5	48	6.0		
3698	1A, 0.4N, 1.0W	472	do	Feb. 2, 1960	7.5	.01	2.2	1.2	6.0	6	1.4	5.3	.1	11	44	6	5	56	5.7		
5655	2B, 0.8N, 1.0W	255	do	Mar. 26, 1957	7.5	.01	1.3	.1	3.4	5	1.0	4.3	.1	1.4	25	4	4	24	6.1	2.7	.7
5762	4A, 1.7N, 1.1W	283	do	Aug. 15, 1960	14	.05	7.9	3.4	6.6	22	6.4	7.6	.1	14	77	34	18	107	6.4	5.9	.7
6675	5C, 1.2N, 0.5W	460	Jameco Gravel	Dec. 5, 1960	21	.38	7.8	4.5	7.6	47	7.0	3.7	.2	.5	71	38	39	132	7.1	6.2	1.4

TABLE 18.—*Summary of chemical analyses of ground water in northeastern Nassau County*

[Chemical constituents are given in parts per million unless otherwise indicated. Data summarized from analyses by Nassau County Dept. of Health and U.S. Geol. Survey. <, less than]

Constituent	Lloyd Sand Member of Raritan Formation [1]		Magothy (?) Formation [2]		Jameco Gravel [1]		Pleistocene deposits [2]		All geologic units	
	Median and range	Number of analyses	Median and range	Number of analyses	Median and range	Number of analyses	Median and range	Number of analyses	Median and range	Number of analyses
Silica (SiO_2)	11 8.3–12	4	7.7 6.3– 14	36	21 ----------	1	9.1 5.4– 9.9	3	7.9 5.4– 21	44
Iron (Fe)	.08 .02–45	24	.04 0– 1.2	223	.1 .03– 9	12	.1 0– 3.3	17	.05 0– 45	276
Calcium (Ca)	2.0 1.0– 5.1	6	2.4 1– 7.9	32	5 3– 7.8	3	4.3 4.0– 4.5	2	2.6 1– 45	43
Magnesium (Mg)	.9 .4– 1.6	5	1.1 .1– 3.4	32	4.5 ----------	1	4.2 1.0– 7.3	2	1.1 .1– 7.3	40
Sodium and Potassium (Na and K)	4.4 3.2– 6.4	5	4.8 1.2– 9.6	35	---------- ----------	----------	9.8 4.2– 17.6	3	4.9 1.2– 18	43
Bicarbonate (HCO_3)	18 6–20	5	9 1– 22	36	23 23–47	3	10 9– 11	3	9 1– 47	47
Sulfate (SO_4)	.8 0– 4	16	1.4 .3– 11	35	1 .02–13	7	90 6.9– 96	3	1.2 0– 96	61
Chloride (Cl)	3.8 3.0–10	22	7 1.6– 36	217	6 3.7–11	12	8.8 3.9– 23	15	6.8 1.6– 36	266
Fluoride (F)	<.1 0– .2	10	<.1 0– .5	173	<.1 <.1– 0.2	7	<.1 0– 1.0	10	<.1 0– 1.0	200
Nitrate (NO_3)	.2 .1– 9.3	11	11 .06–133	188	7.5 .5–19	7	44.3 1.9– 69	39	13.4 .06–133	245
Dissolved solids	38 22–90	18	39 18–200	75	68 48–82	8	70 35–247	3	42 18–247	104
Alkalinity as $CaCO_3$	14 1.9–31	18	5 1– 24	209	18 10–19	10	10 3– 32	12	6 1– 32	249
Carbon dioxide (CO_2)	12 9.5–23	5	11.0 1.4– 70	167	9.8 6.0–19	5	14 3.4– 37	9	11 1.4– 70	186
Hardness as $CaCO_3$	14 4–22	22	17 2–126	209	22 12–38	12	34 14–142	15	18 2–142	258
Specific conductance (micromhos at 25° C)	42 31–77	3	48.8 11–107	38	132 ----------	1	389 56–396	3	51.5 11–396	45
pH	6.4 5.4– 7.4	21	5.8 4.7– 7.0	213	6.6 6– 7.1	11	5.9 5.5– 7.3	15	5.8 4.7– 7.4	260

[1] Deep confined aquifer.
[2] Principal aquifer.

tested samples of ground water in the project area ranged from 11 to 396 micromhos at 25°C, and the median ranged from 42 micromhos in water in the Lloyd Sand Member (deep confined aquifer) to 389 micromhos in water in the Pleistocene deposits (principal aquifer). By comparison, the specific conductance of distilled water is about 5 micromhos and that of ocean water is as high as 50,000 micromhos.

Silica as quartz comprises the bulk of the unconsolidated sediments of Long Island. However, quartz is highly resistant to solution by water and is generally not considered to be the primary source of silica in natural waters of temperate regions such as Long Island (Hem, 1959, p. 52). Most of the dissolved silica in the ground water of Long Island probably originated from the chemical weathering of other siliceous minerals in the saturated deposits. With the exception of quartz and a small amount of heavy minerals, most of the silicate-bearing minerals of the Cretaceous deposits have been nearly completely weathered to stable forms such as clay minerals so that little silica is available for solution. In the deposits of Pleistocene and Recent age, however, other silicates are present and decomposition of them is undoubtedly going on. Water in the deep confined aquifer generally contains more silica than that in the principal aquifer. The median concentration of silica for all samples analyzed is 7.9 ppm.

Most of the iron in the ground water probably originates from the solution of iron-bearing minerals in the unconsolidated sediments. Iron may occur in solution as either the bivalent ferrous ion (Fe^{++}) or the trivalent ferric ion (Fe^{+++}). The ferrous ion is far more common in ground water; however, ferrous salts are unstable in the presence of oxygen and oxidize rapidly to the more stable ferric state. The reddish-brown precipitate of relatively insoluble ferric hydroxide [$Fe(OH)_3$], which forms in some water samples upon exposure to the atmosphere, results from the oxidation of ferrous ions in solution. Analyses made by the Nassau County Department of Health report total iron, which includes all iron in solution at the time of analysis plus the iron that has precipitaed since the sample was collected. Prior to 1957 the U.S. Geological Survey reported concentrations of iron as "total" and "dissolved" (in solution in the sample container at the time of analysis); now, unless otherwise indicated, the iron reported is the amount in solution at the time of sampling (Hem, 1959, p. 61–62).

The iron content of the tested samples of ground water in the report area ranges from 0 to 45 ppm (table 18). The median concentration of samples from each aquifer was less than 0.3 ppm, which is the maximum limit recommended by the U.S. Public Health Service (1962, p. 7) drinking-water standards. This limit is not based on toxicity but on esthetics and taste; iron will stain laundry and porcelain and can be tasted if present in excess of 0.5 to 1.0 ppm (Rainwater and Thatcher, 1960, p. 183). Water having the highest iron content is generally in the Lloyd Sand Member of the Raritan Formation and the Jameco Gravel, which compose the deep confined aquifer, although locally high concentrations occur also in the principal aquifer.

Manganese resembles iron in both chemical behavior and occurrence in ground water, although it is commonly low in concentration. Manganese, in concentration of about 0.5 ppm, forms objectionable deposits on food, laundry, and plumbing fixtures. The maximum manganese content of 300 water samples from both the principal and deep confined aquifers in northeastern Nassau County, analyzed by the Nassau County Department of Health, was less than 0.05 ppm. The recommended maximum concentration of manganese in drinking water is 0.05 ppm (U.S. Public Health Service, 1962, p. 7).

Calcium and magnesium are members of the family of alkaline earth metals. Calcium is usually more abundant in ground water than magnesium. The two elements are the principal cause of hardness of water. In the samples tested, the median concentration of calcium ranged from about 2 to 5 ppm, and the median concentration of magnesium ranged from about 1 to 4 ppm for both the principal and deep confined aquifers.

Sodium and potassium are members of the family of alkali metals. Their presence in ground water results primarily from the chemical decomposition of feldspars, feldspathoids, and certain types of mica, although the potassium-bearing minerals weather much more slowly than those containing sodium (Hem, 1959, p. 90). Sodium tends to remain in solution, whereas potassium recombines readily with other products of chemical weathering, particularly some of the clay minerals. As a result, uncontaminated ground water usually has a higher content of sodium than potassium. Other sources of sodium and potassium in the ground water are contamination from fertilizer, human wastes, and sea water from Long Island Sound. The median content of combined sodium and potassium in samples from both the principal and deep confined aquifers in northeastern Nassau County was 4.9 ppm. Concentrations considerably higher than the median are probably a result of contamination.

Bicarbonates and carbonates are usually present in ground water because of the weathering of carbonate minerals and because carbon dioxide, which helps to dissolve them, is readily available (Rainwater and Thatcher, 1960, p. 93). Carbonate minerals are rare, if present at all, in deposits on Long Island. The presence of bicarbonates and carbonates imparts alkalinity to water. In 47 analyses of ground-water samples from both the principal and deep confined aquifers, the bicarbonate concentration ranged from 1 to 47 ppm, and the median was 9 ppm. No carbonate was detected in a few samples that were tested for this constituent. Water from the deep confined aquifer generally contains more bicarbonate than that from the principal aquifer.

Naturally-occurring sulfate in the ground water probably results in part from the oxidation of pyrite and marcasite and the solution of other minor sulfur-bearing minerals. The sulfate content of the water samples tested ranged from 0 to 96 ppm. The median concentration for all samples from both the principal and deep confined aquifers is 1.2 ppm. Two unusually high values, 90 and 96 ppm, which were determined in water samples from well N2403 in the principal aquifer in Levittown, probably result largely from contamination by chemical fertilizers. The maximum concentration recommended by the U.S. Public Health Service (1962, p. 7) for drinking water is 250 ppm.

Chloride is the predominant anion of sea water. The Atlantic Ocean has a chloride content of about 17,000 ppm, and the water of Long Island Sound has about 16,000 ppm. Rain, which may contain from a few parts per million to as much as 12 ppm of chloride, probably accounts for most of the low chloride in the ground water of northeastern Nassau County. Industrial wastes, contamination from cesspools, and natural salty ground water near the shore, account for the above-normal concentrations. The maximum reported content of chloride in public-supply wells is 36 ppm (table 18), which is considerably below the limit of 250 ppm recommended by the U.S. Public Health Service (1962, p. 7). High chloride content of water causes corrosion in pipes, boilers, and other fixtures, and is toxic to most plants.

No evidence of contamination due to salt-water encroachment was obtained in the report area. However, some thin bodies of salt water occur under natural conditions at shallow depths in parts of the principal aquifer near the shoreline (table 19).

The salt-water front in the deep confined aquifer is an unknown distance beneath Long Island Sound. Available data suggest, however, that this interface may be about 1 to 1½ miles offshore. It is unlikely that the salt-water wedge is moving landward at present because heads and chloride concentrations in wells near the shore have remained relatively constant for the past 10 years; any possible landward advance would be very slow under present conditions. Conceivably, large increases in net withdrawal in the future would induce landward movement of the salt water. Such movement might be anticipated by declining water levels, but the arrival of the salt-water wedge would be

209-982—66——6

TABLE 19.—*Occurrence of salty ground water at selected wells in northeastern Nassau County*

Well	Locality	Remarks
N6675	Cove Neck	Driller reported salty water at 86 ft below land surface, Aug. 1959. Chloride content unknown.
7152	Bayville	U.S. Geol. Survey test well. Salt water extracted from cores of sand, silt, and clayey sand taken at depths of 35 to 70 ft below land surface. Maximum chloride content of water was 5,400 ppm, Aug. 1961.
175	Centre Island	Driller reported salty water at depths ranging from 85 to 155 ft below land surface in 1935. Chloride content unknown.
6578	do	Driller reported salty water containing 2,196 ppm of chloride at depth of 61 ft below land surface, Sept. 1958.
6720	Village of Oyster Bay.	Driller reported brackish water from 38 to 50 ft below land surface in 1935.

detected only by a rise in the chloride content of water from outpost wells at the shoreline. Hence, considerable encroachment might occur in the offshore area without being detected.

Fluoride is usually present under natural conditions in ground water in Long Island in very small amounts. Contamination by industrial waste is a potential source of fluoride in the report area. The Public Health Service (1962) standards for the fluoride content of drinking water vary depending upon the annual average of the maximum daily air temperature. Excessive quantities of fluoride in drinking water cause discoloration of children's teeth, although a beneficial effect is attributed to concentrations of 0.88 to 1.5 ppm (Rainwater and Thatcher, 1960, p. 163). In the report area, the recommended control limits are: lower, 0.8 ppm; optimum, 1.0 ppm; and upper, 1.3 ppm. The maximum concentration found in the samples from report area was 1 ppm, and the median was less than 0.1 ppm.

Nitrate is the most prevalent form of nitrogen in ground water. Nitrogen-fixing plants (legumes) and bacteria, chemical fertilizers, sewage, and decaying organic matter are the principal sources of nitrate in ground water. The nitrate (NO_3) content of unpolluted ground water seldom exceeds 10 ppm (Rainwater and Thatcher, 1960, p. 216). Parts of northeastern Nassau County were formerly farmland, and the repeated application of fertilizers introduced large quantities of nitrate into the soil. The nitrate was dissolved by water and a fraction percolated to the ground-water reservoir. A present-day source of nitrate in the ground water of northeastern Nassau County is the effluent from thousands of cesspools. Only the city of Glen Cove and parts of the village of Oyster Bay and vicinity are sewered. An increase in nitrate from cesspool contamination is generally accompanied by an increase in the chloride content of the ground water. The U.S. Public Health Service (1962, p. 7) recommends a maximum of 45 ppm of nitrate (NO_3) in water for domestic use. Infants whose drinking or formula water contains a high concentration of nitrate may develop nitrate poisoning (U.S. Public Health Service, 1962, p. 48). The median content of the nitrate in all samples from both the principal and deep confined aquifers was 13.4 ppm. However, nitrate concentrations ranging from about 20 to 133 ppm have been found locally in water from some wells screened in the principal aquifer in Garden City, Westbury, Levittown, Hicksville, and Farmingdale. The highest concentrations of nitrate were found in water in relatively shallow wells (N2403, table 20), but concentrations of 20 to 34 ppm were found in wells N3935 (Garden City) and N5654 (Westbury), which are screened in the principal aquifer at depths of about 400 feet. The source of the relatively high concentration of nitrate in the water from the deep wells cannot be readily determined from available data but is probably largely a result of local contamination. Additional studies are required to determine the full extent of the contaminated areas and their bearing on the availability of potable supplies.

Most hardness is caused by the presence of the alkaline earth metals, particularly calcium and magnesium. Because hardness is a property not strictly allocable to any single constituent, it is usually reported in terms of an equivalent quantity of calcium carbonate ($CaCO_3$) (Hem, 1959, p. 146). Hardness in excess of about 100 ppm decreases the cleansing and lathering properties of soap. Some of the carbonates and sulfates of the alkaline earths are relatively insoluble and will cause precipitates to form in pipes, boilers, and cooking utensils. Most of the water in the report area is considered soft. The median hardness of the water samples from both the principal and deep confined aquifers ranges from 14 to 34 ppm (table 18).

The pH is a measure of the concentration of hydrogen ions in water. Water having a pH of 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is alkaline. Most of the ground water in northeastern Nassau County is slightly acidic. The pH of the samples ranged from 4.7 in the principal acquifer to 7.4 in the deep confined aquifer and the median of samples from both aquifers was 5.8 (table 18).

Syndets (synthetic detergents) were first used for cleaning in minor quantities about 15 years ago. Since 1950, the use has increased substantially, and Cusumano (1960, p. 3) estimated that during 1960 the average family would use about 2 pounds of detergent a week. This would amount annually to about 16,000 tons of detergents in all of Nassau County and about 3,500 tons per year in the report area. Syndets reach the ground-water reservoir through cesspools and septic

TABLE 20.—*Nitrate (NO_3) content of water in excess of 10 parts per million in selected wells in northeastern Nassau County*

[Analyses by New York State Dept. of Health, unless otherwise indicated]

Date of sample	Nitrate (ppm)	Date of sample	Nitrate (ppm)	Date of sample	Nitrate (ppm)
Well N150 [Westbury. Depth, 142 ft. Magothy(?) Formation]					
Feb. 4, 1946	[1] 132.8	Jan. 8, 1952	[1] 29.2	Aug. 11, 1954	[1] 35.4
Well N1667 [Westbury. Depth, 237 ft. Magothy(?) Formation]					
July 24, 1952	[1] 39.8	Mar. 9, 1954	[1] 38.7		
Well N2072 [Hicksville. Depth, 159 ft. Magothy(?) Formation]					
Sept. 19, 1949	[1] 31.0	Sept. 28, 1953	[1] 10.0	Aug. 1, 1957	[1] 26.6
Well N2402 [Levittown. Depth, 85 ft, in upper Pleistocene deposits, Nov. 26, 1947–Aug. 22, 1950; depth 207 ft, in Magothy(?) Formation, Sept. 25, 1950–Jan. 25, 1960]					
Nov. 26, 1947	35.4	Aug. 17, 1949	35.4	Sept. 27, 1951	27.4
Dec. 3, 1947	35.4	Nov. 2, 1949	35.4	Jan. 21, 1952	[2] 16
July 8, 1948	59.8	Jan. 9, 1950	46.5	Mar. 30, 1953	[1] 15.9
Apr. 20, 1949	35.4	Aug. 22, 1950	46.5	Mar. 10, 1954	[1] 25.7
Apr. 26, 1949	35.4	Sept. 25, 1950	[2] 11	Mar. 12, 1957	[1] 39.0
July 18, 1949	53.1	Dec. 12, 1950	11.1	Mar. 26, 1957	[1] 17.7
July 27, 1949	53.1	Mar. 9, 1951	14.2	Nov. 4, 1957	[1] 31.9
July 29, 1949	40.3	Sept. 13, 1951	14.2	Jan. 25, 1960	[1] 45.2
Well N2403 [Levittown. Depth, 84 ft. Upper Pleistocene deposits]					
July 8, 1948	59.8	Nov. 2, 1949	35.4	Oct. 9, 1951	44.3
Dec. 8, 1948	44.3	Jan. 9, 1950	53.1	Oct. 24, 1951	57.5
Apr. 20, 1949	62.0	Aug. 22, 1950	46.5	Jan. 21, 1952	[2] 46
Apr. 26, 1949	62.0	Sept. 25, 1950	44.3	Apr. 27, 1953	[1] 66.4
July 18, 1949	66.4	Dec. 12, 1950	37.6	Feb. 18, 1954	[1] 62.0
July 27, 1949	66.4	Mar. 9, 1951	48.7	Apr. 21, 1955	[1] 68.6
July 29, 1949	42.1	Sept. 13, 1951	53.1	Oct. 5, 1961	[1] 66
Aug. 17, 1949	44.3	Sept. 27, 1951	27.4		
Well N3935 [Garden City. Depth, 408 ft. Magothy(?) Formation]					
July 27, 1953	[1] 21.0	Mar. 22, 1955	[1] 18.1	Nov. 24, 1959	[1] 18.1
Aug. 24, 1954	[1] 18.1	Nov. 12, 1957	[1] 20.8		
Well N5654 [Westbury. Depth, 335 ft. Magothy(?) Formation]					
May 14, 1956	[1] 18.1	Dec. 17, 1956	[1] 31.0	Oct. 28, 1957	[1] 34.5
Sept. 17, 1956	[1] 28.9				

[1] Analysis by Nassau County Dept. of Health.
[2] Analysis by U.S. Geol. Survey.

tanks. Most soaps and other domestic wastes generally undergo chemical and bacteriological action which renders them less obnoxious after moving a short distance underground, but syndets degrade much more slowly and apparently remain in the ground water for a long time. Foaming occurs when the concentration of the surfactant part of the detergent, commonly alkyl benzene sulfonate (referred to as ABS), is greater than 1 ppm, and an unpleasant taste may occur if concentrations exceed 1.5 ppm (Cusumano, 1960, p. 6). The Public Health Service (1962, p. 7) recommends a maximum limit of 0.5 ppm of syndet (ABS) in drinking water. Data on the occurrence of syndets from analyses by the Nassau County Health Department show that the water from public-supply wells screened in the middle and lower part of the principal aquifer has not been contaminated by syndets. However, water from a few public-supply wells screened in the upper part of the principal aquifer—for example at Levittown—show a trace of ABS. The highest concentrations of ABS doubtless occur in the shallow ground water in the unsewered areas of greatest population density. Additional detailed studies are required to delineate areas of high syndet concentration and the movement of the contaminated water.

Industrial plants in the project area commonly dispose of their liquid wastes by means of recharge basins or diffusion wells. If toxic substances are dissolved in these wastes they can contaminate the ground water. In addition to cadmium and chromium, which are widely used in plating and anodizing processes, fluoride is present also in industrial wastes disposed of in the report area. The disposal of untreated noxious or obnoxious wastes in the ground water is detrimental to the water supplies because once contamination has occurred many years are generally required for natural recharge to dilute and flush away the contaminated water. The first indication of chromium contamination in northeastern Nassau County was in July 1943 when it was detected in a shallow well belonging to Grumman Aircraft Engineering Corp. in Bethpage. The source was chromic acid wastes from the plant. In 1947 the Nassau County Department of Health reported the presence of hexavalent chromium in two wells just south of the Grumman plant (Davids and Lieber, 1951, p. 530–532). Treatment was begun at that plant in 1948 to eliminate the chromium from the waste water. No data have been collected to date (1962) that indicate the presence of toxic industrial contaminants in the ground water in other parts of northeastern Nassau County.

SUMMARY AND RECOMMENDATIONS

Northeastern Nassau County is a rectangular area of about 112 square miles, which measures about 9 miles from east to west and 13 miles from north to south. Six morphologic units exist in the project area: (1) the headlands, (2) the Harbor Hill terminal moraine, (3) the intermorainal pitted outwash plain, (4) the Ronkonkoma terminal moraine, (5) the Wheatley and Mannetto Hills, and (6) the glacial outwash plain. Land surface ranges from sea level along the shore of Long Island Sound to about 340 feet above sea level on the Ronkonkoma terminal moraine. Surface drainage is accomplished by north- and south-flowing streams, which have their headwaters in the Harbor Hill end moraine and the Ronkonkoma terminal moraine. Flow is usually intermittent in the upper reaches of the streams where they are fed by perched ground water and direct runoff. In the lower reaches of the north-flowing streams the flow is perennial because it is sustained by ground-water inflow. The south-flowing streams, which cross the glacial outwash plain, are effluent and their flow generally ceases a short distance below the headwaters. The climate of the report area is a modified continental type characterized by prevailing westerly winds, moderate temperatures, a moderate number of thunderstorms, and annual precipitation which averages about 45 inches.

Population and industry in the report area have grown rapidly since the early 1930's. The greatest expansion occurred after World War II when improved roads promoted the influx of industry and low-cost housing.

Northeastern Nassau County is underlain by unconsolidated deposits of Late Cretaceous, Tertiary, and Quaternary age, which overlie bedrock of Precambrian age. The deposits of Cretaceous age comprise the Raritan Formation, which is subdivided into the Lloyd Sand Member and an unnamed clay member, and the Magothy(?) Formation. Deposits of probable Tertiary age are represented by the Mannetto Gravel. The Jameco Gravel and the overlying Gardiners Clay are Pleistocene deposits of pre-Wisconsin age. The surface of nearly all the area is underlain by glacial till and related outwash deposits of late Pleistocene age. Relatively thin shoreline and marsh deposits of Recent age occur locally along the beaches, and alluvium is found in some stream valleys.

The ground-water reservoir in the unconsolidated deposits ranges in thickness from about 400 to about 1,300 feet. The upper limit is the water table, and the lower limit is the bedrock. The entire ground-water reservoir is an interconnected hydraulic system in which two major aquifers have been defined: the principal aquifer and the deep confined aquifer. Natural recharge to the principal aquifer from precipitation averages about 1 mgd per sq mi. The deep confined aquifer is recharged by downward leakage from the principal aquifer. Gross pumpage averaged about 43 mgd in 1960, of which 32.6 mgd was for public supply and 10.3 mgd was for industrial use. Withdrawal for agricultural use averaged less than 0.1 mgd. Most of the water pumped is returned to the ground by means of cesspools, diffusion wells, or recharge basins. The average net pumpage is estimated at about 6 mgd and consists largely of sewage effluent discharged to the sea, evapotranspiration losses from lawn sprinkling, and a small consumptive loss. Hence, under present conditions, where nearly all the water pumped returns to the ground-water system, withdrawals could be increased appreciably provided the wells were properly spaced to prevent mutual interference and to minimize sea-water encroachment.

Ground-water temperatures in the report area generally range from about 50° to 60° F. Most of the ground water is of good to excellent quality. The content of dissolved solids is generally less than 100 ppm. Locally, some water in the deep confined aquifer has a high iron content, and water containing higher than normal concentrations of nitrate has been found in wells tapping the principal aquifer in Levittown, Westbury, and Hicksville. Some salty water is reported in the shallow aquifer near the shoreline, but these occurrences are of natural origin, and no evidence of sea-water encroachment due to pumping was found anywhere in the area.

Although supplies are more than adequate for present (1961) needs, precipitation is the only source of recharge, and eventually the net withdrawal may approach available recharge if pumpage increases substantially and most of the water that is withdrawn is lost to the sea through sewers. In addition, estimates of availability of water in the area may have to be reduced if increased pumping in nearby areas in Nassau and Suffolk Counties causes an increase in underflow from the report area.

To conserve water supply, the program of constructing storm-water recharge and impounding basins by Nassau County and private developers should be continued and enlarged. Regulation of pumpage and well drilling by the New York State Water Resources Commission has helped to control the problem of interference between wells and to reduce the danger of salt-water encroachment in critical areas.

Geologic and hydrologic data of the area are far from adequate for detailed quantitative estimates, especially in the northern part where scanty data suggest the presence of several deep buried valleys in the Cretaceous deposits. In some places these buried valleys are filled with permeable material and constitute and excellent source of water. However, if increased withdrawal is accompanied by a decline in water level, the permeable valley fill may serve as conduits for salt-water encroachment. Additional test drilling is needed to better define the depth, width, and length of these buried valleys as well as the character of the valley fill. The program of water-level measurement and sampling in observation wells should be maintained, and additional wells should be installed in the principal and deep confined aquifers to detect any significant trends in water-level fluctuations and quality of water.

The present (1962) mode of water-supply development in the report area may not be the overall plan that might ultimately be needed to get the fullest and best use from the water resources. Much additional research and data collecting will need to be done before the various possible alternatives can be evaluated and the best plan selected.

The fresh water-salt water interface in the deep aquifer is an undetermined distance north of the shoreline. Outpost wells along the shore would help to locate and monitor the possible landward movement of the interface in the future. One such well, N7152, was constructed in 1961 at Bayville; additional wells are needed along other parts of the shoreline.

In parts of the report area shallow ground water is contaminated by household wastes, as indicated by the presence of synthetic detergents and by unnaturally high concentrations of nitrate in the water. Any practical solution to the problem of pollution by domestic wastes will undoubtedly require, as a first step, expanding the existing public sewer systems to include the entire area. However, net withdrawal of water from the area must be minimized to prevent excessive decline of ground-water levels and to retard sea-water encroachment. Therefore, insofar as possible, the sewage should be adequately treated and returned to the ground-water reservoir through stratigically placed injection wells or recharge basins. Unfortunately, techniques have yet to be devised which will reduce syndet concentations to a level recommended by the Public Health Service for drinking water.

If all the effluent from cesspools had been discharged to Long Island Sound through sewers in 1960, net ground-water pumpage would have averaged about 43 mgd rather than 6 mgd. This amount would have been a substantial loss to the reservoir and would have resulted in some landward movement of salty water.

Existing centers of heavy pumping are concentrated in the southern and western parts of the area, whereas the northern and eastern parts are relatively undeveloped. Because the principal aquifer thins in a northerly direction, the optimum location for most new wells tapping this aquifer would be in the central, east-central, and southeastern parts of the project area. In accordance with the present type of water-supply development, new wells in the northern part of the area should be located at least 1 mile from the shoreline to minimize the danger of salt-water encroachment and, where possible, about 1 mile from existing centers of pumpage to reduce the effects of mutual interference.

REFERENCES CITED

Barnell, R. L., and DeLuca, F. A., 1961, Ground-water levels in Long Island, New York, in 1958 and 1959: U.S. Geol. Survey open-file rept., 66 p.

Bentall, Ray, 1963, Methods of determining permeability, transmissibility, and drawdown: U.S. Geol. Survey Water-Supply Paper 1536–I, 341 p.

Blair, T. A., 1942, Climatology, general and regional: New York, Prentice-Hall, 484 p.

Brice, H. D., Whitaker, C. L., and Sawyer, R. M., 1959, A progress report on the disposal of storm water at an experimental seepage basin near Mineola, New York: U.S. Geol. Survey open-file rept., 34 p.

Burr, W. H., Hering, Rudolph, and Freeman, J. R., 1904, Report of the commission on additional water supply for the City of New York: New York, Martin B. Brown Co., 980 p.

Cooke, C. W., Gardiner, J., and Woodring, W. P., 1943, Correlation of the Cenzoic formations of the Atlantic and Gulf coastal plain and the Caribbean region: Geol. Soc. America Bull., v. 54, p. 1713–1723.

Crosby, W. O., 1910, Report on the geological relations of the ground water of Long Island: Board of Water Supply, City of New York, open-file rept., 64 p.

Cusumano, R. D., 1960, Summary report and review of literature on the effects of synthetic detergents on water supplies and waste water treatment processes: Nassau County Dept. of Health, 22 p.

Davids, H. W., and Lieber, Maxim, 1951, Underground water contamination by chromium wastes: Water and Sewage Works, v. 98, no. 12, p. 528–534.

De Laguna, Wallace, and Brashears, M. L., Jr., 1948, The configuration of the rock floor in western Long Island, New York: New York State Water Power and Control Comm. Bull. GW–13, 32 p.

DeLuca, F. A., Hoffman, J. F., and Lubke, E. R., 1965, Chloride concentration and temperature of the waters in Nassau County, Long Island, New York: New York State Water Resources Comm., Bull. 55, 35 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, 174 p.

Fleming, W. L. S., 1935, Glacial geology of central Long Island: Am. Jour. Sci., ser. 5, v. 30, no. 177, p. 216–238.

Fuller, M. L., 1914, The geology of Long Island, New York: U.S. Geol. Survey Prof. Paper 82, 231 p.

Hely, A. G., Nordenson, T. J., and others, 1961, Precipitation, water loss, and runoff in the Delaware River Basin and New Jersey: U.S. Geol. Survey Hydrol. Inv. Atlas HA–11, 11 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Isbister, John, 1959, Ground-water levels and related hydrologic data from selected observation wells in Nassau County, Long Island, New York: New York State Water Power and Control Comm. Bull. GW–41, 42 p.

——— 1963, Records of wells and related hydrologic data in northeastern Nassau County, Long Island, New York: U.S. Geol. Survey open-file rept., 37 p.

Jacob, C. E., 1941, Notes on the elasticity of the Lloyd sand on Long Island, New York: Am. Geophys. Union Trans., pt. 3, p. 783–787.

——— 1945a, The water table in western and central parts of Long Island, New York: New York State Water Power and Control Comm. Bull. GW–12, 24 p.

Jacob, C. E., 1945b, Correlation of ground-water levels and precipitation on Long Island, New York: New York State Water Power and Control Comm. Bull. GW–14, 20 p.

——— 1946, Radial flow in a leaky artesian aquifer: Am. Geophysical Union Trans., v. 27, p. 198–208.

Johnson, A. H., and others, 1958, Record of wells in Nassau County, New York, Supplement 2: New York State Water Power and Control Comm. Bull. GW–39, 308 p.

Langbein, W. B., and Iseri, K. T., 1960, General introduction and hydrologic definitions: U.S. Geol. Survey Water-Supply Paper 1541–A, 29 p.

Leggette, R. M., and others, 1938, Records of wells in Nassau County, New York: New York State Water Power and Control Comm. Bull. GW–5, 139 p.

Lewis, J. V., and Kümmel, H. B., 1915, The geology of New Jersey: New Jersey Geol. Survey Bull. 14, 140 p.

Lounsbury, C., and others, 1928, Soil survey of Suffolk and Nassau Counties, New York: U.S. Dept. Agriculture, ser. 1928, no. 28, 46 p.

Lubke, E. R., 1964, Hydrogeology of the Huntington-Smithtown area, Suffolk County, New York: U.S. Geol. Survey Water-Supply Paper 1669–D, 68 p.

Lusczynski, N. J., 1949a, The piezometric surface of the Lloyd Sand Member, Long Island, N. Y. in 1947: U.S. Geol. Survey open-file rept., 4 pls.

——— 1949b, Levittown pumping test, September 16–18, 1949: U.S. Geol. Survey open-file rept., 8 p.

——— 1950, No ground water flows from Connecticut to Long Island: U.S. Geol. Survey open-file rept., 1 fig.

——— 1951, The water table in Long Island, New York, in January 1951: New York State Water Power and Control Comm. Bull. GW–27, 28 p.

——— 1952, Piezometric levels from 1948 through 1950 for wells screened in the Lloyd Sand Member of the Raritan Formation on Long Island, New York: U.S. Geol. Survey open-file rept., 3 p.

MacClintock, Paul, and Richards, H. G., 1936, Correlation of late Pleistocene marine and glacial deposits of New Jersey and New York: Geol. Soc. Am. Bull., v. 47, p. 289–338.

Meinzer, O. E., 1923, Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

——— 1949, Hydrology: New York, Dover Publications, Inc., 712 p.

Meyer, A. F., 1944, The elements of hydrology: New York, John Wiley & Sons, Inc., 522 p.

Mordoff, R. A., 1949, The climate of New York State: Cornell Extension Bull. 764, 72 p.

Nassau County Planning Commission, 1959, Planning Nassau County: Mineola, N.Y., Nassau County Planning Comm., 26 p.

——— 1961, Population sixty: Mineola, N.Y., Nassau County Planning Comm., 37 p.

Perlmutter, N. M., and Crandell, H. C., 1959, Geology and ground-water supplies of the south-shore beaches of Long Island, New York: New York Acad. Sci. Annals, v. 80, art. 4, p. 1060–1076.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1613–A, 205 p.

Perlmutter, N.M., and Lusczynski, N. J., 1951, Deep artesian observation well at Plainview, Nassau County, Long Island, N.Y.: U.S. Geol. Survey open-file rept., 5 p.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

Roberts, C. M., and Brashears, M. L., Jr., 1946, Records of wells in Nassau County, New York, Supplement 1: New York State Water Power and Control Comm. Bull. GW-10, 191 p.

Rouse, Hunter, 1950, Engineering hydraulics: New York, John Wiley & Sons, Inc., 1039 p.

Sawyer, R. M., 1958, Progress report on streamflow investigations in Nassau County, Long Island, New York: U.S. Geol. Survey open-file rept., 226 p.

Spear, W. W., 1912, Long Island sources—an additional supply of water for the City of New York: Board of Water Supply of City of New York, 708 p.

Strahler, A. N., 1951, Physical geography: New York, John Wiley and Sons, Inc., 442 p.

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 Comm. Bull. GW-18, 212 p.

Swarzenski, W. V., 1963, Hydrogeology of northwestern Nassau and northeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply Paper 1657, 90 p.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Dept. of Health, Education, and Welfare, public service rept., 61 p.

Veatch, A. C., Slichter, C. S., Bowman, Isaiah, Crosby, W. O., and Horton, R. E., 1906, Underground water resources of Long Island, New York: U.S. Geol. Survey Prof. Paper 44, 394 p.

Welsch, W. F., 1960, Conservation in Nassau County, New York: Am. Water Works Assoc. Jour., v. 52, no. 12, p. 1494–1498.

Wenzel, L. K., and Fishel, V. C., 1942, Methods for determining permeability of water-bearing materials, *with a section on* direct laboratory methods and bibliography on permeability and laminar flow: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wistoft, L. R., Barnell, R. L., and Crandell, H.C., 1958, Ground-water levels in Long Island, New York in 1956 and 1957: U.S. Geol. Survey open-file rept., 80 p.

INDEX

[Italic numbers indicate major references]