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Stratigraphy and Hydrologic Conditions at the Brookhaven National Laboratory and Vicinity, Suffolk County, New York, 1994-97

Prepared in cooperation with the Brookhaven National Laboratory and the U.S. Department of Energy

U.S. Geological Survey
Water-Resources Investigations Report 99-4086

Cover Photo: View of Brookhaven National Laboratory, March 1997, showing developed area near center of site, sewage treatment plant in northeastern part of site, and ring-shaped Relativistic Heavy Ion Collider tunnel in northwestern part of site. (Photo courtesy of Brookhaven National Laboratory.)

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Coram, New York
1999

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
inch (in.)	2.540	centimeter
foot (ft)	0.3048	meter
mile (mi	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.0438	cubic meters per second
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day

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—except where specifically noted, and does not represent local mean sea level.

Stratigraphy and Hydrologic Conditions at the Brookhaven National Laboratory and Vicinity, Suffolk County, New York, 1994-97

by Michael P. Scorca[1], William R. Dorsch[2], and Douglas E. Paquette[2]

Abstract

Brookhaven National Laboratory (BNL) has installed many test borings as part of an effort to delineate the extent of ground-water contamination at the site. In 1994, the U.S. Geological Survey began a study in cooperation with BNL to define the stratigraphy in the 28-square-mile area encompassing BNL, and to monitor ground-water levels in the 300 square-mile area of central Suffolk County that surrounds BNL.

The uppermost geologic units at BNL are of Pleistocene age. These sediments are underlain unconformably by the Matawan Group-Magothy Formation, undifferentiated (referred to as the Magothy Formation), of Cretaceous age, which typically consists of light- to dark-gray, variably sorted sand interbedded with light- to dark-gray clay layers; it also contains beds of grayish-brown to brownish-gray sand. Bed thicknesses differ substantially within each boring and tend to be laterally discontinuous as a result of their terrestrial deltaic depositional environment, although a prominent clay unit, referred to as the "grayish-brown clay" in this report, was encountered at many borings. Pollen-sample analyses confirm that this unit is of Cretaceous age and is the uppermost unit of Cretaceous sediments in several parts of the study area.

The upper surface of the Cretaceous deposits is irregular within the 28-square-mile study area and has relief of about 120 feet. Several prominent channels and ridges in the surface are aligned generally northwest-southeast. The Cretaceous surface beneath BNL is characterized more by local erosional features than by the regional cuesta shape that was suggested by previous authors.

The overlying Pleistocene-aged units include (1) a sand layer overlain by the Gardiners Clay, (2) the Gardiners Clay, and (3) upper Pleistocene deposits, which include the Upton unit, glacial outwash, glaciolacustrine deposits, and terminal moraine deposits. The sand unit below the Gardiners Clay was the first Pleistocene unit to be deposited atop the irregular surface of the Cretaceous deposits in this area. The Gardiners Clay was deposited during a major rise in sea level as the sea encroached into parts of the present-day BNL study area. The shallow part of the upper Pleistocene deposits generally consists of light-brown sand and gravel but overlies green to grayish-green, variably sorted sand, silt, and clay at altitudes of 50 to 70 feet below sea level in some parts of the study area. This lower part of the upper Pleistocene deposits in the study area was referred to by previous investigators as the unidentified unit and has been designated as the Upton unit in this report.

The discharge of ground water to the Peconic and Carmans Rivers locally affects the water-table configuration. The main ground-water divide on Long Island is about 0.5 miles north of the site; a secondary divide originates near the start of flow of the Peconic River and extends east-southeastward toward the South Fork. The water-table configuration on the BNL site is

[1] U.S. Geological Survey, Coram, N.Y.
[2] Brookhaven National Laboaatory

affected by pumping from supply wells and remediation wells, by infiltration of the water through recharge basins, by discharge from the sewage-treatment plant, and by local near-surface clay units.

The horizontal hydraulic gradient at BNL typically is 0.001 foot per foot but can steepen near recharge basins and pumping wells. Vertical flow gradients within the upper Pleistocene deposits (upper glacial aquifer) were as large as 0.007 foot per foot (downward) in the northern part of BNL and were negligible in the southern part. Downward vertical gradients between the lower part of the upper glacial aquifer and the upper part of the Magothy Formation (Magothy aquifer) were about 0.018 foot per foot throughout the site.

INTRODUCTION

Brookhaven National Laboratory (BNL) is a multidisciplinary scientific research facility in central Suffolk County, Long Island, N.Y., that is owned by the U.S. Department of Energy (DOE) and was managed by Associated Universities, Inc., until 1997; it is currently managed by Brookhaven Science Associates LLC. BNL is on a 5,300-acre (8.3 mi^2) site in the western part of the area known locally as the Pine Barrens (fig. 1). Much of this part of Suffolk County is relatively undisturbed woodland and is the least industrialized part of Long Island (Krulikas, 1986).

Ground water is the sole source of freshwater supply for the 1.3 million residents of Suffolk County (Long Island Lighting Company, 1991). Development of this resource, and protection of its chemical quality, are major concerns of water-management agencies. The New York State Department of Environmental Conservation has designated the Pine Barrens as a “special ground-water protection area” (SPGA) because it is a sparsely developed region in which precipitation recharges the deep part of the aquifer system (Stackelberg and Siwiec, 1993). Ground-water protection in the Pine Barrens is important for maintaining the water quality in this part of Long Island’s designated sole-source aquifer system.

Past waste-handling and disposal practices, which were previously accepted, and accidental spills have resulted in contamination of soils and ground water in some parts of the BNL site. In 1992, DOE entered into an interagency agreement with the U.S. Environmental Protection Agency and the New York State Department of Environmental Conservation (NYSDEC) to delineate and remediate the contamination under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), also known as the Superfund Act. BNL established seven Operable Units that represent separate geographic parts of the site and related areas of contamination, and conducted extensive drilling programs to define the extent of contamination. Subsurface investigations conducted at the BNL site during 1993-97 provided detailed hydrogeologic information on the site and surrounding areas. The BNL Environmental Restoration Division (ERD), formerly known as the Office of Environmental Restoration (OER), conducted a four-phase hydrogeologic characterization project during 1993-97, which included installation of monitoring wells, piezometers, and geologic borings into the upper Pleistocene deposits and into the shallow part of the Magothy Formation within and near the BNL site. Data from this project were used to supplement data obtained as part of CERCLA remedial investigations and to refine the stratigraphy and ground-water flow patterns.

In 1994, the U.S. Geological Survey (USGS) began a cooperative study with BNL to examine ground-water flow patterns in the 300-mi^2 area (fig. 1A) surrounding and including the site, hereafter referred to as the 300-mi^2 study area, and to examine the stratigraphy in the 28-mi^2 area around BNL, referred to here as the local study site, or BNL site. (fig. 1B.)

The stratigraphy beneath the site had been evaluated as part of several earlier regional investigations (deLaguna, 1963; Jensen and Soren, 1974; Krulikas and others, 1983; Smolensky and others, 1989), but only a few deep borings (more than 100 ft below land surface) were on or near the BNL site at the time of those studies. The recent deep drilling provided detailed geologic information that allows refinements of the geologic history of the Pine Barrens and of regional ground-water flow, and can be used for management and protection of ground water within central Suffolk County.

Factors that affect ground-water flow at the site include (1) the extent of hydrogeologic units, (2) the location of the regional and the secondary ground-

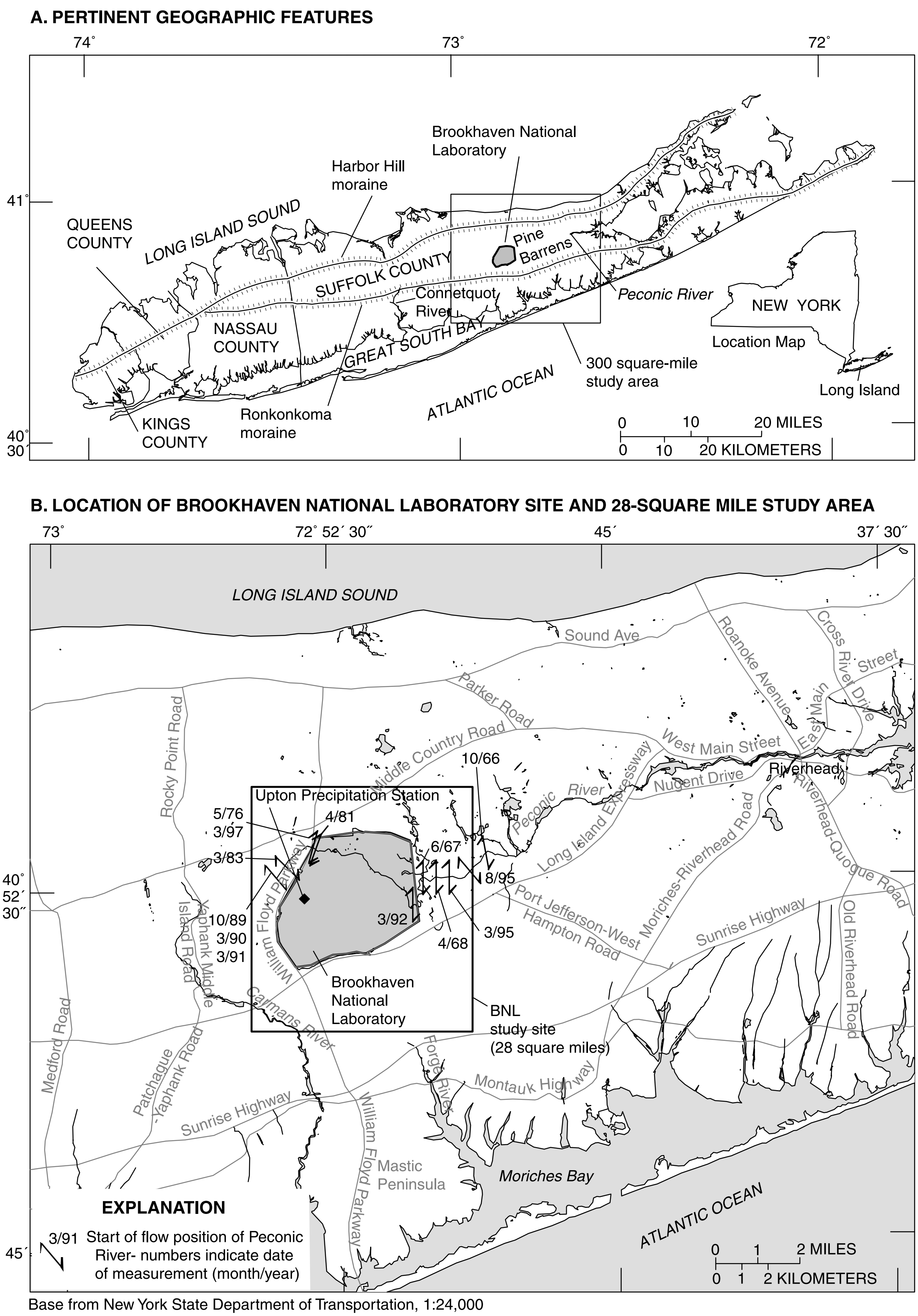


Figure 1. Location and pertinent geographic features of Long Island, N.Y.: A. General location of 300-mi^2 study area in Suffolk County. (Modified from McClymonds and Franke, 1972, fig. 2.) B. Location of Brookhaven National Laboratory (BNL) and of 28-mi^2 study site.

water divides, (3) ground-water discharge to the Peconic and Carmans Rivers, (4) fluctuations in precipitation volume, and (5) onsite pumping, operation of recharge basins, and discharge from the site's sewage-treatment-plant. The interaction of these factors affects hydraulic gradients in the ground-water system and increases the complexity of flow paths, thereby complicating contaminant movement within the aquifer system.

Purpose and Scope

This report refines the stratigraphy of the Pleistocene and uppermost Cretaceous deposits in the vicinity of BNL on the basis of (1) data collected during the BNL test-boring programs of 1993-97, and (2) data from previous investigations. It includes maps and vertical sections depicting stratigraphic relations at the site, and maps showing water-table altitudes and vertical and horizontal flow gradients in March and August 1997.

Previous Studies

The USGS issued a series of reports during the 1960's that described the geology, hydrology, and ground-water quality at the BNL site and vicinity for the U.S. Atomic Energy Commission. deLaguna (1963) described the geology of central Long Island, including the BNL site, and Faust (1963) discussed the physical properties and mineralogy of selected core samples from seven deep borings on or near the site. Warren and others (1968) appraised the hydrology in the BNL vicinity. deLaguna (1964) examined ground-water quality in the area and also gave a hydrologic analysis of postulated liquid-waste releases (1966).

Other studies by the USGS in the BNL vicinity include hydrogeologic mapping of Long Island by Suter and others (1949), and the hydrogeology of Suffolk County by Jensen and Soren (1971, 1974). Krulikas (1981) updated hydrogeologic data previously presented in Jensen and Soren (1971); Krulikas and others (1983) mapped the top of the Matawan Group-Magothy Formation in Suffolk County; Krulikas (1986) examined the geohydrology of the Pine Barrens region; and Koszalka (1980, 1984) investigated the geohydrology of the northern part of the Town of Brookhaven. Buxton and others (1989) and Smolensky and others (1989) described the hydrogeologic framework of Long Island. Weiss (1954) examined geologic samples from eastern Long Island, including BNL, for microfossils in Pleistocene clay and correlated sedimentary units beneath BNL. Wexler (1988a) and Scorca (1990) evaluated geochemistry at two waste-disposal facilities near BNL. Wexler (1988b) and Wexler and Maus (1988) developed a flow model of an 26-mi^2 area southwest of BNL.

Geographic Setting

Most previous investigators concluded that the Laurentide continental ice sheet deposited two major terminal moraines on Long Island during the Wisconsinan stage of the Pleistocene Epoch (Cadwell, 1989). These moraines form two lines of hills that trend generally east-west along the island. BNL lies in the intermorainal area north of the Ronkonkoma moraine and south of the Harbor Hill moraine (fig. 1A). deLaguna (1963) identified some hills on the BNL site as kames (short, irregular ridges composed of stratified sand and gravel deposited by a glacial stream at the margin of or on the surface of a glacier). The present-day surface topography includes short linear depressions that probably are dry relict channels of streams that flowed northward from the Ronkonkoma moraine. Clay layers were observed in the shallow subsurface beneath the relict channels during the recent drilling operations. The clays affect ground-water levels locally, as discussed in a later section.

The BNL site is within the topographic drainage area of the Peconic River and contains the uppermost headwaters reach of the Peconic River channel. The start of flow (location at which flow begins) shifts position, however, in response to the rise or fall of the water table, as discussed further on. A second major stream, Carmans River, is about 2 mi west of the site and flows generally southward to Great South Bay along the western side of the Mastic Peninsula (fig. 1B). The Forge River flows along the eastern edge of the Mastic Peninsula.

The BNL site lies in the western part of the area of Long Island that is known locally as the Pine Barrens (fig. 1A). This area has relatively little urbanization and contains principally vacant land, open space and recreational land, agricultural land, and residential development (Stackelberg and Siwiec, 1993). Land uses in the areas to the west, north, and east of BNL are described by Stackelberg and Siwiec (1993). Additional land-use information can be obtained from the BNL Future Landuse Plan (Brookhaven National Laboratory, 1995). Other descriptions of the area are presented in deLaguna (1963) and Naidu and others (1996).

Acknowledgments

Thanks are extended to William Gunther and Robert Howe, former managers of BNL Environmental Restoration Division (ERD), for their assistance and cooperation during this project. Appreciation also is expressed to Thomas Burke, Michael Hauptmann, William Medeiros, James Brower, and Mary Daum of BNL-ERD staff for providing data and assistance during this investigation, and to Victor Cassella of BNL Department of Applied Science, Oceanographic, and Atmospheric Sciences for providing monthly precipitation data from the Upton station.

METHODS OF INVESTIGATION

Geologic information was collected from 20 deep borings drilled for this study and from more than 200 borings that were drilled during 1994-97 as part of water-quality investigations at BNL. Locations of selected borings used in this study are shown in figure 2. Geologic logs of borings are archived at BNL's Environmental Restoration Division.

Local geology was evaluated from available information, which included (1) BNL contractors' field log descriptions and reference to Munsell color charts, (2) USGS field log descriptions, (3) gamma-ray logs, (4) microscopic examination of selected samples, and (5) results of palynologic analysis.

Sediment-Sample Collection and Analysis

Geologic core samples were obtained with split-spoon samplers at selected depth intervals from many borings by consulting geologists contracted by BNL. A few selected core samples were rinsed to remove silt and clay and were viewed with a reflected-light microscope by the USGS in Coram, N.Y., to identify mineral grains.

Gamma-Ray Logs

Gamma-ray logs were collected by BNL contractors from more than 200 deep borings to help characterize the lithology and to interpret the local stratigraphy. Gamma logs are especially effective for indicating the amount of clay in Long Island's sediments because the natural gamma radiation of the quartz-rich sand and gravel is relatively low, and that of clay minerals is relatively high; therefore, the relative intensity of gamma radiation indicated on the gamma logs generally reflects the proportion of clay.

Palynologic Analysis

About 60 core samples were selected and sent to Dr. Leslie A. Sirkin of Adelphi University, Garden City, N.Y., who was contracted by BNL to analyze the samples for pollen and other microfossils. The outside of each core, which could contain sediment displaced in depth during coring, was trimmed off, and selected fine-grained sediment was removed from the inside of the core. Standard methods of pollen analysis were followed as described by Faegri and Iversen (1965). Pollen was extracted by the flotation method, placed on a gelatin medium, stained with gentian violet, and viewed with a transmitted-light microscope. Identification of Cretaceous pollen focused on index fossils, and age was based on zonation detailed in reports by Christopher (1978, 1979), Doyle and Robbins (1977), Wolfe (1976), and Sirkin (1986). Results of these analyzes were used to assist in identification of geologic units.

Ground-Water-Level Measurements

Water levels in all observation wells were measured by the wetted-steel-tape and electric-tape methods, which are accurate to 1/100 of a foot. The water table in this part of Long Island is within the upper glacial aquifer. Most of the observation wells used in this study are screened in the upper glacial aquifer, but some are screened in the upper part of the Magothy aquifer. Some sites contain clustered wells completed at differing depths, either within the same aquifer or in two aquifers. These were used to determine the vertical hydraulic gradient. Water-level data from wells in the USGS regional network are stored at the USGS office in Coram, N.Y., and are available upon request; data from wells owned by BNL are available from BNL through DOE.

Boring-Numbering System

Borings are referred to herein and on figure 2 by numbers that correspond to the BNL grid system. The first three digits of the BNL numbers (see table 4, at end of report) refer to the blocks within the grid, which includes 131 blocks onsite and several blocks offsite; the last three digits are the boring number assigned sequentially within each grid block. Well-permit numbers are assigned by NYSDEC and are also included in table 4; the prefix S indicates Suffolk County.

Start of Flow of Streams

The start of flow of a stream in its channel changes position in response to the water-table altitude, as discussed in a later section. The position of the start of flow in the Peconic River channel was determined from field observations. Sometimes the start of flow was observed directly; at other times it was estimated from relative magnitude of flow at road crossings of the stream channel.

Precipitation

Daily records of precipitation have been collected by BNL at the Upton station (fig. 1B), in the western part of BNL, since 1949. Precipitation data from the Upton station were used to evaluate trends in hydrologic conditions.

Data Presentation (Water Year or Calendar Year)

Hydrologic data commonly are presented by water year rather than calendar year. (A water year extends from October 1 of the preceding year through September 30 of the named year.) In this report, annual values for streamflow, base flow, and direct runoff are given by water year, but values for ground-water levels, sewage- and treatment-plant outflows, precipitation, and water-table altitudes are given by calendar year.

HYDROGEOLOGIC FRAMEWORK AND STRATIGRAPHY

Long Island is underlain by unconsolidated sediments of Late Cretaceous and upper Pleistocene age deposited on a southeastward-dipping bedrock surface. Suffolk County's hydrogeologic setting has been described in detail by Suter and others (1949), Jensen and Soren (1971; 1974), and Smolensky and others (1989). A summary of principal geologic units is given in table 1. A generalized hydrogeologic section through Suffolk County is presented in figure 3A; gamma-ray logs for borings 130-004 and 122-005 are presented in figures 3B and 3C, respectively. The uppermost major geologic unit on Long Island consists of glacial drift deposited during the Pleistocene Epoch. The area occupied by the BNL contains morainal, outwash, and probably interstadial sediments that together range from 100 ft to 250 ft in thickness.

Reexamination of geologic information obtained by previous investigators has resulted in reinterpretation of the geologic units. The reason for the differences among interpretations by previous investigators probably is the local variability of sediments within geologic units and the sparsity of geologic data; certain beds in one unit resemble those in other units. The glacial environment associated with the Pleistocene deposits, and the deltaic depositional environments associated with the Cretaceous deposits, are the cause of this variation in sediments; furthermore, some Cretaceous sediments could have been eroded and incorporated as grains within Pleistocene deposits. In some localities on Long Island, large masses of Cretaceous or older Pleistocene sediment were detached and thrust as blocks by the ice sheet into positions within younger Pleistocene deposits (Sirkin, 1995)

Identification of geologic contacts at some borings is difficult because many samples lack distinctive characteristics. Most Pleistocene-aged deposits contain more chemically unstable minerals, such as biotite, amphibole, and garnet, than Cretaceous sands, which consist predominantly of chemically stable minerals, such as quartz and muscovite. Several types of evidence, such as gamma-ray logs and pollen analysis, were used to distinguish these units.

A gamma-ray log from boring 130-004, in the southwestern corner of the BNL site (fig. 3B), depicts a representative sequence of Pleistocene and uppermost Magothy sediments, and a gamma-ray log from boring 122-005, about 1 mi east of boring 130-004, in the south-central part of the BNL site (fig. 3C) depicts a boring without significant clay units through most of its depth. The lithology of core samples from boring 122-005 is discussed in a later section.

Cretaceous Deposits

Long Island's Cretaceous units are correlated with sediments in the coastal plain of New Jersey (Suter and others, 1949). Cretaceous deposits on Long Island are the Raritan Formation and the Matawan-Magothy Formation (Magothy aquifer), which are thicker than their counterparts in New Jersey, and the Monmouth Group (fig. 3A). The Raritan Formation, which includes the Lloyd Sand Member and an unnamed clay member, overlies bedrock; it was penetrated by two borings installed in the late 1940's on the BNL site (deLaguna, 1963). The Raritan Formation is not discussed in this report but is discussed by deLaguna (1963). Borings that were installed during this study penetrated only as deep as the shallow part of the Matawan-Magothy Formation; the stratigraphy of the Matawan-Magothy Formation and the Monmouth Group is described below.

Matawan Group-Magothy Formation, Undifferentiated

The Matawan Group and Magothy Formation are undifferentiated on Long Island and are generally treated as one unit (Perlmutter and Todd, 1965). In New Jersey, Matawan Group deposits vary in lithology, and some of those units are briefly described by Olsson (1987). In this report, the term Magothy Formation refers to the undifferentiated Matawan Group and Magothy Formation. Lonnie (1982) noted that clay beds in the Magothy Formation were rich in kaolinite with minor amounts of illite and concluded that the Magothy Formation was probably deposited in a terrestrial (nonmarine) environment or a transitional environment (between marine and terrestrial).

Lithology

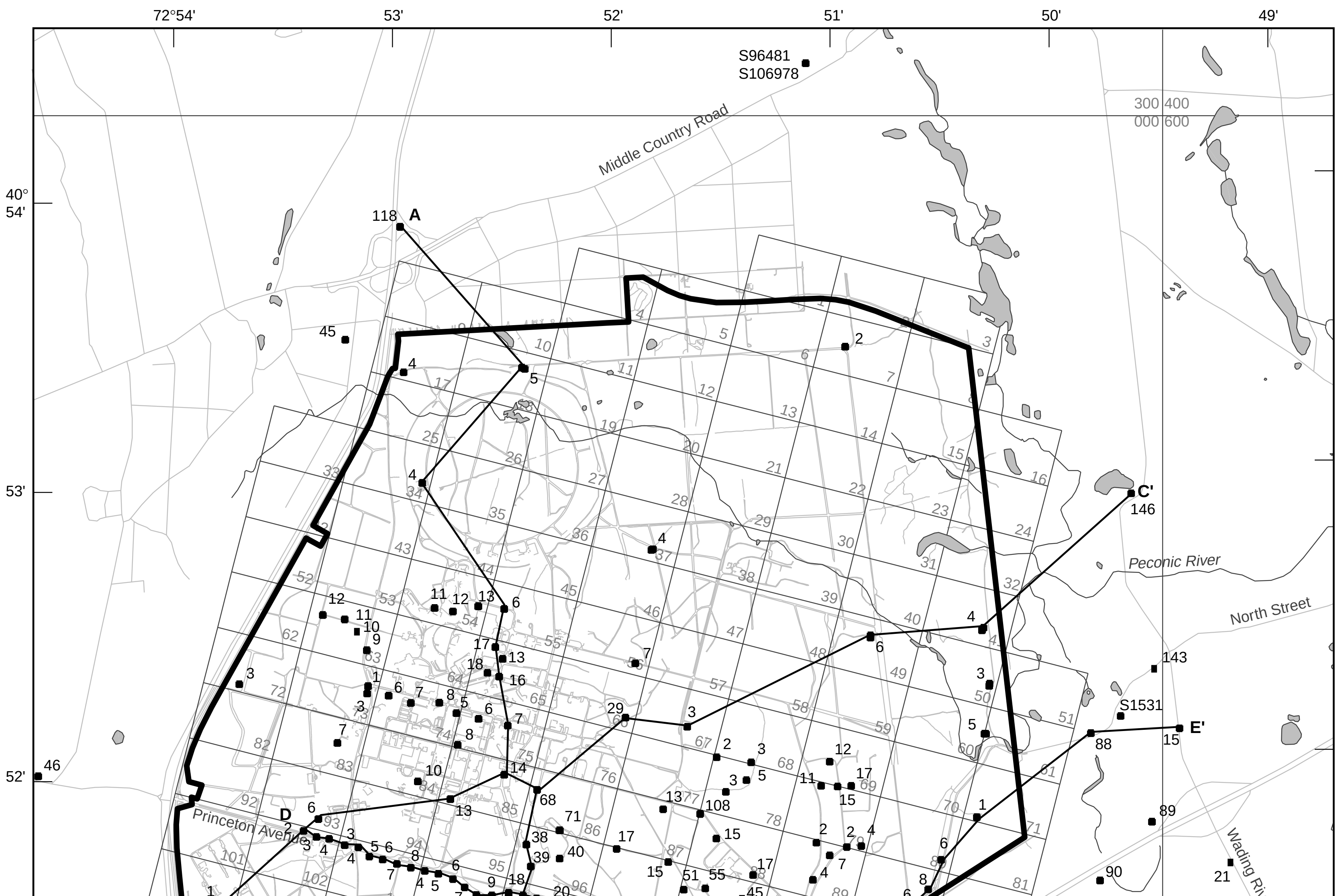
The Magothy Formation consists mainly of continental deltaic sand and clay and ranges from 820 to 885 ft in thickness, as indicated by two borings at BNL (065-013 and 109-001, fig. 2) that penetrated the entire unit (deLaguna, 1963). The sand layers are interbedded with clay layers, and beds tend to be laterally discontinuous and vary in thickness. deLaguna (1963) observed that clay beds are difficult to trace between borings, even in the western part of Long Island, where borings are relatively close together, and therefore inferred that the clay layers are probably lenticular.

The upper part of the Magothy Formation at BNL ranges from solid clay to very well sorted sand. Units of sand and clay are interbedded and differ substantially in thickness within each boring and even between some nearby borings; the degree of sorting in the units also varies widely.

Minerals in the Magothy Formation tend to be chemically stable, and some muscovite grains, rock fragments, and the few less stable minerals, including feldspar and amphibole, commonly show evidence of having weathered to clay minerals such as kaolinite (Suter and others, 1949; Faust, 1963). The top of the Magothy Formation typically is distinguished on many gamma-ray logs by a higher response (owing to a greater amount of clay) than overlying Pleistocene outwash deposits. Bedding structure is prominent in most cores, and some cores contain beds that are composed mostly of lignite fragments. Although most of the Magothy Formation consists of gray sand interbedded with gray to black clay, two other lithologic units within the upper Magothy were observed in the study area—grayish-brown to brownish-gray sand, and the grayish-brown clay. These three units are described in turn below.

Gray sand interbedded with clay.—Sand layers in the Magothy Formation generally range from fine grained to coarse grained and from clayey or silty to very well sorted. Sand color generally ranges from light gray to dark gray but is grayish brown in some borings. Sediments are generally quartz-rich and contain trace to abundant amounts of muscovite, lignite, and pyrite. Sand layers are interbedded with light- to dark-gray clay layers that vary in thickness and have limited lateral extent. Where the uppermost Magothy sediments include gray clay or gray silty sand, their greater gamma-ray response relative to overlying sediments marks the top of the Formation.

The upper sediments of the Magothy Formation at boring 093-006 (fig. 2) are light gray, very well sorted sand with trace lignite and no visible bedding. The upper surface of the Magothy is 116 ft below sea level at this boring, and this sand unit is more than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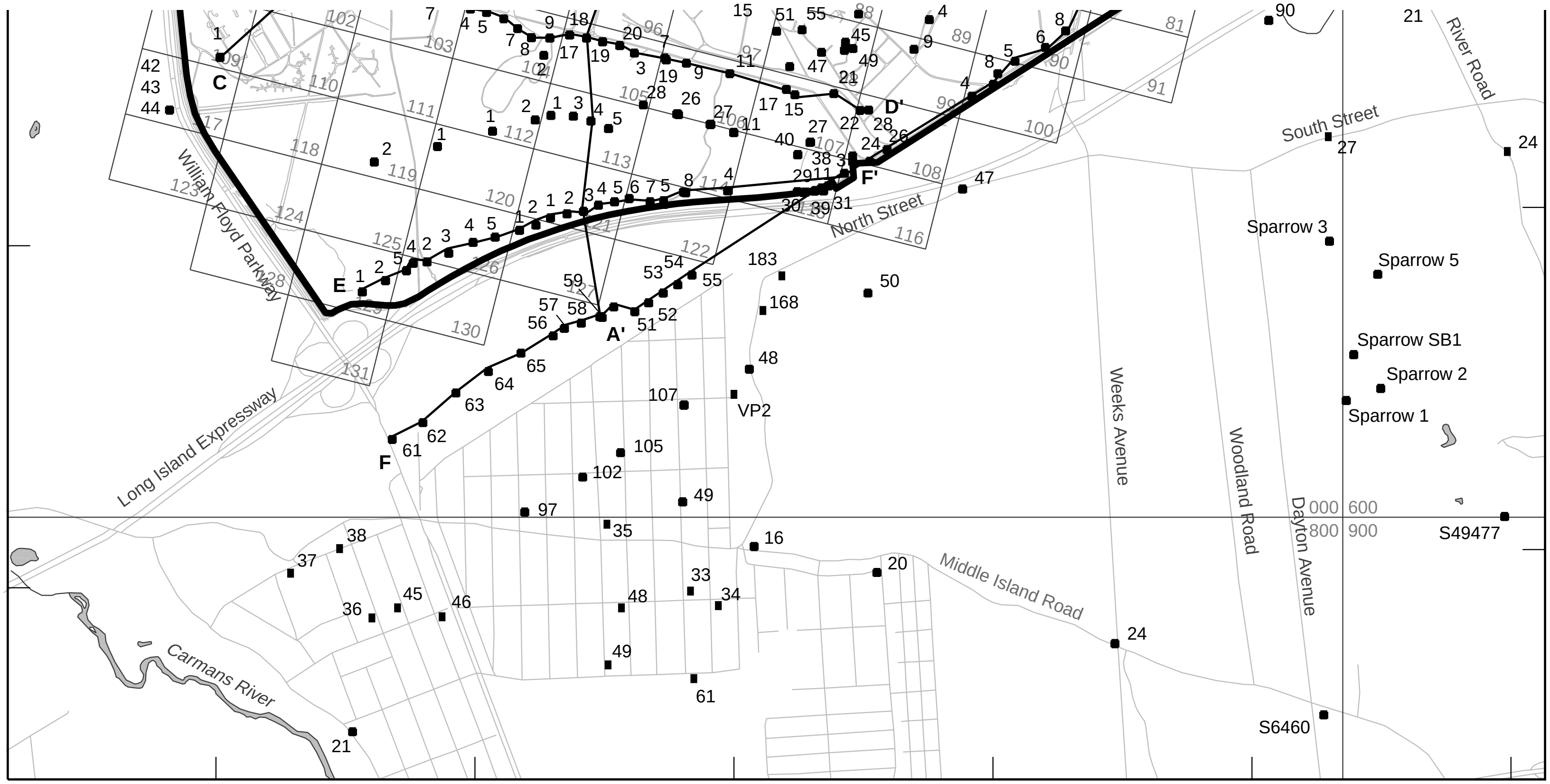


Base from New York State Department of Transportation, 1981, 1:24,000

EXPLANATION

GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL)- Number is grid block number and represents first three digits of borehole numbers.

19 BORING- Number is assigned by BNL sequentially within grid block and represents last three digits of boring numbers. Number with S prefix is assigned by New York State Department of Environmental Conservation.

A——A' LINE OF VERTICAL SECTION- sections are depicted in figures 5,6,8,9 and 11. Line of vertical section B-B' is shown on fig 17.

BOUNDARY OF BNL SITE

Figure 2. Locations of borings and lines of vertical sections in Brookhaven National Laboratory study area, Suffolk County, N.Y. (General location is shown in fig. 1B.)

Table 1. Generalized description of geologic units underlying Brookhaven National Laboratory and vicinity, Suffolk County, N.Y.

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

Series	Geologic unit	Hydrogeologic unit	Description and water-bearing character
PLEISTOCENE	Upper Pleistocene deposits	Upper glacial aquifer	Mainly brown and gray sand and gravel deposits of moderately high horizontal hydraulic conductivity (270 ft/d average for Long Island; about 180 ft/d measured at Brookhaven National Laboratory); may also include deposits of clayey till and lacustrine clay of low hydraulic conductivity. A major aquifer.
	Upton unit	Upper glacial aquifer	Mainly greenish, with shades of yellow-green, greenish-gray, olive-brown, and gray, poorly to well sorted sand, with some silt and clay. Upper surface in some borings is marked by a clay or silty layer, generally less than 10 ft thick, that produces a noticeable response on a gamma-ray log. Horizontal hydraulic conductivity is estimated to be similar to or slightly less than that of the shallow part of the upper glacial aquifer.
	Gardiners Clay	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.
	Sand below Gardiners Clay	Upper glacial aquifer	Mainly light brown, olive-brown, and grayish-brown, poorly to well sorted sand. Hydrologically, unit could also be considered part of Magothy aquifer because of confinement by Gardiners Clay.
CRETACEOUS	Monmouth Group	Monmouth greensand	Interbedded marine deposits of green, dark-greenish gray, greenish-black, dark gray, and black clay, silt, and sand, containing much glauconite. Unit has low hydraulic conductivity (0.001 ft/d) and tends to confine water in underlying aquifer.
	Matawan Group and Magothy Formation, undifferentiated	Magothy aquifer	Gray, white, and brownish-gray, poorly to well sorted, fine to coarse sand of moderate horizontal hydraulic conductivity (50 ft/d). Contains much interstitial clay and silt, and lenses of clay of low hydraulic conductivity. Generally contains sand and gravel beds of low to high conductivity in basal 100 to 200 ft. A major aquifer.
	grayish-brown clay		Dark grayish-brown to yellow-brown, solid to silty clay, in some layers laminated with beds of very fine sand up to 1 in. thick. Unit is encountered in upper part of Magothy Formation. Has low hydraulic conductivity and tends to confine water.
	Unnamed clay member of the Raritan Formation	Raritan confining unit	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 Sand Member of the Raritan Formation	Lloyd aquifer	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.
PALEOZOIC and PRECAMBRIAN	Bedrock	Undifferentiated crystalline bedrock	Mainly metamorphic rocks of low hydraulic conductivity; considered to be the base of the ground-water flow system.

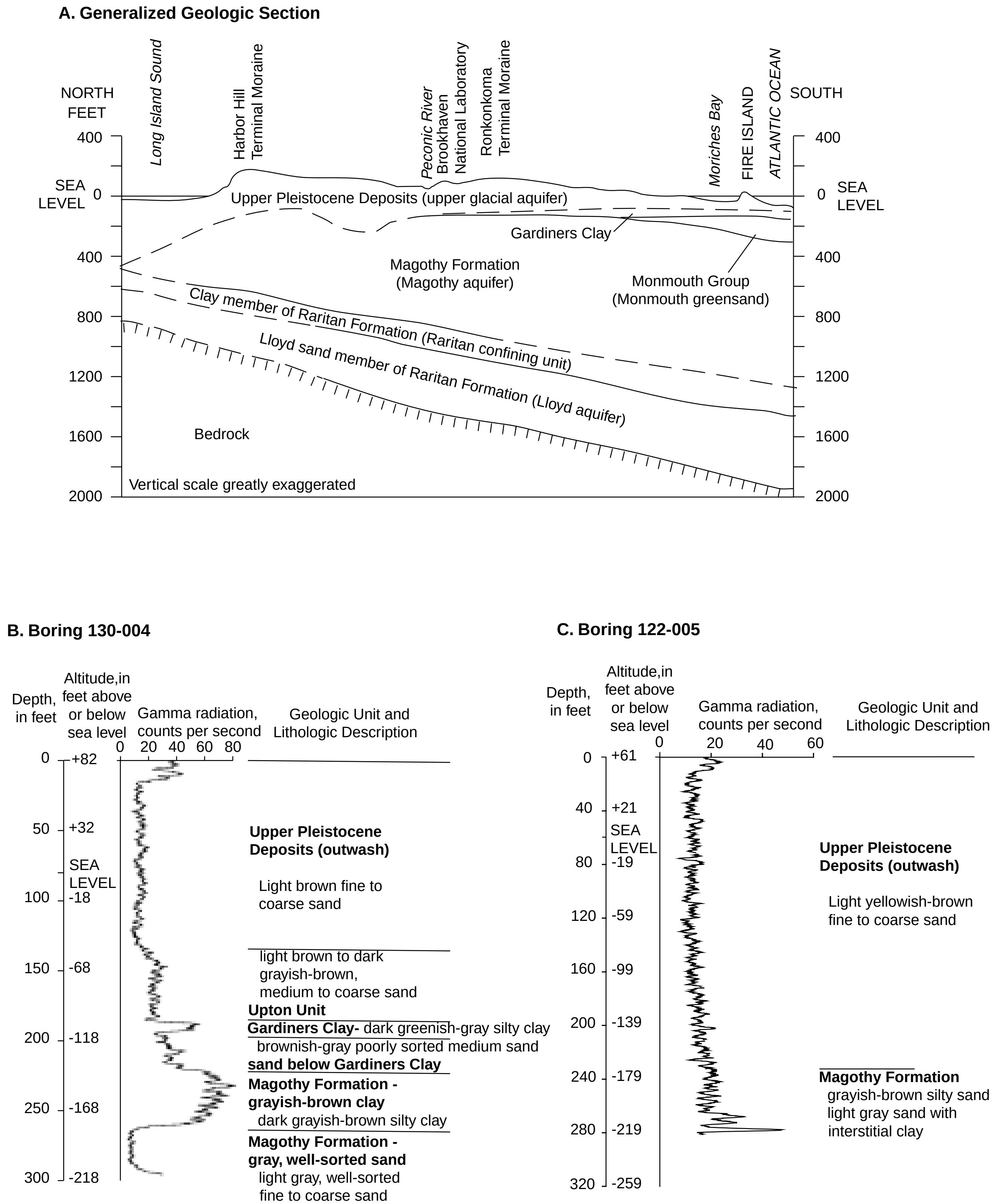


Figure 3. Stratigraphy at Brookhaven National Laboratory site, Suffolk County, N.Y.:A. Generalized geologic section showing relative positions of hydrogeologic units. (Modified from Jensen and Soren, 1974, sheet 1.) B. Gamma-ray log from boring 130-004 and corresponding sediment description. (Location is shown in fig. 2.) C. Gamma-ray log from boring 122-005 and corresponding sediment description. (Location is shown in fig. 2.)

50 ft thick (bottom of sand unit was not reached). Unlike most Cretaceous sediments, this unit produced a smaller response on the gamma-ray log than the overlying Pleistocene deposits. A similar unit was observed in boring 130-004 along the southern boundary of the site, below the grayish-brown clay layer (fig. 3B). Microscopic examination of rinsed core samples of the well-sorted gray sand at the bottom of boring 130-004 contained trace amounts of amphibole without visible weathering. Although the presence of chemically unstable minerals is not common in the Magothy Formation and could indicate some degree of later reworking of sediments, the sediments are considered of Cretaceous age in this report.

Layers of stiff, very dark-gray to black silty clay with lignite were penetrated in borings 000-059, south of the site, and 085-013, in the west-central part of the site. Pollen analysis of samples from this unit confirmed its Cretaceous age (table 2). Similar samples from the Magothy Formation in other parts of Suffolk County contained large amounts of organic carbon and some microscopic pyrite (C.J. Brown, U.S. Geological Survey, written commun., 1997).

A sample of stiff, black, sandy clay from boring 115-027, in the southeastern part of the site, was rinsed to remove clay and silt and was found to contain quartz, mica, and trace amounts of lignite and broken glauconite grains. Other borings in the same vicinity did not encounter this black clay unit, indicating that it is of extremely local extent. Pollen analysis confirmed the Cretaceous age of this layer. The uppermost part of the Magothy Formation in most of the rest of the southeast part of BNL consists of mostly gray to brownish-gray silty sand.

The uppermost Cretaceous sediments at borings 104-006 and 104-008, along Princeton Avenue, and 119-002 and 112-001, in the southwest part of BNL, contained gray, silty sand with lignite. These layers produced a larger gamma-ray response than overlying sediments.

Grayish-brown to brownish-gray sand.—The uppermost Cretaceous sediments in some borings were grayish-brown to brownish-gray, quartz-rich, poorly sorted sand. As discussed earlier, the upper surface of the Cretaceous sediment in many borings was difficult to distinguish from Pleistocene sediment. The color of the sediment at boring 122-005 (fig. 3C), along the southern boundary of the site, shifted slightly with depth from light yellowish brown to grayish brown, and samples contained slightly more silt at 171 ft below sea level than at shallower depths. A subtle inflection on the gamma-ray log at that depth probably resulted from slightly increased amounts of silt or clay particles, but the samples contained no prominent mica, lignite, or pyrite that could indicate a distinct contact. Samples from below 182 ft below sea level contained light-gray sand with interstitial clay and were similar to the Magothy sediments observed in cores from other borings.

Sediment between depths of 155 and 171 ft below sea level in boring 106-019, on Princeton Avenue, is generally a brownish-gray, visibly bedded, poorly sorted sand that is more than 95 percent quartz, although some of the trace-mineral grains and rock fragments are chemically unstable and indicate post-Cretaceous (Pleistocene) deposition. As at boring 122-005, deep sediments typically display the characteristics associated with the Cretaceous-aged Magothy deposits, including light- to dark-gray sand with interstitial clay and laminated bedding. Similarly, many of the core samples from boring 600-015, east of the site, contained moderately to well-sorted sand in shades of olive-, orange-, gray-, and yellow-brown. In this boring, the Cretaceous surface is probably marked by a large response on the gamma-ray log at 120 ft below sea level.

Grayish-brown clay.—An extensive clay unit of variable thickness, referred to as the grayish-brown clay in this report, was encountered at more than 50 borings within, and in the vicinity of, the BNL site. The presence of exclusively Cretaceous pollen identified in 11 samples from this unit is the primary evidence for determining the stratigraphic age of this unit (table 2). Microscopic examination of rinsed core samples of sandy beds of the grayish-brown clay in boring 063-009 show that the samples contain abundant mica. Most of the mica is muscovite, but some biotite is also present. As with the previously described well-sorted gray sand, the presence of chemically unstable minerals is not common in the Magothy Formation and could indicate some degree of later reworking of sediments, but the sediments are considered of Cretaceous age in this report. The grayish-brown clay is the uppermost unit of the Cretaceous sediments in parts of the study area.

The grayish-brown clay unit ranges from dark grayish-brown to yellowish-brown. Its texture is generally solid to silty clay, but in some cores the clay was laminated with bands of well sorted, very fine

Table 2. Microfossils observed in samples from geologic units in Brookhaven National Laboratory study area, Suffolk County, N.Y.

[Modified from L.A. Sirkin, Adelphi University, written commun., 1996. Age correlations of Cretaceous pollen from Sirkin (1986)]

Series	Sediment description	Microfossils observed during this study, including genus and species, where available
Pleistocene	Clay at 75 feet below sea level	Hickory, pine, compositae, alder
	Upton unit	Conifer and hardwood pollen including: pine, birch, oak, grass, and beech; also grass, compositae, common fern, chenopod, lily *Urtica, Ericaceae, Sphagnum*
	Brown sand near base of the Upper Pleistocene deposits	Pine, shells
	Gardiners Clay	Pine, spruce, birch, oak, and *Sphagnum* spores, mixed conifer and hardwood, and lycopod, alder with oak *Ericaceae, Sphagnum*, foraminifera, and shell fragments
	Pleistocene sand below Gardiners Clay	Foraminifera and ostracod-*Candona*
	Brown clay interbedded with sand near base of the Upper Pleistocene deposits	Pine, birch, chestnut and two samples with no microfossils
Upper Cretaceous	Matawan Group and Magothy formation, undifferentiated: (gray sand)	Two samples with no microfossils
	Matawan Group and Magothy Formation, undifferentiated: (grayish-brown clay)	*Betulaceoipollenites* *Brevicolporites* sp B *Brevicolporites* sp. A *Brevicolporites* multiporate form: *Periporites* *Holkopollenites* *Momipites* *Proteacidites* *Pseudoplicapollis* *Tricoloporites* sp. A, B, C cf. CP3B-7 tricolporate angiosperm taxa Tricolporate types 5 and sp. A Tricolporate types (1,3,5, &6) *Tricolpopollenites* spp. and *Porocolporopollenites* sp. and cf. triangulus *Trudopollis* sp. E and *Momipites* spp. L and F.
	Matawan Group and Magothy Formation, undifferentiated: (dark gray to black clay)	*Betulaceoipollenites* *Brevicolporites* *Holkopollenites* *Momipites* sp. I *Retitricoloporites* spp. *Rugubivesiculites* *Proteacidites* and *Retitricolpites* sp. G *Tricolpites minutus* *Tricolporites* Tricolporate types 1 and 5, triporate angiosperm taxa: *Trudopollis* bisaccate pollen triaperaturate pollen

sand, some of which were as much as 0.5 in. thick. These closely spaced, alternating layers of clay and sand, especially in samples from boring 063-009, can result from (1) deposition from storms, (2) seasonal deposition of sediment into lakes, or (3) slight facies shifts of deltaic sediments.

The upper surface altitude of the grayish-brown clay ranged from as shallow as 120 ft below sea level to as deep as 190 ft below sea level at borings 034-004, in the northwestern part of BNL, and 050-003, east of BNL, respectively. Written field logs from borings drilled before 1994 indicate that the unit's upper surface could be as shallow as 109 ft below sea level (boring 074-001 in the western part of BNL). A map showing the upper surface altitude of this unit is presented in figure 4. Most deep borings in the study area were completed upon contact with the top of the grayish-brown clay, but some penetrated into or through the unit; the bottom-surface altitude of the unit as indicated by these borings also is presented in figure 4.

The close spacing of the recent deep borings in some parts of the BNL site allows the grayish-brown clay unit to be traced between some borings. The unit is laterally continuous in three main parts of the study area. One is in the northwestern part of BNL, where it reaches its maximum thickness (greater than 88 ft) at boring 000-118 (fig. 5) and is more than 60 ft thick in borings 018-005 and 034-004 (fig. 5). The second part is near the central part of the eastern boundary of BNL, where the unit's thickness exceeds 70 ft. (Borings 041-004, 050-003, and 061-005 did not penetrate the bottom of this unit.) The upper surface of the clay dips to the east from 148 ft below sea level at boring 049-006 to 190 ft below sea level at boring 050-003, 0.5 mi away. This area could represent an erosional channel in the Cretaceous surface, as discussed in a later section, because the upper surface altitude of the grayish-brown clay is relatively deep. The extent of the clay unit in this area is delineated by its absence in nearby borings in grid blocks 007 and 037, and east of blocks 061 and 081 (fig. 4).

The third area in which the grayish-brown clay is continuous is in the southwestern part of the BNL site and in the area just south of the site. The unit is 50 ft thick at boring 109-001 (fig. 2). The top of this unit was encountered in 15 borings drilled along the southwestern site boundary (section E-E´, fig. 6). Its thickness along section E-E´ was determined only at boring 130-004, where it was 39 ft.

The upper surface of the grayish-brown clay generally slopes eastward, from about 140 ft below sea level in the southwestern corner of the site (boring 129-001) to about 160 ft below sea level in boring 122-007 in the south-central part of the site, but it was not encountered at boring 122-005, just 280 ft northeast of the latter boring. The uppermost Cretaceous deposits at boring 122-005 are grayish-brown silty sand and were encountered at 171 ft below sea level. The upper surface of the grayish-brown clay also generally dips southward toward BNL's southwestern boundary from the north (onsite borings 109-001 and 119-002) and dips northward from the south (offsite borings 000-064 and 000-065) to form a depression in the clay unit's upper surface at the southwestern boundary.

The clay unit was not encountered south of the site in a north-south line of borings (000-049, 000-107, 800-033) between two subcrops of the grayish-brown clay but was encountered east of the line of borings (borings 000-048, 000-050, and 800-016) and at several borings west of the line of borings, including 000-097, 800-021, 000-062, 000-064, and 000-105 (figs. 2 and 4). The grayish-brown clay is absent in the west-central and the southeastern parts of the BNL site. Although this unit was observed at boring 115-011 in the southeastern part, it was not encountered in other deep borings in that part of the BNL site (107-027, 106-019, 056-007 and 088-108).

Sequences of thin, brown clay beds (less than 5 ft thick) interbedded with brown sand were observed in borings 113-001, 113-002, 113-003, 113-005, 085-014, 096-038, 096-039, 085-013, and 088-108 in the south-central part of BNL. These beds generally were not traceable between borings. They produced a significant response on gamma-ray logs. Some of the interbedded sand layers at borings 113-001, 113-002, and 113-003 contained shells. Samples of brown clay beds from borings 113-003 and 088-108 were sent for pollen analysis and were found to contain none. Although these beds could be part of the grayish-brown clay unit, the presence of shells indicates that they are part of the base of the Pleistocene deposits associated with the Upton unit, discussed later on.

The limited lateral extent and variable thickness of the grayish-brown clay unit in parts of the site, and the variability of its upper-surface altitude are probably the result of facies changes commonly observed in deltaic depositional environments. Areas in which the clay is thick could represent areas of large river meanders or flood plains, or possibly lacustrine deposition into oxbow lakes.

Monmouth Group

The Monmouth Group, first identified on Long Island by Perlmutter and Crandell (1959), consists of dark-green, dark-gray, or black glauconitic and lignitic clay, silt, and silty sand. Perlmutter and Todd (1965) found fossil evidence of a shallow marine depositional environment for these sediments. The Monmouth Group overlies the Magothy Formation along the southern shore of Long Island, and its upper surface dips gently southward. It extends beneath the barrier islands and parts of the southern shore, but its northern extent in the BNL study area has not been defined. Previous investigators did not identify Monmouth Group sediment in any wells on the BNL site. Only one boring drilled during this study contained sediment that resembled Monmouth Group deposits (boring 800-024, discussed in a later section).

Surface Configuration of Cretaceous Sediment

The upper surface of the Magothy Formation dips gently to the south in the southern half of central Suffolk County and generally dips more steeply to the north in the northern part of the county. This configuration, which forms a cuesta (a ridge with a gentle slope on one side and a steep slope on the other), is a result of erosion of the upper surface of the Cretaceous sediments during the Tertiary and Quaternary Eras (deLaguna, 1963). Erosion by streams during these periods give the upper Cretaceous deposits an irregular surface configuration; erosion during the Pleistocene could also have included glacial scouring or ice shoving of Cretaceous sediments in some parts of Long Island (Stumm and Lange, 1996).

The upper-surface altitude of the Cretaceous deposits at the BNL site and vicinity is depicted in figure 7. The surface is irregular and has a relief of about 120 ft, with several prominent channels and ridges that trend generally northwest-southeast, the direction of glacial scour. The Cretaceous surface beneath BNL is characterized more by local erosional features than by the regional cuesta shape.

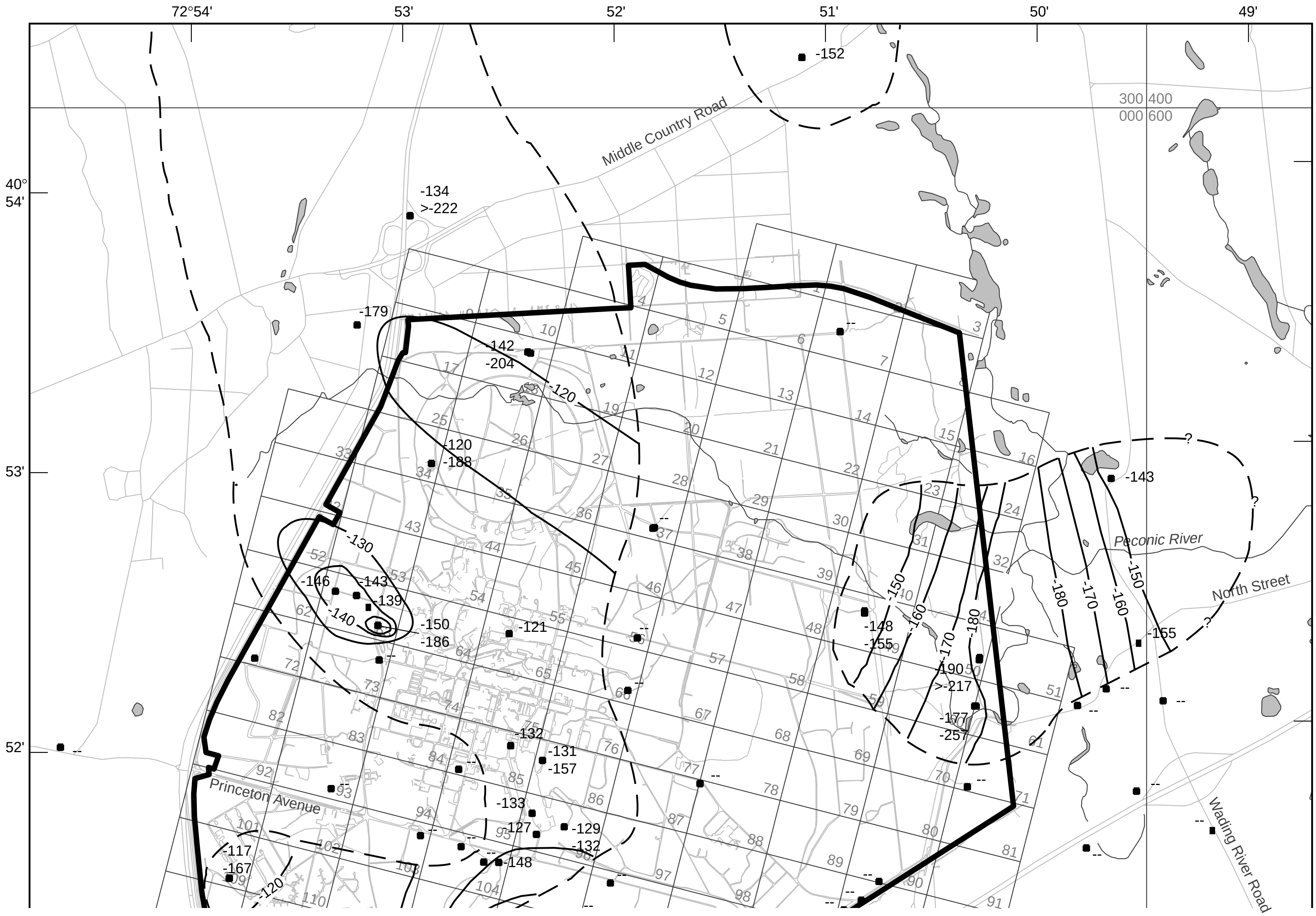
The Cretaceous surface is deepest along the eastern boundary of the BNL site, where it is 175 to 190 ft below sea level (fig 8). The sediment that overlies the Cretaceous deposits is brown, well-sorted fine to coarse sand that is interpreted to be of Pleistocene age. Some core samples from about 10 ft above the Cretaceous surface contained pelecypod and gastropod shells. The Cretaceous surface is encountered at deep altitudes in several borings southeast of BNL (000-090, S49477, Sparrow 5; fig. 2) indicating that it forms an elongated depression oriented north-northwest to south-southeast and is probably the result of an erosional channel that formed during the Pleistocene. The depth of the Cretaceous surface at 120 ft below sea level at boring 600-015 on Wading River Road suggests an eastern limit to the erosional channel.

Cretaceous sediments were observed at depths as shallow as 100 ft below sea level in the few deep borings drilled in the southeastern part of BNL (such as boring 100-004, fig. 8). The shallow part of the Cretaceous surface extends northwestward to borings 037-004 and 017-004 and forms a northwest-southeast-trending ridge.

The Cretaceous surface is as high as 103 ft below sea level (boring 000-044) just west of BNL. Through the southwestern part of BNL, it slopes to the south and to the east, from altitudes of less than 120 ft below sea level at borings 093-006 and 109-001 to more than 170 ft below sea level at borings 122-005 and 122-008. The upper surface of the grayish-brown clay generally slopes eastward along the southwestern boundary of the site but is discontinuous further east and is absent (or below depth of boring penetration) beneath a northwest-southeast-trending ridge near grid block 100 (fig. 4).

The Cretaceous surface at the south-central part of BNL is more than 150 ft below sea level. An elongated trough oriented north-south extends from about 0.7 mi north of the site’s southern boundary (including boring 106-019) to 0.5 mi offsite (including boring 000-048). The depth and slope of the Cretaceous surface, and the absence of Pleistocene green clay, in this area (as discussed in a later section), are further evidence of glacial erosion in the Cretaceous surface.

High and low features in the Cretaceous surface in the area south of BNL are generally oriented northwest-southeast. For example, the Cretaceous surface is deeper along a northwest-southeast trending line of borings (000-057, 000-102) than in neighboring borings (000-059, 000-051, 000-107) (fig. 9).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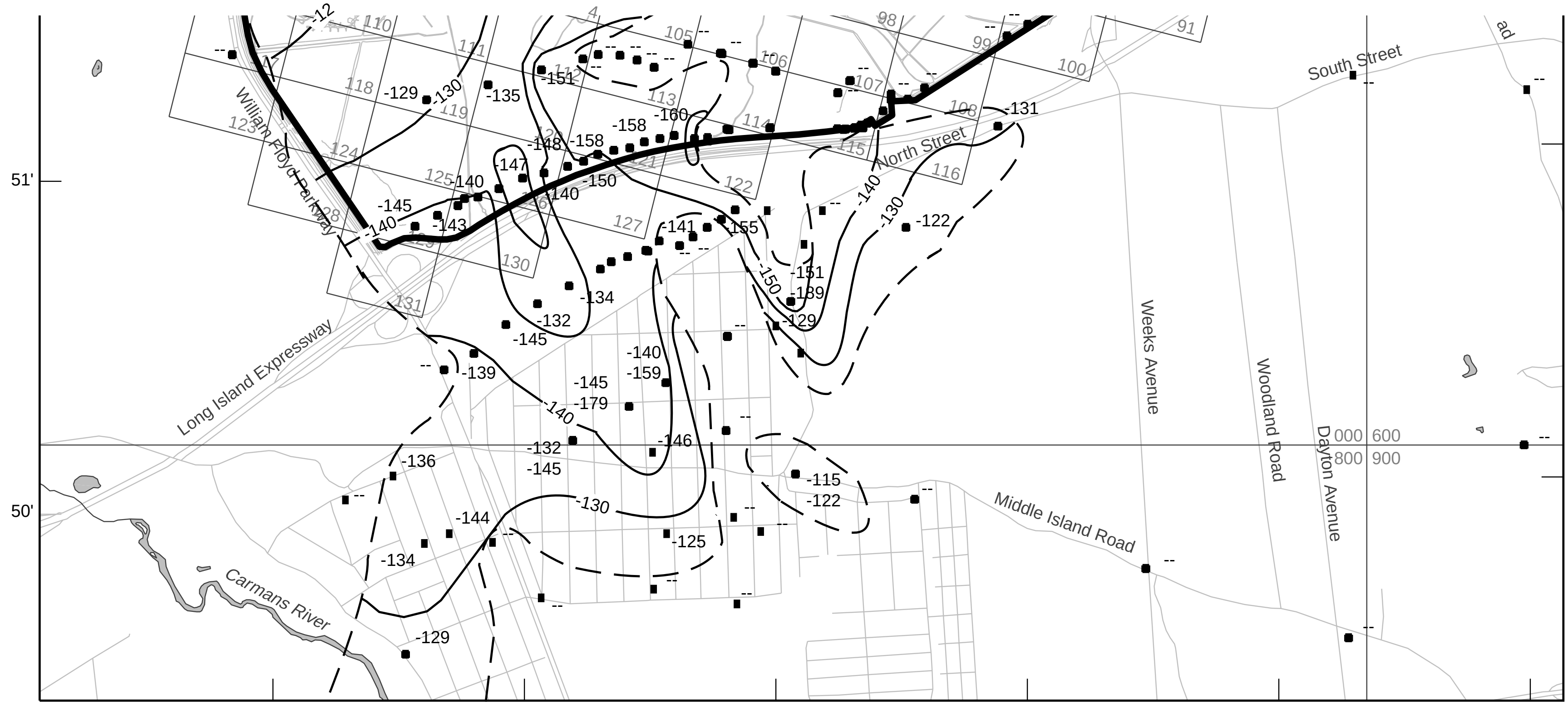

Base from New York State Department of Transportation, 1981, 1:24,000

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EXPLANATION

BOUNDARY OF BNL SITE

EXTENT OF GRAYISH-BROWN CLAY

-120
-188 BORING- Upper number is altitude of upper surface of Cretaceous-aged grayish-brown clay. Lower number is altitude of bottom of clay, where determined. Double dash (--) indicates deep boring that did not encounter the grayish-brown clay.

STRUCTURE CONTOUR- Shows altitude of upper surface of Cretaceous-aged grayish-brown clay. Contour interval 10 feet. Datum is sea level.

42 GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY. Number is grid block number.

Figure 4. Altitude of the upper surface of the grayish-brown clay at selected borings in Brookhaven National Laboratory study area and vicinity, Suffolk County, N.Y. (Location is shown in fig. 1B.)

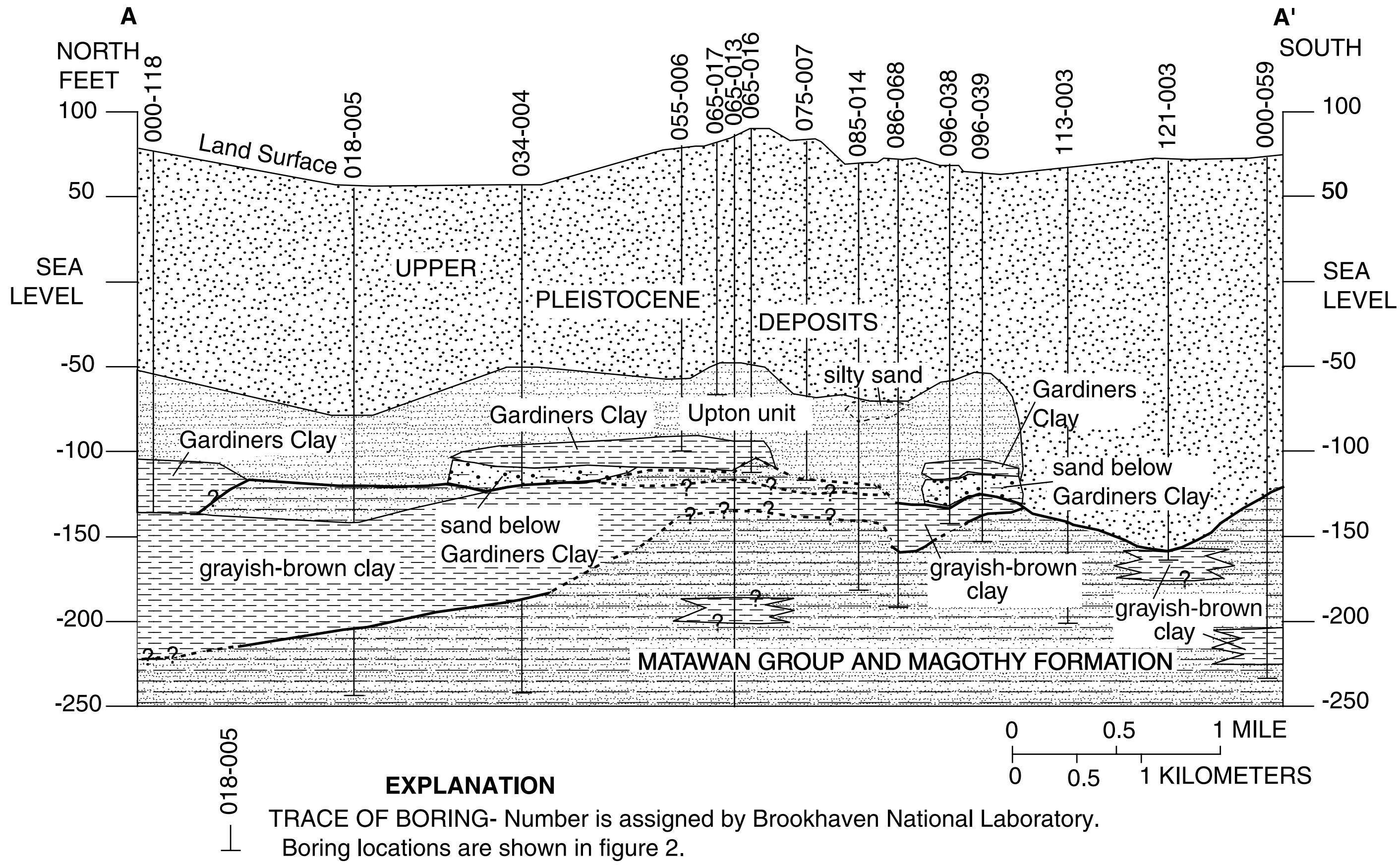


Figure 5. Stratigraphy along north-south section A-A´ through Brookhaven National Laboratory site, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

The Cretaceous surface is particularly shallow (higher than 120 ft below sea level) at borings 800-016 and 800-020 along Middle Island Road (fig. 2) and could be as shallow as 70 ft below sea level in boring 800-024, where three major clay units are present. The upper clay unit was penetrated at 70 to 78 ft below sea level and was described in the geologist's log as a hard, micaceous, dark grayish-green sandy clay with dark-green laminations. The second clay unit is indicated on the gamma log at 100 to 108 ft below sea level; a sample of it contained dark-gray clay with silt and fine sand laminations. The third clay unit was encountered at 132 to 139 ft below sea level and consists of hard, dark, greenish-gray, micaceous sandy clay. Microscopic analysis of a rinsed core from the third clay unit indicated clear quartz grains, traces of dark-green, rounded grains of weathered and broken glauconite, and little lignite. This third clay unit resembled the Monmouth Group in hand sample. Pollen analysis of samples from all three clay units indicate them to be of Cretaceous age. The relatively shallow depth of the Cretaceous surface at borings 800-016 and 800-020 supports the interpretation of a shallow Cretaceous surface (70 ft below sea level) at boring 800-024.

The configuration of the Cretaceous surface shown in figure 7 has a more gradual northward dip within BNL than indicated by previous authors (Smolensky and others, 1989); that is, the steep northward cuesta face lies north of BNL.

Pleistocene Deposits

Two major glacial advances during the Pleistocene Epoch deposited the terminal moraines and extensive outwash sediments across Long Island (Suter and others, 1949). The BNL site lies in an intermorainal area (north of the Ronkonkoma moraine and south of the Harbor Hill moraine, fig. 1), where sediments also were deposited in glaciolacustrine and shallow marine environments. The lowermost Pleistocene sediments vary lithologically and are laterally discontinuous.

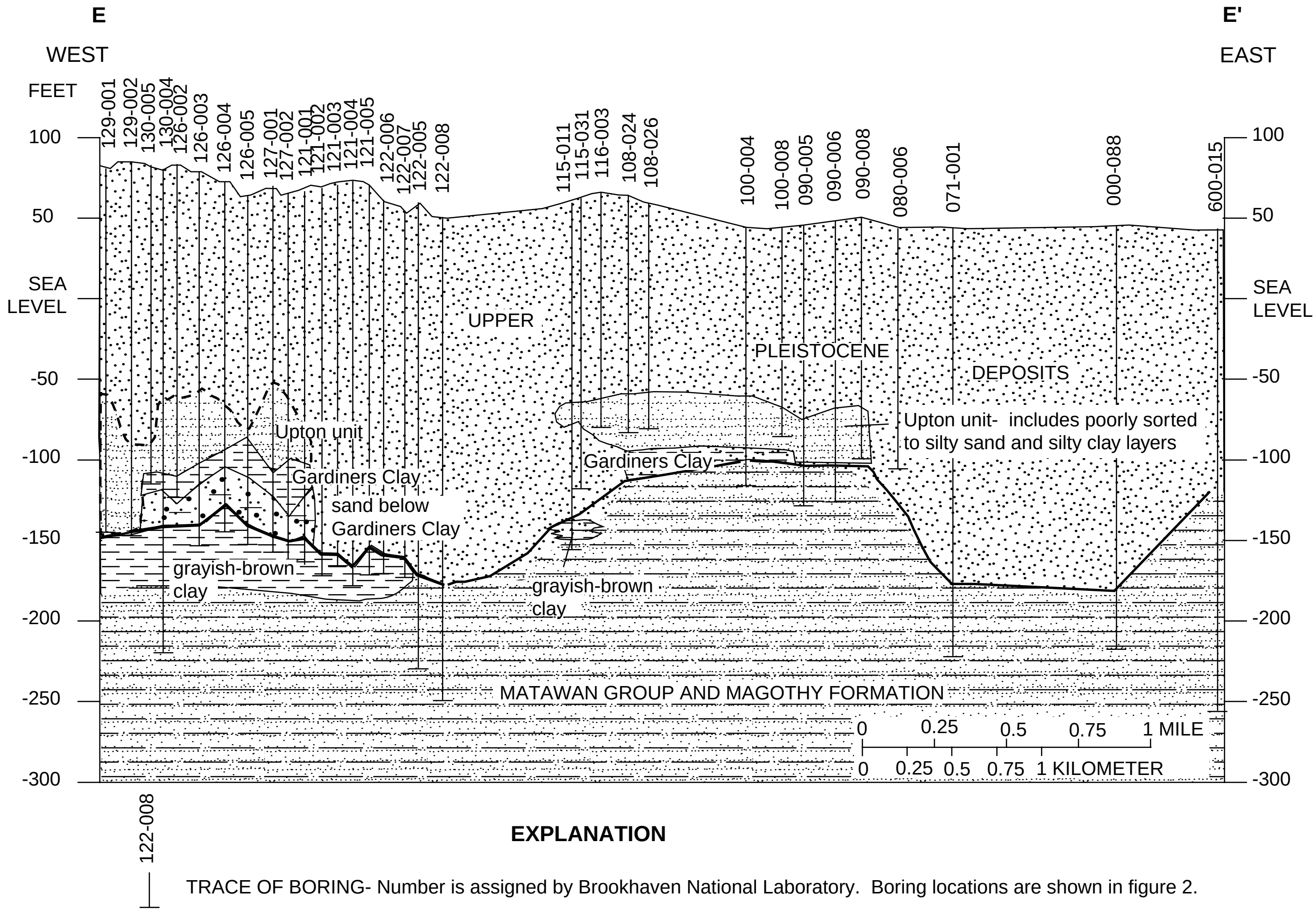


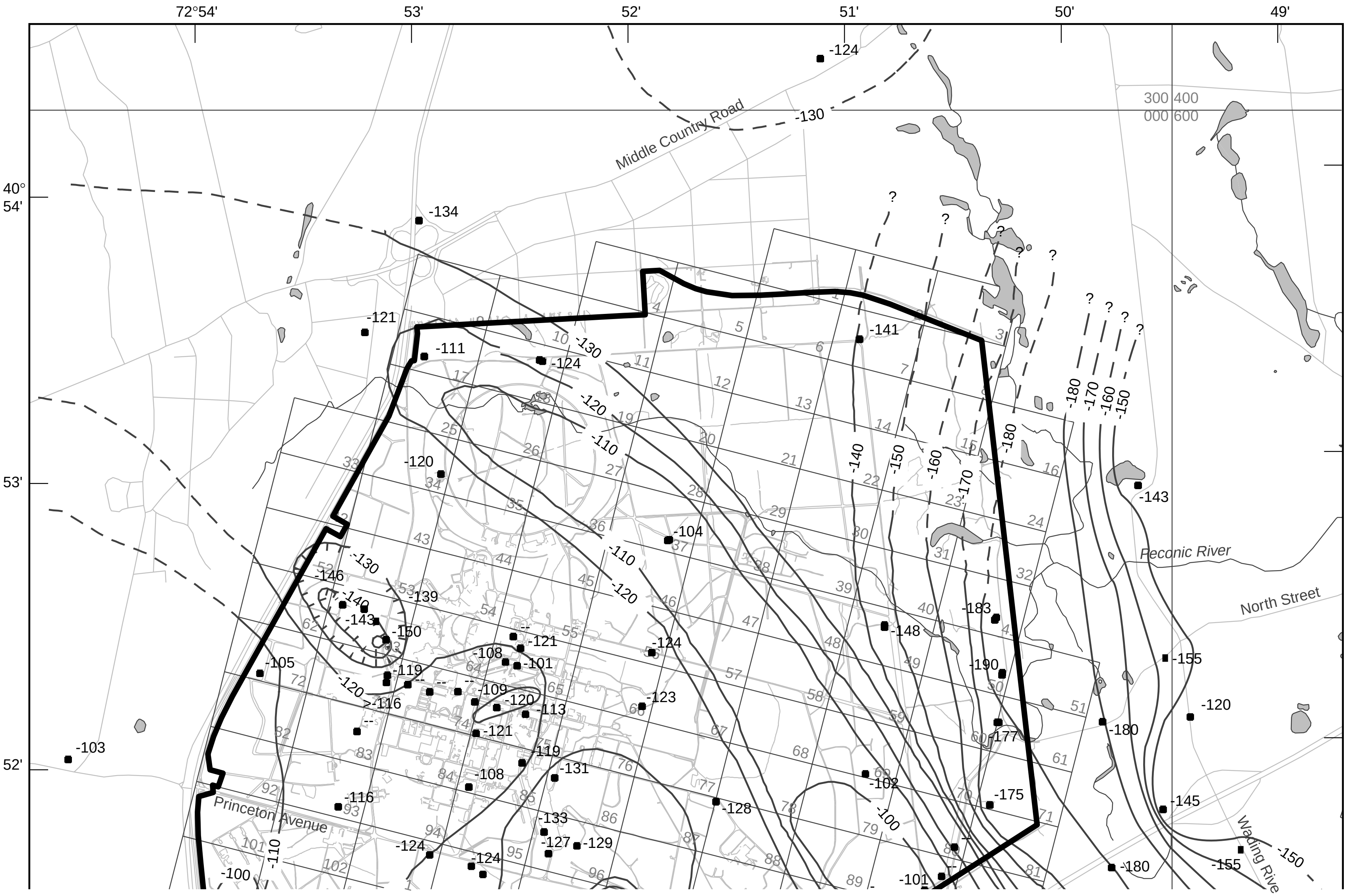
Figure 6. Stratigraphy of west-east section E-E´, along southern boundary of Brookhaven National Laboratory, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

Prominent units observed during the 1993-96 drilling programs were (1) a sand layer below the Gardiners Clay, (2) the Gardiners Clay, (3) sediments identified as the “unidentified unit” by de Laguna (1963) and associated layers, collectively referred to as the Upton unit in this report, and (4) glacial outwash deposits. Each is discussed in turn below.

Sand below Gardiners Clay

A layer of sand overlying the Magothy Formation and beneath the Gardiners Clay was encountered in several borings in the northwestern part of BNL (borings 018-005 and 034-004, section A-A´, fig. 5) and also is traceable along the southern boundary of the BNL site (section E-E´). This unit is composed of poorly sorted sand but some zones contained well-sorted fine to coarse sand; it ranged from light brown to light olive brown and grayish brown. Most samples were rich in quartz and also contained less stable minerals or rock fragments. The unit is 20 to 30 ft thick at most borings in which it was encountered, and its upper surface is generally between 105 and 120 ft below sea level. Rinsed core samples from this layer (boring 130-004, on the southwestern boundary of the site) were examined with a reflected-light microscope and were found to contain quartz, muscovite, rock fragments, traces of biotite and lignite, and fibrous plant material. Pollen analysis of a sample from this layer in boring 130-004 indicated Pleistocene age. The sand unit also contains peat at borings 130-004, 088-108, 063-009, 106-019, 107-015, and 087-017. de Laguna (1963) also noted the presence of a peat layer beneath the Gardiners Clay.

Although previous investigators could have considered this unit to be Cretaceous because it is below the Gardiners Clay, the mineral content, the presence of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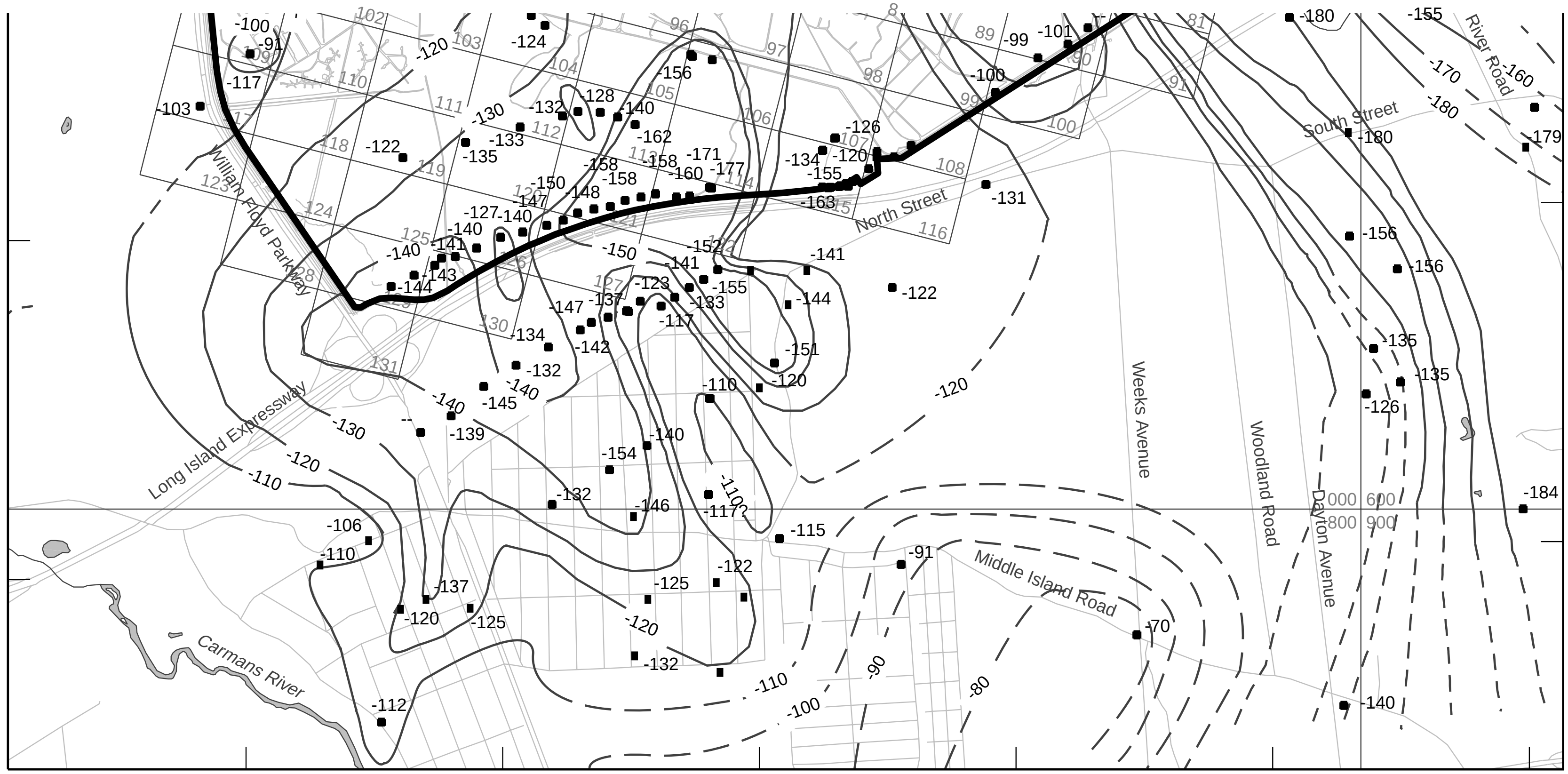
Wading River



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

0 0.25 0.5 0.75 1 MILE

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EXPLANATION

42 GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL)- Number is grid block number and represents first three digits of borehole numbers.

-19 BORING- Number is altitude of upper surface of Cretaceous-aged sediments. Double dash (--) indicates deep boring that did not penetrate Cretaceous sediments.

-150 STRUCTURE CONTOUR- Shows altitude of upper surface of Cretaceous-aged sediments. Contour interval 10 feet. Datum is sea level. Dashed where inferred. Hachures indicate depression.

BOUNDARY OF BNL SITE

Figure 7. Upper surface altitude of Cretaceous deposits in Brookhaven National Laboratory study area, Suffolk County, N.Y. (Location is shown in fig. 1B.)

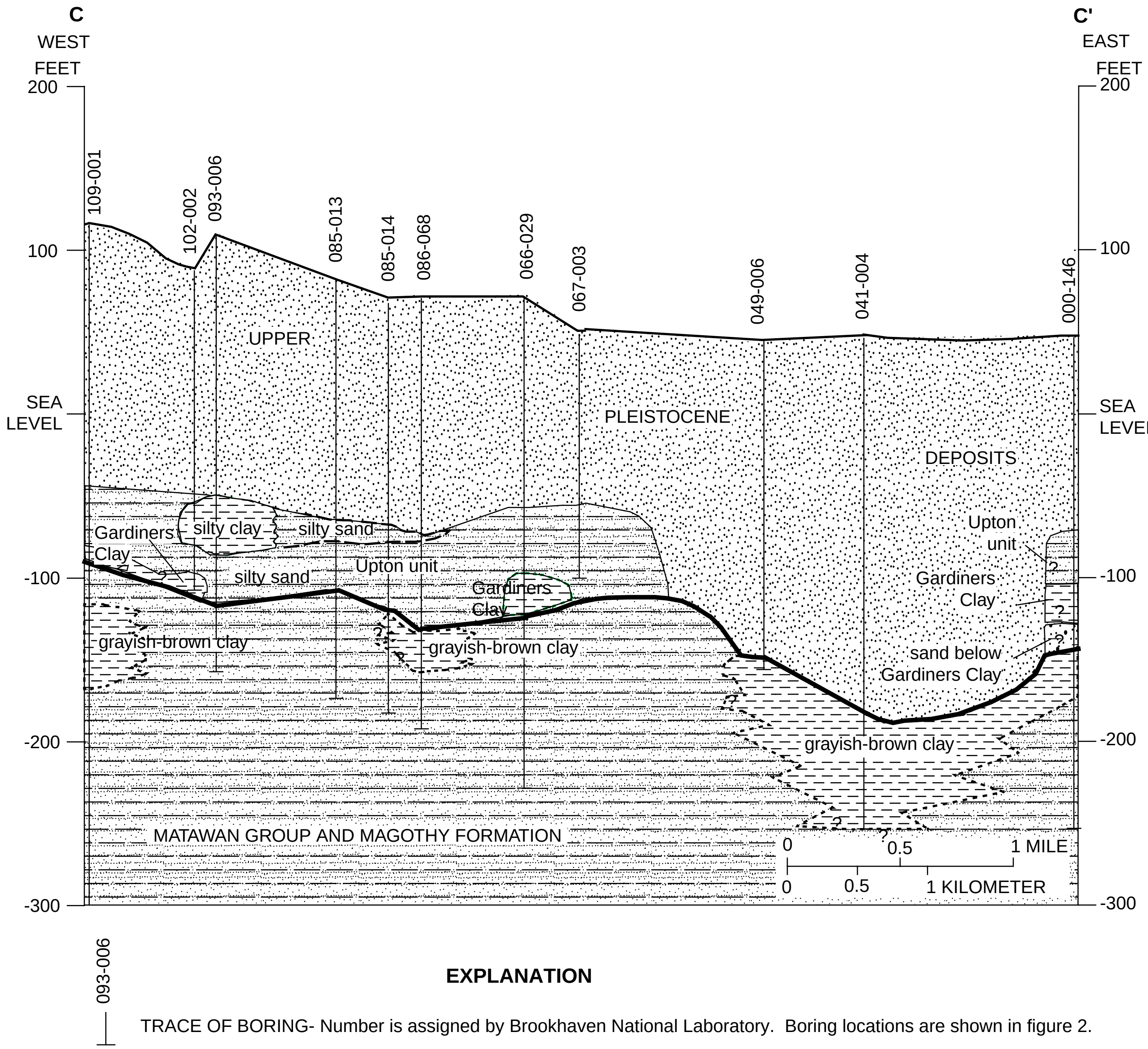


Figure 8. Stratigraphy of west-east section C-C´ through the Brookhaven National Laboratory site, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

fibrous plant material, and results of the pollen analysis indicate that this unit is of Pleistocene age.

Gardiners Clay

The term Gardiners Clay has been assigned to several clay units throughout Long Island. For example, deLaguna (1963) used the term Gardiners Clay to refer to three different bodies of sediment—the thick clay along the southern shore of Long Island, the greenish-gray clay layer beneath the BNL site, and clay layers found in Riverhead and Mount Sinai. As Stone and Borns (1986) explain, most current researchers do not accept correlation of all three clay units (Upson, 1970; Gustavson, 1976). Smolensky and others (1989) considered the Gardiners Clay to be the unit of clay that is found along most of the southern shore of Long Island. Stone and Borns (1986) cited biostratigraphic evidence that the unit was deposited during the Sangamon interglaciation.

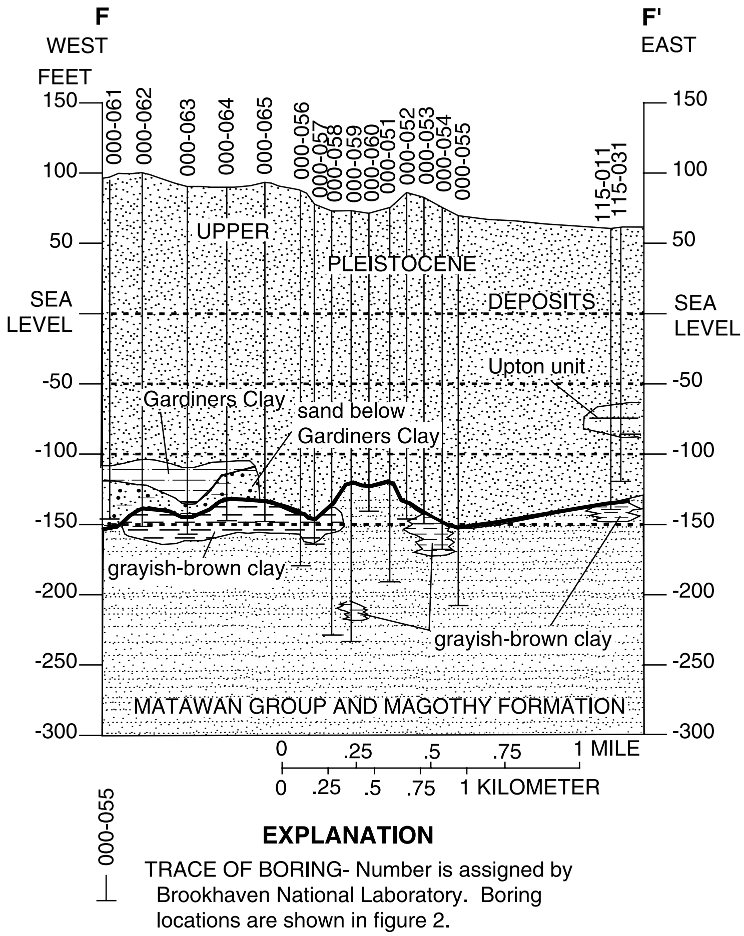


Figure 9. Stratigraphy of west-east section F-F′ along industrial park, south of Brookhaven National Laboratory, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

The northern extent of the Gardiners Clay in the BNL area had not been fully defined by previous investigators. Weiss (1954) and deLaguna (1963) concluded that the greenish-gray clay beneath the BNL site is contiguous with the south-shore Gardiners Clay, however, Smolensky and others (1989) depict the Gardiners Clay as extending only slightly north of Sunrise Highway (fig. 1).

Lithology

Core samples collected during this investigation indicate that the Gardiners Clay in the study area, although greenish-gray in most places, varies locally from dark green to light gray. The texture also is variable and ranges from sandy to silty clay. Sand-sized grains in rinsed samples of the unit included quartz, mica, chlorite, lignite, glauconite, and rock fragments. Muscovite was the most common mica, but grains of biotite also were present in some samples. Many samples contained shell fragments that included clams, snails, scapopods, and foraminifera.

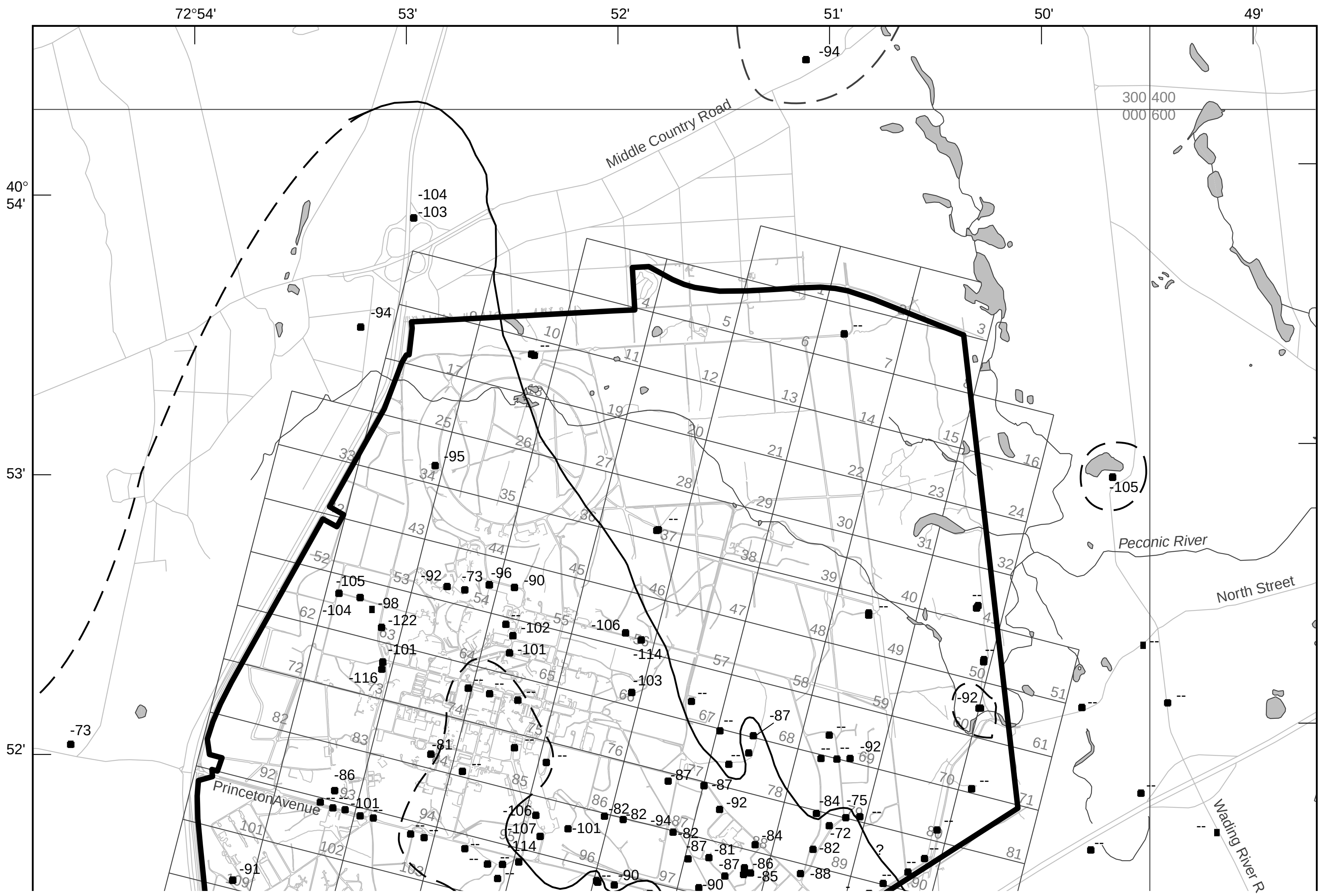
Weiss (1954) suggested that the Gardiners Clay was deposited in a shallow, brackish-water environment similar to the present-day bays along the southern shore of Long Island. deLaguna (1963) noted similarly that the clay was deposited in this type of protected environment in a climate that was similar to, or a little colder than, present-day conditions. Pollen analyses (table 2) confirm the unit's Pleistocene age and indicate that the climate during deposition of the unit was moist and probably temperate, and that the depositional environment was near a wetland.

Core samples from a layer above the Gardiners Clay at several borings in the southeastern part of the BNL site (088-108, HP107-19, 088-017, 105-019) contained shell hash, which includes well-sorted fine sand and large amounts of shells. The high percentage of shells, and the high degree of sorting in these samples, indicate a shallow, near-shore, high-energy depositional environment such as a beach. The shell-hash deposits formed in shallower water than the underlying clayey deposits, which indicates a shallowing upward (regressive) sequence (indicative of a relative decline in sea level) and implies that the shoreline in this area shifted its position through time, as would be expected with the advent of renewed glaciation following an interglacial interval.

Configuration of Unit

Data obtained from the recent drilling have helped to refine the delineation of the Gardiners Clay unit at the BNL site. Its extent in the study area is depicted in figure 10; its absence in some areas probably resulted from erosion. The unit's extent is especially well defined in the southern half of BNL, where borings are most closely spaced.

The upper surface of the Gardiners Clay is traceable between borings along a northwest-southeast-trending line in the southeastern part of the site, where it generally slopes northwestward from 70 ft below sea level at boring 000-047 to 84 ft below sea level at 088-017. The northeastern and southwestern extents of the unit are well defined in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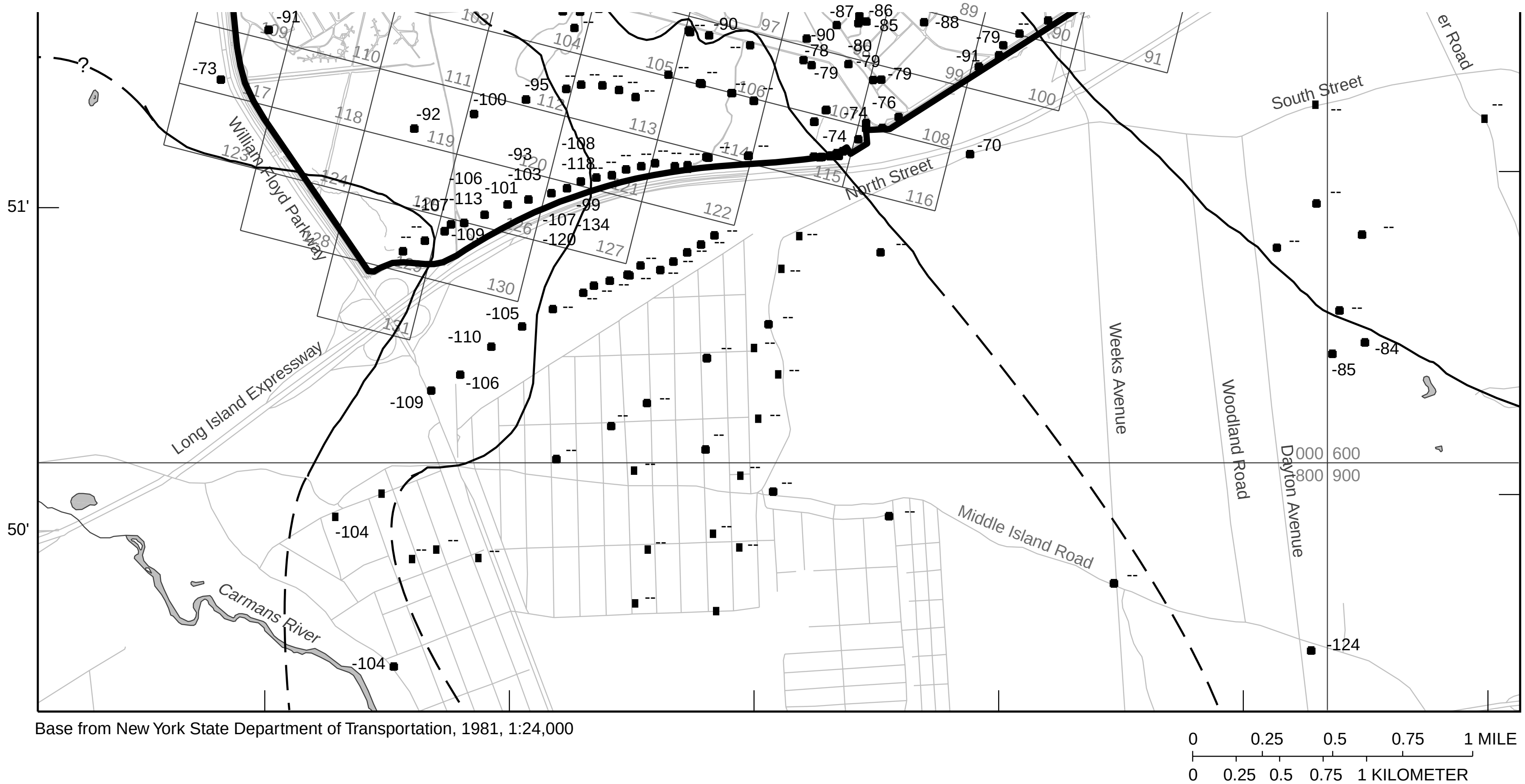


EXPLANATION

GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL). Number is grid number and represents first three digits of borehole numbers.

BORING- Number is altitude of upper surface of Pleistocene-aged Gardiners Clay. Double dash (--) indicates deep boring that did not encounter Gardiners Clay.

EXTENT OF PLEISTOCENE-AGED GARDINERS CLAY

BOUNDARY OF BNL SITE

Figure 10. Extent of Gardiners Clay in Brookhaven National Laboratory study area, Suffolk County, N.Y. (Location is shown in fig. 1B.)

this area because the borings are numerous, but its thickness at those borings could not be defined because most borings were terminated as they entered the top of the unit. This area is bordered on the northeast and southwest by glacial stream channels that incised into the Magothy Formation. The unit is absent in the eastern part of the BNL site, except at boring 061-005, and is also absent near the central part of the southern boundary. Pleistocene sand extends from land surface down to a depth appreciably below the altitude of the Gardiners Clay in these two areas (figs. 6, 8, and 9), suggesting localized erosion of the Gardiners Clay by meltwater streams prior to deposition of sandy outwash. The unit is also absent in a small, narrow, elongate, northwest-southeast-trending area in parts of grid blocks 75, 85, and 86.

The Gardiners Clay can be traced along the southern boundary of the site from boring 130-005 to 121-001 (Section E-E´, fig. 6). It is absent at 129-001 and 129-002 but was encountered offsite to the southwest; it also was encountered north of the site boundary in the southwestern part of the BNL site (borings 119-002, 120-001, 112-001). A green clay was pulled from the lower part of the augers at the well boring for 103-004 on Princeton Avenue. The upper surface of the unit is deeper in the southwestern part of the BNL site than in the southeastern part; it was penetrated at altitudes of 92 to 109 ft below sea level (borings 119-002 and 126-002, respectively) in the southwestern part of the BNL site. The unit's greater depth in this area than in the southeastern part of BNL could indicate that its upper surface generally dips to the west, or that it does not directly correlate to the unit observed in the southeastern part of the site. Although notable gamma-ray responses were recorded at about 80 ft below sea level in borings 102-004 to 104-007 along Princeton Avenue, samples from this zone typically were greenish-, brownish-, and olive-gray fine to medium sand with little silt and, therefore, are interpreted as the Upton unit, discussed further on (fig. 11).

Green or gray clays also were encountered in the central, western, and northern part of the site at altitudes that range from 73 to 122 ft below sea level. The differing altitudes indicate that the unit could not be directly traced between borings in this area; clays at shallower depths also could be related to the Upton unit, discussed further on.

The extent of the clay unit is less well defined in the northeastern part of the site than in the southern part as a result of a lack of closely spaced, deep borings. Although this unit was encountered in borings north of the site, it was absent at three onsite borings (007-002, 037-004, and 049-006) in the northeastern part.

Green clay also was encountered in three offsite borings north of BNL. At 000-045, the greenish-gray clay unit was encountered at 94 ft below sea level and was separated from the grayish-brown clay by 65 ft of Pleistocene and Cretaceous sand and clay layers. At boring 000-118, about 0.5 mi farther north, the greenish-gray clay unit directly overlies the Cretaceous grayish-brown clay whose upper surface is about 40 ft shallower than at 000-045. The written log and the gamma-ray log from boring S96481, nearly 2 mi to the northeast, indicates that 46 ft of gray, medium to coarse sand separates the bottom of the green clay unit from the top of the grayish-brown clay. Cuttings from boring S100608, which was drilled within the same well field as S96481, contained green clay with abundant shells.

Upper Pleistocene Deposits

Upper Pleistocene deposits form the uppermost geologic unit on Long Island; these deposits include morainal sediments, till, outwash, and glaciolacustrine sediments that were deposited during the Wisconsinan glaciation. Morainal sediments on Long Island are a poorly to moderately sorted mixture of sand, gravel, boulders, silt, and clay. Outwash sediments form the bulk of the upper Pleistocene deposits; they consist mostly of well to poorly sorted sand and gravel but locally contain fine-grained layers of silt or clay. The upper Pleistocene deposits directly overlie the Magothy Formation in areas where both the Gardiners Clay and the Monmouth Greensand are absent. In some parts of Long Island, the upper Pleistocene deposits contain extensive clay-rich units such as the Smithtown clay (Krulikas and Koszalka, 1983) and the "20-foot" clay (Perlmutter and Geraghty, 1963; Doriski and Wilde-Katz, 1983). Soren and Stelz (1984) observed a clay layer overlain by sand and a second clay layer within upper Pleistocene deposits near Jamesport, and suggested that this sequence of units (which resembles the Gardiners Clay and the and the overlying Upton unit at the BNL site) was deposited during the interstadial period between the Ronkonkoma and Harbor Hill glacial advances of the Wisconsinan glaciation.

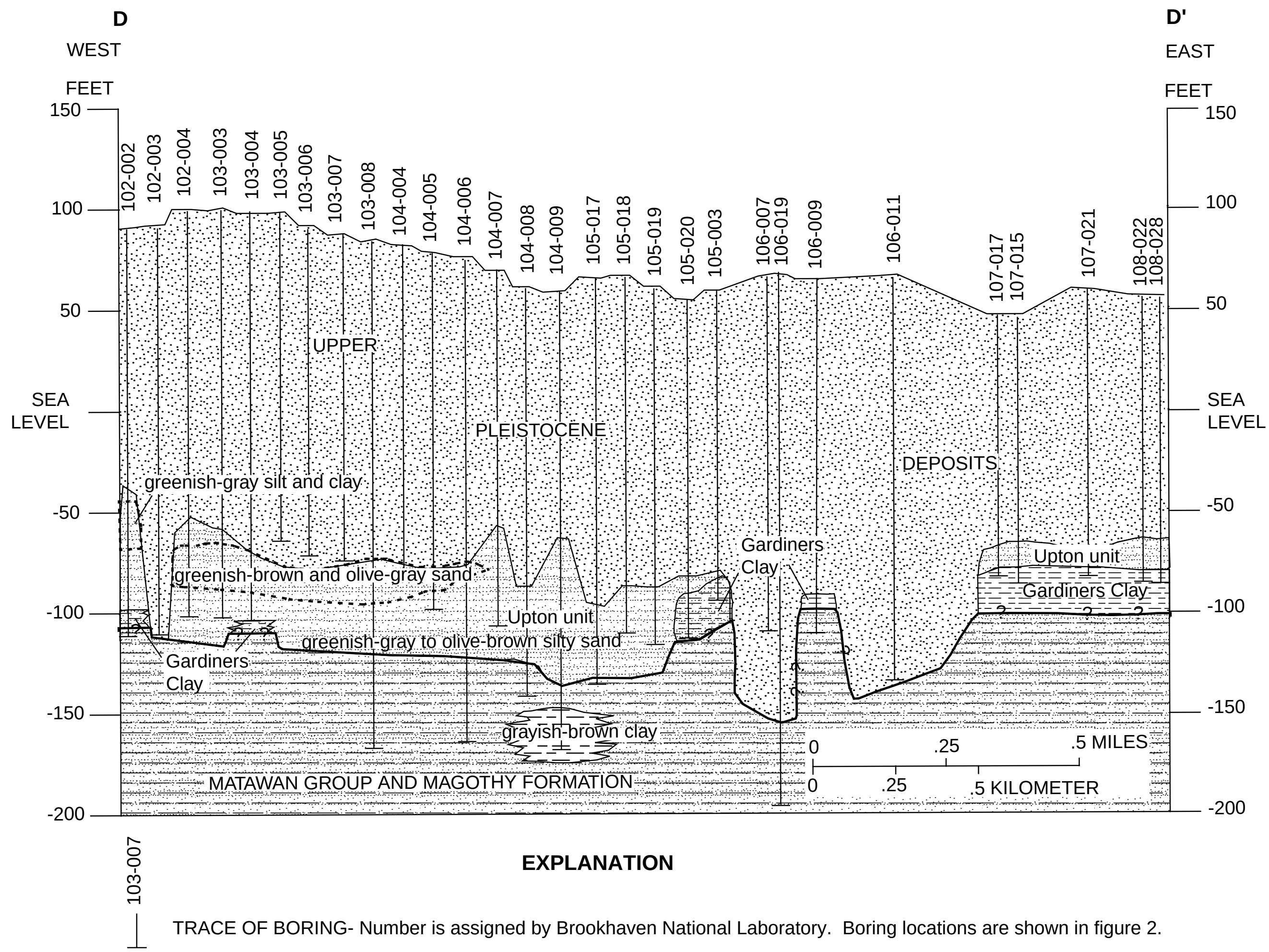


Figure 11. Stratigraphy of west-east section D-D´ along Princeton Avenue, Brookhaven National Laboratory, Suffolk County, N.Y. (Trace of section is shown in fig. 2.)

The upper Pleistocene deposits in the BNL site are 115 to 250 ft thick. Through most of the study area, deposits less than 100 to 150 ft below land surface are outwash, generally light-brown to yellow-brown fine to coarse sand that is poorly to well sorted; some shallow, near-surface clayey units are present within the outwash in areas close to stream channels, including the Peconic River. The lower part of the upper Pleistocene sequence has a more varied lithology, as described in the next section.

Upton Unit

The new, informal name—Upton unit—is proposed in this report for generally greenish sand, or sand and clay sediments in the lower part of the upper Pleistocene deposits at the BNL site and other similar and related deposits. These sediments have been referred to in previous reports as the “unidentified unit” (deLaguna, 1963; Faust, 1963). Although previous investigators were unable to establish the depositional origin of this unit, they considered the unit to be the basal part of the upper Pleistocene deposits.

The Upton unit generally overlies the Gardiners Clay and contains minor clay layers that are lithologically similar to the Gardiners Clay. Pollen analysis of samples from the fine-grained layers of the Upton unit yielded Pleistocene pollen. Sediments similar to those described by deLaguna (1963) were observed in several parts of the BNL site, including borings 086-068, 104-002, 119-002, and 129-001 in the southwestern part. These sediments were yellow-green to olive-brown, fine to medium sand.

The deep part of the Pleistocene deposits contains several lithologic layers that differ subtly or greatly from one another, are laterally discontinuous, and that may represent facies changes during deposition. The altitudes of the upper surfaces of these lithologic layers range from 50 to 70 ft below sea level in many borings throughout the 28-mi^2 study area. These layers include subtly to distinctly differing units of gray sand, greenish-gray silt, and green to greenish-gray clay, and show subtle differences in color (including shades of brown, olive, green, and gray), grain size, sorting, and relative gamma-ray responses. In several borings (for example, 000-118, 034-004, 037-004, 066-029), the shallow Pleistocene deposits are separated from the deep Pleistocene deposits by a clay or silty unit that is generally less than 10 ft thick and produces a noticeable response on the gamma-ray log. The varied layers at the base of the Pleistocene sequence are generally at about the same altitude as the aforementioned "unidentified unit" and could be differing facies associated with that unit; hence, they are included in the Upton unit.

Northwestern part of the site.—Logs from four borings (000-118, 018-005, 034-004, 055-006) show greater gamma-ray responses in the deep part (lower 60 ft) of the Pleistocene deposits than in the shallow part (upper 120 ft). Core samples from these borings consist of gray to light-green, poorly sorted, micaceous sand, silt, and clay. Pollen analysis of selected samples from these borings confirm a Pleistocene age for these deposits. Although the lithology of the sediments does not closely resemble that of the unidentified unit described by deLaguna (1963), this zone probably is of the same age and is correlated with it.

Central part of the site.—Sediments from the deep part of the upper Pleistocene deposits in the central part of the site were coarser grained than those from similar altitudes in the northwestern part (section A-A´; fig. 5). These layers were mostly silty to well-sorted sand with subtle variations in color, but included some clayey units.

Southern part of the site.—Core samples from deep upper Pleistocene deposits in this area contained sediments typical of the unidentified unit as well as light-brown, poorly to well-sorted sand. Deep Pleistocene sediments in this area are generally coarser grained and better sorted than those at similar altitudes in the northern part.

The Upton unit overlies the Gardiners Clay in most of the BNL site, except in the westernmost borings along the south boundary (Section E-E´, borings 129-001 and 129-002, fig. 6). Here the greenish-brown, fine-to-coarse sand of the Upton unit overlies the grayish-brown clay of the Magothy Formation.

In a few borings along Princeton Avenue (103-008, 104-006) and in boring 093-006, in the western part of the BNL site, the Upton unit includes a layer of greenish-gray silt and clay that is underlain by greenish-gray to olive-brown silty sand. The deeper sand layer, which closely resembles the descriptions of deLaguna's unidentified unit, overlies dark-gray sand of the Magothy Formation, except in a few borings where layers of the Gardiners Clay remain (102-002, 103-004, 105-020, 106-009). The Upton unit laterally truncates the Gardiners Clay along Princeton Avenue and in the southwestern corner of the site (borings 129-001, 129-002); therefore, it was probably deposited later than the Gardiners Clay after a period of erosion.

Outwash and Morainal Deposits

The BNL site is in the intermorainal area (fig. 1) and contains outwash deposits from both the Ronkonkoma and Harbor Hill glacial advances. de Laguna (1963) identified some of the hills in the northern part of the study area north of the Ronkonkoma moraine as kames and outwash associated with Harbor Hill glacial advances.

Outwash sediments generally were found in the upper 100 to 150 ft of borings and consist of light-brown to yellowish-brown, quartz-rich sand and fine gravel that is poorly to well sorted; 5 to 10 percent of the grains may consist of feldspar, muscovite, biotite, hornblende, garnets, and rock fragments (Faust, 1963). Some shallow, near-surface clayey units were observed in areas close to stream channels, including the Peconic River. The hydraulic effect of these units is discussed in a later section.

Although gravel, cobbles, and boulders are found in the 28-mi^2 BNL study area, borings drilled into the part of the Ronkonkoma moraine south of the BNL site (000-097, 000-049, 000-107) did not encounter the amounts of cobbles and boulders that are typically observed in the terminal moraines of western Long Island. The hills of the Ronkonkoma moraine in this area contain mostly well-sorted sand and gravel that resemble outwash deposits. Gustavson and Boothroyd (1987) postulated a process of sediment transport and deposition that accounts for the large volumes of stratified drift deposits in the moraine and the outwash sediments. This hypothesis, which is based on observations at a present-day glacier in Alaska that is a partial analog of the Wisconsinan Laurentide Ice Sheet, states that meltwater and precipitation drain from the glacier's surface into englacial and subglacial passages, and transport sediment to discharge points (fountains or tunnels at the ice margin).

Near-surface sediments in the 28-mi^2 study area are somewhat coarser than the underlying outwash. The shallow sediments contain some large boulder erratics that are exposed at land surface or have been unearthed during excavations. The tendency of shallow deposits to be coarser grained than the underlying sequence of outwash sediments suggests that these sediments were deposited in facies nearer to the glacier than the outwash deposits. Sirkin (1995) describes the uppermost (Late Wisconsinan) drift in eastern Long Island as consisting mostly of outwash, commonly capped by thin, sandy, bouldery till, which indicates that the outwash sediments were deposited ahead of the advancing glacier.

Summary of Pleistocene Deposition and Erosion at the BNL Site

Geologic units at the BNL site indicate a complex history of deposition and erosion. The unit described in this report as the sand below the Gardiners Clay is the first Pleistocene unit above the irregular surface of the Cretaceous deposits in this area. Because the sand does not have distinct lithologic or mineralogic characteristics, the interpretation of its age could be revised if additional data are obtained. This sand could have been deposited by an earlier glaciation than the Wisconsinan.

The Gardiners Clay was deposited between glacial advances during the major rise in sea level as the sea encroached over what is now the south shore of Long Island and into parts of the BNL site. It probably was formed in a shallow-bay environment near a migrating shoreline. The abundant shell fragments found in association with the Gardiners Clay in some borings indicate that the shore was near the present BNL site location.

The newly collected core data indicate that the Upton unit consists of several facies of variably sorted sand, silt, and clay. As noted earlier, the Upton unit was probably deposited atop the Gardiners Clay after a period of some erosion. Its upper surface is penetrated from about 50 to 70 ft below sea level, and the lithologic change from the overlying outwash deposits is marked by a silt or clay layer in some parts of the site. The deposition of outwash from the Ronkonkoma and Harbor Hill advances occurred after the deposition of the Upton unit. Erosion by stream channels, probably associated with the Harbor Hill advance, dissected the Upton unit and Gardiners Clay to form the deeply channeled areas in the eastern and south-central parts of the BNL site.

HYDROLOGY

Warren and others (1968) examined the hydrology in the vicinity of BNL and included quantitative assessments of the major components of the hydrologic cycle. Hydrologic conditions during the current project are discussed below.

Hydrogeologic Units

The saturated part of the upper Pleistocene deposits forms the upper glacial aquifer, which contains the water table throughout most of Long Island. This unit consists mostly of moderately to well-sorted sand and fine gravel and is highly permeable in most places. The upper glacial aquifer underlies the entire 300-mi^2 study area (fig. 1A) and is the source of base flow to streams.

The average islandwide horizontal hydraulic conductivity value for the upper glacial aquifer is about 270 ft/d (Smolensky and others, 1989), but aquifer tests conducted at BNL by Warren and others (1968) indicated the value at the site to be one-third lower—about 175 ft/d (based on an aquifer thickness of 145 ft), and the specific yield (effective porosity) to be 0.24. Subsequent tests at BNL have measured similar hydraulic conductivities (Holzmacher, McLendon and Murrell /Roux Associates, 1985). Total porosity of the upper glacial aquifer is estimated to be 0.33 (Warren and others, 1968). A summary of aquifer properties obtained from onsite pumping tests is presented in table 3.

Data from aquifer tests and infiltration tests conducted at BNL (Warren and others, 1968) indicate that the anisotropy (ratio of vertical to horizontal hydraulic conductivity) of the upper glacial aquifer is between 1:4 and 1:18. The average value for the upper glacial aquifer throughout Long Island has been estimated to be 1:10 (Smolensky and others, 1989).

Table 3. Hydraulic conductivity of upper glacial aquifer at Brookhaven National Laboratory, Suffolk County, N.Y., as indicated by aquifer tests

Source of data	Hydraulic conductivity (in feet per day)
Warren and others (1968)	180
Holzmacher, McLendon and Murrell/Roux Associates(1985)	180
Camp Dresser and McKee (1995)	200
Grosser (1997)	60-160
Geraghty & Miller (1997)	150

The hydraulic properties of the basal Upton unit cannot be defined with certainty from the current well network, but the high clay and silt content of the Upton unit, especially in the northwestern part of the BNL site, indicate that these deposits are probably less permeable than the overlying glacial outwash sand and gravel.

The Gardiners Clay, where present, confines water and affects ground-water flow, but its limited extent, as defined in figure 10, indicates that the effects are only local. Studies by Warren and others (1968) indicate that the hydraulic conductivity of the Gardiners Clay is about 0.040 ft/d, but the hydraulic conductivity of sandy zones within the unit is higher.

The Monmouth Group, which lies along the southern shore of Long Island, forms the hydrogeologic unit known as the Monmouth greensand. Monmouth greensand and the Gardiners Clay underlie the upper glacial aquifer and confine water in the Magothy aquifer. The upper glacial aquifer directly overlies the Magothy aquifer in areas where both of these units are absent.

The deltaic sediments of the Matawan Group-Magothy Formation, undifferentiated, make up the Magothy aquifer. The hydraulic conductivity of this unit is estimated to average 50 ft/d (Smolensky and others, 1989) but varies widely as a result of local differences in lithology, thickness, and lateral extent. This hydraulic variation can affect local ground-water flow patterns and contaminant transport. Warren and others (1968) conducted an aquifer test in a coarse sand zone of the Magothy aquifer and obtained a hydraulic conductivity value of 57 ft/d.

Much of the Magothy aquifer consists of silty sand with clayey layers. The upper Magothy sediment at BNL is mostly a silty sand with clayey layers but includes layers of well-sorted sand as well as locally extensive clay layers, such as the grayish-brown clay unit. Although the grayish-brown clay unit has a sandy texture in some intervals, it is fairly solid in general and forms a major local confining unit.

Hydrologic Cycle

The hydrologic cycle on Long Island was summarized by Scorca (1997) and discussed at length by Franke and McClymonds (1972), who evaluated the relations among major hydrologic factors, including precipitation, evapotranspiration, direct runoff, ground-water recharge, ground-water movement, and pumpage, to develop an islandwide water budget. The hydrologic cycle can be thought of as beginning with precipitation, which has averaged 48.29 in/yr at Upton station since 1949 (fig. 12). Upon reaching the ground, precipitation either flows as direct runoff into streams, infiltrates into the highly permeable unsaturated zone, or evaporates. Part of the water that infiltrates the soil evaporates or is transpired by plants; the rest infiltrates downward to the water table.

Ground-Water Recharge and Discharge

The rate of recharge to the water table varies from year to year as a function of precipitation; it also fluctuates seasonally because plants capture and transpire most of the water that enters the unsaturated zone during the growing season (May through October). Thus, in most years, virtually all recharge occurs during the nongrowing season (November through April) (Warren and others, 1968). The water table rises in response to recharge and typically undergoes a net rise in years when precipitation is notably higher than in the preceding year. This rise, in turn, results in increased ground-water discharge to streams, bays, and the ocean. Under long-term conditions in undeveloped areas of Long Island, about 50 percent of precipitation is lost through evapotranspiration and direct runoff to streams; the other 50 percent infiltrates the soils and recharges the ground-water system (Aronson and Seaburn, 1974; Franke and McClymonds, 1972).

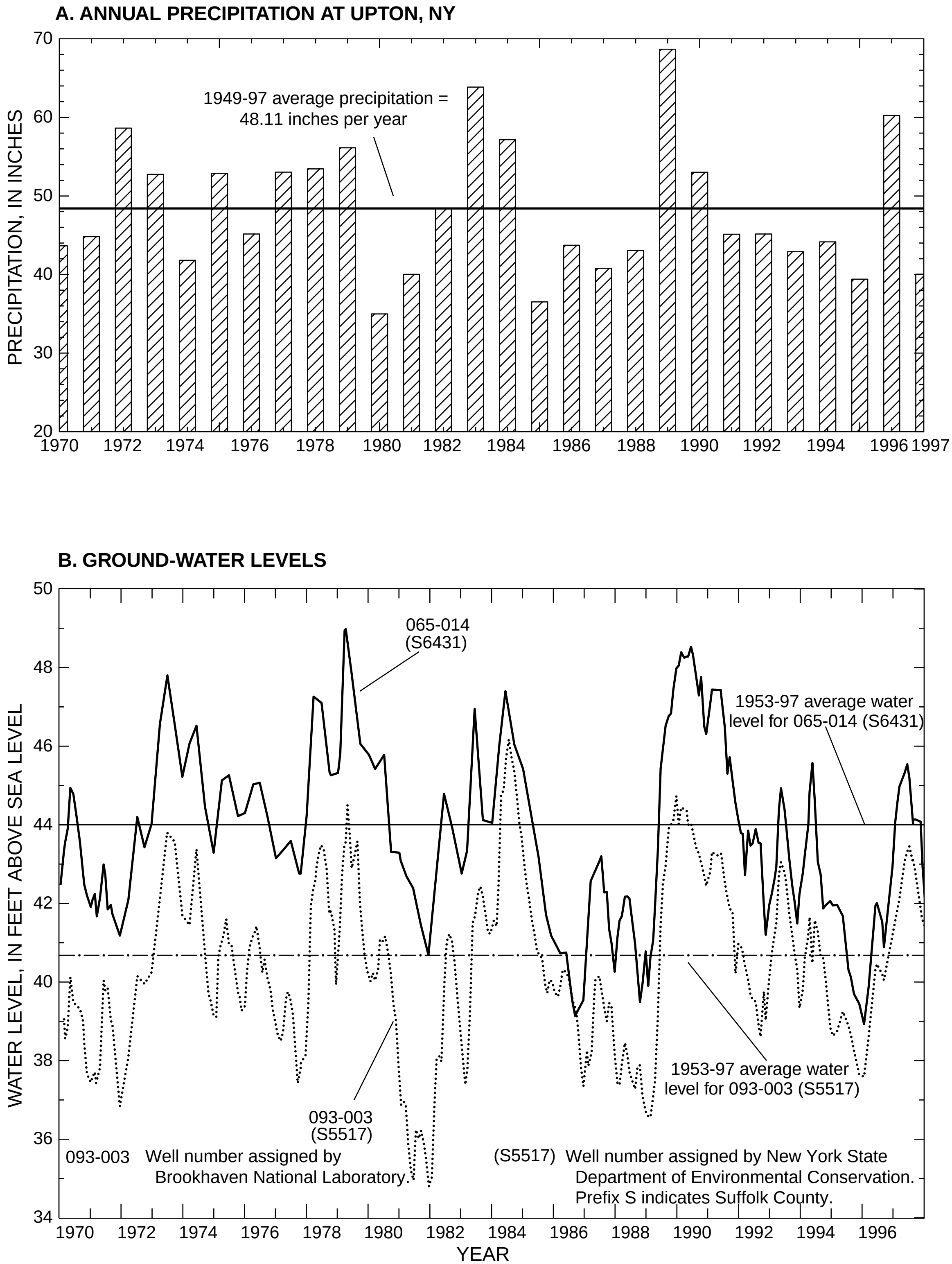


Figure 12. Precipitation and water-table altitude at Brookhaven National Laboratory, Suffolk County, N.Y., 1970-97. A. Annual precipitation at Upton. B. Water levels in wells S5517 and S6431. (Well locations are shown in fig. 2.)

Regional Ground-Water Flow

The Long Island ground-water system consists of two major components—the regional (deep) flow system and the shallow flow system associated with streams. Ground water enters the regional flow system of Long Island in the area bordering the main ground-water divide (fig. 13), where it moves downward through the upper glacial aquifer into the underlying aquifers and eventually moves seaward. Water that enters the regional flow system south of the main divide flows southward, and water that infiltrates north of the divide flows northward. All precipitation that infiltrates upgradient of each stream's shallow-flow system becomes part of the regional flow system, and precipitation that infiltrates within the ground-water contributing area of a stream becomes part of that stream's shallow-flow system (Prince and others, 1988).

Ground-Water-Contributing Area of Streams

The topographic drainage areas of the Peconic and Carmans Rivers encompass 75 and 71 mi^2, respectively. As at other Long Island streams, the surface-water and ground-water divides are not necessarily coincident; the topographic drainage area is not closely related to present-day streamflow because it is a relict of streams that drained meltwater from the glaciers at the end of the Pleistocene Epoch. Rather, the area that contributes ground water to a stream ("ground-water-contributing area") constitutes the effective drainage area of that stream.

The area from which ground water discharges into a stream forms a shallow-flow system, generally referred to as the ground-water-contributing area for that stream. The thickness of the shallow flow system and the positions of ground-water divides (especially the upstream boundary of the shallow-flow system) are dependent on hydrologic conditions and can shift over time (Prince and others, 1988). The boundaries of a ground-water-contributing area are estimated from water-table maps and the inferred positions of interstream divides, but the thickness of the shallow-flow system and the position of the start of flow shift constantly with water-table fluctuations. The shallow-flow system of Connetquot River (fig. 1), for example, has been estimated to be 30 ft thick (Prince and others, 1988), and that of East Meadow Brook in Nassau County, to the west, has been estimated to be 50 to 75 ft thick (Franke and Cohen, 1972). Scorca and Ku (1997) estimated that the shallow-flow system near the headwaters of East Meadow Brook was 30 ft thick in a sandy part of the aquifer.

Streamflow Components

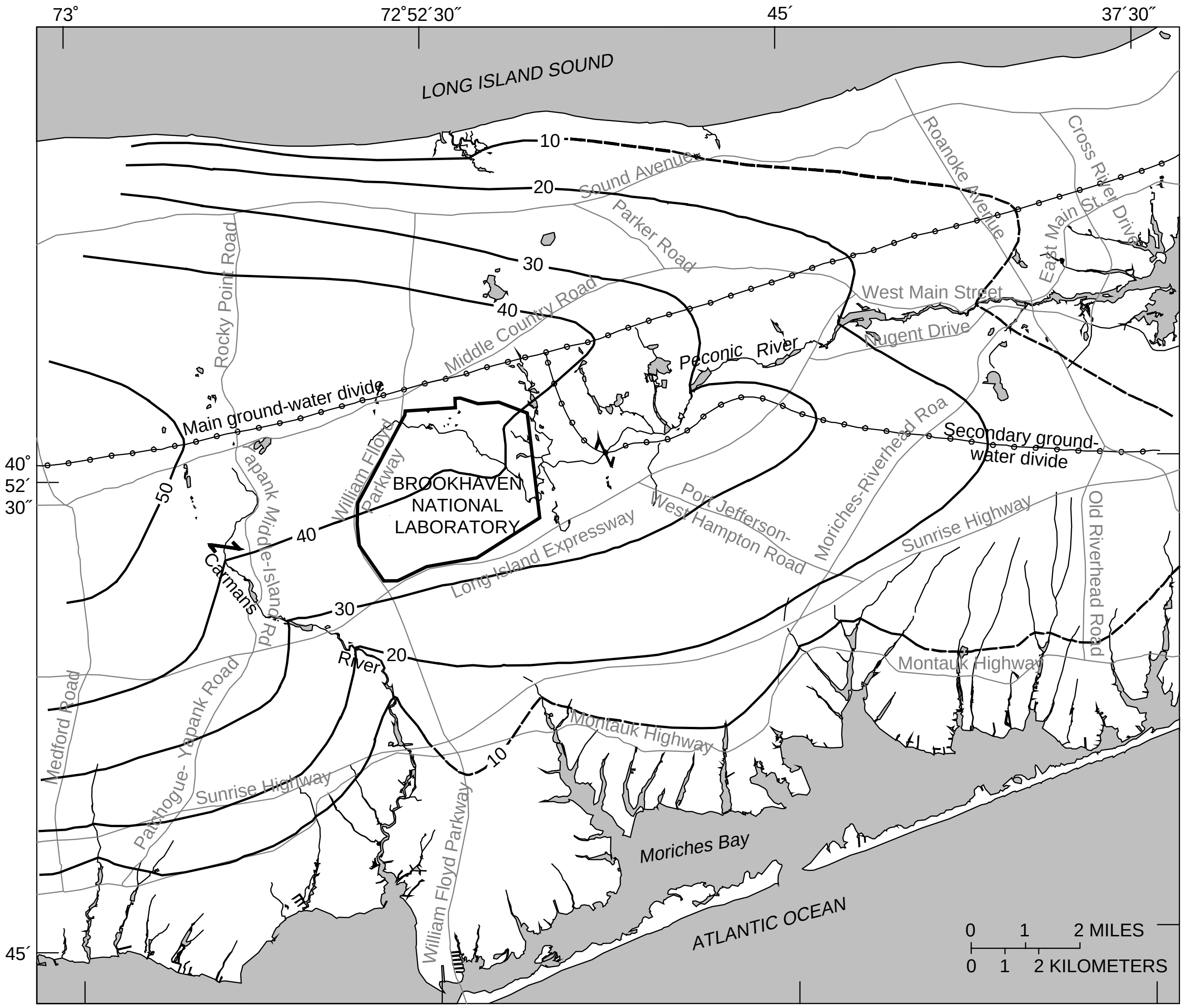
The water-table aquifer provides base flow to Long Island's streams where it intersects a streambed, and fluctuations in ground-water levels near the stream alter the stream length. Stream discharge on Long Island is derived from two sources—base flow (ground-water discharge) and direct runoff of stormwater.

Under natural (predevelopment) conditions, Long Island streams derived 95 percent of their total flow from ground-water discharge (Franke and McClymonds, 1972), and only about 5 percent from direct runoff, which consisted of precipitation falling directly on the streams' surface and overland runoff flowing into the stream channel. Direct runoff represented only about 2 percent of the total precipitation (Cohen and others, 1968) because Long Island's soils and surficial sediments allow rapid infiltration. Currently, the Peconic and Carmans Rivers derive more than 90 percent of their annual flow from ground water, and less than 10 percent from direct runoff because urban development in the adjacent Pine Barrens is fairly sparse and has not greatly affected infiltration and runoff in this part of the hydrologic system.

Start of Flow of Streams

The flowing reach of a Long Island stream begins where the water table intersects the stream channel, causing ground water to discharge to the stream as base flow. This point (the start of flow) represents the altitude of the surrounding water table and moves upstream or downstream in response to water-table fluctuations. The flowing reach of a Long Island stream channel (except during storms) generally is a ground-water-discharge area and is considered to be under "gaining" conditions.

The first measurement of start of flow in the Peconic River was made in October 1966, at the end of the 1962-66 drought; the observed start of flow was about 2 mi east of the BNL site boundary. In August 1995, also a dry period, the start of flow was estimated



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

EXPLANATION

10 — WATER-TABLE CONTOUR -- Shows altitude of water table in August 1995. Dashed where inferred. Contour interval 10 feet. Datum is sea level.

APPROXIMATE POSITION OF GROUND-WATER DIVIDES

APPROXIMATE POSITION OF START-OF-FLOW IN STREAM CHANNEL -- inferred from field observations

Figure 13. Water-table altitude in 300-mi^2 study area surrounding Brookhaven National Laboratory, Suffolk County, N.Y., August 1995. (Location is shown in fig. 1. From Scorca and others, 1997)

to be about 1.2 mi east of the BNL site boundary. The start-of-flow positions that have been observed by the USGS are plotted in figure 1B.

Ground-Water Divide

The position of a ground-water divide depends on the water-table configuration. The main ground-water divide on Long Island is aligned generally east-west and lies about 0.5 mi north of BNL's northern boundary (fig. 13). Ground water north of the divide flows northward and ultimately discharges to Long Island Sound; ground water south of the divide flows southward and discharges to south-shore streams, the Peconic River, Great South Bay, Peconic Bay, and the Atlantic Ocean. Ground water near the divide has a large downward vertical-flow component and recharges the deep aquifers of the ground-water system.

A secondary ground-water divide originates near the start of flow in the Peconic River; this divide (fig. 13) trends east-southeastward toward the South Fork. The position of the secondary ground-water divide was estimated from the water-table altitude, topography, and position of the start of flow in the Peconic River. Ground water north of this divide enters the Peconic River contributing area, whereas ground water south of the divide flows generally southward to bays and the Atlantic Ocean. Near the headwaters of the Peconic River, this divide forms the lateral limit of the river's ground-water-contributing area.

Hydrologic Conditions and Regional Water-Table Configuration during August 1995

The configuration of the water table in central Suffolk County during March 1995 and August 1995 was presented by Scorca and others (1996, 1997). Precipitation during 1995 totaled 39.40 in., the lowest since 1985; ground-water levels during both of these years were below average. The water-table configuration during August 1995 is illustrated in figure 13. Precipitation for August 1995 (0.54 in.) was the lowest ever recorded for August at the Upton station. This extremely dry weather was a factor in several major brush fires in the region.

The sparse rainfall during August 1995 produced almost no runoff; thus, Long Island streamflow at this time consisted almost entirely of base flow. The USGS has monitored the flow of the two major streams in the study area (Peconic and Carmans Rivers, fig. 13) since 1942. Annual mean discharge during 1942-96 at the main continuous streamflow-gaging station on the Peconic River was 36.8 ft^3/s, and that on the Carmans River was 24.0 ft^3/s. Mean discharges for August during the period of record are 28.4 and 22.9 ft^3/s, respectively. Mean discharges of 12.8 and 11.8 ft^3/s at the two streams for August 1995 were close to the record low mean discharges for August (10.8 and 10.5 ft^3/s) (Spinello and others, 1998).

The water table is highest in the northwestern part of the 300-mi^2 study area and generally slopes downward toward the shores. The discharge of ground water to the Peconic and Carmans Rivers locally affects the water-table configuration and causes water-level contours near streams to bend upstream (fig. 13). The Peconic River did not affect the water-table configuration directly beneath BNL during August 1995, however, because its start of flow at that time was estimated to be about 1.2 mi east of the site.

Hydrologic Conditions and Regional Water-Table Configuration during March 1997

In contrast to the below-average precipitation of 1995, precipitation during 1996 was about 12 in. above average, and ground-water levels rose in response. Ground-water levels during March 1997 were slightly above average.

Annual precipitation at the Upton precipitation station in 1996 (60.22 in.) was above the 1949-96 mean (48.28 in.; fig. 12A) for the first time since 1990. Precipitation in March 1997 (5.10 in.) was above the 1949-96 mean for March (4.69 in.), although the monthly totals for January and February 1997 were below their monthly means. Precipitation during all of 1997 totaled 40.04 in., about 8 in. below average.

The water table in March 1997 formed a mound that crested slightly north of the BNL site (fig. 14). It generally sloped downward more steeply toward the northern shore of Long Island than toward the southern shore. The discharge of ground water to streams, especially Peconic and Carmans Rivers, locally affected the water-table configuration, as illustrated by the upstream bend of water-level contours on water-table maps (fig. 14).

Ground-water levels at wells S5517 and S6431 (1 mi to the northeast) during 1970-97 are plotted in figure 12B. Both wells are on the BNL site, and water levels in both wells have been monitored regularly since 1953. Water levels have fluctuated from maximums of 46.93 ft above sea level in 1958 at S5517 and 48.98 ft above sea level in 1979 at S6431, to minimums of 33.34 ft above sea level in 1967 at well S5517 and 38.93 ft above sea level in 1996 for S6431. The long-term average water levels at these wells are 40.7 and 44.0 ft above sea level, respectively. Water levels in these wells during March 1997 were 42.10 and 44.97 ft above sea level, respectively.

The mean discharges of the Peconic and Carmans Rivers (44.7 and 26.3 ft^3/s) for March 1997 (Spinello and others, 1998) were close to the mean discharges for the month of March (47.8 and 25.8 ft^3/s, respectively) for the 55-year period of record.

The start of flow in the Peconic River during March 1997 was near the western boundary of the BNL site, just east of William Floyd Parkway (fig. 1).

This location, about 5 mi upstream of the estimated position in August 1995, indicates that the Peconic River was under gaining conditions (received base flow) throughout its channel within the BNL site.

Hydrologic Conditions and Local Water-Table Configuration during August 1997

Precipitation in August 1997 (3.33 in.) was about 1 in. below the 1949-96 mean for the month of August (4.40 in.). Ground-water levels peaked in early summer and had begun to decline by August 1997. Water levels at this time in wells S5517 and S6431 (fig. 12B) were 43.04 and 44.03 ft above sea level, respectively. The mean monthly discharge of the Peconic River for August 1997 was 20.7 ft^3/s, about 27 percent lower than its mean historical discharge for the month of August (28.4 ft^3/s). The mean monthly discharge of the Carmans River for August 1997 (21.0 ft^3/s) was close to its mean historical discharge for the month of August (22.9 ft^3/s) (Spinello and others, 1998).

Local Ground-Water Flow Patterns near Brookhaven National Laboratory

Ground-water flow at the BNL site is affected by several factors that complicate the ground-water flowpaths and the movement of contaminants in the aquifer system. One factor is the pumping of ground water for supply at the site; this lowers ground-water levels and affects hydraulic gradients in the local ground-water system. Another factor is discharge from BNL's sewage-treatment plant to Peconic River; this can affect the position of the start of flow and the discharge of Peconic River. Recharge basins and pumping of onsite ground-water-remediation systems also affect ground-water levels locally. The stream channel of the Peconic River extends onto the site, but the start of flow can be either east or west of the site under extreme hydrologic conditions. The amount of flow in Peconic River, and base-flow discharge to the stream, affect the position of the secondary (southeastward trending) ground-water divide. The hydraulic properties of several hydrogeologic units, including the upper glacial aquifer, Magothy aquifer, grayish-brown clay, Gardiners Clay, and localized near-surface clay units along the Peconic River drainage system, also affect ground-water flow.

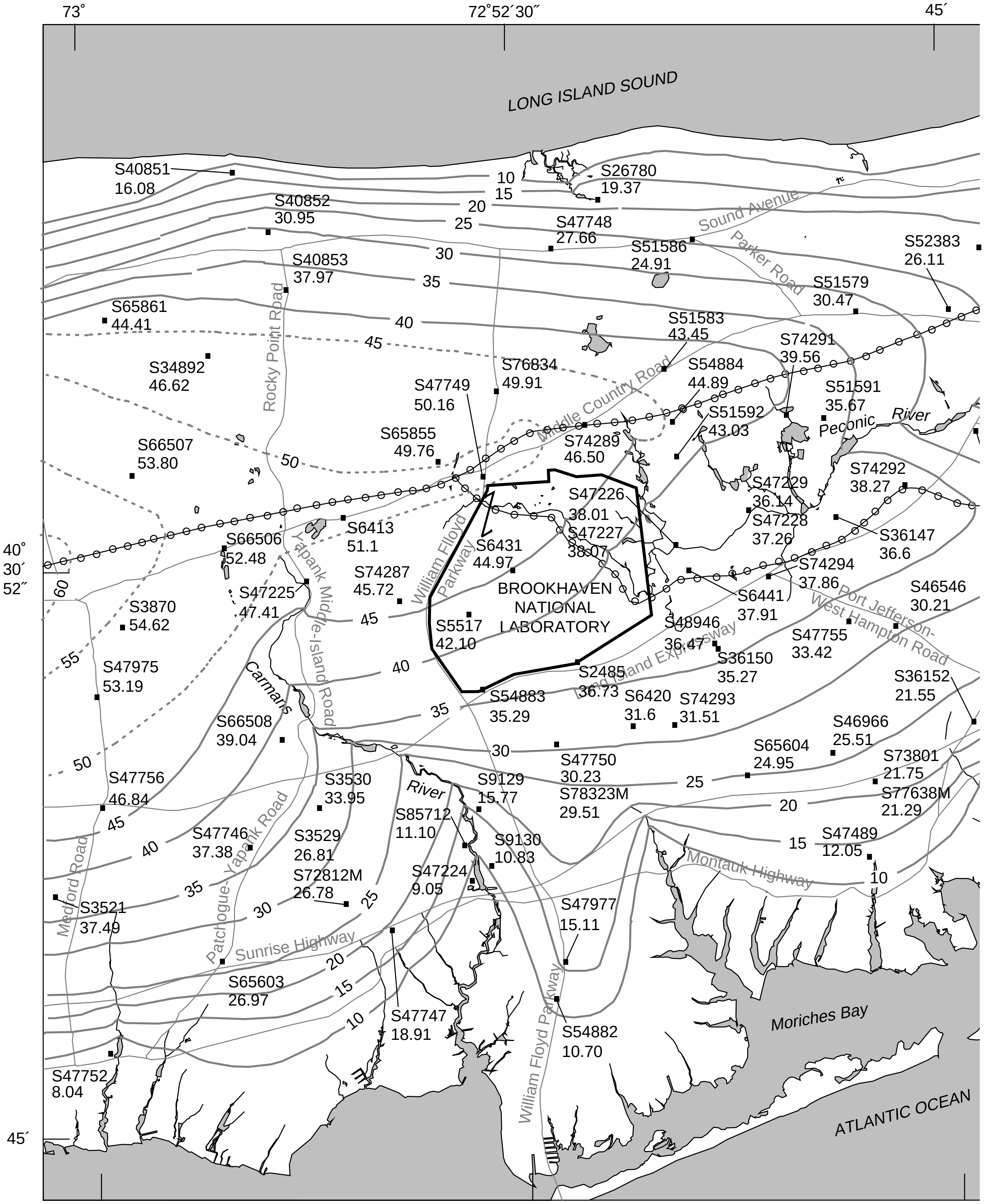
Water-table altitudes at the BNL site in November 1994, a period of slightly below-average water levels, are plotted in figure 15. Pumping of onsite supply wells caused local depressions in the water table. In addition, a ground-water mound developed below the main recharge basin at the center of the site. A localized near-surface clay layer near the sewage-treatment plant impedes ground-water movement and results in localized water-table mounding. Water levels along the reach of the Peconic River east of the sewage-treatment plant indicate that the river is under losing-stream conditions (the water-table gradient is away from the stream channel); thus, ground water did not discharge into the stream along this reach during this period, and an unsaturated zone developed between the streambed and the water table beneath the channel. Much of the water that entered the channel during storms or from the sewage-treatment plant could, therefore, recharge the aquifer system.

Water-table altitudes at the site in March 1997 are depicted in figure 16; this was before several ground-water-remediation systems that were in use during August 1997 affected the water-table configuration at the site (fig. 17). Water levels declined not only near supply wells, but near remediation (extraction) wells along the southern boundary of the site. At the same time, treated water from these systems was discharged to recharge basins (grid blocks 066, 076, and 094, fig. 16), and produced localized ground-water mounds near the basins.

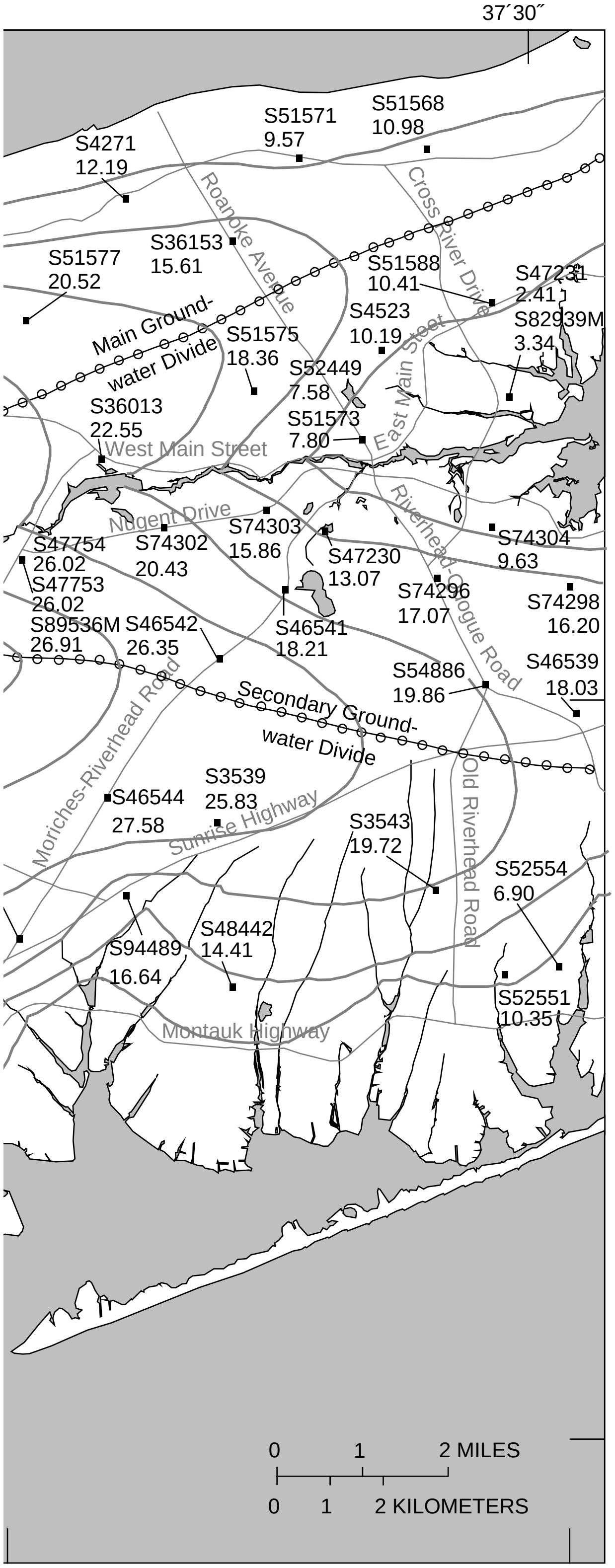
Flow Gradients in Brookhaven National Laboratory Area

The horizontal hydraulic gradient at the BNL site typically is 0.001 ft/ft, but in recharge areas and pumping areas, it can steepen to 0.0024 ft/ft or greater (W.R. Dorsch and Scott Wachino, Brookhaven National Laboratory, written commun., 1999). The natural ground-water flow velocity in most parts of the site is estimated to be about 0.75 ft/d, but flow velocities in recharge areas can be as high as 1.45 ft/d, and those in areas near BNL supply wells have been estimated to have velocities as great as 28 ft/d (Woodward-Clyde Consultants, 1993).

Water-level measurements at paired water-table wells and deep wells screened in the upper glacial aquifer along the northern boundary of the site (near the regional ground-water divide) indicate significant



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



EXPLANATION

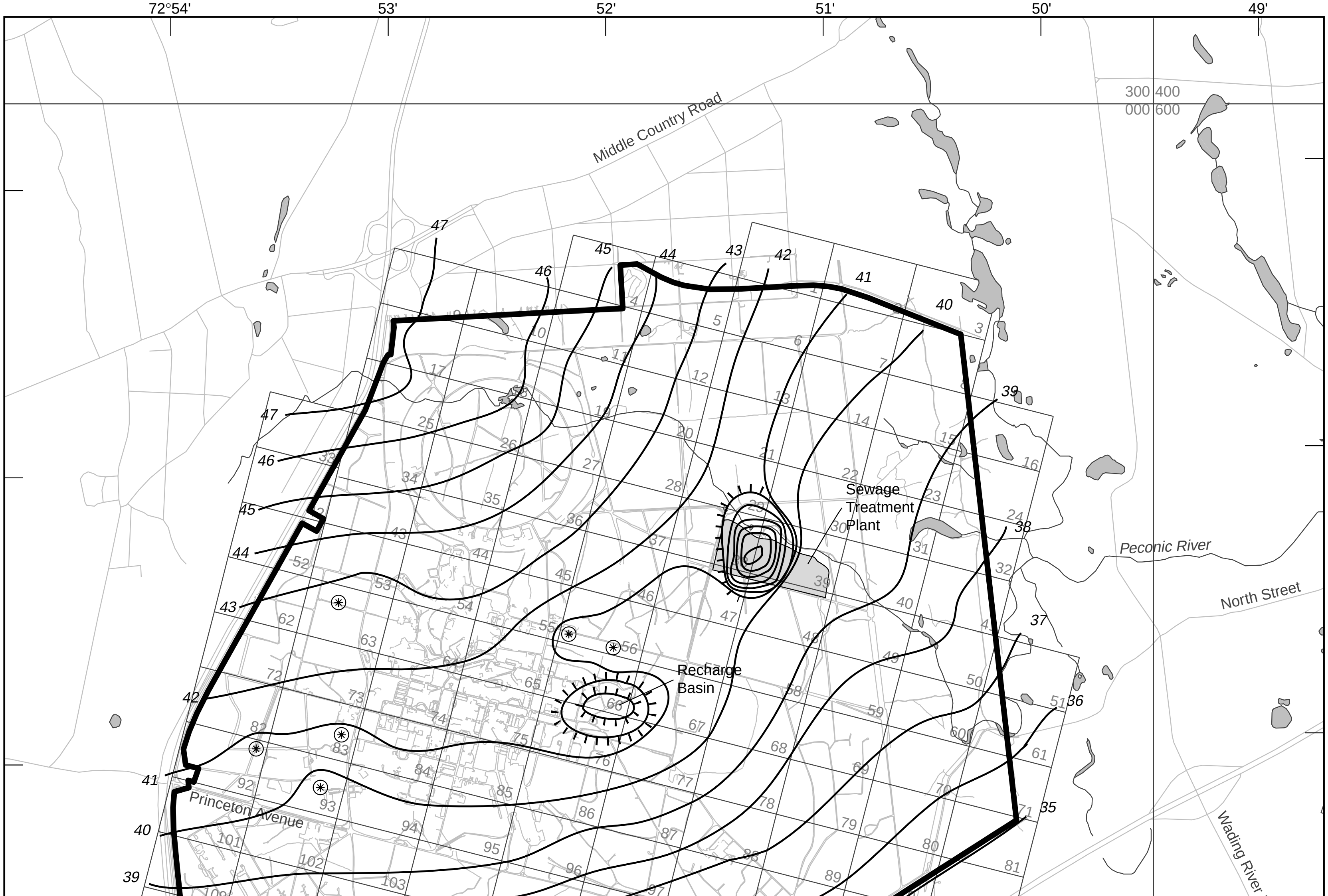
10 — WATER-TABLE CONTOUR -- Shows altitude of water table in March 1997. Dashed where inferred. Contour interval 5 feet. Datum is sea level.

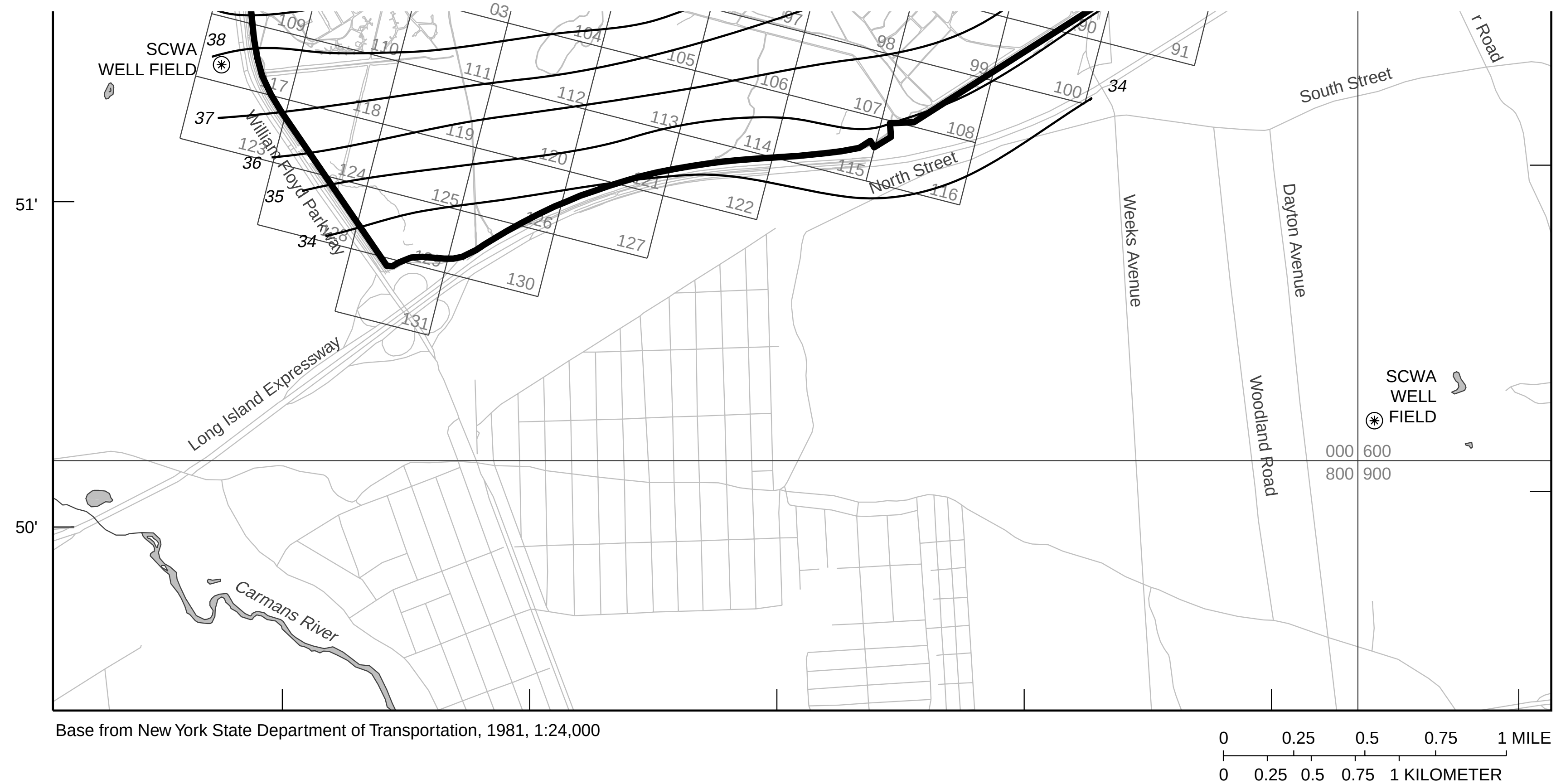
APPROXIMATE POSITION OF GROUND-WATER DIVIDES

APPROXIMATE POSITION OF START-OF-FLOW IN STREAM CHANNEL -- inferred from field observations

S74304 9.63 — OBSERVATION WELL AND WATER LEVEL -- Well number assigned by NewYork State Department of Environmental Conservation. Prefix S indicates Suffolk County. Number is water level in March1997, in feet above sea level. Well numbers and water levels at clustered well sites are listed in order of increasing well depth. Suffix M denotes shallow Magothy aquifer.

Figure 14. Water-table altitude in 300-mi^2 study area surrounding Brookhaven National Laboratory, Suffolk County, N.Y., March 1997. (Location is shown in fig. 1.)


72°54'
53'
52'
51'
50'
49'
40°
54'
53'
52'
Middle Country Road
Sewage
Treatment
Plant
Recharge
Basin
Peconic River
North Street
Princeton Avenue
Wading River R
300 400
000 600



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

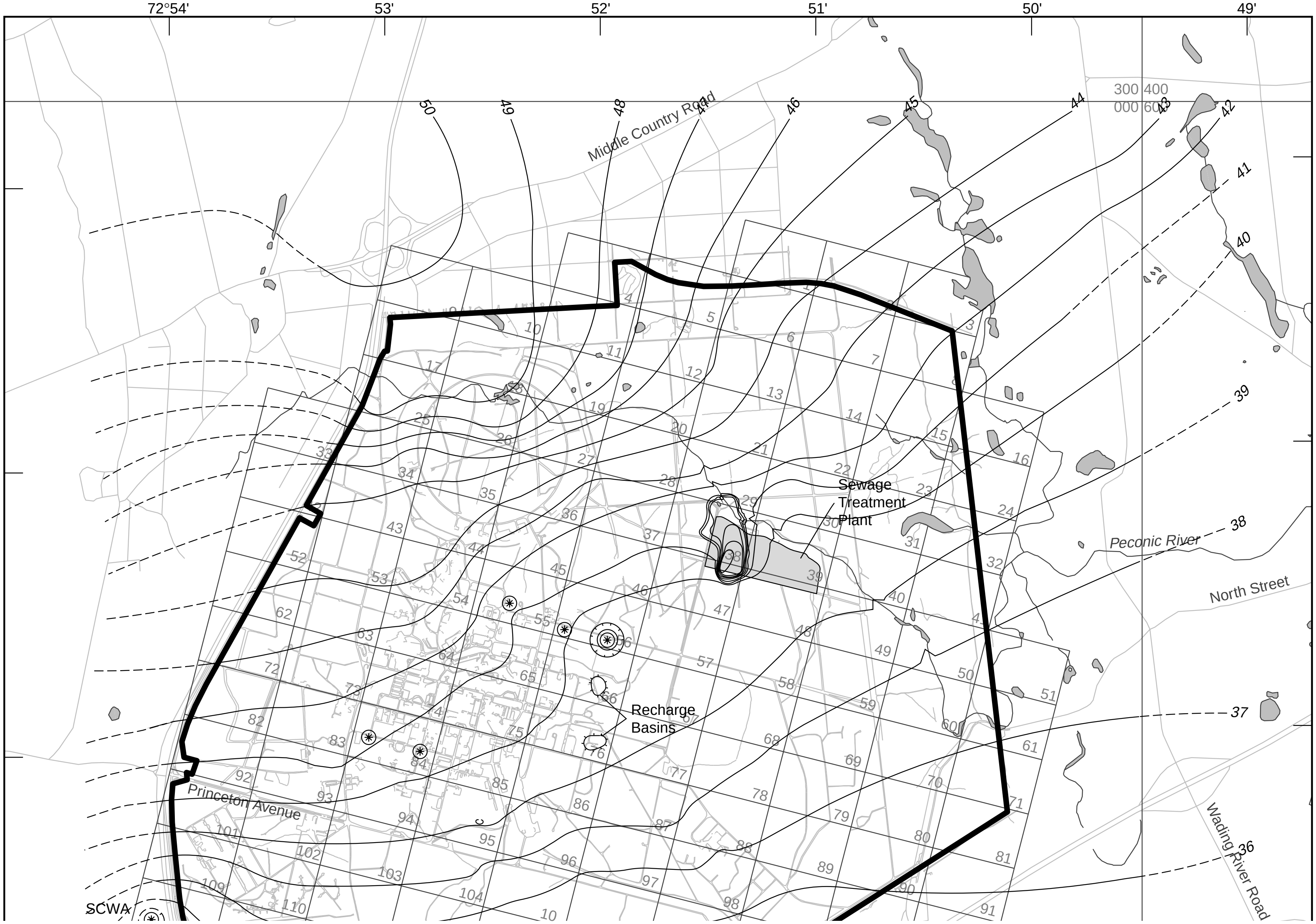
EXPLANATION

43 — WATER-TABLE CONTOUR- Shows altitude of water table in November 1994. Contour interval 1 foot. Datum is sea level. Hachures indicate mound.

SUPPLY WELL

42 — GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL)- Number is grid block number.

Figure 15. Water-table altitude in 28-mi^2 study area surrounding Brookhaven National Laboratory, Suffolk County, N.Y., November 2-4, 1994. (Modified from Naidu and Royce, 1995, fig. 1-8. Location is shown in fig. 1B.)


72°54'
53'
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51'
50'
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Middle Country Road
Sewage
Treatment
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Peconic River
North Street
Recharge
Basins
Princeton Avenue
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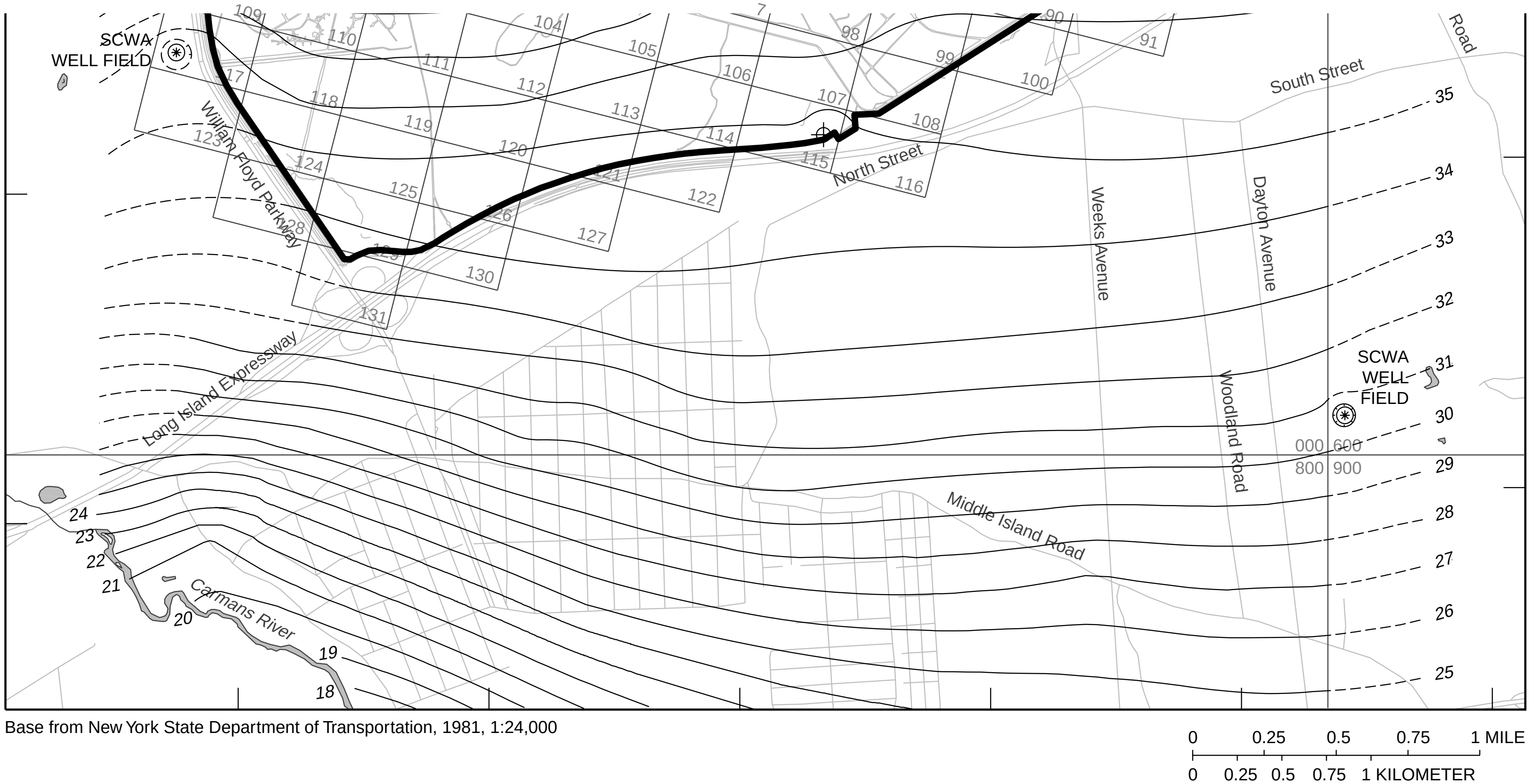


EXPLANATION

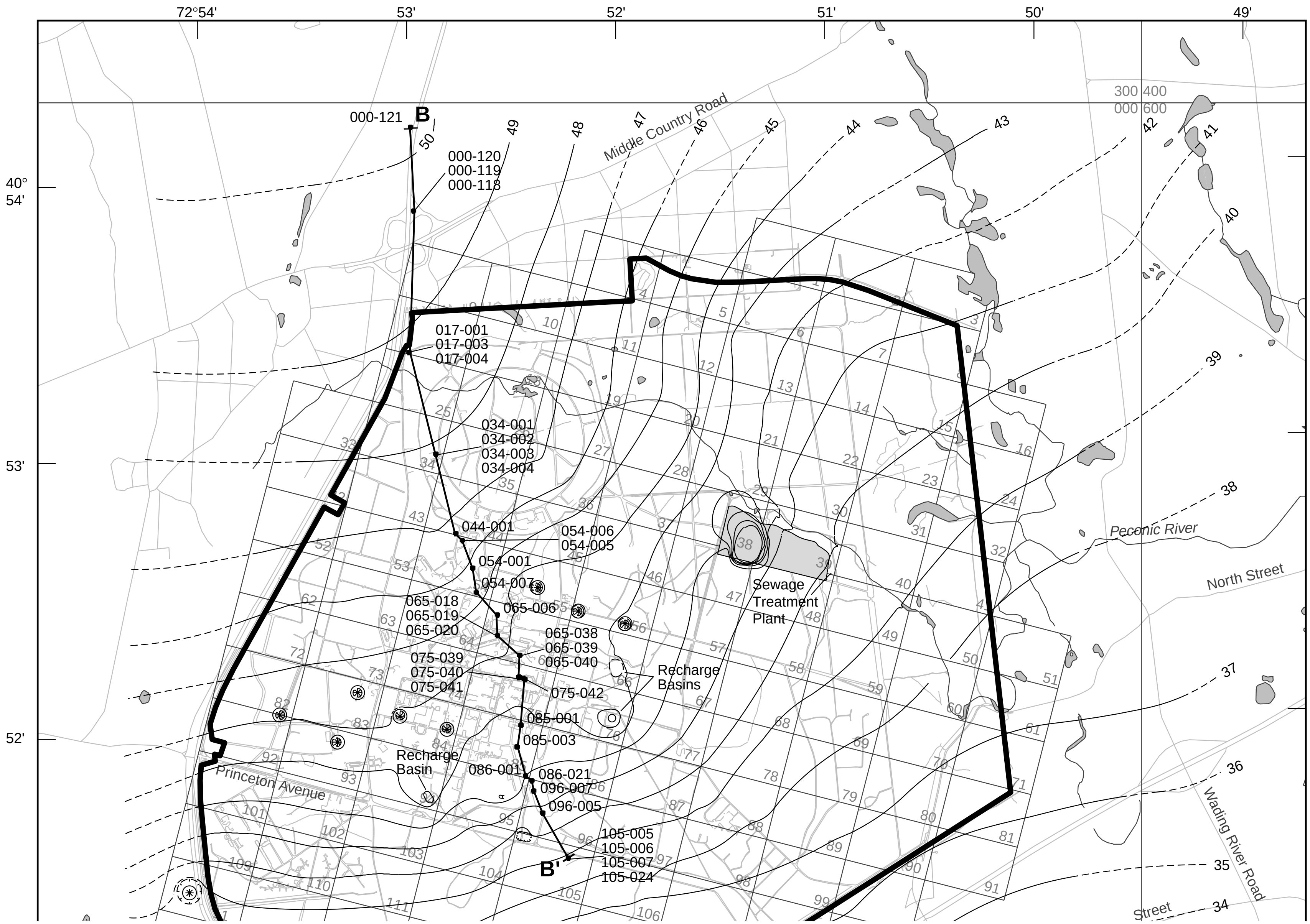
20 — WATER-TABLE CONTOUR- Shows altitude of water table in March 1997. Contour interval 1 foot. Datum is sea level. Hatchures indicate mound or depression.

SUPPLY WELL

REMEDIATION WELL

42 — GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL). Number is grid block number and represents first three digits of borehole numbers.

Figure 16. Water-table altitude in 28-mi^2 study area surrounding Brookhaven National Laboratory, Suffolk County, N.Y., March 1997. (Modified from Scott Wachino, Brookhaven National Laboratory, written commun., 1998. Location is shown in fig. 1B.)


72°54'
53'
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40°
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300 400
000 600
Middle Country Road
Peconic River
North Street
Wading River Road
Street
Princeton Avenue
Sewage
Treatment
Plant
Recharge
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Basin
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000-118
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054-005
054-001
054-007
065-018
065-019
065-020
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065-039
065-040
075-039
075-040
075-041
075-042
085-001
085-003
086-001
086-021
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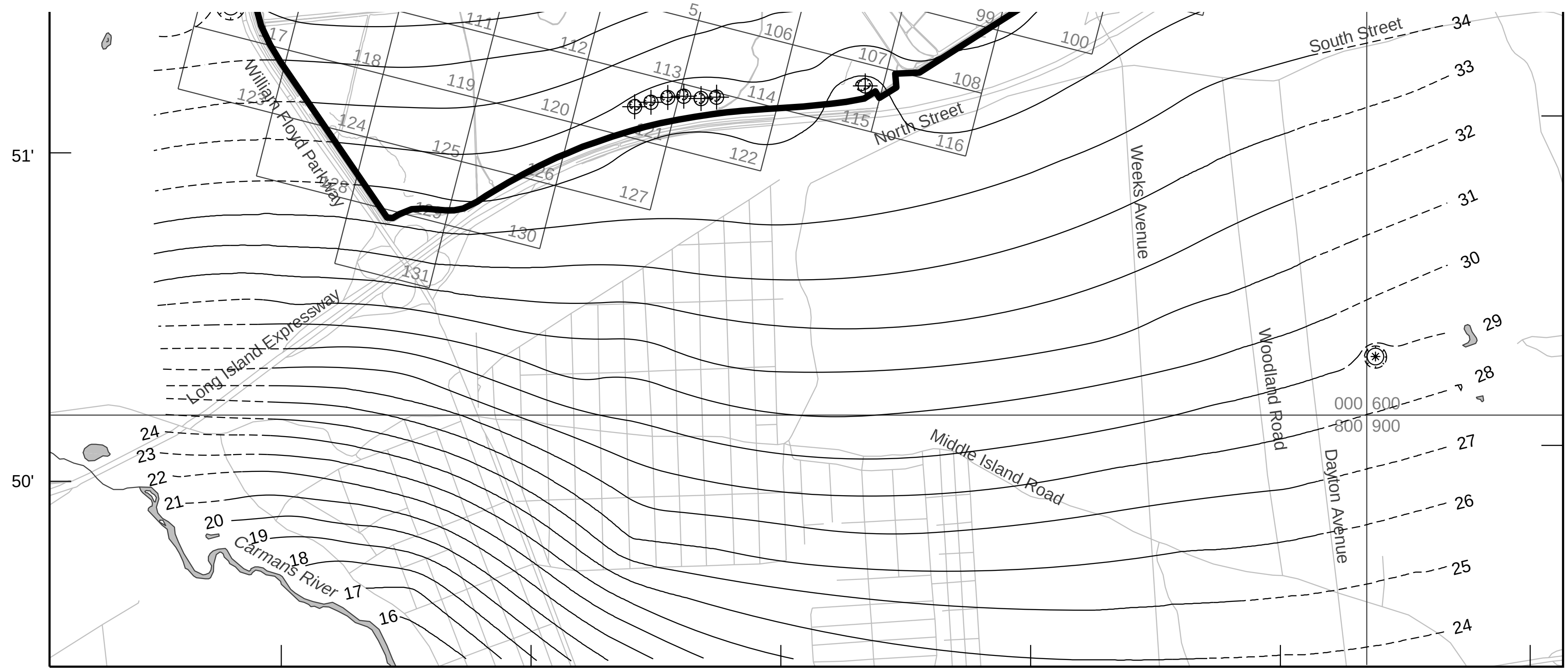


Base from New York State Department of Transportation, 1981, 1:24,000

EXPLANATION

42 GRID ASSIGNED BY BROOKHAVEN NATIONAL LABORATORY (BNL). Number is grid block number and represents first three digits of borehole numbers.

WATER-TABLE CONTOUR- Shows altitude of water table in August 1997. Contour interval 1 foot. Datum is sea level.

B B' LINE OF VERTICAL SECTION- Section is depicted in figure 18.

SUPPLY WELL

REMEDIATION WELL

034-001
034-002
034-003
034-004
OBSERVATION WELL AND NUMBER- Well number assigned by Brookhaven National Laboratory. Well numbers at clustered well sites are listed in order of increasing well depth.

Figure 17. Water-table altitude in 28-mi^2 study area surrounding Brookhaven National Laboratory, Suffolk County, N.Y., August 1997. (Modified from Scott Wachino, Brookhaven National Laboratory, written commun., 1998. Location is shown in fig. 1B.)

deep-flow recharge conditions, with downward vertical hydraulic gradients of as much as 0.007 ft/ft. Head differences at paired wells in the central and southern areas of the site become negligible, however, indicating that ground-water flow within the upper glacial aquifer is predominantly horizontal in these areas. Vertical gradients between the deep part of the upper glacial aquifer and the shallow part of the Magothy aquifer were about 0.018 ft/ft throughout the site.

Vertical gradients in the shallow-flow system along the Peconic River are measurable in clustered wells. The change in direction and magnitude of vertical gradients with changing hydrologic conditions is evident at clustered wells S47228 and S47229 (along the Peconic River, fig. 14). When ground-water levels are low, the start of flow to the Peconic River moves downstream, and vertical flow gradients are downward, and when ground-water levels are high, the start of flow moves upstream as the stream channel receives base flow, and vertical flow gradients are upward.

The distribution of water levels through the upper glacial aquifer and the shallow part of the Magothy aquifer along vertical section B-B′, which extends along a north-south flowpath through the BNL site, is depicted in figure 18. Generally, water levels decrease slightly with depth through the upper glacial aquifer, resulting in a slight natural downward vertical flow gradient, but the main component of ground-water flow through the upper glacial aquifer is horizontal. The hydraulic properties of the sandier zones of the Upton unit are similar to those of the rest of the upper glacial aquifer in that differences in ground-water levels are small or not observable within the few well clusters screened between the Upton unit and the overlying outwash deposits.

Larger head differences are observed where ground water enters the Magothy aquifer than in the upper glacial aquifer; these differences are reflected on the section (fig. 18) by a bending (refraction) of the potentiometric (water-level) contours. A larger vertical component of flow is present along the contact between the upper glacial and Magothy aquifers than within the upper glacial aquifer. Vertical gradients between the deep part of the upper glacial aquifer and the shallow part of the Magothy aquifer were about 0.018 ft/ft throughout the site.

SUMMARY AND CONCLUSIONS

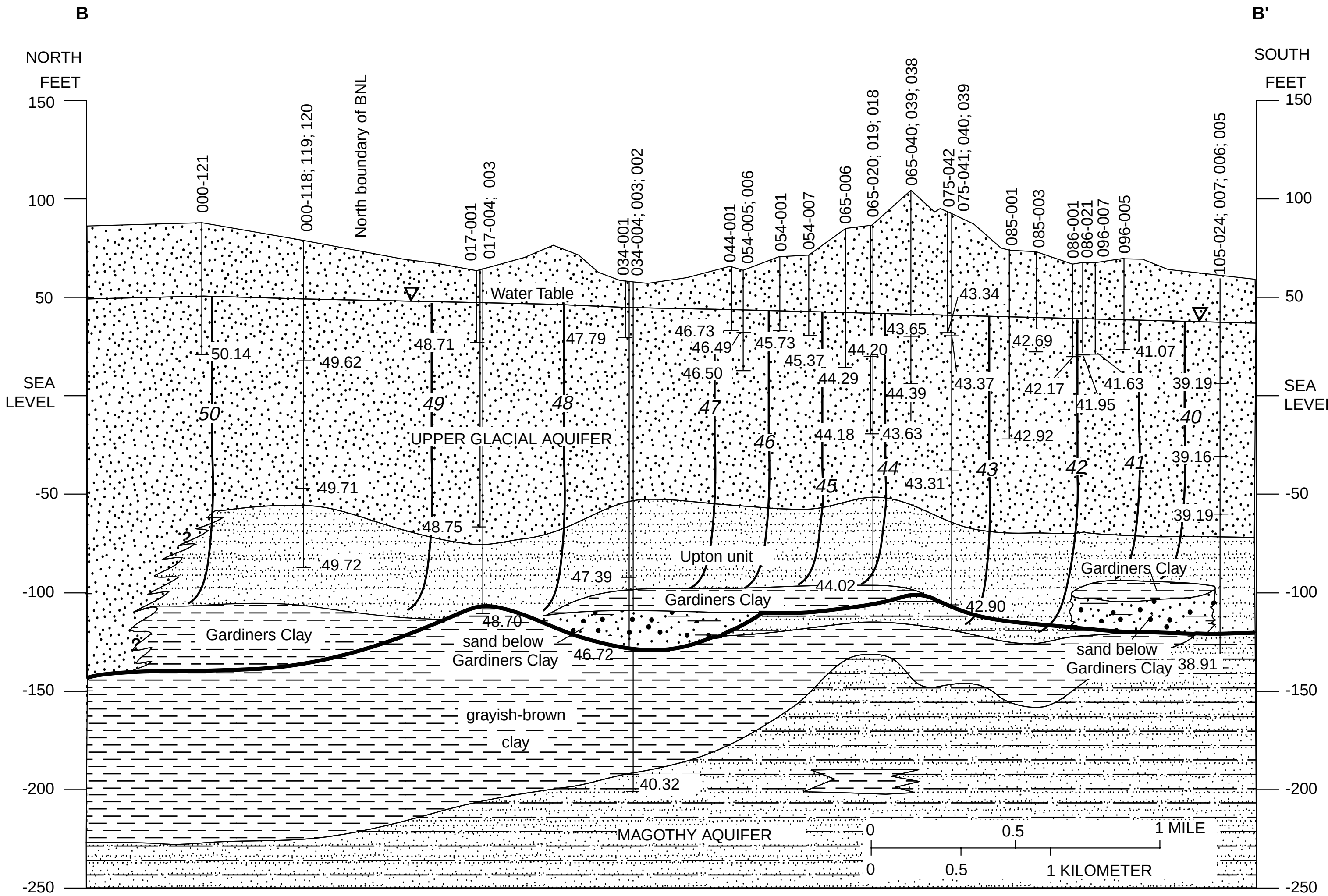
Brookhaven National Laboratory (BNL) has installed many geologic test borings to gain detailed geologic information and to delineate the extent of ground-water contamination. In 1994, the U.S. Geological Survey began a cooperative study with BNL to examine the stratigraphy in the 28-mi^2 study area near the site and to monitor ground-water levels throughout a 300-mi^2 area of central Suffolk County that surrounds BNL.

Sediments in the upper part of the Magothy Formation are varied and include gray, silty to clayey sand interbedded with (1) light- to dark-gray clay, (2) gray, well-sorted sand, (3) grayish-brown clay, (4) grayish-brown sand, (5) brown sand, and (6) hard, black clay. An extensive clay unit of variable thickness, referred to as the grayish-brown clay in this report, was encountered in many borings in the study area. Pollen analyses of samples from this unit confirmed that it is of Cretaceous age. It is the uppermost of the Cretaceous units in several parts of the 28-mi^2 study area.

The upper surface of the Cretaceous deposits has a relief of about 120 ft in the 28-mi^2 study area. Several prominent channel and ridge features in the surface are aligned generally northwest-southeast and may result from a glacial advance. The Cretaceous surface beneath the BNL site is characterized more by local erosional features than by the regional cuesta shape that was suggested by previous authors.

The recent drilling at BNL indicated that the deep upper Pleistocene deposits are more varied than the shallow deposits. Distinct differences in lithology, and subtle differences in color, grain size, sorting, and gamma-ray responses, were observed at depths of 50 to 70 ft below sea level in several parts of the study area. The base of the upper Pleistocene sequence includes distinct units of gray, grayish-brown, and greenish-gray sand, silt, poorly sorted sand, and greenish-gray to gray clay; these units are laterally discontinuous and are generally at about the same altitude as deLaguna's unidentified unit and are probably facies associated with it. This report informally refers to these sediments as the Upton unit. The shallow part of the upper Pleistocene deposits contains outwash sediments of light-brown sand and gravel that generally are highly permeable.

Ground-water levels during March and August 1997 were slightly above or near average. The



EXPLANATION

000-121

50.14 TRACE OF BORING-- Number on top is assigned by Brookhaven National Laboratory. Number next to bar is water level altitude in August 1997. Multiple numbers indicate clustered wells at one site. Boring locations are shown in figure 17.

50 EQUIPOTENTIAL LINE -- In feet above sea level. Contour interval 1 foot.

Figure 18. Water levels in upper glacial aquifer and shallow part of the Magothy aquifer along section B-B′, Brookhaven National Laboratory, Suffolk County, N.Y. (Trace of section is shown in fig. 17)

discharge of ground water to the Peconic and Carmans Rivers locally lowers the water table and results in an upstream bending of water-level contours. The water-table configuration beneath the BNL site is affected by pumping of supply wells and remediation wells, discharges of treated water to recharge basins, discharge from the sewage-treatment plant, and permeability of local near-surface clay units.

The main ground-water divide in the upper glacial aquifer extends east-west along the island through the northern part of Suffolk County. A secondary ground-water divide originates near the start of flow of the Peconic River and extends east-southeastward toward the South Fork. The start of flow in the Peconic River during March 1997 was within the BNL site and near William Floyd Parkway, about 5 mi upstream (west) of its estimated position in August 1995, which was about 1.2 mi east of the site.

The horizontal hydraulic gradient at BNL typically is 0.001 ft/ft but can steepen near recharge basins and pumping wells. Vertical ground-water flow gradients within the upper glacial aquifer were as large as 0.007 ft/ft in the northern part of BNL and were negligible in the southern part. Vertical gradients between the deep part of the upper glacial aquifer and the shallow part of the underlying Magothy aquifer were about 0.018 ft/ft throughout the site.

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Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units
[NA, data not available; --, geologic unit not penetrated; X indicates unit is present in boring. Locations are shown in fig. 2]

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
000-042	S47436	405124	725409	104	196	-92	--	-70	--	--	--
000-043	S47437	405124	725409	104	179	-75	--	-72	--	--	--
000-044	S47438	405124	725409	105	269	-164	--	-73	--	-103	--
000-045	S90910	405330	725317	62	763	-701	--	-94	X	-121	-179
000-046	S95247	405202	725442	80	700	-620	--	-77	--	-103	--
000-047		405106	725104	55	302	-247	-59	-70	X	-131	-131
000-048		405035	725154	78	297	-219	-55	--	--	-151	-151
000-049		405012	725210	97	300	-203	--	--	--	-117	--
000-050		405029	725209	65	300	-235	-68	--	--	-122	-122
000-051		405045	725220	76	267	-191	--	--	--	-117	--
000-052		405047	725217	87	232	-145	--	--	--	-133	--
000-053		405049	725214	83	232	-149	--	--	--	-141	-141
000-054		405050	725210	75	242	-167	--	--	--	-155	-155
000-055		405052	725207	70	277	-207	--	--	--	-152	--
000-057		405043	725236	78	242	-164	--	--	--	-147	-147
000-058		405044	725232	73	302	-229	-72	--	--	-137	-137
000-059		405045	725229	74	307	-233	--	--	--	-121	-211
000-056		405042	725239	88	267	-179	--	--	--	-142	--
000-060		405047	725225	72	212	-140	--	--	--	-123	--
000-061		405024	725317	96	242	-146	--	-109	X	--	--
000-062		405027	725310	101	252	-151	--	-106	X	-139	-139
000-063		405032	725302	90	247	-157	-70	-110	X	-145	-145
000-064		405036	725255	90	237	-147	--	-105	X	-132	-132
000-065		405039	725247	94	242	-148	--	--	--	-134	-134
000-088		405205	724953	45	262	-217	--	--	--	-180	--
000-089		405146	724937	45	262	-217	--	--	--	-145	--
000-090		405134	724952	45	257	-212	--	--	--	-180	--
000-097		405012	725247	100	350	-250	-57	--	--	-132	-132
000-102		405017	725233	101	320	-219	--	--	--	-154	-154

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
000-105		405021	725224	105	300	-195	--	--	--	-140	-140
000-107		405029	725210	115	300	-185	--	--	--	-110	--
000-118		405353	725259	78	300	-222	-82	-104		-134	-134
000-143		405215	724939	50	260	-210	--	--	--	-155	--
000-146		405255	724939	45	260	-215	-80	-105	-130	-143	-143
000-168		405047	725151	66	300	-234	--	--	--	-144	--
000-183		405051	725147	62	300	-238	--	--	--	-141	--
007-002	S6458	405326	725058	61	262	-201	--	--	--	-141	--
017-004	S103711	405322	725301	64	177	-113	-71	--	--	-111	--
018-005		405323	725227	56	300	-244	-80	--	X	-124	-142
034-004		405260	725255	58	300	-242	-49	--	X	-120	-120
037-004	S106358	405245	725152	74	200	-126	--	--	--	-104	--
041-004	S106357	405227	725022	49	300	-253	--	--	--	-183	-183
049-006	S106356	405226	725053	45	200	-155	--	--	--	-148	-148
050-003		405215	725021	45	262	-217	--	--	--	-190	-190
054-011		405234	725252	70	177	-107	-53	-92	--	--	--
054-012		405233	725247	70	177	-107	-48	-73	--	--	--
054-013		405234	725240	70	177	-107	-52	-96	--	--	--
055-006	S105976	405233	725233	80	180	-100	-60	-90	--	--	--
056-007	S105977	405221	725158	80	230	-150	-85	-106	X	-124	--
061-005	S106350	405205	725022	43	300	-257	--	-92	X	-177	-177
063-009	S105963	405225	725311	69	255	-186	--	-98	-132	-150	-150
063-010	S15949	405230	725311	80	224	-144	-55	--	--	-104	-139
063-011	S15950	405231	725318	75	223	-148	-68	-105	--	-107	-143
063-012	S15951	405232	725324	70	218	-148	-66	-104	--	-114	-146
065-013	S6434	405223	725234	85	1598	-1513	-55	-102	--	-121	-157
065-016		405219	725235	90	202	-112	-95	--	--	-101	--
065-017		405225	725236	80	147	-67	-55	--	--	--	--
066-029		405210	725201	72	300	-228	-56	--	--	-123	--
067-003		405207	725144	51	150	-99	-54	--	--	--	--
068-002		405202	725136	50	150	-100	-70	--	--	--	--
068-003		405200	725127	48	150	-102	-72	--	--	--	--

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
069-011		405155	725108	52	150	-98	--	--	--	--	--
069-012		405200	725105	53	150	-97	--	--	--	--	--
069-015		405155	725103	53	175	-122	--	-92	X	-102	--
069-017		405155	725059	56	150	-94	--	--	--	--	--
071-001		405148	725025	45	267	-222	--	--	--	-175	--
072-004		405219	725346	80	NA	NA	-78	--	--	-105	--
073-003		405216	725311	86	202	-116	-74	-112	--	--	--
074-001	S 6456	405218	725311	91	217	-126	-54	-101	-105	-109	-109
074-006		405216	725305	104	202	-98	-43	--	--	--	--
074-007		405214	725259	102	202	-100	-76	--	--	--	--
074-008		405214	725252	100	202	-102	-66	--	--	--	--
075-005		405212	725247	81	202	-121	--	--	--	-109	--
075-006		405211	725241	82	202	-120	-43	--	--	--	--
075-007		405209	725233	84	202	-118	-71.	--	--	--	--
078-003		405154	725134	52	150	-98	-58	--	--	--	--
078-005		405157	725128	47	150	-103	-73	--.	--	--.	--
079-002		405142	725101	50	135	-85	-50	-79	--	--	--
079-004		405142	725057	53	150	-97	-57	--	--	--	--
080-006		405139	725035	45	150	-105	--	--	--	--	--
084-010	S14977	405158	725259	97	302	-205	-63	-81	--	-102	-123
085-013	S105959	405154	725249	82	255	-173	-62	--	--	-108	--
085-014		405159	725234	70	252	-182	-66	--	--	-119	-132
086-068	S105960	405156	725225	73	265	-192	-77	--	--	-131	-131
086-071		405147	725219	75	120	-45	--	--	--	--	--
087-013		405151	725151	68	162	-94	-82	-87	--	--	--
087-015		405143	725148	53	147	-94	-69	-87	--	--	--
087-017		405143	725204	85	170	-85	-70	-82	--	--	--
088-015		405145	725137	48	142	-94	-82	-92	--	--	--
088-017		405137	725127	49	142	-93	--	-84	--	--	--
088-108	S105978	405150	725141	48	235	-187	--	-84	X	-128	--
089-002		405143	725109	43	132	-89	-67	-85	--	--	--
089-004		405136	725110	48	140	-92	-62	-82	--	--	--

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
089-007		405141	725106	43	125	-82	--	-72	--	--	--
090-005		405128	725051	46	175	-129	--	--	--	-99.	--
090-006		405130	725044	49	175	-126	--	--	--	-101	--
090-008		405133	725039	51	150	-99	-64	--	--	--	--
093-006	S105962	405151	725326	109	265	-156	--	-49	X	-116	--
096-038		405144	725229	69	212	-143	-61	-106	X	-121.	-133
096-039		405140	725228	64	217	-153	-56	-107	X	-127	-127
096-040		405141	725220	71	210	-139	-54	-101	X	-129	-129
097-015		405132	725202	76	175	-99	--	--	--	--	--
098-045		405131	725130	55	145	-90	-65	-85	--	--	--
098-047		405130	725136	53	145	-92	-69	-87	--	--	--
098-049		405131	725128	54	145	-91	-61	-86	--	--	--
098-051		405134	725146	53	145	-92	-71	-87	--	--	--
098-053		405128	725143	47	140	-93	-73	-90	--	--	--
098-055		405134	725140	45	135	-90	-75	-81	--	--	--
099-009		405130	725114	47	140	-93	-73	-88	--	--	--
100-004	S 6459	405122	725101	45	160	-115	-60	-91	--	-100	--
100-008		405126	725055	45	130	-85	-70	--	--	--	--
102-002		405148	725330	91	202	-111	-34	-99	--	--	--
102-003		405147	725326	92	202	-110	--	--	--	--	--
102-004		405147	725323	100	202	-102	-50	--	--	--	--
103-003		405145	725318	100	202	-102	-55	--	--	--	--
103-004		405145	725315	99	202	-103	-69	-102	--	--	--
103-005		405143	725312	98	162	-64	--	--	--	--	--
103-006		405142	725308	91	162	-71	--	--	--	--	--
103-007		405141	725304	88	162	-74	-54	--	--	--	--
103-008		405140	725301	85	252	-167	-71	--	X	-120	--
104-002		405131	725240	61	175	-114	-89	--	--	--	--
104-004		405139	725257	83	162	-79	-73	--	--	--	--
104-005		405139	725253	79	177	-98	-76	--	--	--	--
104-006		405138	725249	76	252	-176	-84	--	--	-124	--
104-007		405136	725246	70	177	-107	-55	--	--	--	--

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
104-008		405134	725243	61	202	-141	-84	--	--	-124	--
104-009		405134	725239	59	222	-163	-61	--	--	-136	-148
105-017		405134	725234	66	202	-136	-94	--	--	--	--
105-018		405134	725230	67	177	-110	-83	--	--	--	--
105-019		405133	725226	61	177	-116	-84	--	--	--	--
105-020		405132	725222	55	167	-112	-78	-107	--	--	--
106-007		405130	725212	66	175	-109	--	--	--	--	--
106-009		405129	725207	65	175	-110	--	-90	--	-97	--
106-011		405127	725157	66	200	-134	--	--	--	--	--
106-019	S105961	405130	725212	67	265	-198	-53	--	--	-155	--
106-026		405120	725210	66	210	-144	--	--	--	--	--
106-027		405118	725202	63	210	-147	--	--	--	--	--
106-028		405122	725217	61	210	-149	--	--	--	--	--
107-015		405123	725142	46	132	-86	-64	-79	--	--	--
107-017		405124	725144	47	130	-83	-68	-78	--	--	--
107-021		405123	725133	60	142	-82	-70	-80	--	--	--
107-027		405115	725139	55	210	-155	-63	--	--	-126	--
108-022		405120	725127	56	142	-86	-62	-79	--	--	--
108-024		405111	725125	64	146	-82	-62	--	--	--	--
108-026		405113	725121	61	141	-80	-61	--	--	--	--
108-028		405120	725125	56	142	-86	-64	-79	--	--	--
109-001	S6409	405132	725355	117	1591	-1474	-43	-78	--	-91	-117
112-001		405118	725252	57	217	-160	-73	-95	X	-133	-151
113-002		405120	725242	58	252	-194	-103	--	--	-132	--
113-003		405120	725233	72	267	-195	-108	--	--	-138	-128
113-004		405119	725229	70	262	-192	-70	--	--	-140	-132
113-005		405118	725225	68	252	-184	--	--	--	-162	--
114-004		405106	725202	55	200	-145	--	--	--	--	--
115-011		405106	725136	60	198	-138	-65	--	--	-136	-136
115-018		405107	725158	65	200	-135	--	--	--	--	--
115-020		405107	725156	65	200	-135	--	--	--	-125	--
115-022		405106	725153	64	200	-136	--	--	--	-126	--

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
115-024		405106	725149	57	200	-143	--	--	--	-123	--
115-029		405106	725138	56	215	-159	-133	--	--	-139	--
115-030		405106	725140	54	296	-242	--	--	--	-163	--
115-031		405107	725135	62	180	-118	-63	--	--	--	--
115-038		405106	725136	60	215	-155	--	--	--	-146	--
115-039		405106	725136	76	120	-44	--	--	--	--	--
115-040		405112	725142	53	210	-157	-63	--	--	-120	--
116-003		405109	725131	66	145	-79	-74	--	--	--	--
119-002		405113	725320	86	227	-141	-64	-92	X	-122	-129
120-001		405115	725305	77	222	-145	--	-100	X	-135	-135
121-001		405102	725239	69	232	-163	--	-103	X	-148	-148
121-002		405103	725235	70	242	-172	--	--	--	-158	-158
121-003		405103	725231	72	247	-175	--	--	--	-158	-158
121-004		405104	725228	74	252	-178	-103	--	--	-166	-166
121-005		405105	725224	71	242	-171	--	--	--	-154	-154
122-005	S105965	405104	725213	61	290	-229	--	--	--	-171	--
122-006		405106	725221	62	232	-170	-98	--	--	-158	-158
122-007		405105	725216	54	227	-173	--	--	--	-160	-160
122-008		405106	725208	51	300	-249	--	--	--	-177	--
126-002		405055	725308	84	207	-123	--	-109	--	--	--
126-003		405057	725303	80	237	-157	--	-101	X	-140	-140
126-004		405059	725257	73	217	-144	--	-93	X	-127	-127
126-005		405059	725252	65	217	-152	--	-85	X	-140	-140
127-001		405100	725247	70	227	-157	--	-107	X	-147	-147
127-002		405101	725243	66	227	-161	--	-99	X	-150	-150
129-001		405050	725323	82	227	-145	-58	--	X	-144	-144
129-002		405052	725318	86	232	-146	-89	--	X	-143	-143
130-004	S105964	405055	725311	81	300	-219	-60	-105	X	-141	-141
130-005		405054	725313	83	197	-114	--	-107	--	--	--
600-015		405205	724929	44	300	-256	-58	--	--	-120	--
600-021		405137	724914	50	260	-210	--	--	--	-155	--
600-024		405108	724855	48	260	-212	--	--	--	-179	--

Table 4. Location and depth of borings in Brookhaven National Laboratory study area, Suffolk County, N.Y., and upper surface altitude of geologic units --continued

Boring number							Upper surface altitude, in feet below sea level				
Brookhaven National Laboratory	New York State Department of Environmental Conservation	Latitude	Longitude	Land- surface altitude (feet above sea level)	Boring depth (feet below land surface)	Bottom altitude of boring (feet below sea level)	Upton unit	Gardiners Clay	Sand below Gardiners Clay	Matawan Group and Magothy formation, undifferentiated	Grayish-brown clay
600-027		405114	724928	50	260	-210	--	--	--	-180	--
800-016	S 78323	405004	725154	95	360	-265	--	--	--	-115	-115
800-017	S 71881	404832	725107	48	309	-261	--	--	--	-118	-118
800-018	S 71882	404832	725107	47	318	-386	--	--	--	-123	-123
800-020		404959	725126	86	300	-214	-54	--	--	-91	--
800-021		404933	725328	36	300	-264	--	-104	--	-112	-129
800-024		404945	725031	44	300	-256	--	--	--	-70	--
800-028		404836	725131	56	300	-244	-117	--	--	-117	-129
800-033		404955	725210	93	300	-207	--	--	--	-122	--
800-035		405009	725229	103	252	-149	--	--	--	-146	-146
800-036		404954	725323	84	227	-143	-86	--	--	-120	-134
800-037		405003	725341	86	250	-164	-89	-104	--	-110	--
800-038		405005	725332	99	247	-148	-81	--	--	-106	-136
800-045		404956	725317	83	237	-154	--	--	--	-137	-144
800-046		404951	725308	85	277	-192	--	--	--	-125	-125
800-048		404954	725225	86	252	-166	--	--	--	-125	-125
800-049		404947	725229	80	252	-172	--	--	--	-132	--
OSVP2		405041	725159	102	300	-198	--	--	--	-129	-129
NA	S1531	405208	724945	45	138	-93	--	--	--	--	--
NA	S 6460	404932	724943	50	200	-150	-90	-124	--	-140	--
NA	S 84806	404846	725332	18	849	-831	--	--	--	-100	--
NA	S 92459	404750	725114	46	703	-657	--	--	--	-200	--
NA	S 96232	404750	725114	46	625	-579	--	--	--	-219	--
NA	S96481	405425	725109	70	764	-694	--	-94	X	-124	-152
NA	S106978	405425	725109	63	503	-440	--	-97	X	-117	-125
Sparrow1		405027	724936	94	235	-141	--	-85	--	-126	--
Sparrow2		405029	724928	81	234	-153	--	-84	--	-135	--
Sparrow3		405055	724939	69	254	-185	--	--	--	-156	--
Sparrow5		405049	724928	98	266	-168	--	--	--	-156	--
SparrowSB1		405035	724934	80	220	-140	--	--	--	-135	--