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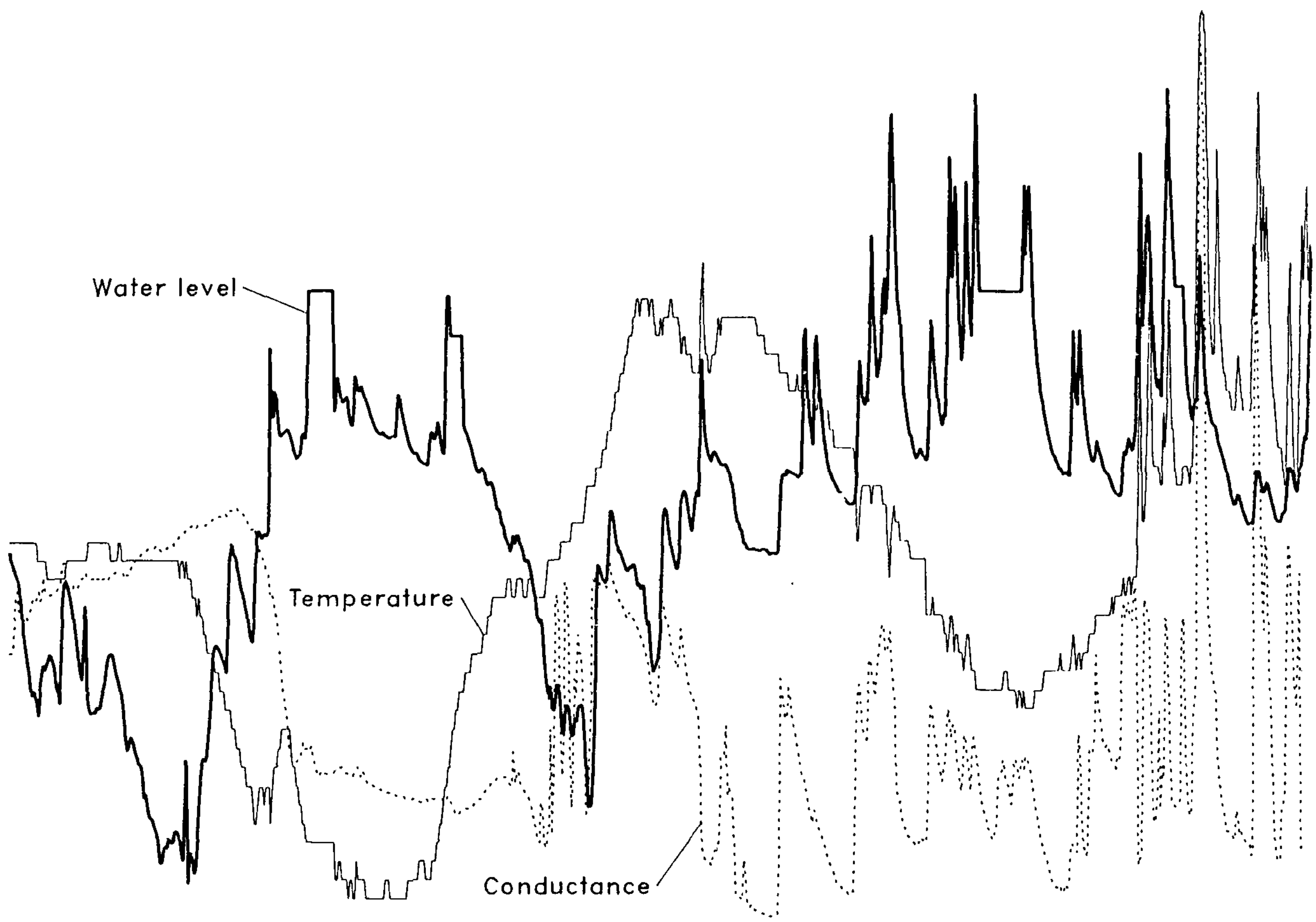
Water-Resources Investigations Report 92-4018

HYDROLOGY OF THE CAVE SPRINGS AREA NEAR CHATTANOOGA, HAMILTON COUNTY, TENNESSEE



Prepared by the

U.S. GEOLOGICAL SURVEY

in cooperation with the

HIXSON UTILITY DISTRICT

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HIXSON UTILITY DISTRICT

Nashville, Tennessee
1992

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	*By*	*To obtain*
foot (ft)	0.3048	meter
square mile (mi^2)	2.590	square kilometer
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
microsiemens per centimeter at 25 °C (µS/cm)	1	micromho per centimeter at 25 °C

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times °C + 32$$

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

HYDROLOGY OF THE CAVE SPRINGS AREA NEAR CHATTANOOGA, HAMILTON COUNTY, TENNESSEE

By Arthur D. Bradfield

ABSTRACT

The hydrology of Cave Springs, the second largest spring in East Tennessee, was investigated from July 1987 to September 1989. Wells near the spring supply about 5 million gallons per day of potable water to people in Hamilton County near Chattanooga. Discharge from the spring averaged about 13.5 cubic feet per second (8.72 million gallons per day) during the study period. Withdrawals by the Hixson Utility District from wells upgradient from the outflow averaged 8.6 cubic feet per second (5.54 million gallons per day). Aquifer tests using wells intersecting a large solution cavity supplying water to the spring showed a drawdown of less than 3 feet with a discharge of 9,000 gallons per minute or 20 cubic feet per second.

Temperature and specific conductance of ground water near the spring outflow were monitored hourly. Temperatures ranged from 13.5 to 18.2 degrees Celsius, and fluctuated seasonally in response to climate. Specific-conductance values ranged from 122 to 405 microsiemens per centimeter at 25 degrees Celsius, but were generally between 163 to 185 microsiemens per centimeter.

The drainage area of the basin recharging the spring system was estimated to be 10 square miles. A potentiometric map of the recharge basin was developed from water levels measured at domestic and test wells in August 1989. Aquifer tests at five test wells in the study area indicated that specific-capacity values for these wells ranged from 4.1 to 261 gallons per minute per foot of drawdown. Water-quality characteristics of ground water in the area were used in conjunction with potentiometric-surface maps to delineate the approximate area contributing recharge to Cave Springs.

INTRODUCTION

Cave Springs, located in Hamilton County north of Chattanooga (fig. 1) is the second largest spring in East Tennessee. The spring was a well-known source of water for local residents during periods of drought before public water supplies were established in the area. Cave Springs was also a stopping point for steam engines and passenger trains before land and water rights to the spring were acquired by the Hixson Utility District (HUD) in 1952. Wells that penetrate a submerged cave near the overflow for Cave Springs are now the sole source of water for the HUD, the third largest ground-water-based utility in Tennessee (Hutson, 1989). Although wells near Cave Springs have been a reliable source of water for the HUD, decreased springflow during periods of drought raised concerns about meeting increased demands for water.

To address these concerns, the U.S. Geological Survey (USGS), in cooperation with the HUD, conducted a hydrologic investigation of the Cave Springs system from July 1987 to September 1989. The study area included about 70 mi^2 north of Chattanooga in southeastern Tennessee (fig. 1). Objectives of the investigation were (1) to obtain additional hydrologic data from this part of the Valley and Ridge province, (2) to identify the area providing recharge to Cave Springs, and (3) to determine the characteristics of ground water in the study area.

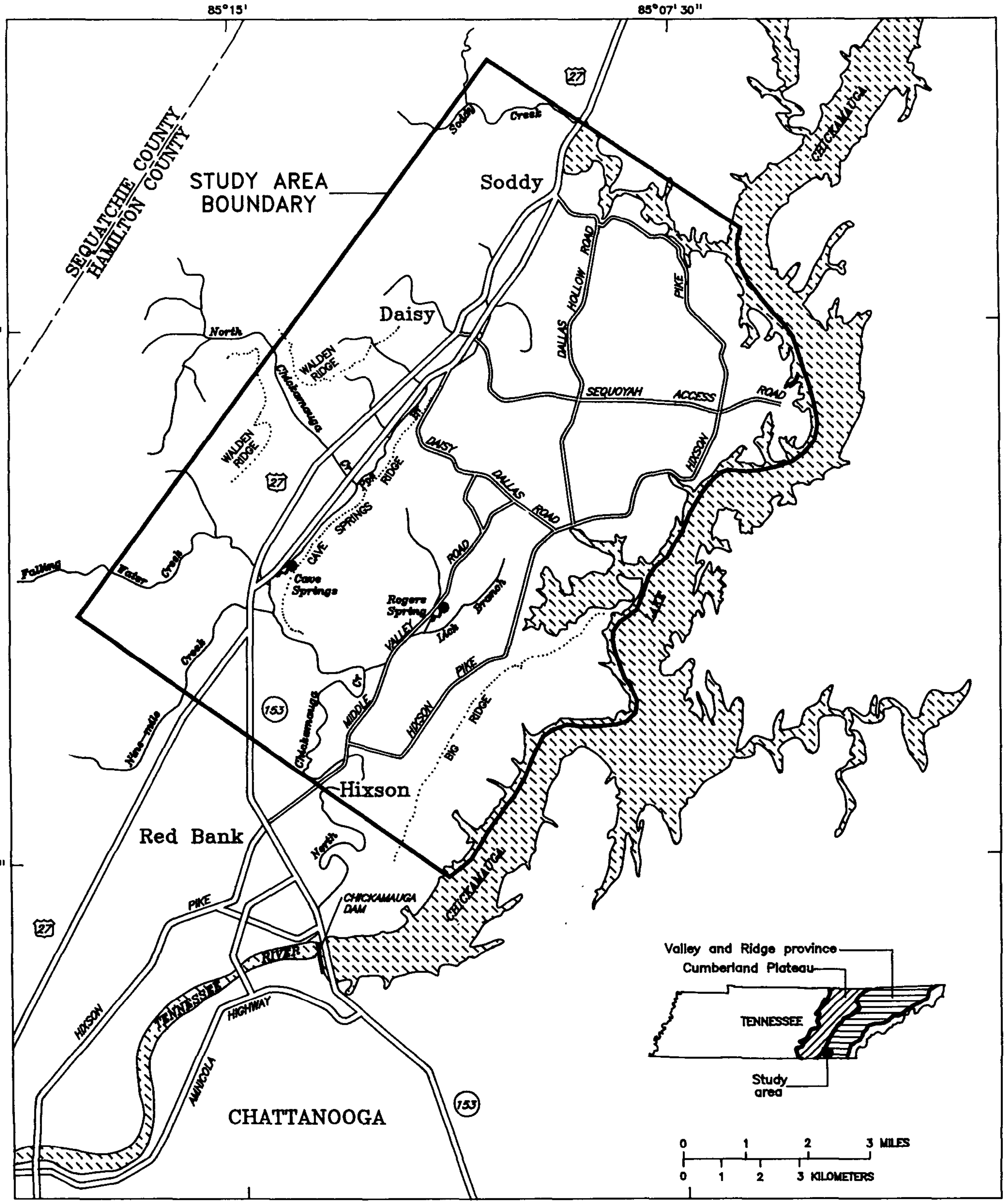


Figure 1.--Physiographic and cultural features in the Cave Springs area near Chattanooga, Tennessee.

Purpose and Scope

This report presents the results of the hydrologic investigation of the Cave Springs ground-water system. Topics discussed include:

- the geology of the study area,
- the properties of wells,
- the pumpage and spring discharge,
- the potentiometric surface of the area recharging Cave Springs, and
- the water quality in the vicinity of Cave Springs.

During this investigation, discharge from the spring outflow was determined from a relation between ground-water levels in a well near the spring and discharge measurements made at the spring approximately every 6 weeks. The water-level and discharge data were used to develop a rating curve, which was applied for the period of record (July 1987 to September 1989). The amount of water pumped from a large solution opening upgradient from the spring outflow was determined from records obtained from the HUD. Specific conductance and temperature of the water also were monitored during the investigation.

The hydrogeology of the basin was defined from data collected during previous studies and from new data collected from 19 test wells drilled during this investigation. Aquifer tests were conducted at wells near Cave Springs and at other selected wells in the basin. Water levels were measured several times at the test wells and other domestic wells throughout the basin. Water samples from the spring outflow and from selected wells and streams in the basin were collected for determination of chemical and physical properties and constituents.

A seepage investigation was conducted throughout the basin. Stream-discharge measurements were made at 84 sites to identify gaining or losing reaches of streams as indicators of ground-water discharge or recharge. Seepage and ground-water-level data were used to develop a map of the potentiometric surface in the study area.

Description of the Study Area

Cave Springs and the recharge area are located in the rolling terrain of the Valley and Ridge physiographic province of southeastern Tennessee (Miller, 1974) (fig. 1), which consists of alternating parallel ridges and valleys that trend northeast. Land surface elevations in the study area range from approximately 660 feet above sea level near the spring overflow to more than 900 feet along Cave Springs Ridge. The study area is bounded on the north and east by Chickamauga Lake, an impoundment of the Tennessee River, and to the west by Walden Ridge, a part of the Cumberland Plateau (fig. 1). The Cumberland Plateau in Tennessee is deeply dissected with maximum land surface elevations more than 1,000 feet above the adjoining ridges and valleys in the study area. Major streams in the study area include the Tennessee River and the North Chickamauga Creek. Minor streams include Poe Branch and Lick Branch. Land use in the area is primarily residential.

Climate

The climate of the study area is temperate, with a mean annual temperature of 59.5 °F (National Oceanic and Atmospheric Administration, 1988). The Chattanooga area normally receives approximately 52 to 53 inches of precipitation annually.

During the study period, climatic conditions were affected by an extreme drought ending in late 1988 as well as a period of above normal rainfall in 1989. Annual precipitation in the Chattanooga area was about 6 to 13 inches below normal for calendar years 1985 through 1988 (table 1). During the 1988 water year (October 1, 1987 to September 30, 1988) precipitation in the area was below normal, and discharges of surface streams also were below normal. Mean annual discharge for water years 1985 through 1989 and departures from normal for Wolftever Creek are presented in table 1. The gage on Wolftever Creek is located about 10 miles southeast of the study area. Wolftever Creek is the nearest stream to the study area in the Valley and Ridge province for which continuous discharge data are available.

Precipitation for 1989 was well above normal. Approximately 20 inches of rain were recorded at the Chattanooga airport from June through July 1989 (National Oceanic and Atmospheric Administration, 1989). Total rainfall for 1989 was 71.6 inches; 19.0 inches above normal, making 1989 the second wettest year on record since 1879 (Ralph Koepsel, National Weather Service, oral commun., 1990).

HYDROGEOLOGY

The hydrogeology of the study area is complex. Limestones and dolomites are the principal rocks in the area. Sinkholes, secondary-permeability solution channels in limestone, and thick regolith occur throughout the area. A major thrust fault is located along Cave Springs Ridge. Cave Springs issues from the Newman Limestone exposed along the thrust fault. The spring is the main source of water to the HUD, serving about 45,000 people in northeastern Chattanooga. Aquifer tests indicate extremes of transmissivity, with yields to wells ranging from 200 to 1,800 gal/min. The Tennessee River and North Chickamauga Creek are the main surface drains in the study area.

Geology

Most of the study area is underlain by folded limestones and dolomites of Cambrian and Ordovician age (Miller, 1974). Formations exposed at land surface in the study area, listed from oldest to youngest, include the Copper Ridge Dolomite, the Chepultepec, Longview, and Newala Formations, the Chickamauga Limestone, and the Newman Limestone (stratigraphic nomenclature is that used by the Tennessee Department of Conservation, 1964). Rocks exposed along the western boundary of the study area include Mississippian and Pennsylvanian shales and sandstones of the Cumberland Plateau (fig. 2a).

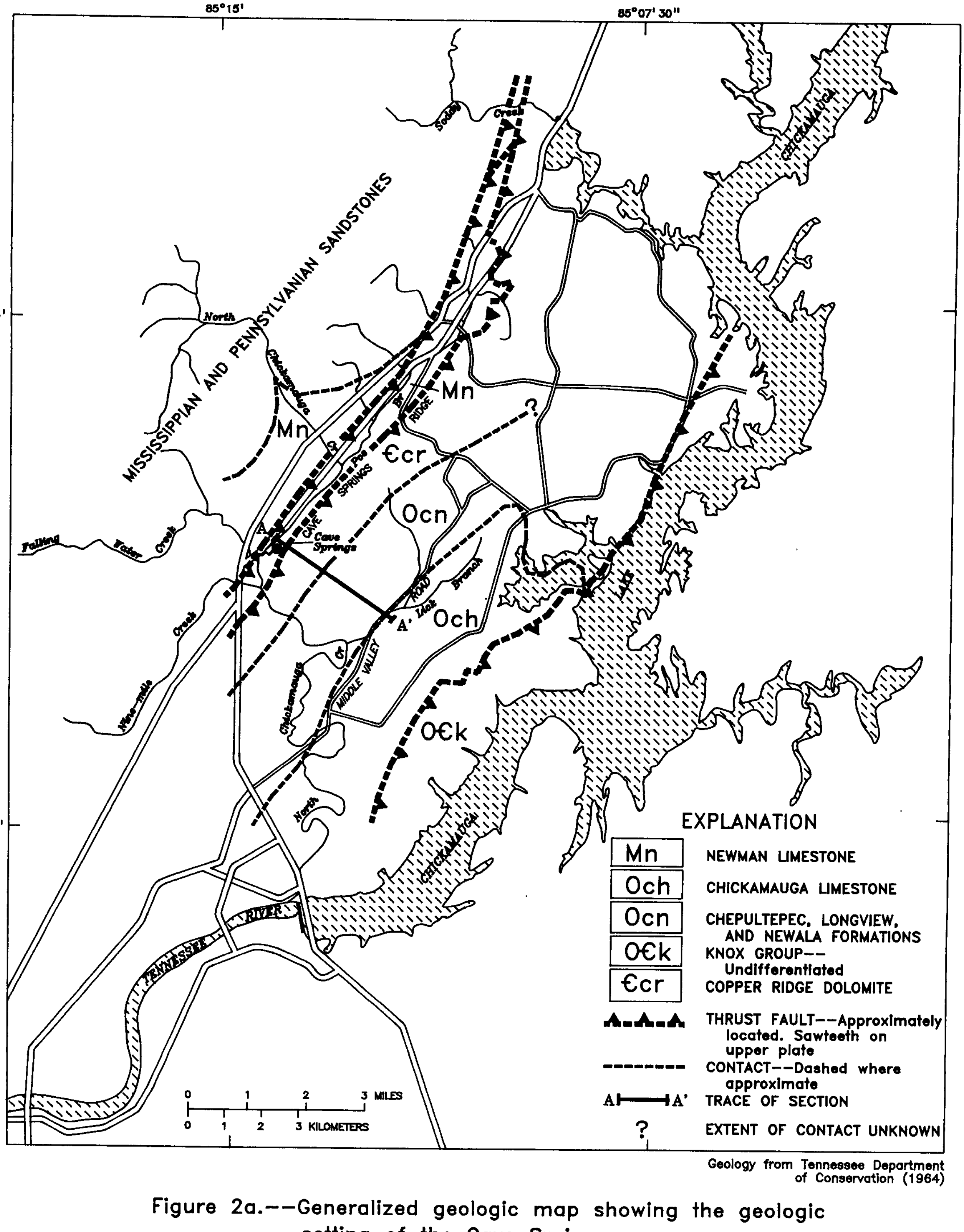
Low angle thrust faults exist in the study area. A major thrust fault trending northeast caused the older Cambrian Copper Ridge Dolomite to overlie the younger Mississippian Newman Limestone

Table 1.--*Hydrologic data for Wolftever Creek near Ooltewah, Tennessee*

Water year	Mean annual discharge (and departure from normal*), in cubic feet per second	Runoff, in inches	Runoff, in cubic feet per second per square mile	Rainfall at Chattanooga airport (and departure from normal**), in inches
1985	21.2 (-10.5 from normal)*	15.28	1.13	39.55 (-13.05 from normal)**
1986	11.1 (-20.6)	8.03	.59	42.49 (- 10.11)
1987	30.3 (- 1.4)	21.85	1.61	46.55 (- 6.05)
1988	12.6 (-19.1)	9.09	.67	43.89 (- 8.71)
1989	41.0 (+ 9.3)	29.61	2.18	71.60 (+19.00)

* Long-term normal for Wolftever Creek computed for period of record from 1964-1989.

** Long-term normal rainfall is computed for calendar years 1951-80. Rainfall data are for calendar years.



Geology from Tennessee Department of Conservation (1964)

Figure 2a.--Generalized geologic map showing the geologic setting of the Cave Springs area.

along the thrust fault (fig. 2b). Formations dip toward the southeast at approximately 20 degrees. Numerous sinkholes occur in the study area, primarily in the Copper Ridge Dolomite and the Chepultepec, Longview, and Newala Formations.

Cave Springs issues from the Newman Limestone beneath the footwall of the thrust fault separating the Newman Limestone from the overlying Copper Ridge Dolomite. These two units, along with the Chepultepec, Longview, and Newala Formations, constitute the geologic framework for the Cave Springs drainage system.

The Copper Ridge Dolomite is comprised of siliceous dolomite, light to dark gray in color, that weathers to a dark colored chert. The Chepultepec, Longview, and Newala Formations are dolomite with interbedded limestones. Records of wells drilled in the Copper Ridge Dolomite on Cave Springs Ridge (east of the thrust fault that separates the Newman Limestone and the Copper Ridge Dolomite, figs. 1 and 2) indicate the presence of a layer of chert and clay regolith as much as 298 feet thick (table 2). The thick regolith provides a large water-storage capacity and provides a path for the infiltration of rainfall to the aquifer.

The thick mantle of chert and clay regolith in the area is typical of weathered Copper Ridge Dolomite and Chepultepec, Longview, and Newala Formations. Mean regolith thickness for 19 wells drilled in the study area (fig. 3) was 124 feet. Thickness ranged from 16 feet at well 5 (drilled in the dolomite of the Chepultepec Formation) at the southern extreme of the study area to 298 feet at well 7 on the east face of Cave Springs Ridge (table 2).

The Newman Limestone is a light- to medium-gray limestone that is oolitic in parts; thickness of this limestone is estimated to be about 700 feet. This formation is covered with a mantle of sandstone, gravel, and boulders that have been eroded from the Cumberland Plateau, particularly in the flood plain of North Chickamauga Creek.

Hydrologic Conditions and Results of Aquifer Tests

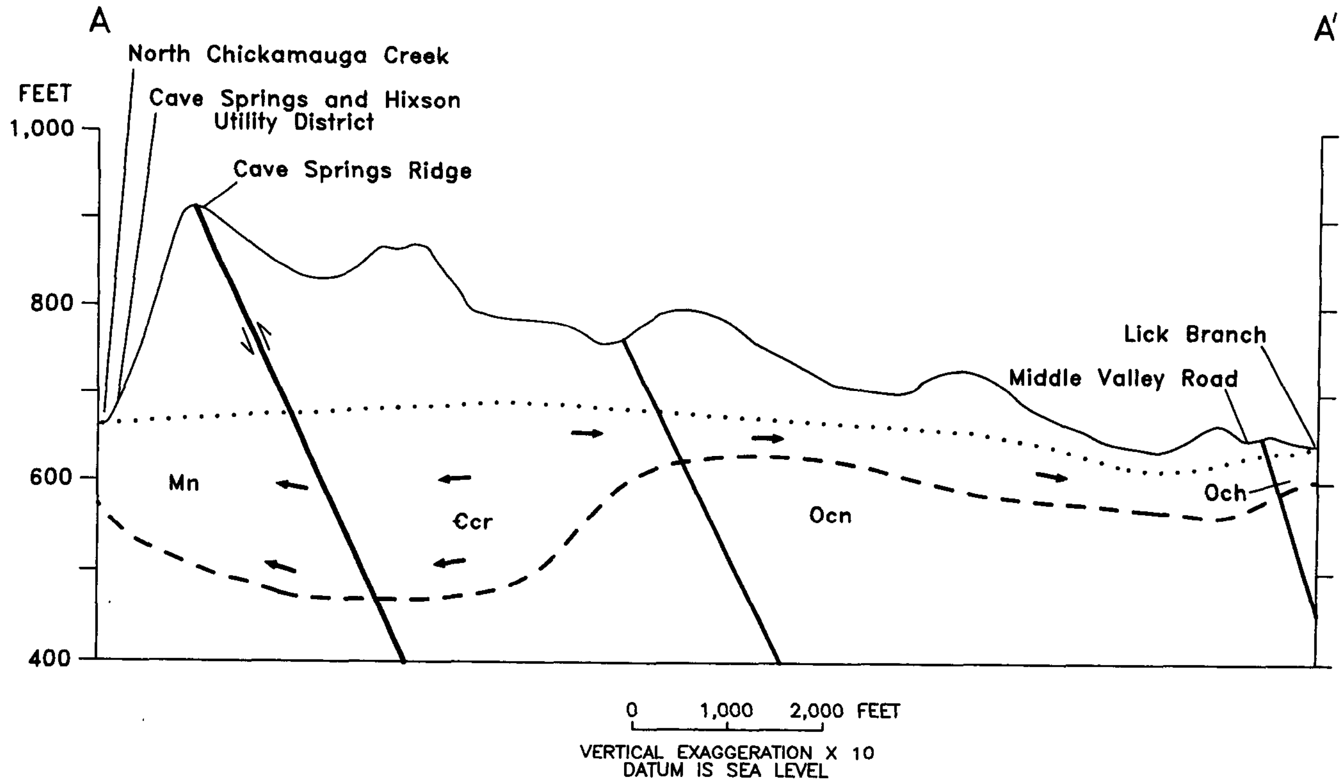
Test Wells in the Study Area

Data collected during a stream seepage investigation were used to identify areas with the greatest potential for yielding substantial amounts of ground water. In the seepage study, streamflow measurements were made at 84 sites throughout the basin to identify stream reaches gaining water from or losing water to the ground-water system. This information was used to select the sites for the location of test wells (wells 5 through 23) drilled by the HUD in the Cave Springs study area (fig. 3). The test wells (6-inch-diameter wells) were used to determine water-bearing zones and for collecting water-level and water-quality data. Data for 21 test wells and 2 existing wells at Cave Springs are given in table 2.

Total depth below land surface of wells drilled in the study area (excluding wells 1 through 4 at Cave Springs) ranged from 101 to 342 feet (table 2) and averaged 229 feet. The thickness of consolidated rock penetrated by the wells ranged from 0 in wells 7, 8, and 15 to 257 feet in well 18 drilled in limestone near the Tennessee River at the extreme eastern edge of the study area.

Well yields in the study area seem to be more dependent on geology and the location of solution openings than on surface drainage features. Estimated yields were variable, ranging from less than 1 to several hundred gallons per minute. Most wells tested had sustainable yields of less than 100 gal/min. Wells yielding greater than 100 gal/min were usually located in areas with dry streams, but at several sites with no surface flow, relatively low yields were obtained. Wells 3, 4, and 20, drilled near the thrust fault and downstream from gaining reaches of streams with above average flow per square mile of drainage area, had high yields.

Step-drawdown aquifer tests were conducted at five wells (6, 11, 12, 17, and 19) that produced at least 100 gal/min during drilling. Pumping rates were increased in 50 gal/min increments to a maximum of approximately 300 gal/min. For each step, the pumping rate was maintained for 1 hour. Specific capacities, or yield per foot of drawdown



EXPLANATION

Mn NEWMAN LIMESTONE

Och CHICKAMAUGA LIMESTONE

Ocn CHEPULTEPEC, LONGVIEW, AND NEWALA FORMATIONS

Ꞓcr COPPER RIDGE DOLOMITE

← GROUND-WATER FLOW DIRECTION

· · · WATER TABLE

— — HYPOTHESIZED BOTTOM OF GROUND-WATER RESERVOIR

⇌ THRUST FAULT--Arrows indicate relative movement

—— GEOLOGIC CONTACT

Figure 2b.--Generalized hydrogeologic section of the Cave Springs area.

Table 2.--*Data for selected wells in the Cave Springs study area*

[*, existing wells at Cave Springs, exact data not available; **, new wells at Cave Springs; <, less than; >, greater than]

Well number[a]	Approximate elevation of land surface in feet above sea level	Depth of well, in feet	Depth of casing, in feet	Appproximate thickness of regolith, in feet	Estimated yield during drilling, in gallons per minute	Depth of of water-bearing zones, in feet
1*	710	71	61	25	3,000	65-70
2*	710	73	63	25	3,000	65-70
3**	710	398	82	25	>300	160, 190 260, 275, 320
4**	710	177	140	25	>4,000	167-173
5	[b]680	242	40	16	15	199
6	661	322	148	127	300	180, 270
7	[b]820	298	296	298	15	160-180, 270-290
8	[b]880	231	226	231	5	200-231
9	685	103	93	37	400	59-71, 75-93, 98-103
10	679	162	90	90	100	131-142, 151-157
11	786	223	180	179	400	201-220
12	723	142	95	95	200	95-131
13	730	242	147	50	100	50-70, 177
14	850	302	130	124	<1	150-200
15	827	202	194	202	30	143-147, 197-202
16	770	251	135	126	40	200-250
17	750	190	188	174	200	175-190
18	703	342	88	85	100	299, 327
19	729	202	154	150	200	170-200
20	692	101	62	37	50	70-90
21	780	171	165	165	50	165-171
22	707	280	84	69	50	78
23	720	342	117	93	200	85-93

Well number	Specific capacity, in gallons per minute per foot of drawndown	Final pumping rate in gallons per minute
6	31.5	300
11	261	235
12	10.2	250
17	4.1	150
19	8.3	270

[a] See figure 3.
[b]Well not surveyed; elevation from 1:24,000 USGS quadrange map.

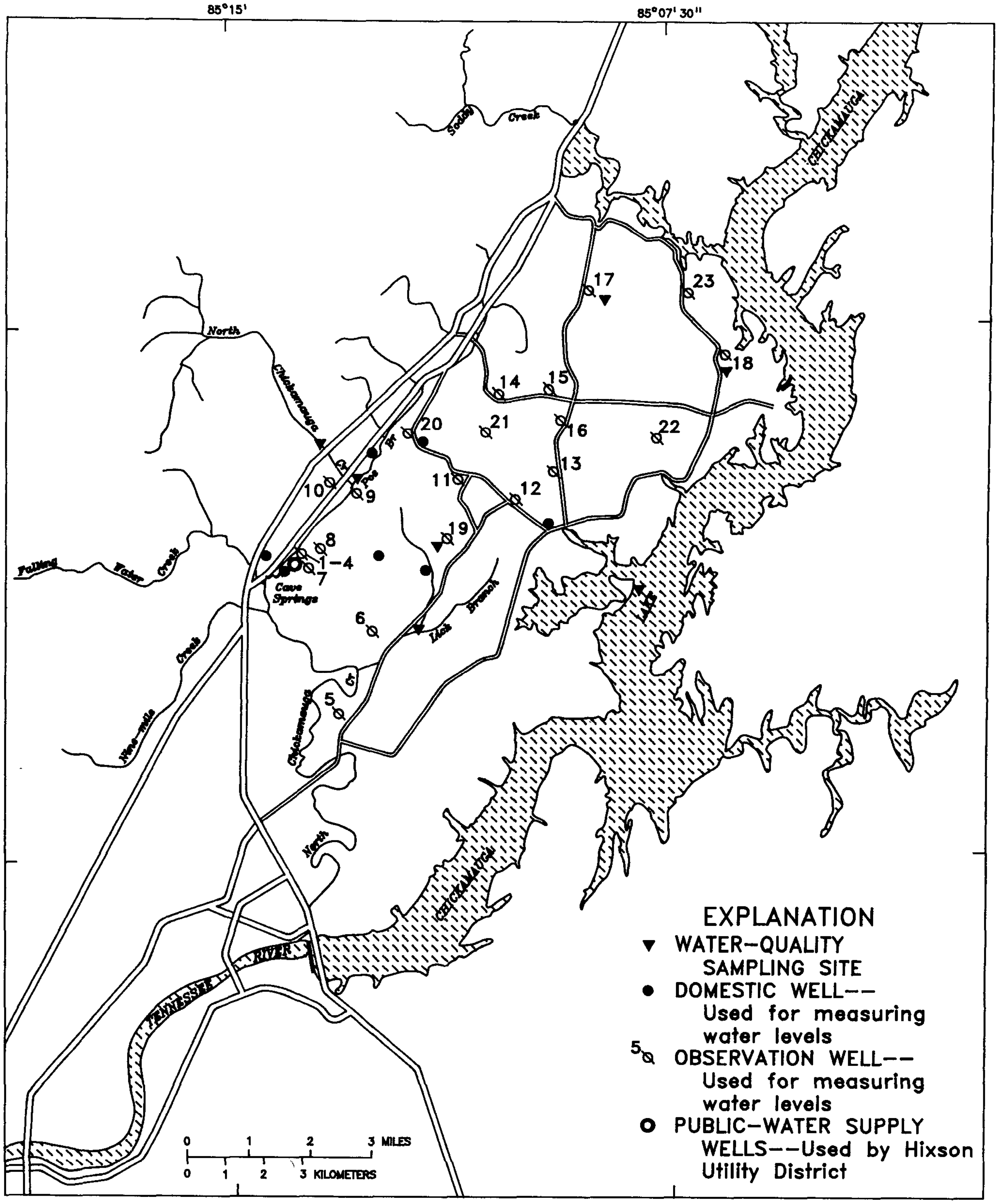


Figure 3.--Location of wells and water-quality sampling sites.

for the final pumping rate, for each well tested are presented in table 2. Pumping rate and drawdown are shown for wells 4 (production well), 6, 11, and 12 in figure 4. The most productive well was number 11, which was drilled near the contact between the Chepultepec, Longview, and Newala Formations and the Copper Ridge Dolomite. This well produced 235 gal/min with only 0.9 foot of drawdown (fig. 5), indicating a specific capacity of 261 (gal/min)/ft of drawdown (table 2).

A 10-inch-diameter well within 500 feet of well 11 was pumped at 1,800 gal/min for 48 hours during aquifer tests conducted by the HUD in October 1989. Drawdown was 25 feet, indicating a specific capacity of 72 (gal/min)/ft (Layne Geosciences, Inc., 1989). Drawdown was only 1.2 feet in observation well 11; however, the influence of pumping had not reached maximum extent before the test was terminated. This test was conducted during a period of high base flow for nearby streams and at a higher pre-pumping water level than the earlier test conducted by the USGS on the 6-inch-diameter well 11. Drawdown due to pumping during periods of low water levels probably would be greater.

Wells at the Pumping Facility

The HUD pumping facility is located on the northwestern side of Cave Springs Ridge, approximately 150 feet southeast of Cave Springs (fig. 2b). The utility district operates two line-shaft turbine pumps in wells that tap a submerged cave 65 to 70 feet below land surface. The water level in well 1, located within 50 feet of the pumping wells, never exceeded 60 feet below land surface, indicating that the cave remained full of water during the period of drought and maximum water usage in 1988. Well 4 and the two existing HUD production wells are much more productive than other wells drilled in the study area because they intercept the submerged cave and have larger diameters.

Aquifer tests using wells at the pumping facility indicated a decrease in specific capacity associated with lower pre-pumping water levels. Two 24-hour aquifer tests were conducted using the two large-capacity pumps operated by the HUD. These tests were conducted for the same length of time and at nearly the same pumping rate. Therefore, drawdown caused by well entrance losses associated with pumping should be fairly consistent for both tests. The decrease in specific capacity with the lower pre-pumping water level is most likely due to differences in aquifer properties that vary with depth.

The first aquifer test began on September 1, 1987, at a pre-pumping water level of 51.8 feet below land surface. Water was pumped from the two HUD wells at a rate of 6,590 gal/min. A total of about 9.5 million gallons (Mgal) were withdrawn with only 2.9 feet of drawdown, indicating a specific capacity of about 2,270 (gal/min)/ft. A second aquifer test, started on November 3, 1987, was conducted at a rate of 6,100 gal/min from a pre-pumping water level of 54.7 feet below land surface. A total of about 8.8 Mgal of water were withdrawn during this test, resulting in 4.3 feet of drawdown. Specific capacity decreased to about 1,420 (gal/min)/ft.

The decrease in specific capacity with lower pre-pumping water levels at Cave Springs may be related to a decrease with depth in the permeability of the aquifer. Larger conduits tend to be located nearer to land surface. As water levels and the volume of water in storage decline seasonally, the gradient of the water surface in the aquifer to the wells must become greater in response to steady pumping demands. Changes in the volume of the aquifer, a decrease in aquifer permeability, or both, with depth would likely result in the additional drawdown observed in the pumped well during the second test.

The need to meet increasing demands for water prompted the HUD to drill and test several additional wells in the immediate vicinity of Cave Springs. Three test wells were drilled within 50 feet of the HUD pumping facility, and each well intersected the large solution opening from which water is currently pumped. These wells (not shown on fig. 3) were later plugged and filled with grout to land surface.

Although all three test wells intersected the large solution opening at 65 to 70 feet below land surface, the occurrence of deeper water-bearing zones near Cave Springs had not been investigated. The HUD later drilled a 400-foot deep observation well (well 3) within 100 feet of the existing wells. Casing in well 3 extends below the 65- to 70-foot-deep water-bearing zone currently being pumped.

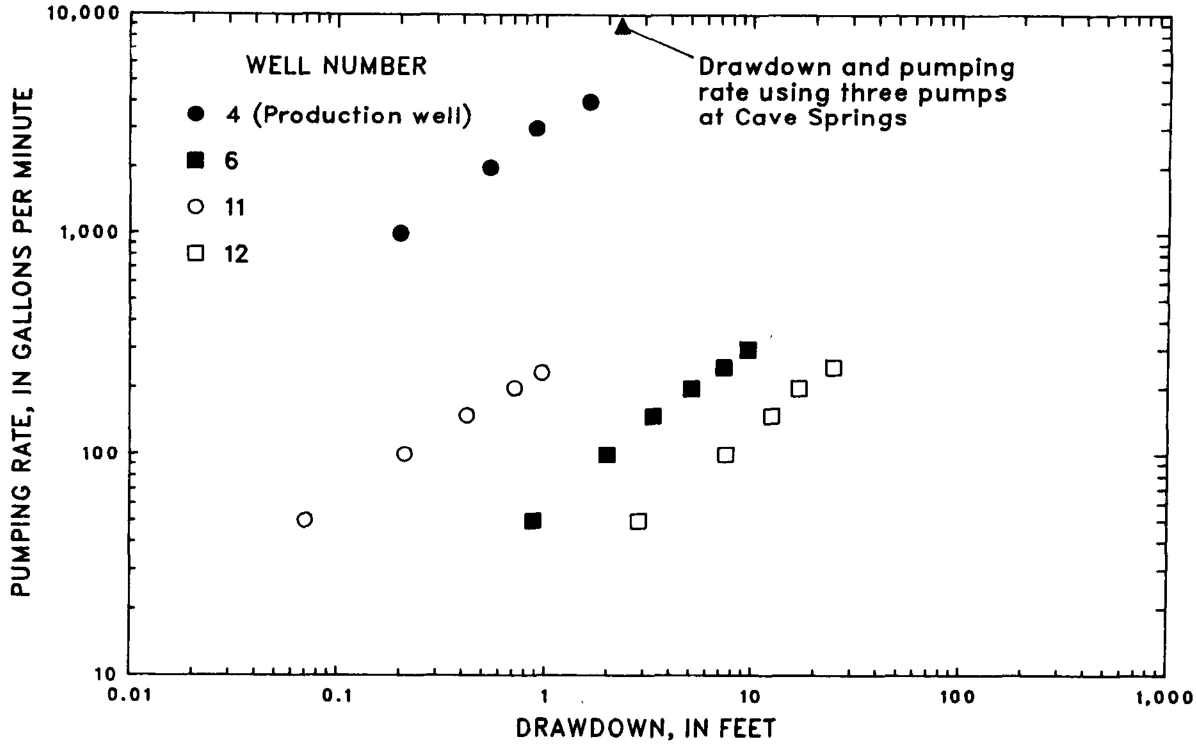


Figure 4.--Drawdown and pumping rate for step-drawdown aquifer tests conducted on wells in the Cave Springs study area.

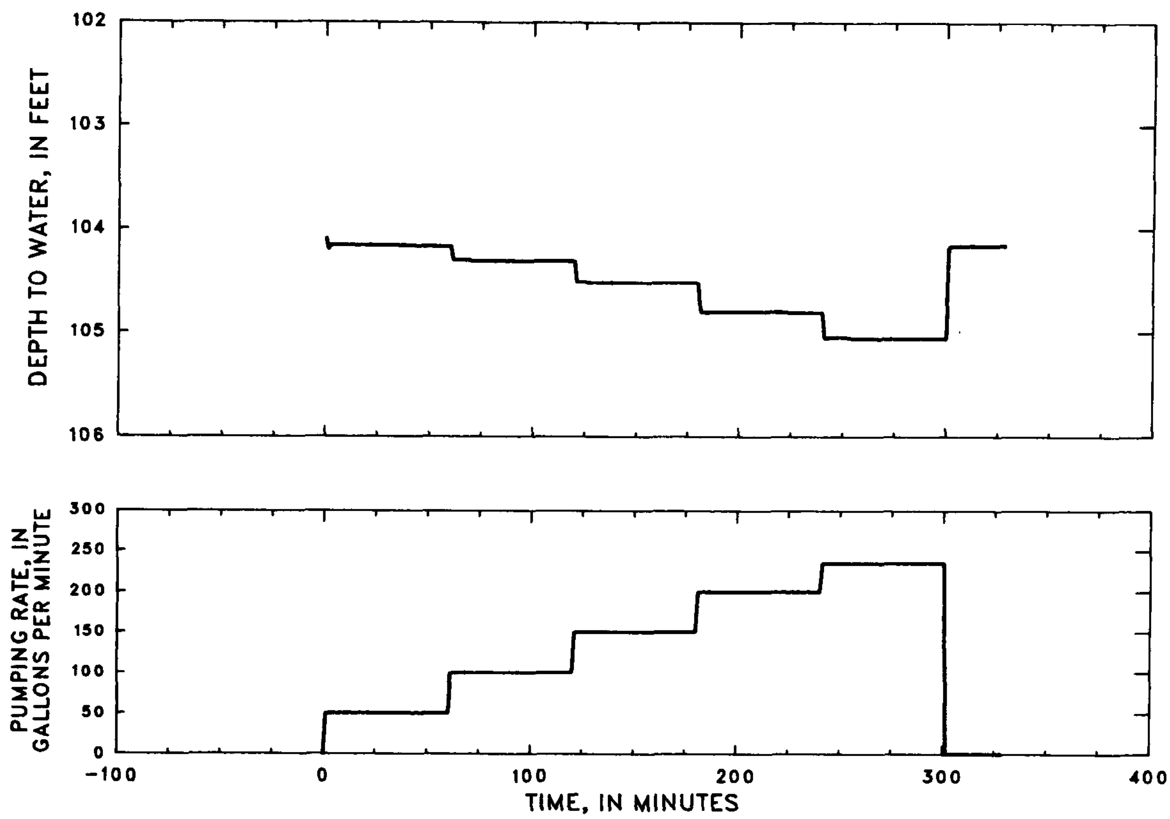


Figure 5.--Pumping rate, drawdown, and recovery of water levels in well 11, December 13, 1988.

Geophysical logs for the 400-foot deep HUD observation well 3 (fig. 6) provided information on the location of water-bearing openings and identified differences in the composition of rock in this section of the Newman Limestone. Caliper and temperature logs are of particular interest. The caliper log showed openings at approximately 90, 160, 190, 260, 275, and 320 feet below land surface. The opening at a depth of 190 feet yielded several hundred gallons of water per minute when blown with pressurized air from the drill rig.

The water temperature log showed that water in openings below 260 feet may not be hydraulically connected to the upper water-bearing zones. Water below 260 feet is slightly warmer, indicating it is less affected by the continuous pumping by the HUD. The gamma log identified a layer of shaley or silty limestone below 290 feet. The HUD later drilled a large diameter (14 inch) production well (well 4) near well 3 and intercepted an opening at 170 feet that provided high yields of water.

An aquifer test at well 4 was conducted during January 1989. This was a period of high base flow for surface streams in the area and the pre-pumping water level in the well was higher than for previous aquifer tests at Cave Springs. Pumping rates during the step-discharge aquifer test were stepped from 1,000 to 4,000 gal/min in 1,000 gal/min increments. A plot of discharge and drawdown for each pumping rate indicated minimal drawdown throughout the test.

The maximum withdrawal from the aquifer was achieved using the two HUD pumps to withdraw an additional 5,000 gal/min from the solution opening at 65 to 70 feet, which resulted in a total pumping rate of 9,000 gal/min. Maximum drawdown in well 4 was 2.3 feet (fig. 7). Drawdown in observation well 3, located about

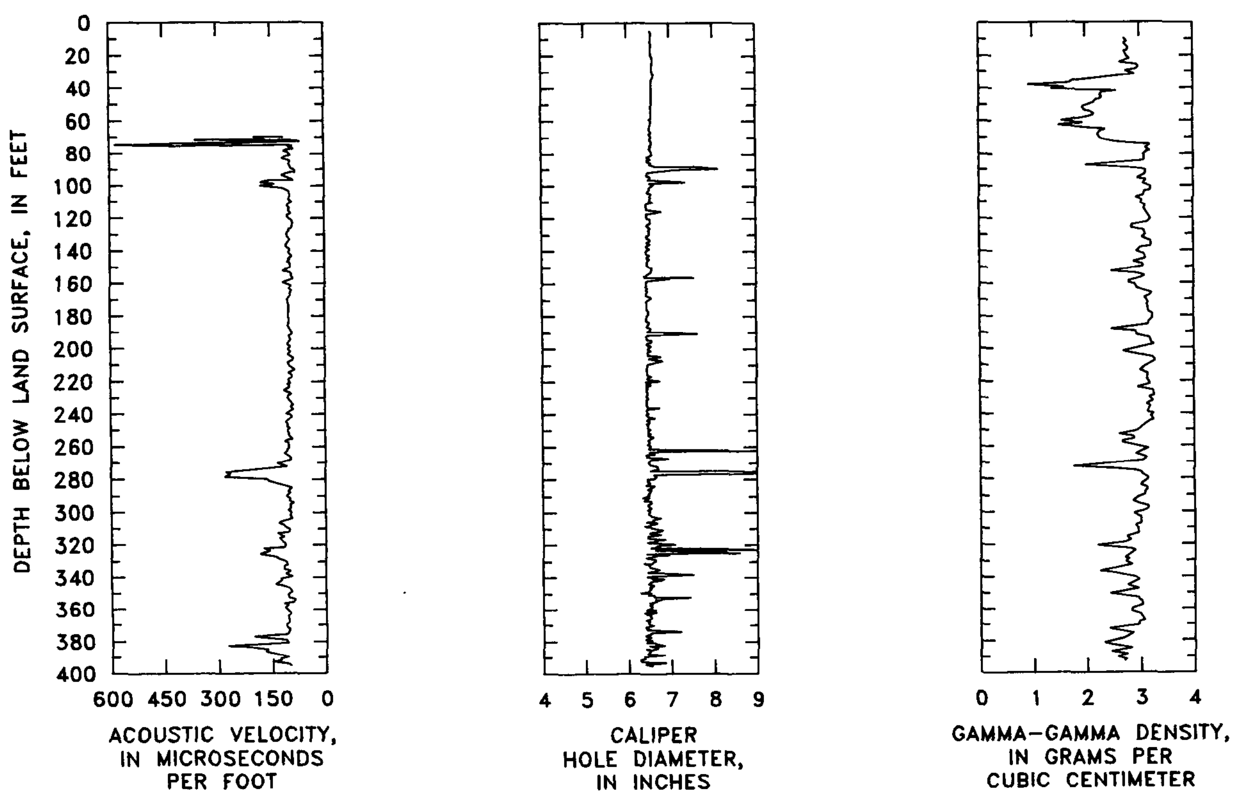


Figure 6.--Geophysical logs of well 3 at Cave Springs.

20 feet from the new production well, was 1.3 feet (fig. 8). Observation well 3 was cased below the solution opening at 65 to 70 feet. Drawdown in a second observation well (well 1), open to the large solution opening at 65 to 70 feet, was equal to the drawdown in observation well 3. Identical drawdown in these two wells indicates the lower solution openings are hydraulically connected to the upper water-bearing zone.

GROUND-WATER-FLOW SYSTEM

The volume of water available to the Cave Springs system in any given year is dependent upon the amount and timing of precipitation. Rain falling on the recharge area contributes water to the aquifer and to streams draining the recharge area. Water that is not transported immediately as surface water is held in storage in the ground-water reservoir. The base flow of streams in the area is maintained during periods of little or no precipitation by water discharged from the ground-water system.

Consolidated limestone and dolomites, the predominant rocks in this part of the Valley and Ridge province, have little porosity to allow for the storage of ground water or primary permeability to enable the flow of water. Water moves from points of high hydraulic head to lower hydraulic head through fractures and bedding plane surfaces enlarged by the dissolution of limestone that occurs along these features. Most water movement is along bedding planes parallel to the strike of the rock (Hollyday and Goddard, 1979). Although fractures and joints transverse to the strike may connect solution openings along bedding planes, most of the flow is parallel to strike. The thick chert and clay regolith that occurs in the study area is an important component of the flow system, allowing for storage and the gradual release of large amounts of water to underlying solution openings in the limestone and dolomite.

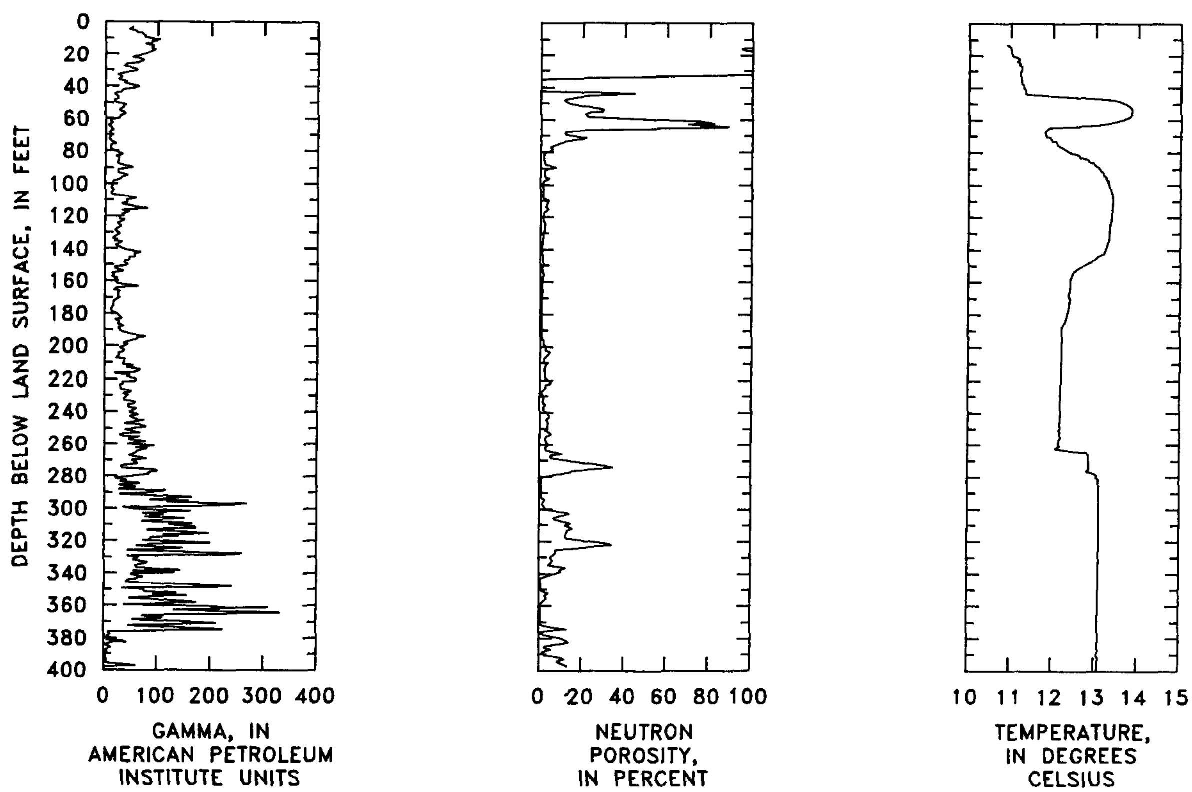


Figure 6.—Geophysical logs of well 3 at Cave Springs—Continued.

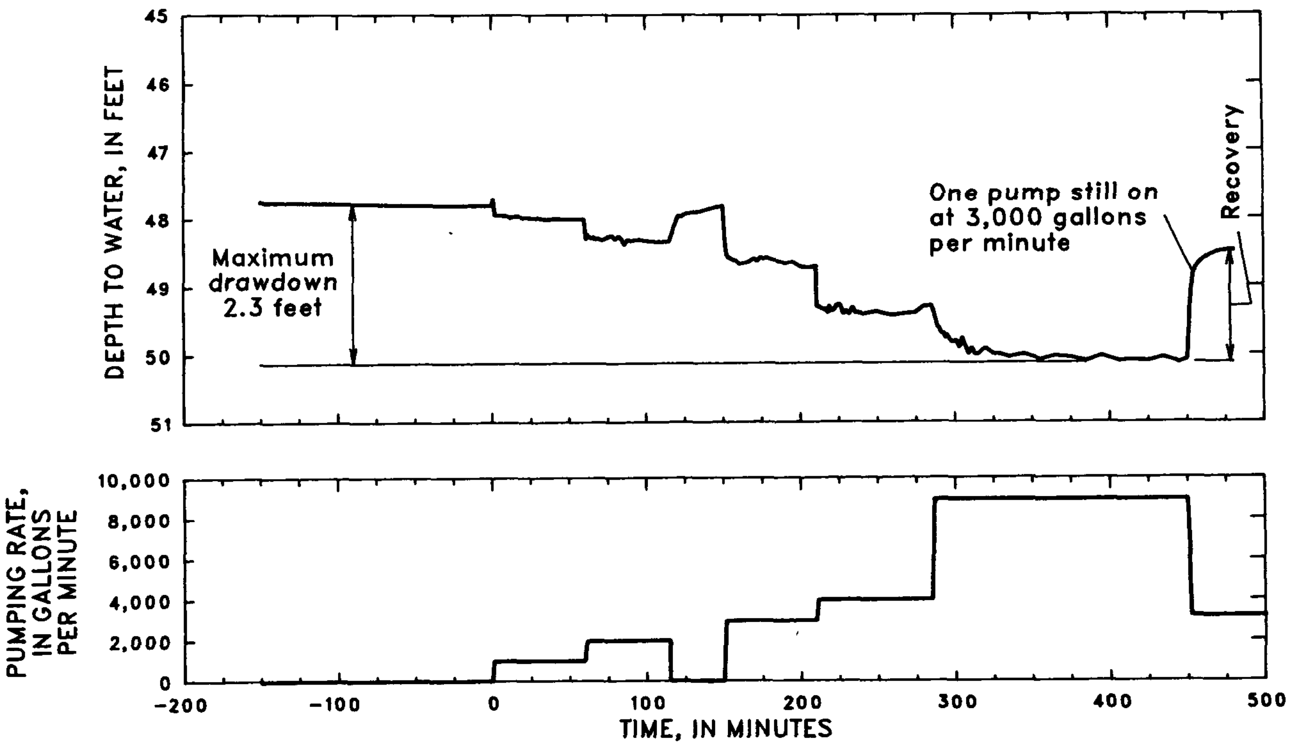


Figure 7.−−Pumping rate, drawdown, and recovery of water levels in the Hixson Utility District production well 4 during the January 20, 1989, aquifer test. (All pumping rates, with the exception of 9,000 gallons per minute, were obtained by pumping well 4 only. The rate of 9,000 gallons per minute was obtained by pumping two Hixson Utility District production wells in addition to well 4.)

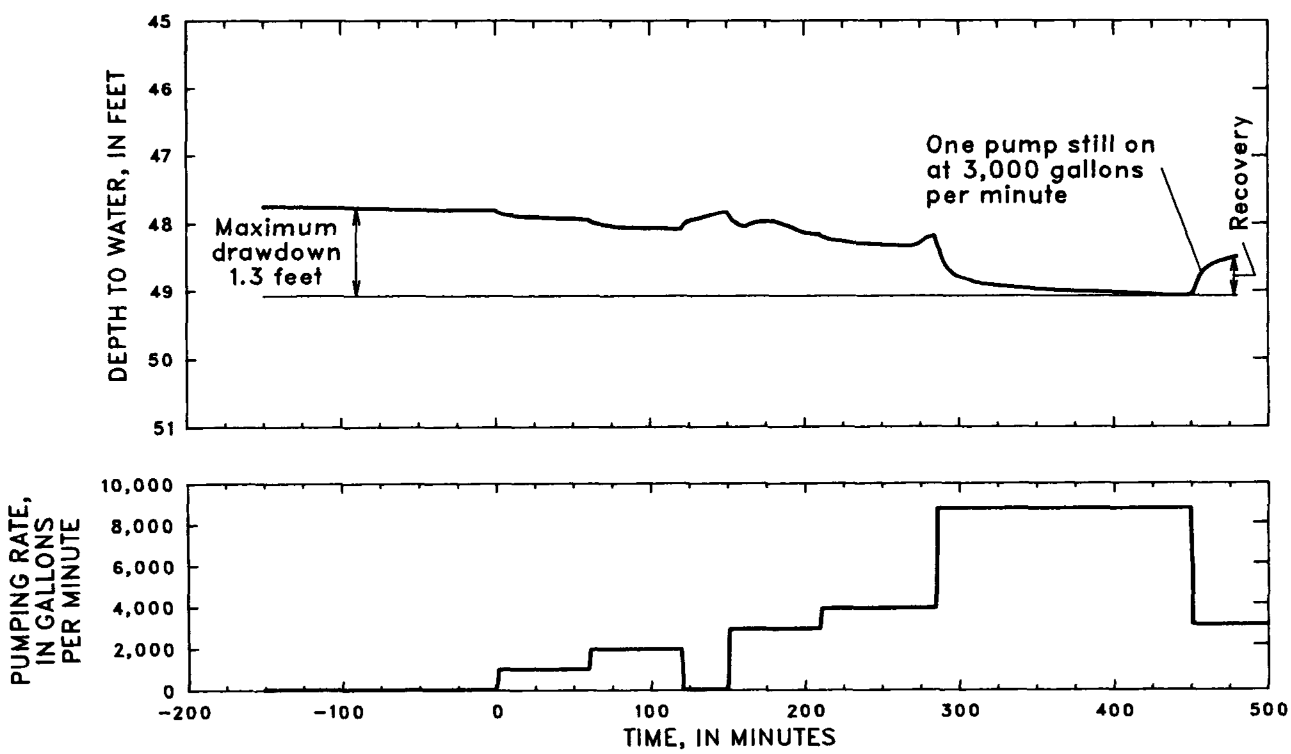


Figure 8.−−Pumping rate, drawdown, and recovery of water levels in observation well 3 during the January 20, 1989, aquifer test. (All pumping rates, with the exception of 9,000 gallons per minute, were obtained by pumping well 4 only. The rate of 9,000 gallons per minute was obtained by pumping two Hixson Utility District wells in addition to well 4.)

Spring Discharge, Ground-Water Withdrawals, and Ground-Water Levels

Historical data on discharge from Cave Springs, other than pumping records provided by the HUD, are limited. The spring discharges from an opening 150 feet northwest of the pumping facility and flows approximately 200 feet before joining North Chickamauga Creek (fig. 1). The site was included in a previous USGS investigation of 90 large springs of East Tennessee (Sun and others, 1963). A total of 28 discharge measurements were made from 1928 to 1953. Discharge ranged from 0.08 to 43.7 ft^3/s, with a mean of 17.5 ft^3/s and median discharge of 15.6 ft^3/s (Hollyday and Smith, 1990). Of the 90 large springs included in the study by Sun and others (1963), only four, including Cave Springs, had sufficient discharge to be classified as a second-magnitude spring (mean annual discharge between 10 and 100 ft^3/s). Compared to the other 89 springs, Cave Springs had the greatest variability in discharge.

Mean daily discharge from Cave Springs for the period July 15, 1987, to September 30, 1989 (fig. 9), was 13.5 ft^3/s and the standard deviation was 9.80 ft^3/s. A comparison of mean daily discharge for 1988 and 1989 water years illustrates the differences in hydrologic conditions between the dry 1988 water year and relatively wet 1989 water year. Mean daily discharge from Cave Springs in the 1988 water year was 10.3 ft^3/s. Mean daily discharge at Cave Springs in the 1989 water year was 19.5 ft^3/s, almost double the mean daily discharge in 1988.

Maximum daily spring discharge was not substantially different for the 1988 and 1989 water years, with a maximum of 31 ft^3/s in 1988 and 34 ft^3/s in 1989. The maximum discharge of the spring is limited by the size of the conduits that discharge water at the overflow. Spring overflow ceased during the summers of 1987 and 1988 because of drought conditions that occurred over much of the southeastern United States. The spring flowed continuously during the 1989 water year. The minimum daily discharge for the 1989 water year, 4.1 ft^3/s, occurred in October 1988.

The Cave Springs system is capable of supplying the current water needs of the HUD. Withdrawals using two line-shaft turbine pumps with intakes in a submerged cave 65 to 70 feet below land surface averaged 5.54 Mgal/d (July 17, 1987, to September 30, 1989, fig. 9). Withdrawals appear to have a minimal effect on the spring overflow during periods of high flow, but cause the overflow to decrease more rapidly or to cease during low-flow periods in late summer and fall. Although more water is removed from storage than is replenished during the dry summer months, annual recharge is sufficient to replenish the aquifer and to meet the needs of the HUD at the current pumping demand.

Water levels in well 1 were monitored at 15-minute intervals from July 17, 1987, to September 30, 1989 (fig. 10). The spring overflow ceases (fig. 9) when the water level in monitoring well 1 near the spring is lower than 52 feet below land surface. Water levels ranged from a low of 58.5 feet in November 1987 to a high of 41.6 feet below land surface following a storm in July 1989. Mean daily depth to water during the 1988 water year fluctuated from 46 to 58 feet below land surface with a mean of 51.4 feet.

During the 1989 water year (October 1, 1988, to September 30, 1989), a relatively wet year compared to the 1988 water year, water levels fluctuated between approximately 41 and 51 feet below land surface. The mean water level for this period was 48.5 feet below land surface, approximately 3 feet higher than the mean water level for the 1988 water year. Higher water levels correlated with the greater discharge of Cave Springs during the 1989 water year (fig. 9).

Ground-water fluctuations near Cave Springs correlate fairly well with water levels at a well in Chattanooga (located about 10 miles southwest of Cave Springs, not shown in fig. 3). Water levels in well 1 at Cave Springs and a 275-foot deep well in downtown Chattanooga have similar seasonal trends and responses to recharge events (fig. 10). The well in Chattanooga (Hm:G-036) was not affected by pumping. The effects of pumping at Cave Springs were indicated by low water levels in well 1 during the period September through November 1987, when recharge was minimal and withdrawals were at an all time high. Drawdown

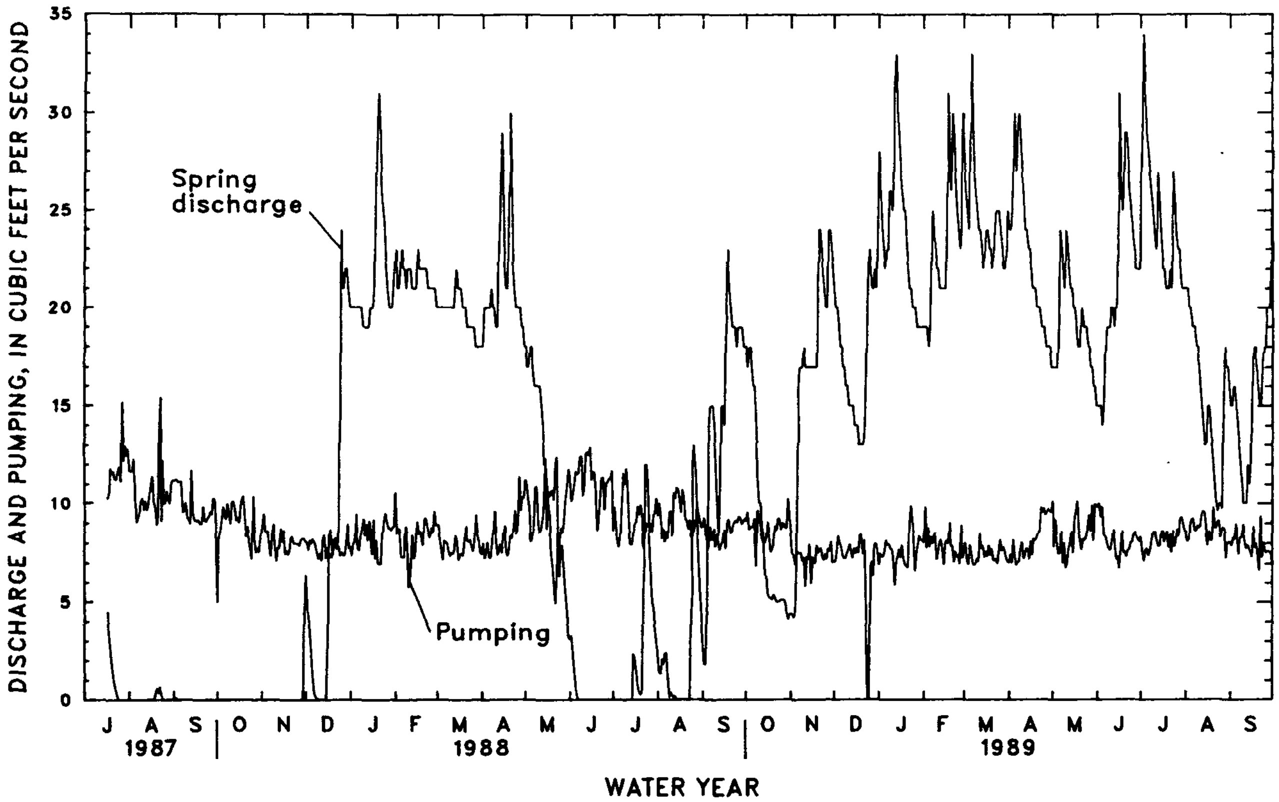


Figure 9.--Daily mean spring discharge and total daily withdrawal by pumping from Cave Springs, July 1987 through September 1989.

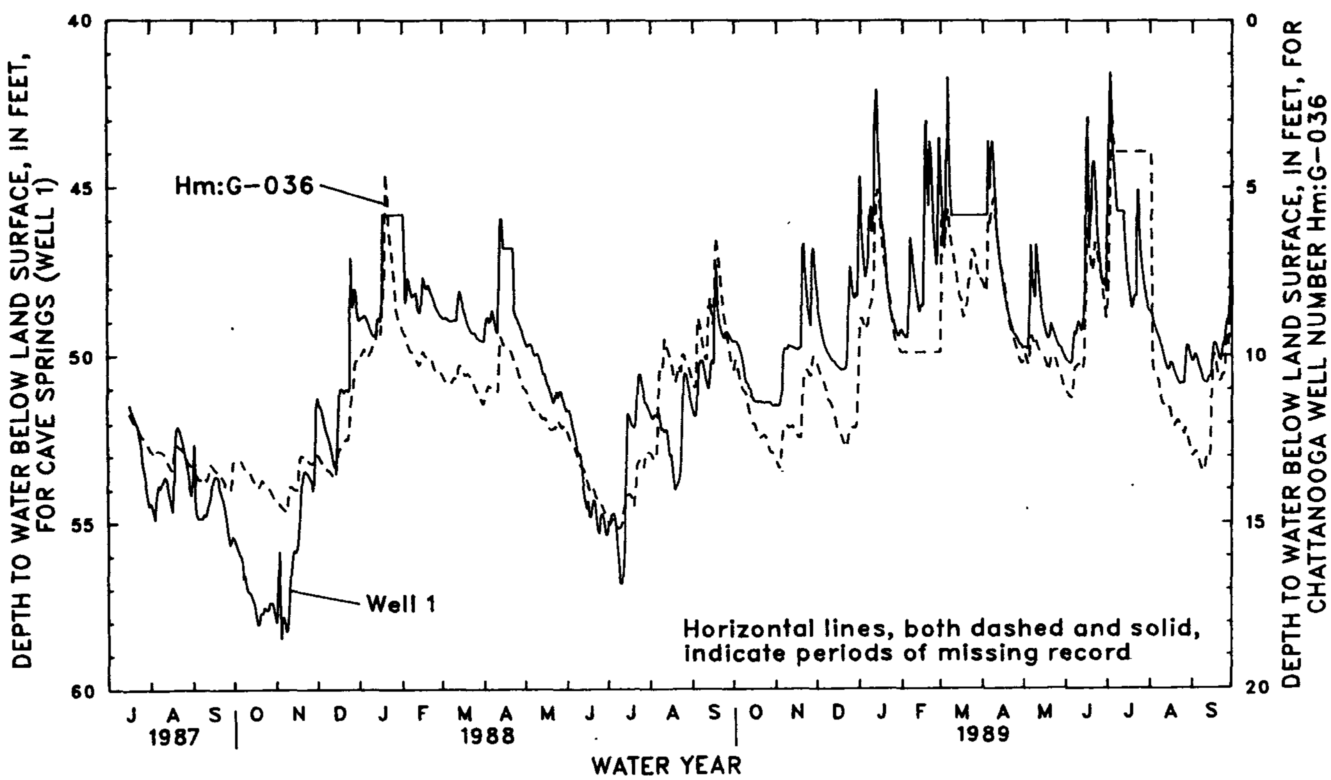


Figure 10.--Daily mean water levels at Cave Springs (well 1) and Chattanooga well (number Hm:G-036), July 1987 through September 1989.

due to pumping does not appear to have a substantial effect on water levels during periods of adequate recharge and normal pumping.

Spring discharge and ground-water levels near Cave Springs vary in response to pumping (figs. 9 and 10) and to rainfall in the area (fig. 11). Daily rainfall data were collected at Chickamauga Dam (fig. 1) near the southern boundary of the study area. Rainfall that infiltrates during the late fall, generally a period of low water levels, begins to replenish the aquifer. During the winter months, pumping decreases and evapotranspiration is reduced, resulting in higher water levels in the aquifer and a corresponding increase in discharge from the spring.

Stream Discharge in the Study Area

Flow characteristics of streams in the study area were studied during an intensive seepage investigation conducted on March 15, 1988. This investigation was during a period of low base-flow relative to most years because of below normal rainfall from 1985 to 1988. During low base-flow periods, most of the stream discharge (base flow) is from ground-water sources. Ground water can constitute as much as 80 percent of total streamflow in basins where carbonate rocks predominate (such as in the Cave Springs basin) compared to about 55 percent in basins underlain by shale (Becher and Root, 1981). Base flows, which consist of the ground-water component of streamflow, are commonly independent of the surface-basin size. Seepage investigations are useful in providing data for determining areas where maximum potential for ground-water discharge to surface streams occurs.

During the seepage investigation conducted to select sites to drill observation wells, stream discharge was measured at 84 sites in the study area during a period of stable base flow. Most sites had flows less than 1 ft^3/s and 24 sites had no discharge. Drainage areas were computed for each

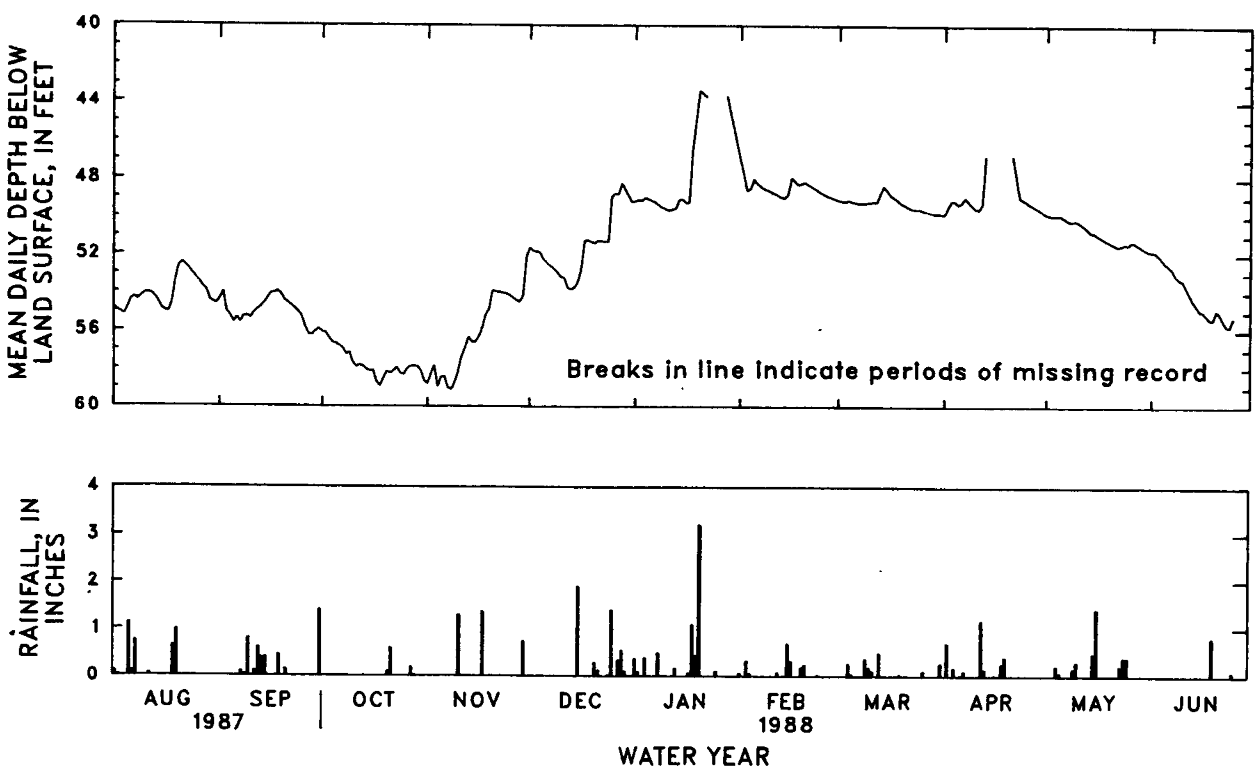


Figure 11.--Daily mean depth to water at Cave Springs (well 1) and daily rainfall at Chickamauga Dam, August 1987 through June 1988.

site. The average flow per unit area at all sites was 0.56 $(ft^3/s)/mi^2$ (7.6 in/yr). Locations of measuring sites, drainage areas, discharge, temperature, and specific conductance data are published in U.S. Geological Survey Water-Data Report TN-88-1 (Lowery and others, 1989).

The seepage data indicated that many of the streams in the study area were dry or had little flow during a time that Wolftever Creek was flowing at a rate more than double the mean annual discharge for the 1988 water year. This is attributed to the small drainage areas of most sites relative to Wolftever Creek. Most of the dry streams drain the Copper Ridge Dolomite and the Chickamauga, Longview, and Newala Formations. Only 25 percent of the sites measured had discharges per square mile greater than the mean discharge for all sites. The majority of streams with large discharges per square mile were located in areas draining the relatively impervious Pennsylvanian sandstones (west of Cave Springs Ridge), or were tributaries to Lick Branch, which drains areas underlain by Chickamauga Limestone (east of Cave Springs Ridge) (fig. 2). Lick Branch, which includes discharge from Rogers Spring, is located near the contact between the more permeable Chepultepec, Longview, and Newala Formations and the Chickamauga Limestone. Lick Branch is a perennial stream with a greater discharge per square mile than most streams in the study area.

Data for Wolftever Creek, a stream in a hydrogeologic setting similar to that of Cave Springs, were examined to relate discharge to drainage basin area. Wolftever Creek drains areas underlain by formations of Mississippian and Middle Ordovician age. The mean annual discharge for the period of record at the USGS gage on Wolftever Creek near Ooltewah (1964-89) was 31.7 ft^3/s. By dividing this mean annual discharge by the drainage area (18.8 mi^2), an average of 1.69 $(ft^3/s)/mi^2$ (22.9 in/yr) for the period of record was obtained. The annual yield per square mile for Wolftever Creek during the study period was 0.67 $(ft^3/s)/mi^2$ (9.09 in/yr) during the dry 1988 water year and 2.18 $(ft^3/s)/mi^2$ (29.61 in/yr) during the unusually wet 1989 water year (table 1).

A preliminary estimate of the area recharging Cave Springs was made based on comparisons of discharge data for Wolftever Creek and an instantaneous discharge measurement made at Cave Springs. On March 15, 1988, the discharge for Wolftever Creek was 29 ft^3/s, or 1.54 $(ft^3/s)mi^2$ (20.9 in/yr). On the basis of instantaneous discharge for Cave Springs on March 15, 1988, of 20 ft^3/s and an instantaneous discharge of 1.54 $(ft^3/s)mi^2$ (2.09 in/yr) for Wolftever Creek on that day, the area recharging Cave Springs was estimated to be about 13 mi^2. Because most sites measured during the seepage investigation were dry, or had flows per unit area less than those in Wolftever Creek, the resultant mean discharge per unit area for all sites was low relative to the higher discharge per unit area for Wolftever Creek. Computations using the low unit discharges at sites with small drainage areas would probably tend to overestimate the recharge area for the spring. Discharge data indicate that a large percentage of annual recharge in the Cave Springs area is retained as ground water that is ultimately discharged at the spring. Consequently, the area recharging Cave Springs could be less than 13 mi^2.

Potentiometric Surface of the Cave Springs Aquifer

A map of the potentiometric surface of the aquifer near Cave Springs was constructed to help define the contributing basin of the spring (fig. 12). Water levels used to define the potentiometric surface in figure 12 were measured on August 23 and 24, 1989. Water levels in wells drilled during this study and in existing domestic wells were measured during stable base-flow conditions. Throughout 1989, water levels remained within 5 to 20 feet of the levels used to construct the potentiometric map.

An analysis of the potentometric surface data indicates that the recharge area for Cave Springs has an area of approximately 10 mi^2. Most of the recharge area appears to be between the thrust fault (fig. 2a) beneath Cave Springs Ridge and the ground-water divide west of Middle Valley Road. The northeastern ground-water divide appears to correspond with the surface-water divide, with ground water flowing south and west to Cave Springs, or north and east to the Tennessee River. The northwestern and western ground-water

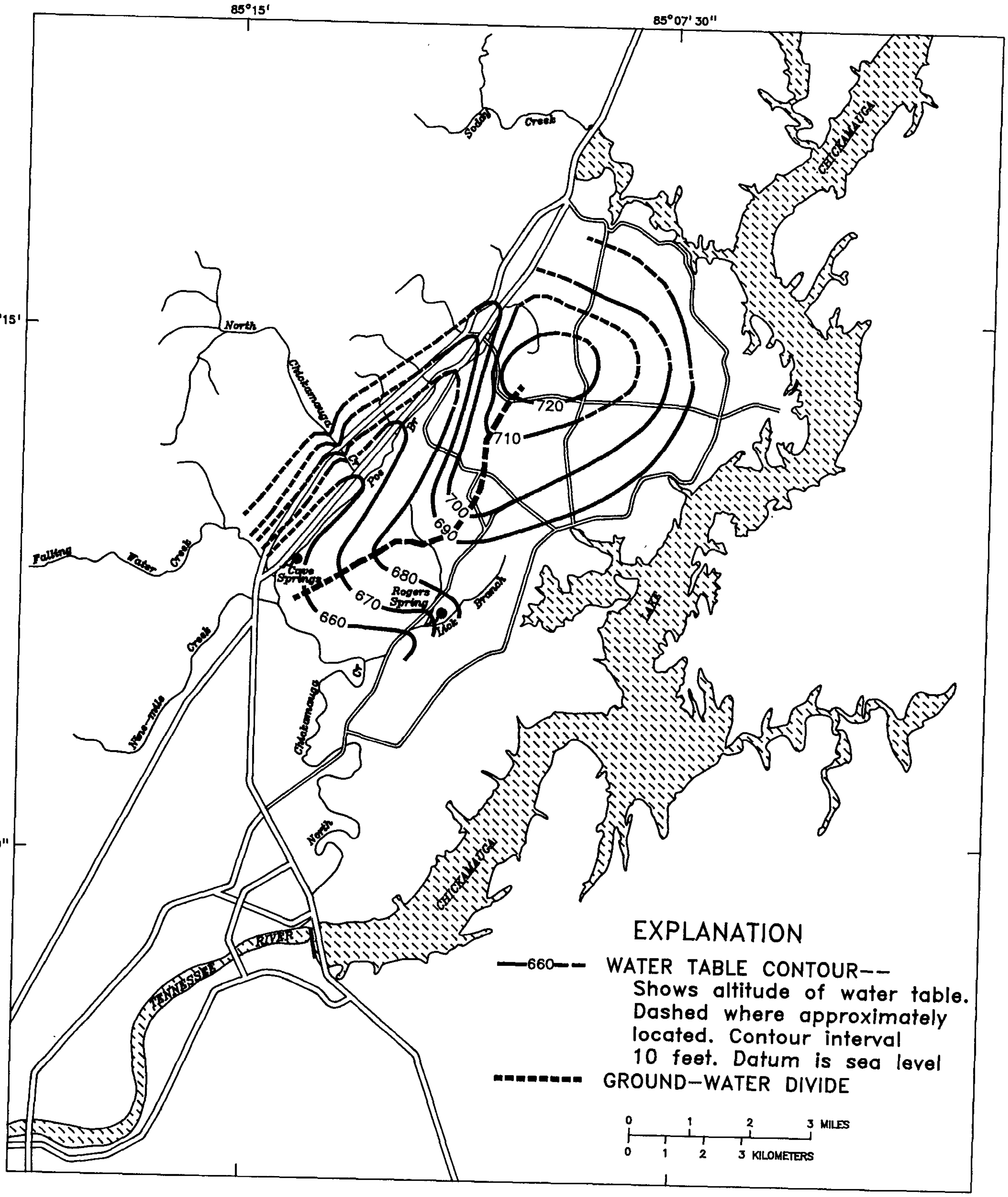


Figure 12.--Approximate altitude of water table in the vicinity of Cave Springs in August 1989.

divides cannot be firmly established with available data.

At the spring, the potentiometric surface has an altitude of approximately 660 feet. A potentiometric high of about 720 feet above sea level occurs near the surface- and ground-water divide northeast of the spring. Based on the potentiometric surface, neither the Tennessee River nor North Chickamauga Creek appears to provide substantial amounts of recharge to the Cave Springs system. However, changes in water quality following storms indicate possible sources of recharge water to the spring that are not readily apparent from the two-dimensional potentiometric surface defined by data collected during stable hydrologic conditions. Sources of recharge might not be adequately defined because of a lack of control points along Cave Springs Ridge near the thrust fault, or because sources of water may vary with changing heads in the areas supplying water to the spring.

WATER QUALITY

Water-quality data were collected at Cave Springs and four surface-water sites in March 1988 (table 3) and in April 1989 (table 4). In addition to Cave Springs and the surface-water sites sampled in 1988, three wells in the study area were sampled in 1989 (fig. 3, table 4). Values for chemical constituents and physical properties were used to compare surface water and ground water in the study area and to aid in identifying sources of recharge to Cave Springs.

Surface-Water and Ground-Water Quality

Variations in surface-water quality in the study area can be attributed to differences in the geology of the different drainage basins. North Chickamauga Creek and Poe Branch drain areas west of Cave Springs Ridge, which is underlain by Pennsylvanian sandstones. These two streams have relatively low pH values and high concentrations of aluminum or iron and manganese. These streams might be affected by drainage from surface and deep coal mines in the higher elevations of the Cumberland Plateau.

Water quality of samples from wells and from Lick Branch, a ground-water-fed stream, is characteristic of the limestones and dolomites that underlie the area east of Cave Springs Ridge. These waters have more dissolved calcium, higher pH values, and higher concentrations of dissolved solids than surface streams west of Cave Springs Ridge. Water from Cave Springs was not distinctly different from most waters sampled, although Cave Springs water seems to be more similar to water from Lick Branch and well 19 than to water from the Tennessee River or North Chickamauga Creek.

Water-quality data for samples collected in April 1989 are summarized in a trilinear diagram (fig. 13). The trilinear diagram allows comparison of the percentage of major cations and anions of different waters, facilitating interpretation of the data (Hem, 1985). Percentages are computed from milliequivalents per liter. The percentage of cations and anions are plotted in each of the lower triangles and the points are then projected into the diamond parallel to its upper edges. The intersection of these projections represents the "type" of water from a well or stream based on the percentage of the various ions.

The trilinear diagram (fig. 13) illustrates differences in water quality between surface water and ground water in the study area. Water from wells 17, 18, and 19, Cave Springs, and Lick Branch is a calcium carbonate type water with calcium and magnesium as the dominant cations. Water from wells 17 and 18 and water from North Chickamauga Creek have a higher percentage of magnesium.

The ratio of calcium to magnesium concentrations in water from Cave Springs (6.8) is most like that of water from well 19 (5.4) and Lick Branch (5.4). Calcium to magnesium ratios from well 17 (1.8), well 18 (2.2), and North Chickamauga Creek (1.8) are lower than the ratio for water at Cave Springs. Ratios for Poe Branch (4.6) and the Tennessee River (4.4)

Table 3.--*Water-quality data collected from surface streams and Cave Springs, March 13, 1988*

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity units; <, less than; --, not analyzed]

Property or constituent	Station name and number				
	Lick Branch 03566616	Poe Branch 035665348	Tennessee River 0356640585	North Chickamauga Creek 03566530	Cave Springs 03566540
Temperature, field (°C)	8.5	8.5	9.0	7.0	12.5
Specific conductance, field (µS/cm)	281	134	184	38	150
Alkalinity, field (mg/L as $CaCO_3$)	139	18	61	2.0	53
pH, field	8.3	6.7	8.7	4.9	7.2
Turbidity, in NTU	8.5	1.8	19	5	1.1
Hardness, total (mg/L as $CaCO_3$)	150	51	66	10	69
Calcium, dissolved (mg/L as Ca)	49	15	19	2.2	22
Magnesium, dissolved (mg/L as Mg)	7.2	3.3	4.5	.99	3.3
Sodium, dissolved (mg/L as Na)	3.8	3.0	9.2	.9	1.6
Potassium, dissolved (mg/L as K)	.8	1.3	1.8	.6	.80
Sulfate, dissolved (mg/L as SO_4)	11	33	17	9.9	14
Chloride, dissolved (mg/L as Cl)	6.1	4.3	10	1.4	2.4
Fluoride, dissolved (mg/L as F)	.1	.1	.2	.1	.1
Silica, dissolved (mg/L as SiO_2)	4.7	1.9	3.8	3.9	5.1
Solids, residue at 180 °C, dissolved (mg/L)	174	83	107	24	88
Solids, sum of constituents, dissolved (mg/L)	166	74	98	22	83
Aluminum, dissolved (µg/L as Al)	10	20	50	190	< 10
Arsenic, dissolved (µg/L as As)	< 1	< 1	< 1	< 1	< 1
Barium, dissolved (µg/L as Ba)	17	27	19	24	32
Beryllium, dissolved (µg/L as Be)	< .5	< .5	< .5	< .5	< .5
Cadmium, dissolved (µg/L as Cd)	1	1	< 1	1	< 1
Chromium, dissolved (µg/L as Cr)	< 1	1	< 1	< 1	< 1
Cobalt, dissolved (µg/L as Co)	< 3	< 3	< 3	< 3	< 3
Copper, dissolved (µg/L as Cu)	< 1	< 1	< 1	< 1	< 1
Iron, dissolved (µg/L as Fe)	18	120	30	18	7
Lead, dissolved (µg/L as Pb)	< 5	< 5	< 5	< 5	< 5
Lithium, dissolved (µg/L as Li)	< 4	< 4	< 4	<4	< 4
Manganese, dissolved (µg/L as Mn)	46	71	9	60	4
Mercury, dissolved (µg/L as Hg)	< .1	< .1	< .1	1.3	--
Molybdenum, dissolved (µg/L as Mo)	< 10	< 10	< 10	< 10	< 10
Nickel, dissolved (µg/L as Ni)	8	5	7	11	3
Selenium, dissolved (µg/L as Se)	< 1	< 1	< 1	< 1	< 1
Strontium, dissolved (µg/L as Sr)	60	58	59	14	79
Vanadium, dissolved (µg/L as V)	< 6	< 6	<6	< 6	< 6
Zinc, dissolved (µg/L as Zn)	< 3	10	< 3	18	4
Carbon, organic total (mg/L as C)	2.5	4.0	3.6	.6	.7

Table 4.--*Water-quality data collected from Cave Springs, wells, and streams, April 1989*

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, not analyzed]

Property or constituent	Cave Springs 04-12-89	Well 17 04-13-89	Well 18 04-13-89	Well 19 04-14-89	Lick Branch 04-19-89	Poe Branch 04-18-89	Tennessee River 04-19-89	North Chickamauga Creek 04-18-89
	Well number or stream and date sampled							
Temperature, field (°C)	14.5	14.5	15.2	14.0	19.5	14.0	17.0	13.2
Specific conductance, field (µS/cm)	185	220	310	245	260	140	160	<50
Alkalinity, field (mg/L as $CaCO_3$)	66	99	138	109	114	32	49	1.5
pH, field	7.3	7.9	8.0	7.7	8.5	7.0	8.5	4.9
Color (platinum cobalt units)	3	120	40	130	15	25	15	5
Hardness, total (mg/L as $CaCO_3$)	84	100	160	120	130	54	62	10
Calcium, dissolved (mg/L as Ca)	27	21	37	37	39	16	18	2.2
Magnesium, dissolved (mg/L as Mg)	4.0	12	17	6.8	7.2	3.5	4.1	1.2
Sodium, dissolved (mg/L as Na)	2.1	1.7	1.0	3.5	3.7	2.8	5.7	.9
Potassium, dissolved (mg/L as K)	.7	.6	1.1	.6	.8	1.1	1.3	.6
Sulfate, dissolved (mg/L as SO_4)	12	2.1	15	6.5	5.5	21	13	11
Chloride, dissolved (mg/L as Cl)	2.2	2.8	1.5	4.1	4.6	3.0	6.4	.9
Fluoride, dissolved (mg/L as F)	.1	.1	.2	.1	.1	.1	.1	.1
Silica, dissolved (mg/L as SiO_2)	5.9	8.3	8.4	7.1	4.7	1.4	3.3	4.2
Solids, residue at 180 °C, dissolved (mg/L)	94	110	162	132	135	77	86	23
Solids, sum of constituents, dissolved (mg/L)	97	111	165	136	141	69	83	22
Nitrogen, NO_2+NO_3, dissolved (mg/L as N)	.797	.785	.081	1.30	1.20	.179	.218	<.010
Nitrogen, ammonia, dissolved (mg/L as N)	.020	.020	.060	.020	.020	.020	.010	<.010
Barium, dissolved (µg/L as Ba)	32	13	140	12	18	30	19	31
Boron, dissolved (µg/L as B)	--	--	--	--	<10	20	<10	10
Iron, dissolved (µg/L as Fe)	5	17	10	21	33	230	17	36
Manganese, dissolved (µg/L as Mn)	1	5	2	2	39	230	2	60
Strontium, dissolved (µg/L as Sr)	100	17	120	30	48	64	50	13

are intermediate. Calcium to magnesium ratios reflect the chemical composition of the rocks in a particular area and indicate that substantial differences in lithology exist in the study area.

Concentrations of chloride ions were useful in eliminating possible sources of recharge to Cave Springs. Based on the differences in concentration of chloride ions, the Tennessee River does not appear to be a significant source of direct recharge to Cave Springs. The concentration of chloride in water samples from the Tennessee River is higher than that in samples from Cave Springs. Substantial dilution of water from the Tennessee River would be required to achieve the chemical composition of water from Cave Springs.

Water-quality data substantiate the conclusion obtained from the potentiometric map that essentially no water moves from the Tennessee River to Cave Springs. However, this conclusion is based on only two water samples collected under stable hydrologic conditions. Additional sampling during rainfall events affecting water levels and the quality of the water at Cave Springs is needed to further define the potential for the Tennessee River to recharge the spring.

Although the trilinear diagram indicates water from North Chickamauga Creek and Poe Branch is distinctly different from Cave Springs water (fig. 13), this may be somewhat misleading. Locations of plotting points on the trilinear

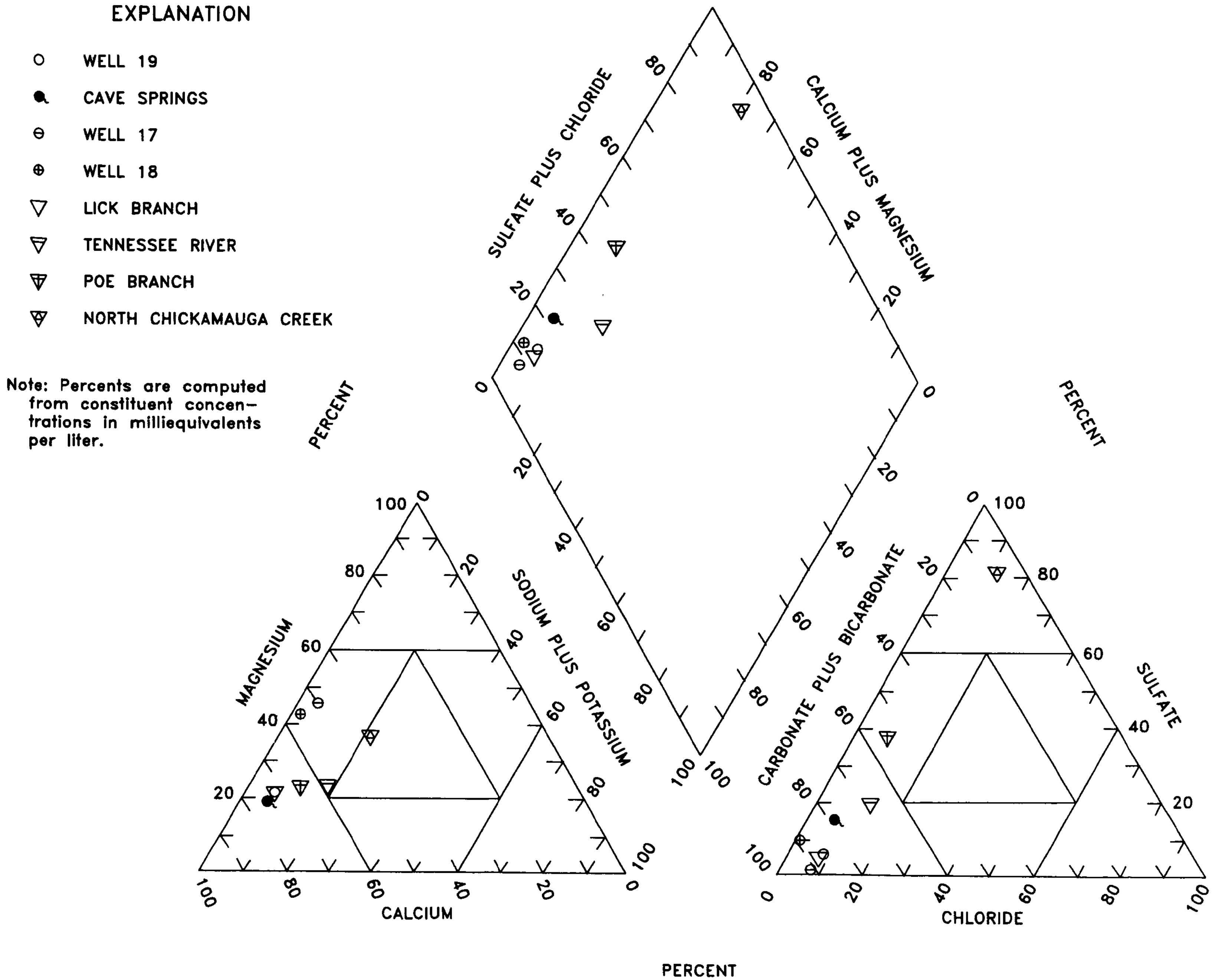


Figure 13.––Trilinear diagram of water-quality data collected in April 1989.

diagram are based on the percentage of cations and anions expressed in milliequivalents per liter, not the actual concentrations. Concentrations of constituents are generally similar for all waters in the study area, and the concentration of dissolved solids in North Chickamauga Creek is low. Consequently, small differences in actual concentrations can make a large difference in the percentage of a particular constituent. A "mix" of water from North Chickamauga Creek and ground water could result in the same water chemistry occurring at Cave Springs. However, based on the small calcium to magnesium ratio for water collected from North Chickamauga Creek and Poe Branch and the concentrations of sulfate in water from Poe Branch, these areas probably do not contribute recharge to Cave Springs during stable hydrologic conditions.

Specific Conductance and Water Temperature at Cave Springs

Specific conductance and water temperature were measured hourly from July 17, 1987 to September 30, 1989 (fig. 14), in the large submerged solution opening near Cave Springs. Specific conductance, which is a function of the concentration of dissolved ions in water (Hem, 1985), was used to study changes in ground-water quality near the spring outflow. Temperature values can be used to determine potential sources of water, seasonal trends, and response times of the aquifer to storms.

The data from July 1987 to May 1988 show seasonal changes in water quality, with only small changes occurring during individual storms. Specific conductance values increased steadily as water levels declined with the progressing drought. These values indicate that additonal ions are dissolved in water in the aquifer and the cave system with increasing residence time. More rapid movement of water recently recharged to the ground-water system dilutes the concentration of ions in the spring system during periods of more active recharge, such as the winter and spring.

After June 1988, fluctuations in water levels in the cave system were accompanied by rapid changes in specific conductance and temperature values. These data indicate hydrologic conditions in the aquifer during this period were different than those during the previous year. Possibly, the increased heads within the aquifer may have induced discharge from shallower zones. The induced rapid movement of water through shallower zones could result in more rapid changes in water-quality characteristics observed at Cave Springs after June 1988.

Daily water temperatures during July 1987 to May 1988 were influenced by seasonal variations in air temperature and by changes in water temperature with depth within the aquifer. In the upper 100 feet of the earth's crust, ambient air temperature has the greatest influence on ground-water temperatures. In this zone that is affected by seasonal climatic conditions, the mean ground-water temperature is usually 1 to 2 °C higher than the mean annual air temperature (Freeze and Cherry, 1979; Heath, 1983).

The mean water temperature for the 1988 water year at Cave Springs was 14.8 °C. Water temperatures during the first 10 months of record were generally between 13.5 and 15.5 °C. Following a rise in water levels during a recharge event on September 17, 1988, an instantaneous temperature of 17.8 °C was recorded by the automatic monitor. This phenomenon was not detected during the previous summer.

Near the end of the 1989 water year, greater ranges in water temperature were recorded and the mean annual water temperature was slightly higher than in the 1988 water year. Mean daily water temperatures at Cave Springs ranged from 14.3 to 18.2 °C with a mean of 15.5 °C in water year 1989. This increase in the mean annual water temperature may be because of a greater influence of recharge water on the Cave Springs system that was not observed in the 1988 water year when rainfall and water levels in the aquifer were generally lower.

Specific-conductance values for the 1988 water year for water from Cave Springs ranged from 122 to 243 μS/cm with a mean specific conductance of 185 μS/cm. Specific conductance in 1989 did not exceed the maximum observed in 1988 until July 23, 1989, when a conductance of 405 μS/cm was recorded on an automatic monitor during a substantial rise in water levels. Instantaneous water temperature also rose sharply from 13.5 °C to 18.0 °C during this event. The

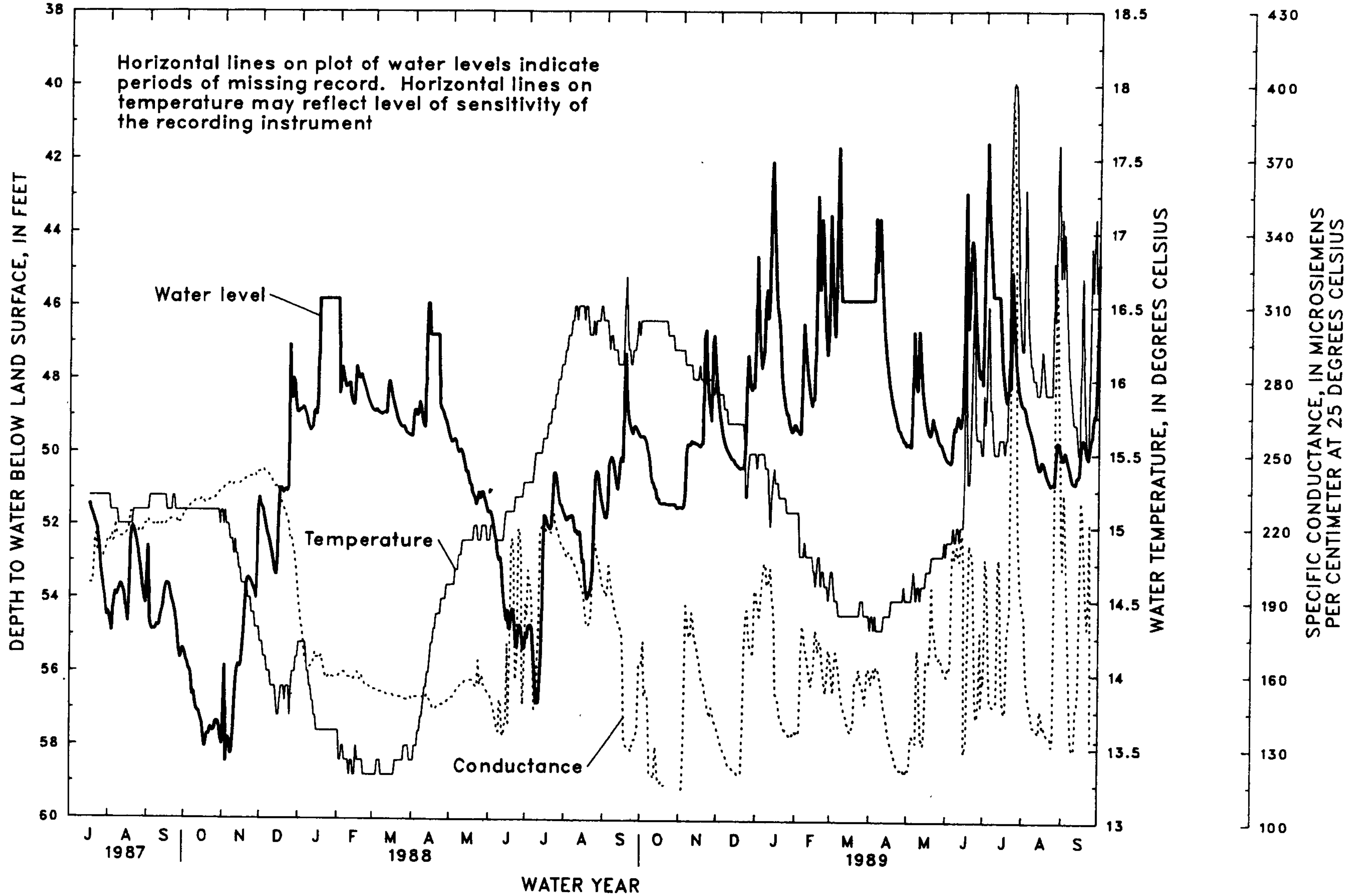


Figure 14.--Daily mean depth to water, water temperature, and specific conductance at Cave Springs from July 17, 1987, to September 30, 1989.

mean specific conductance for the 1989 water year was 163 μS/cm. This is less than the mean for the 1988 water year, consistent with the increased spring discharge and possible shorter residence time of most of the ground water contributing to the discharge of Cave Springs.

Several different sources of recharge water may be responsible for the fluctuations in water quality observed at Cave Springs. The availability of various source waters depends upon heads in the aquifer. Differences in the amount of precipitation that occurred during the dry years of 1987 and 1988, and the extremely wet year of 1989 also may account for the variable response of the Cave Springs system to recharge events. The tendency for water temperatures to decrease with winter storms and to increase as water levels rose in response to summer storms indicates that the system may have received recharge from shallow sources.

The lack of turbidity with the apparent rapid movement of recharge water is unusual. According to HUD records, these fluctuations in physical measurements were not accompanied by changes in water turbidity. Water turbidity, except during unusual circumstances such as drilling, was always less than 1.0 nephelometric turbidity unit (NTU). Changes in water quality seem to be more closely associated with changes in heads within the aquifer that affect ground-water movement than the rapid movement of surface water into the aquifer.

Declines in specific-conductance values following recharge events may indicate possible recharge from waters with low conductance, such as North Chickamauga Creek, or rapid infiltration of precipitation somewhere in the area providing recharge to the spring. Numerous sinkholes occur in the Copper Ridge Dolomite, indicating that rapid infiltration is a possibility. However, low turbidity usually is not associated with rapid surface-water recharge.

Although specific-conductance values rose sharply during some recharge events, sources of high specific-conductance water in the area are not abundant. Samples from several streams measured during the seepage investigation had specific-conductance values ranging from 350 to 400 μS/cm (Lowery and others, 1989). These streams, which include Nine-Mile Creek and Falling Water Creek, are located west of North Chickamauga Creek and drain the Pennsylvanian sandstones and shales of the Cumberland Plateau. Based on the potentiometric map, these streams probably do not provide recharge to Cave Springs. Because of the complexity of the Cave Springs system and the possibility of recharge from other sources, however, these variations in water quality in Cave Springs cannot be explained with available data.

The Tennessee River also may influence heads within the Cave Springs system, particularly with regard to pool levels that vary under different hydrologic conditions. The stage of Chickamauga Lake on the Tennessee River is regulated and possibly influences the base level of the ground-water system in the study area. Lake levels are manipulated to maintain a balance of water among the numerous reservoirs along the Tennessee River. Higher stages in Chickamauga Lake in the summer months corresponded with changes in the magnitude of specific-conductance and water-temperature variations observed at the spring.

In addition to changes in seasonal pool elevations, lake levels also respond by as much as several feet to major rain storms as large volumes of water are discharged through the system of dams. Substantial changes in water elevations in such a large body of water may induce changes in pressure heads throughout the ground-water system. Coupled with the unusual hydrologic conditions observed in the 1988 and 1989 water years, changes in heads in the aquifer may have influenced the movement of water along faults, bedding planes, and solution openings that are hydraulically connected to Cave Springs, resulting in water of different quality moving to the discharge point at the spring outlet.

SUMMARY

Cave Springs and its recharge area are located in the Valley and Ridge province in southeastern Tennessee, an area of parallel ridges and valleys that trend northeast. Cave Springs, the second largest spring in Tennessee, is the main source of water for the Hixson Utility District. Wells near the spring supply about 5 Mgal/d of water to people in an area north of Chattanooga, Tennessee. Most of the study area is underlain by folded limestones and dolomites of Cambrian and Ordovician age. The spring issues from the Newman Limestone beneath the footwall of a thrust fault separating the Newman Limestone from the overlying Copper Ridge dolomite.

Ground-water levels, spring discharge, specific conductance, and water temperature were monitored from July 17, 1987, to September 30, 1989, as part of a cooperative study between the USGS and the Hixson Utility District. The objectives of the investigation were (1) to obtain additional hydrologic data from this part of the Valley and Ridge province, (2) to identify the area providing recharge to the spring, and (3) to determine the characteristics of ground water in the study area.

Nineteen wells were drilled in the study area to provide additional geologic and lithologic data and to provide water-level data needed to determine the potentiometric surface of the spring recharge area. Wells drilled near the HUD pumping facility intersected additional water-bearing zones beneath the large solution opening currently supplying water to the utility district. Aquifer tests in which three wells at Cave Springs were pumped at a combined rate of 9,000 gallons of water per minute documented drawdowns of less than 3 feet. Aquifer tests conducted at five test wells in the study area generated specific-capacity values ranging from 4.1 to 261 (gal/min)/ft of drawdown.

A map of the potentiometric surface of the aquifer in the recharge basin was used to determine the location of the ground-water divide and the direction of most ground-water flow. Available data indicate that most water recharging Cave Springs is derived from sources east of Cave Springs Ridge. An area of approximately 10 mi^2 defined by the potentiometric surface is the likely source for most of the recharge to Cave Springs; however, the possibility of recharge from areas west of the thrust fault and along the thrust fault beneath Cave Springs Ridge cannot be eliminated.

Water-quality data collected from selected wells and streams were useful in characterizing sources of water that may be recharging the Cave Springs system. The concentration of chloride in water from the Tennessee River was large relative to chloride concentrations in water from Cave Springs, indicating the Tennessee River is not a major source of recharge to the spring. Recharge from different ground-water sources and the effect of changing lake levels along the Tennessee River may affect the hydrology of the Cave Springs system.

Results of continuous monitoring of discharge, pumping, specific conductance, and water temperature at Cave Springs indicate that conditions at the spring were affected by extreme climatic conditions that occurred prior to and during the study period. Below normal rainfall occurred from 1985 through 1988, followed by above normal rainfall and higher water levels during 1989. The period of record from July 1987 to May 1988 was different from the period of record from May 1988 to September 1989 with respect to changes in specific conductance and water temperature following storms.

Specific-conductance values for the 1988 water year (October 1, 1987, to September 30, 1988) ranged from 122 to 243 µS/cm and averaged 185 µS/cm. The mean specific conductance for the 1989 water year was 163 µS/cm. This is lower than the mean for 1988, reflecting the higher recharge and spring discharge and possible shorter residence time of most ground-water contributing to the discharge of Cave Springs.

The mean water temperature for the 1988 water year at Cave Springs was 14.8 °C. Water temperature from July 1987 to May 1988 ranged from 13.5 to 15.5 °C. In 1989, greater ranges in water temperature were recorded and the mean annual water temperature was slightly higher. Water temperatures at Cave Springs during the 1989 water year ranged from 14.3 to 18.2 °C and averaged 15.5 °C

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