Karst Hydrogeology and Hydrochemistry of the Cave Springs Basin Near Chattanooga, Tennessee

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96–4248

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A Contribution of the Regional
Aquifer-Systems Analysis-Program

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By Dianne J. Pavlicek

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Nashville, Tennessee
1996

U.S. DEPARTMENT OF THE INTERIOR
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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic feet per second (ft^3/s)	448.831	gallons per minute
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
inch of runoff per square mile per year ([(in/mi^2)/yr])	0.07367	cubic foot per second
microsiemen per centimeter at 25 °Celsius (µS/cm)	1	micromho per centimeter

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentrations are given in milligrams per liter (mg/L). Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

KARST HYDROGEOLOGY AND HYDROCHEMISTRY OF THE CAVE SPRINGS BASIN NEAR CHATTANOOGA, TENNESSEE

By Dianne J. Pavlicek

Abstract

The Cave Springs ground-water basin, located near Chattanooga, Tennessee, was chosen as one of the Valley and Ridge physiographic province type area studies for the Appalachian Valley-Piedmont Regional Aquifer-System Analysis study in 1990. Karstic Paleozoic carbonate rocks, residual clay-rich regolith, and coarse alluvium form the aquifer framework. Recharge from rainfall dispersed over the basin enters the karst aquifer through the thick regolith. The area supplying recharge to the Cave Springs Basin is approximately 7 square miles. Recharge from North Chickamauga Creek may contribute recharge to the Cave Springs Basin along losing reaches.

The flow medium consists of mixed dolomite and limestone with cavernous and fracture porosity. Flow type as determined by the coefficient of variation of long-term continuous specific conductance (18 and 15 percent) from two wells completed in cavernous intervals about 150 feet northeast of Cave Springs, indicates an aquifer with conduit flow. Flow type, based on the ratio (6:1) of spring flood-flow discharge to spring base-flow discharge, indicates an aquifer with diffuse flow. Conduit flow probably dominates the aquifer system west of Cave Springs Ridge from the highly transmissive, unconfined, alluvium capped aquifer and along losing reaches of North Chickamauga Creek. Diffuse flow probably predominates in the areas along and east of Cave Springs Ridge covered with the thick, clay-rich regolith that forms a leaky confining layer.

Based on average annual long-term precipitation and runoff records, the amount of water available for recharge to Cave Springs is 11.8 cubic feet per second. The mean annual long-term discharge of Cave Springs is 16.4 cubic feet per second which leaves 4.6 cubic feet per second of recharge unaccounted for. As determined by low-flow stream discharge measurements, recharge along losing reaches of North Chickamauga Creek may be an important source of unaccounted-for-recharge to the Cave Springs Basin.

Selected ground-water samples in the study area are characterized by calcium bicarbonate type water and calcium magnesium bicarbonate type water. Calcium bicarbonate type water characterizes Lick Branch and Poe Branch. North Chickamauga Creek water is calcium magnesium sulfate type water and reflects interaction with the pyrite-containing siliciclastic rocks of the Cumberland Plateau or acid mine drainage. Seasonal high spring discharge is associated with lower specific conductance and lower temperatures, which lag in response to increasing spring discharge by approximately 2 months. Seasonal decrease in spring discharge is accompanied by an incident increase in specific conductance and temperature increase, which leads by about 4 months.

INTRODUCTION

Ground water is an important resource for domestic, municipal, and industrial supply throughout the Valley and Ridge physiographic province, which extends from Alabama to Pennsylvania. The aquifer systems in the Valley and Ridge and Piedmont Provinces, however, are not regionally continuous. As part of a Regional Aquifer-Systems Analysis (RASA) study of the two provinces, representative areas that typify the flow systems were selected for 'type-area' investigations to characterize the hydrogeology and hydrochemistry. In February 1990, the Cave Springs ground-water basin near Hixson, Tennessee, was selected for one of these areal studies.

Cave Springs, a dominant feature of the Cave Springs ground-water basin, is one of the most productive spring systems in Tennessee and is a single spring used by the Hixson Utility District to supply about 5 million gallons of water per day for domestic and municipal use. Aquifers in the Cave Springs area are characterized by fractures and solution openings in a karstic carbonate system. Ground-water occurrence and flow in the Cave Springs system are typical of spring basins in the carbonate aquifers in the Valley and Ridge physiographic province, and the results of this investigation are intended to provide information on similar karst basins.

Purpose and Scope

This report describes the hydrogeology and hydrochemistry of the Cave Springs Basin. Three test wells were drilled to define the potentiometric surface and the aquifer framework. Continuous water-level data were collected at three wells to determine response time to rainfall events. A continuous record of Cave Springs discharge and specific-conductance data were used to determine the flow type, whether conduit or diffuse, in the Cave Springs Basin. A quantitative dye-trace was performed to determine potential connection, ground-water travel time, and flow paths to Cave Springs. Low-flow stream discharge was measured to identify intervals where gains or losses in discharge occur. Water-quality data were collected at 16 wells and 3 surface-water sites to determine major ion chemistry. A continuous record of Cave Springs discharge, specific conductance, and temperature were used to characterize water-quality trends.

Description of Study Area

Cave Springs is close to the interface of the Appalachian Plateaus and the easternmost part of the Cumberland Plateau Section, which are dominated by siliciclastic rock, and the Valley and Ridge physiographic provinces, which are dominated by carbonate rock (fig. 1). Walden Ridge of the Appalachian Plateaus physiographic province, has altitudes of as much as 1,700 ft above sea level, and borders the study area to the west. At the base of Walden Ridge along the Cumberland Escarpment and throughout the Cave Springs Basin, altitudes range from about 700 to 900 ft above sea level. The Tennessee River forms the eastern boundary of the study area. Land use in Cave Springs Basin is primarily residential.

A humid, temperate climate is characteristic of the study area. In 1990, the average annual temperature in Chattanooga was 62.8 °F (+3.3 °F departure from normal) and annual total precipitation was 68.56 in. (+15.96 in. departure from normal) (National Oceanic and Atmospheric Administration, 1990).

Geology

The geology of the Cave Springs area includes Paleozoic carbonate rock formations with karst features, clay-rich regolith and alluvium. Solution openings have developed in the carbonate units. The rocks have also been fractured and structurally deformed by faulting associated with the formation of the Appalachian Mountains.

Sedimentary rocks ranging in age from Cambrian through Pennsylvanian underlie the study area (fig. 2). Siliciclastic rocks of Pennsylvanian age predominate on the Cumberland Plateau. Carbonate rock units ranging in age from Mississippian through Cambrian predominate in the Valley and Ridge Province. Carbonate units of significance within the Cave Springs Basin study area include, from youngest to oldest: the Mississippian Newman Limestone (limestone), the Ordovician Chickamauga Limestone (shaly and nodular limestone), the Ordovician Knox Group (dolomite and minor limestone), the Cambrian and

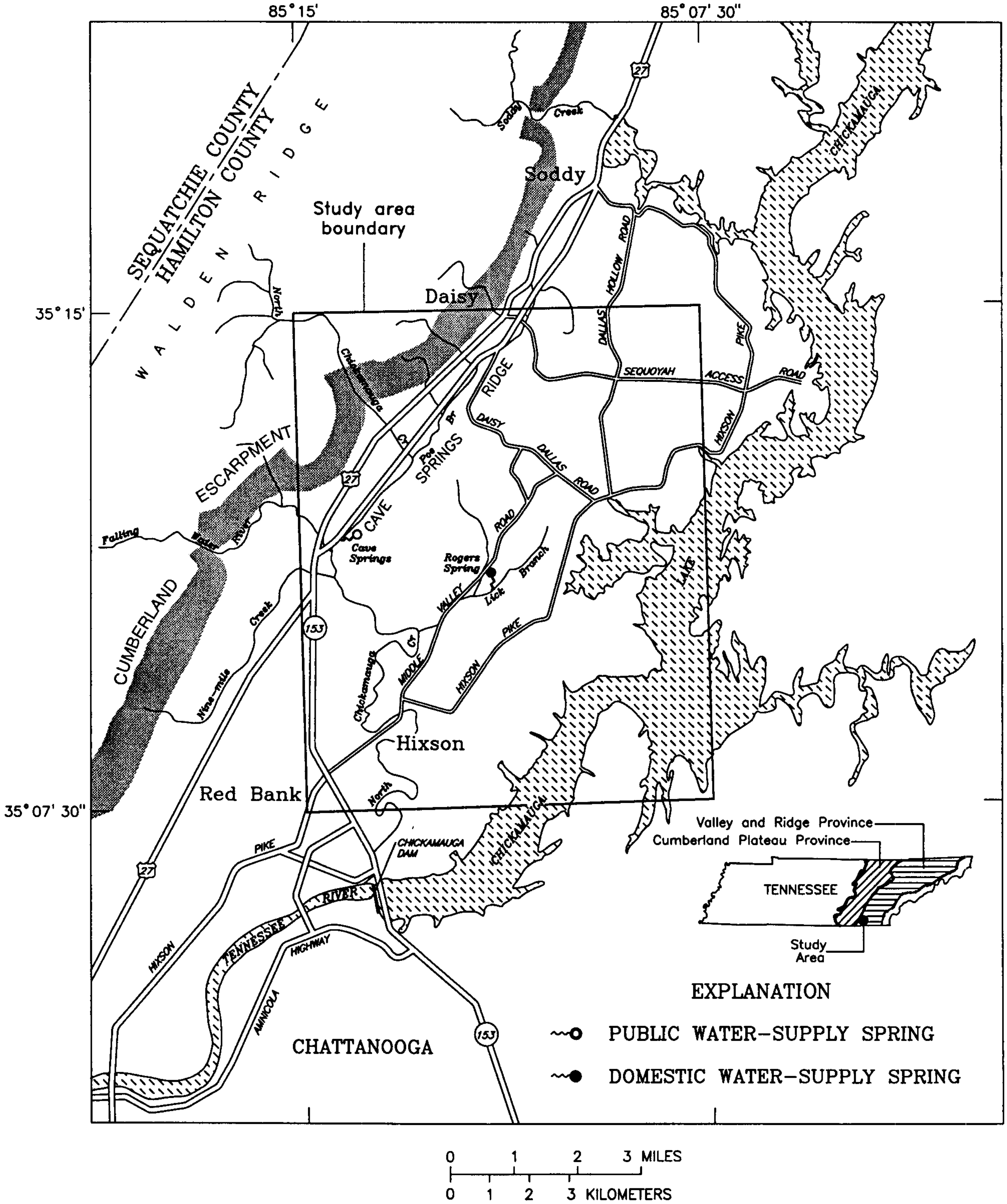


Figure 1.--Physiographic, hydrologic, and cultural features in the Cave Springs area near Chattanooga, Tennessee.

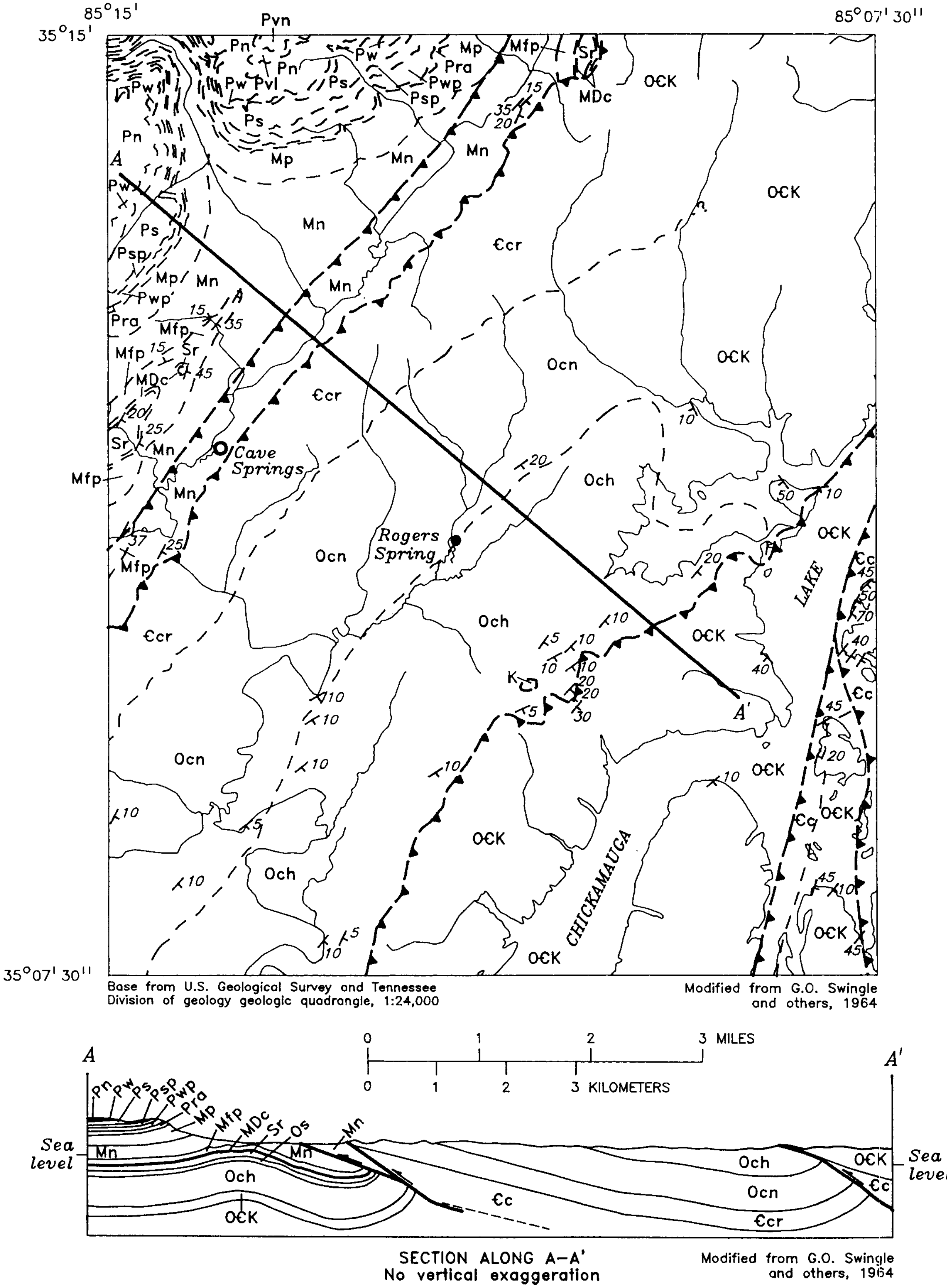


Figure 2.--Geologic map and generalized section of the Cave Springs study area, Tennessee.

EXPLANATION

GEOLOGIC UNITS

Pvn, Pvl	Vandever Formation	PENNSYLVANIAN
Pn	Newton Sandstone	PENNSYLVANIAN
Pw	Whitwell Shale	PENNSYLVANIAN
Ps	Sewanee Conglomerate	PENNSYLVANIAN
Psp	Signal Point Shale	PENNSYLVANIAN
Pwp	Warren Point Sandstone	PENNSYLVANIAN
Pra	Raccoon Mountain Formation	PENNSYLVANIAN
Mp	Pennington Formation	MISSISSIPPIAN
Mn	Newman Limestone	MISSISSIPPIAN
Mfp	Fort Payne Formation	MISSISSIPPIAN
MDc	Chattanooga Shale	DEVONIAN and MISSISSIPPIAN
Sr	Rockwood Formation	SILURIAN
Os	Sequatchie Formation	ORDOVICIAN
Och	Chickamauga Limestone	ORDOVICIAN
Ocn	Chepultepec and Longview Dolomites and Newala Formation (OꞒk Knox Group)	ORDOVICIAN
Ꞓcr	Copper Ridge Dolomite (OꞒk Knox Group)	CAMBRIAN
Ꞓc	Conasauga Group	CAMBRIAN

———? CONTACT—Dashed where approximate, Queried where extent of contact indeterminate

——▲—— THRUST FAULT—Approximately located. Sawteeth on upthrown block

A——A' LINE OF SECTION

K ⬭ KLIPPE

⟋45 STRIKE AND DIP OF BEDS

Note: Stratigraphic nomenclature of Tennessee Division of Geology nomenclature differs from U.S. Geological Survey usage.

Ordovician Knox Group undifferentiated (dolomite and minor limestone), and the Cambrian Copper Ridge Dolomite (dolomite and chert).

A thick regolith consisting of a red, clay-rich residuum or terra rosa was formed by prolonged, in situ chemical weathering (Carroll and Starkey, 1959; Hack, 1965; Mills and others, 1987). The regolith is composed of insoluble residual constituents (clay minerals and chert) weathered from the carbonate rock, and predominates along and east of Cave Springs Ridge. However, regolith-free rock with solution enlarged joints crops out along the west side of Cave Springs Ridge. Within the study area, data from test holes indicate that the regolith covering the Copper Ridge Dolomite ranges in thickness from 124 to 128 ft and that the thickness of regolith covering the upper Knox Group ranges from 16 to 127 ft. A contact between regolith and rock at an abandoned quarry in the Newman Limestone along Cave Springs Ridge shows a variable regolith thickness from about 1 to 20 ft (fig. 3). In the Cave Springs area, thick clay-rich regolith acts as a leaky confining layer and is important as a ground-water storage reservoir (DeBuchananne and Richardson, 1956).

Coarse alluvium eroded from the siliciclastic rocks of the Cumberland Plateau covers the Newman Limestone west of Cave Springs Ridge, particularly in the vicinity of North Chickamauga Creek. The alluvium commonly consists of gravel, cobbles, and boulders.

Thrust faults formed during the Alleghenian mountain building trend northeast to southwest through the study area and the Valley and Ridge physiographic province (Rodgers, 1970; Hatcher and others, 1989). Three thrust faults occur in the Cave Springs area (fig. 2). Cave Springs issues from the Newman Limestone between two of these thrust faults. Fracturing likely is more concentrated in carbonate rock wedges between these two or other closely spaced thrust faults.

Previous Investigations

Rodgers (1953) compiled and described the geology of East Tennessee. DeBuchananne and Richardson (1956) described the ground-water resources of East Tennessee. Sun and others (1963) analyzed 84 springs in East Tennessee in terms of magnitude and variability of discharge. Swingle and others (1964)

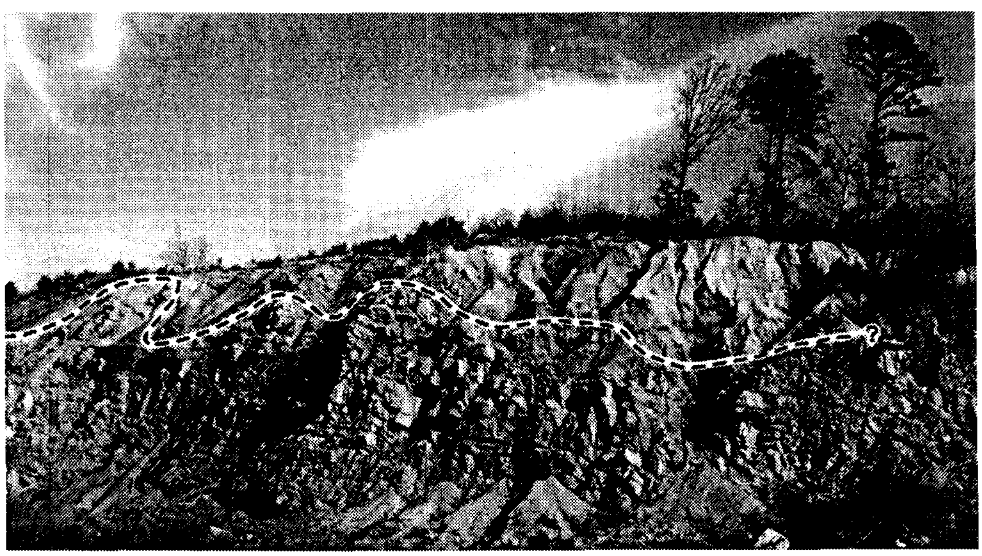


Figure 3.--Regolith and rock contact in the Newman Limestone along U.S. Highway 27, near Soddy-Daisy, Tennessee (1 inch equals approximately 30 feet).

mapped in detail the geology of the Daisy 7-1/2 minute quadrangle and summarized the mineral resources of the area. Data from 171 large springs predominantly within the Valley and Ridge physiographic province were analyzed by Hollyday and Smith (1990). The hydrology of the Cave Springs area was initially described by Bradfield (1992).

Acknowledgments

The author thanks property owners in the study area for granting permission to drill test wells. Extensive discussions with Neven Kresic (U.S. Geological Survey, Visiting Scholar, University of Belgrade, Yugoslavia), James Quinlan (Quinlan & Associates, Inc.), and Albert T. Rutledge (U.S. Geological Survey) aided the author in completing this study.

KARST HYDROGEOLOGY

The Cave Springs area is characterized by karst terrane. Carbonate units including the Newman Limestone, Chepultepec and Longview Dolomites, and Newala Formation, and the Copper Ridge Dolomite have small- and large-scale solution openings and sinkholes (nomenclature follows Tennessee Division of Geology usage). Ground-water movement occurs as conduit flow in the carbonate bedrock and as diffuse flow through the overlying regolith. Recharge to the ground-water system is primarily dispersed over the basin from precipitation and secondarily concentrated at sinkholes and losing streams.

Recharge

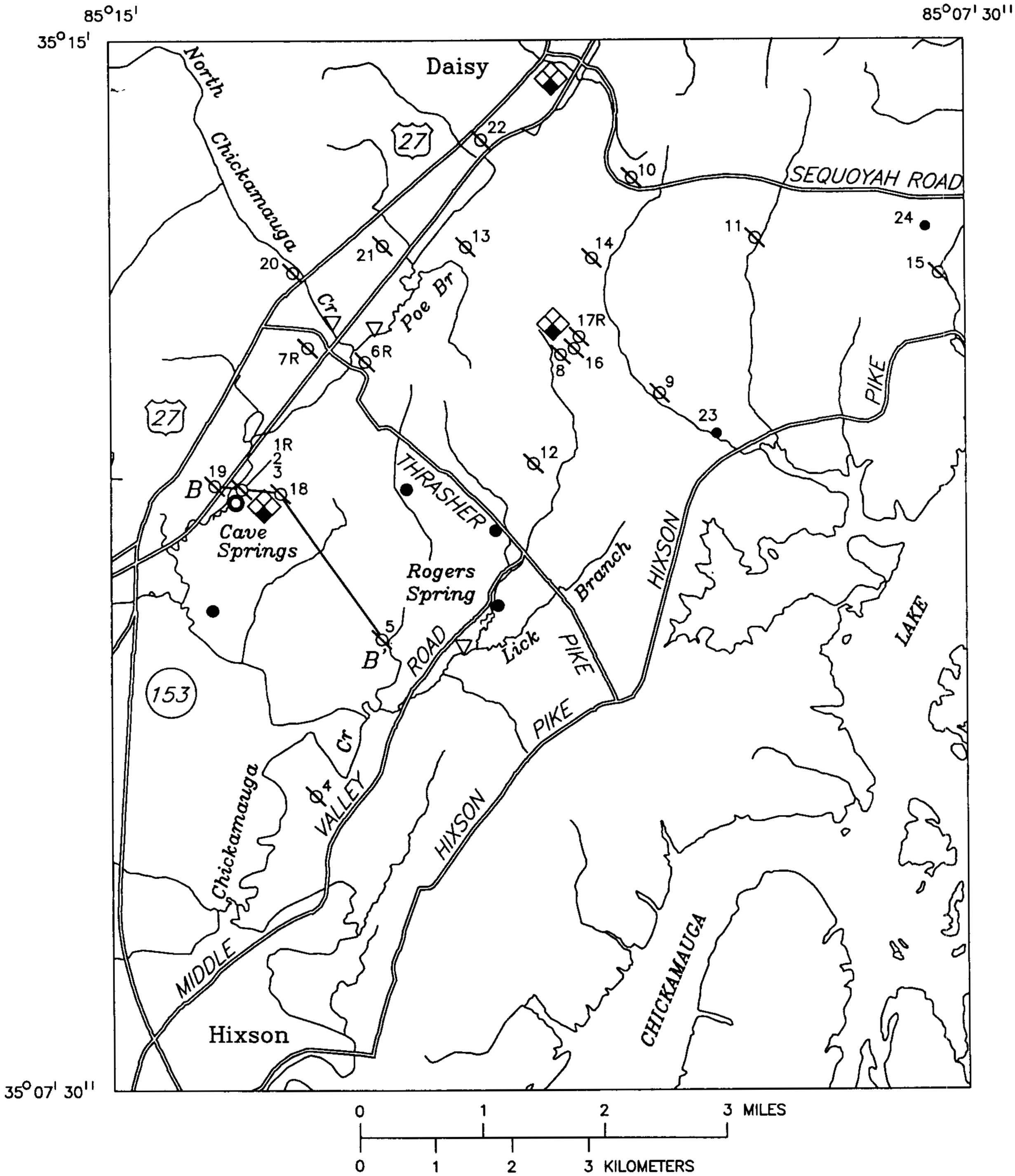
Recharge to the ground-water system in karst terrane varies over a continuum between dispersed and concentrated (Smart and Hobbs, 1986). Recharge within the Cave Springs Basin is primarily dispersed by entering the ground-water system through thick regolith. The significance of recharge associated with sinkholes in the basin is not known. Recharge from losing stream reaches along North Chickamauga Creek and other streams could contribute to the ground-water system. Sinking or disappearing streams, which are characteristic of a mature karst system, have not been observed in the study area.

Subsurface Flow

Subsurface flow in karst terrane occurs over a continuum between conduit and diffuse end members. Conduit flow refers to ground-water flow through solution openings with diameters ranging from inches to tens of feet. Flow is usually turbulent and velocities are commonly on the order of feet per second. Diffuse flow refers to ground-water flow in small fractures and pores with small, interconnected openings. Diffuse flow can be described by Darcy's Law and has relatively low velocities (Schuster and White, 1971).

Fracture and cavernous porosity occurs in the Cave Springs area. Fractures enlarged by solution have been observed in the field along Cave Springs Ridge above Cave Springs where regolith-free Newman Limestone crops out. Geophysical logs from wells throughout the basin commonly indicate cavernous porosity in most of the carbonate formations. Wells 1 and 2 at the Hixson Utility District pumping facility, located about 150 ft northeast of Cave Springs, intercepted an extensive cavernous interval 65 to 70 ft below land surface (fig. 4; table 1). The full extent of this possible conduit is not known. There is also a vadose cave (a cave occurring above the water table) southeast of the pumping facility that trends approximately 260 ft along strike.

The subsurface flow type cannot be determined by only the type of opening at a spring orifice. Because a spring appears to flow from a conduit does not mean that the aquifer is dominated by conduit flow (Quinlan and others, 1991). The subsurface-flow type can be estimated from (1) the coefficient of variation



EXPLANATION

- B—B' HYDROGEOLOGIC SECTION
- PUBLIC-WATER SUPPLY SPRING
- DOMESTIC-WATER SUPPLY SPRING
- DOMESTIC-WATER SUPPLY WELL
- 4 OBSERVATION WELL AND NUMBER
- R OBSERVATION WELL EQUIPPED WITH RECORDER
- PRECIPITATION STATION
- SURFACE-WATER SAMPLING SITE

Figure 4.--Location of springs, wells, and precipitation stations in the Cave Springs study area, Tennessee.

Table 1. Data for selected wells in the Cave Springs study area

[gal/min, gallons per minute; gal/min/ft, gallons per minute per foot; >, greater than; ---, no data]

Well number (fig. 4)	Station number	Depth of well (feet)	Bottom of casing (feet below land surface)	Estimated yield during drilling (gal/min)	Water-bearing zones (depth, in feet)	Specific capacity (gal/min/ft of drawdown)	Pumping rate (gal/min)
1	351148085135301	71	61	3,000	65-70	---	---
2	351148085135302	73	73	3,000	65-70	---	---
3	351148085135303	398	82	>300	160, 190, 260	---	---
4	350937085131401	242	42	15	199	---	---
5	351041085123701	322	150	300	180, 270	31.5	300
6	351239085125001	103	95	400	59-71, 75-93, 98-103	---	---
7	351248085131601	162	90	100	131-142, 151-157	---	---
8	351249085110101	223	182	400	201-220	245	235
9	351228085101001	142	97	200	95-131	0.2	250
10	351356085102501	302	132	1	150-200	---	---
11	351335085091701	250	250	40	200-250	---	---
12	351158085111701	202	202	200	170-200	8.3	270
13	351328085115501	101	101	50	70-90	---	---
14	351326085103701	171	171	50	165-171	---	---
15	351320085074001	280	280	50	78	---	---
16	351250085110201	312	182	200	185-235, 275, 289	---	---
17	351252085110001	222	167	500	130-140, 170, 195-198	---	---
18	351147085133101	480	235	25	320, 417	---	---
19	351150085140501	202	126	600	95-100, 127-129	---	---
20	351320085132001	202	167.5	200	170-174, 178-186	---	---
21	351338085122801	202	62.5	600	80-86, 100-113, 125-128, 185-188	---	---
22	351407085114701	202	120	600	121-126, 135-138, 150-155	---	---

of continuous specific conductance expressed as a percentage and (2) the ratio of flood-flow to base-flow discharge from a spring. A direct relation exists between water hardness and specific conductance when calcium, magnesium, and bicarbonate ions predominate (White, 1988, p. 136). Springs with conduit flow in the Appalachians of central Pennsylvania have water with highly variable hardness values (coefficient of variation, 10 to 24 percent; Schuster and White, 1971). Diffuse flow springs have water with stable hardness values (coefficient of variation, less than 5 percent).

Specific conductance was monitored from October 25, 1990, through September 30, 1991, at wells 2 and 3 at the Hixson Utility District pumping facility. A pump placed 66 ft below land surface in well 2 supplied water to a U.S. Geological Survey (USGS) flow-through monitor which measured specific conductance at 15-minute intervals. Specific-conductance data at well 3, approximately 35 ft north of well 2, was measured by another flow-through monitor which received a continuous flow of water pumped from a cavernous interval at a depth of 170 ft below land surface. A statistical analysis of the mean daily specific conductance was conducted to estimate subsurface-flow type. The coefficients of variation of specific conductance in water from wells 2 and 3 were 18 percent and 15 percent, respectively, which are typical values for an aquifer with conduit flow.

White (1988) and Quinlan and others (1991) reported that subsurface flow-type can be determined from the ratio of flood-flow to base-flow discharge. The peak annual discharge at Cave Springs for the 1991 water year (October 1990 to October 1991) was 44 ft^3/s; the lowest discharge was 7.4 ft^3/s. A 6:1 ratio of flood-flow discharge to base-flow discharge at Cave Springs indicates an intermediate- to slow-response spring system dominated by diffuse flow.

Inconsistent results in determining the flow type of the Cave Springs Basin is caused by to the complexity of the hydrology of the ground-water basin. Areas west of Cave Springs Ridge are covered by a veneer of alluvium, whereas areas along and east of Cave Springs Ridge within the Cave Springs Basin are covered predominantly by thick, clay-rich regolith (fig. 3). Continuous water-level data collected at wells 1, 6, and 7 exhibit a relatively quick and parallel response to recharge events (fig. 5), indicating unconfined conditions. Well 1 is located on Cave Springs Ridge and is completed in the Newman Limestone. Wells 6 and 7 are located in the stream valley of North Chickamauga Creek, in a wedge of Newman Limestone bounded by thrust faults. This may be the most intensely fractured segment in the study area and, therefore, a zone with high transmissivities. In contrast, continuous water-level data collected at well 17, east of Cave Springs Ridge (fig. 6), indicate a slow, steady response to recharge that is typical of leaky confined conditions.

Conduit flow predominates along and west of Cave Springs Ridge as determined by the coefficient of variation of specific conductance. Significant amounts of recharge to the ground-water system occur west of Cave Springs Ridge and along losing reaches of North Chickamauga Creek. Diffuse recharge and flow under semiconfined conditions predominate in the area east of Cave Springs Ridge as determined from flood-flow/base-flow discharge ratios and water-level fluctuations.

Basin Boundaries and Aquifer Thickness

The approximate boundary of the Cave Springs Basin was determined from potentiometric-surface maps prepared for low- and high-stage water levels (figs. 7 and 8). The southeastern boundary is formed by a ground-water divide, and the northeastern boundary is a ground-water divide that approximately corresponds to a surface-water divide. Ford and Williams (1989) caution that in karst areas, ground-water divides often deviate substantially from surface watersheds. Thus, placement of the northeast boundary is tentative. Basin boundaries to the northwest and west appear to be associated with stream divides. The southeastern basin boundary shifts with seasons due to aerial variation in recharge. Based on these approximations and the high-stage potentiometric surface, the area supplying recharge to Cave Springs is about 7 mi^2.

Aquifer thickness in the Cave Springs study area can be estimated from geophysical-log information from test wells 3 and 18, the deepest wells in the study area. Test well 3 penetrates the saturated zone about 350 ft and test well 18 penetrates the saturated zone about 300 ft (fig. 9). Geophysical logs from both wells (fig. 10) indicate karst features at and near the bottom of the wells. Such features can indicate active ground-water flow (Ford and Williams, 1989). Aquifer thickness inferred from the geophysical-log information is at least 350 ft. More wells are needed to define the aquifer thickness more precisely.

Dye-Trace Results

A quantitative dye-trace was started on August 20, 1991, to determine the potential connection, ground-water travel time, and flow paths to Cave Springs. Nine pounds of 20-percent Rhodamine WT were injected into well 6, and 5 pounds of 75-percent Fluorescein were injected into well 7. Monitoring to detect dye was conducted at Cave Springs and Rogers Springs. Samples were retrieved and analyzed with a filter fluorometer on a weekly basis. Selected samples were analyzed with a scanning spectrofluorophotometer as a check for low dye concentrations. As of January 31, 1992, no dye had been detected and the test was

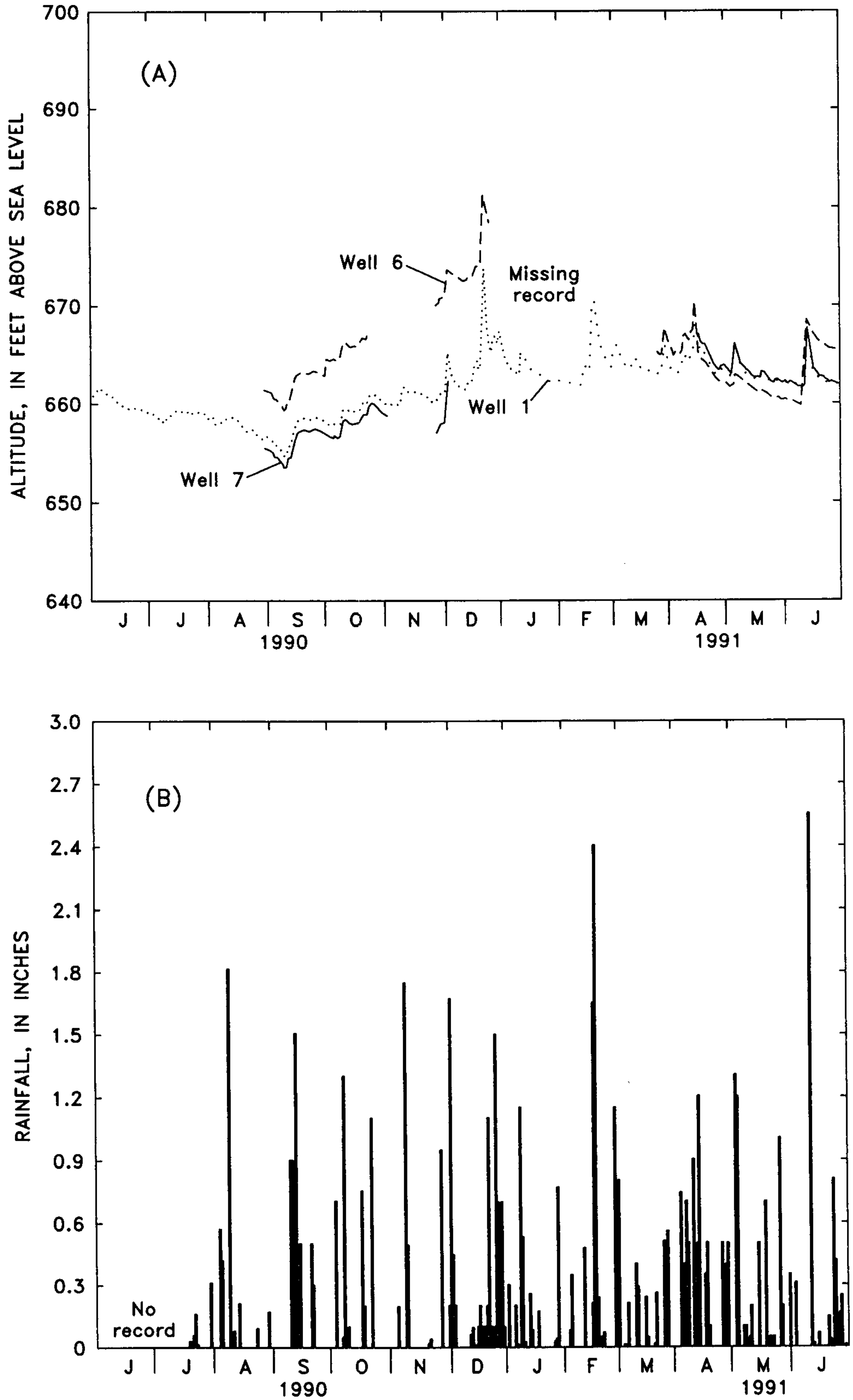


Figure 5.--Continuous water levels in (A) wells 1, 6, and 7 and (B) rainfall data in the Cave Springs study area, Tennessee.

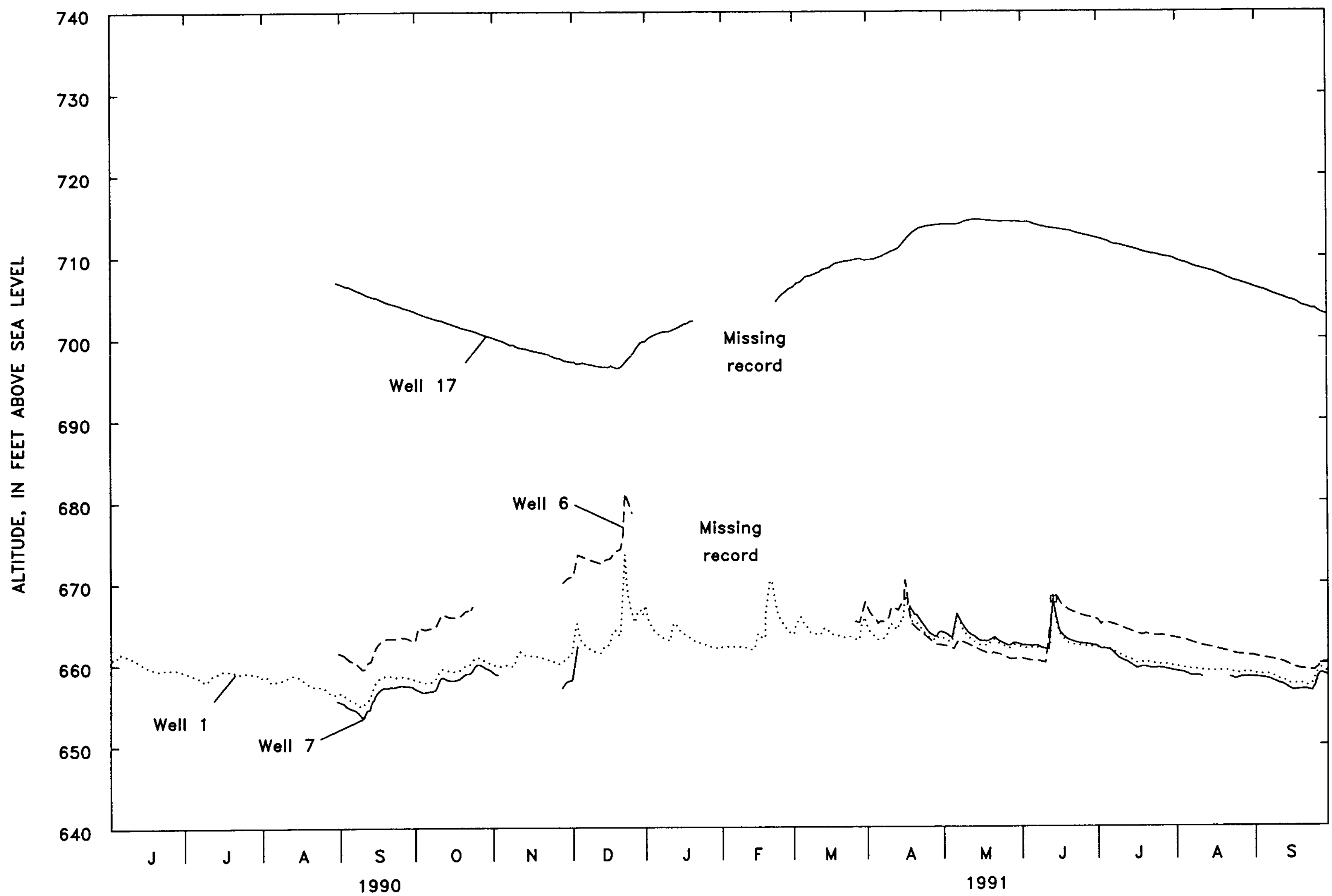
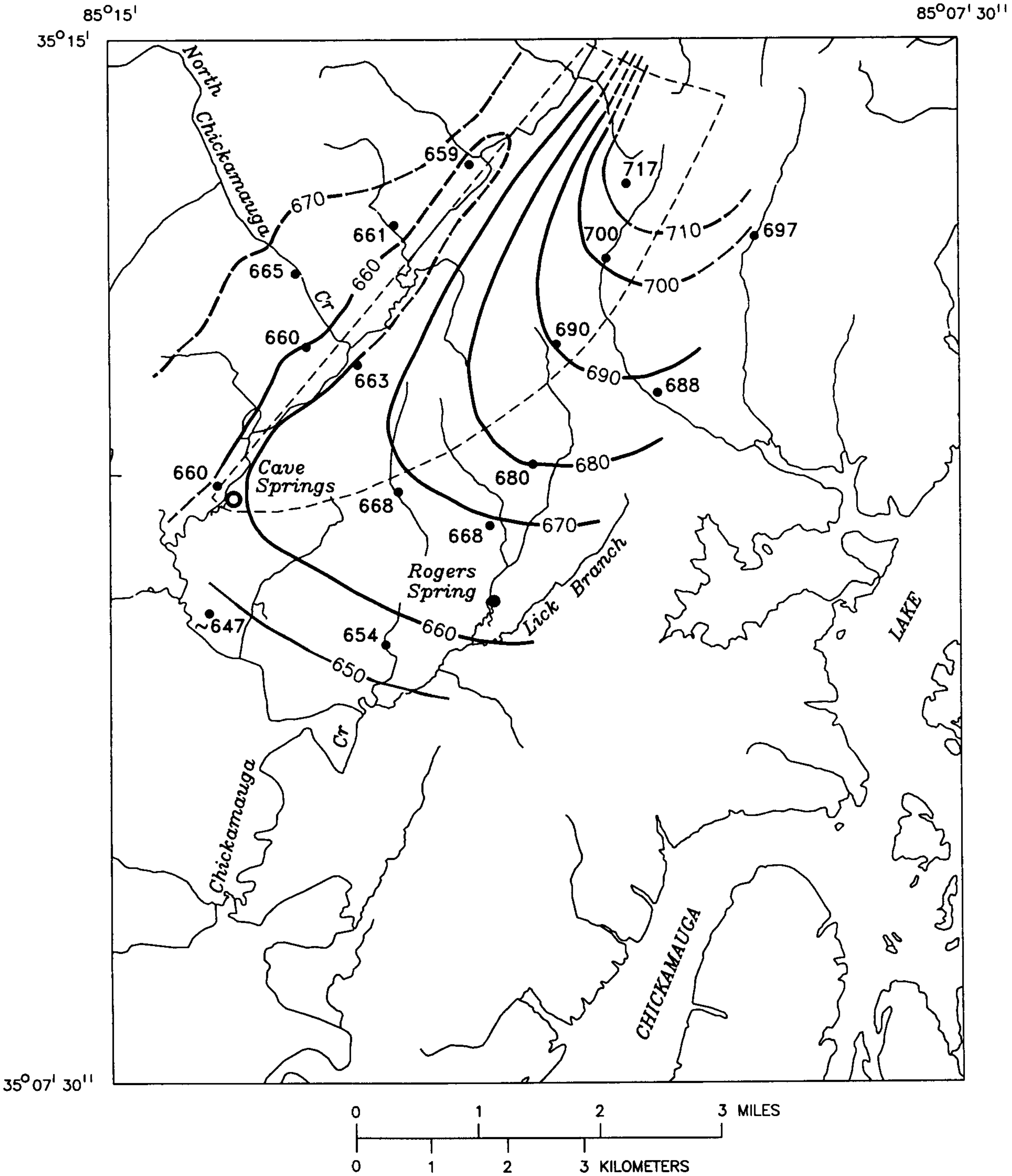


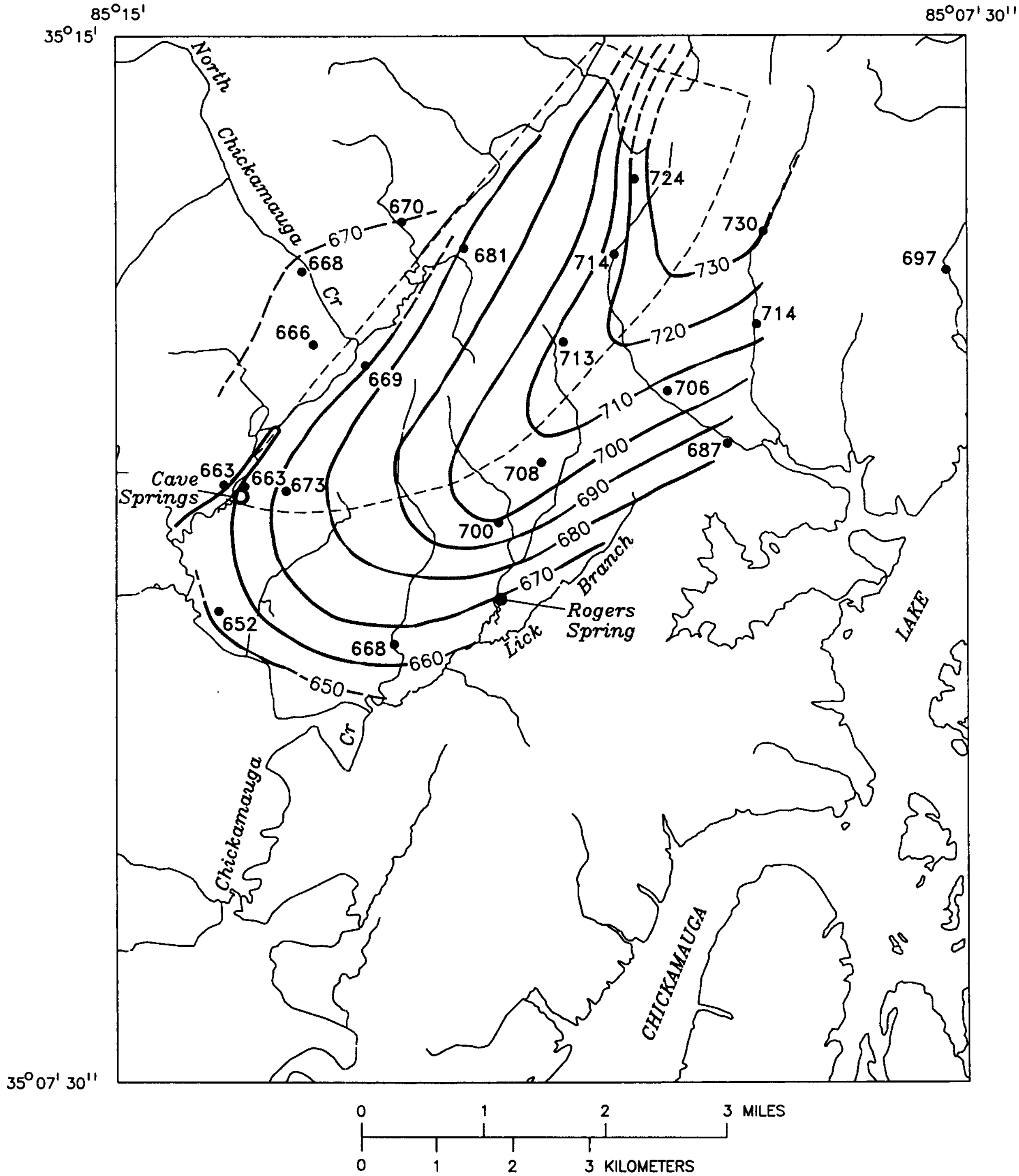
Figure 6.--Continuous water levels in wells 1, 6, 7, and 17 in the Cave Springs study area, Tennessee.



EXPLANATION

—650— —	POTENTIOMETRIC-SURFACE CONTOUR--Shows altitude at which water level stands in tightly cased wells. Dashed where inferred. Contour interval 10 feet. Datum is sea level
- - - - - - -	APPROXIMATE BOUNDARY OF CAVE SPRING RECHARGE AREA
654•	WELL AND MEASURED WATER-LEVEL ALTITUDE

Figure 7.--Low-stage potentiometric surface map of the Cave Springs study area, Tennessee, for November 19-20, 1990.



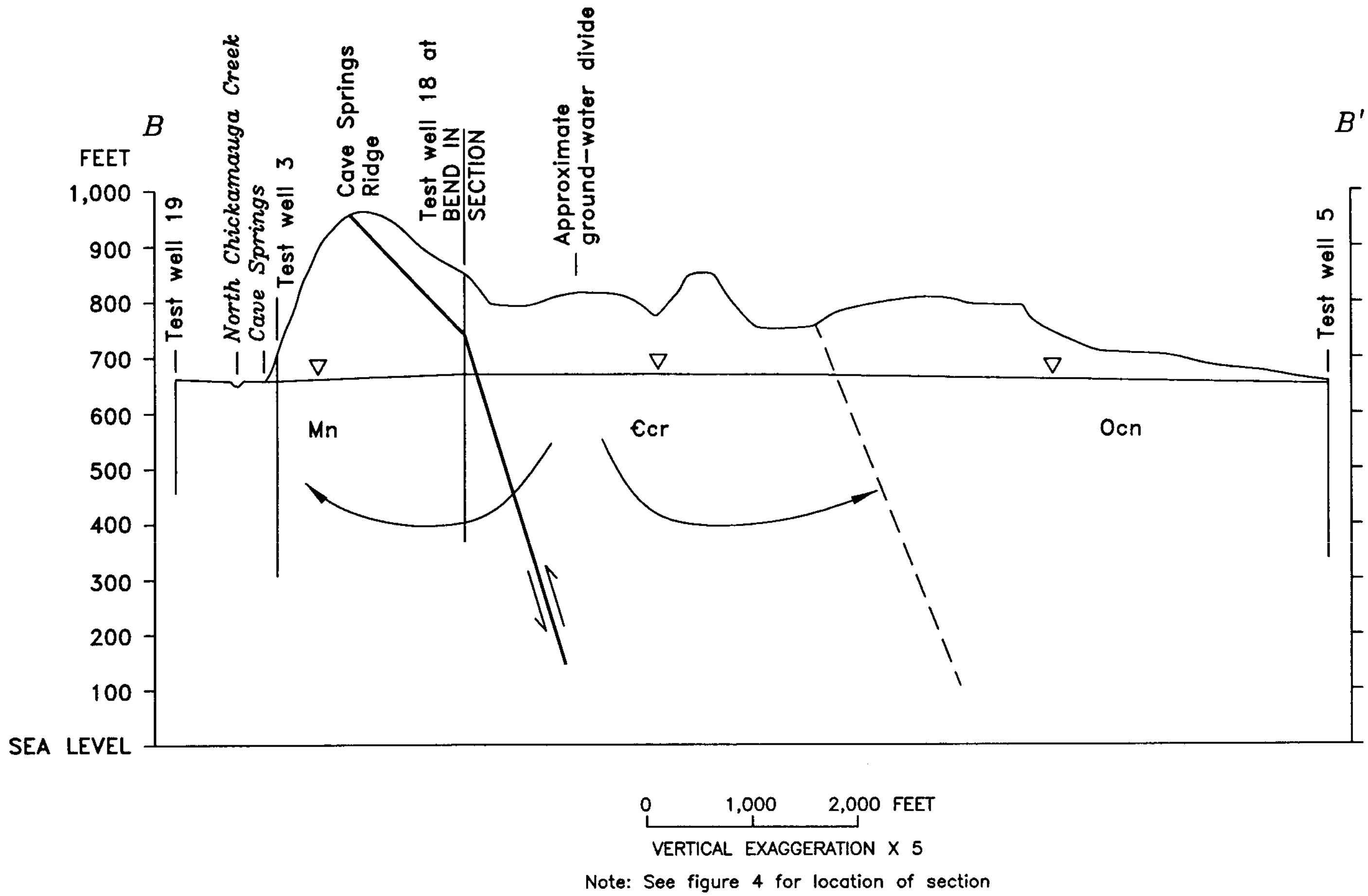
EXPLANATION level stands in

—650— — POTENTIOMETRIC-SURFACE CONTOUR--Shows altitude at which water level stands in tightly cased wells. Dashed where inferred. Contour interval 10 feet. Datum is sea level

- - - - - - - APPROXIMATE BOUNDARY OF CAVE SPRING RECHARGE AREA

668• WELL AND MEASURED WATER-LEVEL ALTITUDE

Figure 8.--High-stage potentiometric surface map of the Cave Springs study area, Tennessee, for April 24-25, 1991.



EXPLANATION

Mn NEWMAN LIMESTONE

Ocn KNOX GROUP

€cr COPPER RIDGE DOLOMITE

— — — — GEOLOGIC CONTACT, APPROXIMATE

THRUST FAULT, ARROWS INDICATE RELATIVE MOVEMENT

ARROWS INDICATE GENERAL DIRECTION OF GROUND-WATER MOVEMENT

▽ WATER TABLE--Represents average conditions

Figure 9.--Generalized hydrogeologic section, Cave Springs area, Tennessee.

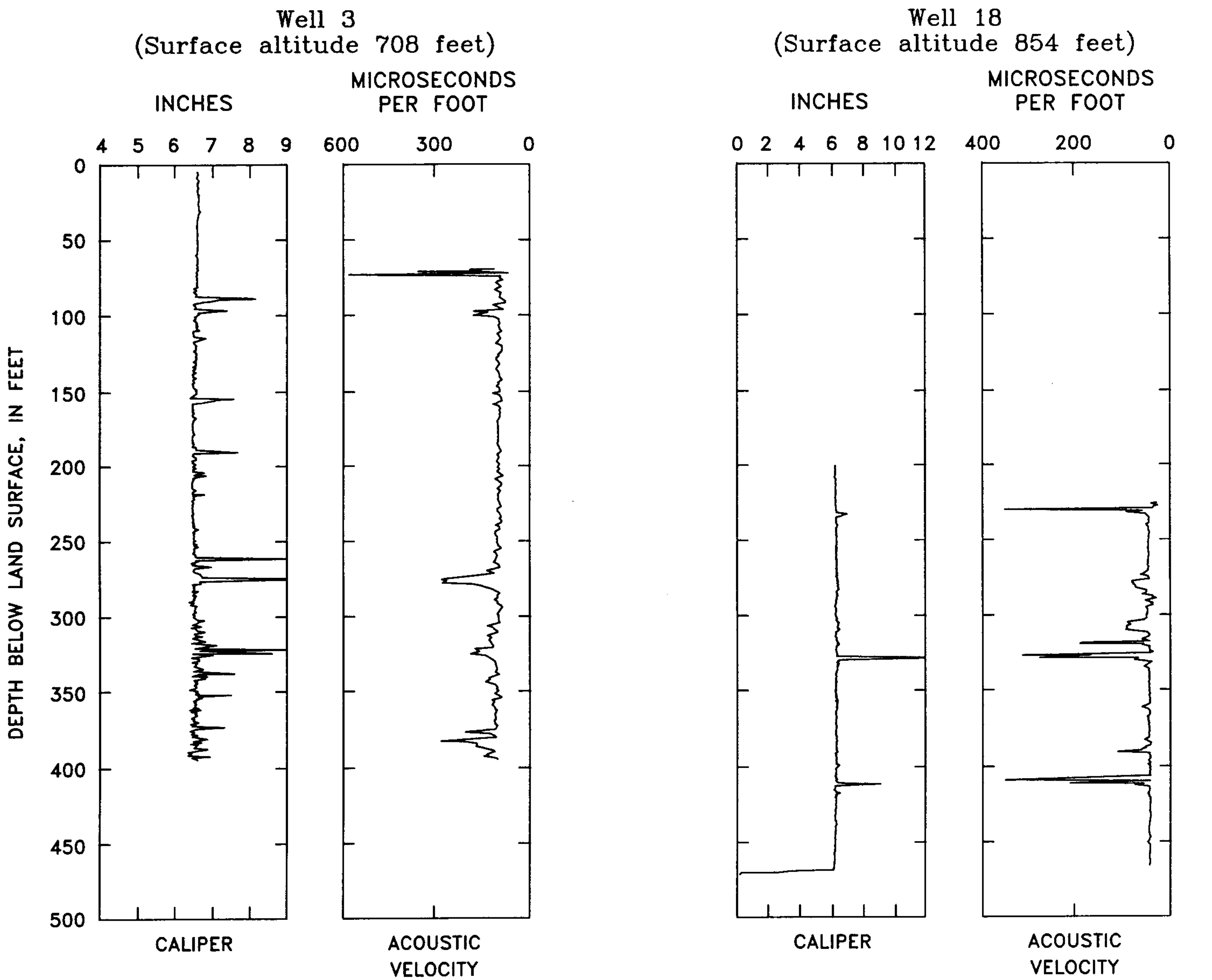


Figure 10.--Caliper and acoustic velocity logs of wells 3 and 18 in the Cave Springs study area, Tennessee.

terminated. The dyes may have dispersed before reaching the spring, may have discharged at unknown point(s), or may have been traveling slowly through the system when the test was terminated.

Low-Flow Discharge Measurements in Streams

Low-flow stream discharge was measured in the study area to identify intervals of gains or losses in discharge and to determine seasonal variation in discharge (Riggs, 1972). Gains in streamflow indicate discharge from the ground-water system, whereas losses in streamflow indicate recharge to the system. Discharge measurements from a low-flow investigation were conducted on March 3, 1988 (fig. 11) (Lowery and others, 1989). Analysis of the data indicates that gaining reaches occur along North Chickamauga Creek and Lick Branch, and a losing reach occurs along North Chickamauga Creek. A comparison of low-flow measurements collected on April 23, 1991, and July 18, 1991 (Mercer and others, 1992) (figs. 12 and 13), reveals predominantly negligible discharge during July. The downstream segments of North Chickamauga Creek were gaining flow in both April and July. The losing reach of North Chickamauga Creek revealed in the March 1988 and April 1991 investigations could be an important source of recharge to the ground-water system.

Cave Springs Discharge and Ground-Water Withdrawals

Cave Springs discharges into a pool from a manmade structure underlying a railway at the base of Cave Springs Ridge. Flow from the pool reaches North Chickamauga Creek through a short tributary. The mean of 28 spring-discharge measurements from 1928 to 1954 is 17.5 ft^3/s (Sun and others, 1963; Hollyday and Smith, 1990). Cave Springs is a second-order magnitude spring (average discharge is 10 to 100 ft^3/s). Mean daily discharge from Cave Springs for the period June 1, 1990, to September 30, 1991, (fig. 14) was 14.2 ft^3/s with a standard deviation of 9.9 ft^3/s. Maximum discharge for the same period was 42.0 ft^3/s. Mean daily spring discharge during the relatively dry 1988 water year was 10.3 ft^3/s, and maximum discharge was 31 ft^3/s. During the relatively wet 1989 water year, mean daily spring discharge was 19.5 ft^3/s and maximum discharge was 34 ft^3/s (Bradfield, 1992).

Daily withdrawals from the Cave Springs ground-water system by the Hixson Utility District from June 1, 1990, to September 30, 1991, ranged from about 4.5 ft^3/s to about 12 ft^3/s (fig. 14), and averaged 7.9 ft^3/s. The hydrographs of figure 14 indicate no visible effect of the utility district's withdrawals on discharge from Cave Springs.

Water Balance

The water balance describes the recharge, discharge, and change in storage in a hydrologic system. When considering long-term average conditions in an unstressed system, the change in storage is zero; thus, the water balance equation can take the form:

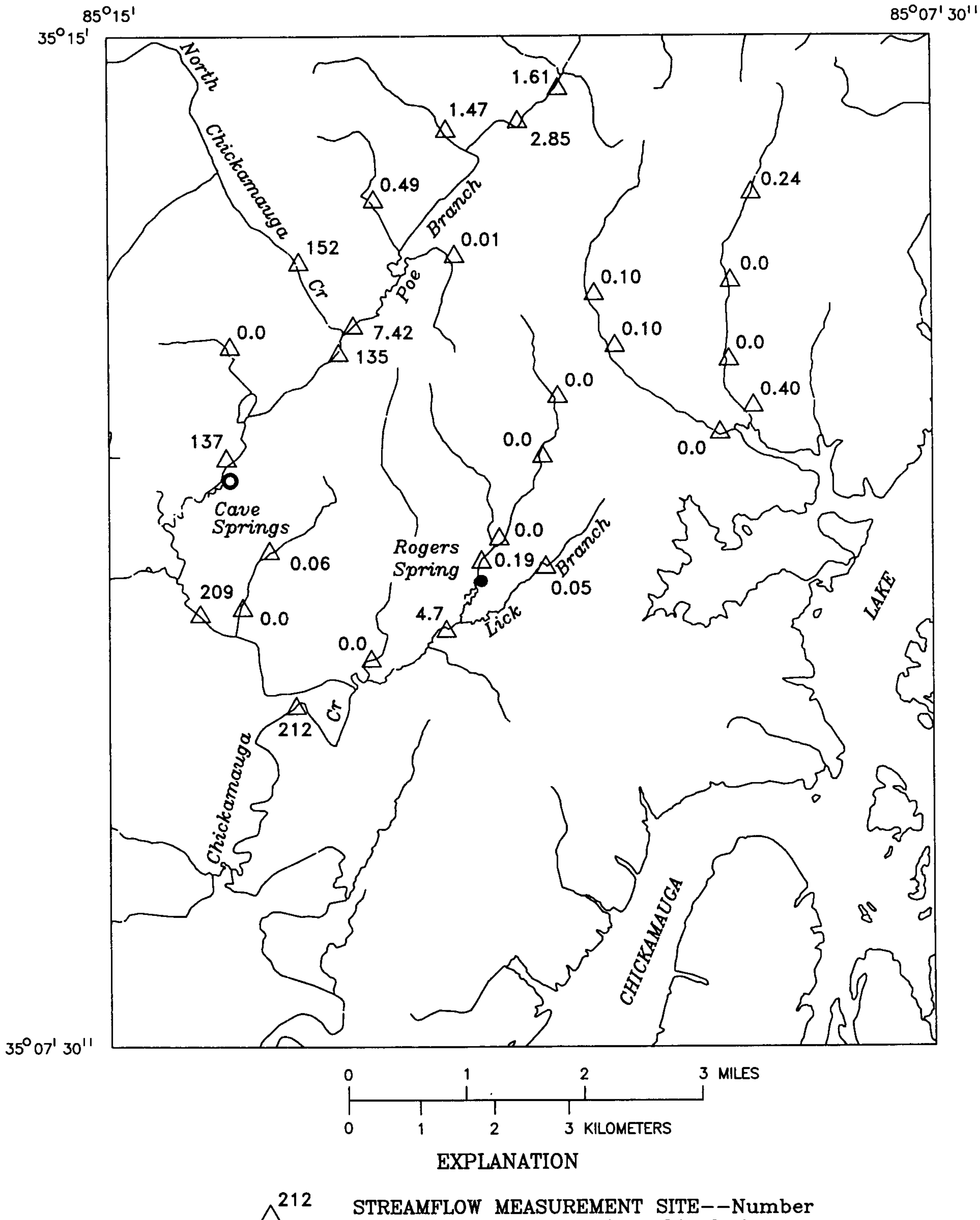
$$P = Q + E \qquad (1)$$

where,

P is average annual precipitation, in inches;

Q is average annual runoff, in inches; and

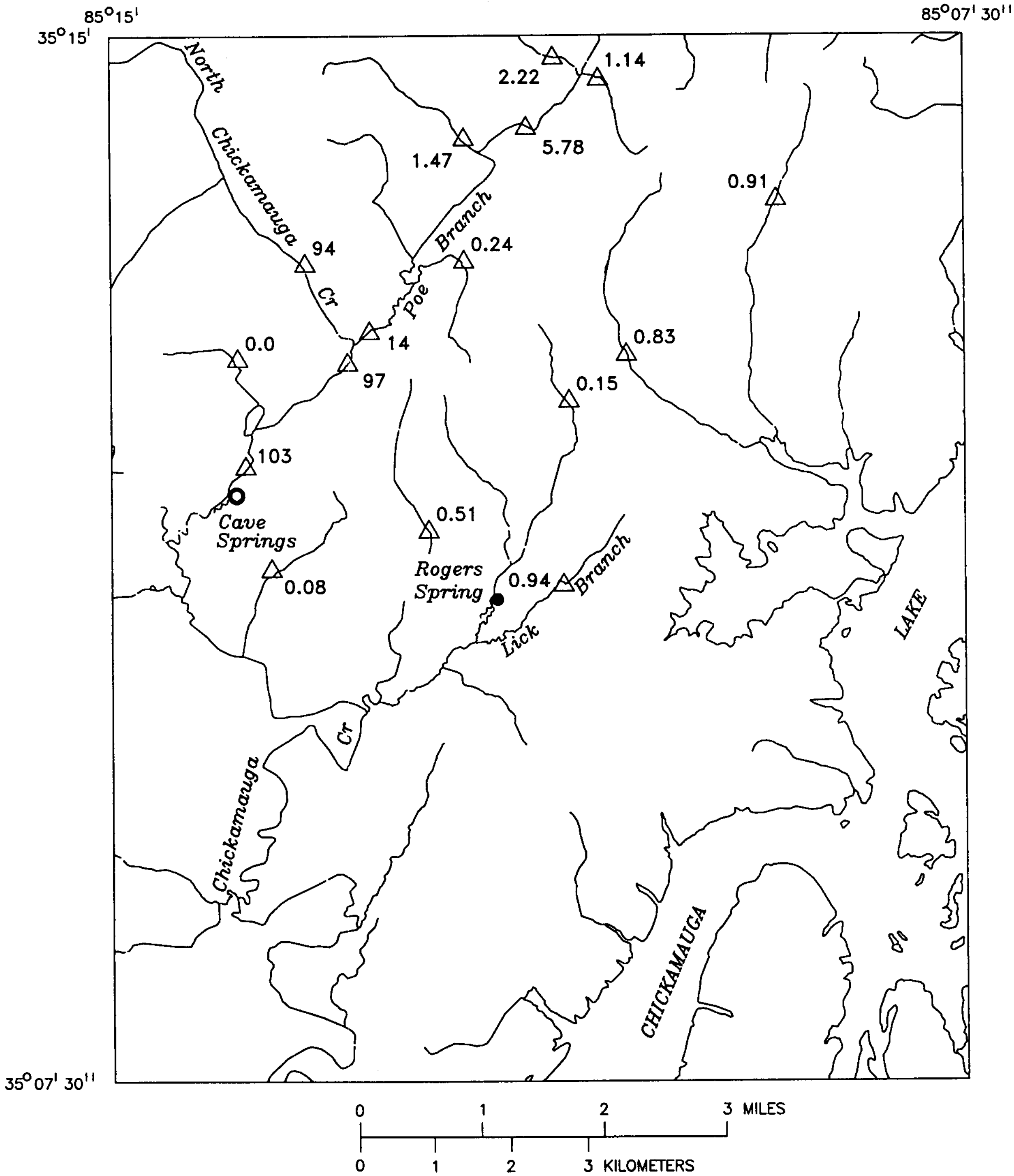
E is average annual evapotranspiration, in inches (Freeze and Cherry, 1979).



EXPLANATION

△212 STREAMFLOW MEASUREMENT SITE--Number indicates discharge, in cubic feet per second

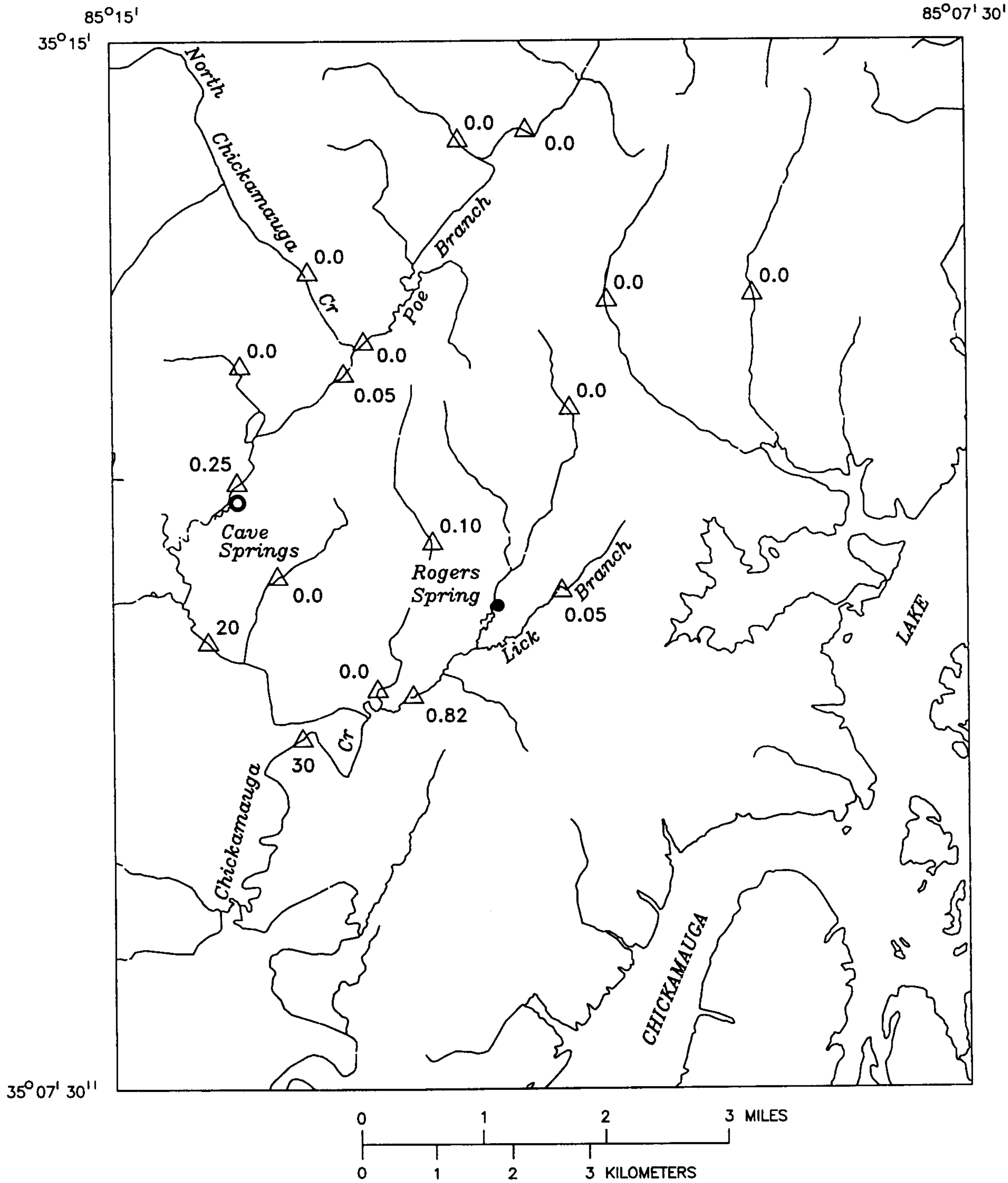
Figure 11.--Streamflow discharge measurements from a seepage investigation conducted on March 3, 1988, in the Cave Springs study area, Tennessee (Lowery and others, 1989).



EXPLANATION

△0.08 STREAMFLOW MEASUREMENT SITE--Number indicates discharge, in cubic feet per second

Figure 12.--Streamflow discharge measurements from a seepage investigation conducted on April 23, 1991, in the Cave Springs study area, Tennessee (Mercer and others, 1992).



EXPLANATION

△30 STREAMFLOW MEASUREMENT SITE--Number indicates discharge, in cubic feet per second

Figure 13.--Streamflow discharge measurements from a seepage investigation conducted on July 18, 1991, in the Cave Springs study area, Tennessee (Mercer and others, 1992).

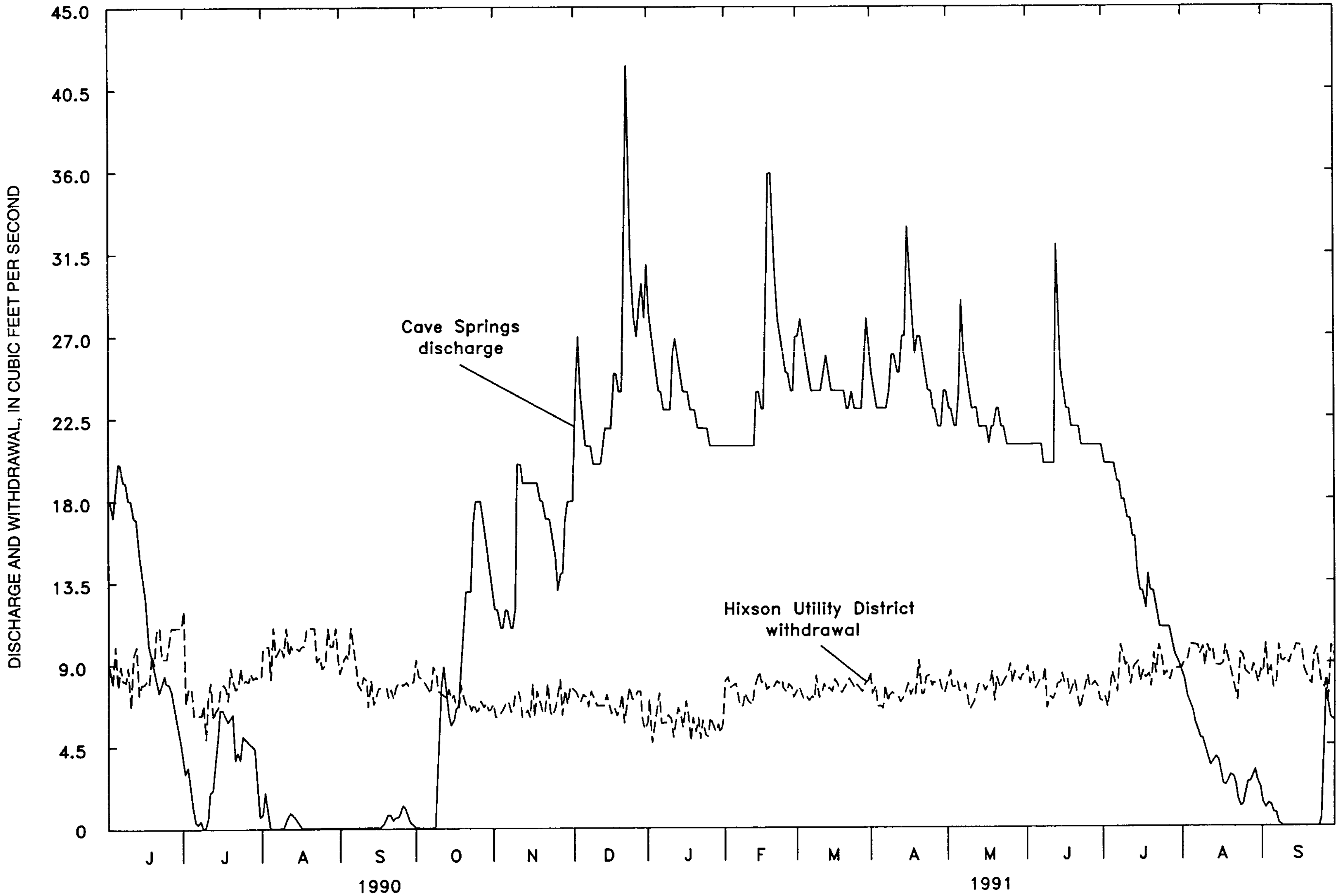


Figure 14.--Cave Springs discharge and ground-water withdrawal by the Hixson Utility District, in the Cave Springs study area, Tennessee.

To determine the water balance of the Cave Springs Basin, average annual long-term data for precipitation and runoff are provided from nearby locations. Average annual precipitation at Chattanooga, Tennessee, during 1951-80 was 52.6 inches (National Oceanic and Atmospheric Administration, 1990). For the same time period, average annual runoff at Sewee Creek, a basin with similar geology and karst features about 45 miles northeast of the Cave Springs Basin, was 22.9 inches. Substituting these values in equation 1, the annual evapotranspiration rate for the Cave Springs Basin is estimated to be 29.7 inches.

If the average amount of water available for recharge to the Cave Springs Basin is assumed to be 22.9 in./yr based on Sewee Creek data, and the recharge area of the Cave Springs Basin is approximately 7 mi^2, then by conversion, 11.8 ft^3/s of water is available for recharge. For 1988-91, the mean discharge of Cave Springs was 16.4 ft^3/s. If this time period is representative of long-term conditions, based on hydrograph separation of streamflow records in the region (A.T. Rutledge, U.S. Geological Survey, written commun., 1992), then this method leaves a difference between mean discharge and available recharge of 4.6 ft^3/s unaccounted for. Potentially important sources of excess recharge to the Cave Springs Basin during 1988-91 are recharge from losing reaches in North Chickamauga Creek (figs. 11 and 12) and other ground-water flow that could cross the northern surface-water divide. This analysis did not include (1) water use (primarily by Hixson Utility District, 7.9 ft^3/s) and (2) small interbasin flow systems. These factors contribute to the apparent discrepancy between estimated recharge and discharge.

HYDROCHEMISTRY

Water chemistry is an important factor in evaluating and describing the hydrology of the study area. Water samples from selected ground- and surface-water sites were analyzed for major ions. Specific conductance and temperature at wells 2 and 3 were recorded continuously from June 1990 to September 1991.

Major Ions

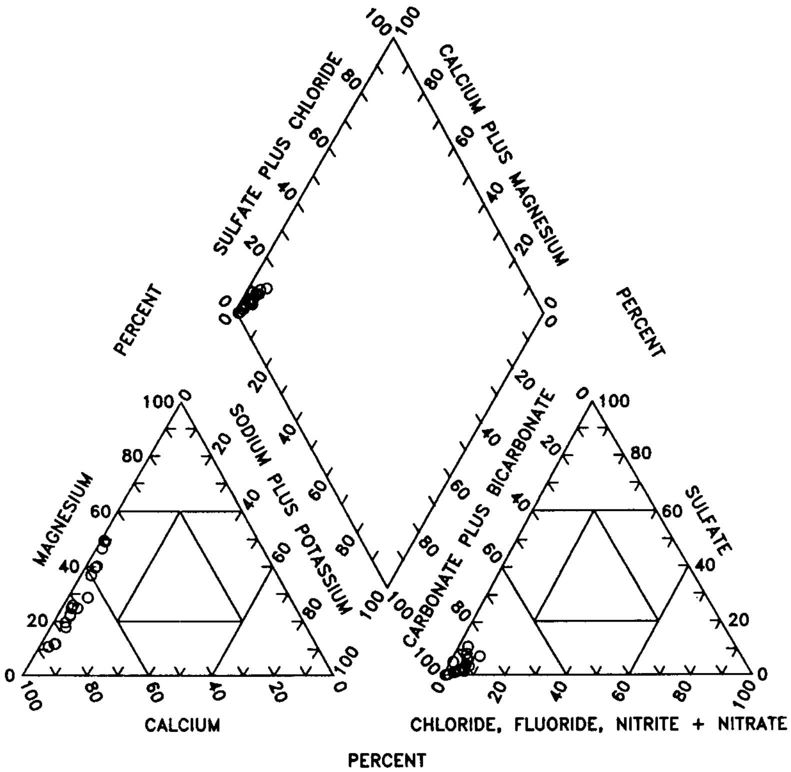
The major ion chemistry of ground- and surface-water samples collected during 1990-91 are presented on trilinear diagrams (fig. 15). These ions include: calcium, magnesium, sodium, potassium, chloride, sulfate, carbonate, and bicarbonate. Only samples with a charge balance less than or equal to 5 percent are plotted on the diagram. Cation and anion concentrations are plotted on the diagrams as percentages of total milliequivalents per liter (Hill, 1940; Piper, 1944). The grouping of data into regions on the diagram are used to identify the water composition types (Back, 1961; Freeze and Cherry, 1979). Tables 2 and 3 include the results of all analyses.

Ground-water samples collected from selected wells in the study area were predominately calcium bicarbonate and calcium-magnesium bicarbonate type waters reflecting the limestone and dolomite rock composition. Surface-water samples collected at Poe Branch and Lick Branch were calcium bicarbonate type waters indicating base-flow and possible spring-flow contributions from a carbonate aquifer. Water from North Chickamauga Creek is a calcium magnesium sulfate type suggesting a possible mixed contribution of flow from a carbonate aquifer, the Pennsylvanian formations, and acid-mine drainage. North Chickamauga Creek originates on the Cumberland Plateau flowing across Pennsylvanian siliciclastics, shales, and coal seams until reaching the base of the Cumberland Escarpment (fig. 1). Pyrite within Pennsylvanian shales and coal is a probable source of sulfate. Acid mine drainage in the upper reaches of North Chickamauga Creek also could be a source of sulfate (Farmer, 1980).

Calcium to Magnesium Ratios

The ratio of calcium to magnesium, as molar equivalents per liter, indicates the mineralogy of the rocks that have influenced the ground-water chemistry. For water in contact with dolomite, the molar

(A)



(B)

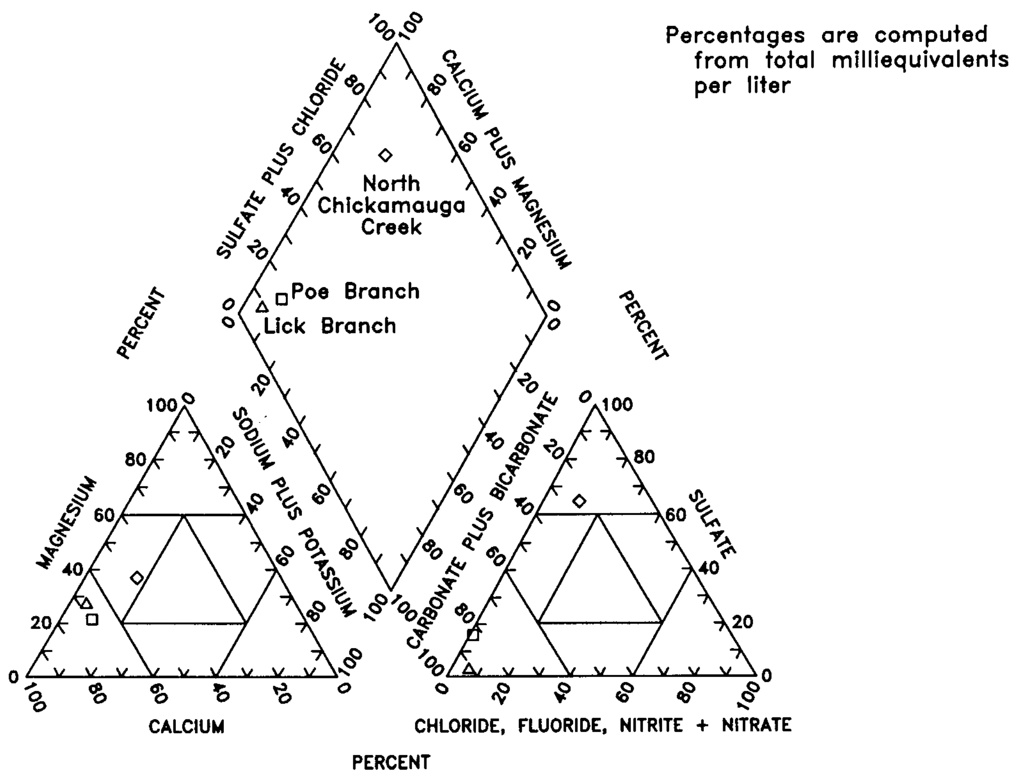


Figure 15.--Trilinear diagrams for analyses of selected (A) ground-water samples and (B) surface-water samples from the Cave Springs study area, Tennessee.

calcium to magnesium ratio is one. For water in contact with limestone, observed calcium-magnesium ratios vary from 2 to 10, and 6 is a common ratio (White, 1988). In the study area, calcium to magnesium ratios range from 2:1 to 13:1 (fig. 16) indicating a mixed limestone and dolomite to limestone mineralogy.

Water-Quality Trends

Changes in recharge and discharge are often accompanied by changes in water quality. Water-quality characteristics that vary include ions in solution, specific conductance, pH, temperature, and suspended sediment. This discussion focuses on temperature and specific–conductance variations.

Ground-water temperature and specific conductance for water from wells 2 and 3 at Cave Springs were continuously monitored during June 1990 through September 1991 (figs. 17 and 18). Data were recorded at 15–minute intervals by flow-through monitors which received a continuous flow of water pumped from 66 ft below land surface in well 2 and 170 ft below land surface in well 3. Total discharge (spring discharge and withdrawals) from Cave Springs and precipitation data collected at the Hixson Utility District pumping facility are shown for comparison (figs. 17 and 18).

Specific conductance in water from wells 2 and 3 (figs. 17 and 18) shows similar trends between November 1990 and September 1991. However, specific conductance in well 3 was slightly higher than in well 2 during December 1990 through May 1991. Ground-water temperature had an inverse relation for wells 2 and 3 during June through July 1990, and during February through March 1991. In both instances, ground water from the deeper well was warmer than that from the shallower well (well 2). The ground-water temperature increased in well 3 while it decreased in the shallower well.

The specific conductance and temperature of ground water at Cave Springs is compared to total discharge and precipitation to identify seasonal patterns. High discharge from Cave Springs during the winter and spring is associated with increased precipitation, lower temperature, and lower specific conductance. Decreases in temperature and specific conductance follow the increase in discharge by approximately 2 months. Specific conductance and temperature increase during summer and fall as precipitation and discharge from the spring decrease. Seasonal decrease in discharge occurs almost coincident with an increase in specific conductance. The ground-water temperature increase leads the decrease in discharge by almost 4 months.

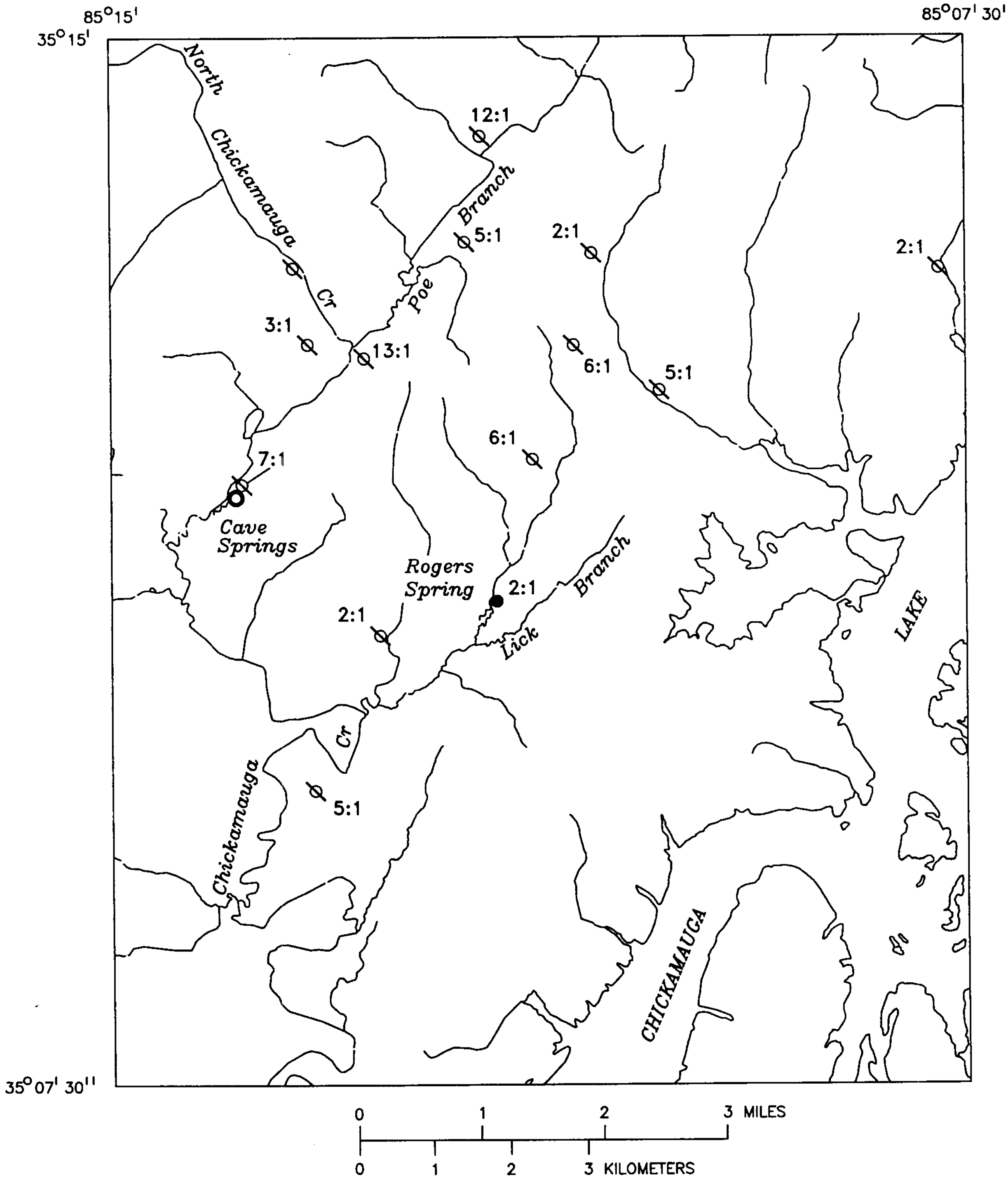
SUMMARY

In 1990, the Cave Springs Basin was selected as a type area for the Regional Aquifer–Systems Analysis program of the U.S. Geological Survey. This area characterizes a typical karstic carbonate ground-water system in the Valley and Ridge physiographic province.

Karstic Paleozoic carbonate rocks, clay-rich regolith, and alluvium form the ground-water system of the Cave Springs Basin. Residual clay-rich regolith, which acts as a leaky confining layer, occurs along and east of Cave Springs Ridge and is important as a storage reservoir. Alluvium eroded from the siliciclastic rocks of the Cumberland Plateau occurs in the valley of North Chickamauga Creek west of Cave Springs Ridge. Alleghenian event thrust faults trend northeast to southwest. Fractures associated with thrust faults may enhance transmissivity.

Recharge from precipitation is dispersed over the basin and enters the karst aquifer through thick regolith. It is not known if recharge associated with sinkholes is significant. Low-flow stream discharge measurements indicate that North Chickamauga Creek may contribute significant amounts of concentrated ground-water recharge to the Cave Springs Basin along losing reaches of the creek.

The aquifer in the Cave Springs Basin consists of a mixed dolomite-limestone with fracture and cavernous porosity. Flow type determined by the coefficient of variation of the mean daily specific conductance from October 25, 1990, through September 30,1991, for wells 2 and 3 indicates an aquifer with conduit flow. However, flow type based on the ratio (6:1) of spring flood-flow discharge to spring base-flow



EXPLANATION

PUBLIC-WATER SUPPLY SPRING

DOMESTIC-WATER SUPPLY SPRING

OBSERVATION WELL

5:1 CALCIUM:MAGNESIUM RATIO

Figure 16.--Calcium:magnesium ratio of water from selected sites in the Cave Springs study area, Tennessee.

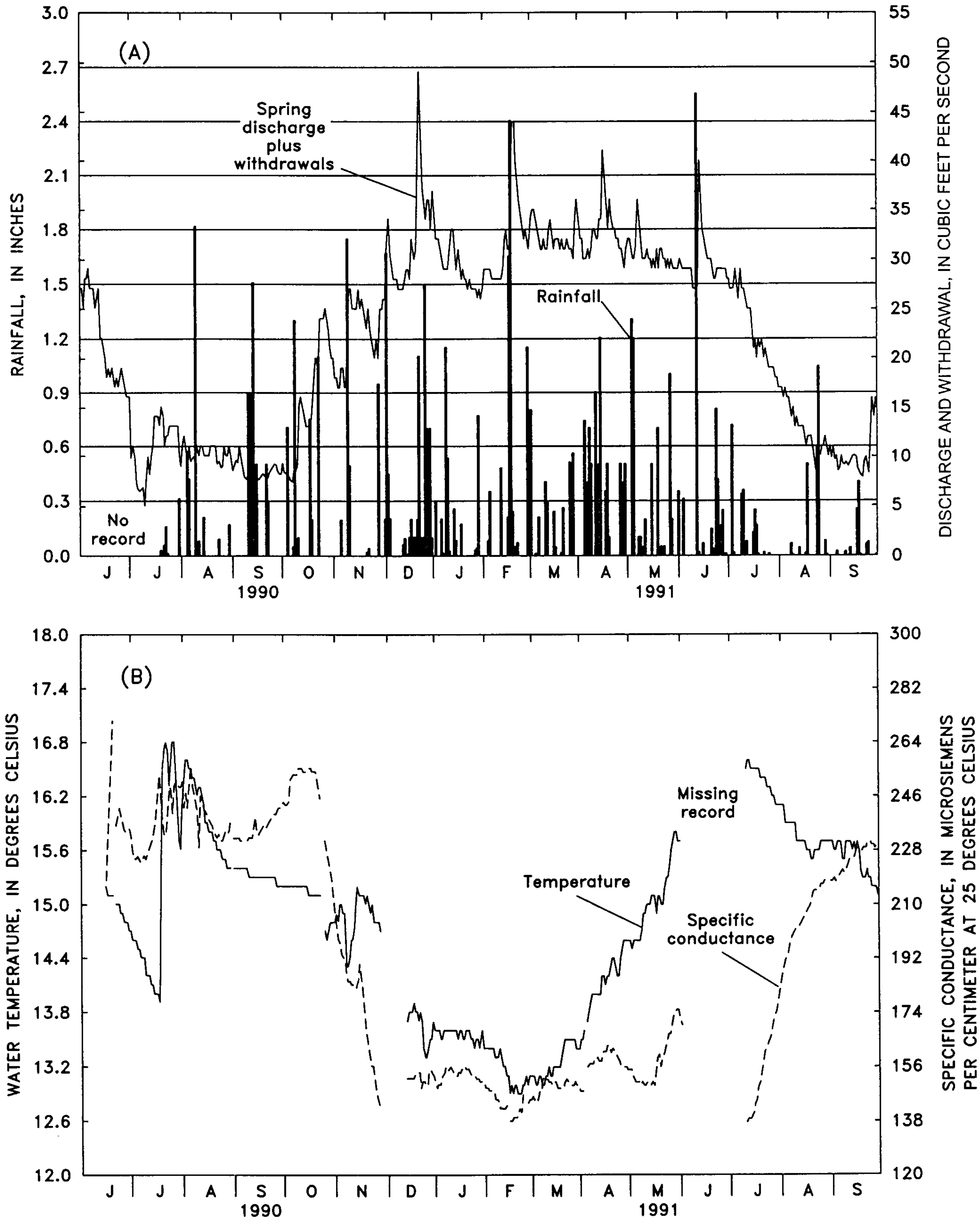
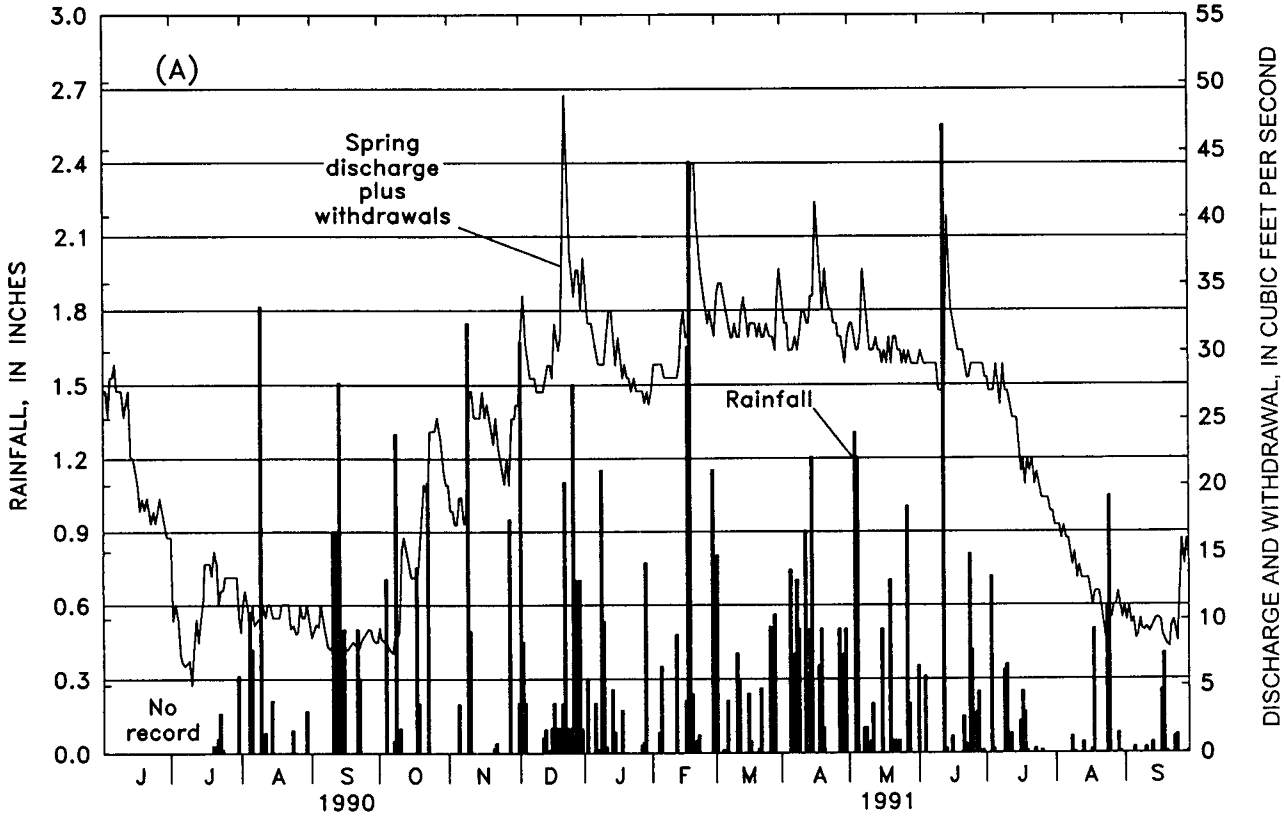


Figure 17.--(A) Cave Springs discharge plus withdrawals and rainfall data, and (B) temperature and specific conductance of water in well 2 near Cave Springs, Tennessee.



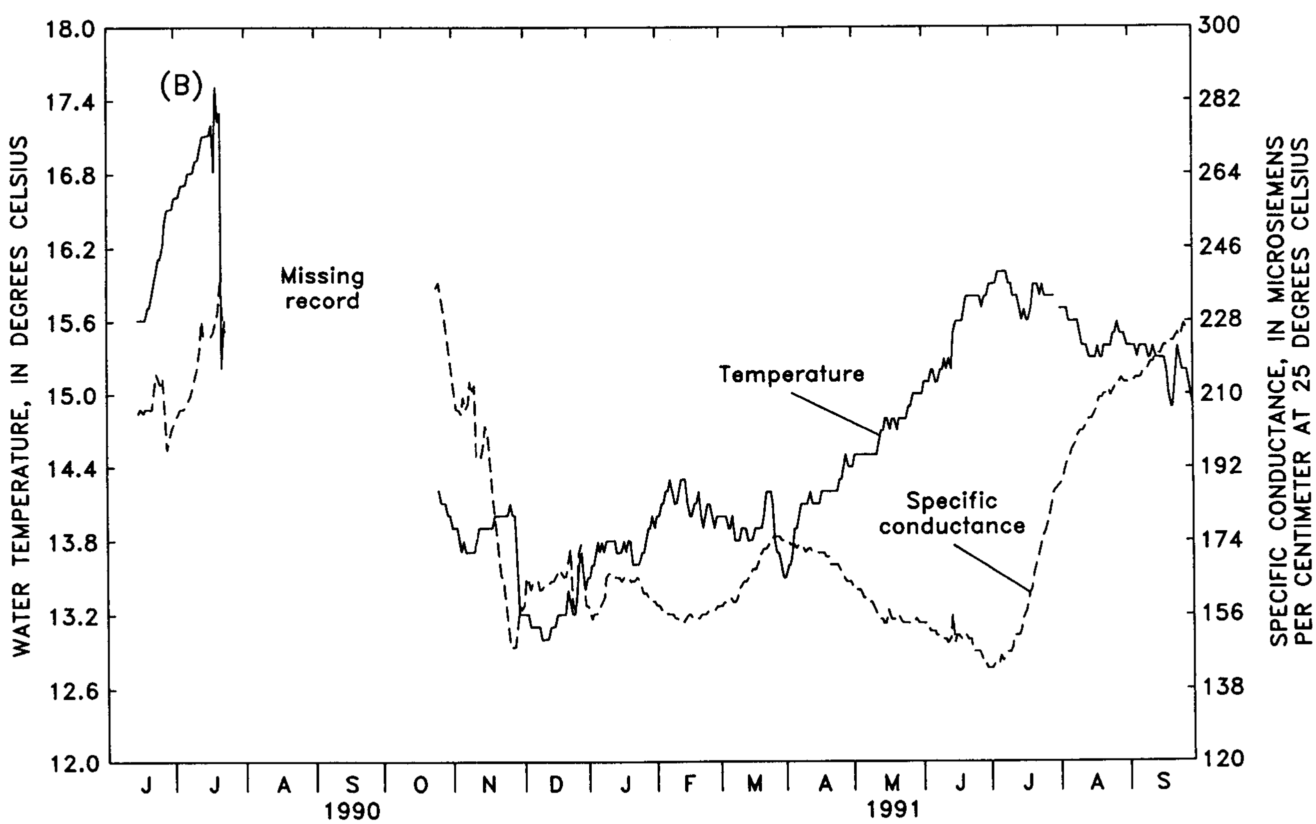


Figure 18.--(A) Discharge plus withdrawals and rainfall at Cave Springs, and (B) temperature and specific conductance of water in well 3 near Cave Springs, Tennessee.

discharge indicates an aquifer with diffuse flow. The type of subsurface flow in the study area ranges from rapidly moving conduit flow to slower diffuse flow.

Inconsistent results in characterizing the flow type may be caused by a mix of conduit and diffuse flow and the hydrologic complexity of the study area. Areas along and east of Cave Springs Ridge are covered by thick clay-rich regolith. The low relief areas along North Chickamauga Creek west of Cave Springs Ridge are covered by coarse alluvium. Continuous water-level data collected at well 17, east of Cave Springs Ridge, indicate a slow response to recharge. Ground-water levels in wells 1, 6, and 7 west of Cave Springs Ridge, responded relatively quickly to recharge events. Wells 1, 6, and 7 are located in a wedge of Newman Limestone between two closely spaced thrust faults in what may be an intensely fractured and highly transmissive zone. Well 7 is also in an area overlain by coarse alluvial deposits in North Chickamauga Creek.

Conduit flow characteristics indicate that recharge to Cave Springs may occur along and west of Cave Springs Ridge. This recharge is associated with the proposed highly transmissive wedge of Newman Limestone and losing reaches of North Chickamauga Creek. Flow characteristics indicate that diffuse flow dominates over the recharge area east of Cave Springs Ridge.

Boundaries of the Cave Springs Basin were approximated from potentiometric-surface maps. The northeastern boundary is a ground-water divide which appears to coincide with the surface-water divide, and the southeastern boundary is formed by a ground-water divide. To the west and northwest, basin boundaries appear to be associated with stream divides. The area supplying recharge to the Cave Springs Basin is approximately 7 mi^2.

Ground-water flow paths in the Cave Springs Basin are generally along strike from northeast to southwest. A dye-trace test was conducted to determine ground-water travel-time and flow paths to Cave Springs. No dye was detected after monitoring for 5 months and the results were inconclusive. The dyes may have discharged at unknown points, may have dispersed before reaching the spring, or may not have reached the monitored springs before the test was terminated.

Cave Springs is defined as a second-order magnitude spring. During June 1, 1990, to September 30, 1991, the mean daily discharge from Cave Springs was 14.2 ft^3/s with a standard deviation of 9.9 ft^3/s; the maximum discharge was 42.0 ft^3/s. Ground-water withdrawals during this time period by the Hixson Utility District averaged 7.9 ft^3/s.

Ground-water from selected wells in the area is characterized by calcium bicarbonate and calcium magnesium bicarbonate type water. Calcium to magnesium molar ratios reflect the mixed limestone and dolomite aquifers of the Cave Springs Basin. Lick Branch and Poe Branch are characterized by a calcium bicarbonate type water. North Chickamauga Creek is characterized by a calcium magnesium sulfate type water. The sulfate is probably derived from pyrite contained within Pennsylvanian formations in the upper reaches of North Chickamauga Creek.

Ground-water temperature and specific conductance from wells 2 and 3 correlate with seasonal changes in precipitation and total discharge from Cave Springs. Lower specific conductance and lower temperatures are associated with higher discharge and precipitation during winter and spring. During summer and fall, precipitation and spring discharge decrease and ground-water temperature and specific conductance increase.

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Table 2. Water-quality data for selected ground-water sites in the Cave Springs study area

[° C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; <, less than; *, well outside boundary of figure 4; ---, no data]

Well number (figure 4)	Station number	Date	Temperature, water (°C)	Specific conductance (µS/cm)	pH (standard units)	Alkalinity, water whole total incremental titration (mg/l as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as $CaCO_3$)	Magnesium, dissolved (mg/L as $CaCO_3$)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
4	350937085131401	06-20-90	16.0	421	7.4	272	220	64	14	2.2	0.60
		06-17-91	18.8	360	7.0	292	220	67	14	2.8	1.1
5	351041085123701	06-13-90	15.0	227	7.7	141	140	34	14	2.1	.60
		06-17-91	17.6	240	7.5	148	150	36	15	2.4	.80
		11-04-91	---	276	7.5	140	140	33	14	1.7	.90
2	351148085135302	06-11-90	15.0	153	7.5	67	84	27	3.9	1.8	.60
		06-19-91	18.5	158	7.3	80	80	26	3.6	1.6	.60
		11-08-91	---	238	7.7	109	120	39	6.0	1.9	1.0
12	351158085111701	06-13-90	14.0	177	8.0	100	110	34	6.2	2.1	.40
		06-18-91	16.8	220	8.0	116	110	35	6.4	2.1	.50
		11-05-91	---	214	7.7	112	110	34	6.4	1.7	.80
23	351207085093701	06-13-90	16.0	155	6.6	88	78	18	8.0	1.8	.70
9	351228085101001	06-18-91	18.6	209	7.9	118	110	32	7.1	1.3	.60
		11-07-91	---	186	8.0	94	98	28	6.7	.90	.80
6	351239085125001	06-12-90	14.5	225	7.8	128	140	50	3.8	2.0	.40
7	351248085131601	06-12-90	14.5	107	8.6	75	60	15	5.5	.90	.40

Table 2. Water-quality data for selected ground-water sites in the Cave Springs study area—Continued

Well number (figure 4)	Station number	Date	Temperature, water (°C)	Specific conductance (µS/cm)	pH (standard units)	Alkalinity, water whole total incremental titration (mg/l as $CaCO_3$)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as $CaCO_3$)	Magnesium, dissolved (mg/L as $CaCO_3$)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
8	351249085110101	06-18-91	19.2	212	7.9	116	110	24	13	.70	.60
		11-05-91	---	209	7.7	124	110	24	13	.70	.80
24	351320085074001	06-18-90	15.0	164	7.7	102	89	19	10	.70	.50
		06-20-91	17.5	192	7.6	104	96	22	10	.80	.60
		11-07-91	---	188	7.9	110	98	21	11	.60	.80
14	351326085103701	06-14-90	15.0	181	8.2	119	90	18	11	.60	.40
		06-19-91	19.5	171	7.8	92	90	18	11	.50	.30
		11-05-91	8.0	169	7.9	100	90	18	11	.50	.60
13	351328085115501	06-14-90	15.5	297	7.7	143	150	43	9.3	3.2	.50
22	351407085114701	06-21-91	19.0	353	7.3	160	190	66	5.6	4.0	.80
		11-07-91	---	356	7.6	169	180	64	5.4	3.2	1.1
*	351432085063701	06-19-90	15.5	289	8.0	148	150	36	15	.60	1.0
		06-20-91	---	292	7.8	182	150	37	15	.70	1.1
		11-06-91	---	287	7.9	150	160	36	16	.60	1.2
*	351522085071201	06-19-90	15.0	256	7.6	140	130	36	10	1.3	.90
		06-20-91	18.0	211	7.0	144	110	30	7.9	1.7	.80
		11-06-91	---	234	7.8	134	130	32	11	1.0	1.5
*	351525085085301	06-19-90	14.5	198	7.9	101	95	20	11	1.3	.50
		06-19-91	18.5	204	7.8	150	100	22	11	1.5	.60
		11-06-91	---	190	7.9	112	100	21	12	1.2	.80

Table 2. Water-quality data for selected ground-water site in the Cave Springs study area—Continued

Well number (figure 4)	Station number	Date	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Barium, dissolved (mg/L as Ba)	Iron, dissolved (mg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Solids, sum of constituents, dissolved (mg/L)	Alkalinity, laboratory (mg/L as $CaCO_3$)
4	350937085131401	06-20-90	7.3	2.6	0.20	7.2	10	7	11	58	224	209
		06-17-91	6.8	2.5	.10	7.5	---	8	3	---	230	213
5	351041085123701	06-13-90	4.2	2.7	.10	7.6	15	10	1	28	149	140
		06-17-91	4.6	3.1	.20	7.5	---	25	2	---	156	144
		11-04-91	2.5	2.3	<.10	7.7	---	10	<10	---	145	138
2	351148085135302	06-11-90	2.6	1.1	.10	8.1	28	6	1	100	88	72
		06-19-91	1.3	9.5	<.10	5.4	---	3	<1	---	86	63
		11-08-91	2.7	10	<.10	6.6	---	10	<10	---	132	108
12	351158085111701	06-13-90	4.6	3.8	<.10	7.4	8	9	1	26	121	104
		06-18-91	3.9	3.5	.10	7.2	---	6	2	---	120	102
		11-05-91	3.1	3.0	<.10	7.5	---	10	<10	---	119	104
23	351207085093701	06-13-90	4.8	1.1	.10	6.6	34	7	13	31	91	83
9	351228085101001	06-18-91	3.6	2.8	<.10	8.0	---	6	1	---	115	99
		11-07-91	2.3	1.4	<.10	7.2	---	<10	10	---	103	93
6	351239085125001	06-12-90	4.3	8.0	.20	7.3	14	14	1	130	156	133
7	351248085131601	06-12-90	.20	4.2	<.10	7.3	15	17	3	53	71	63
8	351249085110101	06-18-91	2.5	1.4	<.10	8.4	---	5	<1	---	116	109
		11-05-91	1.6	1.4	<.10	8.7	---	<10	<10	---	115	108

Table 2. Water-quality data for selected ground-water site in the Cave Springs study area—Continued

Well number (figure 4)	Station number	Date	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Barium, dissolved (mg/L as Ba)	Iron, dissolved (mg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Stron-tium, dissolved (µg/L as Sr)	Solids, sum of constituents, dissolved (mg/L)	Alkalinity, laboratory (mg/L as $CaCO_3$)
24	351320085074001	06-18-90	.30	1.5	.10	7.8	11	43	8	14	97	95
		06-20-91	.80	1.7	<.10	7.3	---	15	3	---	100	95
		11-07-91	1.0	1.7	<.10	7.5	---	<10	<10	---	100	94
14	351326085103701	06-14-90	.60	<10	.20	7.3	5	10	2	10	---	94
		06-19-91	.40	<.10	<.10	7.5	---	12	<1	---	---	92
		11-05-91	.70	.30	<.10	7.5	---	10	<10	---	93	90
13	351328085115501	06-14-90	6.2	2.0	.20	8.4	15	10	<1	110	156	139
22	351407085114701	06-21-91	5.8	11	<.10	7.4	---	29	4	---	197	161
		11-07-91	4.6	13	<.10	7.5	---	40	10	---	196	162
*	351432085063701	06-19-90	.40	13	.30	8.1	130	15	1	110	158	139
		06-20-91	.40	15	.50	7.8	---	27	<1	---	162	141
		11-06-91	1.2	13	.20	7.9	---	<10	<10	---	158	137
*	351522085071201	06-19-90	3.8	2.3	.20	7.8	27	21	6	39	137	124
		06-20-91	1.5	2.0	<.10	7.5	---	42	4	---	111	100
		11-06-91	1.8	1.7	<.10	8.8	---	<10	<10	---	112	90
*	351525085085301	06-19-90	3.3	1.6	<.10	7.5	12	18	3	14	106	101
		06-19-91	1.2	1.6	<.10	7.4	---	8	2	---	106	101
		11-06-91	1.8	1.4	<.10	7.2	---	<10	<10	---	104	97

Table 3. Water-quality data for selected surface-water sites in the Cave Springs study area

[° C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter; <, less than; ---, no data]

Station name (figure 4)	Station number	Date	Water temperature (° C)	Specific conductance (µS/cm)	pH (standard units)	Alkalinity, water whole total increment titration, (mg/L as $CaCO_3$	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)
North Chickamauga Creek	035665302	06-14-90	17.0	42	5.2	4	12	2.6	1.2	0.80	0.50	1.1
Poe Branch	035665348	06-14-90	23.5	130	7.2	52	55	17	3.1	2.5	1.1	.30
Rogers Spring	03566615	06-18-91	23.0	269	7.0	208	130	37	10	4.0	.70	8.1
		11-08-91	--	312	7.4	163	160	44	12	3.1	1.0	4.5
Lick Branch	03566616	06-14-90	23.5	277	7.9	126	140	39	9.2	3.6	.90	5.8

Station name (figure 4)	Station number	Date	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Barium, dissolved (mg/L as Ba)	Iron, dissolved (mg/L as Fe)	Manganese, dissolved (µg/L as Mn)	Strontium, dissolved (µg/L as Sr)	Solids, sum of constituents, dissolved (mg/L)	Alkalinity, laboratory (mg/L as $CaCO_3$)
North Chickamauga Creek	035665302	06-14-90	11	0.20	4.1	68	340	68	19	24	3.0
Poe Branch	035665348	06-14-90	8.8	.20	3.3	35	380	650	62	68	51
Rogers Spring	03566615	06-18-91	10	<.10	7.1	---	16	1	---	150	122
		11-08-91	3.4	<.10	6.8	---	10	.10	---	165	150
Lick Branch	03566616	06-14-90	3.4	<.10	3.8	21	14	85	44	146	134