HYDROGEOLOGIC CONDITIONS IN THE TOWN OF SHELTER ISLAND, SUFFOLK COUNTY, LONG ISLAND, NEW YORK

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-77

Prepared in cooperation with the

Suffolk County Department of Environmental Control

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16. Abstracts The upper glacial aquifer is the sole source of freshwater for a slowly growing population, currently 2,000 to 8,000 seasonally, on Shelter Island (area 11 square miles), between the north and south forks of eastern Long Island. The aquifer is readily susceptible to lateral infiltration by surrounding saline ground water. Clay beds underlying the aquifer contain saline water, and formations below the clay probably contain saline water. Fresh ground water is mostly soft and low in dissolved-solids concentrations; however, several wells near shorelines have yielded salty water from saline-water infiltration. Analyses of well water indicate that contamination of the aquifer by sewage is evident but not severe. The hydrogeologic system is not in equilibrium, and deterioration of water quality is expected to gradually increase as increased pumping of fresh ground water causes further saline-water infiltration and introduces additional effluent to the aquifer from septic tanks and cesspools. Test drilling could help water-supply management by determining the extent of the aquifer, and observation wells could provide early detection of saline infiltration.

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UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

W. A. Radlinski, Acting Director

For additional information write to:

U.S. Geological Survey
5 Aerial Way
Syosset, NY 11791

CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS, AND ABBREVIATIONS OF UNITS

Multiply English unit	by	to obtain SI unit
	Length	
inches (in.)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)

CONVERSION FACTORS (Continued)

	Area	
square miles (mi^2)	2,590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	liters (L)
	Flow	
feet per day (ft/d)	0.3048	meters per second (m/s)
gallons per minute (gal/min)	.06309	liters per second (L/s)
gallons per day (gal/d)	3.785	liters per day (L/d)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,460	cubic meters per day per square kilometer [(m^3/d)/km^2]
	Temperature	
degrees Fahrenheit (°F)	5/9(°F-32)	degrees Celsius (°C)
	Specific Capacity	
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(L/s)/m]
	Hydraulic conductivity	
feet per day (ft/d)	0.3048	meters per day (m/d)
	Slope	
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)

HYDROGEOLOGIC CONDITIONS IN THE TOWN OF SHELTER ISLAND

SUFFOLK COUNTY, LONG ISLAND, NEW YORK

by

Julian Soren

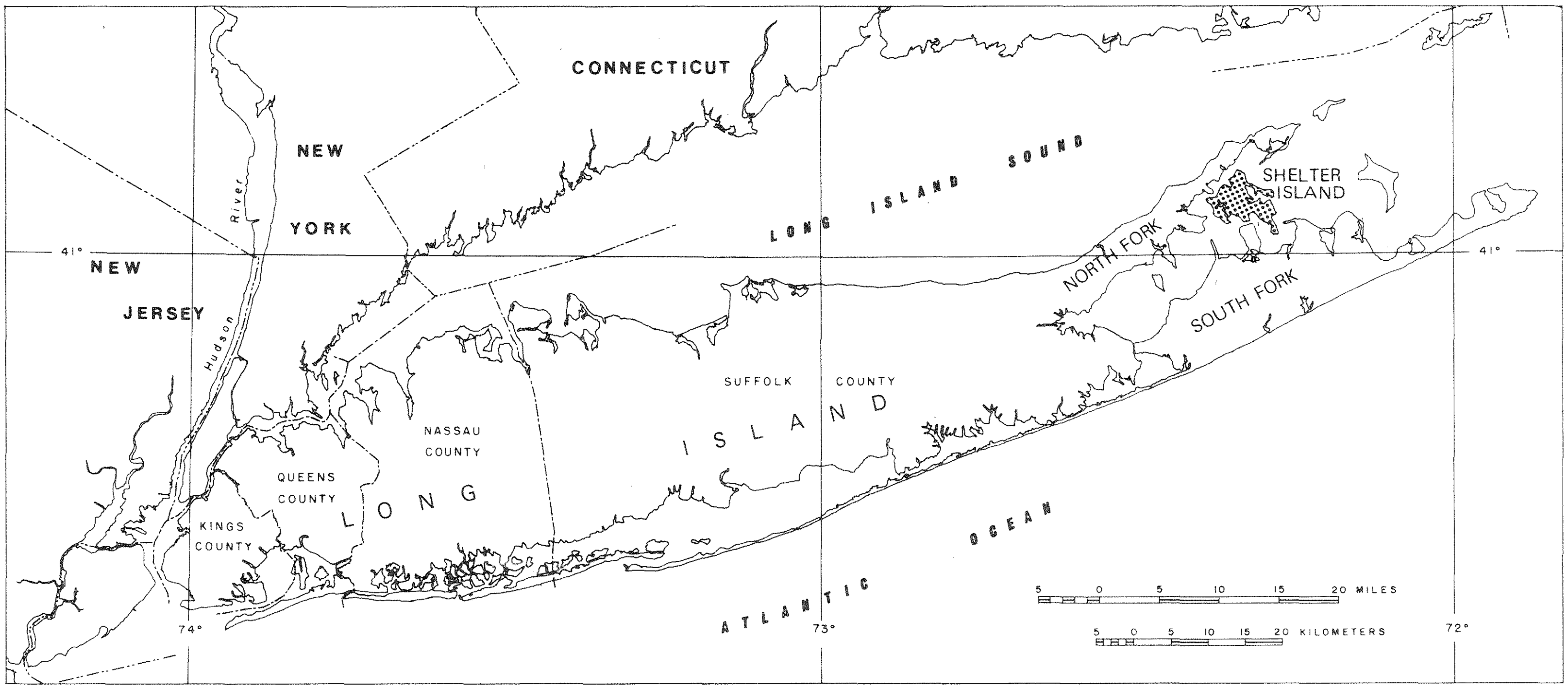
ABSTRACT

Shelter Island, an area of about 11 square miles, in Suffolk County, N.Y., is situated between the north and south forks of eastern Long Island. The upper glacial aquifer is the sole source of freshwater supply for Shelter Island's population, which currently ranges seasonally from 2,000 to 8,000. Fresh ground water seems to be limited to sand and gravel deposits in the aquifer, which is thin and can be readily infiltrated by surrounding saline ground water. Exploratory drilling indicates that the aquifer is underlain by confining clay formations that contain saline water, and the geologic formations below the clay probably contain saline water also.

The fresh ground water is mostly soft and has low dissolved-solids concentrations; however, several wells near shorelines have yielded excessive amounts of chloride. Analyses of ground water show that man-induced contamination of the aquifer is evident but not severe, as shown by somewhat elevated concentrations of nitrate nitrogen and methylene blue active substances (MBAS).

The local hydrogeologic system is not in equilibrium at present as a result of pumping, and chloride concentrations in the ground water can be expected to gradually increase. Increased pumping will cause deterioration of the fresh ground-water supply by inducing saline-water infiltration and by adding greater volumes of septic-tank and cesspool effluents to the aquifer.

Test drilling could help in water-supply management by determining the extent of the aquifer and of fresh ground-water storage, and observation wells could provide early detection of saline-water infiltration.



Base from U.S. Geological Survey
State base map, 1974, 1:500,000 scale

Figure 1.--Location of Shelter Island, Suffolk County, Long Island, New York

INTRODUCTION

The upper glacial aquifer is the sole source of freshwater for the residents of the Town of Shelter Island, a small island community between the north and south forks of Suffolk County, N.Y. (fig. 1). Shelter Island's winter population of about 2,000 increases fourfold during the summer, and the total population has been rising slowly over the years. Nearly all the island's domestic sewage is disposed of through septic-tank systems and cesspools. The increase in water use and in volume of sewage has aroused much local concern about the quantity and quality of the island's ground water.

Purpose and Scope of Investigation

Water pumped from wells that tap the upper glacial aquifer on Shelter Island is the sole source of supply for the island's population. Because of the growing population and the increasing volume of sewage disposed through septic-tank systems and cesspools, and also because of the island's small size, there is much local concern about the adequacy and quality of the freshwater supply.

In November 1973, the U.S. Geological Survey, in cooperation with the Suffolk County Department of Environmental Control, began a hydrogeologic reconnaissance on Shelter Island. Observation wells were installed to obtain water samples to detect cesspool effluents and leachates from agricultural fertilizers, pesticides, herbicides, sanitary landfills, industrial wastes, and radioactive fallout. The study was made to obtain baseline data for the island and as part of a larger study of shallow ground-water quality in Suffolk County. Exploratory drilling at selected sites was carried out to depths greater than those of the observation wells to locate the top of the saline ground-water body below the island. The well installations and exploratory drilling were completed in June 1974.

Methods of Investigation

Seventeen observation wells were installed at locations shown in figure 2. The wells are of 4- or 6-inch inside diameter and are finished with screens 10 ft long. Screen tops are about 10 ft below the water table. Four-inch casings were used where depth to water table was less than 25 ft; the 6-inch casings were used where the water table was deeper. As the wells were finished and developed, water samples were pumped for chemical analyses. Exploratory drilling was carried out to depths of as much as 348 ft at three of the well sites before screens were installed, and water at various depths was sampled for chloride content. The cable-tool (percussion) method was used for most of the drilling. At two of the exploratory sites, rotary drilling equipment was used because casings could not be driven to required depths. The chloride samples taken during the cable-tool drilling were obtained by bailing the casings and allowing formation water from the sampling depths to refill the casings. Formation water was mechanically extracted from core samples obtained from the rotary drilling at selected depths by placing the sample in a steel cylinder and forcing the water out with a tightly fitted steel piston. Pressure was applied to the piston by a large C-clamp and screw arrangement. Locations of the three exploratory-drilling sites are shown in figure 2.

Acknowledgments

Cable-tool drilling and the observation-well installations were done by Harold McMahon, Inc., Amagansett, N.Y., under contract with the Suffolk County Department of Environmental Control. Rotary drilling and core sampling were done by the Layne-New York Co., Inc., Hauppauge, N.Y., under arrangement with the McMahon firm.

Thomas L. Jernick, Town Supervisor of the Town of Shelter Island and members of the Town Council gave valuable assistance in allowing the use of local road rights-of-way for the observation-well installations.

GEOGRAPHY

The Town of Shelter Island encompasses 11 mi^2 and is the smallest of Suffolk County's 10 townships. It lies between the Village of Greenport, Town of Southold, on the North Fork, and the community of North Haven, Town of Southampton, on the South Fork. Figure 1 shows the location of Shelter Island; geographic names used in this report are shown in figure 2.

Topography and Drainage

The highest altitudes are in the western part of the island between West Neck Bay and Shelter Island Heights (fig. 2). In this area, maximum altitudes range from about 100 to about 180 ft; here a steep bluff about 100 ft high faces Shelter Island Sound. Elsewhere, maximum altitudes are mostly lower than 70 ft, and the land surface gradually descends to the shore as a rolling plain pitted with small ponds and dry and marshy depressions. Dry depressions ranging from 10 to 30 ft deep are common, and one dry depression near the middle of the "Mashomac property" in the southwestern part of the island (fig. 2) is about 40 ft deep. Ponds and marshes occur mostly in shallow depressions that are less than 5 ft above sea level.

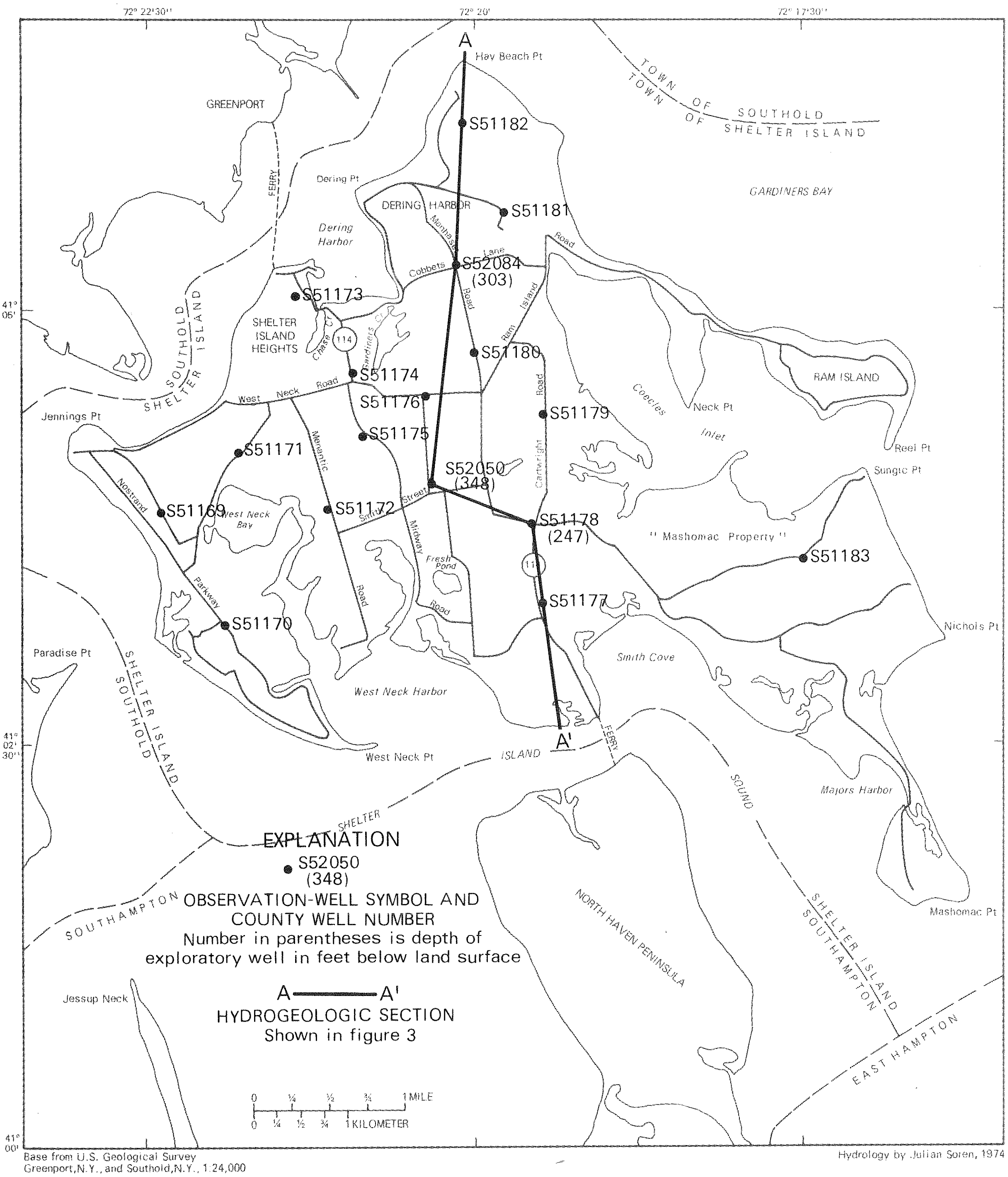


Figure 2.--Location of observation and exploratory wells.

Shelter Island has no significant streams. Most precipitation that does not evaporate seeps into the ground. Local surface flooding may result from heavy rains, where the land surface is underlain by clayey and silty deposits of low permeability, and some overland runoff from heavy rains probably occurs in the high areas of the western part of the island and discharges westward into Shelter Island Sound and eastward into Chase Creek (fig. 2). Some runoff tends to seep into the ground, but ponds may be formed in the West Neck Bay area. Most of the ponded water eventually seeps into the ground; the remainder evaporates. Only a small part of Shelter Island Heights has a storm-sewer system that discharges to tidewater. Thus, most drainage is through the ground-water system, which discharges into saline ground water surrounding the island.

Population

The population varies widely from a small number of year-round inhabitants to a population several times greater during the summer. The estimated year-round population rose slowly from about 500 in 1938 to 1,600 in 1968; in 1969, the year-round population was about 1,700 and the summer population, 6,500 (Johnson, 1970, p. 7). In 1974, the estimated year-round population was 2,000 and the summer population, 8,000 (David Binder, Shelter Island Chamber of Commerce, oral commun., March 22, 1975).

About two-thirds of the island is inhabited; the remainder, the Mashomac property in the southeastern part between Smith Cove and Mashomac Point (fig. 2), is private and virtually uninhabited.

Culture

Shelter Island is not heavily developed. Except in small areas scattered about the shore and in Shelter Island Heights and Dering Harbor, paved streets are generally separated by wide, open areas. There is no manufacturing or industry. Most of the business and commerce consists of stores, restaurants, yacht clubs, and boat marinas. One public school serves the island's children through high school.

Access is by ferry--from Greenport, Town of Southold, on the north and from North Haven, Town of Southampton, on the south. The island is traversed by N.Y. State Highway 114 (Ferry Road) between the ferry piers.

Except for public buildings, stores, motels, yacht and country clubs, and institutional buildings, there are few large buildings. Most structures are individual homes. The Mashomac property is a virtually all open, undeveloped area with only a few buildings on it.

HYDROGEOLOGY

Ground-Water Use

Records of ground-water pumpage on Shelter Island are fragmentary. Partial reports have been made to the New York State Department of Environmental Conservation at Stony Brook, N.Y. by the Shelter Island Heights Association and Dering Harbor Village (public water supplies), and by a monastery, a motel, and a plant nursery in the Dering Harbor area. A small public-supply system in the West Neck area does not report its pumpage. Records from 1965 to 1973 by the reporting pumpers indicate their average daily pumpage to have been 0.15 Mgal/d. Many of the island's residents, however, have individual wells supplying additional amounts for domestic supply and other uses such as lawn sprinkling and swimming pools. If the daily per-capita water useage is estimated to be 200 gal/d during the summer and 100 gal/d during the rest of the year, total pumpage in 1974 would have been about 198 Mgal, and average pumpage rates would have been 1.6 Mgal/d in the summer and 0.2 Mgal/d during the rest of the year.

Geologic Data

Shelter Island is underlain by upper Pleistocene deposits of glacial drift composed of clay, silt, outwash sand and gravel, cobbles, and boulders; these deposits constitute the upper glacial aquifer on the island. The drift appears to be mostly stratified, and sorting of the drift particles ranges from poor to moderate. The drift contains much clay and silt along the northwestern coastline, from the Jennings Point area to Hay Beach Point, where it forms cliffs. It is sandier southeast of the cliffs.

Exploratory drilling revealed hydrogeologic information not previously known. Extensive thicknesses of Pleistocene clay strata were found below the mostly stratified drift at the three exploratory well sites--S52050, S51178, and S52084 (fig. 2). The clay strata form two distinct units--an upper one of marine origin, mainly gray green to dark gray, and a lower one of nonmarine origin, mainly reddish brown to brown. The marine unit was found at all three exploratory sites, but the nonmarine unit was found only at two sites--S52084 and S52050. The marine clay was found at depths below land surface of 130 ft at S52084, 139 ft at S52050, and 85 ft at S51178. Its thickness ranges from 50 ft at S52084 to 95 ft at S51178.

The nonmarine clay unit was not fully penetrated at S52084; it was first penetrated at 180 ft, and drilling was continued to a depth of 303 ft. At S52050, it was fully penetrated from depths of 218 to 341 ft; sand probably of the Upper Cretaceous Matawan Group-Magothy Formation undifferentiated (Magothy aquifer) was penetrated from 341 to 348 ft. At S51178, the nonmarine clay unit was not found; below marine clay from 85 to 180 ft, sand and gravel apparently of glacial origin was found from 180 ft to 247 feet. The nonmarine clay unit is 123 feet thick at S52050 and is thicker at S52084.

The marine clay unit probably extends under all of Shelter Island, and the underlying nonmarine unit probably extends under a major part of the island. Additional exploratory drilling would be required to determine their actual extent.

The geologic units underlying Shelter Island to the depths investigated are shown in a hydrogeologic section in figure 3; drilling logs are given in table 1.

Before the drilling, the Matawan-Magothy surface on the island was inferred to be about 150 ft below sea level (Jensen and Soren, 1974, sheet 1). This surface is now estimated to be about 300 ft below sea level. Geologic units below the Matawan-Magothy (not shown in fig. 3) are, in descending order, the clay member and Lloyd Sand Member of the Raritan Formation of Late Cretaceous age, and crystalline bedrock of Precambrian(?) age. The top of the Raritan clay member is about 400 ft below sea level at the northern part of Shelter Island and slopes southward to about 625 ft below sea level. The top of the Lloyd Sand Member (Lloyd aquifer) slopes southward from about 510 to 800 ft below sea level. Bedrock slopes southward from about 700 to 1,000 ft below sea level. Depths to the units underlying the Matawan-Magothy strata are given in Jensen and Soren (1974, sheet 1).

Source and Occurrence of Ground Water

The source of Shelter Island's ground water is precipitation that infiltrates to the water table. Below the water table, all space between particles in the unconsolidated deposits and all fractures and other openings in the bedrock are filled with water.

About half the precipitation on Long Island is returned to the atmosphere by evapotranspiration, and about 5 percent enters surface-water bodies as overland runoff (Cohen and others, 1968, p. 37, 38). From these percentages, it is calculated that on Shelter Island, where precipitation is about 45 in. per year (Miller and Frederick, 1969, pl. 1), about 20 in., or 3.9 billion gallons of water, enters the ground-water reservoir per year. This represents an average daily recharge of about 1 $Mgal/mi^2$.

Freshwater on Shelter Island is currently pumped from shallow wells that are mostly less than 75 ft deep and are commonly less than 50 ft deep. The wells tap sand and gravel deposits in the upper glacial aquifer, which is the sole source of freshwater on the island. All fresh ground-water in storage on Shelter Island lies between the water table and the top of the marine-clay unit.

The coarser and better sorted sediments yield the greatest quantities of water to wells. Yields of the observation wells ranged from 4 to as much as 130 gal/min, and specific capacitites ranged from 0.5 to 30 (gal/min)/ft of drawdown. At many of the well sites, the highest possible yields and

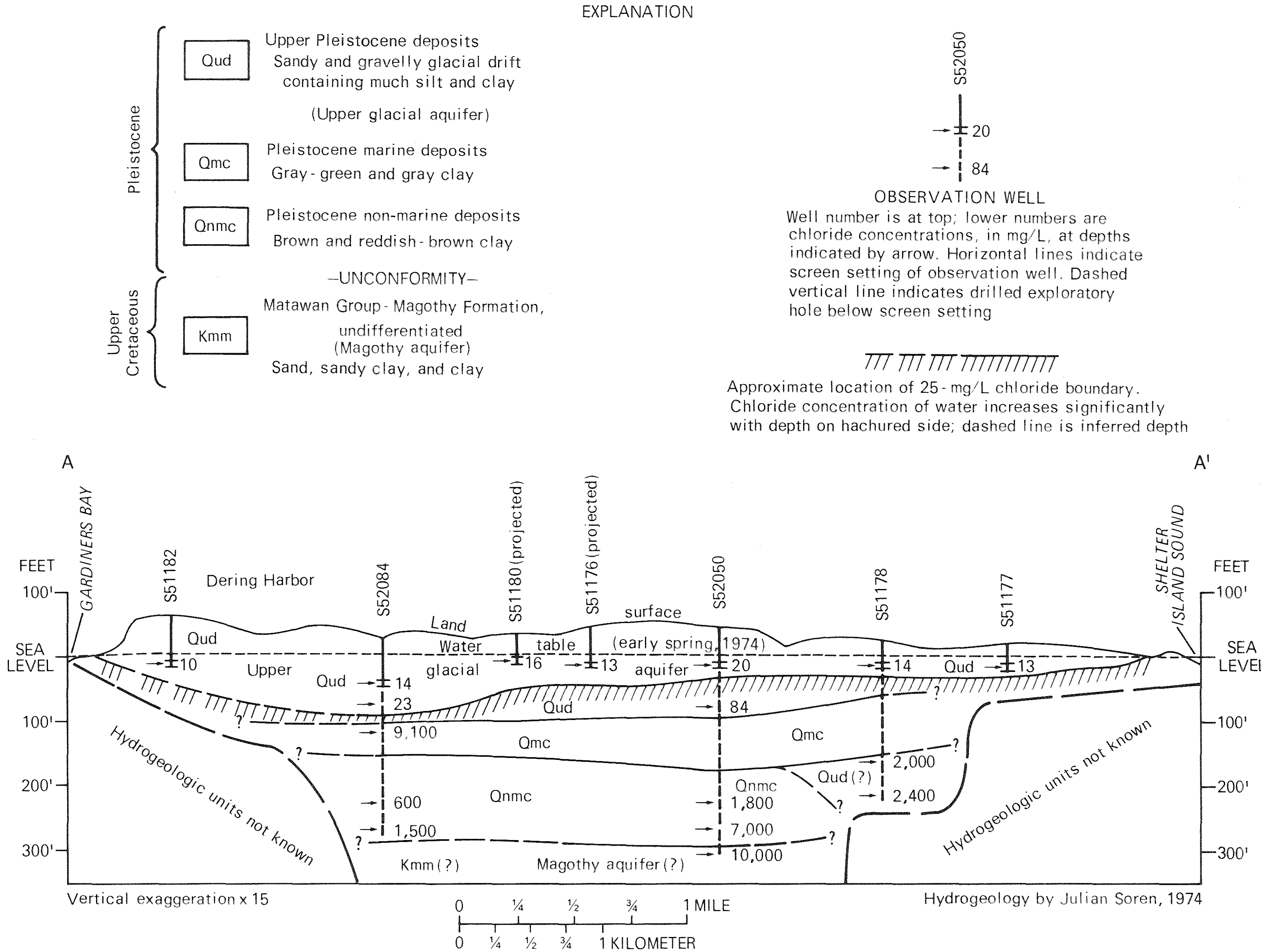


Figure 3.--Hydrogeologic section through Shelter Island.

Table 1.--Logs of exploratory drilling on Shelter Island
[Well locations shown in fig. 2]

WELL S51178

Northeast corner of intersection of New York State Highway 114 and Cartwright Road, lat 41°03'50" N., long 72°19'31" W. Percussion (cable-tool) hole drilled to depth of 145 ft by Harold McMahon, Inc.; hole completed by standard-rotary method to depth of 247 ft by Layne-New York Co., Inc., June 1974. Altitude of land surface about 28 ft above mean sea level. Geologist's log based on examination of driller's log; bailer, flume (mud-ditch), and core samples; and gamma-ray log.

Description	Thickness (ft)	Depth (ft)
PLEISTOCENE		
Upper Pleistocene deposits		
Sand, very fine to very coarse, mostly coarse, brown, and granule to very large-pebble gravel up to 2.5-in diam; a few small to large cobbles up to 5-in. diam; much interstitial clay and silt.	85	85
Pleistocene marine deposits		
Clay, dark grayish-green and dark-gray; some laminae and thin beds of sand and granule gravel	95	180
Upper Pleistocene(?) deposits		
Sand, very fine to coarse, mostly fine to medium, light-gray, and granule to very large-pebble gravel up to 2.4 in. diam	67	247

WELL S52050

Northeast corner Smith Street and School Road, lat 41°04' N., long 72°20'20" W. Percussion (cable-tool) hole drilled to depth of 70 ft by Harold McMahon, Inc.; hole completed by standard-rotary method to depth of 348 ft by Layne-New York Co., Inc., June 1974. Altitude of land surface about 44 ft above mean sea level. Geologist's log based on examination of driller's log; bailer, flume, and core-samples; and gamma-ray log.

Description	Thickness (ft)	Depth (ft)
PLEISTOCENE		
Upper Pleistocene deposits		
Sand, very fine to medium, grayish-brown; many laminae and thin beds of sandy clay and silt; some gravel and small cobbles up to 4-in. diam	5	5
Sand, very fine to very coarse, mostly coarse, brown, and granule to very large-pebble gravel up to 2.5-in. diam; many traces of interstitial clay and silt.	75	80
Clay, sandy, brown.	20	100
Sand, very fine to very coarse, mostly medium to coarse; some granule to small-pebble gravel up to 0.30-in. diam.	39	139

Table 1.--Logs of exploratory drilling on Shelter Island--Continued

WELL S52050 (continued)

Description	Thickness (ft)	Depth (ft)
Pleistocene marine deposits		
Clay, dark-grayish-green and dark-gray.	79	218
Pleistocene non-marine deposits		
Clay, brown and reddish-brown	123	341
UPPER CRETACEOUS(?):		
Matawan Group-Magothy Formation (?)undifferentiated		
Sand, fine, gray.	7	348

WELL S52084

Northeast corner of Cobbets Lane and Manhanset Road, lat 41°05'16" N., long 72°20'09" W. Percussion (cable-tool) hole drilled by Harold McMahon, Inc., April 1974. Altitude of land surface 29 ft above mean sea level. Geologist's log based on examination of driller's log, bailer samples, and gamma-ray log.

Description	Thickness (ft)	Depth (ft)
PLEISTOCENE:		
Upper Pleistocene deposits		
Sand, very fine to coarse, mostly medium, tan and brown, and some granule gravel.	10	10
Sand, very fine to very coarse, mostly coarse, tan and brown, granule to very large-pebble gravel up to 2.5-in. diam; a few small cobbles up to 4-in. diam; some traces of silt	95	105
Sand, very fine to very coarse, mostly coarse, brown; much interstitial clay and silt; some granule gravel . .	10	115
Clay, sandy, brown.	5	120
Sand, very fine to very coarse, mostly coarse, brown; much interstitial clay and silt; some granule gravel . .	10	130
Pleistocene marine deposits		
Clay, dark-grayish-green and dark-gray; many large shell fragments; some laminae and thin beds of sand and granule gravel.	50	180
Pleistocene non-marine deposits		
Clay, brown and reddish-brown; some laminae and thin beds of silt and fine sand	20	200
Clay, greenish-brown; much interstitial sand and some granule gravel.	3	203

specific capacities were not obtained because the well screens were set in zones ranging from 10 to little more than 20 ft below the water table, rather than in the zones that would provide the best yields.

Position of the Water Table

Water levels were measured in the observation wells and were used to make a map of the water table (fig. 4). The water-table map indicates four main water-table highs (areas enclosed by 5-ft contours in fig. 4). The largest of these is centered at about West Neck Road and Route 114. The second-largest is at about the center of the Mashomac property, between Smith Cove and Mashomac Point. The third largest lies in the Dering Harbor area, and the fourth largest is in the Shelter Island Heights area. A small high (3-ft contour) is in the West Neck area between Jennings Point and West Neck Bay, and lesser highs probably occur in the many small necks such as Ram Island and the neck at the south end of Menantic Road at West Neck Harbor.

Fluctuations of the Water Table

Under steady conditions of inflow and outflow, the water table of Shelter Island would remain stable. However, the climate produces an annual water-table fluctuation from a high in early or middle spring to a low in late fall; this variation is caused largely by increased evapotranspiration during the growing season. The fluctuations tend to be most extreme where the water table is highest and decrease to zero at the shore. Increased pumping during the summer causes a greater than natural water-table decline.

Movement and Discharge of Ground Water

The fresh ground water of Shelter Island moves radially from the high areas of the water table (fig. 4) and discharges into the saline ground water that surrounds the island. The saline ground-water has hydraulic continuity with Shelter Island Sound and Gardiners Bay. In the discharge process, the fresh and saline ground waters form a zone of diffusion in which the chloride concentration increases with distance from the island until it approaches the salinity of the Sound and Bay waters.

Before man's use of ground water, recharge and discharge were equal, and this equilibrium maintained the zone of diffusion in a fairly fixed position around the island. However, ground-water pumping reduces submarine outflow of fresh ground water causing a landward advance of the zone of diffusion and a reduction in the amount of freshwater in storage. With each increase in pumpage, the zone of diffusion moves farther landward toward a new equilibrium position. If pumped ground water is returned to the aquifer through septic-tank systems and cesspools, this landward movement

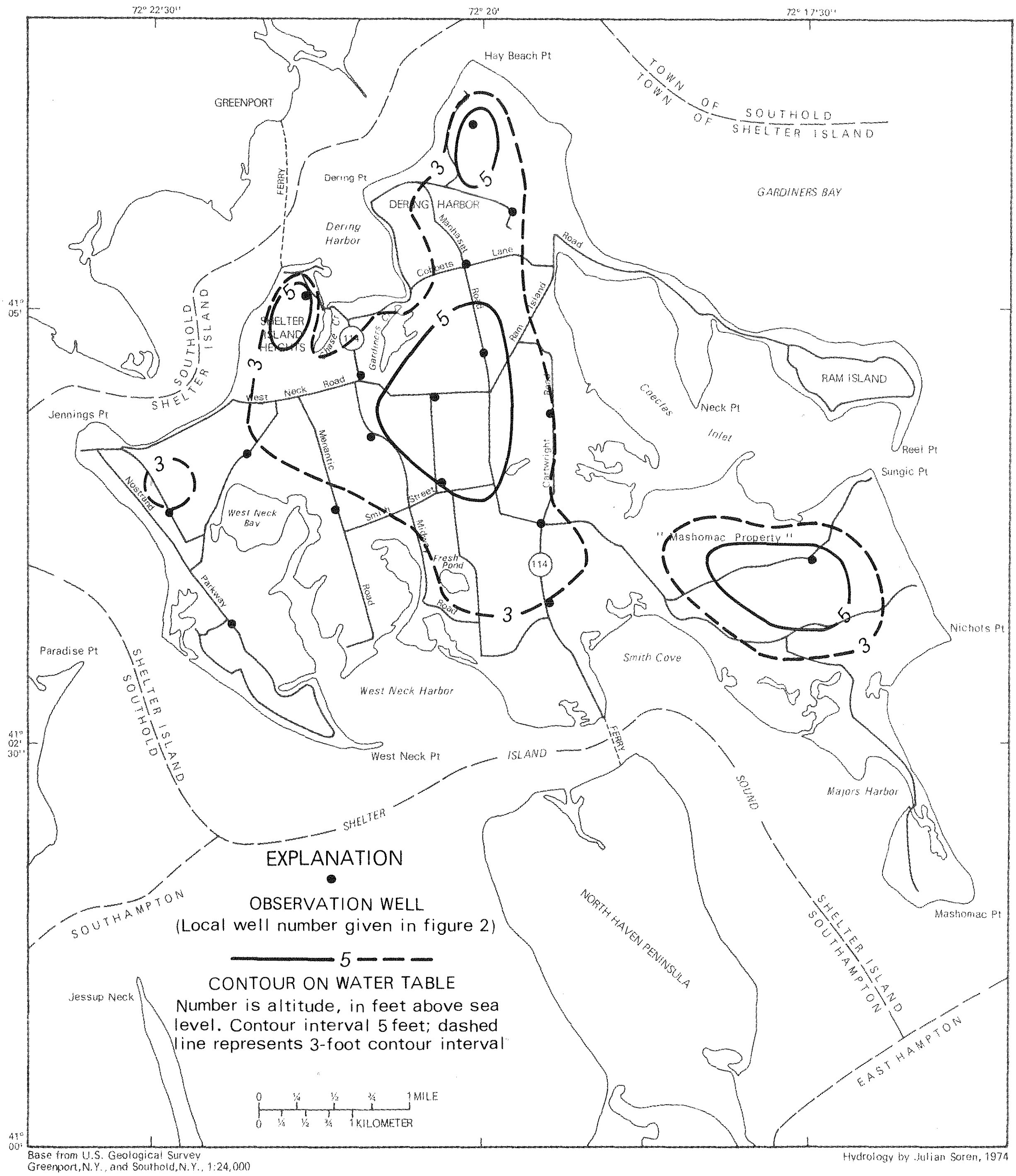


Figure 4.--Approximate position of water table in early spring 1974 on Shelter Island, Suffolk County, New York.

is retarded; however, not all pumped water is returned. Most of the water that is used for irrigation and much of the water used to fill swimming pools is lost from the aquifer system through evaporation and evapotranspiration. Returning water to the aquifer through septic-tank systems and cesspools constitutes a recycling of sewage that continually increases the dissolved-solids content of the ground water.

To indefinitely maintain an adequate supply of ground water of acceptable quality, both outflow from the system and adequate freshwater recharge are necessary. The total amount of recharge from precipitation cannot be considered to be the dependable long-term yield of the system because outflow is necessary to prevent landward movement of saline ground water.

The rate of ground-water movement is the product of the hydraulic conductivity of the aquifer materials and the hydraulic gradient (slope of the water table) divided by the percentage porosity of the aquifer materials. The rate of ground-water movement near the center of Shelter Island is computed in the following example from:

(1) a hydraulic conductivity of 200 to 270 ft/d, which is typical for coarse sand and gravel deposits containing very little clay and silt;

(2) a hydraulic gradient of 0.00115 foot per foot, derived from the slope of water table (fig. 4), which is about 6 ft/mi; and

(3) a porosity of about 30 percent, typical for the materials in (1).

The rate of ground-water movement is $\frac{(200 \text{ to } 270) \times 0.00115}{0.3}$, which equals 0.8 to 1 ft/d. A much steeper hydraulic gradient occurs in the Shelter Island Heights area (fig. 4) as a result of the lower hydraulic conductivity of the aquifer, which there consists of more poorly sorted sand and gravel containing much clay and silt. For ground water to move at 1 ft/d in the Shelter Island Heights area with an estimated aquifer porosity of 35 to 40 percent (fine-grained deposits generally have a higher porosity than coarse-grained deposits), the hydraulic conductivity of the less permeable aquifer is estimated to be 60 ft/d. These examples illustrate the extreme variation in average hydraulic conductivity of the sandy and gravelly deposits in the upper glacial aquifer on the island; the rates of ground-water movement in deposits that are predominantly clayey or silty would be small fractions of these rates.

When a well is pumped, the hydraulic gradient toward the well screen is greatly increased over the natural ground-water gradient as a result of the well's drawdown. In the vicinity of the well, the rate of movement of ground water toward the well increases in proportion to the drawdown in the aquifer and is greatest at the well/aquifer interface.

Boundary Between Fresh and Saline Ground Water

The most notable feature of Shelter Island's hydrogeology is that, except in nearshore areas, the top of the marine-clay unit seems to be the lower boundary of the freshwater body. In the nearshore areas, this boundary rises from the top of the clay toward the shoreline.

Exploratory drilling showed that water in and below the marine clay is brackish to saline. At well S52084, the chloride concentration of water 15 ft below the top of the clay, which is 145 ft below land surface, was about 9,100 mg/L (milligrams per liter). Water from the underlying nonmarine clay at well S52084 at depths of 260 and 303 ft below land surface had chloride concentrations of about 600 and 1,500 mg/L, respectively. No water was obtained from the marine clay at well S52020; however, water from the underlying nonmarine clay at depths of 268 and 308 ft had chloride concentrations of about 1,800 and 7,000 mg/L, respectively. Water from the Matawan-Magothy(?) sand (Magothy aquifer) at well S52050 had a chloride concentration of about 10,000 mg/L. No water was obtained from the marine clay at well S51178; however, water from the glacial sand and gravel below the marine unit (nonmarine clay absent) at depths of 182 and 247 had chloride concentrations of about 2,000 and 2,400 mg/L, respectively. The relationships between depth and chloride as indicated by the exploratory drilling are shown in figure 3. Additional exploratory drilling could provide more precise delineation of the fresh ground-water body on the island.

The clay units' intrinsically low hydraulic conductivity gives them a tendency to confine saline ground water beneath them and retard its mixing with the freshwater above. However, lateral movement of saline ground water from shore areas toward pumping centers is enhanced by the nearly horizontal arrangement of approximately tabular geologic units--a condition that readily permits infiltration of saline water into the aquifer and also greatly limits the amount of freshwater that can be stored between the clay beds and the water table.

On an island where the aquifer is of uniform composition, freshwater is commonly estimated to extend about 40 ft below sea level for each foot of water-table altitude above sea level (Ghyben-Herzberg principle). Thus, where the water table is more than 5 ft above sea level on Shelter Island, freshwater could theoretically extend to more than 200 ft below sea level were it not for the boundary formed by the clay strata from about 65 to 100 ft below sea level (fig. 3), which limit the depth of freshwater storage. Near shore, brackish and saline ground water occur at shallower depths. The saline water in the nonmarine clay strata is probably residual from a period when the overlying marine clay was deposited; the saline water in the marine clay strata is probably residual connate water (water that was trapped in the sediments at the time of deposition). The amount of chloride in the water in the clays has probably decreased, and additional freshening of water in much of the clays is possible if the water table remains at present levels. However, from a practical standpoint, such freshening cannot be relied upon because

(1) the process could take from several thousand to tens of thousands of years as a result of the clay's low hydraulic conductivity and thickness, and (2) potentiometric heads in the overlying fresh ground water are relatively low.

Potentiometric heads in Shelter Island's Magothy aquifer are extrapolated, from known heads in Suffolk County, to be at about sea level. The low head and the high chloride concentration in the Magothy aquifer's water at well S52050 suggest that saline water is present throughout the Magothy on the island. The Lloyd aquifer was not reached by test drilling on the island. An extrapolation of its potentiometric head from nearby parts of Suffolk County indicate that it is at about sea level. Its depth and low potentiometric head practically preclude the Lloyd as a freshwater source on the island.

The distribution of saline ground water seems to limit fresh ground water on Shelter Island to the thin upper glacial aquifer between the water table and the marine-clay unit.

Chemical Quality of Ground Water

The fresh ground water on Shelter Island, except nearshore, is mostly soft (hardness less than 60 mg/L), has low dissolved-solids concentrations (mostly less than 100 mg/L), and for the most part easily meets the recommended potability standards of the U.S. Public Health Service (1962). Principal constituents that affect the water's potability are discussed individually in the following paragraphs, and analyses of selected constituents of water from the 17 observation wells are given in table 2. Concentrations termed excessive are based on recommended standards set by the U.S. Public Health Service (1962). Ground-water analyses for nitrate-nitrogen and synthetic detergents (MBAS) analyses of the island's ground water indicate that human-induced contamination of the aquifer is present but not severe.

Chloride.--Chloride concentrations in shallow ground water from the observation wells were generally less than 25 mg/L, and most were less than 15 mg/L. In a 1975 survey of 32 other wells (domestic and public-supply), in which 275 analyses were made that included several samplings from each well, chloride concentrations ranged from 15 to 348 mg/L but were mostly less than 40 mg/L (J. W. Hallman, written commun., Dec. 3, 1975). Most of the 32 wells were screened deeper than the observation wells in the present study. Excessive chloride concentrations (more than 250 mg/L) occurred in two of the wells, both of which are nearshore. One of the wells, a public-supply well in Dering Harbor, yielded excessive chloride (303 mg/L) when pumped at a peak rate in the summer. The other, a domestic-supply well in the West Neck area, yielded water with as much as 348 mg/L of chloride, probably because it was deeper than neighboring wells that yielded considerably less chloride. In the 32-well survey, one domestic-supply well yielded water with chloride concentrations of

Table 2.--Chemical analyses for selected ground-water constituents, Shelter Island, Suffolk County, N.Y.

(Analyses by U.S. Geological Survey, Albany, N.Y., 1974)

[Concentrations in milligrams per liter]

Well number	Depth below land surface (ft)	Date sampled	Constituent or characteristic: Chloride (Ci)	Iron (Fe)	Manganese (Mn)	Nitrate (NO_3, as N)	MBAS	Dissolved solids	Hardness (as $CaCO_3$): Total	Noncarbonate	pH	Temperature (°C)
S51169	31	3-07-74	10	0.06	0.04	1.9	0.0	93	59	44	6.2	11.0
S51170	28	2-28-74	22	.07	.02	.3	.0	59	16	9.0	5.8	12.5
S51171	53	3-08-74	22	.16	.03	5.8	.0	98	51	40	5.7	11.5
S51172	35	3-04-74	25	.09	1/ .12	6.	.01	115	55	45	5.7	11.5
S51173	48	4-23-74	22	.17	1/ .15	1.7	.03	95	41	22	6.5	13.5
S51174	52	3-08-74	23	.12	.04	2.4	.0	96	44	28	5.9	12.5
S51175	58	3-06-74	19	.09	.0	3.1	.0	86	40	25	5.8	11.0
S51176	56	3-05-74	13	.15	.02	1.2	.0	69	29	14	5.7	11.0
S51177	37	2-28-74	13	.12	1/ .06	0.5	.0	60	22	5.0	5.9	11.5
S51178	47	6-12-74	14	1/ .31	.04	--	.01	--	--	--	--	12.0
S51179	58	4-23-74	11	.29	1/ .07	.3	.01	137	85	72	6.9	12.5
S51180	49	3-04-74	16	.16	.01	1.4	.0	78	35	9.0	6.0	11.0
S51181	72	3-01-74	22	.10	.01	1/ 11.	.02	144	110	100	6.0	11.0
S51182	74	2-28-74	10	.07	.03	.3	.01	46	14	6.0	5.9	10.5
S51183	49	3-12-74	13	.05	.03	1.2	.0	60	26	11	6.1	10.5
S52050	64	6-13-74	20	1/ .38	1/ .13	--	.11	--	--	--	5.7	13.0
S52084	75	6-11-74	14	.14	.05	--	.02	--	--	--	6.1	11.5

1/ Exceeds U.S. Public Health Service drinking-water standards (U.S. Public Health Service, 1962)

144 and 235 mg/l shortly after being pumped to fill a swimming pool in June 1975. Two weeks later, the chloride concentration had decreased to 83 mg/I but rose to 91 mg/L during the remainder of the summer, then declined to 53 mg/L in October. Such chloride changes are usual in wells that pump in or near the zone of diffusion.

Excessive chloride in water gives a salty taste and impairs flavors of foods and beverages prepared with the water.

Fluoride.--Fluoride concentrations analyzed in samples from the observation wells ranged from 0 to 0.3 mg/L and are considered to be low. The maximum allowable concentration of fluoride ranges from 1.7 mg/L at temperatures of 10° to 12°C to 0.8 mg/L at temperatures of 26° to 32.5°C.

Iron and Manganese.--Most concentrations of iron and manganese in water from the observation wells were less than the maximum concentrations recommended (0.3 and 0.05 mg/L, respectively). Iron concentrations ranged from 0.05 to 0.38 mg/L, and manganese ranged from 0 to 0.15 mg/L (table 2). Most of the iron concentrations were less than 0.15 mg/L, and most of the manganese concentrations were not more than 0.04 mg/L. Although excessive iron and manganese concentrations are not hazardous to health, they affect the flavor of the water and of beverages and foods prepared with the water. Excessive iron and manganese also cause rusty and blackish staining of clothing and surfaces that come into contact with the water, also they tend to build up deposits in piping, which leads to clogging.

Nitrate Nitrogen.--Concentrations of nitrate nitrogen (nitrate determined as nitrogen) in water from the observation wells ranged from 0.3 to 11 mg/L (table 2). Only one analysis (well S51181) showed excessive nitrate nitrogen (more than 10 mg/L). Most nitrate nitrogen concentrations were low (less than 3 mg/L); the others were moderate (between 3 and 7 mg/L).

Nitrate in the ground water of Shelter Island originates from cesspool effluents and fertilizers. In built-up areas, septic tanks and cesspools are the most likely nitrate sources; in farmed and cultivated areas, fertilizers are the main source. The well that yielded excessive nitrate (S51181) is at a golf course, where fertilizers are the probable source. A well at the high school (near well S52050) contained excessive nitrate nitrogen in a 1972 sampling (Thomas Martin, Suffolk County Department of Health, oral commun., Feb. 1975). There, excessive nitrate was attributed to cesspool effluents.

Excessive nitrate in water can be injurious or fatal to infants in the first few months of life for it can cause methemoglobinemia, commonly called "blue-baby disease." However, the excessive nitrate-nitrogen concentrations found on Shelter Island were only slightly above the recommended maximum, and the U.S. Public Health Service (1962, p. 47-50) indicates a possibility of considerable latitude in the upper limit. Dilution of high-nitrate water with suitable water from other wells or other sources, or deepening of affected wells, could be used to avoid the problem of excessive nitrate.

MBAS.--MBAS (methylene-blue active substances) detected in the ground water in a build-up area on Shelter Island generally indicates synthetic detergents in cesspool effluents. In cultivated areas, MBAS in the water can result from leachates of decaying vegetation. Excessive MBAS (more than 0.5 mg/L) affects the flavor of the water and causes the water to foam.

MBAS concentrations in water from the observation wells ranged from 0 to 0.11 mg/L (table 2) and are considered to be low. The highest concentration was found at well S52050, near the public school; the second-highest concentration, 0.03 mg/L, was at well S51173, in Shelter Island Heights.

Dissolved Solids.--Dissolved solids in water from the observation wells ranged from 46 to 144 mg/L (table 2) and are considered to be low (recommended maximum allowable concentration is 500 mg/L); most of the concentrations were less than 100 mg/L.

Hardness.--Total hardnesses of water from the observation wells ranged from 14 to 110 mg/L (table 2), and most of the wells yielded soft water (hardness not more than 60 mg/L). Two wells--S51179 and S51181--yielded moderately hard water of 85 and 110 mg/L, respectively.

pH.--The pH of water from the observation wells was acidic, ranging from 5.7 to 6.9 (table 2); most of the samples were lower than pH 6.0, which is sufficiently acidic to be corrosive to piping and plumbing fixtures.

Temperature.--Temperatures of the water from the observation wells (table 2) ranged from 10.5° to 13.5°C and are considered normal for water at the wells' depths in the upper glacial aquifer of the region.

Heavy Metals.--In this report, the heavy metals are those starting with vanadium in the periodic table of elements. Heavy metals (other than iron and manganese) analyzed in samples from the observation wells, their ranges of concentration in μg/L (micrograms per liter), and their maximum allowable concentrations (U.S. Public Health Service, 1962), are given in table 3.

Other Metals.--Metals other than iron and manganese (preceding vanadium in the periodic table) analyzed in samples from the observation wells are listed in table 3 tabulation in similar manner as the heavy metals.

Insecticides and Herbicides

Water from the observation wells was analyzed for the insecticides aldrin, chlordane, DDD, DDE, DDT, diazinon, dieldrin, endrin, ethion, heptachlor, lindane, malathion, methyl-parathion, methyl-trithion, parathion, and toxaphene; and the herbicides 2,4-D; 2,4,5-T; and silvex (2,4,5-TP). None of these pesticides were detected in the ground-water samples.

Table 3.--Concentrations of dissolved heavy and other metals (iron and manganese excluded) in samples from observation wells

[Concentrations are in micrograms per liter]

Heavy Metals	Concentration range in samples (μg/L)	Maximum allowable concentration (μg/L)
Arsenic (As)	0-1	10
Barium (Ba)	0-20	1,000
Cadmium (Cd)	0	10
Chromium [(hexavalent), Cr^{+6}]	0-10	50
Cobalt (Co)	0-3	Not established
Lead (Pb)	0-4	50
Molybdenum (Mo)	0-1	Not established
Nickel (Ni)	0-10	Do.
Silver (Ag)	0	50
Vanadium (V)	0	Not established
Zinc (Zn)	20-480	5,000
Other Metals		
Boron (B, metalloid)	0-270	Not established
Lithium (Li)	0	Do.
Selenium (Se)	0-3	10
Strontium (Sr)	0-13	Not established

Radioactivity

Gross alpha (as natural uranium) and beta (as strontium-90 and yttrium-90, and as cesium-137) radioactivity were analyzed in water from wells S51183 and S52050. The gross alpha counts ranged from 2.3 to 2.9 pCi/L, and the gross beta counts ranged from 1 to 2.1 pCi/L. These levels of radioactivity are considered low and reflect normal background levels.

CONCLUSIONS

The few data obtained from the exploratory drilling indicate that chloride concentration in ground water increases with depth and that it increases abruptly (to more than 1,000 mg/L) in the clay beds that form the lower boundary of the freshwater reservoir of Shelter Island.

The leading edge of the zone of diffusion between fresh and saline ground water is judged to be where chloride concentrations exceed 25 mg/L. This concentration, although fairly low, was selected because it is significantly greater than chloride concentrations measured at most of the observations wells.

Continued pumping of ground water at rates of hundreds of gal/min (10 or more L/s) in areas where chloride concentrations exceed 25 mg/L will increase chloride concentrations further as water is drawn from the zone of diffusion. Near shorelines, saline water will be drawn landward into the upper glacial aquifer along the top of the marine-clay unit more readily than upward from below the clays because the hydraulic conductivity of the sandy beds is much greater than that of the clays; subsequently the saline water will be drawn upward ("upconing") from the bottom of the upper glacial aquifer toward pumping wells.

Although the upper glacial aquifer on Shelter Island is supplying the water needs of the 2,000 permanent and 6,000 summer residents, some saline ground water has probably already infiltrated the aquifer under a large part of the island, particularly near the shore. The island's hydrogeologic system is not in equilibrium with current pumpage, and the chloride concentration in the ground water is expected to gradually increase as the slowly growing population continues its demand for ground water. If local ground water is used to meet the needs of a population significantly larger than the present one, the required pumpage will cause further deterioration of ground-water quality both by inducing infiltration of saline ground water and by introducing greater amounts of septic-tank and cesspool effluents to the aquifer. To minimize saline-water infiltration, it would be desirable to drill future production wells as far as possible from areas that are now heavily pumped to prevent large local drawdown of the water table. This is especially important for areas near shore.

Additional test drilling on Shelter Island could (1) provide better delineation of the clay units that underlie the freshwater supply, (2) help determine the amount of freshwater in storage in the upper glacial aquifer between the water table and the clays' surface, and (3) locate clayey bodies within the freshwater zone, which, if large, would reduce substantially the amount of freshwater recoverable from the aquifer.

Additional observation wells nearshore and between the water-table highs (fig. 4) could provide early detection of saline ground-water infiltration to aid in management of pumping as a means to preserve the water quality on the island.

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