RECONNAISSANCE OF THE GROUND-WATER RESOURCES OF KINGS AND QUEENS COUNTIES, NEW YORK

By Herbert T. Buxton, Julian Soren, Alex Posner, and Peter K. Shernoff

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CONTENTS

TABLES

ILLUSTRATIONS

ILLUSTRATIONS

CONVERSION FACTORS AND ABBREVIATIONS

Multiply inch-pound units	By	To obtain metric (SI)[1] units
cubic feet per second (ft^3/s)	.0283	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	.0438	cubic meters per second (m^3/s)
mile (mi)	1.609	kilometer (km)
foot (ft)	.3048	meter (m)
micromho per centimeter (μmho/cm)	1.001	microsiemens (μS)

National Geodetic Vertical Datum of 1929 (NGVD)

1 International System of units

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ABSTRACT

Western Long Island's ground water is being considered for redevelopment as a supplemental source of public supply. The ground-water reservoir in Kings and Queens Counties supplied an average of more than 120 million gallons per day for industrial and public water supply from 1904 to 1947; however, deterioration of water quality from induced saltwater encroachment caused the cessation of pumping for public supply in Kings County in 1947 and in western Queens County in 1974.

Since the cessation of pumping, the maximum water-table altitude in Kings County has recovered to within 8 feet of the altitude in 1903. At present (1981), eastern Queens County has a major cone of depression, but water levels have not been drawn down to the historical extremes of Kings County.

Chloride and nitrate are indicators of contamination from saltwater intrusion and surface sources. Present chloride and nitrate concentrations in the upper glacial aquifer are generally above predevelopment levels (<0.2 milligrams per liter nitrate as N; <10 milligrams per liter chloride). However, some dilution in areas of past severe saltwater intrusion is evident. Contamination seems most severe in the upper glacial aquifer but decreases eastward and with depth. Contamination of the deeper aquifers from surface sources is attributed mainly to downward migration in zones of hydraulic connection between aquifers. The deeper aquifers show evidence of residual chloride contamination from past intrusion, but the extent of the zone of diffusion in these aquifers is not accurately defined.

Some potable water is available in the Magothy-Jameco and Lloyd aquifers; however, a precise estimate of the quantity of water available is undetermined.

INTRODUCTION

The western part of the Long Island ground-water reservoir (fig. 1) has been a source of public supply since the mid-19th century. However, an incomplete understanding of the hydrology of the ground-water system and the resultant failure to develop a comprehensive management plan for developing this resource resulted in detrimental effects that to some extent continue to the present. Rapid increases in population and the attendant increase in pumping of ground water for industry and public supply, in addition to numerous effects of urbanization, resulted in severe water-level declines and intrusion of water from coastal saltwater bodies. As a result, pumping for public supply in Kings County was stopped in 1947 and in southwest Queens County in 1974. As the early pumping centers in Queens County were abandoned, new ones were established farther east in areas more distant from the shore and where water-table altitudes were higher.

Since the cessation of pumping, water levels in western Long Island have recovered continuously. In some areas where the water table had been severely drawn down, as much as 35 ft below sea level[1], water levels are now above sea level. In many of these areas, subways and deep basements that were constructed in the early 20th century, when water levels were depressed, are now being flooded as the water table recovers, and must be continuously dewatered.

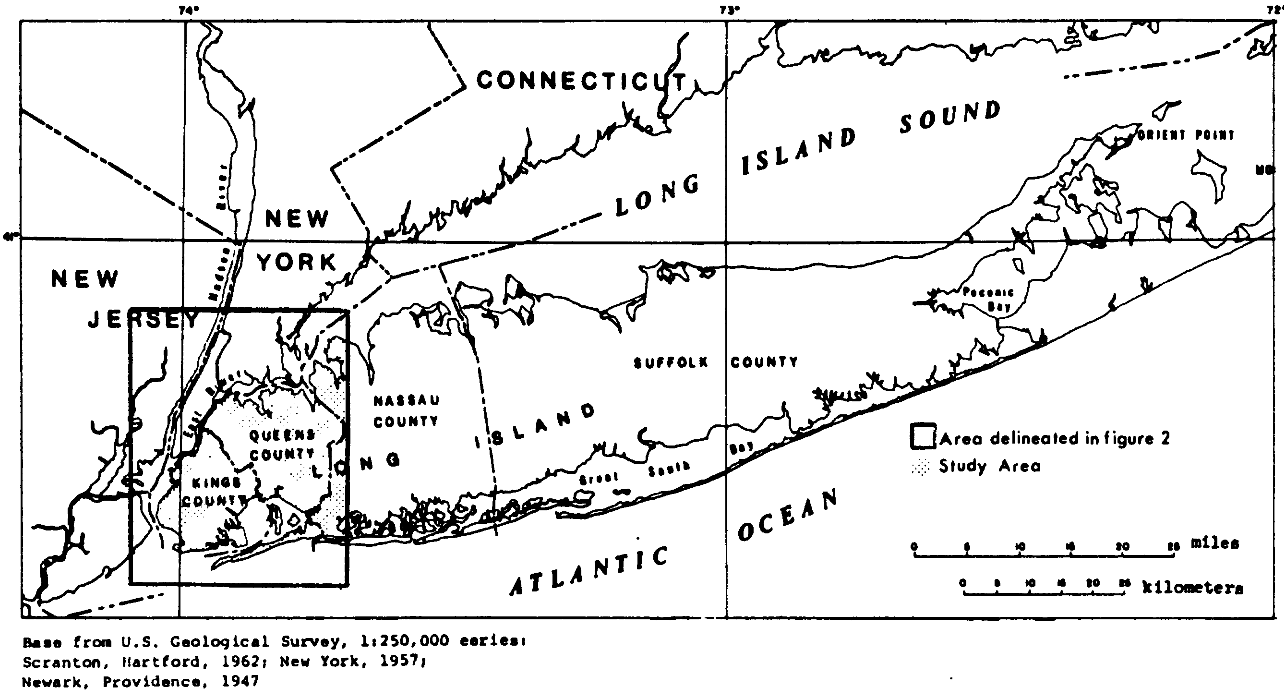

Figure 1.--Location of Kings and Queens Counties, Long Island, N.Y.

Purpose and Scope

This report summarizes results of the first phase of a detailed investigation of the western part of the Long Island ground-water system. The investigation was undertaken by the U.S. Geological Survey, in cooperation with the New York State Department of Environmental Conservation and the Department of Environmental Protection of the City of New York. Its purpose is to determine whether the ground-water reservoir of western Long

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1/"Sea level" is used in place of National Geodetic Vertical Datum of 1929 (NGVD) to indicate fluctuating altitudes, or altitudes that occurred before the establishment of NGVD.

Island is still a useable source of water despite deterioration in quality from past pumping, and, if so, to provide the data and technical interpretation needed to begin developing a management plan for its optimum use.

The first phase of the investigation had the following objectives:

(1) To present a preliminary interpretation of the hydrogeology of the western part of the Long Island ground-water system, including the geometry of the major hydrogeologic units and their water-bearing characteristics.

(2) To briefly describe the predevelopment ground-water system including patterns of ground-water flow and ground-water quality.

(3) To describe the complex effects of urbanization and the development of the ground-water reservoir by summarizing historic pumpage data and the subsequent hydrologic response of the ground-water system.

(4) To develop an observation-well network to determine present ground-water levels and quality and to enable observation of changes resulting from any implemented pumping plan.

(5) To present the results of water-level observations and preliminary water-quality sampling. Water-level data are presented as a map of the 1981 water-table configuration; results of water-quality analyses are presented in a table and on maps showing the distribution of nitrate (NO_3^- as N) and chloride (Cl^-) in the major aquifers.

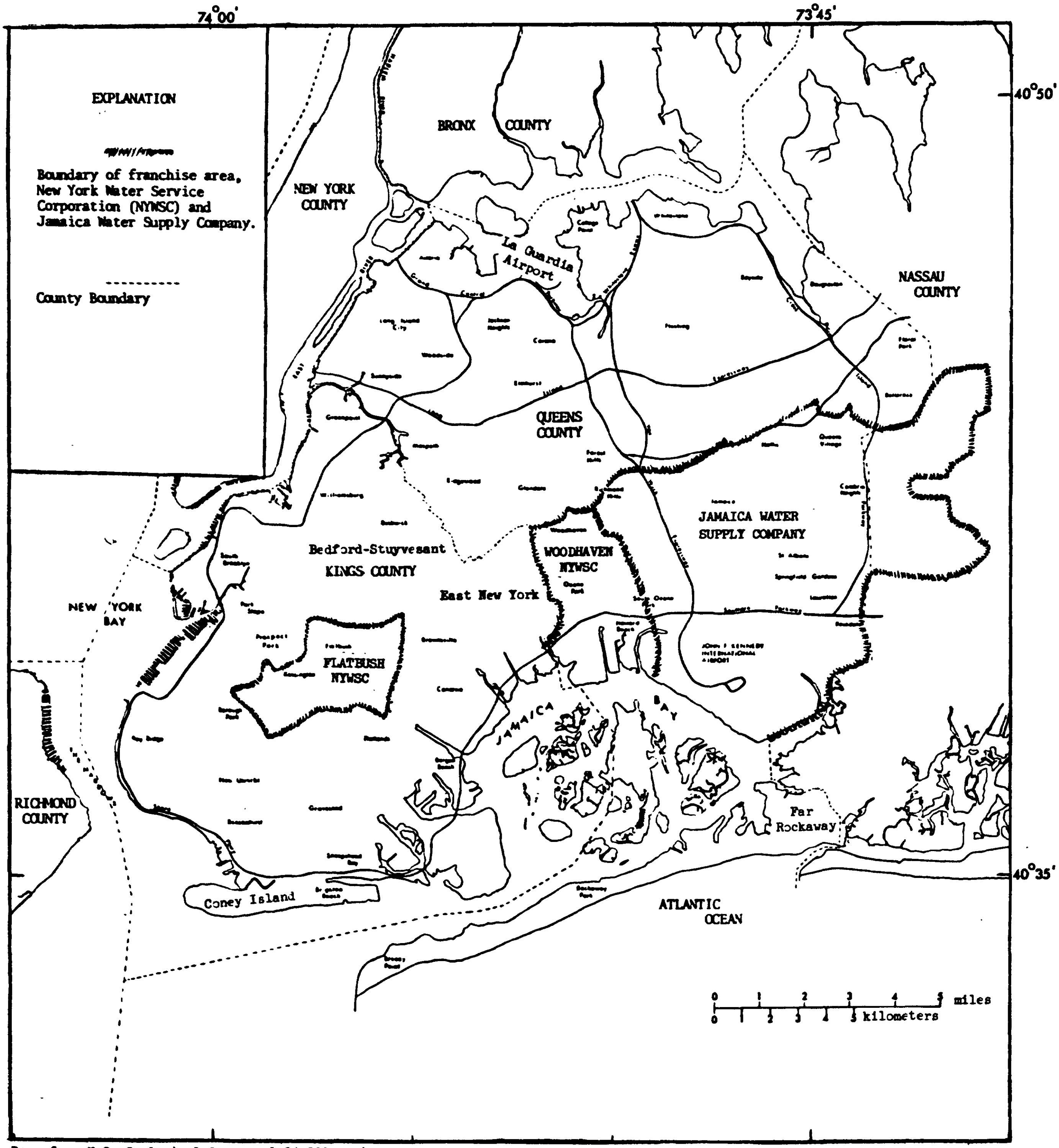
A proposed second phase of the study, not discussed in this report, entails the development and application of a three-dimensional digital model of the ground-water flow system to predict the effects of natural hydrologic fluctuations and proposed water-management plans.

Location and Geography

The area investigated includes all of Kings County (approximately 76 mi^2), all of Queens County (113 mi^2), and westernmost Nassau County. The area studied is bounded on the west by The Narrows, New York Bay, and the East River, on the north by the East River and Long Island Sound, on the south by the Atlantic Ocean, and on the east by Nassau County (fig. 2). Figures 1 and 2 show the location of the study area and major geographic features. Kings and Queens Counties, the Boroughs of Brooklyn and Queens, have been highly urbanized for most of this century. In 1980, the population was 2.22 million in Kings County and 1.89 million in Queens County.

Acknowledgments

Thanks are given the New York State Department of Environmental Conservation and the New York City Department of Environmental Protection for their support and cooperation. Special thanks are given Romola Popper and the staff of the Bureau of Water Supply Laboratory of the New York City Department of Environmental Protection for cooperation in handling and analysis of water-quality samples.



Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 2.--Major geographic features of western Long Island.

GEOLOGIC SUMMARY

The ground-water reservoir that underlies western Long Island is composed of a series of unconsolidated deposits of clay, sand, and gravel of Late Cretaceous and Pleistocene age. The stratigraphic relationship of the hydrogeologic units is summarized in table 1; their relative position is depicted in sections in figure 3. The unconsolidated formations are underlain by crystalline bedrock of Precambrian(?) age (figs. 3 and 4).

The bedrock was eroded to a peneplain before the overlying Cretaceous sediments were deposited; its surface shows signs of later erosion by Pleistocene glaciation in the north. Bedrock crops out in northwestern Queens County near the East River and slopes southward at about 80 ft/mi. Consequently, the overlying formations form a southward-dipping wedge that attains a maximum thickness of 1,150 ft in the southeast corner of Queens County. The maximum thickness of unconsolidated deposits in Kings County is about 800 ft, in southeast Kings.

Overlying bedrock is the Raritan Formation of Late Cretaceous age, consisting of the Lloyd Sand Member and an upper, unnamed clay member. Overlying the Raritan Formation is the Magothy Formation and Matawan Group, undifferentiated, also of Late Cretaceous age, the Jameco Gravel of Pleistocene (Illinoian?) age, the Gardiners Clay of Pleistocene (Sangamon) age, upper Pleistocene deposits of Wisconsin age, and a generally thin soil mantle of Holocene age (fig. 3). Holocene beach deposits make up most of the Rockaway Peninsula and Coney Island in the south (fig. 2), and Holocene salt-marsh deposits underlie and fringe the south-shore bay areas. Artificial filling has been done in low and swampy shoreline areas. Because Holocene deposits occur in relatively small areas of Kings and Queens and are not significant water bearers, they are not included in the geologic descriptions that follow.

Erosion of the Cretaceous strata from Late Cretaceous through Pleistocene time has resulted in a complex buried topography. An understanding of the depositional and erosional sequences associated with these units is integral to an accurate stratigraphic interpretation.

The most recent interpretive publication on the geology of Kings County is Suter and others (1949). More recent mapping of geologic units in Queens County (Soren, 1971 and 1978) made use of a greater number of wells and more detailed geologic and geophysical data; this allowed more accurate definition of the geology and provided new information on the depositional history of the units in western Long Island. The geologic data compiled from these sources, along with drillers' geologic logs, were reinterpreted in light of the current understanding of the erosional history. The resultant hydrogeologic interpretation reflects major revisions in Kings County and several minor revisions in Queens County along the Kings-Queens County border. The descriptions of geologic units in the following paragraphs include maps of the surface configuration of each unit (figs. 4-9).

Table 1.--Western Long Island stratigraphic column with geologic and hydrogeologic interpretation.

SYSTEM	SERIES	GEOLOGIC UNIT		HYDROGEOLOGIC UNIT	RANGE OF THICKNESS, IN FEET	RANGE OF ALTITUDE OF UPPER SURFACE, IN FEET ABOVE OR BELOW NGVD
QUATERNARY	Holocene	Shore, beach salt-marsh deposits and alluvium				
	Pleistocene	Wisconsin Glaciation (Harbor Hill, interstadial marine and Ronkonkoma? Drift	Till (ground and terminal moraine) Outwash "20-foot" clay (marine) unconformity?	Upper glacial aquifer	0-300	Land surface
		Sangamon Interglaciation	Gardiners Clay (marine) unconformity?	Gardiners Clay	0-150	-40 to -200
		Pre-Wisconsin Glaciation (Illinoian?)	Jameco Gravel unconformity?	Jameco aquifer	0-200	-90 to -240
CRETACEOUS	Upper Cretaceous	Magothy Formation and Matawan Group undifferentiated unconformity?		Magothy aquifer	0-500	40 to -400
		RARITAN FORMATION	Clay member	Raritan confining unit	0-200	30 to 650
			Lloyd Sand Member unconformity?	Lloyd aquifer	0-300	-90 to -825
PRECAMBRIAN			Crystalline bedrock	Bedrock	—	15 to -1100

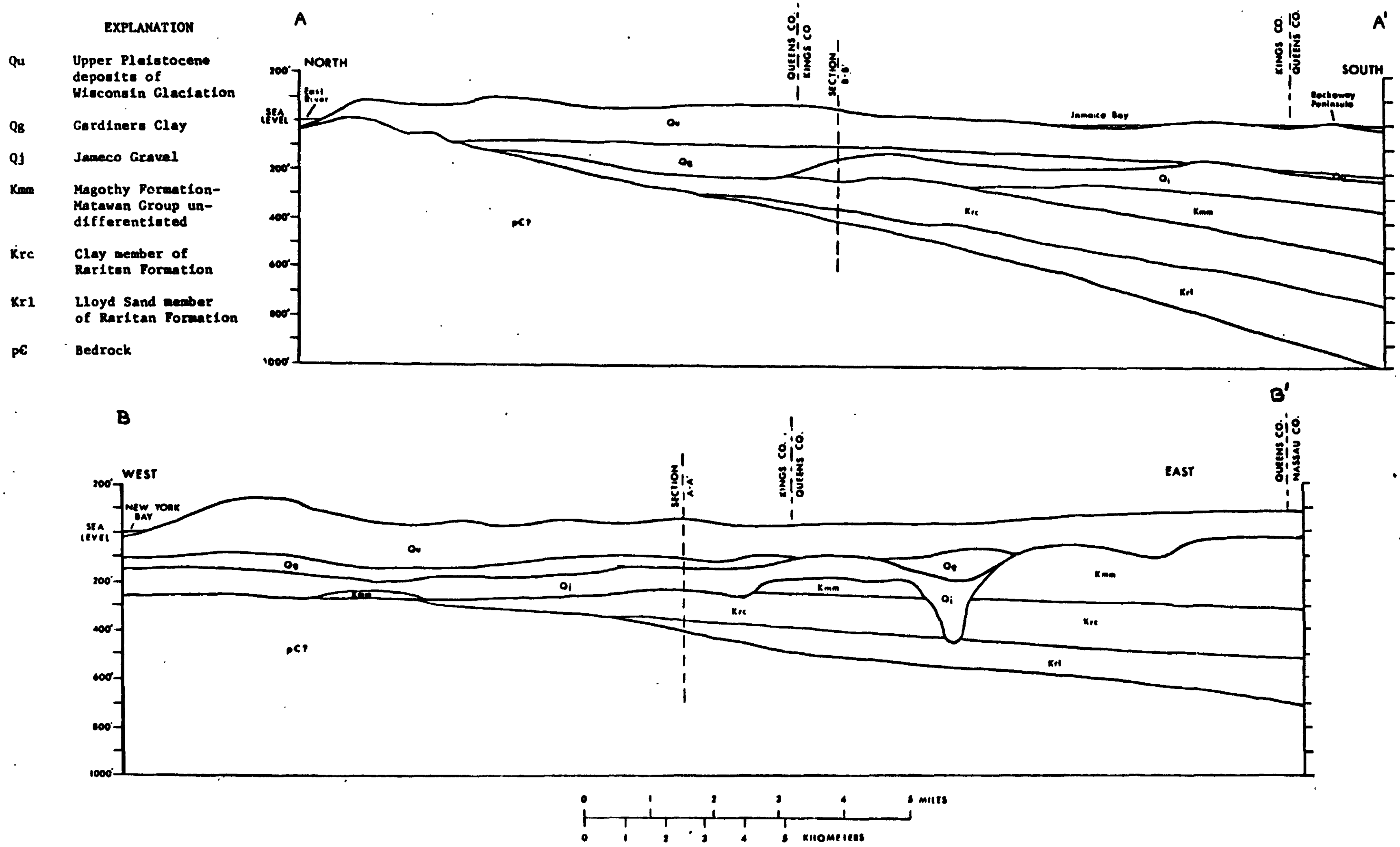
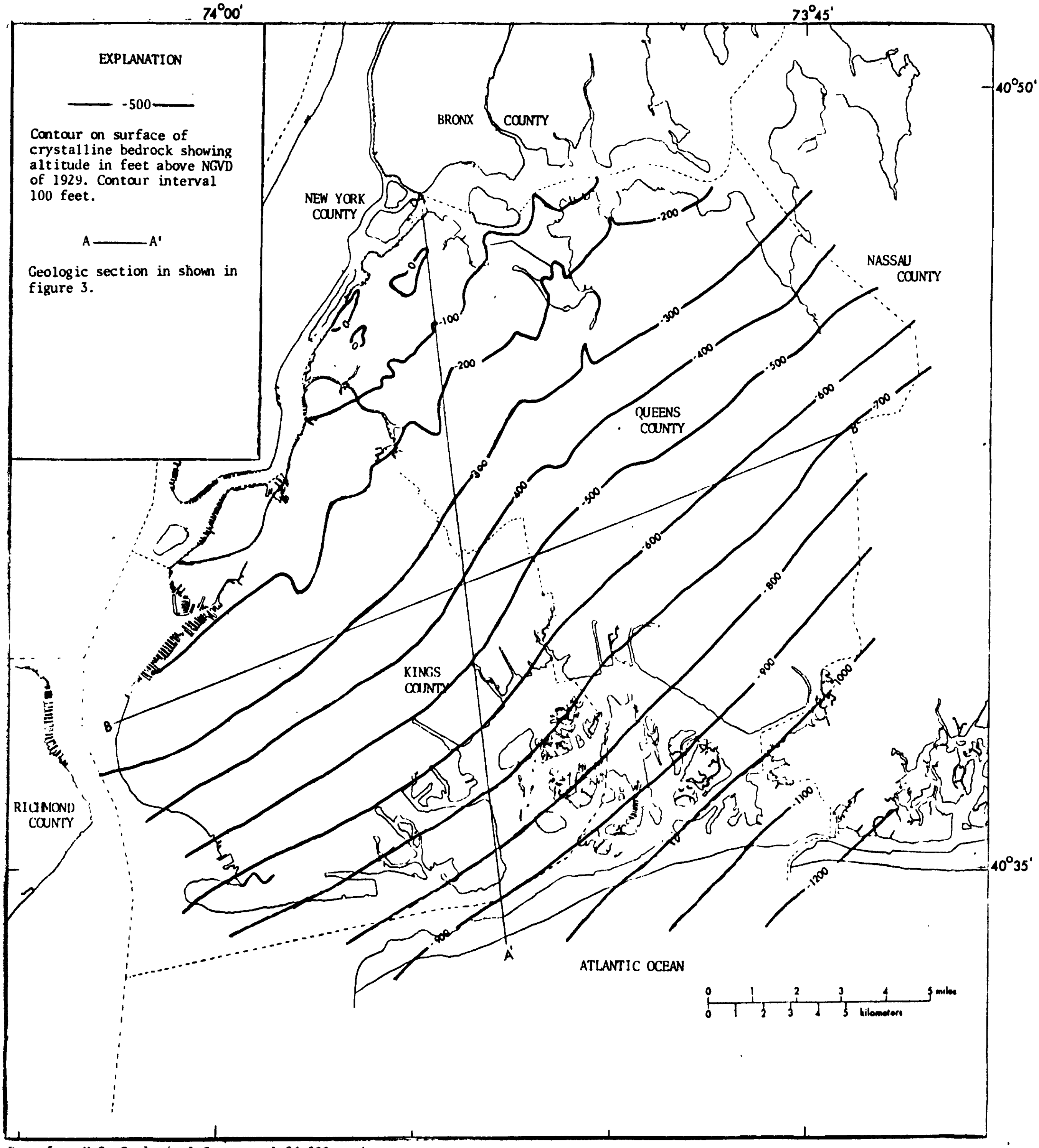


Figure 3.--Hydrogeologic sections. Locations are shown in figures 4-9; stratigraphic relationships are summarized in table 1.



Base from U.S. Geological Survey , 1;24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mt. Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
Far Rockaway, Weehawken, 1954.

Geology by Buxton and others, 1981, and Soren, 1978.

Figure 4.--Surface configuration of the crystalline bedrock.

Upper Cretaceous

Lloyd Sand Member of the Raritan Formation

The Lloyd Sand Member, the earliest Cretaceous deposit in the area, lies unconformably on bedrock. It is absent in northwestern Kings and Queens Counties (fig. 5). The limit generally follows a line from southwest Kings County through central Kings northward to near New York Municipal (LaGuardia) Airport. As a result of pre-Wisconsin erosion, the formation is also missing in a tributary buried valley system extending from near the north shore in central Queens County to south of the Long Island Expressway.

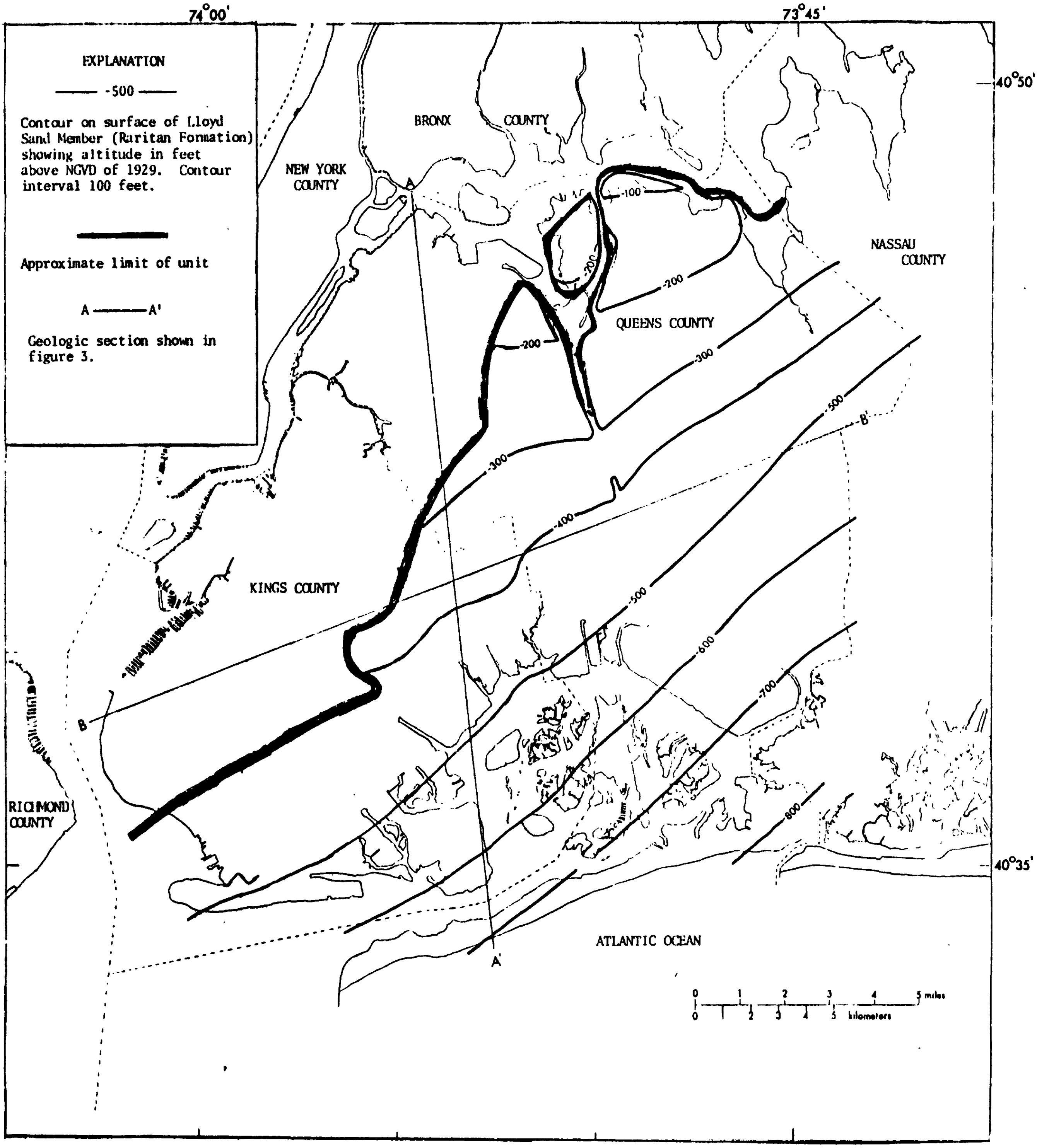
The Lloyd Sand Member consists mainly of deltaic deposits of fine to coarse quartzose sand interbedded with sand and small- to large-pebble quartzose gravel. Interbeds of silt and clay and silty and clayey sand are common throughout the unit. The member is overlain and generally overlapped by the clay member of the Raritan Formation. The extent of the Lloyd Sand Member and the clay member are largely coincident where eroded in the buried valley system in northern Queens, but in some places the clay member extends well north of the underlying Lloyd Sand Member.

Thickness of the Lloyd Sand Member ranges from zero at its northern extent to about 200 ft at Kings County's southeast edge and 300 ft in southeast Queens County. The unit's surface is as shallow as 90 ft below sea level in northern Queens County and as deep as 825 ft below sea level in the southeast.

Clay Member of the Raritan Formation

The clay member of the Raritan Formation is absent in the western part of Kings County and in northwestern Queens (fig. 6) and is eroded in central Queens County in the same buried valley system as the Lloyd Sand Member; however, the clay member has been more extensively eroded, especially to the south. The clay member consists mainly of deltaic clay and silty clay beds and some interbedded sand. The clay member increases in thickness from a knife edge at its northern limit to about 150 ft in southeast Kings County and about 200 ft in southeast Queens County. Its upper surface lies as shallow as 120 ft below sea level in Kings County and a few feet above sea level in parts of northern Queens. It is as deep as 500 ft below sea level in southern Kings County and 650 ft below sea level in southeast Queens.

The clay member overlies the Lloyd Sand Member with apparent conformity and lies unconformably on bedrock. It was disconformably overlain by the remaining Upper Cretaceous deposits; however, as a result of a complex erosional history after the Late Cretaceous Epoch, the clay member became overlain northward by the Magothy Formation, the Jameco Gravel, the Gardiners Clay, and upper Pleistocene deposits, respectively (fig. 3).



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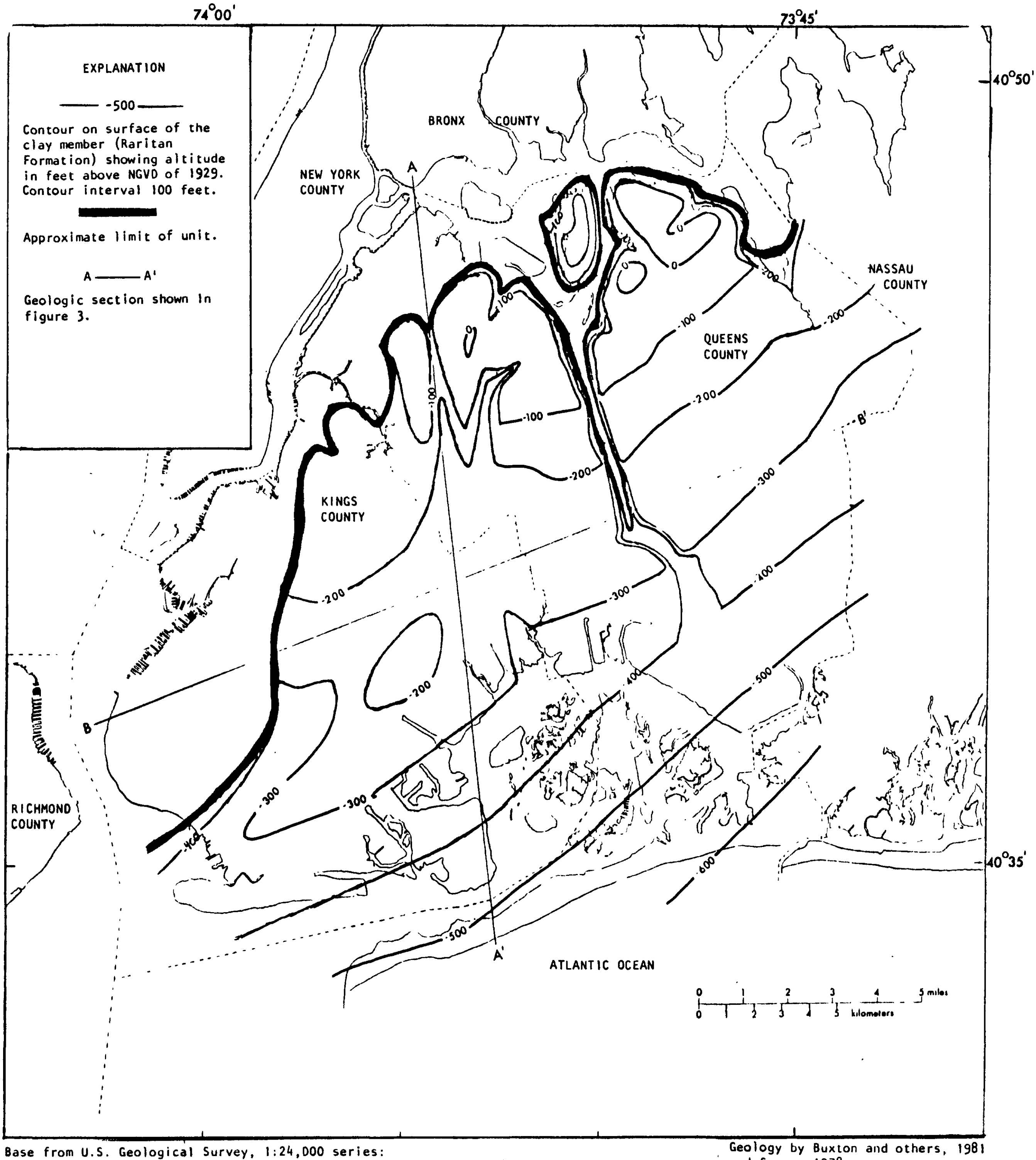
and Far Rockaway, Weehawken, 1954.

Geology by Buxton and others, 1981 and Soren, 1978

Figure 5.--Surface configuration of the Lloyd Sand Member of the Raritan Formation.



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and Far Rockaway, Weehawken, 1954.

Geology by Buxton and others, 1981
and Soren, 1978

Figure 6.--Surface configuration of the clay member of the Raritan Formation.

Magothy Formation and Matawan Group

The Magothy Formation and Matawan Group, undifferentiated comprises the remaining deposits of the Cretaceous Period in this area. This uppermost Cretaceous unit was severely eroded from the Late Cretaceous to the time of deposition of the Jameco Gravel. The erosion is most severe in what was probably a complex channel network from an ancestral diversion of the Hudson River (Soren, 1978, p. 12-15 and plate 2G). The Cretaceous surface in Kings and Queens Counties is a buried erosional surface. The surface configuration and extent of the unit (fig. 7) clearly show the effects of erosion. Two prominent channels have a north-south trend, one through central Queens and one generally parallel to the Kings-Queens County line. These channels have eroded through the unit to very near the south shore, where they seem to join and continue south in a single channel. Where the unit has been completely eroded, dissection is evident in the underlying clay member and Lloyd Sand Member of the Raritan Formation (figs. 5 and 6), and even in the bedrock in a small area of north-central Queens County (fig. 4). Erosion is also evident in Kings County, where northeast-southwest channelization has eroded through the unit and isolated a small area of remaining Magothy deposits in central Kings.

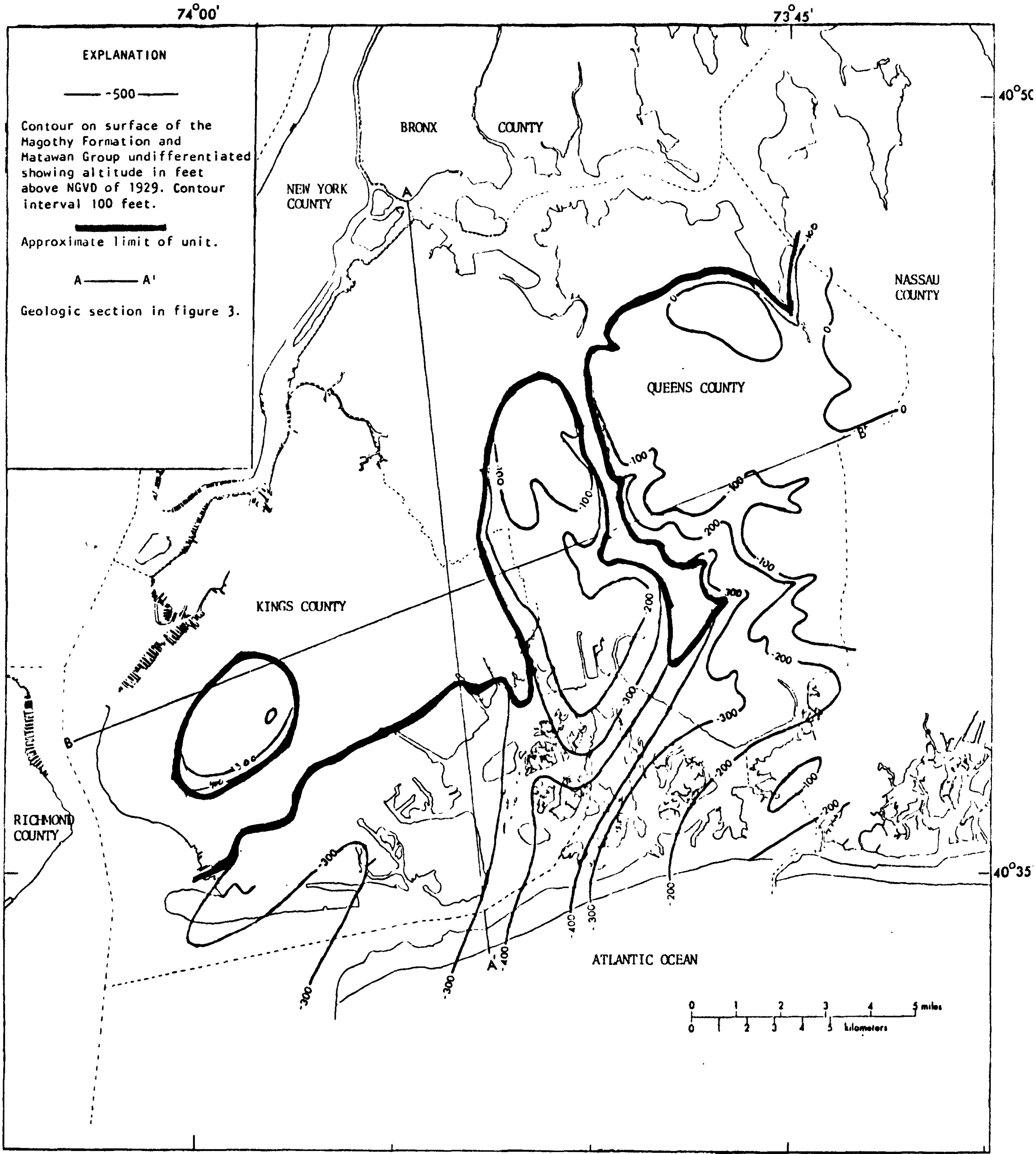
The deposits of the Magothy Formation and Matawan Group, like the earlier Cretaceous deposits, are of continental origin and are mostly deltaic quartzose very fine to coarse sand and silty sand with lesser amounts of interbedded clay and silt. The unit commonly has a coarse quartzose sand and in many places a gravel basal zone 25 to 50 ft thick.

The unit's thickness ranges from zero at its limits to more than 200 ft in southeast Kings and 500 ft in southeast Queens. It is significantly thinner in the buried valleys. Altitudes of the Magothy-Matawan surface range from a few feet above sea level in northeast Queens to more than 400 ft below sea level in the buried valley to the south.

Pleistocene

Jameco Gravel

The Jameco Gravel is the earliest Pleistocene deposit in the area (fig. 8). It is considered to be a channel filling associated with an ancestral pre-Sangamon (Illinoian?) diversion of the Hudson River (Soren, 1978, p. 8). This episode of fluvial erosion was probably also largely responsible for the irregular configuration of the Late Cretaceous land surface. The Jameco Gravel is present in most of Kings County and southern Queens County. It reaches greatest thickness in the deep channels eroded in the underlying unit and thins severely over the higher areas. For example, a small area in southeast Queens in which the Jameco Gravel has not been found coincides with a high point on the surface of the underlying Magothy Formation-Matawan Group (fig. 7). Thickness of the Jameco Gravel ranges from a knife edge at its northern limit to more than 200 ft in the main buried valley in central Queens County.



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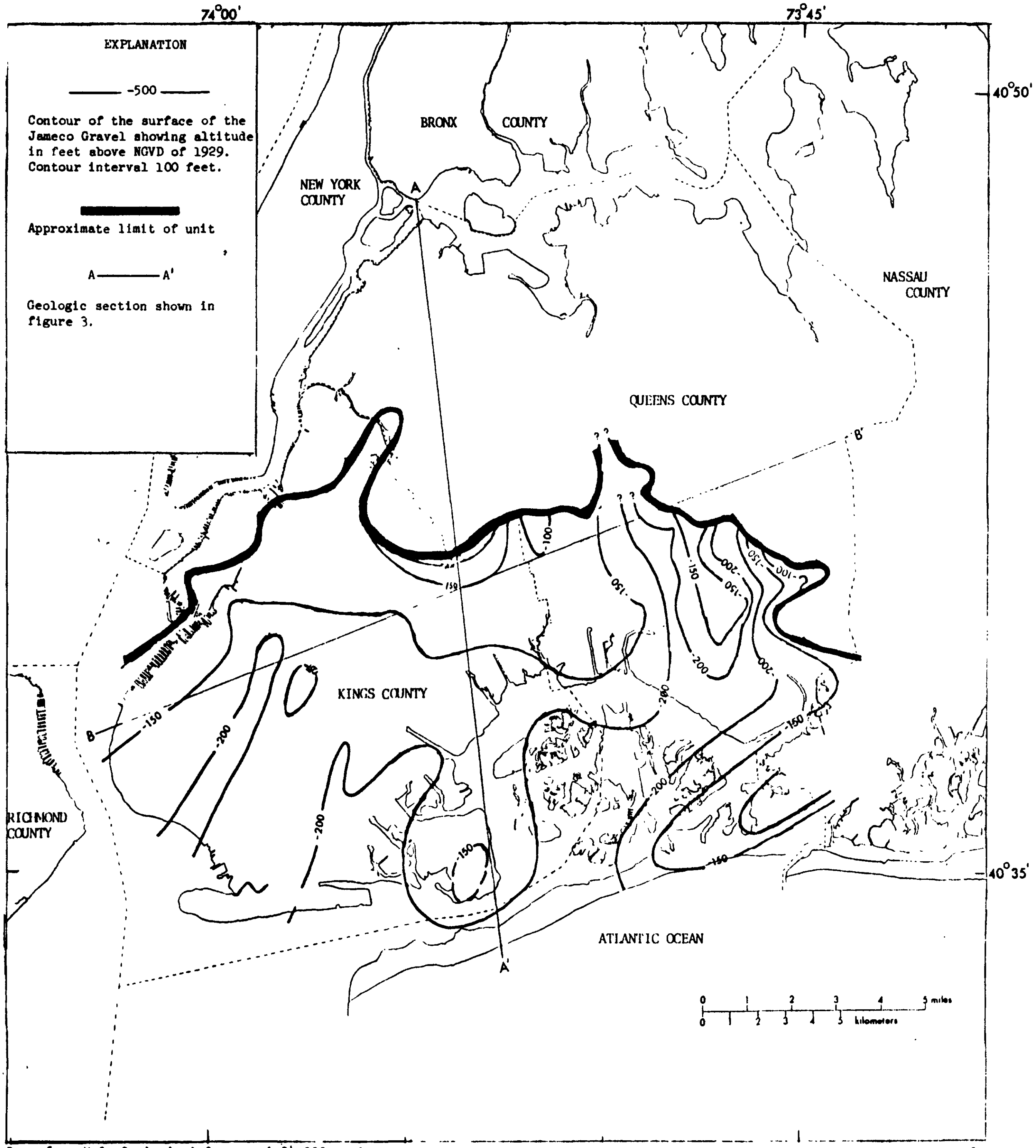
Geology by Buxton and others, 1981 and Soren, 1978

Figure 7.--Surface configuration of the Magothy Formation and Matawan Group, undifferentiated.



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Geology by Buxton and others, 1981 and Soren, 1978

Figure 8.--Surface configuration of the Jameco Gravel.

Jameco deposits consist mainly of a heterogeneous suite of igneous, metamorphic, and sedimentary rock types that are typically dark brown. The deposits grade from coarse sand and gravel with many cobbles and some boulders in the northern part of Kings County to finer particles southward. Many diabase fragments indicate transport by meltwater from a glacial terminus northwest of New York City. Soren (1978, p. 12-13) suggests that the Hudson was diverted from its channel on the west of Manhattan Island to Queens County (via the Harlem River channel) and that, from there, distributary streams carried diabase fragments into Kings and Queens Counties.

The surface altitude of the Jameco Gravel is generally highest along the unit's north edge, as shallow as 110 ft below sea level in northern Kings County, and 90 ft below sea level in Queens County. It is generally deeper to the south and over the deep channels eroded in the Late Cretaceous surface, where it is more than 200 ft below sea level. The surface of the Jameco Gravel was probably shaped by stream erosion and by glaciation.

Gardiners Clay

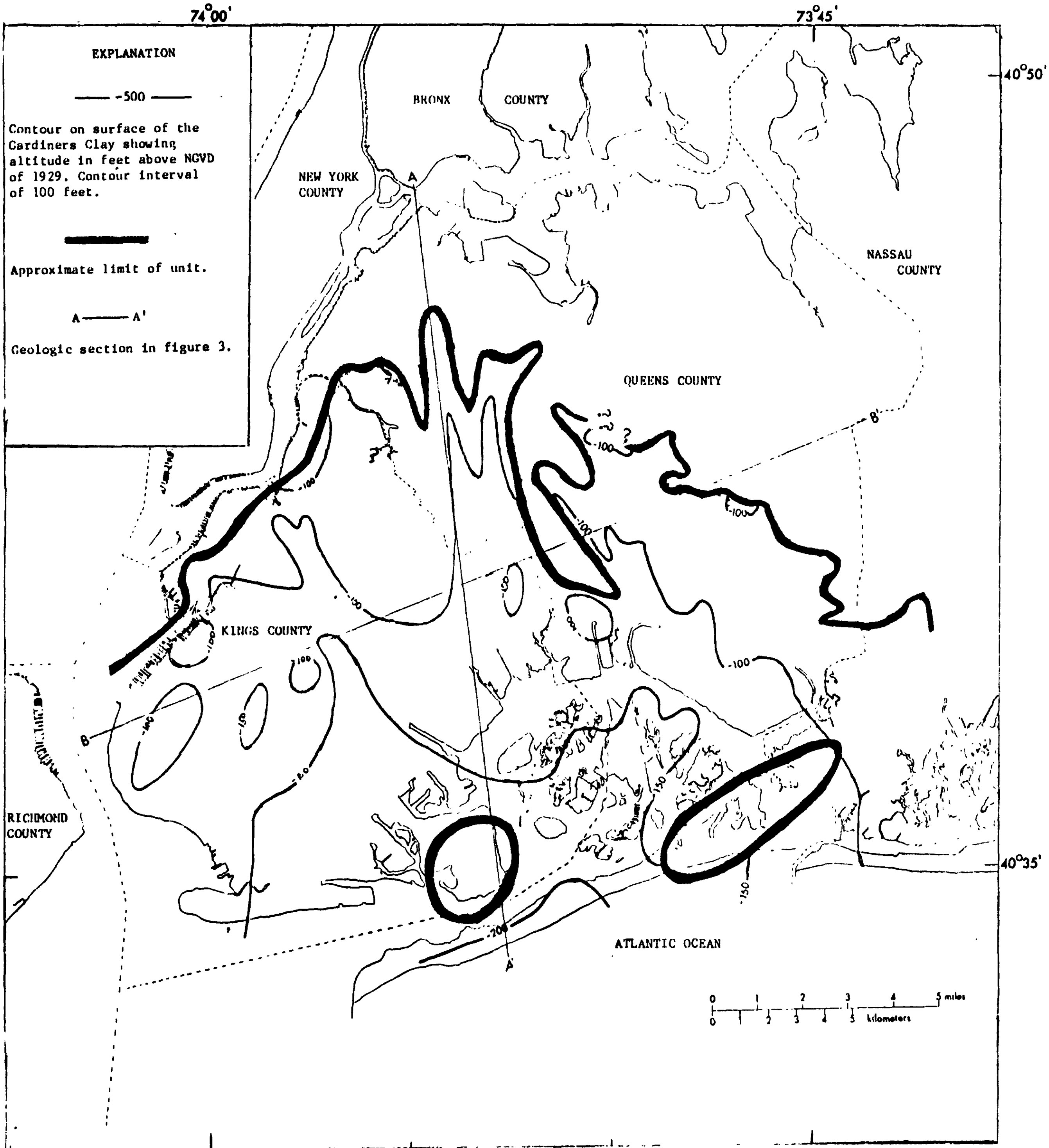
The Gardiners Clay occurs in most of Kings County and in the southwest part of Queens County (fig. 9). It unconformably overlies the Jameco Gravel and generally overlaps it along most of its extent.

The Gardiners Clay consists mainly of greenish-gray clay and silt and some interbedded sand. It was probably deposited in lagoonal and marine environments during an interglacial (Sangamon) interval (Soren, 1978, p. 10). The typical blue or green color of these beds is due to much glauconite, chlorite, and weathered biotite. The Gardiners Clay was commonly described as "blue clay" in many early 20th century drillers' logs. Fossil shells, foraminifera, and disseminated lignite are widespread in the formation.

Thickness of the Gardiners Clay ranges from a knife edge at its northern limit to a maximum of 150 ft in areas of stream and glacial erosion. The surface of the Gardiners Clay is predominantly flat but is probably affected locally by glacial erosion and compaction in the thickest areas. The upper surface ranges from less than 50 ft below sea level in the north to about 200 ft below sea level at the southernmost edge of the area. The Gardiners Clay is generally less than 100 ft below sea level at its northern extent and has not been found higher than 40 ft below sea level anywhere on Long Island. This is probably a result of the deposition during the Sangamon Interglaciation, when sea level is estimated to have been 40 ft lower than at present. The Gardiners Clay is probably absent in two localized areas in the southern part of the area, where underlying deposits (Magothy Formation and Matawan Group and Jameco Gravel) are higher than the expected surface of the Gardiners Clay.

Upper Pleistocene Deposits

These deposits are Wisconsin in age and of glacial origin. The deposits unconformably overlie all underlying units and are found at the surface in nearly all of Kings and Queens Counties. The surficial geology of this area was mapped by Fuller (1914). The glacial deposits include: (1) terminal



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Geology by Buxton and others, 1981 and Soren, 1978

Figure 9.--Surface configuration of the Gardiners Clay.

moraine deposits emplaced by an ice front of Harbor Hill age (see fig. 11, p. 22); (2) ground-moraine deposits north of the terminal moraine; and (3) glacial outwash south of the terminal moraine. Thickness of the upper Pleistocene deposits range from zero in small areas of northwestern Queens, where bedrock crops out, to as much as 300 ft in the terminal moraine and near the buried valleys. The terminal moraine is an unsorted and unstratified mixture of clay, sand, gravel, and boulders that were accumulated at the front of a continental glacier.

The ground moraine is similar in character to the terminal-moraine deposits but was formed at the base of the ice sheet during periods of ablation. Meltwater from the ice front flowed southward and carried sand and gravel in broad coalescing sheets to form an outwash plain that extends from the terminal moraine south to the coast. Pre-Harbor Hill deposits are present at depth in the sequence of upper Pleistocene deposits (table 1). The 20-foot clay in eastern Queens and Nassau Counties is a marine clay deposited during the Ronkonkoma-Harbor Hill interstade (Soren, 1978, p. 11). This unit locally separates the Harbor Hill Drift from the underlying Ronkonkoma Drift and earlier deposits.

HYDROLOGIC SUMMARY

The six major geologic units described in the preceding section correspond to hydrologic units with specific water-bearing characteristics. These hydrologic units and their corresponding geologic names (table 1 and fig. 3) are, in ascending order, the Lloyd aquifer (Lloyd Sand Member of the Raritan Formation), the Raritan confining unit (the clay member of the Raritan Formation), the Magothy aquifer (Magothy Formation and Matawan Group, undifferentiated), the Jameco aquifer (Jameco Gravel), the Gardiners Clay (geologic unit is known by same name), and the upper glacial aquifer (upper Pleistocene deposits).

The aquifers are the unconsolidated formations containing sufficient saturated permeable material to yield significant quantities of water to wells. The most permeable units are the beds of predominantly sand or sand and gravel. The clayey formations of low hydraulic conductivity within the mass of unconsolidated deposits behave as confining units where present and separate the ground-water reservoir into three major aquifer units--the Lloyd, the Magothy-Jameco, and the upper glacial aquifers (fig. 3).

Where present, the Gardiners Clay restricts vertical flow between the upper glacial and the deeper aquifers, and the Raritan confining unit restricts vertical flow between the upper aquifers and the Lloyd aquifer. Both clay units are significant confining beds and have been estimated to have a vertical hydraulic conductivity of 0.001 ft/d (Franke and Cohen, 1972), much lower than that of the aquifers. Large hydraulic gradients are developed across these units, and flow patterns in aquifers are affected. Where these confining units are absent, ground-water flow between aquifer units is uninhibited. Thus, special attention should be paid to the exact extent of the confining units when defining ground-water flow patterns.

The bedrock underlying these unconsolidated deposits has a low hydraulic conductivity and does not yield more than a few gallons per minute to wells. The quantity of water that can flow across this boundary is insignificant compared with the quantities that flow in the overlying unconsolidated units. Therefore, the bedrock surface is considered to be the bottom hydrologic boundary of the ground-water flow system.

Aquifer Characteristics

Lloyd Aquifer

The Lloyd aquifer is of moderate horizontal hydraulic conductivity; Franke and Cohen (1972) estimated its average hydraulic conductivity to be 40 ft/d, but individual sandy and gravelly beds within the aquifer may have much higher values. High-capacity wells tapping the Lloyd aquifer have generally been pumped at rates less than 1,000 gal/min, but pumpage as high as 1,600 gal/min from a single well has been reported (Soren, 1971, p. 11). Specific capacities (gal/min pumped per foot of drawdown in the well) of wells in the Lloyd aquifer have ranged from 4 to about 40 (gal/min)/ft (Soren, 1971, p. 11). Water in the Lloyd aquifer is highly confined between the bedrock and the Raritan confining unit except where the confining unit has been eroded (fig. 6), providing good hydraulic connection with the overlying aquifer.

Magothy-Jameco Aquifer

The lateral hydraulic continuity between the Jameco Gravel and Magothy aquifer enables both units to act as one aquifer in which the Jameco is a zone of higher hydraulic conductivity. The Magothy-Jameco aquifer is to some extent hydraulically separated from the overlying upper glacial aquifer by the Gardiners Clay and from the underlying Lloyd aquifer by the Raritan confining unit.

The Magothy aquifer has been estimated to have an average horizontal hydraulic conductivity of 50 ft/d (Franke and Cohen, 1972) but, as in the Lloyd aquifer, individual sandy and gravelly beds may have values four to five times higher. No pumping of the Magothy aquifer in Kings County is known; however, wells tapping the Magothy aquifer in Queens County have yielded as much as 1,500 gal/min. The specific capacities of wells tested have ranged from 15 to 30 (gal/min)/ft in fine sand to 50 (gal/min)/ft in coarser material (Soren, 1971, p. 10).

Soren (1971, p. 9) estimated the horizontal hydraulic conductivity of the Jameco Gravel to be at least 270 ft/d. Wells tapping the Jameco have yielded 1,600 gal/min, and specific capacities of Jameco wells have been as high as 180 (gal/min)/ft (Soren, 1971, p. 9).

Water in the Magothy-Jameco aquifer system is highly confined in southern Queens and in Kings County, where it lies between the Gardiners Clay and the Raritan confining unit. In northern Queens, however, the Magothy is overlain by glacial deposits and is, therefore, a very "leaky" confined aquifer, practically under water-table conditions. Confinement within the Magothy is somewhat increased by en echelon lenses and beds of clay and silty clay, whose arrangement tends to produce an increased confining effect with depth.

Upper Glacial Aquifer

The upper glacial aquifer includes all of the saturated glacial drift. Sand beds and sand and gravel beds in the outwash south of the terminal moraine are highly permeable and are capable of yielding large quantities of water to properly constructed wells. Horizontal hydraulic conductivity of glacial outwash has been estimated to be 270 ft/d (Franke and Cohen, 1972). Public-supply and other high-capacity wells tapping outwash deposits have commonly yielded as much as 1,500 gal/min, with specific capacities ranging from 50 to 60 (gal/min)/ft (Soren, 1971, p. 8). Terminal and ground-moraine deposits generally have much lower conductivity than outwash because they include clay and silt deposits and are not well sorted. Coarse sand and gravel lenses within the morainal deposits may yield significant amounts of water, but because such lenses cannot be predictably located, their yields are uncertain.

Water in the upper glacial aquifer is under water-table (unconfined) conditions but, within the morainal deposits, it may be locally confined between beds of clay and silt. Perched ground-water bodies and ponds above the main water table, supported by local clayey and silty beds, are also common in the morainal areas.

PREDEVLOPMENT HYDROLOGIC CONDITIONS

Predevelopment Ground-Water Flow Patterns

Hydrologic data from central and eastern Long Island indicate that, under predevelopment conditions, approximately 50 percent of annual precipitation infiltrates to the water table and recharges the ground-water system (Cohen and others, 1968, p. 44-45); the remainder is lost to evapotranspiration and direct runoff. Although precipitation fluctuates on both seasonal and longer term cycles, the intermittent addition of fresh water is adequate to maintain a large reservoir of fresh water in the unconsolidated deposits beneath Long Island. The quantity of water stored in this reservoir fluctuates with recharge, as indicated by fluctuations in the water-table configuration.

The ground-water system is bounded on top by the water table, on the bottom by impermeable bedrock,and on the sides by contact with salty ground water or surface-water bodies (fig. 10). The water stored is in continuous motion. The path of flow from the water table to a point of discharge is complex and three dimensional. This path is affected by the rate and areal distribution of recharge, the geometry and hydraulic characteristics of the aquifers and confining units, the proximity and nature of discharge boundaries, and ultimately, the distribution of hydraulic head throughout the system, which depends on all the aforementioned factors.

Much of the water that enters the ground-water system remains in the upper glacial aquifer, moves laterally, and discharges to surrounding saltwater bodies (fig. 10). Ground-water seepage to streams and springs causes some vertical gradients in the shallow water-table aquifer (Franke and Cohen, 1972). (These are not shown in fig. 10.)

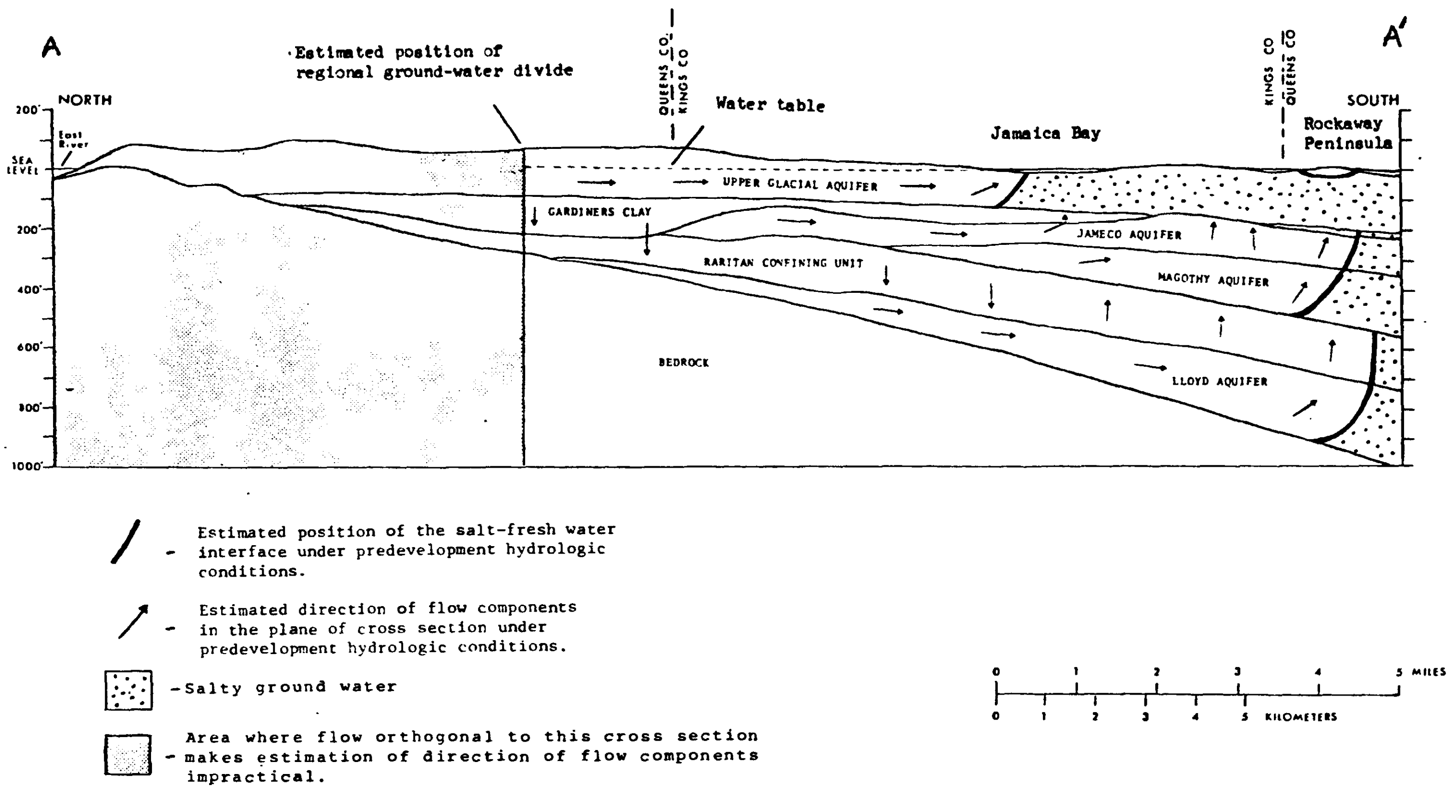


Figure 10.--Generalized hydrologic section showing estimated predevelopment flow patterns. (Location is shown in fig. 11.)

The rest of the water entering the system flows downward to the deeper aquifers (fig. 10). Water enters freely in areas of continuity between aquifer units, but moves more slowly and is refracted to near vertical through the confining units. Water in the deeper aquifer also moves toward the shore, where upward vertical gradients cause flow to shallower aquifers. The water may enter the shallow aquifer where the ground water is still fresh, in which case it would eventually discharge to the surrounding salty surface-water bodies. Where water in the overlying aquifer is salty, the fresh water mixes with the salty ground water and is lost from the freshwater system. Because saline water is of greater density than the fresh water, when the two fluids are in proximity in the aquifer units they behave largely as though immiscible. Although a zone of diffusion forms at the interface, mixing is minimal under nonpumping conditions, and flow normal to the interface is virtually nil.

Predevelopment Water-Table Configuration

The configuration of the water table is a primary indicator of the condition of the ground-water reservoir. The first measure of the water-table configuration on Long Island, made in 1903 (fig. 11), provides the best available estimate of the predevelopment water-table configuration, although urbanization and development of the ground-water system even then had begun to affect ground-water levels.

In the central parts of Long Island, the water-table altitude before urbanization exceeded 90 ft (Veatch and others, 1906) and, at the Queens-Nassau County line, it exceeded 50 ft (fig. 11). A steep water-table gradient westward into Queens County is apparent and indicates that a significant quantity of ground water enters Queens County from the east and assuredly helped maintain water levels in Kings and Queens Counties. Long Island's major ground-water divide trends east-west through Queens County, then gradually southward in Kings County; it is nearer the north shore than the south. The asymmetric shape of the water table in profile, with steep northward gradients and flatter gradients to the south, is apparent in figure 11 and is due to the thickening of the unconsolidated deposits to the south and to the higher hydraulic conductivity of the outwash plain to the south than that of the moraine deposits in the north.

High water levels in 1903 resulted in steep ground-water gradients to several stream channels in Kings and Queens Counties. These channels, which are relict from the glacial period, were sustained primarily by ground-water seepage. An extensive series of stream channels and swampy areas in Kings and Queens Counties suggests that a significant quantity of ground water was discharged at land surface into springs, lakes, and stream channels. Soren (1971, p. A5) estimates that ground-water discharge to streams before development in Queens County alone probably exceeded 30 Mgal/d, which is more than 25 percent of the natural recharge to the ground-water system in that county.

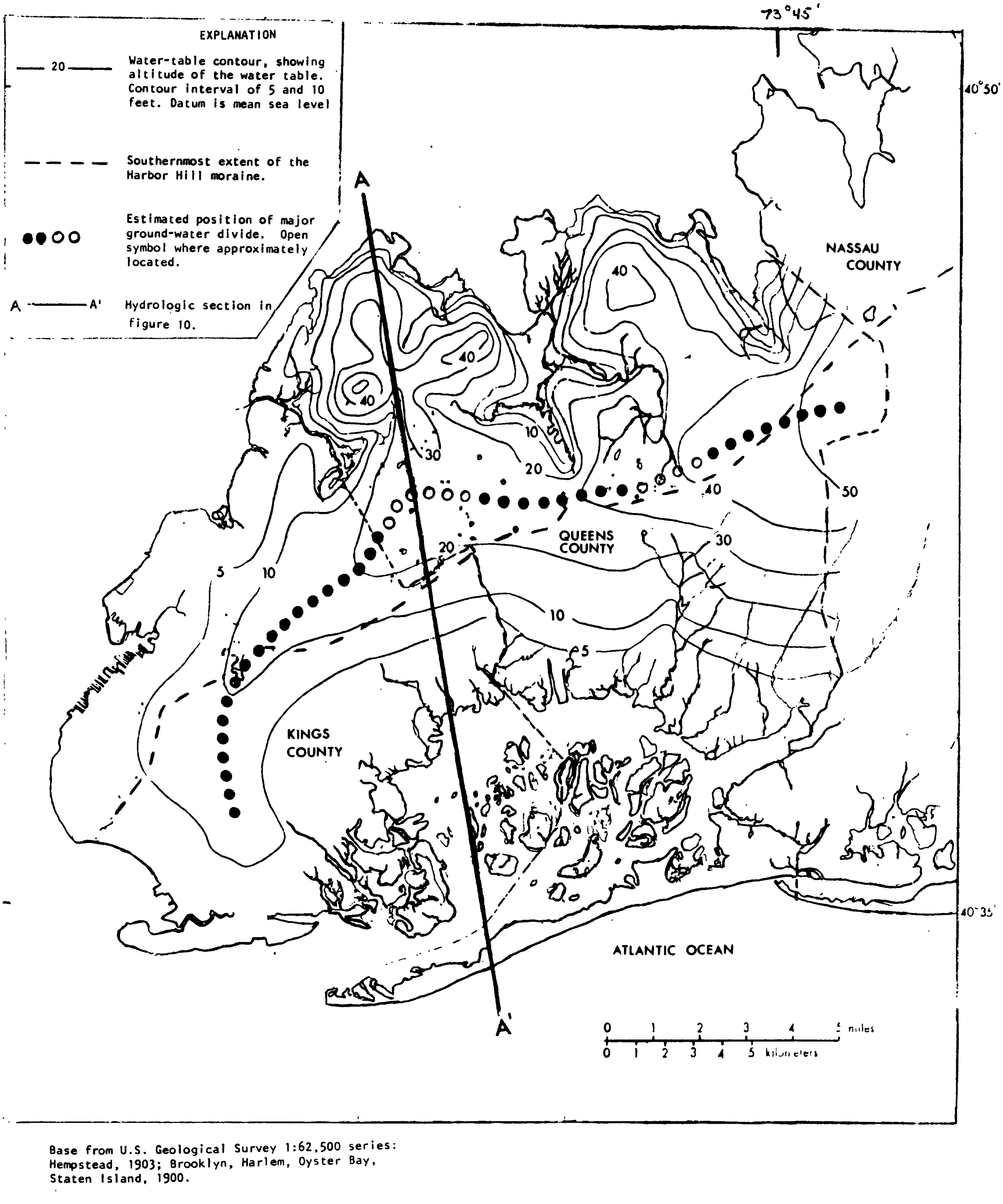


Figure 11.--Water-table configuration in 1903. Section A-A' is depicted in fig. 10. (Modified from Veatch and others, 1906).

The anomalous high areas in the 1903 water table on the north shore of Queens County (fig. 11) are in part the result of the configuration of the bedrock surface (fig. 4), which restricts ground-water discharge along this boundary. Zones of low hydraulic conductivity in the moraine deposits may also cause these highs, which are still present today. (See fig. 21, p. 41.) Similar anomalous water-table highs have been found in association with moraine deposits farther east on Long Island.

Predevelopment Ground-water Quality

The predevelopment ground-water quality of western Long Island is not known in detail. As stated previously, extensive ground-water development and resultant changes in quality in the western part of the island began many decades ago. The eastern part of the island, which has a similar hydrologic character but was not urbanized until later, is probably indicative of predevelopment conditions throughout the island. It is therefore inferred from the earliest records that the ground-water quality in western Long Island was pristine.

Chloride and nitrate are discussed in detail later in this report because they are considered to be good indicators of ground-water contamination from several sources. The concentration of both ions in predevelopment water was probably low; therefore, elevated concentrations indicate contamination. High nitrate concentrations are characteristic of water contaminated by human or animal waste or by fertilizer. Chloride contamination may be due to infiltration of water contaminated by road salt or from landfill or septic tank leachate, or leaky sewer lines, especially when accompanied by high concentrations of nitrate. Chloride contamination may also be the result of encroachment from surrounding salty ground water and surface water.

Chloride

Jackson (1905, p. 29-31) estimates that the predevelopment levels of chloride in water on Long Island ranged from 3 to 8 mg/L. Burr, Hering, and Freeman (1903, p. 406) indicate that in 1898 the normal chloride concentration of ground water and surface water derived from the Ridgewood water-supply system was 5 to 6 mg/L. This agrees with later estimates for the eastern part of Long Island. Lusczynski and Swarzenski (1966, p. 19) assumed that before development, ground water on Long Island contained less than 10 mg/L chloride, that chloride in the 10-40 mg/L range in inland areas suggests contamination by manmade wastes, and that concentrations exceeding 40 mg/L in shore areas indicate saltwater intrusion. In Kings and Queens Counties, however, where contamination from the land surface has continued since before 1900, chloride concentrations before development are uncertain. Burr, Hering, and Freeman (1903, p. 406-423) note that some chloride contamination was already evident by the turn of the century. To summarize the period 1898-02, water supply derived from four streams in Queens County had average chloride concentration ranging from 8.8 to 12.4 mg/L, whereas 12 streams in Nassau County ranged from 5.3 to 6.7 mg/L. Ground water from wells near shore areas had averaged as high as 264 mg/L, and by 1903, pumping had been diverted from some wells because of chloride contamination.

Nitrate

Determination of predevelopment levels of nitrate in western Long Island ground water is as difficult as it is for chloride. Shallow ground water is especially susceptible to contamination by nitrogenous wastes. Kimmel (1972, p. D-200) surveyed the available data on nitrate in ground water in eastern Long Island and inferred that nitrate (as nitrogen) concentration of water in the upper glacial aquifer under predevelopment conditions was less than 0.2 mg/L. Analyses of water from shallow wells in nonurbanized areas and deep wells across the island suggest that predevelopment levels of nitrate may be even lower. In this report, nitrate levels above 0.2 mg/L as N are considered to indicate contamination.

URBANIZATION'S EFFECTS ON THE HYDROLOGIC SYSTEM

Ground water in western Long Island was developed rapidly in the 19th century with the rapid population growth of Brooklyn and western Queens. Man first obtained ground water for supply by pumping from shallow wells and collecting in reservoirs ground-water seepage to streams and springs. Most of the water from these sources was returned to the aquifer by infiltration through underground waste-disposal systems, so that these stresses caused only minor changes in the water-table configuration and shallow ground-water flow patterns. As the demand for public and industrial water supply increased, however, the number of wells and the quantity pumped increased accordingly, and the effects became more serious. As western Long Island became urbanized, new storm and sanitary sewers diverted out to sea wastewater that would have recharged the ground-water system. At the same time, the amount of impervious land surface increased, reducing the area available for infiltration of precipitation and further decreasing recharge. These changes, along with the continuous increase in industrial and water-supply pumpage, caused severe declines in the water table and in potentiometric head in the deeper aquifers through the 1930's and 40's. Declines in the water-table altitude caused many lakes and streams to disappear and severely decreased flow in the remaining streams (Soren, 1971, p. A5). At the same time, drawdown near the shores caused intrusion of salt water into the aquifers.

Development of the Ground-Water Reservoir

History of Ground-Water Development

Pumping for industrial and public supply has probably been the most severe stress on the western part of the Long Island ground-water system in the 20th century. Ground water pumped and lost either by evaporation or discharge to the sea is considered consumptive (net) pumpage and is a net draft on the ground-water system. Pumpage data in this section have been compiled from the literature and represent consumptive ground-water use.

1900-17.--By 1900, the ground-water reservoir of western Long Island was extensively pumped for both public supply and industrial uses. Johnson and Waterman (1952, p. 7) estimate that in 1904, 6.4 Mgal/d was obtained from surface storage of ground-water seepage to springs and streams in Queens County, and 77.4 Mgal/d was obtained from nearby Nassau County.

By 1904, pumpage for public supply had reached 14 Mgal/d in Kings County and 28 Mgal/d in Queens, most of which was used in Kings County. The estimated industrial and public-supply pumpage from 1904 to 1972 is plotted in figure 12. Industrial pumpage, although only a few million gallons per day in Queens, was 14 Mgal/d in Kings County. Industrial pumpage increased markedly in both counties thereafter, and from 1909-16, pumpage for public supply averaged 30 Mgal/d in Kings County and 58 Mgal/d in Queens County (fig. 12).

In 1917, the first New York City water tunnel was completed, and surface water from upstate New York was transported to the New York City water-supply system. This water replaced a significant amount of ground-water pumpage, as indicated in figure 12. The City of New York, Department of Water Supply, Gas, and Electricity, which had pumped more than 14 Mgal/d in Kings County and 40 Mgal/d in Queens County during the preceding 10 years, all but ceased pumping in 1917.

1918-30.--The post-World War I period in western Long Island was marked by a consistent increase in consumptive ground-water use for both public supply and industrial use. After the abrupt reduction in pumpage for public-supply in 1917, continued demand resulted in an increase in public-supply pumpage from 13 Mgal/d in Kings County and 23.1 Mgal/d in Queens in 1918 to 29.2 Mgal/d and 62.0 Mgal/d, respectively, in 1931 (fig. 12). Industrial pumpage in both counties also continued to increase and, by 1930, had exceeded 50 Mgal/d in Kings County and 20 Mgal/d in Queens.

1930-47.--The 1930's brought a noticeable decline in industrial pumpage in both counties (fig. 12) for two major reasons:

(1) Concern over the extensive use of ground water by industry prompted the adoption of the Water Conservation Law of 1933, which required that water pumped at a rate greater than 70 gal/min be reinjected to the source aquifer. Leggette and Brashears (1938, p. 413) estimate that at the end of 1933 only one recharge well was operating in Kings County (60 gal/min), but by 1937, the number had increased to 105, injecting a total of 33,385 gal/min.

(2) The widespread adoption of electric refrigeration severely reduced the quantity of water pumped for ice making. Lusczynski (1952, p. 4) states that from 1936 to 1947 the quantity of water pumped for ice decreased from 18 Mgal/d to 4 Mgal/d.

During World War II (1940-45), industrial pumpage increased slightly in Kings County; a similar increase was likely in Queens County, but no data on industrial pumpage in Queens County from 1937-47 are available.

1947-79.--In 1947, all public-supply pumpage in Kings County was stopped by New York City, primarily because of saltwater intrusion, but pumpage for public supply was continued in Queens County, where it increased from 45 Mgal/d in 1950 to more than 60 Mgal/d in the 1970's (fig. 12). The trend of pumping in Queens County has been to abandon wells showing contamination and to install new ones eastward, farther from the shores and near the higher water levels in the center of the island.

Pumpage declined in 1974 (fig. 12), when all pumping for public supply (10 Mgal/d) in the Woodhaven franchise area of the New York Water Service Corporation (NYWSC) was halted as a result of saltwater intrusion. Compensating pumpage to the east by the Jamaica Water Supply Company is evident during later years (fig. 12).

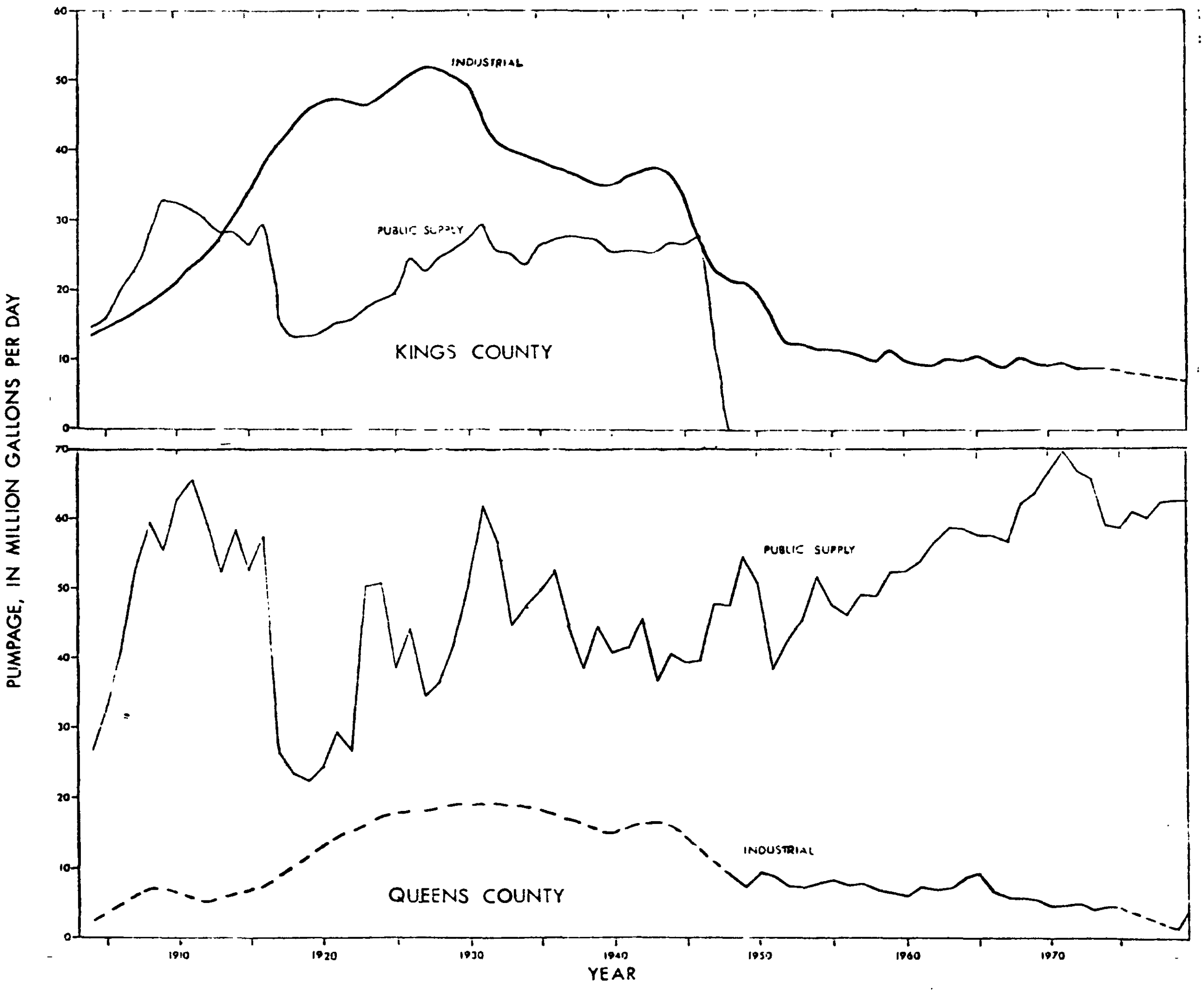


Figure 12.--Estimated net pumpage in Kings and Queens Counties, 1904-79. (Compiled from Johnson and Waterman, 1952; Thompson and Leggette, 1936; Suter, 1937; and New York State Department of Environmental Conservation).

Development of Individual Aquifers

The upper glacial aquifer was the first to be extensively pumped in western Long Island. Public-supply pumpage from this aquifer reached a high in 1910, with 24 Mgal/d in Kings County and 46 Mgal/d in Queens (Johnson and Waterman, 1952). Public-supply pumpage has now ceased in Kings County, but in Queens, the aquifer yielded 35 Mgal/d in 1961 and 30 Mgal/d in 1967 (Soren, 1971). Rapidly increasing demand and contamination of shallow wells by salt water encouraged development of the deeper aquifers.

The Jameco aquifer before 1917 yielded as much as 9 Mgal/d in Kings County and 13 Mgal/d in Queens County. This largely stopped, however, with the introduction of upstate surface water to the city supply. About 1933, pumpage from the Jameco aquifer for public supply reached a maximum of 15 Mgal/d in Kings County (Lusczynski, 1952), and from 1917-50 averaged 5 Mgal/d in Queens County (Johnson and Waterman, 1952, p. 7). In 1961, pumpage for public supply in Queens was 3.5 Mgal/d and in 1967 was 3.8 Mgal/d (Soren, 1971, p. A26).

Before 1935, pumpage from the Magothy and Lloyd aquifers was not differentiated. Their combined pumpage in Kings County was as much as 3 Mgal/d in 1931 but averaged less than 0.5 Mgal/d from 1909-46 (Johnson and Waterman, 1952, p. 7). In Queens County, pumpage for public supply from 1935-50 averaged 7.4 Mgal/d from the Magothy and 5.7 Mgal/d from the Lloyd. Soren (1971, p. A26) estimated that by 1961, public-supply pumpage from the Magothy aquifer in Queens had increased to 18.5 Mgal/d and, by 1967, to 22.7 Mgal/d, whereas pumpage from the Lloyd had not substantially changed (3.5 Mgal/d in 1961 and 4.6 Mgal/d in 1967).

Declines in Water-Table Altitude

The most obvious effect of urbanization on the hydrologic system of Long Island was a decline in the water table and in the potentiometric surface of the deeper aquifers. The configuration of the water table before development is discussed in a previous section (fig. 11, p. 22); the water-table maps for subsequent years (figs. 13-17) are provided to depict the changes resulting from urbanization and related stresses during the 20th century. (Note that the latter maps have been transferred to a common base.)

By 1936, the water table showed severe declines resulting from heavy pumping and loss of recharge. (Compare figs. 11 and 13.) An asymmetric cone of depression in northern Kings County, an area of extensive industrial pumping at that time, reached a depth of 35 feet below sea level. This cone of depression also extended into western Queens County.

The decline in industrial pumping that started around 1930 (fig. 12) resulted in some recovery of the water table by 1943 (fig. 14). The water-table configuration of 1943 shows a recovery of as much as 10 feet in northern Kings County as well as general recovery in western Queens County. After the cessation of pumping for public supply in Kings County in 1947, the water table recovered further. The water-table configuration of 1951 (fig. 15) shows a rise in the southern half of Kings County to altitudes above sea level, and the cone of depression in the north is smaller and shallower than in 1936 (fig. 13).

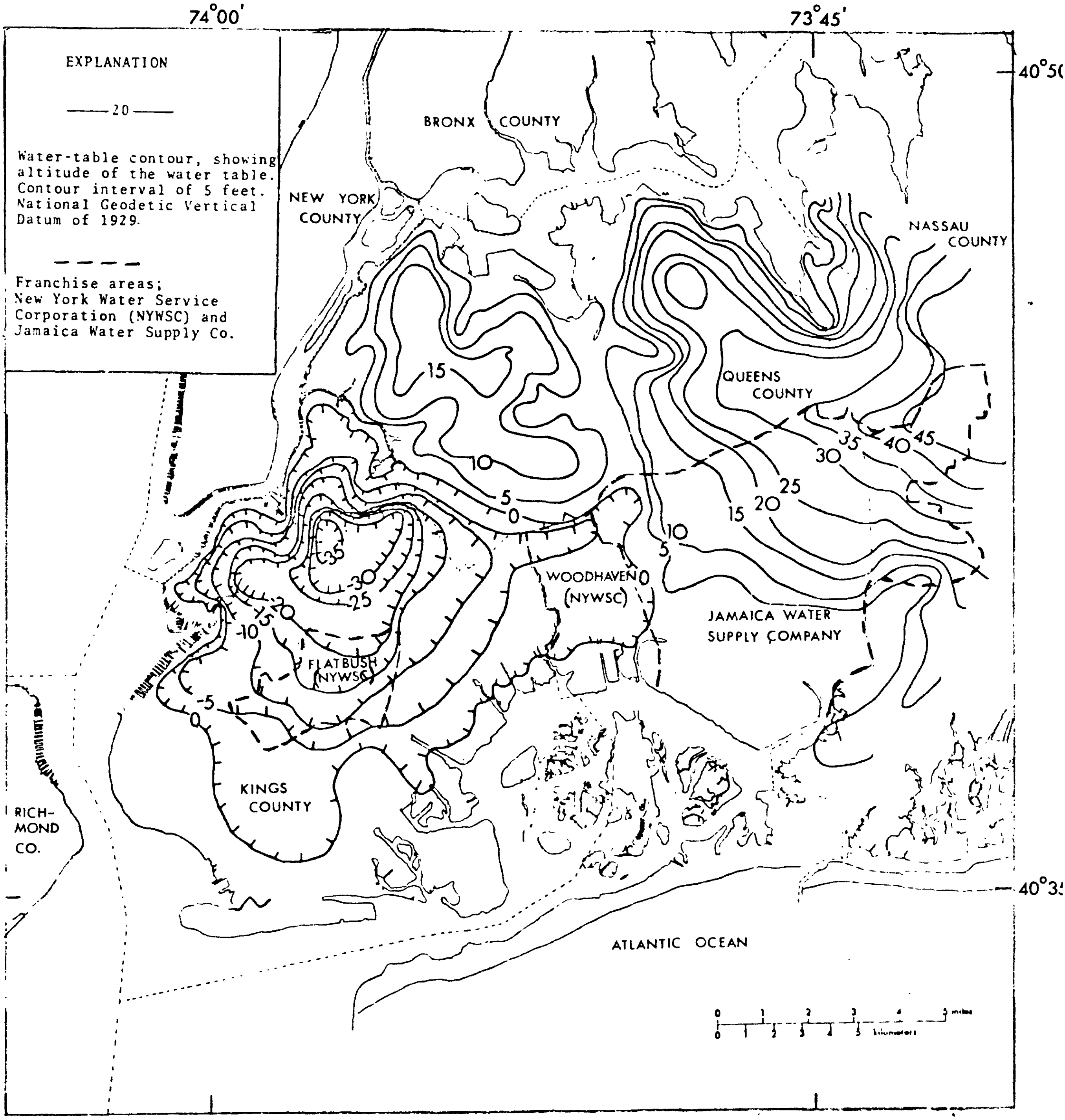
By 1961, the water table (fig. 16) had recovered to above sea level throughout Kings County except in a small area. However, a sizeable cone of depression is evident in the Woodhaven franchise area (NYWSC), which, after 1947, increased pumping to compensate for the stoppage of pumping in Kings County. The cone of depression extended into Jamaica, where the Jamaica Water Supply Company in 1961 was pumping nearly 50 Mgal/d. Although the cone of depression in 1961 was not at as low in altitude as that in Kings County in the 1930's (fig. 13), the initial water levels in Queens County were 20 ft higher than in Kings, so that the respective declines represent a similar loss in ground-water storage.

By 1974, the water table had recovered further in Kings County (fig. 17), and the cone of depression in Queens County had shifted from Woodhaven, where pumping stopped in 1974, to Jamaica, where the Jamaica Water Supply Company was pumping approximately 60 Mgal/d. Water levels in this cone of depression represent a drawdown of about 35 feet from water levels in 1903 (fig. 11).

Similar declines in the potentiometric surface of the deeper aquifers have resulted from increased pumping and urbanization. Historical data on the potentiometric surface of these aquifers are sparse, and recent changes in the definition of hydrogeologic units makes accurate interpretation of the data difficult. However, the observed response of water levels in wells screened in the deeper aquifers confirms that, in areas where confining units are absent, the aquifers have good hydraulic connection (Soren, 1971, p. A19). Here, water can flow freely between aquifers, and fluctuations in head propagate rapidly from one aquifer to the next. Observations have also indicated that pumping in well-confined parts of the deeper aquifers will produce a more rapid expansion of the cone of depression to the boundaries than in the water-table aquifer (Lusczynski, 1952, p. 5). Typical confined storage coefficients are much lower than the specific yield of the water-table aquifer; therefore, the transient response to stress is more rapid in the deeper aquifers.

Deterioration of Ground-Water Quality

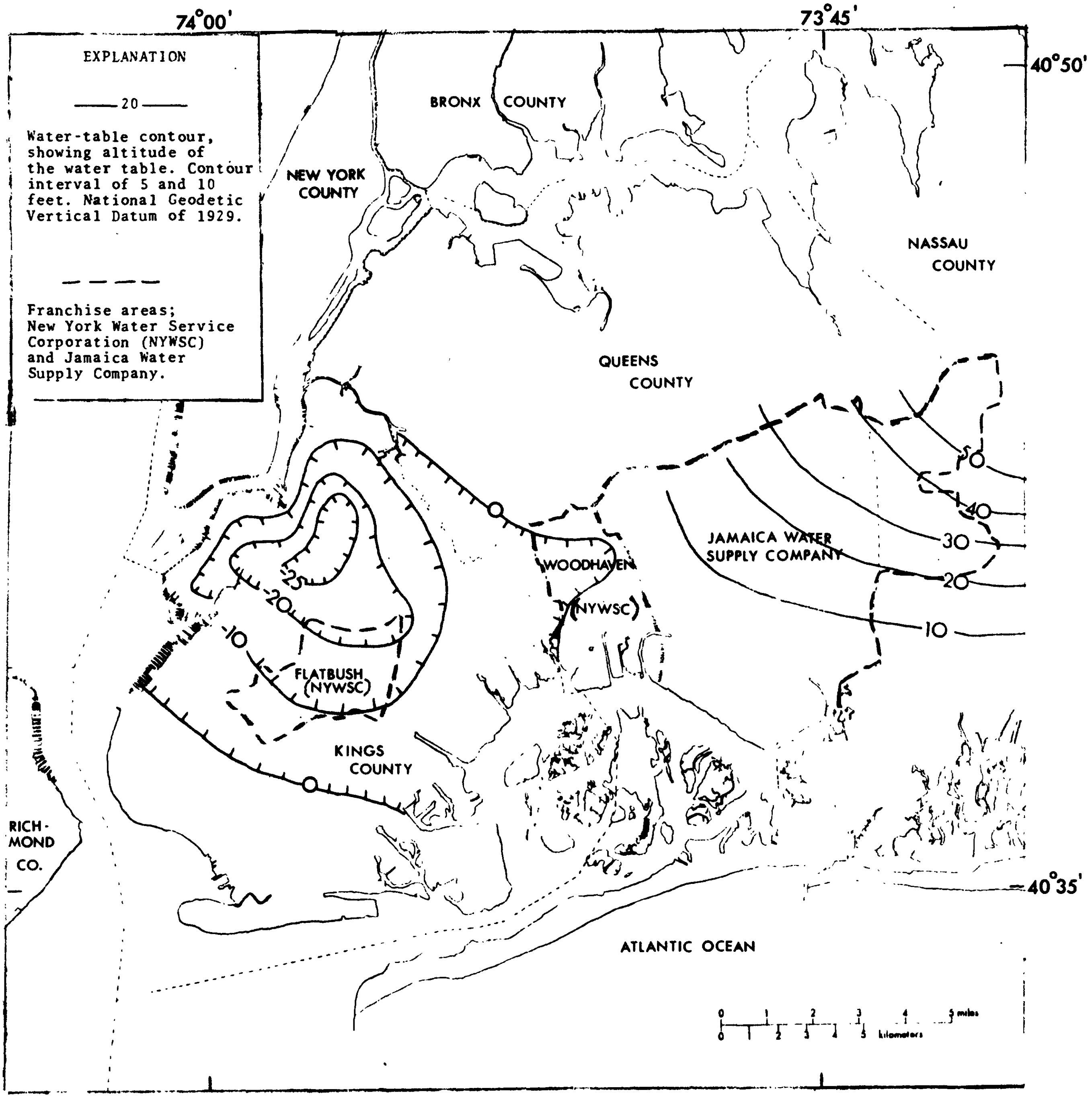
In addition to lowering ground-water levels, urbanization and development of the ground-water system in Kings and Queens Counties have caused serious deterioration of ground-water quality. The most striking example was the encroachment of salt water from surrounding tidewater in response to excessive drawdown. Other sources of contamination, some of which were present from the early stages of development, include fertilizers, underground sewage-disposal systems, landfills, large cemeteries, road salts, leaking sewers, and toxic spills at land surface. Historical water-quality data are sparse; however, chloride and nitrate data were collected as far back as 1900 and are used here to give an indication of the response of ground-water quality during this century.



Base from U. S. Geological Survey, 1:24,000 series: Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956; Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955: and Far Rockaway, Weehawken, 1954.

Modified from Suter, 1937.

Figure 13.--Water-table configuration in 1936. (Modified from Suter, 1937.)



Base from U. S. Geological Survey, 1:24,000 series: Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956; Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955; and Far Rockaway, Weehawken, 1954.

Modified from Jacob, 1945.

Figure 14.--Water-table configuration in 1943. Water-level measurements were taken in late May. (Modified from Jacob, 1945.)

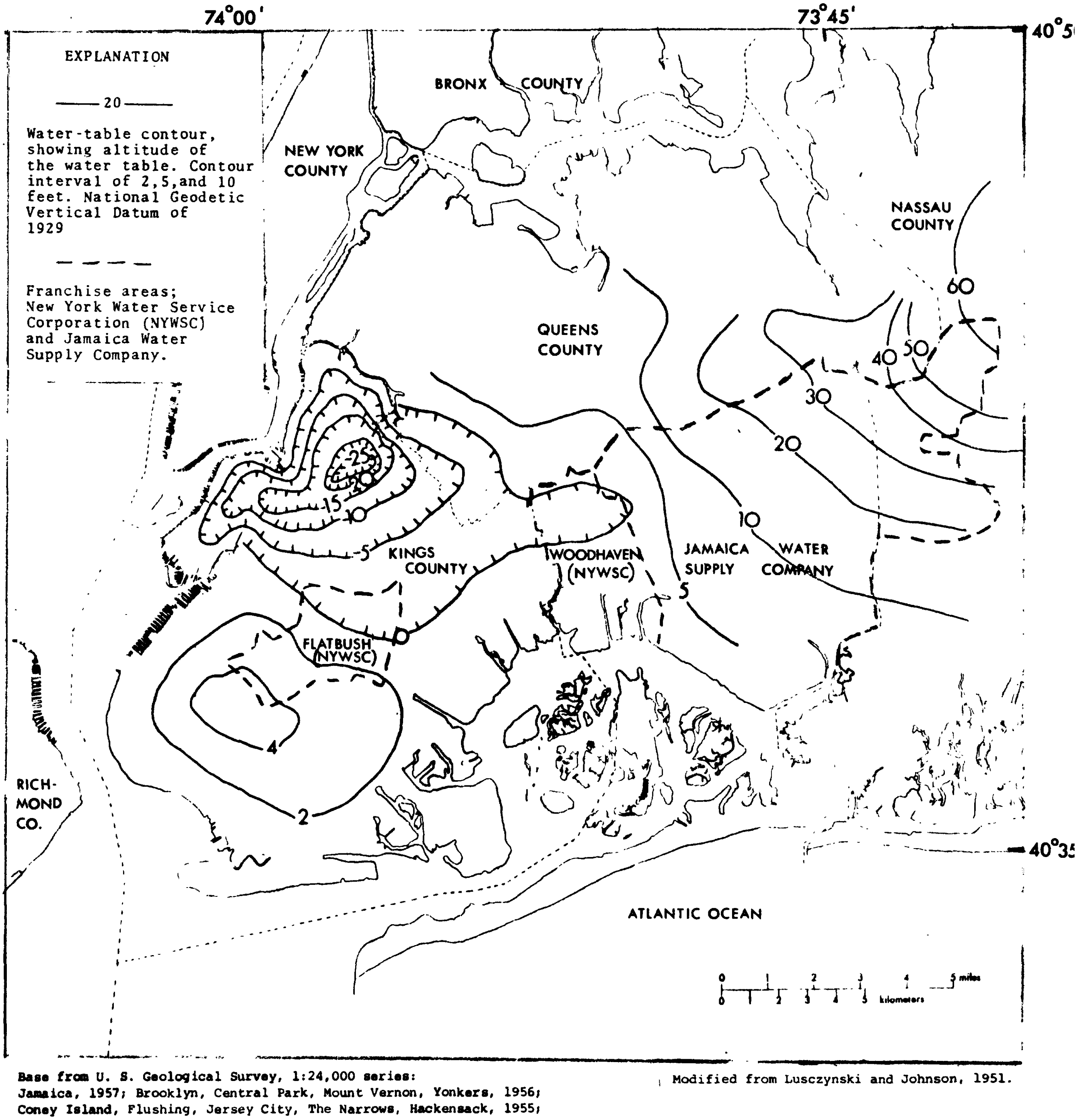


Figure 15.--Water-table configuration in 1951. Water-level measurements were taken in January. (Modified from Lusczynski and Johnson, 1951.)

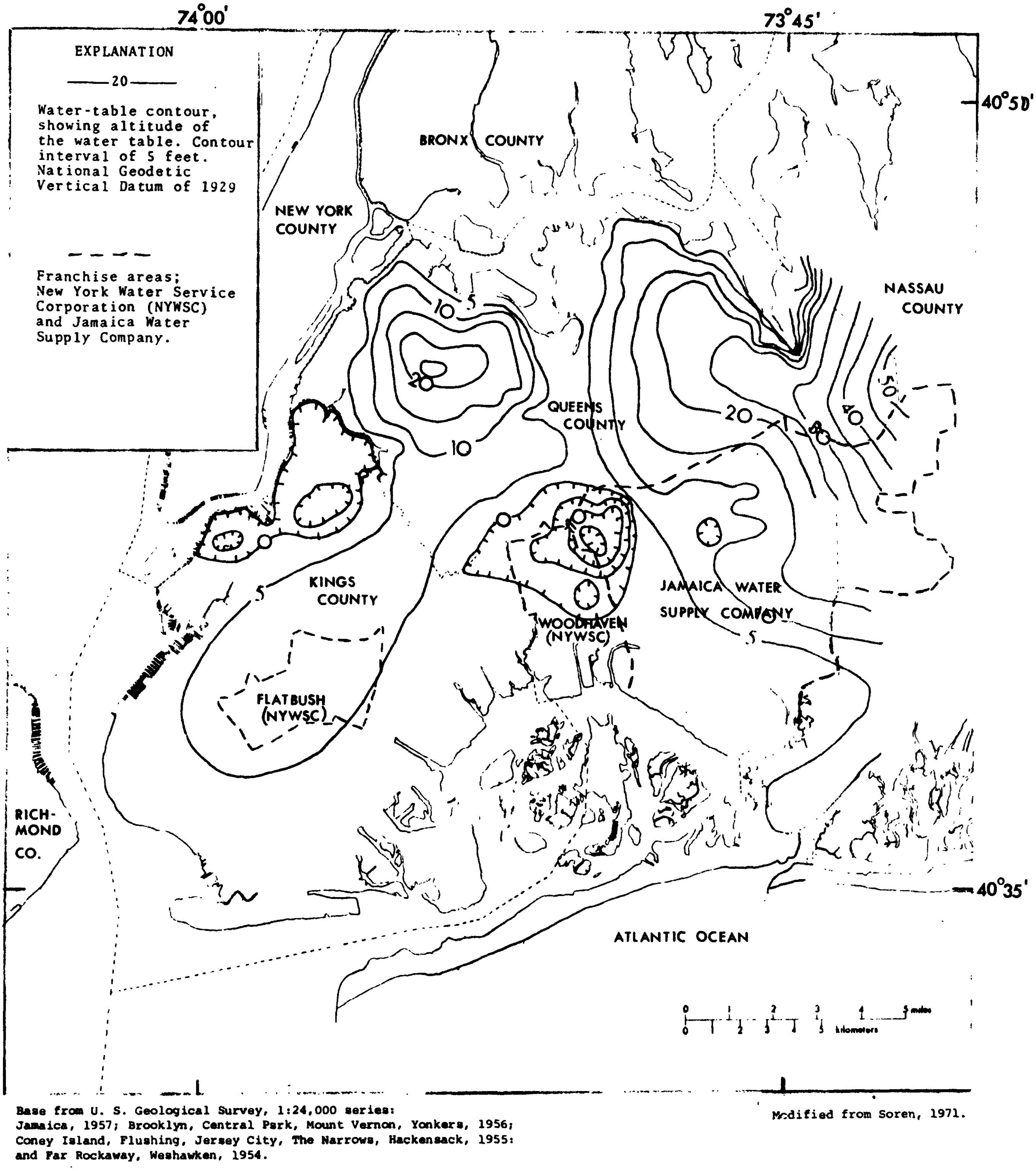


Figure 16.--Water-table configuration in 1961. Water-level measurements were taken in December. (Modified from Soren, 1971.)

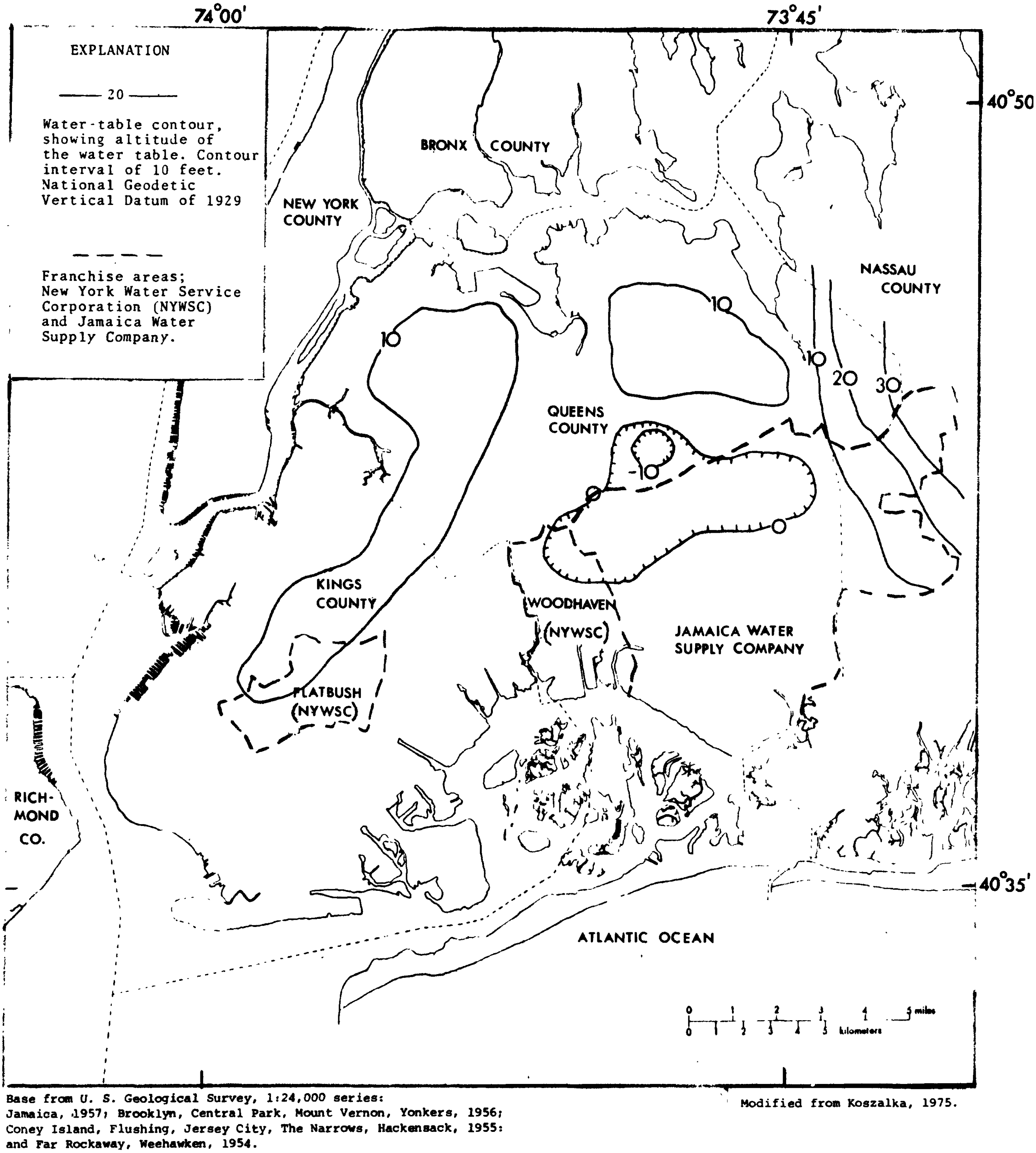


Figure 17.--Water-table configuration in 1974. Water-level measurements were taken in March. (Modified from Koszalka, 1975.)

Chloride

Chloride levels in water from public-supply wells in Kings County first began to show the effects of saltwater encroachment in the early 1930's (Lusczynski, 1952, p. 8). When the chloride concentration of water from the upper glacial aquifer began to increase, pumping was shifted east and to deeper aquifers. However, a similar increase in chloride concentration in the deeper aquifers soon followed. Because the transient response of water levels in the confined aquifers is quicker than that in the water-table aquifer, changes in hydraulic head reach the saltwater-freshwater boundaries more rapidly, and saltwater encroachment follows. Lusczynski (1952, p. 5-6) indicates that in the 1930's and 40's, encroachment into the Jameco aquifer was more rapid, extended farther inland, and caused higher chloride concentration than in the corresponding locations in the upper glacial aquifer.

A dramatic increase in chloride concentration in water from three public-supply wells in the upper glacial aquifer in the Flatbush franchise area (NYWSC) is evident in figure 18. The chloride concentration probably increased because the expanding cone of depression reached shore areas, where the decline in hydraulic head caused encroachment of salty ground water. The water-table configuration of 1903 (fig. 11) shows seaward gradients; that of 1936 (fig. 13) indicates a change to flat or slightly landward gradients near much of the shore in Kings County, which induced saltwater encroachment.

The maximum recommended level of chloride in community water systems is 250 mg/L (New York State Department of Health, 1977), the approximate taste threshold for most people. By 1940, public-supply water in Kings County had begun to exceed this amount, and, by 1947, chloride contamination in the upper glacial aquifer was extensive (fig. 19). Chloride concentrations above 40 mg/L throughout most of the upper glacial aquifer indicate contamination from saltwater intrusion even in inland areas. Water from wells near the shore reached concentrations of 1,000 to 8,000 mg/L and inland were as high as 700 mg/L. At this time, chloride concentration in Kings County was as high as 1,500 mg/L in the Jameco aquifer and exceeded 500 mg/L in the Lloyd aquifer.

In the early 1950's, pumping in Queens County increased sharply (fig. 12), and chloride concentrations in the upper glacial aquifer also increased (Soren, 1971). Water from three wells tapping the upper glacial aquifer in the Woodhaven franchise area (NYWSC) shows a marked increase in chloride from the late 1950's until 1974, when pumping for public supply in that area was stopped (fig. 18).

The map in figure 20 indicates that, in 1961, water from much of the upper glacial aquifer in Queens County had chloride concentrations greater than 40 mg/L. Chloride contamination appears primarily in shore areas and is largely the result of saltwater encroachment. Landward migration of salty ground water is evident in two tongues that originate where drawdown of water levels to near or below sea level reached shore areas. The tongues aline with steep water-table gradients that appear around pumping centers in the Woodhaven franchise area (NYWSC) and the western part of the Jamaica Water Supply Company franchise area.

A part of the chloride contamination in Queens County is undoubtedly from inland surface sources, especially in northwest Queens County, which has been extensively developed since the 19th century and where apparent water-table gradents suggest that saltwater intrusion is unlikely.

Nitrate

High concentrations of nitrate in ground water indicate contamination from surface sources, such as fertilizers, landfills, leachate from cesspools and septic tanks, and leaky sewer lines. Because high nitrate concentrations in water may be harmful, a limit of 10 mg/L nitrate (as nitrogen) is defined as drinking-water standard (New York State Department of Health, 1977). Kimmel (1972) presented data on nitrate concentrations in the upper glacial aquifer in Kings County dating back to 1900. These concentrations ranged from 0.2 to 28 mg/L nitrate (as N), but water from 24 of 28 wells sampled exceeded 10 mg/L nitrate (as N). The trend of these data indicates that the quality of shallow ground water has deteriorated as a result of contamination from surface sources since the turn of the century.

Data on nitrate contamination of the deeper aquifers in Kings County are scarce, but concentrations above predevelopment levels as early as 1929 indicate downward migration of nitrate from the water-table aquifer (Kimmel, 1972, p. D202).

Nitrate data in Queens County are summarized by Soren (1971, table 1), which includes analyses of water from 38 wells (10 in the Lloyd aquifer, 15 in the Magothy-Jameco aquifer, and 13 in the upper glacial aquifer) sampled during the 1950's and 1960's. Nitrate (as N) concentrations were above 10 mg/L in water from only four of the wells; however, many samples, including several from the Magothy aquifer, had concentrations higher than 0.2 mg/L, indicating some contamination in the upper glacial aquifer with local downward movement of nitrate to the deeper aquifers. Nitrate contamination in Queens County is not as extensive as that in Kings County.

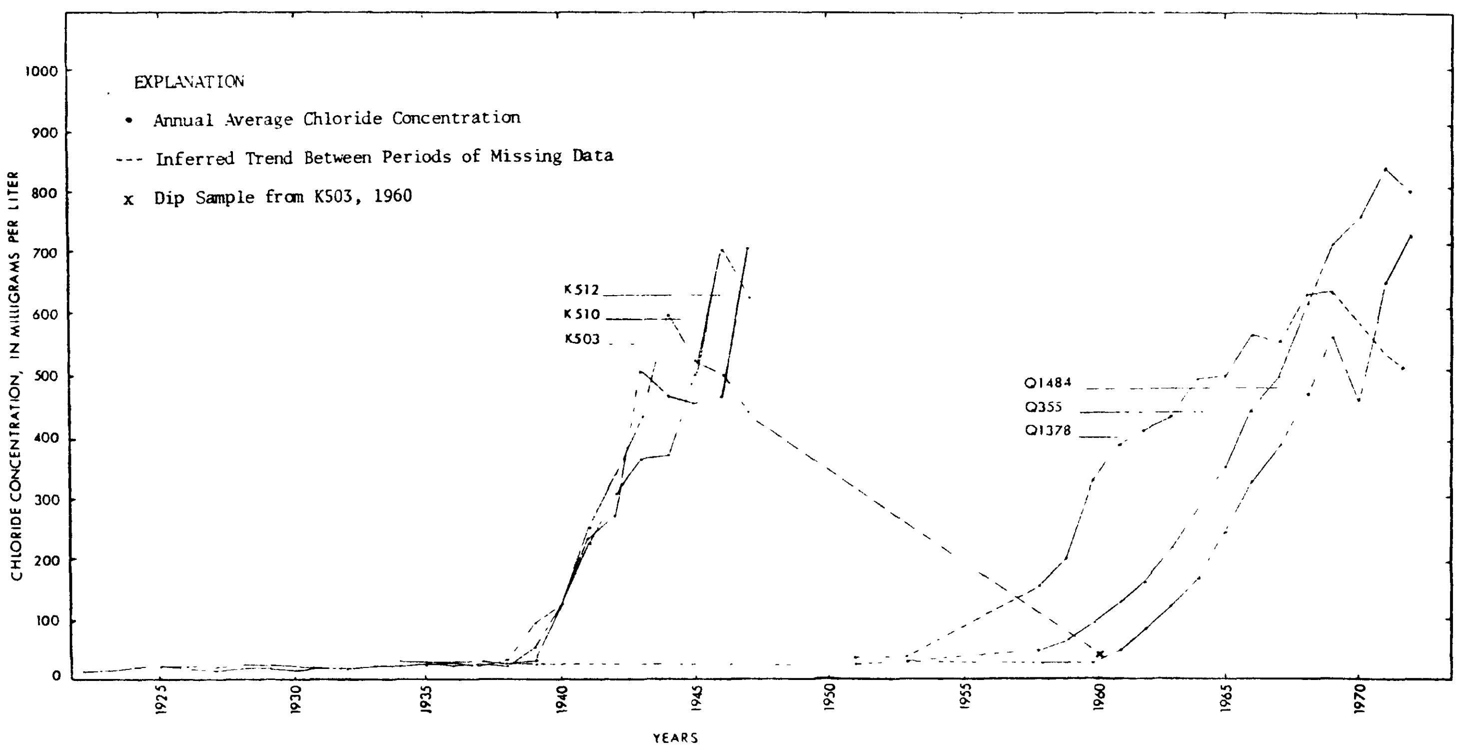
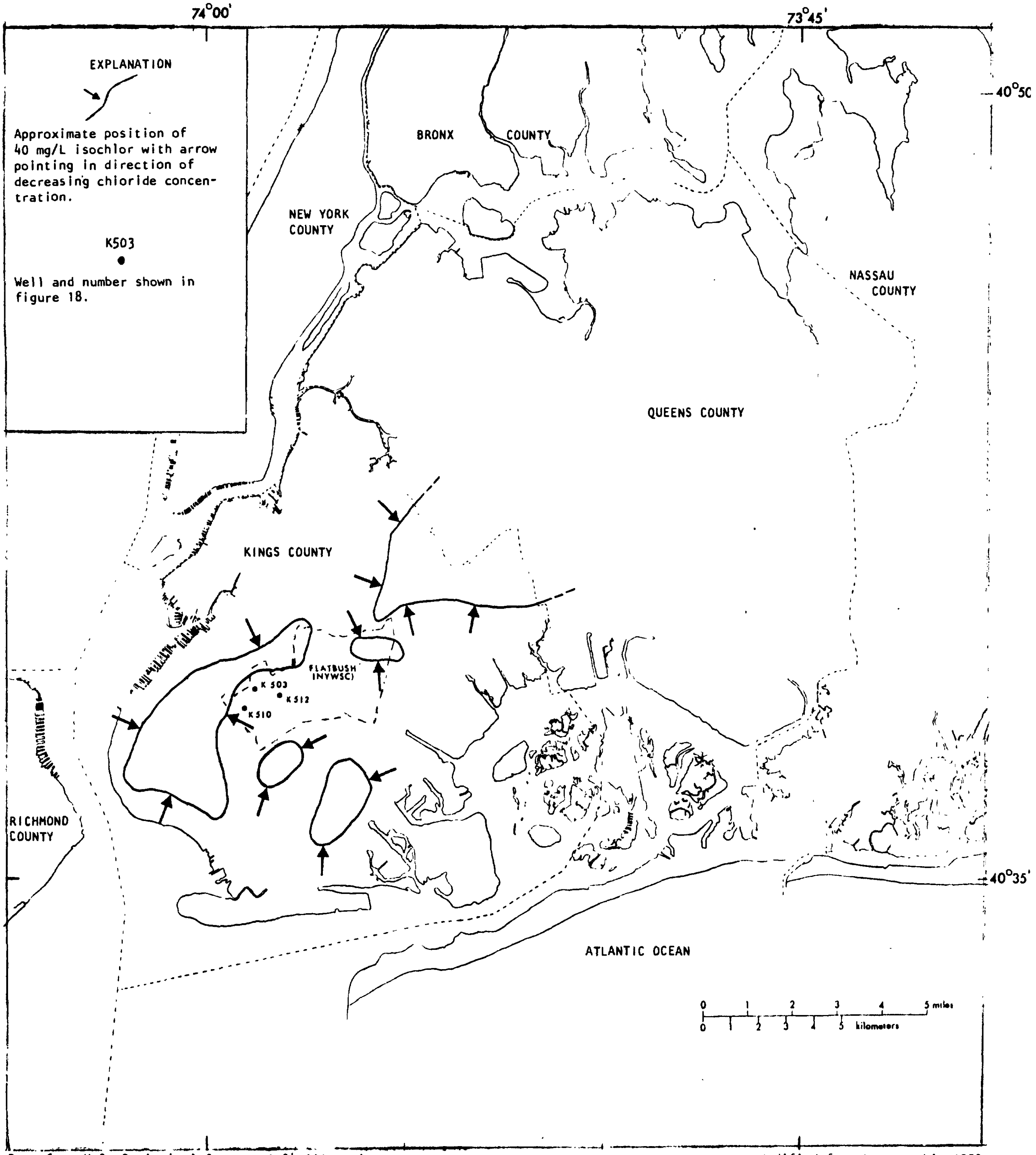


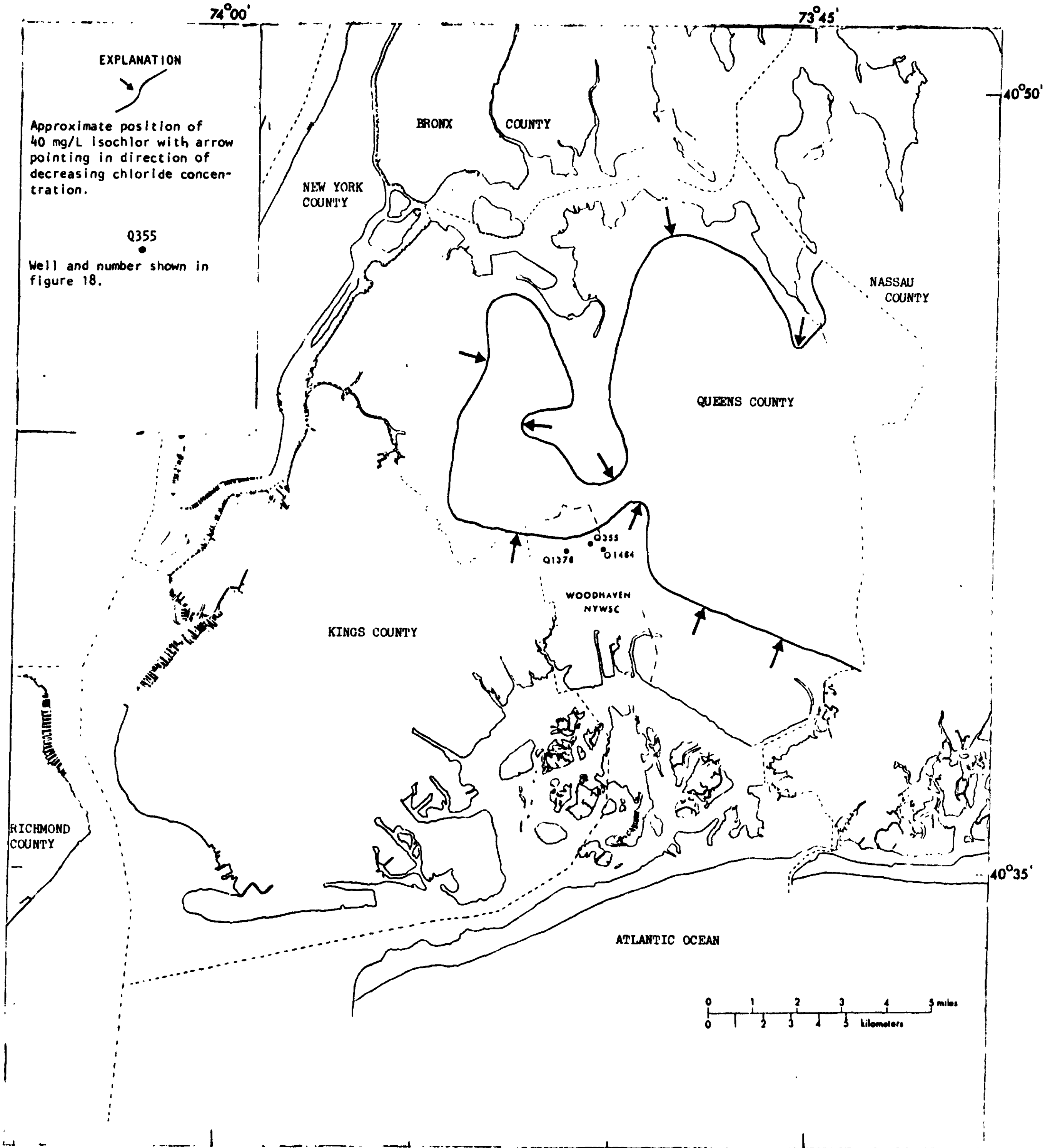
Figure 18.--Chloride levels in water from selected wells in Kings and Queens Counties since the 1920's. (Data are from U. S. Geological Survey files, Lusczynski, 1952, and selected annual reports of the Bureau of Water Supply, City of New York.)



Base from U.S. Geological Survey, 1:24,000 series: Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956: Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955: and Far Rockaway, Weehawken, 1954.

Modified from Lusczynski, 1952

Figure 19.--Areas where chloride concentrations in ground water in Kings County exceeded 40 mg/L, 1947. (Modified from Lusczynski, 1952.)



Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Modified from Soren, 1971.

Figure 20.--Areas where chloride concentration in ground water in Queens County exceeded 40 mg/L, 1961. (Modified from Soren, 1971.)

PRESENT HYDROLOGIC CONDITIONS (1981)

During the 20th century, the ground-water reservoir of western Long Island progressed through a series of development phases. Kings County first felt the effects of pumping and urbanization in the 1930's and 1940's; western Queens County felt similar effects in the 1950's and 1960's. Pumping was continually shifted east from these severely affected areas. Water levels in Kings County and western Queens County have gradually recovered; water quality has also shown improvement in some areas.

Today, the area most intensely stressed in western Long Island is eastern Queens County. Although water levels in this area are declining and water quality is still gradually deteriorating, these effects are not as severe as those previously experienced in Kings County.

At present, the entire population of Kings County and most of Queens is supplied with water from upstate surface-water sources totaling almost 700 Mgal/d (New York City, Bureau of Water Supply, written commun., 1980). However, more than 500,000 people and about 7,600 commercial and industrial users in southeast Queens obtain water from a private water company (Jamaica Water Supply Company) that pumps local aquifers. In 1980, net pumpage for public supply from Queens aquifers was 62.5 Mgal/d, and known net industrial pumpage in 1979 was 1.5 Mgal/d (New York State Department of Environmental Conservation, written commun., 1980). Of the 62.5 Mgal/d public-supply pumpage in Queens County, 16.6 Mgal/d was pumped from the upper glacial aquifer, 38.9 Mgal/d from the Magothy-Jameco aquifer (37.3 Mgal/d from the Magothy aquifer and 1.6 Mgal/d from the Jameco aquifer), and about 7 Mgal/d from the Lloyd aquifer (Jamaica Water Supply Co., written commun., 1981).

Water-table recovery after the cessation of pumping in Kings and southwestern Queens caused flooding in deep basements and subways (Soren, 1976). Dewatering is now (1981) continuous; however, it is difficult to assess the quantity. Perlmutter and Soren (1962, p. 138) report that dewatering at several subway stations in Flatbush rose from less than 20 gal/min to as much as 1,000 gal/min from 1947 to 1961. Currently the subway system is being dewatered in the Flatbush, Bedford, and East New York areas (fig. 2). Permits were issued by the New York State Department of Environmental Conservation to the subway authorities for installation of 20 wells with a total pumpage capacity of 31 Mgal/d. Not all wells are likely to be used simultaneously, nor will pumping be continuous; therefore, current net pumpage is probably less than half the capacity. Although no information is available on the amount of dewatering at numerous homes, businesses, and institutions, the total amount is probably significant.

Although much of the western Long Island ground-water system is recovering and water levels in parts of Kings County are approaching levels of 1903, some severe, perhaps irreversible, deviations from the predevelopment ground-water flow patterns persist. Precipitation still infiltrates the remaining permeable land surface and recharges the ground-water reservoir at the water table; however, Soren (1971, p. A20) estimates that recharge from precipitation is less than half of what it was before the effects of urbanization. An artificial source of recharge is leakage from water-supply lines and combined storm and sanitary sewer lines. Soren (1971, p. A21) estimates that as much as 15 Mgal/d leaked from aging water-supply lines in Queens County in the 1960's; this is less than 6 percent of the average water use in Queens in the 1960's and is probably a conservative estimate. Leakage from sewer lines is also likely (Kimmel, 1972), although this has a more significant effect on quality than quantity. The principal hydrologic concern at present is the degree of recovery from past contamination by saltwater encroachment and the extent of present contamination from surface sources.

Present Water-Table Configuration

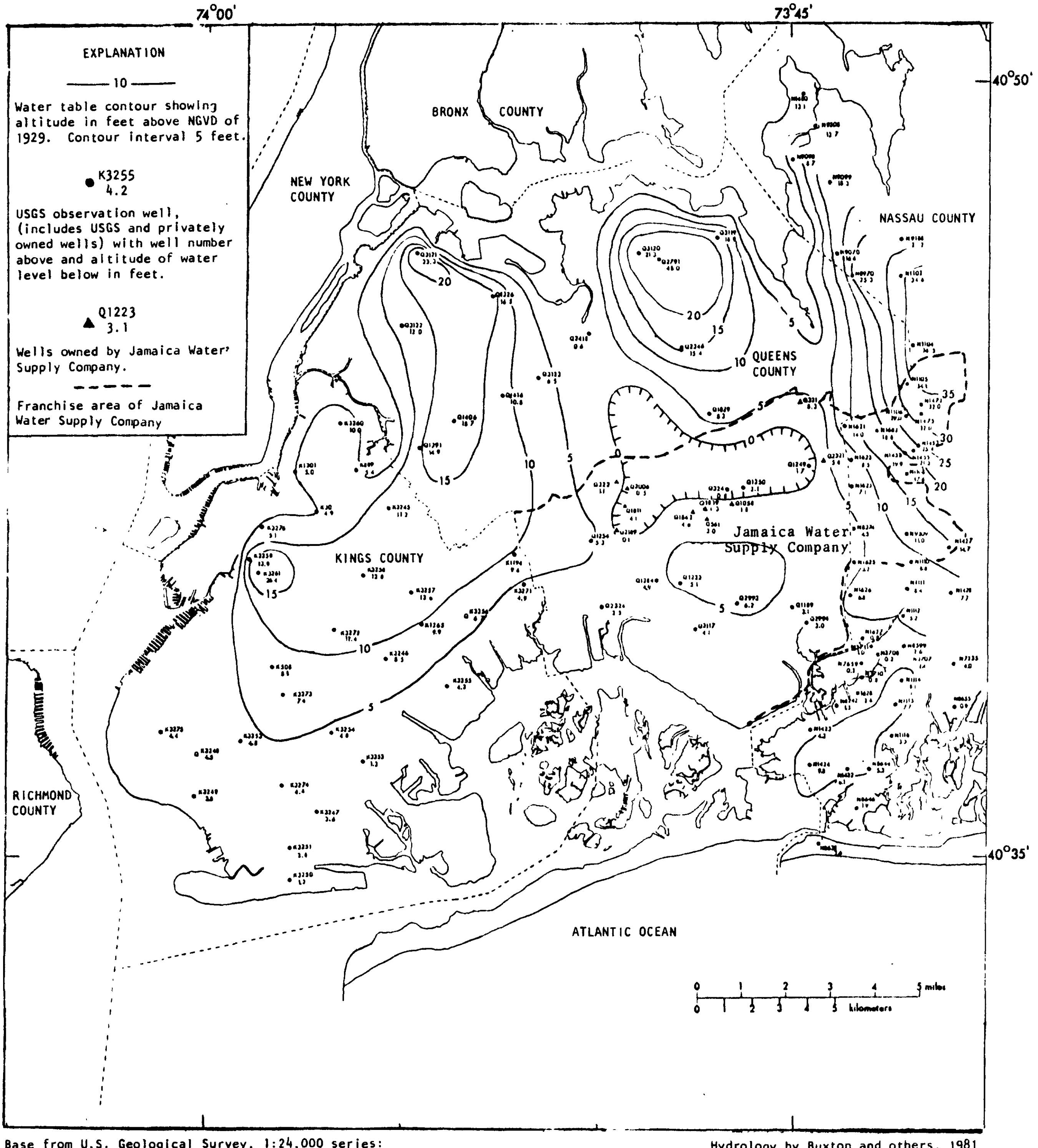
The U.S. Geological Survey measured water levels in 63 wells screened in the upper glacial aquifer in Kings County (29 wells) and Queens County (34 wells) from February through June 1981. Several measurements in Nassau County along the Queens County line were added; a map of the water-table configuration is shown in figure 21.

The water table is above sea level in all of Kings County. Recovery since 1974 (fig. 17) is evident in southeast Kings County and southwest Queens County, probably as a result of continued recovery after cessation of public-supply pumping in Woodhaven in 1974. The highest water levels in Kings County are probably within 8 feet of 1903 levels (fig. 10).

Anomalous high water levels are found in northern Queens County as indicated on several earlier water-table maps (figs. 11, 13-16). High water levels in wells screened near sea level indicate that these highs are not the result of perched conditions but are hydraulically connected to the water table.

A large cone of depression in the central part of Queens County (fig. 21) is most likely the result of public-supply pumping by the Jamaica Water Supply Company. Water levels in this area are measured in pumping wells that are, through the cooperation of the owner, turned off approximately 1 hour before the measurement is taken, so that water levels have time to recover. These water levels are not indicative of the static water level in the well, even over a short period of time; however, they give an approximate indication of the average water-table altitude in this area.

The steep eastward gradient in the water table at the Queens-Nassau County line suggests that a significant amount of water enters western Long Island from the east. The present water-table configuration in Kings and Queens Counties is, therefore, dependent upon this source of ground water, and future changes in the ground-water system in Nassau County that affect this source of water will also have an effect on hydrologic conditions in Kings and Queens Counties.



Base from U.S. Geological Survey, 1:24,000 series: Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956: Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955: and Far Rockaway, Weehawken, 1954.

Hydrology by Buxton and others, 1981

Figure 21.--Water-table configuration in 1981. Water-level measurements were taken from February to June.

Present Ground-Water Quality

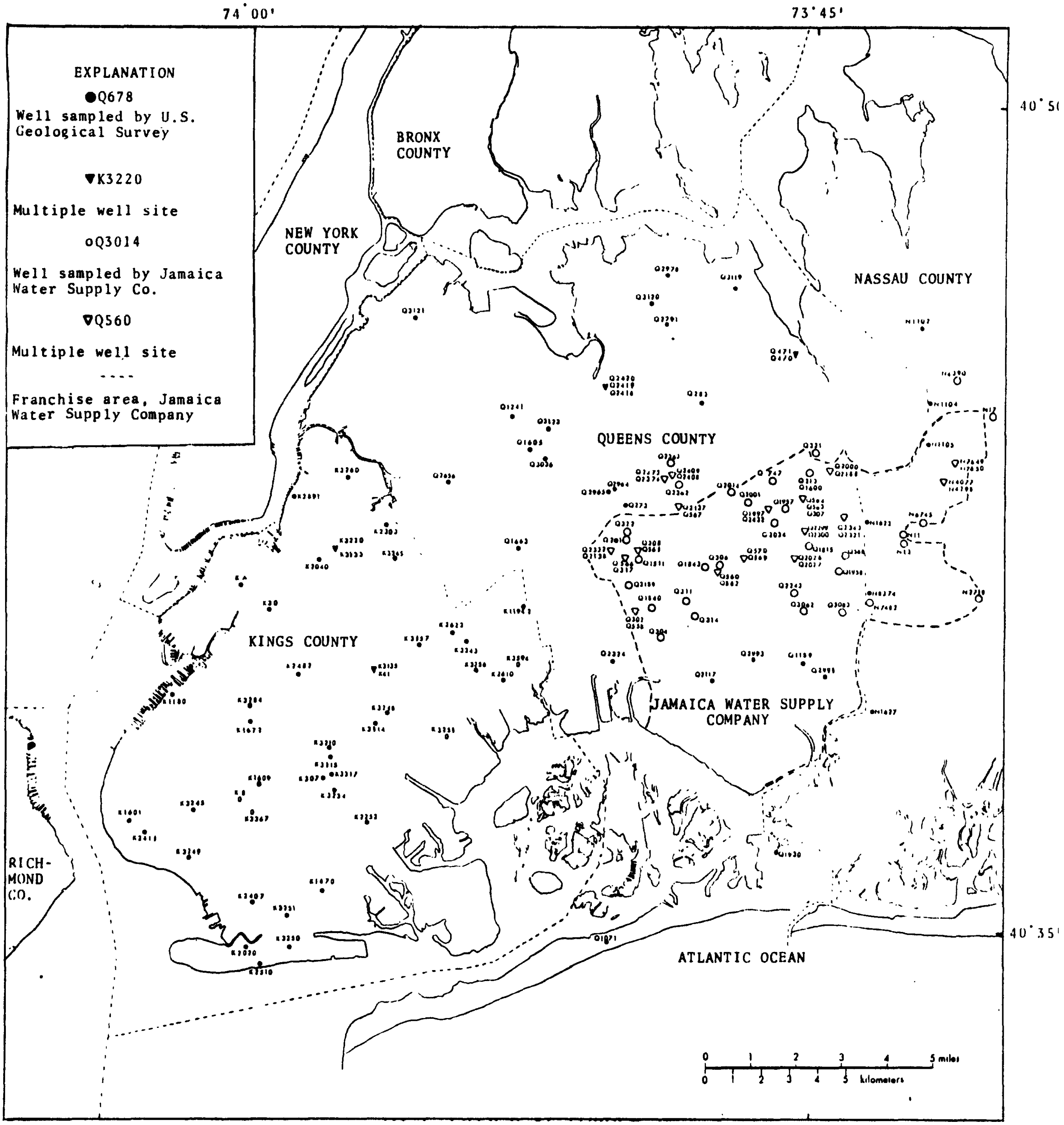
The U.S. Geological Survey undertook a reconnaissance sampling to determine the present ground-water quality in the western part of the Long Island ground-water system. Seventy-seven wells were sampled from February to April 1981; well locations are shown in figure 22. These wells were selected to give a representative estimate of ground-water quality both areally across western Long Island and in each of the aquifer units. Of the 77 wells sampled, 62 were screened in the upper glacial aquifer, 6 were screened in the Magothy-Jameco aquifer, and 9 were screened in the Lloyd aquifer. Few samples were taken from the Magothy-Jameco and Lloyd aquifers owing to a lack of wells. (Many wells have been lost or destroyed in recent years because of the cessation of public-supply pumping and the reduction in industrial pumping. Additional sampling may be possible during summer when deep air-conditioning wells are in operation.) Extensive water-quality analyses were performed; results are listed in table 2 (at end of report).

An additional 67 wells were sampled by the Jamaica Water Supply Company from August 1980 to April 1981. These wells are in the company's southeast Queens County franchise area (fig. 22). Of the 67 wells sampled, 31 were screened in the upper glacial aquifer, 32 were screened in the Magothy-Jameco aquifer, and 4 were screened in the Lloyd. These samples were analyzed by the Jamaica Water Supply Company's water-quality laboratory; results of the chloride and nitrate analyses are incorporated in the following discussion of the occurrence of these constituents in the ground water in the area. Figures 23-25 show the chloride distribution in each of the three major aquifers; figures 26-28 depict the nitrate distribution.

Sampling and Analytical Procedures

The wells sampled by the Geological Survey ranged in diameter from 2 to 32 inches. Generally, the smaller wells are Geological Survey observation wells; those of larger diameter are industrial supply wells. Sample-collection procedures varied accordingly, determined mainly by well diameter and depth to water. Normally, where the depth to water was 25 ft or less, a centrifugal pump was used, otherwise a submersible pump was used. In places where both the centrifugal pump and submersible pump were not practical, the samples were bailed. The volume of water standing in the well casing was evacuated three times, and specific conductance was monitored until stable before sampling.

All samples were stored and preserved with appropriate chemical reagents as prescribed by the Bureau of Water-Supply Laboratory (NYCDEP) (Romola Popper, written commun., 1981). Samples were analyzed according to "Standard Methods" (American Public Health Association and others, 1976).



Base from U.S. Geological Survey, 1:24,000 series
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 22.--Location of wells sampled from August 1980 to April 1981.

Chloride

The most severe chloride contamination in all aquifers is near shore areas. Chloride contamination is present throughout the upper glacial aquifer in western Long Island. Most inland contamination is probably derived from surface contamination, but some inland areas probably also contain remnants of past contamination by saltwater encroachment.

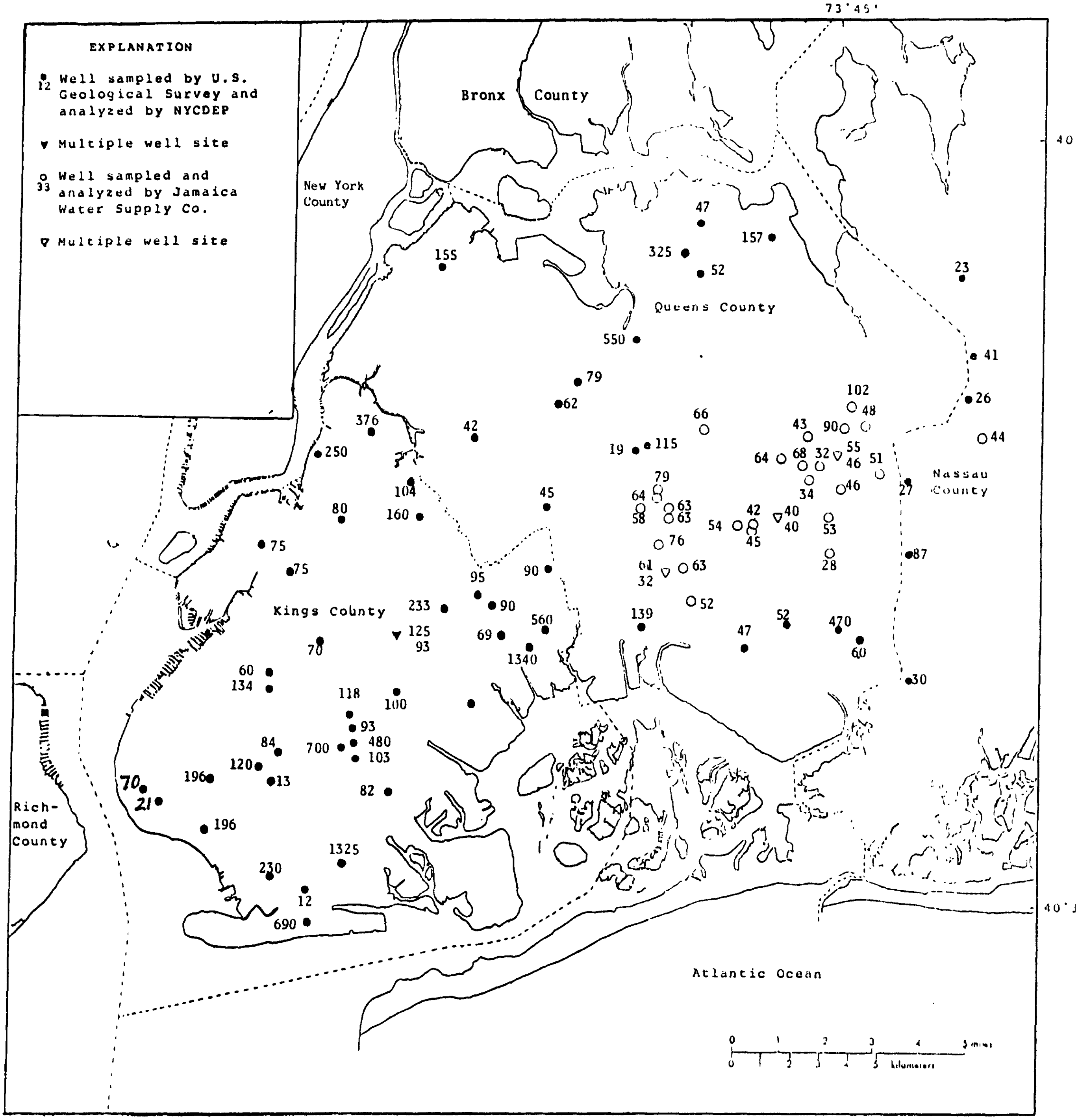
Although inland contamination of the Magothy-Jameco aquifer is likely caused by downward movement of water from the upper glacial aquifer, more data would be needed to define the position of the saltwater interface in this aquifer. The Lloyd aquifer contains no evidence of inland chloride contamination; however, better definition of the saltwater interface on the south shore is needed.

Upper glacial aquifer.--Analyses of samples from 92 wells screened in the upper glacial aquifer are available. Of these, 38 are in Kings County, 47 are in Queens County, and 7 are in Nassau County. Chloride concentrations range from 12 mg/L to 1,340 mg/L. Water from all but three wells in Kings County had chloride concentration greater than 40 mg/L (fig. 23); 27 were in the range of 40 to 250 mg/L, which suggests contamination from saltwater intrusion. Water in the remaining eight wells ranged from 250 mg/L to 1,340 mg/L. The highest concentrations were near the shores and estuaries, which probably indicates the present position of the zone of diffusion. Water from several inland wells also had high chloride concentrations that are probably remnants of intrusion induced from pumping in the defunct Flatbush franchise area (NYWSC).

In Queens County, samples from 8 of the 47 wells had chloride concentration of 40 mg/L or less, and 30 had chloride concentration from 40 to 80 mg/L, indicating some contamination but generally better quality than in Kings County. Water from the remaining nine wells had chloride concentration ranging from 80 to 550 mg/L; the highest concentration was found in shore areas. Chloride concentration inland in Queens County was lower than that in Kings County, probably because past contamination from saltwater intrusion was less severe.

Water from six of the seven wells in Nassau County had chloride concentration less than 45 mg/L, demonstrating still better ground-water quality to the east. Therefore, ground water flowing westward from Nassau County probably aids the recovery of ground-water quality in Queens County.

In summary, chloride contamination in the upper glacial aquifer decreases eastward from Kings County. Chloride concentration has increased as compared with concentration in 1947 in Kings County (fig. 19) and 1961 in Queens County (fig. 20); at present, water from virtually all the upper glacial aquifer in both counties has chloride concentration of 40 mg/L or more. Recovery is evident, however, where severe saltwater intrusion in Kings County had elevated chloride concentration to as high as 15,000 mg/L; the highest concentration observed in 1981 was 1,340 mg/L (fig. 23).



Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 23.--Chloride (Cl^-) concentration in upper glacial aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)

Magothy-Jameco aquifer.--Samples from all 38 wells screened in the Magothy-Jameco aquifer were analyzed (fig. 24). Only four wells were available in Kings County; these are in shore areas, and water from them had concentration ranging from 94 to 15,000 mg/L. They probably all tap the zone of diffusion of the saltwater interface. In Queens County, chloride concentration in the Magothy-Jameco aquifer was noticeably lower than in the upper glacial aquifer. Water from all but five of the 24 wells in Queens County had concentrations of less than 42 mg/L, and only three showed concentrations exceeding 60 mg/L (one of these is in Far Rockaway, which is within the zone of diffusion of the saltwater interface).

Chloride concentrations in 10 samples from Nassau County along the Queens border ranged from 7 mg/L to 33 mg/L, and, as in the upper glacial aquifer, indicate that chloride concentration decreases eastward. The Magothy-Jameco aquifer may be contaminated from the advance of the zone of diffusion or from downward movement of chloride from the upper glacial aquifer. More data are needed to define the exact position of the saltwater interface in this aquifer and to identify recent trends in ground-water quality.

Lloyd aquifer.--Of the 13 wells sampled from the Lloyd aquifer, 12 are in Queens County. Chloride concentration inland ranges from 1 mg/L to 15 mg/L, suggesting that water in the Lloyd aquifer in most areas of Queens is near predevelopment quality (fig. 25). Two wells near the south shore show high chloride concentrations and may be in the leading edge of the zone of diffusion of the saltwater interface. Alternatively, this contamination may have migrated downward through the Raritan confining unit from the Magothy-Jameco aquifer, where the zone of diffusion seems to have advanced farther landward. Additional sampling in the Lloyd aquifer should more accurately define the zone of diffusion of the saltwater interface and areas of good hydraulic connection with the overlying aquifer.

Nitrate

Nitrate contamination is apparent throughout the upper glacial aquifer and is most severe in Kings County. Some contamination has entered the deeper aquifers by downward migration, predominantly in areas where the confining units are absent. Therefore, accurate delineation of these confining units, including their thickness and extent, is important in predicting future trends of nitrate contamination of the deeper aquifers.

Upper glacial aquifer.--Water from 93 wells screened in the upper glacial aquifer was analyzed for nitrate (as N) (fig. 26). Of the 38 samples from Kings County, 16 had nitrate (as N) concentrations of 10 mg/L or more, and 26 had concentrations of 1 mg/L or more. Only two had less than 1 mg/L; one of these had a chloride concentration of 690 mg/L, which indicates contamination by seawater.

In Queens County, 47 wells were sampled. All but 10 samples had nitrate concentrations lower than 10 mg/L, and many of these were below 1.0 mg/L. Water from all seven wells sampled in Nassau County had concentrations of nitrate (as N) less than 10 mg/L.

Overall, the nitrate data for the upper glacial aquifer indicate extensive contamination that seems to be most severe in Kings County and decreases eastward. The relative proximity of high and low concentrations (fig. 26) suggests localized sources of contamination.

Magothy-Jameco aquifer.--Concentrations of nitrate (as N) in samples from 38 wells in the Magothy-Jameco aquifer ranged from 0.1 to 15.8 mg/L (fig. 27). Only four analyses are available for Kings County, and no conclusions can be drawn. Samples in Queens County have nitrate (as N) concentration from 0.1 mg/L to 7.6 mg/L. The distribution of nitrate seems lower where the Magothy-Jameco aquifer is confined by the Gardiners Clay, where downward movement of surface contamination is inhibited, but the data are not conclusive. The analyses for Nassau County (where the Magothy-Jameco aquifer is unconfined) indicate concentrations comparable to those in Queens County where the aquifer is unconfined.

Lloyd aquifer.--Concentration of nitrate (as N) in the Lloyd aquifer ranges from 0.1 to 6 mg/L (fig. 28), generally indicating better quality than the overlying aquifers. Eleven wells were sampled from inland areas; six had concentrations of nitrate within the estimated predevelopment levels (0.2 mg/L as N), and only three exceeded 1.2 mg/L.

SUMMARY

The aquifers underlying Kings and Queens Counties have supplied an average of about 120 Mgal/d from 1904 to 1947. Since 1947, the aquifers in Queens County alone have supplied 60 Mgal/d. Ground-water quality in Kings County after 44 years of pumping deteriorated to the point of condemnation, primarily as a result of saltwater intrusion. The deterioration of ground-water quality in Queens County has not reached the severity noted in Kings County and is still meeting quality standards after 77 years of pumping. The condemnation of pumping for public supply in Kings County and southwest Queens did not mean that this source of water supply was totally unusable, especially as an emergency supply.

Since cessation of pumping in Kings County and southwest Queens County, ground-water levels have recovered steadily, and severe saltwater contamination has been diluted in some areas. However, before any plan to redevelop the ground-water reservoir of western Long Island is implemented, two major questions need to be addressed: (1) Does the present ground-water quality justify redevelopment of the ground-water resources of Kings and Queens Counties, and (2) what levels of ground-water pumpage, either continuous or periodic, can be sustained without jeopardizing ground-water quality?

The most significant findings from this phase of the study are as follows:

1. Heavy pumping in Kings County in the 1930's and in Queens by 1960 severely lowered ground-water levels.

2. Contamination of the aquifers by surrounding salt water began when water levels near shore areas were lowered; the encroachment progressed more rapidly when the cones of depression reached below sea level and near-shore ground-water gradients approached zero.

3. The upper glacial aquifer shows indications of recovery from saltwater intrusion induced during periods of severe pumping, but chloride contamination from surface sources and remnants of past saltwater intrusion are still dominant in inland areas.

4. The expansion of the cone of depression, and subsequent saltwater intrusion, is most rapid in the deeper aquifers where their confined storage properties result in shorter transient response to equilibrium.

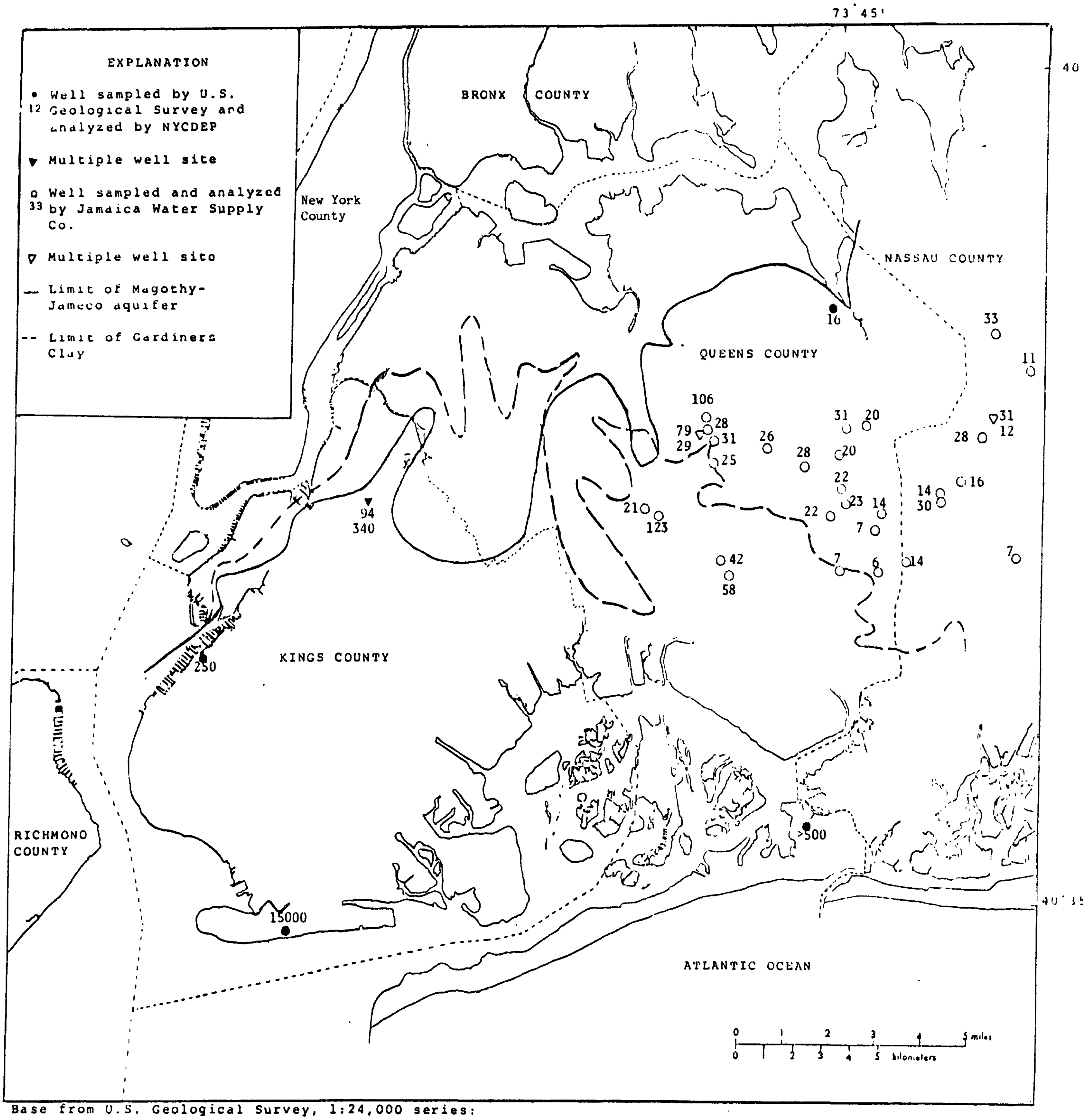
5. At present, the upper glacial aquifer in both counties shows considerable contamination by nitrate and chloride from surface sources. However, the degree of contamination decreases eastward through the area studied.

6. Some contamination of deeper aquifers from surface sources is evident and is attributed to downward migration through areas of good hydraulic connection between aquifers. Pumping these areas of the deeper aquifers is expected to accelerate this downward migration of surface contaminants.

7. Although chloride and nitrate have been used as the principal indicators of ground-water contamination, concentrations of other constituents have not been carefully studied. Point-source contamination could have significant local effects on ground-water quality, especially in the upper glacial aquifer.

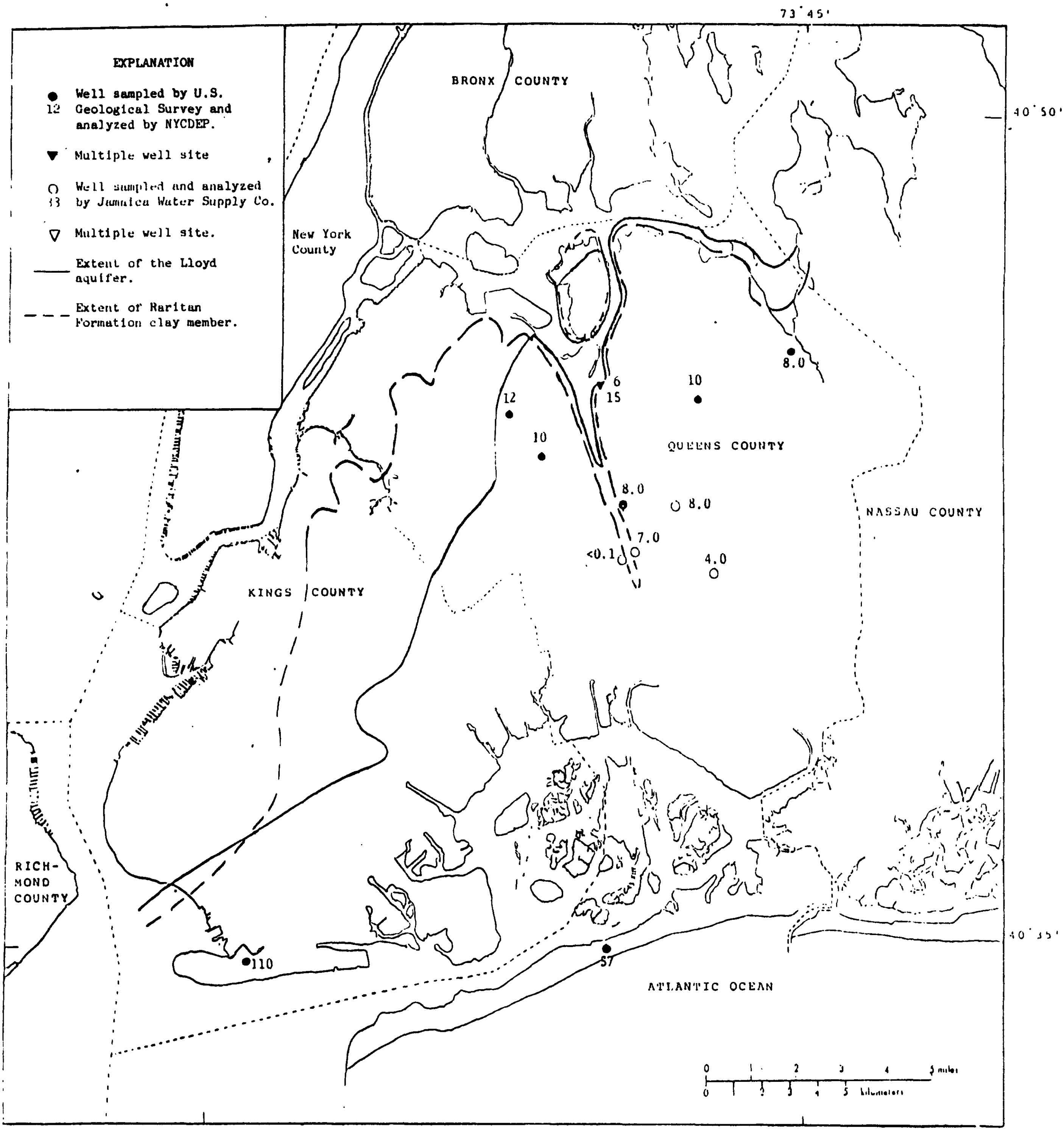
8. The ground-water reservoir of Kings and Queens Counties is an integral part of the entire Long Island ground-water system; the effects of any major stress impact the entire system. Thus, consideration of hydrologic conditions and future trends in central Long Island is integral to the accurate assessment and prediction of hydrologic conditions in Kings and Queens Counties.

The data collected in this investigation indicate that some potable ground water is available in the Magothy-Jameco and Lloyd aquifers. However, an accurate assessment of the quantity of water available and a suitable draft rate is as yet undetermined.



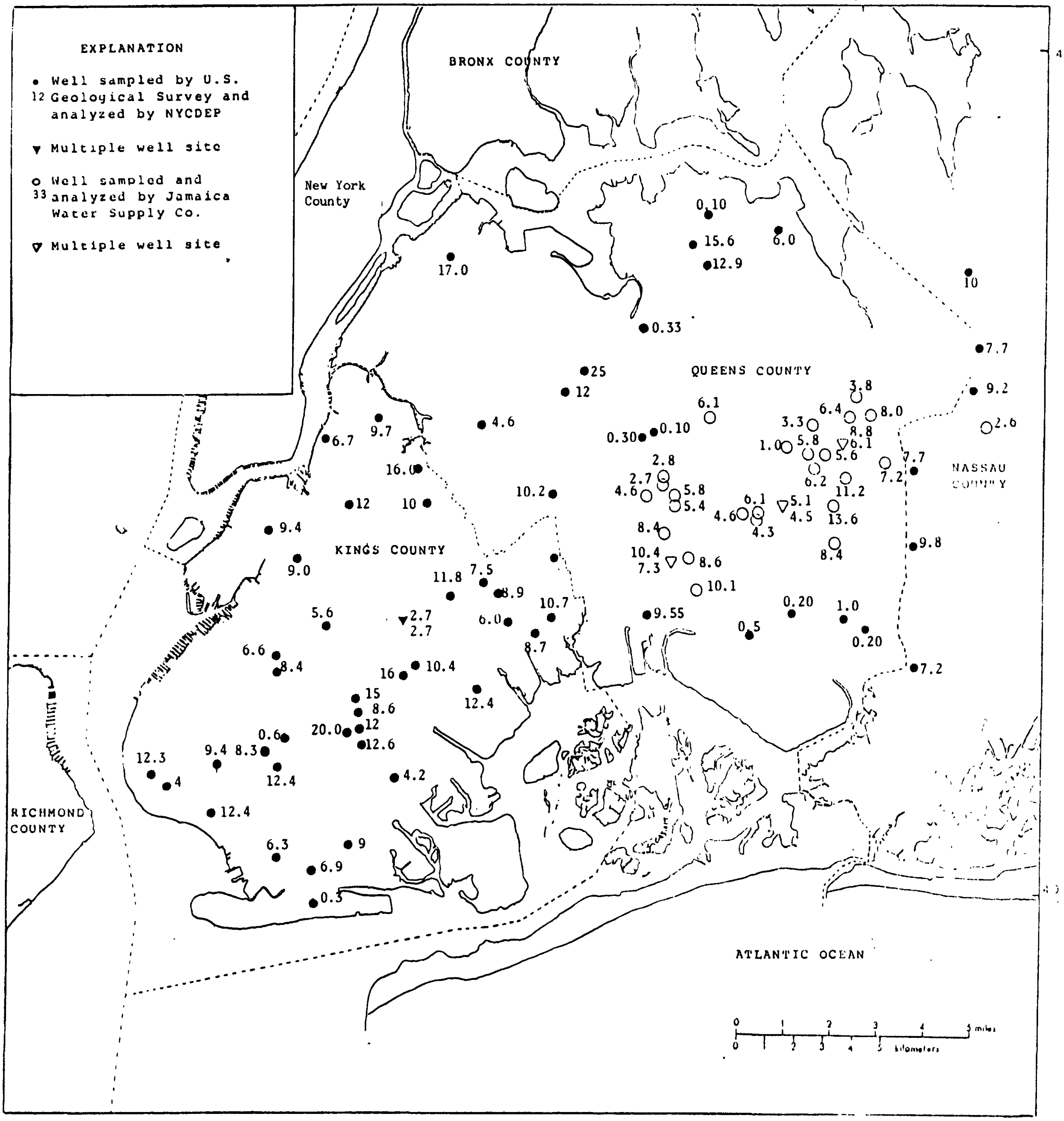
Base from U.S. Geological Survey, 1:24,000 series: Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956; Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955; and Far Rockaway, Weehawken, 1954.

Figure 24.--Chloride (Cl^-) concentrations in the Magothy-Jameco aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)



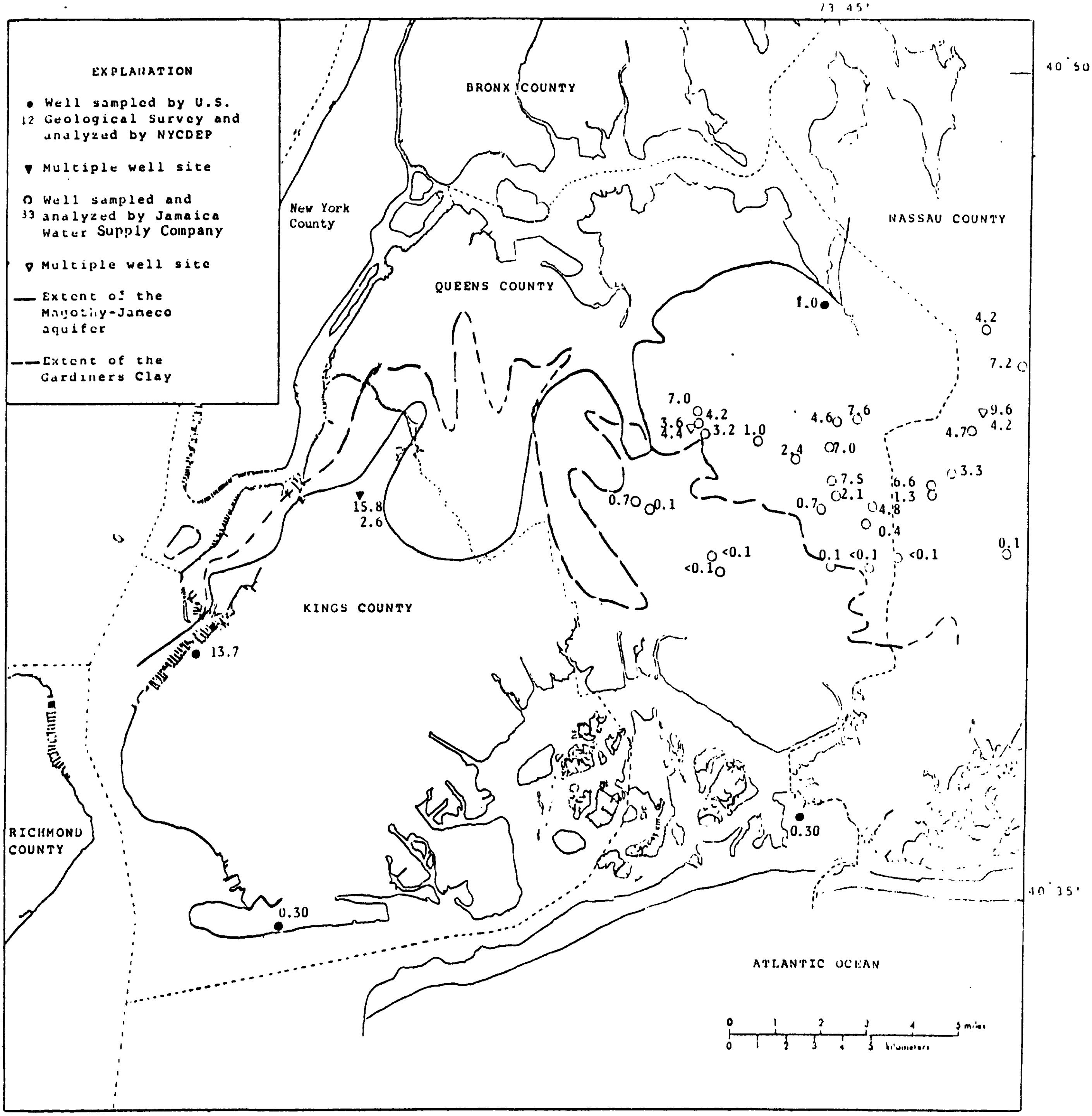
Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockway, Weehawken, 1954.

Figure 25.--Chloride (Cl^-) concentrations in the Lloyd aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)



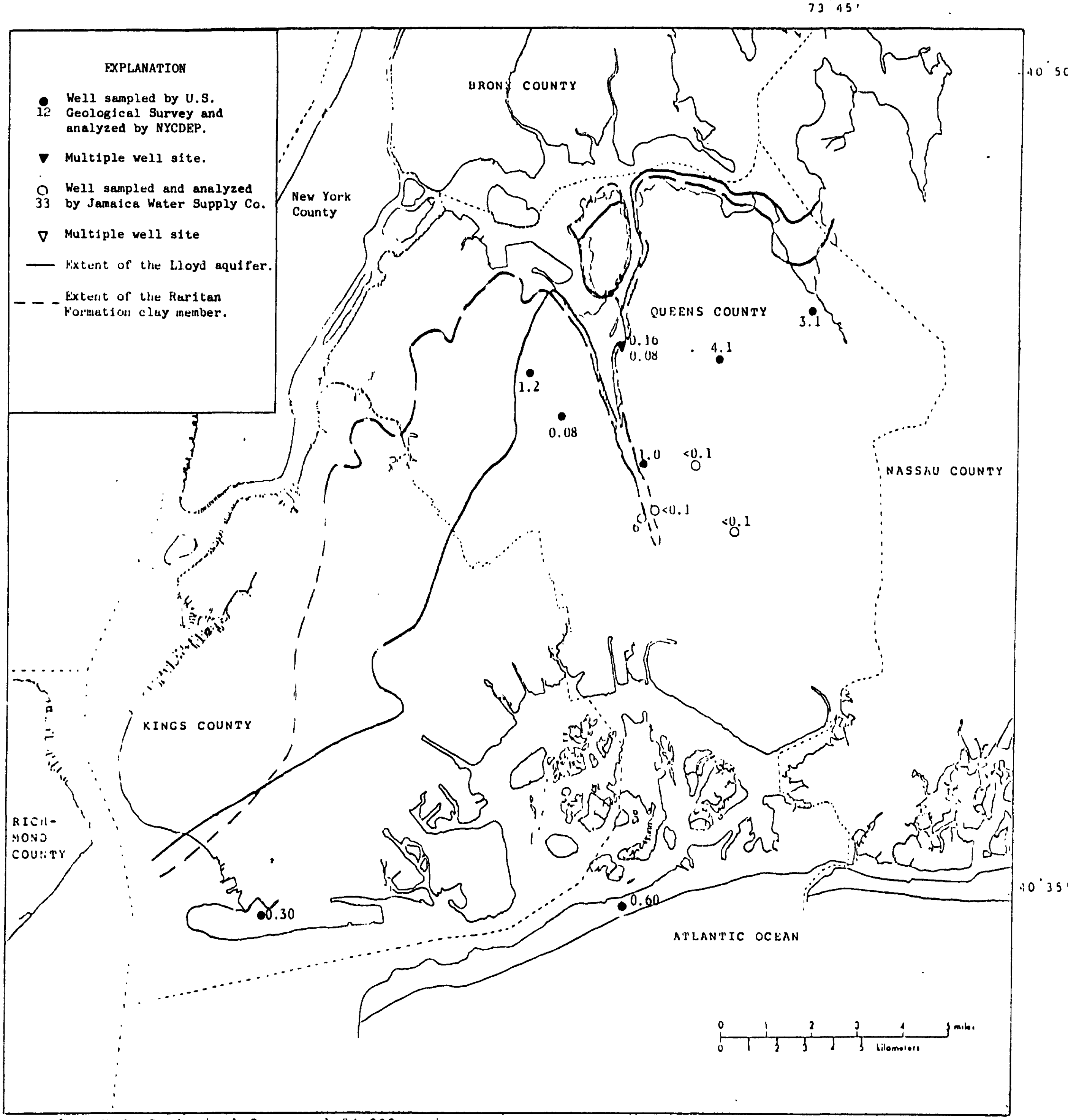
Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 26.--Nitrate (NO_3^- as N) concentrations in the upper glacial aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)



Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 27.--Nitrate (NO_3^- as N) concentrations in the Magothy-Jameco aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)



Base from U.S. Geological Survey, 1:24,000 series:
Jamaica, 1957; Brooklyn, Central Park, Mount Vernon, Yonkers, 1956;
Coney Island, Flushing, Jersey City, The Narrows, Hackensack, 1955;
and Far Rockaway, Weehawken, 1954.

Figure 28.--Nitrate (NO_3^- as N) concentrations in the Lloyd aquifer, 1980-81. (Locations and county well numbers are given in fig. 22; complete analyses are given in table 2.)

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Table 2.--Selected chemical analyses of ground water in Kings and Queens Counties, N.Y.

Well No.	Total Well Depth (ft)	Aquifer[1/]	Date Sampled	Specific conductance (µmho)	pH (units)	Temp. Field (°C)	Color (u)	Turbidity (NTU)	Coliform, Total MF[2/] (cols./100 mL)	Hardness (mg/L as $CaCO_3$)	Calcium, Total (mg/L as Ca)	Magnesium, Total (mg/L as Mg)	Sodium, Total (mg/L as Na)	Potassium, Total (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, Dissolved (mg/L as SO_4)	Chloride, Dissolved (mg/L as Cl)
K20	126	UG	04/03/81	780	7.6	—	5	1.0	3	370	101.15	28.50	28	2.80	210	75.0	75
K41	100	UG	04/08/81	1150	7.2	19.0	8	2.3	<1	560	169.88	33.00	40	5.00	300	140.0	93
K307	73	UG	02/25/81	2500	7.0	16.5	3	.3	<1	240	--	91.50	70	3.84	92	100.0	700
K1189	144	J	03/11/81	1400	7.7	15.0	6	2.0	<1	280	60.00	31.00	200	10.00	180	95.0	250
K1194	52	UG	03/18/81	770	7.2	12.0	10	1.8	TNTC[3/]	310	72.00	31.00	44	2.10	200	160.0	90
K1673	84	UG	02/18/81	890	7.3	15.5	2	.3	<1	400	--	--	--	--	224	86.0	134
K1678	124	UG	04/07/81	4560	7.6	13.0	220	>25.0	<1	880	298.70	32.50	700	14.00	96	260.0	1325
K1681	110	UG	02/24/81	890	7.3	14.0	3	.9	<1	680	237.70	20.40	2.6	3.20	172	125.0	70
K1689	73	UG	02/25/81	1000	7.3	19.5	3	.3	<1	96	--	50.00	40	3.30	240	65.0	84
K2040	101	UG	04/09/81	490	7.3	15.0	18	5.3	<1	170	29.05	23.75	38	2.15	98	50.0	80
K2135	80	UG	04/08/81	1200	6.8	21.5	9	2.5	<1	485	144.68	30.00	73	6.00	300	120.0	125
K2284	71	UG	02/18/81	660	7.3	21.0	2	.6	1	288	--	--	--	--	200	40.0	60
K2303	65	UG	03/31/81	1030	7.2	16.0	23	.3	<1	400	105.74	33.00	62	4.36	212	130.0	104
K2407	58	UG	02/12/81	1210	6.9	7.0	4	.4	<1	164	--	--	--	--	196	78.0	230
K2412	91	UG	04/28/81	600	7.6	15.0	3	1.2	<1	288	76.66	23.50	15	--	404	--	21
K2482	128	UG	03/19/81	720	7.4	14.0	7	.4	<1	282	62.40	30.00	41	2.70	180	88.0	70
K2510	207	J	03/23/81	>8000	7.2	13.0	5	2.1	<1	5250	319.00	1060	8000	360.00	150	2400	15000
K2514	51	UG	04/07/81	950	7.0	16.0	6	.4	<1	292	54.18	104.00	73	2.25	130	110.0	100
K2591	59	UG	04/13/81	1400	6.7	17.0	6	1.8	<1	410	104.14	36.50	150	11.50	194	90.0	250
K2594	66	UG	02/12/81	2500	7.5	24.5	5	.5	<1	620	--	--	--	--	168	148.0	560
K2610	60	UG	02/12/81	4300	6.9	16.0	6	.6	<1	1120	—	--	--	—	200	98.0	1340
K2622	105	UG	04/07/81	650	6.9	11.5	5	1.5	<1	272	29.40	21.50	20	1.10	96	85.0	95
K2859	500	L	03/27/81	500	8.0	15.0	18	30.0	<1	40	4.60	6.80	70	6.00	52	10.0	110
K3133	190	J	03/04/81	1700	7.4	12.0	6	.4	<1	460	176.40	4.50	175	4.08	180	126.0	340
K3215	75	UG	04/14/81	970	7.1	16.5	4	.3	<1	360	87.42	34.50	54	2.76	120	100.0	166
K3217	75	UG	04/14/81	2000	6.7	17.5	—	—	<1	350	39.14	61.50	175	4.40	110	--	480
K3218	70	UG	04/14/81	780	7.4	16.5	4	.3	<1	300	65.06	33.50	38	2.90	140	57.0	93
K3220	185	J	03/04/81	1140	7.4	14.0	5	.5	<1	466	179.00	4.38	56	2.90	222	208.0	94
K3243	—	UG	04/14/81	800	7.0	14.0	4	.3	<1	310	81.36	26.00	40	2.30	144	--	90
K3245	26	UG	02/25/81	1000	6.9	--	40	19.0	>30	190	--	--	--	--	80	156	160
K3246	30	UG	02/10/81	--	6.2	18	--	--	<1	--	--	--	--	--	--	--	--
K3248	42	UG	02/24/81	990	6.4	15.0	28	250.0	TNTC	400	--	134.37	6.6	18.50	100	115.0	196
K3249	32	UG	04/22/81	800	6.2	14.5	76	14.0	480	200	--	54.00	70	—	8	--	196
K3250	30	UG	02/11/81	2700	6.8	16.0	60	15.0	<1	500	--	--	--	--	230	130	690
K3251	23	UG	02/11/81	470	6.7	12.5	5	22.0	3	216	—	--	--	--	186	20	12
K3252	30	UG	02/11/81	580	6.4	16.5	27	10.0	24	124	—	--	--	--	96	56.4	82
K3254	29	UG	05/01/81	800	6.6	11.0	60	.7	<1	260	—	--	--	--	172	--	103
K3255	24	UG	02/11/81	--	--	17.0	--	--	4	--	--	--	--	--	--	--	850

1/ UG - Upper glacial aquifer; J - Jameco aquifer; M - Magothy aquifer; L - Lloyd aquifer.

2/ MF - Membrane Filter.

3/ TNTC - Too numerous to count.

Table 2.--Selected chemical analyses of ground water in Kings and Queens Counties, N.Y.--continued

Well No.	Fluoride Total (mg/L as F)	Total Dissolved Solids (mg/L)	Nitrogen, Nitrate Total (mg/L as N)	Nitrogen, Nitrite Total (mg/L as N)	Nitrogen, Ammonia Total (mg/L as N)	Arsenic, Total (mg/L as As)	Barium, Total (mg/L as Ba)	Cadmium, Total (mg/L as Cd)	Chromium, Total (mg/L as Cr)	Copper Total (mg/L as Cu)	Iron Total (mg/L as Fe)	Lead Total (mg/L as Pb)	Manganese, Total (mg/L as Mn)	Mercury, Total (mg/L as Hg)	Selenium, Total (mg/L as Se)	Silver Total (mg/L as Ag)	Zinc, Total (mg/L as Zn)	Linear Alkyl Sulfonate
K20	.14	--	9.00	<.001	.12	<.05	<.50	<.01	<.05	.01	.16	<.03	.08	<.001	--	<.01	.02	neg
K41	.11	--	2.70	.015	.06	--	<.50	<.01	<.05	.06	.23	<.03	.06	<.001	--	<.01	.27	neg
K307	--	1440	20.00	.002	.08	<.05	<.20	<.01	<.05	.02	.12	<.01	<.01	<.001	<.01	<.03	.03	neg
K1189	--	822	13.70	.009	.06	--	<.20	<.01	<.04	.06	2.60	<.01	.30	<.001	--	<.03	.04	neg
K1194	.13	464	13.10	.040	.18	<.02	<.50	<.01	<.05	.46	36.10	.60	.70	<.001	--	<.03	2.90	neg
K1673	--	616	8.40	.001	.09	<.05	--	<.01	<.04	.01	.03	<.01	.03	<.001	<.01	<.03	.04	neg
K1678	.10	--	9.00	<.001	<.03	--	<.50	<.01	<.05	.03	.10	<.03	.03	<.001	--	<.01	.04	neg
K1681	--	586	12.30	<.001	.18	<.05	<.20	<.01	<.04	.04	.17	<.01	<.01	<.001	<.01	<.03	.16	neg
K1689	--	560	.60	<.001	.03	<.05	<.20	<.01	<.05	.04	.10	<.01	<.01	<.001	<.01	<.03	.05	neg
K2040	.11	--	12.00	.002	.18	--	<.50	<.01	<.05	.01	.69	<.03	.04	<.001	--	<.01	1.96	neg
K2135	.16	--	2.70	.005	.14	--	<.50	<.01	.05	.03	.80	<.03	.40	<.001	--	<.01	.03	neg
K2284	--	430	6.60	<.001	.05	<.05	--	<.01	<.04	.01	.03	<.01	.03	<.001	<.01	<.03	.02	neg
K2303	.13	508	16.00	.004	.12	<.001	<.50	<.01	.60	.01	.06	<.01	.03	<.001	--	<.01	.02	neg
K2407	--	798	6.30	.004	.05	<.05	<.20	<.01	<.04	.01	.04	<.01	.44	<.001	<.01	<.03	.06	neg
K2412	.18	--	4.00	<.001	.05	--	<.50	<.01	<.05	.02	.18	<.03	.03	--	--	<.01	.05	--
K2482	.19	478	5.60	<.001	<.03	--	<.50	<.01	<.05	.01	.10	<.03	<.01	<.001	--	<.02	.01	--
K2510	.60	29220	.30	<.001	.03	<.02	<.50	<.01	<.05	.05	.32	<.03	.90	<.001	--	.05	.04	neg
K2514	.11	--	16.00	<.001	<.03	--	<.50	<.01	<.05	.01	.03	<.03	.05	<.001	--	<.01	.04	neg
K2591	.18	--	6.70	.016	.006	--	<.50	<.01	.35	.05	6.10	<.03	1.90	<.001	--	<.01	.03	neg
K2594	--	1560	10.70	.012	.05	<.05	--	<.01	<.04	.01	.03	<.01	.17	<.001	<.01	<.03	.07	neg
K2610	--	3320	8.70	.002	.03	<.05	<.20	<.01	.15	.02	.06	<.01	.16	<.001	<.01	<.03	.06	neg
K2622	.24	--	7.50	<.001	<.03	--	<.50	<.01	<.05	.01	.06	<.03	.02	<.001	--	<.01	.02	neg
K2859	.35	260	.30	<.001	.03	--	<.50	<.01	<.05	.01	1.70	<.01	.05	<.001	--	<.01	.02	neg
K3133	--	455	2.60	<.001	.21	<.05	<.20	<.01	.04	.05	.18	<.01	.36	<.001	<.01	<.03	<.01	neg
K3215	.12	--	8.60	<.001	.03	--	<.50	<.01	<.05	.01	.06	<.03	.01	<.001	--	<.01	.02	neg
K3217	.13	--	12.00	.002	.06	--	<.50	<.01	<.05	.01	.08	<.03	.25	<.001	--	<.01	.10	neg
K3218	.13	--	15.00	.001	.01	--	<.50	<.01	.05	.02	.05	<.03	.01	<.001	--	<.01	.03	--
K3220	--	720	15.80	<.001	.27	<.05	<.20	<.01	<.04	.03	.13	<.01	.01	<.001	<.01	<.03	.01	neg
K3243	.15	--	8.90	<.001	.11	--	<.50	<.01	<.05	.01	.06	<.03	.02	<.001	--	<.01	.02	neg
K3245	--	615	10.00	.033	.12	<.05	<.20	<.01	<.04	.07	>50	<.01	8.70	<.001	<.01	<.03	25.00	neg
K3246	--	--	10.40	.002	--	<.05	<.20	<.01	<.04	.01	.60	<.01	.17	<.001	<.01	<.03	1.40	neg
K3248	--	610	9.40	.009	.06	<.05	<.20	<.01	.05	2.50	56.00	<.01	5.30	<.001	<.01	<.03	13.80	neg
K3249	.17	--	12.40	.04	.69	--	<.50	<.01	<.05	.65	55.60	<.03	3.80	--	--	<.01	114.00	neg
K3250	--	1624	.30	<.001	.39	<.05	<.20	<.01	<.04	.01	6.70	<.01	1.30	<.001	<.01	<.03	.73	neg
K3251	--	280	6.90	<.001	.06	<.05	<.20	<.01	<.04	.02	2.10	<.01	.40	<.001	<.01	<.03	1.40	neg
K3252	--	338	4.20	.002	.75	<.05	<.20	<.01	<.04	.01	2.70	<.01	.48	<.001	<.01	<.03	1.00	neg
K3254	<.20	--	12.60	.050	.12	--	<.50	<.01	<.05	.09	23.60	<.03	--	--	--	--	--	neg
K3255	--	--	12.40	.003	--	<.05	<.20	<.01	<.04	.01	2.10	<.01	.05	<.001	<.01	<.03	1.40	neg

Well No.	Total Well Depth (ft)	Aquifer[1/]	Date Sampled	Specific conductance (µmho)	pH (units)	Temp. Field (°C)	Color (u)	Turbidity (NTU)	Coliform, Total MF[2/] (cols./100 mL)	Hardness (mg/L as $CaCO_3$)	Calcium, Total (mg/L as Ca)	Magnesium, Total (mg/L as Mg)	Sodium, Total (mg/L as Na)	Potassium, Total (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, Dissolved (mg/L as SO_4)	Chloride, Dissolved (mg/L as Cl)
K3256	29	UG	02/10/81	620	6.3	18.5	5	4.2	<1	180	--	--	--	--	46	92.0	69
K3257	50	UG	03/20/81	1400	5.9	14.0	60	35.0	<1	460	73.00	66.00	41	6.40	116	210.0	233
K3260	23	UG	02/12/81	2000	6.8	18.5	6	2.7	18	540	--	--	--	--	248	192.0	376
K3267	47	UG	04/23/81	400	6.6	13.0	5	.4	<1	168	1.60	40.00	6.5	--	100	--	13
KA	--	UG	04/06/81	1200	7.8	16.0	18	25.0	TNTC	130	10.07	25.50	140	5.60	236	85.0	75
KB	50	UG	04/09/81	850	7.0	18.5	5	.3	<1	354	81.74	36.50	35	3.20	228	45.0	120
Q273	438	L	04/08/81	160	7.0	--	120	50.0	<1	72	15.68	8.00	4.6	1.25	74	0	8
Q283	409	L	04/01/81	145	6.7	14.0	200	>25.0	<1	34	11.05	1.55	16	3.70	54	5.0	10
Q470	375	L	04/20/81	100	6.3	13.0	8	>20.0	<1	38	8.15	4.30	5.4	--	34	33.0	8
Q471	118	M	02/19/81	63	6.8	12.5	30	17.5	<1	40	--	--	--	--	22	4.0	16
Q1071	836	L	04/29/81	275	6.7	14.5	200	64.0	<1	38	12.58	1.60	--	--	22	--	57
Q1189	50	UG	02/18/81	1650	6.2	14.0	27	7.0	1	470	--	--	--	--	86	52.0	470
Q1241	301	L	03/03/81	230	6.5	--	170	>25.0	<1	60	14.90	5.40	22	2.00	74	18.5	12
Q1605	42	UG	02/20/81	850	7.0	15.5	4	1.0	<1	408	--	--	--	--	212	95.0	62
Q1663	139	UG	02/19/81	730	7.3	9.0	9	3.9	58	368	--	--	--	--	154	97.0	45
Q1930	126	J	03/17/81	>8000	6.8	13.5	88	>25.0	<1	2810	242.00	525.00	5600	120.00	112	1000	>500
Q2324	91	UG	02/13/81	1030	7.4	14.0	5	2.8	<1	452	--	--	--	--	210	100.0	139
Q2418	65	UG	03/03/81	2200	6.8	14.0	70	>25.0	<1	296	111.40	4.16	350	1.80	234	4.0	550
Q2419	271	L	03/02/81	150	7.1	13.5	100	30.0	<1	62	14.80	5.92	7.4	1.33	68	6.3	6
Q2420	273	L	02/26/81	155	6.9	14.0	150	4.4	--	70	17.90	6.00	8.5	1.40	68	1.5	15
Q2656	125	UG	04/30/81	700	7.2	12.5	27	3.5	<1	736	--	40.50	--	--	268	--	42
Q2791	76	UG	05/12/81	700	7.0	15.0	5	.7	<1	160	--	--	--	--	156	--	52
Q2964	182	UG	03/24/81	760	7.2	--	11	3.2	<1	220	50.40	22.40	74	2.20	146	36.0	115
Q2965	208	UG	03/30/81	380	7.2	12.0	60	24.0	<1	87	5.20	17.60	9	5.28	150	26.0	19
Q2978	73	UG	05/18/81	600	6.4	13.0	5	1.4	<1	220	--	--	--	--	70	--	47
Q2993	72	UG	02/23/81	420	6.0	16.0	35	16.0	<1	120	--	--	--	--	40	51.0	52
Q2995	100	UG	02/25/81	85	8.7	14.0	88	23.0	TNTC	22	--	--	--	--	38	2.4	6.0
Q3036	269	L	03/02/81	195	6.7	12.5	150	45.0	<1	36	9.00	3.20	30	2.12	72	12.6	10
Q3117	--	UG	02/09/81	740	6.9	14.5	23	13.5	5	254	--	--	--	--	120	96.0	47
Q3119	40	UG	02/09/81	870	5.9	16.5	18	8.5	<1	288	--	--	--	--	20	92.0	157
Q3120	45	UG	03/02/81	1440	6.1	12.0	11	3.5	<1	550	104.00	69.00	41	6.20	94	70.0	325
Q3121	47	UG	02/27/81	1200	7.2	15.0	15	>25.0	<1	400	--	109.00	64	1.80	250	14.0	155
Q3123	24	UG	02/09/81	1100	7.1	15.0	13	25.0	<1	436	--	--	--	--	230	154.0	79
N1102	166	UG	04/22/81	390	7.8	12.0	30	9.5	60	230	60.51	19.20	19	--	92	--	23
N1104	101	UG	04/16/81	410	7.2	14.0	8	180.0	<1	174	53.69	9.70	30	2.10	70	36.0	41
N1105	87	UG	04/20/81	360	6.5	13.5	21	2.0	<1	92	--	--	--	--	260	35.0	26
N1622	85	UG	04/15/81	600	6.8	12.5	250	40.0	<1	252	48.32	32.00	18	4.60	140	73.0	27
N1627	26	UG	04/13/81	440	6.0	16.0	7	1.1	<1	120	25.53	13.70	18	6.70	66	50.0	30
N8374	53	UG	04/10/81	700	6.2	14.5	15	25.0	<1	200	--	50.00	67.5	10.60	130	40.0	87

1/ UG - Upper glacial aquifer; J - Jameco aquifer; M - Magothy aquifer; L - Lloyd aquifer.

2/ MF - Membrane Filter.

3/ TNTC - Too numerous to count.

Table 2.--Selected chemical analysee of ground water in Kings and Queens Counties, N.Y.--continued

Well No.	Fluoride Total (mg/L as F)	Total Dissolved Solids (mg/L)	Nitrogen, Nitrate Total (mg/L as N)	Nitrogen, Nitrite Total (mg/L as N)	Nitrogen, Ammonia Total (mg/L as N)	Arsenic, Total (mg/L as As)	Barium, Total (mg/L as Ba)	Cadmium, Total (mg/L as Cd)	Chromium, Total (mg/L as Cr)	Copper Total (mg/L as Cu)	Iron Total (mg/L as Fe)	Lead Total (mg/L as Pb)	Manganese, Total (mg/L as Mn)	Mercury, Total (mg/L as Hg)	Selenium, Total (mg/L as Se)	Silver Total (mg/L as Ag)	Zinc, Total (mg/L as Zn)	Linear Alkyl Sulfonate
K3256	--	369	6.00	.002	.15	<.05	<.20	<.01	<.04	.01	11.50	<.01	.16	<.001	<.01	<.03	2.50	neg
K3257	.32	872	11.80	.020	.03	--	<.50	<.01	<.05	.36	46.00	3.00	3.80	<.001	--	<.02	70.00	neg
K3260	--	1304	9.70	.002	.06	<.05	<.20	<.01	<.04	.02	1.00	<.01	.06	<.001	<.01	<.03	1.40	neg
K3267	.14	--	12.40	.010	.14	--	<.50	<.01	<.05	.03	.15	<.03	.03	--	--	<.01	1.55	neg
KA	.17	--	9.40	<.001	.09	--	<.50	<.01	.28	.01	.05	<.03	.03	<.001	--	<.01	.02	neg
KB	.11	--	8.30	.012	.20	--	<.50	<.01	<.05	.01	.03	<.03	.02	.060	--	<.01	.02	--
Q273	.15	--	1.00	<.001	.30	--	<.50	<.01	<.05	<.01	4.00	<.03	.40	<.001	--	<.01	.02	neg
Q283	.15	88	4.10	<.001	1.10	<.05	<.50	<.01	<.05	.01	11.00	<.01	.14	<.001	--	<.01	.22	neg
Q470	<.10	--	3.10	<.001	.51	--	<.50	<.01	<.05	.64	70.00	<.03	.13	--	--	<.01	--	neg
Q471	--	45	1.00	<.001	.20	<.05	<.20	<.01	<.04	.015	.79	<.01	.01	<.001	<.01	<.03	.12	neg
Q1071	.10	--	.60	<.001	.54	--	<.50	<.01	<.05	.01	11.15	<.03	.35	--	--	--	.02	neg
Q1189	--	1020	1.00	.002	.96	<.05	--	<.01	<.04	.01	21.50	<.01	1.80	<.001	<.01	<.03	.09	--
Q1241	--	120	1.25	<.001	.45	<.05	<.20	<.01	<.04	.18	16.50	<.01	.07	<.001	<.01	<.03	.01	neg
Q1605	--	560	12.00	.008	.21	<.05	<.20	<.01	<.04	.09	.18	<.01	.02	<.001	<.01	<.03	.20	neg
Q1663	--	570	10.20	.002	.09	<.05	<.20	<.01	<.04	.08	.48	<.01	.04	<.001	<.01	<.03	.15	neg
Q1930	.18	14024	.30	<.001	.15	--	<.50	--	<.05	.06	30.00	<.03	2.40	<.001	--	<.03	.03	neg
Q2324	--	750	9.55	.002	.06	<.05	<.20	<.01	<.04	.01	.85	<.01	.03	<.001	<.01	<.03	.95	neg
Q2418	--	1300	.33	<.001	.44	<.05	<.20	<.01	<.04	.04	32.50	<.01	1.40	<.001	<.01	<.03	.03	neg
Q2419	--	75	.16	<.001	.30	<.05	<.20	<.01	<.04	.07	3.60	<.01	.12	<.001	<.01	<.03	.04	neg
Q2420	--	90	.08	.002	.29	--	--	--	--	--	--	<.01	--	--	--	--	--	--
Q2656	.22	--	4.60	.004	.30	--	<.50	<.01	<.05	.14	4.80	<.03	--	--	--	--	44.00	neg
Q2791	<.20	--	12.90	<.001	.03	--	--	--	--	--	.09	<.03	--	--	--	--	--	neg
Q2964	.21	452	.10	.005	.05	--	<.50	<.01	<.05	.02	.36	<.01	.30	<.001	--	<.02	<.01	neg
Q2965	.18	242	.30	.004	.08	<.001	<.50	<.01	<.05	.01	2.50	<.01	.65	<.001	--	<.01	.03	neg
Q2978	.10	--	.10	<.001	.18	--	--	--	--	--	--	<.03	--	--	--	--	--	neg
Q2993	--	240	.20	<.001	.45	--	--	--	--	--	--	<.01	--	<.001	--	--	--	neg
Q2995	--	60	.20	<.001	3.96	<.05	<.20	<.01	<.04	.05	4.20	<.01	.01	<.001	<.01	<.03	.04	neg
Q3036	--	110	.08	<.001	1.98	<.05	<.20	<.01	<.04	.04	17.20	<.01	.15	<.001	<.01	<.03	.26	neg
Q3117	--	384	.50	.002	2.25	<.05	<.20	<.01	<.04	.13	1.40	<.01	1.60	<.001	<.01	<.03	.15	neg
Q3119	--	543	6.00	.003	.09	<.05	<.20	<.01	<.04	.01	1.30	<.01	.05	<.001	<.01	<.03	1.60	neg
Q3120	.18	1054	15.60	.040	.15	--	<.50	<.01	<.05	.18	30.00	1.20	3.30	<.001	--	<.02	14.90	neg
Q3121	--	800	17.00	.010	.12	<.05	<.20	<.01	<.04	.35	37.00	<.01	4.20	<.001	<.01	<.03	.31	neg
Q3123	--	650	25.00	.003	.90	<.05	<.20	<.01	<.04	.01	2.60	<.01	.12	<.001	<.01	<.03	1.00	neg
N1102	.15	--	10.00	.065	.87	--	<.50	<.01	<.05	1.50	70.20	<.03	2.40	--	--	<.01	21.00	neg
N1104	.15	--	7.70	.040	.21	--	<.50	<.01	<.05	<.01	.03	<.03	.06	--	--	.01	14.00	neg
N1105	.10	--	9.20	<.001	.54	--	--	--	--	--	--	<.03	--	--	--	--	--	neg
N1622	.18	--	7.70	.003	.03	--	<.50	<.01	.30	.13	14.00	<.03	.50	--	--	<.01	43.00	neg
N1627	.10	--	7.20	.021	.01	--	<.50	<.01	<.05	.01	.30	<.03	.03	<.001	--	<.01	.11	neg
N8374	.13	--	9.80	.047	.51	--	<.50	<.01	<.05	.16	225	<.03	10.00	.031	-			