Water-Resources Investigations Report 91-4190

GROUND-WATER HYDROLOGY OF THE LOWER WOLFTEVER CREEK BASIN, WITH EMPHASIS ON THE CARSON SPRING AREA, HAMILTON COUNTY, TENNESSEE

Prepared by the
U.S. GEOLOGICAL SURVEY

in cooperation with the
EASTSIDE UTILITY DISTRICT

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Nashville, Tennessee
1993

U.S. DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
acre	0.4047	hectare
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
gallon per minute (gal/min)	0.000063	cubic meter per second
million gallons per day (Mgal/d)	0.0438	cubic meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per minute (ft^3/min)	0.4720	liter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
microsiemen per centimeter at 25 °Celsius (μS/cm)	1	micromho per centimeter at 25 °Celsius

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.

Abbreviated water-quality units

mg/L	milligrams per liter
μg/L	micrograms per liter
ntu	nephelometric turbidity units

WELL-NUMBERING SYSTEM

Wells discussed in this report are numbered according to an informal numbering system that consists of two parts: a letter designating the purpose of the well (M-monitoring, P-production, T-test), and a one- or two-digit number. In table 7, these numbers are cross-referenced to the formal well numbers of the U.S. Geological Survey, based on county and map location ("Local well number") and latitude and longitude ("USGS station number").

Local well numbers consist of three parts: (1) an abbreviation of the name of the county in which the well is located; (2) a letter designating the $7^1/_2$-minute topographic quadrangle on which the location of the well is plotted; and (3) a number generally indicating the numerical order in which the well was inventoried. The symbol Hm:J-021, for example, indicates that the well is located in Hamilton County on the "J" quadrangle and is identified as well 21 in the numerical sequence. Quadrangles are lettered from left to right, beginning in the southwest corner of the county.

Station numbers provide a unique 15-digit number for each well, based on geographic location. The first 6 digits denote degrees, minutes, and seconds of latitude; the next 7 digits denote degrees, minutes, and seconds of longitude; and the last 2 digits, assigned sequentially, identify the well within a 1-second grid.

GROUND-WATER HYDROLOGY OF THE LOWER WOLFTEVER CREEK BASIN, WITH EMPHASIS ON THE CARSON SPRING AREA, HAMILTON COUNTY, TENNESSEE

By D.A. Webster *and* J.K. Carmichael

ABSTRACT

An investigation of the ground-water-flow system that supplies Carson Spring and the surrounding lower Wolftever Creek basin northeast of Chattanooga, Tennessee, was conducted from September 1986 through December 1989. About two-thirds of the lower basin is underlain by the Chepultepec Dolomite of Ordovician age. Test drilling within a few miles of the spring showed that numerous solution cavities have developed in this formation; many are partly or completely plugged with cherty gravels and mud. In the recharge area to the spring, the formation can provide yields of 100 to perhaps 600 gallons of water per minute to bedrock wells. A well that penetrated a well-integrated cavity system underlying Carson Spring was tested at 2,000 gallons per minute.

From May 1987 through December 1989, mean daily withdrawals from four wells at Carson Spring ranged from 4.78 to 5.83 cubic feet per second; mean daily spring discharge, which includes withdrawals, ranged from 5.53 to 5.79 cubic feet per second. For a 16-month drought period during 1987 and 1988, withdrawals from these wells exceeded natural spring discharge, and demonstrates that for a period of many consecutive months, the aquifer supplying the spring is capable of yielding more water than the spring would have discharged under natural conditions.

Although the lower basin encompasses 17 square miles, the Carson Spring recharge area probably is not greater than 9 square miles. Most water not captured by cavities supplying the spring is discharged to Wolftever Creek. In the lower basin, the rate of ground-water discharge to the creek is about twice the average rate of discharge (0.25 cubic foot per second per square mile of drainage area) to area streams.

Principal constituents in ground water in the lower basin are calcium and bicarbonate, or calcium, magnesium, and bicarbonate. Specific conductance commonly ranges from 100 to 700 microsiemens per centimeter, and pH usually ranges from about 7 to 8. Overall, the ground water is of good quality and suitable for most uses. Several potential sources of degradation are present and arise from industrial, municipal, and domestic activities.

INTRODUCTION

The lower Wolftever Creek basin is the most downstream of three basins drained by Wolftever Creek, the principal drainage in southeastern Hamilton County, Tennessee. In the lower basin, Wolftever Creek receives the discharge of Carson Spring, located about $4^1/_2$ miles northeast of the Chattanooga city boundary (fig. 1).

Carson Spring is one of several large springs in a northeast-southwest-trending band across the width of Tennessee. This spring has a mean natural discharge of about 6 ft^3/s (3.9 Mgal/d), ranking it as a third-magnitude

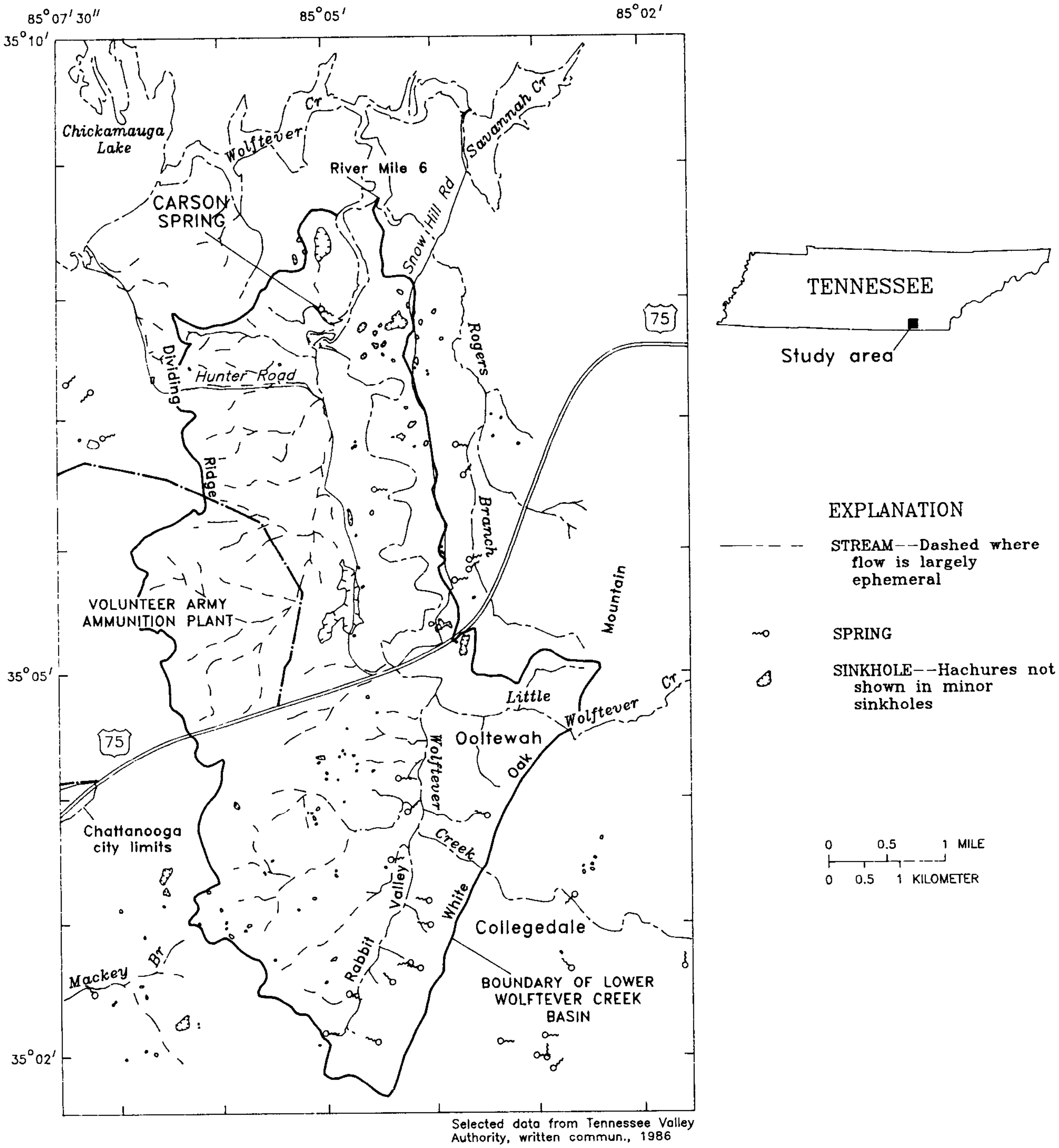


Figure 1. Location of the study area and selected physical features of the lower Wolftever Creek basin.

spring. Long-term records of discharge have not been kept, but Carson Spring probably could be further described as a constant spring (Meinzer, 1923, p. 53-54). Although spring discharge to Wolftever Creek has been reduced since 1958 as a result of withdrawals from wells drilled within a few hundred feet of the spring, average annual total discharge (withdrawals from wells plus remaining outflow from the spring) appears to vary within a narrow range.

Like many large springs, relatively little is known about the source of water for this spring, the characteristics of the aquifer supplying it, or the quality of water in the recharge area. To provide a better understanding of the hydrology of the Carson Spring area, the U.S. Geological Survey (USGS), in cooperation with the Eastside Utility District, conducted a hydrologic investigation of the lower Wolftever Creek basin (fig. 1), with emphasis on the Carson Spring locale, from October 1986 through December 1989. The study was performed in conjunction with the current USGS regional aquifer study of the Appalachian valleys and Piedmont region.

Overall objectives of the study were to obtain additional geologic and hydrologic data for characterizing the Chepultepec Dolomite (from which Carson Spring issues) in the southeastern part of Tennessee; to describe the hydrology of Carson Spring, a typical large spring of the Appalachian-Piedmont region; and to document present water-quality characteristics and areal variations in water-quality characteristics in the basin.

Purpose and Scope

This report presents the results of the lower Wolftever Creek basin study. The report includes discussion of the:

- occurrence and flow of ground water in the lower basin,
- results of a base-flow investigation of area streams,
- findings of exploratory drilling near Carson Spring,
- rate of ground-water withdrawals and discharge at Carson Spring,
- boundary and size of the Carson Spring recharge area,
- ground-water-quality characteristics, and
- potential sources of ground-water-quality degradation.

For the purpose of this report, consideration of the lower Wolftever Creek basin is limited to that part of the Wolftever Creek drainage basin that lies between White Oak Mountain and river mile 6, at which point the creek receives the discharge of Rogers Branch (fig. 1). The most downstream 1 to 2 miles of Wolftever Creek within the lower basin as thus defined, plus the segment downstream of river mile 6, are an embayed interval of Chickamauga Lake.

Previous studies

The ground-water resources of the East Tennessee region were inventoried and described by DeBuchananne and Richardson (1956). Records of 84 of the larger, undeveloped springs in the region were analyzed for magnitude of flow and variations in discharge by Sun and others (1963). Hollyday and Smith (1990) statistically analyzed discharge measurements at 171 large springs in the region. Geology of East Tennessee was compiled and described by Rodgers (1953). The Tennessee Department of Conservation, Division of Geology, prepared an overview of the geology, mineral, and water resources of Hamilton County (1979). Recently, Wilson mapped in detail the geology of the Snow Hill (1983) and Ooltewah (1986) $7\frac{1}{2}$-minute quadrangles and summarized the mineral resources of those areas.

DESCRIPTION OF THE STUDY AREA

The lower Wolftever Creek basin is a lenticularly shaped area of approximately 17 mi^2. The basin lies between White Oak Mountain to the east, Dividing Ridge to the west, river mile 6 to the north, and a saddle in Rabbit Valley to the south (fig. 1). Within this area, the community of Ooltewah is the only population and business center. Land use outside of Ooltewah is largely rural residential, the notable exception being the ammunition storage area at Volunteer Army Ammunition Plant (VAAP), located on Dividing Ridge. The ammunition production facilities are located west of the basin boundary on the west face of Dividing Ridge and have been inactive since 1977. Primary access to the area is by Interstate Highway 75 (I-75).

Physiographic Characteristics

The several drainage basins of southeastern Hamilton County lie within the Valley and Ridge physiographic province, an area characterized by a succession of alternating valleys and ridges trending north and northeast. Altitudes within the lower Wolftever Creek basin range from about 676 feet, the normal altitude of Wolftever Creek at river mile 6 in winter, to about 835 feet at the south end of Rabbit Valley, to about 1,060 feet along the knobs of Dividing Ridge, to about 1,450 feet at the summit of White Oak Mountain (fig. 1).

Wolftever Creek and a tributary to it, Little Wolftever Creek, flow through water gaps in White Oak Mountain to discharge to Chickamauga Lake, an impounded segment of the Tennessee River. Chickamauga Lake is regulated; that is, its level is adjusted to provide energy for hydroelectric power and to control flooding.

During periods of high pool elevation, the backwater of Chickamauga Lake extends up the mouth of Wolftever Creek and a tributary to reach the natural discharge point of Carson Spring. To prevent degradation of water contained in the aquifer by induced recharge from the tributary when wells are pumped, a berm was constructed around the orifice of the spring, thereby creating a spring pool that usually stands several feet above the level of the creek. The spring pool has a surface area of about one-half acre, and contains a column of water about 12 feet high when stage is sufficient to cause flow through a weir built into the berm.

Annual precipitation at Chickamauga Dam, about 4½ miles west of Carson Spring, ranged from 40.0 inches to 85.6 inches during the 30-year period from 1950 to 1979, and averaged 57.6 inches (Drew Thornton, Tennessee Valley Authority, written commun., 1989). Monthly rainfall typically is greatest during the months of December through March, and least during the months of August through October. From 1985 through 1988, the East Tennessee region received less than average amounts of annual precipitation (table 1), resulting in drought conditions. By 1988, which includes the period of this study, the cumulative deficit approached the equivalent of 1 year of normal precipitation. During 1989, rainfall was frequent and greatly exceeded the long-term annual mean.

Springs are common in the lower basin. Most of them have low yields and do not sustain flow throughout the year.

Table 1. Annual precipitation at Chickamauga Dam

[Data sources: Drew Thornton and Wayne Hamburger, Tennessee Valley Authority, written and oral commun., respectively, 1990. Mean annual precipitation, 1950-1979: 57.62 inches]

Year	Annual precipitation (inches)	Cumulative departure from mean, after 1984 (inches)
1985	42.33	-15.29
1986	50.30	-22.61
1987	45.41	-34.82
1988	49.32	-43.12
1989	81.96	-18.78

Geologic Setting

Rock units underlying the lower Wolftever Creek basin range in age from Cambrian to Silurian, and become progressively younger from west to east (fig. 2). Formations of the Knox Group, the oldest unit within the basin, are composed predominately of cherty dolomite (fig. 3). The Kingsport Formation contains limestone in addition to dolomite. Formations overlying the Knox Group are composed predominately of limestone, argillaceous limestone, and fine-grained clastic matter. Of the units considered, the Chepultepec Dolomite (of the Knox Group) is the most significant to this study because it is exposed over about two-thirds of the basin and is the unit from which Carson Spring issues.

The lower Wolftever Creek basin is situated on the White Oak Mountain thrust block, one of multiple thrust blocks in the Valley and Ridge province. Stratigraphic units are complexly deformed near the major thrust faults that border this block, but below much of the basin deformation has been limited to the tilting of beds to the east and southeast (fig. 2, geologic sections). Dip across large areas is gentle. Near Carson Spring, for example, dip is 11° E.

Within a small area near the center of Rabbit Valley, however, dip of as much as 80° E-SE has been measured (Wilson, 1983, 1986). Strike largely follows the topographic grain. North of I-75, strike is close to north; south of I-75, in Rabbit Valley and along White Oak Mountain, it is north-northeast.

Most of the basin is underlain by carbonate rock. The dolomitic formations tend to weather deeply, resulting in substantially thicker regolith than that developed on the limestone formations. The regolith of both lithologies contains large nodules of chert and blocks of chert where chert was a substantial constituent of the parent rock. Cavities are present in the bedrock of both lithologies and are prominent in the formations of the Knox Group.

To the south and west of Carson Spring is an area where drainages tributary to Wolftever Creek commonly are "dry" (fig. 1). The area of "dry drainages" is underlain by the carbonate formations of the Knox Group (fig. 2).

Sinkholes are common in areas underlain by dolomite or limestone where the overburden has collapsed or subsided into a cavity (fig. 1). Two of the largest sinkholes in the lower basin are oriented almost north-south, and a line connecting them passes through Carson Spring.

GROUND-WATER HYDROLOGY OF THE LOWER WOLFTEVER CREEK BASIN

Ground water probably occurs in all of the formations of the Nashville Group, Stones River Group, and Knox Group underlying the lower Wolftever Creek basin. The principal water-bearing units are the formations of the Knox Group, particularly those that are dolomites. Formations of the Nashville and Stones River Groups are thought to contain much less water because of their smaller thickness, fine-grained texture, clay content, and absence of appreciable quantities of chert.

Water occurs in the interstices of the regolith, and along bedding planes and in fractures and solution openings in the bedrock. Saturated regolith provides a continuous supply of water to fractures and solution openings in the bedrock. Where saturated regolith is thick, the potential for recharging bedrock is greatest.

Water occurs in both the regolith and bedrock of the basin under water-table conditions. It also occurs locally under perched conditions. The development of perched water is favored in topographically high areas that are underlain by bedded chert and have a deep regional water table, such as Dividing Ridge.

Recharge, Discharge, and Direction of Flow

The aquifer underlying the lower Wolftever Creek basin is replenished naturally by the infiltration of precipitation through the regolith. A substantial amount of recharge occurs by the loss of flood flow in stream channels underlain by cherty gravel in the Hunter Road area (fig. 1). Additional recharge might occur by losses from Wolftever and Little Wolftever Creeks during prolonged dry periods. The recirculation of water used for the irrigation of lawns and gardens, a common practice in this watershed, provides a minor source of recharge.

Discharge from the aquifer occurs naturally at springs, along the channels of streams, and at or near the ground surface by evaporation and transpiration. Additional discharge occurs by the pumping of wells.

To determine the direction of ground-water flow in the basin, potentiometric-surface maps were prepared for October 1988 (fig. 4) and late March 1989. The maps were based upon water levels in about 60 area wells. Most of the wells were domestic wells that have been drilled into bedrock; at least two of the wells (M-3 and M-4) terminate in the regolith. Coverage is sparse in that part of the VAAP within the basin and in the area immediately south, and absent in the area north of Carson Spring.

Hydraulic heads indicate that some of the ground water in the regolith and weathered bedrock underlying this basin flows toward and discharges into Wolftever Creek and tributaries. Throughout much of the area, water in the regolith also flows downward to recharge the bedrock. The pathways of flow in carbonate bedrock are less readily defined, being strongly influenced by the three-dimensional geometry of the cavity system and the distribution of hydraulic heads within the cavities, and might not directly

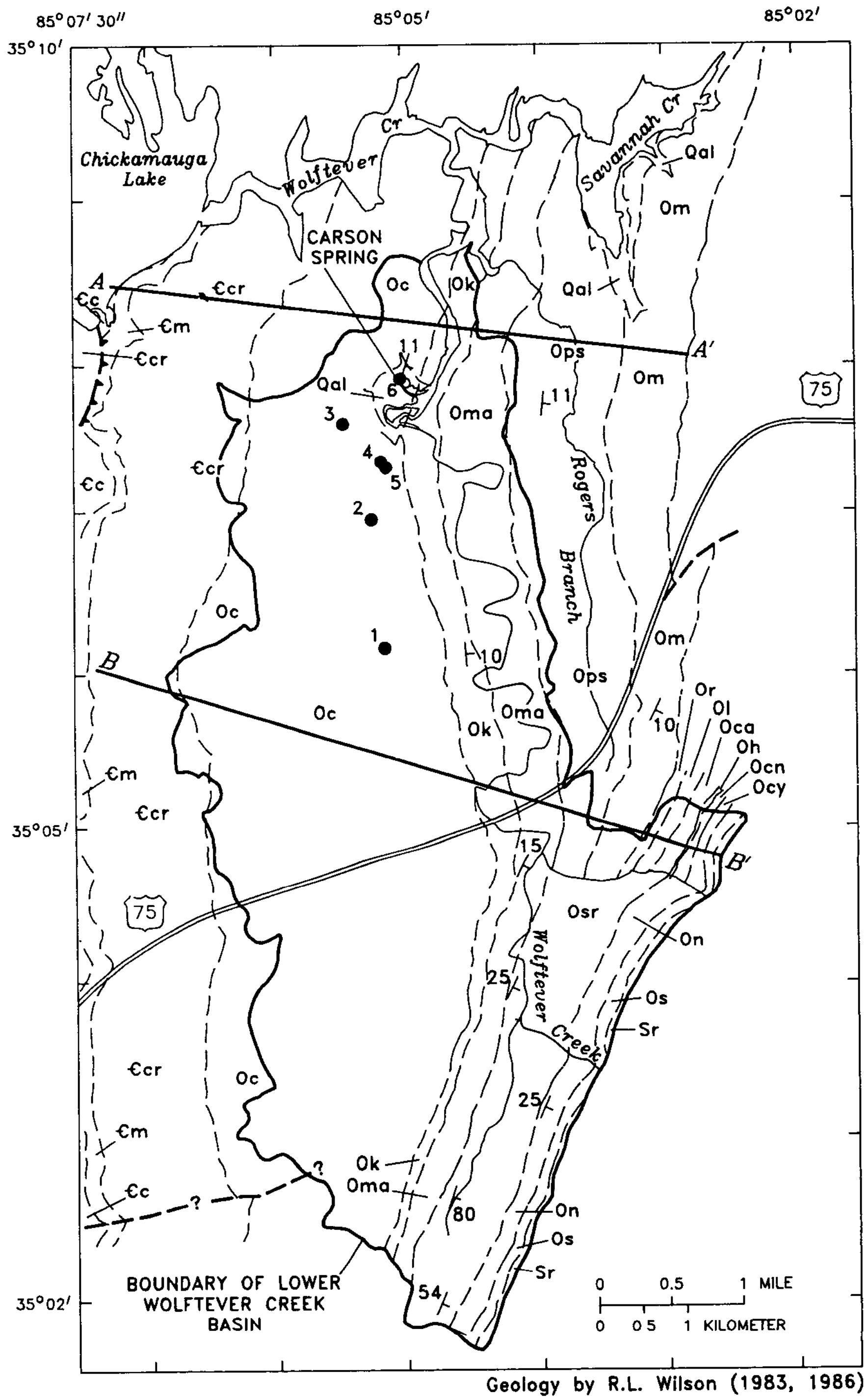
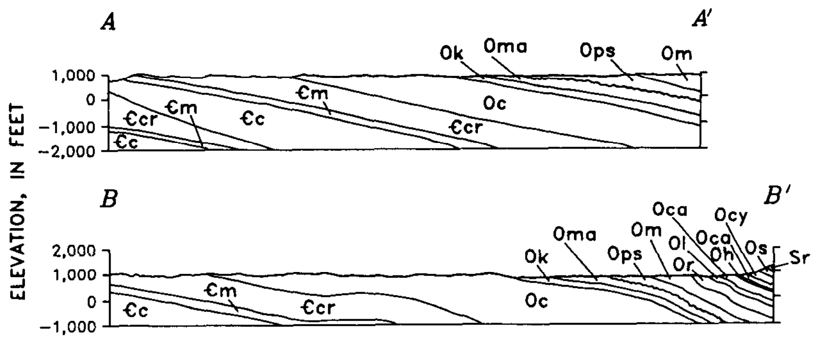


Figure 2. Geologic map of the lower Wolftever Creek basin and geologic sections A-A′ and B-B′.



EXPLANATION

GEOLOGIC UNITS

	Qal	Alluvium		Pleistocene and Holocene
	Sr	Rockwood Formation		Silurian
	Os	Sequatchie Formation		Upper Ordovician
Nashville Group	Ocy	Catheys Formation	On — Nashville Group, undivided	Middle Ordovician
Nashville Group	Ocn	Cannon Limestone		
Nashville Group	Oh	Hermitage Limestone		
Stones River Group	Oca	Carters Limestone	Osr — Stones River Group, undivided	
Stones River Group	Ol	Lebanon Limestone		
Stones River Group	Or	Ridley Limestone		
Stones River Group	Om	Murfreesboro Limestone		
Stones River Group	Ops	Pond Spring Formation		
Knox Group	Oma	Mascot Dolomite		Lower Ordovician
Knox Group	Ok	Kingsport Formation		
Knox Group	Oc	Chepultepec Dolomite		
Knox Group	Ꞓcr	Copper Ridge Dolomite		Upper Cambrian
Conasauga Group	Ꞓm	Maynardville Limestone	Ꞓc — Conasauga Group, undivided	Upper Cambrian / Middle Cambrian

UNCONFORMITY—Queried where indefinite

THRUST FAULT—Sawteeth on upthrown block

GEOLOGIC CONTACT—Dashed where approximately located

FAULT—Approximately located

A——A′ TRACE OF GEOLOGIC SECTION

10 STRIKE AND DIP OF BEDS

1 TEST WELL AND WELL NUMBER

SPRING

Figure 2. Geologic map of the lower Wolftever Creek basin and geologic sections A-A′ and B-B′--Continued.

SYSTEM	GROUP	FORMATION	THICKNESS, IN FEET	DESCRIPTION
QUATERNARY		Alluvium	0–40	Clay, silt, sand, and gravel.
SILURIAN		Rockwood Formation	600	Siltstone, shale, limestone, and sandstone.
ORDOVICIAN		Sequatchie Formation	250	Calcareous siltstone, limestone, mudstone, and interbedded shale.
ORDOVICIAN	NASHVILLE GROUP	Catheys Formation	250	Limestone and silty limestone. Contains zones of calcareous shale.
ORDOVICIAN	NASHVILLE GROUP	Cannon Limestone	190	Limestone and silty limestone.
ORDOVICIAN	NASHVILLE GROUP	Hermitage Limestone	120	Limestone, argillaceous.
ORDOVICIAN	STONES RIVER GROUP	Carters Limestone	300	Upper member–(30 feet)––Limestone and silty limestone. Contains metabentonite beds. Lower member––Limestone.
ORDOVICIAN	STONES RIVER GROUP	Lebanon Limestone	200	Limestone.
ORDOVICIAN	STONES RIVER GROUP	Ridley Limestone	400	Limestone. Calcareous shale and mudstone in middle 75 feet.
ORDOVICIAN	STONES RIVER GROUP	Murfreesboro Limestone	475	Limestone, argillaceous limestone, and thin zones of calcareous shale.
ORDOVICIAN	STONES RIVER GROUP	Pond Spring Formation	350–400	Upper part––Limestone with mudstone. Lower half––Limestone. Basal conglomerate of dolomite with limestone or lenses of shale and sandstone occuring locally.
ORDOVICIAN	KNOX GROUP	Mascot Dolomite	250–300	Dolomite, cherty. Produces minor amounts of chert upon weathering. Upper surface commonly shows evidence of major disconformity.
ORDOVICIAN	KNOX GROUP	Kingsport Formation	245	Upper part––Limestone with minor amount of dolomite. Lower part––Dolomite interbedded with fine-grained limestone. Contains lenses and nodules of chert.
ORDOVICIAN	KNOX GROUP	Chepultepec Dolomite	2,000	Dolomite, very cherty, thin- to very thick-bedded, interbedded near top with limestone. Contains lenses and nodules of chert and lenses of dolomitic chert.
CAMBRIAN	KNOX GROUP	Copper Ridge Dolomite	1,000	Dolomite, cherty.

Figure 3. Stratigraphic column in the lower Wolftever Creek basin. (Modified from R.L. Wilson, 1983, 1986).

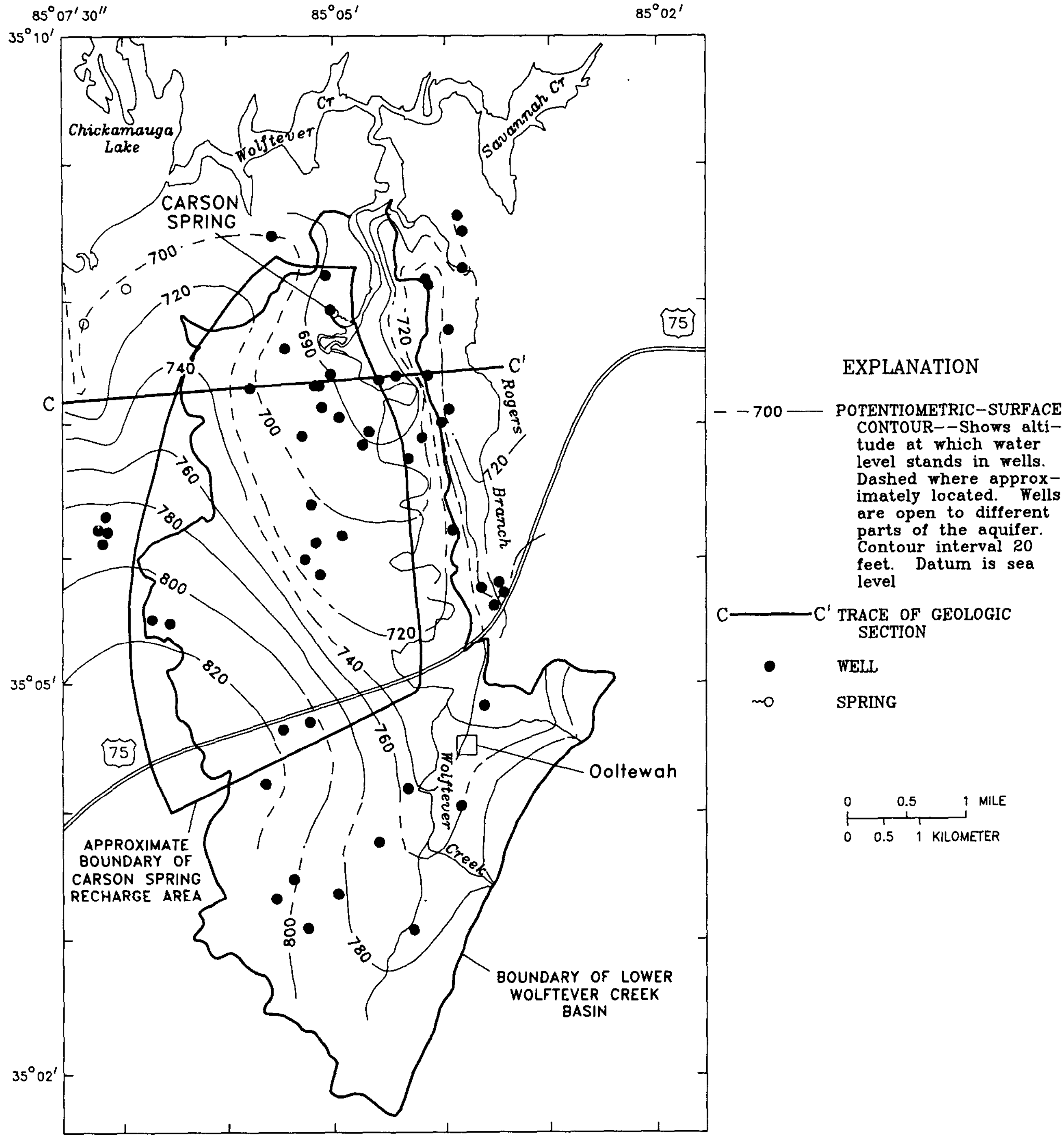


Figure 4. Potentiometric map of the lower Wolftever Creek basin for October 1988 and approximate boundary of Carson Spring recharge area.

correspond to the direction of flow in the overlying regolith. Nevertheless, the potentiometric maps indicate that the net direction of flow is to the north. Lowest heads occur near Carson Spring and the lower reaches of Wolftever Creek, which appear to represent the discharge points of bedrock in the area north of I-75.

South of I-75, water levels at three bedrock wells were 40 to 100 feet below what is interpreted to be the regional water table. The data are too few to draw conclusions, but might indicate that in this area the secondary openings in bedrock are less developed areally than those underlying the Hunter Road area and that the openings might have limited continuity with the overlying reservoir of water in the regolith. Altitudes of the water surface in the three wells reflect a shallow gradient, if meaningful, north-northeast parallel to strike.

The steepest gradient in the area mapped occurs along the west face of the low ridge underlying Snow Hill Road (fig. 1), and corresponds to the contact between the Mascot Dolomite of the Knox Group and the overlying Pond Spring Formation of the Stones River Group (fig. 2). The gentle rise in terrain alone does not account for the steepness of hydraulic gradient. Steepness implies that the Pond Spring Formation has less permeability, at least in an east-west direction (across strike), than the formations of the Knox Group. Less permeability means that flow is impeded and a steeper gradient is required for water to flow in that direction. Low yields of four wells drilled in the Pond Spring Formation at an industrial site near the southern end of the ridge and of domestic well M-8 (112 feet deep), located midway along the ridge, tend to confirm the smaller permeability of this unit.

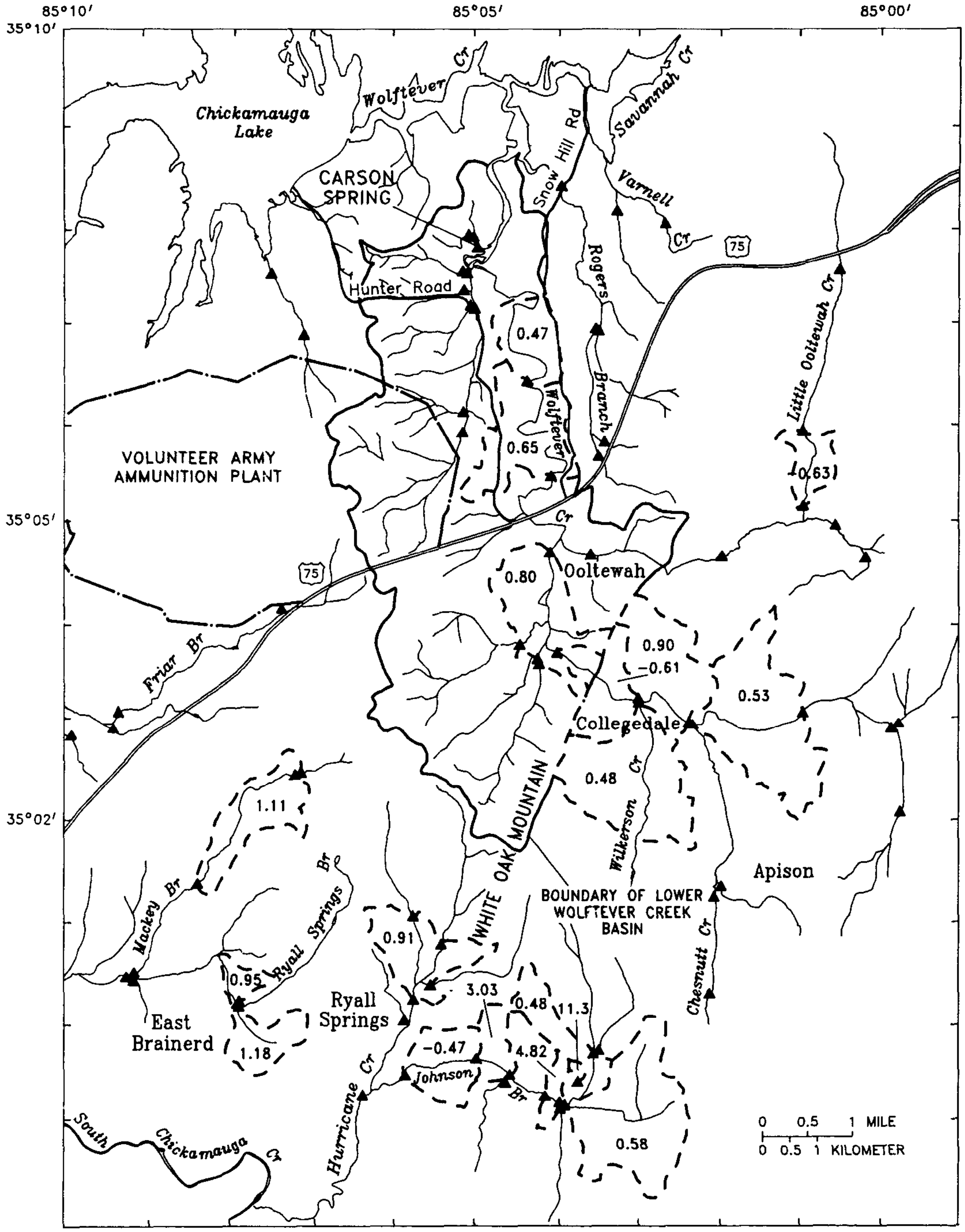
A small number of wells in the Harrison Branch area of the VAAP and in the Rogers Branch area were included in the canvass of water-level measurements. Potentiometric contours indicate that these two areas lie outside the lower Wolftever Creek ground-water basin; therefore, the east and west boundaries of that basin must occur below the ridges (but not necessarily coincide with the ridge crests) that define the surface-drainage divides in these areas.

The potentiometric map of late March 1989 shows the same contour pattern as that of October 1988, adjusted slightly for changes in altitude of the water surface. Of particular interest is the amount of change in depth to water from autumn to spring. Greatest change occurred in the Hunter Road area, an area of dry stream channels, where water levels in many wells rose 10 to 18 feet. Near the north to west bend in that road, where depth to water is shallow, the recovery was about 3 to 9 feet. The magnitude of change attests to the ground-water-recharge capability of this area and identifies it as a primary recharge area for Carson Spring. Least change occurred in the wells along Snow Hill Road, underlain by the Pond Spring Formation. Recoveries in this area were on the order of 3 feet or less. In one well drilled into the Kingsport Formation and located close to the embayed section of Wolftever Creek, the water level declined by 3.6 feet. Between fall and spring measurements, Chickamauga Lake stage, base level of the system, had been lowered about 5.5 feet.

Interaction of Ground Water and Streams

A base-flow investigation (a sequence of relatively closely spaced flow measurements) was conducted of the principal streams in southeastern Hamilton County to identify stream intervals where large gains or losses in discharge occur (fig. 5). Measurements were made at 78 stations along Wolftever Creek, Friar Branch, Mackey Branch, Hurricane Creek, Harrison Branch, and their larger tributaries on May 13, 1987 (Lowery and others, 1988). Gains in stream flow reflect discharge from the aquifer; conversely, losses reflect recharge to the aquifer. Overall, a net gain to streams was recorded. The average rate of ground-water discharge to the streams, measured at the most downstream station on each stream, was 0.25 cubic foot per second per square mile of drainage area.

Gains substantially larger than average were found in three of the four segments measured in the lower Wolftever Creek basin. Two basin segments north of I-75 had gains of 0.65 and 0.47 $(ft^3/s)/mi^2$. One segment south of I-75 had a gain of 0.80 $(ft^3/s)/mi^2$, although part of this gain likely is a return of the large loss in discharge [0.61 $(ft^3/s)/mi^2$] from the next segment upstream of the lower basin. Because most of the boundary between the latter two segments is an impermeable ridge, loss from the upstream segment must occur as channel underflow and flow through nearby



EXPLANATION

— — — BOUNDARY OF BASIN SEGMENT

▲ MEASUREMENT STATION

0.53 GAIN OR LOSS (–) IN STREAM DISCHARGE, IN CUBIC FEET PER SECOND PER SQUARE MILE OF DRAINAGE-BASIN AREA

Figure 5. Basin segments having large gains or losses in stream discharge, May 13, 1987, and location of measurement stations.

materials to discharge back into the creek at points downstream. The fourth basin segment, straddling I-75, had a gain of 0.06 $(ft^3/s)/mi^2$. The average gain along the four stations in the lower basin was 0.50 $(ft^3/s)/mi^2$, twice that of the broader area average. Discharge downstream from the lowermost station (about 1 mile southeast of Carson Spring) could not be measured because of backwater conditions in the embayed interval of Wolftever Creek. At the time of the measurements, all stream channels in the Hunter Road area were dry.

The measurements indicate that ground water is discharging to Wolftever Creek throughout much of its traverse across the lower basin. Because much of that water is thought to originate in the Chepultepec Dolomite to the west, the magnitude of gain in the two segments north of I-75 implies that the geologic units (Kingsport Formation and Mascot Dolomite) between the top of the Chepultepec Dolomite (corresponds approximately to the north-south interval of Hunter Road) and Wolftever Creek have comparatively large transmissivity values in order to transmit ground water at the rates of discharge measured. The small rate of gain of the segment straddling I-75 relative to the gains of other segments might have no hydrologic significance to this study; on the other hand, it could indicate (1) ground water that would have been discharged to this segment of Wolftever Creek was captured en route by a cavity system, or (2) even though this segment had a net gain, it was losing water. The loss could be through underflow to the downstream segment or it could be to a cavity system. Available data are inadequate to provide more complete definition.

GROUND-WATER HYDROLOGY OF CARSON SPRING

Carson Spring has a complex hydrologic system. Like many other large springs, this spring is supplied by water that flows through cavities in carbonate rock. The aquifer-surface water relation in the area is made more complex by intensive pumping of wells close to Carson Spring and seasonal adjustments to the stage of Chickamauga Lake nearby.

Characterization of the Chepultepec Dolomite as an Aquifer

The Chepultepec Dolomite underlies most of the Hunter Road area (fig. 2). Stream channels in this neighborhood lose storm water relatively rapidly, have only brief periods of base flow, and commonly are strewn with poorly sorted gravel. Such dry stream reaches in carbonate terrain elsewhere in Tennessee have been noted as surface indicators of potential ground-water reservoirs (Brahana and Hollyday, 1988). In these areas, much of the runoff carried by drainages is lost by infiltration through the stream bed to the aquifer, commonly composed of sheet-like dissolution openings developed in bedrock parallel to the bedding.

To study the water-bearing characteristics of the Chepultepec Dolomite, six test wells were drilled in that formation to depths ranging from 182 to 284 feet (figs. 2 and 3). The first four wells were constructed adjacent to dry stream channels during September and October 1986. A fifth well was drilled beside the fourth well about a month later, and a sixth well was drilled at the Eastside Utility District well field at Carson Spring (fig. 6) during March and April 1988.

Drilling results indicate that the regolith consists mostly of silt, clay, rock fragments, and chert. Thickness is about 50 to 80 feet at test wells 1 through 5, and 20 feet at test well 6 (table 2). At other wells near test well 6, regolith thickness as reported in drillers' logs ranged from 16 to 26 feet. Bedrock is siliceous, cherty dolomite in which substantial dissolution has occurred. Solution openings in some of the wells are separated only by thin layers of rock. Many openings are partly or completely filled by mud and cherty gravels held in a mud matrix. Mud ejected from some of the bedrock cavities of test wells 3 and 4 was so viscous that it held ripple marks as it slowly moved away from those wells and preserved the impressions of gravels thrown into it. Intervals of unconsolidated cherty gravel were common in each well. At test wells 1 through 4, the inflow of gravel from uncased intervals after removal of the drill column resulted almost immediately in the partial filling of each of those wells.

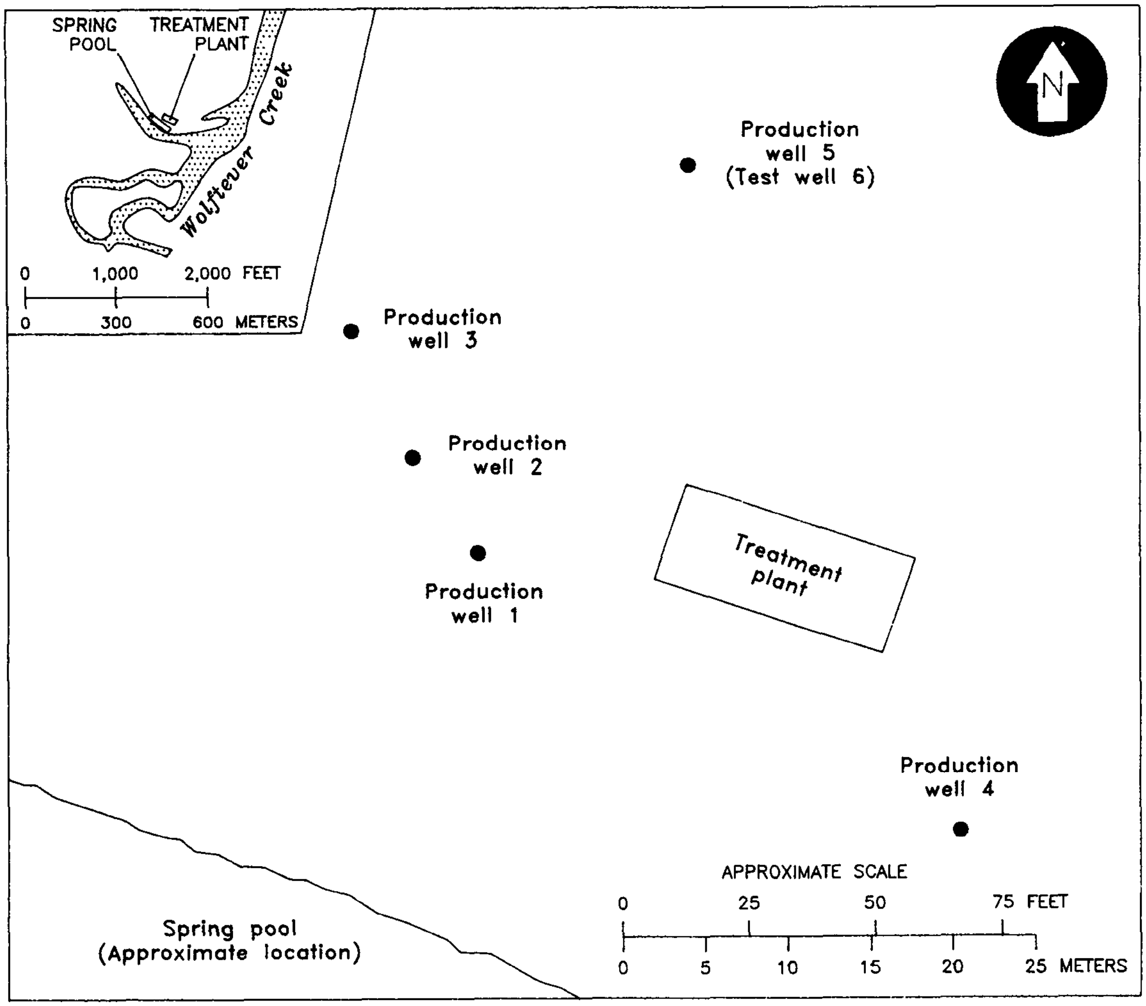


Figure 6. Sketch showing location of wells at Carson Spring.

Geophysical logs of test well 6 illustrate the character of the bedrock at that site. The natural-gamma log of the well (fig. 7) and visual inspection of the drill cuttings indicate that the bedrock has a rather uniform lithology. Major openings or zones of openings were found in the bedrock at depths of 36 to 50.5 feet, 80 to 80.5 feet, 127 to 142 feet, and 251 to 254 feet (see caliper, acoustic velocity, gamma-gamma, and neutron porosity logs, fig. 7). Importantly, the family of logs indicates that even though the aquifer extends to at least 254 feet deep, most of the openings occur within the upper 150 feet at this site.

The televiewer log and a more detailed caliper log (fig. 8) show the character of the openings intercepted in the interval left open (122 to 145 feet) to the completed well, re-designated as production well 5, after reaming to a wider bore. The openings range from a few inches to as much as 3 feet high, and the larger openings contain relatively thin layers of rock. Openings of these dimensions permit the flow of water through the rock at rapid velocity with little filtration by aquifer materials.

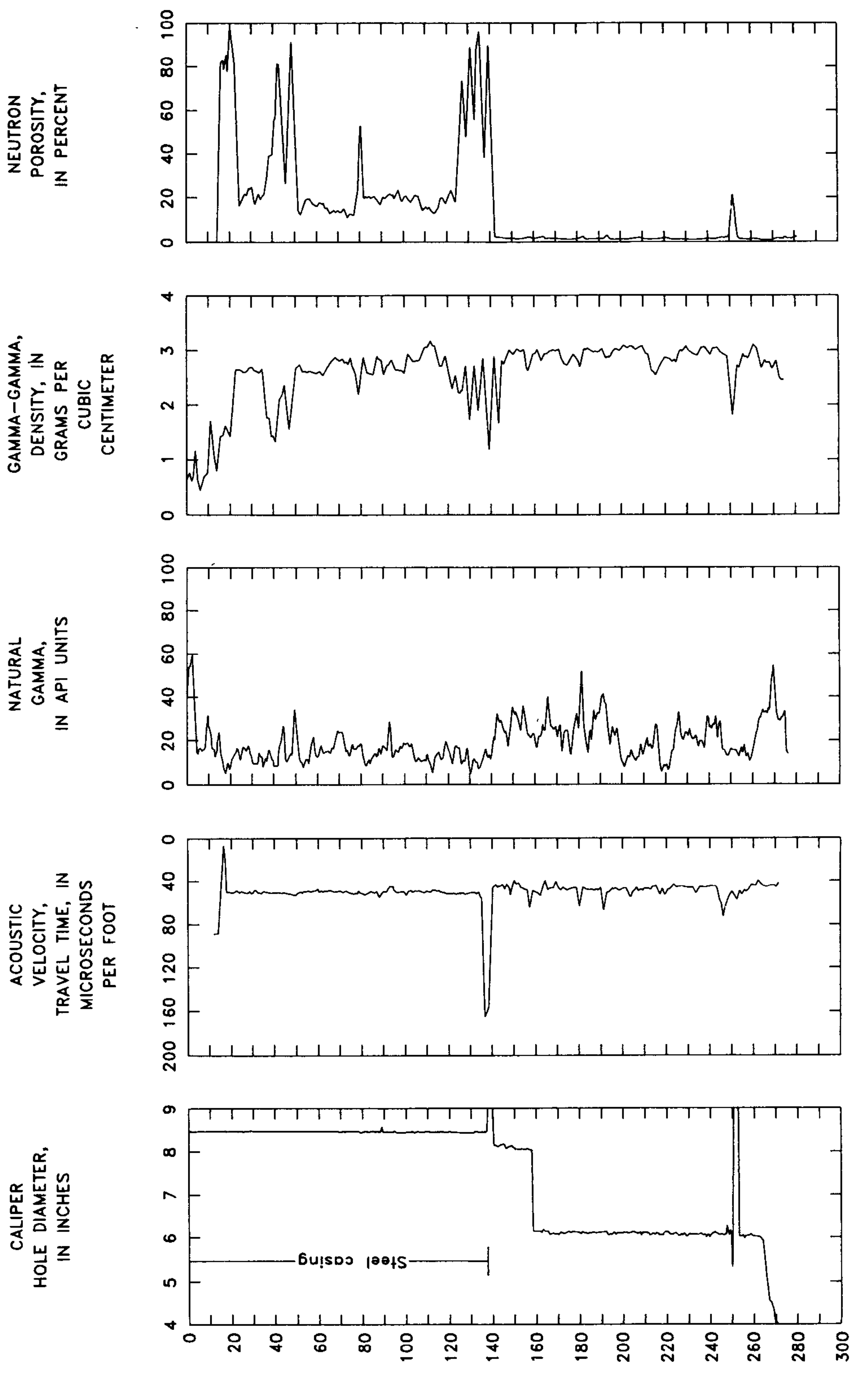


Figure 7. Geophysical logs of test well 6.

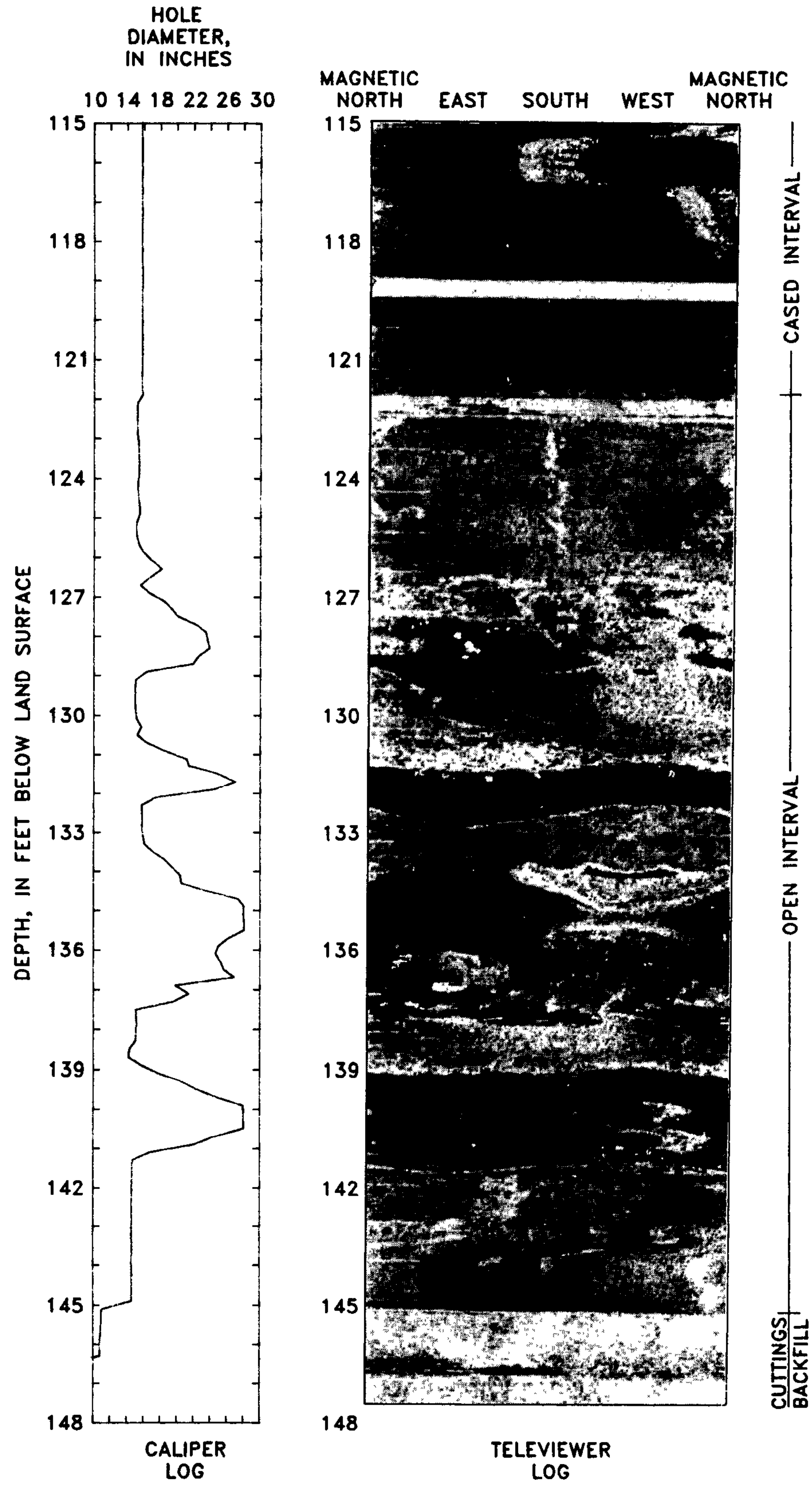


Figure 8. Caliper and televiewer logs of open interval in production well 5.

Table 2. Data for test wells

[--, indicates no data; >, greater than]

Description	Test well 1	Test well 2	Test well 3	Test well 4	Test well 5	Test well 6[1]
USGS well number	350607085051001	350656085051801	350736085052801	350719085050901	350719085050902	350750085055805
Total depth, in feet below land surface	251	250	280	182	257	284
Depth to bedrock, in feet below land surface	60	81	52	69	69	20
Depth of casing, in feet below land surface	169	145	83	162	175	138
Principal water-bearing zones, in feet below land surface	180-195 215-230	195-205 218-225	130-135 240-260	125-140 160-168 170 251-254 282-284	125-175 184 228-232	41-44.5 50-51.5 127-142
Open interval, in feet below land surface	169-251	145-250	83-280	162-182	175-257	138-284
Yield, gallons per minute by air blowing (wells 1, 2, 3, 4) or pumping (wells 5 and 6)	100	120-145, unsteady	103-106	250	>400	>1,000
Water level, in feet below land surface						
11-26-86	49.37	39.67	--	--	14.06	13.88
12-05-86	--	--	30.68	--	--	--
05-13-87	34.5	28.9	24.05	6.63	6.75	--
10-03-88	52.48	--	--	--	--	--
10-04-88	--	41.73	38.10	14.09	14.70	--
03-28-89	34.80	--	--	--	--	--
03-29-89	--	31.74	23.54	--	--	--
Back-filled by cascading gravel to depth, in feet below land surface						
10-03-86	215	164	129	171	--	
06-07-89	(2)	142	--	(3)	(3)	--
06-08-89	--	--	91	--	--	

[1]Test well 6, after further construction, became production well 5. See table 3 for data of finished well.
[2]Test well 1 has an obstruction at 82 feet below land surface.
[3]Test wells 4 and 5 were filled with gravel and cement, February 1989, to protect the aquifer from surface sources of contamination.

Openings below the water table that are not plugged by clay and gravel are water bearing. Increases in yield from each opening varied substantially. Yields of the first five wells upon completion ranged from 100 to more than 400 gal/min. Potential yields of each well could have been from 50 to 150 gal/min greater if the casing had been slotted.

An aquifer test was made at test well 5 shortly after that well was completed. Drawdown was about 58 feet after 8 hours of pumping at a rate of about 410 gal/min. Interpretation of a later aquifer test was that the well could be pumped at 600 gal/min for several months before the water level would reach the top of the open interval of casing (135 feet below land surface) in the unlikely event that no recharge occurred during that period.

The aquifer at Carson Spring is capable of providing large yields to wells. By the time the $8^1/_2$-inch-diameter test hole had advanced to 109 feet, the well yielded more water than could be evacuated with the available 750 ft^3/min of compressed air. The upper 122 feet of well were later cased off, leaving an interval of 23 feet open to the finished well. A 24-hour aquifer test, during which the completed well was pumped at a rate of 2,000 gal/min, caused nearly 9 feet of drawdown after 14 hours of pumping. During the test period, production wells 1, 3, and 4 were pumped for various periods of time to meet water demand. This additional pumpage during the test period added discontinuous stresses to the aquifer and precluded computation of aquifer coefficients.

Substantial evidence, as summarized in the following statements, indicates that a labyrinth of cavities interconnected laterally and vertically occurs in the Chepultepec Dolomite underlying Carson Spring, and that the spring pool has excellent hydraulic connection with the aquifer: (1) Drilling of test well 6 caused water pumped from the three production wells to become turbid (dingy to very muddy) on many occasions. Production well 3 seemed to be particularly affected. Turbidity likely was caused by the flow of muddy water at or near the well under construction through open channels to the production wells. (2) The caliper log of production well 2 indicates that this well intercepted a small number of cavities or other openings. As test well 6 was reamed, a water-level recorder at well 2 indicated oscillations of the water surface in that well of as much as 3 feet every 4 to 5 seconds. The oscillations are thought to have resulted from compressed air moving through cavities and entering the well at some depth below the water surface. (3) Another indication of the passage of compressed air through underground cavities was that during the construction of test well 6, gas bubbles rose intermittently from the bottom of the spring pool. (4) Starting or stopping a pump at production wells 3 or 4 causes an instantaneous water-level decline or recovery, respectively, of about 2 feet at production well 2, and a somewhat smaller change when the pump at production well 1 (a smaller capacity pump than those at wells 3 or 4) is started or stopped. Such instantaneous response reflects a wave transmitted through open channels in the aquifer. (5) The water surface of the spring pool fluctuates in response to intensity and duration of pumping the production wells. By the 15th hour of the 24-hour pumping test at production well 5, for example, the spring pool had been nearly depleted of water. The rate of depletion seemed to be abated during the early morning hours of the test when the other production wells were not being pumped, and a rapid recovery occurred after cessation of the test. (6) Land surface near production well 2 subsided during the initial pumping of that well, indicative of dewatering a cavity. (7) Lastly, production wells 2 and 5 are open to different intervals of the aquifer, but the water-level altitudes are essentially the same when all pumps are off. Hence, no potentiometric gradient from the deeper to the shallower intervals is evident.

On a broader scale, based on the limited amount of drilling done, the more transmissive part of the aquifer is associated with points closest to Wolftever Creek. These points are represented by test wells 4, 5, and 6. Smaller yields, reflecting in a general way less transmissivity, were obtained at test wells 1, 2, and 3, located at greater distances from Wolftever Creek.

Topography, geology, and the presence of cavities in the locale suggest that a cavity system may have developed below the linear depression that topographically connects Carson Spring to large sinkholes about 0.7 mile north and 2.5 miles south of the spring (fig. 1). Hydraulic connection of the cavities would provide a pathway for an underground stream. Quite possibly, in prehistoric time, the natural place of discharge for the postulated stream was at some point north of the present-day spring, but collapse of overburden into the main stem of the cavity in that area blocked or reduced flow, requiring the system to develop a new natural discharge point at a location where fractures or other features weakened the integrity of the overburden. If so, this could provide an explanation for the origin of Carson Spring.

Withdrawals from Wells at Carson Spring

The withdrawal of large amounts of water from wells at Carson Spring affects the rate of spring discharge. Withdrawals, therefore, must be measured in order to quantify discharge from the spring. During the period of this study, the utility district operated pumps on three wells (production wells 1, 3, and 4) drilled within a few hundred feet of Carson Spring (fig. 6). Test well 6 also was used intermittently for 1-day periods in 1988 to meet water demand during the drought, and after further well construction, was placed in service as production well 5 in May 1989. Production well 2 has not been used because land surface near the well subsided into a cavity during the initial operation of the well, and concerns have been that dewatering a cavity might induce further subsidence. Site information about the earlier wells is limited (table 3).

To estimate daily withdrawals, the number of hours per day that each well was pumped was multiplied by measured rates of withdrawal. Initially, hours of pumping were read from circular recorder charts; later, time-totalizers (vibration-sensitive instruments that record the number of hours of pumping) were installed on each producing well. Rates of withdrawal were measured with a non-invasive flow meter applied to the main manifold leading to a million-gallon storage tank. Rates were measured on May 15, 1987, when depth to water was assumed to be about midway between seasonal extremes, and again on June 20, 1989, when depth to water was close to its minimum (table 4). The differences in withdrawal rates between the two dates are attributed to the decrease in depth to water and resulting decrease in pumping lift. Although two or more wells are commonly pumped simultaneously, ratings for individually wells were used in the computations because the time-totalizer data are inadequate to define times of simultaneous use. Small errors likely are inherent in this approach; consequently, the computed values should not be viewed as precise measurements.

Computed mean daily pumpage (or withdrawal) for the last 8 months of 1987 was 5.28 ft^3/s; for 1988, 5.83 ft^3/s; and for 1989, 4.78 ft^3/s (table 5). During the drought years of 1987 and 1988, pumps on the three operational wells were run non-stop for days at a time to meet water demand (see the plateaus of May and June 1988 on fig. 9, for example). Maximum pumpage at that time with the three pumps running is estimated to have been 7.70 ft^3/s, using the earlier pump ratings. (Figure 9 indicates 7.51 ft^3/s. The difference results from summing the discharge of individual wells rather than using the rating for the combination of wells.)

Table 3. Data for production wells at the Carson Spring water-treatment plant

[--, indicates no data; NA, not applicable]

Description	Production well 1	Production well 2	Production well 3	Production well 4	Production well 5
USGS well number	NA	350750085045802	NA	NA	350758085045805
Total depth, in feet below land surface	62	72	92	128	145
Depth to bedrock, in feet below land surface, approximate	16	16	16	26	20
Depth of casing, in feet below land surface	--	26	--	--	122
Principal water-bearing zones, in feet below land surface	--	55-56 64	--	89-90 99-102	126-129 131-132 134-138 139-141
Open interval, in feet below land surface	--	26-72	--	--	122-145
Yield, in gallons per minute	600-680	--	1,700-1,760	1,070-1,140	2,000-2,480
Water level, in feet below land surface 02-01-89	--	17.25 (daily average)	--	--	17.50 (single measurement)

Table 4. Pumping rates for production wells at Carson Spring[1]

[Values in gallons per minute; --, indicates no value]

Production well(s)	Representative rate		Sum of representative rates, June 20,1989	Difference	Percent difference
	May 15, 1987	June 20, 1989			
1	600	680	--	--	--
3	1,700	1,760	--	--	--
4	1,070	1,140	--	--	--
5	--	2,480	--	--	--
1,3	2,360	2,370	2,440	-70	-3
1,4	1,800	1,640	1,820	-180	-10
1,5	--	3,090	3,160	-70	-2
3,4	2,380	2,880	2,900	-20	0
3,5	--	4,310	4,240	70	+2
4,5	--	3,730	3,620	110	+3
1,3,4	3,460	3,580	3,580	0	0
1,3,5	--	4,740	4,920	-180	-4
1,4,5	--	4,320	4,300	20	0
3,4,5	--	5,120	5,380	-260	-5
1,3,4,5	--	5,460	6,060	-600	-10

[1]Measurements were made using a meter with rated accuracy of 2 to 3 percent. Point of measurement was along the 16-inch-diameter ductile iron pipeline as it traverses the chlorination pit southeast of the treatment plant. Depth to water could not be obtained in the measurements of May 1987. At the time of the June 1989 measurements, depth to water at well 2, while well 3 only was being pumped, was 8.67 feet below land surface. Minimum depth to water at well 2 during the period of measurements was 4.77 feet when all pumps were shut off; maximum depth was 13.35 feet after wells 1, 3, 4, and 5 had been pumped for a few minutes. Discharge from the 16-inch-diameter pipeline is through a standpipe about 21 feet tall, which provides a constant pumping head, within a 1-million gallon storage tank northeast of the plant.

Carson Spring Discharge

Carson Spring is the largest single point of ground-water discharge in the basin. Under natural conditions, the "spring boiled from under a bluff" (E.P. Matthews, U.S. Geological Survey, field notes, Nov. 6, 1947), and the entire discharge was represented in the flow of water to Wolftever Creek, a few hundred feet to the east. Under present conditions, spring discharge has three components: (1) withdrawals from the wells, (2) discharge from the spring pool, and (3) evaporation from the surface of the pool. Because losses to the atmosphere are minute relative to withdrawals, evaporation is not further considered.

The spring pool represents the above-ground storage of water that had been stored in the aquifer. Because the pool is hydraulically connected to the aquifer, pool stage rises and falls in response to changes in hydraulic pressure in the aquifer. Discharge through a V-notch weir at the southeast end of the pool occurs when stage reaches an altitude of 688.09 feet. Discharge also occurs through the bottom of the pool (to the aquifer) when pressure in the aquifer becomes less than the static head in the pool.

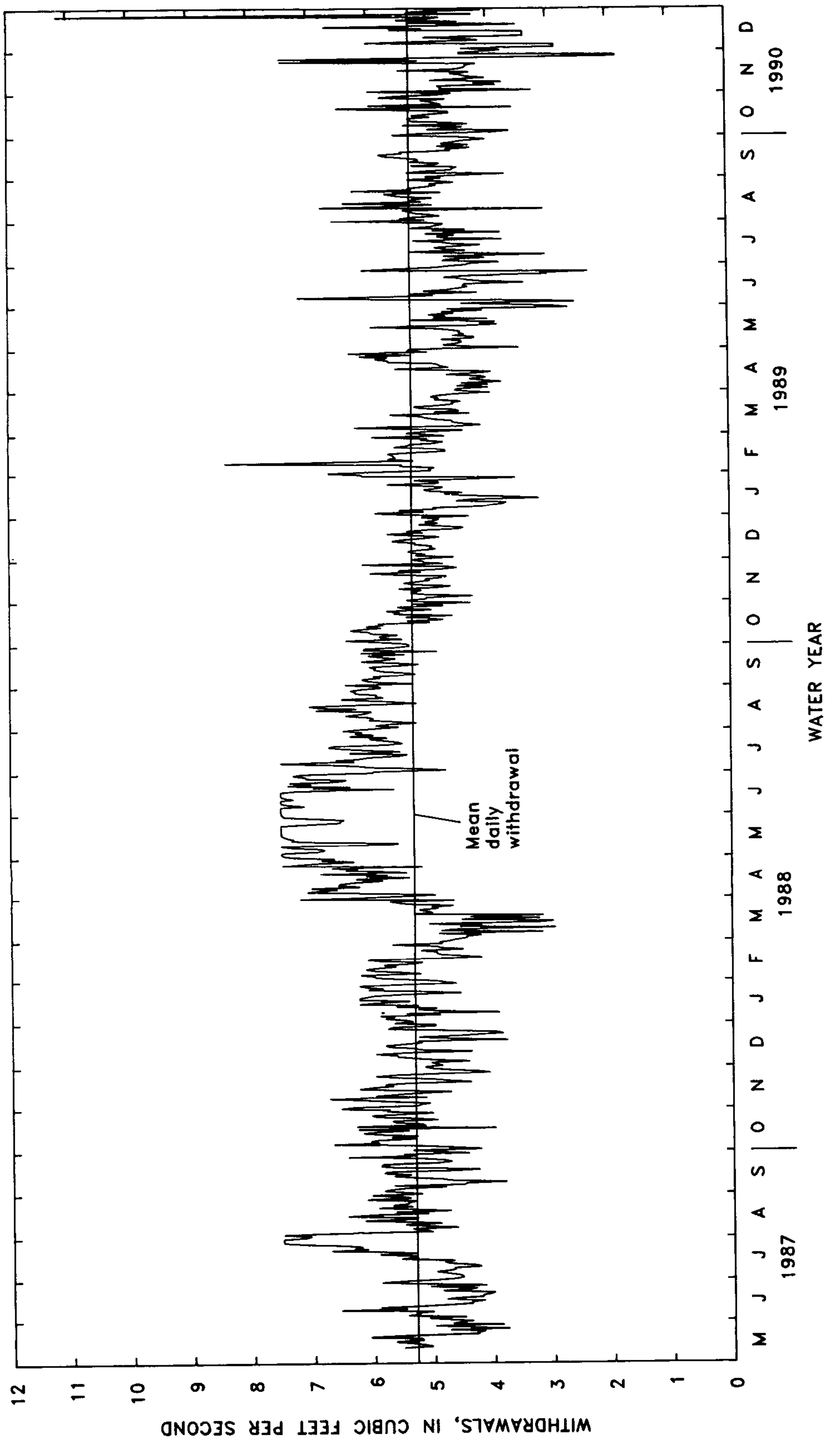


Figure 9. Daily withdrawals from wells at Carson Spring, May 1987 through December 1989.

Table 5. Summary of daily mean withdrawals from wells and spring discharge data at Carson Spring, by month

[All values in cubic feet per second. --, indicates no data]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
						1987							
Pumpage	--	--	--	--	4.87	4.86	5.55	5.67	5.20	5.51	5.42	5.03	5.28
Spring discharge	--	--	--	--	5.75	5.65	5.90	5.77	5.32	5.53	5.34	5.01	5.53
						1988							
Pumpage	5.49	5.32	4.57	6.29	7.13	7.21	6.05	6.06	5.75	5.52	5.12	5.08	5.83
Spring discharge	5.52	5.28	4.56	6.28	7.13	7.22	6.03	6.06	5.74	5.48	5.10	5.07	5.79
						1989							
Pumpage	4.73	5.48	4.83	4.80	4.48	4.39	4.55	5.26	4.83	4.82	4.53	4.66	4.78
Spring discharge	4.73	5.56	5.27	5.81	5.26	5.99	6.60	6.36	6.09	6.49	5.79	5.35	5.78

Mean daily discharge through the weir ranged from 3.1 ft^3/s during 3 days in 1989, to no discharge at all for 16 consecutive months from October 1987 to February 1989 (fig. 10), except for three brief storm-related intervals within that period totalling 6 days. During the period of no discharge, mean daily stage fluctuated from 0 to about 7.6 feet below the level of the weir. Although the water surface commonly was below the weir during the years of rainfall deficiency, at no time is there record of the pool having been completely emptied. However, the location of the spring orifice relative to the bottom of the pool is uncertain. The possibility exists that if the orifice is not at the lowest point in the pool, a residual amount of water could temporarily remain in the pool while the potentiometric level in the aquifer receded below pool bottom.

Discharge through the bottom of the pool is not spring discharge but aquifer recharge, and is caused by intensive pumping of the wells nearby. Pumping reduces the hydraulic pressure in the aquifer in the immediate vicinity of the wells. When the rate of withdrawal becomes large, the area of reduced pressure (or cone of depression) extends through the cavity system underlying the pool, inducing water stored in the pool to flow back into the aquifer and toward the points of lowest pressure which are at the pumping wells. Withdrawals from the system by this means are accounted for in pumpage.

Change in the mean daily amount of water stored in the spring pool reflects net daily discharge from the aquifer to the pool. Changes in storage from 1987 through 1989 have been calculated, using the difference in mean daily pool stage, converted to a rate of discharge (fig. 10). Negative values reflect losses to the aquifer in excess of pool recharge for that day. Values for those days having weir discharge assume the difference from day to day is equivalent to the column of water above the point at which water just begins to flow through the weir; thus, actual discharge through the weir is included in the value. As such, the value does not reflect true change in daily pool storage, but the procedure simplifies calculation of spring discharge.

Spring discharge (fig. 11) was calculated by summing mean daily withdrawals from wells and changes in mean daily storage. Computed mean daily spring discharge was

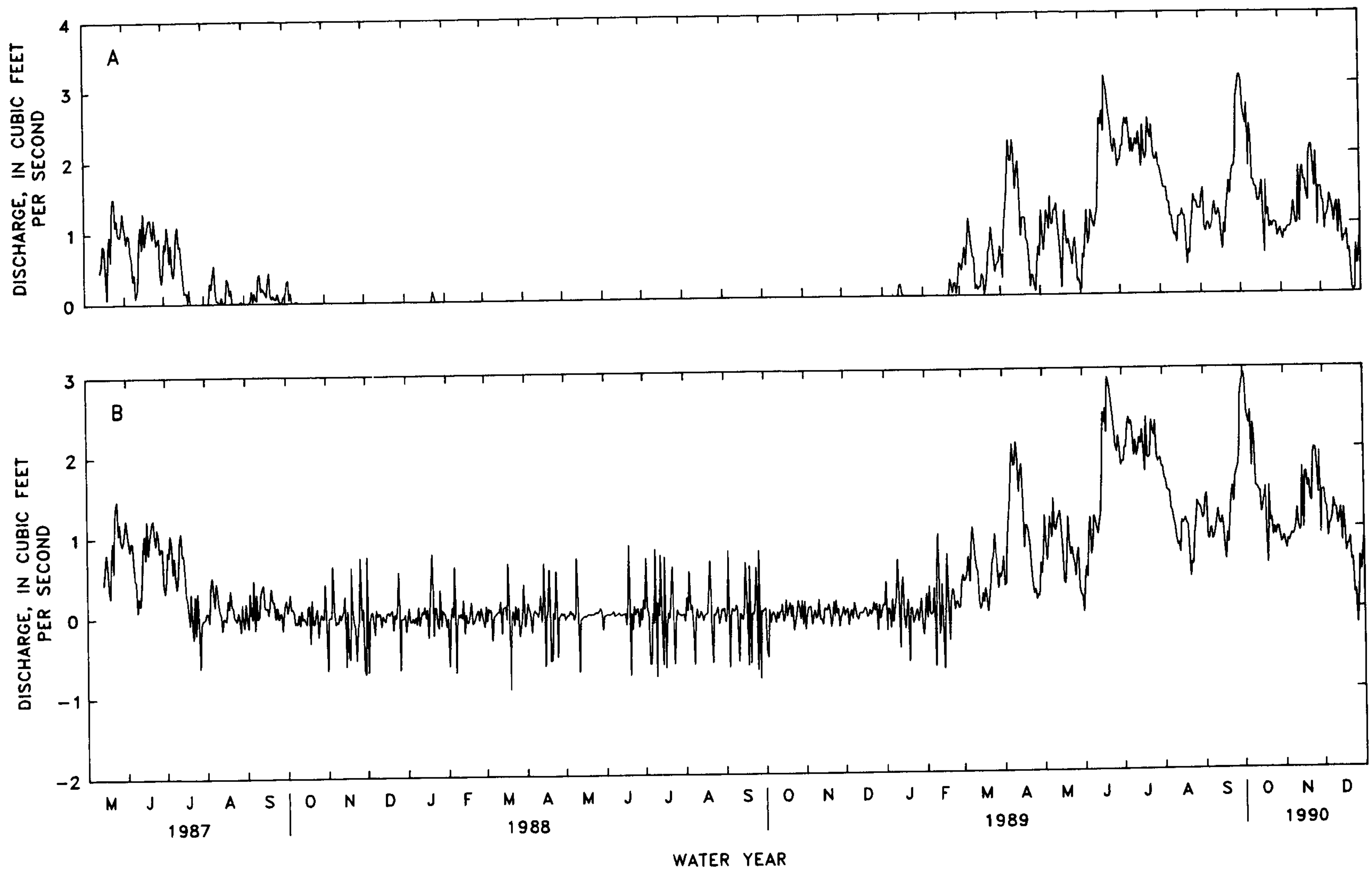


Figure 10. (A) Daily discharge through the weir at Carson Spring and (B) change in mean daily storage of pool at Carson Spring, May 1987 through December 1989.

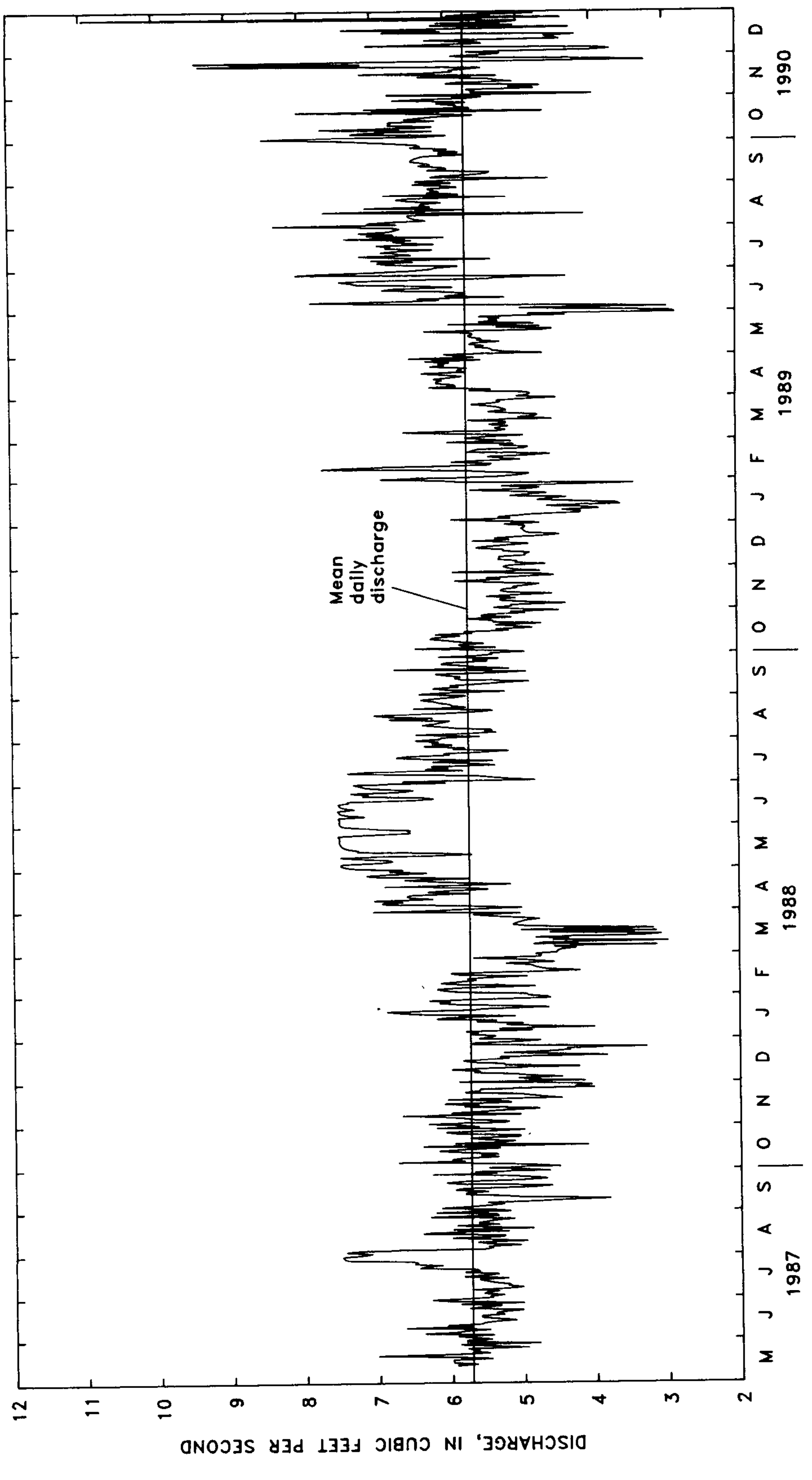


Figure 11. Daily discharge from Carson Spring, May 1987 through December 1989.

5.53 ft^3/s for the last 8 months of 1987; 5.79 ft^3/s for 1988; and 5.78 ft^3/s for 1989 (table 5). During the second half of 1989, stage rose high enough to cause flow outside the confines of the weir. This flow was not measured, but at maximum probably was less than 0.5 ft^3/s. From October 1987 through January 1989, withdrawals equaled discharge (table 5 and fig. 12). The minor differences probably result from imprecision in the data. On those days when mean daily change in storage had a negative value, withdrawals exceeded measured discharge.

During the period that withdrawals and discharge were equal, weir discharge virtually ceased (fig. 10). Lowering the hydraulic head in the system to a level that flow through the weir could no longer be sustained indicates that withdrawals exceeded the natural discharge of the spring. Data are not available to determine what the natural discharge would have been had there not been pumping activity, but the difference between natural discharge and measured discharge had to have come from either or both of two possible sources: (1) ground water stored in the aquifer, and (2) induced recharge to the aquifer from Wolftever Creek. Although which source was the contributor and how much that source (or each source) contributed can not be determined from the data, record from these dry years demonstrates that for a period of several consecutive months, the aquifer supplying water to this spring is capable of yielding more water than the spring discharges under natural conditions.

Long-term trends in discharge and the effects of pumpage at Carson Spring upon the amount of ground water stored in the aquifer cannot be determined without additional data. A few historic measurements, however, can provide insight. On November 6, 1947, following a year of normal precipitation, and again on September 27, 1948, following another year of normal precipitation, discharge of the spring was 6.30 ft^3/s and 6.40 ft^3/s, respectively. These measurements are of interest because they are measurements of natural discharge, made before the aquifer supplying the spring was developed. Another measurement was made on September 29, 1964, following a somewhat wetter than usual spring. Discharge was 5.39 ft^3/s; however, no measurement was made of the water then being pumped from the aquifer. With potential for withdrawing 850 gal/min at that time, mean daily withdrawals probably did not exceed 1 ft^3/s. Spring discharge at the time of the 1964 measurement is thus estimated to have been between 6.2 and 6.4 ft^3/s. If 6.3 ft^3/s can be taken as an approximation of the long-term mean, the drought of recent years and the pumping of many years reduced discharge from this spring by less than 1 ft^3/s during 1988-89. Data for the last half of 1989 (table 5 plus the unmeasured flow outside the weir) indicate that recent discharge has exceeded 6 ft^3/s. The aquifer, therefore, appears to have been replenished. Thus, no evidence is apparent to indicate a long-term overdraft upon the amount of ground water in aquifer storage.

Hydraulic-Head Relation at Carson Spring

The hydraulic gradient between the aquifer at Carson Spring and the adjacent, embayed section of Chickamauga Lake is significant because that gradient determines whether water discharges from the aquifer to the creek, or whether water flows from the creek into the aquifer and ultimately to the well field at Carson Spring. The gradient at Carson Spring can be ascertained by examining the difference in daily altitudes of potentiometric head at Carson Spring and the water surface of Chickamauga Lake (fig. 13). Potentiometric head in the aquifer at the well field for several months in 1989 is represented by the water-level record of production well 2. The water surface in the spring pool can be used to extend the record of well 2 backward in time because the spring-pool record approximates the record of well 2 until pool stage rises sufficiently to cause discharge over the weir. A hydrograph (fig. 13) depicts fluctuations in midnight altitudes of the lake at Chickamauga Dam; at Carson Spring the lake surface probably is less than 0.2 foot higher than at the dam. The consistently higher position of the potentiometric-surface hydrographs relative to the lake hydrograph indicates that heads in the aquifer have been greater than that of the lake, even during the recent drought years and months of near-capacity pumping. It can be reasoned, therefore, that water flows from the aquifer to the impounded interval of creek.

Because the upper curves are based on mean daily values, the head relation may have been reversed for short periods during those days when the difference in altitude was small, such as in May and June 1988. More detailed data for those 2 months show that only once, for a period of

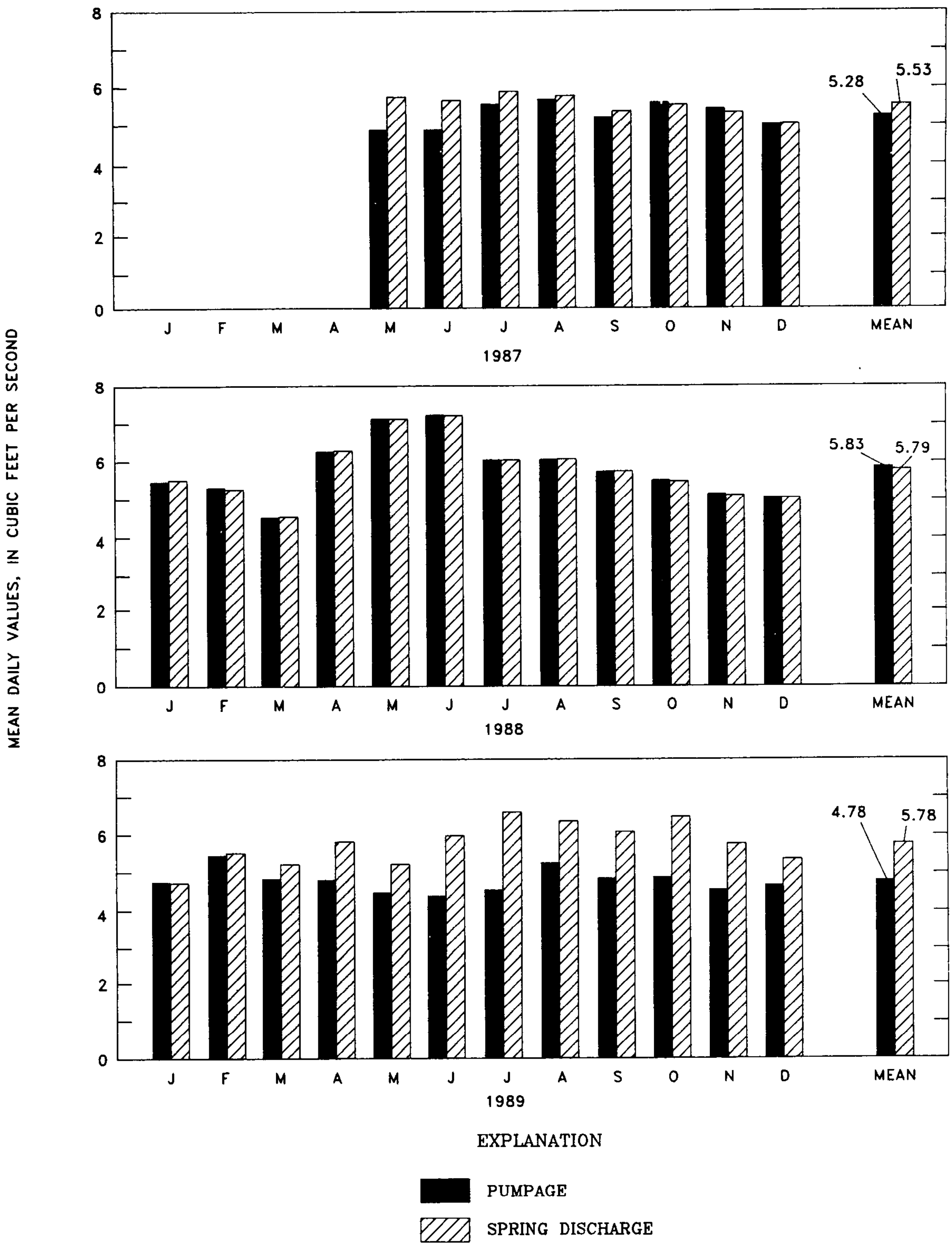


Figure 12. Mean daily withdrawals from wells and spring discharge at Carson Spring, May 1987 through December 1989. Discharge values include withdrawals.

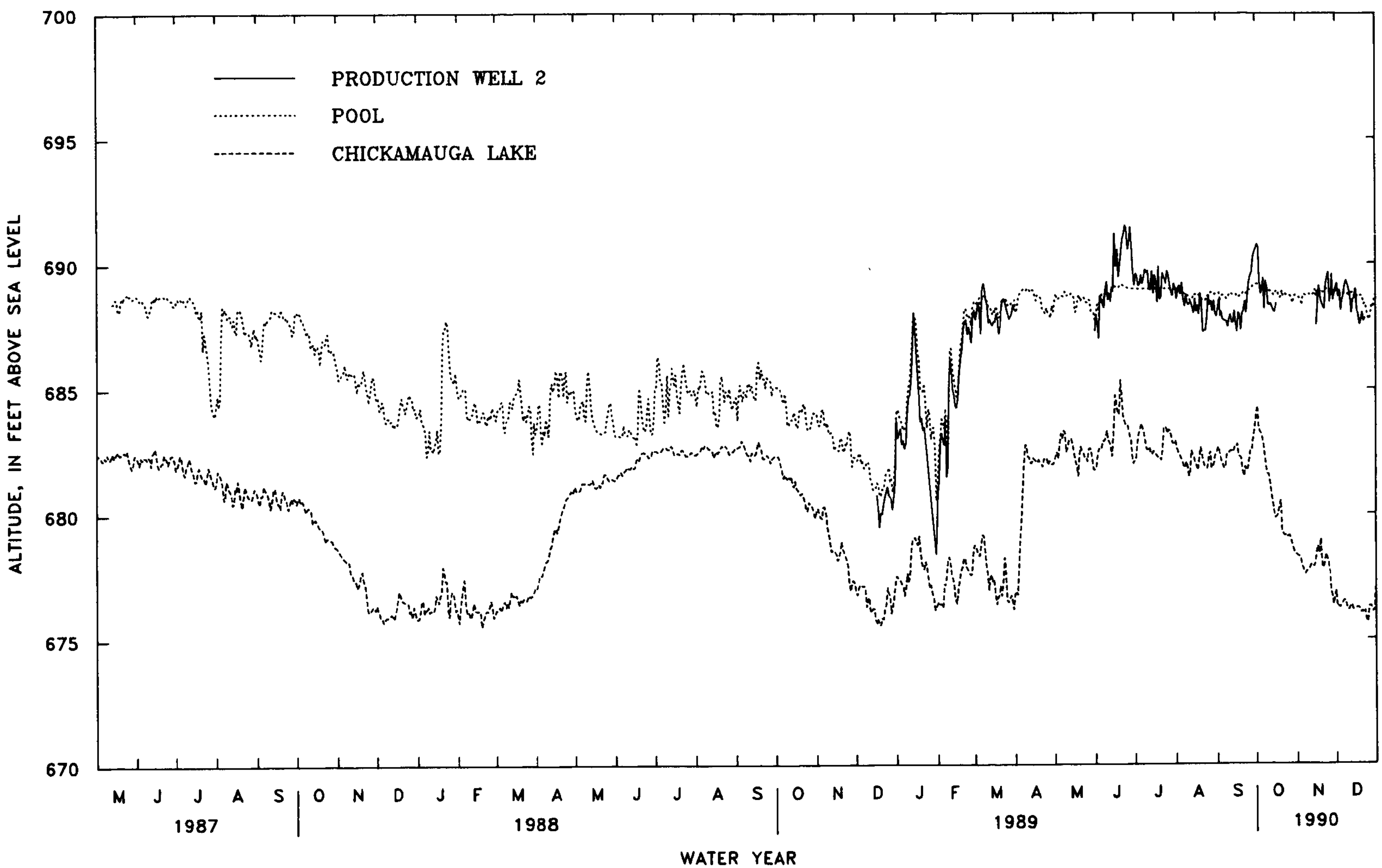


Figure 13. Relation of hydraulic head between production well 2 at Carson Spring, pool at Carson Spring, and Chickamauga Lake, May 1987 through December 1989.

several hours on June 17, was the lake level higher than pool level. If the water surface in the embayment is assumed to be 0.2 foot higher than at Chickamauga Dam, heads had become virtually equal by the end of the day.

During parts of June, the differences between lake level and pool level commonly were small. Given those small differences, Wolftever Creek upstream from the embayment would have had greater head than the aquifer at Carson Spring. If a cavity or other highly permeable zone underlies the creek upstream and has good hydraulic connection with Carson Spring, a substantial source of water to the wells at Carson Spring during that time may have been the creek.

The record shown in figure 11 indicates that if the drought of 1985 to 1988 had continued through 1989, recharge to the aquifer at Carson Spring during spring and summer 1989 probably would have occurred by induced flow from Wolftever Creek. Note that during the summer of 1987, pool level usually stood about 6 feet higher than the stage of Chickamauga Lake. During the summer of 1988, pool level was only 2 to 3 feet higher than lake level, and by December 1988, even though pool level remained a few feet above lake level, it was about a foot lower than the normal summer level of Chickamauga Lake. If a substantial amount of rain had not fallen over the watershed during the winter months of 1988-89, hydraulic head in the aquifer at Carson Spring would have remained low, and would have been exceeded by head of the lake when lake stage was raised in April 1989. Under this postulated condition, Wolftever Creek along the upper end of its impounded interval, and possibly upstream, would have had potential to become a major source of water to the wells at Carson Spring.

An extension of this interpretation is that the ground-water resource at Carson Spring is now fully utilized by the four production wells. Even though aquifer recharge in 1989 would support additional wells at this location, droughts are recurrent phenomena. Near-record pumping of three wells nearly reversed the hydraulic-head relation between aquifer and creek in 1988; construction and operation of another well in addition to the high-capacity well placed in service in 1989 would likely reverse the relation sooner if a similar, extended drought occurred.

The general similarity between hydrographs (fig. 13) suggests that raising or lowering Chickamauga Lake stage causes a rise or decline in pool stage and depth to water at Carson Spring, reflecting a change in potentiometric head in the aquifer. Adjustments in lake stage do effect potentiometric head at Carson Spring, but that head also is influenced by two other factors: (1) the magnitude of pumping, and (2) the amount, intensity, and seasonal distribution of precipitation. The importance of precipitation (fig. 14), and hence aquifer recharge, is shown on figure 13. Note that during the winter of 1987-88, with below average amounts of rain, little change occurred in aquifer head, whereas during the winter of 1988-89, with abundant rain, water levels (and aquifer head) began their recovery at least 2 months before lake stage was raised. Frequent rain throughout 1989 kept the aquifer fully or near fully recharged, and helped maintain head in autumn 1989 when lake stage again was lowered.

Carson Spring Recharge Area

The computed values of spring discharge and the potentiometric map can be useful for estimating the recharge area of the spring and in providing detail about the ground-water-flow system. Discharge to streams from carbonate terrains in the southeastern United States is believed to range from 1 to 2 $(ft^3/s)/mi^2$ of drainage area (E.F. Hollyday, U.S. Geological Survey, oral commun., 1989). If 6.3 ft^3/s represents the long-term mean discharge of Carson Spring, a recharge area of about 3 to 6 mi^2 is indicated, rather than the 17 mi^2 included in the lower Wolftever Creek basin. The Hunter Road area — the area of dry stream channels — is thought to be the primary recharge basin for this spring. Proximity of this area to the spring, magnitude of water-level change from autumn to spring, and the presence of cavities in the dolomite support this interpretation.

The approximate boundary of the Carson Spring recharge area can be determined from the potentiometric-surface map (fig. 4). In the southern part of the lower Wolftever Creek basin, flow lines (not shown on figure 4) indicate that flow through the Knox Group underlying most of Rabbit Valley trends east-northeast to discharge into the Wolftever Creek drainage system. Flow in areas in Rabbit Valley underlain by the Stones River and Nashville Groups trends west or northwest to also empty into that system. North of I-75, flow lines west of Wolftever Creek indicate

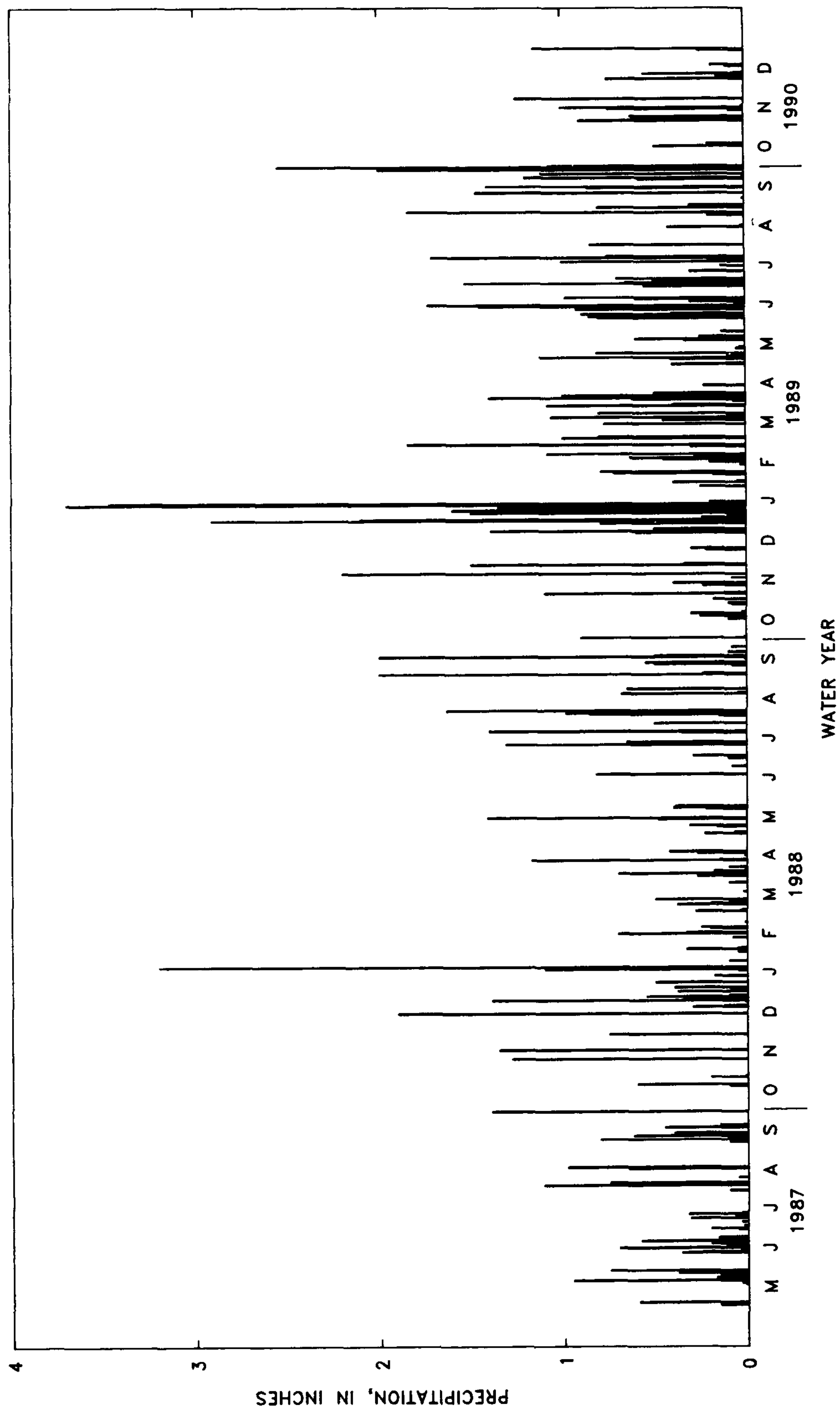


Figure 14. Daily precipitation at Chickamauga Dam, May 1987 through December 1989.

discharge to the lower reaches of that stream and to Carson Spring. Without having more definitive data, the southern boundary of the recharge area is taken as the locus of points where flow lines shift from indicating discharge solely into the drainage system of Rabbit Valley to discharge into both the creek and the spring (fig. 4). The shift occurs about one-half mile south of I-75. Thus, only a minor amount of recharge to this spring, if any, appears to originate in the Wolftever Creek drainage basin south of the interstate highway.

To the west, water-level data for the topographically higher parts of Dividing Ridge are not available, but potentiometric contours can be approximately positioned from points of known ground-water altitude in the Hunter Road area to those at Harrison Branch, based on topography and the magnitude of discharge along Harrison Branch. A ground-water divide extending north and northeasterly is apparent and represents the approximate boundary of the recharge area on the west and northwest. The divide generally parallels the crest of Dividing Ridge (the basin boundary) but does not coincide with it.

The eastern boundary of the recharge area is Wolftever Creek. Flow lines show this meandering stream as the discharge points from the aquifer, but for simplicity the eastern boundary is shown on figure 4 as the axis of the stream. Flow from the area between the creek and the ridge to the east representing the eastern drainage-basin boundary is thought to discharge into the creek.

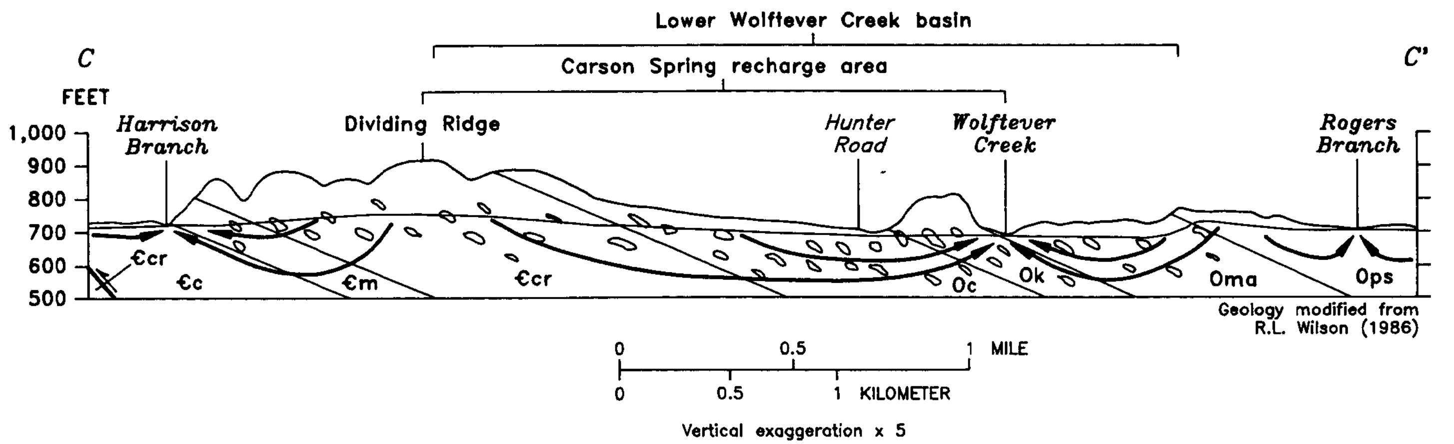
The northern boundary corresponds to the northerly extent of the cone of depression caused by pumping at Carson Spring. Its position is variable, being influenced by the magnitude of daily pumping and perhaps seasonal changes in Chickamauga Lake stage, and is difficult to locate without water-level data north of the spring. For the purpose of this study, that boundary is assumed to extend not further than one-half the distance between the Carson Spring wells and the easterly projection of the ground-water divide to the north-northwest. This is thought to be a highly conservative estimate based on very limited measurements of drawdown at Carson Spring. Flow at points further to the north of the cone of depression would not be diverted to Carson Spring, but would discharge to Wolftever Creek.

The area encompassed comprises about 9 mi^2. Using the relation that each square mile of drainage area yields 1 to 2 ft^3/s, ground-water discharge from this area would then be expected to range from about 9 to 18 ft^3/s. However, actual data indicate that only about 6 ft^3/s are discharged at Carson Spring. The remainder, which cannot be quantified at this time, must be discharged to Wolftever Creek, as flow lines indicate. The cavities supplying Carson Spring simply are not capable of capturing and delivering all of the ground water in the recharge area. The larger size of the recharge area (9 mi^2), as determined by potentiometric contours, than the size implied solely by spring discharge (3 to 6 mi^2) supports this interpretation. The basin-segment map (fig. 5) provides further evidence. Most of Wolftever Creek north of I-75 had gains substantially larger than average. Whereas some of the gain came from the area east of the creek, most of it came from the much larger recharge area to the west.

Conceptualization of the Ground-Water System

The several pieces of data discussed in preceding sections provide the basis for synthesizing a conceptual model of the ground-water system in the Carson Spring recharge basin (fig. 15). Recharge enters the higher and intermediate areas of Dividing Ridge to flow east and northeasterly down gradient toward Wolftever Creek. Bedrock cavities trending north-south, but also connected vertically and laterally with each other, penetrate that flow field to intercept water in transit. Although the cavities may be long, the size and continuity of their openings and extent of interconnection with other cavities determine their transmissivity and limit the amount of water that they can deliver. The excess amount is discharged at diffuse points along Wolftever Creek rather than at a single point such as the spring. It is this supply of water, in effect the aquifer's reserve, that maintains base flow to the creek during times of drought and severe pumping stress, and which the cavities draw upon to maintain flow to the spring.

The conceptual model also implies that if the gradient west of Wolftever Creek were reversed by intensive pumping, the aquifer could receive recharge by induced flow from the creek. This probably could happen near Carson Spring where the creek in summer is an embayed section of Chickamauga Lake. Induced flow also might occur at one



GEOLOGIC UNITS

Middle Ordovician	Stones River Group	Ops	Pond Spring Formation
Lower Ordovician	Knox Group	Oma	Mascot Dolomite
		Ok	Kingsport Formation
		Oc	Chepultepec Dolomite
Upper Cambrian		€cr	Copper Ridge Dolomite
	Conasauga Group	€m	Maynardville Limestone
Middle Cambrian		€c	Conasauga Group, undivided

EXPLANATION

- SOLUTION CAVITY--Position generalized
- THRUST FAULT--Arrow indicates relative movement
- POTENTIOMETRIC SURFACE--Datum is sea level
- GROUND-WATER FLOW PATH

Figure 15. Hydrogeologic section illustrating conceptual model of flow.

or more segments of Wolftever Creek upstream from the embayment if the creek directly overlies or lies near a cavity system having such large transmissivity that a nearly zero gradient exists between points of recharge and the pumping wells. In this situation, the cavity system may function as a direct conduit and deliver water not only from the aquifer, but also from the creek to the pumping wells.

The conceptual model (fig. 15) also implies that formations of the Knox Group have large permeability. That permeability is reflected in such features as the depth to the water table (more than 100 feet) below Dividing Ridge, underlain by the Chepultepec and Copper Ridge Dolomites, and the unnamed ridge that is underlain by the Kingsport Formation between Hunter Road and Wolftever Creek. Large permeability also is indicated by the water table not mimicking topography below that unnamed ridge, and by the very gentle slope of the water table across the formations of the Knox Group. Large permeability also is evidenced by the results of the seepage investigation (fig. 5), which showed that much of the discharge from the aquifer occurs where the creek crosses the Mascot Dolomite and Kingsport Formation (figs. 2 and 15). It is further evidenced by the magnitude of discharge from Carson Spring, which issues from the Chepultepec Dolomite near its contact with the Kingsport Formation. Large permeability across these units underscores the ease with which water in Wolftever Creek could percolate into the cavity system supplying Carson Spring if hydraulic head in the aquifer becomes less than that of the creek.

Because water-table configuration resembles topography in most of the physiographic regions of Tennessee, topography often can be used as a guide for delineating ground-water basins in the State. However, this criterion is not universally applicable, as shown in figure 15. Again, note the lack of correspondence between water-table shape and surface topography through the Kingsport Formation. Where permeability across formations is well integrated, as in this area, the broader topographic features (such as Dividing Ridge) and the regional drains may be more appropriate guides for defining basin boundaries than topographic features of comparatively narrow cross-sectional area.

GROUND-WATER QUALITY

Water samples were collected from Carson Spring and 16 wells in the lower Wolftever Creek basin to determine areal variations in the chemical and physical quality of water in the aquifer (fig. 16 and table 6). Most of the wells were drilled in the Knox Group; four (M-1, M-4, M-6, and M-8) were constructed in formations of the Stones River Group, and one (M-10) was drilled on the mapped contact between the two groups. Two (M-3 and M-4) are shallow, hand-dug wells, each about 21 feet deep, and terminate in the regolith developed from the Knox Group and Stones River Group, respectively; the other wells are known or suspected to have been finished in bedrock.

All ground-water samples were collected after three or more well volumes had been evacuated by pumping, and were treated in accordance with current guidelines. Following pumping, samples for volatile organic compounds (VOC's) were collected in a stainless steel bailer from those wells accessible to bailing. Where bailer access was not possible, a sample obtained by pumping the well was collected at the well head or the closest point of access to it.

Physical, Chemical, and Bacterial Characteristics

General measures of water quality include specific conductance, pH, turbidity, hardness, and dissolved solids. Specific conductance of the samples ranged from 90 to 710 μS/cm. The pH ranged from 7.03 to 7.90, except the pH of one sample measured 6.09. Turbidity ranged from 0.10 to 340 ntu's; the turbidity of most samples was less than 10 ntu's. Hardness ranged from 30 to 330 mg/L as calcium carbonate, and alkalinity ranged from 80 to 328 mg/L as calcium carbonate. Dissolved solids, a measure of the concentration of minerals dissolved in water, ranged from 47 to 417 mg/L.

In these general measures of quality, turbidity in 9 of the 15 samples exceeded the Tennessee standard of 1 ntu for public water systems (Tennessee Department of Health and

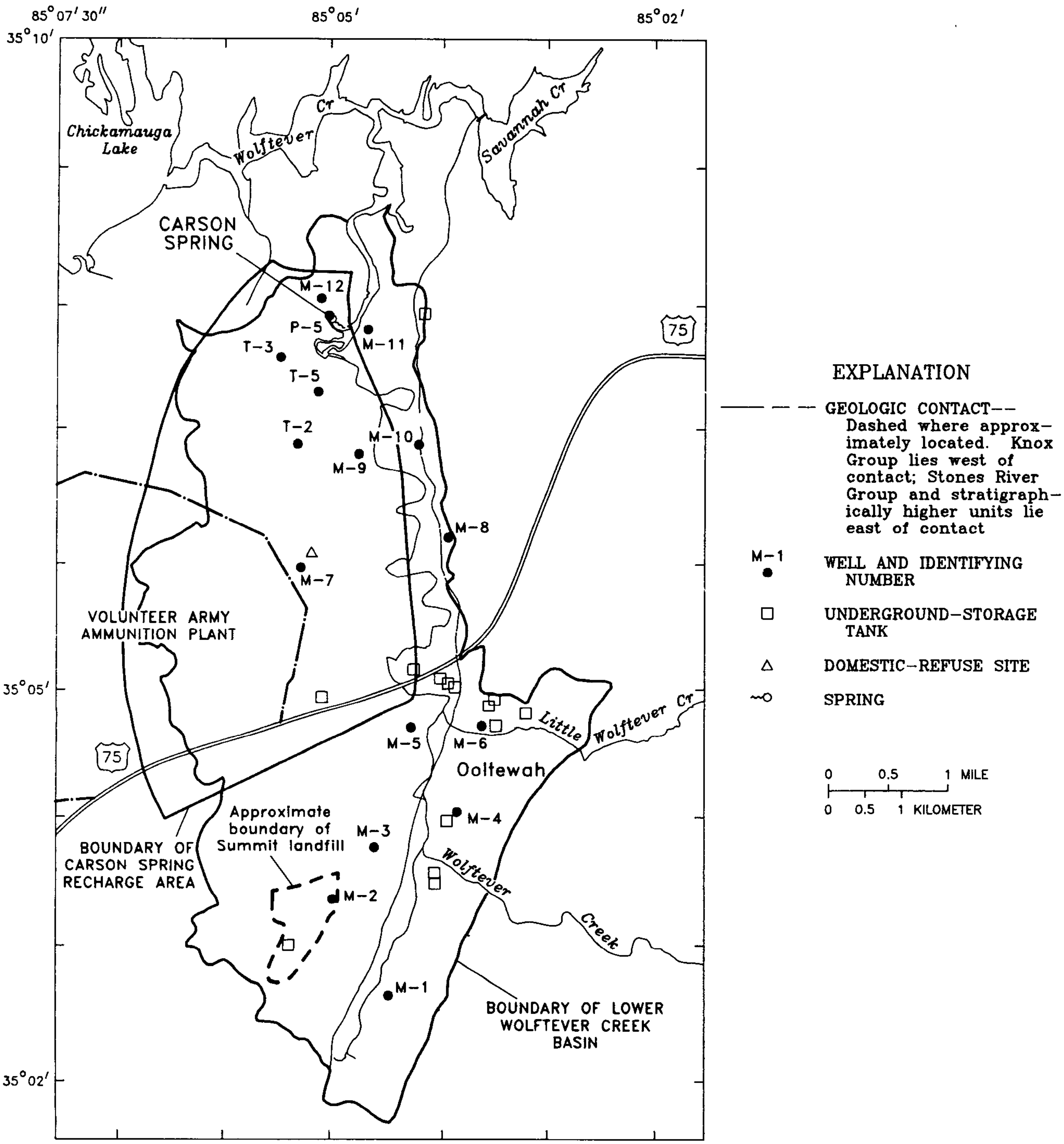


Figure 16. Location of Carson Spring and wells sampled for chemical and physical analyses of water and areas of potential water-quality degradation.

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek basin

[ft, feet; deg C, degrees Celsius; ntu, nephelometric turbidity units; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; wat wh tot fet, water whole total fixed end point titration; tot rec, total recoverable; M, monitoring well; P, production well; T, test well; *, DeBuchananne and Richardson, 1956, p. 205; --, no data, or not applicable; <, less than]

Site identification			Date	Depth to top of water-bearing zone (ft)	Depth to bottom of water-bearing zone (ft)	Depth of well, total (ft)	Water temperature (deg C)	Turbidity (ntu)	Specific conductance, field (µS/cm)	Specific conductance, lab (µS/cm)	pH, field (standard units)	pH, lab (standard units)	Hardness, total (mg/L as $CaCO_3$)
This report	Local well number	USGS station number											
Carson Spring	--	03566446	05-20-86	--	--	--	17.5	--	305	315	7.9	7.6	--
Carson Spring	--	--	12-16-48*	--	--	--	--	--	--	179	--	7.8	93
M-1	HM:J-021	350237085042501	05-19-89	22	57	57	17.5	20	595	598	7.2	7.4	330
M-2	HM:J-026	350325085045701	08-24-89	--	--	--	--	8.7	250	255	7.2	7.8	130
M-3	HM:J-022	350349085043501	05-31-89	6	21	21	18.0	4.7	90	86	6.1	6.6	30
M-4	HM:J-017	350407085034901	05-16-89	--	--	--	16.0	19	710	728	7.2	7.3	320
M-5	HM:J-018	350447085034901	05-17-89	--	--	--	16.0	.4	360	349	7.4	7.6	180
M-6	HM:J-024	350448085033401	06-17-89	--	--	--	17.5	340	690	677	--	7.4	320
M-7	HM:J-020	350559085051601	05-17-89	--	--	--	18.0	3.0	165	162	7.5	7.5	84
M-7	HM:J-020	350559085051601	08-24-89	--	--	--	--	--	--	--	--	--	--
M-8	HM:J-023	350614085035501	06-16-89	--	112	112	17.0	.5	620	622	--	7.5	330
M-9	HM:J-019	350652085044501	05-17-89	--	--	--	18.0	.3	260	256	--	7.7	140
M-10	HM:J-025	350656085041301	06-17-89	--	--	--	17.5	.6	405	388	--	7.6	210
M-11	HM:O-022	350750085044101	06-01-89	--	--	--	17.5	.1	256	254	7.8	7.9	140
M-12	HM:O-021	350804085050601	06-01-89	--	--	--	17.5	.2	236	239	7.0	7.4	130
T-2	HM:J-014	350656085051801	06-08-89	142	142	142	15.5	2.0	163	161	7.9	8.0	85
T-3	HM:O-017	350736085052801	06-09-89	83	91	91	15.5	290	210	204	7.9	7.9	110
T-5	HM:J-016	350719085050902	12-05-86	--	--	--	--	--	--	232	7.8	7.7	129
P-5	HM:O-018	350750085045805	02-09-89	--	--	--	14.5	3.8	245	256	7.1	7.5	130

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek basin--*Continued*

Site identification: This report	Date	Alkalinity wat wh tot fet, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Solids, residue at 180 deg. C, dissolved (mg/L)	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)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
Carson Sp.	05-20-86	166	162	159	35	18	2.0	0.8	2.5	2.9	--	8.5
Carson Sp.	12-16-48	--	91	--	21	10	1.4[1]	--	2.5	2	--	--
M-1	05-19-89	303	298	315	110	13	11	1.1	9.3	19	0.1	11
M-2	08-24-89	141	136	114	29	15	.6	.6	.7	<1.0	.1	8.9
M-3	05-31-89	24	24	47	9.0	1.8	4.6	.7	4.3	8.0	< .1	5.0
M-4	05-16-89	250	250	417	110	12	24	4.6	28	54	.1	8.4
M-5	05-17-89	173	171	176	54	12	2.4	2.5	5.7	<1.0	.1	14
M-6	06-17-89	--	328	386	85	26	22	3.0	20	13	.5	10
M-7	05-17-89	81	80	90	18	9.5	.8	.5	.8	3.0	.1	7.6
M-7	08-24-89	--	--	--	--	--	--	--	--	--	--	--
M-8	06-16-89	--	327	329	67	40	1.8	6.2	4.2	16	.6	7.9
M-9	05-17-89	128	129	114	31	15	1.4	.8	2.1	3.0	.1	8.1
M-10	06-17-89	--	198	189	47	22	1.6	.9	3.3	4.0	.1	8.3
M-11	06-01-89	128	128	132	38	9.8	.8	.8	1.7	2.0	.1	8.3
M-12	06-01-89	125	125	122	30	13	1.0	.4	1.5	<1.0	.1	9.0
T-2	06-08-89	84	83	83	19	9.2	.5	.3	.8	<1.0	.1	8.1
T-3	06-09-89	114	109	89	25	12	.6	.4	.8	<1.0	.1	8.5
T-5	12-05-86	126	122	130	33	12	.7	.5	1.2	1.4	--	8.6
P-5	02-09-89	--	124	127	29	14	2.5	.8	2.9	4.8	.1	8.1

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek basin--*Continued*

Site identification: This report	Date	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia + organic, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO2+NO3, dissolved (mg/L as N)	Phosphorous, total (mg/L as P)	Phosphorous, dissolved (mg/L as P)	Phosphorous ortho, dissolved (mg/L as P)	Aluminum, dissolved (µg/L as Al)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Beryllium, dissolved (µg/L as Be)
Carson Sp.	05-20-86	0.02	0.01	0.20	<0.01	0.25	<0.01	0.02	<0.01	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	--	--	--	--	--	--	--	--
M-1	05-19-89	.05	.04	< .20	< .01	.36	< .01	< .01	< .01	<10	<1	28	<0.5
M-2	08-24-89	.02	< .01	.50	< .01	< .10	.01	< .01	< .01	10	<1	7	< .5
M-3	05-31-89	.02	< .01	.30	< .01	.66	< .01	.01	< .01	10	<1	12	< .5
M-4	05-16-89	.11	.04	.50	< .01	9.00	.05	.05	.05	<10	<1	39	< .5
M-5	05-17-89	.02	.01	.40	< .01	1.20	.02	.02	.01	<10	<1	10	< .5
M-6	06-17-89	.09	.11	< .20	< .01	< .10	.08	< .01	< .01	800	<1	130	< .5
M-7	05-17-89	.02	< .01	< .20	< .01	.10	.01	.01	< .01	<10	<1	10	< .5
M-7	08-24-89	--	--	--	--	--	--	--	--	--	--	--	--
M-8	06-16-89	.06	.04	< .20	< .01	.18	< .01	< .01	< .01	10	<1	63	< .5
M-9	05-17-89	.03	.01	.40	< .01	.50	.01	.01	< .01	<10	<1	66	< .5
M-10	06-17-89	.04	< .01	< .20	< .01	1.20	.01	< .01	< .01	10	<1	19	< .5
M-11	06-01-89	< .01	< .01	.60	< .01	.55	< .01	< .01	< .01	<10	<1	10	< .5
M-12	06-01-89	< .01	< .01	.50	< .01	.23	<.01	< .01	< .01	20	<1	9	< .5
T-2	06-08-89	< .01	.02	.30	< .01	< .10	< .01	< .01	< .01	10	<1	5	< .5
T-3	06-09-89	< .01	.02	.20	< .01	.16	.87	< .01	< .01	10	<1	9	< .5
T-5	12-05-86	--	--	--	--	--	--	--	--	--	--	--	--
P-5	02-09-89	.02	< .01	.20	< .01	.37	.01	.01	< .01	30	<1	34	< .5

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek watershed--*Continued*

Site identification: This report	Date	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Cobalt, dissolved (µg/L as Co)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Nickel, dissolved (µg/L as Ni)
Carson Sp.	05-20-86	--	--	--	--	10	--	--	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	40	--	--	--	--	--	--
M-1	05-19-89	<1	<1	<3	2	6	1	19	2	<0.1	<10	1
M-2	08-24-89	<1	1	<3	2	6	<1	<4	2	.2	<10	<1
M-3	05-31-89	<1	1	<3	1	13	<1	<4	5	< .1	<10	1
M-4	05-16-89	<1	1	<3	3	12	1	7	23	.2	<10	<1
M-5	05-17-89	<1	1	<3	5	9	1	6	2	.1	<10	<1
M-6	06-17-89	2	<1	<3	2	200	1	22	240	.2	<10	<1
M-7	05-17-89	<1	<1	<3	3	13	2	<4	5	.1	<10	2
M-7	08-24-89	--	--	--	--	--	--	--	--	--	--	--
M-8	06-16-89	<1	<1	<3	1	68	1	31	4	1.4	<10	<1
M-9	05-17-89	<1	1	<3	3	12	2	<4	1	.2	<10	3
M-10	06-17-89	<1	<1	<3	3	12	1	7	2	--	<10	<1
M-11	06-01-89	<1	1	<3	1	6	1	6	<1	.3	<10	1
M-12	06-01-89	<1	1	<3	<1	<3	1	5	2	.3	<10	1
T-2	06-08-89	<1	2	<3	3	7	<1	<4	6	< .1	<10	5
T-3	06-09-89	<1	<1	<3	1	13	1	<4	5	< .1	<10	1
T-5	12-05-86	--	--	--	--	16	--	--	6	--	--	--
P-5	02-09-89	<1	<1	<3	3	8	<5	<4	1	< .1	<10	<1

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek watershed--*Continued*

Site identification: This report	Date	Selenium, dissolved (μg/L as Se)	Silver, dissolved (μg/L as Ag)	Strontium, dissolved (μg/L as Sr)	Vanadium, dis solved (μg/L as V)	Zinc, dissolved (μg/L as Zn	Dichlorobromomethane, tot rec (μg/L)	Carbontetrachloride, tot rec (μg/L)	1,2-Dichloroethane, tot rec (μg/L)	Bromoform, tot rec (μg/L)	Chlorodibromomethane, tot rec (μg/L)
Carson Sp.	05-20-86	--	--	--	--	--	--	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	--	--	--	--	--	--
M-1	05-19-89	<1	<1	190	<6	59	<0.2	<0.2	<0.2	<0.2	<0.2
M-2	08-24-89	<1	<1	14	<6	32	< .2	< .2	< .2	< .2	< .2
M-3	05-31-89	<1	<1	17	<6	30	< .2	< .2	< .2	< .2	< .2
M-4	05-16-89	<1	<1	200	<6	29	< .2	< .2	< .2	< .2	< .2
M-5	05-17-89	<1	<1	49	<6	31	< .2	< .2	< .2	< .2	< .2
M-6	06-17-89	<1	<1	1200	<6	180	< .2	< .2	< .2	< .2	< .2
M-7	05-17-89	<1	<1	13	<6	670	< .2	< .2	< .2	< .2	< .2
M-7	08-24-89	--	--	--	--	--	< .2	< .2	< .2	< .2	< .2
M-8	06-16-89	<1	<1	2200	<6	31	< .2	< .2	< .2	< .2	< .2
M-9	05-17-89	<1	<1	47	<6	270	< .2	< .2	< .2	< .2	< .2
M-10	06-17-89	<1	<1	150	<6	19	< .2	< .2	< .2	< .2	< .2
M-11	06-01-89	<1	<1	59	<6	170	< .2	< .2	< .2	< .2	< .2
M-12	06-01-89	<1	<1	25	<6	24	< .2	< .2	< .2	< .2	< .2
T-2	06-08-89	<1	<1	16	<6	10	< .2	< .2	< .2	< .2	< .2
T-3	06-09-89	<1	<1	21	<6	14	< .2	< .2	< .2	< .2	< .2
T-5	12-05-86	--	--	--	--	--	--	--	--	--	--
P-5	02-09-89	<1	<1	25	<6	26	< .2	< .2	< .2	< .2	< .2

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek watershed--*Continued*

Site identification: This report	Site identification: Date	Chloroform, tot rec (µg/L)	Toluene, tot rec (µg/L)	Benzene, tot rec (µg/L)	Chlorobenzene, tot rec (µg/L)	Chloroethane, tot rec (µg/L)	Ethylbenzene, tot rec (µg/L)	Methylbromide, tot rec (µg/L)	Methylchloride, tot rec (µg/L)	Methylene chloride, tot rec (µg/L)	Tetrachloroethylene, tot rec (µg/L)	Trichlorofluoromethane, tot rec (µg/L)
Carson Sp.	05-20-86	--	--	--	--	--	--	--	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	--	--	--	--	--	--	--
M-1	05-19-89	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
M-2	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-3	05-31-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	.4	< .2	< .2
M-4	05-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-5	05-17-89	.3	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-6	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-7	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-7	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-8	06-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-9	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-10	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-11	06-01-89	.2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-12	06-01-89	.2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-2	06-08-89	< .2	.2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-3	06-09-89	< .2	.2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-5	12-05-86	--	--	--	--	--	--	--	--	--	--	--
P-5	02-09-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek watershed--*Continued*

Site identification: This report	Date	1,1-Dichloroethane, tot rec (µg/L)	1,1-Dichloroethylene, tot rec (µg/L)	1,1,1-Trichloroethane, tot rec (µg/L)	1,1,2-Trichloroethane, tot rec (µg/L)	1,1,2,2 Tetrachloroethane, tot rec (µg/L)	1,2-Dichlorobenzene, tot rec (µg/L)	1,2-Dichloropropane, tot rec (µg/L)	1,2-Transdichloroethane, tot rec (µg/L)	1,3-Dichloropropene, tot rec (µg/L)	1,3-Dichlorobenzene, tot rec (µg/L)
Carson Sp.	05-20-86	--	--	--	--	--	--	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	--	--	--	--	--	--
M-1	05-19-89	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
M-2	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-3	05-31-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-4	05-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-5	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-6	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-7	05-17-89	< .2	.2	< .2	< .2	< .2	< .2	< .2	1.8	< .2	< .2
M-7	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-8	06-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-9	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-10	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-11	06-01-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-12	06-01-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-2	06-08-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-3	06-09-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-5	12-05-86	--	--	--	--	--	--	--	--	--	--
P-5	02-09-89	.3	< .2	< .2	< .2	< .2	< .2	< .2	.2	< .2	< .2

Table 6. Water-quality data for Carson Spring and wells in the lower Wolftever Creek watershed--*Continued*

Site identification: This report	Date	1,4-Di-chloro-benzene, tot rec (µg/L)	2-Chlor-ethyl-vinyl-ether, tot rec (µg/L)	Di-chloro-di-fluoro-methane, tot rec (µg/L)	Trans-1,3-di-chloro-propene, tot rec (µg/L)	Cis 1,3-di-chloro-propene, tot rec (µg/L)	Vinyl chlo-ride, tot rec (µg/L)	Tri-Chloro-ethyl-ene, tot rec (µg/L)	Styrene, tot rec (µg/L)	1,2-Dibromo-ethane, tot rec (µg/L)	Total xylenes, tot rec (µg/L)
Carson Sp.	05-20-86	--	--	--	--	--	--	--	--	--	--
Carson Sp.	12-16-48	--	--	--	--	--	--	--	--	--	--
M-1	05-19-89	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
M-2	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-3	05-31-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-4	05-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-5	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-6	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-7	05-17-89	< .2	< .2	< .2	< .2	< .2	3.7	9.7	< .2	< .2	< .2
M-7	08-24-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-8	06-16-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-9	05-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-10	06-17-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-11	06-01-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
M-12	06-01-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-2	06-08-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	0.2
T-3	06-09-89	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2	< .2
T-5	12-05-86	--	--	--	--	--	--	--	--	--	--
P-5	02-09-89	< .2	< .2	< .2	< .2	< .2	< .2	.2	< .2	< .2	< .2

[1]Sodium plus potassium

Environment, 1988). Turbidity of less than 5 ntu usually is not visible to the eye. At several of the wells sampled, turbidity levels greater than normal may have resulted from pumping wells which had not been pumped for extended periods of time, thereby re-suspending sediment that had settled in solution openings or fractures leading to the well. At newly constructed bedrock well M-6, turbidity increased substantially during the pumping period and appeared to result from well development.

Water from all of the sampled wells except M-3 may be described as moderately hard to very hard (Hem, 1985). Water with a hardness level greater than about 100 mg/L may be objectionable for domestic purposes because minerals dissolved in the water react with soap to form soap curds. A drinking-water standard for hardness has not been established.

The principal constituents in water from Carson Spring and all of the wells in the lower basin are calcium and bicarbonate, or calcium, magnesium, and bicarbonate (table 6), reflecting passage of the water through limestone and dolomitic rock. Principal ion data of water from Carson Spring and the 16 wells are plotted on a trilinear diagram (fig. 17) to facilitate a comparison of the analyses. The lower left triangle shows that calcium is the predominant cation in ground water from this basin and that magnesium is a secondary constituent. Percentage of calcium and magnesium is variable, and does not directly correlate with the lithologic character (limestone or dolomite) of the formation in which the well was drilled. The two shallow wells M-3 and M-4 and newly constructed well M-6 stand out as having water with comparatively large percentages (fig. 17) of sodium. The lower right triangle shows that bicarbonate is the dominant anion in water from Carson Spring and all bedrock wells, and that little variability occurs in its dominancy. The two shallow wells stand out as having water with larger percentages of sulfate and chloride than the other samples. When the data are projected to the central diamond, those points representing water from Carson Spring and most bedrock wells plot essentially on top of each other at the left corner. Clustering in one location indicates the relative similarity in major ion composition of the water. The exceptions are water from bedrock well M-6 (Stones River Group), and regolith wells M-4 (Stones River Group) and M-3 (Knox Group).

A major-ion analysis was made of water collected from Carson Spring on December 16, 1948 (table 6). Comparison with a recent analysis (May 20, 1986) indicates that over the 38-year period between samples, water at the spring has become more mineralized by most of the major constituents.

Most samples contained little dissolved nitrogen or phosphorous. The relatively large concentrations of these ions in water from regolith well M-4, however, indicate that neighborhood practices might be impairing water quality locally. Fertilizers are used in nearby gardens, and septic tanks might still be in use in this area. The relatively large concentrations of sodium, chloride, and sulfate in water from this well probably have their origin partly in the geologic materials through which the water has passed, but some part of the concentrations also may result from chemicals applied on several occasions years ago to disinfect the well.

Trace metals and minor elements were present in samples from all wells. Concentrations were small, except for the samples from wells M-6 and M-8. Water from newly constructed well M-6 contained comparatively large concentrations of aluminum, barium, iron, lithium, manganese, and strontium. The manganese concentration in water from this well (240 μg/L) exceeded Tennessee's secondary standard of 50 μg/L of manganese in drinking water (Tennessee Department of Health and Environment, 1988). The sample from well M-8 contained comparatively large concentrations of iron, lithium, mercury, and strontium. Both wells are constructed in formations of the Stones River Group.

Differences exist in the physical properties and concentrations of principal ions between water from the Knox Group and that from the Stones River Group (table 7). Water from the Knox Group is characterized by having smaller specific conductance, hardness, and dissolved-solids concentrations than water from the Stones River Group. Specific conductance of water from wells in the Knox Group ranged from 90 to 405 μS/cm, whereas that from the four wells in the Stones River Group ranged from 595 to 710 μS/cm. Hardness in water from wells in the Knox Group ranged from 30 to 210 mg/L; hardness in water from wells in the Stones River Group ranged from 320 to 330 mg/L. Dissolved-solids concentrations ranged from 47

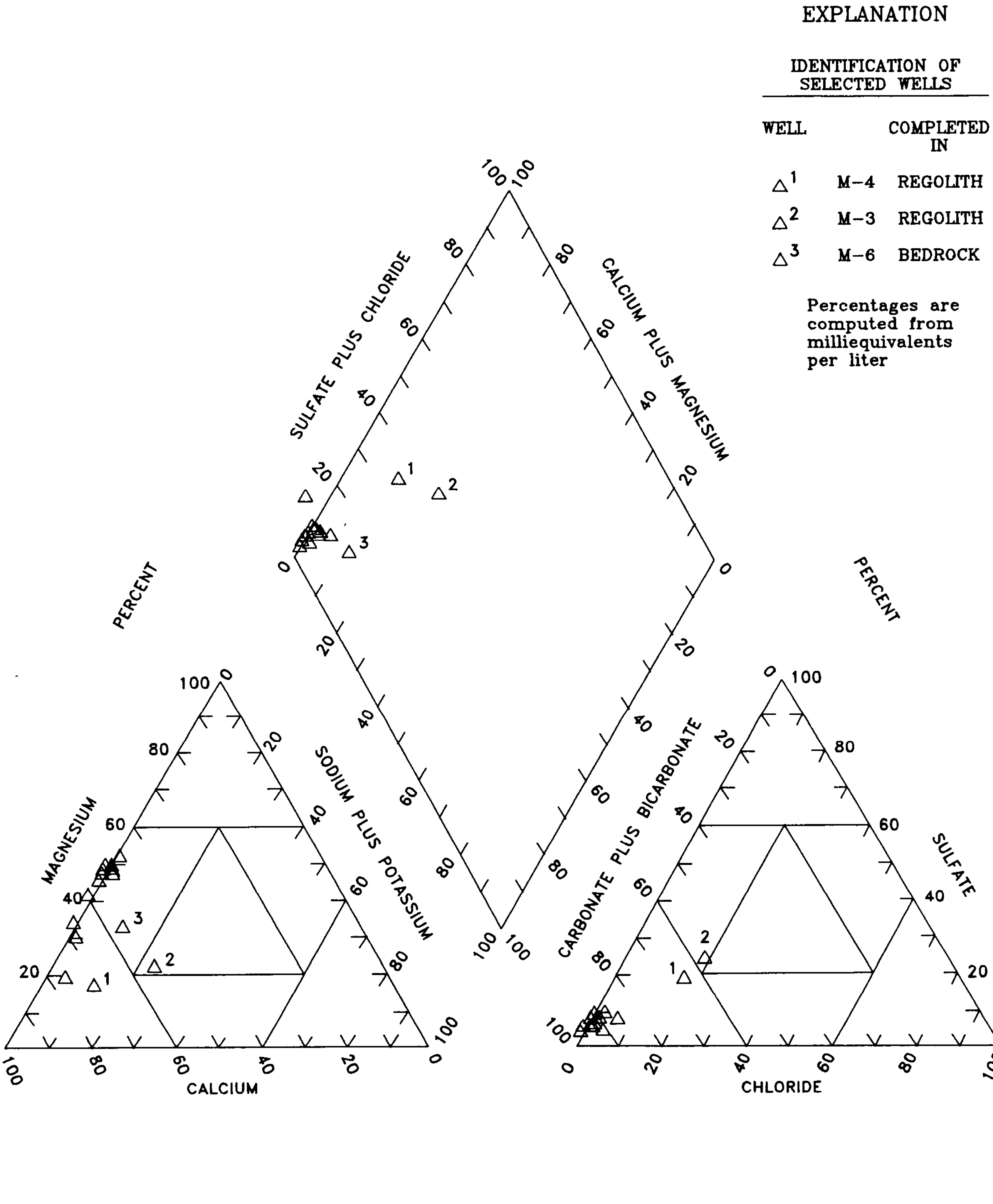


Figure 17. Trilinear diagram showing principal ion composition of ground water from Carson Spring and 16 wells in the lower Wolftever Creek basin.

Table 7. Selected water-quality data for Carson Spring and wells completed in the Knox Group and Stones River Group

[μS/cm, microsiemens per centimeter; mg/L, millligrams per liter; μg/L, micrograms per liter; M, monitoring well; P, production well; T, test well; --, no data; <, less than; wat wh tot fet, water whole fixed end point total titration]

Geologic unit	Site identi-fication	Specific conductance, field (μS/cm)	Hardness, total (mg/L as $CaCO_3$)	Solids, residue at 180 deg. C, dissolved	Alkalinity. wat wh tot fet, field (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Potassium, dissolved (mg/L as K)	Strontium, dissolved (μg/L as Sr)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
Knox Group										
	Carson Spr.	305	--	159	166	35	0.8	--	2.5	2.9
	M-2	250	130	114	141	29	.6	14	.7	<1.0
	M-3	90	30	47	24	9.0	.7	17	4.3	8.0
	M-5	360	180	176	173	54	2.5	49	5.7	<1.0
	M-7	165	84	90	81	18	.5	13	.8	3.0
	M-9	260	140	114	128	31	.8	47	2.1	3.0
	M-10	405	210	189	198[a]	47	.9	150	3.3	4.0
	T-2	163	85	83	84	19	.3	16	.8	<1.0
	T-5	232[a]	129	130	126	33	.5	--	1.2	1.4
	T-3	210	110	89	114	25	.4	21	.8	<1.0
	M-11	256	140	132	128	38	.8	59	0 1.7	2.0
	P-5	245	130	127	124[a]	29	.8	25	2.9	4.8
	M-12	236	130	122	125	30	.4	25	1.5	<1.0
Stones River Group										
	M-1	595	330	315	303	110	1.1	190	9.3	19
	M-4	710	320	417	250	110	4.6	200	28	54
	M-6	690	320	386	328[a]	85	3.0	1200	20	13
	M-8	620	330	--	327[a]	67	6.2	2200	4.2	16

[a]Laboratory value; field value not available.

to 189 mg/L in water from the Knox Group, and from 315 to 417 mg/L in water from the Stones River Group. Water from wells in the Knox Group also contained smaller concentrations of alkalinity, calcium, strontium, and sulfate than water from the Stones River Group. Most of the samples from the Knox Group contained smaller concentrations of potassium and chloride than those from the Stones River Group. The sample from well M-10, drilled on the contact between the two geologic units, appears to have been a mixture of the two waters. Specific conductance, hardness, dissolved solids, alkalinity, and strontium had the largest values of all samples from wells in the Knox Group, but these values were less than the smallest value of the corresponding properties or constituents in water from wells in the Stones River Group.

With one exception, concentrations of VOC's in all samples were either very small or less than the detection limits. Water from domestic well M-7, the exception, contained 3.7 μg/L vinyl chloride and 9.7 μg/L trichloroethylene. Maximum permissable contaminant levels of these substances, if in a public supply system, are 2 μg/L and 5 μg/L, respectively (Tennessee Department of Health and Environment, 1988). A re-sampling of that well 2 months later did not confirm their presence in the water. Water from one well near well M-6 emitted a strong petroliferous odor when pumped. A sample was not submitted to the laboratory; however, the owner stated that the well was abandoned years ago after a substantial quantity of gasoline appeared in his bathtub water. He believed that the gasoline came from a leaking underground storage tank.

Overall, ground water in the lower Wolftever Creek basin is of good chemical quality. It meets State standards for drinking water, with exceptions as noted, and is suitable for most common purposes. However, turbidity, hardness, and dissolved mineral matter, particularly in ground water from the Stones River Group, may preclude application to certain uses having stringent requirements for these properties.

The water chemistry supports the discussion of flow given previously. Greater mineralization of water from the Stones River Group than of water from the Knox Group might result partly from the smaller permeability of the former unit. Smaller permeability implies slower flow velocity. Consequently, time of residence (under conditions of equal gradient and distance of travel) in the aquifer is longer, providing greater opportunity for the mineral content of the water to increase. In the Knox Group, concentrations of calcium, magnesium, and alkalinity in water from wells T-2 and M-7 were appreciably less than in water from wells M-9, M-12, T-3, T-5, and P-5 (fig. 16). This implies that the direction of flow is from the uplands where wells T-2 and M-7 are located, to areas north and northeast where wells with the more mineralized water are located, and conforms to the interpretation of the potentiometric map. However, the general overall similarity in chemistry of water from wells in the Knox Group does not provide evidence as to where the Carson Spring recharge boundary lies.

Locally, bacterial quality of water at the spring pool may be of concern because the pool is habitat for ducks and perhaps aquatic mammals, and at times some of that water is returned to the aquifer. According to D.J. O'Connell (U.S. Geological Survey, oral commun., 1988), a water sample collected from the spring pool in 1987 contained numerous colonies of coliform bacteria. Water collected in February 1989 from production well 5 upon completion of a 24-hour aquifer test, during which time the spring pool was nearly depleted of water, had fecal coliform concentrations of 20 colonies per 100 milliliters and fecal streptococcus concentrations of 48 colonies per 100 milliliters. Larger concentrations could be expected during warmer months if water from that source is drawn into the aquifer. Larger concentrations also might be associated with the other production wells because they are open to the aquifer at shallower depths. As a safeguard to customers, pumped water is chlorinated before the water enters the distribution mains.

Water samples collected at other wells during this study were not analyzed for bacteria.

Potential Sources of Water-Quality Degradation

Within the lower basin are several potential sources of ground-water contamination. Underground storage tanks (UST's) for the holding of gasoline and other organic liquids are prone to developing leaks. Leaking fluids not sorbed by the geologic materials or decomposed by bacteria could percolate to the water table and then be transported on or in ground water. Most known UST's in the lower Wolftever Creek basin (fig. 16) are situated near the Ooltewah business center, which is close to but outside the estimated boundary of the Carson Spring recharge area. Superimposing the potentiometric map (fig. 4) upon the UST-location map indicates that the expected flow path of contaminants from most tanks in the business center is toward Wolftever Creek and discharge from the ground-water system. A potentially greater threat to the Carson Spring water supply would be UST's within the boundary of the recharge area, for if fluids leaked from them, the fluids would be more likely to enter the underground cavity system and be transported to Carson Spring.

Other potential contaminant sources of concern are large spills of gasoline or other chemicals along the road system within the recharge area and activities at the VAAP. Large spills are a potential threat for the same reason as are leaking UST's. The VAAP is the only industrial complex in the lower Wolftever Creek basin that is designated a State of Tennessee Superfund site by the Tennessee Department of Environment and Conservation; the production facilities, however, are west of the basin. Within the Carson Spring recharge area, plant activities are limited to the storage of ammunition in dry, subsurface bunkers. Hence, potential threat from this site appears minimal.

Neighborhood practices at two locations in the recharge area have the potential to impair water quality locally. Domestic refuse continues to be dumped in a 1-acre clearing at the site of test well 1 (fig. 2), near the center of the Carson Spring recharge area. The dump is about 700 feet from well M-7 (fig. 16), and possibly may have been the source of VOC's detected in the first sample of water collected from that well. In a different neighborhood near the southern perimeter of the recharge area, field lines from septic tanks have been routed to wells after the wells were abandoned when municipal water became available. Ground water within some undefined radius of this neighborhood is likely to be contaminated by septic-tank effluent.

A large municipal landfill for the disposal of solid waste from Chattanooga residents is located in the southern part of the lower Wolftever Creek basin (fig. 16). Although flow direction from this area is not well-defined, location in the higher part of the basin implies potential for deep migration of leachates if they are not contained. No leachate was detected, however, in water from one well (M-2) drilled into what is thought to be the deeper part of the aquifer below this site (table 6).

To the north, as noted previously, large withdrawals from wells at Carson Spring during years of rainfall deficiency may induce recharge from Wolftever Creek. Because of the subsurface cavity system, water potentially could move below ground primarily by open-channel flow rather than by intergranular flow, and thus have little contact with those soil biota that destroy pathogens. Under these conditions, water delivered by pumps at Carson Spring could contain harmful bacteria. Similarly, because the spring pool is habitat for ducks and perhaps aquatic mammals, and the pool is hydraulically connected to the aquifer, bacteria and excreta from these sources may be in water returned to the aquifer when potentiometric pressure below the pool becomes less than the static head in the pool.

SUMMARY AND CONCLUSIONS

Carson Spring, a third-magnitude spring located in southeastern Hamilton County, has a natural discharge of about 6 ft^3/s. It is situated in the lower Wolftever Creek basin which is underlain by carbonate and siliceous-carbonate rocks ranging in age from Cambrian to Silurian. Principal geologic units underlying the basin are the Chepultepec Dolomite, Kingsport Formation, and Mascot Dolomite, all of the Knox Group, and formations of the Stones River Group. Carson Spring issues from the Chepultepec Dolomite.

Ground water in the regolith and weathered bedrock of the lower basin discharges to Wolftever Creek and its tributaries. Water in the regolith also flows downward to recharge bedrock cavities and other openings. Lowest hydraulic heads occur at Carson Spring and the lower reaches of Wolftever Creek which are thought to be the discharge points for much of the bedrock system.

A base-flow investigation of area streams in May 1987 indicated that the average rate of ground-water discharge to Wolftever Creek as it traversed its lower basin was 0.50 $(ft^3/s)/mi^2$ of drainage area. This was twice the average gain from the entire Wolftever Creek watershed and adjacent watersheds, implying that formations of the Knox Group underlying the lower Wolftever Creek basin have relatively large transmissivity.

Test drilling in the upper part of the Chepultepec Dolomite to depths of as much as 284 feet showed that substantial dissolution has occurred. Most cavities contain either unconsolidated cherty gravel or a mixture of mud and gravel. Many cavities are water bearing and, when several cavities are penetrated by a bedrock well, the cavity system often is capable of providing a yield of 100 gal/min or more. One well drilled through a cavity system near Carson Spring was tested at 2,000 gal/min.

Mean daily withdrawals from wells (pumpage) at Carson Spring ranged from 4.78 ft^3/s for the year 1989 to 5.83 ft^3/s for the year 1988. Mean daily spring discharge ranged from 5.53 ft^3/s (1987) to 5.79 ft^3/s (1988). For a 16-month period during 1987-88, withdrawals represented the entire output of the spring, and exceeded the natural discharge had there been no development at this site. These data show that the aquifer is capable of yielding more water than the spring discharges under natural conditions for a period of at least several consecutive months.

The recharge area for Carson Spring is the Hunter Road area extending from about $^1/_2$-mile south of I-75 to probably not more than 1 mile north of the spring. This area is characterized by dry, gravel-strewn stream channels, sinkholes, and solution cavities in bedrock. The recharge area probably does not exceed 9 mi^2, which is about one-half the area included in the lower Wolftever Creek basin.

A conceptual model of ground-water flow in the recharge area assumes cavities intercepting the flow field and channeling water to Carson Spring. Because the cavities are not capable of intercepting and delivering all of the water, a substantial part of aquifer discharge within the recharge area is into Wolftever Creek. The model also indicates that the hydraulic gradient between the aquifer and Wolftever Creek at or near Carson Spring might be reversed by extensive pumping, thereby inducing flow from the creek into the aquifer. Data collected over a 31-month period indicate that only for a period of hours did a reversal in gradient between aquifer and creek occur near the spring. During parts of June 1988, however, record pumping maintained an unusually shallow gradient, and the possibility exists that, if Wolftever Creek upstream from its embayment is connected by a cavity to Carson Spring, the creek could have been a source of water to the pumping wells at Carson Spring.

The principal constituents in ground water in this basin are calcium and bicarbonate, or calcium, magnesium, and bicarbonate. Water from most wells has a pH of 7 to 8. Water in the Knox Group tends to be less mineralized than that of the Stones River Group, and characteristically has a specific conductance of about 400 $\mu S/cm$ or less as compared to values of about 500 to 700 $\mu S/cm$ for the latter. Volatile organic compounds generally are not present in concentrations above the minimum level of detection, although water from one well did contain two VOC's in concentrations exceeding standards for public water-supply systems, and water from another well contained a petroliferous substance thought to be gasoline.

Numerous sites and day-to-day activities in the lower Wolftever Creek basin have potential to impair the quality of water in the aquifer. They include underground-storage tanks, chemical spills on the highway system, activities at VAAP, waste-disposal sites, and high-rate pumping of wells at Carson Springs that may induce flow into the aquifer of bacterially contaminated surface water.

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