COMPUTATION OF BEDROCK-AQUIFER RECHARGE IN NORTHERN WESTCHESTER COUNTY, NEW YORK, AND CHEMICAL QUALITY OF WATER FROM SELECTED BEDROCK WELLS

By Stephen W. Wolcott and Robert F. Snow

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	*By*	*To Obtain*
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second (ft^3/s)	28.32	liter per second
inch per year (in/yr)	2.54	centimeters per year
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day (Mgal/d)	3,785	cubic meter per day
	Hydraulic Units	
transmissivity (ft^2/d)	0.0929	meter squared per day
hydraulic conductivity (ft/d)	0.3048	meter per day
	Temperature	
degrees Fahrenheit (°F)	°C = 5/9 (°F-32)	degrees Celsius (°C)

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."

MISCELLANEOUS ABBREVIATIONS

mg/L	milligram per liter
ton/acre-ft	tons per acre-foot
µg/L	microgram per liter
µS/L	microsiemens per liter at 25° C

GLOSSARY

Aquifer.—A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow.—Sustained runoff composed primarily of ground water.

Bedrock.—Solid rock that forms the earth's crust. It is locally exposed at the land surface but more commonly is buried beneath unconsolidated deposits ranging in thickness from a few inches to more than 300 feet.

Crystalline bedrock.—Igneous and metamorphic rocks. The most common types in the study area are granite, gneiss, and schist.

Direct runoff.—Water that moves over the land surface directly to streams or lakes shortly after rainfall or snowmelt.

Dissolved solids.—The residue from a filtered sample of water after evaporation and drying for 2 hours at 180° C; consists primarily of dissolved mineral constituents.

Drainage basin.—Area from which surface runoff is moved through a single drainage system.

Drawdown.—The lowering of the water table or potentiometric surface of an aquifer through the withdrawal of water by pumping; equal to the difference between the static water level and the pumping water level.

Evapotranspiration.—Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil, combined with transpiration by living plants.

Fracture.—A structural break or opening in bedrock along which water can move.

Gaging station.—A site on a stream, canal, lake, or reservoir selected for systematic observations of gage height (water-surface elevation) or discharge.

Ground water.—Water in the saturated zone.

Ground-water discharge.—The discharge of water from the saturated zone by (1) natural processes such as ground-water runoff and evapotranspiration, and (2) artificial discharge through wells and other manmade structures.

Ground-water drainage divide.—The boundary between two adjacent aquifer areas in which ground water flows downward in a direction away from the boundary. Forms an imaginary vertical plane through which ground water does not flow.

Ground-water evapotranspiration.—Ground water discharged into the atmosphere in the gaseous state either by direct evaporation or through transpiration by plants.

Ground-water outflow.—The sum of ground-water runoff and underflow; includes all natural ground-water discharge (except evapotranspiration) from a drainage area.

Ground-water recharge.—Water that enters the saturated zone.

Ground-water runoff.—Ground water that discharges into stream channels, springs, lakes, and reservoirs by seepage from saturated earth materials.

Hardness (of water).—The property of water generally attributable to salts of calcium, magnesium, and the other alkaline earth elements. Hardness has soap-consuming and encrusting properties and is expressed as the concentration of calcium carbonate ($CaCO_3$) that would be required to produce the observed effect.

Head.—The height of the surface of a water column above a standard datum that can be supported by the static water pressure at a given point.

Hydraulic conductivity (K).—A measure of the ability of a porous medium to transmit a fluid. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient, or unit change in head over unit length of flow path.

Hydraulic gradient.—The change in static head per unit of distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decrease in head.

GLOSSARY (continued)

Igneous rock.—Rock or mineral that solidified from molten or partly molten material.

Induced infiltration.—The process by which water in a stream or lake moves into an aquifer in response to a hydraulic gradient induced by a pumping well or wells.

Ion.—An atom or group of atoms that carries an electric charge as a result of having lost or gained electrons.

Mean (arithmetic).—The sum of the individual values of a set, divided by their total number. Also referred to as the "average."

Metamorphic rock.—Any rock that has been altered by mineralogical, chemical, and structural changes, essentially in the solid state, in response to marked increased in temperature, pressure, shearing stress, or chemical environment at depth in the earth's crust.

Micrograms per liter (μg/L).—A unit for expressing the concentration of chemical constituents in solution, by weight, per unit volume of water. One thousand micrograms is equivalent to 1 milligram.

Milligrams per liter (mg/L).—A unit for expressing the concentration of chemical, constituents in solution, by weight, per unit volume of water. One thousand milligrams is equivalent to 1 gram.

pH.—The negative logarithm of the hydrogen-ion activity solution. A pH of 7.0 indicates neutrality; values below 7.0 denote acidity, those above 7.0 denote alkalinity.

Runoff.—That part of precipitation that appears in streams. It is the same as streamflow unaffected by artificial diversions, storage, or other structures in or on the stream channels.

Saturated thickness.—An aquifer's thickness below the water table.

Saturated zone.—The subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone. Water in the saturated zone is under pressure greater than atmospheric.

Sedimentary rock.—Rock resulting from the consolidation of loose sediment that has accumulated in layers.

Specific capacity of a well.—The rate of discharge of water divided by the corresponding drawdown of the water level in the well, given in units of gallons per minute per foot of drawdown.

Specific conductance of water.—A measure of the ability of water to conduct an electric current, expressed in microsiemens per centimeter at 25°C. It is related to the dissolved-solids concentration and serves as an approximate measure thereof.

Stratified drift.—A sorted sediment laid down in layers by, or in, meltwater from a glacier; includes sand and gravel and minor amounts of till and clay deposited in layers.

Till.—An unsorted, unstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay mixed in varying proportions.

Transmissivity.—The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Transpiration.—The process whereby plants release water vapor to the atmosphere.

Unconfined (water-table) aquifer.—An aquifer in which the upper surface of the saturated zone (water table) is at atmospheric pressure and is free to rise and fall.

Unconsolidated sediment.—Loose material, not firmly cemented or interlocked; for example, sand in contrast to sandstone.

Underflow.—The downstream flow of water through the permeable deposits that underlie a stream.

Volcanic rock.—A generally finely crystalline or glassy igneous rock resulting from volcanic action.

Water table.—The upper surface of the saturated zone.

Water year.—A continuous 12-month period, October 1 through September 30, during which a complete streamflow cycle takes place from low to high flow and back to low flow. It is designated by the calendar year in which it ends.

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ABSTRACT

An empirical technique was used to calculate the recharge to bedrock aquifers in northern Westchester County. This method requires delineation of ground-water divides within the aquifer area and values for (1) the extent of till and exposed bedrock within the aquifer area, and (2) mean annual runoff. This report contains maps and data needed for calculation of recharge in any given area within the 165-square-mile study area.

Recharge was computed by this technique for a 93-square-mile part of the study area and used a ground-water-flow model to evaluate the reliability of the method. A two-layer, steady-state model of the selected area was calibrated. The area consists predominantly of bedrock overlain by small localized deposits of till and stratified drift. Ground-water-level and streamflow data collected in mid-November 1987 were used for model calibration. The data set approximates average annual conditions. The model was calibrated from (1) estimates of recharge as computed through the empirical technique, and (2) a range of values for hydrologic properties derived from aquifer tests and published literature. Recharge values used for model simulation appear to be reasonable for average steady-state conditions.

Water-quality data were collected from 53 selected bedrock wells throughout northern Westchester County to define the background ground-water quality. The constituents and properties for which samples were analyzed included major cations and anions, temperature, pH, specific conductance, and hardness. Results indicate little difference in water quality among the bedrock aquifers within the study area. Ground water is mainly the calcium-bicarbonate type and is moderately hard. Average concentrations of sodium, sulfate, chloride, nitrate, iron, and manganese were within acceptable limits established by the U.S. Environmental Protection Agency for domestic water supply.

INTRODUCTION

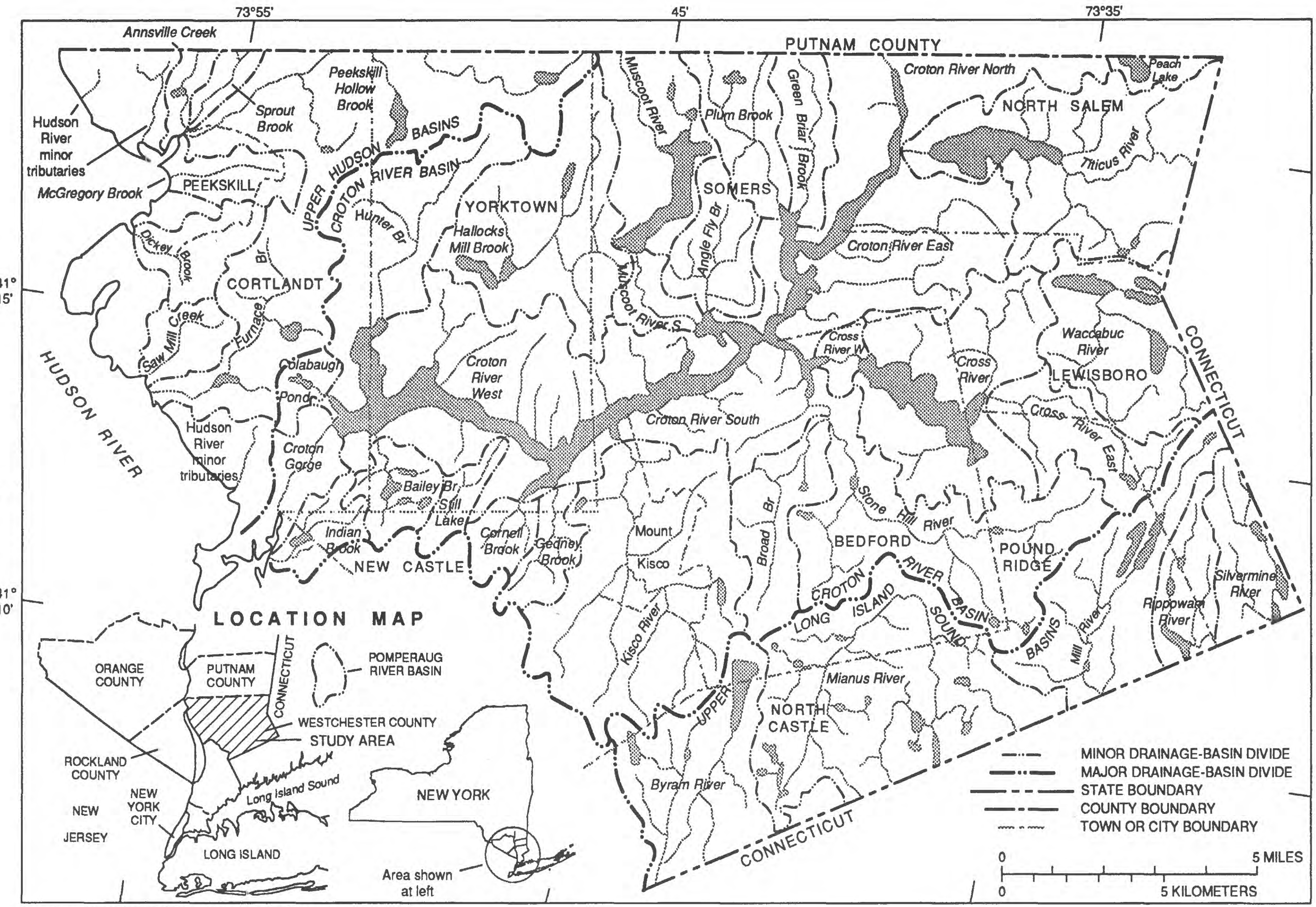
Ground water is the principal source of water supply for most of northern Westchester County, N.Y. (fig. 1). The area's 40 community water systems obtain supplies from unconsolidated and bedrock aquifers. Domestic and industrial users not served by these systems depend on individual wells, most of which tap bedrock aquifers.

Information on the availability of ground water for public and domestic supply, especially that from bedrock aquifers in this rapidly developing area, is limited. Information on the rate of recharge to bedrock aquifers is necessary for evaluation of the effect of increased ground-water withdrawals on the hydrologic system. Potential effects include declining ground-water levels and decreases in aquifer storage and streamflow.

In 1986, the U.S. Geological Survey (USGS), in cooperation with the Westchester County Water Agency, began a 3-year study to evaluate the rates of recharge to bedrock aquifers in the northern part of the county and the chemical quality of water from these aquifers. Recharge rates were calculated through an empirical technique, chemical quality of water sampled during the study was documented, and the geology of unconsolidated deposits and bedrock was reviewed.

Purpose and Scope

This report (1) briefly describes the geologic and hydrogeologic characteristics of the bedrock aquifers of northern Westchester County (fig. 1),



Base from Westchester County Department of Planning, 1982, 1:88,000

Figure 1.--Location of drainage basins and major geographic features in northern Westchester County, N. Y.

(2) presents a technique for estimating recharge to bedrock aquifers, and (3) describes the chemical quality of water from bedrock aquifers in the study area. It also compares results of the recharge-estimating technique with the results of a ground-water flow model. Maps and a table of data for computing ground-water runoff in 165 basins are included along with a table of water-quality data from 53 wells throughout northern Westchester County.

Acknowledgments

The authors thank Legette, Brashers and Graham, Inc., professional ground-water consultants, for use of their aquifer-test data collected at several sites in northern Westchester County. Appreciation is also expressed to the many private and industrial well owners who gave permission to measure water levels and collect water samples from their wells.

Previous Studies

Previous ground-water investigations of northern Westchester County are limited to three reconnaissance studies. Van der Leeden (1962) provides a general evaluation of ground-water resources of the entire county. Geraghty and Miller (1977) describe the hydrogeology of the northern half of the county, and the Westchester County Department of Planning (1982) present an atlas that includes hydrologic data from the entire county that were used primarily for planning purposes. These reports do not provide specific and quantitative hydrogeologic interpretations needed to manage ground-water resources in the area. Reports on previous hydrologic investigations at specific locations within northern Westchester County are summarized in works cited in the list of references (p. 29-30).

Location and Setting

Westchester County is in the southeastern corner of New York State and is adjacent to New York City. The study area encompasses the northern part, which is bordered by the Hudson River on the west, Putnam County to the north, and Connecticut along the east and south (fig. 1). The southwestern border is the drainage divide between the Croton River basin and basins that drain to the Hudson River south of the Croton River basin. The total area is about 165 mi^2. The topography is characterized by small, steep hills and ridges bisected by streams and narrow river valleys. Elevations range from sea level at the Hudson River to about 650 feet above sea level on several of the hilltops and ridges.

Many of the river valleys within the study area contain reservoirs that are part of the New York City water-supply system. The largest reservoirs are in dammed sections of the Croton River, which has only short reaches that flow naturally. Most of the study area is drained by the Croton River, which flows into the Hudson River. Other, smaller, streams that flow directly into the Hudson River include Annsville Creek, Sprout Brook, Saw Mill Creek, and Furnace Brook (fig. 1). Two other minor drainage systems within the study area are the Mianus River and Mill River, which flow into Long Island Sound.

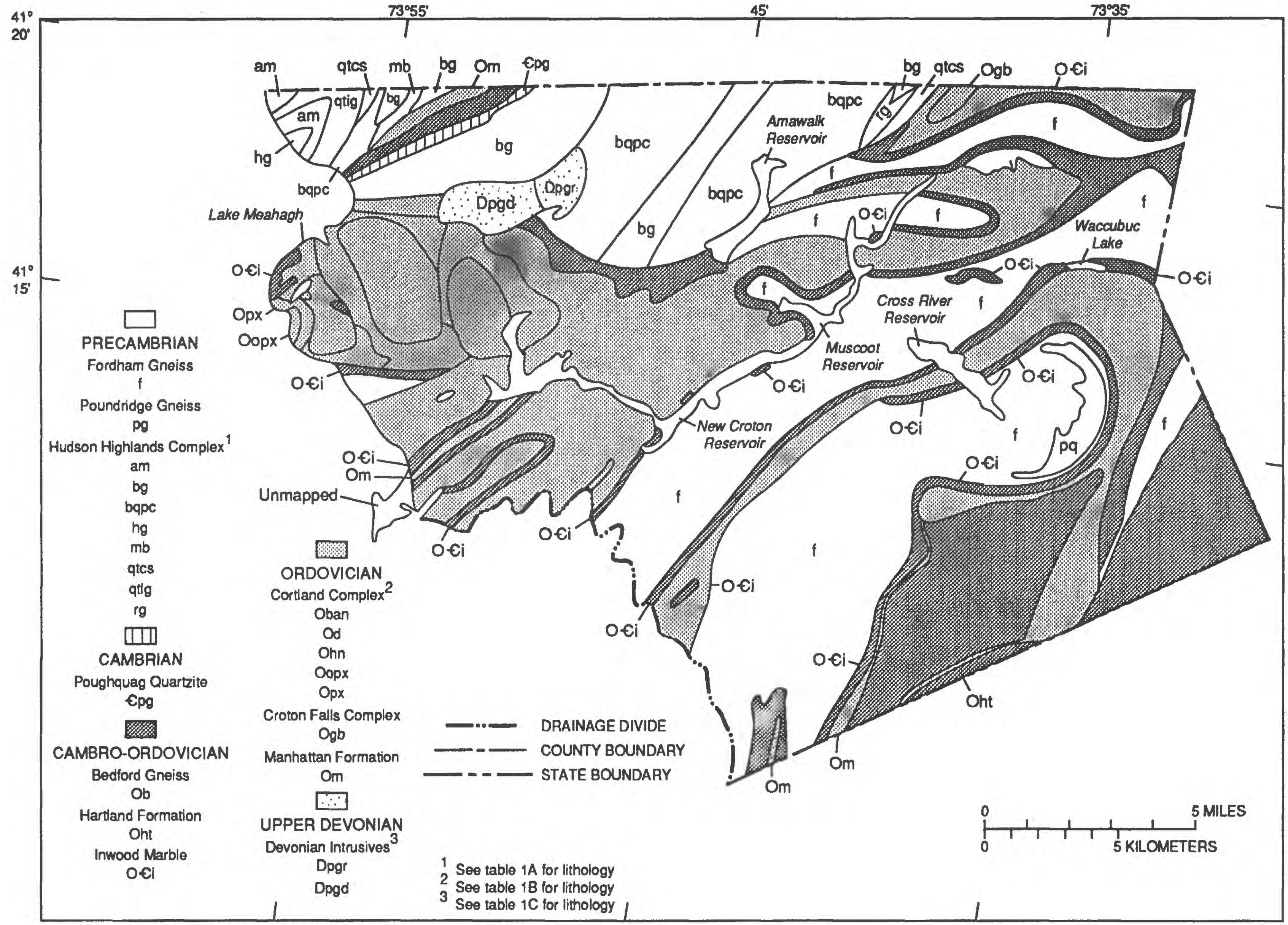
Northern Westchester County has a humid continental climate and maritime influences from the Atlantic Ocean. Monthly mean temperatures for 1951-73 recorded in Putnam County, just north of the study area, ranged from 24.6 °F in January to 70.9 °F in July. The average yearly temperature for this period was 60.0 °F. Monthly mean precipitation during this period ranged from 4.31 in. in December to 2.85 in. in January; the average yearly total is 45.22 in. (National Oceanic and Atmospheric Administration, 1980).

Geologic Setting

Northern Westchester County is underlain by a complex sequence of bedrock that varies greatly in age and composition within the 165-mi^2 study area. The rocks are extensively folded and faulted, and several major fault zones extend throughout the area (Van der Leeden, 1962). The bedrock is mostly metamorphic with some igneous rock and ranges in age from Precambrian to Upper Devonian. Much of the bedrock is overlain by unconsolidated Pleistocene or Recent deposits, some of which are extensive. The Pleistocene deposits typically include a thin mantle of till on hilltops and valley sides and stratified sand, gravel, silt, and clay in the valley bottoms. Recent deposits consist of alluvium in stream valleys and organic-rich sediments in swampy areas.

Bedrock

The many diverse bedrock units in northern Westchester County are grouped by age in accordance with a geochronological classification by Fisher and others (1970), from which the following lithology discussion is modified. The location of each bedrock unit is shown in figure 2.



Base from Fisher, Isachsen, and Rickard, 1970, 1:250,000

Figure 2.--Bedrock geology of northern Westchester County. (Modified from Fisher and others, 1970.)

Precambrian.—Rocks of Precambrian age are by far the most extensive in the study area and consist of three major groups—Fordham Gneiss (f), Poundridge Gneiss (pg), and the Hudson Highlands Complex. The Fordham Gneiss, of sedimentary and volcanic origin, is predominantly in the eastern half of northern Westchester County. It is mostly a coarsely banded hornblende-biotite-quartz-plagioclase gneiss with interbedded layers of amphibolite marble and quartzite. The Poundridge Gneiss is a biotite and(or) hornblende-quartz-feldspar gneiss that is lithologically similar to the Fordham Gneiss. It is present in one part of the eastern part of the study area and is surrounded by the Fordham Gneiss. The Hudson Highlands Complex contains several bedrock units whose exact age is uncertain. These units are almost entirely in the western part of the study area. The Hudson Highlands are part of a continuous range of Precambrian rocks that extends from Reading, Pa. to southern Dutchess County, N.Y. (Prucha and others, 1968 and Wissing, 1979). The various units and associated lithology are listed in table 1A.

Cambrian.— The only bedrock formation in the study area that is exclusively identified as Cambrian is the Poughquag Quartzite (Cpg), which forms as a thin band in the Hudson Highlands Complex.

Cambro-Ordovician.—Bedford Gneiss (Ob), Hartland Formation (Oht) and Inwood Marble (OCi) are formations of uncertain age. The Bedford Gneiss and Hartland Formation in northern Westchester County are generally present near the Connecticut border. The Bedford Gneiss is a biotite-quartz-plagioclase gneiss interlayered with amphibolite; the Hartland Formation is a basal amphibolite overlain by pelitic schists. The Inwood Marble is present almost everywhere in northern Westchester County, mostly in narrow bands that do not crop out. The Inwood Marble, typically between the Manhattan Formation (Om) and the Fordham Gneiss (f), is a white-to-gray, calcitic-to-dolomitic marble that is easily erodible and therefore common in valley bottoms (Van der Leeden, 1962 and Prucha and others, 1968).

Ordovician.—Northern Westchester County contains three major types of Ordovician-age rocks— the Cortlandt Complex, Croton Falls Complex (Ogb), and the Manhattan Formation (Om). The Cortlandt Complex is a mass of intrusive rock that encompasses about 30 mi^2 south of Peekskill (fig. 1). It commonly consists of norites and pyroxenites; the specific rock units are listed in table 1B. The Croton Falls Complex ranges in composition from gabbro or norite to hornblende diorite and contains minor amounts of pyroxenite. A small area of this complex is surrounded by the Manhattan Formation in northeastern Westchester County. The Manhattan Formation, the second most abundant type of rock in the study area, commonly lies adjacent to bands of Fordham Gneiss and Inwood Marble. It is a garnetiferous quartz-biotite-plagioclase gneiss that is foliated and commonly schistose. The Manhattan Formation also contains hornblendes and plagioclase amphibolites (Prucha and others, 1968; Wissing, 1979).

Upper Devonian.—The youngest rocks in the study area are of Upper Devonian age and lie between the Cortlandt Complex (Ordovician) and the Hudson Highlands complex (Precambrian). These rocks are intrusives of either muscovite-biotite granite (Dpgr) or muscovite-biotite granodiorite (Dpgd) (table 1C).

Table 1.—Lithology of selected bedrock units in northern Westchester County.

[Locations are shown in fig. 2.]

Bedrock-unit symbols in fig. 2	Lithology
	A. HUDSON HIGHLAND COMPLEX (PRECAMBRIAN)
am	amphibolite, pyroxenic amphibolite, hornblende gneiss
bg	biotite granitic gneiss
bqpc	biotite-quartz-plagioclase gneiss
hg	hornblende granite and granitic gneiss
mb	calcitic and dolomitic marble
qtcs	garnet-biotite-quartz-feldspar gneiss
qtlg	garnet-bearing gneiss and interlayered quartzite
rg	rusty/gray biotite-quartz-feldspar gneiss
	B. CORTLANDT COMPLEX (ORDOVICIAN)
Oban	biotite-augite norite
Od	diorite with hornblende and/or biotite
Ohn	hornblende norite
Oopx	olivine pyroxenite
Opx	pyroxenite
	C. DEVONIAN INTRUSIVES (UPPER DEVONIAN)
Dpgn	muscovite-biotite granite
Dpgd	muscovite-biotite grandiorite

Unconsolidated Deposits

Unconsolidated deposits in the study area are of either Pleistocene or Recent age and cover most of the County, except where bedrock crops out. Much of the Pleistocene material is till, which consists of unsorted materials ranging in size from clay to large boulders. The thickest deposits of till are in the valley bottoms, and the thinnest are found on hilltops (Van der Leeden, 1962). Because the till is unsorted, it can contain any combination of material. Thicknesses range from less than 1 ft to more than 100 ft. Stratified drift, unlike till, forms sorted deposits of either clay, silt, sand, or gravel that can be interbedded amongst themselves or between till deposits. They are found almost entirely in the valley bottoms or on the valley sides. The extent and thickness of stratified drift within the study area has been mapped by Wolcott and Irwin (1988) and Snow and Wolcott (1992); thickness is estimated to range from zero in areas of no stratified drift to more than 250 ft. Recent deposits are typically alluvium and fine-grained, organic-rich sediments in and near swamps and streams and are generally less than 10 ft thick.

Hydrogeologic Setting

The primary source of aquifer recharge in northern Westchester County is precipitation that infiltrates to the saturated zone. Streams and reservoirs generally are discharge areas but can locally serve as recharge areas. Additionally, minor amounts of water enter the saturated zone as leakage from industrial and domestic septic systems.

Knox and Nordenson (1955) indicate that the average annual precipitation in the study area during 1930-49 was about 47 in. and ranged from slightly greater than 50 in/yr to less than 44 in/yr. North of the study area, in Putnam County, precipitation averaged 45.2 in. during 1951-73. The lowest average annual precipitation in that period was 30.2 in. in 1964, and the highest was 60.8 in. in 1955 (National Oceanic and Atmospheric Administration, 1980). Average annual precipitation analyses, similar to that developed by Knox and Nordenson (1955), were not available for 1951-73.

A water budget for the Pomperaug River basin, Conn. (see inset, fig. 1) was developed by Meinzer and Stearns (1929) for a 3-year period from October 1913 through September 1916. The Pomperaug River basin is 20 mi east of the study area and has a drainage area of 89.3 mi^2, about 15 percent of which is underlain by stratified drift. Because this basin is close to the study area and is geologically similar, its hydrogeologic characteristics are assumed to be similar to those of many basins in northern Westchester County. The average annual water budgets for the 3 years are presented in table 2.

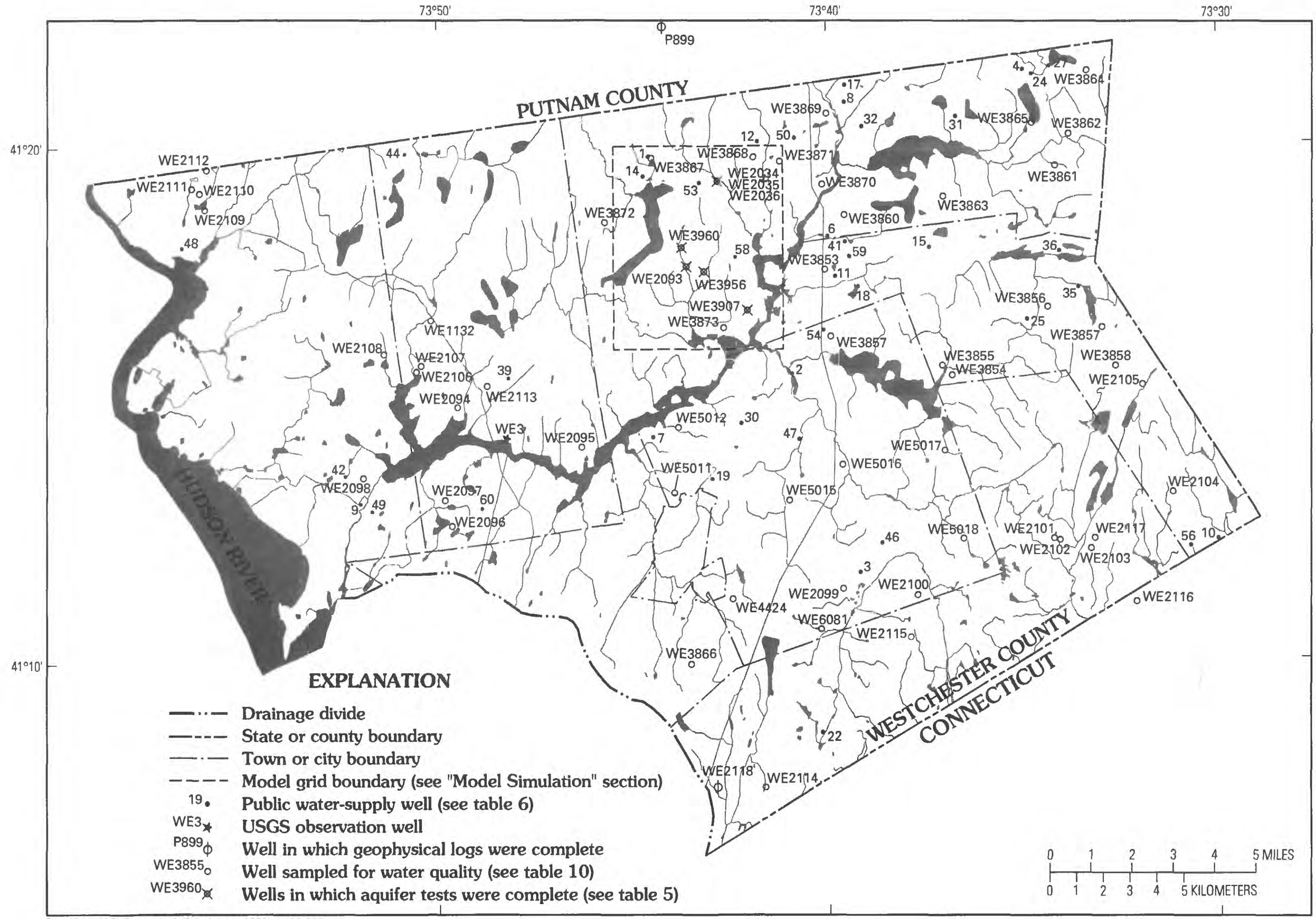
Streamflow

Mean annual runoff in the study area during 1930-49 ranged from about 22 in/yr near the Hudson River to about 28 in/yr near the Connecticut border (Knox and Nordenson, 1955). The nearest continuous-record streamflow-gaging station that has only minor regulation is the Saugatuck River gaging station, near Redding, Conn. (USGS station 01208990) (fig. 3). The drainage area at this gage is 21.0 mi^2. Mean annual runoff from this basin from October 1964 through September 1987 was 27.29 in/yr. The minimum annual runoff from this basin was 10.47

Table 2.—Annual water budgets for the Pomperaug River basin, Conn., October 1913 through September 1916.

[Data from Meinzer and Stearns, 1929. Locations shown in fig. 1. All values are in inches over the drainage area.]

Water year	Precipitation	Increase or decrease of ground water in storage	Ground-water runoff	Ground-water recharge	Ground-water evaporation	Total runoff	Total evaporation plus increase or minus decrease in surface and soil storage
1914	46.66	+0.45	9.05	16.84	7.34	21.04	25.17
1915	45.28	+3.23	7.53	15.83	5.07	16.79	25.26
1916	41.50	-1.83	9.69	14.07	6.21	24.15	19.18
Average	44.48	+.61	8.76	15.58	6.21	20.66	23.20



Base from U.S. Geological digital data, 1983, 1:100,000
Universal Transverse Mercator projection
Zone 18

Figure 3.--Locations of public water-supply, water-quality, aquifer-test, ad observation wells; and model-grid boundary (See "Model Simulation" section) in northern Westchester County.

in/yr in the 1966 water year, and the maximum annual runoff was 48.49 in/yr during the 1984 water year. The yearly annual runoff and associated statistics are listed in table 3.

Table 3.—Annual runoff and associated statistics for Saugatuck River near Redding, Conn. (U.S. Geological Survey station 01208990).
[Location shown in fig. 1. All values are in inches per year.]

Water Year	Annual runoff	Water Year	Annual runoff
1965	12.20	1977	23.69
1966	10.47	1978	37.87
1967	21.93	1979	35.46
1968	25.51	1980	28.53
1969	23.44	1981	13.10
1970	23.17	1982	25.82
1971	23.01	1983	35.68
1972	38.00	1984	48.49
1973	40.68	1985	13.09
1974	28.34	1986	21.28
1975	31.98	1987	31.95
1976	36.24		

Mean annual runoff: 27.39
Median annual runoff: 25.82
Standard deviation: 9.92
Minimum annual runoff: 10.47
Maximum annual runoff: 48.49

Ground Water

Most of the northern Westchester County population uses ground water from public and domestic wells. Ground-water movement is localized and flows from hilltops to streams and reservoirs that serve as areas of discharge.

Hydraulic Characteristics of Bedrock.— Hydraulic conductivity of the bedrock in three areas in northern Westchester County was calculated. Locations of wells for which these values were calculated are shown in figure 3. The values were determined from results of aquifer tests (conducted by consultants) by either of two methods—Walton's specific-capacity method (Walton, 1962) or Theis's method (Lohman, 1972). In each test, saturated thickness of the aquifer was assumed to be equal to the well depth. The resultant hydraulic conductivity values ranged from 0.054 to 0.939 ft/d. All test wells were assumed to fully penetrate a confined aquifer with a uniform hydraulic conductivity. The methods used and the resulting values of hydraulic horizontal conductivity are summarized in table 4.

Hydraulic conductivity varies with depth in northern Westchester County. Caliper logs, which can indicate the relative amount of fracturing within a formation, from two wells at which geophyical logs were collected, show that the most extensive bedrock fracturing is in the first 100 to 150 ft below land surface. A second, but less extensive, fracturing-density pattern appears at greater depths. The caliper logs for well WE 2118 in the southern part of the study area, and well P 899, just north of the study area, are shown in figure 4. Flow within the borehole at well P 899, as measured by a heat-pulse flow meter, indicates that most of the flow is contributed by fracture zones at 50, 75, 250, and 325 ft below land surface.

Table 4.—Horizontal hydraulic conductivity of bedrock at selected wells
[Well locations are shown in fig. 3.]

Well number	Method	Date of test	Horizontal ydraulic conductivity (feet per day)
WE 3956	Specific-capacity test	February 1987	0.792
	Aquifer test	February 1987	.939
WE 3960	Specific-capacity test	February 1987	.330
	Specific-capacity test	March 1987	.251
	Aquifer test	March 1987	.118
	Aquifer test	March 1987	.164
WE 2093	Specific-capacity test	March 1987	.058
WE 2034	Specific-capacity test	March 1983	.507
WE 2035	Specific-capacity test	March 1983	.662
	Aquifer test	March 1983	.435
WE 2036	Specific-capacity test	March 1983	.054
WE 3907	Aquifer test	October 1982	.630

Ground-Water Flow.—The general flow of ground water, as indicated by the distribution of measured water levels, is from the hilltops toward nearby streams and reservoirs. No dominant regional flow pattern is discernible. Ground water also flows vertically downward beneath the hilltops and valley sides and upward in the valley bottoms. This downward flow

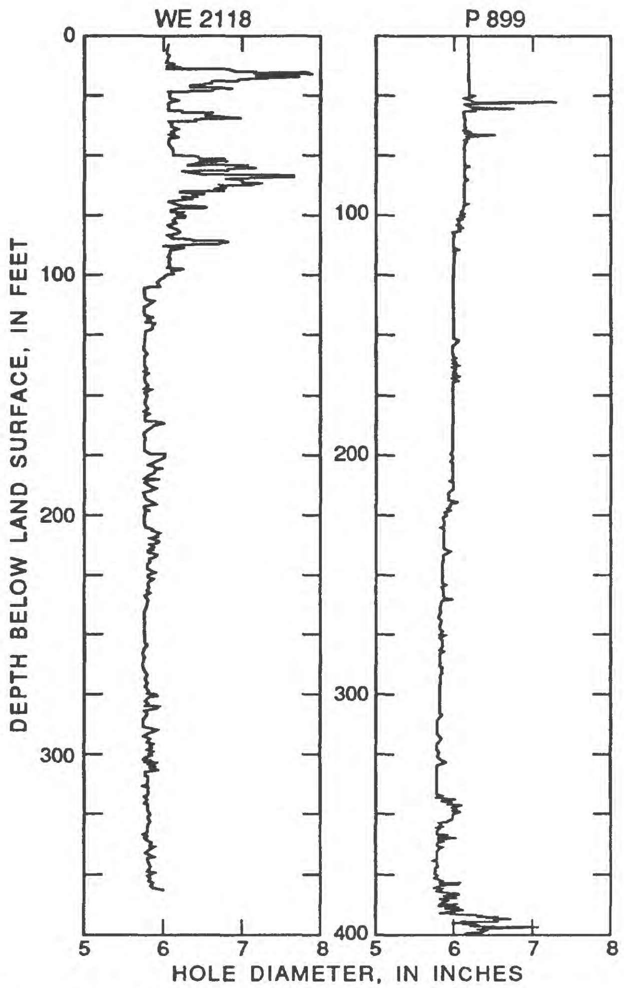


Figure 4.--Caliper logs for wells WE 2118 and P 899. (Well locations are shown in fig. 3.)

pattern indicates that most recharge occurs on hilltops and valley sides. The upward vertical flow in the valley bottoms indicates that these areas are predominantly regions of ground-water discharge.

The rate of horizontal flow through the bedrock aquifers of the study area varies locally. In areas where the rock is not highly fractured, the rate of horizontal ground-water flow can be less than 0.1 ft/d. In areas where the fracturing is extensive, such as within the Inwood Marble, rates of horizontal flow can exceed 1 ft/d.

Unconsolidated deposits do not significantly affect the overall pattern of ground-water flow within the study area because they are not extensive. In valley bottoms, they are hydraulically connected with the bedrock, however, and probably affect ground-water movement locally where they are thick or extensive. The study area contains confined and unconfined aquifers. Most of the unconsolidated aquifers are probably unconfined, whereas bedrock aquifers can be either, depending on their location.

Water Levels.—Water-level fluctuations in observation well WE 3, a 17-ft deep dug well in sand of Pleistocene age (fig. 3), are plotted in figure 5. The average annual water level for the period of record (1934-88) is about 12.2 ft below land surface. This value is an approximation because the water level was not measured continuously over the entire period. Average monthly water levels are listed in table 5.

Water levels recorded at any well that taps unconsolidated material, such as well WE 3, probably reflect the seasonal and annual water-level trends in the bedrock. For example, the drought of the late 1960's is reflected in the recorded water levels of well WE 3 (fig. 5), as are unusually wet periods, 1972-73 and 1983-84.

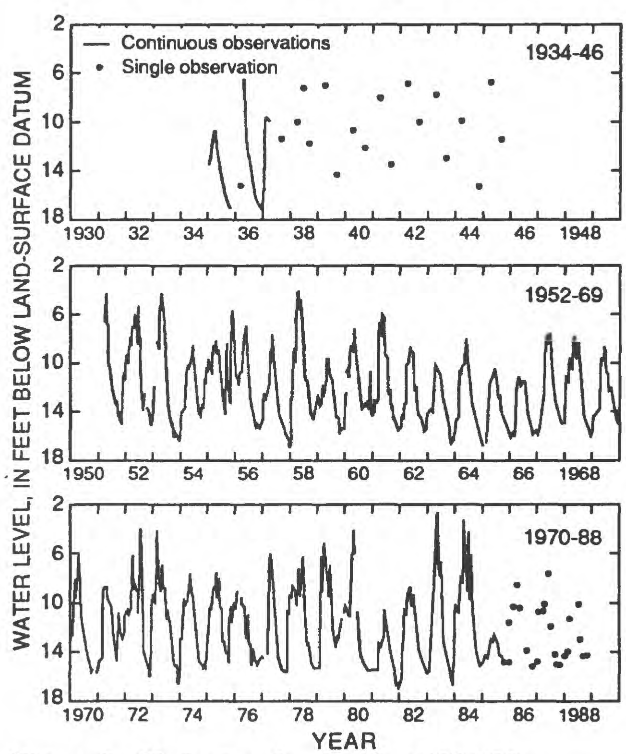


Figure 5.--Hydrographs showing 1934-88 ground-water levels at USGS observation well WE 3. (Location is shown in fig. 3.)

Effects of Pumping and Sewers.—Ground-water uses in the study area that strongly affect the ground-water flow system are (1) pumping for public supply, and (2) the subsequent exportation of this water through sewers. Public water-supply well locations, as determined by the New York

Table 5.—Average monthly water levels at well WE 3 for the period of record (1934-88).

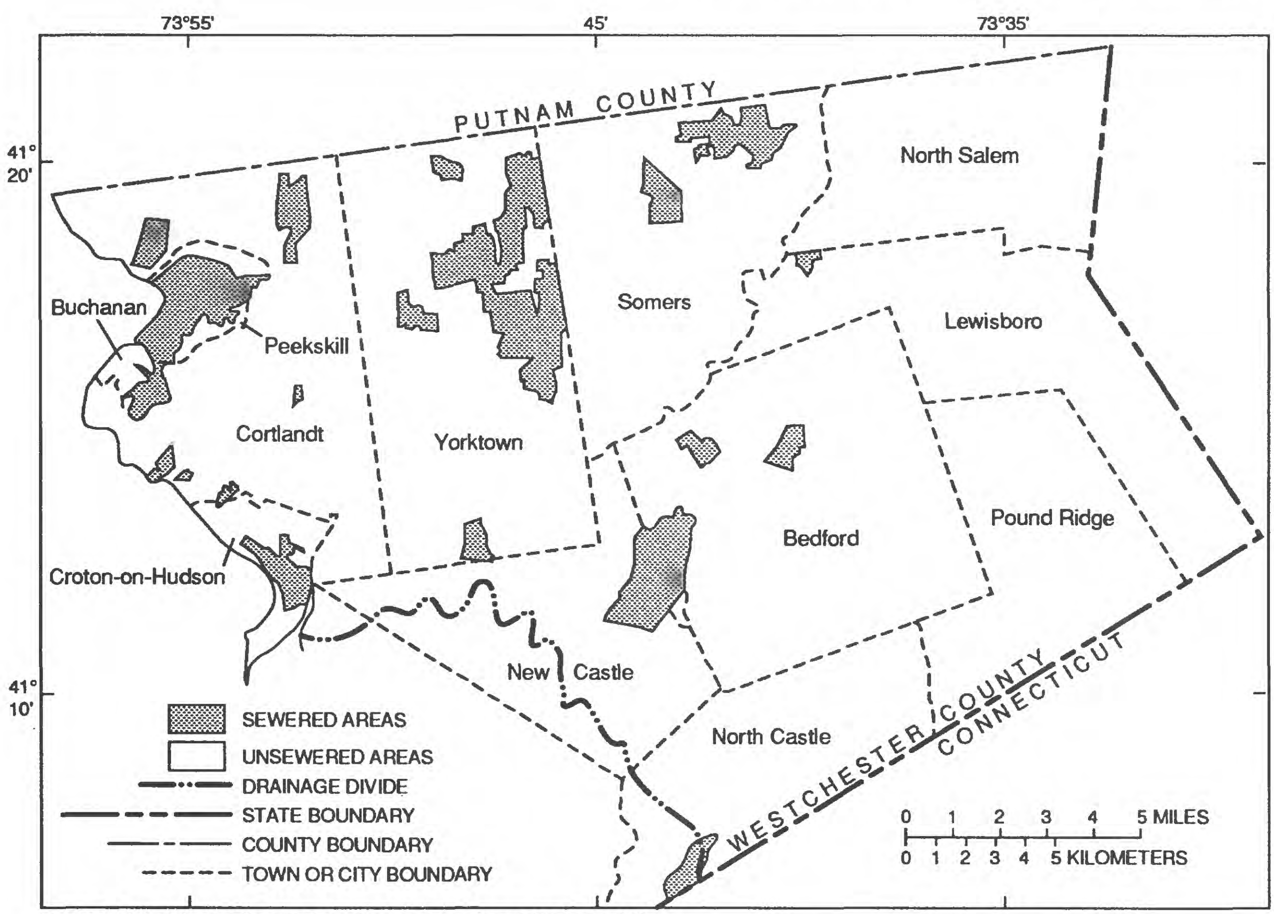
[Location is shown in fig. 3. Water levels are plotted in fig. 5.]

Month	Water level (feet below land surface)
January	12.74
February	11.67
March	9.85
April	8.44
May	9.17
June	10.67
July	12.53
August	13.80
September	14.08
October	14.81
November	14.74
December	13.96

Average annual water level = 12.21 ft below land surface

State Department of Health (1982), are shown in figure 3; these systems and the population served by each are listed in table 6. Average annual pumpage of these community water systems was documented and used in the model simulations described in section "Simulated Recharge."

Areas that are supported by public water-supply wells and also have community sewering are a special consideration in water-use assessments because the sewers prevent water that is pumped from an aquifer from being returned to the ground-water system. If annual pumpage exceeds annual recharge, ground water is removed from storage, and ground-water levels will decline. Locations of all areas in northern Westchester County that have community sewering are shown in figure 6 (Westchester County Department of Planning, 1982). In this study, withdrawals from domestic wells and associated recharge from septic systems were not included as a water-budget component because most of the water pumped from the aquifer is returned to the aquifer through septic systems.



Base from Westchester County Department of Planning, 1982, 1:114,000

Figure 6.--Areas served by community sewer systems in northern Westchester county in 1978 (Modified from Westchester County Department of Planning, 1982).

Table 6.—Public water-supply systems in northern Westchester County that use ground water, and population served by each system.

[Data from New York State Department of Health, 1982). Well locations are shown in fig. 3.]

New York State Department of Health Identification No.	Name of public water-supply system	Population served
1	Amawalk-Shenorock Water District	2,400
2	Bedford Consolidated Water District	6,150
3	Bedford Farms Water Company	280
4	Bloomerside Realty Inc.	300
6	Candlewood Park	175
7	Cedar Downs Water District	251
8	Croton Falls Water District	250
9	Croton-on-Hudson Village	7,000
10	Forest Park Water Company (Plant #3)	76
11	Goldensbridge Community Association	130
14	Horton Estates Water Trust	200
15	Indian Hill Subdivision	96
17	Juengstville Farm Association	50
18	Lake Katonah Club Inc.	390
19	Mount Kisco Village	8,200*
22	North Castle Water District #2	1,200
24	Pabst Water Company Inc.	260
25	Pamela Lane Water Supply	40
27	Pietschs Garden	250
30	Roosevelt Drive Water Users	84
31	Salem Acres Association	154
32	Sunset Ridge Water District	600
35	Truesdale Lake Property Owners Association	400
36	Twin Lakes Water Works Corporation	350
39	Westview Well Association	18
41	Wild Oaks Water Company	410
42	Windsor Oaks Property Owners Association	55
44	Yorktown Water Storage and Distribution	31,988*
46	Bedford Apartments	50
47	Bedford Hills Correctional Facility	800
48	Camp Smith	1,250
49	Danish Home for the Aged Inc.	25
50	Heritage Hill Water Works Corporation	1,200
53	Lincoln Hall School	unavailable
54	Marceca Buildings	unavailable
56	Oakridge Condominium	993
58	Somers Manor Nursing Home Inc.	500
59	The Farm P/O Wild Oaks Park Inc.	36
60	Wiltwyck School for Boys	50

*Wells supplement surface-water supply

COMPUTATION OF BEDROCK-AQUIFER RECHARGE

Recharge is the process through which water is added to the saturated zone. The primary source of recharge to an aquifer under natural conditions is precipitation that infiltrates the land surface and percolates to the water table. Inflow from adjacent aquifers or infiltration from streams can also be significant sources of recharge.

Estimation of Effective Recharge from Ground-Water Runoff

Under natural conditions, aquifer recharge in a steady-state ground-water system is equal to the aquifer discharge, which consists of ground-water runoff (stream base flow), underflow, and ground-water evapotranspiration. Under certain conditions, the effective recharge, which is ground-water recharge minus ground-water evapotranspiration, can be estimated from the ground-water outflow, the sum of ground-water runoff, and underflow.

A quantitative expression for the ground-water mass balance of a basin described by Cervione and others (1972) is:

$$GW_{recharge} = (GW_{runoff} + GW_{et} + U) + \Delta S, \quad (1)$$

where

$GW_{recharge}$ = ground-water recharge,
GW_{runoff} = ground-water runoff,
GW_{et} = ground-water evapotranspiration,
U = underflow,
ΔS = change in ground-water storage.

If the flow system is in a steady state, then ground-water storage remains constant, and equation 1 becomes

$$GW_{recharge} = GW_{runoff} + GW_{et} + U. \quad (2)$$

If the underflow is negligible, then ground-water outflow is equivalent to ground-water runoff. Thus, the ground-water runoff is a measure of the ground-water recharge less ground-water evapotranspiration. That is,

$$(GW_{recharge} - GW_{et}) = GW_{runoff}, \quad (3)$$

where

$(GW_{recharge} - GW_{et})$ = effective ground-water recharge.

If ground-water evapotranspiration is minimal, ground-water runoff is an approximation of basinwide ground-water recharge. Use of equation 3 to estimate effective ground-water recharge requires the following assumptions:

1. The ground-water flow system is under steady-state conditions—that is, ground-water storage undergoes no significant changes over a period of several years. Although storage within an aquifer usually fluctuates throughout the year, annually the system can be considered in steady state if ground-water storage, as indicated by the position of the water table, is the same at the end of an annual cycle as it was at the beginning.
2. Ground-water inflow from adjacent aquifers is negligible. To rule out inflow from adjacent aquifers, the system boundaries (ground-water divides) should be readily identifiable. In humid areas of moderate topographic relief, such as the study area, surface-water drainage divides at hilltops are generally reliable approximations of the location of ground-water divides.
3. Underflow is negligible, so that ground-water outflow is equivalent to ground-water runoff. If the downstream boundary of an aquifer crosses a stream, it should be where underflow is minimal so that the major component of ground-water outflow is ground-water runoff. To meet this criterion, choose a downstream boundary that crosses a stream in areas with little or no stratified drift.
4. Ground-water withdrawals are insignificant, or, if they are large, the same amount is returned to the ground-water system through septic systems or recharge wells. If significant amounts are exported from the basin, they should be subtracted from the calculated ground-water outflow during a period without withdrawals. Additionally, large ground-water withdrawals could cause ground-water drainage divides to expand in response to the increase in size of the capture zone.

Deviations from the above assumptions will decrease the reliability of using ground-water runoff as an estimate of effective recharge.

Annual ground-water runoff can be estimated from annual runoff, which is the sum of ground-water runoff and direct runoff. Cervione and others (1972) calculated the ground-water-runoff component (base flow) of the annual runoff of five stream sites in Connecticut by base-flow-separation analysis techniques and performed similar analyses of 17 other stream sites in Connecticut, Massachusetts, and New York. They also (1) measured the amount of stratified drift within each drainage basin because a previous study (Randall and others, 1966) had shown ground-water outflow to be highly correlated with the percentage of drainage area underlain by stratified drift, and (2) related ground-water outflow, as a percentage of total runoff, to the percentage of total drainage area underlain by stratified drift. From this relation, Mazzaferro and others (1979) estimated that ground-water outflow is 35 percent of the total runoff in areas of till and bedrock and 95 percent of the total runoff in stratified-drift areas.

Estimation of ground-water outflow as discussed above requires certain precautions:

1. Calculation of ground-water outflow by base-flow-separation analysis techniques can be uncertain because the available techniques give differing results.
2. The relation between mean annual runoff and ground-water outflow developed by Cervione and others (1972) and Mazzaferro and others (1979) was based on nonurban areas. Thus, application of this method to urban areas could lead to incorrect estimates of ground-water outflow.
3. The extent of stratified drift is generally estimated in a subjective manner that can lead to a range of interpretations that, in turn, can affect the estimated ground-water outflow value.

Example of Ground-Water Runoff Estimation

If the assumptions necessary to equate recharge to ground-water runoff have been reasonably met, estimates of the amount of water available to recharge till and bedrock can be calculated from the ground-water-runoff value, which in turn can be estimated from the following information:

1. total area of the drainage basin (in which surface-water divides approximate ground-water divides),
2. extent (in square miles) of till and bedrock within the drainage basin (total area of the drainage basin minus the area of stratified drift),
3. mean annual runoff (from Knox and Nordenson (1955) or other reliable source), and
4. a coefficient relating mean annual runoff to ground-water runoff from till and bedrock aquifers, as described by Mazzaferro and others (1979).

Most of the information required for computation of ground-water runoff in northern Westchester County is shown on 7.5 -minute topographic maps in figures 13A through 13I (at end of report). These maps show mean annual runoff (Knox and Nordenson, 1955), approximate areas underlain by stratified drift (Wolcott and Irwin, 1988, and Snow and Wolcott, 1992), and drainage-basin boundaries. Contours of mean annual runoff were interpolated from a 1:1,000,000-scale map (Knox and Nordenson, 1955) showing values of mean annual runoff at 2-in/yr intervals and derived from streamflow data collected during 1930-49. Areas of stratified drift are only approximate, however, because precise delineation was beyond the scope of the study. Surface-water divides that were used to delineate the drainage basins are assumed to represent ground-water divides.

The following is a step-by-step example for calculating the annual ground-water runoff from the till and bedrock aquifer in drainage basin 11H, in the Kisco River basin (location is shown in fig. 13G, p. 52-53):

1. Measure the total area of the drainage basin identified as 11H (1.90 mi^2, from table 12, p. 31-35).
2. Measure the total area underlain by stratified drift within basin 11H (0.10 mi^2).
3. Subtract the total area underlain by stratified drift from the total drainage basin area to obtain the area underlain by till and bedrock (1.90 - 0.10 = 1.80 mi^2).
4. Estimate the mean annual runoff at the centroid of basin 11H (28.4 in/yr).
5. Multiply the mean annual runoff estimated in step 4, above, by the total area of till and bedrock given in step 3, above, and the Mazzaferro and others (1979) ground-water outflow coefficient of 0.35 for till and bedrock, and by the appropriate unit-conversion factor to obtain the mean annual ground-water runoff from the till and bedrock aquifer, in million gallons per day (Mgal/d), in basin 11H, as follows:

   (28.4 x 1.80 x 0.35 x 0.04761 = 0.85 Mgal/d).

Similar quantities for the other 164 drainage basins in northern Westchester County (fig. 13) are given in table 12 (p. 31-35).

Estimates of Ground-Water Runoff

Values of ground-water runoff that approximate recharge to till and bedrock aquifers, calculated by the technique outlined above, are listed for each drainage basin in northern Westchester County in table 12 (p. 31-35). The values combine runoff from till and bedrock because this method cannot distinguish the runoff from till from runoff from bedrock. The combination of these components probably does not affect the result significantly, however, because thick till deposits are relatively sparse throughout most of the study area, except in the few areas where the till is extensive; in these areas, the estimate of amounts of water available for recharge to bedrock aquifers could be in error.

Model Simulation

A computer model that simulates three-dimensional ground-water flow in a selected 9.3-mi^2 area within the study area was used to verify and evaluate estimates of recharge calculated from ground-water runoff. The model grid is depicted in figure 7; the location is shown in figure 3.

Model Description

A modular three-dimensional finite-difference ground-water flow model developed by McDonald and Harbaugh (1988) was chosen to simulate ground-water flow. Flow is simulated in three dimensions through a block-centered finite-difference method. Components of the model that simulate various aspects of ground-water flow are modularized into subroutines. Subroutines relevant to ground-water flow in the study area are discussed in the following sections. The program was altered slightly from the documented version to accommodate larger data sets and the stream module developed by Prudic (1989).

Model grid.—The aquifer, which consists mostly of bedrock, is represented by a series of cells that form a grid. Each cell represents 200 ft^2 and is assumed to represent homogeneous material. The grid consists of 120 rows and 100 columns of cells that together represent a 17.2-mi^2 area. Ground-water flow is simulated only in the active area of the grid, which contains 9.3 mi^2. A major consideration was the size of each cell, which was based on the resolution needed to represent streams and abrupt changes in the irregular terrain. The grid is depicted in figure 7.

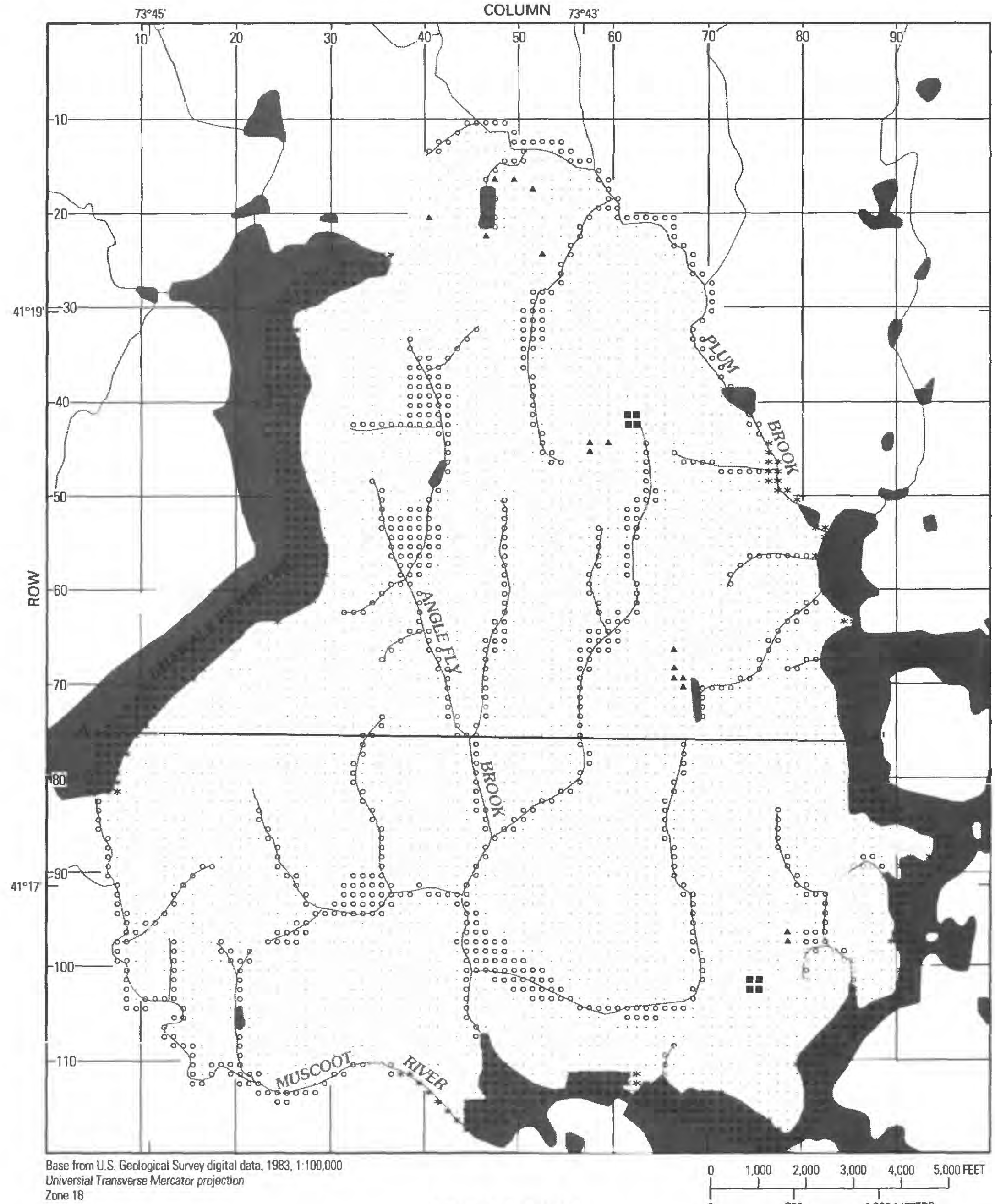
The model contains two layers, each of which represents a thickness of 150 ft thick. A generalized vertical section through the modeled area showing land surface and the upper and lower layers is given in figure 8. Because geophysical logs of wells surrounding the study area indicate that the most extensive fracturing is within the upper 150 ft, the upper layer represents that zone. Although the upper 150 ft contains mostly bedrock, it includes small areas of till and stratified drift. It was simulated with the confined/unconfined option of the modular model, whereby the upper layer is unconfined if hydraulic head is below land surface and confined if the head is above land surface. The ability to change from unconfined to confined conditions was necessary because the bedrock aquifer is unconfined in the uplands and confined in valley bottoms.

Regional flow, if present, would be simulated in the lower model layer because geophysical logs indicate a deep set of fractures in many areas through which regional flow would move. The lower layer was assumed to be confined under most conditions but could convert to unconfined where heads fell below the top of the lower layer. The model was constructed under the assumption that ground-water flow beneath the lower layer is negligible.

Model boundaries.—The Amawalk and Muscoot Reservoirs and Muscoot River and Plum Brook are the lateral boundaries of the upper model layer (fig. 7). A constant head was applied along the reservoirs because they are assumed to act as continuous sinks or sources to the surrounding aquifers. Muscoot River and Plum Brook were simulated with the stream package of Prudic (1989). Lateral flow beneath the boundary streams and reservoirs was assumed to be negligible; therefore a no-flow lateral boundary was placed in the lower layer. The streams and reservoirs are probably discharge areas for local ground-water flow and for most, if not all, large-scale ground-water flow in the model area. This assumption would not apply if stresses in the vicinity of the streams or reservoirs were significant, however.

The lower boundary of the model, as discussed earlier, is at the bottom of the lower layer, which is 300 ft below land surface. Because nearly all flow is within the upper and lower layers, 300 ft was judged an adequate depth for a no-flow boundary.

The upper boundary includes recharge to the upper layer, as discussed in detail below. The constant heads at the reservoirs and the specified heads in the streams at the model boundaries and



EXPLANATION

- Active flow cell
- * Constant-head cell
- ∘ Cell simulating stream or wetland as a head-dependent flux boundary
- ▲ Well simulating discharge from institutional or commercial pumping well (see table 7)
- ■ Well simulating recharge from septic system (see table 7)
- • Cell simulating stream as a head-dependent flux boundary with streamflow augmented by discharge of treated sewage
- A——A' Line of section shown in figure 8
- —— River or stream
- Surface-water body

Note: Each symbol represents a model cell with horizontal dimensions of 200 feet by 200 feet.

Figure 7.--Finite-difference grid and boundary conditions used to simulate ground-water flow in a selected area in northern Westchester County (Location is shown in fig. 3).

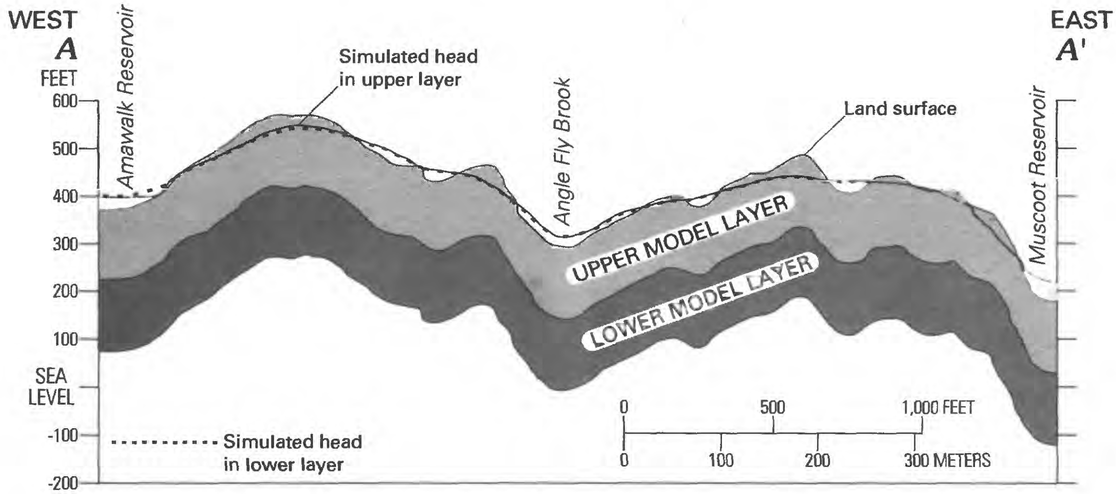


Figure 8.—Vertical section showing simulated heads and dimensions of model layers along section A-A.' (Location is shown in Fig. 7.)

in the interior of the model also provide an upper boundary for the model.

Streams.—In addition to the boundary streams, all interior streams were simulated with Prudic's (1989) stream package, which accounts for the exchange of water between the aquifer and stream and treats this flow as leakage through a semiconfining streambed. When heads in the aquifer are greater than the stage in the stream, leakage is from the aquifer to the stream (gaining stream) and when heads in the aquifer are less than the stage in the stream, leakage is from the stream into the aquifer (losing stream).

The simulated leakage rate and direction are dependent on: (1) differences between the head in the aquifer and the stage of the stream, and (2) streambed conductance (CRIV), defined as

$$CRIV = \frac{K_v LW}{m} \quad (4)$$

where

K_v = vertical hydraulic conductivity of streambed,

L = length of streambed within a model cell,

W = width of streambed within a model cell, and

m = streambed thickness.

A vertical hydraulic conductivity of 1 ft/d and a thickness of 1 ft was assumed for all streambeds throughout the model area. This includes the Muscoot River and Plum Brook as well as all interior streams. An initial streambed vertical hydraulic conductivity of 1 ft/d was chosen on the basis of work by Reynolds (1987) and adjusted during model calibration. Stream stages and streambed areas were estimated from U.S. Geological Survey 7.5-minute topographic quadrangles. The locations of stream cells are shown in figure 7.

Recharge.—Recharge values were calculated by the method described in the "Estimation of Effective Recharge from Ground-Water Runoff" section. In the model, recharge was applied to all upper-layer cells except constant-head cells that were used to simulate water levels in the reservoirs. Recharge was not applied to constant-head cells because these cells represent an unlimited sink or source of water, and recharge would contribute only to the surface-water system. Ideally, a recharge value for till and bedrock and a different recharge value for stratified drift would be used in the evaluation of recharge estimates, but this was not done because stratified-drift deposits within the model area are thin and discontinuous and would have been difficult to represent accurately; therefore, a uniform recharge rate was calculated for the modeled area. Stratified drift covers 6 percent of the total model area and is estimated to contribute 19.91 in/yr to the total recharge, whereas till and bedrock form 94 percent of the total model area and contribute 8.45 in/yr; the average, 9.17 in/yr, was distributed evenly over the model area.

Hydraulic conductivity.—In theory, each cell within the model represents aquifer material that is homogeneous and isotropic. Horizontal hydraulic conductivity was estimated to be between 0.001 ft/d and 10 ft/d. These estimates were derived from published ranges for fractured igneous and metamorphic rocks (Heath, 1983) and an analysis of aquifer tests conducted in the study area. (See section "Hydraulic Characteristics of Bedrock".) Hydraulic conductivity, which is a function of the number, size, and degree of interconnection of secondary openings in the bedrock, was initially believed to be closely related to the bedrock composition, but calibration tests (discussed later) indicated that the topographic setting was the major factor in the distribution of hydraulic conductivity.

Horizontal hydraulic conductivity was estimated to be twice as great in the upper layer as in the lower layer because the fracture density generally decreases with increasing depth. The caliper logs for wells near the model area (fig. 4) support this assumption.

The vertical movement of ground water from the upper to the lower layer is simulated by vertical leakage and is dependent on the vertical hydraulic conductivity of both layers. Vertical leakance (conductance) for a particular cell is calculated by:

$$\text{Vertical leakance} = \frac{2}{\dfrac{b_1}{Kv_1} + \dfrac{b_2}{Kv_2}}, \qquad (5)$$

where

Kv_1 and Kv_2	=	vertical hydraulic conductivity of cells in the upper and lower layers
b_1 and b_2	=	saturated thickness of cells in the upper and lower layers.

The vertical hydraulic conductivity values are assumed to be one-half the horizontal values—that is, the ratio of vertical to horizontal hydraulic conductivity (anisotropy) is 1:2.

Effects of pumping and sewers.—Institutional and commercial pumping was simulated at 1986 pumping rates. One-half of the withdrawal rate from each well that taps bedrock was assigned to each model layer because the depth of the source of water from the bedrock wells was unknown. Withdrawals from domestic wells were not included in this model because (1) they were minor, and (2) the water withdrawn is subsequently returned indirectly to the aquifer through in-ground septic systems.

Recharge wells were used to simulate the return of commercial and institutional water through extensive septic systems. Those systems were simulated in the upper layer only. The septic systems were included because the quantities were large enough to alter local ground-water flow directions.

Discharges from commercial sewage-treatment plants were simulated with the stream module of Prudic (1989) through addition of sewage-treatment plant effluent to the average streamflow. Flow from these plants reenters the ground-water system only when head in the aquifer is less than the stream stage.

The locations of pumped wells, recharge wells that simulate septic systems, and cells at which streamflow is augmented by discharge from sewage-treatment plants are shown in figure 7. The rates of withdrawal from pumped wells and the rates of recharge from septic systems are listed with their associated model layer in table 7.

Model Calibration

The steady-state model was calibrated to ground-water levels and streamflows measured in mid-November 1987. The average annual long-term (1934-88) water level at observation well WE 3, about 3.5 mi southwest of the model area (fig. 3) was 12.2 ft below land surface. The minimum monthly water level is 14.8 ft below land surface in October, and the maximum monthly water level is 8.4 ft in April. Water levels measured before and after the data-collection period (October 26, 1987 through December 7, 1987) were 15.0 ft and 14.4 ft below land surface, respectively, slightly less than the yearly average. The average annual stream discharge for 24 years of record (1965-88) at a gaging station at nearby Saugatuck River near Redding, Conn. (01208990, fig. 3) was 25.8 ft^3/s, and average streamflow at this site for November 1987 was 31.8 ft^3/s, only slightly greater than the long-term annual average. Thus, the water-level and streamflow data set used for calibration was assumed to approximate average annual steady-state conditions, and the model was considered calibrated when simulated heads and stream-seepage rates approximated the observed data.

Table 7.—1986 ground-water withdrawals from pumped wells and recharge from septic systems used in a steady-state model simulation.

[Locations are shown in fig. 7.]

	USGS local well no.		Model		Pumping Rate (gallons per day)	
			Row	Column	Upper layer	Lower layer
Withdrawals from pumping wells						
Somers Manor Nursing Home	WE	2037	67	67	2000	2000
do.	WE	3898	69	67	2000	2000
do.	WE	3910	70	67	2000	2000
do.	WE	3911	70	68	2000	2000
do.	WE	3912	71	68	2000	2000
Primrose Elementary School	WE	3913	45	60	480	480
do.	WE	3914	45	58	480	480
do.	WE	3915	46	58	480	480
Pepsico Corporate Headquarters	WE	3907	97	79	6500	6500
do.	WE	3908	98	79	6500	6500
Lincoln Hall School	WE	1214	23	47	710	710
do.	WE	1215	18	52	4170	4170
do.	WE	1216	21	41	2600	2600
do.	WE	3918	17	48	3740	3740
do.	WE	3919	25	53	3360	3360
do.	WE	3920	17	50	2400	2400
				Total	41,420	41,420
Recharge from septic systems						
Pepsico Corporate Headquarters	—	—	102	75	5000	—
do.	—	—	102	76	5000	—
do.	—	—	103	75	5000	—
do.	—	—	103	76	5000	—
Primrose Elementary School	—	—	43	62	720	—
do.	—	—	43	63	720	—
do.	—	—	44	62	720	—
do.	—	—	44	63	720	—
				Total	28,800	

The calibration procedure consisted of adjusting the horizontal and vertical hydraulic conductivity values of the aquifer and the streambed conductance. Stream cells at wetland areas that are hydraulically connected to the ground-water system were added as needed. The calculated recharge rate was held constant. Horizontal and vertical hydraulic conductivity values were adjusted within the ranges obtained from the field data (see "Hydraulic Characteristics" section) and the literature (Heath, 1983). Streambed-conductance values were varied.

The distribution of head throughout the model area and the root mean square error of the differences between the computed and observed heads were the primary method for evaluating whether the head data were accurately represented in the model. The layer represented by the measured head data from most bedrock wells could not be determined because geophysical logs were not available. Therefore, the measured water levels were used to approximate the root-mean-square error for both layers.

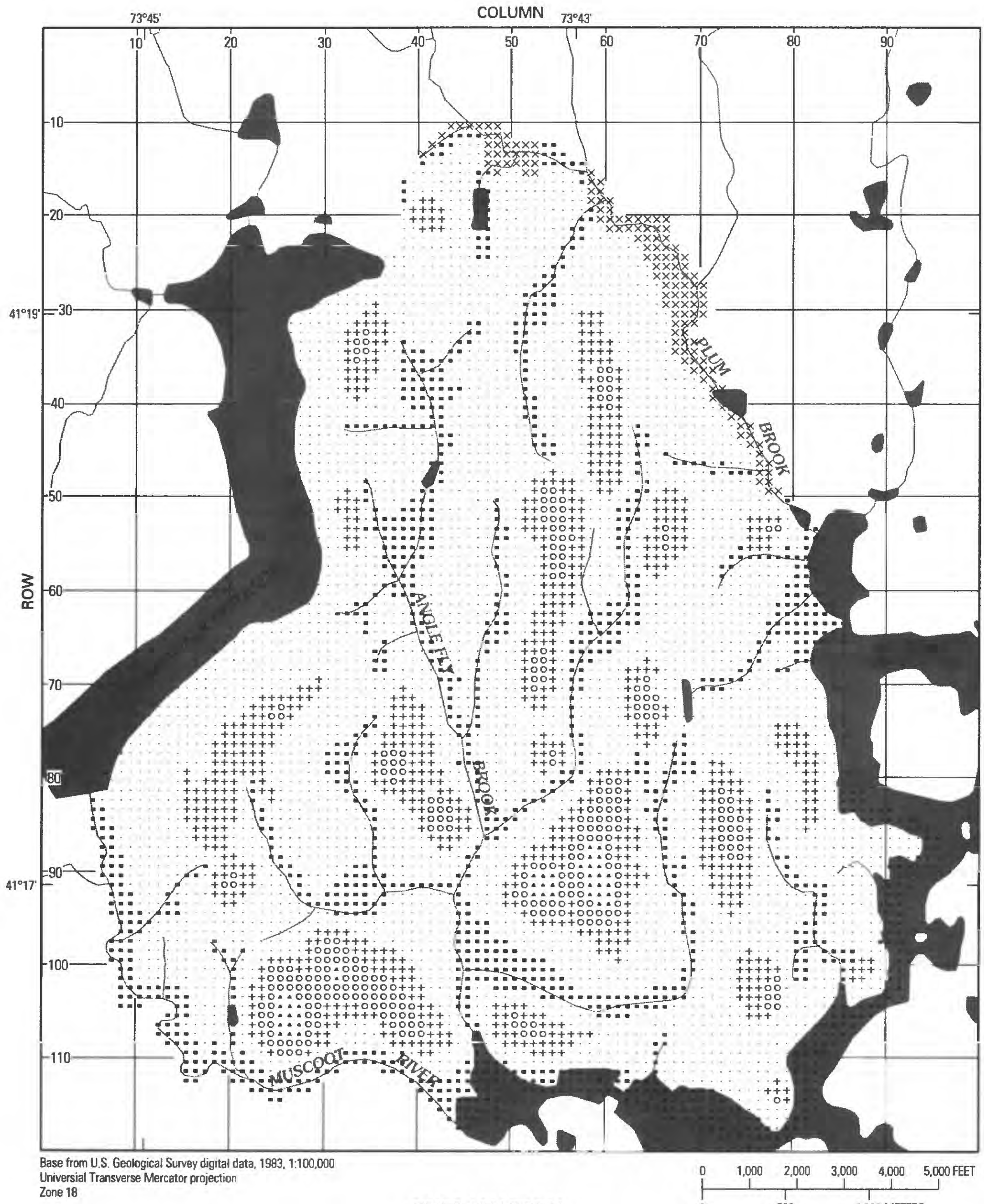
Model-generated streamflows were compared with measured streamflows to assess the reliability of the model. Streamflows at Saugatuck River near Redding, Conn., had a flow duration of about 37 percent, which indicates that, during the data-collection period, a part of the total runoff was direct runoff. Therefore, the ground-water contribution to the total runoff as computed by the model should not exceed the measured streamflow.

The hydraulic conductivity values used in the model were adjusted according to their topographic setting. During initial calibration attempts, hydraulic conductivity values were adjusted in relation to the specific bedrock unit because each unit was believed to have unique hydraulic properties. Various combinations and ranges were tried, but none realistically depicted the distribution of measured head throughout the model area or decreased the root-mean-square error between the computed and measured heads. Specific capacity of bedrock wells in Westchester, as tabulated by Van der Leeden (1962), indicate only slight differences among the dominant bedrock units in the model area. Data compiled by Williams and Eckhardt (1987) on bedrock aquifers in east-central Pennsylvania indicate that specific capacity is greatest in valley bottoms and decreases with increasing altitude. This is due to (1) the increased fracturing in the valley bottoms, (2) steep lateral hydraulic gradients toward the valleys, and (3) greater thickness of permeable unconsolidated material in the valley bottoms than elsewhere that enables bedrock in valleys to receive greater amounts of recharge and contain more ground water in storage than upland till. Williams and Senko (1988) used topographic setting as a basis for adjustment of hydraulic conductivity values of fractured bedrock simulated in a ground-water flow model of an area in east-central Pennsylvania. The topographic settings and associated hydraulic conductivity values used in the northern Westchester model are indicated in figure 9. Most hydraulic conductivity adjustments were based on the topographic setting and location of areas of extensive stratified drift, where they were increased to reflect the higher hydraulic conductivity of that material.

Calibration tests to determine model sensitivity to the vertical leakance between the upper and lower layers showed that changes in vertical leakance have a negligible effect on the distribution of head. The head distribution proved to be much more sensitive to changes in horizontal hydraulic conductivity than to changes in vertical leakance. Therefore, final vertical hydraulic conductivity values for the upper and lower layers were equal to only half the horizontal hydraulic conductivity values. (See fig. 9.)

Streambed conductance was also adjusted over a range of values to assess its effect on head distribution. Calibration tests indicated that variation over a reasonable range of streambed conductance did not affect the head distribution, root-mean-square error, or the rate of ground-water discharge to nearby streams. A final vertical hydraulic conductivity of 1 ft/d was used for the streambed in the calibrated model.

Of critical importance in achieving a calibrated model was the location and number of stream cells in which water either discharges to or is discharged from the stream. The initial calibration tests simulated only streams that appear on the USGS 7.5-minute quadrangles, but the number of stream cells was increased during calibration to give realistic heads in topographically low areas, where ground water was discharging to small, intermittent streams not shown on the maps. Because several swamp and wetland areas in the model still did not yield reasonable head distribution, additional stream cells were added at selected swamp locations on the assumption that swamps are hydrologically similar to streams. In almost all model runs, the streams and swamps acted as discharge areas for the ground-water system. The final locations of stream cells are shown in figure 7, and sites where discharge measurements were made for verification of model results are indicated in figure 10A (p. 22). Simulated and measured discharges are listed in table 8. As previously noted, part of the measured discharge consists of direct runoff; therefore, the measured discharge at each stream should be greater than the simulated value.



EXPLANATION

Topographic settings	Symbol	Hydraulic Conductivity, in feet per day Upper layer	Lower layer
Hilltop	•	0.010	0.005
Hilltop or valley side	o	0.030	0.015
Valley side	+	0.080	0.040
Valley side or valley bottom		0.150	0.075
Valley bottom	▪	0.250	0.125
Valley bottom with extensive stratified drift	×	0.500	0.125

——— **River or stream** ■ **Surface-water body**

Note: Each symbol represents a model cell with horizontal dimensions of 200 feet by 200 feet.

Figure 9.--Topographic setting and associated horizontal hydraulic conductivity value for each model cell used in the steady-state simulation.

Table 8.—Measured streamflow and simulated ground-water discharge to streams at selected sites.
[Site locations are shown in fig. 10A. Flows are in cubic feet per second.]

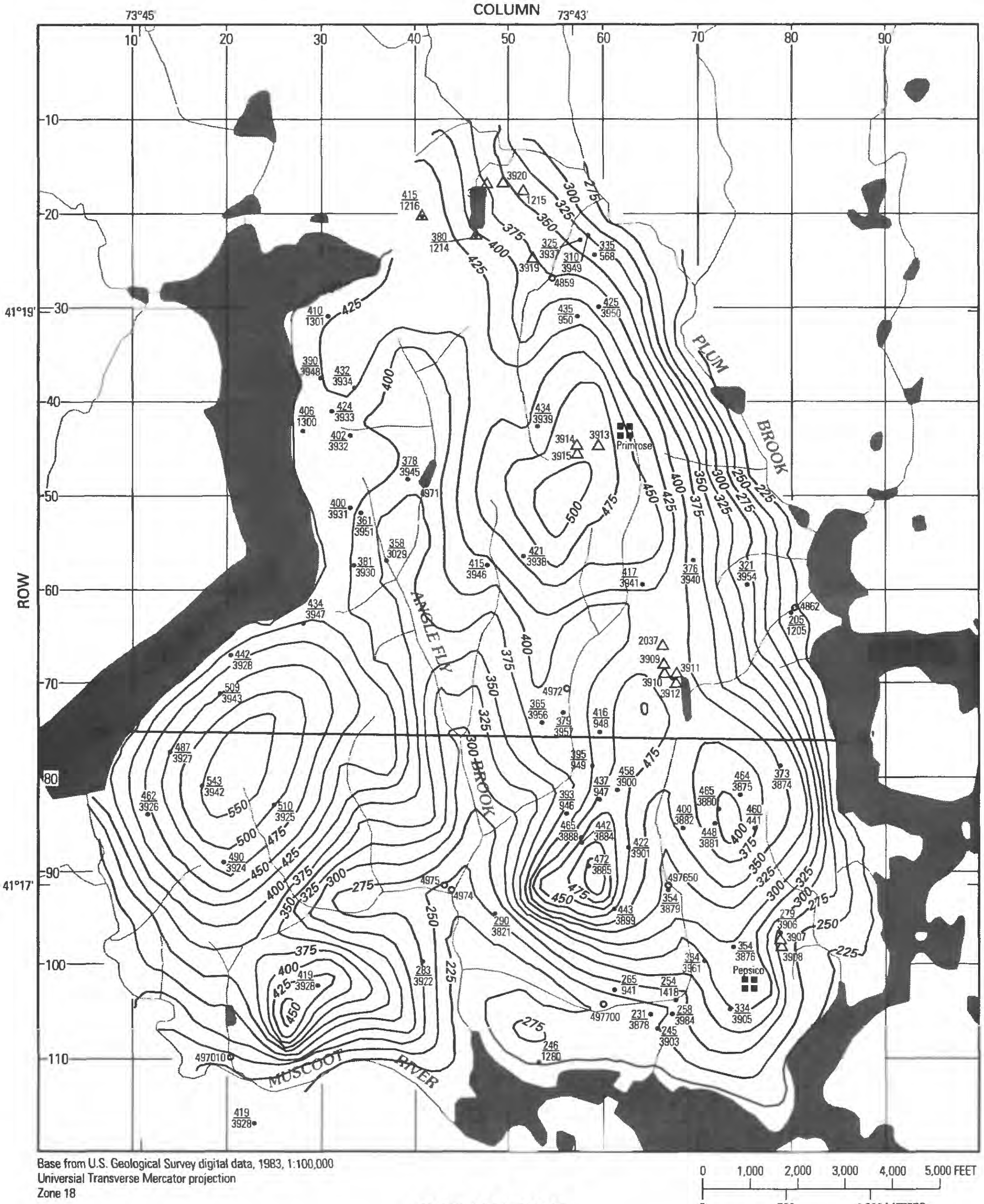
USGS Stream Site Number	Stream name	Model Row	Model Column	Measured streamflow	Date	Simulated ground-water discharge to the stream
01374859	Plum Brook tributary at Lincolndale, N.Y.	28	55	0.55	11-16-87	0.19
01374862	Muscoot Reservoir tributary 2 near Goldens Bridge, N.Y.	63	81	.27	11-16-87	.14
01374977	Angle Fly Brook tributary at site 5 near Katonah, N.Y.	105	60	.75	11-16-87	.37
0137497650	Angle Fly Brook tributary at site 1 near Katonah, N.Y.	91	67	.29	11-16-87	.14
0137497010	Muscott River tributary near Whitehall Corners, N.Y.	112	22	.05	11-16-87	.06
01374975	Angle Fly Brook tributary 3 near Whitehall Corners, N.Y.	93	43	.87	11-16-87	.47
01374974	Angle Fly Brook near Whitehall Corners, N.Y.	93	45	3.49	11-16-87	1.48
01374972	Angle Fly Brook tributary 2 at Lincolndale, N.Y.	72	57	.36	11-16-87	.23
01374971	Angle Fly Brook at Lincolndale, N.Y.	50	42	.46	11-17-87	.30

Results of Simulation

The locations of observation wells and simulated heads for the upper and lower layers are shown in figures 10A and 10B, respectively; the differences between the measured and simulated heads are listed in table 9. The root-mean-square error was 17.5 ft. The head data indicate that ground-water flow is downward near hilltops and ridges and upward toward nearby streams and rivers. No dominant regional flow pattern is evident in this area.

The ground-water budget for the model simulation (table 10, p. 25) indicates the distribution of ground-water inflow and outflow within the simulated ground-water system. This ground-water budget represents a steady-state simulation of average annual ground-water levels and ground-water flow.

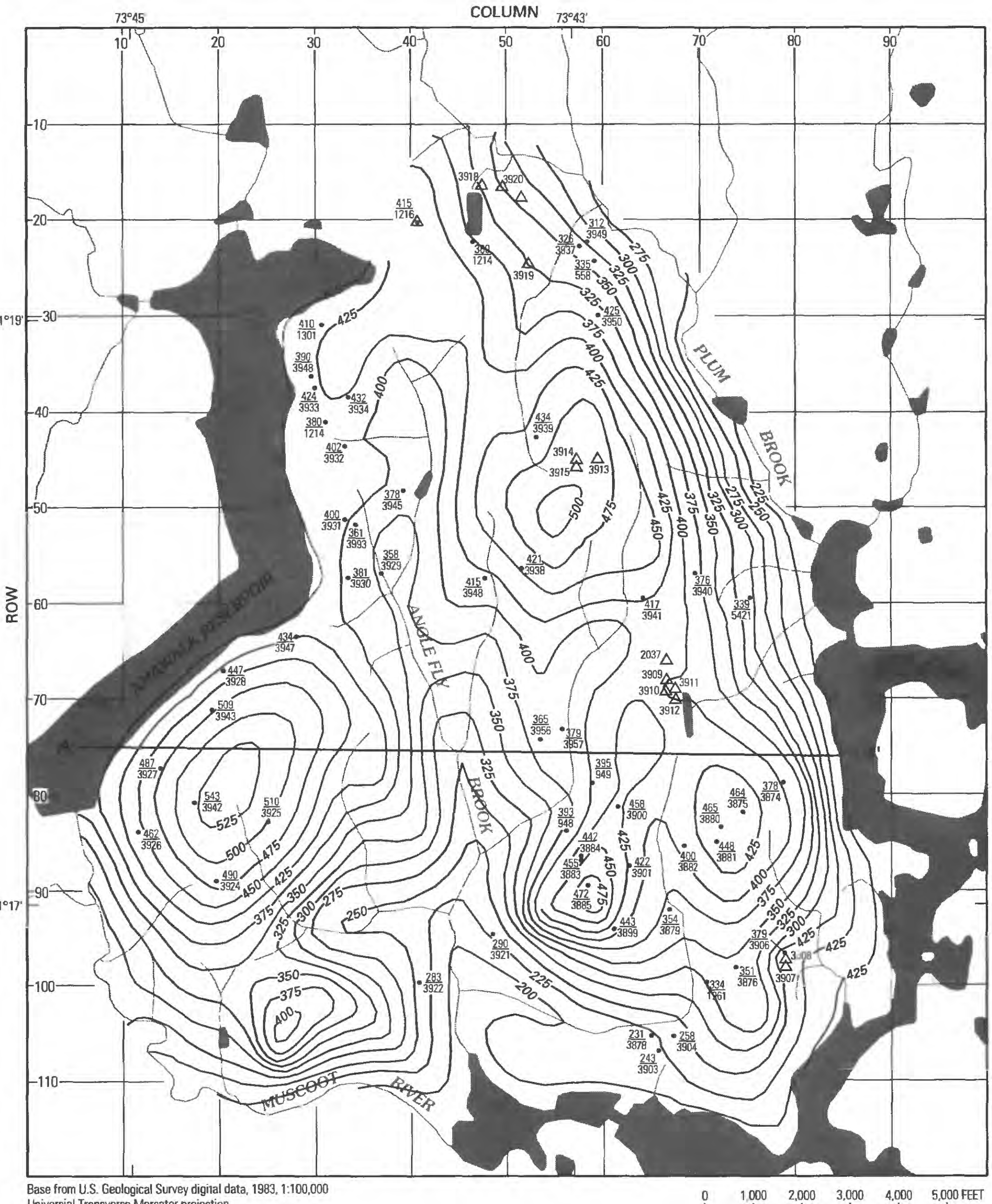
The average annual recharge values computed by the method described in the "Estimation of effective recharge from ground-water runoff" section and used in model calibration closely approximate the average annual natural recharge, as evidenced by the reasonable match between the simulated and measured heads and ground-water discharge to streams. This result reflects the use of expected ranges for hydraulic conductivity of fractured bedrock and streambed conductance derived from the literature. The calibration tests also indicated that a reasonable match between simulated and measured values is highly dependent on the correct placement of stream nodes and ground-water boundaries. During calibration, values of these hydraulic properties were kept within reasonable limits, and recharge was kept at a constant rate. If the assumptions regarding the location of stream nodes and model boundaries and ranges of hydraulic properties are correct, the values of recharge can be considered valid.



EXPLANATION

- 3908△ **Production well**--Number is USGS well-identification number without the "WE" prefix (see table 7)
- Pepsico■ **Septic system**--Shortened name of septic-system owner (see table 7)
- 4862○ **Streamflow-measurement site**--Number is USGS streamflow-site-identification number without the prefix "0137" (see table 8)
- $\frac{419}{3928}$• **Observation well**--Upper number is observed water level, in feet; lower number is USGS well-identification number without the "WE" prefix (see table 9)

Figure 10A.--Simulated heads in upper model layer under average steady-state condition.



Base from U.S. Geological Survey digital data, 1983, 1:100,000
Universal Transverse Mercator projection
Zone 18

0 1,000 2,000 3,000 4,000 5,000 FEET

0 500 1,000 METERS

EXPLANATION (continued)

A——A' **Line of section shown in figure 7**

—400— **Line of equal head simulated by ground-water flow model**--Interval is 25 feet

River or stream

Surface-water body

Figure 10B.--Simulated heads in lower model layer under average steady-state conditions.

Table 9.—Measured and simulated water levels at selected wells in the model area.

[Water levels and differences are in feet above sea level. Well locations and observed water levels are shown in figures 10A and(or) 10B. Blank space in date column indicates date unknown.]

USGS	Model				Water levels		
well no.	Layer [a]	Row	Column	Date	Measured [b]	Simulated [a]	Difference [c]
WE 441	upper	86	76	4-27-51	460	430.8	29.2
WE 558	upper/lower	25	60	9-29-50	335	334.6	-6.5
WE 941	upper	103	61	12- -50	265	257.5	7.5
WE 946	upper/lower	84	56	12-29-50	393	371.3	21.7
WE 947	upper	83	60	12-29-50	437	432.4	4.6
WE 948	upper	76	60	12-29-50	416	413.4	2.6
WE 949	upper/lower	79	59	12-29-50	395	395.4	-0.4
WE 950	upper	31	57	12-29-50	435	409.5	25.5
WE 1205	upper	63	80	12- -50	205	230.8	-25.8
WE 1214	upper/lower	23	47	12- -50	380	398.8	-18.8
WE 1216	upper/lower	21	41	12- -50	415	430.2	-15.2
WE 1280	upper	111	53	1- -51	246	223.6	22.4
WE 1300	upper	43	28	1- -51	406	403.7	2.3
WE 1301	upper/lower	32	31	1- -51	410	420.8	-10.8
WE 1418	upper	104	68	11- -52	254	266.2	-12.2
WE 3874	upper/lower	79	79	11-17-87	373	398.9	-25.9
WE 3875	upper/lower	82	75	11-17-87	464	439.7	24.3
WE 3876	upper/lower	99	74	11-17-87	354	347.3	6.7
WE 3878	upper/lower	106	65	10-21-86	231	242.3	-11.3
WE 3879	upper/lower	93	67	10-21-86	354	369.8	-15.8
WE 3880	upper/lower	84	72	10-22-86	465	440.8	24.2
WE 3881	upper/lower	86	72	10-22-86	448	437.3	10.7
WE 3882	upper/lower	86	68	10-22-86	400	398.7	1.3
WE 3883	upper/lower	88	58	11-18-87	455	457.4	-2.4
WE 3884	upper/lower	87	58	11-18-87	442	442.1	-0.1
WE 3885	upper/lower	90	59	10-21-86	472	496.5	-24.5
WE 3899	upper/lower	95	61	10-23-86	443	418.3	24.7
WE 3900	upper/lower	82	62	11-17-87	458	433.2	24.8
WE 3901	upper/lower	88	63	10-23-86	422	427.6	-5.6
WE 3903	upper/lower	107	66	11-17-87	243	248.8	-5.8
WE 3904	upper/lower	106	68	11-17-87	258	261.2	-3.2
WE 3905	upper	105	74	11-17-87	334	325.4	8.6
WE 3906	upper/lower	97	79	11-17-87	279	259.2	19.8
WE 3921	upper/lower	95	49	11-17-87	290	252.3	37.2
WE 3922	upper/lower	100	41	11-18-87	283	276.0	7.0
WE 3923	upper	103	30	11-17-87	419	432.5	-13.5
WE 3924	upper/lower	89	20	11-17-87	490	486.8	3.2
WE 3925	upper/lower	84	25	11-17-87	510	504.9	5.1
WE 3926	upper/lower	84	12	11-18-87	462	441.1	20.9
WE 3927	upper/lower	78	14	11-19-87	487	466.3	20.7
WE 3928	upper/lower	68	21	10-07-87	447	436.9	10.1
WE 3929	upper/lower	57	37	11-18-87	358	372.8	-14.8
WE 3930	upper/lower	58	34	11-18-87	381	398.0	-17.0
WE 3931	upper/lower	52	33	11-18-87	400	410.4	-10.4
WE 3932	upper/lower	44	33	11-18-87	402	417.9	-15.9

Table 9.—Measured and simulated water levels at selected wells in the model area (continued).

USGS	Model				Water levels		
well no.	Layer [a]	Row	Column	Date	Measured [b]	Simulated [a]	Difference [c]
WE 3933	upper/lower	42	31	11-18-87	424	420.6	3.4
WE 3934	upper/lower	39	34	11-18-87	432	427.2	4.8
WE 3937	upper/lower	23	58	10-08-87	325	328.9	-3.9
WE 3938	upper/lower	57	51	11-18-87	421	445.1	-24.1
WE 3939	upper/lower	44	53	11-18-87	434	454.2	-20.2
WE 3940	upper/lower	57	70	10-17-87	376	387.4	-11.4
WE 3941	upper/lower	60	64	11-17-87	417	428.4	-11.4
WE 3942	upper/lower	82	18	11-18-87	543	523.5	19.5
WE 3943	upper/lower	72	20	11-18-87	509	476.1	32.9
WE 3945	upper/lower	49	40	11-18-87	378	388.5	-10.5
WE 3946	upper/lower	58	48	11-18-87	415	417.9	-2.9
WE 3947	upper/lower	64	29	11-19-87	434	424.5	9.5
WE 3948	upper/lower	38	30	11-19-87	390	418.0	-28.0
WE 3949	upper/lower	23	59	11-19-87	310	320.1	-10.1
WE 3950	upper/lower	30	60	11-19-87	425	382.4	42.6
WE 3953	upper/lower	52	35	11-19-87	361	394.5	-33.5
WE 3954	upper/lower	60	76	11-19-87	321	304.7	16.3
WE 3956	upper/lower	75	54	2-05-87	365	384.1	-19.1
WE 3957	upper/lower	74	56	2-05-87	379	385.5	-6.5
WE 3961	upper/lower	100	71	10-23-86	334	322.4	11.6

a When both upper and lower model layers are indicated in the "model layer" column, the simulated water level is the average of the simulated values.

b The "measured" water level is the depth to water below land surface at the observation well, subtracted from the land-surface altitude of the model cell nearest the observation well.

c The root-mean-square-error is 17.5 feet.

Table 10.—Simulated ground-water budget for the till/bedrock aquifer under average steady-state conditions.

	Yield	
	(million gallons per day	(cubic feet per second)
Aquifer recharge		
Direct areal recharge (9.17 in/yr)	3.67	5.68
Constant-head boundaries (flow from reservoirs to aquifer)	.02	.03
Recharge wells (septic systems, see table 7)	.02	.04
Leakage from streams	.15	.23
TOTAL	3.86	5.98
Aquifer discharge		
Pumping wells (see table 7)	.08	.13
Constant-head boundaries (ground-water flow to reservoirs)	.72	1.11
Leakage to streams	3.06	4.74
TOTAL	3.86	5.98

CHEMICAL QUALITY OF WATER FROM BEDROCK AQUIFERS

Water samples from 53 wells that tap bedrock aquifers throughout the study area (fig. 3) were analyzed to establish a water-quality baseline. Analyses for major anions were done in the USGS laboratory in Albany, N.Y., and analyses for other constituents and characteristics were done in the USGS National Water-Quality Laboratory in Arvada, Colo. Results are presented in table 13 (p. 36-39). The data in table 13 are not grouped by bedrock unit because generally only the first bedrock unit penetrated was known, and whether that formation was the main source of water to an individual well could not be determined.

Most samples were collected from wells of homeowners. Water systems with mechanical filters and chemical water conditioners were not sampled because the samples would not represent untreated formation water. Before each sample collection, the tap water was allowed to run until the water temperature had stabilized. Temperature was used as an indicator to ensure that the water sample collected was from the bedrock aquifer and not from the home storage tank.

Samples were collected once in the fall of 1986 and again in the spring of 1987 at selected wells for evaluation of seasonal variations. The analyses indicated no apparent patterns in water quality.

Ground water from bedrock aquifers in the study area is mainly the calcium-bicarbonate type, as summarized in a Piper diagram in figure 11. The Piper diagram shows the percentages of total milliequivalents per liter for the major dissolved constituents and represent one analysis from each of the 53 wells sampled. Some wells indicate higher than expected percentages of chloride; this could possibly be attributed to road-deicing salt or domestic septic systems.

Most of the ranges and median values presented in the following discussions of major constituents are based on the more recent (spring 1987) sample from each well.

Specific Conductance

Specific conductance is a measure of the electrical conductivity of an aqueous solution at 25 °C and is measured in units of microsiemens per centimeter at 25 °C (µS/cm). Charged ionic species in solution make the solution conductive; therefore, increased ion concentrations result in elevated specific conductance (Hem, 1985). Specific conductance values ranged from 96 to 1,060 µS/cm; the median value was 232 µS/cm. Water with high specific conductance can corrode steel and iron through its high potential for electrochemical action. The U.S. Environmental Protection Agency (USEPA) has not established standards for specific conductance but has recommended ranges for many of the ion species that cause elevated specific conductance.

pH

pH is the measure of hydrogen-ion activity, expressed as a negative logarithm to base 10; pH values of samples ranged from 5.8 to 9.9 and had a median of 7.10. Generally ground water that is either excessively basic or acidic can be corrosive and has the potential to mobilize metal ions (U.S. Environmental Protection Agency, 1986). Water with pH outside the 5.0-to-9.0 range requires treatment. The USEPA (1976) has recommended a pH range of 5.0 to 9.0 for domestic water supplies.

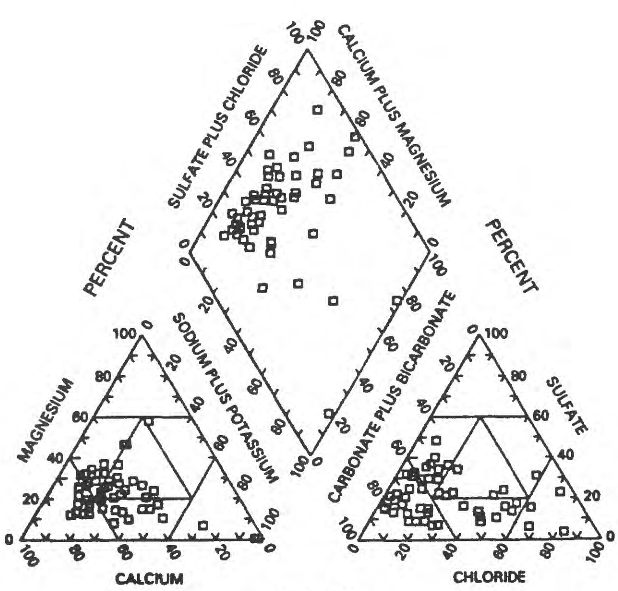


Figure 11.--Trilinear diagram showing chemical quality of ground water as percentage of total milliequivalents per liter. (Based on chemical analysis of most recent sample from each of the 53 bedrock wells used.)

Temperature

The temperature of ground water in the study area is primarily a function of (1) air temperature, (2) geothermal gradient, (3) thermal conductivity of the rock, and (4) ground-water flow paths (Driscoll, 1986; Williams and Eckhardt, 1987). The temperature of water discharged from the 53 sampled wells ranged from 11.5 to 19.0 °C, and the median was 13.0 °C. A temperature log for well WE 2118 is shown in figure 12. This log is representative of the temperature distribution at wells within the study area.

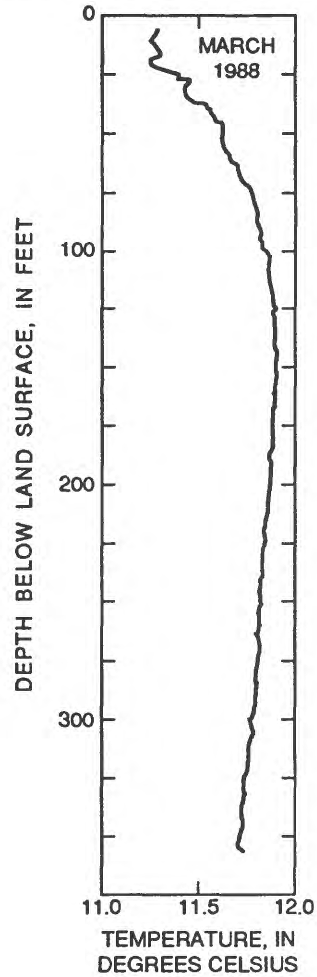


Figure 12.--Temperature log for test well WE 2118. (Well location is shown in fig. 3.)

Hardness

Water hardness is a measure of dissolved-solids concentration and results mainly from calcium and magnesium ions. Water from soluble carbonate rocks, such as the Inwood Marble, commonly is extremely hard. Minerals such as the pyroxenites and amphibolites in igneous rocks that are common throughout the study area contain magnesium, which can also contribute to hardness (Hem, 1985). Hardness is most comonly reported as an equivalent concentration of calcium carbonate, in milligrams per liter.

Excessive hardness is most damaging in pipes, boilers and water heaters, where even small increases in water temperature can cause formation of insoluble carbonate precipitates, known as scale. If the precipitates become thick, the water-carrying capacity of pipes and the efficiency of boilers and heaters can decrease significantly (Chandler, 1989). Hard water requires more soap for lathering than soft water and can leave insoluble deposits on plumbing fixtures.

Hardness is generally categorized as soft, moderately hard, hard, or very hard. The categories and associated hardness ranges are summarized in table 11. Water hardness at the 53 wells ranged from very soft (4 mg/L) to very hard (410 mg/L); the median value was 82 mg/L (moderately hard).

Table 11.—Classification of water hardness.
[From U.S. Environmental Protection Agency, 1976.]

Hardness Range (milligrams per liter)	Description
0-60	soft
61-120	moderately hard
121-180	hard
more than 180	very hard

Sodium

Sodium is highly soluble and tends to remain in solution; therefore, it is found in a wide range of concentrations. This was not evident at the 53 wells sampled in the study area, however. Concentrations ranged from 3.7 mg/L to 98 mg/L; the median concentration was 7.9 mg/L. Sodium is most abundant in igneous and sedimentary rocks; thus, the predominance of metamorphic rock in the study area might explain the small range and low sodium concentrations (Hem, 1985). The USEPA (1976) recommends that sodium intake by individuals not exceed 270 mg/L per day for a diet of moderately restricted sodium intake.

Sulfate

Probably the greatest natural source of sulfate in the igneous and metamorphic rocks of the bedrock aquifers in the study area is the oxidation of pyrite, but rain water, especially that which has been affected by industrial pollution, can introduce sulfate into the ground-water system (Hem, 1985). Sulfate concentrations in water from igneous and metamorphic rocks are typically less than 100 mg/L (Driscoll, 1986). The largest sulfate concentration at all wells sampled was 62 mg/L, which is well below the USEPA (1976) recommended upper limit of 250 mg/L. The lowest concentration was 9.6 mg/L, and the median was 24 mg/L.

Chloride

The natural sources of chloride in ground water in the study area are associated with impurities in igneous rock and with chloride (in low concentrations) in rain water. Concentrations of chloride in rain water can be slightly elevated if the rain is derived from a large salt-water body, such as the Atlantic Ocean (Hem, 1985). Human activities such as highway deicing and septic-waste disposal can also contribute significant amounts of chloride to ground water locally.

The USEPA (1976) recommends that chloride concentrations in drinking water not exceed 250 mg/L, mainly for health reasons (Williams and Eckhardt, 1987). Chloride concentrations in water samples from 53 wells ranged from 1.7 to 320 mg/L, and the median value was 14 mg/L.

Nitrate

Nitrate in ground water in the study area is derived from surface sources rather than the bedrock. Legumes and bacterial decay of plants are natural sources of nitrate that fix other forms of nitrogen in the nitrogen cycle. Fertilizers, animal wastes, septic and sewage systems, and industrial wastes are additional sources of nitrate in the ground-water system (Driscoll, 1986). Animal wastes, lawn or agricultural fertilizers, and domestic septic systems are apt to be the major contributors in northern Westchester County.

Nitrate concentrations ranged from undetectable to 28 mg/L; the median concentration was 3.7 mg/L, well below the USEPA (1976) maximum recommended concentration for nitrate in drinking water of 45 mg/L.

Iron and Manganese

Iron and manganese react similarly and are found as minor constituents of igneous and metamorphic rock (Hem, 1985). Low concentrations of either element can impair the taste of water and stain or damage plumbing fixtures. Iron and(or) manganese-rich water can promote the growth of certain types of bacteria that can accumulate on well screens or in water-bearing bedrock fractures. Oxidized iron can also precipitate as a reddish-brown iron stain, and manganese can precipitate as a black stain on plumbing fixtures that can be damaging if it becomes extensive (Driscoll, 1986).

Iron concentrations in water from bedrock wells sampled in the study area ranged from undetectable to 3,600 µg/L; the median concentration was 5 µg/L. Manganese concentrations ranged from undetectable to 770 mg/L; the median concentration was 3 µg/L. The USEPA (1976) recommends a maximum concentration of 300 µg/L for iron and 50 µg/L for manganese, primarily for reasons of taste and staining.

SUMMARY

A technique for using mean annual runoff to estimate aquifer recharge was applied to bedrock aquifers in northern Westchester County. The resulting estimates were used in a three-dimensional, steady-state ground-water flow model for verification. Water-quality data were collected to establish the baseline water quality of the major bedrock units.

Estimation of recharge requires the following information: (1) mean annual runoff, (2) location of the ground-water divides of the aquifer, and (3) the extent of till and bedrock within the aquifer area. The resultant estimate of recharge is applicable for steady-state conditions where ground-water withdrawals are minimal. If these conditions are met, recharge to the basin can be

equated to ground-water runoff. The ground-water runoff component is then computed from the total annual runoff and the hydrogeologic data mentioned above. The estimates of recharge include recharge to the till; however, till deposits are relatively sparse throughout most of the study area. Maps and tables are included for computation of recharge to 164 basins in the study area.

A two-layer, steady-state ground-water flow model of a representative 9.3-mi^2 area within the study area was developed to evaluate recharge estimated by the technique described above. Streamflow and ground-water levels that were representative of average annual conditions were measured in mid-November 1987 for model calibration. Model horizontal hydraulic conductivity values were adjusted according to topographic setting and ranged from 0.01 to 0.50 ft/d. Vertical hydraulic conductivity was assumed to be half the horizontal hydraulic conductivity, and streambed hydraulic conductivity was assumed to be 1 ft/d. Constant-head boundaries were used where the model area was bordered by reservoirs. Specified heads were used for streams. The heads in all streams were based on information from topographic maps. The root-mean-square errors between the measured and the simulated heads was 17 ft for the upper model layer and 18 ft for the lower model layer. Ground-water flow is predominantly from the hilltops to the valley bottoms, swamp areas, and streams; no dominant regional flow directions were indicated. Recharge values used for model simulation appear to be reasonable for average-annual steady-state conditions for the range of hydraulic properties and boundary conditions tested.

Water-quality data were collected from 53 bedrock wells throughout northern Westchester County to define the baseline water quality of the major bedrock units. The analyses included major cations and anions, temperature, pH, specific conductance, and hardness. Results indicate little difference in water quality among the bedrock aquifers within the study area. The ground water is mainly the calcium-bicarbonate type and is moderately hard. Average concentrations of sodium, sulfate, chloride, nitrate iron and manganese were within limits established by the USEPA (1976) for domestic water supply.

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Table 12.—Estimated values and associated data for computation of ground-water runoff for selected basins in northern Westchester County.

[Location of basins shown in fig. 13A-13I; mi^2, square miles; in/yr, inches per year; Mgal/d, million gallons per day.]

Basin name and identification number	Total area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Annual runoff (in/yr)	Ground-water runoff from till and bedrock (Mgal/d)
*1A	1.79	0.06	1.73	24.8	0.71
*1B	1.04	.07	.97	25.0	.40
*1C	.83	.03	.80	25.0	.33
*1D	.43	.02	.41	24.3	.16
Broad Brook					
2A	2.17	1.14	1.03	27.0	.46
2B	1.51	.39	1.12	28.0	.53
2C	1.48	.32	1.16	28.5	.56
Cross River					
3A	2.79	.70	2.09	26.2	.92
3B	2.71	.78	1.93	26.0	.83
3C	1.26	.18	1.08	25.8	.46
3D	2.06	.07	1.99	26.6	.89
3E	2.16	.61	1.55	27.5	.71
3F	1.48	.08	1.40	27.4	.64
Cross River east					
4A	1.60	.36	1.24	27.5	.57
4B	1.00	.09	.91	27.6	.42
4C	1.76	.25	1.51	28.0	.70
4D	1.75	.24	1.51	28.2	.71
Cross River west					
5A	1.16	.47	.69	25.5	.29
Croton River east					
6A	1.00	.12	.88	23.3	.34
6B	2.09	.32	1.77	23.7	.70
6C	1.36	.15	1.21	23.8	.48
6D	2.28	.28	2.00	24.5	.81
6E	1.48	.51	.97	24.4	.39
6F	2.03	.30	1.73	24.2	.70
Croton River north					
7A	0.87	0.03	0.84	23.4	0.33
7B	1.28	.35	.93	23.0	.36
7C	1.39	.29	1.10	22.8	.42
7D	.75	.14	.61	22.8	.24
7E	.66	.06	.60	23.4	.24
7F	2.26	.62	1.64	23.4	.64
7G	1.06	.18	.88	23.5	.39
Croton River south					
8A	.98	.00	.98	23.3	.38
8B	1.39	.00	1.39	26.0	.61
8C	.59	.00	.59	25.5	.25
8D	2.29	.04	2.25	27.2	1.02
8E	1.66	.13	1.53	26.9	.69
8F	1.46	.72	.74	26.5	.33
8G	1.39	.28	1.11	26.3	.48
8H	2.06	.42	1.64	26.0	.71

*Some or all of basin is in the active region of the ground-water flow model.

Table 12.—Estimated values and associated data for computation of ground-water runoff for selected basins in northern Westchester County (continued).

Basin name and identification number	Total area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Annual runoff (in/yr)	Ground-water runoff from till and bedrock (Mgal/d)
Croton River west					
9A	2.63	.00	2.63	24.0	1.05
9B	1.02	.00	1.02	23.8	.40
9C	2.13	.00	2.13	25.5	.91
9D	1.45	.02	1.43	26.5	.63
9E	1.30	.00	1.30	26.8	.58
9F	1.52	.19	1.33	27.2	.61
9G	2.30	.02	2.28	27.2	1.03
9H	2.27	.01	2.26	26.5	1.03
9I	1.54	.16	1.38	25.5	.59
*9J	2.01	.11	1.90	24.8	.78
Green Briar Brook					
10A	1.63	.28	1.35	23.8	.54
10B	2.06	.96	1.10	23.7	.43
Kisco River					
11A	1.30	0.05	1.25	27.3	0.57
11B	1.86	.41	1.45	27.5	.67
11C	2.03	.05	1.98	28.0	.93
11D	.95	.44	.51	28.0	.24
11E	1.04	.19	.85	28.2	.40
11F	1.86	.46	1.40	28.3	.66
11G	1.73	.42	1.31	28.3	.62
11H	1.90	.10	1.80	28.4	.85
11I	1.58	.11	1.47	27.5	.67
11J	1.22	.06	1.16	27.5	.54
11K	.92	.20	.72	27.5	.33
11L	1.59	.10	1.49	27.9	.69
Muscoot River					
12A	2.36	.27	2.09	25.8	.90
12B	1.11	.07	1.04	25.3	.44
*12C	3.62	.13	3.49	25.5	1.48
Muscoot River south					
*13A	1.68	.21	1.47	25.8	.63
Peach Lake					
14A	1.72	.18	1.54	24.0	.62
Plum Brook					
15A	1.85	.13	1.72	24.8	.71
*15B	1.51	.29	1.22	24.8	.50
15C	1.40	.02	1.38	24.3	.56
*15D	1.14	.16	.98	24.5	.40
*15E	1.23	.39	.84	24.0	.34
Stone Hill River					
16A	.96	.41	.55	26.7	.25
16B	1.48	.92	.56	27.8	.26
16C	1.43	.21	1.22	27.5	.56
16D	2.02	.77	1.25	28.0	.59
16E	2.37	.50	1.87	28.4	.89
16F	1.40	.16	1.24	28.4	.59
16G	1.71	1.00	.71	28.2	.33
16H	2.59	.79	1.80	28.2	.84

*Some or all of basin is in the active region of the ground-water flow model.

Table 12.—Estimated values and associated data for computation of ground-water runoff for selected basins in northern Westchester County (continued).

Basin name and identification number	Total area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Annual runoff (in/yr)	Ground-water runoff from till and bedrock (Mgal/d)
Titicus River					
17A	0.45	0.10	0.35	23.1	0.13
17B	2.58	.20	2.38	23.2	.91
17C	2.04	.02	2.02	23.7	.79
17D	2.53	.27	2.26	24.0	.91
17E	2.60	.42	2.18	25.5	.93
17F	1.00	.08	.92	25.4	.39
17G	1.48	.14	1.34	25.0	.56
17H	1.73	.25	1.48	24.8	.61
17I	2.23	.03	2.20	25.8	.95
Waccabuc River basin					
18A	.65	.04	.61	26.2	.27
18B	2.59	.14	2.45	26.5	1.08
18C	2.08	.32	1.76	27.0	.79
18D	1.21	.01	1.20	27.8	.56
18E	.93	.09	.84	28.1	.39
18F	2.34	.10	2.24	28.0	1.05
Silvermine River basin					
19A	.56	.00	.56	26.6	.25
19B	.78	.00	.78	26.8	.35
19C	1.65	.01	1.64	27.5	.75
19D	1.24	.02	1.22	26.7	.55
Rippowam River basin					
20A	2.08	.07	2.01	26.8	.90
20B	1.52	.01	1.51	27.3	.69
Mill River basin					
21A	1.44	.27	1.17	27.5	.54
21B	1.60	.09	1.51	27.0	.68
21C	.49	.06	.43	26.8	.20
21D	.97	.16	.81	26.8	.36
21E	1.93	.14	1.79	27.8	.83
21F	1.01	.01	1.00	27.5	.46
21G	.65	.01	.64	27.9	.30
21H	1.06	.11	.95	27.8	.44
Mianus River					
22A	2.85	0.27	2.58	26.2	1.12
22B	2.26	.36	1.90	28.0	.89
22C	2.94	1.17	1.77	28.2	.83
22D	2.36	.44	1.92	26.5	.84
22E	.85	.01	.84	27.4	.38
22F	1.13	.00	1.13	27.2	.51
22G	2.13	.11	2.02	25.8	.86
22H	1.09	.03	1.06	25.5	.45
22I	1.25	.18	1.07	25.8	.46
22J	1.85	.19	1.66	26.5	.73

*Some or all of basin is in the active region of the ground-water flow model.

Table 12.—Estimated values and associated data for computation of ground-water runoff for selected basins in northern Westchester County (continued).

Basin name and identification number	Total area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Annual runoff (in/yr)	Ground-water runoff from till and bedrock (Mgal/d)
Byram River					
23A	1.54	.27	1.27	25.3	.53
23B	2.45	.51	1.94	25.6	.82
23C	.89	.24	.65	25.4	.28
23D	.67	.04	.63	25.2	.27
23E	1.10	.09	1.01	26.5	.44
23F	2.99	.31	2.68	26.0	1.16
23G	.27	.00	.27	25.2	.11
23H	.49	.00	.49	25.4	.21
Hallocks Mill Brook					
24A	3.10	.49	2.61	26.5	1.15
24B	1.04	.00	1.04	26.5	.46
24C	2.71	.52	2.19	27.3	1.00
24D	1.77	.48	1.29	27.0	.58
24E	1.20	.03	1.17	26.8	.53
24F	2.12	.01	2.11	26.5	.94
Hunter Brook					
25A	1.59	.04	1.55	25.8	.67
25B	3.18	.19	2.99	25.8	1.29
25C	2.71	.11	2.60	27.0	1.17
Peekskill Hollow Brook					
26A	2.13	0.12	2.01	22.8	0.76
26B	2.31	.44	1.87	24.5	.76
26C	3.06	.69	2.37	24.8	.98
26D	1.77	.30	1.47	26.0	.64
26E	2.67	.85	1.82	26.5	.80
26F	2.19	.81	1.38	27.2	.63
26G	2.20	.48	1.72	27.1	.77
McGregory Brook					
27A	1.82	.22	1.60	22.5	.60
Sprout Brook					
28A	1.75	.44	1.31	23.0	.50
Annsville Creek					
29A	1.34	.00	1.34	22.4	.50
Dickey Brook					
30A	1.97	.02	1.95	21.9	.71
30B	1.01	.01	1.00	21.7	.36
Saw Mill Creek					
31A	2.45	.01	2.44	21.6	.88
Colabaugh Pond					
32A	1.15	.00	1.15	22.0	.42
Croton Gorge					
33A	2.04	.12	1.92	21.8	.70
Furnace Brook					
34A	2.34	.27	2.07	21.8	.75
34B	1.67	.01	1.66	21.8	.61
34C	3.80	.00	3.80	22.5	1.42
Indian Brook					
35A	1.31	.09	1.22	21.9	.44
Bailey Brook					
36A	2.79	0.00	2.79	23.8	1.10
Still Lake					
37A	1.30	.04	1.26	25.5	.54

Table 12.—Estimated values and associated data for computation of ground-water runoff for selected basins in northern Westchester County (continued).

Basin name and identification number	Total area (mi^2)	Stratified-drift area (mi^2)	Till and bedrock area (mi^2)	Annual runoff (in/yr)	Ground-water runoff from till and bedrock (Mgal/d)
Cornell Brook					
38A	1.84	.17	1.67	26.5	.74
Gedney Brook					
39A	2.28	.01	2.27	27.1	1.03
Hudson River Minor Tributary					
40A	.75	.00	.75	21.6	.27
40B	1.67	.13	1.54	21.8	.56
40C	1.40	.18	1.22	21.4	.43
40D	.64	.03	.61	21.5	.22
40E	.66	.00	.66	21.8	.24

*Some or all of basin is in the active region of the ground-water flow model.

Table 13.—Selected chemical analyses of water from bedrock wells in northern Westchester County

[Well locations are shown in fig. 3; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm is microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; ton/acre-ft, ton per acre-feet.]

USGS local well number	Date	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Specific conductance, field (µS/cm)	Specific conductance, lab (µS/cm)	pH, field (standard units)	pH, lab (standard units	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as NO_3)	Nitrogen, ammonia dissolved (mg/L as N)	Ortho phosphorus, dissolved (mg/L as P)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
WE 681	08-23-88	13.0	110	100	234	--	8.02	7.15	--	<0.10	--	--	--	38	4.4
WE 1132	08-25-88	13.0	130	116	280	--	8.02	7.83	--	<0.10	--	--	--	34	12
WE 2094	08-22-88	19.0	60	39	164	--	7.37	6.60	--	<0.10	--	--	--	15	5.4
WE 2095	08-22-88	16.0	110	35	408	--	6.09	6.33	--	2.10	--	--	--	26	11
WE 2096	08-22-88	12.5	67	26	181	--	5.93	6.24	--	0.30	--	--	--	19	4.7
WE 2097	08-22-88	17.0	410	63	1060	--	7.75	6.80	--	<0.10	--	--	--	130	21
WE 2098	08-22-88	13.5	140	104	321	--	7.20	6.51	--	0.11	--	--	--	39	10
WE 2099	08-23-88	14.0	74	59	184	--	7.70	7.28	--	0.56	--	--	--	25	2.9
WE 2100	08-23-88	12.0	84	69	199	--	7.61	7.20	--	0.20	--	--	--	29	2.8
WE 2101	08-23-88	12.0	140	8.7	514	--	5.90	6.08	--	0.79	--	--	--	37	12
WE 2102	08-23-88	11.5	38	24	119	--	6.54	6.57	--	<0.10	--	--	--	10	3.2
WE 2103	08-23-88	15.5	34	22	96	--	6.03	6.29	1.20	--	5.3	--	<0.01	9.8	2.3
WE 2104	08-23-88	14.0	4	49	419	--	6.45	6.64	--	2.30	--	--	--	1.3	0.26
WE 2105	08-23-88	13.0	310	285	698	--	7.47	7.38	--	3.80	--	--	--	53	44
WE 2106	08-24-88	15.5	120	139	310	--	9.14	9.19	--	<0.10	--	--	--	40	4.8
WE 2107	08-24-88	14.0	81	83	404	--	9.65	9.88	--	<0.10	--	--	--	25	4.5
WE 2108	08-24-88	11.5	160	146	333	--	8.90	8.86	--	0.60	--	--	--	16	30
WE 2109	08-24-88	14.5	92	60	193	--	6.94	7.61	--	0.87	--	--	--	21	9.7
WE 2110	08-24-88	12.5	86	54	186	--	8.10	7.68	--	<0.10	--	--	--	29	3.2
WE 2111	08-24-88	11.5	47	50	154	--	7.05	7.54	--	<0.10	--	--	--	12	4.1
WE 2112	08-24-88	16.0	47	31	126	--	6.94	6.96	--	<0.10	--	--	--	12	4.2
WE 2113	08-24-88	13.5	80	32	231	--	6.26	6.65	--	2.40	--	--	--	19	8.0
WE 2114	08-25-88	14.0	82	82	219	--	8.08	7.89	--	<0.10	--	--	--	29	2.4
WE 2115	08-25-88	12.0	98	36	305	--	6.45	6.68	--	1.80	--	--	--	31	4.9
WE 2116	08-25-88	13.0	87	44	203	--	6.49	6.74	--	0.23	--	--	--	15	12
WE 2117	08-25-88	15.5	77	67	220	--	6.60	6.76	--	0.25	--	--	--	18	7.8
WE 3853	05-04-87	13.5	65	43	--	164	--	6.49	0.20	--	0.87	--	--	16	6.1
WE 3853	10-15-86	--	120	94	--	294	--	6.81	0.27	--	1.2	<0.01	--	30	12
WE 3854	05-05-87	11.5	76	52	--	177	--	7.80	0.19	--	0.82	--	--	21	5.8
WE 3854	10-17-86	11.5	79	47	--	198	--	7.85	0.22	--	0.99	<0.01	--	22	5.8
WE 3855	10-17-86	14.0	75	60	--	186	--	8.29	1.36	--	6.0	<0.01	--	19	6.8
WE 3856	05-05-87	13.0	72	38	--	295	--	6.75	2.13	--	9.4	--	--	21	4.8
WE 3856	10-17-86	13.0	62	34	--	198	--	6.48	3.53	--	16	<0.01	--	18	4.1
WE 3857	05-05-87	13.0	83	45	--	220	--	6.83	0.22	--	0.98	--	--	22	6.9
WE 3857	10-17-86	14.0	99	56	--	263	--	6.74	0.26	--	1.2	<0.01	--	27	7.7
WE 3858	05-05-87	11.5	5	155	--	354	--	9.30	0.10	--	0.44	--	--	1.8	0.24
WE 3858	10-17-86	13.5	6	129	--	396	--	9.35	<0.10	--	--	<0.01	--	1.9	0.32
WE 3860	05-04-87	12.5	110	103	--	237	--	7.25	<0.10	--	--	--	--	32	7.6
WE 3860	10-15-86	--	120	101	--	262	--	7.70	<0.10	--	--	<0.01	--	34	7.7
WE 3861	05-06-87	13.0	62	84	--	260	--	8.10	0.10	--	0.44	--	--	19	3.5
WE 3861	10-17-86	14.5	65	83	--	287	--	8.36	<0.10	--	--	<0.01	--	20	3.7

Table 13.—Selected chemical analyses of water from bedrock wells in northern Westchester County (continued).

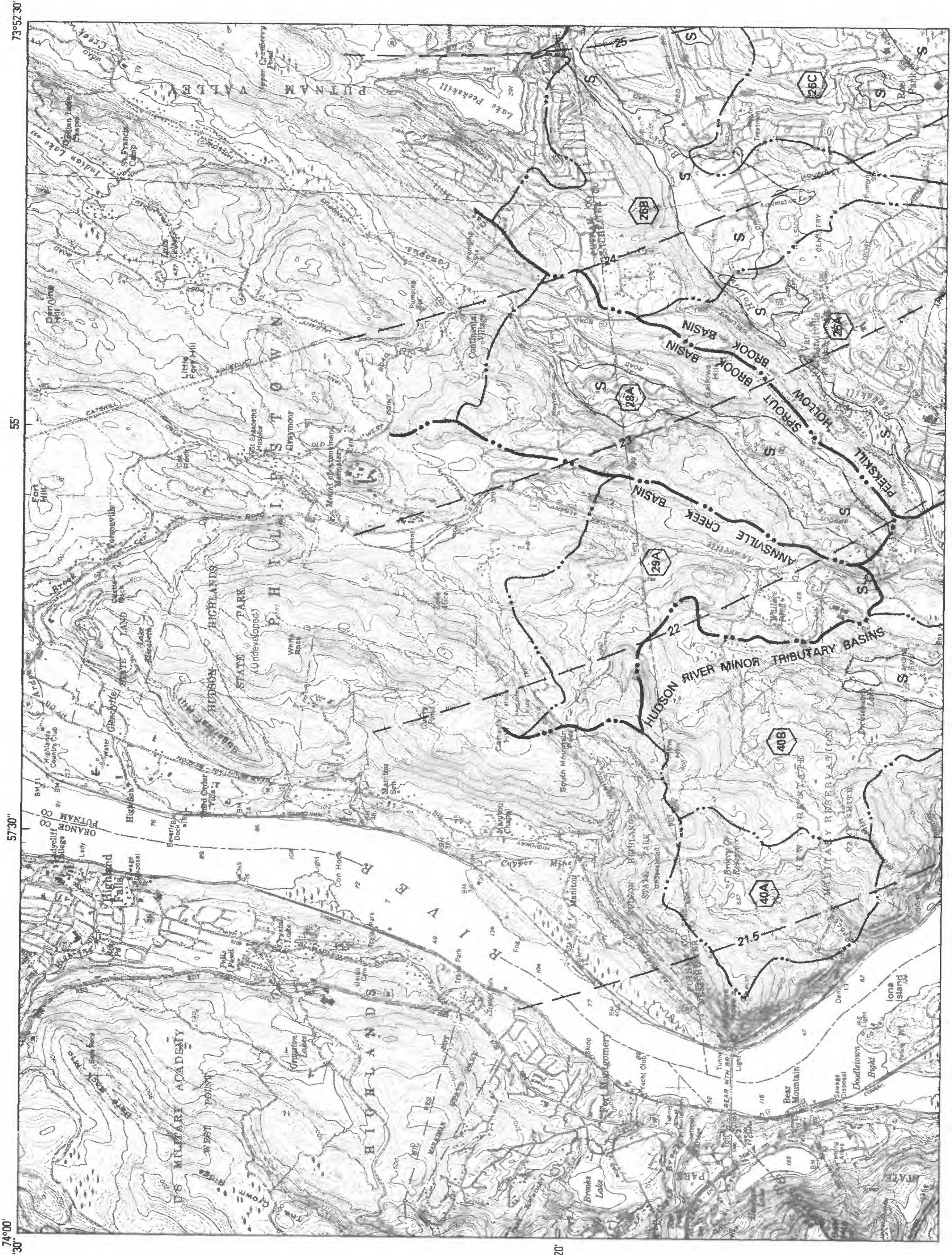
USGS local well number	Date	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Specific conductance, field (µS/cm)	Specific conductance. lab (µS/cm)	pH, field (standard units)	pH, lab (standard units	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as NO_3)	Nitrogen, ammonia dissolved (mg/L as N)	Ortho phosphorus , dissolved (mg/L as P)	Calcium dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
WE 3862	05-06-87	11.5	180	149	--	403	--	7.92	1.32	--	5.8	--	--	38	20
WE 3862	10-17-86	15.0	180	136	--	419	--	7.83	1.28	--	5.7	<0.01	--	40	20
WE 3863	05-06-87	--	53	18	--	158	--	7.09	0.88	--	3.9	--	--	13	5.0
WE 3863	10-17-86	--	59	21	--	186	--	6.78	0.35	--	1.5	<0.01	--	15	5.3
WE 3864	05-06-87	12.5	47	86	--	329	--	8.19	<0.10	--	--	--	--	14	3.0
WE 3864	10-17-86	--	81	99	--	403	--	8.34	0.40	--	1.8	<0.01	--	24	5.0
WE 3865	05-06-87	12.0	110	93	--	247	--	7.47	2.67	--	12	--	--	30	9.6
WE 3865	10-17-86	14.0	120	92	--	294	--	7.12	3.15	--	14	<0.01	--	32	10
WE 3866	05-05-87	11.5	58	50	--	149	--	6.85	<0.10	--	--	--	--	16	4.5
WE 3866	10-16-86	16.0	64	50	--	178	--	6.55	<0.17	--	--	<0.01	--	18	4.6
WE 3867	05-05-87	13.0	130	106	--	285	--	7.55	0.83	--	3.7	--	--	32	12
WE 3867	10-15-86	--	140	118	--	370	--	7.86	0.71	--	3.2	<0.01	--	38	10
WE 3868	05-04-87	13.0	120	100	--	253	--	7.99	<0.10	--	--	--	--	33	8.8
WE 3868	10-15-86	--	120	92	--	276	--	7.81	<0.10	--	--	<0.01	--	33	8.2
WE 3869	05-04-87	12.5	190	109	--	424	--	7.44	1.71	--	7.6	--	--	60	9.1
WE 3869	10-15-86	--	220	115	--	531	--	7.58	1.70	--	7.5	<0.01	--	73	10
WE 3870	05-05-87	13.0	170	85	--	459	--	6.72	0.44	--	1.9	--	--	54	8.1
WE 3870	10-15-86	--	180	96	--	507	--	6.95	0.60	--	2.7	<0.01	--	60	8.3
WE 3871	05-05-87	13.0	220	193	--	555	--	7.00	6.32	--	28	--	--	69	11
WE 3871	10-15-86	13.5	220	192	--	588	--	6.93	3.52	--	16	<0.01	--	68	11
WE 3872	05-04-87	13.0	210	166	--	404	--	7.81	<0.10	--	--	--	--	55	17
WE 3872	10-15-86	16.0	230	166	--	466	--	7.89	<0.10	--	--	<0.01	--	61	18
WE 4424	05-06-87	14.0	82	51	--	202	--	6.39	2.76	--	12	--	--	21	7.1
WE 4424	10-16-86	15.0	100	67	--	280	--	7.15	1.30	--	5.8	--	--	31	6.5
WE 5010	05-04-87	11.5	53	30	--	152	--	6.07	3.56	--	16	--	--	14	4.3
WE 5010	10-15-86	14.5	65	43	--	193	--	6.17	3.15	--	14	<0.01	--	17	5.4
WE 5011	05-05-87	14.0	36	21	--	117	--	6.35	0.38	--	1.7	--	--	9.9	2.7
WE 5011	10-16-86	15.5	49	31	--	156	--	6.38	1.20	--	5.3	<0.01	--	14	3.5
WE 5012	05-05-87	13.0	61	39	--	163	--	6.66	<0.10	--	--	--	--	18	3.9
WE 5012	10-16-86	15.0	100	71	--	260	--	7.54	<0.10	--	--	<0.01	--	31	6.5
WE 5015	05-05-87	13.0	160	80	--	367	--	7.11	0.51	--	2.2	--	--	42	14
WE 5015	10-16-86	14.5	170	76	--	405	--	7.64	0.46	--	2.0	<0.01	--	45	14
WE 5016	05-05-87	11.5	99	80	--	229	--	7.71	1.77	--	7.9	--	--	26	8.2
WE 5016	10-16-86	--	100	75	--	255	--	8.06	1.79	--	7.9	<0.01	--	28	8.1
WE 5017	05-05-87	12.0	82	48	--	207	--	7.93	0.20	--	0.89	--	--	25	4.8
WE 5017	10-16-86	13.5	94	47	--	245	--	8.11	0.23	--	1.0	<0.01	--	29	5.2
WE 5018	05-06-87	12.0	41	7.2	--	174	--	5.77	0.38	--	1.7	--	--	12	2.6
WE 5018	10-16-86	14.0	100	48	--	265	--	6.82	1.07	--	4.7	<0.01	--	33	4.5

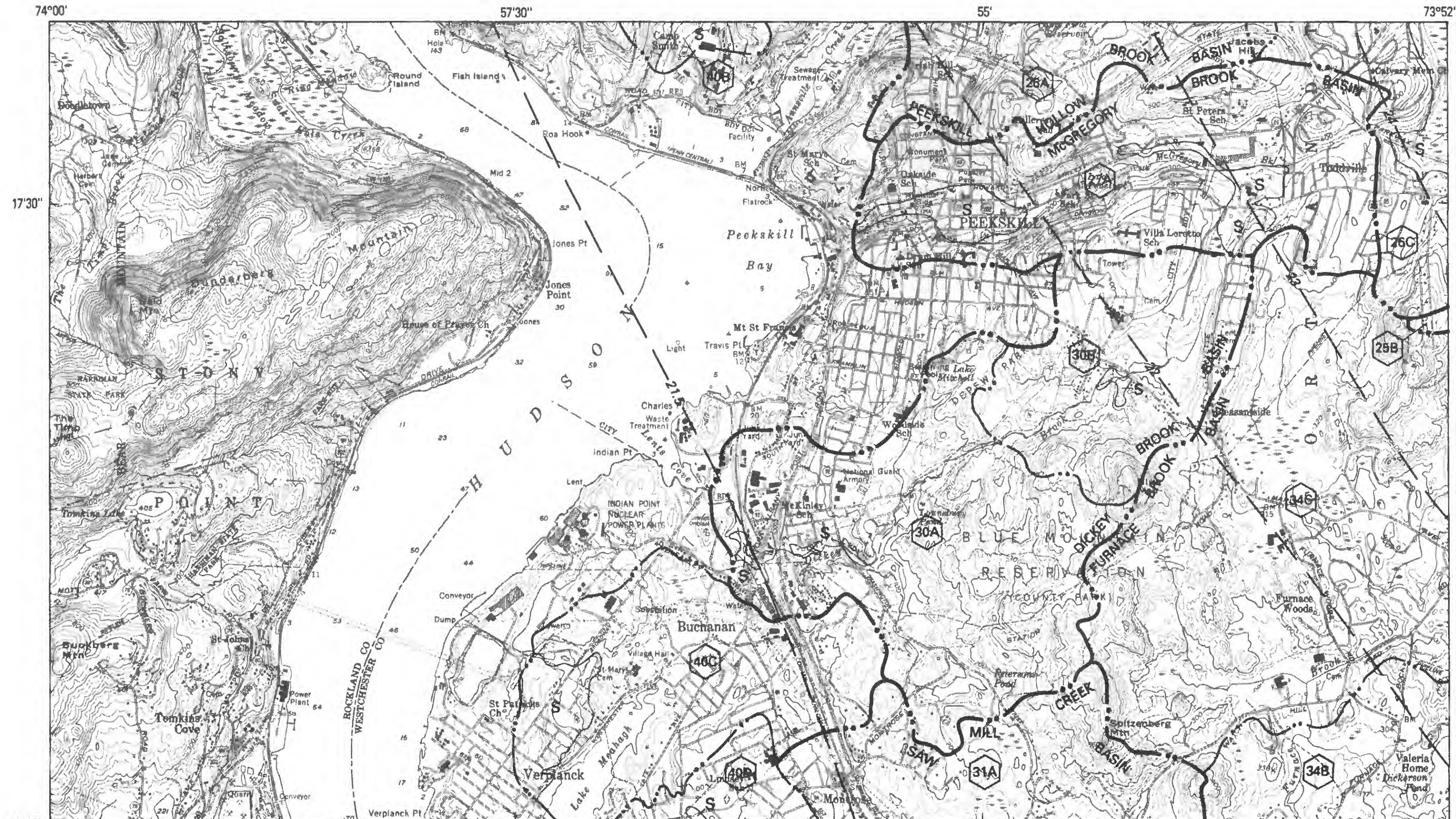
Table 13.—Selected chemical analyses of water from bedrock wells in northern Westchester County (continued).

USGS local well number	Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Bromide adsorption ratio	Sodium adsorption ratio	Sodium percent	Total dissolved solids (mg/L)	Solids, dissolved (ton/acre-ft)	Land surface elevation (ft above sea level)	Depth of well, total (feet)
WE 681	08-23-88	8.8	1.6	3.8	25	0.10	12	5	<1	0.012	0.4	14	154	0.21	400	200
WE 1132	08-25-88	8.8	2.5	2.6	33	0.30	12	11	110	0.023	0.3	12	175	0.24	300	90
WE 2094	08-22-88	7.6	3.3	6.4	31	0.10	24	<3	8	0.017	0.4	21	116	0.16	305	--
WE 2095	08-22-88	35	4.0	80	28	0.10	17	<3	36	0.036	1	40	232	0.32	330	125
WE 2096	08-22-88	5.8	4.0	25	17	0.10	22	<3	<1	0.018	0.3	15	115	0.16	370	80
WE 2097	08-22-88	45	0.10	320	24	0.10	20	3	770	0.077	1	19	599	0.81	360	160
WE 2098	08-22-88	6.1	4.0	23	24	0.10	22	5	51	0.067	0.2	8	191	0.26	440	--
WE 2099	08-23-88	8.4	1.7	9.0	23	0.10	17	5	1	0.019	0.4	19	125	0.17	440	800
WE 2100	08-23-88	4.7	3.4	5.8	25	0.10	11	13	<1	<0.010	0.2	10	124	0.17	555	--
WE 2101	08-23-88	43	4.3	120	54	0.10	25	1700	590	0.72	2	39	307	0.41	595	--
WE 2102	08-23-88	6.5	2.1	2.9	26	0.20	30	2700	150	0.051	0.5	26	98	0.13	545	--
WE 2103	08-23-88	5.6	0.90	3.2	15	0.13	13	19	1	<0.010	0.4	26	68	0.09	520	--
WE 2104	08-23-88	98	1.2	91	14	0.10	12	6	1	0.044	21	97	257	0.35	650	--
WE 2105	08-23-88	23	23	43	35	0.10	35	75	5	0.028	0.6	13	444	0.60	605	--
WE 2106	08-24-88	34	2.7	9.4	24	0.10	14	<3	<1	0.037	1	38	213	0.29	300	--
WE 2107	08-24-88	7.6	1.1	24	9.6	0.10	21	<3	7	0.11	0.4	17	143	0.19	305	--
WE 2108	08-24-88	19	8.3	6.0	42	0.10	18	<3	<1	0.027	0.7	19	230	0.31	320	300
WE 2109	08-24-88	5.8	3.1	7.0	29	0.10	17	19	<1	0.022	0.3	12	133	0.18	210	--
WE 2110	08-24-88	8.9	1.1	7.4	28	1.1	19	<3	<1	0.020	0.4	18	130	0.18	260	180
WE 2111	08-24-88	5.3	1.6	1.7	24	0.30	32	3600	210	0.019	0.3	19	115	0.15	220	--
WE 2112	08-24-88	5.1	1.8	3.8	20	0.20	17	<3	<1	0.16	0.3	18	83	0.11	240	--
WE 2113	08-24-88	19	3.8	38	17	0.10	25	1700	600	0.026	1	33	161	0.22	460	--
WE 2114	08-25-88	18	2.8	15	19	0.10	14	<3	18	0.045	0.9	31	149	0.20	420	--
WE 2115	08-25-88	21	5.1	44	31	0.10	12	6	50	0.022	1	31	179	0.24	500	190
WE 2116	08-25-88	8.2	2.6	13	35	0.10	19	<3	57	0.035	0.4	17	132	0.18	450	--
WE 2117	08-25-88	16	1.0	16	14	0.10	16	9	29	0.032	0.8	31	130	0.18	580	--
WE 3853	05-04-87	4.9	3.4	14	19	--	18	15	2	--	0.2	8	159	0.22	300	--
WE 3853	10-15-86	5.1	2.0	14	17	--	15	27	3	--	0.3	14	102	0.14	300	--
WE 3854	05-05-87	3.9	2.5	3.9	30	--	18	4	<1	--	0.2	9	115	0.16	395	--
WE 3854	10-17-86	4.1	2.5	4.1	28	--	17	<3	1	--	0.2	10	114	0.16	395	--
WE 3855	10-17-86	4.1	1.9	3.6	13	--	16	5	<1	--	0.2	10	106	0.14	360	--
WE 3856	05-05-87	9.9	1.1	10	19	--	20	5	3	--	0.6	25	119	0.16	540	240
WE 3856	10-17-86	27	1.4	52	19	--	14	6	11	--	1	44	172	0.23	540	240
WE 3857	05-05-87	6.6	1.6	32	14	--	21	14	91	--	0.3	14	132	0.18	645	180
WE 3857	10-17-86	7.8	1.7	31	14	--	25	28	160	--	0.4	14	149	0.20	645	180
WE 3858	05-05-87	81	1.0	4.1	29	--	21	<3	<1	--	16	96	231	0.31	600	350
WE 3858	10-17-86	89	1.1	3.5	31	1.3	23	4	<1	--	16	96	229	0.31	600	350
WE 3860	05-04-87	3.7	4.2	3.0	18	--	16	<3	<1	--	0.2	6	146	0.20	470	400
WE 3860	10-15-86	3.7	4.4	2.3	21	--	16	6	<1	--	0.2	6	150	0.20	470	400
WE 3861	05-06-87	31	1.9	5.8	41	--	13	<3	17	--	2	51	166	0.23	550	--
WE 3861	10-17-86	32	1.9	5.5	40	--	14	5	17	--	2	51	167	0.23	550	--

Table 13.—Selected chemical analyses of water from bedrock wells in northern Westchester County (continued).

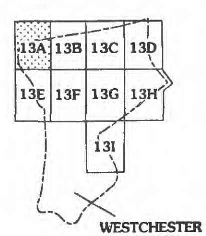
USGS local well number	Date	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Bromide adsorption ratio	Sodium adsorption ratio	Sodium percent	Total dissolved solids, dissolved (mg/L)	Solids, dissolved (ton/acre-ft)	Land surface elevation (ft above sea level)	Depth of well, total (feet)
WE 3862	05-06-87	20	4.2	35	21	--	18	6	1	--	0.7	19	251	0.34	495	--
WE 3862	10-17-86	22	4.2	39	20	--	19	<3	<1	--	0.7	20	252	0.34	495	--
WE 3863	05-06-87	6.5	2.4	28	12	--	15	10	1	--	0.4	20	97	0.13	575	--
WE 3863	10-17-86	6.8	2.6	28	13	--	16	<3	<1	--	0.4	19	101	0.14	575	--
WE 3864	05-06-87	49	2.2	34	37	--	16	5	3	--	2	56	228	0.31	635	750
WE 3864	10-17-86	54	1.6	22	47	--	15	6	2	--	4	70	208	0.28	635	750
WE 3865	05-06-87	8.5	2.5	8.2	22	--	14	7	1	--	0.4	14	162	0.22	525	--
WE 3865	10-17-86	8.6	2.5	5.3	25	--	14	8	1	--	0.4	13	166	0.23	525	--
WE 3866	05-05-87	6.3	1.6	4.6	17	--	20	5	69	--	0.4	18	100	0.14	645	--
WE 3866	10-16-86	6.9	2.0	5.0	20	--	21	140	69	--	0.4	18	107	0.15	645	--
WE 3867	05-05-87	6.5	2.7	19	14	--	19	<3	1	--	0.3	10	172	0.23	460	900
WE 3867	10-15-86	13	3.3	24	15	--	19	5	1	--	0.5	17	196	0.27	460	900
WE 3868	05-04-87	5.4	4.5	7.2	26	--	22	5	43	--	0.2	9	167	0.23	350	--
WE 3868	10-15-86	5.5	4.4	6.0	26	--	22	15	31	--	0.2	9	160	0.22	350	--
WE 3869	05-04-87	9.8	8.2	43	50	--	9.5	<3	<1	--	0.3	10	263	0.36	365	--
WE 3869	10-15-86	12	8.5	59	62	--	9.6	<3	1	--	0.4	10	310	0.42	365	--
WE 3870	05-05-87	22	4.5	76	8.4	--	20	6	9	--	0.7	20	259	0.35	460	425
WE 3870	10-15-86	25	4.7	84	25	--	19	9	11	--	0.9	24	273	0.37	460	425
WE 3871	05-05-87	44	3.2	62	23	--	15	<3	<1	--	1	30	371	0.50	270	80
WE 3871	10-15-86	47	3.2	54	26	--	16	8	2	--	1	32	357	0.48	270	80
WE 3872	05-04-87	6.9	4.1	22	29	--	28	36	42	--	0.2	7	262	0.36	502	205
WE 3872	10-15-86	7.1	4.1	23	31	--	28	10	34	--	0.2	6	272	0.37	502	205
WE 4424	05-06-87	5.7	4.6	16	24	--	15	3	1	--	0.3	10	149	0.20	555	500
WE 4424	10-16-86	6.4	3.1	14	21	--	18	3	2	--	0.3	14	133	0.18	555	500
WE 5010	05-04-87	5.5	2.5	7.1	16	--	19	<3	9	--	0.3	18	102	0.14	520	325
WE 5010	10-15-86	6.6	3.7	7.1	17	--	23	6	8	--	0.4	17	119	0.16	520	325
WE 5011	05-05-87	5.0	3.8	5.5	20	--	15	15	9	--	0.3	17	91	0.12	310	50
WE 5011	10-16-86	5.7	2.5	8.4	17	--	12	21	15	--	0.4	24	72	0.10	310	50
WE 5012	05-05-87	4.6	6.5	12	28	--	13	5	20	--	0.2	8	143	0.20	290	200
WE 5012	10-16-86	5.5	4.4	8.6	26	--	11	<3	<1	--	0.3	15	101	0.14	290	200
WE 5015	05-05-87	6.6	3.0	58	20	--	14	<3	4	--	0.2	8	208	0.28	415	300
WE 5015	10-16-86	6.7	3.1	57	21	--	14	3	4	--	0.2	8	208	0.28	415	300
WE 5016	05-05-87	7.6	2.6	6.6	23	--	14	<3	<1	--	0.3	14	144	0.20	400	--
WE 5016	10-16-86	7.6	2.7	6.7	24	--	14	<3	<1	--	0.3	13	144	0.20	400	--
WE 5017	05-05-87	4.5	2.1	25	16	--	14	<3	<1	--	0.2	10	121	0.16	390	--
WE 5017	10-16-86	4.8	2.3	28	16	--	15	11	3	--	0.2	10	130	0.18	390	--
WE 5018	05-06-87	6.6	2.1	24	29	--	12	26	5	--	0.3	12	144	0.20	450	--
WE 5018	10-16-86	13	1.2	31	23	--	6.7	110	16	--	0.9	40	95	0.13	450	--


73°52'30"
55'
57'30"
41°22'30"
74°00'
20'
PUTNAM VALLEY
PEEKSKILL HOLLOW BROOK BASIN
SPROUT BROOK BASIN
ANNSVILLE CREEK BASIN
HUDSON RIVER MINOR TRIBUTARY BASINS
HUDSON HIGHLANDS STATE PARK
(Undeveloped)
US MILITARY ACADEMY
WEST POINT
Highland Falls
Fort Montgomery
Bear Mountain
Iona Island
Brooks Lake
26A
26B
26C
28A
29A
40A
40B
21.5
22
23
24
25



Base from New York State Department of Transportation, 1982

0 — 1 MILE
0 — 1 KILOMETER



EXPLANATION

—••— Major surface-water drainage divide

—••— Minor surface-water drainage divide

— 25 — Line of equal mean annual runoff (inches per year)

S Area of stratified drift

34C Drainage-basin identifier (see table 12)

Figure 13A.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Peekskill quadrangle.


73°45'
47'30"
50'
73°52'30"
41°22'30"
20'
MUSCOOT RIVER BASIN
HALLOCKS MILL BROOK BASIN
PEEKSKILL HOLLOW BROOK BASIN
HUNTER BROOK BASIN
12B
12A
12C
24A
24F
24E
24C
25C
26G
26F
26E
26D
26C
26B
West Mahopac
Lake Mahopac
Barger Pond
Lake Osceola
Lake Mohegan
Loyola Seminary
High School
Mahopac Falls
Baldwin Place
Lake Baldwin

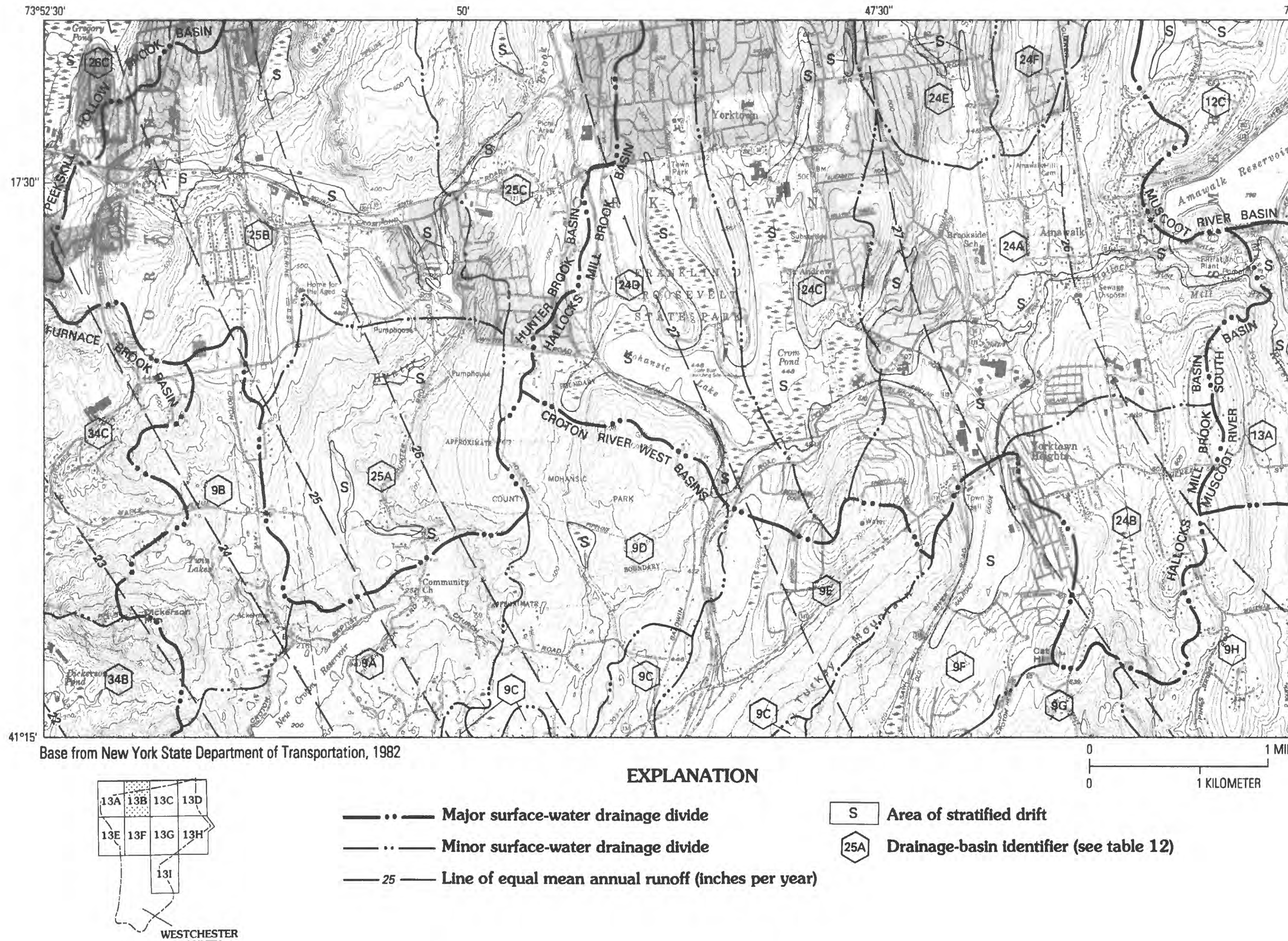
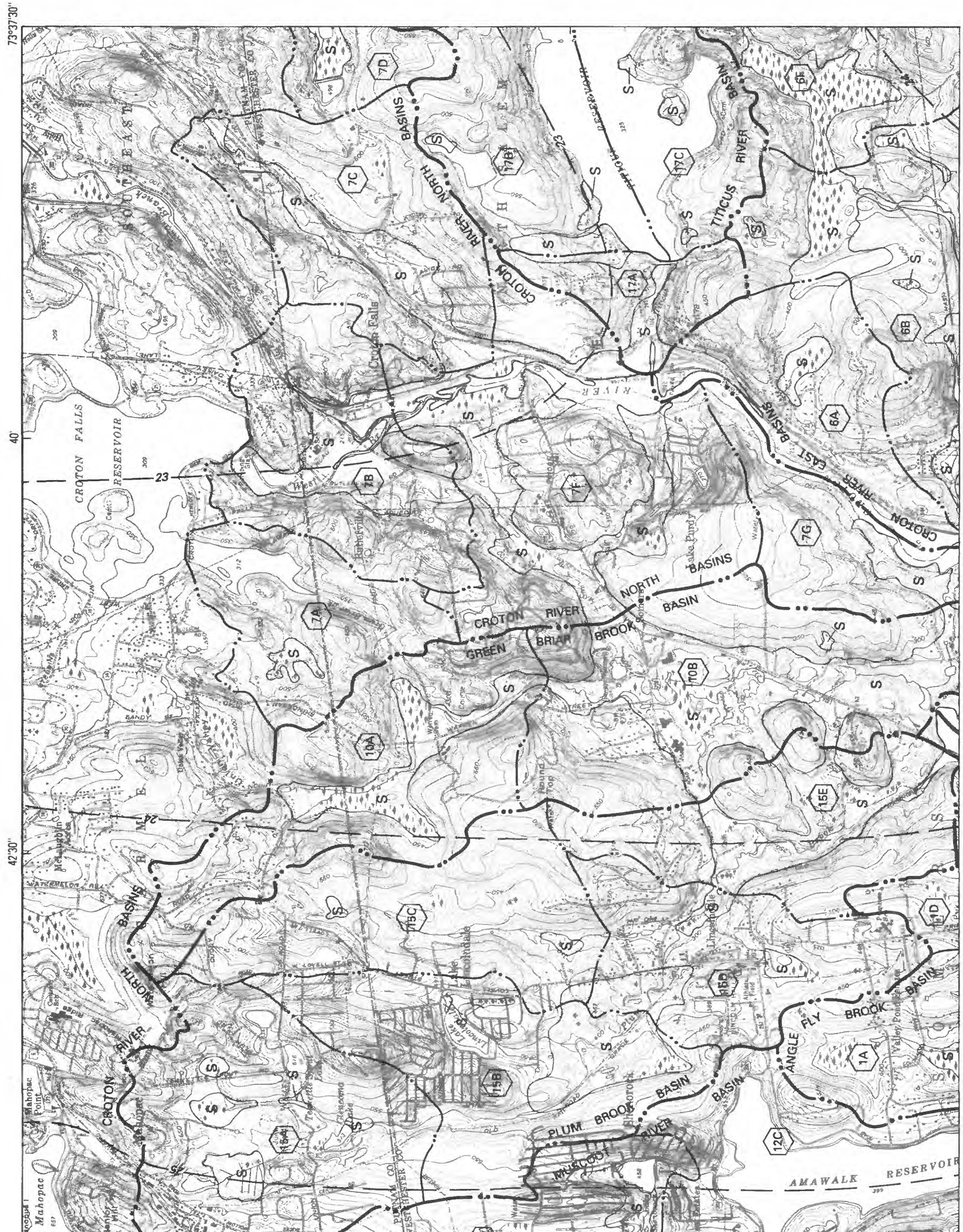


Figure 13B.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Mohegan Lake quadrangle.


73°37'30"
40'
42'30"
41°22'30"
73°45'
20'
CROTON FALLS RESERVOIR
AMAWALK RESERVOIR
NORTH CROTON RIVER BASINS
EAST CROTON RIVER BASINS
TITICUS RIVER BASIN
GREEN BRIAR BROOK BASIN
PLUM BROOK BASIN
ANGLE FLY BROOK BASIN
MUSCOOT RIVER BASIN
Lake Mahopac
Croton Falls
7A
7B
7C
7D
7F
7G
6A
6B
10A
10B
12B
12C
15A
15B
15C
15D
15E
17A
17B
17C
1A
1D

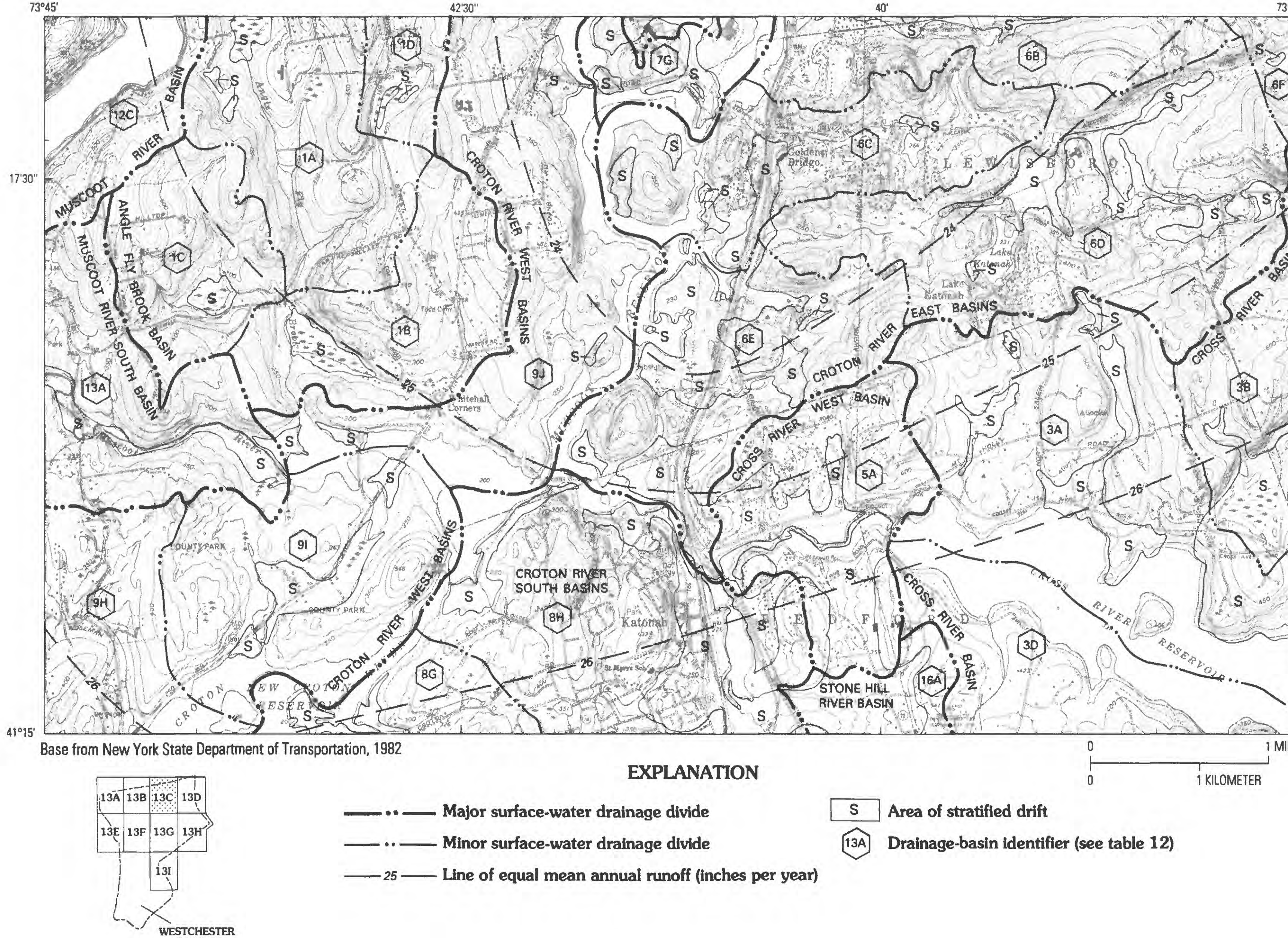


Figure 13 C.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Croton Falls quadrangle.


73°30'
32'30"
35'
73°37'30"
41°22'30"
20'
Peach Lake
Mamanasco Lake
PEACH LAKE
TITICUS BASIN
RIVER BASIN
CROTON RIVER NORTH BASINS
TITICUS RIVER BASIN
CROTON RIVER EAST BASINS
14A
17F
17E
17G
17I
17D
17H
17B
17C
7E
7D
6F

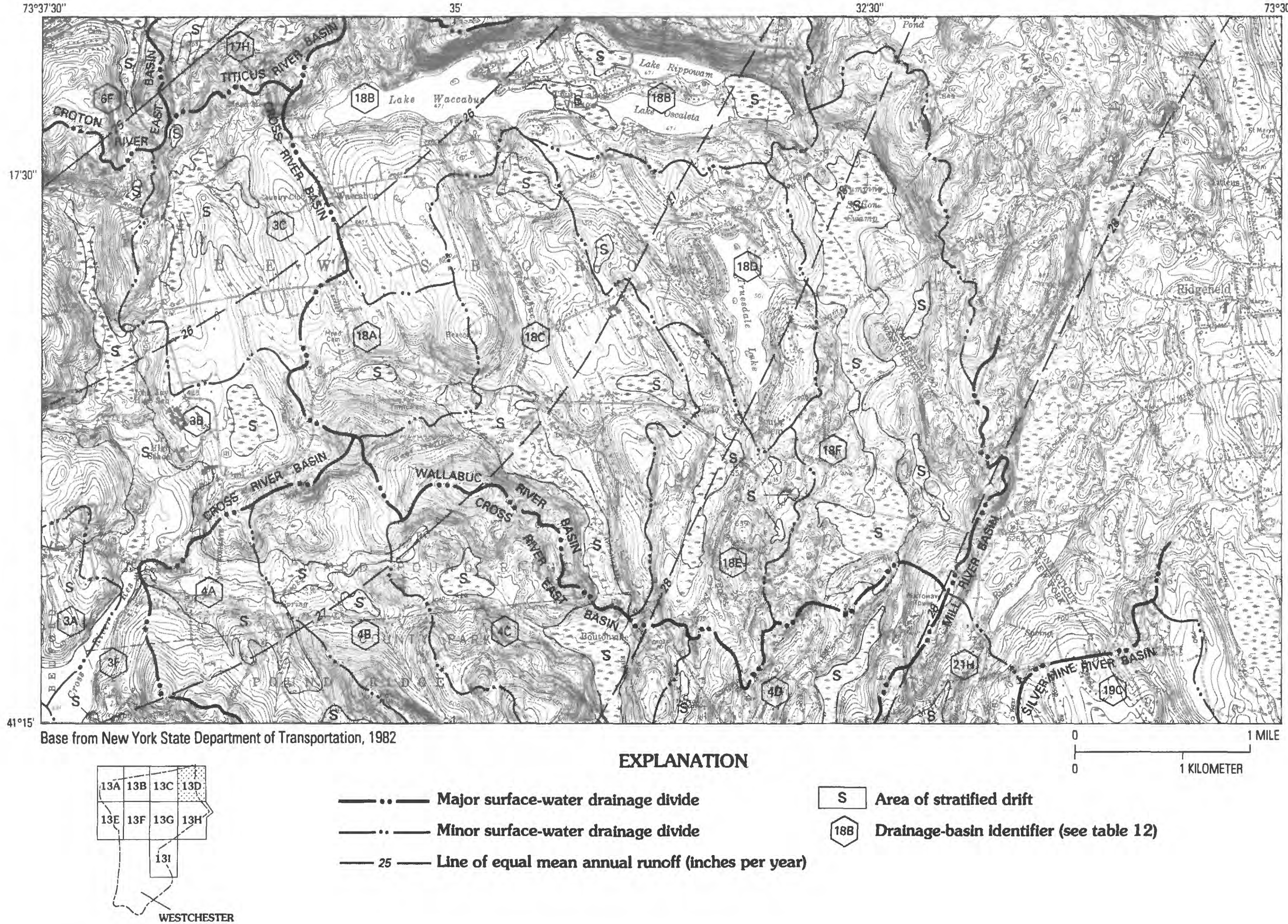
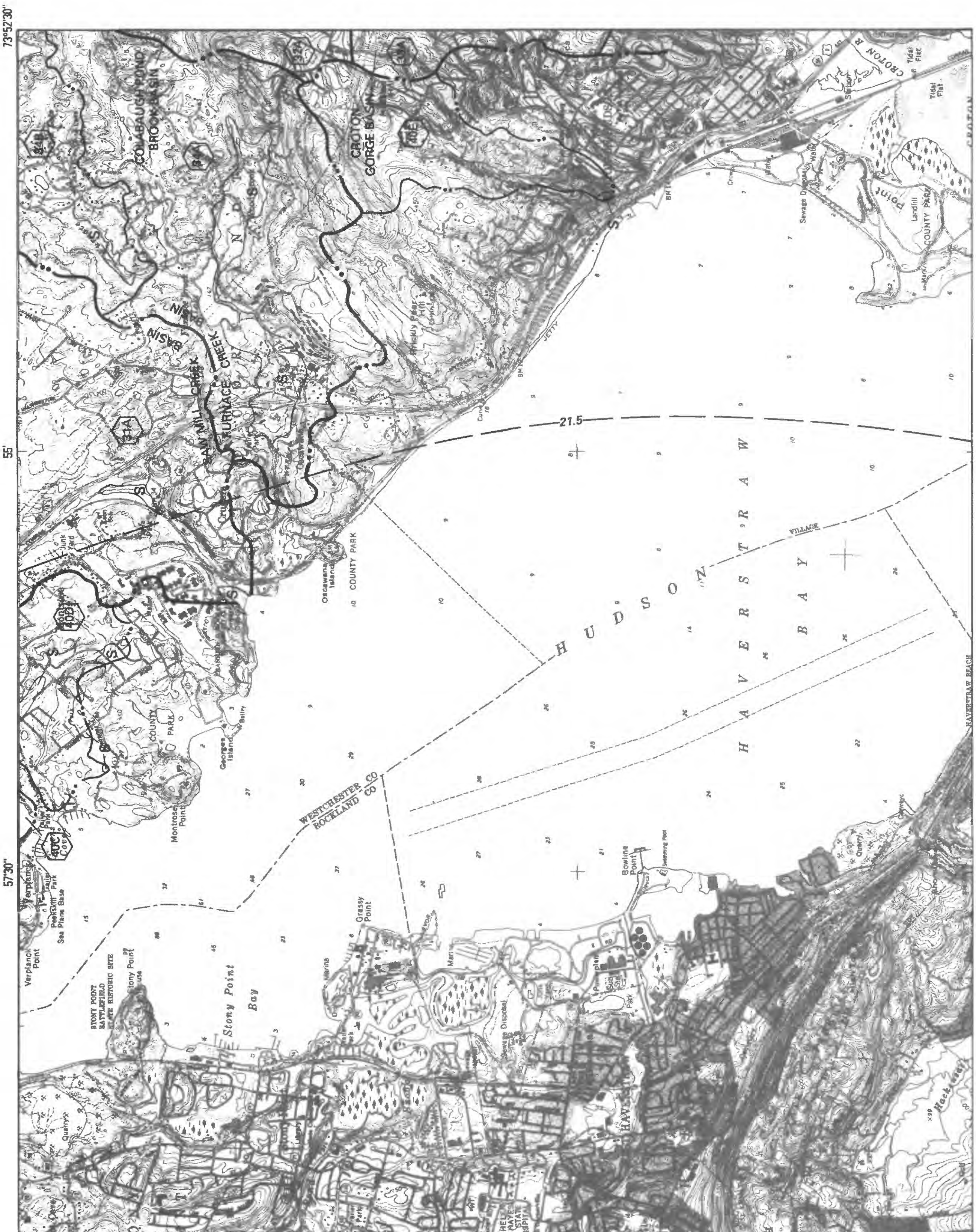
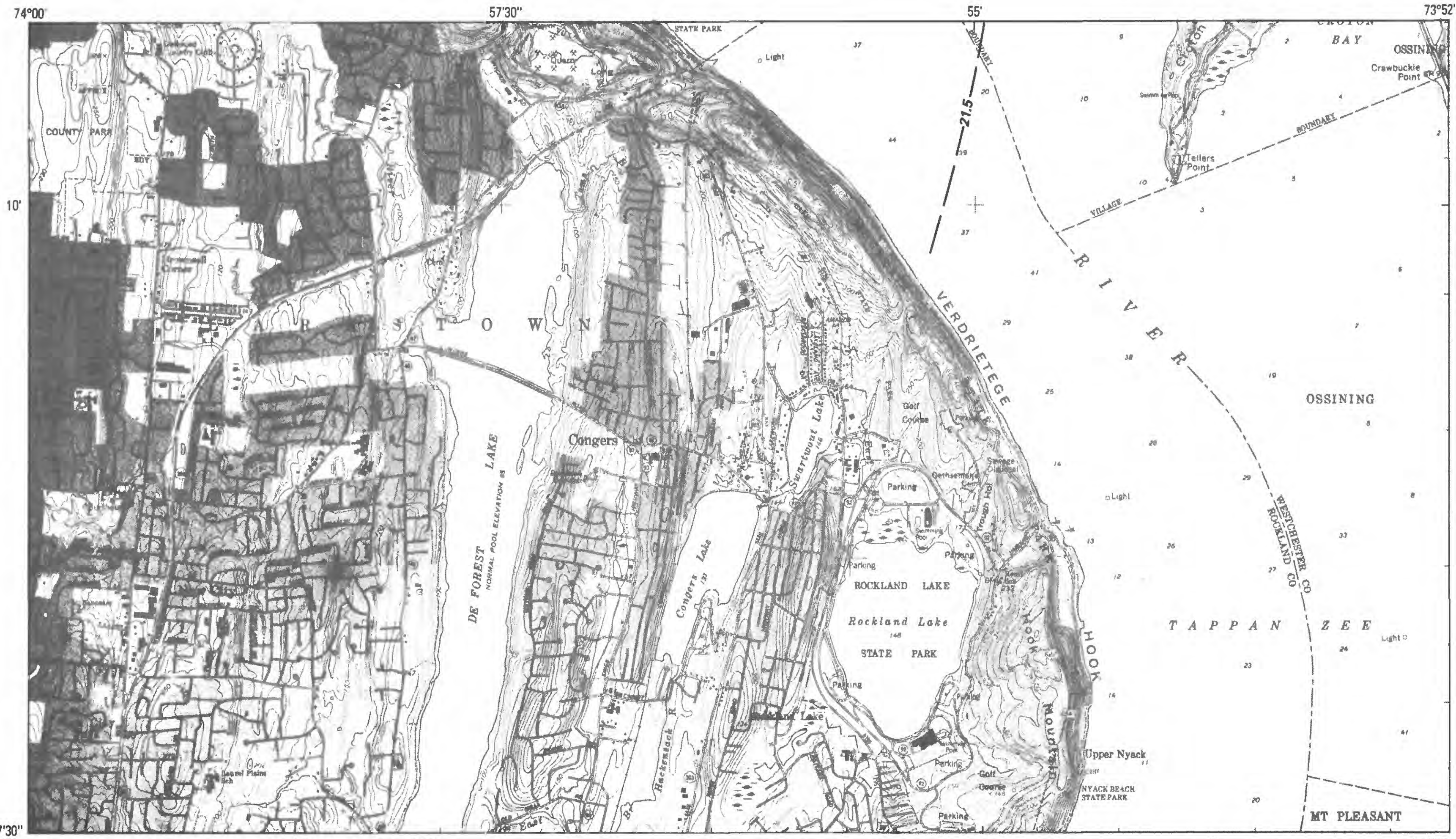


Figure 13D—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Peach Lake quadrangle.



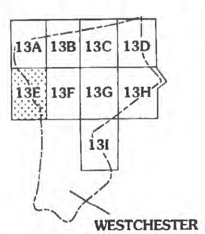
73°52'30"
55'
57'30"
74°00'
41°15'
12'30"
HUDSON
HAVERSTRAW
BAY
WESTCHESTER CO
ROCKLAND CO
Stony Point
Bay
STONY POINT BATTLEFIELD STATE HISTORIC SITE
Verplanck Point
Montrose Point
Georges Island
COUNTY PARK
Oscawana Island
CROTON GORGE BASIN
COLABAUGH POND BROOK BASIN
FURNACE CREEK
SAW MILL CREEK
Bowline Point
Grassy Point
Croton Point
Tidal Flat
HAVERSTRAW BEACH



Base from New York State Department of Transportation, 1982

0 1 MILE
0 1 KILOMETER

EXPLANATION



—••— Major surface-water drainage divide

—••— Minor surface-water drainage divide

—21.5— Line of equal mean annual runoff (inches per year)

S Area of stratified drift

24B Drainage-basin identifier (see table 12)

Figure 13E.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Haverstraw quadrangle.


73°45'
47'30"
50'
73°52'30"
41°15'
12'30"
CROTON RIVER
CROTON RIVER
WEST BASINS
SOUTH BASINS
BAILEY BROOK
CROTON BASIN
SOUTH RIVER
STILL LAKE BASIN
CORNELL BROOK BASIN
GEDNEY BROOK BASIN
KISCO RIVER BASIN
CROTON GORGE BASIN
INDIAN BROOK BASIN
FURNACE POND BROOK BASIN
Croton Heights
Tompkins Corners
Millwood
9H
8E
11A
11C
11E
39A
11I
38A
37A
9P
9G
8D
9E
8B
8C
9C
9D
36A
9A
8A
34B
32A
33A
35A
23
24
25
26
27

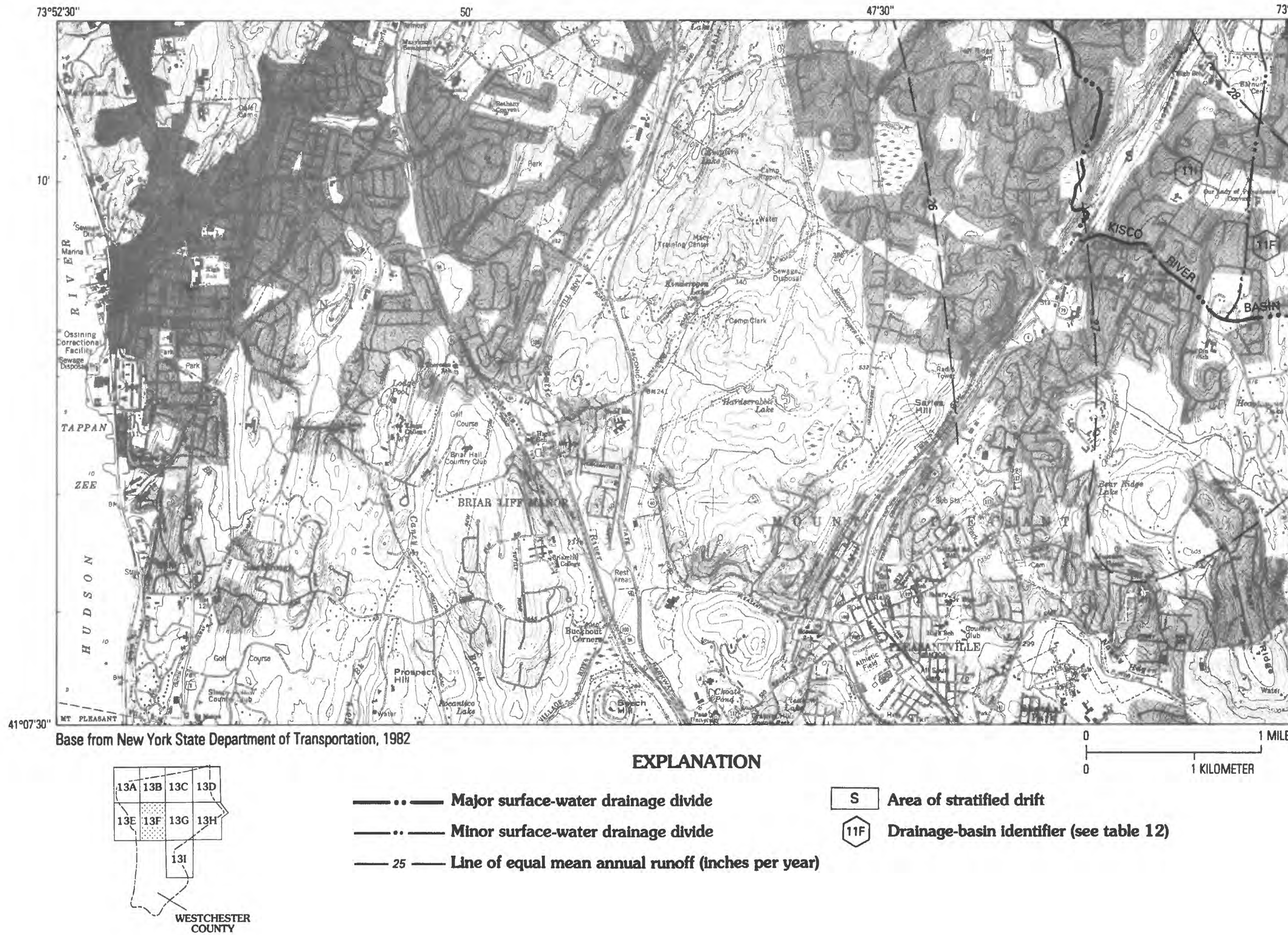
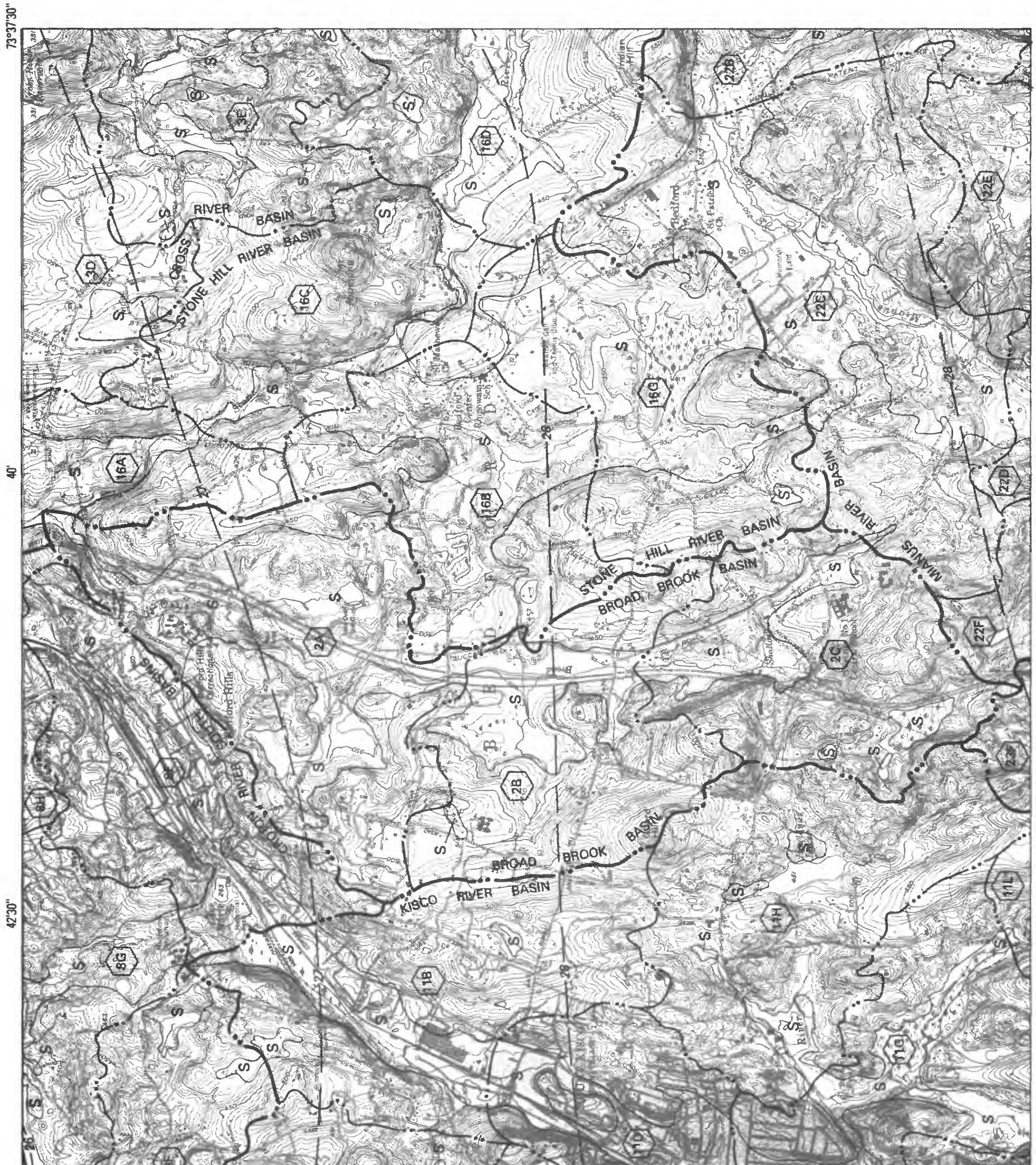
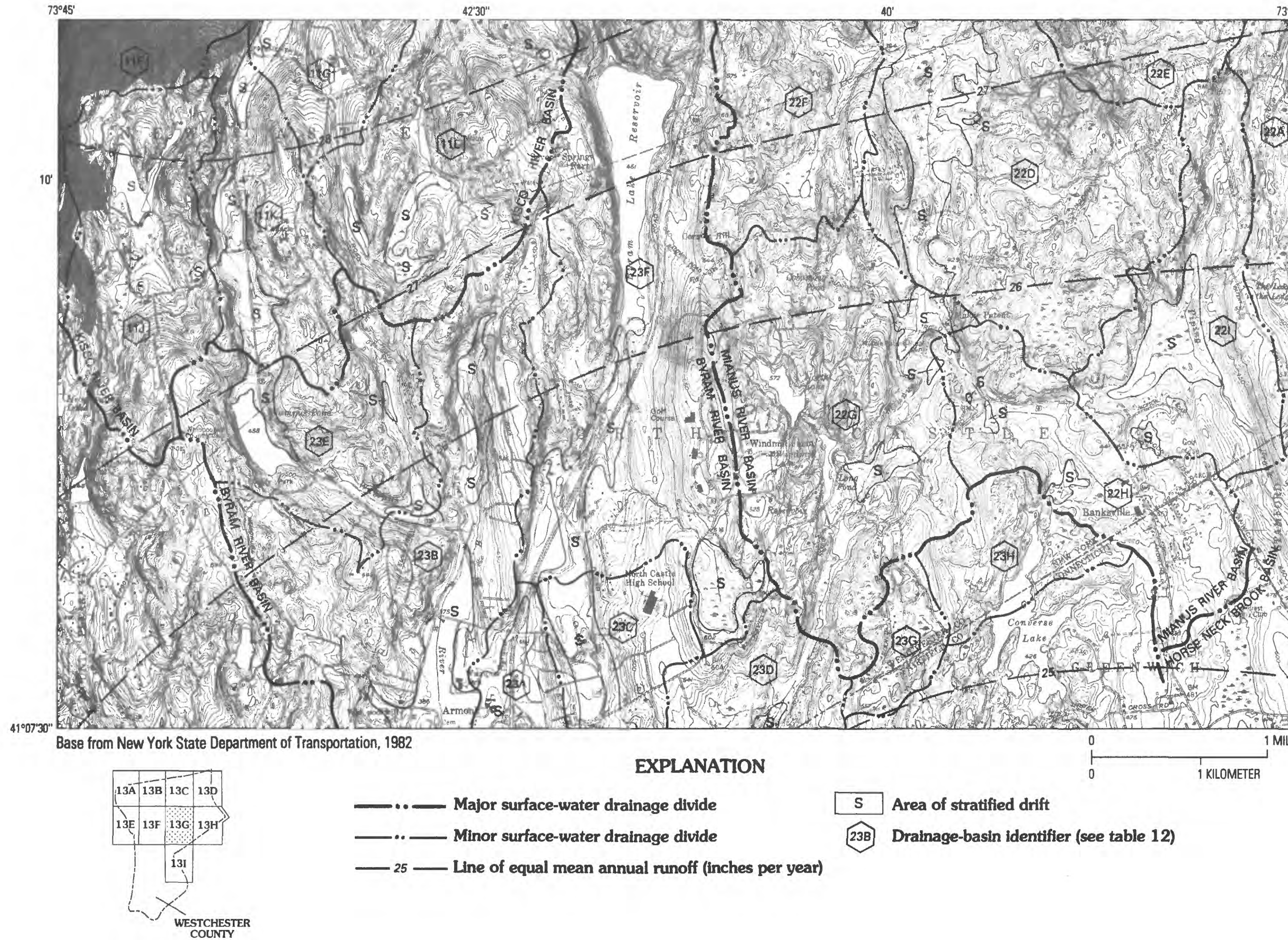


Figure 13F.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Ossining quadrangle.


73°45'
41°15'
73°37'30"
40'
42'30"
12'30"
CROSS RIVER BASIN
STONE HILL RIVER BASIN
BROAD BROOK BASIN
KISCO RIVER BASIN
MIANUS RIVER BASIN
CROTON RIVER
16A
16B
16C
16D
16G
22B
22C
22D
22E
22F
2A
2B
2C
3D
3E
11A
11B
11D
11G
11H
11L
8G
S



EXPLANATION

Major surface-water drainage divide

Minor surface-water drainage divide

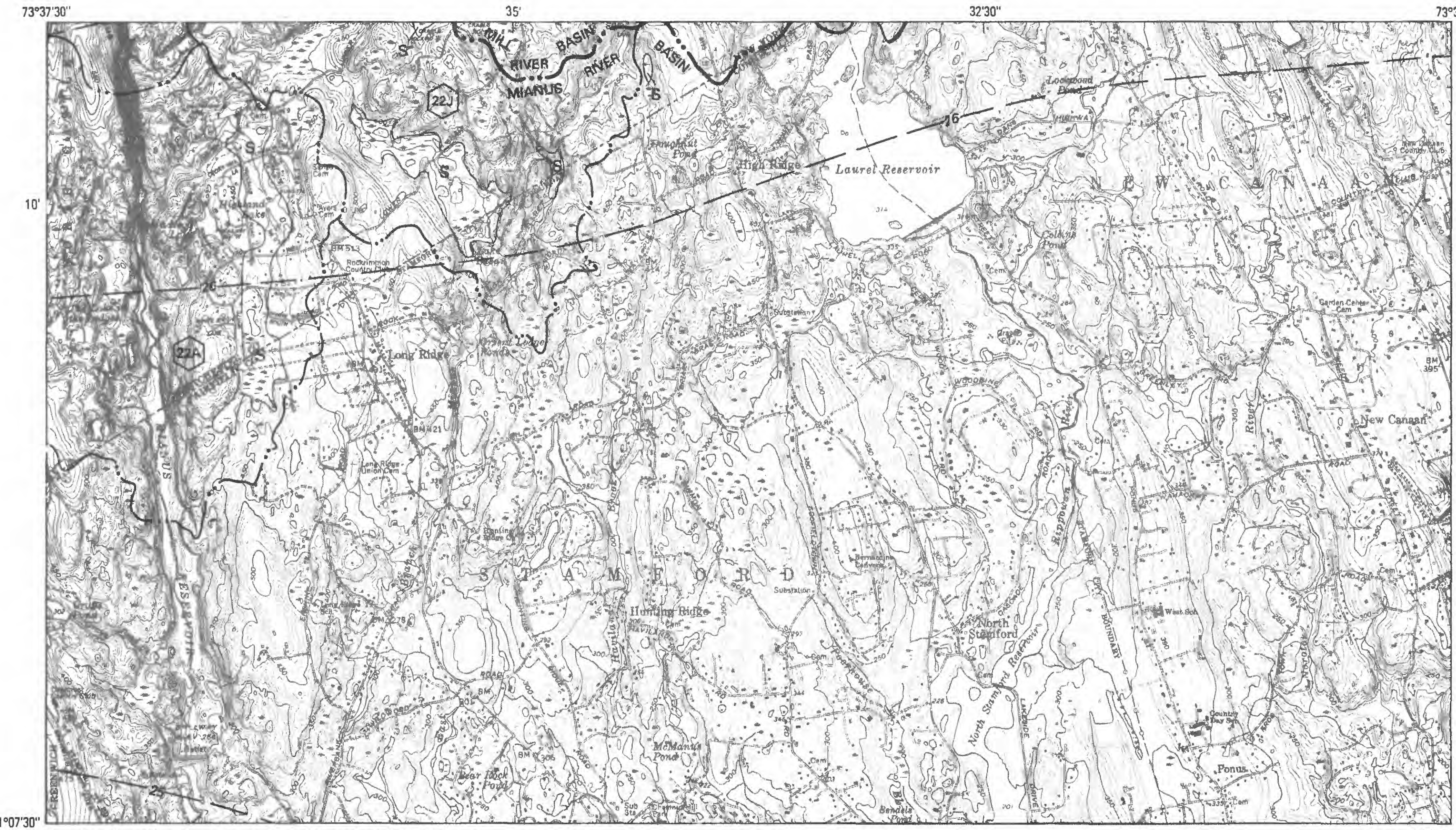
25 Line of equal mean annual runoff (inches per year)

S Area of stratified drift

23B Drainage-basin identifier (see table 12)

Figure 13G.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Mount Kisco quadrangle.


73°30'
32'30"
35'
73°37'30"
41°15'
12'30"
RIDGEFIELD
CONNECTICUT
NEW YORK
Browns Reservoir
SILVER
MINE
RIVER
RIPPOWAM
RIVER
BASIN
MILL
RIVER
BASIN
STONE
HILL
RIVER
BASIN
CROSS
RIVER
EAST
BASIN
Trinity Lake
Cross River Reservoir
Pound Ridge
19A
19B
19D
19C
20A
20B
21H
21F
21D
4D
21G
21C
4C
21E
21A
19E
21B
4A
16E
3E
16H
3F
22B
3D

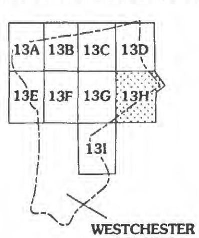


Base from New York State Department of Transportation, 1982

0 1 MILE

0 1 KILOMETER

EXPLANATION



—•• — Major surface-water drainage divide

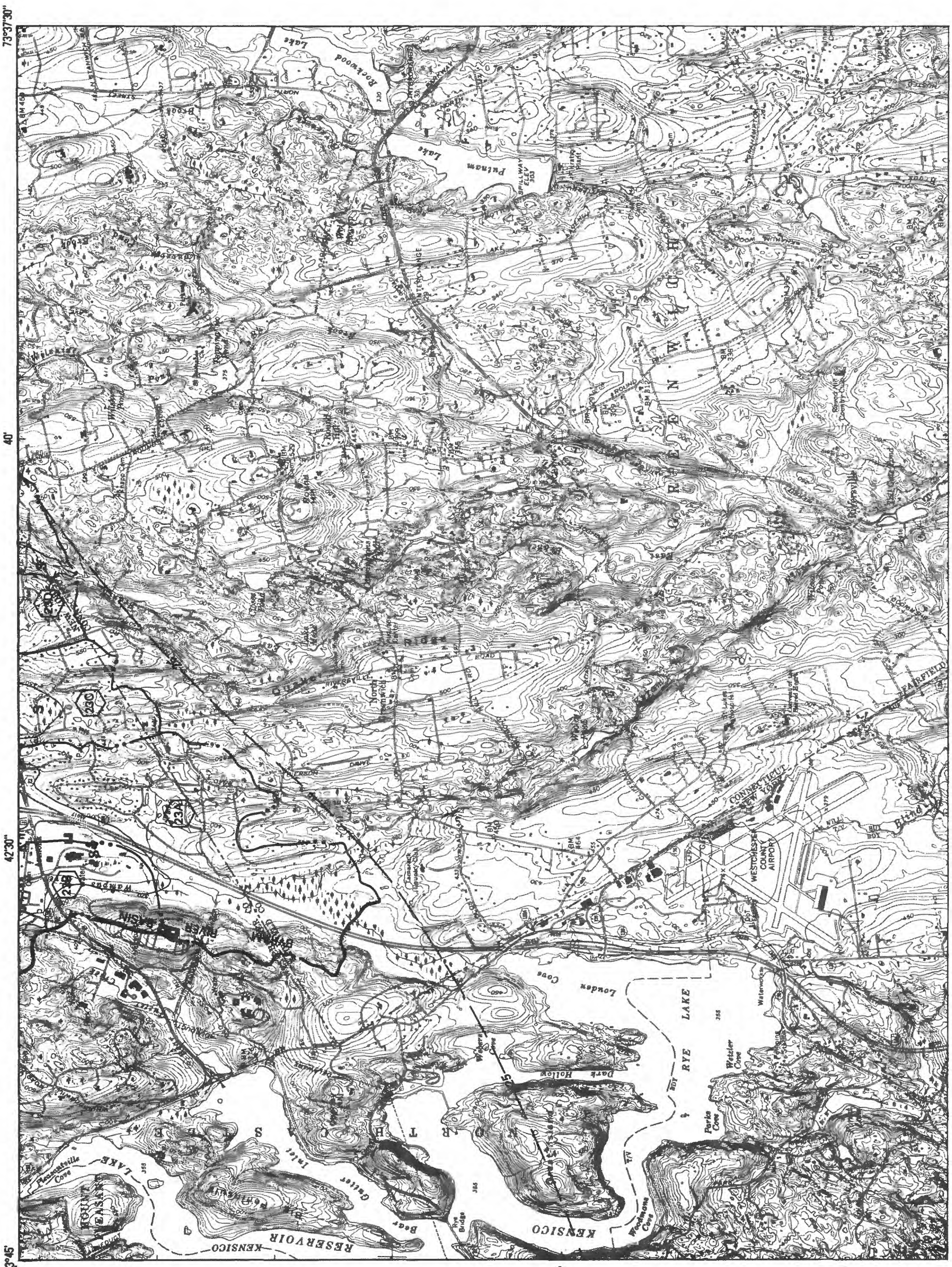
—•• — Minor surface-water drainage divide

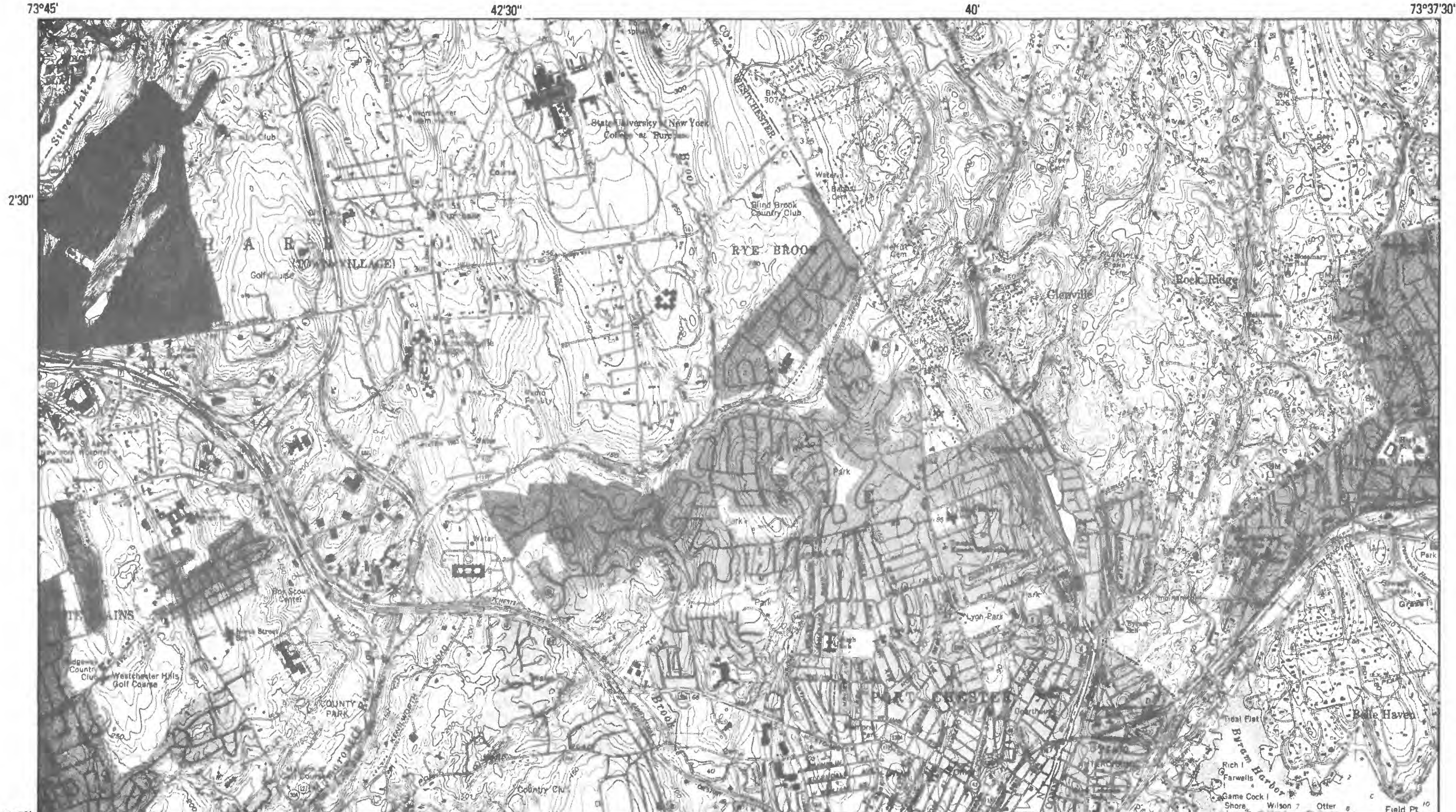
— 25 — Line of equal mean annual runoff (inches per year)

S Area of stratified drift

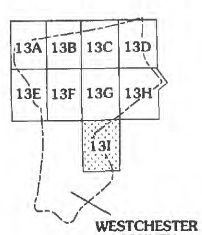
22A Drainage-basin identifier (see table 12)

Figure 13H.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Pound Ridge and part of the Norwalk quadrangle.


73°37'30"
40'
42'30"
73°45'
41°07'30"
5'
Putnam Lake
Rockwood Lake
WESTCHESTER COUNTY AIRPORT
CONNECTICUT
NEW YORK
RYE LAKE
KENSICO
RESERVOIR
Louden Cove
Dark Hollow
Bear Gutter Inlet
Wampus
Pleasantville Cove



Base from New York State Department of Transportation, 1982



EXPLANATION

—— • • —— Major surface-water drainage divide

—— • • —— Minor surface-water drainage divide

—— 25 —— Line of equal mean annual runoff (inches per year)

S Area of stratified drift

23B Drainage-basin identifier (see table 12)

Figure 13I.—Mean annual runoff, approximate areas of stratified drift, and drainage in northern Westchester County, Glenville quadrangle.