HYDROGEOLOGIC FRAMEWORK AND EXTENT OF SALTWATER INTRUSION ON THE MANHASSET NECK PENINSULA, LONG ISLAND, NEW YORK, BY USE OF HYDROGEOLOGIC AND GEOPHYSICAL METHODS

by
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ABSTRACT

Manhasset Neck, a peninsula on the northern shore of Long Island, is underlain by unconsolidated deposits that form a sequence of aquifers and confining units. Ground water at several public-supply wells has been affected by the intrusion of saltwater from the surrounding embayments. Fifteen wells were drilled in 1993-95 for the collection of hydrogeologic, geochemical, and geophysical data (gamma, electric, and induction logs) to delineate the peninsula's subsurface geology and the extent of saltwater intrusion. A series of offshore continuous high-resolution seismic-reflection surveys were completed in 1993 and 1994 to delineate the character and extent of the hydrogeologic deposits beneath Manhasset Bay and Hempstead Harbor, which bound the Manhasset Neck peninsula on the west and east, respectively.

Water levels in wells screened within the confined Port Washington(?) and Lloyd aquifers respond to tidal fluctuations and pumping, but those in the overlying upper glacial (water-table) aquifer do not. Data from synoptic water-level measurements indicate that the Port Washington and Lloyd aquifers are hydraulically connected and that water levels in these aquifers have been lowered to below sea level by pumping at nearby public-supply wells and golf-course wells.

The continuous seismic-reflection surveys identified at least four northwest-southeast-trending buried valleys beneath the northern coast of Manhasset Neck from Manhasset Bay to Hempstead Harbor. The valleys are interpreted to be filled with silt, clay, and sand. Hydrogeologic and geophysical data were used to delineate the landward extent of some of these valleys.

Five areas of saltwater intrusion in Manhasset Neck were delineated by geophysical logging and from water-quality data. The thickness of these zones ranges from a few feet to 105 feet, and the maximum chloride concentrations ranges from 103 to 6,650 milligrams per liter.

INTRODUCTION

Manhasset Neck, a highly populated peninsula on the northern shore of Nassau County, is 3.0 mi (miles) wide and 6.0 mi long and bounded on the west by Manhasset Bay, on the north by Long Island Sound, and on the east by Hempstead Harbor (fig. 1). The peninsula is underlain by unconsolidated deposits that form a sequence of aquifers and confining units. Ground water is the sole source of drinking water for the peninsula. Pumping of public-supply wells and golf-course wells in the Lloyd and Port Washington aquifers typically lowers the hydraulic head to below sea level in Manhasset Neck; this creates a landward gradient that induces saltwater encroachment from the surrounding embayments into the Lloyd and Port Washington aquifers. Contamination of several public-supply wells by saltwater has prompted concern over the potential for further saltwater intrusion.

In 1993-95, the U.S. Geological Survey (USGS), in cooperation with the Nassau County Department of Public Works, investigated the hydrogeology and the extent of saltwater intrusion on the Manhasset Neck Peninsula by drilling, geophysical logging, water-quality sampling, and seismic-reflection surveying. Fifteen observation wells were drilled, and geologic cores and ground-water samples were correlated with borehole geophysical (gamma, electric, and induction) logs. A series of continuous seismic-reflection surveys was conducted in 1993 and 1994 in the embayments surrounding Manhasset Neck and Great Neck (to the west) to investigate and characterize the unconsolidated deposits beneath the embayment floors. Several buried valleys had been delineated previously in the Great Neck Peninsula , which has similar geomorphic features and hydrogeologic deposits (Stumm and Lange, 1994; Stumm, 1995). Geophysical logging and water-quality sampling (observation wells and filter-press) were used to delineate areas of saltwater intrusion within the peninsula.

This paper (1) describes the hydrogeology of the peninsula, (2) delineates two buried valleys identified by seismic-reflection surveys, and (3) defines five areas of saltwater intrusion that were delineated by geophysical logs and water-quality data.

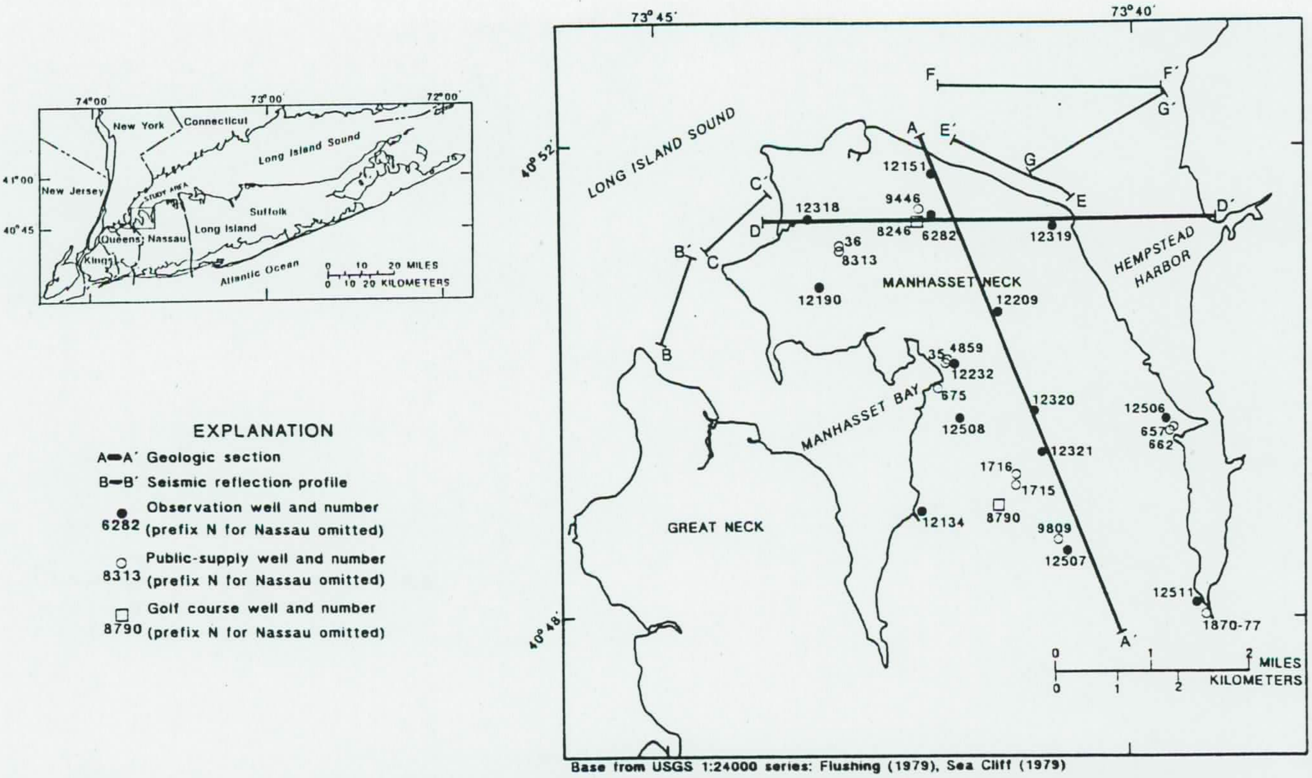


Figure 1.-- Locations of observation wells, geologic sections, and seismic-reflection profiles on Manhasset Neck., Nassau County, N.Y.

METHODS AND RESULTS OF DELINEATION

Fifteen observation wells were drilled, and geologic cores and borehole geophysical logs (gamma and electric) were analyzed to define the hydrogeologic framework. A series of continuous seismic-reflection surveys was conducted to characterize the unconsolidated deposits beneath the embayment floors. Ground-water samples were correlated with borehole geophysical (gamma, electric, and induction) logs to delineate areas of saltwater intrusion.

Hydrogeologic Framework

The Manhasset Neck peninsula is underlain by unconsolidated deposits of Cretaceous and upper Pleistocene age (Kilburn, 1979; Swarzenski, 1963) that form two major aquifers and two confining units (fig. 2). The unconsolidated deposits rest unconformably on bedrock. Extensive glacial scouring and erosion of the Cretaceous deposits in the northern and western parts of Manhasset Neck are indicated by the geologic data obtained during drilling.

The upper glacial (water-table) aquifer, in deposits of Pleistocene age (Suter and others, 1949), consists of various till, sand, gravel, and clay layers underlain in some areas by a gray clay that could be equivalent to the Port Washington confining unit described by Kilburn (1979) and Casson (1992). Another aquifer that could be part of the Port Washington aquifer described by Kilburn (1979) was found in the northern and westernmost parts of the peninsula. The Port Washington(?) aquifer consists of brown and gray sand in contact with the bedrock surface and is confined by the Port Washington confining unit. Hydraulic-head data indicate that the aquifer is hydraulically connected to the Lloyd aquifer to the south.

Also underlying the upper glacial aquifer in the eastern and southern parts of Manhasset Neck is the Raritan clay of Cretaceous age (Suter and others, 1949), which consists of solid (dense), multicolored clays. Glacial erosion has scoured and removed parts of the Raritan clay in the northern and western part of the peninsula.

The Lloyd aquifer consists of discontinuous layers of gravel, sand, and clay of Cretaceous age (Suter and others, 1949); it increases in thickness southeastward within the peninsula and is overlain and confined by the

Raritan clay. Geologic data obtained during drilling indicate that the Lloyd aquifer underlies all but the northernmost and western part of Manhasset Neck (wells N-12209, N-12318, and N-12151, fig 1.), where it and the Raritan clay were removed by glacial erosion.

The unconsolidated deposits beneath Manhasset Neck are underlain by crystalline-metamorphic bedrock. A 50- to 100-ft (foot)-thick zone of highly weathered bedrock, or saprolite, is present, except in areas of the peninsula where some or all of it was removed by extensive glacial scouring (northern and western parts). The bedrock surface forms a relatively impermeable boundary for Long Island's ground-water system (Franke and McClymonds, 1972).

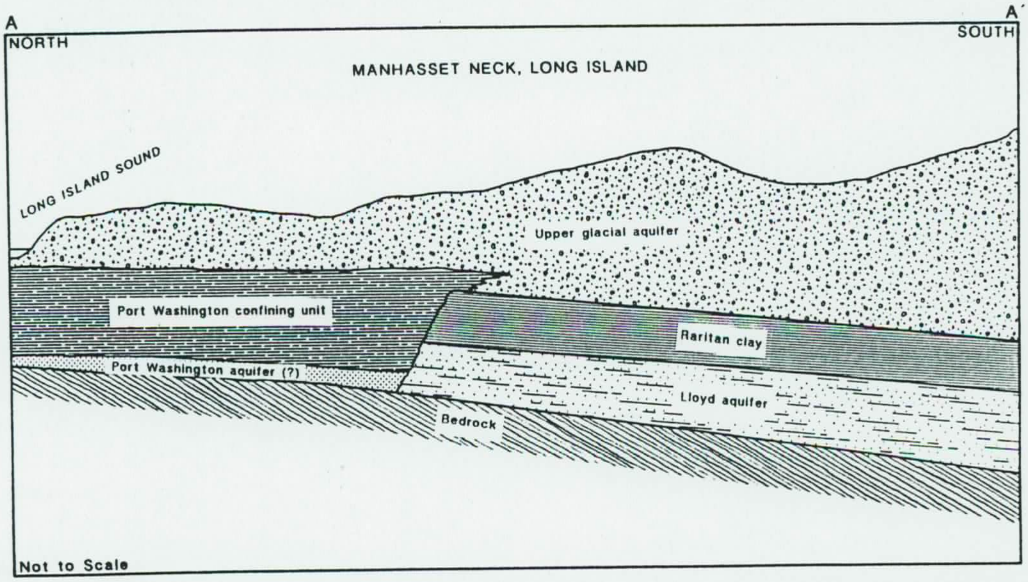


Figure 2.-- Generalized north-south geologic section of the Manhasset Neck peninsula, Nassau County, N.Y. (location shown in fig. 1).

Borehole-Geophysical Logs

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

Spontaneous-potential (SP) logs --These logs provide a record of the potentials that develop at the contacts between clay beds and sand aquifers within a borehole (Keys, 1990). SP logs are used to determine lithology, bed thickness, and salinity of interstitial fluids (Keys, 1990: Serra, 1984).

Single-point-resistance (SPR) logs--These logs provide a measure of the resistance, in ohms, between an electrode in the borehole and an electrode at land surface. SPR logs are affected by the borehole fluid and are used to obtain high-resolution lithologic information (Keys, 1990).

Normal-resistivity (R) logs --Two electrodes are spaced 16 or 64 inches apart in the borehole to measure apparent resistivity, in ohm-meters (Keys, 1990). These logs are used to determine lithology and interstitial fluid quality (salinity).

Natural-gamma radiation (gamma) logs--Gamma logs are a record of the total gamma radiation detected in a borehole (Keys, 1990). Clays and fine-grained sediments tend to be stronger gamma emitters than the quartz-rich sand found on Long Island. Gamma logs are used for lithologic and stratagraphic correlation.

Focused electromagnetic-induction (EM) logs--These logs are obtained from an electromagnetic emitter coil that induces current loops within the surrounding formation to generate a secondary electromagnetic field. The intensity of the secondary electromagnetic field received by the receiver coil is proportional to the formation conductivity (Keys, 1990; McNeil, 1986; Serra, 1984; Keys and MacCary, 1971). EM logs are inversely proportional to normal-resistivity logs but are focused and, thus, are less affected by borehole influences. EM logging has been used to delineate the saltwater-freshwater interface on Long Island (Stumm, 1993; Stumm and Lange, 1994; Chu and Stumm; 1995), landfill leachate in New Hampshire (Mack, 1993), and septage effluent in Massachusetts (DeSimone and Barlow, 1994).

Continuous High-Resolution Seismic-Reflection Surveys

Offshore continuous high-resolution seismic-reflection surveys can be used to interpret the depth and continuity of seismic reflectors, and lithology (Haeni, 1986; 1988). Applications of this technique for hydrogeologic and water-resource studies have been described by Haeni (1986, 1988) and by Reynolds and Williams (1988). Smith (1958) described the first use of high-power, low-frequency seismic-reflection equipment to determine the depth to bedrock beneath selected areas of Long Island Sound. Oliver and Drake (1951) determined the depth to bedrock in Long Island Sound basin using seismic refraction techniques. Williams (1981) used high-resolution seismic-reflection surveys and core samples to describe the sediments beneath Long Island Sound. Lewis and Stone (1991) conducted a systematic seismic-reflection survey to map the deposits beneath most of Long Island Sound, but not the immediate coastal areas and embayments of Long Island's north shore. Grim and others (1970) describe a stratified mantle of glacial-lake sediments that fill the Long Island Sound basin, and channels that correspond to the embayments of Manhasset Bay and Hempstead Harbor.

Several continuous high-resolution seismic-reflection profiles were completed in 1993 and 1994 along the coast of Great Neck and Manhasset Neck to identify the unconsolidated deposits of the subsurface from Manhasset Bay to Hempstead Harbor and to correlate these deposits with geologic and geophysical data obtained from drilling on the peninsulas. The continuous seismic-reflection system consisted of a graphic recorder, an amplifier/filter, power generator, a catamaran-mounted sound source, a hydrophone array, and a digital tape recorder, all of which were installed in a shallow-draft 20-ft boat. The sound source and hydrophone array were towed behind the slowly moving boat, where the seismic-reflection data were digitally recorded and filtered for real-time graphic display.

The seismic signals generated by the sound source travel through the water column and penetrate the deposits underlying the water bottom. Part of the seismic signal is reflected back to the water surface from the water bottom and the interfaces within the deposits at which a change in the acoustic impedance (the product of the density and acoustic velocity of each medium) is encountered (Haeni, 1986; Robinson and Couch, 1988). The reflected signals received by the hydrophone array produce an electrical signal that is then amplified, recorded on digital tape, filtered, and plotted. The resulting seismic section resembles a vertical geologic section, except that the vertical axis is a function of the time required for the seismic signal to travel from the source to the reflector and return (Haeni, 1986). The acoustic velocity of the medium involved is used to convert the two-way traveltime of the seismic signal to an approximate depth scale. Several seismic-reflection and refraction studies indicate that the average velocity of unconsolidated saturated glacial deposits is about 5,000 feet per second (Haeni, 1988; Reynolds and Williams, 1988); this was used as an average velocity in this study. The seismic results were correlated with geologic logs of nearshore observation wells.

Stratigraphic Interpretation

A major result of the observation-well drilling, geophysical logging, and seismic-reflection survey was the discovery of several buried valleys that trend northwest-southeast, are infilled with silt and clay, and extend landward onto Great Neck and Manhasset Neck. Seismic-reflection profile B-B', off the northernmost shore of Great Neck and across the opening of Manhasset Bay, is typical of the buried valleys (fig. 3) (Stumm and Lange, 1994). The water depth here ranges from 20 to 60 ft. The first subsurface reflector is interpreted as the top of a complex, layered unit of silt and sand. Beneath this unit are several draped, parallel reflections interpreted as silt and clay. This extensive deposit fills an asymmetrical valley about 1 mi wide that extends to about 235 ft below sea level. Several seismic-reflection profiles within Manhasset Bay indicate the valley to be more than 2.5 mi long.

Geologic section D-D' (fig. 4) indicates the position and depth of several buried valleys in relation to the surrounding hydrogeologic units obtained from observation-well data and seismic-reflection surveys. Geologic, geophysical and seismic-reflection data indicate that several buried valleys truncate the surrounding hydrogeologic deposits along sharply defined boundaries and are mostly infilled by lacustrine silt and clay. Three of these distinct buried valleys truncate the surrounding hydrogeologic framework in geologic section D-D' . The buried valleys vary in thickness, with the thickest or deepest valleys on the eastern part of the peninsula. The depth of some of the valleys appear to be controlled by the depth to bedrock.

Comparison of geologic and gamma logs of well N-6282 and N-12151 with those of observation wells N-12319, and N-12318 indicates a buried glacial valley within the area occupied by wells N-6282 and N-12151 (figs. 1 and 4). The geologic log of well N-12318 indicates 165 ft of poorly sorted sand, silt, cobbles, and boulders on top of bedrock whereas, the geologic and gamma logs of wells N-12151 and N-6282 indicate about 120 ft of poorly sorted sand, gravel, and silt underlain by 200 ft of soft, gray silt and clay. Beneath these deposits (wells N-12151 and N-6282) is a 40-to 50-ft-thick layer of gray sand that overlies bedrock. The geologic and gamma logs of observation well N-12319 indicate the presence of 175 ft of sand, gravel, and clay layers. The Raritan clay was penetrated from

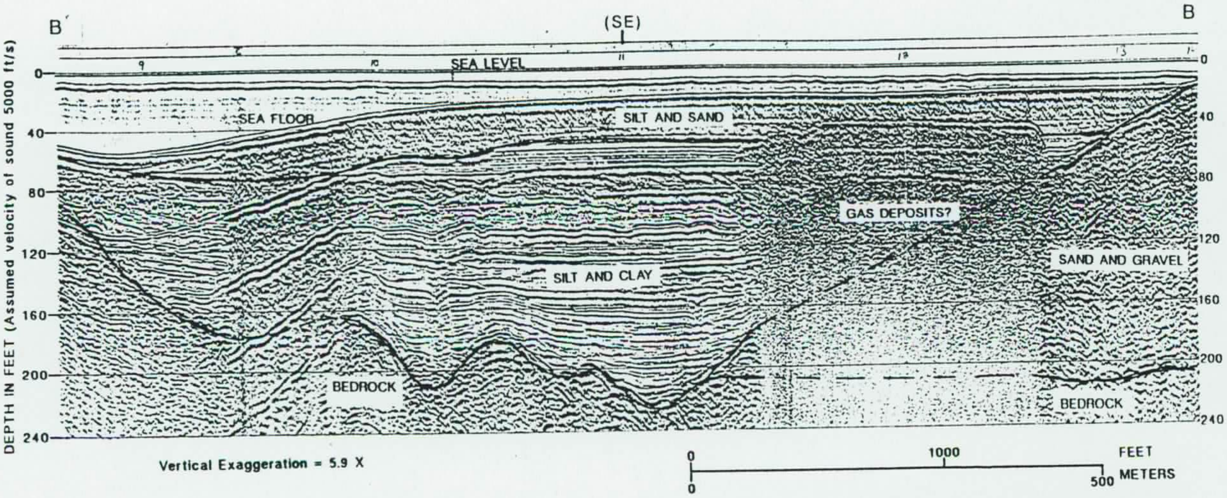


Figure 3.-- Interpreted stratigraphy along seismic-reflection profile B-B', Manhasset Bay, Nassau County, N.Y. (location shown in fig.1). (Modified from Stumm and Lange, 1994.)

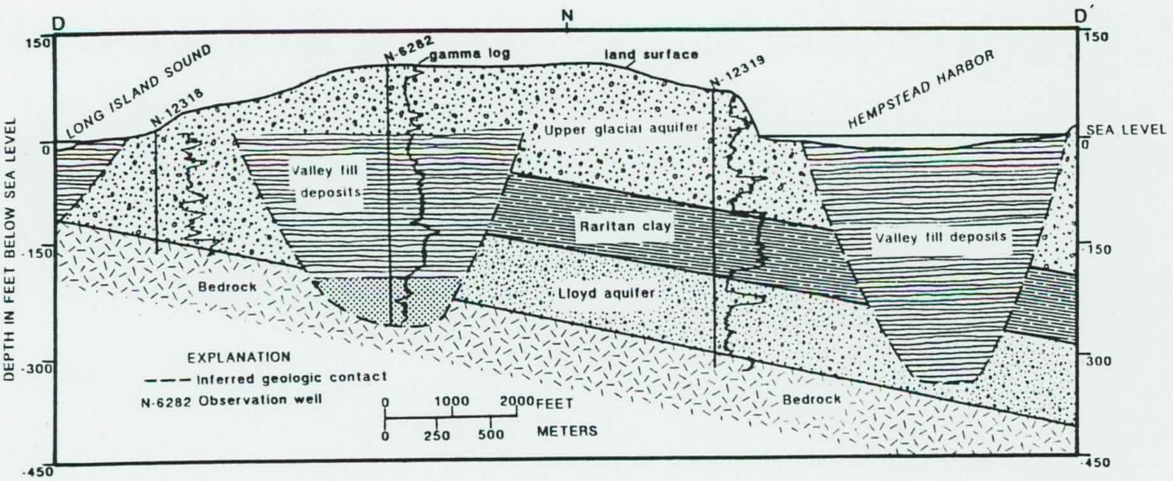


Figure 4.-- Geologic section of D-D', Manhasset Neck, N.Y. (location shown in fig. 1).

110 to 200 ft below sea level. The Lloyd Sand Member of the Raritan Formation underlies these units and overlies weathered bedrock at 315 ft below sea level. This is as far north in Manhasset Neck that Cretaceous deposits have been previously mapped (Swarzenski, 1963; Kilburn, 1979; Casson, 1992). Seismic section E-E' (not shown) suggests a buried valley in the western part of the section that truncates the surrounding deposits. The seismic-reflection profile of the valley is dominated by subhorizontal parallel reflections, which are interpreted to be silt and clay deposits, to a depth of almost 300 ft below sea level. To the east, the seismic reflection profiles correlate with the geologic and geophysical logs from well N-12151.

Seismic sections F-F' (not shown) and G-G' (fig. 5) delineate the buried valley beneath Hempstead Harbor. The valley is almost 1 mi wide and extends 400 ft below sea level. The depth of water here is 30 ft . The first subsurface reflector is interpreted as the top of a complex layered unit of sand and silt about 30 ft thick, beneath which are several draped, parallel reflections that are interpreted as silt and clay more than 300 ft thick. This extensive unit underlies the northern part of the Hempstead Harbor.

Saltwater Intrusion

Several observation wells were drilled in Manhasset Neck during 1993-95, for collection of geologic, geophysical, and geochemical data. Filter-press samples obtained by a nitrogen-gas-pressurized chamber to force

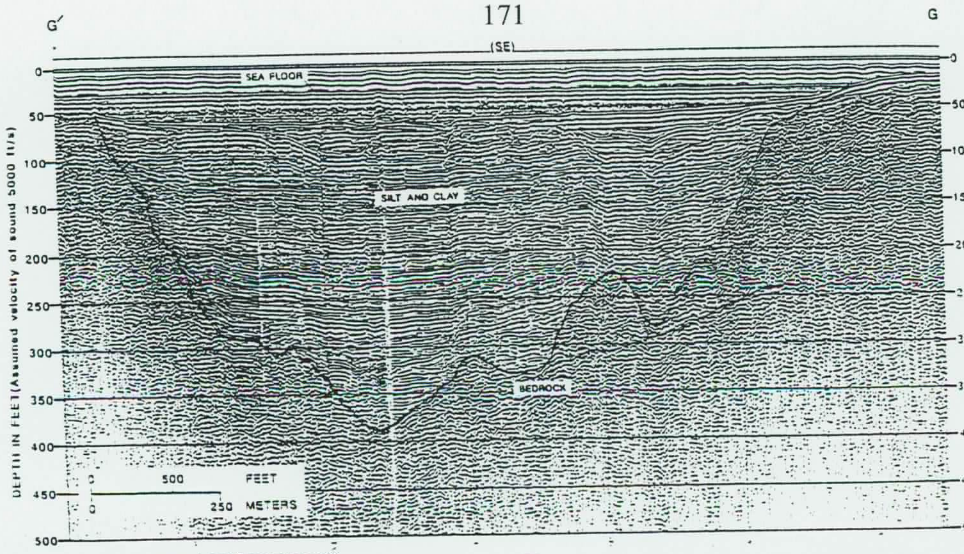
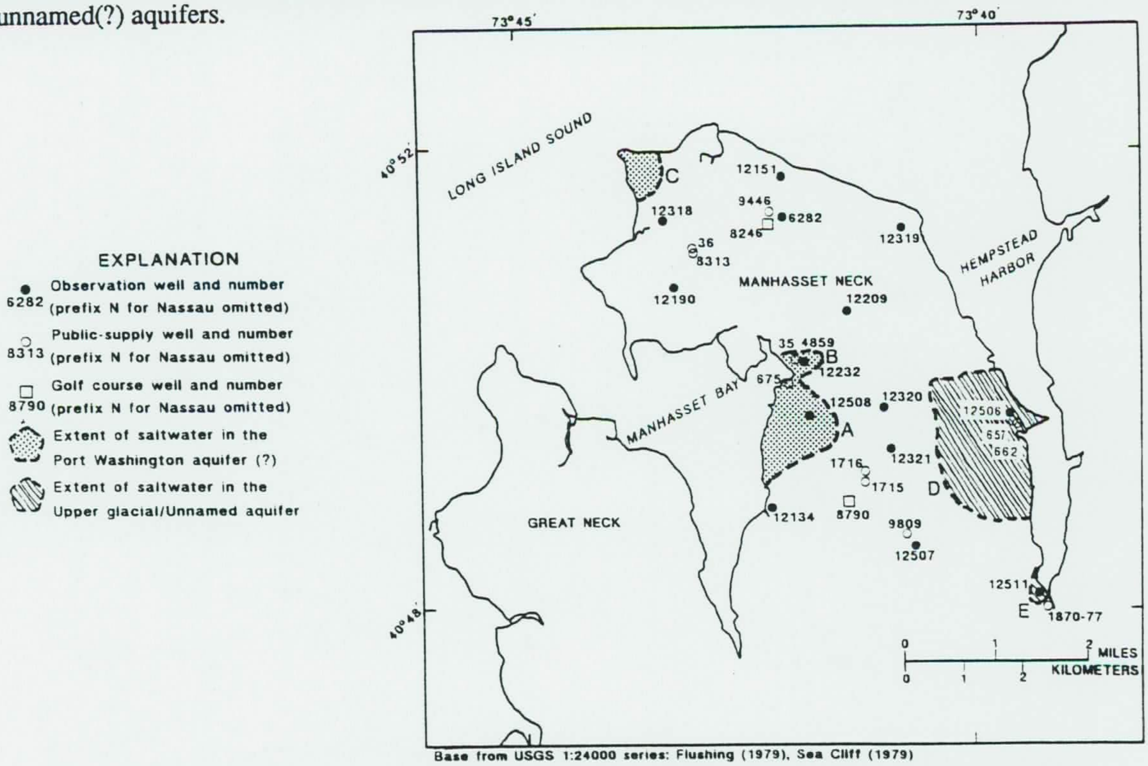


Figure 5.-- Interpreted stratigraphy along seismic-reflection profile G-G′, Hempstead Harbor, Nassau County, N.Y. (location shown fig. 1).

interstitial water from uninvaded parts of a core sample (Lusczynski, 1961) that was obtained during drilling, were analyzed for chloride concentration and correlated with water-quality samples, geologic logs, and geophysical (gamma, electric, and induction) logs to delineate the extent of saltwater intrusion. In this paper, the term "brackish" water is water with chloride concentrations of 40 to 250 mg/L (milligrams per liter), and saltwater is defined as water with a chloride concentration greater than 250 mg/L (Lusczynski and Swarzenski, 1966, Chu and Stumm, 1995).

Five wedge-shaped zones of saltwater intrusion were identified in Manhasset Neck (fig. 6); three (A, B, and C) have intruded the Port Washington(?) aquifer, and the fourth (D) and fifth (E) have intruded the upper glacial/unnamed(?) aquifers.



Base from USGS 1:24000 series: Flushing (1979), Sea Cliff (1979)

Figure 6.-- Location of areas underlain by saltwater wedges A, B, C, D and E in Manhasset Neck, N.Y. (location shown in fig. 1).

Saltwater wedge A is in the western part of Manhasset Neck (fig. 6). The gamma log of well N-12508 indicates a thin upper glacial aquifer underlain by 225 ft of gray silt and clay of the Port Washington confining unit, which confines water in sand of the Port Washington aquifer(?) (fig. 7). The SPR log indicates a major deflection to the right in the upper 25 ft of the Port Washington aquifer(?) and a sudden deflection to the left in the remaining 105 ft. The R logs correlate with the SP and SPR logs and show a zone of low conductivity (high resistivity) in the upper 25 ft of the aquifer and a zone of high conductivity (low resistivity) at its base. The water sample has a chloride concentration of 600 mg/L. Geophysical logging indicates that saltwater has intruded most of the Port Washington aquifer in this area.

Saltwater wedge B, northwest of wedge A, caused the abandonment of public-supply well N-35 (maximum historical concentration 1,200 mg/L chloride) (fig. 6). This wedge extends through the entire thickness of the Port Washington(?) aquifer and has a maximum chloride concentration of 325 mg/L at well N-12232. Whether this wedge is connected to saltwater wedge A to the south is unclear. Chloride concentrations within wedge B have been decreasing, and those associated with wedge A have been increasing; this suggests that they are not connected.

A probable leading edge of saltwater wedge C (fig. 6) at the base of the Port Washington(?) aquifer at well N-12318 is indicated from chloride concentration and geophysical data. This wedge appears to be an interfingering of conductive, brackish ground water within permeable layers. The water sample has a chloride concentration of 103 mg/L, and the estimated peak concentration in the wedge, as inferred from induction-log responses, is 200 mg/L.

Saltwater wedge D is on the eastern shore of the peninsula in parts of a former sand-mining operation (fig. 6). Whether saltwater used in the excavation of sand was introduced into the upper glacial/unnamed aquifer from direct pumping of Hempstead Harbor, or from excessive pumping of industrial wells, or both, is unknown. The gamma log of well N-12506 indicates two major aquifers—the upper glacial/unnamed and the Lloyd (fig. 7). The Raritan clay separates the two aquifers, and a gray, silty clay confines water in the upper glacial/unnamed aquifer. The SP and SPR logs show no change in slope between the confining units and the upper glacial/unnamed aquifer, indicating that the aquifer contains conductive ground water (saltwater). A deflection in both SP and SPR logs within the Lloyd aquifer indicates that the Lloyd contains freshwater. Historical chloride data from nearby abandoned public-supply wells indicate that saltwater has intruded into the Lloyd aquifer in the past. Two distinct zones of resistivity are indicated by the R logs. Interstitial water within the upper glacial/unnamed aquifer is highly conductive (low resistivity), whereas water within the Lloyd aquifer is fresh, and poorly conductive (high resistivity). The EM log correlates with the electric logs and indicates saltwater throughout the entire 100-ft thickness of the upper glacial/unnamed aquifer and a maximum chloride concentration of 6,650 mg/L (fig. 7).

The fifth area of saltwater intrusion (wedge E) is along the southeastern most part of Manhasset Neck at well N-12511 (fig. 6). Gamma and resistivity logs were obtained during the drilling of this well. The geophysical logs indicate two major aquifers—the upper glacial and Lloyd—separated by the Raritan clay. The resistivity log shows an increase in conductivity (decrease in resistivity) with depth in the upper glacial aquifer, suggesting that a 45-ft-thick zone of conductive ground water (saltwater) has intruded into the base of the aquifer.

CONCLUSIONS

Fifteen observation wells were installed in Manhasset Neck during 1993-95 for collection of hydrogeologic, geochemical, and geophysical data. In 1993 and 1994, offshore high-resolution seismic-reflection surveys were used to identify the character and extent of the unconsolidated deposits beneath the embayments surrounding Manhasset Neck.

Water levels in wells screened within the confined Port Washington(?) and Lloyd aquifers respond to tidal fluctuations and pumping, but those in the overlying upper glacial (water-table) aquifer do not. Data from synoptic water-level measurements indicate that the Port Washington and Lloyd aquifers are hydraulically connected and that water levels in these aquifers have been lowered to below sea level by pumping from nearby public-supply wells and golf course wells.

At least four buried valleys beneath the northern coast of Manhasset Neck, from Manhasset Neck Bay to Hempstead Harbor, were delineated by seismic-reflection surveys. The valleys trend northwest-southeast and are filled with silt and clay. They range from 0.5 mi to about 1 mi wide, extend for several miles, and extend more than 300 ft below sea level. Hydrogeologic data from observation wells indicate that one of these valleys extends beneath the northern part of the Manhasset Neck peninsula and truncates the aquifers and confining units locally.

Geophysical logs, and water-quality data from filter-press and observation wells indicate at least five areas of saltwater intrusion in Manhasset Neck. The southwesternmost wedge, which is about 100 ft thick, is at the base of the Port Washington aquifer and has a maximum chloride concentration of 600 mg/L. The wedge to the northwest

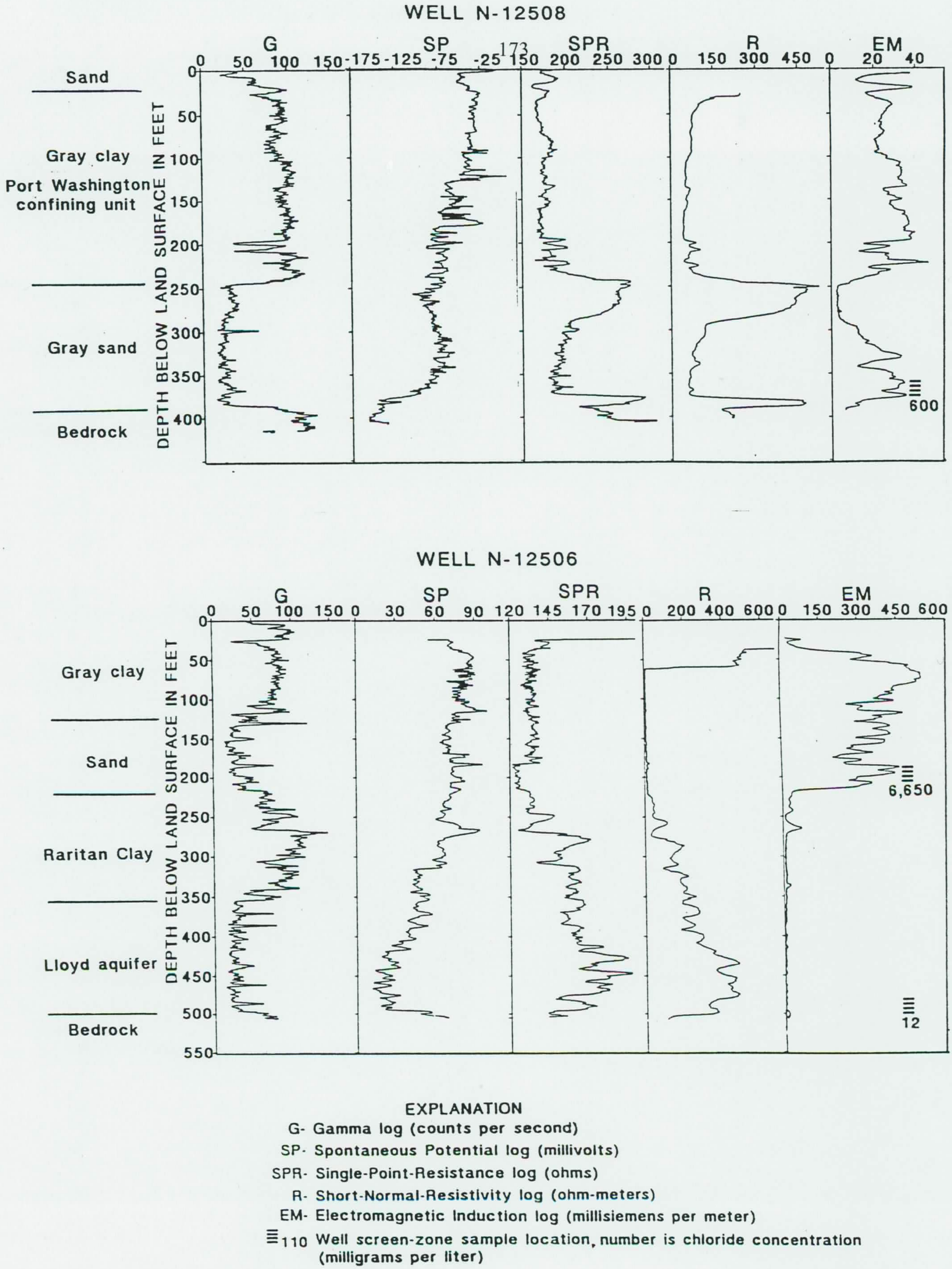


Figure 7 - Geophysical logs of wells N-12508 and N-12506 in Manhasset Neck, N.Y. (location shown in fig. 1).

extends through the Port Washington aquifer's entire thickness and has a maximum chloride concentration of 325 mg/L. A third (probable) wedge, on the northern shore in the Port Washington aquifer(?), has a maximum chloride concentration of about 100 mg/L. A fourth wedge, on the eastern shore in the upper glacial aquifer/unnamed aquifer(?) is about 100 ft thick and has a maximum chloride concentration of 6,650 mg/L. The fifth wedge, in the southeasternmost part of the peninsula, at the base of the upper glacial/unnamed aquifer(?) is about 45 ft thick.

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