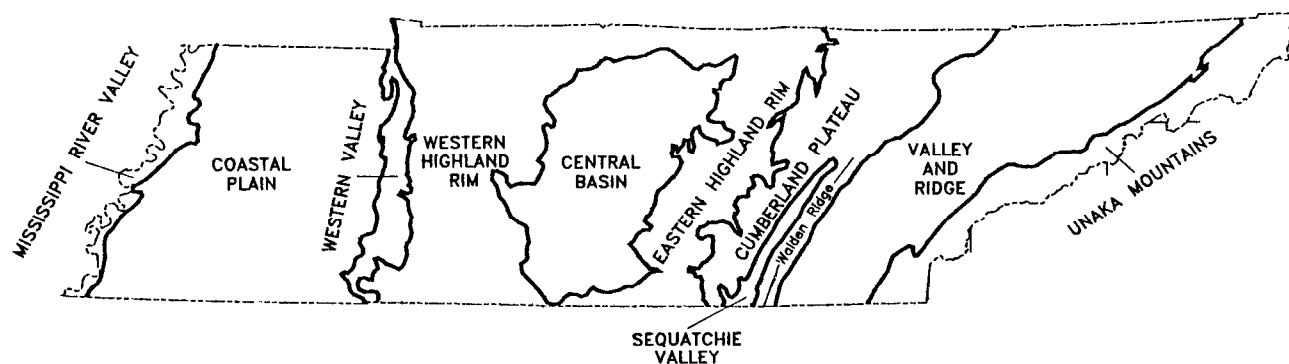


# GROUND-WATER DATA FOR THE SUCK CREEK AREA OF WALDEN RIDGE, SOUTHERN CUMBERLAND PLATEAU, MARION COUNTY, TENNESSEE



Prepared by the  
U.S. GEOLOGICAL SURVEY

in cooperation with the  
MARION COUNTY OFFICE OF PLANNING  
AND DEVELOPMENT



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**By Dorothea Withington Hanchar**

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**U.S. GEOLOGICAL SURVEY**

**Open-File Report 94-704**

**Prepared in cooperation with the  
MARION COUNTY OFFICE OF PLANNING  
AND DEVELOPMENT**



**Nashville, Tennessee  
1995**

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**U.S. GEOLOGICAL SURVEY**

**Gordon P. Eaton, Director**

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# CONVERSION FACTORS, VERTICAL DATUM, WELL-NUMBERING SYSTEM, AND ABBREVIATED WATER-QUALITY UNITS

|                                              | Multiply | By      | To obtain                  |
|----------------------------------------------|----------|---------|----------------------------|
| inch (in.)                                   |          | 25.4    | millimeter                 |
| foot (ft)                                    |          | 0.3048  | meter                      |
| inch per year (in/yr)                        |          | 2.54    | centimeter per year        |
| mile (mi)                                    |          | 1.609   | kilometer                  |
| gallon per minute (gal/min)                  |          | 0.06308 | liter per second           |
| gallon per minute per foot<br>[(gal/min)/ft] |          | 0.2070  | liter per second per meter |

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:  $^{\circ}\text{F} = 1.8 \times ^{\circ}\text{C} + 32$

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

**Tennessee District well-numbering system:** Wells in Tennessee are identified according to the numbering system that is used by the U.S. Geological Survey, Water Resources Division. The well number consists 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 well is plotted; quadrangles are lettered from left to right across the county beginning in the southwest corner of the county; and
- (3) a number generally indicating the numerical order in which the well was inventoried.

For example, Ma:N-024 indicates that the well is located in Marion County on the "N" quadrangle and is identified as well 24 in the numerical sequence.

## Water-quality units:

|       |                                                   |
|-------|---------------------------------------------------|
| mg/L  | milligrams per liter                              |
| µg/L  | micrograms per liter                              |
| µS/cm | microsiemens per centimeter at 25 degrees Celsius |
| ntu   | nephelometric turbidity units                     |

# GROUND-WATER DATA FOR THE SUCK CREEK AREA OF WALDEN RIDGE, SOUTHERN CUMBERLAND PLATEAU, MARION COUNTY, TENNESSEE

By Dorothea Withington Hanchar

## ABSTRACT

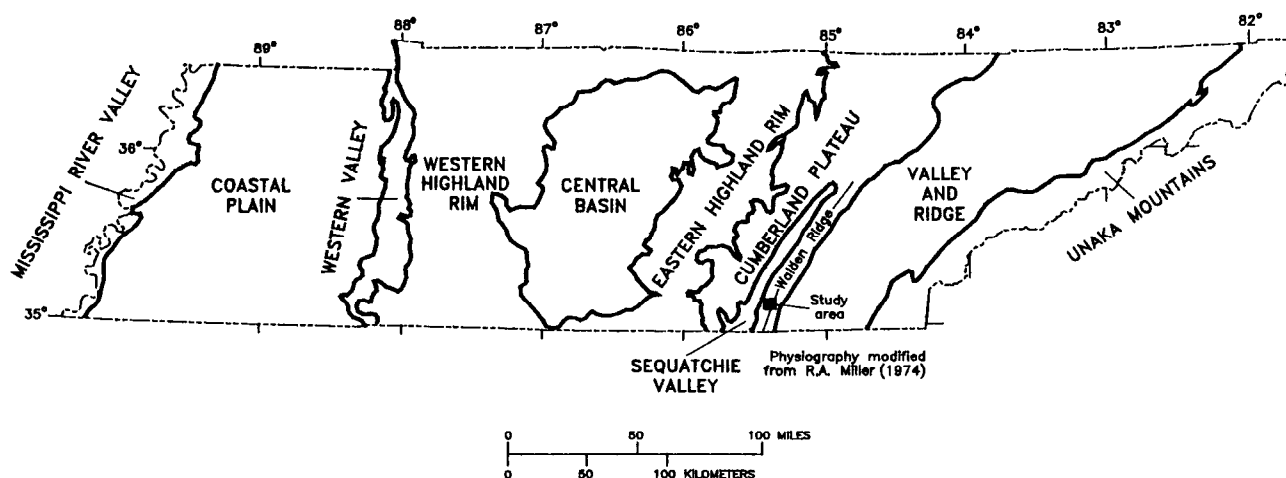
An investigation was made of the ground-water resources of the Suck Creek area, Marion County, Tennessee, 1990-91. Suck Creek is located on the Walden Ridge section of the Cumberland Plateau, and is about 16 miles northwest of Chattanooga. Eight wells were drilled into bedrock of Pennsylvanian age. Drilling sites were chosen at or near fracture traces. Yields of the eight wells ranged from less than 1 to as much as 80 gallons of water per minute. Three wells had yields of 50 gallons per minute or more; two of these had estimated yields of 75 to 80 gallons per minute. These three wells produced water from a well-developed fracture within the Sewanee Conglomerate. Specific capacities for these three wells were 1.1, 1.3, and 2.2 gallons per minute per foot of drawdown.

Samples of water from six test wells and three domestic wells were analyzed for major inorganic constituents, nutrients, major metals, trace elements, and bacteria. In addition, water samples from two of the test wells were analyzed for volatile organic compounds and scanned for the presence of semi-volatile organic compounds. Iron exceeded 300 micrograms per liter in five of the nine samples, and manganese exceeded 50 micrograms per liter in seven of the nine water samples. Toluene, a volatile organic compound, was detected in a concentration slightly above the reporting level; no other volatile organic compounds were detected.

## INTRODUCTION

The Cumberland Plateau is a 50-mile wide physiographic region that extends from Kentucky to Virginia on the north and to Georgia and Alabama on the south. Walden Ridge, in southeastern Tennessee, is that part of the Plateau that lies between the deeply incised Sequatchie Valley to the west and the Valley and Ridge region to the east (fig. 1). Several small communities have been established on Walden Ridge. Suck Creek is near the southern end of the ridge and about 16 miles northwest of Chattanooga.

Most inhabitants of Suck Creek rely on shallow domestic wells for their water supply. Because of low yields and questionable well-construction practices, the community does not have a dependable, safe water supply. To provide greater knowledge of the ground-water resources of the Cumberland Plateau, particularly in the Walden Ridge segment, the U.S. Geological Survey (USGS), in cooperation with the Marion County Office of Planning and Development, conducted a hydrogeologic investigation of the Suck Creek area during 1990-91.



**Figure 1.** Physiographic regions of Tennessee and location of the study area.

## Purpose and Scope

This report presents the results of the investigation. It briefly describes the geology of the area, describes drilling results and well yields, and documents recent ground-water quality.

To accomplish this investigation, eight wells were constructed in four areas. Gamma and caliper logs were made to help define the subsurface stratigraphy. Pumping tests were made at the three most productive wells to determine specific capacity. Water samples were collected from six test wells and three domestic wells to characterize ground-water chemistry. Water levels were measured in 15 domestic wells.

## Acknowledgments

The author is indebted to many people who contributed to this study. Ann Myers Gray, Director, Marion County Office of Planning and Development, was instrumental in expediting the work. James Mills, driller, provided extra assistance that was greatly appreciated during the three pumping tests. Special thanks are given to Portia and Burney McDowell of the Suck Creek Utility District for their support during this effort. Finally, appreciation is expressed to the landowners who permitted the construction of test wells on their property.

## DESCRIPTION OF THE STUDY AREA

Walden Ridge is a topographic peninsula bounded by escarpments with the Sequatchie Valley and the Valley and Ridge region. The Tennessee section of Walden Ridge is about 10 miles wide and 60 miles long. Terrain is gently rolling to hilly, and land-surface altitudes range from about 1,500 to 2,100 feet above sea level. Drainage is by streams of relatively short length that discharge to the Sequatchie River in the Sequatchie Valley and the Tennessee River in the Valley and Ridge region.

The area has a moist, temperate climate. Annual precipitation for the area averages about 54 inches, and ranges from about 35 inches in dry years to about 70 inches in wet years (Hollyday and others, 1983).

Suck Creek has a population of about 700. The community derives its name from Suck Creek which flows south from Walden Ridge to the Tennessee River. Where Suck Creek enters the river, a formidable whirlpool and

rapids, known as the Suck, were once located, and posed a significant navigational hazard on the pre-impounded river.

## GEOLOGY

Much of the Cumberland Plateau is underlain by sandstone and shales of Pennsylvanian age. In the Suck Creek area, five formations are present within 300 feet of land surface (Milici and others, 1979). These formations are, in descending order, the Newton Sandstone, Whitwell Shale, Sewanee Conglomerate, Signal Point Shale, and Warren Point Sandstone (fig. 2) (nomenclature follows Tennessee Division of Geology usage). These formations have been described in detail by Milici (1974) and Milici and others (1979). Unconformities occur at the base of the Newton Sandstone and the Sewanee Conglomerate.

Locally, land surface is underlain by about 1 to 4 feet of regolith, which consists of soil and weathered rock. The Sewanee Conglomerate underlies the regolith throughout most of the study area. The Newton Sandstone and Whitwell Shale underlie the regolith in the southern part of the study area and on the hill tops elsewhere.

The Newton Sandstone has been described as yellowish-gray, very fine- to medium-grained sandstone. Regionally, this formation ranges in thickness from 60 to 100 feet (Milici and others, 1979). In wells Ma:N-028 and Ma:N-029, the Newton Sandstone consisted of medium- to light-gray, very fine- to medium-grained sandstone, with minor shale partings. The thickness of the Newton Sandstone at these two wells was 52 and 55 feet, respectively.

The Whitwell Shale is a major coal-bearing unit of the Cumberland Plateau (Milici, 1974). Regionally, the Whitwell Shale is described as 60 to 80 feet of silty, carbonaceous shale, with interbeds of siltstone and light- to medium-gray, very fine-grained silty sandstone (Milici and others, 1979). The Whitwell Shale contains the Sewanee and the Richland coal seams (Milici, 1974; Milici and others, 1979). In the study area, the Whitwell Shale was encountered in only two wells, Ma:N-028 and Ma:N-029. At these two wells, the formation was 65 and 75 feet thick, respectively.

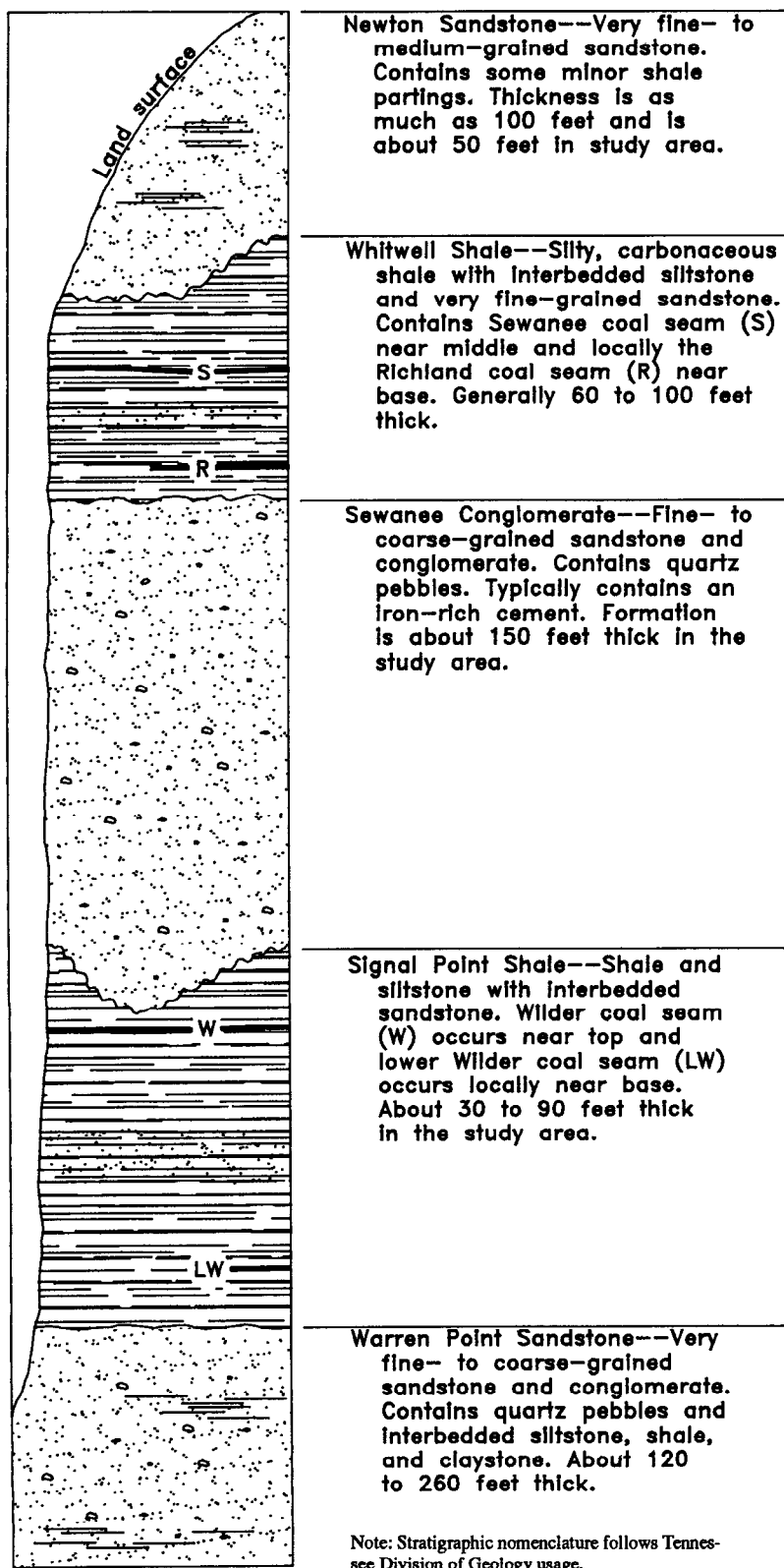
The Sewanee Conglomerate is composed of fine- to coarse-grained sandstone and conglomerate with locally abundant quartz pebbles and has an iron-rich cement (Milici and others, 1979). The formation ranges in thickness from 80 to 90 feet regionally, but can be as much as 200 feet thick (Milici and others, 1979). Within the study area, this formation is as much as 167 feet thick. The Sewanee Conglomerate was identified in all of the test wells constructed.

The Signal Point Shale consists of a gray shale and siltstone interbedded with sandstone. Thickness ranges from 60 to 180 feet regionally (Milici and others, 1979). The Wilder coal seam occurs near the top of the formation, and the lower Wilder coal seam occurs locally near the bottom of the unit. The Signal Point Shale was identified in six of the wells constructed.

The Warren Point Sandstone underlies the Signal Point Shale and crops out near the bottom of the valley formed by Suck Creek and its tributaries. The Warren Point Sandstone was not reached in any of the test wells. The Warren Point Sandstone consists of very fine- to coarse-grained sandstone and conglomerate with quartz pebbles. Interbedded siltstone, shale, and claystone also occur in this formation (Milici and others, 1979). Thickness of the Warren Point Sandstone is 120 to 260 feet regionally (Milici and others, 1979).

Formations of Pennsylvanian age in the Suck Creek area are locally nearly horizontal to gently dipping to the east and southeast. Structurally, Walden Ridge and the Suck Creek area lie between the Sequatchie Valley to the west and the Valley and Ridge region to the east (fig. 1). The Sequatchie Valley is the remnant of a major anticline incised by a river. Walden Ridge is the eastern limb of the anticline. The Valley and Ridge region is characterized by extensive faulting and folding. The eastern escarpment of Walden Ridge is marked by an abrupt upturn and very steeply dipping formations (Wilson and Stearns, 1958). The extensive faulting and folding during the formation of the Sequatchie Valley anticline and the Valley and Ridge resulted in fracturing of the rocks





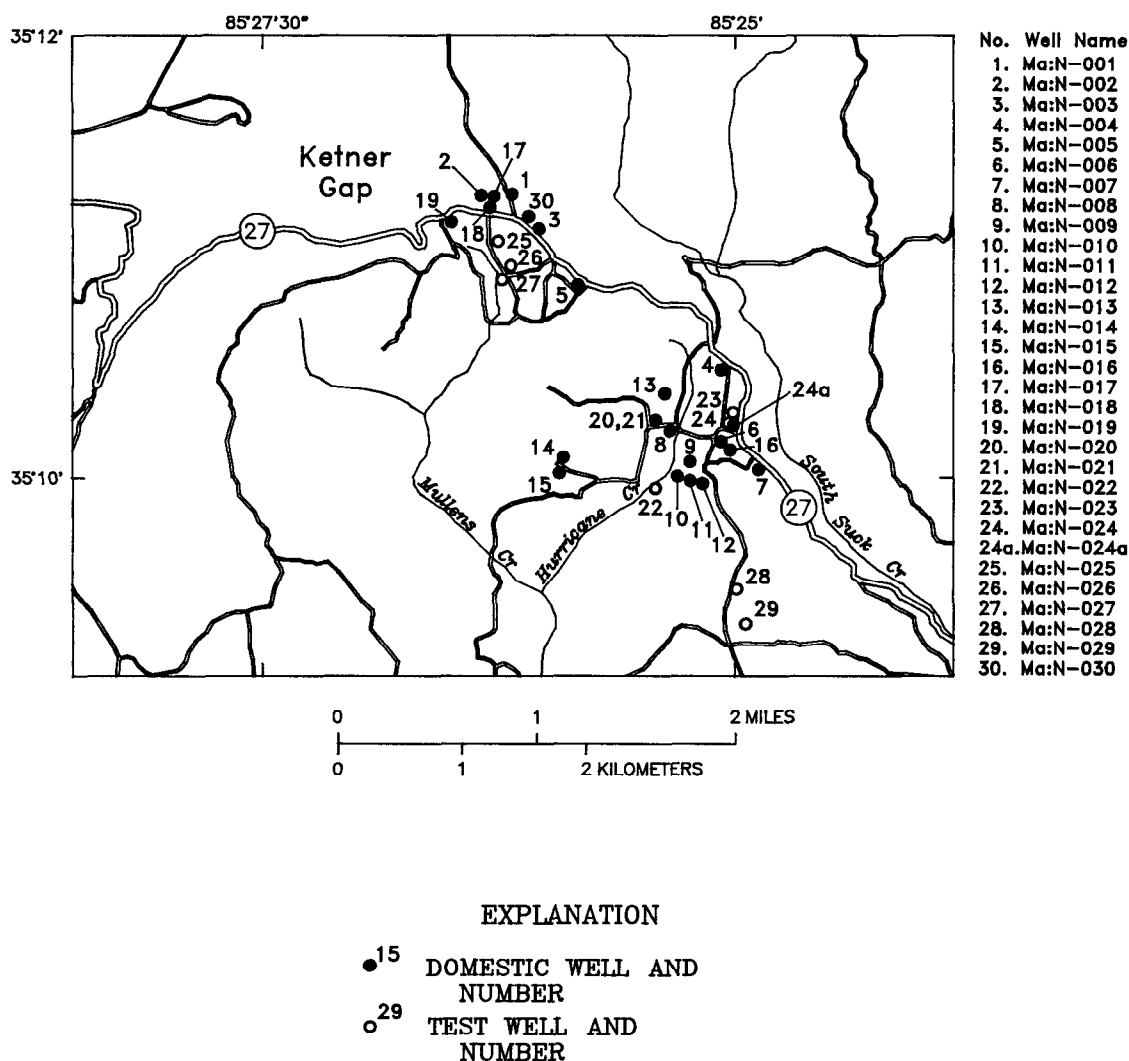
**Figure 2.** Stratigraphic column for the Suck Creek area, Marion County, Tennessee.

underlying the study area (Newcome and Smith, 1958). Orientation of fractures within the study area trends approximately N. 15° E.

## TEST WELLS AND RESULTS OF DRILLING

Fracture trace analysis was used to evaluate potential drilling locations. Data and aerial photographs were provided by the Tennessee Valley Authority, Map Information and Records Unit (F.R. Perchalski, written commun., 1990). Fracture traces, or lineaments, are defined as naturally occurring straight or linear features. They are commonly indicated by stream channels, soil-tonal variation, surface depression features, and topographic alignments (Siddiqui and Parizek, 1971). Lineaments often represent traces of subsurface fracture zones and possibly zones of higher permeability (Lattman and Parizek, 1964).

Drilling sites for eight test wells were chosen at or near fracture traces (fig.3). The wells were drilled to depths ranging from 249 to 332 feet below land surface (table 1). The primary water-bearing zones found during



**Figure 3.** Location of domestic wells and test wells in the Suck Creek area, Marion County, Tennessee.

**Table 1. Summary of test well data**

[&lt;, less than; --, indicates no data]

| Well number | Latitude  | Longitude | Altitude of land surface above sea level, in feet | Depth of well below land surface, in feet | Estimated yield, in gallons per minute | Rate of pumping, in gallons per minute | Specific capacity, in gallons per minute per foot of drawdown |
|-------------|-----------|-----------|---------------------------------------------------|-------------------------------------------|----------------------------------------|----------------------------------------|---------------------------------------------------------------|
| Ma:N-022    | 35°09'59" | 85°25'25" | 1,740                                             | 249                                       | < 1                                    | --                                     | --                                                            |
| Ma:N-023    | 35°10'17" | 85°25'01" | 1,820                                             | 261                                       | < 5                                    | --                                     | --                                                            |
| Ma:N-024    | 35°10'16" | 85°25'02" | 1,820                                             | 269                                       | 80                                     | 105                                    | 1.09                                                          |
| Ma:N-025    | 35°11'03" | 85°26'17" | 1,940                                             | 249                                       | < 5                                    | --                                     | --                                                            |
| Ma:N-026    | 35°10'57" | 85°26'12" | 1,910                                             | 275                                       | 80                                     | 105                                    | 2.2                                                           |
| Ma:N-027    | 35°10'54" | 85°26'12" | 1,890                                             | 250                                       | 50                                     | 113; 80                                | 1.3                                                           |
| Ma:N-028    | 35°09'33" | 85°24'59" | 1,940                                             | 332                                       | < 10                                   | --                                     | --                                                            |
| Ma:N-029    | 35°09'24" | 85°24'56" | 1,940                                             | 312                                       | < 1                                    | --                                     | --                                                            |

drilling were fractures in the Sewanee Conglomerate. An opening above the Sewanee coal seam within the Whitwell Shale yielded between 5 and 10 gallons of water per minute at well Ma:N-028. All water-bearing fractures were within 50 to 100 feet of land surface. Two of the wells had yields of less than 2 gal/min and three wells had estimated yields of between 4 and 10 gal/min. Three of the wells produced 50 gal/min or more. Two of these wells yielded 75 to 80 gal/min. All three higher yielding wells produced water from a well-developed fracture in the Sewanee Conglomerate.

## GROUND-WATER DATA

Ground water throughout the Cumberland Plateau occurs primarily in fractures and bedding planes in sandstones (Newcome and Smith, 1958). The sandstone aquifers have very low intergranular permeability, but fractures and bedding-plane openings provide secondary permeability (Newcome and Smith, 1958). Shale formations are confining units. In the Suck Creek area, the Sewanee Conglomerate is the major water-producing formation. In wells yielding more than 5 gal/min, the water-bearing zones are fractures.

Water levels in 16 domestic wells were measured on April 3, 1990 (fig. 3). All of the wells are open to the Sewanee Conglomerate. Depth to water in the wells ranged from 9.33 to 50.77 feet (table 2). Generally, the greatest depths are associated with wells on topographic highs, and least depths, with wells near perennial or nearly perennial streams.

Wells in the Cumberland Plateau region can yield from 5 to 50 gal/min (Zurawski, 1978). Well records of the Suck Creek area indicate that most domestic wells yield from less than 1 to 30 gal/min (Tennessee Department of Environment and Conservation, written commun., 1989).

## Specific Capacity Data

Specific capacity tests were conducted on three wells (Ma:N-024, Ma:N-026, and Ma:N-027). Specific capacity is the discharge of a well expressed as a rate of yield per unit of drawdown, and can be used as an indicator of the capacity of the well and aquifer to sustain continuous pumping at a given rate.

A 6-hour pumping test was conducted at well Ma:N-024. During the test, measurements were made of the pumping rate and water levels in the pumped well. The pumping rate was 105 gal/min; the specific capacity was calculated to be 1.1 gal/min/ft of drawdown.

**Table 2.** Data of domestic wells in the Suck Creek area

[ --, indicates no data; (R) Reported value]

| Well number | Latitude  | Longitude | Approximate altitude of land surface above sea level, in feet | Depth of well below land surface, in feet | Depth to water below land surface, in feet, April 3, 1990 |
|-------------|-----------|-----------|---------------------------------------------------------------|-------------------------------------------|-----------------------------------------------------------|
| Ma:N-001    | 35°11'16" | 85°26'10" | 2,020                                                         | 102                                       | 9.33                                                      |
| Ma:N-002    | 35°11'13" | 85°26'25" | 1,960                                                         | 66                                        | dry                                                       |
| Ma:N-003    | 35°11'12" | 85°26'20" | 2,050                                                         | 160                                       | 50.77                                                     |
| Ma:N-004    | 35°10'30" | 85°25'04" | 1,825                                                         | 105                                       | 38.13                                                     |
| Ma:N-009    | 35°10'06" | 85°25'14" | 1,790                                                         | 90                                        | 30.99                                                     |
| Ma:N-010    | 35°10'02" | 85°25'18" | 1,775                                                         | 100                                       | 39.45                                                     |
| Ma:N-011    | 35°10'01" | 85°25'14" | 1,800                                                         | --                                        | 18.64                                                     |
| Ma:N-012    | 35°10'00" | 85°25'10" | 1,830                                                         | --                                        | 37.81                                                     |
| Ma:N-013    | 35°10'24" | 85°25'22" | 1,850                                                         | 88                                        | 28.05                                                     |
| Ma:N-014    | 35°10'07" | 85°25'54" | 1,830                                                         | 352                                       | 45.23                                                     |
| Ma:N-015    | 35°10'04" | 85°25'55" | 1,820                                                         | 110                                       | 10.44                                                     |
| Ma:N-016    | 35°10'10" | 85°25'03" | 1,800                                                         | 65                                        | 18.99                                                     |
| Ma:N-017    | 35°11'12" | 85°26'19" | 1,980                                                         | 85                                        | 21.98                                                     |
| Ma:N-018    | 35°11'11" | 85°26'19" | 1,980                                                         | 93                                        | 20.08                                                     |
| Ma:N-019    | 35°11'10" | 85°26'31" | 1,920                                                         | 50                                        | 13.50                                                     |
| Ma:N-020    | 35°10'17" | 85°25'25" | 1,830                                                         | 100                                       | 29.55                                                     |
| Ma:N-024a   | 35°10'16" | 85°25'02" | 1,820                                                         | 110 (R)                                   | --                                                        |
| Ma:N-030    | 35°11'08" | 85°26'10" | 2,040                                                         | 116 (R)                                   | --                                                        |

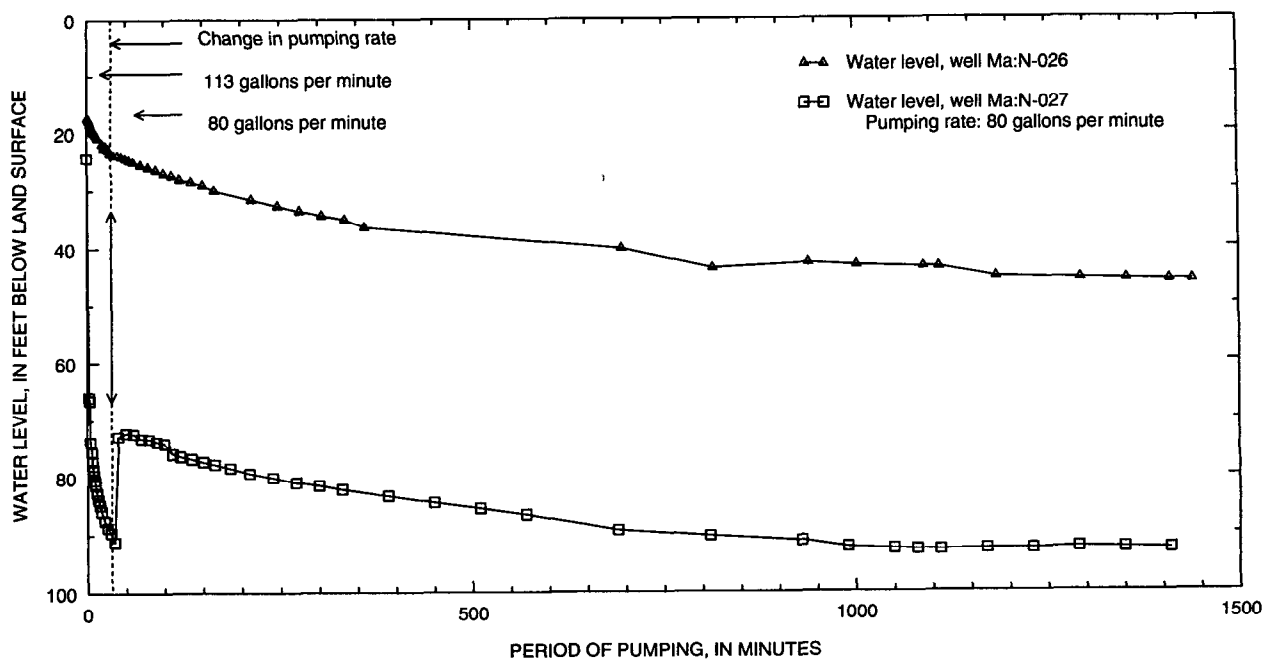
Two 24-hour pumping tests were conducted at wells Ma:N-026 and Ma:N-027. The test on Ma:N-027 was conducted in October 1990, and the test on Ma:N-026 was conducted in November 1990. During the tests, the pumping rate, water levels in the pumped well, and water levels in an observation well were measured. When Ma:N-027 was tested, Ma:N-026 served as the observation well; when Ma:N-026 was tested, Ma:N-027 served as the observation well.

The specific capacity test of well Ma:N-027 was made from October 30 to October 31, 1990. The initial pumping rate was approximately 113 gal/min. This rate caused rapid drawdown in the well and, therefore, the pumping rate was reduced to 80 gal/min after 40 minutes. Response of well Ma:N-026 to the pumping of well Ma:N-027 was nearly instantaneous (fig. 4). Drawdown in well Ma:N-027 was 61.5 feet after 24 hours of pumping. The specific capacity of well Ma:N-027 was calculated to be 1.3 gal/min/ft.

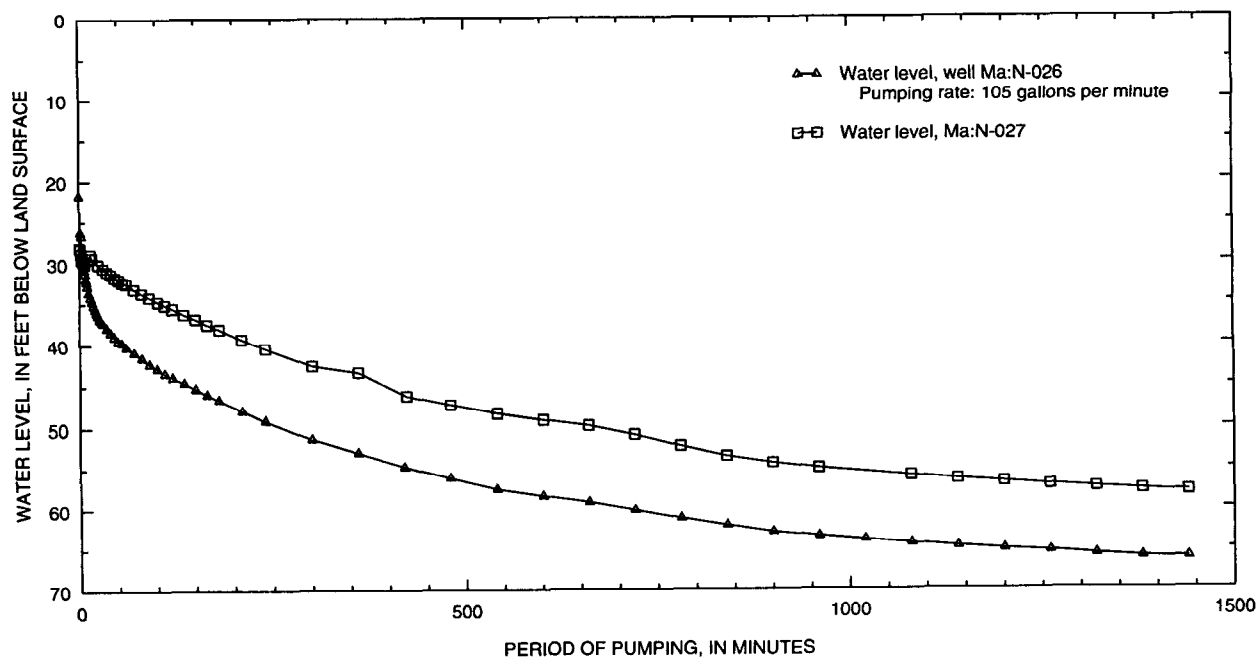
The specific capacity test of well Ma:N-026 was made from November 7 to November 8, 1990. The pumping rate for this test was 105 gal/min. Response of both wells to the pumping of well Ma:N-026 is shown in figure 5. Drawdown in well Ma:N-026 was 47.3 feet. The specific capacity for this well was calculated to be 2.2 gal/min/ft.

## Ground-Water Quality

Well-water samples were collected to determine ground-water quality and to ascertain whether the natural ground-water chemistry had been affected by human activities. Wells Ma:N-026 and Ma:N-027 were sampled in November and October 1990, respectively, following the 24-hour pumping tests. These samples were analyzed for field measurements, major inorganic constituents, nutrients, trace elements, and radioactivity (table 3). The sample from Ma:N-027 was also analyzed for volatile organic compounds (VOC's) (table 4). The sample collected from Ma:N-026 in November was not analyzed due to shipping and analytical problems, and the well was resampled in March 1991.



**Figure 4.** Water levels observed during specific capacity test of well Ma:N-027 and observation well Ma:N-026, October 30-31, 1990.



**Figure 5.** Water levels observed during specific capacity test of well Ma:N-026 and observation well Ma:N-027, November 7-8, 1990.

**Table 3.** Inorganic quality of water from test wells Ma:N-026 and Ma:N-027

[deg. C; degrees Celsius; ntu, nephelometric turbidity units;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter; mg/L, milligrams per liter;  $\text{NO}_2$ , nitrite;  $\text{NO}_3$ , nitrate;  $\mu\text{g}/\text{L}$ , micrograms per liter; pCi/L, picocuries per liter; <, less than; +/-, plus or minus]

| Well number | Date                                                           | Temperature,<br>water<br>(Deg. C)                          | Turbidity<br>(ntu)                                          | Color<br>(platinum-<br>cobalt<br>units)                       | Specific<br>conductance<br>( $\mu\text{S}/\text{cm}$ )      | Solids,<br>residue<br>at 180<br>deg. C<br>dissolved<br>(mg/L) | pH,<br>water,<br>whole<br>field,<br>(standard<br>units)             | Hardness,<br>total<br>(mg/L<br>as $\text{CaCO}_3$ )         | Calcium,<br>dissolved<br>(mg/L<br>as Ca)                     | Magnesium,<br>dissolved<br>(mg/L<br>as Mg)                    |
|-------------|----------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------|
| Ma:N-026    | 11-08-90                                                       | 14.0                                                       | 28                                                          | 8                                                             | 125                                                         | 70                                                            | 6.6                                                                 | 52                                                          | 14                                                           | 4.0                                                           |
| Ma:N-027    | 10-31-90                                                       | 14.0                                                       | 20                                                          | <1                                                            | 135                                                         | 70                                                            | 6.7                                                                 | 54                                                          | 15                                                           | 4.0                                                           |
| <hr/>       |                                                                |                                                            |                                                             |                                                               |                                                             |                                                               |                                                                     |                                                             |                                                              |                                                               |
| Well number | Sodium,<br>dissolved<br>(mg/L<br>as Na)                        | Potassium,<br>dissolved<br>(mg/L<br>as K)                  | Alkalinity,<br>field<br>(mg/L as $\text{CaCO}_3$ )          | Alkalinity,<br>lab<br>(mg/L<br>as $\text{CaCO}_3$ )           | Chloride,<br>dissolved<br>(mg/L<br>as Cl)                   | Sulfate,<br>dissolved<br>(mg/L<br>as $\text{SO}_4$ )          | Fluoride,<br>dissolved<br>(mg/L<br>as F)                            | Silica,<br>dissolved<br>(mg/L<br>as $\text{SiO}_2$ )        | Arsenic,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as As)  | Barium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Ba)    |
| Ma:N-026    | 2.7                                                            | 0.60                                                       | 57                                                          | 47                                                            | 3.3                                                         | 8.1                                                           | <0.10                                                               | 8.1                                                         | 2                                                            | 84                                                            |
| Ma:N-027    | 2.4                                                            | 0.60                                                       | 67                                                          | 52                                                            | 2.9                                                         | 7.3                                                           | <0.10                                                               | 8.3                                                         | 2                                                            | 110                                                           |
| <hr/>       |                                                                |                                                            |                                                             |                                                               |                                                             |                                                               |                                                                     |                                                             |                                                              |                                                               |
| Well number | Beryllium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Be)  | Boron,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as B)   | Cadmium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Cd) | Chromium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Cr)  | Cobalt,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Co)  | Copper,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Cu)    | Iron,<br>total<br>recoverable<br>( $\mu\text{g}/\text{L}$<br>as Fe) | Iron,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Fe)    | Lead,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Pb)     | Manganese,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Mn) |
| Ma:N-026    | <0.5                                                           | <10                                                        | <1.0                                                        | <1                                                            | 2                                                           | <1                                                            | 5,400                                                               | 5,700                                                       | <1                                                           | 670                                                           |
| Ma:N-027    | <0.5                                                           | <10                                                        | <1.0                                                        | <1                                                            | 2                                                           | <1                                                            | 5,400                                                               | 5,400                                                       | 1                                                            | 460                                                           |
| <hr/>       |                                                                |                                                            |                                                             |                                                               |                                                             |                                                               |                                                                     |                                                             |                                                              |                                                               |
| Well number | Molybdenum,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Mo) | Nickel,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Ni) | Silver,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Ag)  | Strontium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Sr) | Vanadium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as V) | Zinc,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Zn)      | Aluminum,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Al)        | Lithium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Li) | Selenium,<br>dissolved<br>( $\mu\text{g}/\text{L}$<br>as Se) | Iodide,<br>dissolved<br>(mg/L<br>as I)                        |
| Ma:N-026    | 3                                                              | 3                                                          | <1.0                                                        | 72                                                            | <1                                                          | 120                                                           | <10                                                                 | <4                                                          | <1                                                           | 0.005                                                         |
| Ma:N-027    | 2                                                              | 2                                                          | <1.0                                                        | 100                                                           | <1                                                          | 110                                                           | <10                                                                 | 7                                                           | <1                                                           | .007                                                          |

**Table 3.** Inorganic quality of water from test wells Ma:N-026 and Ma:N-027--Continued

| Well number | Bromide,<br>dis-<br>solved<br>(mg/L<br>as Br) | Mercury,<br>dis-<br>solved<br>(µg/L<br>as Hg)                 | Nitro-<br>gen,<br>ammonia,<br>dis-<br>solved<br>(mg/L<br>as N) | Nitro-<br>gen,<br>ammonia,<br>total<br>(mg/L<br>as N)       | Nitro-<br>gen,<br>nitrite,<br>dis-<br>solved<br>(mg/L<br>as N) | Nitro-<br>gen,<br>nitrite,<br>total<br>(mg/L<br>as N)          | Nitro-<br>gen, am-<br>monia +<br>organic,<br>total<br>(mg/L<br>as N) | Nitro-<br>gen,<br>NO <sub>2</sub> +NO <sub>3</sub> ,<br>total<br>(mg/L<br>as N) | Nitro-<br>gen,<br>NO <sub>2</sub> +NO <sub>3</sub> ,<br>dis-<br>solved<br>(mg/L<br>as N) |
|-------------|-----------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Ma:N-026    | 0.010                                         | <0.1                                                          | 0.050                                                          | 0.050                                                       | <0.010                                                         | <0.010                                                         | 0.40                                                                 | <0.100                                                                          | <0.100                                                                                   |
| Ma:N-027    | 0.010                                         | <0.1                                                          | 0.050                                                          | 0.060                                                       | <0.010                                                         | <0.010                                                         | <0.20                                                                | <0.100                                                                          | <0.100                                                                                   |
| -----       |                                               |                                                               |                                                                |                                                             |                                                                |                                                                |                                                                      |                                                                                 |                                                                                          |
| Well number | Phos-<br>phorus,<br>total<br>(mg/L<br>as P)   | Phos-<br>phorus<br>ortho,<br>dis-<br>solved<br>(mg/L<br>as P) | Phos-<br>phorus<br>ortho,<br>total<br>(mg/L<br>as P)           | Gross<br>beta,<br>dis-<br>solved<br>(pCi/L<br>as<br>Cs-137) | Gross<br>alpha,<br>dis-<br>solved<br>(µg/L<br>as<br>U-nat)     | Gross<br>beta,<br>dis-<br>solved<br>(pCi/L<br>as Sr/<br>Yt-90) |                                                                      |                                                                                 |                                                                                          |
| Ma:N-026    | 0.030                                         | <0.010                                                        | <0.010                                                         | 0.8 +/- 0.5                                                 | 1.7 +/- 0.8                                                    | 0.7 +/- 0.50                                                   |                                                                      |                                                                                 |                                                                                          |
| Ma:N-027    | 0.030                                         | <0.010                                                        | <0.010                                                         | 0.9 +/- 0.5                                                 | 0.8 +/- 0.7                                                    | 0.8 +/- 0/50                                                   |                                                                      |                                                                                 |                                                                                          |

**Table 4.** Concentrations of volatile organic compounds in water from wells Ma:N-026 and Ma:N-027

[µg/L, micrograms per liter; &lt;, less than; wat, wh, water, whole; --, indicates no data]

| Well number | Date                                         | Di-bromo-methane water whole, recover (µg/L) | Di-chloro-bromo-methane, total (µg/L)      | Carbon-tetra-chloride, total (µg/L)            | 1,2-Di-chloro-ethane, total (µg/L)               | Bromo-form, total (µg/L)                           | Chloro-di-bromo-methane, total (µg/L)            | Chloro-form, total (µg/L)                | Toluene, total (µg/L)                        |
|-------------|----------------------------------------------|----------------------------------------------|--------------------------------------------|------------------------------------------------|--------------------------------------------------|----------------------------------------------------|--------------------------------------------------|------------------------------------------|----------------------------------------------|
| Ma:N-026    | 03-21-91                                     | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Ma:N-027    | 10-31-90                                     | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | 0.3                                          |
| Well number | Benzene, total (µg/L)                        | Chloro-benzene, total (µg/L)                 | Chloro-ethane, total (µg/L)                | Ethyl-benzene, total (µg/L)                    | Methyl-bromide, total (µg/L)                     | Methyl-chloride, total (µg/L)                      | Methyl-ene chlor-ide, total (µg/L)               | Tetra-chloro-ethyl-ene, total (µg/L)     | Tri-chloro-flouro-methane, total (µg/L)      |
| Ma:N-026    | <0.2                                         | <0.20                                        | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Ma:N-027    | <0.2                                         | <0.20                                        | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Well number | 1,1-Di-chloro-ethane, total (µg/L)           | 1,1-Di-chloro-ethyl-ene, total (µg/L)        | 1,1,1-Tri-chloro-ethane, total (µg/L)      | 1,1,2-Tri-chloro-ethane, total (µg/L)          | 1,1,2,2 Tetra-chloro-ethane, total (µg/L)        | 1,2-Di-chloro-benzene, total (µg/L)                | 1,2-Di-chloro-propane, total (µg/L)              | 1,3-Di-chloro-benzene, total (µg/L)      | 1,4-Di-chloro-benzene, total (µg/L)          |
| Ma:N-026    | <0.2                                         | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Ma:N-027    | <0.2                                         | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Well number | Di-chloro-di-flouro-methane, total (µg/L)    | Trans-1,3-Di-chloro-propene, total (µg/L)    | Cis 1,3-Di-chloro-propene, total (µg/L)    | Methy-lene blue active substance µg/L          | Vinyl chlo-ride, total (µg/L)                    | Tri-chloro-ethyl-ene, total (µg/L)                 | 1,2-Di-chloro-ethene water whole, recover (µg/L) | Styrene, total (µg/L)                    | 1,1-Di-chloro-pro-pene, wat,wh, total (µg/L) |
| Ma:N-026    | <0.2                                         | <0.2                                         | <0.2                                       | --                                             | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Ma:N-027    | <0.2                                         | <0.2                                         | <0.2                                       | <0.01                                          | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Well number | 2,2-Di-chloro-pro-pane wat, wh, total (µg/L) | 1,3-Di-chloro-propane wat, wh, total (µg/L)  | O-chloro-toluene water whole, total (µg/L) | Para-chloro-toluene water, whole, total (µg/L) | 123-Tri-chloro-propane water whole, total (µg/L) | 1,1,1,2 Tetra-chloro-ethane, wat, wh, total (µg/L) | 1,2-Dibromo ethane water whole, total (µg/L)     | Xylene total water whole, tot rec (µg/L) | Bromo-benzene water, whole, total (µg/L)     |
| Ma:N-026    | <0.2                                         | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |
| Ma:N-027    | <0.2                                         | <0.2                                         | <0.2                                       | <0.2                                           | <0.2                                             | <0.2                                               | <0.2                                             | <0.2                                     | <0.2                                         |



The quality of water from wells Ma:N-026 and Ma:N-027 was very similar. Water from both wells was of the calcium magnesium bicarbonate type with 70 mg/L dissolved solids. Concentrations of other constituents in water from wells Ma:N-026 and Ma:N-027 were also similar (table 3). Toluene in water from Ma:N-027 was the only organic compound detected. All other volatile organic compounds were below reporting levels. The toluene at well Ma:N-027 was detected at 0.3 µg/L, slightly above the reporting level of 0.2 µg/L.

Water samples from nine wells in the Suck Creek area were collected during March and May 1991. Four of the remaining test wells (wells Ma:N-022, -025, -028, and -029) and three domestic wells (Ma:N-001, Ma:N-024a, and Ma:N-30) were sampled. For comparison, test wells Ma:N-026 and Ma:N-027 were sampled again. Samples were analyzed for field measurements, major inorganic constituents, nutrients, and bacteria (table 5).

The pH of water samples from the study area ranged from 4.9 to 7.2, with a median value of 6.7. The pH of water from well Ma:N-001 was 4.9 and from well Ma:N-024a was 5.4. The pH of water from the other seven wells was above 6.5 (table 5). Low pH may pose water-quality problems with regard to water softening and corrosion control, and could increase treatment and drinking-water costs (Hem, 1985).

Hardness of ground water from the study area ranged from 7 to 120 mg/L as CaCO<sub>3</sub>. Water from five wells (Ma:N-022, -025, -026, -029, and -030) can be classified as moderately hard (60 to 120 mg/L), while water from four wells (Ma:N-001, -024a, -027, and -028) can be classified as soft (0 to 60 mg/L). Hardness becomes objectionable for ordinary domestic use at concentrations greater than 100 mg/L (Hem, 1985).

Sulfate concentrations in ground water in the Suck Creek area ranged from less than 1.0 to 33 mg/L. However, if the data for well Ma:N-024a are excluded, the range in sulfate concentrations was less than 1.0 to 11 mg/L (table 5). Elevated sulfate concentrations can result from sulfide and sulfate minerals occurring in shale or in coal seams (Hem, 1985).

Water from the wells in the Suck Creek area were analyzed for major nitrogen and phosphorus species and fecal coliform and fecal streptococci bacteria. Results show that, for each sample, the concentrations of nitrogen and phosphorus species are at or near the analytical reporting limit. Concentrations for all of the nutrients are 0.26 mg/L or less in all of the wells. Fecal coliform and fecal streptococci bacterial counts were less than 1 colony per 100 milliliters (col./100 mL) from eight of the nine wells sampled. In water from Ma:N-001, the fecal coliform count was less than 1 col./100 mL and the fecal streptococci count was 8 col./100 mL.

Concentrations of iron in water from the wells sampled ranged from 11 to 6,200 µg/L with a median value of 1,900 µg/L. Manganese in water from wells sampled in the Suck Creek area ranged from 12 to 830 µg/L, with a median value of 310 µg/L. Iron and manganese in ground water from the Cumberland Plateau generally occur at elevated concentrations. This is a result of acidic recharge and the occurrence of iron and manganese minerals and iron-rich cement in the aquifers.

## SUMMARY

A hydrogeologic investigation was conducted of the Suck Creek area in Marion County, Tennessee, during 1990-91. Eight wells were drilled to depths ranging from 249 to 332 feet below land surface. Drilling sites were located at or near major linear traces indicating possible fractures in the bedrock. Three of these wells, completed through a well-developed fracture in the Sewanee Conglomerate, had yields of 50 gal/min or more. The specific capacities of these three wells ranged from 1.1 to 2.2 gal/min/ft. The Sewanee Conglomerate was determined to be the dominant water-bearing formation in the study area.

Ground water in the Suck Creek area contained 15 to 149 mg/L dissolved solids. Water from two wells had low pH (4.9 to 5.4), and water from one well had a sulfate concentration of 33 mg/L. The pH of samples from other wells ranged from 6.5 to 7.2, and sulfate concentrations ranged from less than 1.0 to 11 mg/L. Water from four wells was soft, and water from five wells was moderately hard.

**Table 5.** Inorganic quality of water from wells in the Suck Creek area, March and May 1991

[deg. C, degrees Celsius;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter;  $\text{mg}/\text{L}$ , milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter;  $\text{NO}_2$ , nitrite;  $\text{NO}_3$ , nitrate; --, no data; <, less than]

| Well number | Date                                                                          | Temperature<br>water<br>(deg. C)                              | Color<br>(plat-<br>inum-<br>cobalt<br>units)                            | Spe-<br>cific<br>con-<br>duct-<br>ance<br>( $\mu\text{S}/\text{cm}$ )           | Solids,<br>residue<br>at 180<br>deg. C,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$ ) | pH,<br>water,<br>whole,<br>field<br>(stand-<br>ard<br>units)                    | Hard-<br>ness,<br>total<br>( $\text{mg}/\text{L}$<br>as<br>$\text{CaCO}_3$ ) | Calcium,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as Ca)                            |
|-------------|-------------------------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Ma:N-001    | 03-19-91                                                                      | 11.5                                                          | 3                                                                       | 28                                                                              | 15                                                                                    | 4.9                                                                             | 7                                                                            | 1.5                                                                                       |
| Ma:N-022    | 05-16-91                                                                      | --                                                            | 5                                                                       | --                                                                              | 115                                                                                   | --                                                                              | 110                                                                          | 32                                                                                        |
| Ma:N-024a   | 03-21-91                                                                      | 15.0                                                          | 5                                                                       | 129                                                                             | 74                                                                                    | 5.4                                                                             | 37                                                                           | 9.2                                                                                       |
| Ma:N-025    | 05-17-91                                                                      | 16.0                                                          | 2                                                                       | 205                                                                             | 112                                                                                   | 7.2                                                                             | 90                                                                           | 26                                                                                        |
| Ma:N-026    | 03-21-91                                                                      | 14.0                                                          | 5                                                                       | 146                                                                             | 80                                                                                    | 6.9                                                                             | 62                                                                           | 19                                                                                        |
| Ma:N-027    | 03-19-91                                                                      | 13.5                                                          | 5                                                                       | 139                                                                             | 68                                                                                    | 6.7                                                                             | 54                                                                           | 15                                                                                        |
| Ma:N-028    | 03-20-91                                                                      | 14.0                                                          | 5                                                                       | 108                                                                             | 78                                                                                    | 6.5                                                                             | 46                                                                           | 13                                                                                        |
| Ma:N-029    | 03-20-91                                                                      | 14.5                                                          | 3                                                                       | 153                                                                             | 82                                                                                    | 7.1                                                                             | 72                                                                           | 22                                                                                        |
| Ma:N-030    | 05-17-91                                                                      | --                                                            | 3                                                                       | --                                                                              | 149                                                                                   | --                                                                              | 120                                                                          | 38                                                                                        |
| <hr/>       |                                                                               |                                                               |                                                                         |                                                                                 |                                                                                       |                                                                                 |                                                                              |                                                                                           |
| Well number | Magne-<br>sium,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as Mg)         | Sodium,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as Na) | Potas-<br>sium,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as K)    | Alka-<br>linity<br>field<br>( $\text{mg}/\text{L}$ as<br>$\text{CaCO}_3$ )      | Alka-<br>linity<br>lab<br>( $\text{mg}/\text{L}$<br>as<br>$\text{CaCO}_3$ )           | Chlo-<br>ride,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as Cl)            | Sulfate,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as $\text{SO}_4$ )   | Fluo-<br>ride,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as F)                       |
| Ma:N-001    | 0.71                                                                          | 0.50                                                          | 0.50                                                                    | 1                                                                               | 1.4                                                                                   | 0.70                                                                            | 6.9                                                                          | <0.10                                                                                     |
| Ma:N-022    | 7.5                                                                           | 1.8                                                           | 0.60                                                                    | --                                                                              | 100                                                                                   | 0.50                                                                            | 11                                                                           | 0.10                                                                                      |
| Ma:N-024a   | 3.5                                                                           | 4.1                                                           | 0.90                                                                    | 12                                                                              | 5.9                                                                                   | 5.6                                                                             | 33                                                                           | <0.10                                                                                     |
| Ma:N-025    | 6.2                                                                           | 7.0                                                           | 1.2                                                                     | --                                                                              | 102                                                                                   | 2.2                                                                             | 6.6                                                                          | <0.10                                                                                     |
| Ma:N-026    | 3.6                                                                           | 2.2                                                           | 0.90                                                                    | 70                                                                              | 59                                                                                    | 3.5                                                                             | 9.3                                                                          | <0.10                                                                                     |
| Ma:N-027    | 4.0                                                                           | 2.4                                                           | 0.70                                                                    | 68                                                                              | 49                                                                                    | 3.1                                                                             | 8.4                                                                          | <0.10                                                                                     |
| Ma:N-028    | 3.3                                                                           | 2.4                                                           | 1.0                                                                     | 67                                                                              | 50                                                                                    | 1.0                                                                             | <1.0                                                                         | <0.10                                                                                     |
| Ma:N-029    | 4.1                                                                           | 1.9                                                           | 1.0                                                                     | 82                                                                              | 75                                                                                    | 1.3                                                                             | 1.8                                                                          | <0.10                                                                                     |
| Ma:N-030    | 7.3                                                                           | 5.0                                                           | 0.90                                                                    | --                                                                              | 125                                                                                   | 2.1                                                                             | 10                                                                           | 0.20                                                                                      |
| <hr/>       |                                                                               |                                                               |                                                                         |                                                                                 |                                                                                       |                                                                                 |                                                                              |                                                                                           |
| Well number | Silica,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as<br>$\text{SiO}_2$ ) | Iron,<br>dis-<br>solved<br>( $\mu\text{g}/\text{L}$<br>as Fe) | Manga-<br>nese,<br>dis-<br>solved<br>( $\mu\text{g}/\text{L}$<br>as Mn) | Nitro-<br>gen,<br>ammonia,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as N) | Nitro-<br>gen,<br>ammonia,<br>total<br>( $\text{mg}/\text{L}$<br>as N)                | Nitro-<br>gen,<br>nitrite,<br>dis-<br>solved<br>( $\text{mg}/\text{L}$<br>as N) | Nitro-<br>gen,<br>nitrite,<br>total<br>( $\text{mg}/\text{L}$<br>as N)       | Nitro-<br>gen, am-<br>monia +<br>organic,<br>dissolved<br>( $\text{mg}/\text{L}$<br>as N) |
| Ma:N-001    | 4.3                                                                           | 11                                                            | 20                                                                      | <0.010                                                                          | 0.040                                                                                 | <0.010                                                                          | --                                                                           | --                                                                                        |
| Ma:N-022    | 8.5                                                                           | 33                                                            | 140                                                                     | 0.040                                                                           | 0.020                                                                                 | <0.010                                                                          | 0.010                                                                        | <0.20                                                                                     |
| Ma:N-024a   | 8.8                                                                           | 4,100                                                         | 590                                                                     | 0.020                                                                           | 0.060                                                                                 | <0.010                                                                          | 0.020                                                                        | <0.20                                                                                     |
| Ma:N-025    | 14                                                                            | 14                                                            | 12                                                                      | 0.040                                                                           | 0.040                                                                                 | <0.010                                                                          | <0.010                                                                       | <0.20                                                                                     |
| Ma:N-026    | 8.3                                                                           | 3,600                                                         | 830                                                                     | 0.020                                                                           | --                                                                                    | --                                                                              | --                                                                           | --                                                                                        |
| Ma:N-027    | 8.5                                                                           | 5,500                                                         | 510                                                                     | 0.020                                                                           | --                                                                                    | --                                                                              | --                                                                           | --                                                                                        |
| Ma:N-028    | 16                                                                            | 6,200                                                         | 310                                                                     | 0.030                                                                           | 0.050                                                                                 | <0.010                                                                          | <0.010                                                                       | <0.20                                                                                     |
| Ma:N-029    | 10                                                                            | 1,900                                                         | 330                                                                     | 0.040                                                                           | 0.060                                                                                 | <0.010                                                                          | <0.010                                                                       | <0.20                                                                                     |
| Ma:N-030    | 15                                                                            | 230                                                           | 52                                                                      | 0.020                                                                           | 0.010                                                                                 | <0.010                                                                          | <0.010                                                                       | <0.20                                                                                     |

**Table 5.** Inorganic quality of water from wells in the Suck Creek area, March and May 1991--Continued

| Well number | Nitro-<br>gen, am-<br>monia +<br>organic,<br>total<br>(mg/L<br>as N) | Nitro-<br>gen,<br>NO <sub>2</sub> +NO <sub>3</sub> ,<br>total<br>(mg/L<br>as N) | Nitro-<br>gen,<br>NO <sub>2</sub> +NO <sub>3</sub> ,<br>dis-<br>solved<br>(mg/L<br>as N) | Phos-<br>phorus,<br>total<br>(mg/L<br>as P) | Phos-<br>phorus,<br>dis-<br>solved<br>(mg/L<br>as P) | Phos-<br>phorus<br>ortho,<br>dis-<br>solved<br>(mg/L<br>as P) | Phos-<br>phorus<br>ortho,<br>total<br>(mg/L<br>as P) |
|-------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------|------------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------|
| Ma:N-001    | --                                                                   | --                                                                              | --                                                                                       | --                                          | --                                                   | --                                                            | --                                                   |
| Ma:N-022    | <0.20                                                                | <0.050                                                                          | <0.050                                                                                   | 0.080                                       | <0.010                                               | <0.010                                                        | 0.020                                                |
| Ma:N-024a   | <0.20                                                                | 0.230                                                                           | 0.240                                                                                    | 0.010                                       | <0.010                                               | <0.010                                                        | <0.010                                               |
| Ma:N-025    | 0.20                                                                 | 0.160                                                                           | 0.180                                                                                    | 0.040                                       | 0.050                                                | 0.020                                                         | 0.010                                                |
| Ma:N-026    | --                                                                   | --                                                                              | --                                                                                       | --                                          | --                                                   | --                                                            | --                                                   |
| Ma:N-027    | --                                                                   | --                                                                              | --                                                                                       | --                                          | --                                                   | --                                                            | --                                                   |
| Ma:N-028    | <0.20                                                                | <0.050                                                                          | <0.050                                                                                   | 0.110                                       | 0.140                                                | <0.010                                                        | <0.010                                               |
| Ma:N-029    | <0.20                                                                | <0.050                                                                          | <0.050                                                                                   | 0.050                                       | 0.010                                                | <0.010                                                        | <0.010                                               |
| Ma:N-030    | <0.20                                                                | 0.068                                                                           | 0.058                                                                                    | 0.260                                       | 0.010                                                | 0.030                                                         | 0.070                                                |

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