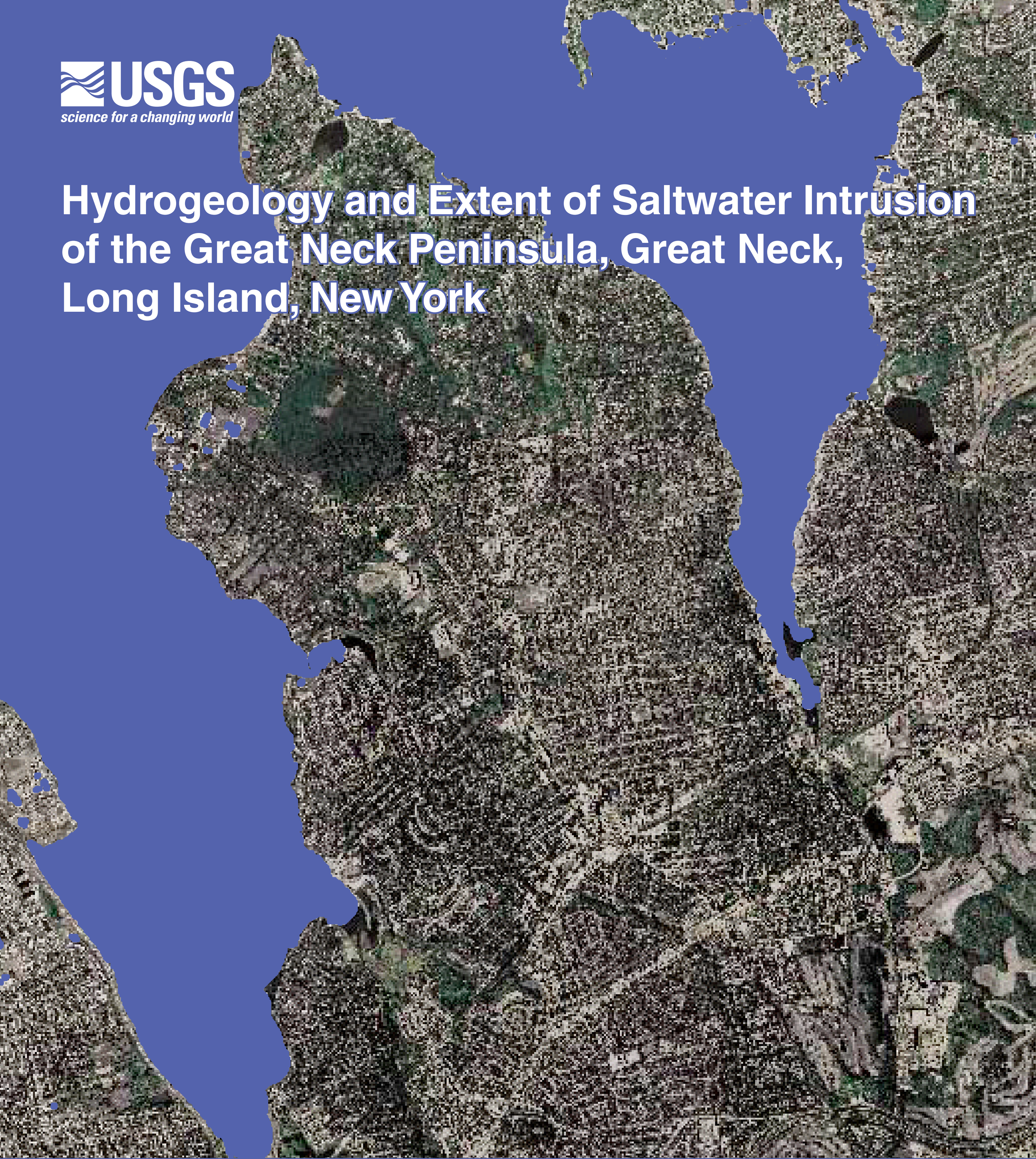

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Hydrogeology and Extent of Saltwater Intrusion of the Great Neck Peninsula, Great Neck, Long Island, New York

U.S. Geological Survey
Water-Resources Investigations Report 99-4280

Prepared in cooperation with the
NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

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By Frederick Stumm

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Coram, New York
2001

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For additional information write to:

U.S. Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report may be purchased from:

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To Obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
million gallons per day (Mgal/d)	0.0438	cubic meter per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Volume	
ounce, fluid (fl oz)	29.57	milliliter
	Acoustic velocity	
foot per second (ft/s)	0.3048	meter per second

Other abbreviations used in this report

hour (h)
milligrams per liter (mg/L)
million gallons (Mgal)
millisiemens per meter (mS/m)
minute (min)

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

Hydrogeology and Extent of Saltwater Intrusion of the Great Neck Peninsula, Great Neck, Long Island, New York

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Abstract

Great Neck, a peninsula, in the northwestern part of Nassau County, N.Y., is underlain by unconsolidated deposits that form a sequence of aquifers and confining units. Seven public-supply wells have been affected by the intrusion of saltwater from the surrounding embayments (Little Neck Bay, Long Island Sound, Manhasset Bay). Fifteen observation wells were drilled in 1991-96 for the collection of hydrogeologic, geochemical, and geophysical data to delineate the subsurface geology and extent of saltwater intrusion within the peninsula. Continuous high-resolution seismic-reflection surveys in the embayments surrounding the Great Neck peninsula and the Manhasset Neck peninsula to the east were completed in 1993 and 1994.

Two hydrogeologic units are newly proposed herein—the North Shore aquifer and the North Shore confining unit. The new drill-core data collected in 1991-96 indicate that the Lloyd aquifer, the Raritan confining unit, and the Magothy aquifer have been completely removed from the northern part of the peninsula by extensive glacial erosion.

Water levels at selected observation wells were measured quarterly throughout the study. The results from two studies of the effects of tides on ground-water levels in 1992 and 1993 indicate that water levels at wells screened within the North Shore and Lloyd aquifers respond to tides and pumping effects, but those in the overlying upper glacial aquifer (where the water table is located) do not. Data from quarterly water-level measurements and the tidal-effect studies indicate the North Shore and Lloyd aquifers to be hydraulically connected.

Offshore seismic-reflection surveys in the surrounding embayments indicate at least two glacially eroded buried valleys with subhorizontal, parallel reflectors indicative of draped bedding that is interpreted as infilling by silt and clay. The buried valleys (1) truncate the surrounding coarse-grained deposits, (2) are asymmetrical and steep sided, (3) trend northwest-southeast, (4) are 2-4 miles long and about 1 mile wide, and (5) extend to more than 200 feet below sea level.

Water from six public-supply wells screened in the Magothy and upper glacial aquifers contained volatile organic compounds in concentrations above the New York State Department of Health Drinking Water Maximum Contaminant Levels, as did water from one public-supply well screened in the Lloyd aquifer, and from three observation wells screened in the upper glacial and Magothy aquifers.

Four distinct wedge-shaped areas of saltwater intrusion have been delineated within the aquifers in Great Neck; three areas extend into the Lloyd and North Shore aquifers, and the fourth area extends into the upper glacial aquifer. Three other areas of saltwater intrusion also have been detected. Borehole-geophysical-logging data indicate that four of these saltwater wedges range from 20 to 125 feet in thickness and have sharp freshwater-saltwater interfaces, and that maximum chloride concentrations in 1996 ranged from 141 to 13,750 milligrams per liter. Seven public-supply wells have either been shut down or are currently being affected by saltwater intrusion.

INTRODUCTION

Increasing stresses on the ground-water system within the coastal areas of northern Nassau County, N.Y., from pumping of public-supply wells, commercial (light industrial) wells, and golf-course wells, coupled with increasing chloride concentrations (saltwater intrusion) in water from public-supply wells, have caused a need for detailed information on the hydrogeologic system in the area. Successful management of ground-water resources in the northern coastal area of Nassau County requires detailed knowledge of the hydrogeologic framework, the extent of saltwater intrusion into the ground-water system, and the effect of pumping on ground-water levels. In 1991, the U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works (NCDPW), began a long-term study to delineate the hydrogeologic framework and the extent of saltwater intrusion in Great Neck and other areas along the northern shore of the county to assist in developing management decisions for the protection and conservation of the ground-water supply.

The study consisted of four major components: (1) evaluation of the current observation-well network; (2) drilling new observation wells in areas of probable saltwater intrusion and in areas where hydrogeologic data were needed; (3) collection of geologic, hydrologic, geophysical (borehole and seismic-reflection), and water-quality data; and (4) compilation of all data to describe the hydrogeologic framework and the extent of saltwater intrusion within the peninsula.

Purpose and Scope

This report (1) depicts the hydrogeology underlying the Great Neck peninsula, (2) describes the ground-water-flow system, and (3) delineates the extent of saltwater intrusion within the major aquifers. This report includes geologic sections and maps showing the extent, thickness, and upper surface altitude of the hydrogeologic units, and water levels and chloride concentrations within these units during 1992-96. Two new hydrogeologic units—the North Shore aquifer and the North Shore confining unit are described in the report.

Location of Study Area

The Great Neck peninsula and its surrounding embayments encompass an area of approximately 19 mi^2 in the northwestern part of Nassau County (fig. 1A). Great Neck is bounded on the west by Little Neck Bay, on the north by Long Island Sound, and on the east by Manhasset Bay (fig. 1B). In 1996, the population of the peninsula was estimated at 31,400, or 2 percent of Nassau County’s population (Nassau County Department of Health, 1996).

Methods of Study

Data collected during this study included (1) observation-well drilling logs and samples, (2) seismic-reflection surveys, (3) borehole-geophysical logs, (4) quarterly water-level measurements, (5) continuous ground-water-level-recorder data, and (6) water-quality analyses. Additional information was obtained from NCDPW, Nassau County Department of Health (NCDH), and New York State Department of Environmental Conservation, and from previous studies. The maps and sections are based on all available geologic data and well drillers’ logs.

Fifteen boreholes were drilled during 1991-96 for the collection of hydrogeologic, geophysical, and water-quality data. Well drilling consisted of mud-rotary drilling and split-spoon core sampling. Core samples were obtained at regular intervals for geologic analysis. Most borings were drilled through the unconsolidated sediments into bedrock. The thickness of each hydrogeologic unit was determined from geologic core data obtained during the drilling of observation wells and, to a lesser extent, from drillers’ logs and interpolation. Color descriptions of core samples in this report are based on the standard Munsell color chart (Kollmorgan Instruments Corporation, 1994).

Seismic-Reflection Surveys

Offshore continuous high-resolution seismic-reflection surveys were used to interpret the depth and continuity of seismic reflectors and lithology (Haeni, 1986, 1988). Applications of this technique for hydrogeologic and water-resource studies have been described by Haeni (1986, 1988) and by Reynolds and Williams (1988).

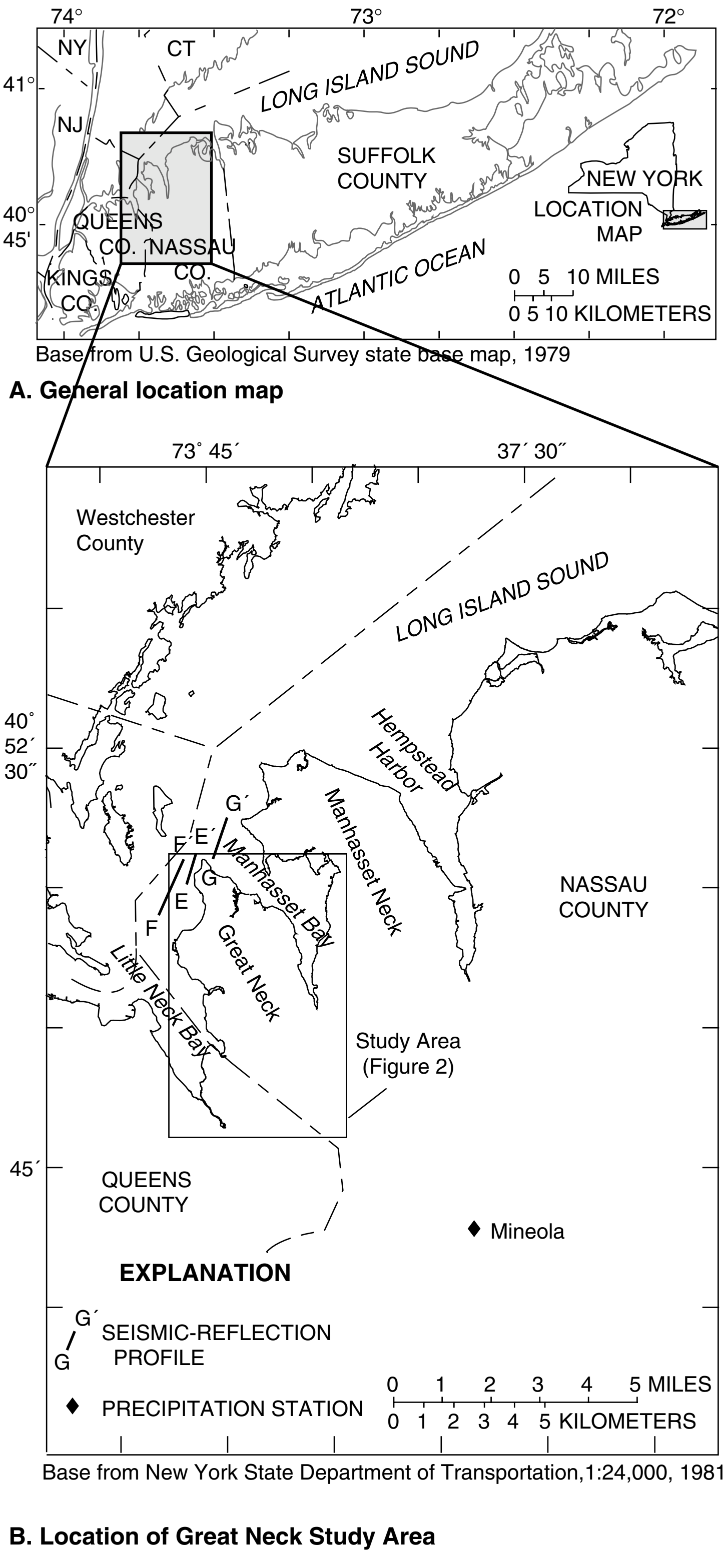


Figure 1. Location of Great Neck and Manhasset Neck peninsulas, and of seismic-reflection profiles, Nassau County, N.Y.: A. General location map. B. Location of Great Neck study area.

Two continuous high-resolution seismic-reflection surveys were completed in 1993 and 1994 along the coast of Great Neck to identify the unconsolidated deposits of the subsurface from Manhasset Bay to Little Neck Bay and to correlate these deposits with geologic and geophysical data obtained from drilling. (Locations of three of the survey lines are shown in fig. 1B.) The continuous-seismic-reflection system consisted of a graphic recorder, amplifier and filter, power generator, catamaran-mounted sound source, hydrophone array, and digital tape recorder, all of which were installed in a shallow-draft 22-ft boat. The sound source and hydrophone array were towed behind the slowly moving boat, where the seismic-reflection data were digitally recorded and filtered for real-time graphic display.

The seismic signals generated by the sound source travel through the water column and penetrate the deposits underlying the sea floor. Part of the seismic signal is reflected back to the water surface from the sea floor and the stratigraphic interfaces at which a change in the acoustic impedance (the product of the density and acoustic velocity of each medium) is encountered (Haeni, 1986; Robinson and Çoruh, 1988). The reflected signals received by the hydrophone array produce an electrical signal that then is amplified, recorded on digital tape, filtered, and plotted. Trapped gas deposits can interfere with the reflected signal and make the geologic data unclear. The resulting seismic sections (see examples in fig. 11) resemble a vertical geologic section, except that the vertical axis is a function of the time required for the seismic signal to travel from the source to the reflector and return (Haeni, 1986). Several seismic-reflection and refraction studies indicate that the average acoustic velocity of unconsolidated saturated glacial deposits is about 5,000 ft/s (Haeni, 1988; Reynolds and Williams, 1988); this value was used as an average velocity in this study.

Borehole-Geophysical Logs

Borehole-geophysical logs from observation wells supplemented information that could not be obtained by drill cores and water-quality sampling. The geophysical-logging systems used in this study provided continuous digital records that reflect the physical properties of the sediment, the rock matrix, and the interstitial fluids. At several sites, natural-gamma radiation (gamma) logs, spontaneous potential (SP), single-point-resistance (SPR), and short- and long-normal resistivity (R) logs were collected in mud-filled open boreholes prior to casing (see examples in fig. 12). At each of the sites, focused electromagnetic-induction (EM) logs were obtained in polyvinyl chloride (PVC) cased wells. The five types of logs are described below.

Natural-gamma radiation (gamma) logs are a record of the total gamma radiation detected in a borehole in counts per second (Keys, 1990). Clays and fine-grained sediments tend to be more radioactive than the quartz-rich sand that forms the bulk of the deposits on Long Island. Gamma logs are most commonly used for lithologic and stratigraphic correlation in the northeast.

Spontaneous-potential (SP) logs provide a record of the potential, or voltage, that develops at the contact between clay beds and sand aquifers within a borehole (Keys, 1990). SP is measured in millivolts and is a function of the chemical activity of the borehole fluid, the water in the adjacent sediments, the water temperature, and the type and quantity of clay (Serra, 1984). SP logs are used to determine lithology, bed thickness, and salinity of formation water (Keys, 1990).

Single-point-resistance (SPR) logs provide a measure of the resistance, in ohms, between an electrode in the borehole and an electrode at land surface. The volume of surrounding material to which the SPR probe is sensitive is spherical and only 5 to 10 times the electrode diameter, and is affected by the borehole fluid (Keys, 1990). SPR logs are used to obtain high-resolution lithologic information.

Normal-resistivity (R) logs measure apparent resistivity in ohm-meters and are used to determine lithology and water salinity (Keys, 1990). This technique uses two electrodes typically spaced 16 to 64 in. apart in the borehole, called short- and long-normal logs, respectively. The volume of surrounding material to which normal resistivity probes are sensitive is spherical, with a diameter about twice the electrode spacing (Serra, 1984; Keys, 1990). Only short-normal resistivity logs were used in this study.

Focused electromagnetic-induction (EM) logs use an electromagnetic emitter coil that induces current loops within the surrounding formation to generate a secondary electromagnetic field. The intensity of the secondary field received by the receiver coil is proportional to the formation conductivity (Keys, 1990; Serra, 1984; Keys and MacCary, 1971). EM logs are measured in units of millisiemens per meter (mS/m) and are inversely related to the ohm-meter value of normal-resistivity logs (Keys, 1990; Serra, 1984; Keys and MacCary, 1971). The normally low conductivity of Long Island's hydrogeologic deposits is favorable for induction logging to delineate highly conductive fluids such as saltwater or leachate. For this reason, EM logging has been used on Long Island to delineate the saltwater-freshwater interface (Stumm, 1993a, 1993b, 1994; Stumm and Lange, 1994). Gamma logs used in conjunction with EM logs are useful for distinguishing between conductive fluids and conductive clays.

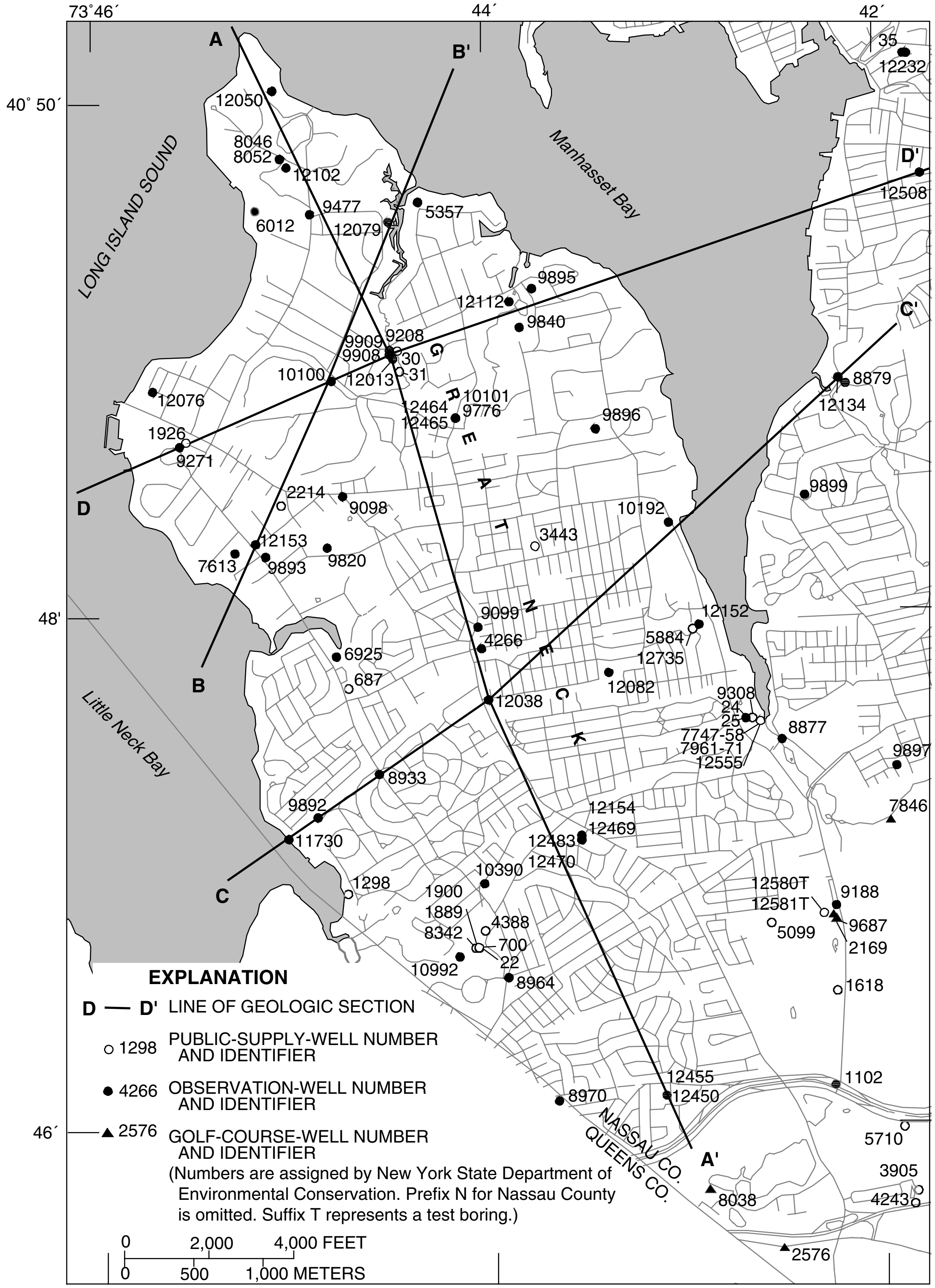
Water-Level Data

Water levels were measured quarterly at selected observation wells throughout the study (1991-96). All wells typically were measured on the same day to minimize discrepancies resulting from nearby sporadic pumping. All water-level data were checked and entered into the U.S. Geological Survey (USGS) data base in Coram, N.Y. A total of 57 observation wells within the Great Neck peninsula and part of the Manhasset Neck peninsula were measured (fig. 2).

Continuous water-level recorders were installed at six selected wells, each screened in a different aquifer. Four of the recorders were digital-pressure transducer data loggers that recorded at 1-hour intervals; the other two were continuous analog recorders. Hydrographs were plotted and used to identify possible aquifer interconnections and to assess the effect of pumping by nearby public-supply wells. In addition, a continuous water-level recorder was used at well Q577 (not shown in fig. 2) to provide historical data for delineation of long-term water-level trends.

Water-Quality Data

The USGS collected water samples from 35 observation wells from August through September



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 2. Locations of public-supply wells, observation wells, and golf-course wells within the Great Neck peninsula, Nassau County, N.Y. (Location is shown in fig. 1B.)

1996 based on established techniques (Hem, 1992), and the NCDPW collected samples from all newly installed observation wells by similar techniques. Three casing volumes were pumped from the well, and stable readings of temperature and specific conductance of the pumped water were obtained before sampling. All water-quality analyses were completed at the NCDPW Cedar Creek Special Projects Laboratory. The USGS resampled selected observation wells in August and September 1996 to minimize temporal effects on water quality. Public-supply-well data were obtained from the USGS data base and the NCDH.

Filter-press samples were obtained at selected well sites for chloride and specific conductance analyses at the USGS office in Coram, N.Y. A filter-press sample is obtained by using a nitrogen-gas-pressurized chamber to force interstitial water from uncontaminated parts of a split-spoon core sample obtained during drilling (Lusczynski, 1961). The sample volume is typically about 0.7 fl oz (2 mL); chloride concentration and specific conductance are measured by hand-held probes. The resulting values were used only as a general indicator of brackish or saltwater within a formation and were correlated with borehole geophysical logs.

Previous Investigations

The ground-water resources of Long Island were first studied by Veatch and others (1906), who described the geologic deposits and occurrence of ground water on Long Island. Fuller (1914) revised and supplemented much of the earlier geologic work. Suter and others (1949) contoured the upper surface of the major geologic units. Swarzenski (1963) described the hydrogeology and hydrologic conditions in northwestern Nassau County during 1955-57; many of his interpretations and his general hydrogeologic framework were verified by the drill-core and seismic-reflection data collected during this study. Kilburn (1979) attempted to redelineate and rename parts of the hydrogeologic framework in Great Neck, largely from drillers' logs, some of which were inaccurate. Much of the drill-core, hydrologic, and seismic-reflection data obtained in the present study are not consistent with Kilburn (1979). The present study has generated several reports that describe the hydrogeology of the Great Neck peninsula and the freshwater-saltwater interface (Stumm, 1993a, 1993b, 1994; Stumm and Lange, 1994). Similar information on the hydrogeology of Manhasset Neck and Long Island Sound is included in Stumm and Lange (1996).

Smith (1958) described the first use of high-power, low-frequency seismic-reflection equipment to measure the depth to bedrock beneath selected areas of Long Island Sound. Oliver and Drake (1951) used seismic-reflection techniques to measure the depth to bedrock in Long Island Sound, and Williams (1981) used high-resolution seismic-reflection surveys and core samples to describe the sediments beneath Long Island Sound. Grim and others (1970) describe the geology and subsurface morphology of Long Island and the Manhasset Bay embayment. Lewis and Stone (1991) conducted a systematic seismic-reflection survey to map the deposits beneath most of Long Island Sound, except the immediate shallow coastal areas and embayments of the northern shore of western Long Island. Tagg and Uchupi (1967) used continuous seismic profiles to define the subsurface morphology of Long Island Sound.

Acknowledgments

Thanks are extended to James Mulligan, Brian Schneider, Raymond Mazza, and others of NCDPW for their assistance and technical support throughout this study. Thanks are extended to F. Peter Haeni, Chief of the U.S. Geological Survey Branch of Geophysical Applications and Support, for his technical assistance and use of the seismic-reflection survey equipment. Thanks also are given to the Great Neck North Water Authority and the Manhasset-Lakeville Water District for providing pumpage information and access to their public-supply well sites, and to the U.S. Merchant Marine Academy at Kings Point for dockage space during the two seismic-reflection surveys. The author also expresses appreciation to Delta Well and Pump Co., Inc. and Hydro Group, Inc. well drillers for providing lithologic samples and access to boreholes for geophysical logging at various sites in Great Neck.

HYDROGEOLOGY

The Great Neck peninsula is underlain by unconsolidated glacial deposits of Pleistocene age and coastal-plain deposits of Late Cretaceous age. These deposits consists of gravel, sand, silt, and clay

Table 1. Generalized description of hydrogeologic units underlying the Great Neck peninsula, N.Y.
[Modified from Smolensky and others, 1989, sheet 1]

Hydrogeologic unit	Geologic unit	Description and hydraulic characteristics
Upper glacial aquifer	Upper Pleistocene deposits	Till and outwash deposits of sand, silt, and clay and boulders. Varied permeability with an average hydraulic conductivity of 270 feet per day and an anisotropy of 10:1. Outwash has the highest hydraulic conductivity.
North Shore confining unit	Pleistocene deposits	Marine and post glacial lake deposits. Clay and silt deposits with minor parts containing shells. The clay is olive brown and olive gray and is poorly permeable. Unit contains a minor sand layer that is moderately permeable.
North Shore aquifer	Pleistocene deposits	Sand, silt, and gravel; brown and olive gray, poor to moderate sorting. Moderately permeable.
Magothy aquifer	Matawan Group-Magothy Formation, undifferentiated	Fine sand with silt and interbedded clay. Gray and pale yellow quartz sand. Lignite and iron-oxide concretions common. Moderately permeable with an average hydraulic conductivity of 50 feet per day and an anisotropy of 100:1.
Raritan confining unit (Raritan clay)	Unnamed clay member of the Raritan Formation	Clay; solid with multicolors such as gray, white, red, or tan. Poorly permeable. Confines water in underlying unit. Average hydraulic conductivity of 0.001 foot per day.
Lloyd aquifer	Lloyd Sand Member of the Raritan Formation	Fine to coarse sand and gravel with clay lenses. White and pale-yellow sand is well sorted. Moderately permeable with an average horizontal hydraulic conductivity of 60 feet per day, and anisotropy of 10:1.
Bedrock	Hartland Formation; crystalline bedrock	Highly weathered biotite-garnet-schist with low hydraulic conductivity. A thick saprolitic zone 50 to 100 feet thick, consisting of white, yellow, and gray clay, underlies most of the peninsula except in the northernmost part. Impermeable to poorly permeable.

underlain by bedrock of early Paleozoic age. The top of the bedrock, which is relatively impermeable, generally forms the base of the ground-water reservoir.

The hydraulic characteristics and description of the aquifers, and the relations between hydrogeologic and geologic units underlying the peninsula, are described in table 1. The upper and lower boundaries of the glacially derived hydrogeologic units are discerned mainly from lithologic differences between units rather than the age of the deposits, which is the basis for geologic correlation.

The geologic and hydrologic units that form Long Island’s hydrogeologic framework are described by Suter and others (1949); Perlmutter and Geraghty (1963); Swarzenski (1963); Kilburn (1979); and Smolensky and others (1989). Geologic correlations are revised from those of Kilburn (1979), Swarzenski (1963), and Fuller (1914). The new drill-core data provide a basis for the two newly proposed hydrogeologic units within the Pleistocene deposits—the North Shore aquifer and the North Shore confining unit—which are used and defined in this report for the first time. All other geologic and hydrologic unit names used in this report are those currently used by the USGS.

Stratigraphy

The unconsolidated deposits beneath the Great Neck peninsula are underlain by crystalline (metamorphic) bedrock. These unconsolidated deposits are of Cretaceous and Pleistocene age. Microscopic and mineralogic analysis of drill-core samples were used to delineate the stratigraphic sequence.

Bedrock

The bedrock underlying the Great Neck area has been mapped as the Hartland Formation of Middle Ordovician to Lower Cambrian age (Baskerville, 1992); its upper surface generally slopes southeastward from 140 ft to 600 ft below sea level. The offshore seismic-reflection surveys done in this study indicated that the base of glacially scoured valleys have an undulating surface. Drill-core data indicate the bedrock underlying Great Neck to be a biotite-garnet schist. The bedrock is highly weathered beneath most of the peninsula, as indicated by a saprolitic zone that ranges from 50 ft to more than 100 ft thick, except in the northernmost part, where glacial erosion has removed most or all of the saprolite. The saprolitic zone consists mostly of white, yellow, and gray clay with quartz fragments. This zone had been previously interpreted by drillers to be a clay or clayey gravel layer above the bedrock surface. Observation wells N4266 and N12013 (fig. 2) penetrated 71 ft and 138 ft into weathered bedrock, respectively, without reaching solid rock.

Bedrock-surface contours (fig. 3) indicate a general dip to the southeast in most areas. Glacial erosion or scouring of the overlying Cretaceous and possibly earlier Pleistocene deposits and the weathered bedrock, formed a series of buried valleys that have truncated the surrounding material. The weathered bedrock at the base of these valleys has been partially or totally removed. Drill-core data from observation wells N12050 and N12102 in the northernmost part of Great Neck (fig. 2) indicate that the bedrock surface is relatively flat and does not follow the regional southeastward dip (fig. 3). The time at which most of the weathered bedrock was removed is unknown, but it could have been during successive glacial advances during the Pleistocene. Drill-core data and continuous seismic-reflection profiles indicate a bedrock cuesta or hogback between wells N12102 and N12079 (figs. 2, 11) with more than 50 ft of relief (fig. 4A) (Stumm and Lange, 1994). Drill-core data generally indicate that wherever Cretaceous sediments are penetrated in place, the bedrock surface beneath them has a saprolitic zone, and the absence of Cretaceous deposits is typically accompanied by a lack of saprolite. Seismic-reflection data collected in this study (1993-94) indicate that the bedrock surface beneath the embayments of Long Island Sound is undulating; this indication is consistent with observations of Tagg and Uchupi (1967) and Lewis and Stone (1991), who found the bedrock surface beneath most of Long Island Sound to have been severely eroded during the Pleistocene.

Lloyd Aquifer

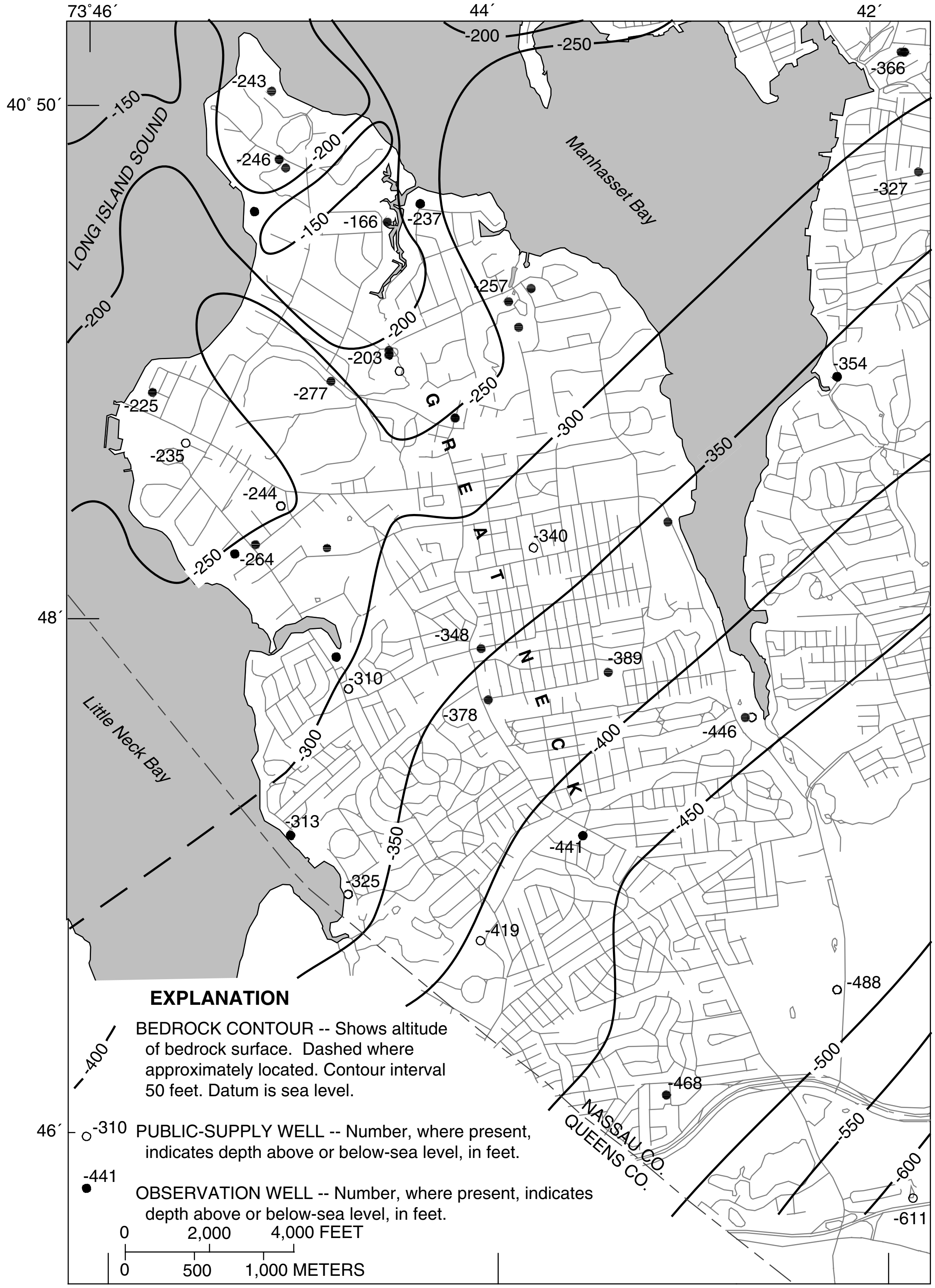
The Lloyd Sand member of the Raritan Formation of Late Cretaceous age (Suter and others, 1949; Cohen and others, 1968) consists of an upward fining sequence of white and pale yellow (Munsell descriptive color value 2.5Y 8/2) sand and gravel with white clay lenses. The coarse fraction consists almost entirely of well-sorted subangular to subrounded quartz and chert fragments. White and grayish silt also may be present in the upper sequences. The clay lenses cannot be correlated over great distances.

Typically, the Lloyd Sand overlies bedrock on the Great Neck peninsula. The Lloyd Sand forms the Lloyd aquifer, which is a major source of water supply in this part of Long Island. Its thickness ranges from less than 50 ft to more than 150 ft. The Lloyd Aquifer was not found in the northernmost part of the peninsula nor within several of the buried valleys penetrated onshore and offshore (fig. 5), nor at wells N12050, N12102, N10101, N12112, or N9840 (figs. 2, 5). The top of the Lloyd generally dips to the southeast except where it has been removed by glacial erosion (fig. 4A) (Stumm and Lange, 1994; Stumm 1993a, 1994). The upper surface of the Lloyd ranges from 121 ft to almost 400 ft below sea level in Great Neck (fig. 5).

In northern Nassau County, the Lloyd aquifer has an average horizontal hydraulic conductivity of about 60 ft/d (McClymonds and Franke, 1972) and an anisotropy (horizontal to vertical) of 10:1 (Smolensky and others, 1989).

Raritan Clay

The unnamed clay member of the Raritan Formation, referred to as the Raritan clay in this report, underlies most of the Great Neck peninsula and dips to the southeast (fig. 6). It consists of solid, compact multicolored clays that include gray (2.5Y 4/1), white (2.5Y 9/1), red or tan (10R 4/8, 2.5YR 4/8), and variegated. The Raritan clay ranges in thickness from 20 ft to more than 150 ft in Great Neck, and the upper surface altitude ranges from 96 ft to more than 250 ft below sea level. The Raritan clay has been severely eroded or completely removed by glacial scouring in many parts of the peninsula (fig. 6) (Stumm, 1993a, 1994). A glacially eroded buried valley truncates the Raritan clay from the northwest corner of Great Neck to the southeast corner (fig. 6). The Raritan clay was not penetrated at wells N12050, N12102, N10101, N12112, nor N9840 (figs. 2, 6).



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 3. Surface altitude of bedrock underlying Great Neck, N.Y.

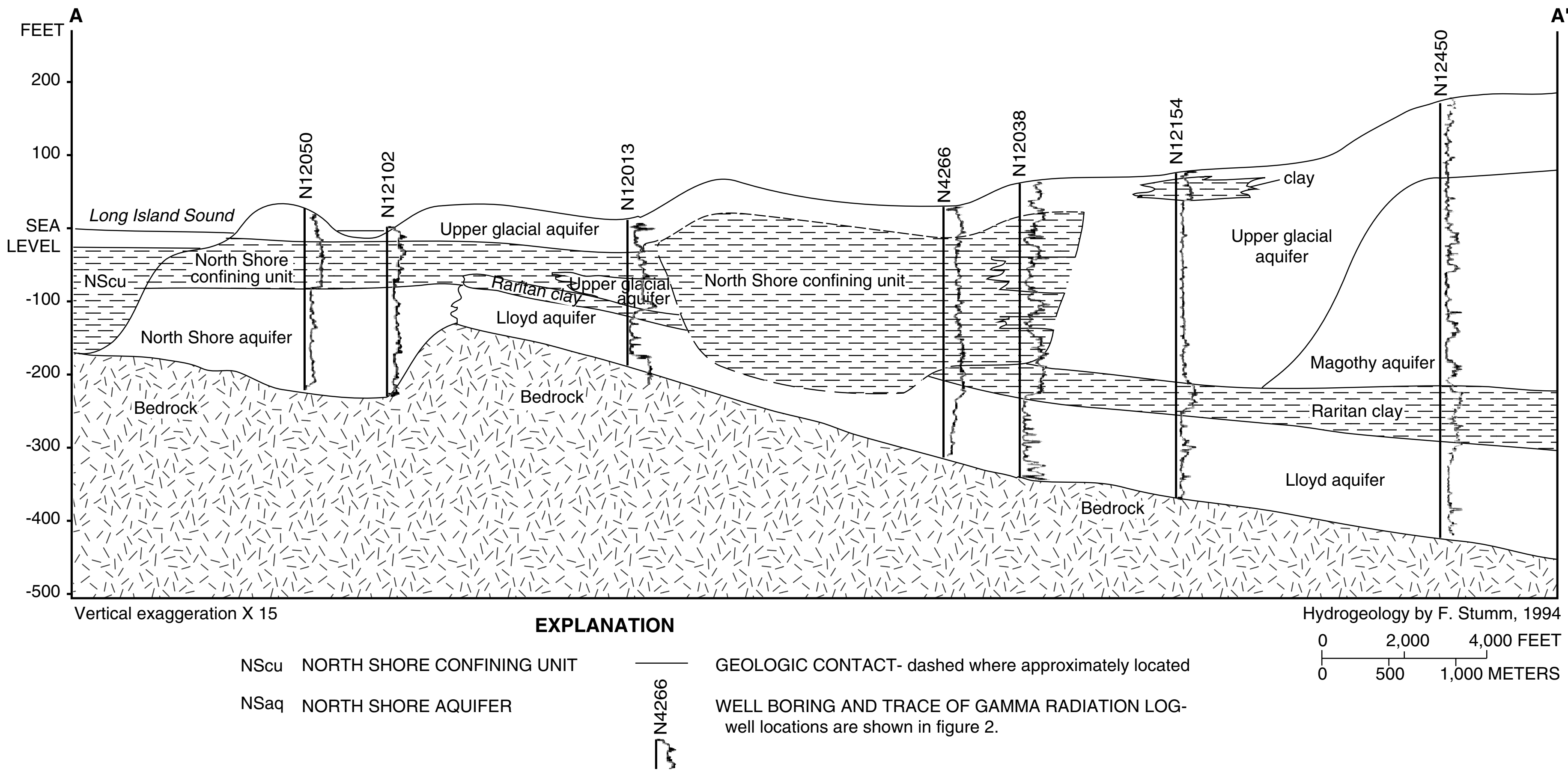


Figure 4A. Hydrogeologic section A-A´ on Great Neck, N.Y. (Trace of section is shown in fig. 2.)

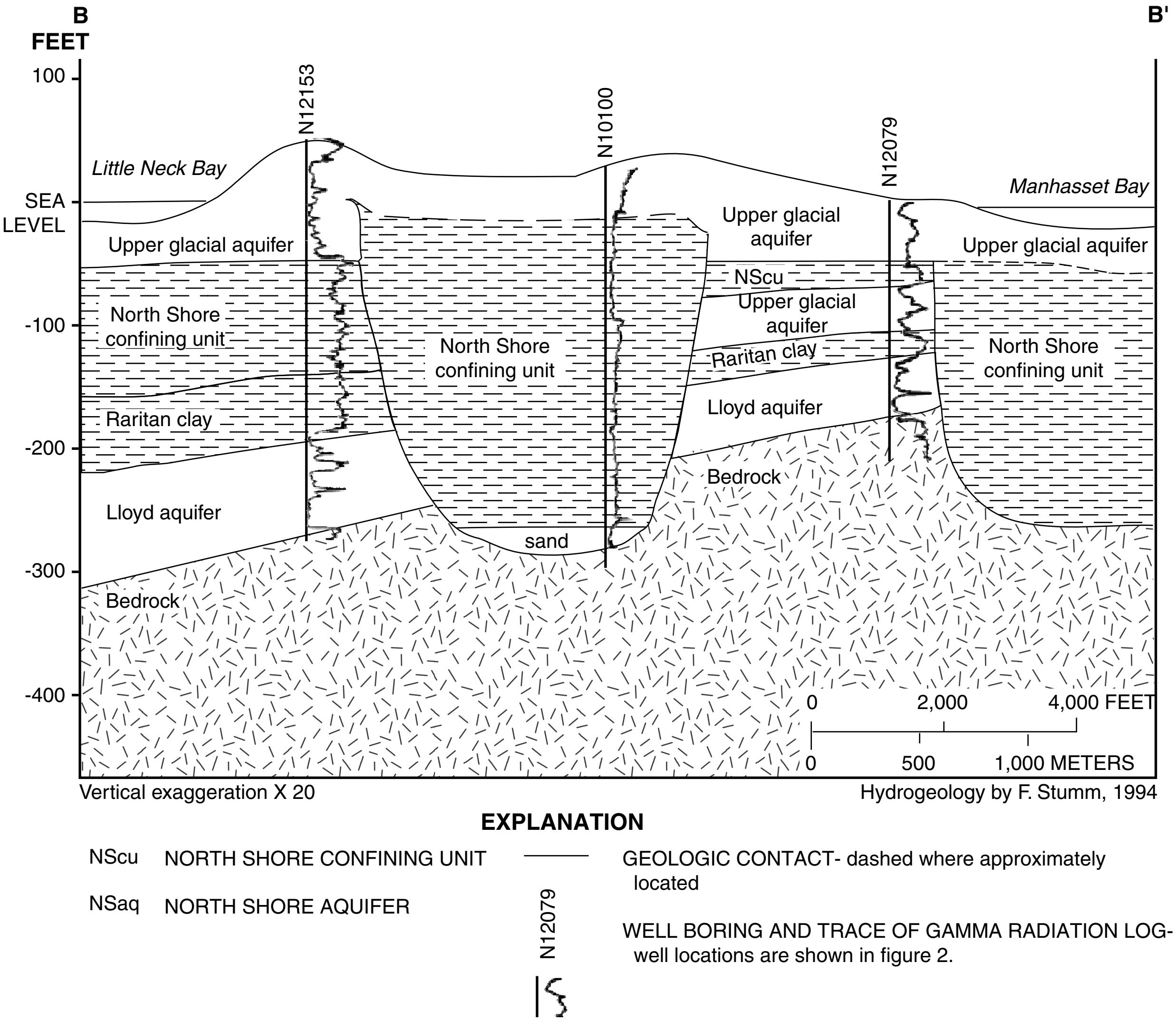


Figure 4B. Hydrogeologic section B-B´ on Great Neck, N.Y. (Trace of section is shown in fig. 2.)

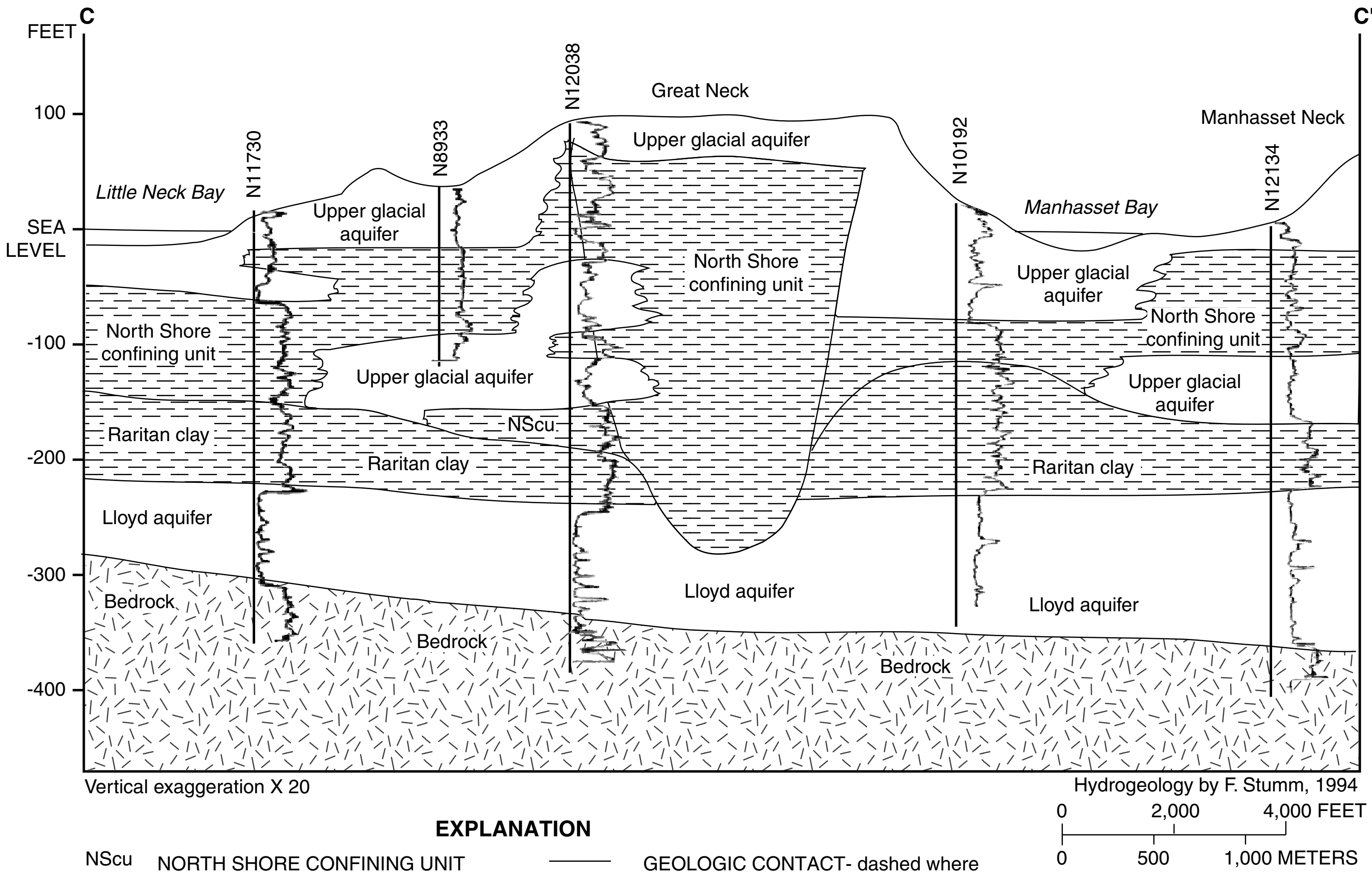
Offshore seismic-reflection profiles indicate that the Raritan clay underlies only the southernmost parts of Little Neck and Manhasset Bays.

The Raritan clay is poorly permeable, with an average vertical hydraulic conductivity of about 0.001 ft/d (Smolensky and others, 1989). It overlies and confines water in the Lloyd aquifer below (Suter and others, 1949) and is a major confining unit on Long Island (Smolensky and others, 1989).

Magothy Aquifer

The Magothy aquifer consists of fine micaceous sand, silt, and interbedded clay sediments of Cretaceous age (Suter and others, 1949; Swarzenski, 1963; Kilburn, 1979). The Magothy aquifer is an upward fining sequence of gray, white, or pinkish sands and clay of the undifferentiated Matawan Group and Magothy Formation (Kilburn, 1979; Smolensky and others, 1989); in some areas it contains lignite and iron-oxide concretions. Most of the Magothy aquifer in Great Neck has been removed by glacial erosion, except in the southernmost part and along the southeastern coast of the peninsula.

Drill-core samples indicate that the Magothy aquifer consists of subrounded silty gray (5Y 6/1) and pale yellow (2.5Y 7/2) quartz with associated lignite



EXPLANATION

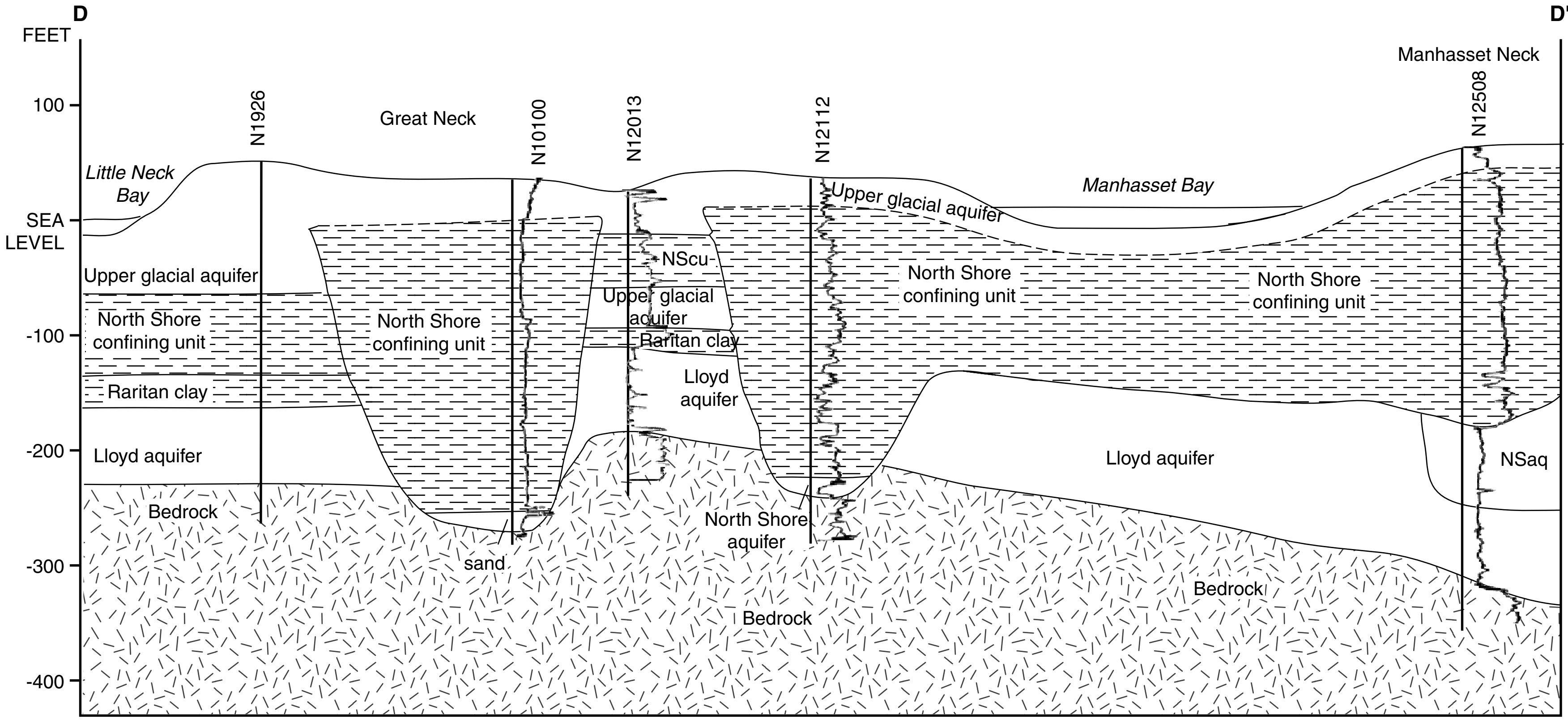
NScu NORTH SHORE CONFINING UNIT

NSaq NORTH SHORE AQUIFER

GEOLOGIC CONTACT- dashed where approximately located

N8933 WELL BORING AND TRACE OF GAMMA RADIATION LOG- well locations are shown in figure 2.

Figure 4C. Hydrogeologic section C-C´ on Great Neck, N.Y. (Trace of section is shown in fig. 2.)



Vertical exaggeration X 18

Hydrogeology by F. Stumm, 1994

EXPLANATION

NScu NORTH SHORE CONFINING UNIT

NSaq NORTH SHORE AQUIFER

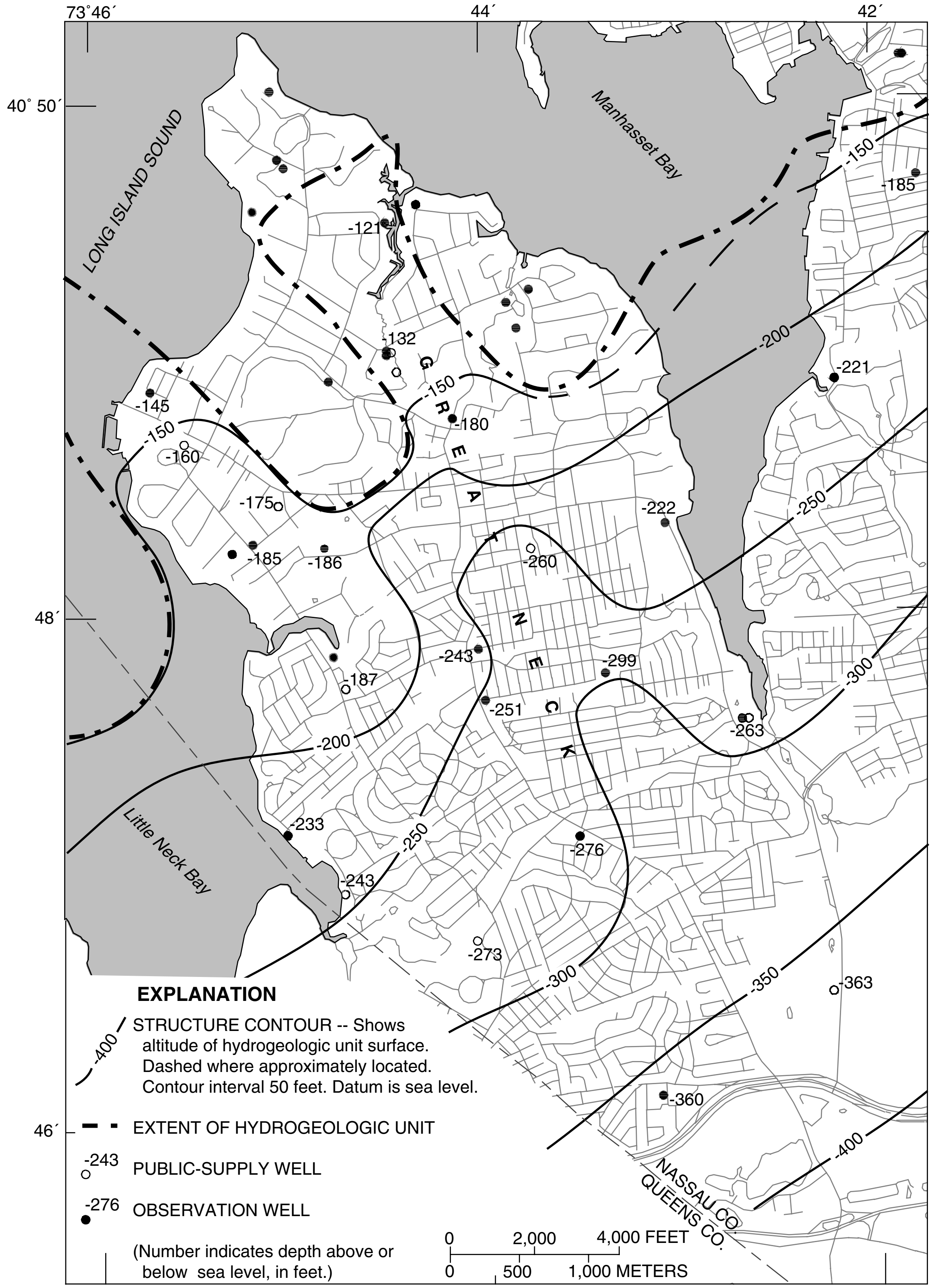
GEOLOGIC CONTACT- dashed where approximately located

N1926 WELL BORING AND TRACE OF GEOPHYSICAL (GAMMA RAY) LOG- well locations are shown in figure 2.

0 2,000 4,000 FEET

0 500 1,000 METERS

Figure 4D. Hydrogeologic section D-D´ on Great Neck, N.Y. (Trace of section is shown in fig. 2.)



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 5. Extent and upper surface altitude of the Lloyd aquifer, Great Neck, N.Y. (Location is shown in fig. 1B.)

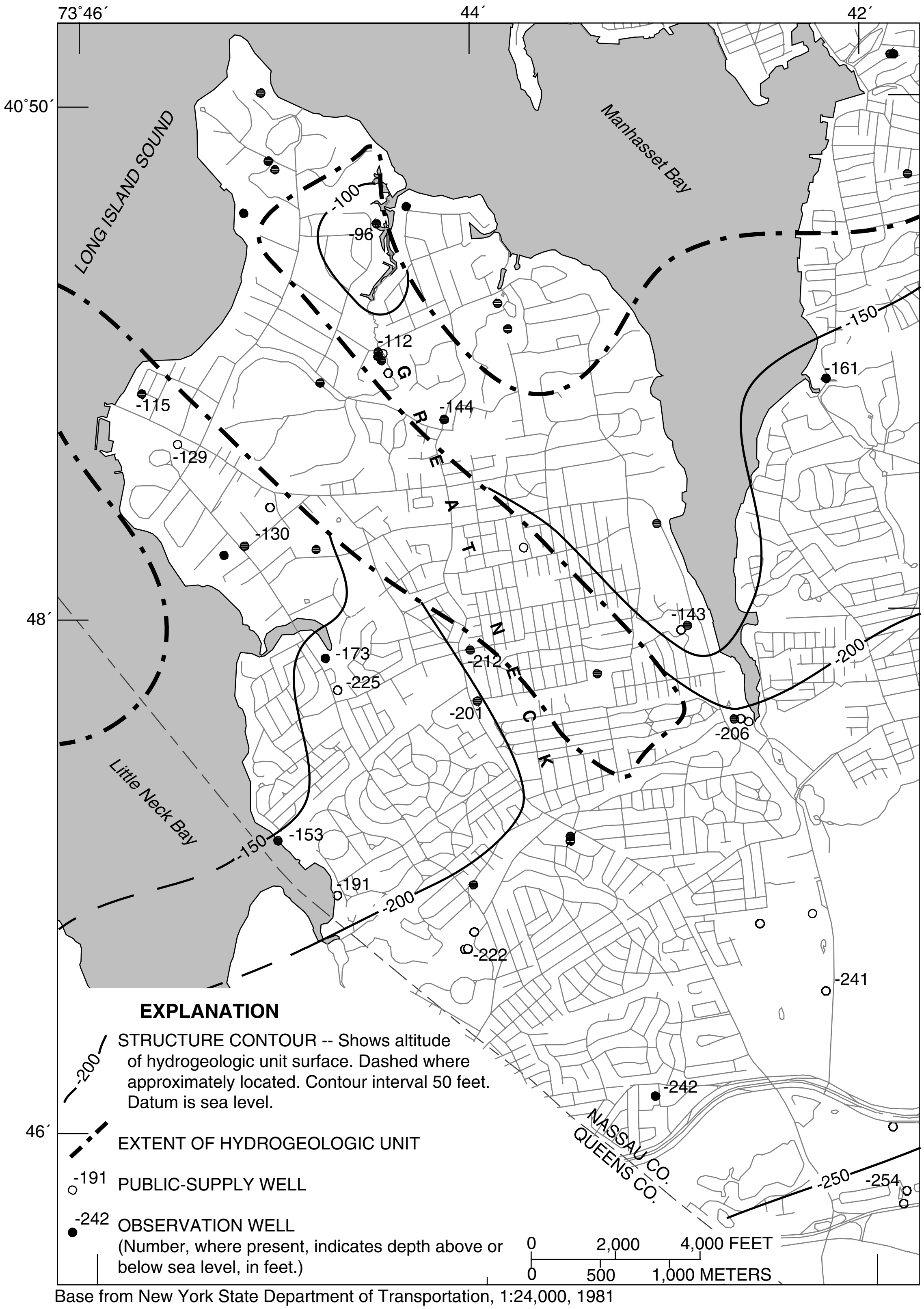


Figure 6. Extent and upper surface altitude of the Raritan clay in Great Neck, N.Y. (Location is shown in fig. 1B.)

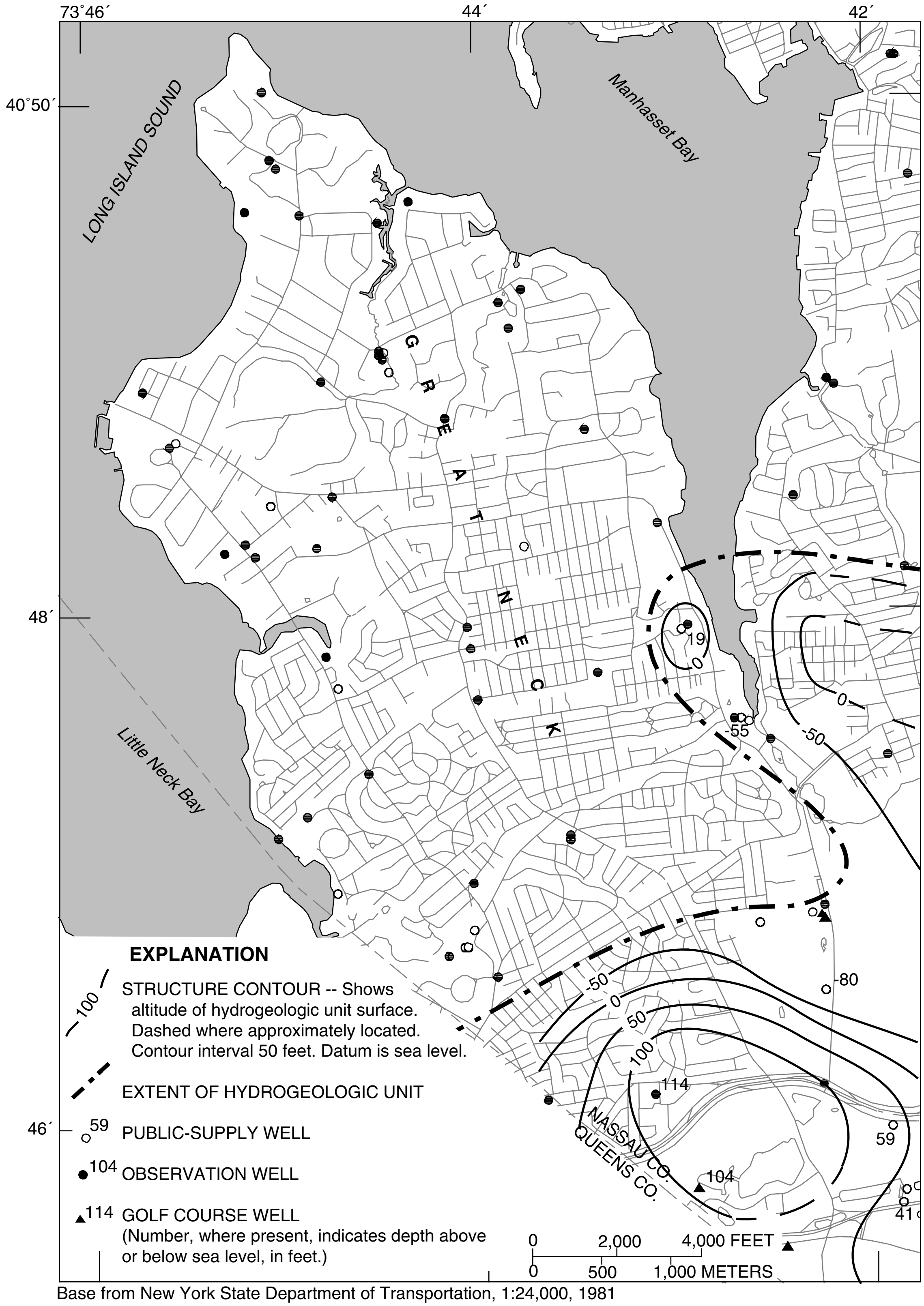


Figure 7. Extent and upper surface altitude of Magothy aquifer in Great Neck, N.Y. (Location is shown in fig. 1B.)

and chemically stable heavy opaque minerals. The top of the Magothy aquifer ranges from 50 ft below sea level to more than 100 ft above sea level (fig. 7). Glacial erosion has produced a steep, undulating, north-facing scarp along the southeastern part of the peninsula (fig. 7). Where present, the Magothy aquifer overlies the Raritan clay and has an anisotropy of 100:1 (Smolensky and others, 1989).

North Shore Aquifer

The name North Shore aquifer is introduced here to represent a sequence of Pleistocene-age sediments that are confined by a Pleistocene-aged clay, are in contact with bedrock, and are hydraulically interconnected laterally with the Lloyd aquifer. The North Shore aquifer was penetrated during drilling in the northernmost part of Great Neck in 1991-96. Drill-core samples obtained during this study indicated a complex hydrogeologic framework that does not resemble that indicated in previous work. Manhasset Neck, to the east, contains similar deposits and a similar hydrogeologic framework (Stumm and Lange, 1996), as does northwestern Queens County, to the west (Chu and Stumm, 1995); therefore, a unifying nomenclature was needed for the northern shore of Long Island. These deposits were called the Jameco Gravel by Swarzenski (1963) and the Port Washington aquifer by Kilburn (1979). The name North Shore aquifer is used in this report in preference to the names Jameco Gravel or Jameco aquifer because the previous names imply correlation with Jameco deposits in southern Queens County; such a correlation is questionable. The Port Washington aquifer, as described by Kilburn (1979), included a large amount of material that was found in this study to be of Cretaceous age (Lloyd aquifer and Raritan clay). Placement of part of the Port Washington aquifer above the Raritan clay is rejected on the basis of drill-core samples and hydrogeologic data (Stumm, 1993a; Stumm and Lange, 1994).

The North Shore aquifer is a distinct hydrogeologic unit directly above bedrock and is overlain by a thick sequence of clays and silt, and named the North Shore confining unit in this report (figs. 4, 9). The North Shore aquifer lies in the northernmost part of the Great Neck peninsula (fig. 8) and consists of moderately sorted stratified drift and outwash deposits that infilled the low-lying areas after the removal of the Cretaceous deposits and parts of the bedrock (saprolitic zone) by ice-contact erosion. The aquifer was then capped by clay and silt of the North Shore confining unit. Subsequent glacial advances in nearby areas eroded northwest-southeast trending valleys that reached the bedrock surface and removed previously deposited sediments, which may have included parts of the North Shore aquifer. These valleys became filled with hundreds of feet of clay and silt (fig. 4). The buried-valley deposits probably represent the most recent glacial advance in the area, however, and may not be of the same age as the North Shore aquifer in northern Great Neck; therefore, they are grouped with undifferentiated Pleistocene-age deposits of the North Shore confining unit. Swarzenski (1963) described the deposits in northernmost Great Neck as pre-Sangamon and possibly Illinoian age and, thus, as the oldest glacial deposits in the area.

The North Shore aquifer is a sequence of poorly to moderately sorted, dark olive brown (2.5Y 3/3) and olive-gray (5Y 6/2) gravel, sand, and silt layers. The sediments consist of subangular to subrounded quartz, rock fragments, unstable opaque minerals, and a large percentage of biotite and muscovite micas. The top of the North Shore aquifer ranges from 70 to about 90 ft below sea level in the northernmost part of the peninsula (N12050, N6012, N12102) to more than 250 ft below sea level within buried valleys in the northeast-coastal (N12112, N9840, N5357) parts (well locations shown in figs. 2, 8). The upper surface of these deposits appears to be relatively flat. The North Shore aquifer is more than 150 ft thick in the northernmost part of Great Neck but may be only 5 to 10 ft thick in the northeast coastal area.

The North Shore aquifer appears to be moderately to highly permeable, as inferred from the rapid response of water levels to tidal fluctuations similar to those in the Lloyd aquifer. No hydraulic conductivity values for this unit have been calculated.

North Shore Confining Unit

The name North Shore confining unit is given here to a sequence of Pleistocene-age clay and silt deposits that occur locally along the northern shore of Queens (Chu and Stumm, 1995), Nassau (Stumm and Lange, 1994, 1996) and Suffolk (Soren, 1971) Counties. Grim and others (1970), Lewis and Stone (1991), and Williams (1981) describe these deposits as part of the stratified glacial-lake clay and silt that underlie Long Island Sound and Manhasset Bay. Stumm and Lange (1994, 1996) used offshore seismic-reflection surveys, borehole-geophysical logs, and

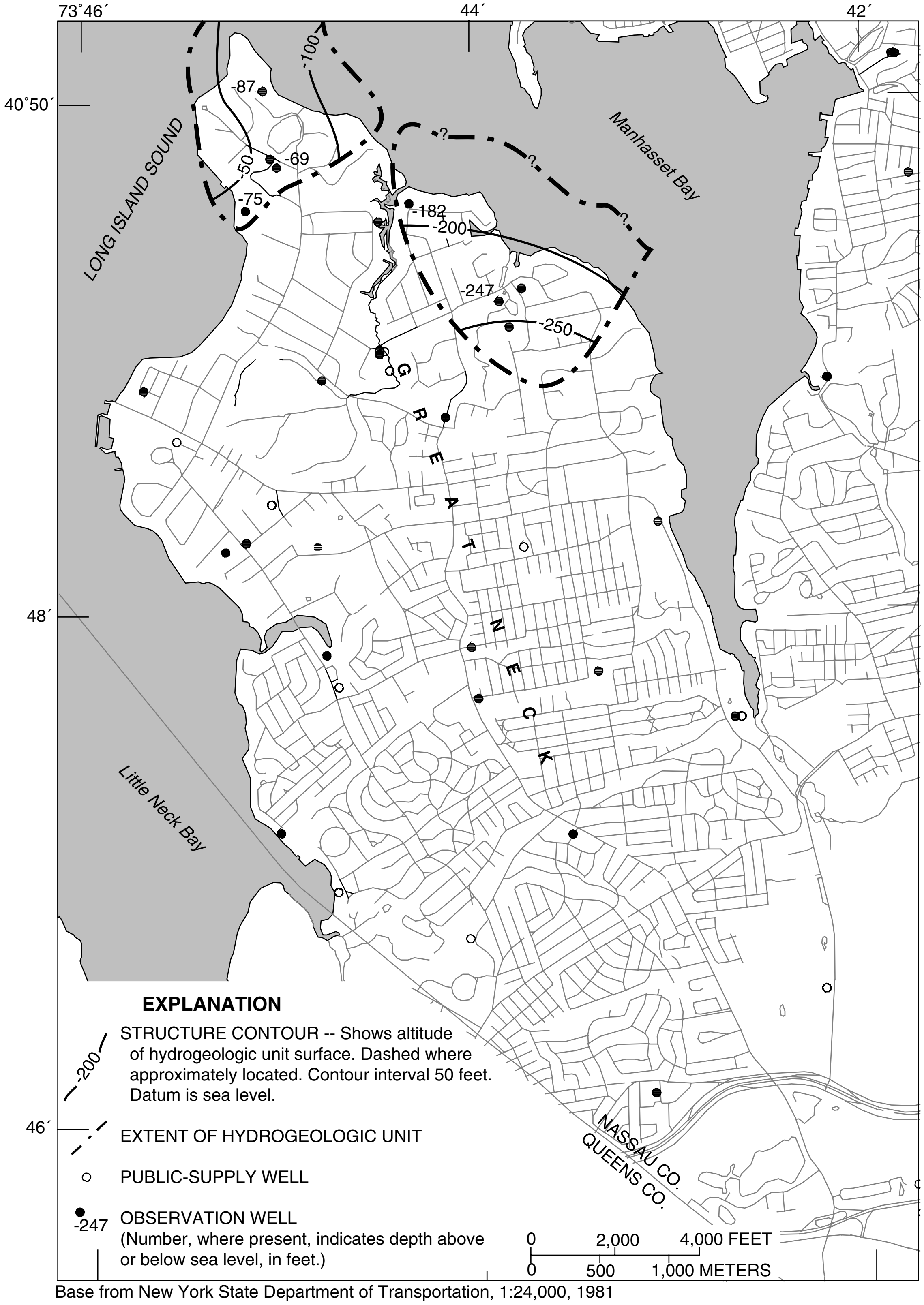


Figure 8. Extent and upper surface altitude of the North Shore aquifer, Great Neck, N.Y. (not shown on Manhasset Neck). (Location is shown in fig. 1B.)

drill-core samples, to correlate these deposits with buried valleys that extend across the Great Neck peninsula and the surrounding embayments of Long Island Sound, Little Neck Bay, and Manhasset Bay.

Swarzenski (1963) called these deposits the Gardiners Clay, and Kilburn (1979) called them the Port Washington confining unit. The name North Shore confining unit is used here in preference to the name Gardiners Clay because correlation with the Gardiners Clay elsewhere on Long Island is questionable. The Port Washington confining unit of Kilburn (1979) was delineated from drillers' logs and includes parts of the Raritan clay of Cretaceous age. Drill-core data obtained in this study are inconsistent with many previous interpretations and delineations; thus, the Port Washington confining unit is no longer considered to be a valid unit.

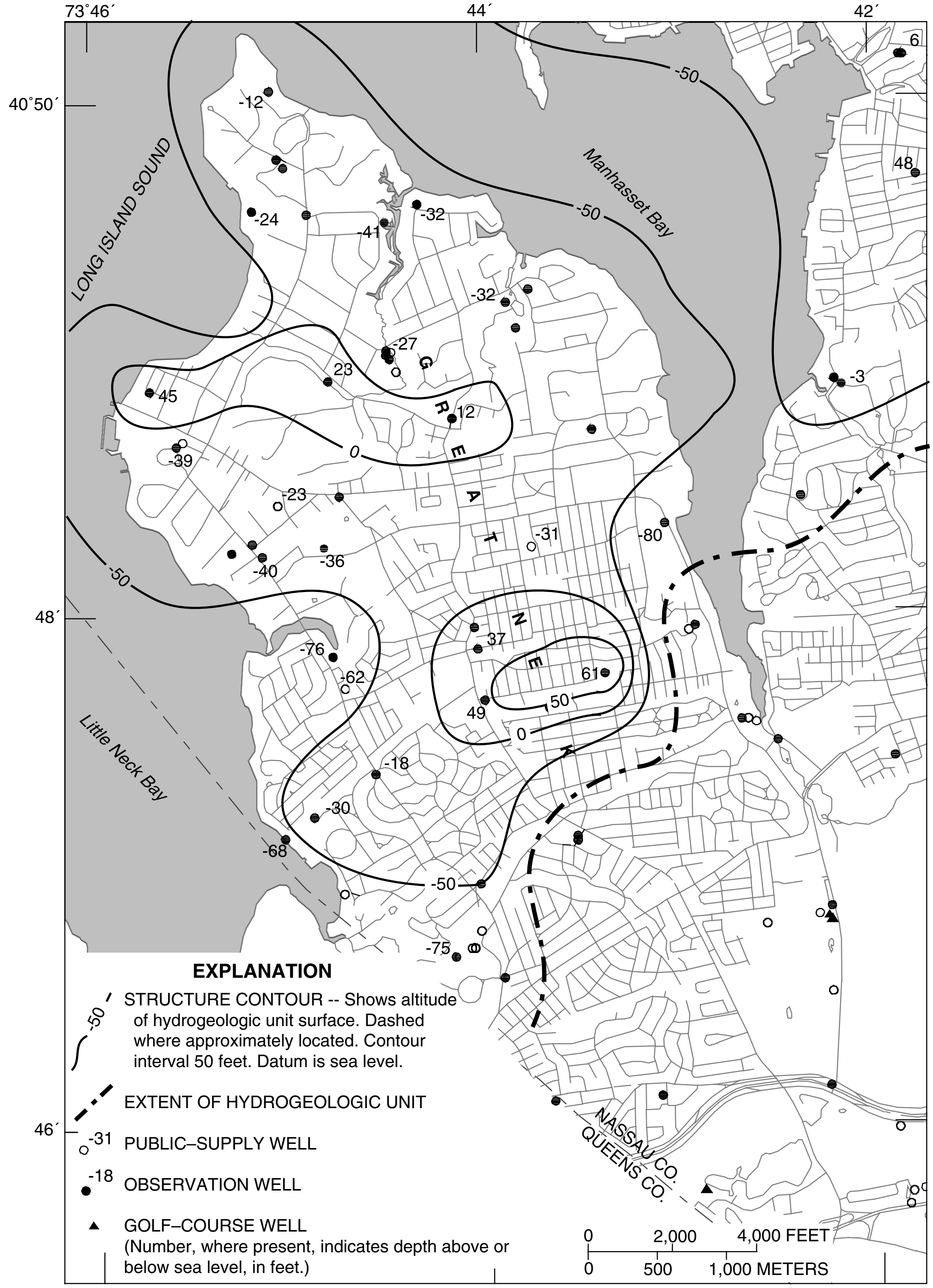
The North Shore confining unit consists of material from two possibly separate depositional sequences—one is a brackish marine clay, the other a proglacial freshwater-lake clay. Drill-core samples from N12013 and N12465 (fig. 2) contain olive-gray clay (5Y 4/2) with oyster shells, which suggest shallow, brackish conditions. Amino-acid-racemization dating of oyster shells from well N10101 (adjacent to N12465) indicates an age of about 225,000 years before present (Ricketts, 1986), which suggests a Yarmouth age for the brackish, shallow marine environment (North Shore confining unit) in this part of Great Neck. This conclusion is consistent with the presence of Cretaceous sediments beneath wells N12013 and N12465 and indicates that these areas probably represent an older remnant that is either in place or was ice shoved into the present location. Cores from several other wells contained gray clay and silt sequences without shell material; this indicates varved clays deposited in a much more recent proglacial lake. Little or no Cretaceous material is typically found beneath many of these areas.

The Gardiners Clay is a greenish-brown or gray marine clay of Pleistocene age that was probably deposited during an interglacial period and contains diatoms, foraminifers, and shell fragments (Suter and others, 1949). Investigation of the stratigraphy and geologic age of these deposits was beyond the scope of this study, but the most widely accepted opinion is that the term Gardiners Clay refers only to this south-shore unit (Suter and others, 1949).

Although the marine clays in central Great Neck might indeed represent an erosional remnant of a brackish interglacial environment, they are placed, in this report, with the younger glacial-lake deposits as an undifferentiated Pleistocene-aged unit of clay and silt that constitute the North Shore confining unit. The offshore seismic-reflection profiles in Little Neck Bay, Long Island Sound, and Manhasset Bay indicate subhorizontal, parallel reflectors that are indicative of draped bedding (varved clays) and imply deposits of silt and clay (fig. 11). These deposits fill two sharply defined buried valleys that truncate the surrounding hydrogeologic deposits (Stumm and Lange, 1994, 1996). The valleys are asymmetrical, steep sided, 2-4 mi long and about 1 mi wide, and trend northwest-southeast. They extend to bedrock, and are sometimes deeper than 200 ft below sea level (figs. 4A, 4B, 4C, 4D) (Stumm and Lange, 1994, 1996).

Tagg and Uchupi (1967) conducted seismic profiles in Long Island Sound and found the bedrock surface to contain deep, flat-bottomed, U-shaped troughs that extend to more than 600 ft below sea level. They interpreted these troughs or valleys to be glacially eroded but were unable to discern whether any of them extend beneath Long Island because near-shore seismic data were lacking. Reeds (1927) described varved clay deposits in the New York City area; his interpretations suggest clay deposition in postglacial freshwater lakes occupying low-lying basins in southern New York. He also proposed a series of interconnected lakes (Glacial Lake Flushing) within parts of Long Island Sound and northern Queens County (fig. 2) and describes these glacial lakes as containing extensive layers of varved clays and silt. Lewis and Stone (1991) describe similar silt and clay deposits infilling extensive parts of Long Island Sound.

The North Shore confining unit underlies almost all of the Great Neck peninsula and ends along an undulating northeast-southwest-trending line in the southeastern part of the peninsula (fig. 9). The upper surface of the North Shore confining unit is relatively flat in most parts of the peninsula (fig. 9); its altitude ranges from 20 ft above sea level to more than 60 ft below sea level, and the unit extends offshore into the surrounding embayments. The North Shore confining unit consists of olive-brown (2.5Y 4/2) varved clay and minor amounts of silt and dark olive-gray clay (5Y 4/2) with shells. Ice-shove deformation and deposition in parts of Great Neck have resulted in localized clay layers at altitudes of more than 20 ft above sea level within the unit (fig. 9).



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 9. Extent and upper surface altitude of the North Shore confining unit in Great Neck, N.Y. (Location is shown in fig. 1B.)

Of interest is the lack of sand and gravel within the onshore and offshore buried valleys beneath Great Neck and Manhasset Bay that Swarzenski (1963) and Kilburn (1979) describe as possible channels or valleys infilled mostly with sand and gravel. All buried valleys delineated in this study were found to be filled with 200- to 300-ft thick sequences of clay and silt. Elsewhere on the peninsula, the North Shore confining unit is about 50 ft thick.

Upper Glacial Aquifer

The upper glacial aquifer consists of till, sand, gravel, silt, and clay deposits and is underlain in some areas by the North Shore confining unit. This aquifer includes Pleistocene-age beds of fine- to coarse-grained and stratified sand and gravel, unstratified boulders, clay, till, and some small, shallow pond deposits (Suter and others, 1949). The upper glacial aquifer consists of a mixture of brown sand (7.5YR 4/6), dark yellowish-brown sand (10YR 4/6), and varying amounts of reworked Cretaceous deposits. The upper glacial aquifer is poorly to moderately sorted and consists of rock fragments and minerals dominated by quartz. Biotite and muscovite micas typically are observed. Offshore seismic-reflection surveys and drill-core data indicate that this aquifer does not extend a great distance offshore, nor does it infill the valleys beneath Manhasset Bay and Little Neck Bay, as interpreted by Kilburn (1979). The upper glacial aquifer overlies the Magothy aquifer in the southernmost part of Great Neck and overlies most of the North Shore confining unit in the rest of the peninsula (fig. 10). The present land surface includes recent deposits and the unsaturated upper part of the upper glacial aquifer. An average horizontal hydraulic conductivity of 270 ft/d was determined for the aquifer (Smolensky and others, 1989).

Seismic-Reflection Surveys

The seismic-reflection survey results were correlated with geologic logs of nearshore observation wells. Three seismic-reflection profiles—E-E´, F´-F, and G´-G (figs. 11A, 11B, 11C)—were selected to depict the major subsurface features encountered during seismic-reflection surveys.

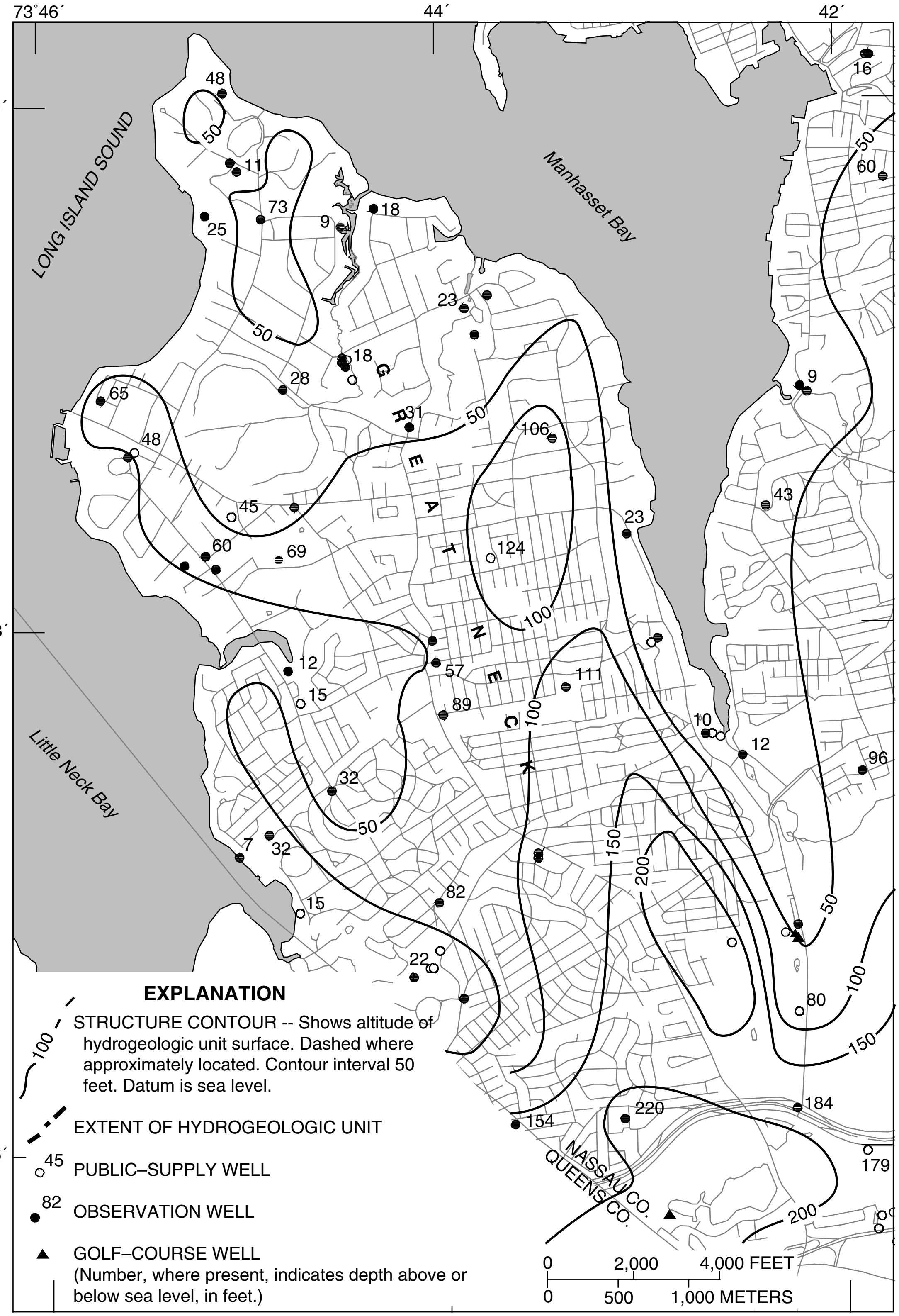
Seismic-reflection profile E-E´ is about 4,250 ft long and lies about 1,000 ft off the northwestern shore of Great Neck in Little Neck Bay (figs. 1B, 11A). The sea floor is 10 to 30 ft below sea level in this area. The first subsurface reflector (at 30- to 50-ft depth) marks the top of a complex, chaotic unit of coarse-grained sand and gravel. A major reflector that was present at depths of 120 to 190 ft below this unit is uneven and has a vertical offset of more than 50 ft. This reflector is interpreted, from nearby wells, to be the bedrock surface. It has a smooth surface that dips to the south midway between E-E´, then drops about 50 ft with a slightly undulating horizontal surface from there to E´, much like a cuesta or hogback.

Seismic-reflection profile F´-F is about 7,000 ft long and lies about 3,000 ft off the northwestern shore of Great Neck, in Little Neck Bay, roughly parallel to E-E´ (figs. 1B, 11B). The sea floor along this section ranges from 50 to 10 ft below sea level. The first subsurface reflector marks the top of a complex, layered unit of fine-grained silt and sand 10 to 40 ft thick. Below this reflector, a series of subhorizontal, parallel reflections indicative of draped bedding is interpreted as silt and clay. These deposits fill a sharply defined, glacially eroded valley that truncates the surrounding coarse-grained deposits. The valley is asymmetrical, trends northwest-southeast, is about 3 mi long and 1 mi wide, and reaches about 200 ft below sea level (Stumm and Lange, 1994).

Seismic-reflection profile G´-G, about 4,600 ft long and crossing the opening of Manhasset Bay, indicates another major buried valley (figs. 1B, 11C). Water depth ranges from 20 to 60 ft. The first subsurface reflector represents the top of a complex, layered unit of sand and silt 35 ft thick, beneath which is a fine-grained deposit of draped, parallel reflections interpreted as silt and clay. This extensive deposit fills an asymmetrical, glacially eroded valley about 1 mi wide that extends to about 235 ft below sea level. Data from the two seismic-reflection surveys in 1993 and 1994 within Manhasset Bay indicate that the valley is about 2.5 mi long and trends northwest-southeast (Stumm and Lange, 1994; 1996). The bedrock surface appears to undulate within the valley. Geologic data from well N12050 (fig. 2) correlate with the seismic-reflection data.

Borehole-Geophysical Logs

The borehole geophysical logs shown in figure 12 are gamma, SP, SPR, R, and EM logs of test well N12581T and are typical of those used in the study (fig. 2). The gamma log (fig. 12A) indicates two



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 10. Extent and upper surface altitude of the upper glacial aquifer in Great Neck, N.Y. (Location shown in fig. 1B.)

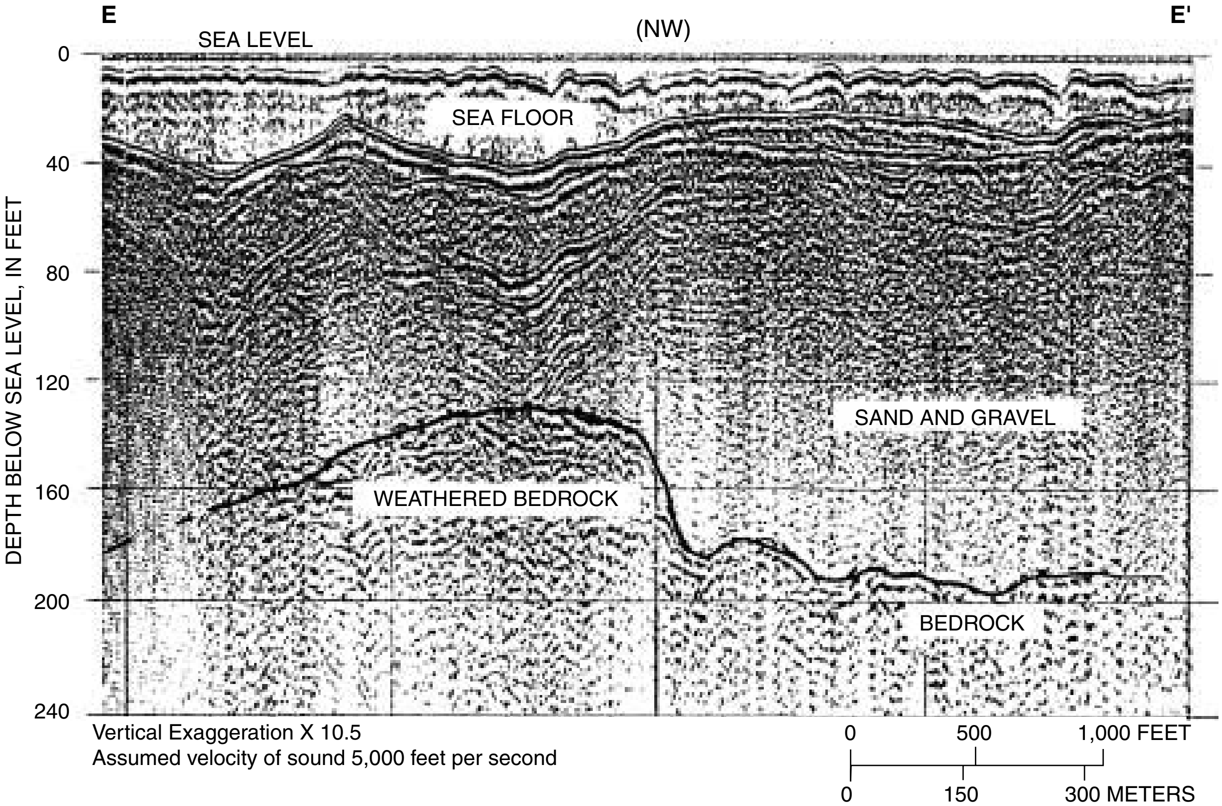


Figure 11A. Interpreted stratigraphy along seismic-reflection profile E-E´ in Long Island Sound off Great Neck, N.Y. (Trace of section is shown in fig. 1B.)

horizons of clay at 110 and 170 ft below land surface (30 and 90 ft below sea level). Drillers' logs indicate extensive ice-shove deposition of reworked Cretaceous sediments, including the Raritan clay. The bottom of the well was set at the surface of the Raritan clay. The SP and SPR logs (figs. 12B, 12C) indicate a steady deflection to lower values just below the water table at about 30 ft below land surface (50 ft above sea level). Resistance values on this log do not appear to fluctuate at the transitions from sand to clay. The R log (fig. 12D) correlates with the SP and SPR logs and indicates moderately conductive ground water above and below the shallow clay layer at 110 ft below land surface (30 ft below sea level). The EM log (fig. 12E) is similar to the SP, SPR, and R logs and shows an increase in conductivity with depth above and below the clay at 110 ft below land surface (30 ft below sea level). The most conductive water detected was just above the deep clay layer at 170 ft below land surface (90 ft below sea level) with a maximum conductivity of about 75 mS/m.

Precipitation

All freshwater in the Great Neck peninsula originates as precipitation. The precipitation infiltrates the land surface, runs off to storm sewers and to

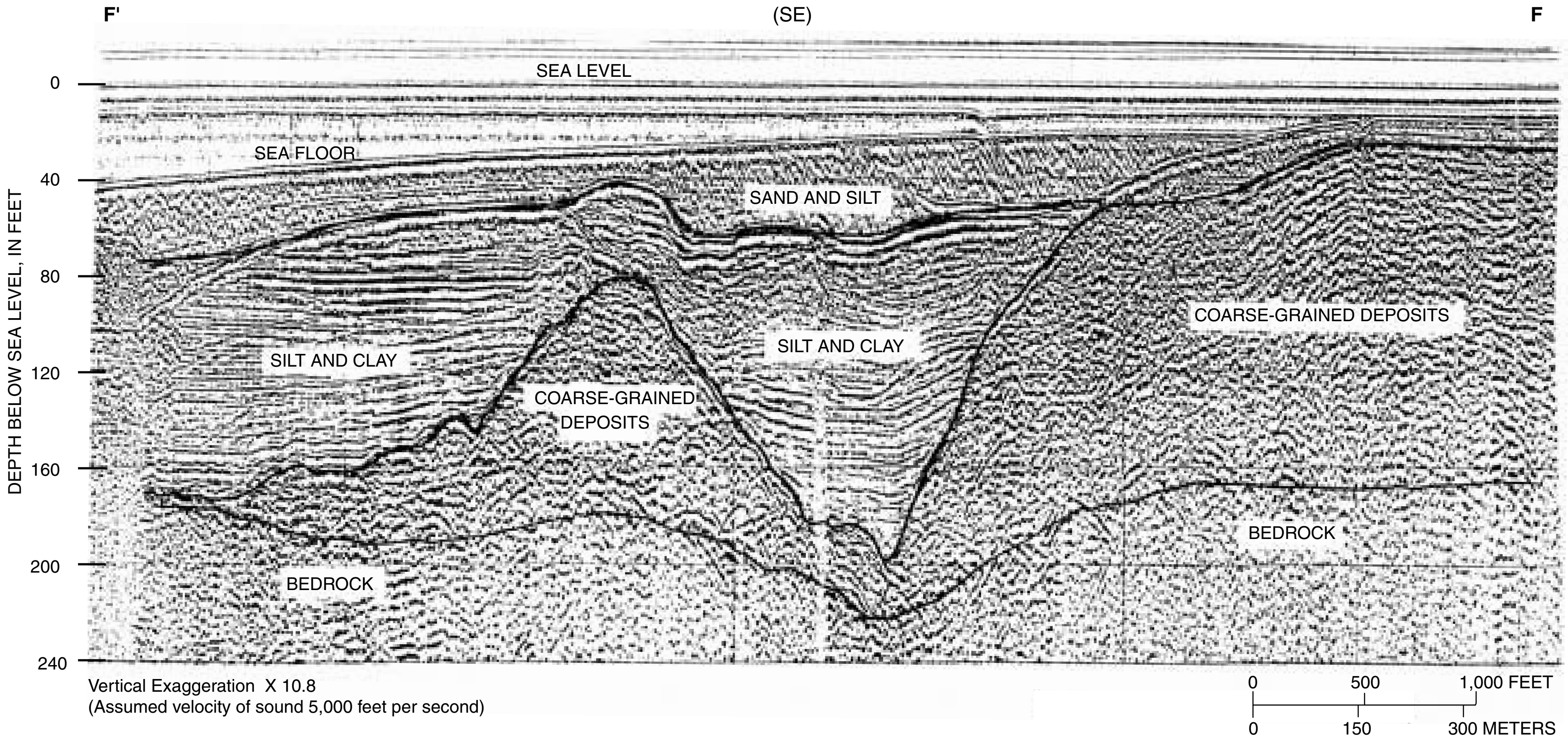


Figure 11B. Interpreted stratigraphy along seismic-reflection profile F´-F in Little Neck Bay off Great Neck, N.Y. (Trace of section is shown in fig. 1B.)

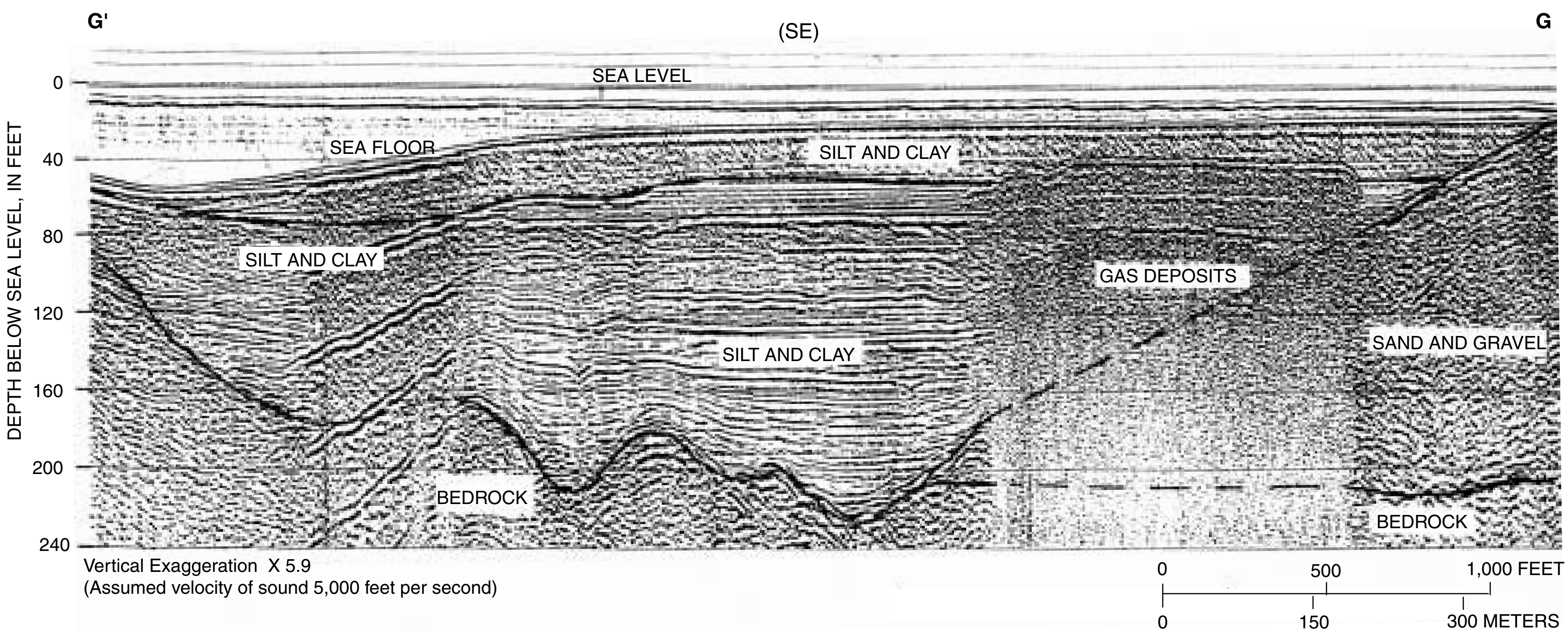


Figure 11C. Interpreted stratigraphy along seismic-reflection profile G´-G in Manhasset Bay off Great Neck, N.Y. (Trace of section is shown in fig. 1B.)

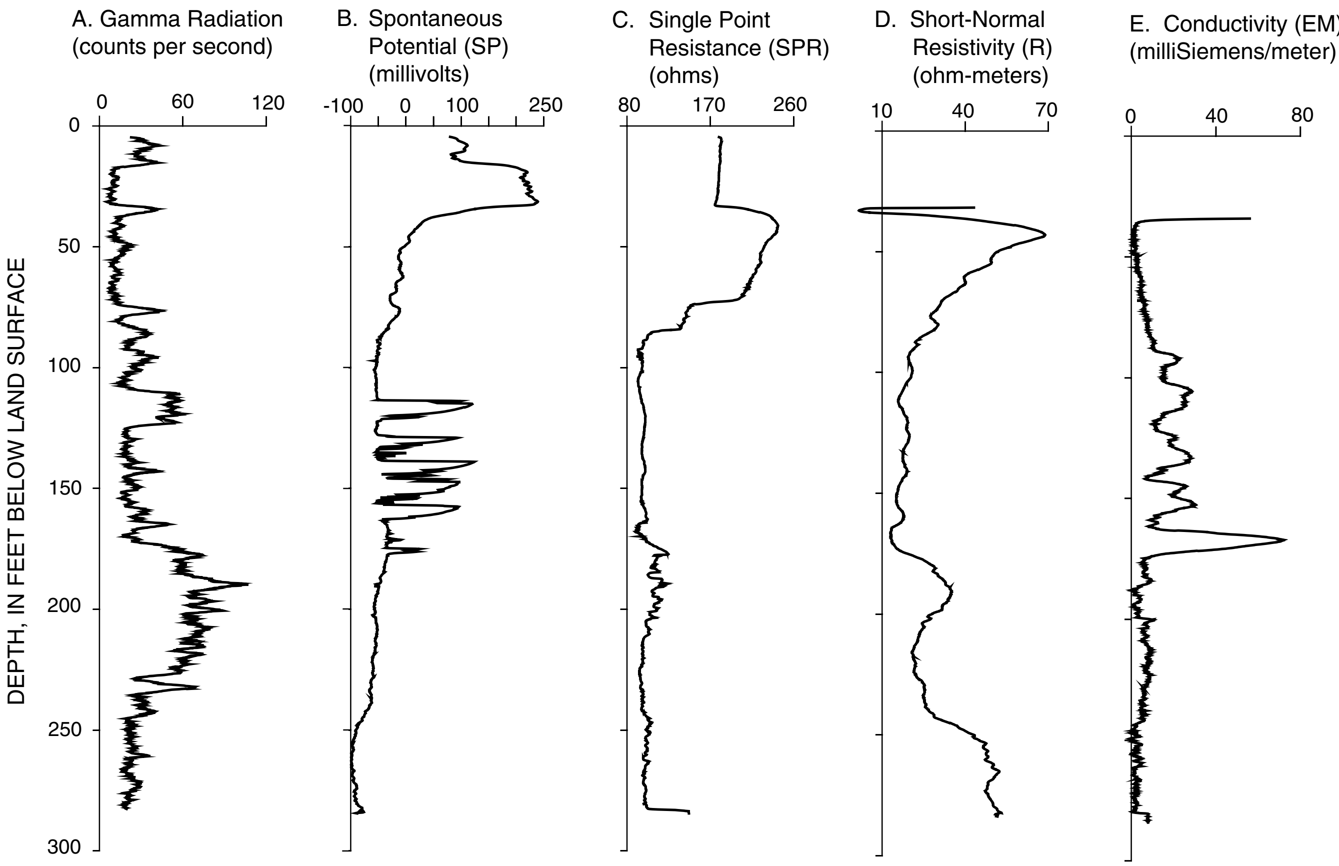


Figure 12. Geophysical logs of test well N12581T, Great Neck, N.Y. (Location is shown in fig. 2.)

tidewater, or returns to the atmosphere through evapotranspiration. Some of the water that infiltrates the soil is returned to the atmosphere through evaporation and transpiration; the rest percolates to the water table, where it becomes shallow ground water. Some water moves laterally into stream channels and becomes base flow; the remainder moves downward into the deeper hydrogeologic units and eventually discharges to the surrounding saltwater bodies.

The average warm-season and cool-season precipitation are almost equal, but more precipitation falls in the spring than at other times. The precipitation regime on Long Island for 1951-65 was studied by Miller and Frederick (1969), who calculated mean annual precipitation on the Great Neck peninsula to be about 42 in. The average annual precipitation recorded by NCDPW at Mineola, in central Nassau County (fig. 1B), during 1937-96 is 44.4 in.

Ground Water

The major uses of ground water in the Great Neck peninsula are for residences, businesses and

Table 2. Total annual pumpage from the Great Neck peninsula, by aquifer, 1992-96
[Data from Great Neck Water Authority, Manhasset-Lakeville Water District, and New York State Department of Environmental Conservation]

	Total pumpage, in millions of gallons		
Year	Upper glacial aquifer	Magothy aquifer	Lloyd aquifer
1992	359.9	1,149.5	1,012.3
1993	539.8	1,054.8	1,034.1
1994	518.9	1,402	1,035.2
1995	514.9	1,259.8	829.9
1996	499.7	806.8	1,131
Mean	486.6	1,134.6	1,008.5

small industry, and for irrigation of lawns and golf courses (Great Neck has no agriculture). Water levels were measured in observation wells screened in all major aquifers within Great Neck.

Pumpage

The vast majority of water for all uses is derived from public-supply wells owned and operated by the Great Neck North Water Authority and the Manhasset-Lakeville Water District; a small amount is from private wells. Ground water is pumped from the upper glacial, Magothy, and Lloyd aquifers. The total annual pumpage from each aquifer during 1992-96 is shown in table 2. Three golf-course-irrigation wells (N2576, N9687, and N8038), all screened in the Magothy aquifer (fig. 2), serve the three golf courses in the study area. A private irrigation well (N7846, fig. 2) is screened in the upper glacial aquifer. Average annual pumpage of the four wells (combined) for 1992-96 was 35.4 Mgal, and that for the pumping season (May-October) was 0.2 Mgal/d.

Pumpage from the Magothy aquifer is greater than that from the Lloyd aquifer (table 2); average annual pumpage for 1992-96 from the upper glacial, Magothy, and Lloyd aquifers (combined) was 486 Mgal (1.3 Mgal/d), 1,135 Mgal (3.1 Mgal/d), and 1,009 Mgal (2.8 Mgal/d), respectively. The effect of public-supply pumpage on water levels in aquifers is discussed in the following sections.

Water Levels

Pumping generally lowers water levels in aquifers and thereby induces a flow gradient toward the pumping wells. A major concern for water suppliers and managers is that contaminated water from adjacent or overlying aquifers may be induced to flow toward the well.

All wells near the coast of Long Island are assumed to be affected by tides; thus, the USGS measures water levels in these wells during the high-tide period (typically 2 h) in the nearest embayment because ground water can fluctuate in a well throughout a tidal cycle. All tidally influenced wells are measured by the USGS only at high tide to maintain consistency over long-term records. The large number of observation wells in Great Neck would have required 5-7 days for measurement; therefore, two studies were conducted in 1992 and 1993 to indicate which aquifers are affected by tidal fluctuations in the surrounding embayments. Results of the tidal influence studies in selected wells are shown in figure 13. Water levels at four Great Neck wells were measured at 20-min intervals during a continuous 14-h tidal sequence from high to low tide.

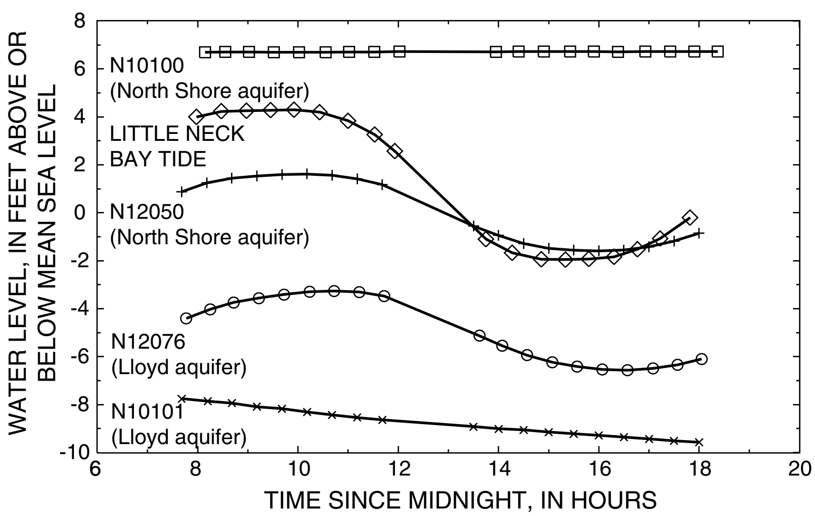
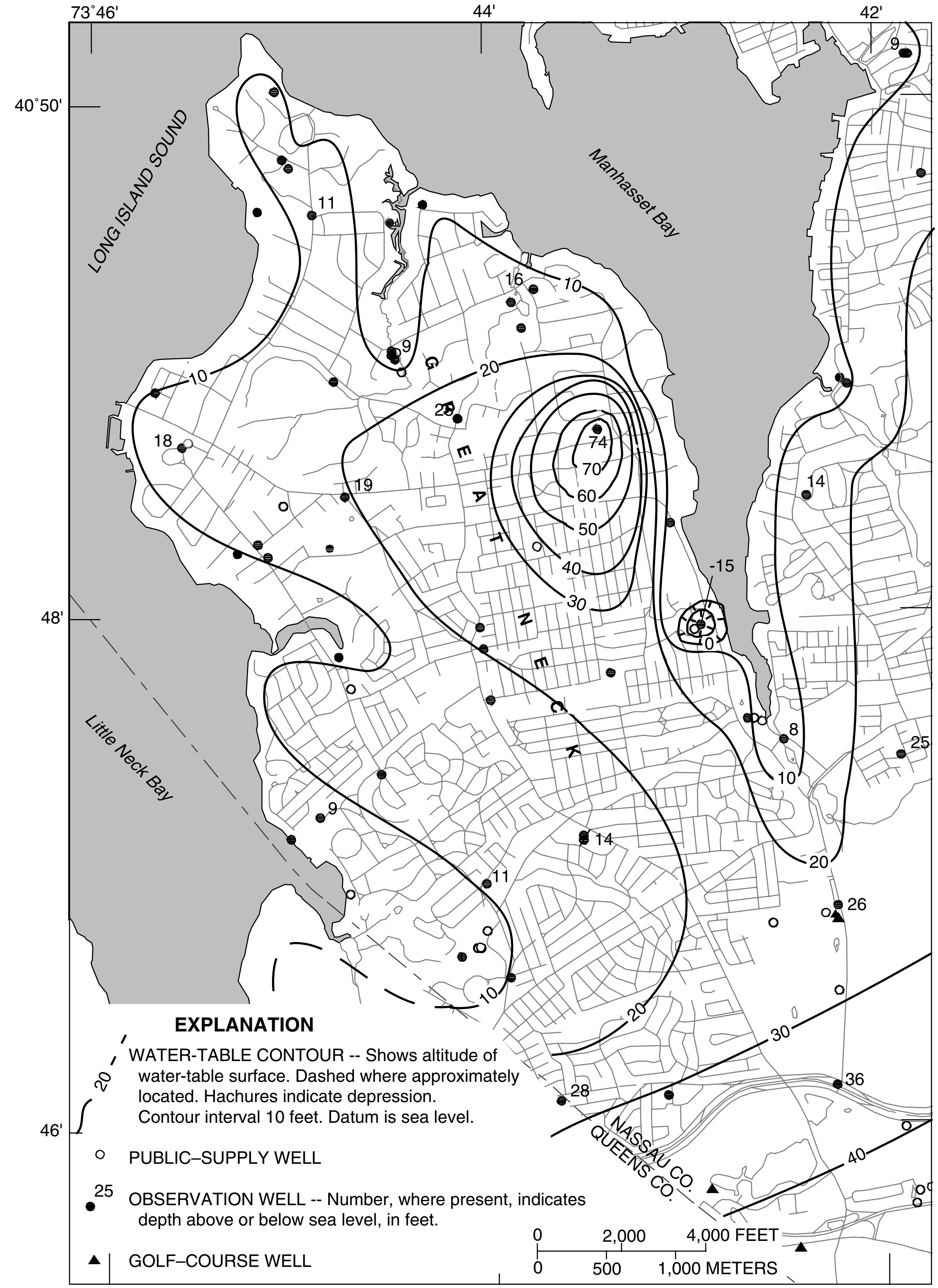


Figure 13. Water levels measured at four selected wells during 1992-93 tidal study on Great Neck, N.Y. (Locations are shown in fig. 2.)



Base from New York State Department of Transportation, 1:24,000, 1981

Figure 14. Water-table altitude in Great Neck, N.Y., August 1995.

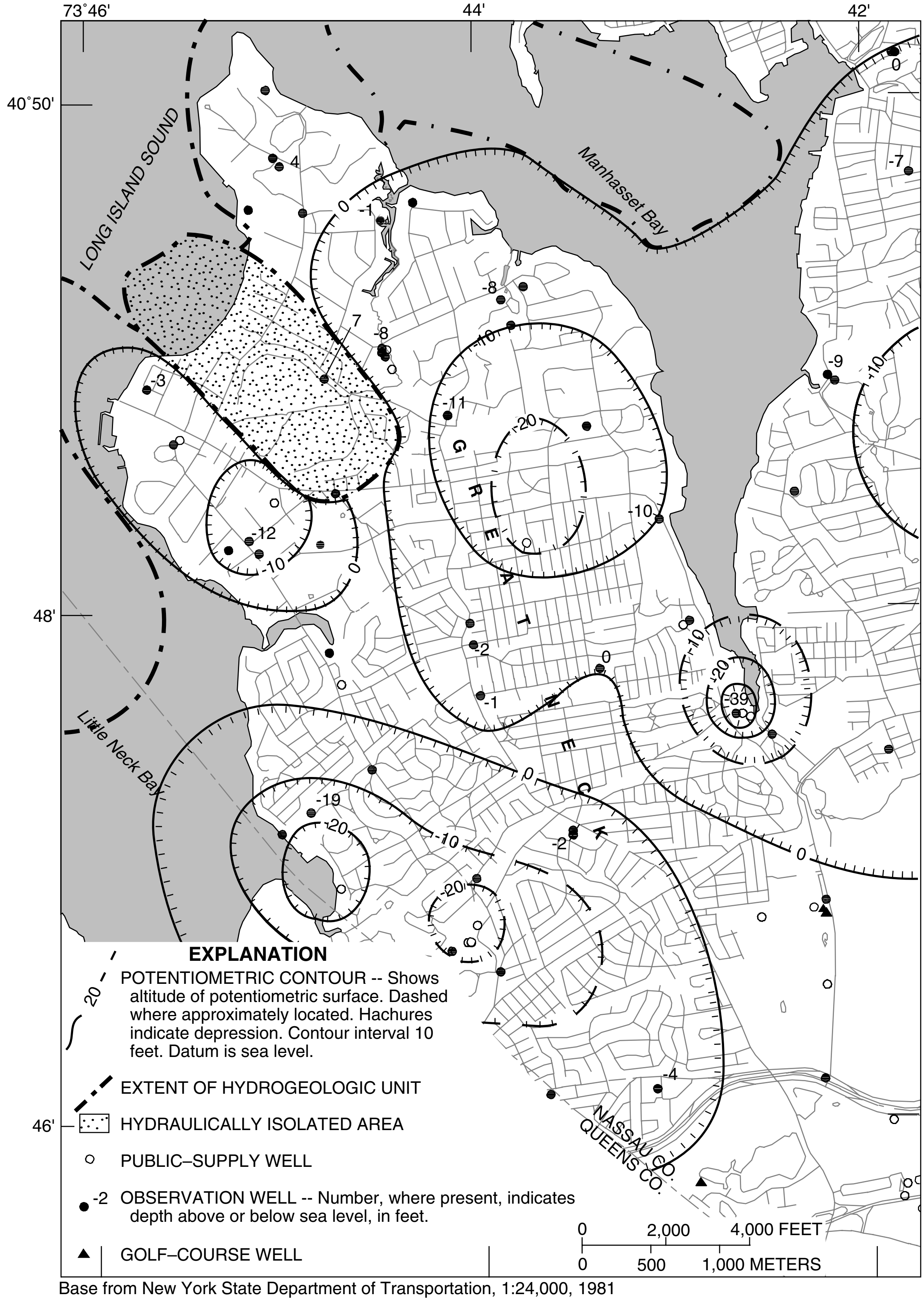


Figure 15. Potentiometric-surface altitudes in the Lloyd and North Shore aquifers in Great Neck, N.Y., August 1995.

A tide-measurement station was established on a dock in Little Neck Bay, on the west coast of Great Neck (fig. 2), for use during the tidal influence studies. Tidally influenced wells (wells requiring measurement during high tide) were selected on the basis of results from the 1992 and 1993 tidal influence studies.

Water levels in observation wells were measured quarterly during 1992-96. Water levels during August 1995 were at their lowest levels and are plotted in figures 14 and 15. The following paragraphs describe water levels in the four aquifers underlying Great Neck during 1992-96.

Upper glacial aquifer (fig. 14).—The water table is within the upper glacial aquifer throughout the Great Neck peninsula, except in the southernmost part, where it is in the unconfined (upper) part of the Magothy aquifer. Farther north, the Magothy is absent (fig. 7). In isolated areas of Great Neck, parts of the upper glacial aquifer are semiconfined by the North Shore confining unit. Water levels during August 1995 in wells screened near the water table (upper glacial and Magothy aquifers) are depicted in figure 14. Generally, the highest water levels are in the southern part of Great Neck, except at well N9896 in the northeast part, where the water level was 74 ft above sea level. Water levels in the remaining wells screened in the upper glacial aquifer wells ranged from 8 ft to 36 ft above sea level.

Data from the two studies of selected tidally affected wells in the Great Neck peninsula in 1992 and 1993 indicate that, on most of the peninsula, water levels in the upper glacial aquifer and the unconfined part of the Magothy aquifer do not respond to tides. An exception was at well N12152 (screened in the Magothy), near the south end of Manhasset Bay (fig. 2), where the Magothy aquifer is affected by pumping from public-supply well N5884 (screened in both aquifers) (fig. 2), and water levels during nonpumping periods fluctuate with the tide.

Magothy aquifer (fig. 14).—Ground water in the Magothy aquifer becomes increasingly confined with depth. Water-level data obtained during quarterly measurements in the aquifer, where present in the southern part of the peninsula, represent the water table because the Magothy in this area is in hydraulic connection with the upper glacial aquifer (fig. 14).

Water levels at wells screened in the upper parts of the Magothy aquifer do not appear to be affected by nearby pumping. An exception is at well N12152, near the south end of Manhasset Bay and screened below sea level; here the water levels respond as in a confined aquifer. This well indicated about 18 ft of drawdown from pumping at public-supply well N5884 (fig. 2).

Lloyd and North Shore aquifers (fig.15).— These two aquifers are in stratigraphic contact laterally and are hydraulically connected. Water in the Lloyd aquifer is confined beneath the Raritan clay, and water in the North Shore aquifer is confined beneath the North Shore confining unit.

Predevelopment (1900) water levels within the Lloyd aquifer are inferred to have been above sea level throughout the Great Neck peninsula (Kimmel, 1973). Water levels within the Lloyd aquifer in Great Neck have been measured below sea level in 1947 (Lusczynski, 1952), in 1971 (Kimmel, 1973), in 1975 (Rich and others, 1975), in 1979 (Donaldson and Koszalka, 1983), and in 1984 (Doriski, 1987). Water-level data from quarterly synoptic measurements during 1992-96 indicate that water in the Lloyd and North Shore aquifers flows northward and develops large cones of depression in response to local public-supply pumping. Water-level data from the studies of tidally affected wells in 1992 and 1993 indicate that both aquifers are strongly affected by tides along the coast and are hydraulically connected (Stumm, 1993a; Stumm and Lange, 1994). Tidal fluctuations at some wells (N12076 for example) can be as much as 4 ft (fig. 13). Water levels in the central part of the peninsula do not seem to be affected by tides but are strongly affected by pumping from public-supply wells. One well, which was previously interpreted to be screened in the Lloyd aquifer (well N10100 in the north-central part of the peninsula, fig. 2), was found to be screened beneath a mostly clay-filled buried valley. Water levels in this well did not fluctuate and were not affected by tides or by pumping, whereas wells screened in the Lloyd aquifer beyond this buried valley were affected by either or both. Drillers' logs and gamma logs indicate that this well is screened not within the Lloyd, but within a thin, Pleistocene-age sand unit (sandy part of the North Shore confining unit) beneath the base of the clay-filled buried valley.

Water levels within the buried valley (near well N10100) in central Great Neck were consistently about 5-10 ft above sea level during 1992-96, in contrast to those on the rest of the peninsula in the Lloyd and North Shore aquifers, which are affected by pumping and tides (fig. 15). Data from 1992-96 also indicate that the sandy unit (N10100) at the base of the buried valley in this part of the peninsula is not hydraulically connected with the Lloyd aquifer or with other surrounding units, and is thus considered part of the North Shore confining unit.

The potentiometric surface of the Lloyd and North Shore aquifers, as measured in August 1995 (fig. 15), has about four or five large cones of depression throughout the peninsula that are caused by public-supply pumping. The potentiometric surface at most wells was below sea level, and these depressions extended over large parts of the peninsula and into the surrounding saltwater embayments. Water levels in 1995 ranged from 4 ft above to almost 40 ft below sea level. The increased pumping in summer causes ground-water flow in the Lloyd and North Shore aquifers to reverse direction; that is, to flow inland from the surrounding saltwater embayments toward the pumping wells (the areas of lowest hydraulic head). This reversal of the normal seaward flow is the primary cause of past and present saltwater intrusion in the peninsula. Analysis of long-term hydrographs of wells screened in the Lloyd and North Shore aquifers indicates that local pumping has a much greater effect than regional trends on water-level fluctuations.

Water Quality

Data on ground-water quality on the Great Neck peninsula are available from analyses made by the NCDH and the NCDPW. In addition, 36 samples from observation wells and 1 sample from Long Island Sound were collected by the USGS during August and September of 1996 and analyzed by the NCDPW Cedar Creek laboratory. The objective was to obtain chloride concentrations and specific-conductance data for delineating the freshwater-saltwater interface. Detailed analysis of the water quality and review of historical data were beyond the scope of this study.

Chloride.—Chloride concentrations in the Magothy and upper glacial aquifers on the Great Neck peninsula generally range from 10 to 50 mg/L; those in the Lloyd aquifer range from 5 to 10 mg/L. One exception is public-supply well N5884, in the southeastern part of the peninsula, which had a peak chloride concentration of 163 mg/L in 1979 and a concentration of 82 mg/L in 1995 (fig. 16A).

Seawater has an average chloride concentration of about 19,000 mg/L (Drever, 1988). A sample from Long Island Sound had a chloride concentration of 13,995 mg/L, indicating significant freshwater inflow into Long Island Sound. Water from three public-supply wells screened in the Lloyd aquifer (N30, N31, and N1926) had chloride

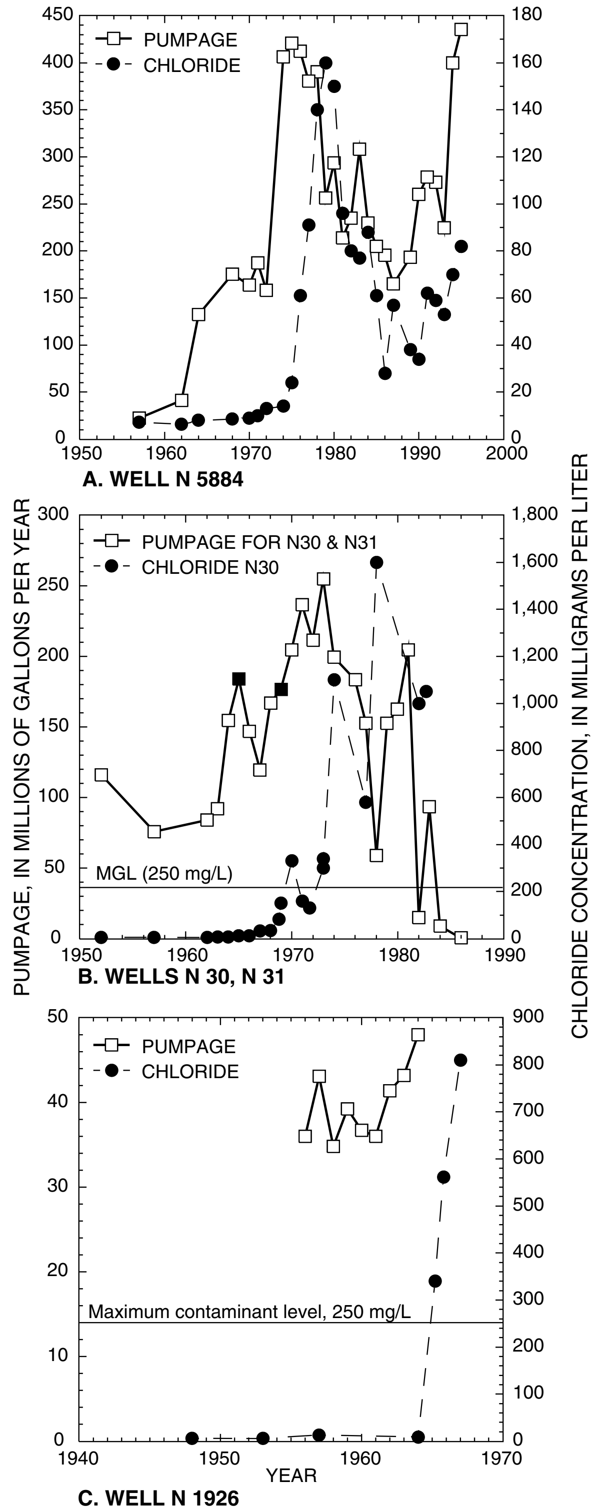


Figure 16. Chloride concentrations and pumpage at selected public-supply wells on the Great Neck, N.Y., peninsula. A. Well N5884, 1957-95. B. Wells N30 and N31, 1952-86. C. Well N1926, 1948-67. (Data from Nassau County Department of Health, Nassau County Department of Public Works, and Great Neck Water Authority. Locations are shown in fig. 2.)

concentrations that exceeded the State MCL (maximum contaminant level, 250 mg/L for chloride) and were shut down as a result (figs. 16B, 16C). Water from two observation wells screened in the Lloyd aquifer (N12153, N12013) had chloride concentrations above the State MCL (4,998 and 737 mg/L, respectively); water from two observation wells screened in the North Shore aquifer (N12050, N12102) also had chloride concentrations above the State MCL (13,748 and 12,250 mg/L, respectively).

Volatile organic compounds.—Volatile organic compounds (VOC's) that have been detected in ground water in the Great Neck peninsula could be derived from domestic cesspool and drain cleaners, and from solvents and degreasers used by industries. The VOC's most frequently detected in Nassau County public-supply wells (raw water) in 1995 were tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichlorethane (TCA) (Nassau County Department of Health, 1996). NCDH data indicate that raw water from public-supply wells N700, N22, N4388, N5710, N4243, and N3905 (fig. 2), screened in the Magothy and upper glacial aquifers, contained VOC's in concentrations above the New York State MCL's. Water from one public-supply well screened in the Lloyd aquifer, N3443 (fig. 2), also had a VOC concentration above the State MCL's.

In 1996, contamination by VOC's was detected in water from the upper glacial and Magothy aquifers. Water from one well screened in the Lloyd aquifer (N3443) had possible VOC contamination that may have been caused by leakage of the well casing or hydraulic connection with the overlying upper glacial aquifer. In general, the Lloyd aquifer appears to be protected from the downward movement of synthetic organic compounds from the overlying shallow aquifers by the Raritan clay and North Shore confining unit.

Water from three of the observation wells screened in the upper glacial, Magothy, and Lloyd aquifers (N9098, N10390, and N10992) (fig. 2) had VOC concentrations above the State MCL's; water from well N9098 had benzene and benzene derivatives, toluene, and xylene in concentrations of hundreds to thousands of times above State MCL's.

Inorganic constituents and metals.—Water from four observation wells screened in the upper glacial aquifer (N9909, N9099, N9271, and N12464, fig. 2) exceeded the State MCL's for iron, lead, and manganese; water from one Lloyd aquifer well (N12082) exceeded the MCL for iron, and water from one observation well (N8052) screened in the North Shore aquifer exceeded the MCL's for iron, lead, and manganese (fig. 2). No public-supply wells on the Great Neck peninsula contained any inorganic constituent in concentrations above the State MCL's (Nassau County Department of Health, 1996).

EXTENT OF SALTWATER INTRUSION

Saltwater intrusion is the most common type of water-quality degradation in coastal-plain aquifers (Fetter, 1994). In coastal areas, the hydraulic head under predevelopment (nonpumping) conditions is higher on land than in the surrounding saltwater embayments; thus, ground water flows from areas of high potential to areas of lower potential, and fresh-water and saltwater meet at an equilibrium point that lies offshore. When the natural hydraulic gradient is reversed by pumping, fresh ground water flows toward the pumping well instead of flowing seaward, and the equilibrium point between freshwater and saltwater moves landward. If this point moves inland, saltwater intrusion results.

The predevelopment chloride concentration of fresh ground water on Long Island was 10 mg/L or less (Lusczynski and Swarzenski, 1966). The ambient chloride concentration of shallow (upper-glacial) ground water in urbanized areas of Long Island is less than 40 mg/L (Buxton and others, 1981; Heisig and Prince, 1993); this increase is attributed to contamination from land-surface sources. In this report, "ambient" water is defined as ground water with a chloride concentration less than 40 mg/L; "brackish" water has a chloride concentration of 40 to 250 mg/L, and "saltwater" has a chloride concentration greater than 250 mg/L (Lusczynski and Swarzenski, 1966). An increase above predevelopment concentrations of chloride in deep, confined aquifers on Great Neck can be indicative of saltwater intrusion from the surrounding embayments in response to pumping.

Historical chloride concentrations at public-supply wells in Great Neck indicate that the background chloride concentration for the Lloyd aquifer is 5 to 10 mg/L. Based on 50 years of chloride-concentration and pumpage data from public-supply wells, once a concentration of 50 mg/L is exceeded at a public-supply well in Great Neck, the concentrations will remain above 50 mg/L even if pumpage is decreased. The technique of pumping only in alternate years at wells with elevated chloride concentrations only slightly delays an inevitable rapid increase in chloride concentrations. This results because once the toe, or leading edge, of the saltwater wedge reaches the public-supply well, it is upconed into the screen zone of the well and responds to decreased pumping for only a very short time before stabilizing into a rapid, continuous increase.

In Great Neck, overpumping of the Lloyd, North Shore, and upper glacial aquifers has caused extensive saltwater intrusion (Stumm, 1993a, 1994; Stumm and Lange, 1994). Filter-press samples obtained during drilling of 12 observation wells for this study were analyzed for chloride concentration and were correlated with core samples from the screen zones, geologic logs, and geophysical (gamma, electric, and electromagnetic induction) logs to delineate the extent of saltwater intrusion. Chloride concentrations of samples from public-supply wells also were analyzed.

Saltwater Wedges A, B, C, and D

Four distinct wedge-shaped areas of saltwater intrusion in Great Neck were identified; three extend into the Lloyd and North Shore aquifers (fig. 17), and the fourth extends into the upper glacial aquifer. Three additional and less distinct areas or wedges of saltwater in Great Neck have been detected through water-quality analyses and borehole-geophysical logs. The saltwater wedges typically form at the base of an aquifer that overlies an impermeable layer (either bedrock or a confining unit) because the density of saltwater is greater than that of freshwater. The wedges decrease in thickness landward and have relatively sharp freshwater-saltwater interfaces (transition zones) about 10 ft thick (Stumm, 1993a) (fig. 18). The saltwater wedges were delineated on the basis of chloride concentrations in water samples from observation wells, hydrogeologic data, gamma and focused-electromagnetic induction logs, and potentiometric-surface data.

Saltwater wedge A, in the northernmost part of Great Neck, was penetrated at the base of the North Shore aquifer at wells N12050 and N12102 (fig. 17). Chloride concentrations from filter-press samples and estimated from induction-log response indicates that wedge *A* at well N12050 is about 125 ft thick. The freshwater-saltwater interface here is sharp, and the chloride concentration of a sample from the observation well screen was 13,750 mg/L (fig. 18), which indicates severe saltwater intrusion. Induction-log responses correlated with chloride data from filter-press and well-screen samples.

The toe of wedge *A* was penetrated at well N12102, about 2,000 ft south of N12050 (fig. 2); here it is 50 ft thick (fig. 17). The maximum chloride concentration in filter-press samples was 13,200 mg/L, and that in a sample from an observation well screened at the base of the North Shore aquifer was 12,250 mg/L. The lack of a wide transition zone in wedge *A* within this tidally affected aquifer indicates active saltwater intrusion due to current overpumping of the Lloyd aquifer in the central part of the peninsula.

Saltwater wedge B is at the base of the Lloyd aquifer and was the cause of the shutdown and abandonment of public-supply wells N30 and N31 in 1974 (figs. 2, 17). A graph of the chloride concentration and public-supply pumpage at this location from 1952 through 1986 (fig. 16B) indicates a typical pattern of saltwater intrusion—first a gradual but steady increase in chloride concentration, and then rapid increases to concentrations above the State MCL. Pumping of wells N30 and N31 began in the early 1950’s and stopped during the late 1980’s. Well N30 and N31 had peak chloride concentrations of 1,600 mg/L in 1978 and 390 mg/L in 1983, respectively. Saltwater wedge *B* also was encountered at the base of the Lloyd aquifer at wells N12079 and N12013, which are 3,000 and 5,000 ft south of well N12102, respectively. Focused-induction logs indicate wedge *B* to be about 20 ft thick at this location. The sample from the screen zone at well N12013 had a chloride concentration of 737 mg/L, indicating saltwater intrusion. Sharp deflections in the induction log at the bedrock surface supports the assumption that the upper bedrock surface (saprolite zone) is a relatively impermeable boundary because of the high clay content.

The western edge of saltwater wedge *B* is interpreted to be near well N12079 (figs. 2, 17); offshore seismic-reflection, drill-core, and structure-contour-map data indicate a nearly 100-ft cuesta of bedrock immediately south of N12102 that wedge *A* probably could not breach; thus, wedge *B* must originate just northeast of N12079. Whether saltwater wedge *B* is directly associated with wedge *A* is unknown. Filter-press samples and the induction log of well N12079 indicate wedge *B* to be about 20 ft thick and to have a chloride concentration of 500 mg/L at the depth of the well screen; this corresponds to an induction-log conductivity of about 50 mS/m. A third

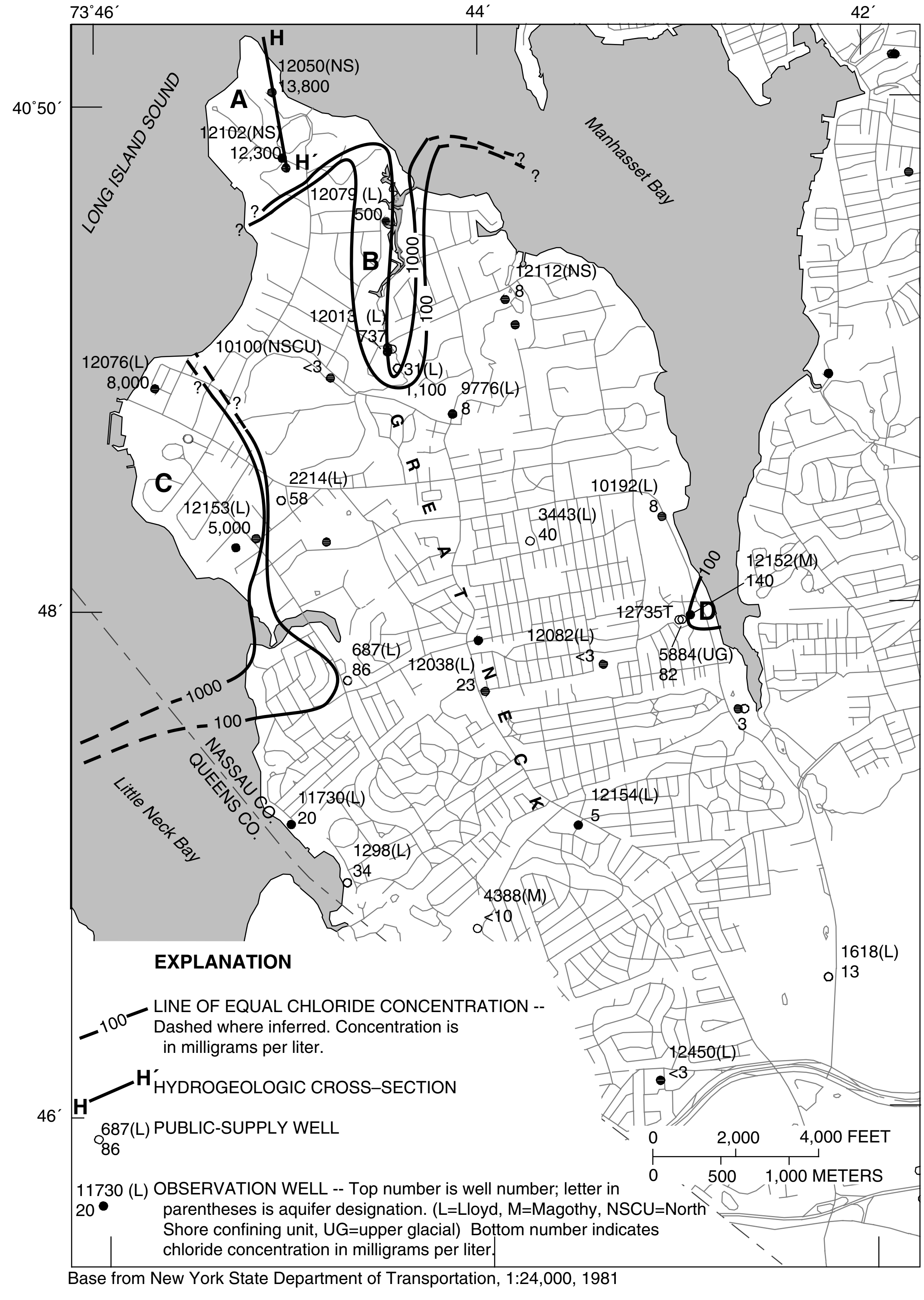


Figure 17. Chloride concentrations in Lloyd, North Shore, and upper glacial aquifers, Great Neck, N.Y., 1996.

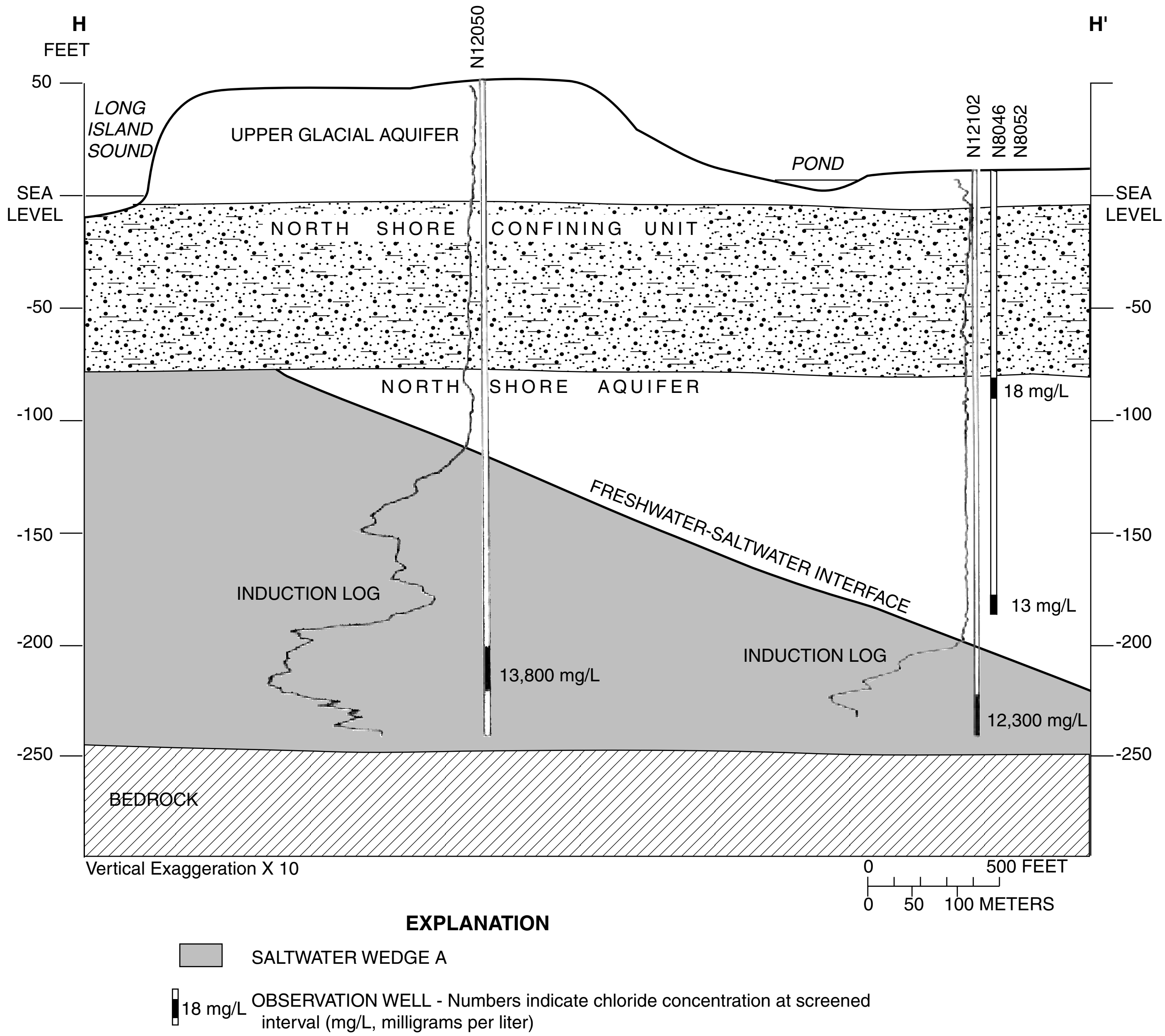


Figure 18. Hydrogeologic section showing extent of saltwater wedge A, Great Neck, N.Y. (Location is shown in fig. 19.)

well (N12112) was drilled about 3,000 ft east of N12013 and screened at the base of the North Shore aquifer (figs. 2, 17), but geophysical logs and water samples from this well did not indicate saltwater intrusion; thus, the eastern boundary of saltwater wedge *B* probably does not extend this far east.

Saltwater wedge C is at the base of the Lloyd aquifer along the western shore of Great Neck (fig. 17). The wedge has affected two public-supply wells (N1926 and N2214) and a private well (N7613). A plot of pumpage and chloride concentrations at public-supply well N1926 (fig. 16C) indicates rapid saltwater intrusion in 1965 with little warning; this intrusion may have been because the well was screened fairly close to the base of the aquifer in an area where the freshwater-saltwater interface was just offshore. The pumpage and chloride graph for public-supply well N2214 (fig. 19B), about 3,000 ft southeast of N1926 (fig. 17), also indicates saltwater intrusion a few years later, in 1968. Samples from this well had a peak chloride concentration of 180 mg/L in 1975. The reduced-pumpage technique has been applied at

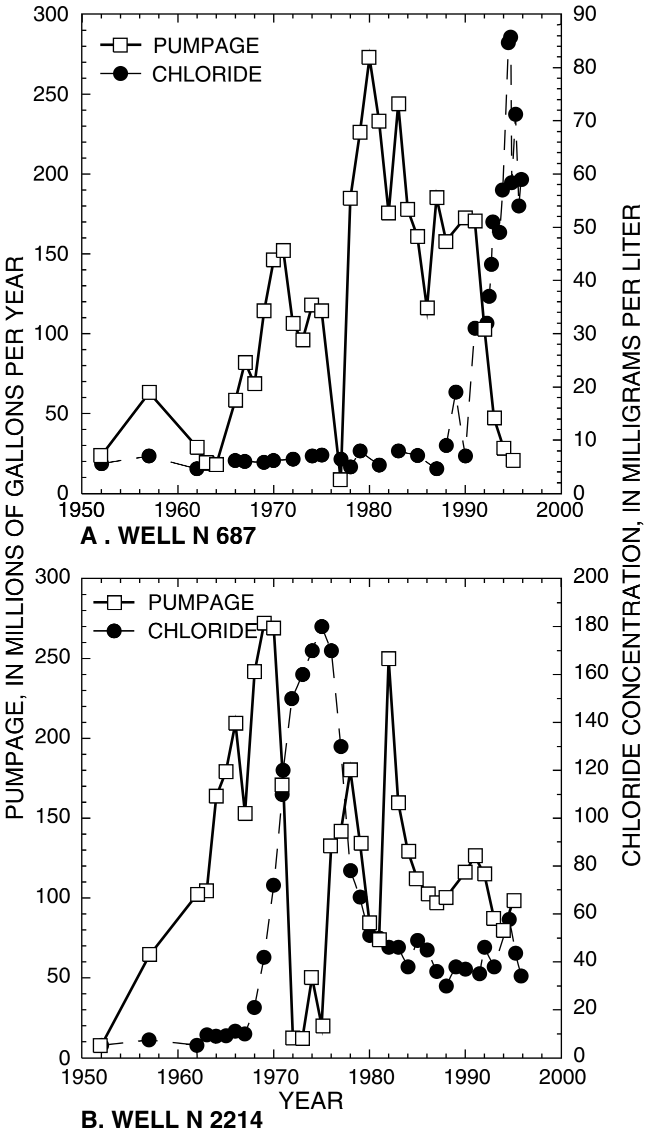


Figure 19. Chloride concentrations and pumpage at two public-supply wells on Great Neck, N.Y., 1950-96: A. Well N687. B. Well N2214. (Data from Nassau County Department of Health, Nassau County Department of Public Works, and Great Neck Water Authority.)

N2214 since 1972 (fig. 19B) but has not resulted in a decrease in chloride concentrations to below about 50 mg/L. Two observation wells on the western shore of the peninsula (N12076 and N12153, fig. 2) were drilled within wedge *C*. Well N12076 was screened in the Lloyd aquifer above wedge *C*, but a sump was installed to bedrock to obtain an induction log through the entire thickness of the Lloyd aquifer. The induction-log response and correlation with stratigraphy at well N1926 indicate the saltwater wedge to have a thickness of about 30 ft at this location and an estimated chloride concentration of about 8,000 mg/L. The induction log and the water-sample data from the screen zone at well N12153, which is 4,000 ft southeast of N12076, indicate a wedge thickness of about 20 ft and a chloride concentration of 5,000 mg/L.

Saltwater wedge D is on the eastern shore of the peninsula within the upper glacial aquifer (fig. 17). The graph of pumpage and chloride concentrations at public-supply well N5884 (fig. 16A) indicates an increase in pumpage in the late 1960’s, followed by a gradual, then rapid, increase in chloride concentration. Well N5884 had a peak chloride concentration of 160 mg/L in 1979. A reduction in pumpage since 1979 has lowered the concentration, but not to pre-intrusion levels. Observation well N12152 (next to N5884) was drilled and screened at the base of the Magothy aquifer; data from drill-core and filter-press samples and geophysical logs indicate a 30-ft-thick wedge of brackish water resting on a thin clay layer within the upper glacial aquifer. The maximum filter-press chloride concentration was 141 mg/L. Gamma logs from well N5884 and an adjacent, recently installed test well N12735T (figs. 2, 17) indicate that the thin clay layer is continuous and extends some distance inland. Well-screen-construction records indicate that well N5884 has two screen zones—one in the upper glacial aquifer and the other in the Magothy aquifer below. The two screen zones are separated by the thin clay layer. Although well N5884 is officially listed as screened in the Magothy aquifer, it pumps water from the upper glacial and the Magothy aquifers. The source of saltwater at this well is the well screen in the upper glacial aquifer.

Other Saltwater Wedges

Two potential public-supply test wells, N12580T and N12581T, were drilled at the Fresh Meadow Country Club, just south of the east end of the peninsula. The borehole-geophysical logs of these wells suggest several wedges of dense, conductive ground water at the base of the upper glacial aquifer resting upon a clay layer (fig. 12). The possible saltwater wedges increase in conductivity with depth, rest upon confining units, and are within aquifers that are locally capped by clay layers. In the absence of nearby landfills or heavy industry, saltwater intrusion is a likely explanation, particularly because several golf-course wells screened in the same zone were abandoned a few years earlier. Neither test well was completed as a public-supply well because analysis of borehole-geophysical logs indicated saltwater intrusion. The source of the conductive ground water is unknown because three shallow public-supply wells (N7747-58, N7961-71, and N12555) at the south end of Manhasset Bay (fig. 2) have not indicated elevated chloride concentrations.

A sixth possible wedge of saltwater appears to have begun to affect public-supply well N687, screened in the Lloyd aquifer 2,000 ft from the southwestern coast (fig. 2). Pumpage and chloride graphs indicate that increased pumping of this well during the 1980's was followed by a rapid increase in chloride concentrations (fig. 19A). Similar trends in pumpage, and chloride plots of six other public-supply wells on the peninsula, indicate that a wedge of saltwater has begun to affect public-supply well N687. No outpost wells have been installed in that area to delineate this wedge, however.

Public-supply well N1298 is the southernmost well on Little Neck Bay (fig. 2). The chloride-breakthrough curve for this well indicates an increasing trend in chloride concentrations since the 1950's (fig. 20A). This increase reflects the landward movement of the freshwater-saltwater interface (a possible seventh wedge) toward the well. This well typically is pumped during the summer, when water levels in the Lloyd aquifer are at their lowest. The Lloyd aquifer in this area may be in jeopardy of saltwater intrusion in the near future.

Public-supply well N3443 is near the center of the peninsula and screened in the Lloyd aquifer. The chloride-breakthrough curve for this well also indicates an increase in chloride concentrations—from 5 to 10 mg/L in the 1950's (fig. 20B) to the 30- to 40 mg/L range by 1995. This increase could have three explanations: (1) the toe of saltwater wedge *B* has begun to reach N3443; (2) the confining units above the Lloyd aquifer are more permeable in this area than on the rest of the peninsula; and (3) the annular seal surrounding the casing may have failed. Although the first explanation is possible, chloride concentrations at well N9776, 3,000 ft upgradient of N3443, are still between 5 to 10 mg/L and, thus, indicate that wedge *B* has not affected the Lloyd aquifer there. The second explanation is not supported by the drill-core data, which indicate the Raritan clay to be a substantial confining unit. The third explanation seems the most plausible. Drawdowns at N3443 during pumping reach 30 to 40 ft below sea level; thus, failure of the

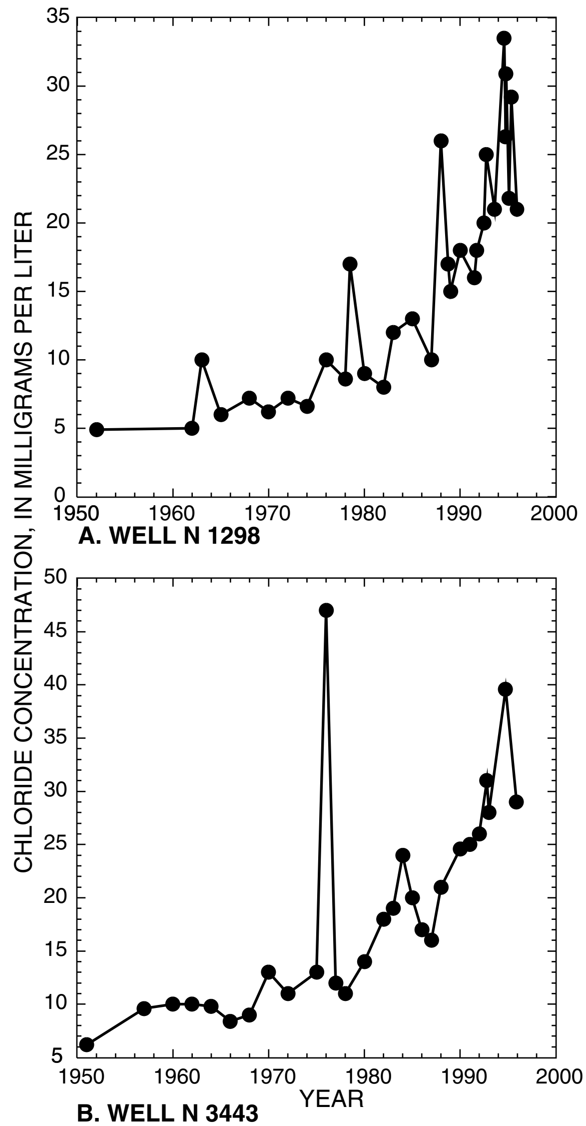


Figure 20. Chloride-breakthrough curves for two public-supply wells screened in the Lloyd aquifer, Great Neck, N.Y.: A. Well N1298, 1952-96. B. Well N3443,1951-96. (Locations are shown in fig. 2.)

annular seal could allow water from the upper glacial aquifer to reach the well screen and could explain the gradual increase in chloride concentrations and the anomalous VOC contamination at the well. In comparison, the maximum chloride concentration at the other public-supply wells screened in the Lloyd aquifer (N8342, N1618, and N9308, fig. 2) in 1994 was 13 mg/L, which is indicative of ambient conditions in the aquifer.

SUMMARY AND CONCLUSIONS

The intrusion of saltwater toward several public-supply wells within the Great Neck peninsula from the surrounding embayments (Little Neck Bay, Long Island Sound, and Manhasset Bay, N.Y.) prompted a cooperative study by the U.S. Geological Survey in 1991-96 with the Nassau County Department of Public Works. The cooperative study collected hydrogeologic, geophysical and water-quality data, and delineated the subsurface geology and extent of saltwater intrusion in Great Neck. Fifteen observation wells were drilled during 1991-96, and continuous high-resolution seismic-reflection surveys were completed offshore in the embayments surrounding the Great Neck and Manhasset Neck peninsulas in 1993 and 1994. The seismic-reflection surveys were used to delineate the hydrogeologic framework underlying Little Neck Bay, Long Island Sound, and Manhasset Bay. Borehole-geophysical logs (gamma, electric, and EM induction) were used to delineate hydrogeologic units and the extent of saltwater intrusion at selected observation wells on the Great Neck peninsula.

The new drill-core data led to the proposal of two hydrogeologic units—the North Shore aquifer and the North Shore confining unit; these names are defined for the first time in this report. The North Shore aquifer is a sequence of Pleistocene-age sediments that were penetrated during drilling in the northernmost part of Great Neck. The Lloyd aquifer was not found in the northernmost part of the peninsula or offshore.

The Raritan clay overlies and confines ground water in the Lloyd aquifer. The Raritan clay has been severely eroded or completely removed in many parts of the peninsula by glacial scouring. A glacially eroded buried valley appears to have incised the Raritan clay from the northwestern corner to the southeastern corner of Great Neck.

Most of the Magothy aquifer has been completely removed in Great Neck by glacial erosion except in the southernmost part and along the southeastern coast of the peninsula.

The North Shore confining unit is a sequence of Pleistocene-age clay and silt deposits that occur locally along the northern parts of Queens, Nassau, and Suffolk Counties. Offshore glacial-lake deposits were correlated, through offshore seismic-reflection surveys, borehole-geophysical logs, and drill-core samples, with buried valleys that extend across the Great Neck peninsula. These deposits infill two sharply defined buried valleys that truncate the surrounding coarse-grained deposits. The valleys are asymmetrical, steep sided, northwest-southeast trending, and are 2-4 mi long and about 1 mi wide; they extend down to bedrock and are more than 200 ft below sea level.

The upper glacial aquifer consists of various till, sand, gravel, silt and clay deposits underlain in some areas by the North Shore confining unit. Offshore seismic-reflection surveys and drill-core data indicate that the upper glacial aquifer does not extend offshore and does not infill the valleys beneath Manhasset Bay and Little Neck Bay, as proposed in previous studies. The water table is in the upper glacial aquifer in all but the southernmost part of Great Neck, where it is in the Magothy aquifer. The water table is not tidally influenced throughout Great Neck.

Ground water in the Lloyd and North Shore aquifers is confined by the Raritan clay and North Shore confining unit, respectively. Water-level data from the tidal-effect studies indicate that both aquifers are hydraulically connected and are greatly affected by tides and public-supply pumping.

The potentiometric surface of the Lloyd and North Shore aquifers in August 1995 contained four large cones of depression throughout the peninsula that reflect public-supply pumping. Potentiometric levels measured in most wells were below sea level and extended over large parts of the peninsula and into the surrounding saltwater embayments. Water levels ranged from 4 ft above to almost 40 ft below sea level. Increased pumping in summer causes ground-water flow in the Lloyd and North Shore aquifers to reverse direction; that is, to flow inland from the surrounding saltwater embayments toward the pumping wells. This reversal of the normal seaward flow is the primary cause of past and present saltwater intrusion in the peninsula.

Water from six public-supply wells and three observation wells screened in the upper glacial and Magothy aquifers contained several VOC's in concentrations greater than the New York State Department of Health maximum contaminant levels (MCL's), and water from one public-supply well (N3443) screened in the Lloyd aquifer also contained a VOC in concentrations above the State MCL's. Water from observation well N9098 contained benzene and benzene derivatives, toluene, and xylene in concentrations of hundreds to thousands of times in excess of the State MCL's.

Chloride concentrations in the Magothy and upper glacial aquifers in the Great Neck peninsula typically ranged from 10 to 50 mg/L. One exception is at public-supply well N5884, in the southeastern part of the peninsula, where the peak chloride concentration was 163 mg/L in 1979 and 82 mg/L in 1995. Three public-supply wells (N1926, N30, and N31) screened in the Lloyd aquifer have been shut down because the chloride concentrations exceeded the State MCL of 250 mg/L. Chloride concentrations at four observation wells screened in the Lloyd and North Shore aquifer (N12050, N12102, N12153, and N12013) exceeded the State MCL; concentrations were 13,748, 12,250, 4,998, and 737 mg/L, respectively.

Overpumping of the Lloyd, North Shore, and upper glacial aquifers on Great Neck has caused extensive saltwater intrusion. Four distinct wedge-shaped areas of saltwater intrusion have been identified in Great Neck; three have extended into the Lloyd and North Shore aquifers, and the fourth has extended into the upper glacial aquifer. Three other areas, or wedges, of saltwater have been detected through water-quality and geophysical-data analyses. The wedges decrease in thickness landward, and the transition zones are about 10 ft thick.

Saltwater wedge *A,* in the northernmost part of Great Neck, was encountered at the base of the North Shore aquifer. The wedge is about 125 ft thick at well N12050 with a chloride concentration at the well screen of 13,750 mg/L. The chloride concentration of the Long Island Sound sample was 13,995 mg/L.

Saltwater wedge *B* was the cause of the shutdown and abandonment of public-supply wells N30 and N31, adjacent to observation well N12013. The chloride concentration at well N30 was 1,600 mg/L in 1978. Wedge *B* was penetrated at wells N12079 and N12013, screened at the base of the Lloyd aquifer. EM logs indicate that the wedge is about 20 ft thick at the base of the Lloyd.

Saltwater wedge *C* is in the Lloyd aquifer along the western shore of Great Neck. It has affected public-supply wells N1926 and N2214 and private well N7613. Two observation wells were drilled within wedge C—N12076 and N12153. The saltwater wedge is about 20 to 30 ft thick at the base of the Lloyd aquifer with an estimated chloride concentration of about 8,000 mg/L at N12076 and 4,998 mg/L at N12153.

Saltwater wedge *D* is on the eastern shore of the peninsula within the upper glacial aquifer; it is 30 ft thick and had a maximum chloride concentration of 141 mg/L. It has affected public-supply well N5884, which has two screen zones—one in the upper glacial aquifer and one in the underlying Magothy aquifer. The source of saltwater at this well is the well screen in the upper glacial aquifer.

Two potential public-supply wells—N12580T and N12581T—were drilled in the southeastern part of Great Neck. Interpretation of the geophysical logs suggests that this area may contain several saltwater wedges.

Other possible wedges of saltwater in the Lloyd aquifer appear to have begun to affect public-supply wells N687 and N1298, screened in the aquifer. Pumpage and chloride-concentration graphs indicate that increased pumpage during the 1980's was followed by a rapid increase in chloride concentrations; this increase indicates that the freshwater-saltwater interface is moving landward toward the wells.

The chloride-breakthrough curve for public-supply well N3443 indicates a gradual increase in chloride concentrations since the 1950's; this increase may be due to a failure of the annular seal surrounding the casing.

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