GEOHYDROLOGY AND WATER QUALITY OF THE WALLKILL RIVER VALLEY NEAR MIDDLETOWN, NEW YORK

By Edward F. Bugliosi, George D. Casey, and
Denise Ramelot

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CONVERSION FACTORS AND VERTICAL DATUM AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
	Precipitation	
inch per year (in/yr)	25.40	millimeter per year (mm/y)
	Flow	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Hydraulic Conductivity	
foot squared per day (ft^2 /d)	0.09290	meter squared per day (m^2/d)

Vertical Datum: In this report, "sea level" refers to the National Geodetic Vertical Datum 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.

Water-quality units: Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L the numerical value is the same as for concentrations in parts per million. Specific electrical conductance of water is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Temperature in degree Celsius (^{o}C) can be converted to degrees Farenheight (^{o}F) by the following equation:

$$^{o}F=1.8X(^{o}C)+32$$

GEOHYDROLOGY AND WATER QUALITY OF THE WALLKILL RIVER VALLEY NEAR MIDDLETOWN, NEW YORK

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Abstract

A 66-square-mile area between Middletown and Goshen, in Orange County, N.Y., was studied to delineate the extent and thickness of the unconsolidated aquifer, define the movement of ground water, and compare the water quality in the unconsolidated and bedrock aquifers with that in the Wallkill River. The extent and thickness of the unconsolidated aquifer in the area was mapped from available data, seismic-refraction techniques, and test-drilling data. Water levels were measured at 253 domestic, commercial, and public supply-wells, including 15 wells that were drilled for this project—seven wells completed in bedrock and eight wells screened in unconsolidated material. Water samples from selected wells and the Wallkill River were analyzed for major anions and cations and selected trace metals.

The unconsolidated aquifer consists of discontinuous sand and gravel lenses within till and lacustrine silt and clay that are laterally continuous for only several thousand feet. Field observations suggest that the till in the study area is sandy and more permeable than most till in other parts of New York State. Unconsolidated deposits more than 20 feet thick that include sequences of till and sand and gravel are considered as a single, mappable aquifer. Ground-water flow patterns indicate that flow from upland areas east and west of the study area is toward and into the Wallkill River. Flow in the highly fractured shale bedrock aquifer also flows toward and directly into the river where bedrock crops out in the streambed.

The Wallkill River is a major regional hydrologic boundary in the study area. Measurements of the flow of the river on February 11, 1988 indicated a downstream increase in discharge of about 127 cubic feet per second between Pellets Island and the Route 17 bridge, 5 miles downstream. This increase can be attributed, in large part, to ground-water discharge to the river.

Waters in the bedrock and unconsolidated aquifers can be generally characterized as a calcium-bicarbonate type. Water in the bedrock is chemically similar to water in the unconsolidated deposits, probably because hydraulic connection between the aquifers allows mixing and because the aquifers are mineralogically similar. Water in the Wallkill River at low flow is chemically similar to water in both aquifers, indicating that ground water from these aquifers discharges to the river.

INTRODUCTION

Recent growth and expansion of communities near New York City have placed increasing pressures on local water resources. Population growth and extensive agricultural development in the area between Middletown and Goshen, in Orange County, N.Y., have increased the demand for water, and solid-waste-disposal sites within this area have also increased. Together, these changes could affect the water resources of the area. As a result, planners and resource managers need hydrogeologic data to develop the ground-water resources and protect them from contamination.

In September 1986, the U.S. Geological Survey (USGS), in cooperation with the Orange County Department of Public Works, began an investigation of the ground-water resources of the Wallkill River valley between Middletown and Goshen (1) to define the local ground-water-flow system and its interaction with the Wallkill River, and (2) document the chemical quality of the water in the unconsolidated and fractured-shale bedrock aquifers and the Wallkill River in the 5 mi reach between Pellets Island and Phillipsburg (fig. 1).

This report describes the aquifer geometry, hydraulic characteristics of the unconsolidated deposits and fractured bedrock, ground-water levels in 1986-87, general directions of ground-water flow, and the chemical water quality of the Wallkill River and both aquifers. Appendix 1 presents data on selected wells in the study area; appendix 2 presents data on the chemical quality of water in the Wallkill River and both aquifers.

Description of Study Area

The study area is a 66-mi^2 rectangle oriented northeast-southwest, parallel to the Wallkill River, between Middletown and Goshen in the western part of Orange County, about 70 mi northwest of New York City and lies between the Shawangunk Mountains, 7 mi north of the Wallkill River, and the Hudson Highlands, about 10 mi to the southeast (fig. 1). The Wallkill River is the largest river in the study area and flows into the Hudson River 15 mi to the east (fig. 1).

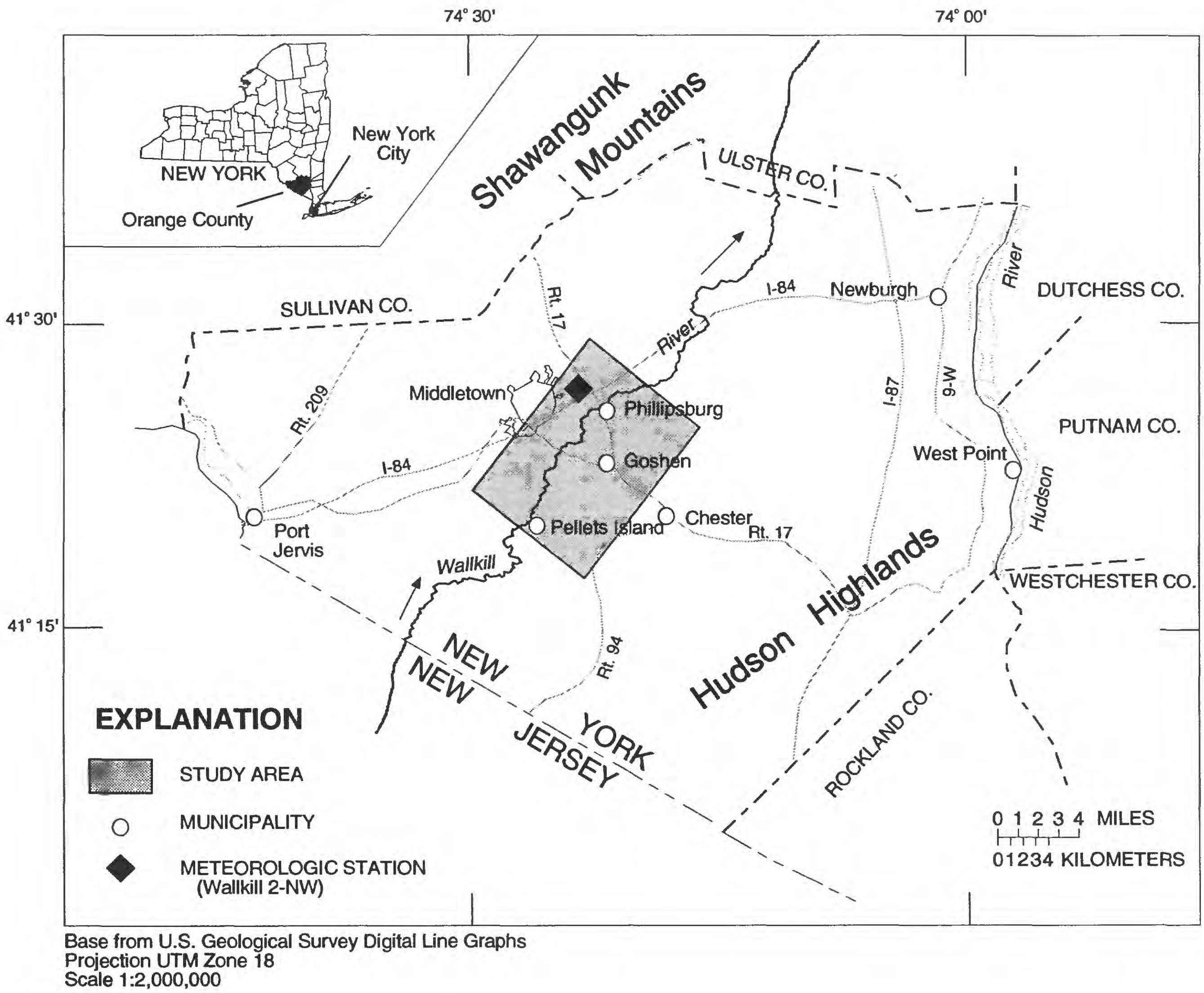


Figure 1. Map showing location and major geographic features of study area.

The only other major stream in the study area is Monhagen Brook, which flows into the Wallkill River 1 mi south of Middletown (fig. 2).

Most of the area has moderate relief with many hills and valleys; locally, relief is as much as 300 ft in less than 1/4 mi. The southern part of the area is flat, with almost no relief other than occasional small bedrock hills, locally called "islands." Traditionally, most of the land outside the towns in the southeastern part of the area (commonly referred to as the "black dirt" area for its organic-rich soils) has been agricultural. Other parts of the study area have been used for livestock production, especially horses.

The climate is temperate, with an average annual temperature of 51.3 °F at the Middletown meteorological station (fig. 1) (National Oceanic and Atmospheric Administration, 1950-85). Average annual precipitation is 44.8 in., and monthly average precipitation ranges from 2.35 in. in February to 4.09 in. in May (National Oceanic and Atmospheric Administration, 1950-85).

Previous Investigations and Data Sources

Several published reports and data from USGS files provided background information for the current study. A regional ground-water investigation that included the study area was completed by Frimpter (1970, 1972). The surficial geology was mapped by Connally and Sirkin (1967, 1970), and the generalized bedrock geology is described by Offield (1967) and Moxham (1972). Unpublished USGS information includes generalized geologic and hydrologic descriptions; several consultant reports concerning ground-water supply development contain results of aquifer-test analyses.

Methods of investigation

Geohydrologic data used in this study were obtained from USGS files, a USGS inventory of wells in the study area in the fall of 1986, and observation wells drilled for this study in March and May 1987. Additionally, a total of about 4 mi of seismic-refraction data were collected in the summer and fall of 1987. These data were used to (1) map the extent and thickness of the unconsolidated aquifer and the altitude of the bedrock surface and (2) map the water-table and potentiometric-surface altitudes in the aquifers to define the response of water levels to seasonal fluctuations in precipitation.

Data from 253 wells and test holes were used to define the extent and thickness of the unconsolidated aquifer and the altitude of bedrock surface. (Data are given in appendix 1; well locations are shown in fig. 2.) These data consist of logs of domestic, public-supply and institutional wells, highway test borings, and 25 observation wells drilled for this project; the logs include location and hydrologic, geologic, and water-use information on the unconsolidated and bedrock aquifers. Analyses of data from six seismic-refraction lines (figs. 2 and 9) helped to define the aquifer geometry.

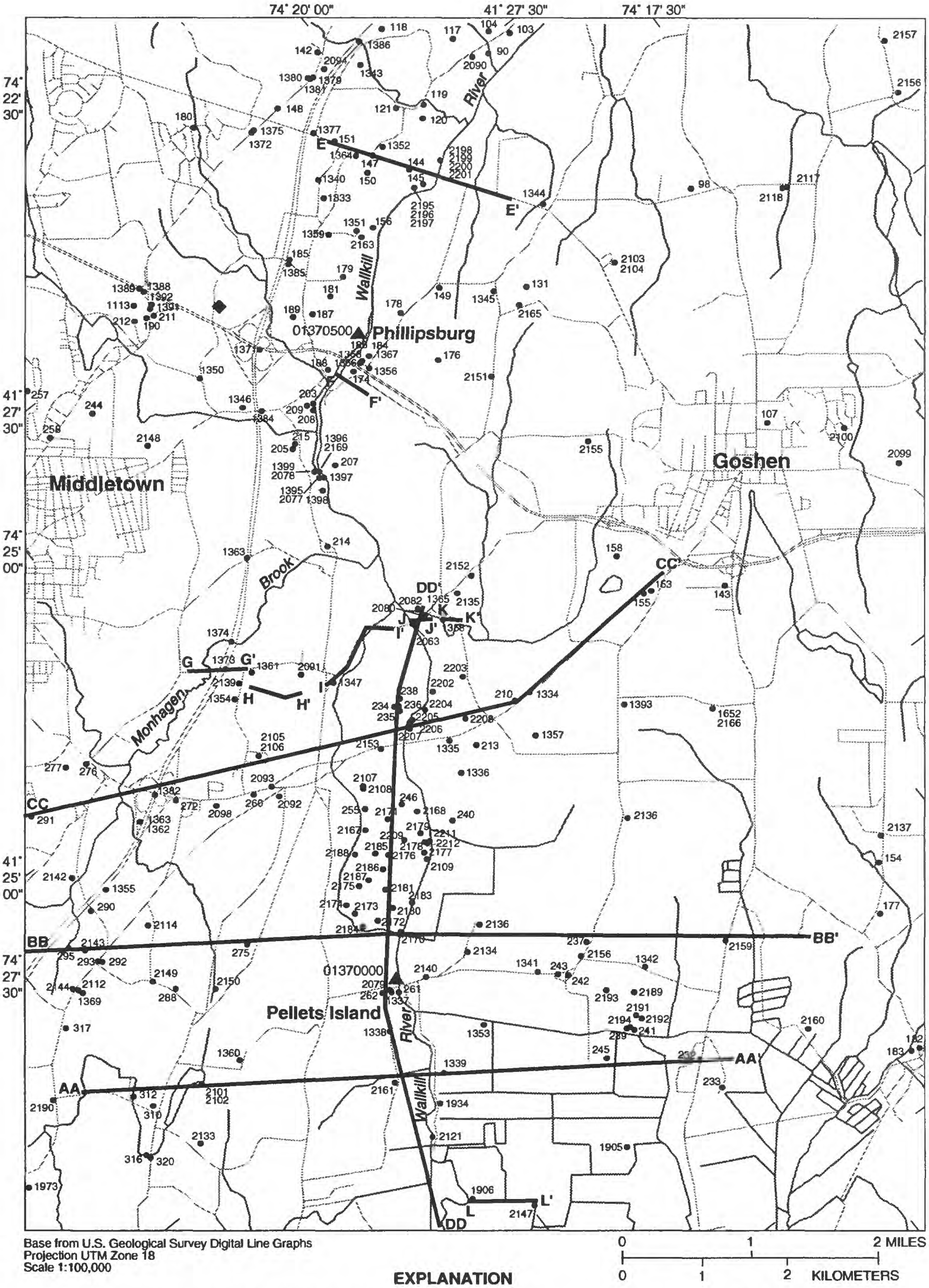
Water samples from the Wallkill River and the unconsolidated and bedrock aquifers were compared to determine the degree of interaction between surface water and ground water in the study area. Standard USGS water-sampling techniques were used (Edwards and Glysson, 1988, p. 61- 63). Wells with water-treatment systems were sampled ahead of the point of entry of any type of treatment system and only after the water pumps had cycled at least twice. All samples from observation wells were obtained by submersible pump, and the samples were collected after three casing-volumes of water had been discharged. All water samples were analyzed by the USGS National Water Quality Laboratory in Denver, Colo.

Acknowledgments

The authors thank the Orange County Department of Public Works for their cooperation and use of facilities and equipment, the New York State Department of Environmental Conservation in New Paltz for providing consultants' reports of pumping tests of wells in the study area, the New York State and Federal Highway Departments for test-boring and seismic data, and the well owners who permitted sampling their wells for water quality and water levels.

GEOHYDROLOGY

The geohydrology of the study area reflects the interaction between bed rock and unconsolidated deposits in a complex sedimentological setting. The bedrock surface was modified by glacial processes within the Wallkill River valley during Pleistocene



EXPLANATION

1973 ●	WELL–OBSERVATION, TEST, OR SUPPLY AND WELL NUMBER	AA——AA'	LINE OF GEOLOGIC SECTION (Sections shown on fig. 7)
◆	METEOROLOGICAL STATION (Wallkill 2-NW)	L——L'	LINE OF SEISMIC REFRACTION SURVEY (Sections shown on fig. 9)
01370000▲	CONTINUOUS DISCHARGE MEASUREMENT SITE AND STATION ID		

Figure 2. Map showing locations of observation wells, test borings, and geologic sections

glaciation and the unconsolidated material was deposited as ice retreated from the valley.

Geology

The study area is underlain by fractured sedimentary rocks of Cambrian and Ordovician age covered by varying thicknesses of glacial drift. The major structural feature is a northeastward plunging anticline in the southeastern part of the study area. Glacial features and deposits include a series of recessional moraines, discontinuous sand and gravel units interbedded within till, and thick lake-clay deposits overlain by peat (figs. 3 and 4).

Bedrock

The bedrock topography in the Middletown-Goshen area is a result of preglacial orogenic activity and subsequent erosion by water and ice. Folding and faulting during the Acadian or Appalachian Orogeny (Offield, 1967) resulted in the development of a northeastward plunging anticline southwest of Goshen. Bedrock includes early middle Cambro-Ordovician carbonates of the Wappinger Group and the Balmville limestone of the Trenton Group, which are overlain by shales, argillites, and siltstones of the Normanskill Formation of the Trenton Group.

The bedrock-surface altitude ranges from more than 600 ft in the northeastern part of the study area to less than 280 ft in the southern part and locally can change by as much as 100 ft within a distance of 500 ft. Well logs from this study and previous data (Frimpter, 1970) suggest that a southward flowing ancestral stream deeply incised the bedrock to produce a gorge grading toward the southwest; its presence was confirmed by test drilling and seismic-refraction data.

Unconsolidated Deposits

Unconsolidated glacial deposits in the Wallkill River valley (fig. 3) are the result of Wisconsin-age glaciation. The valley's headwaters originate at the Ogdensburg-Culvers Gap terminal moraine in northern New Jersey (Connally and Sirkin, 1970). The glacier's eastern and western flanks were confined by the Hudson Highlands and the Shawangunk mountains (fig. 4).

Two recessional moraines have been identified in the study area— the Pellets Island moraine and the New Hampton moraine; another—the Wallkill moraine, is just north of the study area (fig. 4). These moraines represent differing stages of glacial retreat (Connally and Sirkin, 1970). Together the moraines form a series of hills that traverse the valley from east to west; they contain kames and kame-terrace deposits. Till also is present throughout the study area, both interspersed between the moraines and at depth. During each stage of glacial retreat, water was impounded and formed lakes between the moraines and the retreating glacier to the north (Connally and Sirkin, 1967). The bottom deposits of these glacial lakes consist of silt and clay and are locally more than 100 ft thick in the area south of Middletown, locally referred to as the "Black dirt" area.

The Ogdensburg-Culvers Gap moraine in northern New Jersey (fig. 4) served as a dam for a glacial lake whose surface altitude was about 500 ft (Connally and Sirkin, 1970). Subsequent glacial ice retreats formed the Pellets Island Moraine and the New Hampton Moraine, both of which also are associated with the 500-ft water level. The lake subsequently filled with silt, clay, and peat to form most of the black dirt area (fig. 3).

The Wallkill Moraine, the northernmost in the Wallkill valley, is about 1 mi north of the study area (fig. 4). It is associated with a glacial lake whose surface altitude was 400 ft. This lake drained eastward toward the Hudson River through the ancestral Moodna Creek, which is represented by the present-day Otter Kill (Connelly and Sirkin, 1970).

Other stratified-drift deposits in the study area include eskers, massive crevasse fillings, and outwash channels (Connally and Sirkin, 1967). Thickness of the unconsolidated glacial deposits ranges from more than 150 ft near the Pellets Island Moraine to less than 5 ft where they overlie bedrock on many of the hilltops. The thickness of these unconsolidated glacial deposits varies within short distances, making detailed delineation of these aquifer materials difficult.

Hydrology

Surface-water and ground-water data within the study area were used to asses the hydraulic interaction between the Wallkill River and the unconsolidated and bedrock aquifers. Water levels and hydrogeologic information were used to delineate flow patterns within the aquifers in the study area.

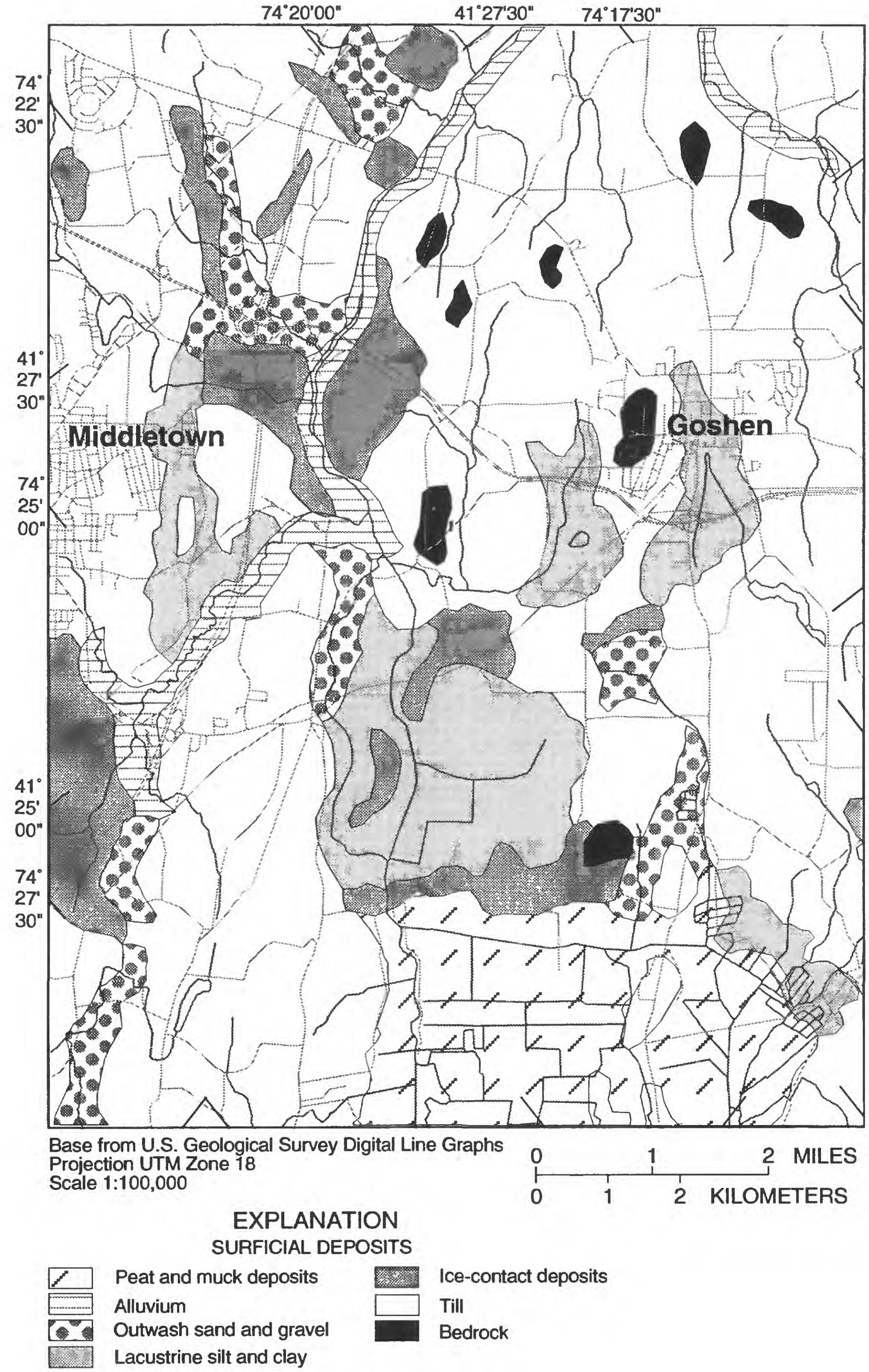
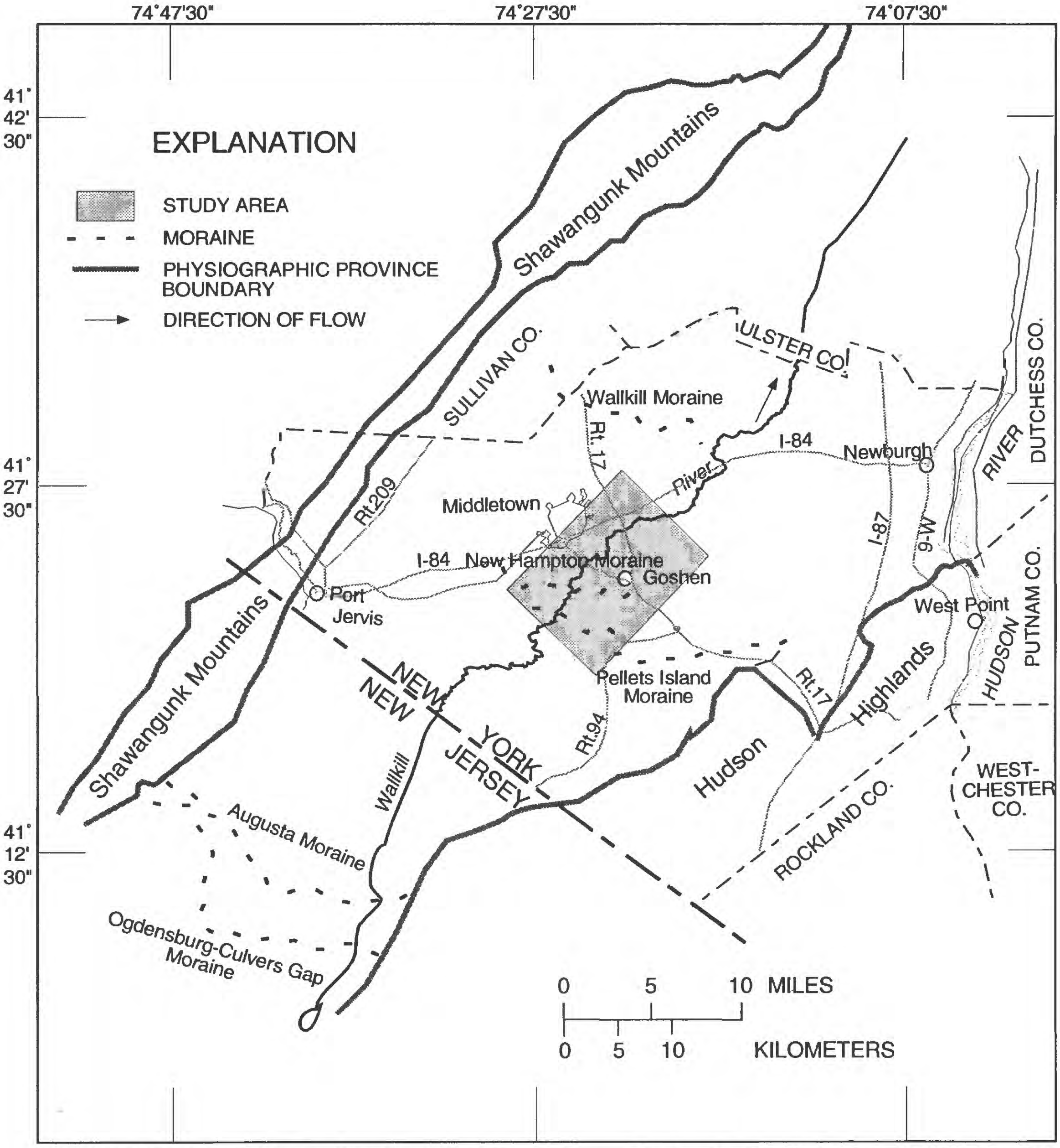


Figure 3. Map showing surficial deposits in the study area.



Base from U.S. Geological Survey Digital Line Graphs
Projection UTM, Zone 18
Scale 1:100,000

Geology modified from Connely and Sirkin, 1967

Figure 4. Map showing location of major physiographic provinces and glacial recessional moraines.

Streams

The Wallkill River flows northeastward through Orange County from its head-waters in northern New Jersey (fig. 4) to its confluence with the Hudson River near Kingston, NY. The USGS has operated two streamflow gaging stations on this river—one near the Town of Pellets Island (station no.1370000) for 48 years (1921-68), and one near Phillipsburg (station no. 1370500) for 23 years (1937- 59) (fig. 2).

A plot of the mean monthly discharges at the two stations for 1937-59 is shown in figure 5. The drainage area of the Phillipsburg station is 406 mi^2, and the station is about 5 mi downstream from the Pellets Island station (drainage area 380 mi^2). The mean annual flow for the period of record (1937-59) at Pellets Island is 590 ft^3/s, and that at Phillipsburg is 652 ft^3/s (U.S. Geological Survey, 1959); this constitutes an increase in flow of 62 ft^3/s within this 5-mi reach. The median annual base flow for Pellets Island and Phillipsburg is 297 and 330 ft^3/s, respectively, which indicates a downstream increase of 33 ft^3/s in that reach.

A series of stream-discharge measurements on February 11, 1988, documented a net gain in the flow of the Wallkill River as a result of discharge from the unconsolidated and bedrock aquifers (fig. 6). The few days preceding the measurements were exceptionally

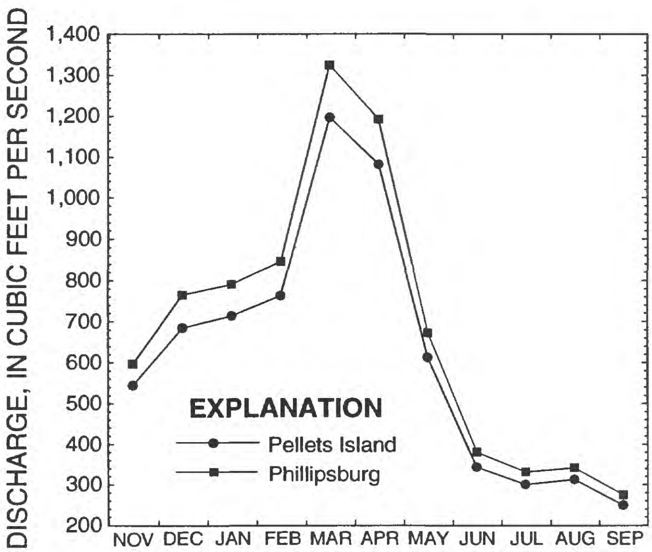


Figure 5. Graphs showing mean monthly discharge at Pellets Island and Phillipsburg gaging stations for the period 1937-39

cold (below freezing), so that there was probably little overland runoff to the river on February 11. Therefore, the flow in the Wallkill River and Monhagen Brook during the measurements on February 11, 1988, was considered to be at or below the average flow for that time of year and probably represents the upper limit of base flow for that period.

The data in the table in figure 6 indicate a total gain in flow of about 152 ft^3/s between Pellets Island and Phillipsburg (near the Route 17 bridge). Part of the increase in flow (17 ft^3/s) is from Monhagen Brook (fig. 6), and a reported 2.5 ft^3/s (1.62 Mgal/d) is discharged by the Wallkill Sewage-Treatment facility, 0.25 mi north of the river (E. Smith, plant operator, oral commun., 1986). The net increase in flow minus the discharge from Monhagen Brook and the sewage-treatment plant is about 127 ft^3/s. The measured net increase in flow (127 ft^3/s) is almost 4 times larger than the calculated median annual base-flow discharge of the Wallkill River at Phillipsburg (33 ft^3/s), and thus possibly represents additional discharge to the river from streambank storage and limited amounts of snowmelt and overland runoff.

Aquifers

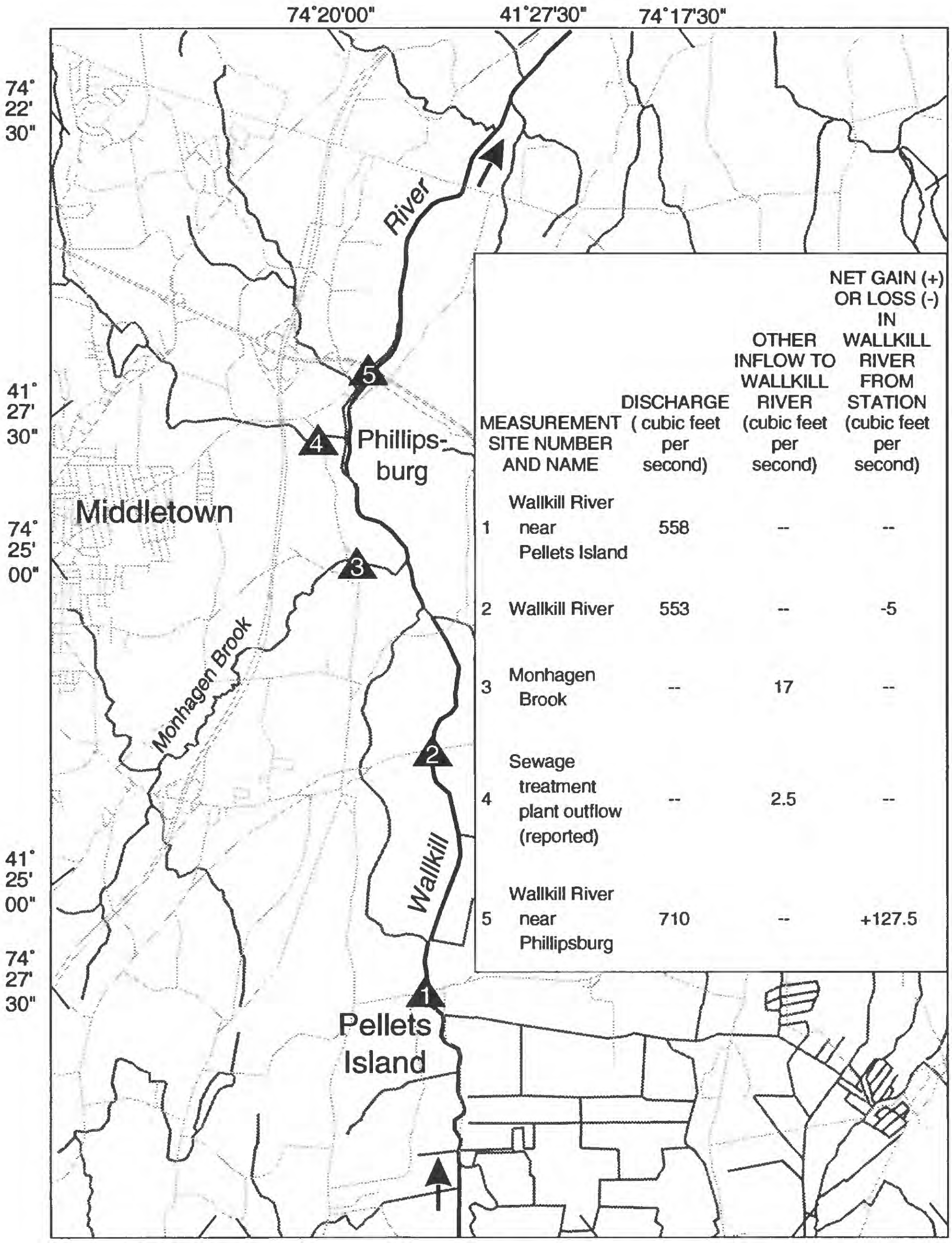
The irregular deposition of glacial sediments on the undulating preglacial bedrock surface in the Wallkill River valley has produced laterally discontinuous outwash sand and gravel aquifers at differing positions within the till and locally adjacent to, and mixed with, lake-clay deposits (fig. 3). Neither logs from test holes and observation wells drilled for this study, nor logs from commercial drillers' or consultants' reports, indicate a major, continuous deposit of sand and gravel extending laterally for more than a few thousand feet (fig. 7).

Composition and Thickness

The only unconsolidated aquifer material that can be mapped continuously for more than about 1,000 ft is alluvium that lies adjacent to the Wallkill River and consists primarily of sand with some gravel. The alluvium represents locally reworked glacial deposits from which most of the fine sediment has been removed; thickness averages about 30 ft but may be greater locally (appendix 1, table 1, well 2168). Several commercial and public water supplies are obtained from shallow wells drilled in this deposit, such as 2080, 2083, and 1366 (fig. 2 and appendix 1).

Till generally is considered to be poor aquifer material in most of southeastern New York because it typically contains large amounts of silt and clay and yields generally less than 10 gal/min to wells (Wolcott, 1987). Till in the study area is extremely sandy and is relatively permeable, possibly because it was deposited by glaciers that advanced into this area from the northeast and east, where the bedrock is mainly silica-rich metamorphic rock. For the purposes of this study, the till was considered to be part of the unconsolidated-aquifer system because (1) it is relatively permeable and (2) it contains individual sand and gravel units that could not be mapped.

The study area was delineated into five different "hydrogeologic zones" on the basis of aquifer thick-



MEASUREMENT SITE NUMBER AND NAME	DISCHARGE (cubic feet per second)	OTHER INFLOW TO WALLKILL RIVER (cubic feet per second)	NET GAIN (+) OR LOSS (-) IN WALLKILL RIVER FROM STATION (cubic feet per second)
1 Wallkill River near Pellets Island	558	--	--
2 Wallkill River	553	--	-5
3 Monhagen Brook	--	17	--
4 Sewage treatment plant outflow (reported)	--	2.5	--
5 Wallkill River near Phillipsburg	710	--	+127.5

Base from U.S. Geological Survey Digital Line Graphs
Projection UTM Zone 18
Scale 1:100,000

0 1 2 MILES
0 1 2 KILOMETERS

EXPLANATION

▲ STREAMFLOW MEASUREMENT SITE

→ DIRECTION OF FLOW

Figure 6. Map showing locations of stream measurement sites measured on February 11, 1988, measured discharges at each station, and change in flow in the Wallkill River

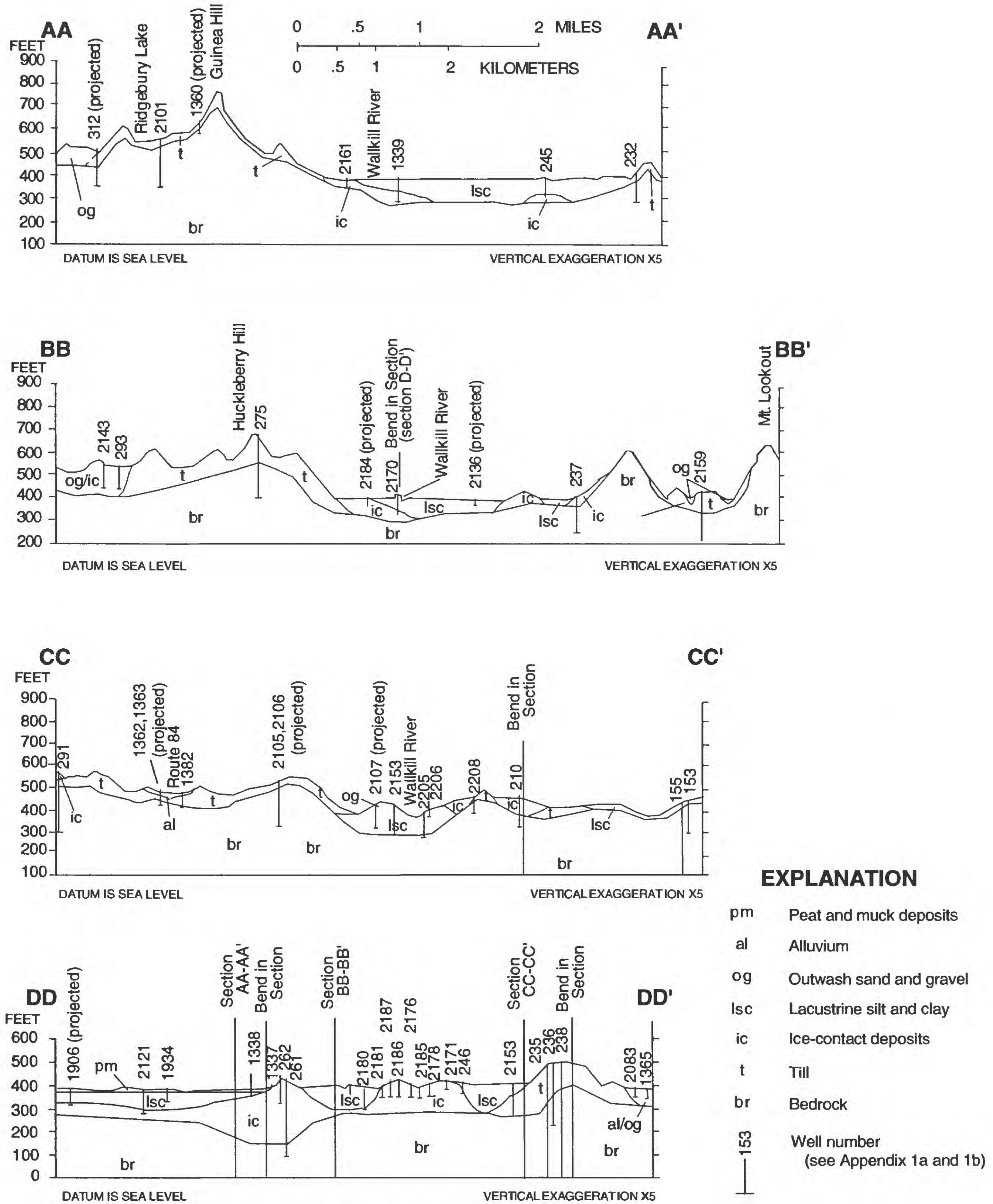


Figure 7. Geologic sections AA-AA' through DD-DD'

ness and hydraulic properties, as shown in figure 8. Because the sand and gravel deposits in this area are discontinuous, and the till relatively permeable, each of these zones represents a part of the study area that generally will differ from the rest in response to well development and in the amount of water that can be obtained from wells screened in these deposits.

Test drilling indicated a sequence of glacial-lake clay as much as 110 ft thick (well 2161 in fig. 2; appendix A; also fig. 2, section AA-AA') that yields virtually no water. This clay deposit, which underlies a 7-mi^2 area (fig. 3), (roughly 10 percent of the study area) is overlain by unconfined, organic-rich deposits averaging 5 to 8 ft thick (locally called "black dirt").

Seismic-refraction profiles were conducted at selected locations where bedrock-surface data were scarce. Observation wells were drilled near the locations of the seismic lines to confirm bedrock altitude as control. Standard seismic-refraction techniques (Haeni, 1986) were used along with a computerized seismic-refraction data-interpretation program SIPT1.FOR (Scott, 1977) that can incorporate multilayer dipping beds and complex field orientations (Grantham and Ellefsen, 1987). The seismic sections generated by computer from the field data are shown in figures 2 and 9. Seismic velocities for the saturated unconsolidated deposits and bedrock were in the range obtained by a private consultant (Ryland-Cummings, Inc. 1982) and are given in table 1.

The seismic-refraction sections in figure 9 depict the undulating surface of the shale bedrock; the undulating surface is consistent with the interpretation of well-log data and the geologic sections (fig. 7). The seismic-survey results also indicate that sand and gravel deposits that are buried by appreciable thicknesses of till or lake-bottom sediments are not thick enough, nor do they have sufficient seismic-velocity contrast, to be detected by seismic-refraction techniques, as described by Haeni (1988).

Hydraulic Characteristics

The hydraulic characteristics of the unconsolidated deposits and bedrock within the study area were determined from existing data, mostly the results of pumped-well tests. These characteristics were generally applied to areas having similar hydrogeologic properties within the study area.

Unconsolidated Aquifer. The deposits that form the unconsolidated aquifer are confined in some areas and are unconfined in others. The unconsolidated, confined aquifers are buried beneath clay or clay-rich till layers. The local variations from confined to unconfined conditions reflect the complexity of the aquifer system in the study area and make the potentiometric surface in the unconsolidated deposits difficult to delineate, especially at a local scale.

The hydraulic conductivity of unconsolidated deposits varies both locally and regionally. Hydraulic conductivity values either were estimated from results of pumping tests or were taken from previous studies. Because the lateral and vertical distribution of the various types of unconsolidated deposits is uncertain, a range of hydraulic-conductivity values was assigned to each of the five hydrogeologic zones and general types of deposits indicated in figure 8.

The hydraulic conductivity of coarse sediments (sand and gravel) in the unconsolidated deposits was calculated by the method of Theis (1963) on the basis of data obtained from five pumping tests by consulting firms investigating potential sites for public water-supply wells (Wheran Engineering, 1974, and Dames and Moore, 1975). The hydraulic properties of the aquifer

Table 1. Range of seismic velocities measured in Wallkill study area (1988-87), Orange County, N.Y., and range of published values.

[Values are in feet per second; Published values from Ryland-Cummings, Inc. 1982; and Haeni, 1988, p. 41.]

		Published values	
Material	Values from this Study	Ryland-Cummings, Inc. (1982)	Haeni(1988)
Unconsolidated deposits	2,400 — 5,600[1]	2,080 — 6,500[1]	4,000 — 6,000[2]
Shale	11,100 — 15,600	8,500 — 13,000	9,000 — 14,000

[1]May represent saturated and unsaturated material
[2]Represents saturated material only

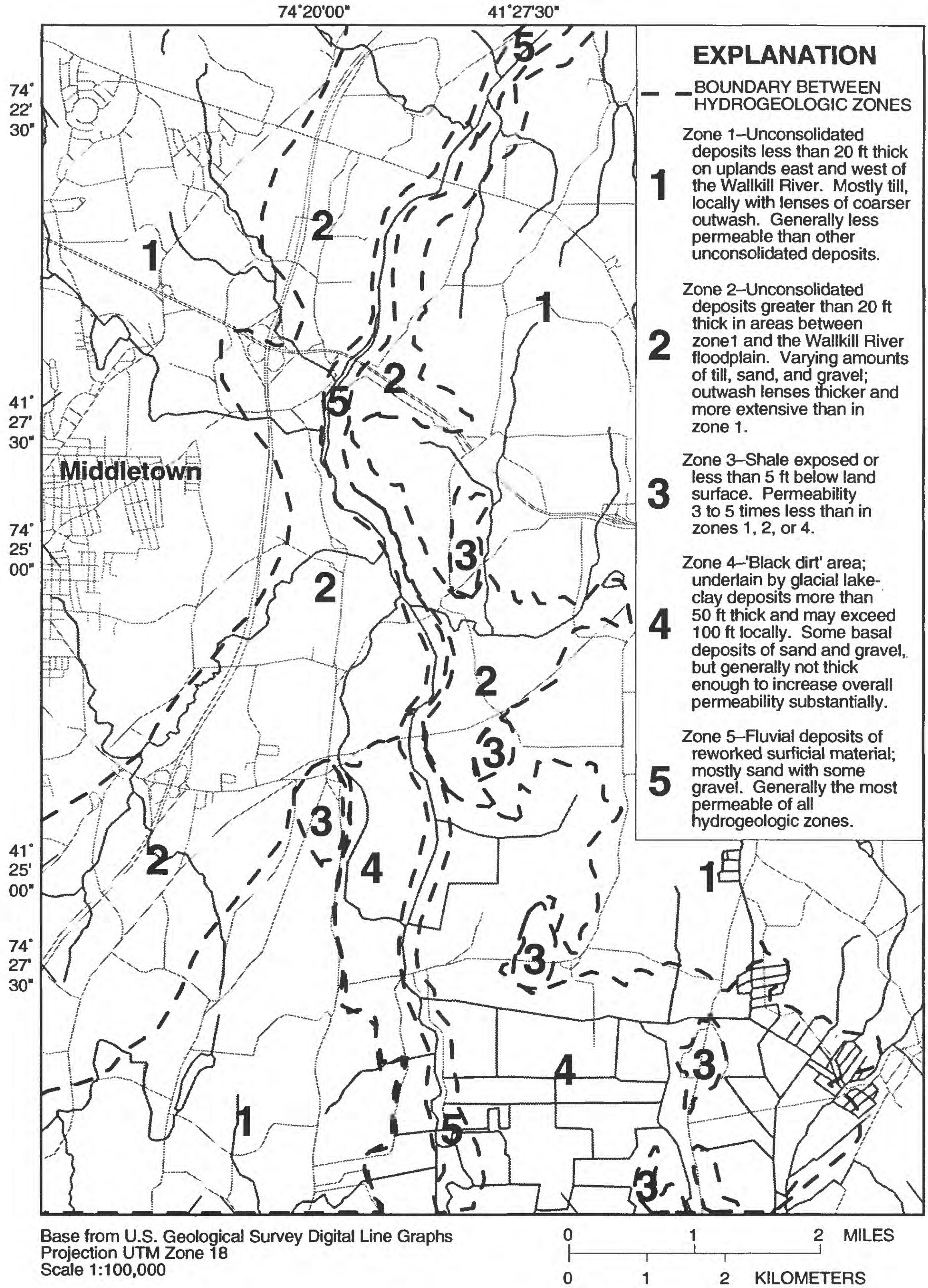


Figure 8. Map of hydrogeologic zones based on generalized aquifer thickness and hydraulic properties, and seismic refraction sections in the study area near Middletown, N.Y.

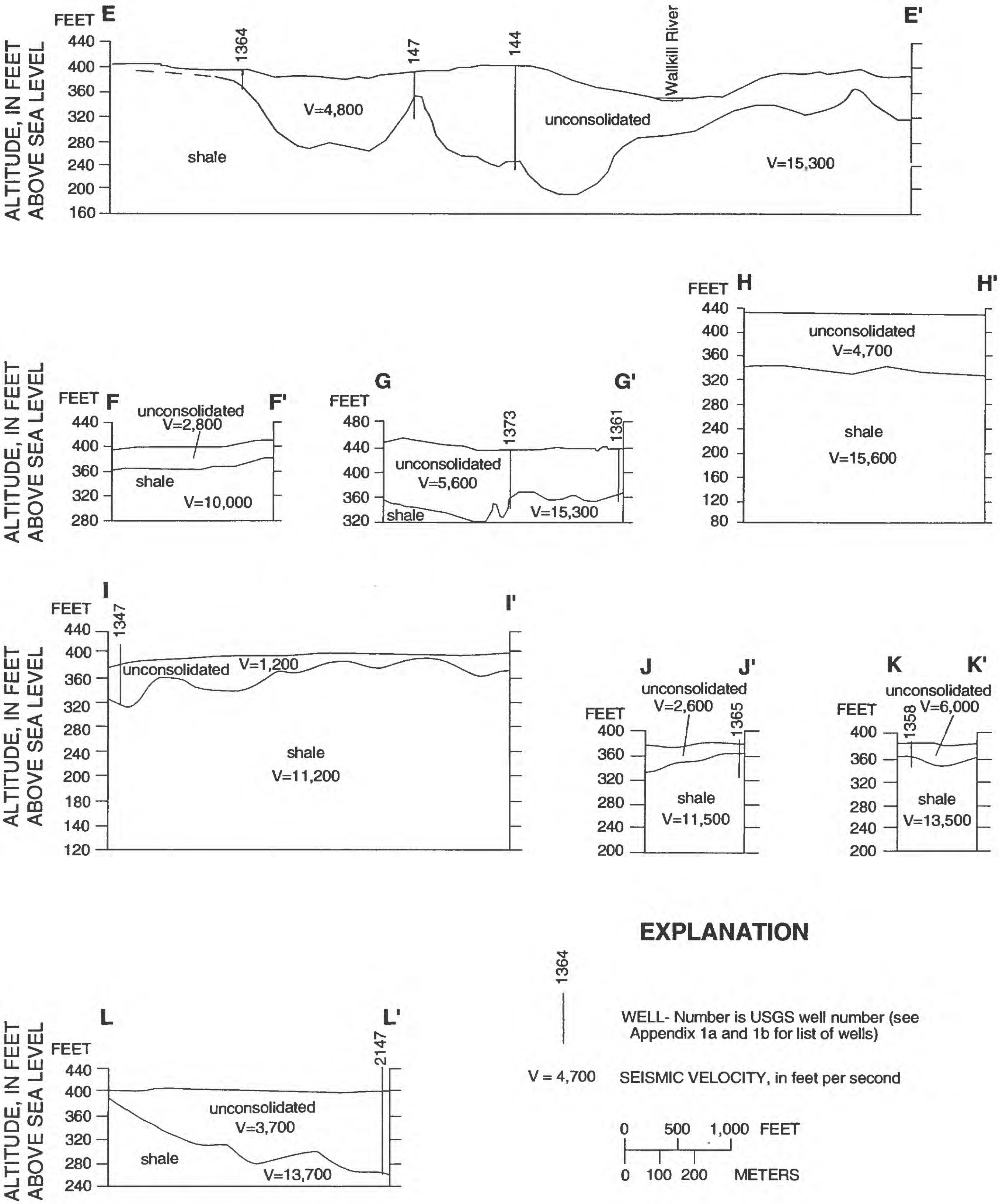


Figure 9. Seismic-refraction sections showing seismic velocities associated with saturated unconsolidated deposits and shale bedrock.

material at wells screened in unconsolidated deposits more than 20 ft thick are shown in Table 2. The average hydraulic conductivity for the fluvial deposits was 812 ft/d, which is greater than the 500 ft/d for outwash deposits given by Randall (1986, p. 23) but within the range of 300 to 1,140 ft/d given by Reynolds (1987, p. 16) for outwash sand and gravel in central New York

Outcrops of till in the study area indicate a silty-to-sandy matrix—field observations suggest that the till in the study area is more permeable than till in other parts of New York. For example, the hydraulic conductivity of a clay-rich till near Springville, in western New York, averages 5.5×10^{-5} ft/d (Bergeron and Bugliosi, 1988), and the calculated hydraulic conductivity of small lenses of sand and silt at the same site range from 5.0×10^{-2} to 1.4×10^{-1} ft/d (Prudic, 1982) in contrast to the hydraulic conductivity of till measured near the Mid-Hudson Psychiatric Center (table 2).

Hydraulic-conductivity values for till were not calculated from field data collected for this study, but observation wells that were installed in the till were developed with nearly the same ease as wells installed in clean sand and gravel, and the water levels in both the till and sand and gravel showed similar responses to recharge from precipitation. This indicates not only that the till is relatively permeable, but that these deposits are hydraulically connected in the study area.

Bedrock Aquifer. No hydraulic-conductivity data on the shale aquifer were collected or found in the literature. The hydraulic conductivity of highly fractured and folded shale results from the secondary permeability, or the openings within the rock that result from fracturing. Hydraulic conductivity of fractured shale commonly ranges from 1×10^{-3} to 1×10^{-5} ft/d (Heath, 1983, p. 13 and Freeze and Cherry, 1979, p. 29). This range, especially the larger value, seems reasonable to apply to shale in the study area and may even be low in light of the highly fractured nature of shale seen in exposures in the study area. Bedrock wells in the study area typically produce 5 to 10 gal/min, although some may produce up to 300 gal/min in localized, highly fractured zones (well 154).

Water-Level Fluctuations

Water levels in the unconsolidated aquifer fluctuate seasonally. Water-level fluctuations in most wells screened in unconsolidated material, for example observation well 1352, averaged about 5 ft from April 1987 through March 1988, and those in wells screened in till, for example well 1350, showed the same range (fig. 10).

The response of water levels in bedrock wells to seasonal fluctuations in precipitation (for example, well 1359, fig. 10) was similar to that in unconsolidated material. These data, together with the similarity of water-level fluctuations in bedrock well 1362 to those in well 1363, which is screened in unconsolidated material about 10 ft away, suggests a good hydraulic connection between the bedrock and overlying unconsolidated materials (fig. 10).

Table 2. Hydraulic characteristics of the unconsolidated aquifer and fluvial deposits (greater than 20 feet thick), near Middletown, NY.

[Well locations are shown in fig. 2.]

Well No.	Type of deposit	Transmissivity (feet squared per day)	Hydraulic conductivity (feet per day)	Owner
2080	outwash	11,600	375	Astro Water Supply
2082	outwash	9,275	300	Astro Water Supply
2083	outwash	9,850	320	Astro Water Supply
2089	till	180	2	Mid-Hudson Psychiatric Center
1366	fluvial sand	38,770	1,210	Kosuga well field
1368	fluvial sand, some silt	16,180	415	Kosuga well field

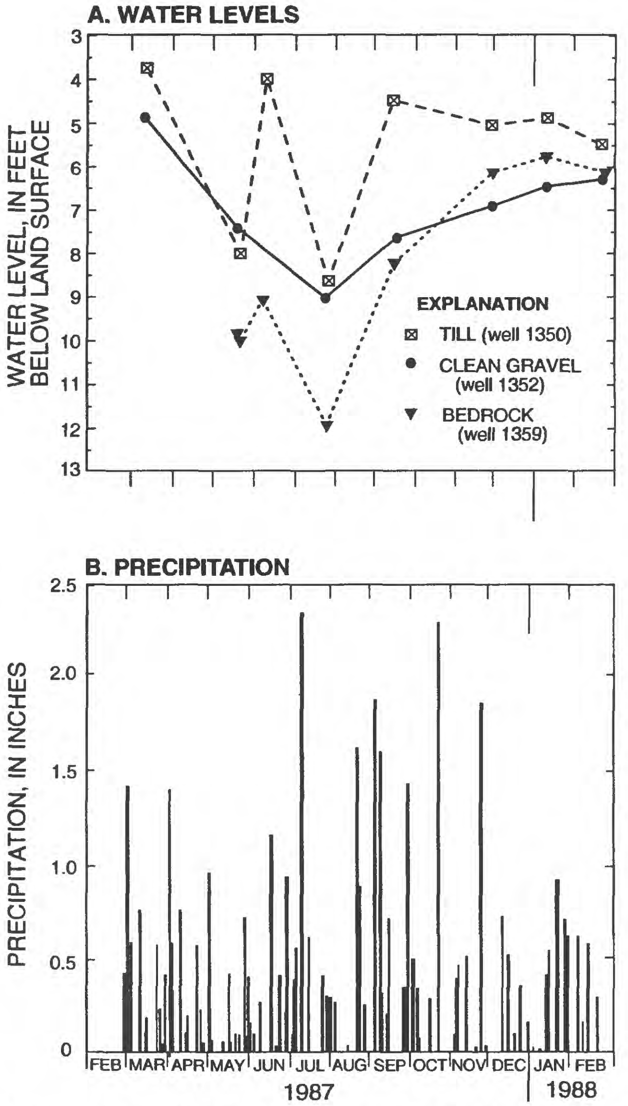


Figure 10. Graphs showing seasonal fluctuations of water levels in selected wells representing sand and gravel, till, and shale in relation to total daily precipitation at meteorological station Wallkill 2-NW.

Recharge

Recharge to the unconsolidated aquifer in the study area was estimated to be equivalent to the average daily precipitation at the Wallkill 2-NW station (National Oceanic and Atmospheric Administration, 1952-85) for the period of record, minus estimated amounts of direct runoff and evapotranspiration. The computed average annual precipitation at the station was about 45 in. About 20 in/yr is lost as total annual runoff in the area, and 15 in/yr is lost through evapotranspiration (Lyford and others,1987); subtracting these values from the average annual precipitation (45 in) gives about 10 in/yr as direct recharge to the ground-water system from precipitation, which is similar to estimates made by Lyford and others (1987).

Ground-water discharge to streams (base flow) is an indicator of recharge to a ground-water system; a computer program (R.A. Sloto, U.S. Geological Survey, written commun., 1988) was used in this investigation to facilitate the separation of streamflow hydrographs by estimating the ground-water (base-flow) component of streamflow through the techniques of Pettyjohn and Henning (1979). Therefore, the base-flow component of total flow in the Wallkill River was calculated from data from the Pellets Island and Phillipsburg gaging stations as a check on the recharge rate (10 in/yr) estimated above. The annual median base-flow calculated was 10.18 in/yr at Pellets Island (drainage area 380 mi^2) and 11.05 in/yr downstream at Phillipsburg (drainage area 406 mi^2); these values compare favorably with the 10 in/yr calculated from Lyford's estimates.

Other recharge to the unconsolidated aquifer in the study area comes as underflow (ground water flowing in at the edges of the study area through the saturated unconsolidated deposits). For example, the possible amount of underflow along the western edge of the study area was calculated as the product of four terms—(1) the estimated water table gradient of 0.0189 (100 ft/mi), which roughly corresponds to the land-surface gradient along the study-area boundary, (2) about 500 ft of boundary having a more than 20-ft thickness of unconsolidated deposits and with a similar gradient, (3) an average saturated thickness of 20 ft, and (4) hydraulic conductivity values between 200 and 800 ft/d, estimated from well and aquifer tests (table 2), as defined by Darcy's law. The resulting estimates of ground-water underflow into the study area through the western boundary ranged from 37,000 to 150,000 ft^3/d.

$$Q = KIA, \qquad (1)$$

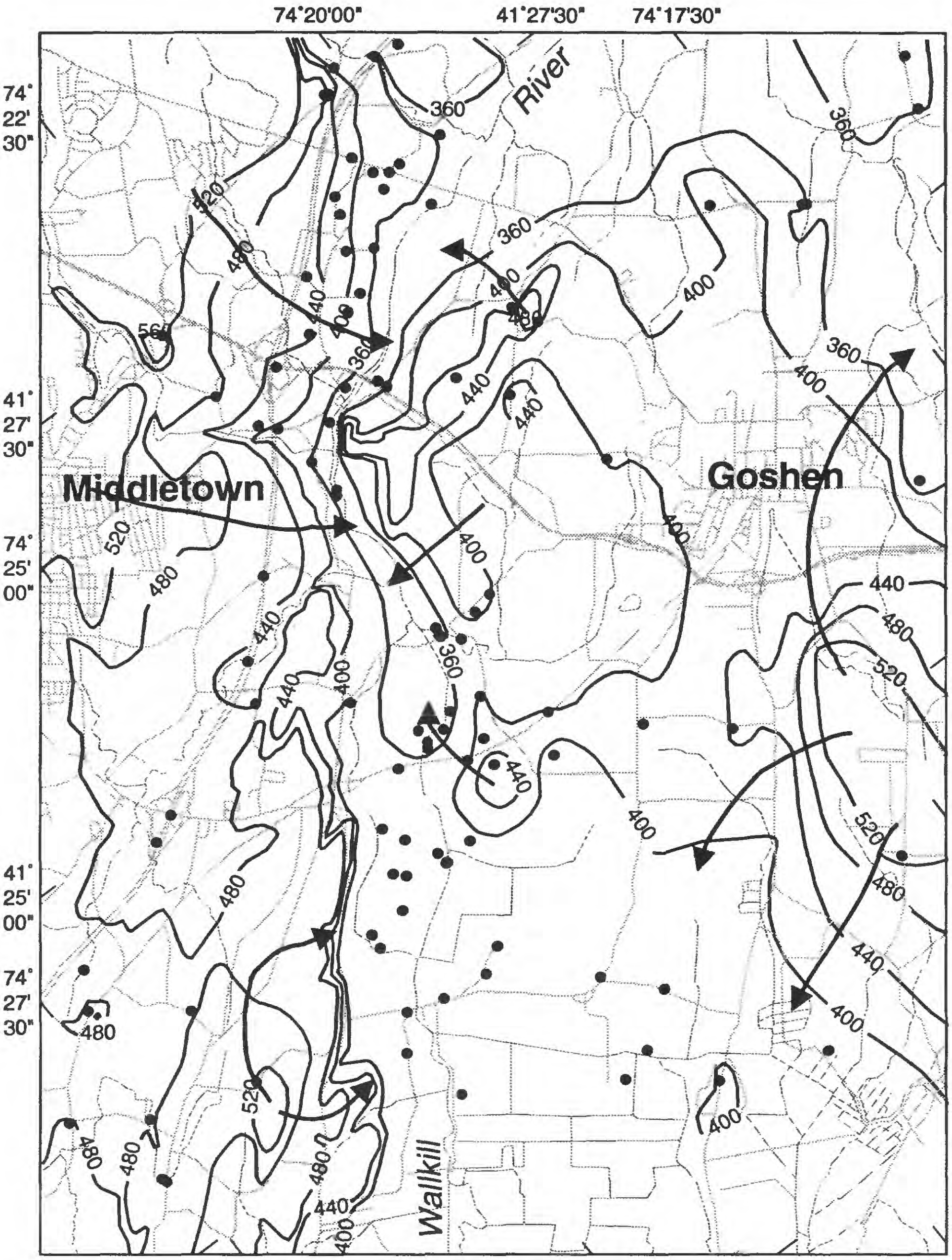
where:

Q = volumetric flux (L x t),

K = horizontal hydraulic conductivity (L x t),

I = water-table gradient (dimensionless), and

A = saturated cross-sectional area of unconsolidated deposits (L).



Base from U.S. Geological Survey Digital Line Graphs
Projection UTM Zone 18
Scale 1:100,000

0 1 2 MILES
0 1 2 KILOMETERS

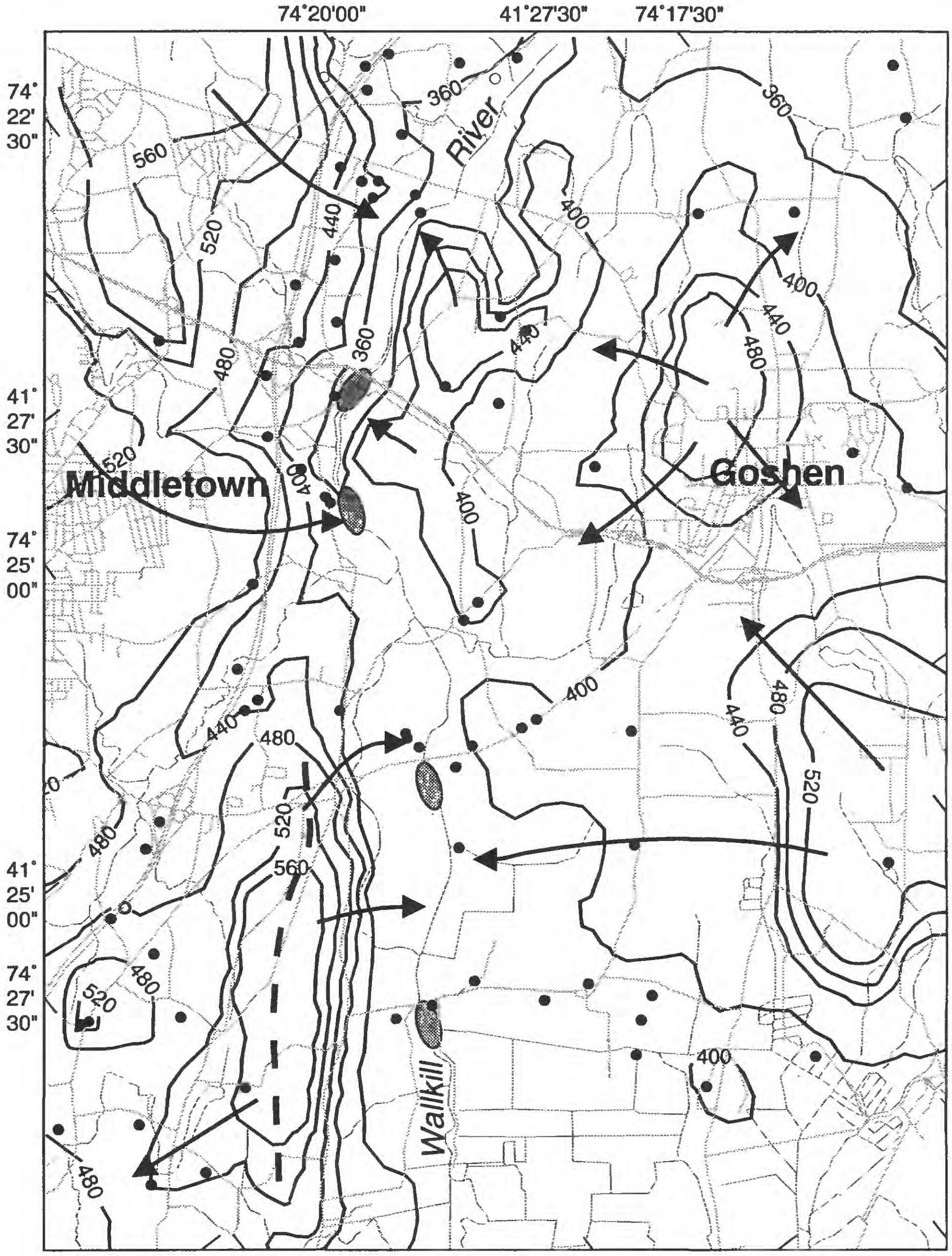
EXPLANATION

– – 450— WATER-TABLE CONTOUR--Shows altitude at which water levels would have stood in tightly cased well. Dashed where approximate, contour interval 40 feet. Datum is sea level.

→ GENERAL DIRECTION OF GROUND-WATER FLOW

• WELL LOCATION USED FOR WATER-LEVEL DATA

Figure 11A. Map showing the water table in unconsolidated deposits and shallow bedrock.



Base from U.S. Geological Survey Digital Line Graphs
Projection UTM Zone 18
Scale 1:100,000

0 1 2 MILES

0 1 2 KILOMETERS

EXPLANATION

— —450— POTENTIOMETRIC CONTOUR-- Shows altitude at which water levels would have stood in a tightly cased well. Dashed where approximate, contour interval is 40 feet. Datum is sea level

— — GROUND-WATER DIVIDE

OUTCROP--Bedrock crops out in streambed

⟶ GENERAL DIRECTION OF GROUND-WATER FLOW

• WELL LOCATION USED FOR WATER-LEVEL DATA

Figure 11B. Map showing the potentiometric surface in bedrock.

Ground Water Flow Patterns

The water table is within unconsolidated deposits in most places and in bedrock where the rock is near, or at, land surface. Flow directions within the unconsolidated deposits were difficult to discern from water-level data except at a regional scale because (1) the fine-grained confining layers and discontinuity of the sand and gravel deposits impart flow patterns within larger generalized water-level patterns, and (2) data were insufficient to determine the local flow paths. Generalized (regional) directions of ground-water flow depicting directions of flow in the unconsolidated deposits and shallow bedrock were plotted, however, and are shown in figure 11A. Local gradients and directions may depart however, from those shown on the map.

In general, the water levels indicate that ground-water flow is toward the Wallkill River from recharge areas at the higher altitudes east and west of the Wallkill River valley. The stream-discharge measurements made on February 11, 1988, which indicated a downstream increase in river discharge during a freezing period, when surface runoff was minimal, support this conclusion. The thick sequence of clay in the southeastern part of the study area, beneath the peat and muck ("black dirt") area (fig. 3), may cause deep ground-water flow in the unconsolidated deposits entering the valley from the east and west to be diverted upward into the peat and muck deposits.

The potentiometric surface of the bedrock aquifer in the study area indicates regional flow from east and west toward the Wallkill River (fig. 11B). Although data from the extreme northeastern part of the area were sparse, the generalized potentiometric contours are considered reasonable. The potentiometric surface in the southeastern part of the study area is not shown because no data on wells drilled into the bedrock in this area were found, probably because the bedrock is a somewhat metamorphosed dolomite—almost marble—that would yield little, if any, water to wells. Regional gradients from the west side of the study area (fig. 11B) are about 50 ft/mi (0.0009 ft/ft).

A downward-flow component from the unconsolidated material to the underlying bedrock was indicated locally on ridges and hilltops (fig. 12) and probably can be inferred in other areas where unconsolidated deposits overlie bedrock hills. As altitude decreases toward the river, local hydraulic gradients between the shale and overlying unconsolidated deposits may change and result in a small upward component of flow from the bedrock into the overlying unconsolidated deposits (Wehran Engineering, written commun., 1988). The bedrock aquifer also is inferred to discharge to the river where it crops out in the river (fig. 11B); many residents whose wells were inventoried in this study reported areas of "cooler" river water during summer at locations near bedrock exposures in the Wallkill River.

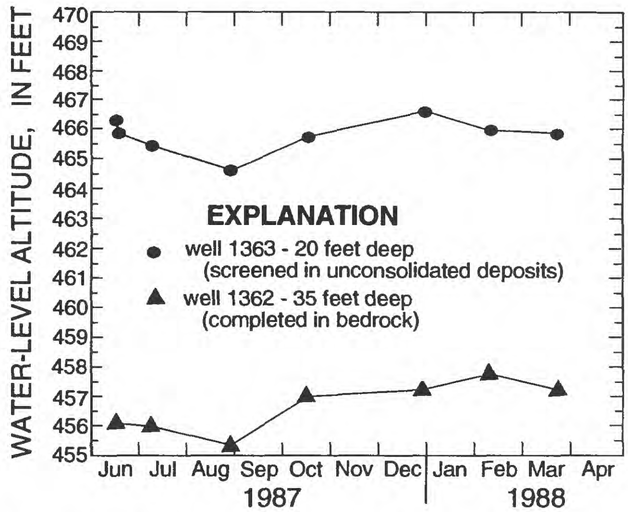


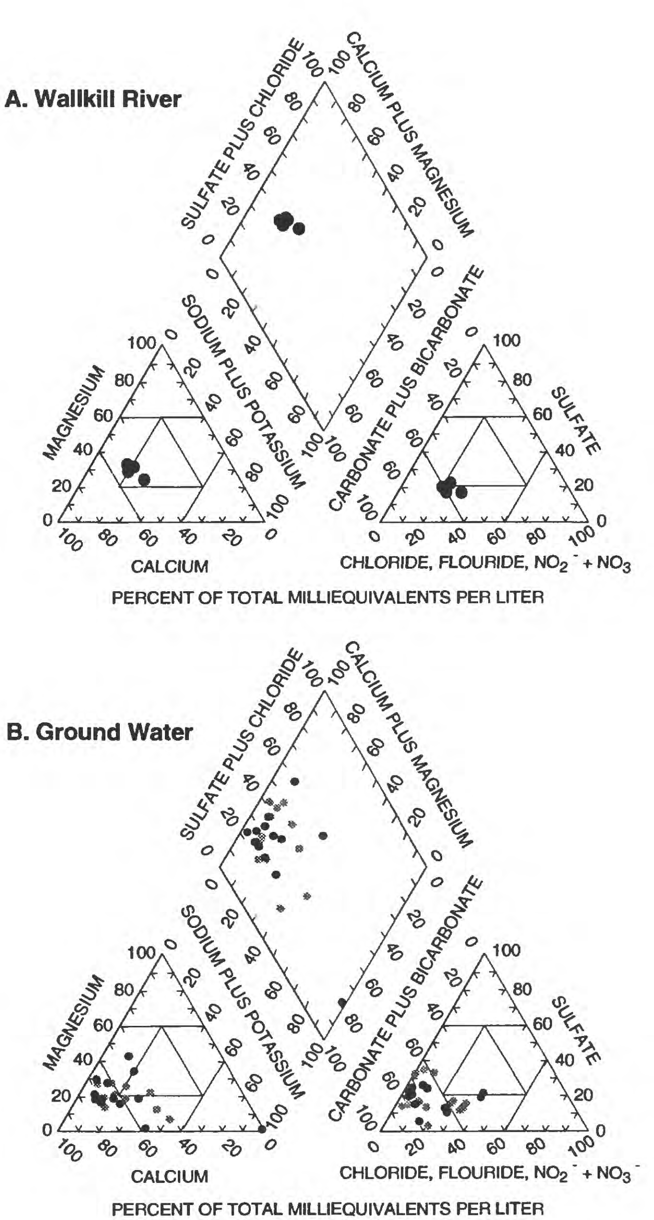
Figure 12. Graphs comparing water levels in wells at the same location (and land surface altitude) completed in unconsolidated deposits and bedrock

WATER QUALITY

Waters from the Wallkill River, the shale aquifer, and the unconsolidated deposits were analyzed, and chemical compositions were compared, to help define the relation between surface water and ground water in the study area.

Surface Water

The chemical quality of surface water is determined by: (1) the chemical composition of precipitation and dryfall, (2) the chemical composition and amount of ground water discharging into streams, (3) land use and soil type in the area that drains to the surface-water body, and (4) other human related influences. The quality of surface water fluctuates seasonally; for example, during periods of precipitation and snowmelt, when the soil is saturated and runoff is the source of much of the streamflow, stream



EXPLANATION

- WELLS COMPLETED IN UNCONSOLIDATED DEPOSITS
- WELLS COMPLETED IN BEDROCK

Figure 13. Trilinear plots of major cations and anions in water samples from: A. Wallkill River, September 9, 1986. B. Selected wells in unconsolidated deposits and bedrock.

water chemically resembles surface runoff more closely than during periods of little or no precipitation or during freezing temperatures, when streamflow consists mostly of ground water (base flow).

The Wallkill River was sampled at five locations on September 9, 1986 (a low-flow period) in a 2.5-mi reach between Pellets Island and a point below the mouth of Monhagen Brook (fig. 6). Results of the analyses are summarized in appendix 2A. A trilinear plot (fig. 13a) indicates that calcium and bicarbonate were the predominant cation and anion species, respectively, during the sampling period. The sample from station (WK-5) indicated downstream increases in concentrations of chloride, sodium, and potassium that probably are due to the inflow of water from Monhagen Brook, which drains the southeastern section of Middletown and receives the outflow from a municipal waste-water-treatment facility.

Ground Water

Ground-water quality is dependent on several factors, including residence time in the aquifer, land use in the recharge area of the aquifer, the mineral makeup of the aquifer material through which the water flows, temperature, and precipitation amount. The residence time of the ground-water, which depends on the length of the flow-path and rate of movement through the unconsolidated material and bedrock, largely determines the extent to which the water will react with the aquifer material.

Water samples were collected at 33 wells during July 7-10, 1987 and August 26-27, 1987. Sixteen of the wells are screened or cased in bedrock; the remaining 17 are screened in unconsolidated materials. Some are observation wells installed by the USGS, some are privately owned, and others are monitoring wells drilled by consulting firms.

Results of the chemical analyses of the water samples are listed in appendix 2B; the trilinear plot in figure 13b depicts the chemical composition of samples during July 7-10, 1987. Most of the water samples from the unconsolidated deposits and the bedrock aquifer can be classified as calcium-bicarbonate types, whereas others are mixed types. The tight clustering of data (fig. 13b) indicates a fairly uniform chemical makeup among most of the samples. Samples from the unconsolidated deposits show slightly more scatter than do those from the bedrock, but some can be classified as calcium-bicarbonate water, others indicate mixed waters. The large degree of scatter among the data for water from the unconsolidated aquifer is attributed to the diversity of materials that form those deposits and to varying residence times of water in those aquifers.

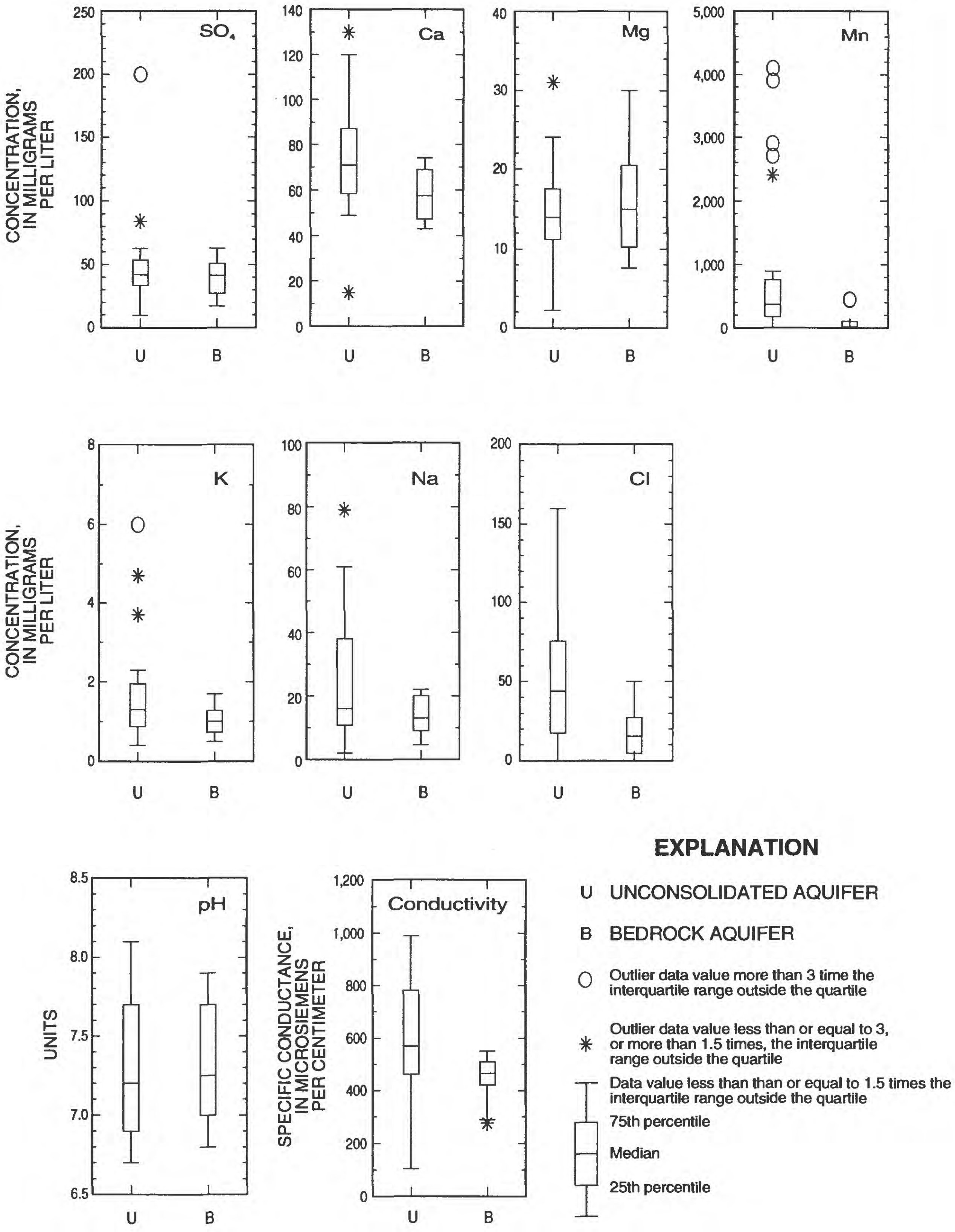


Figure 14. Box plots of selected chemical constituents showing similarity between water from unconsolidated deposits and water from bedrock.

The elevated concentrations of copper (8 samples), lead (6 samples), and zinc (6 samples) (appendix 2B,) may result from heavy metals associated with bedrock 10 mi west of the study area. These trace metals also have been found in the water and bottom materials of streams west of the study area and in deposits mined near Otisville, in the early 1900's (Moxham, 1972). The proximity of the study area to these deposits could account for the elevated concentrations of trace metals in water from these wells. Alternatively, the elevated concentrations could indicate that leachate from nearby landfills is entering the Wallkill River at some point upstream from the sampling sites, either directly or by way of ground-water discharge from the unconsolidated aquifer.

Concentrations of some metal ions were elevated above normal levels for ground water in this area. Elevated concentrations of manganese (greater than 500 µg/l) were found in samples from seven wells (1351, 1352, 1356, 1358, 1360, 1365, and 2109), and elevated concentrations of iron (greater than 200 µg/l), were found in four wells (1353, 1356, 1360, and 2139). The concentration of copper was 1,500 mg/l in well 2139 (section B, appendix 2).

Generally the water from both aquifers ranges from hard to very hard. Dissolved solids concentrations in samples from bedrock ranged from 100 to 720 mg/L, and those in samples from the unconsolidated aquifers ranged from 70 to 520 mg/L. Box plots of selected constituents (fig. 14) indicate that the ranges and concentrations of these constituents in the two aquifers are similar, probably because the unconsolidated aquifer is derived from local bedrock and, thus, consists of similar materials.

Some minerals that are derived from the shale may have been incorporated into the unconsolidated deposits locally through glacial transport and may cause the ground water within these deposits to differ somewhat from that of bedrock (Rogers, 1989), but the difference in this study area is not apparent. The data indicate that water from the bedrock and the unconsolidated aquifers also is similar to that in the Wallkill River, indicating that the Wallkill River receives water from these aquifers.

SUMMARY

The hydrogeology of the 66-mi^2 area of the Wallkill River valley between Middletown and Goshen, N.Y. was studied in 1987-88 to define the aquifer geometry, water levels in the unconsolidated deposits and the shale bedrock aquifer, and directions of ground-water flow. The hydraulic relationship between the Wallkill River and the two aquifers also was investigated, and water-quality data were collected from both aquifers and from the Wallkill River.

The unconsolidated aquifer lies between the bedrock highs and consists of complex, laterally discontinuous deposits of outwash and till interspersed with lake deposits of silt and clay. No continuous sand and gravel deposits could be stratigraphically correlated for more than a few hundred feet owing to their isolated, lens-like form. Sandy till overlies most of the area and, near the center of the valley, is interspersed at depth with sand and gravel. The till is relatively permeable and, therefore, was considered to be part of the unconsolidated aquifer, especially in areas where the unconsolidated deposits are more than 20 ft thick.

The bedrock aquifer consists of fractured shale. A seismic-refraction survey and test drilling confirmed that the bedrock surface as undulating and modified by glacial scouring, and that glacial-lake deposits underlying the "black dirt" area in the extreme southeastern part of the study area are as much as 110 ft thick and divert the flow of ground water northward from the west and east.

The generalized water-table configuration in areas where the unconsolidated aquifer is more than 20 ft thick indicates that flow is toward the Wallkill River from higher elevations to the east and west. Flow directions may depart from this regional trend locally, however, as a result of the topography. Recharge to the unconsolidated aquifer is derived from precipitation and, additionally at lower elevations near the Wallkill River, from the bedrock aquifer as well.

The shale aquifer is highly fractured and exposed locally and is overlain by less than 5 ft of glacial deposits on most of the ridges throughout the study area. Its high degree of fracturing makes it a fairly productive aquifer, especially for water needs of individual households. Wells completed in the upper, highly fractured zone typically yield 10 gal/min or more. The regional flow pattern in the shale is similar to that in the unconsolidated aquifer— generally from the east and west toward the Wallkill River.

A series of stream-discharge measurements on the Wallkill River on February 11, 1988, indicated that discharge increased by about 127 ft^3/s in the 5.5-mi reach between Pellets Island and the Route 17 bridge. This supports the conclusion, based on water levels in

the bedrock and unconsolidated aquifers, that the Wallkill River is a discharge boundary for both aquifers and therefore is a major hydrologic boundary in the area.

Some of the water in the shale aquifer is similar to water in the unconsolidated aquifer with respect to major cations and anions and selected trace metals and is a calcium-bicarbonate type; other waters are mixed types. The water in the Wallkill River is similar to water in the aquifers, presumably because it receives substantial ground-water discharge. Elevated concentrations of copper (in 8 samples), and of lead, and zinc in some of the samples may reflect proximity to ore-bearing deposits 10-mi to the west, or possibly a discharge of leachate from landfills in the study area to the Wallkill River.

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APPENDIX 1. Data on wells in Wallkill River valley study area near Middletown, N.Y.

[gal/min, gallons per minute; --, no data; ft, feet; in, inches; s&g, sand and gravel. Well locations shown in fig. 2.]

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing: Bottom depth (ft)	Casing: Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
				A. Wells screened in unconsolidated deposits							
104	412732	741847	365	5	5	--	--	--	--	W	sand
120	412721	741945	360	16	16	24.00	13.20	1964-06-24	--	W	till
131	412601	741958	360	16	--	6.00	--	--	--	T	--
145	412700	742007	360	26	--	--	--	--	--	T	--
156	412659	742043	360	40	--	--	--	--	--	T	--
179	412651	742112	390	23	23	27.00	13.40	1964-06-23	--	W	till
180	412816	742125	565	115	51	6.00	13.00	1964-04-01	40.00	W	s&g
187	412647	742138	470	164	22	7.00	--	--	4.00	W	--
203	412618	742208	355	18	--	6.00	5.20	1963-08-01	--	T	s&g
207	412553	742219	360	118	--	--	--	--	--	W	--
208	412616	742210	355	20	--	--	--	--	--	O	s&g
209	412619	742211	360	16	16	6.00	--	--	--	T	clay
213	412348	742254	480	5	--	--	1.00	1965-12-08	--	W	s&g
214	412529	742250	390	96	--	--	--	--	10.00	W	--
239	412139	742326	383	47	--	--	0.40	1965-04-20	40.00	W	sand
241	412137	742324	383	47	--	6.00	--	--	18.00	W	grvl
242	412211	742333	400	92	92	6.00	--	--	--	W	s&g
245	412135	742345	395	90	--	1.00	0.10	1964-04-01	5.00	W	s&g
246	412348	742346	400	54	54	6.00	--	--	17.00	W	--
255	412356	742403	400	41	--	6.00	1.00	1965-04-14	120.00	W	s&g
262	412253	742458	380	108	108	6.00	--	--	10.00	W	s&g
293	412415	742647	530	85	85	6.00	31.10	1965-08-02	40.00	W	s&g
295	412427	742655	500	2	2	92.00	-0.10	1964-05-14	3.00	W	sand
320	412259	742732	545	28	28	30.00	10.10	1964-06-17	--	W	till
1333	412721	742054	440	150	20	6.00	8.80	1986-11-20	8.00	W	--
1336	412343	742310	500	--	4	48.00	--	1986-11-22	10.00	W	till
1337	412251	742454	410	113	113	6.00	20.00	1984-00-00	28.00	W	s&g
1338	412239	742508	390	27	27	6.00	4.00	1984-00-00	60.00	W	s&g
1339	412212	742459	390	110	--	--	6.00	1986-11-22	150.00	W	s&g
1340	412728	742050	440	18	18	36.00	10.00	--	--	W	till
1344	412623	741923	450	--	--	6.00	--	--	--	W	--
1346	412635	742239	450	18	18	36.00	10.10	1986-11-21	--	W	s&g
1350	412655	742247	490	18	18	2.00	7.99	1987-06-19	--	O	till
1351	412702	742051	370	13	13	2.00	3.10	1987-03-24	--	O	sand
1352	412722	742012	390	26	26	2.00	17.00	1987-03-24	--	O	till
1354	412504	742421	480	17	17	2.00	--	--	--	O	till
1356	412615	742132	370	30	30	2.00	10.05	1987-06-18	--	O	grvl
1357	412336	742226	390	32	--	--	20.00	1987-05-30	--	O	--
1358	412436	742226	390	27	32	2.00	9.32	1987-06-18	--	O	s&g
1363	412449	742542	480	20	20	2.00	14.10	1987-06-18	--	O	till
1365	412442	742232	370	50	50	4.00	7.60	1987-07-10	--	U	sand

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing Bottom depth (ft)	Casing Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
				A. Wells screened in unconsolidated deposits (continued)							
1366	412619	742134	355	24	24	12.00	1.60	--	--	W	s&g
1367	412619	742134	356	21	16	12.00	--	--	--	W	s&g
1368	412619	742134	358	23	18	12.00	--	--	--	W	s&g
1372	412800	742102	546	81	80	2.75	14.00	1966-11-03	--	O	s&g
1373	412516	742415	470	--	--	--	--	--	--	Z	grvl
1375	412800	742101	546	66	65	2.75	7.00	1966-10-27	--	O	s&g
1379	412803	742020	510	25	6	2.75	1.00	1966-10-20	--	O	s&g
1380	412802	742019	511	33	20	2.75	3.00	1966-10-02	--	O	s&g
1381	412802	742018	507	27	20	2.75	2.00	1966-10-05	--	O	s&g
1388	412737	742241	603	36	35	2.75	--	--	--	O	s&g
1389	412739	742242	633	50	33	2.75	--	--	--	O	till
1391	412730	742244	560	46	45	2.75	--	1966-12-13	--	O	s&g
1392	412731	742242	560	51	50	2.75	22.00	1966-12-19	--	O	s&g
1395	412552	742228	360	44	44	8.00	1.00	--	--	W	grvl
1396	412556	742230	370	42	41	8.00	12.50	1977-08-26	380.00	W	s&g
1397	412553	742230	370	34	28	8.00	11.80	1977-09-22	600.00	W	grvl
1399	412555	742228	360	45	45	8.00	--	--	--	W	grvl
1652	412259	742102	380	400	--	18.00	--	--	90.00	W	--
1905	412101	742407	390	91	--	--	--	--	--	Z	clay
1906	412124	742530	390	74	--	--	--	--	--	Z	s&g
1934	412203	742511	390	67	--	--	--	-	--	Z	clay
2078	412555	742228	360	37	37	8.00	5.00	--	--	W	grvl
2080	412443	742234	364	39	30	8.00	8.00	1973-08-02	620.00	W	s&g
2082	412446	742233	371	46	36	18.00	15.00	--	350.00	W	s&g
2083	412442	742234	364	39	30	12.00	8.00	1973-12-02	900.00	W	s&g
2090	412728	741903	370	180	--	6.00	--	--	--	W	--
2094	412802	742010	440	--	--	--	--	--	--	W	--
2103	412546	741912	465	100	100	8.00	--	--	20.00	W	--
2104	412546	741912	465	125	125	8.00	--	--	20.00	W	--
2107	412404	742356	390	105	--	--	--	--	35.00	W	s&g
2108	412403	742357	390	105	--	--	--	--	35.00	W	s&g
2109	412324	742354	384	50	40	6.00	6.11	1987-03-02	--	O	sand
2112	412411	742705	570	125	125	6.00	28.30	1986-12-05	--	W	s&g
2121	412154	742526	390	110	110	2.00	10.00	1976-06-00	15.00	W	s&g
2136	412250	742354	390	21	21	2.00	-1.10	1986-12-04	--	W	s&g
2143	412422	742649	520	95	70	6.00	25.05	1986-12-05	25.00	W	s&g
2147	412106	742506	390	--	--	--	--	--	--	O	clay
2149	412355	742631	540	--	--	--	--	--	--	O	till
2150	412337	742607	590	--	--	--	--	--	--	O	till
2153	412411	742336	410	135	--	--	13.00	1987-05-20	--	U	till
2166	412259	742102	520	408	--	--	49.00	1969-00-00	35.00	W	--
2167	412349	742410	390	52	40	2.00	--	--	--	O	grvl
2168	412342	742342	390	50	40	2.00	--	--	--	O	grvl
2170	412308	742430	381	74	64	4.00	6.00	1984-0-411	--	T	sand

APPENDIX 1. Data on wells in Wallkill River valley study area near Middletown, N.Y. (continued)

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing: Bottom depth (ft)	Casing: Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
A. Wells screened in unconsolidated deposits (continued)											
2171	412347	742357	395	41	27	4.00	29.00	1984-04-11	--	T	s&g
2172	412317	742436	388	50	48	4.00	13.00	1984-04-11	--	T	sand
2173	412325	742443	386	35	32	4.00	11.17	1984-04-11	--	T	s&g
2174	412330	742444	384	67	57	4.00	7.97	1984-04-11	--	T	till
2175	412333	742432	427	100	95	4.00	51.95	1984-04-11	--	T	sand
2176	412335	742409	404	40	33	4.00	32.45	1984-04-11	--	T	till
2177	412327	742353	407	57	51	4.00	39.94	1984-04-11	--	T	sand
2178	412336	742357	406	50	42	4.00	40.39	1984-04-11	--	T	sand
2179	412334	742348	394	44	37	4.00	28.02	1984-04-11	--	T	clay
2180	412317	742425	431	112	110	6.00	37.04	1983-04-11	--	T	sand
2181	412325	742422	395	32	24	4.00	24.00	1984-04-11	--	T	s&g
2183	412314	742415	385	60	50	4.00	14.00	1984-04-11	--	T	sand
2184	412319	742444	384	31	20	4.00	9.00	1984-04-11	--	T	sand
2185	412339	742414	387	30	25	2.00	15.00	1984-04-11	--	T	sand
2186	412332	742416	400	61	56	4.00	26.00	1984-04-11	--	T	grvl
2187	412332	742426	408	50	46	4.00	28.00	1984-04-11	--	T	till
2188	412344	742423	381	78	75	2.00	7.00	1984-04-11	--	T	sand
2191	412141	742318	380	49	49	6.00	--	--	--	W	till
2192	412139	742317	400	51	51	6.00	--	--	--	W	till
2195	412701	742012	350	--	--	--	--	--	--	T	clay
2196	412701	742012	350	--	--	--	--	--	--	T	s&g
2202	412416	742255	381	34	24	6.00	27.10	1986-11-20	--	O	s&g
2203	412413	742237	422	34	24	4.00	12.43	1986-11-20	--	T	s&g
2204	412412	742304	374	32	20	6.00	17.56	1986-11-20	--	T	sand
2206	412412	742315	373	30	--	--	16.17	1986-11-20	--	T	sand
2207	412410	742317	377	32	19	--	19.75	1986-11-20	--	T	sand
2209	412330	742349	384	44	44	1.25	28.98	1986-10-31	--	O	sand
2211	412329	742348	373	24	24	1.25	4.42	1986-10-29	--	O	sand
2212	412329	742347	362	14	14	1.25	11.17	1986-10-30	--	O	sand
B. Wells completed in bedrock											
90	412725	741855	365	140	80	6.00	4.00	1958-01-01	6.00	W	shle
98	412550	741815	420	64	--	--	10.00	--	11.00	W	shle
103	412726	741839	365	85	40	4.00	4.00	1961-01-01	7.00	W	shle
107	412416	741902	440	108	14	6.00	--	--	30.00	W	shle
117	412739	741905	395	143	53	6.00	30.00	1964-01-01	15.00	W	shle
118	412800	741932	400	190	--	6.00	13.00	1961-01-01	5.00	W	shle
119	412725	741940	360	178	--	--	--	--	--	W	shle
121	412731	741953	365	147	45	6.00	13.00	1959-01-01	20.00	W	shle
142	412809	742007	440	228	--	--	63.00	1965-05-13	--	U	shle
143	412335	742015	440	290	--	--	--	--	58.00	W	shle
144	412708	742008	400	162	110	6.00	45.00	1959-01-01	22.00	W	shle
147	412722	742019	395	85	30	6.00	15.00	1959-01-01	19.00	W	shle

APPENDIX 1. Data on wells in Wallkill River valley study area near Middletown, N.Y. (continued)

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing Bottom depth (ft)	Casing Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
					B. Wells completed in bedrock (continued)						
148	412801	742043	540	91	17	6.00	--	--	12.00	W	shle
149	412623	742035	500	81	--	--	--	--	20.00	W	shle
150	412718	742027	410	70	22	6.00	7.10	1965-07-21	100.00	W	shle
151	412736	742030	430	85	35	6.00	19.00	1953-06-26	30.00	W	shle
153	412352	742048	455	350	17	8.00	--	--	50.00	W	shle
154	412128	742044	535	235	--	--	--	--	300.00	T	shle
155	412353	742052	465	147	20	6.00	--	--	15.00	W	shle
158	412412	742051	380	59	54	6.00	--	--	--	T	shle
174	412618	742140	365	125	--	6.00	--	--	--	W	shle
176	412600	742100	470	152	--	6.00	10.00	1966-01-01	4.00	T	shle
177	412111	742101	610	300	110	6.00	--	--	10.00	W	shle
178	412625	742100	435	102	--	--	--	--	9.00	W	shle
181	412648	742124	460	143	--	--	62.30	1965-05-04	--	W	shle
182	412019	742130	400	203	--	--	--	--	35.00	W	shle
183	412020	742134	400	411	--	--	--	--	49.00	W	shle
184	412619	742128	375	185	--	--	--	--	--	W	shle
185	412710	742129	475	103	14	6.00	30.00	1958-08-01	20.00	W	shle
186	412619	742133	365	194	81	6.00	--	--	30.00	W	shle
188	412625	742150	365	97	--	6.00	17.80	1965-08-03	8.00	W	shle
189	412651	742147	470	150	--	--	22.80	1966-01-10	8.00	T	shle
190	412728	742249	580	155	15	6.00	.20	1949-01-01	2.00	W	shle
205	412609	742232	400	327	--	--	--	--	--	W	shle
210	412352	742223	460	138	80	6.00	12.00	1965-06-00	12.00	W	shle
211	412727	742245	550	420	157	6.00	68.00	1965-10-14	200.00	W	shle
212	412730	742255	600	270	255	6.00	--	--	--	W	shle
215	412610	742229	400	400	--	--	40.50	1964-06-30	--	W	shle
232	412111	742306	430	144	--	--	10.00	1964-05-01	20.00	W	lmsn
233	412056	742306	410	130	127	6.00	--	--	10.00	W	lmsn
234	412421	742316	460	538	165	10.00	--	--	9.00	W	shle
235	412418	742315	432	300	--	--	99.40	1965-04-14	25.00	W	shle
236	412420	742314	454	260	130	8.00	111.50	1965-04-14	12.00	W	shle
237	412217	742314	410	180	--	--	--	--	12.00	W	shle
238	412422	742311	494	785	--	--	--	--	15.00	W	shle
240	412330	742330	440	112	10	6.00	5.00	1964-05-07	--	W	shle
243	412214	742337	425	140	80	7.00	--	--	10.00	W	shle
244	412711	742344	560	345	100	6.00	--	--	40.00	W	shle
257	412736	742405	615	315	60	6.00	--	--	14.00	W	shle
258	412714	742410	535	307	108	7.00	--	--	65.00	W	shle
260	412429	742445	510	164	--	6.00	--	--	17.00	W	shle
261	412249	742451	430	325	291	7.00	--	--	--	W	shle
272	412447	742520	480	300	--	--	--	--	--	W	shle
275	412343	742539	680	278	--	--	--	--	--	W	shle

APPENDIX 1. Data on wells in Wallkill River valley study area near Middletown, N.Y. (continued)

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing Bottom depth (ft)	Casing Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
					B. Wells completed in bedrock (continued)						
276	412521	742545	460	259	46	7.00	--	--	5.00	W	shle
277	412525	742555	540	160	--	--	--	--	--	W	shle
288	412347	742624	530	145	--	--	23.00	1965-08-02	--	W	shle
290	412433	742633	520	150	90	6.00	--	--	6.00	W	shle
291	412518	742626	540	247	--	--	--	--	25.00	W	shle
292	412414	742646	430	149	--	6.00	--	--	--	W	lmsn
310	412315	742713	590	425	--	--	--	--	--	W	shle
312	412323	742718	510	152	--	--	14.40	1965-08-02	10.00	W	shle
316	412301	742733	535	81	7	81.00	6.50	1964-06-17	--	W	shle
317	412402	742723	530	226	17	6.00	--	--	5.00	W	shle
1113	412735	742250	580	220	180	6.00	--	--	--	W	shle
1334	412351	742214	420	150	--	6.00	18.80	1986-11-26	70.00	W	rock
1335	412356	742304	430	--	--	6.00	39.00	1986-11-22	--	W	rock
1341	412220	742345	450	550	50	6.00	77.10	1986-11-22	12.50	W	rock
1342	412154	742258	450	180	30	6.00	63.50	1986-11-22	--	W	rock
1343	412754	741953	390	120	120	6.00	8.00	1986-05-00	20.00	W	rock
1345	412608	742013	450	140	--	12.00	20.00	1986-05-00	17.00	W	rock
1347	412444	742334	420	250	--	6.00	31.90	1986-11-21	5.00	W	rock
1353	412217	742426	400	23	23	2.00	--	--	--	O	rock
1355	412436	742620	460	50	50	2.00	7.53	1987-06-18	--	O	shle
1359	412708	742104	430	25	25	2.00	10.10	1987-06-18	--	O	shle
1360	412308	742621	590	25	25	2.00	10.14	1987-06-18	--	O	shle
1361	412508	742405	470	110	110	2.00	11.57	1987-06-18	--	O	shle
1362	412449	742542	480	35	35	2.00	23.86	1987-06-18	--	O	shle
1364	412726	742026	390	20	20	2.00	7.37	1987-06-18	--	O	shle
1369	412409	742704	520	300	40	8.00	50.00	1956-00-00	100.00	W	shle
1371	412649	742212	480	--	--	--	51.00	1965-06-22	--	W	shle
1374	412523	742403	440	--	--	--	4.00	1965-05-07	--	Z	shle
1377	412744	742036	460	--	--	--	--	--	--	T	shle
1382	412454	742527	470	--	--	--	16.00	1965-04-01	--	Z	shle
1383	412546	742328	450	--	--	--	.50	1965-02-12	--	Z	shle
1384	412629	742232	430	--	--	--	35.00	1965-03-08	--	Z	shle
1385	412709	742131	470	--	--	--	--	--	--	X	shle
1386	412802	741946	370	--	--	--	6.00	1965-11-18	--	T	shle
1393	412323	742138	480	160	--	--	64.30	1986-11-19	--	W	rock
1398	412548	742233	370	115	38	8.00	--	--	--	W	shle
1973	412320	742833	500	186	--	6.00	--	--	--	W	shle
2077	412552	742228	370	155	40	8.00	1.00	--	--	W	shle
2079	412252	742454	400	109	--	--	10.00	--	36.00	W	rock
2091	412455	742345	420	230	--	--	--	--	20.00	W	rock
2092	412422	742435	530	320	65	6.00	--	--	35.00	W	rock
2093	412427	742435	530	320	65	6.00	--	--	35.00	W	rock
2098	412435	742505	480	225	30	6.00	--	--	10.00	W	rock
2099	412330	741820	390	335	--	--	42.11	1983-11-17	15.00	W	rock

APPENDIX 1. Data on wells in Wallkill River valley study area near Middletown, N.Y. (continued)

Well no.	Lattitude ° ' "	Longitude ° ' "	Land-surface altitude (ft)	Well depth (ft)	Casing Bottom depth (ft)	Casing Diameter (in)	Water level (ft below land surface)	Date water level measured (yr-mo-d)	Discharge (gal/min)	Use of well*	Type of Deposit
				B. Wells completed in bedrock (continued)							
2100	412355	741831	430	550	40	6.00	3.00	1984-11-19	32.00	W	rock
2101	412310	742645	550	200	200	6.00	--	--	50.00	W	rock
2102	412310	742645	550	200	200	6.00	--	--	50.00	W	rock
2105	412440	742430	530	200	15	6.00	--	--	35.00	W	rock
2106	412440	742430	530	200	20	6.00	--	--	20.00	W	rock
2114	412414	742614	570	232	45	6.00	53.50	1986-12-05	12.00	W	rock
2117	412526	741734	370	225	30	6.00	6.40	1986-12-06	25.00	W	rock
2118	412527	741736	370	220	--	6.00	7.70	1986-12-06	20.00	W	rock
2133	412251	742706	640	160	150	6.00	130.00	--	10.00	W	rock
2134	412244	742408	390	115	--	6.00	4.80	1986-12-04	10.00	W	rock
2135	412441	742211	440	153	--	6.00	17.40	1986-11-21	22.00	W	shle
2137	412136	742034	580	300	--	6.00	44.42	1987-05-20	100.00	W	rock
2138	412246	742215	430	80	65	6.00	16.60	1987-05-20	--	W	rock
2139	412508	742414	450	85	--	--	26.68	1987-07-10	12.00	W	rock
2140	412247	742434	390	68	--	6.00	18.30	1986-12-04	--	W	rock
2142	412448	742630	520	250	80	6.00	--	--	10.00	W	rock
2144	412413	742707	570	400	20	6.00	13.00	1986-12-05	8.00	W	rock
2148	412647	742332	470	--	--	--	--	--	--	O	rock
2151	412541	742043	380	160	--	6.00	32.00	1987-05-07	--	W	shle
2152	412443	742159	420	162	--	6.00	14.16	1987-05-07	--	W	shle
2155	412456	742024	420	80	--	6.00	17.00	1987-03-00	11.00	W	rock
2156	412528	741615	370	100	--	--	4.00	--	4.00	W	rock
2157	412548	741603	400	110	5	6.00	5.00	--	2.00	W	rock
2158	412214	742321	400	170	--	6.00	23.94	1987-05-20	17.00	W	rock
2159	412142	742215	470	300	80	6.00	--	--	27.00	W	rock
2160	412053	742210	490	200	--	--	18.64	1987-05-20	2.00	W	rock
2161	412221	742523	390	--	--	--	--	--	--	O	lmsn
2163	412659	742051	360	10	10	2.00	--	--	--	O	shle
2165	412557	742007	510	220	20	6.00	26.10	1987-05-19	30.00	W	rock
2169	412555	742228	360	39	29	16.00	5.00	1975-08-29	--	O	shle
2189	412149	742311	390	53	52	6.00	5.00	1956-12-18	--	O	rock
2190	412342	742753	490	165	--	6.00	12.00	1986-11-19	17.00	W	rock
2193	412157	742322	415	62	59	6.00	--	--	--	W	rock
2194	412139	742325	395	50	50	6.00	3.25	1957-03-01	--	W	rock
2197	412701	742012	350	--	--	--	6.00	1983-07-07	--	T	shle
2198	412703	741952	350	--	--	--	--	--	--	T	shle
2199	412703	741952	350	--	--	--	--	--	--	T	rock
2200	412703	741952	350	--	--	--	--	--	--	T	shle
2201	412703	741952	350	--	--	--	--	--	--	T	shle
2205	412412	742313	373	121	101	--	15.28	1986-11-20	--	T	shle
2208	412359	742250	485	83	--	--	68.95	1986-11-20	--	T	shle

*W, withdrawal; T, test; O,observation; U, unused; Z, destroyed; X, waste

APPENDIX 2. Water quality in Wallkill River valley study area near Middletown, N.Y.

[deg. C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter, µg/L, micrograms per liter]

A. Surface-water stations between Pellets Island and Philipsburg, September 11, 1986

Station number	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH, field (standard units)	Air temperature (deg C)	Water temperature (deg C)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
WK-1	83	470	7.2	26.5	19.0	6.7	47	16	20	2.3
WK-2	63	480	7.3	26.5	18.5	6.3	47	16	20	2.3
WK-3	73	480	7.4	26.5	18.5	6.4	49	16	19	2.3
WK-4	66	470	7.3	26.5	18.5	5.8	50	16	20	2.4
WK-5	73	500	7.5	26.5	19.0	6.4	46	14	31	3.8

Station number	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as pb)	Manganese, dissolved (µg/L as Mn)	Zinc, dissolved (µg/L as Zn)
WK-1	141	31	38	0.10	10	64	<5	32	11
WK-2	142	31	38	0.10	10	86	<5	33	13
WK-3	145	37	37	0.10	<10	67	<5	40	17
WK-4	148	36	38	0.10	10	78	<5	56	18
WK-5	124	35	49	0.20	--	190	<5	90	20

APPENDIX 2. Water quality in Wallkill River valley study area near Middletown, N.Y. (continued)

Well number	Date	Depth of well, total (feet)	Land-surface-datum elevation (ft above sea level)	Specific conductance (µS/cm)	pH, field (standard units)	Water temperature (deg C)	Calcium, dissolved (mg/l as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)
B. Wells											
211	07-08-87	420	550	809	7.5	21	20	28		1.1	280
240	07-08-87	112	440	292	6.8	23.5	44	7.6	4.6	0.5	110
1336	07-08-87	--	500	115	6.9	25.5	15	2.3	2	0.4	33
1339	07-09-87	110	390	466	7.8	24	70	14	8.1	0.8	170
1341	07-08-87	550	450	527	7.7	24.5	53	30	16	1.2	230
1347	07-08-87	250	420	528	7.9	23.5	74	13	21	1.7	180
1350	07-10-87	18	490	--	7.7	28.5	81	23	31	3.7	260
1351	07-08-87	13	370	361	7.1	19.5	49	5.9	11	1.6	140
1352	07-08-87	26	390	929	7.3	20.5	110	13	55	2.3	190
1353	07-10-87	23.5	400	509	7.5	28	94	25	4.5	1	250
1354	07-09-87	17	480	796	7.7	30	130	20	20	0.80	--
1355	07-09-87	50	460	497	7.8	20.5	69	10	12	2.2	190
1356	07-07-87	30	370	715	7.4	--	83	16	35	1.4	220
1358	07-10-87	27	390	558	7.8	28	72	12	13	1.9	140
1359	07-08-87	25	430	505	10.9	17	42	0.49	23	19	79
1360	07-10-87	25	590	176	6.1	29.5	19	2.9	7.2	0.6	64
1361	07-09-87	110	470	373	9.2	18	37	3.5	48	1.6	160
1362	07-09-87	35	480	1,310	--	21.5	--	--	--	--	--
1363	07-09-87	20	480	889	--	22	--	--	--	--	--
1365	07-09-87	50	370	605	7.4	24	97	14	14	6	290
1652	07-07-87	400	380	539	7.7	22	69	19	14	0.8	210
2107	07-09-87	105	390	471	7.7	28	64	13	18	1.2	220
2109	07-10-87	50	384	790	7.5	27	31	10		1.1	360
2118	07-08-87	220	370	--	7.7	19.5	64	17	11	0.7	--
2119	07-08-87	70	370	480	8.2	21.5	1.5	0.36	110	0.2	280
2121	07-09-87	110	390	536	8.1	24.5	50	15	41	1.4	150
2132	07-07-87	90	390	342	7.8	21	50	9	6.7	0.8	120
2133	07-08-87	160	640	564	7.8	27	90	14	8.9	0.6	--
2135	07-07-87	153	440	468	7.5	21	68	10	8.8	1.1	160
2137	07-09-87	300	580	492	7.8	29	48	21	22	0.9	200
2138	07-08-87	80	430	594	7.6	20	95	15	15	1.5	220
2139	07-09-87	85	450	590	7.7	22.5	67	14	42	1.6	--
2143	07-08-87	95	520	502	7.8	27	54	8.8	54	1	220

APPENDIX 2. Water quality in Wallkill River valley study area near Middletown, N.Y. (continued)

Well no.	Date	Sulfate, dissolved (mg/L as SO4)	Silica, dissolved (mg/L as SiO_2)	Chloride, dissolved (mg/L as Cl)	Nitrogen nitrate, dissolved (mg/L as N)	Copper, total recoverable (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb	Manganese, dissolved (µg/L as Mn)	Zinc, dissolved (µg/L as Zn)	Aquifer type
					B. Wells (continued)						
211	07-08-87	53	15	100	0.023	20	12	<5	330	110	bedrock
240	07-08-87	36	12	3.2	0.61	<10	12	<5	<1	150	bedrock
1336	07-08-87	18	11	1.3	0.023	30	11	<5	2	20	unconsolidated
1339	07-09-87	63	14	14	0.023	<10	68	<5	340	10	unconsolidated
1341	07-08-87	44	10	20	0.361	20	15	8	10	390	bedrock
1347	07-08-87	63	14	21	0.023	10	6	<5	450	20	bedrock
1350	07-10-87	9.8	13	<52	0.023	<10	6	<5	3	10	unconsolidated
1351	07-08-87	35	12	44	0.113	10	15	<5	540	30	unconsolidated
1352	07-08-87	50	11	160	0.023	30	12	5	710	20	unconsolidated
1353	07-10-87	61	8.4	8.1	0.773	<10	1,200	12	98	20	bedrock
1354	07-09-87	49	12	100	4.29	70	13	9	260	<10	unconsolidated
1355	07-09-87	58	11	77	0.023	--	150	8	330	20	bedrock
1356	07-07-87	53	8.2	99	0.59	20	470	<5	3,900	20	unconsolidated
1358	07-10-87	42	7.8	65	0.023	<10	11	<5	2,700	20	unconsolidated
1359	07-08-87	35	10	53	0.113	10	41	<5	1	<10	bedrock
1360	07-10-87	13	8.9	18	0.226	<10	220	<5	690	80	bedrock
1361	07-09-87	75	19	1.1	0.023	<10	23	<5	91	<10	unconsolidated
1362	07-09-87	53	--	250	0.023	--	--	<5	--	--	unconsolidated
1363	07-09-87	25	--	130	0.565	--	--	<5	--	--	unconsolidated
1365	07-09-87	54	10	44	0.023	20	51	<5	710	30	unconsolidated
1652	07-07-87	47	16	21	0.113	130	23	<5	45	50	unconsolidated
2107	07-09-87	40	15	11	0.023	30	16	<5	410	40	unconsolidated
2109	07-10-87	200	20	39	0.023	10	<3	<5	890	<10	unconsolidated
2118	07-08-87	53	16	7.8	0.023	<10	13	5	100	20	bedrock
2119	07-08-87	17	13	40	0.023	--	20	<5	16	10	bedrock
2121	07-09-87	44	13	50	0.113	<10	5	<5	210	50	unconsolidated
2132	07-07-87	--	14	--	--	10	41	<5	96	<10	bedrock
2133	07-08-87	--	12	--	--	<10	110	8	280	<10	bedrock
2135	07-07-87	25	10	49	0.023	170	7	<5	5	10	bedrock
2137	07-09-87	51	17	7.5	0.023	10	8	<5	11	<10	bedrock
2138	07-08-87	82	14	18	0.023	20	12	<5	350	40	bedrock
2139	07-09-87	72	12	6.7	0.023	1,500	860	5	440	<10	bedrock
2143	07-08-87	37	13	5.8	0.023	30	70	<5	380	<10	unconsolidated