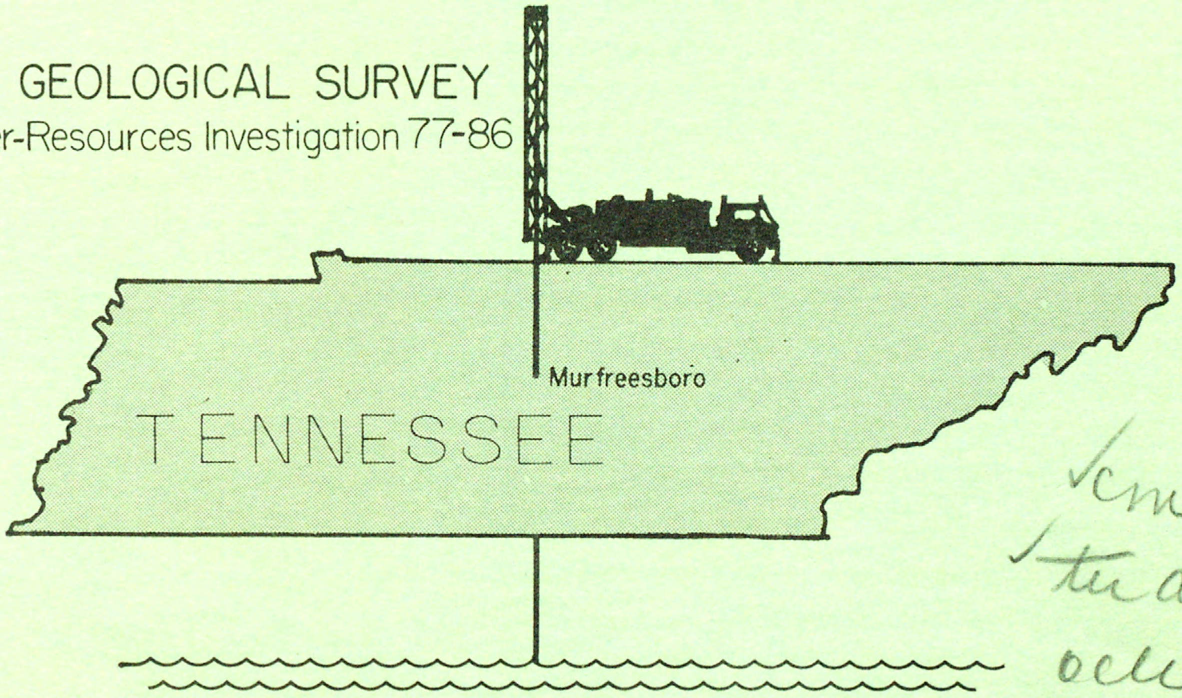
GROUND-WATER SUPPLIES IN THE MURFREESBORO AREA, TENNESSEE

U.S. GEOLOGICAL SURVEY
Water-Resources Investigation 77-86



PREPARED IN COOPERATION WITH THE CITY OF MURFREESBORO, WATER AND SEWER DEPARTMENT

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16. Abstracts

Ground water occurs in the Murfreesboro area in solution openings in the otherwise dense paleozoic limestones that underlie most of central Tennessee. Test drilling based on conceptual models of ground-water occurrence in carbonate-rock aquifers indicate that multimillion-gallon-per-day supplies could be developed from strategically located production wells in the Shiloh and Overall Creek localities. The Shiloh locality which encompasses an elongated synclinal depression in the bedrock has the potential to supply 5 to 8 million gallons per day. The Overall Creek locality which straddles a joint-oriented lineament has the potential to supply 3 to 6 million gallons per day.

Some local springs could be used as a supplemental source of potable water, but storage facilities would be needed to offset poorly sustained flows during dry periods. An exception is Fox Camp Spring which appears to be a natural well.

The quality of ground water in the Murfreesboro area is typically hard, moderately mineralized and moderately to highly alkaline. Although the shallowest aquifers are subject to bacterial contamination from the land surface, aquifers that occur beneath a depth of 100 feet are prone to yield potable water.

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July 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

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DEFINITION OF TERMS AND ABBREVIATIONS

Cubic foot (ft^3). A unit of volume equivalent to 7.4805 gallons (gal), 28.321 liters (L), or 0.02832 cubic meters (m^3).

Cubic foot per second (ft^3/s). The rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second. 1 ft^3/s = 0.02832 m^3/s.

Cubic foot per second per day [(ft^3/s)/d]. The volume of water represented by a flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet (2447 m^3), 1.9835 acre-feet, or 646,320 gallons (2.4 x 10^6L), and represents a runoff of 0.0372 inch from 1 square mile (0.3648 millimeters from 1 square kilometer).

Flow-duration curve. A cumulative frequency curve showing the percentage of time that specified flows are equaled or exceeded.

Gaging station. A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained. When used in connection with a discharge record, the term is applied only to those gaging stations where a continuous record of discharge is obtained.

Gallons per day (gal/d). A unit for expressing water use. 1 gal/d = 3.785 L/d.

Gallons per minute (gal/min). A unit for expressing well yield. 1 gal/min = 0.06309 L/s.

Hydrograph. A graph showing stage, flow, velocity, or other property of water with respect to time.

Inches of water. The rainfall and depth to which the drainage area would be covered if, for example, all the rainfall and runoff for a given time period were uniformly distributed on it. One inch of water = 25.4 mm.

Low-flow frequency curve. A graph showing the magnitude and frequency of minimum flows for a period of given length. Frequency is usually expressed as the average interval, in years, between recurrence of flow equal to or less than that shown by the magnitude scale.

Milligrams per liter (mg/L). A unit for expressing the concentration of dissolved constituents in water as a weight of the constituent in a liter of water.

Million gallons per day (Mgal/d). A unit for expressing water use. One million gal/d = .04381 m^3/s.

Stream-gaging station. A gaging station where a record of discharge of a stream is obtained. Within the Geological Survey this term is used for those gaging stations where a continuous record of discharge is obtained.

Water year. In Geological Survey reports dealing with surface water, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1959, is called the "1959 water year."

7-day 2-year low flow. The average of the annual minimum 7-day streamflow. There is a 50 percent chance that the 7-day 2-year flow will recur in any year.

7-day 10-year low flow. The average of the annual minimum 7-day streamflow. There is a 10 percent chance that the 7-day 10-year flow will recur in any year.

7-day 20-year low flow. The average of the annual minimum 7-day streamflow. There is a 5 percent chance that the 7-day 20-year flow will recur in any year.

3-day 20-year low flow. The average of the annual minimum 3-day streamflow. There is a 5 percent chance that the 3-day 20-year flow will recur in any year.

GROUND-WATER SUPPLIES IN THE MURFREESBORO AREA, TENNESSEE

By D. R. Rima, Mary S. Moran, and E. Jean Woods

ABSTRACT

In view of the growing demand for potable water supplies to meet the needs of the city of Murfreesboro, Tennessee, an investigation was made to determine the feasibility of developing supplemental supplies from wells and springs. The initial phase of the investigation was directed toward a determination of the geologic and hydrologic factors controlling the occurrence of solution openings in the limestone aquifers in the Murfreesboro area. The results of these studies were used in the selection of sites for drilling test wells.

Eleven test wells were drilled within a 5-mile radius of Murfreesboro. Four of these wells were test pumped to determine their yields and specific capacities. The results of the test drilling indicate that at least two localities in the Murfreesboro area have a high potential for the development of large ground water supplies. One of these, the Shiloh locality, probably can supply 5 to 8 millions gallons per day, and the other, the Overall Creek locality, could supply 3 to 6 million gallons per day. Properly located wells in these localities should yield 100 to 300 gallons per minute each. Test drilling would be required, however, to locate sites for individual production wells.

To evaluate spring supplies, data including water samples were collected from 16 of the largest and most dependable springs in the Murfreesboro area. Interpretation of a set of synoptic springflow measurements indicates that 11 of the 16 springs inventoried have estimated average discharges in excess of a million gallons per day. Of these, five have estimated average discharges in excess of 5 million gallons per day and 2 have estimated average discharges in excess of 10 million gallons per day. All of these springs, however, are believed to have poorly sustained low flows as indicated by the correlation of periodic springflow measurements of two of the springs with the mean daily baseflow of the Stones River. Hence, the use of springs as a supplemental source of water supply would require construction of surface storage facilities to offset the minimum flows during prolonged droughts.

The chemical quality of ground water in the Murfreesboro area is typical of that usually found in areas underlain by carbonate rocks. In general the water is hard, moderately mineralized, and moderately to highly alkaline. The water from wells tends to be more mineralized than that from springs.

Although the shallowest aquifers are subject to bacterial contamination from the land surface, aquifers that occur below a depth of 100 feet generally yield potable water.

Judging from the quantity and quality of ground-water supplies available in the Murfreesboro area, the development of supplemental water supplies from wells and springs appears to be feasible.

INTRODUCTION

Murfreesboro, Tennessee, is undergoing a period of very rapid growth and development. The city's potable water-supply needs are increasing and are now (1976) greater than the minimum dependable yield of its current sources of supply, the Town Spring and the East Fork Stones River. As shown in figure 1, the shortfall between the city's maximum daily pumpage and minimum dependable supply from existing sources is about 3 Mgal/d. Considering future increases in water use it is probably that the shortfall could approach 5 or 6 Mgal/d within the next decade. In order to assure an adequate supply of water during extended dry periods and provide for future growth, Murfreesboro has two basic options; either provide additional reservoir storage on the East or West Fork Stones River, or develop some other source of water such as wells or springs. The feasibility of providing additional reservoir storage has been studied at some length, but the availability of water from wells or springs has not been adequately explored.

PURPOSE AND SCOPE

The purpose of this report is to summarize the results of an investigation of the availability and quality of supplemental water supplies from wells and springs in the Murfreesboro area. The investigation was made by the U.S. Geological Survey in cooperation with the city of Murfreesboro. The first phase of the study related the distribution of gaining and losing reaches of streams to structural features to determine the control of structure on the occurrence and movement of ground water. The results of these studies were used to select sites for test drilling. To evaluate well supplies, 11 test wells were drilled within a radius of 5 mi of Murfreesboro. Four of these wells were test pumped to determine their yields and the hydraulic responses of the aquifer systems. Contemporaneous measurements were made of the flow of 16 of the largest and most reliable springs in the area to evaluate spring supplies. To determine the quality of the ground water, water samples were collected from selected wells and springs.

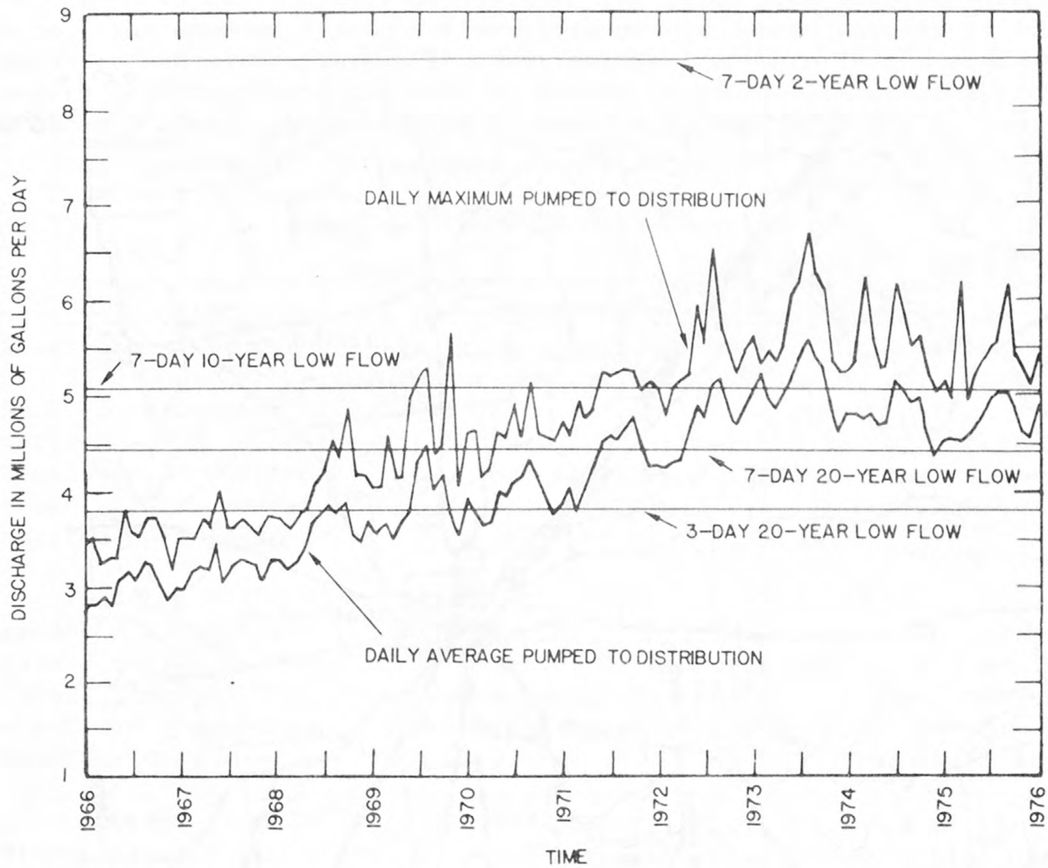


Figure 1.--Water supply and demand for the City of Murfreesboro. The 3-day 20-year low flow is the standard used by the Tennessee Public Health Department in order to determine minimum sustained yield. The supply variables were obtained by adding the yield of Town Spring (2 M gal/d) to the indicated low flows of the East Fork Stones River at Lascassas as determined from gaging station records.

LOCATION AND EXTENT OF AREA

The Murfreesboro area, as used in this report, refers to the area covered by the six 7½-minute quadrangle maps which include and surround Murfreesboro (fig. 2). The names of these quadrangles, beginning in the northwest corner and proceeding in a clockwise direction, are Smyrna, Walterhill, Lascassas, Dillton, Murfreesboro and Rockvale. The area includes about 370 mi^2 of the Upper Stones River Basin. Most of the study areas lies within Rutherford County; the remainder includes adjoining parts of Williamson, Davidson and Wilson Counties.

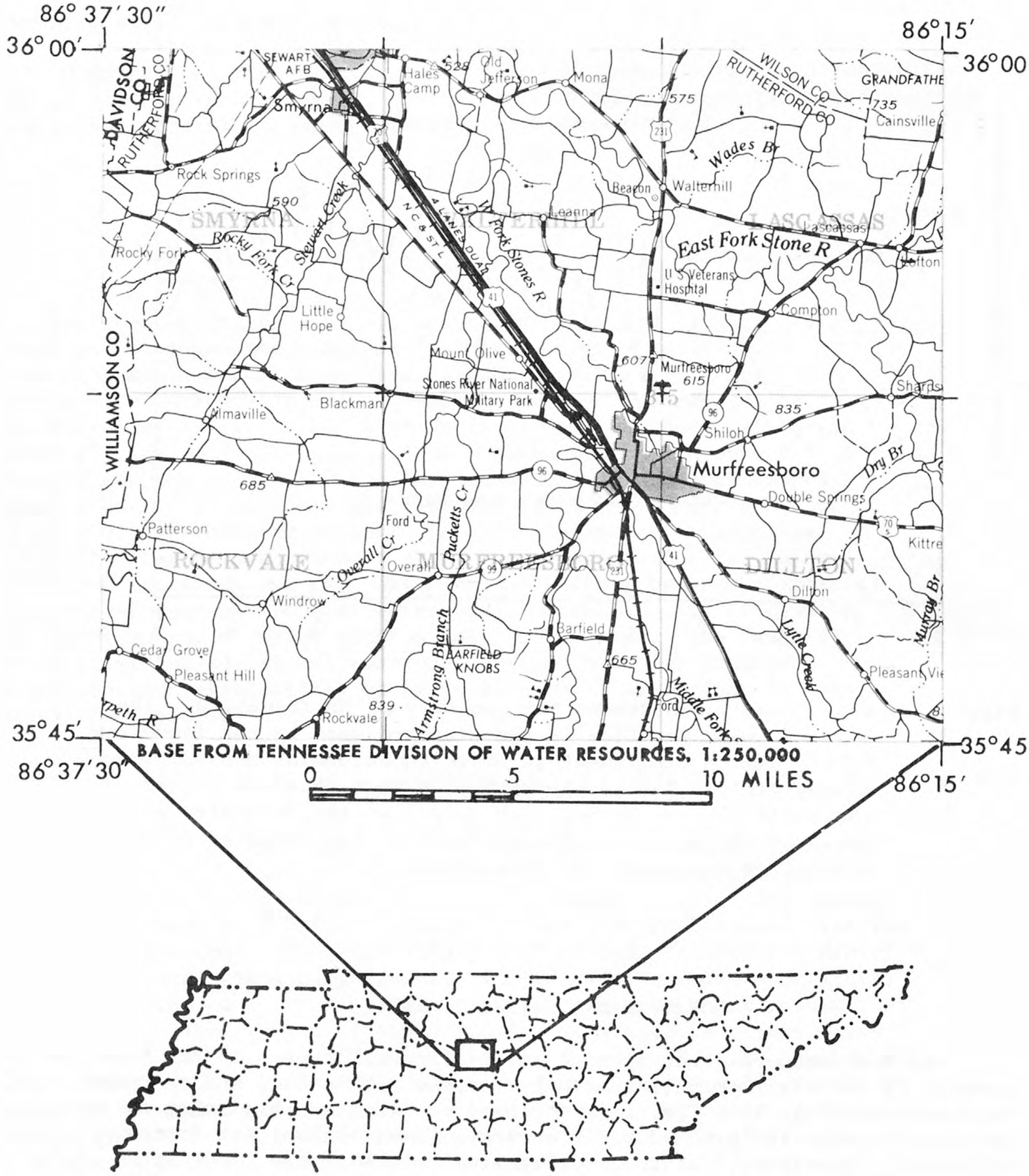


Figure 2. --Location of Murfreesboro study area.

census. Based on this rate of growth the population of the city should have passed the 30,000 mark some time in the mid-1970's. An additional 10,000 to 15,000 people reside within the study area outside Murfreesboro. The economy of the Murfreesboro area is based chiefly on light industry and agriculture. In addition, Murfreesboro is the seat of county government and the site of Middle Tennessee State University, which has a student population of nearly 15,000.

PREVIOUS STUDIES

The occurrence of ground water near Murfreesboro is described in several published reports covering areas or regions that include Murfreesboro. Among the earliest is a brief account by Galloway (1919, p. 76-78) of the general features of streams, wells and springs in Rutherford County. Piper (1932) described the physical character and water-bearing properties of the geologic formations in north-central Tennessee, a multicounty area that includes Rutherford County. Both of these reports contain references to the quality of ground water in the Murfreesboro area.

Newcome (1958) briefly described the water-bearing character of the geologic formations, and presented drilling records and chemical-quality data of wells in the Central Basin of Tennessee. Newcome and Smith (1962) reported on the water-bearing properties of the Upper Cambrian and Lower Ordovician Knox Dolomite, an extensive artesian aquifer in central Tennessee.

Between 1964 and 1971, a study of the water resources of the Upper Stones River basin by the U.S. Geological Survey in cooperation with the Tennessee Division of Water Resources produced two reports. The first, by Moore and others (1969), used the data from 587 wells in the upper Stones River basin to estimate the relative size, shape and extent of solution cavities within the limestones. A second report by Burchett and Moore (1971) describes the water resources of the upper Stones River basin and includes estimates of the specific amounts of water available from ground and surface sources.

C. W. Wilson, Tennessee Division of Geology, prepared a series of unpublished structural contour maps on the top of the Carters Limestone for central Tennessee on a 7½-minute quadrangle map base.

GENERAL FEATURES OF THE AREA

CLIMATE

The Murfreesboro area has a temperate climate, characterized by fairly short, mild winters with a few light snowfalls. Summers are generally hot and humid. Precipitation is fairly abundant, but unevenly distributed throughout the year (fig. 3).

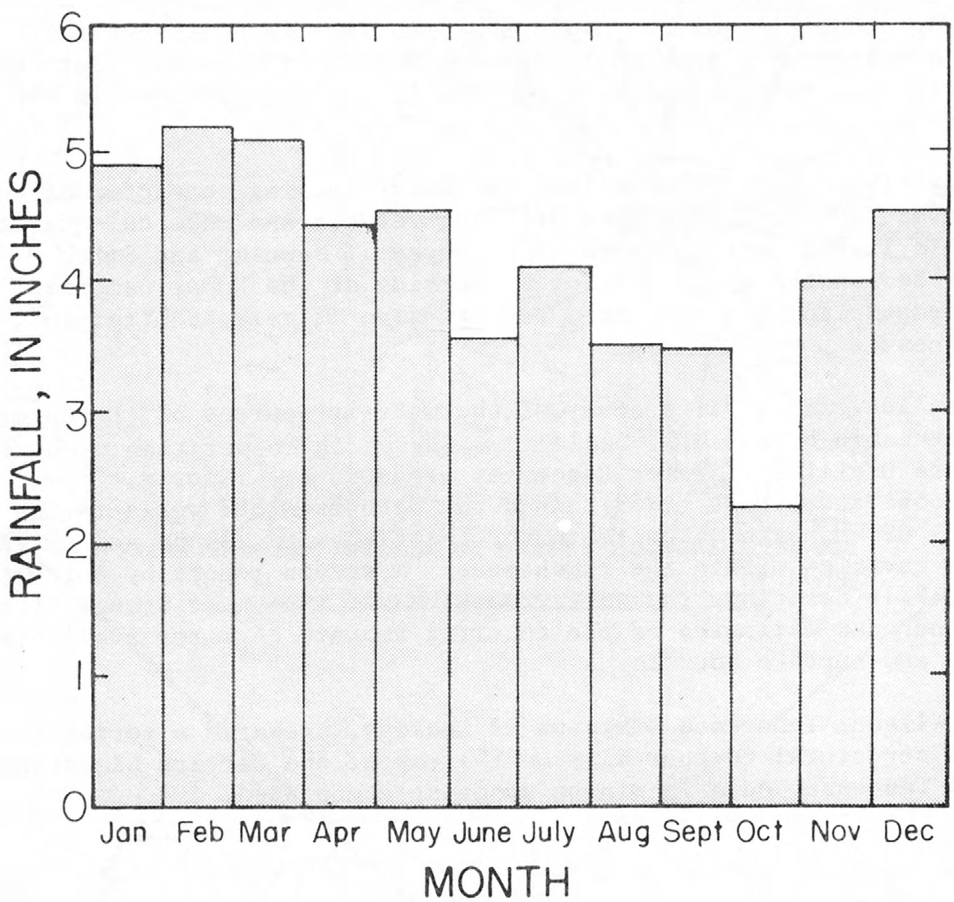


Figure 3.--Normal monthly rainfall at Murfreesboro.

The National Weather Service maintains temperature and precipitation gages at Murfreesboro. Daily highs, lows, and deviations from normal values are reported monthly and summarized annually. Based on the 1941-70 period of record, the mean annual temperature at Murfreesboro is 60.0°F. The mean monthly temperature ranges from a low of 40.1°F in January to a high of 78.9°F in July. Published records (U.S. Department of Commerce, 1973) show the normal annual precipitation at Murfreesboro to be 49.59 in. Monthly normals are shown graphically in figure 3. January, February, and March are generally the wettest months, and August through November are characteristically the driest months. Minimum precipitation occurs typically during October.

TOPOGRAPHY AND DRAINAGE

Murfreesboro lies near the center of the Central or Nashville Basin physiographic subdivision of Tennessee (fig. 4). The Central Basin is an oval-shaped, surface depression approximately 120 mi across in the north-south direction, and 60 mi across in the east-west direction. Land-surface elevations within the Central Basin are among the lowest in middle Tennessee, ranging from about 500 to around 850 ft above sea level.

Most of the Murfreesboro area is a gently rolling plain of low relief, interrupted in places by a scattering of rounded hills called knobs (fig. 5). The knobs have been interpreted (Galloway, 1919) as erosional remnants of the Highland Rim plateau which surrounds the Central Basin. The tops of the knobs have an average elevation of 850 ft above sea level and are the points of highest elevation in the area.

The topography of the Murfreesboro area is also characterized by numerous shallow depressions or sinkholes (fig. 6), formed by the dissolution of the limestone bedrock by circulating ground water. The sinkholes range in size from a fraction of an acre to several square miles (Moore and others, 1969). Although sinkholes are common throughout the area, they are most numerous in the eastern part where they occur at the base of a cluster of knobs.

The Murfreesboro area is drained by a network of streams which flow in a generally northerly direction (fig. 19). The East, Middle and West Forks of the Stones River and Stewart Creek are the major streams draining the area. The Middle Fork joins the West Fork a few miles upstream (southwest) from Murfreesboro. The West Fork, in turn, joins the East Fork about 10 mi downstream (northwest) from Murfreesboro near the small community of Old Jefferson. Stewart Creek flows into the Stones River a few miles downstream from the confluence of the East and West Forks. Numerous smaller tributaries feed each of the four major streams. The largest tributaries are Overall, Pucketts, and Lytle Creeks which join the West Fork, and Cripple and Bradley Creeks which join the East Fork. Overland runoff is generally greatest during the wettest months, January through March (fig. 3).

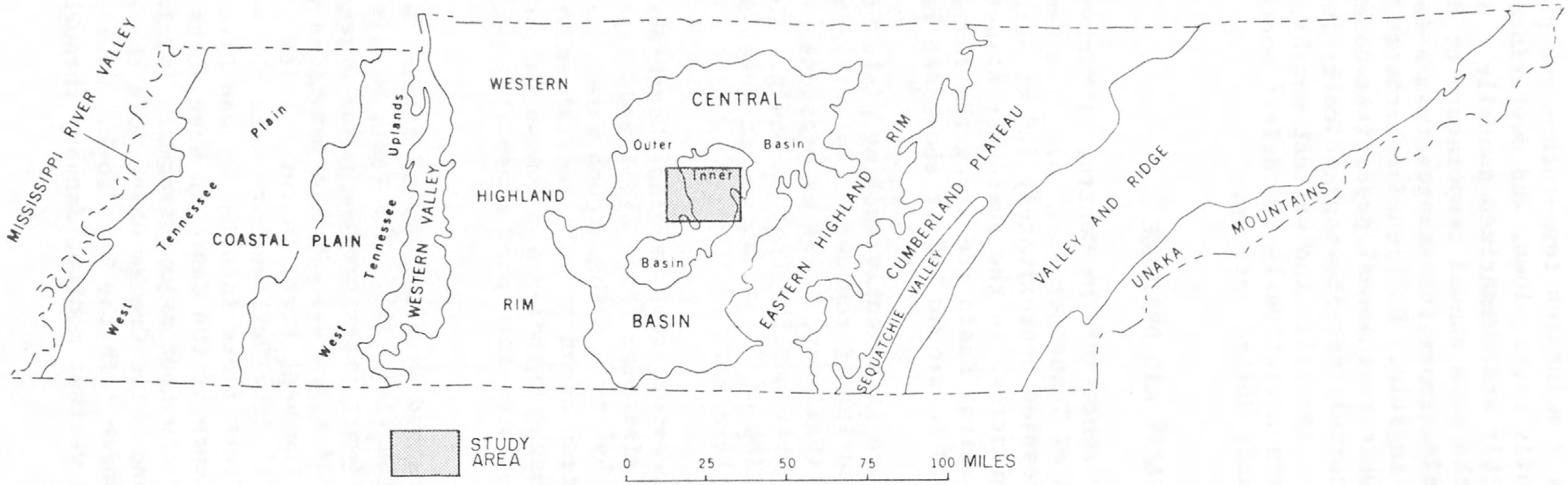


Figure 4. --Generalized physiographic map of Tennessee (from Miller, 1974, p. 2).

A

B

Figure 5. --Elevated land areas near Murfreesboro, Tenn., A, Grassy knob; B, Undulating land surface of rounded knobs.

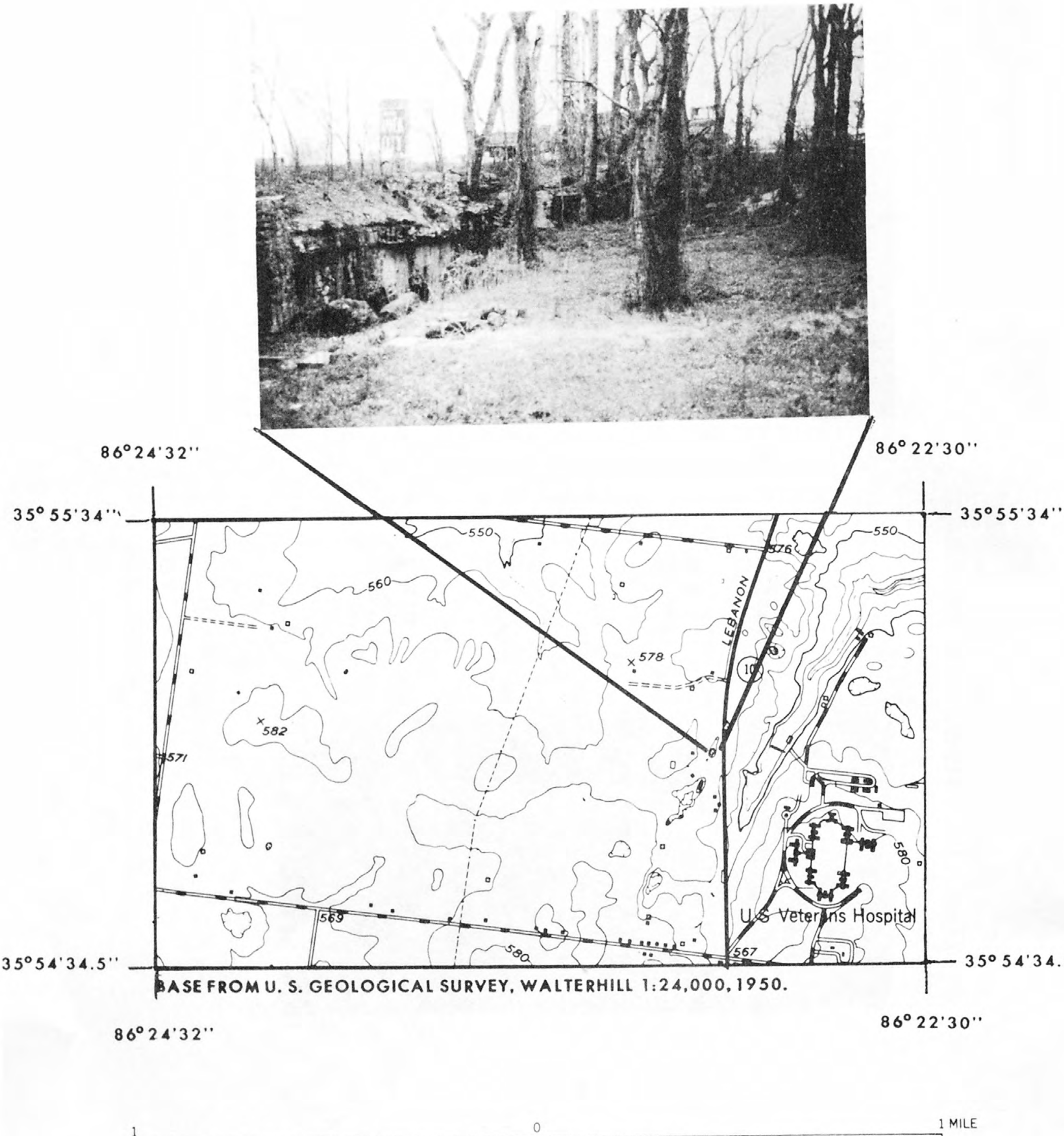


Figure 6. --Sinkhole north of Murfreesboro. Map contour interval is 10 feet, datum is mean sea level.

GEOLOGY

Rock formations underlying the Murfreesboro area are composed chiefly of limestone of Ordovician age. They are generally flat lying, but may be locally flexed into gently undulating folds. The composition of the limestone formations ranges from 75 to 98 percent soluble carbonate material (Moore and others, 1969, p. 11). Noncarbonate material is scattered throughout the rocks but is concentrated mainly in thin layers of limey shale or shaly limestone interbedded with relatively pure limestone.

Owing to the low concentrations of insoluble material within the limestones, only small amounts of residual soil material accumulate on the land surface from weathering. Thus, soil development is minimal; the average thickness is about 4 ft. At some localities, soil develops only within vertical cracks or joints in the limestone bedrock (Moore and Wilson, 1972). In these areas, bare rock is exposed between the joints, resulting in surface features called "glades" (fig. 7).

Figure 7. --A limestone glade near Leanna, with soil and grass occurring only in joints between blocks of limestone.

Thickness of individual limestone beds ranges from 2 in to 6 ft. Shale layers or partings are generally on the order of a few inches thick. The total thicknesses of the limestone formations in the Central Basin is about 5000 ft (Burchett and Moore, 1971). Vertical joints crisscross the formations, striking northeast and northwest (Moore and others, 1969). Water moving through these joints dissolves and erodes the wall rock. This widens and enlarges the openings creating sizeable solution cavities. In general, solution openings are largest in the more massively bedded formations, but more numerous in the thinly bedded formations.

Rock Units

The rock units underlying the Murfreesboro area are divided into two groups and a formation, the Stones River Group, the overlying Nashville Group and Leipers Limestone (table 1). The Stones River Group is characterized by massively bedded, relatively pure limestones alternating with thinly bedded shaly facies. The Nashville Group and Leipers Formation are similar, but contain phosphatic beds of differing grades of purity.

Several formations are exposed at land surface in the Murfreesboro area as shown in figure 8. The Ridley Limestone has the greatest areal extent of outcrop. The Lebanon Limestone occurs somewhat less extensively; however, good exposures are to be found in most parts of the area. The Carters Limestone and Younger Formations are undifferentiated on the map owing to the limited size of their combined area of outcrop. Exposures of these relatively younger formations are restricted to the higher elevations surrounding Murfreesboro.

Exposures of the rather shaly Pierce Limestone and underlying Murfreesboro Limestone, which are shown as a single unit in figure 8, occur in entrenched stream valleys. Areas of outcrop are limited to the Walterhill and Murfreesboro quadrangles. Outcrops of these rock units are elongated in the northeast and northwest directions approximately parallel to surface jointing features.

Structure

The relationship between geologic structure and the land surface is shown in figure 9, a geologic cross section from southwest to northeast through Murfreesboro. The line of section, A-A', is shown in figure 8. As shown on the cross section, Murfreesboro is situated near the axis of a regional anticline (Nashville Dome), which underlies the Central Basin. Smaller scale anticlines are superimposed upon this broad structure.

A contour map of the contact between the Ridley and Pierce Limestones is shown in figure 10. The map was compiled from well-log data and from extrapolation of existing unpublished contour maps of the top of the Carters Limestone, prepared by C. W. Wilson of the Tennessee Department of Conservation, Division of Geology.

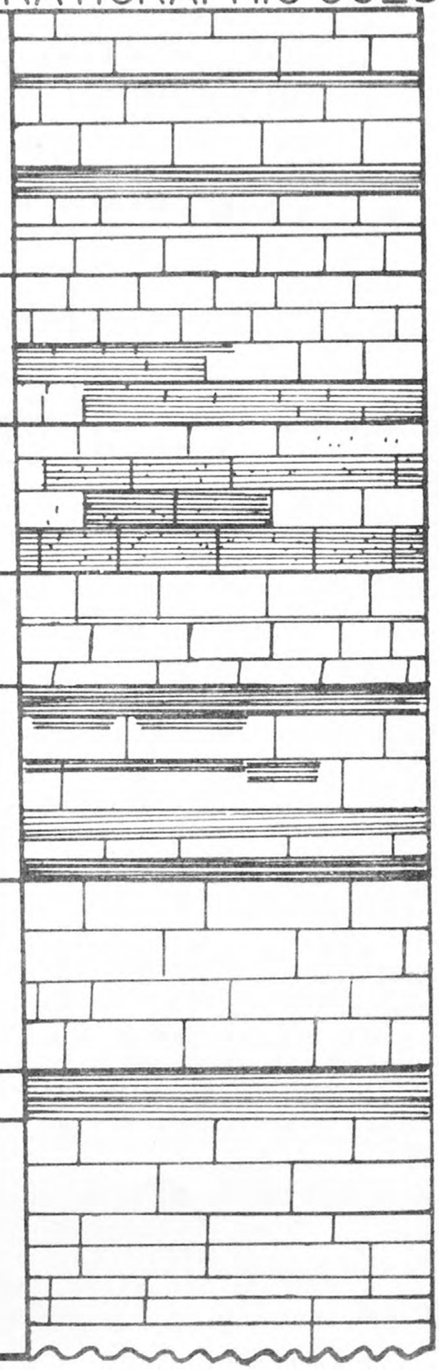
The shape of the contours reflects the configuration of the rock units. The closed contours identify the position of either structural highs or lows in the same manner that topographic contours depict highs and lows on the land surface. The lows are distinguished in figure 10 by hachure marks placed on the low side of the closed contours.

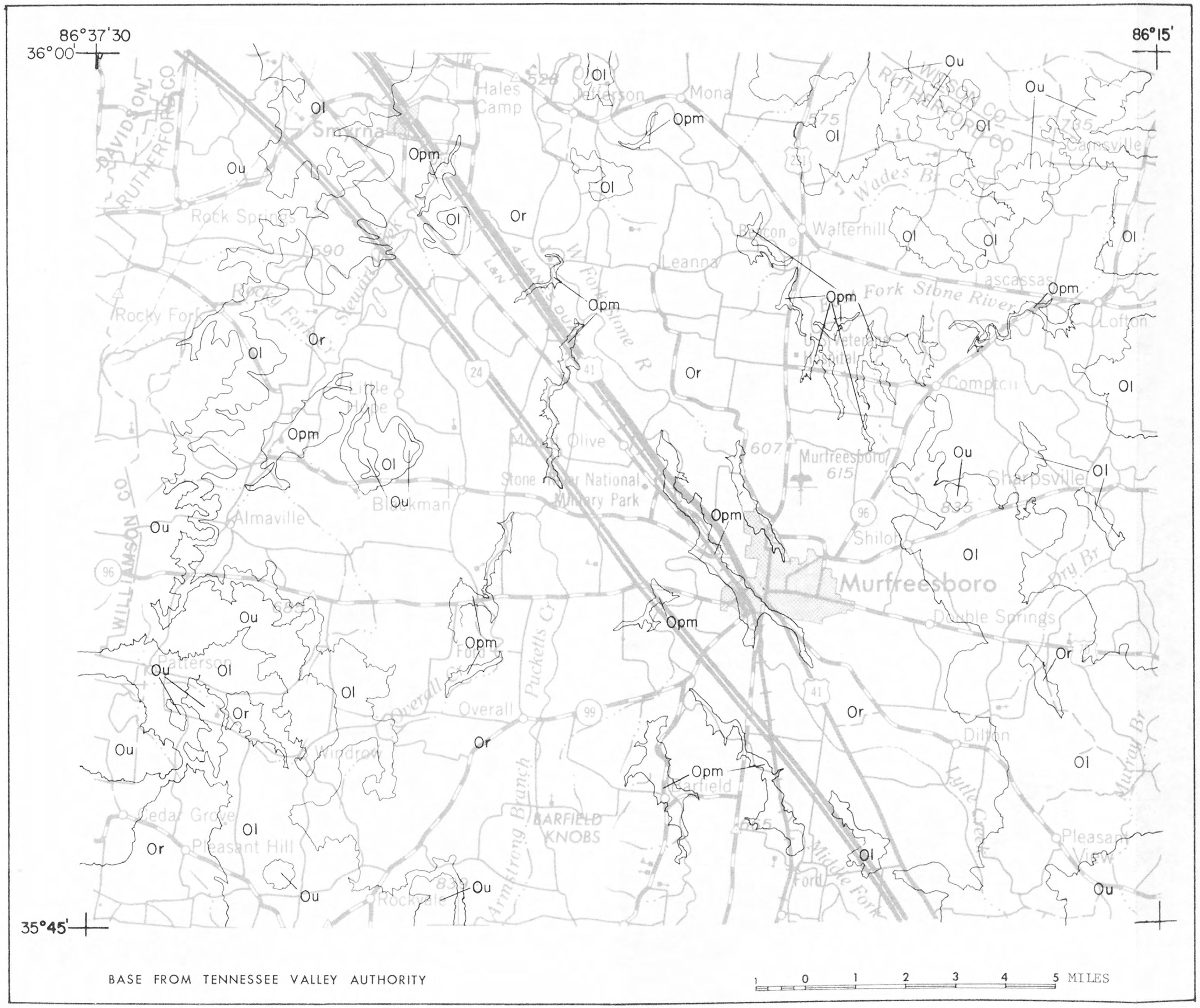
Table 1.--Generalized geologic and hydrologic characteristics

AGE		NAME	GEOLOGY
ORDOVICIAN		LEIPERS LIMESTONE	
ORDOVICIAN	NASHVILLE GROUP	CATHEYS FORMATION	Bluish, knotty, locally phosphatic limestones. Outcrops restricted to the margins of the Central Basin. A maximum thickness of 75 feet occurs along the rim of the basin, thinning toward the interior.
ORDOVICIAN	NASHVILLE GROUP	BIGBY-CANNON LIMESTONE	An impure, sandy limestone containing an important phosphate facies. Also present is about 40 feet of a purer, light gray, massive facies. Total thickness varies from 60 to 100 feet.
ORDOVICIAN	NASHVILLE GROUP	HERMITAGE FORMATION	A dark, shaly, phosphatic, thinly bedded limestone. Thickness ranges from 60 to 100 feet in the Central Basin.
ORDOVICIAN	STONES RIVER GROUP	CARTERS LIMESTONE	Light-brown, massive, pure limestone containing four thin beds of bentonite (altered volcanic ash). Total thickness is approximately 65 feet.
ORDOVICIAN	STONES RIVER GROUP	LEBANON LIMESTONE	A thinly-bedded limestone which crops out in association with the Ridley. The small quantities of impurities present are concentrated in shaly partings. The Lebanon supports the growth of cedar trees. Total thickness is about 115 feet.
ORDOVICIAN	STONES RIVER GROUP	RIDLEY LIMESTONE	Massively bedded, pure limestone. The Ridley is the most widely outcropping formation in the Central Basin. Averages 100 feet in thickness.
ORDOVICIAN	STONES RIVER GROUP	PIERCE LIMESTONE	A thinly bedded, shaly limestone. Total thickness is about 25 feet.
ORDOVICIAN	STONES RIVER GROUP	MURFREESBORO LIMESTONE	Massive, dense, dark blue to bluish-gray, pure limestone. It is exposed where erosion has removed the overlying rocks in valley area. Total thickness approximates 420 feet; however, only the upper few tens of feet are exposed.

of bedrock formations in the Murfreesboro area.

HYDROLOGY	STRATIGRAPHIC COLUMN
Large solution openings do not develop within the Leipers and Catheys Formations. Yields greater than 25 gallons per minute are unusual.	
Small solution openings and yields less than 25 gallons per minute are characteristic of the Bigby facies. Large solution openings occur within the Cannon; yields can be as much as 100 gallons per minute.	
Water-bearing characteristics of the Hermitage are similar to those of the Leipers and Catheys Formations. Shaly partings impede the downward movement of water.	
Large solution openings develop within the Carters Limestone, especially if the T-3 bentonite is weathered. Yields of more than 100 gallons per minute can be expected.	
Thin bedding and shale partings restrict the circulation of groundwater and development of large solution openings. Yields of more than 25 gallons per minute are uncommon.	
Massive bedding of this formation allows large solution openings to develop and remain open. Yields of over 100 gallons per minute can be obtained.	
Water-bearing zones occur either above or below the relatively insoluble Pierce Limestone.	
Solution openings capable of yielding in excess of 100 gallons per minute. These openings occur between shaly zones within the limestone.	

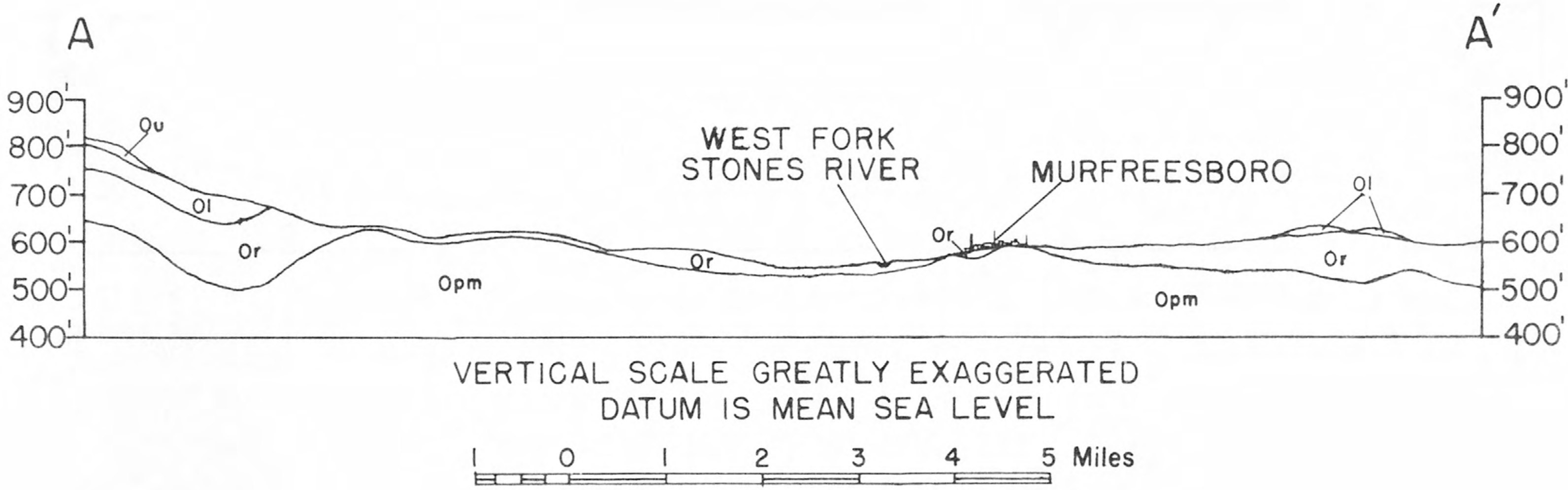




EXPLANATION

Ou	Leipers, Catheys, Bigby, Cannon, Hermitage and Carters Formations Undifferentiated
Ol	Lebanon Limestone
Or	Ridley Limestone
Opm	Pierce and Murfreesboro Limestones,

Figure 8. - Geologic map of the Murfreesboro area.



EXPLANATION

Ou	Leipers, Catheys, Bigby, Cannon, Hermitage, and Carters Formations, undifferentiated
Or	Ridley Limestone
Ol	Lebanon Limestone
Opm	Pierce and Murfreesboro Limestones, undifferentiated

Figure 9. --Geologic cross-section along line A-A' in figure 7.

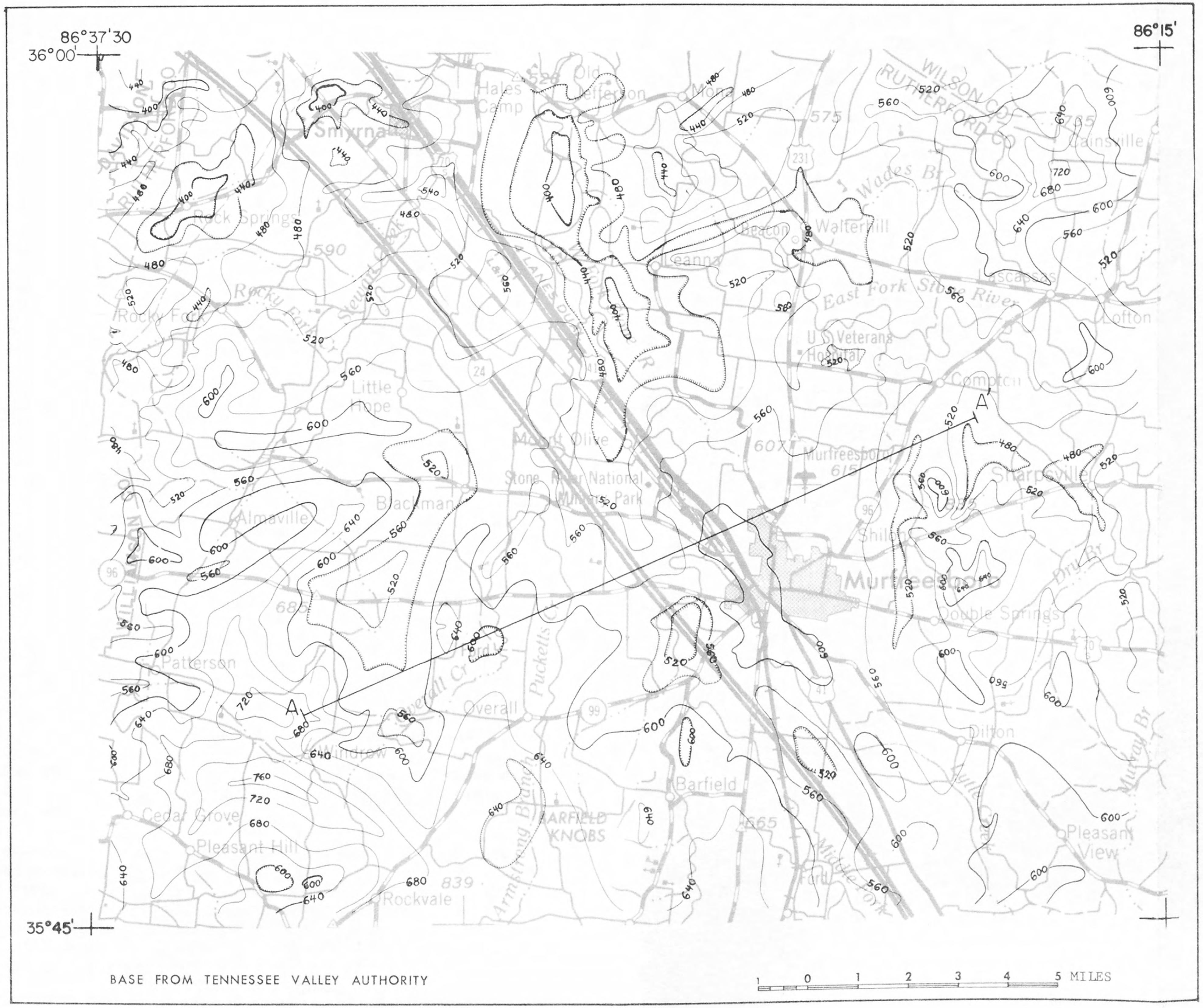


Figure 10.- Geologic structure contour map showing configuration of the contact between the Ridley and Pierce Limestones. Contour interval is 40 feet.

HYDROLOGY

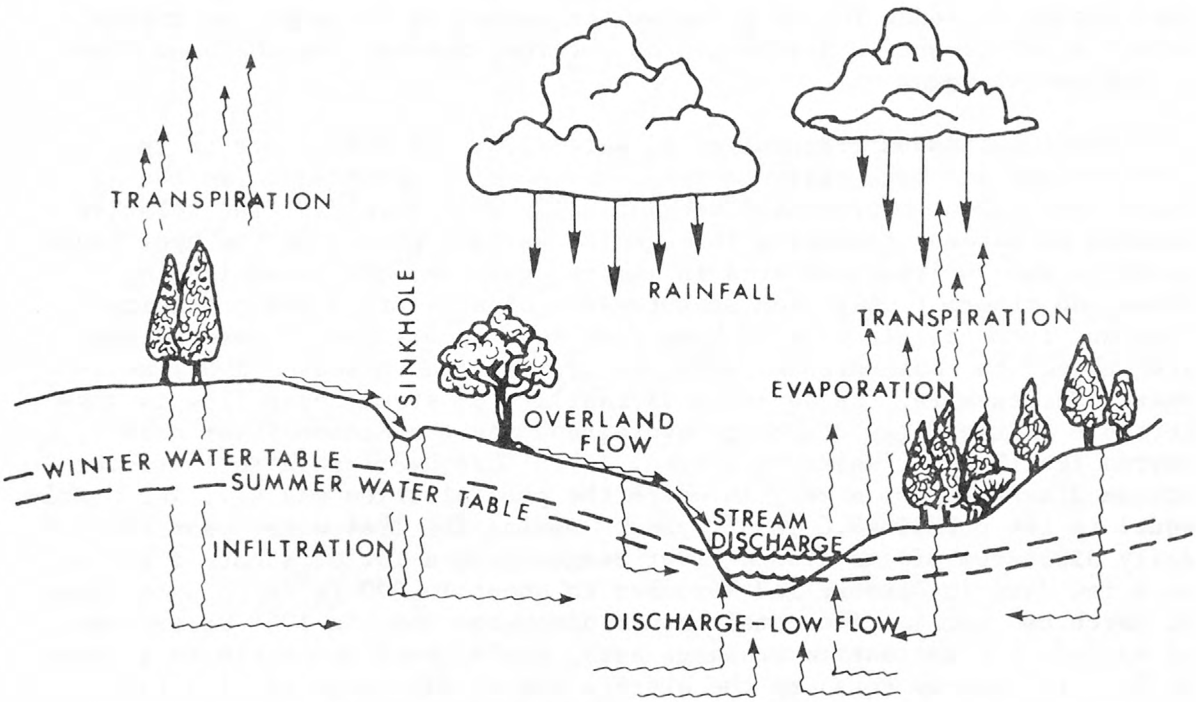
The Murfreesboro area derives its natural water supply entirely from precipitation. Rain falling on the land surface either runs off into surface streams, infiltrates the soil, or evaporates back into the atmosphere. The water that infiltrates the soil is either retained by the soil and subsequently returned to the atmosphere by the transpiration of plants or migrates downward under the force of gravity through the soil and weathered rock to recharge the ground-water system. Whatever amount is added to the ground-water system as recharge, an approximately equal amount is discharged as outflow, maintaining the base flow of surface streams.

This continuous circulation of water from the atmosphere to the land surface and back again to the atmosphere is referred to as the hydrologic cycle, represented schematically in figure 11. The relative amounts of water circulating through the various phases of the hydrologic cycle in the Murfreesboro area in an average year were determined by Moore and others (1969) from measurements of streamflow and precipitation and from calculations of base flow and evaporation. These amounts are subject to considerable variation from season to season and year to year. For example, the seasonal variability of stream base flow is discernible in the daily discharge hydrograph for the Stones River near Smyrna for the 1964 water year (fig. 12). This hydrograph reflects the stream discharge for a year in which the precipitation was 47.1 in, nearly equal to the normal 49.6 in per year. During the 1964 water year the daily discharge of the Stones River ranged from a low of about 15 ft^3/s on a few days in October and November to about 15,000 ft^3/s on a few days in March and April. The total annual discharge for the 1964 water year, if spread over the entire drainage area, would cover the basin to a depth of 20.3 in, nearly equal to the average annual discharge of 21.3 in.

The seasonal variability of water circulating through the ground-water phase of the hydrologic cycle is indicated on the hydrograph (fig. 12) by the dashed line representing estimated base flow of the Stones River. Although the method used to estimate base flow (Moore and others, 1969, p. 22) yields a conservative value for ground-water outflow, the base-flow hydrograph is a valid representation of the seasonal variation in the amount of recharge to and discharge from the ground-water system. As evidenced by the base-flow curve (fig. 12), maximum recharge and discharge occurs during the winter and early spring (January-April) when losses by evaporation and transpiration are least. Conversely, minimum ground water recharge and discharge occur during late summer and early fall (August-October) when evapotranspiration rates are greatest.

Rates of evaporation and transpiration are affected by temperature, humidity, amount and kinds of vegetation, wind velocities, hours of sunshine, and several minor environmental factors (Burchett and Moore, 1971). In general, evapotranspiration is at a maximum during the hot summer months and a minimum during the cool winter months. According to Burchett and Moore (1971, p. 12) about 85 percent of the evapotranspiration losses occur from April through September.

In an average year in the Murfreesboro area, nearly 60 percent of the water from precipitation is returned to the atmosphere by evaporation and transpiration. The remaining 40-plus percent is theoretically available for man's use if adequate storage facilities are provided. Without storage facilities, the supply available is limited to about 10 to 15 percent of the total precipitation, or about 4 to 8 in/yr. This is roughly equivalent to ¼ to ½ (Mgal/d)/mi^2.



Stones River Basin 1964 Water Budget

	Inches (rounded)	Percent of Total
Rainfall at Murfreesboro ---------------	47	100
Stream Discharge-----------------------	20	43
Ground-water outflow---------------	6	13
Overland flow----------------------	14	30
Evaporation and transpiration-----------	27	57

Figure 11. --Water budget for the Murfreesboro area. (From Burchett and Moore, 1971, p. 11).

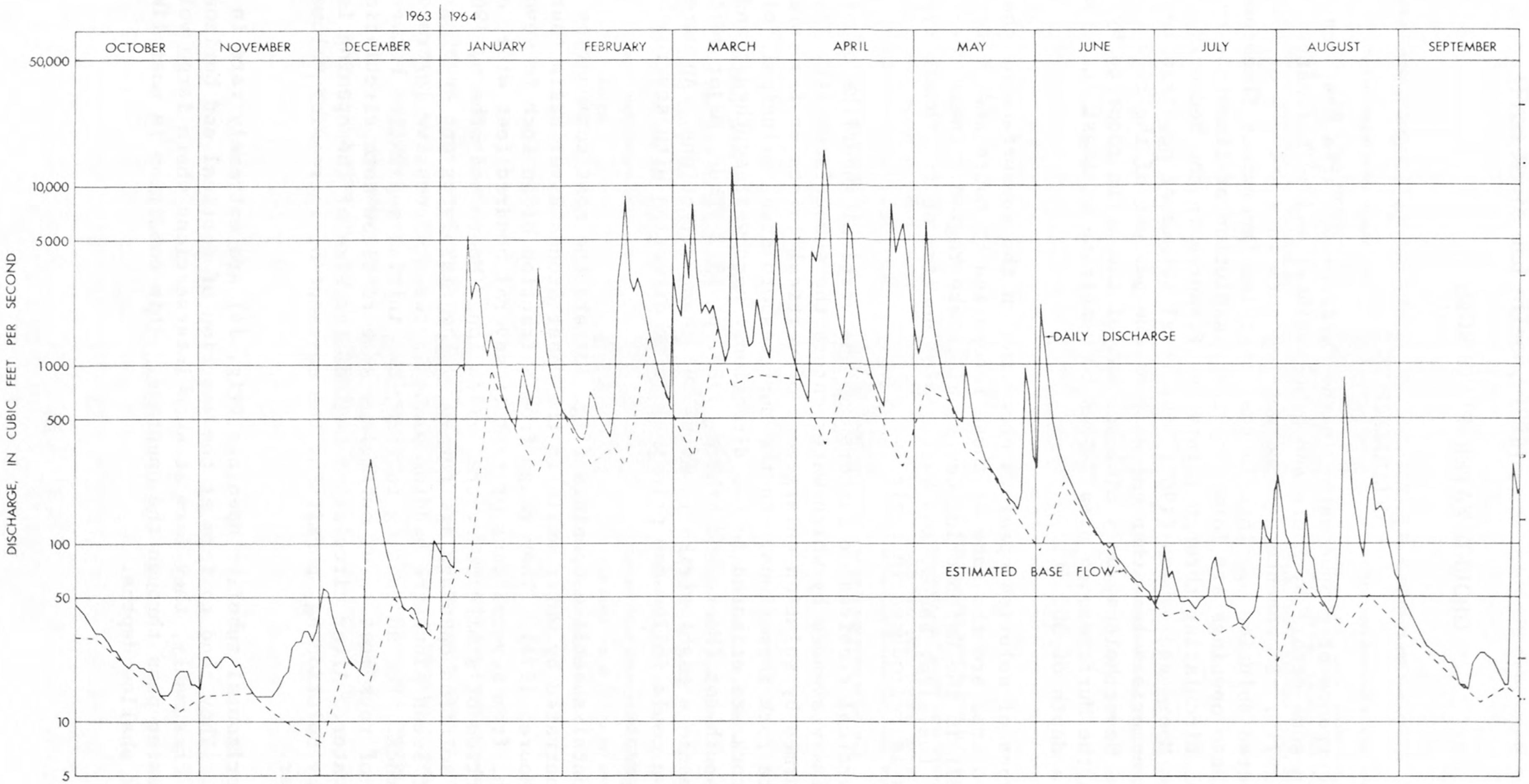


Figure 12. --Hydrograph of Stones River near Smyrna for the 1964 Water Year. (From Moore, Burchett, and Bingham, 1969).

GROUND WATER RESOURCES

OCCURRENCE

The occurrence of ground water in the Murfreesboro area has been described in some detail by Moore and others (1969) and by Burchett and Moore (1971). In essence, ground water occurs in a network of inter-connected solution openings in the otherwise impervious limestone bedrock. These openings are formed by the dissolution of limestone by ground water circulating through joints and fissures in the bedrock. According to Moore and others (1969), the total volume of openings in the bedrock comprises less than one-half of one percent of the rock formations. Nevertheless, only nine percent of the wells reported by drillers in the Murfreesboro area failed to penetrate at least one opening within a depth of 300 ft.

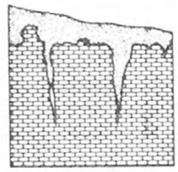
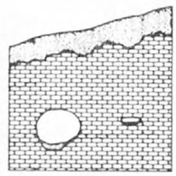
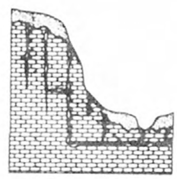
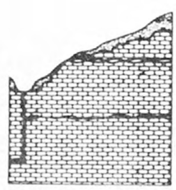
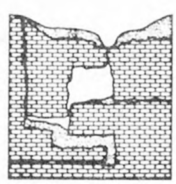
The types of solution openings occurring in the subsurface of the Murfreesboro area are the same as those recognized by Moore and Wilson (1972, p. 37) in the neighboring Center Hill Lake region. Their description of the size, shape, and hydrologic function of five basic types of openings is reproduced in table 2.

The vertical crevices or cutters and the vertical sheetlike openings are the primary avenues by which water enters the subsurface (fig. 13). They are formed by solution enlargement of vertical joints or fractures in carbonate rock formations. In the Murfreesboro area, principal joints in the bedrock are oriented in two directions: northwest-southeast and northeast-southwest (Moore and others, 1969, p. 15). Thus, major vertical solution openings might strike in either of these directions. An extensive opening could follow one principal joint direction with several offsetting segments.

Horizontal sheetlike openings (fig. 13) are the most common type of opening penetrated by water wells in the Upper Stones River basin (Burchett and Moore, 1971). They range from a fraction of an inch to several inches high, from several tens of feet to several hundred feet wide, and from a fraction of a mile to several miles long (Moore and others, 1969). Horizontal solution openings are formed by the dissolving action of ground water as it seeps along the bedding planes between successive layers of carbonate rock. For an opening to form, the initial separation between the layers of rock must be of sufficient size to allow some circulation of ground water. After circulation begins, the size of the opening is increased by solutioning, permitting the movement of increasing volumes of ground water.

The horizontal tubelike openings (fig. 14) are extremely rare in the subsurface. They tend to form at the junction of vertical and horizontal openings. Presumably, they form at such intersections where large volumes of ground water pass through the openings. This condition is most likely to occur at shallow depths.

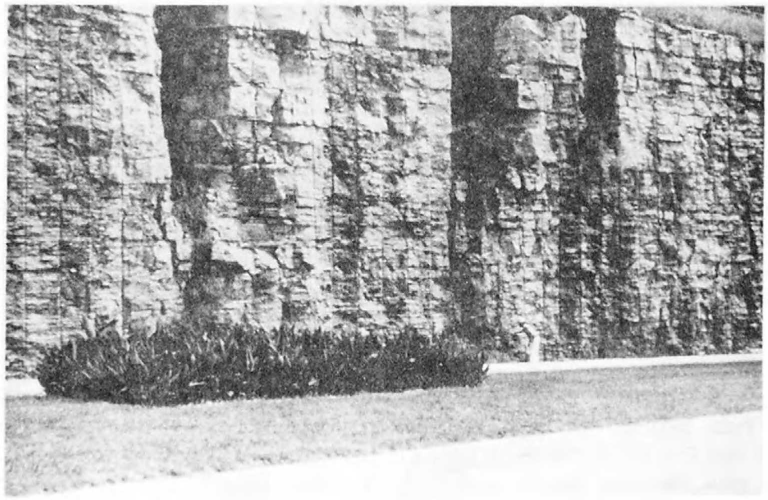
Table 2.--Five types of solution openings occurring in the study area (From Moore and Wilson, 1972)

Type of opening	Nature of opening		Water occurrence and movement
Crevice	Vertical. Several inches to several feet wide at top of rock, pinching out with depth; five to 1000 feet long; ten to 50 feet deep. Commonly filled with silt and clay.		Water percolates downward to water table, than horizontally along crevice. Usually water moves into another type of opening, then discharges into streams. Water occurrence usually not perennial.
Tubelike	Horizontal. Several inches to 20 feet in diameter; several feet to several hundred feet long; usually partly filled with rubble, silt, and clay.		Discharges water to springs above level of streams. Usually contains water only during wet periods. Movement of water turbulent; water commonly muddy.
Sheetlike	Vertical. Less than half an inch to several inches wide; several tens to several hundred feet long; ten to 300 feet deep. Commonly connected. Partly filled with silt and clay.		Feeds recharge water to other types of openings, and discharges most ground water into streams. Prominent near steep hillsides, where ground water moves down to below valley level. Water occurrence perennial only below stream level.
	Horizontal. Several tens of feet to 1000 feet wide interrupted by rock pillars; several hundred feet to several miles long; less than half an inch to 12 inches high. Contains small amount of silt and clay.		Receives recharge from crevices or vertical sheet openings. Water discharges to stream above through vertical sheet opening. In some cases, water discharges to springs near valley floor or to complex openings below stream channels. Water always perennial below level of streams and sometimes perennial above level of streams.
Complex	A combination of two or more types of openings. Common in some areas on hillsides and in valleys beneath or near stream channels. Usually connected with other openings. Always partly filled with rubble, gravel, sand, silt, and clay.		Receives water from streams in losing reaches and discharges water to streams in gaining reaches. Usually dry on hillsides but perennially full of water below stream level. Water movement turbulent.

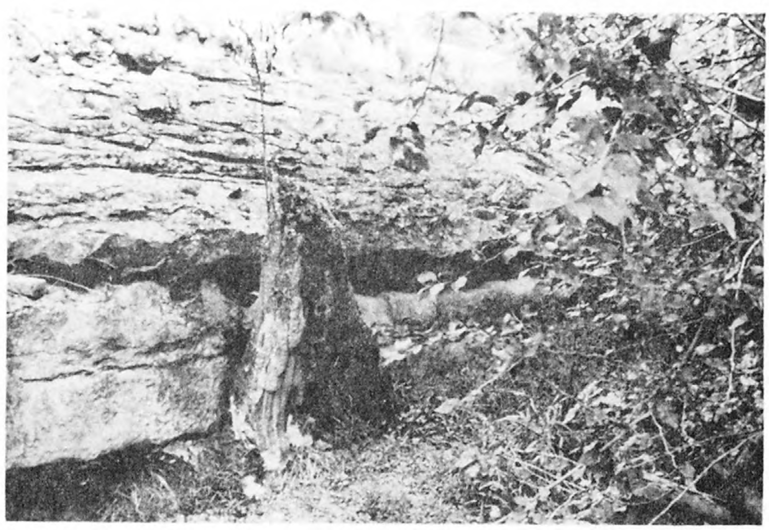
EXPLANATION

Limestone

Mixed gravel, sand, silt, and clay

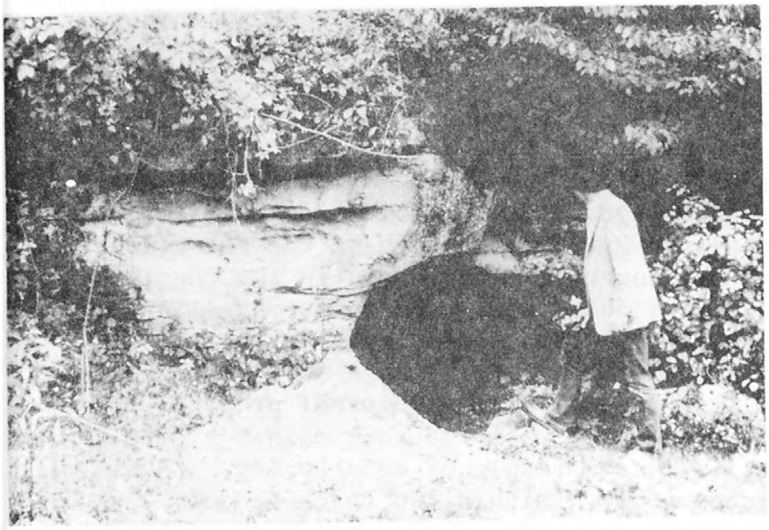


A

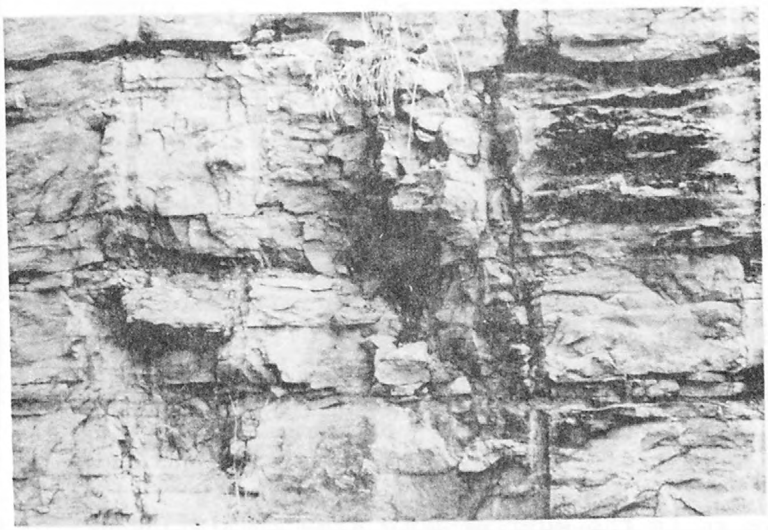


B

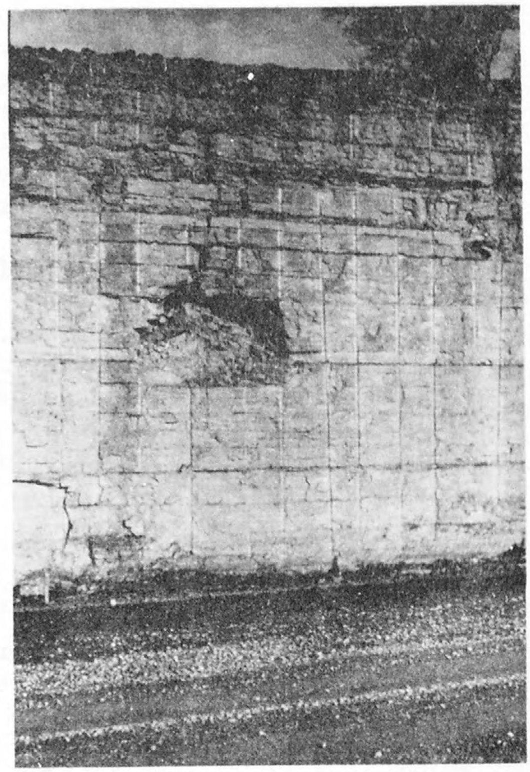
Figure 13. --Solution openings in limestone, A, Cutters developed by dissolution of limestone bedrock along vertical joints; B, Horizontal opening developed by dissolution along bedding plane in limestone bedrock.



A



B



C

Figure 14. --Horizontal tubelike openings in limestone bedrock in central Tennessee, A, Northern Lincoln County; B and C, Briley Parkway at Opryland, Davidson County.

The complex openings are the major arteries of the underground drainage system. They are formed by the combination of two or more of the other types of openings. These openings are most likely to occur near major points of ground water discharge such as large springs. They are generally large and have the capacity to transmit sizeable quantities of ground water.

As mentioned previously, the occurrence of solution openings does not appear to be restricted to any particular geologic formation in the Murfreesboro area. Openings have been penetrated by wells in each of the formations listed in table 1. In all probability, however, differences in the chemical and physical properties of the formations do give rise to differences in the number and size of openings occurring in each of the rock units. Theoretically, the greater the purity of the limestone, the more susceptible it should be to dissolution by circulating ground water. Physical properties such as bed thickness and strength or competency of the rock masses probably determine the size of openings that form as a result of solutioning. Thus, the largest openings might be expected to form within the thick-bedded, relatively massive limestone formations such as the Ridley and Murfreesboro.

As indicated in table 2, each of the five types of openings occur in a wide range of sizes. They are most abundant at depths of less than 50 ft and decrease in size and number with increasing depth. Although the horizontal sheetlike openings are the most common type penetrated by water wells, all five types play an important role in the movement of ground water in the Murfreesboro area.

MOVEMENT

Ground water moves under the influence of gravity from areas where it enters the subsurface as recharge towards points or areas where it reemerges at the land surface as discharge. As ground water moves through the subsurface it must follow the intricate network of passageways provided by the solution openings (fig. 15). The horizontal openings allow ground water to move laterally from place to place; vertical openings permit ground water to move up or down from one horizontal opening to another. In this way, ground water moves continuously through an underground drainage system from points of entry into the sub-surface to points of emergence on the land.

The underground drainage system in the Murfreesboro area is similar in many respects to the surface drainage system. Both systems have major arteries or channels fed by tributaries. Catchment or drainage areas contribute flow at any given point in either system. Surface catchment areas are determined by the configuration or topography of the land surface. In the underground system, however, the catchment areas are determined presumably by the configuration of the bedding plane surfaces along which the major solution openings occur. If such a control is operational, the locations of underground "valleys" or synclines and "divides" or anticlines can be inferred from a geologic structure map such as figure 9. Thus, the approximate location of the major arteries of the underground drainage system in the

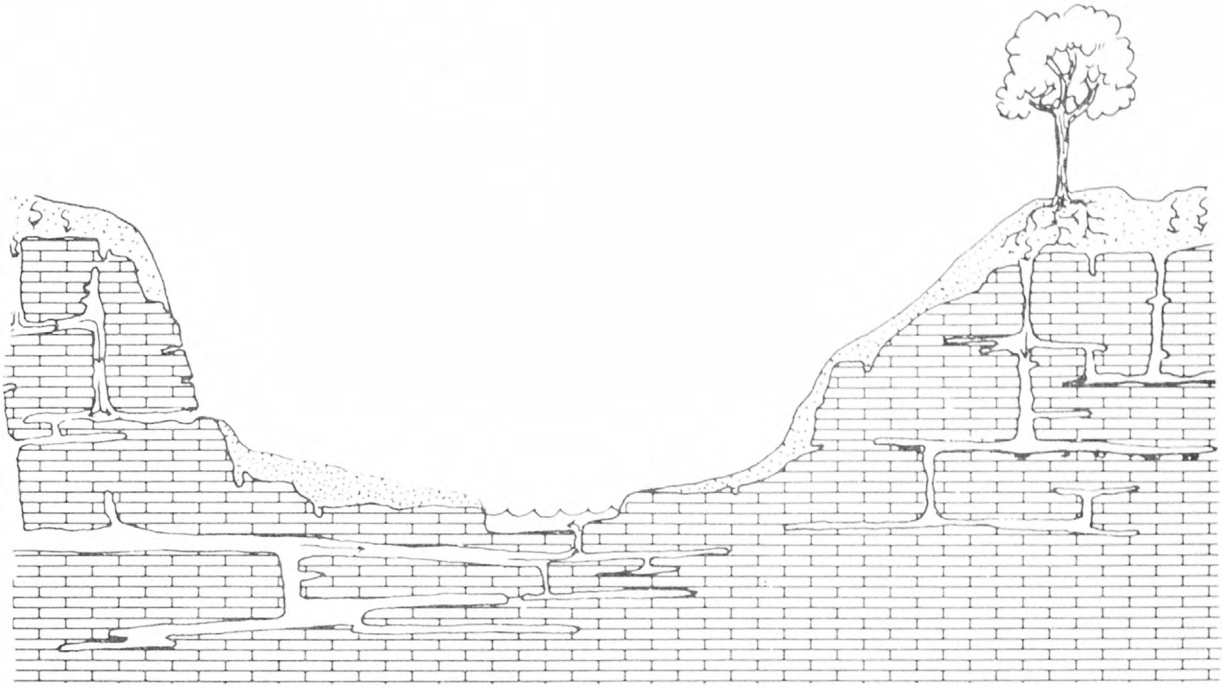


Figure 15. --Schematic diagram showing the movement of ground water through interconnected solution openings in limestone (After Zurawski, 1978)

Murfreesboro area as inferred from the geologic structure map (fig. 9) is shown on figure 16.

The force that drives ground water through the underground drainage system is the hydraulic head exerted by water in the solution opening network above the level of points of discharge from the system. Rates of ground-water discharge increase during periods of rainfall and decrease during periods of no rainfall. During periods of rainfall, ground water is added to the solution opening network, thus filling additional openings. This raises the level of saturation and increases the hydraulic gradient. Discharge of ground water from the system during periods of no rainfall lowers the level of saturation and decreases the gradient toward the point of discharge. These changes in gradient give rise to corresponding changes in the rate of outflow from the ground-water system.

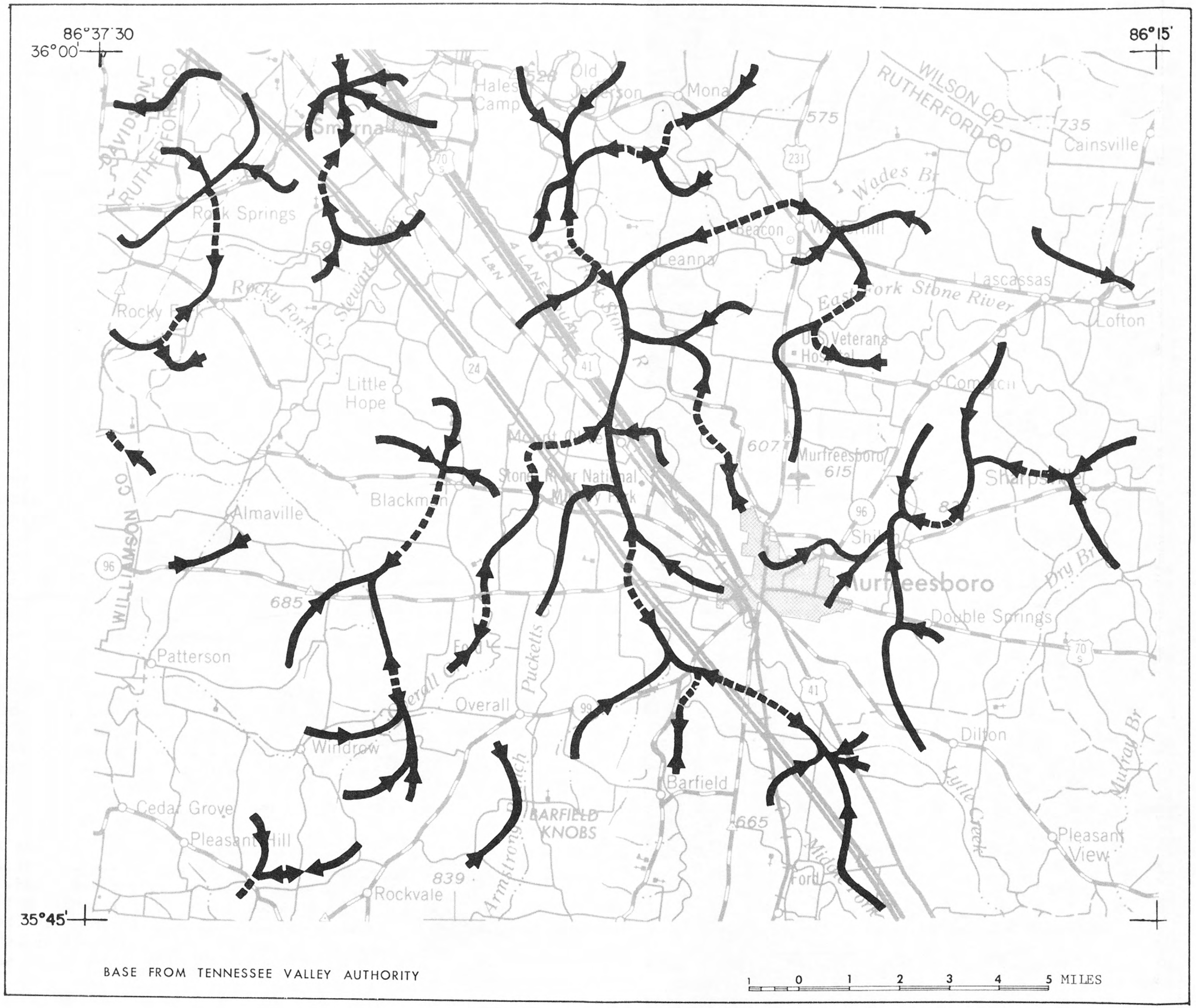


Figure 16. - Inferred locations of major arteries of the underground drainage system in the Murfreesboro area, Tennessee. Solid arrows indicate direction of dip of bedding planes, dashed arrows show inferred structural saddles.

RECHARGE AND DISCHARGE

The amount of ground-water recharge and discharge can be approximately determined from streamflow records by separating the stream hydrograph into base flow and overland flow components (Moore and others, 1969, p. 22). Using the streamflow records from the gaging station on the Stones River near Smyrna, downstream from the Murfreesboro area, Burchett and Moore (1971, p. 18) calculated the average monthly ground-water recharge and discharge in the upper Stones River basin for the period 1959 through 1965 (fig. 17). The monthly values indicate that the largest volume of ground-water recharge and discharge occurs during March, and the least occurs in September. The total quantity of ground-water recharge and discharge in an average year is 6.35 in. This is equivalent to about 200 (gal/min)/mi^2 of catchment area.

This quantity of ground-water recharge and discharge is about twice the rate of pumping that was required to dewater Stoneman quarry on the northwest side of Murfreesboro (fig. 18). Situated near the axis of a sizeable syncline, the quarry apparently intercepts a large part of the flow in a major artery of the underground drainage system. During the active life of the quarry, a pumping rate of slightly more than 4000 gal/min was required to dewater the quarry. The catchment area as determined from the geologic structure map (fig. 9) is about 40 mi^2.

Recharge to and discharge from the ground-water system also can be determined from seepage investigations of surface streams. During a seepage investigation, streamflow, as well as other variables such as ambient water temperature and pH, is measured at closely-spaced intervals along a stream to identify gaining and losing reaches. Theoretically, streamflow should gradually increase in a downstream direction. A gaining reach is one receiving ground-water discharge. A losing reach is one in which surface flow is being diverted to the ground-water system. The flow exchange between the surface- and ground-water systems occurs through the banks and bed of a stream.

Gaining and losing reaches identified by seepage studies in the Murfreesboro area are shown on figure 19. Comparison of these reaches with the structural contour map (fig. 9) indicates that gaining reaches usually occur immediately downstream from synclinal axes. Conversely, losing reaches usually occur downstream from the axes of anticlines.

QUALITY OF GROUND WATER

The kinds and amounts of chemical substances dissolved in ground water are important in determining the uses to which the water can be put. Some constituents, when found in low concentrations in water, present no particular problem for either industrial or municipal use. At higher concentrations, however, allowable limits for dissolved material in drinking water may be exceeded or the water may otherwise be rendered unfit for certain types of use.

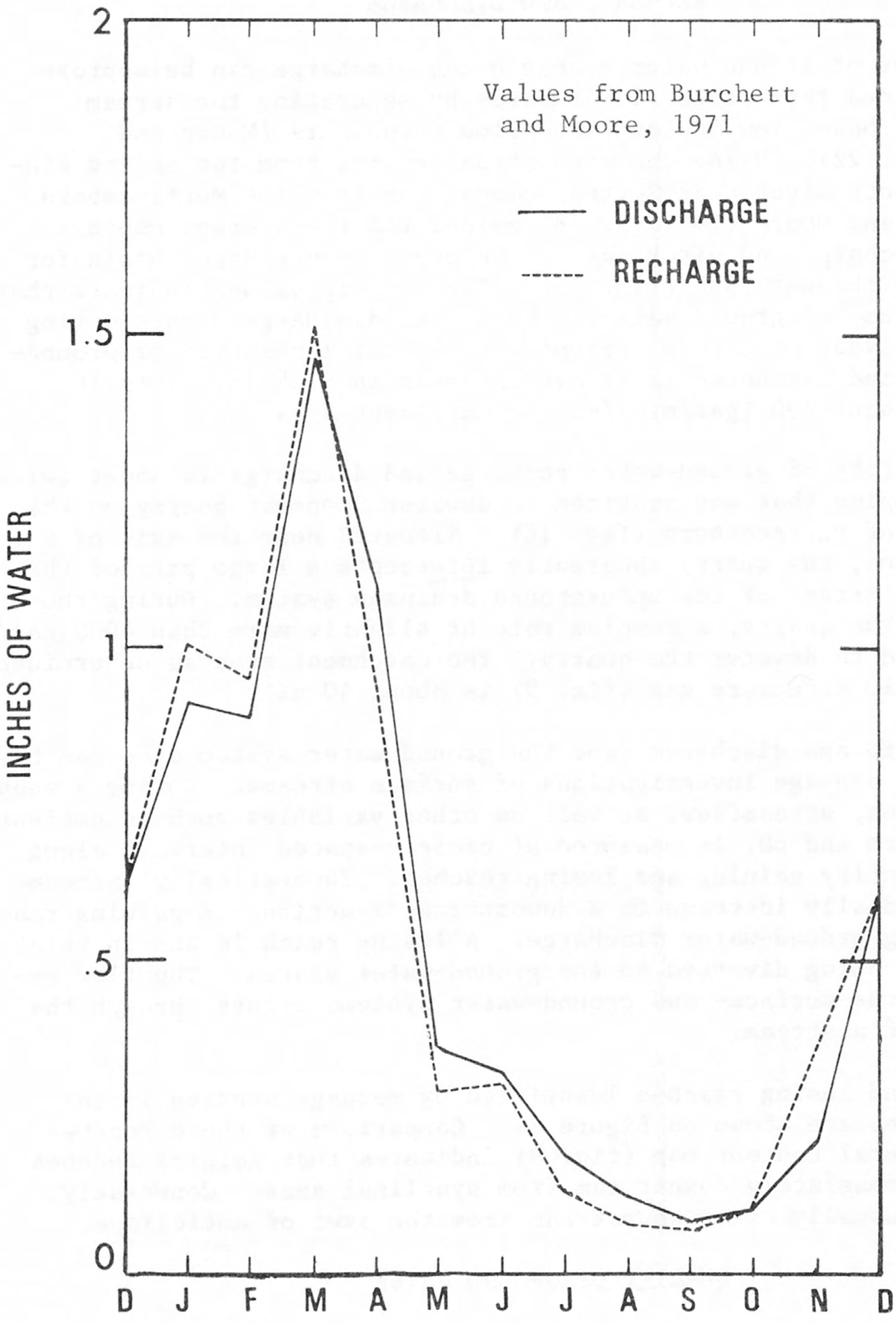


Figure 17. --Monthly average ground-water recharge and discharge from the solution opening network in the upper Stones River Basin, 1959-65.

A

B

Figure 18.--Stoneman quarry showing A, Discharge of 4100 gallons per minute from pump used to dewater the quarry; B, Inflow of ground water from a horizontal solution opening in the Ridley Limestone on west wall of the quarry. Discharge estimated at several hundred gallons per minute.

Samples of water from 23 wells and 15 springs in the Murfreesboro area were collected and analyzed. Fifteen of the well samples were collected from privately owned wells used as a source of domestic water supply. An additional eight samples were collected from test wells drilled by the U.S. Geological Survey. The 15 spring samples were collected from the largest and best known springs in the area.

Three distinct types of water were identified based on the dominant ions in solution as follows:

Water type	No. samples	Percent
Calcium bicarbonate	26	68
Calcium-magnesium bicarbonate	9	24
Sodium bicarbonate	3	8

The geographic distribution of the three types of ground water is shown in figure 20.

Results of the chemical analyses are summarized in table 3. These data show that the quality of ground water in the Murfreesboro area is typical of that usually found in areas underlain by carbonate rocks. In general, the water is very hard, moderately mineralized and moderately to highly alkaline. The water from wells is slightly more mineralized than that from springs.

In general, the chemical quality of ground water in the Murfreesboro area meets or exceeds the 1972 standards for drinking water supplies recommended by the Environmental Protection Agency (National Academy of Sciences and National Academy of Engineering, 1973). The exceptions are occurrences of undersirably high concentrations of iron, fluoride and hydrogen sulfide gas. Of the supplies sampled, fewer than 10 percent contained excessive concentrations of iron, about one-third contained excessive concentrations of fluoride and nearly one-half contained detectable odors of hydrogen sulfide.

The most critical feature of the quality of ground water in the Murfreesboro area with regard to its use as a source of water supply is the susceptibility of the shallowest aquifers to pollution from the land surface. A recent study of the bacteriological quality of private domestic well supplies in Rutherford County by Johnson (1970) showed that 86 percent of the 196 supplies sampled contained some form of bacteria. Furthermore, 53 percent of the supplies sampled were found to contain fecal coliform, an indicator of recent contamination of wastes from warm-blooded animals. Although Johnson (1970) did not indicate why so many of the supplies were found to be polluted, it probably can be attributed to the lack of sanitary conditions at the well head including the absence of sanitary well seals to prevent the entry of pollutants into the water-supply system.

EXPLANATION

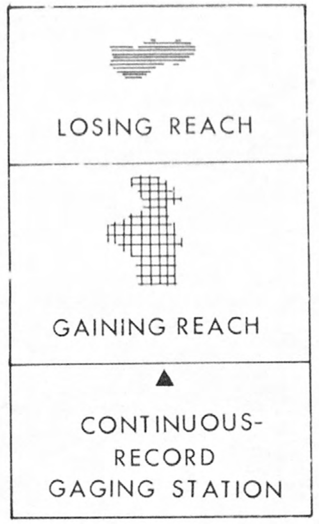


Figure 19.- Gaining and losing reaches as inferred from seepage studies made on the West and East Forks, Stones River, June 24-25, and July 23-24, 1974.

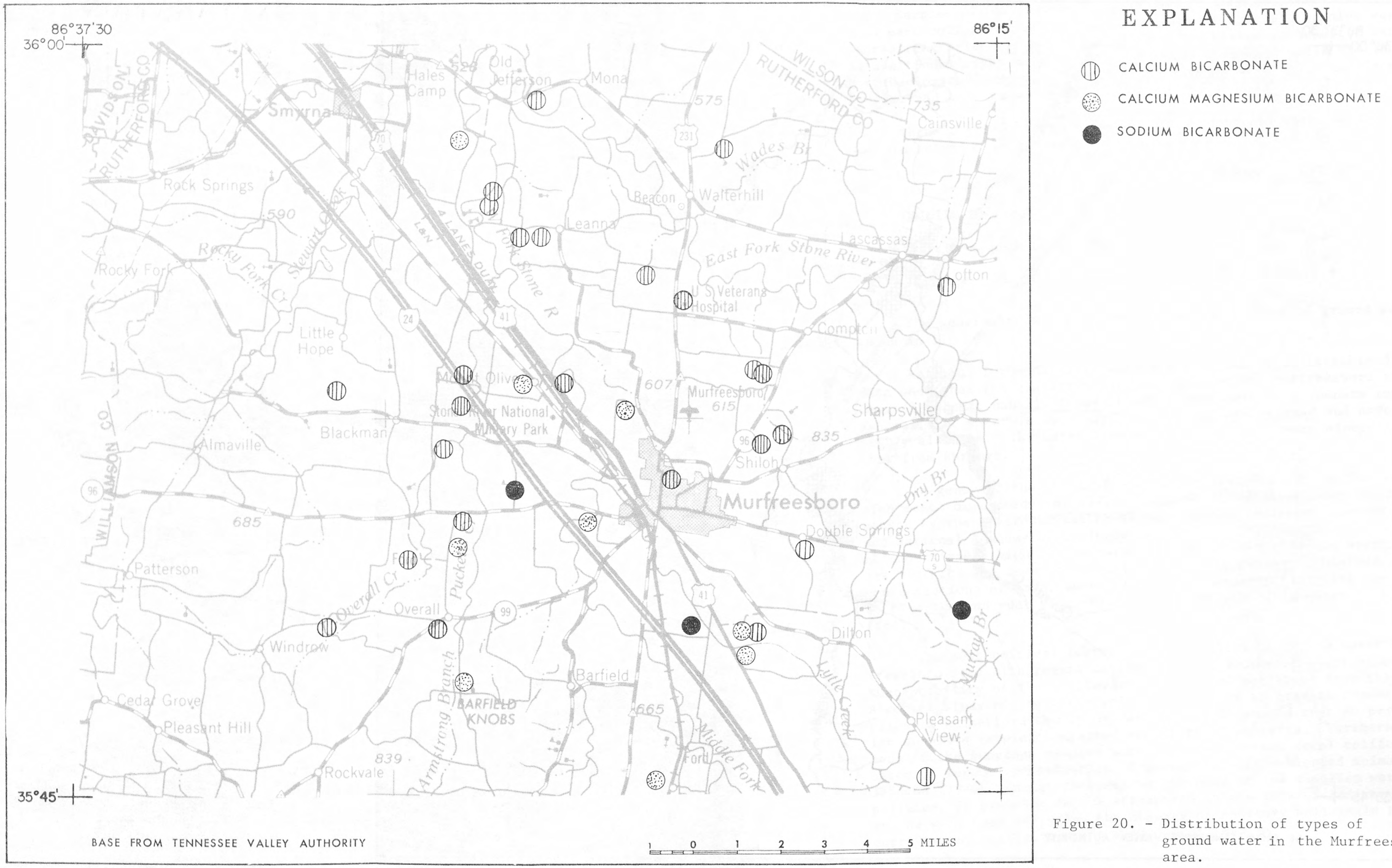


Figure 20. - Distribution of types of ground water in the Murfreesboro area.

Table 3.--Summary of chemical analyses of water from wells and springs in the Murfreesboro area

[Results in milligrams per liter, except as otherwise indicated. Analyses made by the U.S. Geological Survey.]

Constituent or property	Analytical values for water from wells (23 samples)			Analytical values for water from springs (15 samples)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Silica (SiO_2)	5.4	8.2	12	6.0	8.3	9.9
Iron (Fe)	.00	.1	3.4	---	---	---
Manganese (Mn)	.00	.01	.04	---	---	---
Zinc (Zn)	.00	.09	.70	---	---	---
Calcium (Ca)	6.2	67	147	66	94	110
Magnesium (Mg)	3.1	22	47	4.2	4.7	6.4
Sodium (Na)	1.4	13	355	1.3	1.9	4.7
Potassium (K)	.6	5	11	0.7	1.0	3.3
Strontium (Sr)	.2	2.3	5.5	---	---	---
Bicarbonate (HCO_3)	203	292	516	210	272	315
Sulfate (SO_4)	3.9	23	268	6.4	10	16
Chloride (Cl)	1.0	5.4	65	2.6	3.3	5.9
Fluoride (F)	.1	.5	6.9	0.2	0.2	0.7
Nitrate (NO_3)	.0	.19	15	---	---	---
Total dissolved solids (residue at 180°C)	233	332	974	195	264	307
Hardness (as $CaCO_3$)	36	230	393	180	260	300
Specific conductance (µmho/cm at 25°C)	396	520	1,540	340	460	520
pH (units)	6.6	7.3	8.3	6.5	7.6	9.0
Color (units)	0	3	10	---	---	---

Another possible explanation for some of the polluted supplies is the likelihood that there is rapid circulation of contaminated water from the land surface into the wells through solution openings at relatively shallow depths. Owing to the thinness or absence of a soil zone to provide a filter medium, pollutants at the land surface might readily be introduced into the shallowest aquifers by the infiltration of precipitation. The potential for entry of pollutants into the subsurface is increased significantly by the fact that sinkhole areas which are the principal points of entry of recharge water are commonly used to discard all manner of solid and liquid wastes.

In all likelihood, polluted ground-water supplies could be avoided if supply wells are constructed so as to seal off the shallowest sources of ground water. This could be done by installing well casing to a depth of a few tens of feet below the water table.

POTENTIAL FOR DEVELOPMENT

Studies were made to determine the quantity and quality of ground water that might be obtained from wells and springs in the Murfreesboro area.

SPRING SUPPLIES

Springs are natural outlets through which ground water is discharged at the land surface. They are fed from catchment areas through underground reservoirs in which ground water is stored above the level of the spring openings. Contrary to popular belief, springflows do not remain constant. Instead, they fluctuate from season to season in response to changes in the amounts of ground water in storage. In general, the highest annual spring flows usually occur during the winter or early spring when the volume of ground water in storage is at or near maximum for the year. Conversely, the lowest annual flows usually occur in late summer or fall when the volume of ground water in storage is at or near the minimum for the year.

Although springs are numerous in the Murfreesboro area, most of them are unimportant as a source of water supply because they cease to flow for varying lengths of time each year. There are, however, a limited number of springs in the area that seldom, if ever, go dry. The largest and most reliable of these are listed in table 4 ranked in order of their yield. The spring locations are shown on figure 21. It is significant to note that these large perennial springs are geologically and hydrologically very similar. All of them issue from water-filled solution openings in the Ridley Limestone. Most of them are contact springs, so-called because they issue from horizontal bedding-plane openings immediately above the less permeable shaly zones that occur near and at the base of the Ridley. A few, such as Fox Camp Spring, discharge through what appears to be large vertical solution openings into sizeable pools in the bottom of sinkholes. This type of spring is commonly referred to as an "overflow" spring. Examples of these two types of springs are shown in the photographs of figure 22. The contact springs are situated near the axes of synclines which are presumed to be the main arteries of ground-water movement. The overflow springs, on the other hand, are situated in structural saddles near the axes of anticlines which are believed to coincide with the boundaries between adjacent subsurface catchment areas.

Quantity

The value of springs as potential sources of water for municipal use is determined by the amount of water that can be supplied on a sustained basis. The minimum sustained yield that can be obtained is dependent upon the low-flow characteristics of the springs. These characteristics are generally expressed in terms of duration and frequency of recurrence of specific flows. For example, a spring that has a 7-day, 2-year low flow of 2 ft^3/s will experience a mean daily flow of 2 ft^3/s or less for a period

Table 4.--Springs in the Murfreesboro area, Rutherford County, Tennessee

Map No.[1]	Number	Name	Location	Elevation (ft above sea level)
1	8383	Military	4.4 mi above mouth of Overall Creek	560
2	8317	Rucker	5.6 mi W. of Murfreesboro	610
3	7670	Bushnell	0.6 mi N. of Shiloh	600
4	8301	Overall	Head of Overall Creek	630
5	8516	Wilkinson	1.5 mi NW of Leanna	500
6	8518	West Fork	1.8 mi NW of Leanna	500
7	8390	Asbury Pike	1.5 mi W. of Mt. Olive	550
8	8514	Leanna	.5 mi W. of Leanna	540
9	7709	V.A. Hospital	2.2 mi S. of Walterhill	550
10	8182	Oaklands	Northern perimeter of Murfreesboro	600
11	8047	Fox Camp	3.7 mi SE of Murfreesboro	620
12	8300	Snail Shell Cave	1.75 mi N. of Rockvale	700
13	8332	Puckett Creek	4.8 mi W. of Murfreesboro	560
14	7650	Double	At Double Springs	617
15	8126	McFadden	3.5 mi NW of Murfreesboro	540
16	7730	Allen	1.9 mi SW of Walterhill	550

[1]See figure 21.

of 7 consecutive days on an average of once in two years. Stated another way, there is a 50 percent chance that the mean daily flow of the spring will average 2 ft^3/s or less for a period of 7 consecutive days in any one year. Similarly, a 7-day, 10-year low flow will recur on the average of once in 10 years, but it has a 10 percent chance of occurring in any given year.

Several years of continuous springflow records are normally required to define accurately the flow characteristics of springs. In the absence of such records, however, meaningful estimates can be made from a limited number of periodic springflow measurements by correlating the periodic measurements with concurrent records of stream baseflow at a nearby long-term continuous-record gaging station. If a satisfactory correlation can be established, the streamflow characteristics as defined by the gaging station records can then be transposed by means of the correlation to derive corresponding springflow characteristics. The validity of this procedure is based on the fact

Table 4.--Continued

Aquifer	Discharge (ft^3/s)	Date Measurement	Remarks	Map No.
Ridley Limestone	34.3	11-19-75	Opening at Ridley-Pierce contact.	1
------do-------	17.4	---do---	-----------------------	2
------do-------	11.5	---do---	-----------------------	3
Lebanon Limestone	11.4	11-18-75	-----------------------	4
Ridley Limestone	8.3	11-19-75	-----------------------	5
------do-------	6.4	---do---	-----------------------	6
------do-------	4.5	---do---	Opening at Ridley-Pierce contact.	7
------do-------	4.5	---do---	-----------------------	8
------do-------	4.15	---do---	-----------------------	9
------do-------	2.45	---do---	Opening at Ridley-Pierce contact.	10
------do-------	1.55	---do---	-----------------------	11
------do-------	1.35	5-02-69	Tributary to Overall Spring.	12
------do-------	.87	11-19-75	-----------------------	13
------do-------	.45	---do---	-----------------------	14
------do-------	.14	---do---	Opening at Ridley-Pierce contact.	15
------do-------	.11	---do---	-----------------------	16

that the flow of springs and the baseflow of surface streams are both dependent upon the volume of ground water in storage. It follows that springflow characteristics should be related statistically to the baseflow characteristics of nearby surface streams.

To define the statistical relation between the flow of springs and streams in the Murfreesboro area, monthly measurements of the flow of Overall and Snail Shell Springs, were plotted against concurrent records of the mean daily baseflow at the gaging station on the East Fork Stones River near Lascassas. The mean daily baseflow at the gaging station was determined using the method of hydrograph separation described by Moore and others, (1969, p. 22). The results are shown graphically in figure 23. The straight lines represent a least squares regression of each of the two sets of springflow data. Given the variability of data, a statistical test affirms (at the 99 percent confidence level) the hypothesis that the slope of the regression line for Snail Shell Spring can be considered equivalent to the slope of the regression line for Overall Spring.

By extending the regression lines to intersect selected flow values for East Fork, corresponding flow values can then be extrapolated for the springs. For example, the 7-day, 2-year low flow of Overall Spring as derived from the graph (fig. 23) is about 0.2 ft^3/s.

Flow measurement data for the remaining 14 springs listed in table 4 are insufficient to define a satisfactory correlation with the baseflow of the East Fork Stones River. However, the fact that all of the springs listed in table 4 are geologically and hydrologically similar strongly suggests that the least squares regressions relating the flow of individual springs to the baseflow of the East Fork Stones River would have a common slope. It can be proven mathematically that a true correlation between two variables would have a 45-degree slope on logarithmic paper (J. Daniel, U.S. Geological Survey, oral commun, April, 1977). Since the Overall Spring regression closely approximates, but is less than a 45-degree slope (fig. 23), it can be used for conservative estimates of springflow. Assuming this is true, a line representing a least squares regression of the flow of an individual spring and the baseflow of the East Fork can be constructed by plotting on log-log paper a single springflow measurement against the concurrent record of the baseflow of the East Fork and drawing a line through the plotted point parallel to the slope of the regression for Overall Spring. This yields a set of parallel lines that reflect the regressions for individual springs based on the measurements available (figure 24).

Using this procedure, estimates of the average discharge and selected low flow frequencies were derived for each of the springs listed in table 4. The results are given in table 5. Of the values given in table 5 the estimates for average discharge are the most reliable because the least amount of error is introduced in their derivation. The values for the low flow frequencies, however, are subject to considerable error and therefore should be used only as rough approximations of the actual values.

Based on the estimates of average discharge of the springs (table 5), 11 of the 16 springs have maximum potential yields in excess of a million gallons of water per day. Likewise, five of the springs have potential yields in excess of 5 Mgal/d and two are capable of supplying more than 10 Mgal/d. Such development, however, would require sizeable storage facilities to offset deficient flows during dry periods. The estimated low flow values for the springs (table 5) are indicative of the minimum sustained yields that might be developed from individual springs without providing extensive storage facilities. Based on these estimates, none of the springs have minimum sustained yields in excess of a million gallons per day.

Although there is little difference between the natural flow characteristics of the contact and overflow springs, there is perhaps a significant difference in terms of ground-water availability. The contact springs derive their flow essentially from the downward and lateral movement of ground water. In contrast, the overflow springs derive their flow from

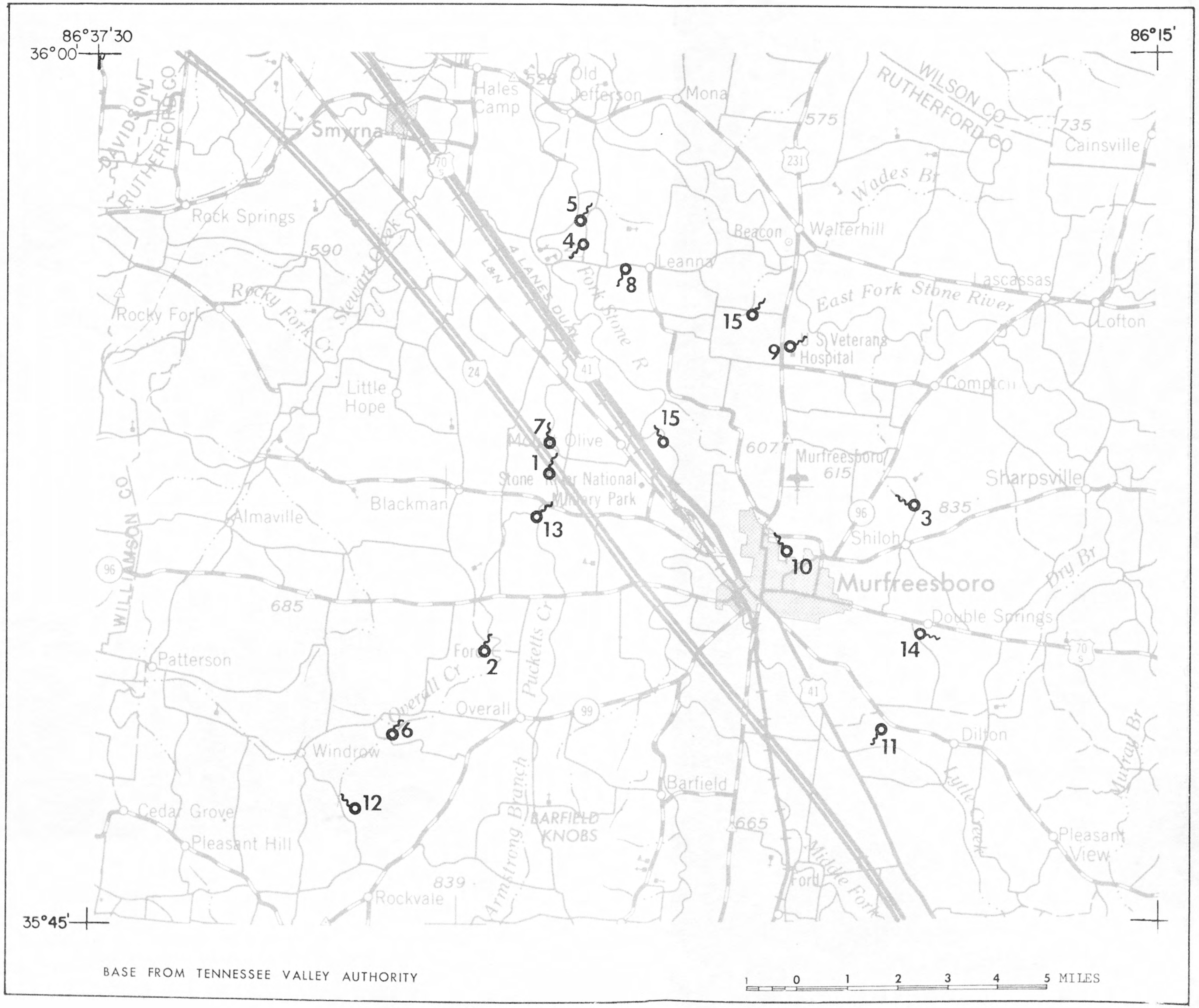
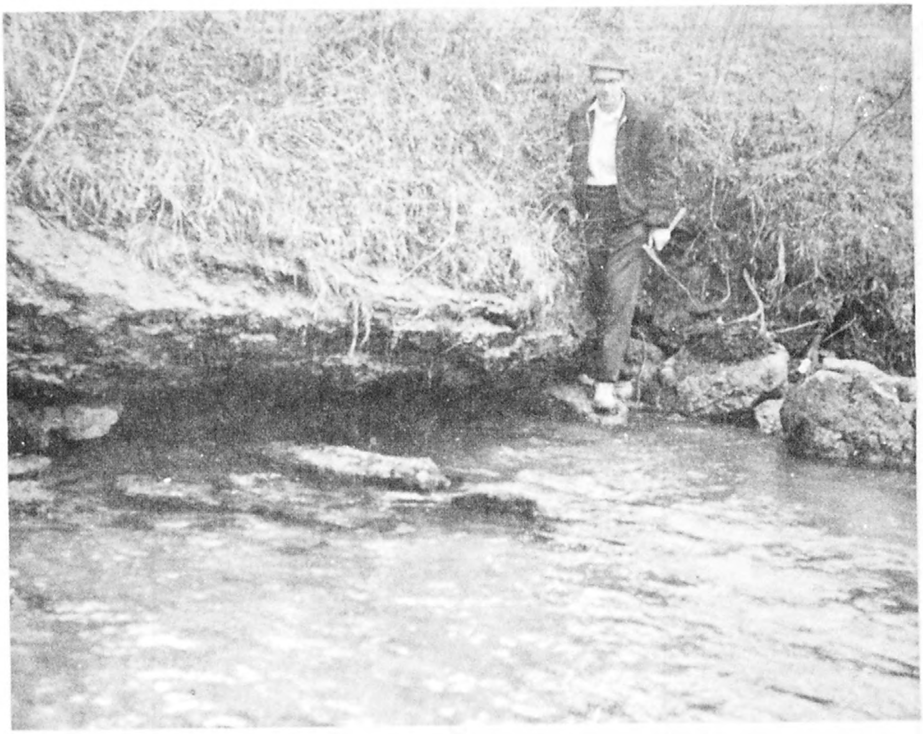


Figure 21. - Locations of springs in the Murfreesboro Area. Numbers beside spring symbols indicate rank in order of discharge measurements made on November 19, 1975.



A

B

Figure 22.--Examples of contact and overflow springs, A, West Fork Spring; B, Fox Camp Spring.

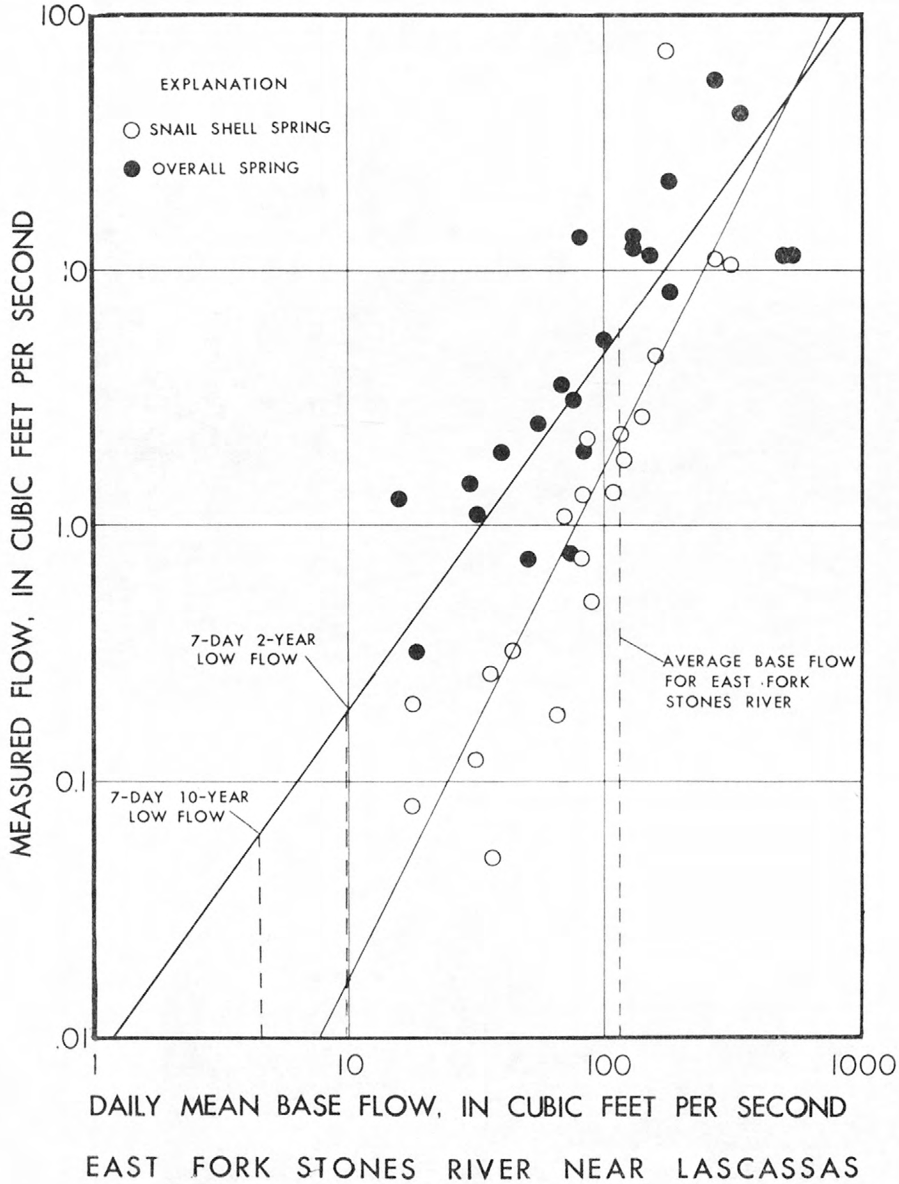


Figure 23. --Correlation of periodic discharge measurements of Overall and Snail Shell Cave Springs with mean daily baseflow of the East Fork Stones River near Lascassas.

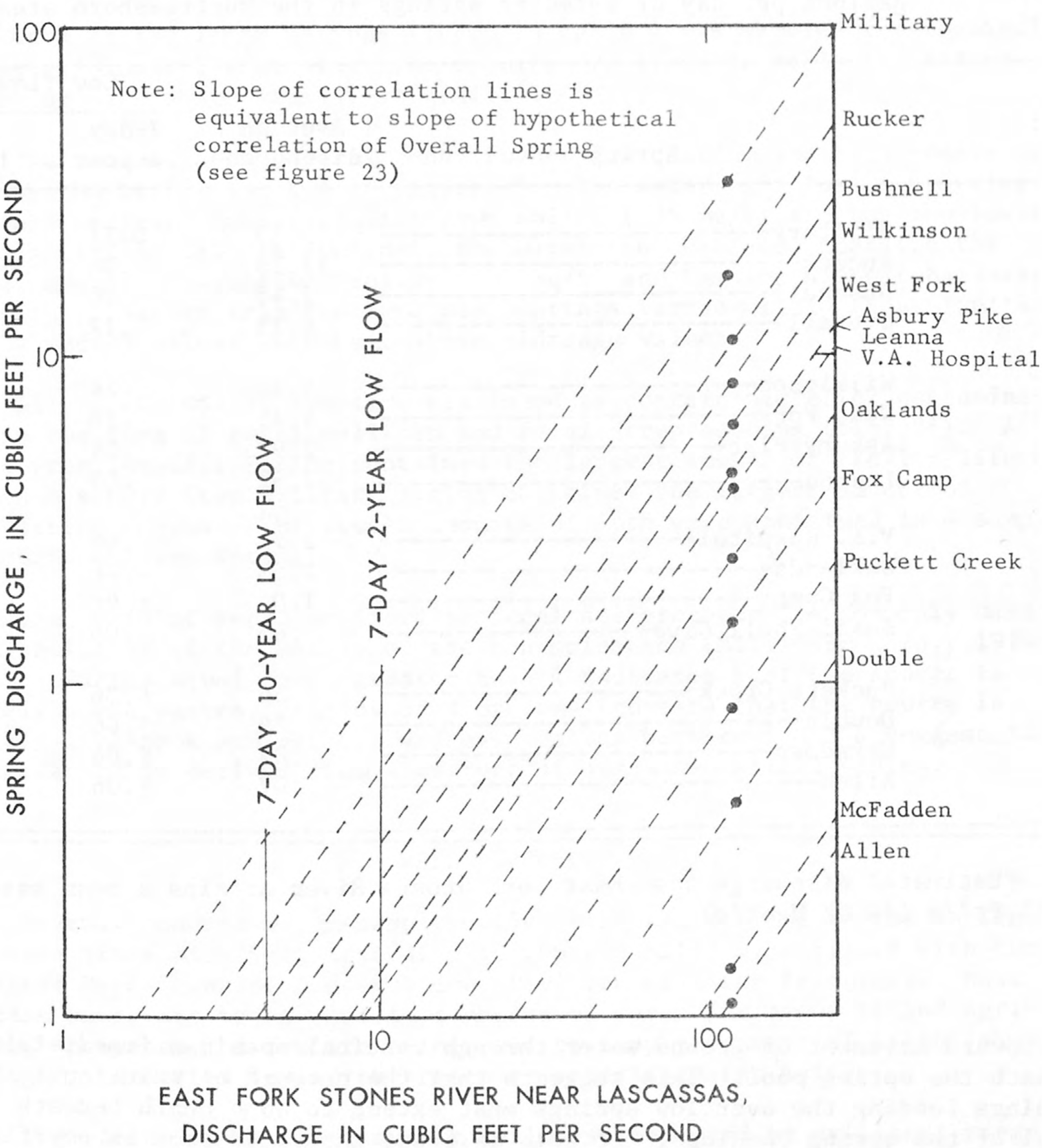


Figure 24.-- Hypothetical correlation of the discharges of 14 Murfreesboro area springs with the baseflow of the East Fork Stones River near Lascassas.

Table 5.--Estimated average discharge and low-flow frequencies, millions of gallons per day of selected springs in the Murfreesboro area.

Map No.	Spring	Average discharge*	Low-flows 7-day 2-year	Low-flows 7-day 10-year
1	Military	22.23	0.71	0.22
2	Rucker	11.28	.36	.12
3	Bushnell	7.45	.24	.08
4	Overall	4.15	.12	<.06
5	Wilkinson	5.38	.24	.08
6	West Fork	4.15	.18	.06
7	Asbury Pike	2.92	.09	<.06
8	Leanna	2.92	.09	<.06
9	V.A. Hospital	2.7	.08	<.06
10	Oaklands	1.59	<.06	<.06
11	Fox Camp	1.0	<.06	<.06
12	Snail Shell Cave	.65	.06	<.06
13	Puckett Creek	.56	<.06	<.06
14	Double	.29	<.06	<.06
15	McFadden	.09	<.06	<.06
16	Allen	.07	<.06	<.06

*Estimated discharge when East Fork Stones River attains a mean baseflow of 115 ft^3/s (74.52 Mgal/d).

the upward movement of ground water through vertical openings immediately beneath the spring pool. This suggests that the network of solution openings feeding the overflow springs must extend to some depth beneath the level of the spring openings. If this is true, the yield from an overflow spring might be increased significantly by pumping from the pool that forms over the orifice. In effect, this would increase the hydraulic gradient toward the spring by lowering the head at the orifice. For example, Fox Camp Spring, which is an overflow type spring, has an average natural discharge of about 1.5 ft^3/s or about 700 gal/min. The lowest recorded measurement is 0.56 ft^3/s or about 250 gal/min. However, during the severe drouth of 1925 this spring was pumped by the city of Murfreesboro at a rate of 2250 gal/min with a drawdown of 18 ft (Piper, 1932, p. 188). Hence, by lowering the head on the spring a total of 18 ft, the inflow of ground water to the spring was increased several fold.

Quality

Each of the large springs listed in table 4 was sampled for chemical and bacteriological analyses. The results are given in table 6. All of the spring waters are similar in quality.

The predominant chemical constituents are calcium and bicarbonate as shown by the Stiff diagrams in figure 25. The water from Fox Camp Spring contains the least amount of dissolved solids (195 mg/L) and has the lowest hardness (180 mg/L). In contrast, the water from Oaklands contains the largest amount of dissolved solids (307 mg/L) and has the highest hardness (300 mg/L). Waters from the remaining springs varied within these limits but the median values were well above midrange values.

All of the spring samples were found to contain bacterial contamination in the form of fecal coliform and fecal streptococcus (fig. 26). A sample from Bushnell Spring contained the largest amount of fecal coliform whereas a sample from Military Spring contained the largest amount of fecal streptococcus. The lowest amounts of both were contained in a sample from Puckett Creek Spring.

The ratio of fecal coliform to fecal streptococcus is commonly used as an indicator of the source of the contamination (Millipore Corp., 1974, p. 12). Ratios equal to or greater than 4 indicates that the source is probably human wastes. Ratios of 1 or less indicate that the source is probably livestock and poultry wastes. Values between 1 and 4 suggest the contamination is derived from a mixture of human and animal wastes.

WELL SUPPLIES

Several hundred water-supply wells have been drilled in the Murfreesboro area since mid-1963, according to reports filed by drillers with the Tennessee Department of Conservation, Division of Water Resources. Most of these wells are being used as a source of water for domestic and agricultural purposes. A few are being used to supply commercial establishments and light industries beyond the reach of existing water mains.

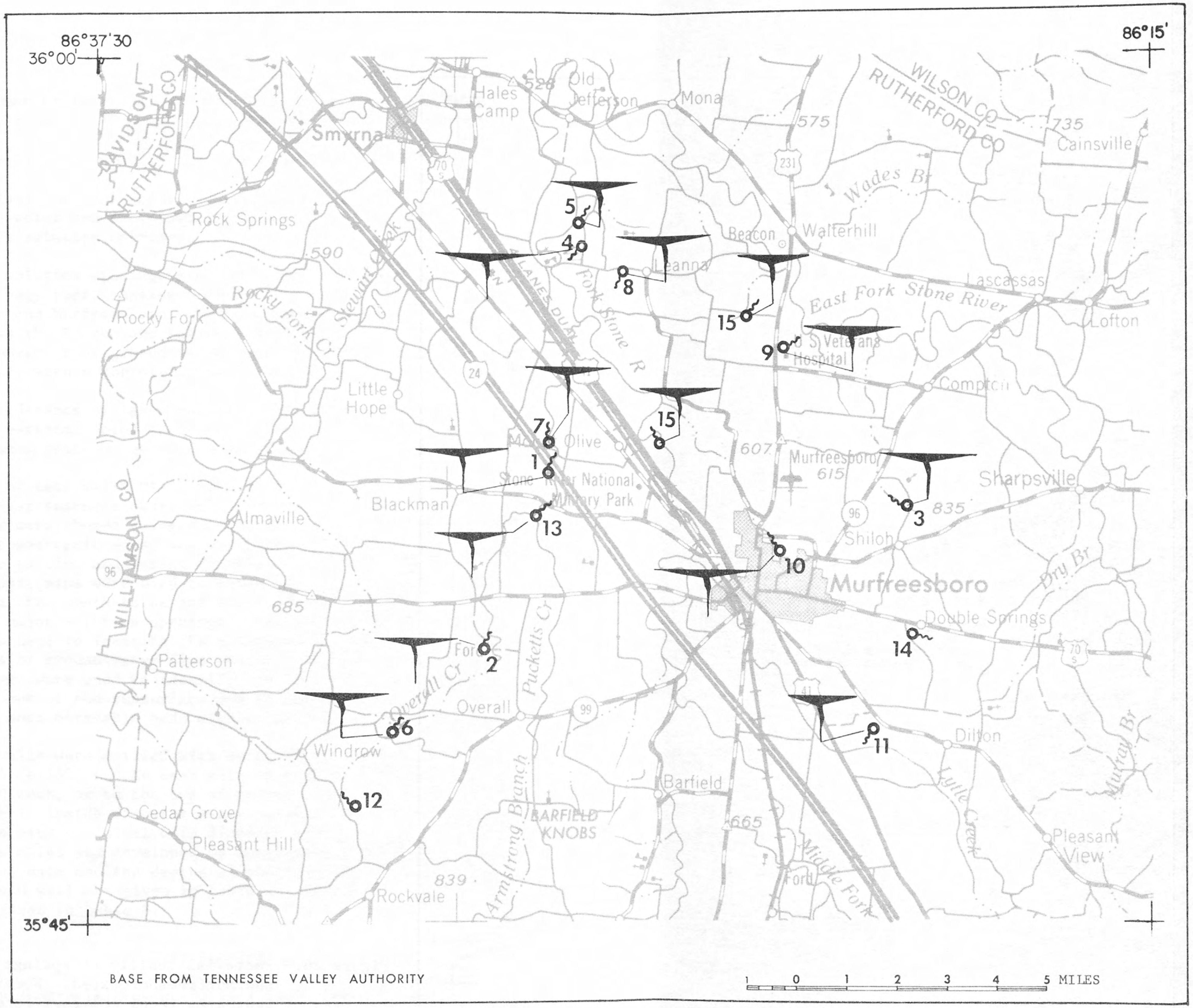
The yields of existing supply wells, as reported by drillers, range from less than 1 gal/min to slightly more than 250 gal/min. About half of the wells are reported to yield 10 gal/min or less but about 10 percent are reported to yield 50 gal/min or more. Burchett and Moore (1971, p. 20, 21) report that in some parts of the Murfreesboro area the chances of obtaining yields of 50 gal/min or more are much better than 10 percent. These areas and locations of existing wells having recorded yields of 50 gal/min or more are shown on figure 31.

Table 6.--Chemical and bacterial quality of raw water from springs in the Murfreesboro area.

[Results are reported in milligrams per liter, except as noted. Analyses made by the U.S. Geological Survey on samples collected November 19, 1975.]

SPRING		Discharge (ft^3/s)	Specific conductance (μmho/cm/ at 25° C)	pH (units)	Temperature °C	Fecal Colonies		Hardness (as Ca CO_3)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Total dissolved solids (TDS)
Map No.	Name					Coliform (counts/100 mL)	Streptococci (counts/100 mL)										
1	Military	34.3	420	8.7	15.1	226	334	260	97	4.5	1.9	1.0	272	11	3.2	0.4	261
2	Rucker	17.4	450	7.4	--	203	82	220	82	4.7	1.5	1.0	260	9.9	3.3	0.5	239
3	Bushnell	11.6	510	7.8	15.5	309*	274	270	97	6.4	1.8	0.8	286	14	2.6	0.3	270
4	Overall	11.4	460	7.3	14.5	156	190	250	94	4.7	1.8	0.8	280	16	2.6	0.3	264
5	Wilkinson	8.43	480	9.0	--	54	38	270	100	5.1	1.9	1.0	297	9.7	2.8	0.7	276
6	West Fork	6.54	470	6.9	15.0	72*	70	270	100	5.1	2.4	1.0	219	9.9	2.6	0.3	277
7	Asbury	4.71	390	6.5	--	80	323	230	83	4.4	1.5	0.9	261	10	3.4	0.3	240
8	Leanna	4.5	470	7.9	15.5	54	50	270	99	5.3	2.7	1.1	290	10	3.5	0.7	274
9	V. A. Hospital	4.15	460	8.1	17.0	51	40	260	94	5.0	2.1	1.3	281	10	3.9	0.6	261
10	Oaklands	2.42	520	7.2	15.9	200	41	300	110	5.9	4.7	1.3	315	14	5.9	0.3	307
11	Fox Camp	1.52	360	7.6	13.0	120	86	180	66	4.2	1.7	0.8	210	6.4	3.1	0.5	195
13	Puckett Creek	0.87	420	6.5	--	4*	23	210	77	4.2	1.3	0.7	246	9.4	3.2	0.2	226
14	Double	0.45	500	7.9	15.0	400	54	270	100	5.4	3.5	0.9	304	14	4.4	0.3	286
15	McFadden	0.14	380	6.7	17.6	60	84	220	80	4.7	2.0	0.7	255	9.7	3.6	0.3	237
16	Allen	0.11	340	7.8	15.0	220	273	190	69	4.4	2.6	3.3	223	7.5	4.4	0.3	206

*Nonideal plate count



EXPLANATION

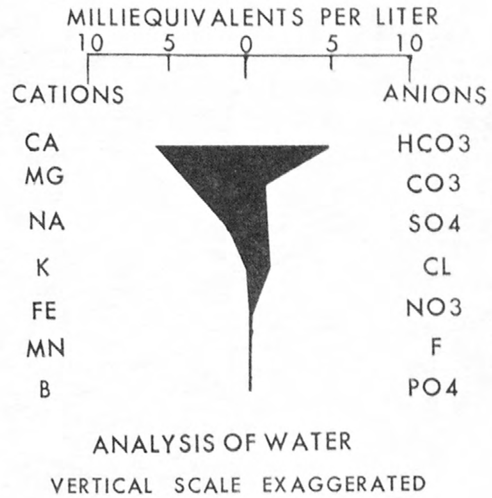


Figure 25. - Stiff diagrams showing similarity of water quality for Murfreesboro area springs.

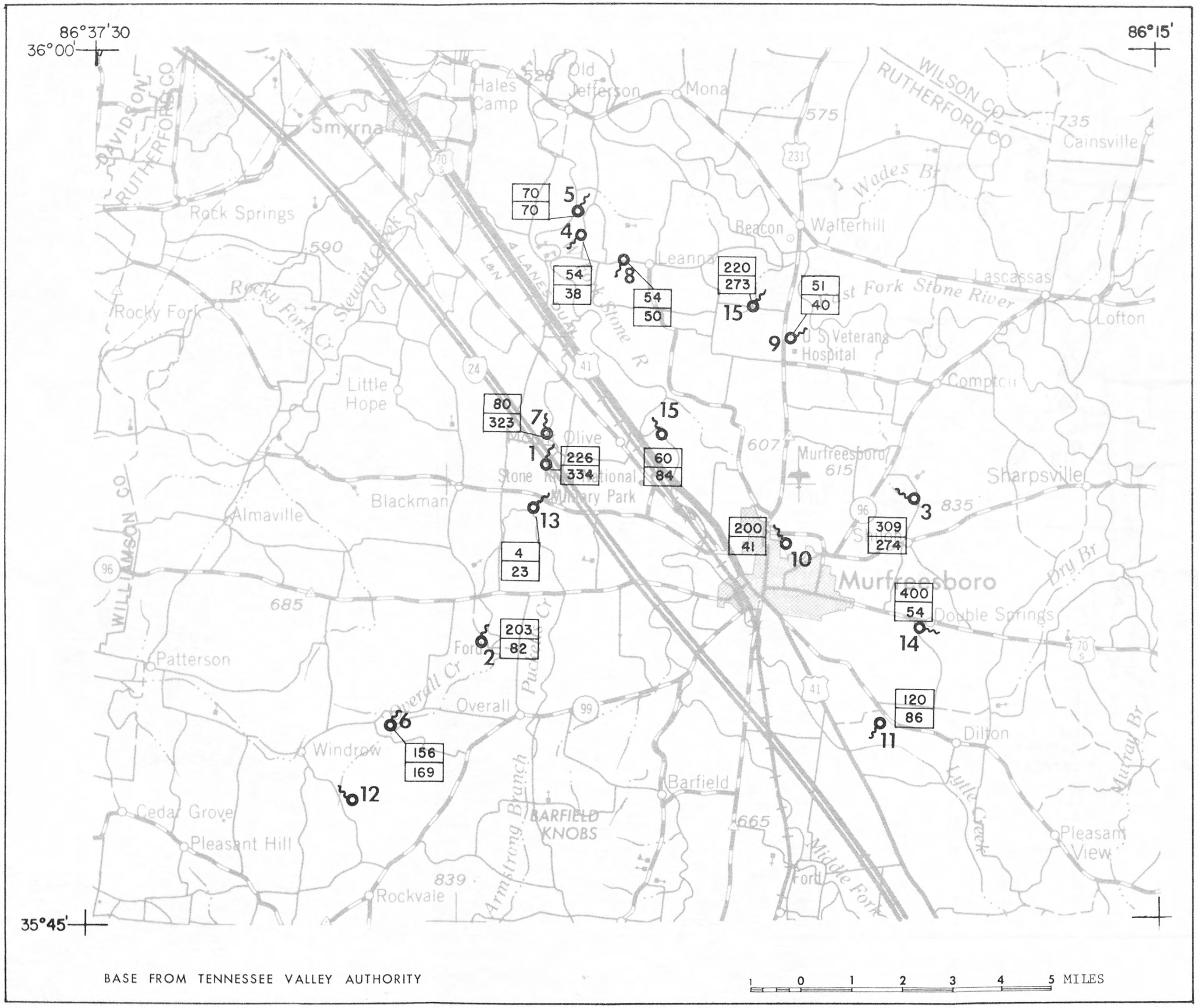


Figure 26.- Bacterial quality of springs in the Murfreesboro area. Numerator indicates fecal coliform colonies per 100 ml; denominator represents fecal streptoccus colonies per 100 ml.

Test Drilling

In an attempt to locate additional areas having a high potential for ground-water development, 11 test wells were drilled between February and June, 1975. The locations of the test wells are shown on figure 27. The working concepts used in choosing the sites to be drilled were as follows:

1. Synclinal "valleys" or structural lows act as collectors of ground water and therefore are more likely to contain the largest solution openings.

2. Large solution openings are most likely to occur in the relatively pure, massive-bedded limestones such as the Ridley and Murfreesboro. Shaly thin-bedded limestones, such as the Pierce and Lebanon, tend to impede the downward movement of ground water, causing greater solution activity within the overlying formations.

3. The occurrence of large solution openings is more probable along vertical joint fractures which are commonly visible as linear features on maps and aerial photographs.

The sites of test wells Mf-1 and Mf-2 were chosen because of their proximity to linear features observed on Landsat satellite imagery. The other nine sites were chosen using information from areal and structural geologic maps, topographic maps, low altitude aerial photographs, and knowledge of the gaining and losing reaches of streams. The areal and structural geologic maps were used to establish the sequence of formations to be penetrated, the depth to be drilled, and the probable subsurface position of the major solution openings. Topographic maps and aerial photographs were used to identify the alinement of any linear features transecting a major ground-water flow system. The gaining and losing reaches of streams were used to identify the relative quantities of water moving into and out of the subsurface and to pinpoint the stratigraphic position of the most permeable beds within the sequence of rock strata.

The test wells were drilled with an air-rotary drilling rig to depths ranging from 175 to 250 ft. At each site an 8-in diameter hole was drilled to a depth of 20 feet, or to the top of bedrock, whichever was greater, to accommodate a 6¼ in inside diameter steel casing. The remainder of the hole was drilled with a nominal 6-in diameter bit. The test wells were finished as open holes and developed by surging with compressed air. The well construction data and the depths at which geologic formations were penetrated in each well are given in table 7. Hydrologic data for the 11 test wells are given in table 8.

Test Pumping

The four highest-yielding wells were test pumped to determine the specific capacities of the wells and the hydraulic properties of the aquifers penetrated. The tests consisted of multiple steps in which the discharge was held constant for periods of an hour or more while observations

Table 7.--U.S. Geological Survey test wells near Murfreesboro, Tennessee.

Test well number	Date drilled 1975	Altitude of land surface (feet)	Total depth (feet)	Depth cased (feet)	Geologic formation	Depth[a] (feet) Top	Bottom
Mf-1	2-10	504	175	46.5	Overburden	0	10
					Ridley Limestone	10	84
					Pierce Limestone	84	103
					Murfreesboro Limestone	103	T.D.
Mf-2	2-12	547	175	20.5	Overburden	0	5
					Ridley Limestone	5	117
					Pierce Limestone	117	136
					Murfreesboro Limestone	136	T.D.
Mf-5A	2-27	605	175	21	Overburden	0	2.5
					Ridley Limestone	2.5	115
					Pierce Limestone	115	150
					Murfreesboro Limestone	150	T.D.
Mf-6	2-17	620	200	21	Overburden	0	4
					Ridley Limestone	4	20
					Pierce Limestone	20	46
					Murfreesboro Limestone	46	T.D.
Mf-7	2-18	575	175	21	Overburden	0	17
					Ridley Limestone	17	87
					Pierce Limestone	87	111
					Murfreesboro Limestone	111	T.D
Mf-8	2-20	560	150	21	Overburden	0	3
					Ridley Limestone	3	72
					Pierce Limestone	72	99
					Murfreesboro Limestone	99	T.D.

Table 7.--Continued

Test well number	Date drilled 1975	Altitude of land surface (feet)	Total depth (feet)	Depth cased (feet)	Geologic formation	Depth[a] (feet) Top	Bottom
Mf-10[b]	2-24	560	150	39	Overburden	0	6
					Ridley Limestone	6	60(?)[c]
					Pierce Limestone	60(?)	80(?)
					Murfreesboro Limestone	80(?)	T.D.
Mf-11	2-25	605	150	22	Overburden	0	18
					Ridley Limestone	18	58
					Pierce Limestone	58	89
					Murfreesboro Limestone	89	T.D.
Mf-12	2-26	615	175	21	Overburden	0	14
					Pierce Limestone	14	36
					Murfreesboro Limestone	36	T.D.
Mf-13	6-09	620	250	21	Overburden	0	5
					Ridley Limestone	5	109
					Pierce Limestone	109	137
					Murfreesboro Limestone	137	T.D.
Mf-14	6-10	620	250	60	Overburden	0	4
					Pierce Limestone	4	32
					Murfreesboro Limestone	32	T.D.

[a] Formation tops picked from natural gamma logs.
[b] Backfilled upon completion.
[c] Formation tops from driller's log for Mf-10.

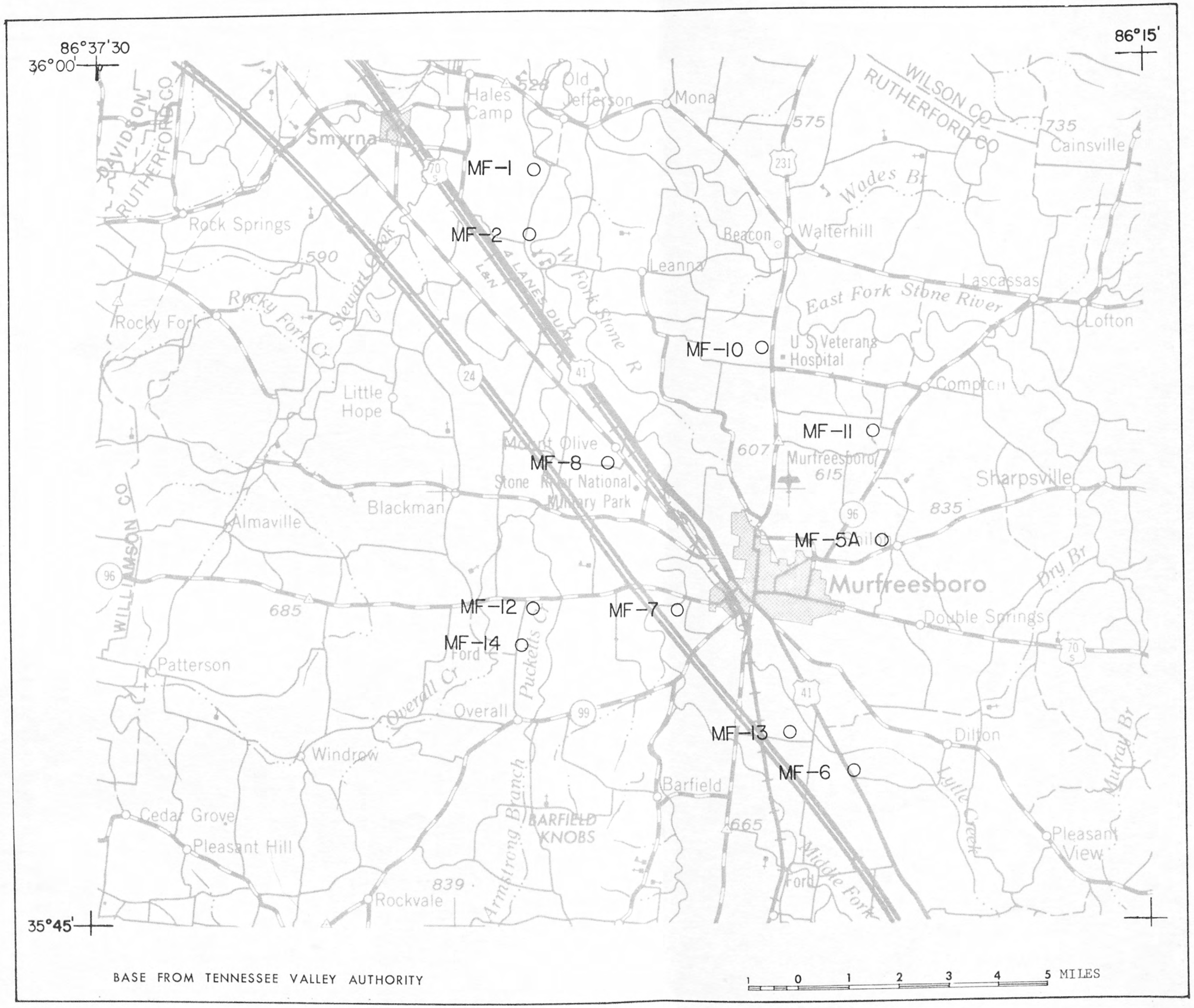


Figure 27. - Locations of U. S. Geological Survey test wells drilled in the Murfreesboro area.

were made of the changes in water level in the pumped well. The discharge was measured by means of an orifice meter; water levels in the pumped well were measured with an electric tape inserted into the well between the pump discharge column and the well casing (figure 28).

Well Mf-5A was pumped during a storm which flooded the Murfreesboro area with 8.9 in of rain during a three-day period (March 12-14, 1975). The well was pumped at rates of 100, 150, and 250 gal/min for periods of 1, 4 and 2 hours respectively. The test results, however, were invalidated by the infiltration of recharge from precipitation, which obliterated the effects of pumping on the water level in the pumped well. The rapidity with which the recharge occurred suggests that the shallow solution openings penetrated by the well are directly connected to a sinkhole in a nearby pasture.

Pumping rates and the drawdown and recovery of water levels in the other three wells tested are shown graphically in figure 29. As shown by the graph in figure 29A, the water level in well Mf-7 stabilized about 20 ft below the non-pumping water level when the well was pumped at a rate of 24 gal/min. When the discharge was increased to 48 gal/min, however, the water level declined an additional 90 ft in a period of a little more than one hour. The pumping rate was then reduced to 40 gal/min and the water level stabilized about 60 ft below the original non-pumping level. Similarly, well Mf-12 could be pumped at rates of 27 and 50 gal/min but not at 70 gal/min. Well Mf-14, on the other hand, was pumped at 50 and 100 gal/min for periods of 3 and 4 hours, respectively, without excessive drawdown. At 50 gal/min the water level was drawn down about 20 ft and at 100 gal/min the water level was drawn down an additional 45 feet. During each stage of pumping the water level stabilized within the first hour of pumping. Water levels in all three wells recovered completely within two hours after the pump was turned off.

Quality of Well Water

Samples were collected from 8 of the 11 test wells at the time of completion of drilling. Additional samples were collected from four of the test wells at the time these wells were test pumped. The results of chemical analyses of the initial eight samples are given in table 9. The relative concentrations of the major ions and the geographic distribution of the wells sampled are shown by means of stiff diagrams on figure 30. Based on the dominant ions in solution, three types of water are represented; calcium bicarbonate, calcium-magnesium bicarbonate and sodium bicarbonate.

The samples collected during the four pumping tests were analyzed for chemical and bacteriological constituents. The results of these analyses are given in table 10.

Table 8.--Hydrologic data for Murfreesboro test wells

Well No.	Thickness of overburden (ft)	Depth to water - bearing openings (ft)	Aquifer
Mf-1	10	24-25.5, 63-43.5 75,144	Ridley, Murfreesboro Limestones
Mf-2	5	None	----
Mf-5A	2.5	52.5-55, 73-74	Ridley Limestone
Mf-6	4	20-25	Pierce Limestone
Mf-7	17	19-20, 40, 86-87	Ridley, Pierce Limestones
Mf-8	3	100, 150	Murfreesboro
Mf-10	6	None	----
Mf-11	18	25-30, 125 145-150	Ridley, Murfreesboro Limestones
Mf-12	0	57, 128	Murfreesboro Limestone
Mf-13	5	62, 180-190 (?)	Ridley, Murfreesboro Limestones
Mf-14	40	70, 105-106, 110 145, 166-170, 205	Murfreesboro Limestone

Table 8.--Continued

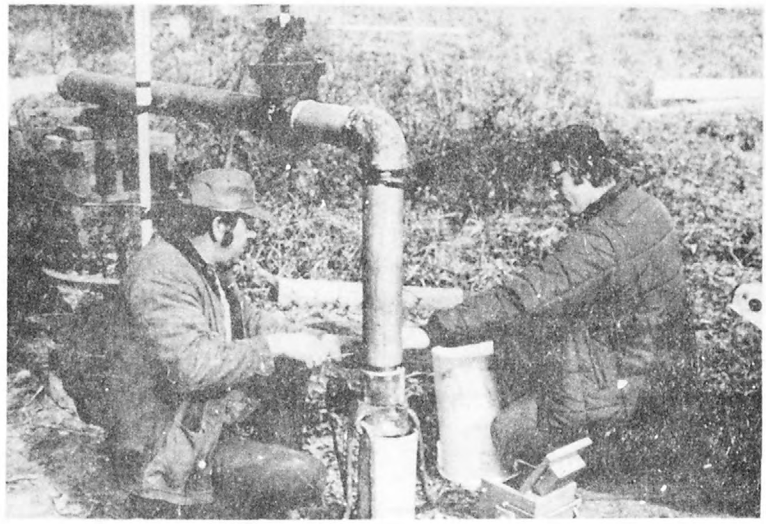
Yield (gal/min)	Depth to water (ft)	Date of measurement	Remarks	Well No.
10+	22	2-11-75	Cased to 46 ft.	Mf-1
	19.4	2-12-75	---------------	
	25.1	2-26-75	---------------	
0	--	--	1-ft dry opening from 32-33 ft.	Mf-2
150	16.6	2-28-75	Water highly polluted.	Mf-5A
13	7.65	2-18-75	----------------	Mf-6
	2.82	2-19-75	----------------	
	2.87	2-27-75	----------------	
	13.0	2-27-75	Hole deepened from 125 to 175 ft., 2-28-75. Slight H_2S odor. Specific capacities 1.2 & .67.	M-7
	13.8	2-28-75		
	52.2	2-20-75	Small amount of natural gas.	Mf-8
4	38.6	2-27-75		
0	--	--	12-ft dry opening. Hole filled 2-24-75.	Mf-10
25	11.5	2-25-75	-------------------	Mf-11
	13.4	2-28-75	-------------------	
50	16.7	2-27-75	Strong H_2S odor. Specific capacity 3.5.	Mf-12
8	68.3	6-10-75	-------------------	Mf-13
100	42.3	6-11-75	Very clear, clean water, slight H_2S odor. Specific capacity of 1.7.	Mf-14
	28.9	6-18-75		

Table 9.--Results of chemical analyses of raw water samples collected at time of drilling from test wells in the Murfreesboro area.

[Results are reported in milligrams per liter, except as noted. Analyses made by the U.S. Geological Survey.]

Chemical constituent or property	MF-1	MF-5A	MF-6	MF-7	MF-11	MF-12	MF-13	MF-14
Date of collection	2-11-75	3-12-75	2-18-75	3-11-75	2-15-75	3-26-75	6-10-75	6-19-75
Depth of well (ft.)	175	175	200	175	150	175	250	250
Discharge (gal/min)	10	150	13	50	25	50	8.0	100
Specific conductance (μmho/cm at 25°C)	460	478	470	510	440	600	520	450
pH (units)	8.0	7.5	8.3	8.0	8.3	7.1	8.0	7.3
Hardness (as $CaCO_3$)	200	230	180	200	210	240	16	220
Calcium (ca)	37	77	36	37	79	70	6.2	48
Magnesium (Mg)	27	8.9	23	25	3.1	16	5.0	24
Sodium (na)	16	9.0	22	28	6.2	33	110	12
Potassium (K)	5.2	1.2	6.5	7.9	0.8	2.6	8.0	5.4
Bicarbonate (HCO_3)	274	269	265	292	203	279	305	276
Sulfate (SO_4)	3.9	23	7.8	17	17	12	21	13
Chloride (Cl)	4.5	5.4	4.9	6.1	5.0	51	9.7	4.6
Fluoride (F)	2.0	.3	1.0	1.0	.2	.2	1.5	1.3
Total dissolved solids (TDS)[1]	250	263	260	274	240	332	290	253

[1]Calculated from specific conductance.



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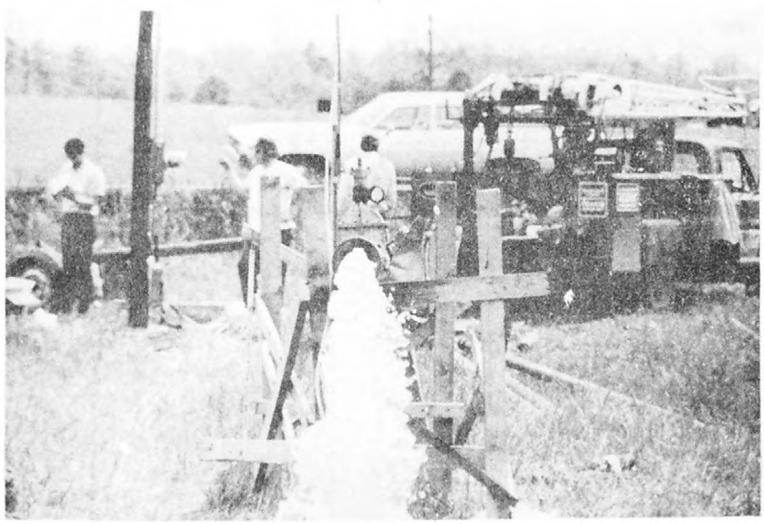


B

Figure 28. -- Aquifer test procedures, A, Measuring water levels; B, Measuring discharge.

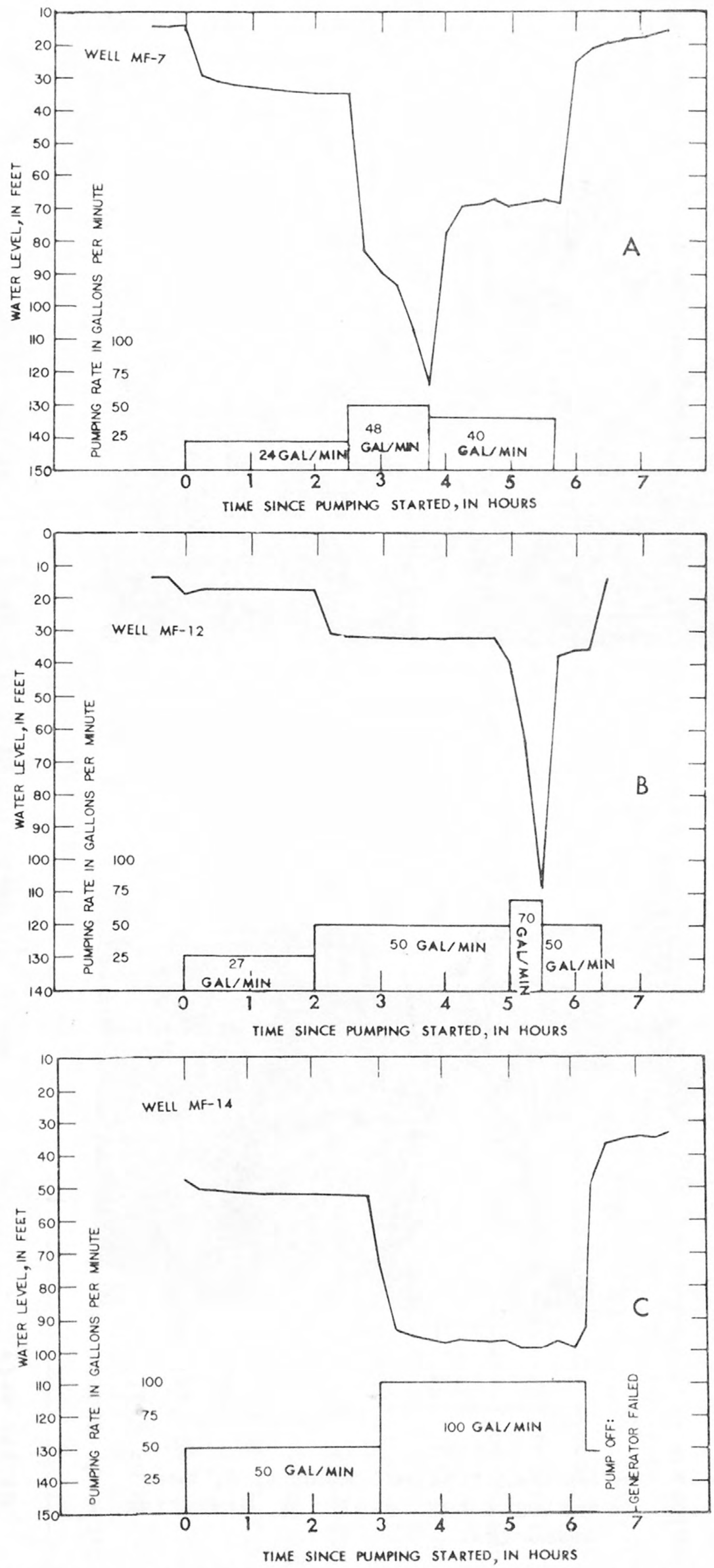
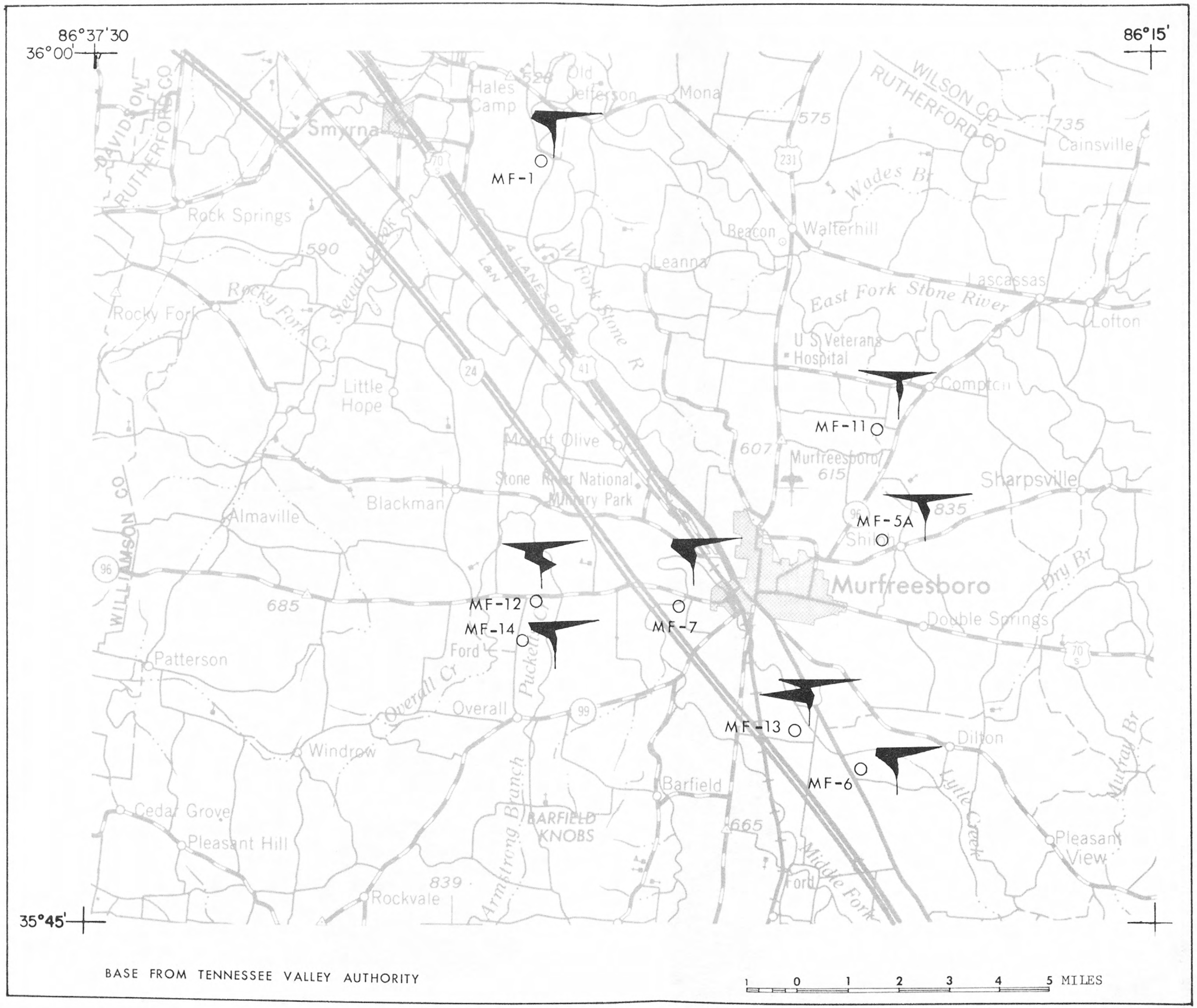


Figure 29. --Pumping rates and drawdowns for selected test wells in the Murfreesboro area.



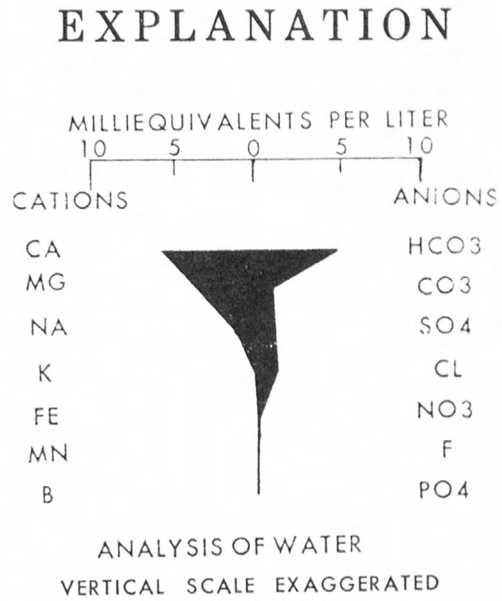


Figure 30. - Stiff diagrams showing water quality in U. S. Geological Survey test wells drilled in the Murfreesboro area.

Table 10.--Analyses of raw water samples collected during test pumping of wells in the Murfreesboro area, Tennessee.

[Results are reported in milligrams per liter except as noted. Analyses made by the U.S. Geological Survey.]

CONSTITUENTS	TEST WELL NUMBER				TENNESSEE STATE LIMIT
	MF-5A	MF-7	MF-12	MF-14	
Date of collection	3-12-75	3-11-75	3-26-75	6-19-75	
Depth of well (ft)	175	175	175	250	
Discharge	150	50	50	100	
Specific conductance (µmhos/cm at 25°C)	478	510	600	450	
pH (units)	7.5	8.0	7.1	7.3	
Temperature, water (°C)	15.0	17.5	16.0	17.0	
Color (platinum cobalt scale, units)	10	1	3	0	
Turbidity (JTU)	100	4	1	1	
Coliform, immediate (col/100 ml.)	6000	23	9	0	
Coliform, fecal (col/100 ml.)	1800	1	3	0	
Streptococci (col/100 ml.)	5400	1	4	0	
Hardness, total	230	200	240	220	
Hardness, noncarbonate	8	0	12	0	
Calcium, dissolved	77	37	70	48	
Magnesium, dissolved	8.9	25	16	24	
Sodium, dissolved	9.0	28	33	12	
Potassium, dissolved (K)	1.2	7.9	2.6	5.4	
Bicarbonate (HCO_3)	269	292	279	276	
Alkalinity, total as $CaCO_3$	221	240	229	226	
Carbon dioxide (CO_2)	14	4.7	35	22	
Sulfate, dissolved (SO_4)	23	17	12	13	250
Chloride, dissolved (Cl)	5.4	6.1	51	4.6	250
Fluoride, dissolved (F)	0.3	1.0	0.2	1.3	
Silica, dissolved (SiO_2)	5.4	8.1	9.7	8.6	
Dissolved solids, residue at 180°C	271	274	321	256	500
Dissolved solids, calc., sum of constituents	263	274	332	253	
Nitrate, total as N	0.13	0.00	0.19	0.00	35.0
Nitrate, total as N	0.00	0.00	0.00	0.00	
Nitrite + nitrate, total as N	0.13	0.00	0.19	0.00	
Phosphorus, total as P	0.09	0.01	0.01	0.01	
Arsenic, total (µg/L)	3	0	1	0	10
Barium, total (µg/L)	80	30	0	300	1000
Cadmium, total (µg/L)	0	0	0	0	10
Chromium, hexavalent (µg/L)	1	0	4	0	50
Copper, total (µg/L)	11	5	10	6	1000
Cyanide	0	0	0	0	0.01
Iron, total (µg/L)	3400	240	170	100	
Iron, dissolved (µg/L)	40	260	180	100	300
Lead, total (µg/L)	13	3	9	2	50
Manganese, total (µg/L)	120	30	60	10	
Manganese, dissolved (µg/L)	40	0	40	0	50
Mercury, total (µg/L)	0.1	0.1	0.2	0.0	5
Selenium, total (µg/L)	0	0	0	0	10
Silver, total (µg/L)	0	0	0	0	50
Zinc, total (µg/L)	50	20	30	90	5000
Total organic carbon	8.3	4.7	2.7	0.2	
Phenols (µg/L)	0	0	0	3	1
Methylene blue active substances	0.0	0.0	0.0	0.1	0.5
Detergents, MBA	0.0	0.0	0.0	0.1	

DISCUSSION OF RESULTS

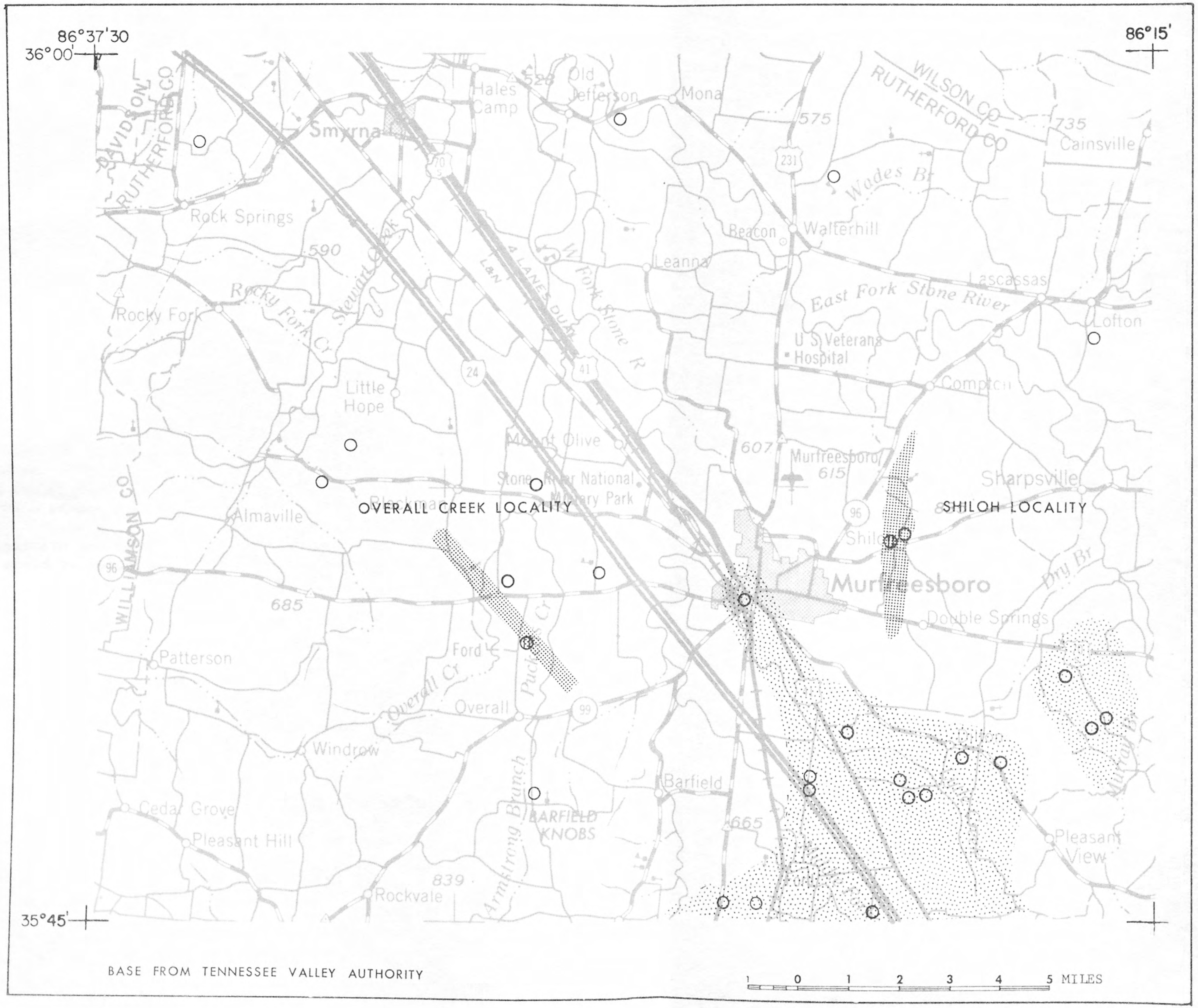
The results of the test drilling indicate that there are at least two additional localities within the Murfreesboro area that have potential for the development of sizeable ground-water supplies. One of these is on the northeast side of Murfreesboro and includes the small community of Shiloh. The other is on the west side of Murfreesboro near Overall Creek. The areal extent of these localities is shown on figure 31.

The Shiloh locality, which was discovered by drilling test well Mf-5A, coincides with an elongated, crescent-shaped synclinal subsurface depression in the bedrock. The principal aquifer is the Ridley Limestone, which extends to a depth of over 100 feet. The most likely occurrence of large solution openings is within the lower part of the formation. To explore the full potential of any proposed well site within the perimeter of this locality as shown on figure 31, test drilling should extend at least to the depth of the bottom of the Ridley and into the underlying Pierce Limestone.

Based on the results of drilling and pump testing well Mf-5A, a typical production well should be capable of yielding between 200 and 300 gal/min. Hence, as few as three such wells would be required to produce a million-gallon-per-day supply. Just how many production wells could be operated successfully within the areal limits of this locality is not known. However, judging from the flow of Bushnell Spring which is, in all probability, derived chiefly from ground water stored within the bedrock depression, it is conceivable that strategically placed production wells could divert most of the water that otherwise would be discharged by the spring. Hence, the Shiloh locality can be expected to supply from 5 to 8 Mgal/day.

The Overall Creek locality (fig. 31) was discovered by drilling test well Mf-14. This locality consists of a long narrow belt centered along a linear feature which is visible on low-level aerial photographs. The trend of this belt and the linear feature it embodies is northwest-southeast, parallel to the direction of one of the major joint sets in the limestone bedrock. The position of the linear feature is marked on the land surface by the alignment of a series of elongated sinkholes. Hence, it is believed that the linear feature represents the trace of a solution-enlarged vertical rock fracture to which is connected an extensive network of horizontal solution openings. In all likelihood, these horizontal solution openings extend outward from the main vertical opening for a distance of possibly as much as 1000 ft (table 2). Thus, wells located less than 1000 ft from the linear feature would more than likely penetrate several horizontal openings. For example, well Mf-14 which is about 500 ft from the linear feature penetrated several openings between depths of 105 and 205 ft below land surface. The most productive zone penetrated was between depths of 166 and 170 ft.

Judging from the yield of test well Mf-14, individual production wells in the Overall Creek locality should be capable of producing 100 to 200



EXPLANATION

- High yielding Survey test wells
- High yielding wells
- Areas of high yielding wells
- Areas showing high potential for ground-water development

Figure 31. - Localities where test drilling indicates a high potential for the development of ground-water supplies from wells, and areas where the percentage of high yielding wells (50 gal/min or more) is much larger than average. (Burchett and Moore, 1971, p. 21).

gal/min. Conceivably, as many as 20 production wells could be installed within the Overall Creek locality to provide a total water-supply ranging from 3 to 6 Mgal/day.

CONCLUSIONS

Ground-water supplies in the Murfreesboro area appear to be adequate in quantity and quality for consideration as a supplemental source of potable water to meet the areas rising demand. The results of test drilling indicate that multimillion gallon supplies could be developed from properly located wells in the Shiloh and Overall Creek localities. The Shiloh locality has the potential to supply 5 to 8 Mgal/d from 15 to 20 strategically placed wells. The Overall Creek locality has the potential to supply 3 to 6 Mgal/d from 20 to 25 wells.

Some local springs could be used as supplemental sources of water supply provided surface storage facilities are constructed to offset the minimum flows during dry periods. However, the flow of Fox Camp Spring, which is an overflow type spring, could be increased by pumping from the pool to lower the water level and thus increase the flow of water into the spring. For example, during the severe drought in 1925, this spring was pumped at a rate of 3 Mgal/d and the water level was lowered about 18 ft.

If supplemental water supplies are to be developed from wells in the Murfreesboro area, test drilling would be needed to locate the most productive sites for production wells. As many as five test wells might be required for each proposed production well.

If springs are to be used for water-supply purposes, additional measurements would be required to evaluate the frequency and magnitude of low flows.

REFERENCES

Burchett, C. R., and Moore, G. K., 1971, Water resources in the upper Stones River Basin, Central Tennessee: Tennessee Div. Water Resources, Water Resources Ser. No. 8, 62 p.

Galloway, J. J., 1919, Geology and natural resources of Rutherford County, Tennessee: Tennessee Div. Geology Bull. 22, 81 p.

Johnson, Charles F., 1970, Water quality survey, Rutherford County, Tennessee: U.S. Public Health Service, Resource Development Internship Project, 9 p.

Miller, R. A., 1974, The geologic history of Tennessee: Tennessee Div. Geology Bull. 74, 63 p.

Millipore Corp., 1974, Field procedures in water microbiology: Millipore Corp., Bedford, Mass., Cat. no. LAB 3140/P, p. 12.

Moore, G. K., Burchett, C. R. and Bingham, R. H., 1969, Limestone hydrology in the upper Stones River basin, Central Tennessee: Tennessee Div. Water Resources, 58 p.

Moore, G. K., and Wilson, J., 1972, Water resources of the Center Hill Lake region, Tennessee: Tennessee Div. Water Resources, Water Resources Ser. No. 9, 77 p.

National Academy of Sciences and National Academy of Engineering, 1973, Water quality criteria 1972: U.S. Environmental Protection Agency Ecological Research Ser. Rept., EPA R3-73-033, 594 p.

Newcome, Roy, Jr., 1958, Ground water in the Central Basin of Tennessee, a progress report: Tennessee Div. Geology Rept. Inv. 4, 81 p.

Newcome, Roy, Jr., and Smith, Ollie, Jr., 1962, Geology and ground-water resources of the Knox Dolomite in Middle Tennessee: Tennessee Div. Water Resources, Water Resources Ser. No. 5, 43 p.

Piper, Arthur M., 1932, Ground water in north-central Tennessee: U.S. Geol. Survey Water-Supply Paper 640, 238 p.

Stiff, H. A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Jour. Petroleum Technology, Oct., p. 15.

U.S. Dept. of Commerce, 1973, Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-70, Tennessee: Climatography of the United States No. 81, 10 p.

Water Quality Criteria 1972, The Environmental Protection Agency, Washington, D.C., p. 48-104.

Zurawski, Ann, 1978, Summary appraisals of the Nation's ground-water resources, Tennessee Region: U.S. Geol. Prof. Paper 813 L.

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