EFFECTS OF INCREASED PUMPAGE ON A FRACTURED-BEDROCK AQUIFER SYSTEM IN CENTRAL ORANGE COUNTY, NEW YORK

By Murray Garber

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CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used to convert inch-pound units of measurement in this report to the International System of Units (SI).

Multiply inch-pound unit	by	To obtain SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
degree Fahrenheit (°F)	5/9(°F-32)	degree Celsius (°C)
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)m]
gallon per day per square mile [(gal/d)/mi^2]	1.46×10^{-3}	cubic meter per day per square kilometer [(m^3/d)/km^2]
square feet per day (ft^2/d)	0.0929	square meters per day
gallons per day per foot [(gal/d)ft]	0.0124	cubic meters per day
note: 1 ft^3 = 7.49 gal.		
fluid ounce (fl. oz.)	0.02957	liters

Other Abbreviations Used in this Report

microgram per liter (μg/L)
milligram per liter (mg/L)
micromhos per centimeter at 25°C (μmho)

EFFECTS OF INCREASED PUMPAGE ON A FRACTURED-BEDROCK AQUIFER SYSTEM IN CENTRAL ORANGE COUNTY, NEW YORK

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ABSTRACT

The bedrock in central Orange County consists of highly indurated siltstone, shale, and conglomerate containing two major fault systems and extensive fracturing; it is overlain by 50 to 100 feet of till. The fracturing permits unusually high well yields. Wells tapping the bedrock yield 75 to 200 gallons per minute; those tapping bedrock in adjacent areas yield only a few tens of gallons per minute. The bedrock aquifer is recharged principally by percolation of water from precipitation through the till.

In 1983, the U.S. Geological Survey began a study to evaluate the hydrologic effects of increased pumpage on a fractured bedrock aquifer system near the Village of Kiryas Joel, in the Town of Monroe. Water levels were measured in several wells in the village's two well fields from February to October 1983, and pumpage data from the same period were tabulated. Water levels responded to variations in both pumpage and precipitation. Pumping tests and water levels in the southeastern well field in 1983 had no effect on the northwestern well field. An observation well between the two fields shows about 20 feet of seasonal fluctuation from recharge and the effects of pumping at the northwestern well field. Aquifer-test data indicate a transmissivity of 900 feet squared per day and a storage coefficient of 0.0001.

The aquifer-test data were used to estimate drawdowns in wells at specific distances in relation to several rates of pumpage through time. Such estimates are valuable in selecting proper well spacing to maintain a long-term yield from a fractured-bedrock aquifer.

INTRODUCTION

Ground water is the principal source of water supply in much of southeastern New York, and many communities depend on fractured-bedrock aquifers as the sole source of public-water supply. In 1977, the U.S. Geological Survey, in cooperation with the Village of Kiryas Joel, made a preliminary appraisal of well yields in fractured bedrock in central Orange County (Waller, 1979) and, in 1983, began a 9-month followup study to evaluate the hydrologic effects of increased pumpage for public supply in the Town of Monroe.

Earlier studies (Frimpter, 1972; Waller, 1979) indicated that highly fractured zones yield much more water than other areas of similar bedrock in Orange County. Recent plans by the Village of KiryasJoel to drill new wells and conduct pumping tests presented an opportunity to evaluate a larger segment of

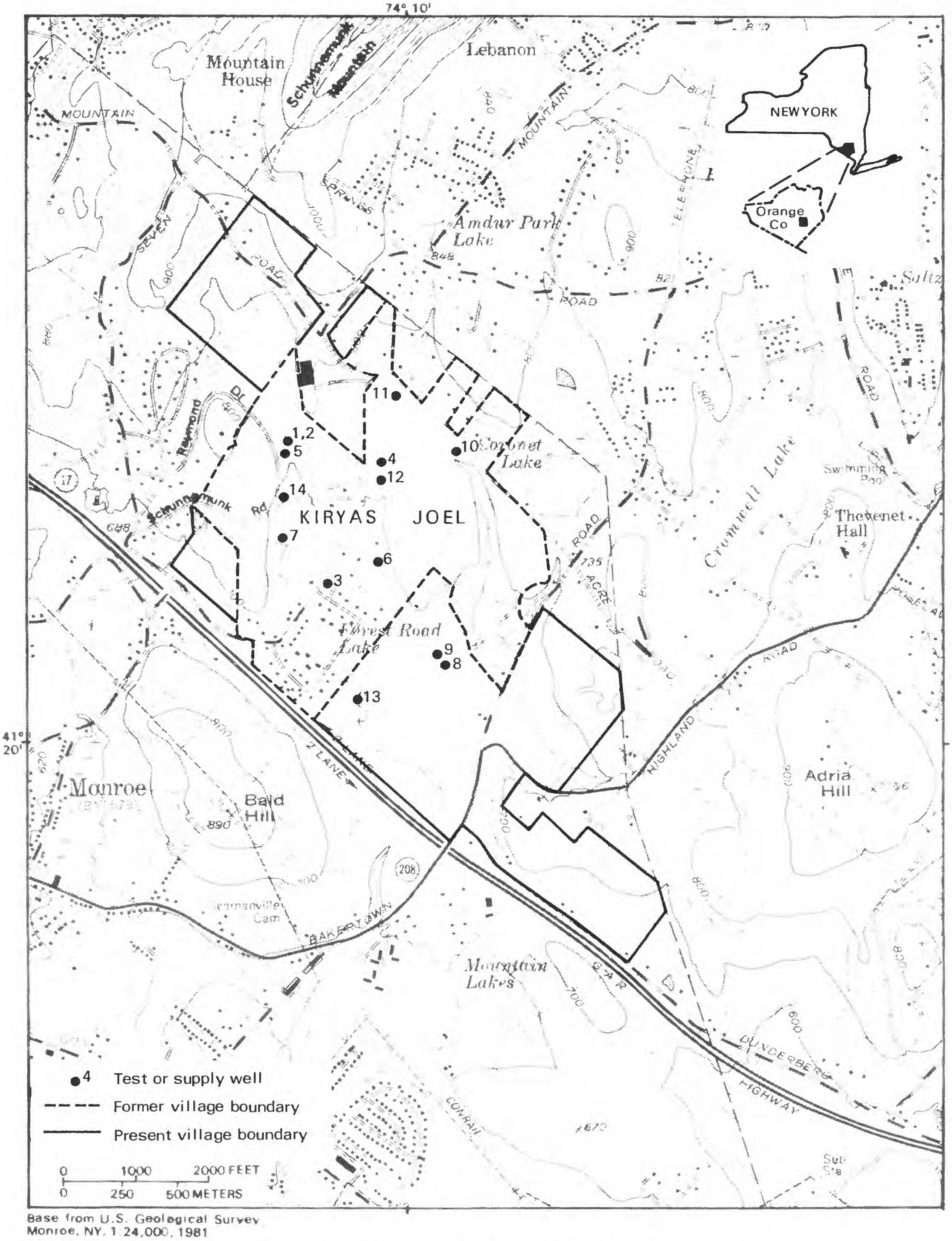


Figure 1.--Location of wells and major geographic features of the study area.

a highly fractured zone postulated by Waller (1979). Consequently, an observation-well network was established, pumpage records compiled, and controlled aquifer tests run to evaluate the effects of stress on the system. A major goal of the study was to evaluate the yield of an apparent concentrated zone of fracturing and its water-transmitting characteristics. The results of the study can be applied to extensions of the fractured zone in areas adjacent or in areas having similar hydrogeologic conditions (Cederstrom, 1972).

This report (1) describes the geohydrologic system, (2) presents results of the 1983 aquifer tests, (3) evaluates the effects of pumping on water levels in the fractured bedrock, and (4) evaluates the potential yield of the bedrock aquifer. Well-field data and water-level hydrographs are given in appendixes.

Location and Geography

The study area occupies about 2 mi^2 northeast of the Village of Monroe in Orange County (fig. 1). It lies entirely within the Town of Monroe and is just north of U.S. Highway 17. The rolling land is blanketed by till and contains several small lakes. It has poor drainage locally, and is drained by several small streams that flow southward to the Ramapo River. Schunnemunk Mountain, a prominent northeast-trending ridge 1/2 mi to the north, forms the northern drainage divide of this stream system.

Previous Work

Little has been published on the development of large-yield water-supply systems in fractured-bedrock aquifers. Cederstrom (1972) evaluated bedrock yields in the northeast (including New York) and concluded that large sustained yields are possible in structurally deformed areas. A recent report by Kohut and others (1983) presents the results of a study of fractured granitic terrain in British Columbia. Many of the hydrologic characteristics found in that study are remarkably similar to those in Orange County. Most significant was pronounced hydraulic anisotropy resulting from the intersections of prominent joints and fractures. Vecchioli and others (1969), in a study of a fractured shale aquifer in New Jersey, observed and analyzed a similar phenomenon.

The bedrock geology of the Monroe 7½-minute quadrangle was mapped by Jaffe and Jaffe (1973). Their map is the most detailed available for this area and was adapted for use in this study.

Acknowledgments

Thanks are extended to Roger M. Waller of the Geological Survey for aid in compiling this report and for advising on methods, and to James Nakao of the Geological Survey for making field measurements and running geophysical logs. Thanks are also extended to Raimondi Associates, Monroe, N.Y., consultants to the Village of Kiryas Joel, especially Ronald Rothenberg, who obtained level control on all wells and helped obtain much of the data used herein. The Village of Monroe water-plant operator, Henry Scheuerman, provided weekly pumpage data and supplied meter readings throughout the project.

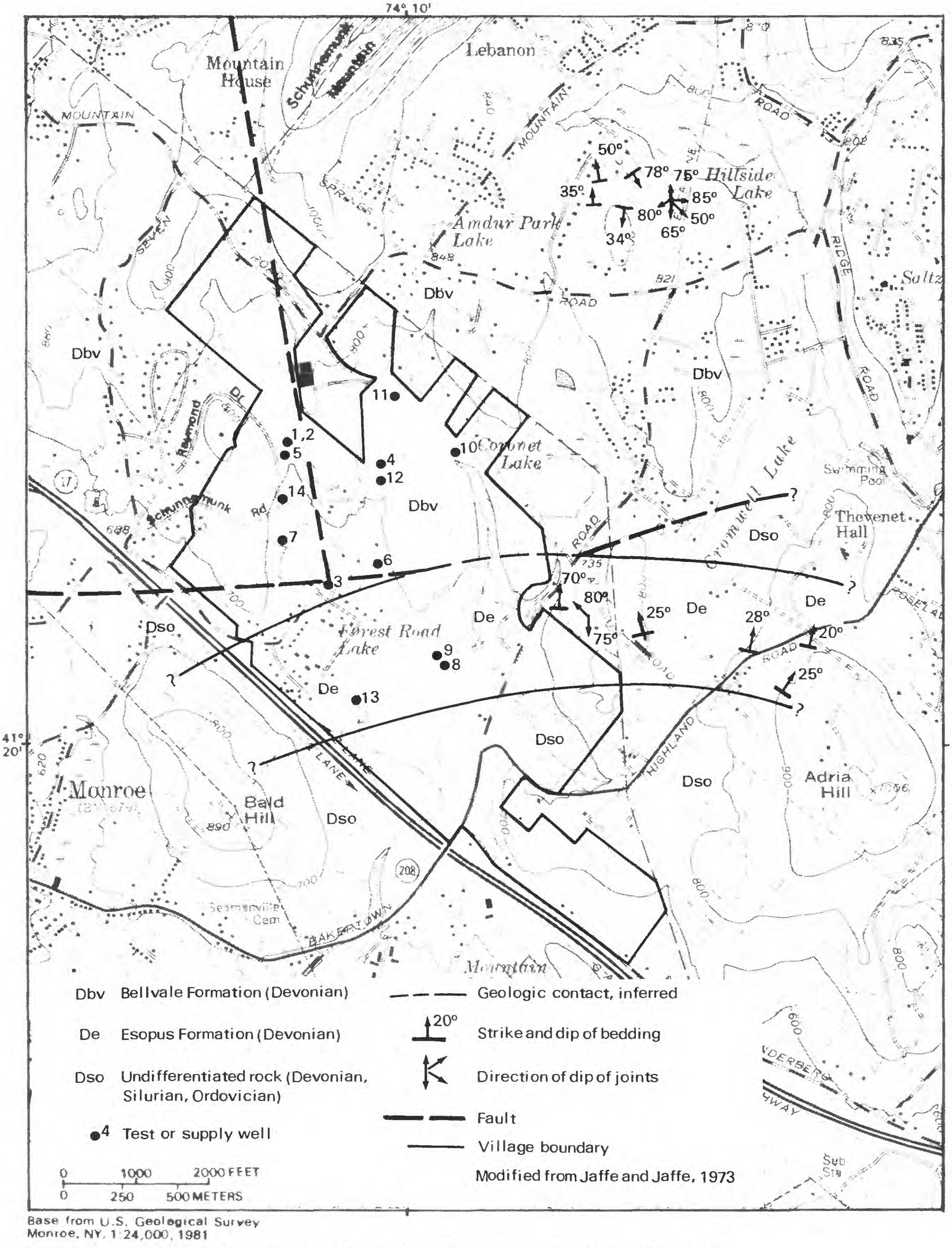


Figure 2.--Generalized geologic map of study area. (Modified from Jaffe and Jaffe, 1973.)

GEOHYDROLOGY

Geology

The study area is underlain by sedimentary rocks of Cambrian, Ordovician, Silurian, and Devonian age (Jaffe and Jaffe, 1973, pl. 1) that are mantled by a thin layer of till (fig. 2). The regional dip of the bedrock is generally northward toward Schunnemunk Mountain, which is a synclinal ridge. Several inferred faults cut through the area, two of which intersect within the study area (fig. 2). Evidence of possible thrust faulting can be seen in a roadcut on U.S. Route 17 west of Forest Road Lake (fig. 2). The bedrock in the study area may possibly be a detached segment (klippe) of a thrust fault, which would explain the extensive fracturing and the resulting high well yields in that area (Julian Soren, U.S. Geological Survey, oral commun., 1983).

The lithologic units in the study area (Jaffe and Jaffe, 1973) are, in ascending order, a concealed section of rocks spanning Ordovocian through Devonian age--the Esopus Formation (siltstone and shale) and the Bellvale Formation (graywacke and conglomerate) of Devonian age. The two make up the principal aquifers of the study area.

Outcrops of the Bellvale and Esopus Formations were examined in the field. The Esopus crops out in a roadcut along Bakertown Road near wells 8 and 9 (fig. 2). There, the shale beds strike N 75° E. and dip 22° N. The bedding is thin to massive, and the bedding planes are open. The rocks are strongly jointed and fractured. Two major high-angle joints were observed; one strikes east-west and dips 75° S, and the other strikes N 12° E and dips 80° west. Outcrops of Bellvale rocks were observed north of the Village of Kiryas Joel, where the strike of the formation is E-W and N 75° E and the dip of the bedding is 30°-35° N. Bedding in these outcrops is flaggy to massive, and the rocks are well jointed.

The area is mantled by a layer of glacial deposits (mainly till) that is 25 to 50 ft thick at most wells, although a thickness of 110 ft was reported at well 12. The till is generally clayey and of low permeability but contains scattered sand and gravel beds that yield water.

Ground Water

Occurrence

Ground water in the study area occurs principally in the joints, fractures, and other secondary openings in the bedrock. Primary porosity and permeability of these rocks is low, which Frimpter (1972, p. 54) found typical of all consolidated-rock aquifers in Orange County and in Ulster County to the north. Well yields in the study area (see appendix A) are as much as six times greater than the countywide average as a result of faulting, fracturing, and other secondary openings such as solution channels in limestone. The frequency of occurrence and size of fractures, in general, decreases with depth.

Isolated sand and gravel deposits are randomly distributed within the till, and most contain small quantities of water. Well 10 (fig. 1) obtains artesian flow from one such deposit. The bedrock there is fully saturated, and the water table (top of the saturated zone) is mostly within the overlying till.

Recharge and Discharge

The aquifer system is recharged by water derived from precipitation and from streamflow that percolates through the unsaturated zone to the water table and into the underlying bedrock. The recharge area for wells tapping the Bellvale Formation is probably limited to the 4- to 5-mi^2 upgradient area southeast of the crest of Schunnemunk Mountain and at elevations above 700 ft. The probable recharge area for the Esopus Formation is the area that is underlain by the Esopus outcrop (fig. 2). Discharge is to the wetlands and stream passing beneath Highway 17 near Bakertown Road. The water table in the area slopes southward at a gradient of about 80 ft/mi.

EFFECTS OF INCREASED PUMPAGE ON WATER LEVELS

Pumping of wells lowers water levels and creates a cone of depression that extends outward in all directions and diverts water toward the wells. In areas where permeability is variable, such as the fracture system postulated here, the water levels will be affected in varying degrees, depending on the transmissive properties of the rock. Hence, the cone of depression may extend farther in some directions than others--generally farthest along zones of high permeability.

A series of pumping tests at three wells was planned during 1983 to document drawdowns resulting from increased withdrawals. This information gives an indication of the extent of fracturing within and between the upper part of the Esopus Formation and the Bellvale Formation. Results are described below.

Aquifer Test at Well 9

Well 9 was pumped on June 28-30, 1983. Water levels were measured during this test in wells 8, 11, 12, and 13 (fig. 1). Discharge from well 10 was also monitored.

Drawdown Observations

The intake of the submersible pump was set at 172 ft below land surface, and the well was pumped for 48 hours with the discharge piped about 50 ft to a stream. It is unlikely that the discharge water reentered the aquifer. Discharge during most of the test was highly variable, generally ranging from 130 to 160 gal/min, although some higher and lower rates were observed (fig. 3). Falling discharge rates required that the pump be shut off momentarily several times during the test. Each time pumping was resumed, the discharge was turbid for several minutes, indicating that the well had not been fully developed before the test. The discharge rate and water level were erratic during the first 34 hours of the test, but in the last 14 hours, the rate remained constant at 138 gal/min, and the level stabilized at 87 ft below land surface.

During this test, no drawdown due to the pumping was discernible in wells 11 or 12 (3,660 and 2,640 ft away, respectively). The declining water level in these wells was believed to be due principally to pumping at wells 4 and 7. The discharge from well 10 remained constant throughout the test. The response

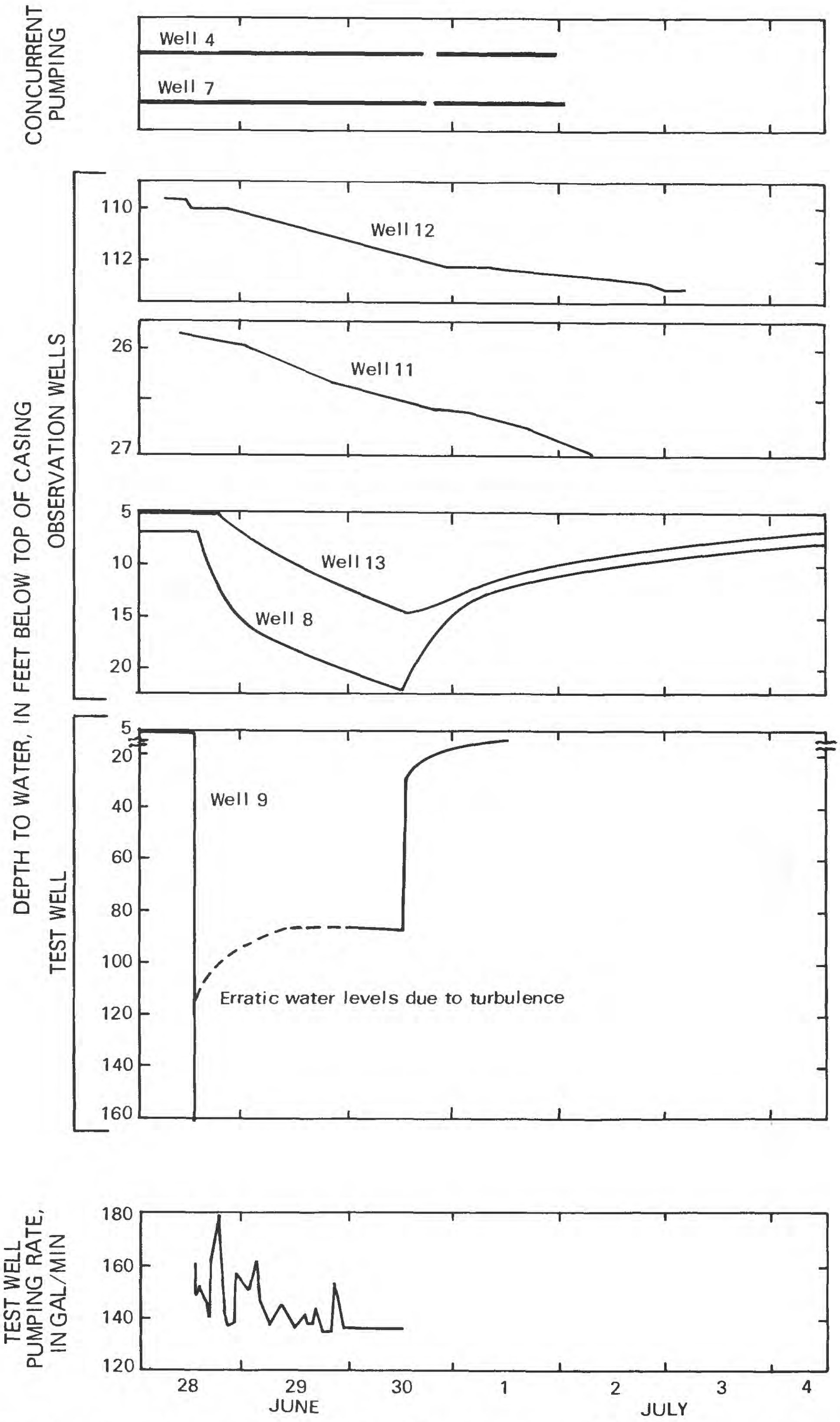


Figure 3.--Pumping rate and water levels at well 9 and water levels in wells 4, 7, 8, 11, 12, 13 during pumping test at well 9, June 28-29, 1983. (Well locations are shown in fig. 4.)

in well 8 (120 ft from the pumped well) was instantaneous, and the total drawdown in well 8 at the end of pumping was about 9 ft. The response was delayed in well 13 (1,590 ft from the pumped well), and the total drawdown at the end of the test was approximately 9 ft.

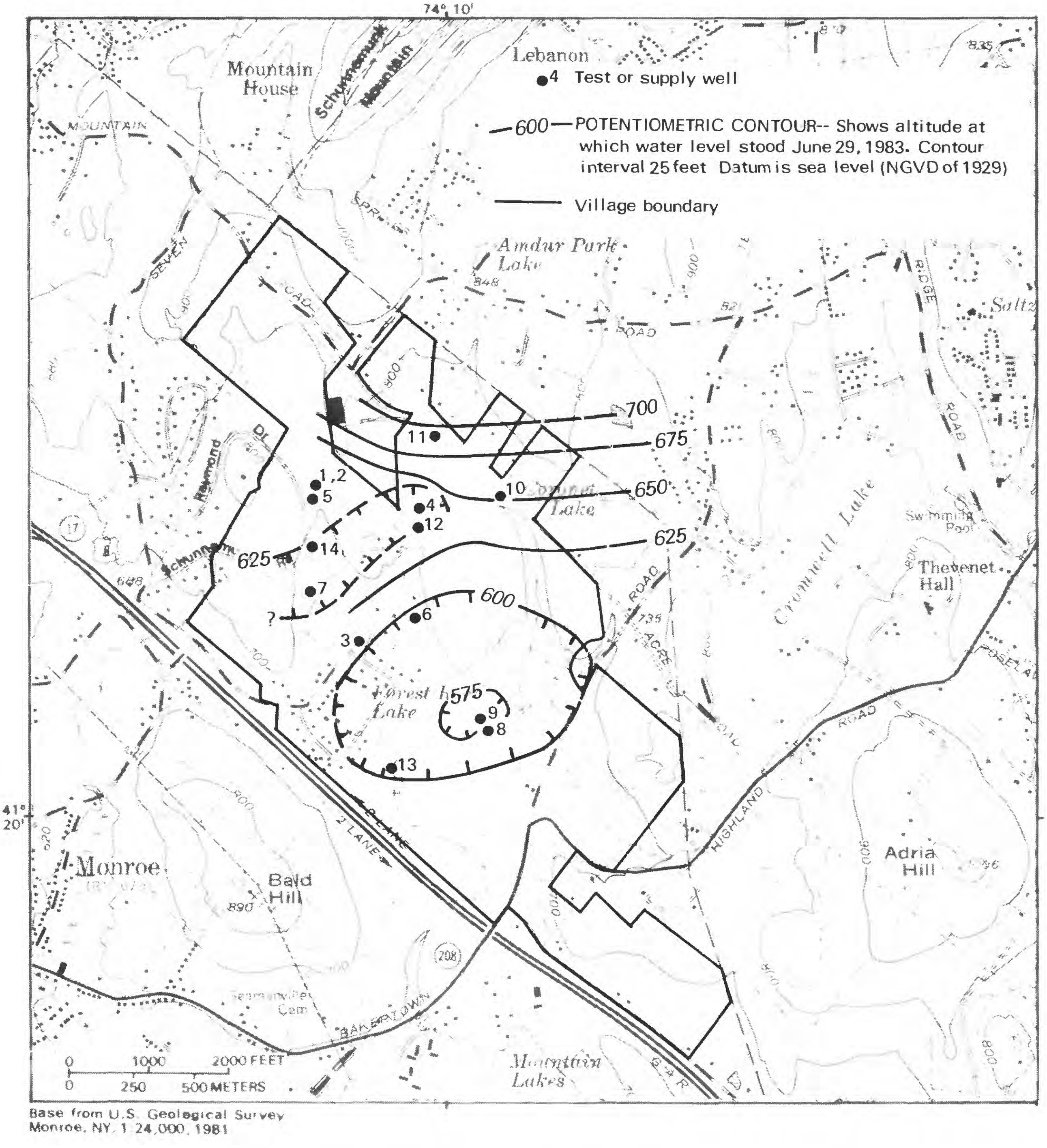
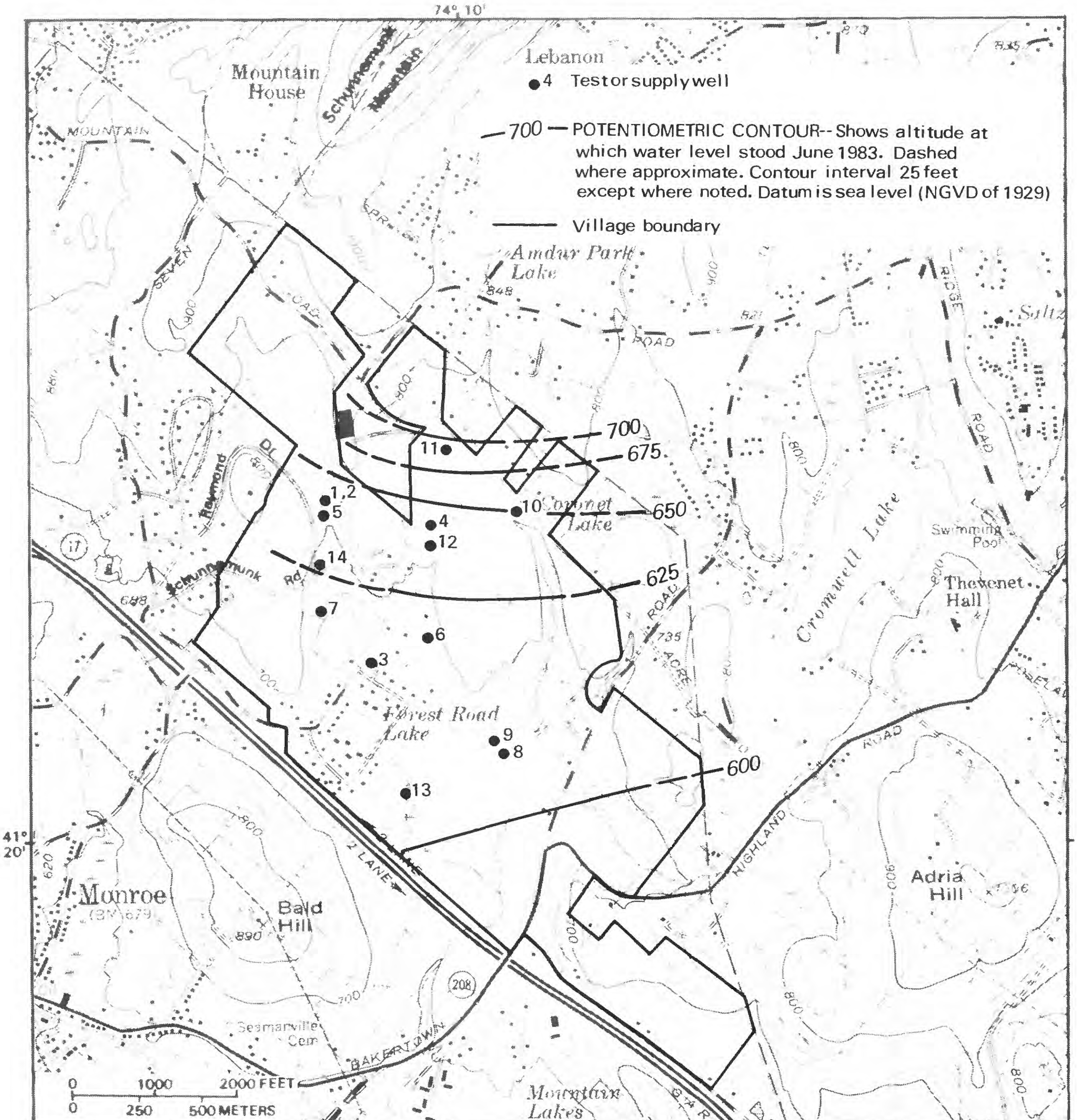


Figure 4.--Potentiometric surface of the bedrock-aquifer system at end of pumping test at well 9, June 28-29, 1983.

Potentiometric maps showing the area of diversion from this test and in June 1983, before testing began, are shown in figures 4 and 5 for comparison. The extent of the area of diversion around pumping wells 4 and 7 in the "old" (western) well field was not determined.



Base from U.S. Geological Survey Monroe, NY, 1:24,000, 1981

Figure 5.--Potentiometric surface of the bedrock-aquifer system in June 1983 before start of pumping test.

Recovery Observations

Measurements of water-level recovery in well 9 were made manually for several hours after the test; the rest of the recovery data were obtained for several days after the test by automatic water-level recorders on observation wells 8, 11, 12, and 13.

Initial recovery in the pumped well (no. 9) was rapid for the first few hours but slowed thereafter. The water level in nearby well 8 responded immediately to the cessation of pumping, but recovery was much more gradual than in the pumped well. Response in well 13 showed that the water level fell an additional 0.125 ft (not discernible in fig. 3) in the first 90 minutes after the pump in well 9 was shut off. This delayed start of recovery, along with a delay in start of drawdown noted earlier, may imply a partial water-table condition rather than a confined system. The two pumping wells nearest to well 13 are wells 6 and 7 (1,960 and 2,320 ft distant, respectively). The pumping rate at well 6 (if it was pumping at this time) is too low to create any measureable drawdown at this distance, and well 13 has not previously shown response to pumping in well 7. None of the wells (8, 13, and the pumped well 9) had recovered to their pretest static water level by the start of the test of well 8 on July 11, 1983, 12 days later, which indicates that some dewatering had occurred in the aquifer. The effect of this pumpage from well 9 on the flow in the nearby stream was negligible, as noted in stage readings.

The apparent lack of response in wells north of the east-west-trending fault (fig. 2) suggests a lack of direct hydraulic connection between the fracture systems surrounding wells 8, 9, and 13 in the southern area and that surrounding wells 11 and 12 in the northern area. The reason for this lack of hydraulic connection is uncertain, but possible explanations are an impermeable zone along the fault, an impermeable zone somewhere near, or at, the contact between the Esopus and Bellvale Formations, a lack of hydraulic connection between the fractures of the two formations, or anisotropic hydraulic properties in the Esopus Formation that cause water to flow more readily parallel to the strike of the beds (Vecchioli and others, 1969).

It is important to note, however, that when well 4 was tested in 1977 (Waller, 1979), the pumping rate was increased in steps until drawdown was observed in the observation wells. In other words, a "pumpage threshold" level was found which, once exceeded, resulted in an observable drawdown in formerly unresponsive wells. A similar relationship may exist between the southern wells tapping the Esopus Formation and those tapping the Bellvale Formation to the north.

Aquifer Test at Well 8

Well 8 was pumped during July 11-15, 1983, and water levels were measured in wells 9, 11, 12, and 13. Drawdowns and pumping rate are plotted in figure 6. The submersible pump intake was set at 194 ft below land surface, and the well was pumped for a total of 96 hours. The pumping rate varied slightly about a mean value of 300 gal/min for most of the test and was increased to 320 gal/min in the last 21 hours. A 90-minute shutdown period occurred on the morning of July 13, when the generator that drives the pump failed. Other

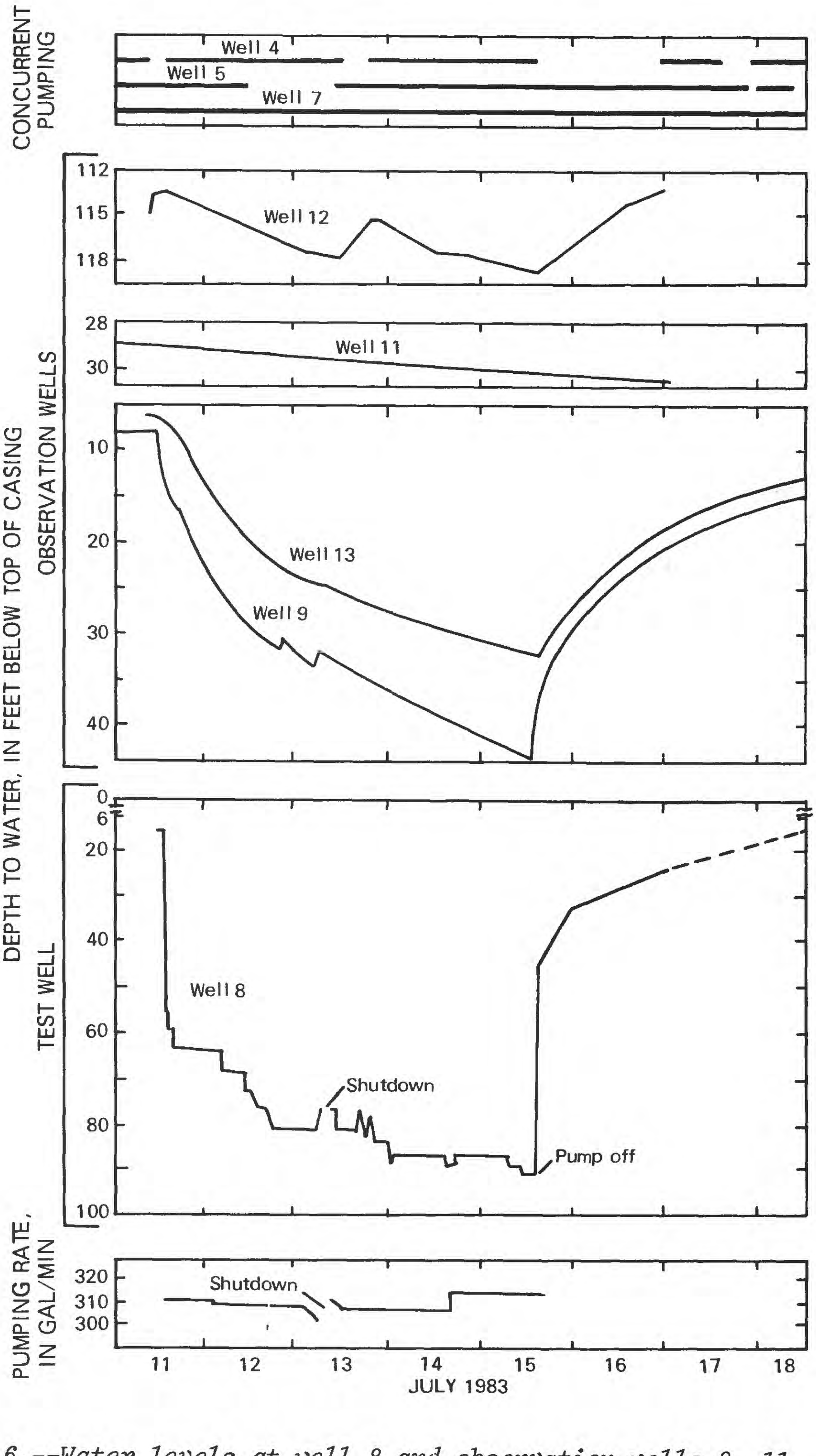


Figure 6.--Water levels at well 8 and observation wells 9, 11, 12, 13 during pumping test of July 11-15, 1983. (Well locations are shown in fig. 7.)

shutdown periods, mostly 5 minutes or less, occurred during the test. The discharge from well 8 was relatively uniform compared to that in well 9; this can possibly be attributed to several hours of well development with high-pressure air jets before pump installation.

Water-level measurements in well 8 during pumping and for a few minutes after pumping stopped were made by air line; at other times, the water level was measured directly by electric line or steel tape. The air line and the direct measurements differ in that lack of resolution in the air-line pressure gage produced an abrupt, step-like drawdown graph (fig. 6). Total drawdown after 96 hours of pumping was about 74 ft.

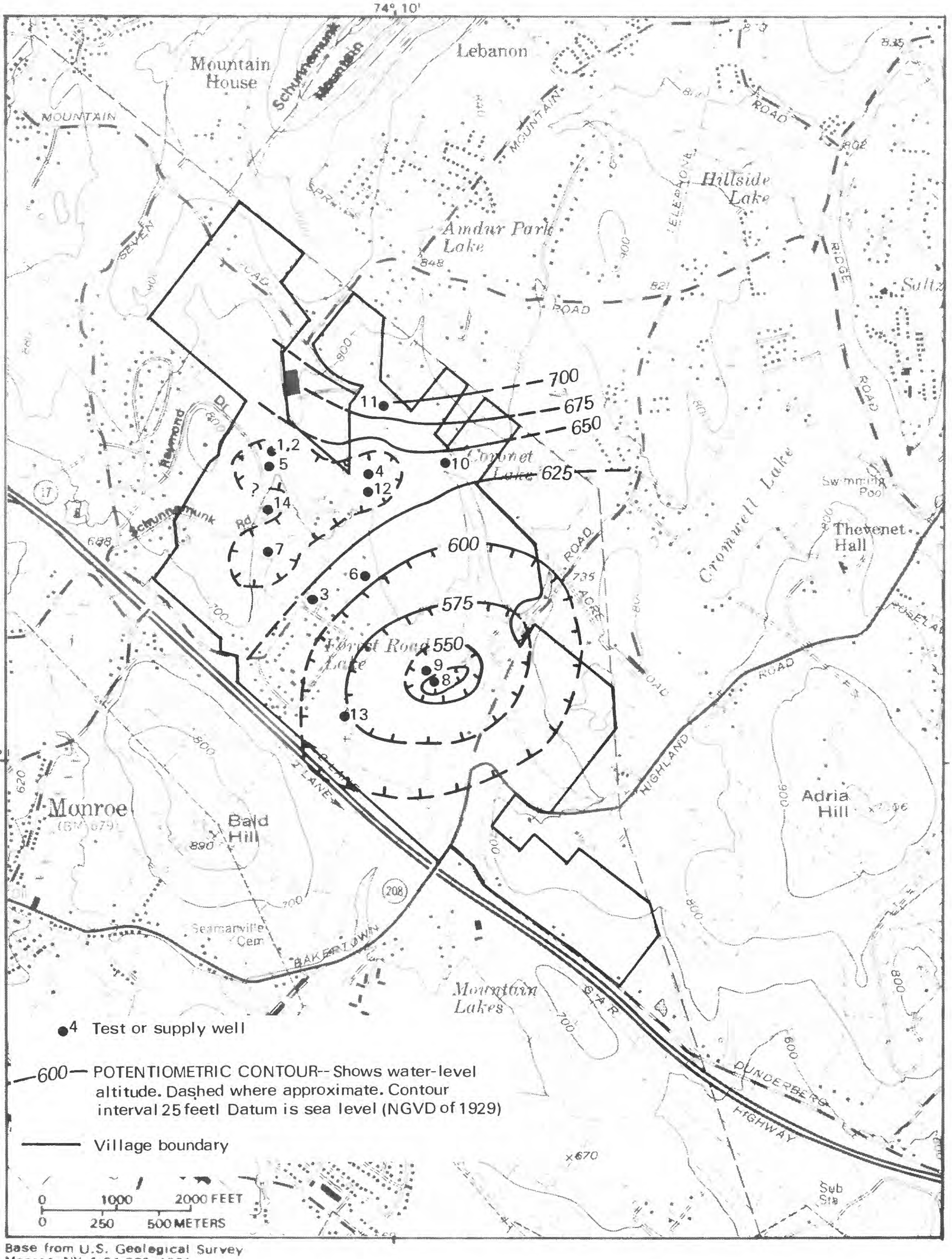
Drawdown Observations

The response in well 9, which is 120 ft away, was instantaneous, and total drawdown at the end of the test was about 35 ft (fig. 6). The small spikes on the drawdown graph represent the immediate response to the shutdown periods. Response in well 13, which is 1,590 ft southwest of well 8, was delayed, and the drawdown curve for this well is relatively smooth. Well 13 also responded sluggishly to the 90-minute shutdown on July 13. The maximum drawdown in this well at the end of pumping was about 26 ft.

Wells 11 and 12, about 3,770 and 2,750 ft away, showed no response to the pumping at well 8. (Well 12 shows effects of concurrent pumping at wells 4, 5 and 7.) A potentiometric map showing the cone of influence at the end of this test is shown in figure 7. As in the map for the test at well 9, the cones of depression around wells 4 and 7 could not be shown with certainty because water-level measurements could not be made in these wells at that time. Hydrographs of observation wells 8, 9, 11, and 13 for January through December 1983 are given in appendix B.

Recovery Observations

Water-level recovery in the test well (no. 8) was measured manually for several hours, and recovery in wells 9, 11, 12, and 13 was measured by automatic water-level recorders for several days. Water-level recovery was, in general, similar to that in the preceding test at well 9. Recovery in well 8 was rapid at first, rising 53 ft in the first 220 minutes after pumping stopped, and slowing gradually thereafter. The response at well 9 was immediate, and the response at well 13 was delayed somewhat but less than in the preceding test at well 9. By the end of September 1983, water levels in wells 8, 9, and 13 still had not recovered to their pretest levels. However, the summer seasonal decline of water levels (the 1983 hydrograph for well 11 in the appendix shows the probable trend) was underway, and aquifer discharge was exceeding recharge. Water levels during the succeeding recharge period (winter 1983-84) would show whether the aquifer recovered. Wells 11 and 12 showed no response to the pumping test at well 8, but well 12 reflects the concurrent pumping at well 4, 5, and 7. (See fig. 6.)



Base from U.S. Geological Survey
Monroe, NY, 1:24,000, 1981

Figure 7.--Potentiometric surface of the bedrock-aquifer system at end of pumping test at well 8, July 11-15, 1983.

Analysis of Aquifer Tests

Data from the pumping tests at wells 8 and 9 (well 13 test was not conducted) were analyzed by several standard methods, including curve-matching techniques, analysis of recovery data from the pumped wells, and estimates of aquifer properties from specific-capacity values (Lohman, 1972). The objective of these analyses was to obtain values of the aquifer's hydraulic properties, which in turn can be used to calculate optimum well yield and spacing. The analytical methods used were originally developed for application in an ideal homogeneous and isotropic aquifer, such as an unconsolidated sand bed, where stresses are transmitted uniformly in all directions without interference. These requirements are seldom fully met in the field, especially in fractured rock aquifers such as the one studied; therefore extreme care and judgment must be exercised to obtain reasonable results.

Aquifer Properties

Transmissivity.--Transmissivity is a measure of the aquifer's ability to yield water to wells and is defined as the volume of water that will pass through a 1-ft-wide section extending the entire thickness of the aquifer in 1 day under a unit (1:1) hydraulic gradient, as shown diagrammatically in figure 8. Transmissivity values for the Esopus Formation range from 400 to 2,000 ft^2/d or 3,000 to 15,000 (gal/d)/ft. The most reasonable value appears to be about 900 ft^2/d or 6,700 (gal/d)/ft.

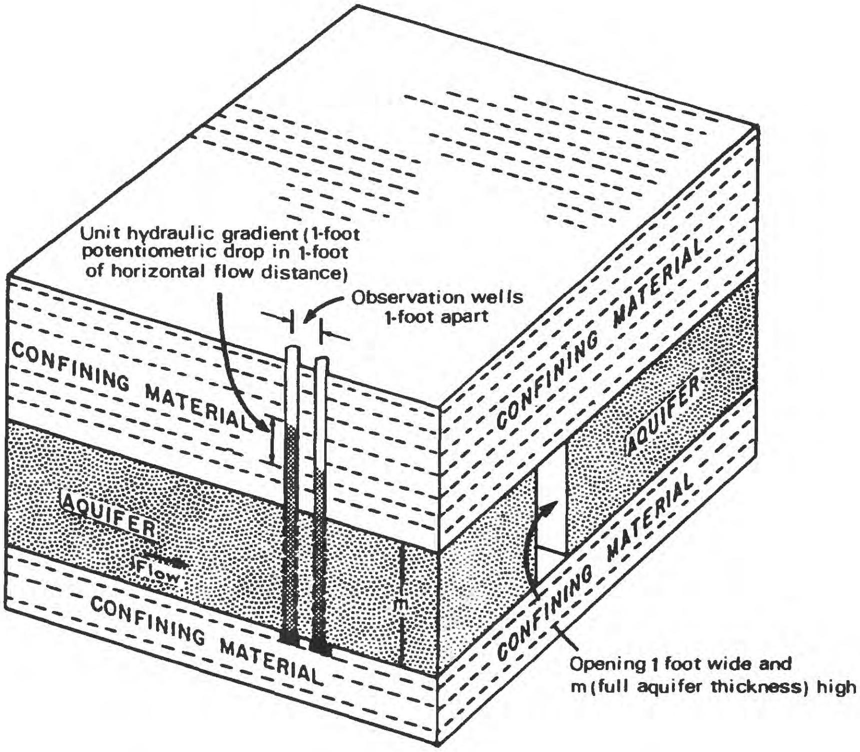


Figure 8.--Aquifer transmissivity, Value represents volume of water passing horizontally through as aquifer section 1 foot wide and m (full aquifer thickness) high in 1 day under a hydraulic gradient of 1. (Modified from Ferris and others, 1962, p. 72.)

Storage Coefficient.--Storage coefficient is defined as the volume of water released from a vertical rectangular prism having a horizontal surface area of 1 ft^2 and extending through the entire aquifer thickness, when the head in the aquifer is lowered by 1 ft. (See fig. 9.) Storage coefficient is dimensionless. Values less than about 0.003 are common for confined aquifers, and values greater than 0.1 are common for water-table aquifers. Values of storage coefficient obtained for the Esopus Formation from these tests range from 0.00008 to 0.003, and the most reasonable value is considered to be around 0.0001. This value, and the range calculated, fall within the values typical of confined aquifer systems.

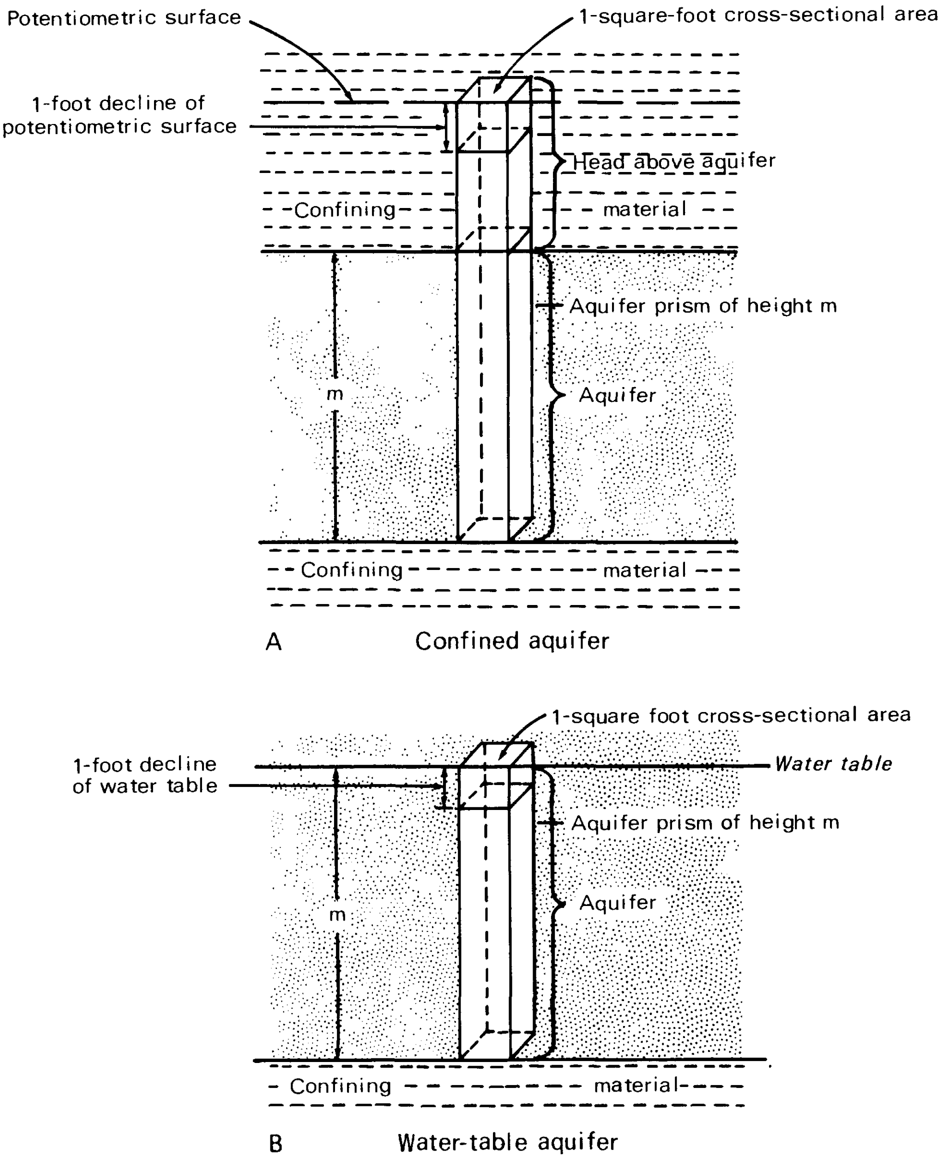


Figure 9.--Storage coefficient. Value represents volume of water released from vertical section 1 ft^2 across and m (full aquifer thickness) high when head in aquifer is lowered 1 foot. (Modified from Ferris and others, 1962, p. 77.)

Specific Capacity.--Specific capacity is a qualitative measure of well and aquifer performance, expressed as the ratio of well yield (gal/min) to drawdown (ft). Values of specific capacity were obtained from the pumping tests and were also computed from pumping-test data reported by drillers. Specific capacities of wells in the Esopus Formation range from 1.4 to 4 gal/min per foot of drawdown, which is from 3 to 10 times greater than those measured in wells 4 and 7 in the Bellvale Formation in the initial study (Waller, 1979, p. 10). Estimates of transmissivity derived from these specific capacities range from about 450 to 1,100 ft^2/d and compare reasonably well with transmissivity values obtained from the pumping tests in wells 8 and 9.

Drawdown Estimates and Future Well Development

Estimates of expected drawdown in the Esopus Formation at distances of 1 ft to 5,000 ft from a well after 1 year of continuous pumping at rates from 100 to 400 gal/min are plotted in figure 10; expected drawdowns for pumping periods of 1 to 5,000 days (about 14 years) at distances of 1 to 2,000 ft at wells pumping continuously at three different rates are plotted in figure 11. These estimates can be used by water-system designers as a basis for deciding optimum well spacing and yield as the system is expanded and as a means of evaluating well behavior in the expanded system. An example of such use would be to evaluate the drawdown at well 13, should that well be added to the supply system, and to determine optimum spacing and yield for any new wells

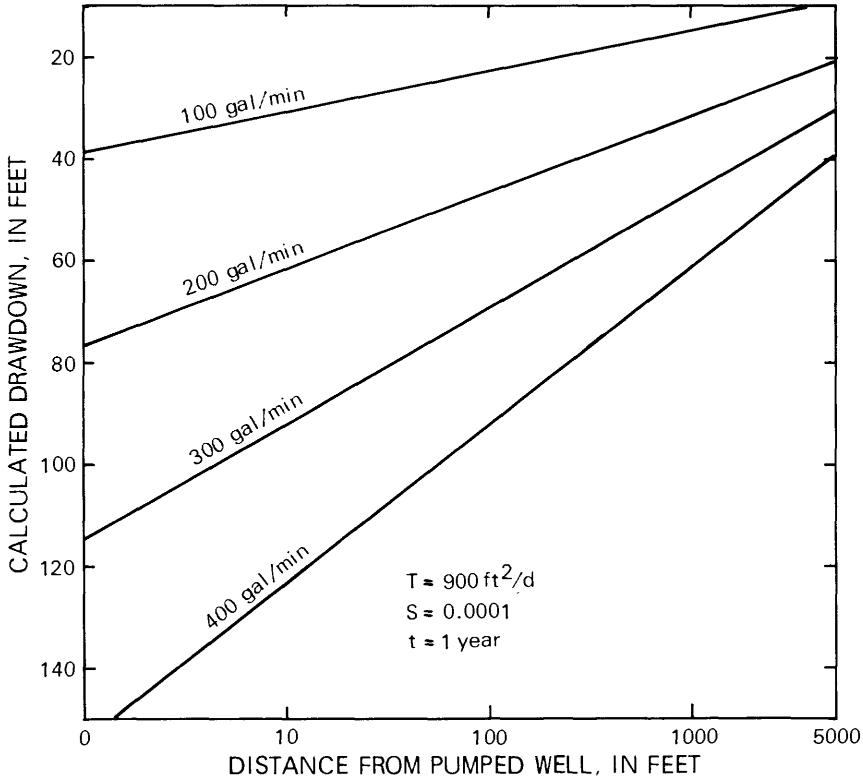


Figure 10.--Estimated drawdown at a well after 1 year of pumping at 100 to 400 gal/min at distances of 1 to 5,000 ft from well.

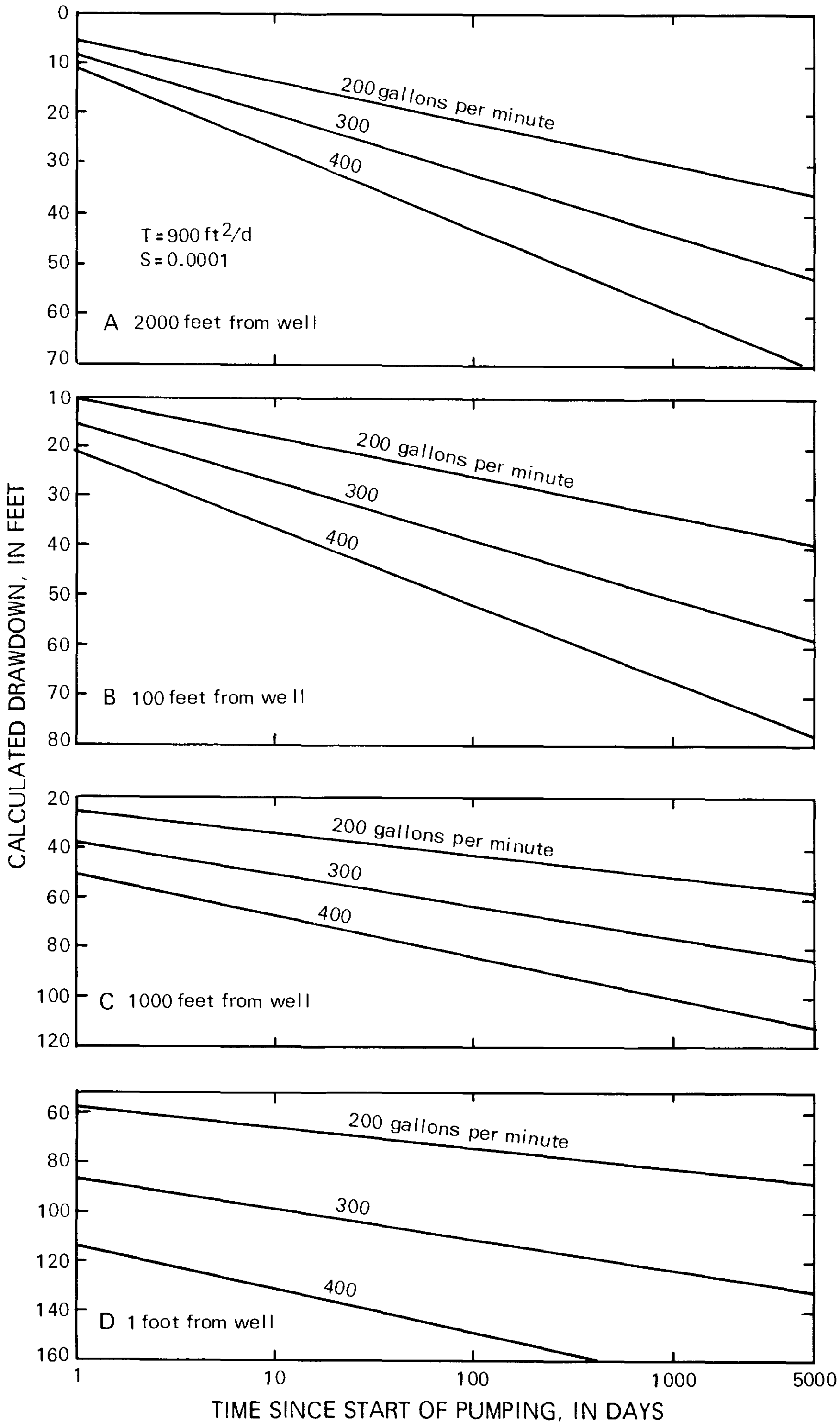


Figure 11.--Estimated drawdowns at specified distances from a well after 1 to 5,000 days of pumping at 200 to 400 gal/min: A, 2,000 ft from well. B, 1,000 ft from well. C, 100 ft from well. D, 1 ft from well.

that may be drilled in the same aquifer. It must be remembered, however, that these graphs are based on only 4 days of continuous pumping and do not take into account the effects of aquifer-boundary conditions that might develop as a result of long-term pumping nor the effects of an extended severe drought, both of which could produce a greater drawdown than is shown.

From the foregoing data, it can be estimated that two distant wells pumped simultaneously and continuously at rates of 175 and 150 gal/min, respectively, can provide a total daily yield in excess of 400,000 gal. If either well were pumped singly, its yield would be increased substantially.

ESTIMATE OF POTENTIAL YIELD

Although pumpage for residential use has increased substantially from this part of the aquifer since 1977, per-capita water use has increased only slightly to a moderate rate of 44 to 50 gal/d per person (table 1). If the current per-capita rate remains constant, an additional 400,000 gal/d from wells 13 and 8 would increase the system's output to 700,000 gal/d and thus provide for a total population of 13,000. Water from additional wells drilled in the area east of Bakertown Road could possibly increase total pumpage to about 1 Mgal/d.

Table 1.--Mean daily pumpage and per-cpaita daily use in 1977 and 1983, by month.

[Data from Village records; a dash indicates no data available.]

	1977		1983	
Month	Average monthly pumpage (gal/d)	Per-capita use (gal/d)	Average monthly pumpage (gal/d)	Per-capita use (gal/d)
Jan.	-	-	-	-
Feb.	112,000	56	203,900	37
March	81,000	41	245,400	45
April	68,000	34	246,100	45
May	67,000	34	255,500	47
June	86,000	43	276,700	50
July	113,000	57	302,600	55
Aug.	189,000	95	346,300	63
Sept.	138,000	69	294,300	54
Oct.	112,000	56	302,300	55
Nov.	93,000	47	296,000	53
Dec.	91,000	46	288,300	52
	average	44	average	50

If the estimates of aquifer recharge that were previously used by Waller (1979) are accurate, the maximum daily withdrawal for this study area under optimum conditions may be no more than 900,000 gal/d. This estimate also accounts for recharge from seepage through the till. Additional water could be derived by induced infiltration from streams and lakes (Waller, 1979, p. 15) that would otherwise be lost as evaporation or streamflow out of the area. Under drought conditions, when streamflow is low or zero, the quantity of water available to wells in the area is limited to the amount of water in storage in the aquifers at that time.

Data from several years of normal recharge and from a dry period during the summer and fall of 1983 indicate that the wells have thus far been capable of supplying around 300,000 gal/d without excessive drawdowns. It is important, however, that future expansion of the water-supply system be accompanied by regular maintenance of accurate records of pumpage, water levels, and precipitation to estimate the severity of lowered water levels. For example, the relationship between precipitation, pumping at well 4, and water levels in well 11, 990 ft distant, is depicted in figure 12. The interpretation is that,

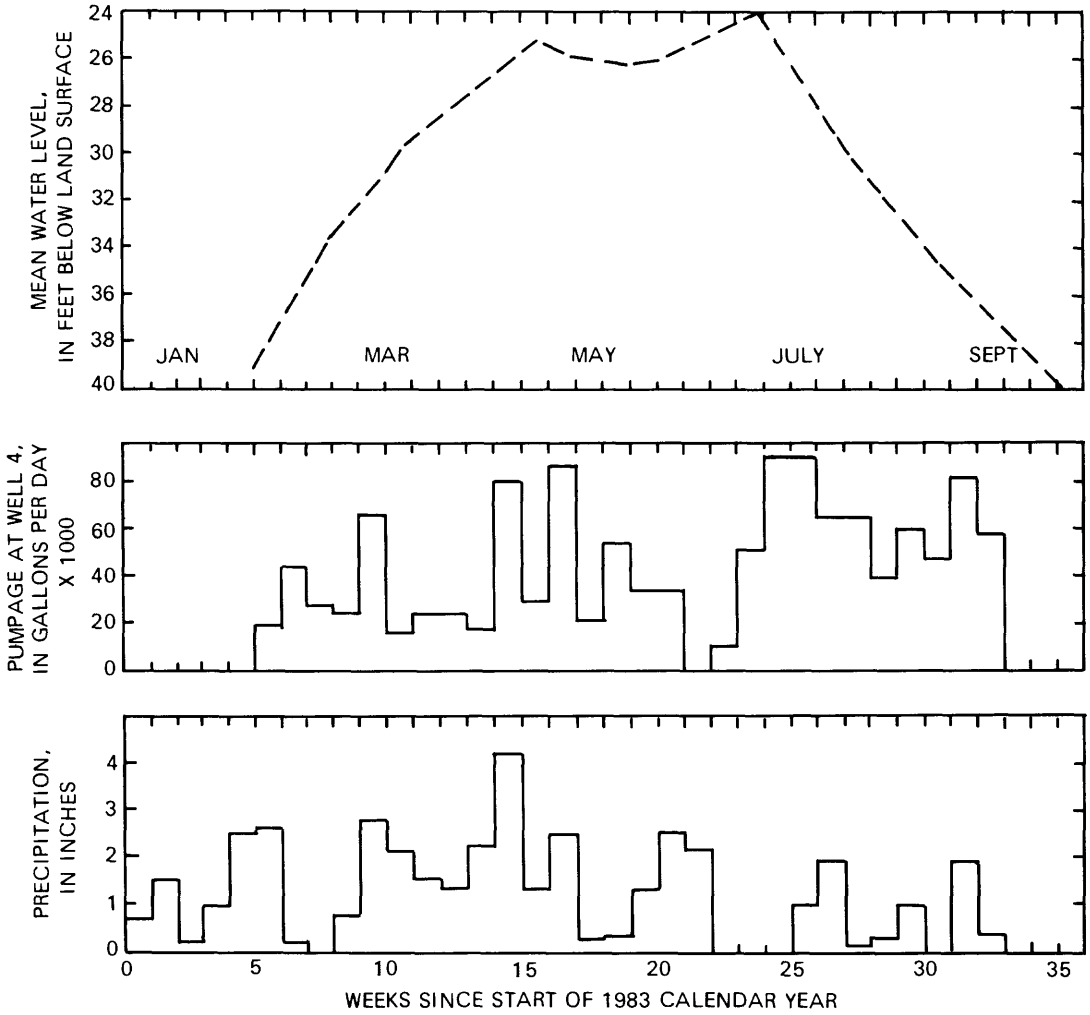


Figure 12.--Comparison of precipitation, pumpage in well 4, and water levels at well 11 during January-September 1983.

at the beginning of 1983, the water level in well 11 was recovering normally from the dry period of the previous summer and fall. Meltwater from snow and rainfall added recharge in March and April. An increase in pumpage at well 4, coupled with the start of vegetation growth and low precipitation in May, contributed to lowered water levels in May. Increased rain and less pumpage caused a rise in water level in late May and June. Increased pumpage at wells 4 and 7, low rainfall, and possibly the two pumping tests in June all contributed to the decline in water level from mid-June through the end of September.

SUMMARY

The sole source of water in the study area is a highly fractured bedrock-aquifer system. The fracturing permits well yields that are several times greater than yields from comparable wells in nearby areas. The bedrock aquifer is recharged principally by percolation of water from precipitation through the overlying till. Public-water supply is from four bedrock wells that are currently pumping about 300,000 gal/d.

Analysis of data from pumping tests in two wells and in nearby observation wells indicate that the Esopus aquifer is capable of meeting a demand of more than 400,000 gal/d.

The study period was too short to obtain an annual hydrograph of the water table. The recharge period from September to April was not monitored fully. However, the hydrographs of the water levels between February and September showed the response to recharge from the preceding winter and the discharge up to the end of September. These data indicated at least a 20-ft range in water levels, which is attributable to normal discharge from the system and the probable lowering due to pumpage. Water levels respond to variations in both pumpage and precipitation.

Supplementary data acquired during this study are included as well-field data (appendix A) and as hydrographs of wells 8, 9, and 13 (appendix B).

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APPENDIXES

A. Well-Field Data

Only three of an original eight supply wells in the study area were in service in 1984--wells 4, 5, and 7 (fig. 1). Driller's logs of these wells are presented in Waller (1979). A new well (no. 14) was drilled midway between wells 5 and 7 and put into service in July 1983. Depths and top-of-casing altitudes of all wells and distances between wells are given in table A-1; aproximate distances between all wells are tabulated in table A-2.

Wells Installed Before 1978

The early wells and test wells were drilled as water needs of the area increased. Wells were discontinued as they were replaced by others, and some were not adequate to develop. Wells installed before 1978 are described below.

Operation of wells 4, 5, and 7 since 1976 has demonstrated that the system is capable of supplying at least 300,000 gal/d without significant difficulty. However, the area has not experienced a significant period of drought during that time, although southeastern New York experienced serious declines in ground-water levels in 1980-81. The response of the aquifer to extended pumping under reduced recharge conditions of an extended drought cannot be predicted from present knowledge (Waller, 1979, p. 15).

Wells 1, 2, 3.--Wells 1 and 2 were discontinued about 1977 and replaced by well 5. Well 3 was never put into service but was sporadically used as an observation well from 1977 until 1982, when it was found to be dry and blocked at a depth of about 40 ft; it evidently had caved in.

Well 4.--Well 4 has remained in service since it was drilled in 1976. The water level in this well on August 1, 1983 was 145.7 ft below land surface. This depth may be too great because the water level at the time of measurement may not have fully recovered from recent pumping. The static water level in 1977 was about 65 ft (Waller, 1979) and, on October 18, 1982, was 87 ft. The pump intake is reported to be at 322 ft.

Well 5.--Well 5 has been in intermittent service since 1976. The high concentration of iron in water from this well produces a gelatinous residue in the well casing and at the pump intake; this reduces well yield and requires periodic removal of the submersible pump for cleaning and repair. On one such occasion (July 1983), static water level in this well was 64 ft below land surface.

Well 6.--Well 6, within a synagogue, is used only as a ceremonial supply and pumped only occasionally and at a low rate that does not produce measurable drawdown in surrounding wells. This well is not accessible as an observation well.

Well 7.--Well 7 has remained in continuous service since its installation in 1977. The water level in this well was not measured during this study because no suitable access port is available for lowering a tape.

Midway between wells 5 and 7 is well 14 (described further on), which was drilled and put into service in July 1983. Because of its proximity to wells 5 and 7, its cone of influence lowers water levels in those wells and thereby reduces pump efficiencies. The mutual interference in the immediate area of wells 5, 7, and 14 (fig. 1) results in low pumping levels in this area.

Table A-1.--Data on wells in study area, Orange, County, N.Y.

[Depths are in feet below land surface; locations are shown in fig. 1]

Well no.	Altitude of top of casing (ft above sea level)	Total well depth	Casing depth	Depth to bedrock
1	712.19	187	?	30
2	712.28	?	?	30(?)
3	656.64	160	42	32
4	764.22	400	84	74
5	704.61	370	40	22
6	667.61	250	57	46
7	664.2	420	60	35
8	611.8	397	38.5	35
9	613.1	267	45	25
10	707.5	70	60	--
11	739.0	350	58	54
12	738.1	275	120	110
13	611.9	500	60	54
14	680+	325	?	?

Table A-2.--Approximate distances between wells in study area.

[All values are in feet; well locations are shown in fig. 1]

	1	2	3	4	5	6	7	8	9	10	11	12	13
1,2	10												
3	1960	1960											
4	1300	1300	1770										
5	90	90	1870	1275									
6	1860	1860	690	1225	1790								
7	1290	1290	860	1700	1210	1200							
8	3670	3670	1980	2950	3580	1630	2800						
9	3580	3580	1880	2850	3480	1560	2730	120					
10	2480	2480	2770	1300	2480	2020	2950	2820	2760				
11	1800	1800	3020	990	1810	2480	2810	3770	3660	1290			
12	1300	1300	1720	335	1250	1100	1610	2750	2640	1400	1300		
13	3600	3600	1580	3430	3530	1950	2320	1590	1590	3850	4400	3150	
14	800	800	1300	1460	720	1560	600	3140	3030	2700	2330	1310	2890

Well Number

Wells Installed Before 1979-83

Attention in the 1983 study was directed to wells 8 through 13, many of which were drilled since the 1977 study was completed (fig. 1). All except well 10 are completed in bedrock and cased through the section of unconsolidated deposits that extends from land surface to depths of 25 to 110 ft. Depths and logs of these wells are summarized below:

Well 8.--The well numbered 8 in the original report (Waller, 1979, p. 2, 4) was destroyed after drilling, and the number was reassigned to the easternmost member of a well pair, locally known as the Zuckerman wells, west of Bakertown Road in the area that abuts the southeast boundary of the Village of Kiryas Joel (fig. 1). This well was drilled to a depth of 397 ft in 1963 and entered bedrock at a depth of 35 ft. A complete driller's log is not available, but geologic maps by Jaffe and Jaffe (1973) suggest that the bedrock at this well is the Esopus Formation. The well is cased with 6-inch casing and grouted in the bedrock to a depth of 38.5 ft. Notable zones of water entry were reported by the driller at depths of 177 ft (33 gal/min), 300 ft (75 gal/min), and 397 ft (100 gal/min). The static water level at that time was reported to be at land surface.

A borehole-caliper log made as part of this study to a depth of 264 ft in June 1983 shows exceptionally large fractures at 114 to 124 ft, at 156 to 170 ft, at 197 to 211 ft, and at 236 to 252 ft. An obstruction in the well bore prevented logging below 264 ft.

Water-level measurements were made in this well throughout the project and during pumping tests on this and other wells. (See hydrograph in appendix B.)

Well 9.--This well is about 120 ft west of well 8 and was drilled to a depth of 267 ft in July 1975. Bedrock was encountered at a depth of 25 ft and is believed to be Esopus Formation. The well was cased and grouted in the bedrock at a depth of 45 ft. Water-level measurements were made in this well also throughout the study. (See hydrograph in appendix B.)

Well 10.--This flowing well was reportedly drilled to a depth of 70 ft in the glacial deposits (primarily clayey till) that mantle the bedrock. A gravel bed was encountered at 53 ft. Bedrock was not encountered in this well. The well is cased to about 60 ft with 6-inch casing and screened from the bottom of the casing to 70 ft.

A low till-covered bedrock ridge to the north rises to 170 ft above the land-surface altitude at well 10 within a distance of about 1,500 ft. This gradient, together with the impermeable clay confining layer above the gravel bed, causes sufficient pressure to force water to the surface at this site. Downward movement of water into the bedrock is inhibited by a clayey till that underlies the gravel bed.

The flow rate was measured at 18 to 20 gal/min in June 1983 and was not affected by pumping of the bedrock wells. This well is not intended for use as a public-supply well and is therefore not considered further in this report.

Well 11.--This well was drilled to a reported depth of 350 ft and cased to a depth of 58 ft. Bedrock was encountered at 54 ft. The driller's log reports "slate" from 54 to 340 ft and "brown granite" from 340 to 350 ft. Geologic mapping of this area by Jaffe and Jaffe (1973) suggests that this well is completed in the Bellvale Formation. A borehole caliper log made in this well in June 1983 shows slight reductions in borehole diameter at 250 ft and 340 ft and a significant reduction in fracture severity below a depth of 280 ft. However, the logging device seems to have malfunctioned below 250 ft. Additional borehole tests would be required to detect changes in the type of rock below 250 ft in this well. The general regularity of the borewall and absence of abundant large fractures in this log indicate a more competent rock than at wells 8 and 13. Comparison of outcrops of the Bellvale and Esopus confirm this; the outcrops of the Bellvale are generally more massive and contain more widely spaced joints than outcrops of the Esopus.

The initial static water level in this well (about 1977) was reported to be 10 ft below land surface. The well was reportedly pumped for 3 hours at a rate of 30 gal/min, with a water-level drawdown of 11 ft. Water-level fluctuations have been recorded in this well with a continuous recorder since March 1983 and seem to respond to pumping in well 4. (See hydrograph in appendix B.)

Well 12.--This well was drilled about 1982 to a total depth of 275 ft and entered bedrock of the Bellvale Formation at 110 ft. Casing was installed to a depth of 120 ft. The initial static water level in this well was reported to be 30 to 65 ft below land surface. Well 4, a large-yield supply well 335 ft north of well 12, produces significant drawdowns in this well, especially when pumped for long or extended periods. The water level was measured periodically in this well starting in February 1983, but by July 22, 1983, the water level had fallen to below 119 ft, where an obstruction or cave-in prevented further observation. On that date, well 14 (described below) was put into service and probably lowered the water level in this area even more.

Well 13.--This well was drilled about 1982 to a total reported depth of 500 ft and entered bedrock (presumably the Esopus Formation) at 54 ft. Six-inch casing was installed to a reported depth of 60 ft. A borehole caliper log shows casing to a depth of 31 ft. Considerable fracturing is indicated above 150 ft and between 420 and 440 ft, and most of the borehole appears to be at least moderately fractured.

The initial static water level in this well was reported to be 4 ft below land surface. The well was reportedly pumped for 4.5 hours at 25 gal/min at the time of drilling with 18 ft of drawdown. Results of pumping tests in wells 8 and 9 completed in the Esopus Formation, (wells 8 and 9, discussed above) suggest that this well can be pumped at a rate of 200 gal/min or more. It would be advisable to develop this well thoroughly before testing at this rate, and the test should last at least 2 days. Water-level measurements were made, and the resulting hydrograph is shown in appendix B.

Well 14.--This new supply well, drilled in July 1983 midway between supply wells 5 and 7, was intended as an alternative supply well to be used when either well 5 or 7 is being serviced. This well was drilled to a depth of 325 ft and completed in the Bellvale Formation. Static water level at the time of completion (wells 5 and 7 were probably pumping) was about 51 ft below land surface. A submersible pump was installed when the well was put into service on July 22, 1983. The pumping level was 164 ft below land surface. No current information on the discharge rate is available, and no water meter has been installed at this site.

Transmissivity at this well is calculated to be about 1,500 ft^2/d or 11,200 (gal/d)ft, from a brief recovery test made in July 1983 after the well had been developed by high-pressure air jet for 3 hours at about 300 gal/min.

APPENDIX B

Water-level measurements in wells 9, 11, 13, and 8, February to October 1983, showing the water before and after pumping tests in wells 8 on July 11-15 and well 9 on June 28-29.