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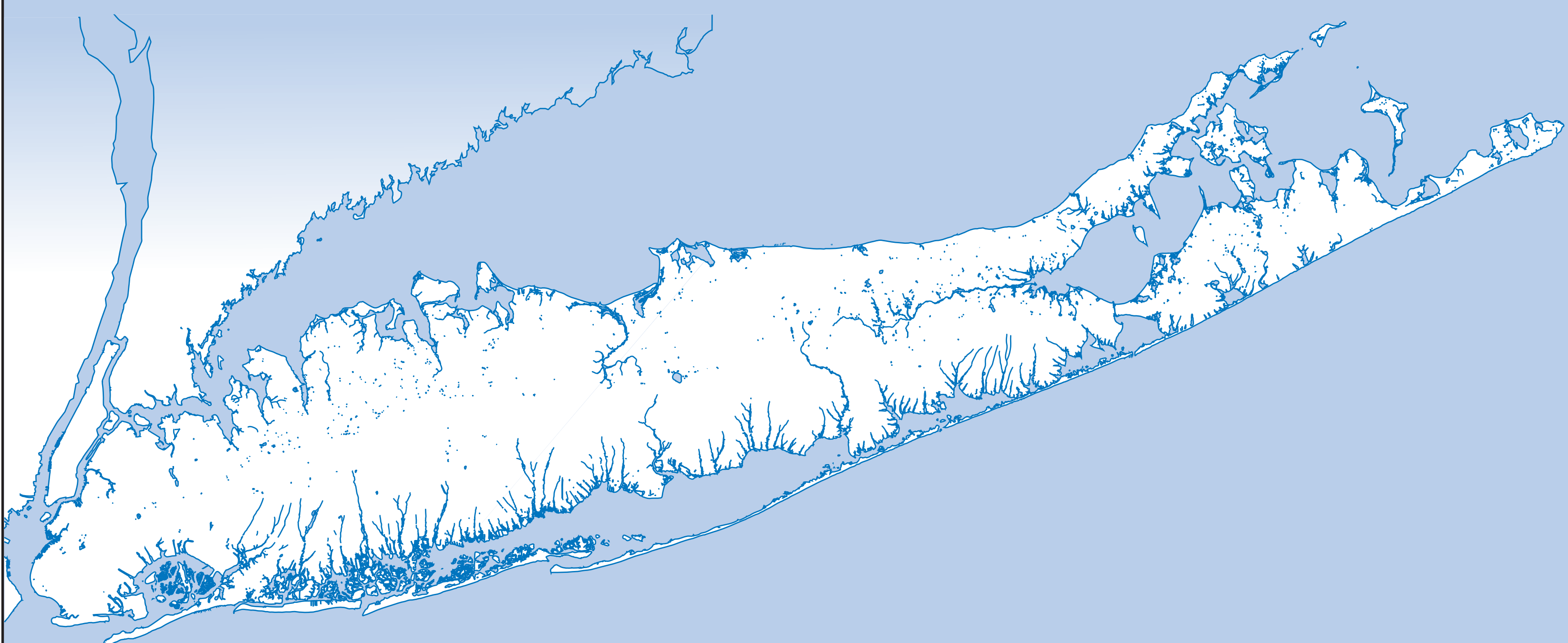
Water-Table and Potentiometric-Surface Altitudes of the Upper Glacial, Magothy, and Lloyd Aquifers on Long Island, New York, in March-April 2000, with a Summary of Hydrogeologic Conditions

Water-Resources Investigations Report 01-4165



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by Ronald Busciolano

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4165

In cooperation with the
NEW YORK CITY DEPARTMENT OF
ENVIRONMENTAL PROTECTION,
SUFFOLK COUNTY DEPARTMENT OF
HEALTH SERVICES, and the
SUFFOLK COUNTY WATER AUTHORITY

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Charles G. Groat, Director

For additional information write to:

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

Copies of this report may be purchased from:

U.S. Geological Survey
Branch of Information Services
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Multiply	By	To Obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer

Other abbreviations used in this report

billion gallons (B/gal)
hour (hr)

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

Water-Table and Potentiometric-Surface Altitudes of the Upper Glacial, Magothy, and Lloyd Aquifers on Long Island, New York, in March-April 2000, with a Summary of Hydrogeologic Conditions

by Ronald Busciolano

Abstract

The three main water-bearing units on Long Island, New York—the upper glacial aquifer (water table) and the underlying Magothy and Lloyd aquifers—are the sole source of water supply for more than 3 million people. Water-table and potentiometric-surface altitudes were contoured from water-level measurements made at 394 observation, public-supply, and industrial-supply wells during March-April 2000. In general, water-level altitudes in the upper glacial, Magothy, and Lloyd aquifers were lower throughout most parts of Long Island than those measured during March-April 1997. Changes in altitude during this period ranged from an increase of about 6 feet in the Magothy aquifer in southwestern Nassau County to a decrease of more than 8 feet in the upper glacial aquifer in eastern Suffolk County.

INTRODUCTION

Long Island extends about 120 mi northeastward from the southeastern part of the mainland of New York State and is surrounded by the Atlantic Ocean, Long Island Sound, New York Bay, and the East River estuary (fig. 1). The island consists of four counties—Kings, Queens, Nassau and Suffolk—that together encompass a total area of about 1,450 mi^2.

Kings and Queens Counties (78 mi^2 and 115 mi^2, respectively), which form the western part of Long Island, are part of New York City and together have a combined population of 4.25 million (U.S. Bureau of the Census, 1990). Nassau and Suffolk Counties (291 mi^2 and 922 mi^2, respectively), which form the central and eastern parts of the island, have a combined population of 2.61 million (U.S. Bureau of the Census, 1990).

The relative abundance of fresh ground water on Long Island has allowed extensive growth and development. The island's population increased from 4.61 million in 1940 to 6.86 million in 1990 (U.S. Bureau of the Census, 1990); the greatest increase was in the central and eastern parts of the island as the population expanded eastward from Kings and Queens Counties into Nassau and Suffolk Counties.

Kings County and most of Queens County derive their water primarily from upstate surface-water sources, whereas Nassau County, Suffolk County, and the eastern part of Queens County obtain water solely from wells that tap the underlying ground-water reservoir. This reservoir consists of a sequence of unconsolidated sediments of Late Cretaceous and Pleistocene age that overlie a southeastward sloping surface of crystalline bedrock. The primary water-bearing units in this sequence are, from top to bottom, the upper glacial (water-table) aquifer, the Magothy aquifer, and the Lloyd aquifer (fig. 2).

About 3.1 million people on Long Island rely on water pumped from about 1,000 public-supply wells that together withdraw about 400 Mgal/d (Nemickas and others, 1989) from the ground-water reservoir. This large-scale pumping, in conjunction with the loss of recharge as a result of the installation of sanitary-sewer and storm-sewer systems, has produced

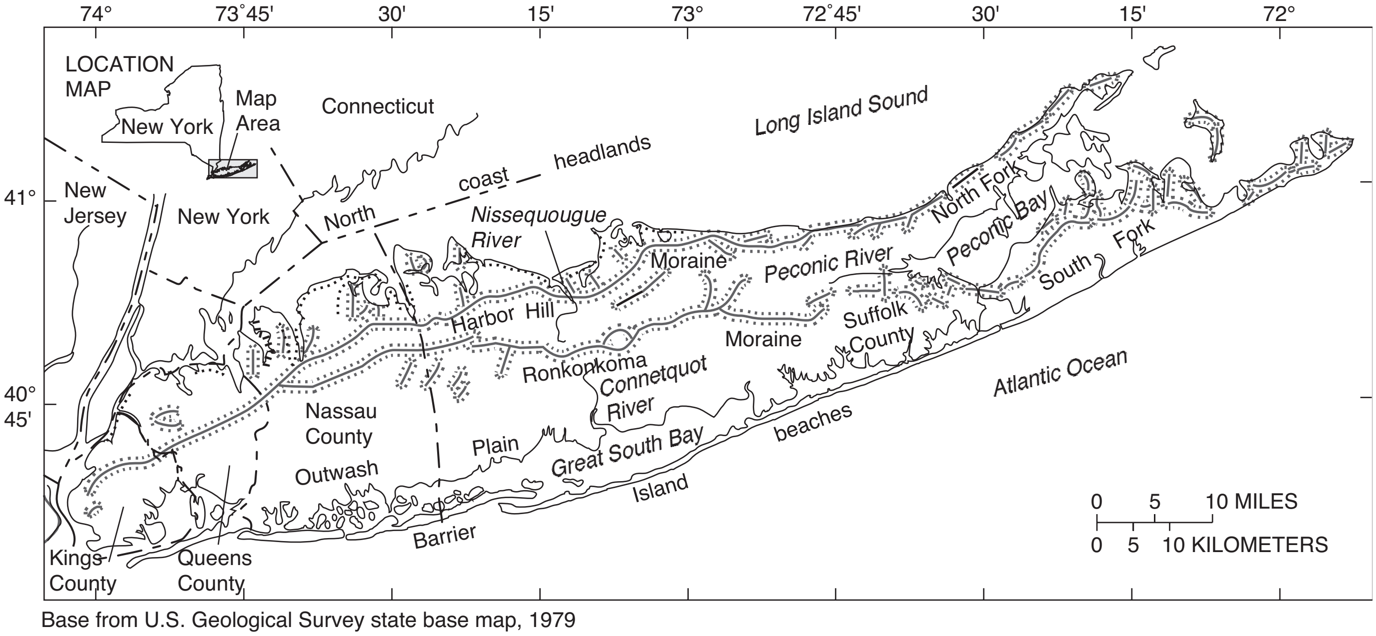


Figure 1. Location and physiographic features of Long Island, N.Y. (Modified from McClymonds and Franke, 1972, fig. 2.)

appreciable declines in the water-table and potentiometric surfaces of the aquifers.

Maps of the water table and potentiometric surface can be used to compare past ground-water conditions with current conditions to locate areas that could be affected by water-level declines; the maps also can be used in the development of ground-water-flow models to simulate the effects of future stresses and management practices on ground-water levels.

The U.S. Geological Survey (USGS), in cooperation with State and local agencies, has monitored water levels in the three primary aquifers of Long Island since the 1930's. In 2000, the USGS began a study to map water levels in the upper glacial, Magothy, and Lloyd aquifers; these maps update the 1997 water-level maps of Busciolano and others (1998). This latest study was done in cooperation with the New York City Department of Environmental Protection, the Suffolk County Department of Health Services, and the Suffolk County Water Authority.

Purpose and Scope

This report describes (1) the hydrogeologic setting of Long Island's ground-water reservoir, (2) the water-table configuration in the upper glacial aquifer and the potentiometric-surface altitudes of the Magothy and the Lloyd aquifers in March-April 2000, and (3) the March-April 2000 water levels in the three aquifers in relation to those in 1997. It includes 1:125,000-scale maps of the water table in the upper glacial aquifer (pl. 1) and the potentiometric-surface altitudes of the Magothy and the Lloyd aquifers (pls. 2 and 3) in March-April 2000.

Study Methods

Water-level data were obtained from measurements at 394 observation, public-supply, and industrial-supply wells screened in the upper glacial, Magothy, and Lloyd aquifers. Forty of the wells were public-supply or industrial-supply wells; the other 354 were observation wells. Many of the supply wells are in continuous operation and, therefore, were turned off for a minimum of 24 hours before measurements were made so that the water levels in the wells could recover to the level of the potentiometric head in the surrounding aquifer. Full recovery time at some of these supply wells can exceed 24 hours; therefore, water levels measured at these wells are assumed to be less accurate than those measured at observation wells, which are not pumped.

Most observation wells were measured during a 2-week period beginning March 20, 2000; public-supply and industrial-supply wells were measured in March and April 2000. Wells were measured by the

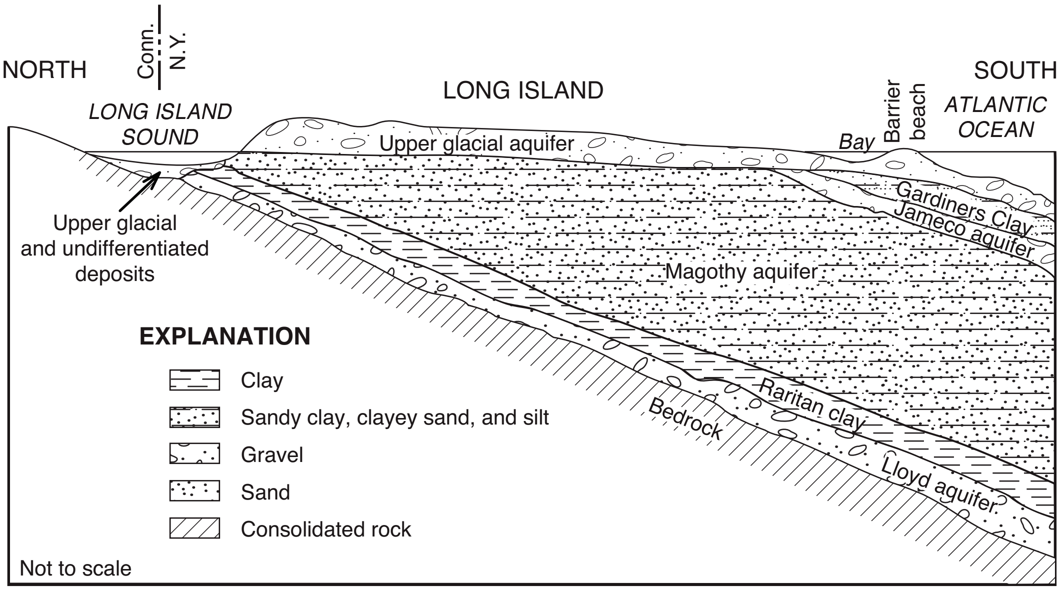


Figure 2. Generalized hydrogeologic section showing major aquifers and confining units on Long Island, N.Y. (From McClymonds and Franke, 1972, fig. 3.)

wetted-tape method to the nearest hundredth of a foot. All water-level altitudes referred to herein are in feet above or below sea level. Water levels that are affected by tidal fluctuations (those in coastal areas) were measured within 1 hour of high tide to record maximum water-level altitudes in the aquifer.

Ground-water levels on Long Island generally follow a seasonal pattern, in which they are highest in March and April and lowest in September and October. The March-April period was selected in this study to represent the annual maximum elevation of water levels in the three primary aquifers.

Previous Studies

Water levels in the upper glacial aquifer (water table), Magothy aquifer, and Lloyd aquifer on Long Island have previously been mapped in detail and are depicted in many reports. The first water-table map was compiled by Burr and others (1904) for 1903. Other water-table maps were compiled by Veatch and others (1906) for 1903; Spear (1912) for 1908; Suter (1937) for 1936; Jacob (1945) for 1943; Lusczynski and Johnson (1951) for 1951; Kimmel (1971) for 1970; Koszalka and Koch (1974) for 1971; Koszalka (1975) for 1974; Vaupel and others (1977) for 1943, 1959, 1966, and 1972; Nakao and Erlichman (1978) for 1975; Donaldson and Koszalka (1983c) for 1979; Doriski (1986) for 1983; Doriski (1987) for 1984, Busciolano (1997) for 1990, and Busciolano and others (1998) for 1997.

The first potentiometric-surface map of the Magothy aquifer was compiled by Koch and Koszalka (1973) for 1972. Other Magothy aquifer maps were compiled by Prince (1976) for 1975; Vaupel and others (1977) for 1959, 1966, and 1972; Donaldson and Koszalka (1983a) for 1979; Doriski (1986) for 1983; Doriski (1987) for 1984, Busciolano (1997) for 1990, and Busciolano and others (1998) for 1997.

The first potentiometric-surface map of the Lloyd aquifer was compiled by Lusczynski (1952) for 1947. Other Lloyd aquifer maps were compiled by Rich and others (1975) for 1975; Donaldson and Koszalka (1983b) for 1979; Doriski (1986) for 1983; Doriski (1987) for 1984, Busciolano (1997) for 1990, and Busciolano and others (1998) for 1997.

Acknowledgments

Special thanks are extended to the local water-supply companies and private industries on Long Island who granted access to their supply wells.

HYDROGEOLOGY

Long Island's ground-water reservoir consists of a sequence of unconsolidated glacial, lacustrine, deltaic, and marine deposits of clay, silt, sand, and gravel that range in age from Upper Cretaceous to Pleistocene (table 1). These deposits overlie a southward sloping surface of Precambrian and (or) Paleozoic-aged crystalline bedrock. The geology and hydrology of Long Island are discussed in detail in many reports, for example, Veatch and others (1906), Fuller (1914), Suter and others (1949), Cohen and others (1968), Jensen and Soren (1974), Soren and Simmons (1987), and Smolensky and others (1989).

Surficial Geology

Most of the major features of the present-day topography of Long Island are a result of Pleistocene glaciation and are oriented in belts or ridges parallel to the island's length. The most prominent are two east-west-trending morainal ridges (Ronkonkoma and Harbor Hill moraines) that traverse the island (fig. 1); these moraines are interpreted as the terminal moraines of two major ice advances. Many small, less continuous ridges on the island were probably deposited between or at the terminus of smaller lobes of the ice sheet, or as other types of glacial features.

The Harbor Hill Moraine (fig. 1) forms the northernmost prominent ridge and extends from the western part of Kings County through central Queens County and northern Nassau County, then eastward through northern Suffolk County to the North Fork; the altitude of the moraine ranges from 100 to 300 ft. The Ronkonkoma Moraine (fig. 1) forms the southern prominent ridge and extends from northwestern Nassau county eastward across central Suffolk County to the South Fork; the moraine reaches a maximum altitude of about 380 ft (the highest point on Long Island) in western Suffolk County.

An outwash plain slopes southward from the base of the Harbor Hill Moraine in Kings and Queens Counties, and from the Ronkonkoma Moraine in Nassau and Suffolk Counties, to the southern shore. The outwash plain has an altitude of 100 to 150 ft along its northern border and slopes southward at about 20 ft/mi (McClymonds and Franke, 1972). It is overlain by recent deposits of sand, silt, and organic material along the south-shore beaches and along stream channels.

Aquifer Characteristics

The Long Island ground-water system consists of three major aquifers (upper glacial, Magothy, and Lloyd aquifers) and two aquifers (Jameco and Port Washington aquifers) of only local importance. The extent, thickness, and hydraulic properties are described in the following summary.

Upper Glacial Aquifer (Water Table)

The upper glacial aquifer of Pleistocene age (fig. 2) is the uppermost unit in Long Island's ground-water reservoir and contains the water table throughout the island (pls. 1A, 1B), except in parts of central and eastern Nassau County and western Suffolk County where its entire thickness is unsaturated. In these areas the water table is in the upper part of the Magothy aquifer (upper Cretaceous age Matawan Group-Magothy Formation, undifferentiated) (fig. 2), which is relatively unconfined and functions hydraulically as part of the upper glacial aquifer.

The upper surface of the upper glacial aquifer forms the present-day land surface of Long Island, except where it is overlain by Holocene-age or manmade deposits. Aquifer thickness ranges from zero in parts of northwestern Queens County, where bedrock crops out (Buxton and others, 1981), to about 300 ft in Suffolk County, beneath parts of the Ronkonkoma Moraine (Suter and others, 1949). Thickness of the upper glacial aquifer locally exceeds 700 ft in areas where it infills buried channels (Smolensky and others, 1989).

The upper glacial aquifer overlies the Gardiners Clay of Pleistocene age (fig. 2) along the southern shore of most of Long Island and, in places, subcrops of the Jameco aquifer (Jameco Gravel of Pleistocene age) (fig. 2) and the Monmouth greensand (Monmouth Group of upper Cretaceous age) (not shown in fig. 2). Along the northern shore of most of the island, the upper glacial aquifer unconformably overlies the subcrops of the Raritan confining unit (clay member of the Raritan Formation of upper Cretaceous age) (fig. 2), the Lloyd aquifer (Lloyd Sand Member of the Raritan Formation of upper Cretaceous age) (fig. 2), and the bedrock surface of Precambrian and (or) Paleozoic age (fig. 2). The hydraulic connection between the upper glacial and the Lloyd aquifers is appreciable where the upper glacial overlies the Lloyd aquifer along the northern shore.

Table 1. Stratigraphic column of geologic and hydrogeologic units on Long Island, N.Y., with corresponding geologic and water-transmitting characteristics
[ft/d, feet per day. Modified from McClymonds and Franke, 1972, table 1]

System	Series	Geologic unit	Hydro-geologic unit	Approx-imate maximum thickness (feet)	Character of deposit	Water-bearing characteristics
Quaternary	Holocene	Recent deposits: beach deposits, salt-marsh deposits, stream alluvium, and artificial fill	Recent deposits	50	Sand, gravel, clay, silt, organic mud, peat, loam, and shells. Colors are gray, brown, green, black, and yellow. Recent artificial-fill deposits of gravel, sand, clay, and rubbish. Present locally in all parts of the island.	Constitutes soil zone and fill areas; is locally hydraulically connected to the underlying upper glacial aquifer. Sandy beach deposits beneath barrier islands are highly permeable; yield fresh water at shallow depths, brackish to salty water at greater depths. Clay and silt deposits beneath bays retard saltwater encroachment and confine the underlying aquifer. Marsh and stream deposits may yield small quantities of water, but are generally clayey or silty and much less permeable than the underlying aquifer.
	Pleistocene	Upper Pleistocene deposits	Upper glacial aquifer	700	Till (mostly along north shore and in moraines) composed of poorly sorted clay, sand, gravel, and boulders, forms Harbor Hill and Ronkonkoma terminal moraines. Also contains reworked deposits. Outwash deposits (mostly between and south of terminal moraines, but also interlayered with till) consist of quartzose sand, fine to very coarse, and gravel, pebble to boulder sized. The Manetto Gravel in extreme east-central Nassau and west-central Suffolk Counties is commonly included with the upper glacial aquifer. Glaciolacustrine deposits and marine clay consist of silt, clay, and some sand and gravel layers. Local units are Port Washington aquifer and confining unit (northern Nassau County), "20-foot clay" (southeastern Nassau and southern Queens Counties), "Smithtown clay" (central Suffolk County), and "Manorville clay" (central and eastern Suffolk County). Colors are mainly gray, brown, and yellow; silt and clay locally are grayish green. Contains shells and plant remains, generally in finer grained beds; also contains Foraminifera. Contains chlorite, biotite, muscovite, hornblende, olivine, and feldspar as accessory minerals; "20-foot clay" commonly contains glauconite. Present in all parts of the island.	Till is poorly permeable; restricts infiltration of water to underlying beds. Outwash deposits are moderately to highly permeable; good to excellent infiltration characteristics. The Manetto Gravel is highly permeable, but is mostly present above the water table. Glaciolacustrine and marine clay deposits are mostly poorly permeable and generally restrict infiltration of ground water, but may locally contain thin, moderately permeable layers of sand and gravel. The water table primarily is in the upper glacial aquifer except for parts of central Nassau and west-central Suffolk Counties, where it is in the Magothy aquifer. Contains fresh water except near shore lines. Till and marine deposits locally retard saltwater encroachment. Constitutes the principal aquifer for public-supply in eastern Suffolk County. Average horizontal hydraulic conductivity is about 270 ft/d; hydraulic conductivity of morainal material is about 50 percent of outwash deposits; anisotropy is about 10:1.
		Gardiners Clay	Gardiners Clay	150	Clay, silt, and few layers of sand and gravel. Colors are grayish green and brown. Contains marine shells, Foraminifera, and lignite; also locally contains glauconite. Present in most of Kings, southern and central Queens, southern Nassau, and southern Suffolk Counties.	Poorly permeable; constitutes a confining layer for the underlying Magothy and Jameco aquifers. Some sand lenses may be permeable. Locally, sand layers yield small quantities of water. Average vertical hydraulic conductivity is about 0.001 ft/d.
		Jameco Gravel	Jameco aquifer	200	Sand, fine to very coarse, and gravel to large-pebble size; few layers of clay and silt. Gravel is composed of crystalline and sedimentary rocks. Color is mostly brown. Contains chlorite, biotite, muscovite, hornblende, and feldspar as accessory minerals. Present in most of Kings, southern and central Queens, and southeastern Nassau Counties.	Moderately to highly permeable. Confined by overlying Gardiners Clay. Contains mostly fresh water, but brackish water and water with high iron content occurs locally in southeastern Nassau and southern Queens Counties. Average horizontal hydraulic conductivity is 200 to 300 ft/d; anisotropy is about 10:1.

Table 1. (continued)Stratigraphic column of geologic and hydrogeologic units on Long Island, N.Y., with corresponding geologic and water-transmitting characteristics—continued

System	Series	Geologic unit		Hydro-geologic unit	Approx-imate maximum thickness (feet)	Character of deposit	Water-bearing characteristics
Cretaceous	Upper Cretaceous	Monmouth Group		Monmouth greensand	200	Interbedded marine deposits of clay, silt, and sand, dark-greenish gray, greenish black, greenish, dark-gray, and black, containing much glauconite. Present in southern Nassau and Suffolk Counties.	Poorly permeable; primarily a confining unit for the underlying Magothy aquifer. Average vertical hydraulic conductivity is about 0.001 ft/d.
		Matawan Group-Magothy Formation, undifferentiated		Magothy aquifer	1,100	Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal zone. Sand and gravel are quartzose. Lignite, pyrite, and iron oxide concretions are common; contains muscovite, magnetite, rutile, and garnet as accessory minerals. Colors are gray, white, red, brown, and yellow. Present in most parts of the island except northern, western and central Kings County, northern Queens County, northern Nassau County, and parts of northern and eastern Suffolk County.	Most layers are poorly to moderately permeable, some are locally highly permeable. Coarse basal zone has higher permeability than overlying sediments. Water is generally unconfined in uppermost parts of the aquifer in northern, central, and eastern parts of the island, elsewhere it is confined. Locally contains the water-table in parts of central Nassau and west-central Suffolk Counties. Water is generally of excellent quality but has a high iron content locally along the north and south shores. Has been invaded by salty ground water locally in southwestern Nassau and southern Queens Counties and in small areas along the north shore. Constitutes the principal aquifer for public-supply in eastern Queens, most of Nassau, and western and central Suffolk Counties. Average horizontal hydraulic conductivity is 50 ft/d; anisotropy is about 100:1.
		Raritan Formation	Unnamed clay member	Raritan confining unit	200	Clay, solid and silty; few lenses and layers of sand; little gravel. Lignite and pyrite are common. Colors are gray, red, and white, commonly variegated. Present in most parts of the island except northern and western Kings County, northern Queens County, northern Nassau County, and extreme northwestern and northeastern Suffolk County.	Poorly to very poorly permeable; constitutes a confining layer for underlying Lloyd aquifer. Very few wells produce appreciable water from these deposits. Average vertical conductivity is about 0.001 ft/d.
			Lloyd Sand Member	Lloyd aquifer	500	Sand, fine to coarse, and gravel, commonly with clayey matrix; some lenses and layers of solid and silty clay; locally contains thin lignite layers and iron concretions. Locally has a gradational contact with the overlying Raritan clay. Sand and most of the gravel are quartzose. Colors are yellow, gray, and white; clay is red locally. Present in most parts of the island except northern and western Kings County, northern Queens County, northwestern Nassau County, and extreme northeastern Suffolk County.	Poorly to moderately permeable. Confined by the overlying clay unit. Water is generally of excellent quality but locally has high iron content. Has been intruded by salty ground water locally in necks near north shore, where aquifer is shallow and overlying clay is discontinuous, and along the south shore barrier islands. Constitutes the principal aquifer for public supply in the north shore necks and south shore barrier islands. Average horizontal hydraulic conductivity is 40 ft/d; anisotropy is about 10:1.
Precambrian and Paleozoic	--	Bedrock		Bedrock	--	Crystalline metamorphic and igneous rocks; muscovite-biotite schist, gneiss, and granite. A soft, clayey zone of weathered bedrock locally is more than 70 ft thick. Present in all parts of the island, outcrops in extreme northern parts of Queens County.	Poorly permeable to virtually impermeable; constitutes lower boundary of ground-water reservoir. Some hard freshwater is contained in joints and fractures but is impractical to develop at most places.

In parts of northern Nassau County, the upper glacial aquifer unconformably overlies the Pleistocene-age deposits of the Port Washington confining unit and (or) the Port Washington aquifer (Kilburn, 1979; Kilburn and Krulikas, 1987; Stumm, 1994) (not shown in fig. 2); throughout the rest of the island, it unconformably overlies the Magothy aquifer. The northern part of the Magothy aquifer contains deep channels that were formed during the last glacial epoch and later became filled by Pleistocene material. These channels provide hydraulic connection between the two aquifers.

The upper glacial aquifer consists of till, outwash deposits, and glaciolacustrine and marine clays (table 1). Till, a poorly sorted mixture of clay, sand, gravel, and boulders, is present mainly within the moraines and along most of the northern shore; the till deposits have an estimated average horizontal hydraulic conductivity of 130 ft/d or less (McClymonds and Franke, 1972). Outwash, a well-sorted, moderately to highly permeable deposit, lies between and south of the moraines and consists of fine to very coarse quartzose sand and pebbles to boulder-sized gravel. The average horizontal hydraulic conductivity of outwash deposits is estimated to be at least 270 ft/d (McClymonds and Franke, 1972).

The outwash deposits contain three major glaciolacustrine and marine clay units (not shown in fig. 2). These include the “Smithtown clay” in north-central Suffolk County (Krulikas and Koszalka, 1983), the “Manorville clay” in east-central Suffolk County (de Laguna, 1963), and the “20-foot clay” in southern Nassau and southwestern Suffolk Counties (Doriski and Wilde-Katz, 1983). These minor clay units impede the downward movement of water, and each one creates locally elevated water levels above, and confined conditions below.

Magothy Aquifer

The Magothy aquifer (Matawan Group-Magothy Formation, undifferentiated, of upper Cretaceous age) is the largest hydrogeologic unit in Long Island’s ground-water reservoir. The altitude of its upper surface ranges from more than 200 ft above sea level in parts of north-central Nassau County and west-central Suffolk County to more than 600 ft below sea level in north-central Suffolk County (Smolensky and others, 1989). Aquifer thickness ranges from zero in northern and western Kings and Queens Counties, northern Nassau County, and parts of northern Suffolk County, to more than 1,000 ft in south-central Suffolk County (Soren and Simmons, 1987).

The Magothy aquifer underlies most of Long Island and the offshore waters (pls. 2A, 2B), except in parts of western and northern Kings and Queens Counties, northern Nassau County, and northwestern and northeastern Suffolk County, where it has been removed by erosion and glacial scour. The Magothy aquifer unconformably overlies the Raritan confining unit (clay member of the Raritan Formation of Upper Cretaceous age) and is unconformably overlain by several hydrogeologic units. The Monmouth greensand (Monmouth Group of Upper Cretaceous age), the oldest of these units, is present in southeastern Nassau County and along most of the southern shore of Suffolk County and functions mainly as a confining unit.

The Jameco aquifer (Jameco Gravel of Pleistocene age) overlies the Magothy aquifer in most of Kings County, in central and southern Queens County, and in extreme southwestern Nassau County. It is hydraulically connected with the Magothy aquifer (Soren, 1971) and is present mainly in valleys that were eroded into the Magothy aquifer during the Tertiary Era.

The Gardiners Clay of Pleistocene age overlies and hydraulically confines the Magothy and Jameco aquifers in most of Kings County, south-central Queens County, and southern Nassau and Suffolk Counties. Beyond the northern extent of the Gardiners Clay, the Magothy aquifer is overlain by Pleistocene-age deposits of the upper glacial aquifer. In this area, the uppermost part of the Magothy aquifer is relatively unconfined and functions hydraulically as part of the upper glacial aquifer.

Northern parts of the Magothy aquifer were deeply eroded during the last glacial epoch and were subsequently filled with Pleistocene deposits, which in many areas are laterally contiguous and hydraulically connected with the Magothy aquifer. In parts of northern Nassau County, the Magothy aquifer is overlain by Pleistocene-age deposits of the Port Washington aquifer and (or) the Port Washington confining unit (Kilburn, 1979; Kilburn and Krulikas, 1987).

The Magothy aquifer consists of fine- to medium-grained sand with interbedded lenses of coarse sand and sandy to solid clay (table 1). It is poorly to moderately permeable and locally contains some highly permeable sand layers. The average horizontal hydraulic conductivity of the Magothy aquifer has been estimated to be 50 ft/d (McClymonds and Franke, 1972).

Lloyd Aquifer

The Lloyd aquifer (Lloyd Sand Member of the Raritan Formation of upper Cretaceous age) is the basal unit of Long Island's ground-water reservoir. The altitude of its upper surface ranges from less than 100 ft below sea level in extreme northern parts of Queens County to more than 1,500 ft below sea level in south-central Suffolk County (Smolensky and others, 1989). Aquifer thickness ranges from zero in northern and western parts of Kings, Queens, and Nassau Counties and extreme northeastern Suffolk County to more than 500 ft in extreme southeastern Nassau and southwestern Suffolk Counties (Soren and Simmons, 1987).

The Lloyd aquifer continuously underlies most of Long Island and the offshore waters (pls. 3A, 3B), except in parts of western and northern Kings, Queens, and Nassau Counties and extreme northeastern Suffolk County, where it has been removed by erosion. The Lloyd aquifer unconformably overlies the Precambrian and (or) Paleozoic-age bedrock surface and is confined by the Raritan confining unit (clay member of the Raritan Formation of upper Cretaceous age).

The Pleistocene-age deposits of the Port Washington aquifer, which are present mainly in northern Nassau County, unconformably overlie and are hydraulically connected to the Lloyd aquifer; the stratigraphic relation between the two aquifers is described by Kilburn (1979), Kilburn and Krulikas (1987), and Stumm (1994). The Port Washington aquifer is hydraulically confined by the Port Washington confining unit.

The Lloyd aquifer consists of fine- to coarse-grained sand and gravel, commonly with a clayey matrix, and contains interbedded lenses of clay and silty clay (table 1). It is poorly to moderately permeable, and its estimated average horizontal hydraulic conductivity is 40 ft/d (McClymonds and Franke, 1972). Northern parts of the Lloyd aquifer were deeply eroded during the last glacial epoch and were subsequently filled with Pleistocene-age deposits of the upper glacial aquifer, which are laterally contiguous and hydraulically connected with the Lloyd aquifer in many areas.

HYDROLOGIC CONDITIONS

Precipitation is the sole source of all naturally occurring fresh ground water on Long Island. Seasonal or long-term fluctuations in precipitation volume and, thus, in recharge, are reflected by the water levels in all aquifers.

Precipitation

Precipitation can be divided into a growing-season (warm-season) component and a non-growing-season (cool-season) component. The type and intensity of precipitation, and the amounts that reach the water table as recharge, differ according to season. The warm season (April through September) is characterized by convective storms that generally form in advance of an eastward moving cold front or during periods of local atmospheric instability. Occasionally, tropical cyclones will move up from southern coastal areas and produce large quantities of rain. Both types of storms typically are characterized by relatively short periods of intense precipitation that produce large amounts of surface runoff and little recharge. Most precipitation that enters the unsaturated zone is quickly absorbed by vegetation and lost through evapotranspiration; therefore, little or no recharge reaches the water table during the summer.

The cool season (October through March) is characterized by large, low-pressure systems that originate in the southern and central United States and move northeastward along the Atlantic coast or the western side of the Appalachian Mountains. Storms of this type are characterized by long periods of steady precipitation in the form of rain, snow, or ice, and tend to produce less surface runoff and more recharge than the summer storms because they have a longer duration and occasionally result in snowmelt. In addition, precipitation that enters the unsaturated zone is not taken up by vegetation, which is dormant during this period, and, therefore, infiltrates to the water table as recharge; thus, most aquifer recharge occurs during the cool season.

Mean annual precipitation ranges from 41 to 45 in. in western parts of Long Island, from 42 to 50 in. in the central part, and from 42 to 46 in. in the eastern part (Miller and Frederick, 1969) (fig. 3). Average summer precipitation generally is equal to average winter precipitation throughout Long Island; 5 to 10 percent of the water equivalent of winter precipitation is in the form of snow (Miller and Frederick, 1969).

Precipitation data from each of six long-term National Weather Service stations on Long Island (fig. 4) were compiled for three time periods (table 2) — (1) total precipitation for the 12 months preceding the 2000 water-level-measurement period (March 1999 through February 2000); (2) total precipitation for the 12 months preceding the 1997 water-level-measurement period (March 1996 through February 1997); and (3) average total precipitation for each 12-month period (March through February) for the period of record at each station. Precipitation amounts for 1999-00 (table 2) were below long-term averages at all six recording stations and were reflected by below-average water levels in the primary aquifers in most parts of the island.

Table 2. Precipitation at selected stations and three time periods, Long Island, N.Y.
[All values are in inches. Data from National Weather Service. Locations are shown in fig. 4]

Precipitation station	March 1999 through February 2000	March 1996 through February 1997	Period of record: Average for March through February	Period of record: Number of years
LaGuardia Airport	35.82	49.38	42.77	51
John F. Kennedy Airport	33.62	50.25	41.23	36
Mineola	35.39	55.17	43.85	44
Upton	44.39	57.95	48.29	51
Riverhead Research Farm	42.43	55.07	45.33	48
Bridgehampton	40.18	63.54	45.92	68

Ground Water

Under natural (predevelopment) conditions, about 50 percent of the precipitation that falls on the land surface recharges the ground-water reservoir (Franke and McClymonds, 1972; Aronson and Seaburn, 1974; Peterson, 1987), but this percentage can vary locally, depending on the climate, geography, and land use. The rest is lost either through evapotranspiration or to the sea as overland runoff to streams. In developed areas, much of the overland flow is diverted through a system of storm drains that discharge either to recharge basins or stream channels.

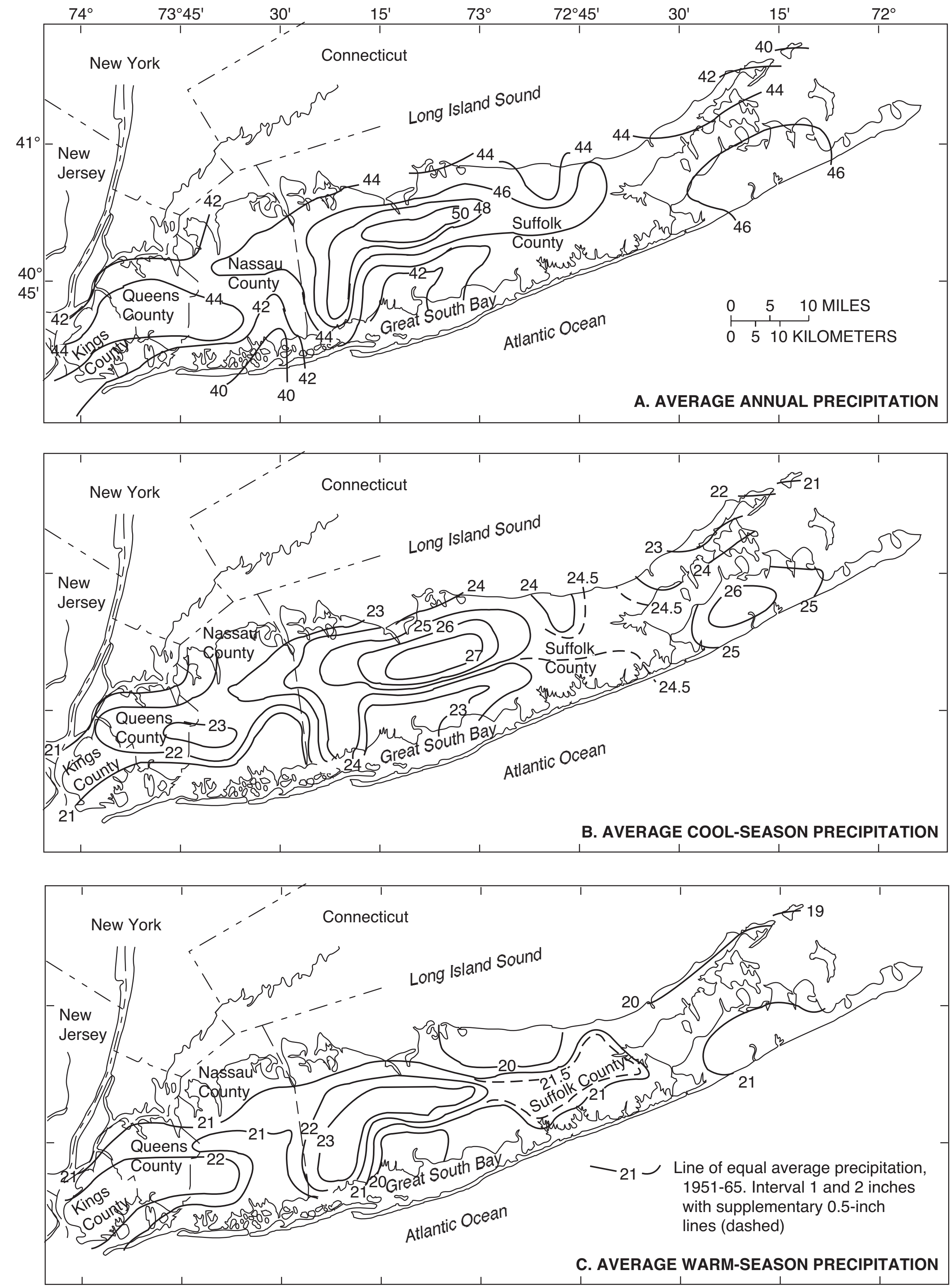
Much of the precipitation that reaches the water table moves laterally and discharges to streams and the saltwater bodies that surround the island; the remainder seeps downward to recharge the deeper aquifers. Water in the deeper aquifers also moves seaward, along lateral and upward gradients that result in seepage into the overlying aquifers (fig. 5).

The boundaries of the ground-water reservoir are the water table, the freshwater-saltwater interface, and the bedrock surface (fig. 5). Under natural conditions, the rate of horizontal ground-water flow through the aquifer system ranges from a few feet to several hundred feet per year. The rate of horizontal flow is 10 to 100 times faster than the rate of vertical flow because stratification and clay layers within and between the aquifers impede vertical flow (Nemickas and others, 1989).

Human activities on Long Island have caused stresses within the ground-water system that have altered the natural balance and produced large-scale changes in the quantity, movement, and quality of ground water in many parts of the island. The major causes of stress are (1) increased ground-water pumping, (2) installation of storm sewers, sanitary sewers, recharge basins, and cesspools, (3) construction of roads, parking lots, and other impervious surfaces.

The upper glacial aquifer (water table) was the principal source of water supply throughout Long Island for several decades, but contamination in many areas since the 1940's has resulted in the widespread curtailment of its use for public supply. This aquifer is no longer used for public supply in Kings and most of Queens Counties, and only its deepest parts are still pumped in parts of Queens, Nassau, and western Suffolk Counties. The upper glacial aquifer is still a major source of public-supply water in central and eastern Suffolk County (table 3), however, where contamination is less severe.

The Magothy aquifer has become the principal source of water supply on Long Island during the past 50 years as a result of the contamination in the upper glacial aquifer. Most of the public-supply pumping from the Magothy aquifer is in parts of central and eastern Queens County, most of Nassau County, most of western and central Suffolk Counties, and in a few parts of eastern Suffolk County (table 3). No public-



Base from U.S. Geological Survey state base map, 1979

Figure 3. Average 1951-65 precipitation on Long Island, N.Y.: A. Average annual. B. Average for cool season. C. Average for warm season. (Modified from Miller and Frederick, 1969, pl. 1.)

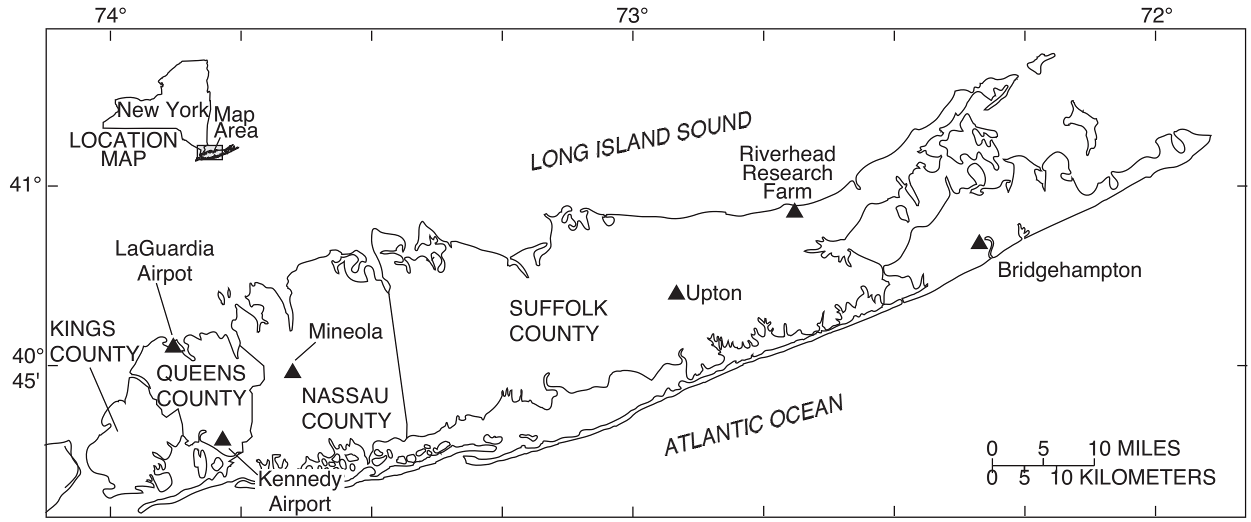


Figure 4. Locations of selected National Weather Service precipitation stations on Long Island, N.Y.

supply wells in Kings County are known to be pumping from the Magothy aquifer.

The Lloyd aquifer has become increasingly important as a source of water supply in some parts of Long Island in recent decades, although it remains virtually undeveloped in most parts of the island and contributes only a small percentage of the overall water supply (table 3). Saltwater intrusion in coastal areas, and contamination of the upper and middle parts of the ground-water reservoir in highly urbanized areas of western Long Island, have necessitated this development; in these areas the Lloyd aquifer has become a major source, or the sole source, of water supply.

All three aquifers are susceptible to saltwater intrusion locally when under heavy pumping stress. The Lloyd aquifer throughout most of Long Island, and the Magothy aquifer in southern and northwestern parts of the island, are especially susceptible. Saltwater intrusion has occurred in the past in Kings, Queens, and southwestern Nassau Counties (Perlmutter and Geraghty, 1963; Lusczynski and Swarzenski, 1966; Cohen and Kimmel, 1971; Buxton and others, 1981; Chu and Stumm, 1995), and in small areas along the northern shore of Nassau County (Stumm, 1994). Parts of all three aquifers are naturally saline throughout the North Fork (Hoffman, 1961; Crandell, 1963; McNew and Arav, 1995; Bohn-Buxton and others, 1996) and South Fork (Perlmutter and DeLuca, 1963; Nemickas and Koszalka, 1982; Prince, 1986) of eastern Long Island.

WATER-TABLE AND POTENTIOMETRIC-SURFACE ALTITUDES IN MARCH-APRIL 2000, AND CHANGES FROM MARCH-APRIL 1997 CONDITIONS

Water-level measurements were used to define the water-table and potentiometric-surface contours in the upper glacial, Magothy, and Lloyd aquifers (pls. 1-3). Each water-level measurement represents a point on the water table or potentiometric surface of an aquifer and is considered to represent the altitude at which water would stand in a tightly cased well. Fluctuations in the water-table or potentiometric-surface altitude generally are caused by variations in the amount of water entering or discharging from the aquifer, such as changes in precipitation or pumpage. Large water-level changes generally are caused by an increase or decrease in pumpage.

The water-table and potentiometric-surface contours probably are accurate to within half a contour interval over most of the island but are less accurate in places where data points are sparse and where the hydraulic characteristics of the aquifer are uncertain.

The location, well-identification number, and water-level altitude for all wells used to delineate the potentiometric surfaces are shown on each map. Wells are identified by their New York State Department of Environmental Conservation (NYSDEC) permit number; the prefix K, Q, N, or S (Kings, Queens, Nassau or Suffolk) indicates the county in which the well is located.

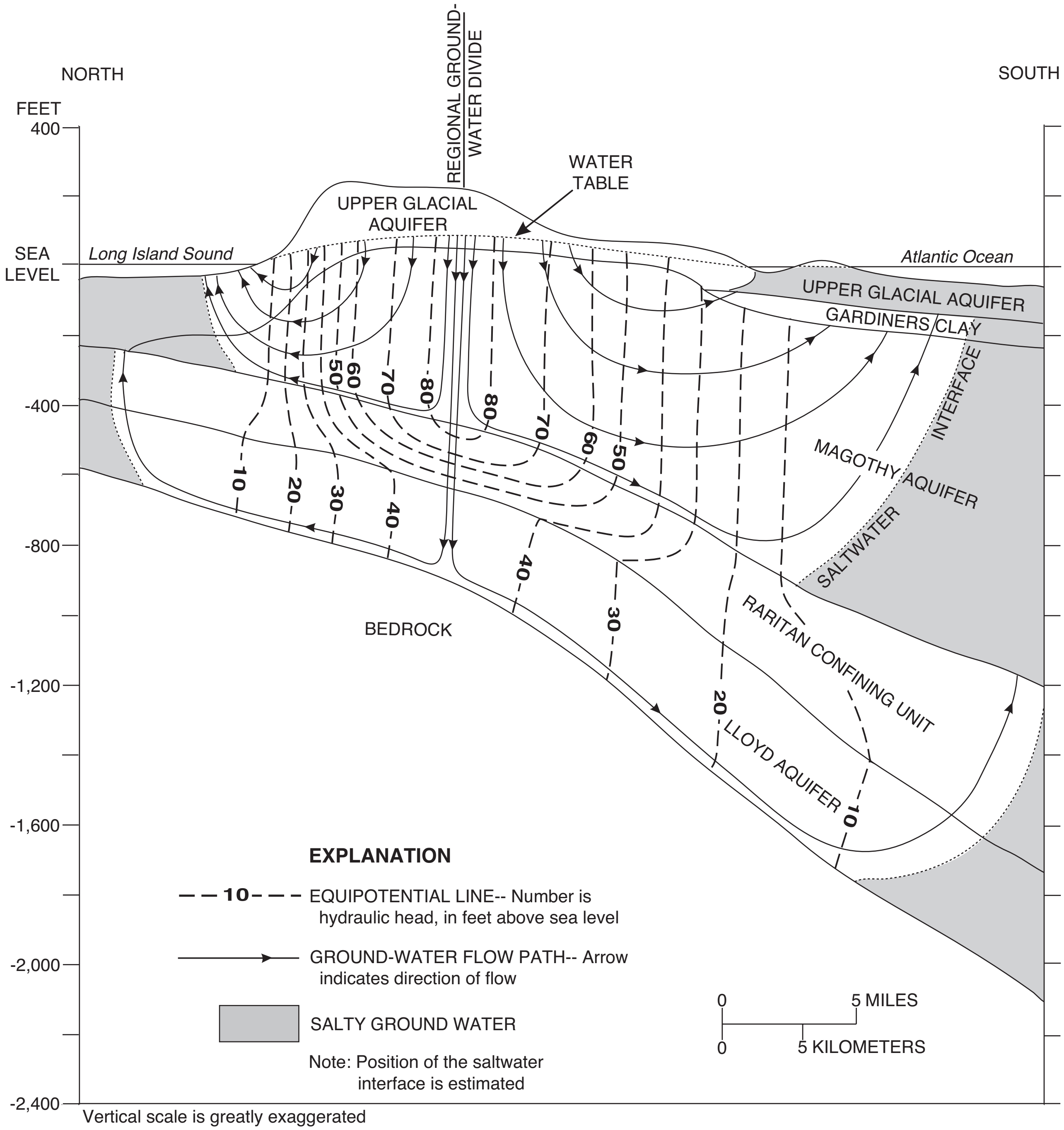


Figure 5. Generalized flow lines in the ground-water system of Long Island, N.Y., under natural (predevelopment) conditions. (Modified from Franke and Cohen, 1972, fig. 2.)

Upper Glacial Aquifer (Water Table)

The water table on Long Island is mainly within the upper glacial aquifer and is recharged by precipitation that infiltrates downward through the unsaturated zone. Static or near-static water levels during March-April 2000 in 283 wells screened in the upper glacial aquifer and in the upper part of the underlying Magothy aquifer are depicted on plates 1A (western Long Island) and 1B (eastern Long Island). Water levels in wells screened in the upper part of the Magothy aquifer are included where the two aquifers are hydraulically connected. Water-level data were not collected in most of Nassau County because resources were not available.

Table 3. Ground-water withdrawals on Long Island, N.Y., by aquifer and county, 1996 and 1999
[Data from New York State Department of Environmental Conservation.]

		Ground-water withdrawals									
		Kings County		Queens County		Nassau County		Suffolk County		Total	
Aquifer	Year	Billions of gallons	Percent of total	Billions of gallons	Percent of total	Billions of gallons	Percent of total	Billions of gallons	Percent of total	Billions of gallons	Percent of total
Upper glacial	1996	0	0	1.2	5.3	1.8	8.0	19.6	86.7	22.6	17.5
	1999	0	0	1.5	4.6	2.3	7.0	29.0	88.4	32.8	20.6
Jameco	1996	0	0	0	0	1.3	100	0	0	1.3	1.0
	1999	0	0	.3	20.0	1.2	80.0	0	0	1.5	0.9
Magothy	1996	0	0	4.1	4.1	56.0	55.6	40.7	40.4	100.8	77.9
	1999	0	0	5.2	4.3	64.9	54.1	49.8	41.5	119.9	75.5
Lloyd	1996	0	0	0	0	4.6	100	0	0	4.6	3.6
	1999	0	0	0	0	4.6	97.9	.1	2.1	4.7	3.0
Totals	1996	0	0	5.3	4.1	63.7	49.3	60.3	46.6	129.3	100
	1999	0	0	7.0	4.4	73.0	45.9	78.9	49.7	158.9	100

The water table generally parallels land surface; it gradually rises from the western part of Long Island to form an east-west-trending mound in Nassau and western Suffolk Counties that is dissected by a low region in west-central Suffolk County beneath the Nissequogue and Connetquot River drainage basins (fig. 1). The water table rises again in central Suffolk County, then gradually declines toward the eastern end of Long Island, where it splits into northern and southern lobes beneath the Peconic River drainage basin (fig. 1).

Local small mounds in the water table, as well as some high regions within the main east-west-trending mound, can be attributed to a combination of topography and zones of low hydraulic conductivity. These mounds are primarily in northwestern Kings County, northeastern Queens County, parts of northern Nassau County (Swarzenski, 1963), western Suffolk County, central Suffolk County (Krulikas and Koszalka, 1983), and the central and eastern parts of the South Fork of eastern Suffolk County (Nemickas and Koszalka, 1982).

The water-table altitude on Long Island in 2000 ranged from 1.36 ft below sea level at well Q3114 in southeastern Queens County (pl. 1A) to 76.26 ft above sea level at well S64313 in western Suffolk County (pl. 1A). Changes in altitude from that in March-April 1997 range from an increase of 4.21 ft at well S64313 in western Suffolk County (pl. 1A) to a decrease of 8.41 ft at well S46527 in eastern Suffolk County (pl. 1B).

In general, the water-table altitude is 0.5 to 4 ft lower in most parts of the island than that reported in 1997 by Busciolano and others (1998), except in parts of northern and southern Kings County, parts of northern Queens County, parts of southwestern and eastern Nassau County, and parts of western, southern, central, and eastern Suffolk County where altitudes have risen from 0.1 to 1 ft. The most notable changes are the 1- to 4.5-ft decline in central and eastern Queens County and western Nassau County, the development of a small depression in southeastern Queens County, and the 2- to 8-ft decline in parts of the eastern forks of Suffolk County.

Magothy Aquifer

Static or near-static water levels during March-April 2000 in 80 wells screened in the Magothy aquifer are depicted on plates 2A (western Long Island) and 2B (eastern Long Island). Water-level data were not collected in most of Nassau County because resources were not available. The northern limit of the Magothy aquifer (Smolensky and others, 1989) is also indicated.

The Magothy aquifer is recharged by downward movement of water from the overlying upper glacial aquifer. The large amounts of clay in the upper half of the Magothy aquifer cause the water to become increasingly confined with depth; this, in turn, can cause potentiometric-surface altitudes in some areas to differ from well to well, depending on the depth of the screen. Therefore, most water-level measurements used to prepare this map were obtained from wells screened at a medium depth and were supplemented by measurements from deeper depths. Measurements in wells screened in the upper part of the aquifer were used only where no deeper wells were available.

The potentiometric-surface altitude of the Magothy aquifer generally parallels that of the overlying water table (pls. 1A and 1B). Like the water table, the potentiometric surface gradually rises from the western part of Long Island to form an east-west-trending mound in Nassau and western Suffolk Counties that is dissected by a low region in west-central Suffolk County beneath the Nissequogue and Connetquot River drainage basins; it then rises in central Suffolk County and gradually declines toward the eastern end of the island. A second, smaller mound is evident in the central part of the South Fork.

The potentiometric-surface altitude of the Magothy aquifer on Long Island in 2000 ranged from 4.41 ft below sea level at well N11634 in southwestern Nassau County (pl. 2A) to 72.18 ft above sea level at well S95964 in western Suffolk County (pl. 2A). Changes in altitude from that in March-April 1997 range from an increase of 5.92 ft at well N6510 in southwestern Nassau County (pl. 2A) to a decrease of 4.66 ft at well Q2300 in east-central Queens County (pl. 2A).

In general, the potentiometric-surface altitude of the Magothy aquifer is 0.5 to 4.7 ft lower in most parts of the island than that reported in 1997 by Busciolano and others (1998), except in parts of southern Kings County, parts of southern Queens County, parts of southwestern Nassau County, and parts of west-central and northern Suffolk County where altitudes have risen from 0.1 to 5.5 ft. The most notable changes are the 2.5- to 4.7-ft decline in central and eastern Queens County and parts of western Nassau County, the shallowing of a large depression in southwestern Nassau County, and the 1- to 2.5-ft decline in southern, central, and eastern Suffolk County.

Lloyd Aquifer

Static or near-static water levels during March-April 2000 in 31 wells screened in the Lloyd aquifer are depicted on plates 3A (western Long Island) and 3B (eastern Long Island). Water-level data were not collected in most of Nassau County because resources were not available. The northern limit of the Lloyd aquifer (Smolensky and others, 1989) is also indicated.

The general configuration of the potentiometric-surface altitude of the Lloyd aquifer is similar to that of the two major overlying aquifers (pls. 1 and 2). The potentiometric surface gradually rises from the western part of Long Island to form an east-west-trending mound in eastern Nassau County that continues east into central Suffolk County. The mound then gradually declines toward the eastern end of Long Island.

The potentiometric-surface altitude of the Lloyd aquifer on Long Island in 2000 ranged from 3.76 ft above sea level at well N12154 in northwestern Nassau County (pl. 3A) to 36.17 ft above sea level at well N12075 in east-central Nassau County (pl. 3A). Changes in altitude from that in March-April 1997 range from an increase of 3.94 ft at well N4266 in northwestern Nassau County (pl. 3A) to a decrease of 2.14 ft at well N11573 in southwestern Nassau County (pl. 3A).

In general, the potentiometric-surface altitude of the Lloyd aquifer is 0.5 to 2 ft lower in most parts of the island than that reported in 1997 by Busciolano and others (1998), except in parts of southern Kings County, parts of southern and northern Queens County, parts of northwestern Nassau County, and parts of western Suffolk County, where altitudes have risen 0.2 to 1.5 ft. The most notable change is the shallowing of the southern part of a large depression in northwestern Nassau County.

SUMMARY AND CONCLUSIONS

The aquifers that form Long Island's ground-water reservoir are the sole source of water supply for more than 3 million people. The abundance of this resource has allowed extensive growth and development on the island. Large-scale ground-water withdrawals and sewer projects have appreciably affected water levels in the upper glacial aquifer (water table) and in the potentiometric-surface altitude of the two other primary aquifers—the Magothy and the Lloyd. These changes have affected the quantity and quality of ground water in the system. The periodic production of water-table and potentiometric-surface maps helps to quantify these changes. In 2000, the USGS began a study to map water levels in the upper glacial, Magothy, and Lloyd aquifers; these maps update the 1997 water-level maps of Busciolano and others (1998).

Long Island's ground-water reservoir is recharged solely from precipitation that infiltrates from the land surface to the water table. Precipitation amounts during the 12 months before the March-April 2000 data collection were below normal and resulted in below-normal water levels in most parts of the primary aquifers.

Water-table and potentiometric-surface altitudes of the three primary aquifers were contoured from water-level measurements made at 394 observation, public-supply and industrial-supply wells during March-April 2000. In general, the water-level altitudes in the upper glacial, Magothy, and Lloyd aquifers were lower throughout most parts of Long Island then those during March-April 1997. Changes in altitude ranged from an increase of 5.92 ft in the Magothy aquifer in southwestern Nassau County to a decrease of 8.41 ft in the upper glacial aquifer in eastern Suffolk County.

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