Water Resources of the Batavia Kill Basin at Windham, Greene County, New York

U.S. GEOLOGICAL SURVEY
Water-Resources Investgiations Report 98-4036

Prepared in cooperation with
New York City Department of Environmental Protection

Photo (cover): View of Cave Mountain and ski area looking south from Mitchell Hollow Road, Windham, New York. (Photo by Paul Heisig)

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science for a changing world

Troy, New York
1998

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

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

For additional information write to:

District Chief
U.S. Geological Survey
425 Jordan Road
Troy, New York 12180

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
cubic feet (ft^3)	0.02832	cubic meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallons per minute (gal/min)	0.06309	liter per second
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity	
square foot per day (ft^2/d)	0.09290	square meter per day
	Temperature	
degree Fahrenheit (° F)	5/9 (° F -32)	degree Celsius (° C)

Chemical Concentration
milligrams per liter (mg/L)
milliequivalents per liter (meq/L)

Specific Conductance
microsiemens per centimeter at 25 degrees Celsius (µS/cm)

Vertical Datum

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

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ABSTRACT

The water resources of a 27.6-square-mile section of the Batavia Kill Basin near the village of Windham, N.Y., which has undergone substantial development, were evaluated. The evaluation entailed (1) estimation of the magnitude and distribution of several hydrologic components, including recharge, (2) measurement of discharge and chemical quality of the Batavia Kill and selected tributaries, (3) analysis of ground-water flow and chemistry, and (4) a conceptualization of the ground-water flow system.

The region consists of deeply dissected, relatively flat-lying, clastic sedimentary sequences variably overlain by as much as 120 feet of glacial deposits. The types of bedrock fractures and their distribution in the Batavia Kill valley are consistent with valley stress-relief characteristics. Till predominates in the uplands, and stratified drift typically dominates within the valley of the Batavia Kill and the lower section of its largest tributary valley (Mitchell Hollow).

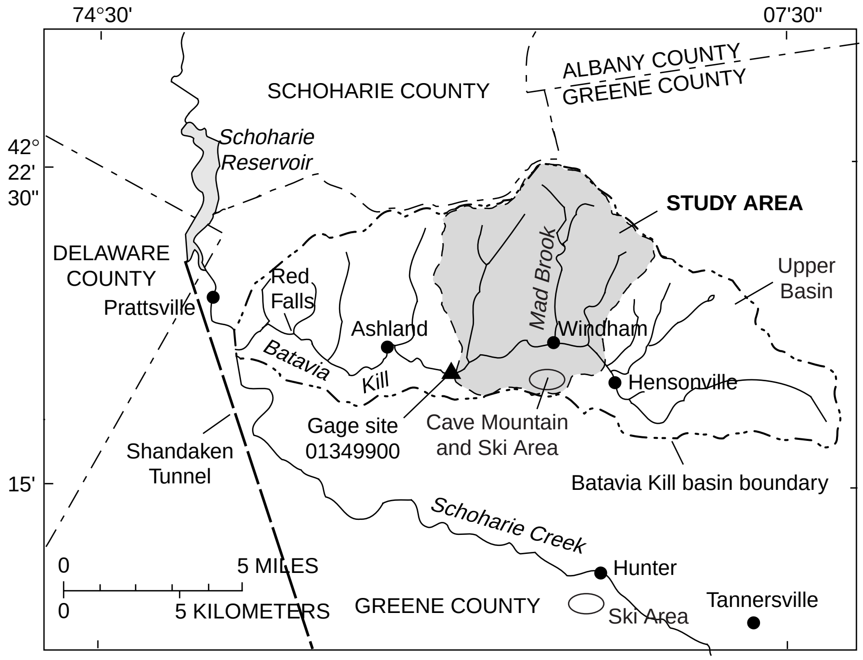
Fractured bedrock is the most commonly used water source within the study area. The areas of highest yielding bedrock generally are with valleys, where the shallow fractures are saturated. Stratified-drift aquifers are also limited to the largest valleys; the greatest saturated thicknesses are in the Batavia Kill valley at Windham. A conceptual model of ground-water flow within the study areas suggests that the zones of most active flow are shallow fractured bedrock in upland areas and the shallow stratified drift in the largest valleys.

The hydrogeologic system has been altered by development; major effects include (1) chemical alteration of natural ground-water and surface-water quality by point- and nonpoint-source contaminants, (2) hydraulic interconnection of otherwise isolated bedrock fractures by wellbores, and (3) drawdowns in wells within the Batavia Kill valley by pumping from the bedrock aquifer. Water resource development of the most promising unconsolidated aquifer beneath Windham may be precluded by the potential for contamination by leachate from an abandoned landfill, road-salt stockpiles, and domestic septic systems in the area.

INTRODUCTION

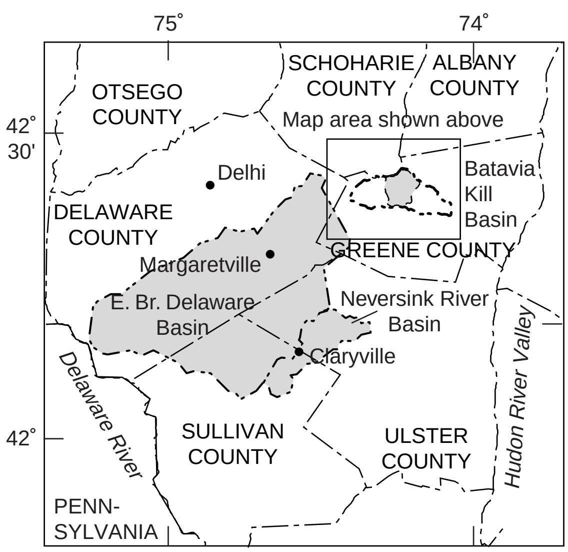
Water resources of the Catskill Mountains in southeastern New York are vital to New York City, which obtains much of its water supply from a system of reservoirs in the Catskill region. The New York City Department of Environmental Protection (NYCDEP) is developing watershed-management regulations in an effort to protect this drinking-water supply as development in the region increases. This process requires information on the water resources of the region, and on the hydrologic effects of development and other human activities. Such information also is of interest to State regulatory agencies and local communities.

In 1990, the U.S. Geological Survey (USGS), in cooperation with the NYCDEP, began a 3-year study to define and evaluate the water resources of a 27.6-mi^2 area of the Batavia Kill Basin near the village of Windham in western Greene County, N.Y. (fig. 1). The study area contains a ski area that opened in 1981 and spurred considerable local development, which in turn caused concern over potential impairment of the water resources.

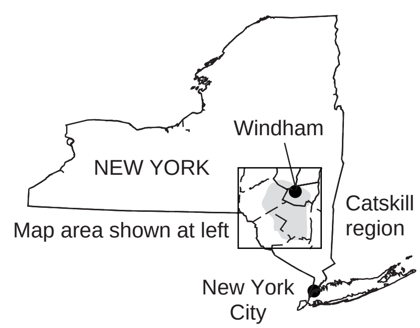


Base from U.S. Geological Survey
State base map, 1:500,000, 1974

A. Location of study area in Batavia Kill basin



B. Location of Batavia Kill basin



C. Location Map

Figure 1. Location and pertinent geographic features of the Batavia Kill study area and vicinity in southeastern New York.

Approach

The study entailed (1) interpretation of the hydrogeologic framework, and (2) an analysis of the local water resources. The hydrogeologic framework consists of bedrock overlain by a mantle of unconsolidated glacial deposits of variable thickness and permeability. Hydrogeologic data collection entailed:

- an inventory of wells and compilation of geologic data from driller's logs
- test-hole drilling and seismic surveys
- **borehole geophysical logging**[1] (results are given in Heisig and Knutson, 1997)
- field measurements of fracture orientations in the bedrock

The water-resources investigation entailed (1) estimation of volumes for major components of the hydrologic system (precipitation, evapotranspiration, total runoff, recharge, and overland runoff), and (2) documentation of the occurrence and chemical characteristics of surface water and ground water. The values for the components of the hydrologic system were estimated from surface-water-discharge data or from published relations.

The surface-water aspect of the study addressed streamflow and stream-water chemistry. Data collection entailed:

- continuous monitoring of **stage**, and periodic measurement of **discharge,** of the Batavia Kill
- two sets of discharge measurements of the Batavia Kill and its tributaries during periods of **base flow**
- chemical analysis of water from the Batavia Kill and six tributaries.

The ground-water aspect addressed (1) the water-resource potential of unconsolidated deposits and bedrock, (2) the chemistry of natural (pristine) ground waters, (3) the effects of human practices on ground-water quality, and (4) development of a conceptual model of the ground-water flow system. Data collection entailed:

- weekly or continuous water-level monitoring at selected wells
- **aquifer** testing
- borehole geophysical logging (results are given in Heisig and Knutson, 1997)
- chemical analysis of ground-water samples.

[1]Boldface terms are explained in glossary (at end of report)

Purpose and Scope

This report (1) summarizes the geology of bedrock (including fractures) and unconsolidated deposits, (2) gives volumetric estimates of hydrologic components of the basin, (3) describes the surface-water and ground-water resources of the area, and (4) presents a conceptual model that describes ground-water flow. Three appendixes provide data on (1) well characteristics, (2) the chemical composition of ground water, and (3) the chemical composition of ground water affected by human practices.

Acknowledgments

The author thanks the many property owners who granted permission to collect hydrogeologic data from their wells or properties. Special thanks are extended to Thomas Sheridan, Eric Goettsche, Paul Mademann, Howard Tuttle, Bernard Brabazon, Percy and Robert Goff, Robert O'Rourke, Jay Chicoy, and the Windham Country Club. Daniel Frank, general manager of Ski Windham, granted permission for installation of monitoring wells and access to property, wells, and water-use data. George Mulford, superintendent of water and highways for the Town of Windham, provided access to water-use data from the Town spring and backup production well and facilitated aquifer testing. The Greene County Highway Department provided logistical assistance and property access for drilling and temporary equipment storage. The author is especially grateful to drillers Thomas Falciano, Jr., Troy Johnson, Wesley Mulford, and George Mulford for providing well data from the area.

Physiography and Water Use

The 27.6-mi^2 study area (fig. 1) occupies the central part of the 73.2-mi^2 Batavia Kill basin, within the northeastern Catskill Mountains, which are part of the Appalachian Plateaus physiographic province (Fenneman, 1938). This province consists of dissected, gently sloping plateaus of sedimentary rocks. Maximum relief within the study area is about 1,500 ft; the lowest altitudes are within the Batavia Kill valley, and the highest altitudes are along the northern and southern drainage divides. The Batavia Kill basin is asymmetrical; most of the drainage area (broad uplands) is north of the Batavia Kill (fig. 1A). The Batavia Kill flows westward to its confluence with Schoharie Creek, which flows north into the Schoharie Reservoir.

The water resources of the study area are jointly used by residents and businesses in the Towns of Windham and Ashland and by New York City. The local communities obtain most of their water from domestic and municipal wells that tap bedrock. Some municipal and domestic wells tap unconsolidated deposits, but these wells are mostly within the Batavia Kill valley. Springs also are used for municipal and domestic supplies. The only significant use of surface water within the study area is for snowmaking at the local ski area. Most wastewater is disposed of through individual or multiple-service septic systems; the ski area operates a wastewater-treatment plant that discharges to a tributary of the Batavia Kill. Most of the flow from the Batavia Kill is ultimately routed to New York City via the Shandaken Tunnel from the Schoharie Reservoir (fig. 1A).

Geology

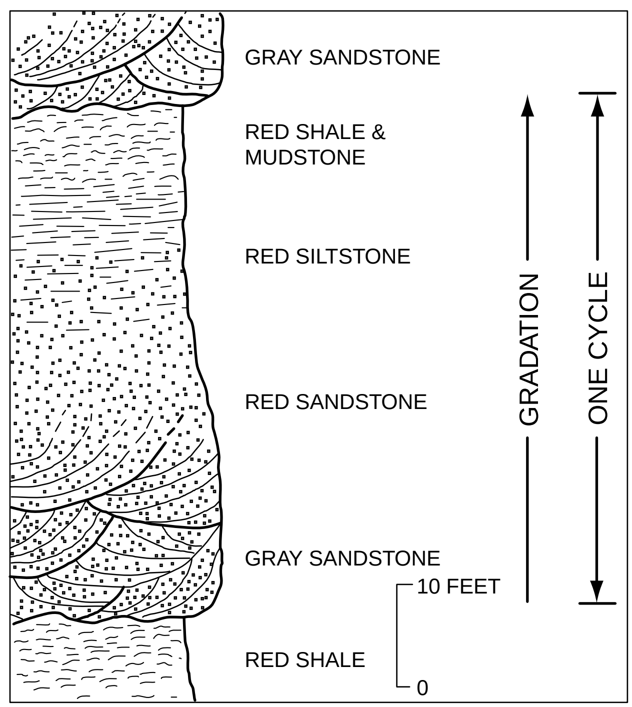
The study area is underlain by Middle to Late Devonian-age clastic sedimentary rocks that dip a few degrees to the southwest (Fisher and others, 1970; Rickard, 1975; Berdan, 1954). Exposures of these rocks are common in steep upland areas but are rare in the valleys. Unconsolidated deposits blanket bedrock over much of the study area and are primarily of glacial origin; till dominates in the upland areas, and stratified deposits are most common in and near the larger valleys. Postglacial flood-plain **alluvium** and swamp deposits are found locally.

Bedrock

Bedrock consists of 50- to 100-ft-thick fining-upward sedimentary cycles (Lucier, 1966; Fletcher, 1967). The cycles typically contain (from base to top) gray sandstone and conglomerate, red sandstone and siltstone, and red shale and mudstone (fig. 2). Some pyritic, dark-gray to black mudstones also may be present (Johnson,1976). These cycles are accentuated at hillslope outcrops, where the resistant sandstones form cliffs, and the more erodible, finer-grained deposits form gentler slopes (Chadwick, 1944).

Bedrock is fractured throughout the region. Fracture occurrence and distribution is important to the hydrology because ground water is restricted mostly to fractures (secondary openings). Fractures in the study area typically are low-angle or high-angle. The low-angle fractures follow bedding planes as well as contacts between rock units, whereas high-angle fractures reflect preferred directions of breakage or cleavage. Regional fracture orientations are attributed to tectonic stresses such as uplift. Fracturing is most clearly expressed within the sandstone units, which are more brittle than the shale and mudstone units. Shales and mudstones may contain a greater fracture density than sandstones but have fewer open fractures because these rocks tend to be more elastic.

Data from outcrops indicate, with few exceptions, that fracture orientations are similar within, and to at least 4 mi east and 5 mi west of, the study area. The dominant fracture sets are oriented (**strike**) north 40 to 70 degrees east, and north 30 to 40 and 50 to 70 degrees west (fig. 3). Variations in the apparent dominance of one of these orientations over the other is noticeable across the study area and vicinity; sites in the eastern half of the study area and beyond tend to show stronger development of the northeast orientation, and sites in the western half and beyond tend to show a strong northwest orientation relative to the composite **rose diagram**. The dominant fracture orientation at a given outcrop in both of these areas is



(From Fletcher, 1967, fig. 6)

Figure 2. Fining-upward sedimentary cycle of bedrock in the eastern Catskill Mountain region, N.Y. (From Fletcher, 1967, fig. 6.)

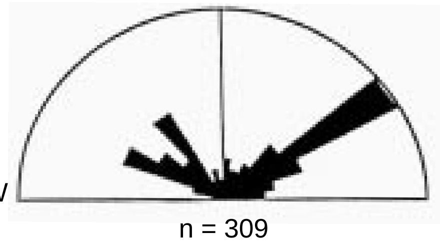


Figure 3. Half-rose diagram showing an equal-weight composite of high-angle-fracture strike orientations from the Batavia Kill Basin, Greene County, N.Y. [n = number of observations.]

generally the regional orientation that most closely parallels the orientation of the local valley segment.

The distributions of high-angle and low-angle bedrock fractures within the Catskill region can be surmised from those identified in similar dissected bedrock terranes within the Appalachian Plateau. In general, high-angle fractures are more common in the valley-wall areas than below the valley floor; bedding-plane fractures are the opposite. The concept of valley stress relief, described by Ferguson (1967, 1974) and Wyrick and Borchers (1981), is one possible explanation for the variations in fracture distribution.

Dip measurements of high-angle fractures across the area ranged from 44 degrees to vertical (90 degrees), although the majority range between 70 and 90 degrees. Scattered dip values between 44 and 60 degrees typically were associated with a small number of north-south oriented fractures.

Unconsolidated Deposits

Unconsolidated sediments in the form of glacial and postglacial deposits cover bedrock over much of the Catskill region. Glacial deposits, which are of **Pleistocene** age, form the bulk of this material. Till is the most common deposit throughout the region, whereas **stratified drift**, which ranges from valley-bottom and ice-contact sand and gravel to lacustrine silt and clay, is largely limited to the valleys. Postglacial deposits of **Holocene** age are widespread, but they tend to be thin and discontinuous. These relatively recent deposits include alluvium (including fluvial gravels), **colluvium**, and swamp deposits.

Most glacial sediments were deposited during retreat of the ice sheet at the close of the Pleistocene Epoch. Deglacial events within the northward-draining Schoharie Basin have been interpreted by Rich (1915, 1935), LaFleur (1969), and Cadwell (1986). Two results of glaciation/deglaciation are of particular interest in terms of water resources. First, glacial ice blocked valleys and prevented drainage to the north; this resulted in the formation of glacial lakes with water-level altitudes as high as 1,600 ft within many of the larger valleys in the Schoharie Creek Basin. Most of the resulting lacustrine deposits are fine grained and thus have poor permeability. Second, ice and associated meltwaters from the Hudson Valley lobe of the ice sheet flowed over the present northern drainage divide into the Schoharie Creek Basin, depositing rock material, including limestone, which can significantly affect water chemistry.

WATER RESOURCES

Water resources of the study area are discussed here in terms of components of the hydrologic system, surface water, and ground water. Components of the hydrologic system are discussed in terms of total volume and areal distribution. Surface water is discussed in terms of flow characteristics and spatial and temporal chemical variations. Ground water is discussed in terms of potential availability within unconsolidated deposits and bedrock, natural chemical variations, effects of human-derived contaminants, and flow paths.

Components of the Hydrologic System

Estimation of values for the components of the hydrologic system provides a hydrologic framework in terms of volume and distribution of water, within the gaged portion of the Batavia Kill Basin. The hydrologic components addressed in this study area were precipitation, evapotranspiration (surface and ground water), total runoff, (effective recharge and overland flow), and water withdrawals (water use and consumptive use). Their estimated values are given in table 1.

Only the gaged part (eastern two-thirds) of the Batavia Kill Basin, referred herein as “the basin” or “the Batavia Kill Basin,” is used as the basis for this analysis because the surface-water flow data and statistics are derived from this area. The gaged area encompasses 51.2 mi^2, of which the study area occupies the lower 27.6 mi^2; and the upgradient remainder referred to as the “upper basin,” contains the remaining 23.6 mi^2 (fig. 1). In general, the upper basin has more runoff per unit area than the study area because it is higher in elevation; precipitation increases, and evapotranspiration decreases, with increasing elevation.

The estimates in table 1 represent a long-term average of climatic conditions across the basin; although the values for individual years can vary significantly, the estimates presented here provide a general indication of the magnitude of each component (fig. 4). The individual components and the estimation procedures are described in the following paragraphs.

Table 1. Estimated long-term mean annual hydrologic component values for the gaged part of the Batavia Kill Basin, Greene County, N.Y.

[Basin area is 51.2 square miles]

Component	Volume: Inches over entire basin	Volume: Millions of cubic feet
Precipitation	42.5	5,050
Evapotranspiration	19.4	2,308
Surface evapotranspiration	16.8	1,998
Ground-water evapotranspiration	2.6	309
Total runoff	23.1	2,748
Effective recharge [1] (baseflow)	14.5	1,720
Total overland flow	8.6	1,023
Water withdrawals	.3	40
Water use	.2	30
Consumptive water use	.006	.7

[1] Effective recharge = Total recharge - Ground-water evapotranspiration

Precipitation

Precipitation is the only source of water to the basin. A National Weather Service rain gage, 1.5 mi northeast of Windham (location shown in fig. 5A) is the only long-term data-collection site within the basin. Mean annual precipitation (1961-90) at this site is 41.09 in. (National Oceanographic and Atmospheric Administration, 1992); mean monthly precipitation values for the same period indicate that precipitation is relatively evenly distributed during the year. Mean annual precipitation serves as a point of reference for the basin, but spatial variation is common, particularly in areas of high relief; a study by Dingman (1981) in New Hampshire and Vermont indicated significant increases in precipitation with increasing elevation. Maximum relief within the basin is about 2,500 ft (altitude range is 1,400 to 3,980 ft).

The spatial distribution of precipitation (fig. 5A) is based on the precipitation-gage data and the distribution given in Knox and Nordenson (1955). The values of the lines of equal precipitation from Knox and Nordenson (1955) were increased by 1 in. to improve the match with the gage data, which represent a longer period of record than was available to Knox and Nordenson.

The strong correlation between elevation and precipitation is evident in figure 5A (compare with topography on pl. 1), although the uplands in the south appear to receive more precipitation than those

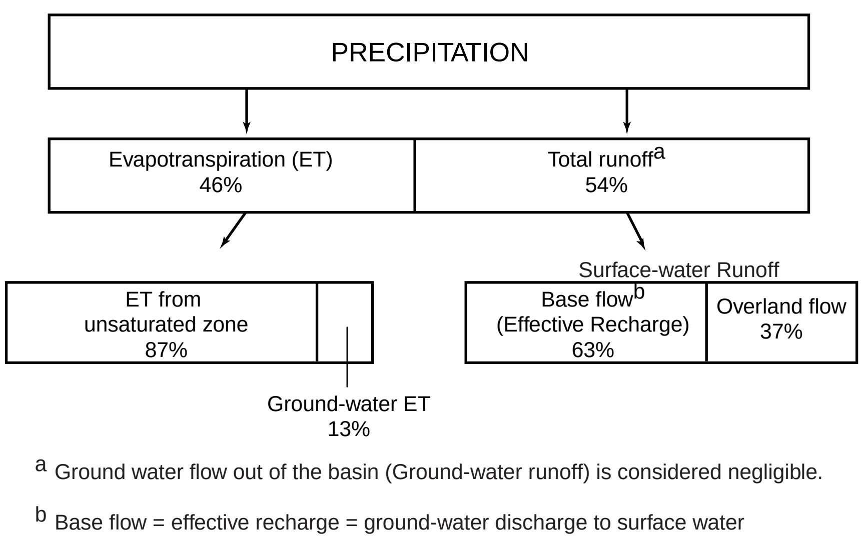
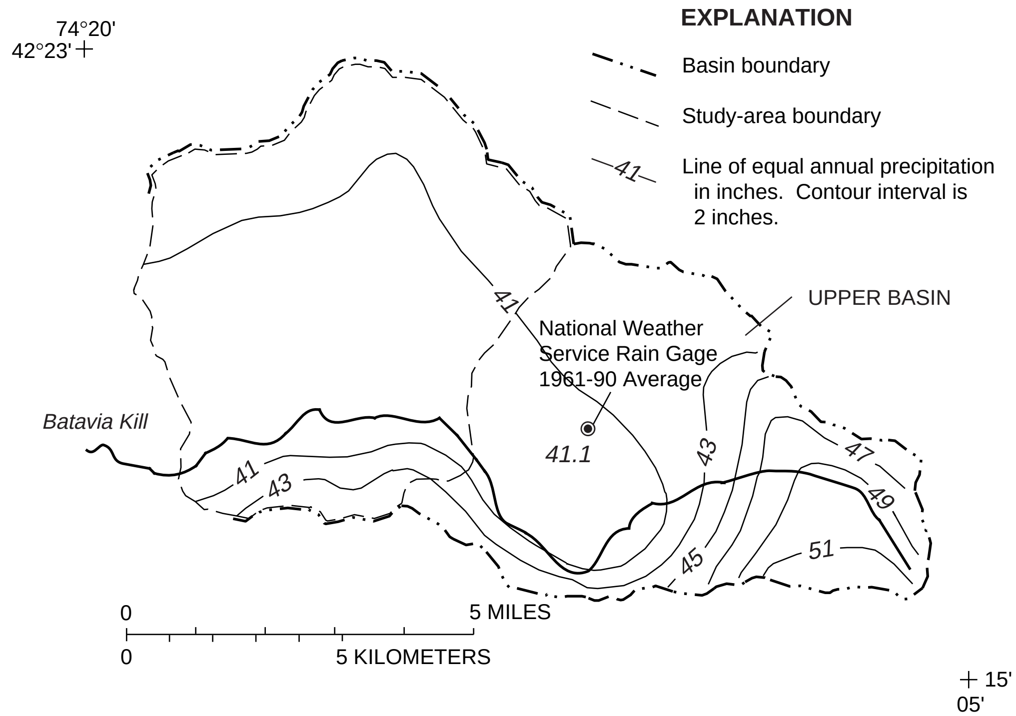
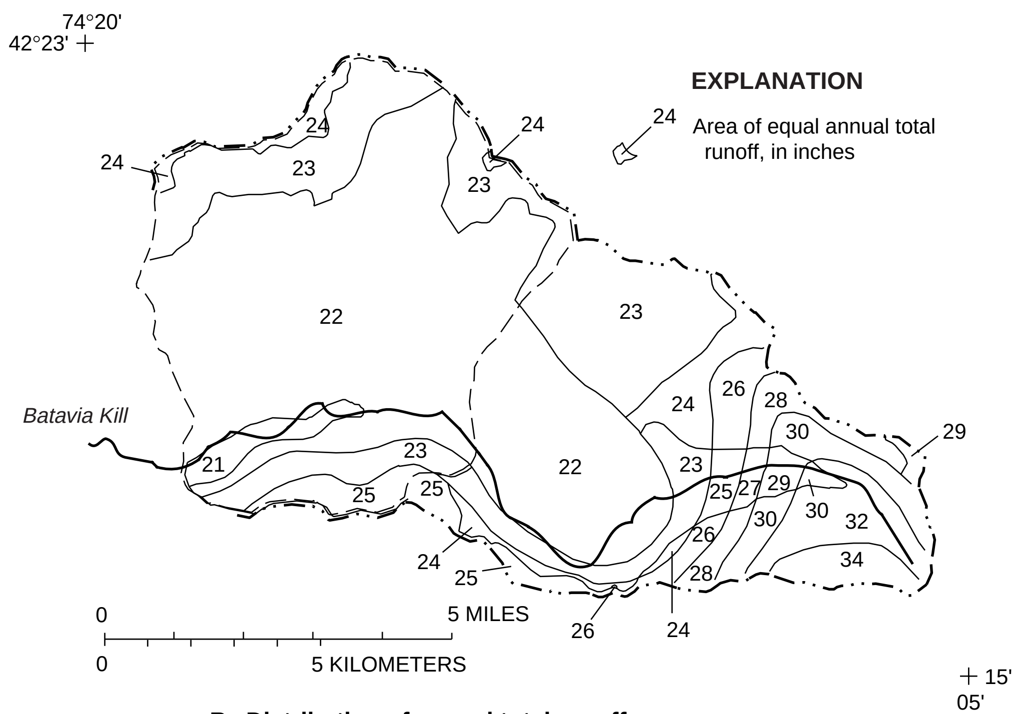


Figure 4. Relative magnitudes of major hydrologic components; each component scaled and listed as a percentage of the preceding component. (Corresponding volumes are given in table 1.)

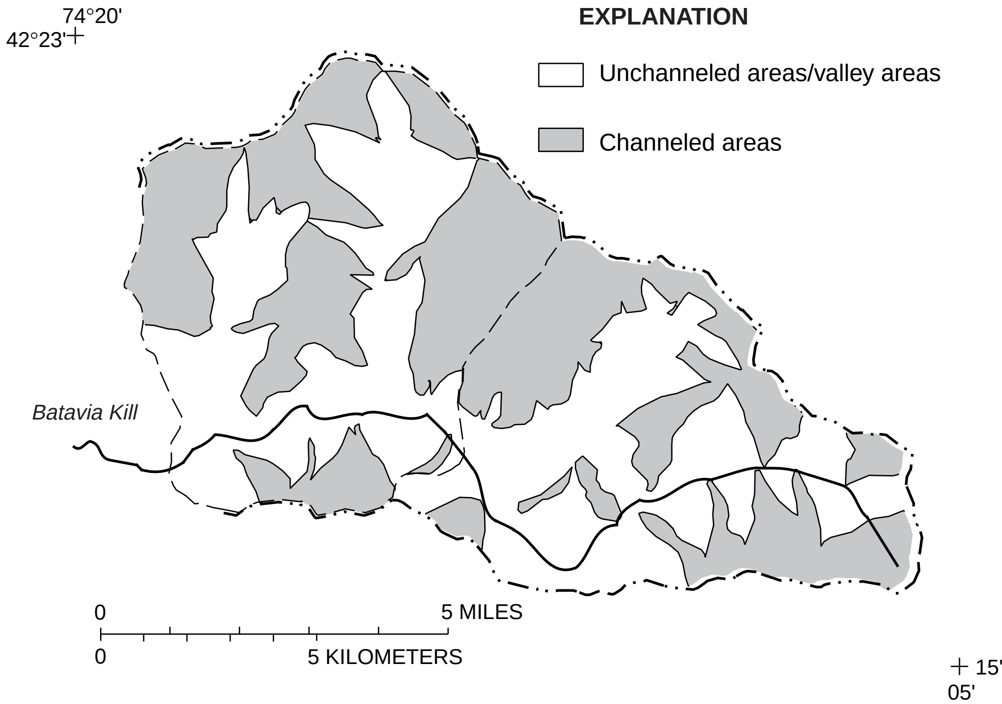


A. Distribution of annual precipitation

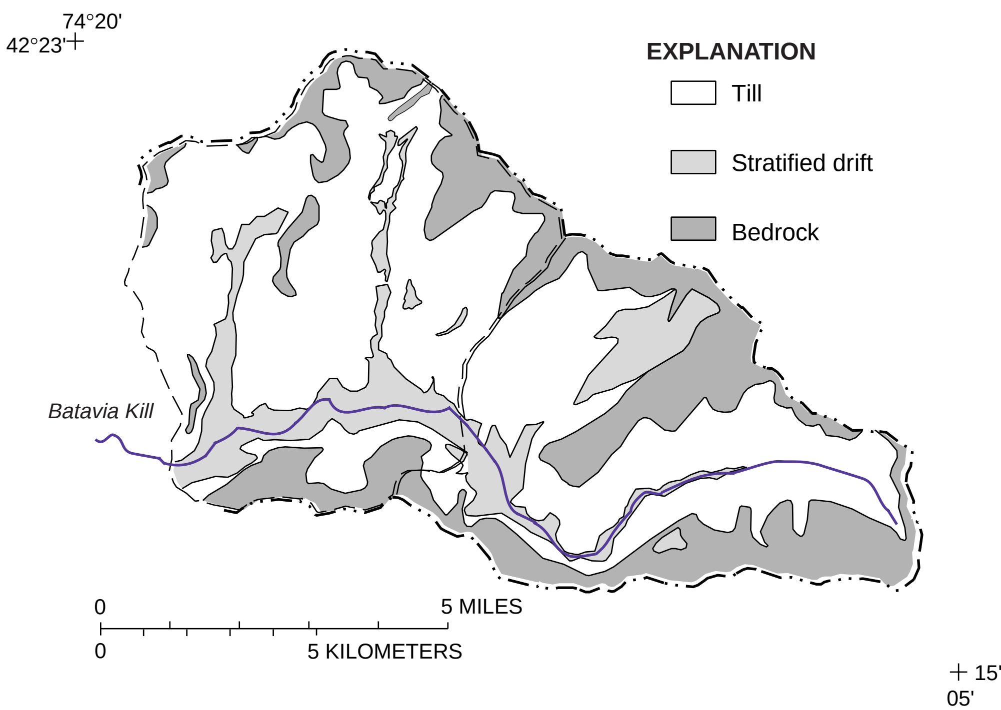


B. Distribution of annual total runoff

Figure 5. Estimated areal distribution of selected hydrologic components and hydrogeologic characteristics in the gaged part of the Batavia Kill Basin, Greene County, N.Y. (Location shown in figure 1.) A. Annual precipitation. B. Annual total runoff. C. Unchanneled areas/valley areas and channeled areas. D. Surface exposures of bedrock, stratified drift, and till.



C. Distribution of unchanneled areas/valley areas and channeled areas



D. Distribution of surface exposures of bedrock, stratified drift, and till

Figure 5. (Continued) Estimated areal distribution of selected hydrologic components and hydrogeologic characteristics in the gaged part of the Batavia Kill Basin, Greene County, N.Y. (Location shown in figure 1.) A. Annual precipitation, B. Annual total runoff, C. Unchanneled areas/valley areas and channeled areas, and D. Surface exposures of bedrock, stratified drift, and till.

of similar elevation in the north. Annual precipitation ranges from about 41 in. at the downgradient (western) end of the basin to about 51 in. at the highest elevations in the easternmost part. Area-weighted average precipitation estimates were obtained by: (1) calculating the areas (mi^2) between all adjacent lines of equal precipitation from a geographic-information-system (GIS) coverage, (2) calculating the percentage of total basin area represented by each area, (3) multiplying each area's percent value by the average of the precipitation values of the two bounding lines of equal precipitation, and (4) summing all resulting precipitation values. The area-weighted mean annual precipitation for the basin is 42.5 in.; the value for the study area is 41.3 in.; and that for the upper basin is 43.2 in.

Evapotranspiration

Evapotranspiration (ET) is that portion of precipitation that is lost from the land surface or subsurface through transpiration by vegetation and by evaporation. Lyford and Cohen (1988) suggested that annual ET in the northeastern United States is relatively constant and that long-term average ET at a given site is equal to the difference between long-term average precipitation and long-term average total runoff. They also suggested that air temperature is the factor that controls total ET most directly and provided a graph, modified from Langbein and others (1949) of mean annual ET as a function of mean annual air temperature (fig. 6). The dependence of ET on air temperature and uptake by vegetation limits it largely to the growing season (April to October). ET is inversely related to elevation because temperature decreases with increasing elevation.

Two methods of ET estimation were used in this study. The first entailed calculation of the difference between the long-term averages of precipitation and total runoff for the basin; as explained in the preceding and following sections, those values yielded a long-term annual ET value of 19.4 in. The second method involved derivation of an area-weighted mean annual air temperature for the basin that was applied to the relation between ET and mean annual air temperature (fig. 6); this yielded in a long-term annual ET value of 19 in.

The area-weighted mean annual air temperature (42.2° F) was calculated from a mean annual temperature distribution, which was estimated by applying a vertical temperature gradient of 3.1° F per 1,000 ft throughout the basin. This gradient was calculated from long-term temperature data from two National Weather Service sites in the Catskill Mountains. A source of error in this estimate is the temperature difference associated with slope orientation; mean annual temperatures or estimates for south-facing slopes should be higher than those on nearby north-facing slopes.

The mean annual ET obtained from the first method (19.4 in.), based partly on records of Schoharie Creek discharge, was used in table 1 and figure 4 because those records also were used in computations of other components of the hydrologic system. The ET estimate represents losses from the unsaturated zone (87 percent of total ET) and from ground water (the saturated zone; 13 percent of total ET). Ground-water ET is part of the total recharge in that it reached the saturated zone before discharging as ET. Ground-water ET can be estimated as the difference between total recharge and effective recharge (that which discharges to surface water). These calculations are discussed in the recharge section.

Total Runoff

Total runoff is the part of precipitation that exits a basin as surface water or ground water. The long-term annual average represents the amount of water available after ET (Lyford and Cohen, 1988). Total runoff within the basin (fig. 5B) is greatest at high elevations, where precipitation is greatest and ET is least. Total runoff consists of two components—**underflow** and surface-water runoff. The underflow is generally

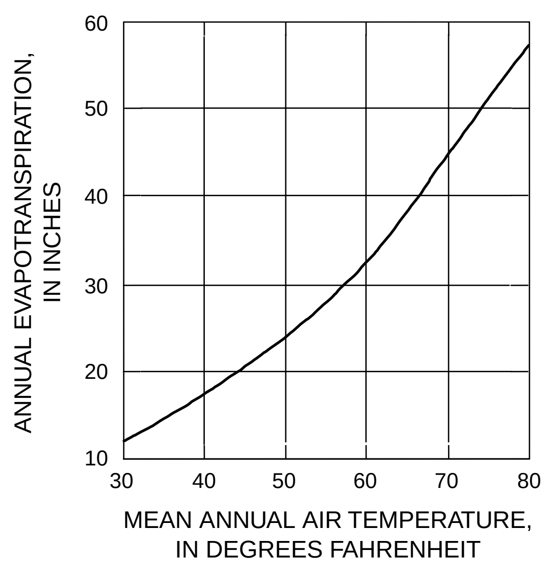


Figure 6. Annual evapotranspiration in humid climates as a function of mean annual air temperature. (Modified from Lyford and Cohen, 1988, fig. 2, as modified from Langbein and others, 1949.)

assumed to be an insignificant fraction of total runoff leaving basins with valley and upland areas, especially where the valley-fill aquifer is relatively thin and narrow, and is not considered further herein. Surface-water runoff is by far the larger component and is derived from overland flow and ground-water discharge to streams within the basin. Overland flow dominates during periods of precipitation and snowmelt, and ground-water discharge dominates other periods.

Runoff is reported as an annual value for most gaging stations represented in USGS annual water-data reports. Annual runoff values for the Batavia Kill Basin are limited to the 1992 and 1993 **water years**, but long-term annual runoff data are available for Schoharie Creek, to which the Batavia Kill is tributary. Schoharie Creek runoff data for 1961-90 (the period corresponding to the mean-annual precipitation data herein) and 1992-93 were the basis for estimates of long-term annual runoff from the Batavia Kill Basin. Direct estimation from Schoharie Creek unit-area runoff values was not used because average precipitation for the Schoharie Basin probably exceeds that of the Batavia Kill Basin, as indicated by Knox and Nordenson's (1955) precipitation map. Mean-annual runoff of the Batavia Kill for 1961-90 (23.1 in.) was estimated by equating the ratio of the mean-annual runoff (MAR) values for 1992-93 for each of the two sites to the ratio for 1961-90, and solving for Batavia Kill 1961-90:

$$\frac{\text{MAR for Schoharie Creek, 1961-90}}{\textit{MAR for Batavia Kill, 1961-90 (value unknown)}} = \frac{\text{MAR for Schoharie Creek, 1992-93}}{\text{MAR for Batavia Kill, 1992-93}}$$

Mean annual runoff also was estimated as the difference between precipitation and ET as determined from GIS coverages. The area-weighted average obtained for the basin by this method is 23.6 in.

Both estimates are subject to error from local, if not regional, variations in precipitation as well as uncertainties in annual runoff values. The estimate obtained from the above equation (23.1 in.) was used in table 1 and figure 4 because it reflects records from Schoharie Creek, which also were used for base-flow computations described in the next section.

The distribution of total runoff and its components (fig. 4) among unchanneled areas/valley areas and channeled areas (fig. 5C) provides an indication of the local variations in water availability within the basin. The lack of channel development in unchanneled areas/valley areas, precludes surface flow to the local valley stream; thus, nearly all water in these areas becomes recharge for the local valley aquifer. In contrast, channeled areas provide less water for recharge because a large percentage of total runoff (overland flow and ground-water discharge) enters channeled area streams and bypasses the valley aquifer. Total runoff from unchanneled areas/valley areas within the basin is essentially equal to total runoff from channeled areas.

Recharge

Recharge is the component of precipitation that infiltrates land surface and reaches the water table, where it becomes ground water. Some of the precipitation that infiltrates land surface does not reach the water table because it is (1) taken up by plants, (2) discharged back to the surface at springs or seeps, or (3) retained within the soil. In general, conditions that favor direct recharge from precipitation include permeable soil or rock material at land surface, minimal slope of the land surface, and the presence of vegetation (for soil bioturbation by root systems). The monthly volume of recharge (given a relatively constant precipitation rate) is controlled largely by air temperature. For example, the amount of water available for recharge increases during the nongrowing season (cold temperatures), when ET approaches zero, although infiltration is impeded or prevented by frozen ground, and precipitation that falls as snow remains at land surface until a thaw or until the spring melt occurs. During the growing season (warm temperatures), recharge is minimal because most precipitation is lost through ET. Therefore, most recharge typically occurs in mid- and late fall and in early to mid-spring.

Basinwide Mean. Two methods were used to estimate mean annual total recharge and mean annual effective recharge from streamflow records from the study area—the recession-curve-displacement method of Rorabaugh (1964), and a base-flow-estimation method (Rutledge, 1992). Computer programs RORA and PART, developed by Rutledge (1993) and described below, were used for the analyses. Effective recharge is defined as the fraction of recharge that discharges from the basin as surface water (base flow) or ground water (negligible); the remainder of total recharge is lost through ground-water ET.

The recession-curve-displacement method (Rorbaugh, 1964) is based on the findings of Glover (1964) and Rorabaugh (1964) that total potential ground-water discharge to a stream at a critical time after a peak in streamflow is approximately equal to one-half the volume of ground-water recharge during the streamflow peak (Rutledge, 1993). Superposition of successive peaks provides a cumulative estimate of recharge over a period of interest. Program RORA was used to estimate mean-annual total recharge to the gaged parts of the Batavia Kill and Schoharie Creek Basins for 1992 and 1993 and to the Schoharie Creek Basin for 1961-90. Recession indices (K) of 32 and 47 days per log cycle were used for the Batavia Kill and Schoharie Creek analyses, respectively. The recession indices were the medians of manually determined recession slopes from nongrowing season (October to April) hydrographs from the respective gages. A mean annual recharge of 17.1 in. for 1961-90 was estimated for the Batavia Kill Basin in the same manner as mean annual runoff, described in the preceding section.

Program PART was used to estimate the mean base flow and the base-flow index (the percentage of mean streamflow that consists of base flow) for the same periods as program RORA. The estimates of mean-annual base flow (effective recharge) for the Batavia Kill during 1961-90 period is 14.5 in., and the base-flow index is 66 percent.

The reliability of these estimates is diminished to some extent by withdrawals from the Batavia Kill for snowmaking, snowmelt runoff, potential peak-flow alteration by flood-retardation basins, and localized summer thunderstorms. In addition, the local variability in surficial geology and in the resulting drainage characteristics of the Batavia Kill Basin probably result in a composite recession curve (several slopes) that departs from theoretical determinations that assume uniform geology in terms of drainage timing (critical time; described in Rutledge, 1993). The applicability of these estimates to given locations within the basin depends on how closely the locations approximate mean-annual conditions.

The difference between the estimates from the RORA (mean annual total recharge) and PART (mean annual effective recharge) analyses (2.6 in.) is considered to be a rough approximation of mean annual ground-water evapotranspiration within the basin. This estimate is considered rough because its magnitude is similar to the magnitude of the uncertainties in the recharge estimates.

Spatial Distribution. The mean-annual-recharge estimate is derived from a wide range of recharge rates within the basin, and these rates reflect the inferred hydraulic properties or conditions associated with the valley deposits and the channeled or unchanneled upland areas along the major valleys. The major valleys (topographic lows) contain the most productive aquifers and ultimately receive gravity drainage or ground-water flow from the surrounding uplands. All total runoff from direct precipitation is assumed to recharge the valley aquifers because the surficial deposits in the valley are relatively permeable. Recharge and overland-flow components in unchanneled upland areas adjacent to the valleys also recharge the valley aquifers, except for the amount that directly enters the valley stream, generally where the stream abuts the valley wall and where drainage ditches divert water to the stream. Quantification of direct losses to the valley stream was beyond the scope of this study, although a high estimate is that about 15 percent of unchanneled runoff does not recharge the valley aquifers. Unchanneled uplands and valley areas together account for about 51 percent of the basin area, and channeled uplands account for 49 percent (fig. 5C).

The volume of water that recharges unchanneled uplands and valley areas was estimated by superimposing the GIS coverage of unchanneled upland areas/valley areas and channeled areas (fig. 5C) on the coverage of total runoff (fig. 5B). The products (area $\times$ amount of water available) for each unchanneled upland and valley polygon were summed. The amount of unchanneled area (in square mi) that was assumed unavailable for recharge (15 percent) was calculated by subtracting the land area underlain by stratified-drift in and near the valleys from the unchanneled land area and multiplying by 22 in. of water available (total runoff) and multiplying the result by 0.15. The resulting annual rate of recharge within the unchanneled upland and valley areas is 20.7 in.

Channeled uplands, by contrast, provide only minor recharge to the adjacent valleys because most of the water leaves these areas as surface-water drainage to the valley stream. In some areas, infiltration through the streambed allows some of the surface water to recharge the valley aquifers. The mean annual rate of recharge within channeled areas (12.3 in.) is calculated as the difference between total runoff and the overland-flow component (discussed further on).

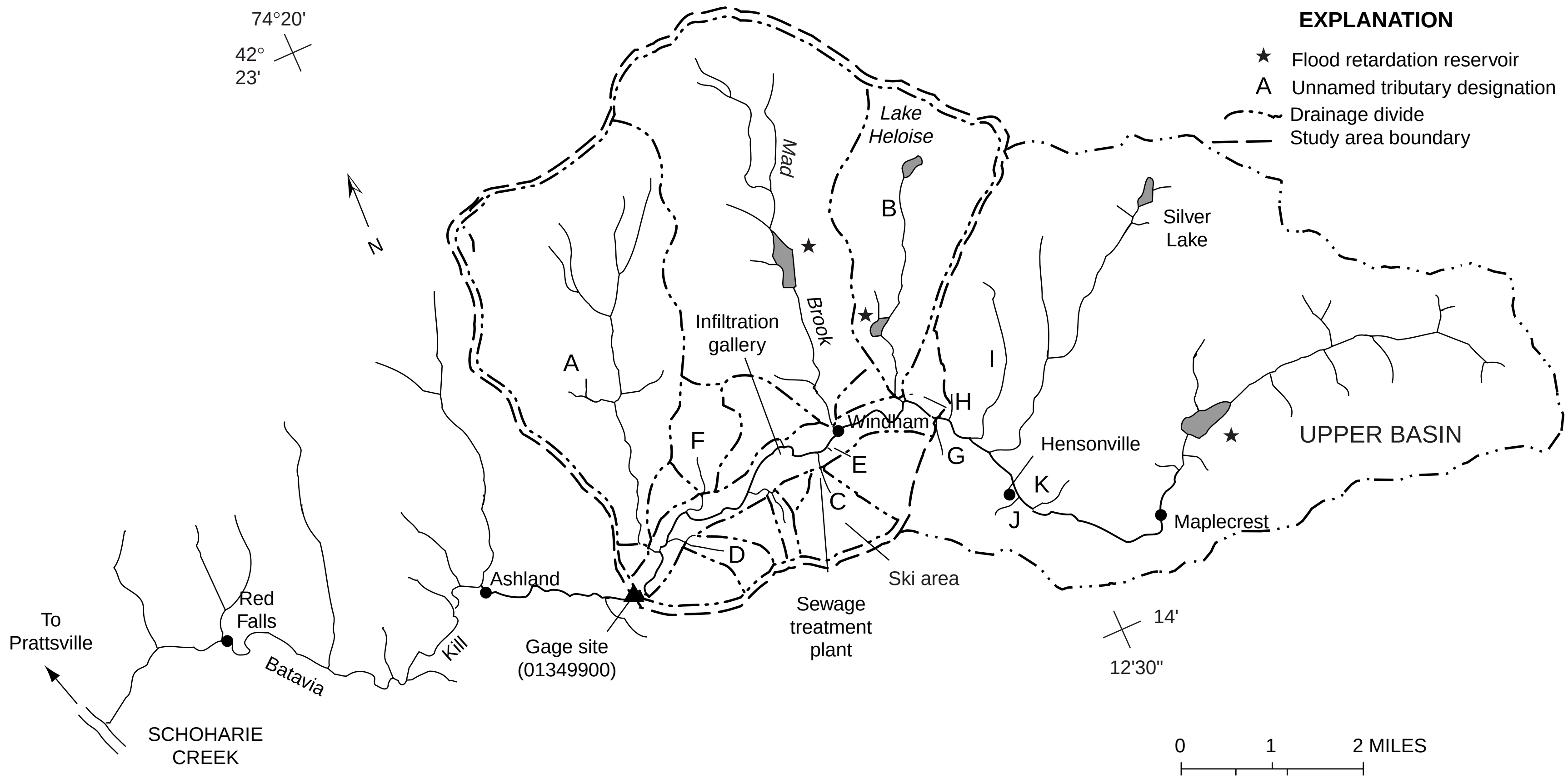
Estimation of potential water resources would incorporate the difference between recharge from channeled areas and that from unchanneled areas. For example, valley areas adjacent to large areas of unchanneled upland can be expected to receive more water than valley areas adjacent to channeled uplands because unchanneled areas lose less water as overland flow.

Rates of recharge from infiltration through streambeds (hereafter referred to as streambed infiltration) along tributary reaches within the Batavia Kill valley vary widely (fig. 7); the calculation of infiltration rates is discussed further on in the surface-water section. Most tributaries upstream from Hensonville (fig. 1) flow over till until they reach a flood plain which, in upstream areas, is generally narrow; thus, streambed infiltration in upstream valley areas is considered minor. Estimates of mean-annual streambed infiltration for **perennial** and **ephemeral streams** are given in table 2. Two perennial streams (tributary B and Mad Brook, fig. 7), which lose some water upon entering the Batavia Kill valley but continue to flow to the Batavia Kill, were assigned an infiltration rate of 1.5 ft^3/s per 1,000 ft of channel along their reaches within the Batavia Kill valley. This rate is within the range of published values and somewhat less than two rates measured at tributary A (discussed in the surface-water section). The data-collection periods for this computation included those when surface flow reached the Batavia Kill, as well as those when all flow was lost through streambed infiltration. Recharge from infiltration was calculated as the number of days with flow reaching the Batavia Kill (assumed to be November 1 through May 31) plus the number of days from June 1 through October 31 on which at least 0.35 in. of rain fell (a rough estimate of the amount necessary to wet the entire channel), plus 2 additional days for recession of streamflow after each storm event. The total number of days with assumed flow was assigned an infiltration rate of 1.5 ft^3/s per 1,000 ft of channel, and the remaining days were assigned a rate of 0.2 ft^3/s, which is within the range measured in this stream when all flow was lost through infiltration (table 2). All streams in the upper-basin that were used in the infiltration estimates were assumed to be ephemeral because they have relatively small drainage areas; three other streams within the study area were considered ephemeral as well. Estimates of infiltration from these streams were based on an infiltration rate of 0.7 ft^3/s per 1,000 ft of channel, the rate calculated for tributary D on May 10, 1991. The number of days that ephemeral tributaries maintained flow was estimated with the assumption that flow occurred each day of April and for at least 3 days (1 storm day and 2 days of recession) for each storm that dropped 0.25 in. of precipitation from May through November (table 2). The resulting total mean annual recharge from streambed infiltration, distributed over valley stratified-drift areas only, is 7.2 in.

In summary, mean annual total recharge within the basin is the sum of (1) total runoff in valley areas and adjacent unchanneled uplands, minus 15 percent of the upland value, (2) total runoff minus overland flow in channeled areas, and (3) streambed infiltration within the Batavia Kill valley. Recharge in unchanneled areas and valley areas accounts for about 61 percent of total recharge within the basin, and recharge in channeled areas accounts for about 34 percent. Streambed infiltration accounts for 5 percent.

Annual recharge values calculated for the Batavia Kill valley within the study area (not the entire gaged area) indicate that recharge from upland sources exceeds recharge from precipitation on the valley floor (2.57 ft^3/s) by a factor of 3 to 4. Upland sources include unchanneled and channeled areas adjacent to the valley floor (7.38 ft^3/s) and tributary streambed infiltration (2.55 ft^3/s). Total runoff values were used to represent most unchanneled areas in the computation, but 15 percent was subtracted for areas where the Batavia Kill abuts the valley wall. Recharge from channeled areas with ephemeral-stream channels was estimated to equal 59 percent of their total runoff, calculated from overland-flow estimates. Streambed infiltration was calculated as the sum of the values for all tributaries within the study area (table 2).

These recharge estimates for the study area indicate that about 79 percent of recharge received by the Batavia Kill valley aquifers (stratified drift and bedrock) is derived from upland sources, and the remainder (21 percent) from direct precipitation. These values are similar to those given by Morrissey and others (1988) for narrow New England valleys about 1/2-mi wide. (The Batavia Kill valley in the study area is about 1/3-mi wide.) One significant difference between this study area and the valleys cited in Morrissey and others (1988) is that recharge from unchanneled and channeled uplands is the dominant source of recharge to the Batavia Kill valley, whereas infiltration through tributary streambeds is the main source of recharge in most New England valleys. This difference is presumably due to the smaller width of the Batavia Kill valley, which results in (1) a smaller valley-floor area that limits the amount of direct areal recharge, and (2) shorter lengths of in-valley tributary reaches through which infiltration can occur.



Base from Keller (1994, fig. 1)

Figure 7. Streams and their subbasin boundaries within the study area, and locations of other surface-water features within the Batavia Kill Basin, Greene County, N.Y.

Table 2. Computation of mean total annual streambed-infiltration rates of tributaries in Batavia Kill study area, Greene County, N.Y., and annual total for the gaged part of the Batavia Kill Basin

[ft, feet; ft^3/s, cubic feet per second, in, inches;. Locations are shown in fig. 7.]

Tributary	In-valley channel length (ft)	×	Infiltration rate per 1,000 ft of channel (ft^3/s)	×	Duration of surface flow (fraction of year)	=	Mean annual infiltration rate (ft^3/s)
Ephemeral							
G	800		0.7[a]		0.31[b]		0.17
H	1,200		.7		.31		.26
I	800		.7		.31		.17
K	900		.7		.31		.20
J	400		.7		.31		.09
D	800		.7		.31		.17
F	1,500		.7		.31		.33
L	1,000		.7		.31		.22
Perennial (Tributaries C and E are omitted because they do not lose water within the Batavia Kill valley)							
A (flow reaches Batavia Kill)	650		1.5[c]		.73[d]		1.10
A (all flow infiltrates streambed)	650		.2[e]		.27		.05
Mad Brook	250		1.5		1.0		.38
B	200		1.5		1.0		.30

Total annual mean infiltration rate = 3.44 ft^3/s

Equivalent annual basinwide mean = 0.9 inches

Equivalent annual total for valley areas underlain by stratified drift = 7.2 inches

[a] Maximum infiltration rate measured at tributary D on May 10, 1991

[b] Duration of surface flow for ephemeral streams, in days = 30 days for April + (3 days of flow for each storm of ≥ 0.25 in. precipitation from May through November 1992) × (28 storms) = 114 days

[c] Infiltration rate for perennial streams with incised channels; value is between rates measured on two occasions at tributary A and those in published literature

[d] Duration of continuous surface flow, in days = number of days from November through May + (3 days of flow for each storm of ≥ 0.35 in. precipitation from June through October 1992) × (18 storms) = 266 days

[e] Total infiltration rate representative of two measurements made at tributary A, when all flow infiltrated the streambed

Recharge rates in upland areas probably vary with the type of surface material—that is, hillslopes with exposed bedrock receive more recharge than areas of till because the bedrock on hillsides typically contains vertical fractures that can enhance infiltration of water, whereas till generally has a low permeability that inhibits infiltration. These differences may be mitigated by the steepness of hillslopes; bedrock typically crops out where slopes are steepest, which tends to enhance overland flow, rather than recharge.

Overland Flow

Overland flow is the component of precipitation (and runoff) that, upon reaching land surface, flows to channels and eventually exits the basin as flow in the trunk stream. The mean basinwide overland flow component (6.3 in.) was calculated as total runoff minus basinwide recharge (table 1; fig. 4).

Basinwide overland flow is a composite of flow from channeled (5.7 in.) and unchanneled (0.6 in.)

areas. The unchanneled-area component of overland flow was estimated to equal about half of the 15 percent of water from precipitation that does not recharge the unchanneled areas (the other half is assumed to discharge to the Batavia Kill as subsurface flow). The channeled-area component of overland flow was calculated as total overland flow minus flow from the unchanneled areas.

Water Withdrawals

Water withdrawals represent the total amount of water withdrawn by human activities from groundwater or surface-water sources within the basin. Water use refers to the component of withdrawn water that is used in some way (rather than lost as overflow or leakage) before discharge back to surface water or ground water such as through septic systems, overland flow, or direct discharge to streams. Consumptive water use is the fraction of water use that is lost and not returned to ground water or surface water within the basin. Examples of consumptive use include evapotranspiration losses from septic leach fields or from lawn and garden irrigation. The annual values estimated for these components indicate that water withdrawals (about 286 Mgal) and water use (211 Mgal) greatly exceed consumptive use (5.1 Mgal), but both are minor in relation to the other components of the hydrologic system (table 1). The largest withdrawals are from valley areas, where about 51 Mgal of septic wastewater is returned annually to shallow ground water. Thus, the areal concentration of septic systems in villages is a water-quality concern despite the relatively small volume of returned wastewater within the basin.

Water withdrawals within the basin were estimated from (1) pumpage data from municipal suppliers, (2) metered withdrawals for snowmaking, and (3) per-capita water-use and population estimates. The water-use value (table 1) differs from the withdrawals/diversions estimate because much of the withdrawn water is lost through leakage or overflow from municipal systems.

Total annual municipal withdrawal was estimated from reported pumping rates and from known or inferred durations of pumping (G. Mulford, Town of Windham Water Superintendent, written commun., 1995). Municipal suppliers account for about 34 percent of water withdrawn; water use by municipal suppliers was estimated from the number of homes or businesses served (G. Mulford, Town of Windham Water Superintendent, oral commun., 1995) and population data (R. Roth, Director, Greene County Planning Department, written commun., 1995), or from sewage-treatment-plant discharge estimates (D. Frank, Ski Windham general manager, oral commun., 1995).

Snowmaking (from surface water and minor amounts of ground water) constitutes the largest water use within the basin (about 55 percent of total water use); it also is the only appreciable commercial use of water in the basin. The ski area is legally restricted to a maximum withdrawal rate of 7 ft^3/s (3,142 gal/min). Withdrawals for snowmaking were recorded by the ski area at 15-minute intervals during November through February 1991-92 (D. Frank, Ski Windham general manager, written commun., 1992); gaps in the data were identified from ground-water fluctuations at a well adjacent to the point of withdrawal. An average daily withdrawal rate of 2.2 Mgal/d was calculated for January 20-28, 1992 (excluding January 23). This value was then multiplied by the number of days with missing pumpage data, and the product was added to the sum of metered withdrawals, to obtain a total of about 157 Mgal. This estimate is considered conservative (low) because March withdrawals, indicated by water-level data at nearby wells, were not reported.

Water-use estimates for single-family homes and apartments range from 40 to 150 gal/d per person (Snavely, 1986). A value of 50 gal/d per person was used to estimate water use by year-round and occasional-use residents and by the motel and inn population (assuming that the estimate includes local restaurant water use). Discussions with residents indicate that they are relatively conservative in their water usage because their well water is occasionally limited in quantity or chemical quality. Population estimates were obtained from the Greene County Planning Department (1990, 1993; R. Roth, director, Greene County Planning Department, written commun., 1995). The water-use estimate for self-supplied domestic users and motel or inn guests accounts for about 12 percent of total water use in the basin.

Consumptive water use was estimated from noncommercial-water-use data. Both municipal suppliers pump more water than is used domestically because (1) the systems have leaks within the transmission lines and (or) reservoirs, (2) maintenance of pressure or flow is needed to minimize start-up stresses in transmission lines to the ski-area reservoirs on Cave Mountain (A. Emerton, Ski Windham operations manager, oral commun., 1992), and (3) many water taps in the town's system are left partly open to prevent frozen pipes (G. Mulford, Town of Windham Water Superintendent, oral commun., 1992).

Consumptive domestic water use has been estimated to represent 10 to 15 percent of total domestic water use (Great Lakes Commission, 1993); therefore, a coefficient of 10 percent was used to estimate most private and municipal consumptive use within the basin. A lower coefficient of 5 percent was used for the population served by the sewage-treatment plant at the ski area because treated wastewater is discharged directly to a stream rather than to infiltration beds, where ET contributes to consumptive loss. The estimated total annual consumptive use (5.1 Mgal) is about 2 percent of total water use within the basin.

An undetermined, but presumably small, volume of water used for snowmaking is lost (consumptive loss) through ET during the winter and the spring. Winter losses occur through sublimation and evaporation, but spring losses include evapotranspiration of snowmelt. Spring losses are probably larger than winter losses because the snowpack on sections of some of the upper ski trails can linger until June.

Downstream Water Diversion

Much of the streamflow from the Schoharie Basin, of which the Batavia Kill Basin is a part, is diverted from the Schoharie Reservoir through the Shandaken Tunnel (fig. 1) for New York City's water supply. This diversion does not affect Batavia Kill Basin hydrology because it occurs downstream; however, estimation of the contribution from the Batavia Kill Basin illustrates the magnitude of diversion relative to the hydrologic components described above. Releases from the Schoharie Reservoir to the Shandaken Tunnel in 1992 and 1993 (J. Boek, Catskill District Engineer, written commun., 1995) were averaged and pro-rated for the percentage of the Schoharie Basin that lies upgradient of the Batavia Kill gage. The resulting estimate, 1.94 billion ft^3 or 16.4 in. of water across the basin per year, is nearly equal to the estimated total recharge within the gaged area.

Surface Water

The major uses of surface water at present (1990's) are (1) local withdrawals for snowmaking, (2) fish habitat, and (3) downstream diversion to New York City reservoirs. A potential future use might be use of waters impounded in flood-retardation reservoirs for water-supply augmentation.

Surface-water-data collection included discharge measurements and chemical analyses of the Batavia Kill and seven tributaries. Flow characteristics were calculated from data collected at streamflow-gaging sites at the downgradient end of the study area and on Schoharie Creek downgradient of its confluence with the Batavia Kill. Paired discharge measurements within the most downgradient reaches of the five largest tributaries were used to calculate streambed seepage losses or gains. Changes in stream discharge associated with withdrawals for snowmaking were documented at the Batavia Kill and Schoharie Creek gages. Chemical data were collected at the Batavia Kill gage site over a period of about 1.5 years and at 10 other sites along the Batavia Kill and its tributaries during a 1-day sampling run on June 27, 1991.

Flow Conditions

Flow conditions encompass (1) human alteration of surface-water flows, (2) infiltration losses from tributary streams, and (3) low-flow frequency and duration. The primary human-induced changes in surface-water flow are the attenuation of peak flood discharges by flood-retardation reservoirs and the reduction of flows during the ski season by withdrawals for snowmaking. Loss of tributary flow through streambed infiltration within the Batavia Kill valley represents a variable, local source of recharge to the valley aquifer and may affect the chemistry of the Batavia Kill during periods of low flow. Low-flow frequency and duration characteristics are needed in waste-assimilative-capacity analyses and for maintenance of fish habitats. Streams are most susceptible to contamination during the low-flow periods of late summer and early fall when dilution is minimal. Maintenance of adequate streamflow for fish and insect communities is a concern during the winter when water is withdrawn for snowmaking.

Daily mean flow values and selected statistics for the Batavia Kill gage near Ashland (01349900) (fig. 7) for the study period are given in annual USGS data reports (Firda and others, 1992, 1993, 1994). Flow data for November through February presumably represent flows that have been diminished by snowmaking withdrawals.

Human Alteration of Surface-water Flows

Flow in the Batavia Kill is altered at times by the effects of hydraulic structures as well as by seasonal withdrawals by the ski area. Hydraulic structures include two flood-retardation reservoirs on tributaries within the study area and a third upgradient of the study area (fig. 7).

The flood-retardation reservoirs (total drainage area about 20 mi^2) were built to prevent catastrophic flooding within the Batavia Kill Basin, such as occurred in September 1960 as a result of Hurricane Donna (Robison, 1961). These reservoirs are drained by vertical outlet pipes that control the impounded-water level during all but the largest flows. The last time the outlet pipe of at least one of the basins (Mad Brook) was overwhelmed by inflows was during a major storm in April 1987. Whether the discharges associated with storms during this study were large enough to be attenuated by the detention basins is uncertain.

The largest human effect on surface-water flow is the withdrawal of water for snowmaking. Water is removed from the Batavia Kill during the late fall and winter and generally remains as snow on the ski slopes until spring, when most of it presumably returns to the surface-water system as snowmelt. The water for snowmaking is withdrawn from an infiltration gallery (fig. 7) along the south bank of the Batavia Kill at the west end of Windham village, beginning in November, when below-freezing night-time temperatures permit snowmaking, and typically continuing through March, depending on weather conditions. Records of pumpage from the infiltration gallery (D. Frank, Ski Windham General Manager, written commun., 1992) for the 1991-92 season indicate a maximum withdrawal rate of about 7 ft^3/s (3,142 gal/min) and a season pumpage of about 139 Mgal. The New York State Department of Environmental Conservation (NYSDEC) restriction on withdrawal is 7 ft^3/s. Data on withdrawals during a few periods were unavailable, but stream stage and ground-water levels indicated that withdrawals were being made; therefore, the pumpage total is considered a conservative estimate. Nearly all water withdrawn from the infiltration gallery is derived from the Batavia Kill; the remainder is ground water.

Streamflow data from three USGS gages—Batavia Kill near Ashland (station 01349900), Schoharie Creek at Prattsville (station 01350000), and East Branch Delaware River at Margaretville (station 01413500, fig. 1B) were compared with one another and with pumpage data from the infiltration gallery during the first half of November 1991 (figs. 8). This period was chosen because the withdrawals from the infiltration gallery consisted of two isolated intervals within an ice-free period of surface-water record. (Ice decreases the reliability of discharge data because corrections or additional estimates must be applied to the raw data.) The Batavia Kill and Schoharie Creek at Prattsville gages are about 3 mi and 13.5 mi downstream of the infiltration gallery, respectively. The Schoharie Creek station is about 2 mi downstream of the confluence of the Batavia Kill with Schoharie Creek. The East Branch Delaware River at Margaretville station, which is below an **unregulated** part of the Delaware River Basin immediately west of the Schoharie Creek Basin, serves as a control site. Withdrawals from the infiltration gallery decrease discharge in the Batavia Kill and the Schoharie Creek at Prattsville relative to the East Branch Delaware River (fig. 8).

Plots of Batavia Kill, Schoharie Creek, and of East Branch Delaware River at Margaretville (as a control site) (fig. 8) discharges, indicate the effects of the surface-water withdrawals in early November 1991 and allow comparison of maximum reported withdrawal rates with the maximum deviations in discharge from estimated natural flow conditions (fig. 8). Average peak withdrawal rates (metered) from the infiltration gallery during this period range from 3.75 to 2.80 ft^3/s. Corresponding flow losses, estimated from discharges at the Batavia Kill gage (3 mi downstream), average about 5.3 ft^3/s, 40 to 90 percent greater than the metered withdrawals. The rates of withdrawal at the gallery are considered more accurate than the gage estimates, however, because the flows are metered directly. Flow losses indicated by the Schoharie Creek gage at Prattsville are about 14 ft^3/s; the apparent increase in loss, is attributed to additional surface-water withdrawals for snowmaking at another ski area upstream on the Schoharie Creek at Hunter, N.Y. (fig. 1).

Discharges during periods of thaw and spring runoff presumably are increased by snowmelt from the ski slopes. This effect cannot be quantified, however, because:

- temporal variations in precipitation mask the effects of snowmelt
- the period of record for Batavia Kill discharge is short (2 years)

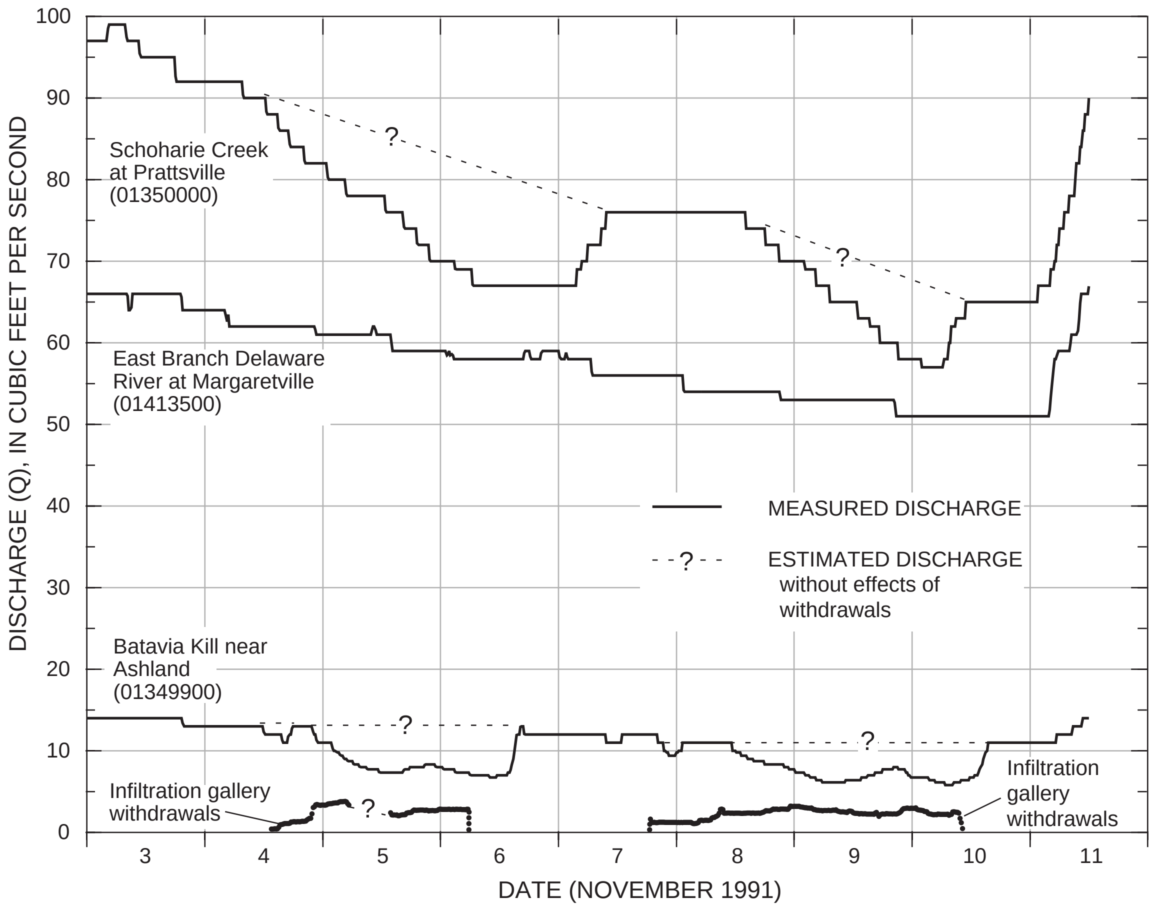


Figure 8. Discharge at three surface-water gages, and withdrawals from the infiltration gallery on the Batavia Kill, November 3-11, 1991. (Site locations are shown in fig. 1.)

- the accuracy of winter-flow estimates is poor because backwater from ice-effect alters the stage-discharge relation
- the ski-slope area is small in relation to the gaged basin area.

Infiltration Losses from Tributary Streams

Tributary streams that cross stratified, permeable deposits as they enter larger valleys are typically subject to losses through streambed infiltration. Such losses have been documented in relatively high-relief settings in the glaciated northeast and recognized as an important source of valley-aquifer recharge (Crain, 1966; Ku and others, 1975; Randall, 1978; Johnson and others, 1987; Morrissey and others, 1988; Williams, 1991).

Randall (1978) and subsequent investigators noted increases in rates of streambed infiltration in tributaries as they enter larger valleys. Infiltration rates near the wall of the main valley are relatively low initially (0.1 to 0.3 ft^3/s per 1,000 ft of wetted channel; Morrissey and others, 1988), but typically increase (1.0 to 2.5 ft^3/s per 1,000 ft of wetted channel; Morrissey and others, 1988) away from the valley wall where valley sediments are permeable. Some downstream reaches dry up during the driest periods of the year. The phrase “in valley” is used herein to refer to tributary reaches that are within the Batavia Kill valley (having crossed the plane of the valley wall), regardless of infiltration rate.

The presence of permeable surficial deposits in the Batavia Kill valley, and the lack of flow in some tributaries during low-flow periods, indicate that streamflow losses through infiltration occur in the study area. Stream discharge was measured at selected sites in the in-valley reaches of five tributaries to calculate rates of infiltration (table 3, fig. 9). Most of the measurements were made during periods of low flow (September 5, 1991 and October 1, 1992) at four tributaries that contained flow just upgradient from and within their in-valley reaches. The drainage areas of these tributaries range from 0.75 to 8.71 mi^2. Four other tributaries with drainage areas of less than 1 mi^2 were dry upgradient of the valley on these dates; discharge measurements were made at one of these (tributary D; fig. 9) on May 10, 1991.

The discharge measurements at most sites were rated "fair," which means that each measurement is considered accurate to within about 8 percent of the true value; therefore, the uncertainty of each streamflow loss measurement is the sum of the uncertainties of the defining discharge measurements. The gains or losses associated with many of the 1992 measurements are less than the error in measurement, whereas most of the gains and losses associated with the 1991 measurements are greater than the error in measurement. This is because the 1992 flows were from 2 to 8 times greater than those in 1991, and infiltration rates were typically 2 to 3 times higher. Thus, the difference between paired downstream discharges and upstream discharges (infiltration rate) is a smaller percentage of total flow under 1992 conditions than under 1991 conditions. Comparison of 1991 discharge measurements with corresponding values for 1992 indicates that the 1991 flows are a fairly consistent percentage (for a given tributary) of the 1992 flows; this indicates that the infiltration values calculated from the 1992 measurements are more accurate than the "fair" designation assigned to the discharge measurements.

Infiltration-rate estimates differ widely among the tributaries (table 3). Most of these differences are due to local variations in geology (permeability) and the length of the tributary reach within the Batavia Kill valley—long in-valley reaches that traverse permeable stratified-drift deposits favor infiltration. Tributary A has these characteristics and regularly lost all flow during dry periods. Two other tributaries (Mad Brook and tributary B) showed some losses, although their relatively short in-valley reaches limited infiltration and, thus, precluded accurate determination of maximum infiltration rates. Tributary C, which has a long, steep in-valley reach, and till exposed near its mouth, consistently showed gains in streamflow. Tributary D, an

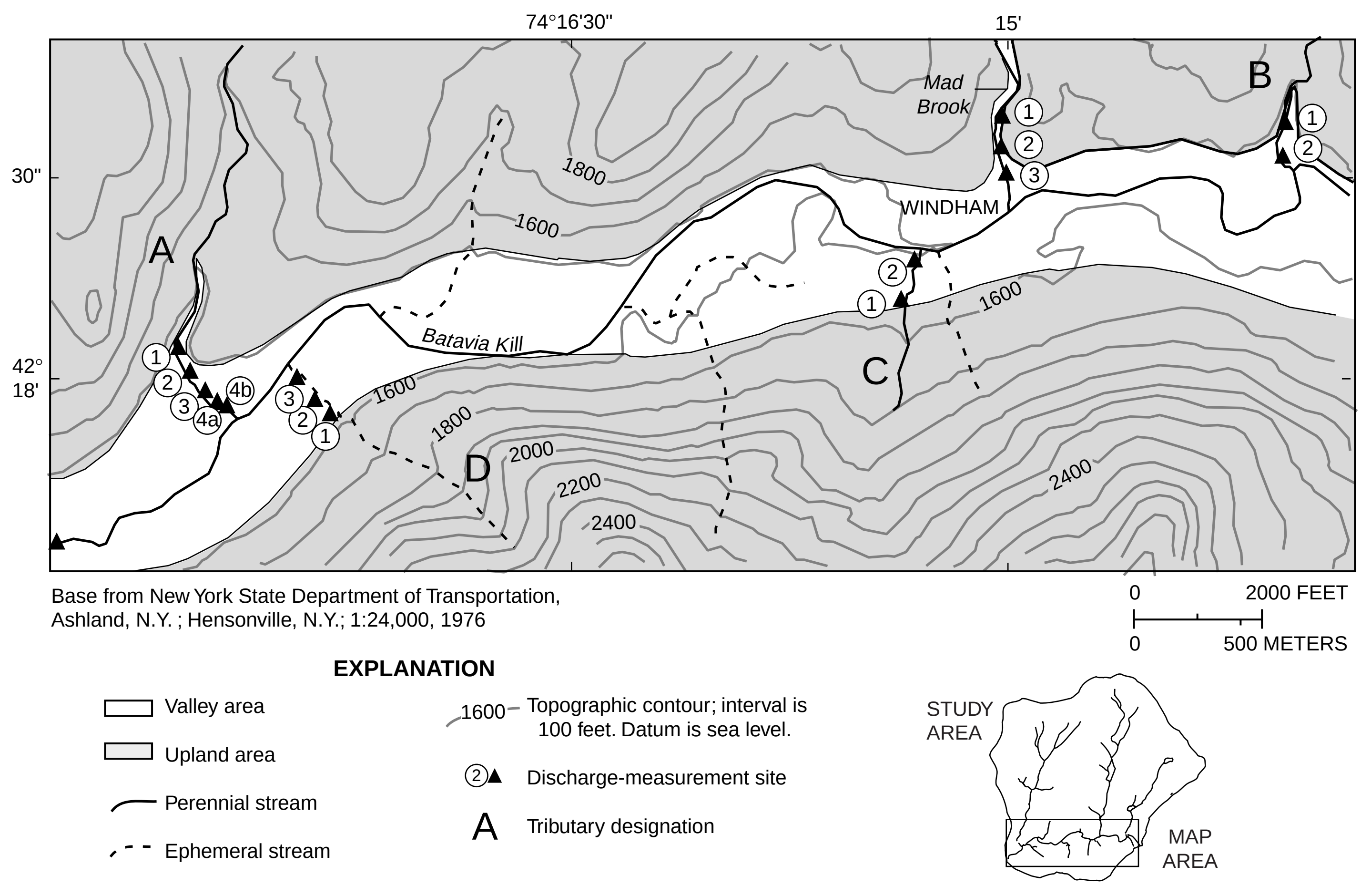


Figure 9. Locations of discharge-measurement sites along lower reaches of Batavia Kill tributaries in the study area, Greene County, N.Y.

Table 3. Discharge and associated infiltration rates of tributaries in Batavia Kill valley, Greene County, N.Y., 1991-92

[ft, feet; ft^3/s, cubic feet per second. Locations are shown in fig. 9.]

Reach (upstream- and downstream-site numbers)	Distance from measurement site to confluence with Batavia Kill (feet)		Date of measure-ment (mo-d-yr)	Discharge (cubic feet per second)		Infiltration rate (ft^3/s per 1,000 ft of wetted channel)[a]
	Upstream site	Downstream site		Upstream site	Downstream site	
Tributary B						
1-2	1,065	180	09-05-91	0.174	0.165	0.01 (0.05)[a]
			10-1-92	.336	.317	.02 (.10)
Mad Brook						
1-2	1,250	850	9-5-91	.156	.176	-.05 [b]
			10-1-92	.597	.525	
2-3	850	450	9-5-91	.176	.084	.23
			10-1-92	.525	.252	.68
1-3	1,250	450	9-5-91	.156	.084	.09
			10-1-92	.597	.252	.43
Tributary C						
1-2	870	50	09-05-91	.088	.137	-.06
			10-1-92	.605	.711	-.13
Tributary A						
1-2	1,380	937	9-5-91	.102	.040	.14
			10-1-92	.496	.477	.04
2-3	937	593	9-5-91	.040	.053	-.03
			10-1-92	.477	.410	.19
3-4a	593	565 (dry)	9-5-91	.053	.00	1.87
3-4b	593	458 (dry)	10-1-92	.410	.00	3.04
1-4a	1,380	565 (dry)	9-5-91	.102	.00	.13
1-4b	1,380	458 (dry)	10-1-92	.496	.00	.54
Tributary D						
1-2	1,033	749	5-10-91	.562	.512	.18
2-3	749	120	5-10-91	.512	.078	.69

[a] Numbers in parentheses are infiltration rate if all losses occur within 300-ft "in-valley" reach.
[b] Negative infiltration rates indicate gains in stream discharge.

ephemeral tributary whose in-valley reach is a shallow, artificial channel, had relatively small losses that may reflect the low permeability of the recent alluvium, that overlies the valley-bottom gravel and sand deposits. The tributaries and their infiltration characteristics are summarized as follows:

Tributary A drains 7.85 mi^2 and provides the best example of streambed infiltration within the study area (fig. 7; fig. 9) because it traverses valley-bottom gravel and sand over a 600 ft reach in the Batavia Kill valley before entering the Batavia Kill. Surface flow ceased 570 ft from the mouth of the tributary on September 5, 1991, and 460 ft from the mouth October 1, 1992. Only relatively small losses (<0.20 ft^3/s per 1,000 ft of wetted channel) or minor gains were measured upstream from the main valley wall. Larger losses (1.87 and 3.04 ft^3/s per 1,000 ft of wetted channel) were measured from the point of dryness to the next site upstream. The infiltration rates generally agree with those reported by Randall (1978) and later investigators, as summarized in Morrissey and others (1988). The temporal variation among the infiltration rates between the point of dryness and the next measurement site upstream appears to be related to the nearly eightfold increase in flow between 1991 and the 1992 measurements. Comparison of the infiltration rates of this tributary (where the most upstream and downstream discharge measurements are used), and comparison of the most upstream discharge measurements of September 5, 1991 with those of October 1, 1992 (table 3), indicates a fivefold increase in discharge and a fourfold increase in infiltration rate, accompanied by an increase in the submerged area of the streambed. This observation contrasts with those of previous investigators, who reported little correlation between infiltration rates and discharge or wetted channel area.

Mad Brook drains the largest subbasin in the study area (8.71 mi^2; fig. 7) but has a shorter in-valley reach than tributary A. The excavation of a pit during reconstruction of a bridge at the upgradient end of the in-valley reach in the summer of 1991 caused channel disturbance that resulted in a complete loss of streamflow at this point and revealed a 5-ft vertical section of unsaturated streambed material. Infiltration rates upstream from this point are typically within the range reported for reaches near valley walls (Morrissey and others, 1988). Again, a threefold increase in flow at the upstream site (site 1 in table 3) from the 1991 to the 1992 measurements corresponds to a fivefold increase in infiltration rate (from site 1 to site 3). Under undisturbed streambed conditions, the highest infiltration rates, similar to those of tributary A, would be expected within the lowest 200 to 300 ft of Mad Brook; the streambed drops about 7 ft within this 300-ft reach. Complete loss of streamflow was not observed in 1992 after the pit in the streambed was filled; this indicates that the shortness of the in-valley reach and, thus, the small area available for infiltration, limits the total amount of water that can be lost from Mad Brook.

When a tributary loses all flow through streambed infiltration, its upgradient flow, with its associated chemistry, is decoupled from the receiving stream. The loss (infiltration) of surface flow from upland areas increases the percentage of ground water (and associated chemistry) from the valley deposits that sustains flow in the receiving stream. When all direct flow from tributary A and Mad Brook was lost through infiltration in the summer-fall dry period in 1991, surface flow from 66 percent of the study area was lost, and stream-water chemistry appears to have changed.

Tributary B drains a 4.01-mi^2 area at the eastern end of the study area (fig. 7; fig. 9) and flows over a small dam, which is in disrepair, about 1,100-ft upstream from the confluence with the Batavia Kill. The dammed area is filled with sediment and probably provides some ground-water storage and release of ground water to the stream. Bedrock crops out in the streambed immediately downgradient of the dam, and the valley is steep-sided. The stream drops about 5 ft per 100 ft of stream channel downstream from the bedrock outcrop, and the in-valley reach is about 300-ft long. Streamflow was observed in this reach throughout the investigation. Discharge measurements made just downstream of the dam (on bedrock) and 885 ft farther downstream indicated only minor infiltration losses in 1991 and 1992. The infiltration rates and upstream discharges in 1992 were 2.1 and 1.9 times the 1991 values, respectively (table 3). Most of the loss presumably occurred down gradient from the bedrock outcrop and within the in-valley part of the measured reach; the infiltration rates, which are calculated on the assumption that all infiltration occurs within the in-valley part of the measured reach (table 3), are low and characteristic of upstream reaches as summarized in Morrissey and others (1988). The low infiltration rates may result from the presence of poorly permeable deposits beneath and adjacent to the stream, and from a shallow water table. Infiltration losses along the most downstream section of the in-valley reach were not calculated because the section is too short for accurate measurements and because the stream splits into several distributary channels near the mouth.

Tributary C drains a 0.75-mi^2 area on Cave Mountain and does not have a well-defined valley (fig. 7; fig. 9). It flows over deposits of relatively low permeability for about 1,800 ft (with a vertical drop of about 120 ft) from the base of Cave Mountain to its confluence with the Batavia Kill. The upper half of the reach is incised into till deposits containing occasional gravel lenses; the lower half is deeply incised into fine-to-medium lacustrine sand and silt, and dense till crops out in the streambed about 50 ft from the Batavia Kill. Discharge measurements made above and below an 820-ft section of the lower reach in 1991 and 1992 indicate small gains in streamflow. The lacustrine sand is a potential source of ground-water discharge to this section of tributary C.

Tributary D is an ephemeral stream that drains an area of 0.28 mi^2 (fig. 7; fig. 9). Discharge measurements were made on May 10, 1991. The in-valley channel has little relief and was constructed to prevent flooding of the surrounding farmland (Howard Tuttle, dairy farmer, oral commun., 1991); sections of the adjacent fields that abut the valley wall are saturated seasonally by springs and seeps. This tributary flows to the Batavia Kill only during the wettest periods of the year and was used for calculation of representative infiltration rate(s) of ephemeral tributary streams because its in-valley reach is relatively long (about 1,000 ft). Measurements were made along a 284-ft upper reach and the lower 629 ft of the in-valley reach. The streambed consists of till at the uppermost measurement site in the upper reach. The middle measurement site roughly corresponds to a break in slope in land surface toward the Batavia Kill. The discharge measurements show an increasing infiltration rate toward the Batavia Kill, although the rate in the lower reach (0.69 ft^3/s per 1,000 ft of wetted channel) is less than most of those reported in Morrissey and others (1988) for similar settings. This may result from the presence of fine alluvium rather than gravel and sand beneath this shallow, poorly developed channel.

In summary, some tributary-stream reaches in the Batavia Kill valley are losing water through streambed infiltration, although the losses are small relative to those in other areas, because the Batavia Kill valley is narrow, and the valley-fill deposits are not uniformly permeable. The infiltration rates of losing streams in the Batavia Kill valley correlate closely with discharge at their respective upstream measurement sites. This finding contrasts with that of Randall (1978) and may be associated with incomplete saturation of stream-channel surfaces, as was noted when the measurements were taken.

Low-flow Frequency and Duration

Low-flow frequency and duration statistics were used to quantify flow characteristics of the Batavia Kill at the gage site (01349900). Low-flow frequency curves relate an average discharge of given duration (consecutive days of lowest flow) to a recurrence interval (in years). Duration curves relate the population of mean daily flows to the percentage of time (probability) that each flow is equaled or exceeded. Annual low-flow statistics, for example, the MA7CD10 (minimum average 7-consecutive-day flow at a recurrence interval of 10 years) derived from frequency curves can be used in modeling the waste-assimilative capacities of streams, and similar statistics for specific months or seasons might be used as a reference for regulatory decisions regarding surface-water withdrawals. At least 10 years of record is generally required for calculation of low-flow-frequency statistics. Frequency statistics and duration curves could not be calculated directly from the data collected at the Batavia Kill gage because the period of record was insufficient (2 years, 2 months) and because flows affected by snowmaking withdrawals do not represent natural conditions; therefore, the values were estimated by procedures described below.

Estimation of flow statistics entails correlating at least 10 base flows at the site of interest with concurrent base flows at a nearby gaged site that has enough record (at least 10 years) for generation of frequency statistics. The long-term-record site is preferably in the same region as the short-term-record site to ensure similar timing and amount of precipitation; similar basin geology, particularly the amount of stratified drift, and similar size of drainage area, also are desirable. The relation between concurrent flows at the two sites is generated with the MOVE.1 (Maintenance of Variance Extension, Type 1) technique (Hirsch,1982), wherein specified discharges (calculated flow statistics) from the long-term site are substituted into the MOVE.1 equation to obtain discharges for the short-term site. Flow statistics for the long-term site were generated through revision 91.2B of the Automated Processing System Component of the USGS’s National Water Information System.

Data from the Schoharie Creek at Prattsville site (01350000) were used to calculate selected flow frequencies and durations for the Batavia Kill (site 01349900). The Prattsville gage monitors flow from the upper part of the Schoharie Creek Basin, which includes the Batavia Kill drainage, and has been in service since 1902. Climatic conditions and geologic conditions at the two sites are similar, although the Schoharie Creek drainage area (237 mi^2) is more than four times larger than that of the Batavia Kill (51.2 mi^2).

Frequency Statistics. A set of 20 paired base flows (daily mean values) were applied to the MOVE.1 equation (fig. 10A) for the low range of flows. The flow values were restricted to the months of June through October to avoid the effects of (1) ski-season surface-water withdrawals in the Batavia Kill and upper Schoharie Creek Basins, and (2) flow data uncertainties resulting from the presence of ice in the streams. The high correlation coefficient (0.994) for the log concurrent base flows and the long period of record at the Schoharie Creek gage indicate a high degree of confidence in the estimated flows.

Selected low-flow frequency statistics for the full year (April through the following March), the month

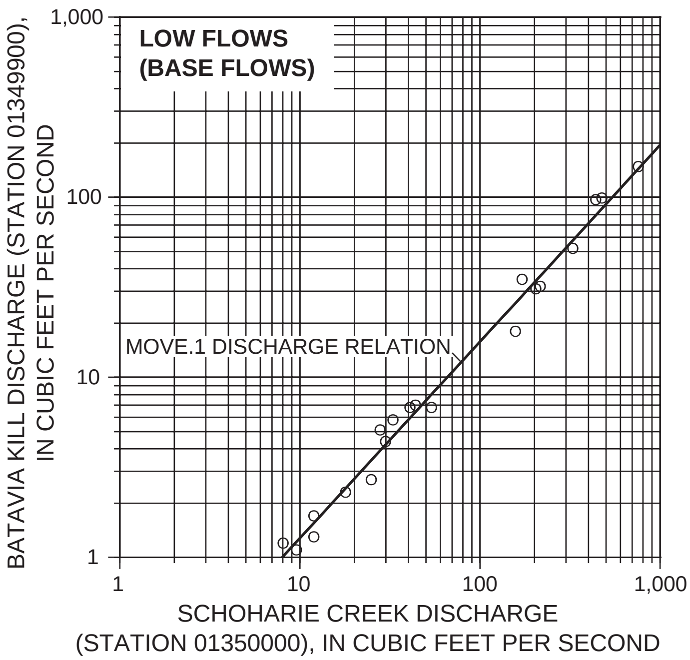
A. LOW FLOWS (BASE FLOW)

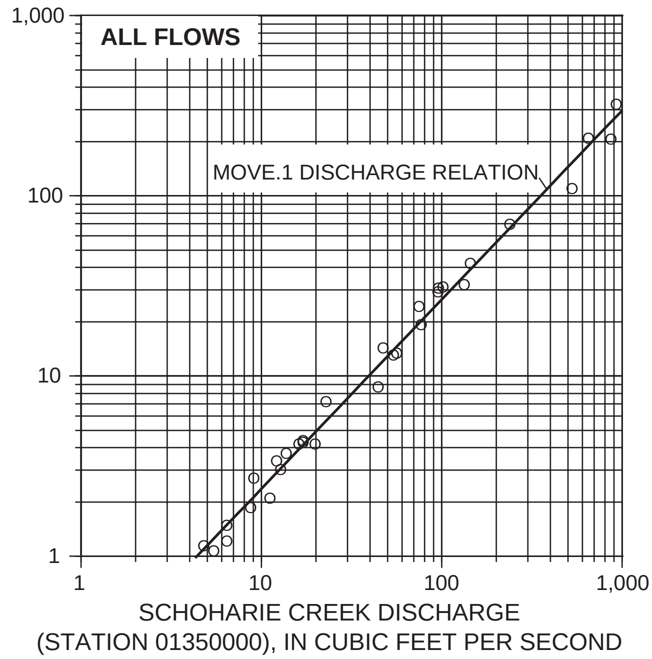
Date	Discharge* Q_{SC}	Discharge* Q_{BK}	Date	Discharge* Q_{SC}	Discharge* Q_{BK}
8/8/91	12.00	1.30	8/24/92	28.00	5.10
9/14/91	9.60	1.10	10/7/92	30.00	4.40
10/5/91	25.00	2.70	10/23/92	54.00	6.80
10/25/91	158.00	18.00	11/20/92	217.00	32.00
11/30/91	441.00	97.00	12/1/92	329.00	52.00
4/30/92	760.00	148.00	5/15/93	172.00	35.00
5/10/92	477.00	99.00	6/19/93	33.00	5.80
6/15/92	205.00	31.00	7/18/93	12.00	1.70
7/12/92	44.00	7.00	8/31/93	8.10	1.20
7/30/92	41.00	6.80	9/22/93	18.00	2.30

*Q_{SC} = Discharge at Schoharie Creek at Prattsville, N.Y. (01350000)
Q_{BK} = Discharge at Batavia Kill near Ashland, N.Y. (01349900)

B. ALL FLOWS

Date	Discharge* Q_{SC}	Discharge* Q_{BK}	Date	Discharge* Q_{SC}	Discharge* Q_{BK}
8/8/91	12.00	1.30	10/7/92	30.00	4.40
9/14/91	9.60	1.10	10/23/92	54.00	6.80
10/5/91	25.00	2.70	11/20/92	217.00	32.00
10/25/91	158.00	18.00	11/23/92	685.00	103.00
11/23/91	5,680.00	1,250.00	12/1/92	329.00	52.00
11/30/91	441.00	97.00	3/30/92	9,130.00	2,230.00
4/27/92	1,490.00	288.00	4/17/93	8,340.00	1,230.00
4/30/92	760.00	148.00	5/7/93	438.00	91.00
5/10/92	477.00	99.00	5/15/93	172.00	35.00
6/6/92	4,300.00	530.00	6/19/93	33.00	5.80
6/15/92	205.00	31.00	7/18/93	12.00	1.70
7/12/92	44.00	7.00	8/3/93	19.00	3.80
7/14/92	44.00	7.2	7/18/93	12.00	1.70
7/30/92	41.00	6.80	8/31/93	8.10	1.20
8/24/92	28.00	5.10	9/22/93	18.00	2.30
9/23/92	65.00	14.00			





MOVE.1 EQUATION

$$\hat{y} = \left(\bar{y} - \frac{S_y}{S_x}(\bar{x})\right) + \frac{S_y}{S_x} x_i$$

where:

$\hat{y}$ = log Q_{BK}
$\bar{y}$ = mean (log Q_{BK})
S_y = standard deviation (log Q_{BK})
x_i = log Q_{SC}
$\bar{x}$ = mean (log Q_{SC})
S_x = standard deviation (log Q_{SC})

RESULTS

A. LOW FLOWS:

$$Q_{BK} = 0.101\ Q_{SC}^{1.098}$$

correlation coefficient = 0.994

B. ALL FLOWS:

$$Q_{BK} = 0.124\ Q_{SC}^{1.055}$$

correlation coefficient = 0.995

Figure 10. Application of the MOVE.1 equation relating flows at Shoharie Creek at Prattsville to those of the Batavia Kill near Ashland, N.Y., 1991-93: A. Lowflows (base flow) (June-October), B. All flows.

of November, and the months of December through February, an given in Table 4. The statistics for the full year actually represent the period from July through October because, historically, one of these months will have the lowest flows of [1] any given year. The entire period of record was used for these statistics. The two cold-weather periods are included to address concerns over flow reductions from snowmaking withdrawals. Only records from 1955 and earlier were used because they reflect natural conditions without snowmaking withdrawals. Snowmaking at the nearby Hunter, N.Y. ski area (fig. 1A) started “around 1960” (Keller and Fieldhouse, 1993). November is given separately from the other months of the snowmaking season (December through February) because persistent low flows of the late summer and early fall period may extend into this month, as seen in the 10- and 20-year recurrence statistics for November, in relation to those for the December-through-February interval.

Duration Statistics. The MOVE.1 technique then was applied to a set of 32 concurrent flows (12 concurrent peak flows and the previous 20 base flows), excluding the cold-weather flows, to provide a full range of flow estimates for the duration curves (fig. 10B). A similarly high correlation coefficient (0.995) for the log concurrent flow data again indicates a high degree of confidence in the estimated flows.

Selected duration-curve percent-flow-exceedence discharge statistics from the Schoharie Creek at Prattsville record were used with the MOVE.1 equation (fig. 10B) to generate corresponding flow statistics (fig. 11) for the Batavia Kill. Flow statistics were generated for essentially the same periods of the year as the low-flow frequency statistics. Again, the entire period of record was used to generate the July-through-October duration curve, and the records after 1955 were excluded from curves for November and December-through-February to avoid the potential effects of snowmaking withdrawals. The resulting Batavia Kill duration curves (fig. 11) illustrate the lowest annual flows (July-October), the relatively high winter low flows (December-February), and the intermediate November low flows. The November duration curve is similar to the December-February curve except for the low discharges associated with the low-flow durations. These discharges represent periods of low flow that have extended into late fall.

Table 4. Estimated 3-day, 7-day, and 30-day low flows of the Batavia Kill (at U.S. Geological Survey gage 01349900), Greene County, N.Y., for 2-, 10-, and 20-year recurrence intervals

[All values are in cubic feet per second; dash indicates statistic was not determined. Correlation equation ($Q_{BK} = 0.101Q_{SC}^{1.098}$) based on 1992-93 base-flow records of the Batavia Kill near Ashland (01349900) and Schoharie Creek at Prattsville (01350000)

Low-flow frequency statistic*	Months represented (period of Schoharie Creek gage record used in analysis is in parentheses)		
	April - March (1908-93)	November (1908-55)	December-February (1908-55)
2-year recurrence interval			
MA3CD2	2.3	19	12
MA7CD2	2.6	24	14
MA30CD2	3.9	—	—
10-year recurrence interval			
MA3CD10	1.0	5.0	5.6
MA7CD10	1.1	6.2	6.7
MA30CD10	1.6	—	—
20-year recurrence interval			
MA3CD20	.8	3.3	4.5
MA7CD20	.9	3.9	5.3
MA30CD20	1.3	—	—

* MA*n*CD*m* = minimum average *n*-consecutive-day flow at a recurrence interval of *m* years

Chemistry

Interpretation of surface-water chemistry in the study area was based on field measurements and chemical or physical analyses of 57 surface-water samples collected from 17 surface-water sites (fig. 12) in 1991-92. Evaluation of temporal and spatial variations in the chemistry of the surface waters entailed two reconnaissance sampling efforts: (1) twice monthly sampling at the Batavia Kill gage (0134990) over a 15-month period, and (2) 1-day sample collection or field measurements of physical properties of surface water at 10 sites in the Batavia Kill Basin under high- and low-flow conditions. All samples collected at the gage were analyzed for **nutrients** and **turbidity,** as were the low-flow samples. High-flow samples were measured for **specific conductance** and temperature only. Five samples from the Batavia Kill, Mad Brook, and tributary B were analyzed for major ions.

The chemical data are presented in tables, in scatterplots, and in Stiff diagrams further on. The results indicate that some effects of human activity within the study area are discernible, but no constituents in any samples exceeded Federal or State surface-water-quality standards.

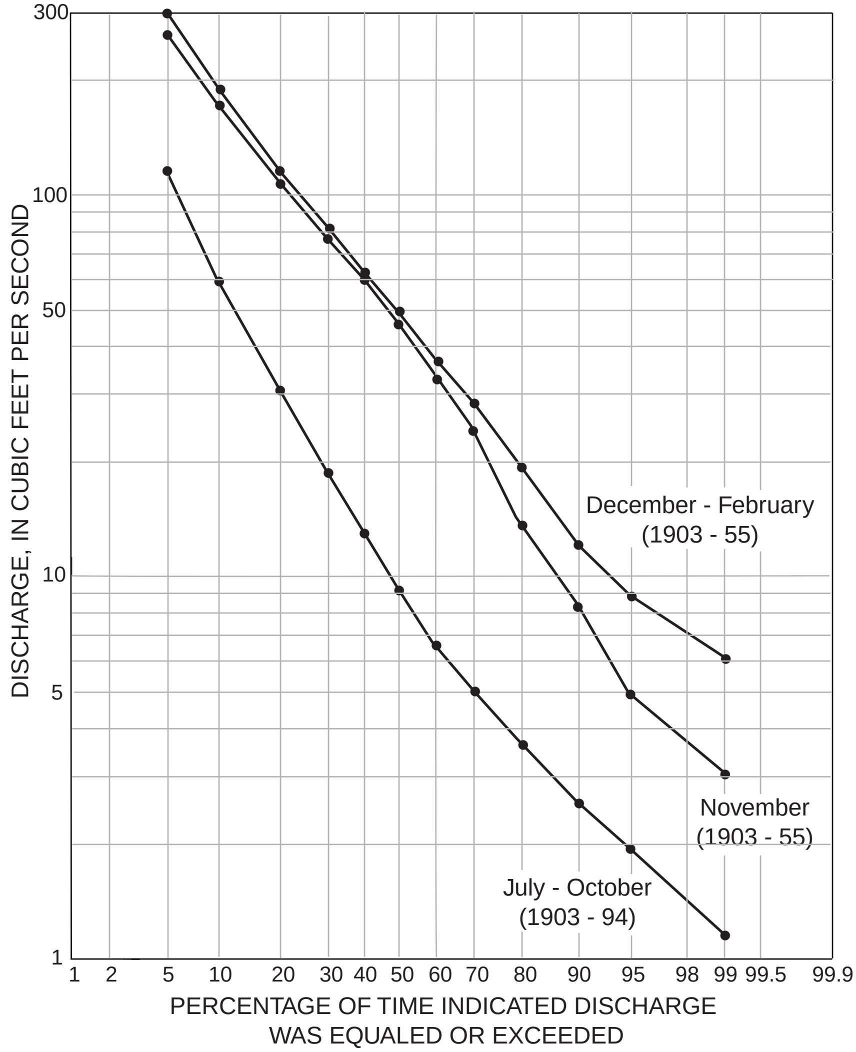


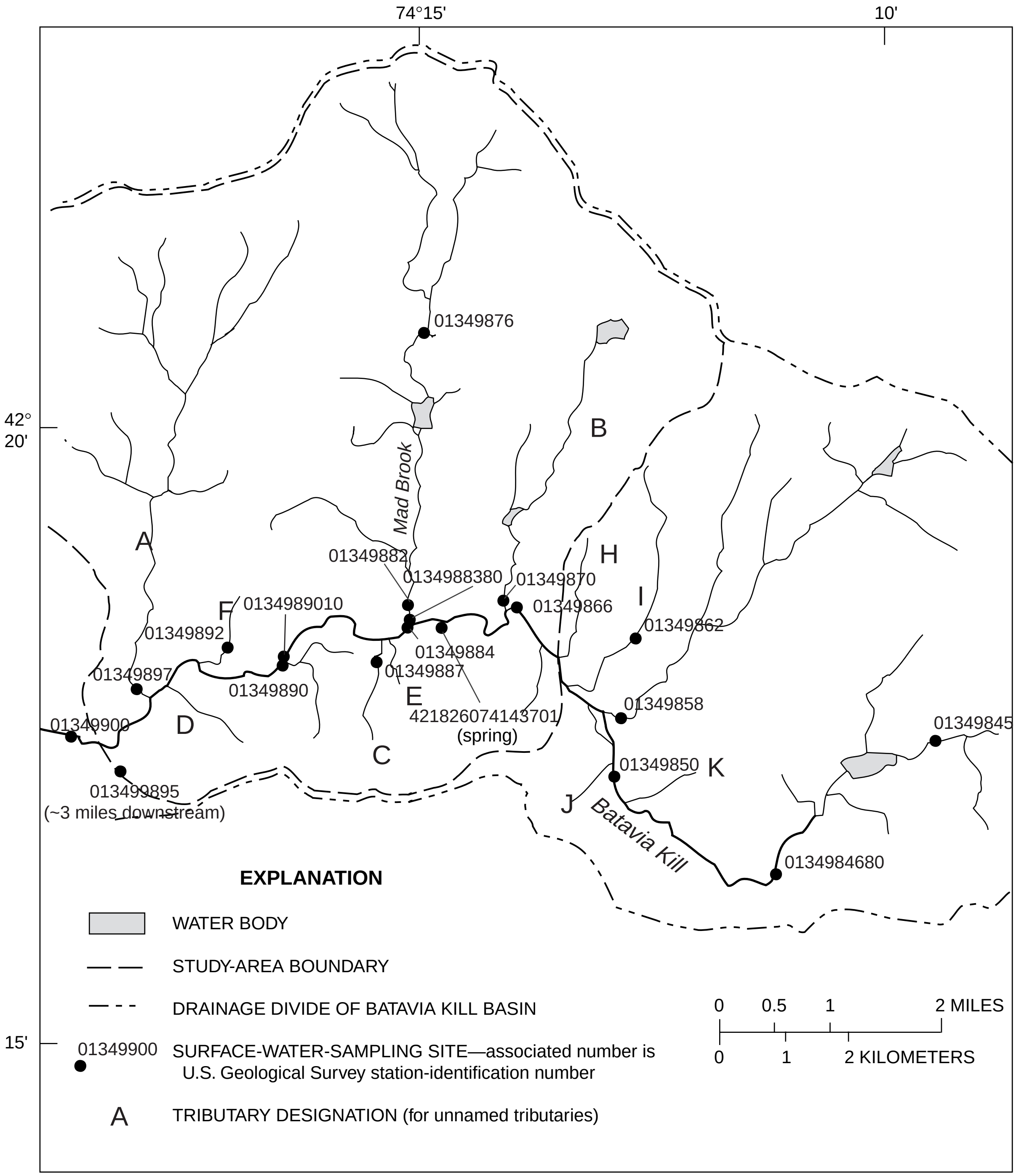
Figure 11. Flow duration curves for the Batavia Kill at the gage near Ashland (01349900), based on indicated periods of record for Schoharie Creek at Prattsville (01350000).

Temporal Variations

Temporal variations in surface-water chemistry generally reflect natural fluctuations in the ratio of overland runoff to base flow (ground-water discharge) in streamflow, but also can reflect inputs from human-derived sources. Temporal changes in chemistry in the Batavia Kill were investigated through (1) analyses of samples collected twice monthly, where possible, during high- and low-flow periods for nutrients and turbidity, and (2) analysis of two samples collected during the summer of 1991, when flow was relatively low, for selected inorganic constituents. All samples were collected from the Batavia Kill at the gage site (at the downgradient boundary of the study area, fig. 7) because (1) the chemistry of water flowing past this gage is a composite of natural and human-affected water draining from the basin, and (2) the corresponding discharge data from the gage are critical for interpretation of variations in the chemical data.

Discharge data stored in the USGS Automated Data Processing System (ADAPS) and associated chemical data (Gregory Lawrence, USGS, written commun., 1994) from the sparsely populated Neversink River basin (66.6 mi^2, gaged at Claryville, N.Y., (site 01435000) in the southern Catskill Mountains) (fig. 1) were used as a reference for assessment of the effects of human activity in the study area.

Physical Properties, Selected Nutrients, and Turbidity. These data, obtained from the twice-monthly samplings, are presented in table 5, which also includes



Base from New York State Department of Transportation,
Ashland, N.Y.; Hensonville, N.Y.; 1:24,000, 1976

Figure 12. Locations of surface-water sampling sites in Batavia Kill study area, N.Y.

the instantaneous discharges, the discharge-hydrograph trend (rising, falling, or stable), and the season (growing or nongrowing). A quantitative statistical analysis was precluded by the limited number of samples relative to the range of flows, flow trends, wastewater discharges, and seasonal conditions; as a result, most trends or associations described or shown in the plots are considered general and preliminary.

The ground-water (base flow) component of streamflow in the study area has a higher specific conductance (particularly during dry periods) than the overland-runoff component; therefore, surface waters show a natural increase in specific conductance during the summer as stream discharge decreases and the ground-water component of flow accounts for all of streamflow. Samples from the Batavia Kill indicate increases in specific conductance as discharges decrease below about 100 ft^3/s; the highest values were detected at flows of less than 20 ft^3/s (table 5; fig. 13).

Specific conductance values in the Batavia Kill during 1991-92 ranged from about 60 to 150 µS/cm, whereas those of the Neversink River at Claryville

Table 5. Water-quality and discharge data for Batavia Kill near Ashland, N.Y. (01349900), 1991-92

[Analyses by U.S. Geological Survey, Arvada, Colo. Concentrations in milligrams per liter unless specified. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25° C; NTU, nephelometric turbidity units; ft^3/s, cubic feet per second. Dashes indicate no data; <, less than]

		Physical Properties and Constituents									
Collection date (mo-d-yr)	Instantaneous discharge (ft^3/s)	Temperature (°C)	Specific conductance (field, µS/cm)	pH (field)	Dissolved oxygen	Total $NO_2 + NO_3$ (as N)	Total NH_3 + Org.-N (as N)	Total phosphorus (as P)	Turbidity (NTU)	Hydrograph trend[1]	Season[2]
6-7-91	5.1	19.1	96	7.1	—	0.30	1.0	0.02	1.7	S	G
6-27-91	5.0	21.4	112	6.9	—	.22	.4	.01	.7	S	G
8-8-91	1.3	24.0	131	7.1	—	<.05	.2	.02	1.0	S	G
8-19-91	7.3	18.7	139	6.8	—	.11	<.2	<.01	.7	R	G
9-17-91	1.7	20.4	147	6.8	—	<.05	<.2	<.01	1.5	S	G
9-19-91	11	17.2	137	6.8	—	.22	.3	.01	1.3	F	G
10-11-91	3.4	12.3	147	6.8	—	.10	<.2	<.01	.4	S	NG
11-1-91	14	9.3	108	7.1	—	.18	<.2	<.01	.6	S	NG
11-22-91	91	8.2	81	7.1	—	.24	.6	.05	5.5	R	NG
12-13-91	129	6.0	67	6.9	—	.25	<.2	.01	1.2	R	NG
12-30-91	74	1.4	69	6.9	—	.29	<.2	<.01	1.0	S	NG
1-2-92	46	.5	80	6.9	—	.38	<.2	<.01	.6	S	NG
1-23-92	61	.5	77	7.1	—	.36	<.2	<.01	1.0	R	NG
2-11-92	27	.4	88	7.0	—	.48	<.2	<.01	.5	S	NG
3-5-92	30	6.0	88	7.3	—	.32	<.2	<.01	1.4	S	NG
3-26-92	48	3.0	95	7.1	—	.41	<.2	<.01	2.9	R	NG
4-15-92	81	8.4	71	7.1	—	.27	<.2	<.01	1.0	S	NG
4-29-92	169	11.2	65	6.9	—	.21	<.2	<.01	1.0	F	NG
5-26-92	36	12.5	72	7.5	—	.11	<.2	.01	.4	F	G
6-23-92	16	18.4	85	7.0	—	.11	<.2	<.01	.6	S	G
7-15-92	28	17.6	99	7.0	—	.31	<.2	.01	.8	R	G
7-29-92	7.2	19.0	110	6.8	8.6	.11	<.2	<.01	.4	S	G
8-13-92	8.6	15.8	105	6.9	9.2	.07	<.2	<.01	.6	F	G
9-8-92	5.7	20.4	118	7.1	8.7	.09	<.2	<.01	1.0	S	G
9-22-92	6.6	17.2	115	6.8	7.3	.11	<.2	<.01	.5	R	G

[1] Hydrograph trend: S = stable (base flow), R = rising, F = falling

[2] Season: G = growing, NG = nongrowing

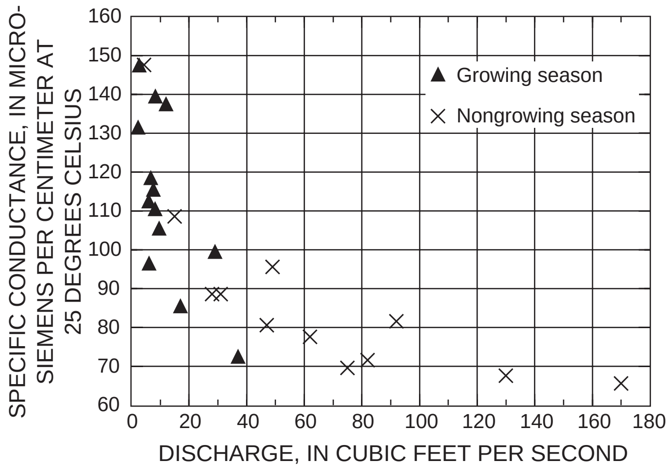


Figure 13. Specific conductance of the Batavia Kill as a function of discharge at station 01349900 near Ashland, N.Y., 1991-92. (Location is shown in fig. 12.)

(fig. 1) ranged from 20 to 35 µS/cm. The higher range in the study area probably reflects (1) the longer residence time of ground water (particularly in valleys containing stratified drift or well-developed flood plains, (2) the greater reactivity of soil and aquifer materials, and (3) the larger chemical inputs from human activities.

pH was fairly stable, ranging between 6.8 and 7.2 over most of the period of record (fig. 14). Values above this range (as high as 7.5) were measured in March and June 1992.

The correlation between the lowest discharges and lowest pH values during late summer and early fall appears to coincide with the decoupling or loss of a portion of upland tributary flow (through streambed infiltration) to the Batavia Kill. The loss of tributary base flow from the uplands, which has typically basic pH, and the resulting increase in the percentage of acidic ground-water contribution to stream discharge from the Batavia Kill valley deposits, is consistent with the observed pH and discharge relation. The highest pH values (7.3, 7.5) were recorded during stable and falling flow conditions, at discharges of 30 and 36 ft^3/s, respectively. These conditions may represent high base flows under which basic shallow ground-water discharges to upland tributaries, and resulting inflows to the Batavia Kill, are maximized.

Nitrate plus nitrite concentrations ranged from less than 0.05 mg/L to 0.48 mg/L (as N) (fig. 15). Dissolved nitrate concentration and instantaneous discharge in the Neversink River basin at Claryville are included in figure 15 for comparison. In general, both streams have low concentrations during the growing season, when uptake by plants is greatest, and highest concentrations during the nongrowing season. Peak concentrations are during late winter and early spring, as Murdoch and Stoddard (1992) found in several other streams within the Catskill region.

The fluctuations in nitrate plus nitrite concentration in the Batavia Kill differed from those of nitrate in the Neversink River during the 1991-92 period in two ways: (1) the lowest dissolved nitrate concentrations in the Neversink River typically occurred at the end of the growing season (Murdoch and Stoddard, 1992), immediately *after* leaf fall (approximately mid-September to mid-October), whereas nitrate-plus-nitrite concentrations in the Batavia Kill decreased *prior* to leaf fall during the lowest flows of the late summer and (2) the nitrate concentrations in the Neversink River tended to show little change or decrease with increasing flow during the summer of 1992 (in agreement with Murdoch and Stoddard, 1992), whereas in the Batavia Kill, nitrate plus nitrite increased with increasing flow during the summer of 1991 and 1992.

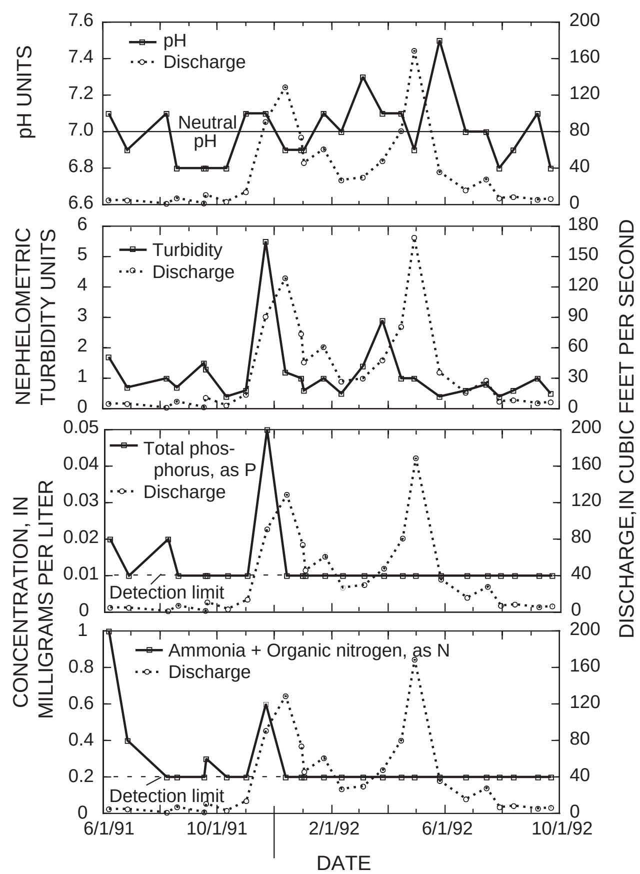


Figure 14. pH, turbidity, and concentrations of total phosphorus and ammonia plus organic nitrogen in the Batavia Kill near Ashland, N.Y., June 1, 1991 through October 1, 1992.

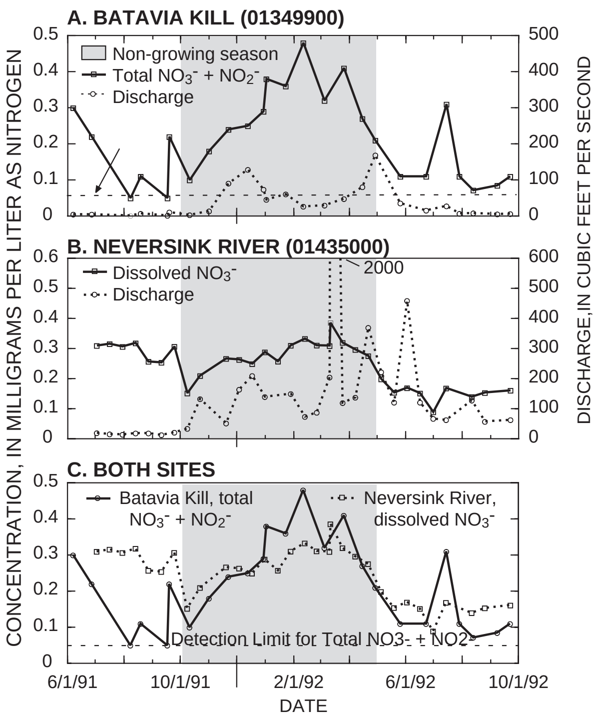


Figure 15. Nitrate (plus nitrite for Batavia Kill) concentration and discharge of Batavia Kill near Ashland and of Neversink River at Claryville, N.Y., June, 1991 to October, 1992. Nitrate plus nitrite concentrations less than 0.05 mg/L as N are plotted at the detection limit (0.05 mg/L). A. Batavia Kill. B. Neversink River. C. Both sites. (Neversink River at Claryville data from G. Lawrence, U.S. Geological Survey, written commun., 1994. Locations are shown on fig. 1.)

Nitrate is a common constituent in secondary-treated wastewater. The nitrate-plus-nitrite concentration of a stream-water sample collected about 200 yards downstream from the treatment-plant outflow on tributary D (fig. 7) during a release in June 1991 was 1.0 mg/L. The timing of releases from the treatment system was dependent upon wastewater inflows and, thus, was irregular. Continuous monitoring of sewage releases was beyond the scope of the investigation; therefore, evaluation of the effect of such releases on the chemistry of the Batavia Kill was not possible, but some inferences can be made. During periods of low flow, inputs of treatment-plant effluent and of shallow ground water affected by septic systems would be expected to have a greater effect on stream chemistry than at higher flows because dilution is minimal. Stream-water samples collected during June 1991 had higher concentrations of nitrate plus nitrite than samples from other low-flow periods (fig. 15); if treated wastewater was the source of the elevated nitrate concentrations, its effect on the Batavia Kill was similar to that of a storm that occurred the following summer (July 15, 1992; fig. 15); the concentrations also were similar to maximum springtime nitrate concentrations of the Neversink River at Claryville (fig. 15).

The volume of treated wastewater discharged from the treatment plant is greatest during the ski season. Although the general trends of nitrate concentrations in the Batavia Kill are similar to those in the Neversink River, the total concentrations of nitrate plus nitrite in the Batavia Kill during the 1991-92 winter was consistently higher (maximum 0.15 mg/L higher) than the concentrations of dissolved nitrate in the Neversink River during this period. This difference represents the maximum possible effect of the present level of direct wastewater discharge to the Batavia Kill but does not positively identify it. Differences between *total* nitrate plus nitrite and *dissolved* nitrate concentrations are probably minimal during winter because the suspended loads, which contribute to the *total* concentrations, are minor.

Total phosphorus detection was similar to that of *total ammonia plus organic nitrogen* (fig. 14). Total phosphorus concentration ranged from less than 0.01 to 0.05 mg/L and was detectable in 32 percent of the samples; total ammonia plus organic nitrogen concentration ranged from less than 0.2 to 1.0 mg/L and was detectable in 20 percent of the samples. Phosphorus was most commonly detected during the 1991 growing season under low-flow conditions but also was detected in three samples collected during stormflows (increasing discharge) in the fall and spring (table 5, fig. 14). The highest phosphorus concentration of the period of record was associated with the large storm in the fall of 1991. Ammonia-plus-organic nitrogen was detected less frequently during similar time periods (excluding spring high flows).

Total phosphorus and ammonium in the Neversink River at Claryville (not shown) were characterized by low baseline concentrations of about 0.004, and 0.01 mg/L, respectively, and none of the Neversink River samples had ammonium concentrations exceeding the 0.2-mg/L detection limit for ammonia-plus-organic nitrogen in the Batavia Kill samples. Whether the elevated ammonia-plus-organic nitrogen concentrations in the Batavia Kill resulted from the inclusion of organic nitrogen in the analyses, or were caused partly by elevated ammonia, cannot be ascertained. Phosphorus maximums generally correspond to high-flow periods (particularly when preceded by periods of relatively low flow), although a minor peak was recorded during low-flow conditions in the summer of 1991. The magnitudes of total phosphorus concentrations in the Batavia Kill are similar to those in Neversink River samples, even though the maximum discharge and total phosphorus concentration of the Neversink River is 20 times and two times that of the Batavia Kill, respectively.

Elevated concentrations of total phosphorus and ammonia-plus-organic nitrogen in the Batavia Kill during low flow, like nitrate, might be derived from treatment-plant discharges. Increases during high flows apparently result from overland runoff during storm events preceded by extended periods without appreciable rainfall. Developed areas, such as farms, residential developments, and golf courses can contribute nutrients to surface runoff.

Turbidity remained relatively stable through much of the study period (table 5, fig. 14). Values less than 1 NTU were typical during the growing season and during nongrowing-season intervals when the ground was frozen or snow covered. The isolated “spikes” of high turbidity occurred during fall and spring storms, when overland runoff was the dominant component of streamflow. Turbidity of the Neversink River at Claryville (not shown) had a similar trend and similar values, except for the highest value (60 NTU), which corresponded to the highest discharge (2,000 ft^3/s) in March 1992. No similarly high stormflows of the Batavia Kill were sampled during the period of investigation.

Reasons for chemical differences between the Batavia Kill and Neversink River. The chemical differences between these two rivers may be related to differences in: storm frequency and intensity, loss of tributary inflow through streambed infiltration, and carbonate availability within each basin.

1. Regional differences in storm frequency and intensity, and timing, as discussed in Murdoch and Stoddard (1992), can affect the chemical concentrations associated with stormflows.

2. Loss of tributary inflow through streambed infiltration during low-flow periods appears to influence chemistry and flow in the Batavia Kill to a much greater extent than in the Neversink River. As discussed earlier, surface flow (and its associated chemistry) from large percentages of the Batavia Kill study area are diminished or lost during low-flow periods. In contrast, the Neversink River has fewer large tributaries that run dry during those times (Peter Murdoch, U.S. Geological Survey, oral commun., 1994), presumably because the basin contains little permeable stratified drift and has only short in-valley tributary reaches within the main valley, which is typically less than 0.25 mi wide. Base-flow minimums from the summer of 1991 reflect this difference; even though the drainage area of the Neversink River is 29 percent greater than that of the Batavia Kill, the minimum 1991 base flow of the Neversink River (13.5 ft^3/s) was more than 10 times greater than that of the Batavia Kill (1.3 ft^3/s). Part of the difference is related to greater precipitation in the Neversink River Basin than in the Batavia Kill Basin.

3. Carbonate rock material is more prevalent in the upland areas of Batavia Kill Basin than in the Neversink Basin as reflected by the low-flow pH in Batavia Kill tributaries (7.8-8.5) in contrast to those (6.5 to 7) of the Neversink River Basin.

In summary, comparison of limited nutrient and turbidity data in the Batavia Kill with those in the Neversink River at Claryville indicate that the present level of development in the study area has little effect on the overall magnitude of nutrient concentrations and turbidity leaving the Batavia Kill Basin.

Inorganic Constituents. A water sample was collected from the Batavia Kill during two periods of relatively low flow—June and August 1991—for analysis for inorganic constituents (Table 6 and fig. 16).

The primary difference between the two samples is the chloride concentration, which is twice as great in the August sample as in the June sample. The June sample represents stable flow conditions and is a sodium/calcium-bicarbonate/chloride water, whereas the August sample represents increasing discharge

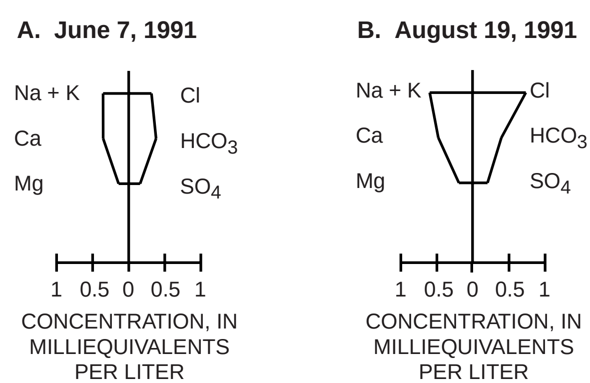


Figure 16. Concentrations of selected ions in samples from the Batavia Kill near Ashland, N.Y., June 7 and August 19, 1991.

Table 6. Chemical composition of surface-water samples from Batavia Kill, Mad Brook, and tributary B, Greene County, N.Y., June and August 1991

[Analyses by U.S. Geological Survey, Arvada, Colo. Concentrations in milligrams per liter (mg/L) unless otherwise specified. °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; < less than. A dash indicates no data. Site locations are shown in fig. 12.]

USGS site no.	Stream	Collection date	Temperature (°C)	Specific conductance (µS/cm at 25°C)	Total dissolved solids	pH (field) (standard units)	Calcium	Magnesium
1349870	Tributary B	06-27-91	18.5	68	41	8.2	6.5	1.8
1349876	Mad Brook	06-27-91	20.5	73	37	7.8	7.7	1.9
1349882	Mad Brook	06-27-91	20	239	120	—	10	2.7
1349900	Batavia Kill	06-07-91	19	96	50	7.1	7.1	1.7
1349900	Batavia Kill	08-19-91	18.5	139	77	6.8	9.5	2.3

Site	Sodium	Potassium	Chloride	Sulfate	Fluoride	Alkalinity (as $CaCO_3$)	Boron (µg/L)	Silica
1349870	3.8	0.50	3.3	7.5	<0.1	22	<10	4.4
1349876	3.6	.70	3.7	4.3	.1	19	<10	3.7
1349882	28	1.1	54	11	<.1	15	10	4.2
1349900	7.7	.80	11	7.6	<.1	19	<10	2.6
1349900	13	1.1	26	10	<.1	20	10	2.8

Site	Ammonia (as N)	Ammonium + organic nitrogen	Nitrite + nitrate [a] (as N)	Ortho-phosphate (as P)	Phos-phorus (as P)	Iron (µg/L)	Manga-nese (µg/L
1349870	0.20	0.40	0.28	<0.01	0.02	10	7
1349876	.20	.30	.16	<.01	.01	56	31
1349882	.20	.30	.34	<.01	.01	9	3
1349900	—	.20	.30	—	.02	10	17
1349900	—	1.0	.10	—	<.01	16	35

[a] Nitrite concentration was < 0.01 in all samples

during a storm and is classified as a sodium/calcium chloride water. Chloride is not a dominant, naturally occurring anion in shallow ground waters within the study area; therefore, the concentration of chloride in these samples is indicative of inputs from human-derived sources, such as sporadic discharges from the wastewater-treatment facility upstream, or runoff of salt residue from roadways.

Spatial Variations

Spatial variations in surface-water chemistry were identified on June 27, 1991 through field measurements of specific conductance and pH, and through laboratory analyses for nutrients and, at selected sites, inorganic constituents (tables 7, 6). Specific-conductance data were collected at the same sites on several other occasions, and turbidity was measured during receding high flow on April 23, 1994. The greatest local chemical variations (except for turbidity) occurred during low-flow conditions, when streamflow consisted entirely of ground-water discharge; turbidity showed the widest spatial variation during high flows, when streamflow included an overland runoff component. The local variations in stream chemistry are related to natural factors as well as human activity.

pH--Chemical analyses of samples from tributary B and Mad Brook (upgradient site 01349876; fig. 12) indicate a calcium bicarbonate water with pH values between 7.8 and 8.0 (table 7), whereas ground-water samples from the valley area (also calcium bicarbonate type) typically are acidic (pH 6.3 to 7.0). The high pH of nearly all tributary streams (but not the Batavia Kill, which is close to neutral; fig. 17) indicate a more abundant carbonate source in the till and stratified drift in the upland areas north and south of the Batavia Kill valley than in the bedrock aquifer and drift near or within the Batavia Kill valley or the uplands to the east. This explanation seems plausible in light of (1) evidence that glacial ice from the Hudson valley entered the Batavia Kill drainage basin through several northern passes (Rich, 1935; Cadwell, 1986), and (2) the presence of limestone fragments derived from source rocks just north of the Catskill Mountains.

Specific conductance and major ions--Comparison of specific conductance values indicate gross, local variations in major-ion chemistry. For example, specific conductance of streams in the basin on June 27, 1991, during low-flow conditions (fig. 17), ranged from 36 µS/cm at site 01349845, which drains the sparsely populated headwaters of the Batavia Kill, to 397 µS/cm at site 01349887 on tributary C, which drains the slopes occupied by the ski area and receives direct discharge from the ski area's sewage-treatment facility.

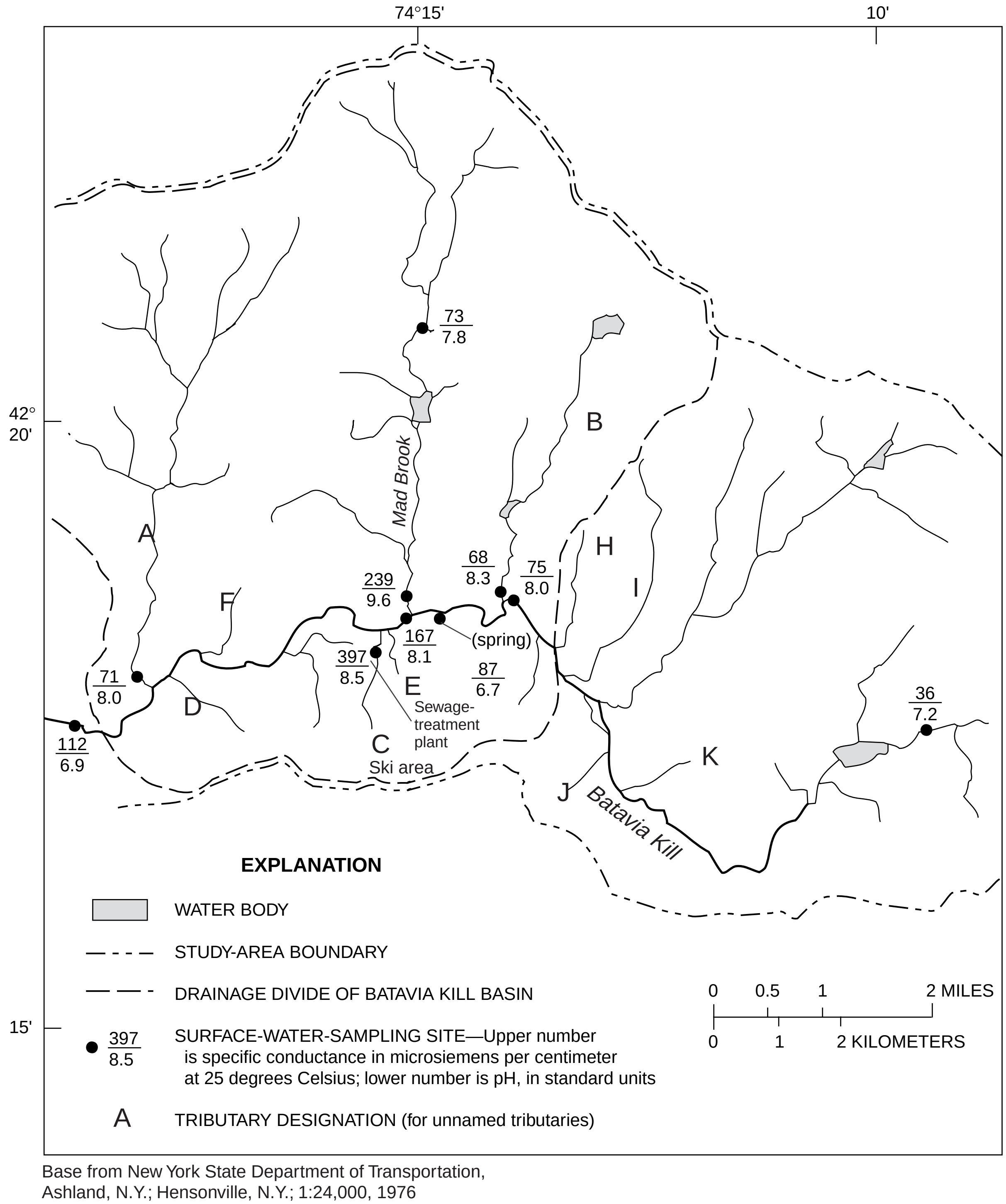
Under natural conditions, specific conductance is an indicator of relative ground-water residence time in the subsurface before discharging as base flow. Residence times depend on the length and direction of flowpaths, the amount of stratified drift, and size of the basin. In general, specific conductance values increase with increasing residence times (contact with soil and aquifer material).

Table 7. Chemical quality of surface-water samples collected in Batavia Kill study area, Greene County, N.Y., June 27, 1991

[Analyses by U.S. Geological Survey, Arvada, Colo. Concentrations in milligrams per liter unless specified. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; NTU, nephelometric turbidity units; <, less than; --, no data. Sampling locations shown in fig. 13.]

Station name	Station number	Turbidity (NTU)	Specific conductance (µS/cm)	pH field (standard units)	Nitrogen, organic total (as N)	Nitrogen, ammonia total (as N)	Nitrogen, nitrite total (as N)	Nitrogen, ammonia + organic total (as N)	Nitrogen, NO_2 + NO_3 total (as N)	Phosphorus total (as P)	Phosphorus ortho total (as P)
Batavia Kill at Peck Road	01349845	0.3	36	7.2	--	0.01	<0.01	<0.2	<0.05	<0.01	<0.01
Batavia Kill at Rte. 296	01349866	.6	75	8.0	.28	.02	<.01	.3	.20	.02	.02
Tributary B at Rte. 23	01349870	1.0	68	8.3	.38	.02	<.01	.4	.28	.02	<.01
Mad Brook at Mitchell Hollow Road	01349876	1.1	73	7.8	.28	.02	<.01	.3	.16	.01	<.01
Mad Brook at Rte. 23	01349882	1.1	239	--	.28	.02	<.01	.3	.34	.01	<.01
Tributary E	01349884	.7	167	8.1	.19	.01	<.01	.2	.68	.01	<.01
Tributary C	01349887	.5	397	8.5	.28	.02	<.01	.3	1.0	.11	.08
Tributary A	01349897	.7	71	8.0	.39	.01	<.01	.4	.28	.02	.01
Batavia Kill at Ashland	01349900	.7	112	6.9	.37	.03	.01	.4	.22	.01	.01
670 (spring)	42182607-4143701	.2	87	6.7	.39	.01	<.01	.4	1.6	.02	.01

Spatial variations in base-flow chemistry in the study area are primarily due to human-derived inputs to the ground-water system. The constituents may be derived from **point sources**, from **nonpoint sources**, or from both. Runoff from salted roads and septic-system discharges from residential areas are major nonpoint sources; road-salt stockpiles and landfills are important point sources.



Base from New York State Department of Transportation, Ashland, N.Y.; Hensonville, N.Y.; 1:24,000, 1976

Figure 17. Specific conductance and pH of surface water at selected sites in Batavia Kill basin, Greene County, N.Y., June 27, 1991.

The lowest base-flow value of specific conductance (36 µS/cm) was in the Batavia Kill upstream of the study area (site 01349845; fig. 17; table 7), where the land is sparsely populated, contains little stratified drift and approximates natural (undisturbed) conditions. This specific conductance value is similar to that in the Neversink River near Claryville, whose basin also is sparsely populated and contains relatively little stratified drift, (P. Murdoch, U.S. Geological Survey, oral commun., 1994).

The highest specific conductance value in the basin (397 µS/cm) was in tributary C (site 01349887; fig. 17, table 7), which drains most of the ski area. Treated wastewater from the ski area and associated residential areas is periodically discharged into the tributary about 800 ft upgradient of the sampling site. This discharge is a direct source of nutrient loading to the surface-water system because treated wastewater typically has elevated concentrations of nitrate plus nitrite, phosphorus, and dissolved organic carbon. Concentrations of total nitrate plus nitrite, total phosphorus, and orthophosphorus in a sample from this tributary were 4 to 10 times higher than those in streams that are not appreciably affected by human activities (table 7).

The Batavia Kill was sampled at the downgradient end of the study area on the same date; this sample did not show elevated concentrations of these nutrients, but whether the sewage-treatment plant was discharging, and whether effluent from the most recent discharge had reached the gage site, is unknown.

Only tributaries C and B flowed directly to the Batavia Kill during the low-flow conditions in the summer of 1991 (the other tributaries lost all flow through streambed infiltration); this increased the percent contribution from tributary C to total flow. The effect of tributary C on Batavia Kill water quality was probably mitigated by small summer discharges from the sewage-treatment plant relative to those during the ski season. The plant has been upgraded since these samples were collected.

The specific conductance of Mad Brook more than tripled (73 to 239 µS/cm) between the upstream measurement site, about 2 mi above the mouth, and the downstream site, 100 yards above the mouth. Much of this increase is attributed to ground-water discharges affected by leachate from a road-salt storage site and an abandoned landfill (discussed further on), about 0.25 mi upstream of the village of Windham. Another potential source is septic waste from homes that line the west side of the Mad Brook channel in the village; nitrate plus nitrite concentrations at the downstream site are higher than the typical low-flow concentrations in the Batavia Kill. Comparison of major-ion concentrations of the upgradient sample with those of the downgradient sample shows large downstream increases in chloride (14.6-fold), sodium (7.8-fold), and sulfate (2.6-fold) (fig. 18; table 6). The water along this reach changes from a calcium-bicarbonate type (indicative of naturally occurring shallow ground water) to a sodium chloride type, which, in shallow ground water, reflects human-derived sources.

Specific conductance of tributary E is relatively high (167 µS/cm). This tributary discharges to the Batavia Kill from a culvert (about 200-ft long) that channels shallow ground water and storm runoff; the flow during low-flow periods, appears to be limited to local ground-water seepage into the culvert. The water is colder than surface water in the area, and the specific conductance and nitrate plus nitrite concentrations are higher, which suggests a ground-water source and possible effects from septic systems.

Turbidity. Water samples were collected from the Batavia Kill (during receding high-flow conditions) and its tributaries on April 26, 1993 for turbidity measurement (fig. 19). The greatest spatial variation in turbidity occurred during high-flow conditions, when the volume of water flowing over the land surface is greatest. In general, the Batavia Kill and its largest tributaries had the lowest turbidity (<2 NTU), and the high-

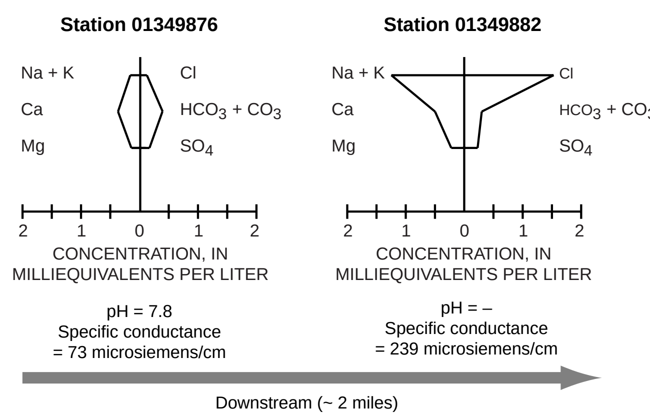


Figure 18. Downstream increases in major-ion concentrations and specific conductance in Mad Brook, June 27, 1991. (Dash indicates no data. Site locations are shown in fig. 12.)

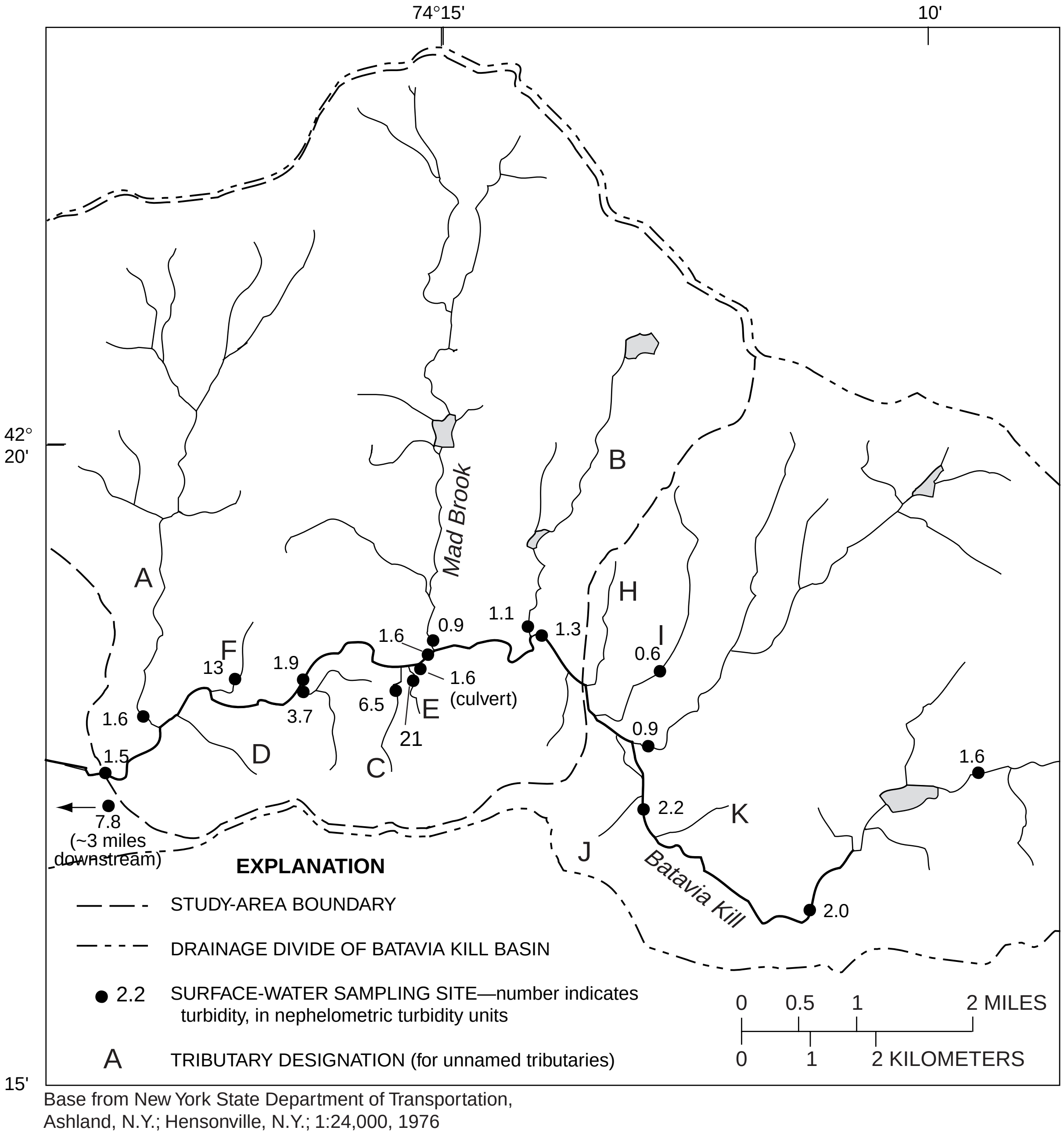


Figure 19. Turbidity at surface-water sites in Batavia Kill study area, Greene County, N.Y., April 26, 1993.

gradient, short tributaries, which are ephemeral (except tributary C), had the highest (2.1 to 21 NTU). The highest turbidity values (sites 01349885 and 01349892, fig. 12) are attributed to human activities that had disturbed soils within the local basins.

Ground Water

Ground water is the sole source of drinking water for domestic and public supplies within the study area. Springs are used in addition to wells. Most of the wells tap bedrock; those screened in unconsolidated deposits are in the largest valleys. Ground water discharges to local streams that flow to the Schoharie Reservoir and thereby contributes to the New York City drinking-water supply. The following sections address ground-water sources, geochemistry of natural ground waters, human effects on ground-water quality, and a conceptual model of the ground-water flow system.

Sources

This section describes the distribution, internal geometry, and hydraulic properties of unconsolidated and bedrock aquifer material within the study area. In general, these resources are limited but have some potential for increased use.

Unconsolidated Deposits

Most of the wells that tap unconsolidated deposits in the study area are within the Batavia Kill valley at the village of Windham. Springs are more commonly used than wells in this area. Most springs discharge from unconsolidated deposits, but one is at least partly fed by a bedrock source. The most productive springs are at local topographic lows and where the slope of the valley walls decrease, such as where the valley wall meets the flood plain. The water-resource potential associated with springs is limited in that the rate of discharge cannot be increased on demand; also the discharge typically decreases during the summer, when demand is usually greatest.

The water-resource potential of unconsolidated deposits is greatest in areas of consistently saturated, highly permeable deposits. These conditions are most common in the bottoms of wide valleys, which receive direct precipitation as well as ground-water and surface-water drainage from adjacent upland areas.

The water-resource potential of unconsolidated deposits in the upland areas is severely limited because (1) the predominant material is till, which is poorly permeable, and (2) the downslope movement of water limits the amount of water held in storage. Saturated till that contains lenses of permeable material may provide sufficient water to large-diameter wells for limited domestic use, but such wells may go dry during extended periods of low rainfall. Stratified-drift deposits in upland hillslope areas are similarly inconsistent as water sources, but such deposits on the lower valley walls are potential conduits for recharge to aquifers in the valleys.

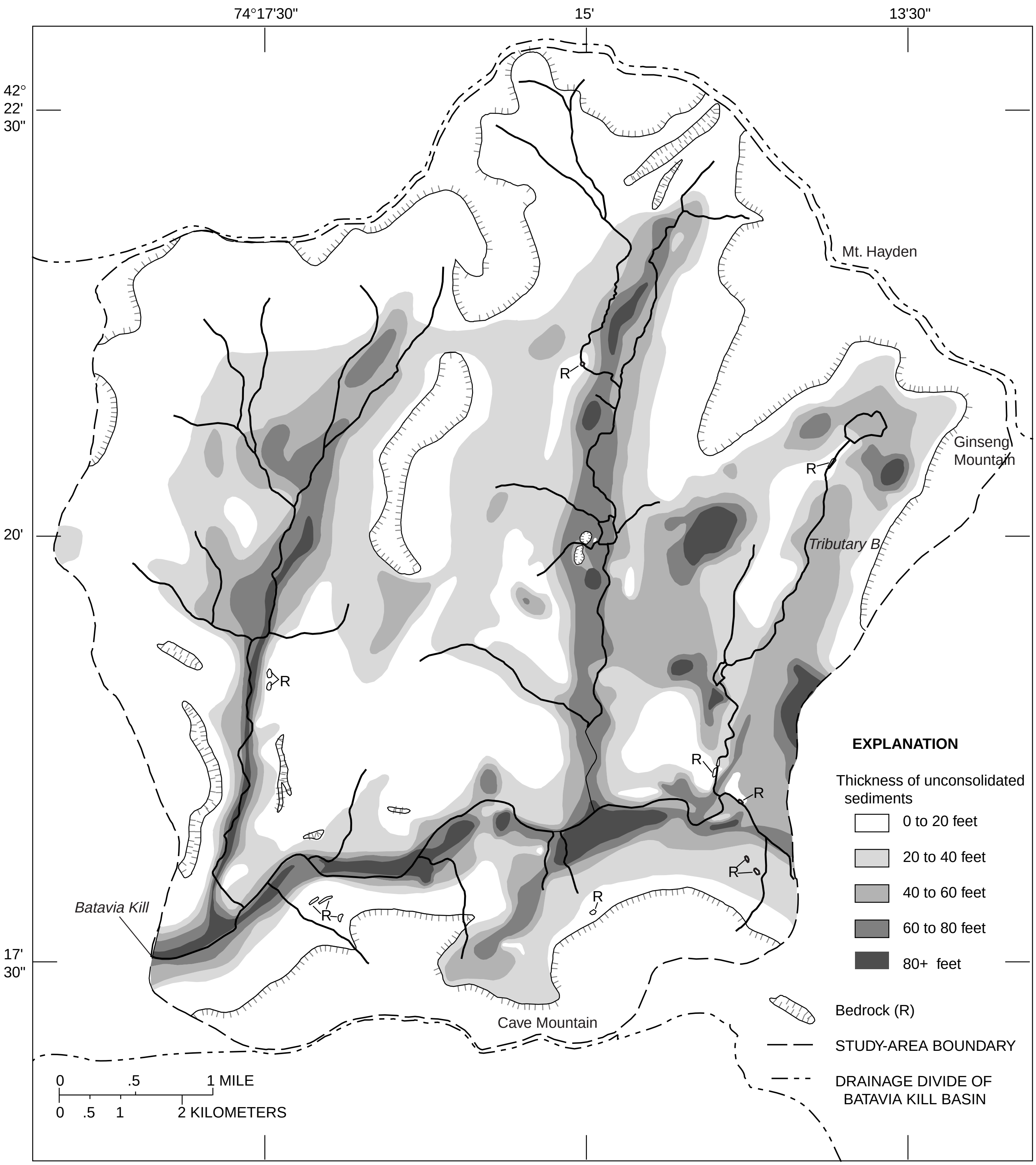
Information on the hydrogeologic framework of unconsolidated deposits contributes to the conceptualization of ground-water flow and availability. This information includes their thickness, type of depositional environment (which broadly relates to permeability), saturated extent, and hydraulic properties.

Thickness and Classification. The thickness and distribution of stratified and unstratified unconsolidated deposits in the study area helps define the geologic framework, which controls the occurrence and movement of ground water. For example, thick deposits of poorly permeable material, such as till, inhibit infiltration of precipitation (recharge) to underlying unconsolidated material and bedrock and thereby increase the potential for runoff to streams. Subsurface data from drillers' logs, test-hole logs, and seismic surveys were used to define the thickness of unconsolidated materials throughout the study area and to classify them.

The thickness of unconsolidated deposits is depicted in figure 20. The areas of thickest unconsolidated material (60 to 120 ft) are mainly within the Batavia Kill valley and its major tributary valleys, and the thinnest (<20 ft) are mainly in upland areas. Two exceptions occur within the tributary B subbasin, the easternmost subbasin in the study area (fig. 7, 20): (1) two upland ridge areas south of Mt. Hayden and southeast of Ginseng Mountain, respectively, are blanketed by 100 to 120 ft of drift, and (2) tributary B flows over bedrock, rather than unconsolidated material, just before its confluence with the Batavia Kill. The tributary B valley contains about 75 ft of drift near this point, but the present drainage is offset from the **thalweg** of the bedrock channel and intersects bedrock along the valley wall. A similar situation is found in the Batavia Kill valley less than 0.25 mi upstream of tributary B (figs. 20, 21).

Unconsolidated deposits are classified into four types. They are, from oldest to youngest: (1) till, which is unstratified, (2) ice-contact deposits, (3) lacustrine deposits, and (4) valley-bottom gravel and sand with recent alluvium. The three latter units consist of stratified-drift, and, except for the recent alluvium, correspond to three depositional facies that are widespread in the glaciated northeastern United States as described by Randall (in press). The origin, texture, and distribution of each unit are summarized as follows.

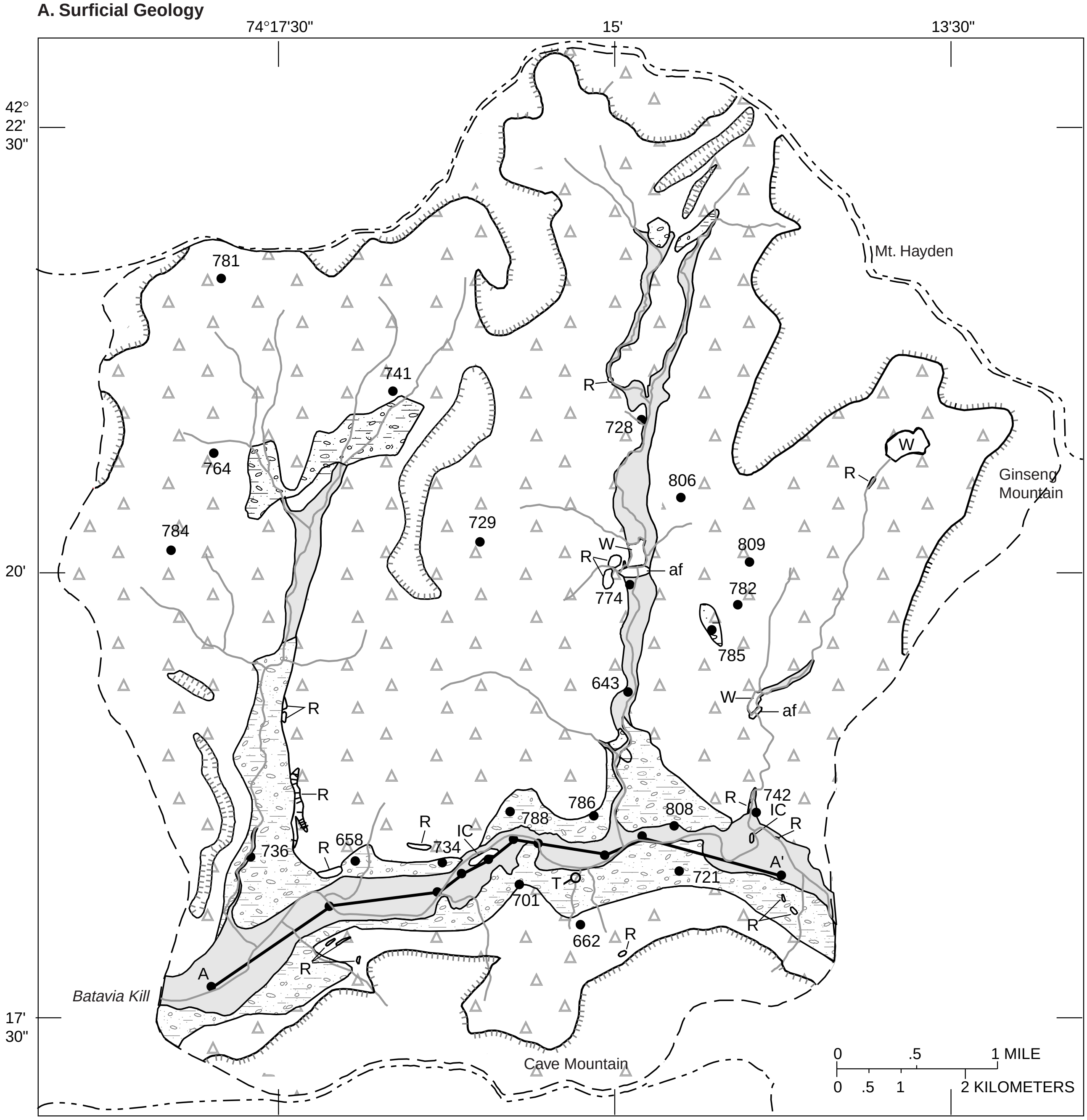
Till is a predominantly unsorted, unstratified heterogeneous mixture of rock material deposited directly by glacial ice, without appreciable reworking by melt-



Base from New York State Department of Transportation,
Ashland, N.Y.; Hensonville, N.Y.; 1:24,000, 1976

Figure 20. Thickness of unconsolidated deposits in Batavia Kill study area, Greene County, N.Y.

A. Surficial Geology



Base from New York State Department of Transportation, Ashland, N.Y.; Hensonville, N.Y.; 1,24,000, 1976

Surficial Geology by D.H. Cadwell, New York State Geological Survey-New York State Museum, Modified by P.M. Heisig, 1994.

EXPLANATION

GEOLOGIC UNITS

VALLEY-BOTTOM GRAVELS AND SANDS AND RECENT ALLUVIUM- stratified gravels and sands with variable fine sand and silt, overlain by 0 to 5 feet of fine-grained alluvium.

LACUSTRINE DEPOSITS- stratified, flat lying, thin bedded fine sand to clay units, well sorted within units.

(IC) ICE-CONTACT DEPOSITS- stratified, heterogeneous sands and gravels ranging widely in degree of sorting from clean sand and gravel to silt and clay-bound units.

(T) TILL- Unstratified and unsorted heterogeneous mixture of rock material; ranges from clay to boulder-size particles

(R) BEDROCK

Figure 21A. Surficial unconsolidated units and bedrock in the Batavia Kill study area, Greene County, N.Y.

B. Stratigraphic Columns

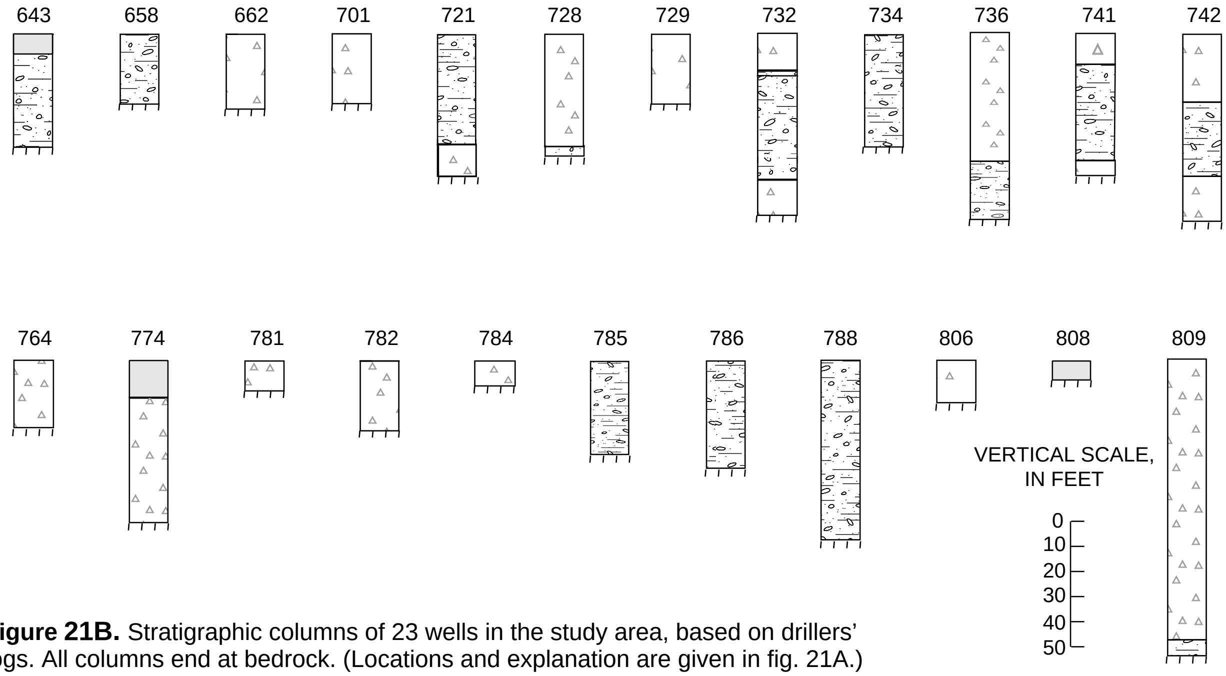
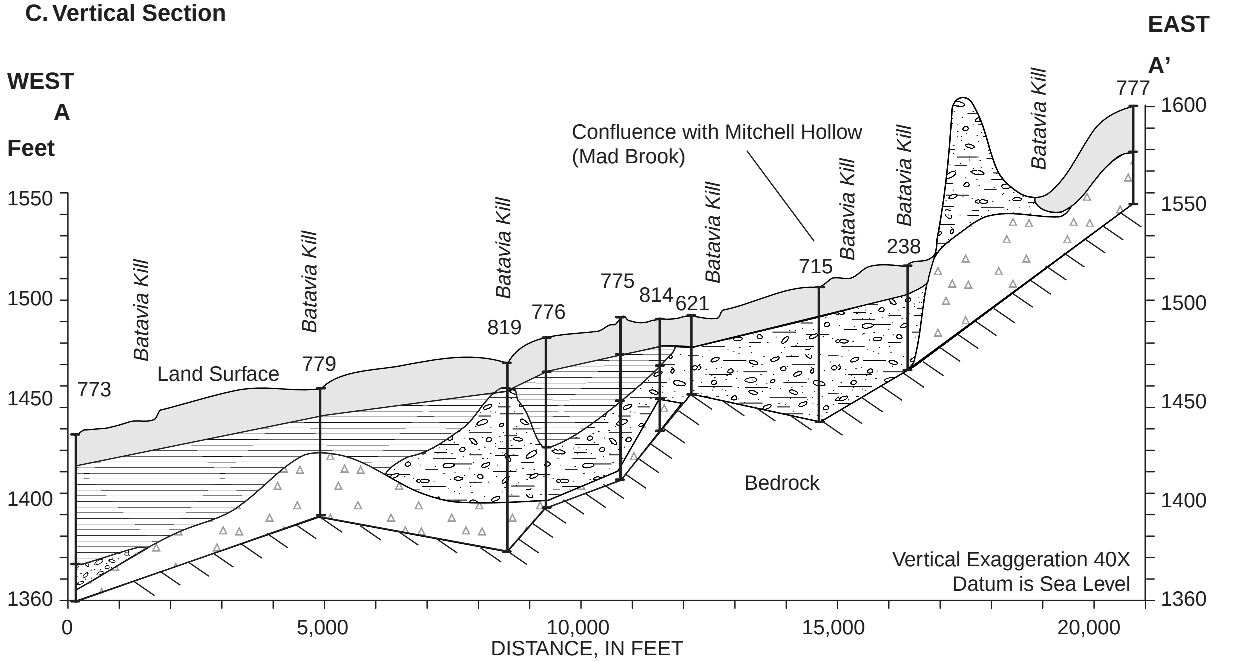


Figure 21B. Stratigraphic columns of 23 wells in the study area, based on drillers' logs. All columns end at bedrock. (Locations and explanation are given in fig. 21A.)

C. Vertical Section



EXPLANATION (CONTINUED)

OTHER

W — WATER

af — ARTIFICIAL FILL

— — Study-area boundary

— - - DRAINAGE DIVIDE OF BATAVIA KILL BASIN

A ●—● A' LINE OF SECTION- shown in figure 21C

729 ● WELL SITE- number is local USGS identification number

Figure 21C. Vertical section A-A' showing unconsolidated units within the Batavia Kill valley. (Explanation and trace of section are given in fig. 21A.)

water. Particle size ranges from clay to boulder size; the larger rock fragments are typically matrix supported and angular. Till in this region is reported to be predominantly clay (Berdan, 1954), which suggests low permeability. Till is the most widespread and thickest unconsolidated material within the study area and is the dominant surficial deposit in the uplands (fig. 21A); it also commonly underlies the stratified deposits in the valleys (fig. 21B,C). The maximum reported thickness is 112 ft (well 809, fig. 21B). Till impedes the movement of water within the local hydrogeologic framework.

Ice-contact deposits consist of stratified, heterogeneous sand and gravel deposited in contact with melting ice early in local deglaciation. Sorting varies over short distances from permeable, clean units to impermeable, dense, clay or siltbound units. Many ice-contact deposits are closely associated with till, and the distinction between them can be unclear. For example, “hardpan with some gravel” or “hardpan with cobbles” described in some driller's logs could represent either till with some washed zones, or poorly sorted ice-contact deposits. Most designations of ice-contact materials from driller's log are conservative; that is, the unit contains discrete, permeable beds (fig. 21B).

The majority of ice-contact deposits in the study area are within and along the lower walls of the Batavia Kill valley and the lower reaches of its two major tributary valleys—Mad Brook and tributary A (fig. 21A, fig. 12). Some of the coarsest ice-contact material lies above the valley floor and extends about 1.5 mi on the north side of the Batavia Kill valley at the village of Windham and at one point on the south side, about 1 mi west of the village center. These deposits appear to be minimally saturated.

Ice-contact deposits within the valley areas are discontinuous and vary greatly in thickness and texture (fig. 21C). They are thickest and coarsest (1) along the last mile of Mad Brook’s valley (Mitchell Hollow) to the confluence with the Batavia Kill valley, and (2) within the Batavia Kill valley for at least 0.25 mi east and 0.5 mi west of this confluence. Deposits west of this area typically are thinner and consist of permeable beds of predominantly sand-size particles along with numerous intervening beds of low permeability.

Lacustrine deposits are stratified, fine-grained sediments ranging from fine sand to clay size that are deposited midway during local deglaciation (Randall, in press) in a body of still water. Such deposits typically have low permeability and act as confining units. Lacustrine deposits within the study area appear to be largely limited to the Batavia Kill valley west of the village of Windham (fig. 21C). They attain a maximum thickness of about 40 ft and are predominantly fine to very fine sand and silt. Cores obtained during drilling indicate that **varves** are common; the bedding thicknesses range up to 1.5 ft for fine sand and to 2 in. for clay.

Valley-bottom gravel and sand with recent alluvium are addressed here as a single unit for ease of illustration. The valley-bottom gravel and sand cap most deglaciation sequences in the glaciated northeastern United States and represent meltwater deposition (outwash) late in local deglaciation (Randall, in press) or postglacial deposition (fluvial gravel). The generic term “valley-bottom” is used here because the timing of deposition is uncertain. Valley-bottom deposits commonly occupy a larger part of low-relief valley bottoms than the current flood plains do. Recent alluvium includes fine-grained sediments deposited in flood-plain areas and reworked valley-bottom gravel and sand in the present stream channels.

Valley-bottom gravel and sand deposits underlying the Batavia Kill valley and Mitchell Hollow are 10 to 15-ft thick and are typically poorly sorted. Grain-size analyses of these shallow gravels (two spin samples obtained during auger drilling, which includes one from Mitchell Hollow) average about 15 percent fine sand size or smaller. Permeability probably ranges from moderate in poorly sorted zones to high in “cleaner” zones. Fine-grained alluvial sediments are present at land surface within valley flood-plain areas but range in thickness from no more than a veneer to about 5 ft in the Batavia Kill valley at the downgradient end of the study area. Alluvial deposits are unsaturated in most localities.

Extent and Saturated Thickness of the Stratified-drift Aquifer. The limited stratified-drift aquifer in the study area consists of the saturated ice-contact deposits and also saturated valley-bottom gravel and sand that directly overlie the ice-contact deposits (fig. 21A,B,C). Areas where valley-bottom gravel and sand are underlain by lacustrine deposits are not included as part of the aquifer; saturated thickness above the lacustrine deposits is thin (about 5 to 7 ft), and the proximity of these deposits to land surface (about 6 to 8 ft) makes them highly susceptible to contamination from human-derived sources in the valley. Thus, the aquifer, as defined here, is confined in its western part by lacustrine deposits, and is unconfined in the eastern part (fig. 21C). The upper boundary of the unconfined aquifer is the water table.

Depth to water within the Batavia Kill flood plain is typically about 7 ft but fluctuates in response to seasonal variations in recharge, as shown in the ground-water hydrograph in figure 22. Recharge from precipitation occurs primarily during late fall and early spring, whereas ground-water discharge to the Batavia

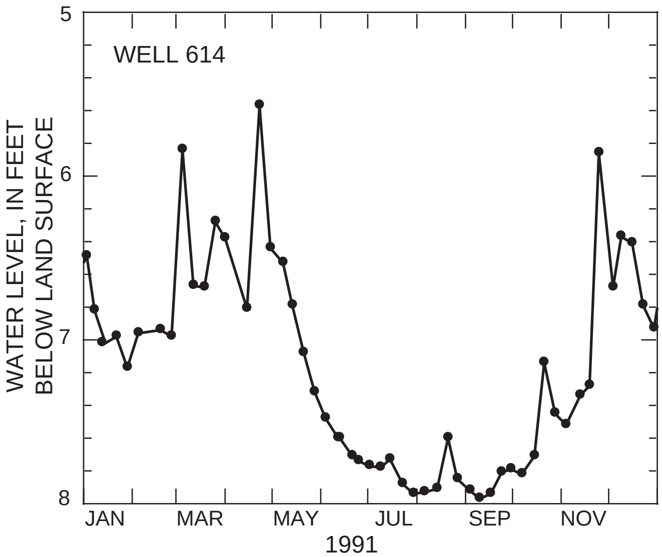


Figure 22. Water-table fluctuations at a shallow well (614) screened in unconsolidated deposits in the Batavia Kill valley, 1991. (Well location is shown on pl. 1.)

Kill is presumably continuous, but slowed or interrupted by high flows in the Batavia Kill. The maximum fluctuation of the water table in several shallow wells on the Batavia Kill flood plain over an 18-month period (October 1990 to April 1992) was about 3.5 ft.

The unconsolidated aquifer underlies much of the Batavia Kill valley and extends into the lower valley segments of the three largest tributaries to the north. No aquifer material was found at two sites within this area (sites 774 and 779; fig. 21). No information on the extent of aquifer material in the upper reaches of the major tributary valleys is available; the most favorable areas for well development probably correspond to low-lying areas adjacent to the stream courses, especially where valley-bottom gravel and sand and recent alluvium are present (fig. 21A).

The saturated thickness of the aquifer is depicted in figure 23. Because ice-contact deposits vary considerably in permeability, an attempt was made to give a saturated-thickness value that is indicative of the permeable parts of the ice-contact material; thus, only beds or units described as sand of medium or larger grain size were included in the thickness tabulations.

Saturated thickness decreases from east to west within the Batavia Kill valley and varies among the major tributary valleys (fig. 23). The greatest thickness (20 to nearly 60 ft) is centered around the lower reach of Mad Brook (Mitchell Hollow) and its confluence with the Batavia Kill valley. Saturated thickness in the confined (western) part of the aquifer is typically about 10 ft, except in two unconfined pods of ice-contact material, where it is thicker (fig. 23). Several intervening units of low permeability in the western part of the aquifer may prevent successful development of wells.

Hydraulic Properties. **Hydraulic conductivity** (*K*) values were estimated from (1) aquifer-test data from wells 813 and 814, screened 34 to 40 ft and 29 to 35 ft below land surface, respectively, in ice-contact sand and gravel beneath lacustrine deposits (Appendix A, pl. 1) and (2) slug tests at well 614, screened 7 to 12 ft below land surface in unconfined poorly sorted sand and gravel above the lacustrine deposits. These values, multiplied by aquifer saturated-thicknesses, provide estimates of the **transmissivity** (*T*) of the aquifer throughout the study area.

A computer program (Bradbury and Rothschild, 1985) was used to estimate transmissivity and hydraulic conductivity from well-log, well-construction, and **specific-capacity** information from wells 813 and 814 (R. Slayback, Leggette, Brashears, and Graham, written commun., 1982). Estimated *K* values for well 813 (570 ft/d) exceed those for well 814 (70 ft/d) by nearly an order of magnitude, even though the two wells are only 90 ft apart.

Hydraulic conductivity values for well 614 (Appendix A and pl. 1), estimated from slug-test analyses (Bouwer and Rice, 1976) ranged from 32 to 57 ft/d; these low values reflect the poor sorting of these deposits. Washed or well-sorted gravel, if present, could have *K* values ranging from hundreds to thousands of feet per day (Freeze and Cherry, 1979).

A range of aquifer-transmissivity values for a given site can be estimated from the *K* values if the saturated thickness is known. Areas with a saturated thickness of 20 ft or more (see fig. 23) are typically unconfined; therefore, the *K* value for the upper 5 to 10 ft of saturated thickness should be between 32 and 57 ft/d, as at well 614. The 20- to 40-ft thick pod of saturated sand and gravel in the center of figure 23 generally divides areas of minimal saturated thickness

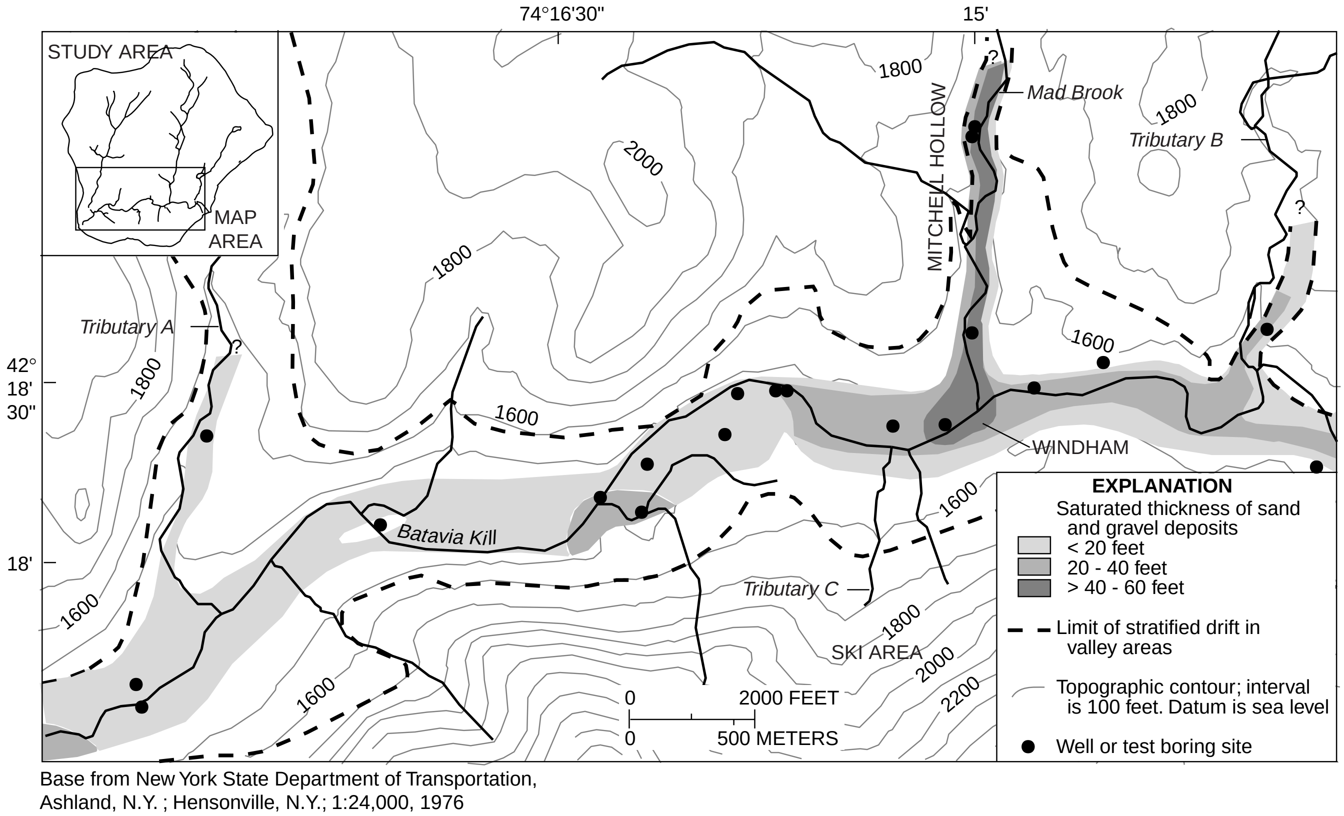


Figure 23. Saturated thickness of the stratified-drift aquifer in the Batavia Kill valley and in lower reaches of major tributary valleys.

(interspersed between the deepest lacustrine sediments and till) to the west from thick, more discreet aquifer sediments to the east, including those tapped by wells 813 and 814. Thus, the aquifer material in the east (below the silty gravel) is assigned a *K* value within the 70 to 570 ft/d range, and those to the west are assigned a value of 70 ft/d or less. The maximum aquifer transmissivity (where saturated thicknesses reach 60 ft, including 10 ft of silty gravel) is between 4,000 and 29,000 ft^2/d, (fig. 23).

Bedrock

Bedrock is tapped for water supply throughout the study area with varying success. Virtually all water within bedrock is stored within and transmitted through fractures (secondary **porosity** and permeability). Intergranular pore space (primary porosity and permeability) in the bedrock is not considered an important component of ground-water flow or available storage within the study area; Gale and Siever (1986) report that the porosity of Catskill Facies sandstones has been reduced by **diagenesis** and compaction to essentially irreducible levels.

The water-resource potential of bedrock is related to (1) the presence of fractures that are permeable and saturated, (2) the degree of hydraulic interconnection among fractures, and (3) the potability of the water. The bedrock aquifer component of this study entailed (1) compilation of driller's logs from about 180 wells, including reported well yields (Appendix A, pl. 1), (2) collection of water-level data at about 60 wells finished in bedrock, and (3) collection of borehole-geophysical data from 21 wells (Heisig and Knutson, 1997) and television logs from four wells. Water levels were measured weekly or continuously for as long as 2 years. Additional measurements were made in conjunction with an aquifer test at well 632 (pl. 1).

The hydrogeologic framework of bedrock, described below, is defined in terms of (1) subsurface continuity of gamma-radiation-based rock units, (2) fracture distribution and frequency as observed in **wellbores**, and (3) the presence of saline water in wellbores. Definition of the subsurface continuity of rock units provides the basic geologic framework upon which the fracture distribution and frequency data can be interpreted. Data on saline water occurrence provides an indication of the lower boundary of fresh or potable water within the hydrogeologic framework.

Subsurface Continuity of Natural-gamma Units. **Natural-gamma-radiation** logs were used to correlate bedrock units among selected wells. Natural-gamma-radiation generally varies with mineralogic composition—clay minerals, which are concentrated in shale, have higher natural-gamma radiation than most other minerals in the fining-upward cycles described earlier. Thus, there is a sharp decrease in gamma radiation across the boundary between the shale or mudstone that caps one cycle to the basal sandstone that initiates the next younger, overlying cycle (fig. 2). A cycle typically fines upward to finer-grained sandstone, siltstone, and ultimately shale, although gamma logs also indicate the presence of coarser or finer interbeds that interrupt the cycles. In the study area, gamma-log response ranges from about 40 to 340 counts per second (cps), and the count population has a bimodal distribution—a gamma-log response less than or equal to 170 cps was interpreted as a coarse-grained unit, and a count greater than 170 as a fine-grained unit.

Natural-gamma-log data from each well was grouped as vertical intervals designated as having high or low natural gamma radiation, (herein referred to as gamma stratigraphic units), and the intervals were assembled into columns. Vertical sections (see example in fig. 24) were created by correlating the units among the wells, to define their continuity. Such information provides a geologic framework from which the fracture distribution and frequency (and ultimately ground-water flow) can be interpreted.

The two vertical sections in figure 24 illustrate two key aspects of the bedrock framework—the degree of lateral continuity of gamma units, and the effect of superimposed regional and local geologic structures. Thick gamma units (10 ft or greater) are generally continuous along each section, although lateral changes are apparent in the lower half of section A-A'. Such changes might be expected to affect hydraulic connections between wells. The sections also indicate an apparent regional westward dip (section A-A') and subtle upwarping of beds beneath the Batavia Kill valley (section B-B'). The upward flexure of gamma units beneath the Batavia Kill valley in section B-B' might be related to valley stress relief as described by Ferguson (1967, 1974) and Wyrick and Borchers (1981).

Fracture Distribution and Frequency. Two types of bedrock fractures are recognized herein—low-angle (or bedding-plane) fractures, which range from flat lying to 30 degrees of dip, and high-angle fractures, which exceed 30 degrees of dip. Several types of geophysical logs were used to investigate fractures that intersect wellbores, and each type of log provides information on some aspect of fracture occurrence. (1) Caliper logs, available from all logged wells, indicate the location and width of fractures at the wellbore (but not the type of fracture, nor the permeability). (2) Television logs, which are available from a subset of logged wells, provide a detailed record of fracture type (high-angle or low-angle) and location. Television logs generally do not identify water-bearing fractures. Comparison of television logs with caliper logs indicates that the caliper tool does not identify most high-angle fractures; therefore, caliper-identified fractures are interpreted as low-angle fractures. (3) Fluid-conductivity logs and (4) temperature logs provide the most conclusive identification of water-bearing fractures where wellbores intersect and interconnect fractures containing waters that differ in dissolved solids concentration or temperature.

Caliper data. Caliper data from 21 wells (Heisig and Knutson, 1997) were used to estimate fracture density within and near the Batavia Kill valley. Many of the fractures are within the shallowest bedrock. The distribution of fractures with respect to altitude (fig. 25) suggests that the most consistently fractured rock in the study area is between altitudes of 1,375 and 1,500 ft, which corresponds to the shallowest bedrock within the valley-floor area. High fracture density in shallow bedrock does not imply the absence of fractures at greater depths; caliper, television, and fluid-conductance data confirm the presence of deeper fractures. Topographic position appears to affect the depth or thickness of the most frequent fracturing; the thickness of fractured intervals (including the upper 10 ft of cased bedrock) associated with valley-bottom wells rarely exceeds 35 ft, whereas that at the few hillside- or upland-area wells ranges from 50 to 90 ft.

Television data. The distribution of low-angle and high-angle fractures in one hillside well and three valley wells was determined from the television logs. The datum for depth of fractures at each well is the bottom of casing, generally 8 to 10 ft below the bedrock surface. Fracture identifications were compiled in 25-ft intervals (fig. 26) to the bottom of each borehole or until turbid water prevented fracture identification. Low-angle and high-angle fractures in these logs are tabulated in three categories: (1) total fractures

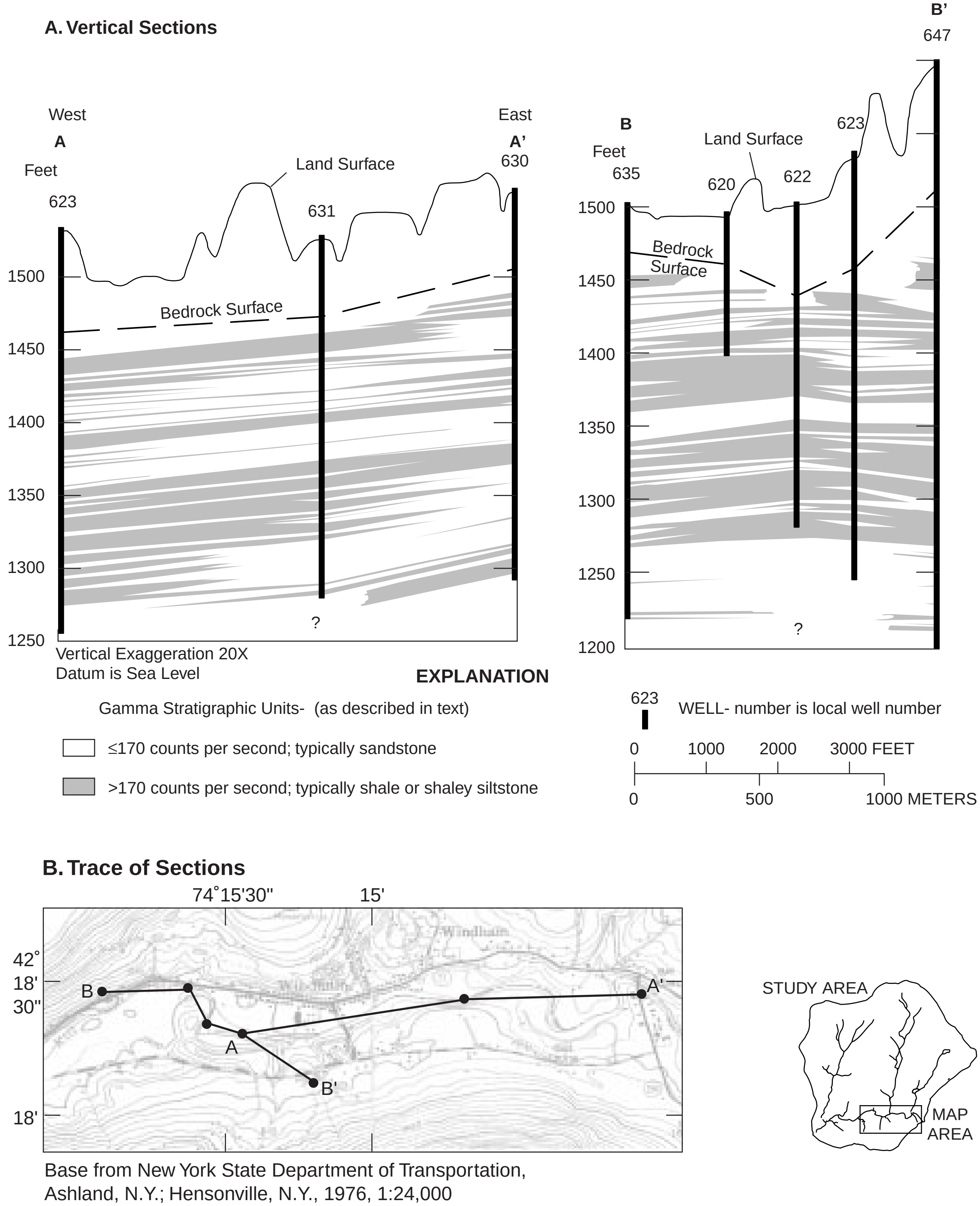


Figure 24. Bedrock gamma stratigraphic units along vertical sections A-A' and B-B' at Windham, N.Y.

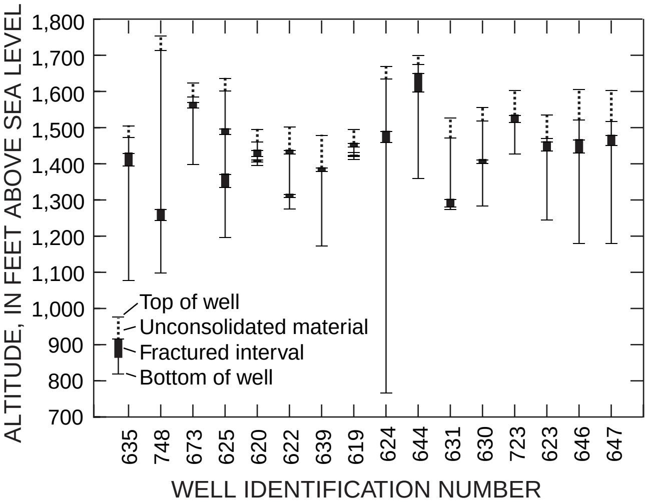


Figure 25. Zones of greatest fracture density at selected wells in the Batavia Kill study area, Greene County, N.Y., as determined from caliper logs keyed to altitude.

(including poorly defined fractures), (2) well-defined fractures, and (3) fracture zones (fractured-rock intervals 0.5 to 10 ft thick in which individual fractures are difficult to differentiate).

Low-angle and high-angle fractures were observed in all wells, although those in the hillside well (767) differ from those in valley wells. Total low-angle fracture frequencies throughout the valley wellbores (150- to 225-ft deep) average about 7 per 25-ft interval; the average for the hillside well is similar in the first 100 ft of record, but the average for the remaining record is less than 2 per 25-ft interval. Fracture zones are also more prevalent within the valley wells than within the hillside well—each valley well contains three fracture zones within the first 150 to 225 ft, whereas the hillside well has only one fracture zone within the first 225 ft. The hillside well has the most numerous and well-defined high-angle fractures; the upper 150 ft of the wellbore averages about 7 fractures per 25 ft, and the remainder (to 425 ft) averages 2 per 25 ft. The average among the valley wells is lower and highly variable (from 1 to about 6 per 25 ft). The data from these four wells, although limited, appear consistent with the observed predominance of low-angle fractures in valley-floor areas and high-angle fractures in hillside areas in geologic settings similar to that of the study area (Wyrick and Borchers, 1981). The most intensely fractured interval at the hillside well is the upper 100 to 150 ft of bedrock; low-angle fracturing at the valley wells is relatively consistent to depths of at least 225 ft (limited by the depth of the wells).

Fluid conductivity and temperature data. The relation of water-bearing fractures to the gamma stratigraphic units described earlier also was investigated. Total number of fractures and number of water-bearing fractures were identified at 19 wells at which natural-gamma-radiation, fluid conductance, temperature, and caliper logs were collected (table 8). Fractures identified on caliper logs are predominantly low-angle fractures; in each well, these fractures were classified according to the gamma level (<170, ~170, or >170 counts per second) or by abrupt changes in gamma radiation. As described earlier, low gamma levels generally indicate coarse-grained units (sandstone), and high gamma levels generally indicate fine-grained units (shale and mudstone). Abrupt changes in radiation correspond to the contact between overbank or flood-plain mudstone and shale, which cap one upward-fining sequence, and the overlying basal sandstone that initiates the next sequence. Identification of water-bearing fractures is limited to fractures indicated by *changes* in the fluid-conductance and temperature logs; permeable fractures without water of differing fluid conductance or temperature cannot be identified by this method. The percentage of water-bearing fractures within each gamma-level classification (table 8) suggests that the fractures that are most likely to be water bearing are in intervals with abrupt radiation changes (sedimentary-cycle breaks, 72 percent of fractures) and in low-gamma intervals (coarse-grained units, 48 percent of fractures), and the fractures that are least likely to be water bearing are those associated with intermediate- and high-gamma intervals (fine-grained units, 35 and 36 percent of fractures, respectively).

The relatively large number of total fractures in the intermediate- and high-gamma (shaley) intervals (relative to the low-gamma, sandstone intervals) may reflect the friable nature of the rock and its susceptibility to developing local broken zones adjacent to the borehole during drilling. These zones of broken material resemble zones of natural fractures but are not water bearing. The large numbers of total fractures within high- and intermediate-gamma intervals could also be related to a greater abundance of these units, than of low-gamma intervals, at most boreholes.

Fluid-conductivity logs keyed to altitude in wells within and near the Batavia Kill valley indicate an increased number of specific-conductance changes (indicative of water-bearing fractures) at altitudes of 1,350 to 1,450 ft. This interval is similar to that deter-

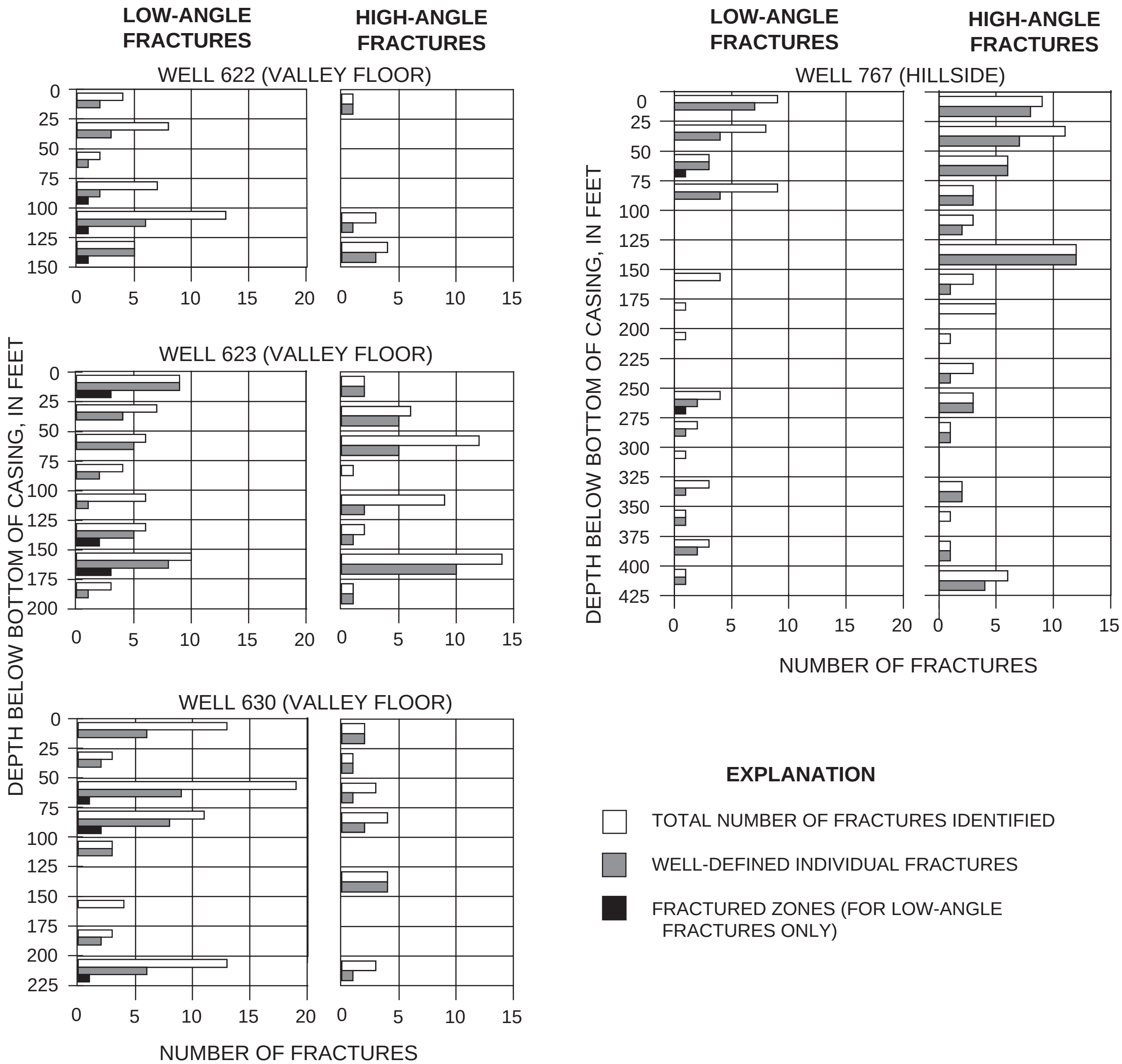


Figure 26. Frequency of high- and low-angle fractures as a function of depth below bottom of well casing, as identified from downhole-television camera logs from four wells in the Batavia Kill study area.

mined for caliper-defined fractures (fig. 25) and corresponds to about the upper 50 to 150 ft of bedrock beneath the Batavia Kill valley, although some of these wells are more than 1,000 ft from the valley. Logs from several wells show fractures at essentially the same altitude; hydraulic interconnections of some wellbores are indicated by water-level data, whereas others are not indicated or their presence is inconclusive. Most fractures in the area are associated with bedding planes; the role of high-angle fractures in transmission of ground water beneath the Batavia Kill valley is unknown.

In summary, ground-water occurrence in bedrock is limited to fracture openings and, thus, depends on the distribution, permeability, and degree of interconnection among fractures. Caliper logs typically show the greatest fracturing in shallow bedrock (the near-surface fracture zone), the thickness of which is generally 35 ft or less in valley-bottom areas and as much as 90 ft in hillside areas. Borehole video-camera data

Table 8. Distribution of total fractures and water-bearing fractures among gamma-radiation-defined intervals or changes, in 19 wells at Windham, N.Y.

[cps, counts per second. Well locations are shown on pl. 1.]

Local USGS well number	Gamma-radiation category [1]						Abrupt changes in gamma radiation (sedimentary-cycle breaks)	
	Low-radiation intervals (less than 170 cps)		Intermediate-radiation intervals (about 170 cps)		High-radiation intervals (more than 170 cps)			
	Total fractures	Water- bearing fractures	Total fractures	Water- bearing fractures	Total fractures	Water- bearing fractures	Total fractures	Water- bearing fractures
635	3	2	9	3	0	0	1	1
748	1	0	2	2	7	3	2	2
767	2	1	3	2	15	3	1	0
673	3	1	2	0	8	4	2	1
625	3	3	5	3	6	2	3	3
620	3	0	7	2	4	2	1	0
621	3	2	2	2	0	0	1	0
622	5	1	7	0	5	1	2	1
639	2	1	3	1	4	2	1	0
619	1	1	4	0	2	1	0	0
624	4	1	3	0	9	3	3	1
644	2	2	3	0	6	0	2	1
714	0	0	2	2	0	0	1	1
631	6	1	5	1	2	2	2	2
630	4	1	3	1	2	0	0	0
723	3	2	6	2	3	2	3	2
623	2	2	3	2	6	1	1	1
646	1	1	4	1	2	2	1	1
647	2	2	6	3	2	2	5	5
Totals	50	24	77	27	83	30	32	23
Percentage of total fractures that are water bearing	**48**		**35**		**36**		**72**	

[1] Low radiation indicates coarse-grained material (sandstone);
intermediate radiation indicates variable mixtures of fine and coarse-grained material;
high radiation indicates fine-grained material (mudstone and shale).
Total fractures were identified from caliper logs; water-bearing fractures were identified from fluid-conductivity and fluid-temperature logs.

from the three valley-bottom wellbores indicate consistent low-angle (bedding-plane) fracturing to at least 225 ft below casing, accompanied by inconsistent high-angle fracturing in two of the three wellbores. The single hillside well with a video record contains inconsistent low-angle fracturing below about 100 ft and the persistence of high-angle fracturing to at least as deep as 425 ft, with the greatest frequencies within the first 150 ft. Fluid-conductivity logs in conjunction with gamma-radiation logs indicate that the units most closely associated with water-bearing fracture zones are the sandstone units (fig. 2) and the sedimentary-cycle contacts between shale and sandstone units.

Saline Water. Fresh ground water in bedrock is underlain by unpotable saline water with a specific conductance range of at least 16,000 to 35,000 µS/cm. The boundary between fresh and saline water represents the lower limit of bedrock water resources. The depth of the interface is largely undefined because only three of the logged wells appear to penetrate it (wells 635, 646, and 799; pl. 1; Appendix A; Heisig and Knutson, 1997). Delineation of the interface, or the source fractures, in these wells is hampered by borehole flow. Water from many other wells shows intermediate levels of specific conductance (discussed further on), which might indicate cross-contamination from the three aforementioned wells. Saline water is penetrated at altitudes ranging from about 1,020 to 1,180 ft. The shallowest saline-water-bearing fracture is between 275 and 375 ft below the Batavia Kill valley flood plain at well 635.

Hydraulic Properties. Fractured bedrock typically has a lower porosity and lower storage capacity than permeable unconsolidated material; thus, withdrawals from a fractured-bedrock aquifer typically affect a much larger area than withdrawals of the same magnitude from a stratified-drift aquifer. Moreover, the decreasing fracture occurrence and permeability away from the valley areas (within the hillsides), and the narrowness of the valleys in the study area, further limit storage within the fractured bedrock and, thus, limit the amount of water available to wells. For example, early water-level responses at observation wells in the valley during an aquifer test indicated limited storage in a confined, productive fracture tapped by the town's backup production well (632, pl. 1). The water levels at three wells (650, 1,600, and 2,800 ft from the pumping well) began to decline after only 10 minutes of pumping at a rate of 75 gal/min (a total of 750 gallons pumped, including some casing storage).

Wells completed in bedrock differ in two ways from those finished in stratified-drift, and these differences are critical to interpretation of data. First, bedrock wells commonly do not act as **piezometers** because they are typically cased from land surface to about 8 to 10 ft below the bedrock surface, and the remainder of the well is an open borehole that may intersect multiple water-bearing fractures with differing **hydraulic head** values. Within the Batavia Kill valley, appreciable vertical (upward) **hydraulic gradients** exist between some bedrock fractures. The water level in a bedrock well typically is a composite of the heads within all fractures intersected by the wellbore, unless the well intersects a single water-bearing fracture or a dominant water-bearing fracture that controls the head. Thus, a map of water levels in bedrock wells in the valley would not be particularly useful because the water level at each well could represent a composite head from some combination of several water-bearing fractures (representing several **potentiometric surfaces**).

Second, the mere presence of bedrock wells alters the physical and chemical dynamics of the hydrogeologic system. Open boreholes can cause **borehole short circuits** within the hydrogeologic system by interconnecting fractures (with differing heads) that would otherwise have little or no hydraulic connection. These interconnections cause flow within the boreholes that tends to locally accelerate the natural ground-water flow tendencies, which include downward flow in hillside areas and upward flow in valley-bottom areas. Head differences (and flow) between fractures also can be developed artificially through pumping.

Well yields in the study area indicate that the most permeable, productive bedrock fractures are beneath the larger valleys and their adjacent, low hillside areas. Water-level and borehole-geophysical data indicate that the bedrock aquifer system is typically confined vertically at several levels and confined laterally within finite hydraulic zones or "compartments."

Well Yields. Reported yield-data from about 180 production wells and domestic wells that tap bedrock within the study area indicate that valley and low hillside areas are the most productive, and that hilltops and upper hillside areas are least productive (pl. 1; Appendix A). This general relation has been reported in other areas within the Appalachian Plateau (Taylor and others, 1983; Williams and Eckhardt, 1987, among others) and in a variety of other geologic terranes (Hanson and Simcox, 1994; Daniel, 1987). The well-yield differences between these topographic settings in the study area are related to the degree of bedrock saturation and the areal extent (water-storage capability) of permeable, well-defined bedding-plane fractures (fig. 26). Fracture frequency and, thus, well yields, are greatest in the near-surface fracture zone beneath the Batavia Kill valley, where the fractures are fully saturated, because the water table exists within the overlying unconsolidated deposits. In contrast, the low yields of hillside and hilltop wells reflect, in part, a lower degree of fracture saturation brought about by relatively rapid gravity drainage of recharge toward the local valley through relatively narrow (low water-storage capability), but permeable near-surface fracture zones in the hillsides. The decrease in number of bedding-plane fractures with depth in hillside areas also constrains well yield. Some of the larger upland areas of low relief, such as that between Bump Mountain and Mitchell Hollow (pl. 1), may provide year-round storage in saturated fractures and, therefore, provide higher yields than sloped areas.

Maximum *reported* bedrock yields along the main valley and the major tributary valleys (fig. 7) are as follows: Batavia Kill valley (320 gal/min), Mitchell Hollow-Mad Brook (153 gal/min), the valley of tributary A (100 gal/min), and the valley of tributary B (25 gal/min). The relatively low reported yield associated with the valley of tributary B probably reflects the small number of wells in the area. The maximum reported yield among a small number of hilltop and upper hillside wells is 4 gal/min.

The poor yields of some wells within otherwise productive areas reflects the discontinuous nature of fractures; open, water-bearing areas of a fracture plane are interspersed among closed areas that support the overlying rock. Thus, if a wellbore misses the open area of a productive fracture plane, the resulting well yield may be small.

Reported yields can be significantly higher than long-term sustainable yields, and sustainable yields can, in turn, be reduced by pumpage interference from other wells. Also, yield estimates can be rendered meaningless where wells tap fractures with unpotable water. Despite reported bedrock-well yields as high as 320 gal/min in the study area, the maximum documented sustainable yield to date (1996) is 100 gal/min. Well yields are maximized where the bedrock aquifer is hydraulically connected to additional ground-water sources, such as permeable, saturated unconsolidated valley-fill deposits, streams, or shallow, fractured bedrock zones in the hillsides. Wells in which one of several water-bearing fractures is in hydraulic connection with a fracture tapped by a production well may develop borehole short circuits such that the other water-bearing fractures contribute water to the production well.

Hydraulic Interconnection of Wells. Ground-water levels at about 60 bedrock wells were measured weekly or continuously for varying time intervals from October 1990 through November 1992. Hydrographs from nearly all wells were characterized by relatively abrupt water-level fluctuations associated with the initiation or cessation of withdrawals at another well (or wells); these responses indicate that the wells are hydraulically interconnected.

Although mapping water-level altitudes from bedrock wells is of limited use, as explained above, plotting relative changes through time can help identify similarities or differences among wells in response to ground-water withdrawals. As water-level data were collected and plotted during this study, wells with similar hydrographs were grouped, and the hydrograph responses of each group were found to correlate with pumpage from bedrock production well(s) within the Batavia Kill valley. Each group represents a different three-dimensional space (hydraulic zone) within the bedrock aquifer system. Water-level hydrographs indicated four hydraulic zones (western, central, west-central, and eastern), each represented by about 10 wells, and several other hydraulic zones represented by fewer wells (not shown). Each hydraulic zone is defined by the water-level response to a specific level of pumping stress at a specific well (or wells) (figs. 27, 28). The response in a given hydraulic zone may change substantially with changes in withdrawal rate, or in the particular well (1) used (water-bearing fractures intersected) for withdrawal. In addition, the boundaries indicated for each zone denote a *minimum* areal extent, as defined by the available wells. The vertical extent of

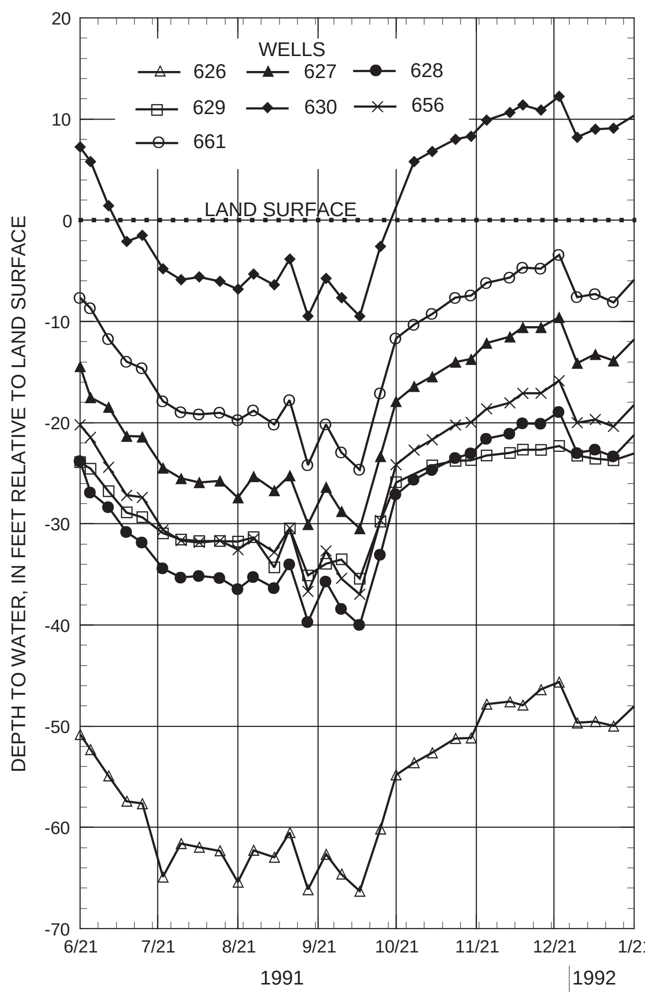


Figure 27. Water levels measured in bedrock wells in the eastern hydraulic zone, Batavia Kill valley, June 21, 1991 through January 21, 1992. (Well locations are shown in fig. 30 and pl. 1.)

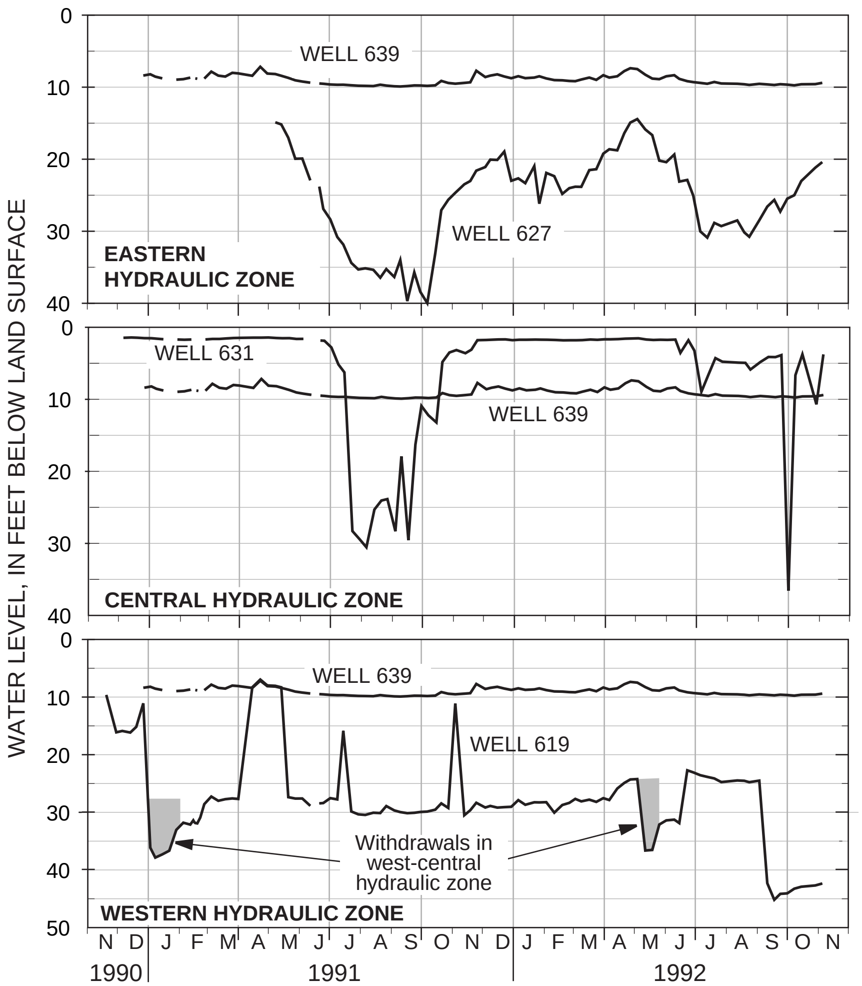


Figure 28. Water levels in bedrock wells that are representative of the eastern, central, and western hydraulic zones, and at bedrock well 639, which approximates natural (nonpumping) conditions (November 1990 to November 1992). Hydrograph for west-central hydraulic zone is omitted; hydrograph for the western hydraulic zone includes effects of pumping in the west-central zone. (Well locations are shown in fig. 30 and pl. 1.)

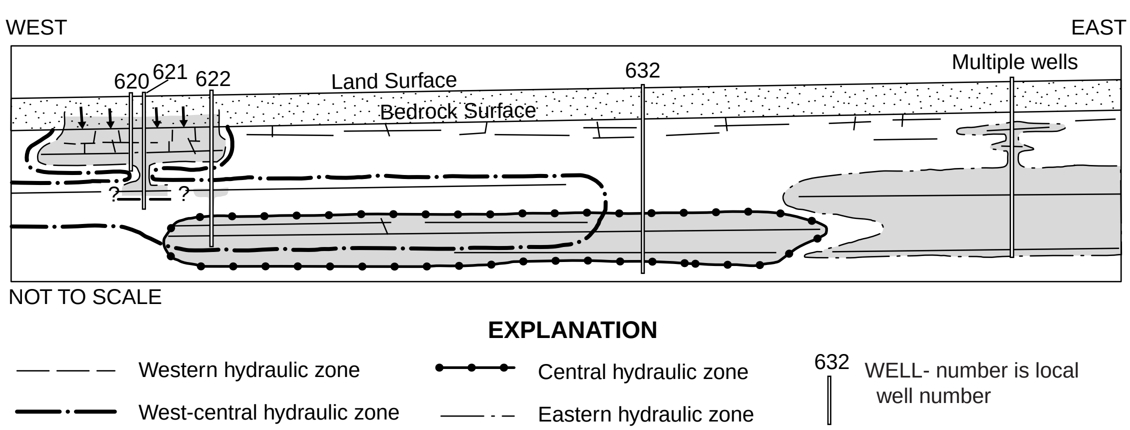


Figure 29. Conceptualized vertical section along the Batavia Kill valley showing approximate extent of the four hydraulic zones.

each zone is limited to the depth(s) of specific fractures or fractured intervals, not the full thickness of the bedrock aquifer system (fig. 29). The four hydraulic zones are described in detail as follows:

Western Hydraulic Zone: The western hydraulic zone (figs. 29, 30) is the shallowest and smallest of the four and is defined by water-level responses to withdrawals from the ski area's production well (620, pl. 1, Appendix A), which is 100 ft deep and open to the upper 65 ft of bedrock. The maximum radial distance from the production well to a well with which it is hydraulically interconnected is about 1,400 ft. The production well was pumped nearly continuously during the period of record (1991-92) except for an interval during April-May 1991 and for occasional maintenance and repairs (fig. 28). Pumpage was 75 to 80 gal/min until September 1992, after which it was increased to about 100 gal/min. The 100-gal/min rate represents the highest documented sustained yield from a bedrock well in the study area to date (1996). Relatively rapid stabilization of water levels in response to pumping (within about 16 hours at the 75- to 80-gal/min rate) at a nearby bedrock well (619; fig. 30, pl. 1) at both rates appears to indicate an adequate water supply with respect to the present level of withdrawal.

The large yield and small size of the western hydraulic zone is due to induced recharge from the overlying stratified-drift aquifer (fig. 29). Hydraulic connection with the overlying stratified-drift deposits in this area was indicated by the response at well 618 (about 75 ft from the production well) to withdrawals at the production well. Well 618 is completed a few feet above the bedrock surface in material described in a driller's log as "sand and clay." The lack of a water-level response in a shallow well point (well 780; pl. 1) adjacent to well 618 to withdrawals at the production well indicates that ground water in the deepest stratified drift and shallow bedrock is at least locally confined.

Withdrawals at the production well caused variable water-level responses (0.5 to 19 ft) in eight wells in the western hydraulic zone. Drawdown generally decreased with increasing distance from the production well, partly as a result of induced recharge to shallow bedrock fractures from the overlying, unconsolidated deposits. The magnitudes of water-level response at wells also were strongly related to the

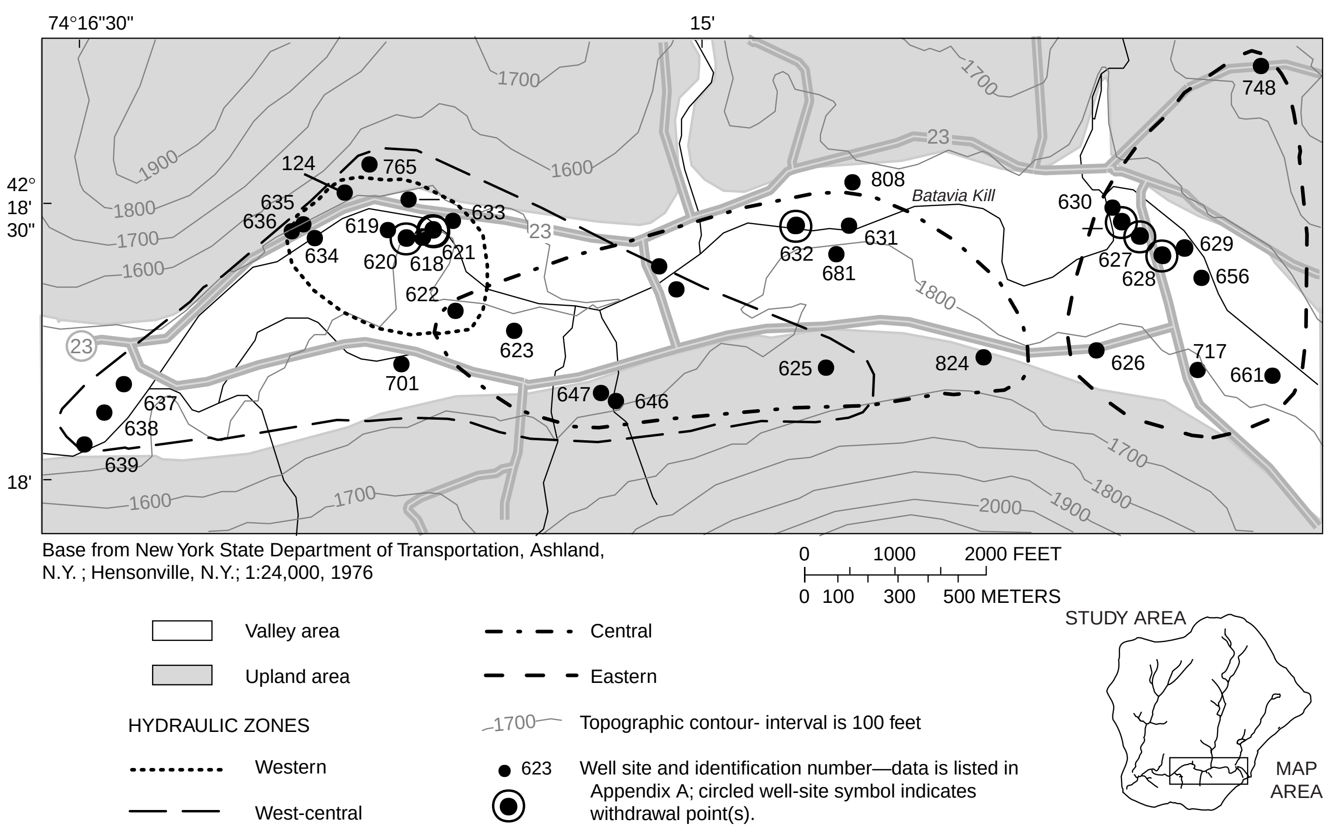


Figure 30. Minimum areal extent of four hydraulic zones in bedrock defined by water-level responses to ground-water withdrawals.

productivity of the fractures intersected (the well yield). For example, well 622, which intersects shallow and deep productive fractures and has a reported yield of about 200 gal/min, showed the smallest response to pumping at the production well, probably because of a high fracture permeability and hydraulic connection with the overlying saturated unconsolidated material, not because this well is farthest from the production well or has the smallest degree of hydraulic interconnection with it.

Central Hydraulic Zone: The central hydraulic zone (fig. 29, 30) consists of a deeper, more confined and areally extensive network of fractures than the western hydraulic zone. The maximum distance from the production well to a well hydraulically interconnected with it is about 3,700 ft, and the area is elongated downvalley from the point of withdrawal. The area is defined by the water-level responses to withdrawals at the village of Windham's backup production well (632), which is a flowing artesian well. This well is 280 ft deep and has an open-borehole interval of about 225 ft. Borehole-geophysical data (Heisig and Knutson, 1997) from a nearby well (631) in hydraulic connection with the production well indicate that the most productive fractures are at least 180 ft below land surface. Withdrawals from this well were sporadic during the period of record, but most frequent during summer dry periods (fig. 28). The pumping rate was typically 55 or 75 gal/min, and pumpage was generally limited to night-time hours. A 48-hour aquifer test and, later, a month of continuous pumping (George Mulford, Town of Windham Water Superintendent, oral commun., 1994) indicated that the 75-gal/min rate was not sustainable.

One reason for the withdrawal limitations and large areal extent of this hydraulic zone appears to be the poor or locally absent hydraulic connection with shallow bedrock fractures or overlying stratified-drift deposits. The lack of cascading water in the production well when the water level was drawn down about 45 ft below the bedrock surface suggests that the well does not intersect any shallow productive fractures. In addition, the water level in a 100-ft-deep bedrock well (808; fig. 30, pl. 1) about 900 ft from the production well did not respond to withdrawals. No hydraulic connection between the bedrock production zone and overlying stratified drift was evident from water-level records from well 238, which taps stratified drift about 30 ft below land surface, 200 ft from the production well.

Water-level responses to 19 hours of withdrawal at 55 gal/min ranged from about 0.8 ft to 57 ft at 10 bedrock wells. Six of the 10 wells are at least 1,600 ft from the production well. Specific responses of water levels at the wells during a 48-hour test are described in the following section.

The central hydraulic zone is asymmetrical relative to the withdrawal point (well 632) (fig. 30). Responses were recorded most frequently at wells downvalley from the pumping well and near the south side of the valley. Upvalley (eastward) hydraulic interconnection was detected at only three wells. The lack of interconnection between the production well (approximated by well 631) and well 630 (eastern hydraulic zone) limits the upvalley extent of this zone. Comparison of the vertical position of water-bearing fracture intersections in the two wellbores with the geologic framework (fig. 24A, section A-A') indicates that the fractures are vertically separated by fine-grained units and that such units are more prevalent at well 631 than at well 630.

West-central Hydraulic Zone: The west-central hydraulic zone (fig. 29, 30) is the largest hydraulic zone identified. It was defined by a period of continuous withdrawal (May 5-21, 1992) of about 80 gal/min from an otherwise unused backup production well (621) at the ski area. This period of withdrawal is indicated in the western hydraulic zone hydrograph in fig. 28. The maximum distance to an interconnected well is 4,700 ft. The area encompasses a valley section about 8,000-ft (1.5 mi) long that is symmetrical with respect to the production well (621, fig. 30). The largest water-level responses (up to 71.5 ft of drawdown) in this hydraulic zone were measured within about 1,500 ft of well 621. Responses at more distant wells did not exceed 3 ft.

The west-central zone differs from the three other hydraulic zones in that the wells that define it include most or all wells used to identify the western and central hydraulic zones. The production well (621) is only 48 ft deeper than the production well (620) associated with the western hydraulic zone and only 140 ft distant from it, yet the horizontal and vertical extents of the zones (and sources of water) are very different. Recognition of the potential for such variability in areas affected by ground-water withdrawals is critical in evaluating the area of influence for water-supply wells in this region.

The production well (621) is 148-ft deep and is open to bedrock from 41 ft below land surface (about

5 ft below bedrock surface) to the bottom of the well. The reported yield of the well is about 100 gal/min; water-bearing fractures were reported at about 70 ft (1 gal/min) and 114 ft (100 gal/min) below land surface. Subsequent borehole-geophysical logging indicated water-bearing fractures at 77, 100, 120, and about 130 ft below land surface (Heisig and Knutson, 1997).

The overlap of the west-central hydraulic zone with the western and central hydraulic zones indicates that well 621 intersects both the shallow and deep fracture intervals associated with the western and central zones, respectively (fig. 29). The large size of this hydraulic zone, and the hydraulic interconnection between well 621 and wells associated with the central hydraulic zone, indicates that most water withdrawn from well 621 is derived from the deepest of the confined, productive fractures intersected by the wellbore. These fractures are similar to, if not the same as, those tapped in the central hydraulic zone; the lack of a strong response at the withdrawal point in the central hydraulic zone (well 632) to withdrawals of well 621 suggests an indirect connection. The intersection of shallow fractures of low productivity by well 621 suggests limited hydraulic interconnection with, and thus, water available from, the productive shallow fractures and unconsolidated deposits associated with the western hydraulic zone.

Eastern Hydraulic Zone: The eastern hydraulic zone differs from the previously described areas in that (1) the defining ground-water withdrawals are from at least three wells rather than a single production well, and (2) nearly half of the area seems to extend beneath a hillslope. Withdrawals are seasonal and are greatest from May through October; this produces a downward exaggeration of the hydrograph (relative to unstressed conditions) during this period (fig. 28). The uniformity of drawdown timing and magnitude among wells within this zone suggests confined conditions and strong hydraulic interconnection among wells within a dominant fracture zone. Most withdrawals are concentrated within the northern half of the valley (fig. 30); the greatest radial distance from a production well to a hydraulically connected well in this area is about 2,100 ft. The most distant well that seems to be affected is unique in that it is on a hillside about 200 ft above the valley floor.

The uniformity of water-level responses among the wells suggests a lack of appreciable hydraulic connection with overlying valley-fill deposits. The suitability of the unconsolidated materials as an additional source of water to the wells in this hydraulic zone is unknown because no descriptions of unconsolidated deposits are included in well logs from this area. Silty fluvial gravel underlain by till upvalley and by thicker deposits of stratified drift downvalley have been described (fig. 22C). No known wells tap the unconsolidated deposits in this hydraulic zone.

The consistent response (in timing and magnitude) of water levels in wells across the eastern zone suggests confined conditions, similar to those in the central hydraulic zone (fig. 29). The known production zone(s) at well 627 (a flowing artesian well) are within 150 to 250 ft of land surface (90 to 190 ft below the bedrock surface). Reported yields of the nine affected wells range from 10 to 200 gal/min.

An important aspect of this hydraulic zone is the apparent hydraulic interconnection with well 748, about 200 ft above and 1,600 ft from the valley floor (fig. 30), as indicated by hydrographs of weekly water-level measurements during the summer, 1992, when the water levels reflected the effects of withdrawals. Well 748 is 655 ft deep— deep enough to intersect the productive fractures within the valley; its intersection of these fractures also is suggested by the similarity of ground-water-level altitudes here to those wells in the valley. This is noteworthy because published descriptions of valley-stress-relief fractures largely limit open bedding-plane fractures to the area beneath the valley floor (Ferguson, 1967, 1974; Wyrick and Borchers, 1981). Apparently, the rock mass over the lower hillsides (200 ft of relief) is insufficient to close all bedding-plane fractures extending from the valley. The reported yield of well 748 (19 gal/min) is lower than that of most wells within this hydraulic zone, and is consistent with decreased permeability in hillside areas. If an inverse relation between thickness of the overlying rock mass and the extent of open bedding-plane fractures is important within hillside areas, fractures might extend farther into hillsides on the north side of the Batavia Kill valley (such as identified at well 748) than on the south side because the local relief and, thus, the thickness of overlying rock mass is less.

Aquifer Test in Central Hydraulic Zone. A 48-hour aquifer test was conducted in the central hydraulic zone to examine the timing, magnitude, and trends of water-level responses under a controlled stress condition. This hydraulic zone was chosen because it had the largest number of unused wells for observation and because the production well (632) was used only sporadically and, therefore, provided stable, non-stress

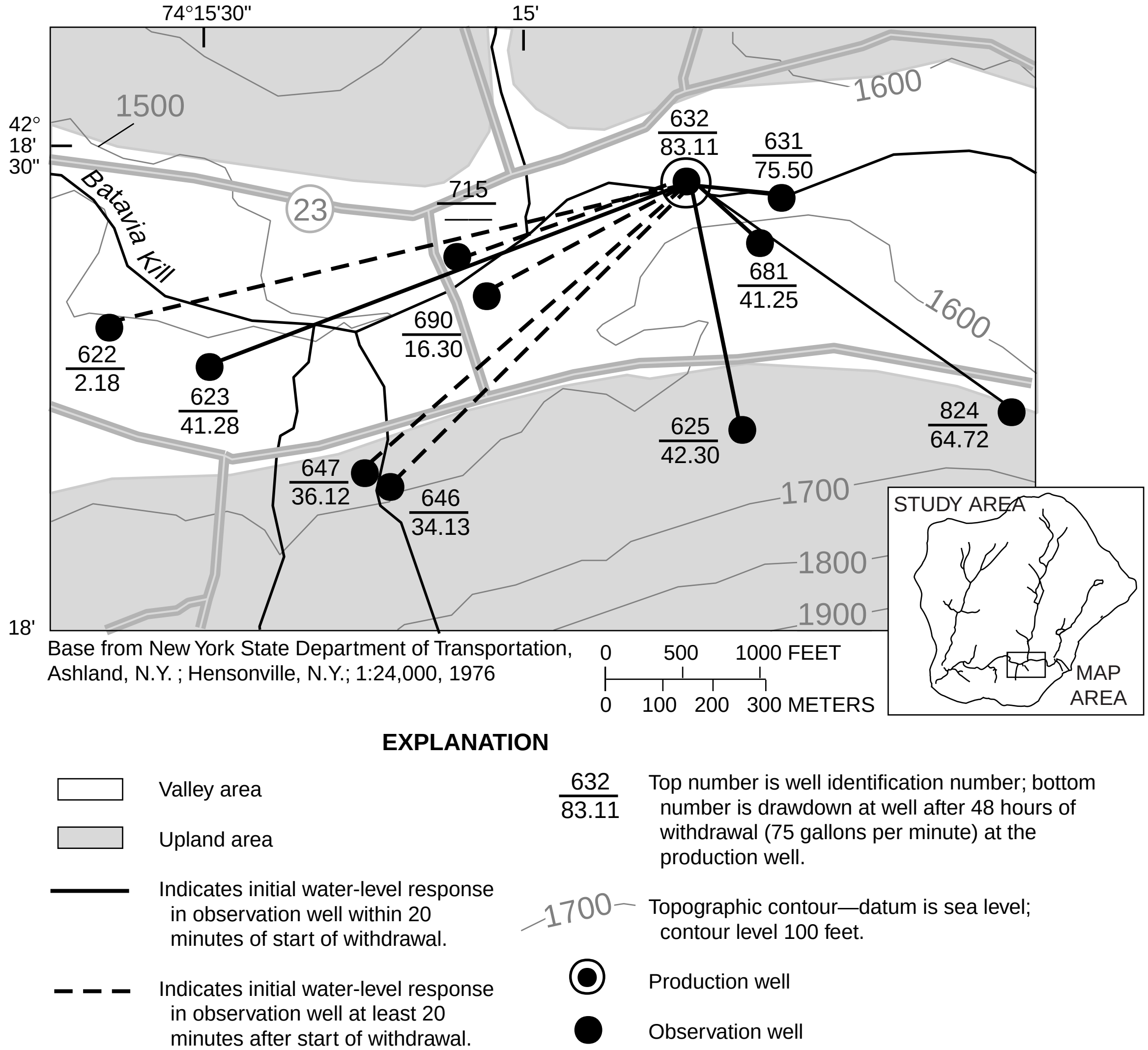


Figure 31. Locations and water-level response data of wells affected by the 48-hour aquifer test at well 632 in the central hydraulic zone of the Batavia Kill valley at Windham, N.Y.

conditions before and after the test. The test was run from June 30, 1992 to July 2, 1992. The withdrawal rate was 75 gal/min and water levels were measured at 10 observation wells (fig. 31). Water levels were measured manually at wells containing pumps, and by continuous water-level recorders at open wells. No precipitation fell during the test, although 0.37 in. of precipitation was recorded nearby at East Windham 3 days before the test (Todd West, New York City Department of Environmental Protection, written commun., 1992). The drawdown data were not analyzed with analytical curve-matching techniques because (1) the production well was turned on for a brief period (without full recovery after cessation) before the test, and because (2) the proximity of hydraulic boundaries, such as valley walls, limits the interval over which the technique is valid. Therefore, emphasis was on the magnitude of water-level response after 48 hours, the timing of initial water-level responses, and drawdown trends relative to that in the production well throughout the 48-hr test.

Magnitude of water-level response.— Drawdowns at observation wells after 48 hours of withdrawal ranged from 83.1 ft at the production well to 2.2 ft at well 622 (table 9). Four factors appear to be associated with the wide disparity among water-level responses in the observation wells; these include:

- wellbore intersection of productive fractures (typically in shallow bedrock) in addition to those most directly affected by the withdrawals
- degree of hydraulic interconnection with the production well
- distance between observation well and withdrawal point
- reported well yield (permeability of fractures intersected by observation wells).

The response at most wells presumably reflects some combination of these factors.

The two wells (622, 690) that are known to intersect productive, shallow fractures as well as the deep fractures that are most directly affected by production-well withdrawals showed a relatively small response (table 9); this is attributed to the inflow of water from the shallow fracture(s) with subsequent downward borehole flow, which presumably moderates the observed water-level response. These wells have relatively high reported yields (200 and 60 gal/min).

Well 715, which was measured during other periods of pumping at the production well (but not during the test), showed only a small water-level response that is attributed to an indirect hydraulic interconnection (through well 690) with the production well. This well is 73 ft deep and taps the upper few feet of bedrock and, thus, has no direct hydraulic connection with fractures tapped by the production well. The homeowner reported a decrease in the quality of water from this well water since well 690 (352 ft deep and about 200 ft away, fig. 31) was drilled; this suggests interconnection through shallow bedrock fractures. As well 690 responds to pumping at well 632, well 715 is indirectly hydraulically interconnected with the production well through a borehole short circuit between shallow and deep fractures at well 690.

Distance between the observation well and the production well can affect well response in a predictable idealized manner or in a less predictable manner. For example, if two observation wells intersect the producing zone at differing distances downvalley from the production well, and the source of water to the production zone is beyond the distant well, a gradient toward the withdrawal point must be maintained within the production zone, and the closer well will show a larger response to the withdrawal. However, the presence of an additional source of water to the production zone, near the closer well, such as from vertical fractures or a well with a borehole short circuit, can lessen the drawdown at the closer well relative to the distant well. Alternatively, if the production zone is localized and receives little water from other fracture zones, the water-level declines may be similar across the hydraulic zone and negate or diminish the effect of distance on drawdown relative to the production well. An example is well 824, which is about 2,500 ft from production well 632, has a low reported

Table 9. Observation-well characteristics and response to withdrawals during a 48-hour aquifer test at production well 632 in the Batavia Kill study area, Greene County, N.Y. (June 30 to July 2, 1992)

[Well locations are shown in fig. 31; gal/min, gallons per minute; dash indicates no data; <, less than.]

Well number	Distance from production well (632) (feet	Measured or extrapolated initial response time after start of pumping (minutes)	Drawdown after 48 hours (feet)	Reported yield (gal/min)
824	2,500	< 10	64.7	1.5
646	2,750	30 - 50	34.1	—
647	2,800	20 - 40	36.1	< 4 (100)[a]
622	3,700	20 - 40	2.2	200+
623	3,100	7	41.3	100
631	600	< 1	75.5	100
690	1,500	25	16.3	60
715	1,500	25+[b]	—	20
632	0	—	83.1	75
681	550	18	41.3	—
625[c]	1,600	< 10	42.3	320

[a] Lower 25 feet of well 647 was partially sealed, as described in text. Driller’s initial reported yield was 100 gal/min; present yield is less than 4 gal/min.

[b] Well 715 was not measured during test, but previous measurements during pumping periods indicate hydraulic connection through well 690, as described in text. Initial response time is probably similar to, or slightly longer than, at well 690, but magnitude of drawdown is less.

[c] Water-level response at well 625 was measured before and at end of test; measurements during previous stress periods indicate strong hydraulic connection with well 623 and nearly identical response to withdrawals at production well. Therefore, the initial response time is assumed to be similar to that of well 623.

yield, and is hydraulically connected to the producing fractures of well 632. This well had one of the largest responses to the aquifer test (table 9) and, therefore, probably does not intersect any other important water-bearing fractures that could moderate water-level declines.

Timing of water-level response.—The timing of initial water-level responses to pumping are related to (1) the permeability of fractures between each observation well and the production well and (2) the length of the flowpaths between them. The measured (or extrapolated) initial response times among observation wells (table 9) range from instantaneous at the production well to as much as 30 to 50 minutes at well 646. Wells with the most rapid response times (631, 623, 625, and 824) probably intersect the deep, confined fractures tapped by the production well. These relatively rapid responses over the large distances (1,600 to 3,100 ft) between the production well and three of these four wells (table 9; fig. 31) indicate that the water in these deep fractures is confined.

Wells with slower response times (681, 647, 646, 622, 690, 715) may be indirectly connected to the confined fractures tapped by well 632 through (1) poorly permeable fractures, (2) long, indirect flowpaths through the fracture network, or (3) a borehole short circuit that taps a highly permeable fracture that largely controls the water level in the well and delays a measurable change, or, most likely, (4) some combination of the above. For example, observation well 681 is closest to the production well, yet did not respond until 18 minutes after pumping started. The open interval the two wells have in common encompasses the lowermost 93 ft in well 681 and the uppermost 93 ft of the production well (which intersects few, if any, water-bearing fractures). Thus, it appears that the fracture interconnection between the production well and well 681 is indirect, yet significant (fig. 31); perhaps the fractures tapped by the production well are connected with shallower low-angle fracture horizons intersected by well 681 through high-angle fractures near the valley walls.

The slow responses at wells 622 and 690 may reflect the presence of productive shallow fractures (discussed in the central hydraulic zone section) in addition to the deeper fractures, which are directly affected by withdrawals at the production well. In wells where shallow fracture(s) are the dominant control on the head in the well, small head changes in deeper fractures may not be readily discernible. For example, pumping well 622 at 30 gal/min from a depth between the shallow and deep water-bearing fractures indicated, through fluid-conductivity differences between the fracture intervals, that about 86 percent (5/6) of pumped water was from the shallow fracture, and 14 percent (1/6) was from the deeper fractures. If head changes in the deep fractures account for only 1/6 of the composite head might be delayed until the head change associated with the deeper fractures is about six times the minimum measurable head change.

Drawdown trends relative to that at the production well.—Comparison of observation-well and production-well drawdown responses was facilitated by plotting production well drawdown data against itself and that of each observation well for the test period (fig. 32). Production-well drawdown data forms a reference trend line from which similarities and departures of near-linear segments of observation well responses can be identified over time. Water-level trend lines for most wells became approximately linear after 16 hours of pumping (fig. 32). Water levels at wells 631 and 824 approached linear trends most rapidly—in about 8 and 250 minutes, respectively, and also declined the most; the rapid stabilization of water-level trends at these wells is probably due to a direct hydraulic connection with fractures tapped by the production well, and a lack of other water-bearing fracture intersections in their wellbores.

A linear or near-linear drawdown trend-line segment that parallels the reference line (wells 631, 623, 625, 646, 647; fig. 33) indicates an essentially direct (1 to 1) correspondence with water-level changes at the production well and few or no other intersections with water-bearing fractures within the wellbore, apart from the interval affected by production-well withdrawals. Such wells appear to approximate piezometers and, together, indicate a hydraulic zone of limited water potential that is being steadily depleted over a wide area (fig. 30, 31).

A drawdown trend line that is steeper than the reference line (well 824; fig. 32) is indicative of an additional withdrawal, which in this instance is domestic water use. The early initial response and apparent stabilization of the drawdown trend at this well suggest that the trend would be essentially parallel to that of the production well if the additional stress were absent.

Drawdown trend lines that are less steep than the reference line (wells 622, 690, 681; fig. 32) are indicative of wellbores that intersect significant water-bearing fractures in addition to those directly affected by

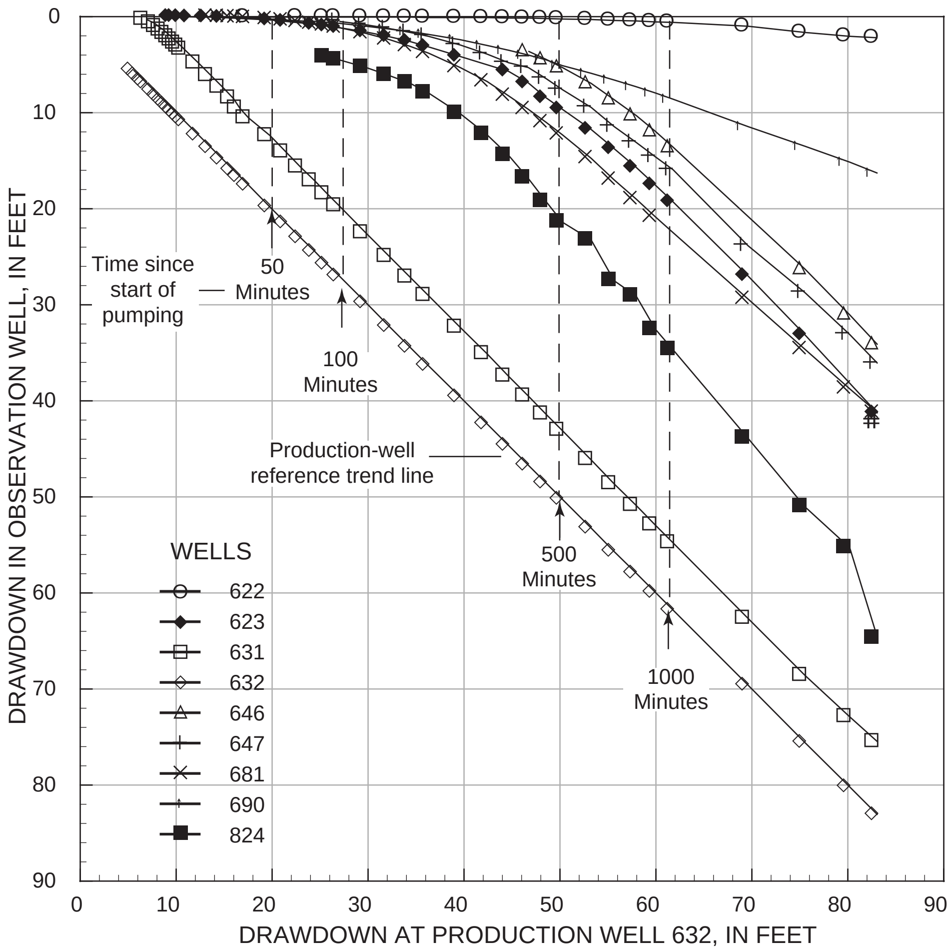


Figure 32. Drawdowns in observation wells as a function of drawdown in the production well during 48-hour aquifer test in central hydraulic zone of Batavia Kill study area, Greene County, N.Y. (Well locations are shown in fig. 31.)

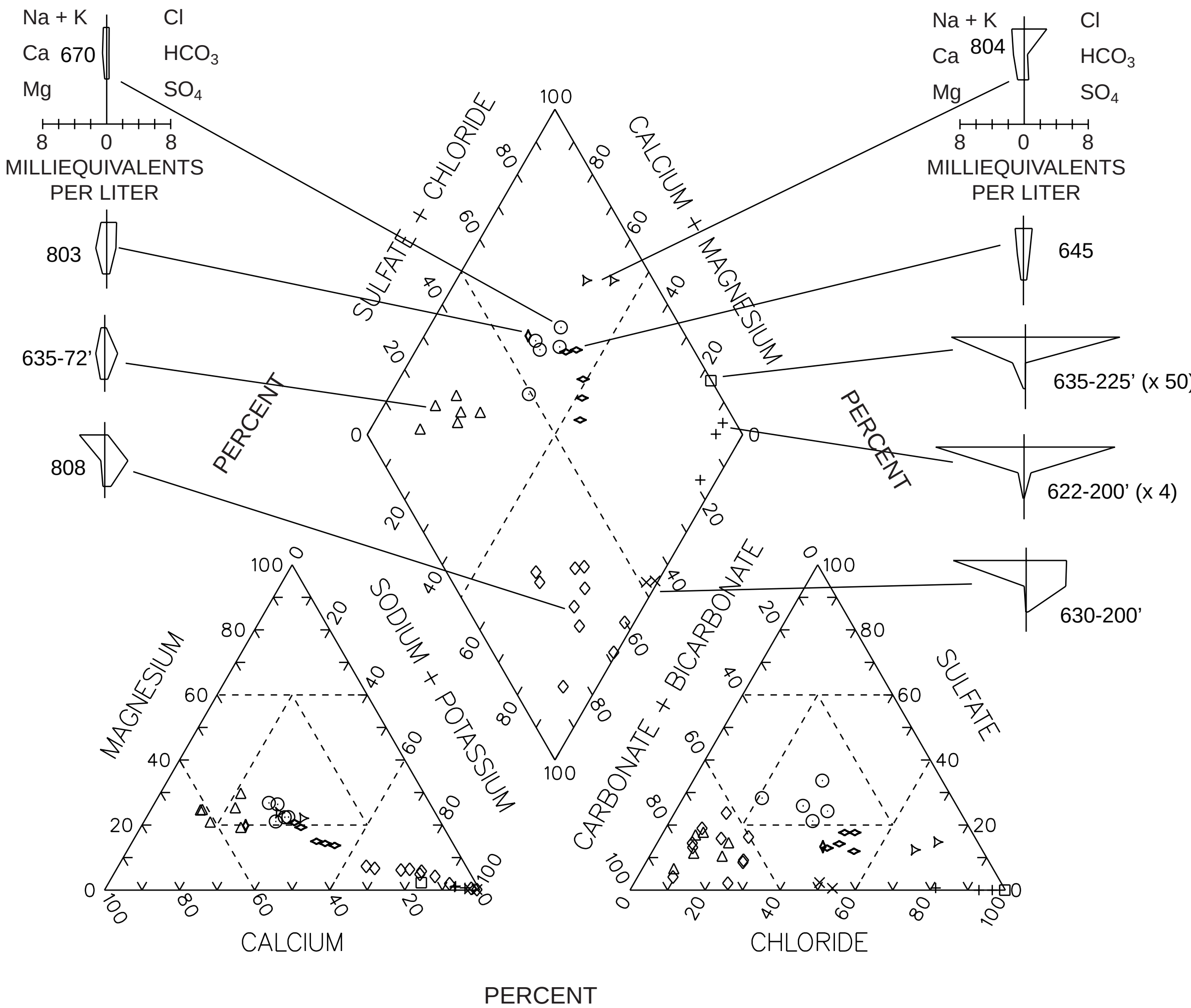
production-well withdrawals. Such fractures provide additional water that damps the water-level response to production-well withdrawals. The departure from the slope of the reference line presumably is positively correlated with the productivity of the additional fractures (fig. 32) and indicates recharge from the shallow fractured bedrock to the deeper pumped fracture zone through the boreholes (borehole short circuits).

Geochemistry of Natural Ground Waters

Chemical analyses of ground-water samples show wide variations in chemistry within and near the Batavia Kill valley at Windham. Specific conductance ranges from about 50 µS/cm in shallow bedrock fractures intersected by hillside wells 767 and 799 to about 34,000 µS/cm for saline water at well 635 within the Batavia Kill valley.

Interpretation of ground-water chemistry in the study area was based on analyses of 45 samples collected from springs and wells completed in unconsolidated deposits and bedrock. Sample collection from most bedrock wells was guided by changes in specific conductance shown in fluid-conductivity logs (Heisig and Knutson, 1997). Variations in specific conductance and, therefore, chemistry, are common within wells that intersect more than one productive fracture (Heisig and Knutson, 1997). Samples were collected within intervals of constant specific conductance with a downhole (point) sampler in wells where wellbore variations were evident; samples from shallow bedrock wells and wellbores with little variation in specific conductance were obtained with either a submersible pump or a downhole sampler.

All samples were analyzed for major ions, nutrients, and physical properties; selected samples were analyzed for tritium and(or) trace metals. Bicarbonate



EXPLANATION

WATER TYPES

Naturally occurring:

- ⊙ Mixed ion
- △ Ca-HCO_3
- ◇ Na-HCO_3
- × Na-HCO_3/Cl
- + Na-Cl
- □ Very saline (Na-Cl)

Dilute human-affected:

- Ca-Cl/HCO_3
- Na-Cl
- ▷ Na/Ca-Cl

STIFF DIAGRAM LABELS

635-225’ (x 50)

Well or spring number (pl. 1, Appendix A)

Sampling depth, in feet below land surface, if grab sample was collected

Multiplication factor indicates number of times the 8 milliequivalent scale must be multiplied (and the Stiff diagram expanded horizontally) to accurately portray the sample

Figure 33. Trilinear diagram and stiff diagrams showing major-ion composition and interpreted water-type designation of ground-water samples from springs and wells finished in bedrock or unconsolidated deposits in the Batavia Kill study area, Greene County, N.Y. (Wells locations are shown on pl. 1.)

and carbonate concentrations and calcite-saturation indices were estimated with WATEQF (Plummer and others, 1984). The chemical data were plotted on Stiff diagrams, a trilinear diagram, and on modified high-low charts. Stiff diagrams were used to group the samples into major-ion water types, which were further defined by physical properties, trace-element concentrations, and tritium content.

Samples are represented on a trilinear diagram in fig. 33, and the water types, as defined by Stiff diagrams, are indicated. Individual chemical analyses are listed, by water type, in Appendix B. Most of the groupings, and one intermediate-type sample, apparently represent incremental changes in the natural chemical evolution of ground water as it flows through the hydrogeologic system, and(or) the limited mixing of the evolved ground water with deeper, presumably stagnant, saline water. The remaining three groups of dilute ground water (either a singular occurrence or as many as five in a group, fig. 33) are enriched in chloride, an indicator of human influences on shallow ground-water chemistry (Appendix C). The dilute, chloride-enriched groups are discussed in a following section non-point source degradation.

Ground water moving along a hypothetical flowpath in the study area evolves from a dilute, mixed-ion type to calcium bicarbonate type in the shallow, active flow system, then eventually changes to sodium bicarbonate water in the deeper, slower, subregional or regional flow systems. The sodium bicarbonate waters may mix (at least partly through borehole short circuits) with relatively stagnant, saline waters at depth, which results in waters with of compositions intermediate between sodium bicarbonate and sodium chloride (figs. 34A,B, Appendix B).

The modified high-low charts of figure 34 depict changes in concentrations of selected constituents, ordered by water type, on the x-axis along the hypothetical flowpath and then along the trend of increased mixing with saline water. Highest and lowest concentrations were chosen over averages, medians, or other measures of a population because the number of samples representing a water of a given type is highly variable (from 1 to 12), and the full range of a constituent within any given type of water can reflect variations in redox or cation-exchange conditions that might not be indicated by such measures.

Two trends are apparent across the sequence of water types in the study area—an increase in specific conductance (implying an increase in total dissolved solids concentration) (fig. 34A) and a progression from oxidizing to reducing conditions (fig. 34B). The trend toward more reducing redox conditions is defined by the decreases in concentrations of dissolved oxygen, nitrite and nitrate, and sulfate, and increases in ammonium, hydrogen sulfide, and methane (fig. 34B). These trends reflect increasing residence time within the system accompanied by microbial activity and separation from the atmosphere.

Chemical Evolution Along Flowpaths

The water samples used in the interpretation of the chemical evolution of ground water, although not collected along a specific flowpath, indicate the range of conditions that occur along flowpaths in the study area. The water's major-ion evolution from a mixed-ion type to a calcium bicarbonate type then to a sodium bicarbonate type, is the result of calcite dissolution and cation exchange. Calcite is recognized as a replacement mineral in Catskill sandstones (Gale and Siever, 1986). Increases in calcium, pH, alkalinity, and calcite-saturation index, associated with dissolution of calcite in the development of calcium bicarbonate waters, are seen in figure 34, as are decreases in divalent cations (especially calcium) and an increase in sodium (through cation exchange), which result in the evolution of sodium bicarbonate waters.

The mixed-ion waters represent the shallowest ground water with the shortest residence times within the study area. All but one sample of this water type were from springs; the other was from a well completed in unconsolidated material. These are the most dilute ground waters because short contact times with the unsaturated zone provides little dissolved solids to infiltrating water. Most of the reactive minerals have been leached out through (1) the repeated flushing action of recharge from acidic precipitation (4.36 was the average pH of weekly precipitation samples from a site in the Catskills in 1984; Murdoch and Stoddard, 1992), and (2) the decomposition of organic matter within the soil zone. Thus, no single cation (fig. 34A) nor anion predominates the major-ion chemistry of this water, and the pH, alkalinity, and calcite-saturation index are the lowest of any water type (fig. 34B). Dissolved oxygen and oxidized nitrogen species concentrations are highest in this water type as a result of their short residence time within the ground-water system and proximity to the atmosphere. The concentration of boron, a trace element, is at or below its detection limit.

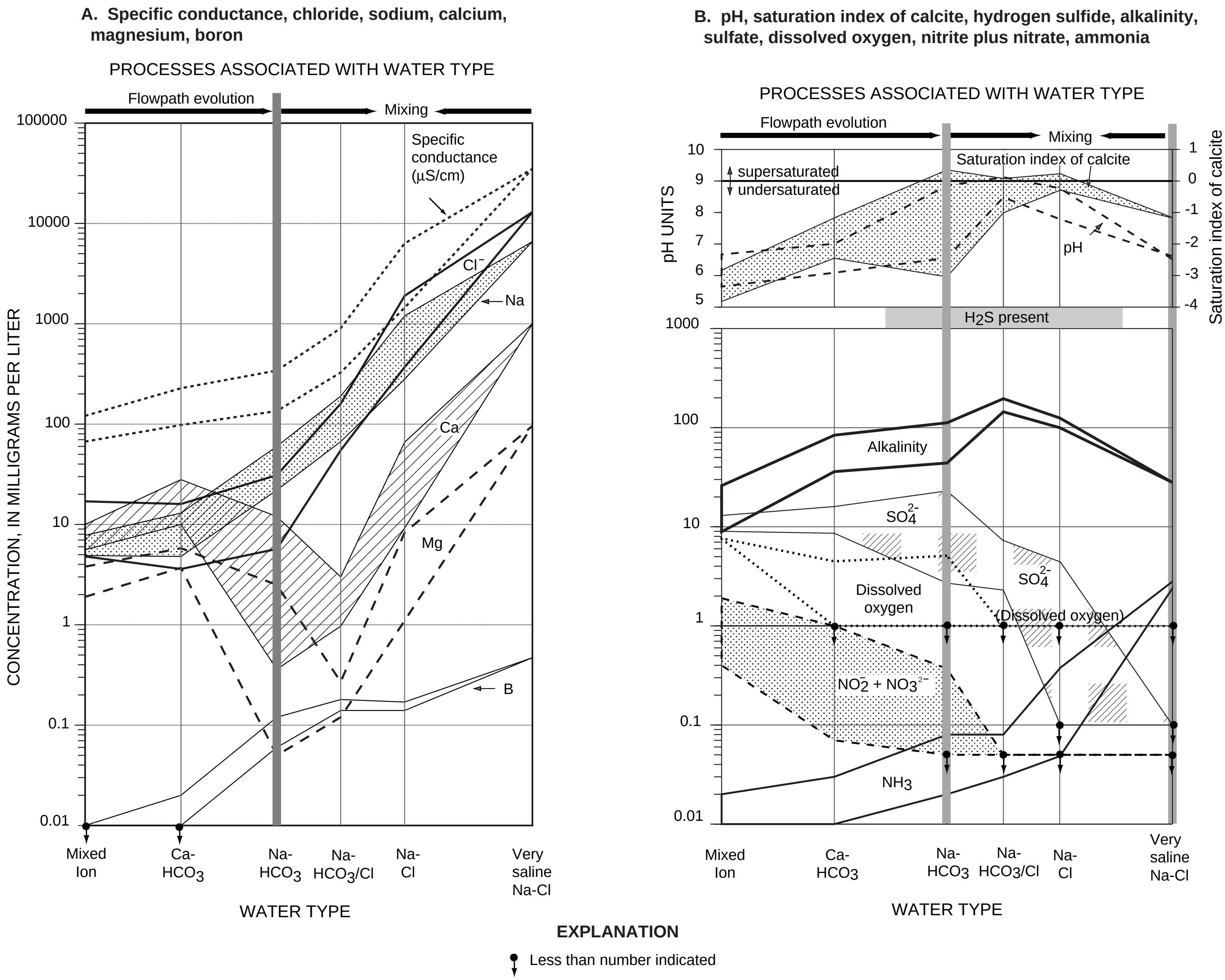


Figure 34. Modified high-low chart showing the range of selected physical property values and constituent concentrations along a hypothetical ground-water flowpath in the Batavia Kill valley at Windham, Greene County, N.Y.: A. Specific conductance, chloride, sodium, calcium, magnesium, and boron. B. Calcite saturation index, pH, hydrogen sulfide (presence of odor), alkalinity, sulfate, dissolved oxygen, nitrite plus nitrate, and ammonia.

Calcium bicarbonate waters evolve as acidic, mixed-ion water flows downgradient through aquifer material where calcite has not been completely leached and can act as a source of calcium and bicarbonate ions (alkalinity) through further dissolution (Back and others, 1993). This type of water is found in unconsolidated deposits and in shallow bedrock within the Batavia Kill valley. The observed increases in the upper limit of pH to neutrality, and decreases in the degree of calcite undersaturation, are consistent with the dissolution of calcite along a flowpath (fig. 34B). An increase in specific conductance suggests a general

Table 10. Interpretations of ground-water age or mixing based on tritium concentrations, Batavia Kill valley, Greene County, N.Y.(R. Michel, U.S. Geological Survey, oral commun., 1993)

[TU, tritium units; ≥, greater than or equal to; <, less than; ≤, less than or equal to.]

Concentration (TU)	Interpretation
≥ 15	≤10 years residence time or mixing of old (<15) and new (≥15) waters
3 - 15	mixture of old (<15 TU) and new (≥15 TU) waters
0.9 - 3	residence since mid-1950s or mixture of pre-1952 (<0.9 TU) and post-1952 (>0.9 TU) waters
<0.9	pre-1952 water

increase in residence time—tritium analyses of three samples of calcium bicarbonate water indicate residence times of less than 10 years (table 10 and Appendix B). Decreases in dissolved oxygen (below detection limit in two samples) and in nitrite plus nitrate as the water moves away from recharge areas suggest that aerobic and nitrogen-reducing respiration are occurring within some environments that contain this type of water, if sufficient organic carbon is available (Chapelle and others, 1993).

Calcium bicarbonate water evolves to sodium bicarbonate water as it flows downgradient into a deeper, slower part of the flow system that is not saturated with respect to calcium at cation-exchange sites (Back and others, 1993). All samples of this water were from bedrock wells. The wide range of several characteristics of sodium bicarbonate waters suggests that this phase of water evolution occurs fairly rapidly and that sodium bicarbonate water is a stable end member within the evolution sequence. The stability of this type of water is supported by its dominance in many stratified sedimentary sequences (Freeze and Cherry, 1979).

Variations in tritium concentrations and redox conditions indicate a wide range of residence times among sodium bicarbonate waters. Tritium concentrations in samples that are not affected by mixing suggest residence times ranging from less than 10 years to more than 45 years (pre-1952) (table 10 and Appendix B). The presence of measurable dissolved oxygen in a few samples suggests fairly rapid development of sodium bicarbonate waters in some areas. Progressively longer residence times (or more reactive flowpaths) are suggested by other water samples that:

- are depleted in dissolved oxygen
- are depleted in nitrate and nitrite and have elevated concentrations of ammonia relative to those in other samples of this water type
- contain hydrogen sulfide (fig. 34B).

Calcite-saturation indices vary widely; saturation was approached in two samples containing the oldest water, yet was exceeded in one recent (<10 years old) sample collected near the valley axis (Appendix B). The high pH and high alkalinity values associated with many samples of sodium bicarbonate water indicate that calcite dissolution continues to occur along the flowpath (unless saturation is reached), especially with the loss of some calcium through cation exchange.

Mixing with Saline Water

Several wells (635, 646, 647, 799) within the Batavia Kill valley contain *very saline water* as defined in Robinove and others (1958). The specific conductance of a water sample from the lower section of well 635 was about 34,000 μS/cm. Chemical analysis of the sample (Appendix B, well 635-225') indicates a highly reduced, sodium chloride water that is enriched in bromide, barium, strontium, iron, and boron. Dissolved oxygen, nitrate, and sulfate are below detection limits, and no hydrogen sulfide odor was detected. The presence of methane in this and the other wells mentioned above, as well as the weight ratios of sodium to chloride (0.50) and bromide to chloride (0.009), suggest derivation from oil- and gas-field brine (Richter and Kreitler, 1991).

The three wells within the Batavia Kill valley (635, 646, 647) intersect very saline water at maximum depths of 420 to 489 ft below land surface; minimum depths are unknown because flow within the boreholes obscures the source fractures. These waters are interpreted as **connate water** (naturally occurring) beneath the active flow system. The lack of detectable dissolved oxygen, nitrate, and sulfate, and the presence of ammonia, suggest that these constituents have been utilized by bacteria in the decomposition of organic matter. The presence of methane indicates that organic carbon (presumably in the source rocks) itself is being, or has been, used by bacteria in the decomposition of organic matter and indicates highly reducing conditions (Chapelle and others, 1993; Stumm and Morgan, 1981). The high dissolved iron concentration (4.3 mg/L) and the absence of hydrogen sulfide odor suggest that sulfide has been removed through precipitation of pyrite at some point in the evolution of this water. High concentrations of barium (73 mg/L) may be derived from cation-exchange sites in the presence of high concentrations of competing cations in saline waters or brines (Wunsch, 1993). These high concentrations are possible because of the lack of sulfate, which prevents precipitation of barite ($BaSO_4$) (Hem, 1985; Wunsch, 1993). The water would presumably be undersaturated with respect to barium carbonate because the solubility of this mineral is similar to that of calcite (Sillen and Martell, 1964), which is undersaturated (fig. 34B).

Although mixing of very saline sodium chloride water with sodium bicarbonate water may occur under natural flow conditions in bedrock, it appears to occur primarily through borehole short circuits within the study area. Three types of water identified through the Stiff diagrams appear to reflect mixing of the aforementioned waters—sodium bicarbonate/chloride water, sodium chloride/bicarbonate water, and sodium chloride water (Appendix B). Most sodium chloride/bicarbonate waters appear to represent mixing through borehole short circuits (Appendix B) and are not considered further in this discussion nor included in figure 34. The mixed sodium chloride water in well 647 and the very saline water in well 635 have similar bromide-to-chloride ratios (0.008 and 0.009, respectively), which indicates a similar source (bromide analyses were performed only on samples from these two wells; concentrations were 111 mg/L in well 635-225' and 14.3 mg/L in well 647-400').

Mass-balance calculations indicate that each of the mixed-water types is predominantly a sodium bicarbonate water by volume, but the small amounts of very saline sodium chloride water are sufficient to alter the major-ion proportions. Chloride, a conservative ion, was used in the mass-balance calculations. End-member chloride concentrations were 12 mg/L (the median) for sodium bicarbonate waters and 13,000 mg/L in sample 635-225' (Appendix B) for very saline sodium chloride water. Very saline sodium chloride water represents 0.4 to 1.1 percent of sodium bicarbonate/chloride waters and 3 to 15 percent of sodium chloride waters.

Apart from the increases in sodium and chloride, sodium bicarbonate/chloride waters are characterized by lower maximum calcium and magnesium concentrations, higher pH and alkalinity, and more highly reducing conditions than sodium bicarbonate waters (fig. 34). The decreases in the maximum calcium and magnesium concentrations suggest continued preferential cation exchange of these divalent cations. Increases in pH and alkalinity indicate continued dissolution of calcite where undersaturation occurs; the degree of undersaturation is less than that calculated for sodium bicarbonate waters. The absence of detectable dissolved oxygen and nitrite plus nitrate suggests depletion by bacterial decomposition of organic matter (fig. 34B). The decrease in the maximum and minimum sulfate concentrations and the presence of hydrogen sulfide indicate that bacterially mediated sulfate reduction is occurring. Last, boron concentrations continue an increasing trend from calcium and sodium bicarbonate waters (fig. 34A).

Sodium chloride waters represent the mixing of 3 to 15 percent of very saline sodium chloride water with sodium bicarbonate water. As a result, the major-ion composition of sodium chloride water is heavily influenced by very saline water composition. Sodium chloride waters have greater concentrations of chloride, ammonia, and all cations, and lower concentrations of sulfate, alkalinity, and pH than sodium bicarbonate/chloride waters (fig. 34). Boron concentration, the presence of hydrogen sulfide, and the calcite saturation index are similar between these two water types. Although pH and alkalinity show some decrease, calcite saturation indices indicate that two of the three samples are supersaturated with respect to calcite (fig. 34, Appendix B). Predicted supersaturation coincides with observation of a light-colored precipitate that may be calcite within the wellbore of well 622. The low sulfate concentrations (below detection limit in two out of three samples), and the continued presence of hydrogen sulfide, indicate that sulfate reduction is occurring in at least two of the sample sites.

Effects of Human Practices on Ground-water Quality

Contamination of ground water from most human practices appears to be limited to the shallow flow system within the unconsolidated deposits. Contaminant-retention times within the system vary with (1) distance between point of entry and the local discharge boundary (generally a streambed or spring) and (2) ground-water velocity, which, in permeable deposits under natural gradients, is on the order of feet per day. Ground-water contamination may be derived from discrete **point sources** or from diffuse **nonpoint sources**, and generally is unnoticed until water from a well is affected.

Point-source Degradation

Point sources can include septic leach fields, road-salt storage piles, solid-waste disposal sites, leaking underground fuel-storage tanks, and livestock feedlots. Plumes of ground water emanating from point sources are localized (restricted to a flowpath within the flow system downgradient from the source), and their concentrations of conservative (nonreactive) constituents are similar in magnitude to those in the source water but decrease with distance from the source through mixing and dispersion. Major point sources within the study area are discussed below.

Wastewater Disposal. Septic systems are the primary source of wastewater entering the shallow ground-water system in the study area. Wastewater from septic systems has elevated concentrations of dissolved organic carbon, nutrients, sodium, chloride, bacteria associated with human waste, and little or no dissolved oxygen. Wastewater from these systems is of particular concern because it is volumetrically the largest source of human-derived contaminants entering the hydrologic system, and the nutrients and organic carbon, which stimulate algal growth and microbial activity, can magnify its effect on surface-water quality to an extent far beyond those of the individual constituents.

The greatest threat posed by septic wastewater is the contamination of well water; the most likely violations are the presence of total and fecal coliform bacteria and exceedence of the New York State drinking-water standard for nitrate (10 mg/L as N). For example, a shallow ground-water sample collected immediately downgradient of a leach field (well 666, pl. 1, Appendix C) contained 11 mg/L as N of total dissolved nitrogen species. The New York State Department of Health requires minimum separation distances between septic systems and wells to protect well water. At present (1997), the minimum separation distance between septic systems and wells is 100 ft; however, if the well is downgradient of the septic system or if the septic system is in coarse gravel, a minimum separation distance of 200 ft is required (New York State Department of Health, 1990). In contrast, an investigation of ground-water transport of septic wastes in a sandy aquifer (Robertson and others, 1991) reported nitrate concentrations in excess of the drinking-water standard at least 425 ft downgradient of a leach field.

Most houses and commercial establishments in the study area have their own septic system. Those that do not (houses along the ski slopes and the ski center) are served by sewers that route wastewater to a treatment plant at the base of the slopes that subsequently discharges to a tributary of the Batavia Kill. Subsurface wastewater disposal from individual septic systems is most concentrated in the village of Windham. These septic sources discharge to the most potentially productive part of the stratified-drift aquifer—beneath the village.

Road-salt Storage. Four road-salt stockpiles (town, county, State, and the local ski area) are stored at three sites for winter use (pl. 1). The town and State supplies are stored at the same site. Rock salt (sodium chloride) is stored at all three sites, and solutions of calcium chloride are stored in tanks at two (town and county) sites. Stockpiles may consist of pure salt or, more commonly, a sand-and-salt mixture. Calcium chloride is sprayed onto the stockpiles or onto loaded salt-spreading trucks. Most of the stockpiles are uncovered, and supplies remaining at the end of the winter are left in place. The State supply is stored within a metal shed that has partly corroded away from contact with the salt. The stockpile of pure salt for the ski area is typically stored on a concrete pad and is usually covered.

Leaching from uncovered or partly covered road-salt stockpiles is rapid in humid climates because the salts are highly soluble. The leachate is characterized by elevated concentrations of sodium and chloride (Appendix C). The Federal drinking-water health guideline for sodium is 20 mg/L, and the secondary maximum contaminant level (SMCL) for chloride is

250 mg/L (U.S. Environmental Protection Agency, 1986).

The fate of road-salt leachate generated by rain or snowmelt is determined by local site conditions. Where the soil has poor permeability, leachate may pond at land surface and eventually evaporate or drain away from the storage site as surface runoff. Where the soil is permeable, leachate will infiltrate and eventually reach the water table. The storage sites are separated from either the Batavia Kill or Mad Brook by 150 ft to 1,300 ft of fields or woods. (pl. 1). Under natural flow conditions (gradients), concentrated leachate-affected ground waters are limited to small areas between the stockpiles and the streams; although these areas pose no immediate threat to present ground-water use, future water-resource development in these areas could be severely limited because pumping could alter the flow conditions and draw affected ground water to pumping wells.

Specific conductance and terrain-conductivity measurements were used to delineate or identify leachate-affected water and earth material. Data from the county and town/State stockpile sites, described below, provide some indication of the annual timing of leachate input to the water table and the vertical and lateral extent of leachate-affected ground water.

County Highway Yard. Water-level and specific-conductance measurements were obtained from two shallow observation wells (613, 614, pl. 1) at the Greene County highway yard for about 1.5 years (fig. 35). One well (614) is immediately downgradient of the salt stockpile; the other (613) is at the other end of the property, about 100 yards upgradient of the stockpile area. Each well was sampled and the water analyzed for major ions. An electromagnetic induction probe also was used in well 614 to a measure the conductivity of the unconsolidated material and ground water surrounding the well casing.

The data from this site indicate that water of high specific conductance, mainly from sodium and chloride (Appendix C), affects the shallow ground-water system variably over time. Overall, the specific conductance record shows good correspondence with seasonal water-level trends (fig. 35). The specific conductance of water from well 614 ranged from background levels of about 200 µS/cm to a maximum of nearly 3,500 µS/cm. The electromagnetic-induction log shows a distinct increase with depth below land surface, to a peak at 1 to 2 ft above water table, then a decrease to background levels within a few feet below the water table. This indicates that the unsaturated zone contains a high concentration of salt and that only the shallowest ground water was affected at the time the well was logged. Thus, salt leachate may reach the water table by (1) transport with recharge from land surface and from unsaturated zone storage and (2) from the resaturation of part of the unsaturated zone by rising ground-water levels.

Differences in the specific conductance of water at well 614 after separate, but equivalent recharge events (water-level rises) suggest that the timing of previous recharge events and preceding water-level conditions affect the concentration of leachate reaching the water table. Apparently, the first major recharge event after a period of little recharge transports the most concentrated leachate to the water table; thus, the first major recharge event of the fall and the spring, or a winter thaw, seems to be most favorable for transport of concentrated leachate to the water table. Fall recharge events may result in particularly concentrated leachate if the summer has been dry; for example, the highest specific-conductance reading (late November 1991) corresponds to a water-level increase (and, therefore, magnitude of recharge) that is comparable to that of two other recharge events (fall 1990; spring 1991) that were characterized by lower specific conductance values. The maximum specific conductance peak of November 1991 differs from the others in that the recharge event took place after about 6 months of sporadic, minor recharge, when ground-water levels were low; therefore, rainfall that infiltrated during the summer and early fall probably transported road-salt

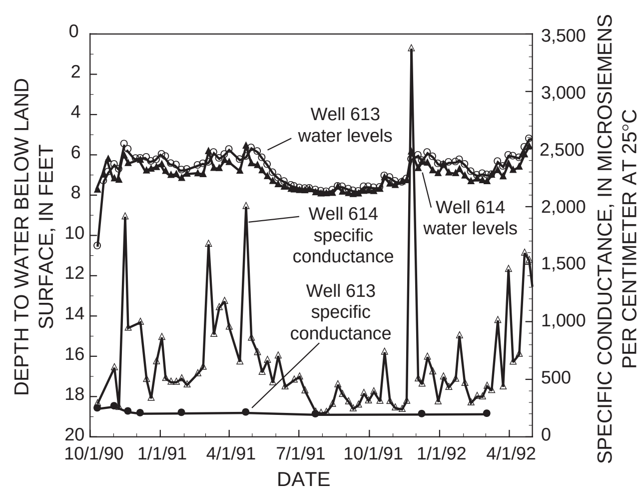


Figure 35. Water levels and specific conductance of water from two shallow wells upgradient (613) and immediately downgradient (614) of a road-salt stockpile at Ashland, N.Y. (Location is shown on pl. 1.)

leachate only into the unsaturated zone. When recharge from the November storm infiltrated through the unsaturated zone, it appears to have transported road-salt leachate held within the unsaturated zone as well as newer leachate from land surface.

The “spikey” nature of the leachate inputs as depicted in the specific conductance plot for well 614 (fig. 35) suggest that (1) ground-water flow in the valley-bottom gravel and sand was capable of flushing leachate from the area around the well within the weekly sampling period, or (2) the well may not be directly downgradient of the areas in which infiltration occurs and, thus, reflects only brief peripheral pulses of leachate. This storage site is on recent alluvium and moderately permeable valley bottom gravel and sand about 150 ft from the Batavia Kill. The alluvium appeared to have a clay component because surface ponding of leachate was common; specific conductance of the ponded water exceeded 20,000 µS/cm at times—much higher than that measured in nearby well 614. This discrepancy is primarily due to dilution at the well by deeper ambient water of low specific conductance entering the lower part of the 5-ft screened interval, as indicated by the extent of highly conductive material on the electromagnetic induction log.

Leachate from this storage site appears to infiltrate downward to the water table and to gradually flow toward, and discharge to, the Batavia Kill, where it becomes highly diluted. This point source has no discernible effect on stream chemistry.

Surface drainage from this site directly to the Batavia Kill has not been observed but could occur periodically, especially in late winter and spring. This could have a greater transient effect on the quality of the Batavia Kill than ground-water discharge, but dilution from the high-flow conditions that occur at this time of year would reduce the effect. Surface drainage from this storage site has been noted, but the flow infiltrates before reaching the Batavia Kill. Periodic drainage by artificial means is another potential direct source of leachate water to the Batavia Kill. For example, a front-end loader was typically used to move ponded water from near the stockpile toward the Batavia Kill, where it infiltrated just before reaching the stream.

Town/State Highway Yard. The salt supplies used by New York State Department of Transportation (NYSDOT) and the Town of Windham Highway Department are stored at adjoining highway yards on a terrace along the east side of Mitchell Hollow near the village of Windham (pl. 1). The flood plain of Mad Brook is about 50 ft below the terrace and is as much as 100-yards wide in this part of the valley. Gravel appears to be the predominant fluvial deposit. Channel segments that are either abandoned by Mad Brook or occupied by it during high-flow conditions are dominant features within the flood plain, which has a maximum local relief of about 8 ft near Mad Brook.

An initial survey of specific conductance of springs and seeps on the east side of the flood plain yielded values as high as 2,580 µS/cm; the highest values were at the spring-and-seep area at the base of the terrace slope. Ground water discharging from seeps in an abandoned channel farther downgradient had a maximum specific conductance of 755 µS/cm. Chemical analysis of a water sample from the base of the terrace slope (site 671, pl. 1, Appendix C) confirmed that the high conductance corresponded to sodium and chloride, derived most likely from the salt supplies immediately upslope from the sample site.

A ground-conductivity survey was done on February 6 and 10, 1992 to delineate the extent of shallow ground water affected by road-salt leachate within the flood-plain area east of Mad Brook (fig. 36). Ground-conductivity measurements ranged from a high of 70.3 mS/m (millisiemens per meter) at the road-salt storage site to a low of 1.3 mS/m on the flood plain.

Specific conductance of water from springs and seeps in the survey area (fig. 36) was used as a control to approximate the lowest ground-conductivity value that might indicate the presence of road-salt leachate—a value of 5 mS/m or greater appears to indicate leachate-affected ground water at most locations. All measurements at the storage area above the flood plain had ground-conductivity values exceeding 5 mS/m (fig. 36); the highest values were adjacent to the town and NYSDOT stockpiles.

The conductivity contours on the flood plain in figure 36 indicate a general westward migration of leachate away from the storage sites and toward Mad Brook. The highest values exceed 25 mS/m and are centered at the base of a gully that drains stormwater and snowmelt from the south end of the storage area. This pattern indicates that infiltration of water from this gully is a major source of leachate to ground water in the flood plain. A second gully with intermittent flow at the north end of the storage site (not shown) apparently does not receive runoff from the storage area because the ground conductivity shows

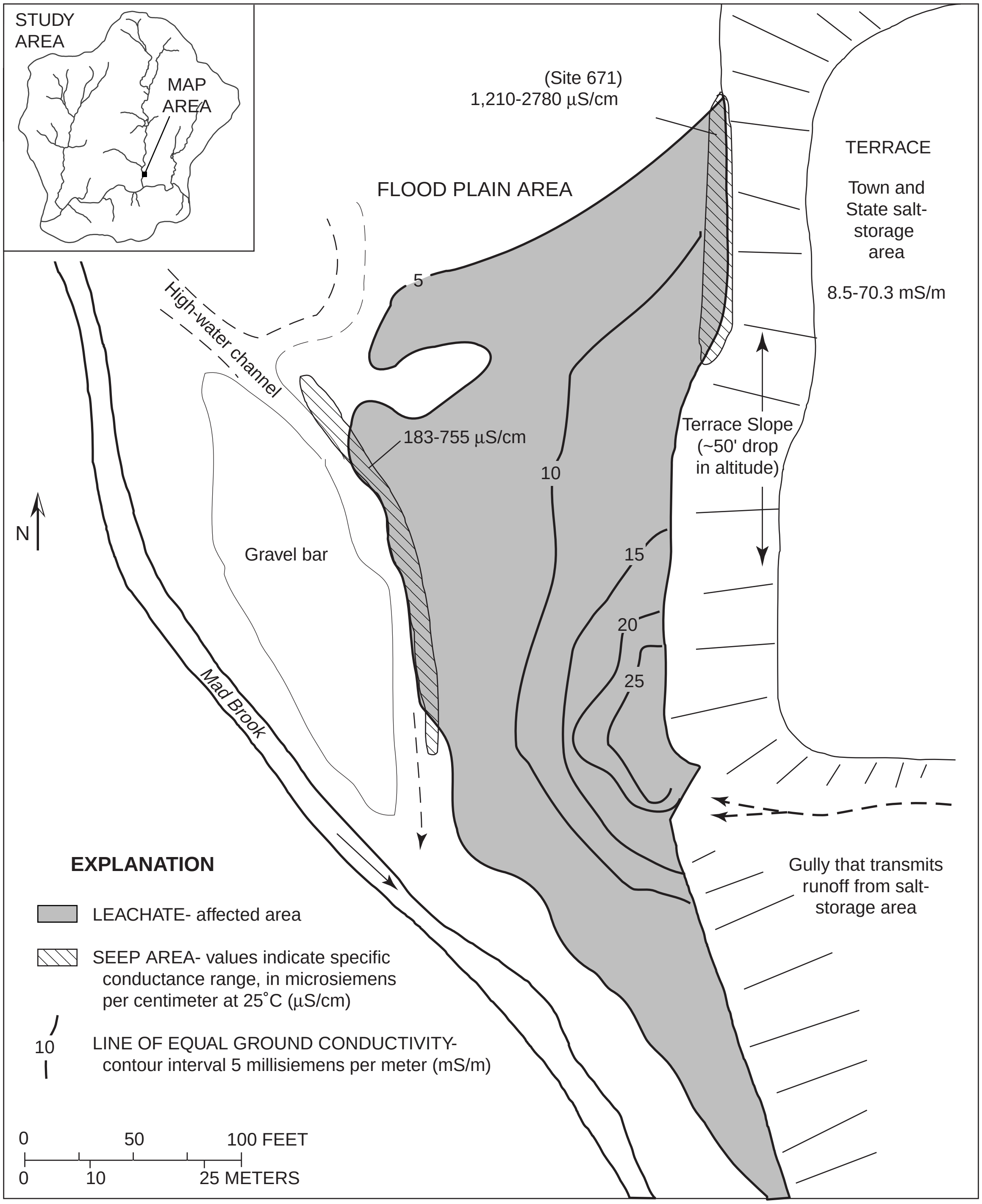


Figure 36. Ground conductivity on the flood plain of Mad Brook, downgradient of road-salt storage area at Windham, N.Y.

no increase where flow from this area enters the flood plain.

The specific-conductance and ground-conductivity data indicate that leachate has not affected the entire flood-plain area between the storage sites and Mad Brook; the trend of the 5-mS/m contour along the east side of a former channel indicates that the flood-plain area to the west (a gravel bar) is free of leachate-affected ground water. The former channel also contains seep waters of higher specific conductance than unaffected shallow ground water elsewhere; thus, the channel acts as a drain that directs leachate-affected ground water downstream to the confluence with Mad Brook (fig. 36).

Leachate-affected ground water probably discharges directly to Mad Brook south of the confluence mentioned above, despite the 5-mS/m contour, which does not appear to reach Mad Brook. Local changes in topography limit the effectiveness of the electromagnetic induction technique. Measurements taken at sites in which local relief decreases or increases the distance between land surface (or water table) and the instrument result in positive or negative biases, respectively. Measurements made near the bank of Mad Brook are negatively biased because earth material is "missing" beyond the bank in the stream channel relative to a level site away from the stream. Two other negatively biased sites form a low-conductance embayment along the 5-mS/m contour (fig. 36) because they are on a topographic high, where the instrument is farther from the water table and adjacent to channel features (farther from land surface).

Solid-waste Disposal. At present, solid wastes are either recycled or carted away from the study area. In the past, wastes were disposed of on individual properties or at the town landfill. Leachate generated at such sites can affect local ground-water quality and, in some settings such as at the landfill, can potentially affect surface-water quality.

The landfill, which served the community for many years, is immediately north of the town and State highway yards off Mitchell Hollow Road (pl. 1) and now serves as a county transfer station. The landfill was closed in the 1970's, before closure practices were regulated, and no clay cap, which would limit leachate generation, was constructed. The landfill was built out onto the flood plain of Mad Brook and now abuts the east side of the stream; this geometry indicates that, under natural ground-water-flow conditions, little ground water beyond this site is affected by landfill leachate because shallow ground water presumably discharges to the stream. The specific conductance of seep water at one point on the landfill slope that abuts the stream was about 725 µS/cm in 1993, which suggests that ground water discharging to Mad Brook from the landfill might affect stream-water quality during low-flow conditions, as discussed earlier.

The town/State highway yards (salt-storage) and the abandoned landfill in the lower part of Mitchell Hollow overlie a potentially productive segment of the stratified-drift aquifer. Contamination from these point sources may prevent water-supply development in this area.

Underground Fuel Storage. Storage of home-heating fuel oil, gasoline, and diesel fuel in underground tanks is a common practice. The potential for leakage from underground storage tanks increases with the age of the tank. Fuel leaks are of particular concern because fuels contain a range of organic compounds that are known carcinogens. Drinking-water standards for these compounds are on the order of micrograms per liter. Leakage from tanks can be identified by abnormal declines in fuel levels in a tank or inferred by obvious changes in well-water quality. One example within the study area was a leaking abandoned fuel tank at the town highway yard, which had affected the well water at the site (well 672, pl. 1). Analysis of a water sample for volatile organic compounds indicated the presence of several compounds in excess of Federal drinking-water standards. The New York State Department of Environmental Conservation (NYSDEC) has since investigated the problem.

Borehole Short Circuits. Borehole short circuits, as discussed earlier, can act as pathways for upward movement of naturally occurring, deep saline ground water into the bedrock aquifer. Pumping from shallow bedrock wells (particularly in valleys) causes upward gradients in other boreholes that intersect both shallow and deep water-bearing fractures, and these gradients may draw saline water into the shallow bedrock aquifer (and the production well). The study area contains several relatively shallow bedrock wells that are near (or are) production wells whose water quality (specific conductance or water type) suggests a contribution of underlying saline water. The potential for this type of contamination can be minimized by identifying and plugging wells that intersect unpotable water.

Other Sources. Other practices within the study area that can affect ground-water quality include storage and application of manure and other fertilizers and pesticide use. A dairy farm and a few smaller farms with livestock locally contribute animal-waste leachate to the shallow ground-water system. Golf courses and the ski area use a variety of fertilizers, particularly during the growing season. Pesticide use by two golf courses, the ski area (infrequently), and a dairy farm also may contribute contaminants to the shallow ground-water system. Known pesticide usage in 1991 is summarized in table 11. Determination of the effect of these practices on shallow ground-water quality was beyond the scope of this study. No known

Table 11. Pesticide use in Batavia Kill study area, Greene County, N.Y., 1991

[°C, degrees Celsius, mg/L, milligrams per liter]

Pesticide commercial name	Chemical name of active ingredient	General type of pesticide	Principal Use	Frequency of use	Solubility [1] in water	User
Atrazine	Atrazine	Herbicide	Corn crops	Annually	33 mg/L at 25°C	Dairy farm
PCNB (in Scotts FF II)	Quintozene, Pentachloro-nitrobenzene	Fungicide	Greens and tees of golf courses	Annually	Practically insoluble	Golf courses
Bayleton	Triadimefon	Fungicide	Greens of golf courses	Semiannually (approximately)	Insoluble	Golf courses
Roundup (in Accord)	Glyphosate isopropyl-ammonium	Herbicide	Right-of-ways, ski trails	As needed (infrequent)	Readily soluble	Ski area

[1] Solubility data from Farm Chemicals Handbook (1994)

withdrawals of shallow ground water occur at or downgradient of any the sites of application, however.

Nonpoint-source Degradation

Nonpoint-source degradation of streams and ground water results from widespread practices within a given area, such as the application of fertilizers, pesticides, or road salt, or the disposal of wastewater through septic systems. Nonpoint-source degradation is typified by a large area of ground water affected by low levels of contamination. This type of contamination is most evident in surface waters during low-flow conditions, when dilution of ground-water inputs is minimal. The few active farms, the ski area, and the two golf courses within the study area might also be considered as point sources, as well as nonpoint sources, because their pesticide and fertilizer applications are limited in area. The distribution of septic-wastewater disposal and road-salt application in the study area corresponds to the distribution of housing and roads, respectively. Septic-system discharge can be considered a nonpoint source in populated, unsewered areas such as the village of Windham because the effect of individual systems would probably be impossible to determine; similarly, the greatest density of roads, which approximate a nonpoint source, are in and close to the village of Windham.

The presence of chloride as the dominant anion in samples of shallow ground water in and near the village of Windham reflects human activities, rather than saline ground water from bedrock. The concentrations do not affect the potability of the water (Appendix C).

The stiff diagrams of dilute, human-affected ground water in figure 33 reflect the alteration of natural ground-water composition locally, presumably from the effects of human activity, as indicated by the elevated chloride concentrations and anion percentages, as well as other constituents of the water (boron, nitrate, tritium).

Sodium chloride waters with variable calcium and bicarbonate concentrations were found in two wells finished in bedrock (654, 673) and three wells finished in unconsolidated material (617, 645, 805). All five wells are within the Village of Windham. These waters are acidic (pH 5.9 - 6.4), oxygenated, recent (less than 10 years old), undersaturated with respect to calcite, and are the closest to natural water on the trilinear diagram (fig. 33).

Calcium/sodium chloride water was found at one spring (804) and in one well (664) that is screened 32 to 46 ft below land surface in unconsolidated material west of the ski area at the base of Cave Mountain. These samples also have low pH values (5.6, 5.8). The sites are downslope of housing associated with the ski area. Chloride from bedrock ground-water inflows is a possible source, as identified in ground-water composition changes with downward borehole flow at well 625, but elevated nitrate concentrations and nondetection of boron (which is present in bedrock water with elevated chloride) in both samples, and elevated tritium values indicating recent water (less than 10 years old, table 10), indicate little input, if any, from bedrock sources of chloride (fig. 35A,B). Thus, human activity upgradient appears to be the most likely influence on the chemical composition of the water at these sites.

The calcium chloride/bicarbonate-type ground water from a spring (site 803 east of the ski area) is also downslope of housing and the road that serves it. Without the human activities upslope, the water would probably be a calcium bicarbonate type.

Conceptual Model of the Ground-water Flow System

Conceptualization of the ground-water flow system includes water entering the system as recharge, ground-water flowpaths within unconsolidated and bedrock material, and ground-water discharge from the system. The flow system is defined and constrained by the areal distribution of water available for recharge (precipitation minus evapotranspiration), the hydrogeologic framework, and water chemistry. The flow system is bounded above by unsaturated material or land surface and below by saline waters, as depicted in the representative hydrogeologic sections across a valley with an established flood plain (the Batavia Kill valley) (fig. 37A) and across an upland tributary valley (fig. 37B).

The shape and depth of the fresh-water/saline-water interface and, thus, the depth of fresh ground-water flow, is largely unknown. Borehole short circuits within wellbores that intersect the interface preclude accurate location of the saline-water-bearing fracture(s) from fluid-conductivity logs, and cross-contamination from flow between wellbores may artificially mix saline water with freshwater in many wellbores; thus, the degree of *natural* mixing in the vicinity of the interface is impossible to determine. The best indication of the fresh-water/saline-water interface in the Batavia Kill valley is at well 635; flowmeter measurements indicate that saline water enters the borehole within an interval 275 to 375 ft below land surface. The uncertainty in location and shape of the freshwater/saline-water interface in the study area is indicated in figure 37. If the depth from land surface to the interface at well 635 is estimated to be 300 ft, a flat interface would be about 600 ft below the valley floors in the highest upland tributary valley reaches. Given the uncertainty in hydrogeologic conditions and the effect of substantial overlying rock mass, however, the depth to the interface might differ from this estimate by several hundred feet. Several studies in the Eastern Kentucky coal field suggest that the interface is lower in the intervalley areas (concave upward) than in the valley areas (Wunsch, 1993; Minns, 1993).

Local ground-water flow refers to waters that recharge, flow, and then discharge to surface water within the same drainage basin (containing second-order or greater streams). Ground-water flow is most active within the shallowest parts of local flow systems. Subregional flow refers to ground water that discharges at the next higher order stream basin. For example, this includes water that enters any of the major tributary basins in the study area and that ultimately discharges to surface water in the Batavia Kill valley. Regional flow discharges still farther downgradient at some undefined area beyond the Batavia Kill valley. Regional flow is combined with subregional flow in the following discussion because the extent of each component is largely undefined. Flow-system dynamics (flow rates and direction) associated with natural conditions change significantly in areas where ground-water withdrawals occur or where bedrock wells have been installed.

A conceptual model of ground-water movement in the study area is depicted in the two vertical sections in figure 37. The following paragraphs discuss the three principal hydrogeologic settings that constitute the conceptual model. The settings are:

- bedrock-dominated high-relief hillsides and hilltops
- till-dominated upland areas of moderate relief (including most second-order stream valleys)
- valleys with established flood plains and the lower parts of adjacent hillsides.

Bedrock-dominated High-relief Hillsides and Hilltops

This setting generally corresponds to areas mapped as bedrock in figure 21A and is conceptualized as an important area for recharge within the hydrogeologic system (fig. 37). The most active zone of ground-water flow within this setting is the near-surface zone of fractured bedrock.

Recharge from direct precipitation is the only source of water in hilltop areas; the bedrock hillside areas below derive water from ground-water flow from higher elevations as well as from direct precipitation. Total runoff, or the volume of water available for recharge (from direct precipitation), is greatest in this setting (fig. 5B), although steep slopes and areas of low fracture permeability can locally increase overland flow.

The primary avenue of ground-water flow in this setting is near-surface fractures in bedrock. Fracture

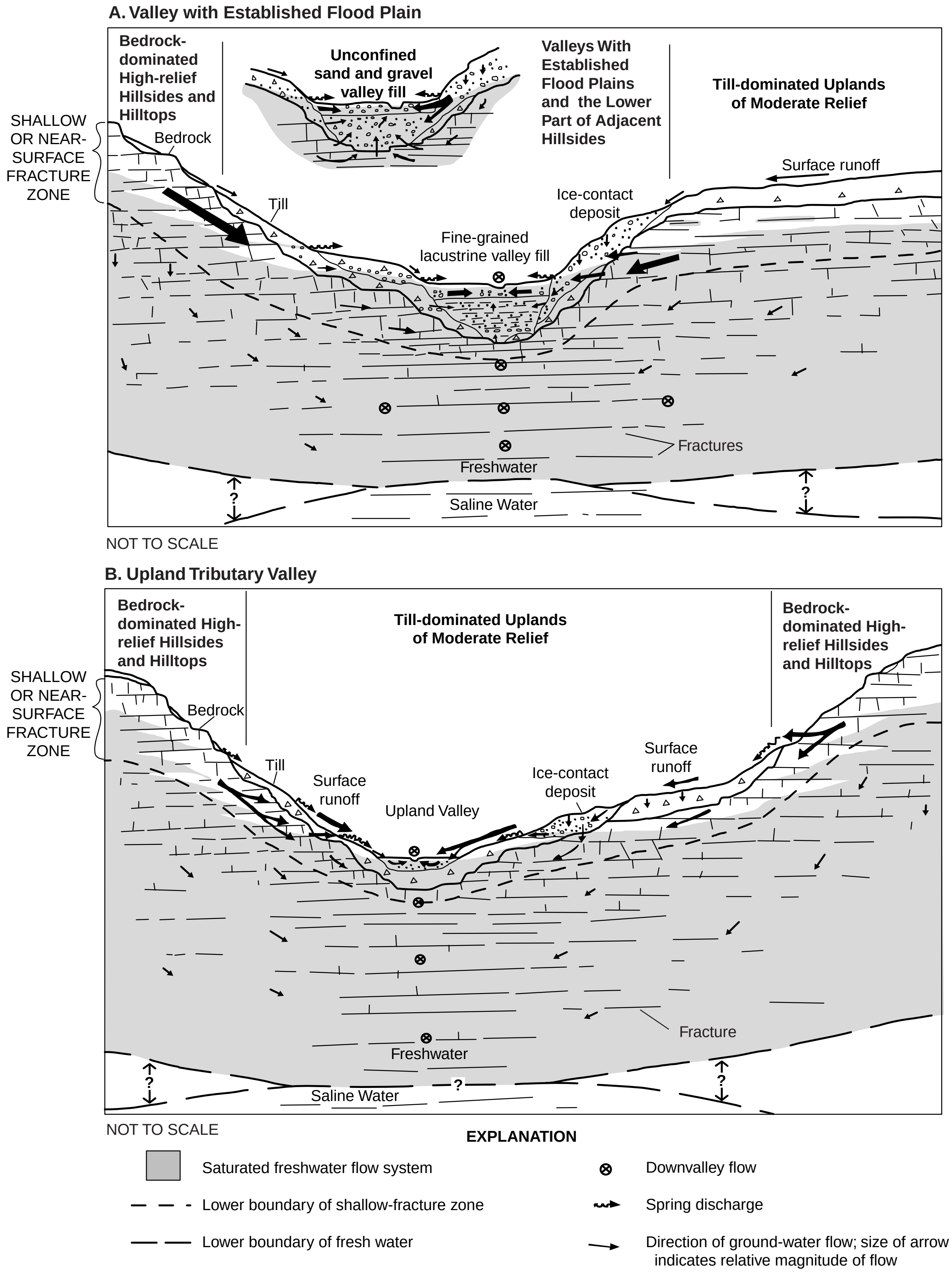


Figure 37. Conceptualization of ground-water occurrence and flow in two generalized vertical sections: A. Valley with an established floodplain (Batavia Kill valley). B. A representtive upland tributary valley.

density at wells 767 and 799 (pl. 1), defined from borehole-geophysical logs and video logs, suggests that the zone of most active flow corresponds to the upper 90 to 130 ft of bedrock. The following field observations and evidence from wellbores indicate (1) the presence of permeable fractures, (2) significant ground-water movement, and (3) the approximate depth of active flow within the near-surface fracture zone:

- cascading water during wet periods (well 799)
- large seasonal fluctuations in water levels (as much as 27 ft in well 767)
- fracture control of water levels (water levels that coincide with fracture locations in wellbores)
- ground water of low specific conductance (suggesting short residence times)
- turbid water

Turbid water proved to be a useful indicator of active ground-water flow at well 799 on Cave Mountain (pl. 1). A nearby homeowner's observations of periodically turbid well water over the course of the year suggested that the occurrences coincided with periods of recharge to the hillside system. Turbid conditions were observed during subsequent borehole-video logging of two nearby wells (799 and 767) in the late spring of 1993. Active ground-water flow within the hillside was indicated 102 ft below the bedrock surface (114 ft below land surface) at well 799 by the discharge of turbid water into the wellbore from a low-angle fracture. Two potential sources of turbidity are (1) scouring and suspension of accumulated fine sediments in normally dry near-surface fractures by periodic recharge events, and (2) suspension of soil material by runoff prior to recharge. The latter may be enhanced where soil disturbance has occurred upslope. A dirt road lies a few hundred feet upslope of wells 799 and 767, but its effect on the shallow ground water is unknown.

A stair-step pattern of alternating subsurface flow and surface discharge was observed on the hillside of Cave Mountain during wet conditions on April 30, 1991. Ephemeral **contact springs** were observed at the base of talus slopes below sandstone ledges. Surface flow typically continued downslope over the finer-grained (and potentially less permeable) part of the upward-fining sequences until it infiltrated just before the next ledge, presumably in response to increasing vertical-fracture permeabilities. Surface flow was probably sustained in part by thin till or colluvial deposits.

Deep ground-water flow within the hillsides is probably minor in comparison to near-surface fracture flow. Yields of 2 gal/min or less are typical of wells from 700 to 1,200 ft deep. The persistence of high-angle fractures to at least 425 ft at well 767 suggests a potential for downward flow to at least this depth. Sodium bicarbonate waters are expected within the deepest part of this flow system. The maximum depth to stagnant saline waters is 820 to 840 ft (well 799).

Ground-water discharge from this setting includes ground-water flow to the next hydrogeologic setting downslope (remaining in the subsurface) and ground-water discharge at land surface as springs and seeps where local fracture permeability is insufficient to contain the flow. Ground water discharged at land surface may either reinfiltrate the land surface or form a stream headwater or wetland.

Till-dominated Uplands of Moderate Relief

This setting corresponds to upland areas mapped as till or ice-contact deposits, including valleys with little flood-plain development (fig. 21A), and is the most extensive of the three hydrogeologic settings described here. Recharge through the till is considered minimal, but ground-water inflows from bedrock-dominated areas upgradient are potentially important. This setting is generally conceptualized as a conduit for ground-water flow from upgradient sources through the near-surface fractured bedrock (fig. 37A), also providing relatively minor downward flow to the subregional and regional flow systems.

A substantial area of moderate relief, predominantly blanketed by till, lies downslope of the high-relief hillside and hilltop areas north of the Batavia Kill (figs. 20, 21, 37). No water-level data or borehole-geophysical logs from this area are available, but a generalized conceptualization of ground-water flow in this area can be made from the hydrologic framework (fig. 37B). The till can be assumed to allow less recharge to enter the ground-water system than permeable unconsolidated deposits or fractured bedrock. Observations of a till-covered section of hillslope at the base of Cave Mountain on April 30, 1991, a day after 0.28 in. of rain and about 10 days after 2.76 in. of rain (over 2 days) indicate poor infiltration—the upper 0.5 to 1 ft of soil material was completely saturated, and the surface had standing water and unchanneled flow that eventually coalesced into channeled flow within ephemeral-stream channels with little or no relief. In addition, the topography in many till-covered areas (fig. 21, pl. 1) suggests the presence of many incised, ephemeral-stream channels. Runoff from these areas probably leaves the study area as surface water except where conditions are favorable for streambed infiltration, such as where tributary A enters the Batavia Kill valley (fig. 9).

Localized areas of ice-contact and alluvial deposits or exposed bedrock may provide the best avenues for direct recharge in this setting; otherwise, most recharge is assumed to come laterally from exposed bedrock in the high-relief areas upslope. Permeable stringers of sand or gravel within till, or isolated bedrock exposures along some first- and second-order-stream valley walls, may provide a means of discharge to these streams; the only other ground-water source for streams is discharge from localized alluvial deposits that receive direct precipitation as well as unchanneled overland flow from the valley walls. Ground water in bedrock is potentially isolated from surface water and localized alluvial deposits in this part of the system. Water that does not discharge at local stream valleys becomes part of sub-regional and regional flow systems.

Valleys with Established Flood Plains and the Lower Parts of Adjacent Hillsides

This setting generally corresponds to valley-bottom gravel and sand and recent alluvium and adjacent ice-contact deposits in the Batavia Kill valley and the lowermost mile of Mitchell Hollow (fig. 21A). This setting has the highest recharge rates because it receives contributions from local and upland sources. Both local and subregional flows converge at the large valleys, although subregional flows may not discharge because of confined conditions. Local, active ground water flows from the valley walls to the valley fill and discharges into the Batavia Kill (fig. 37A). The most active ground-water flow appears to occur (1) within shallow bedrock and the unconsolidated deposits of the lower hillsides, and (2) within the unconsolidated deposits (valley fill) beneath the valley floor. Active ground-water flow in shallow bedrock beneath the valley floor is most likely where the unconsolidated deposits are unconfined (inset, fig. 37A). Deeper, local and subregional ground-water flow presumably moves more slowly downvalley and has a small, upward component toward the Batavia Kill.

Sources of ground water from upland areas range from local, shallow flow derived from recharge in ice-contact deposits adjacent to the valley floor, to deeper local and subregional flow from high-relief areas. Most ground-water inflow to the Batavia Kill valley appears to be shallow, local flow through the near-surface fractured bedrock and the overlying unconsolidated deposits along the valley walls. The predominance of shallow ground-water flow in the study area is further indicated by gross surface-water chemistry. Surface-water samples collected during low-flow periods, when ground water is the sole source of flow, are typically calcium-bicarbonate type waters, which are indicative of short ground-water residence times. (Exceptions in water type occur where human-derived point sources markedly increase the sodium and chloride concentrations).

The abundance of contact and(or) **depression springs** and seeps on lower valley-wall areas also are indicative of shallow ground-water flow to the valley. Most of these features are at the junction of the valley wall with the valley floor on the north side of the valley, although springs also are found on the south side on the lower hillsides, where local permeable zones occur within poorly sorted ice-contact deposits or till. Discharge from springs may infiltrate the valley-bottom deposits and either rejoin shallow ground water or discharge to the Batavia Kill. Mixed-ion or calcium bicarbonate waters associated with springs are indicative of short ground-water residence times.

Unconfined valley fill (fig. 21C), and, to an unknown extent, shallow, fractured bedrock constitute the active, local flow system that discharges to the stream (inset fig. 37A). Chemical analyses of ground-water samples from shallow bedrock fractures at wells 622 and 635 indicate a calcium-bicarbonate type of water that matches water samples from the valley fill and the stream. These wells (and others, see fig. 38A,B) are also responsive to precipitation, which implies hydraulic connection with shallow, unconfined aquifer material.

In areas with lacustrine confining units, underlying valley fill and fractured bedrock are not within the most active part of the local flow system, which presumably lies above the confining unit (fig. 37A); rather, they transmit slower local and subregional flow downvalley until hydrogeologic conditions permit upward movement and discharge to surface water. Confining units also probably shunt a greater amount of shallow flow from the valley walls to the unconfined valley fill rather than to units below the confining unit because the unconfined deposits are the pathway of least resistance to discharge at the valley stream.

Subregional flow from upland areas, along with less active local flow from bedrock, are probable sources of fresh sodium bicarbonate waters found in confined fractures beneath the Batavia Kill valley (fig. 37). The subregional-flow component is probably minor because fracture occurrence and permeability decrease with depth, as documented elsewhere in the Appalachian Basin (Harlow and LeCain, 1991).

Ground water of the subregional flow system (in bedrock) beneath the valley may either flow upward to discharge to the Batavia Kill, or, in confined areas, remain in bedrock and slowly move downvalley until it reaches a point at which upward movement and discharge are possible. The latter condition is the more likely, however, because of the degree of confinement within the bedrock, as indicated by the following observations:

- Borehole videos indicate a much thinner shallow-fracture zone (the upper ≈35 ft of bedrock) in the valley than in hillside areas and typically fewer and less consistent high-angle fractures, despite well-developed low-angle fractures. Thus, horizontal flowpaths appear to be favored over vertical flowpaths.
- Mass-balance calculations based on wellbore variations in specific conductance at five pumped wells within the valley indicated that the near-surface fracture zone is not consistently permeable; three of the wellbores showed no yield within the upper 85 ft of bedrock.
- The water-level response to precipitation at a well (623, fig. 38C) that taps mainly deep, permeable fracture(s) indicates only an indirect connection with the shallower, unconfined flow system in the valley. The hydrograph for this well does not show the rapid peaks and gradual recovery associated with wells completed in permeable unconsolidated material or shallow bedrock, but rather, shows a gradual peak about 10 days after the event and no recovery (recession) to antecedent conditions. This may indicate gradual downward leakage (recharge) from the overlying local flow system through artificial fracture interconnections (short circuits) within wellbores and perhaps through natural fracture pathways.
- Water level responses in observation wells to withdrawals at well 632, described earlier, indicate a confined hydraulic zone of limited yield and large areal extent. In addition, borehole-flow measurements indicate that about 27 percent of the yield is derived from overlying, shallower bedrock or unconsolidated units through induced downward flow (short circuits) in wellbores.
- In addition to confinement by bedrock, fine-grained valley-fill deposits may also confine bedrock (fig. 21).

The lack of a discernible sodium bicarbonate input in surface-water samples collected during this investigation does not rule out the possibility of ground-water discharge from subregional flow systems to the Batavia Kill in the study area, but this component might be too small to significantly affect Batavia Kill chemistry, especially in relation to interferences from sodium (and chloride) inputs from point sources along the lower reach of Mad Brook. Water samples from below-streambed well points might be the most conclusive way to resolve whether subregional flow recharges the Batavia Kill in the study area.

Upward movement and eventual discharge of water from bedrock beneath the valley is potentially

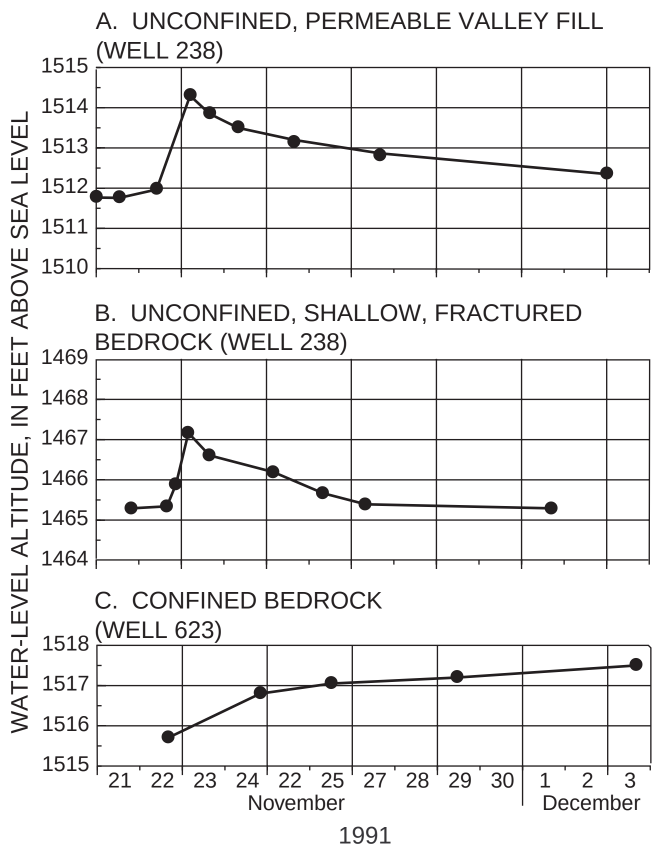


Figure 38. Water-level response to 2.78 in. of rain on November 22-23, 1991 in wells that tap three hydrogeologic settings within the Batavia Kill valley, Greene County, N.Y.: A. Unconfined, permeable valley fill; B. Unconfined shallow, fractured bedrock; C. Deep confined bedrock.

facilitated where low-angle (bedding-plane) fractures intersect or subcrop at the bedrock surface. Direct discharge to surface water may occur at isolated locations where bedrock crops out in streambeds, such as at the Batavia Kill immediately east of the County Road 296 bridge (fig. 21A) and at Red Falls, which is about 3 mi. downvalley from the study area (fig. 1).

Ground-water occurrence and flow within similar dissected deltaic sequences of the Appalachian Basin have been investigated in West Virginia by Wyrick and Borchers (1981), in Virginia by Larson and Powell (1986) and Harlow and LeCain (1991), in Pennsylvania by Booth (1988), and in Kentucky by Kipp and others (1983), Davis (1987), Wunsch (1993), and Minns (1993). Conceptual models of ground-water flow in these areas parallel the conceptual model presented here (apart from the hydraulic effects of coal seams in the former) in the following aspects: (1) active flow in the near-surface fractured zone; (2) decreasing fracture occurrence and permeability with depth, presumably in response to overburden pressures; and (3) identification of ground-water chemical types that constitute a chemical-evolution sequence (Wunsch, 1993) within a hillside and valley flow system.

SUMMARY AND CONCLUSIONS

This study examined the water resources of a 27.6-mi^2 area within the Batavia Kill basin in the northeastern Catskill Mountains that has undergone considerable development since the 1980s. The region consists of relatively flat-lying, fining upward, clastic sequences of Devonian age overlain by as much as 120 ft of Pleistocene and recent deposits. Local relief is about 1,500 ft. Ground water flows within a variable mantle of predominantly glacial deposits and within fractured bedrock. The bulk of ground-water flow appears to be limited to the most intensely fractured shallow bedrock over much of the upland areas and in permeable valley fill in the larger valleys.

Annual precipitation ranges from about 41 in. in the Batavia Kill valley at Windham to 51 in. at the headwaters of the Batavia Kill. Recharge is favored in unchanneled upland areas and valley flood plains, where little water is lost as overland flow during storms. Valley areas ultimately receive the largest total recharge because they receive contributions from adjacent upland areas and from tributary flow that infiltrates within the valley, in addition to direct recharge from precipitation. Upland recharge sources account for about 80 percent of recharge in the Batavia Kill valley.

Surface-water flow was monitored at a gage at the downgradient end of the study area. Flow of the Batavia Kill is (1) decreased seasonally by withdrawals for snowmaking from an infiltration gallery adjacent to its channel and (2) attenuated during the largest stormflows by flood-retardation reservoirs in three tributary basins. The effects of withdrawals for snowmaking were discernible at a gage 13.5 mi downstream on the Schoharie Creek. The loss of discharge at this gage is much greater than at the Batavia Kill gage, probably because other simultaneous snowmaking withdrawals are made by another ski area upstream on Schoharie Creek.

Discharge measurements along in-valley reaches of Batavia Kill tributaries indicate variable flow losses or gains through the streambeds. Optimal conditions for infiltration of streamflow appear to be a long in-valley reach with several feet of relief from valley wall to the confluence with the Batavia Kill and a fully saturated streambed over permeable valley-bottom sediments. These conditions are most nearly met at the tributary A in-valley reach. The maximum streambed infiltration rate within this reach was about 3 ft^3/s per 1,000 ft of channel.

Low-flow frequency and duration statistics for the Batavia Kill at the gage site were estimated through correlation of selected concurrent flows from the Batavia Kill and a long-term-record site in the area (Schoharie Creek at Prattsville) and through generation of Schoharie Creek flow statistics. Low-flow statistics were developed because low-flow periods are when the waste-assimilative capacity of a stream is minimal, and the effect of contaminants from point and nonpoint sources is greatest.

Surface-water chemistry was investigated by reconnaissance sampling to define (1) temporal variations at the gage site during a 16-month period, and (2) spatial variations within the basin on one day during low-flow conditions. Effects of human activity on the system are evidenced by seasonal and local increases in specific conductance and chloride concentration.

Temporal variations in pH appear to reflect changes in the amount of flow contribution from upland drainages to total flow of the Batavia Kill. Water from upland drainages tends to be basic, whereas shallow ground water in the Batavia Kill valley tends to be acidic. Streambed infiltration during low-flow periods greatly reduces the surface-water flows from the uplands; thus, acidic conditions in the Batavia Kill occur during low-flow periods, when flow derived from shallow-ground-water discharge within the Batavia Kill valley is maximized.

Nutrient concentrations in the Batavia Kill were compared with those in the Neversink River at Claryville, which drains a larger, less developed basin in the southwestern Catskill Mountains. No major differences were evident; nitrate-plus-nitrite concentrations in the Batavia Kill were similar to nitrate concentrations in the Neversink River, but with wider seasonal fluctuations.

Spatial variations in stream chemistry were greatest during low-flow periods, when dilution of ground-water discharge is minimal. Human-derived inputs include (1) direct discharge of treated wastewater to a Batavia Kill tributary, and (2) discharge of ground water affected by leachate from an abandoned landfill, road-salt stockpiles, and wastewater from septic systems. The effect of point sources on surface water composition is most evident in the lower reach of Mad Brook, which is probably affected by both road-salt and landfill leachate. Surface water above the reach is a dilute calcium-bicarbonate type, whereas water leaving the reach is a sodium chloride type with specific conductance values three times greater than the upstream values.

Stream turbidity is most variable during high flows, when overland runoff is greatest. Elevated turbidity is associated with high-gradient, typically ephemeral tributaries, and the highest values were associated with soil disturbances within subbasins.

The largest potential ground-water resources in the study area are within and immediately adjacent to the Batavia Kill valley and within the valleys of its three largest tributaries to the north. Bedrock is the main water source within this area, although glacial deposits may be more productive locally. Several springs in the area are used for water supply; they may derive water from one or both ground-water sources.

The most productive part of the stratified-drift aquifer system is centered at the junction of Mitchell Hollow and the Batavia Kill valley at the village of Windham, where maximum saturated thickness approaches 60 ft. Estimates of hydraulic conductivity from previous work in the area indicate transmissivity values of 4,000 to 29,000 ft^2/d in the thickest sections. Less productive sources are (1) valley areas adjacent to mapped ice-contact deposits, and (2) thin ice-contact deposits below lacustrine deposits. Valley-bottom gravel and sand is permeable, but the limited saturated thicknesses of these deposits, and their proximity to land surface, make them unfavorable for development.

Fractured bedrock is the most widespread and frequently tapped source of ground water in the study area. The distribution of high well yields across the study area, and the presence of well-developed low-angle (bedding-plane) fractures in valley wellbores, indicate that the greatest water-resource potential is in or immediately adjacent to the largest valleys. The highest documented sustainable withdrawal rate, 100 gal/min, was from a shallow bedrock well that was obtaining some of its water from the overlying stratified drift. Caliper, downhole-camera, and fluid-conductivity logs indicate that fracturing is most frequent within the upper 35 to 150 ft, depending on the topographic location. The lower boundary of the bedrock aquifer is the interface between fresh and saline ground water. Depth to the interface, as indicated at a single well on the valley floor at Windham, is between 275 and 375 ft below land surface.

Ground-water-level hydrographs indicate that nearly all bedrock wells in the valley are affected by withdrawals at other wells. Four principal hydraulic zones within the Batavia Kill valley at Windham were identified; they differ considerably in size and shape and reflect the fracture(s) intersected and the degree of hydraulic connection with overlying permeable valley fill. The maximum distance from a bedrock production well that obtains some water from stratified drift to a hydraulically interconnected well is 1,400 ft; the maximum distance from a confined bedrock production well to a hydraulically interconnected well is 4,700 ft. These response characteristics are indicative of highly permeable fractures that form multiple confined zones with limited storage and considerable areal extent up- and down-valley. Decreases in fracture permeability toward hillside interiors appear to limit hydraulic zone width.

Wellbores significantly alter the bedrock framework and ground-water flowpaths. Interconnection of fractures within wellbores greatly increases the dynamics of the flow system by connecting fractures that would otherwise have little exchange or be isolated. Augmentation of well yields by interconnection with shallow fractures is potentially desirable, although upward inducement of saline water from deep, fractures can cause contamination of the aquifer.

Chemical composition of ground water within the Batavia Kill valley ranges widely. Much of the variation appears to represent natural evolution along flowpaths, as well as limited local mixing of the evolved ground water with deeper, presumably stagnant saline water. Most of the mixing probably occurs within wellbores. Mixtures of evolved sodium bicarbonate water and saline sodium chloride waters result in sodium chloride or sodium-bicarbonate/chloride water types. Two other trends in hydrochemistry that generally reflect increasing residence time within the flow system are increases in specific conductance (and dissolved solids), and a shift in redox conditions from oxidizing to reducing.

Degradation of ground-water quality stems from several sources within the study area that include septic-system discharges, road-salt storage and application, wellbore short circuits, underground fuel storage, pesticide and fertilizer application, and leachate from an abandoned landfill. Many of these sources are near streams; thus, limited areas of ground water between source and stream are affected. Future development of ground-water resources could potentially alter flow conditions and thereby increase the migration of such contaminants within the ground-water flow system.

Wastewater disposal through septic leach fields is the largest source of contaminants entering ground-water system, and is most intense at the village of Windham. Road-salt stockpiles are commonly uncovered and subject to leaching by precipitation. Two of these stockpiles and an abandoned landfill site (uncapped) contribute leachate to Mad Brook, just north of Windham. The presence of these sources precludes significant ground-water development in the otherwise favorable area underlying Windham and lower Mitchell Hollow.

The hydrogeologic system is conceptualized as consisting of three settings:

- bedrock-dominated high-relief hillsides and hilltops
- till-dominated uplands of moderate relief
- valleys with established flood plains and the lower parts of adjacent hillsides.

Bedrock-dominated high-relief hillsides and hilltops are characterized by surface exposures of fractured bedrock, little ground-water storage, and transient flows associated with recharge (from precipitation) within the permeable, near-surface fracture zone. Following recharge, transient-flow conditions partly resaturate near-surface bedrock fractures, and subsequent downgradient movement follows a stair-step pattern, alternating from low-angle fractures to high-angle fractures. Within the hillsides, fracture frequency and permeability generally decrease with depth, and the rate of ground-water flow decreases. Well yields in this setting are low, primarily because the shallow fracture zone parallels the hillside, allowing rapid downslope drainage and minimal ground-water storage.

Till-dominated uplands of moderate relief are conceptualized as accepting less recharge and generating more overland runoff than areas farther upslope because the till has low permeability. The minor direct recharge in such areas is probably supplemented by downslope flow through fractures from high-relief upland areas. The largest upland valleys in the study area are included in this setting as they are typically underlain by till. Ground water in bedrock probably contributes to surface-water flow only indirectly as lateral discharges from seeps or springs through thin, permeable zones within the till. The largest well yields in this setting are from bedrock in large tributary valleys and in areas of low relief.

Valleys with established flood plains and the lower parts of adjacent hillsides include the two largest valleys (Batavia Kill and lower Mitchell Hollow). These areas receive recharge from upland sources in volumes that exceed (and supplement) that from direct recharge. Water in permeable, low-angle fractures below the shallowest fractured zone in bedrock appears to be confined and is probably part of the sub-regional flow system. This hydrogeologic setting is the most favorable of the three in terms of ground-water-resource potential because it has high well yields, high rates of recharge, including the potential for induced recharge, and consistently saturated unconsolidated and bedrock aquifer materials.

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GLOSSARY

[Asterisks indicate definitions from Bates and Jackson (1980)]

Alluvium*—a general term for stream deposits of recent origin, including clay- to gravel-size sediments or similar detrital material laid down in streambeds, flood plains, alluvial fans, and deltas.

Aquifer*—a saturated body of rock (bedrock or unconsolidated sediment) that is sufficiently permeable to yield economically significant quantities of water to wells and springs.

Base flow—streamflow sustained solely by ground-water discharge; the overland flow component, associated with storms, is absent.

Borehole geophysical logging—collection of subsurface information in wells or boreholes obtained with various probes lowered from land surface. Records or logs generated by the probes and supporting equipment can provide information of the construction of wells and on the physical properties of the rocks and water penetrated by those wells.

Borehole short circuit—a condition under which a wellbore intersects more than one water-bearing fracture, thereby establishing a hydraulic connection. Natural or pumping-induced head differences among the fractures causes waters to flow and possibly mix within the wellbore.

Colluvium—a general term for loose, heterogeneous, and incoherent deposits of soil material and(or) rock fragments deposited by surface runoff (rainwash, sheetwash) or slow downslope creep on hillsides, usually collecting at the base of slopes and cliffs.

Connate water*—water that has been out of contact with the atmosphere for at least an appreciable part of a geologic period.

Contact spring*—a type of gravity spring whose water flows to the land surface from permeable strata over less permeable or impermeable strata that prevent or retard the downward percolation of the water.

Depression spring—a type of gravity spring, with its water flowing onto the land surface from permeable material as a result of the land surface sloping down to the water table.

Diagenesis*—all the chemical, physical, and biologic changes undergone by a sediment after its initial deposition, and during and after its lithification, exclusive of weathering and metamorphism.

Dip*—the angle that a structural surface, such as a bedding or fault plane, makes with the horizontal. measured perpendicular to the strike of the structure.

Discharge—the volume of water passing a given reference point per unit of time. Stream and ground-water discharges in this report are given in cubic feet per second, and pump discharges from wells are reported in gallons per minute.

Ephemeral stream—a stream that is dry for part of the year.

Holocene*—recent; that period of time (an epoch) and those sediments deposited since the last ice age (about 8,000 years ago to the present).

Hydraulic conductivity (permeability)—the capacity of an earth material to transmit water, expressed herein as the rate of flow in feet per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temperature; reported as feet per day.

Hydraulic gradient—the rate of change in total head per unit of distance of flow in a given direction.

Hydraulic head—the height above a datum plane of a column of water; in wells, it represents elevation head and pressure head (the height of the water column above the screen or fracture).

Natural gamma radiation—gamma radiation given off by naturally occurring radioisotopes including potassium-40 and daughter products of the uranium-thorium-decay series within rock material. These radioisotopes commonly are associated with clay minerals.

Nonpoint source—a source of water contamination characterized by diffuse input of a contaminant over a wide area. Definition of this type of contamination, in contrast to that from a point source, depends on the scale of investigation or the ability to differentiate sources. For example, the septic systems in a highly developed residential area would constitute a nonpoint source, whereas a single septic system would constitute a point source.

Nutrient—any inorganic or organic compound that sustains plant life; nitrogen and phosphorus species in particular.

Perennial stream—a stream that flows year round.

Pleistocene*—the epoch (and associated deposits) preceding the Holocene epoch and encompassing glaciation after the Tertiary Period. (Ranges from 2 to 3 million years ago to about 8,000 years ago.).

Piezometer—a well screened in, or open to, a small vertical interval, such that the water level within it approximates the hydraulic head in the aquifer at that point.

Point source—a source of water contamination characterized by input from a discrete location either actively (as water discharging) or passively (leachate generation controlled by precipitation). A septic system actively supplies wastewater, whereas a salt stockpile passively supplies leachate.

Porosity—the voids or openings in a rock or unconsolidated sediments. It is expressed as the ratio of the volume of openings to the total volume of rock material.

Potentiometric surface*—an imaginary surface representing the total head of ground water in an aquifer, defined by the level to which water will rise in a piezometer at any given location.

Rose diagram*—a circular or semicircular star-shaped graph indicating values or quantities in several directions of bearing (compass direction), consisting of radiating rays drawn proportional in length to the value or quantity. In this report, a structural diagram for plotting strikes of planar features is used.

Specific capacity*—the rate of discharge of a water well per unit of drawdown, commonly expressed in gallons per minute per foot.

Specific conductance—a measure of the ability of water to conduct an electrical current at 25 degrees Celsius. Conductance increases as the concentration of charged ionic species in solution increases; thus, a conductance measurement gives an indication of ion concentration in water. Generally reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Fluid conductivity, a more general term used in borehole geophysical logging, is equivalent to specific conductance in this report.

Stage—height of a surface-water body, such as a stream or reservoir, relative to a reference datum. Stage is measured directly at gaging stations.

Stratified drift*—a general term for sorted and layered glacial sediments deposited by a meltwater stream or settled from suspension in a body of quiet water adjoining a glacier.

Strike*—the direction or trend taken by a structural surface, such as a bedding or fault plane, as it intersects the horizontal.

Thalweg*—the line connecting the lowest or deepest points along a streambed or valley. Used herein to refer to the line connecting the deepest bedrock points (channel) beneath valley-fill deposits.

Transmissivity*—the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness, and is herein reported in units of feet squared per day.

Turbidity*—the state, condition, or quality of opaqueness or reduced clarity of water, because of the presence of suspended matter. Generally reported in nephelometric turbidity units (NTUs).

Underflow—ground water flowing downvalley *beneath* the bed of a surface stream.

Unregulated stream or drainage area—a stream or drainage area in which flow is not regulated or altered by impoundments (dams), surface-water withdrawals, or surface-water additions.

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y.

[Well locations are shown on pl. 1. gal/min, gallons per minute; ° , degrees; ', minutes; ", seconds. A dash indicates no data.]

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
82	421755	0741753	Tompkin, B.	B	136	56	15
92	421844	0741450	Karamanis, J.	B	44	26	30
93	421859	0741448	Lewis, W.	B	113	25	3
95	421904	0741402	Heid, F.	B	186	103	5
96	421909	0741453	Doll	B	52	32	15
105	422029	0741451	Anderson, E.	B	143	67	8
107	422105	0741440	Bradley, W.H.	B	100	54	4
108	422108	0741439	Schulter	B	175	43	6
117	421744	0741539	Windham Development Co.	B	600	66	—
120	421806	0741525	Shoemaker, R.	B	101	50	5
124	421832	0741552	Kravitz	B	260	44	20
130	421907	0741452	Koefolo, J.	B	189	43	2
136	421943	0741446	Melody Manor	B	115	44	6.5
138	421943	0741513	Douaihy	B	246	—	—
139	421948	0741502	Fergason, C. and E.	B	108	79	4.5
144	421949	0741740	Wiegandt, L.	B	238	47	2
146	421944	0741724	Conine, H.	B	170	100	35
147	422000	0741902	Gooss, A.	B	120	28	5
148	421814	0741721	Holdridge, F.	B	156	10	10
149	421953	0741715	Tompkins, Mrs. C.L.	B	103	81	2
151	421957	0741716	Rambo, A.	B	93	75	20
155	421932	0741839	Weibel, C.	B	200	7	3
156	421949	0741846	Case, E.	B	150	7	3
157	422011	0741522	Shaw, J.	B	143	29	7
159	422114	0741439	Scott, R.	B	105	65	9
160	422121	0741442	Bradley, F.	B	98	67	12
161	422128	0741438	Moore, V.	B	79	42	6
164	422138	0741432	Palazzo, P.	B	76	51	8
168	421815	0741654	Windham House	B	158	28	10
170	422216	0741405	Overton	B	478	1	4
171	421852	0741444	Turpish, J.	B	38	24	8
172	421940	0741442	Bernhard, S.	B	108	16	30
173	422016	0741511	Bunnell, H.	B	161	32	8
174	422042	0741524	Blake and Sanford	B	98	29	12
175	421836	0741424	Soper, W.	B	135	25	6
176	421823	0741358	Soper, W. (Estate)	B	100	40	35
177	422148	0741501	Kelly Acres	B	128	5	36

[a] Asterisk indicates geophysical logs were collected; T indicates test hole (no well)
[b] B = bedrock; U = unconcolidated material; S = spring
[c] Parentheses indicate redrilled well

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
178	421815	0741623	Muller, G.	B	98	30	15
179	421956	0741711	Le Brun, F.	B	115	100	15
182	421920	0741800	Laine, N.	B	323	17	15
185	421707	0741008	Hoyt, S.	B	155	33	6
194	421833	0741347	Chamberlain, G.	B	143	32	35
198	421823	0741527	School Dist. 1 Central	U	35.0	—	30
238	421828	0741446	Village of Windham	U	50	—	—
613	421745	0741802	Greene County	U	28.4	72	—
614	421740	0741803	Greene County	U	38	—	—
615	421759	0741522	Ski Windham	U	26	—	—
616	421828	0741544	Ski Windham	U	20	—	—
617	421827	0741544	Ski Windham	U	20	—	—
618	421827	0741541	Ski Windham	U	39.5	39.5	—
619*	421827	0741543	Ski Windham	B	83	39	24
620*	421827	0741541	Ski Windham	B	100	35	75
621*	421827	0741540	Ski Windham	B	148	36	100
622*	421818	0741536	Ski Windham	B	227	57	200
623*	421817	0741527	Madtes, W.	B	290	72	150
624*	421804	0741500	Sheridan, T.	B	902	35	2.3
625*	421812	0741441	Priebke, I.	B	440	35	320
626	421814	0741403	Windham Country Club	B	360	40	56
627	421826	0741355	Thompson House Resort	B	350	57	38
628	421824	0741351	Thompson House Resort	B	189	75	50
629	421825	0741349	Thompson House Resort	B	155	52	35
630*	421829	0741359	Thompson House Resort	B	273	52	45
631*	421827	0741438	Town of Windham	B	252	55	100+
632	421828	0741446	Town of Windham	B	280	56	75
633	421829	0741537	GNH Lumber	B	120	39	30
634	421826	0741556	VFW Hall	B	82	—	—
635*	421828	0741558	O'Rourke, R.	B	427	32	—
636	421828	0741558	O'Rourke, R.	B	133	—	—
637	421811	0741626	Chicoy, J.	B	277	90	65
638	421808	0741628	Chicoy, J.	B	202	98	75
639*	421805	0741630	Chicoy, J.	B	305	90	20
640	421756	0741531	Ski Windham	B	600	67	0.5
641*	421729	0741605	Ski Windham	B	480 (610)	48	—(2)
642	421913	0741500	Windham Ridge Club	B	168	58	62
643	421914	0741458	Windham Ridge Club	B	209	46	153
644*	421903	0741523	Town of Windham	B	340	25	10
645	421822	0741515	Morse, R.	U	30	—	—
646*	421809	0741512	Taylor, D.	B	427	85	—
647*	421810	0741514	Taylor, D.	B	200 (424)	86	—(—)

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
648	421838	0741430	Lane, L.	B	—	—	5
649	421838	0741430	Lane, L.	B	—	—	—
650	421834	0741427	Lane, L.	B	237	62	15
651	421834	0741403	Flynn, J.	B	98	32	18
652	421815	0741627	Chicoy, J.	B	229	22	7.5
653	421819	0741622	Gurecki, S.	B	348	32	5
654	421817	0741620	Gurecki, S.	B	—	—	—
655	421821	0741350	Ratlich	B	227	50	—
656	421822	0741347	Ratlich	B	186	47	100
657	421818	0741700	Christman, S.	B	489	37	4
658	421821	0741656	Christman, S.	B	300	28	1
659	421821	0741651	Christman, S.	B	320	33	5.5
660	421819	0741652	Christman, S.	B	158	36	10
661	421811	0741336	Melz, R.	B	288	57	200+
662	421800	0741517	Fromm, R.	B	450	30	4
663	421815	0741549	Sheridan, T.	U	21.5	32	—
664	421810	0741612	Sheridan, T.	U	46.5	81.5	—
665	421809	0741612	Sheridan, T.	U	20	71.5	—
666	421910	0741502	Windham Ridge Club	U	36	—	—
667	421909	0741501	Windham Ridge Club	U	15	—	—
668	421909	0741501	Windham Ridge Club	U	15	—	—
669	421908	0741502	Windham Ridge Club	U	35	—	—
670	421826	0741437	Windham Country Club	U (S)	—	—	—
671	421850	0741458	Town of Windham	U (S)	—	—	—
672	421848	0741454	Town of Windham Highway Dept.	B	85	53	10
673*	421847	0741453	Kokkoris, S.	B	226	40	100
674	421855	0741454	Greene County	B	226	65	100
675	421903	0741523	Town of Windham	U (S)	—	—	—
676	421826	0741447	Town of Windham	U	53	—	30
677	421844	0741449	Giovanis	B	104	22	40
678	421844	0741441	Tomasch	B	152	20	43
679	421858	0741450	Clanner	B	288	—	30
680	421856	0741452	NYSEG	B	208	71	15
681	421823	0741439	Fogarty, K.	B	229	—	—
682	421930	0741452	Krystallis	B	165	58	50
683	421922	0741445	Constantinescu	B	554	52	5
684	421935	0741450	Latuner	B	186	47	20
685	421915	0741449	Wagon Wheels	B	225	—	30
686	421947	0741441	Gonzalez	B	100	12	15
687	421952	0741509	Case	B	418	73	2
688	421948	0741437	Alamia	B	349	37	6

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
689	421948	0741437	Alamia	B	240	37	200+
690	421820	0741504	Delaney, D.	B	352	90	60
691	421936	0741441	Truax	B	209	42	1
692	421953	0741439	Steinman, D.	B	268	34	100+
693	422011	0741440	Inserillo	B	230	23	2
694	421818	0741727	Albert, T.	B	300	12	1.5
695	421820	0741732	Davis, G.	B	148	12.5	5
696	421825	0741727	Debeau	B	480	12	1
697	421838	0741726	Brandow, E.	B	147	22	2
698	421938	0741843	Mitchell, T.	B	596	13	3.5
699	421853	0741726	Kelderhouse, J.	B	103	22	12
700	421906	0741723	Sutton	B	200	2	10
701	421813	0741544	Carter, J.	B	427	28	8
702	421914	0741725	Van Valin	B	181	5	35
703	421920	0741722	Gambella Constr. Co.	B	190	13	12
704	421928	0741733	Gambella Constr. Co.	B	117	68	50
705	421944	0741720	Cooke, T.	B	177	60	60+
706	421942	0741724	Hersch	B	145	69	100
707	421933	0741722	Cooke, C.	B	152	44	10
708	421948	0741724	Coones	B	165	71	35
709	421958	0741713	Tompkins	B	103	—	2
710	422002	0741712	Rambo	B	93	—	20
711	422012	0741719	Vickers, V.	B	105	37	13
712	421748	0741512	Ski Windham	B	776	25	2
713	421812	0741737	Weinfeld	B	288	37	8.5
714*	421836	0741426	Sheridan, T.	B	302	26	100
715	421823	0741506	Donnelly, Mrs. E.	B	73	73	20
716	421816	0741544	Black, T.	B	171	—	—
717	421812	0741347	Mademann, P.	B	195	35	10
718	421907	0741414	Heid	B	506	40	1
719	421904	0741406	Heid	B	276	71	0.8
720	421827	0741601	O'Rourke, R.	U (S)	—	—	—
721	421817	0741433	Windham Lanes	B	216	57	8
722	421835	0741420	Schultz, P.	B	229	72	120
723*	421815	0741446	Turk	B	176	69	1.5
724	421834	0741433	Scarey, Mrs. J.	B	235	22	10
725	421830	0741541	Van Valen, P.	U (S)	—	—	—
726	421834	0741459	Adams, P.	U (S)	—	—	—
727	421817	0741705	Holdridge	B	160	2	3.5
728	422045	0741447	Johnson, J.	B	90	49	3
729	422005	0741559	Knolhoff, R.	B	160	28	2
730	421958	0741559	Leoce, J.	B	100	26	4

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
731	422005	0741844	Edson, S.	B	301	15	3
732	422025	0741726	Dutka, R.	B	99	73	25+
733	421818	0741625	Garbarino, J.	B	161	18	8
734	421820	0741617	Muller, G.	B	140	45	2
735	421817	0741710	Tuttle, H.	B	130	15	10
736	421823	0741745	Lawrence, T.	B	155	75	6+
737	421911	0741720	Baker	B	205	14	20+
738	422026	0741716	Mulford, W.	B	160	75	20
739	422026	0741718	Mulford, W.	B	120	59	6
740	421800	0741744	Alar	B	160	37	5
741	422055	0741637	Comanzo	B	80	57	3
742	421836	0741400	Jensen, W.	B	155	75	6+
743	422037	0741451	Gannon	B	104	68	10
745	422028	0741440	Somma	B	500	38	2
746	422115	0741438	Montana	B	116	65	5
747	422115	0741440	Montana	B	178	82	3
748*	421844	0741337	Porcello, J.	B	655	40	19
749	421844	0741337	Porcello, J.	B	655	40	19
750	421929	0741516	Gleason	B	420	18	3
751	421842	0741347	Porcello, J.	B	375	—	6
752	421754	0741753	Ashland Comm. Church	B	169	62	12
753	421842	0741541	Davis, R.	B	300	6	3
754	421839	0741535	Pooche	B	300	12	7
755	421836	0741538	Benson	B	300	32	1
756	421834	0741526	Smith, K.	B	311	18	2
757	421909	0741547	Brown	B	175	15	30
758	421858	0741554	Bromley	B	255	14	2.5
759	421929	0741623	Singer	B	600	32	1
760	421927	0741622	Melz, R.	B	431	19	2
761	421905	0741439	Schlemmer, W.	B	348	24	25
762	421835	0741355	Briegle, J.	B	186	12	7
763	421840	0741518	La Vecchia, R.	B	297	19	2.5
764	422035	0741757	Nichols, R.	B	142	27	4
765	421835	0741548	Wiener, S.	B	600	72	4
766	422152	0741428	O'Sullivan	B	132	2	12
767*	421800	0741418	Sheridan, T.	B	702	18	1
768	422219	0741403	Brendecke	B	429	4	0.8
769	422144	0741415	Falciano, T., Jr.	B	352	47	20
770	422142	0741416	Flaciano, T., Sr.	B	157	37	40
771	422143	0741411	Flaciano, T., Jr.	B	306	42	25
772 (T)	421738	0741800	Goff, R.	U	—	65	—

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
773 (T)	421741	0741800	Greene County	U	—	80	—
774 (T)	421951	0741454	Town of Windham	U	—	65	—
775 (T)	421821	0741558	O'Rourke and Leary	U	—	80	—
776 (T)	421817	0741609	O'Rourke and Leary	U	—	78	—
777 (T)	421815	0741349	Mademann, P.	U	—	47	—
778 (T)	421801	0741749	Ashland Cemetery	U	—	20	—
779 (T)	421807	0741708	Tuttle, H.	U	—	58	—
780	421826	0741541	Ski Windham	U	14	—	—
781	422130	0741753	Megerle, E.	B	698	12	1
782	421945	0741404	Youssis, W.	B	498	28	4
783	421921	0741418	Murray, M.	B	823	52	2.5
784	422003	0741816	O'Mahoney, P.	B	323	10	4
785	421936	0741418	Eder, A.	B	497	52	1
786	421835	0741510	Reilly, B.	B	348	43	2.5
787	421821	0741353	La Griglia Restaurant	B	265	82	75
788	421837	0741547	Smythe, L.	B	458	72	2
789	421838	0741518	Bohan	B	327	12	2
790	421846	0741517	Bistorelle	B	500	16	1.5
791	421808	0741336	Church of New Life	B	308	27	100+
792	421806	0741346	Morse	B	355	32	1.5
793	421930	0741510	Connelly	B	595	30	1
794	421947	0741506	Kurz	B	462	67	25
795	421947	0741449	Dunbar	B	80	27	50
796	421812	0741523	Jahnsen	B	387	8	1.3
797	421812	0741522	Jahnsen	B	332	55	1.5
798	421814	0741434	Sheridan, T.	B	235	33	6
799*	421801	0741421	Sheridan, T.	B	866	12	.8
800	421814	0741423	Sarrazin, M.	B	595	53	4
801	421842	0741450	Chura	B	165	23	15
802	422146	0741428	Falciano	B	303	63	3
803	421807	0741509	Fromm, R.	U (S)	—	—	—
804	421812	0741546	Stubbs, R.	U (S)	—	—	—
805	421823	0741506	Donnelly, E.	U	30	—	5+
806	422019	0741431	Riggio, J.	B	198	17	2
807	422055	0741510	Mulford, G.	B	100	13	13
808	421833	0741437	Scarey, H.B.	B	100	7	8
809	421958	0741401	Hayden Mtn. Corp.	B	150	119	12
810	422056	0741330	Roach, P.	B	727	4	.5
811	422057	0741326	Greene, R.	B	1,200	4	.1
812	422053	0741337	Savin	B	1,300	1	1
813	421828	0741546	Windham Mtn. Village	U	40	52	52+
814	421828	0741546	Windham Mtn. Village	U	36	50	31

APPENDIX A. Data on wells and test holes in the Batavia Kill study area, Greene County, N.Y. (continued)

Local well or test hole number[a]	Latitude (° ' ")	Longitude (° ' ")	Owner of record	Aquifer code[b]	Depth of well[c] (feet)	Depth to bedrock (feet)	Reported yield[c] (gal/min)
815	421839	0741400	Leslie, K.	B	100	15	30
816	421834	0741405	Lucas	B	100	18	14
817	421810	0741611	Sheridan, T.	U	47	82	35
818 (T)	421812	0741621	N.Y. State Dept. of Transportation	U	—	89	—
819 (T)	421811	0741620	N.Y. State Dept. of Transportation	U	—	85	—
820	422035	0741304	Conklin, R.	B	163	39	24
821	421958	0741308	Zies, H.	B	172	48	25
822	421903	0741352	Besculides, M.	B	136	26	4
823	421810	0741611	Sheridan, T.	U	—	85	—
824	421812	0741419	Mademann, P.	B	479	43	1.5
825	422053	0741510	Mulford, G.	B	136	9	60

APPENDIX B. Chemical analyses of ground water from the Batavia Kill study area, Greene County, N.Y., 1991-92, by water type

[Analyses by U.S. Geological Survey, Arvada, Colo. and Reston, Va. Concentrations in milligrams per liter unless specified otherwise. °C, degrees Celsius; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; TU, tritium units; < less than. Dash indicates no data. Locations are shown on pl. 1.]

Local well or spring number[a]	Source [b]	Collection date	Temperature	Specific conductance (µS/cm)	Total dissolved solids	pH (field)	H_2S odor[c]	Dissolved oxygen	Calcium	Magnesium	Sodium
Mixed ion											
613	U	08-22-91	10.2	121	75	6.2	N	—	10	3.8	7.5
670	Sp	06-27-91	8.6	87	42	6.7	N	—	6.5	1.9	5.5
675	Sp	07-29-92	8.2	67	47	5.7	N	7.6	5.7	1.9	5.2
725	Sp	07-29-92	11.3	70	48	5.7	N	7.6	5.6	2.2	4.9
726	Sp	07-28-92	12.2	102	67	5.9	N	7.6	7.6	2.6	7.8
Ca - HCO_3											
622 (72')	B	10-30-92	8.5	225	133	7.0	N	<1.0	28	5.8	8.8
635 (72')	B	08-19-92	11.8	127	81	6.3	N	2.7	14	4.1	6.2
238	U	10-13-92	9.6	228	132	6.9	N	1.0	24	5.2	13
720	Sp	07-29-92	10.1	98	67	6.5	N	4.5	10	3.7	4.8
Na - HCO_3											
625 (220')	B	08-20-92	9.5	164	101	7	N	3.3	7.9	1.3	25
631 (110')	B	09-14-92	8.9	314	191	8.5	N	<1.0	8.7	1.9	60
631 (140')	B	10-14-92	—	342	—	—	N	—	—	—	—
631 (210')	B	10-14-92	—	264	—	—	N	—	—	—	—
631 (225')	B	09-14-92	9.2	254	154	6.6	Y	<1.0	1	.16	55
632 (Flowing)	B	05-28-92	8.4	265	167	8.5	Y	<1.0	.36	.05	58
646 (340')	B	08-31-92	9.6	198	120	8.7	Y	<1.0	2.8	.47	41
647 (350')	B	09-08-92	9.6	245	149	8.9	Y	<1.0	5	1.3	50
674	B	07-30-92	9.4	210	135	8.1	N	<1.0	12	2	34
714 (170')	B	09-08-92	9.9	135	86	6.3	N	<1.0	4	1	22
715	B	08-13-92	9.4	326	194	8.8	Y	<1.0	12	2.5	58
808	B	08-19-92	10.7	234	149	7.3	N	5.1	6.1	1.7	45
Na - HCO_3/Cl											
625 (275') [d]	B	—	—	327	—	—	—	—	—	—	67
630 (200')	B	09-02-92	9.5	645	351	9.1	N	<1.0	3	.27	130
714 (280')	B	09-08-92	9	903	481	9.1	Y	<1.0	1.1	.19	190
Na - Cl/HCO_3											
630 (150') [d]	B	—	—	1,308	—	—	—	—	—	—	238
Na - Cl											
622 (200')	B	09-02-92	8.5	3,340	—	8.3	Y	<1.0	37	3.4	630
623 (240')	B	09-02-92	9.1	1,447	744	8.9	Y	<1.0	9.2	1.1	280
647 (400')	B	09-08-92	9.5	6,330	—	7.7	N	<1.0	66	8.3	1,200
Na - Cl (Saline)											
635 (225')	B	08-19-92	10.3	35,000	—	6.5	N	<1.0	1,000	96	6,600

[a] Number in parentheses is the sampling depth, in feet (') below land surface

[b] Sample sources: (U) unconsolidated deposits, (B) bedrock, and (Sp) spring

[c] H_2S odor—A qualitative determination (Y)es or (N)o based on smell during sample collection

[d] Specific conductance, chloride, and sodium concentrations estimated from borehole water analyses and flow measurements above and below permeable fractures

Appendix B. Chemical analyses of ground water from the Batavia Kill study area, Greene County, N.Y., 1991-92, by water type (continued)

Local well or spring number	Potas-sium	Chlo-ride	Sul-fate	Fluo-ride	Alkalin-ity	Bicar-bonate[e]	Car-bonate[e]	Calcite Saturation Index (log IAP/KT[e]	Boron	Silica	Tritium total	Tritium 2 sigma
Mixed ion												
613	1.1	17	13	<0.1	26	32	<0.01	-2.83	10	6.7	—	—
670	.8	6.6	9	<.1	8.9	11	<.01	-3.05	<10	6.3	—	—
675	1.2	4.8	9.1	<.1	17	21	<.01	-3.82	<10	7.5	—	—
725	.5	8.4	9.1	<.1	15	18	<.01	-3.80	<10	6.7	—	—
726	.8	12	9.9	<.1	15	18	<.01	-3.45	10	8.3	—	—
Ca - HCO_3												
622 (72')	.8	16	12	.2	84	102	.04	-1.17	20	9.9	16.9	—
635 (72')	1	4.1	11	.1	50	61	<.01	-2.37	<10	9	16.9	1.4
676	1	15	16	.2	76	92	.03	-1.35	20	9.2	20.6	1.4
720	.4	3.6	8.6	<.1	36	44	<.01	-2.45	<10	9.4	—	—
Na - HCO_3												
625 (220')	.4	5.7	11	.3	67	81	.03	-1.78	120	8.2	9.7	1
631 (110')	.3	31	14	<.1	112	132	1.67	-.06	100	7.7	—	—
631 (140')	—	—	—	—	—	—	—	—	—	—	13.8	1.2
631 (210')	—	—	—	—	—	—	—	—	—	—	12.8	1
631 (225')	.1	21	20	<.1	77	94	.01	-3.04	70	10	—	—
632 (Flowing)	.1	16	22	.4	98	116	1.39	-1.50	110	11	—	—
646 (340')	.2	6.7	4.2	.3	94	109	2.20	-.38	90	8	1.3	.6
647 (350')	.2	23	2.7	.3	97	111	2.93	-.03	100	7.7	1.1	.8
674	.3	7.3	16	.2	88	106	.46	-.44	60	9.7	—	—
714 (170')	1.9	6.7	16	.1	44	54	<.01	-2.98	60	6.1	14.7	1.2
715	.4	30	15	.5	111	126	3.18	+.35	120	8	15.9	1.2
808	.3	8.1	23	.3	90	109	.09	-1.46	110	9.9	16.3	1.2
Na - HCO_3/Cl												
625 (275') [d]	—	55	—	—	—	—	—	—	—	—	—	—
630 (200')	.2	110	7.1	.7	154	169	7.96	+.08	150	7.2	2.5	.6
714 (280')	.4	160	2.3	1.4	196	212	11.46	-.25	180	7.2	3.8	.8
Na - Cl/HCO_3												
630 (150') [d]	—	299	—	—	—	—	—	—	—	—	—	—
Na - Cl												
622 (200')	1	1,000	<.1	.6	107	125	1.13	+.10	140	6.4	11.3	1
623 (240')	.5	370	4.1	.7	118	132	4.42	+.23	160	6.7	11.3	1
647 (400')	1.8	1,900	<.2	<.1	97	114	.31	-.33	170	6.9	3.4	.8
Na - Cl (Saline)												
635 (225')	9.1	13,000	<.1	1.4	28	29	.01	-1.16	470	8	<.8	.6

[e] Equilibrium concentration estimates and calcite saturation indices were generated with WATEQ (Plummer and others, 1984)

Appendix B. Chemical analyses of ground water from the Batavia Kill study area, Greene County, N.Y., 1991-92, by water type (continued)

Local well or spring number	N, dissolved (as N)	Ammonia (as N)	Ammonium + organic nitrogen (as N)	Nitrite[f] + nitrate (as N)	Ortho-phosphate (as P)	Iron (µg/L)	Man-ganese (µg/L)	Strontium (µg/L)	Barium (µg/L)
Mixed ion									
613	.3	—	—	—	—	130	4	—	—
670	—	—	—	—	—	<3	2	—	—
675	—	<.01	<.2	.40	.02	<3	2	—	—
725	—	.01	<.2	.44	<.01	<3	<1	—	—
726	—	.02	<.2	1.90	.03	4	1	—	—
Ca - HCO_3									
622 (72')	—	.02	<.2	.07	<.01	17	300	—	—
635 (72')	—	.03	<.2	.38	<.01	7	39	62	23
676	—	.02	<.2	.36	<.01	<3	870	—	—
720	—	.01	<.2	1	.01	10	16	—	—
Na - HCO									
625 (220')	—	.06	.2	.06	.02	18	8	140	42
631 (110')	—	.05	<.2	<.05	.02	67	110	—	—
631 (140')	—	—	—	—	—	—	—	—	—
631 (210')	—	—	—	—	—	—	—	—	—
631 (225')	—	.08	<.2	<.05	.06	110	36	—	—
632 (Flowing)	.1	—	—	—	—	71	7	—	—
646 (340')	—	.05	<.2	<.05	.03	19	24	—	—
647 (350')	—	.05	<.2	<.05	.03	22	55	—	—
674	—	.03	<.2	.05	.01	26	230	180	19
714 (170')	—	.03	<.2	.37	<.01	15	43	—	—
715	—	.06	<.2	.17	.07	20	200	—	—
808	—	.02	<.2	.17	<.01	24	3	—	—
Na - HCO_3/Cl									
625 (275')[d]	—	—	—	—	—	—	—	—	—
630 (200')	—	.03	<.2	<.05	.04	30	15	—	—
714 (280')	—	.08	.2	<.05	.09	200	21	25	7
Na - Cl/HCO_3									
630 (150')[d]	—	—	—	—	—	—	—	—	—
Na - Cl									
622 (200')	—	.29	.3	<.05	<.01	11	140	1,100	1,200
623 (240')	—	.05	<.2	<.05	.06	28	35	280	130
647 (400')	—	.39	.4	<.05	<.01	<12	250	2,400	2,100
Na - Cl (Saline)									
635 (225')	—	2.8	2	<.05	.49	4,300	1,400	53,000	73,000

[f] Nitrite concentration was < 0.01 mg/L in all samples

Appendix C. Chemical analyses of ground-water samples that were affected by human activities, Batavia Kill study area, Greene County, N.Y., 1991-92

[Analysis by U.S. Geological Survey, Arvada, Colo. Concentrations in milligrams per liter except as specified. °C, degrees Celsius; µS/cm, microsiemens per centimeter, µg/L, micrograms per liter; <, less than. Dash indicates no data. Locations are shown in pl. 1.]

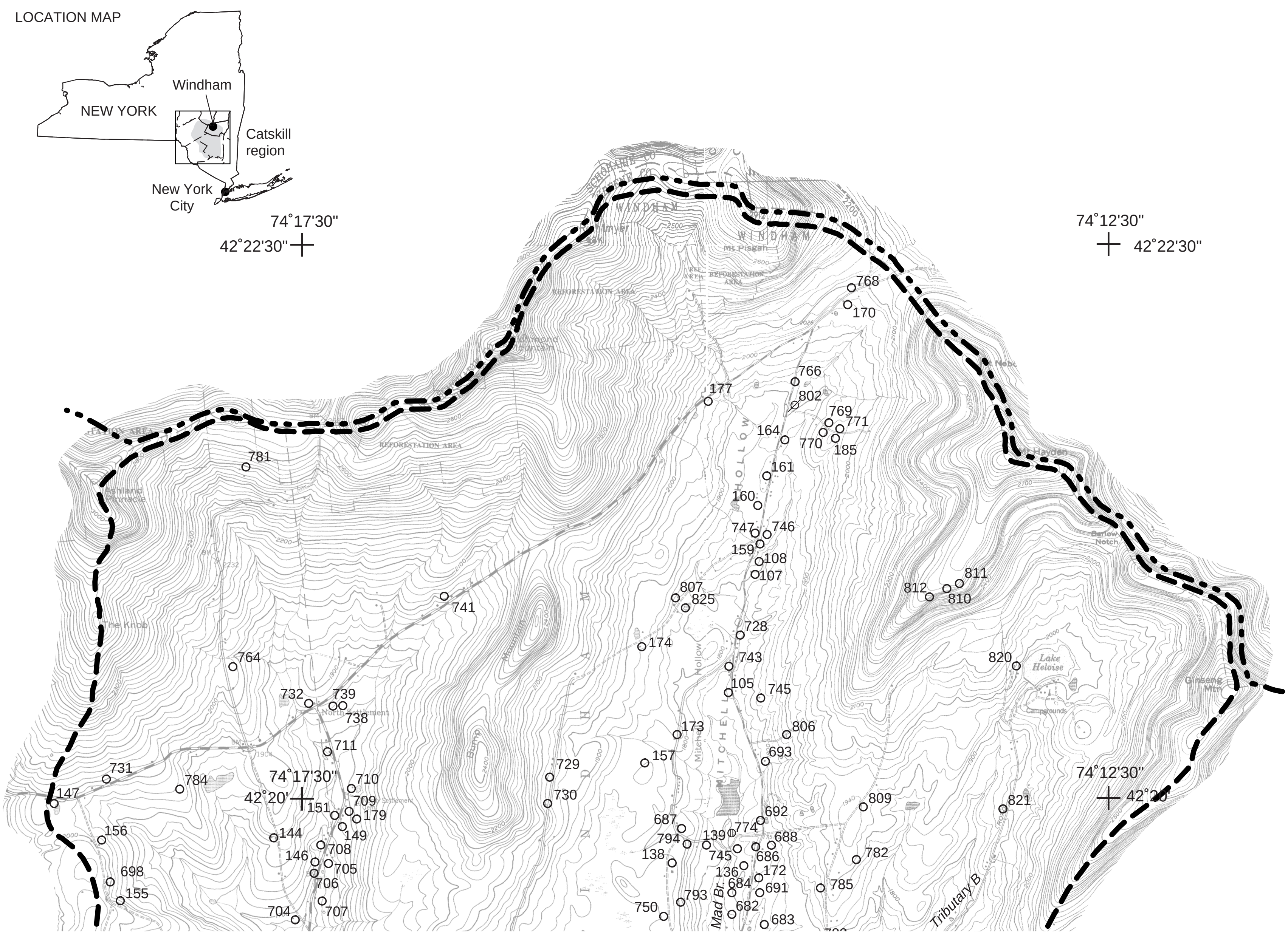
Site	Sample[a] source	Collection date	Temperature	Specific conductance (µS/cm)	Total dissolved solids	pH field (standard units)	Dissolved oxygen	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate	Fluoride
Samples affected by road-salt leachate														
614	U	08-13-92	12.8	247	131	5.9	—	7.9	1.6	36	0.7	62	8	<0.1
671	Sp	01-07-92	3	2,630	1,335	6.1	8.7	26	5.3	490	2	760	38	.4
672	B	01-07-92	—	1,279	588	—	1.9	56	13	150	1.7	280	18	.2
672	B	07-30-92	10.2	1,580	792	6.4	7.9	97	17	170	2.2	410	20	.1
Samples affected by septic leachate														
666 (low-use period)	U	06-26-91	12.6	179	92	7.4	—	18	3.9	8.8	.7	15	7.3	.1
666 (high-use period)	U	01-07-92	7.7	303	136	6.6	3.5	19	4.2	9.5	2.5	19	7.3	2.2
Samples with minor indication of septic or road-salt leachate														
Dilute Ca/Na - Cl														
664	U	10-13-92	7.1	179	94	5.6	6.7	13	4.5	12	.6	38	9.2	<.1
804	Sp	08-31-92	8.5	267	143	5.8	10.2	17	6.3	22	.9	63	17	<.1
Dilute Na - Cl														
617	U	01-08-92	9	106	56	5.9	3	6.5	2	7.9	.8	16	7.6	<.1
645	U	08-22-91	13.9	149	82	6.1	—	9.5	2.4	14	1.4	24	12	<.1
654	B	08-12-92	10.0	210	125	6.4	1.9	13	3.4	25	.9	34	13	<.1
673	B	10-13-92	9.3	195	106	5.9	5.4	13	4.2	15	.6	33	10	<.1
805	U	08-13-92	10.6	144	83	6.2	2	9	2.3	15	1.1	23	9.2	<.1
Dilute Ca - Cl/HCO_3														
803	Sp	08-12-92	8.6	170	96	6.2	4.2	17	3.9	10	.5	27	11	<.1
Ca - HCO_3														
667	U	06-27-91	11.7	143	83	7.8	—	18	4.4	4	1	5.6	7.9	<.1
667	U	01-07-92	7.1	148	79	5.7	1.8	17	4.1	3.8	.6	4.2	4.7	<.1

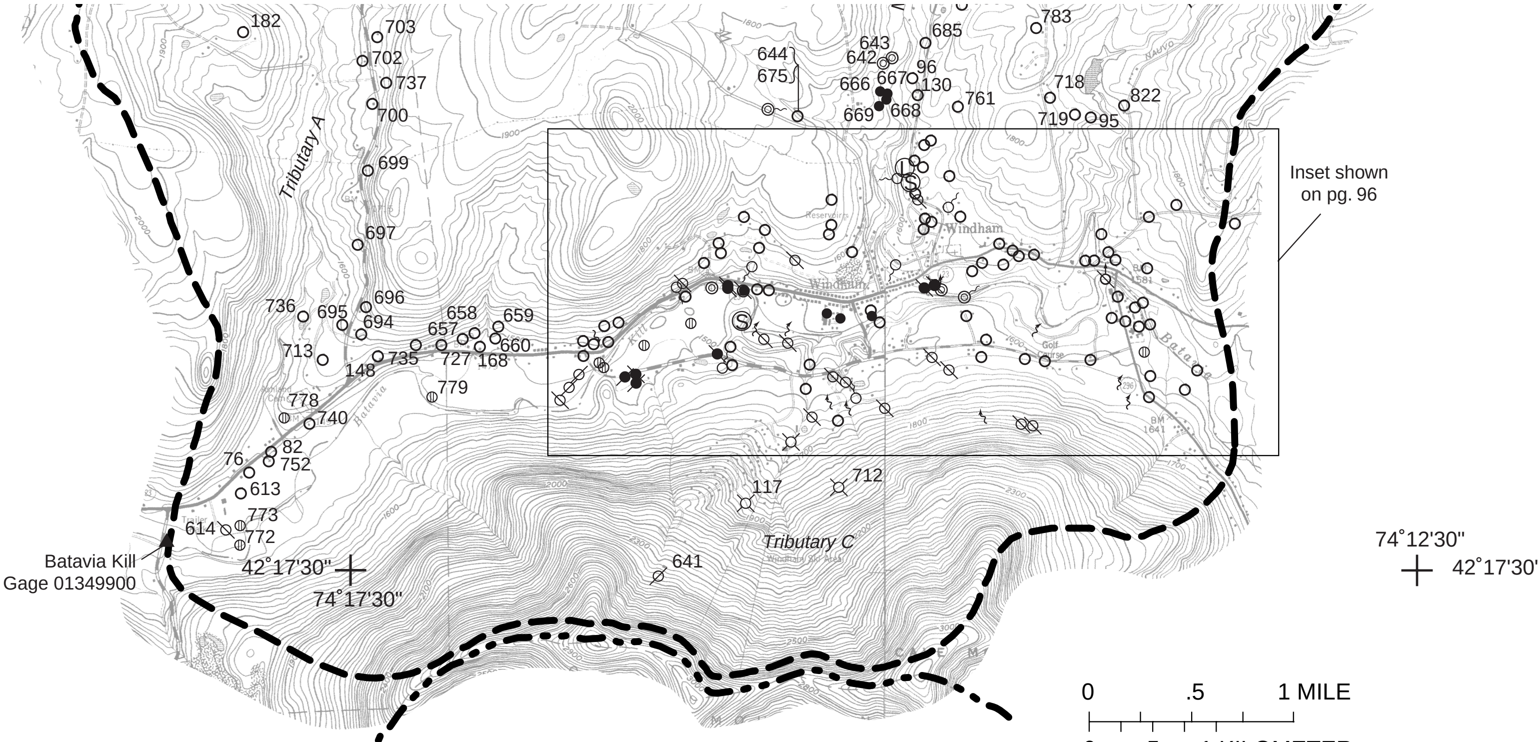
[a] U = unconsolidated deposits; B = bedrock; Sp = spring

Appendix C. Chemical analyses of ground-water samples that were affected by human activities, Batavia Kill study area, Greene County, N.Y., 1991-92 (continued)

Site	Alkalinity (as $CaCO_3$)	Boron (µg/L)	Silica	Tritium total (TU)	Tritium 2 Sigma (TU)	Dissolved nitrogen (as N)	Ammonia (as N)	Ammonium + organic nitrogen (as N)	Nitrite[b] + nitrate (as N)	Ortho-phosphate (as P)	Iron (µg/L)	Manga-nese (µg/L)	Stron-tium (µg/L)	Barium (µg/L)
Samples affected by road-salt leachate														
614	16	<10	4.3	—	—	—	0.09	<0.2	0.12	<0.01	87	150	—	—
671	15	20	3.9	—	—	—	—	—	—	—	20	40	—	—
672	86	20	11	—	—	—	—	—	—	—	2,400	4,600	—	—
672	83	20	11	—	—	—	.05	<.2	<.05	<.01	5,200	8,700	420	260
Samples affected by septic leachate														
666 (low-use period)	48	20	4.9	—	—	2.9	—	—	—	—	3,900	130	—	—
666 (high-use period)	90	30	4	—	—	11	—	—	—	—	14,000	300	—	—
Samples with minor indication of septic or road-salt leachate														
Dilute Ca/Na - Cl														
664	14	<10	6.4	15.7	3.8	—	.02	<.2	.50	<.01	37	7	—	—
804	13	<10	5.6	—	—	—	.03	<.2	.85	<.01	4	6	—	—
Dilute Na - Cl														
617	14	10	6.9	—	—	.6	—	—	—	—	46	5	—	—
645	24	20	4.3	—	—	1.2	—	—	—	—	14	1	—	—
654	43	20	8.9	18.8	4.5	—	.03	<.2	.32	<.01	9	10	—	—
673	30	20	9.5	—	—	—	.01	<.2	.60	.01	11	120	—	—
805	25	<10	4.7	16.9	3.8	—	.03	<.2	.88	.03	56	3	—	—
Dilute Ca - Cl/HCO_3														
803	36	<10	4.6	—	—	—	.04	<.2	.11	<.01	6	4	—	—
Ca - HCO_3														
667 (6-91)	56	<10	8.2	—	—	—	—	—	—	—	560	170	—	—
667 (1-92)	63	<10	6.1	—	—	—	—	—	—	—	640	520	—	—

[b] Nitrite concentration was < 0.01 mg/L in all samples

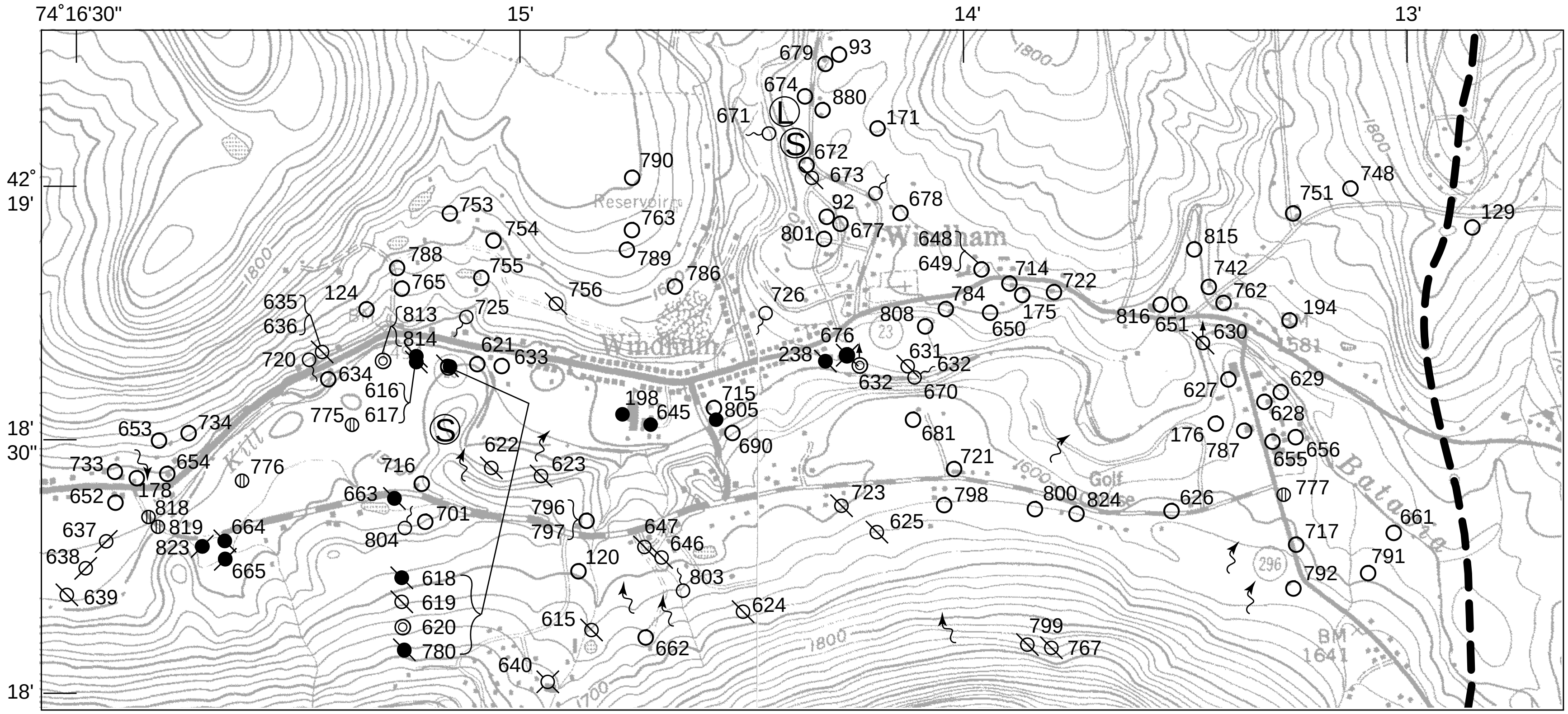

LOCATION MAP
NEW YORK
Windham
Catskill region
New York City
74°17'30"
42°22'30"
74°12'30"
42°22'30"
74°17'30"
42°20'
74°12'30"
42°20'
768
170
766
802
177
769
771
164
770
185
781
161
160
747
746
159
108
107
812
811
810
807
825
741
728
174
743
820
764
105
745
732
739
738
806
173
711
693
729
157
731
784
710
147
730
809
821
151
709
179
692
687
156
144
149
774
139
688
794
708
745
686
146
138
782
705
136
172
698
706
684
691
785
155
793
682
704
707
750
683
Mad Br.
Tributary B



Base from New York State Department of Transportation
1:24,000, Ashland, N.Y., 1976; Hensonville, N.Y., 1976;
Durham, N.Y., 1967; Livingston, N.Y., 1980

EXPLANATION

- Batavia Kill basin drainage divide
- Study-area boundary
- Well completed in bedrock; number is site-identification number listed in Appendix A.
- Well completed in unconsolidated deposits. Domestic use unless noted otherwise.
- Test hole
- Flowing artesian well
- Well used for public supply
- Unused well
- Observation well
- Destroyed well
- Spring or seep
- Inventoried spring
- Spring used for public supply
- Continuous-record streamflow-gaging station
- Salt-storage site
- Landfill



Base from New York State Department of Transportation
1:24,000, Ashland, N.Y., 1976; Hensonville, N.Y., 1976

0 .5 1 MILE

0 .5 1 KILOMETER

EXPLANATION

- Study-area boundary
- Well completed in bedrock; number is site-identification number listed in Appendix A. Domestic use unless noted otherwise.
- Well completed in unconsolidated deposits. Domestic use unless noted otherwise.
- Test hole
- Flowing artesian well
- Well used for public supply
- Unused well
- Observation well
- Destroyed well
- Spring or seep
- Inventoried spring
- Spring used for public supply
- Salt-storage site
- Landfill