Large Springs of East Tennessee

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1755

Prepared in cooperation with the Tennessee Department of Conservation and Commerce, Division of Geology and Division of Water Resources

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By P-C. P. SUN, J. H. CRINER, *and* J. L. POOLE

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library catalog card for this publication appears after page 52.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

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LARGE SPRINGS OF EAST TENNESSEE

By P–C. P. Sun, J. H. Criner, and J. L. Poole

ABSTRACT

Springs constitute an important source of water in east Tennessee, and many individual springs are capable of supplying the large quantities needed for municipal and industrial supplies.

Most of the springs in east Tennessee issue from solution openings and fractured and faulted zones in limestone and dolomite of the Knox Group, Chickamauga Limestone, and Conasauga Group. The ability of these rocks to yield a sustained flow of water to springs is dependent on a system of interconnected openings through which water can infiltrate from the land surface and move to points of natural discharge.

Ninety springs were selected for detailed study, and 84 of these are analyzed in terms of magnitude and variability of discharge. Of the 84 springs analyzed, 4 flow at an average rate of 10 to 100 cfs (cubic feet per second), 62 at an average rate of 1 to 10 cfs, and 18 at an average rate of 1 cfs or less. Of the 90 springs, 75 are variable in their discharge; that is, the ratio of their fluctuations to their average discharges exceeds 100 percent.

Mathematical analysis of the flow recession curve of Mill Spring near Jefferson City shows that the hydrologic system contributing to the flow of the spring has an effective capacity of about 70 million cubic feet of water. The rate of depletion of this volume of water, in the absence of significant precipitation, averages 0.0056 cfs per day between the time when the hydrologic system is full and the time when the spring ceases to flow. From such a curve it is possible to determine at any time the residual volume of water remaining in the system and the expected rate of decrease in discharge from that time to cessation of flow.

Correlation of discharge measurements of 22 springs with those of Mill Spring shows that rough approximations of discharge can be projected for springs for which few measurements are available. Seventeen of the springs analyzed in this manner show good correlation with Mill Spring: that is, their coefficients of correlation were 0.70 or better as compared with a perfect correlation factor of 1.00

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

Springs are important sources of water for municipal, domestic, and farm use in east Tennessee; however, many are not developed, because of their inaccessibility or the lack of information regarding their adequacy and dependable low flows available for small-industry and community supplies. A spring discharging 450 gpm (gallons per minute), or about 1 cfs (cubic foot per second), is capable of supplying a town of 6,500 population, if one assumes a per capita consumption of 100 gpd (gallons per day). The 90 springs described in this report were selected for study because their average yield was estimated to be 450 gpm or more.

The primary purpose of the investigation has been to study the hydrologic characteristics of some of the larger undeveloped springs in east Tennessee, their variations in discharge, and the chemical character of water from a few selected springs. An additional objective has been to interpret the continuous records of one spring for the purpose of predicting flow from other springs in similar geologic and hydrologic settings. Although completely satisfactory correlations of this type could not be made on the basis of available data and records, the study contributed greatly to the knowledge of the relation of springs to geology, precipitation, and the general ground-water conditions.

Fieldwork for this investigation began in 1950 as a continuation of the reconnaissance of ground-water resources of east Tennessee, in which more than 960 springs were observed and described. The present study included the selection of little-used representative springs whose average discharges were initially estimated to exceed 450 gpm and therefore are considered to be adequate for moderate industrial or small municipal supplies. Ninety such springs were measured monthly for periods of 1 to 4 years, water samples were collected from typical springs for chemical analysis, and observations made as to color and temperature of the water and geologic settings of the springs. Records of discharge collected throughout the study show that the average flow from 62 of the 90 springs was greater than 450 gpm.

This investigation was made by the U.S. Geological Survey as a part of the statewide program of water-resources studies in cooperation with the Division of Geology and Division of Water Resources, Tennessee Department of Conservation. Fieldwork was done in cooperation with the Division of Geology prior to the establishment of the Division of Water Resources, and this report was prepared under the joint cooperative program which was initiated in July 1957.

PREVIOUS INVESTIGATIONS

As a result of the drought of 1930, considerable interest was shown in springs in east Tennessee which served as sources of domestic and municipal water supplies. Accordingly, the U.S. Geological Survey initiated a study in March 1931 in which all springs known to be discharging 1,000 gpm or more were measured during March, July, and the latter part of October or first part of November. Discharge from more than 100 springs, measured at the end of a long drought, provided valuable information regarding the dependable low-water yield and the hydrologic characteristics of some of the larger springs in east Tennessee. These data are given in reports by the U.S. Geological Survey (1933) and by De Buchananne and Richardson (1956). Additional measurements were published by the U.S. Geological Survey (issued annually).

A reconnaissance of the ground-water resources of east Tennessee was begun in 1947, fieldwork completed in 1953, and the results published in 1956 (De Buchananne and Richardson, 1956). More than 960 springs are described in this study, furnishing basic information on their hydrologic settings and laying the groundwork for further detailed studies. Selection of the 90 springs described in the present report was based on data gathered as a part of this reconnaissance. A geologic mapping program was conducted concurrently with the ground-water study in order to provide detailed coverage for east Tennessee and information as to the geologic source of the principal springs (Rodgers, 1953).

GEOGRAPHY

LOCATION AND DESCRIPTION OF THE AREA

The area described in this report is the part of Tennessee lying east of the Cumberland Plateau and includes the Tennessee parts of the Blue Ridge and the Valley and Ridge physiographic provinces (fig. 1).

The Blue Ridge province is a narrow strip along the east boundary of Tennessee, characterized by a series of rugged northeastward-trending mountain ranges whose altitudes range from 1,200 to 6,600 feet above sea level. These ranges are virtually continuous and of relatively uniform altitudes, except where tributaries of the Tennessee River have cut deep, steep-sided valleys. The region is little developed and sparsely inhabited because of the rugged topography and because many hundreds of square miles have been reserved for park and recreational facilities as a part of the Cherokee National Forest and the Great Smoky Mountains National Park.

The Valley and Ridge province is a belt of parallel northeastward-trending ridges and valleys lying between the Cumberland Plateau and the Blue Ridge province (fig. 1). The average width of the province is about 40 miles in Tennessee and the altitude generally ranges from about 1,500 feet at the northern Tennessee border to about 700 feet at the southern border. It is a region of complex geologic structure, in which the topography is controlled by faults, and the alternating ridges and valleys are underlain, respectively, by resistant cherty limestone and dolomite and by soluble limestone and shale.

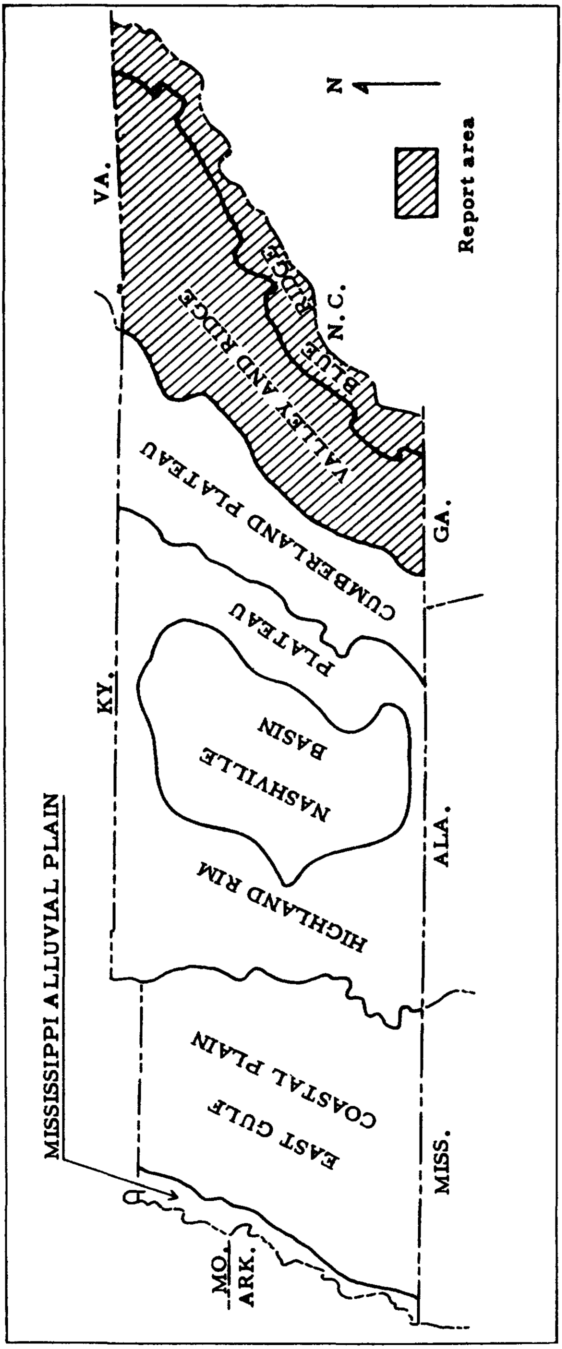

FIGURE 1.—Map showing the physiographic provinces of east Tennessee and the area described in this report.

Because of its strategic location at midpoint between the industrial North and the rapidly developing South, its excellent highway, rail, air, and water transportation networks, its electrical power facilities, and its attractions as a recreational region, east Tennessee has continued the pre-World War II economic expansion through the war years and to the present time (1962). East Tennessee includes about 20 percent of the area of the State but has more than 36 percent of the total population (U.S. Bureau of the Census, 1960). In addition, 6 of the 9 Tennessee cities with populations of more than 25,000 and 14 of the 24 cities with populations of more than 10,000 are within the boundaries of east Tennessee.

CLIMATE

The climate of east Tennessee, considered in its relation to topography, is highly variable; it has wide ranges in temperature and precipitation that are controlled largely by altitude. Because of the shielding effects of bordering mountainous regions and the remoteness of the area from the principal storm paths, the climate is characterized by relatively stable conditions, except those controlled by altitude, and by relative freedom from major atmospheric disturbances.

Mean annual temperature in the Valley and Ridge province ranges from 56.4° F, recorded at Bristol in the north, to about 60° F, recorded at Chattanooga in the south. The mean annual temperature at Knoxville airport, in the approximate geographic center of east Tennessee, is 59.3° F, based on records for the 22-year period ending in 1959. In addition to the north-south variation, the mean annual temperature is decreased by about 3° for each additional thousand feet of altitude. Thus at an altitude of 6,000 feet at the same latitude as Knoxville, the mean annual temperature would be about 15° lower than at Knoxville, or about 44° F. The mean annual temperature is significant to this study in that it is approximately the same as the temperature of ground water within 100 to 200 feet below the land surface and of the water issuing from the numerous springs in east Tennessee.

Precipitation in east Tennessee is also highly varible, ranging from the State's lowest mean of about 40 inches per year in the extreme northern part of the State in the Valley and Ridge province to the maximum of about 80 inches in the higher parts of the Great Smoky Mountains in the Blue Ridge province (Dickson, 1960, p. 2). The average precipitation in east Tennessee is 48.57 inches per year, most of which occurs during the winter and early spring. A secondary maximum of precipitation occurs in midsummer, however, in response to thundershower activity, especially in the mountains where the

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rainfall in July often exceeds that of any other month (Dickson, 1960, p. 2).

Precipitation affects the discharge of the springs relatively soon after it occurs, thus influencing the springs' variability and their value as sources of water supplies. Records of precipitation before, during, and after the investigation indicate that the measurements of discharge from the selected springs were made during a relatively dry period.

GEOLOGY AND HYDROLOGY OF SPRINGS

SUMMARY OF GEOLOGIC CONDITIONS

East Tennessee is underlain by metamorphic rocks and by highly deformed sedimentary rocks ranging in age from Precambrian to Mississippian. Formations in the mountainous Blue Ridge province consist of a basement complex of granite, schist, and gneiss of Precambrian age and include the Ocoee Series, also of Precambrian age, which consists of slate, graywacke, shale, sandstone, and conglomerate.

An intervening belt of ranges forms a transitional zone between the Blue Ridge and the Valley and Ridge provinces. It is a belt in which the linear structural pattern of the Valley and Ridge province is predominant, but it is underlain by formations that are more characteristic of the Blue Ridge province. These include the Unicoi, Hampton, and Erwin Formations of the Chilhowee Group of Early Cambrian and Early Cambrian(?) age, which are found as outliers lying west of the main mountain mass of the Blue Ridge province.

The formations underlying the Valley and Ridge province are of sedimentary origin and are composed largely of dolomite, limestone, and shale ranging from Early Cambrian to Mississippian in age. Formations of the Conasauga and Knox Groups and the Chickamauga Limestone are predominant, but broad belts also are underlain by the Rome Formation, Shady Dolomite, and limestone and shale of Ordovician through Mississippian age (table 1).

Geologic formations referred to in this report (table 1) are described by De Buchananne and Richardson (1956, p. 10–14, 29–50) and Rodgers (1953, p. 21–110, pl. 1–15).

In general, the broad valleys of the Valley and Ridge province are underlain by limestone and shale of the Conasauga Group of Cambrian age and Chickamauga Limestone of Ordovician age. The high ridges are formed on more resistant rocks, principally cherty dolomite and limestone of the Knox Group, sandstone members of the Rockwood and Rome Formations, and other formations. The linear pattern of the geologic structure in the Valley and Ridge province, consisting of northeastward-trending parallel ridges and valleys, resulted from compressive stresses which folded and faulted the sedimentary rocks and resulted in the predominant southeasterly dip of

TABLE 1.—*Geologic formations in east Tennessee*

System	Group	Formation or other subdivision		
Mississippian		Pennington Formation		
		Newman Limestone		
		Fort Payne Chert		
		Chattanooga Shale		
Devonian		Hancock Limestone		
Silurian		Rockwood Formation		
Ordovician	Knox	Sequatchie Formation		
		Chickamauga Limestone	Reedsville Shale	
			Moccasin Formation	Sevier Shale
			Ottosee Shale	
			Holston Formation	
			Lenoir Limestone	
		Newala Formation	Mascot Dolomite	Jonesboro Limestone
			Kingsport Formation	
		Longview Dolomite		
		Chepultepec Dolomite		
Cambrian		Copper Ridge Dolomite		
	Conasauga	Nolichucky Shale		
		Honaker Dolomite	Maryville Limestone	
			Rogersville Shale	
			Rutledge Limestone	
		Pumpkin Valley Shale		
		Rome Formation		
		Shady Dolomite		
Early Cambrian(?)		Erwin Formation		
		Hampton Formation		
		Unicoi Formation		
Precambrian		Ocoee Series, undivided		
		Crystalline complex		

the formations. This structure controls the topography which in turn, in addition to lithology and secondary openings in the rocks, controls the occurrence of the numerous springs in the region. None of the springs in east Tennessee seem to be closely related to faults, although in some places faults may influence the direction of ground-water movement and thus indirectly control, in part, the volume and the variability of spring discharge.

HYDROLOGIC SETTINGS OF SPRINGS

Most of the springs described in this report issue from solution openings in formations of the Knox Group, Chickamauga Limestone, or limestones of the Conasauga Group. Some issue from highly fractured and faulted zones, but they are less common and generally are smaller in the volume of their discharge. Some springs issue from the base of the water-bearing formation just above relatively impermeable shale which tends to prevent the downward movement of water (fig. 2). Most of the shale formations in the Valley and Ridge province may yield small quantities of water in seep areas, but they generally do not support springs of significant size. In some areas springs issue in valleys underlain by shales. Because of their topographic position and the character of the rock in which they occur, such springs must derive water from adjacent ridges of carbonate rocks, and the shale, which generally is fractured and jointed, acts primarily as a conduit and not as a reservoir.

SPRINGS

A spring is a natural issue of ground water at the land surface from a ground-water reservoir that is filled to the level of existing natural openings through which discharge can occur. All the springs

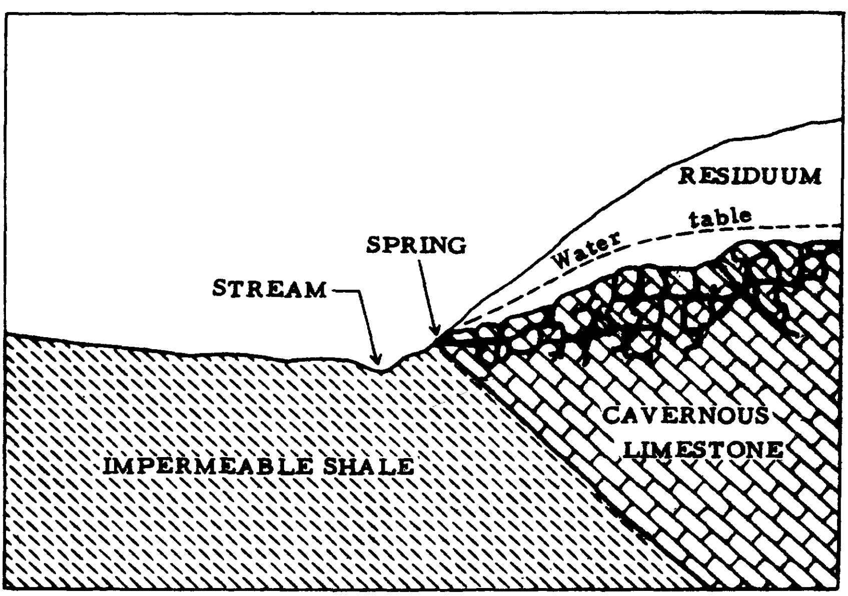

FIGURE 2.—Diagram showing the relation between topography, lithology and structure of rocks, and the locations of springs.

in east Tennessee are gravity springs, caused by an "outcrop" of the water table, and flow under the action of gravity, as a surface stream flows down its channel. Those in east Tennessee are further classified as follows: (1) Depression springs, which flow because the land surface extends down to the water table; (2) contact springs, whose water flows to the surface from permeable material at the outcrop of an underlying less permeable material that impedes the downward percolation of the water; and (3) tubular springs, which flow from relatively large openings in the rocks.

GROUND WATER AND ITS RELATION TO SPRINGS

Most of the rainfall in east Tennessee becomes surface runoff in streams or is returned to the atmosphere by evaporation and transpiration by plants. A part of the rainfall, however, percolates downward through the mantle of soil and decayed rock into underlying water-bearing formations where it fills voids between the rock particles and secondary openings created by solution or jointing. It remains in the ground, moving slowly downgradient through these interconnected openings, until withdrawn through wells or discharged naturally into streams or springs at lower altitudes.

Water-bearing formations are characterized by their capacity to store and transmit water, which, in turn, is related to the number, size, and degree of interconnection of interstitial pores and secondary openings. The limestones and dolomites of east Tennessee have little or no primary porosity, but large volumes of water are stored in the numerous solution cavities and openings along faulted, jointed, and fractured zones. The ability of such rock formations to yield a sustained flow of water to wells and springs is therefore dependent on a system or network of interconnected openings through which water can infiltrate from the land surface and be transmitted to points of natural or artificial discharge.

Water entering the ground-water reservoir directly from precipitation is relatively free of dissolved chemical constituents and is therefore capable of maximum development of solution openings in the soluble limestones and dolomite of east Tennessee. For this reason, solution openings, or cavities, are larger and greater in number near the top of the saturated zone. The dissolving capacity of water is reduced as chemical saturation is approached. Generally, saturation is a function of depth and time that water remains in the ground, and water that has reached greater depths is less effective in producing large solution cavities.

USE AND YIELD OF WATER FROM SPRINGS

In 1959, 39 of the 95 municipal water-supply systems in east Tennessee used water derived solely from springs, and 15 others used

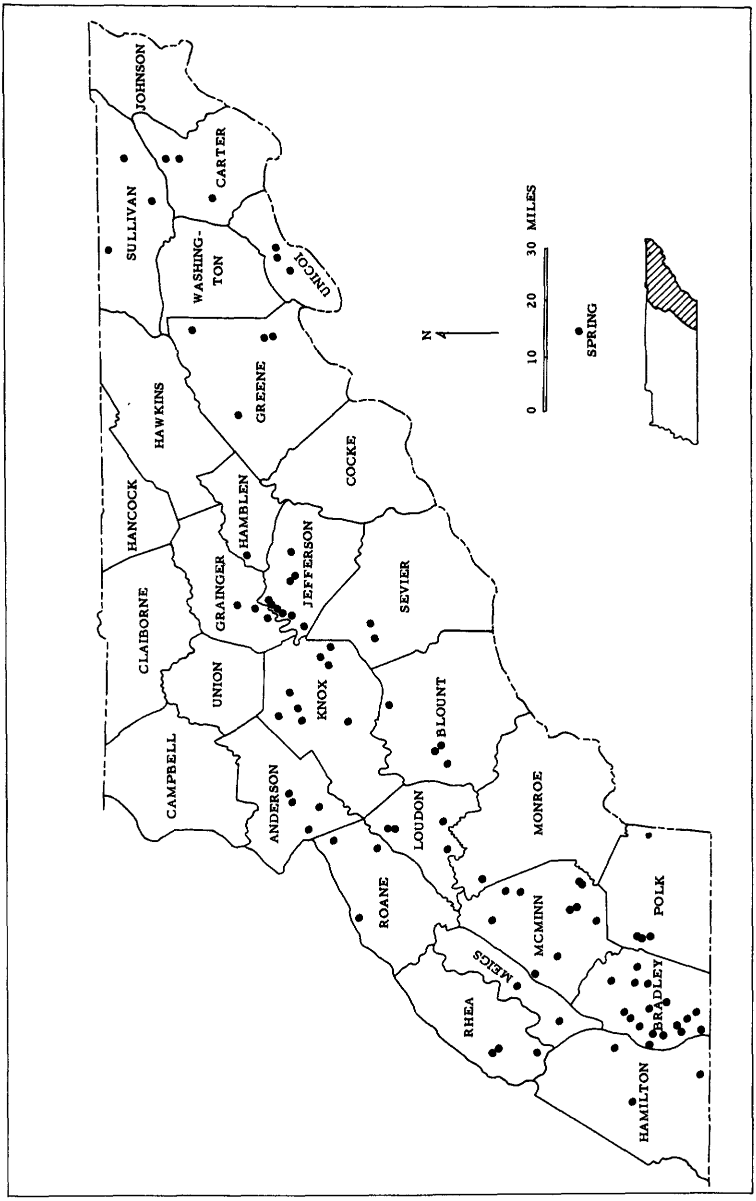

FIGURE 3.—Map of east Tennessee showing counties and locations of selected springs.

spring water as a supplemental source. The average daily use of water for municipal supplies was about 100 million gallons, of which about one-half was pumped from the Tennessee River for use by the cities of Chattanooga and Knoxville. Of the remaining 50 mgd (million gallons per day), about one-third, or 17 mgd, was supplied by springs. In addition, a large amount of water from springs is used for irrigation of crops and pasture during the drier summer months. Much of the water used for irrigation is pumped from streams that are sustained in large part by spring flow; however, the total quantity used and the percentage that comes directly from springs are not known.

More than 960 springs were observed and described by De Buchananne and Richardson (1956, p. 60–391). During their reconnaissance, measurements were made of discharge from many of the springs and estimates made of flow from the remainder. The total of these measurements was about 265 mgd. All but a few of the measurements were made during the relatively dry period June through September; thus, this volume represents a near-minimum, or at least a below-average, total for the 960 springs considered. The 960 springs described by De Buchananne and Richardson (1956, p. 60–391) are classified according to the magnitude of their flow as follows:

Discharge (gpm)	*Number of springs*
<100	653
100–450	155
450–4,500	147
4,500–45,000	5
>45,000	0

For the present study, 90 of the larger springs in east Tennessee (fig. 3), most of which are not in use, were selected on the assumption that each discharged at an average rate of 450 gpm or more. On the basis of a series of measurements, it was observed that the discharge of 84 of the 90 springs was as follows: 2 averaged less than 100 gpm; 16 ranged from 100 to 450 gpm; 62 ranged from 450 to 4,500 gpm; 4 ranged from 4,500 to 45,000 gpm. None averaged more than 45,000 gpm. Six of the springs were not analyzed in detail.

The following table indicates the approximate order of magnitude of the total discharge of the 84 springs, based on monthly measurements for each spring made during the period of record. These averages are fairly representative, having been determined through both wet and dry seasons, but are perhaps lower than normal because the period of record was during the moderate drought of 1951–54.

Average of—	Flow		
	Total (gpm)	Average (gpm)	Total (mgd)
Minimum flows	36, 040	430	52
Average flows	120, 165	1, 465	173
Maximum flows	278, 290	3, 310	401

Springs are excellent sources of water for future development in east Tennessee; however, the variability of their flow may prevent full utilization unless adequate storage facilities are provided. If there is no storage to provide water during periods of peak use and minimum yield, which usually are concurrent, a spring may be developed only to the extent of its lowest dependable flow. If adequate storage facilities are provided, however, development could approach the average annual flow. Inaccessibility of many of the springs and the

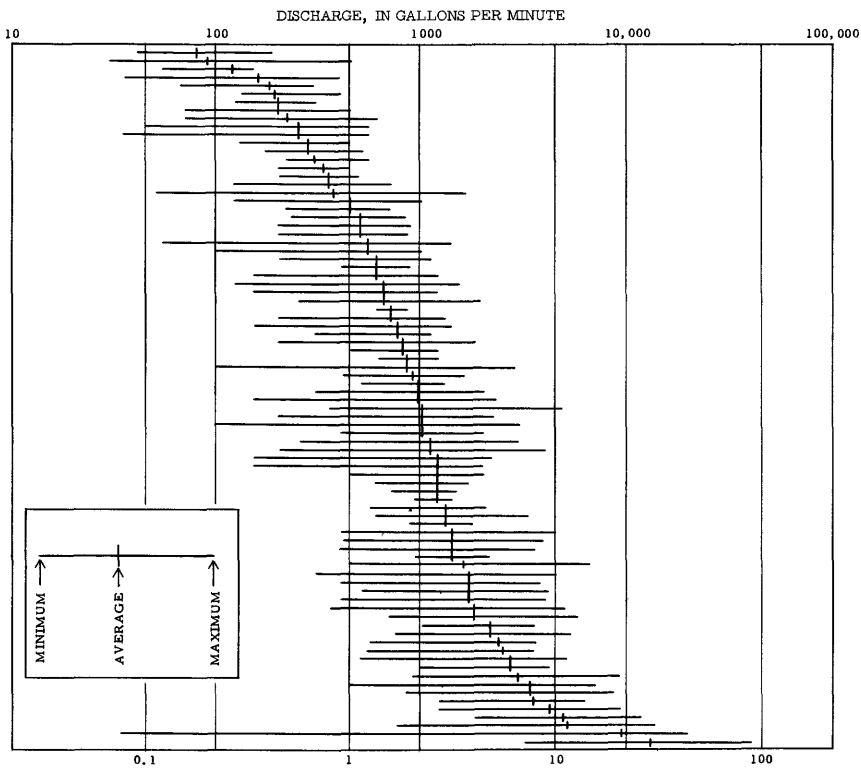

FIGURE 4.—Chart showing the minimum, average, and maximum discharges of 84 springs.

relatively great distances from points where the water is needed are also factors limiting their utilization.

MAGNITUDE AND VARIABILITY OF SPRINGS

A classification of springs based on the magnitude or volume of their average flows has been made by Meinzer (1927, p. 3). This classification is shown in the following table:

Magnitude	*Average discharge*	*Magnitude*	*Average discharge*
First..............cfs..	>100	Fourth...........gpm..	100–448.8
Second............do..	10–100	Fifth..............do..	10–100
Third..............do..	1–10		

NOTE.—448.8 gpm equals 1 cfs.

Figure 4 shows graphically the discharge of 84 of the 90 selected springs in east Tennessee for which records of minimum, average, and maximum flows are available. The horizontal line shows the range of discharge, and the vertical line indicates the average discharge for the spring's period of record. As shown by this chart, the 84 springs may be grouped according to magnitude as follows:

Magnitude	*Number of springs*	*Magnitude*	*Number of springs*
First	None	Fourth	16
Second	4	Fifth	2
Third	62		

Springs also are classified according to their variability, defined by Meinzer (1923, p. 53) as the ratio of their fluctuations to their average discharges. Variability is expressed by the formula

$$V=100\frac{a-b}{c},$$

where V=variability, expressed as a percentage;
a=maximum discharge;
b=minimum discharge;
c=average discharge.

Although the absolute variability of a spring can be determined only from a long period of record, it is convenient to speak of the variability within a designated period. The value computed for each spring in this study is for its respective period of record. According to Meinzer (1923, p. 54), springs having a variability of less than 25 percent are classed as constant, those having a variability of 25 to 100 percent are subvariable, and those having a variability greater than 100 percent are variable. Of the 90 selected springs in east Tennessee, none are constant, 15 are subvariable, and 75 are variable. Figure 5 shows the

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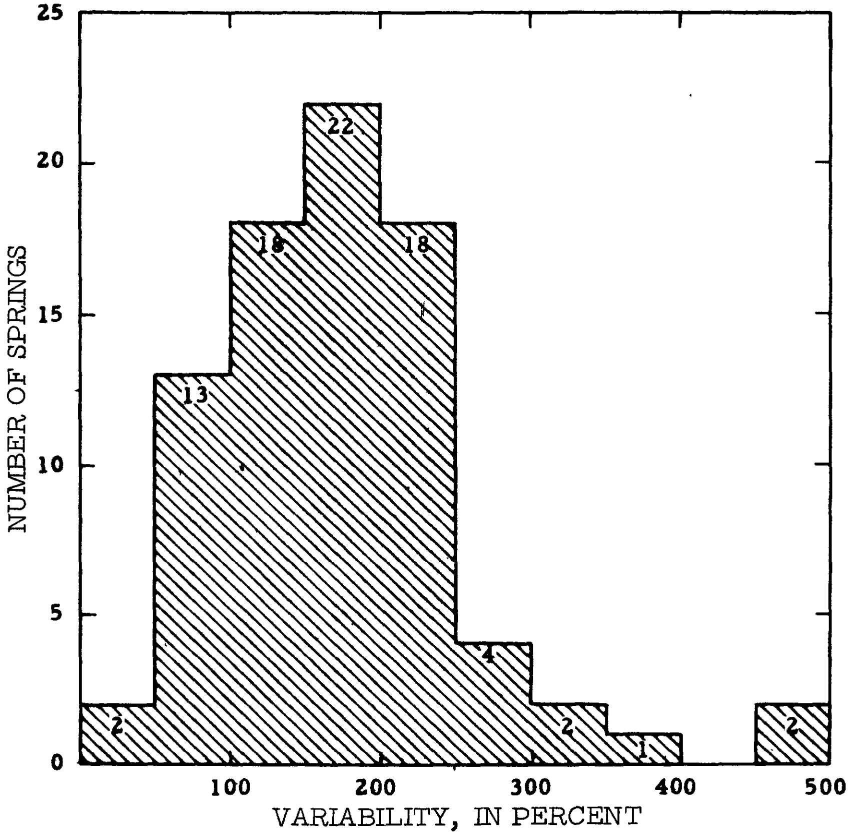

FIGURE 5.—Graph showing the variability of 82 selected springs of the second third, and fourth magnitudes.

variability of the 82 springs of second, third, and fourth magnitudes.

A scatter diagram (fig. 6) of average discharge plotted against variability shows that variability tends to increase as discharge increases. The small degree of correlation exhibited, however, does not warrant any attempt to relate variability to average discharge.

In general, the least variable springs in east Tennessee issue from shale of the Conasauga Group, and all these are of relatively small magnitude. The most variable springs have their sources in solution cavities in limestone or dolomite. These cavities are of such varying size and degree of interconnection that, as the water table fluctuates from wet to dry seasons, spring discharge fluctuates in accordance with the ability of the saturated cavities to transmit the water to the spring orifices.

QUALITY OF WATER FROM SPRINGS

Except for its hardness, which generally exceeds 100 ppm (parts per million), quality of water from springs in east Tennessee is good

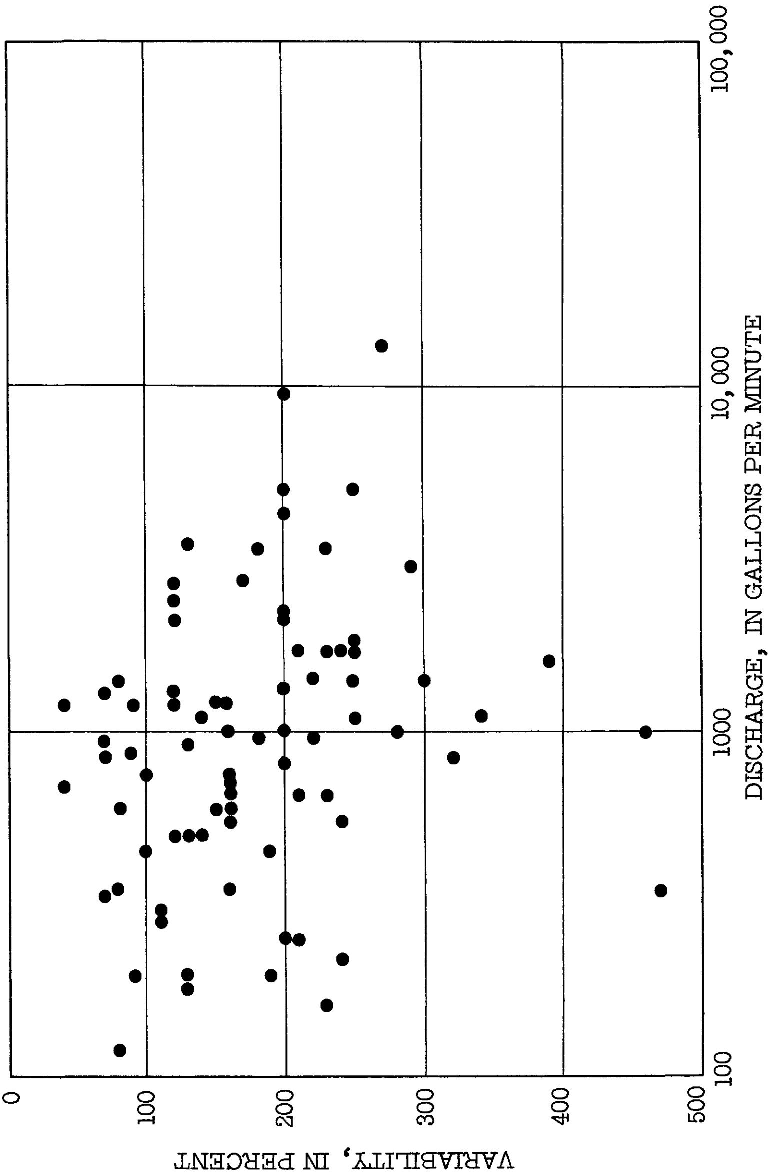

FIGURE 6.—Scatter diagram showing the relation between variability and discharge of 82 selected springs.

TABLE 2.—*Chemical analyses of water from representative springs in east Tennessee*

[Analyses by U.S. Geological Survey]

County	Name of spring	Date of collection	Chemical constituents, in parts per million										Hardness as $CaCO_3$		pH	Specific conductance
			Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)		Calcium, magnesium	Noncarbonate		
Blount	Lovingood	5-20-50	0.02	26	14	2	.9	144	4	3.0	2.7		122	4	7.4	237
Carter	Big	3-17-48	--------	38	9.8	4	.2	154	3	3.0	5.1		135	--------	--------	288
Grainger	Buffalo	4-12-50	.01	34	19		.2	188	4	2.8	1.6		163	9	8.5	289
Greene	Seaton	9-28-49	.05	31	4.5		.4	109	3	2.0	1.7		96	6	8.4	176
Hamblen	Panther	4-12-50	.02	36	16		.7	177	3	3.0	5.8		156	11	8.3	285
Hamilton	Anderson	12-16-48	.05	18	5.1	4	.7	86	2	2.5	--------		146	6	7.1	146
Jefferson	Mill	4-4-50	.01	40	20		.8	212	3	2.8	3.7		182	8	7.7	339
Knox	Fowler	4-18-50	.02	30	17	2	.5	173	2	1.8	2.8		143	2	8.4	268
Loudon	Allen Fine	5-2-49	.13	22	12	--------	--------	128	4	1.5	--------		104	--------	8.3	212
McMinn	Whiteside	1-19-49	.06	17	8.0	1	.2	81	3	3.8	3.9		75	9	8.0	135
Meigs	Maler	1-19-50	.10	13	4.3	1	.3	57	3	2.2	--------		50	3	7.9	101
Monroe	Kilpatrick	8-14-48	.03	24	11		.6	104	1	2.2	2.7		105	5	8.4	201
Sevier	Bailey	2-2-49	.09	16	4.5	51		200	1	2.8	--------		58	0	8.2	315
Sullivan	Wolford	3-2-51	.02	22	16	21		196	3	1.2	--------		121	0	8.2	302
Unicoi	U.S. Fishery	3-10-48	--------	18	9.5	2	.2	81	4	3.0	1.8		84	--------	--------	165

to excellent for most uses. Table 2 shows chemical constituents and physical properties of water samples collected from 15 typical springs in east Tennessee. None of the analyses show any constituent present in concentrations sufficient to be detrimental in normal uses of the water; but hardness and, in some springs, high hydrogen-ion concentration (pH) may restrict use of water for certain manufacturing processes. For a detailed discussion of the chemical constituents and physical properties of water and their effects on various uses, the reader is referred to a report by Hem (1959, p. 34–149).

Chemical quality of spring water varies considerably more than water pumped from deep wells. Increased discharge caused by shallow subsurface flow during rainy periods brings increased proportions of water that is very low in dissolved solids because of the short time the water has been in contact with earth materials. Thus, water supplies from springs require frequent monitoring of chemical content to provide for adjustment of the treatment process and for the maintenance of suitable water quality.

DISCHARGE OF GROUND WATER FROM STORAGE BY SPRINGS

Except for relatively short periods of shallow subsurface runoff immediately after a rain, water discharged by a spring is derived from ground-water storage and is referred to as the base flow of that spring. A flow recession curve may be constructed from continuous records of discharge to show the rate of decline of discharge in the absence of precipitation and, thus, the rate at which water in storage is being depleted. Analysis of the curve also shows the amount of water remaining in storage. Such a curve (fig. 7) has been constructed for Mill Spring, near Jefferson City, from records continuous for a period of 5 years, 2 years of which are shown in figure 8.

The flow recession curve for Mill Spring (fig. 7) is divided into two major parts. The upper part shows spring discharge to be more than 6 cfs and represents the wet season, during which the decline in discharge is about 0.3 cfs per day. The base part shows discharge to be less than 4.5 cfs and represents the dry season, during which the rate of decline is about 0.03 cfs per day. The transitional part of the curve, which has greater curvature, represents the time of unstable discharge, during which the percentage of ground-water flow increases as surface runoff decreases. This part of the curve may vary greatly in time from one spring to another and may be absent from the curves for some springs.

In practice, the base part of a flow recession curve may be used directly to determine future discharge rates of the spring it represents in the absence of appreciable precipitation. Mathematical analysis gives an indication of the porosity of the water-bearing formation

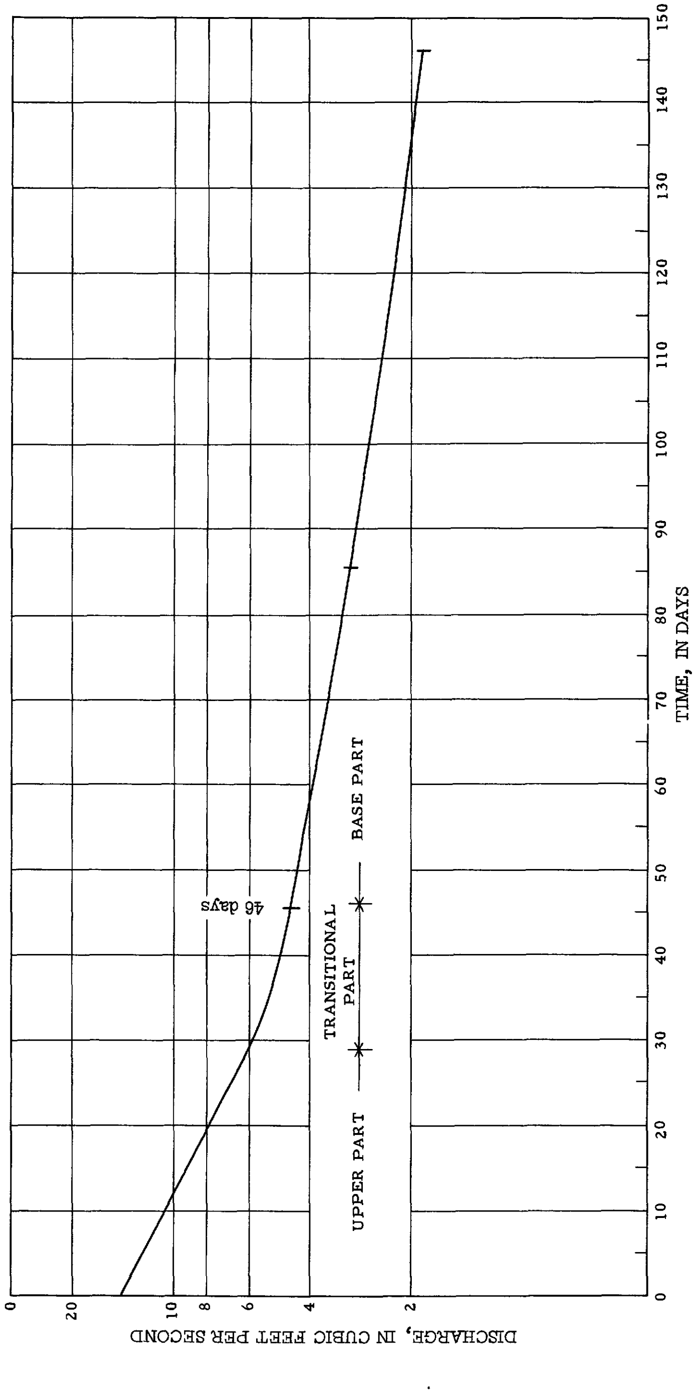

FIGURE 7.—Flow recession curve for Mill Spring near Jefferson City, Jefferson County.

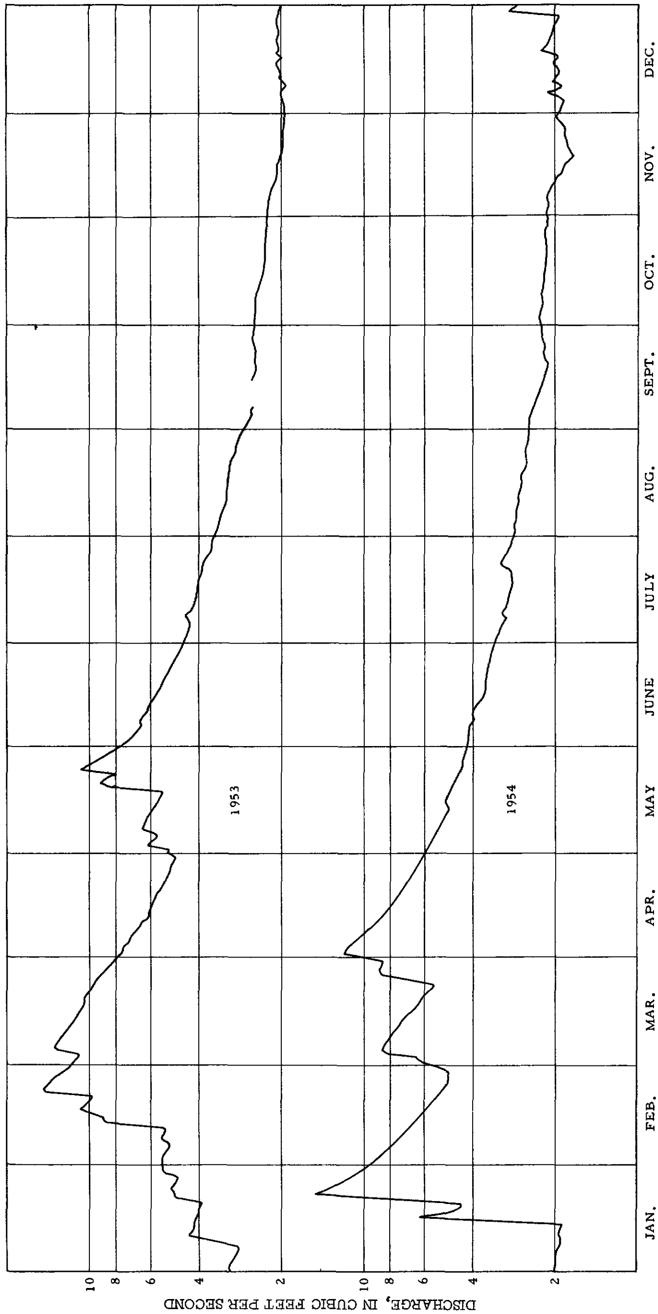

Figure 8.—Hydrograph of discharge from Mill Spring, Jefferson County, for 1953 and 1954.

supplying the spring and the rate of depletion of the available water in storage in the formation.

The base part of the flow recession curve can be analyzed by a method described by Ibrahim Abd-El-Al (1953, p. 60–76) to determine the coefficient of exhaustion or rate of depletion of the ground-water reservoir. The coefficient of exhaustion is in inverse proportion to the magnitude of the ground-water reserves on which the spring draws (Ibrahim Abd-El-Al, 1953, p. 67). The following formula is used to determine this rate:

$$q=\frac{q_o}{(1+at)^2}, \text{ transposed to } a=\frac{\left(\sqrt{\frac{q_o}{q}}\right)-1}{t} \tag{1}$$

where

a=coefficient of exhaustion or rate of depletion per day;

q_o=greatest discharge after cessation of surface runoff, in cubic feet per second;

q=discharge at any time after q_o, in cubic feet per second;

t=time between q_o and q, in days.

The coefficient of exhaustion for Mill Spring thus is determined to be 0.0056 cfs for 1 day, based on a value of 4.5 cfs for q_o and any value of q (fig. 7).

By integrating the base part of the recession curve (Ibrahim Abd-El-Al, 1953, p. 69), the residual volume (V), in cubic feet, of the water in storage to be eventually discharged by Mill Spring can also be approximated.

$$V=\int_o^\infty q dt=\int_o^\infty \frac{q_o dt}{(1+at)^2}=\frac{q_o}{a}. \tag{2}$$

For example, at the beginning of the base part of the recession curve (q_o=4.5 cfs), Mill Spring is indicated as having an estimated residual volume of about 70 million cubic feet of water in storage that will be discharged by the spring in the absence of precipitation and before spring flow ceases.

The validity of this method for determining residual volume may be checked from continuous records of discharge for any period. From the recession curve it was determined that 13 million cubic feet of water was discharged from ground-water storage during the 40-day period in which the flow declined from 4.5 cfs to 3 cfs and that average flow during the period was about 3.8 cfs. Substitution of the new values of q_o and a in equation (2) gives a new residual volume (V) of 57 million cubic feet in storage which remains to be discharged by Mill Spring. The new residual volume plus the volume of water discharged in the 40-day period total 70 million cubic feet, or the maximum volume of water in storage before depletion began.

By determining the volume of water in storage, one can estimate the porosity of the reservoir rocks contributing water to Mill Spring. As shown by the geologic map and section (fig. 9), Mill Spring lies in a shallow syncline open to the southeast. Formations underlying the area include, from youngest to oldest, Copper Ridge Dolomite,

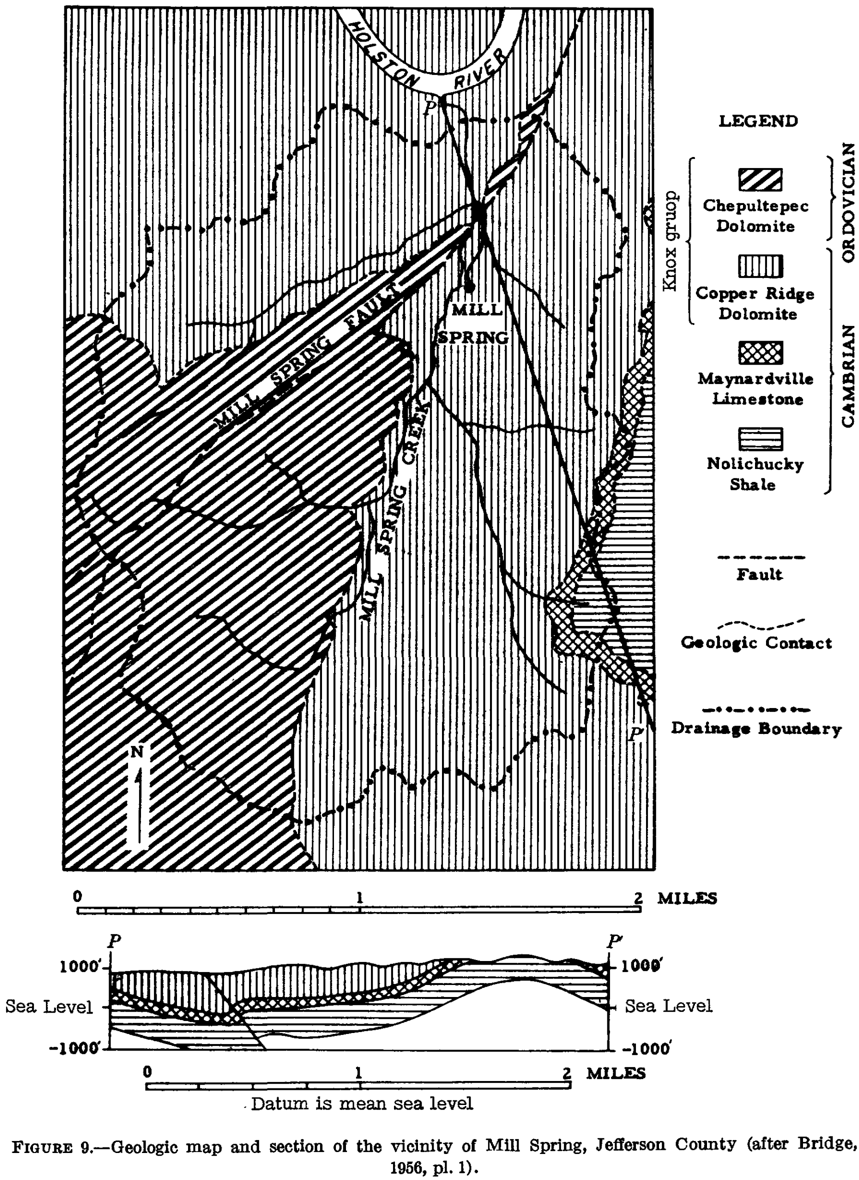

FIGURE 9.—Geologic map and section of the vicinity of Mill Spring, Jefferson County (after Bridge, 1956, pl. 1).

Maynardville Limestone, and Nolichucky Shale. The limestones and dolomites are presumed to be of similar porosity and to be a hydrologically connected unit. Because of the presence of the underlying Nolichucky Shale and the geologic structure and topography of the area, it is assumed that no water can move into the drainage basin by underflow. Thus, virtually all the water discharged by Mill Spring must be derived from precipitation falling within the drainage basin of Mill Spring Creek. The volume of rock lying within the drainage basin and above the outlet of Mill Spring is calculated to be about 7,900 million cubic feet. Of this volume, about 70 million cubic feet (previously determined volume of ground water in storage) is occupied by water in pore spaces or other openings capable of yielding water. Thus, the effective porosity of the reservoir rocks supplying water to Mill Spring is approximately 0.9 percent. This estimate, though based on assumptions made on the degree of interconnection of openings in the rocks, indicates, at least, the order of magnitude of the rocks' porosity.

CORRELATION OF SPRING DISCHARGES

In order to compare the hydrologic similarity of springs, the monthly discharges of 22 springs were each correlated for more than 20 months with those of Mill Spring. An example of the technique used is given in figure 10, which shows the hydrologic relation between Mill Spring and Bacon Spring. This technique makes use of the standard procedure for correlating stream discharges (Searcy, 1960, p. 76–77). Discharge measurements of the springs were plotted against those of Mill Spring for approximately the same times of measurement. Mill Spring was selected because it seems to be representative of springs in the Valley and Ridge province and because of the long-term discharge records available. Discharges were converted to cubic feet per second for ease of plotting. The center line in figure 10, called the curve of correlation, was drawn through the plotted points to represent the mean. Two lines were drawn parallel to the curve so as to enclose two-thirds of the points. The distances from the curve of correlation to the parallel lines above and below represent two standard errors.

To determine the degree of correlation of a spring with Mill Spring, standard deviation (S_y) and standard error (S_e) are determined by measuring their values as shown in figure 10 and computing the coefficient of correlation (r) by the following formula:

$$r=\sqrt{1-\left(\frac{S_e}{S_y}\right)^2}.$$

For example, by use of the correlation graph shown in figure 10,

$$r=\sqrt{1-\left(\frac{0.079}{0.378}\right)^2}=0.98.$$

Ordinarily S_e and S_y are measured in log units and may be read directly from the 20 scale of an engineers scale for 5-inch log-cycle paper such as that shown in figure 10. Generally, one standard error (S_e) of 0.12 log units or less and a coefficient of correlation (r) of 0.70 or more are considered satisfactory correlation. A coefficient of correlation of 1.00 is perfect. Thus, the sample computation for figure 10 indicates that Bacon Spring correlates well with Mill Spring.

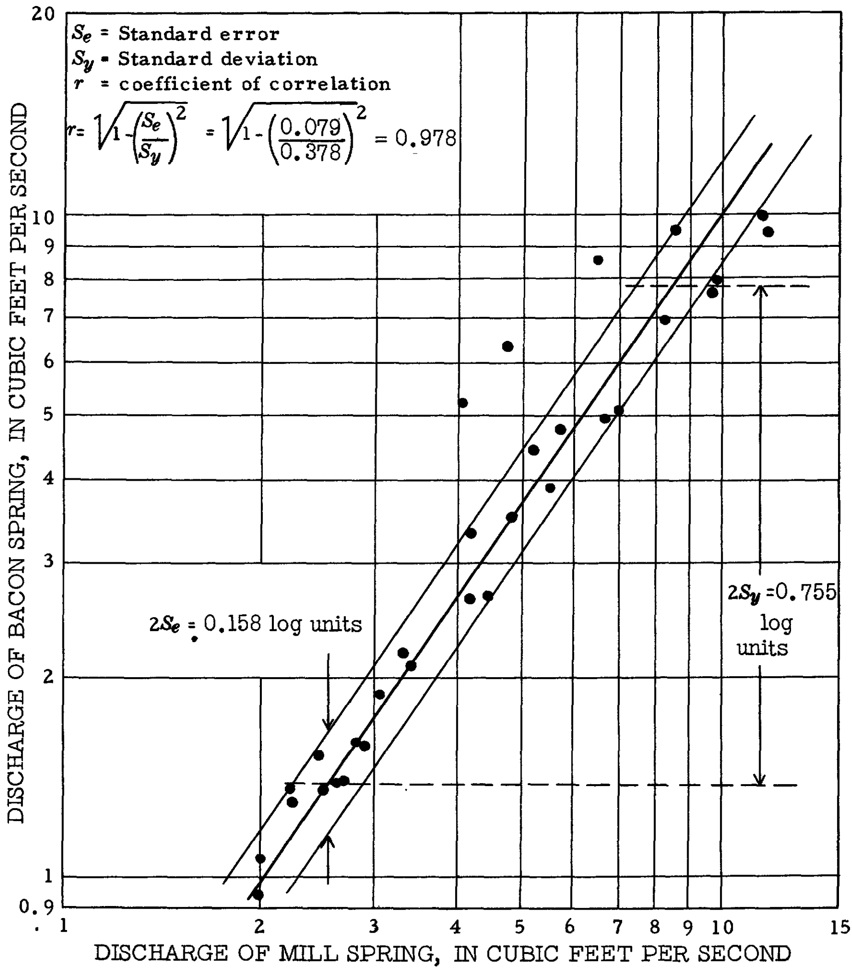

FIGURE 10.—Correlation graph for Bacon Spring, Anderson County, and Mill Spring, Jefferson County.

Of the 22 springs which were correlated with Mill Spring, 17 correlate well; that is, the required number of discharge measurements fall within the range of one standard error from the curve of correlation, and the coefficients of correlation are 0.70 or greater.

No relation is apparent between stratigraphy and the degree of correlation or between the degree of correlation and the magnitude of the springs tested. Poor correlation, however, does not necessarily mean hydrologic dissimilarity. The short period of record during a relatively dry period may be an important factor affecting correlation of spring data. Recession curves for each spring, similar to the one for Mill Spring (fig. 7), would be necessary to bring out and evaluate similarities.

APPLICATION OF BASE-FLOW ANALYSIS AND SPRING-DISCHARGE CORRELATIONS

The values for the coefficient of exhaustion and residual volume and the flow recession curve are useful in the determination, at any time of the anticipated rate of discharge and of the volume of water left in the hydrologic system to support the spring flow. In the face of an extended drought, the rate and duration of flow from a spring can be closely approximated; if the flow is expected to decrease to less than the water required plans can be made in advance for development of other sources or for more conservative use of existing supplies.

Measurements of spring discharge made for construction of a flow recession curve also provide a means of predicting discharge from other springs in similar geologic hydrologic settings. The low-flow characteristics of a spring with periodic or short-term records can be determined approximately by correlating the discharge of the spring with that of another similar spring for which accurate long-term records are available. This method or correlation, as previously described, is most useful in a region where numerous springs constitute a major source of water supply and where only a minimum of discharge records are available or obtainable.

DESCRIPTIONS OF SPRINGS

Table 3 contains information regarding the geologic setting and magnitude and variability of discharge of the 90 springs selected for this study. Generalized maps (figs. 11–30) of the east Tennessee counties show the locations of the springs and the U.S. Weather Bureau stations or towns for which precipitation data are presented for the period of spring-flow record.

In the descriptive information, springs that have been referred to by other names in other publications are so indicated, and appropriate references are made by footnotes. Descriptions of geologic settings of the springs indicate, insofar as known, the source formation and the relation of geologic structure or formation contacts to the occurrence of the springs. Periods of monthly measurements, data of miscellaneous measurements, and maximum, average, and minimum discharges are also given. The data on average discharge are based on the period of monthly measurements only. The sources of maximum and minimum discharge measurements are indicated by footnotes. Magnitude and variability of the discharge of each spring are also based on discharge determined during the period of monthly measurements.

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TABLE 3.—*Records of springs in east Tennessee*

Name of spring	Geologic setting	Discharge							Magnitude	Variability
		Monthly	Other	Maximum		Average	Minimum			
				Gpm	Date		Gpm	Date		
Anderson County										
Bacon	Issues from a cave in a bluff dolomite of Knox Group, adjacent to contact with shale of Conasauga Group.	July 1951 to June 1954	1931 [1]	4,530	4- 1-54	1,720	420	12- 4-53	3	240
Blue	Spring pool about 50 ft in diameter; issues from fractured zone in upper part of Knox Group, adjacent to fault contact with Rome formation.	June 1950 to June 1951	September 1952	1,430	9- 6-50	533	55	9-18-52	3	250
Buress	Solution channel in Copper Ridge Dolomite of Knox Group, adjacent to contact with shale of Conasauga Group.	June 1950 to June 1951	September 1952	2,920	1-16-51	998	110	9-18-52	3	280
Smith	Orifice in Copper Ridge Dolomite of Knox Group, adjacent to contact with shale of Conasauga Group.	June 1950 to June 1952	September 1952	2,840	1-16-51	832	111	9-18-52	3	330
Blount County										
Big	In dolomite of Knox Group, adjacent to contact with Lenoir Limestone.	June 1950 to June 1952	June 1954	9,650	4-21-51	3,040	927	12- 1-50	3	290
Chambers	In shale of Conasauga Group, adjacent to contact with Rome Formation.	June 1950 to June 1952	September 1952, July 1954.	839	4- 3-51	690	597	9-23-52	3	40
Lovingood	Source rock is dolomite of Knox Group	June 1950 to June 1953	June 1954	3,510	3- 2-53	2,130	1,030	12-2-52	3	120
Morton	In shale of Conasauga Group, adjacent to fault contact with Knox Group.	June 1950 to June 1951	September 1952, June 1954.	1,330	3-22-51	934	521	9-23-52	3	90
Bradley County										
Bell Fount	In dolomite of Knox Group, near contact with Conasauga Group.	February 1950 to June 1952.	October 1952	1,280	2- 7-50	686	187	10- 1-52	3	160
Carpenter	In residuum on Maynardville Limestone of Conasauga Group, adjacent to contact with Copper Ridge Dolomite of Knox Group.	March 1950 to June 1952.	October 1952, June 1954.	1,630	12-27-51	892	373	6-18-54	3	140
Fletcher	In dolomite of Knox Group, adjacent to contact with shale of Conasauga Group.	February 1950 to June 1951.	October 1952	439	2- 6-50	90	32	10- 1-52	5	450

Flint	Openings in Lenoir Limestone	February 1950 to June 1951.	September 1952	384	2- 7-50	192	132	9-30-52	4	130
Hall	At foot of ridge formed by dolomite of Knox Group, adjacent to contact with Conasauga Group.	February 1950 to June 1951.	September 1952	533	4-24-51	310	221	9-30-52	4	100
Hardwick	In Maynardville Limestone of Conasauga Group, adjacent to contact with Knox Group.	February 1950 to June 1952.	October 1952	491	12-27-51	280	171	11-27-51	4	110
Higgins	In shale of Conasauga Group	February 1950 to June 1951.	September 1952	574	2- 7-50	257	37	9-30-52	4	170
Magnesia	In Apison Shale Member of Rome Formation.		July 1950, August 1950, September 1952.						4	
Masoner	Issues from residuum on shale of Conasauga Group.	February 1950 to June 1951.	September 1950	904	4-24-51	482	185	9-30-52	3	150
McKenzie	Issues from Maynardville Limestone of Conasauga Group.	February 1950 to June 1951.	October 1952	522	3-22-51	360	216	10- 1-52	4	90
Pullam	In residuum on Copper Ridge Dolomite of Knox Group.	February 1950 to June 1951.	October 1952	465	4-24-51	324	188	10- 1-52	4	90
Richey (Silver [2])	Issues from fissures in Mascot Dolomite of Knox Group.	March 1950 to June 1950.	October 1952, June 1954.	[2] 2,060	4- 7-31	1,000	[2] 422	10-29-31		
Roark	At contact between sandstone member and Apison Shale Member of Rome Formation.	February 1950 to June 1951.	September 1952	296	3-22-51	204	126	9-30-52	4	80
Seaton	Openings in Lenoir Limestone, adjacent to contact with Newala Formation of Knox Group.	February 1950 to June 1952.	September 1952, June 1954.	1,780	2- 7-50	1,360	840	9-30-52	3	70
Taylor	Issues from shale of Conasauga Group	February 1950 to June 1951.	September 1952	289	4- 6-50	187	65	9-30-52	4	120
Triplett	In residuum on shale of Conasauga Group.	February 1950 to June 1951.	September 1952	394	2- 6-50	156	33	9-30-52	4	230
Wildwood (Lake Wildwood [2]).	Flows from base of ridge formed by dolomite of Knox Group, adjacent to fault contact with Conasauga Group.	February 1950 to June 1952.	September 1952	988	[2] 4-17-31	596	387	9-30-52	3	80
Carter County										
Big	Crevices under a bluff formed by Knox Group.	June 1950 to June 1953.	June 1954	8,660	4- 4-51	3,370	871	11- 6-52	3	230
Blue	In Shady Dolomite	July 1952 to June 1954.		4,020	3- 3-54	1,130	221	11- 5-52	3	340
Elliott	do	July 1952 to June 1954.		4,670	4- 5-54	1,620	434	12- 1-53	3	260
Grainger County										
Buffalo	In Copper Ridge Dolomite of Knox Group.	June 1950 to June 1953.	June 1954	11,800	4-13-51	5,070	1,800	11- 5-52	2	200
Heatherly	do	July 1951 to June 1954.		1,790	2-16-53	648	256	11- 5-52	3	240
Indian Cave	do	July 1951 to June 1954.		3,070	3-17-52	1,080	233	12- 3-52	3	260

See footnotes at end of table.

TABLE 3.—*Records of springs in east Tennessee*—Continued

Name of spring	Geologic setting	Discharge: Monthly	Discharge: Other	Maximum: Gpm	Maximum: Date	Average	Minimum: Gpm	Minimum: Date	Magnitude	Variability
Greene County										
Crawford	Issues from residuum at base of hill formed by dolomite of Knox Group.	August 1951 to June 1952.		2,160	1-4-52	1,330	552	11-16-51	3	120
Seaton	Crevices in dolomite of Knox Group at base of bluff.	June 1950 to June 1952.		2,030	4-5-51	1,210	146	9-29-52	3	160
Skyles	Issues at base of hill underlain by dolomite of Knox Group.	June 1950 to June 1951.		1,220	4-5-51	632	150	6-19-50	3	170
Tipton	In Kingsport Formation of Knox Group.	June 1950 to June 1951.		2,040	4-5-51	930	272	9-29-52	3	190
Hamblen County										
Panther	Issues from crevices at base of bluff in Longview Dolomite of Knox Group.	June 1950 to June 1953.	June 1954	4,890	4-10-51	1,780	[3] 364	10-21-31	3	250
Hamilton County										
Andersons	Issues from solution cavities at base of a hill formed by dolomite of Knox Group.	June 1950 to June 1953.	June 1954	7,000	9-13-50	3,380	[3] 458	11-2-31	3	180
Cave	Issues from cave on fault contact between dolomite of Knox Group and Newman Limestone.	July 1951 to June 1953.		19,600	4-3-52	9,640	[3] 36	10-30-31	2	200
Stone	Issues into a circular depression in Chickamauga Limestone.	July 1951 to January 1952.							5	
Jefferson County										
Baker	In Lenoir Limestone adjacent to contact with Holston Formation.	July 1951 to June 1953.	June 1954	5,120	2-16-53	2,660	525	11-5-52	3	170
Blue Hole	In Sevier Shale	July 1951 to June 1953.		1,080	3-6-53	594	198	8-11-52	3	150
Blue	Issues at base of bluff formed by Copper Ridge Dolomite of Knox Group.	July 1951 to June 1954.	1931 [4]	5,250	2-16-53	1,830	678	1-7-54	3	250

Buck Hollow	In Copper Ridge Dolomite of Knox Group.	July 1951 to June 1954	June 1954	1, 220	2-11-52	790	458	10-17-51	3	100
Jones	Issues from crevices in Mascot Dolomite of Knox Group.	July 1951 to June 1953		1, 810	2-14-53	816	193	11- 5-52	3	200
Mill	Issues at base of cliff in Copper Ridge Dolomite of Knox Group.	July 1950 to December 1955.		5, 300	12-26-51	2, 210	767	1- 7-54	3	210
Millican	In Copper Ridge Dolomite of Knox Group.	July 1951 to June 1952		1, 230	12-27-51	598	162	10-17-51	3	180
Mossy	In Mascot Dolomite of Knox Group	May 1953 to December 1955.		39, 300	4- 5-55	13, 300	3, 390	11- 8-54	2	270
Pecks Mill	Issues from crevices at base of bluff in Chepultepec Dolomite of Knox Group.	July 1951 to June 1953		1, 570	2-16-53	633	121	11- 5-52	3	230
Knox County										
Big Blue (Deep [4])	In Chickamauga Limestone	June 1952 to June 1954		4, 760	2-17-53	1, 420	[4] 413	10-28-31	3	310
Boiling (Russell [4])	Discharges at base of bluff in Lenoir Limestone.	June 1950 to June 1952	June 1954	9, 520	1-15-51	4, 180	1, 230	10-24-51	3	200
Cardwell	In Chickamauga Limestone	June 1950 to June 1952		1, 000	4-12-51	460	124	10-22-51	3	190
Carter Mill (Carters Cave [4]).	Issues from cave adjacent to contact between Kingsport and Longview Formations of Knox Group.	June 1950 to June 1953	June 1954	3, 180	3- 6-53	1, 310	592	9-12-52	3	200
Fowler	Dolomite of Knox Group	June 1950 to June 1952	June 1954	4, 850	4-12-51	2, 080	606	10-15-51	3	200
Hobbs	In Chepultepec Dolomite of Knox Group.	June 1950 to June 1951		444	3-19-51	279	134	9-12-50	4	110
Huffaker	In Mascot Dolomite of Knox Group	June 1950 to June 1951	September 1951	1, 710	6-21-50	367	53	9-22-51	4	450
Maxwell	Fractures in Newala Formation of Knox Group.	June 1950 to June 1951		1, 150	4-19-51	746	312	11-13-50	3	110
Loudon County										
Allen Fine (Muddy Creek [4])	Crevices in Copper Ridge Dolomite of Knox Group.	June 1950 to June 1952	June 1954	4, 020	4-19-52	1, 740	[4] 400	10-13-31	3	210
Reed	Issues from Copper Ridge Dolomite of Knox Group.	June 1950 to June 1952		2, 150	3-13-52	1, 200	[5] 166	10-12-31	3	170
Simpson	Issues from a deep hole and crevices in Chepultepec or Longview Dolomites of Knox Group.	June 1950 to June 1952	June 1954	6, 100	4-17-51	3, 480	[4] 1, 400	10-12-31	3	140
Tom Carson	Issues from Lenoir Limestone, adjacent to contact with Newala Formation of Knox Group.	June 1950 to June 1951		853	3-20-51	479	184	9-23-52	3	140

See footnotes at end of table.

TABLE 3.—*Records of springs in east Tennessee*—Continued

Name of spring	Geologic setting	Discharge: Monthly	Discharge: Other	Maximum Gpm	Maximum Date	Average	Minimum Gpm	Minimum Date	Magnitude	Variability
McMinn County										
Arnwine (Cagle[6])	Issues from crevices in Longview Dolomite of Knox Group, adjacent to contact with Chepultepec Dolomite.	June 1950 to June 1951	September 1952, June 1954.	3,540	4-16-51	2,460	543	10-12-51	3	120
Chestnut	In Copper Ridge Dolomite of Knox Group, near contact with Conasauga Group.	July 1951 to June 1952	September 1952	707	1-16-52	471	226	9-30-52	3	100
Crockett	In Newala Formation of Knox Group	June 1950 to June 1951	September 1952	986	4-16-51	533	94	9-30-52	3	170
Dodd	At base of a ledge of Dolomite in Knox Group.	June 1950 to June 1951	September 1952, June 1954.	1,490	3-12-51	1,170	696	9-30-52	3	70
Hicks-Brown (Hicks [5]).	Issues in a deep pool in Conasauga Group at base of hill formed by Chepultepec Dolomite of Knox Group.	June 1950 to June 1952	September 1952, June 1954.	2,020	4-16-51	1,100	[5] 458	10-29-31	3	140
Malone	Flows from residuum under a ledge in Mascot Dolomite of Knox Group.	June 1950 to June 1952	September 1952. June 1954, September 1954.	4,390	12-29-51	2,660	992	9-30-52	3	130
McSpadden	Flows from alluvium overlying shale of Conasauga Group.	August 1951 to January 1952.	----------	548	12-29-51	289	113	10-18-51	4	--------
Thompson	Issues in a pond in shale of Conasauga Group at base of a ridge formed by Copper Ridge Dolomite of Knox Group.	June 1950 to June 1952	June 1954, September 1954.	1,740	3-12-51	1,240	[6] 615	10-12-31	3	90
Tuggle	In shale of Conasauga Group	August 1951 to January 1952.	----------	2,150	12-29-51	883	212	8-15-51	--------	--------
Whiteside	Issues from Dolomite of Knox Group	July 1951 to June 1952	October 1952, June 1954.	1,250	12-18-51	843	606	10-17-51	3	80
Meigs County										
Big	Issues from solution cavities in Chickamauga Limestone.	June 1950 to June 1952	October 1952, June 1954.	4,620	3-13-51	1,710	[5] 310	10-2-31	3	250
Maler	In Dolomite of Knox Group	June 1950 to June 1951	October 1952	2,340	3-13-51	936	130	10-15-52	3	240
Monroe County										
Kilpatrick, (Crystal [5]).	Issues from Maynardville Limestone of Conasauga Group, at base of ridge formed by Copper Ridge Dolomite of Knox Group.	June 1950 to June 1952	----------	4,320	3-13-52	1,730	[5]418	10-12-31	3	230

Polk County										
Maynor	In dolomite of Knox Group	November 1950 to November 1952.		151	3-14-51	80	39	10-11-51	5	140
Maynor and Prestwood (combined).	do	November 1950 to November 1952.		609	3-14-51	221	71	10-11-51	4	240
Shelton	In dolomite of Knox Group, near fault contact with Athens Shale.	November 1950 to November 1952.		565	3-14-51	253	44	11-21-52	4	210
Rhea County										
Henson-Rogers	In Newman Limestone	June 1951 to January 1952.							4	
90-S1 [7]	In Rockwood Formation	June 1950 to June 1951	January 1950	844	2- 5-51	518	229	6- 4-51	3	120
90-S2 [7]	do	June 1950 to June 1951	January 1950	163	9-13-50	124	55	1-24-50	4	90
Roane County										
Blue	In dolomite of Knox Group	June 1950 to June 1952	September 1952	3,860	3- 4-52	1,380	399	9-11-51	3	250
Factory (Post Oak [5])	Issues from a large cave in a bluff of dolomite of Knox Group.	June 1950 to January 1952.	October 1952	2,200	3-22-51	1,040	[5] 216	10-30-31	3	190
Crystal (McKinney [5]).	Issues from crevices in bluff formed by Chickamauga Limestone.	July 1951 to June 1953	June 1954	1,440	1-10-52	744	[5] 144	10-26-31	3	170
Sevier County										
Bailey	In dolomite of Knox Group	June 1950 to June 1952.	September 1952	3,470	4-11-51	1,420	390	9-22-52	3	220
Rocky	do	June 1950 to June 1951		444	4-11-51	182	71	9- 5-50	4	200
Sullivan County										
Bumgardner	In Jonesboro Limestone of Knox Group, adjacent to fault.	June 1950 to June 1951		678	4- 3-51	360	118	1- 3-51	4	160
Morrill	At foot of bluff formed by dolomite of Knox Group.	June 1950 to June 1951	September 1952, June 1954	13,500	12- 4-50	5,120	727	9-30-52	2	290
Wolford	In dolomite of Knox Group	July 1951 to June 1953		4,890	3- 4-53	979	368	11- 6-51	3	460
Unicoi County										
Love	In Shady Dolomite, near contact with Chilhowee Group.		1931, 1951	[8] 1,280	7- 7-31		[8] 745	4-24-31	3	
U.S. Fishery	In Honaker Dolomite of Conasauga Group, near contact with Rome Formation.	July 1951 to June 1954	May 1955	1,430	1- 2-52	1,140	893	12- 1-53	3	50
Birchfield	Crevices in Shady Dolomite adjacent to fault contact with Honaker Dolomite of Conasauga Group.	July 1951 to June 1953	November 1953, June 1954	2,100	2- 4-52	1,380	902	10- 1-52	3	90

[1] U.S. Geol. Survey (1933, p. 333).
[2] U.S. Geol. Survey (1933, p. 334).
[3] U.S. Geol. Survey (1933, p. 335).
[4] U.S. Geol. Survey (1933, p. 336).
[5] U.S. Geol. Survey (1933, p. 338).
[6] U.S. Geol. Survey (1933, p. 337).
[7] Springs 90-S1 and 90-S2 are the larger and smaller, respectively, of two springs referred to as "Two Springs" at Dayton, Rhea County.
[8] U.S. Geol. Survey (1933, p. 339).

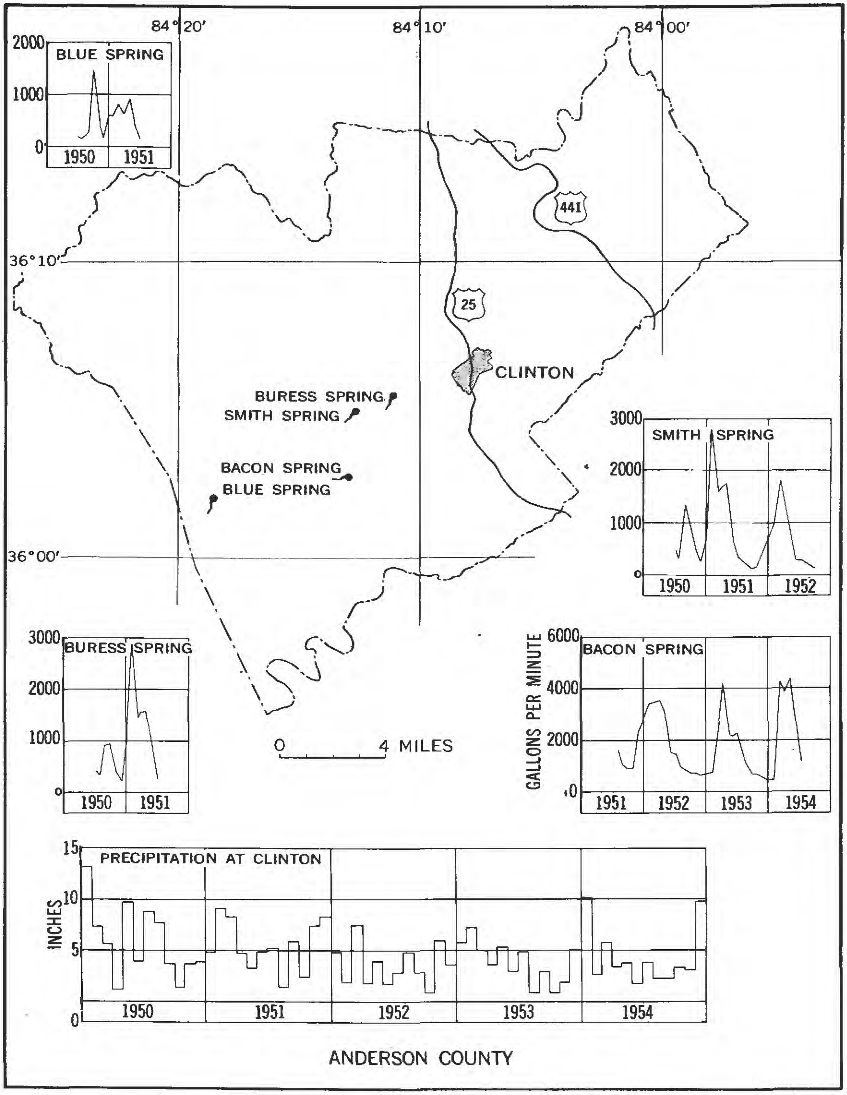

Figure 11.—Map showing location of springs and stations recording precipitation data in Anderson County, Tenn. (See table 3 under Anderson County.)

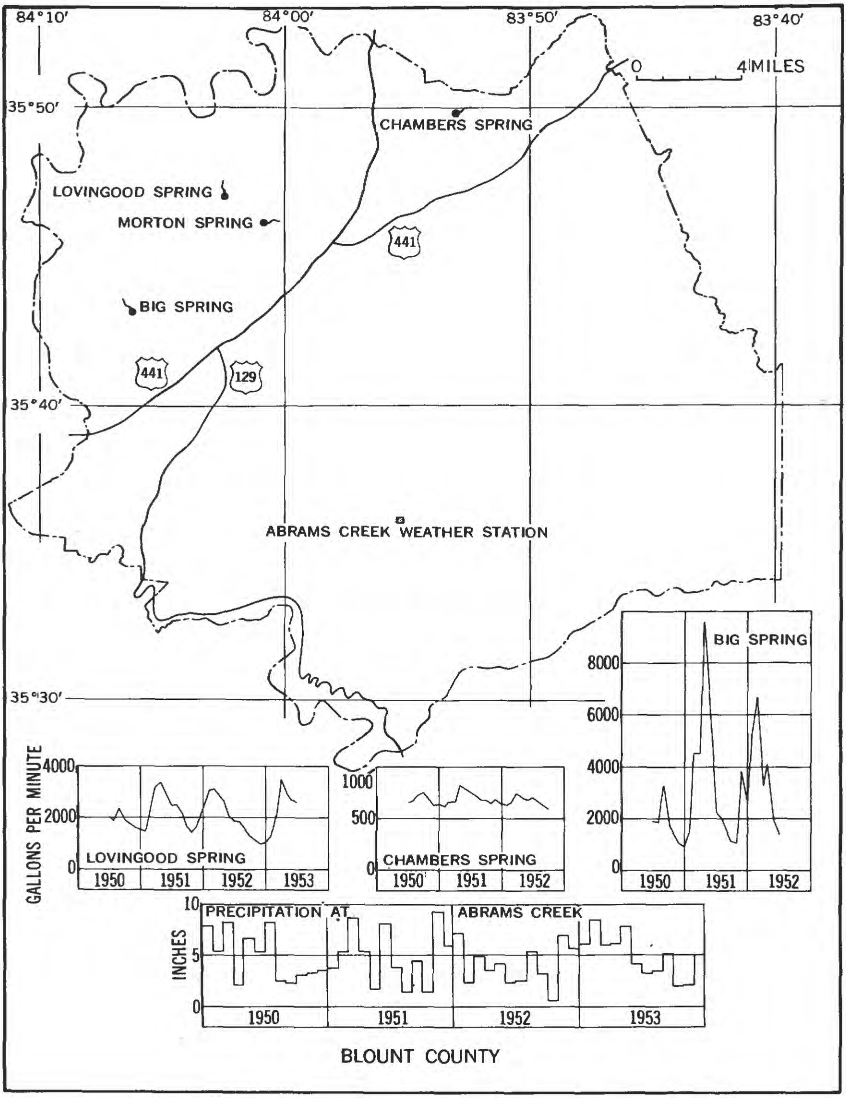

FIGURE 12.—Map showing location of springs and stations recording precipitation data in Blount County, Tenn. (See table 3 under Blount County.)

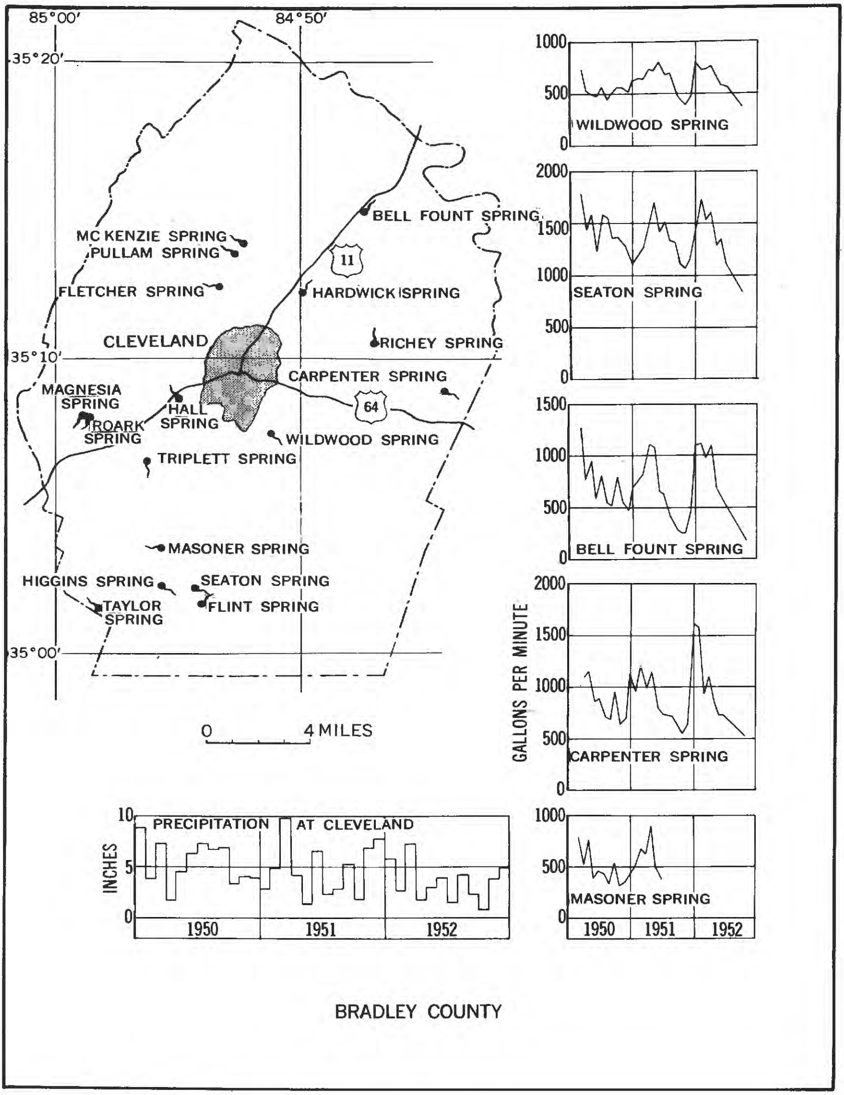

Figure 13.—Map showing location of springs and stations recording precipitation data in Bradley County, Tenn. (See table 3 under Bradley County.)

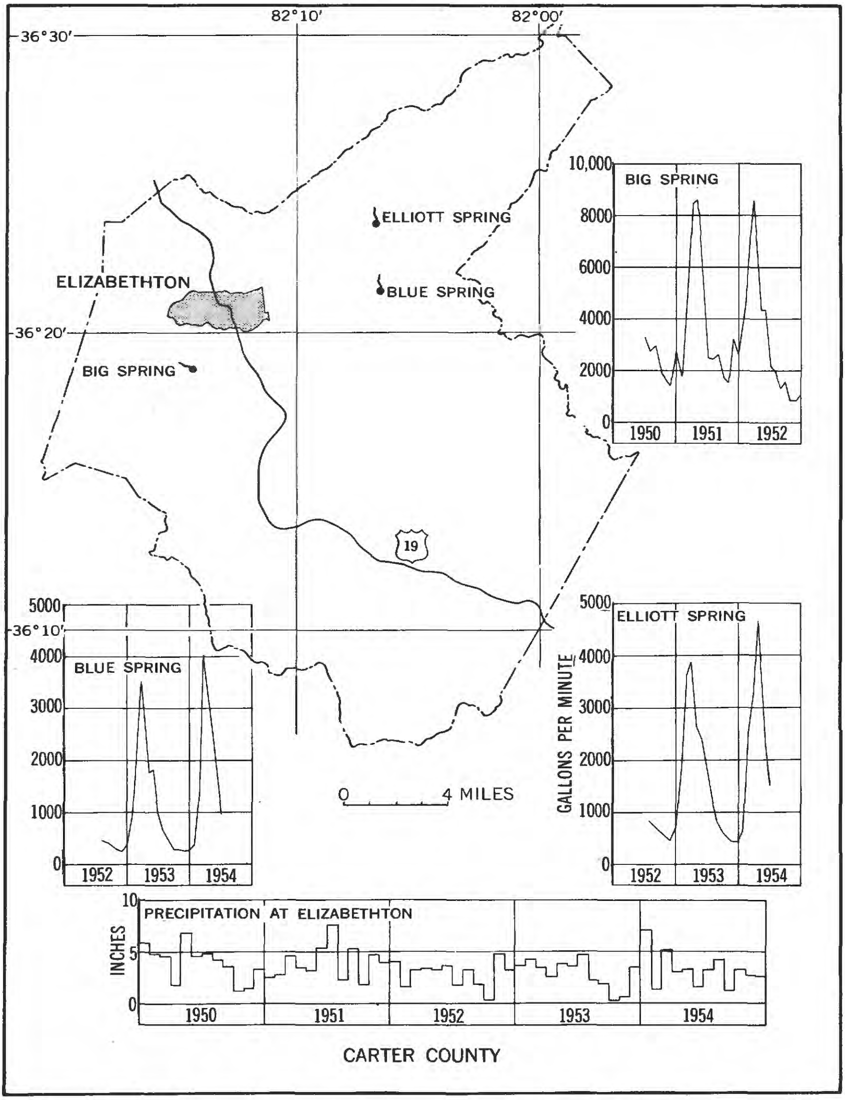

FIGURE 14.—Map showing location of springs and stations recording precipitation data in Carter County, Tenn. (See table 3 under Carter County.)

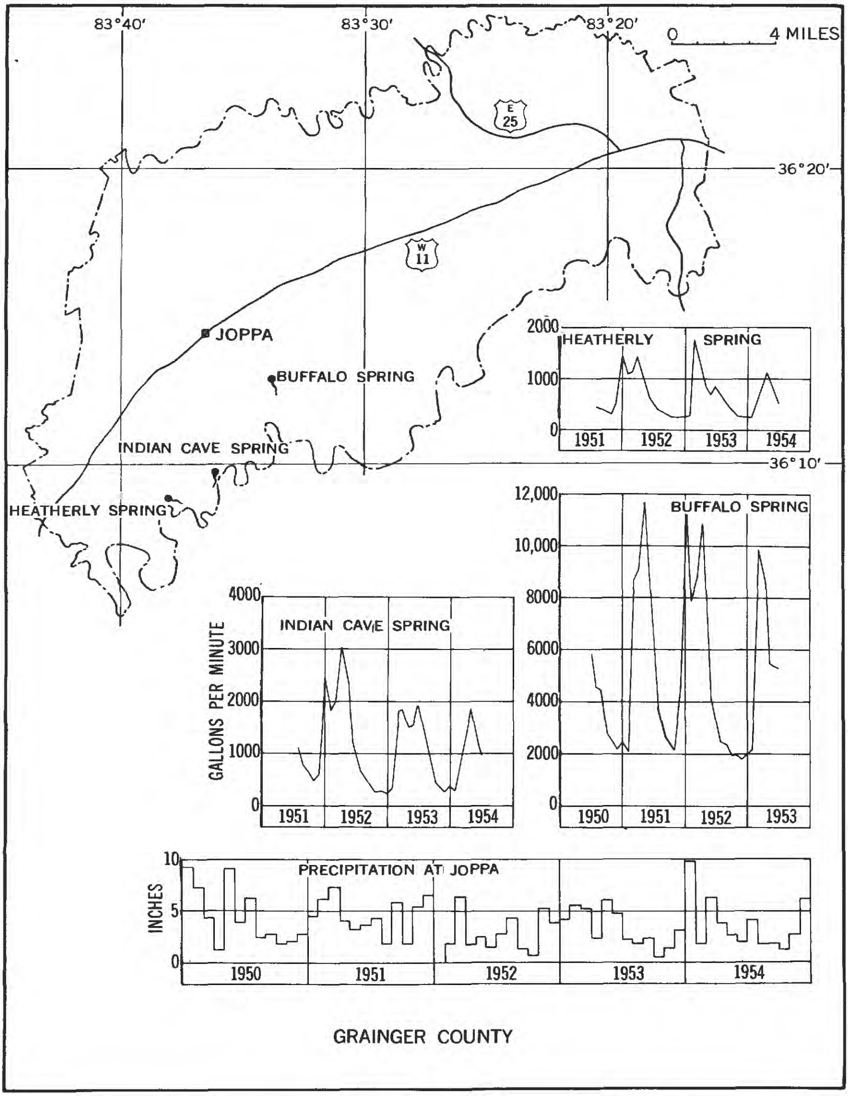

FIGURE 15.—Map showing location of springs and stations recording precipitation data in Grainger County, Tenn. (See table 3 under Grainger County.)

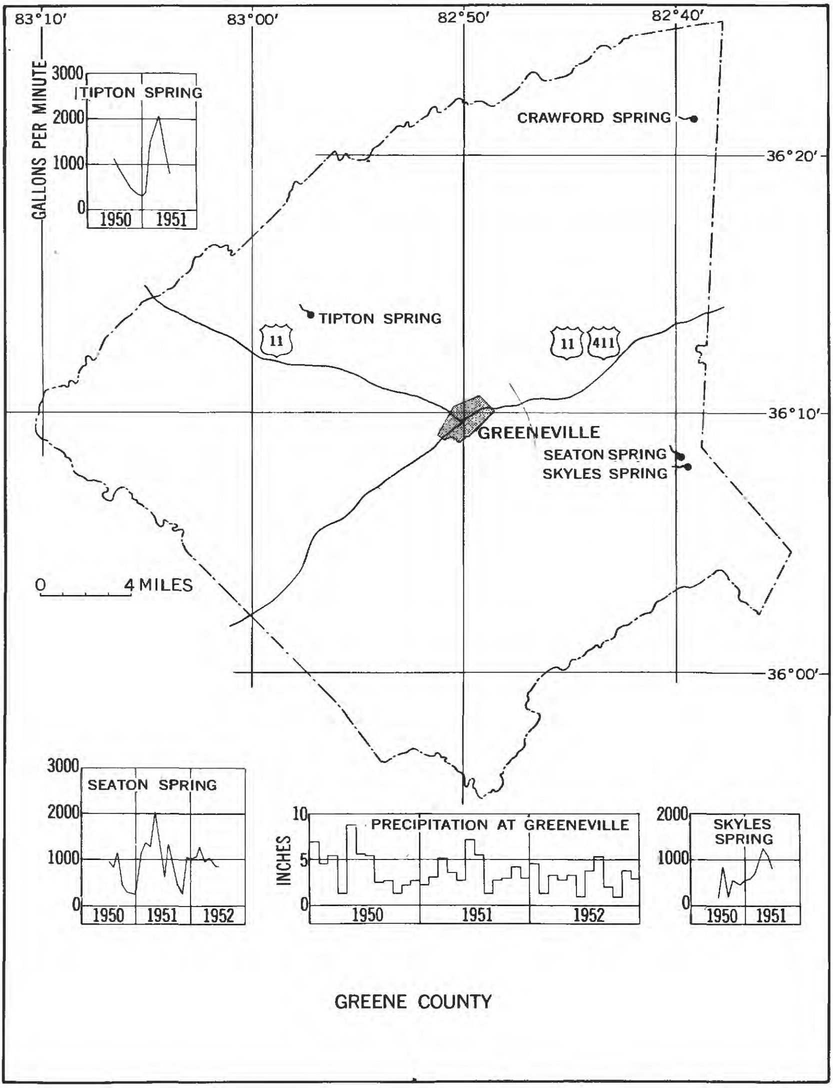

FIGURE 16.—Map showing location of springs and stations recording precipitation data in Greene County, Tenn. (See table 3 under Greene County.)

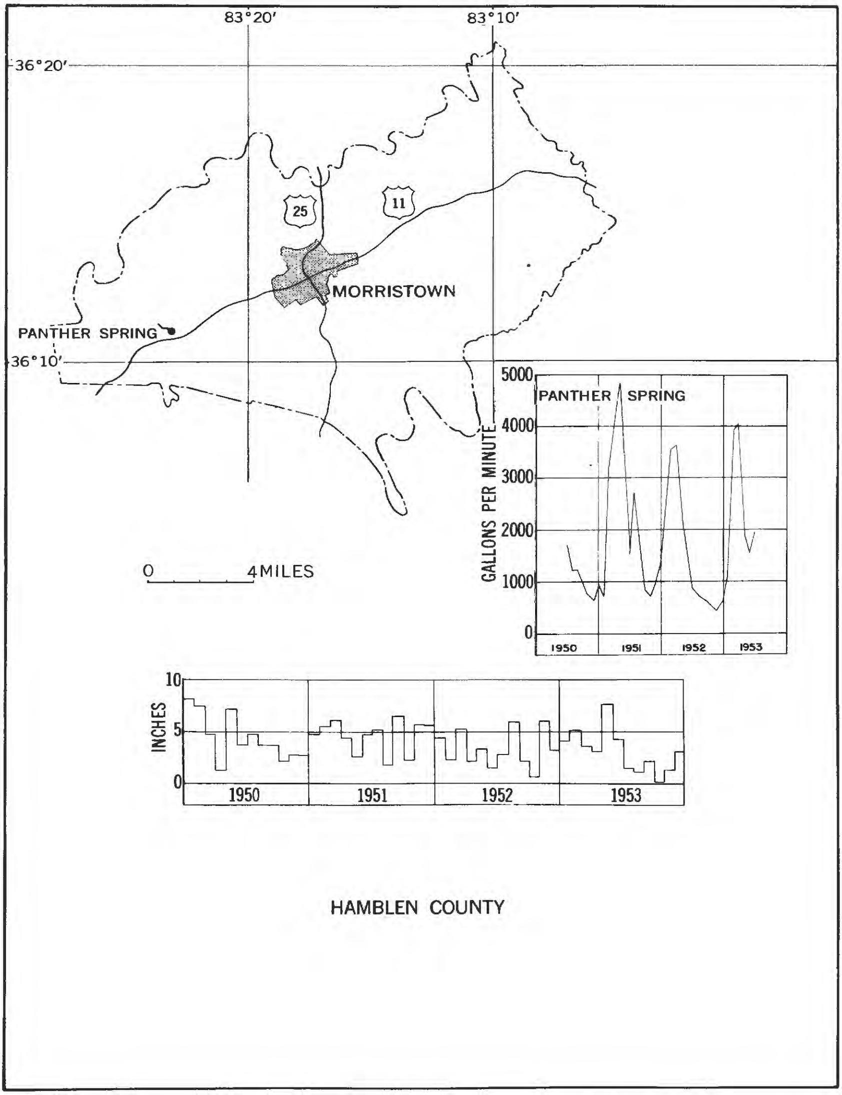

FIGURE 17.—Map showing location of springs and stations recording precipitation data in Hamblen County, Tenn. (See table 3 under Hamblen County.)

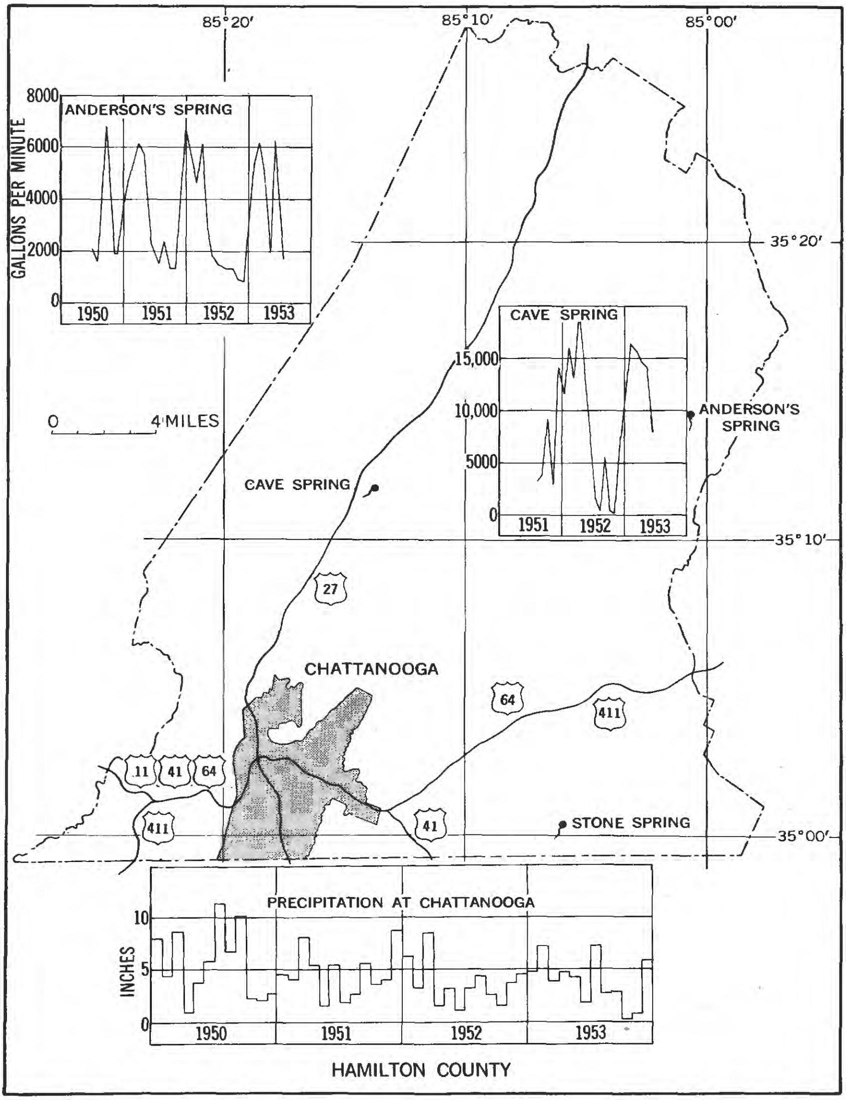

FIGURE 18.—Map showing location of springs and stations recording precipitation data in Hamilton County, Tenn. (See table 3 under Hamilton County.)

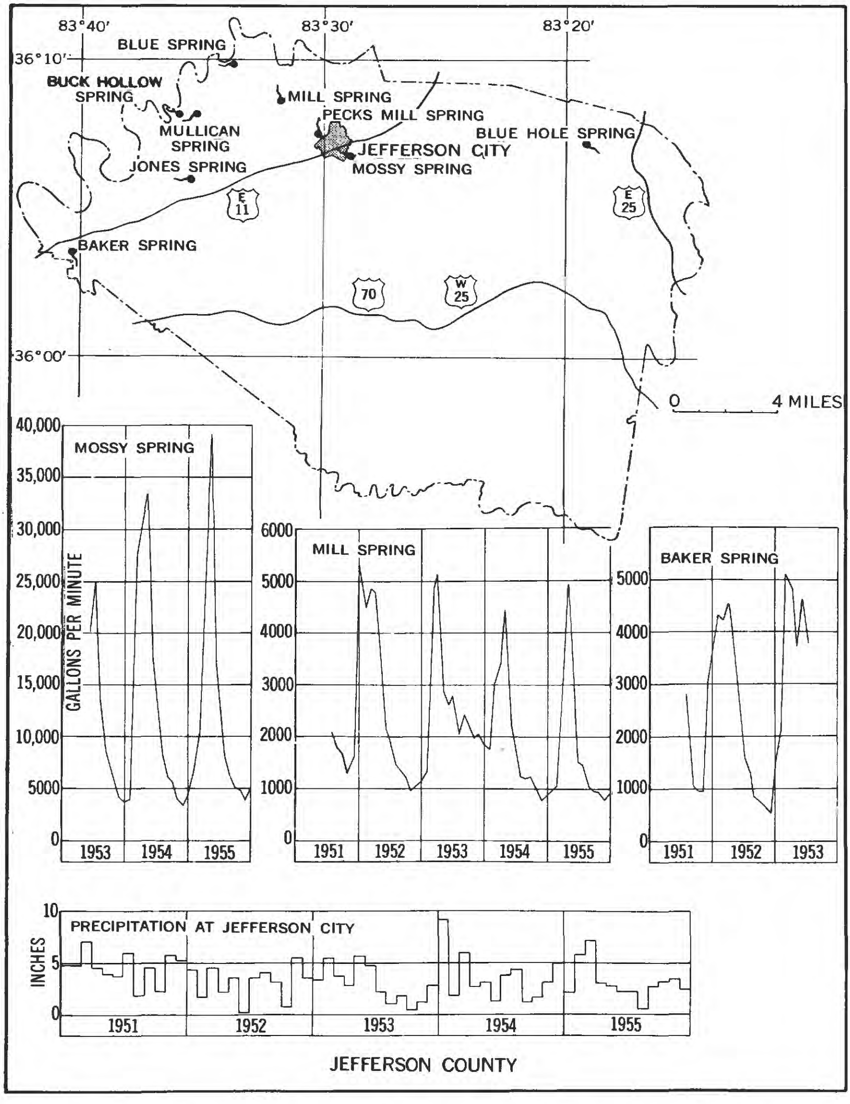

FIGURE 19.—Map showing location of springs and stations recording precipitation data in Jefferson County, Tenn. (See table 3 under Jefferson County.)

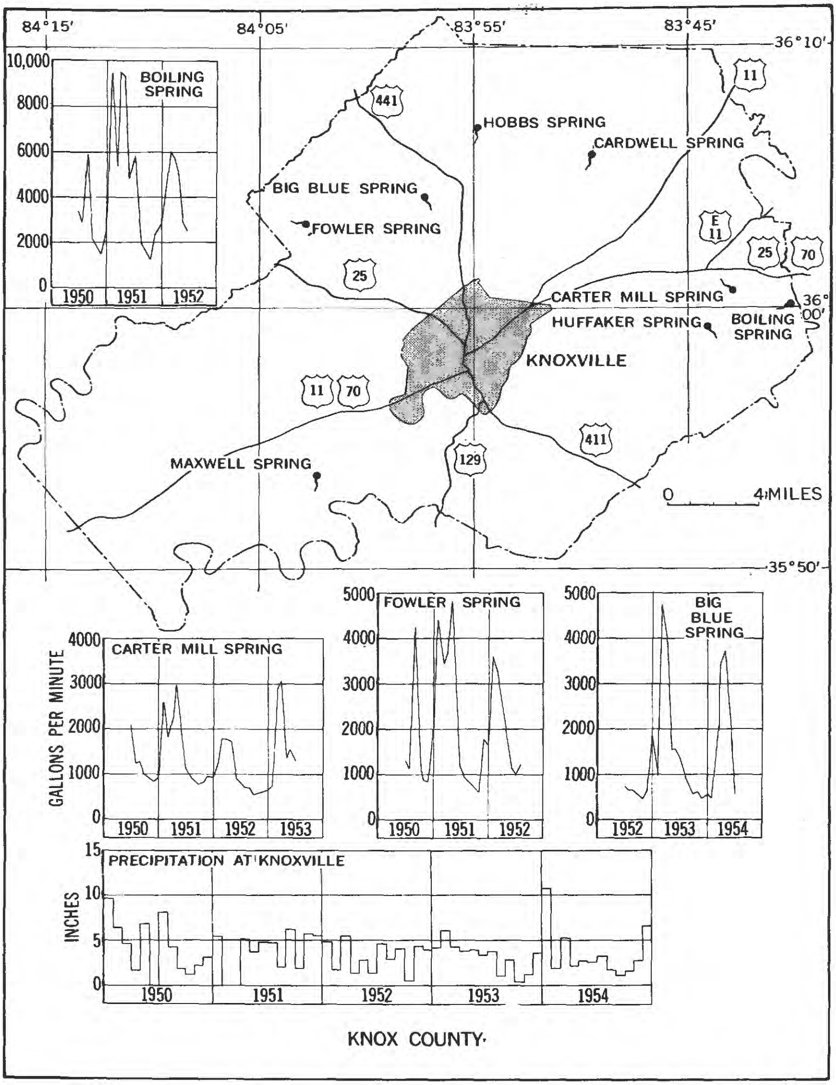

FIGURE 20.—Map showing location of springs and stations recording precipitation data in Knox County, Tenn. (See table 3 under Knox County.)

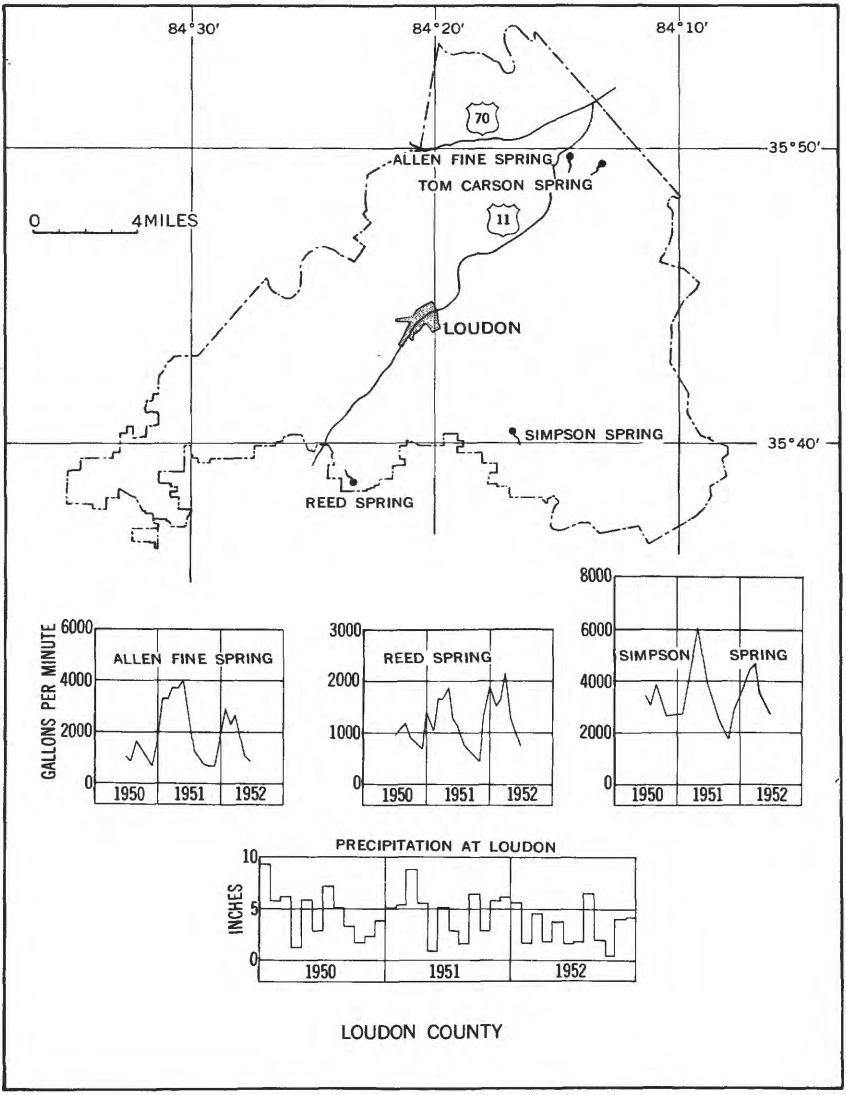

Figure 21.—Map showing location of springs and stations recording precipitation data in Loudon County, Tenn. (See table 3 under Loudon County.)

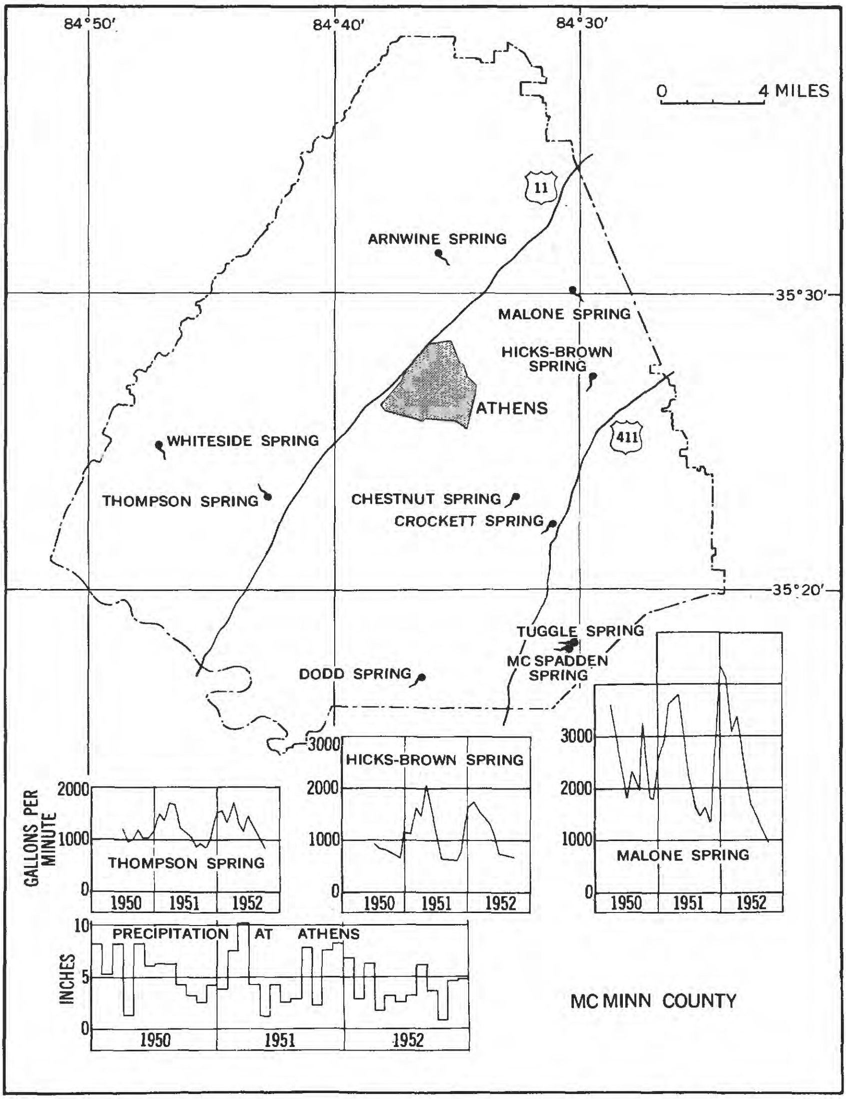

FIGURE 22.—Map showing location of springs and stations recording precipitation data in McMinn County, Tenn. (See table 3 under McMinn County.)

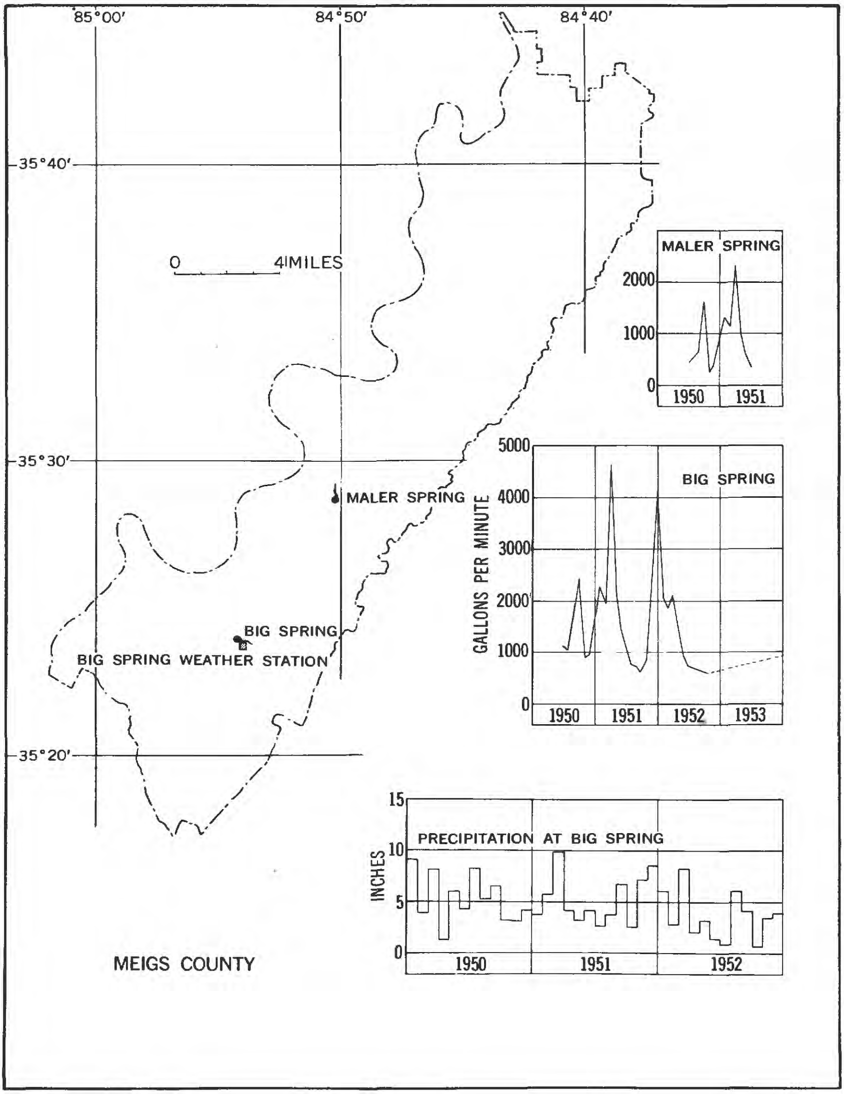

Figure 23.—Map showing location of springs and stations recording precipitation data in Meigs County Tenn. (See table 3 under Meigs County.)

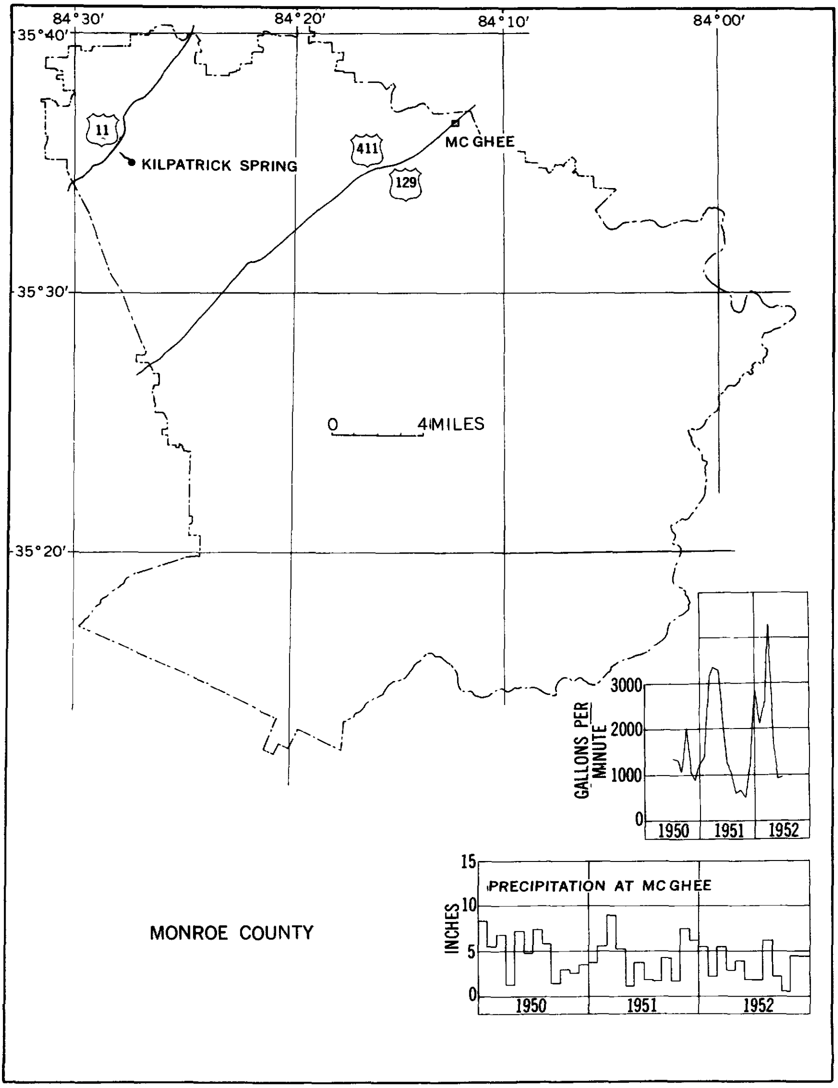

FIGURE 24.—Map showing location of springs and stations recording precipitation data in Monroe County, Tenn. (See table 3 under Monroe County.)

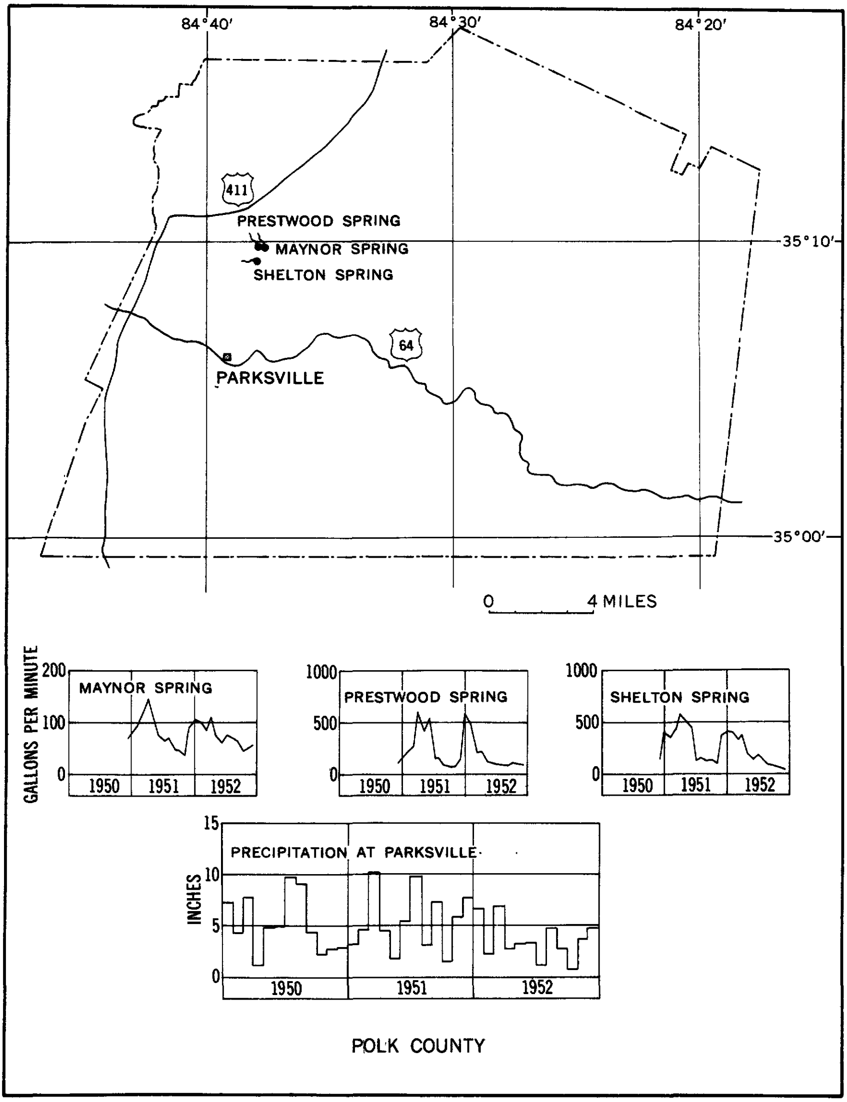

FIGURE 25.—Map showing location of springs and stations recording precipitation data in Polk County, Tenn. (See table 3 under Polk County.)

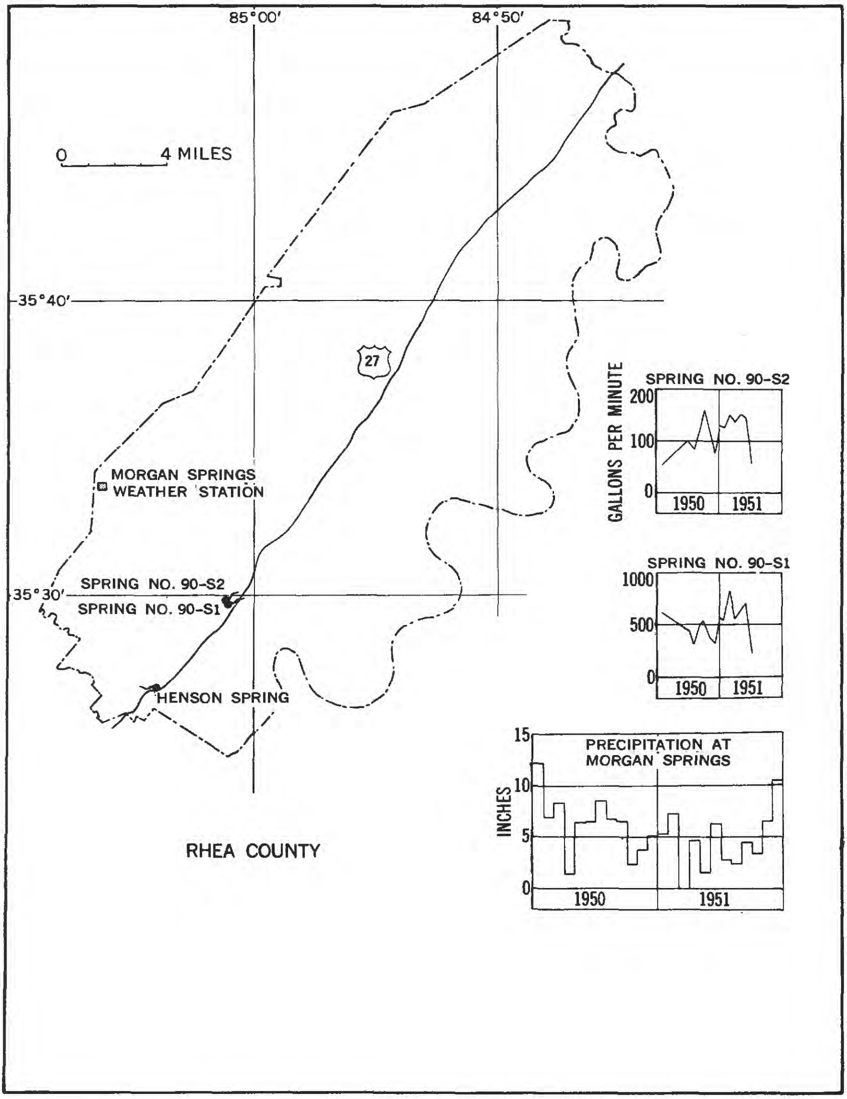

FIGURE 26.—Map showing location of springs and stations recording precipitation data in Rhea County, Tenn. (See table 3 under Rhea County.)

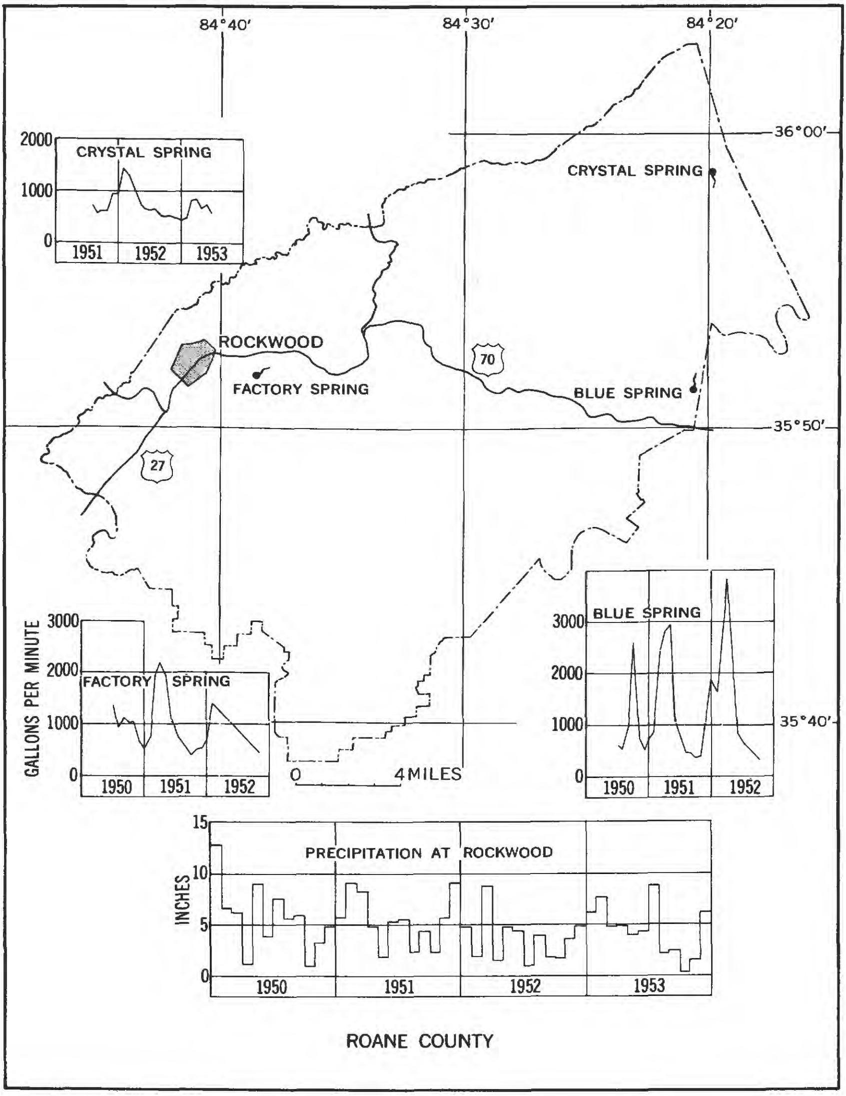

FIGURE 27.—Map showing location of springs and stations recording precipitation data in Roane County, Tenn. (See table 3 under Roane County.)

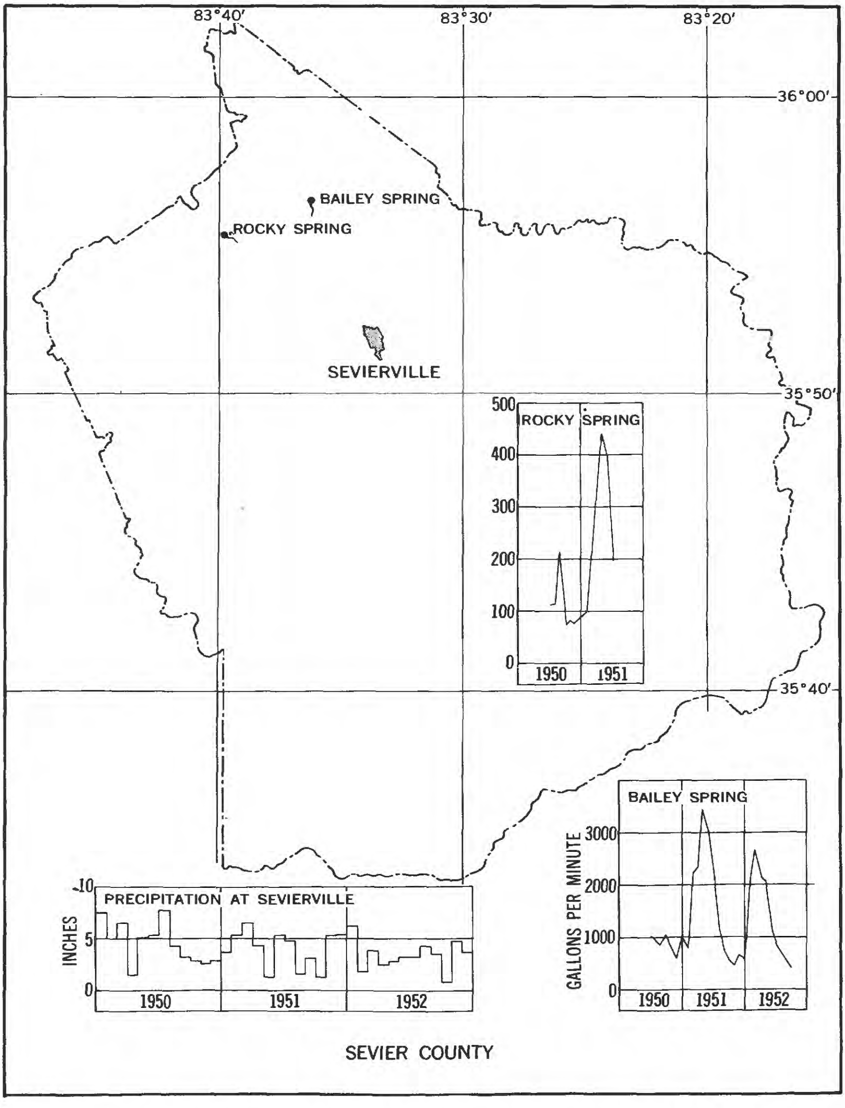

FIGURE 28.—Map showing location of springs and stations recording precipitation data in Sevier County, Tenn. (See table 3 under Sevier County.)

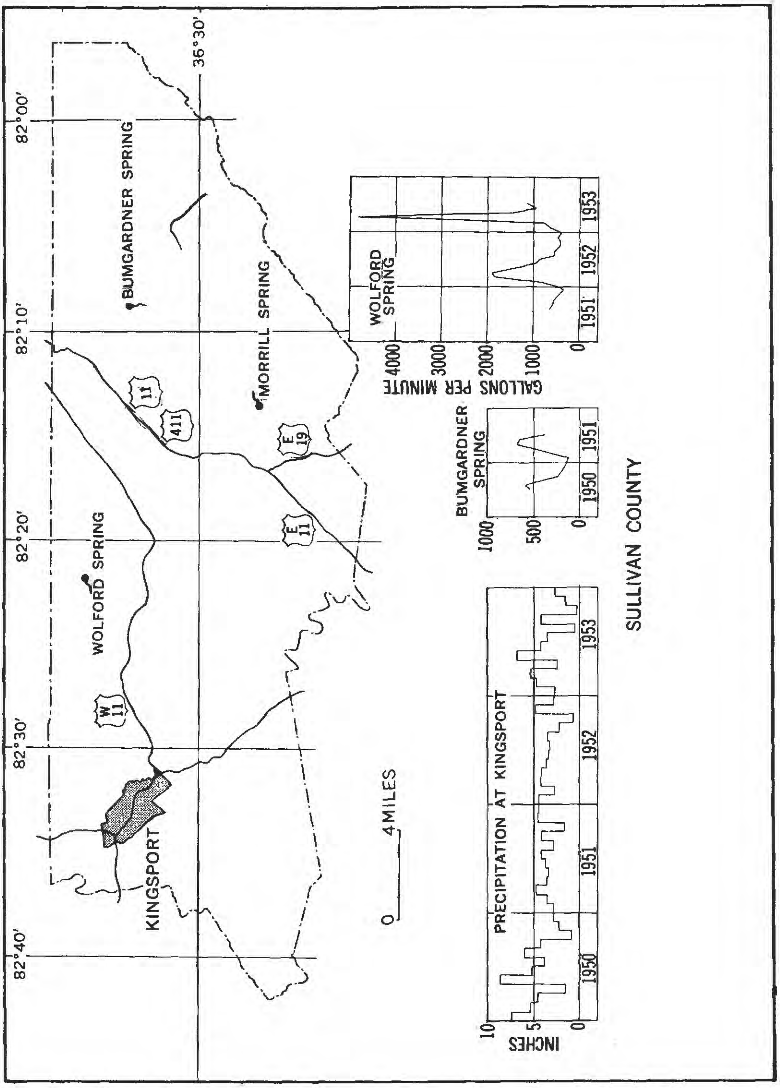

FIGURE 29.—Map showing location of springs and stations recording precipitation data in Sullivan County, Tenn. (See table 3 under Sullivan County.)

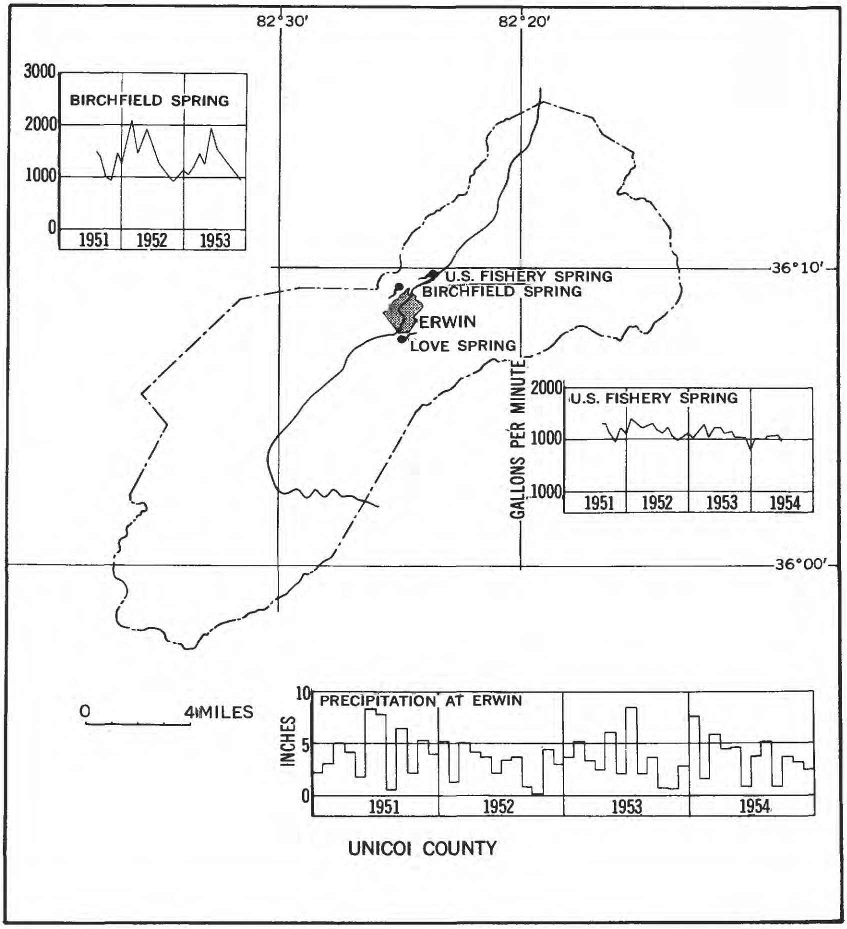

FIGURE 30.—Map showing location of springs and stations recording precipitation data in Unicoi County, Tenn. (See table 3 under Unicoi County.)

REFERENCES

Abd-El-Al, Ibrahim, 1953 Statics and dynamics of water in the Syro-Lebanese limestone massifs, *in* Proceedings of the Ankara symposium on arid zone hydrology (UNESCO), 1953: p. 60–76.

Bridge, Josiah, 1956, Stratigraphy of the Mascot-Jefferson City zinc district: U.S. Geol. Survey Prof. Paper 277, 76 p.

De Buchananne, G. D., and Richardson, R. M., 1956, Ground-water resources of East Tennessee: Tenn. Div. of Geol. Bull. 58, pt. 1, 393 p.

Dickson, R. R., 1960, Climate of Tennessee, *in* Climates of the States: Washington, U.S. Weather Bureau, 16 p.

Hem, J. D., 1959, Study and interpretation of chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Meinzer, O. E., 1923, Outline of ground-water hydrology with definitions: U.S. Geol. Survey Water-Supply Paper 494, 71 p.

———1927, Large springs in the United States: U.S. Geol. Survey Water-Supply Paper 557, 94 p.

Rodgers, John, 1953, Geologic map of East Tennessee: Tenn. Div. of Geol. Bull. 58, pt. 2, 168 p.

Searcy, J. K., 1960, Graphical correlation of gaging-station records: U.S. Geol. Survey Water-Supply Paper 1541–C, p. 67–100.

U.S. Bureau of the Census, 1960, 1960 census of population: Washington, U.S. Dept. of Commerce [November, 1960].

U.S. Geological Survey, 1933, Surface water supply of the United States, 1931, pt. 3, Ohio River basin: U.S. Geol. Survey Water-Supply Paper 713, 346 p.

———issued periodically, Surface water supply of the United States: U.S. Geol. Survey Water-Supply Papers 663, 683, 1173, 1206, 1236.

The U.S. Geological Survey Library has cataloged this publication as follows:

Sun, Pao-chang P.
Large springs of East Tennessee, by P-C. P. Sun, J. H. Criner, and J. L. Poole. Washington, U.S. Govt. Print. Off., 1963.

iv, 52 p. maps, diagrs., tables. 24 cm. (U.S. Geological Survey. Water-Supply Paper 1755)

Prepared in cooperation with the Tennessee Dept. of Conservation and Commerce, Division of Geology and Division of Water Resources.

Bibliography: p. 52.

(Continued on next card)

Sun, Pao-chang P. Large springs of east Tennessee. 1963. (Card 2)

1. Springs—Tennessee. 2. Water-supply—Tennessee. 3. Water, Underground—Tennessee. I. Criner, James Hobart, 1919- joint author. II. Poole, Joe Lester, 1921- joint author. III. Tennessee. Division of Geology. IV. Tennessee. Division of Water Resources. V. Title. (Series)

U. S. GOVERNMENT PRINTING OFFICE: 1963 O - 690-214