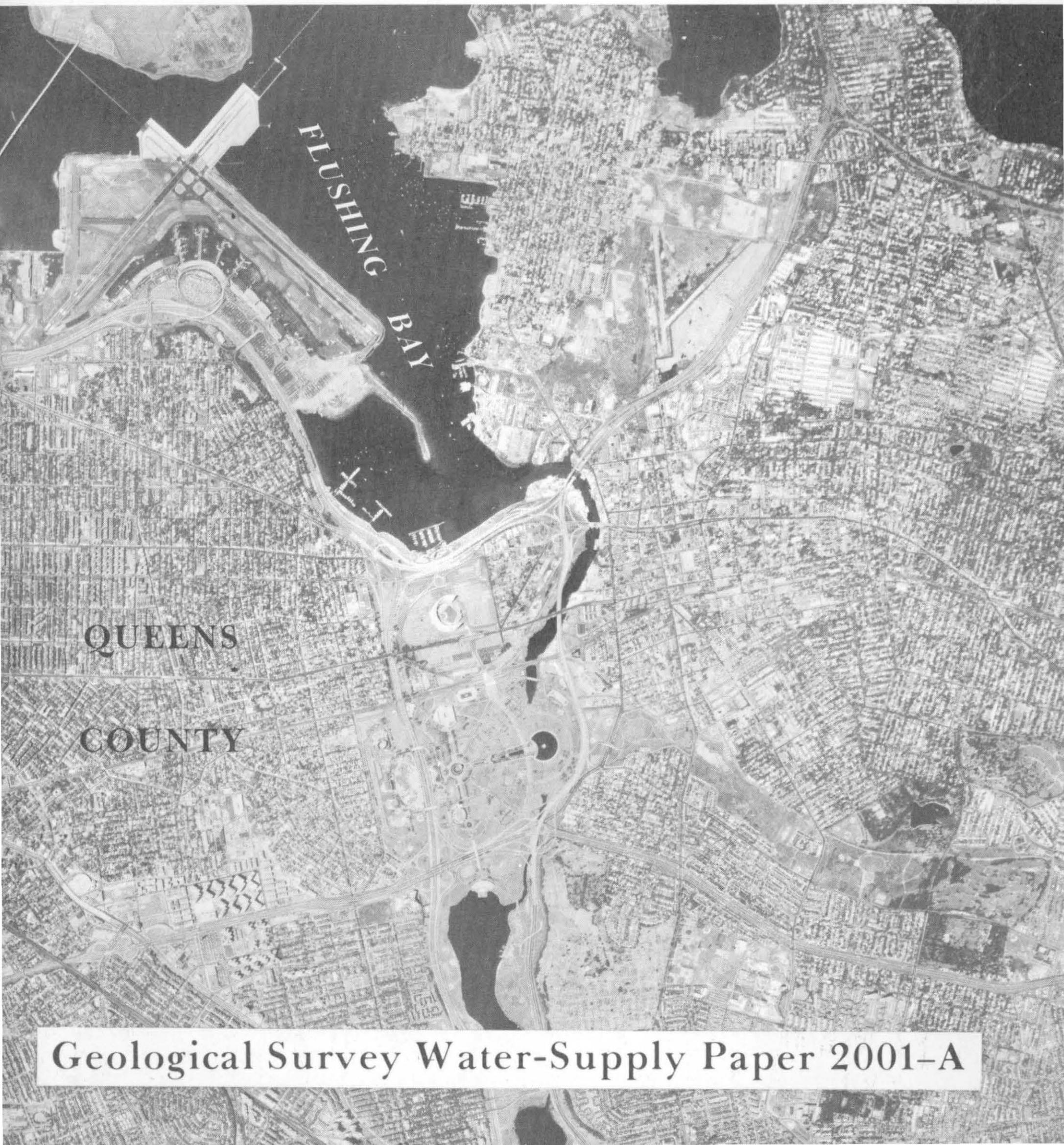
Ground-Water and Geohydrologic Conditions in Queens County, Long Island, New York

Prepared in cooperation with the New York State Department of Environmental Conservation, Division of Water Resources



Geological Survey Water-Supply Paper 2001-A

GROUND-WATER AND GEOHYDROLOGIC CONDITIONS IN QUEENS COUNTY, LONG ISLAND, NEW YORK

By Julian Soren

U.S. Geological Survey Water Supply Paper 2001-A (1971)

Prepared in cooperation with New York State Department of Environmental Conversation

E R R A T A

Page A14, caption to fig. 2: change "approximately" to "approximate"

Page A29: Well Q2373 is 158 ft deep (not 558 ft)

Page A30, 3d and 4th lines from bottom: change "two" to "four" and add well numbers Q307 and Q1378

Page A38: reference to Perlmutter and Soren, 1963: change 420-E to 450-E

Plate 1: Table of geologic and hydrologic units: Switch headings in last two columns

Plate 1: Change well Q2420D to 2402D

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WATER IN THE URBAN ENVIRONMENT

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2001-A

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WATER IN THE URBAN ENVIRONMENT

GROUND-WATER AND GEOHYDROLOGIC CONDITIONS IN QUEENS COUNTY, LONG ISLAND, NEW YORK

By JULIAN SOREN

ABSTRACT

Queens County is a heavily populated borough of New York City, at the western end of Long Island, N. Y., in which large amounts of ground water are used, mostly for public supply. Ground water, pumped from local aquifers, by privately owned water-supply companies, supplied the water needs of about 750,000 of the nearly 2 million residents of the county in 1967; the balance was supplied by New York City from surface sources outside the county in upstate New York.

The county's aquifers consist of sand and gravel of Late Cretaceous and of Pleistocene ages, and the aquifers comprise a wedge-shaped ground-water reservoir lying on a southeastward-sloping floor of Precambrian(?) bedrock. Beds of clay and silt generally confine water in the deeper parts of the reservoir; water in the deeper aquifers ranges from poorly confined to well confined. Wisconsin-age glacial deposits in the uppermost part of the reservoir contain ground water under water-table conditions.

Ground water pumpage averaged about 60 mgd (million gallons per day) in Queens County from about 1900 to 1967. Much of the water was used in adjacent Kings County, another borough of New York City, prior to 1950. The large ground-water withdrawal has resulted in a wide-spread and still-growing cone of depression in the water table, reflecting a loss of about 61 billion gallons of fresh water from storage. Significant drawdown of the water table probably began with rapid urbanization of Queens County in the 1920's. The county has been extensively paved, and storm and sanitary sewers divert water, which formerly entered the ground, to tidewater north and south of the county. Natural recharge to the aquifers has been reduced to about one half of the preurban rate and is below the withdrawal rate. Ground-water levels have declined more than 40 feet from the earliest-known levels, in 1903, to 1967, and the water table is below sea level in much of the county.

The aquifers are being contaminated by the movement of salty ground water toward the deepest parts of the cone of depression in central Queens County. Contamination of ground water is probably also occurring from leaking sewers and from pollutants leaking downward from the land surface.

Thermal pollution of the ground water has occurred locally where ground water pumped for cooling uses is returned, with elevated temperatures, to the source aquifer through recharge wells

The quality of ground water in Queens County in 1967 was generally satisfactory for public-supply and most industrial uses. However, the rate and distribution of ground-water withdrawals in the county are leading to greater decline of the water table and to increasing contamination of the aquifers No "safe limit" on pumpage can be set for the county because limits on the effects of pumping have not been established A safe limit, at the present stage of urbanization, could range from considerably less than the current average 60 mgd to considerably more over a wide-range of pumping effects and acceptable water quality. However, continued removal of fresh water from storage and deterioration of water quality reduces the value of the county's aquifers, not only for current supply, but also for additional supply to the county and other parts of New York City in times of drought or other emergency

INTRODUCTION

Although the water supply for most of the nearly 2 million people in Queens County, Long Island, N.Y., is obtained from upstate surface-water sources of the New York City water-supply system, ground water pumped by two private water-supply companies has been serving the needs of about 750,000 people in the south-central part of the county. Therefore, the ground water in the county is of vital concern to a sizable population. In addition, the county's ground-water resources have significant potential value as a possible emergency water supply for other parts of New York City.

Net pumpage from sand and gravel aquifers in Queens County averaged about 60 mgd (million gallons per day) from about 1900 through 1967, and ground-water levels have declined considerably, reflecting a large loss of ground-water storage. Another result of the reduced ground-water heads is that salty ground water is slowly moving into the aquifers of the county, partially replacing fresh water pumped from the aquifers. An imbalance between pumpage and fresh-water recharge had occurred over a period of decades and still existed at the end of 1967, and salt-water contamination of the aquifers will continue as long as the imbalance exists.

The basis for this report is a study designed to evaluate the hydrologic regimen of Queens County and to emphasize changes in the regimen resulting from the activities of man. The study began in 1959, and fieldwork was completed in 1968; this report largely emphasizes geohydrologic conditions in Queens in 1961 and 1968, at which times comprehensive field studies were made. The report describes the occurrence, availability, and quality of ground water in Queens County, and the relations between various elements of the geohydrologic system. The major purpose of this report is to provide information that will aid in the development, use, and conservation of the ground-water supply for current and future needs; the report will also provide a basis for further studies.

The study of Queens County was made in cooperation with the New York State Department of Environmental Conservation. The report, which includes information obtained from a series of water-resources investigations made on Long Island by the U.S. Geological Survey since 1932, has benefited from previous and contemporary work of colleagues too numerous to cite individually. The study was also aided significantly by the cooperation of the Lauman Co., Inc., and Layne-New York Co., Inc., well-drilling firms that provided many well logs and drilling samples; the Jamaica Water Supply Co. and the New York Water Service, Division of Utilities and Industries Corp., which provided water-level data and chemical analyses. Other industrial and commercial establishments, individuals, and public agencies, too numerous to cite, generously supplied information and permitted collection of water-level data and water samples from their wells.

The report was prepared under the supervision of Philip Cohen, assistant district chief, Long Island, and G. G. Parker, district chief, in charge of U.S. Geological Survey water-resources studies in New York.

Selected reports of related investigations that are especially pertinent to this study are listed under "References cited". A more detailed description of the subsurface geology of the county is presently being prepared by the writer, and many of those geological details were used to evaluate the geohydrologic conditions discussed in this report.

GEOGRAPHY

LOCATION AND EXTENT OF AREA

Queens County, one of the five boroughs of New York City, is in the western part of Long Island (fig. 1). The county has a land area of 113 square miles, comprising numerous urban and suburban communities (pl. 1). Queens County is bounded by the East River on the north, by Jamaica Bay and the Atlantic Ocean on the south, by Nassau County on the east, and by Kings County and the East River on the west.

TOPOGRAPHY

The northern part of Queens County consists of low rolling hills,

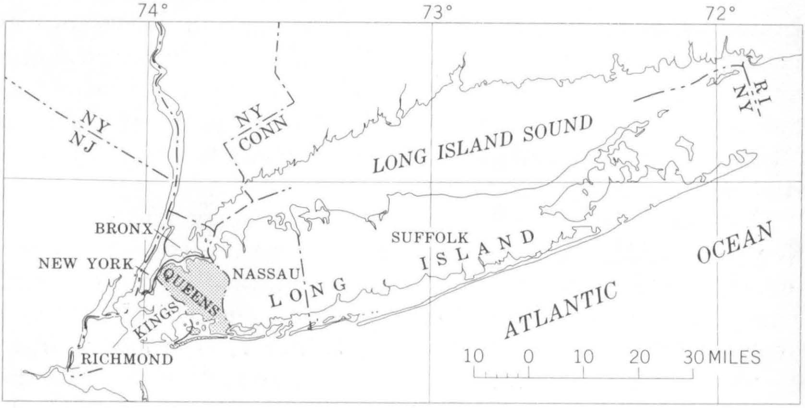


FIGURE 1.—Location of Queens County and general regional geography.

overlooking and locally jutting into the East River between various salt-water bays. A narrow ridge trends about east-northeast across the central part of the county north of and parallel to Jamaica Avenue (pl. 1). The base of the ridge is at an altitude of about 100 feet above mean sea level, and the width of the base ranges from about 0.75 mile on the western part of the county to about 1.5 miles on the eastern part. The crest of the ridge ranges in altitude from about 160 feet on the west to about 260 feet on the east.

Two flat-bottomed valleys extend northward from the ridge to the East River. The larger valley, Flushing Meadow, is in the central part of the area, and the smaller valley, Alley Creek, is near the eastern border of the county. A plain slopes gently southward from the ridge to Jamaica Bay. The southernmost part of the county, the Rockaway Peninsula, lies south of Jamaica Bay and is mainly a barrier bar which trends west-southwest into the Atlantic Ocean. The surface of the peninsula generally is 10 feet or less above sea level, and its maximum height is about 23 feet above sea level in Far Rockaway.

DRAINAGE

According to U.S. Weather Bureau statistics, the long-term average annual precipitation in Queens County is about 44 inches, but precipitation averaged about 33 inches annually from 1962 through 1966, a period of drought in the area. Most of the precipitation runs off paved surfaces to sewers and is discharged to tidewater. Some precipitation, however, penetrates the land surface, principally in unpaved areas, and percolates downward to the water table where it joins the ground-water body. (See the section "Inflow and recharge of ground water.") Little precipitation in the county enters natural streams by direct runoff

In contrast with the many streams that existed in 1897 (as shown on older U.S. Geological Survey topographic maps—Brooklyn, Harlem, Hempstead, and Oyster Bay quadrangles), only a few streams occur in Queens County at present. Brookfield Stream and three former streams, all of which flowed into Jamaica Bay, had a combined discharge of about 13 mgd in the mid-1850's (Veatch and others, 1906, p. 366). Although data are not available for the many other streams in preurban Queens County, the total stream discharge from the county probably exceeded 30 mgd and doubtless consisted mostly of ground-water seepage.

Most of the streams disappeared because of lowering of the water table, artificial filling of channels, and reduction of runoff resulting from other aspects of urbanization. The present streams are in near-shore areas where the water table is near the land surface. Of these present streams, Flushing and Alley Creeks flow northward to Flushing and Little Neck Bays, respectively, and Brookfield Stream flows southward to Jamaica Bay. (See pl. 1.) Flushing Creek is dammed by a tidegate near its mouth, and there is no visible natural outward flow to Flushing Bay. The amount of water that enters Flushing Creek apparently is about equal to evaporation losses from the ponds (Meadow and Willow Lakes) on it. The headwaters of Brookfield Stream originally were in Nassau County, but lowering of the water table has dewatered the upstream reach of this stream.

Selected discharge measurments obtained by the U.S. Geological Survey at Alley Creek and Brookfield Stream are given in the following table:

Stream	Location of measuring site	Date of measurement	Discharge (cubic feet per second)
Alley Creek	South side of Northern Boulevard	June 17, 1967	2 3
		Jan 15, 1963	3 6
		Apr 10, 1962	4 9
Brookfield Stream	About 0 6 mile south of Southern Parkway	June 19, 1967	2
		Feb 5, 1963	4
		Mar 9, 1955	2 0
		Aug-Dec 1852	3 9–7 4

CULTURE

Although highly urban areas occur throughout the county, suburban communities characterized by one- and two-family homes are common. Urban characteristics are most highly developed in the western part of the county, where most of the closely spaced apartment houses, from two to as many as 20 stories, and most industries are located In 1960 Queens County had the second largest population of the five boroughs of New York City. Statistics of the U S Bureau of the Census show that Queens County had a population of about 1.8 million in 1960, which was more than 20 times its population in 1890. The greatest increase in a single decade occurred from 1920 to 1930, when the population increased from about 181,000 to about 610,000. The increased water needs accompanying the population growth were met largely by increased importation of water from the New York City system, except in the south-central part of Queens County where ground water is used

The county census statistics for 1960 list more than 10,000 stores, ranging from small shops to large multilevel department stores, and hundreds of factories and service industries. Although substantial volumes of ground water are pumped for use by these establishments, most of the ground water is not consumed, but is used mainly for air conditioning or industrial cooling and then returned to the ground-water reservoir. (See the section "Utilization of ground water.")

The area is traversed by thousands of paved streets and sidewalks and by many major highways (pl. 1). The central and western parts of the county are traversed by municipal-owned rapid-transit surface and subway railroads and by the Long Island Railroad. Two large commercial airports are in the county: New York Municipal Airport in the northwestern part and John F. Kennedy International Airport in the south-central part. A significant effect of the many streets and buildings is that the land surface in much of Queens County has been made impermeable; consequently, infiltration of precipitation into the ground-water reservoir has been greatly reduced.

SURFICIAL GEOLOGY

The surficial geology of Queens County, which is described briefly in the following paragraphs, significantly affects many aspects of the local hydrology. The subsurface geology of the county is described in the section "Aquifer system" and on plate 1.

More than three-fourths of Queens County is mantled by deposits of Pleistocene (Wisconsin) glacial drift (pl. 1). The remainder of the county (generally along or near shorelines) is covered by shore and salt-marsh deposits and artificial fill of Holocene age.

The topography of the county is largely related to the different glacial deposits. The low rolling hills of northern Queens are mostly underlain by ground moraine, and to a lesser extent, by outwash deposits. The ridge across the central part of the county is part of the Harbor Hill Terminal Moraine, which marks the farthest advance of the Wisconsin Glaciation in Queens County. East of Queens County, the ridge branches into two ridges—the Harbor Hill Moraine, which traverses the length of the north shore of Long Island, and the Ronkonkoma Terminal Moraine, which traverses the length of central Long Island.

Outwash deposits of sand and gravel, laid down by water issuing from the melting glaciers at the end of the Pleistocene Epoch, underlie the plain south of the terminal-moraine ridge in Queens County. Salt-marsh deposits occur in Jamaica Bay, and shore deposits mantle much of the surface of the Rockaway Peninsula Artificial fill has been used to extend and reinforce shorelines and to eliminate swampy areas.

AQUIFER SYSTEM

GEOHYDROLOGIC SETTING

Virtually all the fresh-water resources of Queens County are contained in the ground-water reservoir beneath the county. The reservoir, which comprises a sequence of unconsolidated sedimentary deposits that range in age from Late Cretaceous to Pleistocene, rests on a relatively featureless erosional surface formed on crystalline bedrock of Precambrian (?) age (pl. 1). Small exposures of the bedrock crop out near the East River in Astoria and Long Island City (pl. 1). The bedrock surface dips about 80 feet per mile to the southeast and is at a depth of about 1,100 feet below sea level at Far Rockaway. Thus, the unconsolidated deposits form a wedge-shaped mass which ranges in thickness from zero in northwestern Queens to about 1,100 feet in the southeastern part of the county. For practical purposes, the bedrock surface is considered to be the bottom of the ground-water reservoir.

The deposits that transmit water readily to wells are called aquifers. In Queens County the major aquifers are layers of sand and gravel. The layers of clay and silt in the ground-water reservoir do not transmit water readily, and they confine the water under artesian pressure in the aquifers lying between them. Four distinct aquifers occur in Queens County. They are, in descending order, the upper glacial aquifer, the Jameco aquifer, the Magothy aquifer, and the Lloyd aquifer; the aquifer names are those adopted by Cohen, Franke, and Foxworthy (1968, p. 18).

UPPER GLACIAL AQUIFER

The upper glacial aquifer is the uppermost water-bearing unit. It consists mainly of glacial-outwash deposits of sand and gravel south of the terminal moraine and of ground-moraine deposits north of the terminal moraine Its thickness ranges from a few feet in northwestern Queens and in the Whitestone area of the county (pl. 1, section *A–A′*,) to about 150 feet near Woodhaven and Hollis (pl. 1, section *B–B′*,). Various units included in this aquifer (pl. 1) are exposed at the land surface throughout the county.

Laboratory tests for porosity and permeability of a sample of medium sand from the upper glacial aquifer were made by the U S. Geological Survey Hydrologic Laboratory. The porosity is 40 percent and the coefficient of permeability (rate of water flow, in gallons per day, through 1 square foot under a gradient of 100 percent) is about 1,000 gpd per sq ft. The coefficients of permeability are probably much higher for the coarse sand and gravel in the outwash deposits. Accordingly, the average coefficient of permeability in the horizontal direction of the outwash deposits of the upper glacial aquifer in Queens County is estimated to be 1,500 gpd per sq ft.

Ground water occurs under water table (unconfined) conditions in most of the upper glacial aquifer south of the terminal moraine. From the terminal moraine northward, ground water in the aquifer occurs under conditions of various degrees of confinement because of complex interbedding of layers of sand and gravel, ground-moraine, and other glacial deposits.

In Queens County, the upper glacial aquifer is most extensively pumped in the central part of the county, between the Harbor Hill Terminal Moraine and Jamaica Bay. In this area the aquifer consists of thick coarse outwash deposits that are capable of yielding large quantities of water to wells. From the terminal moraine northward, the aquifer becomes thinner and contains much clayey and silty till and ground moraine. Consequently, in the northern part of the county the aquifer is less permeable and contains less ground water in storage than it does south of the terminal moraine. Public-supply and other large-yield wells tapping outwash deposits south of the terminal moraine produce as much as 1,500 gpm (gallons per minute) per well. The specific capacities (gpm pumped per ft of drawdown) of these wells are generally about 50–60 gpm per ft, but specific capacities as large as 139 gpm have been noted.

JAMECO AQUIFER

The main part of the Jameco aquifer is in a buried valley which extends southward from the Flushing Meadow area to the area of the John F. Kennedy International Airport, from where it passes seaward under the Rockaway Peninsula. Smaller bodies of the aquifer occur in the Ridgewood area (pl. 1, section *B–B′*) and in the Maspeth area. In these latter areas the Magothy aquifer is missing, and the Jameco aquifer lies between the Gardiners Clay and the Raritan clay member (Ridgewood area) or between the Gardiners Clay and bedrock (Maspeth area). The Jameco aquifer attains a maximum thickness of about 250 feet in central Queens County, and it is generally less than 50 feet thick in the Ridgewood and Maspeth areas

In most places water in the Jameco aquifer is confined by the overlying Gardiners Clay. In the Woodhaven-Ozone Park area, however, the Gardiners Clay either was not deposited or it was removed by erosion, and there the Jameco aquifer is overlain directly by outwash deposits of the upper glacial aquifer. Consequently, water in the Jameco aquifer is under water-table conditions in that area.

The Jameco aquifer consists mostly of coarse sand and gravel with only small amounts of silt and clay. Permeability data are not available for the Jameco aquifer, but locally the Jameco probably is the most permeable of all the aquifers in Queens County. Locally, the coefficient of permeability of the Jameco aquifer may be as much as 2,000 gpd per sq ft. Wells tapping the aquifer in central Queens County yield as much as 1,600 gpm, and such wells have specific capacities as large as 180 gpm per ft.

MAGOTHY AQUIFER

The Magothy aquifer underlies the upper glacial aquifer in most of Queens County but is missing in the western and northern parts of the county. The Magothy also is missing in the Flushing Meadow area and in the central part of the buried valley, where it has been replaced by the Jameco aquifer. (See pl. 1.)

The Magothy aquifer, which includes the Matawan Group-Magothy Formation undifferentiated (Perlmutter and Todd, 1965, p. 9), consists chiefly of intercalated beds and lenses of clay, clayey and silty sand, fine to coarse sand, and gravelly sand. The most persistent lithologic zone in the aquifer is a basal unit of sand and gravel about 50 to 100 feet thick. Farther east on Long Island the maximum thickness of the basal zone is about 200 feet The sand and gravel strata commonly contain interstitial clay and silt in amounts ranging from traces to about 25 percent.

The Magothy aquifer ranges in thickness from zero, where it wedges out in western and northern Queens and in the buried valley, to about 450 feet at Far Rockaway. The wide range in thickness reflects the fact that the aquifer was deeply eroded prior to the deposition of the Pleistocene units. (See pl. 1.)

Water in the Magothy aquifer ranges from poorly confined to highly confined. Generally, water in the upper part is poorly confined, where the aquifer is directly overlain by the upper glacial aquifer In most parts of the county, water that occurs farther below the top of the Magothy aquifer is confined by clayey and silty beds within the aquifer itself, and water in the basal sand and gravel locally is well confined. The aquifer is well confined in the buried valley in south-central Queens County by the overlying Gardiners Clay (pl. 1). There, the Gardiners Clay overlies the Magothy aquifer either directly (along the margins of the buried valley) or it overlies the Jameco aquifer which, in turn, overlies the Magothy. The sloping contact between the Magothy and Jameco aquifers results in broad lateral and vertical hydraulic interconnection between them.

The porosity and permeability of the Magothy aquifer range widely because of the varied lithology of its beds. Perlmutter and Geraghty (1963, p. 30) listed coefficients of permeability that range from 500 to 1,450 gpd per sq ft and average about 950 gpd per sq ft, for disturbed sand samples from the aquifer in southeastern Queens County and adjacent southwestern Nassau County. Wenzel and Fishel (1942, p. 13) show a porosity of 31.4 percent and a coefficient of permeability of 1,200 gpd per sq ft for a sample taken from the basal zone of the Magothy aquifer in the Queens Village area. The coefficients of permeability for isolated sand samples, of course, are not necessarily representative of the entire aquifer. The coefficients of permeability of the finer materials in the aquifer probably range from less than 0.2 to about 100 gpd per sq ft. Furthermore, because of the stratification of the sand, clay, and silt beds, the permeability of the Magothy aquifer in the horizontal direction is much greater than in the vertical direction. For the purposes of this report, the average coefficient of permeability of the Magothy aquifer in the horizontal direction is estimated to be 500 gpd per sq ft.

Wells tapping the Magothy aquifer yield as much as 1,500 gpm Specific capacities range from 15 to 30 gpm per ft for wells that tap fine-grained layers in the aquifer to as much as 50 gpm per ft for wells screened in the coarser materials.

LLOYD AQUIFER

The Lloyd aquifer, which consists of the Upper Cretaceous Lloyd Sand Member of the Raritan Formation, is the lowermost major water-bearing unit in Queens County. The aquifer is highly confined between the underlying bedrock and the overlying poorly permeable Raritan clay member. The Lloyd aquifer was not deposited in northwestern Queens. It is about 300 feet thick at Far Rockaway (pl. 1, section *A–A'*), but becomes thinner to the northwest and tapers to a knife edge along a line approximately between Ridgewood and the New York Municipal Airport. The Lloyd aquifer and other Cretaceous units also are missing in buried valleys between the New York Municipal Airport and College Point, between College Point and Whitestone, and in the Flushing Meadow area.

The Lloyd aquifer consists of beds of sand and gravel intercalated with beds of clay and silt The sand and gravel beds commonly contain varying amounts of interstitial clay and silt. Tests by Jacob (1941, p. 784) indicated that the coefficient of permeability of the Lloyd aquifer in the vicinity of Rockaway Park ranges from about 700 to 800 gpd per sq ft. Lusczynski and Swarzenski (1966, p. 19) reevaluated Jacob's data and estimated that the average coefficient of permeability of the Lloyd aquifer in the horizontal direction in that area is about 500 gpd per sq ft. Coefficients of permeability of the Lloyd aquifer at six sites in central Queens County were estimated from specific-capacity data by a method described by Meyer (1963, p. 339). These values range from about 150 to 830 gpd per sq ft and average about 430 gpd per sq ft Thus, the average coefficient of permeability of the Lloyd aquifer (in the horizontal direction) in Queens County is estimated to be between 400 and 500 gpd per sq ft.

High-capacity wells screened in the Lloyd aquifer are commonly pumped at less than 1,000 gpm; however, pumpage of as much as 1,600 gpm from a single well has been reported. Specific capacities of Lloyd wells in the county range from 4 to about 40 gpm per ft.

MOVEMENT OF WATER THROUGH THE HYDROLOGIC SYSTEM

The fresh ground water in Queens County is part of a continuous hydrologic system in which, under natural (preurban) conditions, the long-term average outflow and inflow were equal. Ground water was replenished entirely by local precipitation that infiltrated the land surface and percolated down to the upper glacial aquifer In the upper glacial aquifer, most of the ground water moved laterally toward the north and south shores of the county and ultimately discharged by evaporation, transpiration, seepage into salt-water bodies, and seepage into streams which flowed into the salt-water bodies. In the higher, central part of the county, where the altitude of the water table was higher than the hydraulic heads in the deeper aquifers, some ground water percolated downward from the upper glacial aquifer through leaky confining beds into the Jameco, Magothy, and Lloyd aquifers. Most of the water in these deeper aquifers then moved seaward and discharged into bodies of salty ground water near the shores.

Two of the major factors that have modified the natural hydrologic regimen in the county are the reduced infiltration of precipitation resulting from paving, building, and sewers, and the large-scale withdrawals of ground water. The resulting major declines of the water table and artesian pressures have induced or increased the inflow of ground water from adjacent counties and also have induced landward movement of salty ground water in the near-shore areas. In 1968, salty ground water was moving landward in the upper glacial, Jameco, and Magothy aquifers, and probably also in the Lloyd aquifer, toward centers of pumping. (See the section "Salt-water intrusion.")

At the current (1968) stage of urbanization, precipitation, water imported from the mainland New York City reservoir system (about 195 mgd in 1968), and lateral subsurface inflow from adjacent parts of Long Island are the sole sources of fresh water in Queens County. Fresh water presently recharges the ground-water reservoir of Queens County mainly by: (1) infiltration of precipitation, (2) subsurface inflow of ground water from Kings and Nassau Counties, and (3) leakage from New York City supply pipelines carrying water from upstate New York. In addition to the fresh water, some salty ground water enters the county by induced landward movement resulting from pumping, and possibly minor amounts of water may leak into the ground-water reservoir from storm-sanitary sewers.

Water is discharged from Queens County by: (1) runoff of precipitation to tidewater, mainly through sewers, and to a small degree through the few remaining streams, (2) outflow to tidewater of sewage water derived from local ground water and from imported water, (3) subsurface outflow of ground water to salty water in the shore areas, and (4) evapotranspiration. Subsurface outflow of ground water to adjacent counties is practically negligible.

WATER-TABLE AND PIEZOMETRIC SURFACES

The first known map of the water table (upper surface of the ground water) in Long Island was made in 1903 (Veatch and others, 1906, pl 12), and that map depicted, as nearly as the available data permitted, the natural position of the water table in Queens County. Since about the 1920's decreased ground-water recharge, coupled with large ground-water withdrawals (mostly from the upper glacial aquifer), resulted in the development of cones of depression in the water table and in the piezometric surfaces of the confined aquifers. The cone of depression in the water table was first observed in the early 1930's (Suter, 1937, p. 48) and was still growing in 1968.

The configuration of the water table in Queens County was mapped in 1961 and in 1968, and the water-table maps are shown on plate 2*A* and *B*; these maps show large changes from the 1930's. The cone of depression mapped in 1936 by Suter (1937, fig. 26) was centered in the Woodhaven area of the county where the water table was between 5 and 10 feet below sea level By 1961 the cone's center included the Woodhaven-Richmond Hill areas, in which the water table had declined to more than 15 feet below sea level (pl. 2A). In 1968 the center of the cone of depression was more complex, having spread northeastward into the southern part of Flushing and eastward into Hollis. The water table in 1968 was more than 15 feet below sea level in the Woodhaven, Richmond Hill, and Flushing areas and about 10 feet below sea level in Hollis (pl. 2*B*). The spread of the cone of depression into the Flushing area was caused by new public-supply wells which began pumping in 1963 (pl. 1); the eastward extension of the cone to Hollis was the continuation of the trend of the cone's growth with new well installations, mostly in the east-central part of the county after World War II.

The 1968 water-table map (pl. 2*B*) and the 1903 water-table map made by Veatch and others (1906, pl. 12) were used to prepare figure 2, which is a map showing the net change in the position of the water table between these years. In 1968 the water table in the deepest parts of the complex cone of depression was more than 40 feet below water-table levels of 1903 in the areas, and significant decline of the water-table was evident throughout most of the county's area. However, the water table had not been drawn below the upper glacial aquifer to 1968.

The zero net-change line in figure 2 encloses an area of about 80 square miles in Queens County, and this line is considered to be the extent of the cone of depression in 1968. The cone of depression does not lie wholly within Queens County; it extends eastward into Nassau County where the effects of pumping in Queens County merge with the effects of pumping in Nassau County; the cone also extends westward a short distance into Kings County.

The large central area enclosed by the minus-10-foot line (fig. 2) is oval-shaped, with the long axis of the oval trending east-northeast. This line encloses an area where all the public-supply

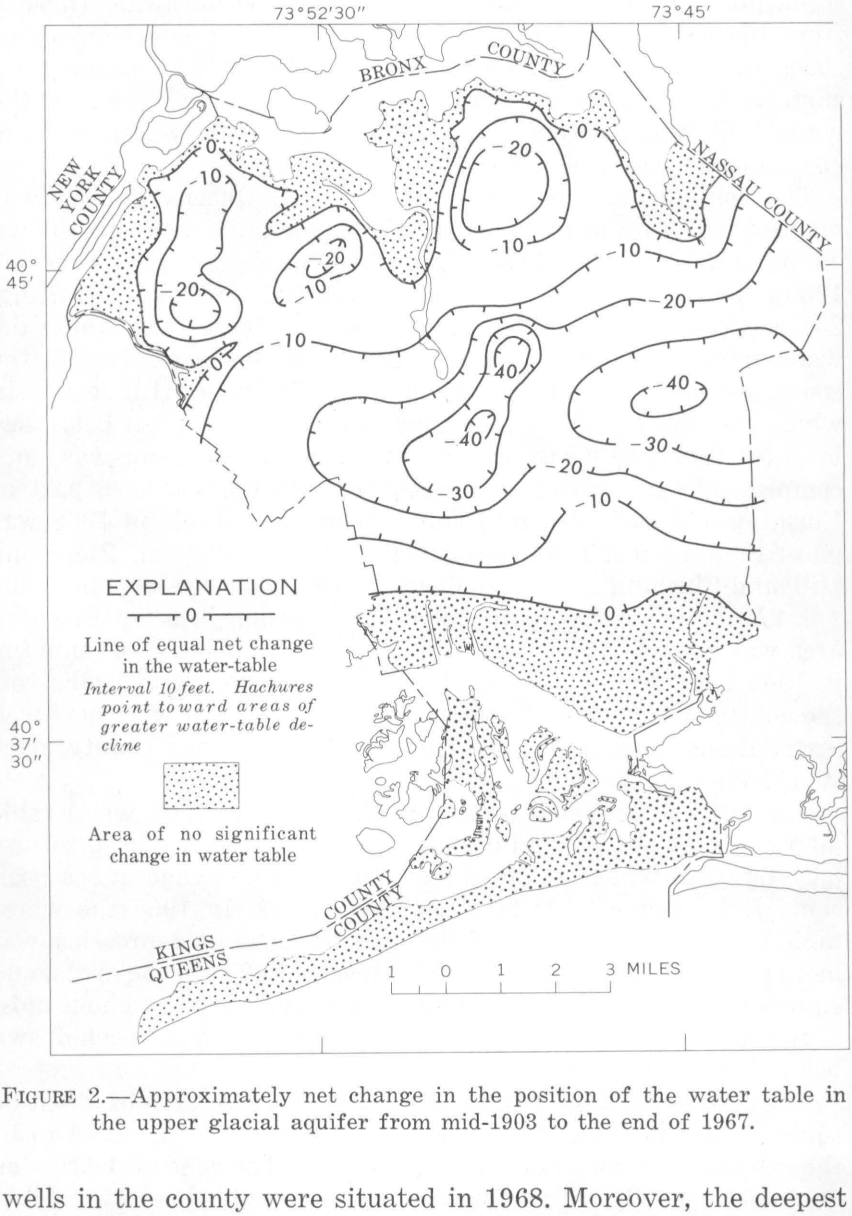


FIGURE 2.—Approximately net change in the position of the water table in the upper glacial aquifer from mid-1903 to the end of 1967.

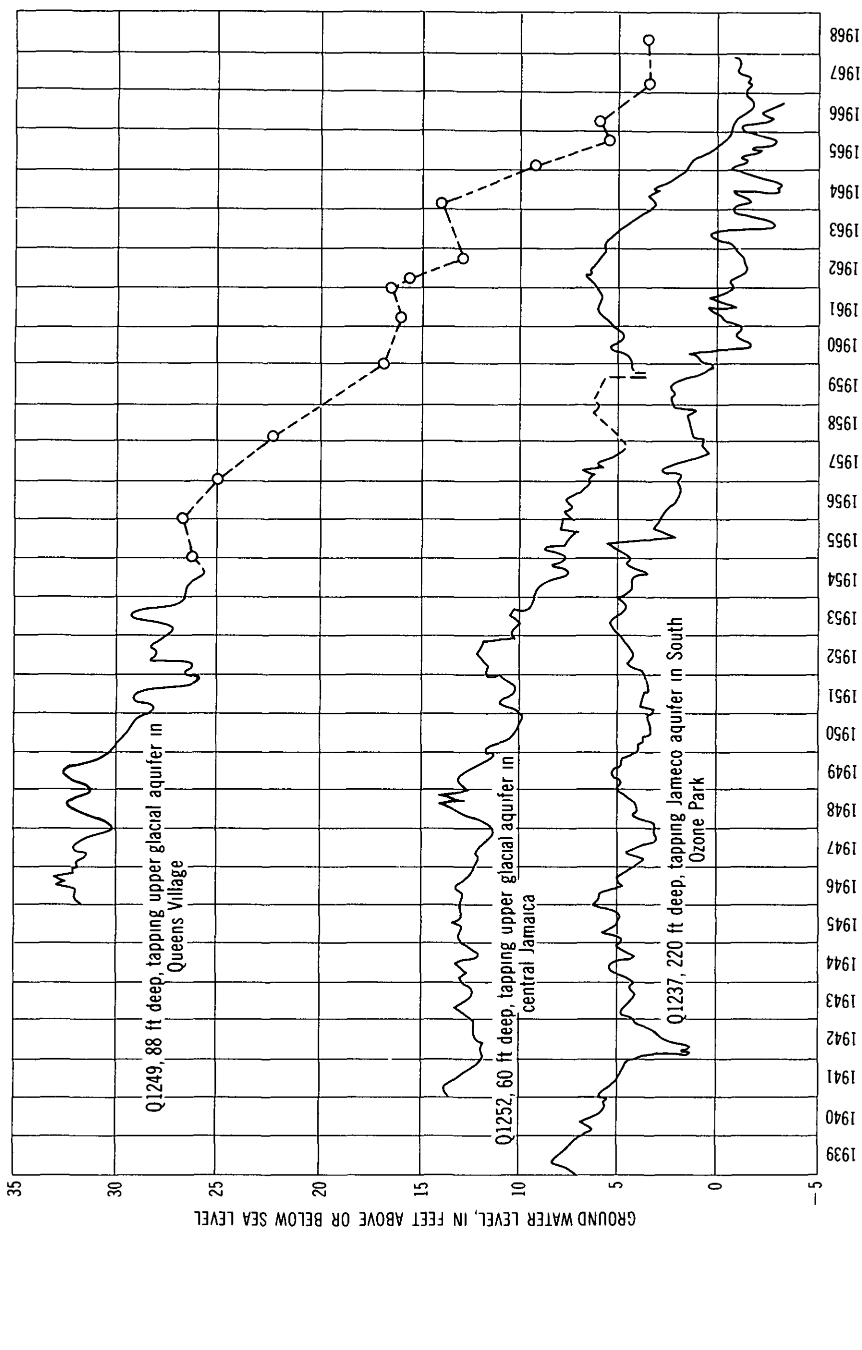
wells in the county were situated in 1968. Moreover, the deepest parts of the cone of depression also reflect this distribution of wells.

The increase in the size of the cone of depression in the water table from 1961 to 1968 (pl. 2*A* and *B*) was caused by a combination of reduced recharge from 1962 through 1966 associated with drought conditions in the area (Cohen, Franke, and McClymonds 1969, p. 9) and continued large ground-water pumpage.

The shape of the water table in 1920 probably was nearly similar to that in 1903. Accordingly, the approximate volume of saturated material in the upper glacial aquifer that was drained from 1920 to 1968 can be calculated from figure 2; this volume is about 0.22 of a cubic mile. Assuming that the specific yield (drainable pore space) of the drained material is 25 percent, the estimated decrease of fresh water in storage in the upper glacial aquifer is about 61 billion gallons. Thus, the estimated average net loss of ground water from storage in the upper glacial aquifer in the county from 1920 to 1968 was about 3.5 mgd

The hydraulic heads in a confined aquifer—the levels at which water will stand in nondischarging wells that tap the aquifer—define what is termed a "piezometric surface." Generalized piezometric surfaces in the upper parts of the Magothy and Jameco aquifers in 1961 and 1968 are shown by contours on plate 2*C* and *D*. A comparison of the water table (pl. 2*A* and *B*) and these piezometric surfaces show that, in most places, water levels in the upper parts of the Jameco and Magothy aquifers were lower than those in the overlying upper glacial aquifer. A cone of depression, similar to that in the upper glacial aquifer, also existed in the Magothy-Jameco piezometric surface in 1961 when the surface was first mapped; this cone also was centered in the Woodhaven-Richmond Hill area. By 1968 the cone was enlarged, and its center had spread into the Flushing area The enlargement of the cone resulted from increased pumpage and decreased recharge related to the drought. Data are not available to prepare piezometric maps for the upper parts of the Jameco and Magothy aquifers for periods prior to 1961; accordingly, the water levels in 1961 cannot be compared to earlier levels.

The piezometric surfaces of the Lloyd aquifer in 1961 and 1968 are shown on plate 2*E* and *F*. The cones of depression in these piezometric surfaces were centered in the Woodhaven-Jamaica area of the county The cone of depression in the piezometric surface of the Lloyd aquifer did not change significantly in areal extent and depth from about 1955 to 1961, according to known water levels. This lack of change mainly reflects a nearly constant rate of pumping from the Lloyd aquifer from 1955 to 1961. (See the section "Utilization of ground water.") The Lloyd's cone of depression in 1968 shows a considerable lateral expansion and deepening compared to the cone in 1961. Pumpage from the Lloyd in 1967 averaged about 1 mgd more than in 1961. The increase in the cone's size was caused by increased pumpage and also by reduced recharge resulting from lower heads in the overlying aquifers.


GROUND WATER LEVEL, IN FEET ABOVE OR BELOW SEA LEVEL
35
30
25
20
15
10
5
0
−5
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
Q1249, 88 ft deep, tapping upper glacial aquifer in Queens Village
Q1252, 60 ft deep, tapping upper glacial aquifer in central Jamaica
Q1237, 220 ft deep, tapping Jameco aquifer in South Ozone Park

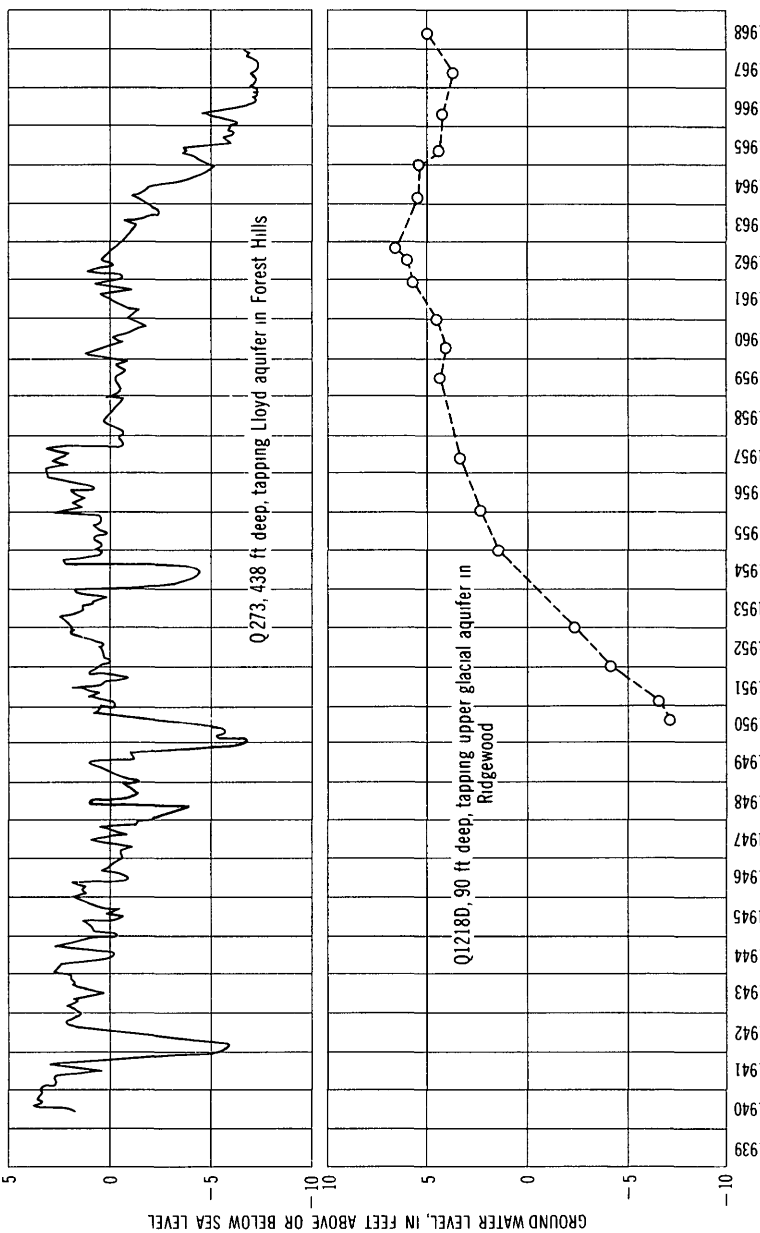


FIGURE 3.—Hydrographs of selected wells, 1939–67

WATER-LEVEL FLUCTUATIONS

Fluctuations of water levels in wells in Queens County reflect variations in recharge to and discharge from the aquifers tapped by the wells. These fluctuations are also related to the distribution, extent, and permeabilities of the aquifers, and the manner by which water moves through the ground-water system. Therefore, changes in ground-water levels afford an insight into the entire pattern of ground-water flow Furthermore, the fluctuations can be used to assess the impact of urbanization on the natural hydrologic system

Data from relatively undeveloped areas in eastern Long Island, where conditions approximate those present in Queens County before urbanization, indicate that under natural conditions ground-water levels fluctuated only a few feet. The water table had a rhythmic seasonal pattern of highest levels in early spring and lowest levels in late autumn. That pattern reflected greatest losses of rain and ground water by evapotranspiration during the growing season, and the least such losses between growing seasons. The pattern of seasonal decline and recovery of the water table now occurs only in shoreline areas of the county.

The general pattern of progressively declining ground-water levels in the county (associated with intensive ground-water development and decreased recharge) are shown by the hydrographs in figure 3. Only one of the hydrographs, that for well Q1218D, shows a rising water level during the years prior to 1961. That rise, which occurred in the Ridgewood area, resulted from a recovery of the water table related to the discontinuation of public-supply pumping in neighboring Kings County in 1947. The decline in the water level at well Q1218D from 1962 to 1967 is interpreted as having been largely due to drought.

The more common declining trend of the water table is shown by the hydrographs for wells Q1249 and Q1252. The hydrograph of well Q1237 reflects the somewhat lesser head declines in the Jameco aquifer during the same period. The hydrograph of well Q273, which taps the Lloyd aquifer in Forest Hills, shows that hydraulic heads in the Lloyd in that locality had declined very little prior to 1961. All the hydrographs in figure 3 show declining water levels from 1962 to 1967. The drought conditions, described previously, probably caused much of the decline.

Depths to ground water from the land surface in 1961 and 1968 can be estimated from plate 2. Contour lines on the land surface and ground-water surfaces are given in the figures. The depth to water in the aquifers, at any given location, is the difference between the land-surface and water-surface altitudes at the location.

HYDRAULIC INTERCONNECTION OF AQUIFERS

Ground water percolates downward readily through the outwash deposits of sand and gravel in the upper glacial aquifer because of the high permeability and general absence of clay and silt layers in these deposits. Ground water moves less readily through the ground-moraine and till deposits in the upper glacial aquifer, and also through the Magothy aquifer, because of the low permeability (especially in the vertical direction) of the clay and silt in these deposits. However, the discontinuous nature of the clay and silt beds in the ground moraine, till, and in the Magothy aquifer locally facilitates downward movement of water through the aquifers.

Ground water moves readily from the upper glacial aquifer into the Magothy aquifer, except in south-central and southern Queens County where the Gardiners Clay separates the two aquifers. The Gardiners Clay also retards the downward movement of ground water into the Jameco aquifer in most of Queens County. However, the Gardiners Clay is missing in the Woodhaven, Ozone Park, and South Ozone Park areas, and ground water moves easily between the upper glacial and Jameco aquifers in these areas. Locally, where the Jameco and Magothy aquifers are adjacent to each other (pl. 1), ground water can move laterally from one aquifer to the other.

Downward movement of ground water into the Lloyd aquifer is generally retarded by the thick and areally extensive Raritan clay member. However, in the buried valley beneath the Flushing Meadow area, the Raritan clay member was removed by erosion, and ground water flows into the Lloyd aquifer from contiguous beds of sand and gravel in the upper glacial aquifer. This downward movement from the upper glacial aquifer into the Lloyd aquifer is confirmed by a mound in the piezometric surface of the Lloyd aquifer in that area, shown by the positive 5- and 1-foot contours on plate 2*E* and *F*. The decrease in the height of the mound from 1961 to 1968 was due primarily to local pumpage for the New York World Fair (1964–65) and new public-supply withdrawals in the Flushing area beginning in 1963, and, probably to a lesser extent, it was due to reduced recharge during the drought years 1962–66.

Most of the water pumped from the Magothy aquifer in Queens County in 1968 entered the aquifer by downward percolation within the county, mainly in the central and eastern parts. This is confirmed by the water-level contours on plate 2 and by the equal potential lines on plate 1, which show that the hydraulic heads in the Magothy aquifer were generally lower than those in the upper glacial aquifer. The remainder of the water pumped from the Magothy aquifer in Queens County was mostly derived from subsurface inflow from neighboring Nassau and Kings Counties (see the section "Inflow and recharge of ground water"), and in part was withdrawn from storage in the aquifer as artesian pressures declined. In early 1968, however, the fact that heads in the Magothy aquifer were higher than water-table heads near Nassau County in east-central Queens indicated a change to an upward movement of water from the Magothy into the upper glacial aquifer there (pl. 1). The head changes in the Magothy aquifer also indicate an increase in the amount of lateral recharge to the Magothy aquifer from Nassau County from 1961 to 1968.

INFLOW AND RECHARGE OF GROUND WATER

Precipitation that percolates to the water table and then downward to the lower aquifers has been the main source of recharge to the ground-water reservoir in Queens County. However, some water also enters the ground-water reservoir by lateral subsurface inflow from outside the county. Most of the lateral inflow of fresh water to the cone of depression in Queens County is from Nassau County. The inflow is mainly through the upper glacial and Magothy aquifers, and to a lesser extent through the Lloyd aquifer.

Natural recharge from precipitation within the county can be estimated only grossly. The maximum rate of recharge on Long Island under natural conditions was estimated to be 1 mgd per square mile by Suter (1937, p. 32). In Queens County recharge from normal amounts of precipitation during the past several decades probably was on the order of 0.5 mgd per sq mi because of the reduced opportunity for infiltration due to the construction of streets, buildings, automobile parking lots, and other impervious surfaces. Accordingly, the estimated average recharge from precipitation in the county during the past several decades was about 55 mgd During the drought years 1962–66, recharge from precipitation probably declined to about 40 mgd or less.

Subsurface fresh-water inflow to Queens County from Nassau and Kings Counties in 1968 was computed by use of the Darcy equation, utilizing the permeability values listed in the preceding text, aquifer dimensions obtained from geologic mapping, and hydraulic-gradient data obtained from plate 2. The computed total subsurface inflow of fresh ground water to Queens County was on the order of 15–20 mgd. Of this amount 6–8 mgd entered through the upper glacial aquifer, 7–9 mgd came through the Magothy aquifer, and 2–3 mgd entered through the Lloyd aquifer. Most of this inflow, about 12–17 mgd, came from Nassau County. Total inflow from Kings County was about 2–3 mgd. The inflow from Kings County is considered to be "fresh water" although ground water there was seriously contaminated by salt water prior to cessation of pumping for public supply in 1947 (Perlmutter and Soren, 1963, p. 138).

Salty ground water, from the zone of diffusion (see the section "Salt-water intrusion"), moving landward into the cone of depression in central Queens also constitutes a form of inflow to the aquifer system, most notably in the Woodhaven area. The amount of such inflow in 1968 was estimated to be at least about 2 mgd.

Some recharge also resulted from leaks and breaks in water-supply mains and, perhaps, from sewers. Records of the City of New York, Department of Water Supply, Gas, and Electricity (1958–64) show that from 1958 to 1964 an average of about 5 mgd of water-main leakage was discovered and repaired in Queens County. A study by the Jamaica Water Supply Co., the larger of the two private water-supply companies in the county, reportedly showed that water losses from its system were about 13 percent of the total pumpage. However, the "losses" included water used for fire fighting, street washing, fire-main testing, and for uses other than supply to customers (oral commun., Mr. Thomas Sebekos, Jamaica Water Supply Co., December 1965) ; the percentage that constituted leakage to the ground-water reservoir is unknown.

From the meager data available on leakage from water mains, the average recharge from leakage in Queens County, including undetected leakage from the New York City water-supply system, is estimated to have been about 15 mgd in the 1960's. The amount of leakage from sewers is unknown, but it is believed to be small in comparison to water-main leakage; sewer pipes generally are only partly full and ordinarily operate under pressures much lower than those in the water-supply mains. Where sewers flow under gravity, they operate without pump pressure.

GROUND-WATER MOVEMENT

Prior to the major decline of ground-water levels in Queens County, ground-water movement was mainly seaward from the higher, central part of the county and, to a lesser extent, westward into Kings County. Large amounts of ground water discharged into many short streams which, in turn, flowed into tidewater in the northern and southern parts of the county. However, since the 1930's most of the ground-water movement has been toward the cones of depression in the central part of the county, and ground-water discharge to streams has become negligible. Submarine outflow of ground water has decreased substantially and, as a result, salty water is moving into the aquifers (Perlmutter and others, 1959, p. 429).

Approximate rates of ground-water movement can be computed from hydraulic gradients, estimated average coefficients of permeability of the aquifers, and estimated porosities of the aquifers. In the parts of the county that are distant from pumping centers, the rate of ground-water movement in the horizontal direction ranges from about 0.5 foot per day in the deeper aquifers to about 1.5 feet per day in the upper glacial aquifer. The extreme rates of ground-water movement in Queens County range from as little as an extremely small fraction of an inch per day in clay to hundreds of feet per day in sand and gravel deposits near pumping wells.

GROUND-WATER DISCHARGE

Net ground-water pumpage—the pumpage that was consumed by evapotranspiration or was discharged to tidewater through sewers—averaged about 63 mgd during the period 1960–68 and was the largest element of ground-water discharge in Queens County during those years (See the section "Utilization of ground water.") Prior to 1930 the second largest element of ground-water discharge in the county probably was evapotranspiration. Since 1930 subsurface outflow to the bordering bodies of salty surface water was the second largest element of ground-water discharge. Subsurface outflow from Queens in 1968 is estimated at about 10–15 mgd. Of this amount, about 1–2 mgd discharged into the East River in the northwestern part of the county; about 4–6 mgd discharged into the East River in the northern part of the county, mostly in the Little Neck Bay area; and about 5–7 mgd discharged into Jamaica Bay and the Atlantic Ocean in the southern part of the county.

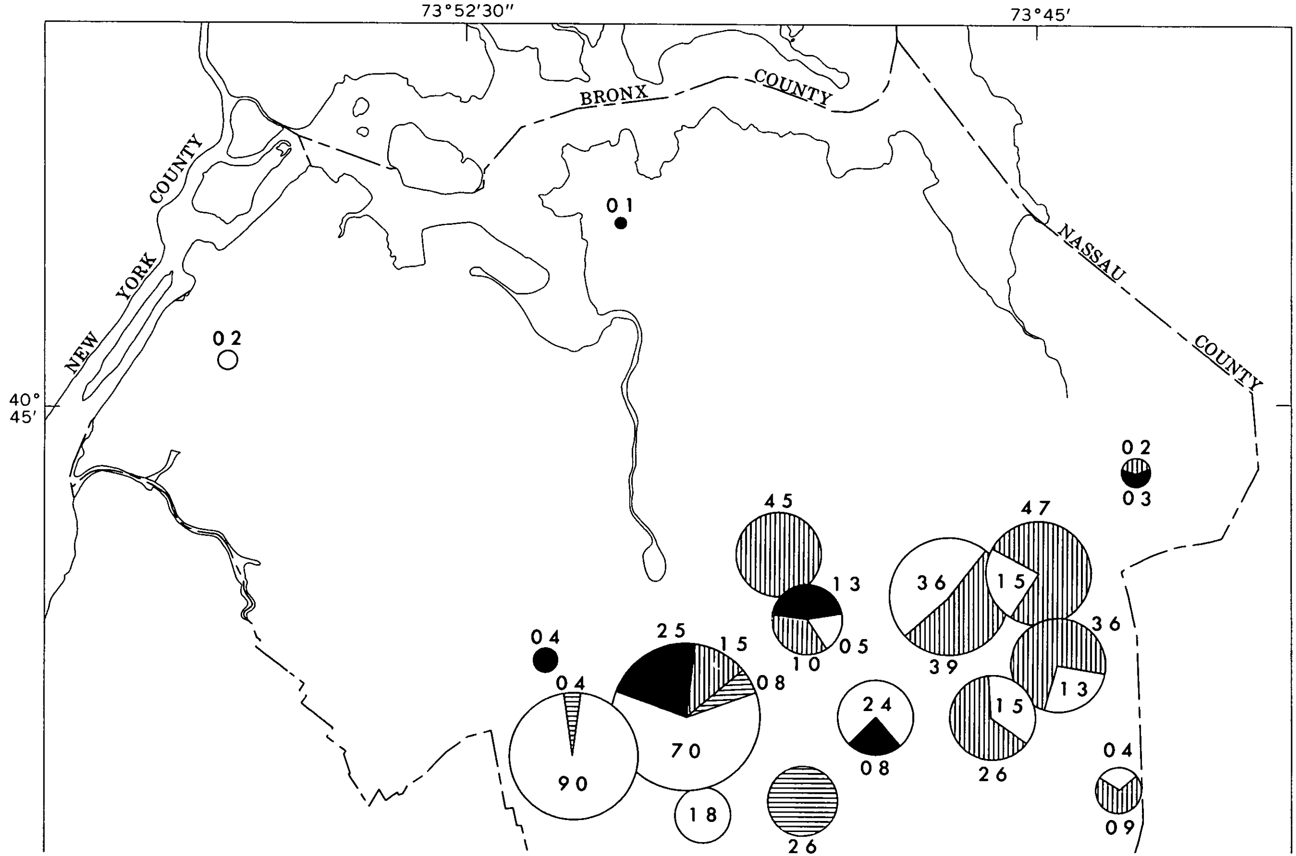
Losses from the Queens County ground-water reservoir in 1968 by direct evapotranspiration or outflow to adjacent counties were negligible compared to other losses. Evapotranspiration of ground water was very small because much of the land surface is paved, most of the natural vegetation has been removed, and former marshy areas are now filled in. Virtually no ground water discharged from Queens County into adjacent counties as underflow from 1961 to 1968 because of the flow of most of the ground water toward the centers of the deep depressions in the water table and the piezometric surfaces in the central part of Queens County. Prior to urbanization of the area, there was some natural underflow from Nassau into Queens and from Queens to Kings County. Underflow to Kings County was undoubtedly increased by pumpage in that county; however, since the cessation of large-scale withdrawals there in 1947, underflow to Kings has virtually ceased.

UTILIZATION OF GROUND WATER

Ground-water development began in Queens County in the 1600's with the settlement of the first Europeans in the New York City area In those days springs, streams, ponds, and shallow dug wells were the sources of most of the water for the people. The use of ground water for large-scale public-supply purposes began in Long Island City in the 1870's. Beginning in 1880, ground water from Queens County was pumped by New York City and exported to neighboring Kings County for public-supply use. However, this pumping was virtually discontinued in the early 1950's, and the pumping plants owned by New York City were abandoned between 1961 and 1968.

Records of ground-water pumpage in Queens County are available only from about the beginning of the 20th century. According to a compilation of pumpage data by Lusczynski and Spiegel (1954), for the period 1904–53, net pumpage for public-supply use during that period averaged about 44 mgd. A compilation of pumpage prepared by the New York State Water Resources Commission in 1963 (written commun.) shows that the average net pumpage for public-supply use during the period 1954–61 was about 50 mgd. Net industrial pumpage is not accurately known prior to 1933, but in that year it was about 20 mgd (Suter, 1937, p. 36). Net industrial pumpage from 1948 to 1961 averaged about 8 mgd Net industrial pumpage declined from about 7 mgd in 1961 to about 4 mgd in 1967. As the ground-water withdrawals for use in Queens County increased from year to year, exportation of ground water to Kings County decreased. Moreover, as pumpage for public-supply use increased in Queens County, industrial pumpage in the county decreased. Therefore, the estimated total net ground-water pumpage (for all uses) in Queens County remained fairly constant from year to year and averaged about 60 mgd from 1904 to 1967.

The average net ground-water pumpage (compiled from data


73°52'30"
73°45'
40° 45'
BRONX COUNTY
NEW YORK COUNTY
NASSAU COUNTY
01
02
02
03
45
13
10
05
47
36
15
39
36
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15
26
04
04
25
15
08
90
70
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09

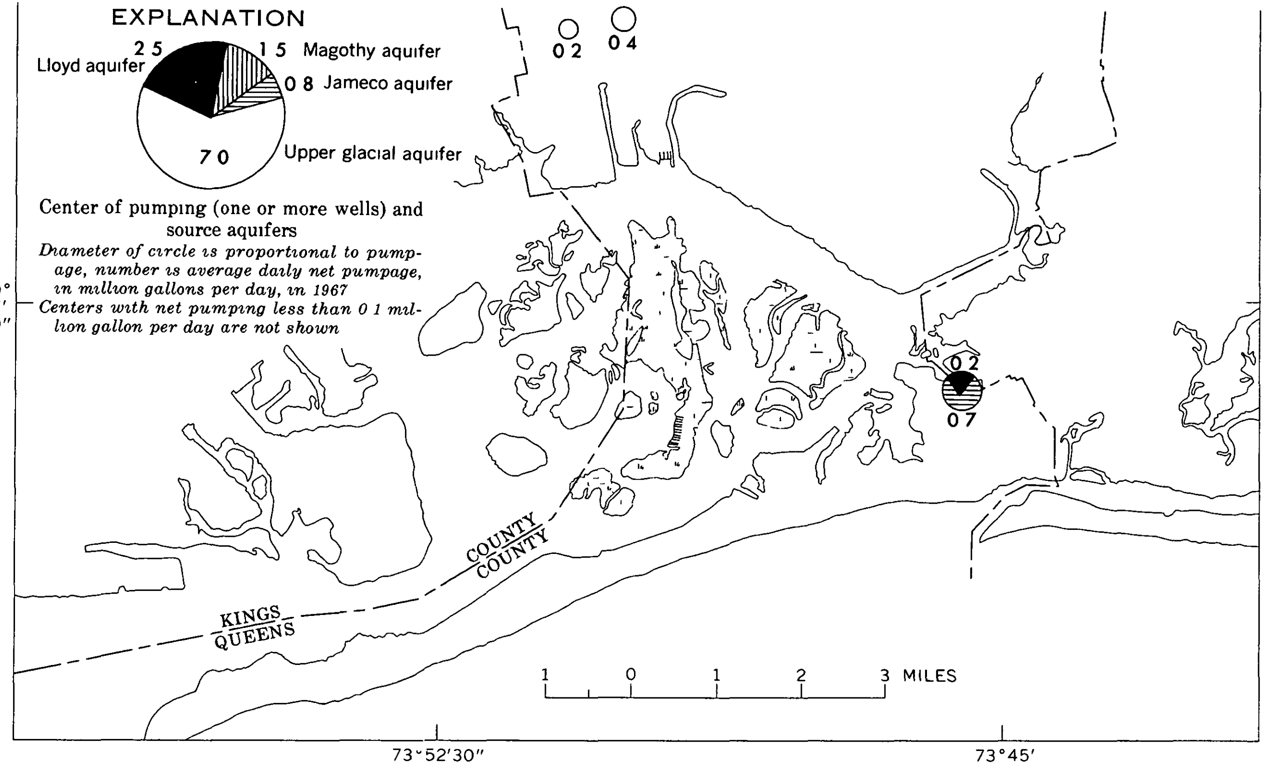

FIGURE 4.—Distribution and sources of net ground-water pumpage in 1967.

supplied by the New York State Water Resources Commission) in Queens County in 1961 and 1967 from the various aquifers was as follows:

Aquifer	Average net pumpage (mgd)					
	Public-supply wells		Industrial and other wells		Total	
	1961	1967	1961	1967	1961	1967
Upper glacial	31 0	27 8	4 4	2 0	35 4	29 8
Jameco	3 5	3 8	9	8	4 4	4 6
Magothy	18 5	22 7	3	2	18 8	22 9
Lloyd	3 5	4 6	1 1	1 0	4 6	5 6
Total	56 5	58 9	6 7	4 0	63 2	62 9

In addition to the pumpage listed in the preceding table, about 10–15 mgd was pumped for air-conditioning and cooling uses, mainly from the upper glacial aquifer. However, practically all this water was returned to the source aquifers through diffusion (recharge) wells, as required by regulations enforced by the New York State Water Resources Commission.

The distribution of the net ground-water pumpage in 1967 in Queens County is shown in figure 4. Two private water-supply companies pumped most of the ground water in the county in 1967. The Jamaica Water Supply Co. pumped about 49 mgd, and the New York Water Service, Division of Utilities and Industries Corp., pumped about 10 mgd. Virtually all the remaining pumpage in 1967, about 4 mgd, was from wells owned by individual industrial and institutional water users; pumpage from privately-owned domestic wells was negligible. In 1967 the private water-supply companies in Queens County operated 90 wells, and about 350 industrial, commercial, and institutional establishments used one or more wells each.

Most of the ground-water pumpage in Queens County, from the beginning of development to 1968, was taken from the upper glacial aquifer. In the 1930's and 1940's, the Jameco aquifer supplied as much as 13 mgd, and the Lloyd aquifer, as much as 10 mgd. However, pumpage from the Jameco and Lloyd aquifers decreased beginning about the end of World War II, because much of the water from the Jameco contained undesirable amounts of iron, and because pumpage from the Lloyd was limited by New York State Water Resources Commission regulations. Since the end of World War II, and especially since 1953, the Magothy aquifer has been extensively developed from central to east-central Queens to replace water formerly withdrawn from the Jameco and Lloyd aquifers and to meet additional ground-water needs for the increasing population in Queens. In 1961 Magothy pumpage was a little more than one half the pumpage from the upper glacial aquifer; in 1967 pumpage from the Magothy aquifer nearly equaled pumpage from the upper glacial aquifer.

QUALITY OF THE GROUND WATER

DISTRIBUTION OF DISSOLVED CONSTITUENTS

The chemical suitability for use of the ground water in Queens County differs from place to place and has changed with time. Representative chemical analyses of ground-water from Queens County are listed in table 1. A few of the analyses in table 1 were made during the period 1939–55 and are shown because later analyses are not available. However, no significant ground-water development has occurred in the areas for which the older analyses are listed, and it is not likely that any large changes in the chemical quality of the water have occurred in these areas since the analyses were made.

Most of the ground water in Queens County meets the standards for drinking water established by the U. S. Public Health Service (1962, p. 7). Locally, however the quality of the ground water is less than optimum and, in some places, the water is not potable because of certain natural characteristics or because of pollution related to the activities of man.

Excessive amounts of iron in solution in the ground water is a major source of difficulty in Queens County, as elsewhere on Long Island. According to the U.S. Public Health Service (1962, p. 43), more than about 0.3 mg/l (milligrams per liter) of iron is undesirable because it stains kitchen fixtures, utensils, and other objects such as painted surfaces, and because it can impart an objectionable color and taste to the water. Commonly, excessive amounts of iron (often as much as 5 or 6 mg/l) are dissolved in water from the Jameco, Magothy, and Lloyd aquifers; the highest concentrations commonly occur in water from the Jameco and Lloyd aquifers in Queens County. Most of the water from the Magothy and Lloyd aquifers is slightly acidic (pH of less than 7.0), and the aquifers contain abundant pyrite (iron sulfide). The acidic water and the natural occurrence of iron minerals in the aquifers probably are largely responsible for the high iron content of the water from the Magothy and Lloyd aquifers. The high iron content of the water from the Jameco aquifer may be largely related to a high content of ferromagnesian (diabase) rock fragments in the aquifer and close hydraulic interconnection, locally, between the Jameco, Magothy, and Lloyd aquifers.

TABLE 1—*Selected chemical analyses of ground water in Queens County, N Y*

Geologic unit Krl, Lloyd Sand Member of Raritan Formation, Kmm, Magothy Formation-Matawan Group undifferentiated, Q_J, Jameco Gravel, Qo, outwash deposits (see plate 1)
Aquifer L, Lloyd aquifer, M, Magothy aquifer, J Jameco aquifer, U, upper glacial aquifer.
Date of collection Year alone indicates average analysis for that year
Analyst a, New York State Department of Health, b, New York City Bureau of Water Supply, Department of Water Supply, Gas and Electricity, c, Jamaica Water Supply Co, Jamaica, N Y, d, Permutit Co, Paramus, N J, e, U S Geological Survey, f, Lowell Senter, Little Neck, N Y, g, O'Brien Industries, Inc, Brooklyn, N Y, h, Dearborn Chemical Co, Chicago, Ill

Well	Community	Depth of well below land surface (feet)	Geologic unit	Aquifer	Date of collection	Milligrams per liter						Specific conductance (micromhos at 25°C)	pH	Temperature (°C)	Analyst	Other constituents (mg/l) and remarks
						Iron (Fe)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)					
Q31	Glendale	491	Krl	L	Apr 15,1948	4 6	5 2	—	97	52	56	—	7 0	—	a	Manganese (Mn), 0 10, sulfate (SO_4), 4 2
Q34	Flushing	245	Krl	L	June 9, 1948	5 4	70	—	554	82	63	—	6 9	—	a	Manganese (Mn), 0 05, sulfate (SO_4), 10
Q276	Douglaston	211	Kmm	M	1951	03	7 7	18	87	34	12	92	6 4	—	b	
Q278	do	512	Krl	L	1939	03	4 6	1 8	50	21	15	—	—	—	b	
Q283	Flushing	409	Krl	L	1934	3 1	9 4	1	73	20	13	—	5 7	—	b	
Q301	Richmond Hill	94	Qo	U	June 26, 1961	14	23	—	—	294	186	—	6 9	—	c	Manganese (Mn), 0 27
					1966	15	37	8 3	434	350	212	680	7 3	13	b	
Q304	South Ozone Park	61	Qo	U	June 26, 1961	04	50	—	—	235	82	—	6 6	—	c	Manganese (Mn), 0 00
Q307	.Hollis	97	Qo	U	1961	05	13	35	—	104	29	260	6 4	11	b	
					1967	30	26	50	254	125	49	415	6 5	12	b	
Q311	Jamaica	258	Q_J	J	1962	40	4 8	4	116	88	94	200	7 5	13	b	
					1967	39	5 9	1 4	132	87	86	220	7 8	12	b	
Q313	Queens Village	106	Qo	U	June 12 1961	00	26	—	—	122	34	—	5 9	—	c	Manganese (Mn), 0 00
					1967	07	43	32	—	182	62	486	6 6	13	b	
Q314	Jamaica	304	Q_J	J	1962	35	21	4	157	100	92	200	7 9	14	b	
					1967	32	19	4 8	151	126	82	230	7 7	12	b	
Q317	Richmond Hill	550	Krl	L	1961	1 0	7 6	4	94	53	48	145	6 8	12	b	
					1967	1 1	6 6	1 1	—	49	52	145	7 0	13	b	
Q321	Queens Village	145	Qo	U	1962	05	9 9	23	178	111	34	260	6 4	14	b	
					1966	02	14	31	225	131	39	330	6 6	13	b	
Q355	Woodhaven	111	Qo	U	1962	05	163	45	728	471	172	796	7 7	13	b	
					1967	02	498	56	1,463	907	160	1,879	7 5	13	b	
Q564	Hollis	282	Kmm	M	1961	05	8 4	24	99	38	16	125	6 3	11	b	
					1967	04	10	23	116	46	19	180	6 7	12	b	
Q566	Richmond Hill	281	Q_J	J	1962	83	7 2	4	140	92	83	175	7 5	13	b	
					1967	56	6	7	128	84	68	200	7 3	13	b	
Q567	Jamaica	618	Krl	L	1962	1 4	6 9	4	82	48	36	112	7 0	14	b	
					1967	2 1	7 3	3	78	39	34	116	6 8	12	b	
Q569	do	60	Qo	U	1962	05	38	12	326	168	55	450	6 5	14	b	
					1967	02	28	35	254	176	58	440	6 6	12	b	

Q582	Bellerose	686	Krl	L	Jan 6, 1953	85	6 0	2 4	104	16	36	—	6 7	—	d	Silica (SiO_2), 14, calcium (Ca), 2 4, magnesium (Mg), 2 3, sulfate (SO_4), 7, sodium (Na), 20, potassium (K), 4 7
Q1030	Rockaway Park	795	Krl	L	Aug 3,1962	3 1	25	0	84	20	34	154	6 6	16	e	Silica (SiO_2), 5 3, calcium (Ca), 4 8, magnesium (Mg), 2 0, sulfate (SO_4), 0 8, fluoride (F), 0 2, manganese (Mn), 0 33
Q1086	Elmhurst	278	Krl	L	Feb 28, 1952	6 8	5 0	—	154	42	68	—	7 1	—	b	Manganese (Mn), 0 08, sulfate (SO_4), 7 3
Q1230	Arverne	161	Qj	J	July 20, 1942	4 8	12,600	0	—	530	156	—	—	—	b	
Q1374	College Point	214	Krl	L	May 18, 1955	53	1,718	—	—	—	26	—	5 3	—	f	Sulfate (SO_4), 260
Q1378	Woodhaven	189	Qo–Qj	U	1962	06	413	39	1,310	698	196	1,420	7 7	14	b	Chloride (Cl), 452, Jan 19, 1962
					1967	04	558	80	1,733	673	205	2,195	7 7	14	b	
Q1506	John F Kennedy International Airport	108	Qo	U	June 26, 1962	02	5,100	—	—	2,341	252	—	7 2	—	g	Composite sample from two closely spaced wells of same depth
Q1747	Hollis	257	Qo	U	1962	05	8 4	7 5	158	104	78	200	7 5	12	b	
			Qo	U	1967	03	12	14	184	114	76	315	7 2	11	b	
Q1811	Richmond Hill	115	Qo	U	1961	05	42	21	433	288	160	600	6 8	12	b	
					1967	06	48	20	454	260	180	583	7 1	13	b	
Q1839	Jamaica	85	Qo	M	June 19, 1961	62	29	—	—	166	70	—	6 3	—	c	Manganese (Mn), 0 08
Q1914	Bellerose	258	Kmm		Dec 31, 1952	2 9	6 1	15	165	57	30	—	7 0	—	h	Silica (SiO_2), 22, calcium (Ca), 13 6, magnesium (Mg), 5 6, sulfate (SO_4), 38
Q2026	Laurelton	431	Kmm	M	1961	10	4 8	4	—	11	6	50	5 3	9	b	
			Kmm	M	1964	14	4 8	6	40	13	7	40	6 0	12	b	
Q2028	Jamaica	285	Kmm	M	1962	05	8 4	5 8	88	32	9	100	6 1	13	b	Manganese (Mn), 0 00
					1964	04	9 1	4 6	87	36	10	87	6 1	13	b	
Q2137	do	250	Kmm	M	1961	40	11	24	249	160	78	350	7 0	11	b	
					Dec 18, 1967	65	15	—	—	160	96	—	6 8	—	c	Manganese (Mn), 0 17
Q2332	Richmond Hill	242	Oj–Kmm	J–M	June 5, 1961	12	16	—	—	128	95	—	6 9	—	c	Manganese (Mn), 0 00
					1964	24	15	4	186	130	98	277	7 3	13	b	
Q2333	Long Island City	38	Qo	U	May 10, 1962	05	133	—	—	280	128	650	7 9	—	d	Silica (SiO_2), 25, sodium (Na), 188, calcium (Ca), 180, magnesium (Mg), 100, sulfate (SO_4), 75
Q2343	Queens Village	225	Kmm	M	1961	10	8 0	24	—	30	10	90	6 0	12	b	
Q2362	Flushing	287	Kmm	M	1962	05	4 8	1 3	100	50	52	140	6 8	12	b	Manganese (Mn), 0 00
					Jan 22, 1968	00	20	—	—	170	95	—	6 7	—	c	
Q2373	do	558	Kmm	M	1962	05	10	58	—	168	88	400	6 4	13	b	Manganese (Mn), 0 00
					Jan 29, 1968	00	27	—	—	237	148	—	7 2	—	c	Manganese (Mn), 0 00

The highest iron content listed in table 1 (53 mg/l) is from a well tapping the Lloyd aquifer in College Point. The water also has a high chloride content (about 1,700 mg/l), and the high iron content probably is related to complex and not fully understood geochemical processes associated with the "zone of diffusion." (See the section "Salt-water intrusion.")

Excessive amounts of chloride (more than about 250 mg/l) impart a salty taste to water and render the water undesirable for drinking and cooking purposes. Under natural conditions most of the ground water in the upper glacial aquifer of Long Island contains less than 40 mg/l chloride, and chloride content usually diminishes in the deeper aquifers to less than 10 mg/l in the Lloyd aquifer. Locally near the shorelines, however, ground water contains thousands of milligrams per liter of chloride and, therefore, is unfit for domestic and most other uses The depression of the water table associated with extensive pumping has caused salty ground water to move landward in Queens County, notably in the Ozone Park-Woodhaven areas. (See the section "Salt-water intrusion.")

Hardness, which results mainly from calcium and magnesium ions in the water, also may significantly affect the suitability of the water for use. Under preurban natural conditions, nearly all the ground water in Queens County, except salty ground water near the shorelines, is believed to have been soft (containing less than 60 mg/l of hardness). However, for many years prior to 1968, hardness of the ground water in the upper glacial aquifer in much of central and eastern Queens County has been above 60 mg/l, and this factor is attributed to a combination of lateral salt-water intrusion and downward movement by pollutants from the surface. The hardness shown in the analyses of water from wells Q301 and Q304, (table 1), for example, is representative of the effects of pollution in various parts of the county.

Most of the pollutants in the upper glacial aquifer are derived from leaking sewers (storm waters and wastes are carried in common sewers in Queens County), salt used to de-ice streets and highways, fertilizers, and the large cemeteries in the county. In addition to hardness and chloride content, nitrate concentrations are often indexes of pollution. Nitrate is especially significant because concentrations in excess of 45 mg/l reportedly can be harmful to the health of infants (U.S. Public Health Service, 1962, p. 50). Of the 37 samples listed in table 1, only two (for wells Q355 and Q2373) had 45 mg/l or more of nitrate. However, many samples had more than 5 mg/l nitrate, which very likely is considerably more than the natural nitrate content of the ground water. Accordingly, the nitrate data are indicative of the widespread extent of pollution in the upper glacial aquifer

Pollution resulting from the downward percolation of contaminated water is less common in the deeper aquifers, but the fairly high nitrate content of water from wells Q276, Q564, Q1914, and Q2137 (table 1) suggests that pollutants also have percolated downward to the Magothy aquifer, at least locally. Gradual increasing pollution of the Magothy aquifer can be expected as development of the aquifer continues.

SALT-WATER INTRUSION

Near the shorelines of Queens County, the fresh ground water grades into salty ground water which, in turn, is hydraulically connected to the bordering bodies of salty surface water The contact between the fresh and salty ground water is gradational, and the zone of mixed ground water commonly is referred to as the "zone of diffusion." The position and the thickness of the zone of diffusion in any area at any given time depend upon many complexly interrelated factors including, but not limited to, the hydraulic heads in the fresh and salty ground water, the amount of fresh subsurface outflow, the rate and distribution of pumpage, and the physical characteristics of the aquifers and confining beds.

Salt-water intrusion occurs when the zone of diffusion moves landward, and fresh ground water is displaced by salty ground water. Under natural conditions, the zones of diffusion bordering Queens County moved back and forth in response to such natural features as ocean tides, atmospheric pressure, and long-term changes in the altitude of sea level. However, the salt-water intrusion that is of principal concern in this report is that related to the landward movement of the zone of diffusion associated with the activities of man—notably, decreased ground-water recharge and increased ground-water discharge.

The precise landward extent of the zones of diffusion in Queens County is difficult to determine because of several factors: (1) changes in chloride content in the zones of diffusion are gradational; (2) under natural conditions the chloride content of the fresh ground water doubtless varied somewhat from place to place in the same aquifer and from time to time; and (3) in addition to increases related to salt-water intrusion, the chloride content of the ground water in Queens County locally has increased because of the downward movement of salty pollutants from the land surface. A further complicating factor is that, locally, a tongue of salty ground water that is laterally invading one aquifer also may be spreading vertically from one aquifer to another at points distant from the shoreline Previous workers on Long Island (Lusczynski and Swarzenski, 1966, p. 19–20) selected the 40-mg/l chloride line (a line joining points of equal chloride content) as an index of the landward limit of the zone of diffusion on Long Island; this line is shown on plates 1 and 2.

Ground water in the upper glacial aquifer beneath about half of Queens County had a chloride content of more than 40 mg/l in 1961 and 1968 (pl. 2*A* and *B*). Although supporting data are sparse, the 40-mg/l chloride line in the upper glacial aquifer probably was very near the shorelines of the county prior to the development of ground water by man. Accordingly, the landward extent of the 40-mg/l chloride line shown on plate 2*A* and *B* is interpreted to have been largely a result of salt-water intrusion into the upper glacial aquifer related to the activities of man.

Widespread salt-water intrusion in the upper glacial aquifer occurred in northwestern Queens County, where the aquifer is thin and is generally of low permeability. In that area comparatively small amounts of pumpage have caused a large decrease of fresh ground water in storage and areally extensive salt-water intrusion.

Ground-water withdrawals concentrated in the Woodhaven-Richmond Hill area are responsible for a distinct salient of salty ground water in that area (pl. 2*A* and *B*). Evidence of continuing increase of chloride content of ground water in the upper glacial aquifer in the Woodhaven area is provided by data from wells Q355 and Q1378 (pl. 1). The chloride content of water from these wells in 1953 was 31 and 37 mg/l, respectively, and in 1959 chloride contents had increased to 65 and 199 mg/l, respectively. In 1962 the average chloride contents of water from wells Q355 and Q1378 were 163 and 413 mg/l, respectively, and in 1967 they were 498 and 558 mg/l, respectively (table 1).

Significant intrusion of salty ground water in the upper glacial aquifer also has occurred in the Flushing Meadow area, in the northern part of Queens County (pl. 2*A* and *B*). The chloride content of water from well Q1730, 260 feet deep, (pl. 1) in that area (not listed in table 1) was 47 mg/l in 1950. By 1962 the chloride content had increased to 128 mg/l, and in 1965 it had increased to 292 mg/l. The marked increase in chloride content at well Q1730 from 1962 to 1965 is mostly related to large ground-water withdrawals in that area in 1964–65 for use by the New York World Fair, about 2 miles south of the well, and to new public-supply wells which came into use in 1963 in the southern part of Flushing, about 3 miles southeast of the well

The position of the 40-mg/l chloride line in the Jameco, Magothy, and Lloyd aquifers under natural conditions is not well known However, the available evidence suggests that salty water has probably intruded the Jameco and Magothy aquifers in the Woodhaven area (pl. 2*C* and *D*) and the Lloyd aquifer in the Flushing Meadow area (pl 2*E* and *F*)

Wedges of landward-moving salty ground water in the upper glacial, Jameco, and Magothy aquifers, extending northward from the Jamaica Bay area, are shown on plate 1, sections *A–A′* In the Flushing Meadow area, where the upper glacial aquifer lies directly on the Lloyd aquifer (not shown in sections), salty ground water in the Lloyd aquifer (pl. 2*E* and *F*) is continuous with the salty ground water in the overlying upper glacial aquifer (pl. 2*A* and *B*) The chloride contents noted at well Q1730 indicate that a salty ground-water wedge is moving south from the Flushing Bay area through the Flushing Meadow area. The salty ground-water wedges moving into the county from Flushing and Jamaica Bays have nearly bisected the county and will probably meet in a few years if the present rate and distribution of ground-water withdrawals continues

The salty ground-water salient that moved into the county from the south in 1961 spread eastward about 1 mile by 1968. The movement was in the upper glacial aquifer from Ozone Park toward Jamacia (pl 1, sections *A–A′;* pl 2*A* and *B*). A narrow and thin tongue of salty ground water moved into the Richmond Hill area between 1961 and 1968 and is indicated on plate 1, section *B–B′*, by chloride contents of more than 40 mg/l at wells Q301 and Q2006. The Richmond Hill tongue is not shown on plate 1 because of the complexity of data there; however, it encloses wells Q301 and Q2006 and is wholly within the upper glacial aquifer Salty ground-water movement into the Jameco and Magothy aquifers between 1961 and 1968 occurred in a small part of Flushing (pl. 2*C* and *D*). This movement is attributed to pumping by new supply wells from 1963. (See the section "Water-table and piezometric surfaces") No significant change in salty ground-water movement into the Jameco and Magothy aquifers was observed in southern Queens County from 1961 to 1968 (pl. 2*C* and *D*), and the apparent stability there is due to a minor amount of pumping from the aquifers in this area (pl 1).

Throughout large parts of Queens County, the chloride content of water in the Magothy aquifer is more than 20 mg/l but less than 40 mg/l. Similarly, in many areas the chloride content of the water in the Lloyd aquifer is more than 5–10 mg/l but less than 40 mg/l (For example, see values at some wells on pl. 1). In the more eastern parts of Long Island, distant from shorelines, chloride contents are generally less than 20 mg/l in the Magothy aquifer and less than 10, usually less than 5, mg/l in the Lloyd aquifer. Thus, the above-normal chloride contents in much of the Magothy and Lloyd aquifers of Queens County may have been caused by lateral salt-water intrusion, by downward leakage of salty water from the overlying aquifers, or by a combination of these factors; however, the evidence is not conclusive, and careful future monitoring of chloride content is warranted.

TEMPERATURE

Ground-water temperatures in Queens County are of concern to many well owners who use ground water for refrigeration, cooling, and air-conditioning systems. In 1967 several hundred wells in the county were used for these purposes, and many of them had been so used for several decades. In 1936 the New York State Water Resources Commission was empowered to require, as a conservation measure, that water from wells on Long Island pumping 70 gpm or more for cooling purposes be returned to the source aquifer through recharge wells, or other approved structures. In 1954 the requirement for recharge was expanded to apply to wells that pumped 45 gpm or more for nonconsumptive uses.

The use of ground water as a sink for heat, by returning water heated in the processes of cooling, can result in "thermal pollution" which can impair or nullify the usefulness of the ground water for cooling. On Long Island, the maximum practical temperature of ground water used by itself for air-conditioning is about 16°C (61°F). If the temperature of the ground water is more than about 16°C, the air-conditioning systems become more expensive to operate and auxiliary mechanical cooling commonly is used.

Ground-water-temperature data listed in table 1 are summarized in the following table:

Depth of water-bearing zone (feet below land surface)	Aquifer	Range in water temperature	
		°C	°F
60–257	Upper glacial	11–14	52–57
189–304	Jameco	12–14	54–57
158–431	Magothy	9–13	48–55
550–795	Lloyd	12–16	54–61

The data are typical of ground-water temperatures in those parts of the county where thermal pollution has not been noted. In such areas there is little practical temperature difference, for cooling uses, in water from the upper glacial, Magothy, and

Jameco aquifers; the temperature of water from the Lloyd aquifer generally is only slightly higher than that from the other aquifers. The highest natural ground-water temperature known in Queens, 19°C (67°F, not shown in table 1), was measured in 1962 at well Q1929, which is 1,020 feet deep, in the Far Rockaway area (pl. 1)

The temperatures of ground water to a depth of about 600 feet generally are low enough in most of the county so that the water can be used satisfactorily in most air-conditioning and cooling systems; progressively rising temperature below this depth (about 0.75°C for each 100 ft) decreases the efficiency of ground water for cooling

Warm to hot ground water (having a temperature as high as 32°C (90°F) in Jamaica) locally occurs in zones into which hot exhaust water from cooling systems is injected through recharge wells. Many large business establishments in Jamaica use ground water for air conditioning, and the efficiency of some of the cooling systems has been impaired by thermal pollution of the ground water in that area.

OUTLOOK FOR THE FUTURE

ENGINEERING CONSIDERATIONS

The deep and widespread decline in ground-water levels has caused problems other than the deterioration of water quality in Queens County. Power costs for pumping have increased because of the greater depth to water, pump settings have had to be lowered, and wells have had to be deepened or abandoned and replaced Moreover, close spacing of wells locally has decreased production efficiency because of the mutual interference (overlapping of cones of depression) of nearby wells.

Locally, the recharge through wells of heated water from air-conditioning installations has resulted in thermal pollution of the ground water, and thereby, has reduced the cooling efficiency of some installations and caused abandonment of others. Although the warm water in the ground-water reservoir may decrease the cooling efficiency of some installations, it may be useful as a source of heat Reverse-cycle heating and cooling systems, similar to those used in the Pacific Northwest (Brown, 1963, p. 19), may become feasible. Such systems might reduce or halt thermal pollution of the ground water by withdrawing, during the cool seasons, the heat added to the water during the warm seasons.

The designs of some buildings and other structures in areas where the water table has declined may have been, or may be, based on the supposition that the lowered water table will persist, and some builders may not be aware that the water table has been lowered artificially. Should ground-water withdrawals decrease substantially or cease entirely, the water table locally will recover markedly and cause seepage into some basements and other subsurface structures. Such seepage occurred in parts of Kings County and caused serious flooding following cessation of public-supply pumping in that county in 1947 (Perlmutter and Soren, 1963, p. 138). Former swampy areas may also tend to become swampy again, and springs may even reappear at low spots if the water table rises sufficiently.

As of 1968 no significant subsidence of the land surface is known to have occurred in Queens County as a result of drawdown of the water table, perhaps because thick clay beds, which are the beds most likely to undergo compaction, have not yet been significantly dewatered. Compaction and associated land subsidence is unlikely in most of western Queens. The areally extensive and thick clay beds include the Gardiners Clay and those in the underlying Cretaceous deposits. The top of the Gardiners Clay is generally more than 40 feet below sea level, and before the water table is drawn down below the Gardiners, the aquifers will have been excessively contaminated by salt water in most of the county and presumably pumping will have been curtailed. Some clay beds in the Magothy aquifer might be dewatered by continued pumping in eastern Queens, near Nassau County, and land subsidence to some degree may possibly occur there in the future. Other places where subsidence may occur in the county are in the Flushing Meadow and Alley Creek areas (pl. 1). These areas are only a few feet to about 10 feet above sea level and are generally underlain by thick beds of clay only a few feet below land surface.

WATER-MANAGEMENT IMPLICATIONS

The long-term net pumpage of ground water in Queens County, which averaged about 60 mgd in the past several decades, has caused extensive cones of depression in the water table and in the piezometric surfaces of the confined aquifers. The cones of depression had extended into adjacent counties and were still growing in 1968. The declining ground-water levels are being accompanied by widespread salt-water intrusion into the aquifers and a concurrent decrease of fresh ground water in storage.

Suter (1937, p 32 and 34) estimated that the "safe development" of ground water in Queens County is 30 mgd, and suggested that this rate, .. could be increased after the Brooklyn depression is removed. . . . The cone of depression caused by overdevelopment in Brooklyn (Kings County) has been largely dissipated, although mainly by salty-water inflow which followed the cessation of public-supply pumping in 1947 (Perlmutter and Soren, 1963, p. E138).

Terms such as "safe development" or "safe yield" commonly are defined in terms of hydrologic, economic, or other effects that water managers wish to avoid; consequently, a quantitative value for the "safe yield" of Queens County can range between wide limits, depending on the water-management decisions that are made and the changes in the hydrologic system that are deemed desirable or tolerable. For example, water-management decisions might be made to attempt to: (1) restrict the effects of ground-water withdrawals entirely to Queens County and thereby avoid inducing additional subsurface inflow from adjacent counties; and (2) prevent a further increase in the chloride content of the ground water. If such decisions were made, net pumpage (and, therefore, the "safe yield"), at the stage of urban development in Queens County in 1968, would have to be considerably less than 60 mgd. Moreover, the pumpage would have to be from a carefully spaced and managed network of wells. Conversely, if limits were not set on the magnitude of the cones of depression and on the positions of the zones of diffusion, and if the average chloride content of the pumped water were allowed to increase to 250 mg/l, the "safe yield" would be considerably more than 60 mgd for an indeterminate period of time. Under the converse set of conditions, it can be readily appreciated that the large storage of fresh water in the ground-water reservoir of Queens County has significant potential importance as a source of emergency water supply for New York City.

The state of imbalance that currently exists in the hydrologic system of Queens County will continue unless net pumpage is reduced, or recharge is artificially augmented, so that the total (natural plus artificial) recharge of fresh water equals the total discharge of fresh water. Until this balance between recharge and discharge is restored, ground-water levels will continue to decline, and salt-water intrusion will become more widespread. Salt-water intrusion occurred in neighboring Kings County to such a degree that public-supply pumping there was halted by New York City in 1947 (Lusczynski, 1952, p. 1). Salt-water intrusion in Queens County in 1968 was not nearly as severe as that in Kings County in 1947. However, if changes are not made in the present use and disposal of water in Queens County, the continued deterioration of ground-water quality may ultimately force the abandonment of most, if not all, public-supply wells in the county.

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