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Hydrogeology of Sand and Gravel Deposits near the Nepaug Reservoir, New Hartford and Burlington, Connecticut

Water-Resources Investigations Report 01-4059

Prepared in cooperation with the Metropolitan District Commission

U.S. Department of the Interior
U.S. Geological Survey

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East Hartford, Connecticut
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
101 Pitkin Street
East Hartford, CT 06108
http://ct.water.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
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Denver, CO 80225

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
million gallons (Mgal)	3,785	cubic meter
	Mass	
ton	0.9072	megagram

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F = (1.8 × °C) + 32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C = (°F - 32) / 1.8

Altitude, as used in this report, refers to distance above or below 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 both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Sand and gravel deposits near the Nepaug Reservoir in New Hartford and Burlington, Connecticut, were studied to provide a basis for ongoing investigations that will evaluate water-quality conditions in the watershed and the effects of sand and gravel mining on the quality of water in the reservoir. In the Nepaug area, surficial glacial materials overlie crystalline bedrock that is predominantly schist and gneiss. Along the western side of Nepaug Reservoir, glacial stratified deposits were laid down as ice-marginal deltas in a series of small glacial lakes that formed sequentially as the ice margin retreated northeastward through the area. These deposits are as much as 250 feet thick and are subdivided into coarse-grained units (gravel, sand and gravel, and sand deposits) and fine-grained units (very fine sand, silt, and clay deposits). Approximately 954 million cubic feet of sand and gravel is contained in four delineated deposits in two areas near the reservoir.

The sand and gravel deposits adjacent to the Nepaug Reservoir can affect the physical and chemical responses of the watershed. Removal of the sand and gravel would likely result in increased streamflow peaks associated with storms and decreased streamflow during low-flow periods. Streamflow during floods and droughts at Burlington Brook and Clear Brook, a tributary to the Nepaug Reservoir, were compared to determine how the volume of sand and gravel in a watershed affects ground-water storage and the way water is released from storage. Removal of unsaturated deposits also may affect chemical interactions between water and sediment and cause changes in the amount of dissolved constituents in the water.

INTRODUCTION

The Metropolitan District Commission (MDC) was chartered in 1929 to provide potable water and sewerage to the City of Hartford and surrounding communities. One of MDC's responsibilities is to monitor and manage land use in their water-supply watersheds to provide high-quality, potable drinking water to the MDC system. Activities in the watershed that may affect water quality include sand and gravel extraction, increased public access, increased residential and commercial development, and changes in forestry practices.

Sand and gravel resources are a high-bulk, low-cost commodity; therefore, transportation is a substantial part of their total cost. To minimize transportation costs, most sand and gravel is used within 30 to 50 mi of its source (Langer and Glanzman, 1993, p. 21). The amount of sand and gravel used in construction is enormous: an average 1-mi stretch of four-lane highway requires 85,000 tons, an average-sized school or hospital 15,000 tons, and an average six-room house 90 tons (Langer and Glanzman, 1993, p. 4). Although a constant supply of sand and gravel is needed, land use and regulatory factors may make some sand and gravel deposits unavailable.

Sand and gravel deposits have been mapped throughout the Nepaug Reservoir watershed (Stone and others, 1992), but the thickness and volume of these materials has not been defined locally. In addition, the effects of sand and gravel mining on water quality in adjacent drinking-water reservoirs are not well understood. Information is needed to determine if the removal of sand and gravel deposits, including the overlying soils and vegetation, will affect streamflow and water quality.

To provide information that could be used to protect water quality and maintain access to sand and gravel deposits, the U.S. Geological Survey (USGS) began a cooperative project with MDC in 1997. The project will study the hydrogeology of the sand and gravel deposits adjacent to Nepaug Reservoir and evaluate the potential effects of sand and gravel mining on the water quality in the reservoir. Additional goals of the project include assessing ground-water quality and quantifying nutrient and other constituent loads in surface water. This information can be used by MDC to supplement source-water protection plans for the Nepaug Reservoir watershed and to develop a policy regarding extraction of sand and gravel deposits.

Purpose and Scope

This report provides information on the hydrogeologic framework that will be used in ongoing studies to evaluate water-quality conditions in the watershed and the effects of sand and gravel mining on the quality of water in the reservoir. The report describes the hydrogeology of sand and gravel deposits in two areas adjacent to the Nepaug Reservoir and includes information on the distribution of glacial stratified deposits (gravel, sand, silt, and clay); the thickness and volumes of these materials; the altitude of the water table; the altitude of the bedrock surface; and the potential effects of sand and gravel mining on the physical and chemical responses of the watershed.

Description of the Study Area

The Nepaug Reservoir watershed in northwestern Connecticut (fig. 1) is about 32 mi^2, primarily in the town of New Hartford, with lesser areas in Burlington, Torrington, Canton, Winchester, and Harwinton. The watershed is about 86 percent forested (undeveloped), 10 percent agricultural land, and 2 percent highway corridor (Civco and Hurd, 1990). Although residential and commercial development account for less than 2 percent of the drainage basin, these categories of land use have increased since the 1980's. Two areas of thick sand and gravel deposits in the watershed—the South Area and the North Area (figs. 2, 3)—are the main focus of this report.

Previous Investigations

The hydrogeology of the Nepaug Reservoir watershed was investigated previously by Handman and others (1986) in a study on the Farmington River Basin. Information was compiled on the distribution of sand and gravel aquifers, the hydraulic properties of unconsolidated materials, the altitude of bedrock in the valleys, and streamflow characteristics. Results from this study indicate a high degree of variability in the hydrogeologic characteristics throughout the Farmington River Basin. Geologic investigations that cover the Nepaug Reservoir watershed include the surficial geologic map of the Collinsville quadrangle (Colton, 1970) and the bedrock geologic map of the Collinsville quadrangle (Stanley, 1964). Information about the geology of the Nepaug area also is included in several statewide investigations (Rodgers, 1985; Stone and others, 1992, 1998; DiGiacomo-Cohen and Quarrier, 1993).

Acknowledgments

The authors would like to thank Leland Sanders of the Metropolitan District Commission for his assistance during various parts of this investigation. We also would like to thank John Mullaney and Remo Mondazzi of the USGS for the assistance they provided during the collection and interpretation of geophysical data, and Steven Kiesman, Gloria Morrill, Joshua Oliva, and Barbara Korzendorfer of the USGS for their assistance in preparation of this report.

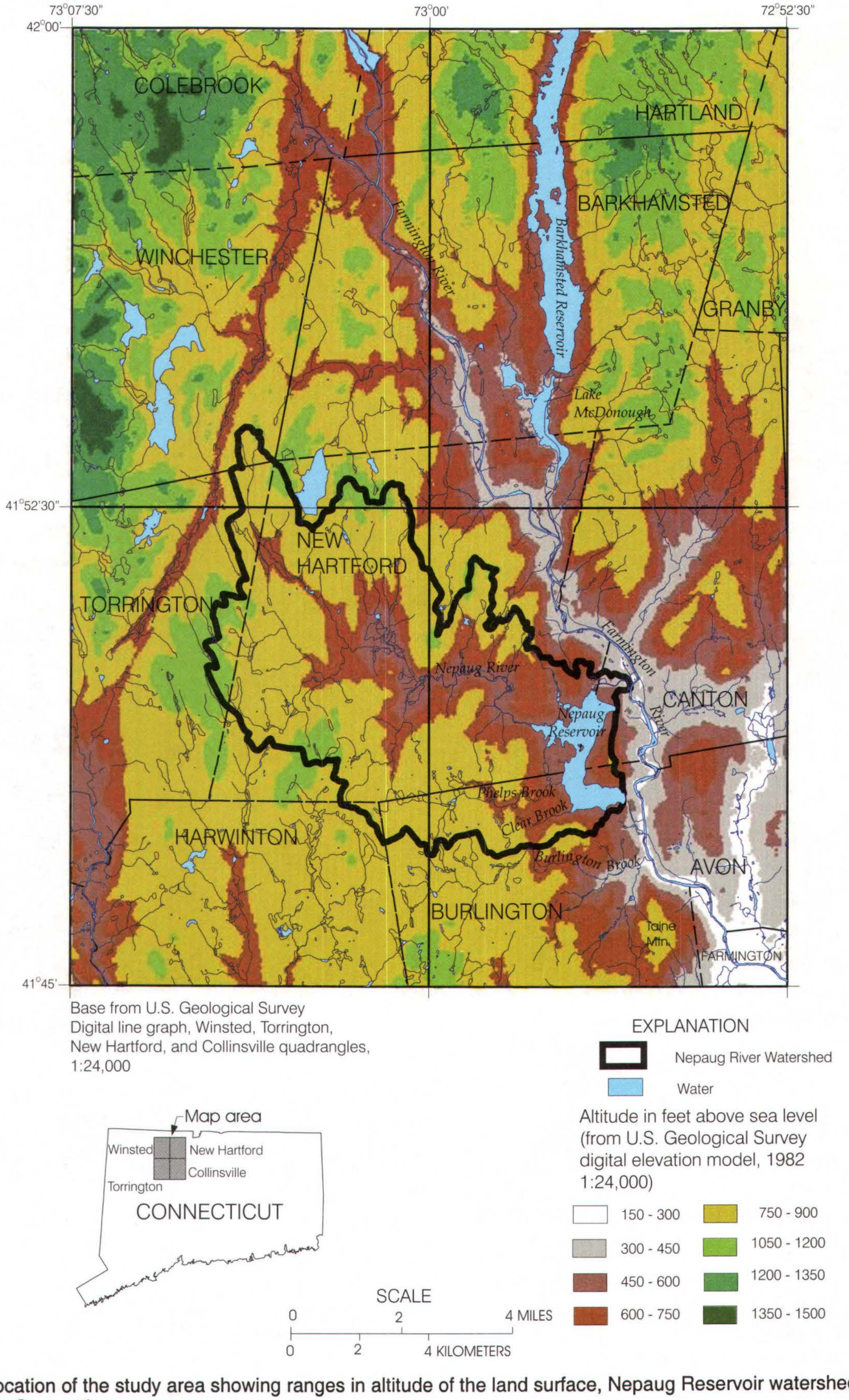


Figure 1. Location of the study area showing ranges in altitude of the land surface, Nepaug Reservoir watershed, northwestern Connecticut.

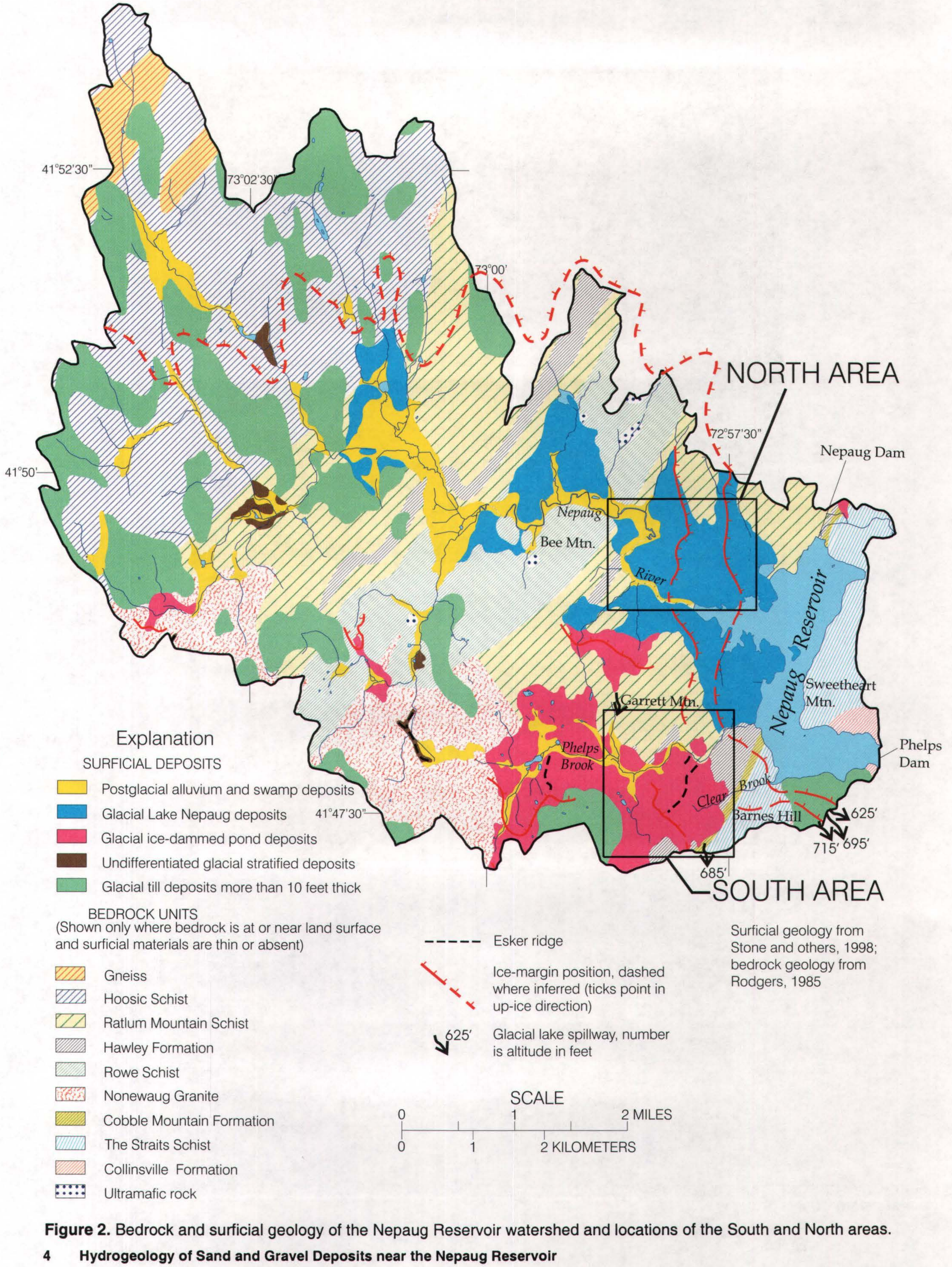
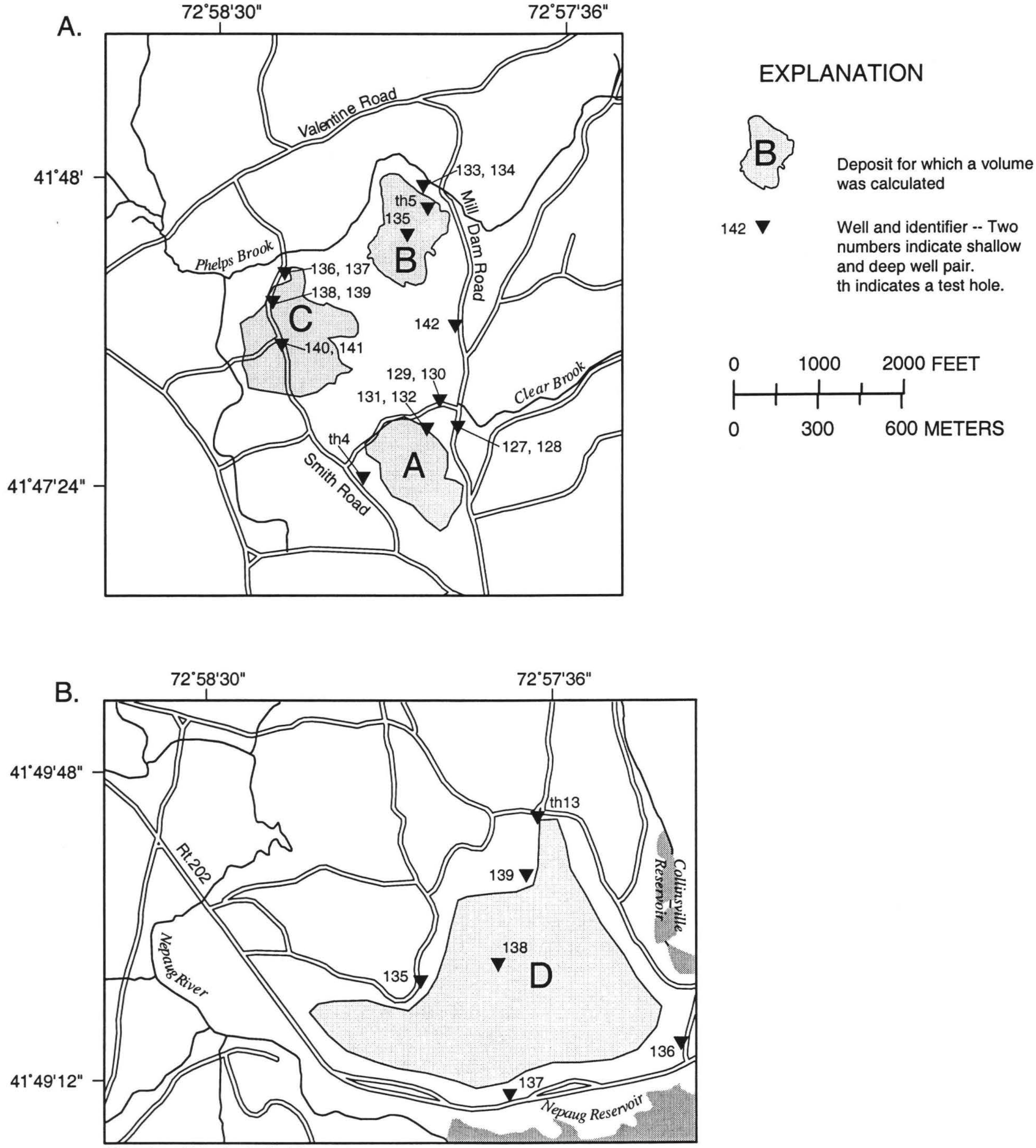


Figure 2. Bedrock and surficial geology of the Nepaug Reservoir watershed and locations of the South and North areas.



Base from U.S. Geological Survey
Collinsville, Connecticut quadrangle
Digital line graph (1988)

Figure 3. Roads, wells, and sand and gravel deposits for which volumes were calculated in the South Area (A) and the North Area (B).

DATA COLLECTION AND ANALYSIS

The hydrogeologic framework of the study area was simulated in a three-dimensional spatial database. The 1996 USGS 1:24,000-scale Collinsville Quadrangle Digital Raster Graphic was used as the base map for the North and South Areas. A digital representation of land surface was created by digitizing contour lines from the 1984 USGS 1:24,000 Collinsville quadrangle map. New maps of the bedrock surface, the water-table surface, and the distribution of surficial materials were constructed for this study in a digital format, based on geologic investigations, seismic-refraction profiling, and monitoring wells and test borings. The spatial database was used to estimate quantities of sand and gravel and ground-water storage in the study area.

Geologic Investigations

Geologic investigations in the study area delineated the character and distribution of the surficial materials and the depth to bedrock. Available exposures of surficial materials were examined, and all lithologic logs from wells were analyzed. Surficial geologic maps and geologic sections were constructed from site information in conjunction with depositional models developed for the region (Stone and others, 1992; 1998). The areal and vertical distribution of glacial stratified deposits was described on the basis of the particle-size classification and textural ranges shown in table 1.

Table 1. Particle-size classification and deposits in glacial sediments

[Particle-size classification from Wentworth, 1922. Deposit classification from Stone and others, 1979, fig. 3]

PARTICLE DIAMETER										
10	2.5	0.16	0.08	0.04	0.02	0.01	0.005	0.025	0.00015	inches
256	64	4	2	1	0.05	0.25	0.125	0.068	0.004	millimeters
Boulders	Cobbles	Pebbles	Granules	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
GRAVEL PARTICLES				SAND PARTICLES				FINE PARTICLES		

SAND AND GRAVEL DEPOSITS

Range from 100 percent gravel particles to 25 percent gravel particles and 75 percent sand particles.

SAND DEPOSITS

Range from 25 percent gravel particles and 75 percent sand particles through 100 percent sand particles to 50 percent sand particles and 50 percent fine particles.

FINE DEPOSITS

Range from 50 percent sand and 50 percent fine particles to 100 percent fine particles.

TILL DEPOSITS

Mixture of gravel, sand, and fine particles in different proportions.

Seismic-Refraction Profiling

Seismic-refraction data were collected during 1997 and 1998. A 24-channel, signal-enhancing seismograph was used to collect and record arrival times of sound-wave energy. Seismic-refraction lines were run using a variety of geophone spacings, line lengths, and energy sources.

Seismic-refraction profiles were collected over a 3-day period in September 1997 along 220-ft long seismic lines with 12 geophones spaced every 20 ft. The sound energy was generated by striking a steel plate on the ground with a 12-lb sledge hammer. Hammer blows were repeated to maximize signal strength. This method worked well in areas where bedrock was less than 70 ft below land surface.

During the summer of 1998, additional seismic-refraction data were collected along 1,150-ft long seismic lines with 24 geophones spaced every 50 ft. The sound energy was generated from a two-part explosive that was set between 2 and 4 ft below land surface. This method produced adequate signal energy to determine depth to bedrock in areas with relatively thick amounts of unsaturated sand and gravel. Depths to bedrock and the water table were determined by seismic-refraction methods described by Haeni (1988, p. 3-13). A computer program developed by Scott (1977) was used to interpret the seismic-refraction data (appendix 1).

Depth to the water table was difficult to determine in areas where less than 50 percent of the unconsolidated material was saturated, a problem referred to as a thin, intermediate-velocity refractor. A two-layer model was used with a velocity override factor to account for some of the unconsolidated thickness being saturated. In these areas, information from test borings and wells was used to verify the location of the water table and interpret the seismic-refraction data. Maximum and minimum water-table altitudes were calculated for these areas using methods described by Haeni (1988, p. 13-20).

Monitoring Wells and Test Borings

During the summer of 1998, test borings were drilled and wells were installed to confirm interpretations from the seismic-refraction data, collect samples, and measure ground-water levels. Sixteen wells and two test borings were drilled in the South area (fig. 3A; appendix 2), and five wells and one test boring were drilled in the North area (fig. 3B; appendix 2). Test borings and monitoring wells were installed with a hollow-stem auger drill rig operated by USGS personnel using methods described by Lapham and others (1997). Split-spoon samples of the surficial materials were collected every 10 ft during the drilling process. Data from drilling logs (appendix 3) were used to verify depth to the water-table and bedrock surface, as well as provide information on the textural variations of surficial materials with depth in each well or test boring. In the South Area, most monitoring wells were installed in pairs—a deep well with a 5-ft section of slotted well screen below the water table, and a shallow well with a 10-ft section of slotted well screen through the water table. In the North Area, single monitoring wells were installed with a 5-ft section of slotted well screen below the water table.

Calculation of Sand and Gravel Volumes

To understand the hydrologic characteristics of the sand and gravel deposits in the Nepaug River watershed, an accurate estimate of the volume of the deposits is needed. Volume estimates can be used to calculate the amount of ground-water storage available and to identify areas where mining might change ground-water storage. The spatial database was used to calculate the volume of saturated and unsaturated sand and gravel in selected deposits in the South and North Areas. These deposits were selected because they are distinct topographic features and are composed primarily of sand and gravel.

The spatial database consists of digital contour maps of the altitude of land, water-table, and bedrock surfaces. Continuous surfaces were created from the contour maps in a geographic information system (GIS). The continuous surfaces were converted to grids so that calculations could be made on a cell-by-cell basis. Specifically, the altitude of the water table was subtracted from the altitude of land surface, and the altitude of the bedrock was subtracted from the altitude of water table. This calculation yields the thickness of the unsaturated and saturated deposits, respectively, at each grid cell. Continuous surfaces were made for unsaturated and saturated thicknesses in each of the deposits, and the function called "area and volume" in GIS was used to estimate the volumes (Environmental Systems Research Institute, 1997).

The maps produced by this method are limited by the accuracy and detail of the contour maps on which they are based. Land-surface altitudes in the digital data base are from USGS 1:24,000-scale topographic maps (1984) with a 10-ft contour interval. The bedrock surface in the North and South Areas was contoured at a 25-ft interval; the water table was contoured at a 10-ft interval in the South Area and a 20-ft interval in the North area, using data obtained during this study. Additional test borings and (or) monitoring wells could improve the accuracy of the water-table and depth-to-bedrock maps. To provide a conservative estimate, volumes of sand and gravel were calculated for saturated deposits 10 ft or more below the water table and unsaturated deposits 10 ft or more above the water table. Volume estimates do not reflect any recent mining.

REGIONAL HYDROGEOLOGY

Physiography, Hydrography, and Bedrock Geology

Nepaug Reservoir is near the eastern edge of the western highlands of Connecticut in an area of irregular hills and valleys with maximum relief of about 400 ft (figs. 1, 2). Hills surrounding the reservoir, such as Sweetheart Mountain to the east, Barnes Hill to the south, and Garrett Mountain to the west, reach altitudes of 800 to 900 ft above sea level. The downstream ends of valley bottoms are below 500 ft in altitude where streams enter the western side of Nepaug Reservoir.

The Nepaug River and two smaller streams to the south—Phelps Brook and Clear Brook—are easterly flowing tributaries to the Farmington River. These stream valleys have been artificially impounded by two dams—Nepaug Dam on the Nepaug River and Phelps Dam on Phelps Brook—to form the Nepaug Reservoir. The reservoir occupies an irregularly shaped basin, about 1.3 mi^2 in area, that straddles a former drainage divide between the Nepaug River watershed to the north and Phelps Brook and Clear Brook watersheds to the south (fig. 2). The spillway altitude of 482 ft (at Phelps Dam) limits the water level in the reservoir.

The broad-scale physiography, that is, the position and orientation of hills and valleys in the reservoir area, is largely controlled by the composition and structure of the crystalline (metamorphic) bedrock that underlies the region. The bedrock is predominantly schist and gneiss with local lenses of amphibolite and small intrusive pegmatites. The higher hills, such as Barnes Hill and Bee Mountain, are underlain by quartz-rich schist and gneiss, whereas many lower lying areas are underlain by feldspar-rich schist and gneiss (Stanley, 1964). The linear trend of major hills and some valleys reflects the regional strike of northeast-trending folds in the bedrock. Other valleys, such as the Nepaug River valley, trend northwest and have developed along joint sets and near-vertical fracture zones that cut across the northeast-trending fold structures. Smaller-scale physiographic features in the reservoir area are the result of glacial deposition and postglacial erosion by modern rivers and streams.

Surficial Geology

Surficial (unconsolidated) materials overlie bedrock in most places in the Nepaug Reservoir watershed (fig. 2). These materials are predominantly glacial deposits laid down during the advance and retreat of the last (late Wisconsinan) continental ice sheet, which covered most of the Earth's northern hemisphere 25,000 to 20,000 years ago. Locally, deposits of an earlier (probably Illinoian) ice sheet are preserved, mostly in the subsurface. The terminal position of the section of the last ice sheet covering western New England was on Long Island, N.Y. Northerly retreat of the glacier margin from Long Island began soon after 20,000 years ago and reached the Collinsville/Burlington area by about 16,000 years ago (Stone and Borns, 1986; Stone and others, 1998). Surficial deposits include glacial till, laid down directly by glacial ice during advance of the ice sheet, and glacial stratified deposits, laid down by meltwater streams and in glacial lakes during retreat of the last ice sheet. Postglacial deposits are present locally and include sediments beneath modern stream floodplains (alluvium) and in wetland areas (swamp deposits; peat and muck). Postglacial deposits are generally thin (less than 10 ft thick) and overlie glacial deposits.

Till

Glacial ice-laid deposits (till) overlie the bedrock surface in most places near the reservoir. Till in the western highlands is typically gray and consists of a nonsorted, nonlayered mixture of grain sizes with a matrix of 65 to 85 percent sand, 20 to 30 percent silt, and 5 to 10 percent clay; larger rock fragments (clasts) generally constitute 20 to 30 percent of the total volume of the material (Melvin and others, 1992). Logs of wells and test borings and interpretation of aerial photographs indicate that till is generally less than 10 to 15 ft thick in much of the study area; areas where till is thicker than 10 to 15 ft are shown as thick till in figure 2. Till is locally absent where bedrock is at land surface or where the bedrock surface is overlain directly by glacial stratified deposits. Till in the study area was deposited predominantly as basal till beneath continental ice sheets during the late Wisconsinan and earlier (Illinoian) glaciations. Its color and lithology closely resemble the underlying crystalline bedrock from which it was derived.

Glacial Stratified Deposits

In much of the area adjacent to the western side of the Nepaug Reservoir, glacial stratified deposits up to 250 ft thick overlie till and (or) bedrock. Here, as elsewhere in Connecticut, these deposits consist of mappable units of coarse-grained sediments (gravel, sand and gravel, and sand) and fine-grained sediments (very fine sand, silt, and clay). Coarse-grained, poorly sorted, and relatively angular gravels were deposited at and proximal to the ice front and were commonly laid down on top of ice at the glacier margin. Subsequent melting of the ice produced collapsed ice-contact scarps and closed depressions (kettle holes) in and to the north of the proximal deposits. Finer-grained and better-sorted sand and gravel was deposited farther away from the ice margin, commonly in deltas that prograded into glacial lakes (ice-marginal deltas). Well-sorted, very fine sand, silt, and clay settled out as bottom sediments in the glacial lakes. These packages of contemporaneously deposited sediments that grade from coarse-grained near the ice margin to fine-grained in areas distal from the ice are called morphosequences (Koteff and Pessl, 1981; Stone and others, 1992; 1998). Individual morphosequences are commonly 0.5 to 1 mi long and are present in valleys in shingled form; that is, the coarse-grained, northern part of one sequence is overlain by the fine-grained, distal end of the next sequence to the north.

In the Nepaug Reservoir area, coarse-grained deposits were laid down predominantly as ice-marginal deltas in a series of small glacial lakes ("Glacial ice-dammed pond deposits" on fig. 2) that developed sequentially in the Burlington Brook and Phelps Brook valleys as the ice margin retreated northeastward through the area. Fine-grained deposits accumulated locally as lake-bottom sediments in these glacial lakes. Water levels in the series of small lakes were controlled by successively lower spillways across a drainage divide to the south. Each small glacial lake controlled the altitude at which deltaic sand and gravel was deposited in the valleys. Two levels of glacial ponding are recorded by delta surfaces in the Phelps Brook and Clear Brook valleys. West of Mill Dam Road (deposits A, B, and C), sand and gravel deposits with surface altitudes of 795 to 805 ft are the tops of deltas graded to a glacial pond controlled by a spillway at 765 ft across the Burlington Brook drainage divide. East of Mill Dam Road, sand and gravel deposits with surfaces altitudes of 695 to 705 ft are deltaic deposits graded to a glacial pond controlled by a spillway at 685 ft across the local drainage divide between Clear Brook and Burlington Brook valleys.

Sand and gravel deposits on the northwestern side of the reservoir are ice-marginal deltas built into glacial Lake Nepaug (fig. 2), which was impounded in the Nepaug River valley by the retreating ice margin. Water levels in glacial Lake Nepaug were controlled by three successively lower spillways at altitudes of 715, 695, and 625 ft carved into till on the eastern side of Barnes Hill, just south of the reservoir (Stone and others, 1992; 1998).

HYDROGEOLOGY OF SAND AND GRAVEL DEPOSITS IN THE SOUTH AND NORTH AREAS

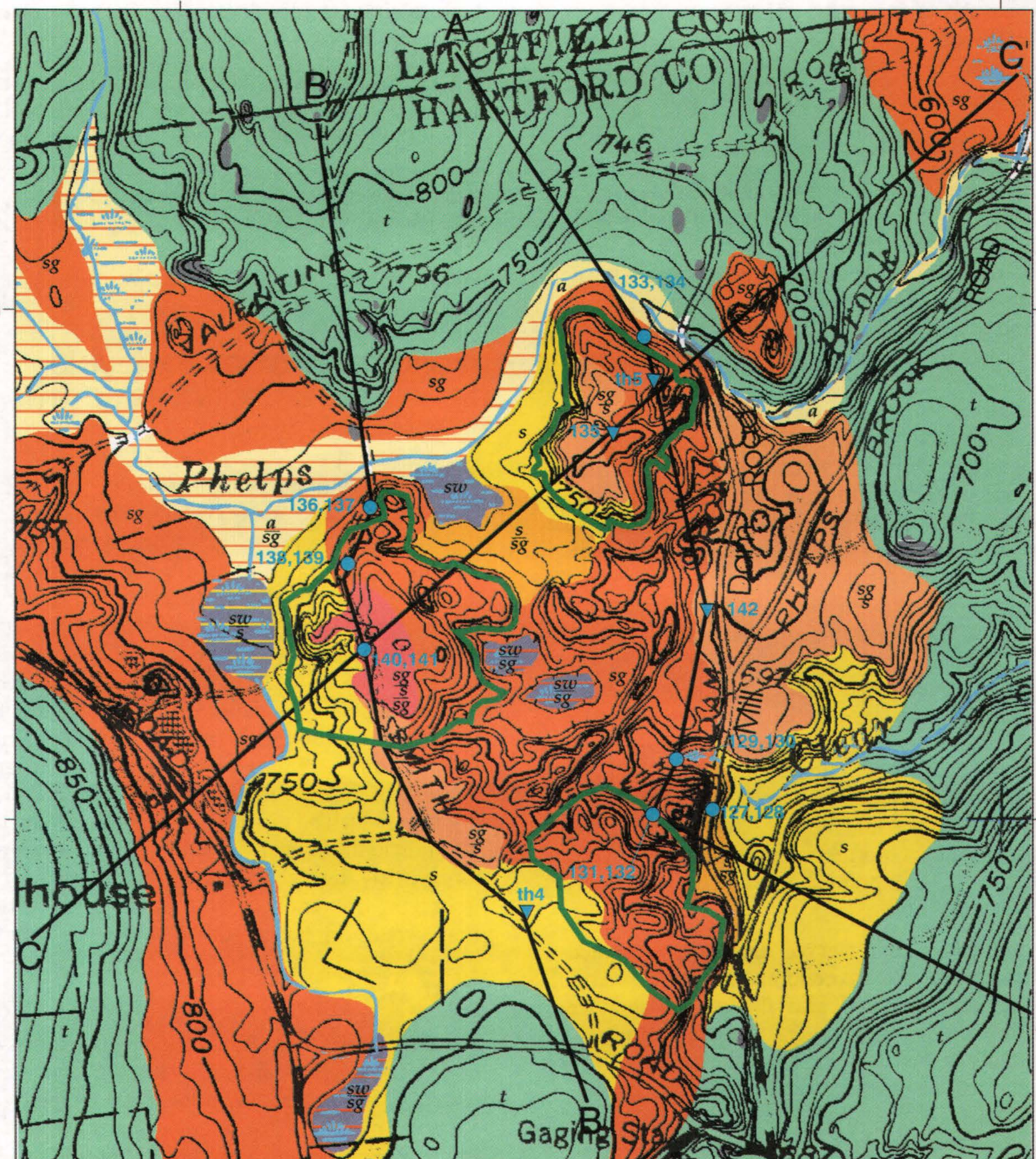
A description of the distribution, thickness, and volume of the sand and gravel deposits near the Nepaug Reservoir (South and North Areas) is needed to characterize ground-water flow in the area. Glacial stratified deposits in the South and North Areas are described as textural units on the basis of grain-size distribution (table 1). These deposits are subdivided into (1) coarse-grained units (sand and gravel deposits and sand deposits), including grain sizes that range from fine sand through coarse gravel (cobbles and boulders); and (2) fine-grained units (fine deposits), including grain sizes that range from clay and silt to very fine sand. The distinction between (1) and (2) is important hydrologically because ground water moves more quickly through the coarse-grained deposits than through the fine-grained deposits. Large quantities of ground water can be stored in both types of deposits.

South Area

The South Area (fig. 2) encompasses parts of the Phelps Brook and Clear Brook valleys. Three separate deposits of thick sand and gravel were targeted for volume calculations (fig. 3A, 4). Deposit A and Deposit B, both on the western side of Mill Dam Road, have been mined for sand and gravel. (Deposit A was being mined for sand and gravel during this study.) Deposit C, along Smith Road, has not been mined.

Distribution, Thickness, and Volumes of Sand and Gravel Deposits

Sand and gravel deposits west of Mill Dam Road have surface altitudes as high as 795 to 805 ft. The distribution of textural units in this area results from the deposition of several ice-marginal deltaic morphosequences built at successive positions of the glacial ice



Base from U.S. Geological Survey
Collinsville, Connecticut quadrangle,
1:24,000, 1956, photo revised 1984.
Digital raster graphic file.

SCALE
0 500 1,000 FEET
0 100 200 300 METERS

Contour interval 10 feet
National Geodetic Vertical Datum of 1929

Geologic mapping by
J.R. Stone 1998

Figure 4. Surficial materials map of the South Area, Nepaug Reservoir watershed. [Location of wells, test borings, and geologic sections are shown. Description of map units applies to figs. 4 and 8.]

DESCRIPTION OF MAP UNITS
(figs. 4 and 8)

POSTGLACIAL DEPOSITS

Alluvium is present beneath the floodplain surfaces of the Nepaug River, Phelps Brook, and Clear Brook; in some places, these surfaces are also underlain by swamp deposits; swamp deposits also are present in positions isolated from the floodplain, such as in kettle holes. Swamp deposits and alluvium are generally thin (less than 10 feet thick) and are underlain by thicker glacial stratified deposits (see description below).

Alluvium--composed of sand and silt, locally gravel, with some organic material. Areas where alluvium overlies sand and gravel deposits shown by orange lines and fine deposits by blue lines

Swamp Deposits--composed of peat and muck with minor amounts of sand, silt, and clay. Areas where swamp deposits overlie sand and gravel deposits shown by orange lines and sand deposits by yellow lines

GLACIAL STRATIFIED DEPOSITS (STRATIFIED DRIFT)

Gravel, sand, silt, and clay particles (as defined in the particle-size diagram, table 1) that are present in layers and are classified into three textural units based on grain-size distribution—Sand and Gravel Deposits, Sand Deposits, and Fine Deposits. The texture of glacial stratified deposits is described throughout their vertical extent either as a single textural unit or two or more units in various orders or superposition referred to as "stacked units." Contacts between subsurface textural units are not mapped with as great an accuracy and detail as those at the surface. All units of glacial stratified deposits overlie glacial till and (or) bedrock, which is not included in the stacked unit

Sand and Gravel Deposits--Composed of mixtures of gravel and sand particles within individual layers and as alternating layers; sand and gravel layers range from 25- to 50-percent gravel particles and from 50- to 75-percent sand particles. Layers are well- to poorly sorted; bedding may be distorted by post-depositional collapse. (Proximal deltaic and fluvial deposit and delta topset beds) *Typical horizontal hydraulic conductivity is 100 to 500 feet per day*

Sand Deposits--Composed mainly of very coarse to fine sand particles; coarser layers may contain up to 25-percent gravel particles, generally granules and pebbles; finer layers may contain some very fine sand, silt, and clay. Layers are commonly well sorted. (delta foreset beds, distal lacustrine fan deposits and distal fluvial deposits) *Typical horizontal hydraulic conductivity is 25 to 250 feet per day*

Fine Deposits--Composed of very fine sand, silt, and clay particles, generally in well-sorted, thin layers of alternating silt and clay and (or) very fine sand; locally may contain lenses of coarser material (lake-bottom deposits) *Typical horizontal hydraulic conductivity is less than 5 feet per day*

Stacked Map Units

Sand and Gravel overlying Sand--Sand and gravel is generally less than 20 feet thick, horizontally bedded and overlies thicker, inclined layers of sand (deltaic deposits)

Sand overlying Sand and Gravel--Sand of variable thickness overlies sand and gravel of variable thickness (distal deltaic deposits overlying collapsed ice-marginal sediment)

Sand and Gravel overlying Sand overlying Sand and Gravel--Sand and gravel is generally less than 20 feet thick, horizontally bedded and overlies thicker inclined beds of sand, which in turn overlie sand and gravel of variable thickness (deltaic deposits overlying collapsed ice-marginal sediment)

Sand overlying Fines--Sand is of variable thickness, commonly in inclined foreset beds and overlies thinly bedded fines of variable thickness (distal deltaic deposits overlying lake-bottom sediment)

GLACIAL DEPOSITS (NONSTRATIFIED)

Till--Nonsorted, nonstratified, compact mixture of grain sizes ranging from clay to large boulders; matrix is largely sand particles containing up to 25-percent silt and clay. Till blankets the bedrock surface in most places and underlies glacial stratified drift but is not included in the stacked units. *Hydraulic conductivity is generally less than 1 foot per day*

Bedrock outcrop

Deposit for which a volume was calculated (see fig. 3 for location)

Contact between map units

A——A' Line of geologic section shown in figures 5 and 9.

137, 138 / 135 Location of wells and test holes; number is local U.S. Geological Survey well number used in appendixes 2 and 3; dots indicate paired deep and shallow wells; triangles indicate single wells; wells in South Area have BU prefix and wells in North Area have NH prefix (see appendixes 2, 3)

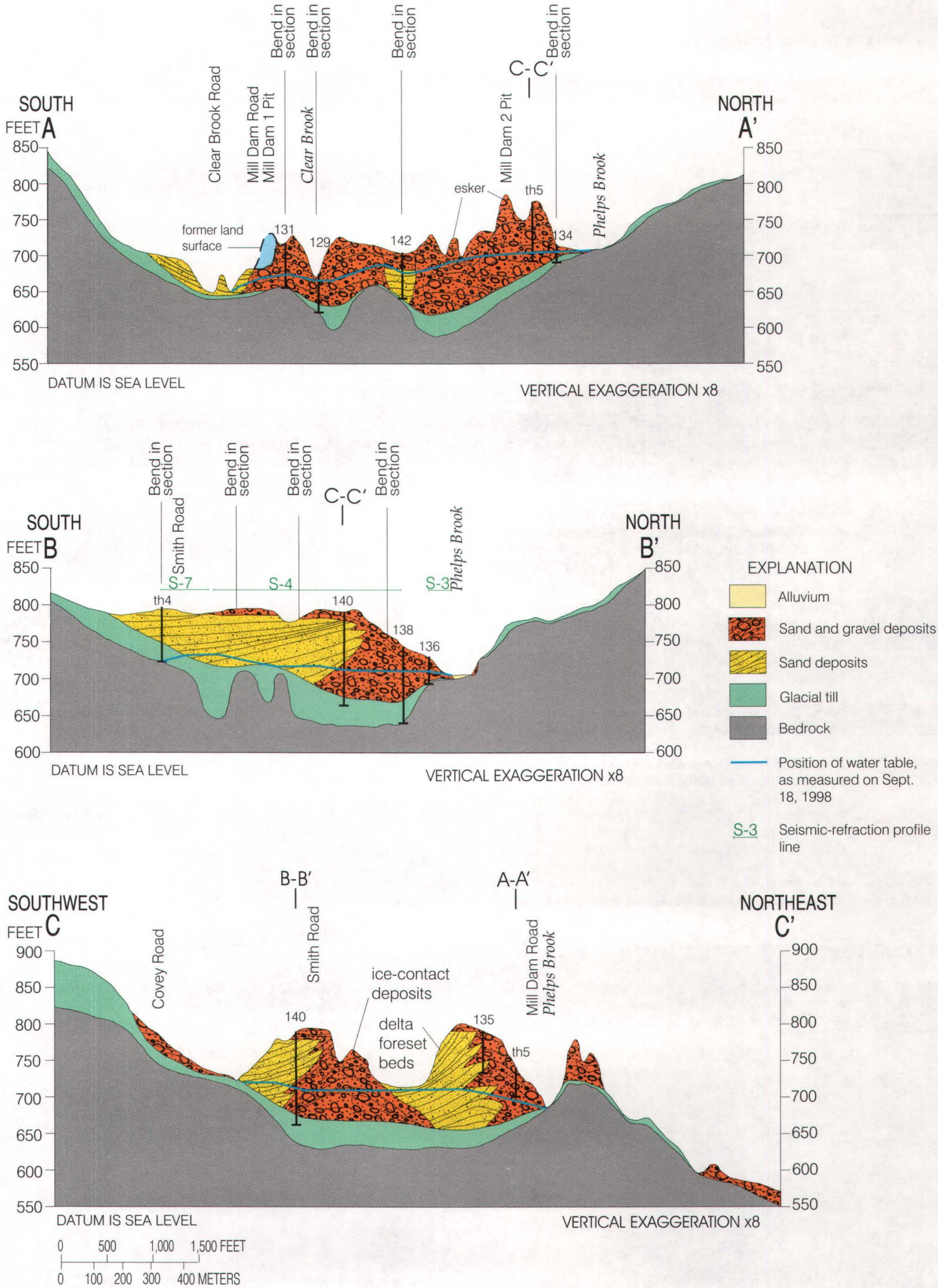


Figure 5. Geologic sections A-A', B-B', and C-C' in the South Area, Nepaug Reservoir watershed. [See fig. 4 for location of section lines.]

margin (fig. 2). One deltaic morphosequence (which includes deposits A and C on fig. 4) was built at an ice-margin position roughly parallel with and just northeast of Smith Road; sediment was supplied to this delta by glacial meltwater from an ice-tunnel stream within stagnant ice along the ice margin. Gravels laid down in the tunnel stream compose the narrow sinuous ridge (esker) that trends northeast-southwest between Mill Dam Road and Smith Road. Areas northeast of Smith Road (including the esker) in this deltaic deposit are underlain by coarse gravels and sands in which the bedding is collapsed—that is, distorted or destroyed when the underlying stagnant glacial ice melted. The surface topography of the collapsed deposits is irregular and includes kettle holes also produced by melting ice. The flatter surfaces along and to the southwest of Smith Road are underlain by finer-grained gravels and sand deposited in the delta farther from the ice margin. In these sediments, bedding is generally not collapsed.

A second deltaic morphosequence (with surface altitudes of 805 ft) lies immediately south of Phelps Brook and west of Mill Dam Road (deposit B on fig. 4). As in the first morphosequence, coarse gravels and sands with collapsed bedding are present in the northeastern part of the deposit, and noncollapsed, finer-grained gravels and sand are present in the southwestern part. The shingled nature of the two morphosequences can be seen on section C-C' (fig. 5). These two deltaic morphosequences were controlled by the 765-ft spillway. Deltaic surfaces to the east of Mill Dam Road are at altitudes of about 700 ft (100 ft lower than those to the west) and were built when the ice margin retreated to the northeast uncovering a lower spillway at 685 ft that caused the level of ponding to drop from the 765-ft spillway.

The thickness and textural heterogeneity of the glacial stratified deposits and the position of the water table are shown on geologic sections A-A', B-B', and C-C' (fig. 5). Sand and gravel deposits in the South Area occupy a large bowl-shaped depression in the bedrock surface (fig. 6). The deposits taper to a feather edge at the margins of the depression and are thickest in the middle, particularly where the land surface is much higher than surrounding areas (see cross-sections on fig. 5). The thickness of the surficial materials ranges from less than 10 ft to as much as 150 ft in several areas. The altitude of the lowest part of the closed bedrock depression lies below 600 ft, with an outlet at an altitude between 600 and 625 ft near the headwaters of the Clear Brook watershed.

The volume of sand and gravel in the South Area has been calculated for three areas (fig. 3A, 4) where the unsaturated deposits are thickest and the potential for mining is highest. The total volume in Deposits A, B, and C is 275.5 million cubic ft. The individual volumes of sand and gravel in each deposit are shown in table 2, along with a breakdown between volumes of saturated and unsaturated material. The volume of sand and gravel that is saturated can be used to determine the volume of ground water stored in the deposits, if the volume of pore space in the deposit is known. The volume of unsaturated sand and gravel gives an indication of (1) how much sand and gravel could be mined without dewatering the saturated deposits and (2) the potential for ground-water storage and chemical transformations that could take place in this zone.

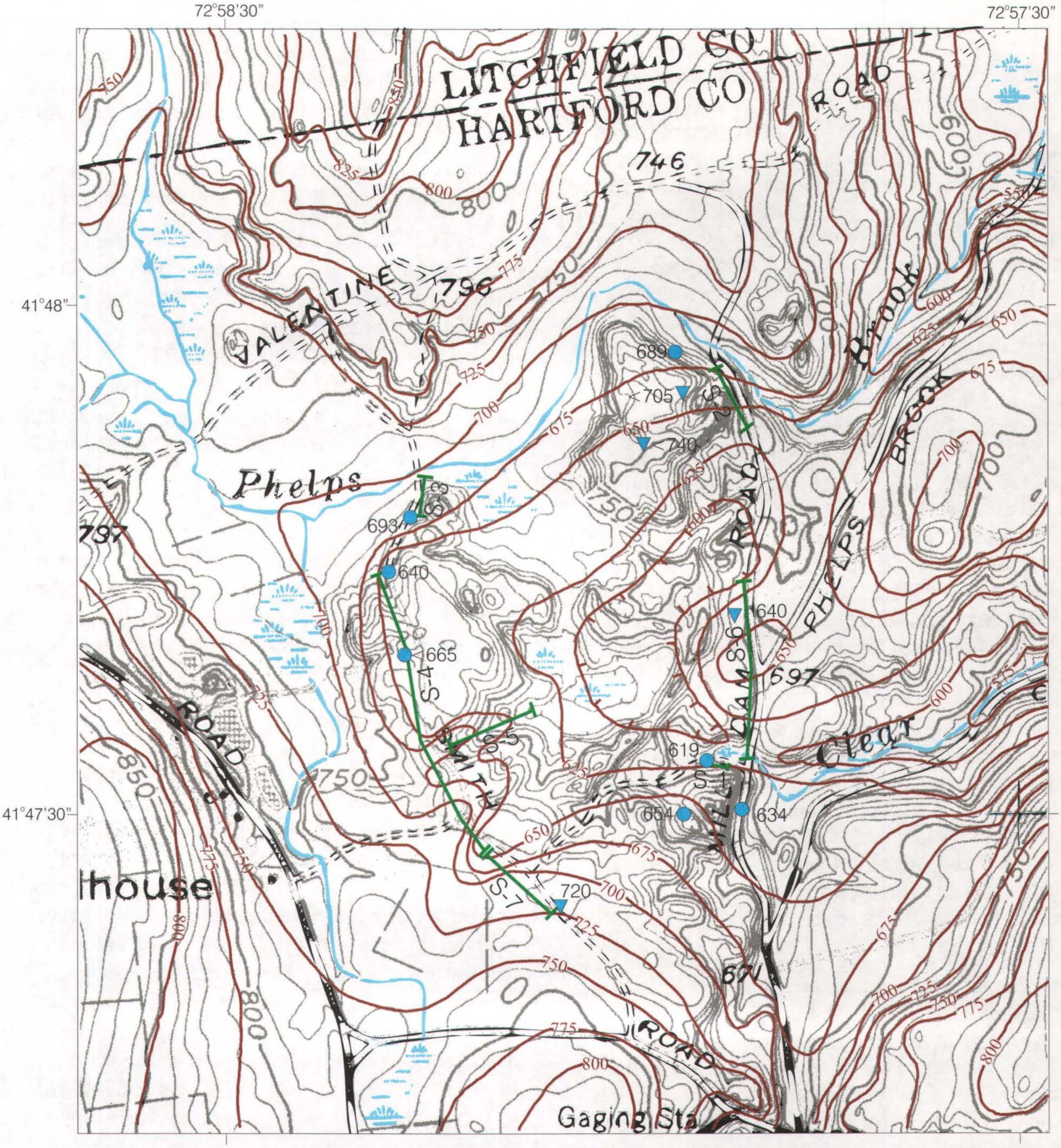
Ground-Water Flow

Ground water generally flows from surrounding till-covered hills in an easterly direction and discharges along seeps from the base of the sand and gravel deposits into Clear and Phelps Brooks. Water flows readily through the large pore spaces in the sand and gravel; therefore, the water table generally is flat, especially in the area between Phelps Brook at Smith Road to Clear Brook (fig. 7). Steep gradients are present near the boundaries of the sand and gravel deposit and are steepest along the slope where ground water discharges into Clear and Phelps Brooks. This area has the thickest saturated deposits of sand and gravel, ranging from 50 to 100 ft thick. The thinnest saturated deposits of sand and gravel are less than 10 ft on top of the hill at the southern end of Smith Road.

Table 2. Volumes of sand and gravel (exceeding 10-feet thick) for the South and North Areas, Nepaug Reservoir watershed

[Volumes of sand and gravel in million cubic feet]

Area	Deposit	Total volume of sand and gravel	Saturated volume of sand and gravel	Unsaturated volume of sand and gravel
South Area	A	52.3	4.4	47.9
	B	84.1	34.4	49.7
	C	139.1	77.6	61.5
North Area	D	678.6	227.7	450.9



Base from U.S. Geological Survey Collinsville, Connecticut quadrangle, 1:24,000, 1956, photorevised 1984. Digital raster graphic file.

SCALE

0 500 1,000 FEET

0 100 200 300 METERS

Contour interval 10 feet
National Geodetic Vertical Datum of 1929

EXPLANATION

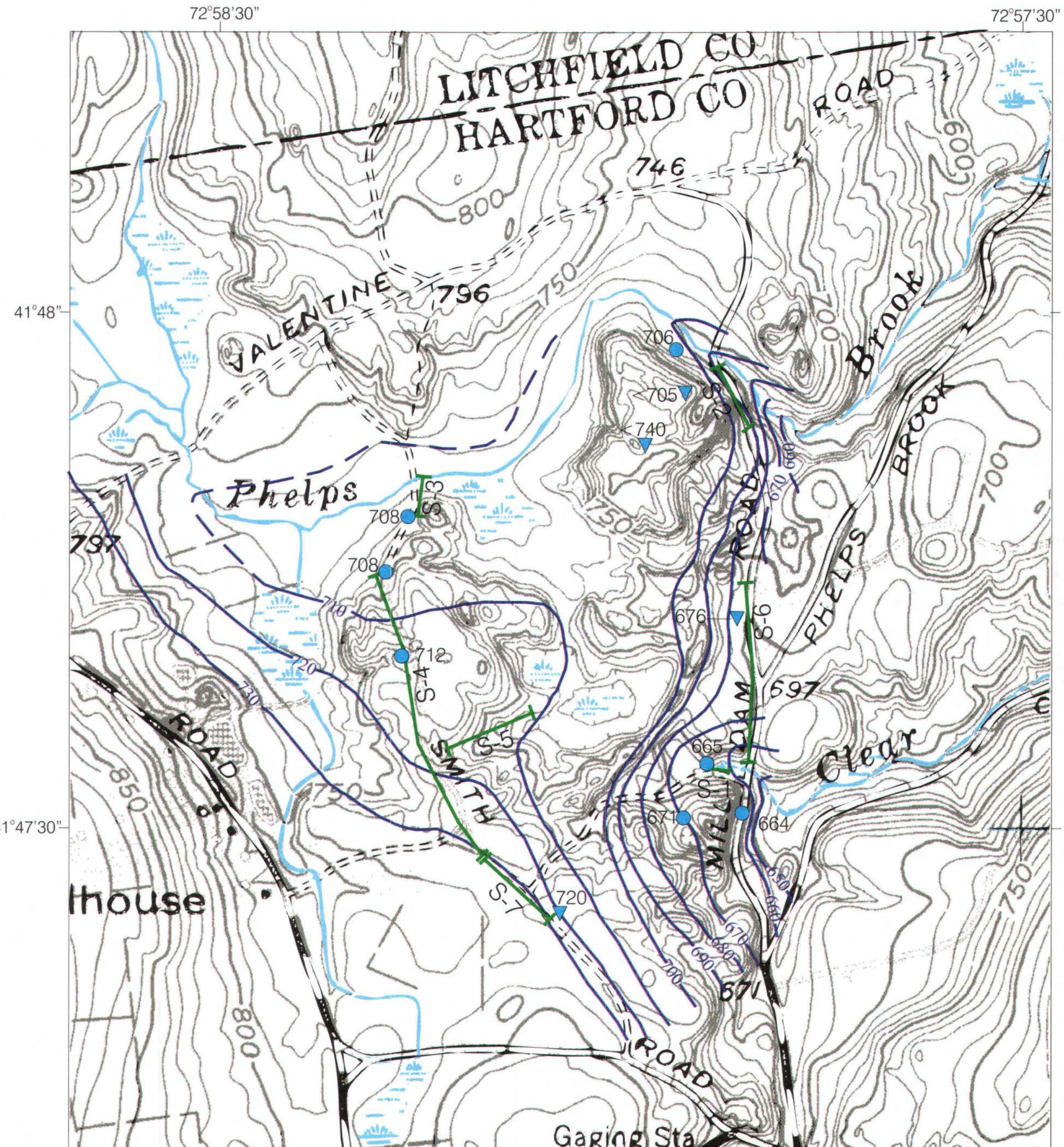
700 — BEDROCK SURFACE CONTOUR- Altitude of the bedrock surface in feet above sea level. Contour interval 25 feet

S-5 — SEISMIC-REFRACTION PROFILE LINES

654 — WELL PAIR - Number is altitude of the bedrock surface in feet above sea level

720 — SINGLE WELL OR TEST BORING - Number is altitude of the bedrock surface in feet above sea level

Figure 6. Bedrock contour map of the South Area, Nepaug Reservoir watershed.



Base from U.S. Geological Survey
Collinsville, Connecticut quadrangle,
1:24,000, 1956, photorevised 1984.
Digital raster graphic files.

SCALE

0 500 1,000 FEET

0 100 200 300 METERS

Contour interval 10 feet
National Geodetic Vertical Datum of 1929

EXPLANATION

—700— WATER TABLE CONTOUR - Altitude of the water table in feet above sea level as measured on Sept. 18, 1998. Shown only in sand and gravel deposits. Contour interval 10 feet

S-6 SEISMIC-REFRACTION PROFILES LINES

● 706 WELL PAIR - Number is altitude of water table in feet above sea level as measured on Sept. 18, 1998

▼ 720 SINGLE WELL OR TEST BORING - Number is altitude of water table in feet above sea level as measured on Sept. 18, 1998

Figure 7. Altitude of the water table in the South Area, Nepaug Reservoir watershed.

North Area

The North Area (fig. 2) is north and northwest of Nepaug Reservoir and includes a section of the Nepaug River at and upstream from the confluence with the reservoir. Thick and areally extensive sand and gravel deposits are present, although no mining has taken place. Volumes of sand and gravel were calculated for only part of the North Area (Deposit D on figs. 3B, 8).

Distribution, Thickness, and Volume of Sand and Gravel Deposits

Most of the glacial stratified deposits in the North Area (fig. 8) were deposited as two successive ice-marginal deltas in glacial Lake Nepaug (section E-E' on fig. 9). The western delta has the highest surface altitudes of 725 ft and was built into the higher stage of glacial Lake Nepaug, which was controlled by the 715-ft spillway on the eastern side of Barnes Hill (fig. 2). The eastern delta reaches an altitude of 635 ft and was built when eastward retreat of the ice margin caused water levels in glacial Lake Nepaug to drop nearly 100 ft to a stage controlled by the 625-ft spillway.

The distribution of sand and gravel, sand, and fine deposits in the North Area results from the sequential deposition of these two ice-marginal deltas. Coarse-grained gravels and sands that are highly collapsed underlie surfaces on the eastern sides of both deltas; finer gravels and sands are present on the western sides of both deltas (section E-E' on fig. 9). The western delta built westward into open waters of glacial Lake Nepaug, and lake-bottom deposits of very fine sand, silt, and clay settled out in the lake in front of the delta. The eastern (later) delta was built immediately behind the western (earlier) one, and delta sands of the second delta overlie collapsed ice-marginal gravels of the first delta.

Surficial materials in the North Area range from less than 10 ft thick in areas underlain by till to more than 250 ft thick near the western edge of the deltaic deposits. Here, deltaic sand and gravel fills a deep bedrock valley (fig. 10). The bedrock surface is at or near land surface at altitudes as high as 700 ft on the northern and western sides of the area. The lowest bedrock altitudes are below 450 ft in the bedrock valley bottom, which trends northwest-southeast through the area. The bedrock valley underlies the Nepaug River valley near the road intersection in the northwestern part of the area. Farther along its southeasterly trend, however, the bedrock valley diverges from the river valley and passes beneath thick sand and gravel deposits.

The volume of sand and gravel in the area delineated as Deposit D (figs. 3B, 8) in the North Area is 678 million cubic ft (table 2). The water table here is deeper below land surface than in the South Area, and most of this deposit is unsaturated.

Ground-Water Flow

No perennial streams are evident near Deposit D; however, several ground-water seeps are present along the southern edge of the deposit, in the area south of Route 202 near the confluence of the Nepaug River and the Nepaug Reservoir. The water table (fig. 11) is relatively flat in the northern part of Deposit D and slopes towards the edges of the deposit. Ground water discharges to the Nepaug River on the western side and to the Nepaug and Collinsville Reservoirs on the southern and eastern sides. Saturated thickness of sand and gravel ranges from less than 10 ft in the northern section to more than 100 ft in the southern and western areas of the delta deposits.

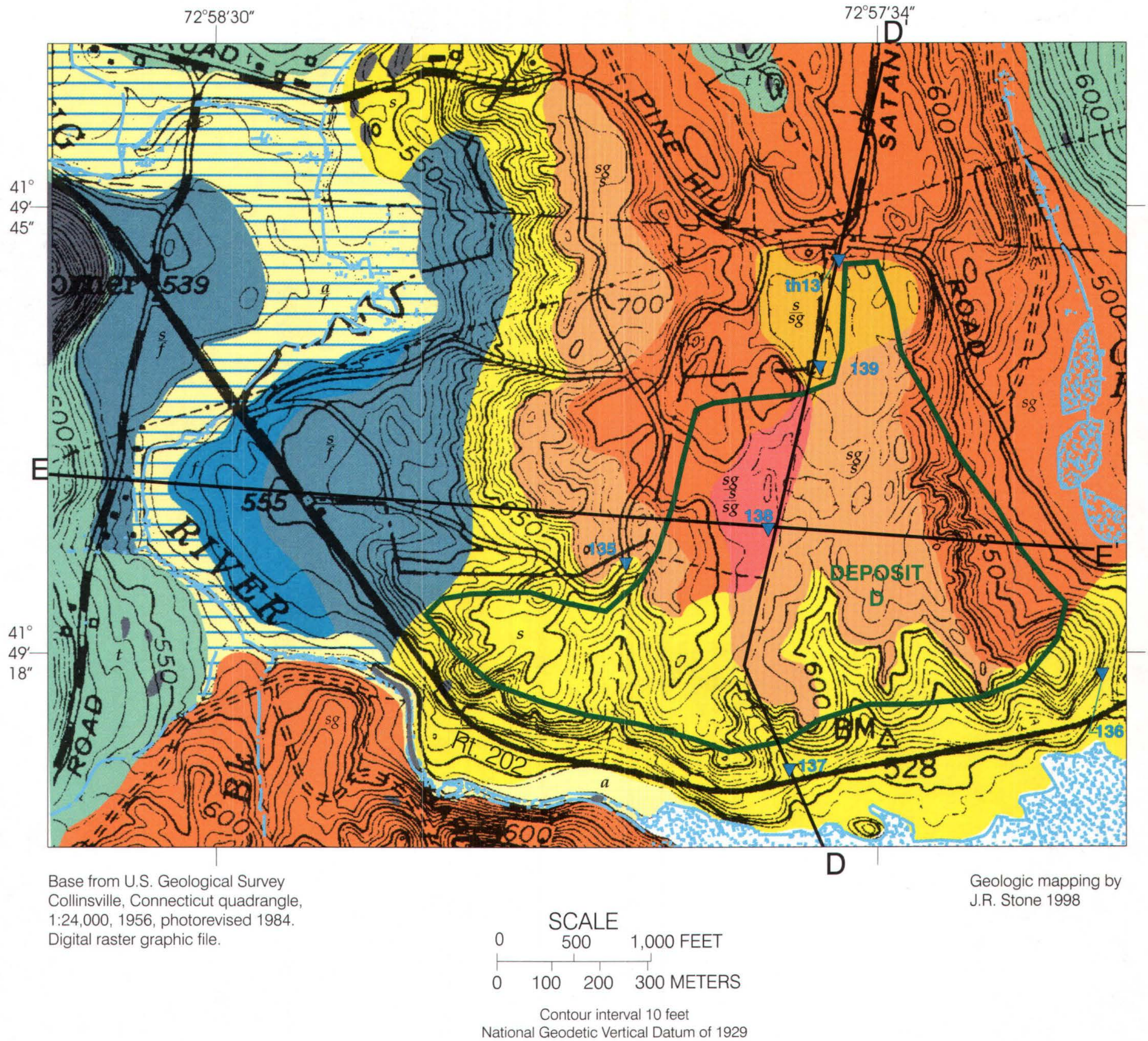


Figure 8. Surficial materials map of the North Area, Nepaug Reservoir watershed. [Locations of wells, test borings, and geologic sections are shown. See fig. 4 for description of map units.]

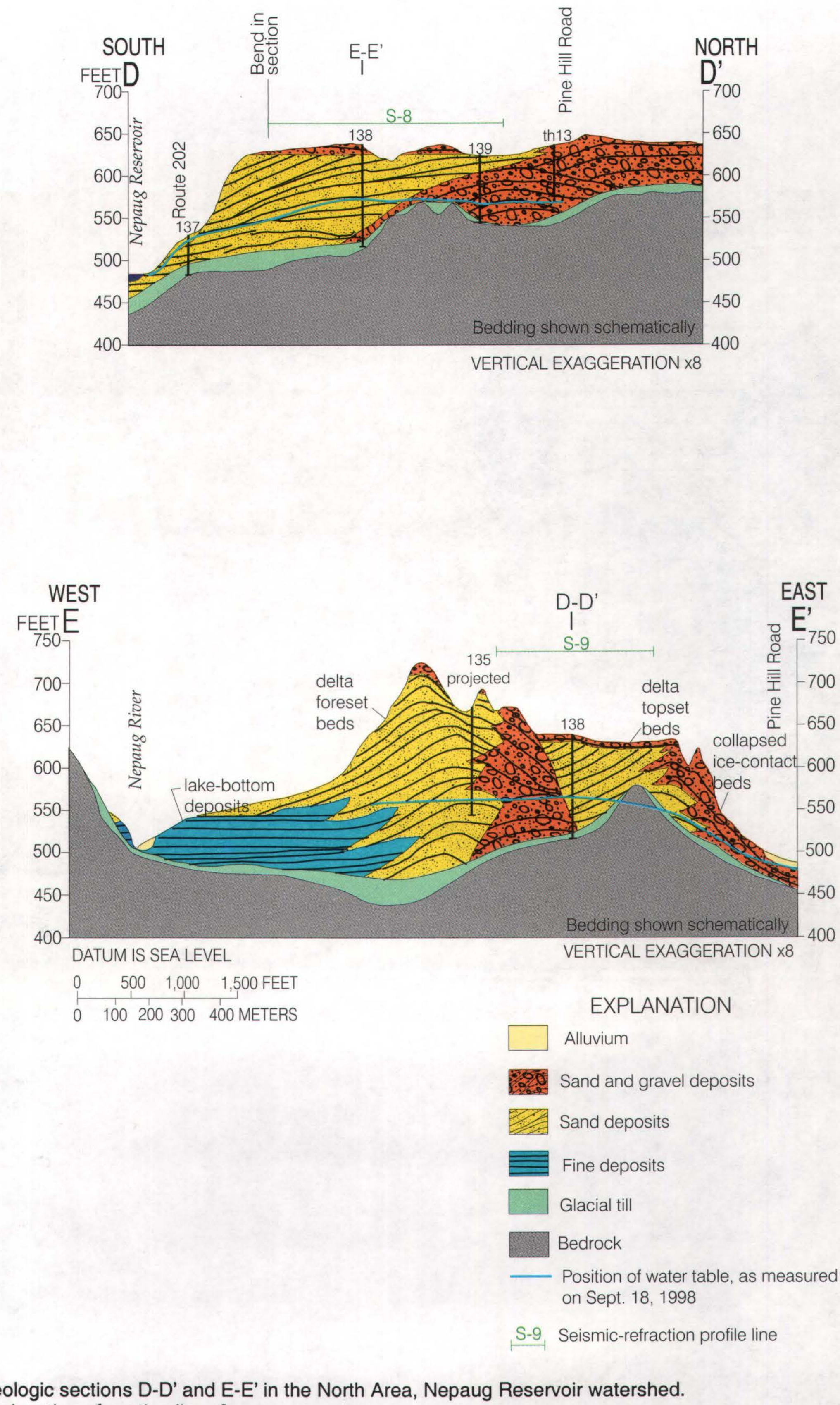
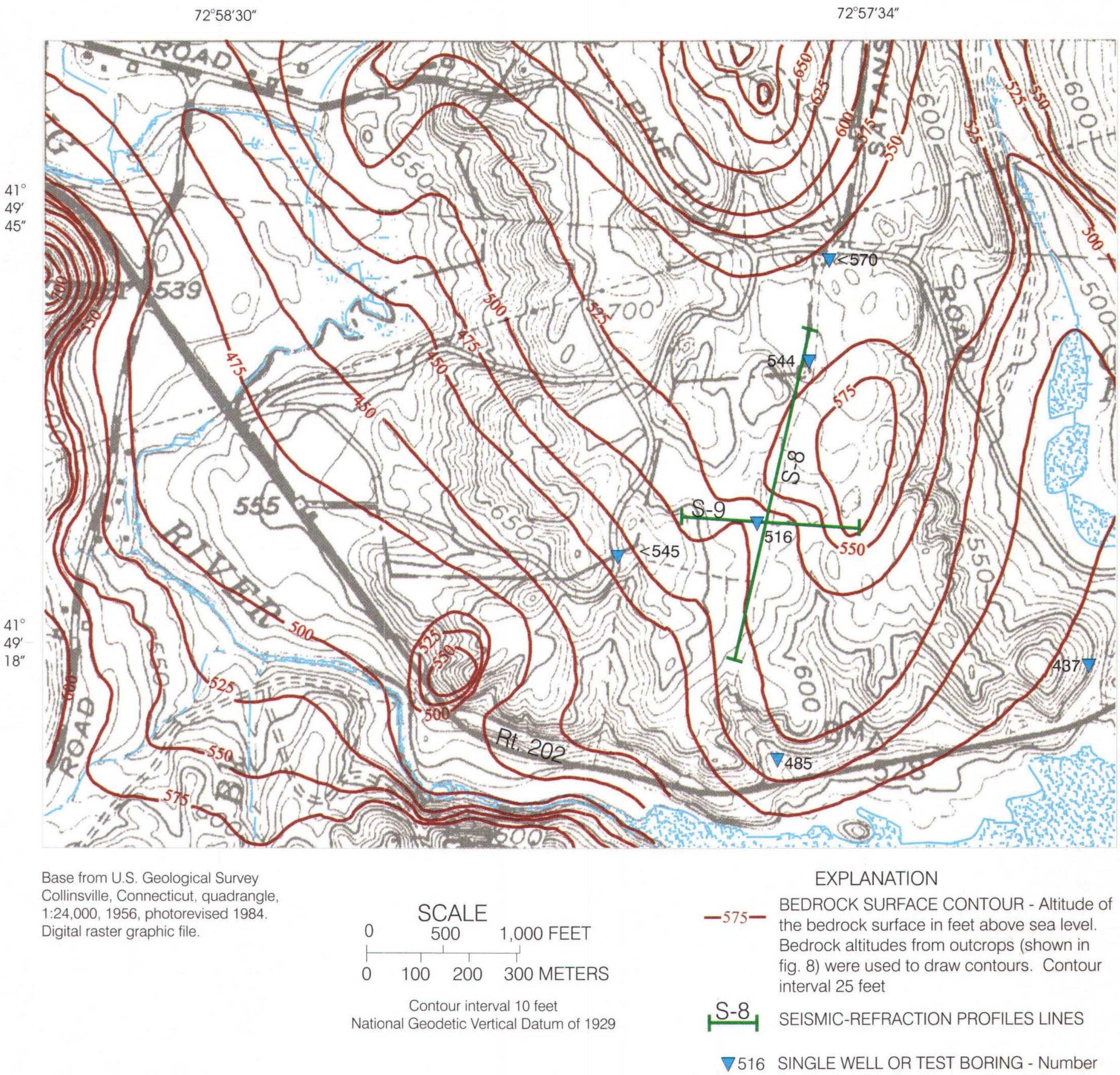


Figure 9. Geologic sections D-D' and E-E' in the North Area, Nepaug Reservoir watershed. [See fig. 8 for location of section lines.]



Base from U.S. Geological Survey Collinsville, Connecticut, quadrangle, 1:24,000, 1956, photorevised 1984. Digital raster graphic file.

SCALE

0 500 1,000 FEET

0 100 200 300 METERS

Contour interval 10 feet
National Geodetic Vertical Datum of 1929

EXPLANATION

—575— BEDROCK SURFACE CONTOUR - Altitude of the bedrock surface in feet above sea level. Bedrock altitudes from outcrops (shown in fig. 8) were used to draw contours. Contour interval 25 feet

S-8 SEISMIC-REFRACTION PROFILES LINES

▼516 SINGLE WELL OR TEST BORING - Number is altitude of the bedrock surface in feet above sea level

Figure 10. Bedrock contour map of the North Area, Nepaug Reservoir watershed.

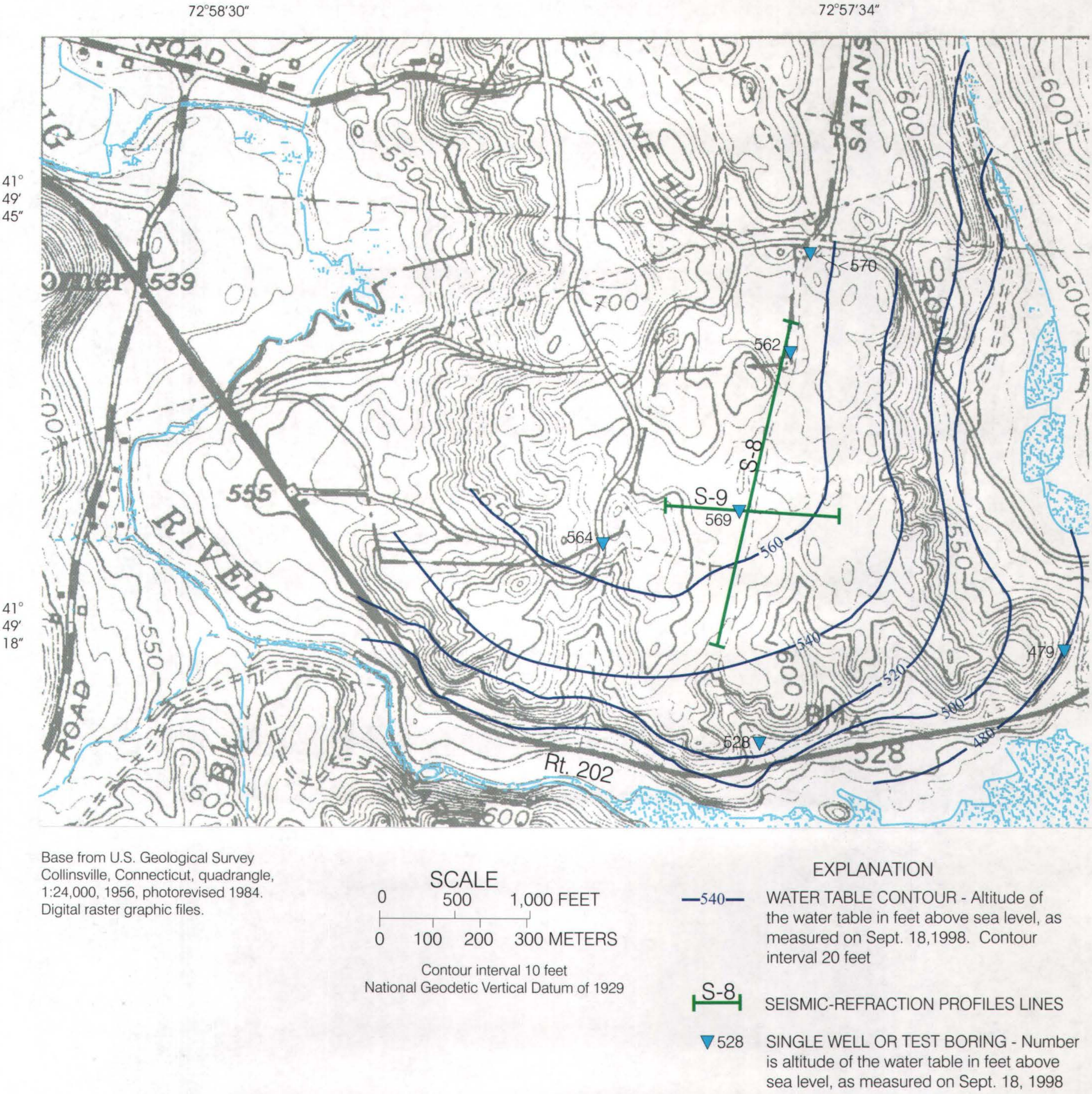


Figure 11. Altitude of the water table in the North Area, Nepaug Reservoir watershed.

EFFECTS OF SAND AND GRAVEL DEPOSITS ON THE HYDROLOGIC RESPONSE OF THE NEPAUG RESERVOIR WATERSHED

Sand and gravel deposits are important factors in the physical and chemical responses of a watershed to inputs of water. Freeze (1972a) noted that the response of a watershed to inputs of water is "strongly influenced by the subsurface hydrogeologic configuration, the saturated permeabilities of the component formations, and the unsaturated soil characteristics of the soil types." In terms of the physical response, the deposits act as ground-water reservoirs that reduce streamflow peaks during storms and increase streamflow during low-flow periods (Thomas, 1966). In terms of the chemical response, unsaturated sand and gravel along the periphery of reservoirs may be critical to maintaining water quality by facilitating chemical reactions that reduce concentrations of contaminants. If sand and gravel deposits are removed through mining, the hydrologic response of the watershed, both physical and chemical, probably would change.

Physical Responses

The saturated deposits around Nepaug Reservoir are a reservoir for ground water, and the release of water stored in these deposits maintains streamflow during periods of low flow. The ratio of the volume of water that drains by gravity to the total volume of the deposits is called the specific yield, which can be from 23 to 28 percent (Domenico and Schwartz, 1990, p. 118) for sand and gravel deposits. The amount of usable ground water in storage can be estimated by multiplying the saturated volume (table 2) by the specific yield. For example, Deposit D in the North Area contains an estimated 426 Mgal of water (227.7 million cubic ft x 0.25 x 7.48 gallons per cubic foot). Although this area currently is not used for water supply, there may be the potential for the development of high-capacity sources.

The unsaturated deposits are hydrologically complex. In this zone, water flows downward under the pull of gravity and the suction force created as water is pulled into air-filled pore spaces by capillary action. The suction force is proportional to differences in moisture content and is lower in coarse-grained deposits than in fine-grained deposits. At the water table, water completely fills the pore spaces, and the suction force is 0. Between rainfalls, evaporation and transpiration (the use of water by plants) act to reduce the moisture content of the soil so that some water that infiltrates the ground surface never reaches the water table (Freeze, 1969). During a rainfall, water saturates the deposits close to land surface and the rate of downward movement is high. As the water is redistributed, the differences in moisture content become less, and the rate of downward movement slows. As the infiltrating water moves downward, it displaces deeper water, so that dissolved constituents in the water move at a slower rate than the apparent rate of water movement (Fetter, 1993).

Ground-water flow in the unsaturated zone affects rises in the water table. For example, infiltrating water is most likely to reach the water table where the water table is shallowest (Freeze, 1969). A ground-water mound at these shallow locations may spread back beneath the surrounding hills so that a ground-water rise underneath thick unsaturated deposits may be the result of lateral flow in the saturated zone rather than downward flow in the unsaturated zone (Winter, 1983). In the Nepaug area, this means that the water table probably rises first at the base of the hills at Deposits A, B, C, and D.

In addition, the geometry of the hillsides and the permeability of the deposits strongly influences the timing and mechanisms of stormflow generation (Freeze, 1972b). For convex slopes with high permeability, such as Deposits A, B, and C, stormflow is generated by shallow subsurface flow. On convex slopes with lower permeability and on concave slopes, stormflow is generated by precipitation on transient, near-channel wetlands, such as wetlands near the Nepaug River, Phelps Brook, and Clear Brook (Freeze, 1972b, p. 1282). Increases in peak stormflow can cause more sediment and potential sediment-associated nutrients to be transported into the reservoir.

The combined effect of saturated and unsaturated sand and gravel deposits on the response of streams in the study area to droughts and floods can be illustrated by comparing streamflow records from Clear Brook near Collinsville, Connecticut (USGS 01187850; period of record 1921-73) to nearby Burlington Brook (USGS 01188000; period of record 1931-current) (fig. 12). The two watersheds are hydrologically similar except for the amount of sand and gravel in each. The percentage of the drainage area underlain by sand and gravel is about 52 percent in the Clear Brook watershed and about 32 percent in the Burlington Brook watershed. For comparison, streamflow was normalized by dividing the mean daily streamflow by the respective drainage areas, resulting in units of cubic feet per second per square mile.

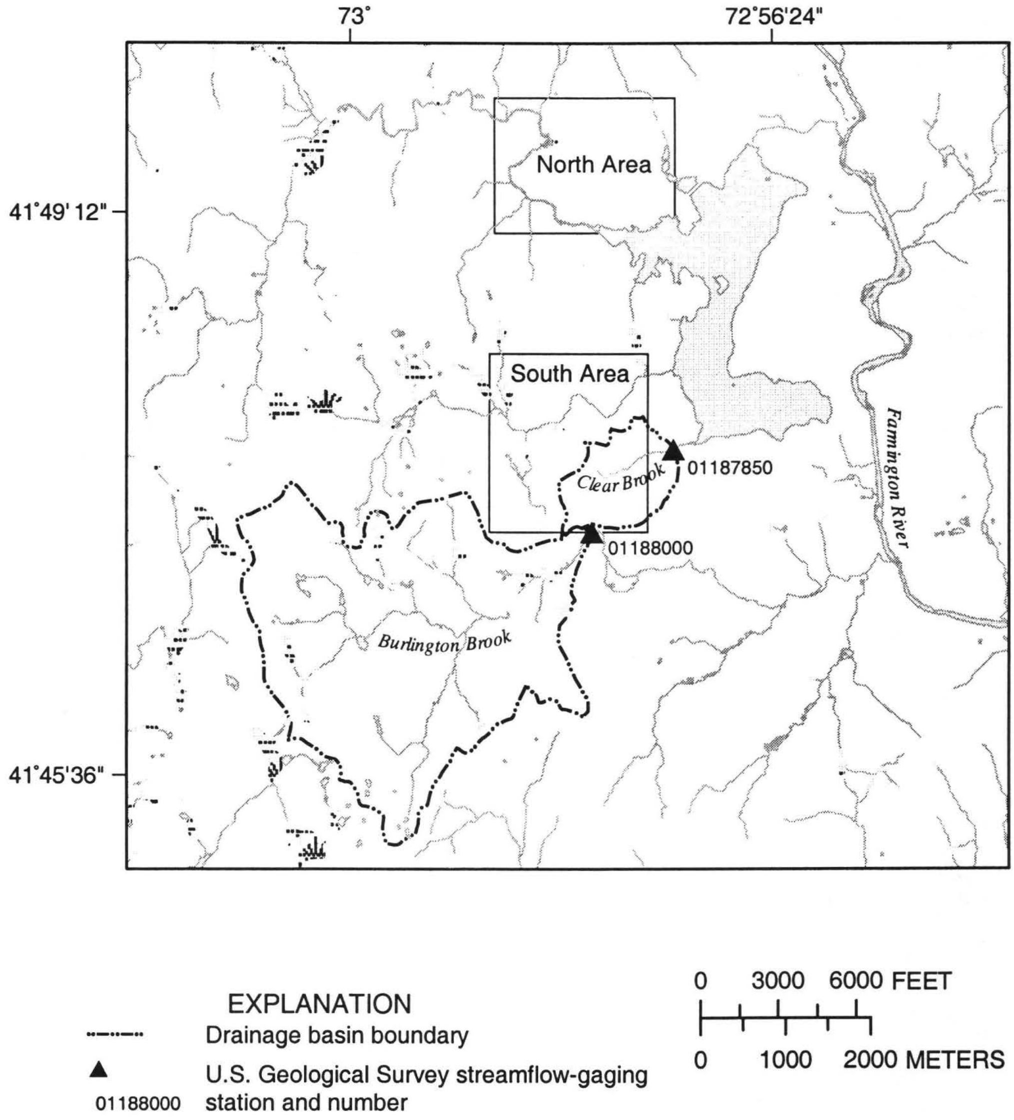


Figure 12. Burlington Brook and Clear Brook drainage areas.

During the drought of the mid-1960s, streamflow at Burlington Brook dropped an order of magnitude, from about 2 $ft^3/s/mi^2$ in February to March 1965 to 0.2 $ft^3/s/mi^2$ in June to August 1965 (U.S. Geological Survey, 1966) (fig. 13A). Conversely, Clear Brook flowed steadily and only dropped from about 2 $ft^3/s/mi^2$ to 1.2 $ft^3/s/mi^2$ during the same time period. On June 26, 1965 (the lowest daily mean prior to 1995 for Burlington Brook), the flow of Clear Brook per square mile of drainage area was 24 times greater than for Burlington Brook. Sand and gravel deposits in the Clear Brook watershed store large amounts of water that can sustain flow during lengthy dry periods compared to the Burlington Brook watershed, where the flow receded steeply.

During the flood of August 1955 (fig. 13B), the opposite effect was observed. The peak runoff per square mile of drainage area at Clear Brook was only one-quarter as much as the runoff at nearby Burlington Brook. In this case, the sand and gravel deposits in the Clear Brook watershed stored the flood-causing rainfall and slowly released it to streams in the weeks and months after the August 1955 flood. Flow at Burlington Brook receded more steeply after the same storm. The difference in flow characteristics may not be fully explained by the area of stratified glacial deposits. Other variables, such as the thickness or volume of unsaturated deposits and ground-water flow from outside the basin, also may be factors in predicting flow characteristics.

Chemical Responses

The unsaturated zone may play a role in chemical changes that take place as water moves towards the water table. Inorganic reactions, which include gas dissolution, oxidation and reduction, ion exchange, sorption processes, and precipitation reactions, can affect the pH, temperature, and specific conductance of water (Domenico and Schwartz, 1990). Organic reactions, which include dissolution of organic soil litter, sorption of organic-metal complexes, and oxidation of organic compounds, can decrease the dissolved oxygen content of water. The unsaturated zone is biologically active, and most of these reactions are microbially mediated (Chapelle, 1993). The dissolution of organic soil litter is the major source of dissolved organic carbon (DOC) in shallow ground water (Domenico and Schwartz, 1990). DOC is important in the movement of metals and soil formation and as disinfection by-product precusors. DOC is sorbed onto soil particles, and its concentration typically decreases with depth in the unsaturated zone (Domenico and Schwartz, 1990).

The degree of chemical interactions with sand and gravel deposits is related to the thickness of the unsaturated zone. If the thickness of sand and gravel is reduced through mining, contact time between the water and the deposits is reduced, providing less opportunity for chemical transformations to take place. For example, Robertson and Cherry (1992) found that in a 13-ft thick unsaturated zone, water had a residence time of 7 days during which 75 percent of the DOC was removed from the water. (The residence time in that study was affected by the large amount of sewage applied through a septic system.) In another study, Johnston and others (1998) found that in an 82-ft thick unsaturated zone, water had a residence time of 10 to 15 years. The long travel time in the thicker deposit allowed for depletion of dissolved oxygen and changes in chemical transformation processes.

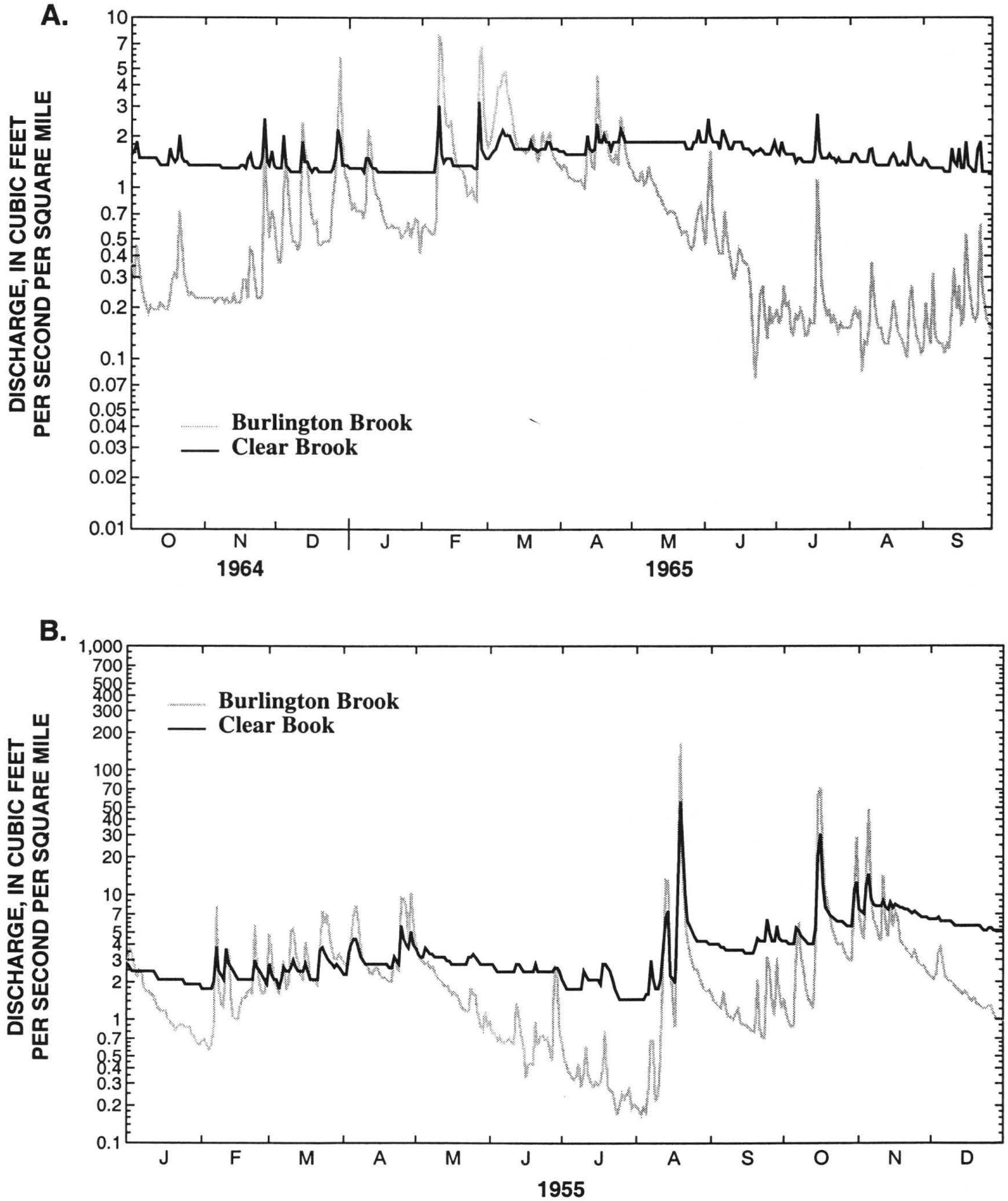


Figure 13. Mean daily streamflow in Burlington and Clear Brooks during
A. The 1965 drought, and
B. The 1955 flood.

SUMMARY AND CONCLUSIONS

Areas adjacent to the Nepaug Reservoir have thick and extensive deposits of sand and gravel. Information on the hydrogeology of the sand and gravel deposits was compiled to provide a basis for ongoing studies that will evaluate water-quality conditions in the watershed and the potential effects of sand and gravel mining on the water quality of the reservoir.

Sand and gravel deposits consist of several ice-marginal deltaic morphosequences. The deposits were formed at the margin of retreating glacial ice where meltwater deposited sand and gravel in a series of small glacial lakes. Particle sizes range from coarse gravel and sand in the northern and eastern parts of the deltaic deposits to fine sand, silt, and clay in the southern and western parts. The sand and gravel deposits range from more than 250 ft thick in the North Area and 150 ft thick in the South Area to less than 10 ft thick in both areas. Estimated volumes of sand and gravel are 275.5 million cubic ft in three deposits in the South Area and 678.6 million cubic ft in part of the North Area. Ground water flows from upland areas underlain by till and bedrock through sand and gravel deposits and discharges to Clear Brook, Phelps Brooks, the Nepaug River, the Collinsville Reservoir, or directly to Nepaug Reservoir.

The sand and gravel deposits adjacent to the Nepaug Reservoir can affect the physical and chemical responses of the watershed. The volume of sand and gravel in the watershed affects ground-water storage and the way water is released from storage. Removal of thick unsaturated deposits would probably result in increased streamflow peaks associated with storms and decreased streamflow during low-flow periods. Increases in peak stormflow can cause more sediment and potential sediment-associated nutrients to be transported into the reservoir. The thickness of the unsaturated sand and gravel deposits also can affect chemical transformations and cause changes in the amount of dissolved constituents in the water.

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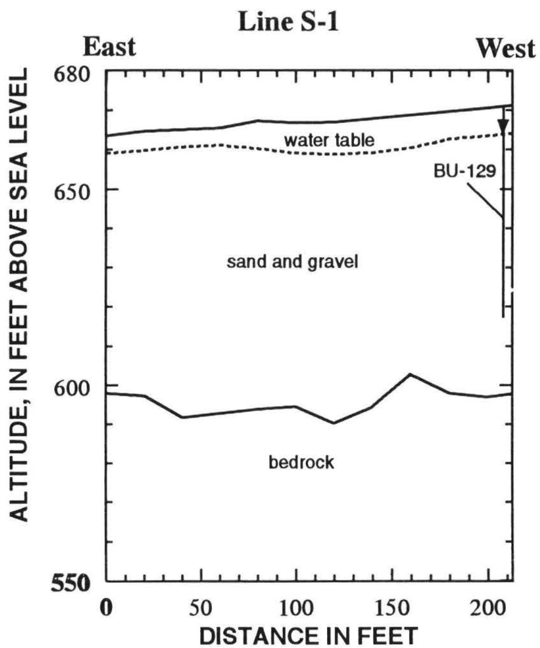
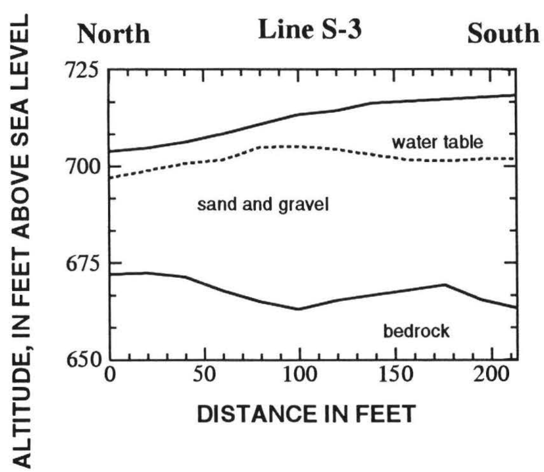
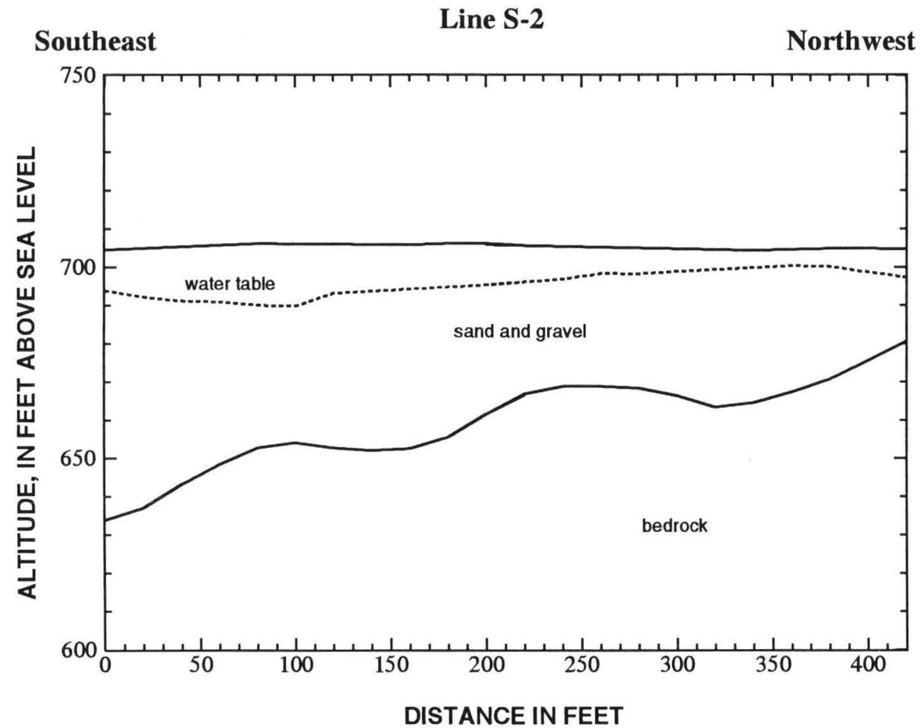
APPENDIXES

Appendix 1. Interpreted seismic-refraction profiles, Nepaug Reservoir watershed, northwestern Connecticut

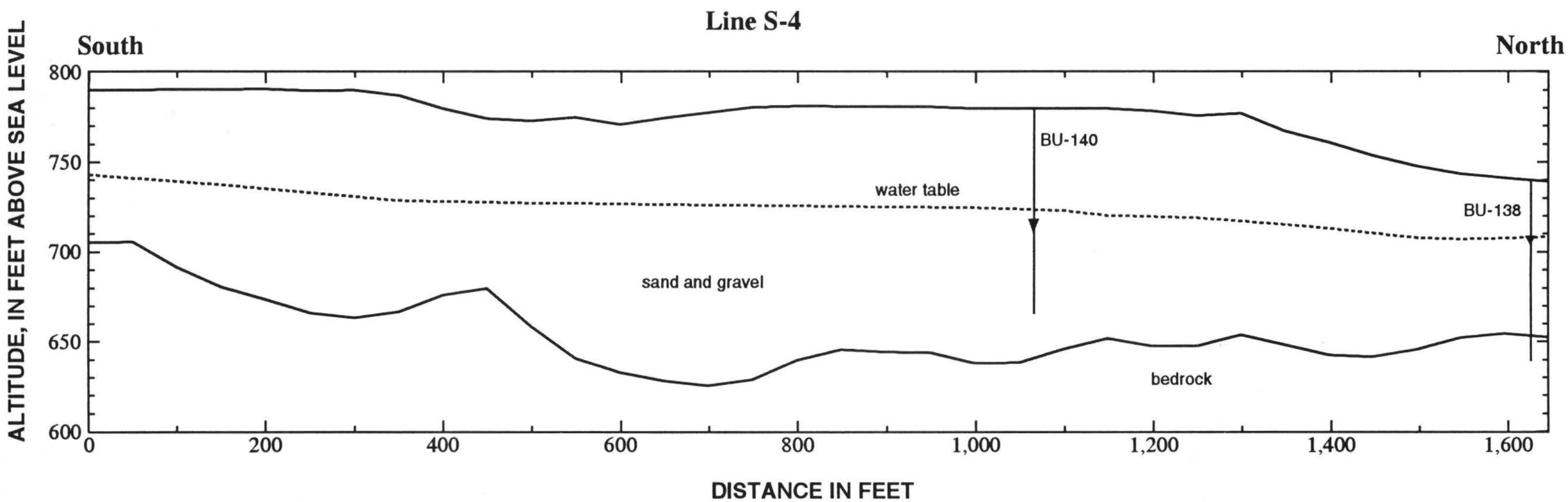






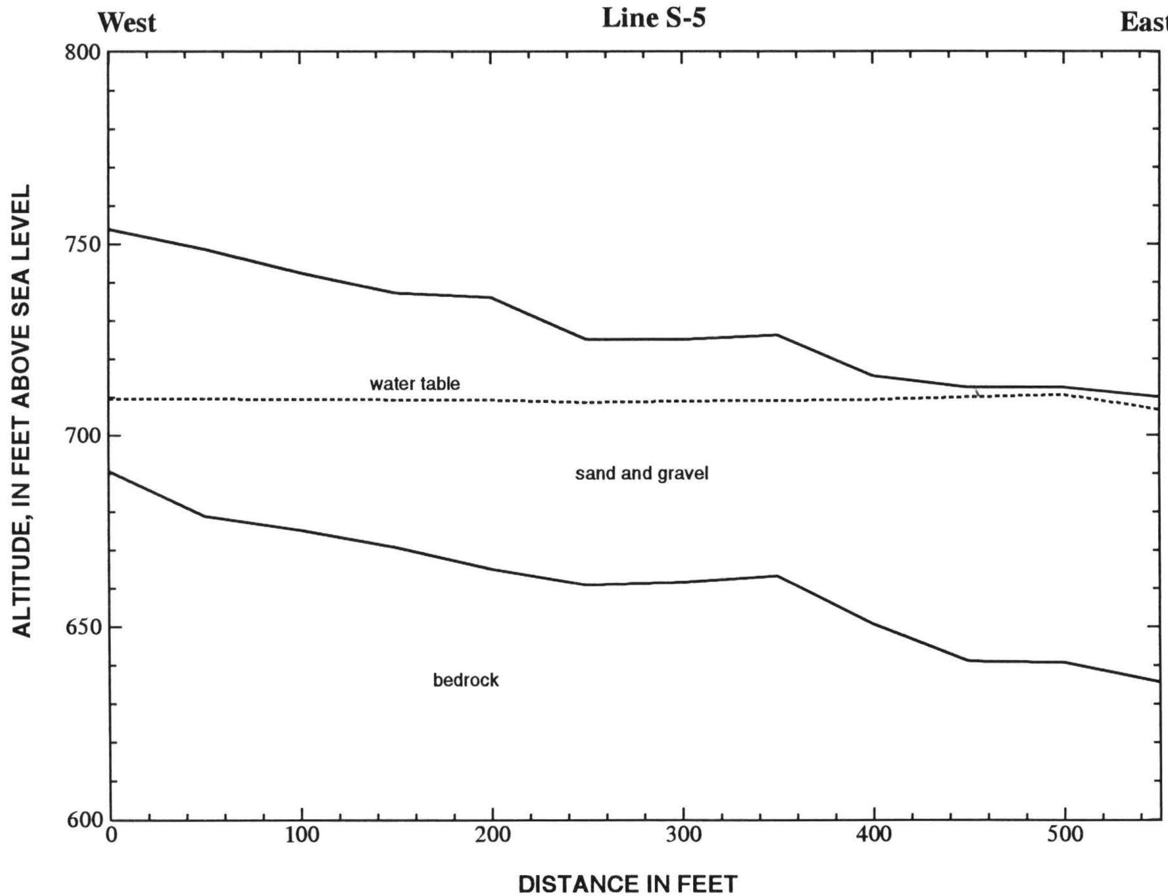
Well with number and water level

Seismic lines shown on figure 6.

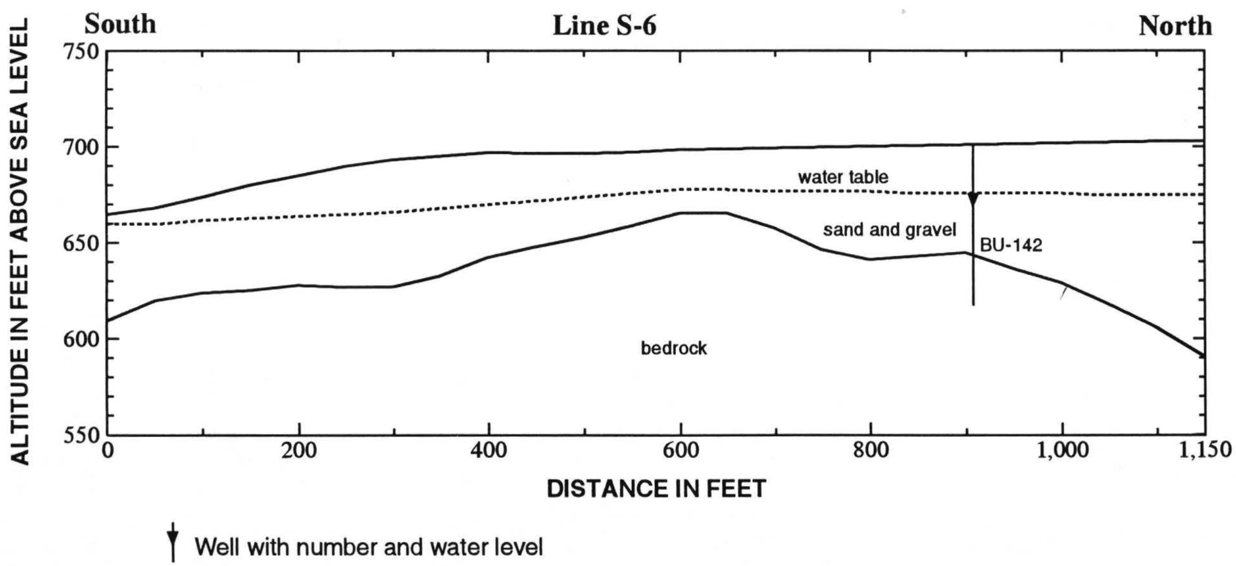


Well with number and water level

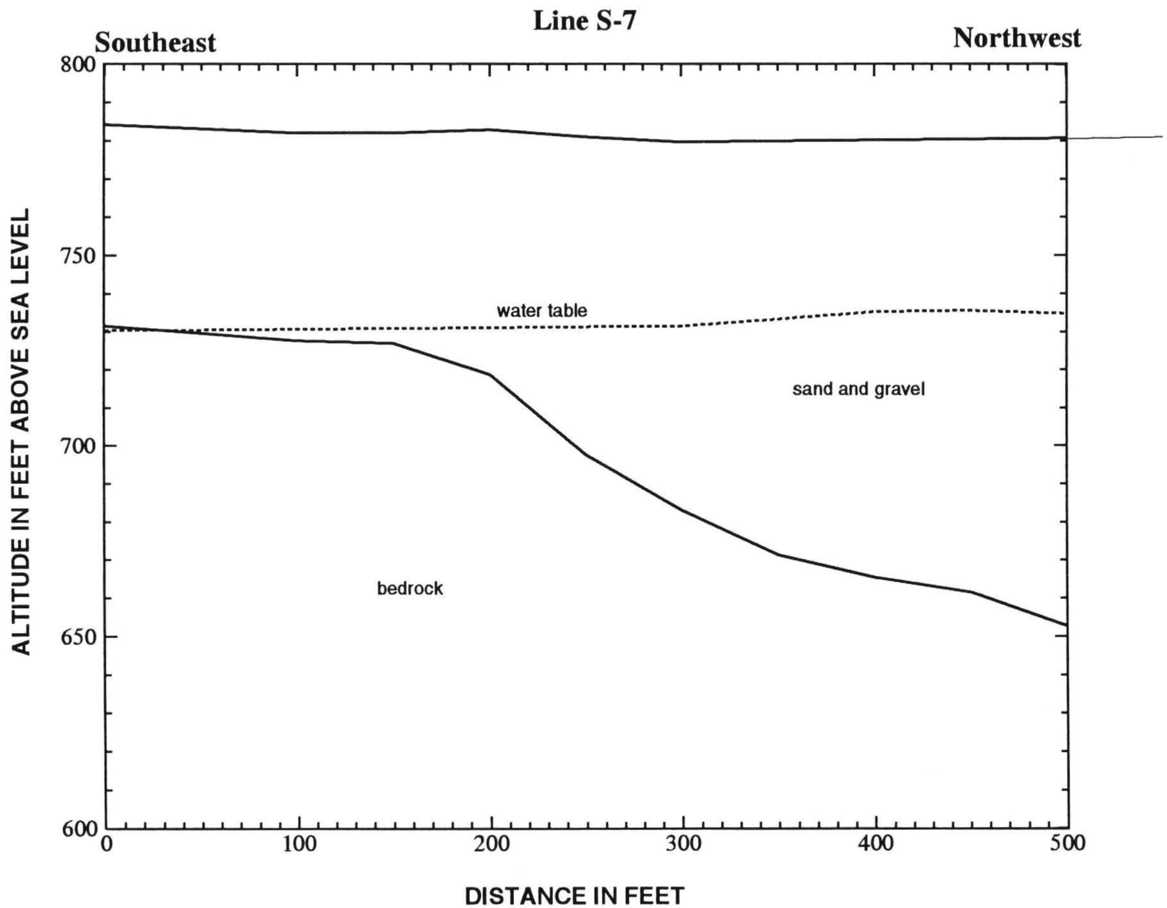
Seismic line shown on figure 6.



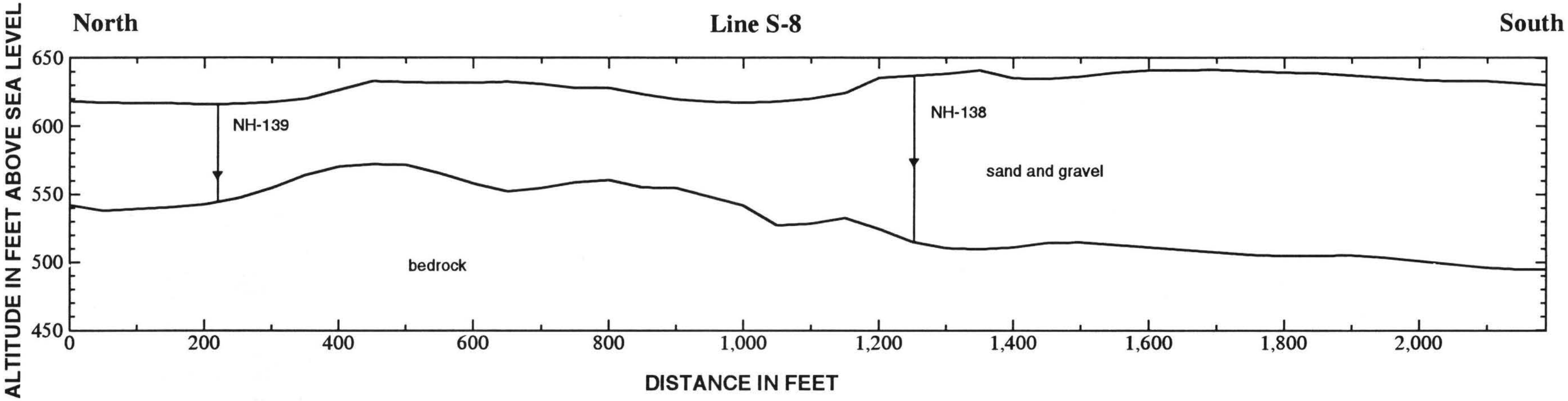
Seismic line shown on figure 6.

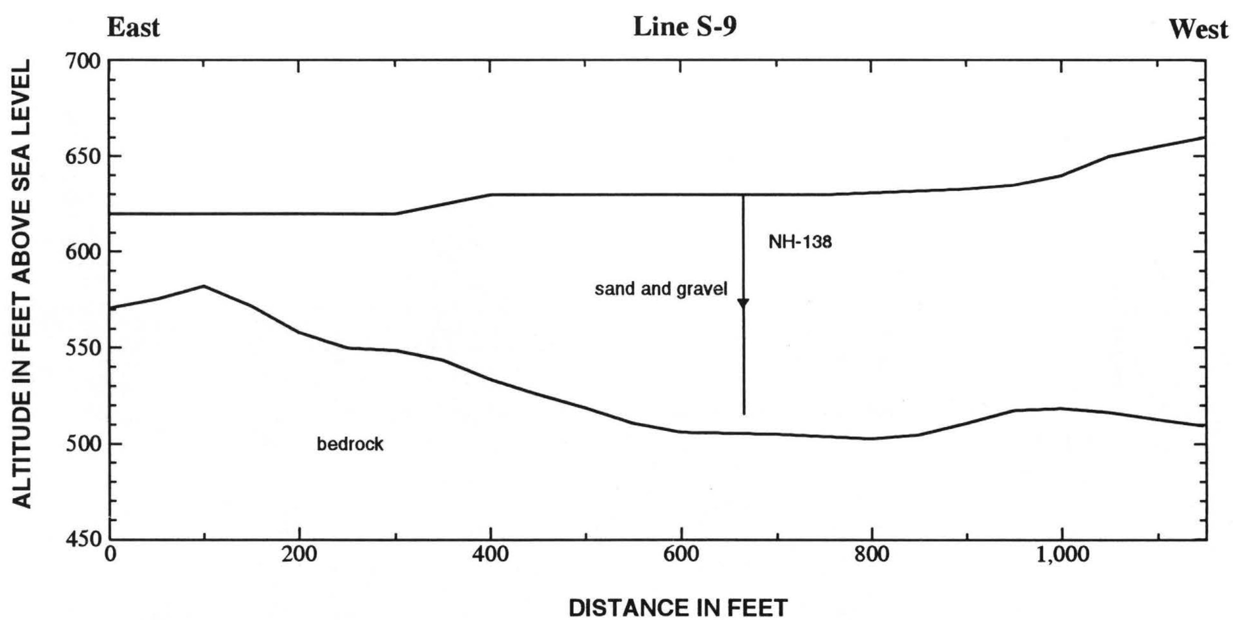


Seismic line shown on figure 6.



Seismic line shown on figure 6.





Seismic lines shown on figure 10.

Appendix 2. Selected data on wells and test borings in the South and North Areas, Nepaug Reservoir watershed, northwestern Connecticut

[Water levels measured on September 18, 1998; --, data not applicable; <, less than. Location of wells shown on fig. 3]

Local U.S. Geological Survey well number	Date drilled	Depth drilled (in feet)	Altitude of land surface (in feet)	Altitude of water table (in feet)	Altitude of top of screen (in feet)	Altitude of bottom of screen (in feet)	Altitude of bedrock (in feet)
			South area				
BU-127	6-9-98	49	683.1	663.8	639.1	634.1	634
BU-128	6-9-98	25	683.1	663.2	668.1	658.1	--
BU-129	6-9-98	51	669.7	664.7	634.7	629.7	619
BU-130	6-9-98	13	669.7	664.6	666.7	656.7	--
BU-131	6-15-98	63	716.7	671.07	659.7	654.7	654
BU-132	6-16-98	53	716.7	671.1	676.7	666.7	--
BU-133	6-11-98	20	714.6	706.4	699.6	694.6	--
BU-134	06-11-98	26	714.6	706.4	703.6	688.6	689
BU-135	09-01-98	60	785	725	738	728	<725
BU-136	6-10-98	33	726.4	707.8	701.4	696.4	693
BU-137	6-10-98	25	726.4	707.8	668.9	658.9	--
BU-138	6-11-98	101	740.9	707.8	683.4	678.4	640
BU-139	6-11-98	45	740.9	707.8	705.9	695.9	--
BU-140	6-16-98	120	786.0	710.8	671.0	666.0	<665
BU-141	6-17-98	80	786.0	711.6	716.0	706.0	--
BU-142	8-31-98	61	700.7	676.4	653.7	648.7	640
BUth-4	6-10-98	71	780	<720	--	--	<720
BUth-5	6-17-98	80	785	<705	--	--	<705
			North area				
NH-135	6-18-98	125	670	564.0	550	545	<545
NH-136	6-19-98	80	518.0	478.6	443.0	438.0	437
NH-137	6-18-98	47	532.4	527.8	512.4	507.4	485
NH-138	9-2-98	121	637.3	569.4	542.3	537.3	516
NH-139	9-2-98	77	621.2	562.5	552.2	546.2	544
NHth-13	9-1-98	60	630	<570	--	--	<570

Appendix 3. Geologic logs of deep wells and test borings, Nepaug Reservoir watershed, northwestern Connecticut

[Paired shallow wells not logged]

Well or test hole identifier	Description of material	Depth interval (feet below land surface)
	WELLS	
BU 127	Sand, brown, medium to fine, some granules	0-20
	Sand, brown, coarse to medium	20-30
	Sand, brown, medium, silty, micaceous, some stones,	30-40
	Sand and gravel	40-50
	Till, refusal at 51 feet	50-51
BU - 129	Sand and gravel	0-40
	Till, refusal at 50 feet	40-50
BU - 131	Sand, medium to fine	0-10
	Sand, coarse to medium, some granules	10-20
	Sand, medium to fine, some granules	20-30
	Sand, coarse, some granules	30-45
	Sand, medium, silty, some granules	45-60
	Till, refusal at 63 feet	60-63
BU - 134	Sand and gravel	0-15
	Till	15-26
	Bedrock	26
BU - 135	Gravel	0-40
	Sand and gravel	40-60
BU - 136	Sand and gravel, gray, interbedded	0-10
	Sand, gray, medium, layers of coarse and fine	10-20
	Sand and gravel, brown	20-30
	Till, refusal at 33 feet	31-33
BU - 138	Sand, brown, medium, some granules	0-20
	Sand, brown, coarse to medium, micaceous, some granules	20-40
	Sand, coarse to medium, layers of fine to very fine	40-70
	Till, gray, sandy	70-101
	Bedrock	101
BU - 140	Sand, brown, medium to very fine,	0-20
	Sand, gray, fine to very fine, micaceous, bedded	20-70
	Sand, brown, coarse to medium, micaceous, bedded	70-90
	Sand and gravel	90-110
	Till	110-120
BU - 142	Sand, brown, medium to fine, some granules	0-10
	Sand and gravel	10-30
	Sand, fine, some granules	30-40
	Till, refusal at 61 feet	40-61

Well or test hole identifier	Description of material	Depth interval (feet below land surface)
NH - 135	Sand, medium to fine, micaceous	0-10
	Sand, fine to very fine, micaceous	10-80
	Sand, medium, some granules	80-125
NH - 136	Sand, fine to very fine,	0-20
	Sand, medium to fine	20-40
	Sand, fine to very fine	40-80
	Bedrock	80
NH - 137	Sand, medium to fine, some granules	0-40
	Sand and gravel, refusal at 47 feet	40-47
NH - 138	Sand, fine, some granules	0-60
	Sand, coarse to medium, some granules	60-80
	Sand, medium to fine	80-100
	Till	100-120
	Bedrock	120
NH - 139	Sand and gravel	0-70
	Till	70-77
	Bedrock	77
	TEST BORINGS	
BUth-4	Sand, medium, some granules	0-20
	Sand and gravel	20-50
	Till	50-71
	Bedrock	71
BUth-5	Sand and gravel	0-80
NHth-13	Sand and gravel	0-60