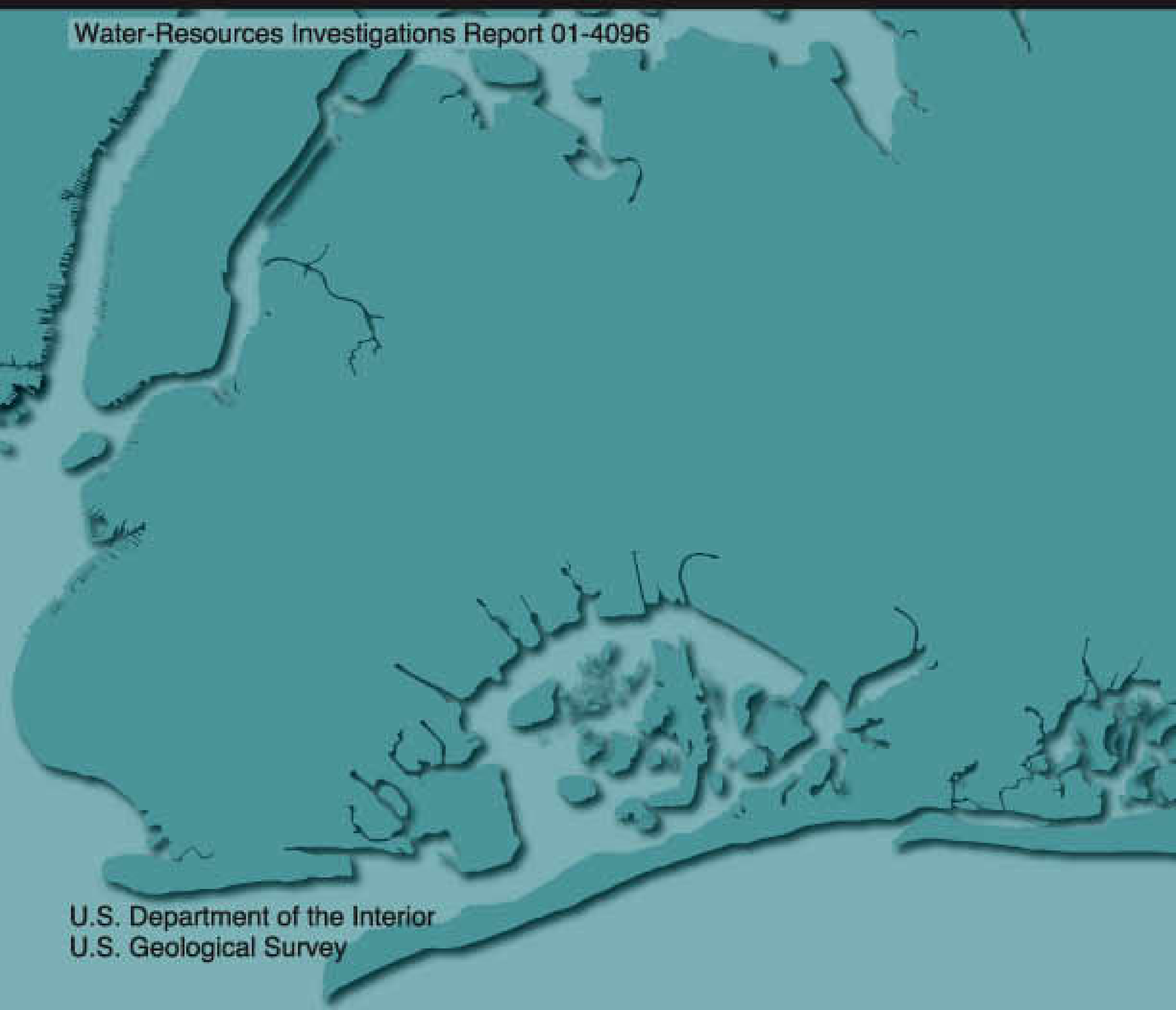
In cooperation with New York City
Department of Environmental Protection

History and Hydrologic Effects of Ground-Water Use in Kings, Queens, and Western Nassau Counties, Long Island, New York, 1800's through 1997

Water-Resources Investigations Report 01-4096



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By Richard A. Cartwright

U.S. GEOLOGICAL SURVEY
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NEW YORK CITY DEPARTMENT
OF ENVIRONMENTAL PROTECTION

Coram, New York
2002

U.S. DEPARTMENT OF THE INTERIOR
Gail A. Norton, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, ABBREVIATIONS AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
inch (in)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.59	square kilometer
	Flow	
million gallons per day (Mgal/d)	0.0438	cubic meters per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Other abbreviations used in this report	
	micrograms per liter (µg/l)	
	milligrams per liter (mg/L)	
	millisiemens per meter (mS/m)	

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

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Abstract

Ground-water withdrawals from the aquifers underlying Kings and Queens Counties varied temporally and spatially during the 20th century and caused extreme changes in water levels. The resultant lowering of water levels during periods of heavy pumping caused saltwater intrusion in nearshore areas and the migration of contaminants from land surface into deep aquifers. The recovery of water levels in response to countywide curtailment of pumping has resulted in the flooding of underground structures. Combined withdrawals for public and industrial supply in Kings and Queens Counties were greatest during the 1930's—about 130 million gallons per day. During this period, a large cone of depression developed in the water table in Kings County; within this depression, water levels were about 45 feet lower than in 1903. All pumping for public supply was halted in Kings County in 1947, and in Jamaica (in Queens County) in 1974. Water levels in Kings County had recovered by 1974 and have remained similar to those of 1903 since then, except for minor localized drawdowns due to industrial-supply or dewatering withdrawals. A large cone of depression that had formed in southeastern Queens County before 1974 has now (1997) disappeared. The estimated combined withdrawal for public supply and industrial supply in Kings and Queens Counties in 1996 was only about 50 million gallons per day.

The water-level recoveries in the water-table and confined aquifers generally have resulted in the dilution and dispersion of residual salty and nitrate-contaminated ground water. The majority of recently sampled wells indicate stable or decreasing chloride and nitrate concentrations in all aquifers since 1983. Organic contaminants remain in ground water in Kings, Queens, and Nassau Counties, however; the most commonly detected compounds in 1992-96 were tetrachloroethene, trichloroethene, chloroform, and total trihalomethanes. Water samples from monitoring wells in Kings County indicate a greater number of occurrences of these compounds in the upper glacial aquifer than in the Jameco-Magothy aquifer, whereas samples from public-supply wells in Queens County indicated a greater number of occurrences in the Jameco-Magothy aquifer than in the upper glacial aquifer. This distribution suggests that organic contaminants were not drawn into the deeper aquifers in Kings County before 1947, when their use was limited and deep withdrawals were greatest, and (or) that the longer period of water-level recovery in Kings County than in Queens has allowed greater degradation, dilution, and dispersion of any organic contaminants that might have entered the deep aquifers before the cessation of pumping in 1947.

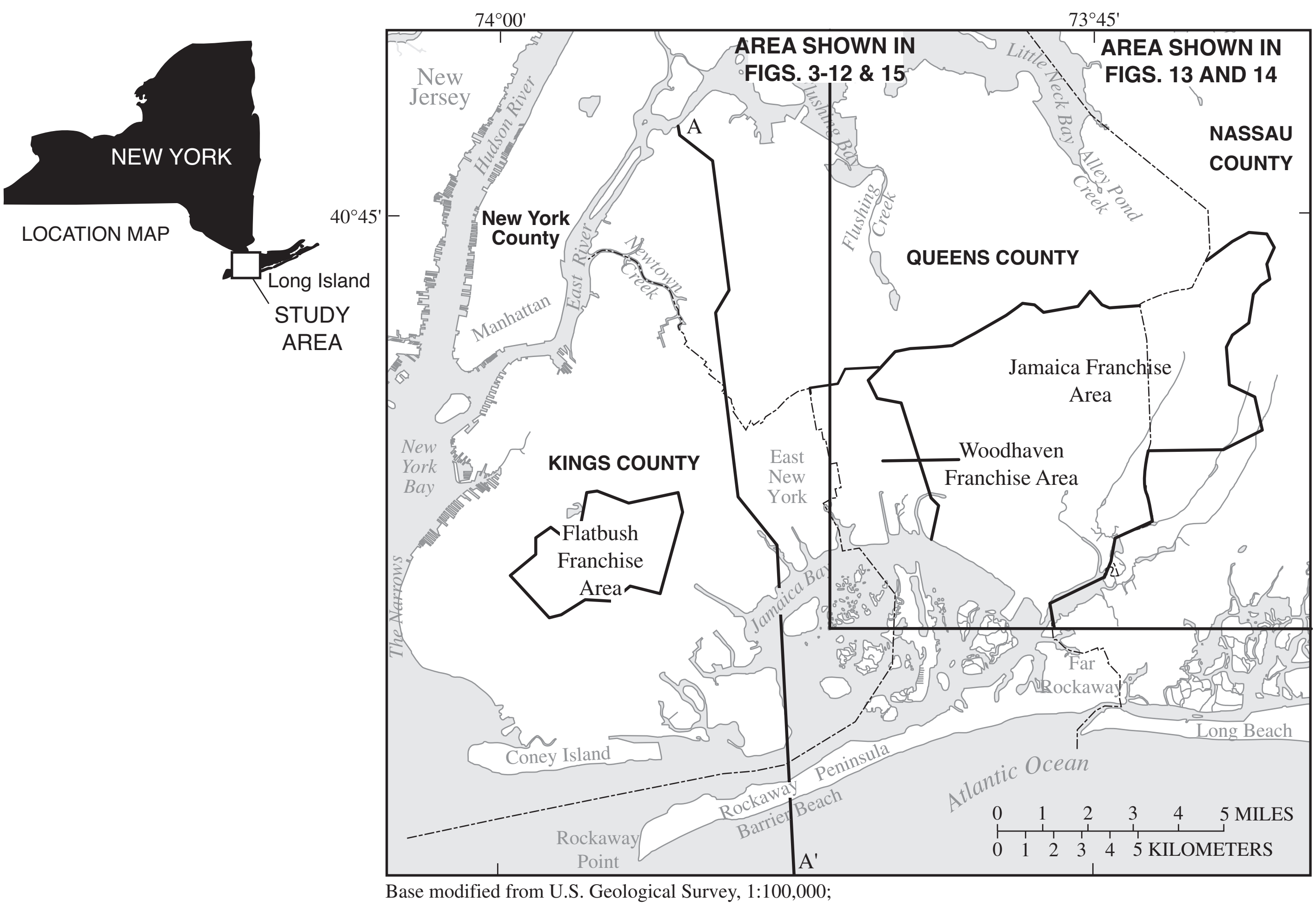
INTRODUCTION

Most of the water used by the 4.25 million inhabitants of Kings and Queens Counties, on western Long Island, N.Y. (fig. 1) (U.S. Department of Commerce, 1990) is surface water derived from an upstate reservoir-and-tunnel system owned and operated by the New York City Department of Environmental Protection (NYCDEP). In 1991, this system supplied an average of 1,445.5 Mgal/d to New

York City's five boroughs—Manhattan, Brooklyn (Kings County), Queens (Queens County), Bronx, and Staten Island; about 412 Mgal/d was supplied to Kings County and about 304 Mgal/d to Queens County (New York City Department of Environmental Protection, 1992) and supplied an additional 123.6 Mgal/d to other upstate communities. The remaining water-supply requirements of Kings and Queens Counties are met by ground-water withdrawals from a single public-supply wellfield in Queens County, formerly owned by the Jamaica Water Supply Company (JWS), now owned and operated by the NYCDEP. Water-supply managers are concerned that the surface-water reserves may be insufficient to meet the City's demand during periods of drought or other water-supply emergencies and that alternative sources of potable water will be needed (New York City Department of Environmental Protection, 1992). One possible source is ground water from Kings and Queens Counties.

Historical Background

Trends in ground-water use on western Long Island (Kings and Queens Counties) have been variable throughout the 20th century, and the ground-water reservoir has been subjected to a wide range of pumping practices as water demands have increased. In the past, high rates of withdrawal resulted in extremely large drawdowns of the water table and in large declines in potentiometric heads of underlying aquifers. The development and completion of sanitary sewer systems during the 1930's caused additional losses from the ground-water system by diverting the return flow of wastewater to coastal water bodies. By



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York–New Jersey–Connecticut,1984;
Newark, New Jersey–New York, 1986

Figure 1. Location of Kings, Queens, and western Nassau Counties, Long Island, N.Y.

1936, water levels in northern Kings County had declined as much as 45 ft below 1903 levels, and, by 1961, water levels in southern Queens County had declined as much as 35 ft. The decline in water levels caused natural seaward flow gradients to reverse in some areas, inducing saltwater intrusion and local ground-water contamination, which, in turn, necessitated the shutdown of all public-supply wells in Kings County and some in Queens County. The cessation of pumping allowed the severely depressed water table to recover, and the rising water levels in some areas ultimately began to flood manmade subterranean structures, such as basements and subway tunnels that had been built during the period when the water table was depressed. As a result, many basements and subway tunnels in Kings County today require nearly continuous dewatering. This series of events has been the focus of several investigations throughout western Long Island. A summary of ground-water development in Kings and Queens Counties from 1900 through 1981 is given in Buxton and others (1981).

The present investigation began in April 1992 as a 4-year study in cooperation with the NYCDEP that was designed, in part, as an update to a similar investigation completed in the early 1980's (Buxton and Shernoff, 1995). The main objectives of the Buxton and Shernoff study were to (1) define ground-water quality in the aquifer system of Kings and Queens Counties (hereafter referred to as the Kings-Queens aquifer system) with emphasis on the concentrations and distribution of nitrate, chloride, and to a lesser degree, volatile organic compounds (VOC's); (2) establish a hydrologic-data-collection network in Kings and Queens Counties that would include ground-water-level and streamflow measurements, and (3) estimate the effects of current and proposed water-supply and dewatering operations on ground-water levels and flow in the Kings-Queens aquifer system through numerical model simulation.

Previous Investigations

The earliest USGS investigations of the geology and ground-water resources of Long Island include Veatch and others (1906), Fuller (1914), Suter (1937), Suter and others (1949), and Cohen and others (1968). Subsequent investigations that have examined specific aspects of the ground-water system, including water-table fluctuations and ground-water quality, are described in Lusczynski (1952), Lusczynski and Spiegel (1954), Perlmutter and others (1959), Perlmutter and Geraghty (1963), Perlmutter and Soren (1962), Lusczynski and Swarzenski (1966), and Soren (1971, 1976, and 1978).

Studies by the USGS, NYCDEP, and New York State Department of Environmental Conservation (NYSDEC) were precursors to the present study. These include Buxton and others (1981), Holzmacher, McLendon & Murrell (1982), Buxton and Shernoff (1995), O'Brien and Gere and New York City Department of Environmental Protection (1986), Austin and others (1988), Buxton and Smolensky (1999), and Buxton and others (1999). Buxton and others (1981) designed a ground-water-sampling network from which a water-quality data base was developed; available wells from this network were used for water-quality analyses during the 1983 investigation (Buxton and Shernoff, 1995) and the present study. A ground-water-flow model of Buxton and Smolensky (1999) was refined and updated in the present study to provide more detailed simulations of the effects of ground-water withdrawals on the Kings-Queens aquifer system.

Several aspects of the present study are described in other reports; these include the collection of ground-water-quality data (Cartwright and others, 1998), the compilation of specific-capacity-test results (Chu, 1996), the compilation of historical pumpage records (Chu and others, 1997), the preliminary delineation of the freshwater-saltwater interface (Chu and Stumm, 1995), the development of a two-dimensional model (Kontis, 1999) and a three-dimensional model (Misut and Monti, 1999) of ground-water flow demonstrating the feasibility of using ground water as a supplemental water supply, a compilation of water-level measurements made in the study area from 1910 through 1995 (Monti, 1997), and a 1997 water-table map of Kings and Queens Counties (Monti and Chu, 1997).

Purpose and Scope

This report describes the recent (1992-97) hydrologic conditions (withdrawals, inputs, water levels, and water quality) in Kings, Queens, and western Nassau Counties, and compares them with historical data. The report also summarizes the relations among water-use practices, and ground-water levels and ground-water quality. The hydrogeologic framework of western Long Island is revised, and a list of wells sampled for water quality during 1981-96 is provided. USGS water-quality sampling in Kings, Queens, and western Nassau Counties during 1981-96 is summarized in table 1; the data indicate the attrition of wells available for sampling during that period.

Acknowledgments

The author thanks Richard Gainer, Michael P. Rennard, Joseph Iannuzzi, Anthony Bellitto, Jr., and Edmund Parrish of the NYCDEP Bureau of Water Supply and Wastewater Management for providing information used during the investigation. Thanks also are extended to Thomas Attridge (President) and Richard Groth (Superintendent) of Maple Grove Cemetery for their cooperation during well installation on cemetery property; to Julius Spiegel and Michael Siegel (New York City Department of Parks and Recreation, Brooklyn), Mary Fox (Prospect Park Alliance), Ronald Cianciulli and Peter Mantione (New York City Department of Parks and Recreation, Queens), and Richard Ocken (New York City Department of Transportation, Highways) for permission to drill and for assistance with drill-site selection on City property. The author also is grateful to Alfonso R. Lopez of the NYCDEP Bureau of Clean Water for permission to store drill rigs on water-pollution-control plant properties.

STUDY AREA

The study area represents all of Kings and Queens Counties and the western part of Nassau County (fig. 1). This area encompasses about 261 mi^2, of which Kings County occupies about 76 mi^2, Queens County about 113 mi^2, and western Nassau County about 72 mi^2. The study area is bounded to the west, north, and south by The Narrows, New York Bay, the East River, Long Island Sound, and the Atlantic Ocean, and on the east by the remainder of Nassau County. The entire study area is densely populated and includes scattered parks and cemeteries, industrial and commercial areas, and transportation facilities.

Hydrogeologic Setting

Long Island consists of a sequence of unconsolidated, Pleistocene and Cretaceous deposits that lie unconformably on Precambrian bedrock. Total sediment thickness in the study area ranges from about 100 ft in the northwest (except in northwestern Queens County where bedrock crops out) to about 1,000 ft in the southeast. Most of the sediments in northern Kings and Queens Counties are Pleistocene deposits, whereas the bulk of the deposits in the rest of the study area is of Cretaceous age.

Depositional History

The depositional history of the study area is, with minor exceptions, typical for all of Long Island. The Precambrian bedrock surface was eroded to a nearly horizontal plain over much of the eastern United States by Silurian or early Cretaceous time. The timing of this erosion cannot be determined because Paleozoic and Mesozoic deposits are absent above bedrock (Smolensky and others, 1989). A period of widespread folding followed, in which the mainland was uplifted and the coastal area was downwarped, causing the area of the present Long Island to be inundated. Streams from the highlands to the west

Table 1. U.S. Geological Survey ground-water-quality sampling in Kings, Queens, and western Nassau Counties, N.Y., 1981-96

Sampling period	Number of wells sampled	Percentage of 1981 wells sampled	Percentage of 1983 wells sampled	Percentage of 1992-93 wells sampled	Source of data
February-April 1981	78	100	0	0	Buxton and others (1981)
June-October 1983	106	68	100	0	Buxton and Shernoff (1995)
August 1992-January 1993	87	58	82	100	Cartwright and others (1998)
July-September 1995	21	0	0	0	Cartwright and others (1998)[1]
March-July 1996	101	46	70	84	Cartwright and others (1998)

[1]New wells installed from November 1992 to October 1995.

carried large volumes of sediment to the coast, where they formed the thick, deltaic deposits of Cretaceous age that underlie Long Island. During the Tertiary period, a series of sea-level changes resulted in alternating episodes of minor deposition and erosion offshore south of Long Island; whether these episodes occurred on Long Island is uncertain, however, because Tertiary deposits are not present onshore (Smolensky and others, 1989). The last erosional period, which may have been during late Pliocene time, generated many of the topographic features of Long Island, including the ancestral Long Island Sound and erosional scouring of a deep north-south channel in Queens County described by Soren (1978) as having been incised by an ancestral Hudson River system. During the Quaternary, Pleistocene glacial episodes and the resulting changes in sea level caused alternating periods of deposition and erosion that reworked the surficial sediments. The last major features to be formed on Long Island are the glacial moraines, which were emplaced during the Wisconsinan glacial stage, and outwash that was deposited south of the moraines by glacial meltwater.

Hydrostratigraphy

The hydrostratigraphy of the study area is thoroughly discussed in reports cited in the reference section and is summarized by Buxton and Shernoff (1995). The following sections briefly outline the major stratigraphic units from the surface downward and their hydrologic properties within the study area. Major hydrogeologic units are depicted in figure 2.

Pleistocene Deposits

The Pleistocene deposits consist of three hydrogeologic units—the upper glacial aquifer, the Gardiners Clay, and the Jameco aquifer. These units form the thickest part of the sediment column in the northwestern part of the study area and are present in varying degrees throughout Kings, Queens, and western Nassau Counties.

Upper Pleistocene Deposits

The Upper Pleistocene deposits are present at the surface throughout most of the study area, except in parts of northwestern Queens County, where bedrock crops out. These deposits consist of two general types of Wisconsinan-aged glacial deposits: (1) terminal-moraine and ground-moraine deposits, both of which consist of poorly sorted mixtures of clay, silt, sand, gravel, and boulders, and (2) glaciofluvial outwash deposits, which consist of moderately to well-sorted mixtures of sand and gravel. The thickness of these deposits ranges from zero where bedrock crops out to about 500 ft in buried valleys, but typically is 100 to 200 ft. The Upper Pleistocene deposits form the upper glacial aquifer, which has a relatively high but locally variable permeability. The horizontal hydraulic conductivity of outwash deposits on Long Island is reported to be 270 ft/d (Franke and Cohen, 1972), but probably is half this value in poorly sorted moraine deposits (Buxton and Shernoff, 1995). The upper glacial aquifer, although generally unconfined, is confined locally by layers of silt and clay within the moraine deposits.

Gardiners Clay

This unit underlies Upper Pleistocene deposits and is present throughout most of Kings, southern Queens, and western Nassau Counties. The Gardiners Clay is described by Soren (1978) to have been deposited in lagoonal and marine environments during the Sangamon interglacial interval. The unit consists of greenish-gray clay and silt with interbedded sand; its thickness ranges from zero at the northern limit in northern Kings County and southwestern Queens County to more than 100 ft in southern parts of the study area. The Gardiners Clay has a vertical hydraulic conductivity of about 0.001 ft/d (Franke and Cohen, 1972) and is a major confining unit.

Jameco Gravel

The Jameco Gravel is the oldest Pleistocene deposit on Long Island; its extent in the study area is similar to that of the Gardiners Clay. The Jameco Gravel was deposited as channel fill in a river-scour system described as part of an ancestral Hudson River channel (Soren, 1978). Thickness in the study area ranges from zero at the northern limit (northern Kings and southern Queens Counties) to more than 200 ft in the deepest part of the buried channel. The Jameco Gravel consists of dark, coarse sand and gravel with cobbles and boulders and constitutes the Jameco aquifer. Horizontal hydraulic conductivity of the Jameco aquifer exceeds 270 ft/d (Soren, 1971) and is among the highest of any unit in the study area.

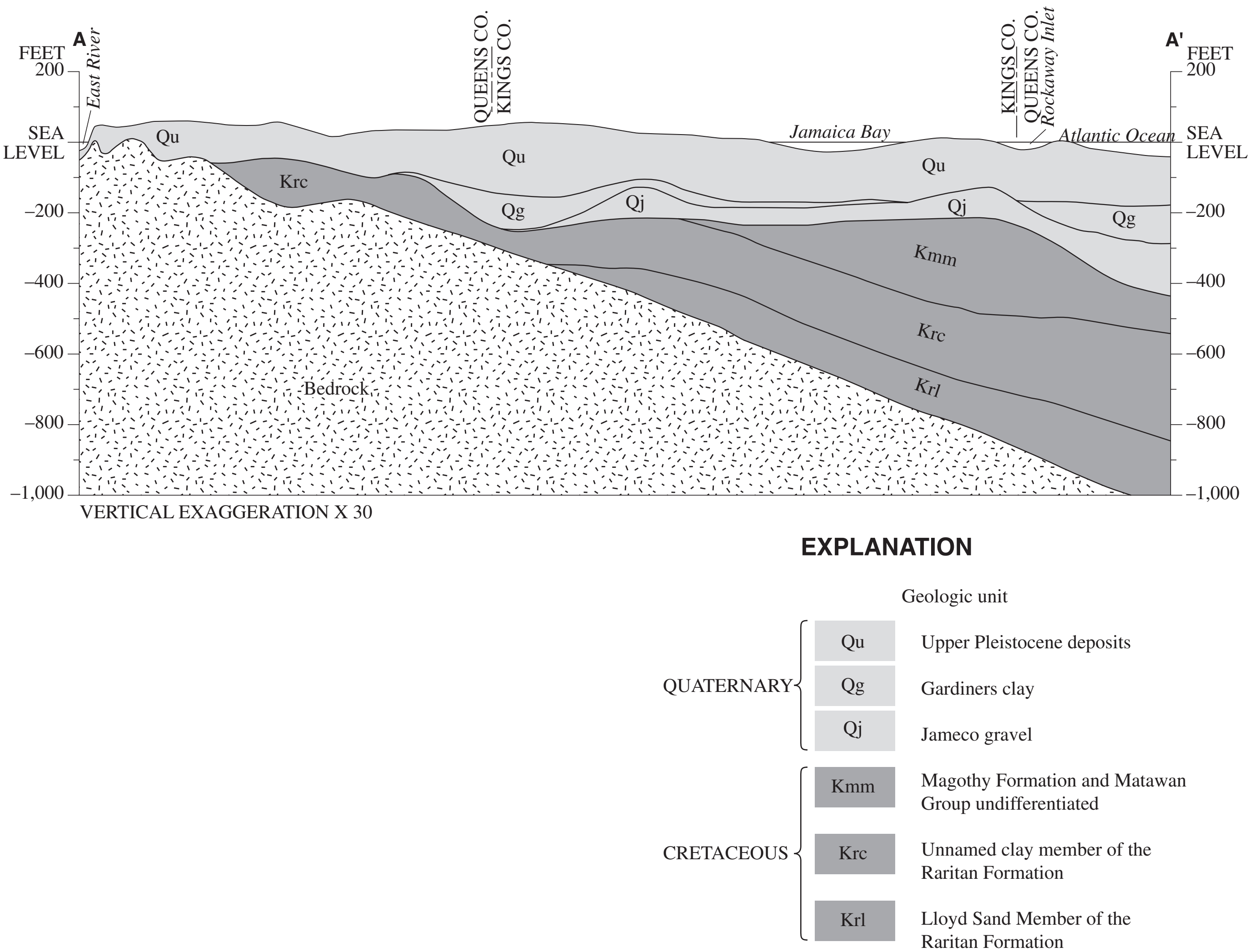


Figure 2. Hydrogeologic section through Kings and Queens Counties, N.Y. (Modified from Buxton and Shernoff, 1999, pl. 2. Trace of section is shown in fig. 1.)

Upper Cretaceous Deposits

Upper Cretaceous deposits make up the bulk of the sediments in the southeastern part of the study area. These deposits dip to the southeast and consist of the Magothy Formation and Matawan Group, undifferentiated, and the unnamed clay and Lloyd Sand Members of the Raritan Formation.

Magothy Formation and Matawan Group

The Magothy Formation and Matawan Group, undifferentiated, generally is the thickest stratigraphic unit on Long Island but was partly removed from northwestern Long Island by extensive post-Cretaceous erosion. This unit is present in the southern halves of Kings and Queens Counties; its northern extent is irregular and poorly defined as a result of post-Cretaceous channel erosion. These deposits constitute the Magothy aquifer and consist mostly of light-colored quartzose sand and silty sand, with some interbedded clay. Thickness of this unit ranges from zero at its northern limits and along channel margins to more than 200 ft in southern Kings County, and to more than 500 ft in southeastern Queens County. As described in the "Depositional History" section, the most striking feature of this unit is the nearly 300-ft-deep erosional channel that was carved in Queens County during post-Cretaceous time by an ancestral diversion of the Hudson River (Soren, 1978). This channel subsequently was filled with Pleistocene deposits. Horizontal hydraulic conductivity of the Magothy aquifer on Long Island is estimated to range from 60 to 90 ft/d (McClymonds and Franke, 1972) but can be much higher or lower locally, depending on sediment types. The Magothy aquifer and overlying Jameco aquifer (where present) are hydraulically connected and, therefore, commonly are considered as one hydrogeologic unit (Buxton and Shernoff, 1995). In this report, these units are jointly termed the Jameco-Magothy aquifer.

Clay Member of the Raritan Formation

The Clay Member of the Raritan Formation extends throughout most of Kings and Queens Counties and is the most extensive Cretaceous deposit in the study area. It is absent from northwestern Kings County and extreme northwestern Queens County and also has been eroded from the area of the buried channel described earlier. Thickness of the Clay Member ranges from zero in northwestern Kings and Queens Counties and along the margin of the buried channel to about 250 ft in southeastern Kings County and about 200 ft in southeastern Queens County. The Clay Member generally consists of clay and silty clay with some interbedded sand. Vertical hydraulic conductivity of this unit generally is estimated to be about 0.001 ft/d (Franke and Cohen, 1972). The terms “Clay Member of the Raritan Formation” and “Raritan clay” are used interchangeably in this report.

Lloyd Sand Member of the Raritan Formation

The Lloyd Sand Member of the Raritan Formation is the oldest Cretaceous deposit on Long Island and lies unconformably on Precambrian bedrock. It is absent from northern Kings and northwestern Queens Counties, and from the buried channel in Queens County. Thickness ranges from zero at its northern limit to about 200 ft in southeastern Kings County, and to about 300 ft in southeastern Queens County. The Lloyd Sand Member consists of quartz sand and gravel with interbedded silt and clay and constitutes the Lloyd aquifer. The Lloyd aquifer is confined by the Clay Member of the Raritan Formation (fig. 2), except locally along its northwestern margin, where the clay member is absent. Horizontal hydraulic conductivity of this unit on Long Island ranges from about 50 to 70 ft/d (McClymonds and Franke, 1972), but is higher in gravel and lower in clayey zones. The terms “Lloyd Sand Member” and “Lloyd aquifer” are used interchangeably in this report.

DATA COLLECTION

This study entailed monitoring-well installation, water-level measurements, ground-water sampling, and geophysical logging. Monitoring-well installation included the completion of 29 new monitoring wells and the incorporation of 8 other (not USGS) wells in the National Water Information System (NWIS). The placement of new wells was designed to provide water-level measurements and ground-water samples in areas where these data were sparse. Water-level measurements were collected from a network of more than 100 wells—initially on a monthly basis, then quarterly. Ground-water sampling was conducted during three different sampling periods to provide 116 samples for chemical analysis for organic and inorganic compounds and nutrients. Chemical data are presented in Cartwright and others (1998); interpretations of these data are discussed here. Lithologic logs and down-hole geophysical logs from new well installations helped to refine the conceptualization of the hydrogeologic framework and, in some areas, to detect saltwater intrusion.

Monitoring-Well Installation

A total of 29 new monitoring wells was installed from November 1992 through October 1995 (27 drilled and installed by the USGS, and 2 drilled by the NYCDEP and cased by the USGS). Four wells were screened in the Lloyd aquifer, 3 in the Magothy aquifer, 4 in the Jameco aquifer, and 18 in the upper glacial aquifer.

Three drilling techniques were used for well installation. Augering was adequate for shallow wells in areas of outwash containing gravel, sand, silt or clay, but reverse mud-rotary and air-rotary methods were required in areas containing glacial moraine deposits, where cobbles and boulders were present. In addition to the 29 new wells, 8 other wells were installed by the Brooklyn Union Gas Company and NYCDEP; the drilling techniques used for these installations are not recorded. All new wells were assigned NYSDEC well-identification numbers and have been added to NWIS. Well-completion data for all 37 wells are given in table 2.

Table 2. Well-completion data for 37 new wells, Kings and Queens Counties, N.Y.

[Well numbers assigned by New York State Department of Environmental Conservation. Prefix K, Kings County; Q, Queens County; --, data not available; BUG, Brooklyn Union Gas, well destroyed; USGS, U.S. Geological Survey, NYCDEP, New York City Department of Environmental Protection]

Well number	Latitude	Longitude	Completion date	Aquifer	Depth of well, in feet below sea level	Top of open interval, in feet below sea level	Bottom of open interval, in feet below sea level	Owner
K3405	403719	735733	09/15/94	Upper glacial	214	204	214	USGS
K3406[a]	403806	740219	09/08/94	Jameco	155	135	145	USGS
K3407	403520	735757	12/02/94	Jameco	405	385	405	USGS
K3410[b]	404039	735550	10/18/94	Lloyd	360	330	350	USGS
K3414	403431	735811	11/10/94	Magothy	410	390	410	USGS
K3423[a]	403806	740219	09/08/94	Upper glacial	38	18	38	USGS
K3424	403840	735921	09/17/93	Upper glacial	75	70	75	USGS
K3425[b]	404039	735550	11/19/92	Upper glacial	80	70	75	USGS
K3426	403952	735137	06/26/87	Lloyd	494	474	494	Private
K3430[c]	403941	735743	10/05/95	Upper glacial	120	100	110	USGS
K3431[c]	403941	735743	10/03/95	Magothy	385	355	375	USGS
Q3587[e]	404138	735351	10/11/94	Upper glacial	175	160	170	USGS
Q3589	404026	734721	09/29/94	Magothy	320	310	320	USGS
Q3593[d]	404733	734829	12/22/94	Lloyd	215	165	185	USGS
Q3604[d]	404732	734829	12/22/94	Upper glacial	58	48	58	USGS
Q3627[f]	404239	734930	06/05/95	Lloyd	510	480	500	USGS
Q3628[f]	404239	734929	06/15/95	Lloyd	340	310	330	USGS
Q3629[f]	404239	734928	06/18/95	Upper glacial	80	50	70	USGS
Q3644	404537	735458	--	Upper glacial	84	79	84	NYCDEP
Q3645	404534	735402	--	Upper glacial	--	--	--	NYCDEP
Q3646	404544	735344	--	Upper glacial	24	19	24	NYCDEP
Q3647	404519	735325	--	Upper glacial	35	30	35	NYCDEP
Q3648	404437	735354	--	Upper glacial	90	80	85	USGS
Q3649[e]	404138	735351	11/18/92	Upper glacial	110	100	105	USGS
Q3650	404402	735209	04/07/93	Upper glacial	50	40	50	USGS
Q3651	404251	735126	11/20/92	Upper glacial	80	70	75	USGS
Q3652	404350	734945	11/17/92	Upper glacial	90	80	85	USGS
Q3653	403929	734930	--	--	--	--	--	BUG
Q3654	403916	734932	--	--	--	--	--	BUG
Q3655	403918	734940	--	--	--	--	--	BUG
Q3656	403928	734942	--	--	--	--	--	BUG
Q3657	403925	734934	06/09/89	Lloyd	695	608	650	BUG
Q3658	404027	734645	11/08/93	Upper glacial	40	30	35	USGS
Q3659	404313	734752	04/06/93	Upper glacial	125	115	120	USGS
Q3660	404450	734703	11/16/92	Upper glacial	90	80	85	USGS
Q3661	404357	734620	11/20/92	Upper glacial	95	85	90	USGS
Q3662	404500	734300	04/05/93	Upper glacial	120	110	115	USGS

a,b,c,d,e = well doublets
f = well triplet

Most of the 37 new wells are constructed of either 2-in or 4-in-diameter PVC casing and slotted screen with a 5-ft or 10-ft sump at the bottom. The five wells that required air-rotary drilling have an additional outside casing of 8-in-diameter steel that extends 75 to 100 ft below land surface. Two of the new wells were designed with 1.25-in-diameter PVC pipe and slotted screen, which was placed in the annular space between the borehole, and a 2-in or 4-in-diameter PVC casing. Wells that were installed by mud- or air-rotary techniques were developed by air-lifting for as long as 6 hours to remove fine-grained material from the sump, screen, and gravel pack.

Water-Level Measurements

A large amount of ground-water-level data were collected during this study. As part of an initial reconnaissance effort, the 106 monitoring wells sampled in 1981 and 1983 (Buxton and Shernoff, 1995) were visited in 1992, and a water-level measurement was made, if possible. The hydrogeologic units in which these wells are screened are as follows: upper glacial aquifer, 64 wells; Jameco-Magothy aquifer, 31 wells; Raritan clay, 1 well; and Lloyd aquifer, 10 wells. A water-level-monitoring network was designed from a subset of these sampled wells and other available wells. Water-level measurements were obtained by the "wetted-tape" method (U.S. Geological Survey, 1980). Water level measurements were collected monthly beginning in 1992, but the frequency of measurements was decreased to quarterly in 1994. Water-table maps and potentiometric heads are depicted in figures 3A-I, 4, and 5, and are discussed further on. In addition to water-level data collected specifically for this study, the USGS has maintained a monitoring-well network in Kings and Queens Counties at which water levels have been measured monthly since as early as 1934. The number of water-level measurements obtained from all wells in Kings and Queens during 1910-95, by decade, are presented in Monti (1997).

Ground-Water Sampling

The water-quality data collected during this study form the most comprehensive data set for the study area. Methods of sample collection and quality-assurance techniques used are described in Cartwright and others (1998). Water samples were collected from monitoring wells with a pump or bailer; samples from industrial-supply or other private wells typically were obtained from a spigot. Chemical analyses of samples collected by the USGS were performed at the USGS laboratory in Arvada, Colo. Water-quality data for public-supply wells, which were not sampled by the USGS, are from the Jamaica Water Supply Company (JWS) data base. All JWS water-quality data presented in this report are from raw well water, which was collected prior to any treatment or distribution. All wells in the ground-water sampling network and the periods of sampling are summarized in table 3; well locations and aquifer designation are depicted in fig. 6A-I. Data on chloride, nitrate, and volatile organic compound concentrations are discussed further on.

Geophysical Logging

Five borehole-logging techniques were used in this study—natural gamma (G), spontaneous potential (SP), single-point resistance (SPR), normal resistivity (R), and electromagnetic induction conductivity (EM). Eleven wells were logged with at least one, and as many as five, of these techniques (three wells were logged with all five techniques, five were logged with only with G and EM probes, and three were logged only with the G probe). All SP, SPR, and R logs were obtained in an open borehole; the G logs were obtained through open boreholes or PVC casing, and all EM logs were obtained through PVC casing.

HISTORY AND HYDROLOGIC EFFECTS OF GROUND-WATER DEVELOPMENT

The amount, distribution, movement, and quality of surface water and ground water in Kings and Queens Counties have been altered by human activities since the early 1800's. The history of ground-water development in Kings and Queens Counties from 1900 through 1983 is presented in Buxton and Shernoff (1995), which describes the development of the ground-water supply, including withdrawals by aquifer and location in each of the two counties; it also describes the water-level changes that have resulted from the pumping practices, and the changes in chloride and nitrate concentrations through time. The following section (paraphrased from Buxton

Table 3. Water samples collected from the monitoring-well network in Kings, Queens, and western Nassau Counties, N.Y., 1983-96

[Well locations are shown in figure 5A-I. Prefix K, Kings County; Q, Queens County; N, Nassau County. I, industrial well; M, monitoring well; D, diffusion well; NA, not available. U. glacial, upper glacial aquifer; Jameco, Jameco aquifer; Magothy, Magothy aquifer; Raritan, Raritan clay; Lloyd, Lloyd aquifer. Dashes indicate well status unknown]

Well number	Well use	Hydrogeologic unit	Well status on date of sample collection				
			February through April 1981	June through October 1983	August 1992 through January 1993	July through September 1995[1]	March through July 1996
K20	I	U. glacial	sampled	--	--	--	--
K41	I	U. glacial	sampled	--	--	--	--
K307	NA	U. glacial	sampled	--	--	--	--
K922	I	Jameco	--	sampled	--	--	--
K1189	I	Jameco	sampled	sampled	--	--	--
K1194	M	U. glacial	sampled	--	--	--	--
K1673	I	U. glacial	sampled	sampled	sampled		sampled
K1678	I	U. glacial	sampled	sampled	sampled		sampled
K1681	I	U. glacial	sampled	--	--	--	--
K1689	I	U. glacial	sampled	sampled	sampled		sampled
K2040	I	U. glacial	sampled	sampled	--		inaccessible
K2135	NA	U. glacial	sampled	--	--	--	--
K2284	I	U. glacial	sampled	--	--	--	--
K2303	I	U. glacial	sampled	--	--	--	--
K2407	I	U. glacial	sampled	sampled	sampled		sampled
K2412	I	U. glacial	sampled	sampled	sampled		sampled
K2482	I	U. glacial	sampled	sampled	sampled		sampled
K2510	I	Jameco	sampled	sampled	sampled		sampled
K2511	I	Jameco	--	sampled	--		sampled
K2514	NA	U. glacial	sampled	--	--	--	--
K2582	I	Jameco	--	sampled	sampled		sampled
K2591	I	U. glacial	sampled	sampled	--		destroyed
K2594	NA	U. glacial	sampled	--	--	--	--
K2598	I	U. glacial	--	sampled	sampled		sampled
K2610	I	U. glacial	sampled	sampled	sampled		sampled
K2622	I	U. glacial	sampled	sampled	sampled		sampled
K2859	I	Lloyd	sampled	sampled	sampled		obstructed
K3130	I	Jameco	--	sampled	--		obstructed
K3132	I	Jameco	--	sampled	--		inoperable pump
K3133	I	Jameco	sampled	sampled	sampled		sampled
K3151	I	U. glacial	--	sampled	sampled		sampled
K3214	I	U. glacial	--	sampled	sampled		sampled
K3215	I	U. glacial	sampled	--	--	--	--
K3216	I	U. glacial	--	sampled	sampled		--
K3217	I	U. glacial	sampled	--	--	--	--
K3218	I	U. glacial	sampled	sampled	sampled		sampled
K3220	NA	Jameco	sampled	--	--	--	--
K3242	I	U. glacial	--	sampled	sampled		sampled
K3243	NA	U. glacial	sampled	--	--	--	--
K3245	M	U. glacial	sampled	sampled	sampled		obstructed
K3246	M	U. glacial	sampled	sampled	sampled		sampled
K3247	M	U. glacial	sampled	sampled	--		low yield
K3248	M	U. glacial	sampled	sampled	sampled		sampled
K3249	M	U. glacial	sampled	sampled	sampled		obstructed
K3250	M	U. glacial	sampled	sampled	sampled		sampled
K3251	M	U. glacial	sampled	sampled	sampled		sampled
K3252	M	U. glacial	sampled	sampled	sampled		sampled
K3253	M	U. glacial	--	sampled	sampled		sampled
K3254	M	U. glacial	sampled	sampled	sampled		sampled
K3255	M	U. glacial	sampled	sampled	sampled		low yield

Table 3. Water samples collected from the monitoring-well network in Kings, Queens, and western Nassau Counties, N.Y., 1983-96--continued

			Well status on date of sample collection				
Well number	Well use	Hydrogeologic unit	February through April 1981	June through October 1983	August 1992 through January 1993	July through September 1995[1]	March through July 1996
K3256	M	U. glacial	sampled	sampled	sampled		poor yield
K3257	M	U. glacial	sampled	sampled	sampled		poor yield
K3260	M	U. glacial	sampled	sampled	--		low yield
K3267	I	U. glacial	sampled	sampled	sampled		sampled
K3271	M	U. glacial	--	sampled	sampled		inaccessible
K3272	M	U. glacial	--	sampled	destroyed	destroyed	destroyed
K3273	M	U. glacial	--	sampled	sampled		dry
K3275	M	U. glacial	--	sampled	sampled		sampled
K3276	M	U. glacial	--	sampled	sampled		sampled
K3405	M	Jameco	nonexistent	nonexistent	nonexistent	sampled	sampled
K3406	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
K3407	M	Jameco	nonexistent	nonexistent	nonexistent	sampled	sampled
K3410	M	Lloyd	nonexistent	nonexistent	nonexistent	sampled	sampled
K3414	M	Magothy	nonexistent	nonexistent	nonexistent	sampled	sampled
K3424	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	dry
K3425	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
K3426	M	Lloyd	nonexistent	nonexistent	nonexistent	sampled	sampled
K3430	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
K3431	M	Magothy	nonexistent	nonexistent	nonexistent		sampled
KA[2]	I	U. glacial	sampled	--	--	--	--
KB[2]	I	U. glacial	sampled	--	--	--	--
Q 273	M	Lloyd	sampled	sampled	sampled		--
Q 277	M	Magothy	--	sampled	sampled		sampled
Q 283	M	Lloyd	sampled	--	--	--	--
Q 287	M	Lloyd	--	sampled	sampled		sampled
Q 470	M	Lloyd	sampled	sampled	sampled		sampled
Q 471	M	Magothy	sampled	sampled	sampled		sampled
Q1071	M	Lloyd	sampled	sampled	sampled		sampled
Q1187	M	Jameco	--	sampled	sampled		inaccessible
Q1189	M	U. glacial	sampled	sampled	sampled		sampled
Q1237	M	Jameco	--	sampled	sampled		sampled
Q1241	I	Lloyd	sampled	sampled	sampled		denied access
Q1373	M	Lloyd	--	sampled	sampled		sampled
Q1472	I	Magothy	--	sampled	sampled		sampled
Q1506	I	U. glacial	--	sampled	--		destroyed
Q1605	I	U. glacial	sampled	sampled	sampled		denied access
Q1663	I	U. glacial	sampled	sampled	sampled		sampled
Q1914	I	Magothy	--	sampled	sampled		sampled
Q1930	I	U. glacial	sampled	sampled	sampled		sampled
Q2289	I	U. glacial	--	sampled	--		denied access
Q2324	M	U. glacial	sampled	sampled	sampled		sampled
Q2384	I	U. glacial	--	sampled	--		denied access
Q2407	I	U. glacial	--	sampled	sampled		sampled
Q2418	M	U. glacial	sampled	sampled	sampled		sampled
Q2419	M	Lloyd	sampled	sampled	sampled		sampled
Q2420	M	Lloyd	sampled	sampled	sampled		sampled
Q2426	I	Magothy	--	sampled	pump removed	pump removed	pump removed
Q2656	I	U. glacial	sampled	sampled	sampled		sampled
Q2791	I	U. glacial	sampled	sampled	sampled		sampled
Q2814	I	U. glacial	--	sampled	sampled		sampled
Q2964	NA	U. glacial	sampled	--	--	--	--
Q2965	NA	U. glacial	sampled	--	--	--	--
Q2978	I	U. glacial	sampled	sampled	sampled		sampled
Q2993	M	U. glacial	sampled	sampled	--		destroyed
Q2994	M	U. glacial	--	sampled	sampled		sampled
Q2995	M	U. glacial	sampled	sampled	sampled		sampled

Table 3. Water samples collected from the monitoring-well network in Kings, Queens, and western Nassau Counties, N.Y., 1983-96--continued

Well number	Well use	Hydrogeologic unit	Well status on date of sample collection				
			February through April 1981	June through October 1983	August 1992 through January 1993	July through September 1995[1]	March through July 1996
Q3003	I	Magothy	--	sampled	sampled		sampled
Q3015	I	Magothy	--	sampled	pump removed	pump removed	pump removed
Q3036	I	Lloyd	sampled	sampled	sampled		sampled
Q3109	M	Magothy	--	sampled	sampled		sampled
Q3110	M	Jameco	--	sampled	sampled		sampled
Q3112	M	Jameco	--	sampled	sampled		sampled
Q3114	M	U. glacial	--	sampled	sampled		sampled
Q3115	M	U. glacial	--	sampled	sampled		sampled
Q3117	M	U. glacial	sampled	sampled	sampled		sampled
Q3119	M	U. glacial	sampled	sampled	sampled		sampled
Q3120	M	U. glacial	sampled	--	--	--	--
Q3121	M	U. glacial	sampled	sampled	sampled		poor yield
Q3123	M	U. glacial	sampled	sampled	--		destroyed
Q3134	I	U. glacial	--	sampled	sampled		sampled
Q3150	M	Jameco	--	sampled	--		bent casing
Q3587	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3589	M	Magothy	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3593	M	Lloyd	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3604	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3627	M	Lloyd	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3628	M	Lloyd	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3629	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3644	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3646	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3648	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
Q3649	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3650	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
Q3651	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3652	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
Q3658	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
Q3659	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3660	M	U. glacial	nonexistent	nonexistent	nonexistent	sampled	sampled
Q3661	M	U. glacial	nonexistent	nonexistent	nonexistent		sampled
Q3662	M	--	nonexistent	nonexistent	nonexistent		obstructed
N1102	M	U. glacial	sampled	--	--	--	--
N1104	M	U. glacial	sampled	--	--	--	--
N1105	M	U. glacial	sampled	--	--	--	--
N1429	M	U. glacial		sampled	sampled		obstructed
N1622	M	U. glacial	sampled	--	--	--	destroyed
N1627	M	U. glacial	sampled	sampled	sampled		sampled
N3864	M	Magothy	--	sampled	sampled		sampled
N3867	M	Magothy	--	sampled	sampled		sampled
N3932	M	Jameco	--	sampled	sampled		sampled
N4026	M	Jameco	--	sampled	sampled		sampled
N4062	M	Jameco	--	sampled	sampled		sampled
N4213	M	Jameco	--	sampled	sampled		sampled
N6581	M	Magothy	--	sampled	sampled		sampled
N6701	M	Raritan	--	sampled	sampled		sampled
N6703	M	Magothy	--	sampled	sampled		sampled
N6707	M	Magothy	--	sampled	sampled		sampled
N6792	M	U. glacial	--	sampled	sampled		sampled
N7161	M	Magothy	--	sampled	sampled		sampled
N8373	D	U. glacial	sampled	--	--	--	--
N8877	M	U. glacial	--	sampled	sampled		sampled

[1] Only new wells were sampled during this period; blanks indicate non-targeted well

[2] New York State Department of Environmental Conservation well-identification number unavailable

and Shernoff, 1995) discusses the history of ground-water development; this information and more recent data are summarized in table 4.

Water-Supply Practices and their Effects on the Hydrologic System

Early residents of Kings and western Queens Counties obtained water from shallow wells and streams, and returned most of it to the aquifer through septic systems. This practice had a negligible effect on the ground-water system initially, but as the population grew, the demand for public and industrial supply increased and required more wells and increased pumpage. By the mid-1800's, storm sewers and sanitary sewers had been installed in Kings County. These systems channeled wastewater to coastal water bodies to minimize the amounts of contaminants reaching the ground-water system, but also sharply diminished recharge. By the turn of the 20th century, rapid population growth and development in Kings and Queens Counties was demanding even greater ground-water withdrawals, while the increasing amounts of impervious-surface area (streets and parking lots) and sewering further decreased aquifer recharge. The first New York City tunnel to bring water from upstate reservoirs to Kings and Queens Counties was completed in 1917. This importation of water resulted in a large decrease in ground-water withdrawals, but the continued population growth soon prompted increased ground-water withdrawals once again. By the 1930's, large water-level declines had developed in the water table and in deeper aquifers; these declines in northwestern Kings County caused saltwater encroachment. In 1933, the New York State Conservation Law required that ground-water withdrawals greater than 100,000 gal/d (0.1 Mgal/d) be returned to the aquifer. This law, and the increasing use of electric refrigeration, which reduced the amounts of water pumped for ice-making, resulted in a decreased net loss from the aquifers through industrial ground-water pumping. In 1936, the second water tunnel to Kings and Queens Counties was completed, but this additional supply was probably used in newly developed areas, and no noticeable decrease in ground-water withdrawals was observed. As the water table and heads in the deep aquifers continued to decline, saltwater intrusion increased until it forced the cessation of all public-supply withdrawals in Kings County by 1947. This cessation allowed the system to recover, and by 1950, the water table in Kings County had risen about 20 ft. The water-supply deficit caused by the cessation of pumping in Kings County was made up by additional supplies from wellfields in Queens County. Eventually, many wells in Queens, also became contaminated with salty ground water. As a result, new wellfields were developed farther inland and to the east until 1974, when all public-supply pumping in Queens County ceased, except for the former JWS in southern Queens County (now owned and operated by NYCDEP).

Historical Ground-Water Levels

The water-table configuration in Kings and Queens Counties from 1903 to 1983 is depicted in a series of water-table maps in Buxton and Shernoff (1995). Those maps are reproduced here (figs. 3A-3I) for comparison with recent (1992-97) conditions. The chronology of events and effects regarding historical water-table changes are summarized in table 4. The relation between ground-water development, use, and disposal, and the effects these practices have had on ground-water levels, are discussed in the "Ground-Water Levels" section.

RECENT (1992-97) HYDROLOGIC CONDITIONS

The recent (1992-97) ground-water system is relatively static in relation to conditions earlier in the 20th century, mainly because withdrawals for public supply have decreased to historic lows and are confined to a small area of southeastern Queens County. Much of the system now is close to equilibrium conditions after decades of recovery, or is undergoing only slight adjustments in response to localized withdrawals for public or industrial supply (including dewatering operations). This relative stability does not imply an absence of stress on the system, but rather a balance of ground-water inflow and outflow, as described in the following sections.

Ground-water quality in the study area varies areally and with depth. Many point sources of contamination at land surface continue to affect water quality, and saltwater intrusion remains a concern in some areas, especially where water-level gradients were reversed twice during the 20th century. Ground-

Table 4. History and hydrologic effects of ground-water use in Kings and Queens Counties, N.Y., 1800's through 1996

[Mgal/d, million gallons per day; NYC, New York City; JWS, Jamaica Water Supply Company. Data from Buxton and Shernoff, 1995, unless cited otherwise]

Period	Event or trend	Estimated ground-water withdrawals, in Mgal/d: Public supply, Kings County	Public supply, Queens County	Industrial supply, Kings County	Industrial supply, Queens County	Effects
Early 1800's	Rapid population growth in Kings and western Queens Counties, and development of shallow ground-water use. Most water was returned to the ground through septic systems.	Unknown	Unknown	Unknown	Unknown	Negligible effect on water-table configuration and shallow flow paths. Wastewater contributed nitrate to shallow ground-water system.
Mid 1800's	Continued population growth and attendant development of roads and other impervious surfaces. Continued development of ground-water use. In Kings County, installation of storm and sanitary sewers that discharged wastewater to the sea.	Unknown	Unknown	Unknown	Unknown	Water table probably showed declines.
1904	Withdrawals for public- and industrial-supply continued to increase. Subways were constructed in the early 1900's as water table was declining.	14	28	14	Few	Water table probably showed further declines. Salt-water encroachment in coastal areas near Jamaica Bay (Spear, 1912). Nitrate contamination in glacial aquifer in Kings County (Kimmel, 1972).
1910	Withdrawals continued to increase; highest public-supply withdrawals in Kings County to date.	33	65	21	Few	Water table probably showed further declines.
1917	First NYC Water Tunnel completed; replaced significant amount of ground water pumped for public supply by NYC Department of Water Supply, Gas and Electricity. Private water suppliers continued withdrawals, and industrial withdrawals increased. Until this time, most ground water came from upper Glacial and Jameco aquifers.	12	23	42	Probably between 10 and 20	Despite reduction in public-supply withdrawals by NYC Department of Water Supply, Gas and Electricity, water table probably did not recover because withdrawals for industrial supply and by private water suppliers had increased.
1927	Withdrawals continued to increase; highest industrial-supply withdrawals were in Kings County.	22	35	52	Probably about 20	Water table probably showed further declines. Saltwater intrusion into upper glacial aquifer probably became more widespread.
1928-33	Pumping shifted from upper glacial to Jameco (and to a lesser extent, Lloyd) aquifers in Kings County, and withdrawals from all deep aquifers increased in Queens County. Maximum amount of public and industrial supply in Kings County totaled 75 Mgal/d in 1929. By 1933, as much as 16 Mgal/d was pumped from confined aquifers (mostly from Jameco), and nearly all withdrawals were ultimately discharged to sewers (Perlmutter and Soren, 1962).	Averaged about 25	Averaged about 49	Averaged about 46	Probably averaged about 17	Saltwater encroachment into upper glacial aquifer required a shift to pumping deeper, confined aquifers. Water levels in confined aquifers declined rapidly in response to excessive pumping and low storage coefficient characteristic of confined aquifers. Cone of depression noted in Queens County (Perlmutter and Soren, 1962).
1930's	Decline in industrial withdrawals in response to adoption of New York State Water Conservation Law requiring that pumpage in excess of 0.1 Mgal/d be reinjected to source aquifer, and widespread use of electric refrigeration resulting in decreased pumpage for making ice.	Averaged about 25	Averaged about 49	Averaged about 38	Probably averaged about 17	Severe declines in water levels of water-table and confined aquifers. Many lakes and streams dried up, and flow in remaining streams was reduced. Saltwater encroachment progressed inland. Reduced industrial-supply withdrawals allowed a small recovery.

Table 4. History and hydrologic effects of ground-water use in Kings and Queens Counties, N.Y., 1800's through 1996--continued

Period	Event or trend	Estimated ground-water withdrawals, in Mgal/d: Public supply, Kings County	Public supply, Queens County	Industrial supply, Kings County	Industrial supply, Queens County	Effects
1936	Second NYC Water Tunnel completed; no reduction in ground-water withdrawals evident. Imported water probably used to convert new areas to public supply. An estimated 49 billion gallons of freshwater had been removed from the shallow aquifer in Kings from 1903 through 1936 (Perlmutter and Soren, 1962).	27	44	37	Probably about 18	Water levels continued to decline, and salt-water encroachment progressed inland. A cone of depression 35 feet below sea level developed in northern Kings County, where water levels dropped over 45 feet since 1903 (Veatch and others, 1906). Water table in most of Kings County was below sea level; the cone of depression extended into southwestern Queens County (Suter, 1937).
1943	Continued decline in industrial-supply withdrawals since about 1930.	25	36	25	Probably about 15	Water table showed some recovery in northern Kings and western Queens County (Jacob, 1945). Saltwater encroachment continued in confined aquifers.
1947	Withdrawals for public supply in Flatbush (Kings County) were stopped, mostly in response to saltwater intrusion. Withdrawals increased in Queens County to compensate for shutdown of wellfields in Kings County.	0	47	25	Probably about 15	Widespread chloride contamination in upper glacial aquifer in Kings County. Water levels and heads started recovery in Kings County. Subway flooding in Flatbush required dewatering at less than 20 gallons per minute. Increased withdrawals in Queens County caused water-level declines and saltwater contamination of public-supply wells in upper glacial aquifer in Flatbush franchise area.
1951	Industrial-supply withdrawals decreased in Kings and Queens Counties.	0	36	16	10	Cone of depression in northern Kings County became smaller and rose to 25 feet below sea level. Water levels in southern Kings County were now above sea level (Lusczynski and Johnson, 1951). Water table in central Kings County had recovered by as much as 19 feet since 1947 and storage in the water-table aquifer increased by about 20 billion gallons (Lusczynski, 1952). Basement and subway flooding began to the west and northwest of East New York (Kings County) (Soren, 1976).
1955-76	Shift in pumping from upper glacial aquifer to Magothy aquifer (and to a lesser degree, Lloyd aquifer) in Queens County. Overall increase in public supply withdrawals in Queens County. Maximum withdrawal for public supply in Queens County was 70 Mgal/d in 1970.	0	45 to 61	About 10	About 8 to about 4	Water-table recovery continued in Kings County. Basement and subway flooding occurred in central East New York (Kings County). Chloride concentrations increased in public-supply wells in Queens County.

Table 4. History and hydrologic effects of ground-water use in Kings and Queens Counties, N.Y., 1800's through 1996--continued

		Estimated ground-water withdrawals, in Mgal/d				
		Public supply		Industrial supply		
Period	Event or trend	Kings County	Queens County	Kings County	Queens County	Effects
1961	Public-supply withdrawals in Queens County increased; all other withdrawals remained steady. Wells with high chloride concentrations in Queens County were abandoned and new wells were installed farther inland and eastward. From 1903 to 1961, about 51 billion gallons of fresh-water were removed from the water-table aquifer in Queens County (Perlmutter and Soren, 1962).	0	54	About 10	About 5	Water table throughout Kings County was above sea level, recovering by as much as 40 feet, except in the extreme northern part; chloride concentrations were declining. Subway-tunnel dewatering rates had increased to 1,000 gallons per minute in Flatbush. A cone of depression (about 35 feet lower than 1903 levels) developed in southwestern Queens County (Woodhaven franchise area); slight declines in water table throughout southern Queens County (Perlmutter and Soren, 1962).
1974	Withdrawals for public supply in Woodhaven franchise area of Queens County stopped because of saltwater intrusion; withdrawals by JWS continued at about 57 Mgal/d.	0	57	<10	About 4	Further recovery of water table in Kings County; water-table configuration now similar to that of 1903. Cone of depression in Queens County shifted from Woodhaven area toward Jamaica area, where deepest part of cone was 35 feet deeper than 1903 water levels. Potentiometric surfaces of deeper aquifers declined, but data on historical levels are sparse.
1983	Continued withdrawals by JWS from southeastern Queens County; mostly from Jameco-Magothy aquifer, with lesser amounts from upper glacial and Lloyd aquifers. An additional 6 Mgal/d was pumped from wells in Kings County, and about 2 Mgal/d from wells in Queens County for dewatering operations.	0	57	6.6	2.3	Since 1974, water-table fluctuations of only 1 foot in Kings County indicate a condition close to equilibrium. Water levels in northwestern and southwestern Queens County had risen as much as 4 feet and more than 1 foot, respectively, since 1974. Although data are sparse, water levels in northeastern Queens County apparently dropped about 2 feet, and those in southeastern Queens County (Jamaica Franchise area) dropped 2 to 5 feet. Water levels in extreme southwestern Nassau County showed similar declines of as much as 4 feet.
1991	Continued reductions in withdrawals from Queens County, partly through successful implementation of NYCDEP's water-conservation plan; public-supply withdrawals are from former JWS wells in Jamaica. Repairs to water mains result in decreased leakage into ground-water reservoir. Increased dewatering in Kings County; industrial-supply withdrawals in Kings County are estimates and include dewatering operations (Misut and Monti, 1999).	0	24	22	15	Water-table recovery in Jamaica area of Queens County in response to decreased withdrawals for public supply. Water-table declines in parts of Kings County result from increases in industrial-supply and dewatering withdrawals.
1996	Continued reductions in ground-water withdrawals from Queens County, as NYCDEP takes over JWS; public-supply withdrawals are from former JWS wells in Jamaica (Misut and Monti, 1999). Increased dewatering withdrawals in southeastern Queens County.	0	14	22	15	Continued water-table recovery in Jamaica area of Queens County results from decreased withdrawals for public supply.

water quality in the study area varies areally and with depth. Many point sources of contamination at land surface continue to affect water quality, and saltwater intrusion remains a concern in some areas, especially where water-level gradients were reversed twice during the 20th century.

Ground-Water Withdrawals

Ground-water withdrawals can be classified as consumptive—no water is returned to the ground-water reservoir—or nonconsumptive—water is returned to the ground-water system through reinjection, wastewater-disposal systems, or leakage from the water-distribution system. Water suppliers report ground-water withdrawals as the total amount of water pumped or supplied to customers, whether or not it is ultimately returned to the ground-water system. The difference between the two totals represents the amount that is reinjected into the ground after use plus the amount that is returned to the system through leaking distribution mains. The net effect is that withdrawals reported by water suppliers are greater than the amount that is permanently removed from the system. Available records of ground-water withdrawals compiled in this study from various water suppliers represent estimates of the total amounts pumped. The principal types of withdrawals, and their estimated amounts, are as follows.

Public Supply

Public-supply withdrawals were greatest before the 1930's and decreased until the early 1990's, when the only public-supply pumping in Kings and Queens Counties was 22 Mgal/d from the former JWS wellfields in Queens County (Chu and others, 1997). Most of this amount is considered consumptive. By 1995, withdrawals had decreased to about 17 Mgal/d and, when the NYCDEP purchased the JWS in 1996, withdrawals were cut further to about 14 Mgal/d; most of this also is considered consumptive withdrawals (John Dydland, New York City Department of Environmental Protection, written commun., 1996). Plans to increase withdrawals from the Jamaica wellfields to help alleviate underground flooding are in progress (John Dydland, New York City Department of Environmental Protection, oral commun., 1996).

Industrial Supply

Industrial-supply withdrawals are more difficult to estimate than public-supply withdrawals, and the only source of this information is the NYSDEC. Establishments planning to install wells from which water will be withdrawn at rates exceeding 40 gal/min (0.058 Mgal/d) are required to obtain a permit from the NYSDEC, and those pumping more than 70 gal/min (0.1 Mgal/d) must return the used water into the source aquifer. If all water pumped at a rate greater than 70 gal/min (0.1 Mgal/d) is reinjected to the source aquifer, then the amount of consumptive use for industrial supply is equal to the reported amounts pumped at rates between 40 and 70 gal/min, plus the amounts that are pumped at rates less than 40 gal/min (which are not required to be reported); this estimate assumes no return flow of water pumped at rates less than 70 gal/min for industrial supply. Misut and Monti (1999) estimated industrial-supply withdrawals (derived from pump capacities filed with NYSDEC) to be 22 Mgal/d for Kings County and 15 Mgal/d for Queens County. These estimates, which are calculated from individual pump capacities and assume a pumping period of 8 hours per day, probably are high because actual pumping rates generally are less than the maximum capacity rating of each pump.

Dewatering

The recovery of ground-water levels in response to decreased withdrawals has caused flooding of underground structures such as basements and subway tunnels that were constructed in some coastal areas during the early development of Kings and Queens Counties. Dewatering of these structures requires continuous pumping. The pumped water is directed to the combined sanitary and stormwater sewer system, which ultimately discharges to nearby saltwater bodies and thereby removes the water from the ground-water system; thus, dewatering operations are considered a consumptive use. Dewatering accounts for at least 30 percent of the estimated 37 Mgal/d pumped for industrial use in Kings and western Queens Counties. The Metropolitan Transit Authority (MTA) alone withdraws more than 10 Mgal/d from subway tunnels in Kings County (Misut and Monti, 1999).

Ground-Water Inputs

Most ground-water systems are recharged by precipitation that infiltrates the soil. In the highly developed area of Kings and Queens Counties, however, recharge from precipitation is impeded by impervious surfaces, and recharge from leaky sewer and supply lines is significant by comparison.

Precipitation

Precipitation supplies virtually all recharge in central and eastern Long Island. Recharge in undeveloped areas of Long Island is estimated to equal about 50 percent of mean annual precipitation, but recharge from precipitation in the highly urbanized and industrialized areas of Kings and Queens Counties is far less because the large amount of impervious surfaces such as streets and parking lots impede infiltration. In 1983, Buxton and Shernoff (1995) estimated recharge from precipitation to equal only about 15 percent of precipitation (24 Mgal/d) in Kings County, and about 35 percent of precipitation (83 Mgal/d) in Queens County. These 1983 values are considered accurate for present conditions because the amount of impervious surfaces has not changed appreciably since then.

Leaky Sewer Lines and Water Mains

Wastewater in Kings and Queens Counties initially was returned to the ground through septic systems before sewers were installed in the 19th century. Septic systems provided continual recharge of the ground-water system, but soon caused widespread nitrate contamination of the upper glacial aquifer. The first combined sanitary and storm sewers on Long Island were installed in Kings County by the mid-1800's, and Queens County had an extensive sewer network by the turn of the 20th century. Although sewers prevented most surface-derived contamination from reaching the water table, it also prevented large volumes of water from recharging the ground-water system and, thereby, resulted in lowering the water table. Leakage from sewer connections and broken lines initially was small, and probably was insignificant in relation to the large public-supply withdrawals. The amount of leakage from combined sanitary and storm sewers has probably increased, as the lines have aged, however. Leakage into the ground water from leaky sewer lines and water-supply mains in 1983, as calculated from the number of miles of mains and the number of connections, multiplied by a leakage factor, is estimated to have been about 30 Mgal/d in Kings County and 40 Mgal/d in Queens County (Buxton and Shernoff, 1995). Ground-water leakage from sewer and supply lines has become an increasingly large component of the ground-water budget as public-supply withdrawals decline and sewer and supply lines age.

Recent water-conservation efforts by New York City, such as shutting off running water in vacant buildings, repairing leaks, reducing water-supply waste, installing water meters in areas that had flat-rate billing, and educating consumers in water conservation, probably have decreased the amount of water returning to the ground-water system through sewers and water-supply main leakage. Also, the infiltration of ground water from the recovering water table into sewer lines probably occurs more widely now than when the water table was depressed. The potential for greater leakage from aging sewer and supply lines is countered by leakage decreases resulting from water-conservation efforts and the rising water table. Therefore, with a lack of additional data, the estimated ground-water input from water-supply and sewer lines is probably similar to the 1983 estimates (Buxton and Shernoff, 1995).

Ground-Water Levels

The water-table configurations in Kings and Queens Counties in 1903, 1936, 1943, 1951, 1961, 1974, 1981, 1983, and 1997 are depicted in figures 3A-3I, respectively. Water levels in the Jameco-Magothy aquifer in 1983 and 1996 are depicted in figure 4; water levels in these years in the Lloyd aquifer are depicted in figure 5. Well-design and water-level data from wells installed before 1983 are presented in table 8 of Buxton and Shernoff (1995), and well-completion data from new wells (since 1992) are presented in table 2 of this report. The following sections describe present (1997) ground-water levels in the major aquifers in Kings, Queens, and western Nassau Counties, and discuss them in relation to those of 1983 in light of the sharply reduced public-supply withdrawals in Queens in 1974.

Upper Glacial Aquifer

Kings County.—The cessation of public-supply withdrawals in Kings County in 1947 caused water levels to begin rising. By 1974, the water-table configuration in Kings County (fig. 3F) was similar to that of 1903 (fig. 3A). This condition, and the relatively small (about 1-ft) water-level fluctuations observed since 1974, indicate that the system is now close to equilibrium. By 1991, small localized water-level declines were observed; these were caused by dewatering in response to ground-water flooding and had a negligible effect on the overall recovery of water levels. The 1997 water-table map (fig. 3I) indicates water levels throughout Kings County to be mostly from 0 to 10 ft above sea level.

Queens and western Nassau Counties.—Since 1974, water levels in Queens County have risen above sea level in all but one area in the southern part of the county that contains the JWS wellfields. In 1974, water levels in this area were between 0 and 10 ft below sea level (fig. 3F), but by 1983, continued recovery had divided this depression into two smaller depressions—one less than 1 ft below sea level in south-central Queens County, and one about 10 ft below sea level in southeastern Queens County (fig. 3H). The latter depression is due to past pumping by the JWS for their Woodhaven operations, and the former depression is the result of continued (but decreased) withdrawals by the JWS. Water levels about 3 mi east-northeast of this depression (in western Nassau County) are as much as 40 ft higher

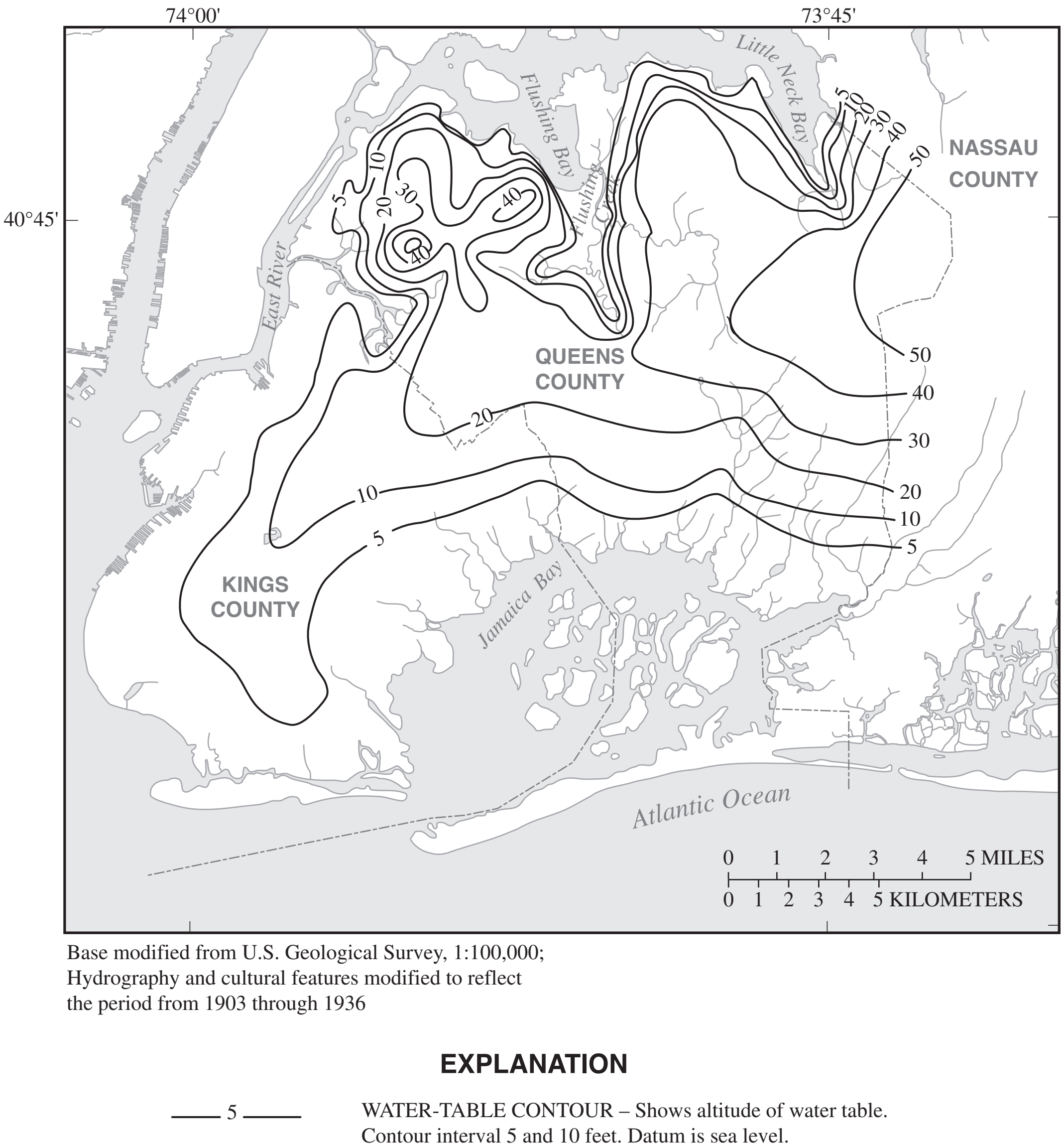
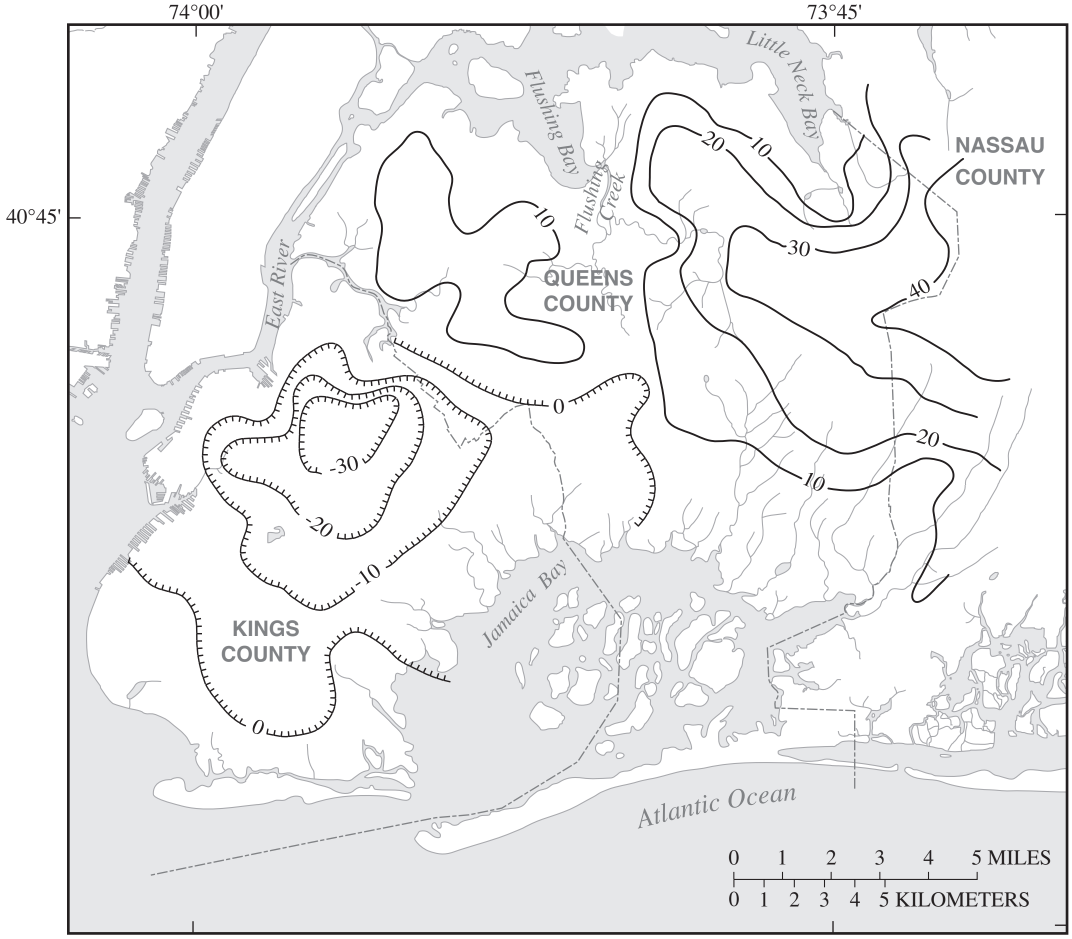


FIGURE 3A. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1903. (From Buxton and Shernoff, 1995, fig. 3.)



Base modified from U.S. Geological Survey, 1:100,000;
Hydrography and cultural features modified to reflect
the period from 1903 through 1936

EXPLANATION

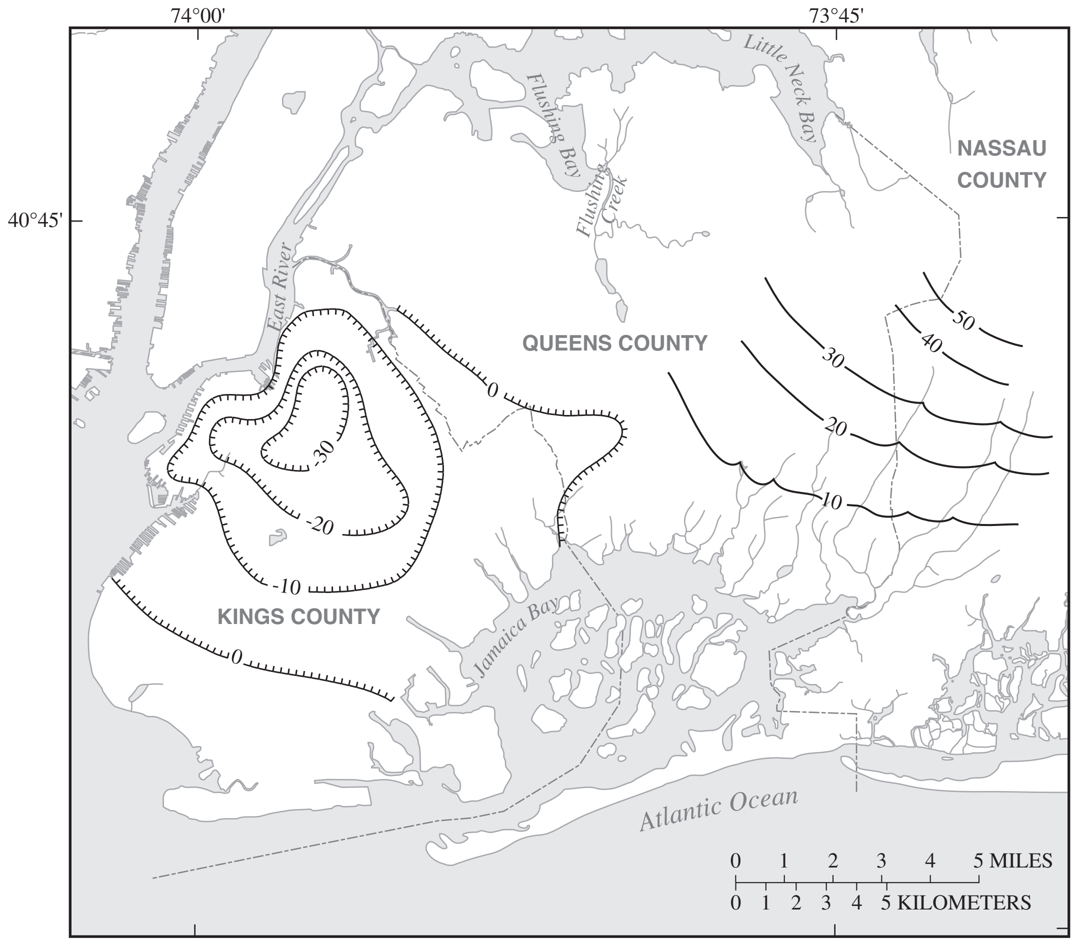
—— 0 ┬┬┬┬┬┬ WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 10 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3B. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1936. (From Buxton and Shernoff, 1995, fig. 6A.)

and provide a steep southwestward gradient. Both depressions in Queens County had disappeared by 1997, as indicated by the most recent water-table map (Monti and Chu, 1997), which shows little, if any, indication of residual effects of pumping (fig. 3I). Currently (1997), water levels are about 20 ft above sea level in areas where they were 10 ft below sea level in 1983. This recovery is the result of a 75-percent reduction in ground-water withdrawals for public supply in Jamaica, from about 57 Mgal/d in 1983 to about 14 Mgal/d in 1996. Water levels in western Nassau County also show a recovery, especially in areas closest to the former depression in Queens County. Especially notable is the shift in direction of ground-water flow, which was to the southwest (toward Queens County) in 1983, and to the south-southwest (closer to the direction of regional southward flow) in 1997.

Jameco-Magothy Aquifer

The 1983 potentiometric surface of the Jameco-Magothy aquifer in Kings County, as indicated by data from two wells (Buxton and Shernoff, 1995, pl. 5),



Base modified from U.S. Geological Survey, 1:100,000;
Hydrography and cultural features modified to reflect
the period from 1943 through 1951

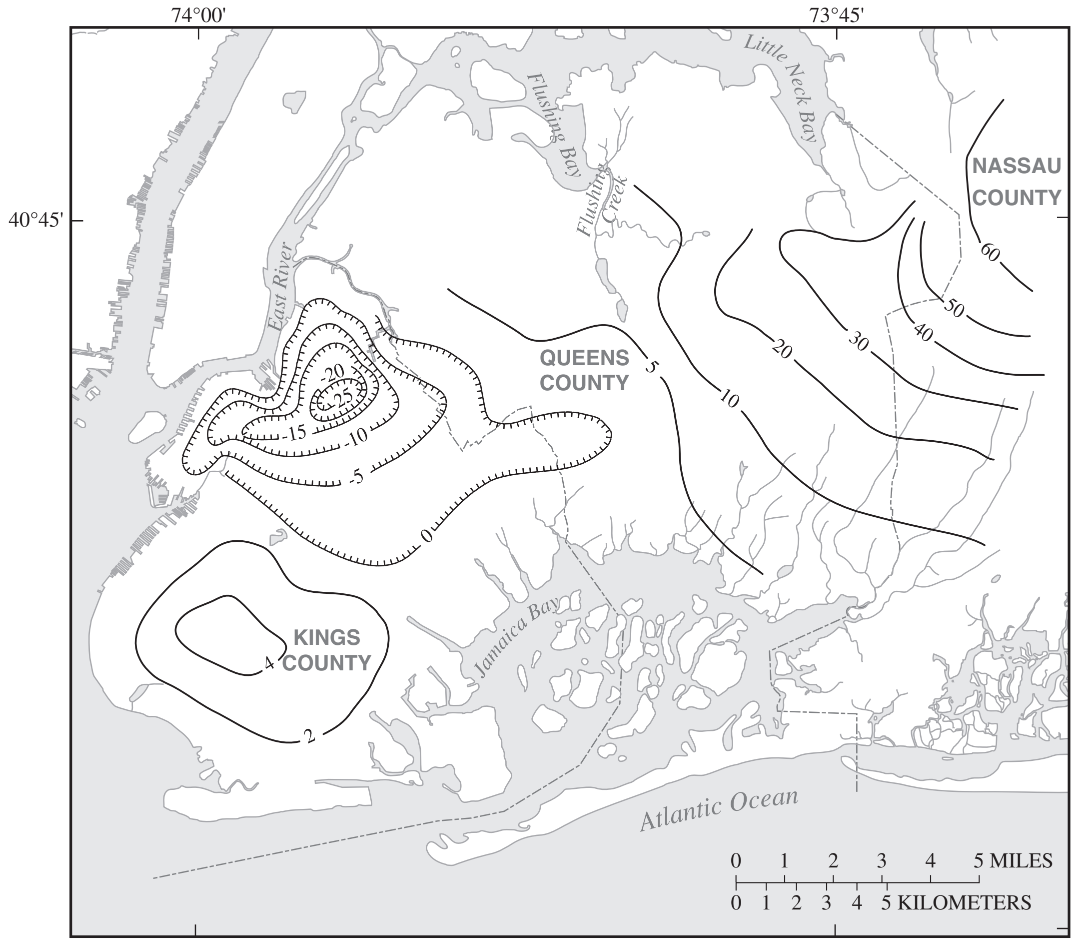
EXPLANATION

—— 0 ┬┬┬┬┬┬ WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 10 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3C. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1943. (From Buxton and Shernoff, 1999, fig. 7B.)

generally was less than 10 ft above sea level. The 1983 potentiometric surface in Queens County, based on data from 18 wells, indicates a large depression beneath the southern half of the county's mainland, where water levels range from 0 to about 10 ft below sea level. This depression is the result of public-supply withdrawals from 22 wells at a combined rate of about 31 Mgal/d during the March-through-April 1983 measurement period (Buxton and Shernoff, 1995). Water levels in adjacent western Nassau County indicate a potentiometric surface that dips steeply to the southwest toward this depression—from 30 ft to less than 5 ft above sea level in about 2.5 mi. The few water-level measurements made in northern Queens County in 1983 range from 0 to about 13 ft above sea level, and those along the coast south of the large depression in Queens County range from 0 to 4 ft above sea level. Water levels in southern Nassau County also range from 0 to 4 ft above sea level.

Public-supply withdrawals from the Jameco-Magothy aquifer in Queens County in 1995 averaged 11.7 Mgal/d. This value is calculated from the total yearly amount divided by 365 and, therefore, probably should be higher than the 1983 daily averages (31 Mgal/d) calculated only for March through April, when pumping rates typically are lower than in other seasons. Thus, the decrease in average daily withdrawals from 1983 to 1995 is at least 62 percent.



Base modified from U.S. Geological Survey, 1:100,000;
Hydrography and cultural features modified to reflect
the period from 1943 through 1951

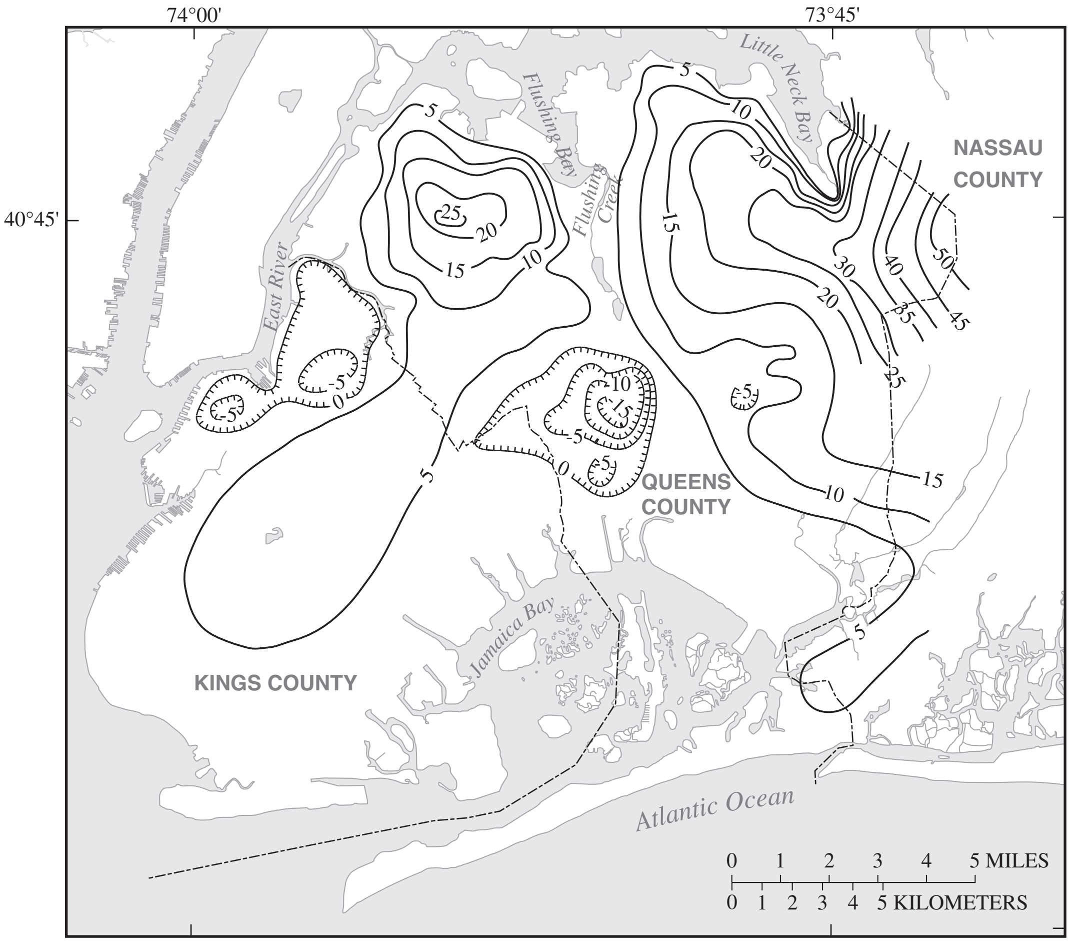
EXPLANATION

0 WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 2, 5 and 10 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3D. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1951. (From Buxton and Shernoff, 1999, fig. 7C.)

This decrease is reflected in the recent (1996) water levels in Kings, Queens, and western Nassau Counties, as discussed below and depicted in figure 4.

Kings County.—Data from Kings County are sparse, even though four new Jameco-Magothy aquifer wells were installed in 1994 and 1995, tripling the number of wells available for water-level measurements in this aquifer from two to six (fig. 4). Water levels at the two older wells in Kings County (K522 and K3132, fig. 4) in 1995 were similar to those in 1983 and are in agreement with the previously described equilibrium conditions in the upper glacial aquifer since 1983. The water level at the new well in central Kings County (K3431) in 1996 was 11.74 ft above sea level, which agrees with the 10-ft contour of 1983 presented by Buxton and Shernoff (1995). The remaining three new wells are in coastal parts of Kings County, where water-level data are lacking. The water level in well K3406, in western Kings County, was about 3 ft above sea level in 1996. Wells K3407 and K3414, near the southern shore of Kings County, were screened in saline ground water. Density differences between fresh and saline ground water requires that a simple calculation be made on water levels measured in saline wells so that the adjusted water levels (freshwater equivalent head) can be compared to those



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

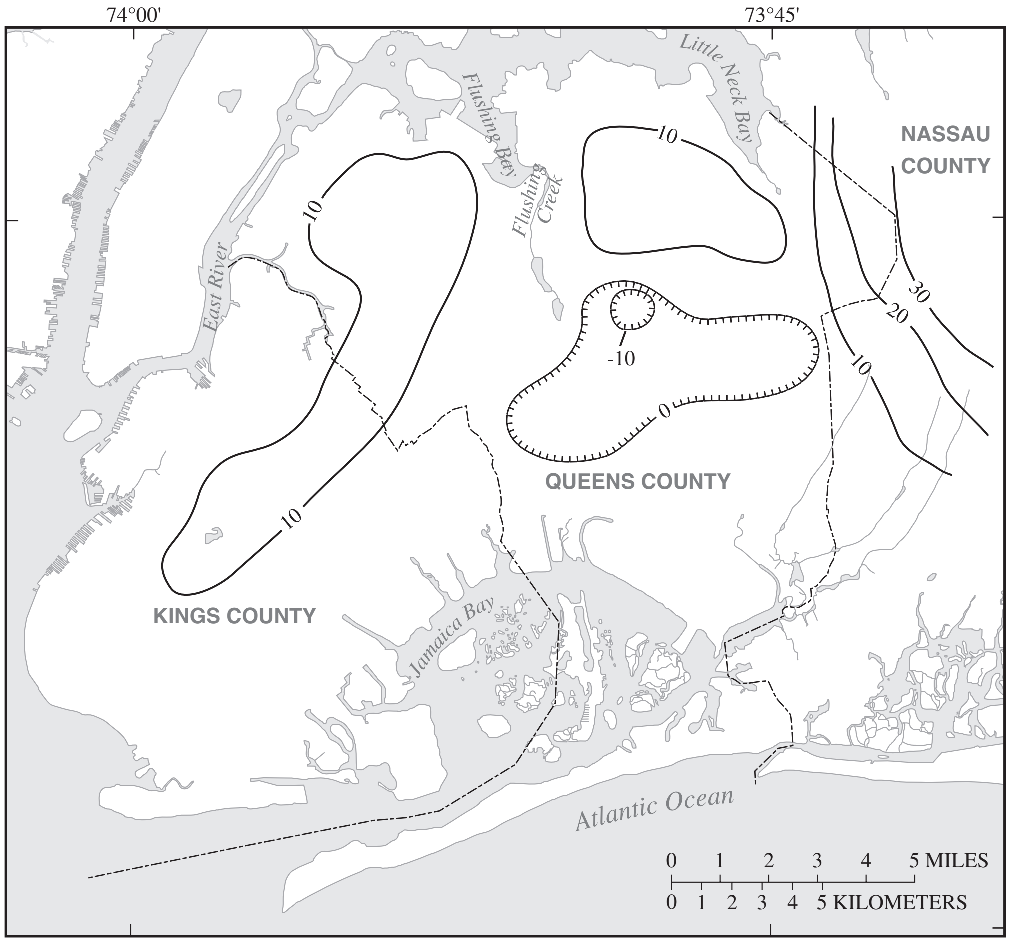
WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 5 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3E. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1961. (From Buxton and Shernoff, 1999, fig. 7D.)

in freshwater wells. After correction to freshwater equivalent head, wells K3407 and K3414 had water levels of 10.30 and 8.45 ft above sea level, respectively, in 1996. The latter two nearshore wells indicate upward ground-water movement, which is consistent with the flow patterns in this area as indicated on plate 7 of Buxton and Shernoff (1995).

Queens County.—Recent (1992-97) water-level measurements were obtained from 12 of the 15 Jameco-Magothy aquifer wells measured in Queens County in 1983; additional water-level data are available for three wells measured between 1983 and 1992. Water levels in all 15 wells indicate that the potentiometric surface of the Jameco-Magothy aquifer has been recovering since 1983 in response to reductions in public-supply withdrawals (fig. 4). Specifically, water levels recovered at least 1.37 ft along the coast (well Q3150) and by almost 32 ft near the public-supply wells in central parts of the county (well Q2300). These data indicate that the potentiometric surface of the Jameco-Magothy aquifer is not below sea level in any part of Queens County; the water levels generally areabout 5 ft above sea level near the southern coast, and increase inland to about 20 ft above sea level near western Nassau County.

Nassau County.—Water-level measurements made in 1983 and thereafter at eight wells screened in the Jameco-Magothy aquifer in western Nassau



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

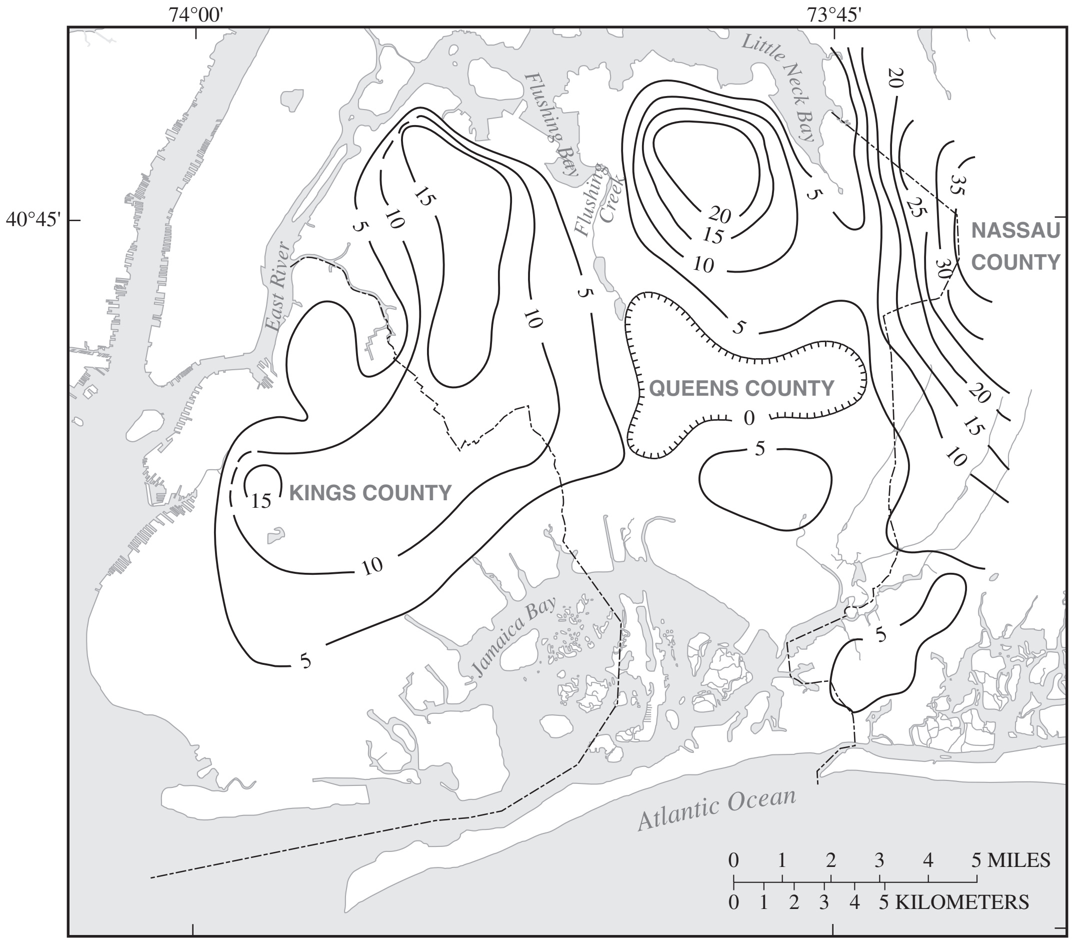
—— 0 ┬┬┬┬┬┬ WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 10 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3F. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1974. (From Buxton and Shernoff, 1999, fig. 7E.)

County (fig. 4) are available. Recent (1992-96) water levels in wells farthest from the former cone of depression in Queens County are similar to, or slightly higher than in 1983, and water levels in all wells closer to the cone of depression are much higher than in 1983. From 1983 through 1996, water levels at all Jameco-Magothy aquifer wells in Nassau County increased at least 2.7 ft and by as much as 18.6 ft.

Lloyd Aquifer

The potentiometric-surface map of the Lloyd aquifer in Kings, Queens, and western Nassau Counties in January 1983 (plate 6 of Buxton and Shernoff, 1995) shows water levels at 20 wells, only one of which is in Kings County. The most prominent feature on that map (not displayed here) is a large depression that originates in central Queens County



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

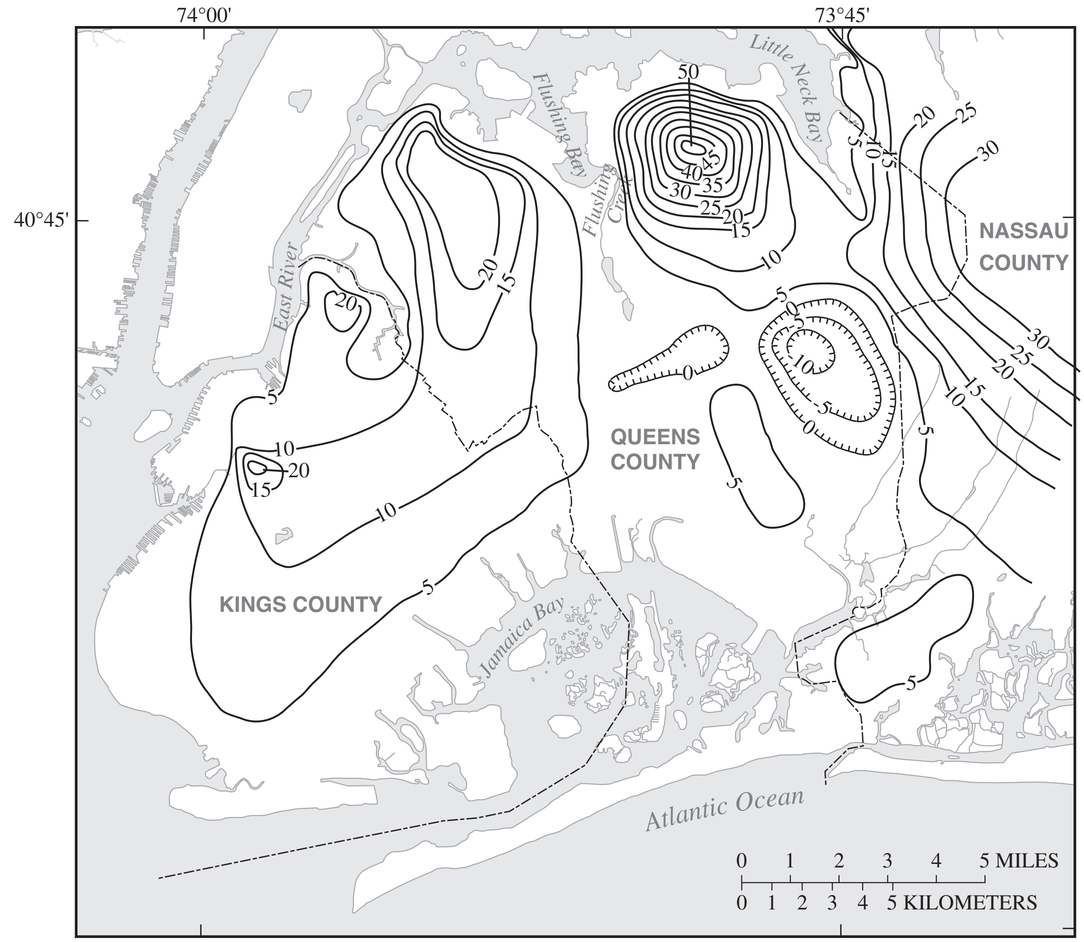
EXPLANATION

0 WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 5 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3G. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1981. (From Buxton and Shernoff, 1999, fig. 13A.)

and extends into western Nassau and eastern Kings Counties. The -20-ft contour of this depression is centered around four public-supply wells (Q317, Q562, Q567 and Q3069, fig. 5) whose combined withdrawals averaged about 6 Mgal/d in 1983. The 1983 water-level measurements were made several hours after the pumps were temporarily shut down; thus, the cone of depression probably extended deeper during typical withdrawal periods. Water levels measured in 1983 near the buried channel described previously indicate that ground water in this area flows downward through the units that fill the channel and into the Lloyd aquifer.

Recent (1996) water-level measurements in wells screened in the Lloyd aquifer indicate substantial recovery of the potentiometric surface since 1983 (fig. 5). By 1996, water levels at the four public-supply wells mentioned earlier had recovered by at least 19 ft, and by as much as 35 ft, as a result of the 1994 reduction of pumping to a combined total of about 54,000 gal/d from these wells—less than 1 percent of the 1983 withdrawals. Water levels in every Lloyd well measured in the study area had partially recovered. Measurements from wells as far south as Jamaica Bay (Q287) and Rockaway Beach (Q1071) show water-level increases of about 6.5 ft. This rapid and



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

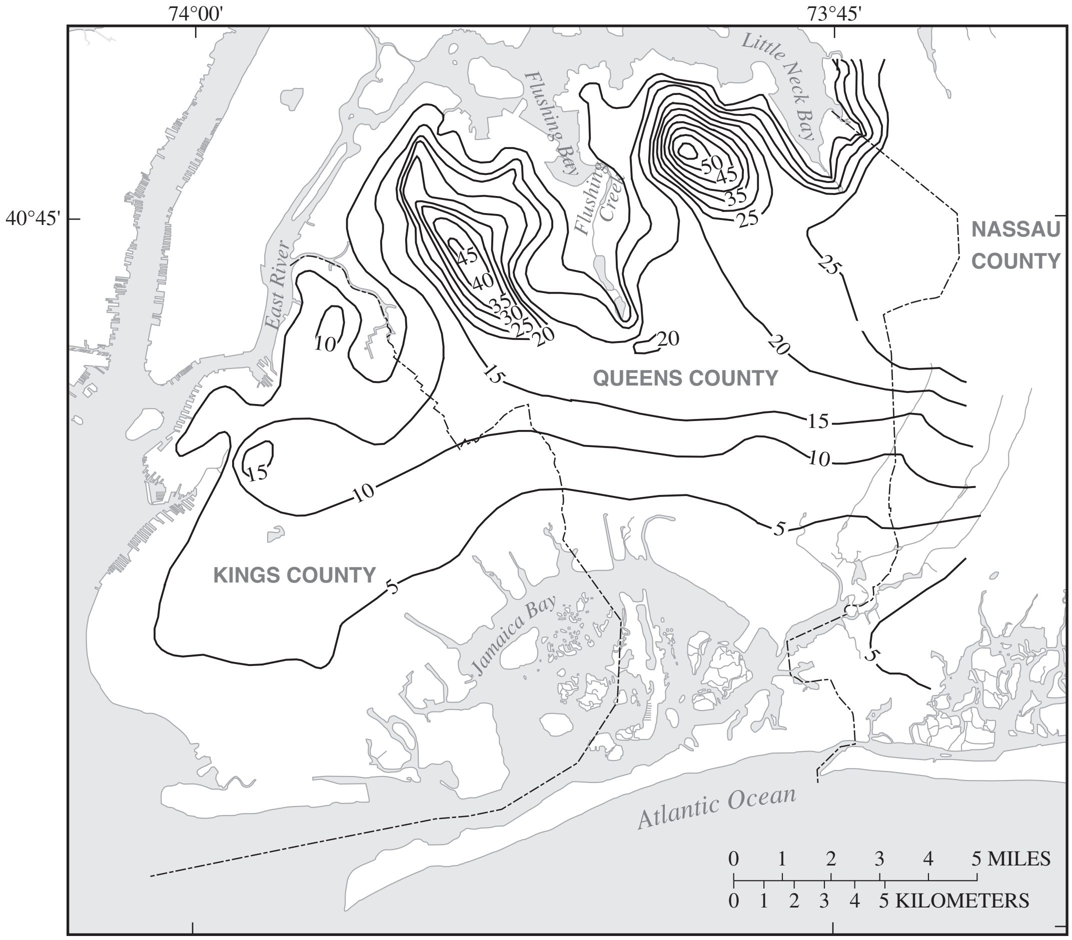
0 WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 5 feet. Datum is sea level. Hachures indicate depression.

FIGURE 3H. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (From Buxton and Shernoff, 1999, plate 3.)

widespread recovery is as expected for a relatively thin, confined aquifer. Additional water-level measurements were obtained from the four newly installed wells screened in the Lloyd aquifer (fig. 5)—one in Kings County (K3410), and three in Queens County (Q3627, Q3628 and Q3593). The water level at well K3410, near the northern extent of the Lloyd aquifer, was about 8 ft above sea level in 1996; in 1983 water levels were close to sea level (Buxton and Shernoff, 1995, pl. 6). Water levels at wells Q3627 and Q3628 in west-central Queens County, near the southern extent of the buried channel (fig. 5), were 10.7 and 11.2 ft above sea level, respectively, in 1996; in 1983 they were near or at sea level. These latter data indicate a downward flow of ground water into the Lloyd aquifer, as in 1983. Recent (1992-97) data from western Nassau County are sparse and variable and, thus are not presented here.

Ground-Water Quality

This section describes recent (1992-96) water-quality conditions in Kings and Queens Counties and relates them to historical water-quality trends described in Buxton and Shernoff (1995). Emphasis is



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

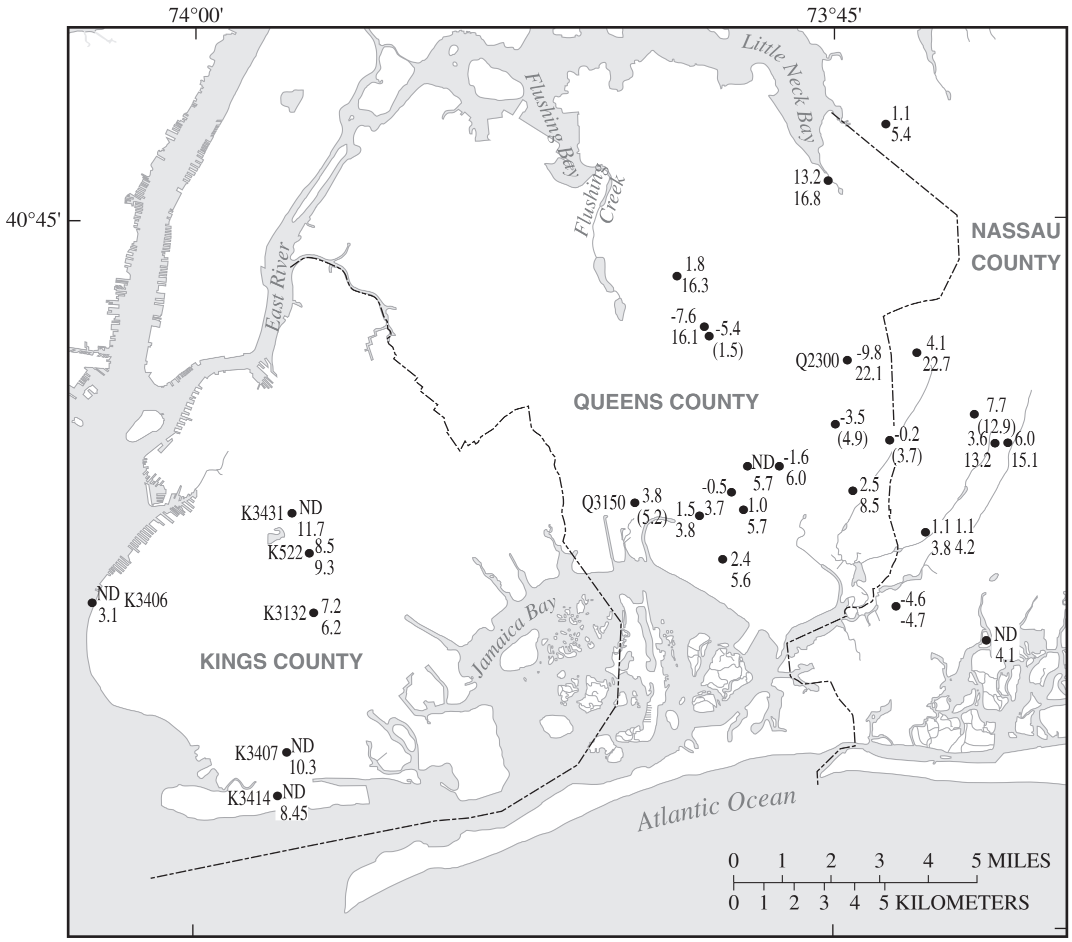
—— 5 —— WATER-TABLE CONTOUR – Shows altitude of water table. Contour interval 5 feet. Datum is sea level.

FIGURE 3I. Water-table configuration in Kings, Queens, and western Nassau Counties, N.Y., in 1997.

on nitrate and chloride concentrations, by aquifer, since 1983 and on results from the first extensive data set of organic-compound concentrations in ground water of Kings and Queens Counties (Cartwright and others, 1998). Locations of wells from which water samples were collected are shown in figures 6A through 6I; the general relations between chloride and nitrate concentrations in ground water, and withdrawal rates in Kings and Queens Counties, are summarized in table 4.

Chloride

Predevelopment concentrations of chloride in ground water on Long Island probably ranged from about 3 to 12 mg/L (Buxton and Shernoff, 1995), but by the early 1900's, ground-water withdrawals in Kings and Queens Counties had caused saltwater intrusion in the upper glacial aquifer in coastal areas, where chloride concentrations as high as 500 mg/L were reported (Spear, 1912). New, deeper public-supply wells were installed farther inland and



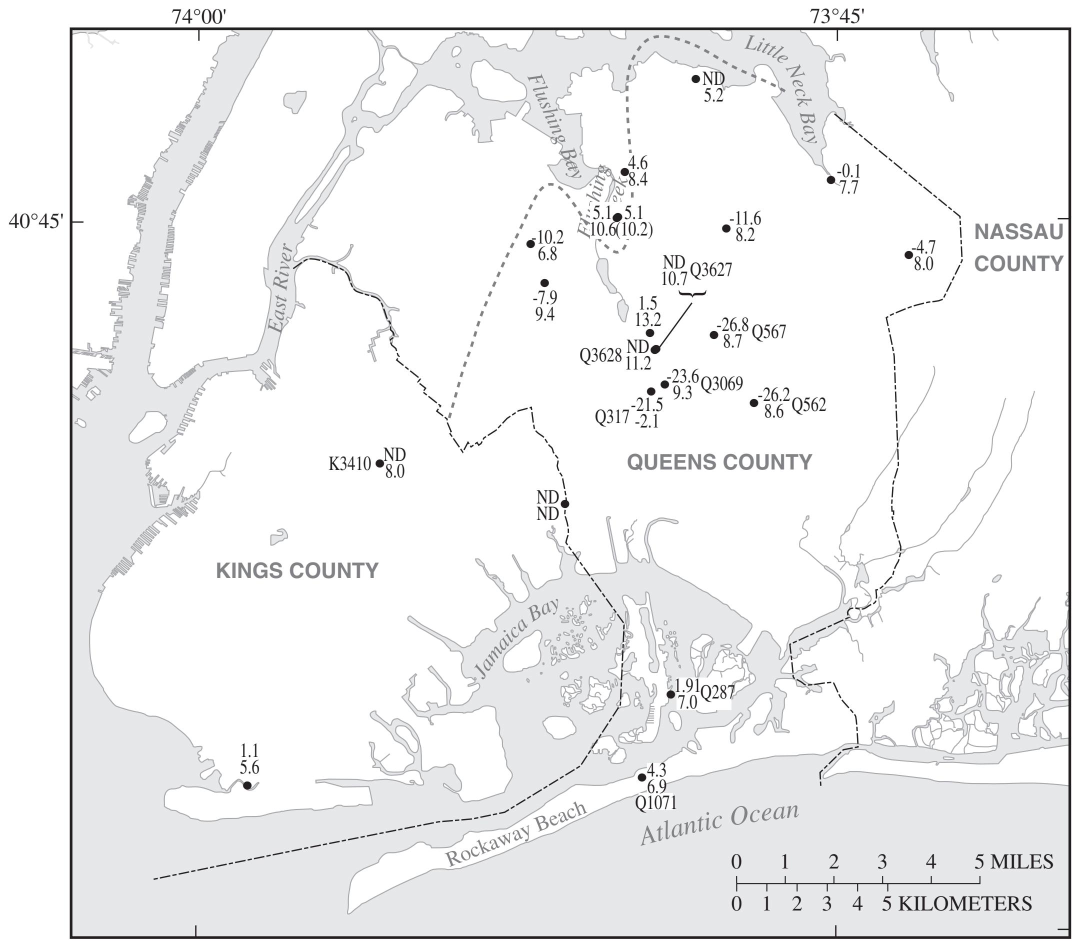
Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

• 7.2 / 6.2	Monitoring well - upper number is 1983 water level in feet above sea level, lower number is 1996 water level: Number in parentheses is water level between 1983 and 1992.
K3406	NYSDEC well-identifier for well mentioned in text
ND	No data available

Figure 4. Ground-water levels in 1983 and 1996 in wells screened in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y. (Modified from Buxton and Shernoff, 1995, pl. 5.)

eastward to avoid the migrating saltwater front but the number of supply wells contaminated with saltwater continued to increase through the 1940's, even in the deeper Jameco-Magothy aquifer and at inland locations. The elevated chloride concentrations at some wells were probably due to surface-derived sources (mostly road salting), but no attempt was made to differentiate saltwater-derived chloride from surface-derived chloride. By 1947, chloride concentrations were as high as 700 mg/L at some inland wells, and as high as 8,000 mg/L at wells along the southern shore (Buxton and Shernoff, 1995). The history of the saltwater-front migration is outlined in table 4.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

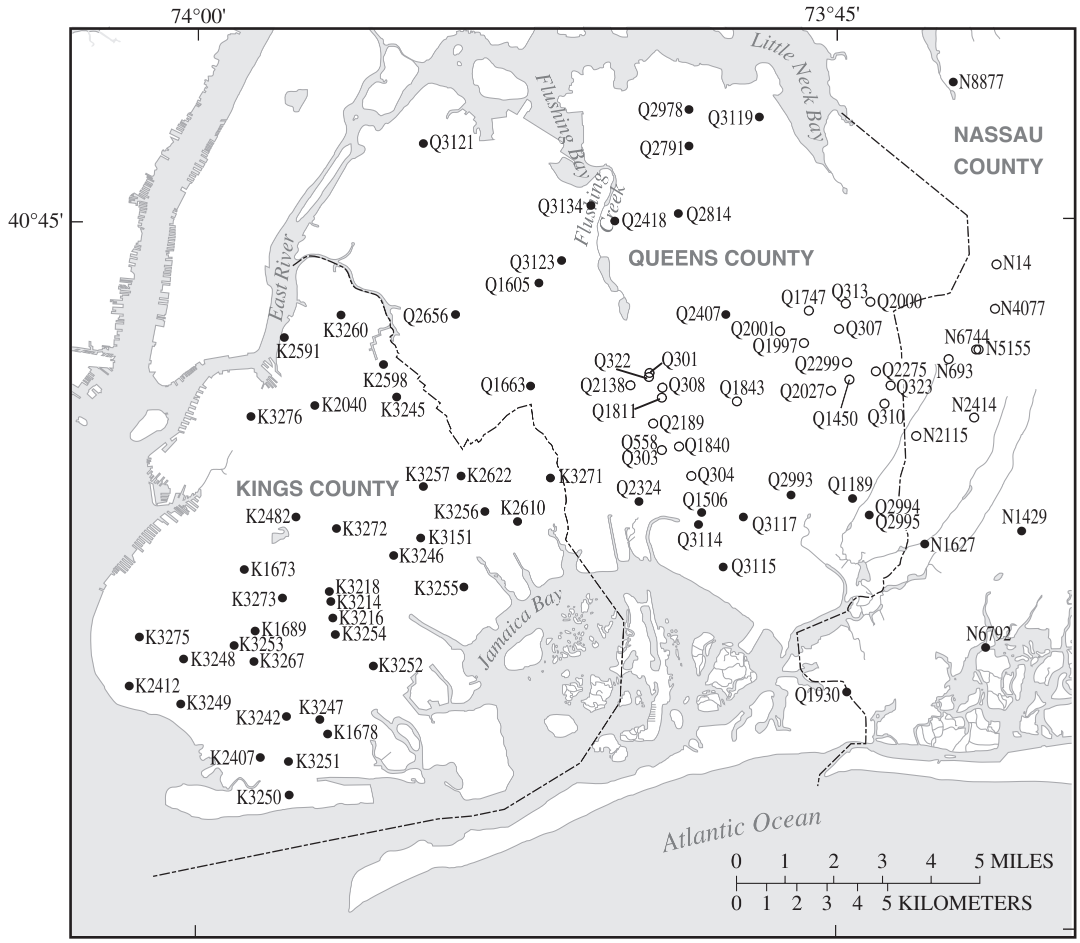
EXPLANATION

• -10.2 6.8	Monitoring well - upper number is 1983 water level in feet above sea level, lower number is 1996 water level: Number in parentheses is water level between 1983 and 1992.
K3406	NYSDEC well-identifier for well mentioned in text
ND	No data available
- - - - - - - - -	Northern limit of Lloyd aquifer in Queens County, indicating the buried river channel where the sediments of the Lloyd aquifer were eroded.

Figure 5. Ground-water levels in 1983 and 1996 at wells screened in the Lloyd aquifer in Kings and Queens Counties, N.Y. (Modified from Buxton and Shernoff, 1995, pl. 6.)

Upper Glacial Aquifer

Kings County.—In 1983, chloride concentrations in water samples from 36 monitoring wells screened in the upper glacial aquifer ranged from 15 to 1,100 mg/L (Buxton and Shernoff, 1995). Chloride concentrations in inland areas of Kings County show no discernible pattern; thus, no contours are depicted. The elevated chloride values in inland areas are probably the result of past saltwater intrusion as well as surface-derived contamination (Buxton and Shernoff, 1995). Most chloride values above 250 mg/L were in nearshore areas, particularly near natural or



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

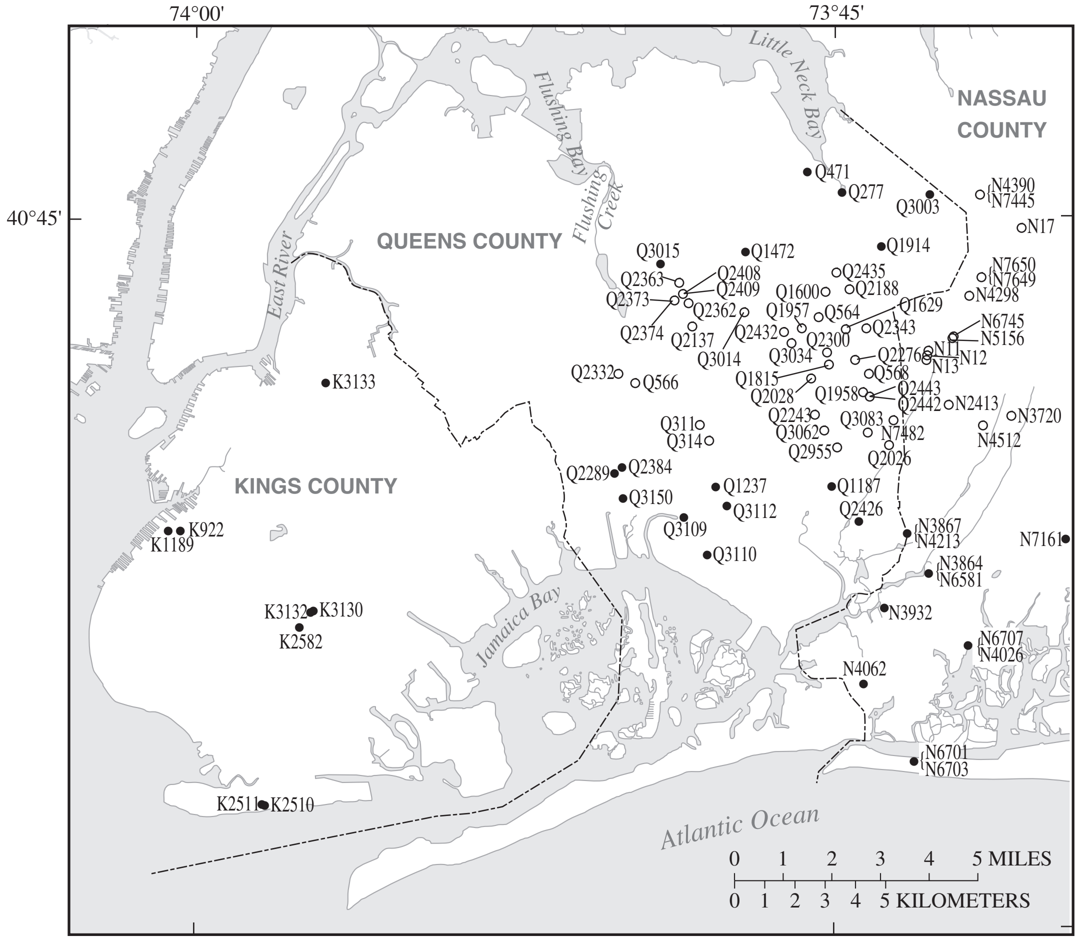
● K3275 MONITORING WELL

○ Q1843 PUBLIC - SUPPLY WELL - for which concentration of nitrate or chloride is available

FIGURE 6A. Locations of wells screened in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1983. (Modified from Buxton and Shernoff, 1995, fig. 12A.)

manmade coastal embayments. An isolated concentration of 1,100 mg/L at a well about 3 mi from Jamaica Bay and about 1.5 mi from the nearest saltwater embayment is probably from a surface source. Historical concentrations of chloride in the upper glacial aquifer in 1947, 1961, 1970, 1981, and 1983, in Kings County are indicated in figures 7A through 7E, respectively.

Chloride concentrations at the majority of wells (74 percent) screened in the upper glacial aquifer in Kings County have remained steady or have declined since 1983. Chloride concentrations at 23 wells from which 1983 and 1996 data are available remained nearly constant at 1 well, decreased at 16 wells, and increased at 6 wells (figs. 7E, 7G). Of the six wells at which chloride concentrations increased, three are within 0.5 mi of the shore (K2412, K1407, K3250) with concentrations of 41 to 1,000 mg/L, and three are 1 to 1.5 mi from a saltwater body (K3242, K3275, K1678) with concentrations of 55 to 470 mg/L. Water-quality data also were collected at eight other upper glacial wells in Kings County in 1983 and 1992, but not in 1996; chloride concentrations remained constant at two wells, declined at four wells, and increased at two wells. Well K3245 is 0.75 mi from Newtown Creek, in the northeastern part of the county



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

● K1189 MONITORING WELL

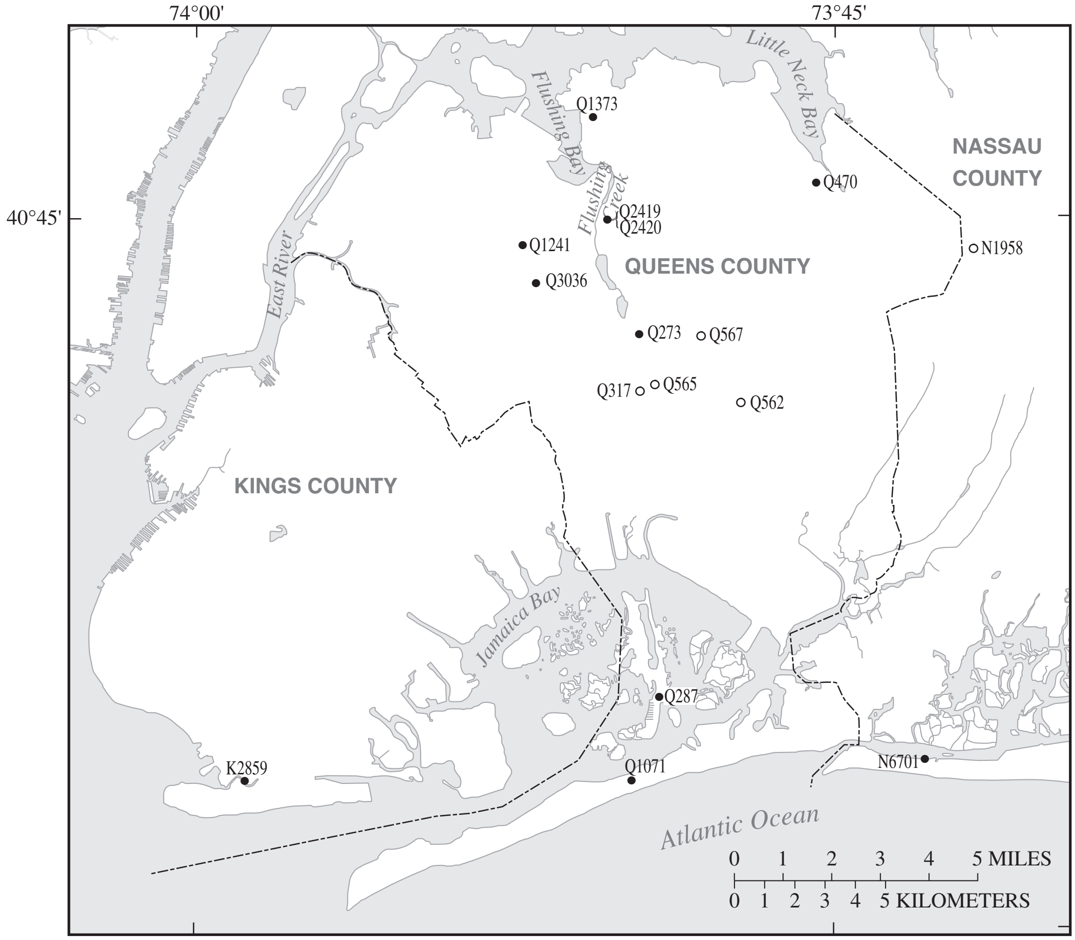
○ Q2332 PUBLIC – SUPPLY WELL

FIGURE 6B. Locations of wells screened in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1983. (Modified from Buxton and Shernoff, 1995, fig. 13A.)

(figs. 7F, 7G), and well K3257 is in east-central Kings County, where the elevated concentrations probably are due to surface-derived contamination.

The chloride-concentration data presented in this report indicate that the upper glacial aquifer in Kings County is being flushed of saline water from past saltwater encroachment. This process probably has been occurring since about 1974, when water levels in Kings County recovered to 1903 levels. This flushing is further supported by the 1997 water levels, which indicate seaward gradients throughout the county. Increasing chloride concentrations since 1983 at upper glacial wells in nearshore areas may be due to incomplete flushing, and those farther inland are probably a result of surface-derived contamination.

Five additional wells screened in the upper glacial aquifer installed in Kings County during this investigation have provided chloride data for 1995 and (or) 1996. One of these wells (K3406) is on the East River at the western edge of Kings County (fig. 7G); it is screened just above bedrock (possibly in the Jameco aquifer) but is representative of shallow ground-water quality in this area because no overlying confining unit was observed. The chloride concentration in water



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

● K2859 MONITORING WELL

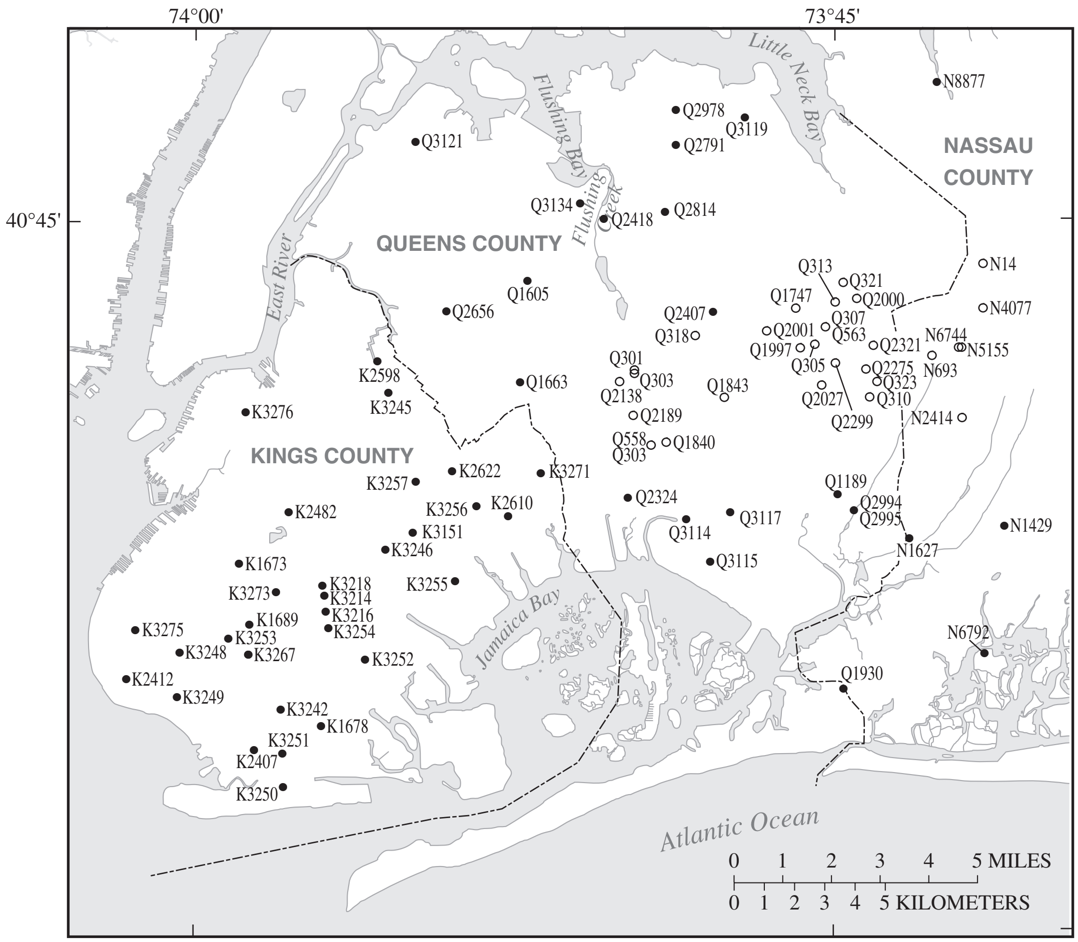
○ Q3036 PUBLIC – SUPPLY WELL

FIGURE 6C. Locations of wells screened in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1983. (Modified from Buxton and Shernoff, 1995, fig. 14A.)

from this well in 1995 was 520 mg/L and indicates that the well is screened within a zone of diffusion. This indication is supported by an electromagnetic (EM) log, which indicates a 10-ft zone of saline water at the base of the well (Chu and Stumm, 1995). The other four wells (K3405, K3424, K3425 and K3430) are further inland with chloride concentrations of 57, 14, 91, and 90 mg/L, respectively, in 1996. These values are typical of the upper glacial aquifer in Kings County and are probably due to past saltwater encroachment in the Flatbush Franchise area of the former JWS (fig. 1), although they also could be partly due to surface-derived contaminants.

Queens County.—The 1983 chloride concentrations in all of Queens County at 22 monitoring wells and 23 public-supply wells screened in the upper glacial aquifer ranged from 17 to 9,000 mg/L, whereas concentrations in inland areas ranged only from 31 to 160 mg/L. The 160-mg/L concentration at public-supply well Q2189 (fig. 6A and 7E) is near the center of a cone of depression that developed around the Woodhaven Franchise area in southwestern Queens County (fig. 3E) in the 1960's and, therefore, may reflect residual chloride from saltwater intrusion.

Recent (1992 and 1996) data from Queens County indicate that chloride concentrations at most



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

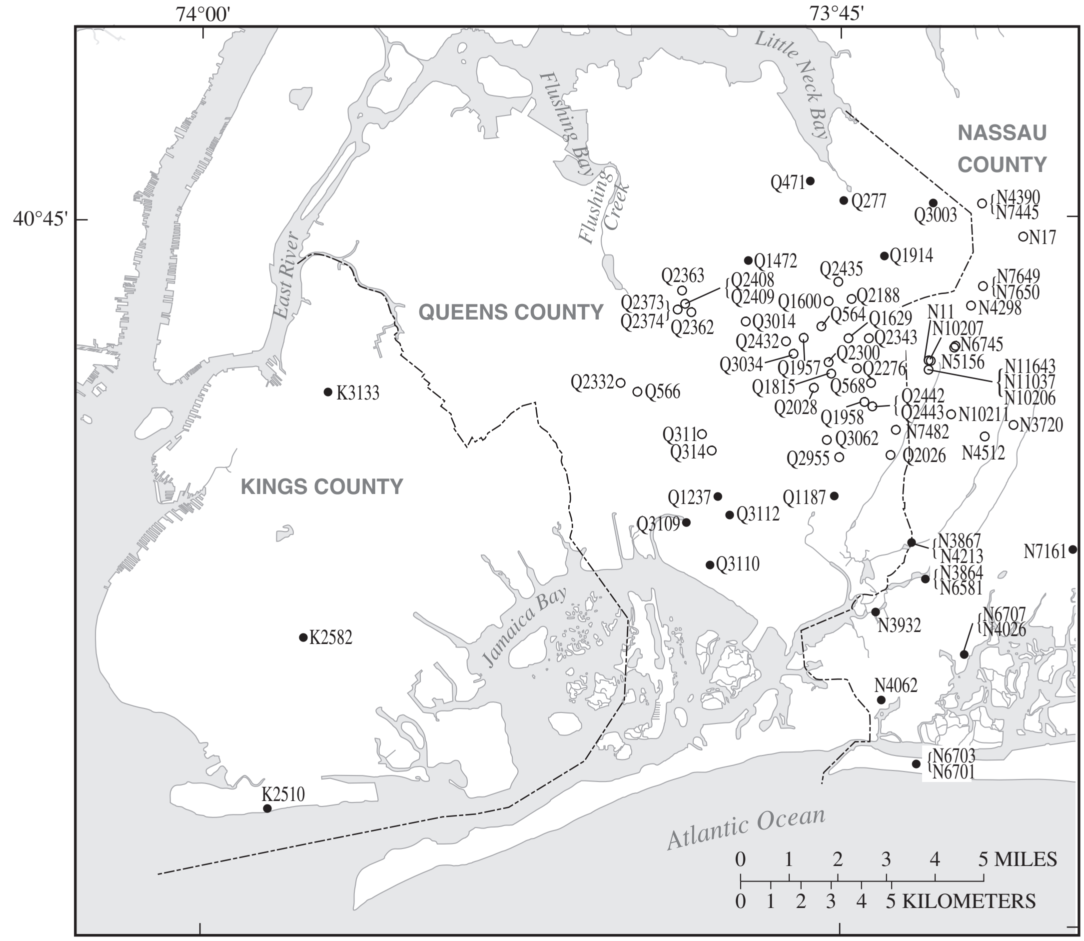
•K2482 MONITORING WELL

○Q2187 PUBLIC – SUPPLY WELL

FIGURE 6D. Locations of wells screened in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1992.

wells screened in the upper glacial aquifer have declined or remained steady since 1983 (figs. 7E, 7F, and 7G). Chloride concentrations have remained constant at 1 of 16 wells for which 1983 and 1996 chloride data are available, have decreased at 11 wells, and have increased at 4 wells. Of the four wells at which chloride concentration increased, Q3117 had a value of 160 mg/L in 1996 and is in southern Queens County in an area likely to be affected by previous public-supply withdrawals from JWS wellfields; Q2656 and Q2978 are in northern Queens County with chloride concentrations of 24 and 32 mg/L, respectively, in 1996, and Q2407 is in central Queens County with a chloride concentration of 93 mg/L. These concentrations are relatively low and, except for the value at Q3117 (160 mg/L) in southern Queens County, probably do not reflect past saltwater intrusion.

In addition to the 16 wells for which 1983 and 1996 data are available, 7 other wells screened in the upper glacial aquifer in Queens County were sampled in 1983 and 1992. Chloride concentrations at five of these wells increased, and those at two wells decreased. Of the five wells with higher chloride concentrations in 1992 than in 1983, four are public-supply wells in southern Queens (Q558, Q1747, Q2001, Q2138) and may reflect residual effects of long-term, widespread withdrawals, and one is a



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

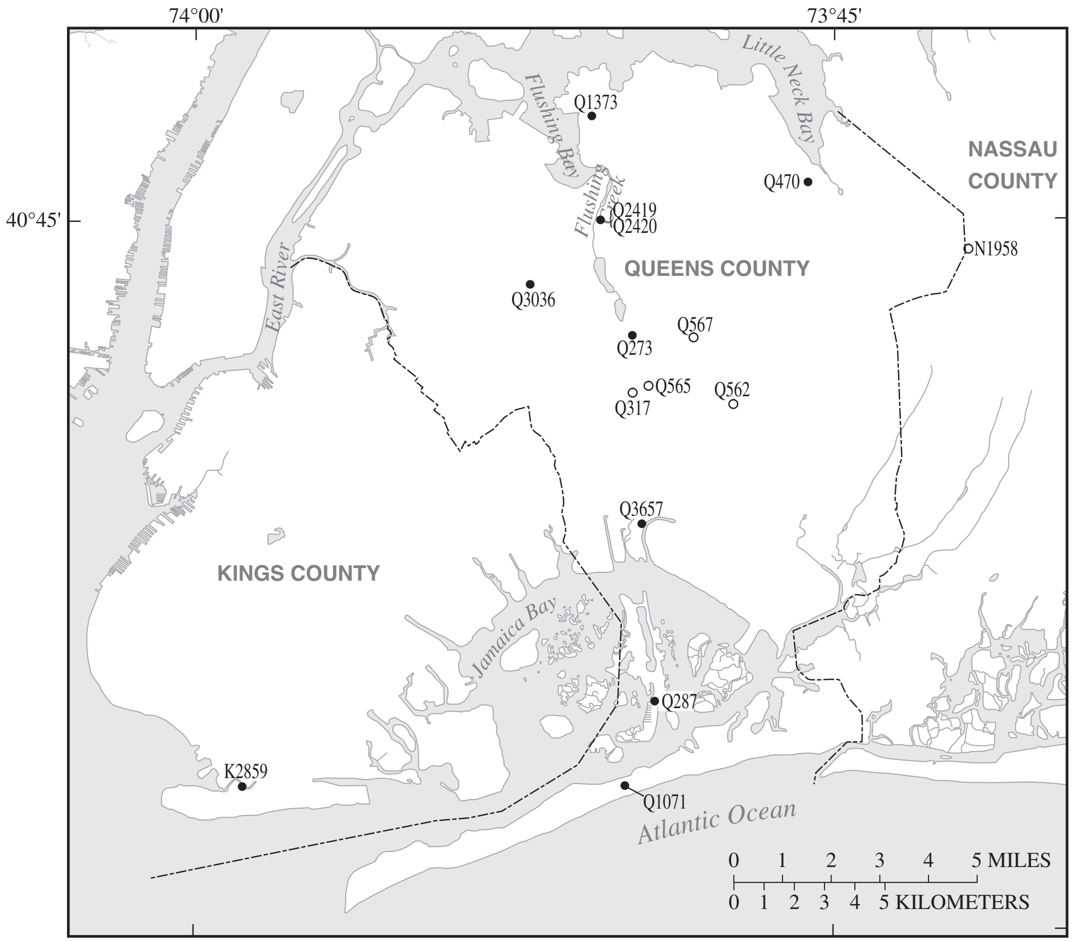
● K2582 MONITORING WELL

○ Q2332 PUBLIC – SUPPLY WELL

FIGURE 6E. Locations of wells screened in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1992.

monitoring well (Q2418) in northern Queens County, about 0.5 mi from an embayment of the East River, where localized saltwater contamination is likely. Chloride concentrations of the four public-supply wells ranged from 56 to 92 mg/L in 1992, and that at the monitoring well in northern Queens County (Q3121) was 140 mg/L. Two of the seven wells showed a decline in chloride concentrations during 1983-92; the 1992 concentration at a public-supply well in east-central Queens County (Q307) was 4 mg/L, and that at a monitoring well, less than 0.5 mi from a saltwater embayment in north-central Queens (Q2418), was 320 mg/L. Chloride concentrations in the majority of upper glacial aquifer wells in Queens County indicate an overall decrease in chloride concentration from past saltwater intrusion. The nine wells at which chloride increased after 1983 are either near a saltwater body, or are in inland areas with chloride concentrations less than 100 mg/L.

Most of the 11 additional wells installed in the upper glacial aquifer in Queens County for this investigation are in inland parts of the county, where data were lacking; some were installed as the shallow well of a well cluster, and others were installed near the coast for saltwater monitoring. Chloride concentrations in 1996 at these 11 wells ranged from 10 to 96 mg/L, a range comparable to that in Kings County, and also may reflect past saltwater



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

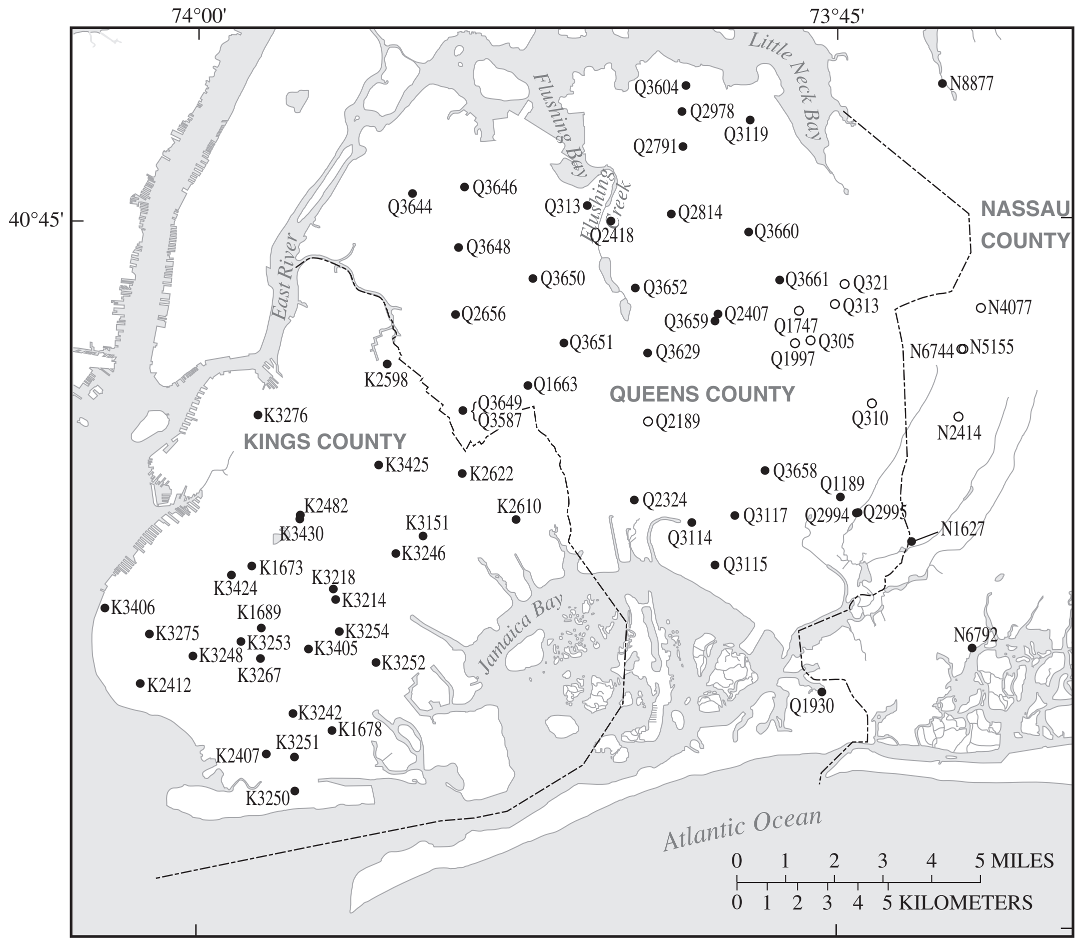
EXPLANATION

● K2859 MONITORING WELL

○ Q273 PUBLIC – SUPPLY WELL

FIGURE 6F. Locations of wells screened in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1992.

encroachment or surface-derived contamination. Wells Q3587 and Q3649 are a doublet (two wells installed at the same location, but screened at different depths) in west-central Queens County; Q3587 is screened from 72 to 82 ft below sea level, and Q3649 from 12 to 22 ft below sea level. Chloride concentrations at the two sampled depths do not differ appreciably, nor did they change significantly from 1995 to 1996; measured 1995 and 1996 concentrations at Q3649 were 86 and 71 mg/L, respectively; those at Q3587 were 75 and 88 mg/L, respectively. Of the 11 new wells screened in the upper glacial aquifer, chloride concentrations in the six inland wells (Q3629, Q3650, Q3651, Q3659, Q3660, and Q3661) were 10, 87, 69, 73, 56, and 39 mg/L, respectively. These values are typical of urbanized areas of Kings and Queens Counties and probably are the result of surface-derived contamination. The 2 wells with the highest chloride concentrations of all 11 new wells are Q3604, on the northern coast of Queens County and screened from 27 to 37 ft below sea level, and well Q3658, in southern Queens County and screened from 10 to 15 ft below sea level. Chloride concentrations in 1996 for these two wells were 96 mg/L and 100 mg/L, respectively. Comparison of these values with background levels from 3 to 12 mg/L (Buxton and Shernoff, 1995), indicates some saltwater contamination, but neither the source nor the time of



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

● K3276 MONITORING WELL

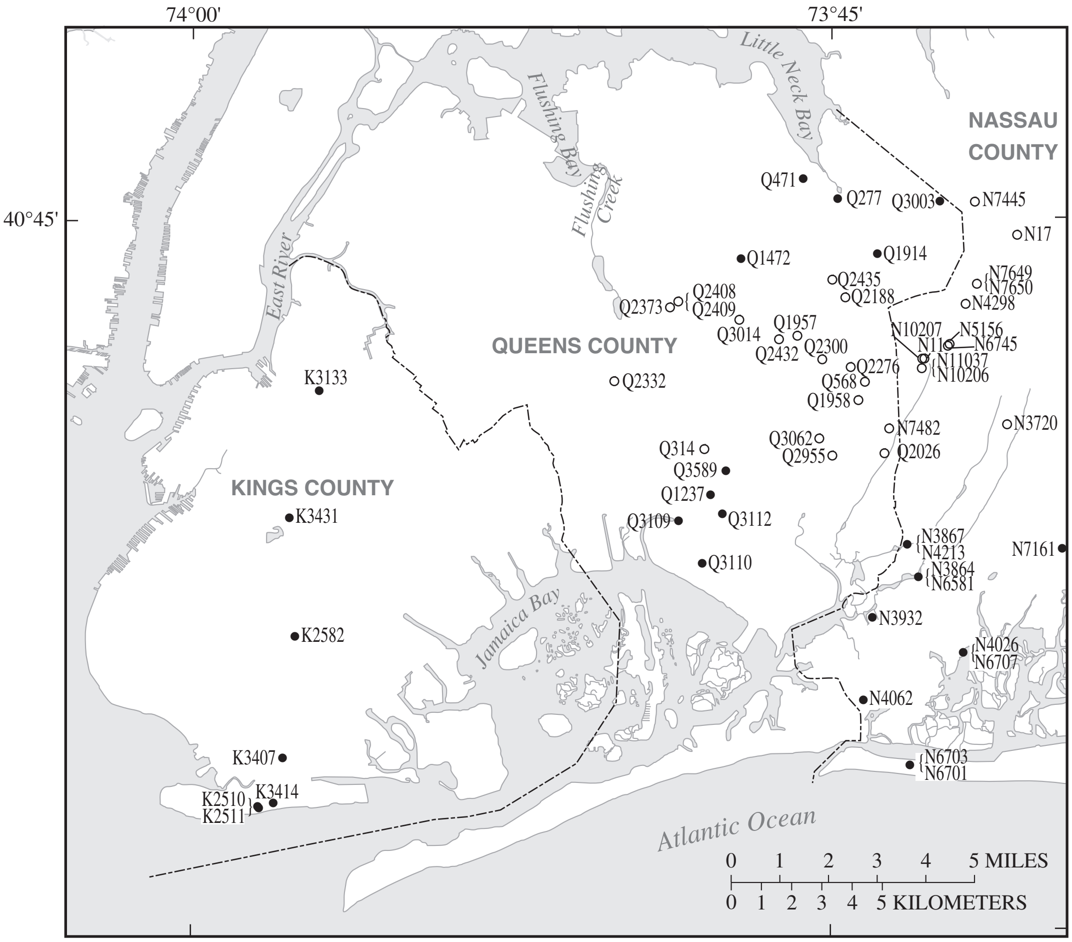
○ Q2189 PUBLIC – SUPPLY WELL

FIGURE 6G. Locations of wells screened in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1995-96.

occurrence is certain. Geophysical logs of the deeper well, Q3593 (Chu and Stumm, 1995), indicate a shallow zone of elevated electrical conductivity from background levels in the upper glacial aquifer and a deeper zone of lower electrical conductivity in the confined Lloyd aquifer, suggesting the presence of a saltwater wedge within the upper glacial aquifer. Chloride concentrations in the shallow and deep zones in 1995 were 110 and 8.9 mg/L, respectively, and are consistent with the data from the geophysical logs. The presence of brackish water in the upper glacial aquifer near the northern shore of Queens County probably does not present a problem of widespread contamination, however, because the aquifers in this area are thin and unlikely to ever be developed.

Jameco-Magothy Aquifer

Kings County.—The range of chloride concentrations in 1983 at eight Jameco-Magothy aquifer wells in Kings County was from 140 to 18,000 mg/L; this includes wells screened in formerly salty ground water with residual chloride concentrations, and wells screened in salty ground water in 1983 (Buxton and Shernoff, 1995, fig. 13A). Data are too sparse to allow contouring; nevertheless, chloride concentrations in the two southernmost wells



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

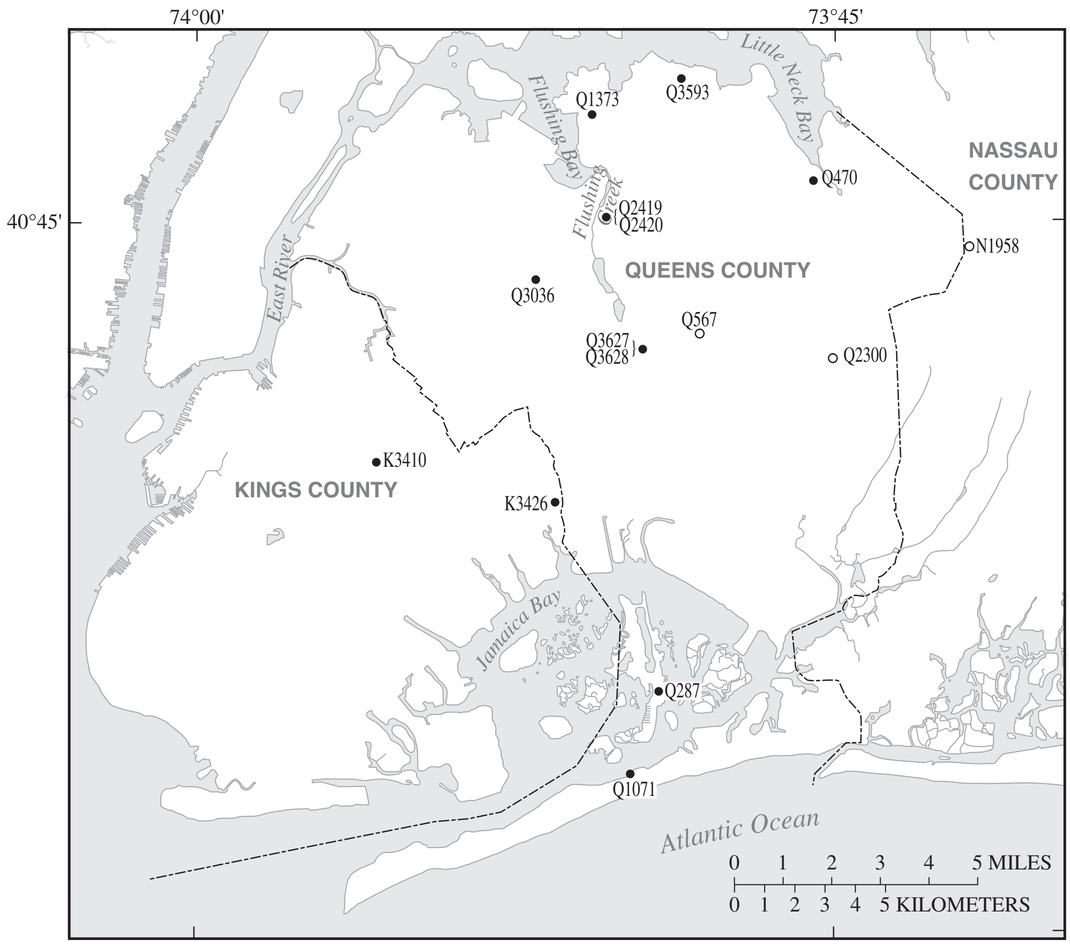
● K3133 MONITORING WELL

○ Q2332 PUBLIC – SUPPLY WELL

FIGURE 6H. Locations of wells screened in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1995-96.

(K2510 and K2511) are elevated from background concentrations; each of these wells is screened about 200 ft below sea level near the coast at Coney Island (fig. 8A). Elevated chloride concentrations at these wells (16,000 and 18,000 mg/L, respectively) indicate that the freshwater-saltwater interface in the Jameco-Magothy aquifer is farther inland than in the upper glacial aquifer. The toe of this interface in 1983 was estimated to be about 1 mi inland (Buxton and Shernoff, 1995).

Recent (1992 and 1996) water-quality data from the Jameco-Magothy aquifer in Kings County (figs. 8B, 8C) are relatively sparse in relation to data available for the upper glacial aquifer because fewer wells are available for sampling. Only five Jameco-Magothy aquifer wells provide chloride data from 1983 and 1996—wells K2510 and K2511, along the southern shore; K3407, about 1 mi inland from wells K2510 and K2511; well K2582, in south-central Kings County; and well K3133, in northern Kings County. The chloride concentration in 1992 and 1996 at well K2510 was 16,000 mg/L, and that at well K2511 in 1996 was 16,000 mg/L. These wells are not screened at the freshwater-saltwater interface and, therefore, do not provide information on interface extent and movement. A decrease in chloride



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

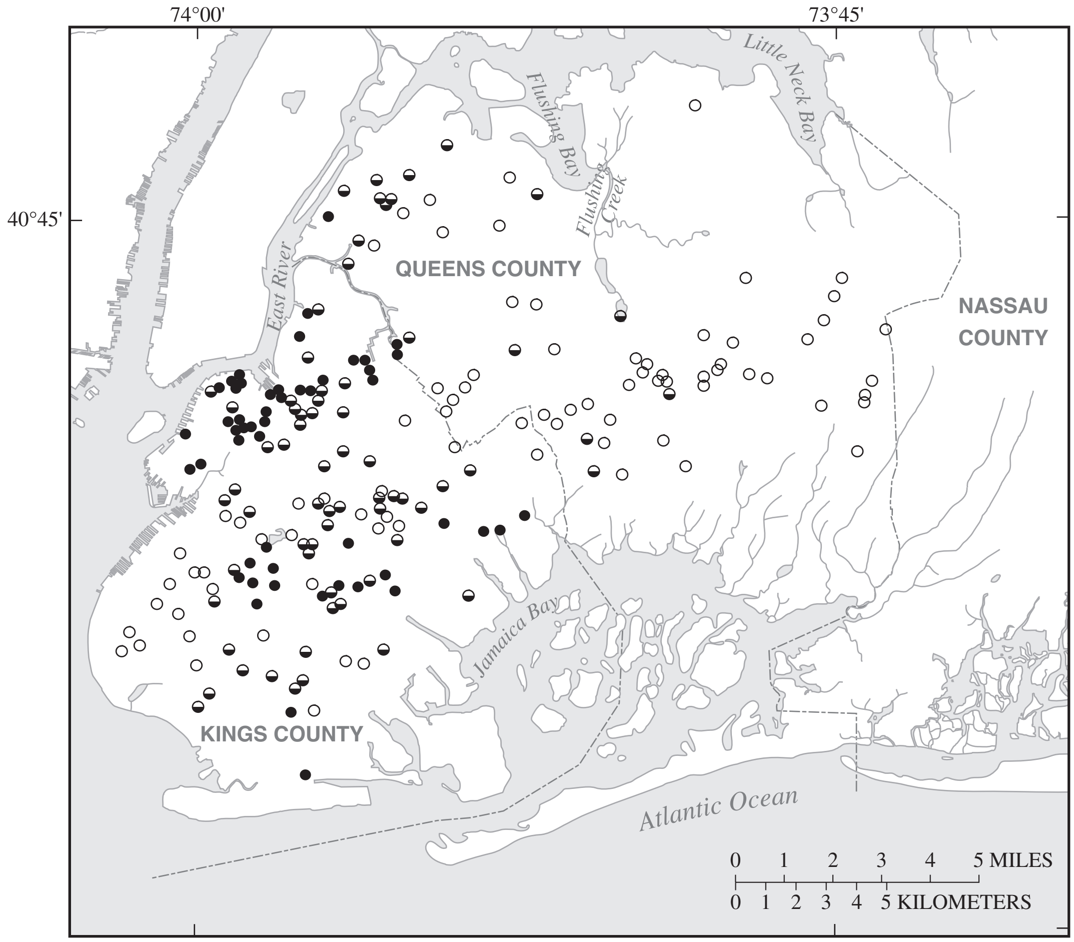
● K3410 MONITORING WELL

○ Q3036 PUBLIC – SUPPLY WELL

FIGURE 6I. Locations of wells screened in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., from which ground-water samples were collected in 1995-96.

concentration at well K2511 from 18,000 mg/L in 1983 to 16,000 mg/L in 1996 may indicate flushing of the system since the recovery of water levels to elevations above sea level since the early 1960's. This theory is supported by continually decreasing chloride concentrations at well K2582, about 3.5 mi inland (figs. 8A-C) from 170 mg/L in 1983 to 140 mg/L in 1992 and to 47 mg/L in 1996. In contrast, chloride concentrations at well K3133 (figs. 8A-C) in northern Kings County increased from 140 mg/L in 1983 to 180 mg/L in 1992 and to 300 mg/L in 1996; this well is about 1.25 mi from the saline waters of the East River and 1 mi from Newtown Creek, and where aquifers are thin. High chloride concentrations at this well are, therefore, probably the result of saltwater migration from either or both of these water bodies in response to unidentified local withdrawals.

Three additional Jameco-Magothy wells (K3414, K3407, and K3431) were installed in Kings County for this study (fig. 4). The first two were installed in the southern part of the county to help define the depth and northern extent of the saltwater interface. Well K3414 is along the coast near wells K2510 and K2511 but is screened deeper (283 to 303 ft below sea level), and well K3407 is about 1 mi inland of wells K2510 and K2511 at the estimated northern extent of the 1983 saltwater interface; it is screened from 246 to 266 ft below sea level. The 1996 chloride



Base modified from U.S. Geological Survey, 1:100,000;
Hydrography and cultural features modified to reflect
the period from 1943 through 1951

EXPLANATION

CHLORIDE CONCENTRATION,
IN MILLIGRAMS PER LITER

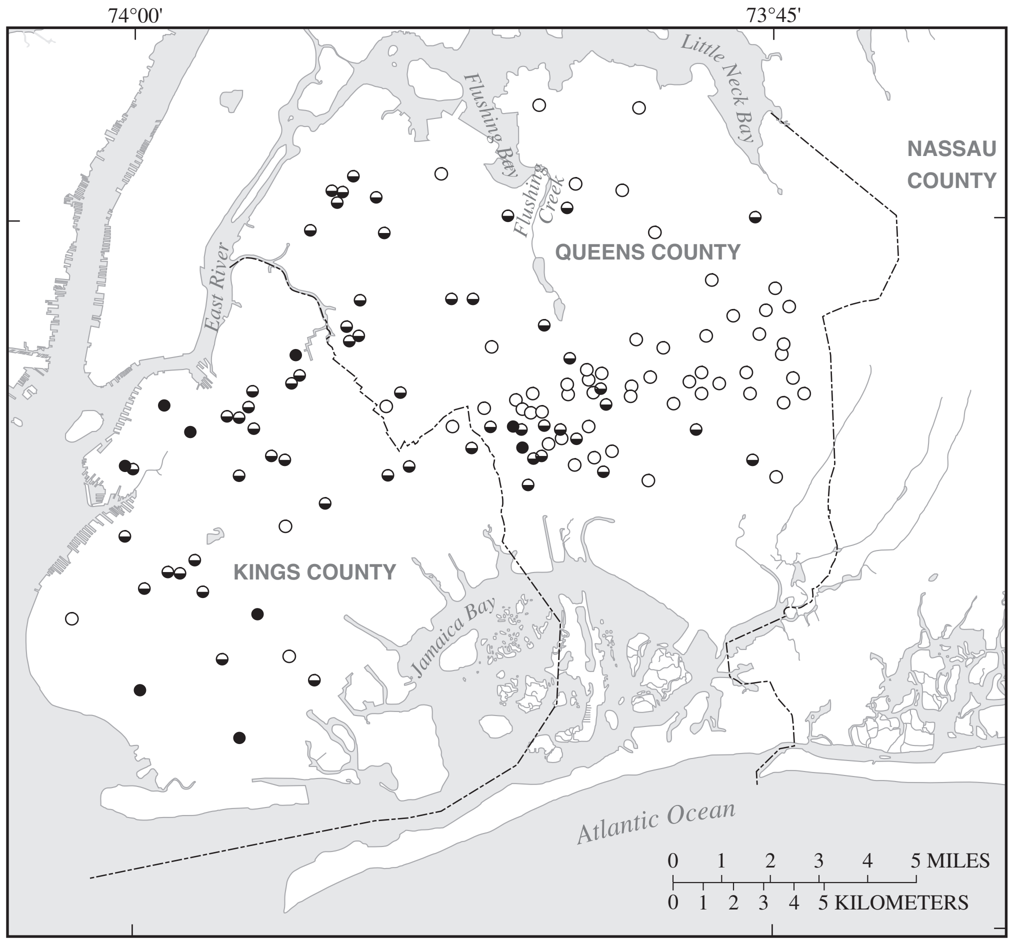
LESS THAN 40

40 TO 250

MORE THAN 250

FIGURE 7A. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1947. (Modified from Buxton and Shernoff, 1995, fig. 9A.)

concentration at K3414 was 15,000 mg/L, slightly lower than at the two shallower wells at this site, which may indicate that saltwater has moved farther inland at a shallower depth in the Jameco aquifer, where horizontal hydraulic conductivity generally is greater than in the deeper Magothy aquifer. The 1996 chloride concentration at well K3407 was 16,000 mg/L, which strongly indicates that the freshwater-saltwater interface is farther inland than previously estimated, about 1.5 mi from the shore. In addition, geophysical logs from wells K3414 and K3407 (Chu and Stumm, 1995) indicate the thickness of a saltwater wedge at each site to be about 215 ft and about 155 ft, respectively. The slight decrease in chloride concentrations in this area since 1983 could indicate that the interface was even farther inland in 1983. The third new well (K3431) is screened from 274 to 294 ft below sea level in central Kings County



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

CHLORIDE CONCENTRATION,
IN MILLIGRAMS PER LITER

○ LESS THAN 40

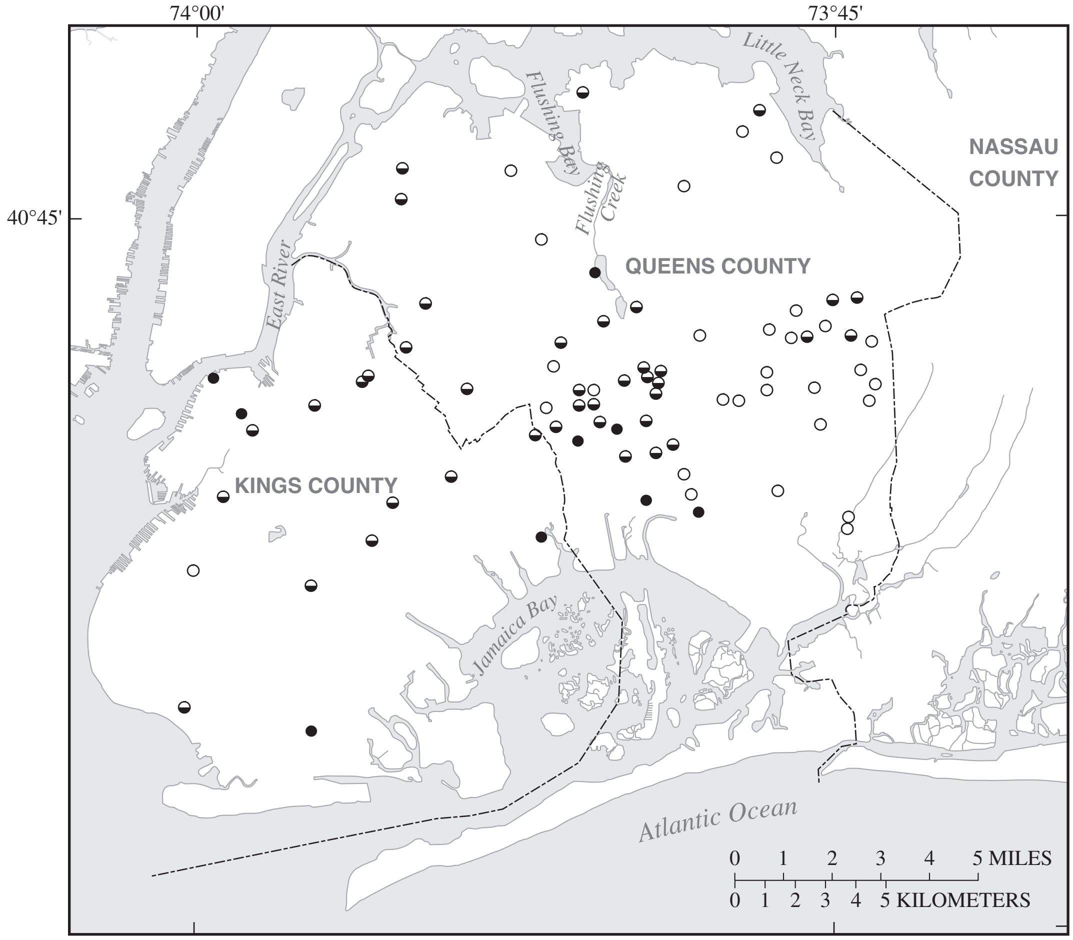
◒ 40 TO 250

● MORE THAN 250

FIGURE 7B. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1961. (Modified from Buxton and Shernoff, 1995, fig. 9B.)

and appears to have been unaffected by saltwater intrusion; the chloride concentration at this well in 1996 was 26 mg/L.

Queens County.—The 1983 chloride concentrations in Queens County at 15 monitoring wells and 34 public-supply wells screened in the Jameco-Magothy aquifer (fig. 8A) ranged from 6 to 15,000 mg/L (Buxton and Shernoff, 1995). Chloride concentrations at most inland wells were less than 100 mg/L, and many were between 20 and 30 mg/L. These concentrations are lower than those at the three inland wells in Kings County; this difference is attributed to the practice of shifting pumping stations eastward and inland to avoid saltwater intrusion that occurred from the 1930's to 1974 (Buxton and Shernoff, 1995). Despite this practice, however, saline



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

CHLORIDE CONCENTRATION,
IN MILLIGRAMS PER LITER

○ LESS THAN 40

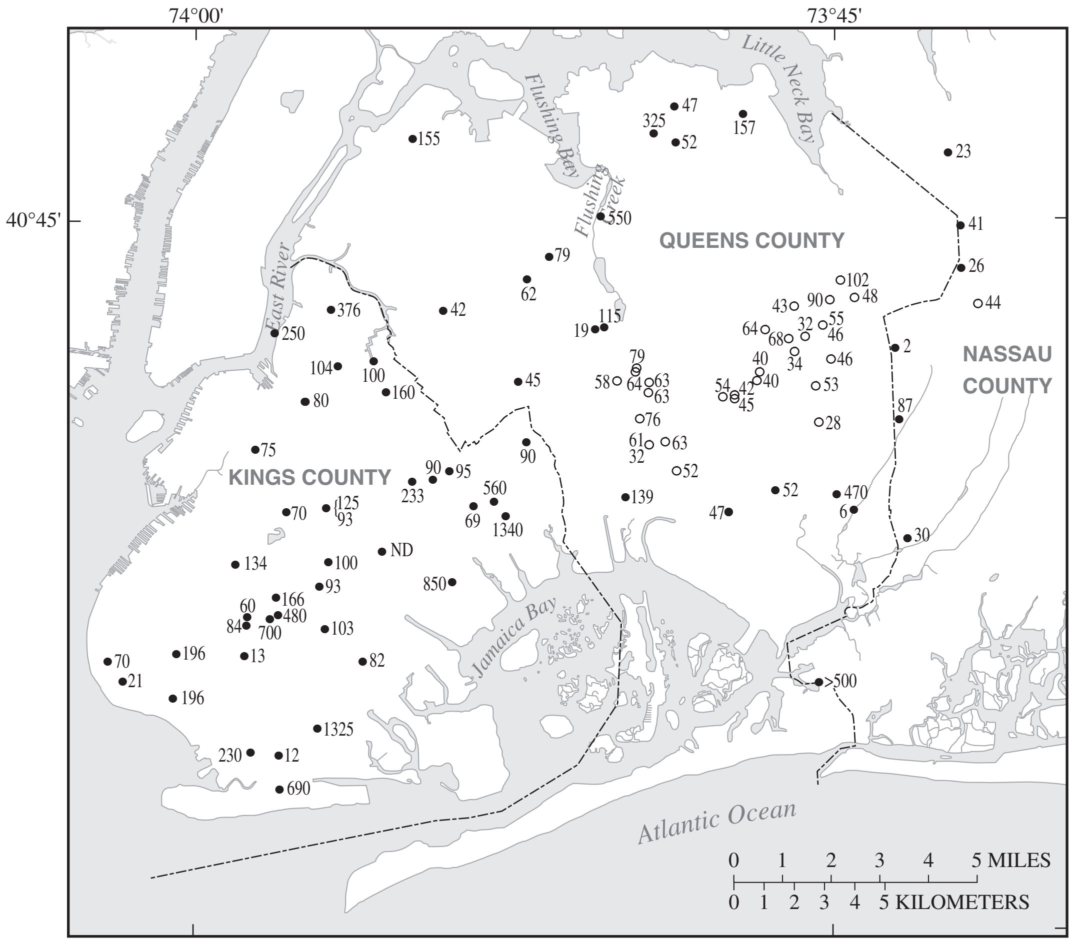
◒ 40 TO 250

● MORE THAN 250

FIGURE 7C. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1970. (Modified from Buxton and Shernoff, 1995, fig. 9C.)

water was drawn into coastal areas of southern Queens County, where chloride concentrations at six wells in 1983 ranged from 330 to 15,000 mg/L.

Recent (1992-96) water-quality data for the Jameco-Magothy aquifer in Queens County are more extensive than those for Kings County (figs. 8B, 8C), mostly because Queens County contains many public-supply wells from the former JWS. Chloride data for 1996 are available for only 12 of the 34 public-supply wells sampled in 1983, however, because many of these were shut down as a result of the recent decrease in pumping for public supply. An additional six public-supply wells provide chloride data for 1983 and 1992. Chloride values from 1996 also are available for 10 of 15 monitoring wells sampled in 1983. Of the 28 public-supply and monitoring wells, 15 showed increasing chloride concentrations, 8 showed little or no change, and 5 showed decreases. Most wells at



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

134 MONITORING WELL - number is chloride concentration in mg/L.

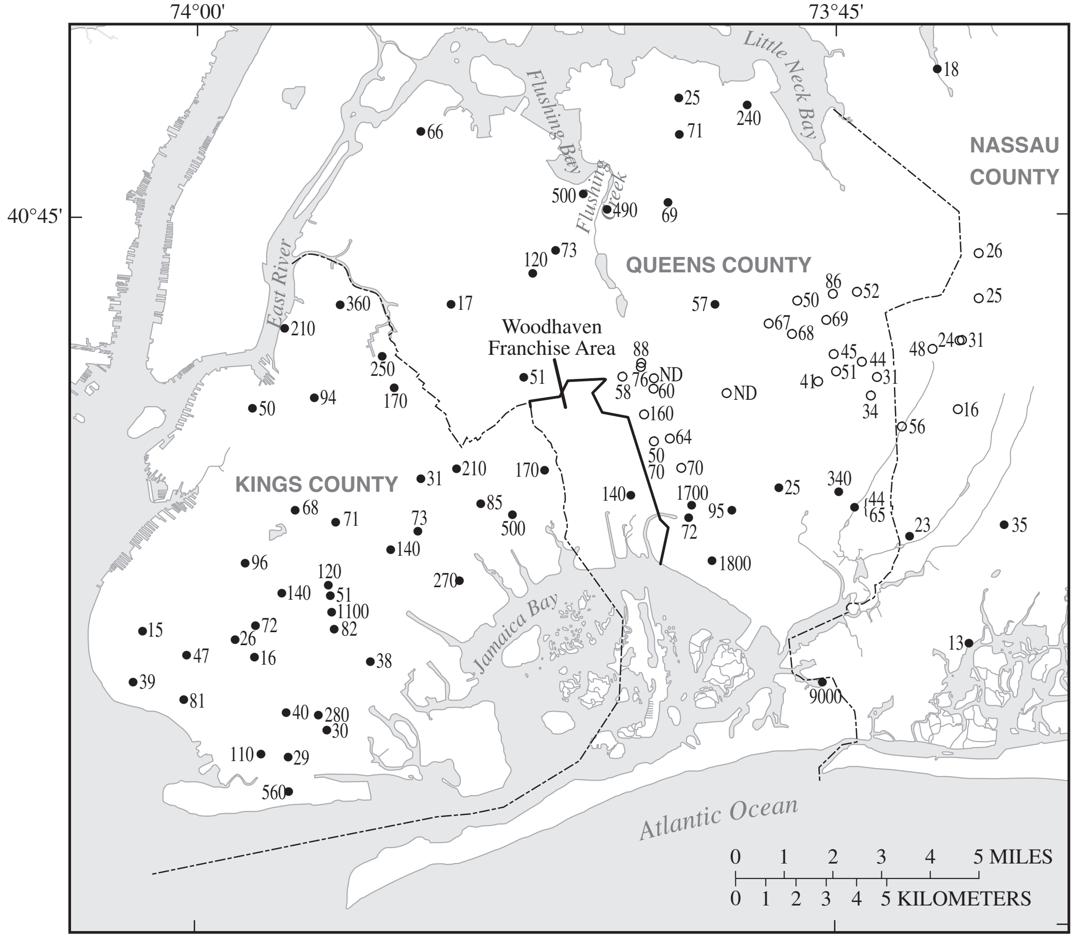
52 PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

ND No Data Available

FIGURE 7D. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1981. (Modified from Buxton and others, 1981, fig. 23.)

which chloride concentrations increased are in inland areas, and the concentrations are relatively low—from 11 to 47 mg/L. These small increases from 1983 values probably do not indicate saltwater intrusion because the concentrations are low, and withdrawals for public supply have been diminishing, thereby lessening the likelihood of saltwater intrusion into inland areas. The concentration increases are more likely to be the result of contamination from surface sources in areas where the Gardiners Clay is absent.

Four wells with high chloride concentrations are Q3110, Q3109, Q1237, and Q3112 in southern Queens County (fig. 6E), near the 1983 estimated position of the freshwater-saltwater interface (Buxton and Shernoff, 1995). Well Q3110 is the southernmost well; it is less than 0.5 mi from the coast and is screened from 296 to 316 ft below sea level. The chloride concentrations were 2,300 mg/L in 1983, 2,500 mg/L in 1988, and 2,600 mg/L in 1992 (fig. 8B). The 1996 chloride concentration, estimated from a specific conductance measurement, is about 2,950 mg/L. The steady increase in chloride concentration at this well since 1983 could indicate landward migration of saltwater through 1996, possibly as a result of continued (but decreased) withdrawals from the JWS Jamaica operations. Well



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

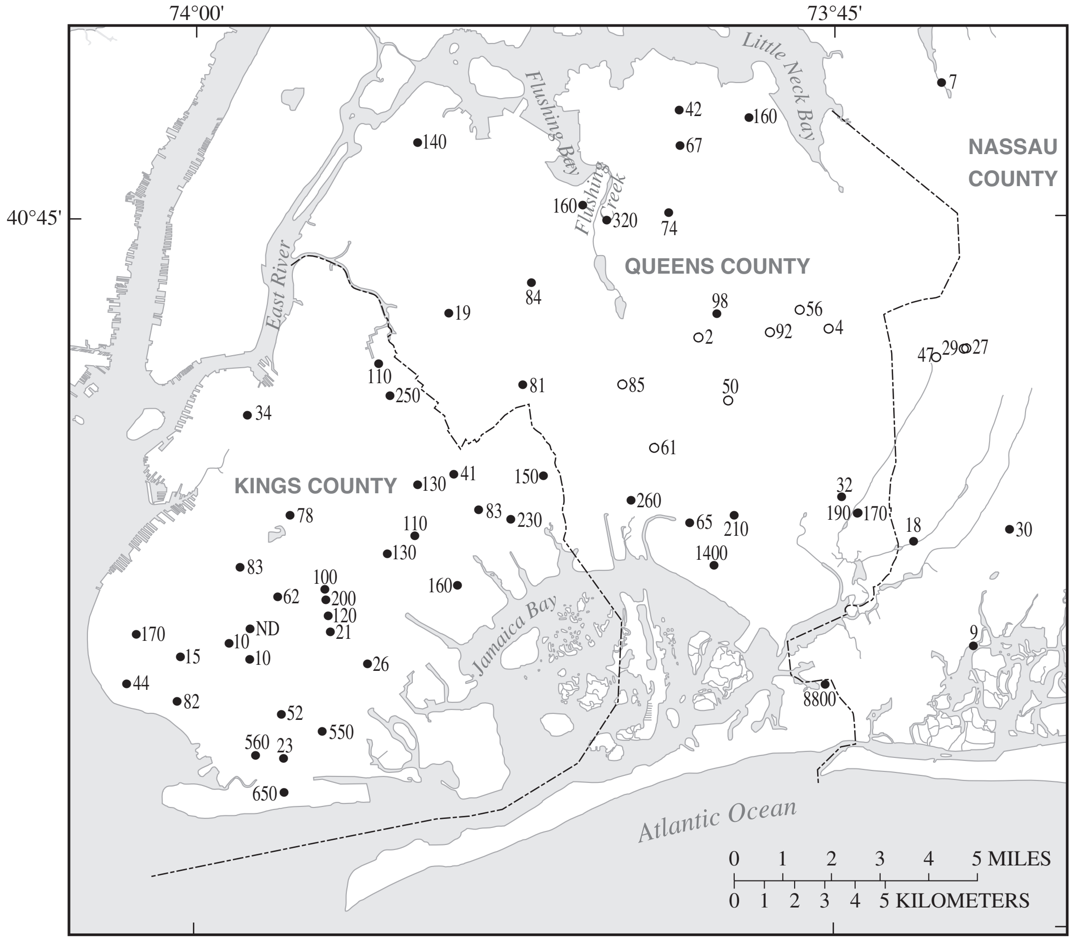
50 ● MONITORING WELL - number is chloride concentration in mg/L.

160 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

ND No Data Available

Figure 7E. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 12A.)

Q3109 is farther from the coast than well Q3110, is shallower (screened from 267 to 287 ft below sea level), and had higher chloride concentrations in 1983, 1988, 1992, 1995—6,400, 4,700, 3,200, and 3,200 mg/L, respectively (Chu and Stumm, 1995) and 4,700 mg/L in 1996. The higher concentrations at well Q3109 than at well Q3110, along the southern shore, probably reflect this well's proximity to the past cone of depression associated with JWS Woodhaven operations. The well's proximity to a saltwater canal is not a factor because the canal does not penetrate the confined Jameco-Magothy aquifer. Well Q3109 shows a decrease in chloride concentrations during 1983-92 and stabilization in these values by 1995. The 1996 concentration was elevated (4,700 mg/L), possibly as a result of unidentified withdrawals in the area; the 1996 value could be in error, however, because the specific conductance and sodium concentration in 1996 were the same as in 1992. A 1994 EM log of this well indicates a 70-ft thick saltwater zone (from 37 to 107 ft below sea level) in the upper glacial aquifer. The peak EM response exceeded 600 mS/m, which corresponds to a chloride concentration of about 6,000 mg/L (Chu and Stumm, 1995). The EM log also



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

34 ● MONITORING WELL - number is chloride concentration in mg/L.

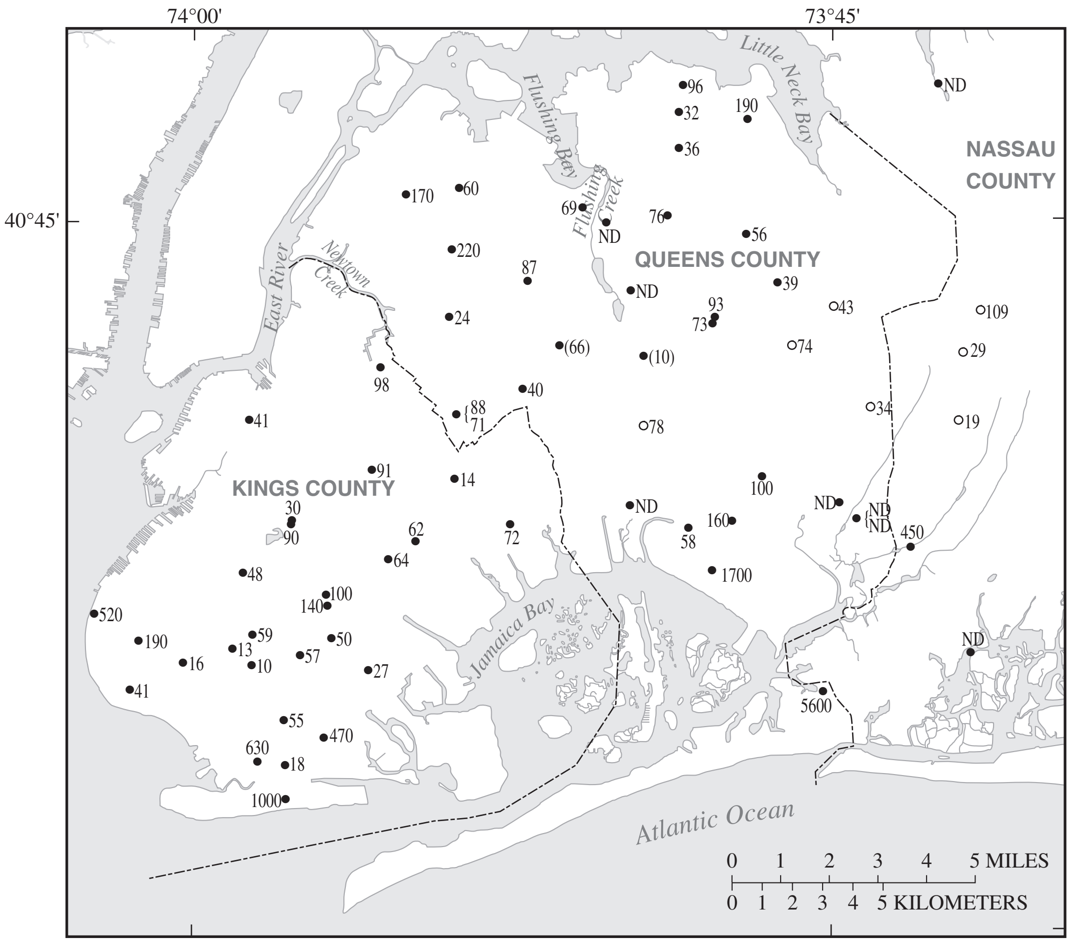
61 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

ND No Data Available

FIGURE 7F. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992.

indicated an 80-ft-thick saltwater zone (from about 192 to 272 ft below sea level) in the Jameco-Magothy aquifer with a peak EM response of about 300 mS/m; the 1995 chloride concentration at the screen zone was 3,200 mg/L. The two other Jameco-Magothy aquifer wells (Q1237 and Q3112) are slightly farther north, near the generalized inland extent of the freshwater-saltwater interface of Buxton and Shernoff (1995). Well Q1237 is screened from 0 to 200 ft below sea level and sampling indicates that chloride concentrations increased—from 330 mg/L in 1983 to 370 mg/L in 1992 and to 460 mg/L in 1996. The reason these values were higher than those at well Q3112, about 1.5 mi seaward of well Q1273, (110 mg/L in 1983, 140 mg/L in 1992, and 120 mg/L in 1996), is that the samples from well Q3112 were from the upper glacial aquifer as well as the Jameco-Magothy aquifer.

A new Jameco-Magothy aquifer well (Q3589) was installed in 1994 in southern Queens County



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

41 ● MONITORING WELL - number is chloride concentration in mg/L.

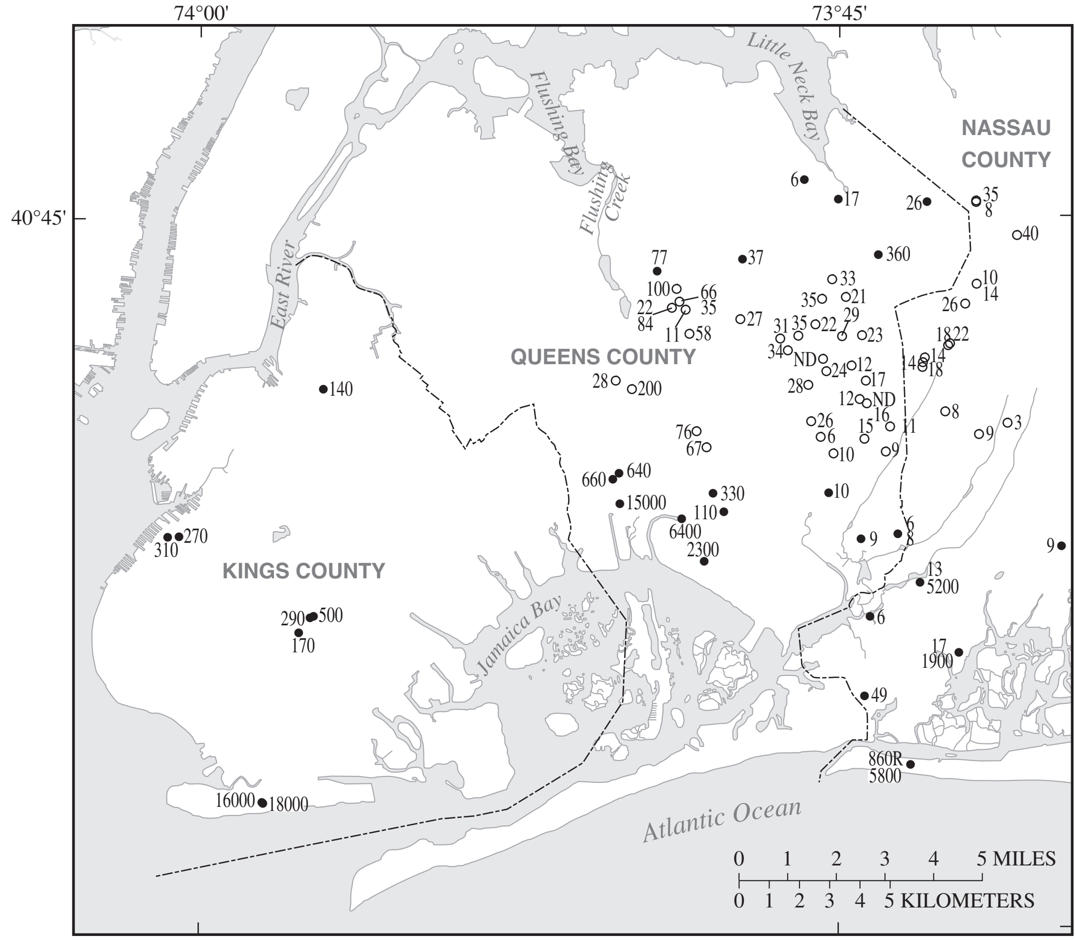
78 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

ND NO DATA AVAILABLE

(66) CHLORIDE CONCENTRATION IN 1995

FIGURE 7G. Chloride concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1995-96.

about 0.5 mi north-northeast of well Q1237 and is screened from about 167 to 177 ft below sea level (fig. 6H). Chloride concentrations during 1992-96 averaged about 67 mg/L. The EM log indicates a small (about 5-ft-thick) saltwater zone at the base of the upper glacial aquifer, and no saline water in the Jameco-Magothy aquifer (Chu and Stumm, 1995). These data, together with the water-quality and geophysical data from nearby well Q3109, indicate that the saltwater wedge in the upper glacial aquifer has moved farther inland than that in the deeper Jameco-Magothy aquifer.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

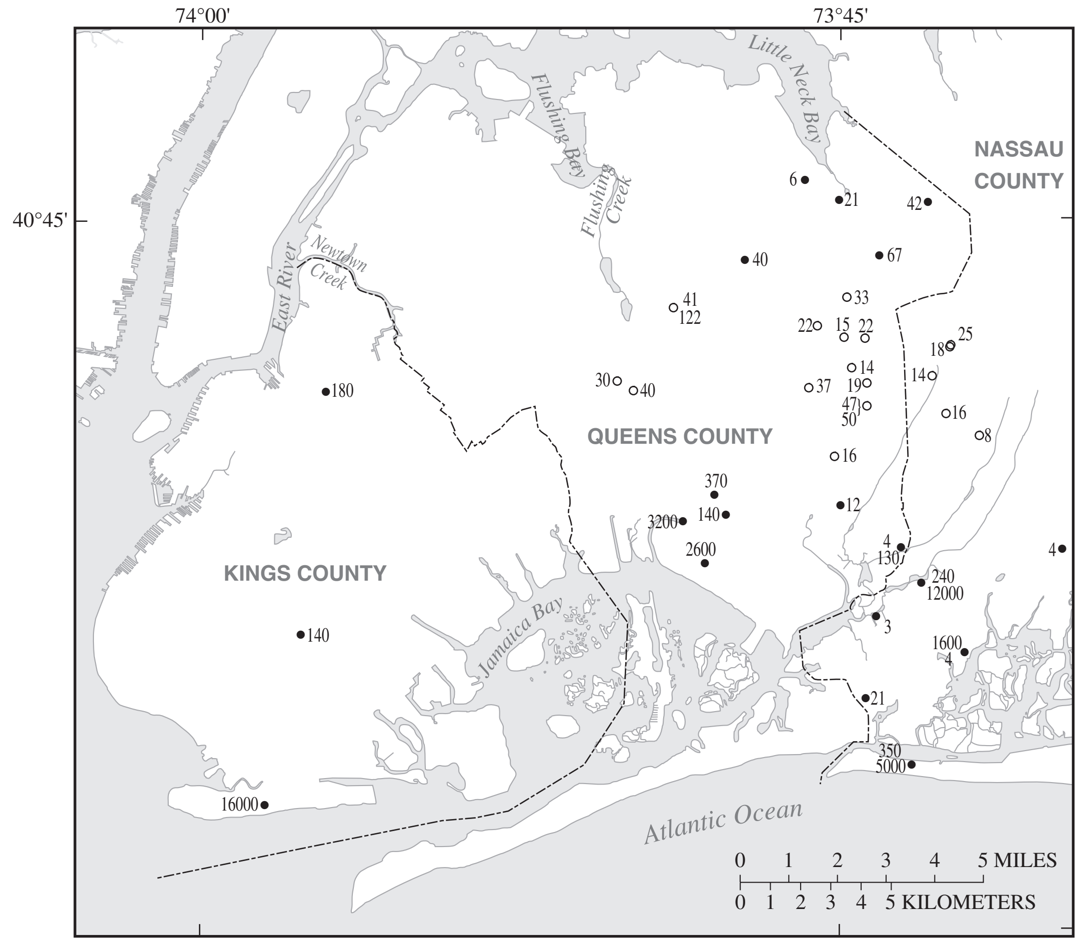
EXPLANATION

140 ●	MONITORING WELL - number is chloride concentration in mg/L.
28 ○	PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.
ND	No data available
R	Raritan clay unit

FIGURE 8A. Chloride concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 13A.)

Lloyd Aquifer

Kings County.—Ground-water-quality data for the Lloyd aquifer in Kings County in 1983 are derived from only one well (K2859, fig. 9A), because (1) the Lloyd aquifer is absent in the northern half of Kings County, and (2) potable water is readily obtained from shallower wells elsewhere in the county; thus, few deep Lloyd aquifer wells have been installed. Well K2859 is near the southern shore on Coney Island (fig. 6C) and is screened from 466 to 492 ft below sea level. The 1983 chloride concentration of 52 mg/L at this well indicates that the freshwater-saltwater interface was farther seaward; Buxton and Shernoff (1995) estimate it to have been 1 to 2 mi south of Coney Island.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

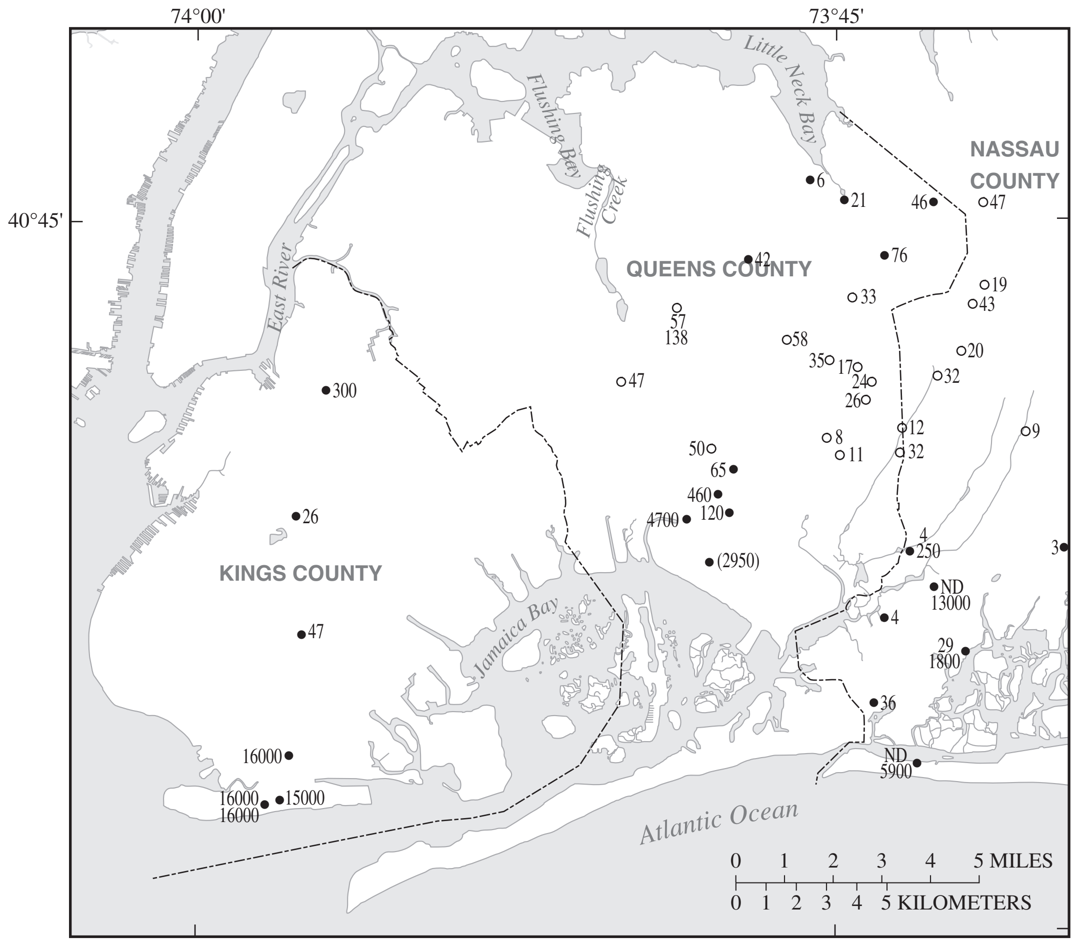
EXPLANATION

● 180 MONITORING WELL - number is chloride concentration in mg/L.

○ 30 PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

FIGURE 8B. Chloride concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992.

Recent (1992 and 1996) data on water quality in the Lloyd aquifer in Kings County are derived from wells K2859 and K3426, in southern Kings County at the border with Queens County (fig. 6F, 6I), and are described earlier (figs. 9B, 9C). The chloride concentration in 1996 at K2859 is unavailable, but that in 1992 was 54 mg/L; this indicates that the freshwater-saltwater interface probably has not moved since 1983. Well K3426 is a relatively new well (installed in 1986) and is screened from about 464 to 484 ft below sea level. The chloride concentrations at this well were 8,200 mg/L (analysis by a private laboratory) in 1986, 8,200 mg/L in 1989 (Nassau County Department of Public Works [NCDPW] Cedar Creek Laboratory), 8,400 mg/L in 1995, and 8,500 mg/L in 1996. These data suggest that the cone of depression in southern Queens County generated by public-supply withdrawals from the Lloyd aquifer (Buxton and Shernoff, 1995, pl. 6) has caused inland migration of saltwater and that the freshwater-saltwater interface may be about 7 mi farther inland than previously estimated by Buxton and Shernoff



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

300 ● MONITORING WELL - number is chloride concentration in mg/L.

47 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

ND No data available

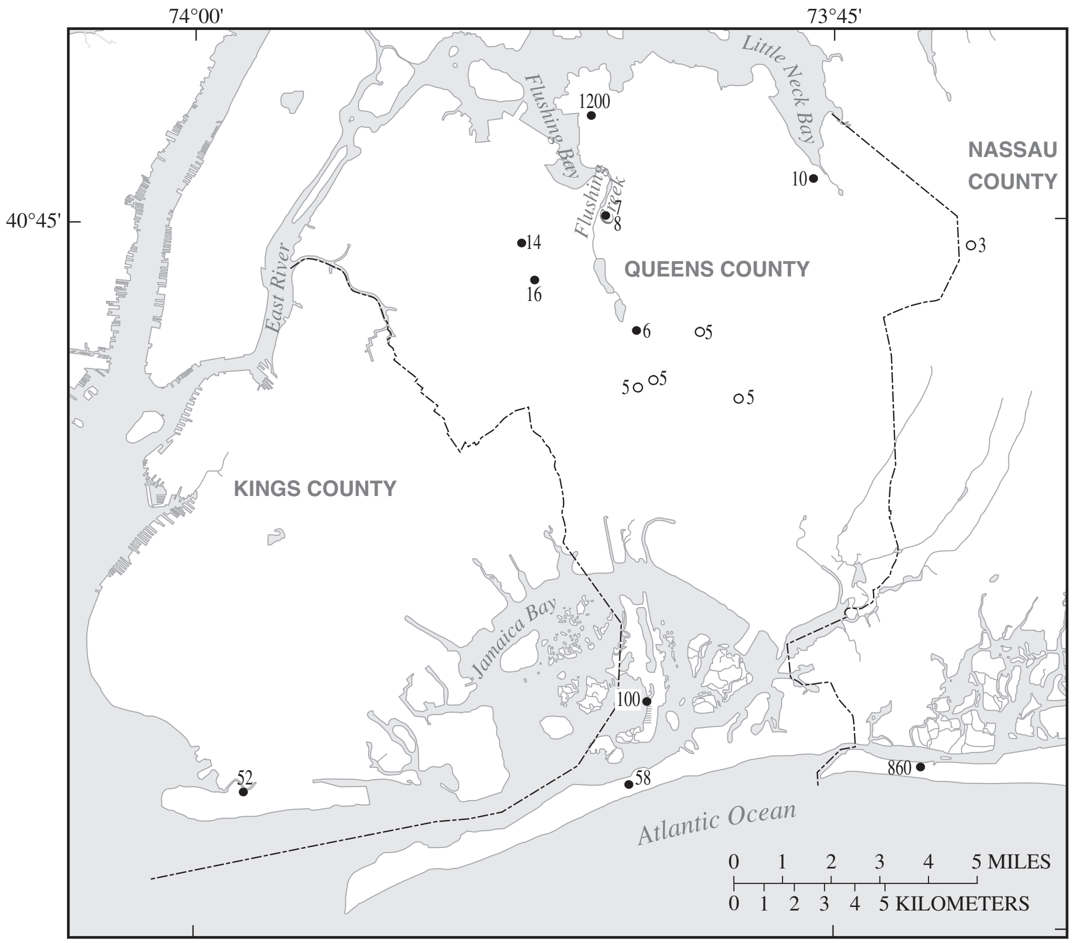
( ) Estimate based on specific conductance

FIGURE 8C. Chloride concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1996.

(1995). These results are contradicted by analysis of data from nearby wells in Queens County, however, as discussed further on.

One additional well (K3410, fig. 6I) was installed in the Lloyd aquifer during this study. This well is in the interior of northeastern Kings County and was installed as part of a well doublet; the second well at this site is screened in the upper glacial aquifer. Well K3410 is screened from 268 to 288 ft below sea level with chloride concentrations of 17 mg/L in 1995 and 1996; these values indicate nearly predevelopment quality.

Queens County.—Data on chloride concentrations in the Lloyd aquifer in Queens County in 1983 are more abundant than those for Kings County—the data for Queens County are derived from 10 monitoring wells and four public-supply wells (fig. 9A). Chloride concentrations at inland wells



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

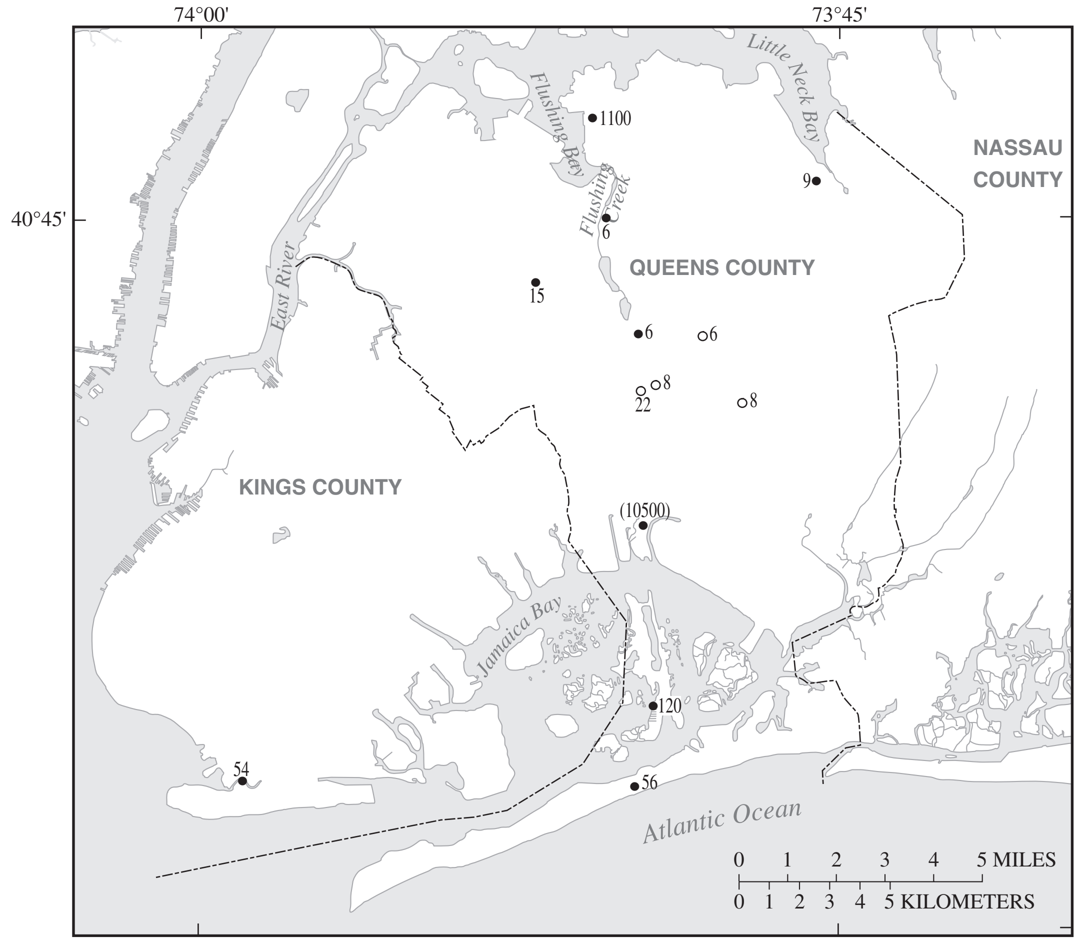
EXPLANATION

14 ● MONITORING WELL - number is chloride concentration in mg/L.

5 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

FIGURE 9A. Chloride concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 14A.)

ranged from 5 to 18 mg/L, equivalent to predevelopment conditions (Buxton and Shernoff, 1995), but an area near Flushing Bay in northern Queens County contained an elevated chloride concentration of 1,200 mg/L at Lloyd aquifer well Q1373 (and 500 mg/L at upper glacial well Q3134). This is the area of the buried channel described by Soren (1978), where saltwater has been drawn into the Lloyd aquifer laterally or vertically through the upper glacial aquifer, which in this area is in hydraulic contact with the Lloyd aquifer. Two wells in southern Queens County, Q287 on an island in Jamaica Bay, and Q1071 on the barrier beach, show chloride concentrations of 100 and 58 mg/L, respectively, in 1983; these concentrations probably indicate the landward extent of the freshwater-saltwater interface (Buxton and Shernoff, 1995), although the freshwater-saltwater interface is moving landward in this area at an estimated rate of 0.02 to 0.05 ft/d (7.3 to 18.25 ft/yr). The most recent data (discussed below) suggest that these concentrations in southern Queens County are anomalous, however.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

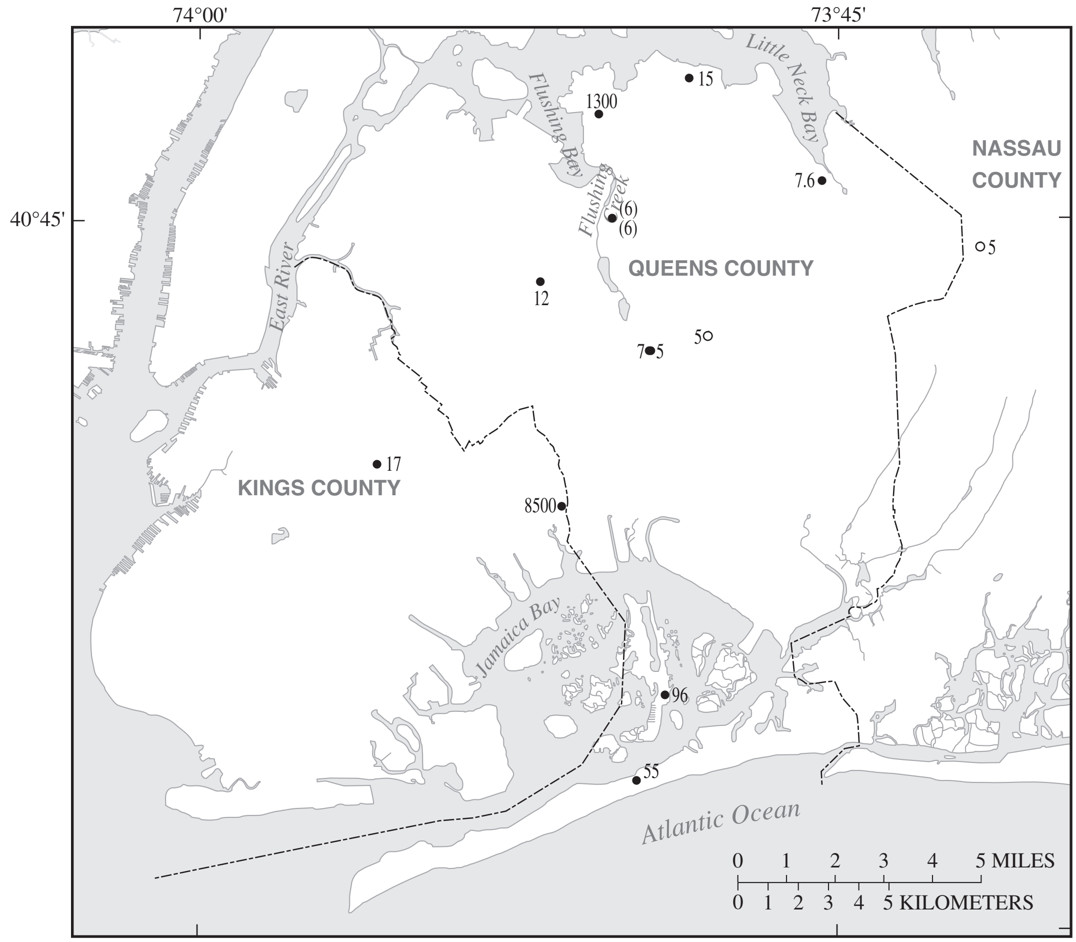
15 ● MONITORING WELL - number is chloride concentration in mg/L.

22 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

( ) Chloride concentration in1990

Figure 9B. Chloride concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992

Recent (1992-96) data on ground-water quality in the Lloyd aquifer in Queens County are derived from four public-supply wells (sampled by JWS in 1992) and eight monitoring wells sampled in 1992 and (or) 1996 (figs. 9B, 9C). Chloride concentrations at inland wells (all four public-supply wells and five monitoring wells) ranged from 6 to 22 mg/L in 1992, and were similar to 1983 values. Chloride concentrations at well Q1373 in northern Queens County also were similar to those in 1983, ranging from 1,100 mg/L in 1992 to 1,300 mg/L in 1996. Chloride concentrations at the two southernmost wells, Q287 and Q1071, also were similar to those of 1983, but the chloride concentrations at a new well in southeastern Kings County on the Kings/Queens County border (K3426, fig. 6I) for 1986, 1989, 1995, and 1996 were 8,200, 8,200, 8,400, and 8,500 mg/L, respectively.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

17 ● MONITORING WELL - number is chloride concentration in mg/L.

5 ○ PUBLIC – SUPPLY WELL - number is chloride concentration in mg/L.

( ) Estimate based on specific conductance

FIGURE 9C. Chloride concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1996.

Samples from new well Q3657 in southern Queens County (fig. 6F) were collected by the USGS and analyzed by the NCDPW Cedar Creek Laboratory in 1989 and 1990; chloride concentrations for these years were 10,700 and 10,500 mg/L, respectively. These values are considerably higher than those at wells Q287 and Q1071, which are 3.75 and 5.5 mi farther south, respectively, where higher chloride concentrations would be expected. This discrepancy also was recognized by Terracciano (1996), who suggested that additional data would be necessary for a proper assessment. These data suggest that either (1) chloride values for the two older, southern wells (Q287 and Q1071) or those for the two newer, northern wells could be in error, or (2) the data from all four wells are correct and indicate that an unidentified hydrologic or chemical process is occurring. The validity of data from the older wells would be easiest to dismiss because of the age of the wells, and because vandals had repeatedly dropped debris into well Q287 until 1956, by which time it was completely full and not usable. The USGS prepared a plan in 1956 to remove the debris, but whether the work was performed is unknown. Similarly, well-construction data for well Q1071 are sparse—three casing sizes are reported to have been used, but no information on the length of each has been found. Therefore, estimates of casing length must be used to calculate casing volumes for well purging before sampling. Also, because the estimated casing volumes were large, only two casing volumes were removed prior to sampling in 1983 and 1996. Either factor could have resulted in the collection of a water sample unrepresentative of local ground-water conditions. In addition, water in the upper glacial and Magothy aquifers in the vicinity of the two old, southern wells Q287 and Q1071 is saline; thus, if their casings are no longer sound and allow water to leak from overlying aquifers, only saline water would leak into the well. Therefore, the relatively fresh water obtained from these wells is probably from the Lloyd aquifer, an indication that the low chloride values are valid and that saltwater has not moved this far inland.

In contrast to the questionable well-completion data of Q287 and Q1071, well-completion data for the newer wells K3426 and Q3657 indicate grouting of the annular space through the Raritan clay and backfill to land surface; this probably eliminates seepage from the overlying Magothy aquifer as a source of saltwater contamination. The large cone of depression and head distribution in the Lloyd aquifer (Buxton and Shernoff, 1995, pl. 6 and 7, respectively), both of which indicate landward movement of the freshwater-saltwater interface in this aquifer, also support the validity of the elevated chloride concentrations at K3426 and Q3657. Nevertheless, installation of new deep (Lloyd aquifer) wells near the older wells and in bordering areas are needed to (1) help assess the integrity of data from older wells, (2) discover any hydrogeologic anomalies, and (3) define the inland extent of saltwater in southern Queens County.

Nitrate

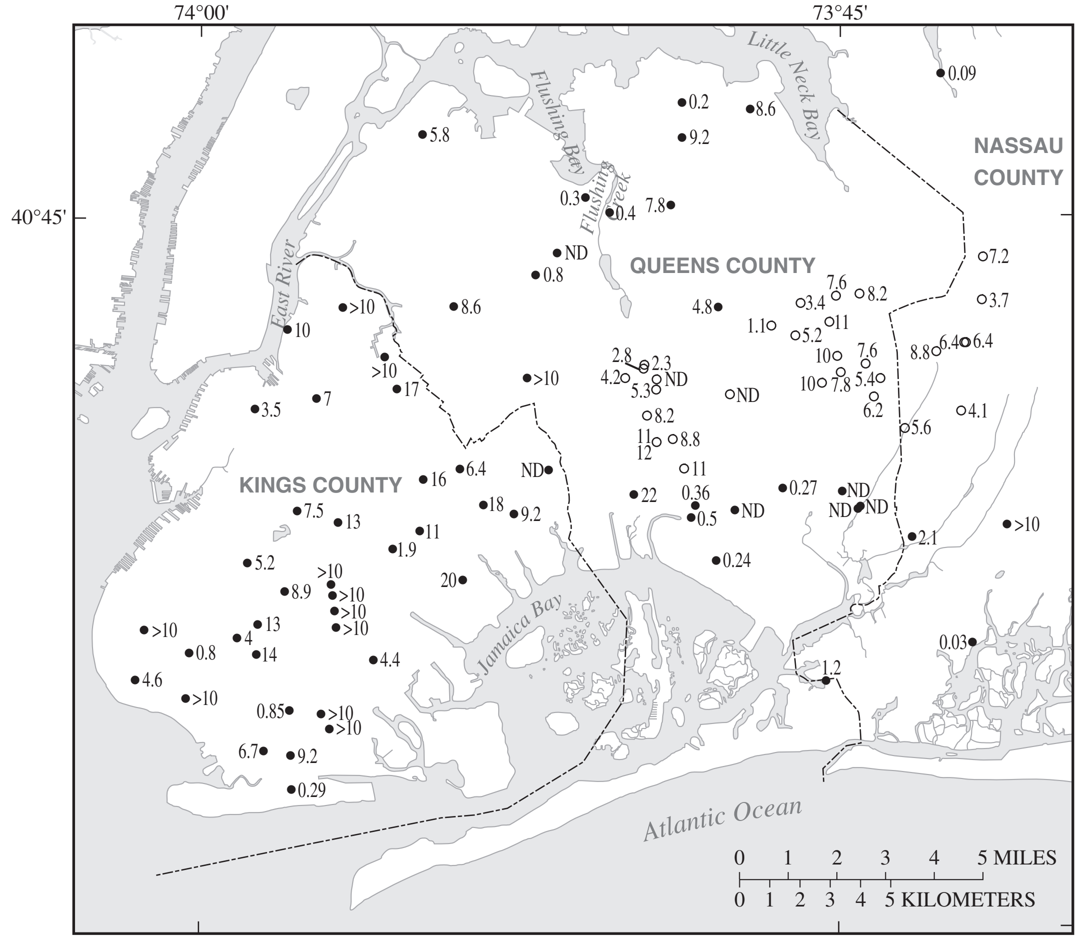
Predevelopment nitrate concentrations in ground water on Long Island probably were less than 0.2 mg/L as N (Buxton and Shernoff, 1995). Nitrogen, in the form of nitrate, typically is introduced into ground-water systems from fertilizers and domestic waste dissolved in recharge. Nitrate also enters the ground-water system in Kings and Queens Counties through leakage from New York City's combined-sewer network (Kimmel, 1972).

The following sections discuss the concentrations of nitrate in water from the three major aquifers underlying Kings, Queens, and western Nassau Counties in 1983, 1992, and 1996.

Upper Glacial Aquifer

Concentration in 1983.—Nitrate contamination of the upper glacial aquifer in Kings County in 1983 was widespread (fig. 10A). Nitrate concentrations, in mg/L (as N), at 35 monitoring wells ranged from 0.29 mg/L to 20 mg/L. Concentrations in 19 of the 35 wells exceeded the New York State public-health standard of 10 mg/L. In Queens County, nitrate concentrations in 24 of 39 wells exceeded 5 mg/L, and in 8 of the 39 wells they exceeded the public-health standard. The range in nitrate concentrations (0.2 mg/L to 22 mg/L) in Queens County is similar to that in Kings County. Nitrate concentrations mentioned above are from Buxton and Shernoff (1995) and probably decrease eastward and with depth.

Concentrations in 1992 and 1996.—Recent (1992 and 1996) nitrate concentrations are reported as dissolved nitrate plus nitrite (figs. 10B, 10C); whereas those for 1983 were reported as total nitrate. The values for these two sampling periods are comparable, however, because: (1) nitrite concentrations typically represent only a negligible fraction of the nitrate concentrations and can, therefore, be ignored, and (2) the percentage of colloidal (undissolved) nitrite plus nitrate in ground water is negligible in relation to the dissolved fraction. Concentrations at 26 monitoring wells in Kings County in 1996 ranged from less than 0.05 to 17 mg/L. Nitrate concentrations at 23 wells that were sampled in 1983 and 1996 are available; of these 23 wells, 13 showed a decrease in nitrate concentration during this period, 4 wells showed no change, and 6 wells showed an increase. Similar results are seen in Queens County data. Nitrate concentrations at 25 of 31 wells sampled in 1996 in Queens County ranged from less than 0.05 to 13 mg/l. Nitrate concentrations at 12 wells that were sampled in 1983 and 1996 are available; of these 12 wells, 11 wells showed a decrease, and only 1 well showed an increase. Additional nitrate data from 9 monitoring wells sampled in 1996 but not in 1983 are available. Of these, 7 samples showed concentrations below the



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

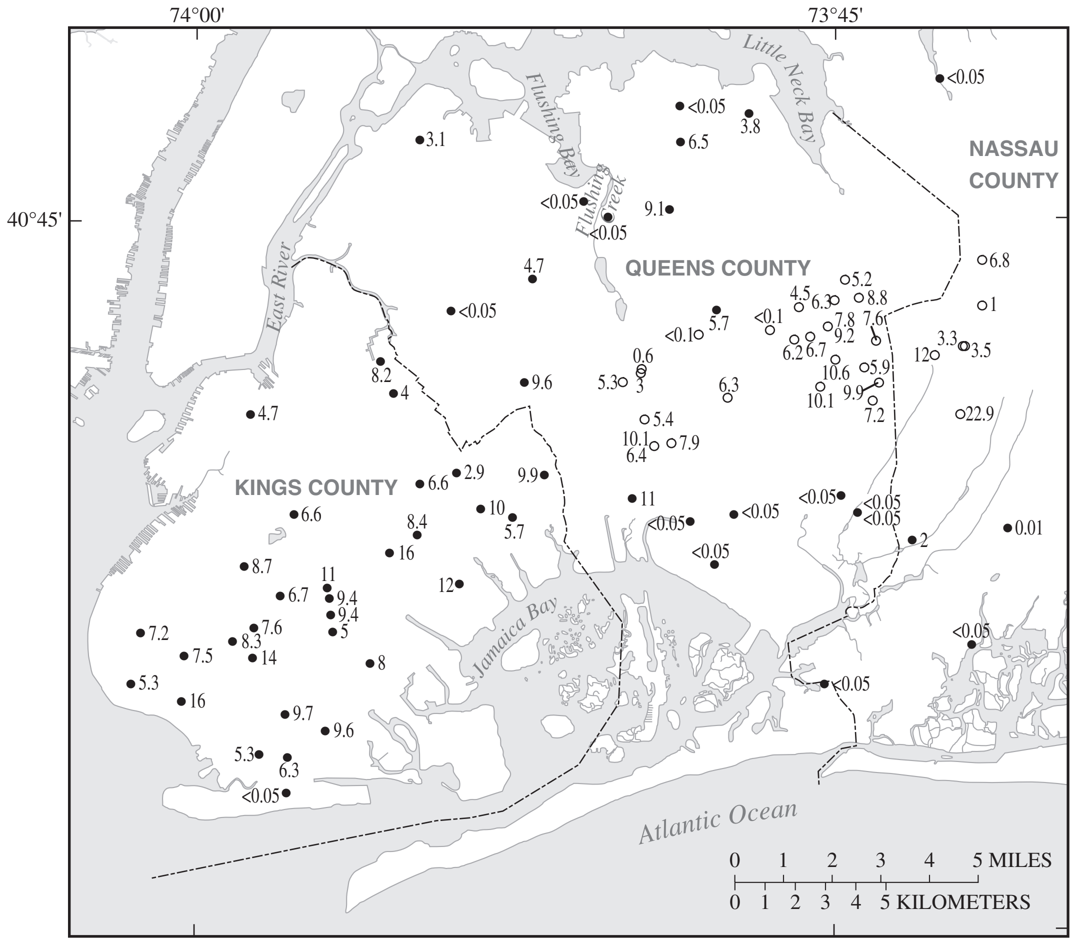
3.5 ●	MONITORING WELL - number is nitrate concentration in mg/L.
4.2 ○	PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.
ND	No Data Available

FIGURE 10A. Nitrate concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 12B.)

public health standard of 10 mg/L. Nitrate concentrations for Nassau County are available for 4 wells sampled in 1983 and 1992 and (or) 1996. All values were well below 10 mg/L and did not change significantly during this period.

Nitrate concentrations at seven public-supply wells in Queens County in 1996 are available. All concentrations were below 10 mg/L and ranged from 3.9 to 7.3 mg/L (analyses performed by former JWS). Five of these wells were sampled in 1983; the concentrations had decreased in two wells and increased in three wells, apparently in opposition to the decreasing trends described earlier for all monitoring wells. These nitrate concentrations are low, however, and the small changes from 1983 to 1996 may not be significant.

The majority of nitrate concentrations measured in the upper glacial aquifer in Kings, Queens, and western Nassau Counties in 1992 and 1996 were lower than in 1983. This observation is consistent with the



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

4.7 ● MONITORING WELL - number is nitrate concentration in mg/L.

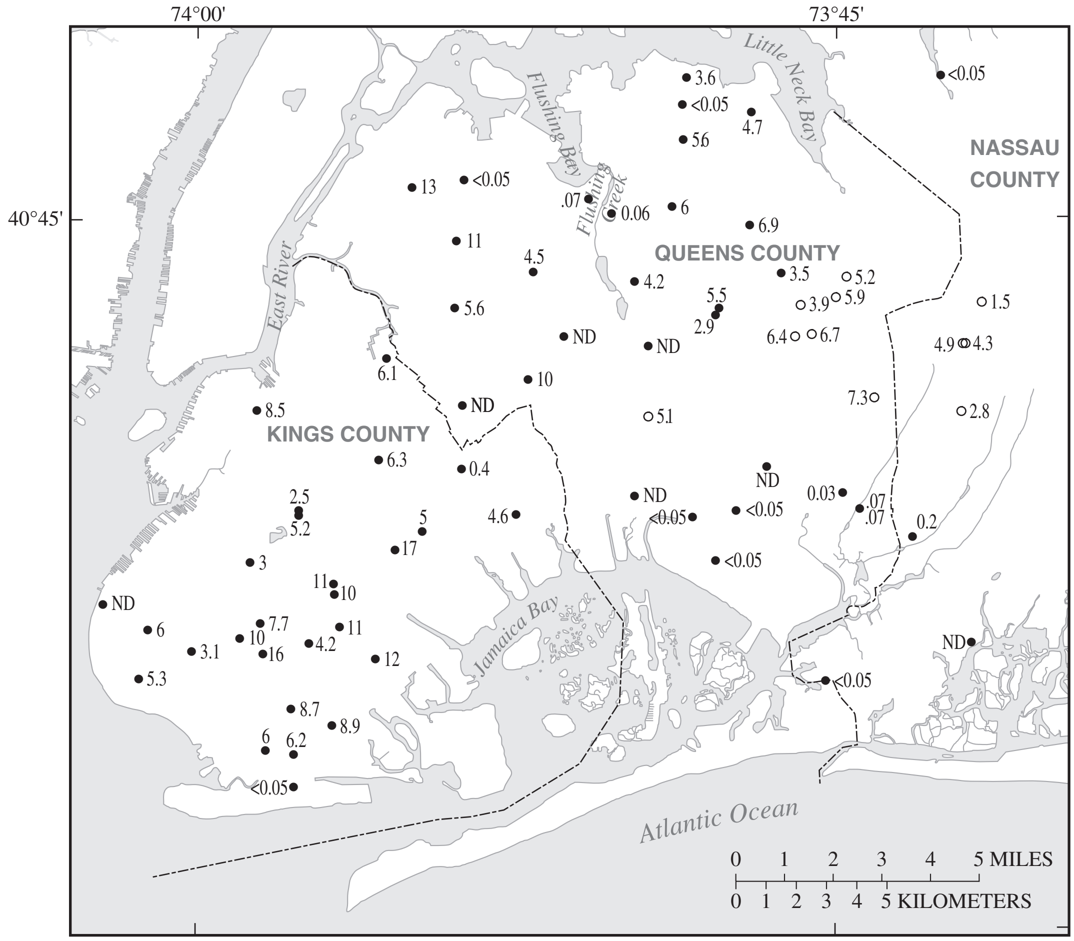
5.3 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

FIGURE 10B. Nitrate concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992.

decrease in chloride concentrations described earlier and can be attributed to the same mechanism of dispersion, degradation, and (or) dilution resulting from the long-term water-level recovery as well as denitrification.

Jameco-Magothy Aquifer

Nitrate concentrations at six wells screened in the Jameco-Magothy aquifer in Kings County in 1983 are depicted in figure 11A (Buxton and Shernoff, 1995) and range from 0.24 to greater than 10 mg/L. These concentrations generally are higher than those in Queens and western Nassau Counties, where the Gardiners Clay is present, and are attributed to a greater vertical hydraulic conductivity of this unit in Kings County than in Queens and Nassau Counties. This high hydraulic conductivity allows rapid movement of nitrate-contaminated water to the Jameco-Magothy aquifer.



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

8.5 ● MONITORING WELL - number is nitrate concentration in mg/L.

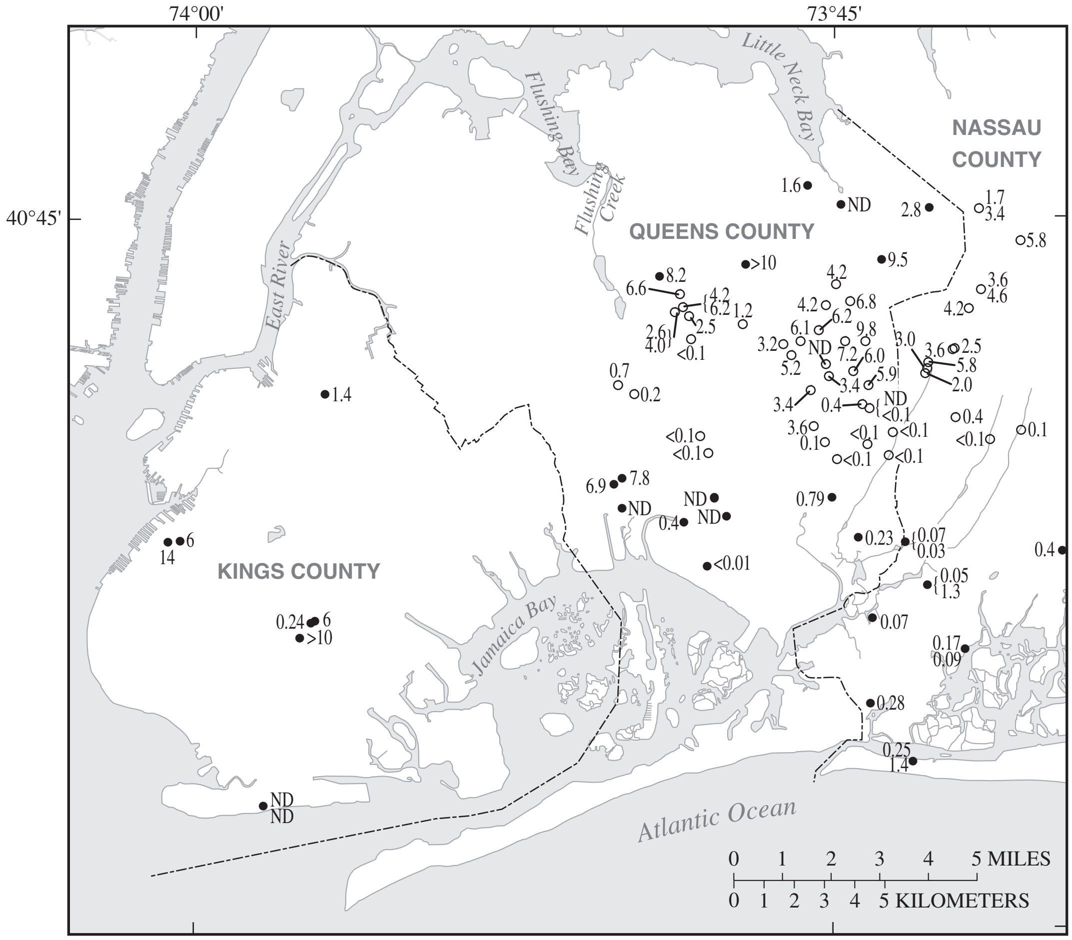
5.1 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

ND No Data Available

FIGURE 10C. Nitrate concentration in the upper glacial aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1996.

Nitrate concentrations at 10 of 12 Jameco-Magothy aquifer wells sampled in 1983 in parts of southern Queens and Nassau Counties, where the Gardiners Clay is present, were 0.28 mg/L or less. The highest nitrate concentration among these 12 wells was 0.79 mg/L. In contrast, the 1983 nitrate concentrations at 34 of 47 inland wells, where the Gardiners Clay is absent, exceeded 2 mg/L. These data reflect the effect of the Gardiners Clay on nitrate concentration, as described earlier.

Recent (1992 and 1996) nitrate concentrations in the Jameco-Magothy aquifer at seven monitoring wells in Kings County are available (figs. 11B, 11C); concentrations range from less than 0.05 to 8.5 mg/L. Nitrate concentrations at two wells sampled in 1996 showed an increase from 1983. Concentrations at nine monitoring wells in Queens County in 1996 ranged from less than 0.05 to 5.9 mg/L; those at five of six wells sampled in 1983 were lower in 1996, and that at one was higher. Similar trends are observed in western Nassau County—recent (1996) nitrate concentrations



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

1.4 ● MONITORING WELL - number is nitrate concentration in mg/L.

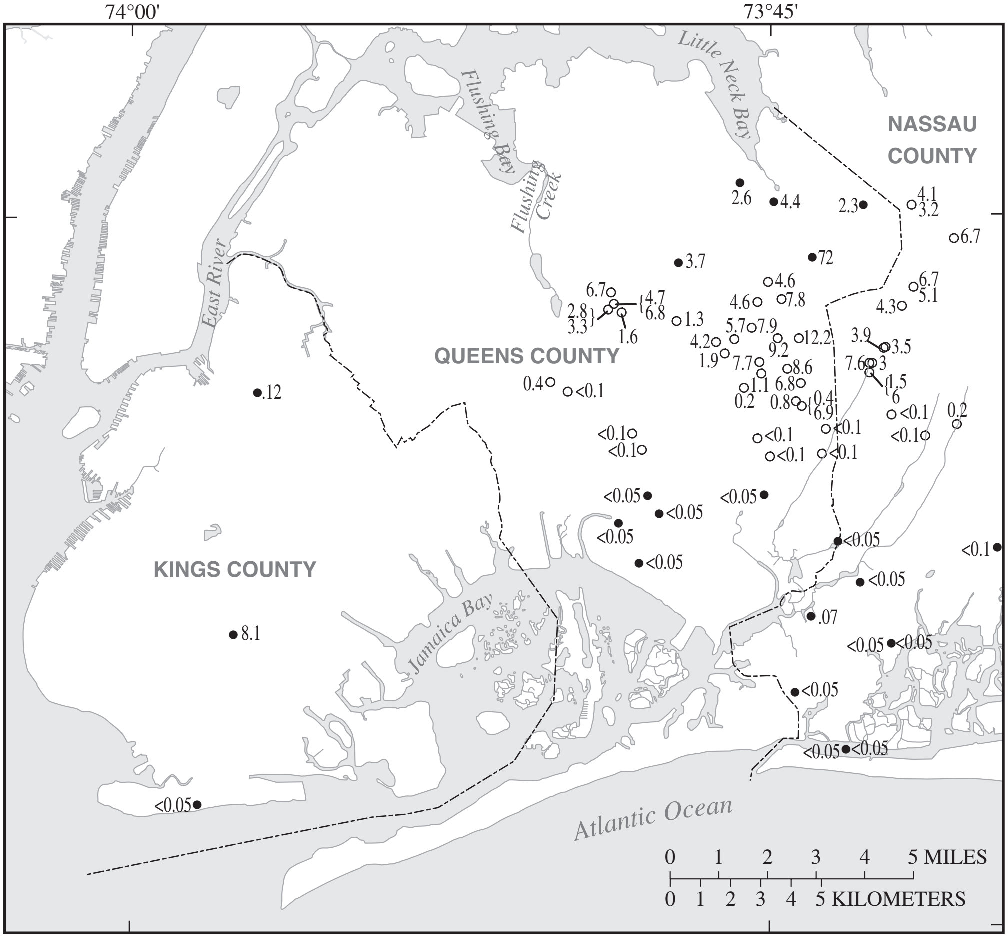
0.7 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

ND No Data Available

FIGURE 11A. Nitrate concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 13B.)

at nine monitoring wells ranged from less than 0.05 to 0.54 mg/L. All of these wells were sampled in 1983; the nitrate concentration at four wells had decreased by 1996, at three wells it had increased, and at two wells it remained constant.

Nitrate concentrations for 1996 at an additional 17 JWS wells screened in the Jameco-Magothy aquifer in Queens County are available. These public-supply wells are in central and eastern parts of the county, and the nitrate concentrations in 1996 ranged from less than 0.1 to 8 mg/L. These values, although less than 10 mg/L, generally are higher than those at Jameco-Magothy aquifer wells farther south, where the Gardiners Clay is present. Nitrogen concentrations at all 17 wells for 1983 and 1996 are available. A comparison of these data indicates that nitrate concentration decreased at seven wells, increased at three wells, and remained constant at seven wells. JWS provided 1996 data for 14 Jameco-Magothy aquifer wells in Nassau County; there the nitrate concentrations ranged from less than 0.1 to 7.2 mg/L. Concentrations at 13 of these public-supply wells in 1983 are available for comparison. The concentration



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

12 ● MONITORING WELL - number is nitrate concentration in mg/L.

1.3 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

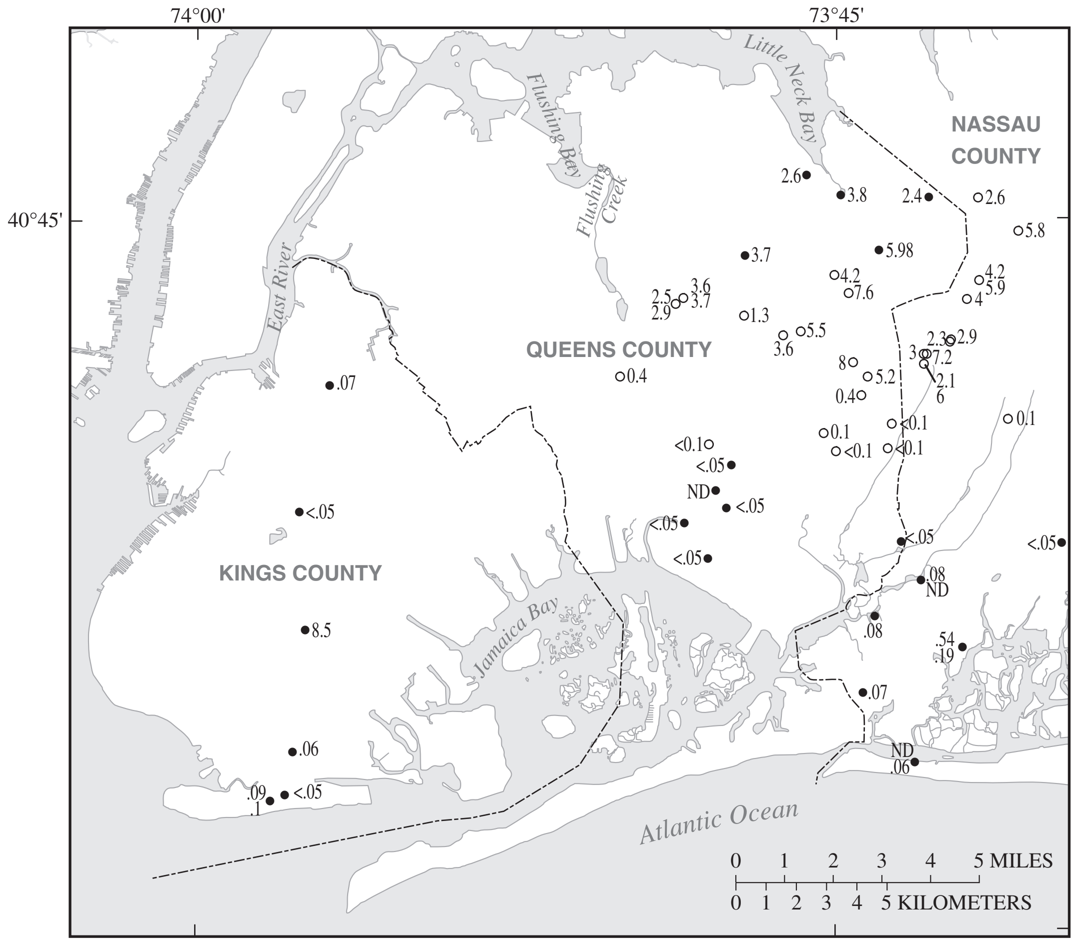
FIGURE 11B. Nitrate concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992.

at five wells decreased; at six wells they remained constant, and at two wells they increased.

Lloyd Aquifer

Nitrate data from 14 wells screened in the Lloyd aquifer in 1983 are available (fig. 12A) (Buxton and Shernoff, 1995). The 1983 concentrations ranged from less than 0.1 to 0.72 mg/L, indicating little or no contamination from land surface, despite (1) the hydraulic connection provided by the buried channel in central Queens County, and (2) the increased downward gradients produced by progressively greater public-supply withdrawals from the Lloyd aquifer in southeastern Queens from about 3 Mgal/d to 6 Mgal/d since 1960. Traveltimes of ground water through the buried channel and into the Lloyd aquifer probably would be decades, whereas the traveltime for movement through the Raritan clay into the Lloyd aquifer would probably be millennia (Buxton and Shernoff, 1995).

Recent (1992 and 1996) water-quality data from 19 observation and public-supply wells screened in the Lloyd aquifer in Kings, Queens, and western Nassau Counties are available (figs. 12B, 12C). Nitrate concentrations at 18 wells ranged from less than 0.05



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

8.5 ● MONITORING WELL - number is nitrate concentration in mg/L.

1.3 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

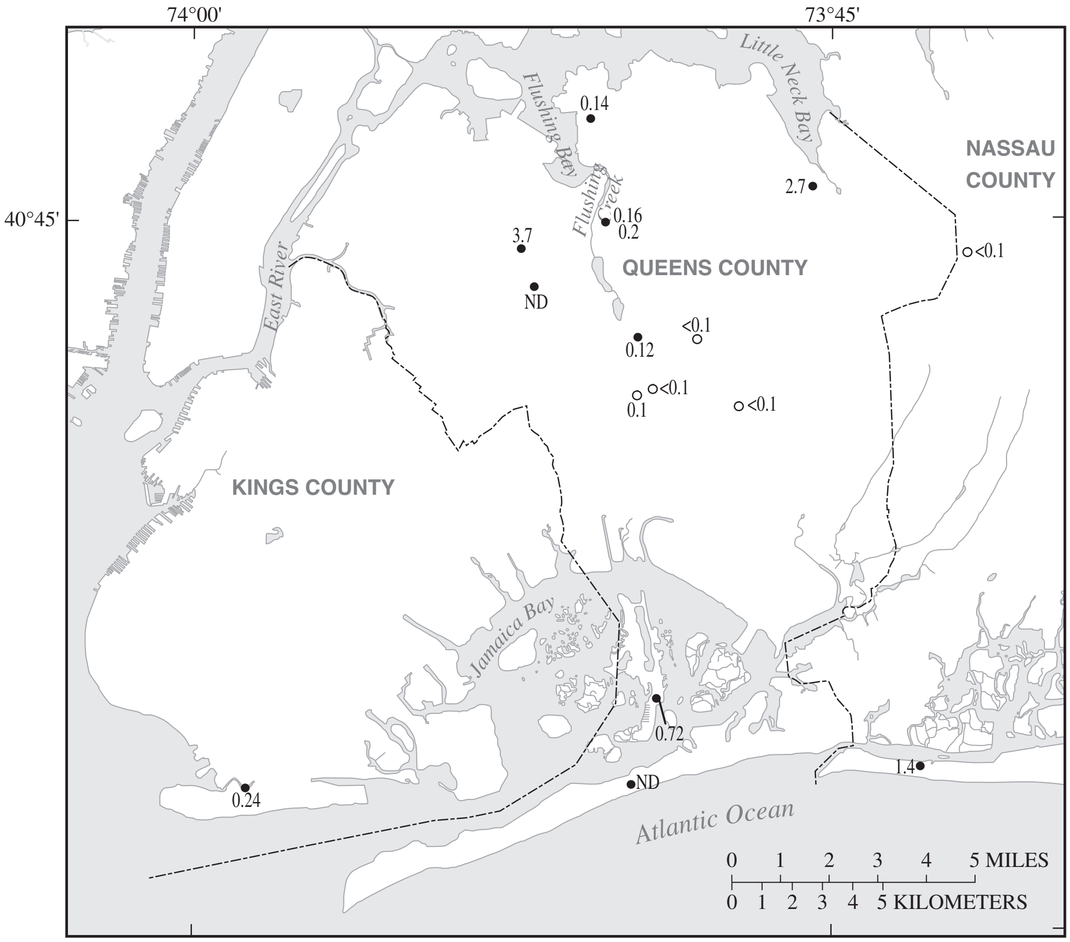
ND No Data Available

FIGURE 11C. Nitrate concentration in the Jameco-Magothy aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1996.

to 1.6 mg/L, indicating little or no contamination from land surface; the concentration at a single public-supply well was slightly elevated above background levels (6.6 mg/L) but below the public health standard. Nitrate data for 1992 and (or) 1996 are available for 7 of the 19 wells sampled in 1983; nitrate concentrations at all 7 wells decreased during this period, indicating that (1) 1983 concentrations were slightly elevated, probably by minor contamination from the surface, and (2) the water quality in terms of chloride concentration is improving.

Organic Compounds

Prior to 1983, no comprehensive ground-water sampling had been undertaken in Kings or Queens Counties to document the presence of organic compounds (Buxton and Shernoff, 1995). In 1979, however, JWS (under the auspices of the New York City Department of Health, NYCDH) began analyzing ground water from public-supply wells in Queens and western Nassau Counties for total volatile organic compounds (VOC’s). In 1983, 42 of 54 JWS wells



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

3.7 ● MONITORING WELL - number is nitrate concentration in mg/L.

0.1 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

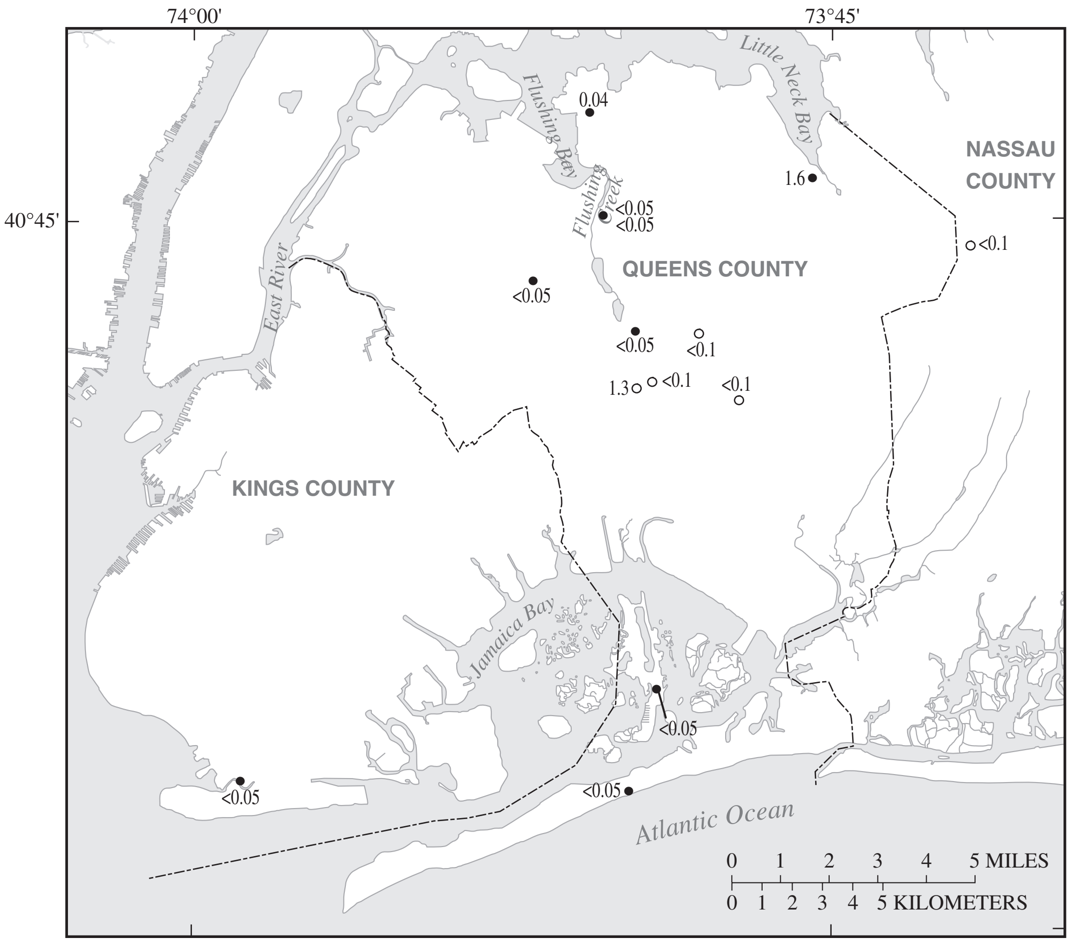
ND No Data Available

FIGURE 12A. Nitrate concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1983. (Modified from Buxton and Shernoff, 1995, fig. 14B.)

sampled showed detectable concentrations of total VOC's (detection limit 0.1 μg/L); and the VOC concentration in two of these exceeded recommended guidelines set by NYCDH. Most of the contamination was in the upper glacial and Magothy aquifers (where most of the pumping occurs), 22 of 23 upper glacial aquifer wells, 19 of 27 Jameco-Magothy aquifer wells, and one of four Lloyd aquifer wells showed detectable VOC concentrations (Stern and Todd, 1984). The contamination in southeastern Queens County was attributed to migration from scattered point sources near the surface, through the upper glacial aquifer, and into the Jameco-Magothy aquifer (Buxton and Shernoff, 1995).

Public-Supply Wells

Concentrations of organic compounds (VOC's and pesticides) in public-supply wells in 1992 and 1996 presented here are from JWS records. Only those concentrations that exceed their respective detection limits are reported here. When organic compounds are detected in a JWS well, either (1) water from the well is blended with uncontaminated water from another



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

0.04 ● MONITORING WELL - number is nitrate concentration in mg/L.

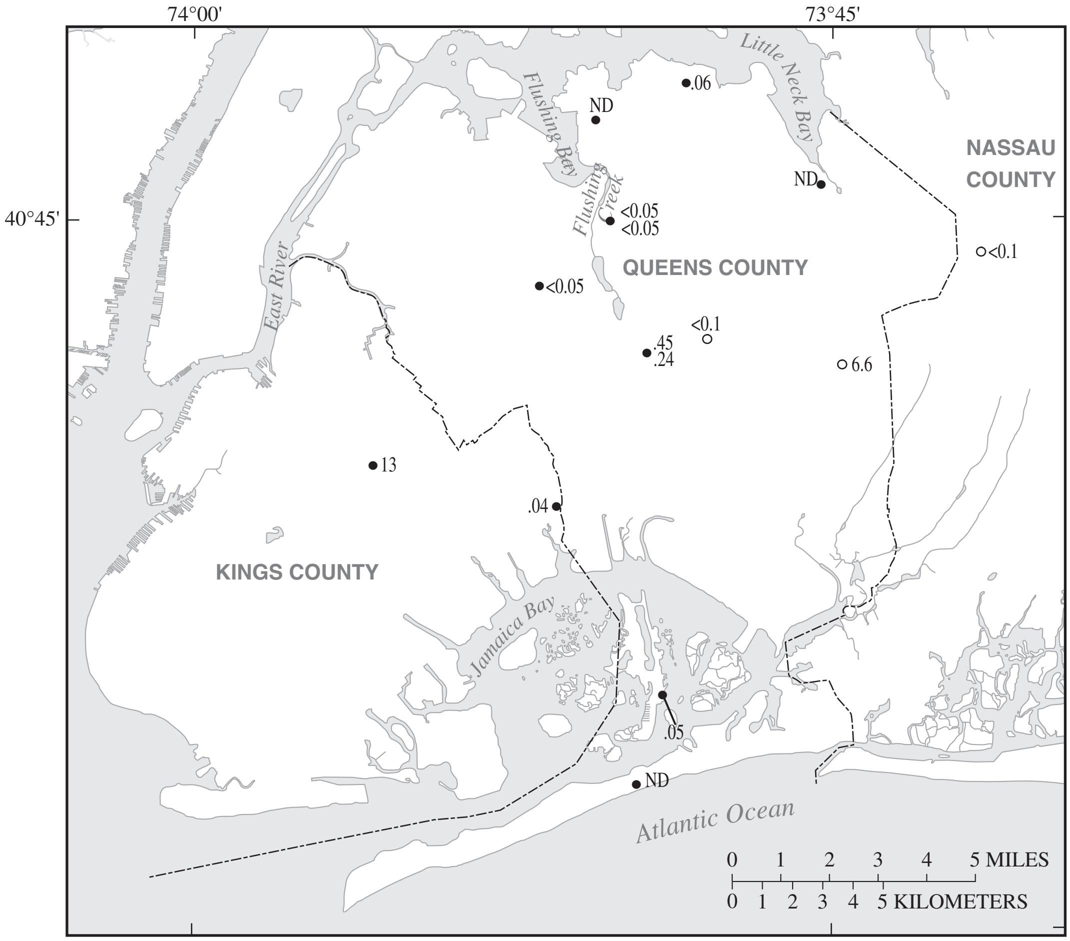
1.3 ○ PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.

FIGURE 12B. Nitrate concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1992.

well to lower the concentrations to allowable levels, or (2) the well is taken offline and no longer routinely sampled. Results of blended-water analyses are not reported here because they are not representative of the water quality at a single site. For these reasons, the data presented here indicate water quality at public-supply wells where detection limits have been exceeded and are not representative of the water quality in the entire Jamaica area of Queens County.

The locations of public-supply wells in the Jamaica area of Queens County (including western Nassau County) at which organic constituents were detected in 1992 are presented in figure 13A (upper glacial aquifer) and 13B (Magothy and Lloyd aquifers); locations of those wells affected in 1996 are shown in figure 14A (upper glacial aquifer) and 14B (Jameco-Magothy aquifer). The corresponding water-quality data are presented in table 5 (Queens County, 1992), table 6 (Nassau County, 1992), table 7 (Queens County, 1996), and table 8 (Nassau County, 1996).

1992 - Queens County.—Detectable concentrations of organic compounds were present in 39 public-supply wells in Queens County in 1992; 19 wells were screened in the upper glacial aquifer, 19 in



Base modified from U.S. Geological Survey, 1:100,000;
Long Island West, New York-New Jersey- Connecticut, 1984;
Newark, New Jersey - New York, 1986

EXPLANATION

13 ●	MONITORING WELL - number is nitrate concentration in mg/L.
6.6 ○	PUBLIC – SUPPLY WELL - number is nitrate concentration in mg/L.
ND	No Data Available

FIGURE 12C. Nitrate concentration in the Lloyd aquifer in Kings, Queens, and western Nassau Counties, N.Y., in 1996.

the Jameco-Magothy aquifer, and 1 in the Lloyd aquifer (figs. 13A, 13B; table 5). The most frequently detected compounds were tetrachloroethene (28 wells), chloroform (16 wells), total trihalomethanes (14 wells), and trichloroethene (13 wells). Other individual organic compounds were present in less than 20 percent of the 39 wells (7 wells) at which organic compounds were detected.

Tetrachloroethene detections were distributed evenly between the upper glacial and Jameco-Magothy aquifers—in 14 of the 19 upper glacial aquifer wells, and in 14 of the 19 Jameco-Magothy aquifer wells. Chloroform was detected most frequently in samples from upper glacial aquifer wells—in 10 of the 19 upper glacial aquifer wells, in 5 of the 19 Jameco-Magothy aquifer wells, and in the 1 Lloyd aquifer well. Total trihalomethanes also were detected most frequently in samples from upper glacial aquifer wells—in 9 of the 19 upper glacial aquifer wells, in 4 of the 19 Jameco-Magothy aquifer wells, and in the Lloyd aquifer well. trichloroethene detection in upper glacial aquifer wells was similar to that in Jameco-Magothy aquifer wells—in 6 of the 19 upper glacial aquifer wells, and in 7 of the Jameco-

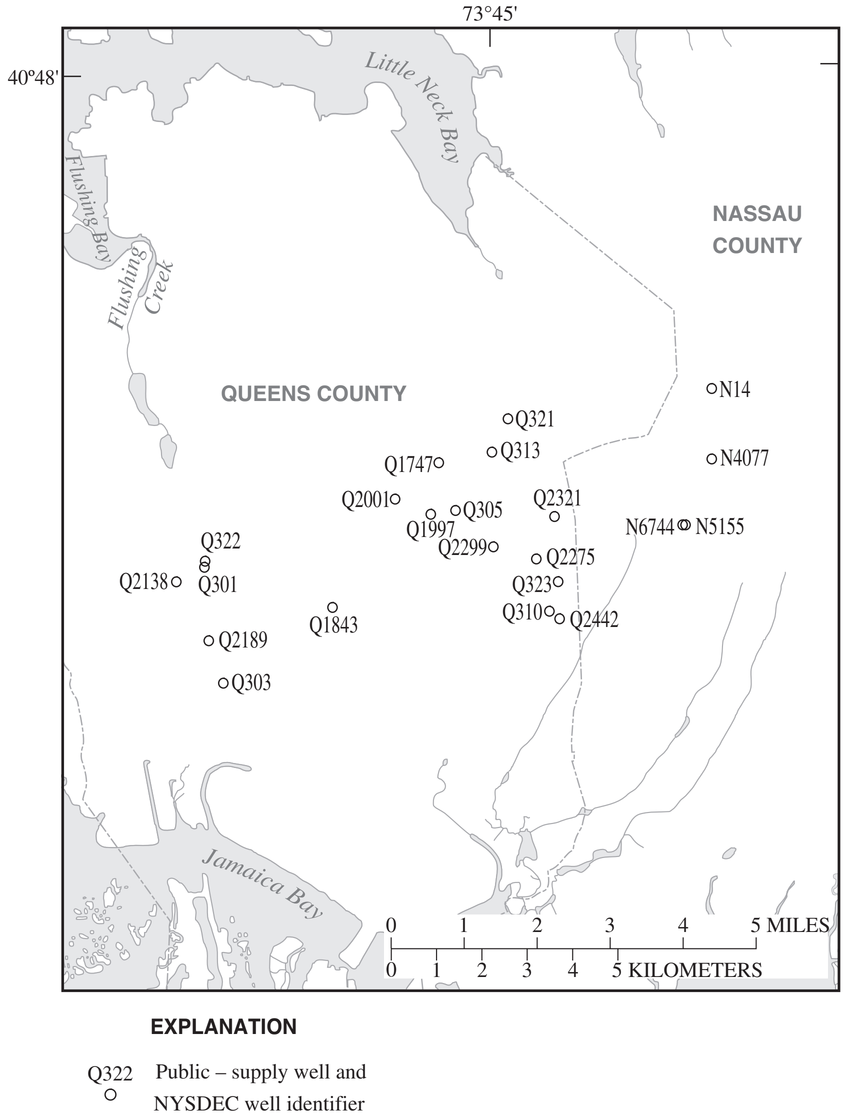


FIGURE 13A. Locations of public-supply wells screened in the upper glacial aquifer in Queens and western Nassau Counties, N.Y., at which volatile organic compounds were detected in 1992.

Magothy aquifer wells. Concentrations of organic compounds ranged from 0.5 µg/L to 150 µg/L; tetrachloroethene had the highest concentration (150 µg/L), and total trihalomethanes the next-highest concentration (37 µg/L).

1992 - Nassau County—Detectable concentrations of organic compounds were present in 16 public-supply wells in Nassau County in 1992; 4 wells were upper glacial aquifer wells, and 12 were Jameco-Magothy aquifer wells (figs. 13A, 13B; table 6). The most frequently detected compounds were tetrachloroethene (12 wells), trichloroethene (9 wells), chloroform (5 wells), and total trihalomethanes (5 wells). Other organic compounds were detected in 3 or less of the 16 wells at which organic compounds were detected. Tetrachloroethene was detected in 2 of the 4 upper glacial aquifer wells and in 10 of the 12 Jameco-Magothy aquifer wells. Similarly, trichloroethene was detected in 2 of the 4 upper glacial aquifer wells, and in 7 of the 12 Jameco-Magothy aquifer wells. Chloroform and total trihalomethanes, in contrast, were detected in 3 of the 4 upper glacial aquifer wells, but in only 2 of the 12 Jameco-Magothy aquifer wells. Organic compound concentrations ranged from 0.5 µg/L to 160 µg/L. Trichloroethene had the highest concentration (160 µg/L), 1,2-

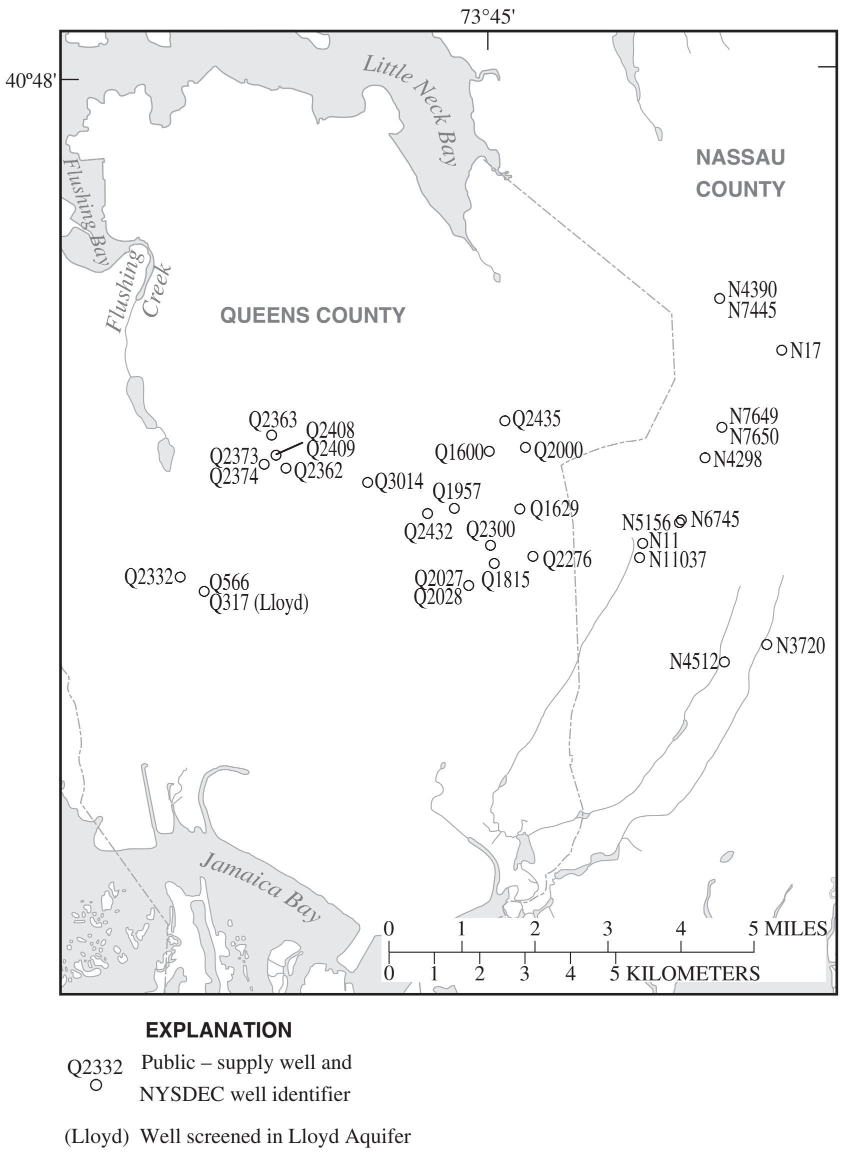


FIGURE 13B. Locations of public-supply wells screened in the Jameco-Magothy or Lloyd aquifers in Queens and western Nassau Counties, N.Y., at which volatile organic compounds were detected in 1992.

dichloropropane had the second highest (150 µg/L), and tetrachloroethene had the third highest (25 µg/L).

1996 - Queens County—Detectable concentrations of organic compounds were present in 19 public-supply wells in Queens County in 1996; 7 wells were screened in the upper glacial aquifer, and 12 in the Jameco-Magothy aquifer (figs. 14A, 14B; table 7). The most frequently detected compounds were tetrachloroethene at 17 of the wells, and trichloroethene at 7 of the wells. Other individual organic compounds were detected in 4 or less of the 19 wells. Tetrachloroethene detections were distributed roughly equally between the two aquifers, with detections in 6 of the 7 upper glacial aquifer wells, and 11 of the 12 Jameco-Magothy aquifer wells. trichloroethene was detected at 5 of the 12 wells in the Jameco-Magothy aquifer and at 2 of the 7 wells in the upper glacial aquifer. Organic compound concentrations in both aquifers ranged from 0.5 µg/L to 220 µg/L. Tetrachloroethene had the highest concentrations (220, 79, 54, and 24 µg/L); trichloroethene had the next highest concentration (34 µg/L).

1996 - Nassau County—Detectable concentrations of organic compounds were present in 10 public-supply wells in western Nassau County in

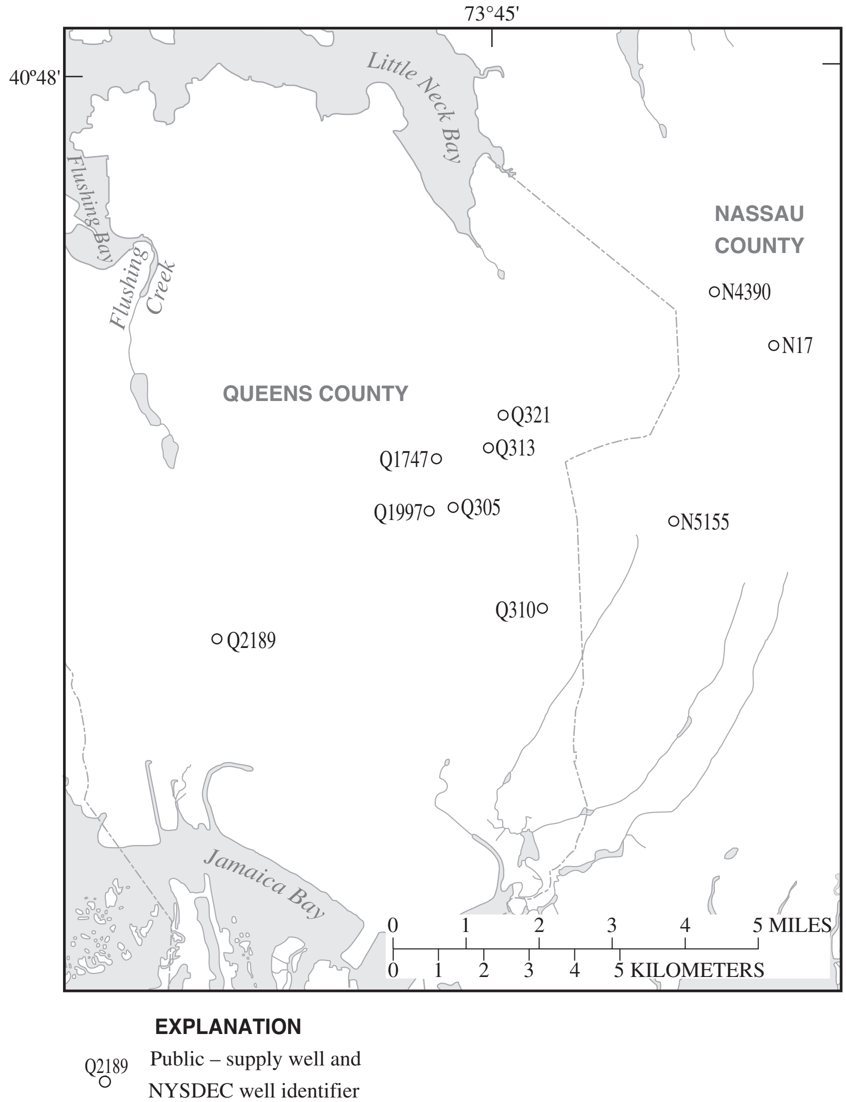


FIGURE 14A. Locations of public-supply wells screened in the upper glacial aquifer in Queens and western Nassau Counties, N.Y., at which volatile organic compounds were detected in 1996.

1996; 2 wells were screened in the upper glacial aquifer, and 8 in the Jameco-Magothy aquifer (figs. 14A, 14B; table 8). The most frequently detected compounds were tetrachloroethene (8 of the 10 wells), and trichloroethene (6 of the wells). Other organic compounds were detected at 3 or less of the 10 wells. Tetrachloroethene was detected at seven of the eight Jameco-Magothy aquifer wells and at one of the two upper glacial aquifer wells. Trichloroethene was detected at five of the eight Jameco-Magothy aquifer wells and at one of the two upper glacial aquifer wells. Organic compound concentrations ranged from 0.06 μg/L (dieldrin) to 170 μg/L (trichloroethene). Trichloroethene had the highest concentrations (170, 22, and 21 μg/L); and tetrachloroethene the next highest (16 μg/L).

Monitoring Wells

Concentrations of organic compounds, including VOC's and pesticides, also were measured in water from monitoring wells. Data from the USGS 1992-93 and 1995 sampling periods are available for wells in Kings, Queens, and western Nassau Counties; data from the 1996 sampling period are available from the NYCDEP. Locations of wells at which at least one organic compound was detected are shown in figure 15; the data associated with these wells are summarized in table 9.

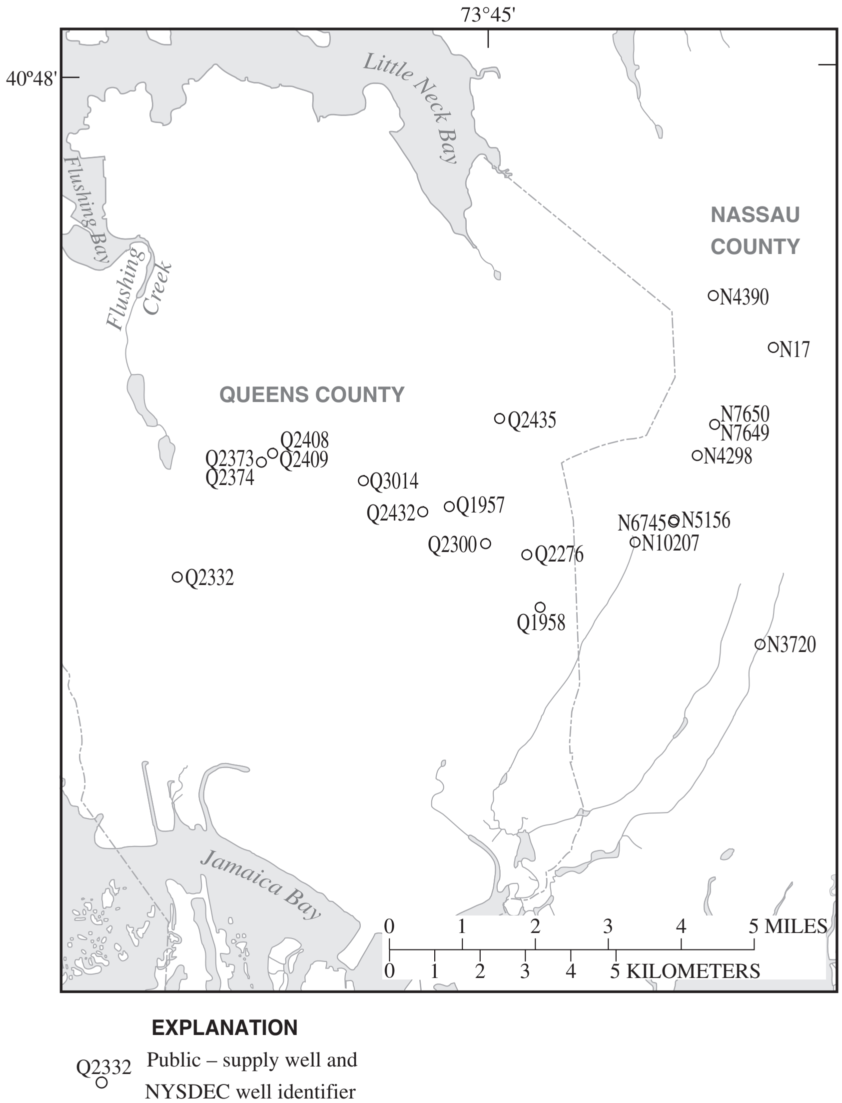


Figure 14B. Locations of public-supply wells screened in the Jameco-Magothy aquifer in Queens and western Nassau Counties, N.Y., at which volatile organic compounds and one pesticide were detected in 1996

Ground water collected during the 1992-93 and 1995 sampling periods from 108 wells in Kings, Queens, and western Nassau Counties was analyzed for organic compounds. Of these wells, 26 had detectable concentrations of at least one organic compound. The number of organic compound detections in Kings County is twice the number in Queens County—16 of the 43 wells in Kings County had detectable concentrations, in contrast to only 9 of the 50 wells in Queens County, and only 1 of the 15 wells in Nassau County. Again, the most commonly detected organic compounds were tetrachloroethene (12 detections) and trichloroethene (9 detections), followed by chloroform (5 detections). Maximum concentrations were similar to those in public-supply wells and ranged from 0.02 µg/L for p,p´-DDT and 2,4-D (pesticides) to 150 µg/L for tetrachloroethene. A single value of 1,000 µg/L was reported for *tert*-butyl methyl ether.

The distribution of organic compounds among the aquifers at monitoring wells in Kings County is substantially different from those at public-supply wells in Queens County. All Kings County wells with detectable concentrations of organic compounds were screened in the upper glacial aquifer, as were seven of the eight Queens County wells (the other one was

Table 5. Concentrations of selected volatile organic compounds in water from public-supply wells in Queens County, N.Y., 1992

[Well locations are shown in fig. 13A and 13B. Concentrations are in micrograms per liter (μg/L). Detection limits for all compounds is 0.5 μg/L. NYSDEC, New York State Department of Environmental Conservation. JWS, Jamaica Water Supply Company]

Well number		Aquifer	Sampling date	Constituent	Concentration
NYSDEC	JWS				
Q1600	13-A	Magothy	11/19/92	Tetrachloroethene	1.8
Q1629	29-A	Magothy	9/11/92	Trichloroethene	1.1
			12/2/92	Trichloroethene	1
Q1747	27	Upper glacial	5/11/92	1,2,4-Trimethylbenzene	0.6
				1,2-Xylene	2.1
				1,3-Xylene	2.9
				Bromodichloromethane	7.9
				Bromoform	7.7
				Chlorodibromomethane	9.4
				Chloroform	12
				Ethylbenzene	1.3
				Isopropylbenzene (cumene)	0.7
				Naphthalene	1.7
				Total trihalomethanes	37
			10/28/92	Tetrachloroethene	0.5
Q1815	26-A	Magothy	2/3/92	Dichlorodifluoromethane	8.1
				Tetrachloroethene	12
Q1843	33	Upper glacial	12/4/92	Chloroform	1.7
				Tetrachloroethene	1.7
				Total trihalomethanes	1.7
				Trichloroethene	0.5
Q1957	5-A	Magothy	10/15/92	Dichlorodifluoromethane	2.8
				Tetrachloroethene	9.7
			12/10/92	Tetrachloroethene	14
				Trichloroethene	0.6
			1/13/92	Trichloroethene	0.6
Q1997	38	Upper glacial	10/15/92	Benzene	0.6
			12/10/92	1,1,1-Trichloroethane	1.4
				Tetrachloroethene	6.4
				Trichloroethene	0.6
			1/13/92	*cis*-1,2-Dichloroethene	0.6
Q2000	39	Upper glacial	3/16/92	Chloroform	1.1
				Tetrachloroethene	8.1
				Total trihalomethanes	1.1
Q2001	37	Upper glacial	11/24/92	Tetrachloroethene	0.9
Q2027	42	Upper glacial	3/16/92	Chloroform	1.3
				Total trihalomethanes	1.3
Q2028	42	Magothy	3/20/92	Trichloroethene	0.5
Q2138	43	Upper glacial	7/29/92	1,1,1-Trichloroethane	0.6
			12/11/92	Tetrachloroethene	7.7
				Trichloroethene	4.2
Q2189	5	Upper glacial	11/19/92	Tetrachloroethene	0.9
Q2275	47	Upper glacial	9/14/92	Tetrachloroethene	0.5
			12/2/92	Chloroform	0.8
				Total trihalomethanes	0.8
Q2276	47-A	Magothy	4/27/92	Chloroform	0.6
				Total trihalomethanes	0.6
			1/22/92	Chloroform	1.6
				Total trihalomethanes	1.6
Q2299	48	Upper glacial	4/16/92	Total trihalomethanes	0.6

Table 5. Concentrations of selected volatile organic compounds in water from public-supply wells in Queens County, N.Y.1992--continued

Well number NYSDEC	Well number JWS	Aquifer	Sampling date	Constituent	Concentration
				Chloroform	0.6
				1,2,3-Trichloropropane	0.7
			11/12/92	1,2,3-Trichloropropane	0.5
			12/10/92	Tetrachloroethene	31
				Trichloroethene	1.4
Q2300	48-A	Magothy	1/13/92	1,1,1-Trichloroethane	0.5
			2/14/92	1,1,1-Trichloroethane	0.5
			11/12/92	*cis*-1,2-Dichloroethene	1.3
				Tetrachloroethene	140
				Trichloroethene	16
			12/10/92	*cis*-1,2-Dichloroethene	1.4
				Tetrachloroethene	150
				Trichloroethene	19
Q2321	49	Upper glacial	4/27/92	Chloroform	0.8
				Total trihalomethanes	0.8
Q2332	43-A	Jameco	3/30/92	1,2-Xylene	1.8
				1,3-Xylene	2.6
				Chloroform	1.4
				Ethylbenzene	0.8
				Tetrachloroethene	2.5
				Total trihalomethanes	1.4
			11/18/92	Tetrachloroethene	2.8
				Trichloroethene	0.9
Q2362	51	Magothy	2/3/92	Tetrachloroethene	11
Q2363	52	Magothy	2/13/92	1,1,1-Trichloroethane	0.8
				Tetrachloroethene	8.7
Q2373	50	Magothy	12/17/92	Tetrachloroethene	24
Q2374	50-A	Magothy	11/12/92	Tetrachloroethene	10
			12/17/92	Tetrachloroethene	9.7
Q2408	53	Magothy	9/9/92	Chloroform	0.5
			12/10/92	1,1,1-Trichloroethane	0.6
				Tetrachloroethene	22
Q2409	53-A	Magothy	11/12/92	Tetrachloroethene	6.9
			12/10/92	Tetrachloroethene	7.1
Q2432	38-A	Magothy	11/12/92	1,1,1-Trichloroethane	2.7
				1,1-Dichloroethane	0.8
				1,1-Dichloroethene	1.2
				cis-1,2-Dichloroethene	30
				Tetrachloroethene	110
				Trichloroethene	13
			12/10/92	1,1,1-Trichloroethane	3.5
				1,1-Dichloroethane	0.8
				1,1-Dichloroethene	1.2
				cis-1,2-Dichloroethene	26
				Dichlorodifluoromethane	0.5
				Tetrachloroethene	100
				Trichloroethene	12
			1/13/92	Chloroethane	0.7
				Dichlorodifluoromethane	1.7
				Fluorotrichloromethane	0.8
Q2435	21-A	Magothy	4/27/92	Tetrachloroethene	0.7
			10/28/92	Tetrachloroethene	0.9
Q2442	54	Magothy	9/14/92	1,1,1-Trichloroethane	0.5

Table 5. Concentrations of selected volatile organic compounds in water from public-supply wells in Queens County, N.Y.1992--continued

Well number					
NYSDEC	JWS	Aquifer	Sampling date	Constituent	Concentration
			11/24/92	Bromodichloromethane	6.1
				Bromoform	3.4
				Chlorodibromomethane	5.1
				Chloroform	11
				Total trihalomethanes	25.6
Q301	1	Upper glacial	3/9/92	Trichloroethene	0.5
Q3014	58	Magothy	1/13/92	Trichloroethene	0.5
				cis-1,2-Dichloroethene	0.5
			8/5/92	Dichlorodifluoromethane	0.5
			12/10/92	Tetrachloroethene	10
Q303	3	Upper glacial	2/3/92	Chloroform	1.8
Q305	5	Upper glacial	7/27/92	Dichlorodifluoromethane	0.5
			12/10/92	Tetrachloroethene	79
				Trichloroethene	3.4
Q310	10	Upper glacial	8/17/92	Tetrachloroethene	0.7
			11/19/92	Chloroform	0.5
				Total trihalomethanes	0.5
Q313	13	Upper glacial	10/28/92	Tetrachloroethene	1.1
Q317	17	Lloyd	9/18/92	Bromodichloromethane	5.1
				Bromoform	1
				Chlorodibromomethane	1.8
				Chloroform	16
				Total trihalomethanes	23.9
Q321	21	Upper glacial	8/10/92	Dichlorodifluoromethane	0.6
			10/28/92	Tetrachloroethene	2.7
Q322	22	Upper glacial	8/13/92	Tetrachloroethene	2.5
Q323	23	Upper glacial	11/19/92	Chloroform	1.1
				Total trihalomethanes	1.1
Q566	17-A	Jameco	12/11/92	Chloroform	1.8
				Total trihalomethanes	1.8

Table 6. Concentrations of selected volatile organic compounds in water from public-supply wells in Nassau County, N.Y., 1992

[Well locations are shown in fig. 13A and 13B. Concentrations are in micrograms per liter (μg/L). Detection limit for all compounds is 0.5 μg/L. NYSDEC, New York State Department of Environmental Conservation. JWS, Jamaica Water Supply Company]

Well number		Aquifer	Sampling date	Constituent	Concentration
NYSDEC	JWS				
N11	15-A	Magothy	11/19/92	Chloroform	1.2
				Total trihalomethanes	1.2
N11037	15-B	Magothy	8/31/92	Tetrachloroethene	0.5
N14	9	Upper glacial	12/11/92	Chloroform	1.6
				Tetrachloroethene	1.6
				Total trihalomethanes	1.6
N17	20	Magothy	12/8/92	Tetrachloroethene	25
N3720	30	Magothy	10/23/92	Toluene	1.9
N4077	35	Upper glacial	6/5/92	1,1,1-Trichloroethane	2.1
				1,1-Dichloroethene	0.7
				Tetrachloroethene	1.8
				Trichloroethene	14
N4298	35-A	Magothy	12/17/92	1,1,1-Trichloroethane	2.3
				1,1-Dichloroethene	0.9
				Tetrachloroethene	2.1
				Trichloroethene	14
			2/4/92	Dichlorodifluoromethane	1.5
N4390	40	Magothy	10/22/92	*cis*-1,2-Dichloroethene	0.6
				Tetrachloroethene	1.8
				Trichloroethene	0.6
N4512	34	Magothy	8/14/92	Chloroform	0.9
				Tetrachloroethene	1.8
				Total trihalomethanes	0.9
N5155	44	Upper glacial	4/28/92	Chloroform	1
				Total trihalomethanes	1
N5156	44-A	Magothy	11/10/92	Tetrachloroethene	0.5
			12/17/92	Trichloroethene	22
N6744	44-B	Upper glacial	1/2/92	Chloroform	1.4
				Total trihalomethanes	1.4
			7/16/92	Trichloroethene	0.5
N6745	44-C	Magothy	11/18/92	Tetrachloroethene	0.8
				Trichloroethene	2.2
N7445	40-A	Magothy	7/6/92	Dichlorodifluoromethane	0.5
			12/17/92	*cis*-1,2-Dichloroethene	4.8
				Tetrachloroethene	3.7
				Trichloroethene	3.8
N7649	57	Magothy	8/3/92	1,2-Dichloropropane	150
			11/17/92	1,1,1-Trichloroethane	2.8
			12/8/92	1,1-Dichloroethene	1.9
				1,1-Dichloropropene	2.7
				cis-1,2-Dichloroethene	6.1
				Dichlorodifluoromethane	0.5
				Fluorotrichloromethane	0.7
				Tetrachloroethene	22
				Trichloroethene	160
				Vinyl chloride	0.8
N7650	57-A	Magothy	12/17/92	*cis*-1,2-Dichloroethene	0.6
				Tetrachloroethene	1.3
				Trichloroethene	10

Table 7. Concentrations of selected volatile organic compounds in water from public-supply wells in Queens County, N.Y., 1996

[Well locations are shown in fig. 14A and 14B. Concentrations are in micrograms per liter (μg/L). Detection limit for all compounds is 0.5 μg/L. NYSDEC, New York State Department of Environmental Conservation. JWS, Jamaica Water Supply Company]

Well number		Aquifer	Sampling date	Constituent	Concentration
NYSDEC	JWS				
Q1747	27	Upper glacial	2/5/96	Tetrachloroethene	0.8
Q1957	5-A	Magothy	5/1/96	Dichlorodifluoromethane	3.7
				Tetrachloroethene	24
			3/5/96	Trichloroethene	0.5
Q1958	10-A	Magothy	3/2/-96	Dichlorodifluoromethane	0.8
Q1997	38	Upper glacial	2/8/96	1,1,1-Trichloroethane	1.7
				Trichloroethene	0.5
				Benzene	0.5
			5/3/96	Tetrachloroethene	14
Q2189	45	Upper glacial	4/1/96	Tetrachloroethene	0.6
Q2276	47-A	Magothy	4/8/96	Tetrachloroethene	0.6
Q2300	48-A	Magothy	4/5/96	*cis*-1,2-Dichloroethene	1.6
				Tetrachloroethene	220
				Trichloroethene	34
Q2332	43-A	Jameco	5/7/96	Tetrachloroethene	1.4
				Trichloroethene	0.9
Q2373	50	Magothy	3/5/96	Trichloroethene	0.5
			5/4/96	Tetrachloroethene	11
Q2374	50-A	Magothy	5/4/96	Tetrachloroethene	4.2
Q2408	53	Magothy	5/1/96	Tetrachloroethene	10
Q2409	53-A	Magothy	5/1/96	Tetrachloroethene	12
Q2432	38-A	Magothy	5/3/96	1,1,1-Trichloroethane	5.6
				1,1-Dichloroethane	1.1
				1,1-Dichloroethene	1.9
				cis-1,2-Dichloroethene	6.6
				Tetrachloroethene	54
				Trichloroethene	7.1
Q2435	21-A	Magothy	4/8/96	Tetrachloroethene	1.4
Q3014	58	Magothy	3/5/96	Bromodichloromethane	1
				Bromoform	1.5
				Chlorodibromomethane	1.2
				Chloroform	2.6
			5/1/96	Dichlorodifluoromethane	0.9
				Tetrachloroethene	11
Q305	5	Upper glacial	5/1/96	*cis*-1,2-Dichloroethene	0.5
				Tetrachloroethene	79
				Trichloroethene	5.5
Q310	10	Upper glacial	5/1/96	Chloroform	0.5
Q313	13	Upper glacial	5/1/96	Bromoform	3.8
				Chlorodibromomethane	3.4
				Dibromomethane	0.5
				Tetrachloroethene	0.6
Q321	21	Upper glacial	2/5/96	Dichlorodifluoromethane	0.5
			4/8/96	Tetrachloroethene	2.2

Table 8. Concentrations of selected volatile organic compounds and one pesticide in water from public-supply wells in Nassau County, N.Y., 1996

[Well locations are shown in figs. 14A and 14B. Concentrations are in micrograms per liter (μg/L). Detection limit for all compounds is 0.5 μg/L except for dieldrin, which is 0.1 μg/L. NYSDEC, New York State Department of Environmental Conservation; JWS, Jamaica Water Supply Company]

Well number		Aquifer	Sampling date	Constituent	Concentration
NYSDEC	JWS				
N10207	15-E	Magothy	4/11/96	Tetrachloroethene	0.5
N17	20	Magothy	5/2/96	Tetrachloroethene	16
N3720	30	Magothy	2/5/96	Tetrachloroethene	1.4
			5/7/96	Chloroform	3.5
N4298	35-A	Magothy	5/2/96	1,1,1-Trichloroethane	1.4
				1,1-Dichloroethene	0.7
				Dichlorodifluoromethane	0.7
				Tetrachloroethene	1.9
				Trichloroethene	10
N4390	40-A	Upper glacial	5/8/96	*cis*-1,2-Dichloroethene	2.6
				Dichlorodifluoromethane	0.9
				Tetrachloroethene	2.7
				Trichloroethene	3.2
N5155	44	Upper glacial	1/3/96	Dieldrin	0.06
N5156	44-A	Magothy	5/14/96	Trichloroethene	21
N6745	44-C	Magothy	3/5/96	Tetrachloroethene	0.8
				Trichloroethene	5.
N7649	57	Magothy	5/2/96	1,1,1-Trichloroethane	3.6
				1,1-Dichloroethane	0.7
				1,1-Dichloroethene	4.6
				cis-1,2-Dichloroethene	6
				Dichlorodifluoromethane	0.6
				Fluorotrichloromethane	0.6
				Tetrachloroethene	22
				Trichloroethene	170
				Vinyl chloride	1.1
N7650	57-A	Magothy	4/18/96	Tetrachloroethene	0.8
			5/21/96	Trichloroethene	14

Table 9. Monitoring wells in Kings, Queens, and Nassau Counties, N.Y., at which organic constituents were detected in ground water in 1992-93 and 1995

[Well locations are shown in fig. 15. UG, upper glacial aquifer; MAG, Magothy aquifer; --, no detection. Concentrations are in micrograms per liter (μg/L)]

Well	Aquifer	Constituent and detection limit														
		PCB (0.01)	Chlordane (0.01)	p,p´-DDD (0.01)	p,p´-DDT (0.01)	2,4-D (0.01)	Carbon tetrachloride (3.0)	Chloroform (3.0)	*cis*-1,2-Dichloroethylene (3.0)	Dichlorodiflouromethane (3.0)	1,1 Dichloroethane (3.0)	1,1-Dichloroethylene (3.0)	Freon-113 (3.0)	*tert*-Butyl methyl ether (5.0)	Tetrachloroethene (3.0)	Trichloroethene (3.0)
K1673	UG	--	--	--	--	--	--	4.8	--	--	--	--	--	5.1	3	--
K1689	UG	--	--	--	--	--	--	4.8	--	--	--	--	--	--	100	--
K2407	UG	--	--	--	--	--	--	--	--	--	4.1	13	--	1,000	--	--
K2482	UG	--	--	--	--	--	--	4.8	--	--	--	--	--	--	--	--
K2598	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.5
K2610	UG	--	--	--	--	--	--	--	8.4	--	--	8.7	--	--	88	36
K2622	UG	--	--	--	--	--	--	15	--	--	--	--	--	--	--	5.1
K3214	UG	--	--	--	--	--	--	--	--	3	--	--	--	--	3	--
K3216	UG	--	--	--	--	--	--	--	--	--	--	--	--	11	11	--
K3218	UG	--	--	--	--	--	--	--	--	14	--	--	--	--	--	--
K3252	UG	0.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K3254	UG	0.8	--	--	--	--	--	--	6.1	--	--	--	--	--	150	3.1
K3255	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.3
K3256	UG	0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K3271	UG	0.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K3425	UG	--	--	--	--	--	--	--	5.5	--	--	--	--	--	17	80
Q1605	UG	--	--	--	--	--	--	8.9	--	--	--	--	--	--	--	--
Q1663	UG	--	--	--	--	--	3.8	--	--	--	--	--	--	--	--	--
Q1914	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	10	--
Q2407	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	5.3	--
Q3003	MAG	--	--	--	--	--	--	--	88	--	--	--	8.7	--	23	40
Q3121	UG	--	--	--	0.02	0.02	--	--	--	--	--	--	--	7.9	--	--
Q3644	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	21	--
Q3659	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	4	--
Q3660	UG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4
N6703	MAG	--	1.1	0.06	--	0.07	--	--	--	--	--	--	--	--	--	--

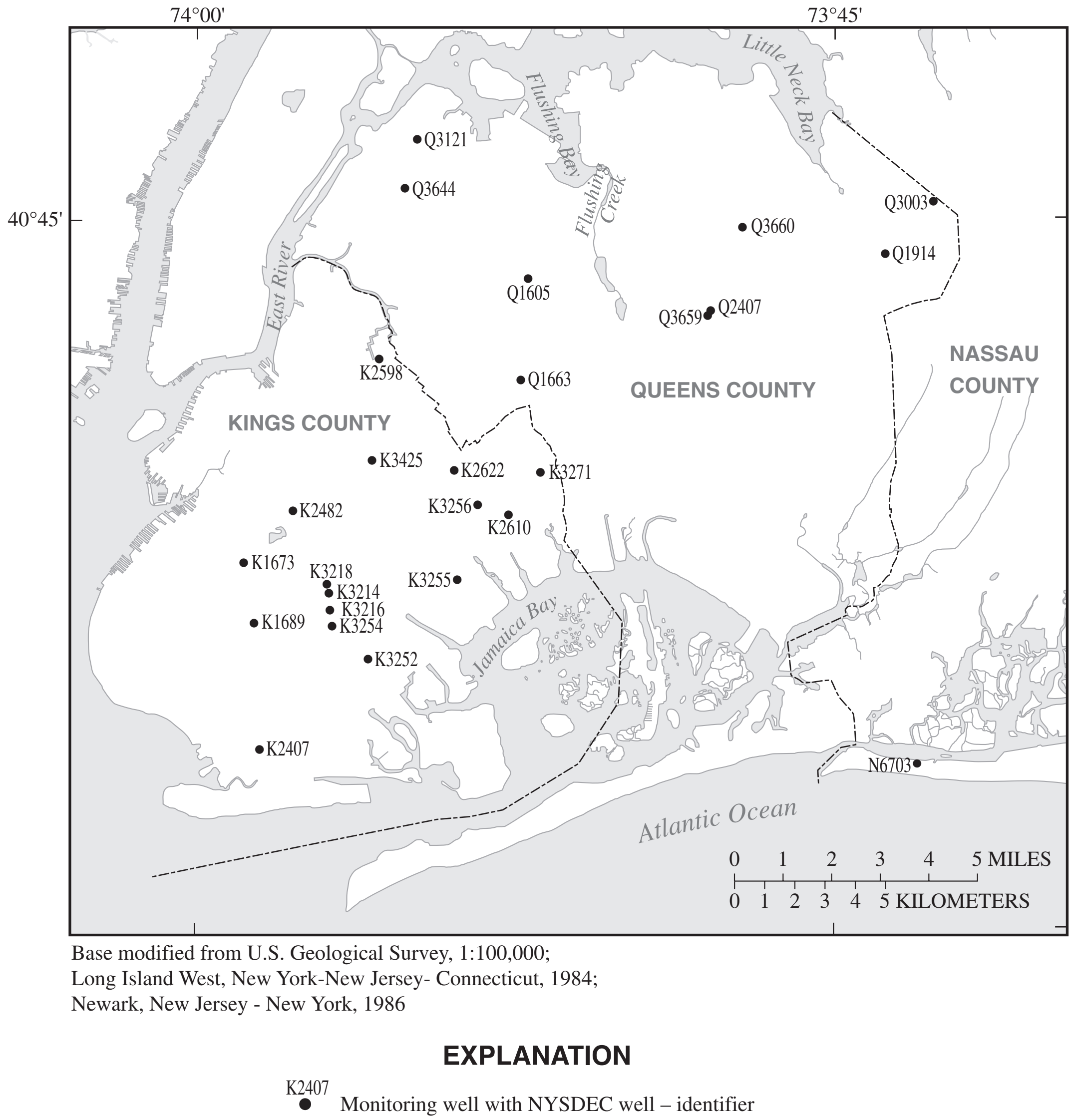


Figure 15. Locations of monitoring wells in Kings, Queens, and western Nassau Counties, N.Y., at which organic compounds were detected in 1992-93 and 1995.

screened in the Jameco-Magothy aquifer). These data indicate that the Jameco-Magothy aquifer is more widely contaminated in Queens County than in Kings County. Surface-derived organic contamination in the Jameco-Magothy aquifer in Queens County is probably the result of downward flow gradients resulting from the large cone of depression generated in southeastern Queens County during the earlier (mid-1960's to mid-1970's) public-supply withdrawals. The data in table 9 indicate more widespread organic contamination of the upper glacial aquifer in Kings County than in Queens County (tables 5 and 7), which, in turn, suggests a greater number of point sources of contamination in Kings County. The lack of organic contamination in the Jameco-Magothy aquifer in Kings County may indicate the limited use of synthetic organic compounds prior to 1947, when these compounds could have been drawn into deeper aquifers by extensive public-supply withdrawals.

Table 10. Revised hydrogeologic framework at selected new wells in Kings and Queens Counties, N.Y.

[Well locations are shown in figures 6G, 6H, and 6I. All elevations are in feet above or below (-) sea level; all thicknesses are in feet. ABS, unit is absent; ND, no data available; >, greater than; < less than. Numbers in parentheses are from Buxton and Shernoff (1995) in the absence of new values]

Well number	Land surface elevation	Well depth	Well data and information source*	Upper glacial aquifer: Thickness	Gardiners Clay: Top of unit	Gardiners Clay: Thickness	Jameco aquifer: Top of unit	Jameco aquifer: Thickness	Magothy aquifer: Top of unit	Magothy aquifer: Thickness	Raritan clay: Top of unit	Raritan clay: Thickness	Lloyd aquifer: Top of unit	Lloyd aquifer: Thickness	Bedrock: Top of unit	Remarks
K3405	33	220	PUB	160	-127	20	-147	50	200	30	-235	100	-330	180	-510	Framework consistent with that in Buxton and Shernoff (1995), except Gardiners Clay is absent.
			LOG	210	ABS	ABS	-147	>10	ND	ND	ND	ND	ND	ND	ND	
K3406[1]	14	175	PUB	~50	-64	~100	-164	50	ABS	ABS	ABS	ABS	ABS	ABS	-214	Well is near northwest extent of Gardiners Clay and Jameco aquifer; presence of these is uncertain. Gardiners Clay is absent; Jameco aquifer is present. Bedrock is about 40 feet shallower than earlier estimates.
			LOG	105	ABS	ABS	-119	55	ND	ND	ND	ND	ND	ND	-174	
K3407	8	405	PUB	158	-150	40	-190	30	-220	110	-330	120	-450	200	-650	Framework consistent with that in Buxton and Shernoff (1995), except Gardiners Clay is absent.
			LOG	180	ABS	ABS	-172	40	-212	75	-287	<110	ND	ND	ND	
K3410[2]	62	395	PUB	162	-100	50	-150	130	ABS	ABS	-280	40	ABS	ABS	-320	Framework consistent with that in Buxton and Shernoff (1995); Gardiners Clay is absent; Magothy aquifer is present.
			LOG	185	-123	110	ABS	ABS	-233	63	-296	37	ABS	ABS	-333	
K3414	7	440	PUB	170	-163	30	-193	25	-218	155	-373	140	-513	205	-718	Jameco aquifer is absent; Magothy aquifer is thicker; top of Raritan clay is deeper than that in Buxton and Shernoff (1995).
			LOG	(-170)	ABS	ABS	(-168)	34	-202	235	-437	ND	ND	ND	ND	
K3424	75	75	PUB	195	-120	20	-140	70	ABS	ABS	-210	40	250	130	-380	Boulders caused difficult drilling.
			LOG	>75	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
K3431[3]	81	390	PUB	206	-125	25	-150	50	ABS	ABS	-200	100	ABS	ABS	-300	Magothy aquifer is not this far north in earlier estimates. Magothy aquifer is at least 45 feet thick. Jameco aquifer is absent.
			LOG	250	-169	95	ABS	ABS	-264	<45	ND	ND	ND	ND	ND	
Q3587[4]	83	475	PUB	213	-130	100	ABS	ABS	ABS	ABS	-230	70	ABS	ABS	-300	Raritan clay is thicker and bedrock is about 100 feet deeper than than in Buxton and Shernoff (1995) (unless clays are weathered bedrock).
			LOG	195	-112	125	ABS	ABS	ABS	ABS	-237	>155	ABS	ABS	>-392	
Q3589	22	325	PUB	97	-75	75	-150	200	ABS	ABS	-350	175	-525	225	-750	Framework consistent with that in Buxton and Shernoff (1995); Jameco aquifer is thinner.
			LOG	98	-76	65	-141	136	ABS	ABS	-277	>26	ND	ND	ND	
Q3593[5]	15	225	PUB	10	ABS	ABS	ABS	ABS	ABS	ABS	-5	95	-100	70	-170	Framework consistent with that in Buxton and Shernoff (1995); upper glacial aquifer is thicker; 40 feet deeper to bedrock.
			LOG	60	ABS	ABS	ABS	ABS	ABS	ABS	-45	94	-139	71	-210	
Q3627[6]	77	540	PUB	297	ABS	ABS	ABS	ABS	ABS	ABS	-220	140	-360	140	-500	East-west extent of erosional channel is refined. Thick Gardiners Clay and Magothy aquifer encountered.
			LOG	150	-73	162	ABS	ABS	-235	218	-453	ND	ND	ND	ND	

1 Deep well of doublet with K3423.
2.Deep well of doublet with K3425.
3.Deep well of doublet with K3430.
4.Deep well of doublet with K3649.
5.Deep well of doublet with K3604.
6.Deep well of three-cluster with Q3628 and Q3629.
*PUB, published value (Buxton and Shernoff, 1995); LOG, Interpreted from lithologic and geophysical logs.

Revised Hydrogeologic Framework

Data from the 29 new wells enabled a refinement of the previously described hydrogeologic framework in Kings and Queens Counties. This updated information is outlined in table 10.

The hydrogeologic information given in table 10 represents only 11 of the 29 new monitoring wells described earlier; the remaining 18 new wells are omitted because they are shallow (upper glacial aquifer) wells that provide no new hydrogeologic information, or are the shallow wells of a well doublet or triplet. Each well in table 10 has two rows of data—the upper row presents data interpreted from plates 2 and 3 of Buxton and Shernoff (1995), and the lower row presents information derived from drillers' logs and geophysical logs of the new wells. (Only a few cores were obtained during drilling.)

The new hydrogeologic information obtained in this study generally is consistent with that presented in Buxton and Shernoff (1995), but because new wells were installed in areas where information was lacking, each provided a refinement of the hydrostratigraphy in its respective area. In addition to differences in thickness of the various units, a few changes in the updip extent of some units were defined. The revised hydrogeologic framework is summarized in table 10; other information provided by the new wells is summarized below.

Upper Glacial Aquifer

The only new data on the upper glacial aquifer pertain to its thickness (table 10). No new information regarding its areal extent is available, however, because this unit is present at land surface in nearly all of Kings and Queens Counties.

Gardiners Clay

No evidence of the Gardiners Clay was found in wells K3405, K3407, or K3414 in south-central and southern Kings County; this result suggests an elongated hole in the Gardiners Clay in that area, similar in size to two other holes in the Gardiners Clay to the east in Kings and Queens Counties. The presence of Gardiners Clay in well Q3627 extends the previously defined northern limit about 0.5 mi northward.

Jameco Aquifer

The absence of the Jameco aquifer in well K3410 indicates that the northern limit of these deposits is more than 1 mi south of its previously estimated position. New data indicate no other revisions to the extent of the Jameco aquifer.

Magothy Aquifer

New data for the Magothy aquifer are in fairly close agreement with data of Buxton and Shernoff (1995), except those data from wells K3410 and K3431. These wells are northwest of the Magothy aquifer's northern extent as defined by Buxton and Shernoff (1995) and contain about 50 ft of gray sand and clay similar to that found in the Magothy aquifer. These wells are surrounded by wells that do not penetrate the Magothy aquifer; thus, the question remains as to whether wells K3410 and K3431 penetrate an isolated stringer of the Magothy aquifer. A second refinement to the northern extent of the Magothy aquifer is in Queens County, near the buried channel. Wells Q3627 and Q3589, along the eastern and southeastern extent of the channel, provide new data on channel boundaries.

Raritan Clay and Lloyd Aquifer

Four of the new wells were drilled deep enough to penetrate the Raritan clay, but only one provided new data. Well K3410, in central Kings County, penetrated the Raritan clay about 1 mi east-southeast of the previously defined northern limit of this unit. Only three of the new wells were drilled deep enough to penetrate the Lloyd aquifer. The differences in unit thickness are presented in table 10; no changes in the extent of the Lloyd aquifer as defined by Buxton and Shernoff (1995) were found.

SUMMARY AND CONCLUSIONS

Pumpage from the aquifers underlying Kings and Queens Counties during 1904-47 averaged 120 Mgal/d. This resulted in extremely large drawdowns and saltwater encroachment, and necessitated the cessation of all public-supply withdrawals in Kings County in 1947. Withdrawals in Queens County were increased to compensate for the shutdown in Kings County, and pumping shifted from the upper glacial aquifer to the Magothy aquifer to avoid contamination. By 1974, all remaining public-supply wells in Queens County were shut down except for JWS wellfields in eastern Queens County, which continued to pump at an average rate of about 57 Mgal/d. The elimination of public-supply withdrawals in Kings and western Queens Counties resulted in a steady recovery of ground-water levels in these areas. By 1983, ground-water levels in Kings County were close to predevelopment levels (1903), and contamination by saltwater had partly dispersed and become diluted. In contrast, all three aquifers (upper glacial, Jameco-Magothy, and Lloyd) in eastern Queens County showed a large cone of depression toward which the freshwater-saltwater interface in the Jameco-Magothy aquifer was moving. Similar landward movement of the interface had been detected in the Lloyd aquifer, although the location was estimated to be offshore.

Elevated nitrate and chloride concentrations (above background levels) in the upper glacial aquifer in 1983 indicated widespread contamination from land surface. Some effects of surface contamination also were present in the Jameco-Magothy aquifer in areas of good hydraulic connection with the upper glacial aquifer. Ground water in the Lloyd aquifer in 1983 still was largely uncontaminated, although the observed cone of depression and the hydraulic connection provided by the buried channel have been a cause for concern over the potential for the migration of contaminants into the Lloyd aquifer.

Recent reductions in public-supply withdrawals in Queens County from 57 Mgal/d in 1983 to 24 Mgal/d in 1991 and to 14 Mgal/d in 1996 have resulted in the recovery of ground-water levels in the eastern part of Queens County. Concurrently, increased withdrawals for industrial supply and dewatering in Kings County have resulted in local drawdowns in some areas, although water levels throughout Kings County are still above sea level.

By 1997, the upper glacial aquifer in Kings County generally was stable, and water levels at most wells were between 0 and 10 ft above sea level. The two large depressions in the 1983 Queens County water table had recovered, and water levels had risen as much as 30 ft at certain wells. Similarly, the water table in western Nassau County, adjacent to past cones of depression in Queens County, showed some recovery. The result has been a shift in the general direction of ground-water flow from southwestward in 1983 to south-southwestward in 1997.

The 1996 potentiometric surface of the Jameco-Magothy aquifer in Kings County was delineated from data from six wells, as compared with two wells used in 1983. Water levels in these wells in 1996 were similar to those measured in 1983 and indicated near-equilibrium conditions. In contrast, water levels in all 15 Jameco-Magothy aquifer wells in Queens County had risen sharply—by as much as 27 ft. Available data indicate that the potentiometric surface in 1996 was above sea level throughout Queens County. Water levels in the Jameco-Magothy aquifer in western Nassau County also have been recovering since 1983. Water levels at wells closest to the coast showed little, if any, change since 1983, whereas wells in west-central Nassau County, adjacent to the 1983 cone of depression in eastern Queens County, had recovered by as much as 18.6 ft by 1996.

The recent potentiometric surface of the Lloyd aquifer in Kings County is defined by only two wells; one was measured in 1983 and 1996, and the other only in 1996. The former measurements indicate a water-level recovery of 4.5 ft in southern Kings County since 1983, and the latter measurement indicates a water level of 8 ft above sea level. More data are available on the Lloyd aquifer in Queens County than in Kings County; all wells in Queens County showed increases in water levels from 1983 to the present. The largest recoveries were at public-supply wells in central Queens County, where water levels increased as much as 35 ft.

Recent water-level recoveries generally have resulted in the dilution and dispersion of residual saline and nitrate-contaminated ground water. Dilution and dispersion probably have been occurring since public-supply withdrawals were halted in Kings County in 1947, and in Queens County in 1974.

Chloride concentrations at 75 percent of wells screened in the upper glacial aquifer in Kings and Queens Counties have decreased or remained the same since 1983. Similar trends in chloride concentrations are evident in the Jameco-Magothy aquifer in Kings and Queens Counties, although data from Kings County are limited. Geophysical logs, together with chloride data, indicate that the freshwater-saltwater interface in southern Kings County may be 1.5 mi farther inland than estimated in 1983. This result does not suggest that the interface has moved farther inland since 1983, but that its inland extent may have been underestimated in 1983. Recent chloride-concentration data from the Lloyd aquifer, although limited, indicate that concentrations are similar to those of 1983. Data from new wells indicate that saline ground water in the Lloyd aquifer is about 7 mi farther inland than estimated in 1983. These data are in question, however, and additional information would be necessary to evaluate the position of the interface.

Nitrate concentrations at the majority of wells screened in all three aquifers in Kings, Queens, and western Nassau Counties have declined since 1983, probably in response to the dilution, degradation, and dispersion that have resulted from the long-term water-level recovery.

Data on organic-compound concentrations at public-supply wells in Queens and western Nassau Counties, and for monitoring wells in Kings, Queens, and western Nassau Counties, are available. The organic-compound data set for the monitoring wells is the first of this type of data collected in the study area.

Queens County had 39 public-supply wells with detectable concentrations of organic compounds in 1992; half of these were screened in the upper glacial aquifer, and half in the Jameco-Magothy aquifer. The most frequently detected compounds were tetrachloroethene, chloroform, total trihalomethanes, and trichloroethene; concentrations of all compounds ranged from 0.5 µg/L to 150 µg/L. These compounds were detected in a higher percentage of upper glacial aquifer wells than in Jameco-Magothy aquifer wells.

Nassau County had 16 public-supply wells with detectable concentrations of organic compounds in 1992, 25 percent (4) of which were upper glacial aquifer wells, and 75 percent (12) Jameco-Magothy aquifer wells. The most frequently detected compounds were the same as in Queens County, and concentrations ranged from 0.5 µg/L to 160 µg/L. Tetrachloroethene and trichloroethene were detected most frequently in the Jameco-Magothy aquifer wells, whereas chloroform and total trihalomethanes were detected mostly in upper glacial aquifer wells.

Queens County had 19 public-supply wells with detectable concentrations of organic compounds in 1996. Seven of these were upper glacial wells, and about 12 were Jameco-Magothy aquifer wells. The most frequently detected compounds were tetrachloroethene and trichloroethene; the concentrations of all compounds ranged from 0.5 µg/L to 220 µg/L. Tetrachloroethene was detected in the same percentage of upper glacial aquifer wells as Jameco-Magothy aquifer wells, whereas trichloroethene was detected more frequently in Jameco-Magothy aquifer wells.

Nassau County had 10 public-supply wells with detectable concentrations of organic compounds in 1996; two of these were upper glacial aquifer wells, and eight were Jameco-Magothy aquifer wells. The most frequently detected compounds were tetrachloroethene and trichloroethene; the concentrations of all compounds ranged from 0.06 µg/L (dieldrin) to 170 µg/L (trichloroethene). These compounds were detected most frequently in the Jameco-Magothy aquifer wells.

Detectable concentrations of at least one organic compound were found in 26 of the 108 monitoring wells in Kings, Queens, and Nassau Counties in 1992-93 and 1995. Organic compounds were detected in twice as many wells in Kings County as in Queens County, and in only one well in Nassau County. The most commonly detected organic compounds were tetrachloroethene and trichloroethene, followed by chloroform. Maximum concentrations of all organic compounds measured ranged from 0.02 µg/L (pesticides) to 150 µg/L for tetrachloroethene. Of the 25 monitoring wells in Kings and Queens Counties with detectable concentrations of organic compounds, 24 were upper glacial aquifer wells, whereas most of the public-supply wells in Queens County with detectable concentrations were Jameco-Magothy aquifer wells (1992 and 1996 data). This result suggests that the public-supply wells screened in the Jameco-Magothy aquifer in Queens County drew organic contaminants downward from a surface source during the 1960’s and 1970’s, when a large cone of depression was present. In contrast, limited use of synthetic organic compounds prior to 1947 would minimize the possibility of these contaminants presence in the deeper aquifers. In addition, any organic contaminants that were drawn down into deeper aquifers in Kings County before 1947, when pumping was extensive, probably have had time to become degraded, diluted, and dispersed.

The installation of new monitoring wells in the study area from September 1992 through October 1995 has resulted in a refinement of hydrogeologic boundaries, both laterally and with depth. Although most of the refinements are relatively minor, they could prove valuable for localized studies in the future.

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