Hydrogeology of the Middleton-Lowndesville Fault Zone Research Site, Elbert County, Georgia

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INTRODUCTION

The Middleton-Lowndesville Hydrologic Research Site is located in Elbert County, Georgia, about five miles south-southeast of the intersection of State Highways 77 and 72 in Elberton. The site is approximately 115 miles east of Atlanta in the Elberton East 7 1/2 minute quadrangle (Figure 1). Access is by a county maintained road from State Highway 17. The center point of the study area is approximated by the intersection of this road and an unnamed stream (Figure 2, p. 3).

This investigation was part of the Georgia Geologic Survey's five year program, Ground-Water Resources of the Piedmont and Blue Ridge Provinces. The purpose of the investigation was to evaluate the ground-water yielding potential of a well constructed in the Middleton-Lowndesville fault zone and to measure the aquifer properties within the site. The research site, similar to the Barnesville Hydrologic Research site (Steele, in preparation) in Lamar County, was designed to evaluate the concept that the large scale brittle structures of the Georgia Piedmont could be significant aquifers capable of supplying water to towns or small cities.

No previous hydrologic investigations in the vicinity of the research area are known. However, the general geology of the Middleton-Lowndesville fault zone and surrounding area has been mapped by several investigators, primarily University of Georgia faculty and students. Master's theses which include geologic maps of the fault zone are Rozen (1978), Davis (1980), and Turner (1987). A report by Allard and Whitney (in press), discusses the geology of the Inner Piedmont, Carolina Terrane, and Modoc Zone of Northeast Georgia and includes most of the Middleton-Lowndesville fault zone.

The authors wish to thank John Sword for use of his property. His cooperation and assistance are greatly appreciated. Middle Georgia Water Systems constructed the two production and the soil monitoring wells, and also provided the generator, pump, and maintenance personnel during the pumping test.

METHODOLOGY AND QUALITY ASSURANCE

This project required seven tasks to be performed toward its completion. These were (1) choosing the research site, (2) geologic mapping, (3) coring and drilling, (4) background water-level monitoring, (5) geophysical logging, (6) aquifer testing, and (7) data analysis. Moreover, the authors undertook several procedures to assure the quality of this investigation. All rock-core hole sites were located on the basis of site geology and structure. The principal investigator supervised the drilling and construction of all wells, logged the cuttings, and recorded these data. The well identification, distance from ground level to the top of the casing, and measuring point were labeled on the casing of each well. All down hole geophysical logs were run twice; the duplicate logs were compared to the originals and found to be identical. Finally, the data collected during the aquifer test were entered into a spread sheet computer program, reviewed for typing errors, and analyzed.

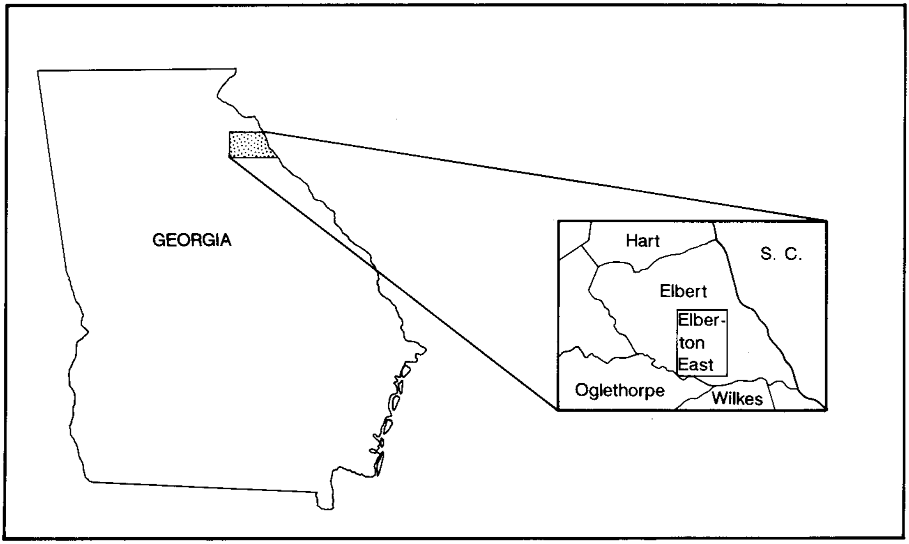


Figure 1. Location of the Elberton East 7.5' quadrangle.

The investigators chose the research site using fracture trace methods in areas where the Middleton-Lowndesville fault zone previously had been geologically mapped at the 1:24,000 scale (Davis, 1980; Rozen, 1978; Turner, 1987). The potential site was selected on the basis of the intersection of a pronounced topographic lineament with the fault zone. The topographic lineament, which can readily be identified on a topographic map, is defined by an unnamed northwest trending stream which is a tributary of Dry Fork. The orientation of joints in outcrops at the site indicate that the northwest trending stream is fracture controlled. Fracture orientation and density data (Sneyd, unpublished) collected during a subsequent geologic mapping of the site and surrounding area support this conclusion.

In order to make a more accurate interpretation of the subsurface geology, the Survey drilled five NX-size rock cores across the research site between June 12, 1990 and November 15, 1990. Core holes 1-4 were arranged in a linear fashion, perpendicular to the strike of the fault zone. Core Hole 5 was drilled in a location along strike to the northeast (Figure 3, p. 5). Coring provided a means to evaluate the nature and attitude of the fault zone, the general lithology, as well as the extent of fracturing. The principal investigator located each core hole site on the basis of surface geology and structures. The core holes were cased and pressure grouted through the drill stem with cement through the soil and saprolite to the bedrock so they could serve as monitoring wells for the bedrock portion of the aquifer. Each core hole was drilled from the surface to bedrock using a 5 7/8 inch diameter rock bit. The drillers then set four inch inside diameter PVC casing into the bore hole and sealed the casing into the bedrock by a pumping portland cement slurry down the casing until it flowed up the annular space to the surface. Next they redrilled the cement through the inside of the casing to the bedrock using a diamond-faced core bit. Coring continued through the bedrock to the depths shown in the well construction diagrams (Figures 4-7, p. 10). The drilling supervisor stopped the drilling of Core Hole 4 when drilling fluid was observed flowing from Core Hole 1 and Core Hole 2; this was done to prevent the drilling fluids and cuttings from clogging the fracture system. Because of repeated problems with hole collapse and breaches in the casing, the drilling supervisor stopped the drilling of Core Hole 5 at a depth of 163 feet. The hole could not be used as a monitoring well because of the casing breeches and was therefore plugged with portland cement slurry.

Middle Georgia Water Systems drilled two 6 inch diameter production wells in August, 1991 using the air-hammer method (Figures 8 and 9, p. 11). The principal investigator supervised the construction of the wells and collected and logged the cuttings. The drillers used a 10 inch diameter rock bit to drill from the surface to a minimum of three feet into the bedrock. Six inch diameter steel pipe was set and sealed into the bedrock with bentonite grout. The drillers emplaced the grout by pouring hydrated bentonite pellets into the annular space after the casing was set and drilling resumed using a 6 inch hammer bit. The location of Production Well 1 is at the intersection of the fault zone and the lineament. The location of Production Well 2 is in the fault zone, but out of the lineament, for comparison. Because the silicified cataclasite that separates the hanging wall and foot wall of the fault may act as a hydrologic barrier, Production Wells 1 and 2 were located to pass through the hanging wall then the cataclasite and into the footwall. In this way the open fracture systems of the hanging wall and the footwall might be utilized to supply water to the wells. A better geologic location for Production Well 1 is most likely 150 feet northwest of the current location. A well at that location would penetrate deeper into the foot wall; however, the location is in marshland and would not support the weight of a drilling rig. Air lift tests of Production Well 1 and Production Well 2 immediately after drilling revealed yields of 80 gpm and 20 gpm respectively.

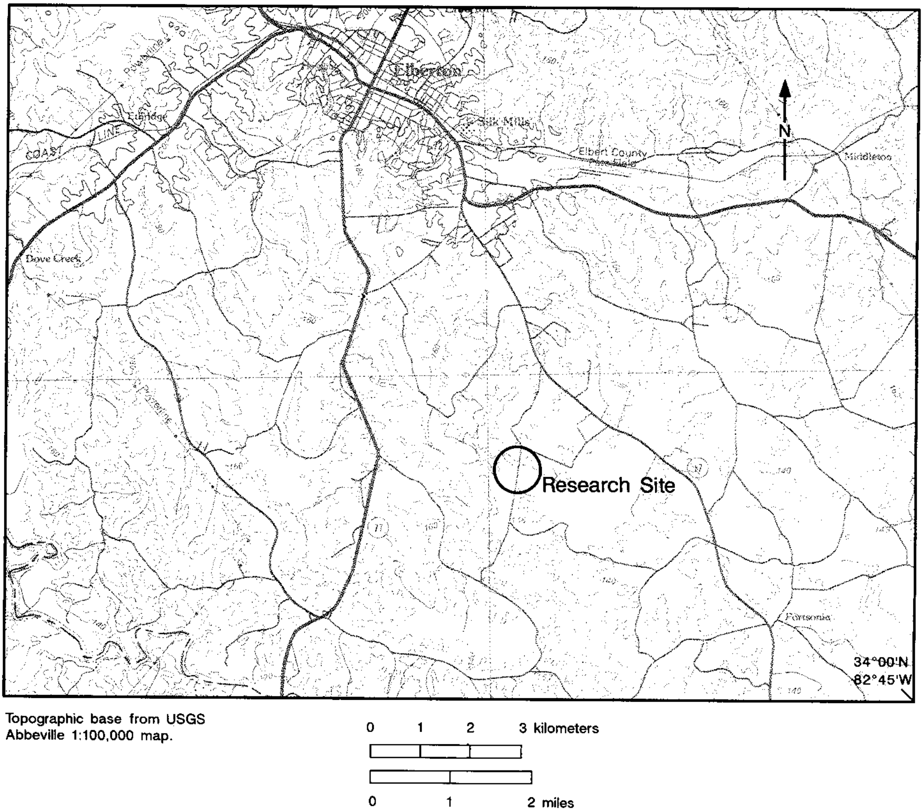
Eight 2 inch diameter soil monitoring wells (Soil Wells 1-8) were drilled to compare drawdown of the soil/saprolite portion of the aquifer to that of the fractured bedrock portion. The principal investigator supervised the construction of the soil wells. The drillers installed the soil wells using 4.25 inch augers to drill to the bedrock. They cased the wells with 2 inch inside diameter pvc pipe and screened below the water table then filter packed the annular space with sand to a level 1 to 1.5 feet above the top of the screen. The wells were grouted with bentonite to a level 2 feet above the top of the filter pack. The drillers emplaced the grout by pouring hydrated bentonite pellets down the annular space, then backfilled the remaining space with cuttings. See Figures 10-17 (p. 12-14) for construction details. All well locations are shown in Figure 3. Cement pads measuring 5 feet x 5 feet x 6 inches were poured around all the wells.

The investigators collected background water level measurements once a week from each rock well, soil well, and production well beginning August 7, 1992 and ending January 29, 1993.

The Survey's geophysical logging crew ran downhole logs of Production Well 1 (resistivity, temperature, and caliper) to help locate the water producing zones. The investigators compared these data to core and well cuttings.

The investigators and other Survey associates performed a 72 hour constant-head pumping test of Production Well 1 during the week beginning October 19, 1992, generally following the methods described by Brackett and others, 1989. The drawdown and recovery of all wells at the research site were measured using conductive water level indicators. The discharge (Q) of Production Well 1 was measured using an orifice bucket and discharged water directed into the unnamed stream about 20 feet north of the well. The authors used the data from this test to estimate the optimal yield of Production Well 1, and also to establish the area and degree of influence of Production Well 1 on the ground-water levels in the immediate vicinity. The data were reviewed for recording errors, then entered into a computer program that converted time from hours, minutes, and seconds to minutes elapsed since the pump was turned on. The program also converted water level measurements from the top of the casing to drawdown from the static water level.

Computer generated hydrographs of each well were produced using the data from the pumping test. Hydrographs provide a visual representation of the effects of the pumping test



Topographic base from USGS
Abbeville 1:100,000 map.

Figure 2. Location of the research site.

on each well. A graph of the pumping rate of Production Well 1 over time reflects the optimal yield of that well. The graphs of the other wells were plotted as drawdown and recovery over time. These hydrographs reflect the area and degree of influence of the pumpage of Production Well 1 on the ground-water levels in the immediate vicinity.

On May 16, 1994, all soil wells at the research site were abandoned in accordance with the Georgia Well Water Standards Act. Georgia Geologic Survey staff removed the pads and casing, plugged the wells with neat cement to plow depth, then filled the remainder of the opening to the ground level with native materials. The Survey released the two production wells to the land owner for personal use.

PHYSIOGRAPHY AND CLIMATE

The research site lies within the northeastern corner of the Washington Slope District, Midland Georgia Subsection, Southern Piedmont Section of the Piedmont Physiographic Province (Clark and Zisa, 1976). The district is characterized by a gently undulating topographic surface, sloping from an elevation of approximately 700 feet in the north to approximately 500 feet in the south. Most of the research site is comprised of open, gently rolling pastures with a narrow wooded area along the stream. Topographic relief on the site is approximately 25 feet with the highest elevation at approximately 465 feet above mean sea level and the lowest at approximately 440 feet above mean sea level.

The unnamed stream that flows through the research site is part of the Broad River drainage basin. The stream intercepts the Broad River 5 miles southeast (airline) of the research site. The Broad River flows into the Savannah River, which empties into the Atlantic Ocean. A steep to near vertical channel indicates that the unnamed stream is a down-cutting stream. The depth from the top of the bank to the stream bed ranges from four to six feet in the research area. A drainage pattern diagram of the stream basin shows chiefly rectangular patterns and a few dendritic patterns (Figure 18, p. 15). The rectangular drainage pattern probably reflects control by faults or joints.

Climatological information was obtained from data published by the National Oceanic and Atmospheric Administration (NOAA). The Elberton Climatological Station is located at the Elberton Water Treatment Laboratory, 6.6 miles (airline) from the research site. Precipitation data that have not yet been published were obtained directly from the station. The normal mean temperature (as defined by NOAA) for northeastern Georgia is 59.7^{O}F. The normal annual precipitation (as defined by NOAA) in Elberton is 48.46 inches. For the year 1992, in which the aquifer test was performed, the total precipitation was 56.17 inches. The monthly precipitation data for the year 1992 and annual precipitation from 1982 to 1992 are shown in Figures 19a and 19b respectively. Precipitation totals for six of the ten years that preceded the aquifer test were below normal. The total precipitation for 1992, the year during which the investigation was conducted, was above normal.

GEOLOGY

The Middleton-Lowndesville fault zone is a zone of both ductile deformation and a later brittle movement located at the boundary between the Inner Piedmont terrane and the Carolina terrane. Allard and Whitney (in press) describe the brittle component as the actual boundary between the two terranes. These tectonostratigraphic terranes were formerly described as a number of geologic belts based on lithology, structure, and metamorphic grade (Crickmay, 1952; Hatcher, 1972). Geologists conducting more recent studies theorize the development of the southern Appalachian orogen through a series of accretionary events, and, finding the belt boundaries inappropriate to describe this model, have divided the lithologies into tectonostratigraphic terranes (Williams and Hatcher, 1982; Secor and others, 1983; Hatcher, 1987; Horton and others, 1989). The Inner Piedmont Flank is the lithologically and structurally distinctive, southeastern flank of the Inner Piedmont composite terrane. Horton and others (1989) describe the Inner Piedmont terrane as a stack thrust sheet consisting of schists, gneisses, amphibolites, and sparse ultramafic bodies; they also suggest that the Inner Piedmont may be an agglomeration of several disrupted terranes, based on the variation in tectonic affinities of the metamorphic complexes within.

Lithologies of the Inner Piedmont Flank consist of a megacrystic microcline gneiss interlayered with biotite schists and gneisses along with minor amphibolites (Allard and Whitney, in press). Much of the Inner Piedmont Flank in the region near the research site is intruded by the Elberton granite.

Secor and others (1983) used the term Carolina terrane in reference to rocks assigned to the Charlotte belt and Carolina Slate belt. The Carolina terrane is thought to be a composite terrane with volcanic-arc affinities (Whitney and others, 1978; Horton and others, 1989). The rocks of the Carolina terrane consist of greenschist to amphibolite grade metavolcanic, metavolcaniclastic, and metasedimentary rocks which are intruded by a variety of premetamorphic to postkinematic plutons. The Carolina terrane rocks in the research area are part of the Heardmont intrusive complex, which consists mostly of diorite, meladiorite, and quartz diorite (Allard and Whitney, in press).

Two soil series have been mapped at the research site by Frost and others (1979). These are the Cartecay series and the Iredell series. Most of the site is underlain by Cartecay soils. This soil type occurs in flatlands with slopes of 0 to 2 percent. The Cartecay series is described as somewhat poorly drained, rapidly permeable, loamy soils, which have formed in alluvial sediments on flood plains along small branches, creeks, and rivers. The Iredell series underlies the more steeply sloped areas of the site. This soil type is described as a deep, moderately well drained to somewhat poorly drained sandy loam, which occupies the ridge tops and slopes (2 to 10 percent) of the Piedmont Upland. Iredell soils are yellowish brown and formed from material weathered from basic igneous rocks. Both the Cartecay and the Iredell series are found on either site to the fault zone.

Five rock cores positioned in a line approximately perpendicular to the strike of the Middleton-Lowndesville fault zone provide information about the complex geology of the site. A generalized geologic map and cross section (Sneyd, unpublished) of the area was compiled from the core logs (Figures 20 and 21, p. 17-18). In general the eastern two thirds of the research site are underlain by rocks of the Heardmont complex, mainly fine to medium grained metamorphosed quartz diorite and diorite. Northwest of the Heardmont complex is a zone of cataclasis, about 100 feet wide, and the Inner Flank of the Piedmont. The zone of cataclasis is comprised of a white aphanitic cataclasite; whereas the Inner Piedmont Flank is dominated by a megacrystic microcline gneiss. Each of these lithologic units is described in detail below:

> The cores of the metadiorites of the Heardmont complex are black and white mottled, fine to medium grained, equigranular diorites composed of chlorite, hornblende, plagioclase, and sometimes minor quartz. The fabric ranges from undeformed to mylonitic. The lithologies become brecciated near the cataclastic zone. Felsic dikes were also noted in the core. These dikes may be related to the nearby Elberton granite.

Surface outcrops of the cataclasite reveal a very competent, white, silicified, microcrystalline rock. On close inspection, small fragments of surrounding lithologies are observed in minor quantities. Breccia of neighboring lithologies flank the cataclasite.

The megacrystic microcline gneiss of the Inner Piedmont Flank consists of variable amounts of microcline, plagioclase, biotite, and quartz, along with minor chlorite, hornblende and epidote. In hand sample, orange to pinkish-orange megacrysts of microcline up to 1.5 inches long and 1 inch wide are set in a matrix of fine to medium-fine grained biotite, plagioclase, and quartz. Visual estimates of the mode of five samples from Core Hole 1 (Sneyd, unpublished) illustrates the variability of phase proportions in this lithology (Table 1, p. 53). The fabric of the rock varies from protomylonitic to ultramylonitic as one approaches the cataclasite zone. Breccia composed of mylonite fragments was observed in the core. The breccia is cemented by silica. The remaining fractures and vugs are commonly coated with calcite. This unit is also intruded by felsic dikes.

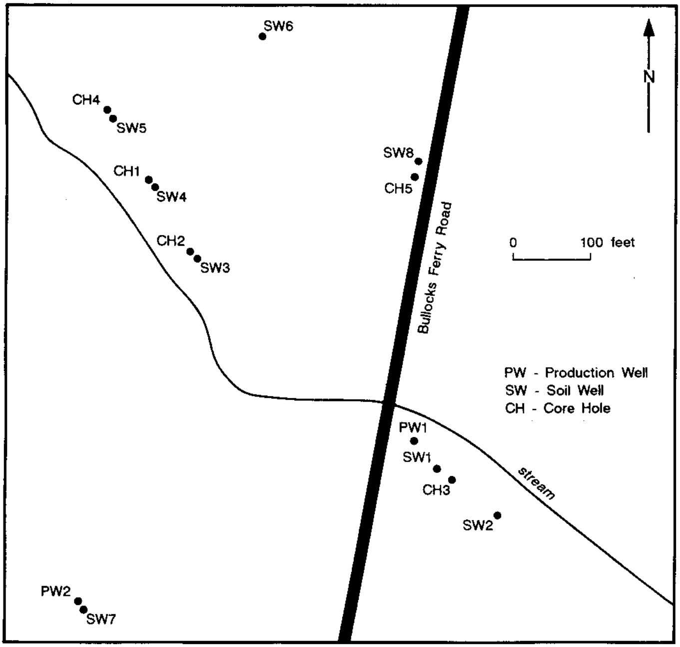


Figure 3. Map of the research site showing well locations.

As previously mentioned, the lithologies of the research site have undergone ductile deformation and a later brittle deformation. As a result of the brittle deformation the Inner Piedmont Flank and Heardmont lithologies are separated by a 75 to 100 foot wide cataclastic zone. The intensity of shearing and fracturing of the Inner Piedmont Flank rocks and the Heardmont complex increases proportionally to the proximity of the cataclasite.

Although the strike of the cataclastic zone varies somewhat between specific locations, Allard and Whitney (in press) report a regional strike of N40°E. The strike of the upper edge of the cataclasite within the research site is N35°E, as approximated by a measurement between outcrops in the road and the unnamed stream. Corings suggest a dip of approximately 50-55°SE. Thirty-four foliation and 91 joint measurements were collected by Sneyd (unpublished) within a one mile radius of the research site. The foliation generally strikes about N35°E and dips about 61°SE. Joints in the area are commonly near vertical. The average strike of joints within a one mile radius of the research site is N42°W; this is nearly parallel to the lineament formed by the unnamed stream, supporting the conclusion that the flow pattern of the unnamed stream is probably fracture controlled.

A suite of down hole geophysical logs was run on Production Well 1 using the Survey's geophysical logging unit. To log the well, a multi-functional logging tool was lowered to the well bottom, activated, and then raised at a rate of about 20 to 30 feet/minute. Geophysical properties are recorded as the tool moves up through the well base.

The geophysical logs run on Production Well 1 are caliper, natural gamma, spontaneous potential, normal resistivity, 16-inch normal resistivity, 64-inch normal resistivity, lateral resistivity, temperature, and fluid resistivity. The caliper log shows changes in hole diameter as it moves up the well. Increases in hole diameter may indicate fracture zones. The caliper log is considered to be very reliable since it represents direct measurement of the size of the bore hole. Resistivity is a measurement of the electrical resistivity of the rock. Fractures are sometimes indicated by a decrease in resistivity (Keys and McCary, 1971); however, since a number of factors can affect resistivity logs, they should only be used as support for information obtained by the more reliable caliper log.

A blockage in Production Well 1 was discovered during geophysical logging. The logging tools were unable to pass beyond the blockage; and, therefore, the well was only logged to a depth of 410 feet. Because the discharge rate increased during air hammer drilling, it appears that some water-contributing fractures occur below this depth to the bottom of the hole at 605 feet. The extent of the blockage and its affect on the yield of the well are unknown.

Though the geophysical logs of Production Well 1 are limited to the depth of 410 feet, they nevertheless provide useful hydrogeologic information. Because the well is located in a major fault zone, various degrees of fracturing occur throughout its depth. The caliper and resistivity logs indicate two zones of intense fracturing (Figure 22, p. 19). These are at 33-140 feet and 393-410 feet. Discreet fractures within these zones are indicated at the following intervals: 33-37 feet, 45-47 feet, 76-77 feet, 85-88 feet, and 398-399 feet.

The natural gamma log is a measurement of the amount of gamma radiation emitted by the rock. Change in natural gamma usually indicates a change in rock type. Some of the spikes (sudden increases followed by rapid decreases) in the natural gamma log of Production Well 1 (Figure 23, p. 20) correlate with the general depths of felsic dikes that were noted during drilling. Two of the natural gamma spikes occur at the fracture intervals 33-37 feet and 85-88 feet. These two gamma spikes may indicate that the "near surface" fractures could be the result of differential weathering between the mafic country rock and the more resistant felsic dikes.

HYDROLOGY

The hydrology of a ground-water system in Piedmont bedrock can be very complex. To understand ground-water flow in the Piedmont, a fundamental understanding of the hydrologic cycle is necessary. The cycle consists of four components; namely, precipitation, evaporation and transpiration, run-off, and infiltration (sometimes referred to as recharge). After water is introduced to the land's surface by precipitation, most of it re-enters the atmosphere as water vapor (evaporation) or is utilized by plant life and transpired back into the atmosphere (transpiration). A smaller percentage flows along the surface of the ground (runoff) to intercept and contribute to the flow of streams. An even smaller percentage of the water infiltrates the surface to become ground-water. A significant portion of the ground-water, in turn, flows through the substrate to intercept and contribute to stream base flow.

Figure 24 (p. 21), from Carter and Stiles (1983) illustrates the hydrologic cycle in Georgia. Georgia receives an average of fifty inches of rain per year. Approximately thirty-five inches is lost to evaporation and transpiration. Runoff to streams accounts for approximately nine inches, while the remaining 6 inches becomes ground-water by infiltration. The drainage basin upstream from the research site has a surface area of 38,360,000 square feet (Figure 25, p. 22). Assuming that about six inches of rain a year infiltrates the surface to become ground-water, then the ground-water recharge to the basin is approximately 143 million gallons/year.

According to O'Conner and others (1993), the Piedmont ground-water system is a two-part system consisting of a nearly continuous layer of regolith overlying fractured, crystalline rock. In general, Piedmont aquifers are of limited areal extent, generally restricted to a single drainage basin with perennial streams acting as natural ground-water divides. Water is mostly stored in the soil/saprolite residuum and transmitted to the well bore via fractures or other geologic discontinuities. The principal components of the Piedmont ground-water system are shown on Figure 26 (p. 23) (from Daniel, 1990). Daniel (1990) also points out that one of the most significant factors affecting well yield of Piedmont bedrock wells is the number of fractures, both horizontal and vertical that the well bore intersects. Fractures can be mapped from bedrock or assessed from rock cores as was done in this study.

PRE- AND POST- AQUIFER TEST MONITORING

Background water levels of all wells were monitored weekly for 26 weeks from August 7, 1992 to January 29, 1993. This information was compared to weekly precipitation data obtained from the National Climatic Service station in Elberton. Graphs of weekly water levels plotted against precipitation indicate a direct correlation between rainfall and water levels in all wells (Figures 27-40, p. 24-37). Another factor contributing to the increase in water levels over the observation period is the reduced rate of evaporation and transpiration as the late summer progresses into winter. The line graphs of water level fluctuations in each of the soil wells (Soil Wells 1-8) have the same basic pattern, although the intensity of the fluctuations vary from well to well (Figures 27-34). A two week period of no precipitation occurred between weeks 11 and 13. A sharp decrease in water levels was observed between weeks 11 and 12. Even though there was no rainfall between weeks 12 and 13, each soil well shows an increase in water level.

Line graphs of the water level data from the core holes and production wells also have similar patterns (Figures 35-40). During the time interval beginning week 11 and ending week 13, Core Hole 1, Core Hole 2, and Core Hole 4 show a steady decrease in water levels. During week 14, 2.58 inches of precipitation fell and the water levels in each of these wells increased. The water levels in Core Hole 3, Production Well 1, and Production Well 2 dropped sharply between week 11 and week 12, then rose between weeks 12 and 13 when there was no precipitation.

Aquifer Testing

Survey associates conducted a 72-hour aquifer test at the study site. The purpose of the test was to measure the affects of pumping on the aquifers in the saprolite and the bedrock. A contracted company installed a 6-inch diameter pump rated at 200 gpm in Production Well 1. The depth to the top of the pump was 250 feet. The well was equipped with two 3/4 inch inside diameter stilling wells, so that water levels could be accurately measured while the pump was running. The test began at 10:45 am on Monday, October 19, 1992. The flow rate was measured using an orifice bucket. The discharge pipe was equipped with a check valve, which was used to slow the flow rate when the water level dropped too close to the pump. The pumping of the well ended at 10:45 am, October 22, 1992 and water table recovery monitoring began.

When the test began, the initial flow rate from Production Well 1 was 187 gpm (Figure 41, p. 38). The flow rate dropped quickly and, 18 minutes from the start of the test, began to stabilize at approximately 133 gpm. The static water level of Production Well 1 just prior to the test was 0.12 feet below ground level. Within 34.4 minutes the drawdown of the water level was 241.59 feet. Approximately 198 minutes into the test the pump failed and twelve minutes elapsed before it was operating again. During this time interval the water level rose to approximately 45 feet from static level. Nine minutes after the pumping resumed the drawdown reached 241.59 feet. The check valve was used nine times during the test to reduce the flow rate. The pumping rate stabilized at about 102 gpm from 402 to 2640 minutes into the test. During the last 720 minutes of the test, the flow rate held at 99 gpm. The drawdown graph (Figure 42 p. 39) shows only a slight drawdown in the water level over this time period, suggesting that the optimal yield for the well is near, but somewhat less than 99 gpm.

After the pump was turned off, Production Well 1 showed an 80% recovery (250 feet to 50 feet) in 10 minutes and an 87% recovery when 60 minutes had elapsed. The water level had risen to 1.9 feet below the original static water level (99.98% recovery) 1472 minutes after the pump was shut off.

The static water level of Production Well 2 prior to the test was 11.43 feet below ground level. The well responded to pumping approximately 13 minutes into the test. A drawdown of 9.4 feet was measured 1348 minutes into the test (Figure 43, p. 40). A gradual drawdown continued through out the test to reach a maximum of 11.25 feet below the static water level. After the pump was turned off the water level began to rise. A measurement taken 1338 minutes after the pump was turned off shows that Production Well 2 recovered to 3.38 feet below static water level. Approximately 4320 minutes after the test the water level had risen to 1.68 feet below the static level.

Core Holes 1, 2, and 4, which are drilled into the footwall of the fault, show cyclic water level fluctuations throughout the test (Figures 44, 45, and 47, p. 41, 42, & 44). However, these fluctuations were minor and do not exceed the typical fluctuations noted in the wells over an eight hour period during background monitoring. In addition, background water level data indicates that the water levels of all the other wells rose between weeks 12 and 13 even though there was no rainfall, indicating continued recovery from the aquifer test, while the water levels in Core Holes 1, 2, and 4 fell (Figures 27-40). For these reasons Core Holes 1, 2, and 4 are thought not to have been affected by the aquifer test.

Core Hole 3 is located in the hanging wall of the fault approximately 50 feet southeast of Production Well 1 (Figure 3, p. 5). Prior to the aquifer test, water flowed out of the well at a rate of 2 gpm. The top of the casing is 1.5 feet above ground level. This figure was used as an approximation of the static water level. Core Hole 3 showed an immediate response to the aquifer test (Figure 46, p. 43). A drawdown of 48.22 feet was recorded 131 minutes after turning on the pump. Twelve minutes after the pump failed, the water level rose to 33.04 feet below the static level. Drawdown resumed immediately with renewed pumping. The rate of drawdown slowed about 600 minutes into the test and reached a maximum of 55.17 feet. After the pump was shut off, the water level rose to 3.8 feet below the static level (99.93% recovery) in 1517 minutes.

Soil Well 1 is located between Production Well 1 and Core Hole 3. The static water level prior to pumping was 3.97 feet. Within 1440 minutes from the start of the test, the drawdown of the well was nearly 11.5 feet (Figure 48, p. 45). The drawdown data for Soil Well 1 show only a slight response to the 12 minutes of pump failure between 198 and 210 minutes. The drawdown gradually continued to reach a maximum of 12.38 feet. After the pump was turned off the water level recovered to 1.75 feet below static level in 1476 minutes.

Soil Well 2 is located 150 feet southeast of Production Well 1. The response of Soil Well 2 to pumping was more gradual than that of Soil Well 1 (Figure 49, p. 46). The maximum drawdown was 6.43 feet. The well recovered to 1.78 feet below static water level 1478 minutes after the pump was turned off.

Soil Well 7 is adjacent to Production Well 2. A very clear, but gradual response to the test was observed in this well (Figure 54, p. 51). The maximum drawdown from static water level was 4.5 feet. The water level recovered to within 1 foot of the static water level 4260 minutes after the pump was turned off.

Soil Well 8 is northwest of Production Well 1, but is still in the hanging wall of the fault zone. This well's response to the aquifer test was very gradual, with a maximum drawdown of 3.05 feet (Figure 55, p. 52). 1488 minutes after the test, the water level was 2.75 feet below the static level.

Soil Wells 3-6 are all located in the foot wall of the fault zone. With the exception of Soil Well 4, each of these wells showed cyclic fluctuations in water level during the test (Figures 50-53, p. 47-50). The hydrographs do show a general downward trend, indicating that the wells were affected by the test. Figure 52 shows very unusual water level fluctuations in Soil Well 4 during the first 1680 minutes of the test. The well responded quickly to pumping with a drawdown of 1.55 feet in the first 26 minutes; however, within 120 minutes the water level was near the static level. The data show a maximum drawdown of 3.11 feet approximately 660 minutes into the test. Through the remainder of the test, the fluctuations diminished. These drastic fluctuations were not seen in Soil Well 3, which is located between Production Well 1 and Soil Well 4.

SUMMARY AND CONCLUSIONS

After choosing the research site and concluding from field data and core analyses that the hydrologic potential of the site was favorable, Production Wells 1 and 2 were drilled. Production Well 1 was located at the intersection of the fault zone and a structurally controlled topographic lineament in a topographically low area, in accordance with the theory that drilling at the intersection of two fracture systems increases the chances of encountering significant quantities of water compared with drilling a single fracture system. Production Well 2 was sited in the fault zone, but away from the lineament and in a location topographically higher than Production Well 1. The investigators located a soil well near each core hole and production well. Soil Well 6 was located on a topographically high area to the north west of Production Well 1. A 72-hour aquifer test was conducted by pumping water from Production Well 1.

Airlift tests indicated the yield of Production Well 1 to be 4 times greater than that of Production Well 2 (80 gpm and 20 gpm respectively), demonstrating the advantage of siting wells in fracture intersections. The results of the 72-hour aquifer test indicate an optimal yield of approximately 99 gpm for Production Well 1. Bedrock wells located in the hanging wall of the fault zone were affected by the aquifer test, while those in the foot wall were not. However, core logs and the fact that drilling fluids were observed flowing from Core Hole 1 and Core Hole 2 while Core Hole 4 was being drilled prove that the foot wall rocks are fractured and can transmit water. This information suggests that these fractures were not fully utilized due to insufficient penetration of Production Well 1 into the foot wall or the blockage in the well 1 at 410 feet. A better geologic location for Production Well 1 is most likely 150 feet northwest of the current location. A well at that location would penetrate 250 feet into the foot wall. However, this is an area of very poor drainage, and would not support the weight of a drilling rig.

All of the soil wells responded, to some degree, to the aquifer test. This is not surprising because the regolith forms a continuous layer across the fault zone. The response of Soil Well 7 (approximately 750 feet southwest of Production Well 1) to the aquifer test was much stronger than that of Soil Well 3 (400 feet northwest of Production Well 1). This suggests that the zone of influence within the regolith is elliptical, with the longer axis in the direction of the strike of the fault. An elliptical well head protection zone with the long axis parallel to strike would be appropriate for Production Well 1. The fluctuations noted in Soil Well 4 during the early part of the test may be related to the proximity of the stream to the well. As the water level in the well dropped below that of the stream, the stream may have become a losing stream providing recharge to the regolith. As the well developed the recharge may have become more continuous, accounting for the diminishing of the fluctuations. The cyclic water level fluctuations noted in Core Holes 1, 2, and 4 and Soil Wells 3, 5, and 6 may represent a tidal effect. Any other possible explanations for these fluctuations other than speculation are beyond the scope of this study.

Within the scope of this investigation, it was not possible to characterize the hydrologic properties of the entire Middleton-Lowndesville fault zone. This investigation does indicate, however, that the methods for locating Production Well 1 were appropriate and can be used with positive results in areas where the fault zone is well defined. Lineament analyses and verification of fracture control by field observation can be performed by a qualified hydrogeologist to increase the probability of locating and drilling an economically viable well.

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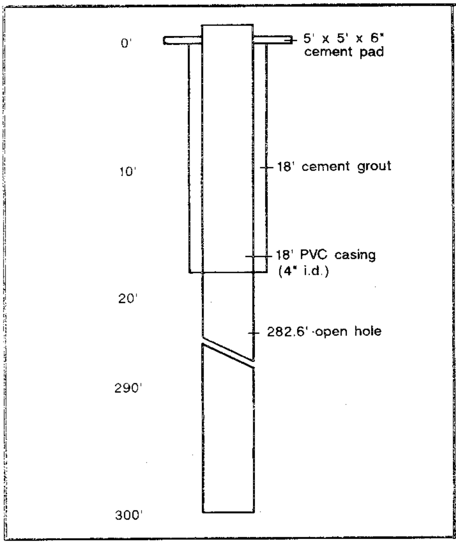


Figure 4. Construction diagram of Core Hole 1.

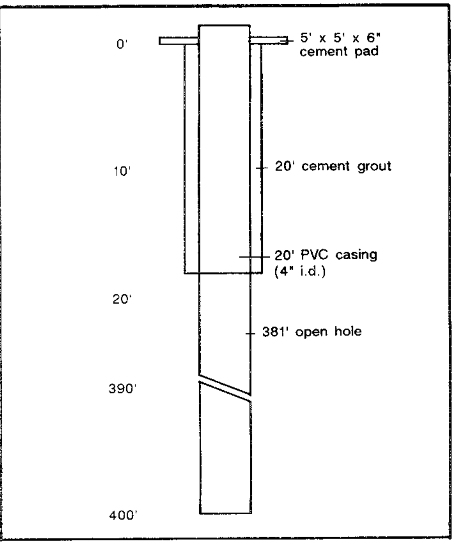


Figure 6. Construction diagram of Core Hole 3.

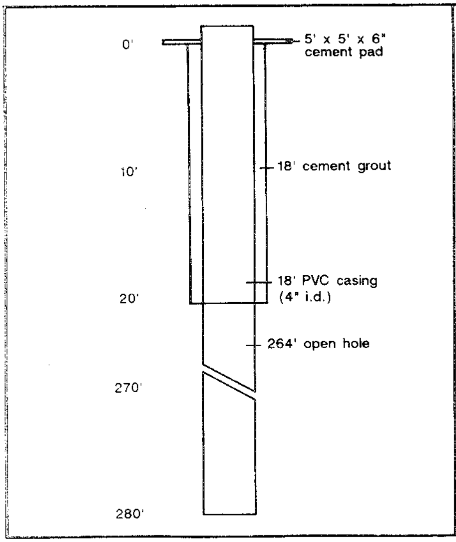


Figure 5. Construction diagram of Core Hole 2.

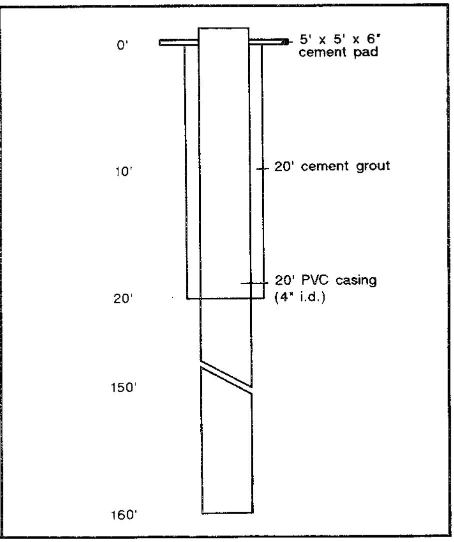


Figure 7. Construction diagram of Core Hole 4.

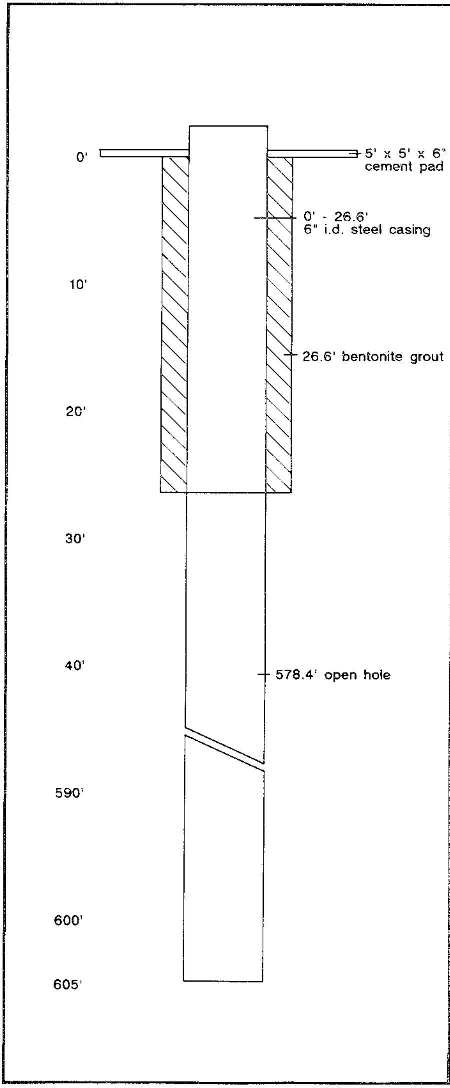


Figure 8. Construction diagram of Production Well 1.

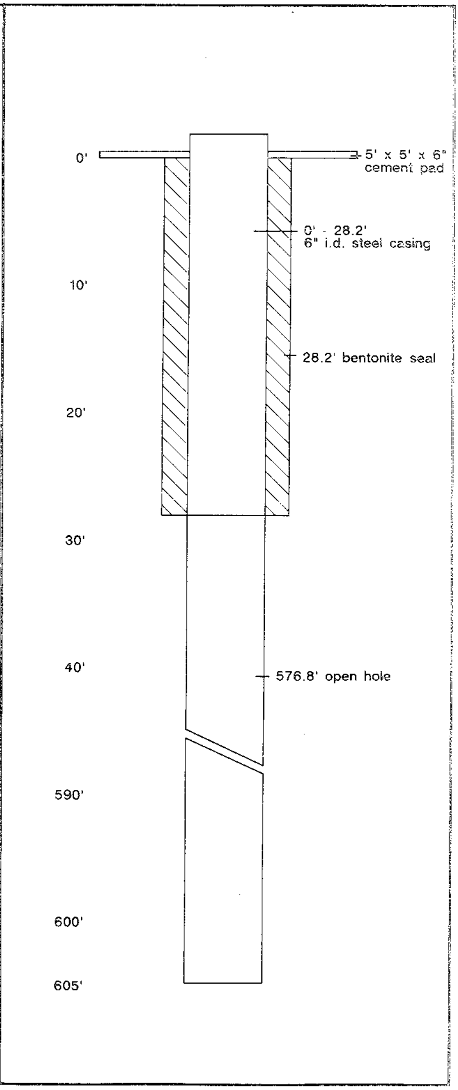


Figure 9. Construction diagram of Production Well 2.

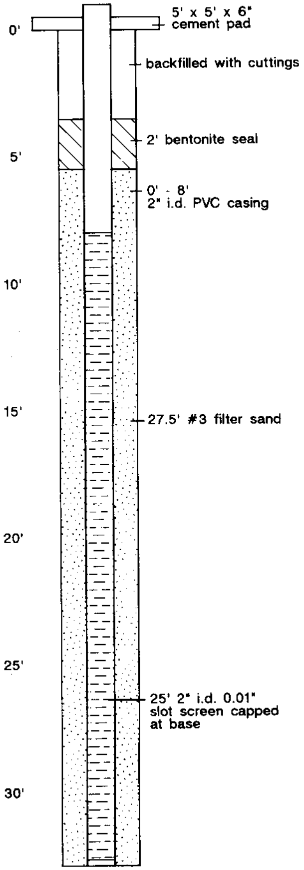


Figure 10. Construction diagram of Soil Well 1.

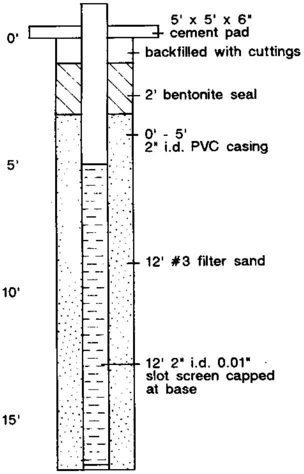


Figure 11. Construction diagram of Soil Well 2.

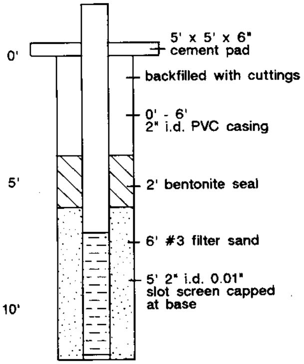


Figure 12. Construction diagram of Soil Well 3.

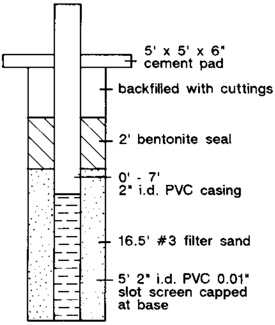


Figure 13. Construction diagram of Soil Well 4.

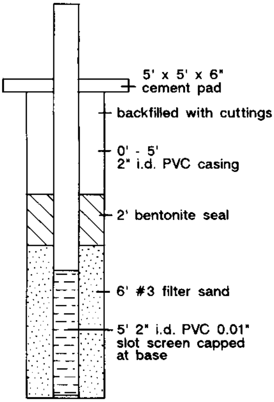


Figure 15. Construction diagram of Soil Well 6.

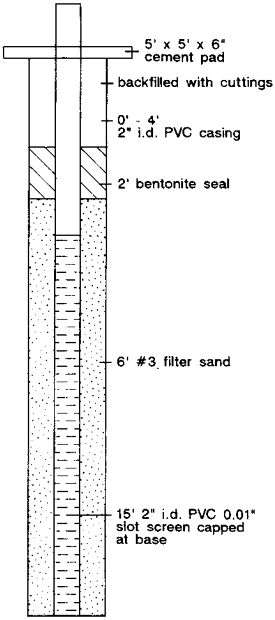


Figure 14. Construction diagram of Soil Well 5.

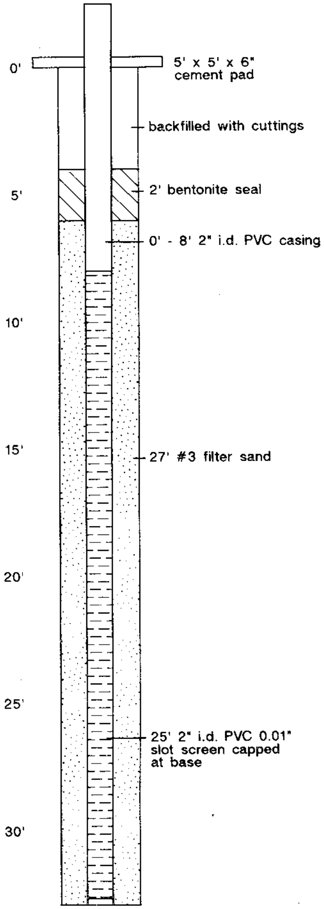


Figure 16. Construction diagram of Soil Well 7.

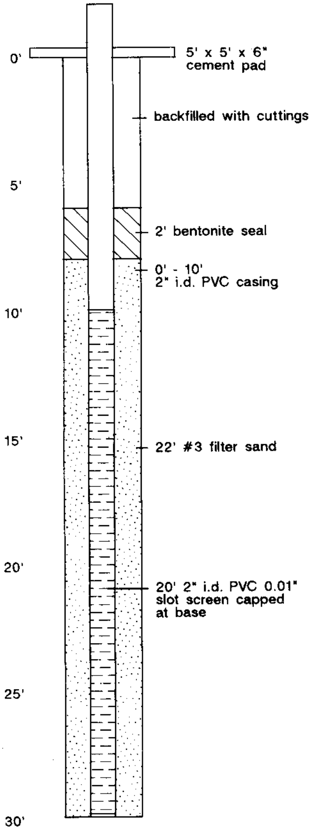


Figure 17. Construction diagram of Soil Well 8.

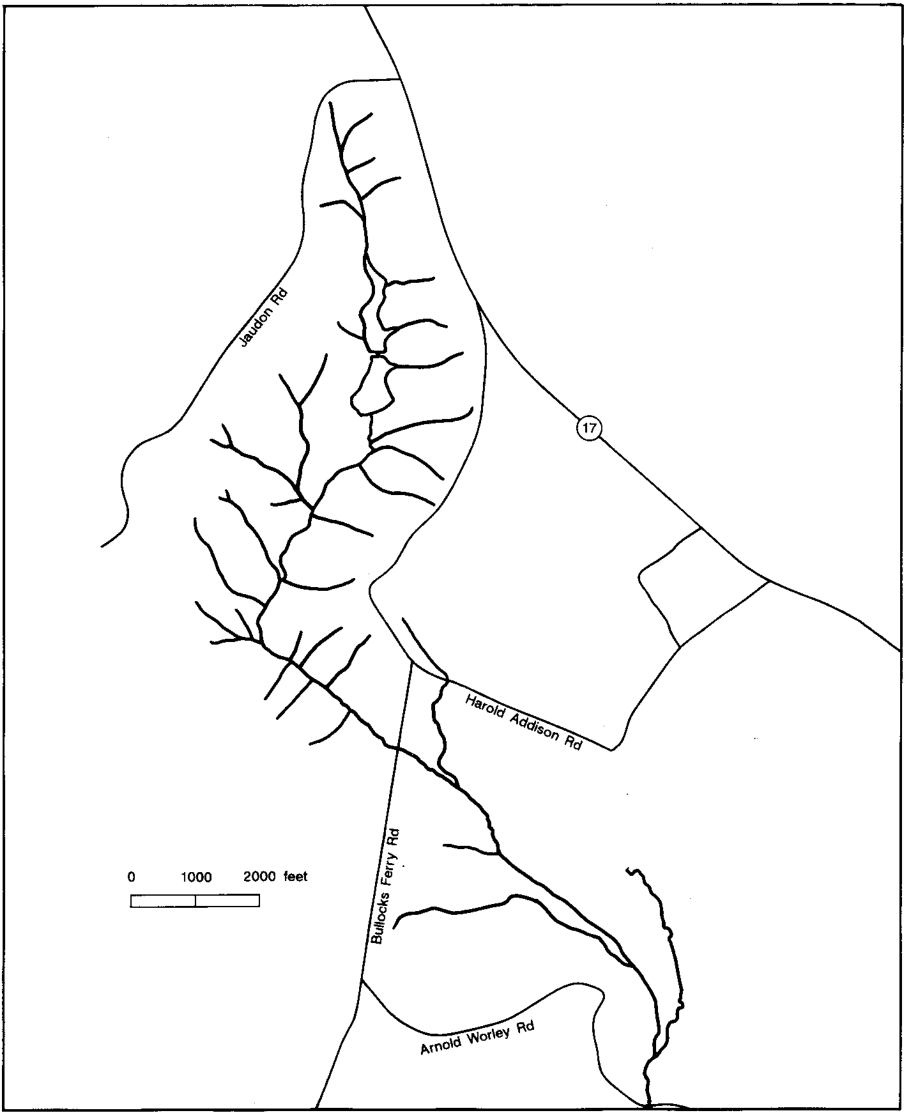


Figure 18. Drainage pattern map of the research site drainage basin.

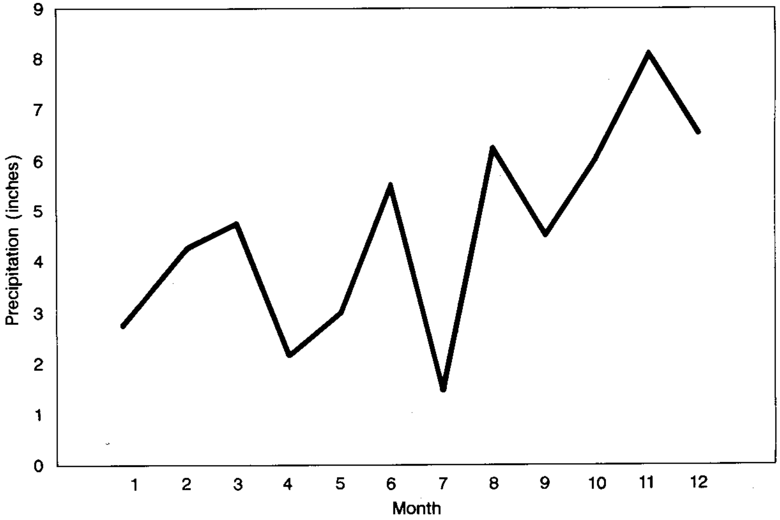


Figure 19a. 1992 monthly precipitation totals in Elberton, Georgia.

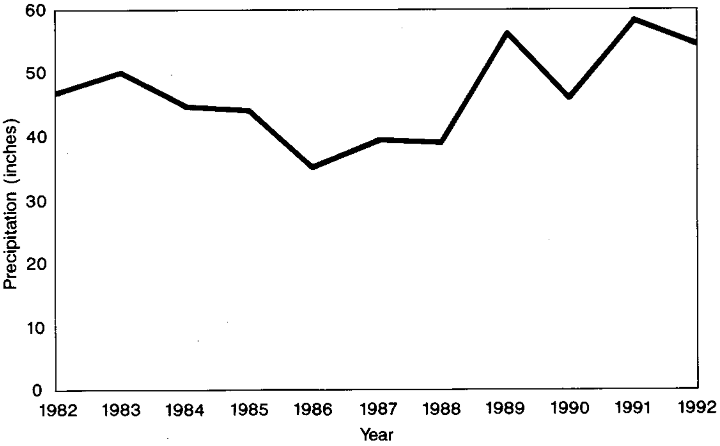


Figure 19b. 1982-1992 annual precipitation totals in Elberton, Georgia.

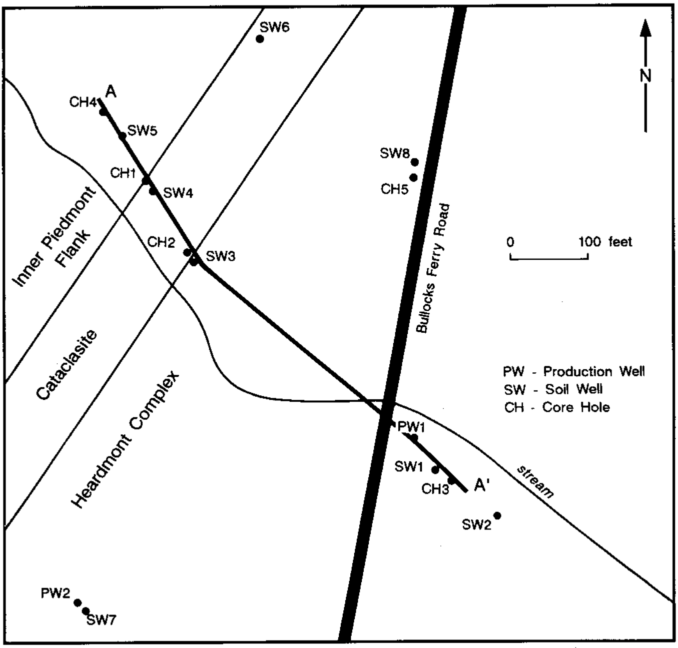


Figure 20. Location of cross-section A-A' through the research site.

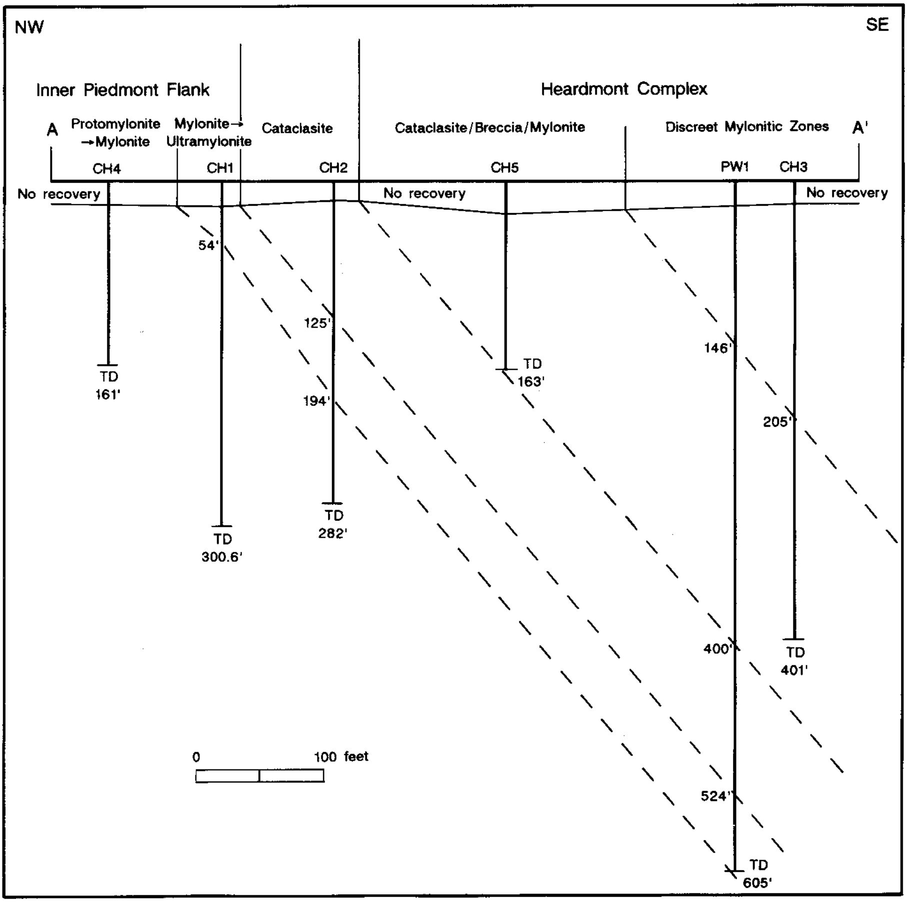


Figure 21. Generalized cross-section of the research site (modified from Sneyd, unpublished).

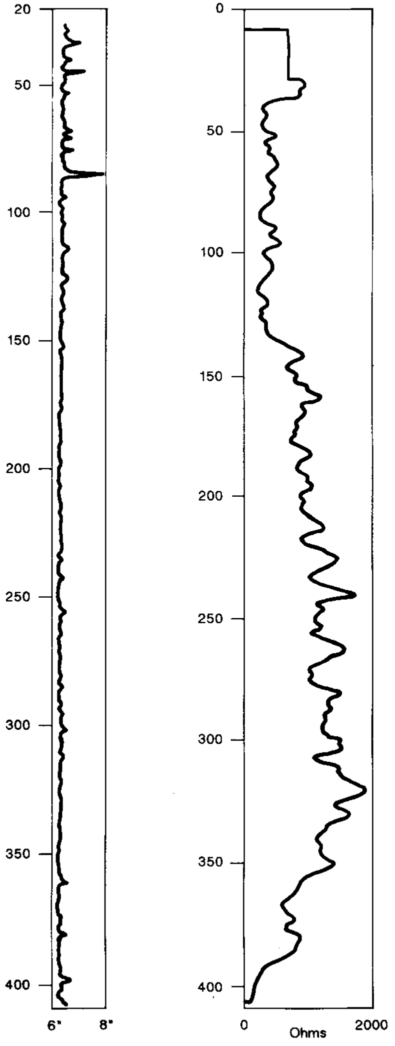


Figure 22. Caliper and resistivity logs for Production Well 1.

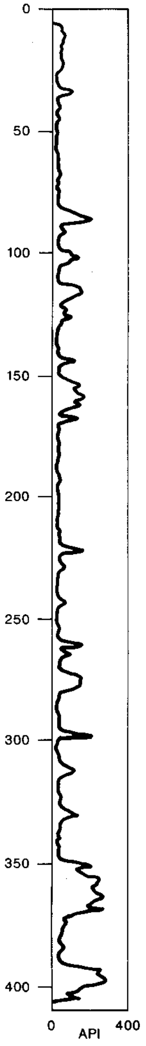


Figure 23. Natural gamma log for Production Well 1.

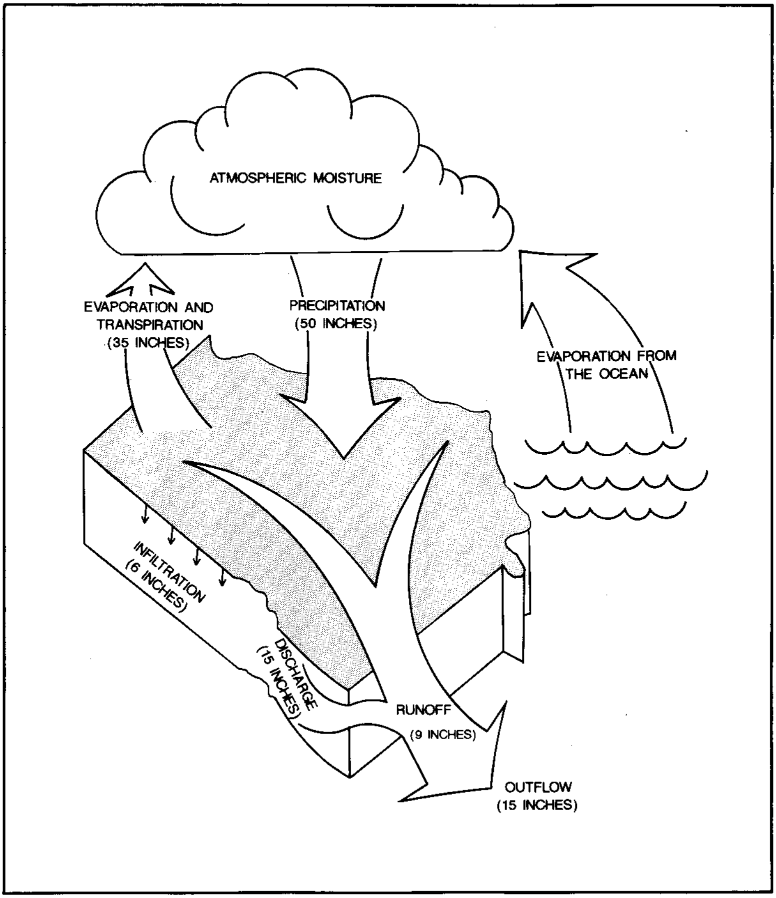


Figure 24. The hydrologic cycle in Georgia (from Carter and Stiles, 1983).

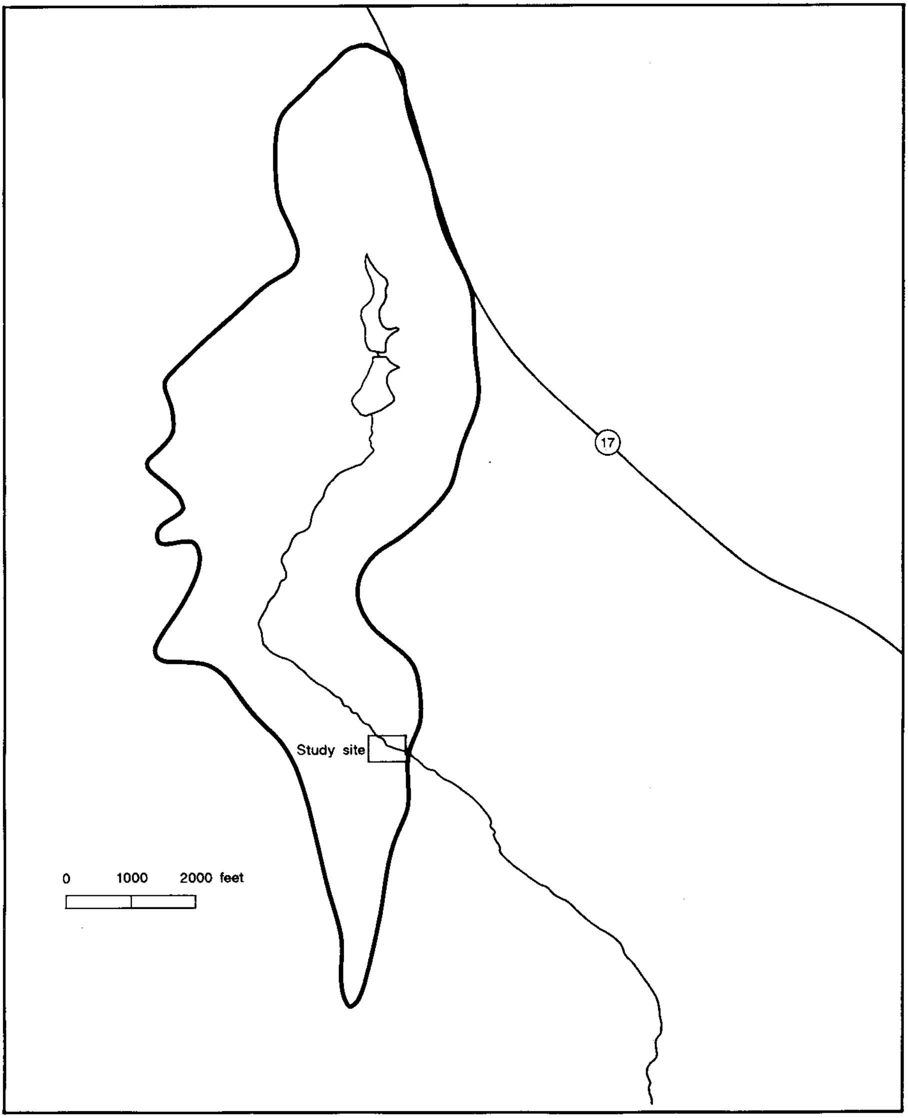


Figure 25. Outline of the drainage basin upstream of the research site.

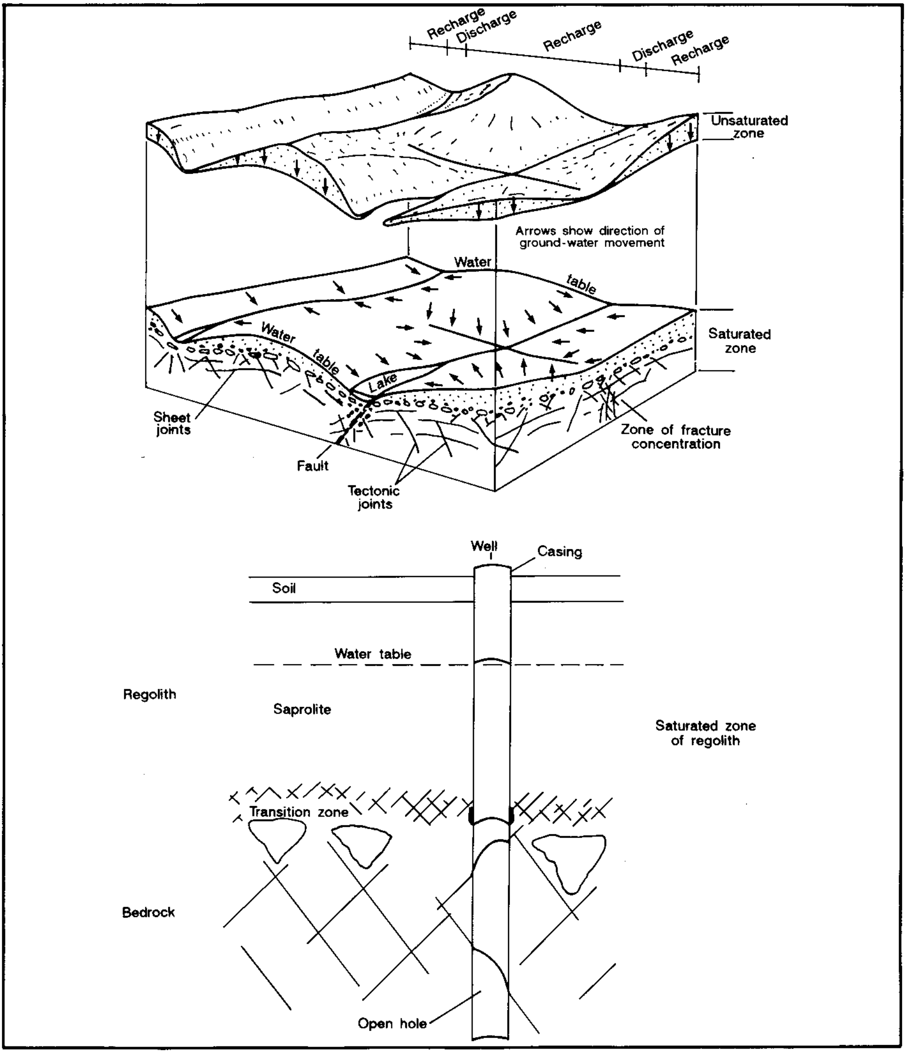
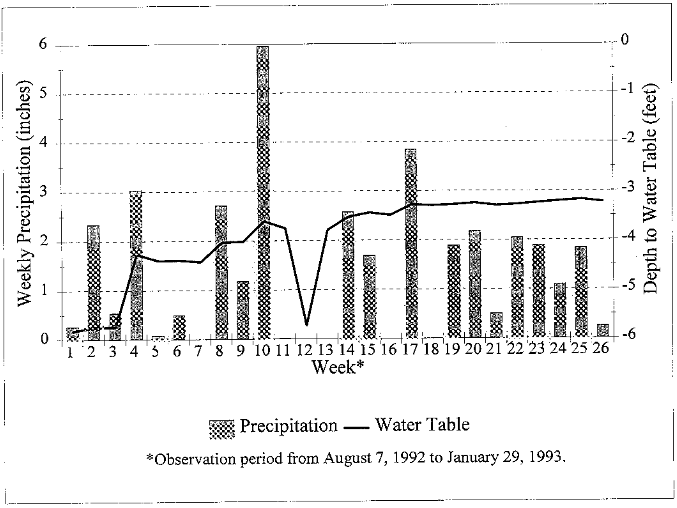
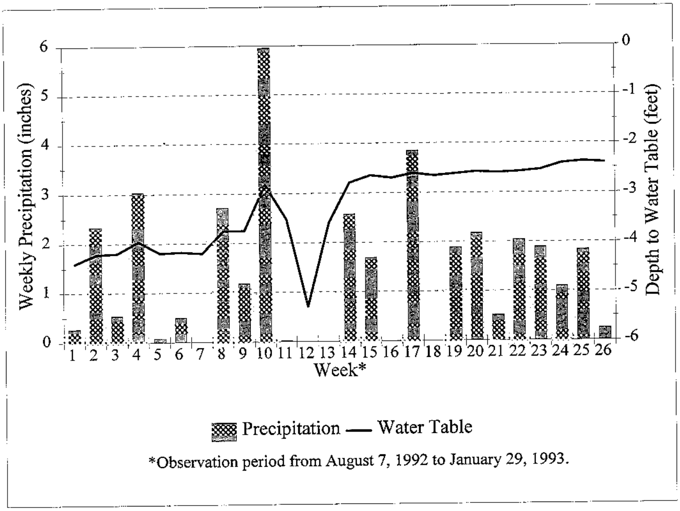


Figure 26. Principal components of the ground-water system in the Piedmont province. 1) Conceptual view of the unsaturated zone, water-table surface, and direction of ground-water flow; and 2) detailed view of the ground-water system showing construction of a typical drilled open-hole well with casing installed to the top of the unweathered bedrock (modified from Daniel, 1990).



*Observation period from August 7, 1992 to January 29, 1993.

Figure 27. Comparison of weekly rainfall totals to Soil Well 1 water levels.



*Observation period from August 7, 1992 to January 29, 1993.

Figure 28. Comparison of weekly rainfall totals to Soil Well 2 water levels.

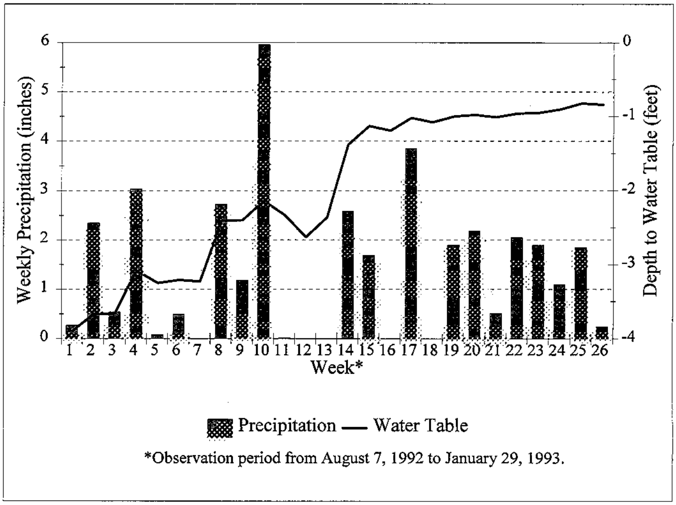


Figure 29. Comparison of weekly rainfall totals to Soil Well 3 water levels.

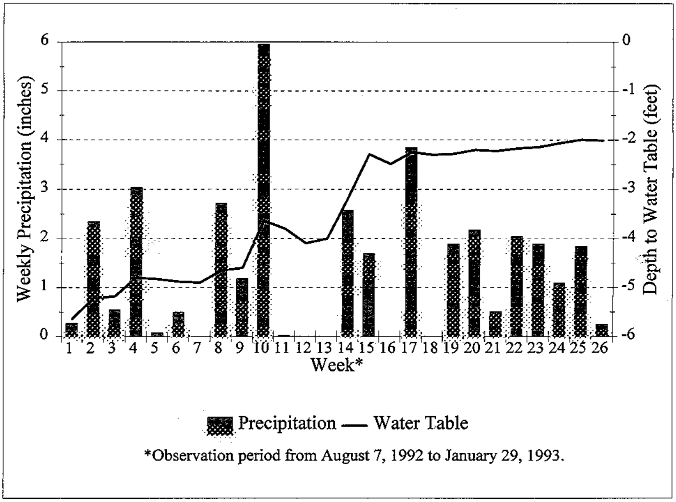
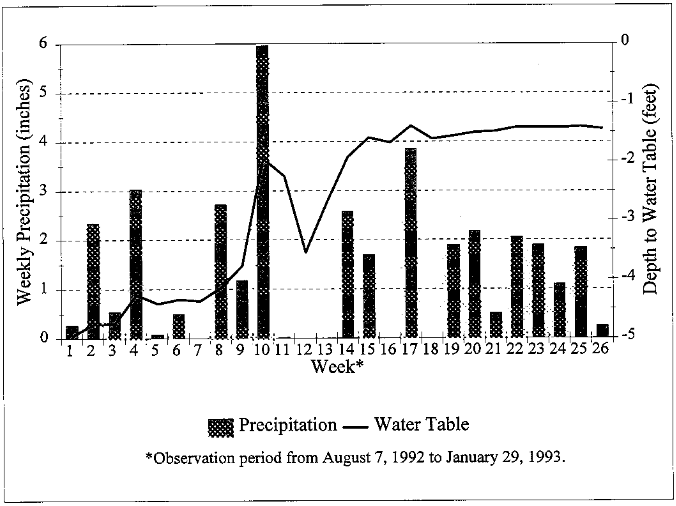
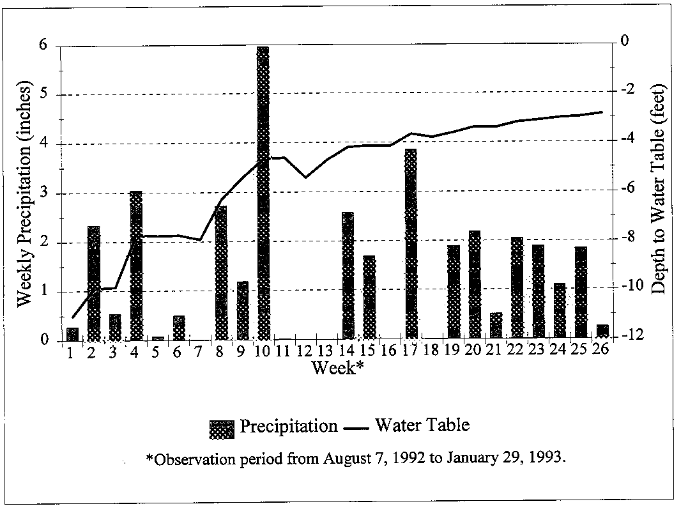


Figure 30. Comparison of weekly rainfall totals to Soil Well 4 water levels.



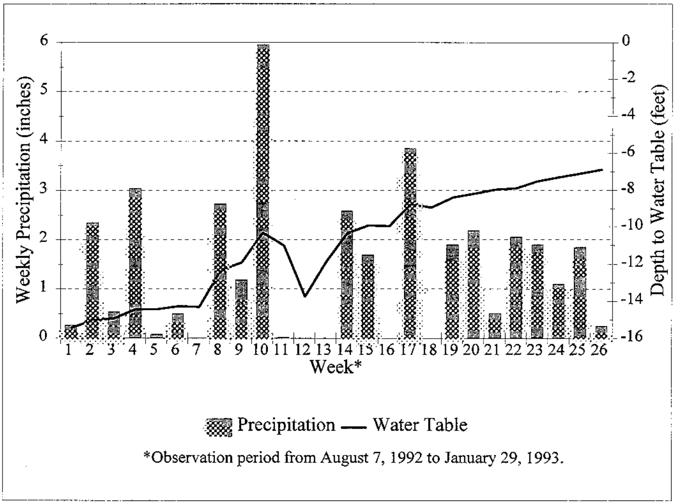
*Observation period from August 7, 1992 to January 29, 1993.

Figure 31. Comparison of weekly rainfall totals to Soil Well 5 water levels.



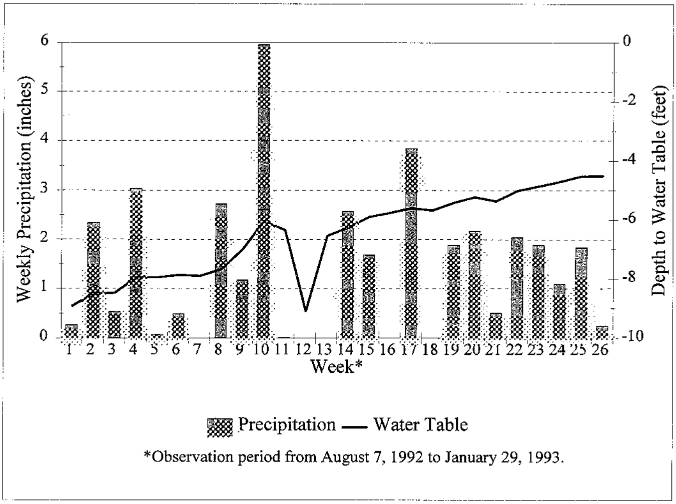
*Observation period from August 7, 1992 to January 29, 1993.

Figure 32. Comparison of weekly rainfall totals to Soil Well 6 water levels.



*Observation period from August 7, 1992 to January 29, 1993.

Figure 33. Comparison of weekly rainfall totals to Soil Well 7 water levels.



*Observation period from August 7, 1992 to January 29, 1993.

Figure 34. Comparison of weekly rainfall totals to Soil Well 8 water levels.

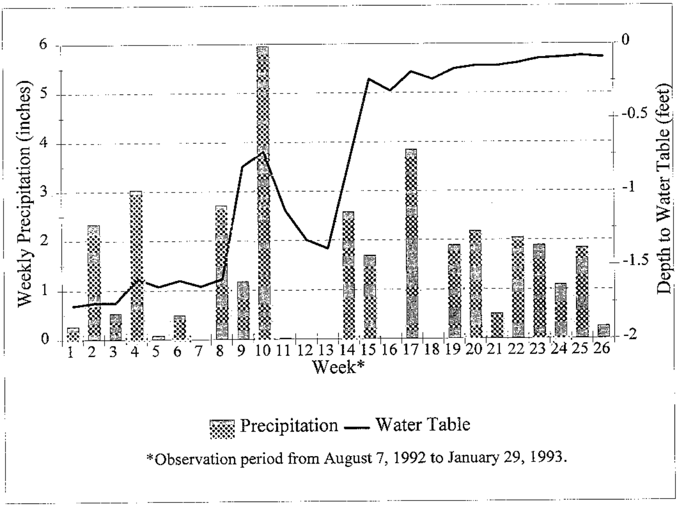


Figure 35. Comparison of weekly rainfall totals to Core Hole 1 water levels.

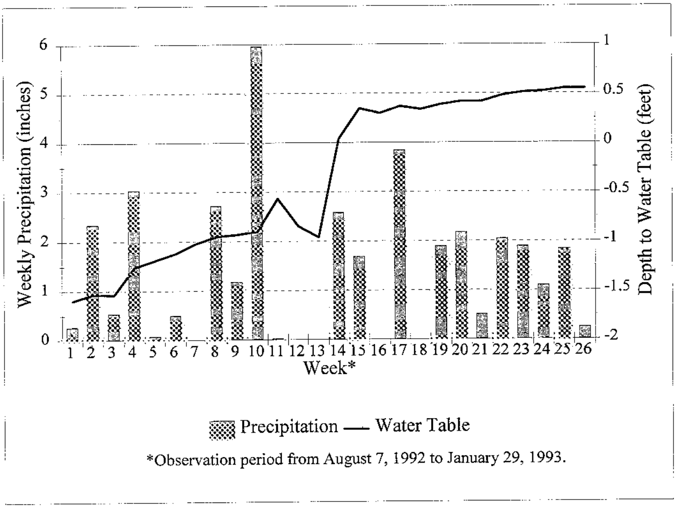


Figure 36. Comparison of weekly rainfall totals to Core Hole 2 water levels.

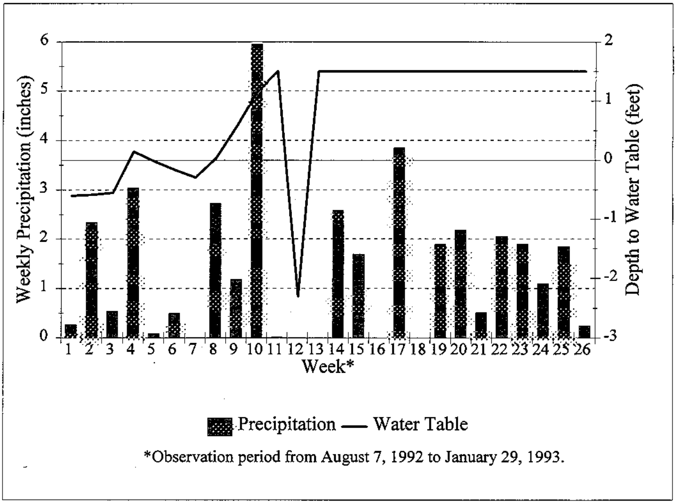


Figure 37. Comparison of weekly rainfall totals to Core Hole 3 water levels.

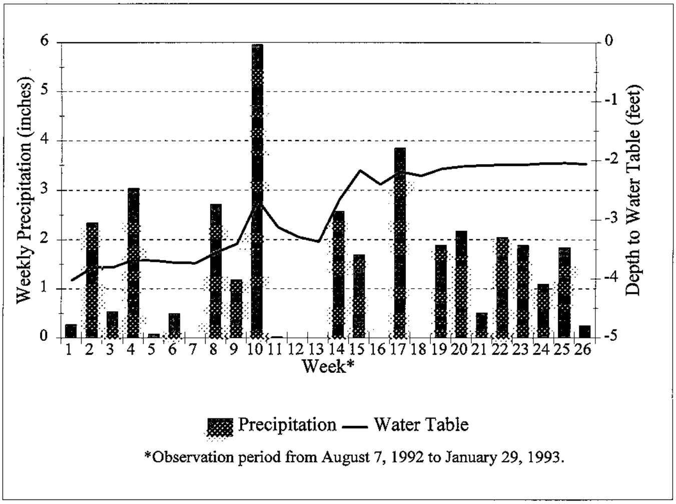
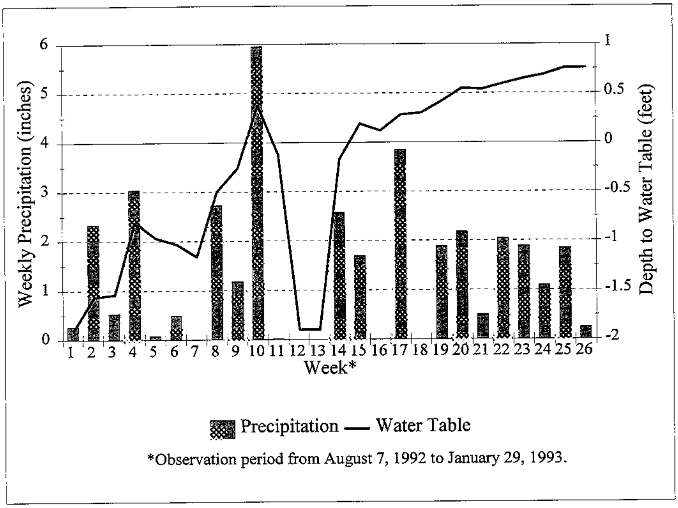
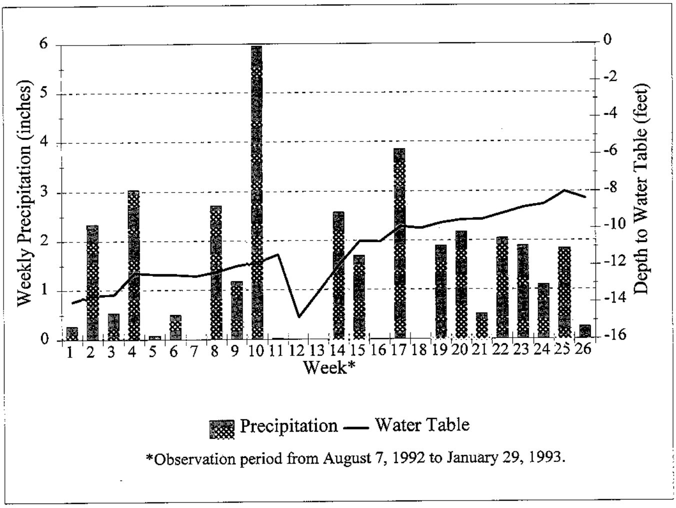


Figure 38. Comparison of weekly rainfall totals to Core Hole 4 water levels.



*Observation period from August 7, 1992 to January 29, 1993.

Figure 39. Comparison of weekly rainfall totals to Production Well 1 water levels.



*Observation period from August 7, 1992 to January 29, 1993.

Figure 40. Comparison of weekly rainfall totals to Production Well 2 water levels.

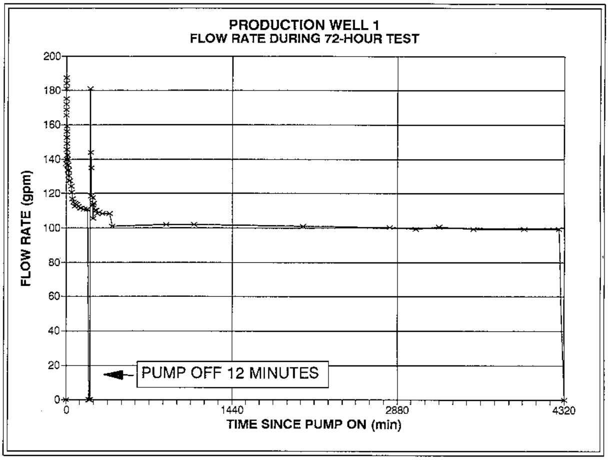


Figure 41. Changes in flow rate during the 72-hour aquifer test.

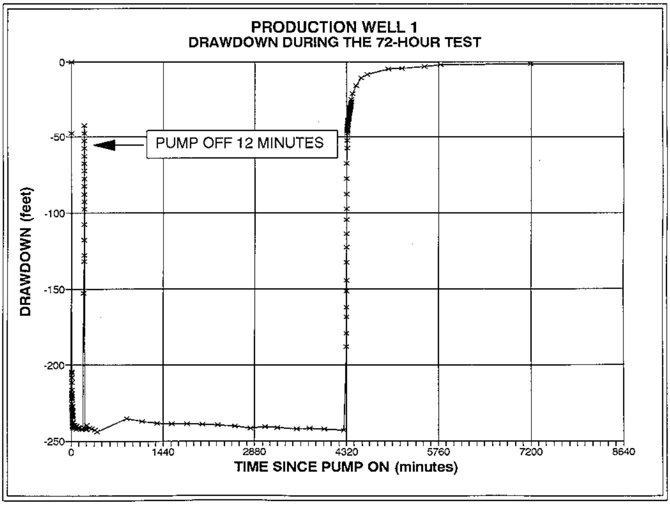


Figure 42. Drawdown and recovery curves for Production Well 1.

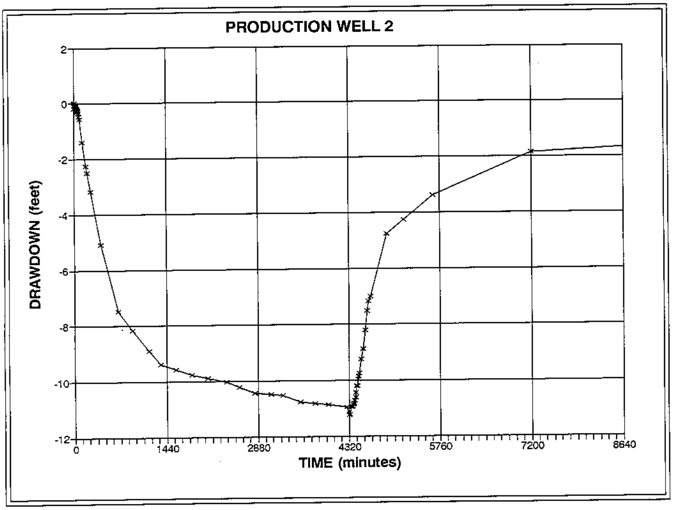


Figure 43. Drawdown and recovery curves for Production Well 2.

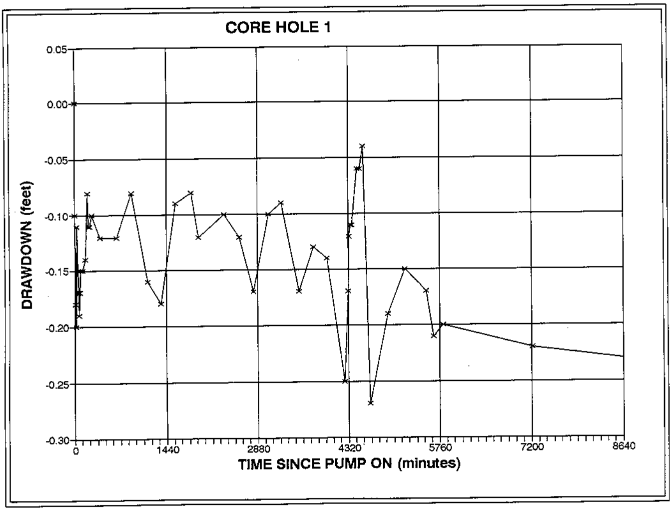


Figure 44. Drawdown and recovery curves for Core Hole 1.

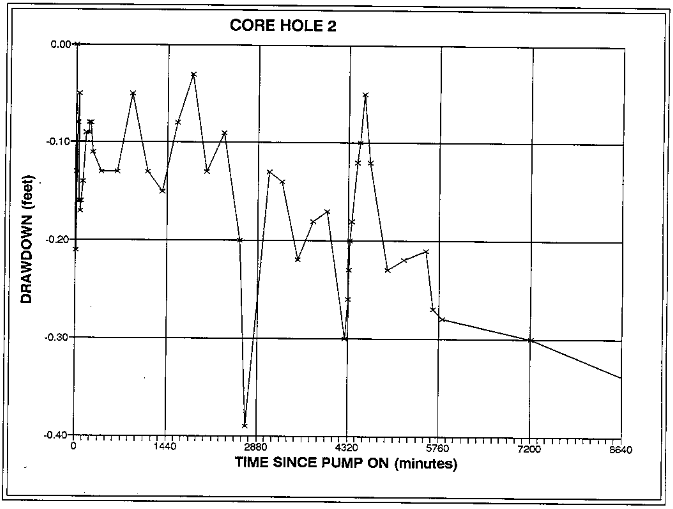


Figure 45. Drawdown and recovery curves for Core Hole 2.

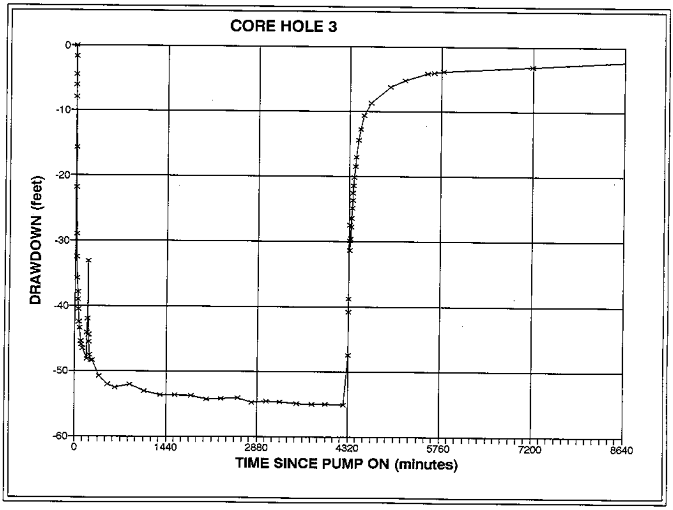


Figure 46. Drawdown and recovery curves for Core Hole 3.

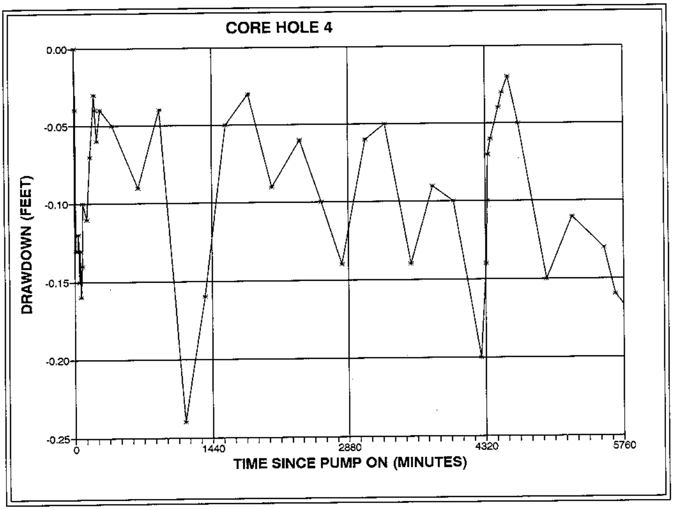


Figure 47. Drawdown and recovery curves for Core Hole 4.

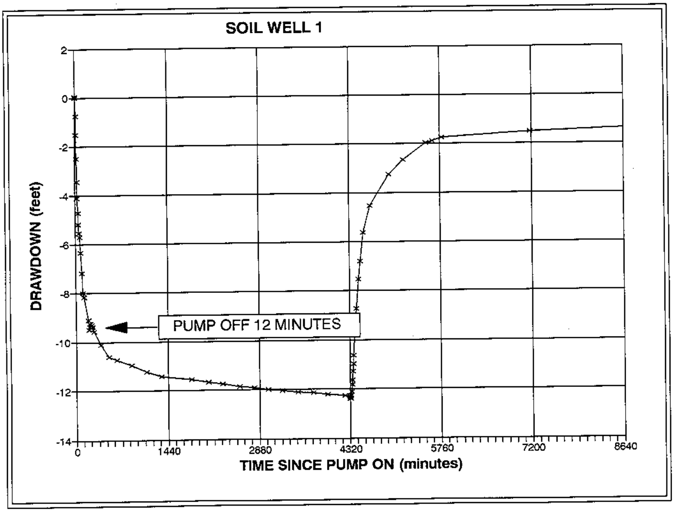


Figure 48. Drawdown and recovery curves for Soil Well 1.

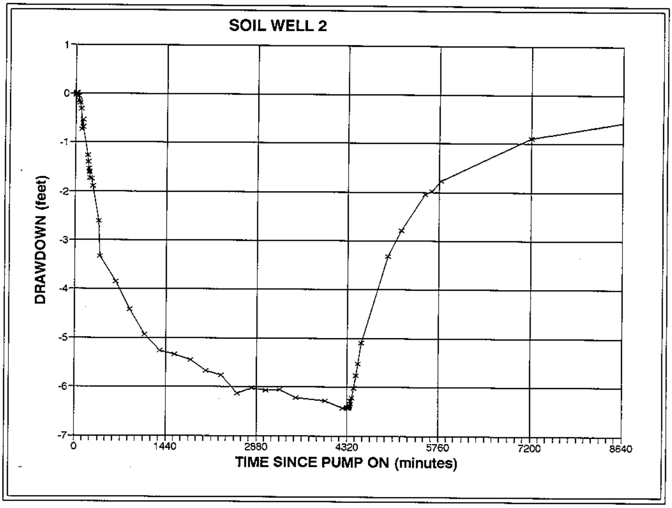


Figure 49. Drawdown and recovery curves for Soil Well 2.

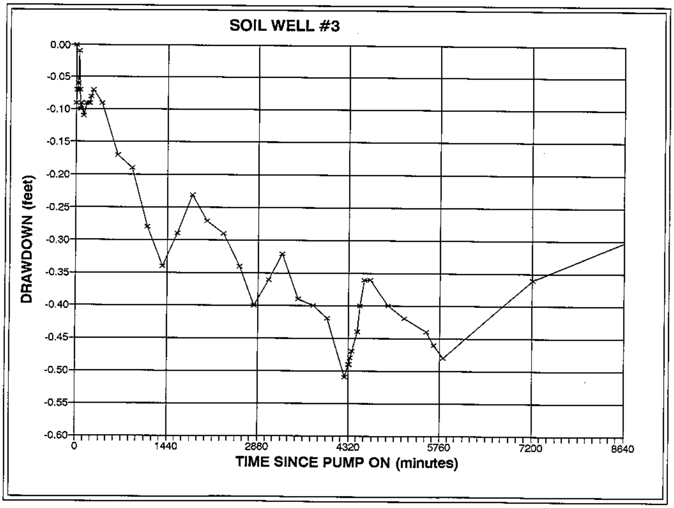


Figure 50. Drawdown and recovery curves for Soil Well 3.

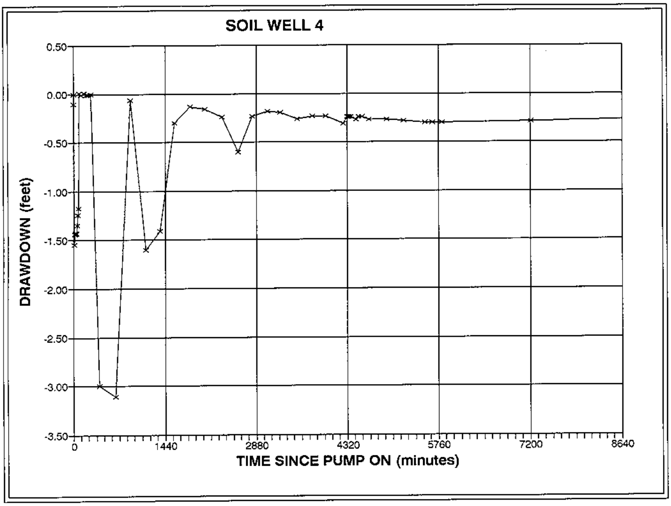


Figure 51. Drawdown and recovery curves for Soil Well 4.

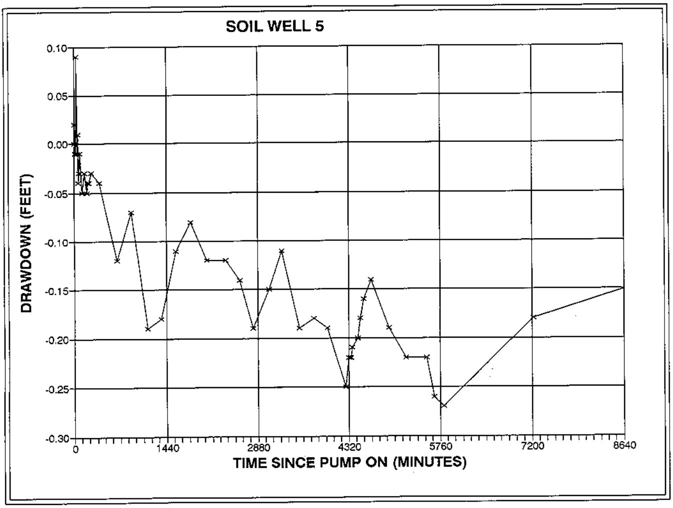


Figure 52. Drawdown and recovery curves for Soil Well 5.

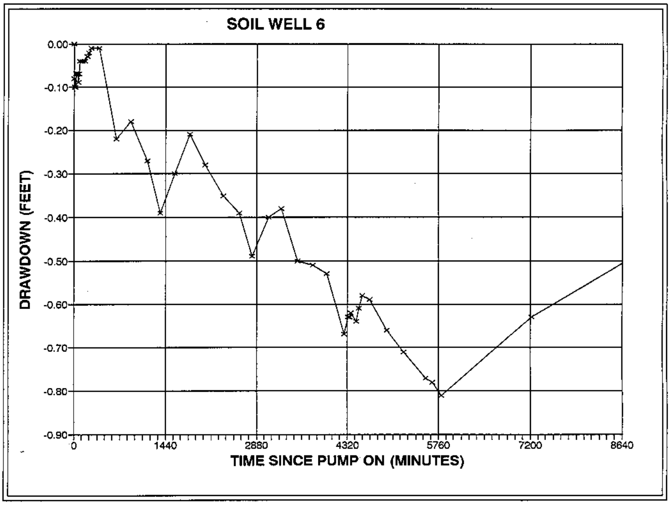


Figure 53. Drawdown and recovery curves for Soil Well 6.

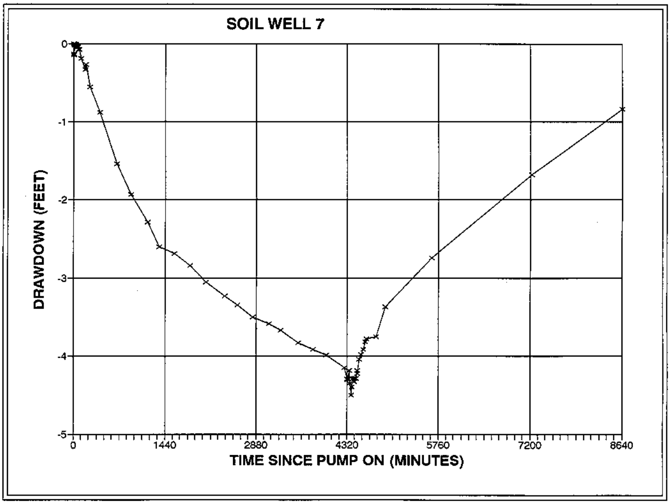


Figure 54. Drawdown and recovery curves for Soil Well 7.

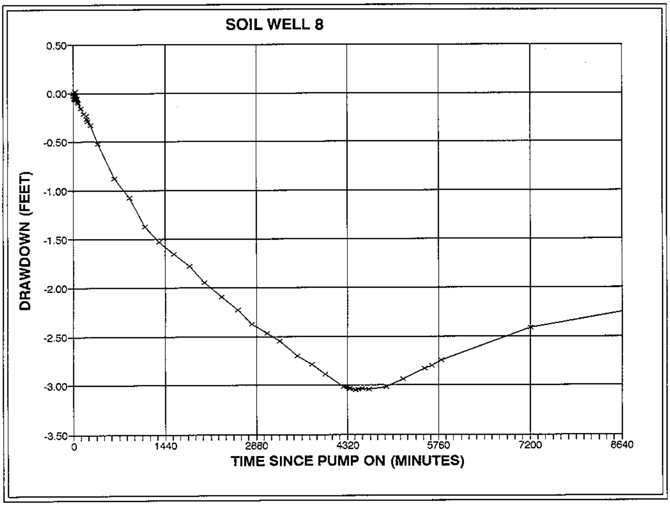


Figure 55. Drawdown and recovery curves for Soil Well 8.

Approximate sample depth	**25'**	**54'**	**140'**	**162'**	**230'**
Quartz	40	15	15	20	10
Biotite	10	25	35	40	40
Chlorite	-	5	2	2	30
Plagioclase	30	10	25	20	15
K-Feldspar	20	50	20	10	5
Hornblende	-	-	-	5	-
Epidote	-	-	3	3	-

Table 1. Modal analyses of megacrystic microcline gneiss samples from Core Hole 1 (visual estimate).

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Editor: Melynda Lewis