

# **Hydrogeology And Ground-Water Flow At The Muddy Brook Riparian Zone, North-Central Connecticut**

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***By J.R. Mullaney***

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## CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi <sup>2</sup> )	2.590	square kilometer
cubic foot (ft <sup>3</sup> )	0.02832	cubic meter
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft <sup>2</sup> /d)	0.09290	meter squared 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 both the United States and Canada, formerly called Sea Level Datum of 1929.

# **HYDROGEOLOGY AND GROUND-WATER FLOW AT THE MUDDY BROOK RIPARIAN ZONE, NORTH-CENTRAL CONNECTICUT**

by John R. Mullaney

## **ABSTRACT**

The hydrogeology and ground-water flow of the Muddy Brook riparian zone were investigated as part of a study to determine the effects of restoring agricultural riparian land to forest on water quality. Test-hole drilling, well installation, and slug-test analyses indicated that the part of Muddy Brook studied is underlain by thin stratified-drift deposits. These deposits are mostly less than 10 feet thick and have estimated horizontal hydraulic conductivities of 4 to 30 feet per day. Till deposits from 1 to 14 feet thick underlie the stratified-drift deposits and have estimated horizontal hydraulic conductivities of 0.1 to 4.3 feet per day. The water table in stratified drift is less than 10 feet below land surface during most of the year, and the horizontal hydraulic gradient varies seasonally and areally from 0.015 to 0.07 foot per foot. The horizontal hydraulic gradient in the till deposits is as great as 0.1 foot per foot. Vertical hydraulic gradients of as large as 0.4 foot per foot are present between the till and stratified drift and are predominantly upward from the till into the stratified drift but can reverse direction in response to recharge. Ground-water discharge to Muddy Brook comes mostly from the saturated stratified-drift deposits, and during April through September 1992, flowed at a rate of 0.015 to 0.027 cubic feet per second. Average ground-water velocity is about 1 feet per day in the stratified drift and about 0.2 foot per day through the till deposits. Discharge of ground water from the till can contribute as much as 0.006 cubic feet per second of water to the stratified drift.

## **INTRODUCTION**

Nonpoint-source contamination of surface water and ground water has become a major water-quality issue in Connecticut. Nutrient loading is believed to be the cause of hypoxic conditions, which occur seasonally in some sections of Long Island Sound. It was estimated that 4,900 tons per year, or 24 percent, of the nitrogen input from rivers to Long Island Sound can be attributed to anthropogenic nonpoint sources (Long Island Sound Study, 1990). Recent studies have shown that high concentrations of nitrogen, in the form of nitrate, are present in the ground water beneath agricultural areas (Mullaney and others, 1991; Grady, 1994). The maintenance and restoration of forested riparian zones to filter or remove nutrients from surface runoff and ground water have been proposed by the Connecticut Department of Environmental Protection (DEP) as a method of decreasing nonpoint-source contamination (Connecticut Department of Environmental Protection, 1989).

A study of the effects of restoring agricultural riparian land to a native forest on water quality was initiated in 1992 by the University of Connecticut, College of Agriculture and Natural Resources. The study objectives were to (1) evaluate the effect of establishing a forested riparian zone on existing cropland on surface and ground-water quality and (2) demonstrate, in cooperation with Federal and State regulatory agencies, the effectiveness of restoring a forested riparian zone, thus showing it to be a Best Management Practice

(BMP). The need to characterize the hydrogeology and the ground-water-flow system in the study area was identified by University of Connecticut researchers and the DEP. Consequently, the U.S. Geological Survey (USGS) entered into a cooperative agreement with the DEP to investigate the hydrogeology of the study site and to determine a simple method to estimate ground-water flow. As a result of this study, more information is now available on the hydraulic properties of stratified-drift and till deposits in central Connecticut, and there is an increased understanding of ground-water flow in riparian areas.

## **Purpose and Scope**

This report describes the hydrogeology and ground-water flow in a riparian zone located in the Muddy Brook valley, an upland glaciated valley in north-central Connecticut. The report includes information on the hydraulic conductivity and texture of the stratified drift and till derived from Mesozoic rocks of the Connecticut Valley Lowland.

## **Location and Description of the Study Area**

The study area is an 800-ft long by 300-ft wide section of corn fields on both sides of Muddy Brook, a tributary of Broad Brook, in the north-central part of the town of Ellington, Connecticut (fig. 1). The drainage area of Muddy Brook at the downstream end of the study area is 0.80 mi<sup>2</sup>; the altitude of the study area ranges from 220 to 240 ft above sea level. Corn is grown on approximately 160 acres (about 30 percent) of the land drained by the brook at the study area. The remainder of the land in the drainage area is forested or contains low-density residential housing. Median annual precipitation during 1951-80 in nearby Rockville was 42.75 in/yr (Hunter and Meade, 1983).

Researchers from the University of Connecticut have divided the study area into two halves. A 100-ft wide section on either side of Muddy Brook has been designated as the riparian zone. In the southern half of the riparian zone, land use will remain the same (corn production). In the northern half of the riparian zone, corn production will continue for 1 year. After this calibration period, corn will be replaced with native plants and grasses.

## **Acknowledgments**

We would like to thank personnel from the University of Connecticut, College of Agriculture and Natural Resources, Department of Natural Resources Management and Engineering. In particular, we would like to thank the graduate assistants who collected all water-level data used in this report.

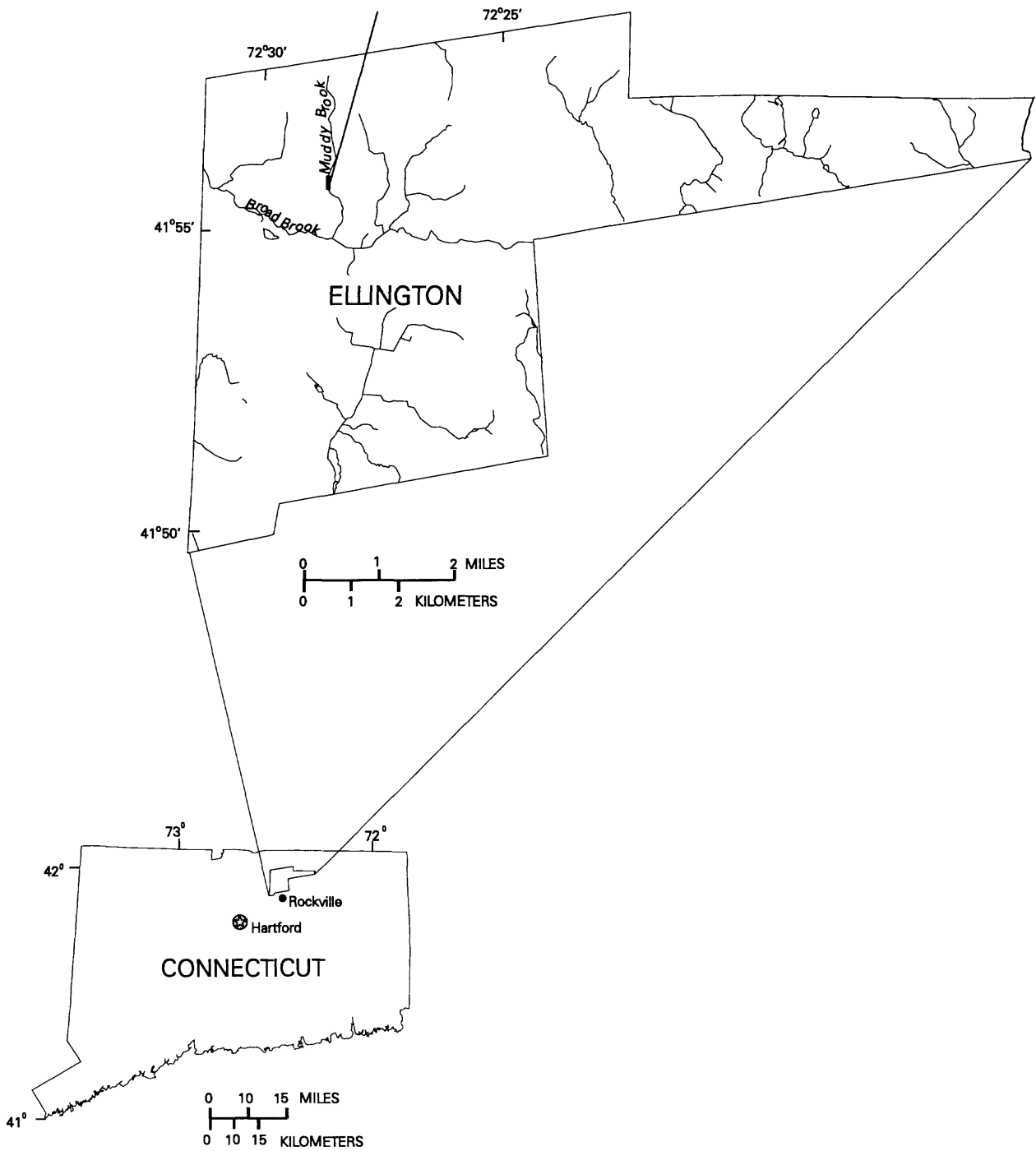
## **DATA COLLECTION AND ANALYSIS**

The objective of the study was to determine the head distribution at the site, the hydraulic conductivity, and the seasonal changes in magnitude and direction of the water-table gradient. This was done by installing wells and taking water-level measurements, collecting core samples for grain-size analysis, and conducting slug tests. Estimates of ground-water flow were made by constructing flownets for different times of the year and using Darcy's law to calculate ground-water flow from flownet geometry.

## **Well Installation**

In the first phase of the study, a grid of wells in six transects was set up so that the water table could be accurately mapped. A hollow-stem-auger drill rig was used to drill a 6-in. hole to bedrock at each of the grid locations. At most sites, the first layer penetrated was loose sand and gravel that was easily drilled; this was followed by a layer of compact till and then refusal or bedrock. A 2-in.

# Muddy Brook study site



**Figure 1.** Location of the Muddy Brook Study site, Ellington, Connecticut

polyvinyl chloride (PVC) piezometer with a 1-ft-long screen (with 0.008-in.-wide slots) was installed at each site in the till on the top of the bedrock surface. The annulus around the screen was packed with coarse sand, and a bentonite seal was placed to ensure accurate head measurements and to prevent surface runoff from leaking down the side of the well casing. These piezometers were used to determine vertical gradients between the till and the overlying stratified drift. Information on geologic materials and water-table depths collected during drilling was used to install a second well at each site to measure the depth to the water table accurately. In some places on the edge of the study area, only water-table wells were installed. These wells were designed so that the zone of water-level fluctuation would fall within a 5-ft-long screened section. A sand pack was placed in the annulus around the screen to improve well yield when sampling and to ensure quick response to water-level changes. A thin layer of glacial till from the drill cuttings and 1 ft of bentonite were used as seals to prevent surface runoff from entering the well. A 2-ft-long removable section of 2-in.-diameter galvanized pipe, with a locking cap, was placed at the surface for protection. These protective covers were designed to be removed periodically so that the corn could be planted and harvested. A total of 51 wells and piezometers were installed at 30 locations.

## Core Sampling

Continuous cores were collected with a 5-ft-long split-tube sampler at 16 of the well locations on both sides of Muddy Brook. Representative sections of stratified drift were selected and analyzed for grain-size distribution. Using an empirical relation between median-grain diameter and horizontal hydraulic conductivity of stratified drift, values of horizontal hydraulic conductivity for selected samples were estimated (Melvin and Bingham, 1991).

## Slug Tests

Slug tests were conducted at 17 wells to estimate the hydraulic conductivity of stratified drift and till deposits. A pressure transducer and data logger were used to measure head and record recovery time for tests that were performed mostly by adding a known volume of water. A curve-matching technique was used to analyze the data and to estimate hydraulic conductivity (Cooper and others, 1967). Because the saturated thickness of the stratified drift at the study area was limited, many wells could not be slug tested if the water level was below the top of the slotted section. If water were added to these wells, it would leak out through the part of the screen that was located next to unsaturated materials.

## Estimation of Ground-Water Flow

Estimates of ground-water flow across the riparian zone and to Muddy Brook were calculated by use of Darcy's law:

$$Q = -KA \frac{dh}{dl}, \quad (1)$$

where *Q* is the ground-water discharge,  
*K* is the hydraulic conductivity,  
*A* is the cross-sectional area or the saturated thickness multiplied by the width, and  
*dh/dl* is the hydraulic gradient  
 (Freeze and Cherry, 1979, p. 16).

The negative sign indicates that the ground-water flow is in the direction of decreasing head. Areal flownets were constructed, and flow lines were drawn at 50-ft widths. Ground-water altitudes were contoured at 1-ft intervals. The horizontal hydraulic gradient was measured over a 100-ft section near the downgradient end of each 50-ft width. Cross-sectional areas were determined by multiplying the saturated thickness, at the downgradient end of each section, by the 50-ft width. All flow was assumed to be horizontal



through an isotropic medium of uniform thickness within each streamtube. Of the measured hydraulic properties, values of hydraulic conductivity have the most uncertainty. These values were estimated by analysis of slug test data and grain-size distribution, as discussed earlier. The method for calculating ground-water discharge is shown in figure 2.

### Estimation of Ground-Water Velocity

An estimate of ground-water velocity can be useful in computing time of travel for selected water-quality constituents. At the Muddy Brook study area, this may be useful for determining the amount of time required to detect a particular constituent or may be used to give an estimate of the age of ground water.

The average linear velocity of ground water in the Muddy Brook aquifer system can be estimated using the following equation from Todd (1980, p. 74):

$$V = \frac{K dh}{\alpha dl}, \quad (2)$$

where  $V$  is the average linear velocity, in feet per day;

$K$  is the horizontal hydraulic conductivity, in feet per day;

$\alpha$  is the porosity; and

$dh/dl$  is the horizontal hydraulic gradient in feet per foot.

### HYDROGEOLOGY OF THE MUDDY BROOK AREA

The Muddy Brook basin is located on the eastern side of the Connecticut Valley Lowland. The basin is underlain by sedimentary rocks, primarily red arkose and siltstone of Jurassic age. Unconsolidated materials in the basin and surrounding areas include glacial till and stratified drift. The glacial till in the area is reddish brown, poorly sorted, compact, and contains variable proportions of gravel, sand, silt, and clay. Till was deposited directly

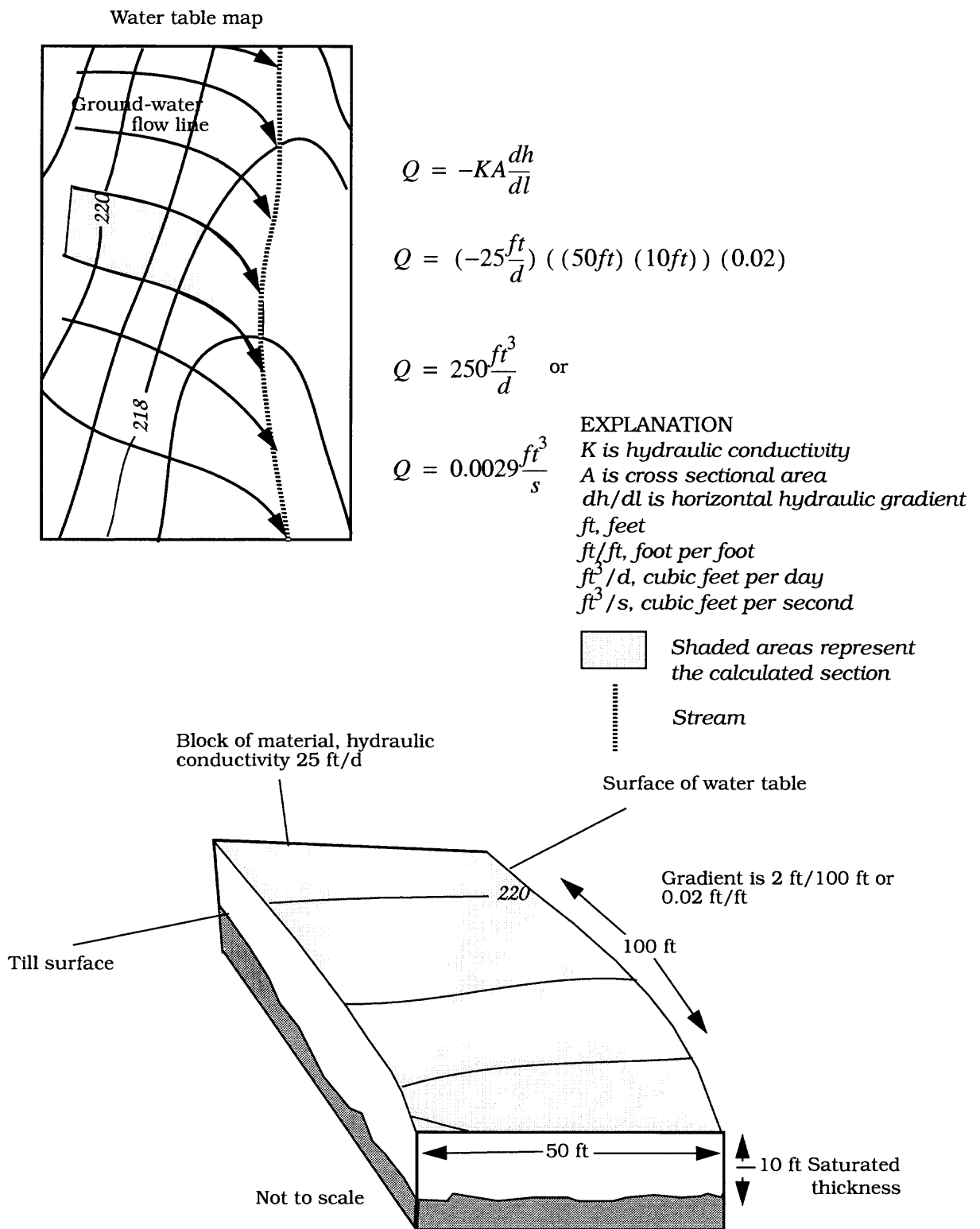
beneath glacial ice during the Pleistocene Epoch. Well logs indicate that till deposits are as much as 45 ft thick in areas east of Muddy Brook (Colton, 1972). The stratified-drift deposits in the study area appear to be the remnants of an ice-marginal delta that extended southward into an ice-dammed glacial lake. Once the ice sheet retreated to the north, the ice that blocked the downstream end of Broad Brook valley melted, and the lake drained. Sediment-laden meltwater continued to flow down Muddy Brook valley, eroding the previously deposited deltaic sediments, leaving less than 20 ft of stratified drift. Sections of the delta immediately south of the study area have not been significantly eroded. A map of the generalized surficial geology of the study area is shown in figure 3.

### Distribution, Texture, Thickness, and Hydraulic Conductivity of Hydrologic Units

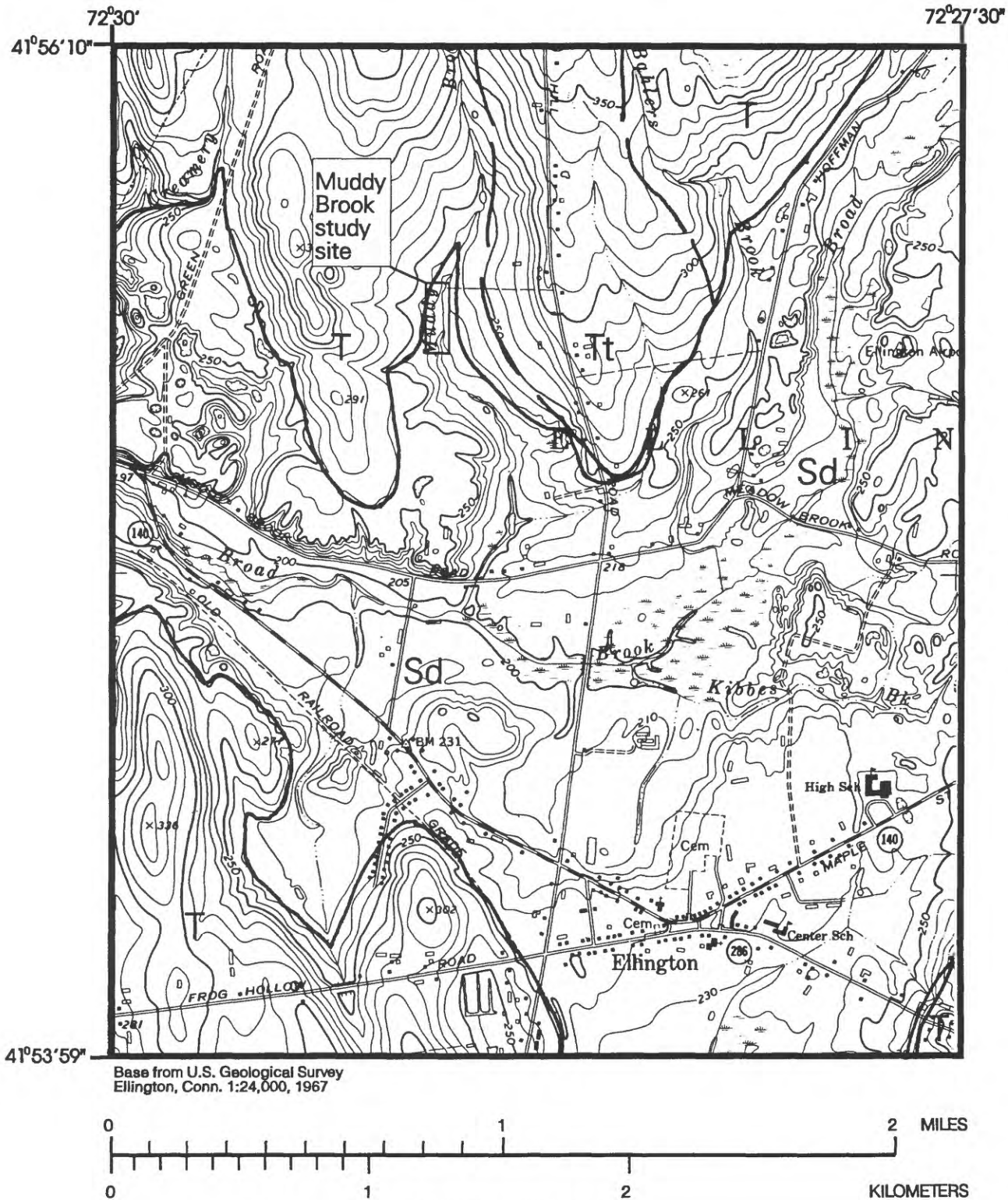
Stratified drift underlies most of the study area, with the exception of the northwestern corner, which is underlain by till. A thin layer of stratified drift overlies a thin layer of till throughout most of the study area. Bedrock underlies the till and is less than 25 ft below land surface at all locations where test-hole drilling was done.

#### Stratified drift

Thickness of stratified drift in the study area ranges from 0 to 18 ft, and the texture ranges from silty clay to very coarse sand with some gravel. The thickest deposits, located on the northeastern side of the study area, are composed of very coarse sand that overlies silty clay. West of Muddy Brook, the stratified-drift deposits consist of poorly sorted fine to medium sand with some gravel. Much of the eastern side of the Muddy Brook study area has deposits of coarse to very coarse sand overlying finer materials. The thickness and texture of the stratified-drift deposits are



**Figure 2.** Example calculation of ground-water discharge within a 50-foot section of aquifer, using Darcy's law.



**Figure 3.** Surficial geology of the Muddy Brook area.  
(Modified from Colton, 1972; Stone and others, 1985.)

EXPLANATION	
<span style="border: 1px solid black; padding: 2px;">Sd</span>	Stratified drift
<span style="border: 1px solid black; padding: 2px;">T</span>	Till
<span style="border: 1px solid black; padding: 2px;">Tt</span>	Thick till

illustrated in figures 4 and 5. The horizontal hydraulic conductivity of the stratified-drift deposits at the study area ranges from 4 ft/d for very fine and fine sand to 30 ft/d for coarse to very coarse sand. Values of hydraulic conductivity estimated from grain-size and slug-test analyses are presented in table 1.

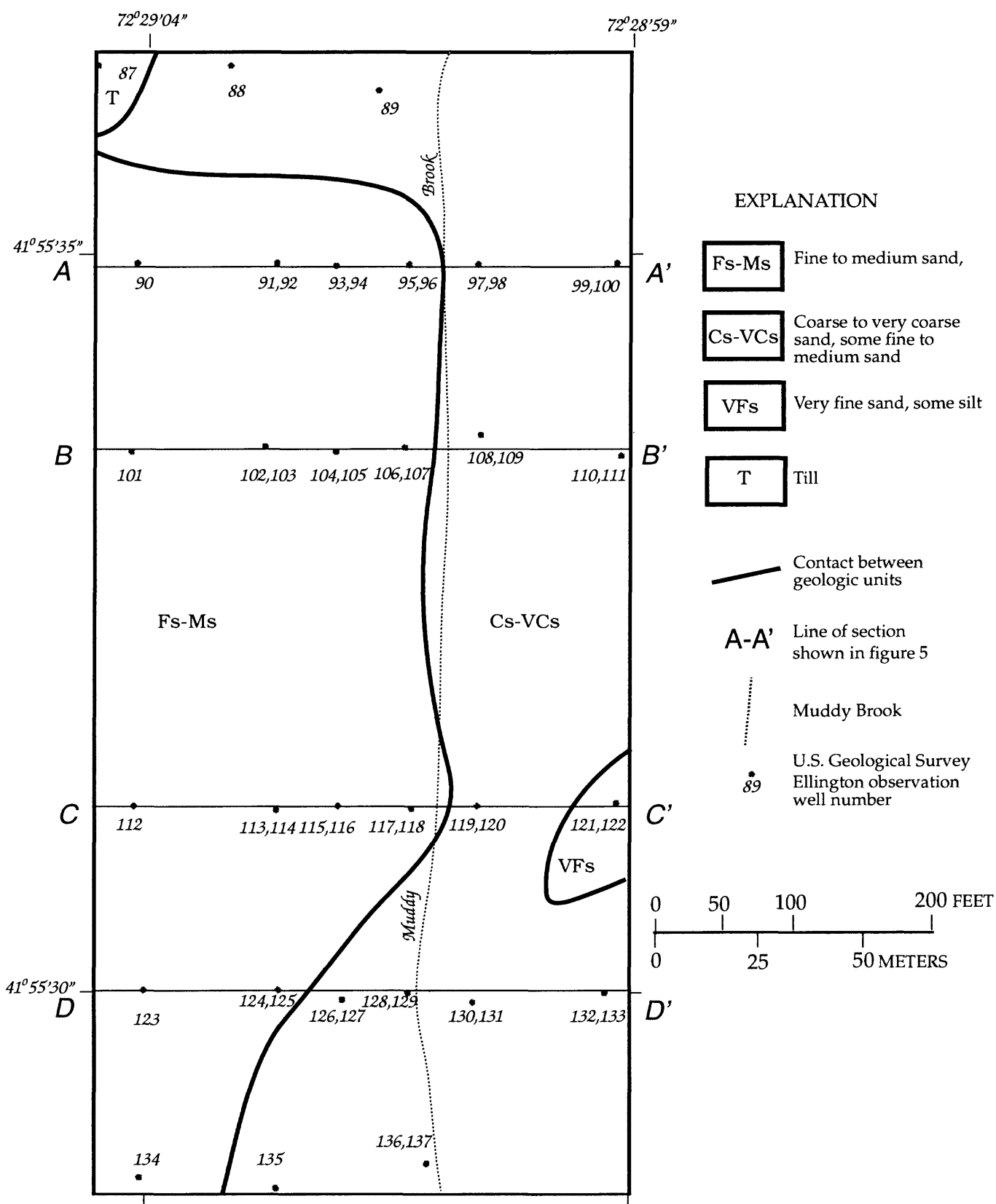
## Till

Till at the Muddy Brook study area is reddish-brown and ranges in texture from sandy at the till surface to silty or clayey near the interface between till and bedrock. The till deposits encountered during core sampling locally contained stratified sand and (or) gravel layers. The thickness of till ranges from 1 to 14 ft in test holes drilled at the study area. A con-

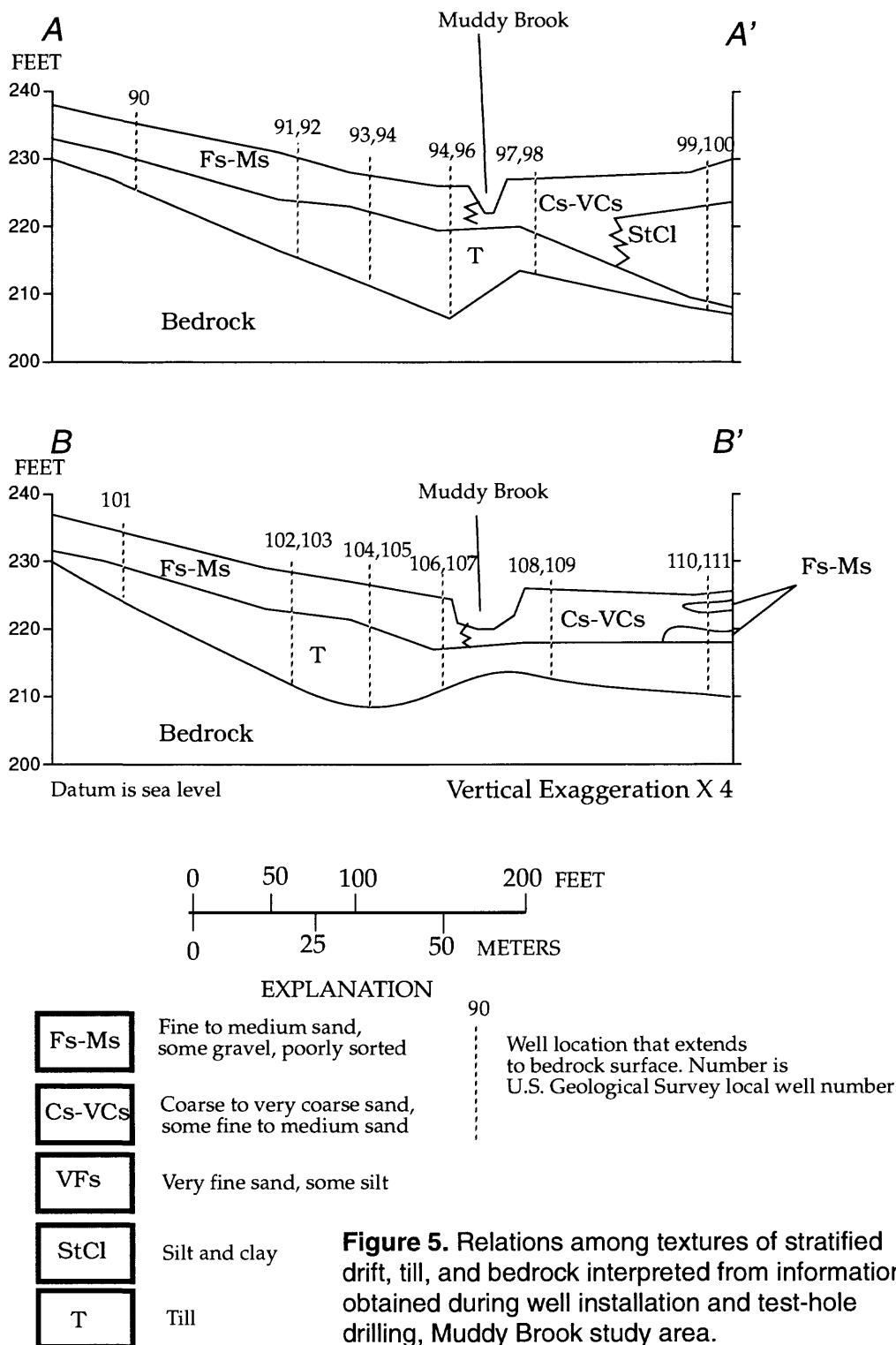
tour map of the till surface is shown in figure 6. Horizontal hydraulic conductivities of till at the Muddy Brook site, estimated from slug-test analyses, ranged from 0.1 to 4.3 ft/d. Some slug tests indicated horizontal hydraulic conductivities as large as 20 ft/d, but the wells tested may have been screened in weathered rock and not till. A value of 1 ft/d was used for all calculations in this report involving hydraulic conductivity of till deposits. The range of horizontal hydraulic conductivities for surface tills derived from sedimentary rocks of the Connecticut Valley Lowland is 0.01 to 3.4 ft/d (Melvin and others, 1992). Horizontal hydraulic conductivity values estimated from slug-test analyses are shown in table 1.

**Table 1.** Estimates of hydraulic conductivity from grain-size analyses and slug-test analyses

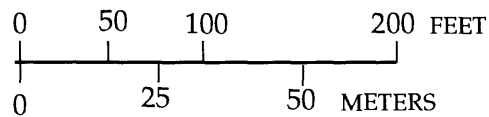
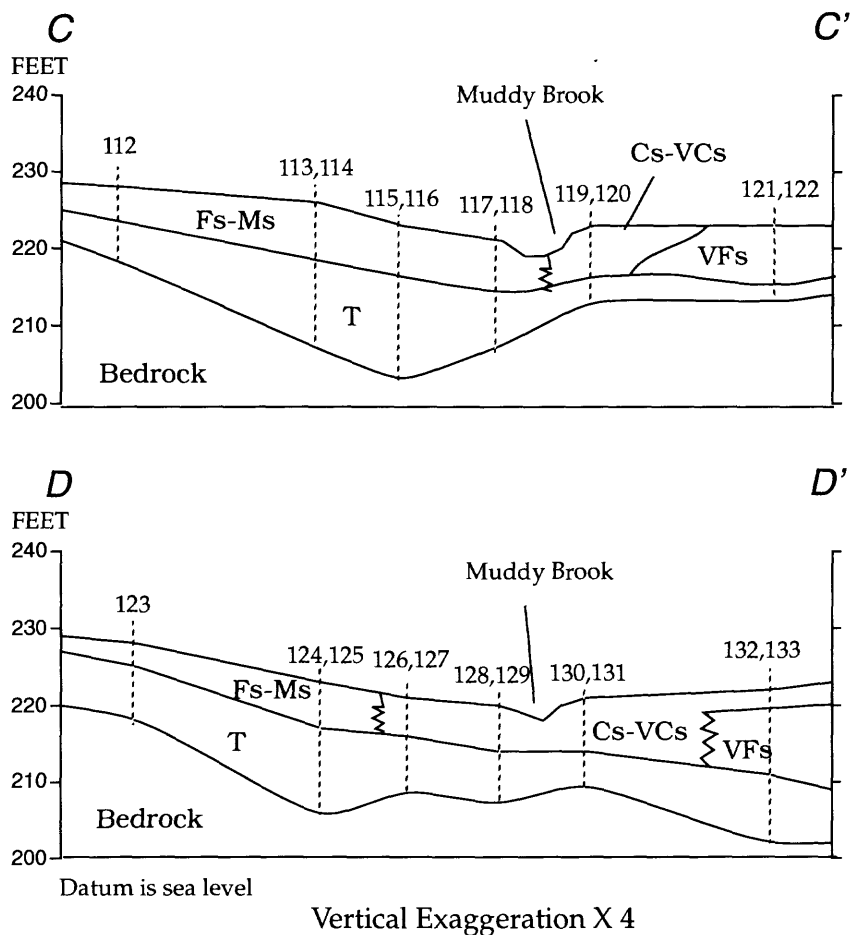
Well number	Material screened	Estimated hydraulic conductivity, in feet per day	Method of estimation
EL91	silty till	0.6	slug test
EL92	fine to medium sand	10	grain-size analysis
EL93	stony till	3	slug test
EL95	silty till	1.5	slug test
EL100	coarse sand	11	slug test
EL102	compact till	1.6	slug test
EL103	medium sand	20	grain-size analysis
EL104	till	1.9	slug test
EL107	fine sand	8	slug test
		15	grain-size analysis
EL109	very coarse sand, silty	9.4	slug test
EL111	coarse over medium sand	49	slug test
		30	grain-size analysis
EL112	till	3	slug test
EL114	fine sand	10	grain-size analysis
EL118	fine to medium sand	4.6	slug test
EL122	very fine sand	4	slug test
EL124	sandy till	4.3	slug test
EL125	fine to medium sand	17	slug test
EL131	fine to medium sand	31	slug test
		25	grain-size analysis
EL133	very fine to fine sand	6.5	slug test
		8	grain-size analysis
EL136	till	.13	slug test



**Figure 4.** Texture of surficial materials and locations of wells, Muddy Brook study area.

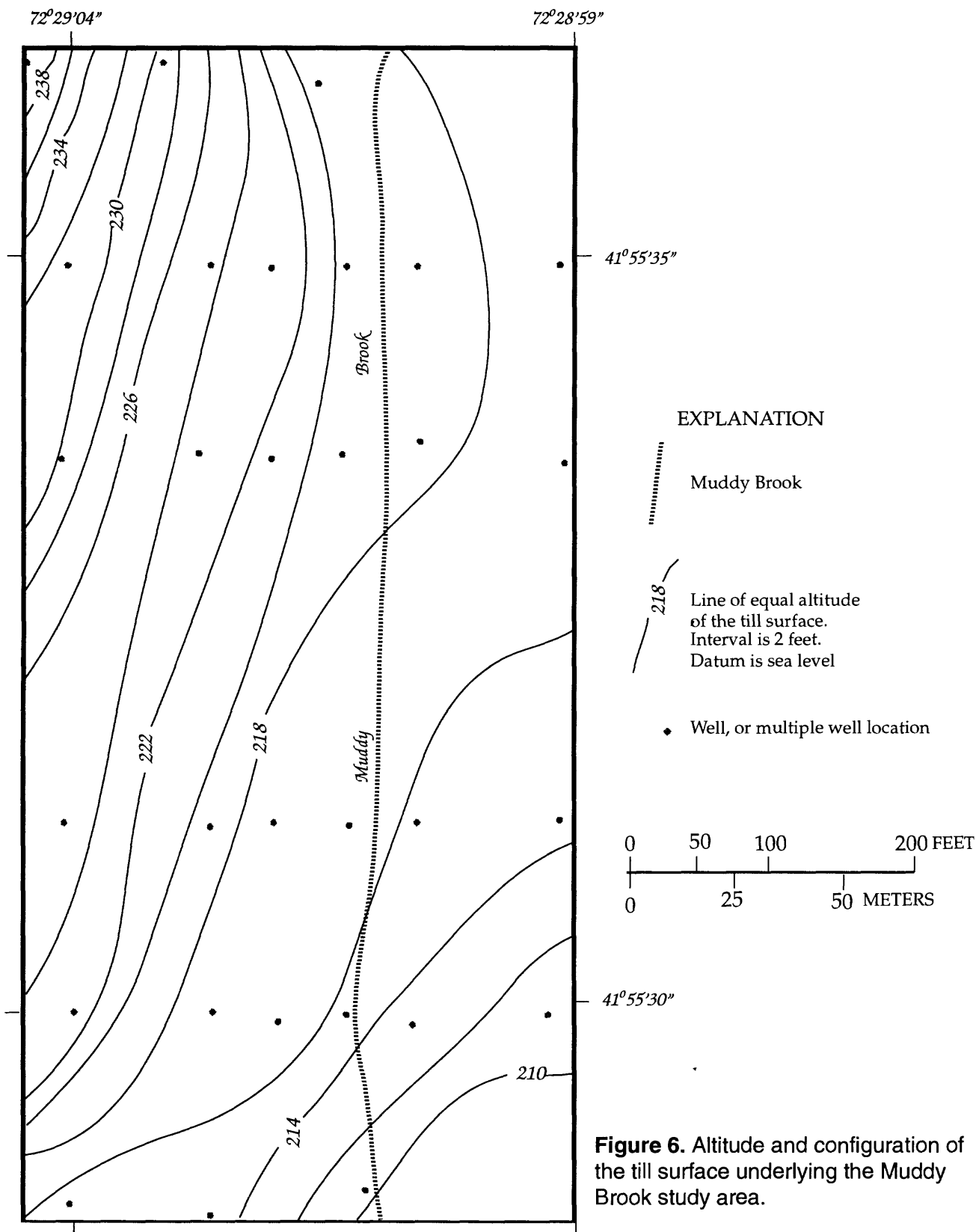


**Figure 5.** Relations among textures of stratified drift, till, and bedrock interpreted from information obtained during well installation and test-hole drilling, Muddy Brook study area.



EXPLANATION		
<b>Fs-Ms</b>	Fine to medium sand, some gravel, poorly sorted	<div>112</div> <div>Well location that extends to bedrock surface. Number is U.S. Geological Survey local well number</div>
<b>Cs-VCs</b>	Coarse to very coarse sand, some fine to medium sand	
<b>VF</b>	Very fine sand, some silt	
<b>StCl</b>	Silt and clay	
<b>T</b>	Till	

**Figure 5.** Relations among textures of stratified drift, till, and bedrock interpreted from information obtained during well installation and test-hole drilling, Muddy Brook study area--continued



**Figure 6.** Altitude and configuration of the till surface underlying the Muddy Brook study area.



## Bedrock

Depths obtained during drilling and coring were used to interpret the configuration of the underlying bedrock. Bedrock depth ranges from 7 ft below land surface on the western side of the study area to about 20 ft in the northeastern corner. A southwest to northeast-trending valley that is not coincident with the position of Muddy Brook appears to be present. Because no wells were drilled into the bedrock at the study area, there is no information on hydraulic head and hydraulic conductivity, or on whether water from the bedrock is recharging the stratified drift or till. A contour map of the bedrock surface at the study area is shown in figure 7. Four geologic cross sections interpreted from drilling and core sampling show the relations among stratified drift, till, and bedrock at the Muddy Brook site (fig. 5).

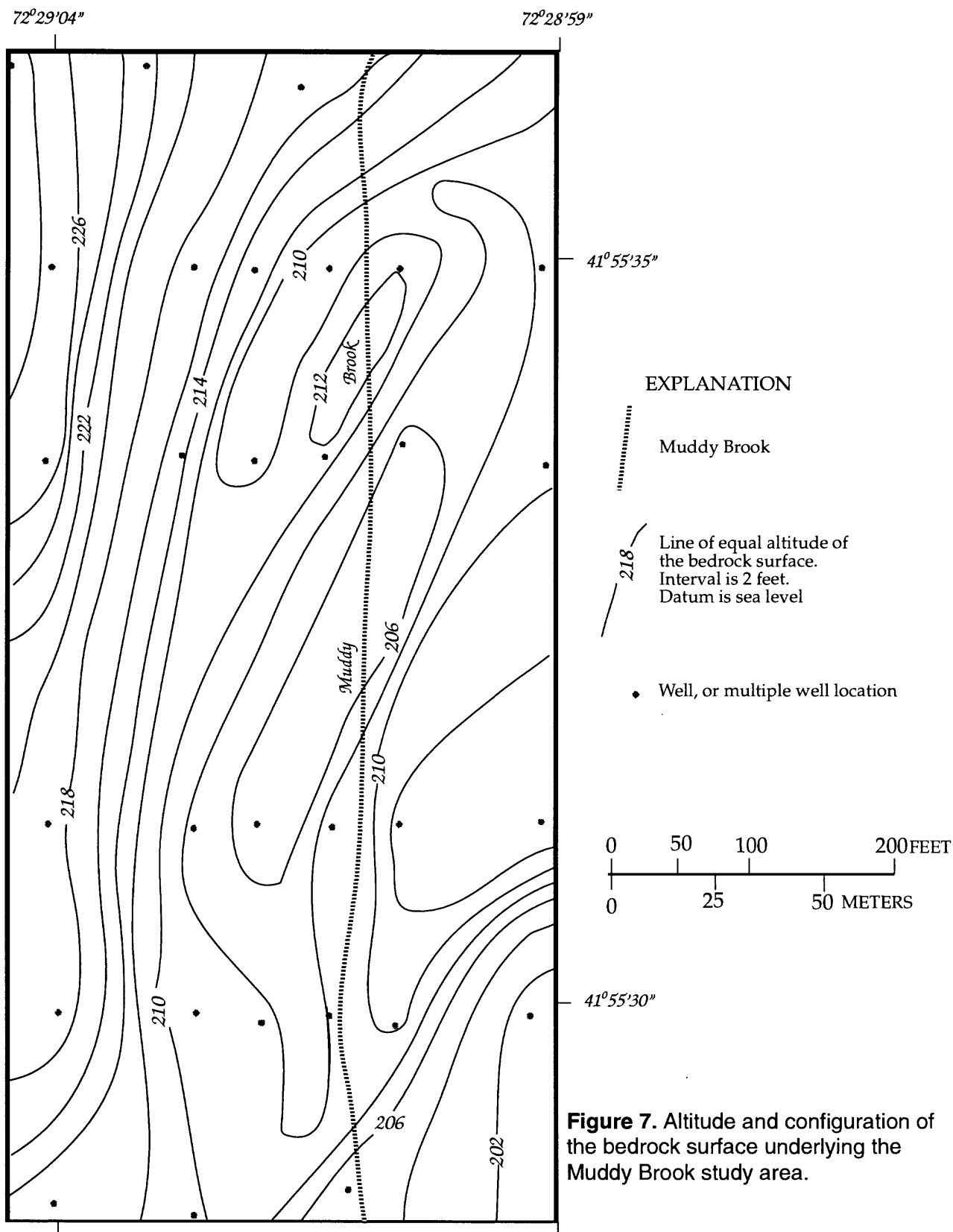
## Water-Table Configuration

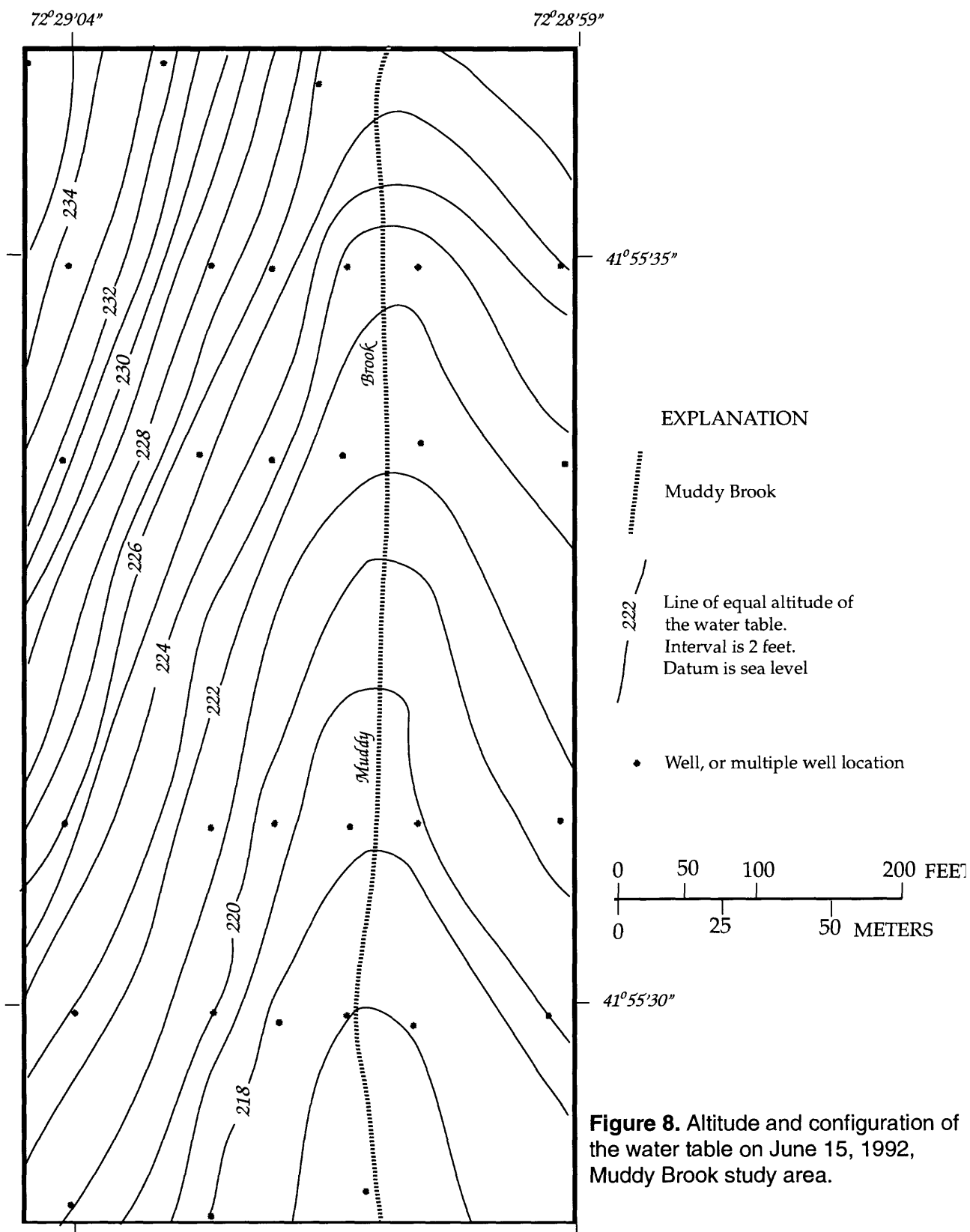
The water table at the Muddy Brook site is within 10 ft of land surface during most of the year. Variations in altitude of the water table across the study area range from 16 to 21 ft, depending on the season. The altitude of the water table is highest in the northwestern corner of the study area (about 237 ft above sea level) and is lowest at the southern end, where Muddy Brook leaves the study area (about 216 ft above sea level). The water-table contours show that the direction of groundwater-flow is both downstream and towards the brook. The map in figure 8 shows water-table contours on June 15, 1992; these contours represent intermediate water-table altitudes during the time of the study.

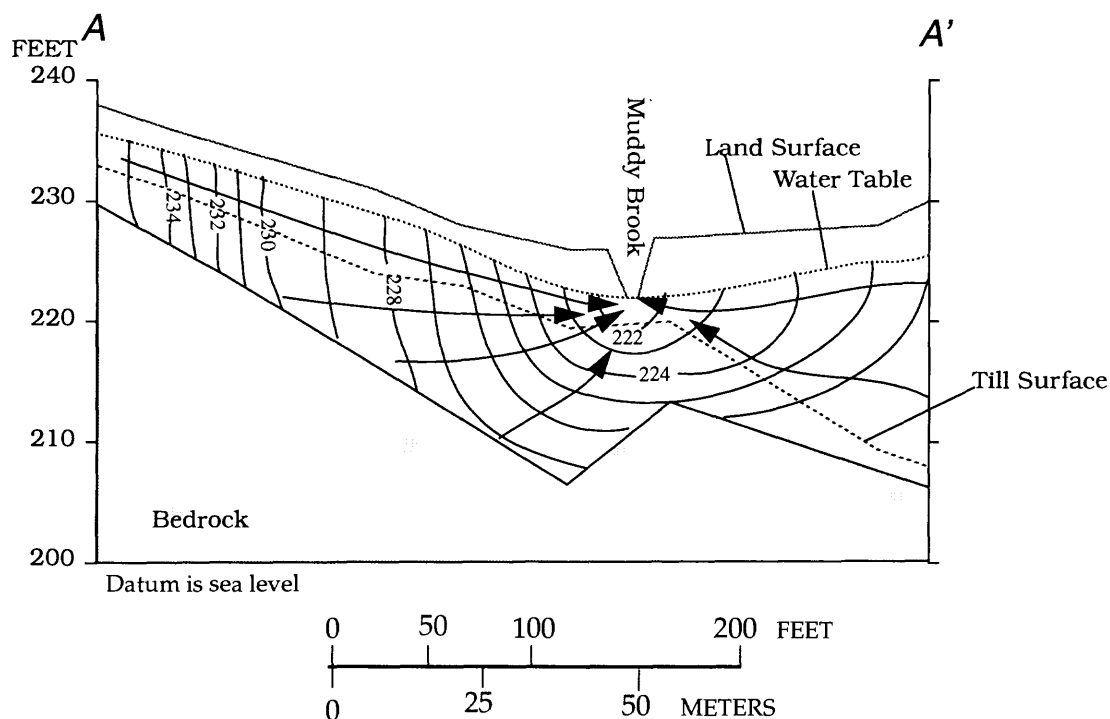
## Hydraulic Gradients

The horizontal hydraulic gradient at the Muddy Brook site depends on the season and the type of geologic material that underlies the area. Water-table contours on the western edge of the study area are the most closely spaced, because of the low hydraulic conductivity of the till, which is the predominant saturated formation in this area. The bedrock that underlies this area is less than 10 ft below land surface and has a steep slope that may affect the gradients. Horizontal hydraulic gradients range from 0.04 ft/ft in September to 0.07 ft/ft in June. In areas close to Muddy Brook, where the stratified drift thickens, gradients are less steep, ranging from 0.015 ft/ft to 0.04 ft/ft during most of the year. Horizontal hydraulic gradients in the till underlying areas close to Muddy Brook are as large as 0.1 ft/ft.

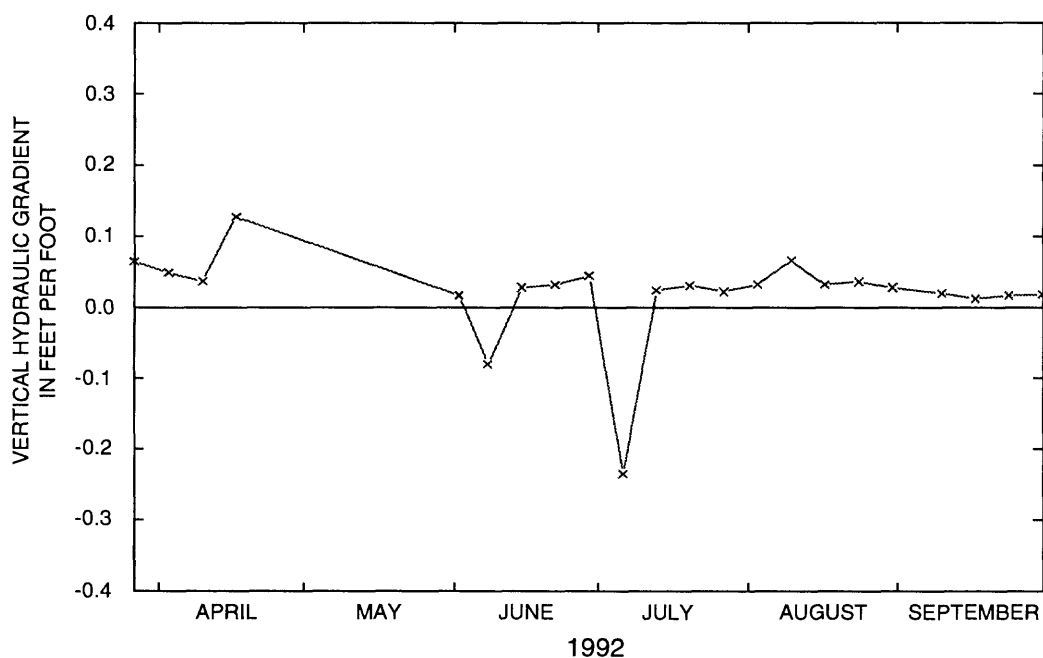
Vertical gradients are present between the till and stratified drift at most well locations. The water-level data collected during 1992 show that the hydraulic head at the bottom of the till is greater than the altitude of the water table at many of the well locations, and this condition continues during much of the year. This indicates that some water is moving from the till upward into the stratified drift (fig. 9). The vertical hydraulic gradient is predominantly downward or upward at each well location, but the gradient may switch direction temporarily in response to recharge. Vertical hydraulic gradients between the till and stratified drift are 0 to 0.4 ft/ft, but typically are about 0.15 ft/ft. The seasonal fluctuation in the vertical hydraulic gradient between wells EL 128 and EL 129 (between the till and stratified drift) during part of 1992 is shown in figure 10.







**Figure 9.** Hydraulic head distribution at section A-A' on June 15, 1992. (See figs. 4 and 5. Arrows indicate direction of ground-water flow. Contour lines connect areas of equal hydraulic head.)



**Figure 10.** Seasonal fluctuation in vertical hydraulic gradient between well EL 128 (till), and EL 129 (stratified drift). A positive gradient indicates that the hydraulic head in the till is higher than the water table in the stratified drift.

## Seasonal Water-Table Fluctuations

Depth to the water table at the Muddy Brook site ranges from a few inches to 8 ft below land surface. The water-table altitude trended downward at most sites from the end of March to the end of September 1992. At locations 200 ft west of Muddy Brook, wells that were screened in mostly till showed the largest seasonal changes in water levels—as much as 7 ft. At locations closer to the stream, most wells showed only about 2 ft of seasonal fluctuation during 1992. Seasonal fluctuations of the water table at wells EL 101 (200 ft from Muddy Brook) and EL 107 (15 ft from Muddy Brook) are shown in figures 11 and 12.

## GROUND-WATER FLOW IN THE MUDDY BROOK AREA

Ground water discharges to Muddy Brook during most of the year, except for short periods when the brook dries up. The amount of ground water that discharges from the study area into Muddy Brook is generally small compared to the flow of the stream. The volume of ground water discharging to Muddy Brook is largest during spring and smallest during late summer and early fall. Most of the ground water discharging to Muddy Brook at

the study site comes from the stratified drift. Water-level measurements indicate that the hydraulic head in the till is generally higher than the hydraulic head in the stratified drift, and some water may be discharging from the till into the stratified drift. Ground-water discharge was estimated during April, June, and September. These times were selected to represent high, intermediate, and low water-table conditions during the period of study.

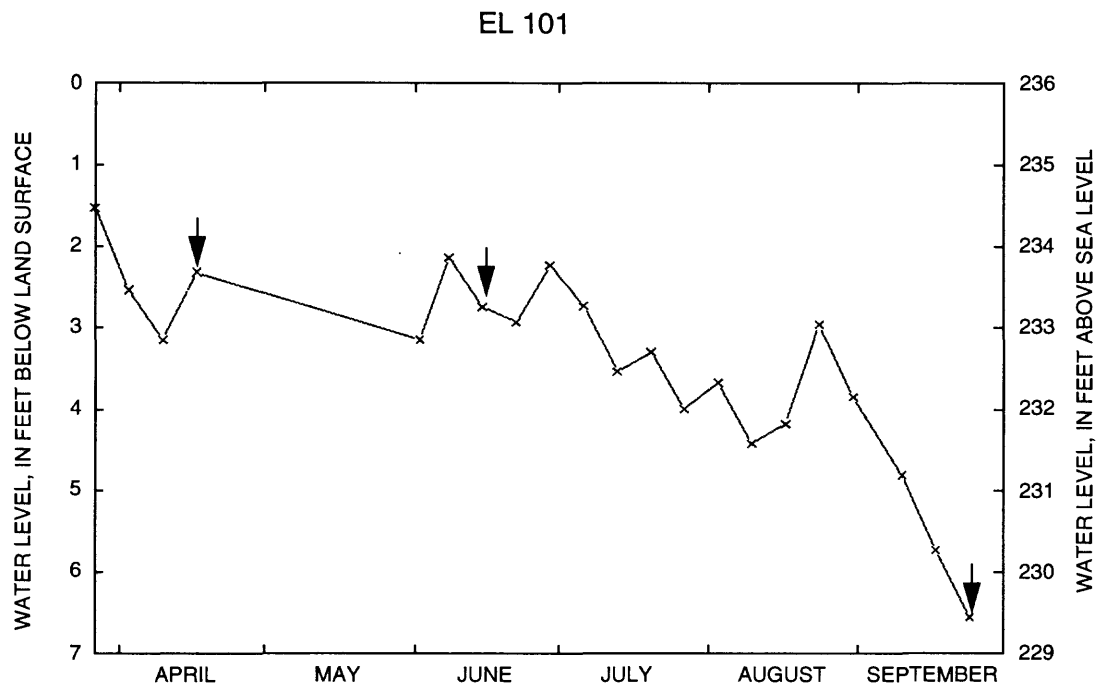
## Ground-Water Flow into the Riparian Zone

The ground water that enters the 100-ft wide riparian zone comes from both the till and the stratified drift. The stratified drift beyond the 100-ft zone has a very limited saturated thickness. During the spring, the saturated thickness of the stratified drift in this area is as much as 6 ft; however, during the summer, the water table declines to the till surface, and the saturated thickness is 0 ft. The estimates of ground-water flow across the 100-ft boundary on the western side of Muddy Brook are 0.012 ft<sup>3</sup>/s during April, 0.010 ft<sup>3</sup>/s in June, and 0.004 ft<sup>3</sup>/s in September. Ground-water flow to the riparian zone and to Muddy Brook are shown in table 2.

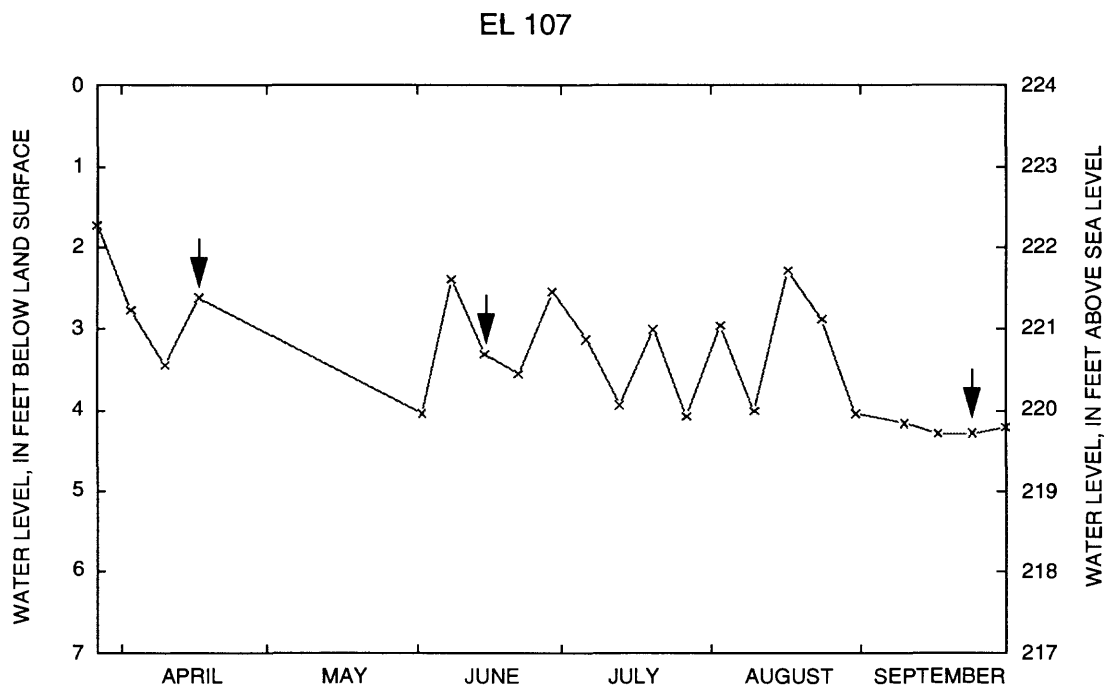
**Table 2.** Ground-water flows for April 17, June 15, and September 26, 1992 for western and eastern sides of Muddy Brook, for northern and southern halves, and for water entering the 100-foot riparian zone on the west side of Muddy Brook

[Flows are in cubic feet per second]

Section of study area	April 17	June 15	September 26
<i>Flow to Muddy Brook from:</i>			
Western side	0.010	0.009	0.007
Eastern side	.017	.012	.008
Northern half, western side	.006	.005	.004
Southern half, western side	.004	.004	.003
Northern half, eastern side	.009	.007	.004
Southern half, eastern side	.008	.005	.004
<i>Flow into riparian zone on west side of Muddy Brook</i>	.012	.010	.004



**Figure 11.** Water level at well EL 101 (200 feet from Muddy Brook) from March to September 1992. (Arrows indicate data points used in ground-water discharge estimation.)



**Figure 12.** Water level at well EL 107 (15 feet from Muddy Brook) from March to September 1992. (Arrows indicate data points used in ground-water discharge estimation.)

## Ground-Water Discharge to Muddy Brook

Discharges of ground water to Muddy Brook from the study area during April, June, and September are estimated to be 0.027, 0.021, and 0.015 ft<sup>3</sup>/s, respectively. Ground-water flow from the eastern side of the study area to Muddy Brook is usually greater than flow from the western side, primarily because the eastern side has coarser and thicker saturated materials and consequently a greater ability to transmit water. Estimates of flow (table 2) were made with the assumption that there is minimal or no flow of ground water from the till into the stratified drift. If till is included in the flow calculations, it is estimated that an additional 0.006 ft<sup>3</sup>/s is flowing from the till to the stratified drift during most of the year. Because this is almost half of the water discharging to Muddy Brook during September, it may be useful to add this number to any future calculations.

## Ground-Water Velocity

Assuming a  $K$  of 10 ft/d, an  $\alpha$  of 0.3, and a gradient of 0.03, ground-water velocity in the stratified drift near Muddy Brook would average about 1 ft/d. Consequently, ground-water recharge would take about 100 days to cross the 100-ft riparian zone. Ground-water velocity in the till would be 0.2 ft/d if  $K$  were 1 ft/d,  $\alpha$  were 0.3, and  $dh/dl$  were 0.05. Assuming all ground-water flow in the till stays in the till, it would take about 500 days for this water to cross the 100-ft riparian zone and discharge to Muddy Brook. It is likely that the ground-water discharge to Muddy Brook is a mixture of different waters coming from the stratified drift and till.

## SUMMARY AND CONCLUSIONS

The Muddy Brook study area is underlain by stratified drift that is mostly less than 10 ft thick and consists of silty clay to very coarse sand. Horizontal hydraulic conductivity of the stratified drift, estimated from grain-size

analyses and slug tests, is 4 to 30 ft/d. Till deposits at the study area range in thickness from 1 to 14 ft and have horizontal hydraulic conductivities of 0.1 to 4.3 ft/d. Bedrock at the study site is located less than 25 ft below land surface and has about 25 ft of relief over the 800-ft long by 300-ft wide study area.

In areas near Muddy Brook, the water table is generally within 5 ft of land surface; however, at 200 ft from the stream, the water table may be as deep as 7 ft, particularly during dry times of the year. Water-table contours, which point upstream, show that ground water discharges to Muddy Brook. Horizontal hydraulic gradients in the stratified drift range from 0.015 ft/ft to 0.04 ft/ft, depending on the location within the study area and the season. Horizontal hydraulic gradients in the till are as large as 0.1 ft/ft. Vertical hydraulic gradients are present between the till and stratified drift at most locations where multiple wells were installed. Hydraulic head in the till was generally higher than the water table in the stratified drift, but this relation was reversed at different times of the year, in response to recharge. Vertical gradients were 0 to 0.4 ft/ft.

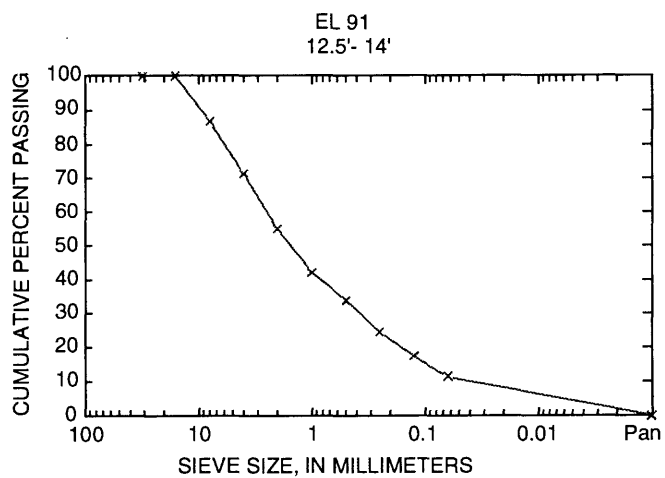
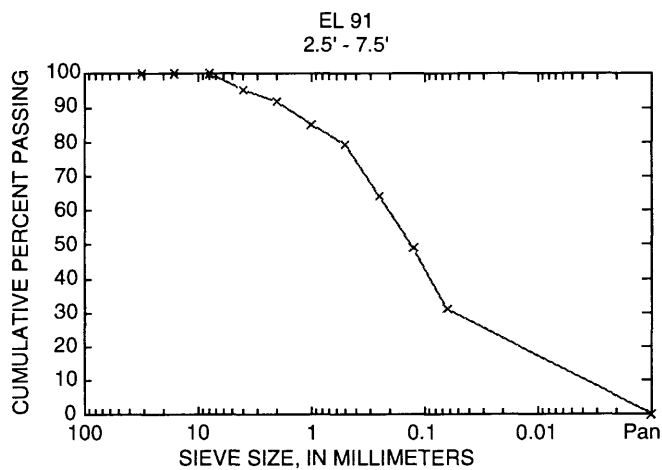
Ground-water flow from the western side of Muddy Brook into the 100-ft wide riparian zone was 0.004 to 0.012 ft<sup>3</sup>/s; and was highest during the spring. Estimated ground-water discharge to Muddy Brook from stratified drift was 0.015 to 0.027 ft<sup>3</sup>/s, with the highest flow in April and the lowest flow in September. An additional 0.006 ft<sup>3</sup>/s may be discharging from the saturated till underlying the riparian zone to stratified drift during most of the year. Ground-water velocity at the study site averaged about 1 ft/d for stratified drift and about 0.2 ft/d for till. This means that, for a given area, the water in the till may be older and may travel more slowly than water in the stratified drift. This water is likely to have a different chemical composition than the water in the stratified drift. It is likely that some mixing of the water from both till and stratified drift occurs near the discharge point at Muddy Brook.

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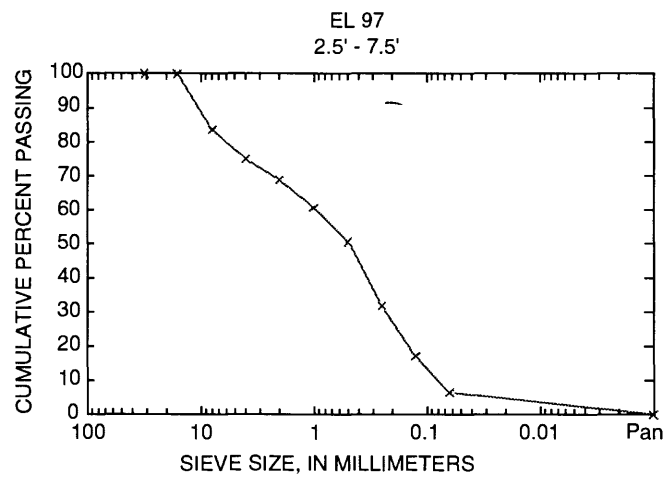
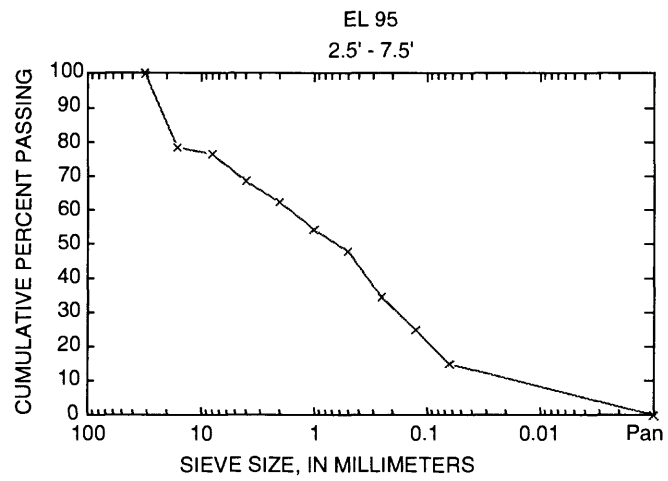
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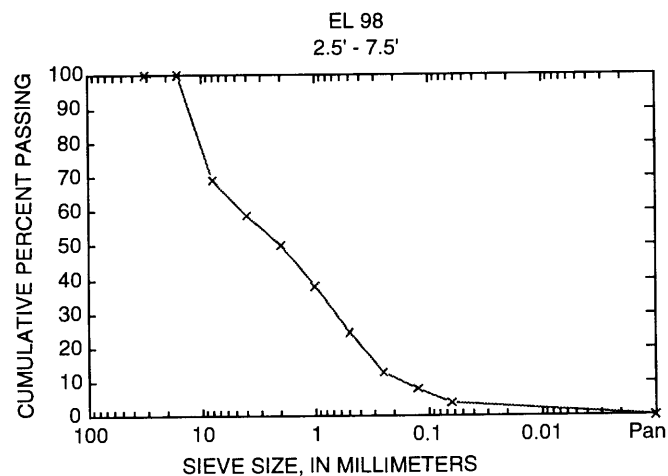
**APPENDIX:** Grain-size analyses of unconsolidated materials at selected well locations and depths at the Muddy Brook study site, Ellington, north-central Connecticut



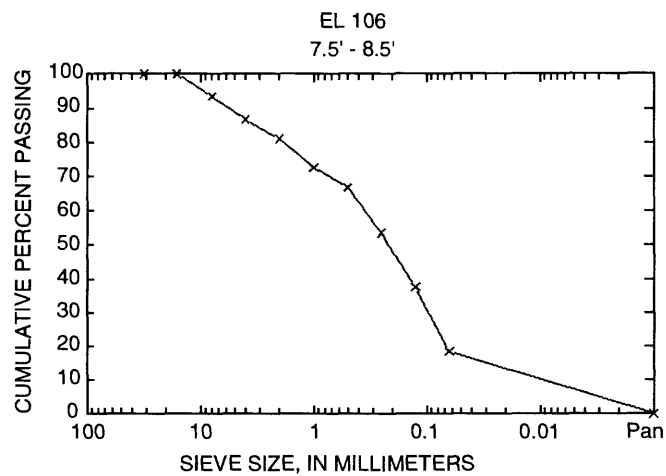
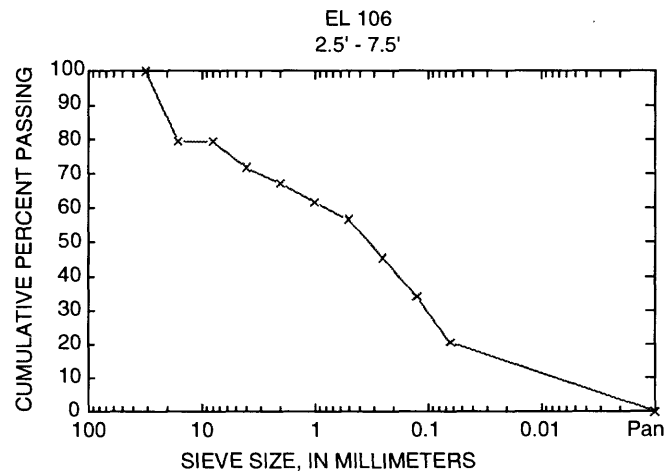
Grain-size analyses of unconsolidated materials at selected well locations and depths



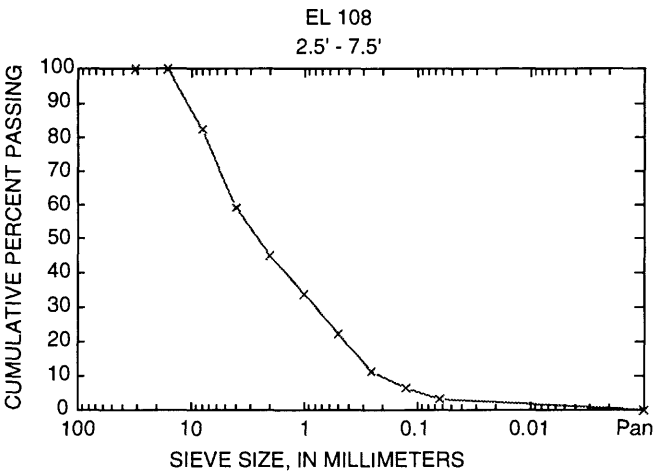
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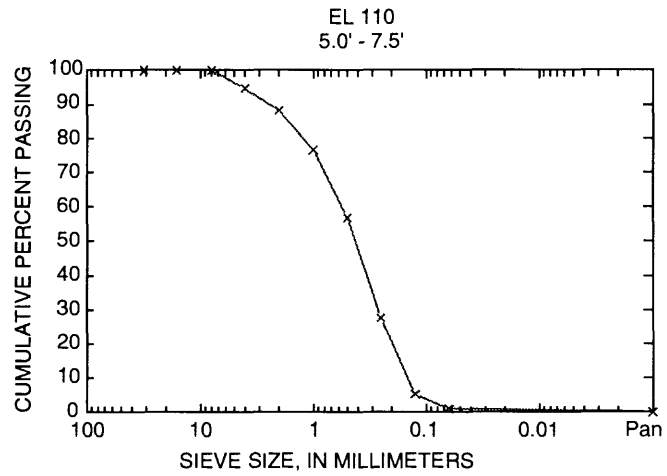
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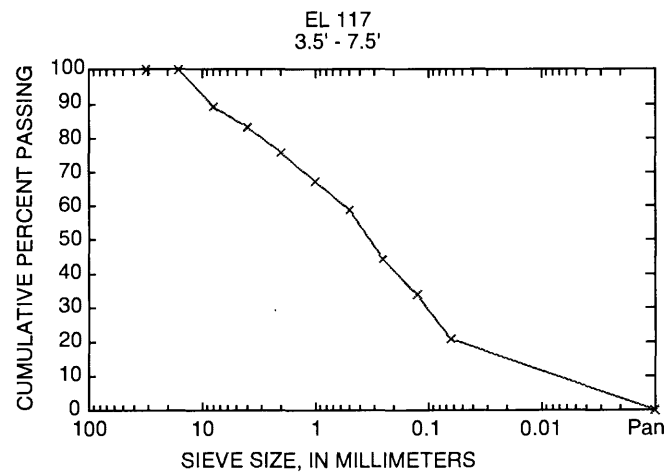
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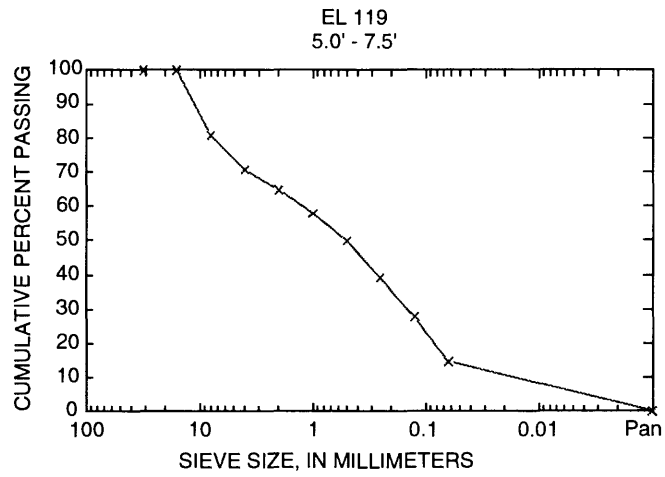
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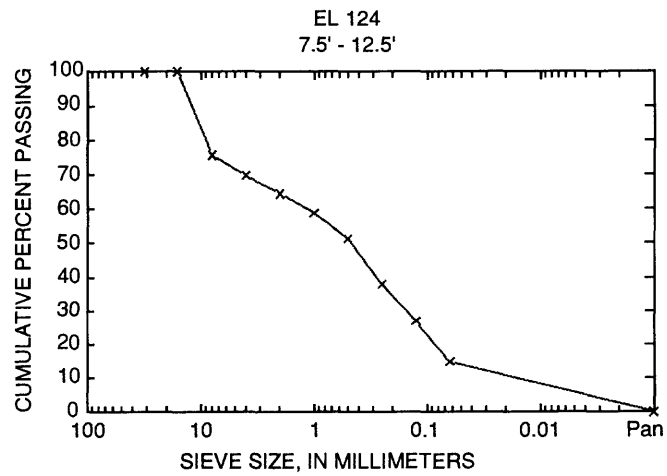


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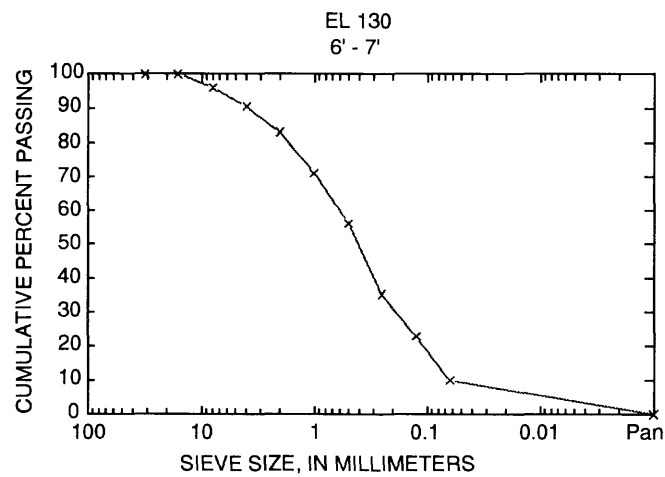
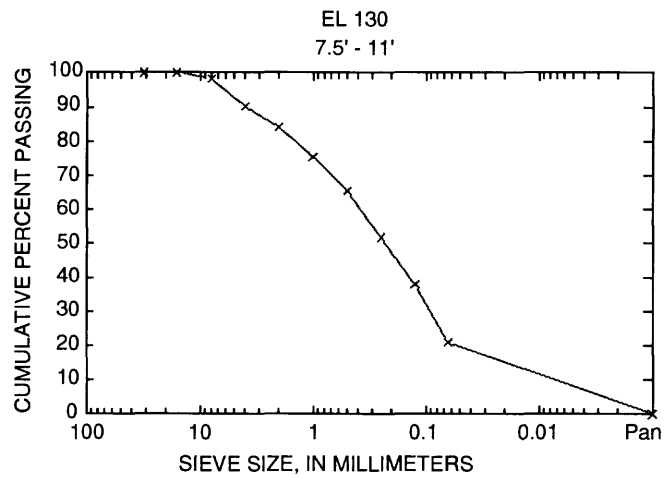




Grain-size analyses of unconsolidated materials at selected well locations and depths



### Grain-size analyses of unconsolidated materials at selected well locations and depths



### Grain-size analyses of unconsolidated materials at selected well locations and depths

