In cooperation with
Nassau County Department of Public Works

Hydrogeology and Extent of Saltwater Intrusion in the Northern Part of the Town of Oyster Bay, Nassau County, New York: 1995-98

Water-Resources Investigations Report 03-4288

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CONVERSION FACTORS AND DATUM

Multiply	By	To Obtain
	Length	
inch (in)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi 2)	2.590	square kilometer
	Flow	
million gallons per day (Mgal/d)	0.0438	cubic meters per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Volume	
ounce, fluid (fl oz)	29.57	milliliter
	Acoustic velocity	
foot per second (ft/s)	0.3048	meter per second
	Other abbreviations used	
	hour (h)	
	milligrams per liter (mg/L)	
	million gallons (Mgal)	
	millisiemens per meter (mS/m)	
	minute (min)	
	gallons per minute per foot (gal/min)/ft of drawdown	

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

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Hydrogeology and Extent of Saltwater Intrusion in the Northern Part of the Town of Oyster Bay, Nassau County, New York: 1995-98

By Frederick Stumm, Andrew D. Lange, and Jennifer L. Candela

Abstract

The Oyster Bay study area, in the northern part of Nassau County, N.Y., is underlain by unconsolidated deposits that form a sequence of aquifers and confining units. At least one production well has been affected by the intrusion of saltwater from Hempstead Harbor, Long Island Sound, and Cold Spring Harbor. Nineteen boreholes were drilled during 1995-98 for the collection of hydrogeologic, geochemical, and geophysical data to delineate the subsurface geology and the extent of saltwater intrusion. Continuous high-resolution marine-seismic-reflection surveys in the surrounding embayments of the Oyster Bay study area were conducted in 1996.

New drill-core data indicate two hydrogeologic units—the North Shore aquifer and the North Shore confining unit—where the Lloyd aquifer, the Raritan confining unit, and the Magothy aquifer have been completely removed by glacial erosion.

Water levels at 95 observation wells were measured quarterly during 1995-98. These data and continuous water-level records indicated that (1) the upper glacial (water-table) and Magothy aquifers are hydraulically connected and that their water levels did not respond to tidal fluctuations, and (2) the Lloyd and North Shore aquifers are hydraulically connected and their water levels responded to pumping and to tidal fluctuations.

Marine seismic-reflection surveys in the surrounding embayments indicate at least four 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 several miles long and about 1 mile wide, and (5) extend to more than 500 feet below sea level.

Water samples taken during 1995-98 from three production wells and six observation wells screened in the upper glacial and Magothy aquifers contained volatile organic compounds in concentrations that exceeded the New York State Department of Health Drinking Water Maximum Contaminant Levels. High iron or nitrate concentrations were detected in water samples taken in 1997-98 from 39 observation wells. Previous high concentrations resulted in the shutdown of two production wells.

Four distinct areas of saltwater intrusion in the Oyster Bay study area were delineated— three were in the upper glacial aquifer, and the fourth was in the Lloyd aquifer. Borehole-geophysical-logging data indicated that three of these saltwater "wedges" ranged from a few feet thick to more than 100 feet thick and had sharp freshwater-saltwater interfaces. Chloride concentrations in water from eight observation wells within these wedges in 1997 ranged from 125 to 13,750 milligrams per liter. One production well in Bayville has been shut down as of 1996 and others in the area may be affected by these saltwater wedges.

Introduction

The ground-water system within the coastal areas of northern Nassau County is under increasing stress from pumping by production, industrial, and golf-course-irrigation wells. Increasing chloride concentrations in ground water pumped from production wells have caused a need for detailed information on the area's hydrogeologic system. Ground-water-resources managers in Nassau County's northern coastal area are concerned about increasing concentrations of chloride in ground water pumped from production wells and will require information on the hydrogeologic framework, the effect of pumping on ground-water levels, and the extent of saltwater intrusion into the ground-water system.

In 1991, the U.S. Geological Survey (USGS), 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 northern Nassau County. Results of the study will be used by water-resources managers for the protection and conservation of the local ground-water supply.
The study entailed an evaluation of the current (1998) observation-well network; drilling of new observation wells in areas of probable saltwater intrusion and in areas where hydrogeologic data were scarce; collection of geologic,

hydrologic, geophysical (borehole and marine-seismic-reflection) and water-quality data; and compilation of data to characterize the hydrogeologic framework and the extent of saltwater intrusion.

The study area and its surrounding embayments encompass about 64 mi^2 in the northeastern part of Nassau County (fig. 1). The Oyster Bay study area is bounded on the west by Hempstead Harbor, on the north by Long Island Sound, and on the east by Cold Spring Harbor (fig. 1). The southern boundary of the study area is between Northern Boulevard (Route 25A) and the Long Island Expressway (fig. 1). In 1996, the population of the study area was estimated to be 160,750, or about 11 percent of Nassau County's population (Nassau County Department of Health, 1997).

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 throughout Long Island. Fuller (1914) revised and supplemented much of the earlier geologic work. The geologic correlations used herein are revised from those of Fuller (1914) as well as those of Isbister (1966), and Kilburn and Krulikas (1987). Suter and others (1949) contoured the upper surface of the major geologic units underlying Long Island. Swarzenski (1963) described the hydrogeology and hydrologic conditions in northwestern Nassau County during 1955-57; many of his interpretations and general hydrogeologic framework were verified by the drill-core and marine-seismic-reflection data. Isbister (1963) discussed the relation of freshwater to saltwater in Centre Island, and Isbister (1966) described the hydrogeology and hydrologic conditions in the northern part of Oyster Bay in 1958-60. Kilburn and Krulikas (1987) attempted to restructure and rename parts of the hydrogeologic framework in the northern section of the Town of Oyster Bay, largely from driller's logs (some of which were questionable). The hydrogeologic framework was remapped by recent USGS work that resulted in the identification of the North Shore aquifer and North Shore confining unit in the Great Neck peninsula by Stumm (2001) and in the Manhasset Neck peninsula by Stumm and others (2002). The most recent water-table reports that include the study area are Kimmel (1971) for 1970, Donaldson and Koszalka (1983) for 1979, Doriski (1987) for 1984, and Busciolano and others (1998) for 1997.

Smith (1958) described the first use of high-power, low-frequency marine-seismic-reflection equipment to measure the depth to bedrock beneath selected areas of Long Island Sound. Oliver and Drake (1951) used marine-seismic-reflection techniques to measure the depth to bedrock in Long Island Sound, and Williams (1981) used high-resolution marine-seismic-reflection surveys and core samples to identify the sediments beneath Long Island Sound. Grim and others (1970) described the geology and subsurface morphology of Long Island and the Manhasset Bay embayment. Lewis and Stone (1991) conducted a systematic marine-seismic-reflection survey to map the deposits beneath most of Long Island Sound, except the shallow coastal areas and embayments along the northern shore of western Long Island. Tagg and Uchupi (1967) used continuous marine-seismic-reflection profiles to define the subsurface morphology of Long Island Sound. Stumm (2001) and Stumm and others (2002) completed marine-seismic-reflection surveys along the north shore of Nassau County and correlated these units with observation-well core samples.

Purpose and Scope

This report (1) characterizes the hydrogeology underlying the Oyster Bay study area, (2) describes the ground-water flow system, and (3) delineates the extent of saltwater intrusion within the major aquifers as of 1998. It also presents maps and hydrogeologic sections that summarize the geologic and hydrologic data in the area of investigation. Included are water-table and potentiometric-surface maps of major aquifers, surface-altitude maps of hydrogeologic units, and hydrogeologic sections that show the extent and thickness of the units and chloride concentration within these units during 1992-98.

Acknowledgments

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Methods of Study

Data collected during this study included (1) drilling logs and core samples from observation-wells, (2) borehole-geophysical logs, (3) marine-seismic-reflection surveys, (4) water-level measurements, and (5) water-quality analyses. Additional information was obtained from the NCDPW, the

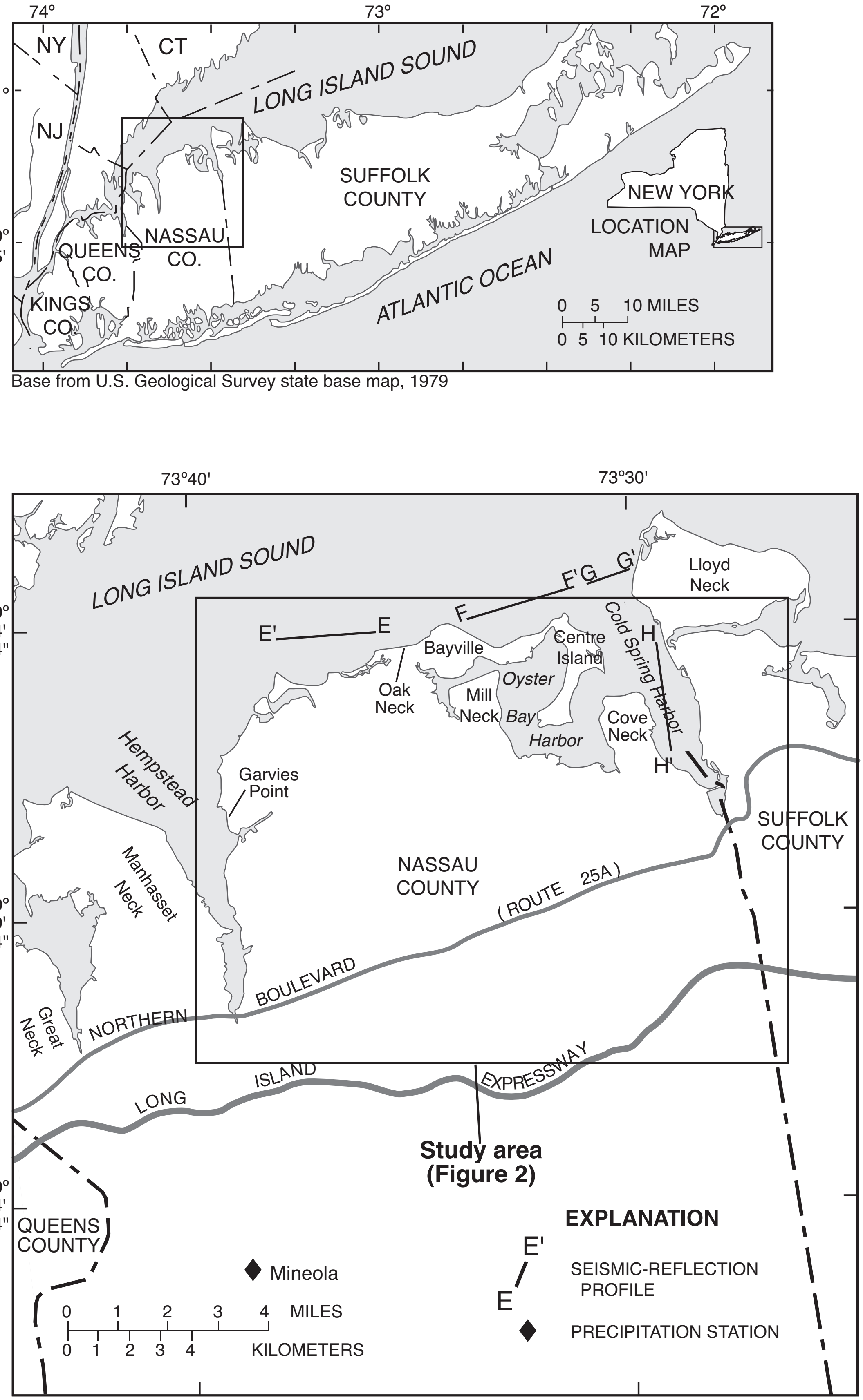


FIGURE 1. Location of Oyster Bay study area and marine-seismic-reflection profiles, Nassau County, N.Y.

Nassau County Department of Health (NCDH), the New York State Department of Environmental Conservation, and from previous studies. The maps and sections are based on all available geologic data and well-driller's logs, as of 1998.

Drilling Logs and Core Samples

Nineteen boreholes were drilled during 1995-98 to collect hydrogeologic, water-quality, and borehole-geophysical data. The drilling program consisted of mud-rotary drilling and split-spoon core sampling. Most boreholes were drilled through the unconsolidated sediments into bedrock, and core samples were obtained at regular intervals for geologic analysis. The thickness of each hydrogeologic unit was estimated primarily from core data obtained during the drilling of observation wells, from borehole-geophysical logs, driller's logs, and through interpolation. Color descriptions of the core samples were based on the standard Munsell color chart (Kollmorgan Instruments Corporation, 1994).

Marine-Seismic-Reflection Surveys

Several continuous high-resolution marine-seismic-reflection profiles were completed in 1996 along the coast of the study area to identify the unconsolidated deposits from Hempstead Harbor to Cold Spring Harbor (fig. 1) and to correlate these deposits with hydrogeologic and borehole-geophysical data obtained during the drilling of the observation wells. Locations of four of the survey lines are shown in figure 1. The continuous seismic-reflection system consisted of a graphic recorder, an amplifier and filter, a power generator, a catamaran-mounted sound source, a hydrophone array, and a 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 marine-seismic-reflection data were digitally recorded and filtered for noise and displayed in real-time graphics.

The continuous high-resolution marine-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), Reynolds and Williams (1988), Stumm (2001), Stumm and Lange (1994, 1996), and Stumm and others (2002).

The sound source generates seismic signals that travel through the water column and penetrate the deposits underlying the sea floor. Some of the seismic signal is reflected back to the water surface from the sea floor. Stratigraphic interfaces will show a change in the acoustic impedance (the product of the density and acoustic velocity of each medium) (Haeni, 1986; Robinson and Çoruh, 1988). The reflected signals received by the hydrophone array produce an electrical signal that is amplified, recorded on digital tape, filtered, and then plotted. The resulting seismic sections, which resemble geologic sections, were correlated with geologic logs of nearshore observation wells. In this situation, the vertical axis is a function of the time required for the seismic signal to travel from the source to the reflector and back (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 was used as an average velocity in this study.

Borehole Geophysical Logs

Borehole geophysical logs were collected from observation wells to provide information that could not be obtained by drilling and sampling. The geophysical-logging systems used in this study provided continuous digital records that were dependent upon the physical properties of the sediment, the rock matrix, and the interstitial fluids. At several sites, natural-gamma radiation (gamma), spontaneous potential (SP), single-point-resistance (SPR), and short-and long-normal resistivity (R) logs were collected in mud-filled open boreholes before the casing was installed, then focused electromagnetic-induction (EM) logs were obtained after installation of the polyvinyl chloride (PVC) casing. The types of geophysical logs are described below.

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

Spontaneous-potential (SP) logs—provide a record of the electrical potential, or voltage, that develops at the contact between clay beds and sand aquifers within a borehole (Keys, 1990). SP differs from one formation to the next and is measured in millivolts (Serra, 1984). SP 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. SP logs are used to determine lithology, bed thickness, and salinity of formation water (Keys, 1990).

Single-point-resistance logs (SPR)—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 interpret 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—measure formation conductivity and are used in conjunction with gamma logs for distinguishing between conductive fluids and conductive clays. This technique uses 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 geologic deposits on Long Island 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 freshwater-saltwater interface (Chu and Stumm, 1995; Stumm, 1993, 1994, 2001; Stumm and Lange, 1994, 1996; Stumm and others, 2002).

Water-Level Measurements

Water levels were measured quarterly at selected observation wells throughout the study area from 1992 to 1998. All wells were measured on the same day to minimize the effect of nearby sporadic pumping. All water-level data were checked and entered into the USGS data base in Coram, N.Y. A total of 95 observation wells were measured within the Oyster Bay study area and surrounding areas (fig. 2).

Continuous water-level recorders were installed at seven wells, each screened in a specific aquifer. Five of these recorders were digital pressure-transducer data loggers that recorded at 1-hour intervals; the other two were continuous analog recorders. The continuous analog recorder at well N7152 (near Oak Neck, figs. 1, 2), was replaced with a digital pressure-transducer data logger in 1997. Historical (pre-1992) continuous water-level recorder information from 12 additional wells was used to supplement the data. The resulting hydrographs were used to identify tidal effects on water levels, possible aquifer interconnections, and the effect of pumping from nearby production wells.

Water-Quality Data

Water samples were collected from 42 observation wells during 1994-97 by the NCDPW and analyzed by the NCDPW Cedar Creek Special Projects Laboratory. Additional data on ground-water quality in the study area are available from the NCDH and the NCDPW. The results were compared with the New York State Department of Health (NYSDH) maximum contaminant levels (MCL's) for drinking water for 1996 to summarize the general water quality of the study area. These wells were also sampled for chloride concentration and specific conductance for delineation of the freshwater-saltwater interface.

Filter-press samples were obtained from selected core samples for chloride and specific-conductance measurement at the USGS office in Coram. Filter-press samples were collected using nitrogen-gas pressure to force interstitial water from uninvaded (by drilling mud) parts of a split-spoon core sample obtained during drilling (Lusczynski, 1961). The sample volume typically was about 0.07 fl oz. (2 mL); chloride concentration and specific conductance were measured by hand-held probes. The resulting values were used only as a general indicator of brackish or salty water within a formation and were correlated with borehole geophysical logs and the values from samples collected from screened wells.

Hydrogeology

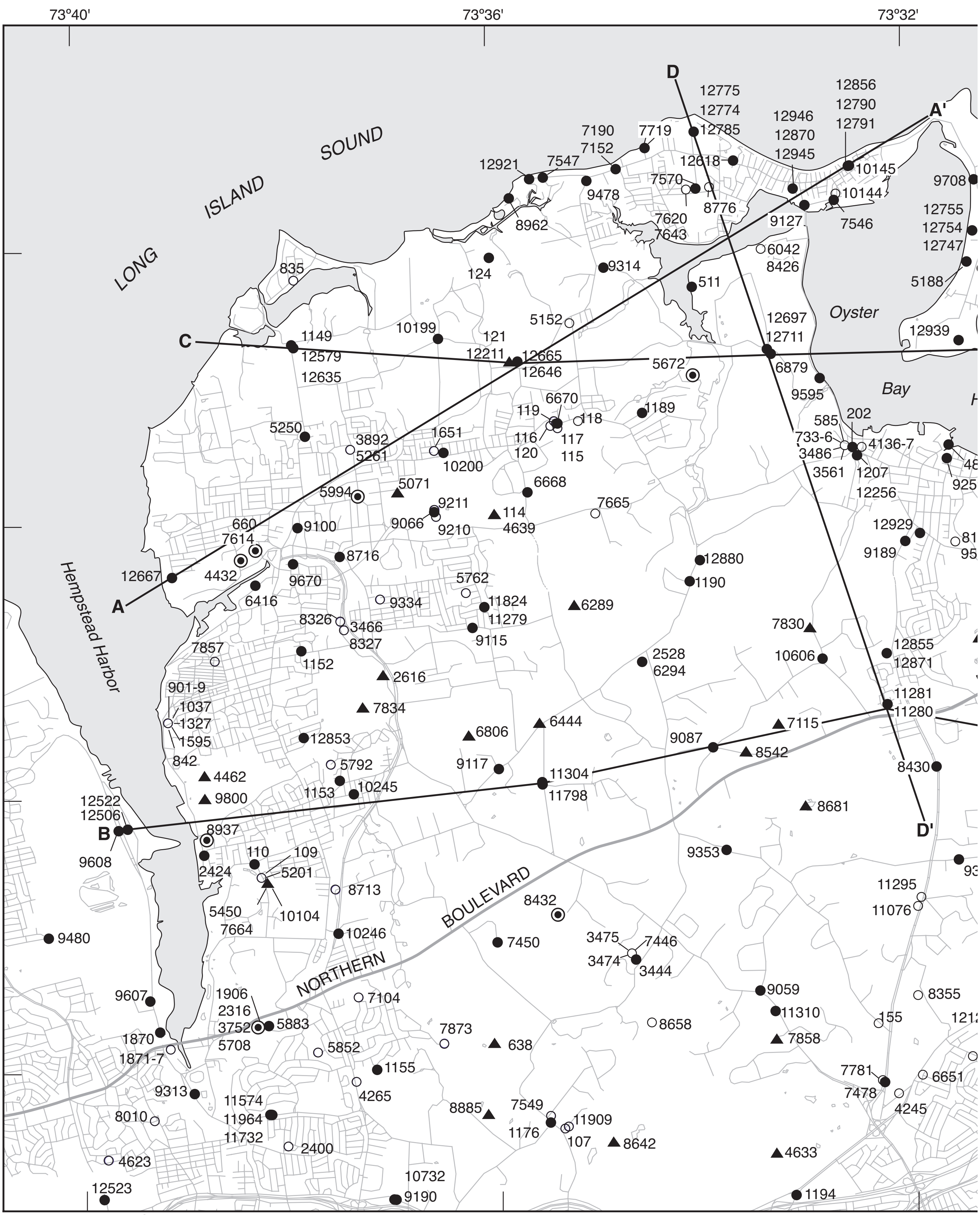
The Oyster Bay study area is underlain by unconsolidated Holocene deposits, glacial deposits of Pleistocene age, and Coastal-Plain deposits of Late Cretaceous age. These sediments consist of gravel, sand, silt, and clay underlain by crystalline bedrock of early Paleozoic age. The bedrock is relatively impermeable and forms the base of the ground-water-flow system on Long Island.

The relations between the hydrogeologic and geologic units, and the hydraulic characteristics and description of the aquifers and confining units underlying the study area are shown in table 1. The upper and lower boundaries of the glacially derived hydrogeologic units are mainly delineated from lithologic differences between units rather than the age of the deposits.

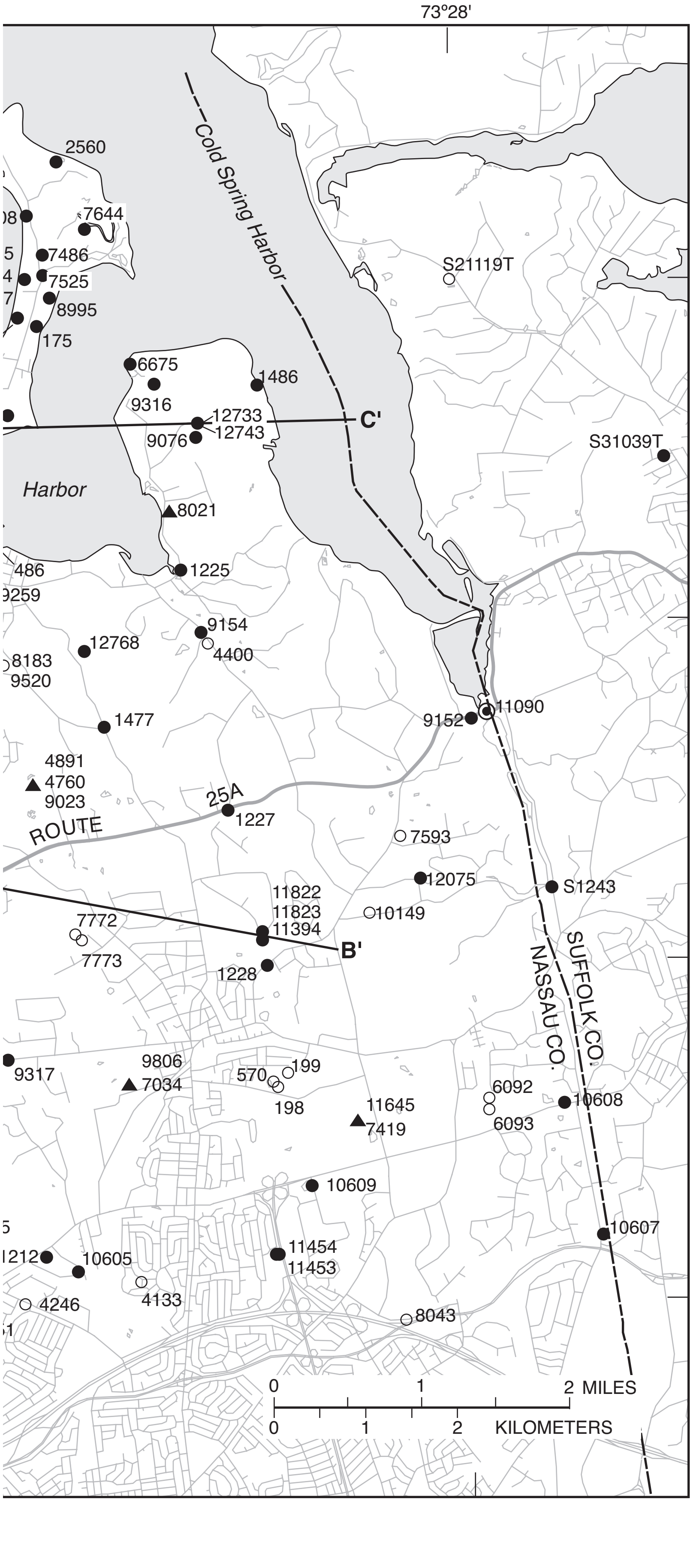
The geologic and hydrologic units underlying Long Island are described by Suter and others (1949); Perlmutter and Geraghty (1963); Swarzenski (1963); Kilburn (1979); Kilburn and Krulikas (1987); and Smolensky and others (1989). The drill-core data obtained in this study and previous studies in Great Neck and Manhasset Neck provide a basis for the naming of two hydrogeologic units—the North Shore confining unit and the North Shore aquifer (Stumm, 2001; Stumm and Lange, 1994, 1996; Stumm and others, 2002) for the first time. All other geologic and hydrogeologic unit names used in this report are those currently (1998) used by the USGS.

Stratigraphy

The unconsolidated deposits beneath the study area are of Cretaceous and Pleistocene age and are underlain by crystalline (metamorphic) bedrock. Microscopic mineralogic analysis of drill-core samples and borehole geophysical logs were used to delineate the stratigraphic sequence.



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



EXPLANATION

A —A' LINE OF HYDROGEOLOGIC SECTION

● 1149 OBSERVATION WELL

○ 3892 PRODUCTION WELL

▲ 5071 GOLF-COURSE WELL

⊙ 4432 INDUSTRIAL WELL

Numbers are assigned by New York State Department of Environmental Conservation. (Prefix N for Nassau County is omitted; prefix S represents Suffolk County; suffix T represents test boring.)

FIGURE 2. Locations of production, observation, industrial, and golf-course-irrigation wells within the Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)

Table 1. Generalized description of hydrogeologic units underlying the Oyster Bay study area, Nassau County, N.Y.

[Modified from Smolensky and others, 1989, sheet 1; McClymonds and Franke, 1972]

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 horizontal 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 postglacial lake deposits. Clay and silt deposits with minor lenses containing shells. The clay is olive brown and olive gray and poorly permeable. Unit contains a minor sand unit 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 horizontal 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. Very poorly permeable. Confines water in underlying unit. Average vertical 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 40 feet per day, and an 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.

Bedrock

The bedrock underlying the study area has been mapped as the Hartland Formation of Middle Ordovician to Lower Cambrian Age (Baskerville, 1992). The bedrock surface generally slopes southeastward from about 350 to 800 ft below sea level (fig. 3), except in the northernmost parts of the study area where glacial scouring has created north-northwestward dipping valleys. Drill-core data indicate the bedrock is a biotite-garnet schist and gneiss. A 50-to 100-ft-thick zone of saprolite (highly weathered bedrock), is present, except in the northwestern part of the study area, where some or all of it was removed by glacial erosion. The bedrock surface forms a virtually impermeable boundary for Long Island's ground-water system (McClymonds and Franke, 1972).

The saprolitic zone consists of mostly yellow, gray, and white clay with quartz fragments. This zone has been previously interpreted by drillers to be a clay or clayey gravel layer above bedrock. All observation wells drilled during this study penetrated weathered bedrock except N12855 and N12921 (fig. 2), where this layer has been removed through glacial erosion.

Glacial erosion or scouring of the overlying Cretaceous and possibly early Pleistocene deposits and weathered bedrock left at least four valleys that truncate the surrounding material. The four buried valleys are in (1) Hempstead Harbor, (2) the area along the northwestern part of the study area, (3) in Bayville, and (4) in Cold Spring Harbor (fig. 1). The weathered bedrock at the base of these valleys has been partly or totally removed. Drill-core data and driller's logs from wells N835 and N12921, along the northern shore of the study area (fig. 2), indicate that the penetrated bedrock is devoid of a saprolitic zone. The time during which the weathered bedrock was removed is unknown, but it probably was during successive glacial advances during the Pleistocene. In general, bedrock beneath Cretaceous sediments has a saprolitic zone, and the absence of Cretaceous deposits typically is accompanied by a lack of saprolite. The marine-seismic-reflection data collected in this study in 1996 indicate that the bedrock surface beneath the embayments of Long Island Sound is undulating; this is consistent with observations of Tagg and Uchupi (1967), who found the bedrock surface beneath most of Long Island Sound to have been severely eroded during the Pleistocene. The buried valley in the northwestern part of the study area appears to extend southeastward through the central part, thus creating a northeastward dip in the bedrock surface due to extensive erosion as far south as well N12855 (fig. 2, 3). Bedrock is anomalously deeper (711 ft below sea level) at this well site.

Aquifers and Confining Units

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 2.5Y7/3) sand and gravel with white clay lenses. Some white and grayish silt is in the upper sections of the unit.

The Lloyd Sand overlies bedrock and generally is overlain by Raritan clay. The upper surface of the Lloyd Sand generally dips to the southeast and ranges from 150 ft to more than 400 ft below sea level (fig. 5). The Lloyd Sand, where present, ranges from 150 to 300 ft. in thickness. The Lloyd Sand has been removed from the northwestern, central, and northeastern parts of the study area by glacial erosion; this erosional pattern is also seen in the Great Neck peninsula (Stumm, 2001) and the Manhasset Neck peninsula (Stumm and others, 2002). The Lloyd Sand was not encountered within the buried valleys onshore or offshore (fig. 5), nor at wells N835, N12921, N11280 and N12855 (fig. 2, 4). A deep glacial valley, more than 6 mi long and more than 1 mi wide, was delineated on the basis of marine-seismic-reflection-survey data, geophysical logs, and drill cores from observations wells N12921, N11280 and N12855. No Cretaceous sediments were encountered within this valley.

The Lloyd Sand forms the Lloyd aquifer, which is a major source of water supply along the northern parts of the study area. In northern Nassau County, the Lloyd aquifer has an average horizontal hydraulic conductivity of about 60 ft/d (McClymonds and Franke, 1972) and a horizontal to vertical anisotropy of 10:1 (Smolensky and others, 1989).

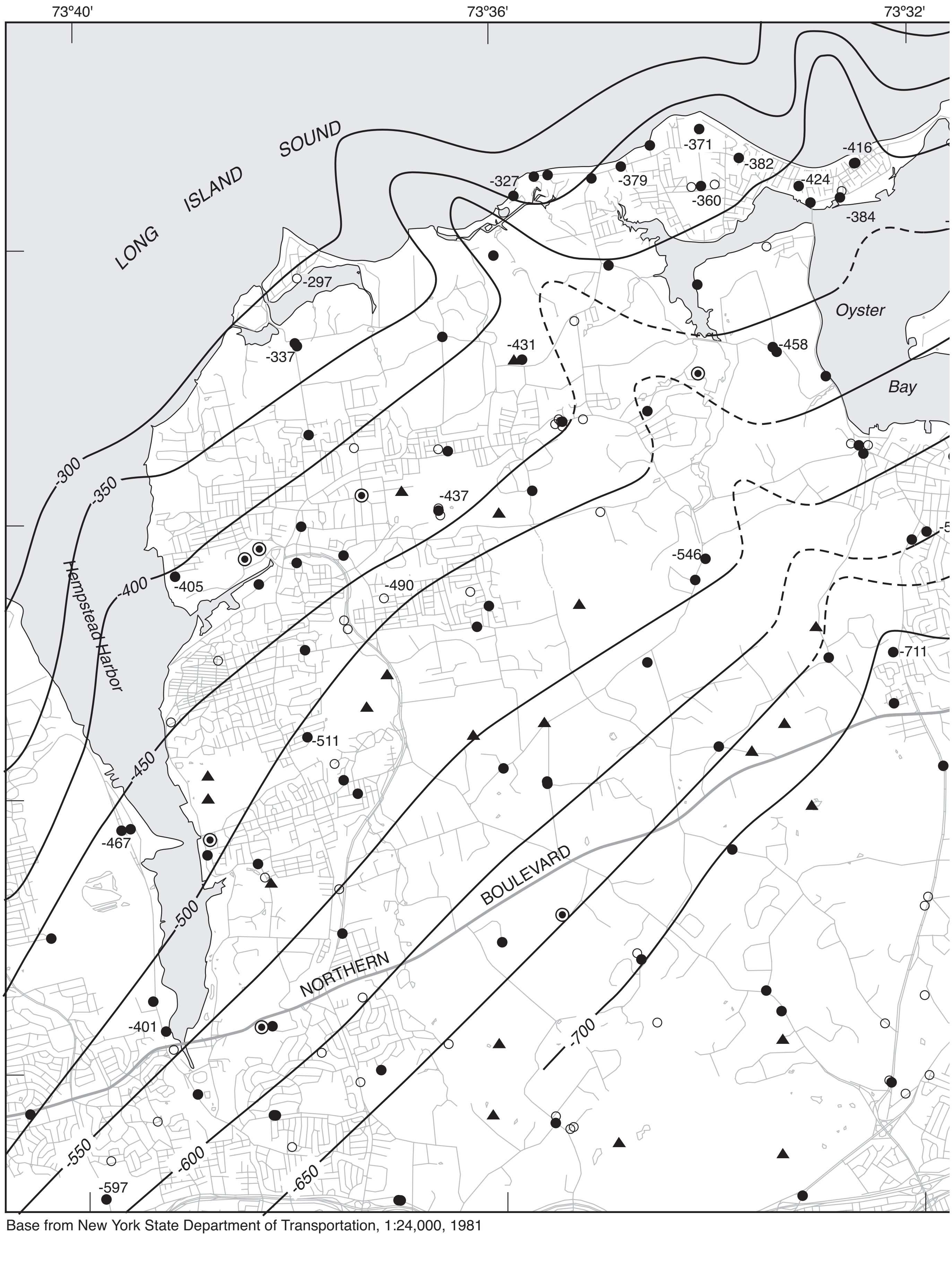
Raritan clay—The unnamed clay member of the Raritan Formation, referred to as the Raritan clay in this report, overlies and confines the Lloyd aquifer (Suter and others, 1949; Stumm, 2001; Stumm and others, 2002). It is a major confining unit throughout Long Island (Smolensky and others, 1989) and is present throughout the study area except along the northwestern, central, and northeastern parts. It is a solid, compact clay that includes red (10R4/8), gray (2.5Y4/1), white (2.5Y9/1), tan (2.5Y4/2), and variegated colors.

The upper-surface altitude of the Raritan clay in the study area ranges from 75 ft to more than 350 ft below sea level; thickness ranges from less than 26 ft to more than 125 ft. The Raritan clay was removed by extensive glacial erosion in the northern, central, and northeastern parts of the study area (fig. 6). Evidence of similar glacial erosion is present in the Great Neck peninsula (Stumm, 2001) and the Manhasset Neck peninsula (Stumm and others, 2002). The Raritan clay was not penetrated at wells N835, N12921, N12855, and N11280 (figs. 2, 4, 6). Marine-seismic-reflection profiles indicate that the Raritan clay underlies the southernmost parts of Hempstead Harbor and Cold Spring Harbor and in two isolated offshore ridges north of Oak Neck and Centre Island (fig. 1, 6). The Raritan clay is poorly permeable, with an average vertical hydraulic conductivity of about 0.001 ft/d (Smolensky and others, 1989).

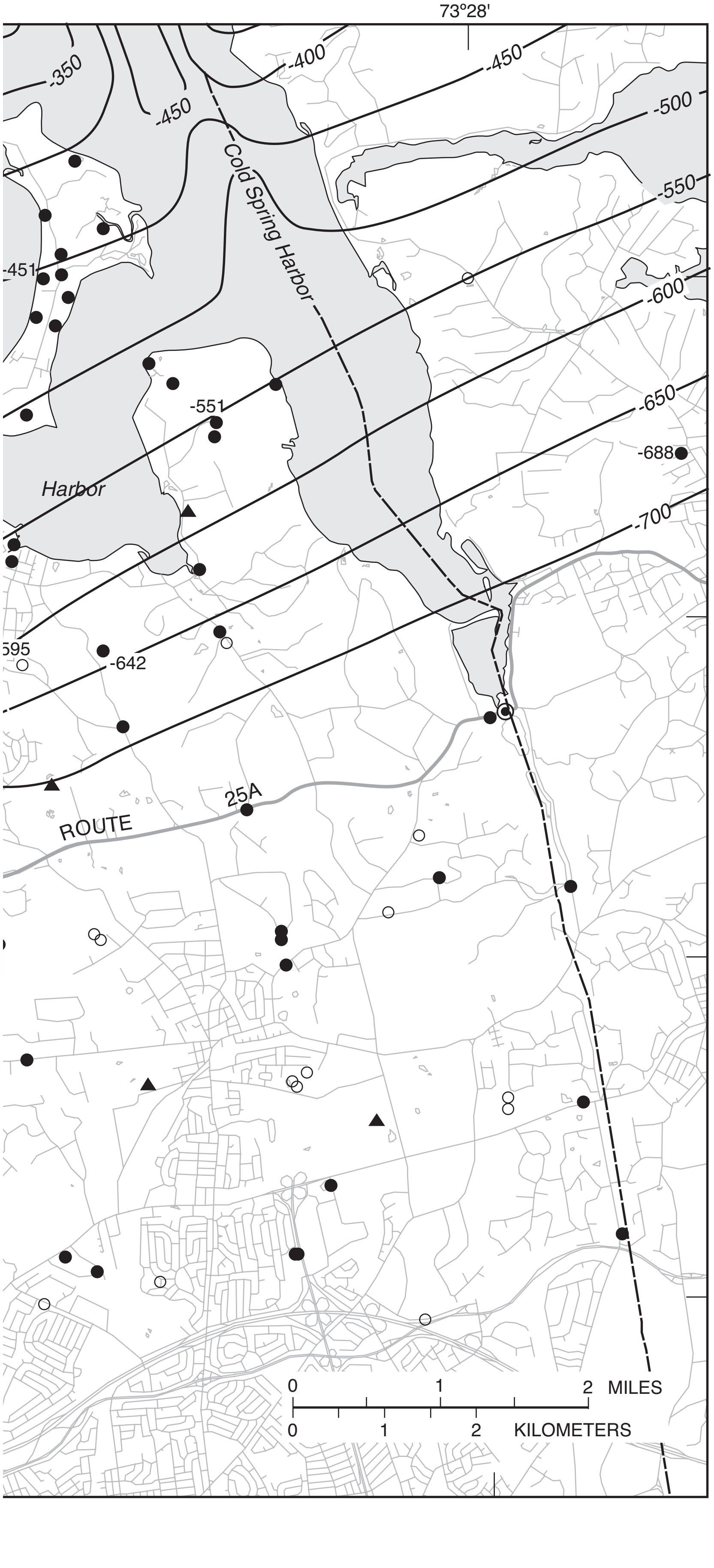
Magothy aquifer—The Magothy aquifer consists of fine micaceous sand, silt, and interbedded clay sediments of Cretaceous age (Suter and others, 1949; Isbister, 1966; Kilburn and Krulikas, 1987). It has an upward fining sequence of gray, white, or pinkish sands and clays of the undifferentiated Matawan Group and Magothy Formation (Isbister, 1966; Kilburn and Krulikas, 1987; Smolensky and others, 1989; Stumm and others, 2002). Drill-core samples indicate that the Magothy aquifer consists of subrounded, silty, gray quartz sand (5Y6/1) and pale-yellow quartz sand (2.5Y7/2) with associated lignite and chemically stable, heavy, opaque minerals.

The Magothy aquifer has been removed by glacial erosion from the northern and central parts of the study area and is present mainly in the southern part, where it overlies the Raritan clay (figs. 4,7). Its upper surface ranges from more than 60 ft above sea level to more than 170 ft below sea level (fig. 7). Glacial erosion has produced a steep, undulating, northeast-trending scarp in the Magothy aquifer along the southern part of the study area (fig. 7). Similar features are present beneath the Great Neck (Stumm, 2001) and Manhasset Neck (Stumm and others, 2002) peninsulas. The Magothy aquifer has an average horizontal hydraulic conductivity of 50 ft/d and an anisotropy of 100:1 (Smolensky and others, 1989).

North Shore aquifer—The North Shore aquifer consists of a sequence of Pleistocene-age sediments found only in the northwestern, central, and northeastern parts of the study area, and is described in detail by Stumm (2001) and Stumm and others (2002). These types of deposits are found in similar hydrogeologic settings elsewhere on the northern shore of Long Island; including to the west on the Great Neck peninsula (Stumm, 1994, 2001) Manhasset Neck peninsula (Stumm and Lange, 1994, 1996; Stumm and others, 2002), and in northeastern Queens County (Chu and Stumm, 1995). The North Shore aquifer deposits were called the Jameco Gravel by Swarzenski (1963) and Isbister (1966), and the Port Washington aquifer by Kilburn and Krulikas (1987). The name “North Shore aquifer” is used in this report in preference to Jameco Gravel or Jameco aquifer because these imply correlation with Jameco deposits in southern Queens County; such a correlation is questionable. The Port Washington aquifer, as described by Kilburn (1979) and Kilburn and Krulikas (1987), contains deposits of Cretaceous age (Lloyd aquifer and Raritan clay)(Stumm, 2001; Stumm and others, 2002). The existence of the Port Washington aquifer or



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



EXPLANATION

-500

BEDROCK CONTOUR – Shows altitude of bedrock surface. Dashed where approximately located. Contour interval is 50 feet. Datum is sea level.

WELL TYPES
Number, where present, indicates depth above or below sea level, in feet.

● -511 OBSERVATION WELL

○ -297 PRODUCTION WELL

▲ GOLF-COURSE WELL

⦿ INDUSTRIAL WELL

FIGURE 3. Surface altitude of bedrock underlying Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)

Jameco Gravel above the Raritan clay in the study area is not supported by the drill-core samples, marine-seismic-reflection data, and hydrologic data (Stumm and Lange, 1996; Stumm and others, 2002).

The North Shore aquifer is a distinct hydrogeologic unit that either rests upon bedrock or the eroded surface of the Lloyd aquifer and is overlain by a thick sequence of clay and silt (the North Shore confining unit) (figs. 4, 8). It is a sequence of poorly to moderately sorted, dark-olive-brown (2.5Y3/3) and olive-gray (5Y6/2) gravel, sand, and silt. It contains subangular to subrounded quartz grains, rock fragments, unstable opaque minerals, and a large percentage of biotite and muscovite. The aquifer consists of moderately sorted stratified drift and outwash deposits that infilled the low-lying areas after the partial removal of the Cretaceous deposits and parts of the bedrock (saprolitic zone) by glacial erosion. It was then capped by clay and silt of the North Shore confining unit. Subsequent glacial advances here and in nearby areas carved northwest-southeastward trending valleys that reached the bedrock surface; they also removed previously deposited sediments that may have included parts of the North Shore aquifer. These valleys later became filled with hundreds of feet of clay and silt (figs. 4, 8, 11). The buried-valley deposits probably represent the most recent glacial advance in the area and may be younger than the North Shore aquifer material in other parts of the study area; therefore, they are grouped with undifferentiated Pleistocene-age deposits of the North Shore confining unit. The North Shore aquifer is about 100 ft thick in the northern part of the study area and about 230 ft thick in the central part (fig. 4A, 4B, 4D). The top of the North Shore aquifer ranges from 150 ft to almost 500 ft below sea level (fig. 8). The rapid response of water levels to tides and (or) pumping indicates that this aquifer is confined and moderately permeable. No hydraulic conductivity values for this unit were calculated; however, golf-course irrigation well N5152, which is screened in the North Shore aquifer, was calculated to have a specific capacity of 11.2 (gal/min)/ft. Similar hydraulic responses observed in the surrounding Lloyd aquifer indicate the North Shore aquifer is confined and in hydraulic connection with the Lloyd aquifer. The North Shore aquifer infills the lower part of the buried valley in the central part of the study area (fig. 8).

North Shore confining unit—The name “North Shore confining unit” is given to a sequence of Pleistocene-aged clay and silt deposits that are locally present along the northern shore of Queens County (Chu and Stumm, 1995), Nassau County (Stumm and Lange, 1994, 1996; Stumm, 2001; Stumm and others, 2002), and Suffolk County (Soren, 1971). The North Shore confining unit underlies the northernmost and central parts of the study area and extends offshore. The term “North Shore confining unit” is extensively described in Stumm (2001) and is used here for the first time in reference to the northern parts of the Town of Oyster Bay. These deposits have been described by Grim and others (1970), Lewis and Stone (1991), and Williams (1981) as part of the stratified glacial-lake clay and silt that infill Long Island Sound and Manhasset Bay. Previous studies have used marine-seismic-reflection surveys, borehole geophysical logs, and drill-core samples to correlate these deposits with buried valleys that extend across the northernmost part of Nassau County (Stumm, 2001; Stumm and Lange 1994, 1996; Stumm and others, 2002). The stratigraphy and geologic age of the North Shore confining unit were not investigated in this project.

Swarzenski (1963) and Isbister (1966) called these deposits the “Gardiners Clay”; Kilburn (1979) referred to them as 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 Gardiners Clay is along the southern shore of Long Island and was probably deposited during an interglacial period. It is a greenish-brown or gray marine clay containing diatoms, foraminifera, and shell fragments (Suter and others, 1949). The current widely accepted interpretation is that the term “Gardiners Clay” should be applied only to the shallow marine clay unit along the south shore of Long Island.

The term “Port Washington confining unit” is similarly questionable. This unit, described by Kilburn (1979) and Kilburn and Krulikas (1987), 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 of the previous interpretations and delineations; therefore, the term Port Washington confining unit is no longer considered valid in this area.

Tagg and Uchupi (1967) conducted seismic profiles in Long Island Sound and describe the bedrock surface as deeply cut by 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 determine whether any of them extend beneath Long Island because nearshore seismic data were lacking. Reeds (1927) described varved clay deposits in the New York City area that imply clay deposition in postglacial freshwater lakes occupying low-lying basins in southern New York. He also proposed several 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.

The North Shore confining unit consists of olive-brown (2.5Y4/2) varved clay and minor amounts of silt and dark olive-gray clay (5Y4/2). Its upper surface ranges from 13 ft to 140 ft below sea level (figs. 4, 9) and its thickness ranges from 0 to less than 130 ft, except where it fills the buried valleys beneath Hempstead Harbor, Oyster Bay, and Cold Spring Harbor. In contrast, these embayments are described by Swarzenski (1963), Isbister (1966), Kilburn (1979), and Kilburn and Krulikas (1987) as infilled with mostly sand and gravel. Marine-seismic-reflection and drill-core data obtained during this study indicate that most of these buried valleys are filled with more than 300 ft of clay and silt. In general, the North Shore confining unit is a relatively flat-lying deposit.

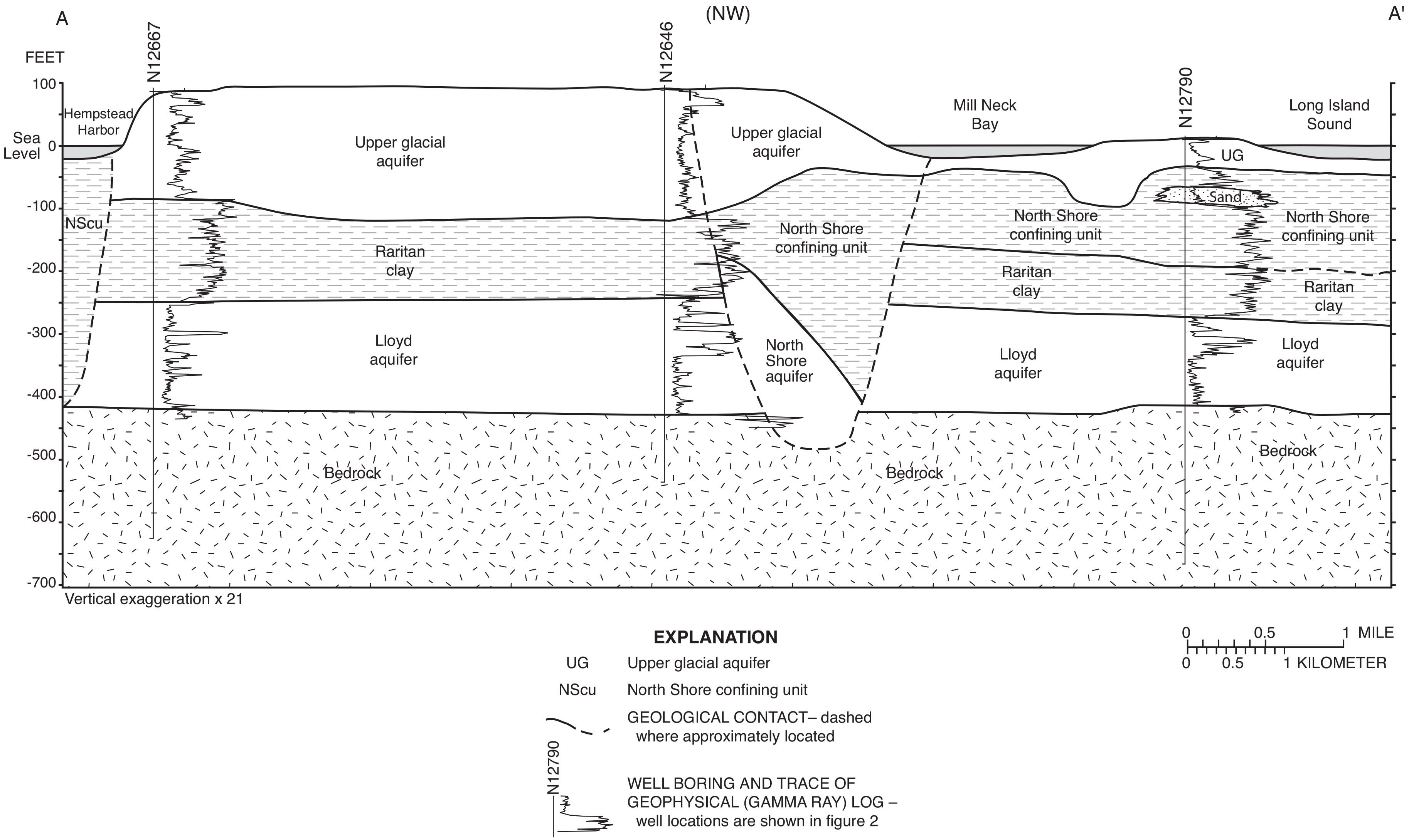


FIGURE 4. Hydrogeologic sections in Oyster Bay study area, Nassau County, N.Y. A. Section A-A´. B. Section B-B´. C. Section C-C´. D. Section D-D´. (Locations are shown in fig. 2.)

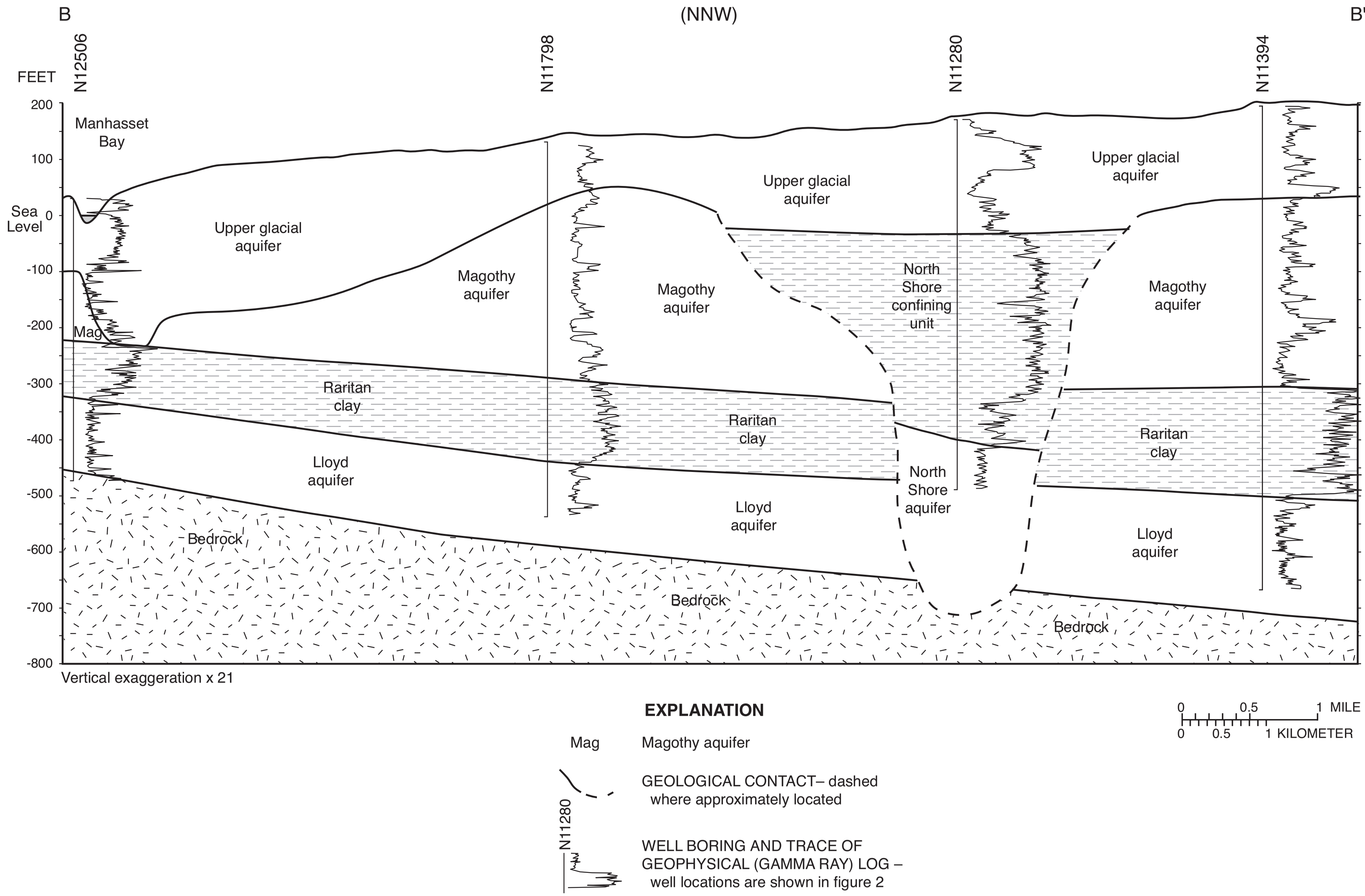


FIGURE 4. (continued) Hydrogeologic sections in Oyster Bay study area, Nassau County, N.Y. A. Section A-A´. B. Section B-B´. C. Section C-C´. D. Section D-D´. (Locations are shown in fig. 2.)

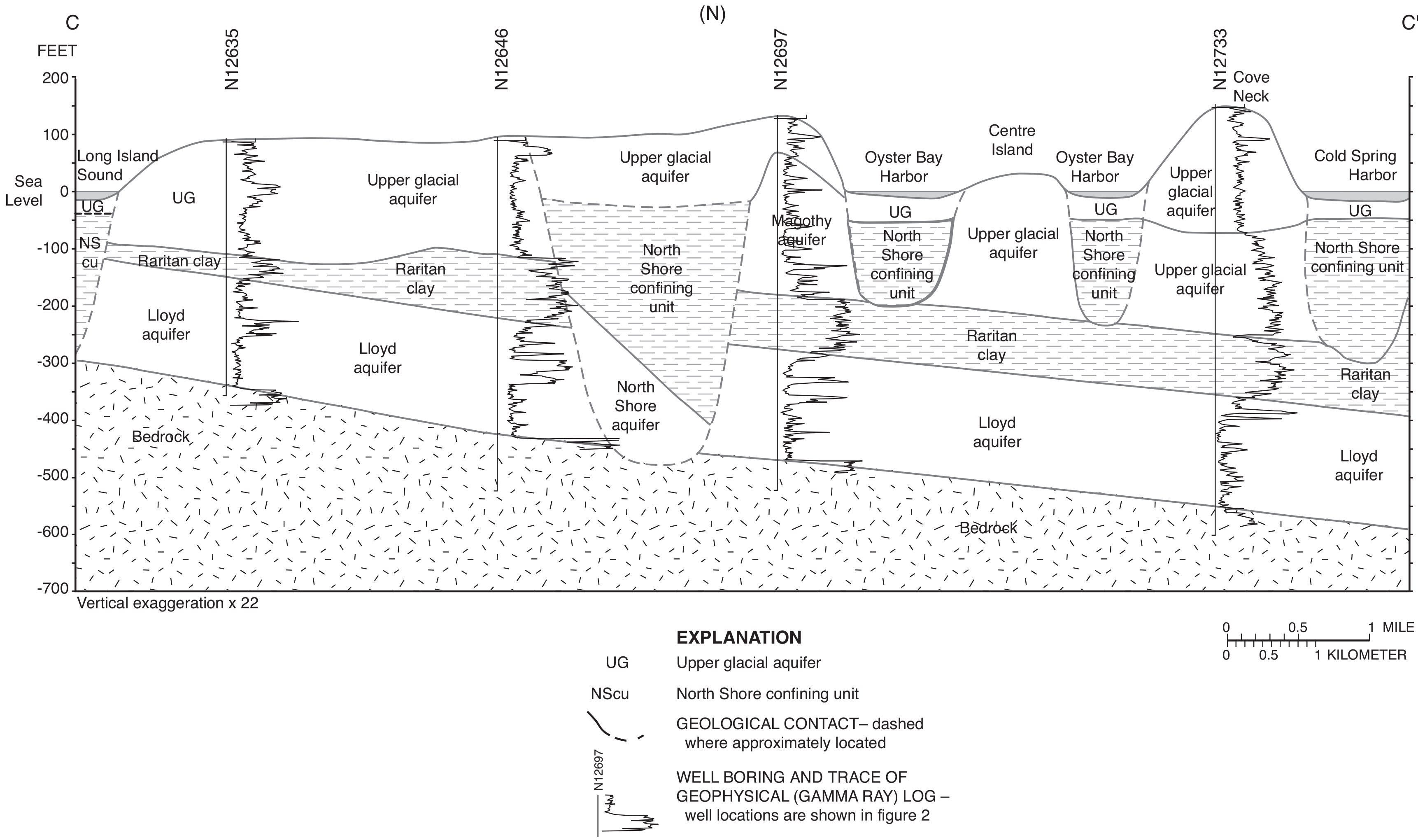


FIGURE 4. (continued) Hydrogeologic sections in Oyster Bay study area, Nassau County, N.Y. A. Section A-A´. B. Section B-B´. C. Section C-C´. D. Section D-D´. (Locations are shown in fig. 2.)

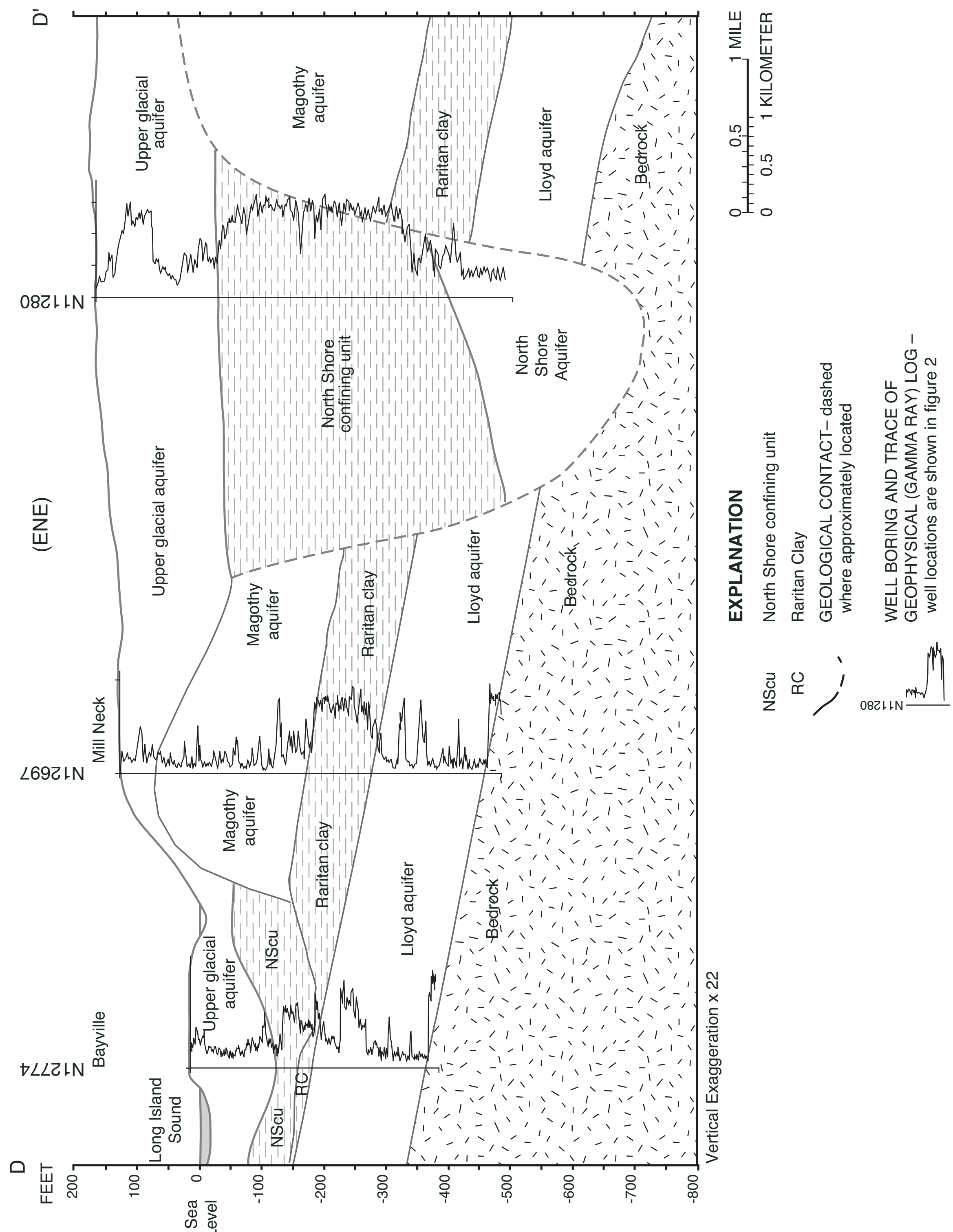


FIGURE 4. (continued) Hydrogeologic sections in Oyster Bay study area, Nassau County, N.Y. A. Section A-A´. B. Section B-B´. C. Section C-C´. D. Section D-D´. (Locations are shown in fig. 2.)

Upper glacial aquifer—The upper glacial aquifer includes the saturated parts of the upper Pleistocene deposits. It consists of beds of stratified fine- to coarse-grained sand and gravel, boulders, clay, till, and some small, shallow pond deposits (Suter and others, 1949) and, in the northern part of the town of Oyster Bay, is underlain in some areas by the North Shore confining unit. In some areas, Cretaceous deposits have been thrust upward by ice shove and are incorporated into the upper glacial aquifer. An example of this can be observed in outcrops along the northwestern coast at the Nassau County Department of Parks' Garvies Point (fig. 1) Museum and Preserve; where several blocks of Raritan clay have been ice-shoved and crop out 75 ft above their original stratigraphic locations. The upper glacial aquifer is poorly to moderately sorted and contains mostly quartz minerals, rock fragments, and biotite and muscovite; it also contains brown sand (7.5Y4/6), dark yellowish-brown sand (10YR4/6), and varying amounts of reworked Cretaceous deposits. Marine-seismic-reflection surveys and drill-core data indicate that this aquifer does not extend very far offshore, nor does it infill the buried valleys beneath Hempstead Harbor and Cold Spring Harbor, as interpreted by Kilburn (1979) and Kilburn and Krulikas (1987). The upper glacial aquifer overlies the Magothy aquifer in the southernmost part of the study area, and overlies the Raritan clay or the North Shore confining unit in the rest of the study area (figs. 4, 10). The present land surface consists of recent Holocene deposits and the unsaturated upper part of the upper glacial aquifer. The upper glacial aquifer has an average horizontal hydraulic conductivity of 270 ft/d (Smolensky and others, 1989).

Interpretation of Geophysical Data

Marine-seismic-reflection surveys — The seismic-reflection survey results were correlated with geologic logs of nearshore observation wells. Four seismic-reflection profiles (E-E´, F-F´, G-G´ and H-H´, figs. 11A-D) show interpretations of the major subsurface features observed during the marine-seismic-reflection surveys.

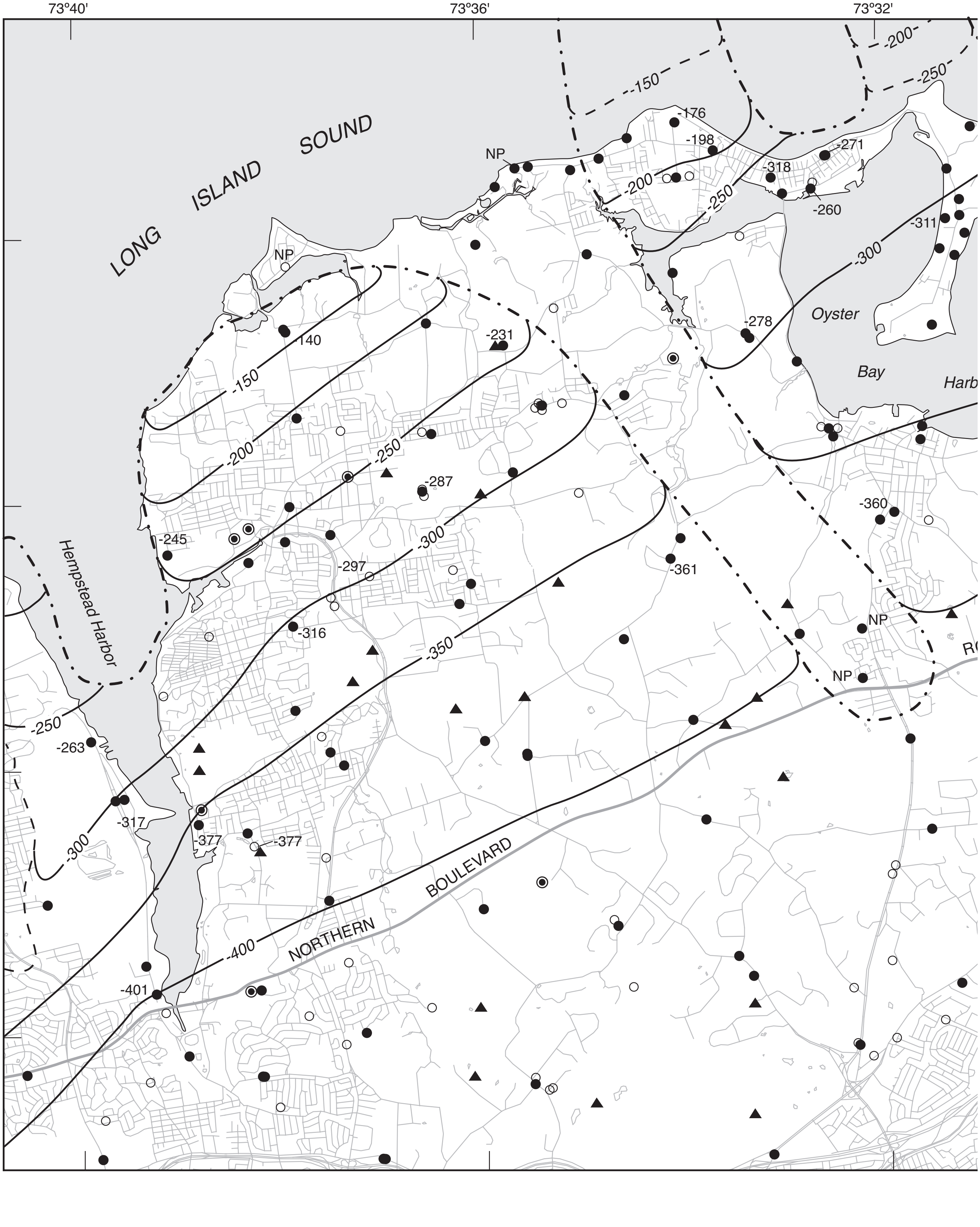
Seismic-reflection profile E-E´ (fig. 11A) is about 8,600 ft long and was surveyed 1.5 mi off the northern coast of the study area (fig. 1). The sea floor in this section is about 40 ft below sea level. The seismic-reflection survey shows subhorizontal parallel reflections, which are interpreted to be silt and clay deposits that fill two buried valleys that extend to more than 250 ft below sea level. These valleys are bounded by coarse-grained deposits and are apparently underlain by bedrock. Borehole geophysical logs and drill cores from wells N12921, N12855, and N11280 indicate that these buried valleys may merge to form the 6 mi-long valley in the central part of the study area.

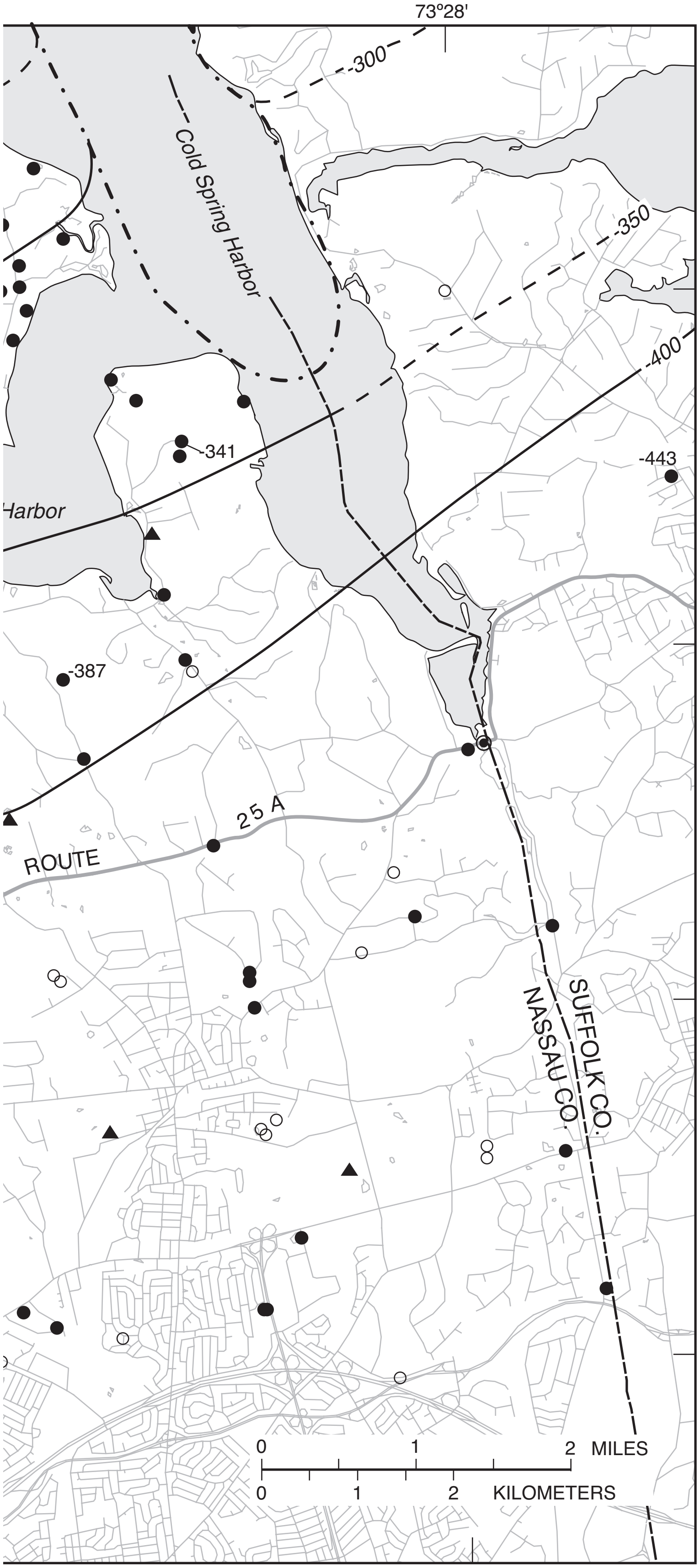
Seismic-reflection profile F-F´ (fig. 11B) is about 9,600 ft long and was surveyed 1 mi north of the eastern shore of the Bayville area (fig. 1). The profile indicates a buried valley that extends to the bedrock surface, about 360 ft below sea level. The profile of the valley is dominated by subhorizontal parallel reflections, which are interpreted to be silt and clay. Borehole geophysical logs and drill cores from observation well N12790, near Bayville, indicate that this valley becomes increasingly shallower as it approaches the Bayville shore. The valley is infilled with more than 300 ft of silt and clay. A strong reflector along the eastern boundary of the buried valley correlates with the Raritan Clay and is interpreted as the offshore extension of the Cretaceous deposits on Centre Island.

Seismic-reflection profile G-G´ (fig. 11C) is about 11,500 ft long and is roughly perpendicular to the strike or trend of a buried valley beneath Cold Spring Harbor (fig. 1). The Cold Spring Harbor valley is about 1 mi wide and extends to bedrock, which is about 420 ft below sea level. The sea floor here ranges from 10 to 60 ft below sea level. The buried valley truncates the surrounding coarse-grained deposits (chaotic reflectors) and is infilled with more than 400 ft of silt and clay deposits, as interpreted from the subparallel horizontal reflectors. Draped bedding is indicated along either edge of the valley.

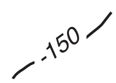
Seismic-reflection profile H-H´ (fig. 11D) trends along the apex or strike of the buried valley within Cold Spring Harbor (fig. 1). The profile is about 13,500 ft long. The sea floor in this section ranges from 20 to 60 ft below sea level. The seismic-reflection profile shows subparallel horizontal reflectors that are interpreted as silt and clay infilling the buried valley. The valley appears to extend to more than 540 ft below sea level at its deepest part and is infilled with more than 500 ft of silt and clay. The valley's decreasing depth southward is consistent with ice-contact erosion documented in other areas of northern Nassau County (Stumm, 2001; Stumm and others, 2002). A strong horizontal reflector at about 300 ft below sea level in the southern part of the seismic section is interpreted as the Raritan Clay.

Borehole geophysical logs —The borehole geophysical logs (gamma, SP, SPR, R, and EM) for well N12774, near Bayville (location shown on fig. 2), are shown in figure 12. The gamma log indicates (1) a zone of clay and silty clay at 150 ft below land surface (130 ft below sea level) and (2) a clay unit in the Lloyd aquifer at about 240 ft below land surface (220 ft below sea level). This well was drilled into bedrock, and the base of the well was set at 392 ft below land surface (372 ft below sea level) within the Lloyd aquifer. The SP log shows a steady deflection with decreasing values from the top of the clay zone at 150 ft below land surface (130 ft below sea level). The SPR log shows a zone of lowest resistance at about 135 ft below land surface (115 ft below sea level). This zone of high conductivity also appears on the R and EM logs. The R log shows this zone to be in the areas with the lowest resistivity values. The EM log indicates a sharp increase in conductivity above the clay unit at 150 ft below land surface (130 ft below sea level). The filter-press sample obtained from 147 ft below land surface (127 ft below sea level) had a chloride concentration of 19,800 mg/L. This is interpreted as a wedge of saltwater 15-ft thick at the base of the upper glacial aquifer. The conductivity of ground water


73°40'
73°36'
73°32'
40°54'
40°52'
40°50'
40°48'
LONG ISLAND SOUND
Hempstead Harbor
Oyster Bay Harb
NORTHERN BOULEVARD
-150
-200
-250
-300
-350
-400
-176
-198
-271
-318
-260
-311
-278
NP
-140
-231
-287
-245
-297
-316
-361
-360
-263
-317
-377
-401



EXPLANATION



STRUCTURE CONTOUR – Shows altitude of Lloyd aquifer surface. Dashed where approximately located. Contour interval is 50 feet. Datum is sea level.

EXTENT OF LLOYD AQUIFER

NP LLOYD AQUIFER NOT PRESENT

WELL TYPES
Number, where present, indicates depth above or below sea level, in feet.

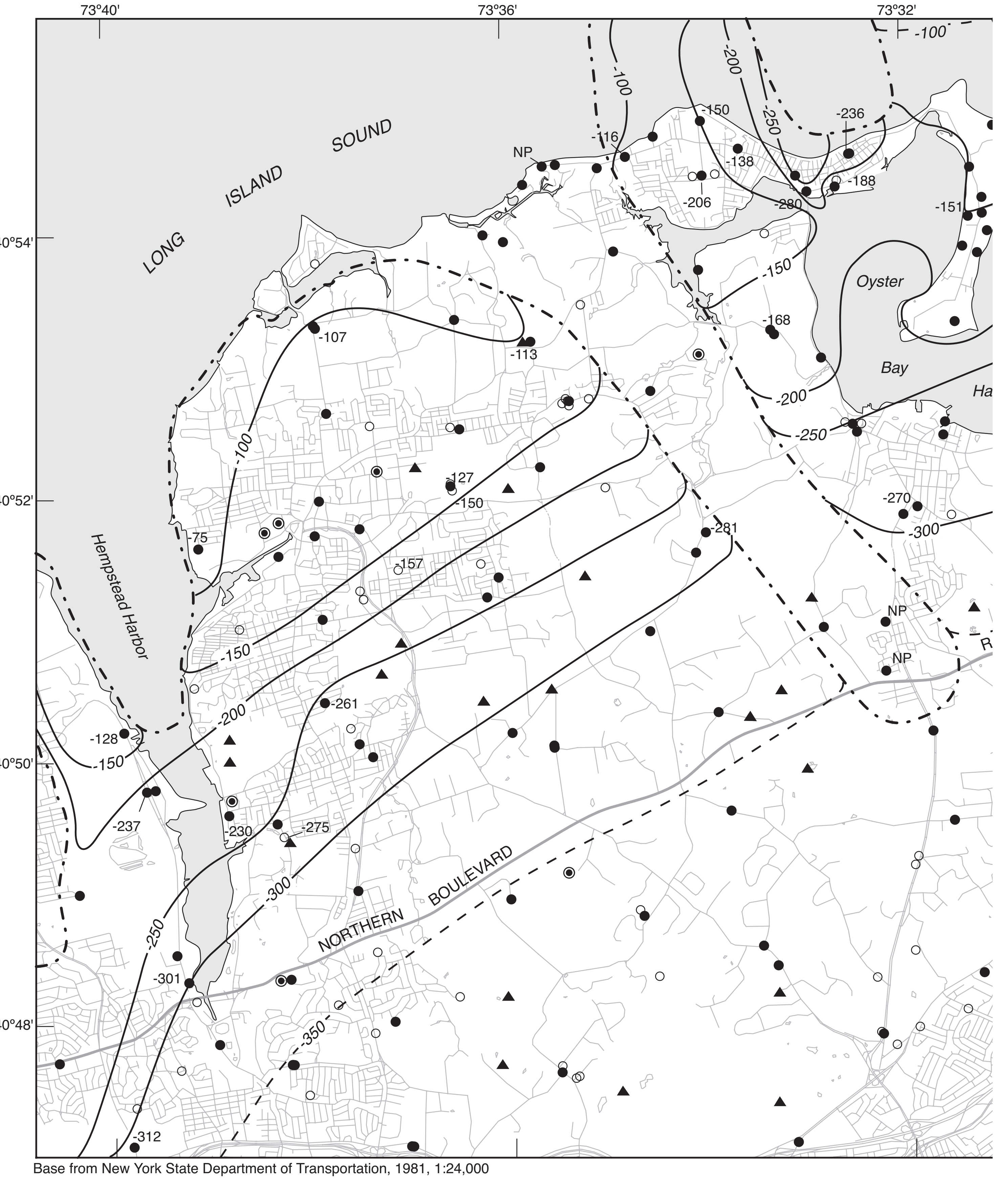
377 OBSERVATION WELL

360 PRODUCTION WELL

GOLF-COURSE WELL

INDUSTRIAL WELL

FIGURE 5. Extent and upper surface altitude of the Lloyd aquifer in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)



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

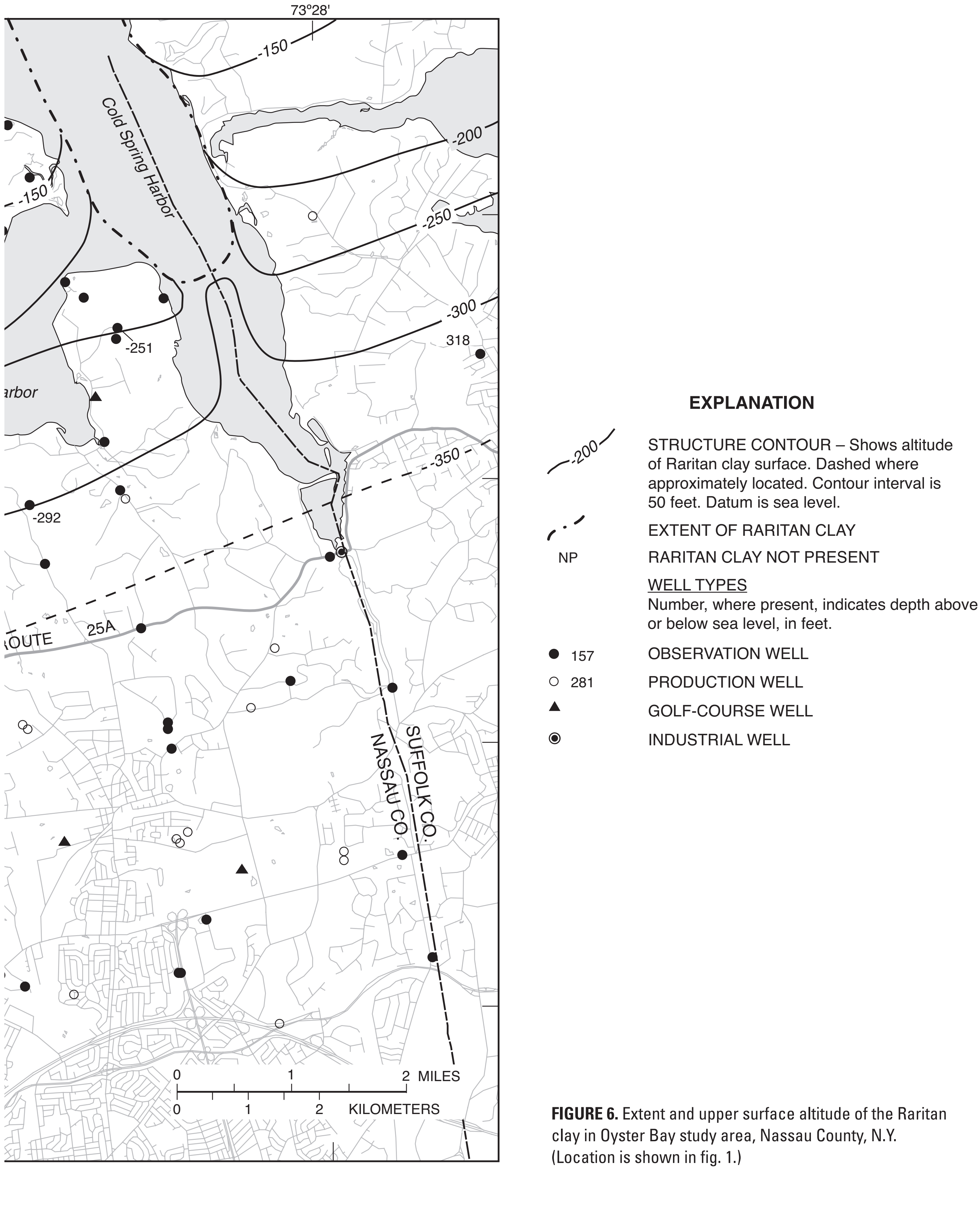
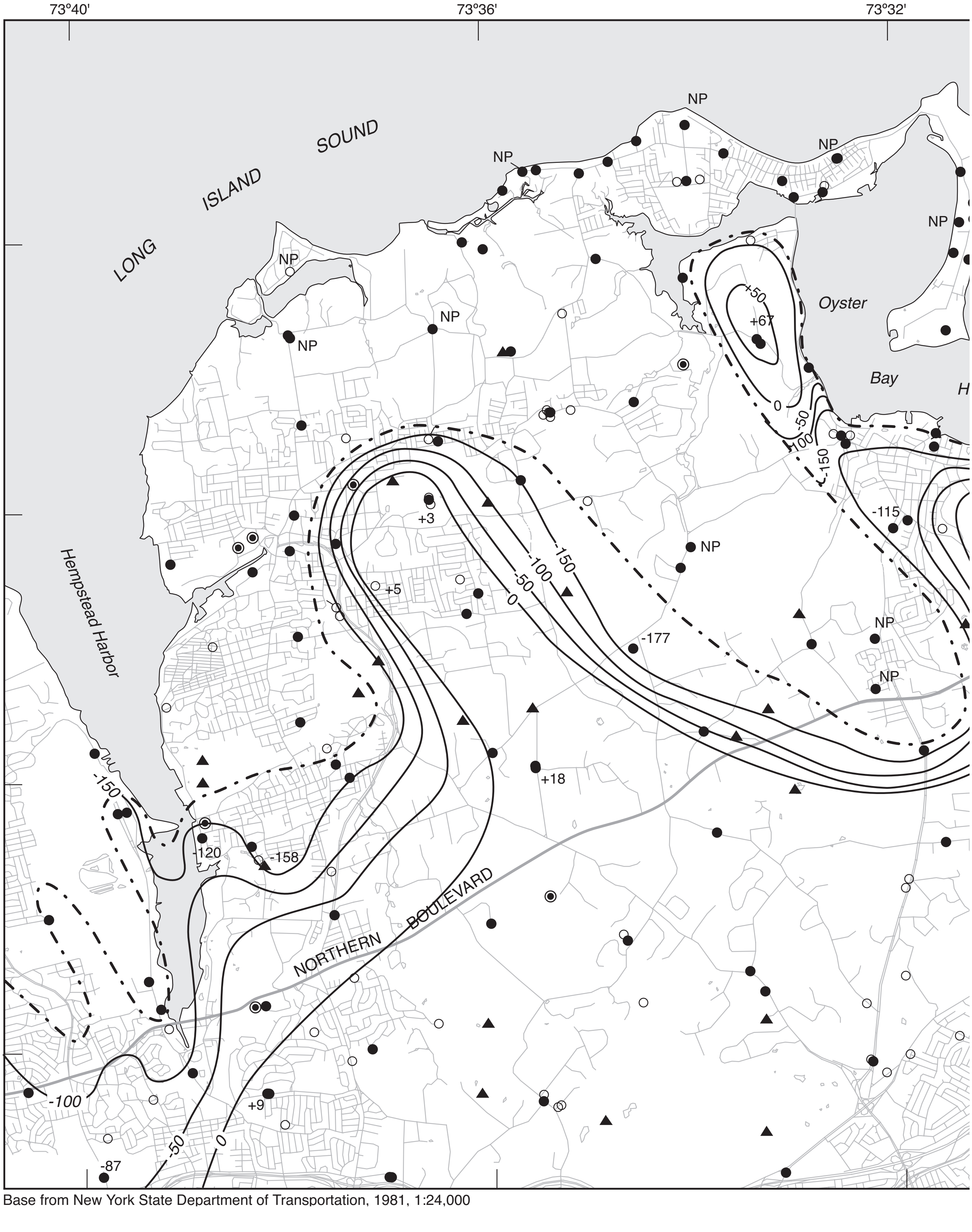


FIGURE 6. Extent and upper surface altitude of the Raritan clay in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)



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

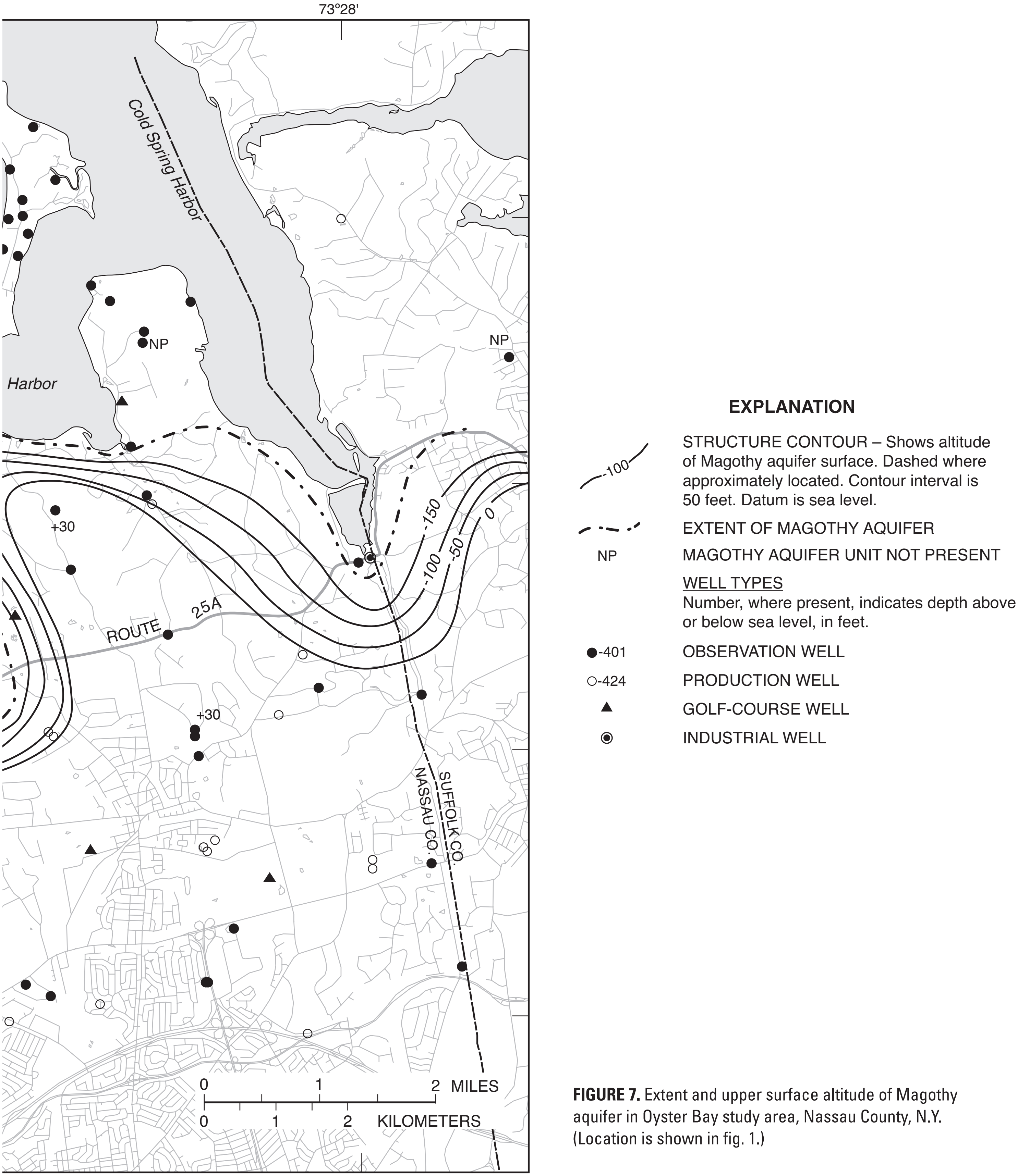
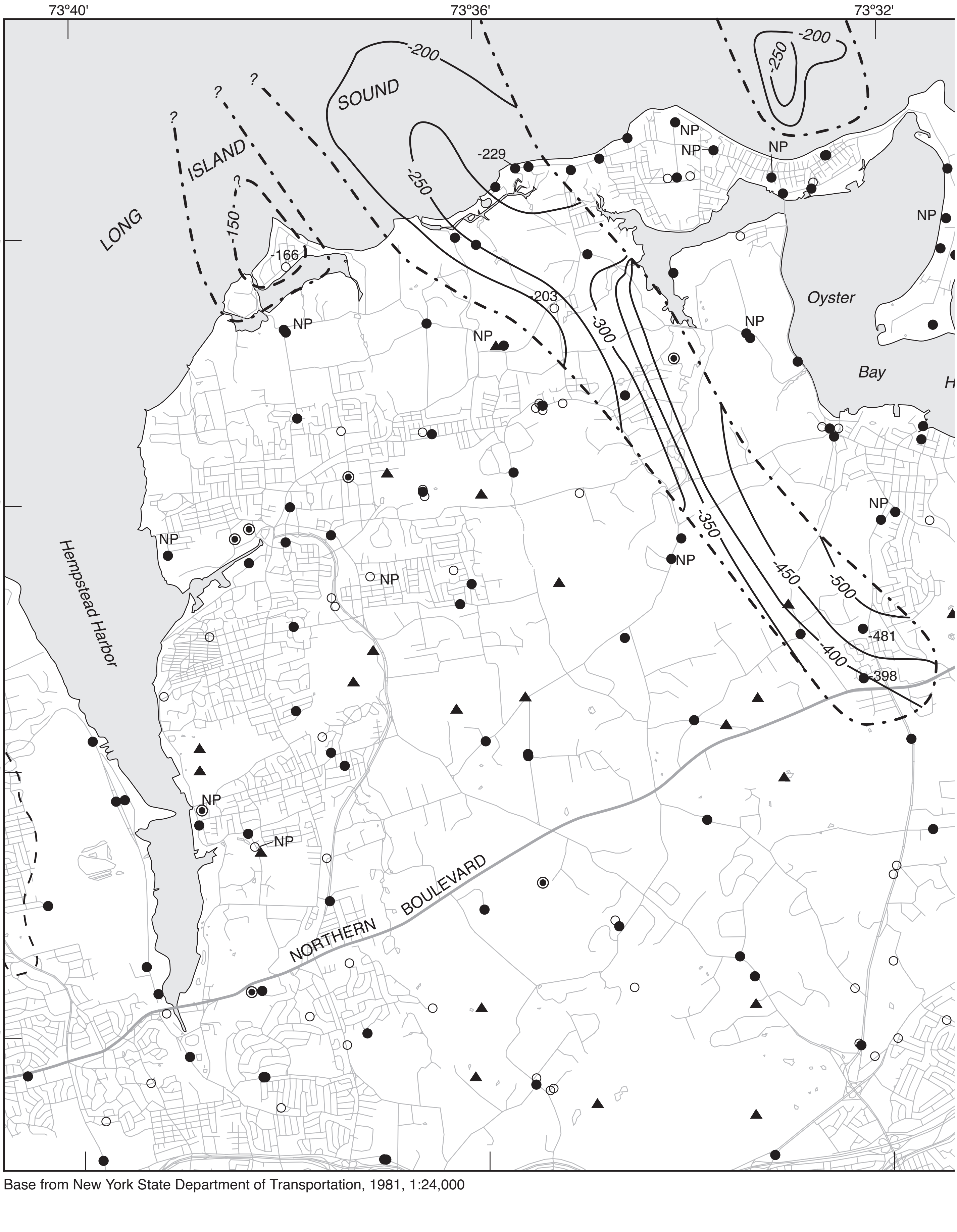
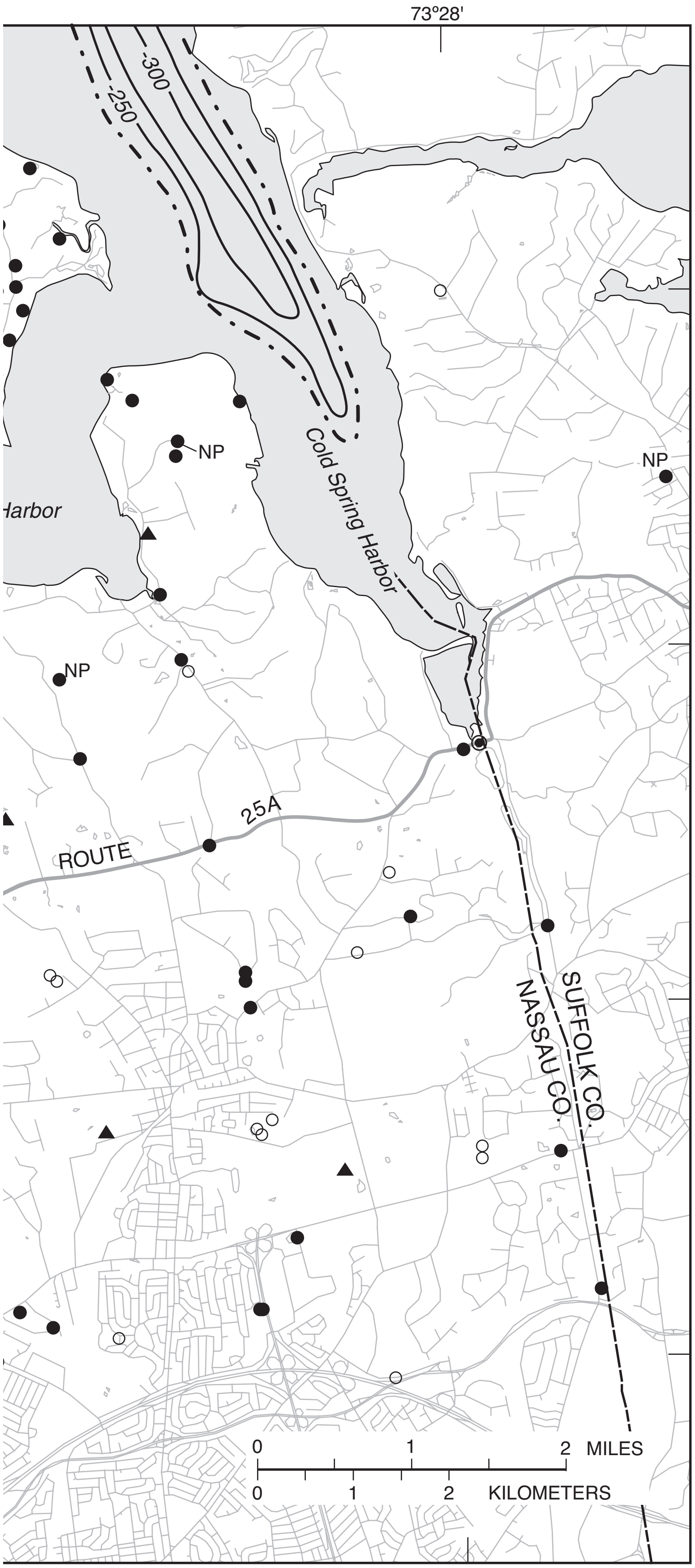


FIGURE 7. Extent and upper surface altitude of Magothy aquifer in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)



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



EXPLANATION

-400 STRUCTURE CONTOUR – Shows altitude of North Shore aquifer surface. Dashed where approximately located. Contour interval is 50 feet. Datum is sea level.

EXTENT OF NORTH SHORE AQUIFER

NP NORTH SHORE AQUIFER NOT PRESENT

WELL TYPES
Number, where present, indicates depth above or below sea level, in feet.

● 176 OBSERVATION WELL

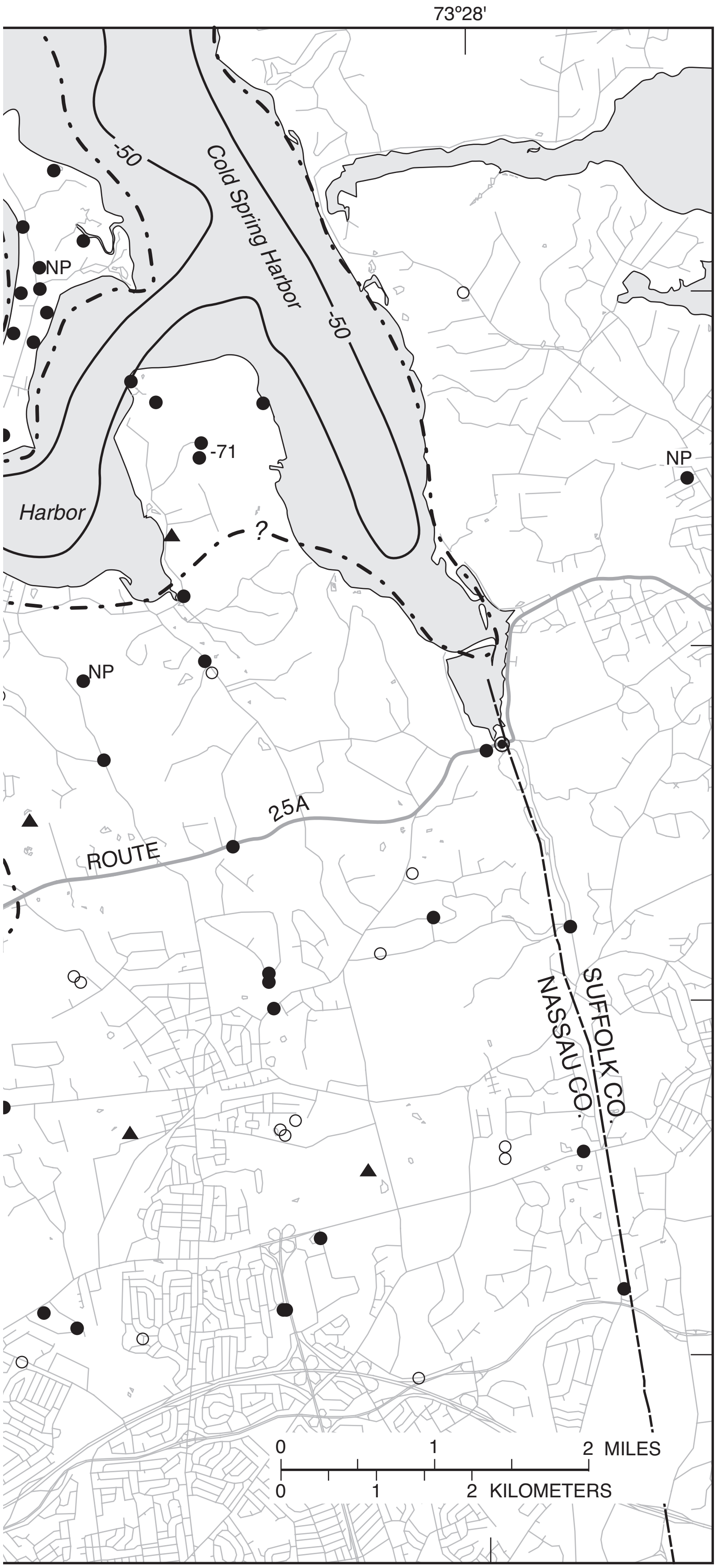
○140 PRODUCTION WELL

▲ GOLF-COURSE WELL

◉ INDUSTRIAL WELL

FIGURE 8. Extent and upper surface altitude of the North Shore aquifer in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)


73°40'
73°36'
73°32'
40°54'
40°52'
40°50'
40°48'
LONG ISLAND SOUND
Oyster Bay
Hempstead Harbor
NORTHERN BOULEVARD
-50
-100
-130
-140
-41
-46
-39
-68
-28
-56
-97
-15
-21
-36
-13
-84
NP
?
Base from New York State Department of Transportation, 1981, 1:24,000



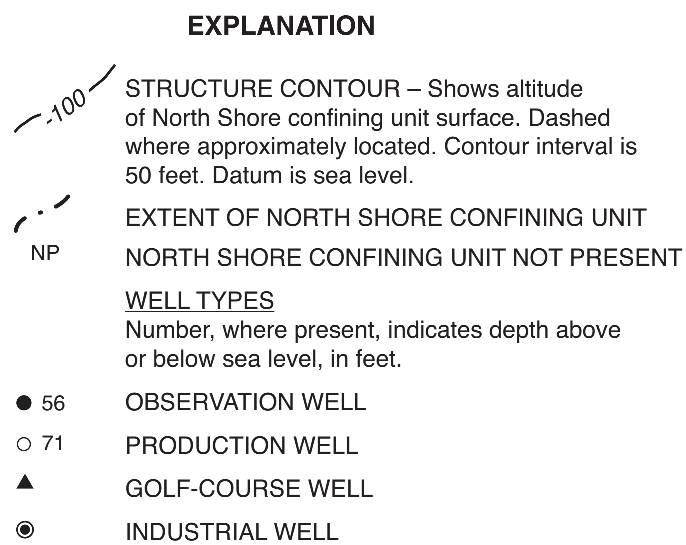
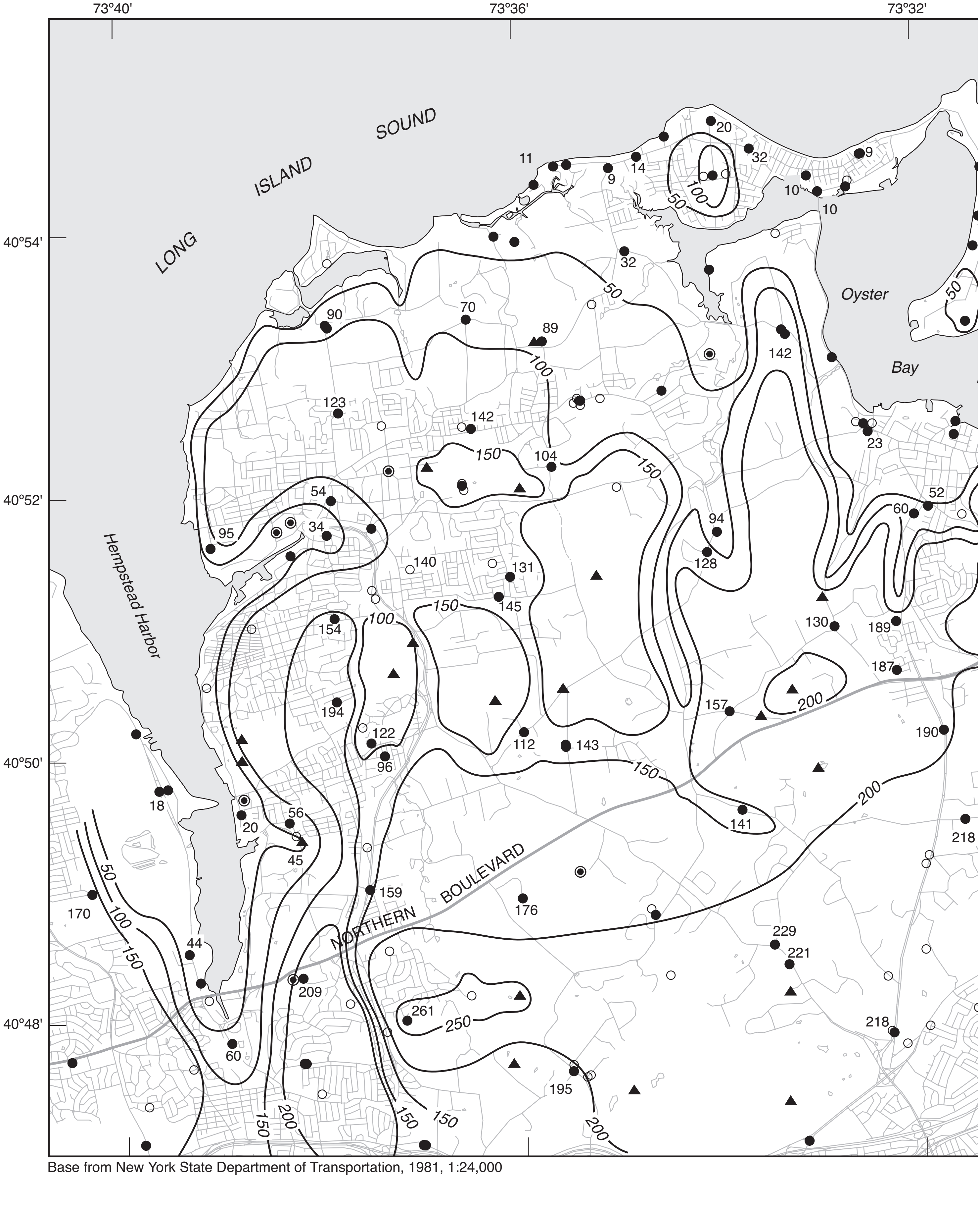


FIGURE 9. Extent and upper surface altitude of the North Shore confining unit in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)



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

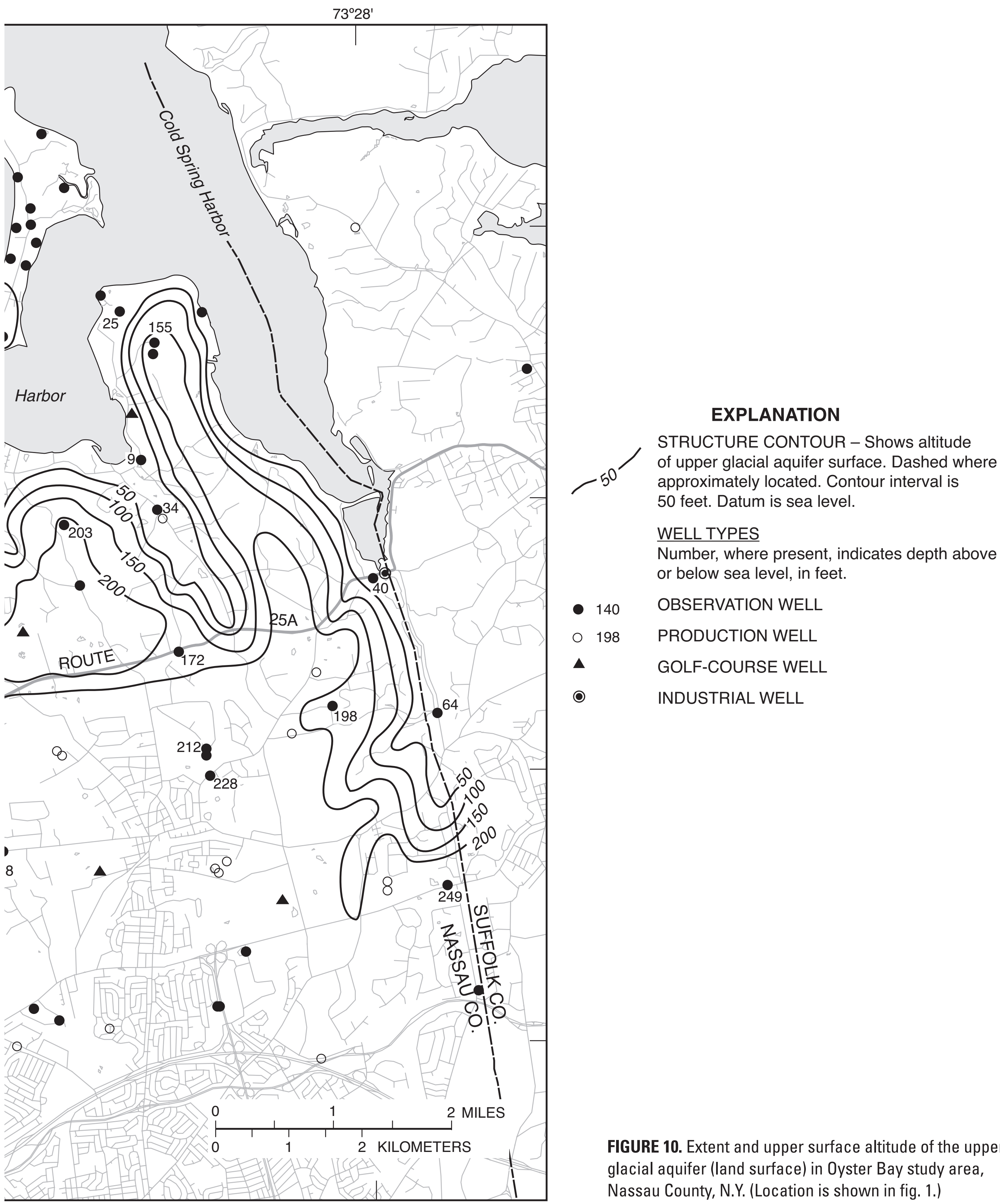


FIGURE 10. Extent and upper surface altitude of the upper glacial aquifer (land surface) in Oyster Bay study area, Nassau County, N.Y. (Location is shown in fig. 1.)

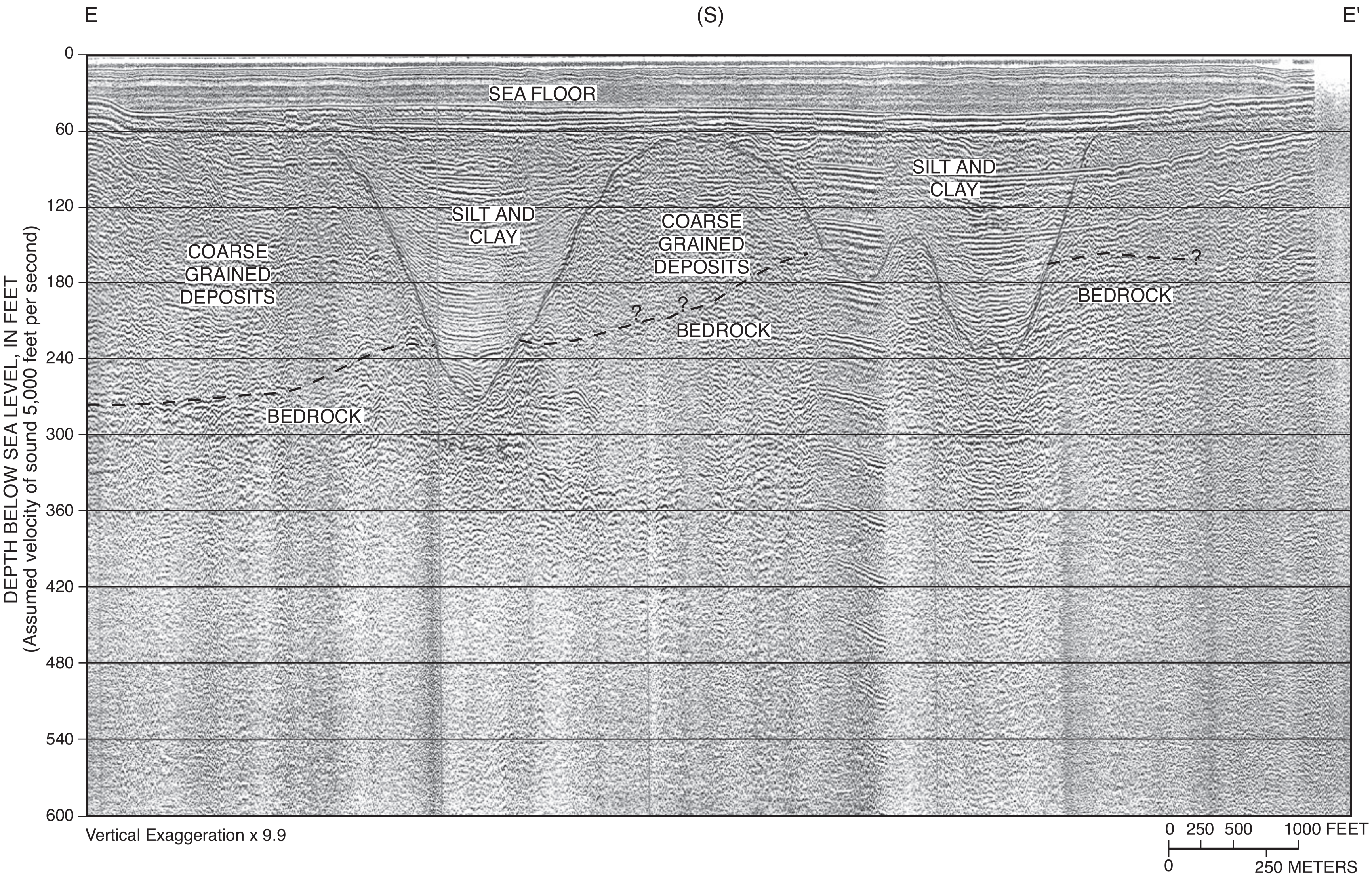


FIGURE 11. Interpreted stratigraphy along seismic-reflection profiles: A. E-E´ in Long Island Sound. B. F-F´ in Long Island Sound. C. G-G´ in Long Island Sound. D. H-H´ in Cold Spring Harbor. (Trace of profile is shown in fig. 1.)

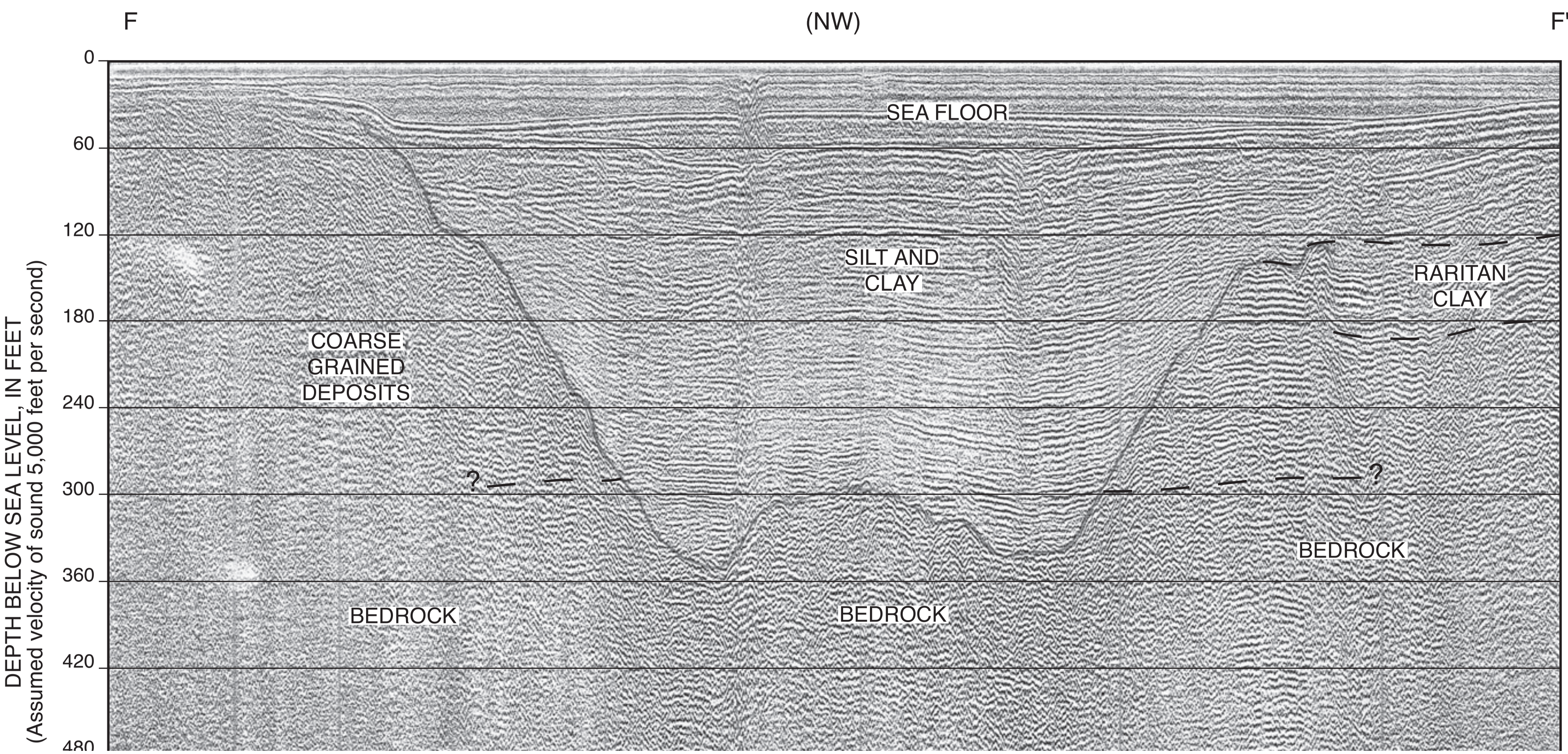


FIGURE 11. (continued) Interpreted stratigraphy along seismic-reflection profiles: A. E-E´ in Long Island Sound. B. F-F´ in Long Island Sound. C. G-G´ in Long Island Sound. D. H-H´ in Cold Spring Harbor. (Trace of profile is shown in fig. 1.)

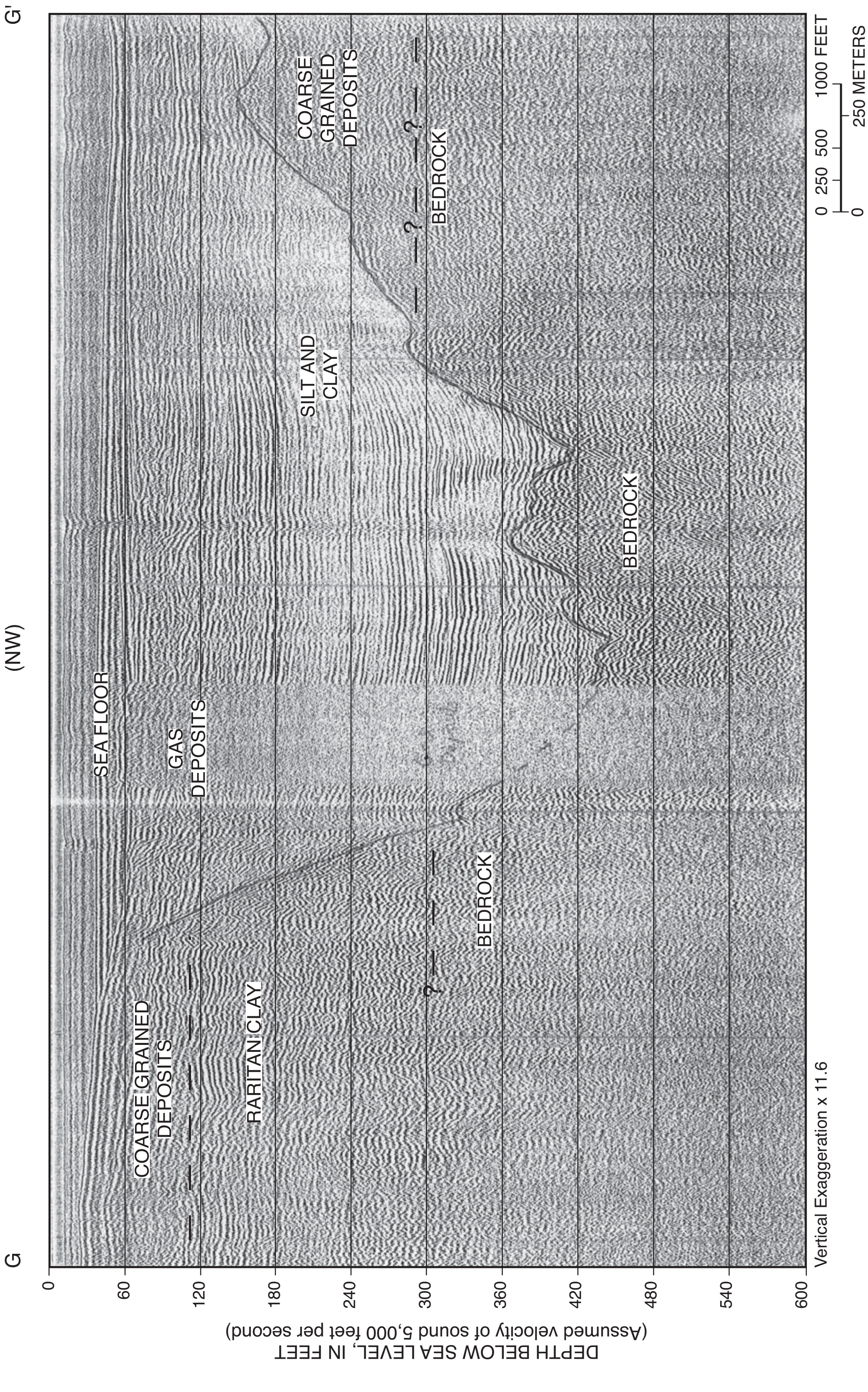


FIGURE 11. (continued) Interpreted stratigraphy along seismic-reflection profiles: A. E-E´ in Long Island Sound. B. F-F´ in Long Island Sound. C. G-G´ in Long Island Sound. D. H-H´ in Cold Spring Harbor. (Trace of profile is shown in fig. 1.)

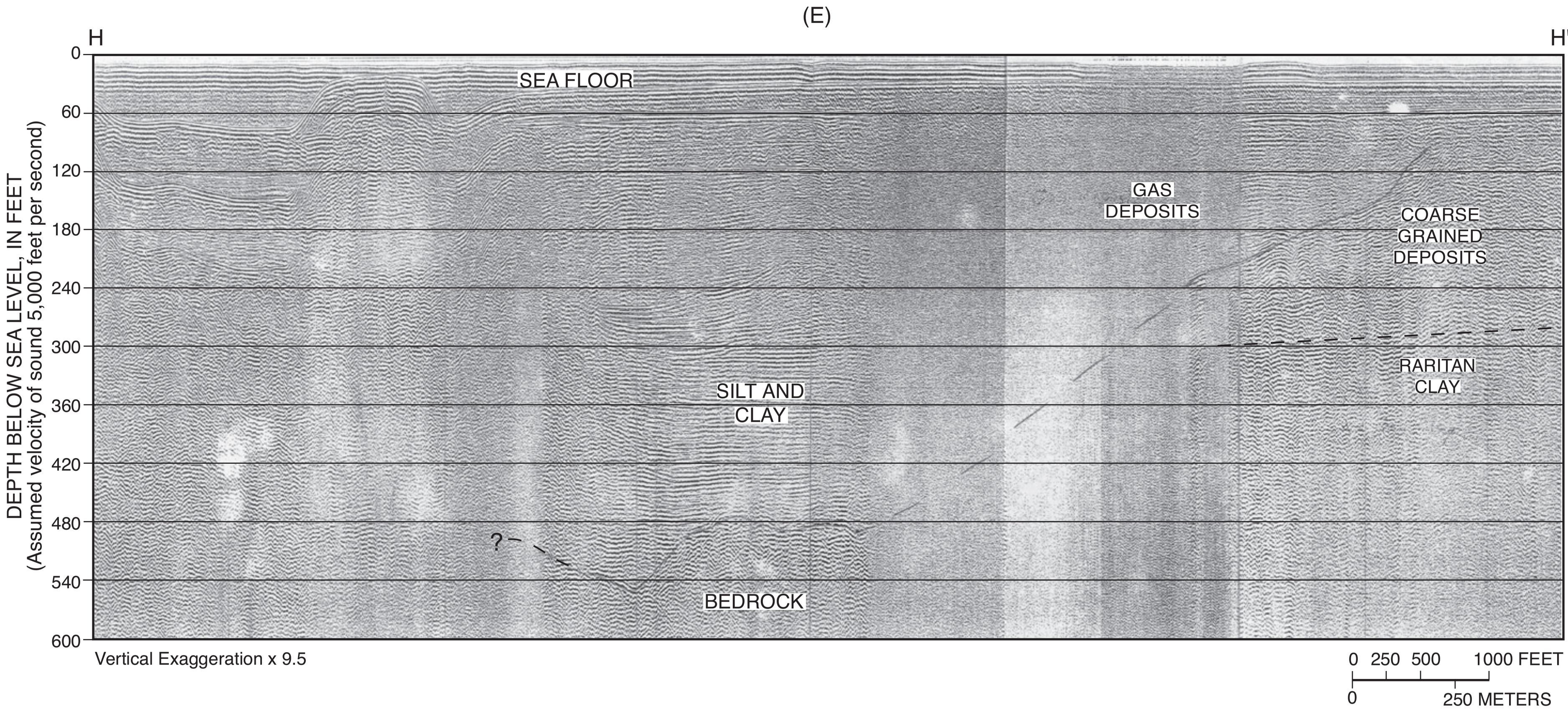


FIGURE 11. (continued) Interpreted stratigraphy along seismic-reflection profiles: A. E-E′ in Long Island Sound. B. F-F′ in Long Island Sound. C. G-G′ in Long Island Sound. D. H-H′ in Cold Spring Harbor. (Trace of profile is shown in fig. 1.)

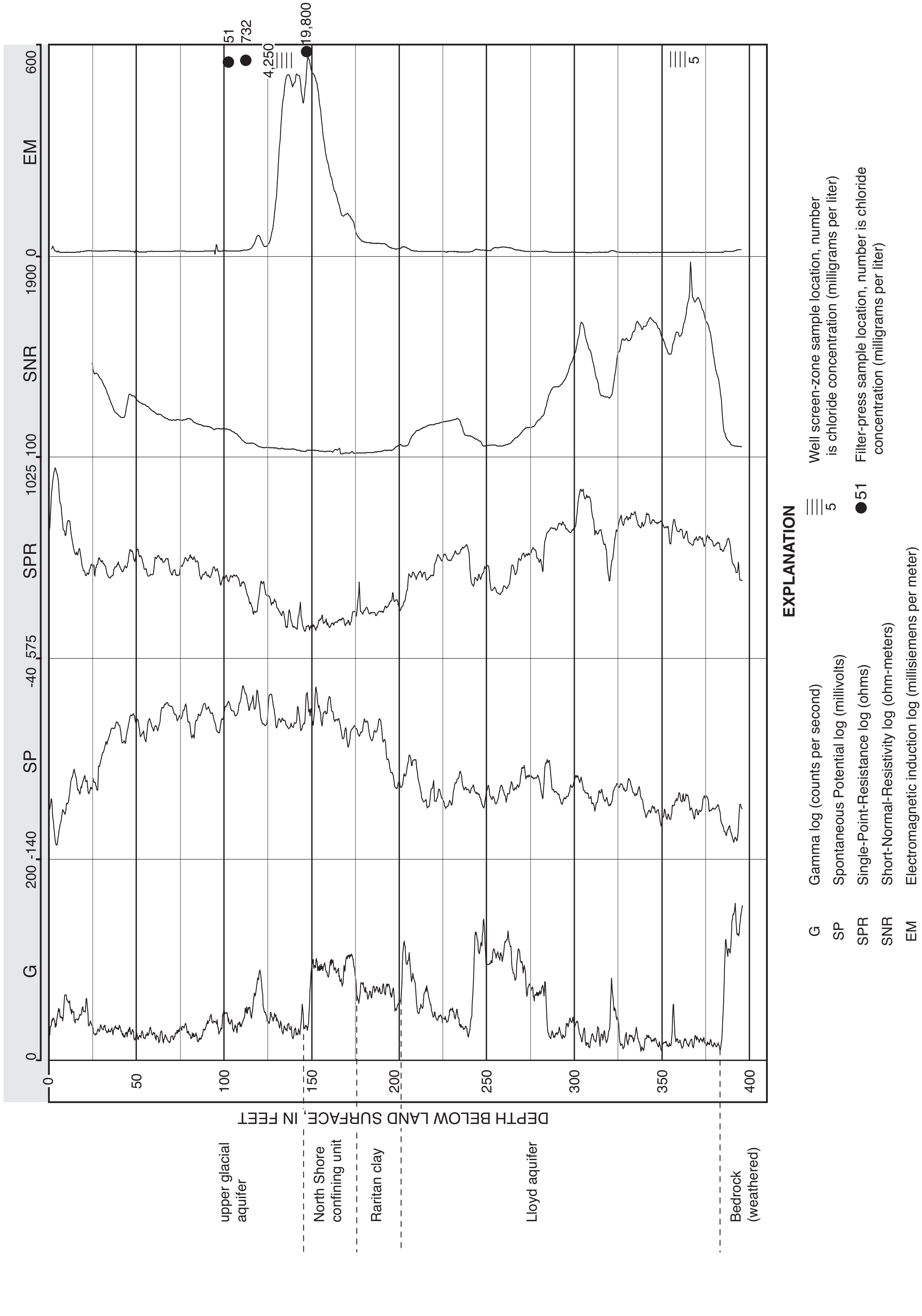


FIGURE 12. Geophysical logs of well N12774, Bayville, N.Y. (Location is shown in fig. 2.)

tends to increase with depth in saltwater wedges and typically rests upon impermeable clay horizons.

Precipitation

All freshwater in the Oyster Bay study area originates as precipitation. Some of the precipitation that falls infiltrates the land surface, and some runs off to storm sewers and to tidewater. Of the water that infiltrates the soil, some is returned to the atmosphere through evaporation and transpiration; the rest percolates to the water table and becomes shallow ground water. Some of this shallow ground water moves laterally and discharges to stream channels as base flow; the remainder moves downward into the deeper hydrogeologic units and eventually discharges upward to the surrounding saltwater bodies.

The mean annual precipitation recorded at Mineola, in central Nassau County (fig. 1) by NCDPW for 1937-97 is 44.42 in; the mean annual precipitation for the Oyster Bay study area calculated by Miller and Frederick (1969) is about 43.5 in. The precipitation regime of Long Island during 1951-65 was studied by Miller and Frederick who found the average warm-season precipitation to be almost equal to cold-season precipitation, and that precipitation is greatest in the spring and least in the fall. The relation between precipitation and recharge on Long Island is further described in Busciolano and others (1998).

Ground Water

Ground water in the Oyster Bay study area is used primarily for residences, small industry, businesses, and golf-course irrigation. Water levels in all major aquifers within the Oyster Bay study area were measured at observation wells on a quarterly basis during 1995-98.

Pumpage

Production wells in the Oyster Bay study area are owned and operated by eight companies—the Incorporated village of Bayville Water Department, the city of Glen Cove Water Department, the Jericho Water District, the Locust Valley Water District, the Old Westbury Water District, the Oyster Bay Water District, the Roslyn Water District, and the Sea Cliff Water Company. All of these companies pump water from the upper glacial, Magothy, and Lloyd aquifers. Pumpage from the Magothy aquifer is much larger than that from the Lloyd aquifer. Mean annual pumpage for the upper glacial, Magothy, and Lloyd aquifers during 1993-97 is listed in table 2A; mean annual pumpage values for total public supply, industry, and golf-course irrigation are summarized in table 2B.

Twelve industrial wells in the Oyster Bay study area report pumpage to New York State Department of Environmental Conservation, which categorizes them as

Table 2. Total annual pumpage in Oyster Bay study area, Nassau County, N.Y., by aquifer, 1993-97.

[Values are in million gallons; Mgal/d, million gallons per day. Data from the Incorporated Village of Bayville Water Department, the City of Glen Cove Water Department, the Jericho, Locust Valley, Old Westbury, Oyster Bay, and Roslyn Water Districts; the Sea Cliff Water Company, and the New York State Department of Environmental Conservation]

Year	Total pumpage, in millions of gallons		
	Upper glacial aquifer	Magothy aquifer	Lloyd aquifer
A. Total pumpage, by year			
1993	900.4	8,481.3	567.0
1994	860.8	8,580.2	678.4
1995	874.7	8,856.2	812.7
1996	558.7	7,889.0	976.4
1997	825.8	8,669.6	623.7
Mean	804.1 (2.2Mgal/d)	8495.3 (23.3Mgal/d)	731.6 (2.0Mgal/d)
B. Total pumpage, by well category			
Public Supply	434.0 (1.2Mgal/d)	8,312.9 (22.8Mgal/d)	664.1 (1.8Mgal/d)
Industrial	261.6 (0.7Mgal/d)	40.6 (0.1Mgal/d)	33.7 (0.1Mgal/d)
Golf-course irrigation (values are pumping-season means for the 34 wells; March-October)	108.4 (0.4Mgal/d)	141.8 (0.6Mgal/d)	33.9 (0.1Mgal/d)

industrial use or unspecified withdrawal. Six of these wells (N2316, N5672, N5994, N8937, N11090, and N11906) (fig. 2) are screened within the upper glacial aquifer, four (N3752, N5708, N8432, N8601) are screened within the Magothy aquifer, and two (N660, N7614) (fig. 2) are screened within the Lloyd aquifer.

The study area contains 34 golf-course irrigation wells, which supply 23 golf courses. Of these, 16 are screened within the upper glacial aquifer, 14 in the Magothy aquifer, and 4 in the Lloyd aquifer. The irrigation season extends from March through October (table 2B).

Water Levels

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

Wells near the coast of Long Island generally are affected by tides; thus, the USGS Coram office protocol for water-level measurements is that these wells be measured during the 2-hour (h) period of high-tide in the nearest embayment. Water levels in observation wells were measured quarterly during 1995-98; those in July 1997 are shown depicted in figures 13 (water-table aquifers) and 14 (confined aquifers). The following sections describe water levels in the four aquifers of the Oyster Bay study area during 1995-98.

Upper glacial and Magothy aquifers (fig. 13)—The water table is within the upper glacial aquifer in most of the study area, except in the southernmost part where it is within the Magothy aquifer. Water levels measured during July 1997 in wells screened in the water table (fig. 13) ranged from 3 ft to 79 ft above sea level. The highest water levels were at well N6670 in the north-central part of the study area and at well N10605 in the south-central part. Typically, the water-table tends to parallel the land-surface topography. The Magothy aquifer becomes increasingly confined with depth. Water-level data obtained during quarterly measurements in the Magothy aquifer, where it is present, generally are representative of the water table because the Magothy in this area is hydraulically connected with the upper glacial aquifer; thus, heads in the two aquifers differ by only a few feet (Busciolano and others, 1998).

Water-level data from selected nearshore wells indicate that the upper glacial aquifer near the shore of the study area is affected by tidal fluctuations only in areas where it is confined by localized silt and clay layers. Two tidal studies and analyses of digital water-level records of the upper glacial, North Shore, and Lloyd aquifers on the north shore of Nassau County indicate that the upper glacial aquifer is only slightly affected by tidal fluctuations (Stumm, 2001; Stumm and others, 2002). High concentrations of saltwater in the upper glacial aquifer in parts of Centre Island and Bayville (wells N12755 and N12791) caused water levels to be nonequivalent to freshwater heads; thus, these values were not used for water-level contouring.

Lloyd and North Shore aquifers (fig. 14)—Analysis of water-level data from quarterly measurements and continuous water-level recorders indicate the Lloyd and North Shore aquifers are affected by tidal fluctuations along the coast and are hydraulically connected to each other (Stumm, 2001; Stumm and others, 2002). Both aquifers respond to local production pumping and show a large cone of depression near Bayville (fig. 14). Predevelopment (1900) water levels within the Lloyd aquifer are inferred to have been above sea level throughout the northern part of Nassau County (Kimmel, 1973) and were found to be above sea level in 1947 (Lusczynski, 1952), 1971 (Kimmel, 1973), 1975 (Rich and others, 1975), 1979 (Donaldson and Koszalka, 1983), 1980 (Kilburn and Krulikas, 1987) and in March-April 1997 (Busciolano and others, 1998). Water-level data from quarterly synoptic measurements made during 1994-98 indicate that water in the Lloyd and North Shore aquifers flows northward from a local ground-water high in the south-central part of the study area (fig. 14). A large cone of depression in the Bayville coastal area is attributed to local production pumping of the Lloyd aquifer. Two wells along the coast of the study area (N12667 and N12774) show tidal fluctuations of as much as 3 ft (figs. 2, 15). Lloyd and North Shore aquifer wells in the central part of the study area, such as wells N11798 and N11280, do not respond to tidal fluctuations (fig. 15). Water levels in the Lloyd and North Shore aquifers increase in the fall and winter in response to a seasonal decrease in pumping.

The potentiometric surface of the Lloyd and North Shore aquifers in July 1997 (fig. 14) indicates that water levels ranged from 58 ft above mean sea level at the local ground-water high in the south-central part of the study area to about 2 ft below mean sea level in the Bayville coastal area. The large cone of depression extended offshore into Long Island Sound. The potentiometric surface at several wells in western Bayville was below sea level in July 1997. Summer pumping causes ground-water flow in the Lloyd and North Shore aquifers to reverse direction from seaward to landward; that is, from the surrounding saltwater embayments inland toward the pumping wells (areas of lowest hydraulic head). This reversal is the primary reason for the past and present (1998) saltwater intrusion in the study area.

The hydrograph of observation well N12697 (fig. 15), screened in the Lloyd aquifer near the intersection of C-C´ and D-D´ (fig. 2), shows the smallest (1.0 ft) tidal fluctuation of any recorder well near the coast because it is the farthest from the coast. The two hydrographs with the least amount of fluctuations are from wells in the central part of the study area, well N11798 screened in the Lloyd aquifer, and well N11280 screened in the North Shore aquifer. The aquifers in this part of the study area are not affected by tidal fluctuations but are affected by local pumping and natural factors such as barometric and climatic changes. The hydrograph of observation well N110 near Hempstead Harbor (fig. 15), screened in the Lloyd aquifer, shows sharp declines in water levels in response to localized production pumping. The water level at this well was 14 ft above sea level during the quarterly synoptic measurement of July 1997, but this was lower than normal as a result of summer pumping; it also was below sea level during October 1997 (fig. 15) (Spinello and others, 1999). In general, all hydrographs from the Lloyd and North Shore aquifers for July-August 1997 indicate similar trends—the lowest hydraulic heads in mid-July, an increase or peak in late July, and a slow increase during August (fig. 15). The similarity between the hydrograph for well N11280, (fig. 15), which is screened in buried valley deposits of the North Shore aquifer, and those of the other observation wells, also screened in the Lloyd aquifer (N12697, N11798, N12667 and N12774) (fig. 15), suggests hydraulic connection. A similar hydraulic connection between the North Shore aquifer and the surrounding Lloyd aquifer in the Great Neck and Manhasset Neck peninsulas has been documented by Stumm (2001), and Stumm and others (2002). The narrower range in water levels at observation well N11280 (North Shore aquifer) than at other Lloyd observation wells probably indicates that the North Shore aquifer within that area is less permeable, or that the hydraulic connection is less efficient than in other buried valleys in northern Nassau County. The installation of new observation wells within this buried valley was completed too late in the study to identify the cause of these measured fluctuations.

Water Quality

Data on ground-water quality in the Oyster Bay study area were obtained from analyses made by the NCDH and the NCDPW. A brief summary of the current (1998) water-quality and review of the historical data were made to obtain chloride concentrations and specific-conductance values for delineation of the freshwater-saltwater interface. These data were compared with the New York State Department of Health's MCL for Drinking Water (Nassau County Department of Health, 1997), but a detailed analysis of water quality and review of historical data were beyond the scope of this study.

Chloride—The chloride concentrations at production wells screened in the upper glacial and Magothy aquifers in the Oyster Bay study area generally range from 5 to 75 mg/L. One Lloyd production well (N10144, near Bayville) had a peak chloride concentration of 101 mg/L in 1994 and a concentration of 5 mg/L in 1995. As of 1998, no production wells screened in the Lloyd aquifer had chloride concentrations that exceeded the State's MCL (250 mg/L).

Water from seven observation wells screened in the upper glacial aquifer (N12791, N12856, N12755, N12946, N12775, N12945, N12754, fig. 2) exceeded the State's MCL for chloride; the values ranged from 1,025 mg/L to 13,750 mg/L. Drever (1988) states that seawater has an average chloride concentration of 19,350 mg/L. Water from one Lloyd observation well (N12790, near Bayville) had a chloride concentration of 700 mg/L in 1997, and 1,800 mg/L in 1998, and water from one observation well screened in the Magothy aquifer (N9059, in the southern part of the study area) had a chloride concentration of 170 mg/L in 1994.

Volatile organic compounds—The three most commonly detected volatile organic compounds (VOC's) in raw-water samples from Nassau County production wells in 1996 were tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,1,1-trichloroethane (TCA) (Nassau County Department of Health, 1997). No high concentrations of VOC's have been detected (as of 1998) at production wells or observation wells screened in the Lloyd aquifer; the Lloyd generally is protected from the downward movement of contaminants by the Raritan clay. Water from one production Magothy well (N9334, near Garvies Point, fig. 2) is treated with an airstripper to remove VOC's from the raw water. Two production upper glacial wells (N8327 and N3466, both near Garvies Point, fig. 2) have been shut down (as of 1989) because the VOC concentrations exceeded the State's MCL (0.005 mg/L).

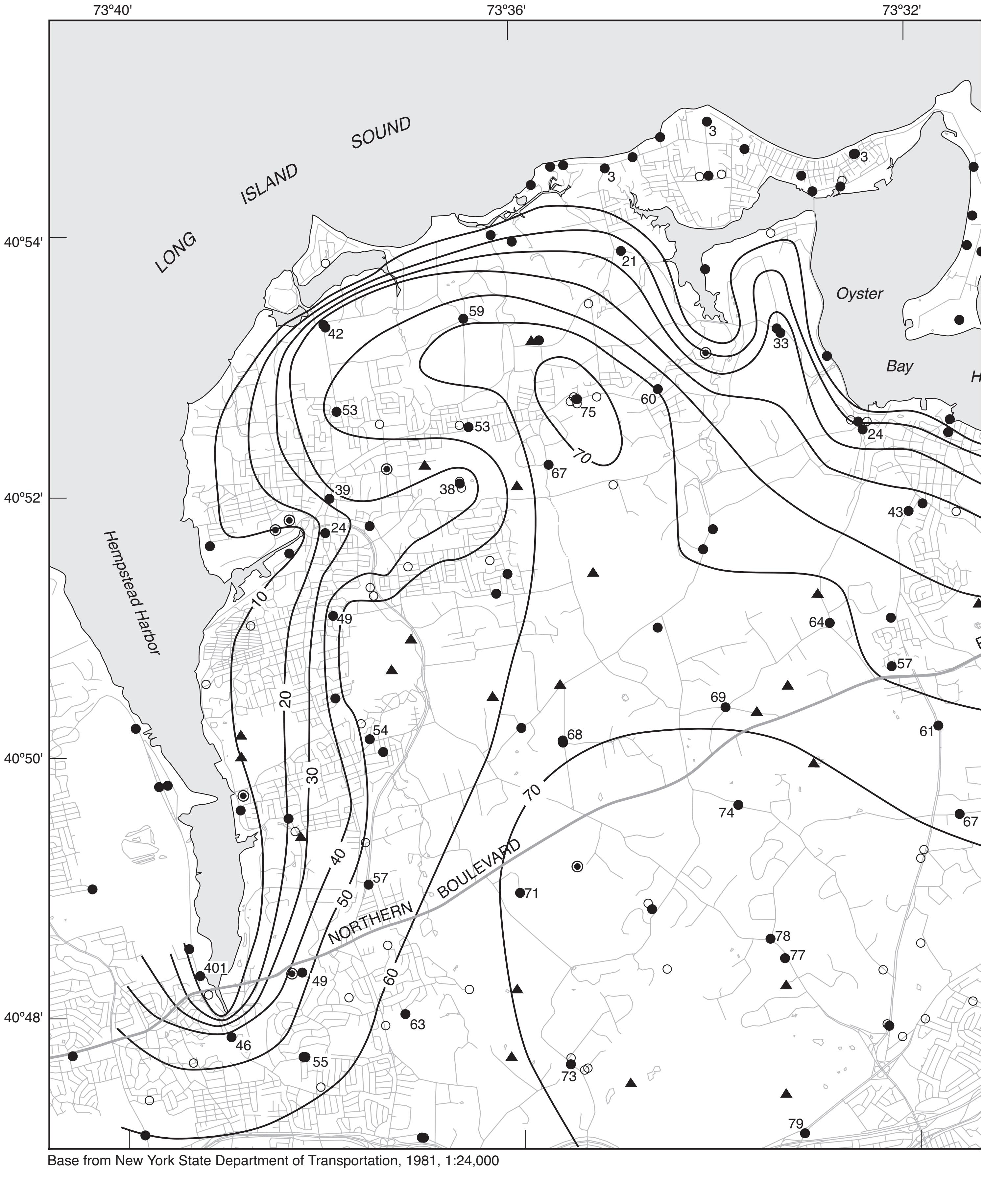
Water from six observation wells—four screened in the upper glacial aquifer (N12856, N12791, N9100, N12775) and two in the Magothy aquifer (N10609, N11280)—have VOC concentrations above the State's MCL's.

Inorganic constituents, nitrate, and metals—As of 1998, no inorganic constituents have been detected in production wells screened in the Lloyd aquifer at concentrations above the State's MCL's. Nitrate contamination (MCL-10 mg/L) has led to restricted use of one upper glacial production well (N7643, near Bayville). Iron concentrations exceeded the State's MCL (0.3 mg/L) at one unused production Magothy well (N5261, near Garvies Point).

Water from three observation wells screened in the upper glacial aquifer (N12775, N10199, N12754) exceeded the State's MCL for iron and manganese combined (0.5 mg/L) and water from 10 others (N12945, N12711, N1152, N9670, N9478, N12256, N9189, N12856, N9100, N9353) exceeded the State's MCL for iron.

Water from 11 Magothy observation wells (N11824, N9059, N1176, N11823, N11281, N 9115, N 10606, N10609, N 9117, N11732, N 7478) had iron concentrations above the State's MCL for drinking water and water from three Magothy observation wells contained several other constituents in concentrations that exceed the State's MCL. Nitrate concentrations at well N10246 (near Hempstead Harbor) exceeded the State's MCL. The State's MCL for zinc and iron concentrations (5 and 0.3 mg/L, respectively) were exceeded at well N1243 (near the Suffolk County border) and the State's MCL for lead, iron and manganese concentrations (0.015 and 0.5 mg/L, respectively) were exceeded at well N2528 (near the center of the study area, fig. 2).

Iron concentrations in water from 13 observation wells screened within the Lloyd aquifer exceeded the State's MCL (wells N12075, N11574, N11798, N11279, N 12697, N12733, N12853, N12855, N12880, N12929, N12747, N12790, N12870).



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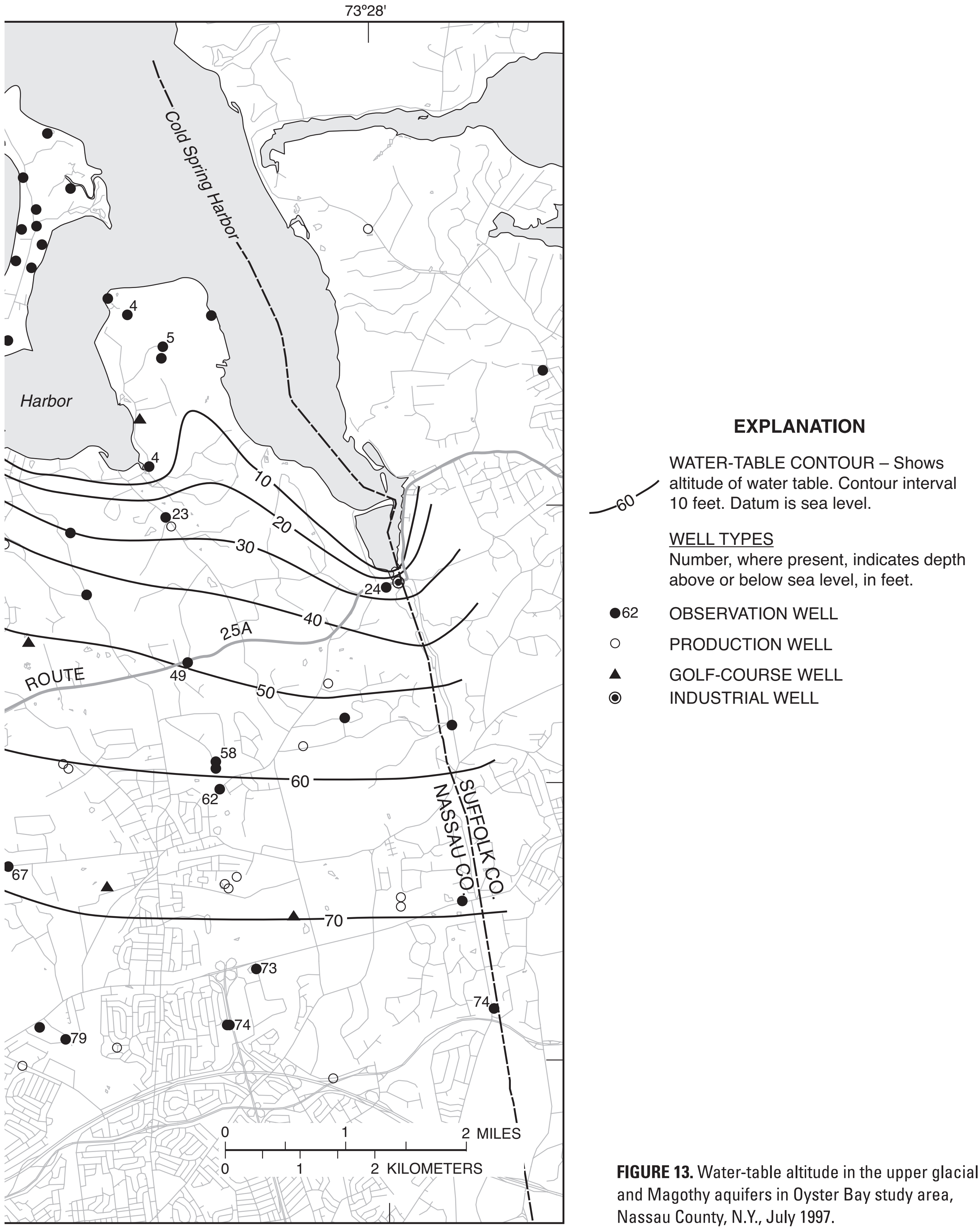
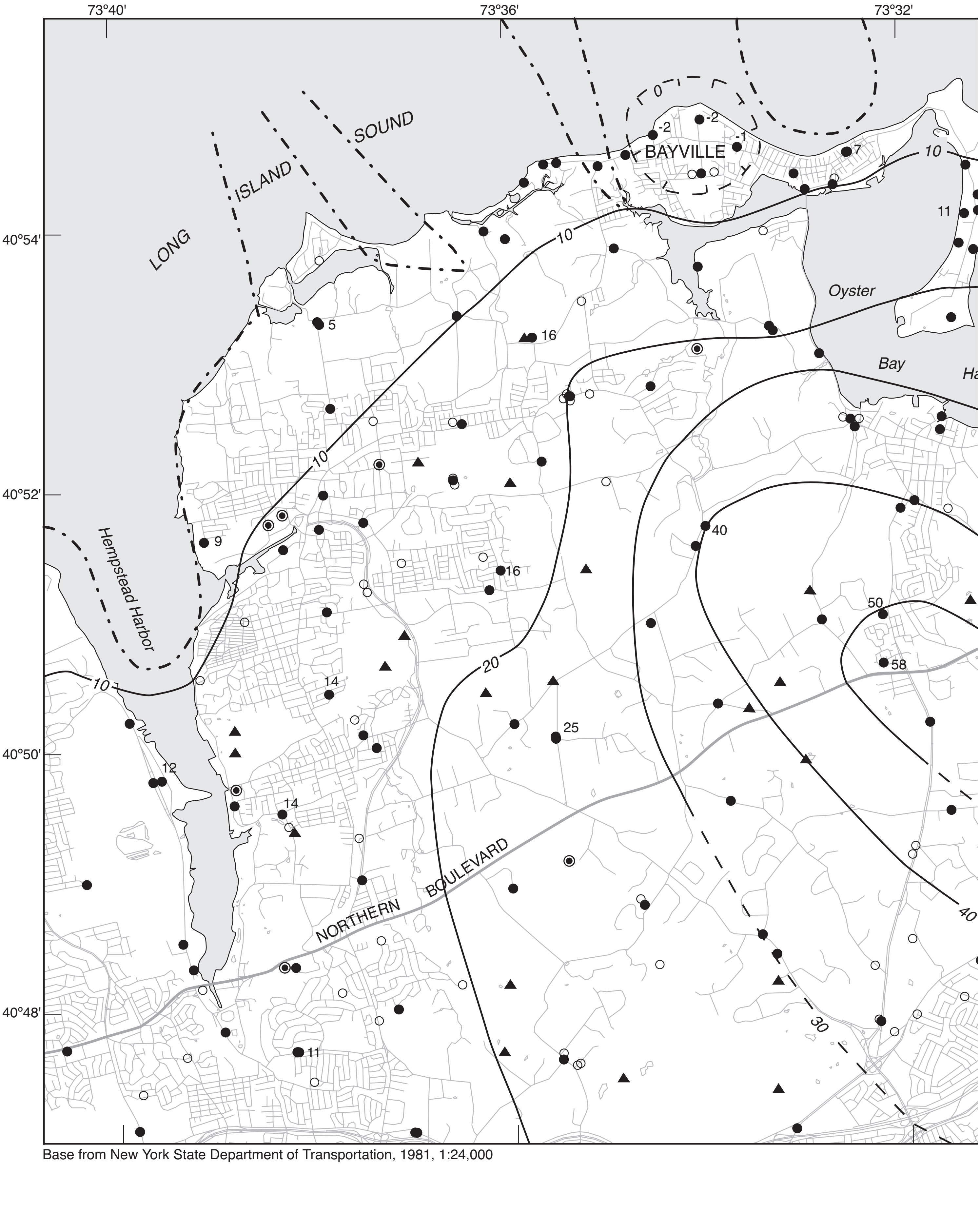


FIGURE 13. Water-table altitude in the upper glacial and Magothy aquifers in Oyster Bay study area, Nassau County, N.Y., July 1997.



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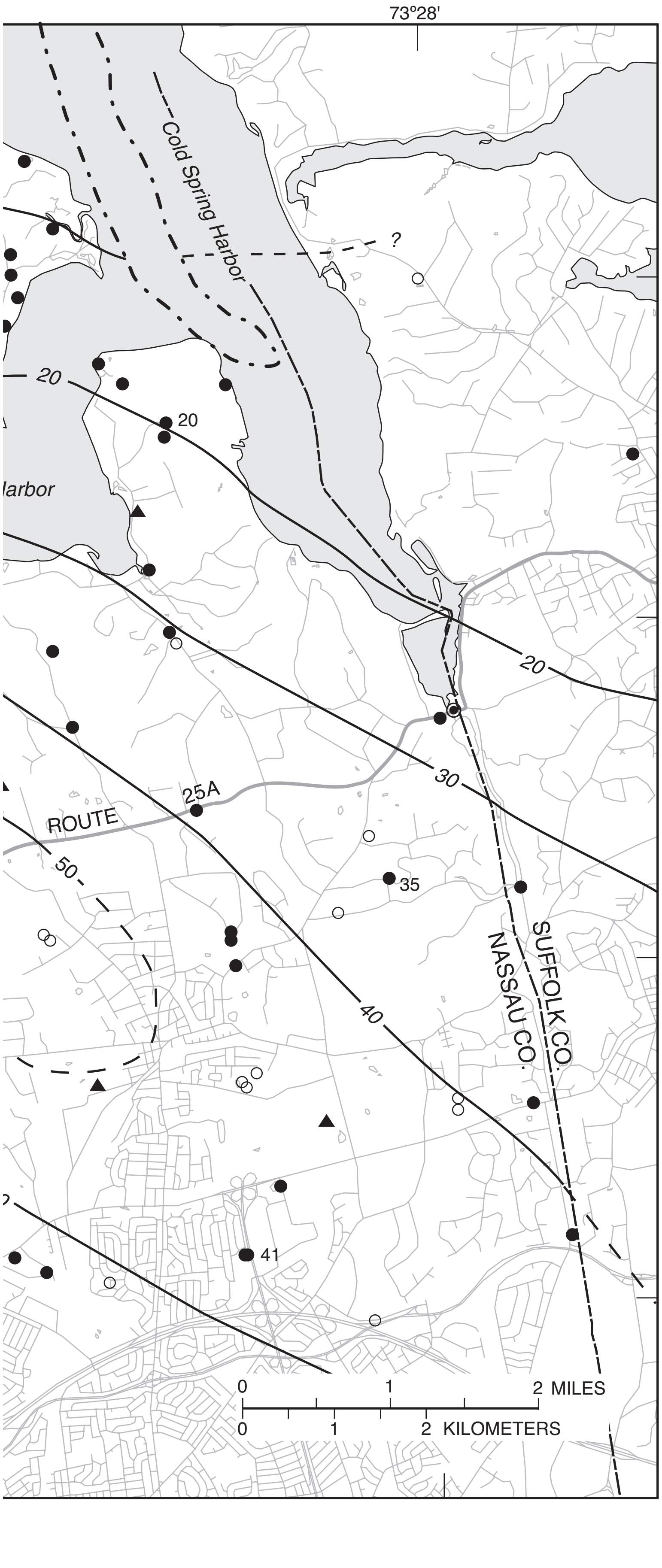


EXPLANATION

POTENTIOMETRIC SURFACE CONTOUR – Shows altitude of potentiometric surface. Dashed where approximately located. Hachures indicate depression. Contour interval 10 feet. Datum is sea level.

EXTENT OF THE LLOYD AND NORTH SHORE AQUIFERS

WELL TYPES
Number, where present, indicates depth above or below sea level, in feet.

OBSERVATION WELL

PRODUCTION WELL

GOLF-COURSE WELL

INDUSTRIAL WELL

FIGURE 14. Potentiometric-surface altitude in the Lloyd and North Shore aquifers in Oyster Bay study area, Nassau County, N.Y., July 1997.

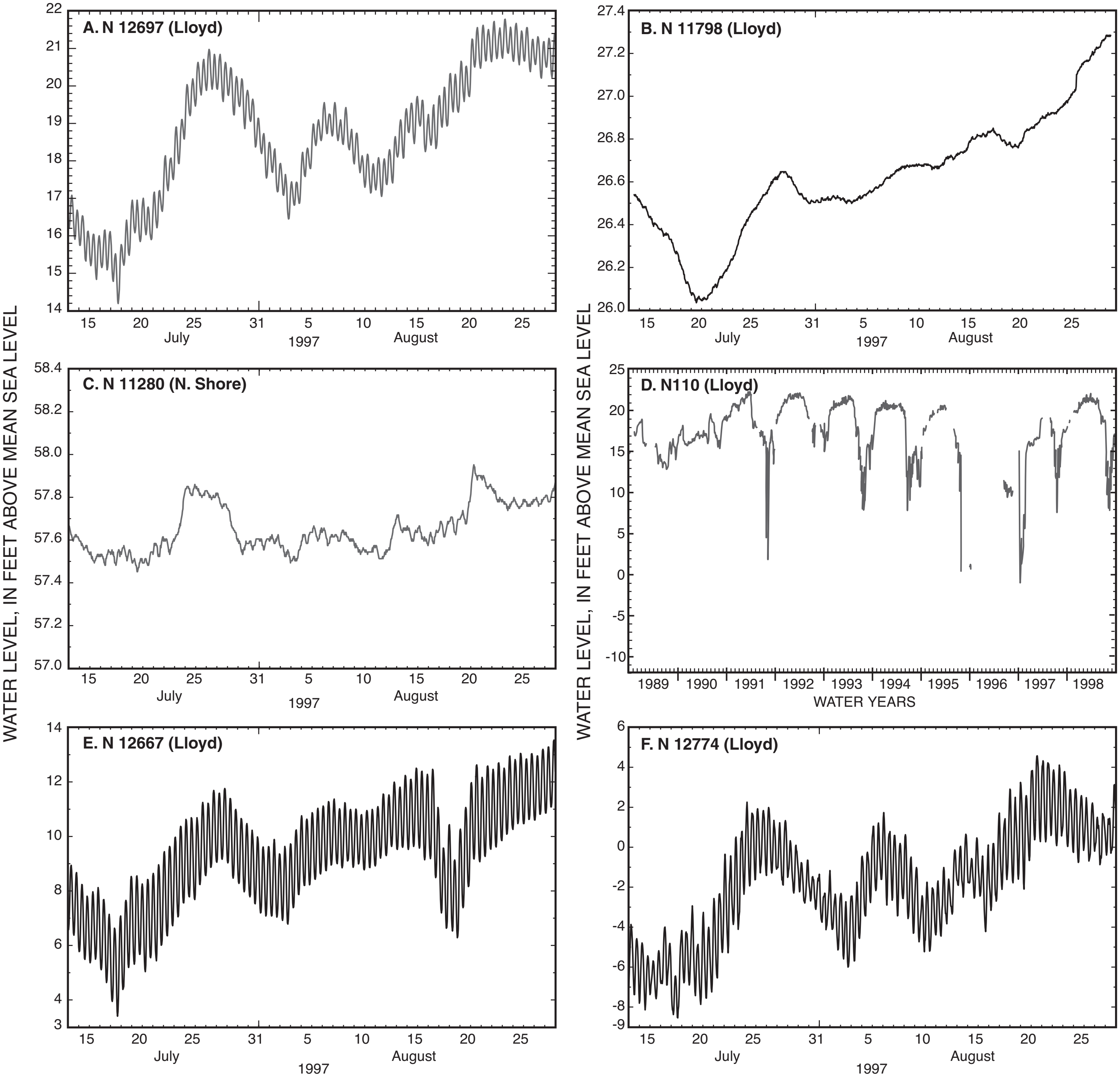


FIGURE 15. Graphs of water level data from Lloyd and North Shore aquifer wells in Oyster Bay study area, Nassau County, N.Y.: A. Well N12697, July 13-August 28, 1997., B. Well N11798, July 13-August 29, 1997., C. Well N11280, July 13-August 28, 1997., D. Well N110, October 1988-September 1998., E. Well N12667, July 13-August 28, 1997., F. Well N12774, July 13-August 28, 1997. (Locations are shown in fig. 2)

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, fresh ground water flows seaward (from areas of high potential to areas of lower potential) and meets saltwater at an equilibrium point (interface) offshore. If the natural hydraulic gradient is reversed by pumping, however, fresh ground water flows toward the pumping well instead of seaward toward the interface, the interface moves landward, and saltwater intrusion occurs.

Characteristics of Saltwater Intrusion

Seawater has an average chloride concentration of 19,350 mg/L (Drever, 1988). A grab sample taken in 1996 from the nearshore area of Long Island Sound, near Great Neck, had a chloride concentration of 13,995 mg/L; this indicated some freshwater inflow into Long Island Sound (Stumm, 2001). The predevelopment concentration of chloride in fresh ground water on Long Island was 10 mg/L or less (Lusczynski and Swarzenski, 1966), and shallow (upper glacial) ground water in urbanized areas of Long Island generally has an ambient chloride concentration of less than 40 mg/L (Buxton and others, 1981; Heisig and Prince, 1993). The increase since the predevelopment period is associated with contamination from land-surface sources. In this report, “ambient” water is defined as ground water with a chloride concentration of less than 40 mg/L; “brackish” water as ground water with a chloride concentration of 40 to 250 mg/L; and “saltwater” as ground water with a chloride concentration greater than 250 mg/L (Lusczynski and Swarzenski, 1966; Chu and Stumm, 1995; Stumm, 2001; Stumm and others, 2002). The following section describes the extent of saltwater intrusion into the Oyster Bay study area.

Historic chloride concentrations at production wells and in samples from inland observation wells within the study area indicate that the background chloride concentration in the Lloyd aquifer is 5 to 10 mg/L. Any increase in chloride concentrations above predevelopment levels in the Lloyd and North Shore aquifers within the study area would be indicative of saltwater intrusion from the surrounding saltwater embayments in response to pumping. Ground water has been affected by saltwater intrusion in at least one production well (N10144, near Bayville.

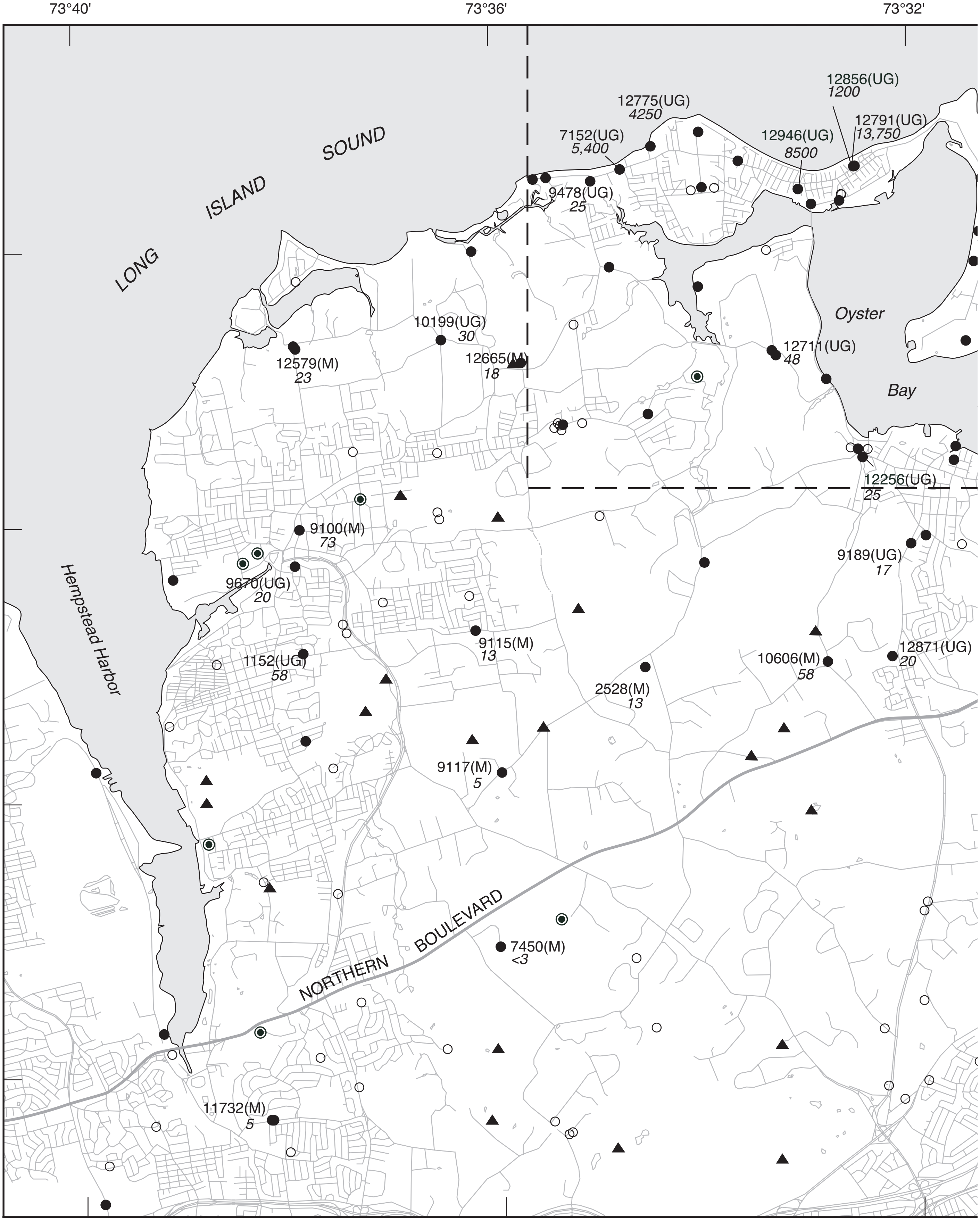
The 50 years of chloride-concentration and pumpage data from production wells on Great Neck (to the west of the study area) indicate that once a concentration of 50 mg/L is exceeded at a production well screened in the Lloyd aquifer, the concentrations will remain above 50 mg/L even if pumping is decreased (Stumm, 2001). 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 is because once the toe, or leading edge, of the saltwater wedge reaches the production well, it is “upconed” into the screen zone of the well and responds to decreased pumping for only a short time before stabilizing into a rapid, continuous increase.

Filter-press samples were obtained from 16 boreholes installed for this study and were analyzed for chloride concentrations. If multiple boreholes were in the same vicinity, only one was sampled. The values were then correlated with those in water samples from the well-screen zone and with data from geologic and geophysical logs to delineate the extent of the saltwater intrusion. Water samples from production wells were also analyzed for chloride concentrations.

Saltwater Wedges A,B,C, and D

Four wedge-shaped zones of saltwater intrusion were identified within the Oyster Bay study area (figs. 16, 17)—three (A,B,C; fig. 16B) in the upper glacial aquifer, and one (D; fig. 17B) in the Lloyd aquifer. Typically, the saltwater wedges form at the base of an aquifer above the surface of an impermeable or poorly permeable layer because the density of saltwater is greater than that of freshwater. The underlying impermeable or poorly permeable layer can be bedrock, as with the Lloyd or North Shore aquifer, or a confining unit, as with the upper glacial aquifer. Saltwater wedges decrease in thickness landward and have relatively thin (about 10-ft thick) saltwater-freshwater interfaces in northern Nassau County, N.Y. (Stumm, 1993).

Saltwater wedge A (fig. 16) was at the base of the upper glacial aquifer in the easternmost part of Bayville and most of Centre Island. Water from well N12791, screened at 52 to 72 ft below sea level, had a chloride concentration of 13,750 mg/L in 1997. Geophysical logs obtained at the site in 1997 indicate that saltwater had intruded the entire upper glacial aquifer in the vicinity of this well (fig. 18A). Similar conditions were detected at observation well N12946 near Bayville, screened 80 to 100 ft below sea level, where the chloride concentration was 8,500 mg/L. Saltwater wedge A extended into Centre Island. In addition, Isbister (1966) described high chloride concentrations at two wells in the upper glacial aquifer in Centre Island, N175 (85 to 155 ft below land surface, BLS), and N6578 (61 ft BLS)(fig. 2). Water from a new observation well near Bayville, N12755, which is screened from 89 to 109 ft below sea level in the upper glacial aquifer, had a chloride concentration of 10,250 mg/L in 1997. Geophysical logs of well N12747, from this site indicate that all of the upper glacial aquifer had been intruded by saltwater (fig. 18B). Although parts of eastern Bayville are low lying, much of Centre Island is not. It is unknown whether overpumping of private wells in the past or insufficient freshwater heads were the cause of saltwater in wedge A. No production wells were pumping from the upper glacial



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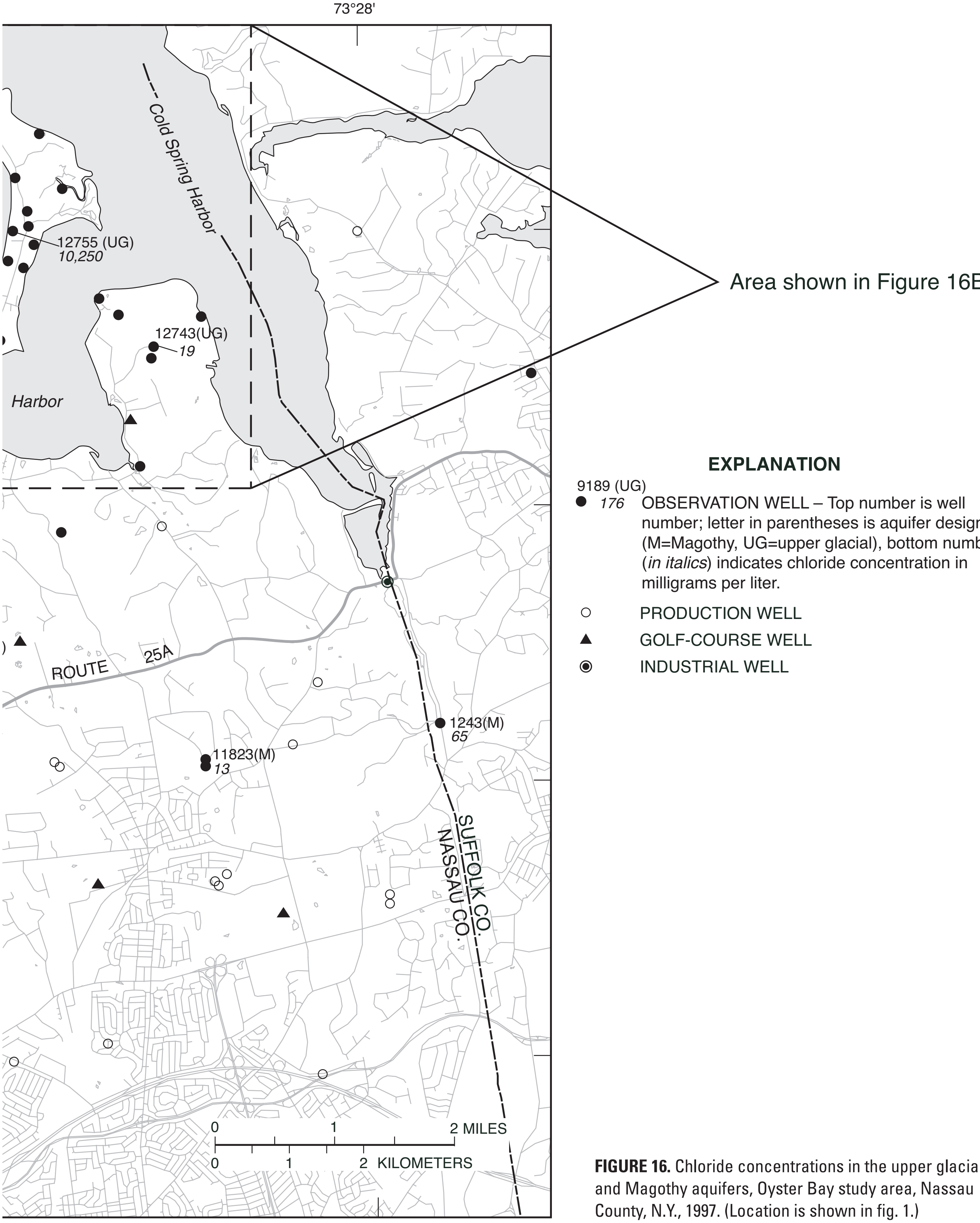


EXPLANATION

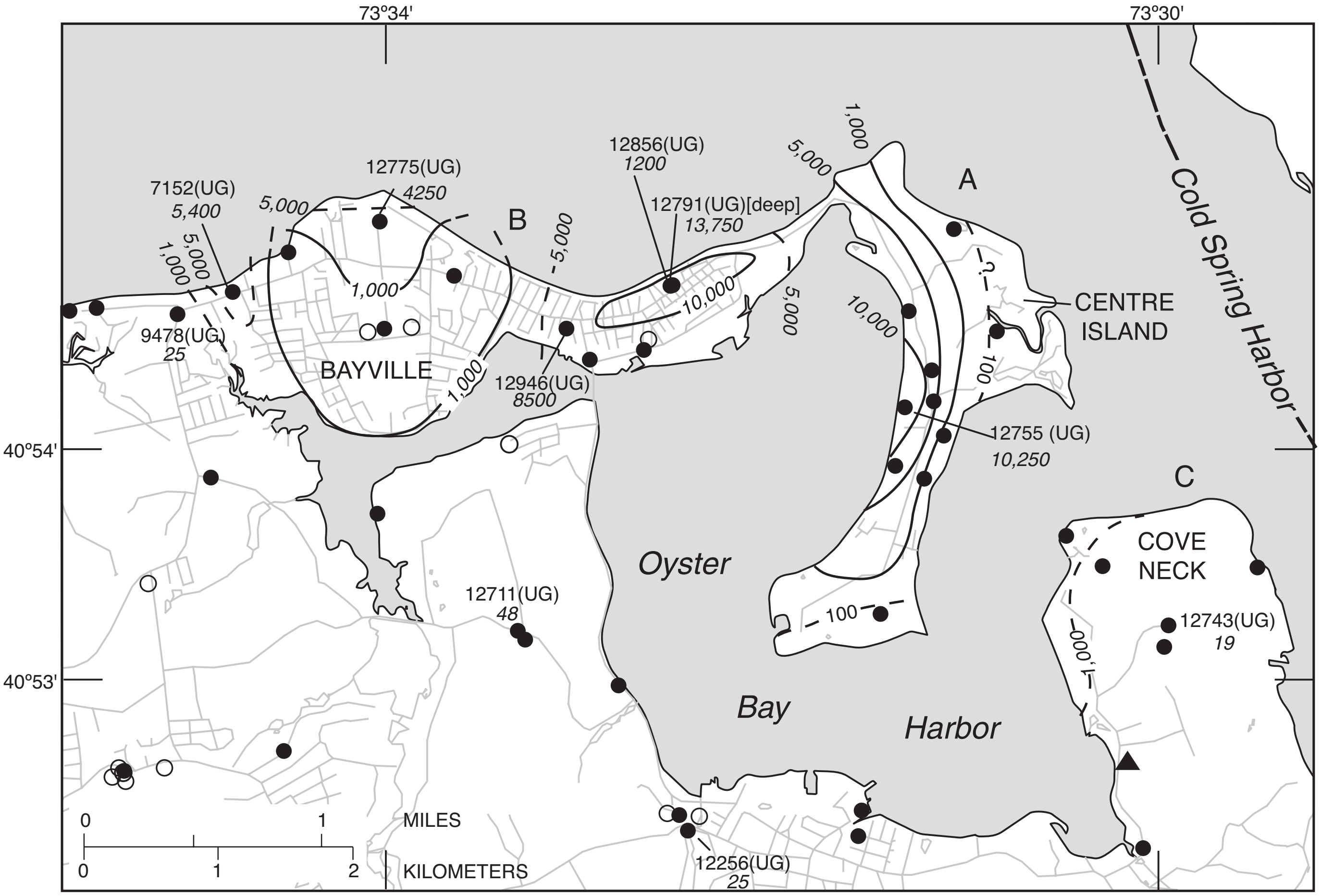
9189 (UG) *176* OBSERVATION WELL – Top number is well number; letter in parentheses is aquifer designation, (M=Magothy, UG=upper glacial), bottom number (*in italics*) indicates chloride concentration in milligrams per liter.

PRODUCTION WELL

GOLF-COURSE WELL

INDUSTRIAL WELL

FIGURE 16. Chloride concentrations in the upper glacial and Magothy aquifers, Oyster Bay study area, Nassau County, N.Y., 1997. (Location is shown in fig. 1.)



EXPLANATION

1000	LINE OF EQUAL CHLORIDE CONCENTRATION -- Dashed where inferred. Concentration is in milligrams per liter.
A	SALTWATER WEDGE
12856(UG) *1200* ●	OBSERVATION WELL -- Top number is well number; letter in parentheses is aquifer designation (UG=upper glacial). Bottom number (*in italics*) indicates chloride concentration, in milligrams per liter.
○	PRODUCTION WELL
▲	GOLF-COURSE WELL

FIGURE 16B. Chloride concentrations in the upper glacial and Magothy aquifers, Oyster Bay study area, Nassau County, N.Y., 1997. (Location is shown in fig. 16A.)

aquifer in this area as of 1998. Private wells on Centre Island are screened in the Lloyd aquifer, probably because the upper glacial aquifer in this area contains saltwater.

Saltwater wedge B (fig. 16) was about 0.4 mi northwest of wedge A and is in the upper glacial aquifer. Pumping of production well N7643, in western Bayville and screened in the upper glacial aquifer, appears to have resulted in an increase in chloride concentration during 1965-84. Chloride-breakthrough curves for this well indicate rapid increases in chloride concentration during the 1960's and 70's (fig. 19A); chloride concentrations were less than 20 mg/L in 1965 and reached a peak of about 57 mg/L in 1974 (fig. 19A). This well was shut down in 1984 and no chloride data is available since that time. Water from observation well N12775, screened 106 to 126 ft below sea level, in the upper glacial aquifer near Bayville, had a chloride concentration of 4,250 mg/L in 1997. Geophysical logs of the adjacent deep observation well N12774 from 1997 indicated a saltwater wedge about 25-ft thick with a sharp interface at the base of the upper glacial aquifer (fig. 12). The sharp interface indicated active saltwater intrusion in response to overpumping of the upper glacial aquifer in this area. A wedge of saltwater appeared to be migrating landward toward the production pumping center south of observation well N12774. Saltwater wedge B appeared to extend landward as of 1997 past observation well N7152, at which the chloride concentration at 35 to 70 ft below land surface was 5,400 mg/L in 1961 (Isbister, 1966). The chloride concentration was only 25 mg/L in 1996 in well N9478, which is in the upper glacial aquifer, and is approximately 1300 ft west of N7152.

Saltwater wedge C (fig. 16), along the northwest coast of Cove Neck, appeared to be within the upper glacial aquifer. Drillers' logs on file at the USGS Coram office indicate that water at wells screened in the upper glacial aquifer had elevated chloride concentrations during the late 1950's to the early 1960's. The extent and thickness of this wedge was undefined because this area lacks observation wells. Well N6675, in Cove Neck (86 ft below land surface), was described by Isbister (1966) as a well in the upper glacial aquifer with high chloride concentrations. Borehole geophysical logs and filter-press samples taken during this study in 1996 at observation well N12743, in the north-central part of Cove Neck, did not indicate brackish or salty water.

Saltwater wedge D (fig. 17B), in eastern Bayville, caused the shutdown and abandonment of production well N10144, screened in the Lloyd aquifer, after only 10 years of operation. Chloride-breakthrough curves (1984-95) for this well indicated rapid intrusion of saltwater into the Lloyd aquifer because of overpumping (fig. 19B). Chloride concentrations at this well were less than 5 mg/L in 1984 and rose to more than 50 mg/L within 6 years of operation. The maximum chloride concentration was 101 mg/L in 1994. Despite a drastic reduction in pumpage, chloride concentrations generally continued to increase until the well was subsequently taken out of service. Water from observation well N12790, approximately 1300 ft northeast of N10144 on the coast of eastern Bayville and screened at the base of the Lloyd aquifer, had a chloride concentration of 1,800 mg/L in 1998. Geophysical logs and water samples from this well indicated that a thin wedge of saltwater had intruded the Lloyd aquifer in the eastern part of Bayville because of overpumping (fig. 18A). Observation well N12870 (fig. 2), approximately 2000 ft west of N10144 and screened at the base of the Lloyd aquifer, had a peak chloride concentration of 125 mg/L in 1998. This well is near the western boundary of saltwater wedge D.

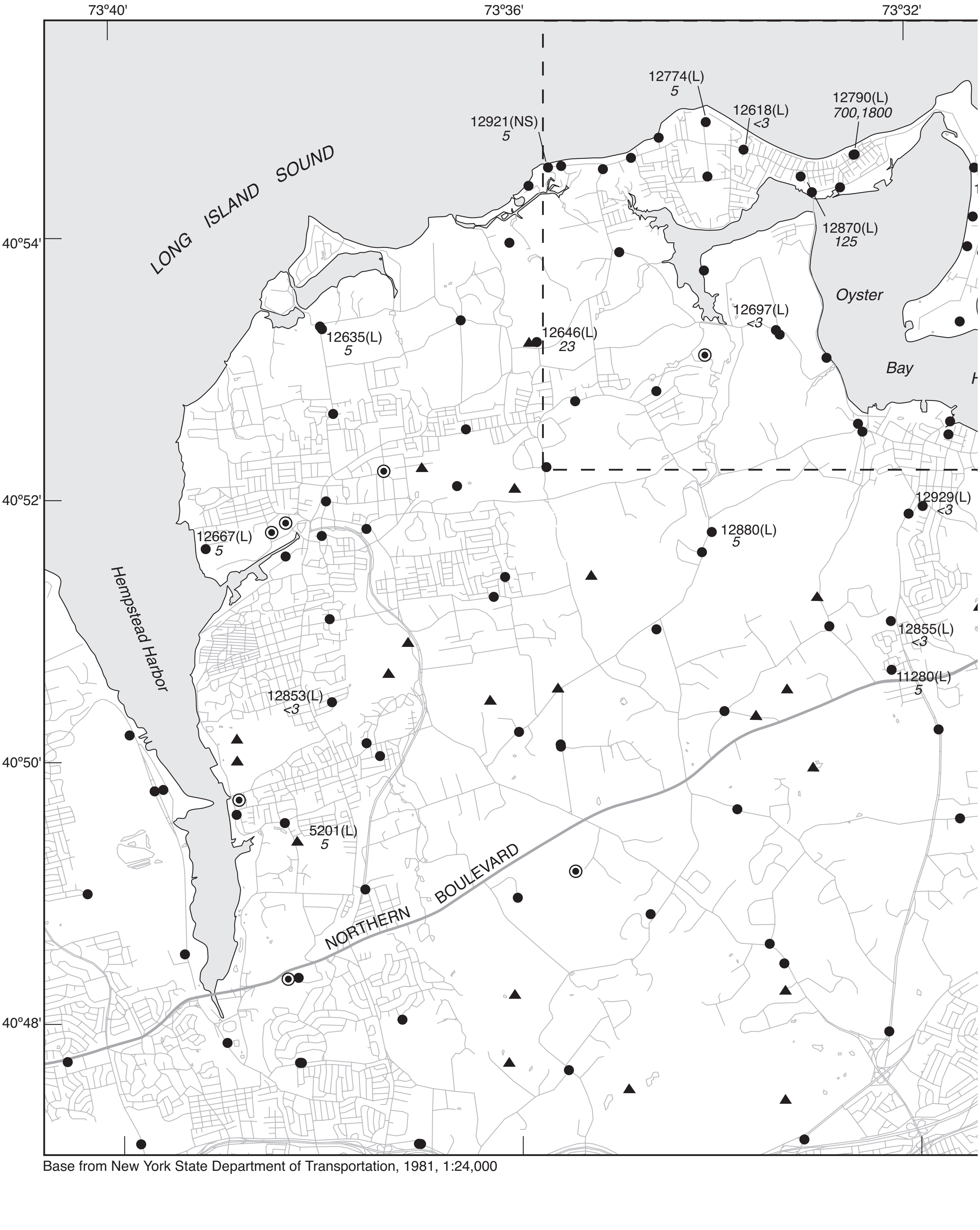
Production pumping of the Lloyd aquifer by wells N7620 and N8776 (fig. 14), in western Bayville, appeared to have lowered the water levels to below sea level. Chloride concentrations at observation well N12774 in 1997 did not indicate that the saltwater-freshwater interface had moved inland; however, the rapid saltwater intrusion into the Lloyd aquifer in eastern Bayville indicates that western Bayville may be prone to similar saltwater intrusion in the future. Chloride-breakthrough curves from 1972-95 for production well N8776, screened in the Lloyd aquifer near Bayville, indicated low chloride concentrations (fig. 19C) except for one outlier point at which the chloride concentration peaked at 38 mg/L in 1990. The data seem to indicate that the Lloyd aquifer in the western part of Bayville, as of 1998, had not been affected by saltwater intrusion .

SUMMARY AND CONCLUSIONS

The intrusion of saltwater toward several production wells within the northern part of the town of Oyster Bay prompted a study by the USGS in cooperation with the NCDPW from 1995 through 1998 to collect hydrogeologic, geophysical, and water-quality data, define the subsurface geology, and delineate the extent of saltwater intrusion. Nineteen boreholes were drilled during 1995-98, and continuous high-resolution marine-seismic-reflection surveys were completed to define the hydrogeologic framework from Hempstead Harbor to Cold Spring Harbor. Borehole geophysical logs (gamma, electric, and EM induction) were used to delineate hydrogeologic units and the extent of saltwater intrusion at selected observation wells.

New drill-core data led to the identification and naming of two hydrogeologic units—the North Shore aquifer and the North Shore confining unit. The North Shore aquifer is a sequence of Pleistocene-age sediments in the northwestern, central, and northeastern parts of the study area. 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 where the Lloyd aquifer, Raritan clay, and Magothy aquifer were severely eroded or removed by glacial scouring.

The Raritan clay overlies and confines water in the Lloyd aquifer. A glacially eroded buried valley appears to incise the Raritan clay from the northwest to the central part of the study



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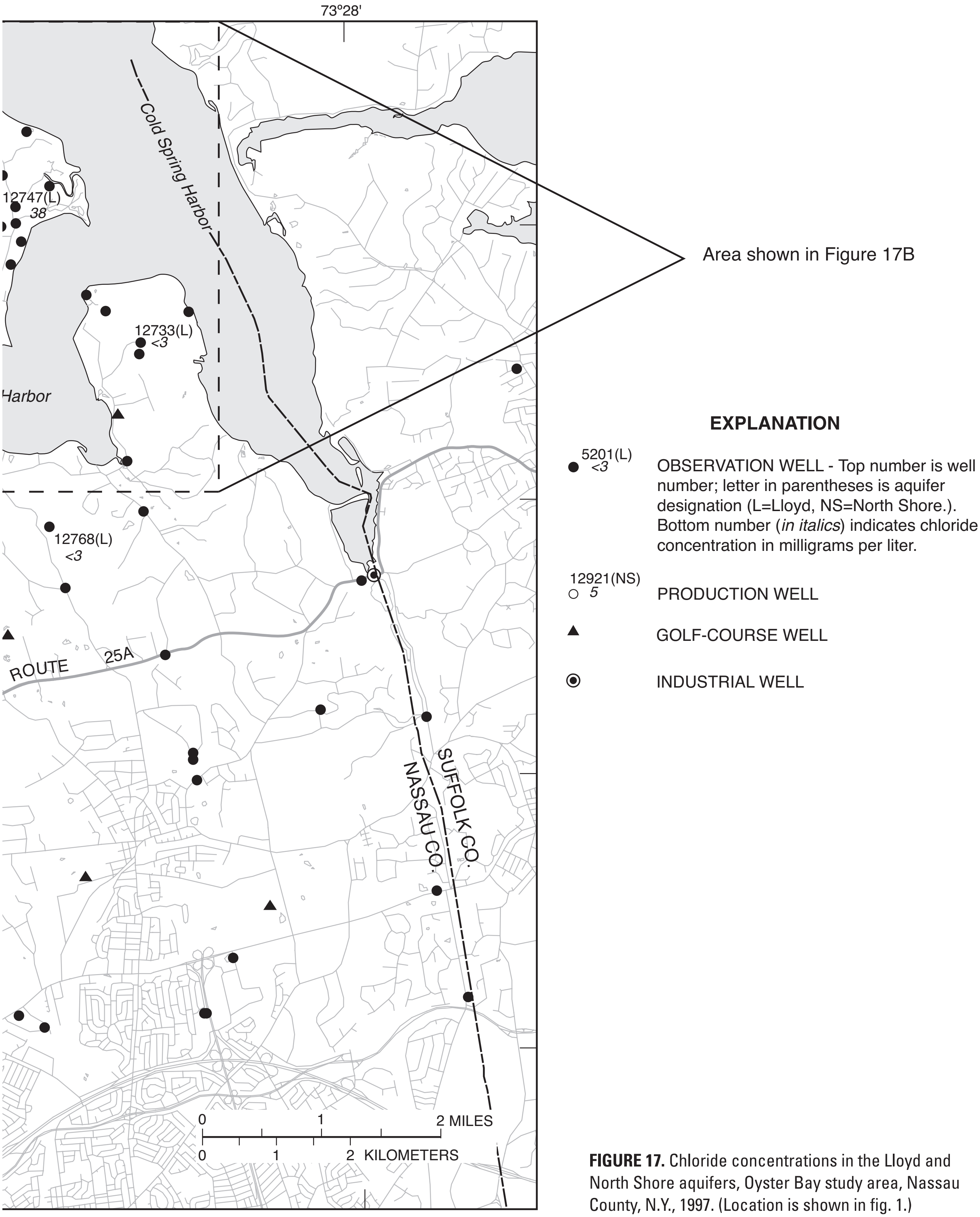
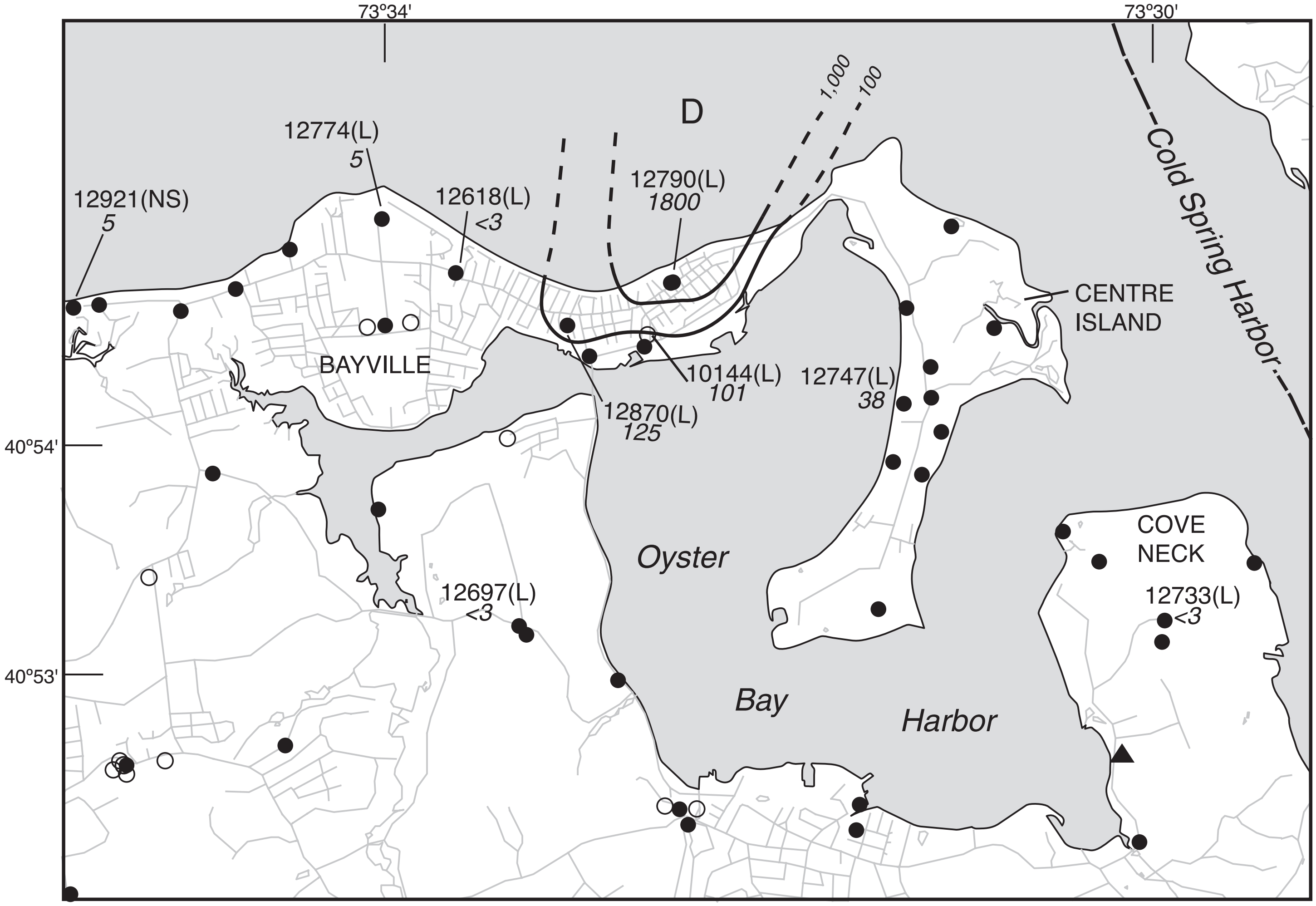


FIGURE 17. Chloride concentrations in the Lloyd and North Shore aquifers, Oyster Bay study area, Nassau County, N.Y., 1997. (Location is shown in fig. 1.)



EXPLANATION

1000	LINE OF EQUAL CHLORIDE CONCENTRATION -- Dashed where inferred. Concentration is in milligrams per liter.
D	SALTWATER WEDGE
12921(NS) *5* ●	OBSERVATION WELL -- Top number is well number; letter in parentheses is aquifer designation (L = Lloyd, NS = North Shore). Bottom number (*in italics*) indicates chloride concentration in milligrams per liter.
10144(L) *101* ○	PRODUCTION WELL
▲	GOLF-COURSE WELL

FIGURE 17B. Chloride concentrations in the Lloyd and North Shore aquifers, Oyster Bay study area, Nassau County, N.Y., 1997. (Location is shown in fig. 17A.)

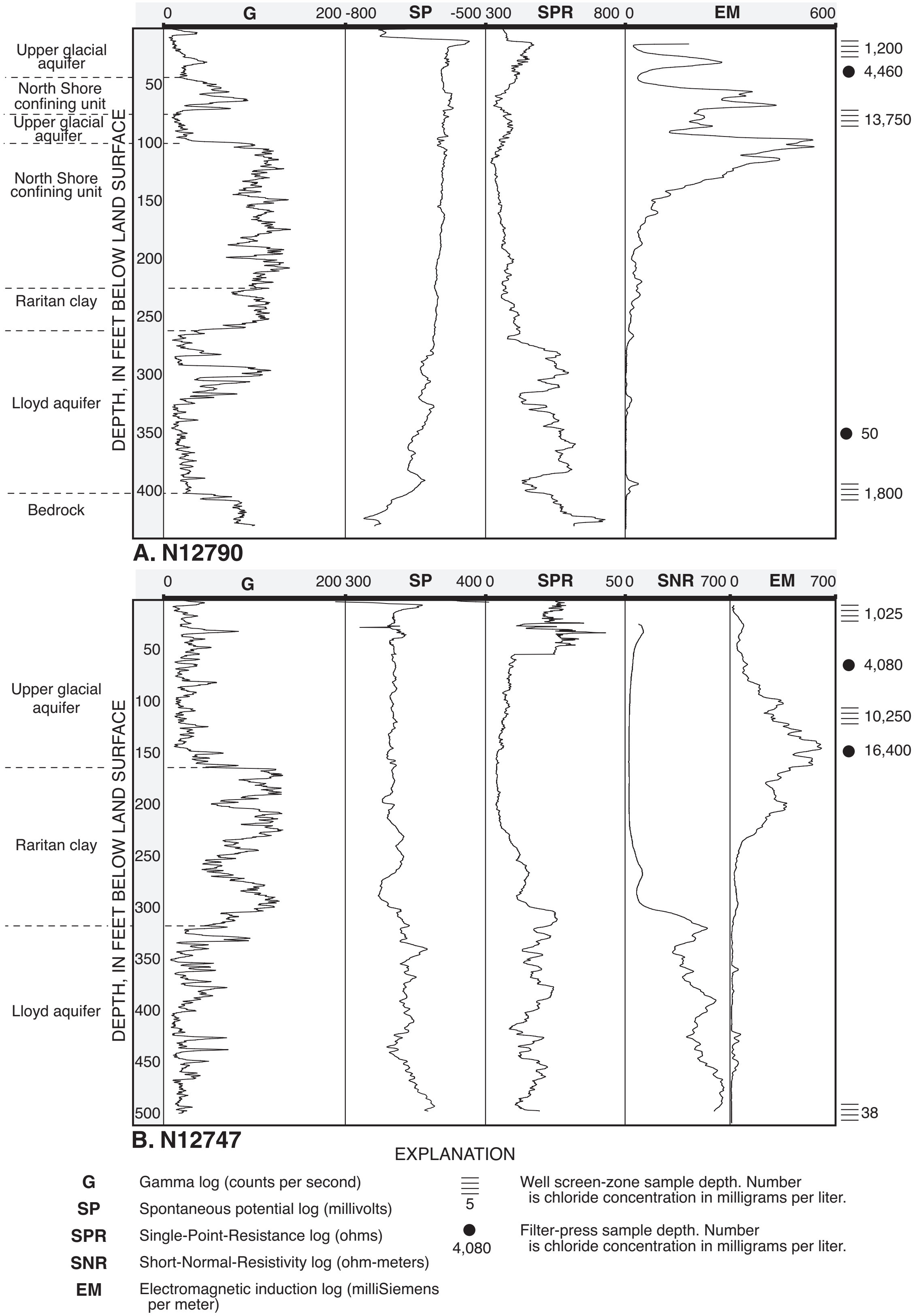


FIGURE 18. Geophysical logs from two observation wells in northern Oyster Bay study area, Nassau County, N.Y.: A. Well N12790. B. Well N12747. (Locations are shown in figure 2.)

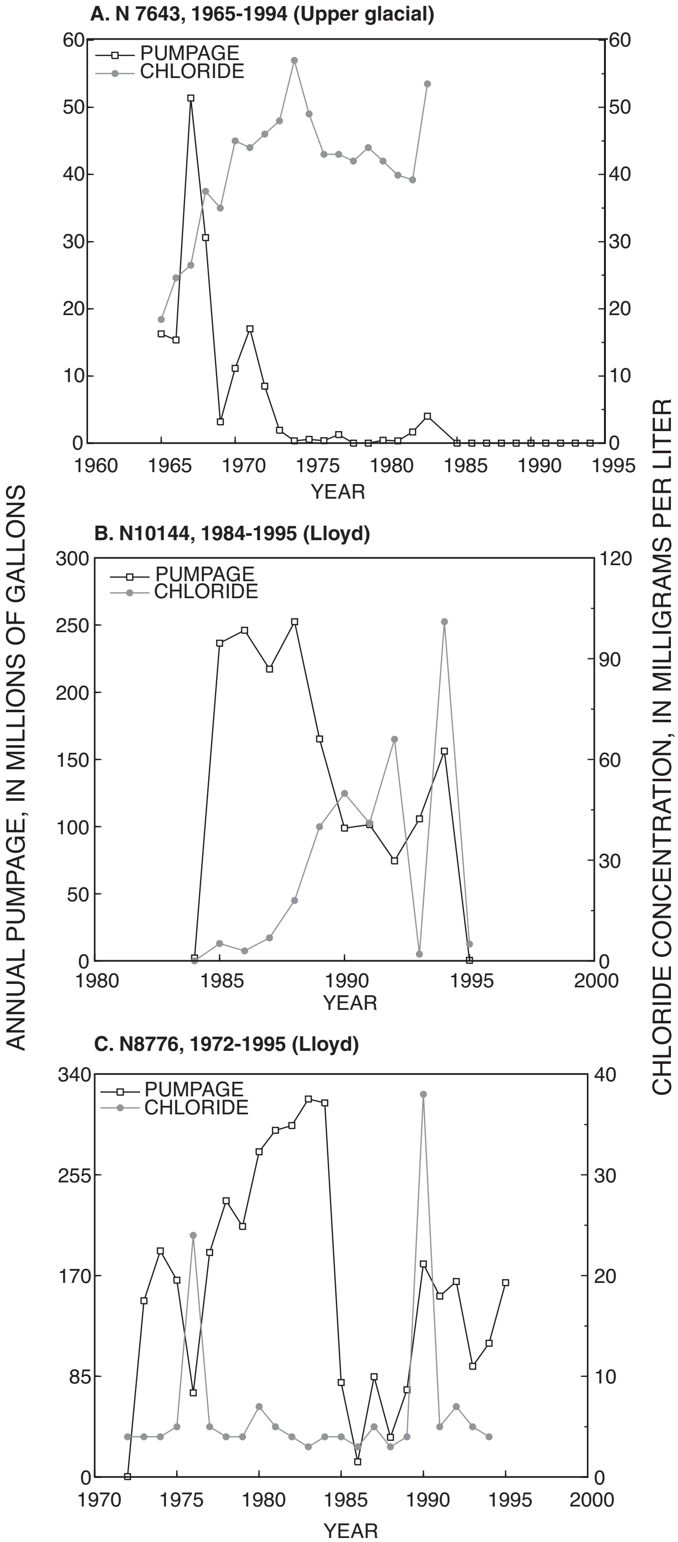


FIGURE 19. Chloride concentration and pumpage at selected production wells in northern Oyster Bay study area, Nassau County, N.Y.: A. Well N7643. B. Well N10144. C. Well N8776. (Locations are shown in figure 2; incorporated village of Bayville.)

area, where the Raritan has been completely removed. The Magothy aquifer has been removed by glacial erosion in the northern and central parts of the study area, except just west and south of Oyster Bay Harbor.

Marine-seismic-reflection surveys, borehole geophysical logs, and drill-core samples were used to correlate offshore glacial-lake deposits with buried valleys that extend across the study area. Marine-seismic-reflection profiles in Long Island Sound, Hempstead Harbor, Oyster Bay Harbor, and Cold Spring Harbor indicate silt and clay deposits that infill four sharply defined buried valleys that truncate the surrounding coarse-grained deposits. The valleys are asymmetrical, steep sided, northwest-southeast-trending, are several miles long, and about 1 mi wide. The floors of these valleys extend to bedrock; their depths range from 250 ft to more than 500 ft below sea level.

The upper glacial aquifer consists of till, sand, gravel, silt, and clay deposits underlain in some areas by the North Shore confining unit. The marine-seismic-reflection surveys and drill-core data indicate that the upper glacial aquifer does not extend far offshore and does not infill the valleys beneath Hempstead Harbor and Cold Spring Harbor, as proposed in previous studies. The water table is in the upper glacial aquifer in all but the southern part of the town of Oyster Bay, where it is in the Magothy aquifer.

Water-level data from quarterly measurements and continuous water-level recorders during 1995-98 indicate that the upper glacial aquifer is hydraulically connected to the Magothy aquifer in the study area and that water levels in these aquifers did not respond to tidal fluctuations. However, water levels in the Lloyd and North Shore aquifers, which are hydraulically connected, were affected by production pumping and by tides.

The potentiometric surface of the Lloyd and North Shore aquifers in July 1997 indicates a large cone of depression that results from production pumping. Water levels ranged from 58 ft above to about 2 ft below mean sea level. However, water levels were measured more than 10 ft below mean 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 saltwater intrusion in the study area.

Water from three production wells and six 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 level (MCL) of 0.005 mg/L. Two production wells contained high iron or nitrate concentrations, and were shut down as a result; water from 39 observation wells screened in the upper glacial, Magothy and Lloyd aquifers had iron concentrations in excess of the State's MCL of 0.3 mg/L.

The chloride concentration at production wells screened in the upper glacial and Magothy aquifers ranged from 5 to 75 mg/L. Production well N10144, which is near Bayville and is screened in the Lloyd aquifer, had a maximum chloride concentration in 1994 of 101 mg/L and was subsequently shut down. No production wells screened in the Lloyd aquifer had chloride concentrations that exceeded the State's MCL of 250 mg/L in 1998. Chloride concentrations at seven observation wells screened in the upper glacial aquifer and one well screened in the Lloyd aquifer, exceeded the State MCL; one observation well screened in the Magothy aquifer had a chloride concentration of 170 mg/L.

Four areas of saltwater intrusion were delineated—three in the upper glacial aquifer and one in the Lloyd aquifer. The saltwater wedges decreased in thickness landward and had relatively sharp saltwater-freshwater interfaces.

Saltwater wedge A was at the base of the upper glacial aquifer in the easternmost part of Bayville and most of Centre Island. Water from observation wells N12791, N12946, and N12755 had chloride concentrations of 13,750, 8,500, and 10,250, respectively. Geophysical logs of wells N12791 and N12747 from 1997 indicated that all of the upper glacial aquifer at these sites contained saltwater.

Saltwater wedge B was in the upper glacial aquifer about 0.4 mi northwest of wedge A. Observation well N12775 had a chloride concentration of 4,250 mg/L. In 1997, the wedge at well N12774 was about 25 ft thick; its sharp interface indicated active saltwater intrusion from overpumping. In 1997, wedge B appeared to be migrating landward toward the production pumping center south of well N12774. The wedge extended past well N7152, at which the chloride concentration in 1966 was 5,400 mg/L.

Saltwater wedge C, within the upper glacial aquifer, was on the northwest coast of Cove Neck. Drillers' logs of several upper glacial wells indicated elevated chloride concentrations; but the wedge's extent or thickness was unknown because observation wells were lacking.

Saltwater wedge D caused the shutdown and abandonment of production well N10144, which is near Bayville and is screened in the Lloyd aquifer. Chloride concentrations at this well increased so rapidly in the 10 years after the well's installation in 1984 that this well had to be shut down. Water from observation well N12790, along the eastern coast of Bayville, had a chloride concentration of 1,800 mg/L in 1998. The wedge was thin and extended westward to the vicinity of well N12870, which had a peak chloride concentration of 125 mg/L in 1997.

Production pumping of Lloyd aquifer wells in western Bayville appears to have lowered Lloyd aquifer water levels to below sea level as of 1997. The Lloyd aquifer in western Bayville was not affected by saltwater intrusion as of 1998, but the rapid saltwater intrusion in eastern Bayville indicates that it may be prone to saltwater intrusion.

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