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Statistical Analysis of Long-Term Hydrologic Records for Selection of Drought-Monitoring Sites on Long Island, New York

Scientific Investigations Report 2004-5152

U.S. Department of the Interior
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By Ronald Busciolano

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U.S. Department of the Interior
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Conversion Factors, Abbreviations and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
million gallons per day (Mgal/d)	0.0438	cubic meter per second (m^3/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Other abbreviations used in this report

milligrams per liter (mg/L)
million gallons (Mgal)
billion gallons (Bgal)
cubic feet per second (CFS)
autoregressive integrated moving average (ARIMA)

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

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

Statistical Analysis of Long-Term Hydrologic Records for Selection of Drought-Monitoring Sites on Long Island, New York

By Ronald Busciolano

Abstract

Ground water is the sole source of water supply for more than 3 million people on Long Island, New York. Large-scale ground-water pumpage, sewering systems, and prolonged periods of below-normal precipitation have lowered ground-water levels and decreased stream-discharge in western and central Long Island. No method is currently (2004) available on Long Island that can assess data from the ground-water-monitoring network to enable water managers and suppliers with the ability to give timely warning of severe water-level declines.

This report (1) quantifies past drought- and human-induced changes in the ground-water system underlying Long Island by applying statistical and graphical methods to precipitation, stream-discharge, and ground-water-level data from selected monitoring sites; (2) evaluates the relation between water levels in the upper glacial aquifer and those in the underlying Magothy aquifer; (3) defines trends in stream discharge and ground-water levels that might indicate the onset of drought conditions or the effects of excessive pumping; and (4) discusses the long-term records that were used to select sites for a Long Island drought-monitoring network.

Long Island's long-term hydrologic records indicated that the available data provide a basis for development of a drought-monitoring network. The data from 36 stations that were selected as possible drought-monitoring sites—8 precipitation-monitoring stations, 8 streamflow-gaging (discharge) stations, 15 monitoring wells screened in the upper glacial aquifer under water-table (unconfined) conditions, and 5 monitoring wells screened in the underlying Magothy aquifer under semi-confined conditions—indicate that water levels in western parts of Long Island have fallen and risen markedly (more than 15 ft) in response to fluctuations in pumpage, and have declined from the increased use of sanitary- and storm-sewer systems. Water levels in the central and eastern parts, in contrast, remain relatively unaffected compared to the western parts, although the effects of human activity are discernible in the records.

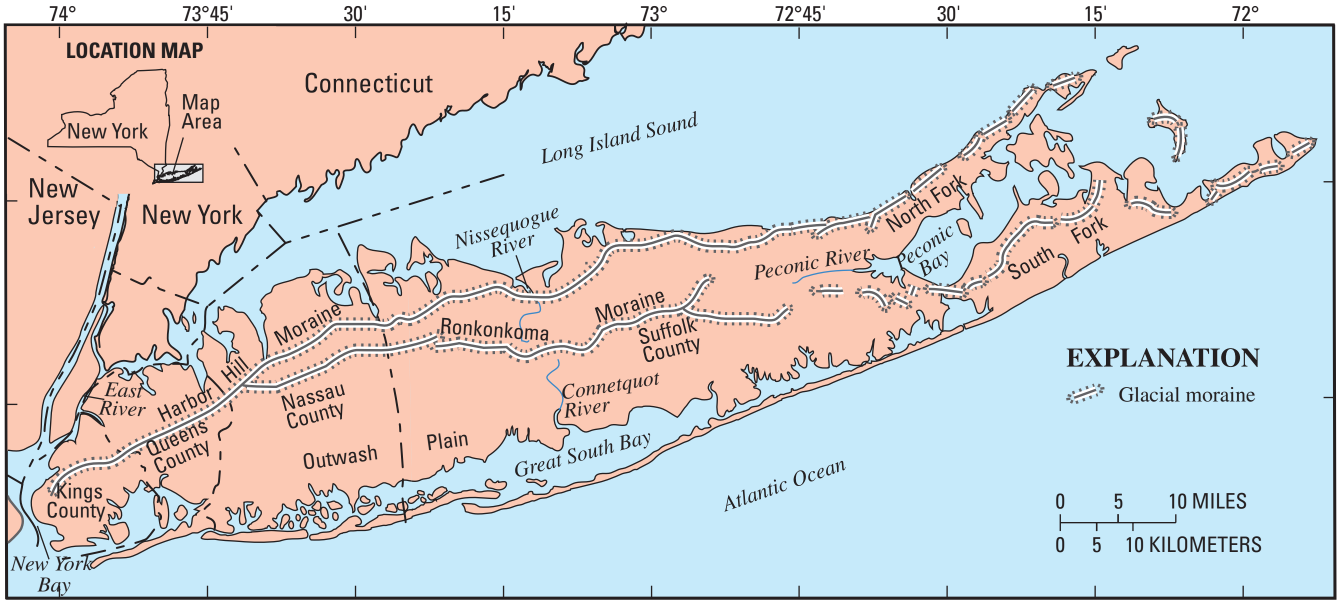
The value of each site as a drought-monitoring indicator was assessed through an analysis of trends in the records. Fifty-year annual and monthly data sets were created and combined into three composite-average hydrographs—precipitation, stream discharge, and ground-water levels. Three zones representing the range of human effect on ground-water levels were delineated to help evaluate islandwide hydrologic conditions and to quantify the indices. Data from the three indices can be used to assess current conditions in the ground-water system underlying Long Island and evaluate water-level declines during periods of drought.

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 contains four counties—Kings, Queens, Nassau, and Suffolk—that together encompass about 1,450 mi^2.

Kings County and most of Queens County obtain most of their water from upstate reservoirs, whereas Nassau County and Suffolk County obtain water solely from wells that tap the underlying ground-water system, which consists of a sequence of unconsolidated sediments of Late Cretaceous and Pleistocene age that overlie a southeastward sloping surface of crystalline bedrock (fig. 2).

The U.S. Geological Survey (USGS), in cooperation with Federal, State, and local agencies, has continuously monitored ground-water levels and stream discharge on Long Island for more than 50 years. The monitoring data provide a basis for analysis of changes resulting from natural and human-induced stresses in the ground-water system. In the past, prolonged periods of below-normal precipitation, together with increases in large-scale pumping from public-supply production wells and sewering by completion of extensive sanitary-sewer and storm-sewer systems (which export water from the system), have produced major water-level declines. These declines,



Base from U.S. Geological Survey State base map, 1:100,000, 1979,
Universal Transverse Mercator projection, NAD 27, Zone 18

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

in turn, have resulted in decreased stream discharge and local saltwater encroachment into the ground-water system; therefore, the ground-water system requires close monitoring. No method is currently (2004) available on Long Island that can assess data from the ground-water-monitoring network to enable water managers and suppliers with the ability to give timely warning of severe water-level declines.

In 2000, the USGS, in cooperation with the New York State Department of Environmental Conservation, began a study to analyze the long-term records of 36 selected precipitation, stream-discharge, and ground-water sites on Long Island for possible use as drought-monitoring stations. The objective was to provide water managers with a means of defining when the ground-water system underlying Long Island is being adversely affected by drought or excessive pumping—the first step in the development of a drought-warning system that can provide timely data on the current status of the ground-water system. The resulting information can be used in times of drought to determine the effects water-conservation programs are having on the ground-water system.

Purpose and Scope

This report (1) quantifies past drought- and human-induced changes in the ground-water system underlying Long Island, New York by applying statistical and graphical methods to long-term precipitation, stream-discharge, and ground-water-level records from selected monitoring sites, (2) evaluates the relation between water levels in the upper glacial aquifer and those in the Magothy aquifer to discern whether water-table fluctuations can be an indicator of changes in the underlying Magothy aquifer, (3) defines trends in stream discharge and ground-water levels that might indicate the onset of drought conditions or the effects of excessive pumping, and (4) describes and rates the long-term data to identify which sites are appropriate for inclusion in a Long Island drought-monitoring network.

Methods

Long-term records from 13 National Weather Service (NWS) long-term precipitation-monitoring stations, 18 USGS streamflow-gaging (discharge) stations, and 40 USGS ground-water-monitoring wells (30 screened in the upper glacial aquifer and 10 screened in the underlying Magothy aquifer) were compiled and evaluated to determine which of these stations could be used as representative sites for a drought-monitoring network.

Site Selection

Sites were selected if (1) their records were complete (measurement frequency at least monthly for most of the period of record), and (2) the period of record began before or during the 1962-66 drought, which is the longest period of consistently below-average precipitation on record for Long Island and is regarded as a benchmark indicator for natural (not human induced) declines in the ground-water system. Some monitoring wells did not meet the criteria listed above

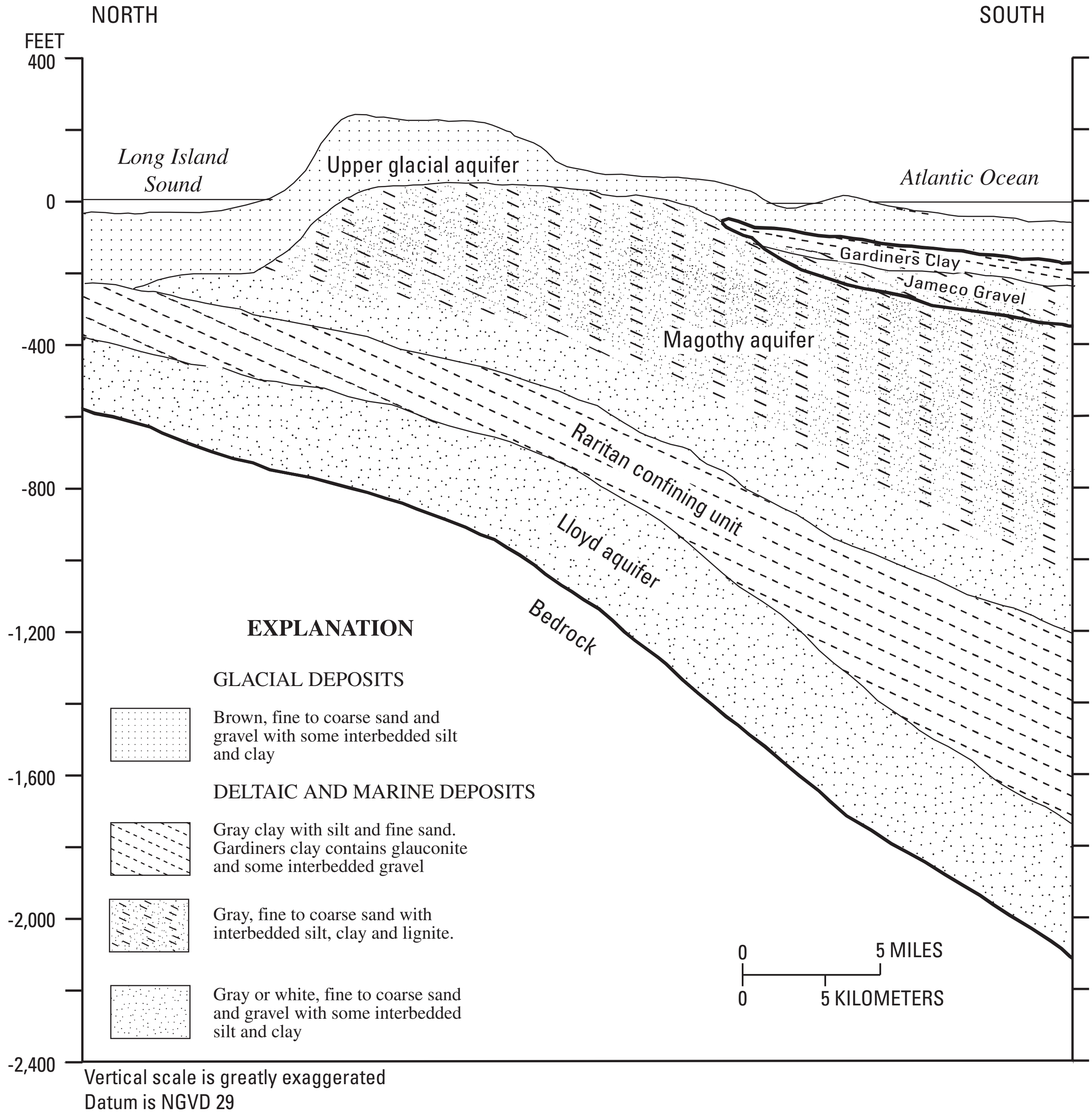


Figure 2. Major hydrogeologic units along a generalized north-south section through the ground-water system of Long Island, N.Y. (Section represents an area near the boundary between Nassau and Suffolk Counties.) (Modified from McClymonds and Franke, 1972, fig. 3.)

but were nevertheless selected as potential drought-monitoring sites because they are in areas, or screened in parts of the ground-water system, where data are lacking. Most of the wells selected for study are on or close to the glacial moraines that extend east-west along the spine of Long Island (fig. 1), where ground-water levels show the greatest response to precipitation.

Data Analysis

Data from each site were analyzed by graphical and statistical methods to identify which could be used as representative indicators of drought conditions. Data plots and hydrographs for each site were created and compared to identify the sites at which the effects of human-induced stresses, such as pumping or sewering, were most severe.

The precipitation and stream-discharge data generally were collected by daily measurement or by continuous-recording equipment. Water-level data were generally collected at monitoring wells monthly, although the measurement interval for some wells may have been variable. Water-level records from wells with more than one measurement per month were averaged to obtain a monthly mean, whereas means for wells with less than one measurement per month were estimated, if possible, by interpolation of values from preceding and subsequent months; if this estimation was impossible, the data were omitted.

The data analysis was based on water years unless otherwise stated. A water year is defined by the 12-month period beginning on October 1 and ending on September 30 of the following year and is designated by the calendar year in which the 12-month period ends.

The initial data set was analyzed, and all redundant and unrepresentative sites were removed. The final data set consists of 8 precipitation-monitoring stations, 8 streamflow-gaging (discharge) stations, 15 monitoring wells screened in the upper glacial aquifer, and 5 monitoring wells screened in the underlying Magothy aquifer. Data sets for sites with more than 50 years of record were trimmed to include only the last 50 years (1951-2000); for sites with less than 50 years of record, the entire period of record was used. Various statistics were calculated for each site—50-year mean and monthly mean; departure and cumulative departure from mean; annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance values; and autoregressive integrated moving average (ARIMA) and polynomial trend lines. An ARIMA trend of 12-month frequency was used for the precipitation and stream-discharge data and 18-month frequency for the ground-water-level data. Trends were computed by averaging the 12 or 18 months prior to and after the value of interest.

The term "normal" generally is used as a standard of comparison for a particular value over a specific 30-year period (Langbein and Iseri, 1960). In this report, a period of 50 years was selected for comparison so that the long-term drought of the 1960's, and the 10 years preceding it, were included in the data set for comparative purposes.

Exceedance values are used in this report to quantify how a mean for a selected period relates to the long-term (1951-2000) record. An exceedance value of 100 percent indicates that the value of interest was exceeded 100 percent of the time and, thus, is less than all other measured values for the period of record (record low); an exceedance value of 50 percent indicates that half of the values are above the value of interest, and half are below it; and an exceedance value of 0 percent indicates that the value of interest is greater than all other measured values for the period of record (record high).

Data are considered to be in the well-above-normal range if they are above the 10-percent exceedance percentile, in the above-normal range if they are between the 10-percent and 25-percent exceedance percentiles, in the normal range if they are between the 25-percent and 75-percent exceedance percentiles, in the below-normal range if they are between the 75-percent and 90-percent exceedance percentiles, and in the well-below-normal range if they are below the 90-percent exceedance percentile.

Long-term records were reviewed, and the utility of each site as a drought indicator was assessed through an analysis of temporal trends in the records. These assessments, in combination with a review of islandwide population density, distribution of large sewer systems, and the distribution of public-supply wells were used to develop a map delineating three aquifer "human-impact zones" that reflect the extent to which pumping and sewers have affected ground-water levels—significant (high), moderate, or insignificant (low). Monthly data from sites in each of these three zones were then combined to create multiple composite-average hydrographs. The composite-average hydrographs for each data type (precipitation, stream discharge, and ground-water level) in the low-human-impact zone were selected as drought-monitoring indices. The composite-average hydrographs for the other two areas are to be monitored for human-induced changes that could be detrimental to the ground-water system underlying Long Island.

Previous Drought Studies

Several USGS studies have evaluated the effects of drought on Long Island. The most comprehensive of these studies (Cohen and others, 1969), analyzed the hydrologic effects of the 1962-66 drought on Long Island's ground-water system. Miller and Frederick (1969) and Franke and McClymonds (1972) also studied the hydrologic effects of that drought.

Other selected USGS reports that study historical trends and the effects of drought in the ground-water system are Fowler (1992), which reviewed the effects of drought on ground-water levels, streamflow, and reservoir levels in Indiana; and Schreffler (1997), which studied drought-trigger ground-water levels and historical trends in Chester County, Pennsylvania.

Hydrogeology and Effects of Human Activity (Pumping and Sewers)

Precipitation is the only natural source of freshwater on Long Island. Under natural (undeveloped) 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 other 50 percent 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 infiltrates downward to recharge the deep (Magothy and Lloyd) aquifers (fig. 3). Water in the deep aquifers also moves seaward along lateral and upward gradients that result in flow into the overlying aquifers. The boundaries of the ground-water system are the water table, the freshwater-saltwater interface (fig. 3), and the bedrock surface.

Under natural conditions, the rate of horizontal ground-water flow through the ground-water system ranges from a few feet to several hundred feet per year. The rate of horizontal flow in most aquifers is 10 to 100 times faster than the rate of vertical flow (Nemickas and others, 1989) because stratification and clay layers within the aquifers and between aquifers impede vertical flow.

Human activities on Long Island have produced large changes in the quantity, movement, and quality of ground water in many parts of the island. The major causes for these changes are (1) increased ground-water pumping, which has created local and widespread drawdowns; (2) storm sewers and sanitary sewers, which discharge wastewater to the surrounding bays and ocean, thereby removing water from the ground-water system and contributing to water-level declines; and (3) roads, parking lots, and other impervious surfaces that prevent the infiltration of precipitation and decrease recharge to the ground-water system. The installation of numerous ground-water-recharge basins (that divert storm-water runoff back into the ground-water system) has helped to minimize water-level declines in some areas of Long Island.

The ground-water system underlying Long Island consists of three major aquifers—the upper glacial, the Magothy, and the Lloyd—and various other smaller hydrogeologic units of limited extent (fig. 2). These units consist 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 and 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). This report pertains to the two uppermost units—the upper glacial and Magothy aquifers, whose hydrogeologic properties and water-level configurations are described below.

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 features 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 probably were deposited between or at the terminus of smaller lobes of the ice sheet, or as other types of glacial features. 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.

Upper Glacial Aquifer

The upper glacial aquifer of Pleistocene age (fig. 2) is the uppermost unit in Long Island's ground-water system and forms the present-day land surface of Long Island, except where it is overlain by Holocene-age or man-made deposits. The upper glacial aquifer contains the water table throughout the island, 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, which is unconfined (under water-table conditions) and functions hydraulically as part of the upper glacial aquifer. The upper glacial aquifer unconformably overlies the Magothy aquifer throughout most of Long Island.

Magothy Aquifer

The Magothy aquifer (Matawan Group-Magothy Formation, undifferentiated, of upper Cretaceous age) is the most extensive hydrogeologic unit in the ground-water system underlying Long Island (fig. 2). The Magothy aquifer underlies most of Long Island and the offshore waters, 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 aquifer unconformably overlies the Raritan confining unit (clay member of the Raritan Formation of Upper Cretaceous age) throughout Long Island and is hydraulically confined by the Gardiners Clay of Pleistocene age in most of Kings County, south-central Queens County, and southern Nassau and Suffolk Counties. The Magothy aquifer is overlain by Pleistocene-age deposits of the upper glacial aquifer in the area north of the Gardiners Clay. In this

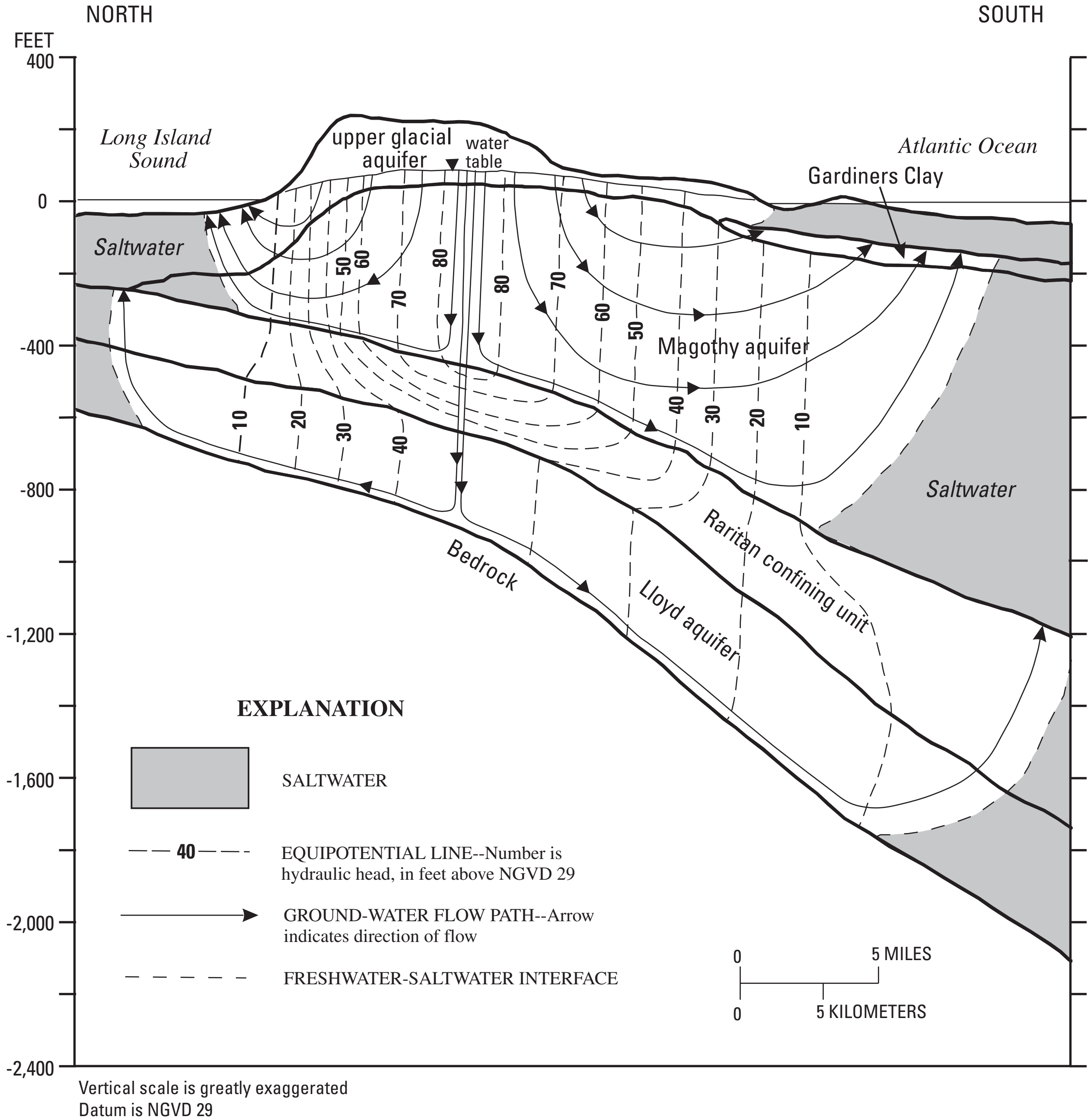


Figure 3. Major hydrogeologic units, hydraulic heads, and ground-water flow paths along a generalized north-south section of Long Island in an area near the Nassau-Suffolk County boundary, under natural (predevelopment) conditions. (Modified from Franke and Cohen, 1972, fig. 2.)

area, the uppermost part of the Magothy aquifer is unconfined and functions hydraulically as part of the water table.

Relation between the Upper Glacial and Magothy Aquifers

The upper glacial aquifer on Long Island is recharged by precipitation that infiltrates downward through the unsaturated zone. The water table (located in the upper glacial aquifer and parts of the uppermost Magothy aquifer) 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. 4A). 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. 4A).

The Magothy aquifer is recharged by downward movement of water from the overlying upper glacial aquifer. Small silty or clayey layers within the Magothy aquifer cause the water to become increasingly confined with depth. The potentiometric-surface altitude of the Magothy aquifer generally parallels the overlying water table (fig. 4A,B); it gradually rises from the western part of Long Island to form an east-west-trending mound in Nassau and western Suffolk Counties, then declines to form a low region in west-central Suffolk County beneath the Nissequogue and Connetquot River drainage basins. The potentiometric surface rises again in central Suffolk County, then gradually declines toward the eastern end of Long Island. A second, smaller mound is evident in the central part of the South Fork of eastern Long Island (fig. 4B). Parts of the Magothy aquifer are naturally saline (chloride concentration greater than 250 mg/L; Lusczynski and Swarzenski, 1966) on the North and South Forks (Nemickas and Koszalka, 1982).

Water levels in the upper glacial aquifer generally parallel those in the Magothy aquifer as a result of the good hydraulic connection between the two hydrogeologic units in areas where confining units are absent. Five upper glacial and Magothy aquifer monitoring-well pairs were selected for a water-level comparison to measure the lag time between an increase in pressure head from precipitation entering the water table and the head (water-level) responses in the underlying Magothy aquifer. An increase in pressure head does not indicate the rate of downward water movement from land surface to the Magothy aquifer, which could take years or decades; it does, however, indicate the degree of hydraulic connection between the two aquifers, which is useful for drought or pumpage analysis.

Well pairs in areas that are hydrologically similar to those of the 15 monitoring wells screened in the upper glacial aquifer, and 5 monitoring wells screened in the underlying Magothy aquifer that were selected as drought-monitoring wells (along and near the ground-water divide) were evaluated; locations are shown in figure 5. Hydrographs of the five well pairs (fig. 6) were created for selected 3-year time periods, which were identified based on two criteria: (1) water levels in both wells of a pair were measured at least monthly, and (2) the record encompassed a period of water-level fluctuations related to changes in precipitation. The water levels in each paired well were compared to determine whether wells screened in the upper glacial aquifer could be used as indicators of general conditions in the underlying Magothy aquifer. This information would be useful for drought monitoring in areas where deep wells are sparse, such as in central and eastern Suffolk County. Results of the comparison are summarized in table 1.

The data from the four selected well pairs that had measurement intervals of 1 month (A, B, C, and D) indicate no discernible pressure-head lag time (fig. 6). Well pair E, which has a weekly measurement interval, indicates a pressure-head lag time of as much a 1 week at a few points in the record. However, the short lag times (less than 1 month) at all five well pairs indicate that most water-table wells on Long Island that are screened above the unconfined part of the Magothy aquifer can be used to evaluate heads (water levels) in the underlying Magothy aquifer where deep monitoring wells are lacking.

Effects of Human Activity on Ground-Water Levels

The abundance of fresh ground water on Long Island has allowed extensive growth and development during the past 100 years. The island's population increased from about 2 million in 1900 to about 7 million in 2000 (U.S. Bureau of Census, 2000). The greatest increase since the 1940's has occurred in the central and eastern parts of the island as the population expanded eastward from Kings and Queens Counties into Nassau and Suffolk Counties. Today, population densities range from less than 10 persons per acre in most parts of eastern, central, and northwestern Suffolk County and in parts of northern Nassau County, to more than 180 persons per acre in parts of Queens and Kings Counties (fig. 7A). This wide range in population density is reflected by ground-water levels, which have been drawn down in some parts of the island (areas with high density), but not in others (areas with low density). The ground-water system in low density areas remains relatively unchanged from predevelopment conditions.

About 3.1 million people on Long Island rely on water pumped from about 1,000 public-supply wells (fig. 7B) that together withdraw about 400 Mgal/d (Nemickas and others, 1989) from the ground-water system. Large-scale pumping in the past caused severe ground-water-level declines that have led to saltwater intrusion (Lusczynski, 1952; Perlmutter and Soren, 1962); this, in turn, required the curtailment of long-term pumping in most of Kings and Queens Counties. The

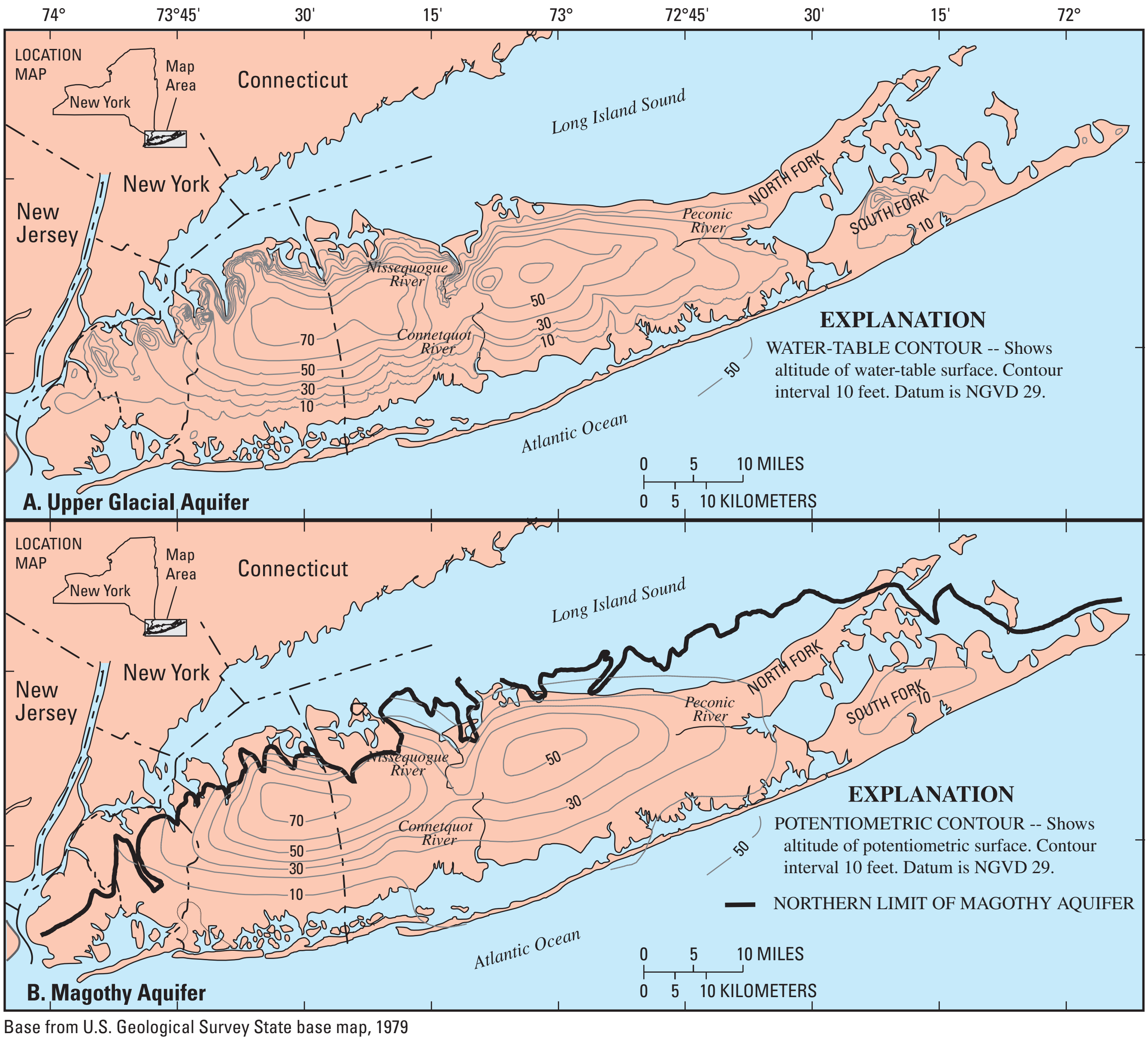
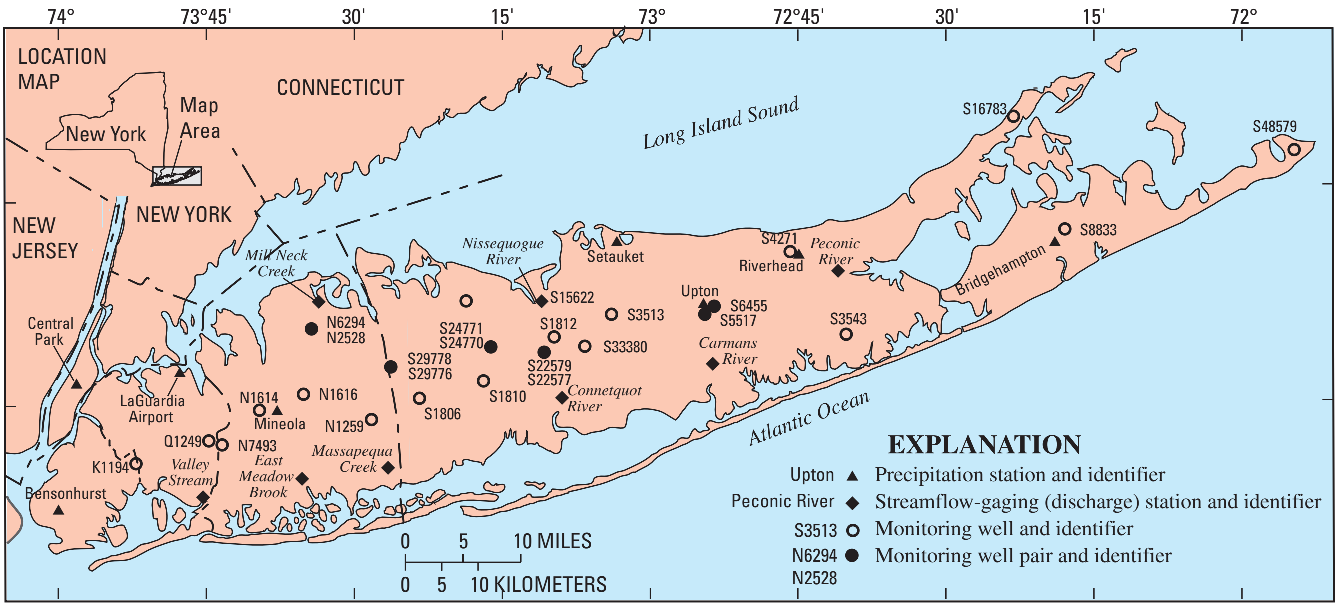


Figure 4. Ground-water levels on Long Island, N.Y., March-April 1997: A. Water-table altitude in the upper glacial aquifer. B. Potentiometric-surface altitude in the Magothy aquifer. (Modified from Busciolano, and others, 1998, pls. 1 and 2.)



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

Figure 5. Locations of the selected precipitation-monitoring stations, streamflow-gaging (discharge) stations, and monitoring wells on Long Island, N.Y.

water-table recovery that followed has caused local flooding of basements and subways that were installed during periods of water-table decline.

The installation of large sanitary and storm-sewer systems (fig. 7B), and the increase in impervious surfaces, such as roads and parking lots, have caused regional water-level declines; these declines, in turn, have caused a decrease in ground-water storage and a loss of freshwater habitat through the lowering of pond and lake levels and the reduction of stream length and discharge. A brief history of the large-scale pumping and sewering activities on Long Island during the past century is given below.

Ground-Water Pumping

Nassau County, Suffolk County, and parts of eastern Queens County rely solely on water pumped from the underlying ground-water system. The upper glacial aquifer was the principal source of water supply throughout these areas for several decades, but its gradual contamination by surface sources and septic waste resulted in the widespread curtailment of its use for public supply. The upper glacial aquifer remains a major source of water supply in eastern parts of Suffolk County, but the Magothy aquifer is now the principal source of water supply in parts of eastern Queens County, most of Nassau County, and most of western and central Suffolk Counties. The deepest aquifer, the Lloyd aquifer, remains mostly undeveloped, except in parts of eastern Queens County and along the north and south shores of Nassau and western Suffolk Counties, where it is a major source of water.

In 1900, Long Island had a population of about 2 million, which resided primarily in Kings and western and central Queens Counties. The first large-scale pumping from the ground-water system began in Kings County during the late 19th century; the water supply for most of the island before that was from local surface-water sources. Pumpage increased rapidly throughout the early 1900’s, and by 1916 the combined pumpage for Kings, Queens, and Nassau Counties was estimated to be about 225 Mgal/d (Thompson and Leggette, 1936). By 1917, the first water tunnel carrying water from upstate reservoirs to New York City was completed, and ground-water pumping in western Long Island decreased sharply.

By the mid-1930’s and early-1940’s, pumpage in western Long Island had again increased sharply, and by 1947, saltwater intrusion in Kings County necessitated the shutdown of all public-supply wells in the New York Water Service Corporation’s Flatbush system. The shutdown of the Flatbush system caused a water-level rise of 19 ft in some parts of central Kings County (Lusczynski, 1952).

From the late 1940’s through the 1960’s, most of Queens County and parts of Nassau County became increasingly urbanized, and pumpage in these areas continued to increase. By the early 1970’s, wells in western Queens County were pumping more than 60 Mgal/d (Chu and others, 1997), which led to new saltwater intrusion in southern Queens County; by 1974, most public-supply wells in western Queens County (New York Water Service Corporation’s Woodhaven system) were shut down. This curtailment of pumping caused a water-level rise of more than 10 ft, which resulted in basement flooding and foundation damage in some parts of eastern Kings and western Queens Counties (Soren, 1976).

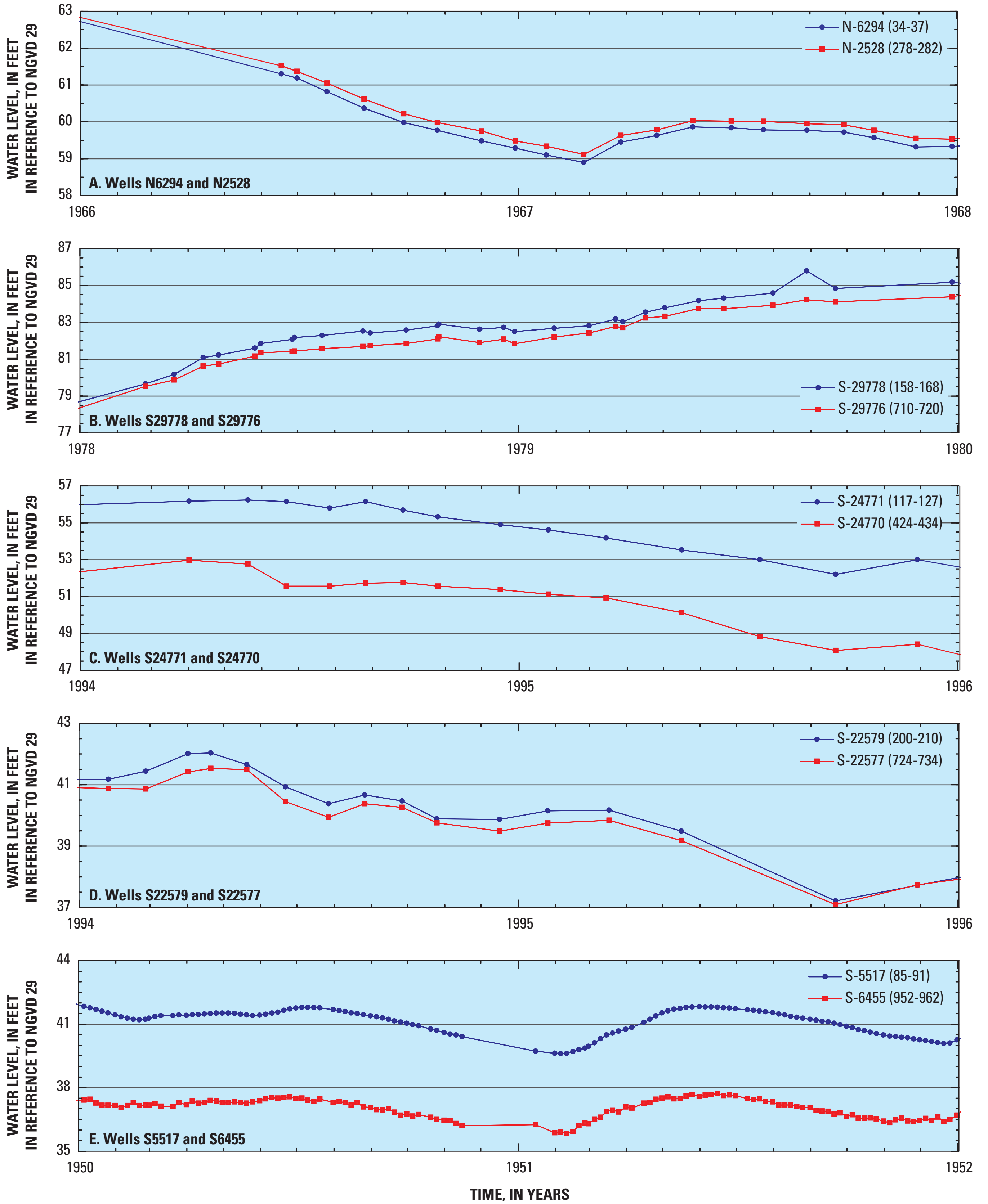


Figure 6. Relation between heads (water levels) in the upper glacial and Magothy aquifers at five well pairs on Long Island, N.Y., during selected 3-year periods. (Well pairs are listed in west-to-east order. Screened interval shown in parentheses. Locations are shown in figure 5.)

Table 1. Well pairs used in analysis of the hydraulic connection between the upper glacial and underlying Magothy aquifer, Long Island, N.Y.

[Locations are shown in figure 5.]

Well pair and county	Wells and aquifer			Screened depth (feet below land surface)	Variation in head (water-level) difference (feet)	Remarks
A. Northeastern Nassau	Shallow well Deep well	N6292 N2528	Upper glacial Magothy	34-37 278-282	0.25	Deep-well head generally higher
B. Western Suffolk	Shallow well Deep well	S29778 S29776	Magothy (water table) Magothy	158-168 710-720	0.25 - 0.5	Shallow-well head generally higher
C. West-central Suffolk	Shallow well Deep well	S24771 S24770	Upper glacial Magothy	117-127 424-434	3 - 4	Shallow-well head generally higher
D. Central Suffolk	Shallow well Deep well	S22579 S22577	Upper glacial Magothy	200-210 724-734	0.25 - 0.5	Shallow-well head generally higher
E. East-central Suffolk	Shallow well Deep well	S5517 S6455	Upper glacial Magothy	85-91 952-962	3.5 - 4.0	Shallow-well head generally higher

During the 1970’s and early 1980’s, pumpage continued to increase in eastern Queens County, Nassau County, and western Suffolk County as the population increased in these areas. By the mid-1980’s, more than 60 Mgal/d were being pumped from wells in eastern Queens County, and by the late-1980’s, new concerns about saltwater intrusion and ground-water contamination caused the Jamaica Water Supply Company to sharply decrease pumpage in central and eastern Queens County (table 2). In response, ground-water levels rose more than 20 ft in these areas and caused severe basement and subway flooding. Annual 1985-99 pumpage, by county and aquifer, is plotted in figure 8.

Ground-water pumpage in Nassau and Suffolk Counties continued to increase during the late-1980’s and 1990’s (table 2, fig. 8), and saltwater intrusion developed locally. The current areas of major concern are in southwestern Nassau County, where water is pumped from the Lloyd aquifer (Terracciano, 1997), and in northern Nassau County, where a combination of increased pumpage and complex stratigraphy have led to saltwater intrusion (Stumm, 2001; Stumm and others, 2002; Stumm and others, 2004).

Sewer Systems

In the early 1900’s, most homes on Long Island disposed of wastewater through private septic-waste systems that returned the water directly to the water-table aquifer. The rapid urbanization and population growth that followed resulted in the gradual contamination of this aquifer by these systems until the water in some places was impotable. This contamination led to the installation of extensive sanitary sewer systems in the heavily populated parts of western Long Island. The first systems were installed in Kings and Queens Counties in the early and mid-1900’s; Nassau County Sewage Disposal District 2, in southwestern Nassau County, was completed in the early 1960’s (fig. 7B), and Nassau County Sewage Disposal District 3 (in southeastern Nassau County) and the Southwest Sewer District (in southwestern Suffolk County) were completed in the mid-1980’s (fig. 7B).

All of the sewer systems described above slowed the contamination of the upper glacial aquifer but resulted in major declines in regional ground-water levels by diverting the water to treatment plants and to the surrounding bays and ocean, instead of returning it to the aquifer. Water levels during the first 15 years after the completion of the Nassau County Sewage Disposal District 2 in the 1960’s declined markedly, and by the mid-1970’s, had reached a new equilibrium at about 9 ft below pre-sewer conditions (Franke, 1968; Garber and Sulam, 1976; Sulam, 1979).

The lowering of ground-water levels in the upper glacial aquifer has decreased the base flow of nearby streams. Base flow of East Meadow Brook, in south-central Nassau County, decreased by about 45 percent during 1965-74 (Pluhowski and Spinello, 1978); 75 percent of this decrease was attributed to the effects of sanitary sewers and the remainder to storm sewers, which route storm runoff to streams, where it flows to tidewater.

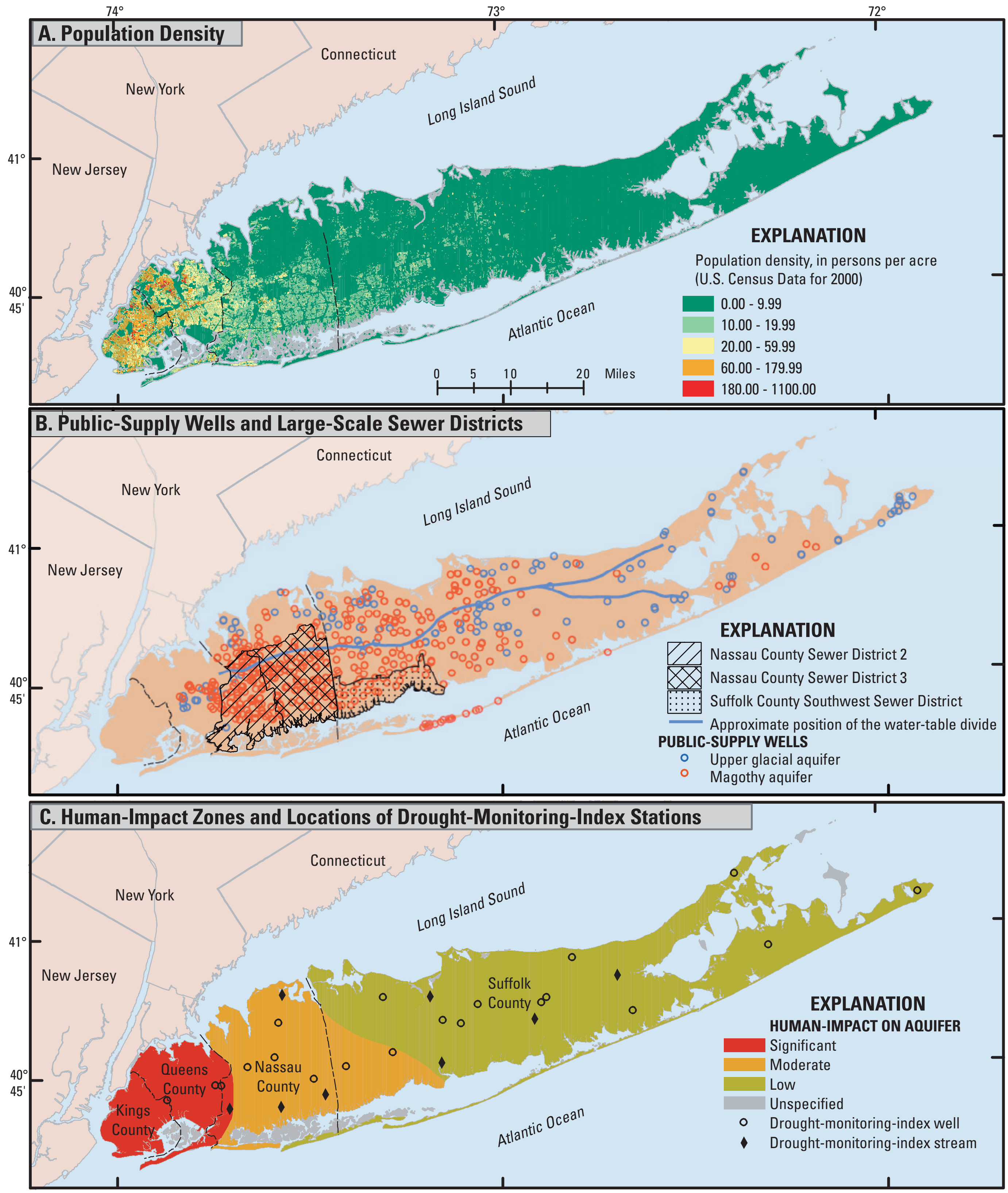


Figure 7. Distribution of A. population density, B. upper glacial and Magothy aquifer public-supply wells and large-scale sewer districts, C. inferred human-impact on aquifer zones and selected drought-monitoring-index stations on Long Island, N.Y.

Table 2. Public-supply ground-water withdrawals on Long Island, N.Y., by aquifer and county, for 1985-89, 1990-94, and 1995-99.

[Data from the New York State Department of Environmental Conservation.]

		Ground-water withdrawals									
		Kings County		Queens County		Nassau County		Suffolk County		Total	
Aquifer	Years	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	1985-89	0	0	12.6	10.0	12.7	10.1	100.7	79.9	126.0	19.0
	1990-94	0	0	12.2	9.4	11.8	9.1	105.4	81.5	129.4	19.4
	1995-99	0	0	9.4	6.8	10.6	7.7	117.5	85.5	137.5	19.1
Magothy	1985-89	0	0	38.7	7.5	296.4	57.6	179.3	34.9	514.4	77.3
	1990-94	0	0	28.6	5.5	291.2	56.2	198.6	38.3	518.4	77.6
	1995-99	0	0	26.7	4.8	303.2	54.2	229.7	41.0	559.6	77.9
Lloyd	1985-89	0	0	2.3	9.3	22.5	90.7	0	0	24.8	3.7
	1990-94	0	0	0.2	1.0	19.6	99.0	0	0	19.8	3.0
	1995-99	0	0	0	0	21.0	98.6	0.3	1.4	21.3	3.0
Totals	1985-89	0	0	53.6	8.1	331.6	49.8	280.0	42.1	665.2	100
	1990-94	0	0	41.0	6.1	322.6	48.3	304.0	45.6	667.6	100
	1995-99	0	0	36.1	5.0	334.8	46.6	347.5	48.4	718.4	100

A study of the expected effects of the Nassau County Sewage Disposal District 3 and the Suffolk County Southwest Sewer District (Kimmel and others, 1977) indicated that, when equilibrium is reached, water-table declines could be as much as 18 ft in Nassau County and 8 ft in western Suffolk County (Reilly and others, 1983; Buxton and Reilly, 1985; Reilly and Buxton, 1985). Potentiometric-surface declines in the Magothy aquifer could be comparable, and stream base flow in those areas could decrease by 70 to 90 percent. Much of this predicted decline has already occurred in parts of Nassau County and has begun to occur in western Suffolk County.

Delineation of Human Effect on Ground-Water Levels

Three zones representing the range of human effect on ground-water levels, “human-impact zones”, were delineated to help evaluate islandwide hydrologic conditions and to quantify the drought-monitoring indices described further on. Four data sets were the basis for zone delineation: (1) population density, (2) locations of large sanitary- and storm-sewer systems, (3) locations of public-supply wells screened in the upper glacial and Magothy aquifers, and (4) long-term records of selected monitoring wells and stream-discharge stations.

The first zone (significant-human impact) encompasses Kings and Queens Counties and parts of western Nassau County (fig. 7C). It represents population densities greater than 20 persons per acre (fig. 7A). The construction of impervious surfaces, such as roads, parking lots, and buildings, and the installation of large sewer systems before the 1950’s, generally decreased recharge to the ground-water system. Historically, this area has relied heavily on ground water, but overpumping in the past has caused severe saltwater intrusion in Kings and Queens Counties that has necessitated the cessation of ground-water pumpage for most public use. In western Nassau County, where ground water is still the sole source of potable water, pumping caps, conservation, recharge basins, and aquifer monitoring have helped to avert severe saltwater intrusion problems.

Ground-water and surface-water records from wells and streams in this western zone indicate that overpumping and lack of aquifer protection has severely affected the ground-water system. Large increases in pumpage, and the reductions in aquifer recharge caused by sewer systems and impervious surfaces, have obscured all natural water-level fluctuations in the hydrologic record. Therefore, this western area is designated as a zone of significant-human impact (fig. 7C).

The second zone (moderate-human impact) encompasses most of Nassau County and parts of western Suffolk County. The zone generally represents population densities of 10 to 20 persons per acre (fig. 7A), but includes some parts of

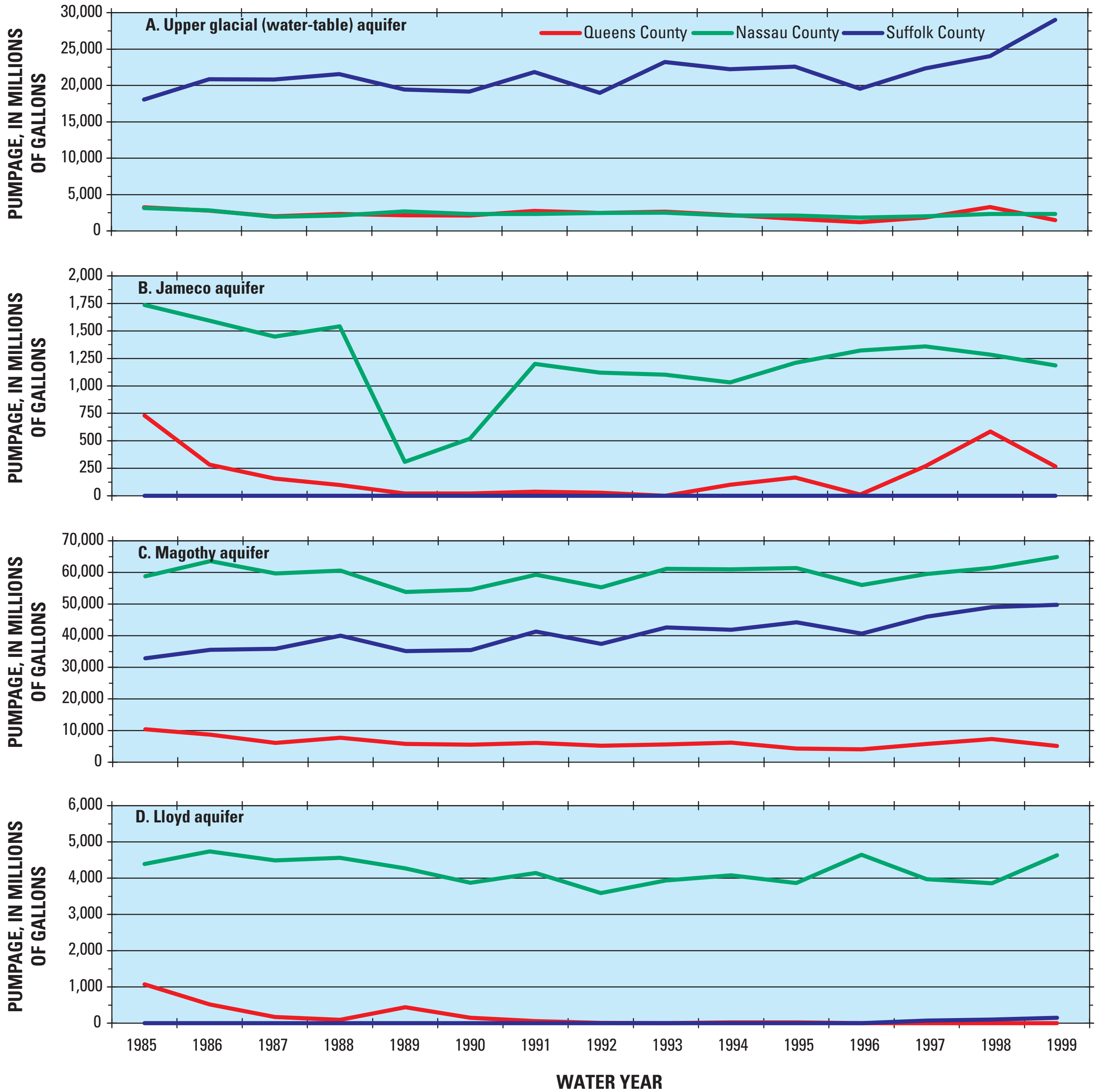


Figure 8. Annual ground-water pumpage from Long Island's major aquifers, by county, 1985-99: A. Upper glacial (water-table) aquifer. B. Jameco aquifer. C. Magothy aquifer. D. Lloyd aquifer.

northern Nassau and northwestern Suffolk Counties that are less densely populated. Impervious surfaces are less extensive in this zone than in the western zone, but the installation of large sewer systems (fig. 7B) since the 1950's has severely decreased aquifer recharge. The construction of numerous recharge basins in parts of this zone has helped to offset the loss of recharge through the sewer systems and has minimized water-level declines north of the ground-water divide. This central area relies solely on ground water for public-water supply.

Ground-water and surface-water records from wells and streams in the central area indicate that large increases in pumpage and a decrease in recharge have greatly affected ground-water levels. Water levels have declined sharply (greater than 15 ft) in some areas during the past 50 years; these declines began in the western areas during the 1950's, and more recently have been detected in central and eastern areas as the population and urbanization expanded eastward. These declines have altered the ground-water system such that human-induced changes are now a primary cause of fluctuations in the stream-discharge and water-level records. Natural fluctuations remain visible, but are partly masked by the human-induced changes. Therefore, this central area is designated as a zone of moderate-human impact (fig. 7C).

The third zone (low-human impact) encompasses eastern and central parts of Suffolk County. It generally represents population densities of less than 10 persons per acre (fig. 7A). Impervious surfaces are less extensive than in the western and central zones, and no large sewer systems have been installed. This area also relies solely on ground water for public-water supply.

Ground-water and surface-water records from wells and streams in this eastern area indicate that most parts of the ground-water system remain relatively unaffected by human activity, and natural fluctuations are still the primary cause of changes in the hydrologic record. Therefore, this eastern area is designated as a zone of low-human impact (fig. 7C).

Statistical Analysis of Long-Term Hydrologic Records

Various types of hydrologic data have been collected on Long Island for more than 100 years. Long-term precipitation data collection by the NWS began in the mid- to late 1800's, and ground-water levels were first measured by the USGS in the early 1900's. Long-term surface-water-data collection by the USGS in most parts of the island began in the 1930's and 1940's.

Precipitation

Precipitation is the sole source of all fresh ground water on Long Island. Seasonal or long-term fluctuations in precipitation, and the associated recharge rate, are reflected by changes in water levels in the ground-water system. Mean annual precipitation on Long Island ranges from about 40 in/yr across southernmost Nassau County and on the eastern tip of the North Fork to about 50 in/yr across central and west-central Suffolk County (fig. 9A). Mean summer precipitation generally is equal to mean winter precipitation throughout the island; 5 to 10 percent of the water equivalent of winter precipitation is in the form of snow (Miller and Frederick, 1969).

Precipitation on Long Island can be divided into a growing-season (warm-season) component (fig. 9B) and a dormant-season (cool-season) component (fig. 9C). The type and intensity of precipitation, and the amounts that reaches the water table as recharge, differ seasonally. 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 are typically characterized by relatively short periods (hours) 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 summer.

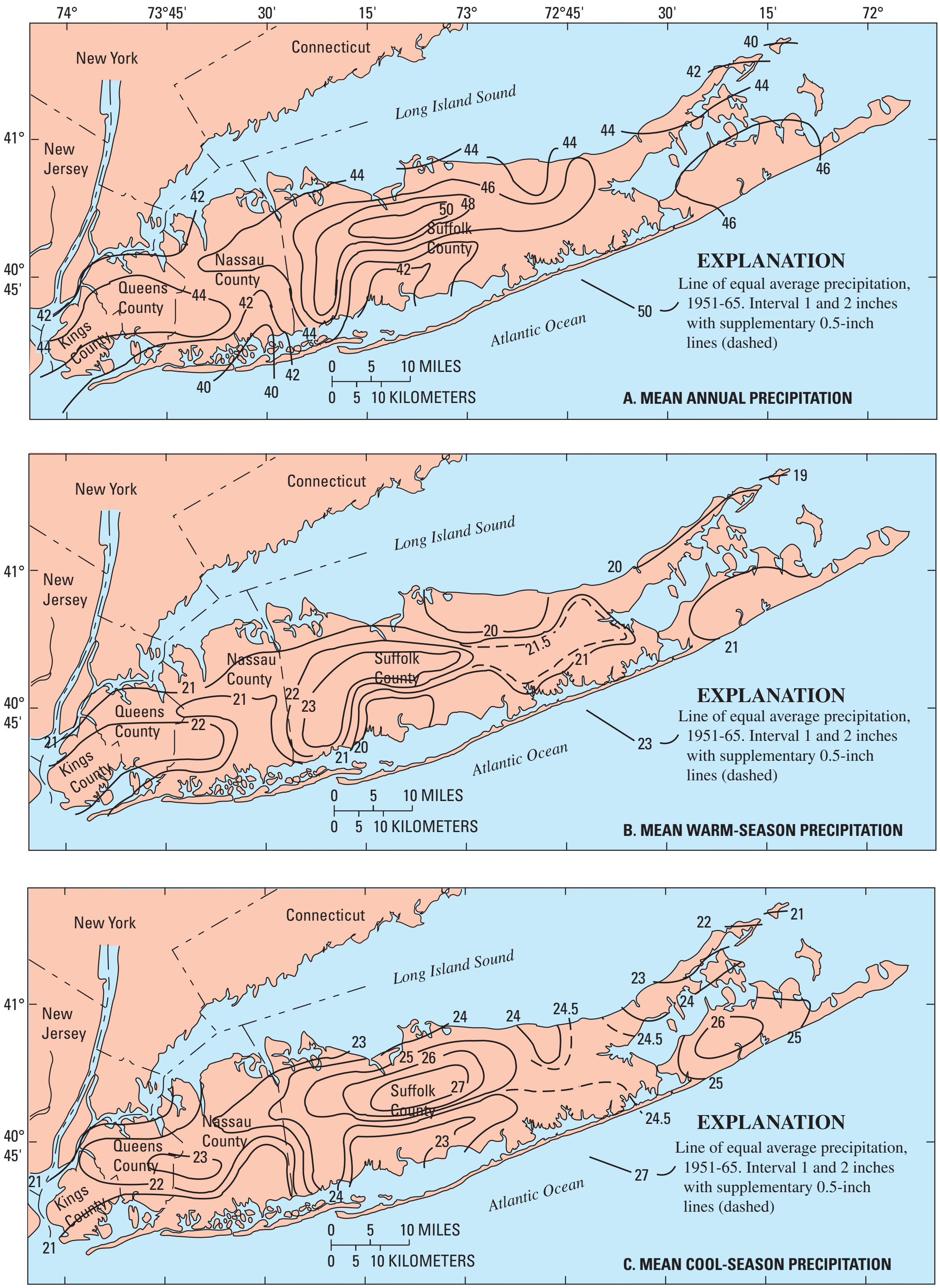
The cool season (October through March) is characterized by large, low-pressure systems that originate in the southern and central United States and move northeastward along the Atlantic coast or the western side of the Appalachian Mountains. Storms of this type are characterized by long periods (days) of steady precipitation in the form of rain, snow, and ice, and tend to produce 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 the dormant vegetation, and, therefore, infiltrates to the water table as recharge; thus, most aquifer recharge occurs during the cool season.

Of the 13 active precipitation stations on or near Long Island, only 8 have continuous periods of record that go back to 1951 and were selected as possible indicators of islandwide precipitation. These stations are: in Central Park in central New York County, in Bensonhurst in southwestern Kings County, at LaGuardia Airport in northern Queens County, in Mineola in central Nassau County, in Setauket in north-central Suffolk County, in Upton in central Suffolk County, in Riverhead in northeastern Suffolk County, and in Bridgehampton in southeastern Suffolk County. Station locations are shown in figure 5.

Annual and monthly precipitation data were compiled for each of the eight stations. The period of record at each site was trimmed to include only the last 50 years of record (1951-2000); this period was selected to include the 1960's drought as well as the 10 years preceding it, for comparative purposes; the station at Bensonhurst is missing 2 years (1952-53) of data. The 50-year hydrographs and boxplots for each of the eight stations (fig. 10) include the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, and the ARIMA trend line.

The long-term precipitation records from each of the eight selected stations are summarized in table 3 and figure 10. The minimum, mean, and maximum annual precipitation for 1951-2000, and the values for selected exceedance percentiles are given in table 3A, and the minimum and maximum monthly precipitation and mean precipitation for the driest and wettest months on record are given in table 3B. Notable short- and long-term trends in precipitation are given in table 3C. The stations are presented in west-to-east geographical order.

In summary, the records for all eight stations generally indicate similar long-term trends, although most of the Long Island stations lack the large extremes seen at Central Park, probably because they are subject to the moderating effects of Long Island's coastal climate. The deficit of the 1960's was the major feature in the record for most stations, but stations on eastern parts of Long Island show a much smaller cumulative deficit for this period than in western parts.



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

Figure 9. Mean precipitation on Long Island, N.Y., 1951-65: A. Mean annual. B. Mean for warm season (April through September). C. Mean for cool season (October through March). (Modified from Miller and Frederick, 1969, pl. 1.)

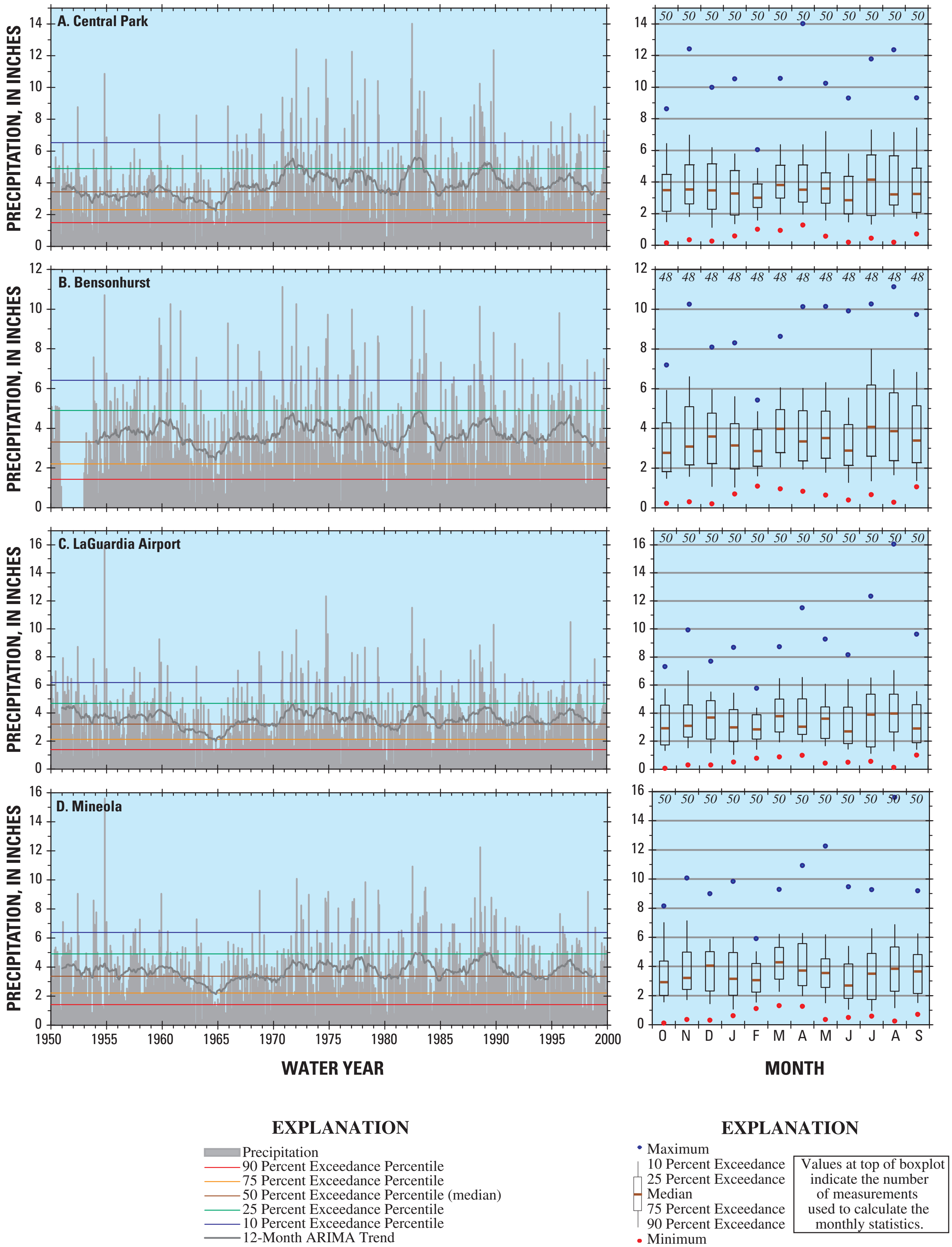


Figure 10. Monthly precipitation and exceedance statistics for eight selected stations on or near Long Island, N.Y., 1951-2000. (Station locations are shown in figure 5.)

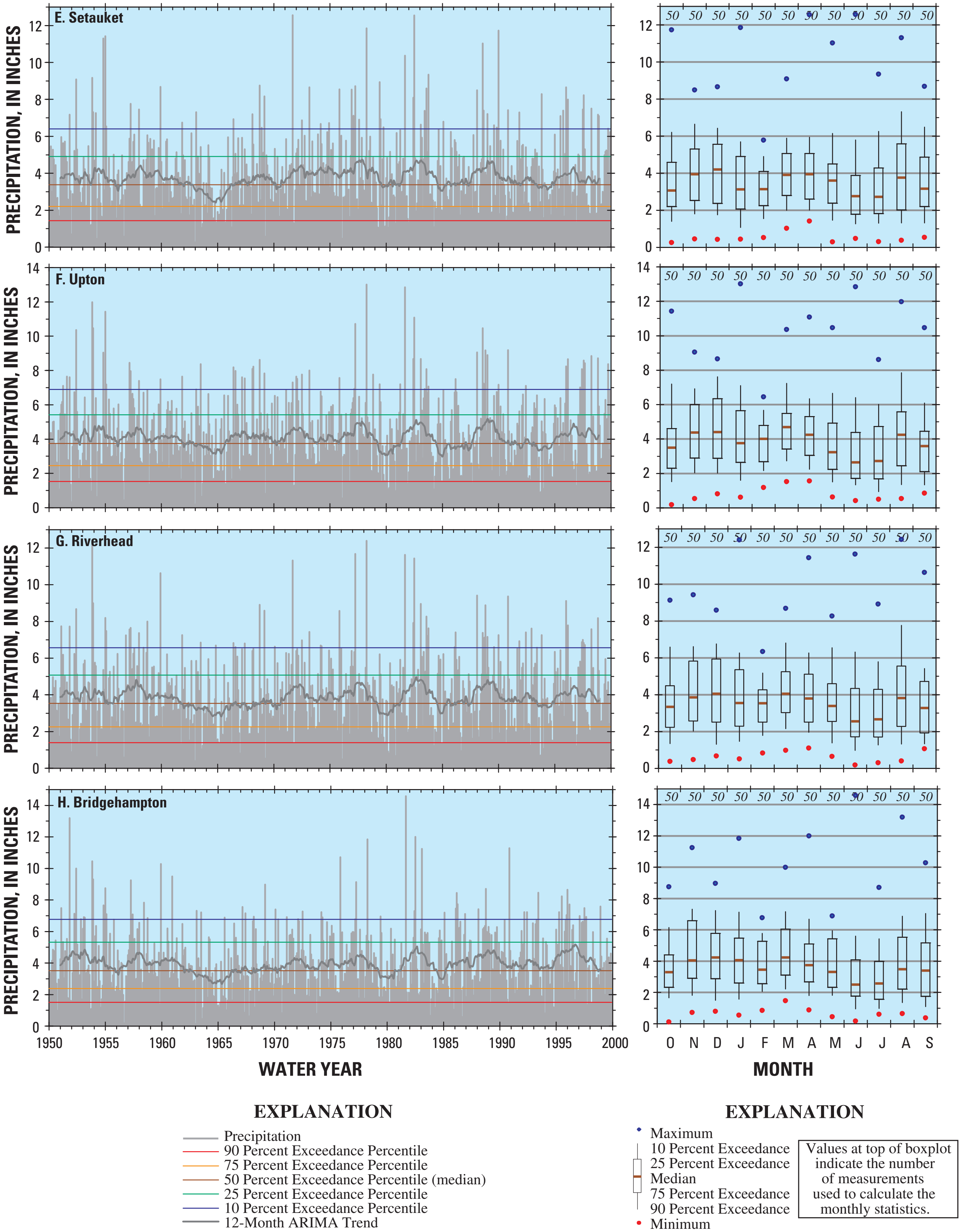


Figure 10. (continued) Monthly precipitation and exceedance statistics for eight selected stations on or near Long Island, N.Y., 1951-2000. (Station locations are shown in figure 5.)

Table 3A. Annual minimum, mean, and maximum precipitation volume, and volumes for selected exceedance percentiles, at the eight selected precipitation-monitoring stations on or near Long Island, N.Y., 1951-2000.

[Amounts are in inches. %, percent. Locations are shown in figure 5.]

Station name	Annual mean	Years of record	Annual minimum Volume	Annual minimum Year	Annual maximum Volume	Annual maximum Year	Exceedance percentile† 10%	25%	50% (median)	75%	90%
Central Park*	45.98	50	29.19	1965	71.15	1984	59.69	52.21	44.98	38.20	33.92
Bensonhurst	44.55	48	30.48	1965	66.01	1984	55.18	50.43	43.57	37.87	34.74
La Guardia Airport	43.14	50	25.55	1965	60.78	1984	56.79	47.60	44.33	36.85	31.92
Mineola	44.67	50	25.82	1965	70.33	1984	56.31	50.04	42.95	38.22	35.53
Setauket	44.93	50	30.19	1995	63.00	1984	53.72	48.71	46.14	38.66	36.27
Upton	48.85	50	35.59	1995	68.79	1989	59.99	55.11	47.71	43.11	37.59
Riverhead	46.01	50	30.99	1966	65.16	1984	58.11	50.24	46.50	40.11	35.87
Bridgehampton	47.05	50	30.76	1966	64.04	1958	60.36	52.33	46.84	39.86	36.42

† Percentage of time during which the given amount is exceeded.
* Proximity to Long Island makes this station representative of conditions on western Long Island.

Table 3B. Monthly minimum and maximum precipitation volume, and means for driest and wettest months, at the eight selected precipitation-monitoring stations on or near Long Island, N.Y., 1951-2000.

[Amounts are in inches. Locations are shown in figure 5.]

Station name	Monthly minimum Volume	Monthly minimum Month	Monthly minimum Year	Monthly maximum Volume	Monthly maximum Month	Monthly maximum Year	Driest monthly mean Volume	Driest monthly mean Month	Wettest monthly mean Volume	Wettest monthly mean Month
Central Park	0.14	Oct.	1963	14.01	Apr.	1983	3.12	Feb.	4.22	Mar.
Bensonhurst	.20	Dec.	1955	11.12	Aug.	1971	3.09	Feb.	4.52	July
La Guardia Airport	.06	Oct.	1963	16.05	Aug.	1955	2.94	Feb.	4.21	Aug.
Mineola	.11	Oct.	1963	15.60	Aug.	1955	3.18	Feb.	4.31	Mar.
Setauket	.26	Oct.	1963	12.56	June	1972	3.15	Feb.	4.13	Mar.
Upton	.18	Oct.	1963	13.01	Jan.	1979	3.30	July	4.83	Mar.
Riverhead	.19	June	1994	12.42	Aug.	1954	3.25	July	4.30	Nov.
Bridgehampton	.11	Oct.	1963	14.58	June	1982	3.00	July	4.63	Mar.

Mean annual precipitation ranges from 43.14 in. (LaGuardia Airport) to 48.85 in. (Upton); the average for all eight stations was 45.52 in. This value is close to the combined Long Island long-term precipitation average of 44 in/yr calculated by Cohen and others (1968). Mean monthly precipitation values for all stations are fairly uniform, although the wettest and driest months are variable throughout the island. Data from all eight stations indicate conditions that are representative of Long Island and are to be included in the composite-average precipitation index (described later in the report).

Stream Discharge

Most streams on Long Island are broad and shallow and have gentle gradients that average about 10 ft/mi (Cohen and

Table 3C. Notable short- and long-term trends in precipitation at the eight selected precipitation-monitoring stations on or near Long Island, N.Y., 1951-2000.

[Values are in inches. no., number; --, not applicable. Locations are shown in figure 5.]

	Period of record			Relation to mean		Cumulative value	
Station	Long or short term	Period	No. of years	1951-2000 mean	Above or below	Surplus (inches)	Deficit (inches)
Central Park	Short term	1953-59	7	45.98	below	--	54.60
		1961-66	6		below	--	68.53
		1971-75	5		above	58.81	--
		1980-82	3		below	--	11.16
		1989-91	3		above	38.51	--
		1996-98	3		above	21.23	--
	Long term	1951-70	20		below	--	128.09
Bensonhurst	Short term	1962-66	5	44.55	below	--	41.10
		1971-75	5		above	38.77	--
		1980-82	3		below	--	19.52
		1989-91	3		above	20.80	--
		1996-98	3		above	20.20	--
	Long term	1962-70	9		below	--	55.30
La Guardia Airport	Short term	1951-53	3	43.14	above	25.63	--
		1962-68	7		below	--	70.09
		1971-75	5		above	34.46	--
		1980-82	3		below	--	19.86
		1989-91	3		above	20.78	--
		1996-98	3		above	18.17	--
	Long term	1962-70	9		below	--	79.76
Mineola	Short term	1982-84	3	44.67	above	31.73	--
		1989-91	3		above	33.27	--
		1992-95	4		below	--	23.71
		1996-98	3		above	14.80	--
	Long term	1962-72	10		below	--	85.53
Setauket	Short term	1958-60	3	44.93	above	17.22	--
		1961-66	6		below	--	44.48
		1972-76	5		above	22.85	--
		1982-84	3		above	25.45	--
		1989-91	3		above	19.50	--
	Long term	1961-68	8		below	--	50.88
		1972-79	8		above	41.57	--
Upton	Short term	1962-66	5	48.85	below	--	32.19
		1982-84	3		above	27.49	--
		1985-88	4		below	--	38.16
		1989-91	3		above	26.98	--
		1992-95	4		below	--	30.61
	Long term	1972-79	8		above	25.10	--
Riverhead	Short term	1958-61	4	46.01	above	20.90	--
		1962-66	5		below	--	37.96
		1982-84	3		above	28.37	--
		1989-91	3		above	25.30	--
		1996-98	3		above	19.42	--
	Long term	1962-71	10		below	--	60.19
		1972-79	8		above	29.98	--
Bridgehampton	Short term	1952-55	3	47.05	above	26.65	--
		1958-61	4		above	25.74	--
		1982-84	3		above	20.42	--
		1989-91	3		above	24.65	--
		1996-98	3		above	38.63	--
	Long term	1952-61	10		above	35.37	--
		1962-71	10		below	--	67.43

others, 1968). The streambeds consist mainly of sand and gravel and are highly permeable; thus, Long Island's streams are in direct hydraulic contact with the upper glacial aquifer. Under natural (undeveloped) conditions, 95 percent of the total stream discharge originates as ground-water seepage (Franke and McClymonds, 1972); the remaining 5 percent consists of direct runoff. Accordingly, the flows of Long Island's streams closely reflect changes in the water-table altitude.

Discharge data have been collected continuously since the early 1930's at most of Nassau County's major streams, and since the early 1940's at most of Suffolk County's major streams. Annual and monthly mean discharge data were compiled for the eight streams (fig. 5) that were selected as indicators of ground-water conditions in the underlying ground-water system. Totals for water year 2000 were not computed for most streams in Nassau County because data collection ceased in March or April of that year. The period of record at each station was trimmed to include only the last 50 years of record (1951-2000); this period was selected to include the 1960's drought as well as the 10 years preceding it, for comparative purposes. The 50-year hydrographs and boxplots for each of the eight streams (fig. 11) include the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, and the ARIMA trend line.

The long-term discharge records from each of the eight selected streamflow stations are summarized in table 4 and figure 11. The minimum, mean, and maximum annual discharge for 1951-2000, and the values for selected exceedance percentiles are given in table 4A, and the minimum and maximum monthly discharge, and mean discharge for the lowest and highest months on record are given in table 4B. Notable trends in discharge, and the stations relation to human impact are given in table 4C. The stations are presented in west-to-east geographical order.

In summary, discharge records for all eight streams indicate the effects of the 1960's drought; the monthly mean discharges were well below average from the early 1960's through the early 1970's (fig. 11). Precipitation returned to near normal by the late 1960's, but stream discharge did not return to normal until the early 1970's because ground-water levels were well below normal and did not recover until the wet period in the early 1970's.

Stream discharge in western parts of Long Island, particularly Valley Stream, East Meadow Brook, and Massapequa Creek, has never returned to pre-drought levels as a result of regional water-level declines from sanitary- and storm-sewer systems in Nassau and western Suffolk Counties. Stream discharge in central and eastern parts of Long Island returned to near or slightly above normal conditions after the drought.

Table 4A. Annual minimum, mean, and maximum discharge, and selected exceedance percentiles at the eight selected streamflow-gaging (discharge) stations on Long Island, N.Y., 1951-2000 or period of record.

[Discharge values are in cubic feet per second (ft^3/s). mi^2, square miles; %, percent. Locations are shown in figure 5.]

Station name	Station number	Drainage area (mi^2)	Annual mean	Years of record	Lowest annual mean		Highest annual mean		Exceedance percentile*				
					Value	Year	Value	Year	10%	25%	50% (median)	75%	90%
Valley Stream at Valley Stream	01311500	4.5	1.96	46	0.11	1986	8.86	1956	5.35	1.82	1.22	0.58	0.39
East Meadow Brook at Freeport	01310500	31	11.6	49	2.08	1995	23.3	1961	20.7	15.5	10.4	5.97	3.67
Mill Neck Creek at Mill Neck	01303000	11.5	8.81	49	5.59	1966	12.1	1984	10.7	10.1	8.49	7.48	6.79
Massapequa Creek at Massapequa	01309500	38	9.62	49	2.27	1995	19.4	1973	16.8	13.2	8.71	5.91	3.78
Connetquot River near Oakdale	01306500	24	38.6	50	24.9	1966	52.5	1984	48.5	42.2	38.2	34.2	30.0
Nissequogue River near Smithtown	01304000	27	43.3	50	27.0	1966	58.9	1991	52.3	47.0	43.9	38.0	34.8
Carmans River Yaphank	01305000	71	24.4	50	12.9	1967	37.7	1979	32.5	28.6	24.3	20.2	17.0
Peconic River at Riverhead	01304500	75	38.3	50	16.1	1966	67.9	1984	55.5	43.5	36.1	29.2	23.1

* Percentage of time during which the given amount is exceeded.

Table 4B. Monthly minimum and maximum mean discharge, and means for lowest and highest months, at the eight selected streamflow-gaging (discharge) stations on Long Island, N.Y., 1951-2000 or period of record.

[Discharge values are in cubic feet per second (ft^3/s). Locations are shown in figure 5.]

Station name	Station number	Monthly minimum			Monthly maximum			Lowest monthly mean		Highest monthly mean	
		Value	Month	Year	Value	Month	Year	Value	Month	Value	Month
Valley Stream at Valley Stream	01311500	0.00	multiple times		16.8	Aug.	1955	1.50	Sep.	2.84	Apr.
East Meadow Brook at Freeport	01310500	0.03	Aug.	1995	39.7	Aug.	1955	8.71	Sep.	16.1	Apr.
Mill Neck Creek at Mill Neck	01303000	4.10	July	1966†	17.9	July	1984	8.14	Sep.	9.76	Mar.
Massapequa Creek at Massapequa	01309500	0.59	Aug.	1995	33.4	Apr.	1953	6.68	Sep.	14.0	Apr.
Connetquot River near Oakdale	01306500	17.3*	Nov.	1982	70.4	June	1998	33.0	Sep.	45.1	Apr.
Nissequogue River near Smithtown	01304000	22.1	Aug.	1966	76.1	Oct.	1990	38.8	Sep.	49.4	Apr.
Carmans River at Yaphank	01305000	9.35†	Jan.	1967	49.2	June	1984	22.1	Oct.	27.6	Apr.
Peconic River at Riverhead	01304500	10.8	Aug.	1966	109	Mar.	1979	26.9	Sep.	53.2	Apr.

* Result of regulation.
† Result of temporary construction upstream.

Ground-Water Levels

Ground-water levels on most of Long Island are generally highest in March, April, or May and lowest in September, October, or November. This pattern can be attributed largely to seasonal variations in natural recharge and partly to seasonal pumping patterns. This pattern is no longer evident in western parts of Long Island, however, where large-scale ground-water pumping and the loss of recharge (through sanitary- and storm-sewer systems) have caused large declines in ground-water levels.

Ground-water-level data have been collected continuously since the early 1900's at many wells on Long Island. Water-level data from the 15 upper glacial aquifer wells and the 5 Magothy aquifer wells that were selected as drought-monitoring sites (fig. 5) were compiled. All of the selected water-table wells are screened in the upper glacial aquifer except well N1616, which is screened in the upper part of the Magothy aquifer. Magothy wells are screened in the middle or bottom part of the aquifer. Like the stream-discharge records, the period of record for each site was trimmed to include only the last 50 years of record (1951-2000), to include the 1960's drought as well as the 10-year period preceding the drought, for comparative purposes. For wells with less than 50 years of record, the entire period of record was used in the analysis. The 50-year hydrographs and boxplots for each of the 20 wells (fig. 12) include the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, and the ARIMA trend line.

The long-term water-level records from each of the 20 selected wells are summarized in table 5 and figure 12. The mean water levels for 1951-2000, values for selected exceedance percentiles, and the screen zone depths are given in table 5A, and the minimum and maximum water levels, and mean water levels for the lowest and highest months on record are given in table 5B. Notable trends in water level, and the wells relation to human impact are given in table 5C. The wells are presented in west-to-east geographical order.

In summary, water levels at most wells, excluding those in the westernmost part of Long Island, indicate the effects of the 1960's drought and were well below average from the early 1960's through the early 1970's (fig. 12). Precipitation had returned to near normal by the late 1960's, but water levels remained below average until the early 1970's, when a period of above-normal precipitation occurred.

Water levels on western Long Island show the effect of extensive urbanization; those farther east reflect the eastward decrease in human activity. Water levels at wells K1194, Q1249, and N7493, in western Long Island (fig. 5), generally do not show the declines associated with the 1960's drought because they were already well below normal as a result of heavy pumping and sewering. Water levels in other western

Table 4C. Notable trends in discharge at the eight selected streamflow-gaging (discharge) stations on Long Island, N.Y., 1951-2000 or period of record.

[Discharge values are in cubic feet per second (ft^3/s). mi^2, square miles; %, percent; ARIMA, autoregressive integrated moving average. Locations are shown in figure 5.]

Significant period of below normal annual discharge in relation to annual mean				ARIMA trend at or below monthly exceedance percentiles (part or all of each year)		
Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
Valley Stream at Valley Stream (01311500). Drainage area 4.5 mi^2. Significant-human-impact zone. Not useful for drought monitoring.						
Long-term (46-year) annual mean discharge (1955-2000) 1.96 ft^3/s*; minimum annual mean discharge 0.11* ft^3/s*, 1986; maximum annual mean discharge 8.87* ft^3/s*, 1956.*						
1963-72 1980-83 1985-88	-1.82 -1.85 -1.85	1965 1981 1986	Decreased from well above normal to below normal, 1955-65; increased to normal, 1966-68; remained near normal, 1969-80; decreased to below normal, 1980-81; increased to normal, 1982-84; decreased to below normal, 1985-86; increased to normal, 1987-90; remained near normal, 1991-95; increased to above normal, 1996-97; decreased to normal, 1998-2000.	1964-67, 1971, 1980-83, and 1986-88.	1965, and 1987-88.	• Data missing from 1951 to 1955. • Decline from 1955 to 1960 attributed to increased pumping and sewering in eastern Queens County and western Nassau County; sharp decline from 1961 to 1965 attributed to effects of 1960's drought; slight rise since mid-1980's attributed to decreased pumping in eastern Queens County. • Discharge never returned to pre-drought levels; attributed to effects of increased pumping and sewering. • Long-term averages and exceedance values strongly skewed; effects of pumping and urbanization mask fluctuations associated with precipitation; not useful as a drought-monitoring site; useful for monitoring human-induced changes.
East Meadow Brook at Freeport (01310500). Drainage area 31 mi^2. Moderate-human-impact zone. Not useful for drought monitoring.						
Long-term (49-year) annual mean discharge (1951-1999) 11.6 ft^3/s*; minimum annual mean discharge 2.08* ft^3/s*, 1995; maximum annual mean discharge 23.3* ft^3/s*, 1961.*						
1964-68 1970-72 1981-83 1985-89 1991-99	-9.08 -5.70 -5.88 -8.30 -9.53	1966 1971 1981 1988 1995	Increased from normal to above normal, 1951-52; remained above normal, 1953-61; decreased to well below normal, 1962-64; increased to above normal, 1965-78; decreased to normal, 1979-82; remained in normal range, 1983-84; decreased to below normal, 1985-87; increased to normal, 1988-90; decreased to well below normal, 1991-95; increased to normal, 1996-97; decreased to below normal, 1998-1999.	1965-67, 1971, 1982, 1986-88, 1992-99.	1966, 1987-88, and 1994-96.	• Data missing for 2000. • Sharp decline from 1961 to 1964 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in Nassau County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.
Mill Neck Creek at Mill Neck (01303000). Drainage area 11.5 mi^2. Moderate-human-impact zone. Not useful for drought monitoring.						
Long-term (49-year) annual mean discharge (1951-1999) 8.81 ft^3/s*; minimum annual mean discharge 5.59* ft^3/s*, 1966; maximum annual mean discharge 12.1* ft^3/s*, 1984.*						
1963-72 1981-83 1986-89 1992-97	-3.21 -1.72 -1.72 -2.01	1966 1982 1988 1995	Increased from normal to above normal, 1951-52; remained above normal, 1953-61; decreased to well below normal, 1962-66; increased to well above normal, 1967-78; decreased to below normal, 1979-81; increased to above normal, 1982-84; decreased to below normal, 1985-88; increased to normal, 1989-90; decreased to below normal, 1991-95; increased to normal, 1996-99.	1964-72, 1982, 1987-88, 1993-97.	1965-71, and 1982.	• Data missing for 2000. • Sharp decline from 1961 to 1966 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in Nassau County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Table 4C. (Continued) Notable trends in discharge at the eight selected streamflow-gaging (discharge) stations on Long Island, N.Y., 1951-2000 or period of record.

Significant periods of below normal annual discharge in relation to annual mean				ARIMA trend at or below monthly exceedance percentiles (part or all of each year)		
Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
Massapequa Creek at Massapequa (01309500). Drainage area 38 mi². Moderate-human-impact zone. Not useful for drought monitoring.						
Long-term (49-year) annual mean discharge (1951-1999) 9.62 ft³/s*; minimum annual mean discharge 2.27* ft³/s*, 1995; maximum annual mean discharge 19.4* ft³/s*, 1973.*						
1964-72 1981-83 1985-89 1991-99	-6.41 -3.22 -6.13 -7.35	1966 1981 1986 1995	Increased from normal to above normal, 1951-52; remained above normal, 1953-61; decreased to below normal, 1962-66; increased to above normal, 1967-72; decreased to normal, 1973-76; increased to well above normal, 1977-78; decreased to normal, 1979-81; increased to above normal, 1982-83; decreased to below normal, 1984-86; increased to normal, 1987-90; decreased to well below normal, 1991-95; increased to normal, 1996-99.	1965-69, 1971, 1982, 1986-89, 1992-99.	1966, 1986-88, and 1993-97.	• Data missing for 2000. • Sharp decline from 1961 to 1966 attributed to effects of 1960s drought; gradual decline since late-1970s attributed to increased pumping and sewering in eastern Nassau County and western Suffolk County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.
Connetquot River near Oakdale (01306500). Drainage area 24 mi². Low-human-impact zone. Useful for drought monitoring.						
Long-term (50-year) annual mean discharge (1951-2000) 38.6 ft³/s*; minimum annual mean discharge 24.9* ft³/s*, 1966; maximum annual mean discharge 52.5* ft³/s*, 1984.*						
1963-72 1981-83 1985-88 1992-96	-13.68 -8.33 -11.45 -9.19	1966 1981 1988 1995	Increased from normal to above normal, 1951-55; decreased to normal, 1956-62; decreased to well below normal, 1963-66; increased to normal, 1967-72; remained in normal range, 1973-76; increased to above normal, 1977-78; decreased to below normal, 1979-81; increased to above normal, 1982-83; decreased to below normal, 1984-87; increased to well above normal, 1988-90; decreased to below normal, 1991-95; increased to normal, 1996-2000.	1951, 1963-72, 1981-82, 1986-88, 1994-96, and 2000.	1965-71, 1982, 1986-88, and 1995.	• Sharp decline from 1962 to 1967 attributed to effects of 1960s drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.
Nissequogue River near Smithtown (01304000). Drainage area 27 mi². Low-human-impact zone. Useful for drought monitoring.						
Long-term (50-year) annual mean discharge (1951-2000) 43.3 ft³/s*; minimum annual mean discharge 27.0* ft³/s*, 1966; maximum annual mean discharge 58.9* ft³/s*, 1991.*						
1951-52 1963-72 1981-82 1986-88 1994-96	-7.42 -16.25 -7.57 -7.02 -8.43	1951 1966 1981 1988 1995	Increased from below normal to above normal, 1951-55; decreased to normal, 1956-62; decreased to well below normal, 1963-66; increased to normal, 1967-72; remained in normal range, 1973-76; increased to above normal, 1977-78; decreased to normal, 1979-81; increased to above normal, 1982-83; decreased to normal, 1984-87; increased to well above normal, 1988-90; decreased to below normal, 1991-95; increased to above normal, 1996-97; decreased to normal, 1998-2000.	1951-52, 1963-72, 1981-82, 1986-88, 1994-96, and 2000.	1951, 1964-72, 1982, 1987-88, and 1995.	• Sharp decline from 1962 to 1967 attributed to effects of 1960s drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Table 4C. (Continued) Notable trends in discharge at the eight selected streamflow-gaging (discharge) stations on Long Island, N.Y., 1951-2000 or period of record.

Significant periods of below normal annual discharge in relation to annual mean				ARIMA trend at or below monthly exceedance percentiles (part or all of each year)		
Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
Carmans River at Yaphank (01305000). Drainage area 71 mi^2. Low-human-impact zone. Useful for drought monitoring.						
Long-term (50-year) annual mean discharge (1951-2000) 24.4 ft^3/s*; minimum annual mean discharge 12.9* ft^3/s, *1967; maximum annual mean discharge 37.7* ft^3/s, *1979.*						
1951-52 1964-72 1981-82 1986-89 1992-96	-6.23 -11.48 -4.23 -7.30 -8.22	1951 1967 1981 1988 1995	Increased from below normal to above normal, 1951-55; decreased to normal, 1956-62; decreased to well below normal, 1963-66; increased to above normal, 1967-73; decreased to normal, 1974-76; increased to well above normal, 1977-78; decreased to normal, 1979-81; increased to well above normal, 1982-83; decreased to below normal, 1984-87; increased to above normal, 1988-90; decreased to below normal, 1991-95; increased to normal, 1996-2000.	1951, 1965-72, 1981-82, 1987-88, and 1994-96.	1965-71, 1988, and 1995-96.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.
Peconic River at Riverhead (01304500). Drainage area 75 mi^2. Low-human-impact zone. Useful for drought monitoring.						
Long-term (50-year) annual mean discharge (1951-2000) 38.3 ft^3/s*; minimum annual mean discharge 16.1* ft^3/s, *1966; maximum annual mean discharge 67.9* ft^3/s, *1984.*						
1951 1963-72 1981-82 1985-88 1992-96	-15.15 -22.16 -16.71 -15.58 -16.80	1951 1966 1981 1986 1995	Increased from below normal to above normal, 1951-58; decreased to normal, 1959-62; decreased to well below normal, 1963-66; increased to above normal, 1967-72; decreased to normal, 1973-76; increased to well above normal, 1977-78; decreased to normal, 1979-81; increased to above normal, 1982-83; decreased to below normal, 1984-87; increased to normal, 1988-90; decreased to below normal, 1991-95; increased to normal, 1996-2000.	1951-52, 1963-71, 1981-82, 1986-88, 1992-96, and 2000.	1951, 1964-69, 1971, 1981, 1986-88, and 1995.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

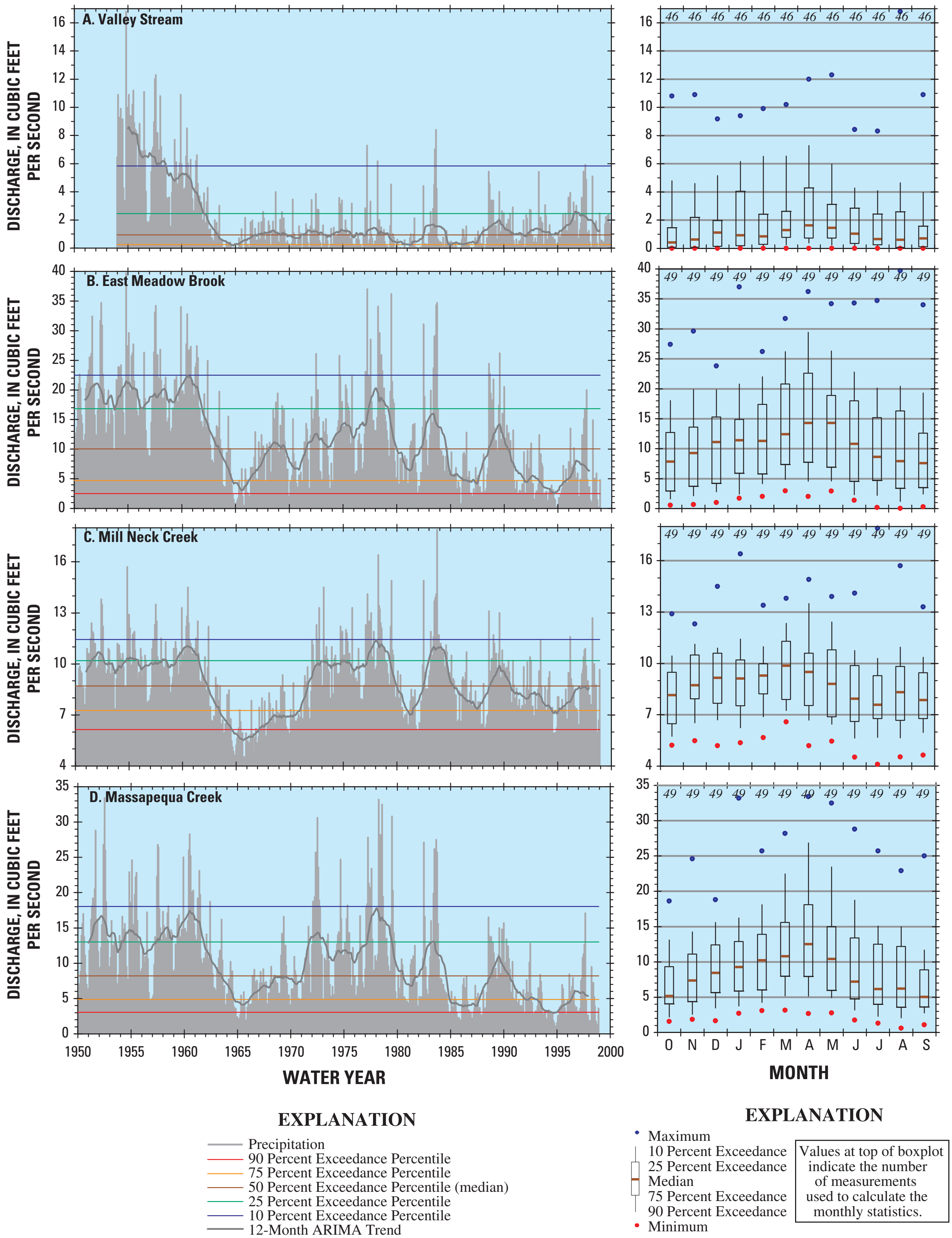


Figure 11. Monthly mean discharge and exceedance statistics for eight selected streamflow-gaging stations on Long Island, N.Y., 1951-2000 or period of record. (Station locations are shown in figure 5.)

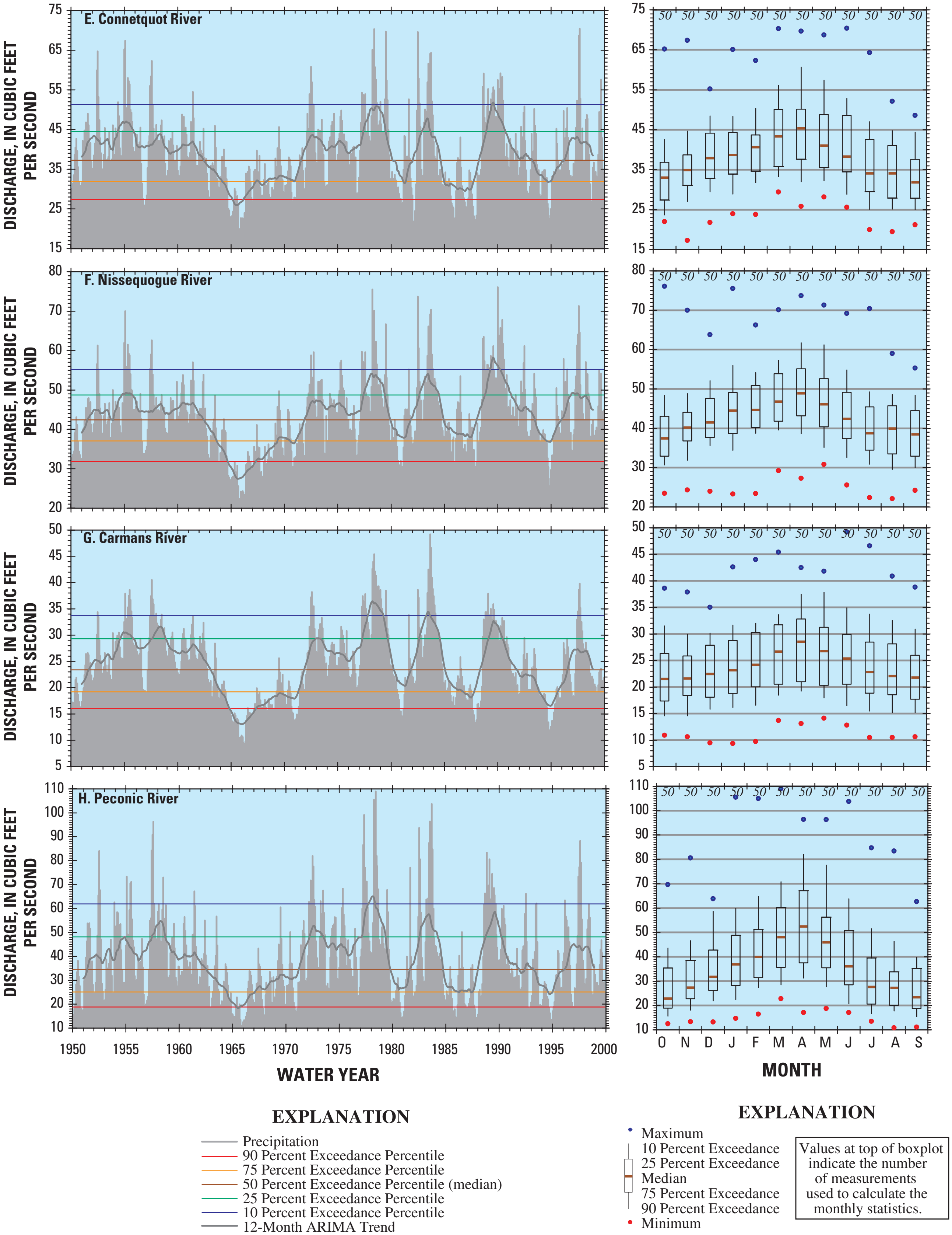


Figure 11. (Continued) Monthly mean discharge and exceedance statistics for eight selected streamflow-gaging stations on Long Island, N.Y., 1951-2000 or period of record. (Station locations are shown in figure 5.)

Table 5A. Annual mean ground-water levels, selected exceedance percentiles, and screen depths, at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

[Values are in feet above (+) or below (-) NGVD 29; %, percent. Locations are shown in figure 5.]

Well number	Station number	Aquifer	Screen zone (feet below land surface)	Annual mean	Start of period of record	Number of values used for statistics	Exceedance percentile* 10%	25%	50% (median)	75%	90%
K1194	404059073520702	Upper glacial	52-55	5.75	1951	264	10.39	10.04	8.93	0.46	-0.27
Q1249	404240073443401	Upper glacial	85-88	18.96	1951	192	27.92	25.44	20.16	17.55	3.65
N7493	404237073433701	Magothy (deep)	349-353	13.76	1968	348	24.29	22.74	11.09	7.55	6.09
N1614	404446073392904	Upper glacial	50-53	57.06	1951	580	67.33	61.48	55.22	52.19	50.38
N1616	404554073351502	Magothy (shallow)	65-68	75.79	1951	592	82.14	80.22	75.71	71.25	69.26
N2528	405101073343401	Magothy (middle)	278-282	67.54	1953	400	71.81	70.53	68.05	65.21	61.78
N1259	404317073291105	Upper glacial	38-41	50.40	1951	587	54.60	53.18	50.77	48.06	45.58
S1806	404442073240503	Upper glacial	41-45	54.45	1951	582	57.93	56.59	54.76	52.30	50.37
S15622	405250073180801	Magothy (middle)	437-457	40.83	1969	196	43.92	42.64	40.75	39.20	37.59
S1810	404614073164404	Upper glacial	52-55	50.46	1951	578	53.93	52.27	50.63	48.71	47.03
S1812	404958073085001	Upper glacial	46-50	46.27	1951	463	48.95	47.84	46.51	44.70	43.38
S33380	404932073055902	Magothy (deep)	840-850	49.06	1968	347	51.94	50.66	49.01	47.34	46.09
S3513	405146073031801	Upper glacial	63-65	63.88	1951	536	66.92	65.72	64.52	62.42	59.62
S5517	405149072532201	Upper glacial	85-91	40.90	1951	543	44.42	43.08	41.20	39.04	36.87
S6455	405223072523402	Magothy (deep)	952-962	38.18	1951	411	40.44	39.35	38.13	37.02	36.14
S4271	405743072425701	Upper glacial	100-105	10.89	1951	561	12.31	11.61	10.90	9.98	9.55
S3543	405037072390301	Upper glacial	56-58	18.24	1951	520	20.37	19.18	18.22	17.11	16.10
S16783	410634072223601	Upper glacial	20-24	2.06	1958	349	2.85	2.35	1.99	1.67	1.41
S8833	405756072173501	Upper glacial	10-13	16.08	1951	280	17.98	17.26	16.17	14.90	14.09
S48579	410316071535501	Upper glacial	53-56	3.31	1974	213	3.80	3.51	3.31	3.06	2.89

* Percentage of time during which the given amount is exceeded.

parts of Long Island, particularly at wells N1614 and N1616 (fig. 5), have never returned to pre-drought levels; a result of regional water-level declines caused by increased pumpage and the completion of sanitary- and storm-sewer systems in Nassau and western Suffolk Counties. Water levels in central parts of Long Island returned to near normal after the drought, but have been generally declining since the mid- to late 1980's as a result of increased pumpage and the effects of sanitary- and storm-sewer systems. Only in eastern parts of Long Island do water levels still generally reflect natural conditions, although the effects of human activity are becoming discernible in the record.

Selection of Drought-Monitoring Sites

Analysis of long-term hydrologic records on Long Island indicates that the data available provide a sufficient basis for development of a drought-monitoring network. Data from the 8 precipitation-monitoring stations, 8 streamflow-gaging (discharge) stations, 15 monitoring wells screened in the upper glacial aquifer, and 5 monitoring wells screened in the underlying Magothy aquifer selected as possible drought-monitoring sites reflect the wide variation in hydrologic conditions across Long Island.

Table 5B. Monthly minimum and maximum ground-water levels, and means for lowest and highest months, at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

[Values are in feet above (+) or below (-) NGVD 29. Locations are shown in figure 5.]

Well number	Station number	Minimum			Maximum			Lowest monthly mean		Highest monthly mean	
		Value	Month	Year	Value	Month	Year	Value	Month	Value	Month
K1194	404059073520702	-1.88	Oct.	1966	11.30	Mar.	1995	3.55	Oct.	6.70	Aug.
Q1249	404240073443401	-5.66	Mar.	1982	29.56	May	1953	11.14	Mar.	22.41	Dec.
N7493	404237073433701	3.73	Sep.	1982	27.82	June	1997	13.00	Oct.	14.56	June
N1614	404446073392904	48.42	Dec.	1970	72.26	May	1953	56.36	Dec.	57.59	May
N1616	404554073351502	66.82	Jan.	1996	84.94	June	1953	75.41	Dec.	76.27	June
N2528	405101073343401	59.12	Feb.	1967	73.59	Sep.	1984	66.55	Jan.	68.47	June
N1259	404317073291105	41.64	Oct.	1995	57.60	Feb.	1978	49.67	Nov.	51.24	Apr.
S1806	404442073240503	46.97	Jan.	1967	62.37	June	1984	53.54	Dec.	55.54	May
S15622	405250073180801	34.33	Apr.	1969	47.09	Jan.	1980	40.18	Feb.	41.37	Jan.
S1810	404614073164404	43.30	Feb.	1967	56.28	July	1984	49.75	Dec.	51.28	May
S1812	404958073085001	40.09	Feb.	1967	51.97	Mar.	1979	45.60	Jan.	47.09	Apr.
S33380	404932073055902	43.90	Aug.	1995	54.30	Apr.	1979	48.76	Dec.	49.51	May
S3513	405146073031801	56.06	Mar.	1967	69.91	May	1979	63.27	Dec.	64.41	July
S5517	405149072532201	33.34	Mar.	1967	47.43	July	1998	39.97	Dec.	41.72	June
S6455	405223072523402	33.82	Dec.	1966	42.50	Apr.	1979	37.54	Nov.	38.83	June
S4271	405743072425701	8.20	Aug.	1966	14.24	Aug.	1984	10.74	Aug.	11.24	May
S3543	405037072390301	14.94	Nov.	1986	22.53	July	1984	17.66	Jan.	18.86	June
S16783	410634072223601	0.89	July	1964	4.11	Mar.	1998	1.71	Aug.	2.55	Mar.
S8833	405756072173501	12.84	Mar.	1982	19.31	June	1998	14.68	Nov.	16.84	June
S48579	410316071535501	2.46	Dec.	1976	4.30	May	1998	3.06	Nov.	3.58	May

As discussed previously, a map showing three degrees of human impact on water levels (significant, moderate, and low) was created to qualify the changes in the ground-water system underlying Long Island (fig. 7C). These zones reflect the extent to which ground-water levels have been affected by increased urbanization.

The hydrologic data were used to calculate 50-year composite annual and monthly averages for six indices—an islandwide precipitation index representing the eight stations; two stream-discharge indices, one representing a moderate-human-impact zone (three streams) and one representing a low-human-impact zone (four streams); and three water-level indices, one representing a significant-human-impact zone (three wells), one representing a moderate-human-impact zone (six wells), and one representing a low-human-impact zone (nine wells). These composites were created to simplify comparison among data sets, to minimize the effects of local fluctuations in the record, and to present the relative condition of Long Island's water-level conditions in an easy-to-view format. The following section discusses each of these indices.

Precipitation

The long-term precipitation records from the eight selected precipitation stations on or near Long Island (fig. 5) indicate a general similarity among stations, although some in the western part of the island show more variability in the record than the eastern part. A 50-year composite-average hydrograph and boxplot of monthly precipitation for the eight selected stations are shown in figure 13. Data for each month's composite average was calculated only for months in which

Table 5C. Notable trends in ground-water levels at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.
[Values are in feet above (+) or below (-) NGVD 29. ft, feet; %, percent; ARIMA, autoregressive integrated moving average. Locations are shown in figure 5.]

Significant periods of below normal water level in relation to annual mean				ARIMA trend at or below monthly exceedance percentiles (part or all of each year)		
Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	
Well K1194 (404059073520702). Screened 52-55 ft below land surface in the upper glacial aquifer. Significant-human-impact zone. Not useful for drought monitoring.						
Long-term (50-year) mean water level (1951-2000) +5.75 ft; minimum water level -1.88 ft, October 1966; maximum water level +11.30 ft, March 1995.						
1951-73	-7.63	1966	Increased about 2 ft from well below normal to below normal, 1951-55; remained below normal, 1956-64; increased about 9 ft to normal, 1965-79; remained near normal, 1980-88; increased about 1 ft to above normal, 1989-90; remained above normal, 1990-2000.	1951-57 and 1959-62.	1951-1952.	• ARIMA trend and exceedance values skewed by sparse data from 1957 to 1988. • Sharp rise from the mid-1960's to late-1970's attributed to cessation of pumping in western Queens County. • Long-term averages and exceedance values strongly skewed; effects of pumping and urbanization mask fluctuations associated with precipitation; not useful as a drought-monitoring site; useful for monitoring human-induced changes.
Well Q1249 (404240073443401). Screened 85-88 ft below land surface in the upper glacial aquifer. Significant-human-impact zone. Not useful for drought monitoring.						
Long-term (50-year) mean water level (1951-2000) +18.96 ft; minimum water level -5.66 ft, March 1982; maximum water level +29.56 ft, May 1953.						
1960-90	-24.62	1982	Well above normal, 1951-52; decreased about 8 ft to normal, 1953-54; decreased about 15 ft to well below normal, 1955-75; remained well below normal, 1976-79; increased about 2 ft to below normal, 1980-87; increased about 13 ft to normal, 1988-89; remained in normal range; 1990-2000.	1959-61, 1966, 1972, 1985-91, and 1993.	1959, 1961, 1964-66, 1972, and 1985-90.	• ARIMA trend and exceedance values skewed by sparse data from 1954 to 1984. • Sharp decline in mid-1950's attributed to increased pumping in eastern Queens County; gradual decline in late-1950's to mid-1970's attributed to increased pumping and the effects of the 1960's drought; sharp rise since early-1980's attributed to decreased pumping in eastern Queens County. • Long-term averages and exceedance values strongly skewed; effects of pumping and urbanization mask fluctuations associated with precipitation; not useful as a drought-monitoring site; useful for monitoring human-induced changes.
Well N7493 (404237073433701). Screened 349-353 ft below land surface in the deep part of the Magothy aquifer. Significant-human-impact zone. Not useful for drought monitoring.						
Long-term (33-year) mean water level (1968-2000) +13.76 ft; minimum water level +3.73 ft, September 1982; maximum water level +27.82 ft, June 1997.						
1968-83	-10.03	1982	Decreased about 6 ft from normal to well below normal, 1968-82; increased about 19 ft to above normal, 1983-91; remained above normal, 1992-93; increased about 3 ft to well above normal, 1994-98; decreased about 2 ft to above normal, 1999-2000.	1972-83.	1981-83	• Data missing from 1951 to 1967. • Sharp rise since early-1980's attributed to decreased pumping in eastern Queens County. • Long-term averages and exceedance values strongly skewed; effects of pumping and urbanization mask fluctuations associated with precipitation; not useful as a drought-monitoring site; useful for monitoring large human-induced changes.
Well N1614 (404446073392904). Screened 50-53 ft below land surface in the upper glacial aquifer. Moderate-human-impact zone. Not useful for drought monitoring.						
Long-term (50-year) mean water level (1951-2000) +57.06 ft; minimum water level +48.42 ft, December 1970; maximum water level +72.26 ft, May 1953.						
1965-78 1980-84 1985-89 1994-96	-8.64 -7.91 -5.74 -6.39	1971 1983 1989 1996	Well above normal, 1951-53; decreased about 5 ft to above normal, 1954-62; decreased about 11 ft to well below normal, 1963-67; remained well below normal, 1968-71; increased about 7 ft to normal, 1972-79; decreased about 5 ft below normal, 1980-82; remained in normal range, 1983-2000.	1966-74, 1982, and 1987.	1967-72.	• Gradual decline from 1954 to 1962 attributed to increased pumping and sewering in eastern Queens County and western Nassau County; sharp decline from 1963 to 1967 attributed to effects of 1960's drought; slight rise since early-1980's attributed to decreased pumping in eastern Queens County. • Water levels never returned to pre-drought levels; attributed to effects of increased pumping and sewering. • Long-term averages and exceedance values strongly skewed; effects of pumping and urbanization partially mask fluctuations associated with precipitation; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Table 5C. (Continued) Notable trends in ground-water levels at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

Significant periods of below normal water level in relation to annual mean				ARIMA trend at or below monthly exceedance percentiles (part or all of each year)		
Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks

Well N1616 (404554073351502). Screened 65-68 ft below land surface in the shallow part of the Magothy (water-table) aquifer. Moderate-human-impact zone. Not useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +75.79 ft; minimum water level +66.82 ft, January 1996; maximum water level +84.94 ft, June 1953.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1965-73 1981-84 1985-90 1991-2000	-7.51 -3.21 -6.81 -8.97	1967 1983 1989 1996	Increased about 3 ft from above normal to well above normal, 1951-53; decreased about 2 ft to above normal, 1954-62; decreased about 12 ft to well below normal, 1963-67; increased about 11 ft to above normal, 1968-79; decreased about 5 ft to normal, 1980-82; remained near normal, 1983-84; decreased about 5 ft to below normal, 1985-87; increased about 4 ft to normal, 1988-90; decreased about 6 ft to well below normal, 1991-96; remained below normal, 1997-2000.	1966-71, 1987-88, and 1993-2000.	1967-68, 1995-97, and 2000.	• Gradual decline from 1954 to 1962 attributed to increased pumping and sewering in western Nassau County; sharp decline from 1963 to 1967 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in central and eastern Nassau County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Well N2528 (405101073343401). Screened 278-282 ft below land surface in the middle part of the Magothy aquifer. Moderate-human-impact zone. Not useful for drought monitoring.

Long-term (48-year) mean water level (1953-2000) +67.54 ft; minimum water level +59.12 ft, February 1967; maximum water level +73.59 ft, September 1984.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1963-73 1981-83 1986-89 1992-2000	-8.42 -2.34 -3.60 -5.67	1967 1983 1989 1996	Above normal, 1953-62, decreased about 11 ft to well below normal, 1963-67; increased about 11 ft to above normal, 1968-77; decreased about 5 ft to normal, 1978-88; remained near normal, 1989-91; decreased about 4 ft to below normal, 1992-96; remained near normal, 1997-2000.	1964-72 and 1994-2000.	1966-69.	• Data missing from 1951 to 1952. • Sharp decline from 1963 to 1967 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in central and eastern Nassau County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Well N1259 (404317073291105). Screened 38-41 ft below land surface in the upper glacial aquifer. Moderate-human-impact zone. Not useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +50.40 ft; minimum water level +41.64 ft, October 1995; maximum water level +57.60 ft, February 1978.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1964-72 1981-83 1985-89 1991-2000	-4.79 -2.30 -5.99 -8.76	1966 1983 1988 1996	Above normal, 1951-62; decreased about 6 ft to below normal, 1963-67; increased about 7 ft to above normal, 1968-78; decreased about 4 ft to normal, 1979-81; remained near normal, 1982-83; decreased about 5 ft to below normal, 1984-86; increased about 3 ft to normal, 1987-90; decreased about 5 ft to well below normal, 1991-95; increased about 2 ft to below normal, 1996-97; remained below normal, 1998-2000.	1966-68, 1986-89, and 1992-2000.	1987-88 and 1993-2000.	• Sharp decline from 1963 to 1967 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in eastern Nassau County and western Suffolk County. • Long-term averages and exceedance values strongly skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Well S1806 (404442073240503). Screened 41-45 ft below land surface in the upper glacial aquifer. Moderate-human-impact zone. Not useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +54.45 ft; minimum water level +46.97 ft, January 1967; maximum water level +62.37 ft, June 1984.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1963-73 1981-83 1985-89 1992-98 1999-2000	-7.48 -2.14 -3.95 -6.38 -3.33	1967 1983 1989 1995 2000	Increased about 2 ft from normal to above normal, 1951-52; remained above normal, 1953-62; decreased about 8 ft to well below normal, 1963-67; increased about 9 ft to above normal, 1968-78; decreased about 3 ft to normal, 1979-81; increased about 2 ft to above normal, 1982-83; decreased about 5 ft to below normal, 1984-86; increased about 5 ft to above normal, 1987-90; decreased about 6 ft to below normal, 1991-95; increased about 2 ft to normal, 1996-97; remained near normal, 1998-2000.	1964-73, 1987-88, and 1993-2000.	1965-71 and 1995-96.	• Sharp decline from 1963 to 1967 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping and sewering in eastern Nassau County and western Suffolk County. • Long-term averages and exceedance values moderately skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Table 5C. (Continued) Notable trends in ground-water levels at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

Well S15622 (405250073180801). Screened 437-457 ft below land surface in the middle part of the Magothy aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (32-year) mean water level (1969-2000) +40.83 ft; minimum water level +34.33 ft, April 1969; maximum water level +47.09 ft, January 1980.

Significant periods of below normal water level in relation to annual mean: Period	Maximum departure	Year	ARIMA trend in relation to annual mean	ARIMA trend at or below monthly exceedance percentiles (part or all of each year): 75% exceedance	90% exceedance	Remarks
1969-73 1977-78 1980-83 1986-89 1994-98	-6.50 -4.31 -3.35 -4.99 -4.00	1969 1978 1982 1988 1995	Increased about 2 ft from below normal to normal, 1969-81; decreased about 2 ft to below normal, 1982-88; increased about 4 ft to above normal, 1989-91; decreased about 2 ft to normal, 1991-94; remained near normal, 1995-2000.	1969-70, 1972, 1985-89, and 1994-95.	1988.	• Data missing from 1951 to 1968. • ARIMA trend and exceedance values skewed by sparse data from 1969 to 1987. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Well S1810 (404614073164404). Screened 52-55 ft below land surface in the upper glacial aquifer. Moderate-human-impact zone. Not useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +50.46 ft; minimum water level +43.30 ft, February 1967; maximum water level +56.28 ft, July 1984.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1951-52 1962-73 1977-78 1981-83 1985-89 1993-98 1999-2000	-2.91 -7.16 -1.50 -2.31 -3.60 -4.38 -1.94	1951 1967 1977 1982 1988 1996 2000	Increased about 3 ft from normal to above normal, 1951-56; decreased about 1 ft to normal, 1957-61; decreased about 6 ft to well below normal, 1962-66; increased about 8 ft to above normal, 1967-79; decreased about 3 ft to normal, 1980-82; remained in normal range, 1983-84; decreased about 3 ft to below normal, 1984-87; increased about 4 ft to above normal, 1988-90; decreased about 4 ft to below normal, 1991-95; increased about 2 ft to normal, 1996-97; remained near normal, 1998-2000.	1964-72, 1988, and 1994-96.	1965-70.	• Sharp decline from 1962 to 1967 attributed to effects of 1960 s drought; gradual decline since late-1970's attributed to increased pumping and sewering in eastern Nassau County and western Suffolk County. • Long-term averages and exceedance values moderately skewed; precipitation is no longer primary source of variability in record; not useful as a drought-monitoring site; useful for monitoring human-induced changes.

Well S1812 (404958073085001). Screened 46-50 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +46.27 ft; minimum water level +40.09 ft, February 1967; maximum water level +51.97 ft, March 1979.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1951-52 1964-72 1977-78 1981-83 1985-89 1993-96 1997-98 1999-2000	-2.17 -6.18 -1.88 -2.92 -4.04 -5.93 -2.95 -2.40	1951 1967 1977 1981 1989 1995 1998 1999	Increased about 2 ft from normal to above normal, 1951-53; remained above normal, 1954-61; decreased about 6 ft to well below normal, 1962-67; increased about 6 ft to above normal, 1968-79; decreased about 2 ft to normal, 1980-84; decreased about 2 ft to below normal, 1985-87; increased about 4 ft to above normal, 1988-90; decreased about 3 ft to below normal, 1991-95; increased about 2 ft to normal, 1996-2000.	1964-71, 1986-89, 1994-96, and 1998.	1965-70 and 1987-88.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought; very gradual decline since late-1970's attributed to increased pumping and sewering in western Suffolk County. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Well S33380 (404932073055902). Screened 840-850 ft below land surface in the deep part of the Magothy aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (33-year) mean water level (1968-2000) +49.06 ft; minimum water level +43.90 ft, August 1995; maximum water level +54.30 ft, April 1979.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1968-73 1977-78 1981-83 1986-89 1993-98	-3.86 -1.76 -2.42 -3.74 -5.16	1969 1977 1982 1988 1995	Increased about 6 ft from below normal to above normal, 1968-79; decreased about 3 ft to normal, 1980-82; increased about 2 ft to above normal, 1983-84; decreased about 4 ft to below normal, 1985-87; increased about 4 ft to above normal, 1988-91; decreased about 4 ft to below normal, 1992-95; increased about 2 ft to normal, 1996-2000.	1969-71, 1987-88, and 1994-96.	1969-70.	• Data missing from 1951 to 1967. • Very gradual decline since late-1970's attributed to increased pumping in western Suffolk County. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Table 5C. (Continued) Notable trends in ground-water levels at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

Well S3513 (405146073031801). Screened 63-65 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +63.88 ft; minimum water level +56.06 ft, March 1967; maximum water level +69.91 ft, May 1979.

Significant periods of below normal water level in relation to annual mean: Period	Maximum departure	Year	ARIMA trend in relation to annual mean	ARIMA trend at or below monthly exceedance percentiles (part or all of each year): 75% exceedance	90% exceedance	Remarks
1951-53 1964-73 1977-78 1981-83 1986-89 1995-98	-3.76 -7.82 -1.21 -1.81 -3.59 -3.84	1951 1967 1978 1982 1989 1996	Increased about 4 ft from below normal to above normal, 1951-56; remained above normal, 1957-61; decreased about 7 ft to well below normal, 1962-67; increased about 8 ft to well above normal, 1968-79; decreased about 3 ft to normal, 1980-82; increased about 2 ft to above normal, 1983-84; decreased about 3 ft to below normal, 1985-87; increased about 3 ft to above normal, 1988-91; decreased about 2 ft to normal, 1992-95; remained near normal, 1996-2000.	1951-53, 1964-74, 1987-89, and 1995-97.	1966-71.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought; gradual decline since late-1970's attributed to increased pumping in western and central Suffolk County. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Well S5517 (405149072532201). Screened 85-91 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +40.90 ft; minimum water level +33.34 ft, March 1967; maximum water level +47.43 ft, July 1998.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1951-52 1963-73 1975-78 1980-83 1985-89 1991-93 1994-96	-1.27 -7.56 -3.47 -6.10 -4.34 -2.29 -3.31	1951 1967 1977 1982 1989 1992 1996	Increased about 3 ft from normal to above normal, 1951-55; remained above normal, 1956-61; decreased about 9 ft to well below normal, 1962-67; increased about 5 ft to normal, 1968-79; decreased about 3 ft to below normal, 1980-81; increased about 4 ft to normal, 1982-84; decreased about 4 ft to below normal, 1985-87; increased about 4 ft to normal, 1988-91; remained in normal range, 1992-94; increased about 3 ft to above normal, 1995-2000.	1965-73, 1976, 1980-83, and 1986-88.	1966-69.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought; gradual rise since early-1980's attributed to a local decrease in pumping from the upper glacial aquifer. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Well S6455 (405223072523402). Screened 952-962 ft below land surface in the deep part of the Magothy aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +38.18 ft; minimum water level +33.82 ft, December 1966; maximum water level +42.50 ft, April 1979.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1951-52 1957-58 1963-72 1981-82 1986-89 1994-98 1999-2000	-2.31 -1.15 -4.36 -2.42 -2.88 -3.12 -1.25	1951 1958 1967 1982 1989 1996 2000	Increased about 2 ft from normal to above normal, 1951-56; remained above normal, 1957-60; decreased about 4 ft to well below normal, 1961-67; increased about 3 ft to normal, 1968-76; remained in the normal range, 1976-88; increased about 2 ft to above normal, 1989-91; decreased about 2 ft to normal, 1992-94; remained in normal range, 1995-2000.	1951, 1964-71, 1985, 1987-88, 1994, and 1996.	1965-68.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Well S4271 (405743072425701). Screened 100-105 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring.

Long-term (50-year) mean water level (1951-2000) +10.89 ft; minimum water level +8.20 ft, August 1966; maximum water level +14.24 ft, August 1984.

Period	Maximum departure	Year	ARIMA trend in relation to annual mean	75% exceedance	90% exceedance	Remarks
1951-52 1953-54 1957-58 1961-72 1980-83 1985-89 1995-96	-1.68 -1.18 -1.74 -2.69 -2.19 -1.48 -1.58	1951 1954 1957 1966 1981 1986 1995	Increased about 1.5 ft from normal to above normal, 1951-59; decreased about 2.5 ft to well below normal, 1960-66; increased about 2.5 ft to above normal, 1967-74; decreased about 0.5 ft to normal, 1975-76; increased about 0.5 ft to above normal, 1977-78; decreased about 1.5 ft to below normal, 1979-81; increased about 2 ft to above normal, 1982-83; decreased about 2 ft to below normal, 1984-86; increased about 2 ft to above normal, 1987-90; decreased about 0.5 ft to normal, 1991-94; increased about 0.5 ft to above normal, 1995-2000.	1951, 1963-71, 1981-82, and 1987.	1965-68.	• Sharp decline from 1960 to 1966 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.

Table 5C. (Continued) Notable trends in ground-water levels at the 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record.

Significant periods of below normal water level in relation to annual mean: Period	Maximum departure	Year	ARIMA trend in relation to annual mean	ARIMA trend at or below monthly exceedance percentiles (part or all of each year): 75% exceedance	90% exceedance	Remarks
Well S3543 (405037072390301). Screened 56-58 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring. *Long-term (50-year) mean water level (1951-2000) +18.24 ft; minimum water level +14.94 ft, November 1986; maximum water level +22.53 ft, July 1984.*						
1951-52 1957-58 1964-72 1980-82 1985-89 1992-96 1999-2000	-3.06 -1.57 -3.21 -3.19 -3.30 -2.51 -1.27	1951 1957 1967 1982 1987 1996 2000	Increased about 3.5 ft from below normal to above normal, 1951-60; decreased about 3 ft to below normal, 1961-66; increased about 3.5 ft to above normal, 1967-79; decreased about 3 ft to below normal, 1980-81; increased about 2 ft to above normal, 1982-83; decreased about 3 ft to below normal, 1984-87; increased about 3 ft to above normal, 1988-90; decreased about 1.5 ft to normal, 1991-93; remained in normal range, 1994-2000.	1951, 1964-70, 1981-82, 1986-88, 1993-96, and 1999.	1951, 1965-67, and 1986-87.	• Sharp decline from 1962 to 1967 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.
Well S16783 (410634072223601). Screened 20-24 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Not useful for drought monitoring. *Long-term (43-year) mean water level (1958-2000) +2.06 ft; minimum water level +0.89 ft, July 1964; maximum water level +4.11 ft, March 1998.*						
1962-71	-1.17	1964	Decreased about 1 ft from normal to below normal, 1958-65; increased about 1 ft to normal, 1966-71; remained near normal, 1972-84; increased about 0.5 ft to above normal, 1985-2000.	1959-74, 1976-81, 1983-85, and 1987-88.	1959, 1961-70, 1978, and 1984.	• Data missing from 1951 to 1957. • Sharp decline from 1961 to 1964 attributed to effects of 1960's drought; gradual rise since mid-1980 s attributed to a local decrease in pumping from the upper glacial aquifer. • Long-term averages and exceedance values slightly skewed; water levels affected by tidal fluctuations that tend to mask seasonal variations in the record; not useful as a drought-monitoring site.
Well S8833 (405756072173501). Screened 10-13 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Useful for drought monitoring. *Long-term (50-year) mean water level (1951-2000) +16.08 ft; minimum water level +12.84 ft, March 1982; maximum water level +19.31 ft, June 1998.*						
1951-53 1957-58 1963-72 1980-83 1985-89 1992-96 1999-2000	-2.81 -1.55 -3.21 -3.24 -2.56 -2.92 -2.11	1951 1958 1967 1982 1986 1996 2000	Increased about 3 ft from well below normal to normal, 1951-55; remained in normal range, 1956-2000.	1951-52, 1960-61, 1972, 1978-79, 1981-85, 1987, 1992-94, and 1999-2000.	1951.	• ARIMA trend and exceedance values skewed by sparse data from 1953 to 1988; sharp decline (not seen in trend) from 1962 to 1967 attributed to effects of 1960's drought. • Long-term averages and exceedance values slightly skewed; precipitation is primary source of variability in record; useful as a drought-monitoring site.
Well S48579 (410316071535501). Screened 53-56 ft below land surface in the upper glacial aquifer. Low-human-impact zone. Not useful for drought monitoring. *Long-term (27-year) mean water level (1974-2000) +3.31 ft; minimum water level +2.46 ft, December 1976; maximum water level +4.30 ft, May 1998.*						
1980-82	-0.84	1980	Decreased about 0.5 ft from normal to below normal, 1974-80; increased about 0.5 ft to normal, 1981-84; remained near normal, 1985-93; increased about 0.5 ft to above normal, 1994-96; decreased about 0.5 ft to normal, 1997-2000.	1974-84 and 1987.	1980-81.	• Data missing from 1951 to 1973. • Gradual rise since mid-1980's attributed to a local decrease in pumping from the upper glacial aquifer. • Long-term averages and exceedance values slightly skewed; water levels affected by tidal fluctuations that tend to mask seasonal variations in the record; not useful as a drought-monitoring site.

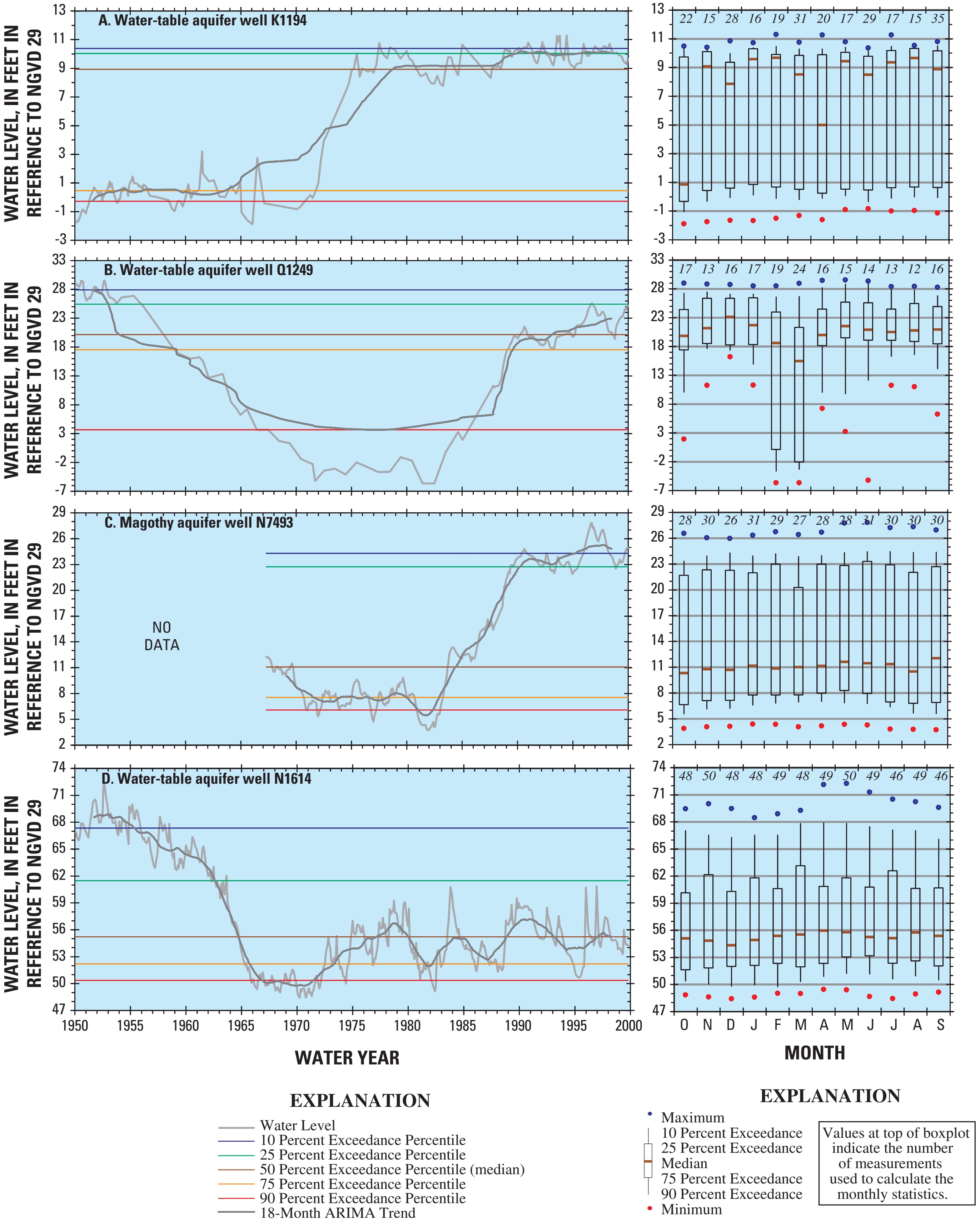


Figure 12. Monthly water levels and exceedance statistics for 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record. (Well locations are shown in figure 5.)

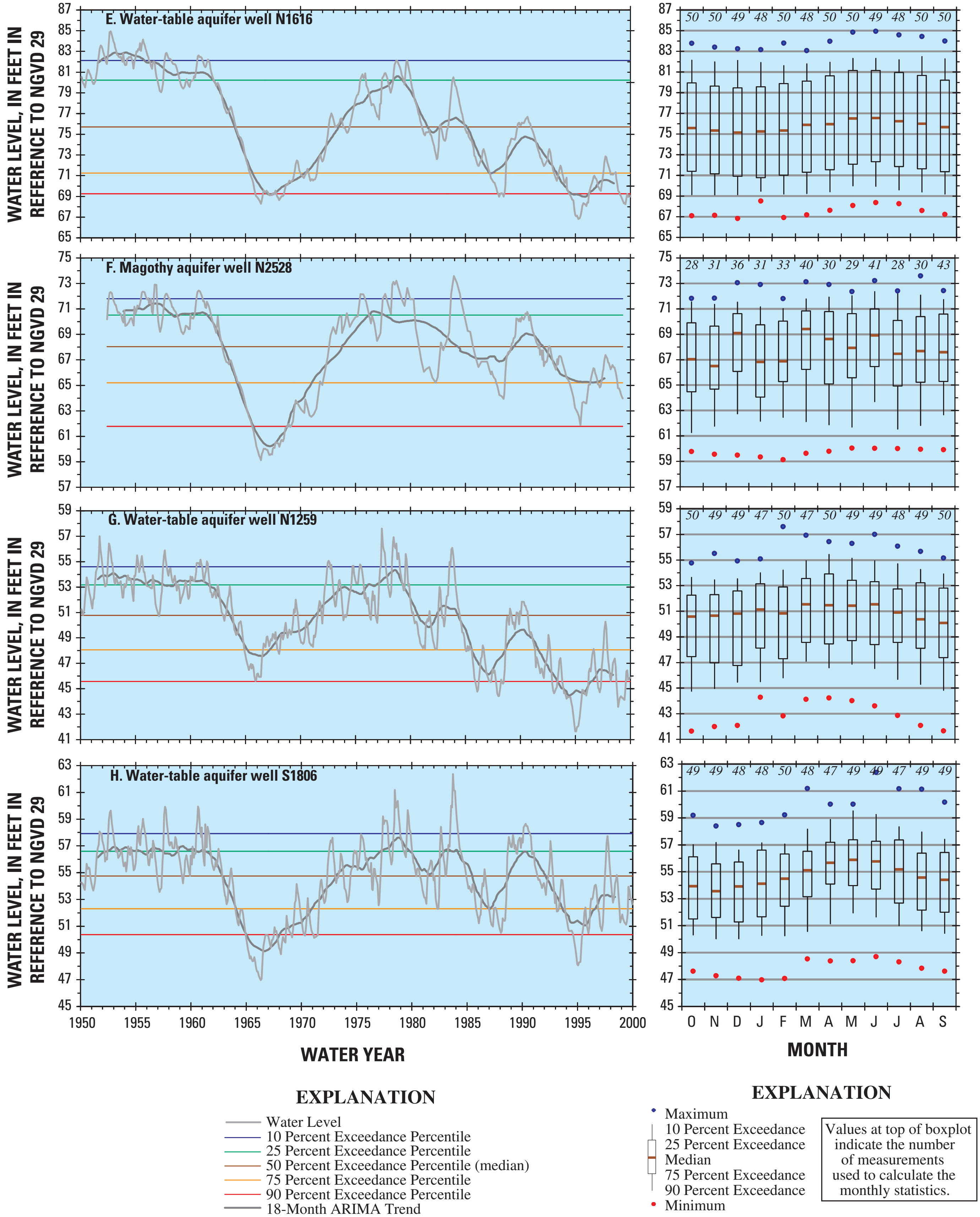


Figure 12. (Continued) Monthly water levels and exceedance statistics for 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record. (Well locations are shown in figure 5.)

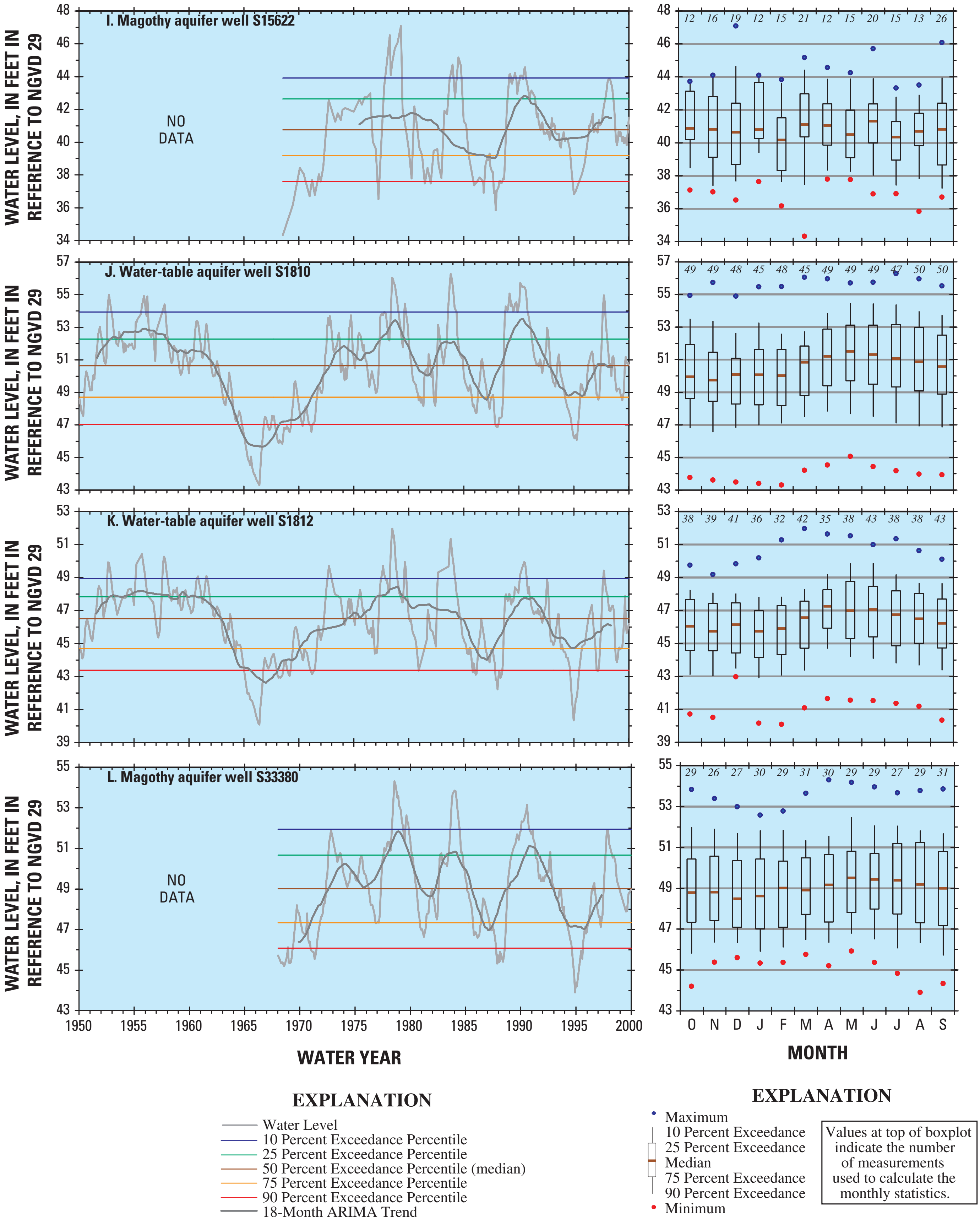


Figure 12. (Continued) Monthly water levels and exceedance statistics for 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record. (Well locations are shown in figure 5.)

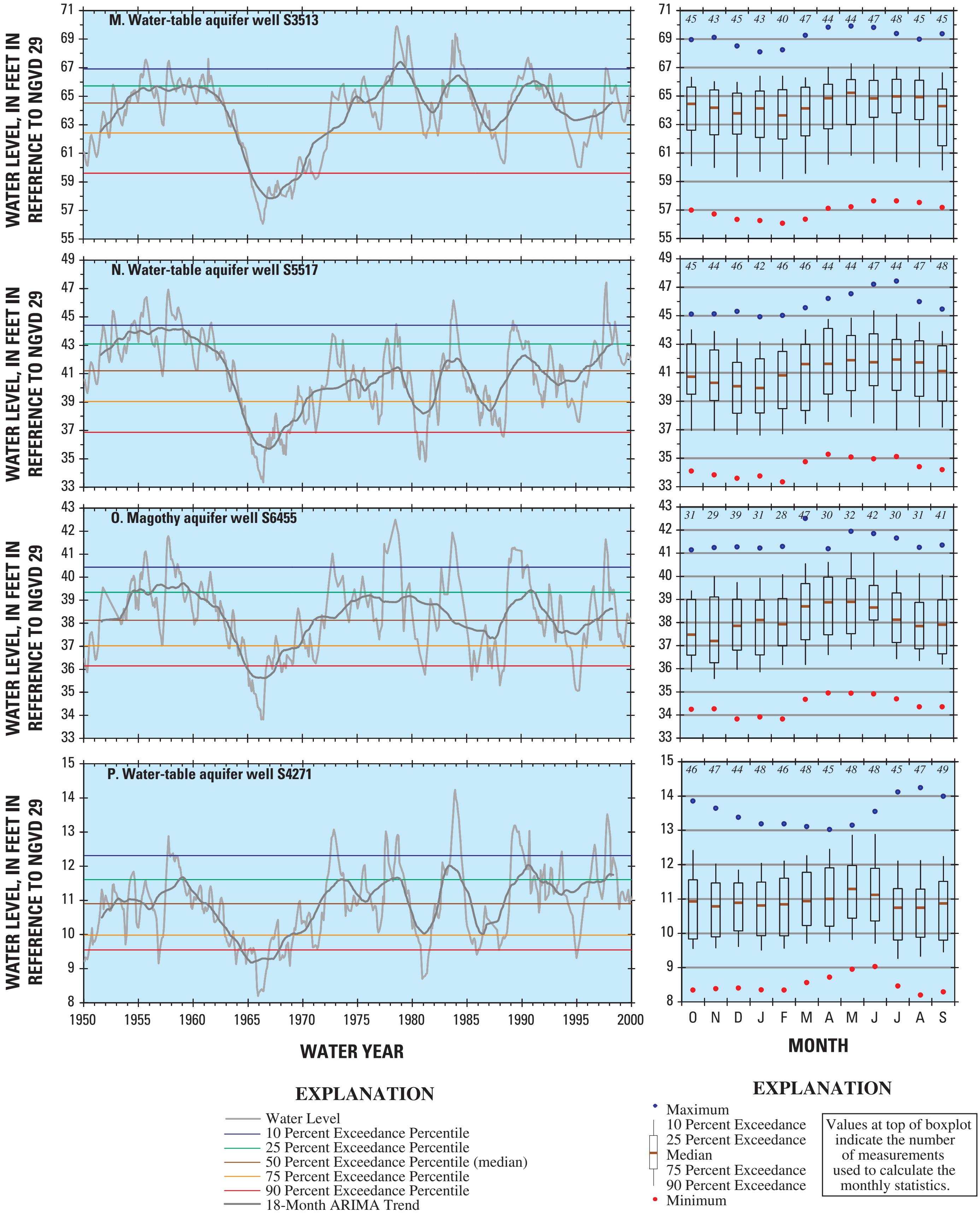


Figure 12. (Continued) Monthly water levels and exceedance statistics for 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record. (Well locations are shown in figure 5.)

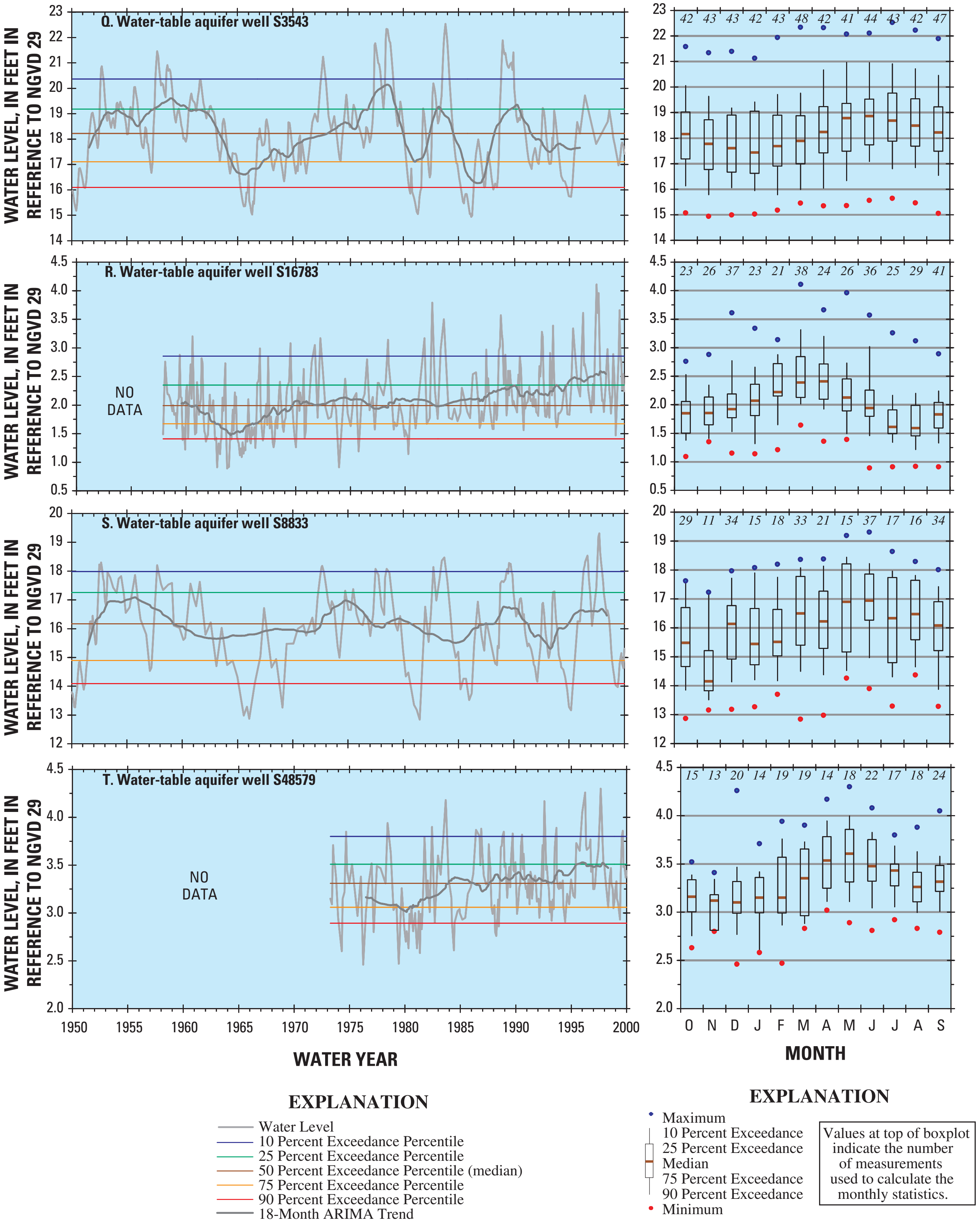


Figure 12. (Continued) Monthly water levels and exceedance statistics for 20 selected monitoring wells on Long Island, N.Y., 1951-2000 or period of record. (Well locations are shown in figure 5.)

at least five of the eight stations had data for that month. Also indicated on the hydrograph are the monthly means, the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, the ARIMA trend line, and the polynomial trend line.

The ARIMA trend line in the composite-average hydrograph (fig. 13) reflects many of the precipitation fluctuations depicted and tabulated earlier, including the 1960’s drought as the major period of below-average precipitation and the above-average periods of 1971-79, 1981-84, 1987-90, and 1995-98 (table 3C). The polynomial trend line for this composite shows that mean monthly precipitation since the 1960’s drought has been slightly above normal.

Stream Discharge

The long-term discharge records from the eight selected streams on Long Island (fig. 5) indicate that discharge of the four westernmost streams—Valley Stream, East Meadow Brook, Mill Neck Creek, and Massapequa Creek—showed large decreases in response to pumping and sewering. Valley Stream in the significant-human-impact zone, and the other three streams in the moderate-human-impact zone, no longer represent an aquifer under natural conditions. All four streams in Suffolk County (Connetquot River, Nissequogue River, Carmans River, and Peconic River) are in the low-human-impact zone and reflect relatively natural conditions in the aquifer and, therefore, are useful as drought-monitoring-indicator stations (table 6).

The 50-year composite-average hydrograph and boxplot of mean monthly stream discharge for three western index streams (moderate-human impact) are given in figure 14A; the composite-average hydrograph and boxplot for the four eastern streams (low-human impact) are given in figure 14B. No composite-average hydrograph and boxplot was developed for the significant-human-impact zone because Valley Stream is the only station in this zone. Data for each month’s composite average were calculated only for months in which at least half of the streams for each index (moderate and low impact) had data for that month. Also indicated on the hydrographs are the monthly means, the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, the ARIMA trend line, and the polynomial trend line.

The ARIMA trend lines in the two hydrographs (fig. 14) indicate that the two data sets were generally similar before the 1960’s drought and indicated above-average discharge; the trend lines also show the 1960’s drought (the major period of below-average discharge), and the above-average period through the 1970’s. Hydrograph A (streams in the moderate-human-impact zone), shows the effects of increased pumpage and sewering generally from the late 1970’s to the end of the record (fig. 14A). The polynomial trend line for hydrograph A shows a sharp decline of average mean discharge that falls to near the 75-percent exceedance percentile by the end of the record. In contrast, hydrograph B (streams in the low-human-impact zone), does not show this decline and the polynomial trend line generally remains above normal from the 1970’s to the end of the record (fig. 14B). This above-normal trend is also evident in the composite-average precipitation hydrograph described earlier (fig. 13), and indicates that this stream-discharge index (hydrograph B) is representative of natural conditions in the aquifer.

Ground-Water Levels

The long-term water-level records from the 15 selected water-table wells and the 5 Magothy wells (fig. 5) indicate wide variability across Long Island. Water levels at the three westernmost wells (those in the significant-human-impact zone—K1194, Q1249, and N7493, fig. 15A) have been affected by human activity to the extent that natural fluctuations are no longer evident in the record. Water levels at the six wells in the moderate-human-impact zone (N1614, N1616, N2528, N1259, S1806, and S1810) have also been affected by human activity, but at a lesser extent than at the three westernmost wells. Natural fluctuations at these wells, although largely masked by human-induced effects, are still apparent in the record. Water levels at the 11 wells in the low-human-impact zone (S15622, S1812, S33380, S3513, S5517, S6455, S4271, S3543, S16783, S8833, and S48579) are relatively unaffected (as compared to wells in the other zones) by human activity and generally show only the natural fluctuations that result from changes in precipitation. Water levels at two of these wells (S16783 and S48579) are affected by tidal fluctuations that tend to mask seasonal variations in the record and produce unwanted variability in a composite index; therefore, these wells were omitted from the composite-average index. The remaining nine wells were included and are useful as drought-monitoring-indicator stations (table 6).

The 50-year composite-average hydrographs and boxplots of monthly water levels at the 18 selected wells are shown in figure 15. Composite-average hydrograph A (fig. 15A) shows the averaged monthly water-level data for the three wells in the significant-human-impact zone; composite-average hydrograph B (fig. 15B) shows those for the six wells in the moderate-human- impact zone; and composite-average hydrograph C (fig. 15C) shows those for the nine wells in the low-human-impact zone. Data for each month’s composite average were calculated only if more than half of the wells for each index had data for that month. Also indicated on the hydrographs are the monthly averages, the annual and monthly 10th, 25th, 50th (median), 75th, and 90th exceedance percentiles, the ARIMA trend line, and the polynomial trend line.

The ARIMA trend lines in the three hydrographs (fig. 15) indicate that the three data sets differ significantly. Composite-average hydrograph A (significant-human-impact zone, fig. 15A) is missing large amounts of data, especially before

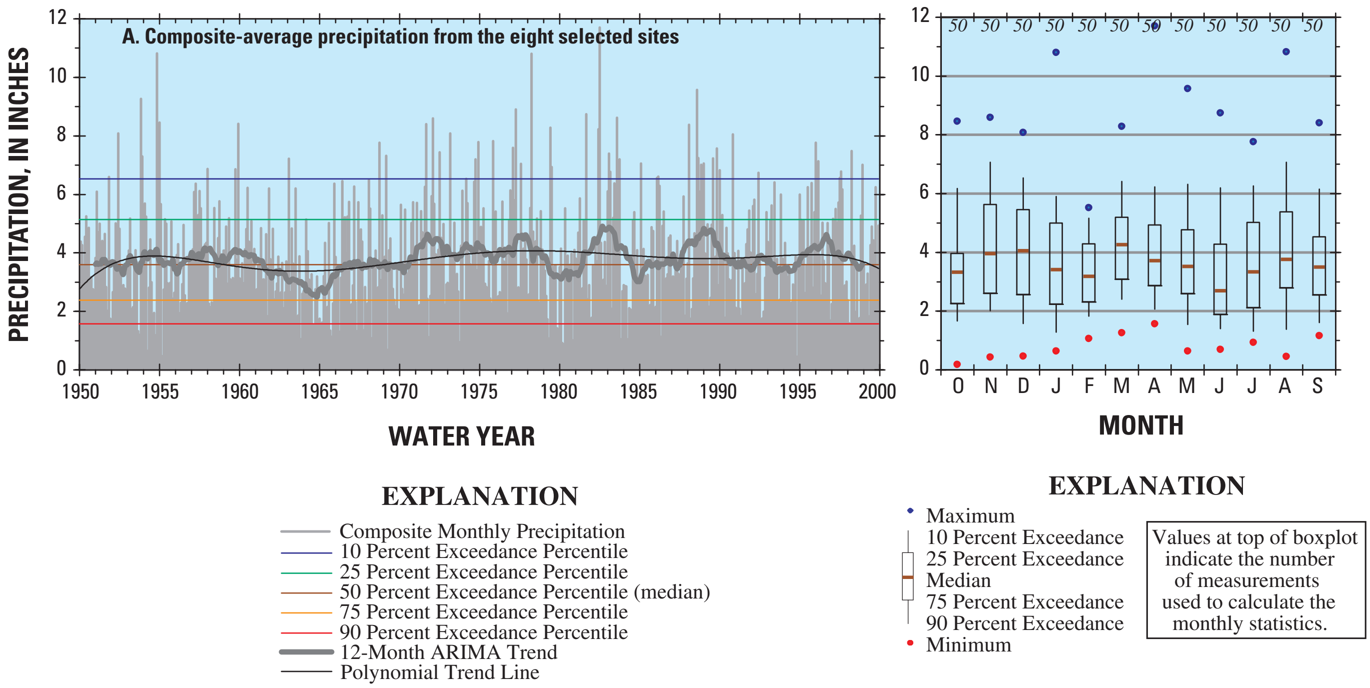


Figure 13. Composite-average monthly precipitation and exceedance statistics for eight selected stations on or near Long Island, N.Y., 1951-2000.

and during the 1960's drought; then, in the early 1980's, a significant rise in water levels in this index to the well-above-normal range is indicated and is attributed to a reduction in ground-water pumpage in southeastern Queens County. Composite-average hydrograph B (moderate-human-impact zone, fig. 15B) shows the effects of increased pumpage and sewering after the late 1970's. The effect of the 1960's drought appears exaggerated in this index because pumping and sewering in the western part of this zone had begun to lower water levels before the drought. The polynomial trend line for hydrograph B indicates a sharp decline of average water levels beginning in the mid-1980's, and a decline to below the 90-percent exceedance percentile by the late 1990's. In contrast, composite-average hydrograph C (low-human-impact zone, fig. 15C), shows the effect of the 1960's drought to have been of shorter duration than in the other zones; this hydrograph also does not show the decline beginning in the late 1970's that is found in hydrograph B. The polynomial trend line for hydrograph C is generally above normal after the mid-1980's. This above-normal trend is also evident in the composite-average precipitation and stream-discharge hydrographs described earlier (figs. 13 and 14) and indicates that this index is representative of natural conditions in the ground-water system.

Future Implementation of Drought-Monitoring Indices

The sites selected in this study to be part of the Long Island drought-monitoring network are the eight stations in the precipitation index (Central Park, Bensonhurst, LaGuardia Airport, Mineola, Setauket, Upton, Riverhead, and Bridgehampton, fig. 13), the four stations in the low-human-impact stream-discharge index (Connetquot River, Nissequogue River, Carmans River, and Peconic River, fig. 14B, table 6), and the nine wells in the low-human-impact ground-water-level index (S15622, S1812, S33380, S3513, S5517, S6455, S4271, S3543, and S8833, fig. 15C, table 6). The three drought-monitoring indices developed in this study could be used by Federal, State, and local agencies to monitor monthly conditions in the ground-water system underlying Long Island during periods of below-normal precipitation and to determine whether ground-water levels are approaching

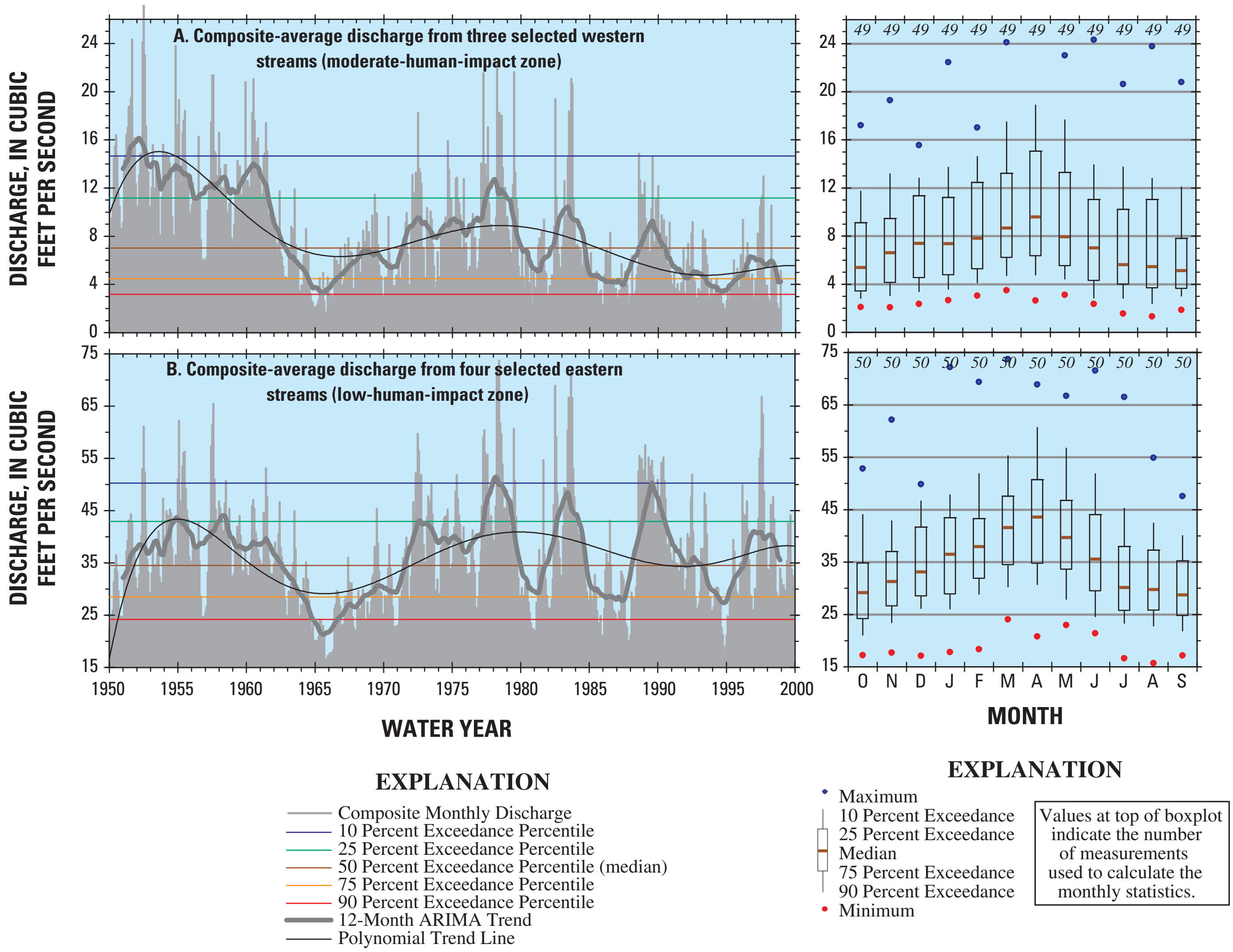


Figure 14. Composite-average monthly mean discharge and exceedance statistics for two stream-discharge index groups in the (A) moderate-human-impact zone, and (B) low-human-impact zone, on Long Island, N.Y., 1951-2000.

detrimental levels. This information could signal a need for prompt action by local water managers to help avoid water shortages and long-term adverse effects to the ground-water system.

The sites selected in this study that are not suitable to be part of a drought-monitoring network—Valley Stream and wells K1194, Q1249, and N7493, in the significant-human-impact zone; East Meadow Brook, Mill Neck Creek, Massapequa Creek and wells N1614, N1616, N2528, N1259, S1806, and S1810, in the moderate-human-impact zone; and wells S16783 and S48579, in the low-human-impact zone—could be used by Federal, State, and local agencies to evaluate local or regional declines in the ground-water system associated with overpumping or other human-induced changes (table 6). Indices from sites not selected for drought monitoring could be used in combination with the drought network to monitor ground-water pumpage in the heavily populated western parts of Long Island during severe droughts. This action would ensure that water levels do not decline sufficiently to cause permanent degradation of the ground-water system by saltwater intrusion, nor to lower water levels in streams and wetlands.

Data should be collected at each of the drought-index sites at least monthly to keep the averages current. These sites would be periodically reevaluated to assess whether human activity has affected the record such that it is no longer representative of conditions in that low-human-impact zone. Sites that are summarized in this report but not represented in the monthly composite averages also would be monitored at least monthly so that trends in those parts of the island could be identified.

Future studies are needed to determine (1) how to best implement the use of these indices to monitor the ground-water system, and (2) what exceedance percentiles should be used to implement water-use restrictions during a drought

Table 6. Summary of degree of human impact and primary monitoring use of eight selected streamflow-gaging (discharge) stations and 20 selected monitoring wells on Long Island, N.Y., 1951–2000 or period of record.

[Refer to tables 4C and 5C for additional details. Locations are shown in figure 5.]

Gaging station or well name and station number	Degree of human impact [1]	Primary monitoring use	
		Natural conditions (drought) [2]	Human-induced conditions [3]
Streamflow-gaging (discharge) stations			
Valley Stream at Valley Stream (01311500)	Significant	No	Yes
East Meadow Brook at Freeport (01310500)	Moderate	No	Yes
Mill Neck Creek at Mill Neck (01303000)	Moderate	No	Yes
Massapequa Creek at Massapequa (01309500)	Moderate	No	Yes
Connetquot River near Oakdale (01306500)	Low	Yes	No
Nissequogue River near Smithtown (01304000)	Low	Yes	No
Carmans River at Yaphank (01305000)	Low	Yes	No
Peconic River at Riverhead (01304500)	Low	Yes	No
Monitoring wells (ground-water levels)			
Well K1194 (404059073520702)	Significant	No	Yes
Well Q1249 (404240073443401)	Significant	No	Yes
Well N7493 (404237073433701)	Significant	No	Yes
Well N1614 (404446073392904)	Moderate	No	Yes
Well N1616 (404554073351502)	Moderate	No	Yes
Well N2528 (405101073343401)	Moderate	No	Yes
Well N1259 (404317073291105)	Moderate	No	Yes
Well S1806 (404442073240503)	Moderate	No	Yes
Well S15622 (405250073180801)	Low	Yes	No
Well S1810 (404614073164404)	Moderate	No	Yes
Well S1812 (404958073085001)	Low	Yes	No
Well S33380 (404932073055902)	Low	Yes	No
Well S3513 (405146073031801)	Low	Yes	No
Well S5517 (405149072532201)	Low	Yes	No
Well S6455 (405223072523402)	Low	Yes	No
Well S4271 (405743072425701)	Low	Yes	No
Well S3543 (405037072390301)	Low	Yes	No
Well S16783 (410634072223601)	Low, but tidally affected [4]	No	No
Well S8833 (405756072173501)	Low	Yes	No
Well S48579 (410316071535501)	Low, but tidally affected [4]	No	No

[1] Refer to figure 7.

[2] Indicates that precipitation is the primary source of variability in the record (near-natural conditions). These stations are useful for drought monitoring and for monitoring the encroachment of human-induced stresses in the aquifer system.

[3] Indicates that precipitation is no longer the primary source of variability in the record, human-induced stresses such as pumping and sewering mask natural fluctuations. These stations are not useful for drought monitoring, but are useful for monitoring human-induced changes.

[4] Indicates that even though these stations represent near-natural conditions, fluctuations associated with tidal variations mask the natural changes in the aquifer system. These stations are not useful for drought monitoring, but are useful for monitoring long-term climatic and human-induced changes that may effect baseline averages and percentiles.

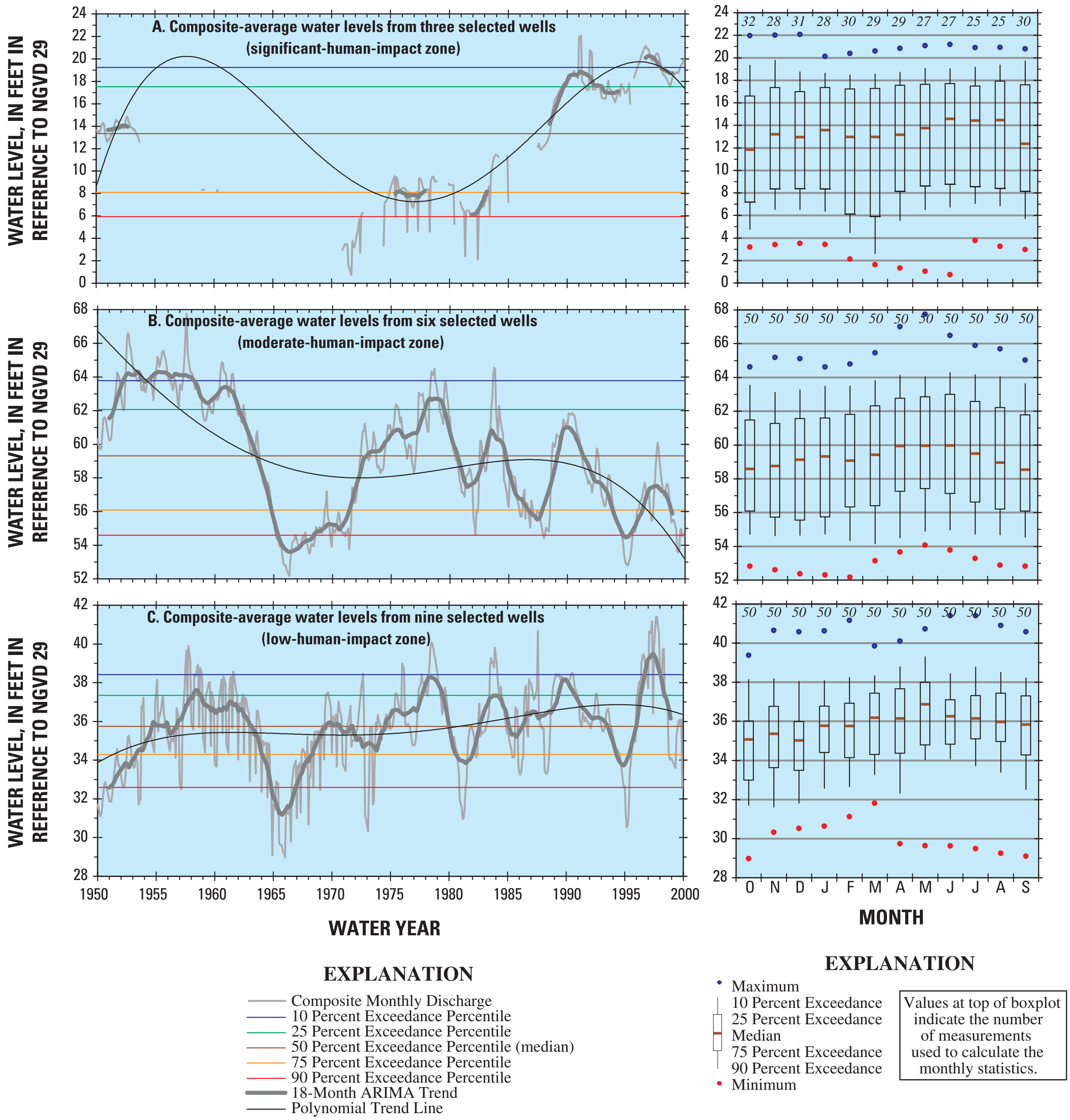


Figure 15. Composite-average water levels and exceedance statistics for three ground-water-level index groups in the (A) significant-human-impact zone, (B) moderate-human-impact zone, and (C) low-human-impact zone, on Long Island, N.Y., 1951-2000.

or other water emergency. Results obtained through these additional studies would give water managers a comprehensive and adaptable tool for drought monitoring and protection of the ground-water system underlying Long Island.

Summary and Conclusions

Aquifers underlying Long Island are the sole source of water supply for more than 3 million people on the island. About 1,000 public-supply wells together withdraw about 400 Mgal/d from the ground-water system. Large-scale pumping projects have caused severe (greater than 15 ft) water-level declines that have led to saltwater intrusion and the curtailment of long-term pumping in some areas. The water-table recovery that followed this cessation of pumping has caused local flooding of basements and subways.

Installation of large-scale sanitary and storm-sewer systems, and the increase in impervious surfaces, such as roads and parking lots, has caused regional declines in ground-water levels; this, in turn, has caused a reduction in ground-water storage and a loss of freshwater habitat through the lowering of pond and lake levels and the reduction of stream length and discharge.

No method is currently available that can assess data from Long Island's ground-water-monitoring network to provide Federal, State, and local agencies with timely warning of severe water-level declines. This report, describing the results of a study performed by the U.S. Geological Survey in cooperation with the New York State Department of Environmental Conservation, (1) quantifies past drought- and human-induced changes in the ground-water system underlying Long Island by applying statistical and graphical methods to long-term precipitation, stream-discharge, and ground-water-level data from selected monitoring sites; (2) evaluates the relation between water levels in the upper glacial aquifer under water-table conditions to those in the underlying Magothy aquifer; (3) defines trends in stream discharge and ground-water levels that might indicate the onset of drought conditions or the effects of excessive pumping; and (4) discusses the long-term records that were used to select sites for a Long Island drought-monitoring network.

The results from this report indicate that long-term hydrologic records on Long Island provide a sufficient basis from which to select sites for a drought-monitoring network. The data from 8 precipitation-monitoring stations, 8 streamflow-gaging (discharge) stations, 15 monitoring wells screened in the upper glacial aquifer, and 5 monitoring wells screened in the underlying Magothy aquifer indicate that hydrologic conditions vary widely across Long Island—ground-water levels in parts of Kings and Queens Counties have risen markedly (greater than 15 ft) in response to a cessation in pumping, those in Nassau and western Suffolk Counties have declined sharply (greater than 10 ft) in response to pumping and sanitary- and storm-sewer systems, whereas, those in central and eastern Suffolk County remain relatively unaffected (as compared to other areas on the island), although the effects of human activity are discernible in the long-term record.

Four hydrologic-data sets were examined to produce three "human-impact zones" as a basis for evaluation of islandwide hydrologic conditions. These data sets were (1) population density, (2) locations of large-scale sanitary- and storm-sewer systems, (3) location and distribution of public-supply wells screened in the upper glacial and underlying Magothy aquifers, and (4) long-term records of selected monitoring wells and streamflow-gaging (discharge) stations.

Fifty-year composite annual and monthly averages were calculated for precipitation, stream discharge, and ground-water levels. The precipitation composite represents eight stations on or near Long Island; the two stream-discharge composites represent a moderate-human-impact zone (three streams) and a low-human-impact zone (four streams); and the water-level composite represents all three human-impact zones—significant-human impact (three wells), moderate-human impact (six wells), and low-human impact (nine wells).

The indices developed in this study could be used to monitor monthly conditions in the ground-water system underlying Long Island and be used in times of drought to predict whether the ground-water system is approaching detrimental levels that require prompt action to avoid long-term adverse effects and water shortages. Future studies are needed to determine how to best implement the use of these indices to monitor the ground-water system and what exceedance percentiles should be used to implement conservation during droughts.

Acknowledgments

Virtually all data on ground-water levels and stream discharge used in this study were collected through previous studies done by the USGS in cooperation with other Federal, State, and local agencies. Thanks are extended to all agencies and individuals who participated in this data-collection effort.

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