V200.G3
S1
I5
92

Pumping Test Results from a Flowing Artesian Well System, Cherokee County, Georgia

Madeleine F. Kellam
David A. Brackett
William M. Steele

GEORGIA DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
GEORGIA GEOLOGIC SURVEY

Atlanta
1994

INFORMATION CIRCULAR 92

Pumping Test Results from a Flowing Artesian Well System, Cherokee County, Georgia

Madeleine F. Kellam
David A. Brackett
William M. Steele

GEORGIA DEPARTMENT OF NATURAL RESOURCES
Joe D. Tanner, Commissioner
ENVIRONMENTAL PROTECTION DIVISION
Harold F. Reheis, Director
GEORGIA GEOLOGIC SURVEY
William H. McLemore, State Geologist

Atlanta
1994

INFORMATION CIRCULAR 92

Table of Contents

List of Tables

List of Figures

INTRODUCTION

PURPOSE

This study was conducted as a part of a continuing program by the Georgia Geologic Survey (GGS) to assess the ground-water resources of the crystalline-rock aquifers of the Piedmont and Blue Ridge Physiographic Provinces of north Georgia (Figure 1). Knowledge of the behavior of these aquifers is necessary to properly develop and manage water supplies in north Georgia and to aid in the prevention and mitigation of ground-water pollution. Some major goals of the north Georgia hydrogeology program are to develop geologic techniques to locate potentially high-yielding well sites, to study the occurrence and flow of ground water in crystalline-rock aquifers, and to publish the results of these studies to provide a technical basis for ground-water protection decision-making in the future.

The purpose of this study was to measure the response to pumping in a well developed in a fractured crystalline-rock aquifer representative of those found in north Georgia. The study was conducted on the campus of Reinhardt College in Cherokee County, at one of three GGS research sites established for the purpose of testing the hydrologic properties of crystalline-rock aquifers and explaining the behavior of wells completed in such aquifers. The Reinhardt site is somewhat unusual in that it contains two flowing artesian wells. The other two sites are also located in the Piedmont Physiographic Province, one at Barnesville, Lamar County, and one near Elberton, in Elbert County, Georgia. A secondary purpose of this study was to examine the use of various types of pumping tests in estimating the sustainable yield of wells completed in crystalline-rock aquifers.

ACKNOWLEDGMENTS

The development of this study site would not have been possible without the interest of Dr. Floyd Falany, president of Reinhardt College, and the cooperation and assistance of the faculty and staff of the College. Thomas J. Crawford of West Georgia College graciously consented to map the rocks of the study area. Deana S. Sneyd examined and logged the two cores obtained from the study site. The authors thank Mr. Jim Breaky and Middle Georgia Water Systems for their assistance with the installation and repair of the pumping systems used at the site. We are also grateful to Mr. Robert Kissling of Waleska, Georgia for providing daily precipitation data for the Waleska area.

STUDY AREA DESCRIPTION

LOCATION

The study area is located near Waleska, Georgia in northwestern Cherokee County (Figure 1), approximately 40 miles north-northwest of Atlanta. The Reinhardt hydrologic research site is located on the campus of Reinhardt College, at the intersection of Georgia highways 140 and 108. The study site is on the south bank of Moore Creek and extends approximately 1000 feet on either side of Georgia Highway 108 (Figure 2).

Prior to the construction of water lines through the Waleska area, Reinhardt College relied on two production wells for its water supply. Both are located on the southwest bank of Moore Creek, one (PW1) approximately 500 feet northwest of Highway 108 and the other (PW2) approximately 30 feet southeast of highway 108 (Figure 3). Reinhardt College allowed the GGS to use these two out-of-service production wells as the nucleus of the Reinhardt hydrologic research site. Well PW1 was chosen for use as the production well during pumping tests at the site. Well PW2 is currently being used as a water-level monitoring station. The water-level recorder located at the well is currently maintained by the U.S. Geological Survey (USGS), under a cooperative agreement with the GGS.

PHYSIOGRAPHY AND CLIMATE

The study area lies in the Cherokee Uplands District of the Piedmont Physiographic Province (Clarke and Zisa, 1976). The study site occupies a partially wooded floodplain of Moore Creek, a tributary of Shoal Creek in the Etowah River Basin. Elevations in the site vicinity range from approximately 1050 feet above sea level at the creek, to over 1140 feet on the hill overlooking the site to the west. Streams in the vicinity of the site flow southwestward and occupy valleys that are fairly wide, with approximately 200-300 feet of relief. The drainage pattern in the vicinity of the study site is primarily rectangular, indicating some degree of structural control.

Climatological data for the area were obtained from the National Oceanic and Atmospheric Administration. The nearest weather station for which temperature data are available is the Jasper 1 NNW station, located in Pickens County, approximately 13 miles (airline) northeast of the site. The average annual temperature for the period of record (1951-1980) is 58.8° F with an average January temperature of 39.8° F and an average July temperature of 76.0° F. Data on average annual precipitation gathered by NOAA at the Jasper NNW station indicate that rainfall is usually highest in Spring and lowest in Fall. Daily precipitation data for the near vicinity of the Reinhardt site was collected by Mr. Robert E. Kissling of Waleska, Georgia (Figures 4 and 5). Total rainfall for 1990, measured at Waleska, was 64.91 inches. Rainfall was atypical in 1990, being highest in March and lowest in April.

METHODOLOGY

Investigations at the Reinhardt site included geologic mapping and a magnetic survey to aid in siting observation

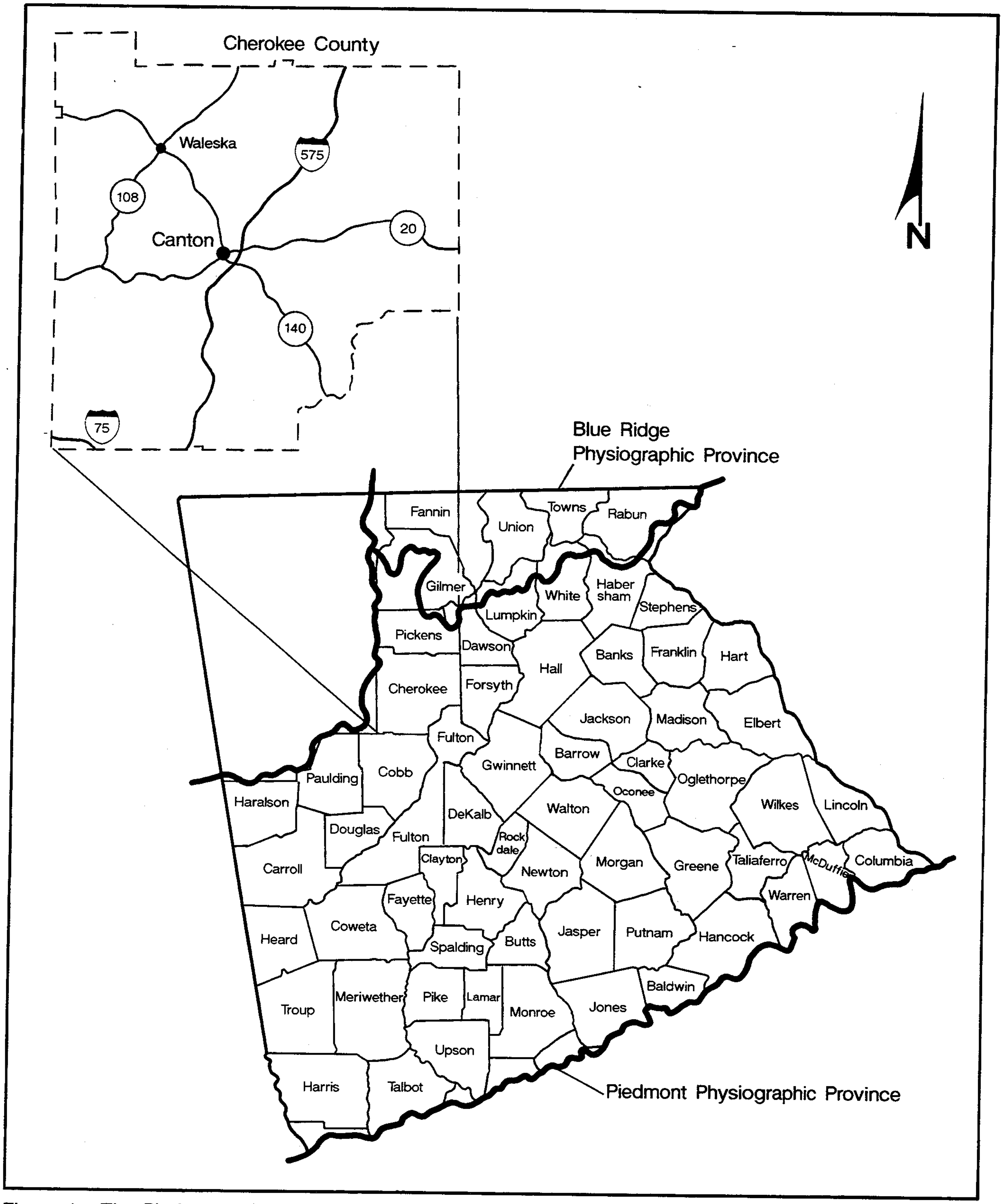

Figure 1. The Piedmont and Blue Ridge physiographic provinces of Georgia, including Cherokee County.

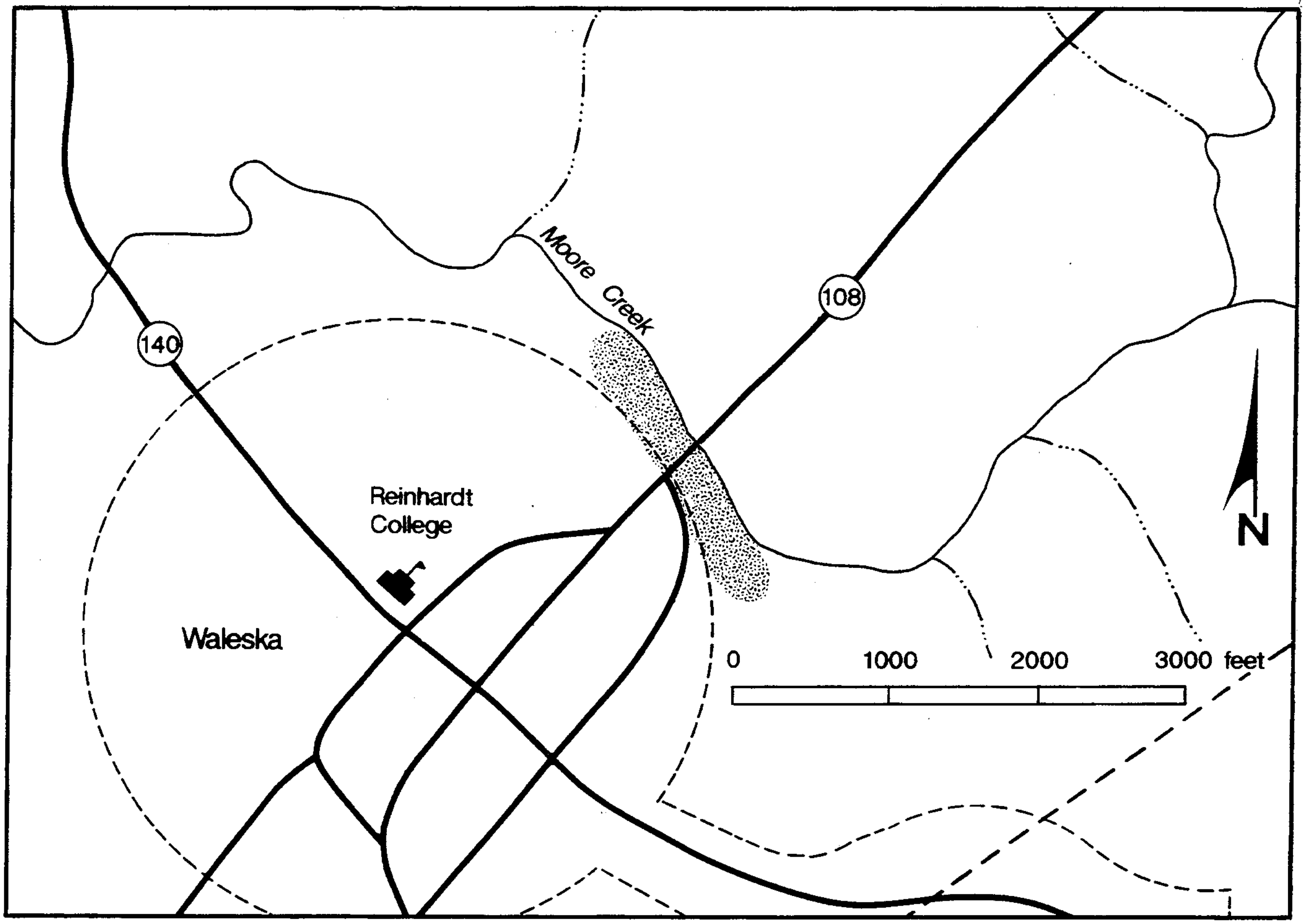

Figure 2. Location of the Reinhardt hydrologic research site near Waleska, Georgia. (Shaded area indicates the approximate location of the study site.)

wells, geophysical logging of the two existing production wells, coring and geophysical logging of two deep observation wells, lithologic logging of the cores, drilling of three shallow observation wells, background water-level monitoring, and two pumping tests.

The two out-of-service production wells owned by Reinhardt College, PW1 and PW2, were used by the GGS in conducting pumping tests at the Reinhardt site. PW1 was chosen for use as the pumping well for both tests. Construction information on these wells was obtained using downhole geophysical logging equipment. Both of these wells are flowing artesian wells.

Reconnaissance-level geologic mapping was conducted by Thomas J. Crawford, assisted by David A. Brackett. Lithologic and structural data were collected in an area approximately 1 mile in radius from PW1. Mapping was focused on describing and measuring the orientations of joints, foliation, faults and other potentially water-bearing geolog... tures.

A magnetic survey was conducted in the immediate area around PW1. Measurements were made using an EG & G Model G-856A Proton precession magnetometer. Base station readings were taken before, during and after each profile to measure natural fluctuations in magnetic intensity to allow any necessary corrections to be made. Individual magnetic readings were compared to an average of readings at the site in order to identify magnetic anomalies.

Geologic and magnetic survey data were used to choose locations for coring. Two core holes were drilled at the site to serve as observation wells during pumping tests and to provide information on the subsurface geology. Corehole 1 (CH1) is located 146 feet northwest PW1, parallel to the strike of rocks in the vicinity of PW1. The well was drilled using a 5 7/8-inch tricone bit until bedrock was reached at 17

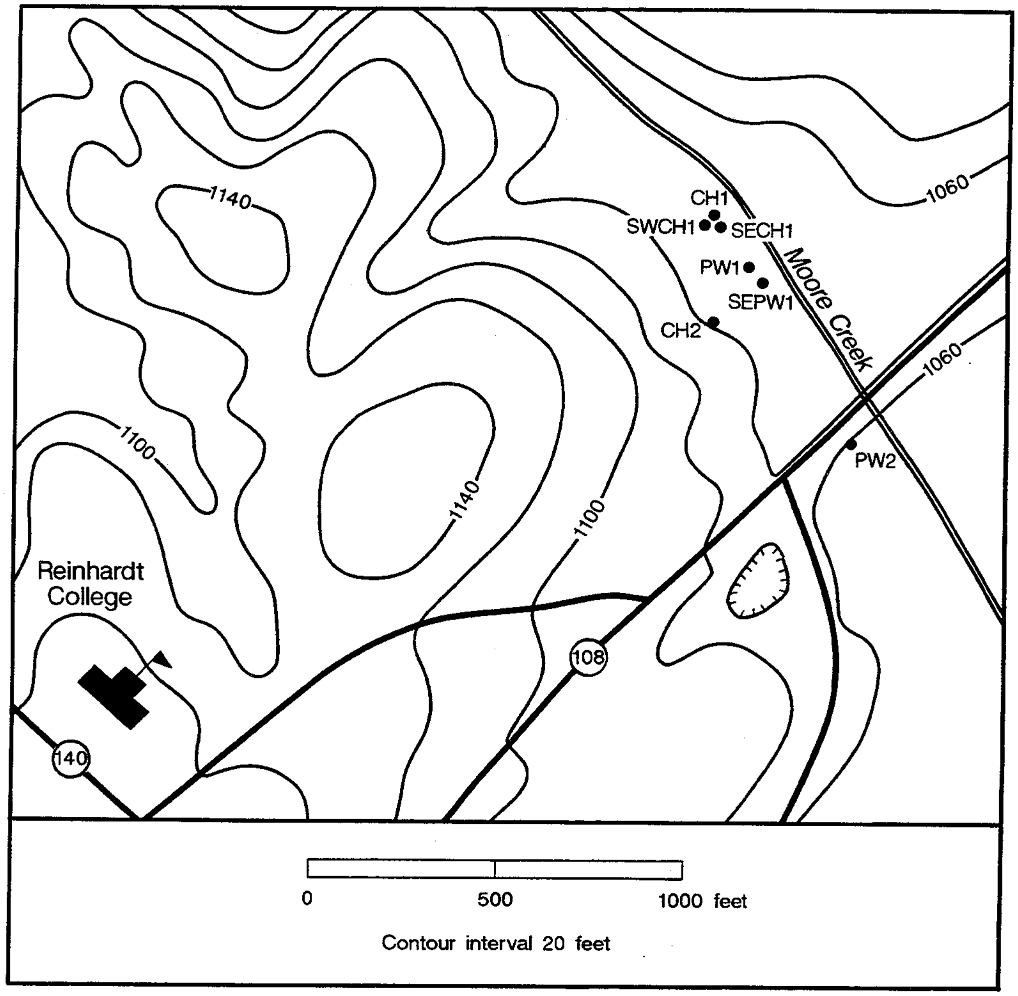

Figure 3. Sketch map of the Reinhardt Hydrologic Research Site, showing well locations.

feet. Coring was begun at 17 feet (NX core) and proceeded to a total depth of 300 feet. The well is cased with 4-inch diameter schedule 40 PVC casing to a depth of 17 feet. The annular space was filled with bentonite grout. The remainder of the well is open hole of 3-inch diameter (Figure 6). CH1 is a flowing artesian well. Corehole 2 (CH2) is located 108 feet southwest of PW1, perpendicular to strike. The well was drilled with a 5 7/8-inch tricone bit to bedrock at 12.5 feet. Coring (NX) was begun at 12.5 feet and completed at 361 feet. This well was cased with 4-inch diameter schedule 40 PVC to a depth of 12.5 feet, and the annular space filled with bentonite grout. The remainder of the well is open hole of 3-inch diameter (Figure 7). Both wells were surrounded with concrete pads. Lack of access prevented any observation wells from being drilled on the north bank of Moore Creek. Well locations are shown in figure 3.

Three regolith observation wells were also constructed at the research site. Their locations were selected on the basis of geologic structure, proximity to the production wells and core holes, and accessibility. Two of these wells were drilled in the vicinity of CH1. Well SECH-1 was drilled using an 8 7/8-inch diameter fishtail bit through 9 feet of alluvium to refusal in saprolite at a depth of 15 feet (Figure 8). Well SWCH-1 was similarly drilled through 15 feet of alluvium and completed in saprolite at a depth of 18.5 feet (Figure 9). The third regolith observation well (SEPW-1) was drilled southeast of the pumping well and was completed in saprolite at a depth of 7.5 feet (Figure 10). These wells were cased with 2-inch diameter schedule 40 PVC with a 5-foot screened interval, backfilled with sand, and sealed with a 2-foot layer of bentonite. Concrete pads were installed around all of these wells. The locations of these shallow observation wells are shown in figure 3.

Four wells at the Reinhardt site were geophysically logged by the USGS's Borehole Geophysical Services Unit in order to document well construction and to locate water-bearing discontinuities. Logs run on the two production wells (PW1 and PW2) included caliper, temperature, single-point

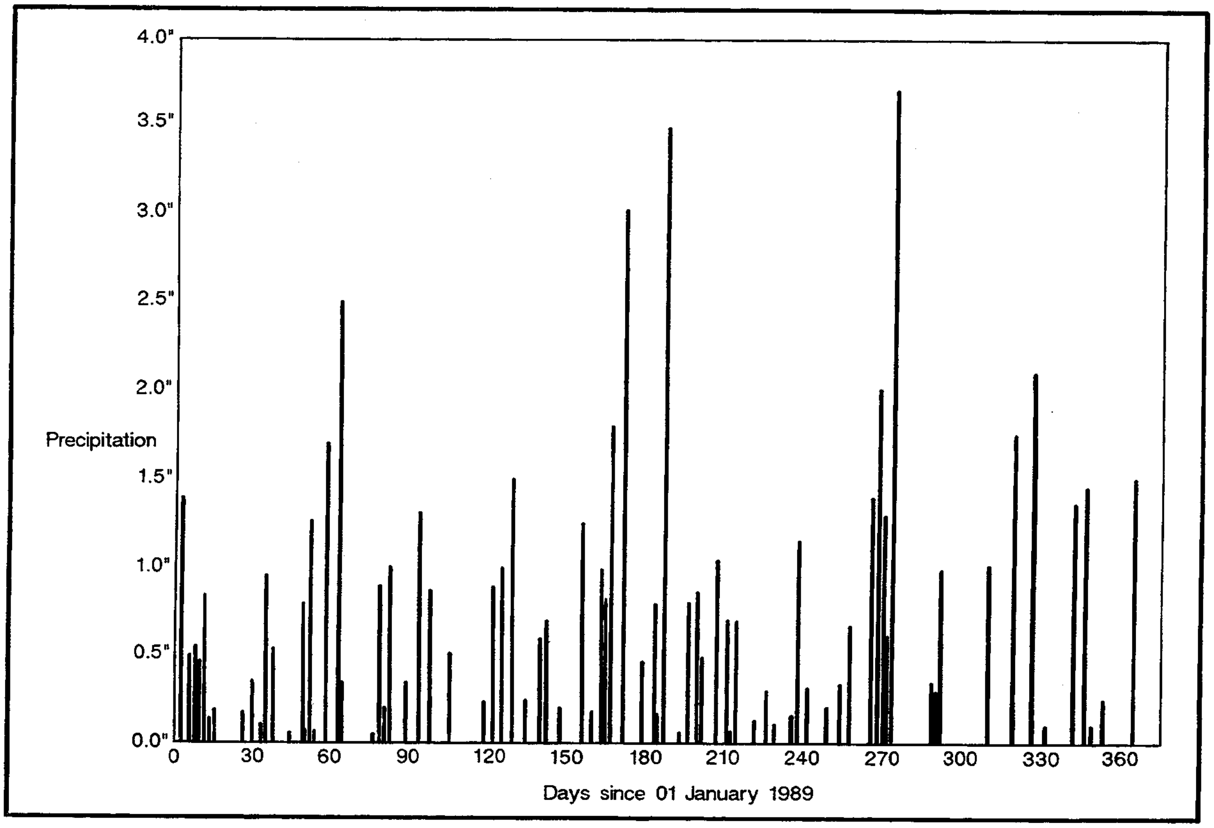

Figure 4. Daily precipitation for 1989, measured at Waleska, Georgia. (Kissling, pers. commun.)

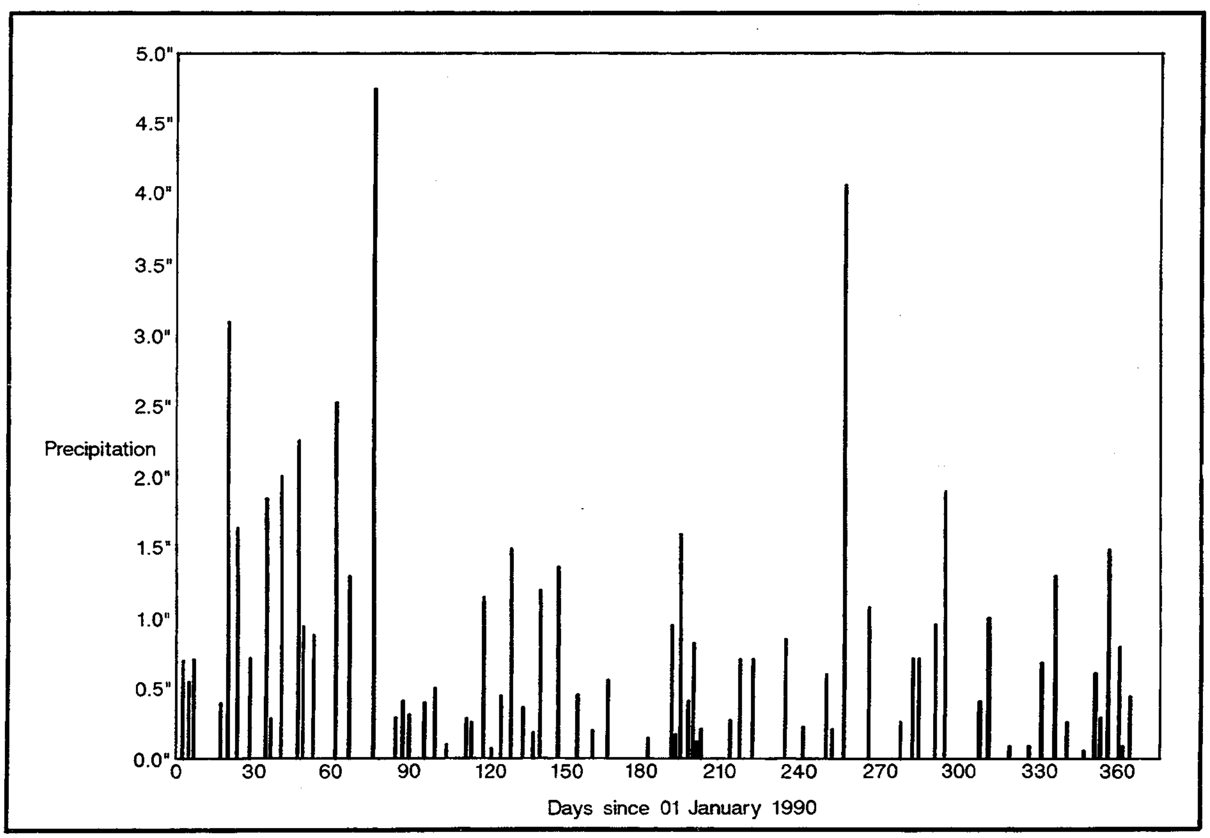

Figure 5. Daily precipitation for 1990, measured at Waleska, Georgia. (Kissling, pers. commun.)

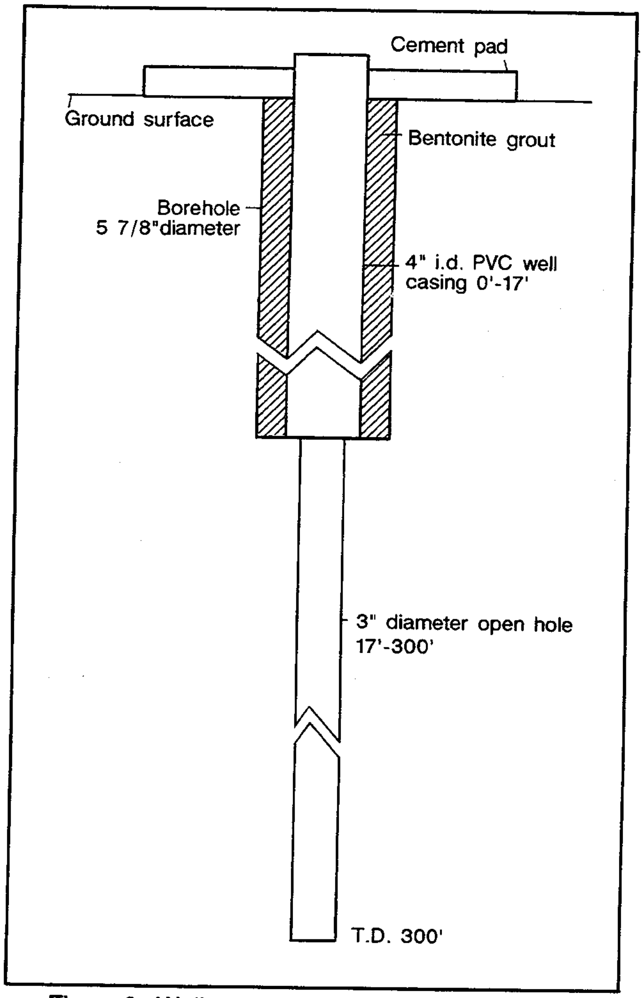

Figure 6. Well construction diagram of corehole 1 (CH1).

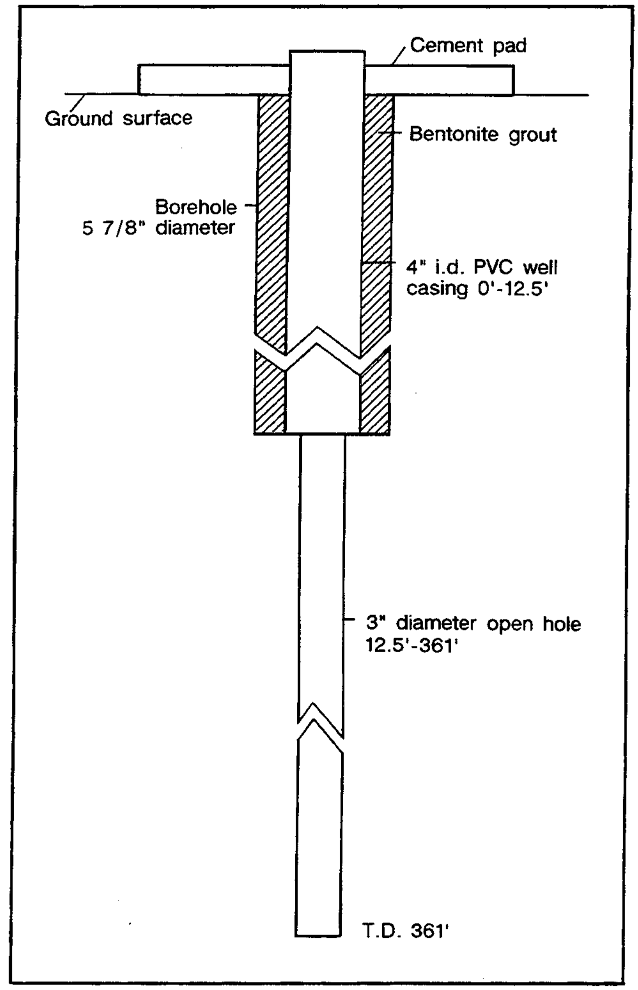

Figure 7. Well construction diagram of corehole 2 (CH2).

resistivity, fluid resistivity, acoustic velocity, spontaneous potential and natural gamma logs. In addition, the sonic televiewer log was used to record the orientation of all observable discontinuities in these production wells. The two core holes (CH1 and CH2) were also logged by USGS, however the small diameter of these wells prevented the use of acoustic velocity and sonic televiewer logging equipment.

Caliper logging indicates that PW1 contains approximately 19 feet of 6-inch casing (steel); the remainder of the well is open hole to a total depth of approximately 340.5 feet (Figure 11). PW2 is cased to approximately 32 feet with 8-inch PVC casing; the remainder of the well is open hole to a depth of approximately 359.5 feet (Figure 12). The caliper log shows a borehole diameter of roughly 8 inches to a depth of 70 feet, and a diameter of 6 inches from 70 feet to T.D. Because of the age of these wells (1962) construction details, such as borehole diameter and grouting, are uncertain. Neither production well has a concrete well apron.

Background water-level measurements were made at the site prior to the conduct of pumping tests in order to obtain records of prevailing water-level trends. These measurements were obtained using a variety of equipment, including steel tapes, conductive probes, Stephens Type F float recorders and electronic data loggers equipped with pressure transducers.

Two pumping tests were completed at the research site. The first pumping test, 24 hours in duration, was a constant-drawdown test. The second test, 72 hours in duration, was a constant-rate test. In a constant-drawdown test, the water level in the well is rapidly lowered to a point just above the lowest water-bearing discontinuity. The water level is then held constant for the duration of pumping, using a gate valve or other means to regulate flow. Residual drawdown is then measured for a period of time at least equal to the pumping period (Brackett and others, 1992). A constant-rate test requires holding the pumping rate constant for the duration of the test, while recording drawdown with respect to time. After the pump is shut off, the residual drawdown is recorded for a period of time at least equal to the pumping period.

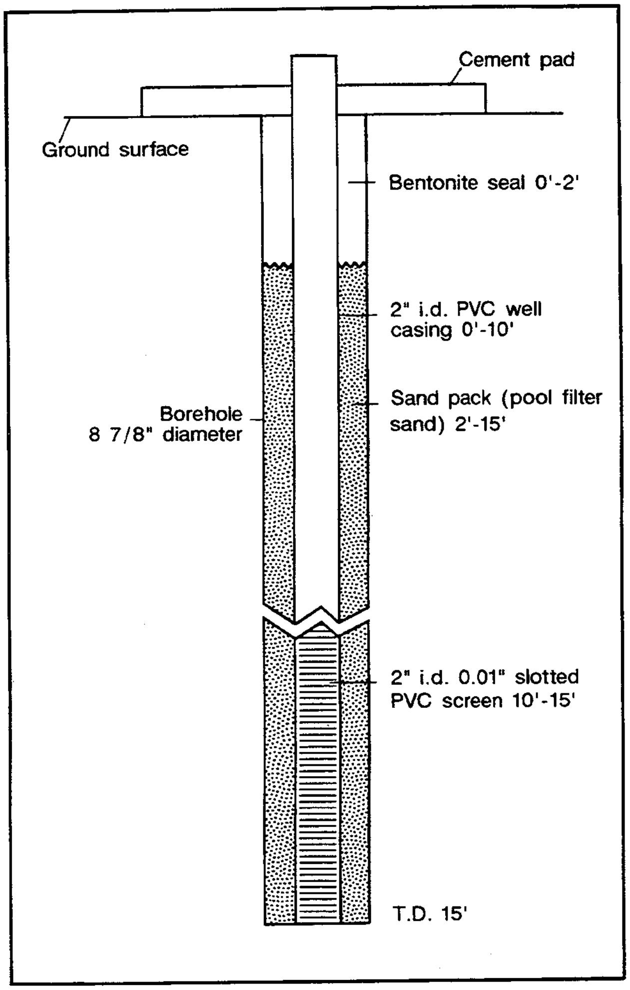

Figure 8. Well construction diagram of regolith observation well SECH-1.

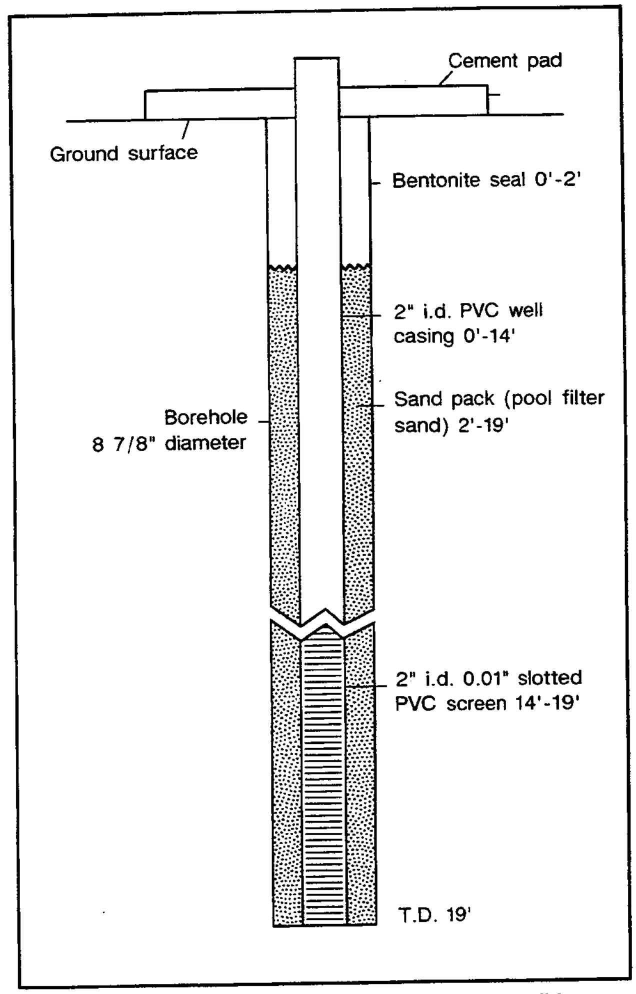

Figure 9. Well construction diagram of regolith observation well SWCH-1.

Both tests were performed using submersible turbine pumps. Power was supplied during the 24-hour test by a diesel generator. Utility power was used for the 72-hour test. The pumping rate for both tests was measured using an orifice bucket. A stilling well (1-inch PVC pipe) was installed in the production well to minimize the effects of turbulent water and hence allow for accurate water-level measurement during the pumping tests. The discharge water was directed to Moore Creek, via a drainage ditch approximately five feet northeast of the pumping well. The drainage ditch resulted from years of flow from the production well. Usually during a pumping test, the discharge water is piped to a nearby stream, or to some distance from the well so that artificial recharge to the production well does not occur. Because the production well at Reinhardt had been flowing for a number of years, and the saprolite in the vicinity of the well was already saturated, it was deemed unnecessary to pipe the discharge water further away from the well. During the 24-hour test, water levels were measured using steel tapes and conductive probes. During the 72-hour test, water levels were measured using electronic data loggers equipped with pressure transducers.

Remotely measured water-level data were imported into QuattroPro IV spreadsheet software (by Borland) for data reduction and checking. The time measurements were converted from date, hour:minute:second format to time since pump start format. The water-level measurements were likewise converted from feet of water over the transducer format to drawdown format. Time/drawdown curves were generated by the spreadsheet program.

During the 24-hour pumping test, water samples were collected from the production well for water quality analysis, including both organic and inorganic analyses. The analyses were performed by the Georgia Environmental Protection Division.

PREVIOUS INVESTIGATIONS

Clarke and Zisa (1976) placed the Waleska area in the Piedmont Physiographic Province on the basis of such factors as slope, relief and drainage. The geology of the

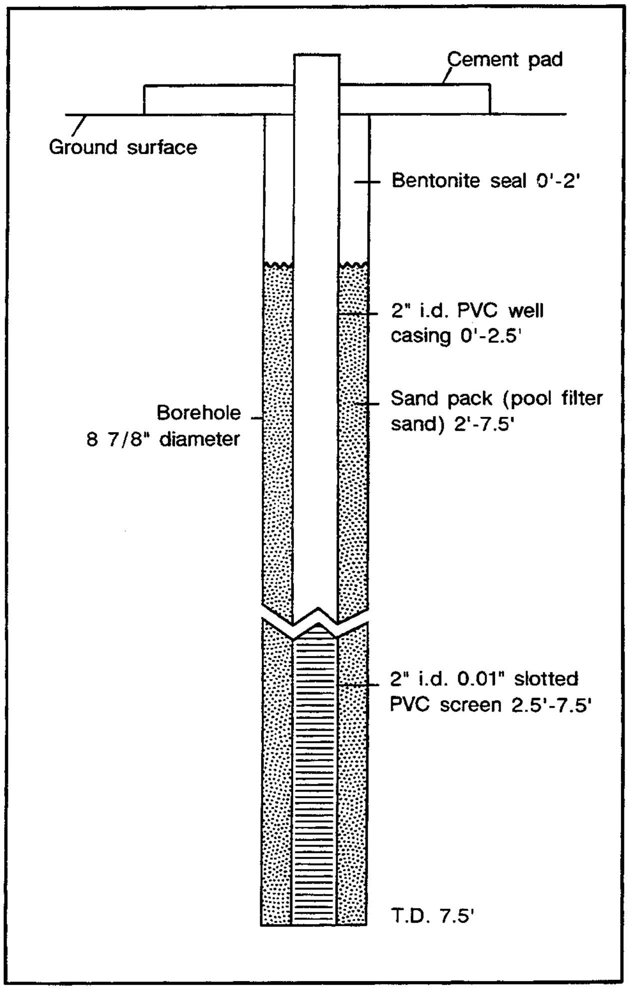

Figure 10. Well construction diagram of regolith observation well SEWP-1.

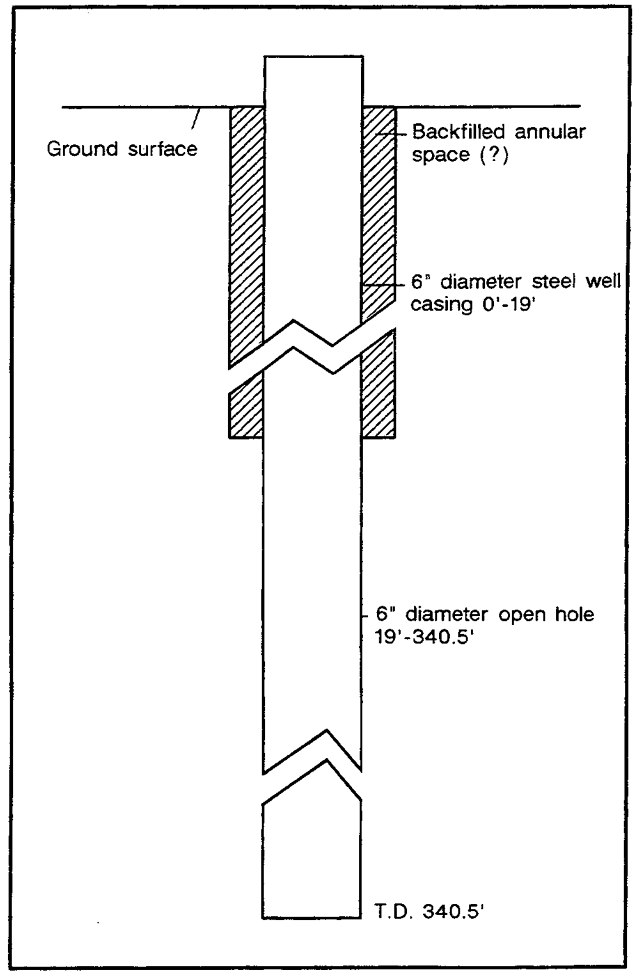

Figure 11. Well construction diagram of production well 1 (PW1).

Cherokee County area was summarized by McConnell and Abrams (1984) in their study of the Geology of the Greater Atlanta Region. They ascribed the rocks of the Waleska area to the Great Smoky Group, which comprises a portion of the Ocoee Supergroup (McConnell and Abrams, 1984). Higgins and others (1988) mapped the Waleska area. They placed the Waleska area within the Bill Arp thrust sheet, which they describe as a relatively unmetamorphosed and undeformed thrust sheet at the base of the Georgiabama thrust stack.

Cressler and others (1979) included the Waleska area in a description of the Geohydrology of the Bartow, Cherokee, and Forsyth Counties. They grouped the rocks in the region into water-bearing units on the basis of similarities in lithology, well yield and water quality. According to Cressler and others (1979), the highest well yield reported from the unit underlying the study area was 32 gallons per minute (gpm). Wells completed in this unit usually produce soft water low in iron and other constituents although high concentrations of iron appear locally. In a later study, Ground Water in the Greater Atlanta Region, Cressler and others (1983) redefined their hydrogeologic units. They included the Waleska region in a hydrogeologic unit which produced well yields ranging from 20 to 150 gpm, averaging 47 gpm. The hydrologic properties of Piedmont wells were investigated in a study by Brackett and others (1991). Fanning and others (1992) reported that total ground-water use in Cherokee County was 1.16 million gallons per day in 1990. Approximately 14 percent of water use in Cherokee County for 1990 was supplied by ground water.

GEOLOGY

The soils at the Reinhardt site include Chewacla-Cartecay complex soils and Tallapoosa series soils (Jordan and others, 1973). The floodplains in the near vicinity of the site contain Chewacla-Cartecay complex soils. These soils are somewhat poorly drained to moderately well drained. The Chewacla-Cartecay complex soils are developed on alluvial sediments. Typically they consist of a layer of loam approximately 8-9 inches deep, underlain by sandy loam or clay loam. They occur as long, narrow strips adjacent to major creeks and rivers and thus are frequently flooded. Tallapoosa soils are

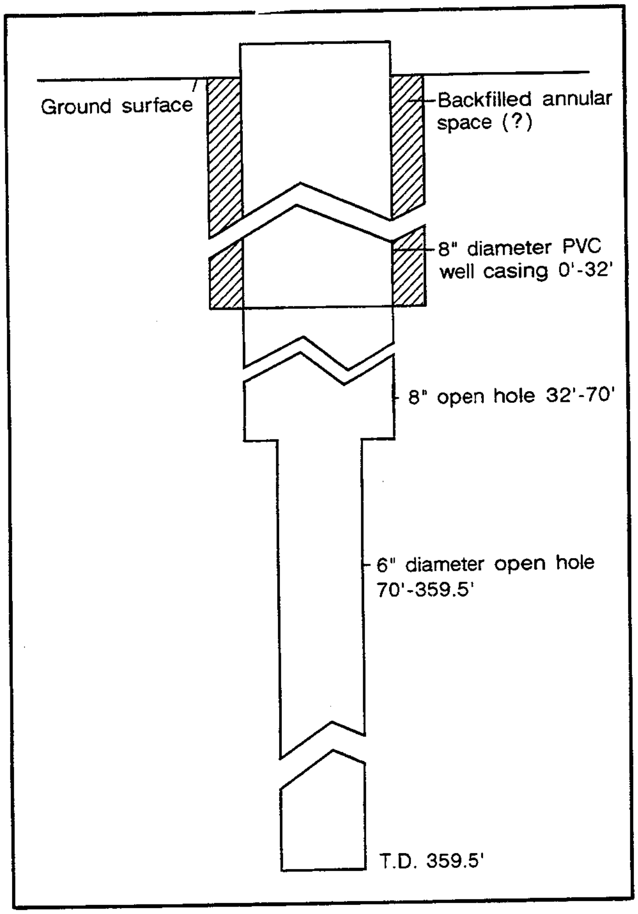

Figure 12. Well construction diagram of production well 2 (PW2).

gravelly sandy clay loam soils that occur on ridges and hillsides in the upland areas of the Reinhardt site. These soils typically are developed on weathered mica-schist. They are typified by a pebbly surface layer and are commonly 8 to 18 inches thick over bedrock. Tallapoosa soils have a clay loam surface layer which makes runoff rapid on bare surfaces (Jordan and others, 1973).

Below the soil zone the saprolite is light orange, micaceous, and foliated to massive. Deeply weathered schistose zones can be identified within the saprolite, as well as quartz-rich zones probably developed on metagraywacke. The thicknesses of saprolite encountered during drilling of coreholes and monitoring wells in the lowlying areas of the site range from approximately 15 to 27 feet.

Geologic mapping at a 1:24,000 scale was conducted in December of 1988 by Thomas J. Crawford, assisted by David A. Brackett. Mapping included lithologic and structural characterization of an area approximately 1 mile in radius from the study site (Figure 13). The rocks in the vicinity of the study area are folded, jointed, and faulted crystalline metamorphic rocks. They include graphitic garnet schist with calc-silicate pods interlayered with metagraywacke, and garnet-quartz-muscovite schist with calc-silicate lenses and pods. The rocks are foliated to crenulated, with foliation orientations ranging from N45°E, dipping 16°SE to N67°E, dipping 34°SE. A northeast-southwest-trending thrust fault (oriented approximately N33°E) lies immediately southeast of the site. Rocks southeast of the fault include phyllite/schist interlayered with fine-grained metagraywacke produced by metamorphism of sedimentary protoliths.

The rocks at the study site are jointed, with steeply dipping joint sets in the vicinity of PW1 oriented approximately N32°-N45°W and N35°-N50°E (Figure 13). The rectangular drainage pattern exhibited by Moore Creek and its tributaries includes stream and valley segments oriented N30°-N45°W and N41°-N55°E, indicating that the jointing exerts structural control on the topography and surface drainage near the study site.

The two core holes drilled at the Reinhardt site yielded information on the bedrock lithology. The bedrock is composed primarily of interlayered metagraywacke and schist. The metagraywacke is variable, ranging from a fine- to medium-grained light gray, massive to poorly foliated, calcite-biotite-muscovite quartzite with accessory garnet, graphite and pyrite to a medium- to coarse-grained, white, biotite-garnet-amphibole quartzite. The schist is silvery gray to brownish-gray quartz-biotite-muscovite schist which locally contains calcite, chlorite, plagioclase and pyrite. Both the metagraywacke and the schist locally contain calc-silicate lenses and pods. Locally, the rocks are cut by mafic dikes containing chlorite, biotite and amphibole. Detailed lithologic and structural logs were made by D. S. Sneyd (personal comm., 1991) for these two cores (Core Descriptions).

GEOPHYSICS

SURFACE GEOPHYSICS

A magnetic survey was conducted on November 15, 1988 at the Reinhardt site in the vicinity of PW1. Changes in magnetic intensity can sometimes indicate the presence of subsurface discontinuities which may provide pathways for ground-water flow. The survey was intended to help locate such discontinuities for the purpose of siting monitoring wells. The survey consisted of 2 profile lines. Profile 1 was oriented approximately N35°W, parallel to the trend of Moore Creek; profile 2 was oriented approximately N45°E, perpendicular to and crossing Moore Creek (Figure 14).

Profile line 1 had a net difference in magnetic intensity of 63 gammas. The "flat" nature of the profile is probably due to the orientation of the profile parallel with the strike of the rock foliation and compositional layering (Figure 15). Profile 2, on the other hand, had a net difference in magnetic

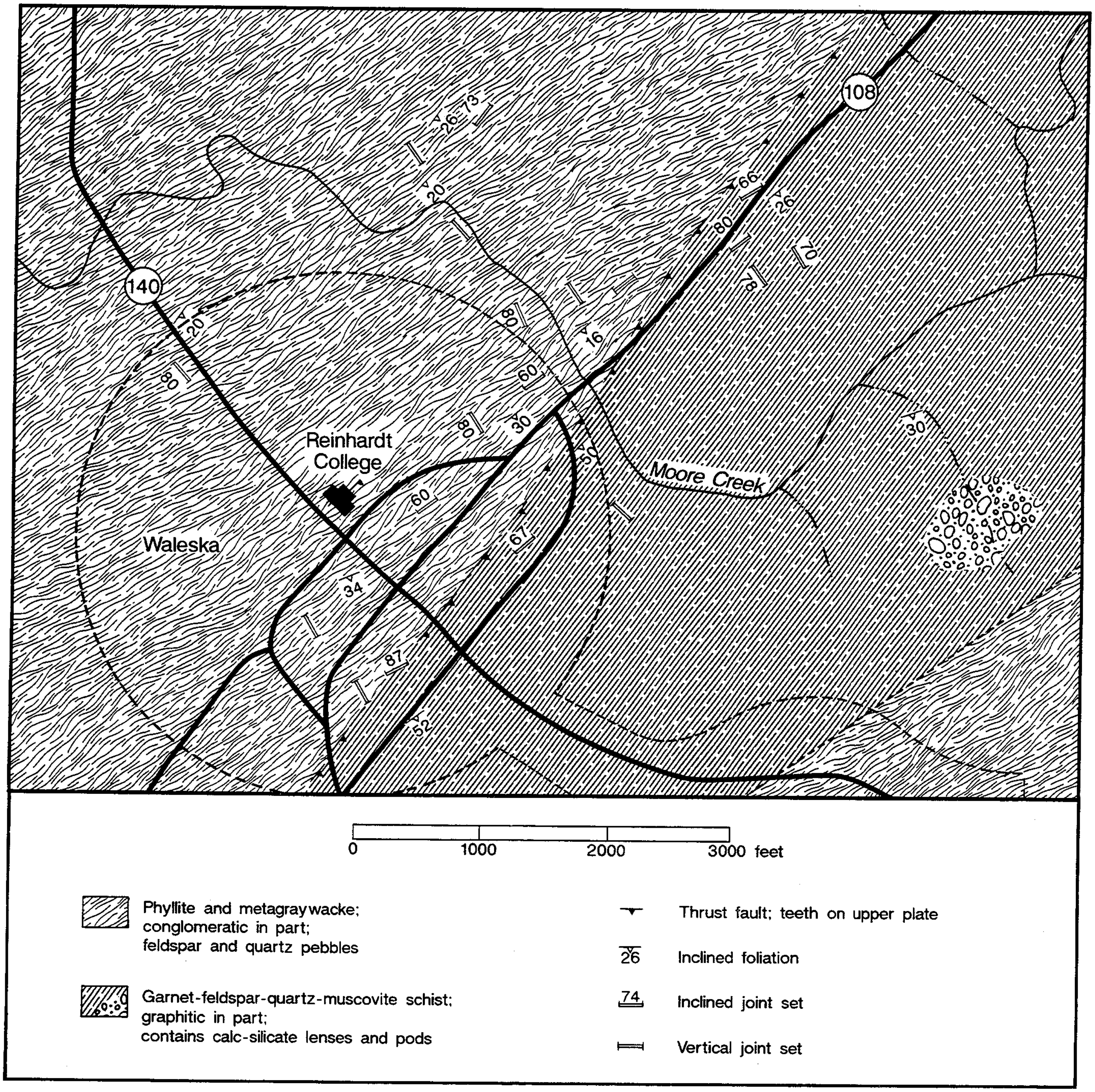

Figure 13. Geology of the Waleska area, Georgia.

intensity of 305 gammas. This profile was run perpendicular to the strike of the foliation and compositional layering, and hence reflects magnetic field differences at depth across layers of varying composition (Figure 16).

Borehole Geophysics

A suite of borehole geophysical logs were run on four wells at the Reinhardt Research site. These include the two production wells (PW1 and PW2) and the two coreholes (CH1 and CH2). The suite of logs included caliper, temperature, acoustic velocity, natural gamma, single-point resistance, fluid resistivity and spontaneous potential logs. Sonic televiewer logs were run on the two production wells. Those well logs most relevant to the purposes of this paper are shown or summarized below. The full suite of logs is available for inspection on open file at the Georgia Geologic Survey office (Atlanta).

Borehole geophysical logs are useful for assessing well construction and in interpreting the location of fractured and weathered zones or any other discontinuities which may

Depth in Feet	Dip Azimuth in Degrees	Dip Magnitude in Degrees
22	N/A	subhorizontal
77	60	86
105	60	85
107	N/A	subhorizontal
229	300	76
257	N/A	subhorizontal
265	N/A	subhorizontal
305	0	63
322	N/A	subhorizontal

Table 1. Summary of major discontinuities visible on sonic televiewer log of PW1.

Depth in Feet	Dip Azimuth in Degrees	Dip Magnitude in Degrees
38	240	72
58.5	180	63
87	50	72
103.5	80	63
124.5	60	63
183.5	180	63
310.5	N/A	subhorizontal

Table 2. Summary of major discontinuities visible on sonic televiewer log of PW2.

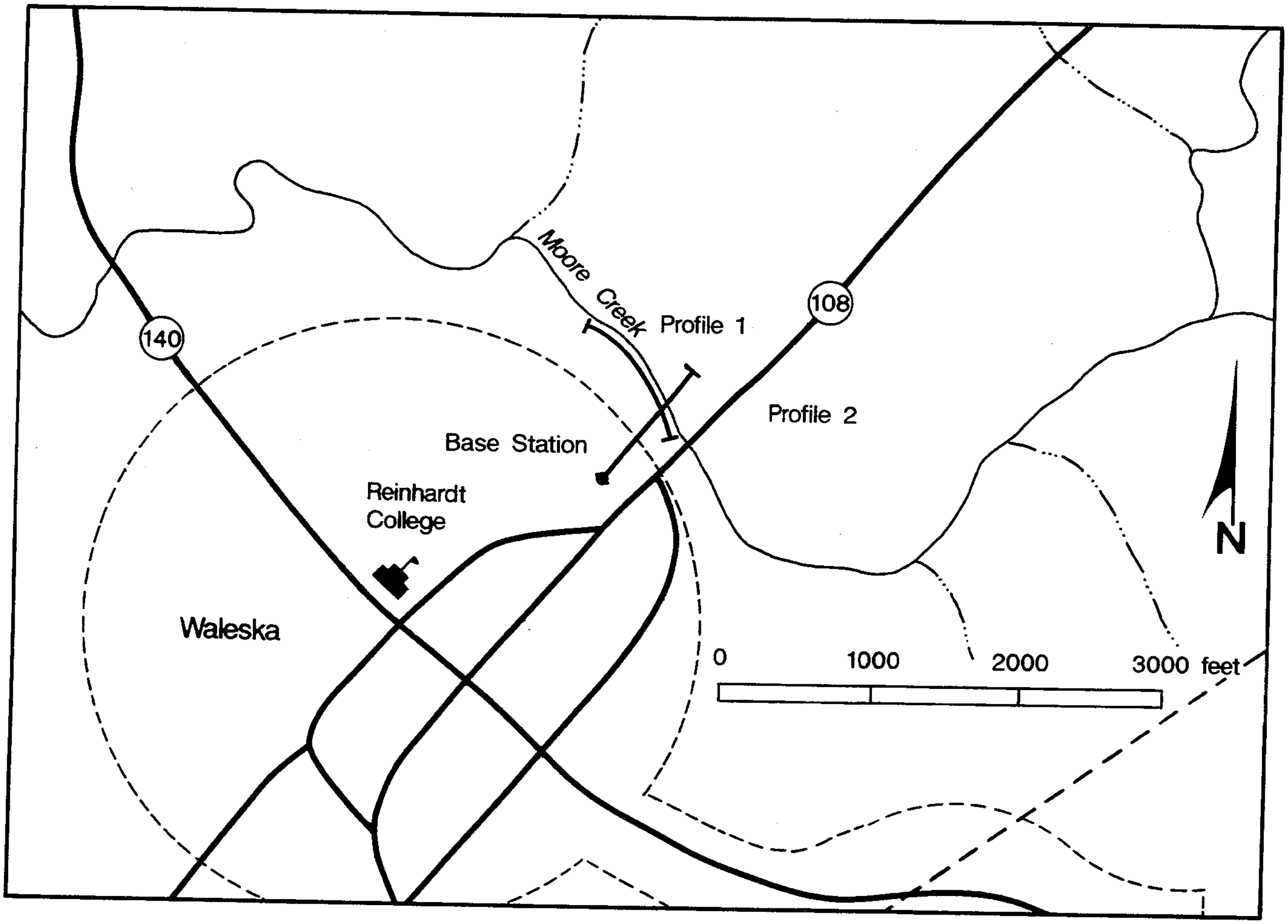

Figure 14. Locations of magnetic profiles 1 and 2.

supply water to wells. Certain types of geophysical logs give convincing evidence of the location of such discontinuities. Caliper logs show changes in borehole diameter which may be fractured or weathered zones. Temperature logs record changes in water temperature which may indicate areas where water enters the borehole. Acoustic velocity logs are useful in identifying discontinuities, and sonic televiewer logs allow observation of these features directly, as well as making measurement of their orientations possible. Sonic televiewer logs provide an oriented, 360-degree image of the borehole and allow measurement of the structural orientation of discontinuities. Discontinuities interpreted as joints or fractures usually appear as very dark gray to black areas with sharp boundaries on televiewer logs. The image generated by dipping discontinuities is sigmoidal in shape, with the phase directly proportional to the dip direction and the amplitude directly proportional to the dip magnitude. Weathered zones or discontinuities caused by compositional layering often appear as gray mottled or gray and black mottled areas with uneven and indistinct boundaries on televiewer logs. Other types of geophysical logs provide supporting evidence of the presence of discontinuities. Among these are spontaneous potential, resistivity, and natural gamma logs.

The caliper log is a record of the average hole diameter. The caliper sonde consists of three arms that follow the wall of the borehole as it is drawn up the well. The average spacing between the tips of the arms recorded as the diameter of the borehole. The caliper log is used in crystalline rock wells to indicate areas in the borehole of larger diameter than the drill bit size. Dilated areas of the borehole are frequently the location of the intersection of a discontinuity in the rock with the borehole. These discontinuities frequently supply water to the borehole.

The caliper logs of PW1 and PW2 show boreholes with drilled diameters of approximately 6 inches. The logs show relatively irregular boreholes with total depths of approximately 340 feet and 360 feet, respectively (Figures 17 and 18). These boreholes show a number of dilations beyond the nominal 6-inch hole diameter, suggesting the likely locations of discontinuities intersecting the well. The caliper logs of the two coreholes CH1 and CH2, show much smoother boreholes characteristic of coring operations; however some dilations of

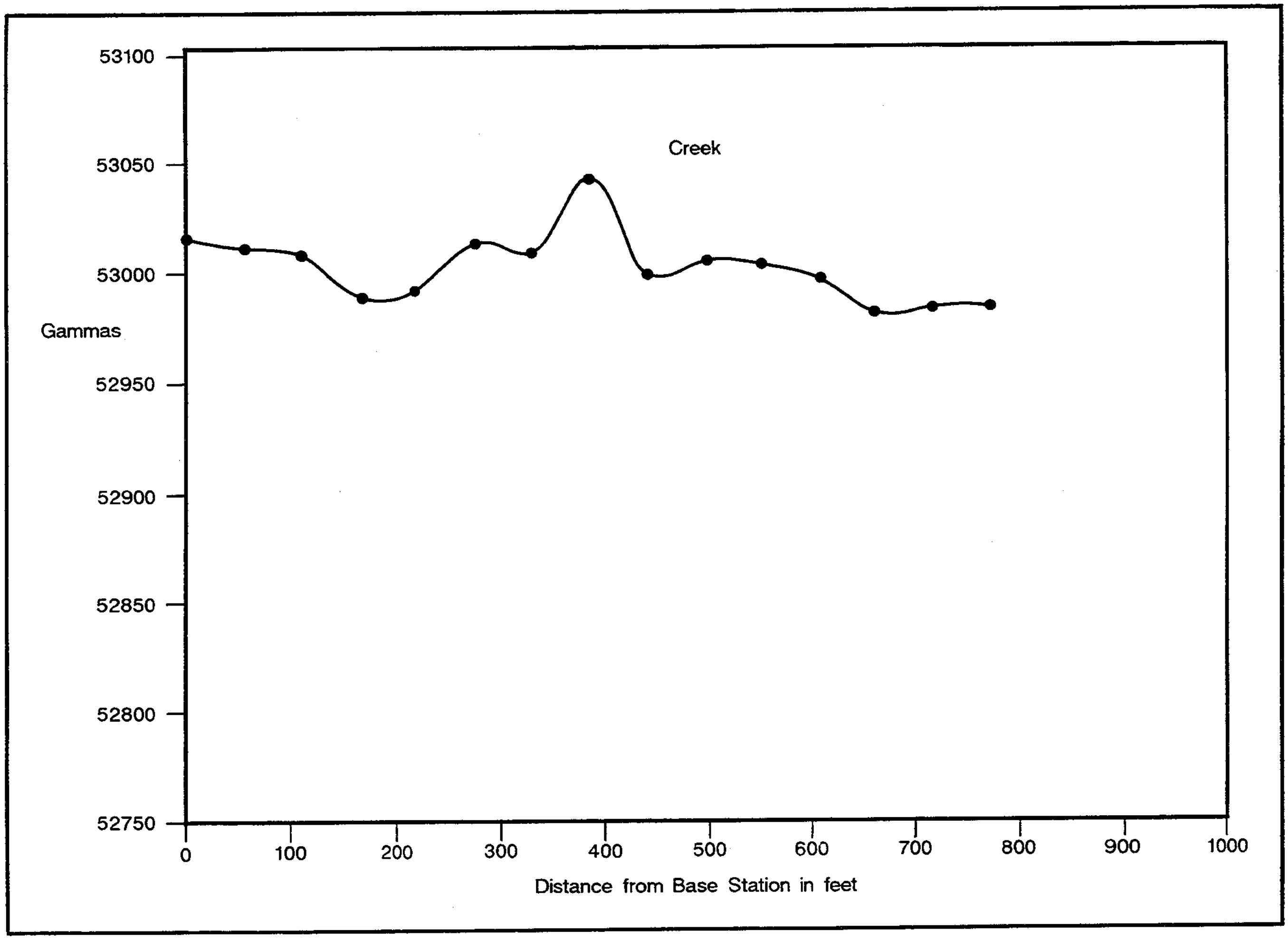

Figure 15. Magnetic profile 1.

the borehole beyond the nominal 3-inch diameter are observable (Figures 19 and 20).

Acoustic velocity logs of PW1 and PW2 indirectly indicate the presence of discontinuities intercepting these boreholes (Figures 21 and 22). Rightward deflections on the log indicate areas of more rapid transmission of sound waves. These deflections may represent areas of less dense rock, such as weathered areas, which may not be visible on the caliper log, but which may yield water to wells.

Sonic televiewer logs were run on PW1 and PW2, allowing the depth and orientation of the major discontinuities to be observed directly. The subhorizontal discontinuities are interpreted as compositional layers. The higher-angle discontinuities are interpreted as joints or fractures. Table 1 summarizes the major discontinuities intersected in PW1, and table 2 summarizes the discontinuities in PW2.

HYDROGEOLOGY

GENERAL

All ground water is ultimately derived from rainwater. Georgia receives an average of 50 inches of rainfall per year. Approximately 9 inches of rainfall enters streams and lakes as runoff, and evapotranspiration returns another 35 inches per year to the atmosphere. The remaining rainfall, approximately 6 inches per year, infiltrates the regolith, eventually reaching the water table, or zone of saturation (Carter and Stiles, 1983). In the unconfined (water table) crystalline-rock aquifers typical of the Blue Ridge and Piedmont Physiographic Provinces, water levels respond quickly to rainfall. Evapotranspiration causes daily fluctuations in water levels. Seasonal ground-water highs and lows in these aquifers emulate those of rainfall, highest in Spring and lowest in Fall. Artesian wells may sometimes occur in areas where relatively impervious material impedes the downward flow of water. Differences in head between recharge and discharge points can then produce flowing wells in cases where fractures serve as conduits to deliver water from areas of high head to areas of

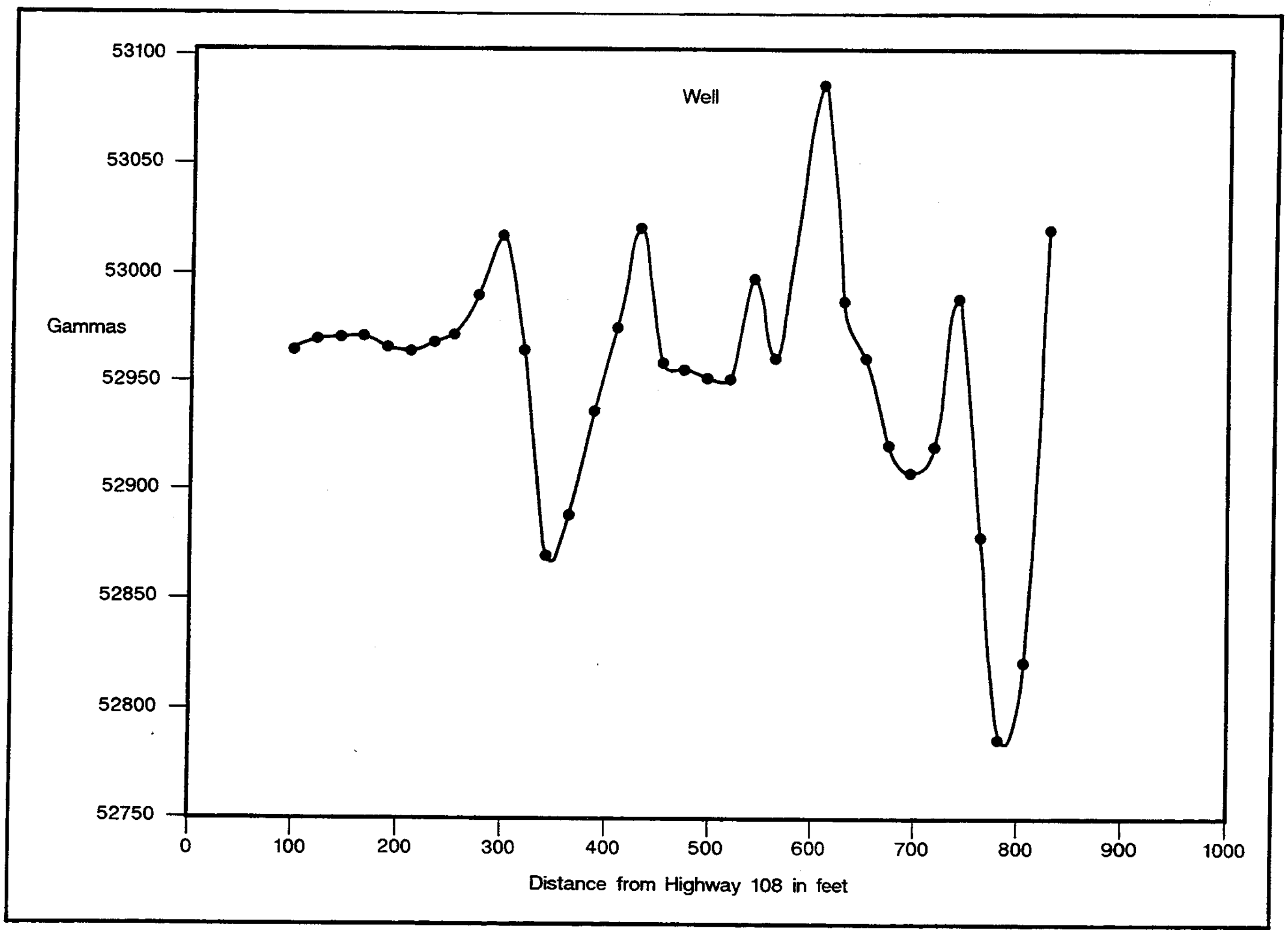

Figure 16. Magnetic profile 2.

lower head.

The components of crystalline-rock aquifers include the saturated, permeable regolith and underlying fractured bedrock. The regolith is composed of soil, alluvium, and saprolite derived from weathering of the bedrock. The bedrock is made up of various metamorphic and igneous rocks of low permeability, and has discontinuities such as joints, compositional layers, and lithologic contacts. Weathering has modified all of these features, causing many of them to become more permeable, thereby providing storage for ground water and pathways through which ground water can flow. These discontinuities deliver water from the saturated regolith to wells completed in crystalline-rock aquifers. The behavior of crystalline-rock aquifers is governed by the complex hydraulic interaction between the regolith and the discontinuities, which vary in geometry, permeability, storage characteristics, and degrees of interconnection.

The inhomogeneous and anisotropic nature of crystalline rocks create directional differences in the permeability of crystalline-rock aquifers. Wells drilled in different parts of the aquifer may exhibit varying hydrologic characteristics. Each well possesses unique production characteristics; the aquifer as a whole can only be described in terms of the range of yield values for all the wells which tap it.

Wells drilled in crystalline-rock aquifers do exhibit some overall similarities. During pumping, early well yields reflect the depletion of storage in the borehole and depressurization of the discontinuities that the well intersects. Tests designed to stress crystalline-rock aquifers, such as constant-drawdown tests, show that as pumping continues, the well will undergo a decline in yield when this storage is depleted. This lower production rate reflects the sustainable yield of the well, or the maximum that can be derived from storage in the regolith, by way of the discontinuities, over an extended period of time (Brackett and others, 1992). Thus, well yields are influenced not only by the placement of wells with respect to discontinuities but also by the amount of recharge supplying the regolith.

HYDROLOGIC INVESTIGATIONS

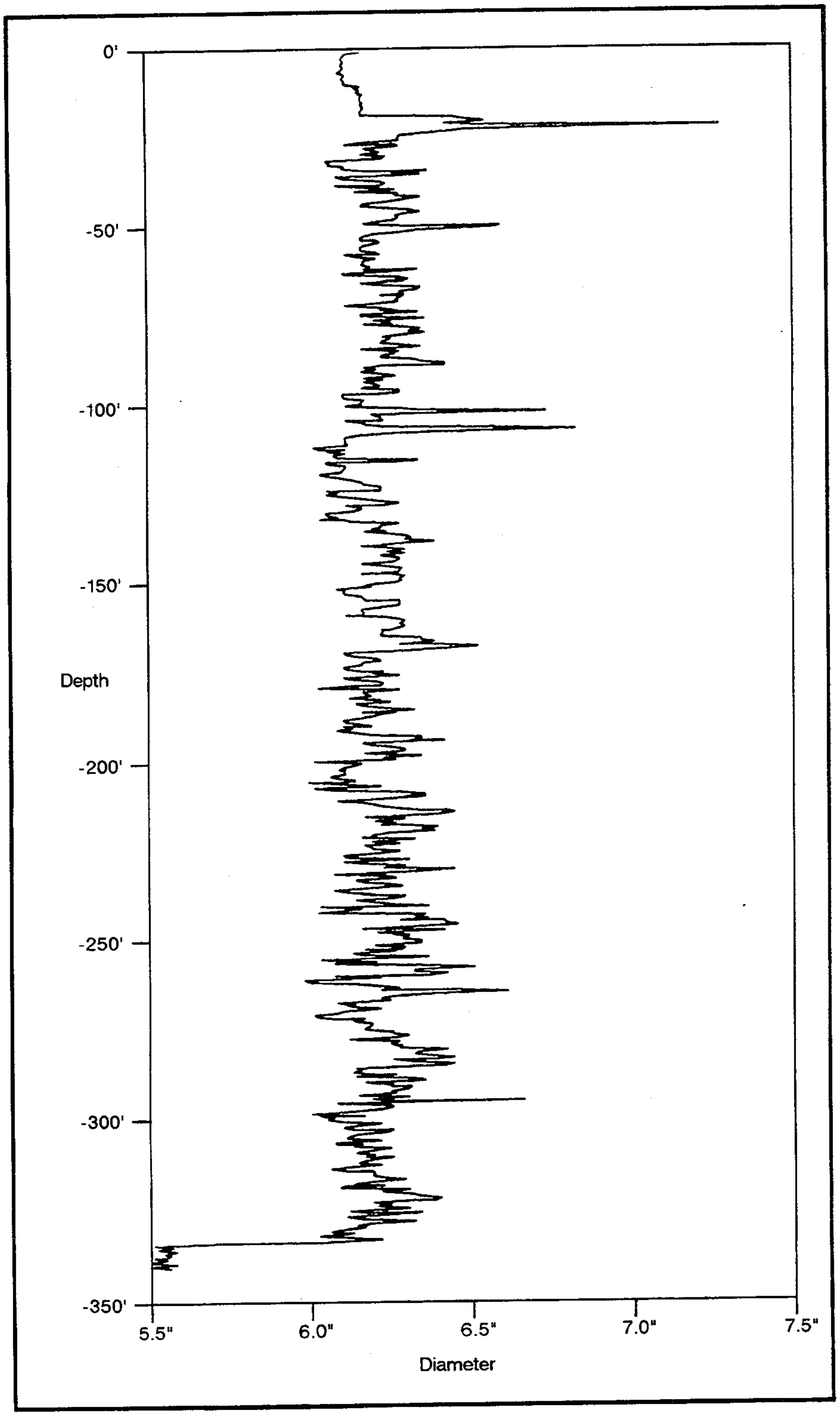

Figure 17. Caliper log of PW1.

Hydrologic investigations at the Reinhardt Research Site included background water level monitoring, an analysis of ground water chemistry, and two pumping tests, a 24-hour and a 72-hour test. The pumping tests were conducted to measure the response to pumping of both bedrock and regolith observation wells.

Water-level Monitoring

Water levels at the Reinhardt site were monitored periodically from March 1989, when drilling began at the site, through December 1990 when the 72-hour pumping test was completed. The water table at the site ranges from approxi-

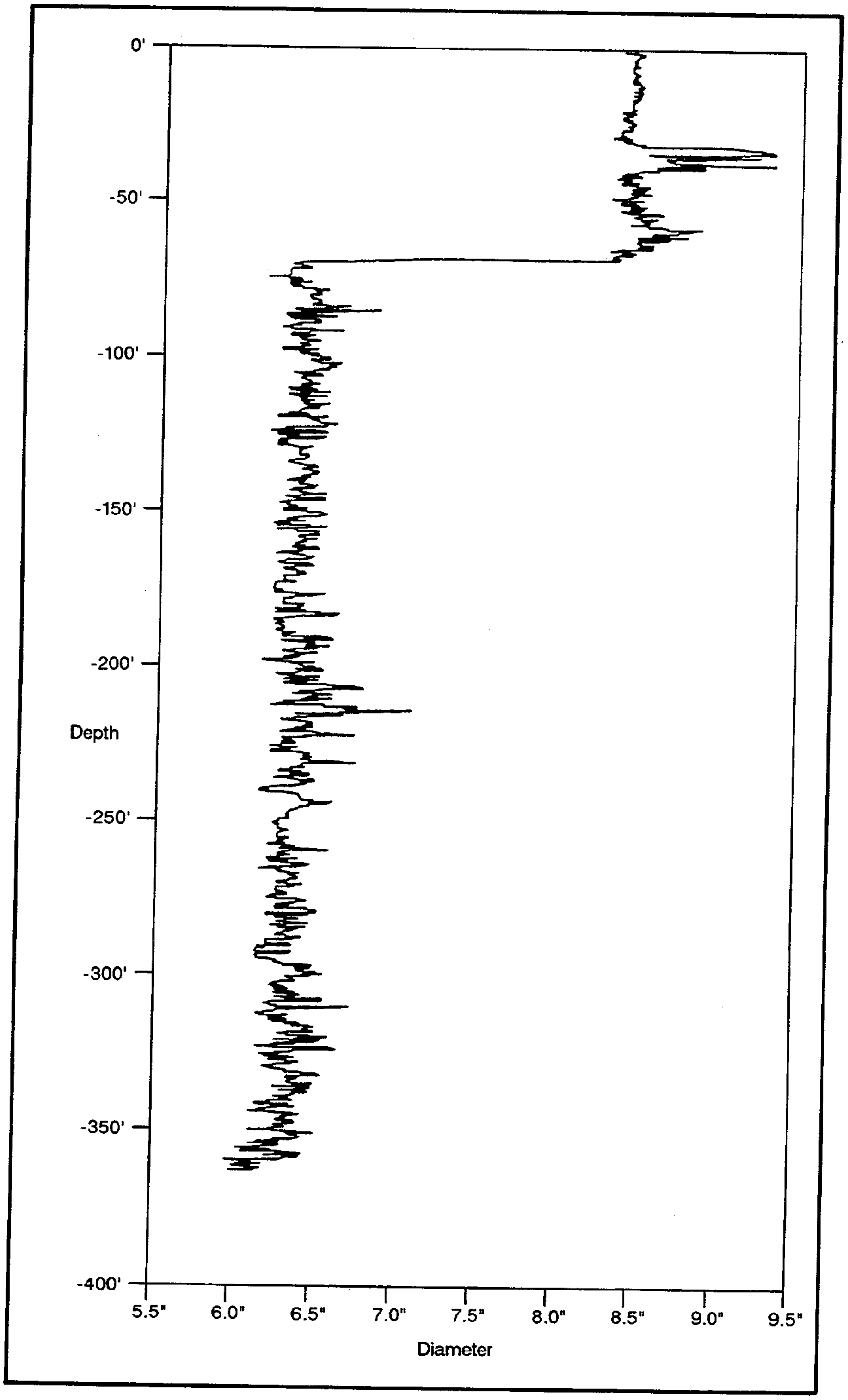

Figure 18. Caliper log of PW2.

mately 8 feet below the land surface to as much as 9 feet above the surface in PW2 (measured by manometer). Water levels typically responded to rainfall, with shallow regolith-monitoring wells responding the most rapidly. Gradual declines in water levels occurred between rainfall events, and a gradual overall decline could be observed in Summer and early Fall. Shallow wells located in wooded areas of the site showed daily fluctuations in water levels during the Summer months due to high rates of evapotranspiration. PW2 showed abrupt increases in water levels during the drilling of CH1 and CH2, reflecting artificial recharge by drilling fluids.

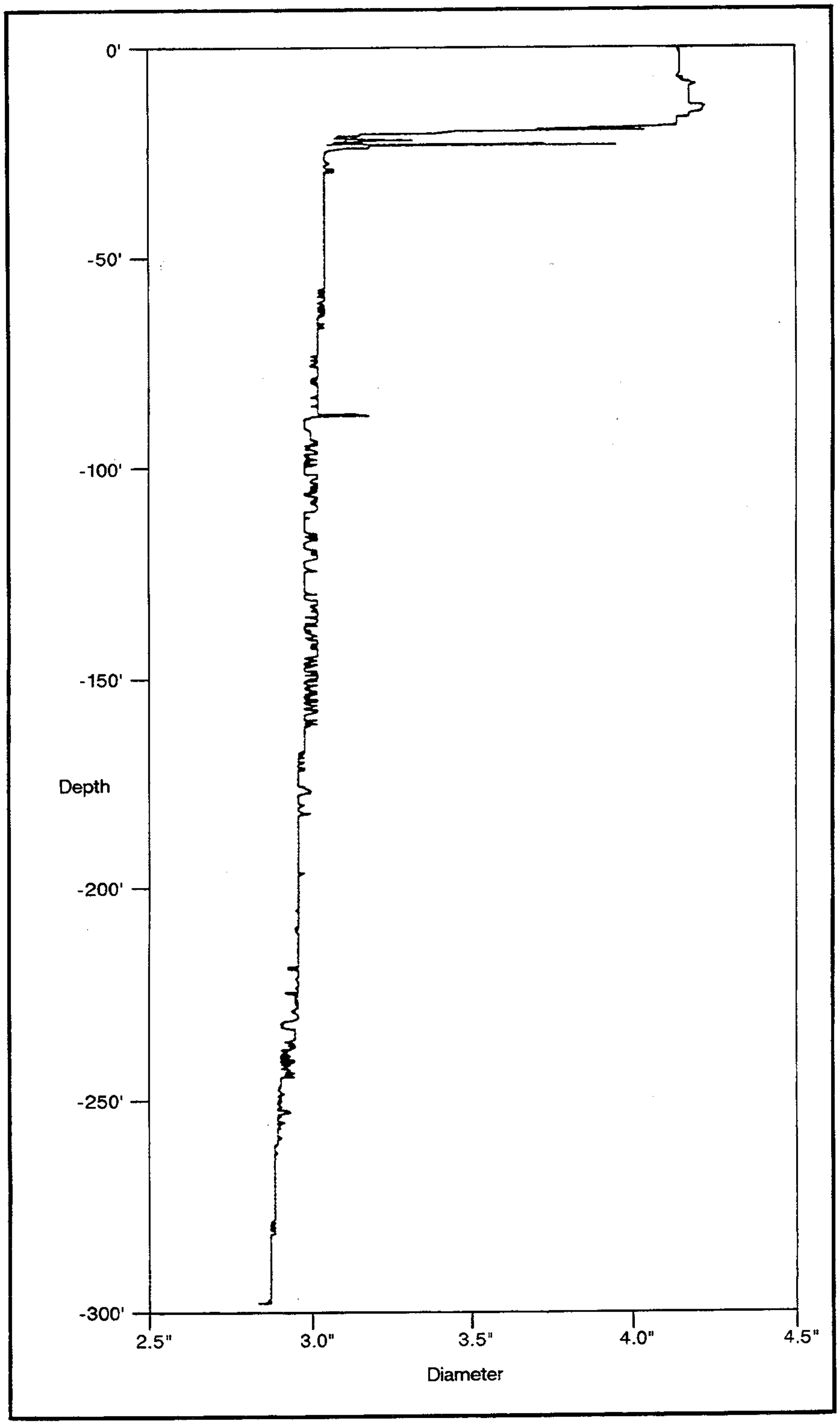

Figure 19. Caliper log of CH1.

The three wells at the Reinhardt site closest to Moore Creek are flowing artesian wells; PW1, CH1, and PW2. PW1 has flowed continuously since it was taken out of service. In 1989, prior to the 24-hour pumping test, when the well casing was extended with PVC pipe and a manometer was installed, the water level was approximately 5 feet above land surface. The water level in CH1, as mentioned above, stood approximately 8.5 feet above land surface. The water level in PW2 ranged from approximately 9 feet above land surface to approximately 3 feet below land surface. The artesian conditions in these three wells probably reflect the presence of a highly permeable discontinuity contained within rock of lower

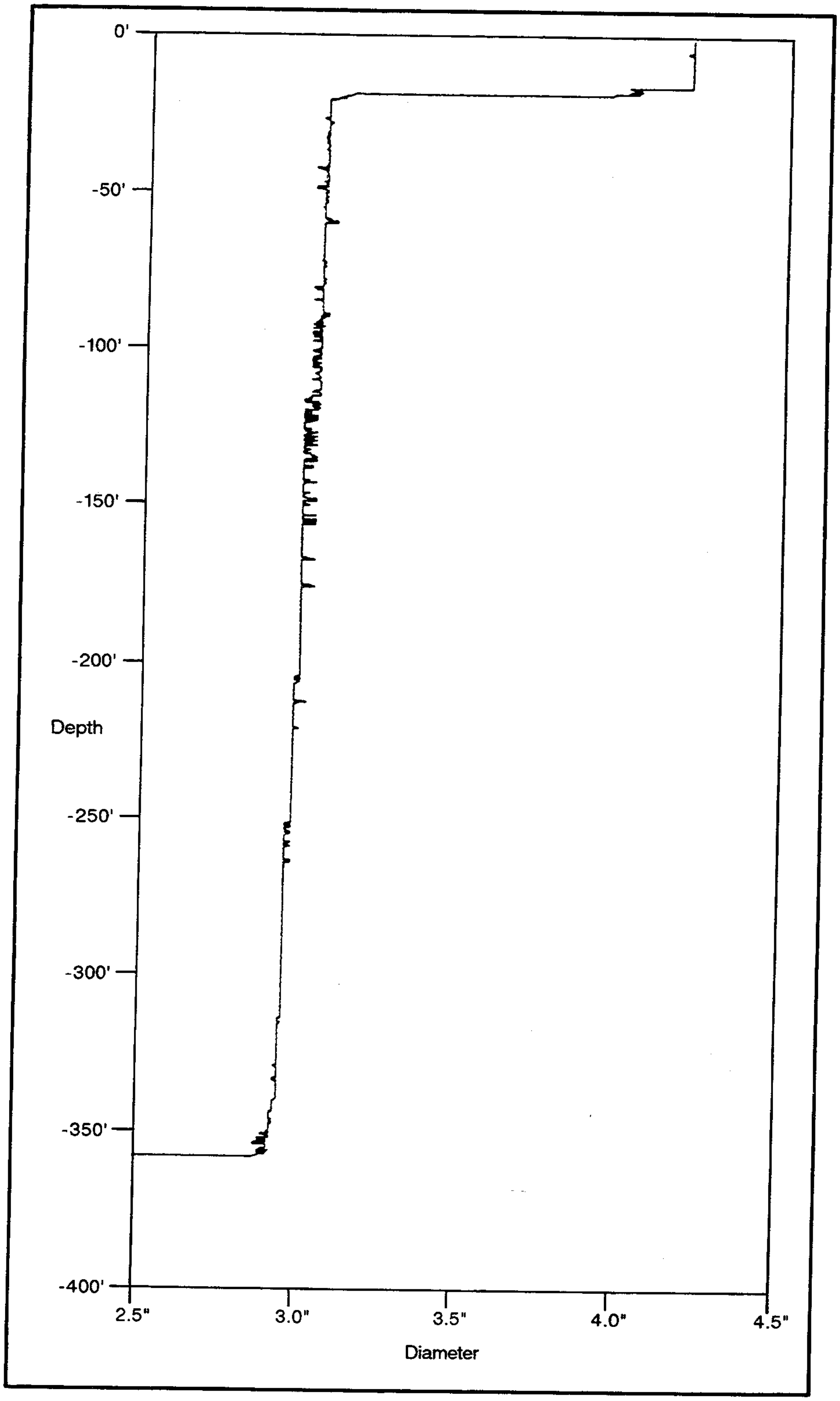

Figure 20. Caliper log of CH2.

permeability. The discontinuity channels water from an upgradient recharge area, probably consisting of saturated regolith. Wells which intercept this discontinuity have head higher than that of the saturated regolith in the immediate vicinity of the well and higher than Moore Creek.

24-Hour Pumping Test - July, 1989

The first pumping test completed at the Reinhardt site was performed beginning July 17, 1989. It was designed as a 24-hour constant-drawdown test. The purpose of this test was to measure the response to maximum pumping stress of a

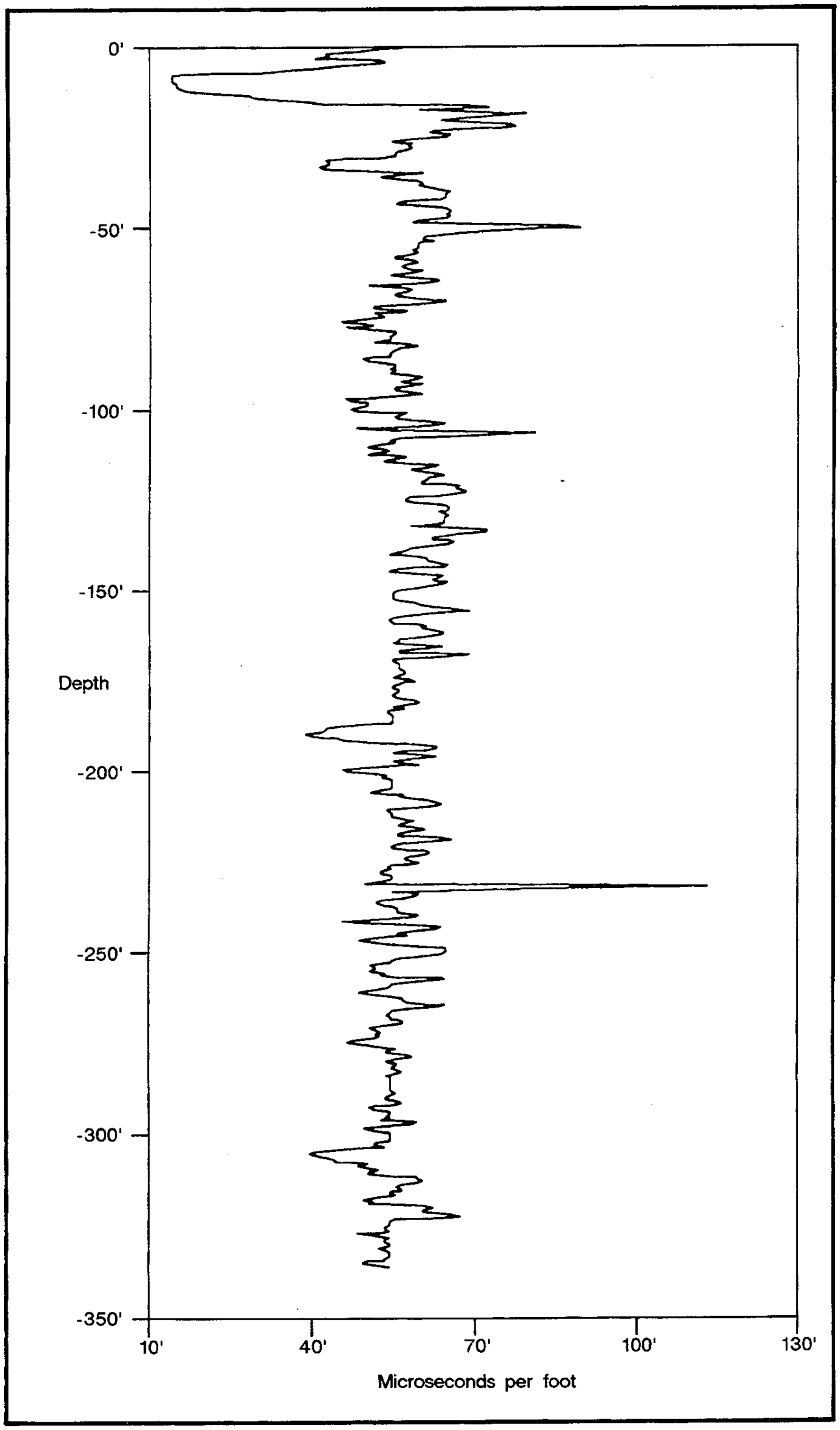

Figure 21. Acoustic velocity log of PW1.

production well, bedrock monitoring wells, and regolith monitoring wells completed in a Piedmont aquifer. In order to induce maximum stress, the pump was set in the production well (PW1) at 315 feet, just below the lowest contributing discontinuities as estimated from the caliper and acoustic velocity logs; the water level was rapidly lowered and then held at approximately 285 feet for the duration of the pumping period (Figure 23). The water level was maintained at the desired 285-feet level by varying the pumping rate using a gate valve. Several water-level "spikes" on the drawdown curve occurred as a result of these adjustments.

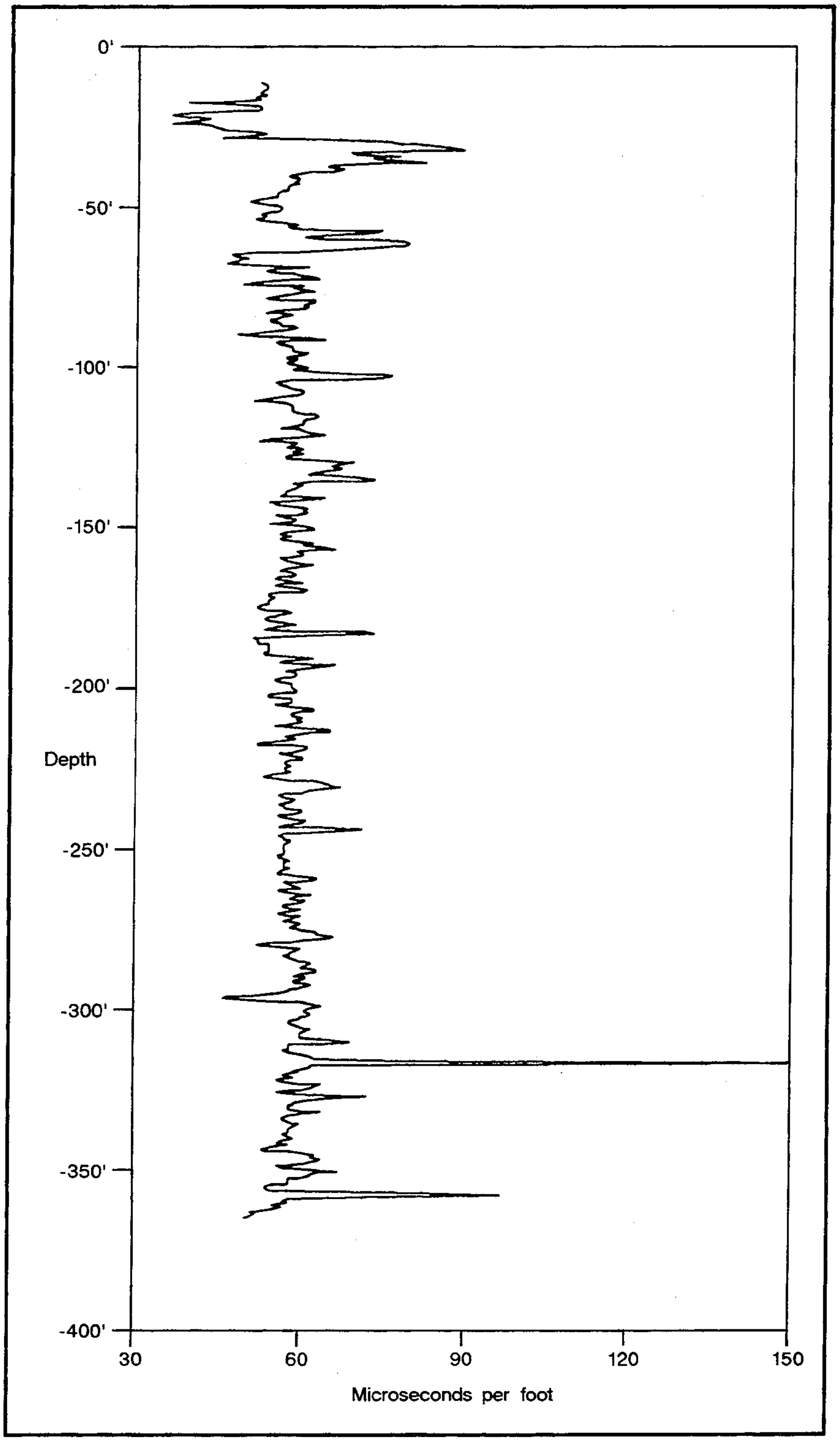

Figure 22. Acoustic velocity log of PW2.

A total of approximately 52,686 gallons was pumped from PW1 during the 24-hour test. The pumping rate declined from an initial high of 127 gallons per minute (gpm) to a low of 33 gpm (Figure 24). The average pumping rate for the test was 36.6 gpm. Pumping was completed 1440 minutes into the test.

The production well showed a very slow but steady decline in yield, suggesting that the well was probably being pumped at a rate somewhat above its sustainable yield. The decline in well yield from 127 gpm to 33 gpm reflects the difference in permeability between the discontinuities and the regolith. Once the borehole storage was depleted and the

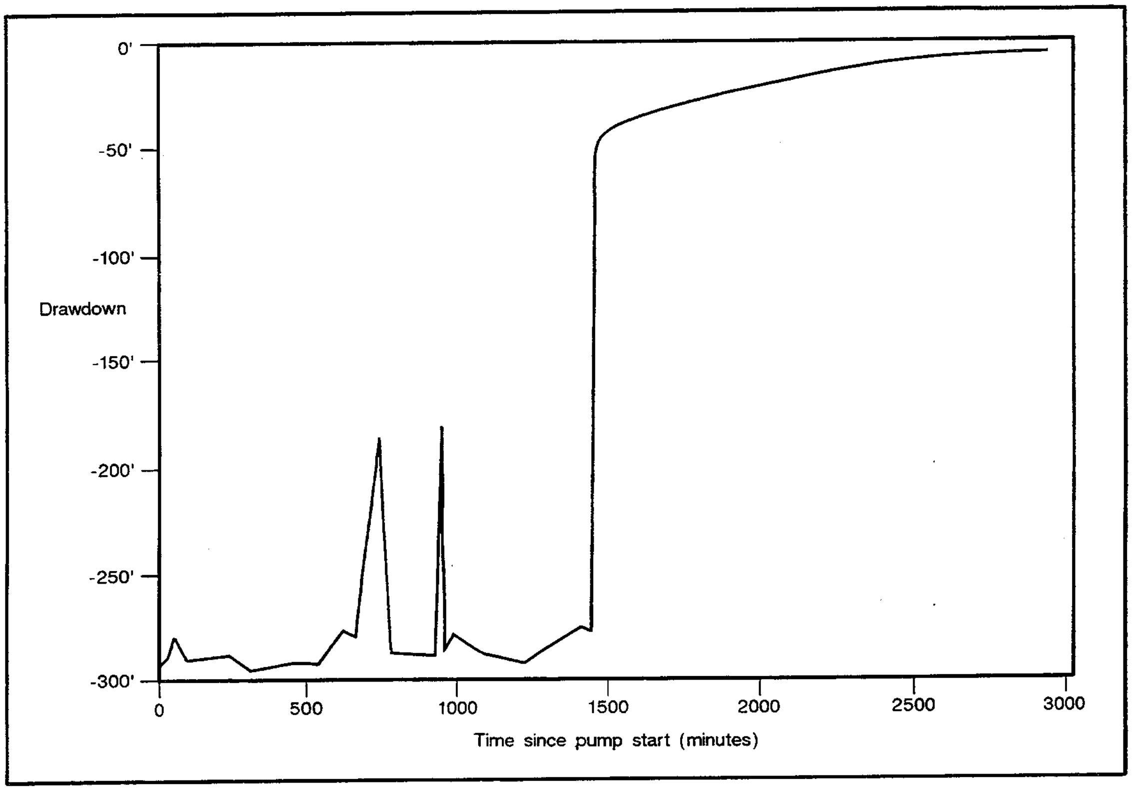

Figure 23. Drawdown/recovery curve for PW1. 24 hour pumping test, July, 1989.

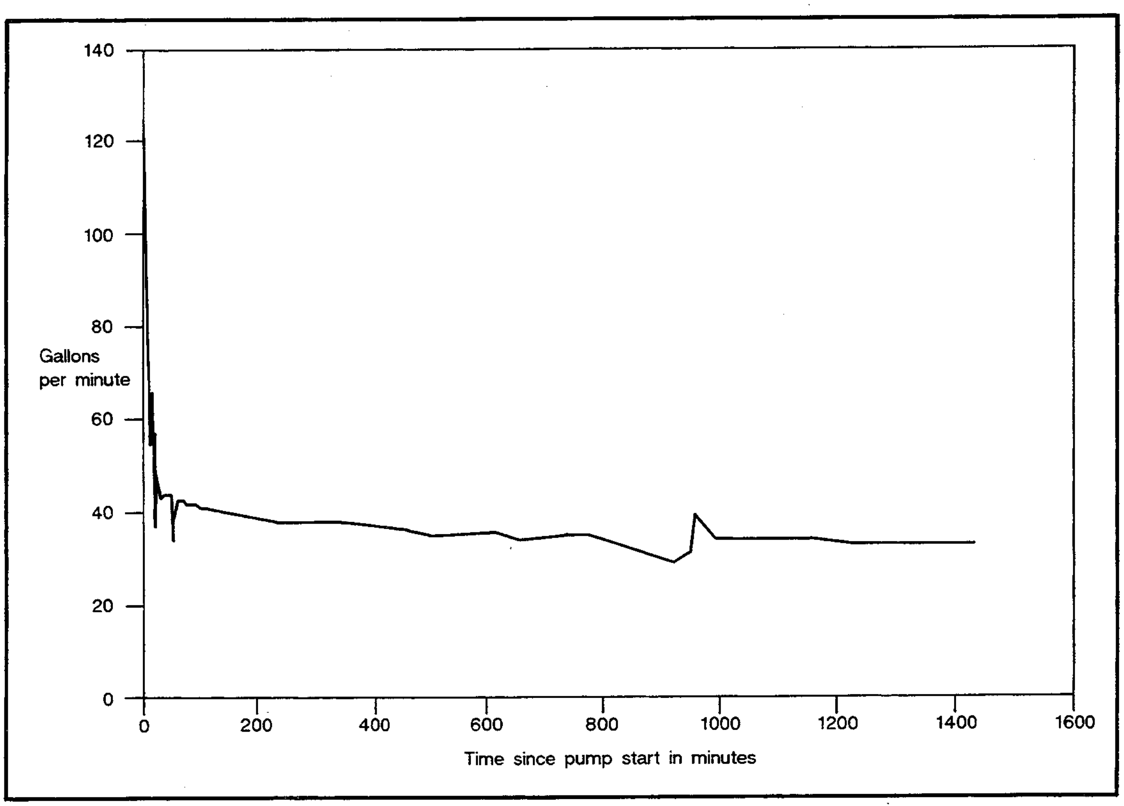

Figure 24. Pumping rate for PW1. 24 hour pumping test, July, 1989.

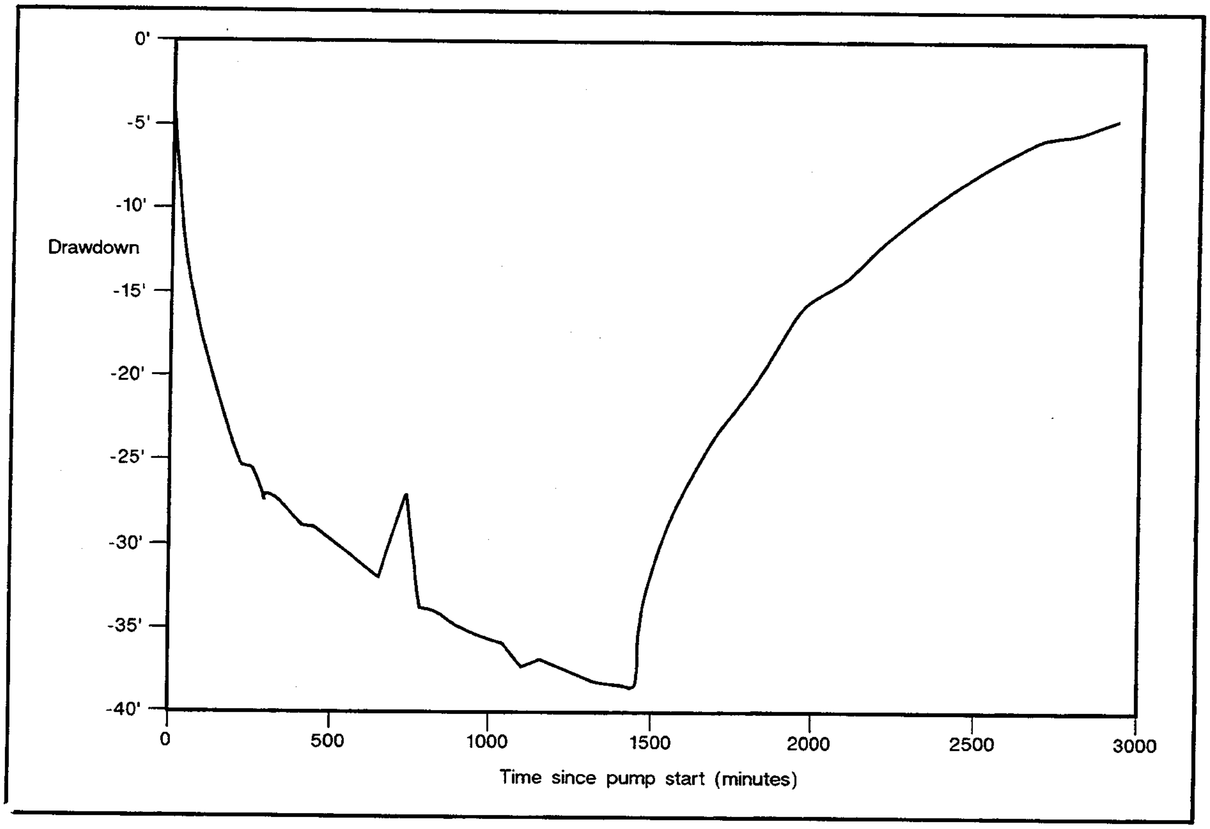

Figure 25. Drawdown/recovery curve for CH1. 24 hour pumping test, July, 1989.

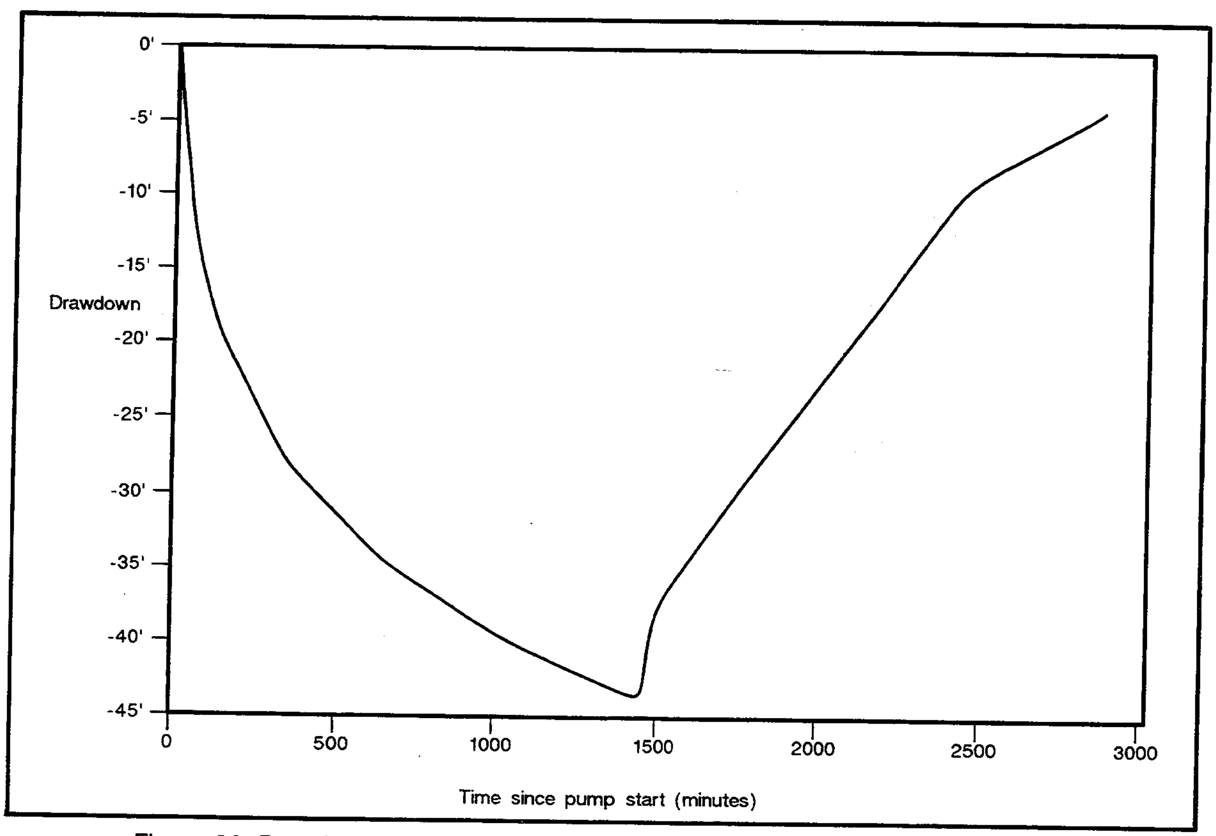

Figure 26. Drawdown/recovery curve for PW2. 24 hour pumping test, July, 1989.

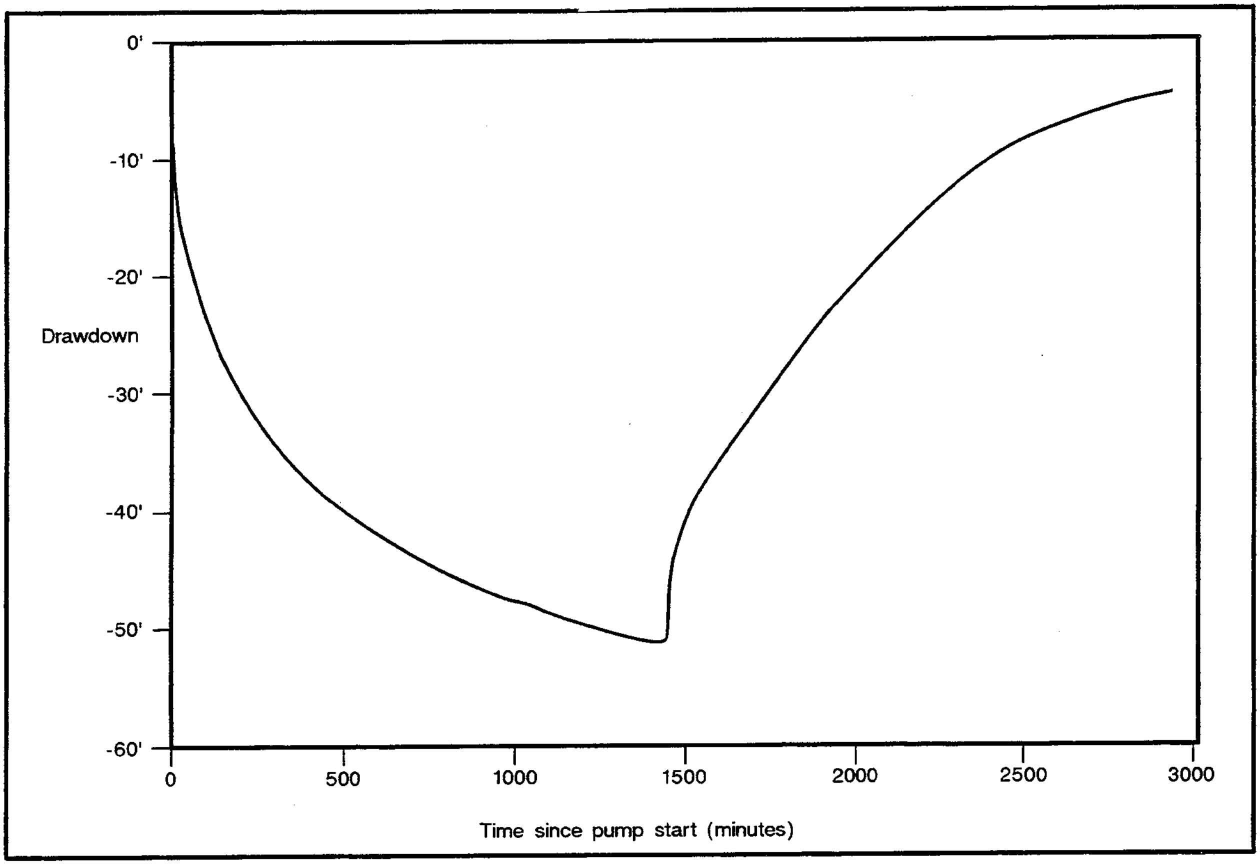

Figure 27. Drawdown/recovery curve for CH2. 24 hour pumping test, July, 1989.

discontinuities were depressurized, the well yield began to reflect the amount of recharge continuously available to the well from storage in the regolith. The sustainable yield of this well is lower than 33 gpm, as evidenced by the continuing decline in yield and the continuing drawdown at the end of the pumping period.

The water level in PW1 did not fully recover within a period of time equal to the pumping period. Residual drawdown at 2937 minutes was 6.54 feet, approximately 2.3% of the total measured drawdown (measured from the top of the well casing). It should be noted, however, that this well was flowing prior to the beginning of the test. On June 26, 1989, for instance, the water level in PW1 was measured at 5.14 feet above the top of the casing. The 2.3% recovery figure thus overestimates the actual recovery of this well. The well was never observed to resume flowing during the course of investigations at the Reinhardt site. The failure of this well to completely recover is an indication that the well was pumped at a rate in excess of its safe long-term (sustainable) yield.

Water levels were recorded in the bedrock observation wells, PW2, CH1 and CH2. The first of these observation wells to respond to pumping was CH1, 146 feet from the production well (Figure 25). The water level in this well began to decline 20 seconds from the start of pumping. Total drawdown in CH1 was 38.64 feet. Drawdown did not stabilize during the test. PW2, 529 feet from the PW1, responded at 1 minute from the start of pumping (Figure 26). Total drawdown in PW2 was 43.74 feet. Drawdown did not stabilize during the test. CH2, 108 feet from the PW1, was not measured until 1.2 minutes after the start of the pump, at which time 2.95 feet of drawdown was recorded (Figure 27). Total drawdown in CH2 was 51.43 feet. Drawdown did not stabilize during the test.

The SWCH1 and SECH1 regolith monitoring wells were measured on an irregular basis during the 24-hour test. Both wells showed a small amount of drawdown in response to pumping of PW1 within 40 minutes of the start of the test. Maximum drawdown in SWCH1 was 0.46 feet, and it occurred 197 minutes after the start of pumping. Maximum drawdown in SECH1 was 0.36 feet, also at 197 minutes after the start of pumping. The response of these wells to pumping PW1 indicates the potential for some degree of hydraulic connection between the regolith and PW1. The 72-hour pumping test subsequently performed at the Reinhardt site was, in part, designed to more closely observe this phenomenon.

Water Chemistry Analysis

During the 24-hour pumping test, water samples were taken from PW1 and analyzed for chemical makeup

Parameter	Units	Value
Arsenic	ug/l	<40
Barium	ug/l	<50
Cadmium	ug/l	<5
Chromium	ug/l	<25
Lead	ug/l	<25
Mercury	ug/l	<0.2
NO2 + NO3	mg/l (N)	<0.5
Selenium	ug/l	<5
Silver	ug/l	<25
Fluoride	mg/l	0.2
pH	-	7.5
Specific Conductance	umho/cm	170
Iron	mg/l	0.64
Manganese	mg/l	0.12
Copper	ug/l	<50
Zinc	ug/l	75
Sodium	mg/l	6.9

Table 3. Water quality analysis for PW1, July, 1989.

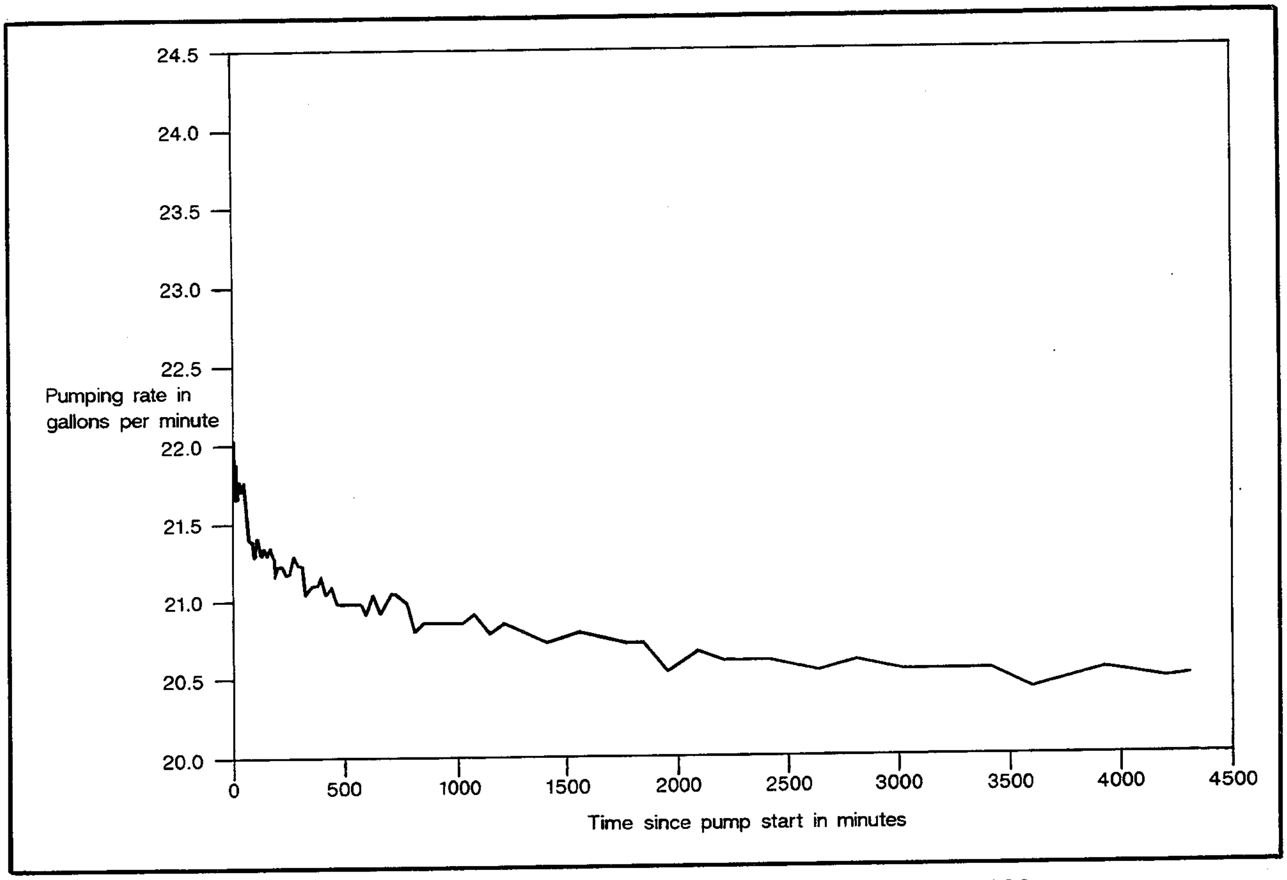

Figure 28. Pumping rate for PW1. 72 hour test, December, 1990.

(Table 3). The water sample had levels of iron and manganese in excess of the secondary maximum contaminant levels, but showed no measurable organic contaminants. Elevated levels of iron and manganese occur in ground water from some areas of the Piedmont.

Despite the close proximity of PW1 to Moore Creek, the chemistry of water discharged from the well provided no evidence of mixing with surface water. The higher initial head of PW1 and the ground water chemistry indicate that water pumped from PW1 was supplied by discontinuities which tap a recharge area upgradient from the production well. No direct hydraulic connection of PW1 with Moore Creek could be established from these results. The lack of such a connection may explain why the yield of PW1 was not higher. Many very high-yielding Piedmont wells are hydraulically connected to a perennial stream. The apparent lack of hydraulic connection between two such closely located features as Moore Creek and PW1 suggests a strongly directional component to recharge in the area, most likely as a result of some combination of rock fabric and structure, which effectively isolates PW1 from the creek.

72-Hour Pumping Test - December, 1990

The second pumping test completed at the Reinhardt site was performed beginning December 18, 1990. This 72-hour constant-rate test was designed to test the sustainable yield of a Piedmont well, and to measure the response of shallow, regolith-monitoring wells to pumping of a deep Piedmont well. This was done by measuring the response of the production well (PW1) and bedrock and regolith monitoring wells to pumping at a lower rate, over a longer period than the previous test. As in the 24-hour test, the pump was set at 315 feet, just below the lowest contributing discontinuities. The pumping rate was fixed at approximately 20 gpm, on the assumption that the safe yield of the well would be somewhat lower than the 33 gpm yield at the end of the 24-hour test. Water levels during the 72-hour test were recorded in five wells. Monitored wells included PW1 and the adjacent regolith monitoring well, SEPW1; CH1 and the adjacent regolith monitoring well SECH1; and CH2.

A total of approximately 88,525 gallons was pumped from PW1 during the 72-hour test. The pumping rate quickly stabilized between 20 and 21 gpm (Figure 28). The average pumping rate for the test was 20.5 gpm. Pumping was terminated 4320 minutes into the test.

Drawdown in PW1 was very slow but did not stabi-

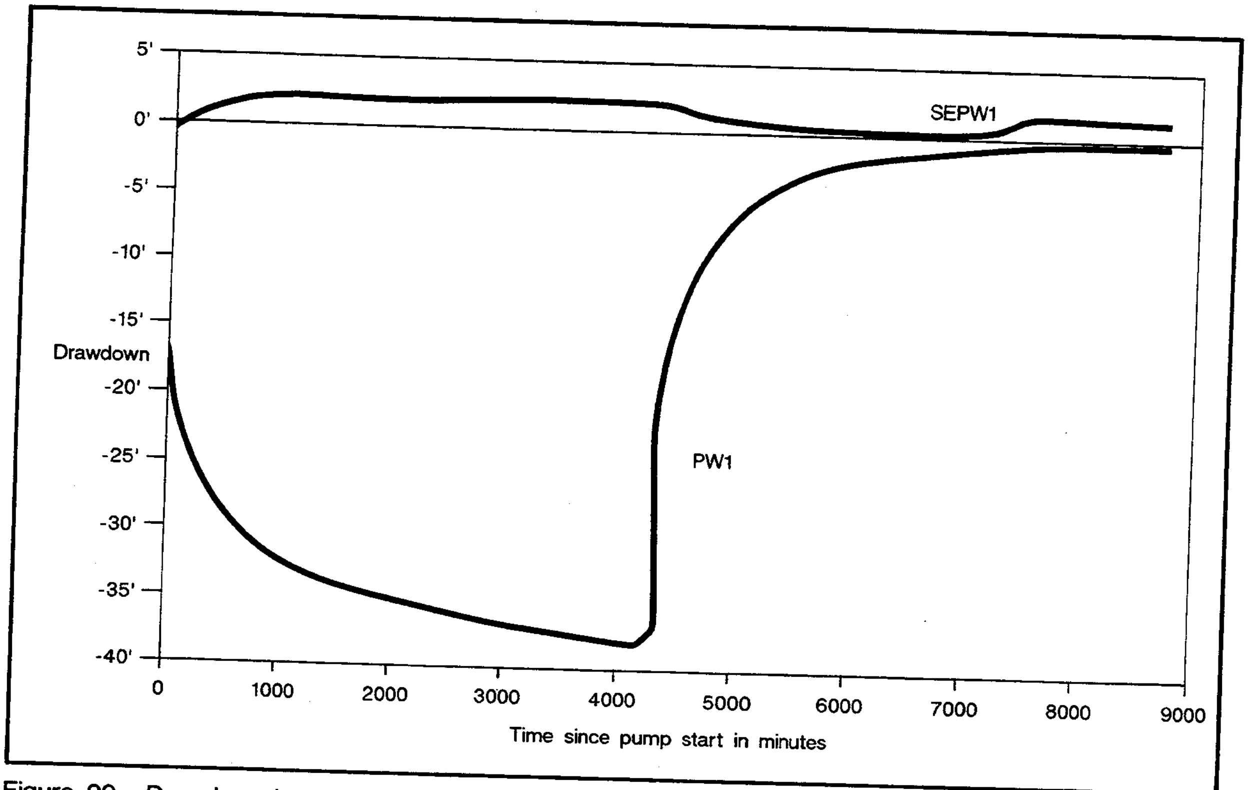

Figure 29. Drawdown/recovery curves for PW1 and SEPW1. 72 hour pumping test, December, 1990.

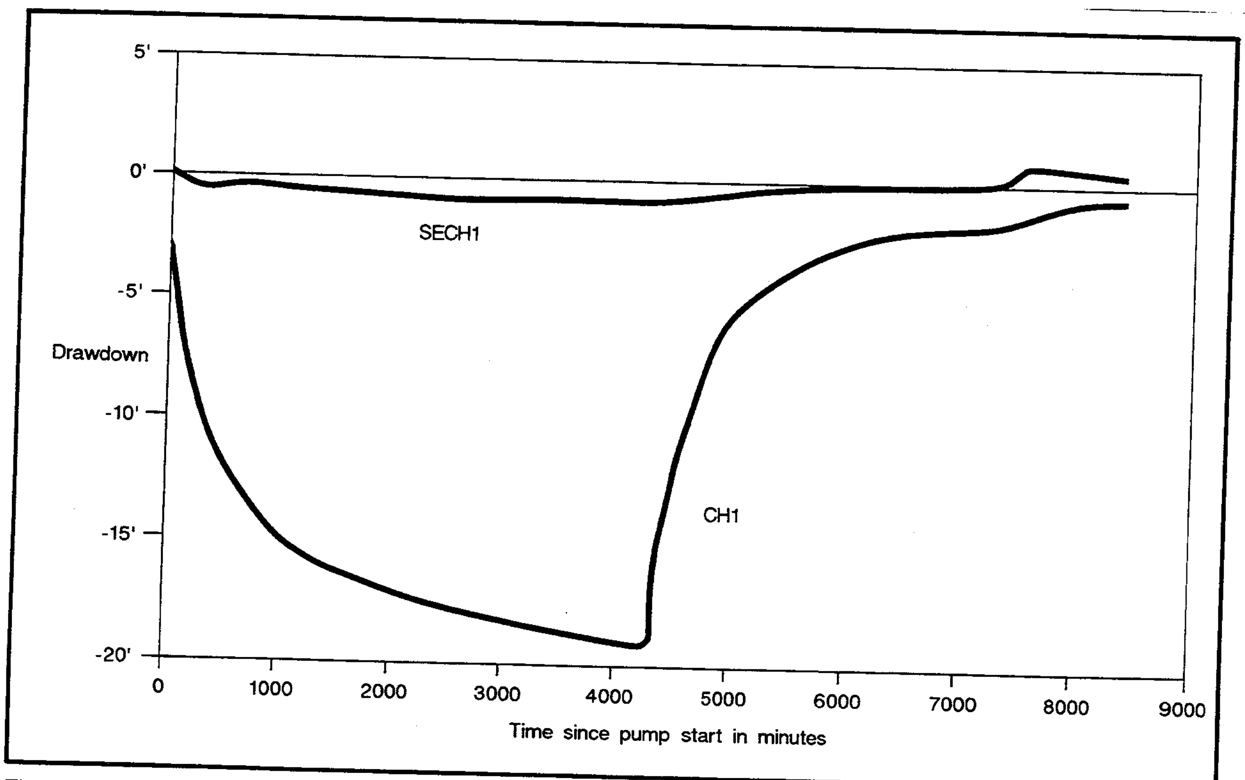

Figure 30. Drawdown/recovery curves for CH1 and SECH1. 72 hour pumping test, December, 1990.

lize. At the end of the pumping period 37.17 feet of drawdown was recorded (Figure 29). The water level in the regolith monitoring well (SEPW1) adjacent to the PW1 began to decline within 4 minutes of the start of pumping (Figure 29). Maximum drawdown of 0.085 feet was recorded at 18 minutes after the start of pumping. After that time, SEPW1 began to

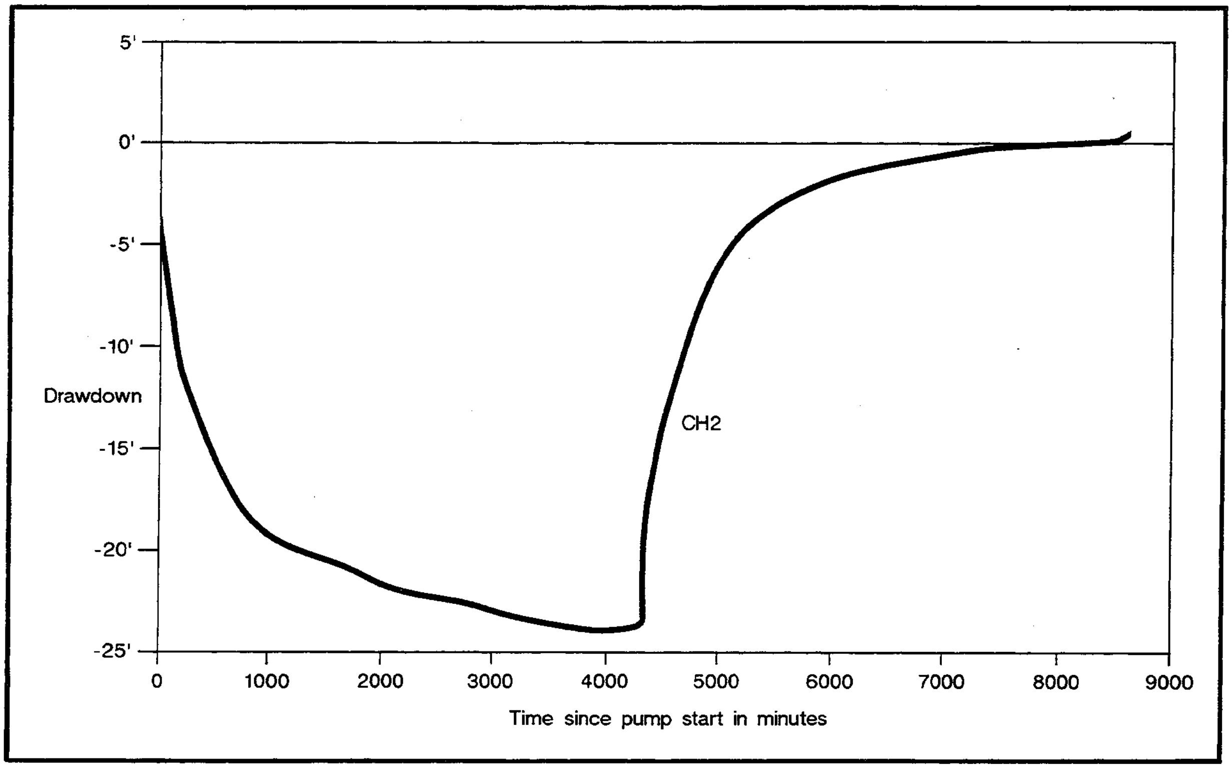

Figure 31. Drawdown/recovery curve for CH2. 72 hour pumping test, December, 1990.

respond to minor artificial recharge by the discharge water from PW1. At the end of the pumping period, the water level in SEPW1 was 1.98 feet higher than the static water level measured before the test. When pumping ended, the water level began to decline as a result of the cessation of artificial recharge.

It appears that during the time between the 24-hour and 72-hour pumping tests, when PW1 ceased flowing, that the water level in the regolith immediately adjacent to PW1 declined. When discharge from PW1 was resumed as a result of pumping, the water level recovered. This response was observed in the shallow observation well SEPW1. The short time (18 minutes) required to produce a response in this well indicates that rapid infiltration can take place even in a clayey regolith.

Well CH1 responded to pumping within 1 minute (Figure 30). A maximum drawdown of 19.0 feet was recorded at the end of the pumping period. The water level in this well did not stabilize during this time. The adjacent regolith monitoring well, SECH1, responded within 2 minutes (Figure 30). A maximum drawdown of 0.86 feet was recorded at the end of the pumping period.

Well CH2 responded to pumping within one minute (Figure 31). A maximum drawdown of 24.05 feet was recorded at the end of the pumping period. Drawdown was slow but did not stabilize during the test.

The water level in PW1 recovered to within 0.39 feet of the static water level in a period of time approximately equal to the pumping period. Residual drawdown at 8725 minutes was approximately 1% of the total drawdown. The recovery of this well and the stable pumping rate indicate that the well was being pumped at a rate close to the sustainable yield.

Rainfall during the recovery period increased the recovery rates of all wells. The shallow regolith monitoring wells, SEPW1 and SECH1, show upward deflections on the recovery curves at approximately 7200 minutes (Figures 29 and 30). All bedrock wells also responded to rainfall, including the artesian wells, PW1 and CH1 (Figures 29, 30, and 31), demonstrating the hydraulic connection of the bedrock to a regolith "reservoir". The areal extent of the reservoir was not assessed. The artesian nature of the wells near Moore Creek suggest that such a hydraulic connection may operate at some distance.

SUMMARY OF OBSERVATIONS

The soils at the Reinhardt site include Tallapoosa series soils and Chewacla-Cartecay complex soils. Below the soil zone the saprolite is light orange, micaceous, and foliated to massive. Schistose zones can be identified within the saprolite, as well as zones probably developed on metagraywacke. The schistose zones are more deeply weathered. Drilling in the low-lying areas of the site indicated that the thickness of saprolite ranged from 15 to 27 feet.

The rocks in the vicinity of the study area are folded, jointed, and faulted crystalline metasedimentary rocks. They include graphitic garnet schist with calc-silicate pods interlayered with metagraywacke, and garnet-quartz-muscovite schist with calc-silicate lenses and pods. The rocks are foliated to crenulated, with foliation orientations ranging from N45°E, dipping 16°SE to N67°E, dipping 34°SE. A northeast-southwest-trending thrust fault (oriented approximately N33°E) lies immediately southeast of the site. Rocks southeast of the fault include phyllite/schist interlayered with fine-grained metagraywacke.

The rocks at the study site are jointed, with steeply dipping joint sets in the vicinity of PW1 oriented approximately N32°-45°W and N35°-50°E. The rectangular drainage pattern exhibited by Moore Creek and its tributaries includes stream and valley segments oriented N30°-N45°W and N41°-N55°E, indicating that the jointing exerts structural control on the topography and surface drainage near the study site. Borehole geophysical logs indicate that numerous discontinuities (joints and/or differentially weathered layers) intercept wells PW1 and PW2.

The water table at the site ranges from approximately 8 feet below the land surface to as much as 9 feet above the surface in PW2. Wells PW1, PW2 and CH1 all had water levels above land surface. Water levels in the regolith monitoring wells showed daily fluctuations in response to evapotranspiration, as well as seasonal variations. All wells responded to rainfall.

A 24-hour constant-head pumping test was performed beginning July 19, 1989. A total of approximately 52,686 gallons was pumped from PW1 during the 24-hour test. The pumping rate declined from an initial high of 127 gallons per minute (gpm) to a low of 33 gpm. The average pumping rate for the test was 36.6 gpm. Drawdown was observed in all bedrock monitoring wells within 1.2 minutes of the start of pumping. Drawdown did not stabilize in any of these wells. Small water-level declines were observed in the regolith monitoring wells within 40 minutes after the start of pumping, indicating that there is some degree of hydraulic connection between the regolith and PW1. The chemistry of water discharged from PW1 provided no evidence of mixing with surface water. No direct hydraulic connection of PW1 with Moore Creek could be established from these results.

A second pumping test completed at the Reinhardt site was performed beginning December 18, 1990. This 72-hour constant-rate test was designed to test the sustainable yield of a Piedmont well. The pumping rate was fixed at approximately 20 gpm, on the assumption that the safe yield of the well would be somewhat lower than the 33 gpm yield at the end of the 24-hour test. A total of approximately 88,525 gallons was pumped from PW1 during the 72-hour test. The pumping rate quickly stabilized between 20 and 21 gpm. The average pumping rate for the test was 20.5 gpm. Drawdown was slow but did not stabilize during the test. Both bedrock monitoring wells responded to pumping within one minute. The water levels in the regolith monitoring wells both showed a response within 4 minutes after the start of pumping. Drawdown was slow but did not stabilize in any of the observation wells during the test. Well SEPW1 reflected artificial recharge from the discharge water directed onto the ground nearby. This response was observed within 18 minutes of the start of pumping. Rainfall during the recovery period caused a response in all of the monitored wells.

CONCLUSIONS

This study demonstrates that progress has been made towards understanding the behavior of crystalline-rock aquifers. Sustainable well yields can be estimated using the constant-drawdown pumping test methodology designed for crystalline-rock aquifers. The attainment of stable pumping rate and slow drawdown can indicate when a well is being pumped at a rate very close to its sustainable yield.

Surface/ground-water relationships are, in many cases, more complex than commonly realized. Local geologic conditions determine the degree to which surface water bodies and ground-water reservoirs are hydraulically connected. At the Reinhardt site, both the shallow regolith observation wells and the deeper rock observation wells responded quickly to pumping (discharge) and rainfall (recharge). This demonstrates the hydraulic connection of the bedrock to a regolith "reservoir" which is recharged by rainfall and tapped by pumpage. Even in clayey Piedmont Soils, infiltration can occur fairly rapidly, as evidenced by the fact that one shallow regolith monitoring well responded within 18 minutes to artificial recharge by discharge water from the production well.

The artesian nature of the deep wells near Moore Creek, however, suggest that the hydraulic connection between the regolith "reservoir" and the deeper fractured bedrock may operate at some distance, rather than just in the immediate vicinity of the production well. The higher initial head of PW1 and the ground water chemistry data from the 24-hour test indicate that water pumped from PW1 was supplied by discontinuities which tap a recharge area upgradient from the production well, rather than by Moore Creek. The apparent lack of hydraulic connection between PW1 and Moore Creek may explain the relatively low yield of PW1. Recharge in the area of PW1 appears to exhibit a strongly directional character as a result of rock fabric and/or structure which isolates PW1 from Moore Creek.

REFERENCES

Brackett, D.A., Schmitt, T.J., Steele, W.M., Atkins, R.L., and Kellam, M.F., 1992, The constant-head pumping test methodology: A useful test for production wells completed in crystalline-rock aquifers of Georgia: in C.C. Daniel III, R.K. White, and P.A. Stone, eds., Proceedings of the Conference on Ground Water in the Piedmont of the Eastern United States: Clemson University, Clemson, South Carolina, p. 606-612.

Brackett, D.A., Steele, W.M., Schmitt, T.J., Atkins, R.L., Kellam, M.F., and Lineback, J.A., 1991, Hydrogeologic data from selected sites in the Piedmont and Blue Ridge Provinces, Georgia: Georgia Geologic Survey Information Circular 86, 160 p.

Carter, R.F., and Stiles, H.R., 1983, Average annual rainfall and runoff in Georgia, 1941-70: Georgia Geologic Survey Hydrologic Atlas 9.

Clarke, W.Z., and Zisa, A.C., 1976, Physiographic map of Georgia: Georgia Geologic Survey.

Cressler, C.W., Blanchard, H.E., and Hester, W.G., 1979, Geohydrology of Bartow, Cherokee, and Forsyth counties: Georgia Geologic Survey Information Circular 50, 45p.

Cressler, C.W., Thurmond, C.J., and Hester, W.G., 1983: Ground water in the greater Atlanta region, Georgia: Georgia Geologic Survey Information Circular 63, 144 p.

Fanning, J.L., Doonan, G.A., and Montgomery, L.T., 1992, Water use in Georgia for 1990: Georgia Geologic Survey Information Circular 90, 98 p.

Higgins, M.W., Atkins, R.L., Crawford, T.J., Crawford, R.F., III, Brooks, R., and Cook, R.B., 1988, The structure, stratigraphy, tectonostratigraphy, and evolution of the southernmost part of the Appalachian orogen: U.S. Geological Survey, Guidebook 16, p. 16-20.

Jordan, D.H., Bramlett, G.L. Gaither, G.A., Tate, R.J., Blevins, M.M., and Murphy, J.O., 1973, Soil survey of Cherokee, Gilmer, and Pickens Counties, Georgia: U.S. Department of Agriculture, 73 p.

McConnell, K.I., and Abrams, C.E., 1984, Geology of the Greater Atlanta Region: Georgia Geologic Survey Bulletin 96, 127.

Core Description

Reinhardt Core Hole 1

GGS No. 3630

Description by Deana Sneyd 10/02/91

Depth (feet)	Description and Mineralogy
0 - 18.6	No core
18.6 - 22	Saprolite, no description
22 - 159.5	A heterogeneous package of metagraywacke containing three distinct, but repeating rock types.
	1. Calcite-biotite-muscovite quartzite, fine to medium grained, light gray, with accessory garnet, graphite, and pyrite. The garnet content is variable, some quartz grains are coarse grained and slightly elongate. Nodule at 40 feet appears to be partially assimilated by surrounding graywacke; at 80 feet, a lens of epidote-garnet-quartz-biotite. Mineralogy: 40% - 50% quartz, 20% muscovite, 10% - 15% biotite, trace chlorite, trace graphite, trace magnetite-hematite, trace pyrite, 0% - 5% garnet, 10% calcite.
	2. Chloritic, garnetiferous, calcite-quartz-biotite-muscovite schist with or without pyrite. Medium to coarse grained, silvery-gray to brownish-gray, moderately foliated, defined by discontinuous wisps of mica which are generally crenulated. This defines a vague strain-slip cleavage oriented at 60° to main foliation, foliation angle is variable. Garnet is present in two varieties, fine to medium grained subhedral and white, and medium to coarse grained, euhedral pink and red. Relative abundance of biotite and muscovite is also variable. Pyrite occurs concordant to foliation and along fracture. Below 101 feet, muscovite is coarse grained and biotite diminishes. 139 feet - 144 feet, weathered coarse grained schist containing garnet, quartz, biotite, and muscovite. Mineralogy: 20% quartz, 40% muscovite, 10% - 20% biotite, 0% - 5% chlorite, trace graphite, 0% - 2% pyrite, 2% - 5% garnet, 8% clacite.
	3. Quartzite grading to calcareous quartzite. Medium to coarse grained, white, banded with bands defined by amphibole rich segregations, local lineation-defined foliation. Biotite-garnet-actinolite(?) quartzite with or without calcite and/or pyrite. Actinolite is green and acicular, locally occurs with biotite clusters. Calcite is variably abundant with the resistance of layers a function of calcite vs. quartz abundance. The calcite zones occur interlayered in the quartzite with sharp contacts. These layers have been observed in outcrop as being discontinuous pods and lenses. Mineralogy: 10% - 70% quartz, 0% - 10% biotite, 5% - 20% actinolite, trace - 2% pyrite, 5% - 10% garnet, and 0% - 70% calcite. Quartz decreases and biotite and calcite increase near base.
159.5 - 162	Muscovite-biotite-actinolite "rock". Medium grained, green. Mineralogy: 25% biotite, 15% chlorite, 50% actinolite, trace pyrite, 10% calcite.
162 - 168	Quartzite and metagraywacke with garnet, muscovite, and biotite. Interlayered with minor schist and calc-silicate pods. Mineralogy: 50% quartz, 10% muscovite, 20% biotite, 5% plagioclase, trace graphite, trace pyrite, 5% garnet, 10% calcite.
168 - 176	Plagioclase-garnet-biotite schist with some quartz-rich zones. Medium grained, moderately well foliated, bronze-gray. Mineralogy: 35% quartz, 48% biotite, 5% plagioclase, 1% graphite, trace - 1% pyrite, trace-1% garnet, 10% calcite. Garnet and plagioclase are flattened.
176 - 190.5	Garnet-feldspar-quartz-biotite-muscovite schist with thin layers of quartzite and calc-silicate pods. Medium grained, well foliated to undulating, bronze-gray. Mineralogy: 10% quartz, 45% muscovite,

25% biotite, 10% plagioclase, 5% garnet, 5% calcite. Ragged high angle joint at 182, 183, and 185 with euhedral crystals.

190.5 - 283	Garnetiferous plagioclase-carbonate-muscovite-biotite quartzite with several interlayers of biotite-muscovite schist and calc-silicate pods. Quartzite is medium grained, light gray, and poorly foliated. Pyrite occurs as fresh, coarse grained cubes. Graphitic lenses appear to be related to remobilization. Calc-silicate pods appear to be more abundant in the quartzite. Biotite enrichment 230 - 231. Around 240, garnet is less and largely restricted to calc-silicate and schistose interlayers. 257 - 261, banding becomes vari-colored, folded and faulted with zones of schist abruptly juxtaposed against zones of quartzite and local increase in pyrite abundance and size. Very few fractures, usually occur concordant with foliation an schistose zones. 193, a 0.5 foot amphibolite lens. 194, a ragged, high-angle joint. Mineralogy: 40% - 45% quartz, 10% muscovite, 25% - 30% biotite, 5% plagioclase, trace graphite, 3% graphite, 3% pyrite, 2% garnet, 10% calcite.
283 - 284	Chlorite-biotite-actinolite mafic dike. Medium grained, dark green, abrupt contact with quartzite, appears intrusive. Acicular ilmenite in calc-silicate pod uphole of dike. Mineralogy: 50% actinolite, 15% chlorite, 15% biotite, 10% carbonate.
284 - 295	Garnet-biotite-muscovite quartzite. Medium-grained, poorly foliated, light gray. Increasing garnet in quartzite when compared to interlayered garnet-quartz-biotite-muscovite schist and calc-silicate pods. Rough fractures at 285.5, 287.5, and 290. Fractures show some oxidation and secondary deposits of quartz or carbonate.

Core Description

Reinhardt Core Hole 2

GGS No. 3631

Description by Deana Sneyd 10/02/91

Depth (feet)	Description and Mineralogy
0 - 4	Soil, brown, with clasts of micaceous saprolite. Calcite vein from 1 - 2 feet.
4 - 10	Saprolite, medium to coarse grained, orange, faint foliation, micaceous.
10 - 18	Saprolite, medium grained, orangish-bronze, moderately to well foliated, interlayered garnet-plagioclase-biotite quartzite and muscovite-quartz-biotite schist. Much more weathered along schist beds.
18 - 29	Plagioclase-garnet-muscovite-biotite quartzite with garnet-quartz amphibolite, calc-silicate pods, and schistose interlayers. Mineralogy: 25% biotite, 3% garnet, 15% sericite, 7% forsterite, 50% quartz.
29 - 33	Interlayered micaceous quartzite and coarse grained, dark green, chlorite-biotite-amphibole-pyrite mafic dikes.
33 - 149	Plagioclase-muscovite-garnet-biotite schist with thin interlayers of micaceous quartzite. Medium grained, bronze-gray, moderately foliated. Two generations of garnet: (1) Medium grained, moderately rounded pink-red and (2) coarse to very coarse grained flattened and stretched to moderately rounded, white. 43 - 44 feet, mafic dike. 59 feet, 50° fracture, rough, oxidized. 100 feet, 30° fracture, pyrite and carbonate coating. 121 feet, 80° fracture, annealed with epidote and quartz. 142 - 143 feet, several 2 - 3 cm schistose zones, weathered. A 5 cm band of biotite with very coarse garnets at 45 feet. Calc-silicate pods at 64 - 65 feet. From 44 feet down, micaceous quartzite layers dominate. At 86 feet, thin laminae of biotite rich and sericite rich schist, sheared? Mineralogy at 33 feet: 40% biotite, 5% garnet, 10% sericite, 5% forsterite, 40% quartz. Mineralogy at 76 feet: 35% biotite, 2% garnet, 15% sericite, 3% forsterite, 45% quartz. Mineralogy at 121 feet: 30% biotite, 2% garnet, 15% sericite, 8% forsterite, 45% quartz.
149 - 159	Dominantly quartz-biotite schist with 2 - 15 cm interlayers of quartzite. Mineralogy: 45% biotite, 2% garnet, 8% sericite, 5% forsterite, 40% quartz.
159 - 193	Mixture of schist and quartzite basically identical to the 23 - 149 foot interval. A rough fracture with oxidation of pyrite at 167 feet and an annealed vertical fracture at 190 - 191.
193 - 216	Similar to 33 - 149 and 159 - 193 intervals except that biotite and sericite rich laminae are regularly banded and crenulated. Some schistose zones are weathered. Mineralogy: 35% biotite, 2% graphite, 3% garnet, 45% sericite, 15% quartz.
216 - 241	Plagioclase-muscovite-biotite quartzite with interlayers of well foliated, crenulated quartz-biotite-muscovite schist. Medium grained, light gray, poorly foliated, muscovite and biotite proportions are variable. Rough fracture along schist band at 218 feet, rough fracture at 10° from horizontal at 225 feet and broken core at 235 feet.
241 - 255	Garnet-quartz-biotite-muscovite schist with a few interlayers of calc-silicate pods and one quartz lens. Medium grained, bronze-gray, well foliated. Mineralogy: 1% pyrrhotite, 35% biotite, 1% graphite, 3% garnet, 45% sericite, 15% quartz.
255 - 302	Garnet-plagioclase-muscovite-biotite quartzite with interlayers of muscovite-biotite schist. Medium grained, moderately foliated, light gray to bronze-gray, weathered. Strongly weathered at 270 feet. At 282 feet, a fracture at 40°. Mineralogy: 30% biotite, 0% - 2% garnet, 18% sericite, 5% forsterite,

45% quartz.

302 - 303.5 Mafic dike, chlorite-biotite-amphibole. Medium to coarse grained, dark green. Mineralogy: 1% pyrrhotite, 50% hornblende, 15% chlorite, 35% biotite.

303.5 - 361 Same as 255 - 302. Mafic dikes like 302 - 303.5 from 310 to 311 and at 345. From 311 to 318, rock is well-banded to foliated, defined by biotite rich and garnet rich laminae, abundant garnet. Fractures at 312, 30° with vuggy quartz coating, pyrite, oxidized; 322 feet, core broken up; 341 feet, near vertical rough fracture.

For convenience in selecting our reports from your bookshelves, they are color-keyed across the spine by subject as follows:

Red	Valley and Ridge mapping and structural geology
Dk. Purple	Piedmont and Blue Ridge mapping and structural geology
Maroon	Coastal Plain mapping and stratigraphy
Lt. Green	Paleontology
Lt. Blue	Coastal Zone studies
Dk. Green	Geochemical and geophysical studies
Dk. Blue	Hydrology
Olive	Economic geology
	Mining directory
Yellow	Environmental studies
	Engineering studies
Dk. Orange	Bibliographies and lists of publications
Brown	Petroleum and natural gas
Black	Field trip guidebooks
Dk. Brown	Collections of papers

Colors have been selected at random, and will be augmented as new subjects are published.

Editor: Melynda Lewis

The Department of Natural Resources is an equal opportunity employer and offers all persons the opportunity to compete and participate in each area of DNR employment regardless of race, color, religion, national origin, age, handicap, or other non-merit factors.