Reconnaissance of Ground-Water Resources in the Mississippian Plateau Region Kentucky

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 160

Prepared in cooperation with the Commonwealth of Kentucky, University of Kentucky, Kentucky Geological Survey, and the Department of Economic Development

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By R. F. BROWN *and* T. W. LAMBERT

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RECONNAISSANCE OF GROUND-WATER RESOURCES IN THE MISSISSIPPIAN PLATEAU REGION, KENTUCKY

By R. F. Brown and T. W. Lambert

ABSTRACT

The U.S. Geological Survey, in cooperation with the Kentucky Geological Survey, and previous to 1958 with the Department of Economic Development of Kentucky, presents in this report a reconnaissance study of ground-water occurrence in the Mississippian Plateau region of central Kentucky. Included in the region are three major physiographic units—the Mammoth Cave plateau, the Pennyroyal plain, and the Knobs. The region is drained by the Cumberland, Tennessee, and Green Rivers, all of which are tributary to the Ohio River. The mean annual precipitation is about 48 inches; the minimum annual precipitation is about 30 inches, and the maximum annual precipitation about 74 inches. The mean annual temperature is 57°F.

The region is underlain chiefly by limestone, shale, and sandstone ranging in age from Ordovician to Pennsylvanian. Alluvial deposits of sand and gravel of Quaternary age occur along the Ohio River and its tributaries.

More than half of the wells in the region yield supplies adequate for modern domestic use, and a few wells yield more than 1,000 gpm (gallons per minute). Many large springs are in the Pennyroyal plain. Some of these springs were measured quarterly to determine the variability of discharge and the quality of water. Measured maximum flows were as high as 150,000 gpm. Many small springs occur in the Mississippian rocks of Chester and Osage ages. Hydrographs in the report show the effects of recharge and discharge of shallow and deep aquifers. Diagrammatic sketches of observation wells and a spring show the conditions, such as lithology of the aquifer, topographic situation, distance from streams and sinkholes, and height of water level above stream level, controlling the occurrence of ground water in the Mississippian Plateau region. The factors controlling occurrence of ground water are correlated with the yield of wells by means of tables and charts.

The water from most limestone aquifers in the region is hard, and during periods of heavy rainfall, the water becomes turbid. Charts and tables show the quality of water from aquifers in the region and the relationship of discharge of a few springs to the dissolved constituents and specific conductance.

INTRODUCTION

Ground-water investigations in Kentucky are being made by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey. Previous to July 1958 cooperation was with the Department of Economic Development of Kentucky. Investigations under way are of three general types: (a) detailed investigations of ground-water resources of small areas; (b) statewide reconnaissance to locate promising sources warranting detailed study in relation to large-scale public, industrial, and agricultural demands; and (c) statewide reconnaissance of ground-water resources for other uses.

This investigation is of the third type and is 1 of a series of 5 which will cover the Commonwealth. The chief purpose of this study is to provide general information on the availability of ground water for all uses in the Mississippian Plateau region of Kentucky. This report will serve also to point out areas where further detailed studies are most needed.

The investigation was under the immediate supervision of G. E. Hendrickson, district geologist.

For convenience in making the ground-water reconnaissances, the Commonwealth of Kentucky has been divided into five regions of more or less distinctive geology and physiography, as follows: Eastern Coal Field, Blue Grass, Mississippian Plateau, Western Coal Field, and Jackson Purchase (fig. 1). The boundaries of the regions are drawn on county lines which approximate but do not coincide exactly with the geologic and physiographic boundaries.

The Mississippian Plateau (pl. 1) includes 30 counties in the central part of the Commonwealth covering an area of about 11,800 square miles. It is bounded on the east by the Eastern Coal Field, on the north and northeast by the Blue Grass region and the Ohio River, on the north and northwest by the Western Coal Field and the Ohio River, on the west by the Jackson Purchase and on the south by the State of Tennessee.

The geology of the Mississippian Plateau region has been described by many authors. "Geology of Kentucky," by A. C. McFarlan (1943), contains a summary of the stratigraphy, structure, physiography, and natural resources of the region, plus an extensive bibliography.

There have been no previous reports that give the details of the occurrence of ground water in the Mississippian Plateau. A report by Brown (1954) describes public and industrial ground-water supplies of the region. E. G. Otton (1948 a, b) described ground-water conditions in the vicinity of Elizabethtown and Campbellsville, and E. H. Walker (1957) made a study of ground-water resources in the vicinity of Hopkinsville. A report by Hopkins (1962) describes the geology and ground-water resources in the vicinity of Scottsville. These reports were pilot studies for the present report, and many of the principles of ground-water occurrence in the Mississippian Plateau were first described therein.

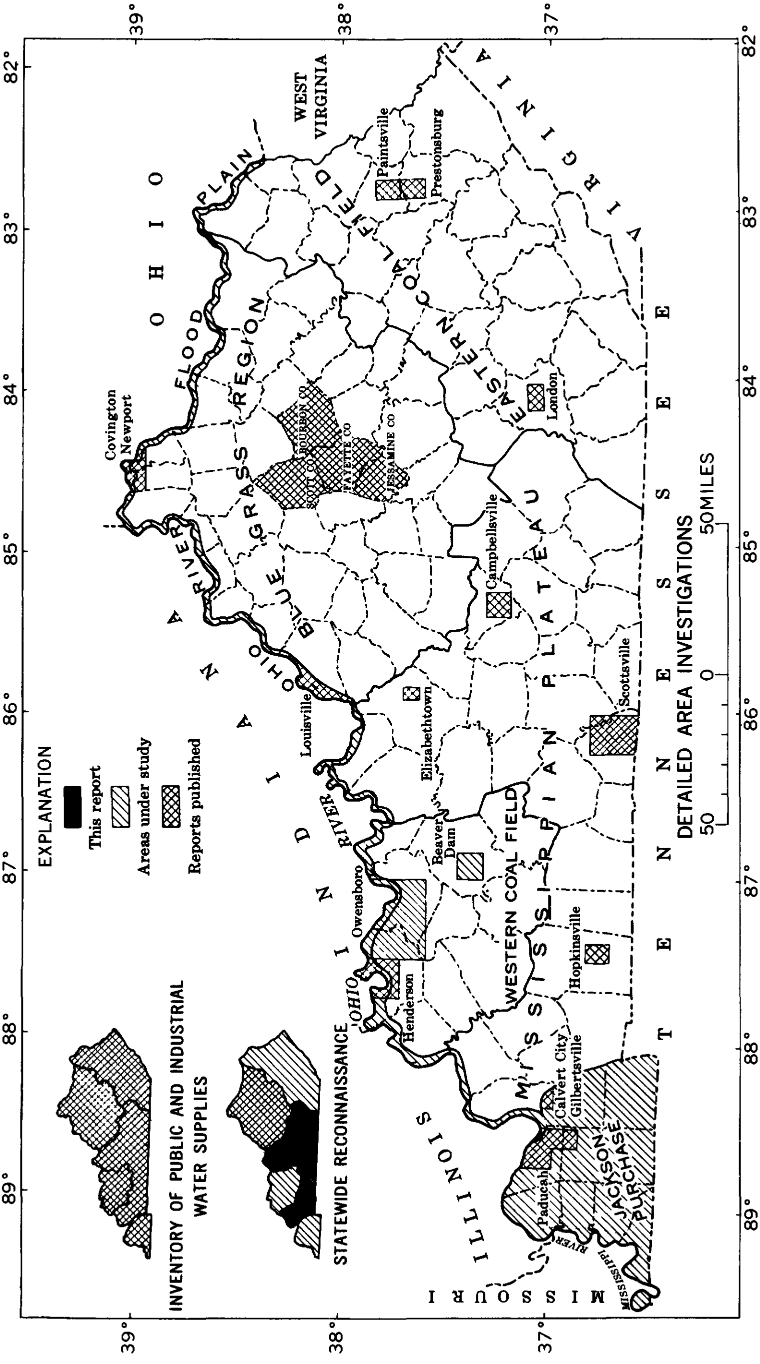

FIGURE 1.—Index map of Kentucky showing progress of ground-water investigations.

Fieldwork for this report consisted chiefly of inventorying wells and springs, and studying by observation and by pumping tests and laboratory tests of samples the characteristics of the rocks that affect the storage and movement of ground water. The fieldwork was done from October 1954 to October 1957 by the writers and by W. B. Hopkins, who worked on the project from its beginning to June 1955, and by H. L. Young, who was assigned to the project in August 1955 and continued with it through December 1955. Specific-capacity tests of representative wells were made by W. H. Walker from November 1954 through February 1955.

An average of 50 representative wells and springs were inventoried in each county. A schedule was prepared for each well and spring inventoried and complete information on each was collected as available. Depths of wells and depths to water were measured where possible, and the aquifer supplying each well and spring was identified. A report on the permanence and adequacy of the supply was obtained from the owner in most instances. Samples of water from representative wells and springs were collected for chemical analysis. Drillers' logs and samples of drill cuttings were collected as convenient, but no attempt was made to obtain all the available logs. Information obtained in the well and spring inventory is summarized by means of well symbols and notations on the well-location maps included in the four atlases of the hydrologic investigations series (Brown and Lambert 1962 a, b; Lambert and Brown, 1962 a, b) that are to be used in conjunction with this report.

Selected wells in the more important aquifers were pumped to determine their specific capacity (fig. 2). Most of the larger springs were gaged to determine their flow; selected springs were gaged several times to determine the range of flow. The resulting data are presented in table 11.

Core samples were taken from selected surface exposures and additional core samples were obtained from exploratory holes drilled by the Aluminum Co. of America. These samples were analyzed at the hydrologic laboratory of the Geological Survey in Denver. Results of these analyses are shown in table 10.

The geologic map (fig. 3) was adapted from the geologic map of Kentucky (Jillson, 1929). The four hydrologic atlases covering the region present the geology in more detail.

The reconnaissance was aided greatly by the interest and cooperation of well owners, well drillers, county agricultural agents, and Soil Conservation Service employees in the region.

A. C. McFarlan, former director of the Kentucky Geological Survey, cooperated in the compilation of the stratigraphic correlation chart of the region.

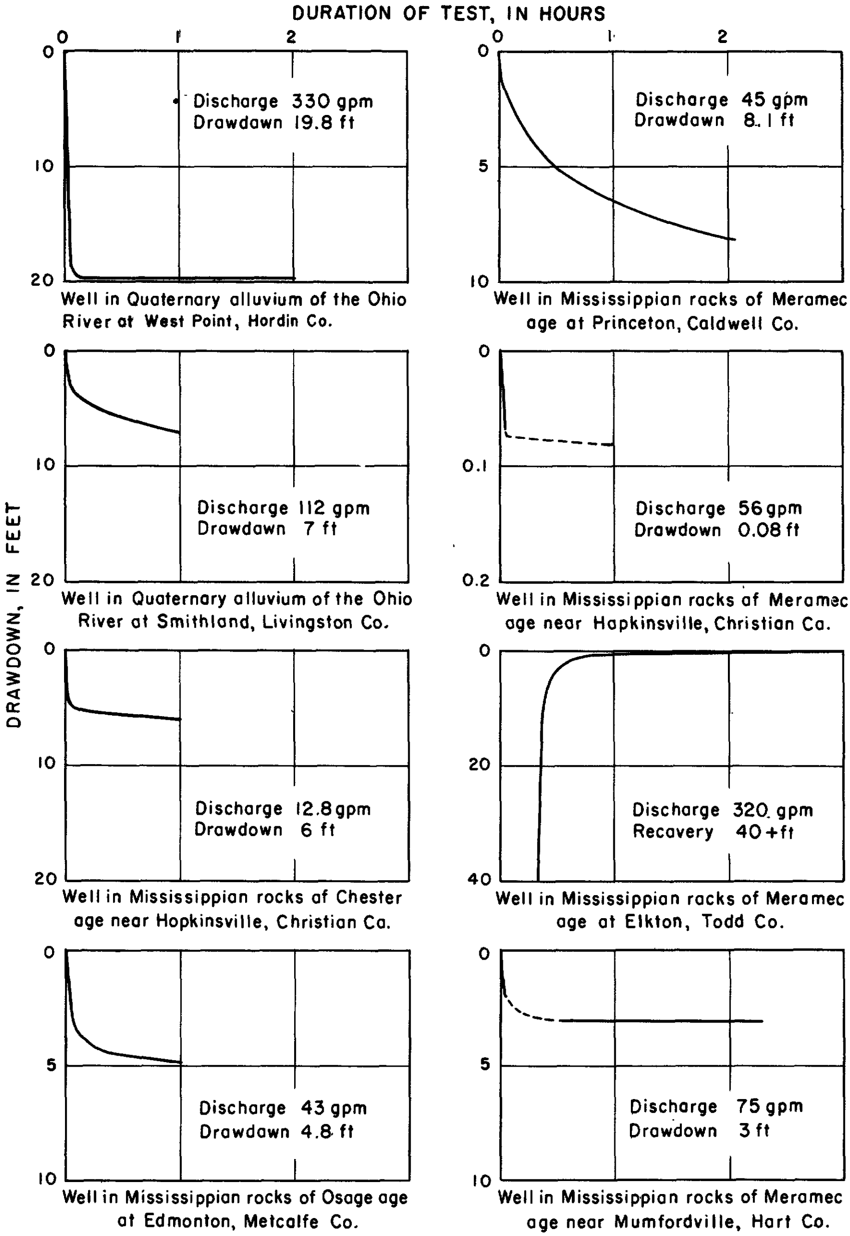

FIGURE 2.—Time-drawdown curves and recovery curve of water levels in pumped wells in the Mississippian Plateau region, Kentucky

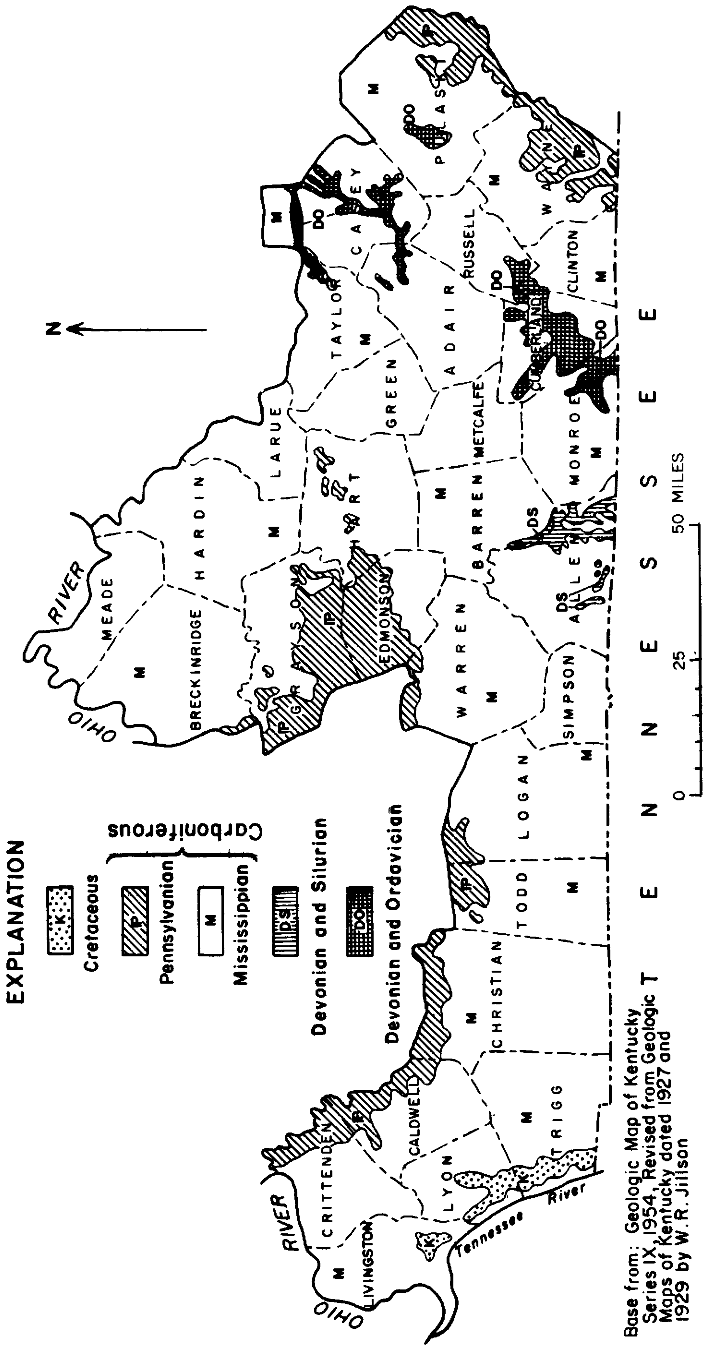

FIGURE 3.—Geologic map of the Mississippian Plateau region, Kentucky.

GEOGRAPHY

The Mississippian Plateau region includes two major plateau areas which are separated by the southward-facing U-shaped Dripping Springs escarpment (fig. 4). The high plateau, herein called the Mammoth Cave plateau (McFarlan, 1943, p. 185–187), lies between the escarpment and the Western Coal Field. The lower plateau, the Pennyroyal plain, which lies generally to the south and is concentric to the escarpment, extends to the east to the eastern Kentucky mountains, and is bounded on the northeast by the arcuate Knobs subregion of the Blue Grass region. For the purpose of this report, the interfluvial area between Kentucky Lake (Tennessee River) and the Cumberland River is included, as are the parts of the adjoining physiographic regions in the geographical boundaries of the 30 counties described.

The Dripping Springs escarpment and the Mammoth Cave plateau to the north of it are underlain by rocks of the Chester series of Late Mississippian age. The Chester rocks consist of relatively thin alternating formations of limestone, sandstone, and shale. Most of the streams in the Mammoth Cave plateau are small and short and have relatively steep gradients. The Green River and its larger tributaries, the Rough, Nolin, and Barren Rivers, are the only streams that cross the escarpment. Mature topography developed by surface drainage is characteristic of most of the Mammoth Cave plateau area; however, sinkhole depressions are found near the escarpment, surface drainage into them having developed after the rocks of the Chester series had collapsed into caverns in the underlying limestone of the Meramec series.

The Pennyroyal plain is underlain by rocks of the Osage and Meramec series and the lowermost limestones of the Chester series. The rocks of Meramec age, which underlie the central part of the Pennyroyal plain, are relatively pure limestones which are very soluble in ground water. In this area drainage is dominantly subsurface. Short ephemeral streams flow to terminal sinkholes. From there the water flows underground through openings enlarged by solution to surface discharge points on major streams some distance away.

The rocks of Osage age lie generally across the Cincinnati arch, the axis of which extends from southeastern Monroe County toward the northeast through the center of the Blue Grass region. The formations consist of alternating beds of impure limestone and shale. In some places drainage is controlled by structure; elsewhere it is dendritic and controlled by other factors. In general the area is characterized by mature topography. West of the Cincinnati arch the drainage is to the Green River and its major tributaries, the Bar-

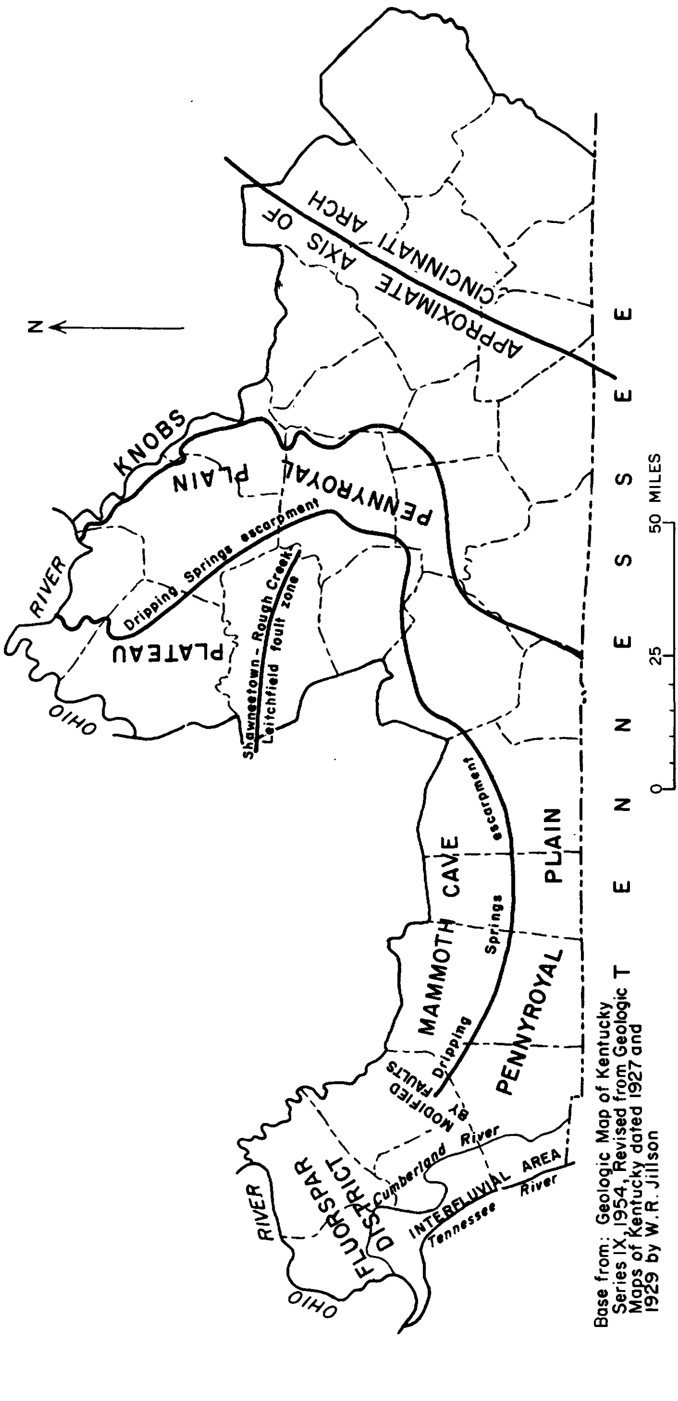

FIGURE 4.—Geomorphic map and selected features of the Mississippian Plateau region, Kentucky.

ren and Little Barren Rivers. East of the arch the drainage is by the Cumberland River and its tributaries.

The Ohio River valley is underlain by extensive terrace deposits of sand, gravel, and clay. Along the Kentucky side of the Ohio River in this region these deposits are as much as several miles wide, and attain a maximum measured thickness of 134 feet. In general the deposits are flat and undissected.

In the interfluvial area between Kentucky Lake (Tennesseé River) and the Cumberland River, the surface materials in most places are Cretaceous, Tertiary, and Quaternary nonmarine sediments consisting largely of sand, gravel, and clay. These are underlain by cherty limestones of late Osage and early Meramec age. Rocks of Chester and Pottsville age are exposed to a limited extent in Livingston County. This area is drained almost equally by the Cumberland River on the east and Kentucky Lake on the west. The central part of the area has a maximum relief of about 200 feet. Near the Cumberland River and Kentucky Lake (Tennessee River) there are extensive flood plains of very low relief.

The entire Mississippian Plateau is in the drainage basin of the Ohio River. The principal tributaries that drain the region are the Green River, which heads northeast of Casey County in the Blue Grass region and flows generally westward toward the interior of the Western Coal Field, and the Cumberland River, which drains the southeastern part of the region, crosses into Tennessee in southeastern Monroe County, reenters Kentucky in Trigg County and drains the western part of the region. The Nolin, Rough, and Barren Rivers are the major tributaries to the Green River. They flow generally downdip to the west across the Drippings Springs escarpment and are incised into the Mammoth Cave plateau. In the eastern part of the region the Cumberland River flows on the east side of the Cincinnati arch along the strike of the rocks. Here it has meanders incised more than 500 feet below the surrounding plateau, and flows in a relatively narrow steep-sided trench. The southwestern part of the region is drained by the Red and Little Rivers, which are tributaries to the Cumberland.

Subsurface drainage is of great importance in the Mississipian Plateau region. Through the broad belt of the Pennyroyal plain that is underlain by rocks of Meramec age most of the drainage tributary to the larger rivers is subsurface. Even in the small area of Meramec rocks east of the Cincinnati arch most of the surface streams that flow down to the Pennyroyal plain drain into solution depressions in the limestone, and the water discharges to the Cumberland River from springs and seeps. The pattern of this subsurface drainage is very difficult to determine. In general it is composed of many small independent units much like the many small watersheds that make up the surface drainage. These individual conduit systems are very difficult to delineate accurately except through careful and thorough investigation. In many places the subsurface drainage divides do not coincide with the surface divides, and the position of the major subsurface streams and their tributaries cannot be determined by reconnaissance methods.

The Mississippian Plateau region has a humid continental climate. The mean annual temperature is about 57°F. Minimum temperatures below 0°F occur occasionally in December, January, and February but subzero cold seldom lasts longer than a few days. Maximum temperatures higher than 100°F are reached on several days of each summer. The average growing season, or frost-free period, is about 187 days. The annual precipitation ranges from 40 to 50 inches. About half of this amount falls during the warm period from April to September. Usually there is sufficient rain for staple crops, although prolonged droughts do occur.

Plate 2 shows precipitation and cumulative departure from the mean for weather stations at Hopkinsville, Greensburg, and Leitchfield. Table 1 summarizes the information on precipitation and gives additional temperature records at these stations.

TABLE 1.—*Weather data for three selected stations in the Mississippian Plateau region, Kentucky*

Station	Precipitation (inches)			Mean temperature (° F)		
	Mean	Maximum	Minimum	Annual	January	July
Hopkinsville	48. 36	74. 18	31. 68	58. 6	37. 5	79. 1
Greensburg	47. 97	66. 82	32. 42	56. 3	35. 6	76. 9
Leitchfield	48. 10	73. 26	29. 69	56. 4	35. 6	77. 3

Agriculture is the most important industry in the Mississippian Plateau region. The chief crops are tobacco and corn; however, dairying is becoming increasingly important as the use of land is converted from crop to pasture. In the Mammoth Cave plateau area north of the Dripping Springs escarpment, farms and towns are generally small. In the Pennyroyal plain where the surface is underlain by rocks of the Meramec series the land is fertile, and farms are mostly large and prosperous; where the area is underlain by rocks of the Osage series the land is less fertile, and, particularly where the relief is great, the farms are relatively small. In the Ohio River valley where there are extensive terrace and flood-plain deposits, the land is very fertile, and most of the farms are large and prosperous. Most of the interfluvial area between the Tennessee and Cumberland Rivers is included in the Kentucky Woodlands Wildlife Refuge of the U.S. Fish and Wildlife Service.

A variety of mineral resources is present in the Mississippian Plateau region, but as of 1958, only limestone, petroleum, fluorspar, and water were of major economic importance. Limestone suitable for most uses is quarried throughout the Mississippian Plateau region from rocks of Mississippian age. Petroleum and natural gas are produced from formations ranging in age from Ordovician to Mississippian, and have been found in most of the counties in the region. Sand and gravel are obtained from deposits in the Ohio River valley, and sandstone is quarried from the Chester series of late Mississippian age. Natural rock asphalt was quarried in Edmonson and Grayson Counties from large deposits in sandstone formations of Lower Pennsylvanian and Upper Mississippian age; however, at present quarrying of asphalt is not economical. Iron once was produced from deposits in Lyon and Trigg Counties but the ores are of little economic value at present. The Chattanooga and New Albany shales of Devonian age which crop out over much of the region, contain petroleum and radioactive elements but their removal is not practical with present processes.

GEOLOGY

The rocks that crop out in the Mississippian Plateau region (table 2) range in age from Ordovician to Quaternary, and are of sedimentary origin with the exception of a few igneous dikes in the fluorspar district of Livingston, Caldwell, and Crittenden Counties. Rocks of Mississippian age crop out in more than 90 percent of the area.

The areal extent of the consolidated and unconsolidated rocks of the region is shown on the generalized geologic map (fig. 3).

The oldest rocks exposed in the Mississippian Plateau region are of Ordovician age, and crop out in Cumberland and Monroe Counties in the gorge of the Cumberland River where it crosses the Cincinnati arch. Overlying these are consolidated sedimentary rocks of Silurian, Devonian, Mississippian, and Pennsylvanian ages. Unconsolidated deposits of clay, silt, sand, and gravel of Cretaceous, Pliocene, Pleistocene, and Recent ages mantle the consolidated rocks.

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TABLE 2.—*Stratigraphic column of the Mississippian Plateau region, Kentucky*

System		Series	Western area		Central area	Northern area	Eastern area
Quaternary		Recent and Pleistocene	Alluvium		Alluvium	Alluvium	Alluvium
Tertiary			Gravel and sand				
Cretaceous		Upper Cretaceous	Ripley formation				
			Tuscaloosa formation				
Carboniferous	Pennsylvanian		Caseyville sandstone		Caseyville sandstone	Caseyville sandstone	Lee formation
	Mississippian	Chester	Kinkaid limestone		Leitchfield formation [1]	Buffalo Wallow formation	Pennington shale
			Degonia sandstone				
			Clore limestone				
			Palestine sandstone				
			Menard limestone				
			Waltersburg sandstone				
			Vienna limestone				
			Tar Springs sandstone			Tar Springs sandstone	
			Glen Dean limestone		Glen Dean limestone	Glen Dean limestone	Glen Dean limestone
			Hardinsburg sandstone		Hardinsburg sandstone	Hardinsburg sandstone	Hardinsburg sandstone [2]
			Golconda formation	Haney limestone [3]	Haney limestone [3]	Haney limestone [3]	Haney limestone [2]
				Fraileys shale [3]	Big Clifty sandstone [3]	Big Clifty sandstone [3]	Beech Creek-Reelsville limestones [2]
				Beech Creek limestone [3]	Girkin Ls.	Beech Creek limestone [3]	
			Cypress sandstone			Elwren sandstone [3]	
						Reelsville limestone [3]	

		Ridenhower shale[3]	Girkin formation[4]	Sample sandstone[3]	Beaver Bend-Paoli limestones[2]
				Beaver Bend limestone[3]	
		Bethel sandstone[3]		Mooretown sandstone[3]	
		Paoli limestone[3]		Paoli limestone[3]	
	Meramec	Ste. Genevieve limestone	Ste. Genevieve limestone	Ste. Genevieve limestone	Ste. Genevieve limestone
		St. Louis limestone	St. Louis limestone	St. Louis limestone	St. Louis limestone
		Spergen limestone[5]	Spergen limestone[5]	Spergen limestone[5]	Spergen limestone[5]
		Warsaw limestone	Warsaw limestone	Warsaw limestone	Warsaw limestone
	Osage	Fort Payne chert	Fort Payne chert	Borden group[6]: Muldraugh[7]	Borden group[6]: Muldraugh[7] — Fort Payne chert
				Floyds Knob formation[6]	Floyds Knob formation[6]
				Brodhead formation[7]	Brodhead formation[7]
		New Providence shale	New Providence shale	New Providence shale[6]	New Providence shale[6]
Devonian		Chattanooga shale	Chattanooga shale	New Albany shale	Chattanooga shale
			Sellersburg limestone		Sellersburg limestone
Silurian			Louisville limestone		
			Waldron shale		
			Laurel dolomite		
			Osgood formation		
			Brassfield limestone		Brassfield limestone
Ordovician			Richmond group		
					McMillan formation
			Maysville group		Fairview formation

[1] As used by Weller (1927).
[2] As used by McFarlan and Walker (1956).
[3] As used by McFarlan and others (1955).
[4] Of Sutton and Weller (1932).
[5] As used by Stockdale (1939) = Salem limestone of Cumings (1901).
[6] As used by Stockdale (1939). According to Hass (1956, p. 24) in some places the basal beds of the New Providence shale contain conodonts of Kinderhook age.
[7] Of Stockdale (1939).

Between the oldest exposed rocks, the upper part of the Ordovician, and the Precambrian basement is a series of shales, limestones, and dolomites and locally the St. Peter sandstone. The Shell Oil Co. M. D. Davis No. 1 well in Crittenden County penetrated 1,485 feet of shale, limestone, and dolomite, and 71 feet of St. Peter sandstone in the Ordovician, and drilled 4,005 feet farther into the Cambrian and Ordovician Knox dolomite without reaching Precambrian rocks (Shell Oil Co., written communication). Probably similar thicknesses would be penetrated above the basement rocks throughout the rest of the area. Freeman (1953, p. 209) shows a log of the California Co. A. R. Spears No. 1 well, in Lincoln County in the Blue Grass region north of Pulaski County, which penetrated 4,450 feet of Cambrian rocks before entering a Precambrian rhyolite porphyry.

The major structural features in the Mississippian Plateau region are the Cincinnati arch and the Eastern Interior Basin. In the east-central part of the region the axis of the Cincinnati arch trends north-northeast from southeastern Monroe County through central Casey County. It is on this structural high that rocks of the Osage series crop out throughout the southeastern part of the region; and rocks of Ordovician age are exposed in the bottom of the deep trench of the Cumberland River. There are many minor structures associated with this arch. Structural contour maps of Clinton, Cumberland, and part of Monroe County by Hudnall and Pirtle (1924) show highly complex structure and many small faults. As far west as Allen and Barren Counties there are many small flexures and faults.

The rocks dip away from the Cincinnati arch toward the Eastern Coal Field and the Eastern Interior Basin. In places this dip is greater than 70 feet per mile; however, the average dip is about 30 feet per mile.

In the western part of the Mississippian Plateau the dip is northeast toward the Eastern Interior Basin; in northern Todd County the dip is about 50 feet per mile, in eastern Crittenden County it is about 90 feet per mile.

There are two areas of intensive faulting in the western part of the region. The Shawneetown-Rough Creek-Leitchfield fault zone (fig. 4) crosses central Grayson County and swings south into Hart County. Associated with the main fault are a large number of smaller faults, some parallel and some at sharp angles to the main fault. McFarlan (1943, p. 145) states: "It is a structural uplift varying greatly in detail from place to place, but typically an anticline or series of steep anticlines with reversed faulting from the south accompanied by en echelon normal faulting." This fault is generally considered to mark the southern boundary of the Eastern Interior Basin.

The second area of faulting is just south of the Shawneetown-Rough Creek-Leitchfield fault zone in Livingston, Lyon, Crittenden, and Caldwell Counties. The faulted area is about 60 miles in diameter and contains a cluster of high-angle faults; the main ones trend northeast and east and have displacements of as much as 2,000 feet (Weller and Sutton, 1951). Associated with the faults are peridotite dikes and commercial veins of fluorspar. The faults are post-Pennsylvanian and pre-Cretaceous in age. Eardley (1951, p. 235) states,

> It has been customary to associate the faults with igneous activity; such is probably true for the fluorspar district, but they seem to tie in, especially the Shawneetown–Rough Creek fault zone, with the major arcuate fault zone (that extends from Texas to West Virginia), and therefore perhaps the volcanic activity is incident to the major arc and not an independent entity.

Throughout the Mississippian Plateau region there was almost continuous deposition of marine sediments from Precambrian time to the end of Mississippian time. Most of these sediments were limestone and dolomite. Near the end of Devonian time the Chattanooga and New Albany shales were deposited over the entire area. Above the shale, sediments of Mississippian age were deposited in successive layers of silty and cherty limestone containing discontinuous shale beds, relatively pure limestone, and alternating beds of sandstone, shale, and limestone. These latter formations represent a transition from dominantly marine to dominantly nonmarine deposition. At the close of the Mississippian there was pronounced elevation of the land surface, and Pennsylvanian sediments were deposited, principally in broad stream valleys as sand and gravel channel fills. Erosion continued through Permian time, and was accelerated by further elevation of the land at the close of the Paleozoic.

The Mesozoic era was marked by erosion throughout most of the Commonwealth, but in the interfluvial area between the Cumberland River and Kentucky Lake (Tennessee River), the Tuscaloosa and Ripley formations of Cretaceous age were deposited.

Following the close of the Mesozoic there was another period of broad upwarping, the uplift ranging from about 1,000 feet in the Cumberland Mountain section to about 200 feet in the Jackson Purchase region (McFarlan, 1943, p. 156). Additional uplift occurred near the end of Tertiary time. The present surface is the result of erosion, which started during the Mesozoic, and repeated rejuvenation at the beginning and end of Tertiary time. The last cycle of uplift and erosion resulted in entrenchment of the Cumberland River, where it crosses the Cincinnati arch, and entrenchment of the Green River and its major tributaries, where they cross the Dripping Springs escarpment.

The several glacial stages that occurred during the Pleistocene determined the topography of the Ohio River valley. According to Walker (1957, p. 6) the valley was cut to its present depth and width during the Yarmouth interglacial stage and was filled principally during the Wisconsin stage. Several episodes of erosion and alluviation occurred between these stages. The river now is entrenched 75 to 115 feet below the highest level of the Wisconsin fill.

GENERAL HYDROLOGY

The primary purpose of this study is to provide information on ground water for the residents of the region. Therefore, the use of technical terms is restricted to those which are considered essential to an understanding of the occurrence of ground water. The following definitions are based largely on those given by Meinzer (1923a, b). A few terms not given in the following list are defined where they are used in the text.

DEFINITION OF TERMS

Aquifer.—A formation, group of formations, or part of a formation that is water yielding.

Aquifer, confined.—Aquifer which is overlain by a confining bed and which contains water that is under sufficient pressure to rise above the bottom of the confining bed. Also called artesian aquifer.

Aquifer, semiconfined.—Aquifer overlain by a confining bed which itself is somewhat permeable and may act as an aquifer and through which water may move either into or out of the lower aquifer.

Aquifer, unconfined.—Aquifer which is not overlain by a confining bed and in which, therefore, the water table is free to rise and fall. Also called water-table aquifer.

Discharge, ground-water.—Discharge of water from an aquifer, either by natural means such as evapotranspiration and flow from seeps and springs, or by artificial means such as pumping from wells.

Drawdown.—Lowering of the water level in a well as a result of withdrawal of water.

Evapotranspiration.—Total discharge of water to the air by direct evaporation and plant transpiration.

Permeability.—The capacity of earth materials to transmit water under pressure. In general, the larger the connected pore spaces or other openings in the material the greater the permeability.

Piezometric surface.—The imaginary surface defined by the level to which water will rise in wells tapping a confined aquifer. Is analogous to the water table in that its shape and slope are indicative of the direction and relative rate of movement of water in the aquifer.

Porosity.—The ratio of the volume of the openings to the total volume of a rock or soil. A high porosity does not necessarily indicate a high permeability.

Recharge, ground-water.—Addition of water to an aquifer by infiltration of precipitation through the soil, by flow from streams or other bodies of surface water, by flow of surface water through sinkholes, or by flow of ground water from another aquifer.

Saline water.—Saline water has been defined in some reports as water containing more than 1,000 ppm (parts per million) of dissolved solids. In some areas, however, no better water is available and water containing more than 1,000 ppm is not considered unpotable; on the other hand, some water containing less than 1,000 ppm, but having a high proportion of sodium and chloride, has a salty taste.

Specific capacity.—The rate of yield of a well per unit of drawdown, generally expressed in gallons per minute per foot of drawdown at the end of a specified period of discharge. Not an exact quantity, as drawdown increases with time. Gives an approximate indication of how much water a well can yield.

Water table.—The upper surface of the zone of saturation except where that surface is formed by impermeable material.

Zone of saturation.—The zone in which the openings in the rocks are filled with water under hydrostatic pressure.

HYDROLOGIC CYCLE

The hydrologic cycle may be defined as the natural travel of water from the atmosphere to, on, and under the surface of the earth, and from the earth back to the atmosphere. This travel includes atmospheric movement, precipitation, streamflow, underground flow, and evapotranspiration. The hydrologic cycle is complex and in any specific area is controlled mainly by such factors as amount and rate of precipitation, temperature, type of soil and plant cover, topography, and geology. This report is concerned primarily with the recovery of water that is in the underground part of the hydrologic cycle.

Most water of economic importance in the Mississippian Plateau region comes from local precipitation. The precipitation falling on the ground evaporates, runs off in streams, or soaks into the soil. Part of the water that seeps downward into the soil is evaporated directly or is intercepted by plant roots and transpired. Part continues downward to the water table and becomes a part of the zone of saturation, moving slowly in that zone to points of lower elevation. Eventually, this water either discharges through springs, seeps into surface-water bodies, or is discharged by evapotranspiration. In dry weather the discharge of ground water is the principal source of streamflow (base flow).

If no net change occurs in the amount of water stored on the surface of an area or in the soil and rocks under the area in a given period of time, the amount of stream runoff from that area plus the amount of water discharged by evapotranspiration will be equal to the amount of precipitation on the area in the same period of time. In the Mississippian Plateau region, the average annual precipitation ranges from about 42 inches near northern Meade County to about 50 inches in the south-central part of the region. The average annual runoff ranges from about 15 inches (per unit area) from the North Fork of the Nolin River above Hodgenville to about 21 inches from the watershed of the Barren River above Pageville. Using information from selected stations the average precipitation in the region was estimated to be about 46.5 inches, and the average annual runoff about 19 inches. On the basis of these figures the average discharge of water by evapotranspiration was estimated to be about 27.5 inches. This means that under present conditions only about one-third of the water that falls on the area is even potentially available for development, and only a part of that can be developed practicably.

A large part of the Mississippian Plateau region is drained through subsurface solution channels. Because of this it is difficult to delineate subsurface drainage divides. In many areas subsurface divides, drawn on the basis of topography, miss by several miles the actual subsurface divides indicated by the shape of the water table. Thus, although the surface drainage area of the North Fork Rough River above Westview, Ky., is computed as 42.4 square miles, approximately 19.8 square miles are probably noncontributing (Wells and others, 1956, p. 423). The limited data thus far obtained in the Mississippian Plateau region show that surface watershed divides generally approximate the ground-water divides but do not coincide with them. The source of ground water at any point within the region is the precipitation that has fallen on an area which extends from that point to the ground-water divide. This area may be larger or smaller than the area encompassed by the similar surface watershed but generally will include about the same drainage area.

The volume of ground water in storage at any time in a given drainage basin is directly related to the rate and amount of precipitation that has fallen in that basin. During periods of above-average precipitation the volume of surface water and ground water within the basin increases. Conversely, during periods of below-average precipitation the volume of surface water and ground water within the basin decreases. Because surface water moves out of the basin relatively rapidly the quantity of surface water stored in the basin decreases rapidly after periods of precipitation. The volume of ground water stored in the basin decreases at a much slower rate because water moves more slowly through the openings in the rock than it does in surface streams.

In the Mississippian Plateau precipitation, natural discharge, and the character of the rocks are the important factors in controlling the amount of ground water in storage; however, other factors have a measurable effect. Floods and high water in streams, and lakes created by damming streams increase the volume of ground water in storage near the streams or lakes. Artificial drainage and pumping from wells and springs decrease the volume of ground water in storage. The position of the water table is related directly to the amount of water in underground storage. Therefore, fluctuations of water levels in wells are a measure of change in ground-water storage. By the use of automatic water-stage recorders continuous records of water-level fluctuations can be obtained. These records indicate the effects of precipitation, flooding, lake formation, soil-moisture deficiency, atmospheric-pressure changes, pumping, and other similar phenomena.

FLUCTUATION OF WATER LEVELS

At least one water-level measurement was made in most of the wells tabulated in this report. In 14 wells continuous measurements were made for extended periods by means of automatic water-level recorders. The continuous trace of water-level fluctuations on a graph over a period of time is termed a hydrograph.

The following hydrographs show fluctuations of water levels in selected wells and springs in the Mississippian Plateau region. The topographic and geologic situation of each observation well or spring is shown in the accompanying diagrammatic sketch.

Plate 3 illustrates the relations between precipitation, evapotranspiration, and water level in a dug well in Pleistocene and Recent alluvium. Recharge to the well is principally from local precipitation. Although the Ohio River is near this well, the permeability of the alluvium is so low that there is no determinable effect of short-term changes in river stage. The pattern of fluctuation is typical of other wells in the region that tap fine-grained alluvial deposits.

The major influence on the water-level fluctuation in this well is evapotranspiration. Nearly all recharge takes place during the winter when plants are dormant and evapotranspiration is at a minimum. Shortly after the last killing frost in the spring, evapotranspiration increases, most of the soil moisture is consumed, and a soil-moisture deficiency is present near the surface. Most precipitation during the summer partly replenishes the soil moisture, but does not recharge the ground water. In general, measurable recharge takes place during the growing season only when there is an unusually large amount of precipitation, as in May, June, and July 1955. After the first killing frost in the fall, plants become dormant, and measurable recharge takes place as soon as the soil-moisture deficiency is met.

Plate 4 illustrates the relations between precipitation, evapotranspiration, and water-level fluctuation in a drilled well tapping Mississippian limestone of Meramec age and occurrence of ground water in the vicinity of the Dripping Springs escarpment. The rapid rise and fall of the water level in the well in response to precipitation is due to the rapid recharge from the surface to the water table. This flow is principally through sinkholes into subsurface solution channels. The large amount of rise reflects the small volume of voids in the rocks. It requires only a relatively small amount of water to fill all of the voids to a great height. The effect of vegetation on the amount of recharge reaching the water table is relatively small in the area because much of the recharge is surface runoff into sinkholes and does not percolate through a soil zone. Even during extended dry periods, as soon as the near-surface soil-moisture deficiency is satisfied, water will run into sinkholes and cause a large and rapid rise in the water table. Because the soil-moisture deficiency is not completely replenished during summer rains, and because discharge through the cavernous limestone is nearly as rapid as recharge, the level of the water table declines at about the same rate as it rises during the growing season. During the late winter and early spring, however, when the soil is saturated with moisture, there is a continuous recharge from the soil zone to the water table; thus, the water table generally is maintained at a slightly higher level between periods of direct recharge through sinkholes.

In areas of cavernous limestone the water table may decline so far in the summer and fall that many wells go dry. The open channels in the limestone permit rapid drainage, and the water table commonly falls several feet below the level at which it stands in the spring of the year. In some wells solution openings are encountered only at high levels. Thus when the water table drops below these openings no more water can flow into the well, and many wells may go dry during a prolonged dry period although neighboring wells drilled to the same depth may remain adequate. Deeper drilling will result in a satisfactory well if additional solution openings are penetrated in the zone of fresh water, but if the well reaches below the zone of active circulation of ground water, sulfurous or saline water may be encountered.

Plate 5 illustrates the relations between precipitation, evapotranspiration, and water-level fluctuations in a dug well tapping mantle and Mississippian limestone of Chester age. There are some sinkholes in the vicinity of the well and heavy rains in the winter result in relatively rapid recharge when the soil is saturated, but during the growing season, after soil moisture has been depleted, there is almost no appreciable recharge. In this well, as in the well in plate 4, the openings in the rocks are small but relatively well connected. Water moving downward through saturated soil to the water table fills the solution openings in the rocks, and the water level in the solution openings rises rapidly in response to small recharge inasmuch as the volume of the openings is small.

The sharp increase in the rate of rise that takes place at a depth of about 16 feet results from the difference in permeability of the limestone and the overlying mantle. When recharge has filled the openings in the limestone up to the mantle, additional recharge results in temporary artesian conditions, and the well functions as a relief point from the hydrostatic head developed by the pooled water in connected sinkholes.

Plate 6 shows the relations between fluctuations of atmospheric pressure and water-level fluctuations in a drilled well tapping a semiconfined aquifer in limestone of Osage age. Fluctuation of atmospheric pressure causes an inverse, but smaller, fluctuation of the water level in the well. Water levels in wells in confined and semiconfined aquifers also fluctuate in response to pressure changes caused by earth tides, earthquakes, passage of nearby trains or heavy trucks, and pumping from relatively distant wells (Jacob, 1939).

Plate 7 illustrates the relation of water levels in a drilled well tapping cavernous limestone to the stage of a nearby stream. Water flowing in the stream enters solution openings in its bed that connect with solution openings on either side of the stream channel. The solution openings are relatively large and interconnected, and a rise in stream level results in a nearly simultaneous rise in the level of the ground-water table near the stream. During the period shown there was no precipitation in the vicinity of the well. The rise in stream level was from a thundershower in the upstream area.

Much of the recharge to the water table in the areas of the Mississippian Plateau that are underlain with rocks of Osage age occurs in this manner. The residual weathered rock and soil that caps the rocks of Osage age is largely clay, and where this material is present very little water percolates through it to the consolidated rocks. Accordingly, the principal source of recharge to ground water probably is water flowing over solution openings on the bare-rock floors of streams. After periods of high water on major streams some of

See next p.

this water that recharges the ground-water body is discharged back into the stream and helps maintain flow in the stream.

Plate 8 illustrates the relations between the stage of Lake Cumberland and water level in a drilled well tapping limestone of Meramec and Osage ages near Somerset.

Lake Cumberland was impounded in 1950. A recorder was installed on the well in September 1952, after the lake had been completely filled. The trace in the hydrograph shows a sharp use through 1953 followed by a gentle but continuous rise in water level in the well as a result of increase of ground water in storage. As shown in the sketch the water level has always been above maximum lake level. The change in altitude of the water level in the well is the result of a change in the altitude of the level of ground-water discharge and the gradient of the entire water table. Before the impoundment of Lake Cumberland the water table was perched above the level of local drainage. A prominent spring horizon was at the top of the siltstone. Except at minimum pool stage this spring horizon is now submerged and discharge occurs at higher altitudes.

The very sharp rise in the water level near the end of 1957 resulted from the saturated zone reaching a level at which the volume of openings in the rocks decreased sharply. This is the result of water filling most of the larger solution openings and rising more rapidly as it reaches higher levels where it encounters fewer and smaller voids per unit volume of rock.

Plate 9 illustrates the relations of water-level fluctuations in three wells that obtain water from different depths, near the Dripping Springs escarpment at Mammoth Cave National Park.

Well *A* is a dug well that taps a perched water body in the Big Clifty sandstone (as used by McFarlan and others, 1955). The water table is supported by a discontinuous layer of shale at the base of the formation. The trace in the hydrograph shows most prominently the recharge effects of heavy winter and spring precipitation, depletion of ground water in storage and lowering of the water table by evapotranspiration during the growing season, and drainage to the underlying formations and to points of discharge on both sides of the escarpment.

p. 21 Clifty changes St Gen -St. Louis well, are ks in Big Clifty.

Well *B* is a drilled well that taps perched water bodies of very small dimensions in the Girkin formation of Sutton and Weller (1932) that underlies the Big Clifty sandstone. Drainage from the overlying sandstone is the principal source of the water to the Girkin formation. The period of maximum recharge to the Girkin lags several months behind the period of maximum recharge to the Big Clifty sandstone. Thus, the water level in well *B* rises during most of the period that the water level in well *A* is falling. Superimposed upon this general

Doesn't this indicate that recharge through the clay from the Big Clifty is - even though retarded?

pattern are sharp rises due to heavy rains which apparently replenish the well through open solution channels. The water level in this well is affected also by siphon action. A siphon is not primed until the water level in the well is high enough to fill the siphon tube. When the water level in the surrounding solution openings falls, the siphon pulls the water level in the well down to the level of the siphon opening, frequently below the standing level before the water level had started to rise. ?

Well *B* is unused at present (1958), and its yield when used is not known but probably was small. It is believed to be typical of many wells in the limestone rocks of Chester age and the shaly limestone rocks of Osage age. Many of these wells yield less than an eighth of a gallon per minute and are satisfactory only for hand bailing. During prolonged dry spells the quantity of water migrating downward through solution openings diminishes to nearly zero, and the wells are then virtually dry until precipitation refills the solution openings. Many owners report that wells are adequate one day, and the next day, after water has been bailed out, they do not recover. The water moving through solution openings has migrated to a lower level and there is no recharge. Such wells remain completely dry until recharged by precipitation.

Well *C* is a drilled well that taps the major water body in the area. From a point just west of Munfordville to near Brownsville this water body is continuous from the Pennyroyal plain to Green River. It is recharged in the following ways: 1 by precipitation that falls on the Pennyroyal plain, enters sinkholes, and flows through solution channels under the Mammoth Cave plateau; 2 by precipitation that falls on the Mammoth Cave plateau, enters sinkholes, and flows rapidly downward through the natural vertical shafts that are present below many of the sinkholes in the plateau; 3 and by precipitation that falls on the Mammoth Cave plateau, enters the Big Clifty sandstone, migrates downward through the complex of solution openings in the Girkin formation, and enters the large solution channels that are present in the horizon adjacent to the water table. 4 Recharge directly from Green River may take place also during high stages.

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The fluctuation of water levels shown by the hydrograph is a result of recharge from the sources described and discharge through a complex of solution openings and siphons from near the well to Green River. The sharp rises in water level during the winter are due largely to precipitation on the Pennyroyal plain, plus some rapid recharge from precipitation on the Mammoth Cave plateau that flows rapidly downward through vertical shafts. Like well *B*, well *C* is affected by siphons, as shown by the sharp decline of the water level in the well to a point below the level at which it stood before each major

Unlike Dolo - Rapid discharg from tubula opening rise. As in many other wells in limestone the very sharp rise in water level (as much as 20 feet in 12 hours) following periods of heavy precipitation is the result of water filling most of the larger solution openings and rising more rapidly as it reaches higher levels and fills more widely spaced and smaller voids per unit volume of rock.

Several large springs discharge at Green River level. Their flow is very large during the winter and decreases to almost zero during the later summer and early fall. The springs at higher altitudes in the rocks of Chester age discharge small quantities of water individually but together represent a significant discharge from these rocks.

Plate 10 shows the relation of precipitation to discharge of a spring that discharges from Silurian rocks near Scottsville. The trace in the hydrograph shows gage height in the natural channel of the spring outlet.

Precipitation causes the water in the channel to rise, but the rise occurs about half a day after the precipitation. The Chattanooga shale underlies most of the area near the spring and prevents local recharge. Therefore, the water that discharges from the spring probably enters the ground at least half a mile away. This theory is supported by the fact that water discharged from Calvert Spring and other springs flowing from the Silurian rocks is clear, even at high stages, indicating that sediment has had ample time to settle.

Figure 5 compares the discharge of two springs with the discharge of nearby rivers. Many springs have the same discharge characteristics as streams flowing through the same area. Long-term records

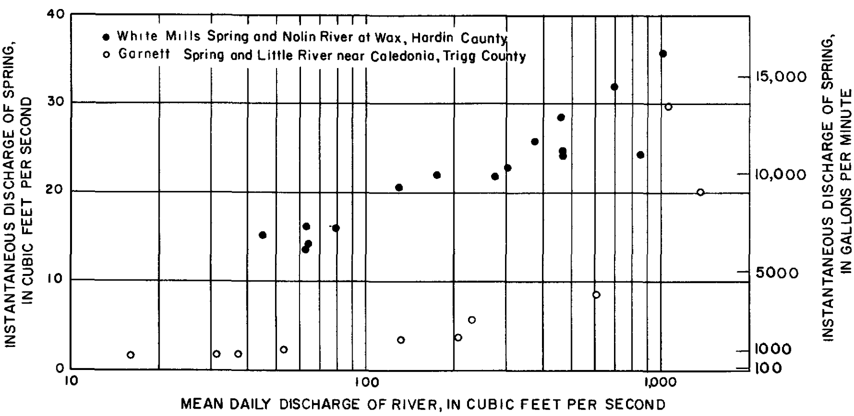

FIGURE 5.—Relation of spring discharge to river discharge in Hardin and Trigg Counties, Mississippian Plateau region, Kentucky.

of discharge are available for many streams in the Commonwealth thus, once the relationship between any given stream and spring is established the flow of the spring may be approximated from the discharge records of the stream.

AVAILABILITY OF GROUND WATER

Ground water occurs in openings in both consolidated and unconsolidated rock. The nature of the openings controls the amount of water that can be stored in the rocks, and the rate at which it can be replenished or yielded to wells and springs. In unconsolidated material, such as gravel, sand, and silt, the openings consist of spaces (pores) between individual particles or grains. The amount of open space (porosity) and the size and interconnection of the openings, which together control permeability, are determined by the size, shape, and arrangement of the grains. In consolidated clastic rocks, such as sandstone, siltstone, or shale, openings also occur between the grains but the porosity and permeability are lower than in unconsolidated rocks owing to the greater proportion of cementing material which may range from practically none to enough to fill the openings completely. In carbonate rocks, such as limestone, the principal openings are generally secondary, and exist as a result of solution along joints and bedding planes. These openings generally are larger and more numerous near the surface, and decrease in size and number with depth. The size of the openings and the depths to which they extend are determined chiefly by the relative solubility of the rock, and by the amount and the chemical and biological characteristics of water that has been in contact with the rock. Solution openings are largest and extend to greatest depths in sections of thick relatively pure limestone; they are confined to shallower depths where layers of shale, silt, or impure limestone serve as barriers below which the process of solution is ineffective. Limestones that are relatively insoluble include those which contain significant amounts of impurities, such as clay, silt, or precipitated silica.

The basis for the information on the availability of water in the Mississippian Plateau region is the data gathered during the well and spring inventory (p. 4). Tables 3–7 show the relation of items of well data gathered during the inventory. For example, in table 3, of 375 wells equipped with a bailer or bucket, 75.2 percent are classed as adequate and 21.6 percent as inadequate (will yield less than 100 gpd).

The yield subdivisions are based on the quantities of water needed for different uses. A yield of more than 500 gpd (gallons per day) is assumed to be adequate for maximum household use and is sufficient to supply a power pump and pressure system. An amount less than this is considered to be inadequate for a power pump and pressure system. A yield of 100 gpd is assumed to be the smallest quantity adequate for household use, but insufficient for a power pump and pressure system. A yield of less than 100 gpd is assumed to be insufficient for normal household use.

The occurrence of ground water in the Mississippian Plateau region is controlled primarily by geologic factors with modifications determined generally by hydrologic controls. Figure 6 shows the relation of the age of the rocks to the yield of wells. The geologic control of ground water may be divided into two distinct environments: one consisting of unconsolidated sand and gravel in the valleys of the Ohio River and its larger tributaries, and the other consisting of the consolidated bedrock that underlies the entire region.

Time-drawdown curves and recovery curves of water levels in selected wells are shown in figure 2. These wells do not represent any formation or series, but do indicate the range in specific capacity of wells in the aquifers of the Mississippian Plateau. Most of these wells are used for public or industrial supply and their yields are among the largest known in the region.

The unconsolidated alluvial deposits occur principally along the Ohio River (Walker, 1957) and include terrace deposits and deposits underlying the flood plain. Almost everywhere the alluvium of the Ohio River valley will yield sufficient water for domestic and farm use, and in many places it will yield as much as several hundred gallons per minute to single vertical wells. The largest known yield in the section of the valley that borders the Mississippian Plateau region is 300 gpm from single vertical wells at West Point and Cloverport. Compound horizontal wells serving industries in this area yield as much as 5,000 gpm. Such large quantities are replenished largely by induced infiltration from the river. Alluvium in the valleys of the larger tributaries, particularly parts of Green River, Cumberland River, and Tennessee River (Kentucky Lake), will furnish more than 100 gpm in some places. Alluvium in the smaller tributaries is generally thin and consists largely of silt and clay. Small amounts of water probably may be obtained from these thin deposits but few wells are known to obtain water from this source. It is possible that, in some areas, infiltration galleries consisting of drain tile or horizontal well screens could be constructed so as to yield more than 100 gpm from these deposits. Specific-capacity tests of two wells in the alluvium are shown in figure 2.

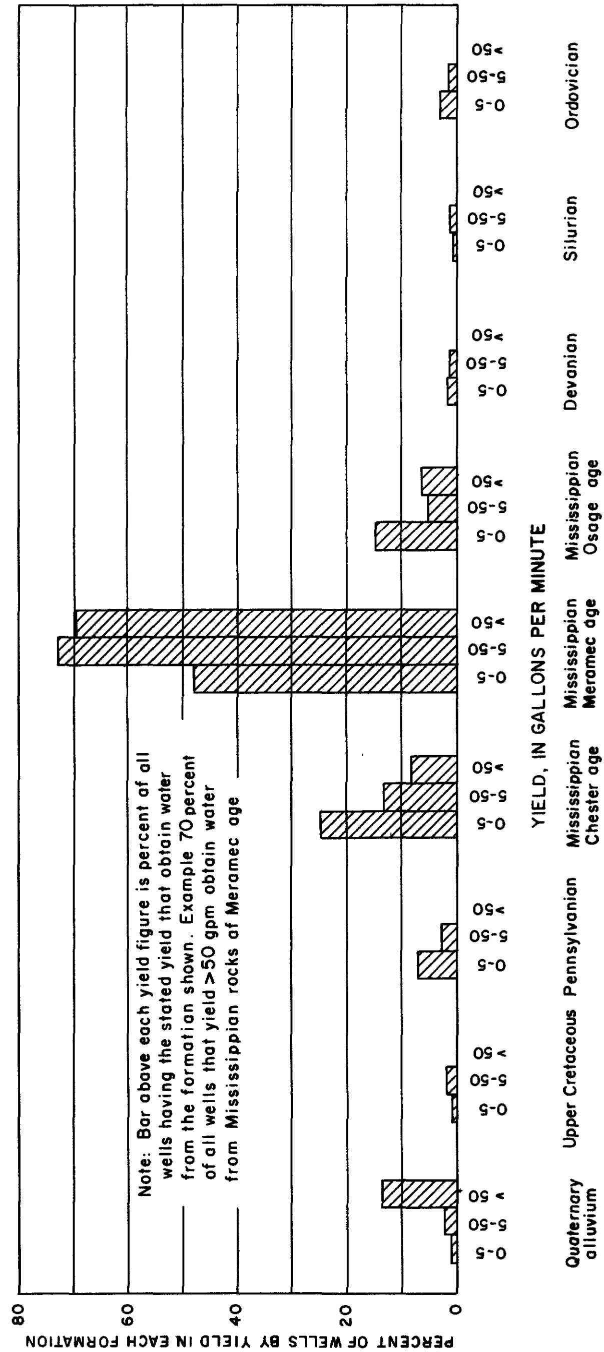

FIGURE 6.—Drilled wells in the Mississippian Plateau region, Kentucky, subdivided by yield and aquifer.

Where the aquifers consist of sandstone, shale, and impure limestone the largest supplies of water are obtained close to streams from wells in which the water level is not far above the local perennial stream level. Plate 11 shows this relation for drilled wells in bedrock. The wells are subdivided according to their topographic situation as upland area, hillside, valley bottom, or karst wells (see table 3). The wells on upland areas, hillsides, and valley bottoms (underlain by sandstone, shale, and impure limestone aquifers) are in one group in plate 11 and the wells in karst (underlain by relatively pure limestone aquifers) are in the second group. Each of these groups is further subdivided into four yield categories: less than 500 gpd, 500 gpd to 5 gpm, 5 gpm to 50 gpm, and more than 50 gpm. All wells in each of the yield categories are subdivided by height of the water level in the wells above local perennial stream levels, and the distance from the wells to streams. The percentage of wells in each of these situations is shown by the area of a circle. The total number of wells in each yield category is shown next to the yield figure. Thus, of 7 drilled bedrock wells that are situated on upland areas, hillsides, and valley bottoms and yield more than 50 gpm, about 57 percent are in the group which is less than 1,000 feet from streams and whose water level is less than 50 feet above local stream levels. By comparison, of 79 drilled bedrock wells that are situated in upland areas, hillsides, and valley bottoms and yield less than 5 gpm, about 15 percent are in this group. Yield also increases with increasing depth, although wells that penetrate below the zone of active circulation encounter sulfurous or saline water. Yields of drilled wells in the Mississippian Plateau region are listed by counties in table 8. This shows the approximate areal distribution of the wells used to make plates 11 and 12.

In karst areas, where the aquifers consist of relatively pure limestone, such as the Meramec rocks, the largest yields are obtained from drilled wells distant from streams but in which the water level is not far above the local perennial stream levels. Where the height of water level in wells above perennial stream levels is greater and distance is the same, yields are generally smaller. Some high-yield wells may be obtained in karst areas close to streams, as shown in the graph of wells yielding more than 50 gpm, but the number of such wells is small. Generally solution channels are very large near the streams and carry large quantities of water as they approach streams, but the channels are spaced far apart. If a well encounters one of these large channels very high yields will be obtained, but most wells in this topographic situation yield little or no water.

TABLE 8.—*Yields of drilled wells in the Mississippian Plateau region, Kentucky, by counties*

County	Total wells[1]	Drilled wells in karst						Drilled wells (except in Quaternary alluvium) in uplands, hillsides, and bottoms; not in karst						Drilled wells in Cretaceous, Devonian, Silurian, and Ordovician rocks in uplands, hillsides, and bottoms					
		Inadequate <500 gpd		Adequate				Inadequate <500 gpd		Adequate				Inadequate <500 gpd		Adequate			
				500 gpd-5 gpm		5-50 gpm	>50 gpm			500 gpd-5 gpm		5-50 gpm	>50 gpm			500 gpd-5 gpm		5-50 gpm	>50 gpm
		Power	Others	Power	Others			Power	Others	Power	Others			Power	Others	Power	Others		
Adair	40								8	6	24	2					3	1	
Allen	27								1	4	20	1	1				1	1	
Barren	40	2	1	9	4	3	3		1	11	6								
Breckinridge	48	1		2		2			12	17	5	8	1						
Caldwell	30		2	3	2	6	1		3	3	6	4							
Casey	33							1	9		22	1		1	4		3		
Christian	64			10	2	13	1	3	8	7	19	1							
Clinton	13			2					1	2	7	1							
Crittenden	31			1				1	6	4	12	7							
Cumberland	30				1				5	4	20				2	4	13		
Edmonson	18			1		2				7	7	1							
Grayson	42				1			3	6	12	16	2	2						
Green	18			1	3			1	2	2	9								
Hardin	38		2	2	6	2		1	3	6	9	6	1						
Hart	36	1		9	1	7	1		2	4	8	3							
Larue	23			4	2	2		1		9	2	1	2			1			
Livingston	21			1				1	1	4	7	6	1						
Logan	49	1	3	9	2	4		3	7	5	12	1	2						
Lyon	9							1		3		5				3			
Meade	22		1	8		3				5	2	3							
Metcalfe	25			2	4				6	5	6		2		1		1		
Monroe	24			2				1	3	6	10	2				1	2	1	
Pulaski	45							3	8	12	20	2							
Russell	26								3	4	15	4					1	1	
Simpson	15			5	8				1		1								
Taylor	20				2			1	2	3	11	1							
Todd	40		1	6	3	8	6		5	3	8								
Trigg	25			2	2	2	1	4	1	8		5						1	
Warren	38	1	1	12	8	3	3	1	1	6	2								
Wayne	28						1	1		8	17	1							
Total	918	6	11	91	51	57	17	27	105	170	303	68	12	1	7	9	24	5	

[1] Does not include drilled wells in Cretaceous, Devonian, Silurian, and Ordovician rocks in uplands, hillsides, and bottoms.

An exception to these general relations is found where extensive karst areas are a considerable height above drainage, and a perched water body in cavernous limestone is supported by underlying beds that are relatively impermeable. Plate 11 shows a relatively large number of wells in karst, yielding 500 gpd to 5 gpm, which are 100 to 200 feet above streams. These wells obtain water from perched water bodies in karst areas particularly in the southeastern part of the region where the perennial streams flow on rocks of Osage age, and extensive high plateaus capped by rocks of Meramec age are present. Yields from these areas are not generally as large as those found at lesser heights above stream level but large areas of sinkholes are present on these plateaus, and wells that are distant from streams generally yield sufficient water for a domestic supply with a pressure system. Close to the streams most of the water drains out, and most wells near the edge of such karst areas are inadequate during the summer and fall.

Plate 12 is similar to plate 11, and shows that in general higher yields can be expected from wells drilled close to sinkholes than from those drilled at considerable distance from sinkholes if the water level in the well is close to perennial stream levels. Of the 51 wells that yield more than 5 gpm, 49 percent are less than 500 feet from sinks and have a water level less than 50 feet above the local stream level, and of the 80 wells that yield less than 5 gpm but are adequate for power, about 25 percent are in the same category. The percentage of low-yield wells increases as the water level becomes higher above the local stream level, whereas the percentage of high-yield wells decreases. Of the 16 inadequate wells that yield less than 5 gpm, only 18 percent are less than 500 feet from sinks and have a water level less than 50 feet above the local stream level. Therefore, for wells less than 500 feet from sinks and water level less than 50 feet above the local stream level, the chances are 3 to 1 in favor of obtaining a well that yields more than 5 gpm, and 4 to 1 in favor of obtaining an adequate well. Moreover, it can be shown that for wells whose water level is more than 50 feet above the local stream level and the same distance from sinks, the ratio is 1 to 10 against obtaining more than 5 gpm.

In the same situation, however, the ratio is about 3 to 2 in favor of obtaining a well adequate for a power pump. If the water level in the wells is less than 50 feet above the local stream level, there is a sharp decrease in the number of these wells distant from sinks (pl. 12). The graph shows that there is a 7 to 2 chance in favor of obtaining a well that yields more than 5 gpm within 500 feet of a sink as compared to one between 500 to 1,000 feet distant, provided the water level is less than 50 feet above the local stream level.

Large areas of the Mississippian Plateau region are drained through solution channels in limestone; in these areas no surface tributary streams are present. The solution channels are concentrated along enlarged joint systems in most places, and a determination of the orientation of these joint systems will aid in determining the direction of drainage and the position of subsurface solution channels. Generally sinkholes are concentrated above the major solution channels developed in the joint systems; therefore alinement of sinkholes generally indicates that a solution channel underlies the area, and is oriented in about the direction indicated by the alinement of the sinkholes. Table 8 shows that most of the wells from which high yields are obtained are in the counties in which there is little surface drainage, and where large areas of cavernous limestone of Meramec age are present close to perennial stream level. These include Barren, Christian, Hardin, Hart, Larue, Logan, Meade, Todd, Trigg, and Warren Counties. In these areas high yields may generally be obtained if a well is located near sinkholes. In areas near major surface streams, however, ground-water flow is concentrated in solution openings that are widely spaced. In such areas alined sinkholes may indicate the location of a major subsurface solution channel from which higher than average yields may be obtained. Wells drilled on either side of such channels probably will be inadequate. Plate 12 also shows the distribution of wells in karst areas in relation to distance from streams and distance from sinks. The largest percentage of wells in all yield categories is less than 500 feet from sinkholes and more than 10,000 feet from streams, but the pattern of the high-yield category (greater than 5 gpm) is not significantly different from the pattern of the low-yield categories. Thus, it is apparent that the yield of drilled bedrock wells in karst is not determined by the relationship of distance from streams and distance from sinkholes.

Where perched or semiperched water bodies are present, as in sandstone formations underlain by shale, or impure limestone that contains discontinuous layers of shale, moderate supplies of water may be obtained. Such perched water bodies are common throughout the Mississippian rocks of Chester age which consist largely of alternating formations of sandstone, limestone, and shale, and Mississippian rocks of Osage age which consist largely of impure limestone and include discontinuous layers of shale.

Where extensive areas of Mississippian rocks of Meramec age are present at high levels, a perched water body is generally present at the base of the Meramec series, supported by shale in the underlying Osage series. In the southeastern part of the region the Meramec includes several layers of siltstone and shale and these support perched water bodies of moderate areal extent. Water tends to drain out of these perched water bodies at the exposures of the aquifer where it has been dissected by streams. Therefore, most wells that are close to major escarpments do not yield adequate supplies of water if they tap only perched water bodies. In general, deeper wells in such topographic situations will yield larger quantities of water; however, where thick sections of saturated rocks are encountered yields of more than 50 gpm may be obtained from perched water bodies, but such high yields are very uncommon. This is shown in the graph of drilled bedrock wells in karst areas that yield more than 50 gpm (pl. 11). Of 15 wells, 2, or about 13 percent, were in the group whose water level is 100 to 200 feet above local streams. Both of these wells yield water from perched water bodies in thick sections of saturated rocks.

Most of the dug wells in the Mississippian Plateau region obtain water from perched water bodies. Wells dug in sandstone formations, or sand and gravel, are generally adequate for a domestic supply with a bucket or bailer if there is a minimum thickness of about 10 feet of saturated deposits during late summer and fall. Dug wells in limestone and shale are less dependable, and many are dry during much of the year. Dug wells in mantle are generally inadequate where they tap perched water bodies. Where they are dug in lowland areas close to streams they generally are adequate for a bucket or bailer. Yields of dug wells in each county in the Mississippian Plateau region are shown in table 9.

Table 10 gives the results of tests of the physical character of several samples of Chester sandstones, and one sample of the Fredonia oolite member of the Ste. Genevieve limestone. The sample from Grayson County, taken from the Big Clifty sandstone, has a permeability sufficient to yield on the order of 5 gpm to large-diameter wells where there is a thickness of about 40 feet or more of saturated material. The permeability of all other samples tested was so low that it must be assumed that the water these formations yield to wells is derived largely from fractures. In general the permeabilities are much lower in the cores taken at depth than in the cores that were taken from surface exposures. Probably leaching of the cementing material in the formations where they are exposed at the surface has increased their permeability. However, all of the deep cores were obtained from the fluorspar mining district in Livingston County, and it is possible that the permeabilities of the deposits in this area are generally lower than those in the same formations elsewhere in the region.

TABLE 9.—*Yields of dug wells in the Mississippian Plateau region, Kentucky, by counties*

County	Total wells [1]	Dug wells in karst						Dug wells (except in Quaternary alluvium) in uplands, hillsides, and bottoms; not in karst						Dug wells in Cretaceous, Devonian, Silurian, and Ordovician rocks in uplands, hillsides, and bottoms					
		Inadequate <500 gpd		Adequate				Inadequate <500 gpd		Adequate				Inadequate <500 gpd		Adequate			
				500 gpd–5 gpm		5–50 gpm	>50 gpm			500 gpd–5 gpm		5–50 gpm	>50 gpm			500 gpd–5 gpm		5–50 gpm	>50 gpm
		Power	Others	Power	Others			Power	Others	Power	Others			Power	Others	Power	Others		
Adair	2								1		1								
Allen	8								2	3	3					2			
Barren	6		1		2			1			2								
Breckinridge	14								9	2	3								
Caldwell	10	1				1		2	2	3	1								
Casey	13								8		5				1		1		
Christian	6		2			1			1		2								
Clinton	4								1		3								
Crittenden	4								2	1	1								
Cumberland	3								1		2								
Edmonson	15		1					1	7	1	5								
Grayson	16							1	7	3	5								
Green	4				3						1								
Hardin	4								1	1	2								
Hart	5			2					2		1								
Larue	14							2	9		3								
Livingston	6							1	2	1	2							2	
Logan	17				3			1	6		6	1							
Lyon	5								2		3				1	2			
Meade	7								3	2	1	1							
Metcalfe																			
Monroe	9		1						2	2	3	1							
Pulaski	11							3	2		6								
Russell	4									1	2	1					1		
Simpson	3	1								1	1								
Taylor	9							1	4		4								
Todd	9	1		1	1		1		1	2	2								
Trigg	14			1					4	1	8				1	1	6		
Warren	11			1	1				3	3	2	1							
Wayne	6							1	1	2	2								
Total	239	3	5	5	10	2	1	14	83	29	82	5			3	5	8	2	

[1] Does not include dug wells in Cretaceous, Devonian, Silurian, and Ordovician rocks in uplands, hillsides, and bottoms.

TABLE 10.—*Hydrologic properties of core samples from the Mississippian Plateau region, Kentucky*

County	Geologic unit	Depth below land surface (feet)	Orientation of core	Coefficient of permeability (gpd per day per square foot)	Porosity (percent)	Specific yield [1] (percent)	Specific retention [1] (percent)
Breckinridge	Mississippian sandstone of Chester age.	Surface	Horizontal	0.03	24.0	22.2	1.8
Do	do	do	Vertical		23.2	20.3	2.9
Caldwell	Tar Springs sandstone.	do	Horizontal	.03	19.1	14.4	4.7
Do	do	do	Vertical	.04	18.0	12.5	5.5
Crittenden	Mississippian sandstone of Chester age.	do	do	.03	16.5	12.4	4.1
Grayson	Big Clifty sandstone.	do	Horizontal	11	26.2	22.3	3.9
Do	do	do	Vertical	5	28.1	24.3	3.8
Hart	do	do	Horizontal	.2	19.8	15.5	4.3
Do	do	do	Vertical	.1	20.6	14.9	5.7
Livingston	Hardinsburg sandstone.	do	do	.01	14.2	12.7	1.5
Do	do	30	do	.04	15.0	12.4	2.6
Do	Cypress sandstone	5½	do	.0004	12.0	9.3	2.7
Do	do	31	do	.0006	7.9	6.3	1.6
Do	do	300	do	.0009	10.1	6.2	3.9
Do	Bethel sandstone	162	do	.0003	6.7	4.5	2.2
Do	do	210	do	.003	7.9	6.3	1.6
Do	do	397	do	.0005	8.6	5.8	2.8
Do	Ste. Genevieve limestone, Fredonia oolite member.	448	do	.00004	3.3	2.4	.9
Logan	Hardinsburg sandstone.	Surface	Horizontal	.05	19.9	14.5	5.4
Do	Cypress sandstone	do	do	.7	23.2	20.8	2.4
Do	do	do	Vertical		20.6	19.2	1.4

[1] Specific yield of a rock is the ratio of (a) the volume of water which, after being saturated, it will yield by gravity to (b) its own volume.

[2] Specific retention of a rock is the ratio of (a) the volume of water which, after being saturated, it will ~~return~~ against the pull of gravity to (b) its own volume.
retain

Tables 5 and 6 show the correlation of yield data obtained during pumping tests of drilled (table 5) and dug wells (table 6), in Pennsylvanian rocks and Mississippian rocks of Chester and Meramec age. Most of these wells obtain water from perched water bodies. The location of these wells is shown on plate 13.

Springs are an important source of water supply in the Mississippian Plateau region. In areas underlain by Mississippian rocks of Meramec age they are the major source of public and industrial water supplies. Table 11 shows, by counties, the discharge of springs that were inventoried during this study. Table 12 gives detailed information on discharge of 23 of the larger springs in the region. Three of these springs are in Louisville limestone of Silurian age; the remainder are in Mississippian rocks of Meramec age. The large springs in Silurian rocks occur only in a small area in Allen and Barren Counties where the Barren River has entrenched itself into the Silurian rocks.

TABLE 11.—*Yields of springs in the Mississippian Plateau region, Kentucky, by counties*

County	Total springs	Discharge of springs in karst areas						Discharge of springs in uplands, on hillsides, and at stream level					
		Goes dry	<10 gpm	10–100 gpm	100–450[1] gpm	1–10 cfs	>10 cfs	Goes dry	<10 gpm	10–100 gpm	100–450 gpm	1–10 cfs	>10 cfs
Adair	2								1	1			
Allen	10				1	1			7	1			
Barren	12		2	1	1	1			2	2	1	2	
Breckinridge	2					1			1				
Caldwell	11				2	2			1	3	2	1	
Casey	4								3	1			
Christian	7								1	2	3		1
Clinton	10				3	1				3	2	1	
Crittenden	10		1	1					1	3	3	1	
Cumberland	2								1	1			
Edmonson	13		1	2		1	2		2	1	3		1
Grayson	2										2		
Green	7								3	2	2		
Hardin	20			1	4	5				2	4	4	
Hart	17		1		2	1	1		2		4	4	2
Larue	6				1					1	2	2	
Livingston	5		1		1				1	1	1		
Logan	12		1	1	4	4			1	1			
Lyon	7	1	1			1		1		2	1		
Meade	5					2			1		1	2	
Metcalfe	13						1		5	5	1	1	
Monroe	9		1						3	3	2		
Pulaski	11			1					9	1			
Russell	2				2								
Simpson	9									3	3	3	
Taylor	2								2				
Todd	6	1			2	2				1			
Trigg	13				1	5	1			2	2	2	
Warren	7				1				2	1	1	2	
Wayne	8								5	1	1	1	
Total	244	2	9	7	25	27	5	1	54	44	41	25	4

[1] One cubic foot per second is about 450 gallons per minute.

In this report springs are classified as seepage, tubular, and depression types (table 7). The depression springs are further subdivided into those having surface discharge and those not having surface discharge. Seepage springs are those having very small openings that are not well defined. Many seepage springs discharge along escarpments where rocks of Chester age and rocks of Pennsylvanian age are exposed. Some occur also in the Chattanooga and New Albany shales of Devonian age and at certain horizons in the rocks of Osage age where layers of shale are present. Tubular springs have a well-defined tubular opening, commonly partly filled with air, and discharge over the floor of the opening. In some springs the floor is composed of relatively insoluble rock such as shale but in most the floor is limestone that is indistinguishable from that on the walls and roof. Depression springs have tubular openings but the openings are submerged. Some depression springs discharge into a surface channel but others flow across the floor of a sinkhole or are sinkholes which intercept the water table. Figure 7 shows the relation between the several types of springs.

The variability of flow of springs in the Mississippian Plateau region is determined by the topography in the area of recharge, and by the type of opening from which the water is discharged. Thus, 80 percent of the discharging depression springs have a variability of less than 400, whereas only 38 percent of the tubular springs have a variability of less than 400 (table 7).

In some areas a few large chains of sinkholes occur. These sinkholes feed into large partly air filled solution channels, and the water is discharged from a partly air filled tubular opening. Where major solution channels are well connected and much larger than required to transmit the water fed into them through sinkholes, the discharge from the system is highly variable. Variability of discharge from the system is smaller where the water-table gradient is low and the areas are underlain by smaller solution channels not alined toward a nearby single point of discharge. In these areas the saturated thickness of the aquifer is large, and the volume occupied by saturated solution channels is relatively large. Depression springs generally are found where these conditions prevail.

The yield of discharging depression springs is generally greater than the yield of tubular springs. About 85 percent of the discharging depression springs yield more than 100 gpm, but only about 42 percent of the tubular springs yield more than 100 gpm. Many of the depression springs without discharge will yield large quantities of water when pumped.

TABLE 12.—*Maximum and minimum discharge and variability of 23 springs in the Mississippian Plateau region, Kentucky*

Name of spring	County	Formation	Number of measurements	Discharge (gpm)		Variability percentage [1]
				Maximum	Minimum	
Big	Allen	Louisville limestone	22	20,944	903	307
Calvert	do	do	63	10,462	386	613
Stinking	Barren	do	7	3,560	598	184
Bluff	Caldwell	St. Louis limestone	16	[2] 60,000	235	881
Harpending	do	do	6	6,262	678	203
Town Creek	Clinton	do	19	55,074	279	787
Dyers	Hardin	do	12	4,244	180	329
White Mills	do	do	16	13,608	3,128	136
Terhune	Larue	do	19	8,530	393	662
Gum	Livingston	do	9	73	20	103
Puckett	Livingston and Crittenden.	Ste. Genevieve limestone	15	22,331	263	770
Smotherman	Logan	St. Louis limestone	11	22,932	136	376
Schenley	Meade	do	13	23,600	1,810	264
Arrow	Simpson	Warsaw limestone	6	15,905	333	362
Rum	Todd	St. Louis limestone	7	20,535	181	558
Town	do	St. Louis limestone	8	3,262	703	147
Big	Trigg	do	6	5,434	198	310
Blue	do	do	11	7,486	302	420
Garnett	do	do	9	13,368	764	353
Martin	do	Ste. Genevieve limestone	6	15,446	613	268
Mill Stream	do	St. Louis limestone	7	[2] 150,000	663	588
Cloud	Warren	do	13	19,172	25(?)	550
Monticello	Wayne	Ste. Genevieve limestone	8	32,015	320	527
Average			13	21,434	570	406

[1] Computed as $\frac{\text{Maximum}-\text{Minimum}}{\text{Average}} \times 100$ (Meinzer, 1923~~a~~b, p. 53).

[2] Estimated.

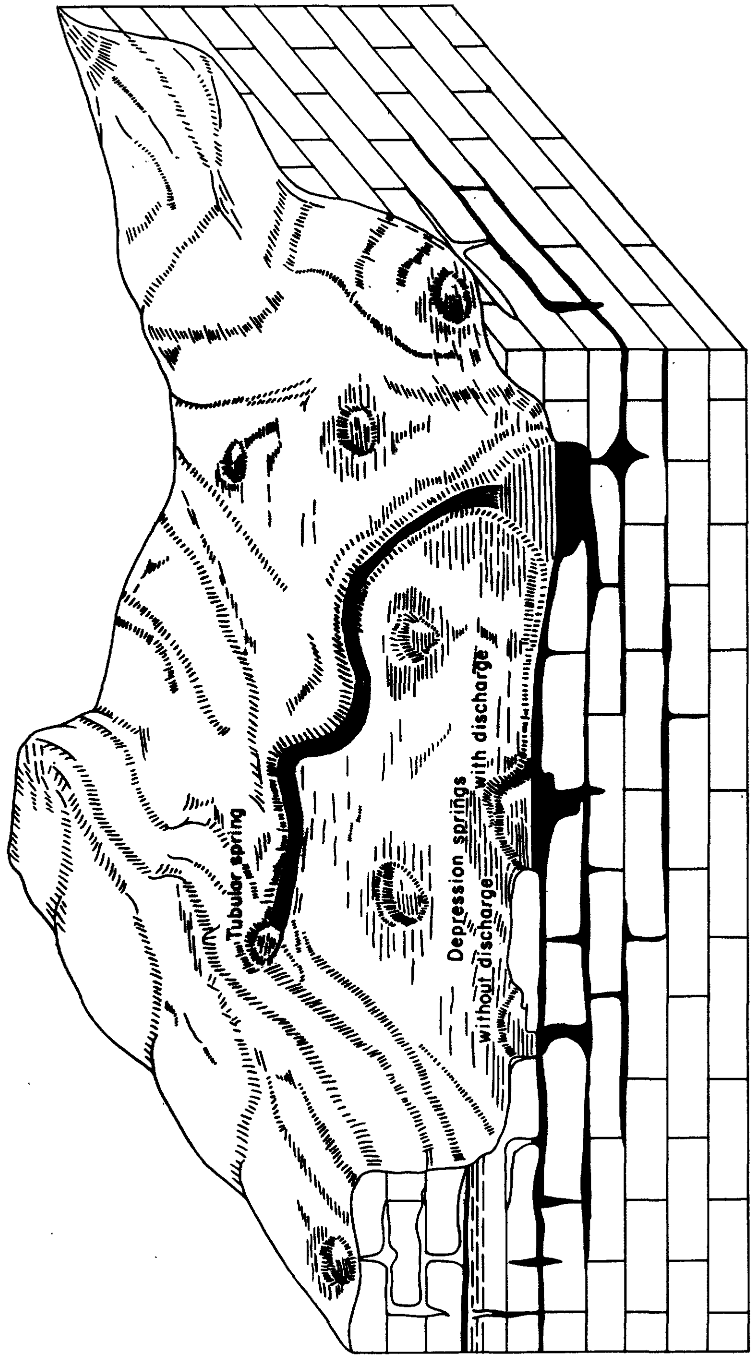

FIGURE 7.—Diagrammatic sketch showing relation of tubular springs and depression springs with and without discharge in the Mississippian Plateau region, Kentucky.

Plate 14 shows the relation of the discharge of springs to distance from streams and height above streams for tubular and depression springs. The springs with the largest discharge are near streams and not far above perennial stream levels. A few springs that discharge from 1 to 10 cfs (cubic feet per second) occur at high levels where they discharge from perched water bodies in the rocks of Meramec age. All these springs are in karst areas.

By comparison, most wells in the karst areas have a water level less than 50 feet above stream level, but are farther from streams (pl. 11). Near streams, much water for domestic use is supplied from cisterns, and residents report that many drilled wells are dry or yield saline water. These wells generally were filled soon after completion and are forgotten and therefore they could not be inventoried. Of 197 wells inventoried in the karst area, 9 were near streams and have a water level less than 50 feet above perennial stream level. Of these 9 wells, 2 yield more than 50 gpm from large solution channels from which nearby springs discharge, 1 yields more than 5 to 50 gpm, and 6 yield less than 5 gpm. Thus, most wells drilled near streams are dry or yield saline water. Most of the few successful wells yield less than 5 gpm, but a very few wells yield more than 50 gpm from the same solution channels that discharge water to large springs.

The relation of discharge to distance from sinks, distance from streams, and height above perennial stream level is shown in plate 15.

Most of the springs having large flows are slightly above perennial stream levels and near sinks, whereas most springs having smaller flows are higher above perennial stream levels and farther from sinks. A high percentage of the large springs are grouped near streams and near sinks with a progressive shift away from streams and sinks in the lower flow categories.

More detailed investigations of the availability of ground water will be needed in many areas as demands for water increase. Some of these areas will be determined by the increased need for water by existing consumers, such as cities and industries. However, the demand for water is so great that in the future industries generally will be established in areas where an adequate supply of water is known to be available. Irrigation, which is growing in importance in Kentucky, will also be stimulated by information on the availability of ground water.

The occurrence of ground water in the fluorspar mining district in Caldwell, Crittenden, and Livingston Counties is so complicated that only general conclusions could be drawn from the data obtained in this reconnaissance study. Very detailed investigations are needed to work out the ground-water hydrology of this area.

One well in the alluvium of the Green River valley yielded 75 gpm from coarse sand and gravel. Test holes in the alluvium of some of the larger streams may indicate other areas where relatively large yields could be obtained.

Most of the rocks of Osage age yield very little water to wells. In many areas nearly all wells yield less than 5 gpm. However, additional studies might reveal areas in which larger supplies could be obtained. Because most of the rocks of Osage age in Kentucky have not been mapped or described accurately, the hydrology of this entire series should be restudied. Facies of these rocks, which control the occurrence of ground water, change from place to place within the region.

The Mammoth Cave area is one of the finest places in the world for the study of the hydrology of soluble limestones, and warrants a separate detailed study.

Detailed information is needed to delineate more accurately areas of high yield in the karst regions. Detailed studies should be made in the karst regions to determine the factors that influence the occurrence of ground water. Although this report establishes several general principles of ground-water occurrence in such areas, much more information must be obtained and analyzed before accurate predictions of well yield can be made. Special attention should be given to the many large springs in the karst region. Although they are one of the most important sources of water, their flow characteristics, areas of drainage, and chemical characteristics are little understood.

Several sandstones of Chester age in the northern area may yield enough water for small industrial supplies. Detailed information on the areal extent and yield of these aquifers is not available. Many of the rocks of Chester and Meramec age in the southeastern part of the area, particularly in Wayne County, yield relatively large quantities of water. More detailed studies would indicate where additional large supplies of ground water could be obtained.

METHODS OF OBTAINING GROUND WATER

Most water supplies in the Mississippian Plateau region are obtained from drilled wells. Except in the alluvium of the Ohio River valley all wells were drilled by the cable-tool method in which cutting is accomplished by repeatedly raising and dropping a cutting tool or bit suspended from a tripod or derrick.

Most wells ending in unconsolidated material are equipped with a screen extending below the casing, and are developed by pumping, surging, and backwashing to remove fine-grained materials from around the screen. Large-capacity tubular wells constructed in the alluvium of the Ohio Valley are as much as 18 inches in diameter. Many of these are gravel packed, that is, a gravel envelope is placed around the screen after it is inserted in the drilled hole. Horizontal collector wells, also used in the alluvium, are constructed by a combination of digging, jetting, and driving. Horizontal screens are driven out from the bottom of a caisson that has been constructed so that its base is below the water table. Several screens, each more than 100 feet in length, may be driven out radially from the center caisson. Some collector wells in the Ohio Valley alluvium yield as much as 9,000 gpm (Maxwell, 1954, p. 14).

Most wells drilled in bedrock are cased to rock with metal pipe 6 to 8 inches in diameter. Seepage and pollution may be minimized by firmly sealing the casing in the bedrock. Cable-tool drilling in rock produces a mud or slurry, consisting of pulverized rock mixed with water, which is bailed out of the well repeatedly as drilling progresses. The action of the bit forces some of the mud into the openings in the wall of the well, and may partly seal the sides. The well should be developed by removing this material to allow water to enter the well freely. Development may be by brushing, surging, or bailing. Yields from properly developed wells generally are greater than from wells that have not been developed. The use of chemicals, dry ice, or blasting may further increase yields in some wells. Where very large solution openings are present unusual drilling conditions may be encountered. Drilling tools may fall through free space for several feet. In some places further drilling is prevented by angled openings which cause the tools to slide to one side and become caught. Wells near Monticello, Glasgow, Bowling Green, and at two places in Hart County end in caverns so large that the pump bowls are reported to be accessible from caves, and in some the bowls are serviced from below rather than by pulling the bowls up through the well as is normally done.

Dug wells are an important source of water in many areas of the Mississippian Plateau region. Where ground water is difficult to obtain in quantity, and where the water table is not much more than 40 feet below the surface, dug wells have certain advantages over drilled wells. Their relatively large diameter, commonly 2 to 4 feet, offers a relatively large storage capacity and a large infiltration area. On ridgetops, where the ground water occurs mainly in the soil and in the underlying weathered-rock zone on top of relatively impermeable bedrock, water is yielded more readily to dug wells than to drilled wells. Where thin perched water bodies are present in sandstone formations dug wells will generally yield more water than drilled wells because of their greater infiltration area. In such areas drilled wells are advantageous only if they are drilled to perennial stream level, as much as 200 to 400 feet below the surface. Many dug wells, however, go dry during late summer and early fall because they extend only a short distance below the water table. In sandstone aquifers, wells can generally be deepened to the lowered water table unless they already extend the full thickness of the aquifer. If the water is obtained at the contact between mantle and bedrock, deepening of a well probably will not result in an increase in yield. Most dug wells in mantle have been excavated to bedrock by hand. Some extend into bedrock a few feet to provide additional storage capacity. Those in sandstone generally extend 25 to 50 feet into bedrock. Few dug wells are deeper than 50 feet, and more than half are less than 25 feet. Most are lined with masonry or with tile or concrete pipe to prevent caving.

Springs are the source of water for 14 municipalities and 4 major industrial installations in the Mississippian Plateau region. About 20 percent of rural domestic water supplies are obtained from springs, and thousands more are used for stock-water supplies. Many of the larger springs are not utilized except for stock water. Locally, with proper development springs could be utilized to provide additional, and in many places much-needed, supplies of water.

There are many methods of developing springs, and each spring requires a unique installation best fitted to the local environment. The most important factor in spring development is that the flow of water from the mouth of the spring should be unimpeded. Damming or ponding of the water to a level higher than the mouth will allow sediment to collect which may clog the spring. In addition, increasing the head at the discharge point may cause the spring to cease flowing or to flow at a greatly decreased rate. When flow is impeded the water may discharge from some other opening located a few feet or as much as several miles from the original opening. Returning the water to its original level will not necessarily result in a renewal of normal flow. Once the spring discharges at a new outlet new channels may develop in the subsurface solution openings, and the flow may continue to discharge from the new outlet. In general any change in the natural outlet, except clearing mud and debris from the mouth, may result in a decrease in flow, or diversion of the discharge to another opening.

An increase in yield may be obtained from many springs by inserting the intake pipe of a pumping unit into the lowest part of the spring opening. In depression springs particularly, the volume of water that can be pumped from such an installation commonly will be much greater than the low flow of the spring. One depression spring in Christian County, which had no visible discharge, was reported to yield 3,000 gpm to a pump having the intake pipe near the bottom of the spring. This yield was maintained for about 2 months.

The minimum flow of many small springs is less than the pumping rate of most small domestic power pumps, and has been considered inadequate for a perennial water supply. However, a spring that flows at the rate of half a gallon per minute will yield 720 gpd which is adequate for a household. In order to permit utilizing such a small spring sufficient storage should be provided to equal the daily water demand.

Water obtained from wells and springs in many limestone aquifers is subject to pollution. Water is transmitted through solution openings in limestone at rates up to 1 mile or more per day, and is not subject to any filtering action. Nearly all wells and springs in the Mississippian Plateau region that obtain water from cavernous limestone become turbid after intensive rainfall, indicating that very little settling action takes place. To be safe for domestic consumption all water supplies obtained from cavernous limestone should be treated to eliminate bacterial pollution.

QUALITY OF WATER

The quality of ground water in the Mississippian Plateau region is determined by the geologic source of the water and the length of time the water has been in contact with the rocks. Most dug wells intercept water that has been in contact with the aquifer for only a relatively short period of time. Drilled wells, which are generally deeper, yield more mineralized water that has been in contact with the aquifer for a longer period of time. Springs discharge water that may be characteristic of either dug wells or drilled wells, depending on the source of discharge.

Table 13 shows median values of dissolved constituents and other characteristics in ground water from the aquifers in the Mississippian Plateau region. Median values were used in preference to average values because a few of the samples are very high in dissolved solids, and do not represent the majority of the samples. Figure 8 shows typical analyses of ground water from the aquifers in the Mississippian Plateau region.

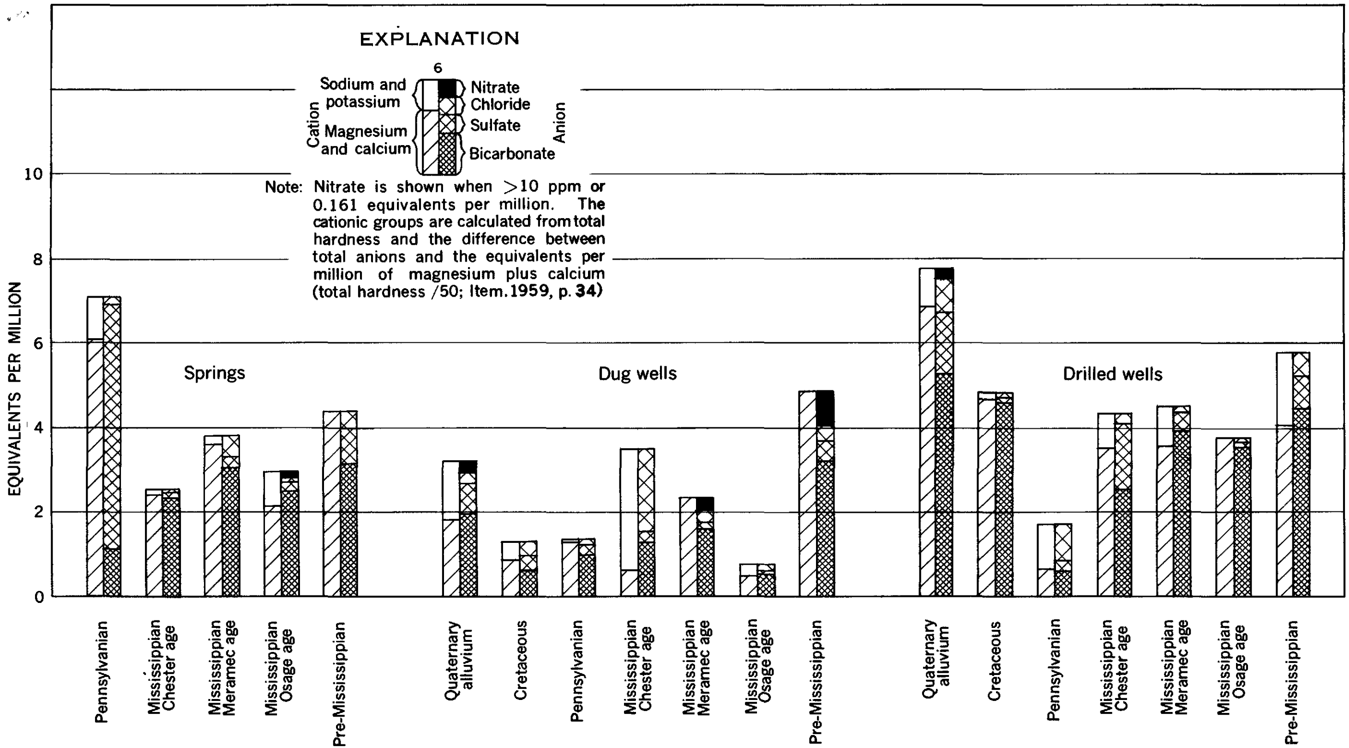

FIGURE 8.—Typical analyses of dissolved constituents in ground water subdivided by aquifer, and by springs, dug wells, and drilled wells, in the Mississippian Plateau region, Kentucky.

TABLE 13.—*Median values of dissolved constituents, other characteristics, and analyses of ground water, by aquifer and by drilled and dug wells and springs, in the Mississippian Plateau region, Kentucky*

[Iron and hardness values expressed in parts per million; other constituents expressed in equivalents per million]

Constituent	Quaternary alluvium	Cretaceous	Pennsylvanian	Mississippian			Pre-Mississippian
				Chester	Meramec	Osage	
Drilled wells							
Iron (Fe)	1.07	0.21	4.8	0.66	0.26	0.38	1.0
Bicarbonate (HCO_3)	4.95	4.57	.75	3.93	3.87	3.83	4.75
Carbonate (CO_3)	0	0	0	0	0	0	0
Sulfate (SO_4)	1.53	.09	.29	1.27	.33	.67	.87
Chloride (Cl)	.76	.10	.56	.28	.20	.51	.51
Fluoride (F)	.01	.01	.08	.02	.01	.01	.01
Nitrate (NO_3)	.33	.02	.03	.02	.06	.11	.01
Hardness	280	232	69	275	246	301	270
Specific conductance (micromhos at 25° C)	717	459	219	645	473	581	589
pH	7.3	7.0	6.2	7.2	7.4	7.3	7.1
Number of analyses	8	3	6	32	73	14	9
Dug wells							
Iron (Fe)	1.26	.26	7.1	.31	.19	.48	.05
Bicarbonate (HCO_3)	1.54	1.38	.98	3.56	1.88	1.14	3.21
Carbonate (CO_3)	0	0	0	0	0	0	----------
Sulfate (SO_4)	.51	.24	.35	.30	.16	.22	.48
Chloride (Cl)	.28	.28	.11	1.02	.27	.30	.34
Fluoride (F)	.02	.002	.01	.01	.01	.00	.01
Nitrate (NO_3)	.23	.16	.01	.22	.27	.16	.81
Hardness	84	71	67	280	136	78	----------
Specific conductance (micromhos at 25° C)	257	210	146	430	272	199	462
pH	6.3	6.5	6.7	7.0	7.2	6.3	----------
Number of analyses	2	2	1	4	8	4	1
Springs							
Iron (Fe)	----------	----------	31	.08	.16	.06	.14
Bicarbonate (HCO_3)	----------	----------	1.11	2.33	3.21	2.49	3.15
Carbonate (CO_3)	----------	----------	0	0	0	0	0
Sulfate (SO_4)	----------	----------	5.79	.19	.17	.21	.75
Chloride (Cl)	----------	----------	.14	.09	.07	.09	.16
Fluoride (F)	----------	----------	.04	.01	.01	.01	.01
Nitrate (NO_3)	----------	----------	.01	.01	.06	.07	.04
Hardness	----------	----------	304	120	174	147	199
Specific conductance (micromhos at 25° C)	----------	----------	672	252	335	279	422
pH	----------	----------	5.8	7.5	7.3	7.2	7.5
Number of analyses	----------	----------	1	5	44	5	3

Water from most wells and springs in the Mississippian Plateau region is of the calcium bicarbonate type. A single sample from a spring in Pennsylvanian rocks is calcium sulfate water but on the basis of the Pennsylvanian samples obtained from dug and drilled wells this is believed to be abnormal. Brines are usually encountered below the Chattanooga, or New Albany, shale where it is overlain by a considerable thickness of younger rocks but they are not satisfactory for domestic or industrial use, and therefore, are not included in the analyses on which table 13 is based.

Then the figures for pre-Miss. wel in table 13 is mi leading EJK

Nitrate is present in significant amounts only in water from dug wells and drilled wells in alluvium; several samples had a nitrate content in excess of 45 ppm. Nitrate concentration in excess of 45 ppm may be regarded as making the water unsafe for infant feeding (Cumly, 1945).

Fluoride is combined with chloride in the bar diagrams. The median content of fluoride in water from all aquifers is less than 1.5 ppm; however, 2 samples from rocks of Chester age and 1 sample from rocks of Meramec age contained more than 1.5 ppm of fluoride. Samples from 18 water supplies contained no detectable quantities of fluoride. It has been shown (Maier, 1950) that about 1 ppm of fluoride in water is sufficient to decrease the incidence of tooth decay when the water is consumed by children whose teeth are developing. Fluorosis (mottling of the tooth enamel) may become evident if, during the period of tooth development, the water consumed contains more than about 1 ppm of fluoride (Hem, 1959, p. 113).

Common salt (sodium chloride) and hydrogen sulfide are the two constituents most often encountered in objectionable amounts in ground water in the Mississippian Plateau region. Salt is generally encountered only in wells that penetrate the Chattanooga, or New Albany, shale or in wells penetrating older formations which are buried under younger rocks. In some places contamination from old unplugged oil wells that were drilled below the shale is reported to have reached higher aquifers. Hydrogen sulfide is encountered in many wells where the circulation of ground water is slow. All the Mississippian limestones contain abundant pyrite, and this mineral decomposes to iron oxide and hydrogen sulfide from the action of ground water.

Table 14 shows the source and significance of dissolved mineral constituents and physical properties of natural water.

TABLE 14.—*Source and significance of dissolved mineral constituents and physical properties of natural water*

Constituent or physical property	*Source or cause*	*Significance*
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts, 1 to 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline water.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May be derived also from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface water usually indicates acidic wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry, utensils, and fixtures reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. Federal drinking-water standards (U.S. Public Health Service, 1946) state that iron and manganese together should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acidic water.	Same objectionable features as iron. Causes dark-brown or black stain. Federal drinking-water standards provide that iron and manganese together should not exceed 0.3 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brine. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming. (*See* "Hardness.") Water low in calcium and magnesium desired in electroplating, tanning, dyeing and, textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brine, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salt may cause foaming in steam boilers and a high sodium ratio may limit the use of water for irrigation.

Bicarbonate (HCO_3) and carbonate (CO_3)	Produced by action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine water and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Federal drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brine, sea water, and industrial brine.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal drinking-water standards recommend that the chloride content should not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, when consumed regularly by children it may cause permanent mottling of the tooth enamel, according to the concentration of fluoride, age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, 1950, p. 1120–1132.)
Nitrate (NO_3)	Originates in decaying organic matter, including sewage and nitrate fertilizers.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 ppm of nitrate may cause a type of methemoglobinemia ("blue baby" disease) in infants, sometimes fatal. Water of high nitrate content should not be used in baby feeding (Maxcy, 1950, p. 265, app. D). Nitrate has been shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Federal drinking-water standards recommend that the dissolved solids should not exceed 500 ppm. Water containing more than 1,000 ppm of dissolved solids is unsuitable for many purposes.

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TABLE 14.—*Source and significance of dissolved mineral constituents and physical properties of natural water*—Continued

Constituent or physical property	*Source or cause*	*Significance*
Hardness as $CaCO_3$	Nearly all the hardness of most water is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness, as does free acid.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters having a hardness up to 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; and more than 200 ppm, very hard.
Specific conductance (micromhos at 25° C)	Mineral content of the water	Specific conductance is a measure of the capacity of the water to conduct an electric current; it varies with concentration and degree of ionization of the constituents. Varies also with temperature; reported at 25° C.
Hydrogen-ion concentration (expressed as pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonate, bicarbonate, hydroxide, phosphate, silicate, and borate raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increase with decreasing pH. However, excessively alkaline water also may attack metals.
Temperature		Affects usefulness of water for many purposes. For most uses, water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground water from moderate depths commonly is nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases about 1°F with each 50 to 100 ft of increased depth. Seasonal fluctuations in temperatures of surface water are comparatively large but do not reach the extremes of air temperature.

Table 15 and plate 16 show the maximum and minimum concentration of some dissolved constitutents and other characteristics, based on total anions, in water from 25 springs which have been sampled at quarterly intervals for several years. Figure 9 shows the variation in concentrations of dissolved constituents with variations in discharge in Puckett and Bluff Springs. The relation is generally one of low concentration of dissolved constituents at high discharges, and high concentration of dissolved constituents at low discharges. During periods of high flow the discharge is composed principally of recent runoff from precipitation, but the low flow is composed of water that has been in storage for a longer period. The irregularity of the pattern of figure 9 probably is due in part to the duration of rainfall, intensity of rainfall, time of sampling in relation to rainfall, and the area contributing runoff to the spring during each rise. Figure 10 shows a similar relation of discharge and specific conductance in Garnett, Puckett, and White Mills Springs.

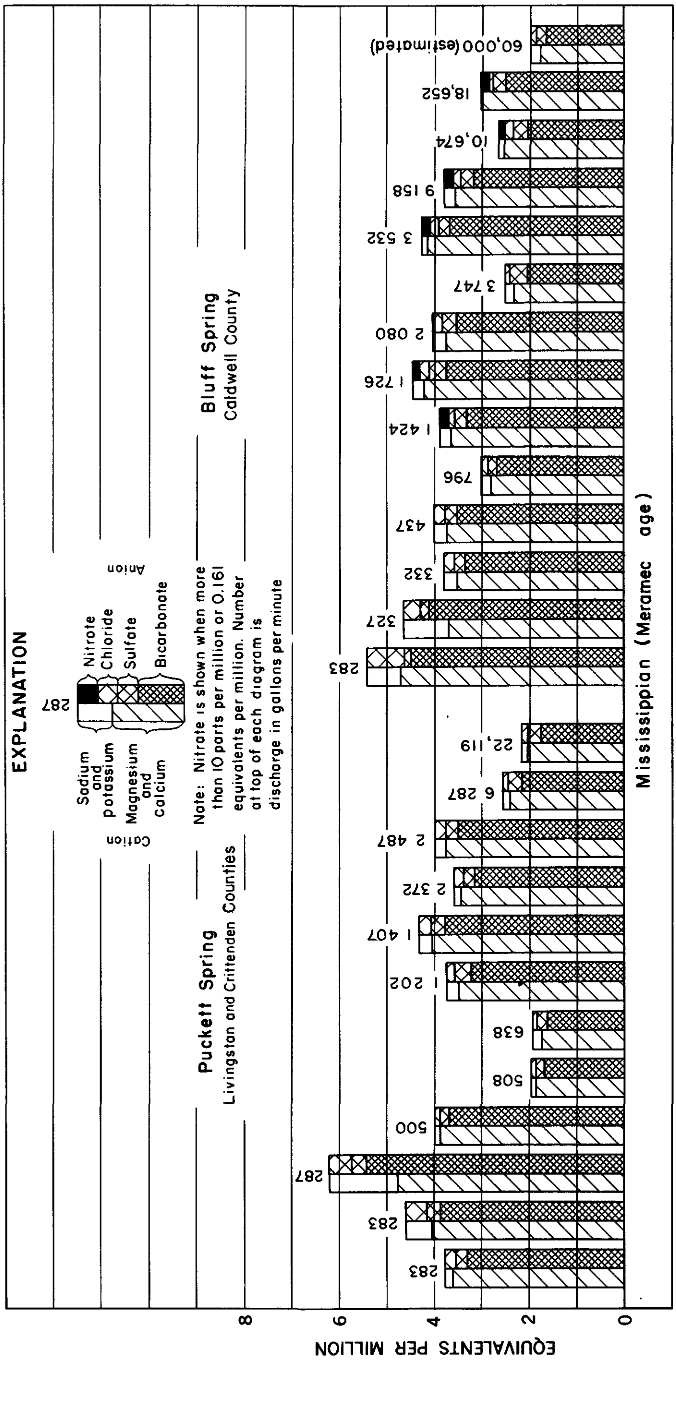

FIGURE 9.—Relation of discharge to dissolved constituents in ground water from two tubular springs, Mississippian Plateau region, Kentucky.

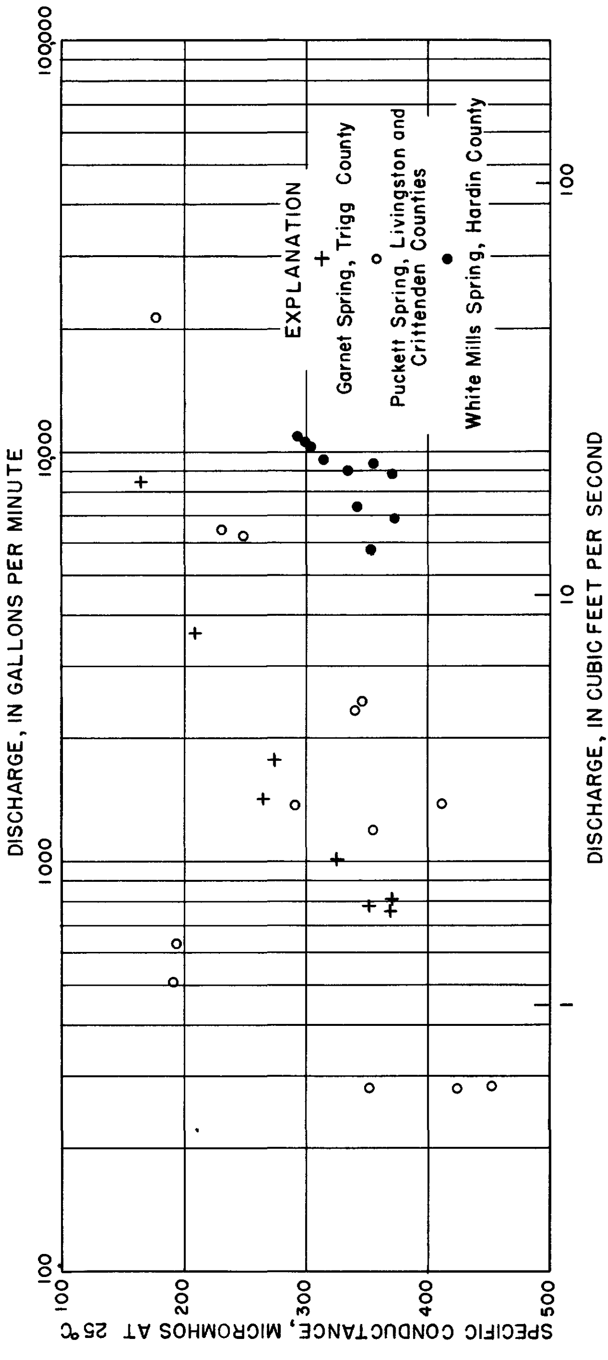

FIGURE 10.—Relation of discharge to specific conductance in ground water from three tubular springs, Mississippian Plateau region, Kentucky.

TABLE 15.—*Chemical characteristics of spring water, and spring discharge rates at minimum and at maximum concentrations of total dissolved constituents (based on total anion values) in the Mississippian Plateau region, Kentucky*

[Iron and total hardness values expressed in parts per million; values of other constituents expressed in equivalents per million. Aquifer is Mississippian limestone of Meramec age except where otherwise indicated]

Name of spring	County	Value of total anion	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH	Discharge, at time of collection of water sample (gpm)
Calvert [1]	Allen	Minimum	0.07	1.90	0.14	0.05	----	0.06	66	213	----	554
		Maximum	.14	2.62	.21	.62	0.01	.05	147	276	8.0	1,851
Big [1]	do	Minimum	.12	.80	.19	.06	----	.06	53	116	7.4	2,789
		Maximum	.32	3.44	.27	.09	.01	.12	195	382	7.4	>20,000
Stinking [1]	Barren	Minimum	.15	1.85	.23	.04	.01	.03	103	208	7.3	755
		Maximum	.23	2.88	.48	.08	.00	.04	170	336	7.7	2,811
Bluff	Caldwell	Minimum	.08	1.64	.14	.06	.01	.01	88	190	6.8	283
		Maximum	.98	4.51	.23	.68	.02	.10	235	448	7.5	[2] 60,000
Harpending	do	Minimum	.07	2.61	.09	.11	.01	.05	147	287	7.2	750
		Maximum	.12	4.33	.23	.31	.01	.12	224	452	7.4	5,552
Cartwright	Clinton	Minimum	.02	1.41	.14	.05	.01	.05	78	146	8.1	3
		Maximum	.09	2.80	.20	.14	.01	.10	143	288	7.8	33
Town Creek	do	Minimum	.26	1.93	.13	.04	.01	.05	108	208	7.6	455
		Maximum	.28	3.66	.31	.34	.01	.09	196	382	7.7	23,692
Echo River	Edmonson	Minimum	----	1.95	----	.04	----	.02	97	208	7.4	629
		Maximum	.26	2.85	.21	.11	.01	.07	153	301	7.6	----
White Mills	Hardin	Minimum	.04	2.33	.15	.09	.01	.07	134	262	6.6	6,888
		Maximum	.07	3.57	.21	.10	.02	.12	193	373	7.1	[2] 30,000
Dyers	do	Minimum	.06	3.07	.06	.11	.01	.03	169	350	7.2	942
		Maximum	.54	3 67	.11	.34	.01	.07	199	361	8.2	4,244
Terhune	Larue	Minimum	.12	1.85	.12	.06	.01	.03	99	200	7.5	410
		Maximum	.26	2.92	.16	.11	.02	.08	158	311	7.6	1,203
Gum	Livingston	Minimum	.00	2.95	.12	.04	.01	.02	147	290	7.4	65
		Maximum	.12	3.02	.17	.05	.01	.04	159	311	7.6	40
Puckett	Livingston and Crittenden.	Minimum	.18	1.25	.31	.04	.02	.05	73	161	6.5	287
		Maximum	1.2	5.39	.31	.42	.03	.05	238	453	7.0	[2] 25,000
Smotherman	Logan	Minimum	.07	2.29	.11	.05	.01	.07	128	253	7.0	305
		Maximum	.17	4.39	.15	.06	.01	.12	224	422	7.5	[2] 25,000
Schenley	Meade	Minimum	.23	3.57	.54	.07	.01	.07	222	414	7.1	2,233
		Maximum	.45	4.62	4.7	.17	.02	.16	468	820	----	[2] 50,000
Arrow	Simpson	Minimum	.07	2.21	.18	.06	.01	.16	132	256	7.2	333
		Maximum	.02	4.16	.13	.68	.01	.21	229	430	7.7	7,786

Rum	Todd	Minimum	.22	2.61	.07	.07	.01	.15	145	283	7.4	181
		Maximum	.07	4.38	.08	.40	.01	.19	227	434	7.6	[2] 25,000
Guthrie	do	Minimum	.12	1.98	.12	.07	.01	.12	111	231	7.3	703
		Maximum	.04	3.39	.21	.14	.01	.19	189	372	7.5	2,680
Big	Trigg	Minimum	.12	.69	.15	.06	.01	.02	38	98	7.0	198
		Maximum	.18	3.64	.09	.62	.01	.04	185	350	7.5	5,434
Blue	do	Minimum	.16	1.48	.13	.07	.01	.05	78	172	6.9	302
		Maximum	.04	3.64	.10	.51	.01	.08	185	360	7.3	2,756
Martin	do	Minimum	.33	1.87	.37	.10	.01	.07	111	240	7.2	613
		Maximum	.14	4.39	.15	.57	.01	.09	231	426	7.6	15,446
Mill Stream	do	Minimum	.40	2.61	.29	.09	.01	.10	156	304	7.2	663
		Maximum	.09	4.33	.11	.14	.01	.18	222	440	7.4	[2] 50,000
Garnett	do	Minimum	.18	1.39	.13	.06	.01	.05	76	164	7.0	784
		Maximum	.02	3.67	.14	.14	.01	.06	188	370	7.2	8,578
Cloud	Warren	Minimum	.18	1.79	.18	.23	.01	.09	117	231	6.8	25(?)
		Maximum	.55	4.49	.20	.25	.02	.14	238	453	7.4	[2] 25,000
Monticello	Wayne	Minimum	.33	1.92	.15	.06	.01	.09	111	219	7.1	599
		Maximum	.04	3.70	.42	.59	.01	.12	213	434	7.4	[2] 15,000

[1] Aquifer is Silurian limestone.
[2] Estimated discharge.

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