Geology and Ground-Water Resources of Plum Island Suffolk County, New York

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1539-X

Prepared on behalf of the Agricultural Research Service, U.S. Department of Agriculture

Crandell—GEOLOGY AND GROUND-WATER RESOURCES OF PLUM ISLAND, N.Y.—Geological Survey Water-Supply Paper 1539-X

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By H. C. CRANDELL

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF PLUM ISLAND, SUFFOLK COUNTY, NEW YORK

By H. C. Crandell

ABSTRACT

Plum Island, which has a total area of about 1.3 square miles, is about 2 miles off the northeast tip of Long Island. It is underlain by Cretaceous and Pleistocene unconsolidated deposits resting on a southeastward-sloping Precambrian bedrock surface. The island's fresh ground-water reservoir is contained in stratified upper Pleistocene glacial deposits and probably assumes the shape of a shallow lens, in accordance with the Ghyben-Herzberg principle. Precipitation is the only source of recharge to this reservoir, but it is more than sufficient to replenish the fresh-water draft. This draft was about 31 million gallons in 1958. The well field of the Department of Agriculture probably has been contaminated slightly by sea water during the past few years—possibly as a result of the hurricanes of 1954 and 1955, by vertical encroachment of sea water, or both. Recommendations to control and alleviate this contamination include a water-conservation program, artificial recharge, a continuing water-level and chloride-monitoring program including construction of "outpost" wells, and the establishment of an alternative or auxiliary well field.

INTRODUCTION

LOCATION OF THE AREA

Plum Island is in the town of Southold, Suffolk County, Long Island, N.Y. (fig. 1). The town of Southold occupies a narrow peninsula at the northeastern end of Long Island and also includes a northeastward-trending chain of four small islands. Plum Island is the first of these islands and is separated from the tip of the Southold peninsula by a strait about 1 mile wide. The island has an area of about 1.3 square miles and lies almost entirely between lat 41°10′ and 41°11′15″ N. and long 72°10′ and 72°12′30″ W. It is about 1½ miles northeast of Orient Point, town of Southold, and about 12 miles southwest of New London, Conn. The bodies of water surrounding Plum Island include Long Island Sound on the north, Block Island Sound on the south, and the treacherous current of Plum Gut separating the island from Orient Point on the west.

The island is included on the Plum Island topographic quadrangle

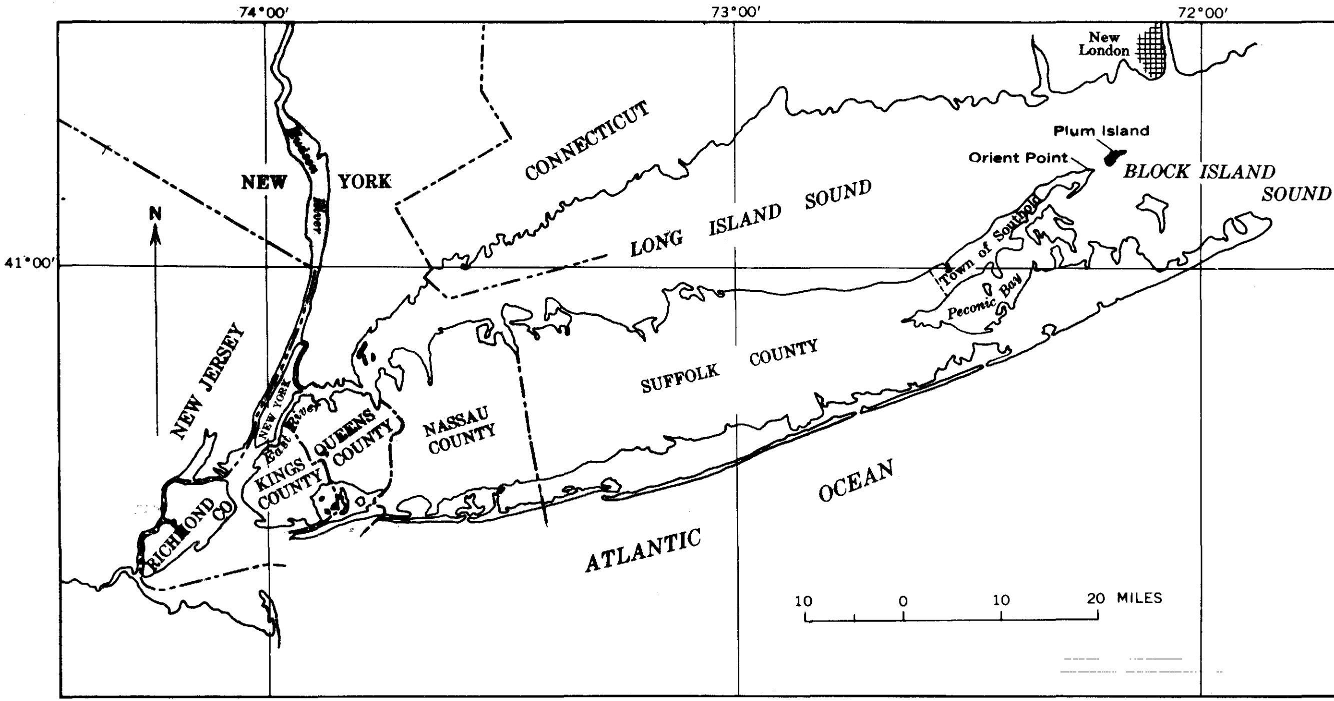

FIGURE 1.—Map showing location of Plum Island.

map of the U.S. Geological Survey, which was published in 1954 at a scale of 1:24,000 with a contour interval of 10 feet.

PURPOSE AND SCOPE OF THE INVESTIGATION

Because of the isolation afforded by Plum Island, the Agricultural Research Service of the U.S. Department of Agriculture has established there a large laboratory facility for the study of contagious animal diseases. Prior to the establishment of the facility in 1954, the island had been occupied by military installations, for which a well field had been constructed to furnish the necessary fresh-water supplies. After abandonment of these installations, the well field was reconditioned and equipped for the use of the laboratory. However, owing to the exposed position of the well field, withdrawals of ground water or sea-water inundation during occasional violent storms make saline contamination of the ground water an ever-present hazard. Because of this situation and the primary importance of a dependable fresh-water supply to the operation of the facility, the Department of Agriculture in August 1958 requested the Geological Survey to investigate the ground-water resources of Plum Island and particularly the availability of ground-water supplies additional or auxiliary to those from the existing well field.

The investigation, which extended from December 1958 to June 1959, included study of (a) the areal extent, thickness, and characteristics of the water-bearing sediments; (b) the hydrologic properties of the aquifer; (c) the conditions under which salt-water contamination may be taking place or impending; (d) the extent and nature of any overdevelopment of the ground-water reservoir; (e) the establishment of an effective monitoring program to observe any future trends toward salt-water contamination or depletion of the ground-water supply; and (f) the location of an area suitable for an additional or auxiliary well field. Also, pertinent data from previous investigations, logs of test holes, and chemical analyses of ground water have been included in this report to present the geology and hydrology of the island more comprehensively.

PREVIOUS INVESTIGATIONS

Plum Island has received only brief notice in the published geologic and hydrologic literature of the Long Island area. The extensive erosion of the island's shoreline is noted by Mather (1843, p. 20), and Merrill (1886, p. 343) mentions a similarity of geologic features to those of parts of the north shore of Long Island. Veatch and others (1906, p. 336) present the log of a well drilled by the U.S. Army on Plum Island in 1899, and Fuller (1914) presents the island's geology more extensively.

From time to time several short water-supply reports have been prepared by consulting firms specifically for the agencies concerned.

WELL-NUMBERING SYSTEM

On Long Island, the Geological Survey uses a well-numbering system established by the New York State Water Resources Commission. Each well number is assigned in serial order as drilling reports are received by the Commission, and is prefixed by the initial letter of the county in which it is located. Thus, a well in Suffolk County is designated by the letter "S" followed by the assigned number (as S10361).

ACKNOWLEDGMENTS

The writer acknowledges the assistance gained from data furnished by Alexander D. Crosett & Associates, C. W. Lauman & Co., Inc., Mathies Well & Pump Co., the U.S. Army Corps of Engineers, and the U.S. General Services Administration. The excellent cooperation of many members of the staff of the Plum Island Animal Disease laboratory is especially appreciated.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Plum Island is roughly triangular in outline, ranging in width from about 300 feet near the northeastern end to about 1 mile at the southwestern end. The island's total length is almost 3 miles from Plum Island lighthouse on the west to East Point. Low beach ridges that seldom reach more than 10 feet in altitude alternate with marshy depressions in the southwestern part of the island; and an undulating terrain of slight relief, characterized by many depressions, scattered boulders, and low hills less than 40 feet in altitude, occupies the northwestern part. An almost featureless plain slopes gently to the northeast and thence to the southeast in the central part of the island and separates two ridges of irregular hills. The southeastern hills range in altitude from about 40 to about 75 feet, whereas the northwestern group rises to an altitude of more than 100 feet at the reservoir near its western terminus. A small group of hills at the eastern end of the island reaches an altitude of more than 85 feet and, although separated from most of the island by a low narrow strip of land, it forms a continuation of the northwestern ridge.

The hilly areas terminate at the shoreline in steep bluffs as much as 50 feet high, and the beaches are covered with many large boulders. However, the southeastern and southwestern shores are occupied by broad attractive sandy beaches having only scattered cobbles or boulders. The island's vegetation consists mainly of beach grasses, wild shrubs, bushes, and some deciduous and coniferous trees.

Plum Island has no permanent streams; most runoff occurs in poorly defined natural channels that drain into the sea or into ponds and marshy areas. However, an artifical channel has been dredged to drain the swampy area in the southwestern part of the island and to control mosquito breeding. A sea gate is used to control the flow in this channel, and it has recently (1959) been kept closed to retain ponded rainwater.

CLIMATE

The marine environment of Plum Island controls its climate. Moderate temperatures predominate, and abundant precipitation occurs during the fall, winter, and spring. The following table, compiled from information collected by Mordoff (1949) and periodic climatic summaries of the U.S. Weather Bureau, contains climatological data from those stations nearest Plum Island.

Mean annual temperature and precipitation at stations near Plum Island

Station	Distance (miles) and direction from Plum Island	Temperature		Precipitation	
		Period of record (years)	Mean annual (°F)	Period of record (years)	Mean annual (inches)
Bridgehampton	17 south-southwest	41	51. 1	41	48. 41
Cutchogue	19 southwest	40	51. 0	53	46. 31
New London	12 northeast	77	50. 8	77	44. 83
Orient Point	4 southwest			17	45. 67

A 3-inch rain gage was installed on the island in September 1958. Its record through April 1959 is shown below with monthly precipitation records for the same period from the stations at Orient Point, Bridgehampton, Cutchogue, and Groton, Conn. The Groton station is about 1 mile southeast of the New London station, which it replaced in 1953.

Precipitation, in inches, on Plum Island and at four nearby stations

Month	Plum Island	Orient Point	Groton, Conn.	Bridgehampton	Cutchogue
1958					
October	4. 28	4. 88	5. 37	6. 55	5. 59
November	1. 37	1. 95	2. 84	2. 88	2. 39
December	2. 70	2. 35	2. 51	3. 58	2. 26
1959					
January	2. 10	2. 31	2. 77	2. 27	2. 19
February	2. 68	2. 88	3. 62	2. 76	2. 49
March	6. 22	5. 56	6. 81	7. 83	5. 80
April	3. 70	4. 01	4. 23	4. 03	4. 10

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Generalized stratigraphic section for Plum Island

System	Series	Geologic formation or unit shown on geologic map	Estimated thickness (feet)	Lithologic properties	Water-bearing properties
Quaternary	Recent	Beach and marsh deposits	0–20±	Beach and dune sand and gravel. Marshy areas contain sand, silt, and clay mixed with decaying plant debris.	Beach deposits yield small supplies of fresh water from very shallow depths. Contain salt water in lower part.
	Pleistocene	Upper Pleistocene deposits	200±	Stratified and unstratified sand and gravel. May be mixed with clay or contain thin beds of clay.	Stratified deposits highly permeable and in upper part form excellent fresh-water aquifer. Chief source of fresh ground water on Plum Island. Lower part probably contains salt water.
		Unconformity(?)			
		Gardiners(?) clay	0–20±	Gray and gray-brown solid and sandy clay.	Permeability generally low. Locally may form a confining unit.
		Unconformity			
Cretaceous	Upper Cretaceous	Post-Raritan deposits	200±	White, gray, and pink fine to medium sand mixed with silt and clay; some beds of coarse sand and gravel and solid clay.	Include several permeable water-bearing zones, but probably contain brackish or salty water beneath Plum Island.
		Unconformity			
		Raritan formation: Clay member	100±	Gray, white, red, and black silt and clay and some lenses of sand and gravel.	Of low permeability; an extensive confining unit.
		Raritan formation: Lloyd sand member	100±	Gray sand and gravel and some beds of red, white, and gray clay and silt.	Good aquifer, but probably contains brackish or salty water beneath Plum Island.
		Unconformity			
Precambrian(?)		Crystalline rocks	--------	Possibly granite and granite gneiss.	Of low permeability; not an aquifer.

HISTORY OF DEVELOPMENT

Plum Island was probably settled near the beginning of the 18th century. A lone tombstone on the island is inscribed, "Thomas Gardner, 1724 to 1786, son of John Gardner of Narragansett." In 1826 the U.S. Coast Guard purchased 3 acres of land at the western end of the island for the construction and operation of a lighthouse. A. S. Hewitt sold 150 acres to the U.S. War Department in 1897 and 690 acres, the remainder of the island, in 1901. Fort Terry was constructed by 1899 and was manned from that time through World War II. In June 1948 the War Department transferred an additional 47 acres to the Coast Guard and the rest of the island to the War Assets Administration for subsequent disposal. The Agricultural Research Service of the U.S. Department of Agriculture took complete possession of the island in 1954, and the Animal Disease and Parasite Research Division established the Plum Island Animal Disease Laboratory.

GEOLOGY

Although no geologic formations older than the Pleistocene crop out on Plum Island, it is inferred that older formations are present at depth. A generalized stratigraphic section of the formations believed to be in the Plum Island area and their water-bearing characteristics are shown in the following stratigraphic section. The estimated thicknesses and descriptions of the formations are based largely on the log of well S189 (Leggette and others, 1938), drilled in 1935 about 4 miles southwest of Plum Island at Orient Beach State Park on the North Fork peninsula of Long Island, and the general work on Long Island stratigraphy by Suter and others (1949).

Crystalline rocks of probable Precambrian age form a bedrock basement, whose surface in the Plum Island area presumably slopes to the southeast at about 80 feet per mile, as it does on most of Long Island. Resting on this surface are younger semiconsolidated or unconsolidated deposits of Cretaceous and Quaternary age, which probably were eroded from the elevated parts of the bedrock surface north of Plum Island.

The Lloyd sand member of the Raritan formation of Late Cretaceous age was deposited on the Precambrian surface. The Lloyd generally consists of beds of coarse quartz sand and gravel, fine sandy clay, clayey sand, and some very thin layers of clay. Although the Lloyd sand member is an excellent aquifer and yields a good supply of fresh water in the main part of Long Island, it probably contains brackish or salty water in the Plum Island area. The Lloyd grades upward into the predominantly gray silty and solid clay of the clay member of the Raritan formation. The clay member contains some sandy layers, but its general permeability is very low and therefore it is not an aquifer

Above the Raritan formation, and separated from it by an unconformity, lie the varicolored post-Raritan deposits of Late Cretaceous age, which consist of fine sand, silt, layers of solid clay, and local beds of coarse sand and gravel in the lower part of the unit. An extension of the Magothy formation of New Jersey is included in the post-Raritan deposits of Long Island, but its vertical limits are not easily distinguished in logs of wells that penetrate these deposits (Perlmutter and Crandell, 1959). Several water-bearing zones in the post-Raritan deposits are excellent aquifers and yield large supplies of fresh water in most of Long Island, but in the Plum Island area they probably contain only brackish or salty water.

During Tertiary and possibly early Quaternary time, the post-Raritan deposits of Late Cretaceous age were eroded into a hilly terrain of moderate relief. On this irregular surface were laid down Pleistocene glacial deposits, which on Plum Island consist largely of sand and gravel. It is the upper and more permeable part of these deposits that contains Plum Island's chief reservoir of fresh ground water.

The complex Pleistocene glacial history of Long Island and its vicinity has been studied by several geologists, including Veatch and others (1906); Fuller (1914); Fleming (1935); MacClintock and Richards (1936); Thompson and others (1937); and Suter and others (1949), who have established the fact that Long Island was subjected to two or more periods of glaciation. However, the present investigation is concerned with only the most recent glaciation, which tentatively has been correlated with the Wisconsin stage of the Pleistocene epoch by several of the above writers. The following discussion is based in part on their findings and in part on recent field observations and data obtained from the logs of wells, drill holes, and test pits (table 4). The location of the wells and test holes is shown in plate 1.

During the Wisconsin stage, a part of the Hudson-Ontario lobe of the great Laurentide ice sheet was responsible for the creation of most of the present topographic features and surficial deposits of Long Island and vicinity (Flint, 1947). The Wisconsin ice in its southward movement accumulated rock debris from the land over which it passed and shoved additional material ahead of it. After passing over most of Long Island and the deposits of earlier ice advances, as well as the beds of sand and gravel deposited ahead of the ice by its melt-water streams, the movement of the ice front was checked by increased melting. This released the accumulation of rock debris held in the ice and, with the material previously pushed ahead, created a ridge of stratified sand and gravel along the ice front. This ridge at the southern terminus of the ice sheet is known on Long Island as the Ronkonkoma terminal moraine. Melt waters also spread a broad apron of well-sorted sand and gravel south of the terminal moraine. Continued melting and lack of nourishment in the region of ice accumlation caused the ice front to retreat northward. According to Fleming (1935), the Harbor Hill end moraine, part of which is on Plum Island (pl. 2), was formed when the retreating ice front again remained stationary and great quantities of melt water deposited large coalescing outwash fans of stratified sand and gravel, which were then covered with till by a later readvance of the ice (fig. 2).

FIGURE 2.—Southeastern shore of Plum Island showing stratified drift and till cap. (U.S. Department of Agriculture photograph.)

In the central part of the southeastern shoreline of the island, gray to grayish-brown sandy to solid clay is exposed in several localities (pl. 2). Because of the appearance and stratigraphic position of this clay, it is tentatively assigned to the Gardiners clay in this report, although no substantiating fossil evidence has been found. Irregular bodies of the clay in shoreline exposures may have been formed by ice shoving or "snowplowing" during an earlier advance of the ice, or possibly the weight of the overlying ice and outwash deposits may have forced the plastic clay upward, much as toothpaste is squeezed from a tube. Study of well and test-hole logs does not indicate that this clay underlies the whole island (pl. 3). If the clay underlies the island, it probably is considerably thinner than the 10- to 15-foot sections exposed on the southeastern shore and may occur as small discontinuous lenses.

The retreat of the Wisconsin ice and its subsequent stagnation along the present trend of Long Island's north shore provided the opportunity for the rapid melt-water deposition of the large coalescing outwash fans of stratified sand and gravel that make up the core of the Harbor Hill end moraine. A broad outwash channel partly removed and covered these deposits at the southwestern end of Plum Island when the ice front again retreated northward. A subsequent readvance of the ice and its slow wastage deposited a veneer of unstratified silt, sand, gravel, and boulders (till) on the preexisting stratified materials, including the low-lying southwestern part of the island. The great accumulation of stratified drift presented an obstacle to the thin readvancing ice, so that most of the material it carried was deposited on the northern face of the ridge. This till veneer is only about 5 to 10 feet thick along the southeastern shore, but it appears to be as thick as 40 feet, or more, where wave erosion has exposed it in steep bluffs on the northern shore (figs. 2, 3, and pl. 3). Melt water also scoured the northeastward-trending channel in the central part of the island and filled it with outwash material consisting largely of medium to coarse sand and gravel. The water supply on Plum Island is drawn from wells screened in this material.

As the melting of the Wisconsin ice continued, the sea level rose correspondingly. During recent time, wave erosion has removed large quantities of glacial drift, and wave action and tidal currents have redeposited some of this material in the form of low beach ridges in the southern part of the island. The older of these ridges, which alternate with marshy depressions, have almost east-west trends, but successively younger ridges approach north-south trends (pl. 2). In those areas where the bluffs contain till, wave erosion of surrounding finer sediments has left the present shoreline strewn with large boulders or glacial erratics. The rate of shoreline erosion evidently has been rapid, at least since the construction of Fort Terry's concrete gun emplacements. Several of these, which initially were high on the bluffs, have been undermined by wave action and now lie demolished on the beach.

Table I contains data on physical properties of upper Pleistocene outwash or stratified drift in which 10 observation wells (pl. 1) were

FIGURE 3.—Northern shore of Plum Island showing till bank and erratic-strewn beach. (U.S. Department of Agriculture photograph.)

screened. A power auger was used to obtain samples for analysis and to provide holes in which well screens and casing were driven to construct the observation wells. The hydrologic laboratory of the Geological Survey provided the determinations of specific yield and coefficient of permeability (table 1), and the mechanical analyses were made by the writer. The sediments consist mainly of angular quartz grains and rock particles and smaller amounts of biotite, feldspar, magnetite, garnet, and hornblende. Particle diameters are commonly greater than 0.25 mm (medium sand), and most are about 0.5 mm (coarse sand).

In plate 3, section *A–A′* is drawn along a northeast-southwest line passing through well S17135 and well S17137, which is in the well field. Well S17130 is projected about 200 feet to the southeast into the line of the section. At the northeastern end of the section a steep bluff, largely composed of till, rises above the boulder-strewn shoreline. Till (unstratified drift) blankets stratified drift in the northeastern part of the section but is believed to be truncated near well S17135 by the outwash-filled channel, which may extend to a depth of 35 feet below sea level. The beach-ridge deposits which occupy the southwestern part of the section extend perhaps 5 or 10 feet below sea level and presumably overlie the channel outwash and stratified drift.

Section *B–B′* of plate 3 trends northwest-southeast and intersects section *A–A′* at well S17135. Well S17129 also is in the line of section *B–B′*, and drill hole 13 and test pit 3 are projected into it about 100 feet to the northeast and to the southwest, respectively. The northwestern half of section *B–B′* is almost identical to the northeastern third of section *A–A′*. The central part of section *B–B′* crosses the outwash-filled channel at almost a 90° angle to its trend, and a layer of till less than 10 feet thick again veneers the underlying stratified drift at the southeastern end of the section. The Gardiners(?) clay appears at the shoreline, but its lateral extent and thickness are indefinite.

GROUND WATER

OCCURRENCE, MOVEMENT, AND STORAGE

The replenishment of the ground-water reservoir on Plum Island depends solely on precipitation, which averages about 45 inches each year. Part of this precipitation runs off, part is returned to the atmosphere by evaporation and by transpiration of plants, and part seeps into the ground. Of this last part, some eventually reaches the ground-water reservoir and may become available for use through the island's water-supply system.

Overland runoff from Long Island as a whole has been estimated by Burr and others (1904) as 20 percent of drought-year precipitation (35 inches) and 33 percent of average-year precipitation (45 inches). However, Leggette (*in* Paulsen, 1940) has estimated that only 5 percent of storm precipitation, even during hurricanes, reaches Long Island streams as overland runoff. Hoffman (1959) suggests that a runoff of about 10 percent of the annual precipitation may prevail in the town of Southold, which includes most of the North Fork of Long Island. This estimate is based on the low moisture-retention capacity of the prevailing silty-loam soil, excellent subsoil drainage of the silty loam by the underlying sand, retardation of overland runoff by the furrows of cultivated fields, and flatness of the terrain in most of the North Fork. On Plum Island, in contrast to most of Southold, much of the land surface consists of glacial till, which is not as permeable as the loam and underlying sand; vegetation covers most of the island instead of large expanses of cultivated fields; the island has considerable topographic relief—steep slopes extend to the sea, especially along the northern shore; and the small area of the island allows runoff only a short distance to travel before it discharges into the sea. These factors suggest that a higher runoff figure should be applied to Plum Island—probably about 15 percent of the annual precipitation.

Much of the precipitation is returned to the atmosphere by evaporation and by transpiration of plants. A combination of these two processes is called evapotranspiration. Although evapotranspiration on Plum Island cannot be estimated closely, Hoffman (1959) has estimated that the annual evapotranspiration in the town of Southold should range from about 21 to 26 inches. The evaporation, based on the precipitation records of the Cutchogue gage, was estimated to be 12 inches for the year of least annual precipitation (1908), 17 inches for the year of greatest annual precipitation (1948), and 14 inches for the year in which annual precipitation closely approached the long-term average (1949). Average annual transpiration was estimated to be 9 inches. Although the transpiration rate on Plum Island may be somewhat less than that for the cropland area of the town of Southold, the evaporation rate on Plum Island probably is greater than that in Southold because of the large ponds in the southwestern part of the island. Thus, the total annual evapotranspiration rate for the island probably is within the 21- to 26-inch range.

Recharge to the ground-water reservoir on Plum Island is the difference between precipitation and the sum of runoff and evapotranspiration. This sum may range from about 75 percent of the annual precipitation in very dry years to about 60 percent in very wet years. Thus, only 25 to 40 percent of the total annual precipitation would be available for recharging the ground-water reservoir. If the total area (1.3 square miles) of the island is considered, recharge from precipitation during a year of average precipitation would be about 328 million gallons. However, the eastern taillike area of Plum Island and a part of the island's southwestern area probably provides little recharge to the ground-water reservoir in the main body of the island. The total area of the island available for recharge, therefore, is reduced by about 50 percent to an effective recharge area of about 0.66 square mile. Thus, recharge during a year of average precipitation would be about 164 million gallons. The paved and built-up areas of the island, which would prevent infiltration of precipitation, are considered in these revised estimates.

The fresh ground water available for use on Plum Island is contained in the interstices of the upper Pleistocene glacial deposits. This ground-water body is under water-table or unconfined conditions. It is also believed to occur as an irregularly shaped lens, which overlies glacial deposits saturated with salt water (pl. 3). As the specific gravity of the fresh ground water is less than that of the underlying salt water, the fresh water tends to float on the salt water generally within the boundaries of the island. Figure 4 presents a hypothetical cross section of an island composed of permeable sand and surrounded entirely by sea water and demonstrates this relation under ideal conditions. Fresh water fills the sand to the depth at which its head is balanced by the head of the salt water. At equilibrium, the depth of fresh water below sea level at any point on the island is proportional to the fresh-water head above sea level and dependent on the difference between the specific gravities of fresh and salt water. This relation is summarized in the following equation, which is often referred to as the Ghyben-Herzberg principle:

$$h=\frac{t}{g-1}$$

where,

h=depth of fresh water below sea level,
t=height of fresh water above sea level, and
g=specific gravity of salt water as compared to the assumed specific gravity of 1 of fresh water.

Although the specific gravity of sea water varies somewhat from place to place, the average of 1.025, if used in the Ghyben-Herzberg formula, shows that fresh water would extend 40 feet below sea level for each foot it extends above sea level. Hubbert (1940) has shown that the Ghyben-Herzberg formula may apply only under conditions of hydrostatic equilibrium and is approximately correct only under low hydraulic gradients. The 40:1 ratio probably is approximately correct on Plum Island and has been used to define the shape (pl. 3) of the fresh-water lens and to estimate fresh ground-water storage.

The upper surface of the unconfined fresh-water lens on Plum Island is marked by a water table, whose configuration is shown in plate 4 by contour lines referred to mean sea level. These contour lines are based on water-level measurements made on April 9, 1959, in 10 observation wells and several ground-water ponds and swamps in the western part of the island. The contour lines represent the shape of the water table as it approaches the spring seasonal maximum level.

In effect, the movement of ground water on Plum Island is radially away from the highest point on the water table, whose maximum observed altitude is 2.53 feet above mean sea level, at well S17131. However, a relatively narrow ground-water divide passes through the highest points on the water table and generally bisects the trend of the 2.5-foot closed contour shown in plate 4. From the vicinity of

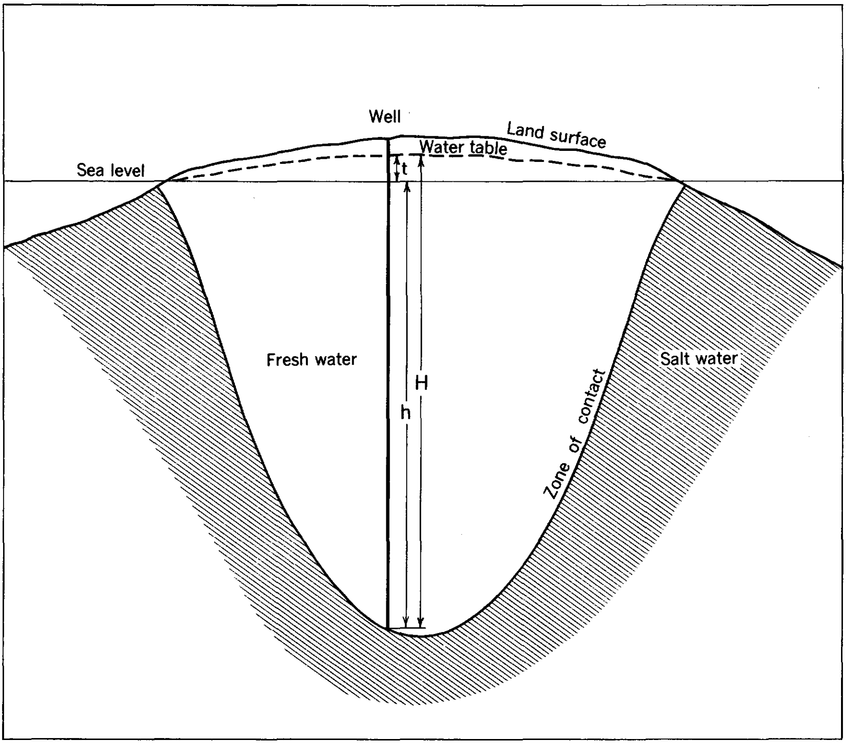

FIGURE 4.—Idealized cross section of an island showing relation of fresh water to salt water, according to the Ghyben-Herzberg principle. From Petitt and Winslow (1957, pl. 8).

this divide, ground water moves toward the sea along lines normal to the water-table contours. Section *B–B′* in plate 3 illustrates this movement by means of arrows that indicate the direction of flow in the vertical plane. The ground-water discharge by lateral outflow into the sea is dependent on the permeability of the glacial deposits (table 1) and the hydraulic gradient, and it probably approaches the amount of recharge to the ground-water reservoir. Most of the lateral outflow takes place at or below sea level.

The fresh ground water in storage under Plum Island is contained in upper Pleistocene glacial desposits estimated to be 1,700 million cubic feet in volume. However, not all the water filling the intergranular spaces of this large body of sediment is available. The volume of available water is roughly equivalent to the specific yield (table 1) of the deposit. The average specific yield of the saturated glacial deposits of Plum Island, established from table 1, is about 21.8 percent. When this figure is applied to the volume of sediments under the whole island, it is computed that about 2,800 million gallons of fresh ground water was in storage in April 1959. However, a factor of about one-half must again be applied as in recharge estimates; effective storage, therefore, would be about 1,400 million gallons.

WATER-LEVEL FLUCTUATIONS

During January 8 to May 28, 1959, weekly water-level measurements were made in 10 observation wells (table 2) on Plum Island. The average of these measurements is given in the hydrograph on figure 5. Although the period of record is too short to define long-term fluctuations, the spring (April–May 1959) high shown in figure 5 coincides generally with the pattern of water-level fluctuation in observation wells on the North Fork peninsula of Southold. From this it is inferred that water-level fluctuations of the ground-water body on Plum Island would follow the seasonal fluctuation pattern of the shallow ground-water body of the North Fork peninsula.

GROUND-WATER WITHDRAWAL

In a balanced hydrologic system natural discharge equals recharge plus or minus changes in ground-water storage. When artificial withdrawal from wells is introduced, the system is at first unbalanced by removal of water taken from storage. Later the balance is re-established when part of the recharge replenishes the water artificially withdrawn. The effective recharge to the ground-water reservoir of Plum Island may range from 164 million gallons annually or 0.45 mgd (million gallons per day) in an average year, to 131 million gallons annually or 0.36 mgd in a dry year. Practically, however, it is necessary to restrict the withdrawal to an amount substantially less than the recharge in order to avoid a heavy demand on storage and to prevent sea-water encroachment.

Monthly pumpage, in millions of gallons, from supply wells on Plum Island from January 1957 through May 1959 is shown in the table below.

Monthly pumpage, in millions of gallons, from supply wells on Plum Island from January 1957 through May 1959

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1957 [1]	1.82	1.72	1.72	1.65	1.47	1.84	1.83	2.08	1.78	1.65	1.39	1.47	20.42
1958 [2]	1.98	1.94	2.25	2.76	2.75	2.39	2.85	2.60	2.55	2.97	2.84	3.16	31.04
1959	3.20	2.86	3.34	3.00	3.12								

[1] Daily average: 0.06 million gallons.
[2] Daily average: 0.09 million gallons.

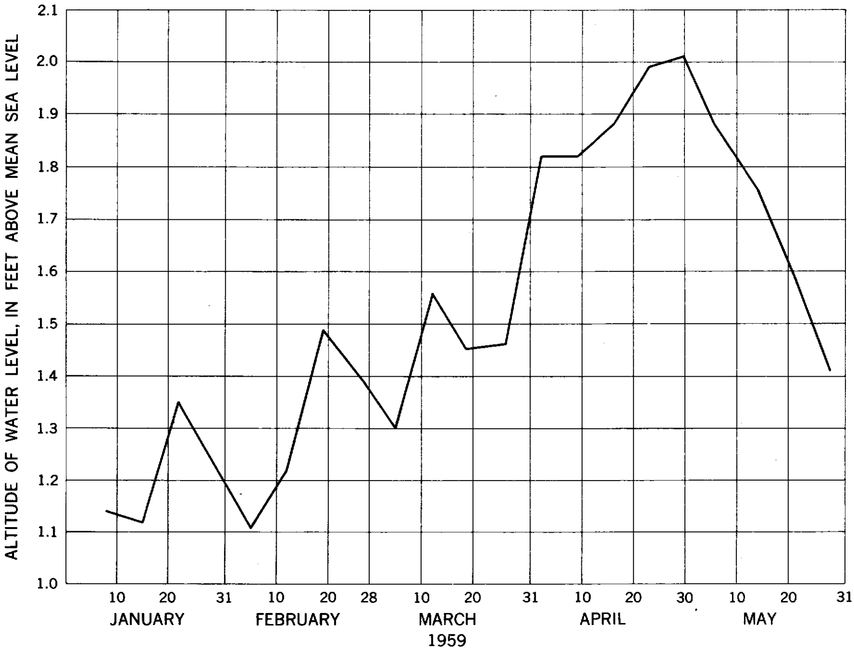

FIGURE 5.—Hydrograph of average water levels measured in 10 wells on Plum Island.

Pumpage during 1958, a year of above-average recharge, totaled only about 31 million gallons, or an average of 0.09 mgd. However, during the first 5 months of 1959 pumpage increased by 3.84 million gallons over pumpage for the same period in 1958, and was almost double that for the first 5 months of 1957. To minimize the effect of pumping in contributing to possible sea-water encroachment, total withdrawals during any one year probably should not exceed about 75 million gallons, or 0.2 mgd—assuming that such withdrawals are made from points as widely spaced as economically feasible within the area of effective recharge.

SEA-WATER CONTAMINATION

Sea-water contamination of fresh ground water in the area of the well field on Plum Island can present various problems, according to the extent of contamination. The U.S. Public Health Service (1946) recommends that the chloride concentration in drinking water not exceed 250 ppm (parts per million). Water having a chloride concentration of 250 ppm probably would taste very slightly salty, but even higher concentrations of chloride are not harmful to the human body or to livestock.

Several factors indicate that, although ground-water supplies on Plum Island are ample for present and foreseeable needs, sea-water contamination of the well field is a potential hazard. The topo-

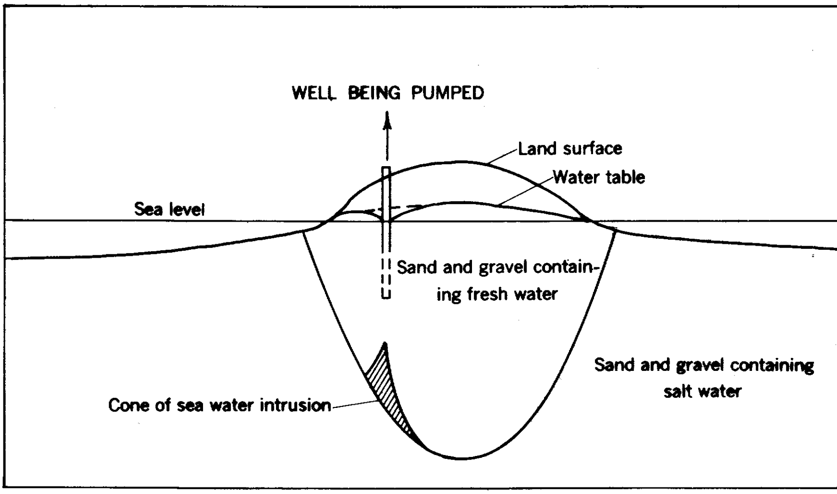

FIGURE 6.—Idealized cross section showing vertical sea-water encroachment caused by pumping.

graphic position of the well field, between 10 and 15 feet above mean sea level in the south-central part of the island, exposes the well-field area to occasional inundation by storm waves or soaking by salt spray. Winds of gale or hurricane force presumably can sweep enough salt water over the well field to cause considerable contamination. For example, chloride determinations listed in table 3 for water from the supply wells indicate an increase from about 10 ppm to as much as 40 ppm between 1951 and early 1959. Although the data are not conclusive, they suggest that this increase may have resulted, at least partly, from contamination by the hurricanes of 1954 and 1955.

The ground-water reservoir might also be encroached by sea water, as illustrated in figure 6, by the upward movement of a salt-water tongue toward the pumping wells, or by landward migration of the zone of diffusion between the fresh-water lens and the surrounding salt water (fig. 7). Section *A–A′* on plate 3 suggests that the well field is located where the thickness of the fresh-water lens and the depth to the zone of diffusion begin to diminish southwestward. If pumping at high rates were continued for prolonged periods—particularly during drought—water levels in the well field would decline, and the fresh-water head would be reduced so that it could no longer balance the head of the salty water at the contact between fresh and salt water. Salty water would then move upward toward the well field. An extensive thick layer of relatively impermeable material such as the Gardiners clay might provide some protection

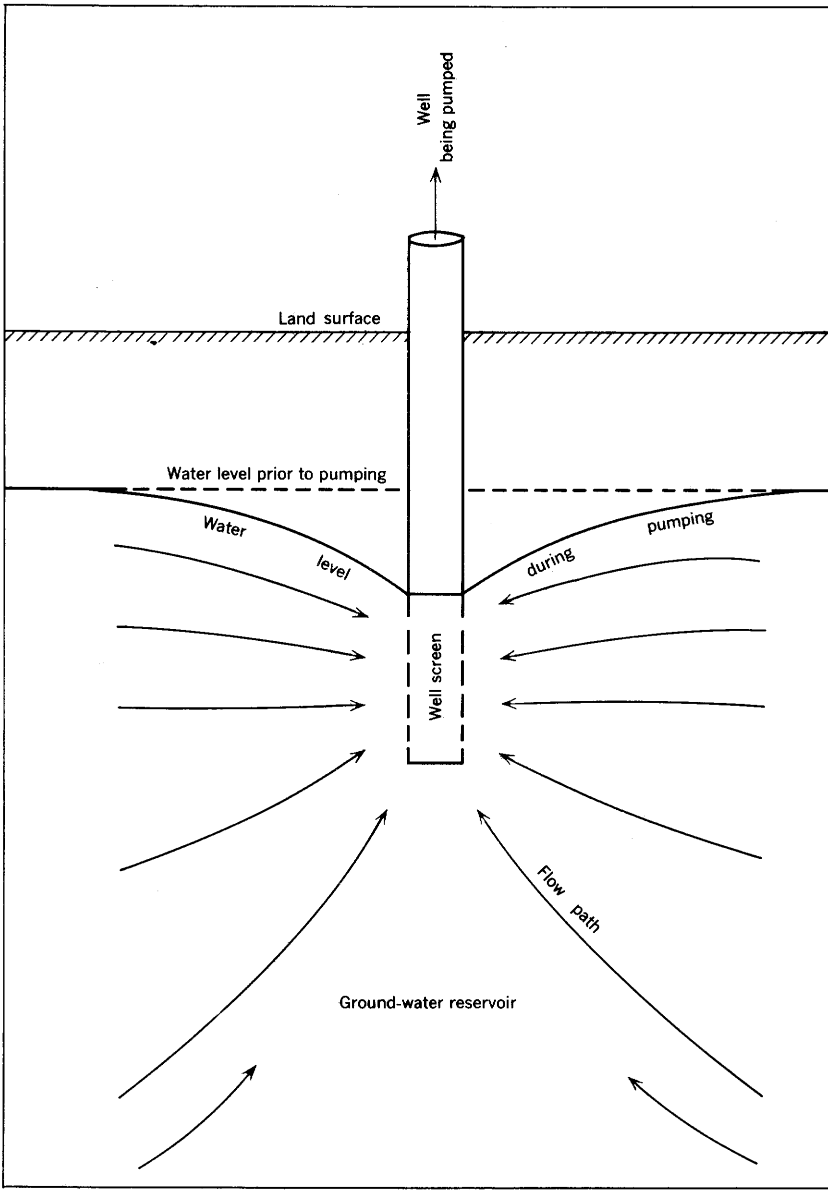

FIGURE 7.—Idealized cross section showing movement of ground water toward a well being pumped.

against salt-water contamination of the well field if it lay between the underlying salt water and the well screens. However, the geologic conditions previously described indicate that the clay is neither thick nor continuous on Plum Island.

CHEMICAL QUALITY OF THE GROUND WATER

Table 3 summarizes the findings of several laboratories in regard to the chemical quality of the fresh ground water on Plum Island. One analysis was made in 1939 and the rest between 1951 and 1959. The Geological Survey made comprehensive chemical analyses of water from observation wells S17128, S17134, and S17136, near the island's northwestern and southeastern shores (pl. 1), as well as chloride determinations in water from most wells and ponds. For comparison, the standards of the U.S. Public Health Service (1946) are given below in terms of the maximum allowable concentration for certain common constituents:

	Parts per million
Iron (Fe) and manganese (Mn) together	0.3
Magnesium (Mg)	125
Chloride (Cl)	250
Sulfate (SO_4)	250
Dissolved solids (for water of good chemical quality)	500

Except for the generally high iron and manganese content of water from both observation and supply wells, the quality of the ground water meets the Public Health Service standards. Present water-treatment practices effectively control the iron-manganese problem and raise the pH of the slightly corrosive water.

The high-chloride concentration in water from observation well S17130 suggests that the well screen is within the zone of diffusion between fresh and salty water, as shown in section *A–A′*, plate 3.

CONCLUSIONS AND RECOMMENDATIONS

The investigation has shown that water-bearing sediments of considerable thickness underlie Plum Island, but only the upper Pleistocene glacial deposits contain a relatively thin lens of fresh ground water. The lowest point on this lens probably does not lie more than 100 feet below mean sea level. The sediments that contain the ground-water supply are characteristically uniform and permeable and are apparently uninterrupted by less permeable material. Sediment texture and specific-yield determinations also indicate that ground water can be withdrawn safely from wells in the interior parts of the island. Obviously, such withdrawals should not be made near the periphery of the island because of the potential hazard of sea-water encroachment.

From available data, the shape of the fresh ground-water lens is thought to follow essentially the Ghyben-Herzberg principle, which states in general that for each foot of fresh water above sea level 40 feet of fresh water is below sea level. The amount of fresh ground water in storage probably exceeds 1,500 million gallons.

Recharge, even during years of drought, is considered to be more than adequate to replenish present (1959) modest withdrawals from storage in the ground-water reservoir.

The chemical quality of the ground water is satisfactory according to Public Health Service standards, and only a small amount of treatment for a few problem constituents is necessary.

Plum Island is small and surrounded by sea water and its fresh ground-water reservoir is subject to contamination by encroaching sea water, but definitive evidence that the well field was being contaminated by sea-water encroachment was lacking in early 1959. A slight increase in chloride concentration in the water from the supply wells occurred between 1951 and early 1959, and the location of the well field suggests the possibility that some slight contamination may have resulted from the hurricanes of 1954 and 1955. However, this contamination could have resulted from the vertical or lateral encroachment of sea water.

The following four measures could offset the danger of sea-water contamination of Plum Island's fresh ground-water supply:

1. A reduction in the total use of fresh water could be effected by instituting a water-conservation campaign. All water-supply equipment and mains should be carefully maintained and examined periodically for evidence of leakage. As fresh water is a precious commodity on the island, all personnel should be instructed to keep faucets tightly closed when not in use and to report defective plumbing immediately. The effectiveness of such a program can be determined by comparing pumpage rates or waste-water (sterilized by the laboratories) discharge rates with those for a similar period before the institution of conservation measures.
2. The ground-water reservoir could be artificially recharged by return of sterile waste water and storm runoff to the ground. Such water could be collected in natural depressions near the ground-water divide (pl. 4) in the central part of the island. In particular, natural depressions in the hilly north-central part of the island could be deepened, and runoff from storms could be diverted into these basins through culverts built along natural drainage channels. The till cover in these basins should be removed down to the underlying stratified drift, which would allow water to infiltrate at the optimum rate. The recharge basins should be cleaned periodically to remove accumulated fine sediments, which retard infiltration.
3. Of utmost importance is a continuation of the water-level and chloride-monitoring program. Water levels in the observation wells should be measured periodically to monitor changes in

ground-water storage. Determination of chloride in raw water from supply wells and surrounding observation wells should be made at regular intervals, especially during periods when the water table is low and pumpage is increased. It is only through the accumulation of such data over a considerable period that clear evidence of sea-water encroachment or overdevelopment of the well field can be established.

In this regard, the construction of two "outpost" wells would aid greatly in defining the position and movement of the interface between fresh and salt water. One "outpost" well should be placed between the well field and the sea, especially in that area south of the well field where the fresh-water lens is thinnest and the hazard of sea-water encroachment is greatest. The other outpost well should be placed at the site of S17135 to monitor the position of the interface under the center of the island. The wells should be about 300 feet deep, or deep enough to penetrate the upper part of the post-Raritan deposits. Cores and electric logs would provide sufficient data to determine the position of the interface between fresh and salt water and the thickness of any confining clay layer. The wells could then be screened just above the interface, and periodic determinations of chloride in water from them would indicate whether or not the interface is migrating toward the well field.

4. An additional source of supply of fresh ground water is desirable. An additional well field not only would serve as an auxiliary supply if the present well field were contaminated or otherwise disabled, but it would also provide a means of reducing the draft on the ground-water reservoir at the present field by alternate pumping of the well fields. The best location for a second well field probably would be near observation well S17135, where it would be protected from sea-water inundation. Also, it would be immediately adjacent to the present booster station and the main pipeline leading to the reservoir. Table 3 indicates that water from the observation well at this location had the lowest chloride concentration of all samples from similar wells installed in December 1958. The specific yield at this location is satisfactory, and the area is very near the water-table divide, which would afford the wells maximum protection from sea-water encroachment. Wells in this vicinity probably would need to be no deeper than about 50 feet.

REFERENCES CITED

Burr, W. H., Hering, Rudolf, and Freeman, J. R., 1904, Report of commission on additional water supply for city of New York: New York, Martin B. Brown Co.

Fleming, W. L. S., 1935, Glacial geology of central Long Island: Am. Jour. Sci. v. 30, p. 216–238.

Flint, R. F., 1947, Glacial geology and the Pleistocene epoch: New York, John Wiley & Sons, 589 p.

Fuller, M. L., 1914, The geology of Long Island, N.Y.: U.S. Geol. Survey Prof. Paper 82, 231 p.

Hoffman, J. F., 1959, Hydrology of the shallow ground-water reservoir of the town of Southold, Suffolk County, L.I., N.Y., with particular reference to sea-water encroachment: U.S. Geol. Survey open-file report.

Hubbert, M. King, 1940, The theory of ground-water motion: Jour. Geology, v. 48, no. 8, p. 785–944.

Leggette, R. M., and others, 1938, Record of wells in Suffolk County, N.Y.: New York State Water Power and Control Comm. Bull. GW–4, p. 93–97.

MacClintock, Paul, and Richards, H. R., 1936, Correlation of late Pleistocene marine and glacial deposits of New Jersey and New York: Geol. Soc. America Bull., v. 47, no. 3, p. 289–338.

Mather, W. W., 1843, Geology of New York; pt. 1, Comprising the geology of the first geological district: Albany, N.Y., Carroll and Cook, 653 p.

Merrill, F. J. H., 1886, On the geology of Long Island: New York Acad. Sci. Ann., v. 3, nos. 11–12, p. 341–364.

Mordoff, R. A., 1949, The climate of New York State: Cornell Ext. Bull. 764, 72 p.

Paulsen, C. G., 1940, Hurricane floods of September 1938: U.S. Geol. Survey Water-Supply Paper 867, 562 p.

Perlmutter, N. M., and Crandell, H. C., 1959, Geology and ground-water supplies of the south-shore beaches of Long Island, N.Y., *in* Lowe, K. E., ed., Modern aspects of the geology of New York City and environs: New York Acad. Sci. Annals, v. 80, art. 4, p. 1060–1076.

Petitt, B. M., Jr., and Winslow, A. G., 1957, Geology and ground-water resources of Galveston County, Texas: U.S. Geol. Survey Water-Supply Paper 1416, 157 p.

Suter, Russell, deLaguna, Wallace, and Perlmutter, N. M., 1949, Mapping of geologic formations and aquifers of Long Island, N.Y.: New York State Water Power and Control Comm. [now the New York State Water Resources Comm.] Bull. GW–18, 212 p.

Thompson, D. G., Wells, F. G., and Blank, H. R., 1937, Recent geologic studies of Long Island with respect to ground-water supplies: Econ. Geology, v. 32, p. 451–470.

U.S. Public Health Service, 1946, Public Health Service drinking water standards, 1946: Public Health Repts., v. 61, no. 11, p. 371–384.

Veatch, A. C., and others, 1906, Underground water resources of Long Island, New York: U.S. Geol. Survey Prof. Paper 44, 394 p.

TABLE 1.—*Physical characteristics of upper Pleistocene water-bearing materials on Plum Island*

Well	Depth of sample below land surface (feet)	Coefficient of permeability [1] (gpd per square foot)	Specific yield [2] (percent)	Mechanical analysis (percent by weight)						
				<0.0625 mm	0.0625–0.125 mm	0.125–0.25 mm	0.25–0.5 mm	0.5–1 mm	1–2 mm	>2 mm
S17128	45–50	210	24.6	1.8	1.4	6.8	18.1	27.0	16.8	28.1
S17129	50–55	89	22.8	2.8	2.7	10.1	24.8	33.4	14.6	11.6
S17130	47–50	40	24.0	3.9	3.1	12.0	28.0	39.5	9.4	4.1
S17131	60	45	19.8	3.6	4.3	10.5	17.0	33.4	17.0	14.2
S17132	40	250	27.5	1.9	1.9	8.6	22.1	39.7	17.0	8.8
S17133	40	15	18.0	5.0	3.1	17.2	32.4	26.7	8.1	7.5
S17134	23	290	23.4	1.4	1.0	3.4	9.8	32.7	21.6	30.1
S17135	40–45	30	17.6	3.3	2.6	8.1	13.8	29.3	20.7	22.2
S17136	20	53	23.9	4.5	6.3	19.7	22.6	25.8	9.1	12.0
S17137	22	230	25.4	1.3	1.9	9.2	16.8	32.0	19.8	19.0

[1] The rate of flow of water, in gallons per day, through a cross section of 1 square foot under a unit hydraulic gradient. The standard coefficient is defined for water at a temperature of 60°F.
[2] The quantity of water that a formation will yield under the pull of gravity if it is first saturated and then allowed to drain; the ratio expressed as a percentage of the volume of this water to the total volume of the formation that is drained.

TABLE 2.—*Water levels in observation wells on Plum Island, January through May 1959*

[Water levels, in feet above or below (—) mean sea level. All wells were installed by the Geological Survey by augering and driving in December 1958. Screen and casing diameter is 1¼ in. See pl. 1 for locations]

Well	Depth below land surface (feet)	Altitude of measuring point at top of casing (feet)	Jan. 8	Jan. 15	Jan. 22	Jan. 29	Feb. 5	Feb. 12	Feb. 19	Feb. 26
S17128	34	16.30	1.10	1.18	1.21	0.91	0.96	1.07	1.41	1.35
S17129	53	35.71	.89	1.03	1.10	.74	.84	.88	1.22	.92
S17130	53	38.45	.26	.51	.83	—.23	.45	.38	1.18	.95
S17131	79	65.09	2.25	--------	2.18	2.12	2.09	2.06	2.12	2.09
S17132	49	36.68	—.17	.96	1.18	.78	.88	1.05	1.30	1.25
S17133	59	43.13	1.24	1.14	1.25	1.07	1.03	1.19	1.35	1.31
S17134	28	14.61	1.06	1.21	1.41	.97	1.16	1.28	1.55	1.51
S17135	44	36.38	1.65	1.47	1.51	1.40	1.34	1.44	1.61	1.57
S17136	23	8.61	1.69	1.46	1.56	1.35	1.35	1.60	1.78	1.73
S17137	33	16.51	1.41	1.16	1.22	1.08	.98	1.20	1.39	1.35

Well	Mar. 5	Mar. 12	Mar. 19	Mar. 26	Apr. 2	Apr. 9	Apr. 16	Apr. 23	Apr. 30	May 6	May 14	May 21	May 28
S17128	1.22	1.56	1.50	1.53	1.76	1.86	1.86	1.86	1.92	1.70	1.58	1.36	1.24
S17129	1.04	1.10	.96	.91	1.40	1.20	1.40	1.55	1.67	1.46	1.35	1.14	1.05
S17130	.31	.34	.02	.47	.81	.43	.62	.85	.94	.69	.60	.28	.17
S17131	2.11	2.24	2.24	2.21	2.40	2.53	2.68	2.88	3.15	3.19	3.22	3.11	3.03
S17132	1.23	1.24	1.07	.98	1.58	1.38	1.54	1.77	1.68	1.56	1.40	1.31	1.07
S17133	1.35	1.47	1.39	1.26	1.73	1.74	1.70	2.04	2.02	1.93	1.71	1.56	1.41
S17134	1.42	1.53	1.34	1.48	1.88	1.74	2.01	2.06	1.91	1.81	1.86	1.39	1.29
S17135	1.55	1.86	1.88	1.91	2.14	2.37	2.18	2.53	2.45	2.40	2.19	2.03	1.87
S17136	1.63	2.30	2.20	2.07	2.36	2.52	2.47	2.33	2.22	2.15	2.00	2.08	1.59
S17137	1.13	1.94	1.94	1.73	2.16	2.38	2.30	2.05	2.16	1.93	1.67	1.66	1.37

TABLE 3.—*Chemical analyses of water*

[Chemical constituents in parts per million. All

Well or pond	Depth of sample (feet)	Date of collection	Source of analysis [1]	Silica (SiO_2)	Iron (Fe) total	Manganese (Mn)		Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
						Dissolved	Total				
Supply wells											
S10261	30	Apr. 18, 1955	A	5.5	Trace						
S10262	34	Aug. 29, 1955	B	10	0		0	7.6	1.9		
S10263	32	Oct. 29, 1951 [2]	C		0						
		Apr. 18, 1955	A	6.5	Trace						
S10264	29	Oct. 29, 1951 [2]	C		.3						
		Apr. 18, 1955	A	7.0	.1						
S10265	30	Oct. 29, 1951 [2]	C		9.3						
		Apr. 18, 1955	A	6.5	Trace						
S10266	29	Oct. 29, 1951 [2]	C		0						
		Apr. 15, 1955	A	7.0	Trace						
S10267	29	Oct. 29, 1951 [2]	C		1.0						
		Apr. 14, 1955	A	7.5	.1						
S10268	29	Apr. 13, 1955	A	8.0	.1						
S10269	27	Aug. 29, 1955	B	10	0		0	4.8	2.8		
S10270	28	Apr. 18, 1955	A	8.0	.1						
		Apr. 24, 1959	F								
Composite sample (all supply wells)		May 17, 1939	D		.1						
		Oct. 29, 1951 [2]	C		.7						
		June 14, 1953	E		1.8						
		Apr. 20, 1955	A	6.0	Trace						
Observation wells											
S17128	34	Dec. 3, 1958	F								
		do	F	7.3	0.16	0.04	0.05	4.8	3.6	16	1.2
S17130	53	do	F								
S17131	79	do	F								
S17132	49	do	F								
S17133	59	do	F								
S17134	28	do	F								
		do	F	11	.36	.77	.89	8.0	6.0	23	2.1
S17135	44	do	F								
S17136	23	do	F								
		do	F	12	2.8	.76	.81	8.8	17	63	8.9
S17137	33	do	F								
Ponds											
P1		May 1952	G								
		April. 24, 1959	F								
P2		May 1952	G								
		Apr. 24, 1959	F								
P3		May 1952	G								
		Apr. 24, 1959	F								
P4		May 1952	G								
P5		do	G								
P6		do	G								
		Apr. 24, 1959	F								
P7		do	F								

[1] A, The Bowers Co.; B, South Shore Analytical and Research Laboratory, Inc.; C, U.S. Army Chemical Corps.; D, Connecticut State Department of Health; E, Suffolk County Health Department; F, U.S. Geological Survey; G, C. W. Lauman & Co., Inc.
[2] Date of report.

from wells and ponds on Plum Island

wells are screened in upper Pleistocene deposits]

Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$		Alkalinity as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Color
						Carbonate	Noncarbonate				
Supply wells—Continued											
--------	--------	26	--------	--------	--------	32	--------	20	--------	6.1	1
27	--------	22	--------	--------	--------	27	5	27	--------	6.2	5
--------	4.0	10	--------	--------	280	49	--------	30	--------	6.9	--------
--------	--------	24	--------	--------	--------	26	--------	24	--------	6.1	1
--------	2.5	10	--------	--------	120	52	--------	45	--------	7.5	--------
--------	--------	24	--------	--------	--------	24	--------	18	--------	6.1	1
--------	4.0	10	--------	--------	96	22	--------	32	--------	6.4	--------
--------	--------	28	--------	--------	--------	24	--------	18	--------	6.1	1
--------	2.5	10	--------	--------	104	44	--------	21	--------	6.3	--------
--------	--------	30	--------	--------	--------	24	--------	20	--------	6.1	1
--------	2.5	10	--------	--------	120	44	--------	41	--------	6.8	--------
--------	--------	34	--------	--------	--------	24	--------	10	--------	5.7	2
--------	--------	26	--------	--------	--------	20	--------	16	--------	6.1	2
27	--------	26	--------	--------	--------	23	1	27	--------	6.9	5
--------	--------	34	--------	--------	--------	28	--------	16	--------	6.1	2
--------	--------	40	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	20	--------	0.1	--------	30	--------	11	--------	6.5	0
--------	4.0	10	--------	--------	150	39	--------	25	--------	6.5	--------
--------	--------	33	0.1	2.5	--------	40	--------	15	--------	6.2	--------
--------	--------	30	--------	--------	--------	40	--------	16	--------	6.1	1
Observation wells—Continued											
--------	--------	36	--------	--------	--------	--------	--------	--------	--------	--------	--------
8	6.6	32	0.0	6.0	91	27	20	--------	159	6.0	7
--------	--------	3,400	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	42	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	90	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	32	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	52	--------	--------	--------	--------	--------	--------	--------	--------	--------
20	16	35	.1	1.7	136	45	28	--------	240	6.4	7
--------	--------	24	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	68	--------	--------	--------	--------	--------	--------	--------	--------	--------
130	46	65	.0	.0	284	92	0	--------	514	7.3	10
--------	--------	42	--------	--------	--------	--------	--------	--------	--------	--------	--------
Ponds—Continued											
--------	--------	25	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	138	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	8,800	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	100	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	1,900	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	142	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	700	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	6,800	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	50	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	18	--------	--------	--------	--------	--------	--------	--------	--------	--------
--------	--------	28	--------	--------	--------	--------	--------	--------	--------	--------	--------

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*

Material	Thickness (feet)	Depth (feet)
Well S17128		
[Land surface about 16 ft above mean sea level. Bottom of casing at 34 ft; screen at 31–34 ft]		
Sand, coarse, brown, and gravel; much clay	9	9
Sand, medium to coarse, brown, and gravel; some cobbles and boulders; some clay	14	23
Sand, coarse; some gravel	27	50
Sand, medium to coarse	9	59
Sand, clayey, brown to gray	2	61
Well S17129		
[Land surface about 35 ft above mean sea level. Bottom of casing at 53 ft; screen at 50–53 ft]		
Sand, medium to coarse, brown, and gravel; some clay	10	10
Sand, medium to coarse, and gravel; some cobbles and boulders; some clay	5	15
Sand, fine to coarse, grayish-green, and gravel; some clay	19	34
Clay, sandy, brown	1	35
Sand, medium to coarse, brown	15	50
Sand, fine to coarse, dark-brown, and gravel; some silt	19	69
Clay, sandy, gray	1	70
Well S17130		
[Land surface about 38 ft above mean sea level. Bottom of casing at 53 ft; screen at 50–53 ft]		
Sand, medium to coarse, brown, and gravel; some clay	7	7
Sand, medium to coarse, brown, and gravel; some cobbles and boulders; some clay	4	11
Sand, fine to coarse, grayish-green to brown; some gravel; clay	24	35
Sand, medium to coarse, brown	12	47
Sand, coarse, light-brown	23	70
Sand, clayey, grayish-brown, grading into gray sandy clay	5	75
Well S17131		
[Land surface about 65 ft above mean sea level. Bottom of casing at 79 ft; screen at 76–79 ft]		
Sand, medium, brown	8	8
Sand, medium to coarse, brown, and gravel	30	38
Sand, medium to coarse, brown	32	70
Sand, fine to coarse, light-brown; some gravel; silt	25	95
Clay, dark-gray	1	96
Well S17132		
[Land surface about 36 ft above mean sea level. Bottom of casing at 48 ft; screen at 45–48 ft]		
Sand, fine to coarse, brown and gravel; clay	17	17
Sand, coarse, dark-brown, and gravel; streaks of black clay	20	37
Sand, medium to coarse	3	40
Sand, coarse, reddish-brown	10	50
Clay, dark-gray	1	51

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Well S17133		
[Land surface about 43 ft above mean sea level. Bottom of casing at 59 ft; screen at 56–59 ft]		
Sand, fine, and grayish-brown clay	4	4
Sand, fine to coarse; some gravel; streaks of clay	10	14
Sand, fine to coarse, grayish-green; some feldspar pebbles; silt	21	35
Sand, medium to coarse, brown; some gravel	15	50
Sand, medium to coarse; clay	10	60
Clay, sandy, grayish-brown	1	61
Well S17134		
[Land surface about 15 ft above mean sea level. Bottom of casing at 28 ft; screen at 25–28 ft]		
Sand, fine to coarse, and gravel; clay	5	5
Sand, medium to coarse, reddish-brown; some gravel	11	16
Sand, coarse, brown	6	22
Clay, sandy, brown	4	26
Sand, medium, brown	16	42
Well S17135		
[Land surface about 36 ft above mean sea level. Bottom of casing at 44 ft; screen at 41–44 ft]		
Sand, medium to coarse; some gravel; clay	5	5
Sand, medium to coarse	19	24
Sand, medium, light-brown	16	40
Sand, coarse	15	55
Clay, dark-brown	1	56
Well S17136		
[Land surface about 8 ft above mean sea level. Bottom of casing at 23 ft; screen at 20–23 ft]		
Sand, medium brown; some clay	8	8
Sand, coarse, and gravel	3	11
Sand, medium	14	25
Well S17137		
[Land surface about 16 ft above mean sea level. Bottom of casing at 33 ft; screen at 30–33 ft]		
Clay, sandy, grayish-brown	5	5
Sand, medium to coarse	4	9
Sand, medium to coarse, and gravel	13	22
Sand, coarse, and gravel	20	42

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Drill hole 1 [Land surface about 40 ft. above mean sea level]		
Grass matting, roots	0. 5	0. 5
Sand, coarse, brown, and gravel; traces of silt; trace of vegetation	3. 5	4
Sand, medium to coarse, brown, and gravel	5	9
Sand, medium, dark-brown, and gravel; some cobbles	12	21
Sand, medium to coarse, dark-brown, and gravel; small boulders	10. 5	31. 5
Drill hole 2 [Land surface about 22 ft. above mean sea level]		
Grass matting, roots	0. 5	0. 5
Sand, a little silt; trace of gravel	2. 5	3
Sand, medium; trace of gravel	5	8
Sand, some medium to large gravel; a little silt	10	18
Sand; some medium gravel	4	22
Sand, coarse; trace of gravel	5	27
Sand, medium to coarse; a little gravel; trace of silt	3	30
Drill hole 3 [Land surface about 7 ft. above mean sea level]		
Grass matting, topsoil and roots	1	1
Sand, medium to fine, brown; a little gravel; trace of silt	2. 5	3. 5
Sand; some gravel; trace of silt; a few small boulders	16. 5	20
Sand, medium to coarse; some fine to coarse gravel	10	30
Drill hole 4 [Land surface about 17 ft. above mean sea level]		
Topsoil, sandy; roots and vegetation	1	1
Sand, medium, brown; a little gravel; a little silt	4. 5	5. 5
Sand, medium to coarse, brown; some gravel	24. 5	30
Drill hole 5 [Land surface about 19 ft. above mean sea level]		
Topsoil, sandy; roots	1	1
Sand, fine to coarse, brown; a little gravel; a few small 6-in. boulders	25	26
Sand, medium, brown; a little fine to medium gravel	4	30
Drill hole 6 [Land surface about 14 ft. above mean sea level]		
Topsoil; tree roots	1	1
Sand, fine, and silt; slightly plastic	3	4
Sand, medium to coarse, brown; some fine to medium gravel	15	19
Sand, coarse, brown	3	22
Sand, coarse, brown; trace of gravel	3	25

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Drill hole 7 [Land surface about 10 ft. above mean sea level]		
Topsoil, sandy; grass roots	1	1
Sand, fine, brown; some silt	2	3
Sand, medium to coarse, brown; some gravel	13	16
Sand, medium to fine	2	18
Sand, medium to coarse, gray; trace of gravel; trace of silt	7	25
Drill hole 8 [Land surface about 21 ft. above mean sea level]		
Topsoil, sandy; roots	1	1
Silt; some fine sand	4	5
Sand, medium to fine, brown, and gravel	3	8
Sand, fine to medium, brown, and gravel; small boulders	11	19
Sand, fine, silty, brown	2. 5	21. 5
Sand, medium to coarse, brown; some gravel	8. 5	30
Drill hole 9 [Land surface about 30 ft. above mean sea level]		
Topsoil, sandy; grass and brush roots	1	1
Sand, silty, brownish-gray	3	4
Sand, fine to medium; some gravel	12	16
Sand, medium; some large gravel; a few small stones	9	25
Drill hole 10 [Land surface about 34 ft. above mean sea level]		
Topsoil, sandy; roots	1	1
Sand, fine, silty, gray	4. 5	5. 5
Sand, medium, gray; trace of silt	9. 5	15
Sand, fine, silty, gray	1	16
Sand, medium to coarse, brown; some gravel	2	18
Sand, medium to coarse, brown, and gravel; small boulders	7	25
Drill hole 11 [Land surface about 22 ft above mean sea level]		
Topsoil; sandy; roots	1	1
Sand, fine, brown; trace of silt	4	5
Sand, fine to medium, brown; lenses of gray silt	5	10
Sand, fine to medium, brown; some gravel	6	16
Sand, fine to medium, brown; some gravel; a few small boulders	9	25
Drill hole 12 [Land surface about 45 ft above mean sea level]		
Topsoil, sandy; roots	1	1
Sand, fine to medium, brown; some silt	3	4
Sand, medium, brown; some gravel; trace of silt; a few small stones	16	20
Sand, fine to medium, brown; some gravel	5	25

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Drill hole 13 [Land surface about 50 ft above mean sea level]		
Topsoil, sandy; grass matting; roots	1	1
Sand, fine, brown; some silt	3	4
Sand, fine to medium, grayish-brown; trace of silt	1	5
Sand, fine, brown; trace of silt	3	8
Sand, fine to medium, brown; a little medium gravel	8	16
Sand, medium, brown; a little silt; trace of gravel	2	18
Sand, medium, brown; a little gravel	7	25
Drill hole 14 [Land surface about 45 ft above mean sea level]		
Topsoil, sandy; grass and shrub roots	1	1
Sand, fine, and silt	3	4
Sand, medium, brown; some gravel	12	16
Sand, medium to coarse, brown; trace of gravel	9	25
Drill hole 15 [Land surface about 32 ft above mean sea level]		
Topsoil, sandy; grass roots; matting	1	1
Sand, fine, silty, gray; trace of clay	3	4
Sand, medium to fine, brown; some gravel	9	13
Sand, medium, to fine, brown	7	20
Drill hole 16 [Land surface about 10 ft above mean sea level]		
Topsoil, sandy; grass roots	1	1
Sand, fine to medium, brown	7	8
Sand, fine, silty, grayish-brown	2	10
Sand, medium to fine, brown	10	20
Drill hole 17 [Land surface about 62 ft above mean sea level]		
Clay, very fine, brown, sandy; loam; topsoil	2	2
Sand, brown; gravel and boulders	18	20
Drill hole 18 [Land surface about 63 ft above mean sea level]		
Clay sandy, brown; loam	2	2
Sand, brown; gravel and boulders	18	20
Drill hole 19 [Land surface about 74 ft above mean sea level]		
Clay, sandy, brown; loam	2	2
Sand, brown; gravel and boulders	38	40

Table 4.—*Logs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Drill hole 20 [Land surface about 66 ft above mean sea level]		
Clay, sandy, brown; loam	1.5	1.5
Sand, brown; gravel and boulders	18.5	20
Drill hole 21 [Land surface about 58 ft above mean sea level]		
Clay, sandy, brown; loam	4	4
Sand, very fine, silty, light-brown; silt	12	16
Sand, fine, brown	4	20
Sand, fine, medium to coarse, brown; small gravel	20	40
Drill hole 22 [Land surface about 10 ft above mean sea level]		
Clay, soft, sandy, brown; loam	2	2
Clay, sandy, brown and gray	3	5
Sand, brown, and gravel	3	8
Sand, brown, and gray; clay; traces of gravel	2	10
Sand, brown, and gravel	2	12
Sand, fine, light-brown	8	20
Drill hole 23 [Land surface about 3 ft above mean sea level]		
Sand, fine to medium, brown	1.5	1.5
Sand, fine to medium	7	8.5
Sand, fine to coarse, brown; gravel	3.5	12
Sand, fine to coarse, gray; gravel	8	20
Drill hole 24 [Land surface about 2 ft above mean sea level]		
Sand, black; roots; decayed vegetation	0.5	0.5
Sand, fine, light-pink	1	1.5
Sand, fine to medium, brown	6.5	8
Sand, fine to coarse, gray; gravel	8	16
Sand, fine, gray	4	20
Test pit 1 [Land surface about 25 ft. above mean sea level]		
Grass matting and roots	0.5	0.5
Sand, fine; trace of fine to medium gravel	1.5	2
Silt, fine to coarse, gray; some gravel; a little sand; trace of clay	1.5	3.5
Sand, fine to medium, brown; some fine to medium gravel	2.5	6
Sand, fine, brown; a little coarse silt; trace of vegetation	1	7
Sand, fine to medium, brown; some fine to medium gravel	3	10

Table 4.—*Legs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Test pit 2 [Land surface about 22 ft above mean sea level]		
Grass matting	0. 5	0. 5
Silt, fine to coarse; some sand; trace of gravel and clay	. 5	1
Sand, fine to medium; pockets of clay; trace of roots	1	2
Sand, fine to medium; a little clay; a little gravel	1. 5	3. 5
Sand, medium to coarse; trace of gravel	3. 5	7
Sand, medium to coarse; a little fine to coarse gravel	3	10
Test pit 3 [Land surface about 25 ft above mean sea level]		
Topsoil, sandy; grass roots	1	1
Sand, fine; some silt	2	3
Sand, fine; layers of gray silty sand; little gravel	3. 5	6. 5
Sand, fine to coarse; some fine to medium gravel	1. 5	8
Sand, medium	2	10
Test pit 4 [Land surface about 18 ft above mean sea level]		
Topsoil, sandy; grass roots	1	1
Sand, fine; some silt; trace of grass roots	1	2
Sand, medium, and silt in layers	1	3
Sand, medium, and gravel	. 5	3. 5
Sand, medium, brown; fine to coarse gravel	2. 5	6
Test pit 5 [Land surface about 13 ft above mean sea level]		
Topsoil, sandy; grass and shrub roots	1	1
Sand, fine; some silt	1. 5	2. 5
Sand, fine to medium; some gravel; trace of silt	1. 5	4
Test pit 6 [Land surface about 5 ft above mean sea level]		
Topsoil, sandy; grass roots	1	1
Sand, medium to coarse, brown	2	3
Test pit 7 [Land surface about 6 ft above mean sea level]		
Sand, fine to medium, light-brown; trace of gravel	4. 5	4. 5
Sand, coarse	----------	4. 5+

Table 4.—*Legs of wells, drill holes, and test pits on Plum Island*—Continued

Material	Thickness (feet)	Depth (feet)
Test pit 8 [Land surface about 5 ft above mean sea level]		
Sand, fine; roots; vegetation	0. 5	0. 5
Sand, fine to medium, light-brown	3. 5	4
Test pit 9 [Land surface about 7 ft above mean sea level]		
Sand, fine to medium, light-brown	4	4
Test pit 10 [Land surface about 4 ft above mean sea level]		
Sand, fine to medium, white	1. 5	1. 5
Vegetation, decayed, black (peat)	. 3	1. 8
Sand, fine to coarse, white	2. 2	4
Test pit 12 [Land surface about 12 ft above mean sea level]		
Clay, sandy, brown; and loam	3. 3	3. 3
Sand, fine to medium, light-brown	. 7	4
Test pit 13 [Land surface about 25 ft above mean sea level]		
Sand, very fine, silty, brown; some gravel	4	4
Test pit 14 [Land surface about 25 ft above mean sea level]		
Sand, very fine, silty brown	4	4
Test pit 15 [Land surface about 50 ft above mean sea level]		
Clay, fine, sandy, brown; loam; some large gravel and boulders	4	4
Test pit 16 [Land surface about 58 ft above mean sea level]		
Cinder road fill	0. 5	0. 5
Sand, fine, brown; clay; loam; large boulders	2. 5	3
Sand, fine to medium, brown; some large gravel	1	4

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