Urbanization and Recharge in the Vicinity of East Meadow Brook, Nassau County, New York

Part 3—Ground-Water Levels and Flow Conditions, 1988-93

By MICHAEL P. SCORCA and HENRY F.H. KU

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4265

Prepared in cooperation with the
NASSAU COUNTY DEPARTMENT OF PUBLIC WORKS

Coram, New York
1997

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information
write to:

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

Copies of this report may be
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U.S. Geological Survey
Branch of Information Services
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CONVERSION FACTORS, ABBREVIATIONS AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.59	square kilometer
	Flow	
foot per day (ft/d)	0.3048	meter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second

Other abbreviations used

year (yr)
second (s)
inches per year (in/yr)

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

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By Michael P. Scorca and Henry F.H. Ku

Abstract

The stream channel at the headwaters of East Meadow Brook was excavated in 1992 to form a 7-acre, unlined stormflow-retention basin to increase streamflow and ground-water recharge and to decrease bacteria levels in streamflow. Extensive data on streamflow, ground water, and water quality were collected during the 3 years before basin construction, and less extensive data on ground water and water quality were collected for 1 year after basin construction.

Gamma-ray logs indicate that fine-grained layers, which retard ground-water flow, are directly below the stream channel in the northern part of the headwaters area and are absent or less extensive in the southern part. Water levels measured in a network of 89 new wells and 75 older observation wells near the stream indicate that the water-table configuration in the headwaters study area fluctuated with changes in hydrologic conditions during the project. In water year 1988, for example, precipitation was about 5 inches below average, and the water table declined below the streambed, causing base flow to cease. The general decline left a ground-water mound beneath the stream, from which flow gradients radiated outward (0.001 to 0.008 foot per foot) and downward (0.010 to 0.090 foot per foot). In water year 1989, by contrast, precipitation reached its second highest total on record (19 inches above average) and in 1990 was about 9 inches above average, and the water table rose as a result. The water table at a well cluster in Eisenhower Park, just east of the headwaters area, rose 6 feet between March and July 1989 and an additional 2 feet by June 1990. Ground-water flow gradients at this time were about 0.002 foot per foot (ft/ft) horizontally and ranged from 0.002 to 0.006 ft/ft vertically. At the stream channel, the water table rose above the streambed, causing base flow to resume. In addition, local pumping for construction near the headwaters, followed by a water-main break, and discharge of water from a nearby gasoline-filling station undergoing ground-water remediation, temporarily affected local hydrologic conditions during the study.

Hydrologic conditions after completion of the basin are similar to the 1988 losing-stream conditions that had been observed before basin construction but differ in that: (1) the water-table mound in the headwaters study area is wider, (2) the water-table altitude in the northern part of the headwaters study area has risen about 0.5 foot, (3) the basin contains water at all times, and (4) ground-water flow gradients during May 1993 ranged from 0.002 to 0.0035 ft/ft, horizontally, and 0.001 to 0.073 ft/ft, vertically.

INTRODUCTION

Ground water is the sole source of freshwater supply for the 1.3 million residents of Nassau County, N.Y. (Long Island Regional Planning Board and Long Island Lighting Company, 1987). Ground-water levels fluctuate naturally in response to precipitation, but human activities, such as construction of roads, other large impervious surfaces, and large-scale stormwater and sanitary-sewer systems, have altered the water-table configuration and ground-water flow patterns. For example, the routing of stormwater from paved surfaces to storm sewers decreases recharge to the ground-water system (Franke, 1968; Ku and others, 1992) because this water, which would otherwise infiltrate into the soil, is directed to streams that flow into south-shore bays or the Atlantic Ocean. Similarly, sanitary sewers produce a net loss of water from the aquifer system because they discharge the wastewater offshore rather than returning it to the ground (Ku and Sulam, 1979). Thus, sewers and paved surfaces have resulted in a severe decline in the water-table altitude throughout western Long Island (Franke, 1968), and this, in turn, has decreased the discharge of ground water to streams (base flow).

The loss of base flow has decreased the total annual streamflow of many streams in Nassau County (Pluhowski and Spinello, 1978). Under natural conditions, the streams derive 95 percent of their flow from base flow and 5 percent of their flow from storm runoff. Some streams in western Nassau County now have no flow except during storms, and all streams in central and eastern Nassau County have a decreased base-flow component (Spinello and Simmons, 1992).

During the 1980's, the U.S. Environmental Protection Agency and the Nassau County Department of Public Works (NCDPW) studied the environmental effects of decreased streamflow (Lawler, Matusky & Skelly Engineers, 1982) and developed methods to augment the flow of selected south-shore streams. One of the streams selected for study was East Meadow Brook (fig. 1), which flows southward through central Nassau County and is one of the longest streams on Long Island. Base-flow discharges of East Meadow Brook have decreased by about 65 percent from estimated predevelopment conditions as a result of urbanization, especially the construction of Sewer Districts 2 and 3 (fig. 2) (Scorca, 1997). In 1988, the NCDPW began a related project to increase recharge and streamflow at East Meadow Brook. Modifications of the stream channel included (1) excavation of a 7-acre unlined stormflow-detention basin, retained by a sheet-pile dam, in the headwaters study area, (2) construction of four check dams along the length of the stream, and (3) dredging of Mulleners Pond, about halfway along the stream's length (fig. 2). An added benefit of this effort is that detention of stormwater in

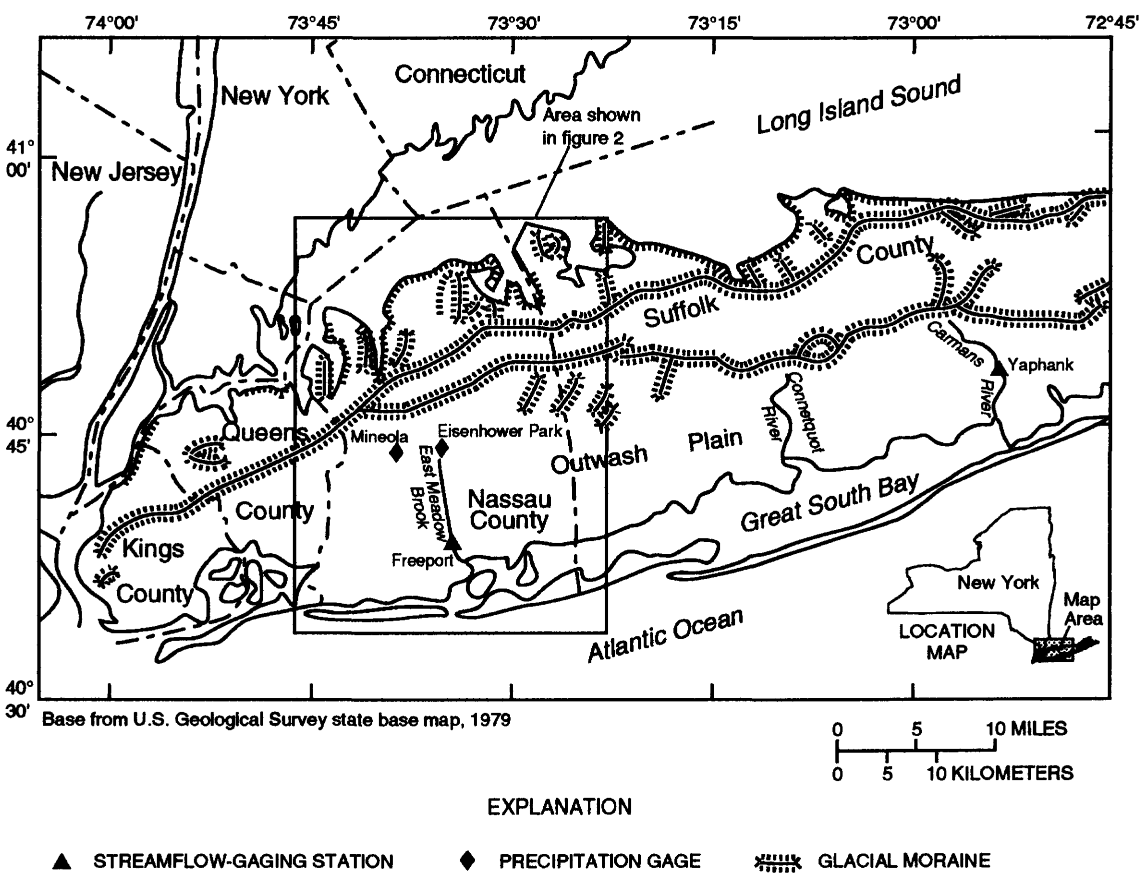


Figure 1. Location of selected geographic features on Long Island, N.Y. (Modified from McClymonds and Franke, 1972, fig. 2.)

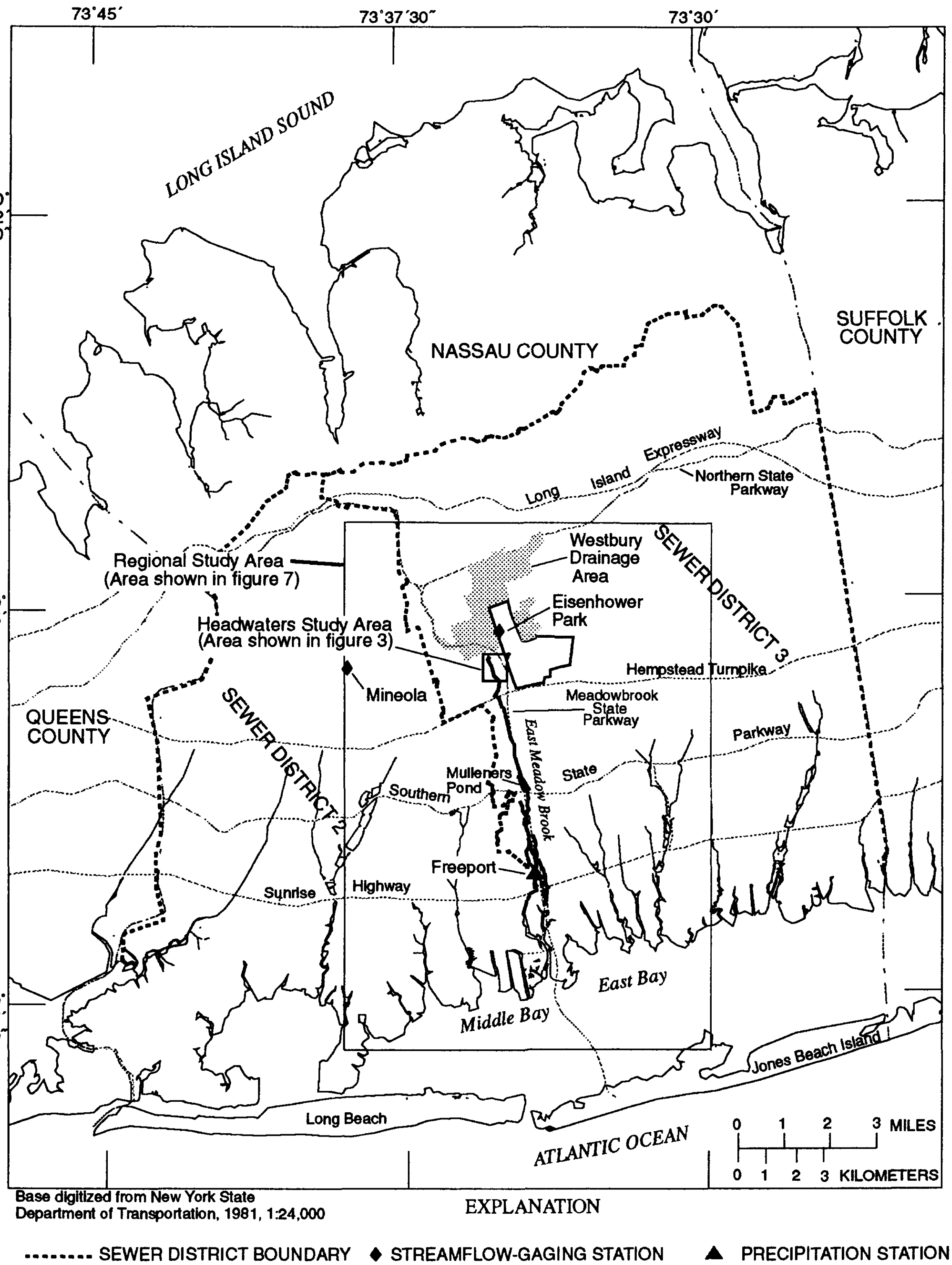


Figure 2. East Meadow Brook, the regional and headwaters study areas, and Sewer Districts 2 and 3, Nassau County, N.Y.

the basin also could result in a decrease in the concentrations of bacteria and other contaminants transported by storm runoff.

In 1988, the U.S. Geological Survey (USGS) began a cooperative study with NCDPW to evaluate the effects of the stormflow-detention basin on streamflow, ground-water flow, and water quality in the vicinity of the headwaters of East Meadow Brook, hereafter referred to as the headwaters study area (fig. 2). The USGS collected data during the 3 years before basin construction to evaluate hydrogeologic and water-quality conditions. Basin construction disrupted the streamflow-gaging network in the headwaters study area; thus, stream discharge could not be measured continuously after completion of the basin, but limited ground-water-level and water-quality data were collected during the first year after basin construction.

Purpose and Scope

This report describes ground-water levels and flow conditions in the East Meadow Brook headwaters study area before construction of the stormflow-detention basin and during the first year thereafter. It describes (1) the stratigraphy of the upper glacial aquifer at the headwaters study area, (2) ground-water levels and ground-water flow conditions during a dry period and a wet period before stream-channel modification, and (3) the effects of basin construction on water levels and flow conditions. The report includes stratigraphic and hydrologic sections, and regional and local water-level maps.

Acknowledgments

Thanks are extended to James Mulligan, Director of Water Management, NCDPW, and Brian Schneider, of NCDPW, who helped coordinate well-drilling operations, provided information about wells monitored by their agency, coordinated gage-house construction, and provided other technical assistance.

Previous and Related Studies

Results of the first comprehensive study of the hydrologic effects of urbanization on East Meadow Brook was described by Seaburn (1969). As part of the current project, Scorca (1997) discussed long-term changes in regional hydrologic conditions near the stream and included a discussion of the suburban character of Nassau County. Stumm and Ku (in press) discussed the response of streamflow to urban runoff and the percentage of streamflow that recharges the local ground-water system during storms in the headwaters study area. Brown and others (in press) discuss water-quality conditions in streamflow and ground water in the headwaters study area.

Local ground-water-flow conditions near two other south-shore streams on Long Island have been investigated through networks of relatively closely spaced wells or borings. Prince (1984) modeled ground-water-flow conditions near a stream in western Nassau County during streamflow-augmentation-feasibility tests, and Prince and others (1988) examined head gradients beneath the streambed at Connetquot River (fig. 1) and modeled the shallow ground-water-flow system.

Data Collection

Extensive data-collection networks were established for this project. The methods of collection for the data used in the aspect of the project described in this report are discussed below.

Ground-Water Levels

The USGS installed 55 wells from 1988 through 1993 (fig. 3), and the NCDPW installed 34 wells, to monitor water-level changes in the headwaters study area of East Meadow Brook. Existing wells were incorporated into the data-collection networks. Physical descriptions of wells used in this project are given in table 3 (at end of report).

Most of the initial wells were installed in 1988 by a hollow-stem auger drill rig and were constructed of either threaded-steel or solvent-welded PVC casing. Additional wells were hand driven by a cathead directly into the streambed. Well sites were selected to form five lines of vertical sections parallel and perpendicular to the stream (sections A-A′ through E-E′, fig. 3). Most wells were installed in clusters of two or three to allow measurement of water levels, hydraulic gradients, and water quality at differing depths at each site. Water levels in the initial set of wells were first measured as a group in October 1988.

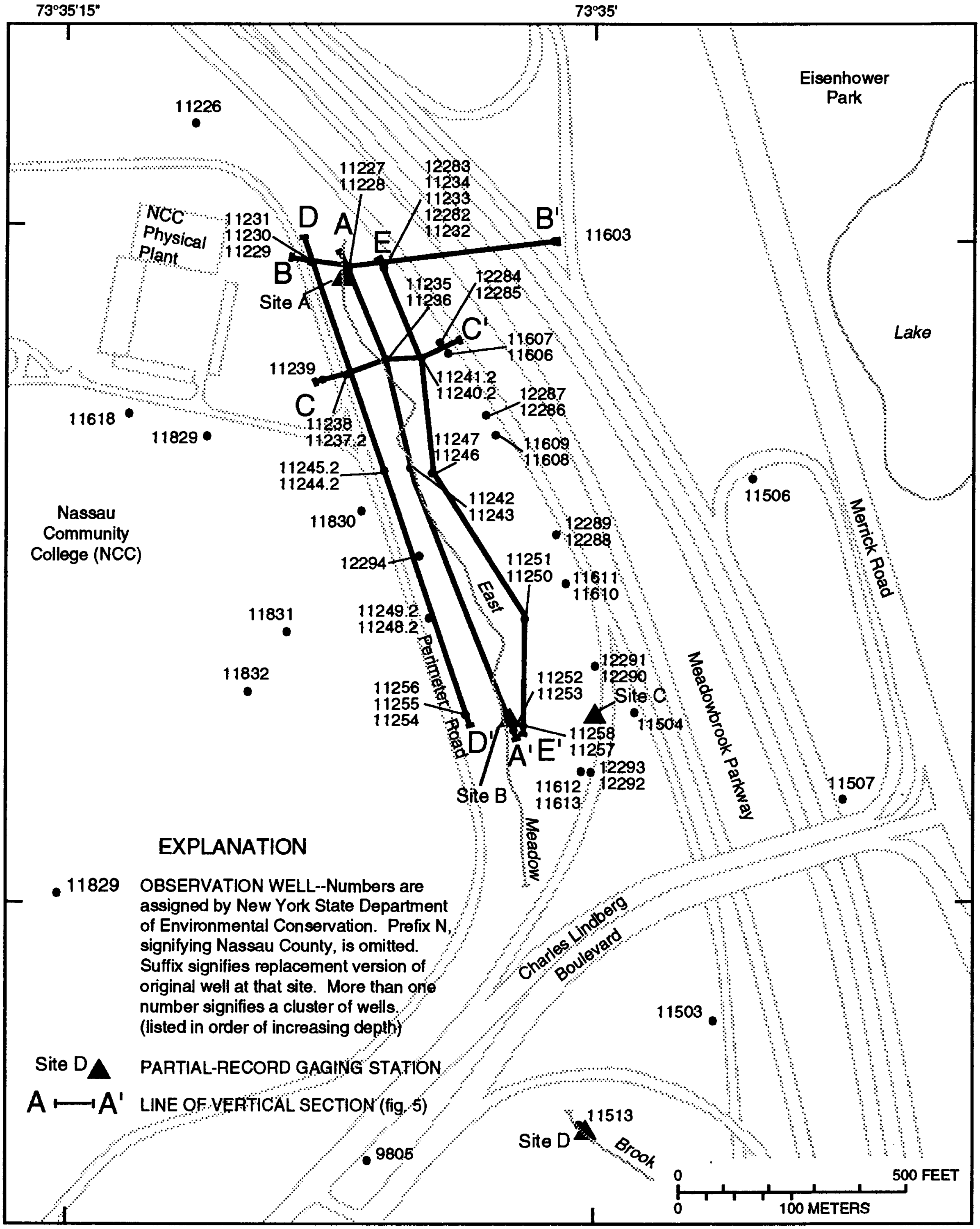


Figure 3. Locations of wells and lines of section in the East Meadow Brook headwaters study area, Nassau County, N.Y. (Location shown in fig. 2. Well data are given in table 3, at end of report.)

In late 1989, the USGS drilled another set of wells to replace clogged or destroyed wells and to expand the observation-well network. NCDPW installed additional wells during 1989 at sites farther from the stream to augment the local-well network. In March 1993, NCDPW installed a final set of wells along the stormwater basin's perimeter to replace several observation wells that were destroyed during basin construction.

Water levels were measured regularly during the project (1988-93) to monitor water-table fluctuations. Measurements were made by the wetted-(steel) tape method to the nearest hundredth of a foot, except at the few wells that were equipped with recording instruments. Water-level data are stored at the USGS office in Coram, N.Y., and are available upon request.

Water levels in the regional well network, which extended through the southern half of central Nassau County, were measured about 3 or 4 times per year for the first 3 years of the project, and water levels in the headwaters-study-area network were measured about twice as often. Dates of water-level-measurements for the two networks are presented in table 1.

Streamflow

The USGS established four temporary streamflow-gaging stations in the headwaters study area (sites A, B, C, D in fig. 3) and collected water samples at each station during selected storms for chemical analysis. Results of the surface-water and water-quality aspects of the project, respectively, are summarized in Stumm and Ku (in press) and Brown and others (in press).

Gamma-Ray Logs

Gamma-ray logs were collected at selected wells to help characterize the lithology of the sediments and to interpret the local stratigraphy. Gamma logs are especially effective for indicating the amount of clay in Long Island's outwash-plain deposits because natural gamma radiation of the sand and gravel is low; therefore, the relative intensity of gamma radiation indicated on the logs generally reflects the amount of clay present.

Precipitation

Precipitation data were collected to evaluate the relations between precipitation and (1) storm-runoff volume, and (2) ground-water levels, in the study area. Daily records of precipitation have been collected by the NCDPW at a station in Mineola (fig. 1), about 3.5 mi west of the headwaters study area, since 1938. A weighing-bucket rain gage has been operated by the USGS since 1973 at Eisenhower Park, in the southern part of the Westbury drainage area (fig. 2). In 1989 the USGS installed a second rain gage at Eisenhower Park to collect data at shorter (5-min) intervals than the Mineola and first Eisenhower Park gages and to quantify the relation of precipitation to stormwater runoff (Stumm and Ku, in press).

DESCRIPTION OF STUDY AREA

East Meadow Brook flows through a suburban residential area of Nassau County. The history of urbanization near the stream is included in Scorca (1997). A summary of the geologic setting and hydrologic characteristics in the East Meadow Brook headwaters study area is presented in the following sections.

Regional Hydrogeology

Long Island is underlain by unconsolidated sediments of Late Cretaceous to Quaternary age that rest on a southward-dipping bedrock surface. Nassau County's hydrogeologic setting has been described in detail by Suter and others (1949), Perlmutter and Geraghty (1963), and Ku and others (1975). A summary of principal hydrogeologic units is given in table 2; a generalized hydrogeologic section through Nassau County is shown in figure 4.

The upper Pleistocene deposits, which form the uppermost major stratigraphic unit on Long Island and are the only unit of concern in this study, consist mostly of glacial outwash, till, and glaciolacustrine sediments. Long Island was at the southern extent of the Wisconsinan continental ice sheet, which deposited two major terminal moraines (fig. 1). Morainal sediments consist of sand, gravel, silt, clay, and boulders. Although these sediments can be stratified, they are poorly to moderately sorted and less permeable than

Table 1. Periods of water-level measurements for the local headwaters and regional networks at East Meadow Brook, Nassau County, N.Y.
[Well locations are shown in figs. 3 and 7]

Date or time period	Water-level measurements made: Local headwaters network	Water-level measurements made: Regional network	Date or time period	Water-level measurements made: Local headwaters network	Water-level measurements made: Regional network
March 28, 1988		X	December 5-6, 1989		X
April 13, 1988		X	January 16-17, 1990	X	X
June 8-9, 1988		X	February 12-13, 1990	X	
July 5, 1988		X	March 26-27, 1990	X	X
August 11, 1988		X	June 18-19, 1990	X	X
August 25, 1988	X		August 15-16, 1990	X	X
August 29, 1988	X		October 29-30, 1990	X	X
September 7, 1988	X		December 3, 1990	X	
September 13-15, 1988	X	X	December 11, 1990	X	
September 19, 1988		X	January 10-11, 1991	X	
October 3, 1988	X		February 21-22, 1991	X	
October 11, 1988	X		March 21-22, 1991	X	X
October 21, 1988	X		April 25-26, 1991	X	
November 21, 1988	X		May 21-22, 1991	X	
December 5-7, 1988	X		June 25-26, 1991	X	X
January 13, 1989		X	August 6, 1991	X	
February 13, 1989	X		September 4-5, 1991	X	
March 9, 1989	X		September 13, 1991	X	
March 13, 1989	X		September 15, 1991	X	
March 23, 1989	X	X	October 22-23, 1991	X	X
April 12-13, 1989	X	X	November 21, 1991	X	
May 17, 1989	X		January 2, 1992	X	
May 18, 1989	X		February 4, 1992	X	
May 19, 1989	X		March 16-18, 1992	X	X
May 20, 1989	X		June 29-30, 1992	X	X
May 22, 1989	X		August 4, 1992	X	
May 23, 1989	X		September 2, 1992	X	
June 17, 1989	X		January 7, 1993	X	
June 19, 1989	X		March 1993	X	X
June 21, 1989		X	May 1993	X	
July 18-19, 1989		X	July 1993	X	
August 15-16, 1989	X				
September 20, 1989	X				
September 27, 1989		X			
October 24-26, 1989	X	X			

Table 2. Generalized description of hydrogeologic units underlying Nassau County, N.Y.

[Modified from Jensen and Soren, 1971, table 1, and Smolensky and others, 1989, table 1. ft/d, feet per day]

Hydrogeologic unit	Geologic unit	Description and water-bearing character
Upper glacial aquifer	Upper Pleistocene deposits	Mainly brown and gray sand and gravel deposits of moderate to high horizontal hydraulic conductivity (270 ft/d); may also include deposits of clayey till and lacustrine clay of low hydraulic conductivity. A major aquifer.
Gardiners Clay (confining unit)	Gardiners Clay	Green and gray clay, silt, clayey and silty sand, and some interbedded clayey and silty gravel. Unit has low vertical hydraulic conductivity (0.001 ft/d) and tends to confine water in underlying aquifer.
Magothy aquifer	Matawan Group and Magothy formation, undifferentiated	Gray and white fine to coarse sand of moderate horizontal hydraulic conductivity (50 ft/d). Generally contains sand and gravel beds of low to high conductivity in basal 100 to 200 ft. Contains much interstitial clay and silt, and lenses of clay of low hydraulic conductivity. A major aquifer.
Raritan confining unit	Unnamed clay member of the Raritan Formation	Gray, black, and multicolored clay and some silt and fine sand. Unit has low vertical hydraulic conductivity (0.001 ft/d) and confines water in underlying aquifer.
Lloyd aquifer	Lloyd Sand Member of the Raritan Formation	White and gray fine-to-coarse sand and gravel of moderate horizontal hydraulic conductivity (40 ft/d) and some clayey beds of low hydraulic conductivity.
Bedrock	Undifferentiated crystalline bedrock	Mainly metamorphic rocks of low hydraulic conductivity; considered to be the bottom of the ground-water reservoir.

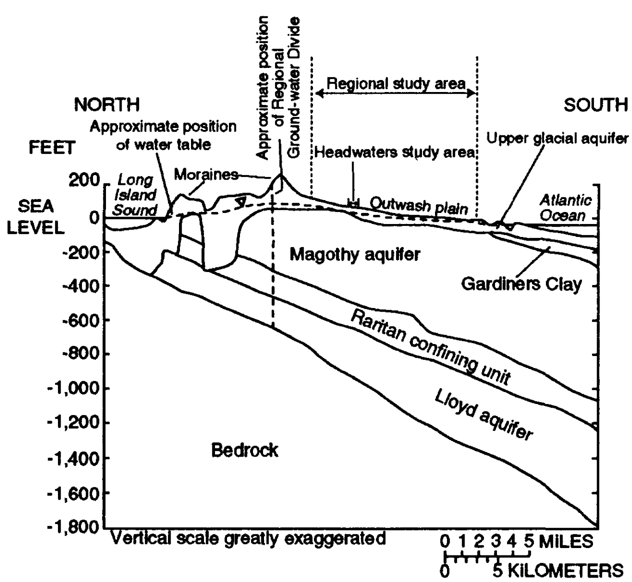


Figure 4. Generalized section through Nassau County, N.Y., showing hydrogeologic units. (Modified from Smolensky and others, 1989, sheet 1.)

outwash. The part of Long Island that lies south of the moraines contains outwash deposits of mostly brown quartzose sand and gravel. Sediments generally are 90 to 95 percent quartz and can include grains of alkali feldspar, muscovite, biotite, hornblende, garnets, and rock fragments (Faust, 1963). The upper Pleistocene deposits contain extensive regional clayey units, such as the Smithtown clay (Krulikas and Koszalka, 1983) and the "20-foot" clay (Doriski and Wilde-Katz, 1983); less extensive fine-grained layers of silt or clay also are present.

Upper Pleistocene deposits in central Nassau County generally range from 50 to 100 ft thick but may be as thick as 300 ft near the moraines. This unit contains the upper glacial aquifer throughout most of Long Island. These deposits generally are highly permeable, as indicated by the estimated average horizontal hydraulic conductivity of 270 ft/d (Smolensky and others, 1989) but contain localized zones of less permeable silt and clay that impede ground-water movement. The upper glacial aquifer underlies the entire study area and is the source of base flow in East Meadow Brook.

Stratigraphy of Headwaters Study Area

Cuttings observed during auger drilling included glacial outwash sediments of medium to coarse sand mixed with gravel, as well as finer grained sediments that contain varying amounts of sand, silt, and clay. The fine-grained sediments ranged from silty and clayey fine to medium sand to sandy silt and clay.

Gamma-ray logs from wells along five vertical sections are presented in figure 5. The relative gamma-ray intensities on these logs indicate that fine-grained deposits are present in the northern half of the headwaters study area but are less extensive or absent in the southern half. The fine-grained layers beneath the headwaters study area tend to be discontinuous, to vary in thickness, and to grade laterally to sandier facies. Some fine-grained layers beneath the northern half of the headwaters study area could be somewhat continuous because their upper surface altitudes in gamma-ray logs are similar throughout the area and range from about 46 to 55 ft above sea level.

Gamma-ray logs from the three northernmost wells in the streambed (fig. 5A) indicated a significant gamma-radiation increase at the bottom of each well, which suggests the top of a fine-grained layer about 10 ft below the streambed. The log from the southernmost well in the streambed (N11253) shows a slight increase in gamma radiation, but this does not clearly indicate the presence of a fine-grained layer.

Gamma-ray logs from wells along sections that intersect the stream (figs. 5B and 5C) indicate some fine-grained sediments laterally beyond the streambed as well as beneath it. For example, some fine-grained layers are indicated on logs from wells N11229, N11228, and N11232 along section B-B′. Gamma-ray logs from most wells along section C-C′ indicate substantial fine-grained layers. Well N11236, for example, penetrated just the top of a fine-grained layer, but logs from wells N11237.2, N11240.2, and N11606 display the largest gamma-ray responses in the study area and indicate that some fine-grained units are at least 20 ft thick.

Logs from wells N11506 and N11507, on the east side of Meadowbrook Parkway (locations shown in fig. 3), indicate that some fine-grained sediments may be present, but these layers probably are not continuous with similar layers near the streambed. Logs for wells N11604, N11605, and N11618, on the campus of Nassau Community College, and for well N11505, on the east service ramp of the Meadowbrook Parkway, about 300 ft from the stream channel, do not indicate the presence of fine-grained layers. (Locations are shown in figures 3 and 7.)

Logs from wells along sections D-D′ and E-E′, which parallel the stream, indicate that fine-grained layers are absent or less extensive in the southern half of the headwaters study area than in the northern half. Logs from wells N11249.2 and N11250 indicate no fine-grained layers. Hydraulic data from these well clusters support the conclusions inferred from the geophysical logs—that water levels from both wells at each cluster are usually equal or similar, as expected in a water-table aquifer in which flow is not restricted by fine-grained units. Also, the near uniformity of ground-water levels throughout the measured part of the aquifer at these locations indicates that almost all flow is horizontal. In contrast, water levels among wells in clusters in the northern part of the headwaters study area, where fine-grained layers are more extensive, differed substantially. The effects of fine-grained sediments on ground-water flow are discussed in detail in a later section.

Hydrologic Characteristics of East Meadow Brook

East Meadow Brook is just east of the border between Sewer Districts 2 and 3 (fig. 2) and flows from central Nassau County southward with a gentle gradient of about 12 ft/mi (Seaburn, 1969). Mean-annual discharge at the USGS streamflow-gaging station at Freeport (fig. 1) during water years 1938-90 was 13.9 ft^3/s. The channel generally is less than 5 ft deep and is 10 to 20 ft wide, except at the few shallow ponds along its length. The point at which flow begins (start-of-flow) in the channel shifts with the rise or fall of ground-water levels; therefore, the length of the flowing stream also fluctuates. The maximum measurable length of the present-day stream channel is 7.5 mi because the channel north of the headwaters study area has been modified by construction and no longer receives base flow naturally.

Storm sewers that divert runoff from roads have altered the stream physically and affected the flow characteristics. Stormwater runoff enters the stream from about 150 sewer culverts that drain streets along its length (James Ahearn, Nassau County Department of Public Works, written commun., 1991).

The convergence of one 5-ft- and two 6-ft-diameter culverts, 4,500 ft north of Hempstead Turnpike (fig. 2), marks the headwaters of the stream. These culverts direct storm runoff from the 2-mi^2 Village of

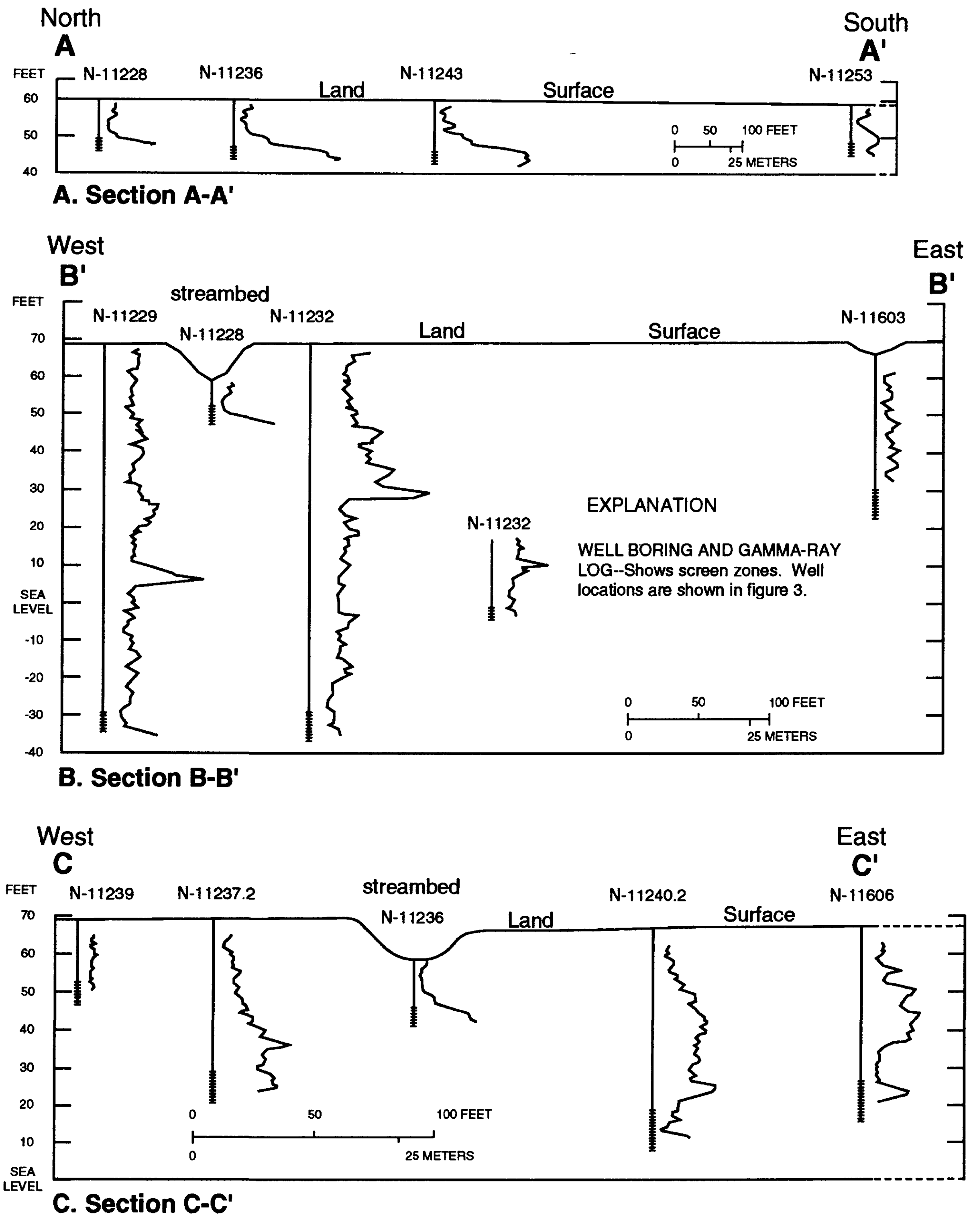
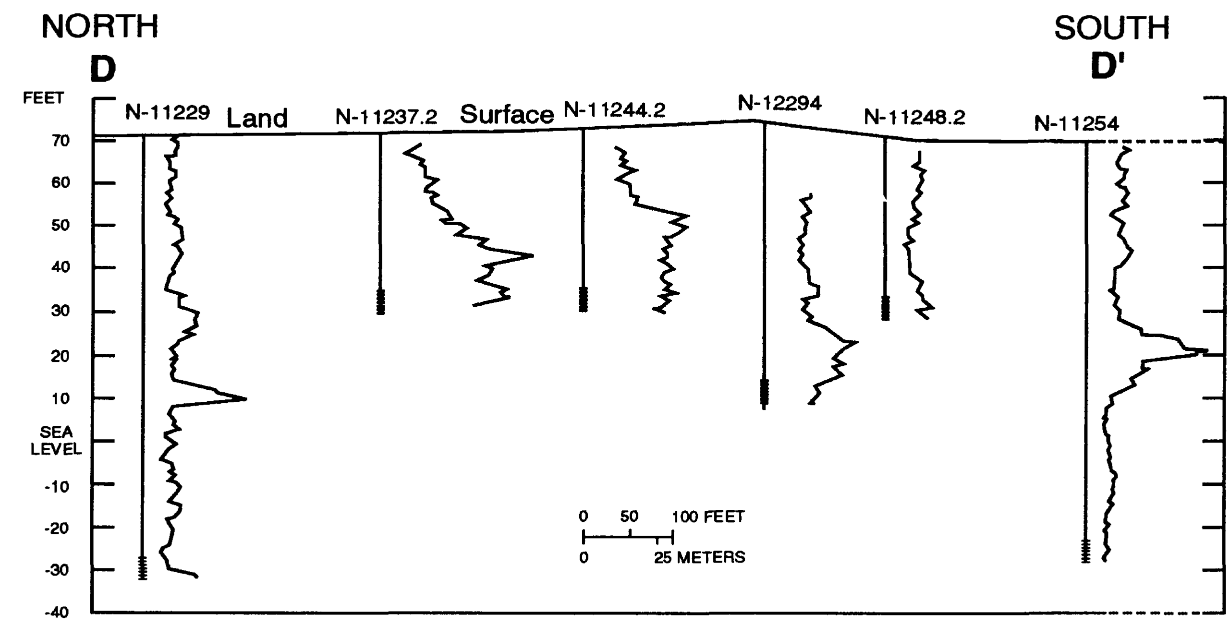
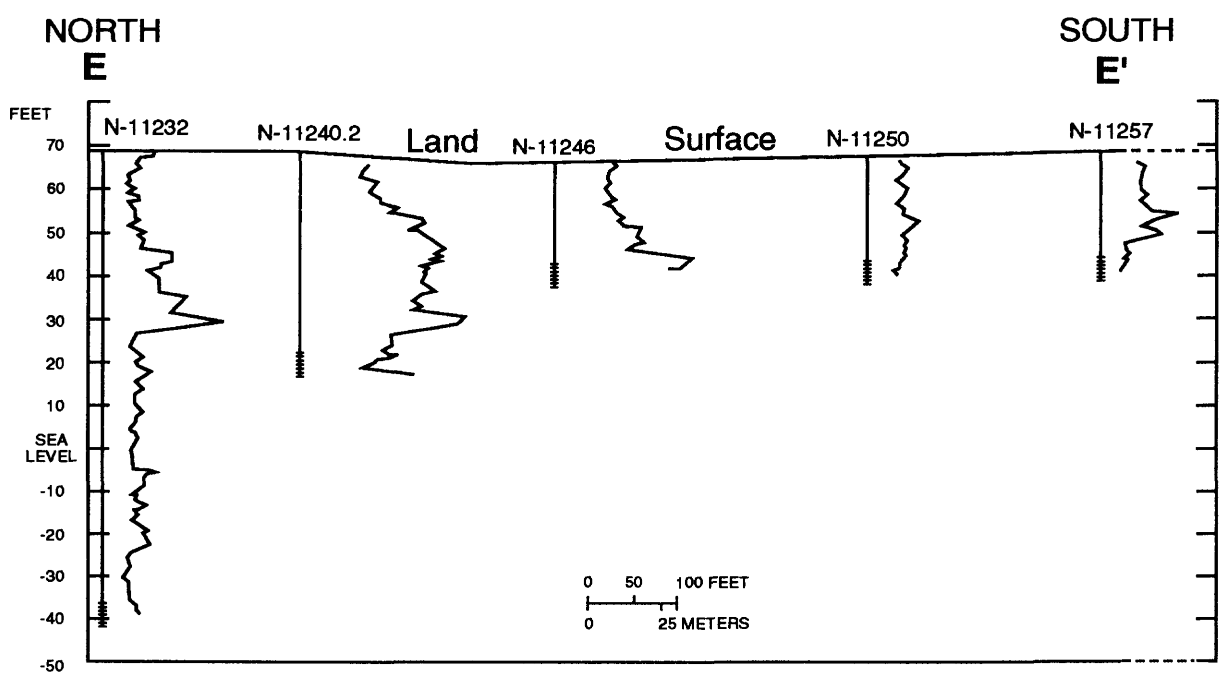


Figure 5. Vertical sections through the East Meadow Brook headwaters area, Nassau County, N.Y., showing gamma-ray logs at selected wells: A-A′, along stream channel. B-B′, northernmost section transverse to stream. C-C′, transverse to stream.



D. Section D-D'



E. Section E-E'

Figure 5 (continued). D-D′, longitudinal to stream along its west side. E-E′, longitudinal to stream along its east side. (Traces of sections are shown in fig. 3.)

Westbury drainage area to the headwaters study area (Stumm and Ku, in press).

GROUND-WATER LEVELS AND FLOW CONDITIONS

A losing stream is defined as a stream or reach of stream that is losing water to the ground, and, conversely, a gaining stream is defined as a stream or reach of stream whose flow is being increased by inflow of ground water (Lohman and others, 1972). East Meadow Brook is a gaining stream along its lower reach, where ground water continuously supplies base flow to the stream, but can be either a losing stream or a gaining stream along its upper length, depending upon the water-table altitude. About 20 percent of the storm runoff that enters the stream channel at the main headwaters culverts infiltrates downward through the streambed to the water table (Stumm and Ku, in press), then flows through the sediments horizontally away from the stream as well as vertically downward. When the water table is low, the flow gradients remain directed away from the stream between storms because the underlying fine-grained layers inhibit downward flow and result in ground-water mounding. When the water table is higher than the bottom of the stream channel, ground water flows into the stream channel, providing base flow (gaining-stream conditions).

Water-table altitudes at selected wells were averaged to determine the mean water-table altitude within the study area during the study (1988-93). Water levels were near average during the spring of 1989, but rose rapidly in response to large amounts of precipitation that started in March 1989. (Hydrologic conditions at that time are discussed in the section "Above-Average Water Levels.") The effect of East Meadow Brook on local directions of ground-water flow is seen in the water-level maps shown in figures 9, 10, 13, and 18 (further on in this report). These maps reflect the fluctuations in precipitation during 1988-93; they also indicate the heads in each of the wells at clusters and show contours for the heads measured in the shallowest well of each cluster. The head measurements and water-level contours indicate the vertical hydraulic gradients. Contours bend upgradient at the stream channel, where head data indicate the stream is gaining water, and bend downgradient where head data indicate the stream is losing water.

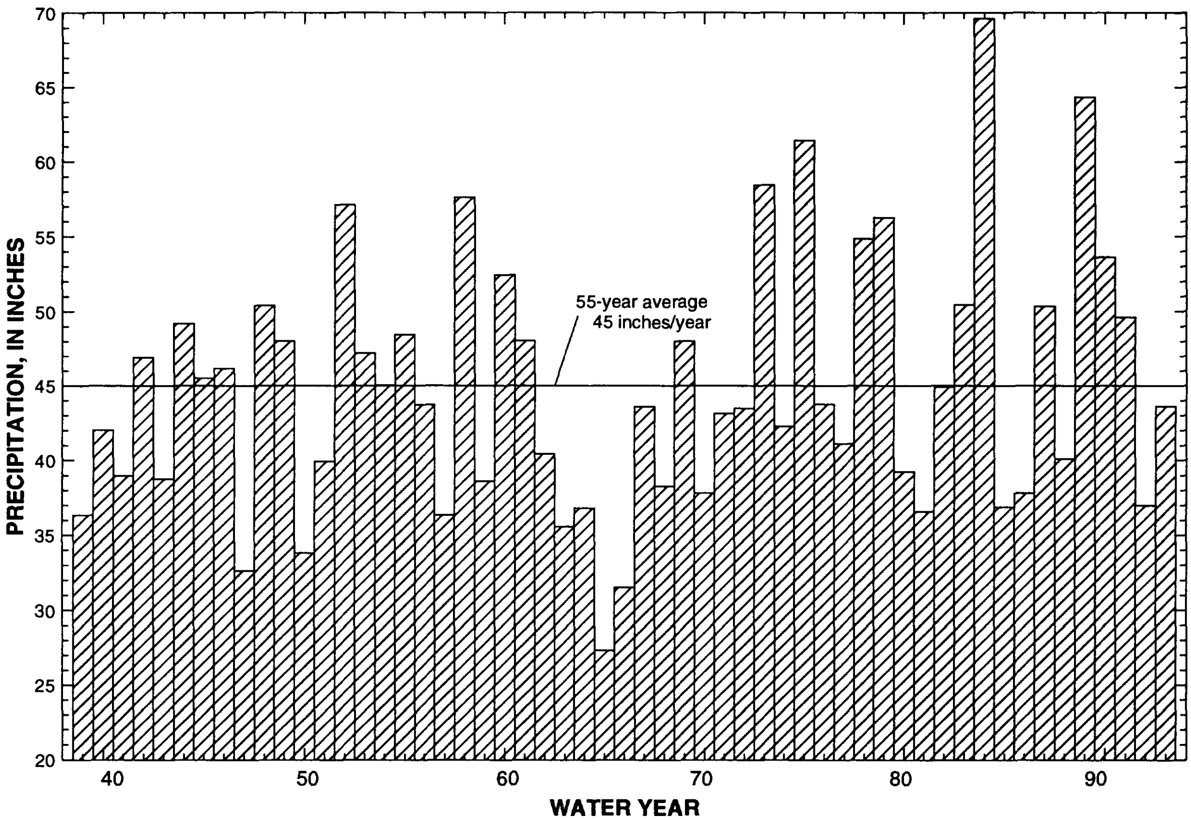
Regional Fluctuations

Annual precipitation at the Mineola station (fig. 1) during water years 1939-93 is plotted in figure 6A. (A water year extends from October 1 of the preceding year through September 30 of the named year.) Precipitation during the period of record averaged about 45 in/yr and ranged from 69 in. in water year 1984 to 27 in. in water year 1965, during the 1962-66 drought. Examination of the 10-year-moving average and standard deviation of precipitation by Scorca (1997) indicated that annual precipitation was greater and more variable during the 1980's than previously. Precipitation in water year 1988 totaled 40 in., about 5 in. below average, and in water year 1989 totaled 64 in., the second highest total on record at the Mineola gage, 19 in. above average. Precipitation totals in water years 1992 and 1993 were below average.

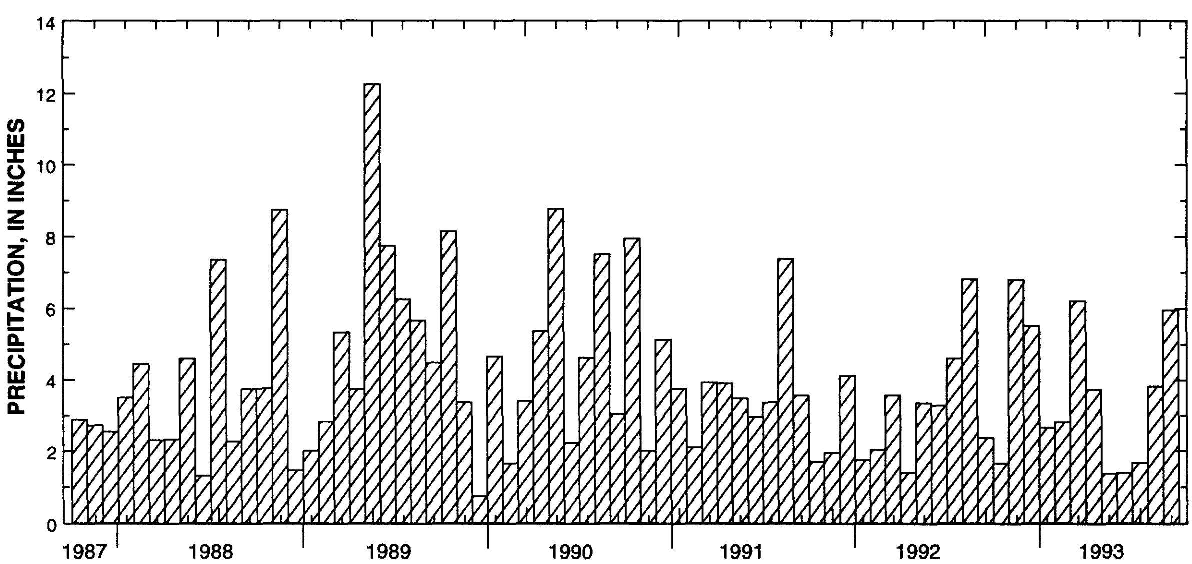
Monthly rainfall totals during water years 1988-93 are presented in figure 6B. Despite a few months of average to above-average precipitation during water year 1988, the annual total was below average. Monthly precipitation was below average during the winter (December 1988 through February 1989), when ground-water recharge is usually at its maximum (Warren and others, 1968). Precipitation increased substantially in the spring of 1989, with monthly totals as much as three times their long-term average, and precipitation totals for 6 consecutive months (from May 1989 through October 1989) were above their long-term monthly averages.

Many storms, especially spring and summer thunderstorms, are local and, thus, can produce differing amounts of precipitation in nearby areas. A review of monthly data indicated little difference in precipitation between Mineola and Eisenhower Park, however.

Water levels in an area outside the stream's influence were monitored at a cluster of three wells (N9239, N9240, N9241) in Eisenhower Park (fig. 7) that was instrumented with water-level recorders. Wells N9240 and N9241 are screened in the deep and shallow parts of the upper glacial aquifer, respectively, and well N9239 is screened in the upper part of the underlying Magothy aquifer. The recorder on well N9240 was not replaced when it malfunctioned during

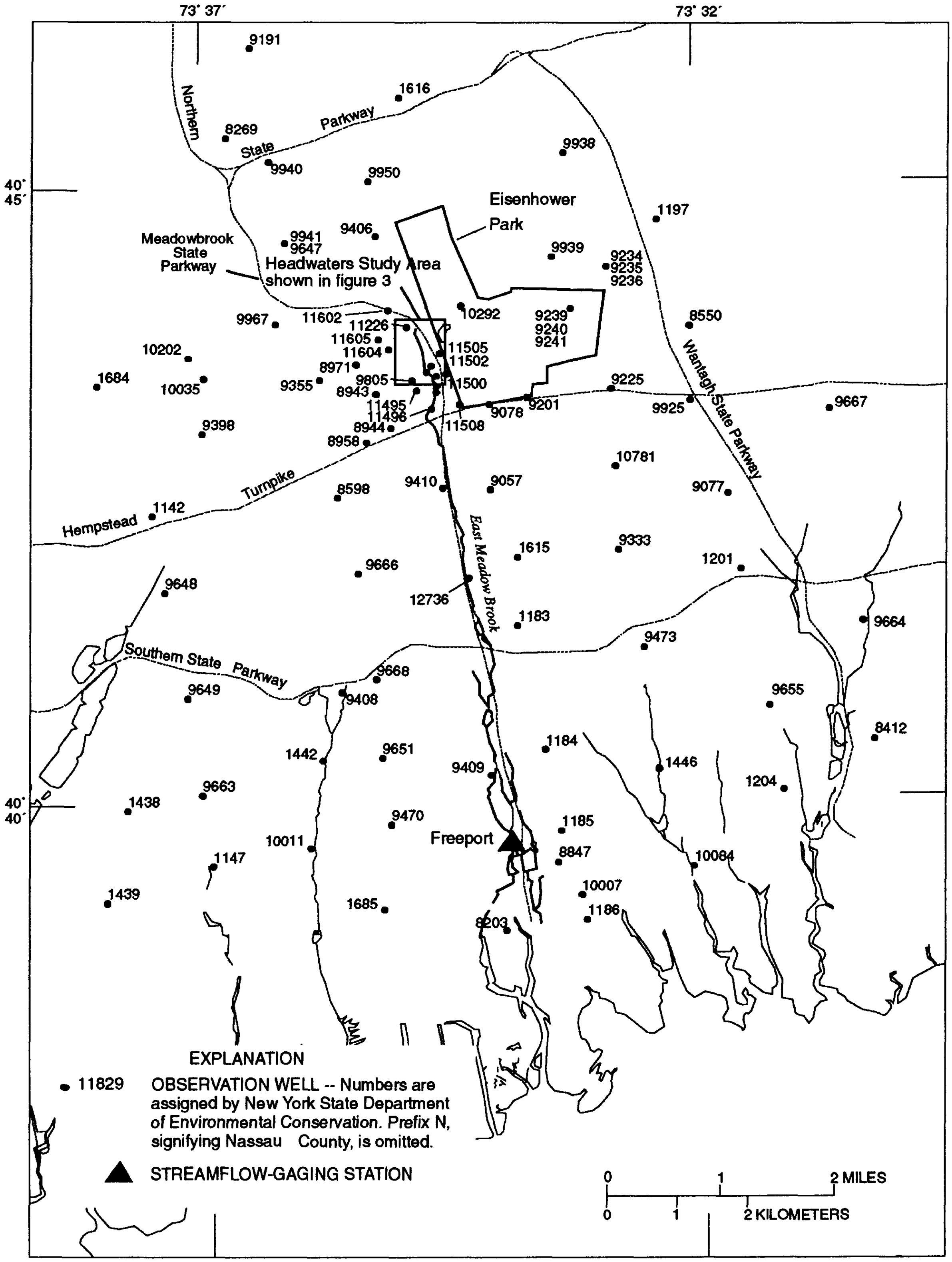


A. ANNUAL PRECIPITATION



B. MONTHLY PRECIPITATION

Figure 6. Precipitation at Mineola, N.Y. A. Water years 1939-93. B. Monthly totals October 1987 through September 1993.



Base digitized from New York State Department of Transportation, 1981, 1:24,000

Figure 7. Locations of wells in regional network, southern Nassau County, N.Y. (Location shown in fig. 2.)

the first year because the water levels at that well were similar to those in adjacent well N9241.

Average daily ground-water levels at these wells, and monthly precipitation (1987-93) at the Mineola station, are plotted in figure 8 to illustrate the response of ground-water levels and base flow to precipitation. Rainfall at Mineola during water year 1988 was about 5 in. below average, and infiltration was below average during this period as a result of storm characteristics, such as duration, intensity, and antecedent soil-moisture conditions; therefore, ground-water levels in the fall of 1988 also were below average. These conditions, combined with the hydrologic effect of Sewer District 3, produced record-low water levels at some wells in southeastern Nassau County during late 1988 and into early 1989 (Scorca, 1997).

The low ground-water levels from late 1988 through early 1989 caused losing-stream conditions along the northern part of the stream. The fine-grained sediments beneath the headwaters study area, which impede ground-water flow, were a major factor in prolonging the losing-stream conditions beyond the duration of storms. Most of the southern reach of the channel in the regional study area was gaining water during that period, however, and base flow at the Freeport streamflow-gaging station averaged about 2 ft^3/s.

Increased precipitation from March 1989 through July 1989 (about 29 in., twice the average amount) caused the water table at Eisenhower Park to rise 6 ft. Precipitation during water year 1990 was about 9 in. above average, and the water table at Eisenhower Park rose an additional 2 ft, to an altitude of 66 ft above sea level during June 1990. Base flow was observed at the headwaters study area after the spring of 1989. As precipitation decreased to a near-average amount in 1991, the water table began a similar decline through the end of 1992 that was temporarily interrupted by slight increases during short periods of above-average precipitation (fig. 8).

Water levels at the two wells screened in the upper glacial aquifer at the well cluster in Eisenhower Park usually differed by less than 0.07 ft during the study period (N9240 is screened 60 ft deeper than N9241); this indicates that the vertical component of flow within the upper glacial aquifer at this site is small. The vertical head difference between the Magothy aquifer (well N9239) and the upper glacial aquifer (well N9241, fig. 8) ranged from about 0.08 to 0.32 ft downward; thus, water from the upper glacial aquifer still flowed downward into the upper part of the Magothy aquifer in this area.

Ground water in the northern half of the regional study area flows south-southwestward from the ground-water divide in northeastern Nassau County, then turns southward near the southern shore. The water-table configuration during September 1988, a period of below-average water levels, and October 1990, a period of above-average water levels, is illustrated in figures 9A and 9B. Although the flow pattern remained fairly constant during that period, water levels rose several feet in response to precipitation; for example, water levels between October 1989 and October 1990 rose about 6 ft in the northern part of the regional study area (near the ground-water divide) and about 2 ft in the southern half of the area.

Water levels in the regional study area were above average from June 1989 through June 1991 and the natural start-of-flow point in East Meadow Brook was north of the main headwaters culverts. The stream was gaining water during this period, and base flow in the headwaters study area and at the Freeport streamflow-gaging station averaged about 1 ft^3/s and 8 ft^3/s, respectively (Stumm and Ku, in press).

Fluctuations within the Study Area

The water-table configuration at the headwaters study area changed with the hydrologic conditions during the project. For example, the upper reach of East Meadow Brook was under losing-stream conditions at the beginning of the project (October 1988 through May 1989), and the stream was flowing only during storms; this water consisted entirely of storm runoff from the Westbury drainage area (fig. 2). About 23 percent of the streamflow during any given storm infiltrated through the streambed and streambanks into the ground-water system within the 1,300-ft reach between the upstream and midstream gaging stations (sites A and B, fig. 3) (Stumm and Ku, in press). In contrast, the above-average rainfall during 1989 and 1990 raised ground-water levels and stream stage, and ground-water discharge provided base flow to the headwaters channel.

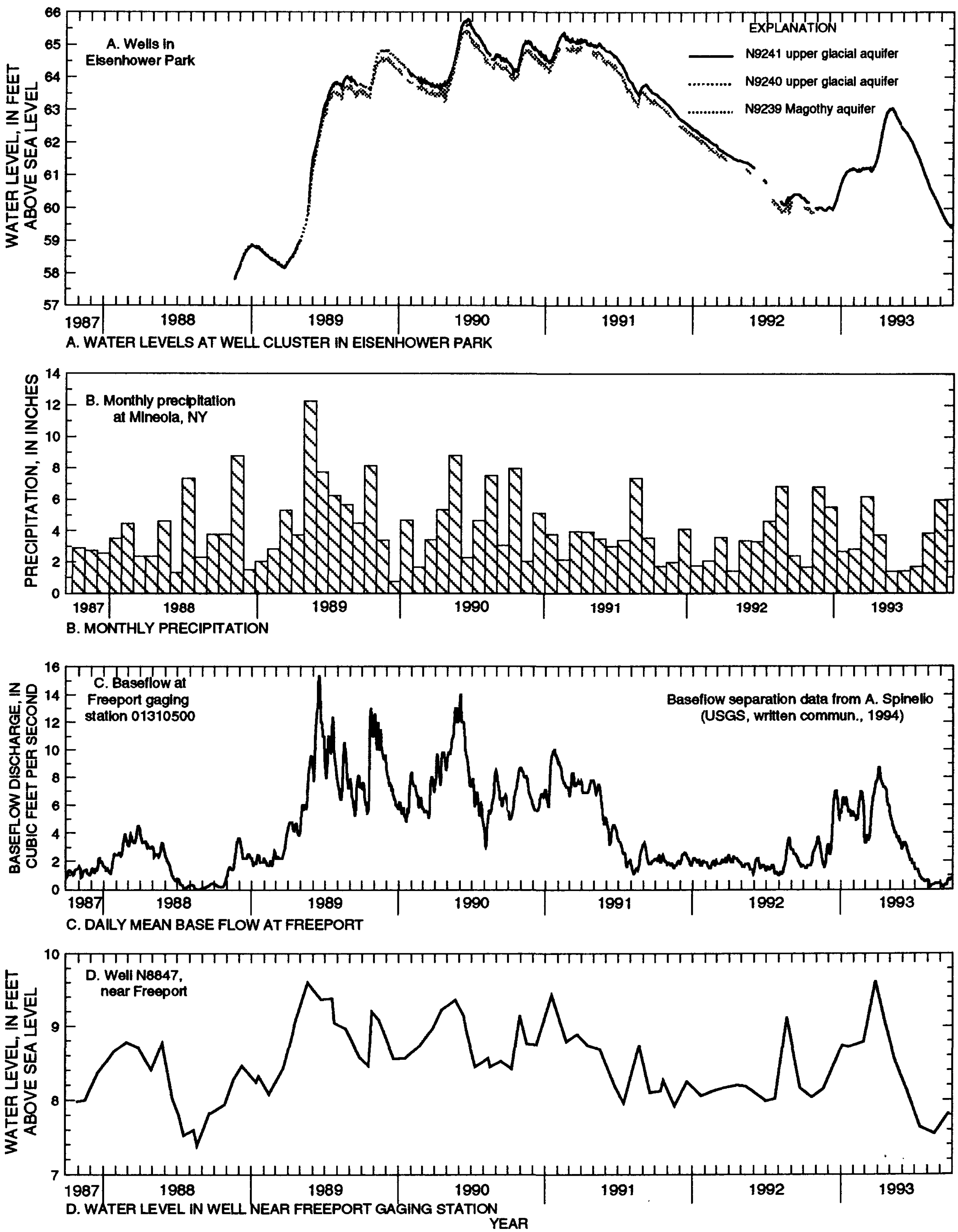


Figure 8. Relation of precipitation to ground-water levels and base flow during water years 1988-93, Nassau County, N.Y.: A. Water levels at well cluster in Eisenhower Park. B. Monthly precipitation at Eisenhower Park. C. Daily average base-flow discharge at Freeport streamflow-gaging station. D. Hydrograph of well N8847 near Freeport streamflow-gaging station.

Below-Average Water Levels (October 1988 through March 1989)

Below-average precipitation during 1988 resulted in low ground-water levels from October 1988 through March 1989 and a 2.5- to 4-ft unsaturated thickness beneath the stream channel. Base flow was absent in the headwaters study area as a result.

A representative water-table map of the headwaters study area for this period (fig. 10) was prepared from water-level measurements made on October 21, 1988, about 12 days after a 1-in rainfall. The regional water-table configuration was significantly altered in the northern half of the study area; a localized mounding of the water table that results from losing-stream conditions is indicated by the elliptical contours. Heads decreased radially away from the stream channel in the northern half of the study area, where the maximum head value (57.34 ft) was measured at well N11235. The fine-grained layers, which impede ground-water movement, were a major factor in prolonging the losing-stream conditions beyond the duration of storms by slowing the downward infiltration of stormwater.

Heads measured in the deep wells at each cluster in the northern part of the headwaters study area were lower than those in the adjacent shallow wells because the underlying fine-grained layers slowed ground-water movement and resulted in downward flow gradients. Water level contours along sections B-B′ and C-C′ (figs. 11A and B) illustrate the magnitude of the gradients. The downward vertical gradients in the northern part of the headwaters study area at that time were also substantially larger than those in the southern part, where no clay is present. Vertical gradients at most well clusters in the northern part of the headwaters study area in October 1988 were downward and ranged from about 0.010 ft/ft (wells N11233 and N11234, fig. 3) to 0.090 ft/ft (wells N11240 and N11241, fig. 3).

Pairs of wells were selected to coincide with flowpaths, estimated from water-level contours, to calculate horizontal ground-water-flow gradients. Each calculated horizontal gradient is only an approximation, however, because (1) water-level contours provide only an estimate of the water level at any location, and (2) wells are not necessarily placed along the direction of maximum flow. Sets of gradients can be used to interpret overall trends in ground-water flow. Most calculated horizontal gradients at the headwaters study area during October 1988 ranged from 0.001 to 0.008 ft/ft, although a few measurements were much higher.

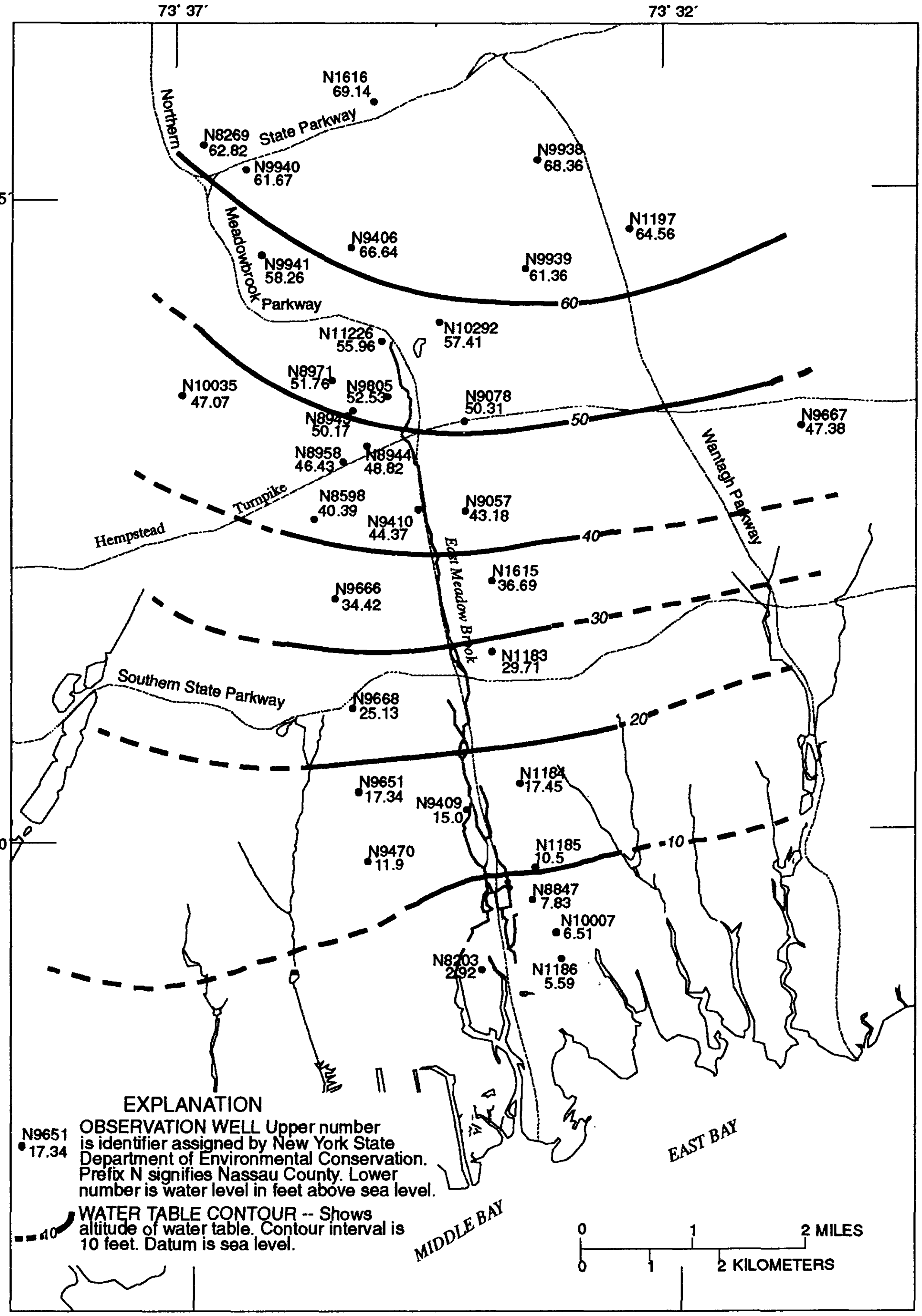
As mentioned previously, fine-grained layers are absent or less extensive in the southern half of the headwaters study area than in the northern half. Water levels in wells N11248.2 and N11249.2 in the southern part of the study area west of the stream were equal, or very close, to each other during all measurements (fig. 12) because no clay layers that would inhibit flow are present, and water levels can equalize through most of the thickness of the water-table aquifer once they have stabilized after storms. Vertical gradients at most well clusters in the southern part of the headwaters study area were less than 0.005 ft/ft, except at wells N11252 and N11253, which are in the stream channel and could be slightly affected by a thin, fine-grained layer (fig. 5A).

Above-Average Water Levels (March 1989 through December 1990)

Water levels began to rise in March 1989 in response to the above-average precipitation that continued through 1990 (fig. 9). By summer 1989, water levels in wells at the stream had risen 2 to 3 ft higher than their March 1989 levels, and the water table intersected the streambed in the headwaters study area, providing base flow. As the water table rose, the mounding that had resulted from infiltration during losing-stream conditions became less distinct. Water levels in June, August, and October 1989 and in October 1990 are depicted in figure 13.

Horizontal ground-water flow gradients in the regional flow system are south-southwestward; thus, the main component of flow beneath the headwaters study area is directed across the stream, as illustrated in figure 14 (sections B-B′ and C-C′, transverse to the stream), where shallow heads generally decrease westward, and little or no flow enters the stream from the west side as a result. Vertical gradients at most well clusters on both sides of the stream are downward; thus, in general, flow moves southwestward below the stream and downward.

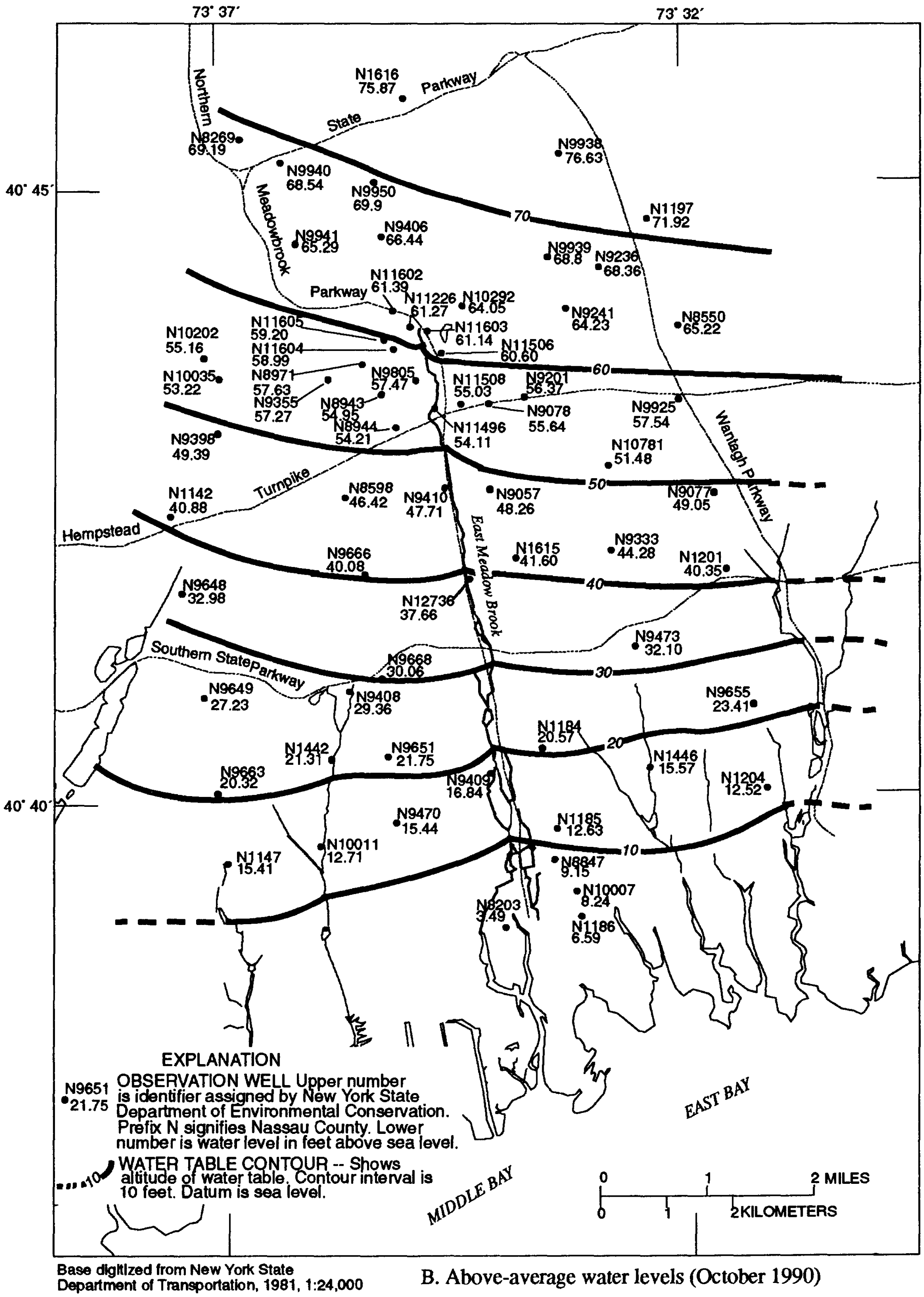
Some characteristics of both losing- and gaining-stream conditions were present at the same time in differing parts of the headwaters study area as a result of (1) the above-average precipitation from frequent storms and the attendant above-average ground-water recharge, and (2) the flow-retarding effects of clay



Base digitized from New York State Department of Transportation, 1981, 1:24,000

A. Below-average water levels (September 15 to October 14. 1988)

Figure 9A. Regional water-table altitude in southern Nassau County, N.Y., October 1988.



B. Above-average water levels (October 1990)

Figure 9B. Regional water-table altitude in southern Nassau County, N.Y., October 1990.

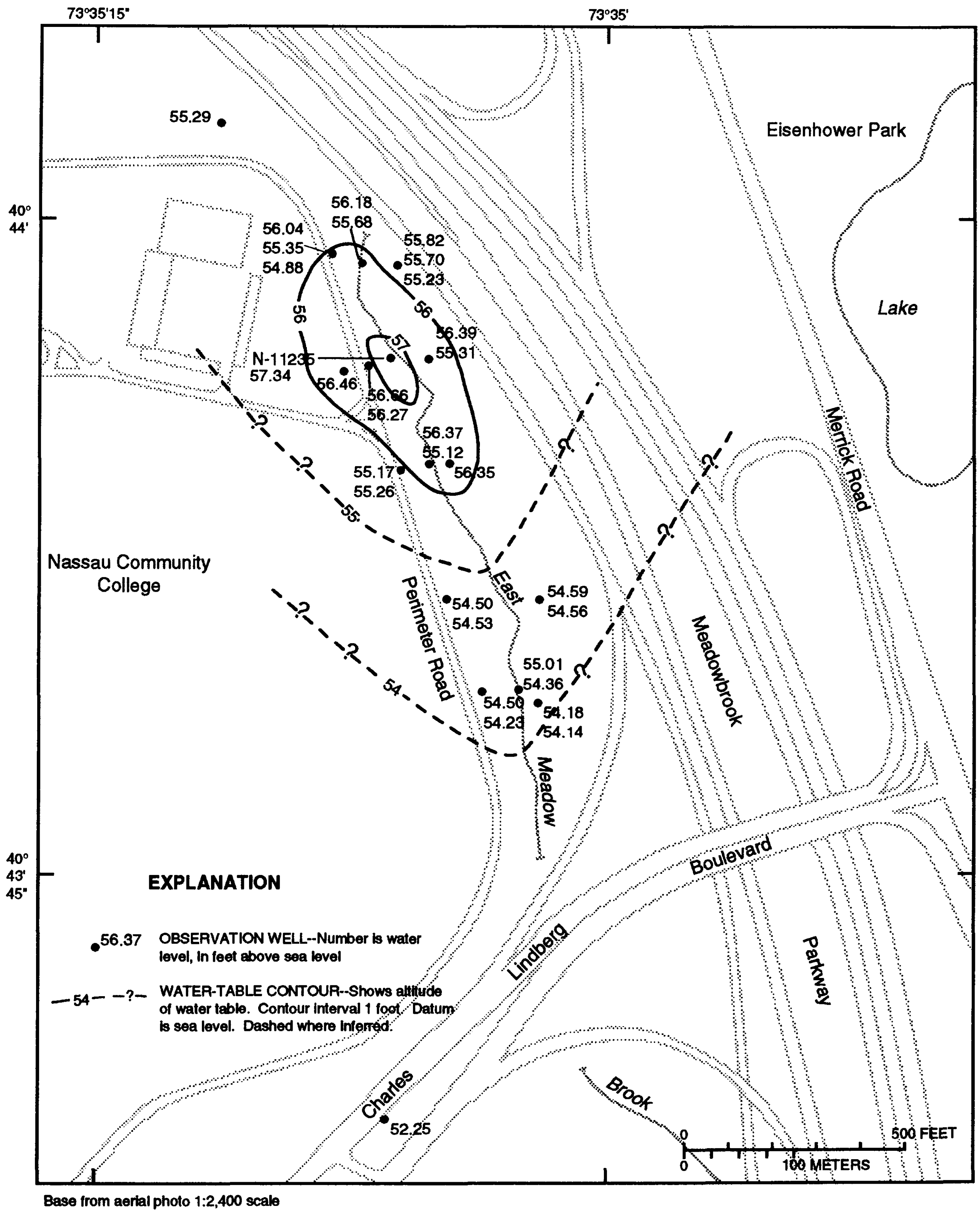
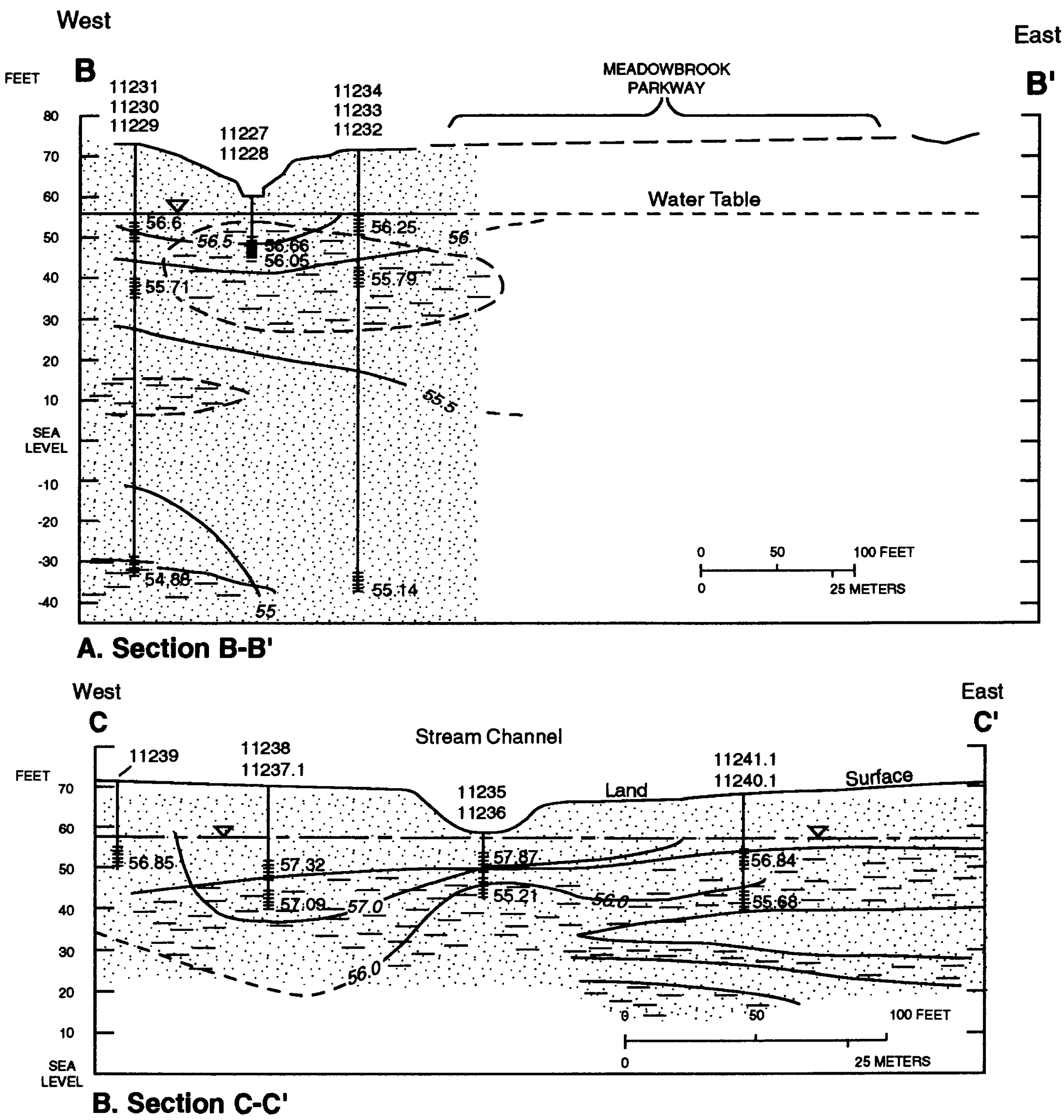


Figure 10. Water-table altitude at East Meadow Brook headwaters study area, Nassau County, N.Y., in October 1988. (Well numbers and locations are given in fig. 3.)



EXPLANATION

11239 / 56.85 TRACE OF MONITORING WELLS -- Shows screen zones. Clustered wells at a site are shown along one trace. Number is water level, in feet above sea level. Well numbers assigned by NYSDEC are listed above well trace in order of increasing depth. Prefix N signifying Nassau county is omitted.

56 WATER-LEVEL CONTOUR -- Datum is sea level. Dashed where inferred.

FINE-GRAINED UNITS

SAND UNITS

Figure 11. Ground-water levels along sections B-B′ and C-C′ of the East Meadow Brook headwaters area during October 1988. (Trace of sections and well locations are shown in fig. 3.)

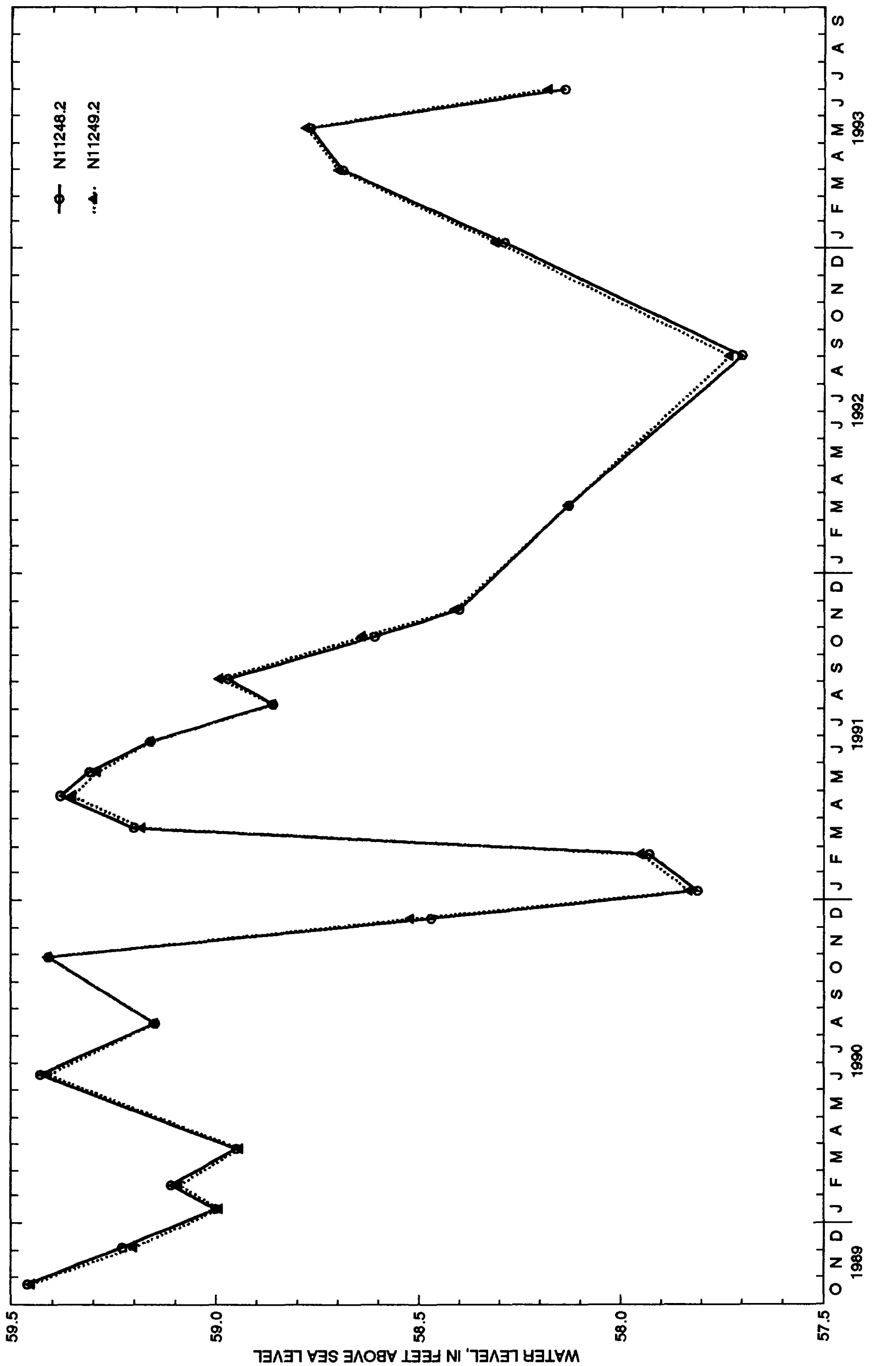


Figure 12. Water-levels at wells N11248.2 and N11249.2, Nassau County, N.Y., 1989-93. (Locations are shown in fig. 3.)

layers near the stream in the northern half of the study area. For example, vertical hydraulic gradients were upward at some well clusters and downward at others during the dry period of August 1989 (fig. 13B), and horizontal flow was toward the stream in some parts of the headwaters study area and away from it in other parts. The reason that losing- and gaining-stream conditions could occur simultaneously was that more than 5 in. of rain fell 2 days before the water levels were measured, and the water-level response in the aquifer was more rapid in the southern part of the headwaters study area, where clay layers are absent, than in the northern part, where clay layers impede the water-level response to recharge.

Two months later, during October 1989, vertical gradients at wells along section B-B′ were downward, but heads in the shallow wells of each cluster indicate a slight horizontal gradient toward the stream (fig. 13C), which denotes slightly gaining-stream conditions. Flow along section C-C′ (fig. 15B) was toward the stream from both sides. In addition, an upward vertical gradient was observed at wells N11237 and N11238 on the west side of the stream, where the water level in the deeper well was higher than in the adjacent shallow well.

A year later, in October 1990, the main component of regional ground-water flow was still south-southwestward, but the slight upgradient bend in water-level contours near the streambed at each line of section in the headwaters study area (fig. 13D) indicates a continued gaining condition. Horizontal gradients between selected pairs of wells were about 0.002 ft/ft during this month, which is at the low end of the range observed during October 1988, when water levels were below average. Vertical head gradients were mostly about 0.002 ft/ft but ranged as high as 0.006 ft/ft and were mostly upward. Vertical gradients during the period of above-average water levels generally were only one-tenth as large as they had been during the period of below-average water levels; this is why the density of water-level contours in vertical sections is lower when the water-table altitude is above average (fig. 15) than when it is below average (fig. 11).

Base flow of about 1 ft^3/s was measured at two stations at the headwaters study area during periods when the water table intersected the streambed (Stumm and Ku, in press). Most of the flow entered the stream from the east side as a result of (1) the orientation of the stream with respect to the water table, and (2) the prevailing horizontal and vertical gradients, but flow from the west side was possible during periods when the water table was high and vertical flow gradients were upward (figs. 13C, 13D). Upward vertical gradients were observed in October 1990 at well clusters along section C-C′ (fig. 16B), where heads in deep wells were greater than in the adjacent shallow wells; some base flow also entered the stream from the west side because horizontal and vertical gradients were toward the stream from both sides.

Gaining-stream conditions predominated until June 1991. Water levels began to decline steadily in the spring of 1991 and dropped below average after the fall of 1991.

Hydrologic Effects of Dewatering and Flow Augmentation

A dewatering project and a leaking water main near the headwaters study area affected local hydrologic conditions for short periods of the study. From December 1990 through February 1991, construction of a steampipe to a nearby building required temporary installation of a dewatering-well system near the southern part of the headwaters study area; this resulted in a maximum drawdown of ground water (7.74 ft) at well N11504 (location is shown in fig. 3). Drawdowns in wells in the northern part of the headwaters study area generally were less than 0.5 ft, but horizontal flow gradients along the east side of the stream were diverted eastward, away from the stream. Drawdowns generally were greatest in the deepest well of a given cluster, especially in the northern part of the headwaters study area. By February 1991, the water table in the southern part of the headwaters study area had declined below the streambed, and no base flow entered the stream in this area. After the dewatering system was relocated during early spring 1991, gaining-stream conditions redeveloped in April and May, and most horizontal and vertical gradients were again toward the stream.

In June 1991, a water main north of the headwaters study area broke and discharged water into the storm-sewer network that flows into the main headwaters culverts of East Meadow Brook. During the next 3 months, the leak was a constant source of water to the stream. Stream stage rose, and streamwater infiltrated to the aquifer along the length of stream in the headwaters study area. Ground-water flow gradients

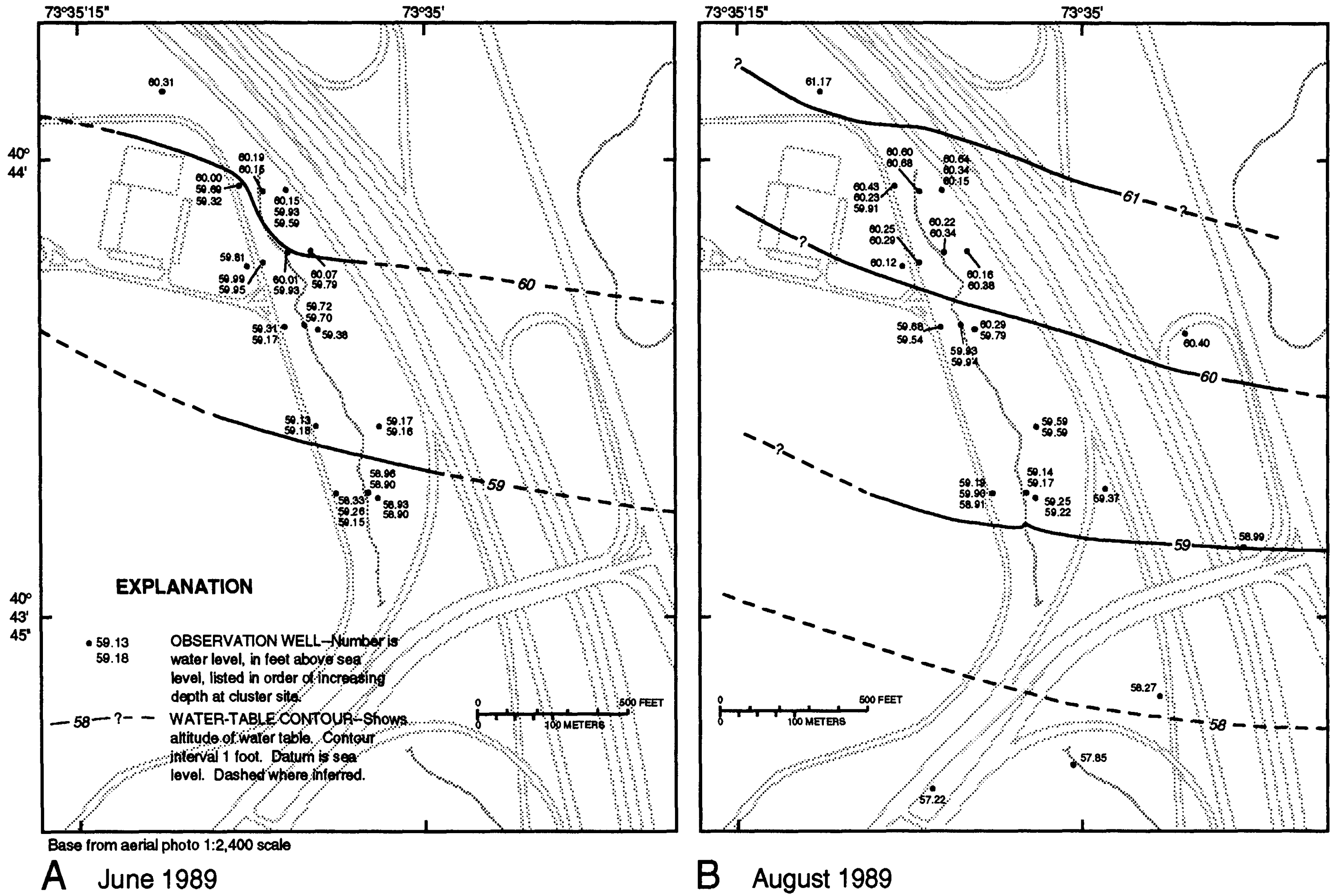


Figure 13. Water table at the East Meadow Brook headwaters area, Nassau County, N.Y.: A. June 1989. B. August 1989.

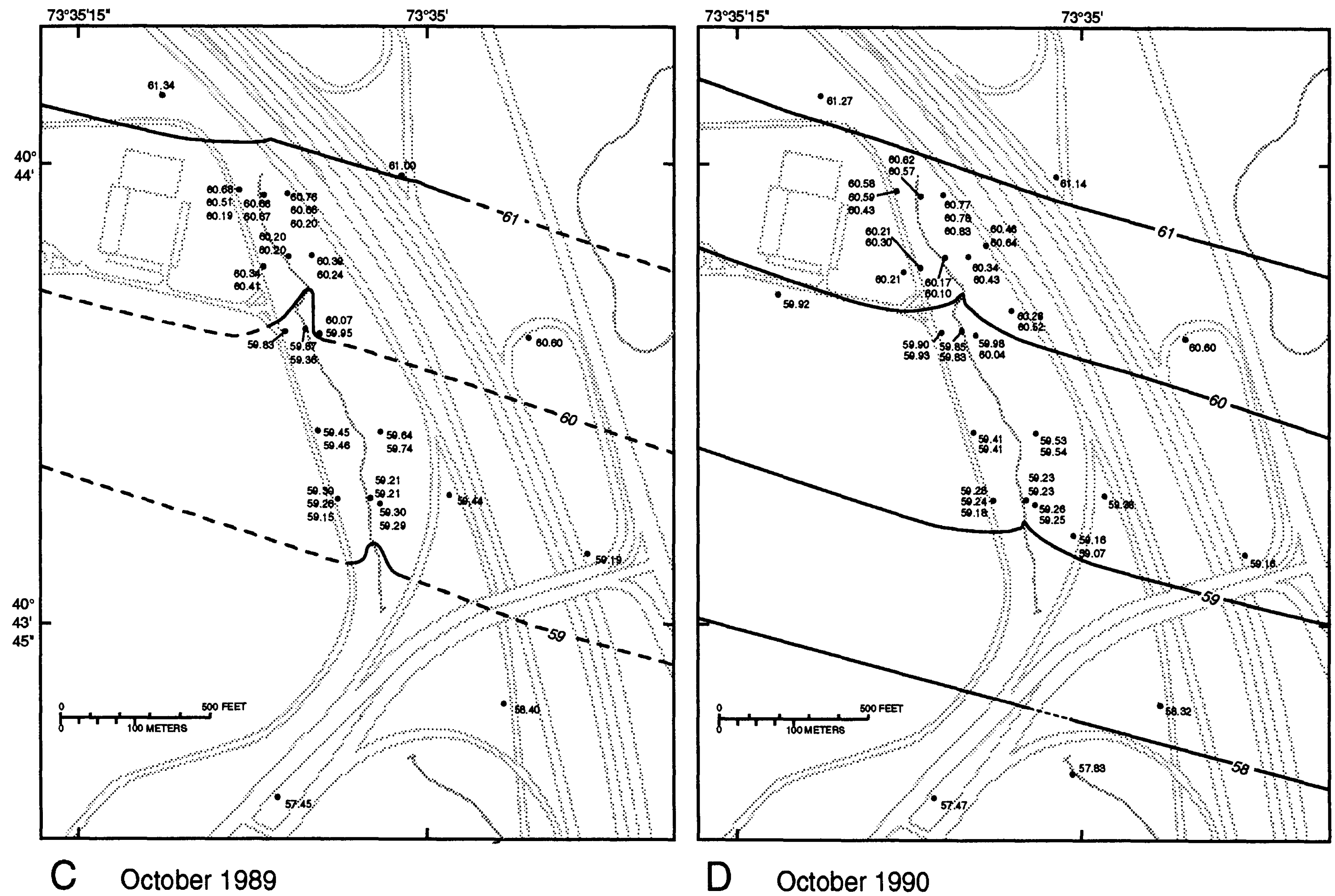


Figure 13 (continued). Water table at the East Meadow Brook headwaters area, Nassau County, N.Y.: C. October 1989. D. October 1990.

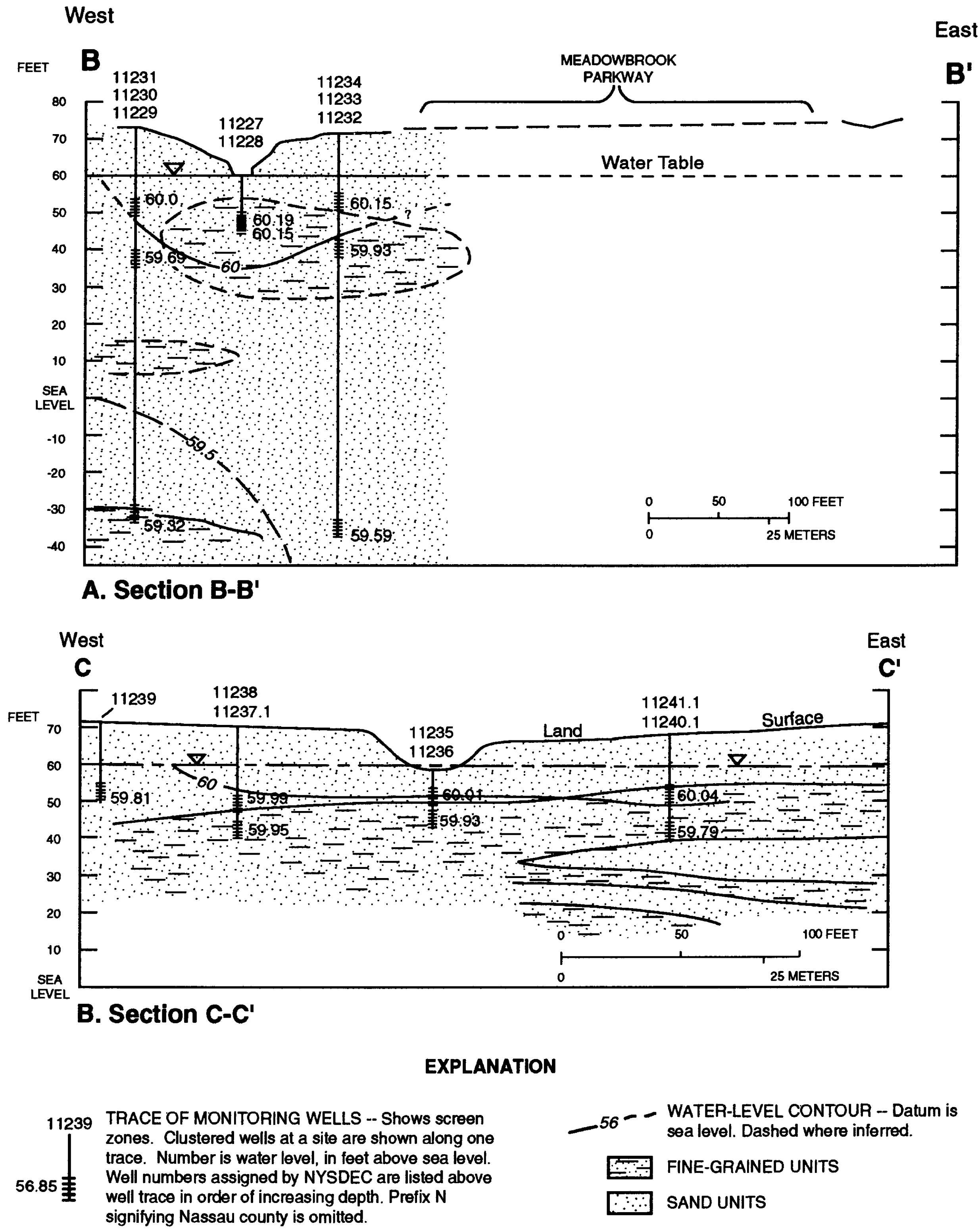


Figure 14. Vertical sections at the East Meadow Brook headwaters area, Nassau County, N.Y., showing water levels in June 1989: A. Section B-B′. B. Section C-C′.

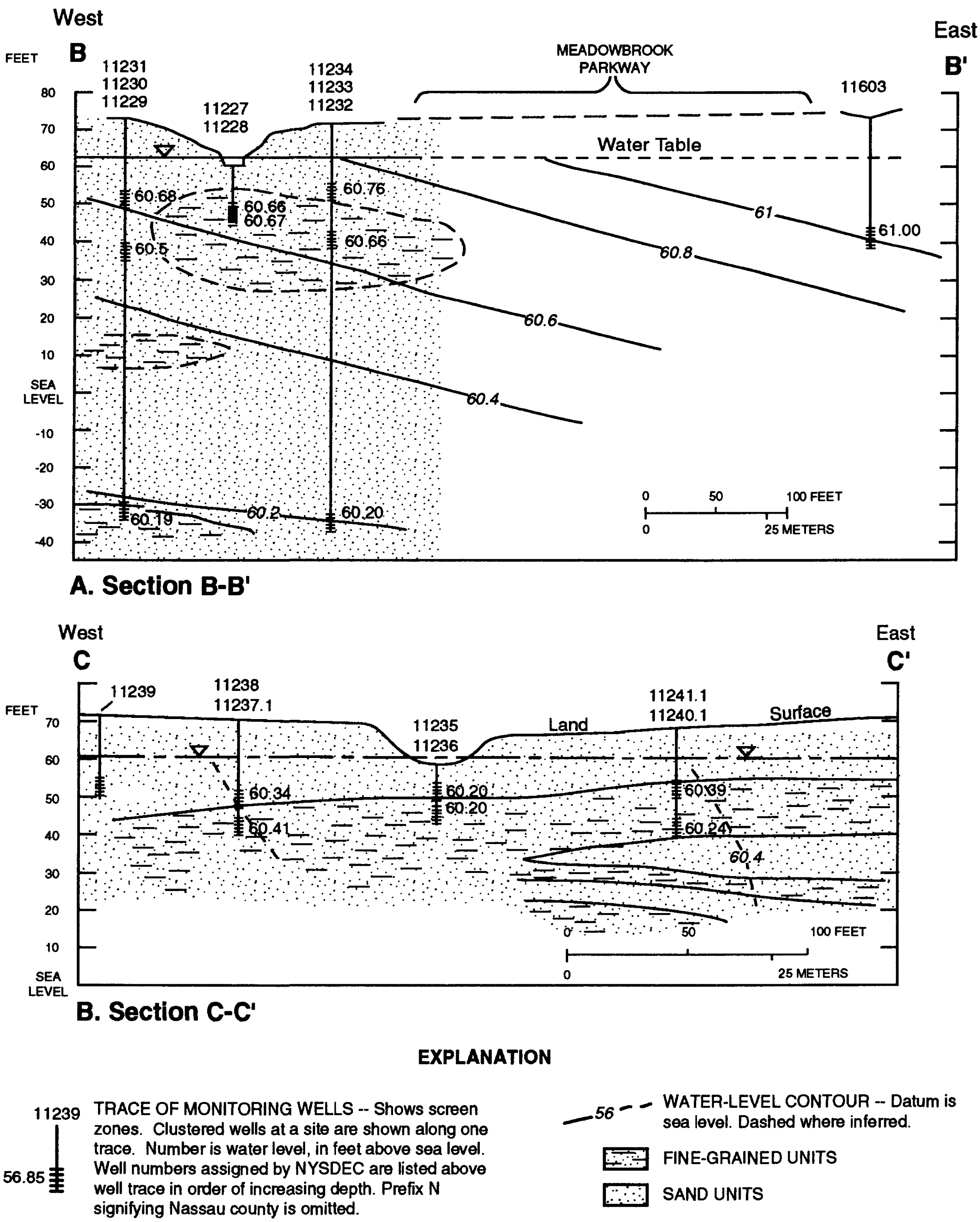
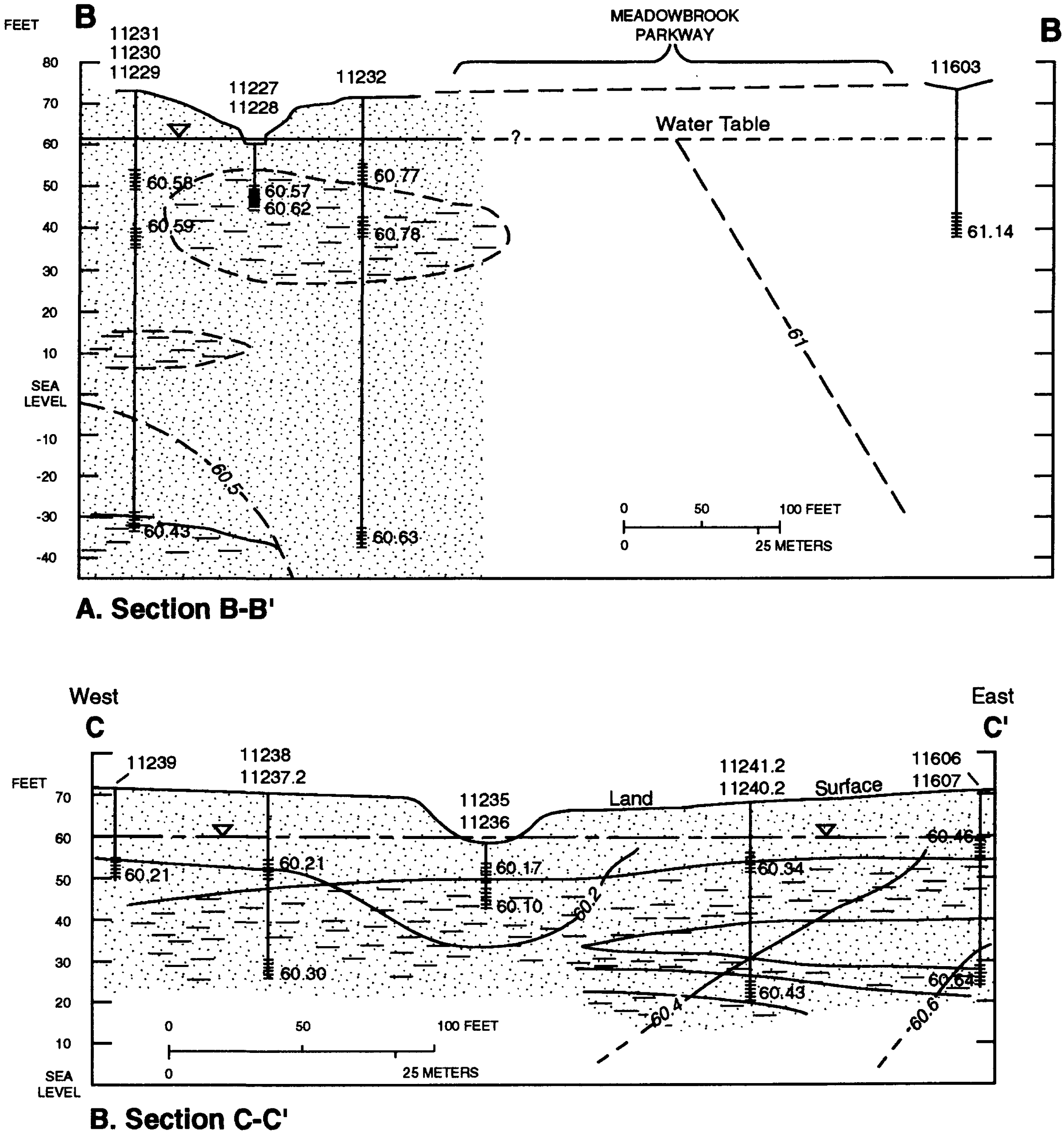


Figure 15. Vertical sections at the East Meadow Brook headwaters area, Nassau County, N.Y., showing ground-water levels in October 1989: A. Section B-B′. B. Section C-C′. (Locations are shown in fig. 3.)



EXPLANATION

11239 / 56.85 TRACE OF MONITORING WELLS -- Shows screen zones. Clustered wells at a site are shown along one trace. Number is water level, in feet above sea level. Well numbers assigned by NYSDEC are listed above well trace in order of increasing depth. Prefix N signifying Nassau county is omitted.

56 WATER-LEVEL CONTOUR -- Datum is sea level. Dashed where inferred.

FINE-GRAINED UNITS

SAND UNITS

Figure 16. Vertical sections at the East Meadow Brook headwaters area, Nassau County, N.Y., showing ground-water levels on October 29-31, 1990: A. Section B-B′. B. Section C-C′.

were outward and downward away from the stream (characteristic of a losing stream).

After the water main was repaired in September 1991, another artificial source of inflow to the headwaters study area was observed—at least one ground-water-remediation system for a gasoline-filling station discharged treated water into the storm-sewer network north of the headwaters study area (B.J. Schneider, Nassau County Department of Public Works, oral commun. 1991) and produced streamflow at the main headwaters culverts of East Meadow Brook. This discharge was less than that during the water- main break, and its effects were difficult to quantify because hydrologic conditions had changed since the preceding spring. Despite the added discharge, water levels in background wells declined steadily through the end of 1991 and through most of 1992 (fig. 8), and losing-stream characteristics redeveloped as the water table declined below the streambed. Thus, all of the artificially derived discharges that entered the stream at the main culverts infiltrated through the streambed within the headwaters study area, and none reached as far as site D (fig. 3) during the periods of water-level measurement from November 1991 through June 1992 (table 1).

Although losing-stream conditions would have redeveloped as the water table in the headwaters study area declined below the streambed, the magnitude of the downward vertical gradients at the study area could have increased as a result of the infiltration of the artificially derived streamflow. Water levels in the deepest well of two well clusters in the northern part of the headwaters study area (N11240.2 and N11244.2, fig. 3) declined more quickly than those in the shallowest well of each cluster (N11241.2 and N11245.2, fig. 17).This is attributed to the fine-grained layers, which impede vertical flow and produced an increased flow gradient from the added recharge.

Hydrologic Effects of Stormflow-Detention Basin

Construction of the 7-acre, unlined stormflow-detention basin began in August 1992, and the basin was fully functional by November 1992 (B.J. Schneider, Nassau County Department of Public Works, written commun., 1993). The basin is 1,200 ft long and ranges from about 100 ft to 300 ft in width (fig. 18). Soil was excavated to establish a bottom altitude of 58 ft above sea level, and the steel sheet-pile dam was installed at the south end of the basin during October 1992. The basin was designed to retain about 7 Mgal of stormwater for infiltration to the ground-water system. Construction disrupted operation of the four streamflow-gaging stations at the headwaters study area and prevented reestablishment of a streamflow-gaging network.

As mentioned previously, the headwaters reach was under losing conditions at the beginning of the project in 1988, when the water table was low, but became a gaining reach as the water table rose during 1989. Losing-stream conditions redeveloped in 1991, the year before basin construction, as near-average precipitation caused the regional water table to decline. Hydrologic conditions after completion of the basin were similar to the losing-stream conditions observed before basin construction but differ in that: (1) the water-table mound is wider and longer, (2) the water table is higher, (3) the basin intersects the water table and contains water at all times, and (4) ground-water flow gradients are larger.

The effect of the basin on ground-water flow was assessed through a review of data to select a period before basin construction during which ground-water levels were similar to those during a selected period after construction. Ground-water levels in May 1993 were closest to those measured during the pre-construction period in October 1991 (fig. 17), and discharge from the gasoline-remediation system(s) was entering the stream at the main culverts during both periods. This inflow could not be quantified after basin construction but is likely to have been similar during both periods.

Ground-water flow gradients were outward and downward away from the stream during both periods. Impoundment by the dam raised the water stage in the basin to about 60.5 ft above sea level during May 1993, about 2.5 ft above the bottom of the basin. The water-table mound is estimated to have increased in width after basin construction because the basin facilitates recharge over a wider area than the streambed did before construction. The stream overflowed its banks during some storms before construction, when the stream channel was only about 15 ft across; the basin now ranges from 7 to 20 times as wide.

The local water-table altitude rose about 0.5 ft in the northern half of the headwaters study area after basin construction. Although water levels within each of three nearby background wells (N11618, N9805, and N11603) in October 1991 were within 0.07 ft of

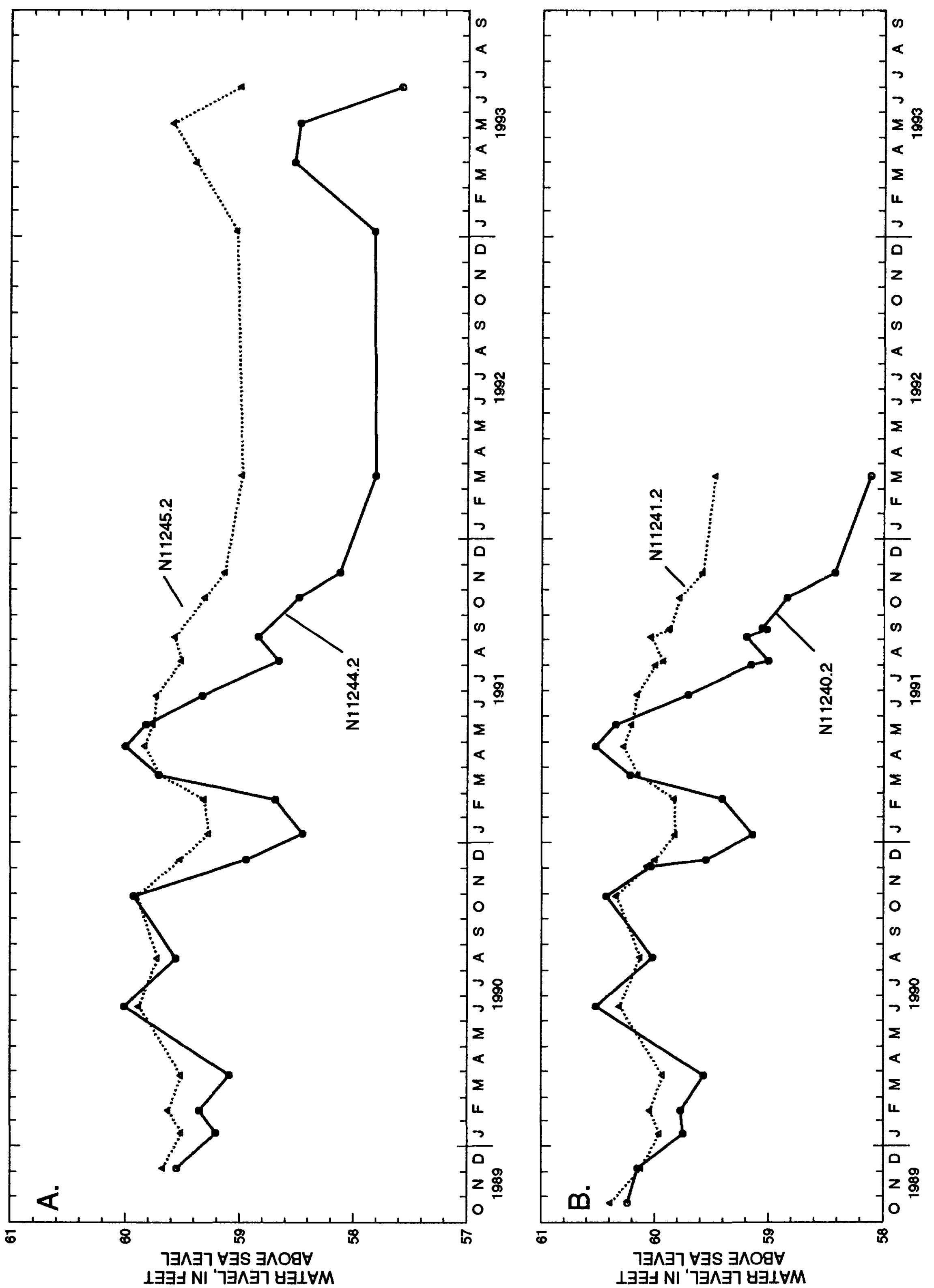


Figure 17. Water levels in shallow and deep wells at two well clusters in northern part of the East Meadow Brook headwaters area, Nassau County, N.Y., 1989-93. A. Wells N11244.2 and N11245.2. B. Wells N11240.2 and N11241.2. (Well locations are shown in fig. 3.)

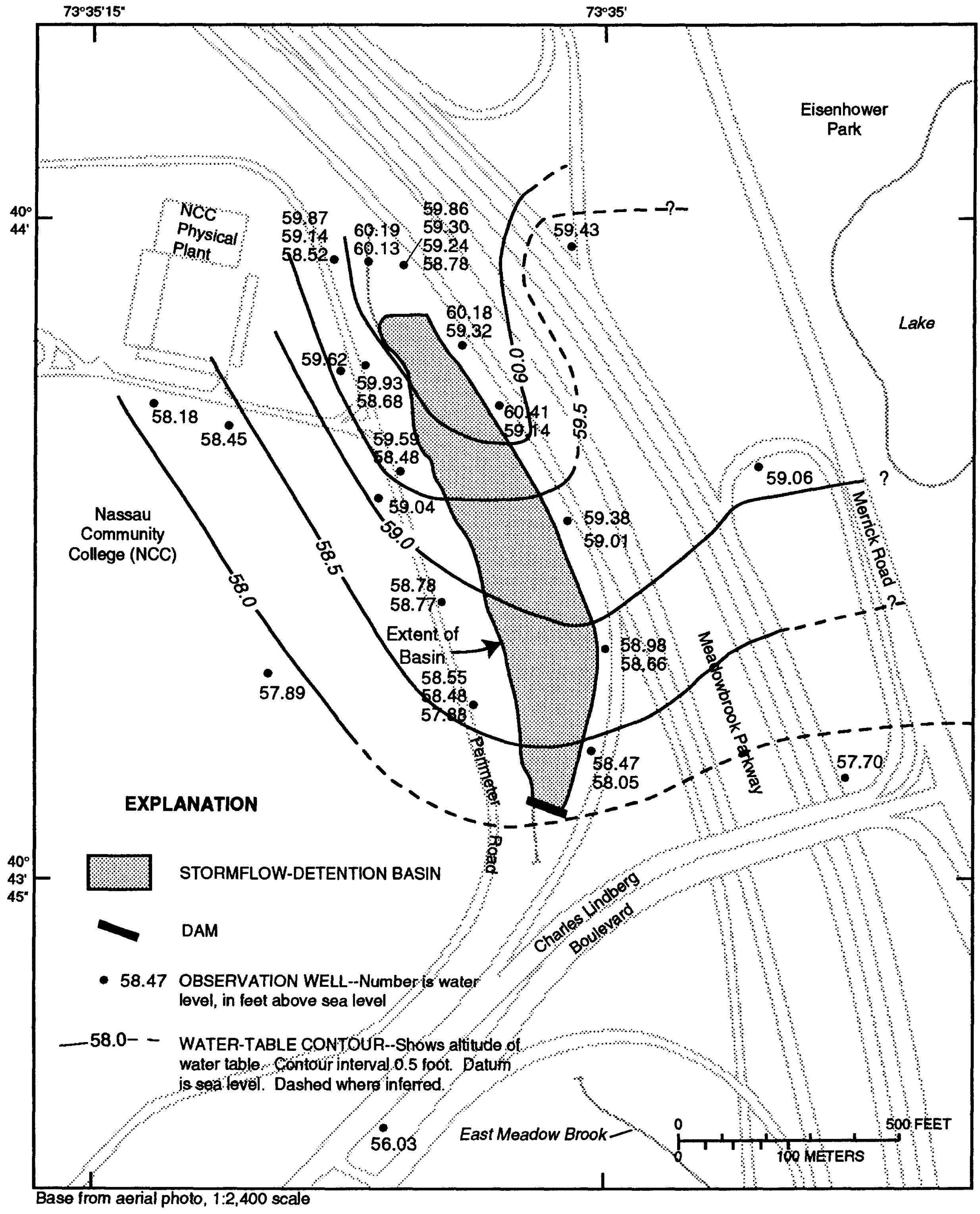


Figure 18. Water-table altitude at the East Meadow Brook headwaters area, Nassau County, N.Y., after construction of stormflow-detention basin, May 1993.

those in May 1993, water levels in the shallowest well of clusters on the basin's western perimeter rose about 0.15 ft in the southern part of the headwaters study area and about 0.5 ft in the northern part. This difference is attributed to the fine-grained layers in the northern part of the study area, which retard flow and cause water to move away from the area more slowly than in the southern part, thereby increasing the water-table altitude.

Some water has been present in the basin at all times since construction because the local water table intersects the basin floor. Water levels at wells in the northeastern part of the basin (N12283, N12284) also were above the bottom elevation of the basin; thus, ground water discharges into the basin in that area also. During May 1993, the water stage in the basin reached about 60.5 ft above sea level.

Westward horizontal flow gradients along estimated flow directions between selected pairs of wells during May 1993 (after basin construction) were calculated and ranged from about 0.002 to 0.0035 ft/ft—slightly greater than those observed during periods of average to above-average water levels before basin construction in October 1991 (about 0.0025 ft/ft) and in October 1990 (0.001 to 0.002 ft/ft). In contrast, most horizontal flow gradients in October 1988, when the water table was about 2.5 ft lower than during May 1993, ranged from 0.002 ft/ft to 0.008 ft/ft.

Vertical flow gradients in the northern half of the headwaters study area during May 1993 (fig. 19) ranged from 0.025 to 0.073 ft/ft and were generally larger than those observed in October 1991 (0.021 to 0.038 ft/ft). The vertical gradient is related to the amount of fine-grained sediments around a well, which can be inferred from gamma logs (fig. 5).The vertical gradient measured at all well clusters in May 1993 was greater than the gradient measured during October 1991, before construction of the basin. In May 1993 vertical gradients observed in the southern half of the headwaters study area were 0.001 to 0.017 ft/ft, similar to those observed in October 1991 (0.003 to 0.024 ft/ft).

In summary, hydrologic conditions after completion of the basin are similar to the losing-stream conditions observed before basin construction, but differences include: (1) an increase in the width of the local water-table mound, (2) a water-table rise of about 0.5 ft in the northern part of the headwaters study area, (3) continuous water in the basin as a result of intersected water table, and (4) the magnitude of ground-water flow gradients, which, during May 1993, ranged from 0.002 to 0.0035 ft/ft horizontally and from 0.001 to 0.073 ft/ft vertically.

SUMMARY AND CONCLUSIONS

A 7-acre, unlined stormflow-detention basin was constructed in 1992 at the headwaters of East Meadow Brook to impound storm runoff and thereby increase ground-water recharge and streamflow. Ground-water data were collected before and after basin installation to document the effects on local ground-water levels.

The U.S. Geological Survey established a network of new and previously installed observation wells near the stream and monitored ground-water levels. The new wells were installed in clusters in the headwaters study area, and gamma-ray logs were collected from the deepest well of each cluster. The logs indicate that fine-grained sediments are discontinuous or absent in the southern half of the headwaters study area but are present directly below the stream and at some well clusters as far as 200 ft from the stream in the northern part.

The water-table configuration in the headwaters study area reflected the changing hydrologic conditions during the 1988-93 project. Precipitation at Mineola, about 3.5 mi west of the headwaters, in water year 1988 was about 5 in. below average, and the area was under losing-stream conditions. Ground-water levels declined below the streambed, and base flow ceased. Ground-water flow gradients were downward and outward away from the stream and ranged from 0.001 ft/ft to 0.008 ft/ft horizontally and from 0.01 ft/ft to 0.09 ft/ft vertically.

Precipitation in water year 1989 reached its second highest total on record and was about 9 in. above average in water year 1990. From March through June 1990, the water table rose 8 ft at a well cluster in Eisenhower Park, east of the headwaters study area. At the headwaters study area, the water table rose higher than the streambed, causing base flow to resume. During periods of above-average water levels before basin construction, ground-water flow gradients were about 0.002 ft/ft horizontally and ranged from 0.002 ft/ft to 0.006 ft/ft vertically.

Nearby construction work during the study affected local hydrologic conditions temporarily. During the winter of 1990-91, construction activities at a nearby building required installation of a dewatering

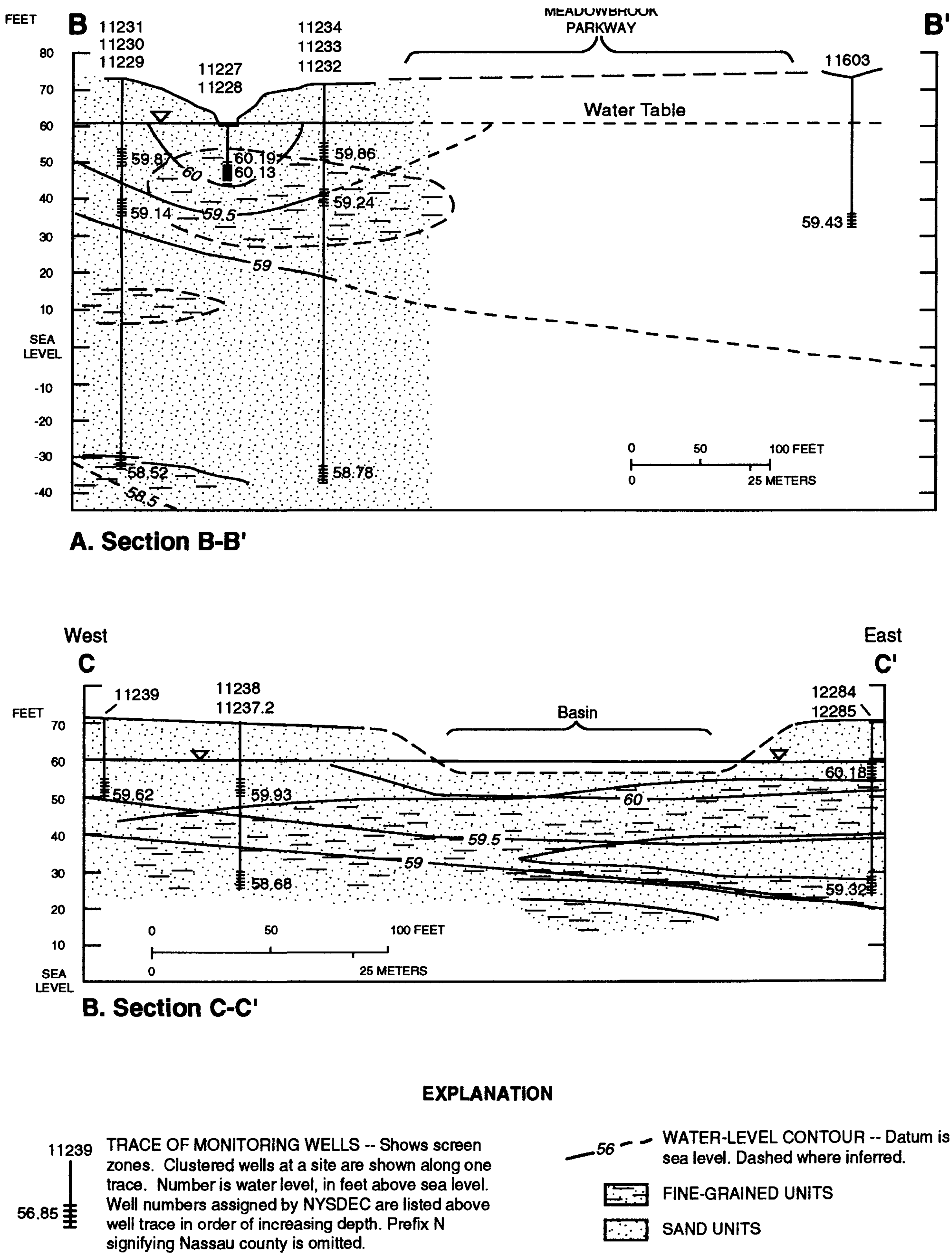


Figure 19. Vertical sections at the East Meadow Brook headwaters area, Nassau County, N.Y., showing water levels in May 1993: A. Section B-B′. B. Section C-C′.

system, and during the summer of 1991, a water main broke and discharged into the storm-sewer network that flows into the main headwaters culverts of East Meadow Brook. After the water main was repaired, water pumped from at least one gasoline-filling station's ground-water-remediation system north of the headwaters study area discharged treated water into the storm-sewer network.

Basin-construction activities disrupted the four streamflow gages at the headwaters study area and prevented subsequent continuous measurement of streamflow; ground-water and water-quality data that were not dependent on streamflow were collected for 1 year after the basin was excavated. Hydrologic conditions after completion of the basin were similar to the losing-stream conditions observed before basin construction except for: (1) an increase in the width of the local water-table mound, (2) a 0.5-ft rise in the water-table altitude in the northern part of the headwaters study area, (3) the continuous presence of water in the basin, and (4) the magnitude of ground-water flow gradients, which, during May 1993, ranged from 0.002 to 0.0035 ft/ft horizontally and from 0.001 to 0.073 ft/ft vertically.

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Table 3. Physical descriptions of wells in study area, Nassau County, N.Y.
[--, no data available. Depths are in feet below land surface]

Well number	Latitude	Longitude	Aquifer	Measuring point (feet above sea level)	Land surface altitude (feet above sea level)	Depth	Depth to screen Top	Depth to screen Bottom	Screen length (feet)
N1142.4	404231	733747	GLACIAL	62.26	62	35	32	35	3
N1147.2	403942	733713	GLACIAL	26.91	27	24	21	24	3
N1183.3	404136	733407	GLACIAL	49.73	50	31	29	31	2
N1184.3	404036	733351	GLACIAL	32.30	32	31	26	31	5
N1185.3	403957	733342	GLACIAL	21.10	21	18	15	18	3
N1186.2	403914	733327	GLACIAL	10.11	10	23	20	23	3
N1197.4	404453	733239	GLACIAL	116.05	117	69	64	69	5
N1201.3	404202	733151	GLACIAL	55.90	56	30	26	30	4
N1204.2	404015	733127	GLACIAL	21.20	21	40	37	40	3
N1438.2	404009	733804	GLACIAL	35.27	35	28	--	--	--
N1439.2	403925	733817	GLACIAL	26.77	27	29	26	29	3
N1442.3	404032	733606	GLACIAL	29.08	29	24	21	24	3
N1446.1	404026	733242	GLACIAL	19.52	20	19	--	--	--
N1615.3	404209	733406	GLACIAL	60.87	61	33	30	33	3
N1616.2	404554	733515	MAGOTHY	122.08	122.5	68	65	68	3
N1684.3	404335	733819	GLACIAL	88.23	88	50	46	50	4
N1685.2	403920	733530	GLACIAL	19.41	19	18	15	18	3
N8203.1	403909	733416	GLACIAL	6.50	7	16	13	16	3
N8269.2	404535	733700	MAGOTHY	111.55	111.7	86	81	86	5
N8412.1	404039	733032	GLACIAL	26.40	26	28	25	28	3
N8550.3	404401	733220	MAGOTHY	101.30	101	66	61	66	5
N8598.1	404239	733555	GLACIAL	69.83	70	45	42	45	3
N8847.1	403942	733344	GLACIAL	15.63	16	26	21	26	5
N8943.1	404329	733531	GLACIAL	81.50	82	52	47	52	5
N8944.1	404313	733522	GLACIAL	79.84	80	55	50	55	5
N8958.1	404306	733537	GLACIAL	77.48	78	35	30	35	5
N8971.1	404344	733543	GLACIAL	88.21	88	38	--	38	--
N9057.1	404242	733422	GLACIAL	70.24	70	47	42	47	5
N9077.1	404239	733158	GLACIAL	69.53	70	52	47	52	5
N9078.1	404324	733422	GLACIAL	83.62	84	65	60	65	5
N9190.1	404703	733702	MAGOTHY	156.42	156	133	128	133	5
N9191.1	404619	733645	MAGOTHY	170.25	170	135	130	135	5
N9201.1	404327	733359	GLACIAL	82.90	85	46	40	45	5
N9225.1	404331	733308	GLACIAL	87.56	90	45	39	44	5
N9234.1	404430	733310	MAGOTHY	105.02	107	206	200	205	5
N9235.1	404430	733310	MAGOTHY	105.02	107	106	100	105	5
N9236.1	404430	733310	GLACIAL	105.02	107	51	45	50	5
N9239.1	404410	733332	MAGOTHY	98.51	101	206	200	205	5
N9240.1	404410	733332	MAGOTHY	98.54	101	106	100	105	5
N9241.1	404410	733332	GLACIAL	98.53	101	46	40	45	5
N9333.1	404212	733305	--	53.25	55	50	--	--	--
N9355.1	404337	733605	GLACIAL	86.63	87	58	53	58	5
N9398.1	404311	733716	GLACIAL	64.61	65	22	21	22	1
N9406.3	404446	733530	GLACIAL	103.93	104	58	50	58	8
N9408.1	404105	733554	GLACIAL	39.40	39	15	14	15	1

Table 3. Physical descriptions of wells in study area, Nassau County, N.Y.--continued

Well number	Latitude	Longitude	Aquifer	Measuring point (feet above sea level)	Land surface altitude (feet above sea level)	Depth	Depth to screen Top	Depth to screen Bottom	Screen length (feet)
N9409.1	404024	733424	GLACIAL	32.46	32	20	19	20	1
N9410.2	404243	733451	GLACIAL	57.63	58	15	14	15	1
N9470.1	404001	733525	GLACIAL	27.84	28	29	24	29	5
N9473.1	404125	733250	GLACIAL	41.83	42	42	37	42	5
N9647.1	404443	733625	GLACIAL	87.24	88	63	58	63	5
N9648.1	404154	733740	GLACIAL	52.84	53	51	46	51	5
N9649.1	404103	733727	--	46.73	0	50	45	50	5
N9651.1	404033	733530	GLACIAL	39.55	40	47	42	47	5
N9655.1	404056	733135	GLACIAL	26.96	27	31	26	31	5
N9663.1	404016	733719	GLACIAL	37.76	38	50	45	50	5
N9664.1	404136	733038	--	35.46	36	31	26	31	5
N9666.1	404202	733543	GLACIAL	55.18	55	47	42	47	5
N9667.1	404320	733056	GLACIAL	76.30	76	55	50	55	5
N9668.1	404111	733533	GLACIAL	48.81	49	50	45	50	5
N9803.1	404330	733530	MAGOTHY	82.37	83	62	54	59	5
N9805.1	404336	733509	GLACIAL	76.60	77	61	53	58	5
N9925.1	404325	733220	GLACIAL	86.03	86.6	51	44	49	5
N9938.1	404526	733335	GLACIAL	124.40	125	80	72	77	5
N9939.1	404435	733343	GLACIAL	105.05	105.5	74	66	71	5
N9940.1	404523	733634	GLACIAL	107.05	107.5	53	45	50	5
N9941.1	404443	733625	GLACIAL	86.51	87	50	42	47	5
N9950.1	404513	733534	GLACIAL	111.52	112	69	61	66	5
N9967.1	404404	733631	GLACIAL	81.68	82	54	48	54	6
N10007.1	403926	733330	--	12.54	12	36	--	--	--
N10011.1	403950	733614	GLACIAL	18.22	18.5	26	21	26	5
N10035.1	404338	733715	GLACIAL	77.22	77.6	56	48	53	5
N10084.1	403939	733222	GLACIAL	5.48	5	--	16	21	5
N10202.1	404348	733724	GLACIAL	90.32	91	45	42	45	3
N10292.1	404412	733438	GLACIAL	78.45	78	50	45	50	5
N10781.1	404253	733306	--	76.03	76.5	61	55	60	5
N11226.1	404402	733512	GLACIAL	65.56	62	--	--	--	--
N11227.1	404359	733507	GLACIAL	66.16	60	14	11	14	3
N11228.1	404359	733507	GLACIAL	64.15	60	14	11	14	3
N11229.1	404359	733508	MAGOTHY	72.68	70	108	105	108	3
N11230.1	404359	733508	GLACIAL	71.88	70	33	30	33	3
N11231.1	404359	733508	GLACIAL	71.72	70	23	20	23	3
N11232.1	404359	733506	MAGOTHY	70.58	70	108	105	108	3
N11233.1	404359	733506	GLACIAL	73.28	70	30	27	30	3
N11234.1	404359	733506	GLACIAL	69.61	70	20	17	20	3
N11235.1	404356	733505	GLACIAL	64.20	60	11	8	11	3
N11236.1	404356	733505	GLACIAL	64.05	60	16	13	16	3
N11237.1	404356	733506	GLACIAL	71.67	75	28	25	28	3
N11237.2	404356	733506	GLACIAL	71.16	71.5	44	40	44	4
N11238.1	404356	733506	GLACIAL	71.50	70	23	20	23	3
N11239.1	404356	733508	GLACIAL	73.24	70	23	20	23	3

Table 3. Physical descriptions of wells in study area, Nassau County, N.Y.--continued

Well number	Latitude	Longitude	Aquifer	Measuring point (feet above sea level)	Land surface altitude (feet above sea level)	Depth	Depth to screen Top	Depth to screen Bottom	Screen length (feet)
N11240.1	404356	733504	GLACIAL	70.78	70	32	29	32	3
N11240.2	404356	733504	GLACIAL	68.03	68.5	53	45	53	8
N11241.1	404356	733504	GLACIAL	71.64	70	17	14	17	3
N11241.2	404356	733504	GLACIAL	67.94	68.5	17	9	17	8
N11242.1	404355	733505	GLACIAL	63.55	60	9	6	9	3
N11243.1	404355	733505	GLACIAL	63.57	60	15	12	15	3
N11244.1	404354	733506	GLACIAL	72.66	70	34	31	34	3
N11244.2	404354	733506	GLACIAL	71.70	72	45	40	45	5
N11245.1	404354	733506	GLACIAL	72.52	70	24	21	24	3
N11245.2	404354	733506	GLACIAL	71.77	72	19	10	19	9
N11246.1	404355	733504	GLACIAL	68.25	65	31	28	31	3
N11247.1	404355	733504	GLACIAL	68.35	65	21	18	21	3
N11248.1	404352	733504	GLACIAL	74.25	75	33	30	33	3
N11248.2	404352	733504	GLACIAL	74.41	75	45	40	45	5
N11249.1	404352	733504	GLACIAL	75.13	75	23	20	23	3
N11249.2	404352	733504	GLACIAL	74.25	75	22	16	22	6
N11250.1	404352	733502	GLACIAL	67.25	65	32	29	32	3
N11251.1	404352	733502	GLACIAL	67.17	65	21	18	21	3
N11252.1	404349	733502	GLACIAL	62.81	60	13	10	13	3
N11253.1	404349	733502	GLACIAL	62.64	60	14	11	14	3
N11254.1	404349	733503	MAGOTHY	72.61	70	102	99	102	3
N11255.1	404349	733503	GLACIAL	72.56	73	32	29	32	3
N11256.1	404349	733503	GLACIAL	73.02	73	22	19	22	3
N11257.1	404349	733501	GLACIAL	66.79	65	32	29	32	3
N11258.1	404349	733501	GLACIAL	66.67	65	22	19	22	3
N11495.1	404331	733506	GLACIAL	82.44	83	45	40	45	5
N11496.1	404322	733457	GLACIAL	66.60	67	37	32	37	5
N11500.1	404330	733454	GLACIAL	63.82	64	27	22	27	5
N11501.1	404333	733454	GLACIAL	65.52	66	27	22	27	5
N11502.1	404338	733454	GLACIAL	66.08	66.5	34	29	34	5
N11503.1	404343	733457	GLACIAL	63.77	64	27	22	27	5
N11504.1	404349	733459	GLACIAL	66.04	66.5	26	21	26	5
N11505.1	404339	733448	GLACIAL	74.25	75	37	32	37	5
N11506.1	404356	733456	GLACIAL	66.86	67	37	32	37	5
N11507.1	404349	733452	GLACIAL	65.30	66	37	32	37	5
N11508.1	404324	733440	GLACIAL	78.88	79	44	39	44	5
N11511.1	404359	733507	GLACIAL	66.39	60	7	4	7	3
N11512.1	404349	733502	GLACIAL	66.37	59	7	4	7	3
N11513.1	404340	733500	GLACIAL	64.03	57.5	8	5	8	3
N11602.1	404410	733523	GLACIAL	86.39	87	45	40	45	5
N11603.1	404400	733501	GLACIAL	70.87	71.5	45	40	45	5
N11604.1	404351	733523	GLACIAL	87.60	88	45	40	45	5
N11605.1	404356	733529	GLACIAL	88.49	89	45	40	45	5
N11606.1	404356	733503	GLACIAL	68.69	69	47	39	45	6
N11607.1	404356	733503	GLACIAL	68.11	69	17	10	17	7

Table 3. Physical descriptions of wells in study area, Nassau County, N.Y.--continued

Well number	Latitude	Longitude	Aquifer	Measuring point (feet above sea level)	Land surface altitude (feet above sea level)	Depth	Depth to screen Top	Depth to screen Bottom	Screen length (feet)
N11608.1	404353	733501	GLACIAL	67.78	68	39	35	39	4
N11609.1	404353	733501	GLACIAL	67.78	68	18	10	18	8
N11610.1	404350	733501	GLACIAL	66.43	68.5	49	45	49	4
N11611.1	404350	733501	GLACIAL	66.81	68.5	18	10	18	8
N11612.1	404347	733500	GLACIAL	64.22	65	39	35	39	4
N11613.1	404347	733500	GLACIAL	64.35	65	18	10	18	8
N11617.1	404353	733513	GLACIAL	88.88	89	45	38	43	5
N11618.1	404356	733513	GLACIAL	90.43	91	45	38	43	5
N11829.1	404356	733511	GLACIAL	89.14	90	47	41	46	5
N11830.1	404354	733507	GLACIAL	75.08	75.5	31	11	31	20
N11831.1	404352	733509	GLACIAL	85.90	86.4	47	40	45	5
N11832.1	404350	733511	GLACIAL	85.44	86	43	36	41	5
N11833.1	404349	733513	GLACIAL	83.76	84	48	41	46	5
N11834.1	404351	733515	GLACIAL	85.43	86	47	40	45	5
N12282.1	404359	733506	GLACIAL	70.93	71	51	41	46	5
N12283.1	404359	733506	GLACIAL	70.68	71	25	15	20	5
N12284.1	404357	733504	GLACIAL	70.78	71	24	14	19	5
N12285.1	404357	733504	GLACIAL	70.90	71	49	39	44	5
N12286.1	404356	733502	GLACIAL	70.50	71	49	39	44	5
N12287.1	404356	733502	GLACIAL	70.04	71	24	14	19	5
N12288.1	404353	733500	GLACIAL	69.08	70	55	45	50	5
N12289.1	404353	733500	GLACIAL	68.22	70	24	14	19	5
N12290.1	404350	733459	GLACIAL	66.18	67	49	39	44	5
N12291.1	404350	733459	GLACIAL	66.39	67	24	14	19	5
N12292.1	404348	733459	GLACIAL	68.29	69	54	44	49	5
N12293.1	404348	733459	GLACIAL	68.27	69	24	14	19	5
N12294.1	404353	733505	--	73.90	74	70	60	65	5
N12295.1	404410	733534	GLACIAL	94.85	95	68	58	63	5
N12736.1	404159	733436	GLACIAL	41.56	42	18	10	15	5