Reconnaissance of Ground-Water Resources in the Eastern Coal Field Region Kentucky

By W. E. PRICE, JR., D. S. MULL, *and* CHABOT KILBURN

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By W. E. PRICE, JR., D. S. MULL, and CHABOT KILBURN

ABSTRACT

In the Eastern Coal Field region of Kentucky, water is obtained from consolidated sedimentary rocks ranging in age from Devonian to Pennsylvanian and from unconsolidated sediments of Quaternary age. About 95 percent of the area is underlain by shale, sandstone, and coal of Pennsylvanian age. Principal factors governing the availability of water in the region are depth, topographic location, and the lithology of the aquifer penetrated. In general, the yield of the well increases as the depth increases. Wells drilled in topographic lows, such as valleys, are likely to yield more water than wells drilled on topographic highs, such as hills. Sand and gravel, present in thick beds in the alluvium along the Ohio River, form the most productive aquifer in the Eastern Coal Field. Of the consolidated rocks in the region sandstone strata are the best aquifers chiefly because joints, openings along bedding planes, and intergranular pore spaces are best developed in them. Shale also supplies water to many wells in the region, chiefly from joints and openings along bedding planes. Coal constitutes a very small part of the sedimentary section, but it yields water from fractures to many wells. Limestone yields water readily from solution cavities developed along joint and bedding-plane openings.

The availability of water in different parts of the region was determined chiefly by analyzing well data collected during the reconnaissance. The resulting water-availability maps, published as hydrologic investigations atlases (Price and others, 1961 a, b; Kilburn and others, 1961) were designed to be used in conjunction with this report. The maps were constructed by dividing the region into 5 physiographic areas, into 10 subareas based chiefly on lithologic facies, and, in the case of the Kanawha section, into 2 quality-of-water areas. The 5 physiographic areas are the Knobs, Mississippian Plateau, Cumberland Plateau section, Kanawha section, and Cumberland Mountain section. The 10 subareas are as follows:

1. The Chattanooga shale. This black shale yields only enough water for a minimum domestic supply—100 to 500 gpd (gallons per day).
2. Mississippian-Devonian rocks exposed along Pine Mountain. These rocks consist of shale, limestone, and sandstone. The limestone yields water to springs, and faulted limestone and sandstone lying below drainage may yield several hundred gallons per minute to wells.

3. Mississippian rocks exposed along the western margin of the region. These rocks consist of thick limestone underlain by shale. The limestone yields enough water for a modern domestic supply (more than 500 gpd), and discharges as much as 100 gpm (gallons per minute) to springs. The shale yields only enough water for a minimum domestic supply.
4. Subarea 1 of the Lee formation of Pennsylvanian age. The thin shaly rocks of this subarea generally yield only enough water for a minimum domestic supply.
5. Subarea 2 of the Lee formation of Pennsylvanian age. This subarea is predominantly underlain by massive sandstones; it generally yields enough water for a modern domestic supply, and in some places, enough water for small public and industrial supplies.
6. Subarea 1 of the Breathitt and Conemaugh formations of Pennsylvanian age. Rocks in this subarea contain more shale than sandstone. Wells in this subarea range from adequate for a minimum domestic supply to adequate for a modern domestic supply.
7. Subarea 2 of the Breathitt formation of Pennsylvanian age and undifferentiated post-Lee Pennsylvanian rocks. Wells in this subarea yield enough water for a modern domestic supply, and in many places, enough water for small public and industrial supplies.
8. Alluvium along the Ohio River. Mostly composed of glacial outwash sand and gravel, the alluvium is reported to yield as much as 360 gpm to wells.
9. Alluvium along the Big Sandy River and lower reaches of its Tug and Levisa Forks. Where consisting mostly of sand, this alluvium may yield as much as 20 or 25 gpm to properly constructed screened wells.
10. Alluvium of Ohio River tributaries other than the Big Sandy River and its Tug and Levisa Forks. The alluvium is generally thin or fine grained, and furnishes enough water only for a minimum domestic supply.

Salty water in strata of Middle and Late Pennsylvanian age underlies the topographically lowest parts of the Kanawha section. In these areas salty water may be present at depths of less than 100 feet below the level of the principal valley bottoms. Elsewhere in the Kanawha section salty water probably is present only at greater depths.

Water from wells and springs in the Eastern Coal Field region varies widely in chemical character, but most of the water is of the calcium magnesium bicarbonate or sodium bicarbonate type. Chloride and iron are the most objectionable constituents in the ground water of the region. Salty water is known to occur at depths of less than 300 feet in all the physiographic sections of the region except the Cumberland Mountain section. Salty water also is known to occur in all the formations of the region except alluvium and the Conemaugh formation. In general, the chloride content of the ground water becomes higher with increasing depth below drainage, and water that is salty enough to be called a brine eventually will be met in wells drilled deep enough in any part of the region.

Iron is present in noticeable quantities in the water from wells and springs in all formations in the region. Areas in which vadose water drains through beds of black shale or coal, or areas in which acidic mine drainage recharges the ground water probably will have water that has a high iron content. Under these circumstances the iron-bearing water probably will occur only at shallow depth.

INTRODUCTION

To plan intelligently the use and conservation of the water resources of Kentucky, ground-water investigations are being made by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey. Prior to July 1, 1958, ground-water investigations were made in cooperation with the Department of Economic Development of Kentucky. The investigations are of three general types: (a) detailed investigations of the ground-water resources of relatively small areas, such as one or more 7½-minute quadrangles; (b) an inventory of public and industrial water supplies of the Commonwealth; and (c) a reconnaissance to determine the availability of ground water throughout the Commonwealth.

This report describes the results of the third type of investigation, and is one of a series of five reports which together cover the Commonwealth. The purpose of this publication and the three atlases of the hydrologic investigations series (Price and others, 1961a, b; Kilburn and others, 1961) which are to be used in conjunction with this publication, is to provide general information on the availability of ground water for all uses, but particularly for domestic use, in the Eastern Coal Field region of Kentucky (fig. 1). The report will serve also to point out areas where further detailed studies are most needed.

For convenience in making the ground-water reconnaissance studies the Commonwealth of Kentucky has been divided into five regions of distinctive geology and physiography. These regions are as follows: Eastern Coal Field, Blue Grass, Mississippian Plateau, Western Coal Field, and Jackson Purchase, as shown on figure 1. The boundaries of the regions were drawn along county lines for convenience and do not coincide exactly with the natural geologic and physiographic boundaries.

The Eastern Coal Field region (pl. 1) includes 29 counties in the eastern part of the Commonwealth and covers an area of 10,450 square miles. The region is bounded on the north by the State of Ohio, on the northeast by West Virginia, on the southeast by Virginia, on the southwest by the Mississippian Plateau region, and on the northwest by the Blue Grass region.

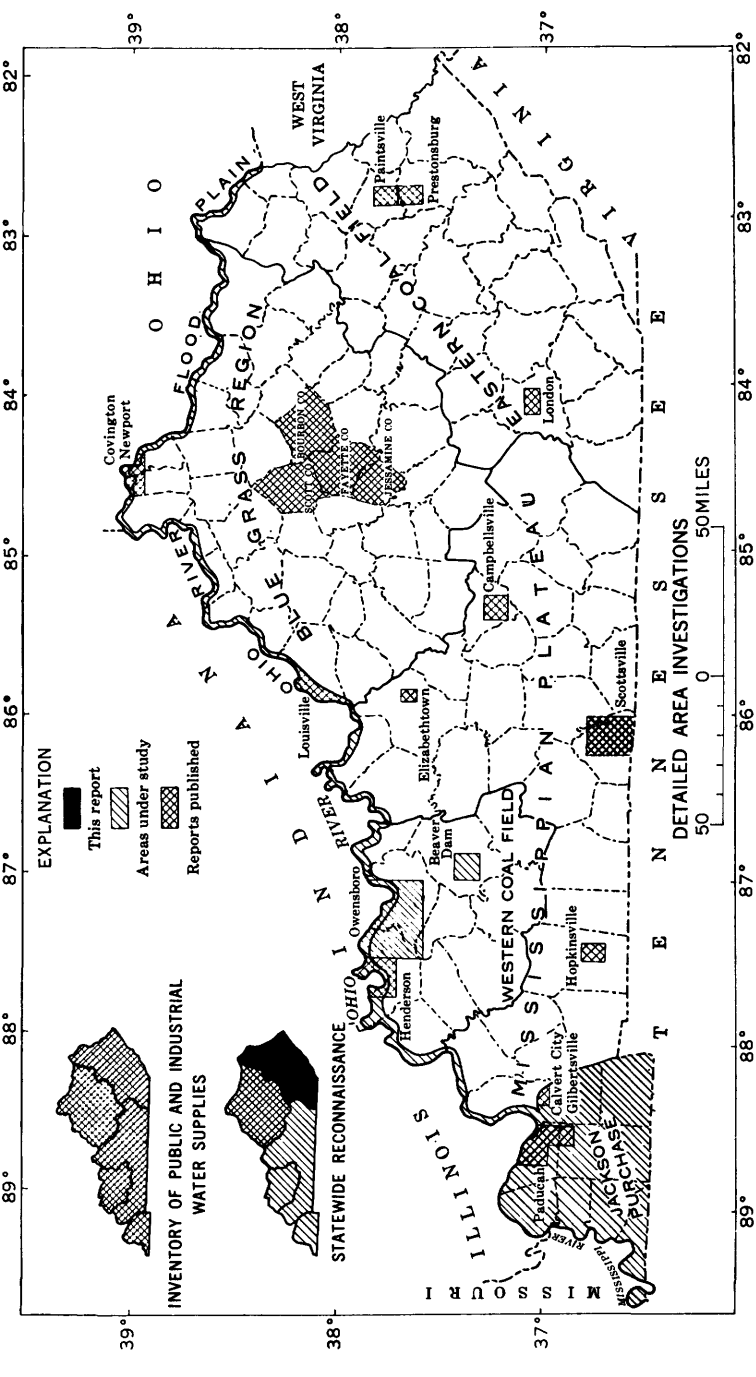

FIGURE 1.—Index map of Kentucky showing progress of ground-water investigations.

The geology of the Eastern Coal Field region has been described by many authors. "Geology of Kentucky," by A. C. McFarlan (1950), contains a summary of the stratigraphy, structure, physiography, and natural resources of the region, plus an extensive bibliography.

Baker and Price (1956) described the public and industrial water supplies of the Eastern Coal Field region, but no previous publications have dealt with the occurrence of ground water in the region as a whole. Prior ground-water studies in the region have covered only small areas. Ashley (1905) described the water resources of the Middlesboro-Harlan area. A report by Fohs (1912) contains a short description of the occurrence of springs in Rockcastle County. Unpublished reports describe the ground-water supplies of the Clayton and Lambert Manufacturing Co. in Ashland, Ky. (W. F. Guyton and D. K. Hamilton, written communication, 1944), the city of Corbin, Ky., and the Cumberland Falls State Park (W. F. Guyton and D. J. Jones, written communication, 1944). Otton (1948) prepared a report on the ground-water resources of the London area. A brief memorandum describes the geology and occurrence of ground water at Carter Caves State Park (E. H. Walker, written communication, 1950). Reports by Baker (1955) and Price (1956), describe the ground-water resources of the Paintsville and Prestonsburg areas, respectively.

Fieldwork for this report consisted chiefly of inventorying wells and springs, and studying rock characteristics that affect the storage and movement of ground water. The fieldwork was done from March 1954 to May 1955 by W. E. Price, Jr., who was joined by Chabot Kilburn in June 1954. Specific-capacity tests of four wells were made by W. H. Walker in January 1955. D. S. Mull and E. H. Earles collected rock samples for hydrologic analysis during August 1956.

An average of about 45 representative wells and springs were inventoried in each county. An attempt was made to obtain complete information on each well and spring. The depth of the well and the depth to water were measured where possible, and the aquifer that supplied each well and spring was identified. Reports on the permanence and adequacy of the supply were obtained wherever possible. Samples of water were collected from representative wells and springs for chemical analysis. Well logs and samples of drill cuttings were collected in places, but no attempt was made to obtain all the available logs. Seven wells were pumped to determine their discharge and drawdown (fig. 11).

Core samples were taken from selected surface exposures. Additional core samples were obtained from an exploratory hole drilled by the Worthington Sand and Gravel Co. These samples were sent to the U.S. Geological Survey laboratory in Denver, Colo., for hydrologic analysis (pl. 7).

The geologic maps, included in the atlases of the hydrologic investigations series (Price and others, 1961, a, b; Kilburn and others, 1961), were compiled from published geologic maps prepared by the Kentucky Geological Survey and U.S. Geological Survey and from field notes and unpublished coal-outcrop maps prepared by the U.S. Geological Survey. In areas where no geologic information was available, the authors made brief field investigations and interpreted geologic features from aerial photographs and topographic maps. Well records and other data obtained in the field also aided the mapping.

J. W. Huddle, E. J. Lyons, and J. C. Ferm, of the U.S. Geological Survey, provided some of the data for the geologic maps in the atlases. A. C. McFarlan, former director of the Kentucky Geological Survey, cooperated in the compilation of the stratigraphic correlation chart of the region. W. W. Hagan, state geologist and director of the Kentucky Geological Survey, made a helpful review of the report.

The reconnaissance was aided greatly by the interest and cooperation of well owners and drillers in the region.

GEOGRAPHY

Nearly all the Eastern Coal Field region is in the Appalachian Plateaus physiographic province, a large, intricately dissected upland that extends from New York to Alabama (Fenneman, 1946). In eastern Kentucky most of the western margin of the plateau is a westward-facing escarpment, called the Pottsville escarpment, which is underlain principally by sandstones of Early Pennsylvanian age. At the Tennessee State line the escarpment is about 700 feet high, but northward the relief decreases and the escarpment disappears in Rowan County.

The topography of the Appalachian Plateaus province (pl. 2) differs from place to place in character and relief. Fenneman (1946) subdivided the province into sections, three of which, the Cumberland Plateau section, the Cumberland Mountain section, and the Kanawha section, are present in the Eastern Coal Field region (pl. 3). The Cumberland Plateau section extends northeastward from eastern Tennessee into southeastern Kentucky. The Cumberland Mountain section extends southwestward from western Virginia into southeastern Kentucky, and the Kanawha section extends southwestward from West Virginia and Ohio into northeastern Kentucky.

The Cumberland Plateau section, throughout most of its extent in the Eastern Coal Field region, is a broad upland of moderate relief, but is intricately dissected in the northern part and along its western margin. The section extends northeastward in a belt 5 to 30 miles wide along the western border of the Eastern Coal Field region from the Kentucky-Tennessee State line to southern Carter County. The western margin of the plateau, the Pottsville escarpment, is characterized by very narrow ridges bordered on each side by deep valleys having precipitous walls. The boundary between the Cumberland Plateau and the adjacent Kanawha section on the east is indefinite; it is defined by a change in the character of the topography from a rolling upland to a rugged hilly area.

The Kanawha section, which forms the largest part of the Eastern Coal Field region, is a much dissected plateau characterized by narrow, crooked valleys and narrow irregular steep-sided ridges. Some of the major streams are entrenched in flood plains of moderate width, but most of the smaller creeks have no valley floors. The local relief of the Kanawha section increases from 300 or 400 feet in the north near the Ohio River to about 2,500 feet in the south where it borders Pine Mountain (pl. 2).

The Cumberland Mountain section consists of two parallel ridges, Pine Mountain and Cumberland Mountain, ranging from about 2,000 to 3,000 feet in altitude and trending northeastward. Between them lies a rugged hilly area similar in topography to that of the Cumberland Plateau section, but of greater relief. Here Black Mountain rises in Harlan County to 4,139 feet, the highest point in the Commonwealth.

Because the western boundary of the Eastern Coal Field region is drawn along county lines, it does not follow exactly the western boundary of the Appalachian Plateaus province, but includes parts of two other physiographic areas, the Knobs and the Mississippian Plateau (McFarlan, 1950, p. 194–99, 184–93). The Knobs is an area of conical or flat-topped hills separated by broad valleys. The Mississippian Plateau is generally a rolling plain developed on limestones and characterized by solution features. These two physiographic areas are not delineated as such by Fenneman (1946), but are included in his Interior Low Plateaus province.

The Eastern Coal Field region is drained by the Ohio River and six large tributaries. The Cumberland River drains the southern part of the area; the Kentucky and Licking Rivers drain the central part; the Big Sandy River drains the northeastern part; and the little Sandy River and Tygarts Creek drain the northern part.

The Cumberland River rises near the Virginia State line in southeastern Letcher County, then flows westward in a winding course and leaves the region in western Laurel County. The principal tributaries of the Cumberland River in the Eastern Coal Field region are the Laurel and Rockcastle Rivers.

The Kentucky and Licking Rivers drain the central part of the Eastern Coal Field. The Licking River rises southeast of Salyersville in Magoffin County and flows northwestward into the Blue Grass region. The Kentucky River is formed by the confluence of the North and South Forks at Beattyville in Lee County; the Middle Fork joins the North Fork a few miles east of Beattyville. The Kentucky River flows northwestward from the Appalachian Plateaus across a narrow strip of isolated hills known as the Knobs into the Blue Grass region. The principal tributary to the Kentucky River in the Eastern Coal Field, in addition to the headwaters forks, is the Red River. The Red River, however, joins the Kentucky River west of the report area. The Kentucky River has been developed extensively for navigation; 14 locks and dams provide a minimum depth of 6 feet from the confluence with the Ohio River.

The Big Sandy River is formed by the confluence of the Levisa and Tug Forks at Louisa in Lawrence County. From Louisa the Big Sandy River flows northward to Catlettsburg where it joins the Ohio River. Levisa Fork, which is considered to be the headwaters of the Big Sandy River, rises in Virginia and flows northward through the Eastern Coal Field. The Tug Fork also rises in Virginia and flows northward to form the boundary between Kentucky and West Virginia for 93 miles. The lower section of the river has been improved for navigation by the construction of 3 locks and dams between Louisa and the mouth and 1 lock each in the Levisa and Tug Forks several miles upstream from Louisa.

The Little Sandy River and Tygarts Creek rise in southern Elliott and southwestern Carter Counties, respectively, and flow northeastward to join the Ohio River.

The Eastern Coal Field region has a humid continental climate and an average annual temperature of about 57°F. The lowest average minimum monthly temperatures occur in January, and the highest average maximum monthly temperatures occur in July. Temperatures sometimes fall below zero during the winter and rise above 100°F during the summer. Because the last killing frost occurs about April 25 and the first killing frost about October 15, the growing season is about 175 days long.

The mean annual rainfall ranges from about 40 inches in the northeastern part of the region to about 50 inches in the southeastern part. At Paintsville, in the central part of the region, the lowest recorded annual rainfall was 33.4 inches and the highest 63.1 inches. Figure 2 shows the average monthly temperature (1931–55) for 2 stations and average monthly precipitation (1931–55) at 8 stations in the eastern division of Kentucky (U.S. Weather Bureau). The eastern division covers about the same area as the Eastern Coal Field region.

Agriculture in the Eastern Coal Field region is on a small-scale subsistence basis. The area produces few commercial crops. Because the best farmland is in the valley bottoms, they are actively cultivated. Some crops are grown on the gentler hillsides and upland flats, but these areas are not as productive as those containing alluvial soils. Corn is the leading crop; other products are hay, small grains, sorghum, vegetables, and tobacco. Cattle are the principal livestock raised, but some horses, sheep, hogs, and poultry are raised also. Timber is cut locally and sawed at many small sawmills.

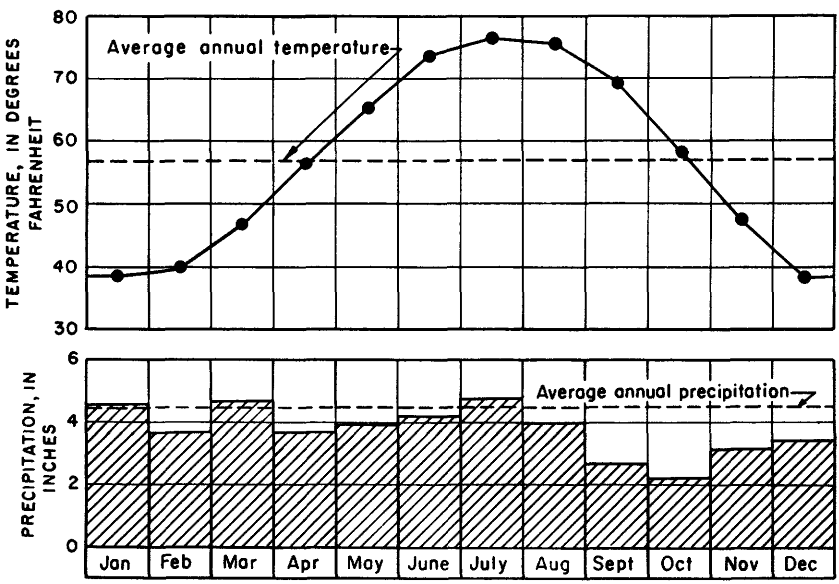

FIGURE 2.—Average monthly temperature (1931–55) at 2 stations and average monthly precipitation (1931–55) at 8 stations in the eastern division of Kentucky. (From records of the U.S. Weather Bureau.)

The industrial growth of the region depends chiefly upon its mineral resources of coal, gas and oil, clay and claystone, sandstone, limestone, sand and gravel, and water.

In 1956 about 60 percent of the coal mined in Kentucky came from the eastern part of the Commonwealth. Although some coal is produced in all the counties of the region, most of the coal mined in 1956 came from Harlan, Pike, Letcher, Perry, Floyd, Leslie, Bell, Clay, and Knott Counties. The higher grade coals occur in the southeastern area where a very thick section of Pennsylvanian rocks containing many coal beds is present (Phalen 1956). The coals are bituminous, highly volatile, and of good coking quality. They have a sulfur content (largely due to marcasite), which increases from less than 1 percent in the southeastern part of the region, to about 3 percent in the western part. The fixed-carbon content and heating value increase progressively toward the southeast. In 1956, 52 percent of the coal mined came from three zones and their correlatives; the Upper Elkhorn No. 3 seam, the Hazard No. 4 seam, and the Harlan seam.

The region contains many oil and gas fields. In 1956, 3,578,703 barrels, or nearly 20 percent of the oil produced in Kentucky, came from the eastern part of the Commonwealth. About 70 percent of the daily oil production from eastern Kentucky comes from fields in which water flooding is used to recover the oil (McGrain, 1958). Secondary-recovery operations produce oil from the Weir sand (local usage) of Early Mississippian age in the Oil Springs pool in Magoffin and Johnson Counties, the Martha pool in Lawrence and Johnson Counties, and the Isonville pool in Elliott County. Oil is also extracted by secondary-recovery methods from the Corniferous limestone (local usage) and dolomite of Silurian and (or) Devonian age in the Big Sinking pool in Lee and Wolfe Counties.

In 1956 eastern Kentucky produced virtually all the 73,500 million cubic feet of gas that was marketed in the Commonwealth. The Big Sandy gas field, the principal source of the gas, yielded more than 70,000 million cubic feet.

Refractory clays are mined from basal Pennsylvanian strata in the Olive Hills district of Carter and Greenup Counties. Exploration for reserves of clay is being extended southward into northwestern Morgan County.

Sandstone of Pennsylvanian age is quarried for construction purposes. Building and flagging stones, possibly from the Breathitt formation, are quarried in McCreary County. On Pine Mountain between Pineville and Whitesburg, friable sandstones from the

Lee formation are quarried, crushed, and screened for use in concrete and for other building purposes. Sand for brick manufacture is obtained from the Lee formation in Carter County.

Limestone of Mississippian age is quarried along the western margin of the Eastern Coal Field region in Carter, Morgan, Jackson, Lee, and Rockcastle Counties and on Pine Mountain in Letcher and Bell Counties.

Quaternary sand and gravel of glacial origin are obtained for construction purposes from deposits along the Ohio River. Alluvial sands also are dredged from the bed of the Levisa Fork of the Big Sandy River.

Water, an important mineral resource, is widely used for public, industrial, and domestic purposes. Studies have been made (McGrain and Thomas, 1951) of the possibility of obtaining commercial brine in the region, but brine of sufficient concentration to be of commercial value has not yet been found.

GEOLOGY

Rocks exposed in the Eastern Coal Field region range in age from Devonian to Quaternary, and with the exception of a few igneous dikes in Elliott County are all of sedimentary origin. More than 90 percent of the area is underlain by bedrock of Pennsylvanian age. The stratigraphic column (table 1) lists all the rocks that are exposed or underlie alluvium in the Eastern Coal Field region. For convenience in describing the stratigraphy of the region, the stratigraphic column is divided into three parts: each representing an area of the Eastern Coal Field with distinctive stratigraphic nomenclature. These parts do not correspond to the three approximately equal areas represented on plate 3.

The areal extent of the sedimentary rocks of the region is shown on the generalized geologic map, figure 3. A cross section through the central part of the region is shown in plate 4.

The oldest rocks exposed in the region are of Devonian age. In the western part of the region these rocks crop out in two or possibly three small areas. One area is in Rockcastle County, a second in Jackson County, and a third, if present, is in Menifee County (Jillson 1928, 1929). Devonian rocks crop out also in a larger area along the base of Pine Mountain. Overlying them are sedimentary rocks of Mississippian and Pennsylvanian age. Unconsolidated deposits of clay, silt, sand, and gravel of Quaternary age fill valleys which have been cut in the consolidated rocks.

TABLE 1.—*Stratigraphic column of the Eastern Coal Field region, Kentucky*

System	Series	Northern part			Western border and central part			Southeastern border	
		Group	Formation	Member [1]	Group	Formation	Member [1]	Group	Formation
Quaternary	Recent and Pleistocene		Alluvium			Alluvium			Alluvium
	Pleistocene		High gravel deposits (unnamed)						
Pennsylvanian			Conemaugh formation	Morgantown (?) sandstone member Ames limestone member Buffalo sandstone member Brush Creek limestone member Mahoning sandstone member					
			Breathitt formation	Vanport limestone member Homewood sandstone member [3] Magoffin beds [2]		Breathitt formation	Flint Ridge flint [2] Magoffin beds [2] Kendrick shale [4]		Harlan sandstone Wise formation Gladeville sandstone Norton formation
iferous			Lee formation	Sharon conglomerate member Olive Hill fire clay [6]		Lee formation	Corbin sandstone member Rockcastle sandstone member Beattyville shale [5] Livingston conglomerate [7]		Lee formation

Carbon-						Pennington shale			Pennington shale
Mississippian	Upper Mississippian		Glen Dean limestone			Glen Dean limestone			Glen Dean limestone
			Limestones of early Chester age			Limestones of early Chester age			Limestones of early Chester age
			Ste. Genevieve limestone			Ste. Genevieve limestone			Ste. Genevieve limestone
			St. Louis limestone			St. Louis limestone			St. Louis limestone
			Spergen limestone [8] (=Salem limestone [9] =Somerset shale member of Warsaw).			Spergen limestone [8] (=Salem limestone [9] =Somerset shale member of Warsaw).			Spergen limestone [8] (=Salem limestone [9] =Somerset shale member of Warsaw).
			Warsaw limestone			Warsaw limestone			Warsaw limestone
	Lower Mississippian	Borden [8]	Muldraugh formation [10]		Borden [8]	Muldraugh formaion [18]			Price and Maccrady formations
			Floyds Knob formation [8]			Floyds Knob formation [8]			
			Brodhead formation [10]			Brodhead formation [10]			
			New Providence shale [8]			New Providence shale [8]			
			Sunbury shale			Sunbury shale	Chattanooga shale (south of lat 37°15′N)		Chattanooga shale
			Berea sandstone			Berea sandstone			
			Bedford formation			Bedford formation			
Devonian	Upper Devonian		Ohio shale			Ohio shale (north of lat 37°15′N).			
	Middle Devonian		Duffin and Boyle limestones [11]			Duffin and Boyle limestones [11]			

1 Member, as used by Stockdale (1939).
2 Of Morse (1931).
3 As used by Phalen (1912).
4 Of Jillson (1919).
5 Of Miller (1917).
6 Of Crider (1913).
7 Of Miller (1908).
8 As used by Stockdale (1939).
9 Of Cumings (1901).
10 Of Stockdale (1939).
11 Of Foerste (1905, 1906); as used by Savage (1930).

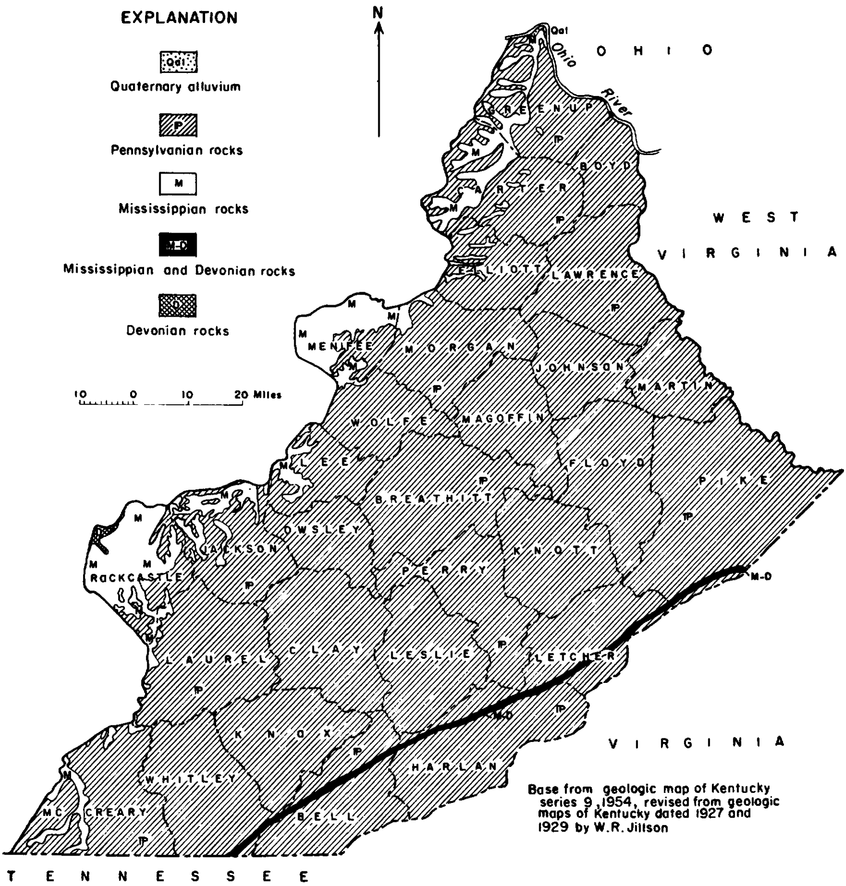

FIGURE 3.—Generalized geologic map of the Eastern Coal Field region, Kentucky.

The major structural features of the Eastern Coal Field region are the Allegheny synclinorium, the Irvine-Paint Creek uplift, the Eastern Kentucky syncline, and the Cumberland Mountain overthrust block (pl. 5). The Allegheny synclinorium extends from the vicinity of Pittsburgh, Pa., across West Virginia to Carter, Boyd, and Lawrence Counties, Ky., where it is bordered on the south by the Irvine-Paint Creek uplift. This uplift is an eastward-trending zone of folds and faults which extends entirely across the Eastern Coal Field and divides it into two provinces. Most of the faults are normal, are downthrown on the south, and have parallel anticlines (too small to be shown on pl. 5) to the south. Between the Irvine-Paint Creek uplift and the Cumberland Mountain overthrust block is a broad basin, the Eastern Kentucky syncline (McFarlan, 1950). The Cumberland Mountain overthrust block borders the Eastern

Kentucky syncline on the southeast and extends from Kentucky into Virginia and Tennessee. The Pine Mountain fault, a low-angle thrust fault that strikes northeast along the base of Pine Mountain, marks the boundary between the Cumberland Mountain overthrust block and the Eastern Kentucky syncline. Southeast of Pine Mountain, within the Cumberland Mountain overthrust block, the elongate Middlesboro syncline parallels the Pine Mountain fault.

Throughout the Eastern Coal Field region there was almost continuous deposition of marine lime and dolomitic lime during much of the Devonian period. Near the end of Devonian time or the beginning of Mississippian time, what is now the Ohio or Chattanooga shale was deposited over the entire area. Above the shale, predominantly calcareous sediments of Mississippian age were deposited as successive layers of silty and cherty lime and discontinuous beds of mud and silt, relatively pure lime, and alternating beds of sand, mud, silt, and lime. These alternating beds represent a transition from dominantly marine to dominantly nonmarine deposition.

At the close of the Mississippian period, the entire region, with the exception of the extreme southeastern part, was uplifted and widespread erosion began. Erosion was most pronounced in the northern part of the region, where most rocks younger than the Borden group (Lower Mississippian) were removed. Erosion was slight in the southern part, and rocks of Chester age were preserved there. Most of the region was elevated again in a second episode of regional uplift and streams flowing through the area to the south or southwest entrenched themselves in their channels.

When the region subsided at the beginning of the Pennsylvanian period, the stream channels became choked by thick deposits of pebbly quartz sand, probably derived principally from folded sedimentary rocks in highlands to the east and far to the north. As further subsidence occurred, the streams spilled over their interfluvial divides and laid down deposits of sand and mud, beginning in the southwest part of the region and progressing northeastward. By this time deposition was widespread, and shifting loci of sedimentation on a broad, low-lying coastal plain produced swampy areas in which thin deposits of organic matter were laid down. A few thin beds of lime were deposited locally in the region, probably during incursions of a large inland sea lying to the southwest. By the end of Early Pennsylvanian time, from 100 to 1,800 feet of sediments, thickest in the southeast, and thinnest in the north, had been deposited over the region.

Deposition continued into the Middle and Late Pennsylvanian, but streams probably flowing into the region from the east deposited finer grained and more poorly sorted sediments. The sediments were laid down in a fluvial environment, possibly that of a low-lying delta, or series of coalescing deltas, constructed by small streams or distributaries of large streams, and consisted for the most part of mud and silt. Fine-grained, micaceous sand was deposited in stream channels, while, in the interfluvial areas, thick deposits of organic matter accumulated in swamps. Infrequently, shallow seas invaded the area and thin beds of lime and marine mud were laid down. Sedimentation continued into Late Pennsylvanian time until as much as several thousand feet of mud, silt, and sand had accumulated in the sinking basin. Sediments of Permian age may have been deposited in the region, particularly in the northern part, but if so, they subsequently were removed by erosion.

By the close of the Paleozoic era the two major structures in the region, the Cumberland Mountain overthrust block and Irvine-Paint Creek uplift, had been developed. During the Mesozoic era erosion removed great thicknesses of strata in the region, particularly from the Cumberland Mountains. In the early Tertiary, reelevation of the region and subsequent erosion occurred. In the late Tertiary this cycle was repeated.

Early in the Quaternary period, ice advanced into the area; it left glacial erratics in the northern part of the region and blocked the northward drainages of the old Kanawha River which flowed by Ashland, Ky., and Portsmouth, Ohio, and the old Scioto River, which flowed from near Manchester, Ohio, to beyond Portsmouth, Ohio. Impounded water from these two streams spilled over divides near Manchester and Portsmouth, Ohio, to form the present course of the Ohio River. By the time the Illinoian ice sheet advanced into the area, the Ohio River had developed to about its present size and a deep channel had been excavated. During the Wisconsin glacial stage, glacial outwash filled this deep channel and ponding of northward-flowing tributaries resulted in the deposition of thick alluvium along tributary streams such as the Big Sandy River. Partial excavation of the glacial and alluvial fills followed, forming the stream valleys as they are today.

GENERAL HYDROLOGY

The primary purpose of this report 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.

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.

Perched ground water.—Ground water is said to be perched if it is separated from an underlying body of ground water by unsaturated rock.

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.

Permeability, coefficient of.—The amount of water, in gallons per day, that will flow through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent (loss of 1 ft in head for each foot the water travels) at a temperature of 60°F.

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 from all sources; in this region, chiefly from infiltration of precipitation through the soil, seepage from streams or other bodies of surface water, flow of surface water through sinkholes, or flow of ground water from another aquifer.

Semiperched ground water.—Ground water may be said to be semiperched if it has a greater pressure head than the underlying body of ground water. However, the underlying body of water is not separated by any unsaturated rock from the water above.

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. It is not an exact quantity, as drawdown increases with time, but it gives an approximate indication of how much water a well can yield.

Specific retention.—The ratio of the volume of water that a rock will retain against gravity, after being saturated, to its own volume.

Specific yield.—The ratio of the volume of water that a rock will yield by gravity, after being saturated, to its own volume.

Transmissibility, coefficient of.—The rate of flow of water at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent.

Vadose water.—Water present between the land surface and water table.

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 from the zone of saturation in the underground part of the hydrologic cycle.

Most water of economic importance in the Eastern Coal Field 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 ground-water body, moving slowly through the zone of saturation to points of lower altitude. Under natural conditions, this water discharges through springs or 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, 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. In the Eastern Coal Field region the average annual precipitation ranges from about 40 inches in the northeastern part to about 50 inches in the southeastern part.

The average annual runoff during 1952–57 was 14.62 inches from the drainage area of the Levisa Fork of the Big Sandy River above Paintsville, 17.93 inches from that of the Kentucky River above Heidelberg, and 20.71 inches from that of the Cumberland River above Cumberland Falls. The average annual precipitation for the same period at 8 U.S. Weather Bureau stations in each of these 3 drainage basins was 43.85 inches, 46.99 inches, and 50.37 inches, respectively. Based on these figures, the average annual discharge of water by evapotranspiration in the Eastern Coal Field region is estimated to be about 29 inches or roughly two-thirds of the total supply. 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.

The quantity of water lost by evapotranspiration each year generally varies less than the amount discharged by runoff. Therefore, a good correlation generally exists between runoff and precipitation, as shown in figure 4.

The volume of ground water in storage at any time in a given drainage basin is directly related to the rate and amount of recharge to and discharge from the basin. Following periods of above-average precipitation the volume of surface water and ground water stored within the basin will first increase, then decrease. Because surface water generally moves out of the basin 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 Eastern Coal Field, precipitation, natural discharge, topography, and the character of the rocks are the important controlling factors in the amount of ground water in storage; however, other factors have a measurable effect. Floods and high water in streams, and lakes created by dammed streams increase the volume of ground water in storage near the streams or lakes. Drainage from coal mines and pumping from wells decrease the volume of ground water in storage. Whatever the causes of the changes in storage, these changes cause the position of the water table to vary.

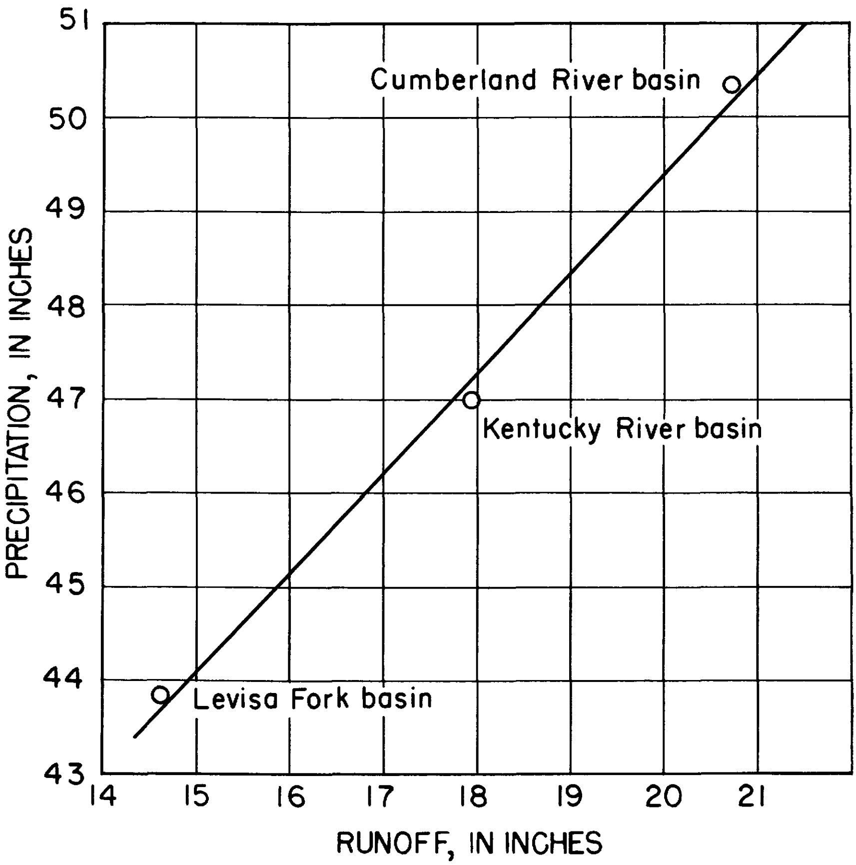

FIGURE 4.—Graph showing the correlation of runoff to precipitation during 1952–57 in three basins of the Eastern Coal Field region, Kentucky.

FLUCTUATION OF WATER LEVELS

Variations in the height of the water table produce water-level fluctuations in wells. By the use of automatic water-stage recorders continuous records of these water-level fluctuations can be obtained. The records indicate the effects of precipitation, soil-moisture deficiency, changes in stages of nearby streams, and pumping.

Single measurements of water level were made in most of the wells tabulated in this report. In addition, continuous measurements were made for extended periods by means of automatic water-level recorders in nine wells. The continuous trace of water-level fluctuations on a graph over a period of time is termed a hydrograph. The hydrographs of figures 5–7 and plate 6 show typical fluctuations of water levels in selected wells and springs in the Eastern Coal Field region.

The hydrograph in figure 5 shows the effect of precipitation on the water level in a shallow well dug in the Breathitt formation. Because the water level in the well is only 4 to 6 feet below the surface, water percolating into the ground during and after a rain reaches the water table quickly and causes a rapid rise in its level. When recharge ceases, the amount of ground water in storage and the corresponding water level in the well slowly decline.

During the growing season plants withdraw water from the soil zone; hence, most of the water that percolates into the ground from rainfall is used to replenish a moisture-deficient soil and does not reach the water table. For this reason ground-water levels generally decline during the growing season and rise during the nongrowing season. Annual repetition of this cycle is shown in the hydrograph of figure 6.

Fluctuation of water levels in wells also may be caused by changes in the stage of nearby streams if the water in the well and in the stream is hydraulically connected. During high flow, water from the stream entering the aquifer may cause the water table adjacent to the stream to rise. Conversely, during times of low flow when the water table is higher than the stream level, water may drain from the aquifer into the stream, augmenting the streamflow and causing a decline in ground-water levels. Plate 6 shows the fluctuation of water level in a well reportedly drilled in coarse sand of the Levisa Fork alluvium near Concord, and the stage of the Levisa Fork at Paintsville. Changes in river stage evidently are primarily responsible for the water-level fluctuation in the well, which is about 175 feet from the bank of the stream. The water level in the well and in the Levisa Fork are at nearly the same altitude and the rise and fall of the water level in the well is similar to, but not as pronounced as, the rise and fall of the water level in the river.

Figure 7 is a hydrograph of a well that taps the Breathitt formation at Seco. The trace shows short-term drawdown and recovery over about a 1-month period resulting from intermittent pumping at a well about 1,000 feet away. The two wells probably are hydraulically connected by open joints. The water level in the unpumped observation well rose swiftly each time pumping in the nearby well ceased, but failed to regain its previous level before pumping was resumed. During the period of record the water level in the observation well generally declined. This decline is due partly to decrease in ground-water storage by natural discharge to streams, and partly to withdrawal of water from storage by the pumping. Because the pumping occurred during the growing

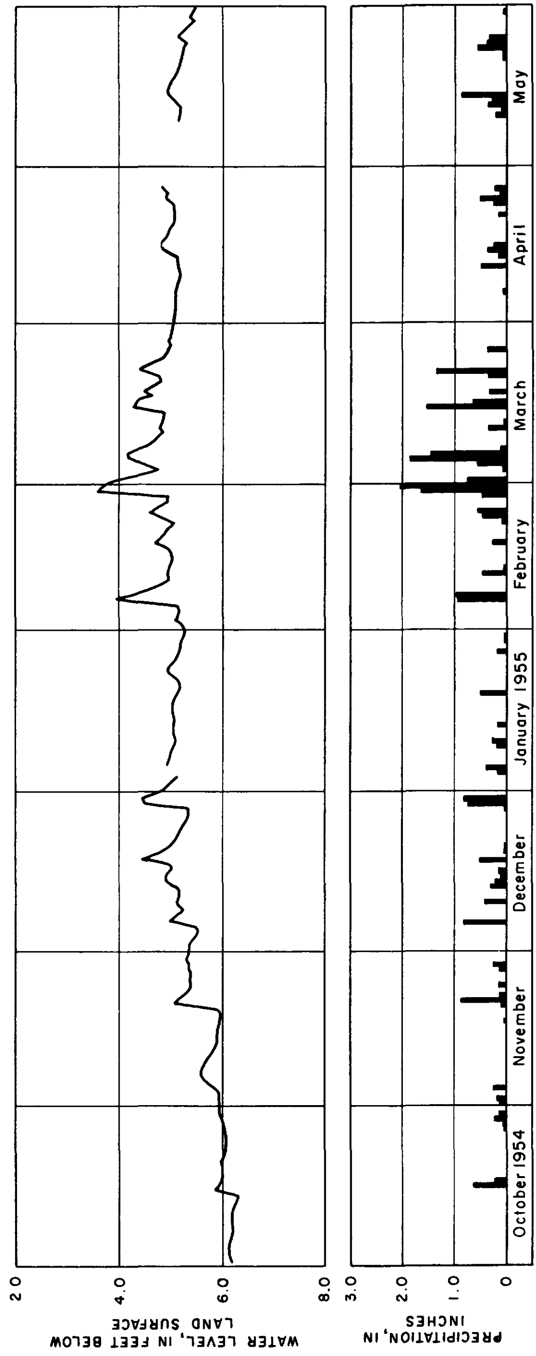

FIGURE 5.—Fluctuation of water level in a well 9 feet deep near Rosefork, Wolfe County, and precipitation at Salyersville, Magoffin County, Ky.

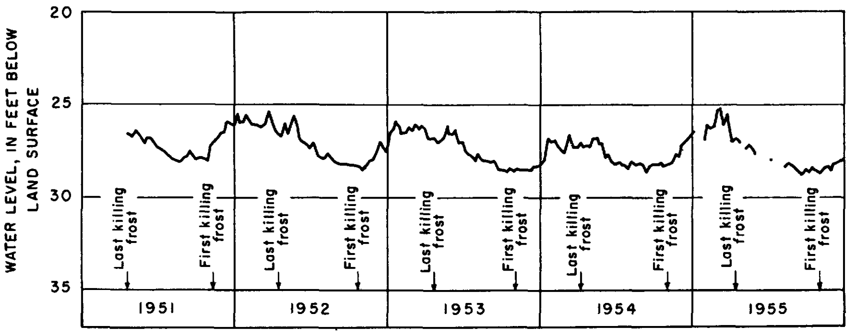

FIGURE 6.—Seasonal fluctuation of water level in a well at Van Lear, Johnson County, Ky.

season, little water from precipitation was added to the ground-water reservoir.

Much smaller fluctuations of water levels in wells, caused by variations in atmospheric pressure and compression of aquifers by passing railway trains, also have been recognized in the Eastern Coal Field region. However, these forces do not change the

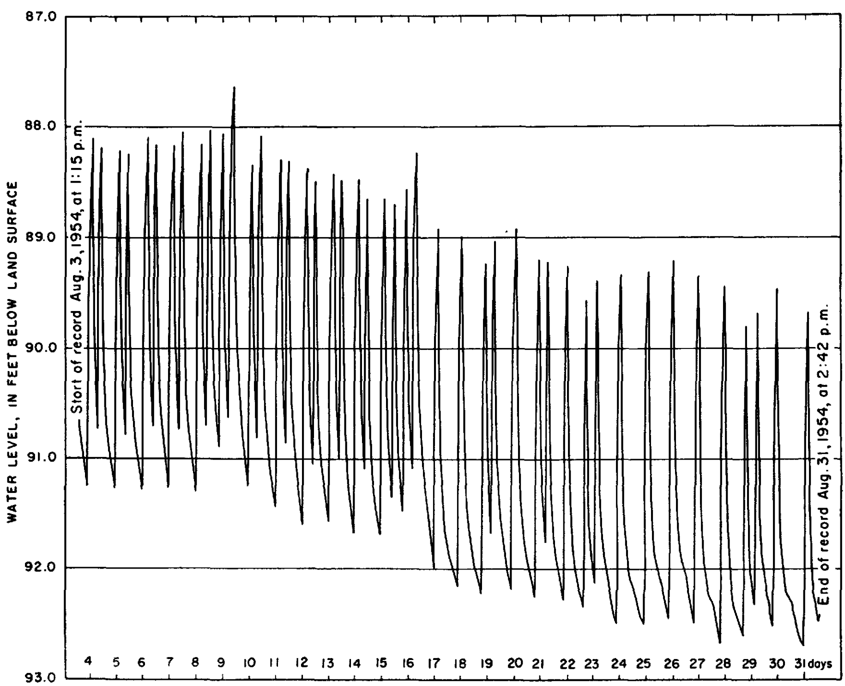

FIGURE 7.—Fluctuation of water level in a well at Seco, Letcher County Ky., caused principally by pumping from a well about 1,000 feet away.

total quantity of water stored in the aquifer and are not discussed for that reason.

AVAILABILITY OF GROUND WATER

PRINCIPLES OF OCCURRENCE

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 given up 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 proportion of open space (porosity) and the size and degree of 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 and shale, openings occur also between the grains, but the intergranular porosity and permeability commonly have been considerably reduced by cementing material which may range in amount from practically none to enough to fill the openings completely.

Consolidated rocks of all types may contain, in addition to primary openings (pores), openings of a secondary nature formed after deposition. These openings may be present in sandstone, shale, or coal as fractures transecting the beds or as openings along bedding planes. Limestone strata in the Eastern Coal Field region generally are solid throughout except for secondary openings that have been enlarged by solution. Secondary openings generally are larger and more numerous near the surface, and decrease in size and number with depth. Water in the consolidated rocks of the Eastern Coal Field region moves more readily through secondary openings than through primary openings. For this reason most of the water yielded to wells comes from fractures (secondary openings).

FACTORS GOVERNING AVAILABILITY

The principal factors governing the amount of water that may be obtained from wells in rocks of Pennsylvanian age in the Eastern Coal Field region are the depth of the well, the topographic position of the well, and the lithology of the rocks tapped. The relation of each of these factors to the yields of wells tapping rocks of Pennsylvanian age is shown in figures 8 and 9. These figures show that wide variations in yield occur in wells penetrating the Lee formation and the Breathitt formation at the same depth and under similar topographic situations. This variability is due partly to the inaccuracy of the well-yield data obtained.

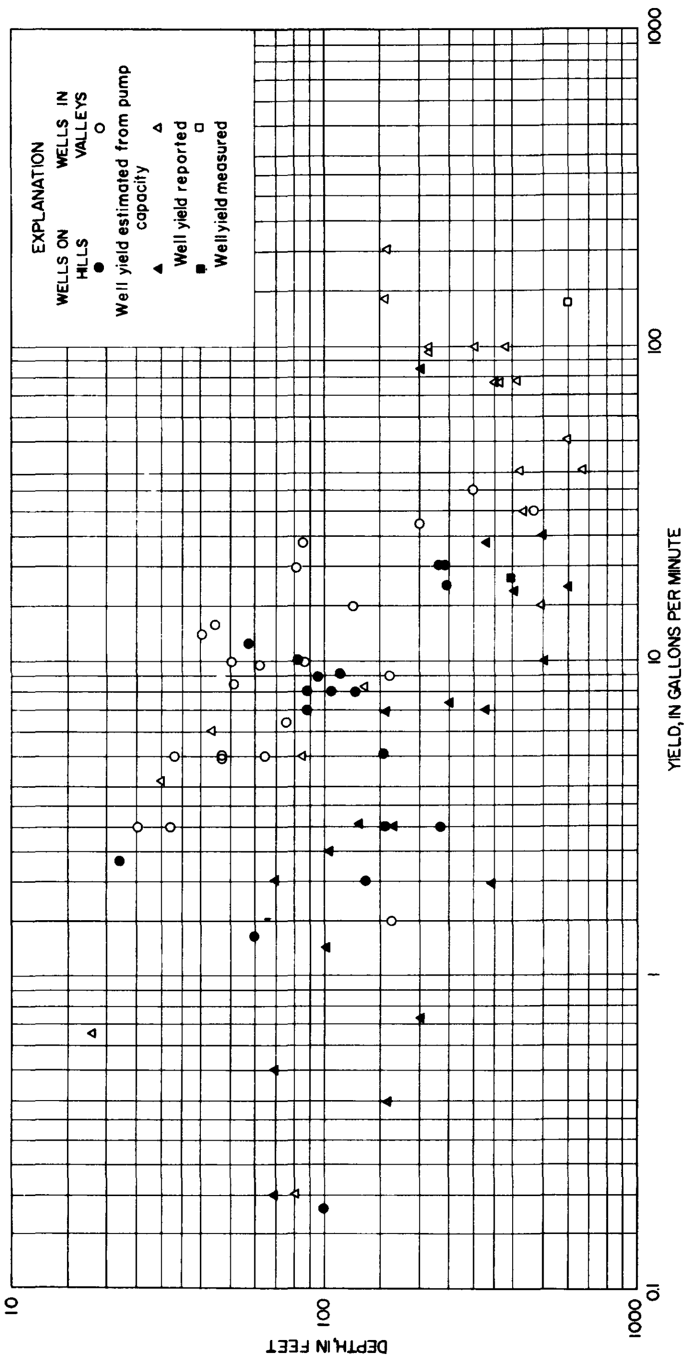

FIGURE 8.—Relation of depth to yield in wells penetrating the Lee formation, Eastern Coal Field region, Kentucky.

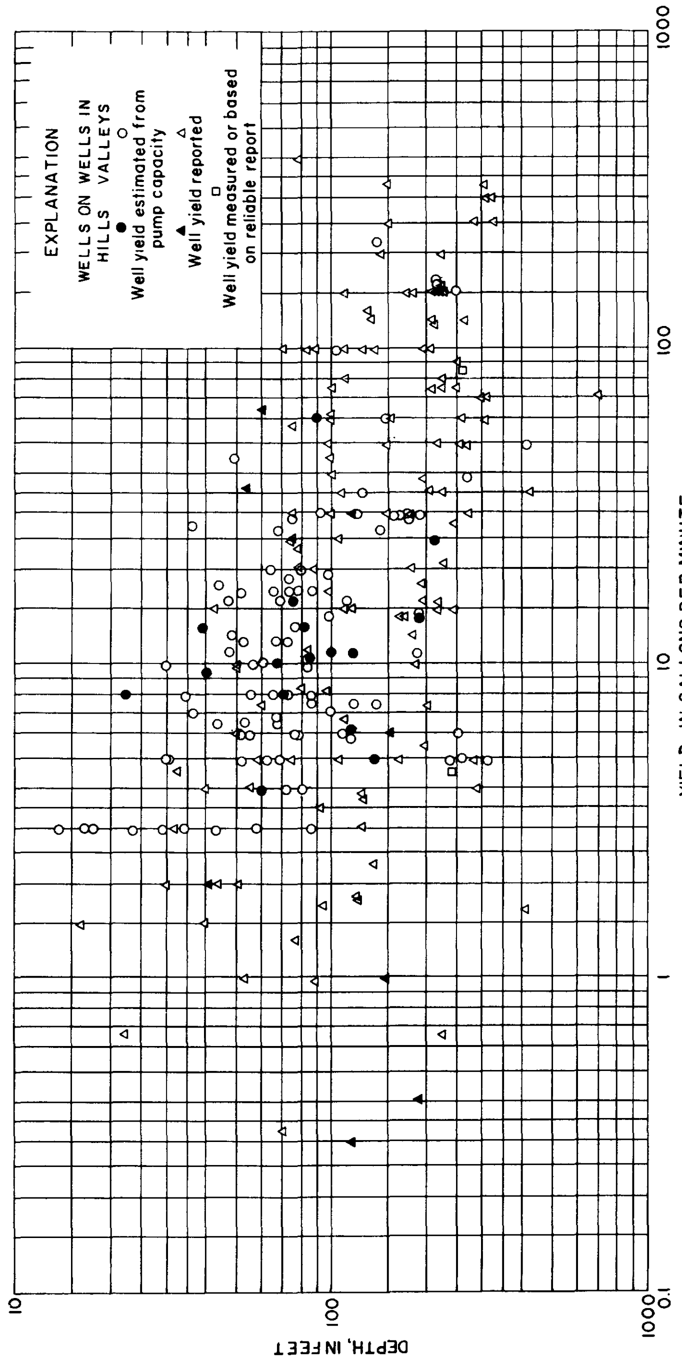

Figure 9.—Relation of depth to yield in wells penetrating Pennsylvanian rocks younger than the Lee formation, Eastern Coal Field region, Kentucky.

Almost all yields were estimated from the capacity of the pump, or were determined from the reports of owners who made or observed pumping tests at rates and drawdowns that probably did not accurately represent the maximum yield of the well. These tests were conducted for varying lengths of time, and most had only one thing in common—they were short. The term "yield" used in this report, then, generally refers only to an observed or estimated pumping rate, or an average of these rates.

The variability in well yield is due also to the fact that water enters wells from joints and bedding planes, which generally vary greatly in width and number at a given depth. The correlation between depth and yield is shown better in the wells on valley bottoms than in wells on hills because water in the former lies at more nearly the same depth below the surface than water in the latter.

In general, the deeper the well, the greater the yield will be, because most deep wells encounter more fractures than shallow wells. The relation of depth to the median yield of wells drilled in rocks of Pennsylvanian age in the region is shown in figure 10.

Wells drilled in topographic lows such as valleys are likely to yield more water than wells drilled on topographic highs such as hills. This is true because wells in valleys quickly intercept relatively large quantities of water moving down from the hills. Wells on hills, on the other hand, must create a more extensive cone of depression with correspondingly greater drawdown to obtain quantities of water as large as those obtained from wells in valleys. For the same reason, wells drilled on sharp hilltops or narrow ridges generally yield less water than those drilled on broad hills or ridges.

There are other reasons why wells drilled in valleys are likely to yield more water than those drilled on hills. Saturated alluvium may contribute water to the underlying rock when wells that tap the rock are pumped. Even larger well yields may be obtained where a perennial stream flows on bare bedrock and joints intersecting the well are open to the streambed. Possibly this is one of the reasons for the reported large yields (400 gpm each) of the two municipal wells at Pineville.

Valley bottoms receive water from streams and from precipitation; however, hills readily shed water as surface runoff. Water in valleys is generally found at shallow depth where joints are likely to be larger and more numerous than at greater depth. Relatively small quantities of water are stored in hills because wide joints near the surface that could furnish large amounts of water on the hills, instead drain them readily to lower altitudes. Ground

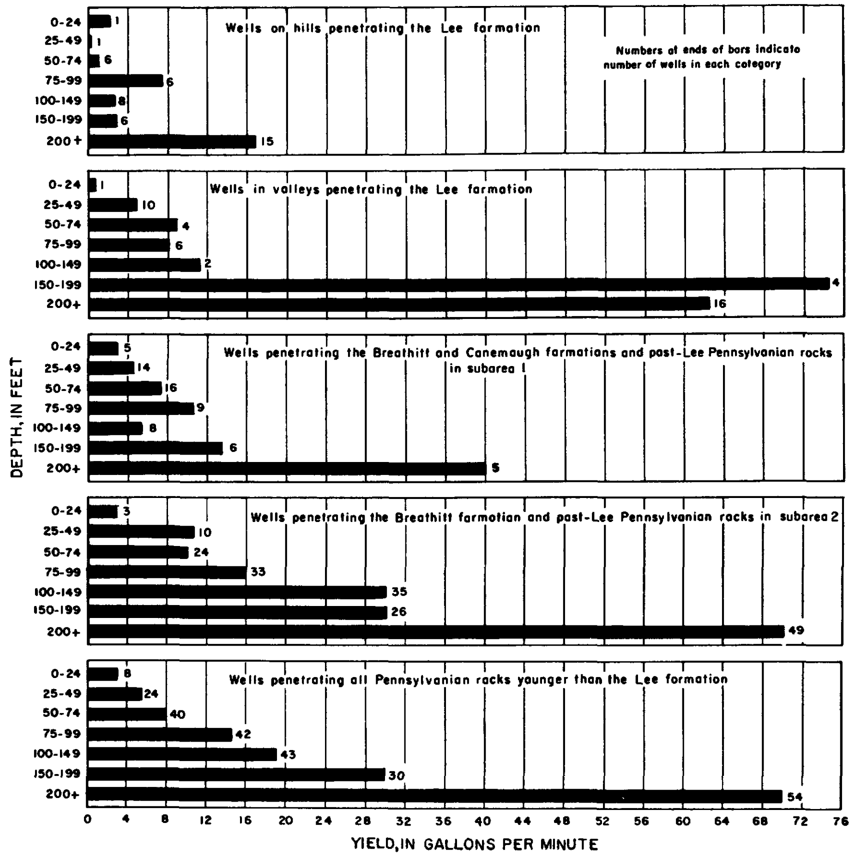

FIGURE 10.—Relation of depth to median values of well yield in rocks of Pennsylvanian age, Eastern Coal Field region, Kentucky.

water found at shallow depth on a hill probably is perched or semi-perched and does not furnish large quantities of water because the areal extent of the aquifer can be no greater than the hill itself.

Possibly some valleys exist because the rocks are more susceptible to erosion owing to close jointing. Joints facilitate the entrance of ground water which promotes chemical decomposition and permits mechanical erosion. Thus, the rocks underlying valleys may contain more openings through which ground water can move than the rocks underlying hills.

The lithology of the water-bearing beds penetrated has a direct bearing on the number, size, and character of the openings supplying water to wells. Ground water in the region occurs in silt, sand, and gravel of Quaternary age, in sandstone and shale of Pennsylvanian, Mississippian, and Devonian ages, in coal of Pennsylvanian age, and in limestone of Mississippian age.

Sand and gravel, present in the alluvium along the Ohio River, and in a few places immediately above bedrock in valleys which are tributary to the Ohio River, yield water readily to wells from intergranular pore spaces. Some of the results of laboratory tests made by the U.S. Geological Survey laboratory in Denver, Colo., on samples of sand from the Ohio Valley alluvium, and from alluvium along streams which are tributary to the Ohio River, are shown in plate 7. Sample 18, of Ohio Valley alluvium, had a porosity of 37.0 percent, specific retention of 3.3 percent, specific yield of 33.7 percent, and a coefficient of permeability of 450 gpd (gallons per day) per square foot. Samples 16 and 17, of sand from the alluvium along the Levisa Fork of the Big Sandy River, had porosities of 48.1 and 46.8 percent, specific retentions of 3.7 and 3.8 percent, specific yields of 44.4 and 43.0 percent, and coefficients of permeability of 70 and 8 gpd per square foot, respectively. The laboratory tests indicate that the relatively coarse alluvium present in the Ohio Valley and in places along the Levisa Fork generally has the highest porosity, specific yield, and permeability of any water-bearing material in the region.

Silt, mixed with a small quantity of sand and clay, generally fills the bottoms of valleys which are tributary to the Ohio River. Because the silt is much less permeable than sand or gravel, it yields only small quantities of water to dug wells. Samples 19 and 20 collected from the Kentucky River alluvium contained about 50 percent silt. Porosities of these samples were 38.5 and 40.0 percent, specific retentions 15.3 and 8.5 percent, specific yields 23.2 and 31.5 percent, and coefficients of permeability 0.2 and 2 gpd per square foot, respectively. Because silty alluvium in the tributary valleys generally contains a smaller quantity of sand than is present in samples 19 and 20, the permeability of most of the fine-grained fill probably is lower than 0.2 or 2 gpd per square foot. Laboratory analyses of samples of alluvium collected elsewhere in the Eastern Coal Field region, and not given in this report, indicate permeabilities as low as 0.002 gpd per square foot—less than the permeabilities of consolidated-rock samples 4, 9, 10, 11, 13, and 14.

However, the unjointed consolidated rocks of the region generally store much smaller quantities of water and yield water more slowly to wells than the unconsolidated deposits of sandy alluvium. Sample 11, a very fine grained sandstone of Mississippian age had a porosity of 9.0 percent, a specific retention of 4.4 percent, a specific yield of 4.6 percent, and a coefficient of permeability of 0.005 gpd per square foot. The porosity of 11 samples of fine-grained sandstones and medium-grained conglomeratic sandstones from the Lee formation of Pennsylvanian age ranged from 6.0 to 15.0 percent, the specific retention from 0.8 to 8.7 percent, and the specific yield from 1.3 to 14.2 percent. The coefficient of permeability of 7 of these samples collected perpendicular to the bedding ranged from 0.0002 to 0.02 gpd per square foot; the coefficient of permeability of 4 samples parallel to the bedding ranged from 0.0002 to 0.03 gpd per square foot. The porosity of 10 samples of very fine grained to medium-grained sandstones from the Breathitt formation of Pennsylvanian age ranged from 7.1 to 15.9 percent, the specific retention from 2.2 to 9.8 percent, and the specific yield from 1.1 to 11.8 percent. The coefficient of permeability of 7 of these samples collected perpendicular to the bedding ranged from 0.00038 to 0.005 gpd per square foot, and the coefficient of permeability of 5 samples collected parallel to the bedding ranged from 0.00071 to 0.002 gpd per square foot.

Median and average values of porosity, specific retention, specific yield, and permeability computed from samples of the Lee and Breathitt formations indicate the following:

1. The porosity of samples from the Lee and Breathitt formations is about the same.
2. Samples from the Breathitt formation have a higher specific retention than those from the Lee formation.
3. Samples from the Lee formation have a higher specific yield and permeability than those of the Breathitt formation.
4. The permeability of samples in both the Lee and Breathitt formations is slightly higher parallel to the bedding than perpendicular to it.

The hydrologic characteristics of samples from the Lee formation differ from those of the Breathitt formation probably because the sandstones themselves are of different types. Sandstones of the Breathitt formation generally contain much interstitial material in the form of clay and therefore would have a higher specific retention than the "cleaner" sandstones of the Lee formation. The higher specific yield and permeability of the Lee formation samples might be due not only to the smaller quantity of interstitial material, but also to the fact that they are generally coarser grained.

Probably the permeability of both formations is better in a horizontal than in a vertical direction because alinement of the mineral grains parallel to the bedding during deposition produces a greater permeability in this direction.

If it were not for the fact that the consolidated rocks have secondary openings such as joints and cracks along bedding planes, they would be very poor aquifers. In the Corbin area, W. F. Guyton and D. J. Jones (written communication, 1944) conducted two short pumping tests on wells penetrating the Lee formation. In one test they obtained an approximate coefficient of transmissibility of 430 gpd per foot and in another test an approximate coefficient of transmissibility of 7,000 gpd per foot. The average permeability of four horizontal core samples taken from the Lee formation in the Eastern Coal Field (pl. 7) is 0.085 gpd per square foot. Assuming that 400 feet of the Lee formation in the Corbin area is saturated, the coefficient of transmissibility of a well penetrating unjointed rock would be only about 560 gpd per foot. Obviously then, successful wells penetrating the Lee formation obtain most of their water from joints in the rock or intergranular zones of very high permeability, or both. Price (1956) came to similar conclusions about the Breathitt formation in the Prestonsburg area. However, because most of the sandstones in the Breathitt formation are fine grained, they would be much less likely to yield water from intergranular pore spaces to wells than would the sandstones of the Lee formation.

In addition to obtaining water from joints, which are not present in alluvium, bedrock wells commonly penetrate a much greater thickness of aquifer. Some bedrock wells tap as much as 500 feet of rock that, to a greater or lesser extent, is water bearing, whereas the saturated thickness of alluvium is almost everywhere less than 100 feet throughout the region.

Of the consolidated clastic rocks in the region, sandstone strata are the best aquifers, chiefly because joints, openings along bedding planes, and intergranular pore spaces are best developed in them. Generally, two types of sandstone are present. The first type, a quartzose sandstone, which is typical of the Lee formation, is characteristically fine to medium grained, conglomeratic in places, well sorted, massive, and crossbedded. The second type, a subgraywacke (Pettijohn, 1949) which is typical of the Breathitt formation is fine to very fine grained, poorly sorted, and contains much clay and sericite in the interstices. Water in both types of sandstone occurs in intergranular pore spaces and joints. Water from between the grains seeps slowly into joints and openings along bedding planes which function as pipes (W. F. Guyton and D. J. Jones, written communication, 1944) to conduct water rapidly to the wells. The quartzose sandstones probably supply water to joints and intersecting wells more readily than the subgraywacke sandstones and are, therefore, more important as aquifers. Significant quantities of water may come from intergranular pore spaces where the sandstones of the Lee formation are poorly cemented. Possibly some of the larger flows of water from depths greater than about 300 feet in the Lee formation come from intergranular pore spaces, because joints at this depth are thin, few, and widely spaced.

Shale also supplies water to many wells in the region, chiefly from joints and openings along bedding planes. Most of the shale consists of silt-sized particles. Because shale consisting of clay-sized particles yields little or no water to wells, it is fortunate that such material comprises only a small part of the sedimentary section. Although sandstones are more productive aquifiers than shales, shale strata do furnish water to many wells because they probably form a greater part of the bedrock of the Eastern Coal Field than the sandstones.

Coal constitutes a very small part of the sedimentary section, but it yields water from fractures to many wells. Probably, water is commonly found in coal because the underclays prevent further downward movement of ground water.

Limestone, like coal, yields water to wells and springs almost exclusively from fractures, but solution along joints and bedding-plane cracks produces much larger secondary openings that generally yield water readily. Limestone strata yield more water where they contain few or no shaly beds to inhibit solution and where they underlie large valleys in which much water is available to dissolve the rock.

AVAILABILITY BY AREAL SUBDIVISIONS

The availability maps in the atlases of the hydrologic investigations series (Price and others, 1961a, b; Kilburn and others, 1961) were prepared as follows:

First, the region was divided into five physiographic sections (p. 6–7). Second, the geologic formations in the Eastern Coal Field were mapped and divided into subareas for the most part on the basis of lithologic facies. The boundaries of these subareas purposely were made indefinite for two reasons: (a) sedimentary facies commonly do not have sharp boundaries, and (b) little is known of the Pennsylvanian facies in the Eastern Coal Field aside from the small-scale maps made by Mitchum (1954).

Third, areas in the Kanawha section in which salty water (water reported to taste salty or known to contain more than 250 ppm (parts per million) of chloride) was known to occur at shallow depths were outlined. These three maps based on physiography, geology, and quality of water, were superimposed on each other to make the availability maps.

After the maps were combined, the well data previously collected in the field were sorted, tabulated, and analyzed to determine the quantity and quality of water available for domestic use in each of the geologic or physiographic divisions on the map. Table 2 summarizes the data on drilled wells collected from the entire region during the reconnaissance.

The following assumptions were made in the construction of the availability maps:

1. The well data analyzed, which were obtained by combining data collected during the reconnaissance with data obtained previosly from an inventory of the public and industrial water supplies of the region, together with a few wells selected from areas in which detailed studies had been made, at least approximately represent the ground-water potential of the formations in the Eastern Coal Field.
2. The well-yield figures in gallons per day, shown on the availability maps, indicate actual quantities of water used for domestic purposes. These usage estimates are as follows: Wells yielding more than 500 gpd will provide enough water for peak demands on a domestic water-supply system equipped with a power-driven pump and a pressure tank (modern domestic supply); wells yielding less than 500 gpd but more than 100 gpd will provide enough water only for a domestic supply when a hand pump is used (minimum domestic supply); and wells yielding less than 100 gpd will be inadequate for domestic use even with a hand pump.

Each of the physiographic sections and geologic facies units in the region has distinctive geologic and hydrologic characteristics. In the Cumberland Plateau section, ridges are broad and valleys are narrow. Many people live on hilltops, hence their wells have been drilled in topographic locations unfavorable for obtaining ground water. Wells generally yield small to ample supplies of water for domestic use. Because most wells tap deposits above the local drainage, the water in them is rarely, if ever, salty. Perched or semiperched water bodies are common.

In the Kanawha section, almost all the people live in the valleys; therefore, few wells are drilled on hills and ample ground water for domestic use may be obtained in the valleys. However, because most wells are drilled to depths below the local drainage, salty water may be found.

Except for the ridges of Pine and Cumberland Mountains, the Cumberland Mountain section is hydrologically similar to the southeastern part of the Kanawha section. Salty water, however, is not present at shallow depth in this section because the Cumberland Mountain overthrust has (a) fractured the bedrock in many places, thereby increasing the ground-water circulation, and (b) elevated the Cumberland Mountain section, thereby allowing any remaining salty water to drain out, probably over long periods, to lower altitudes. The pronounced dip of the Lee formation, 65° at the summit of Cumberland Gap (Ashley and Glenn, 1906), probably is responsible for the flowing wells in and near Middlesboro.

The Knobs and Mississippian Plateau areas are not properly part of the Eastern Coal Field region and occupy only a small part of the area covered by this report. For these reasons little well information was collected in these two physiographic areas and the water-availability maps in them are highly generalized. Rocks in these areas generally yield from small to ample supplies of water for domestic use.

In addition to these five physiographic sections the region was divided into 10 subareas based principally on lithologic facies. These are: (1) Chattanooga shale, (2) Mississippian-Devonian rocks, (3) Mississippian rocks, (4) subarea 1 of the Lee formation of Pennsylvanian age, (5) subarea 2 of the Lee formation of Pennsylvanian age, (6) subarea 1 of the Conemaugh formation and part of the Breathitt formation, (7) subarea 2 of undifferentiated post-Lee Pennsylvanian rocks and part of the Breathitt formation, (8) alluvium along the Ohio River, (9) alluvium along the Big Sandy River and lower reaches of its Tug and Levisa Forks, and (10) alluvium of all other streams, which are tributary to the Ohio River.

The Chattanooga shale, a black fissile shale, is exposed in a few valleys in the western part of the region. The shale generally yields enough water for a minimum domestic supply.

Mississippian-Devonian strata exposed along Pine Mountain consist of shale, limestone, and some sandstone. Limestone generally yields about 10 gpm to springs. Limestone and sandstone lying below drainage in faulted areas may yield as much as several hundred gallons per minute. Shale yields little water.

Rocks of Mississippian age, exposed along the western margin of the region, consist of thick limestone underlain by shale. Limestone is the only rock in the region that yields water from solution cavities, and large springs, some of which yield as much as 100 gpm, discharge from the limestone. Along the western margin of the region pre-Pennsylvanian erosion has truncated southward-dipping beds so that successively younger beds underlie the Pennsylvanian system from north to south. Because the Mississippian rocks in the Cumberland Plateau section are mostly limestone of

Chester and Meramec age, and those in the Kanawha section are predominantly shale of Osage age, the Mississippian rocks in the Cumberland Plateau section are the better aquifers. The limestone aquifers generally yield enough water for a modern domestic supply, while the shale aquifers yield only enough for a minimum domestic supply.

The Lee formation is distinguished hydrologically from other Pennsylvanian rocks in the region by the facts that it consists predominantly of massive quartzose sandstones instead of shale, yields water from intergranular pore spaces to some wells, and generally contains large quantities of saline water at depth. The area underlain by the Lee formation is divided into two subareas. In subarea 1, including northwest Laurel County, all of Jackson County except for the southeastern part, western Lee County, and most of Carter and Greenup Counties, the Lee formation contains a large proportion of shale and is a few hundred feet or less thick. Subarea 1 thus represents a shaly facies of the Lee formation, probably along the margin of the basin in which the principal deposition took place. Subarea 1 is unfavorable for obtaining ground water, not only because it is underlain by shales, but because most of the Lee formation lies above the drainage. Wells in subarea 1 of the Lee formation generally yield only enough water for a minimum domestic supply.

The boundary between subarea 2 and subarea 1 is arbitrary, and was determined partly from the lithofacies maps of Mitchum (1954), and partly from the topographic expression of the formation, particularly in Lee, Carter, and Greenup Counties. Subarea 2 is predominantly underlain by massive sandstones and, in general, the Lee formation in this subarea is an excellent aquifer except where it forms high narrow ridges along the western margin of the Cumberland Plateau section and in places in the Irvine-Paint Creek uplift. Wells in subarea 2 of the Lee formation generally yield enough water for a modern domestic supply. Eastward from the Cumberland Plateau section, the Lee formation dips below drainage and is likely to contain salty water. Between the western margin of the Cumberland Plateau section with its adverse topography, and the western margin of the Kanawha section where water in the Lee formation is likely to be salty, is a transition area in which the chances of obtaining good supplies of ground water are favorable. In this transition zone are located the old municipal-supply wells of London and Corbin, which yielded 20 to 75 gpm. Wells in northern Magoffin County also penetrate the full thickness of the Lee formation and yield fresh water.

The Breathitt formation, undifferentiated post-Lee Pennsylvanian rocks, and the Conemaugh formation are similar lithologically; they consist predominantly of shale interbedded with coal and fine-grained sandstone. These rocks generally increase in coarseness toward the southeast (Wanless, 1946) and the arenaceous ratio (the proportion of sandstone to shale in a given sedimentary section as sandstone/shale) also increases in this direction (Mitchum, 1954). Therefore, the area covered by these three formations was divided into two subareas. Subarea 1, along the western margin and in the northern part of the area, generally contains more shale than sandstone; wells in this subarea range from adequate for a minimum domestic supply to adequate for a modern domestic supply. Subarea 2, along the southwestern border of the region, generally contains as much, or more, sandstone than shale; wells in this subarea are generally adequate for a modern domestic supply. The boundary drawn between the two subareas is arbitrary. Almost all the large public and industrial groundwater supplies in the Eastern Coal Field region are in subarea 2 (pl. 8).

The alluvium, although rarely more than 100 feet thick, stores larger quantities of water and yields it more freely to wells from intergranular pore spaces than do the bedrock formations. The alluvium extends over a greater area in the Eastern Coal Field than the geologic or water-availability maps indicate because only alluvial flats 0.1 mile wide or greater were mapped. The bedrock formations extend underneath the alluvial areas shown on the maps. With the exception of the Ohio Valley, larger supplies of water commonly may be obtained from the bedrock beneath the alluvium than from the alluvium itself because the alluvium, unlike the bedrock, does not yield water from joints.

At last three alluvial facies are probably present in the Eastern Coal Field region. The first alluvial facies occurs along the Ohio River. This alluvium, of glacial origin, is composed of outwash sand and gravel, which is overlain by silty material. The alluvium in the Ohio Valley has been reported to yield as much as 360 gpm to wells and is the most productive aquifer in the Eastern Coal Field.

The alluvium of the second facies, found along the Big Sandy River and the lower reaches of the Tug and Levisa Forks, was derived from the Pennsylvanian formations in which it is entrenched. Test holes in the alluvium of the tributary valleys of the Eastern Coal Field indicate that the alluvium along the Levisa Fork between Allen and Paintsville is sufficiently coarse and has a great enough thickness below the stream level to yield as much as 20 or 25 gpm to properly constructed screened wells. Borings by the Corps of Engineers indicate that about 30 feet of saturated material is present along the Big Sandy River and the lower stretches of its Tug and Levisa Forks. For these reasons the alluvium in the lower part of the Big Sandy River drainage basin is believed to have greater ground-water potentialities than the alluvium in the remainder of the Eastern Coal Field region, and therefore it was denoted by a different pattern on plate 8. It is possible that equally favorable areas may be present along other streams in the region, such as the Little Sandy River, which is known to have a saturated thickness of at last 66 feet (G. A. Kirkpatrick and others, written communication, 1958).

The third facies is the alluvium of tributary valleys other than the Big Sandy River and its Tug and Levisa Forks, and the upper reaches of those forks where the alluvium is probably thin or fine grained. The alluvium of the tributary valleys generally furnishes enough water only for a minimum domestic supply.

The pattern showing areas in the Kanawha section, in which wells drilled to depths of less than 100 feet below the principal valley bottoms may encounter salty water, is very generalized and probably represents a composite of many small areas in which salty water is found only locally. For instance, many wells in Auxier, Floyd County, yield saline or salty water, but a few miles upstream, near Prestonsburg, water in wells of about the same depth is fresh (Price, 1956). Salty water in strata of Middle and Late Pennsylvanian age are centered in those parts of the Kanawha section which are topographically the lowest and therefore probably have the poorest ground-water circulation. In any given subarea the yield of fresh-water wells drilled where salty water may be encountered at shallow depth generally will be smaller than the yield of wells in the same subarea drilled outside the parts denoted by the salt-water pattern because the depth at which salty water occurs limits the depth to which satisfactory wells may be drilled.

YIELDS OF WELLS

Tables 3–6 show the median, minimum, and maximum yields to be expected from wells drilled to different depths in the Lee and Breathitt formations. Values for these yields were taken from the data plotted on figures 8 and 9 and then, with the exception of the measured yields of wells in the London and Corbin areas, were arbitrarily divided in half. This was done because nearly all the well yields given in the figures were determined from reports of owners, pump capacities, or short pumping or bailing tests, all of which tend to overstate the yield. Again, the long-term yield of wells in the Eastern Coal Field may be only half as much as that listed in tables 3–6 because large quantities of water probably will be removed from storage during periods of heavy pumping and (or) drought.

The yield tables were designed primarily for estimating the probable yields of wells drilled for institutions, commercial establishments, and small industries and municipalities, all of which require greater quantities of water than households. The tables should be used in conjunction with the availability maps in the atlases. Because there were not enough wells inventoried in each of the units of the water-availability maps to accurately compute median values of yield, data from entire subareas were analyzed to construct tables 3–6.

Table 3 shows the approximate yields to be expected, by depth zones, from wells drilled on the sides or tops of hills into the Lee formation. Wells in subarea 1 of the Lee formation in the Cumberland Plateau section and in the Kanawha section should yield somewhat less than the amounts in the table; wells in subarea 2 of the Cumberland Plateau and Kanawha sections should yield somewhat more.

TABLE 3.—*Probable yields of wells drilled on hillsides or hilltops into the Lee formation*

Depth (feet)	Yield (gpm)		
	Median	Minimum	Maximum
0–24	<1	<1	1
25–49	1	<1	1–2
50–74	1	<1	5
75–99	1–2	<1	5
100–149	1–2	<1	5
150–199	2–3	<1	10
200+	10	<1	20

Table 4 shows the approximate yields to be expected, by depth zones, from wells drilled at the base of hills and in the valley bottoms into the Lee formation. Wells in subarea 1 of the Lee formation in the Cumberland Plateau and Kanawha sections should yield somewhat less than the amounts in the table; wells in subarea 2 of the Cumberland Plateau sections and Kanawha plateaus should yield somewhat more. To yield as much as 50 gpm, a well should penetrate at least 500 feet of the Lee formation.

TABLE 4.—*Probable yields of wells drilled at the base of hills and in valley bottoms into the Lee formation*

Depth (feet)	Yield (gpm)		
	Median	Minimum	Maximum
0–24	<1	<1	3
25–49	1–2	<1	10
50–74	3–4	<1	10
75–99	6	<1	50
100–149	10	<1	50
150–199	15	<1	100
200+	50	5	150

Table 5 shows the approximate yields to be expected, by depth zones, from wells drilled in the Breathitt formation in the Cumberland Plateau section and in subarea 1 in the Kanawha section. Wells drilled on the sides or tops of hills will yield much less than the amounts in the table. Wells drilled in the valley bottoms in the Cumberland Plateau section should yield somewhat less than the amounts in the table; wells in subarea 1 of the Breathitt formation in the Kanawha section should yield somewhat more.

TABLE 5.—*Probable yields of wells drilled in the Breathitt formation in the Cumberland Plateau section and in subarea 1 of the Kanawha section*

Depth (feet)	Yield (gpm)		
	Median	Minimum	Maximum
0–24	1	<1	2
25–49	2	<1	4
50–74	4	<1	15
75–99	5–6	<1	25
100–149	8	<1	25
150–199	12	<1	25
200+	20	<1	75

Table 6 shows the approximate yields to be expected, by depth zones, from wells drilled on valley bottoms in subarea 2 of the Breathitt formation in the Kanawha section and on valley bottoms in subarea 2 of the post-Lee Pennsylvanian rocks in the Cumberland Mountain section. Wells drilled on hills will yield less than the amounts shown in table 6.

TABLE 6.—*Probable yields of wells drilled on valley bottoms in subarea 2 of the Kanawha section (Breathitt formation) and in subarea 2 of the Cumberland Mountain section (post-Lee Pennsylvanian rocks)*

Depth (feet)	Yield (gpm)		
	Median	Minimum	Maximum
0–24	1–2	<1	2
25–49	3	<1	10
50–74	5	<1	50
75–99	6–7	<1	50
100–149	10	<1	100
150–199	15	<1	125
200+	35	<1	150

Seven wells in the region were pumped to determine accurately their discharges and drawdowns. The results of these tests are shown in figure 11. Too few tests were run to determine conclusively the comparative yields of the formations pumped, but the tests do indicate that the specific capacities (0.4 to 4.3 gpm per foot of drawdown at the end of 1 hour of pumping) of wells in the bedrock are much lower than the specific capacity (17.5 gpm per foot of drawdown at the end of 1 hour of pumping) of the well in the Ohio Valley alluvium at Greenup. The two recovery curves illustrated in figure 11 indicate that the wells on which the recovery tests were run probably have specific capacities of less than 1 gpm per foot of drawdown.

The water level in the well that taps the Breathitt formation near Noble still had not recovered to its prepumping level several hours after the pump was shut off. This suggests that water in the Breathitt formation was withdrawn from storage during the test.

METHODS OF OBTAINING GROUND WATER

In the Eastern Coal Field region, ground water is recovered from wells penetrating the zone of saturation, from springs at the outcrop of an aquifer, and from coal mines.

Most of the wells in the region were dug or drilled, but a few in alluvium were bored or driven. Dug wells generally are less than 25 feet deep and most obtain their water from silt, sand, and gravel in the valley alluvium; some obtain their water from bedrock, particularly the weathered zone. Dug wells are large enough in diameter (2 to 4 ft) to admit a man, and are constructed with hand tools. Most are walled with rock, although some are lined with tile or concrete pipe. Dug wells have the advantage of being able to

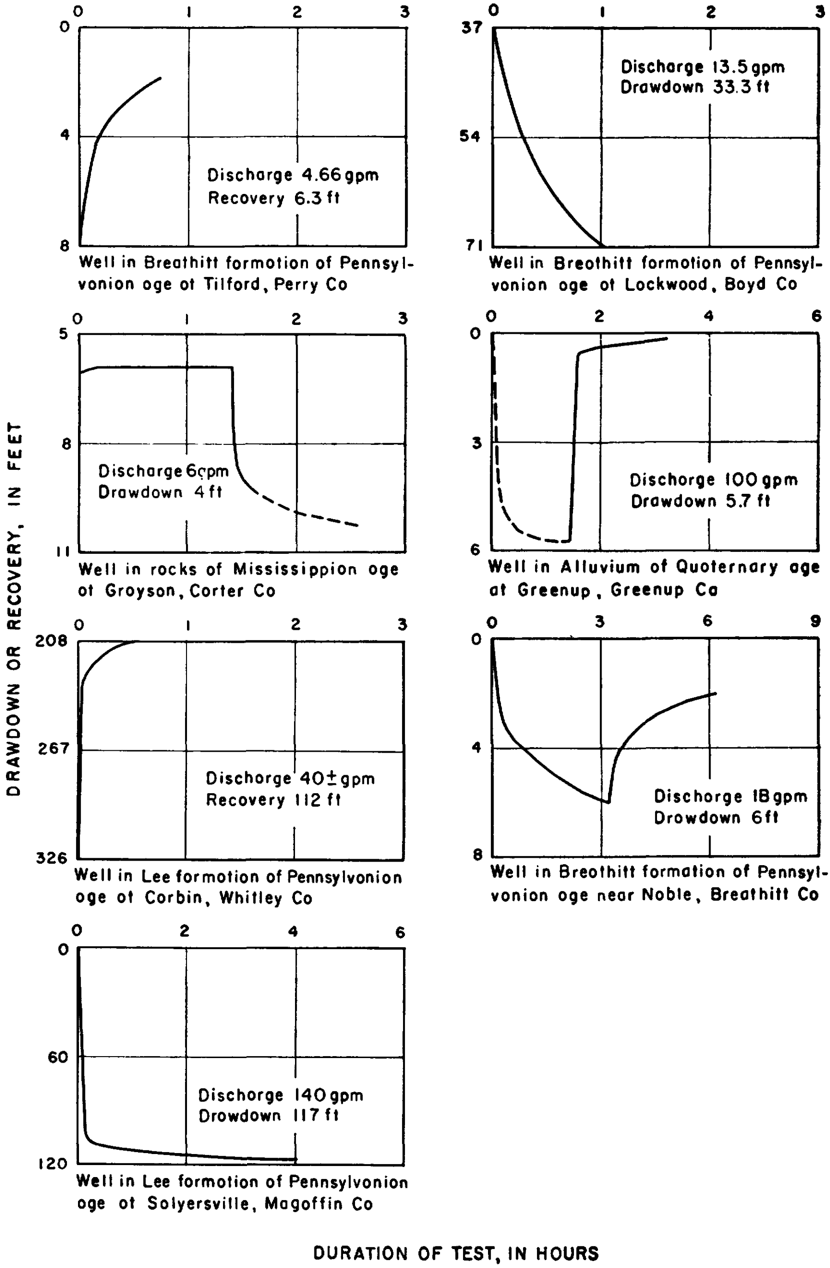

FIGURE 11.—Time-drawdown and time-recovery curves of water levels in pumped wells in the Eastern Coal Field region, Kentucky.

economically develop water supplies in thin deposits of alluvium and weathered bedrock on hills where the water table is perched or semiperched. The water they furnish is generally of good chemical quality, although it is subject to surface pollution.

Drilled wells, however, are gradually replacing dug wells because drilled wells, being deeper, generally give a larger more dependable water supply and are less subject to pollution. Most of the drilled wells were constructed by the cable-tool or percussion method, in which drilling is accomplished by repeatedly raising and dropping a cutting tool (bit) into the ground. The bit breaks up the rock material in the bottom of the hole; the cuttings are removed periodically with a bailer.

Most of the wells bottomed in the alluvium of the Ohio Valley are finished with a screen extending below the casing. They are developed by pumping, surging with a block, or backwashing to remove fine-grained materials from around the screen. Large-capacity wells in the alluvium of the Ohio Valley are as much as 24 inches in diameter. In many of these wells, a gravel envelope is poured in around the screen after it is inserted in the drilled hole, thus forming a gravel pack.

Wells drilled in the alluvium of the valleys tributary to the Ohio River are rarely finished with a screen. It has been found by experience that many open-end drilled wells in the alluvium fill up with sand and reduce the yield and effective depth of the well. Attempts to prevent sand from heaving into the wells by pouring gravel into the bottoms of the wells have been only partly successful. Commonly, drilled wells have been finished in the alluvium only where fresh water cannot be obtained in the bedrock beneath the valley and water-bearing sand and gravel is known to be present in the alluvial fill above the rock floor.

Most bedrock wells are cased to the rock with 6-inch-diameter steel pipe. Commonly, the casing is driven 1 or 2 feet firmly into the bedrock to prevent shallow water, which may be polluted, from entering the well. The well is deepened until the first adequate supply of water is struck. Under unfavorable topographic conditions such as on the tops of hills, where well yields generally are small, a hole of larger diameter (commonly 8 inches) may be drilled beneath the horizon at which water was found, to provide greater storage in the well. Sometimes where water of poor quality, commonly water high in iron sulfate, is struck at a relatively shallow depth, the water of poor quality is cased off and the well is drilled deeper to obtain a water supply of better quality. At still greater depth, salty water may be found. The salty water may be plugged off if fresh water enters the well at a higher level. If the maximum yield is desired from a well, it may be deepened until salty water is found, and then plugged to just above the horizon at which the salty water enters. After the well is completed, a bailing test is made to determine whether the well will yield an adequate supply of water.

Several factors should be considered in developing springs. The most important is not to impede the flow of water from the mouth of the spring. Damming or ponding the water to a level higher than the mouth will allow sediment to collect and may clog the spring. Furthermore, increasing the head at the discharge point may cause the spring to cease flowing or to flow at a greatly decreased rate. The minimum flow of most springs in the Eastern Coal Field region is 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 generally is adequate for a household. To utilize such a small spring sufficient storage should be provided to allow for the daily water demand.

Some coal mines yield enough water for small public and industrial supplies. In effect, coal mines are large infiltration galleries. Most have the disadvantage, however, of being located above the local drainage. Most mines that have been used for a water supply have been modified by sealing the opening of the mine to impound the water within. Water is either conducted from the mine by gravity, or pumped out by a well drilled through the roof of the mine. Coal mines used for water supply should be sealed to prevent air circulation. In unsealed mines, the oxidation of sulfides which are present in many coals and black shales may produce acidic water that has a high content of sulfate and iron.

QUALITY OF WATER

The quality of ground water in the Eastern Coal Field region is governed by its geologic source and the amount of time it 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. Drilled wells, which are deeper, generally yield more mineralized water that has been in contact with the aquifer for a longer period. Springs discharge water that is generally more like that of dug wells than of drilled wells.

Tables 7–9 show the range in median values for iron, the principal anions, hardness, specific conductance, and pH in ground water from aquifers in each of the physiographic divisions of the Eastern Coal Field region. Median values are shown in preference to average values because a few of the samples are very high in dissolved solids and do not represent most of the samples.

Water from wells and springs in the Eastern Coal Field region varies widely in chemical character, but most of it is of the calcium magnesium bicarbonate or sodium bicarbonate type. Brine is commonly found beneath the fresh water throughout the Eastern Coal Field region, but because it is not satisfactory for domestic or industrial use it is not included in the analyses on which tables 7–9 are based. Reports by McGrain (1953) and McGrain and Thomas (1951) summarize data available on the highly mineralized water of Kentucky.

Nitrate is present in significant amounts in many dug and drilled wells in the alluvium along the Ohio River. Three analyses show a nitrate content in excess of 45 ppm, a concentration above which water may be unsafe for infant feeding (Cumly, 1945).

The median content of fluoride in water from all the aquifers sampled is less than 1.5 ppm; however, 6 samples from the Breathitt formation contained more than 1.0 ppm of fluoride and 2 contained more than 1.5 ppm. Maier (1950) has shown 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, or mottling of the tooth enamel, may become evident if, during the period of tooth development, the water consumed contains more than about 1.5 ppm of fluoride (Maier, 1950).

Chloride, a constituent in common table salt (sodium chloride), and iron are the most common objectionable constituents in the ground water of the Eastern Coal Field region. Salty water is known to occur at depths of less than 300 feet in all the physiographic divisions of the region except the Cumberland Mountain section. Salty water also is known to occur in all the formations of the region except alluvium and the Conemaugh formation. The presence of chloride affects not only the quality of the water, but also the quantity of water yielded, for the depth at which salty water occurs is the maximum depth to which a well can be drilled for a satisfactory supply.

In general, the concentration of chloride becomes higher as the depth increases below drainage. Water salty enough to be called brine eventually will be reached in any part of the region where wells are drilled sufficiently deep. This salty water represents a transitional phase between fresh meteoric water, which occurs at depths of 5 to 300 feet, and concentrated brine found several hundred to several thousand feet below the surface. Brine is ancient

TABLE 7.—*Dissolved constituents, in parts per million, and other properties of water from drilled wells*[1]

Physiographic division	Geologic unit	Subarea	Number of samples	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH
The Knobs	Mississippian rocks		1	0.45	12	4.1	5.0	0.1	18	22	85.0	5.8
Mississippian Plateau	do		1	.48	216	18	1.4	.1	2.0	195	373	7.0
Cumberland Plateau section	Breathitt formation		8	3.0	108	18	7.5	.1	.8	94	295	6.7
Do	Lee formation	1	1	.13	14	2.5	2.0	.0	3.5	9	39.8	6.0
Do	do	1	1	.75	104	2.3	.8	.1	.2	62	164	----
Do	do	2	21	1.6	182	22	16	.1	1.0	88	327	6.9
Do	Mississippian rocks		8	.43	231	34	9	.1	1.5	125	432	7.5
Kanawha section	Alluvium, Ohio Valley		8	.28	118	105	29	.1	19	209	522	6.8
Do	Alluvium, tributary valley		1	14	51	60	4.2	.1	.2	83	227	6.4
Do	do		1	51	248	7.3	8.0	.4	.2	98	426	6.6
Do	Conemaugh formation; Breathitt formation	1	39	.71	204	7.8	16	.3	.4	105	508	7.2
Do	Breathitt formation	2	41	.85	183	14	30	.1	.5	107	470	7.1
Do	Lee formation	1	1	6.6	77	13	2.0	.1	.2	69	164	6.8
Do	do	1	1	16	126	.8	169	.1	.2	175	748	6.5
Do	do	2	26	.70	188	4.0	6.0	.2	1.0	80	318	7.4
Do	Mississippian rocks		8	.9	221	10	152	.2	.5	201	1,032	7.4
Cumberland Mountain Section	Undifferentiated post-Lee Pennsylvania rocks	2	9	.67	162	24	10	.1	.4	94	306	7.3
Do	Lee formation		6	.45	81	19	8.5	.3	1.7	38	304	6.6

1 **Median values are shown where there are more than two samples.**

TABLE 8.—*Dissolved constituents, in parts per million, and other properties of water from dug wells*[1]

Physiographic division	Geologic unit	Subarea	Nember of samples	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
Cumberland Plateau section	Breathitt formation		1	0.05	66	72	48	0.2	21	149	453	7.4
Do	do		1	.24	80	264	17	.3	11	368	727	
Kanawha section	Alluvium tributary valley		9	.39	30	28	6.0	.1	13	69	204	6.4
Do	Breathitt formation	1	1	.14	18	132	20	.3	2.4	132	394	
Do	Mississippian rocks		3	.19	142	18	92	.1	19	69	654	7.1
Cumberland Mountain section	Alluvium tributary valley		1	.17	16	14	4.0	.1	6.3	20	84.2	6.0

[1] Median values are shown where there are more than two samples.

TABLE 9.—*Dissolved constituents, in parts per million, and other properties of water from springs*[1]

Physiographic division	Geologic unit	Subarea	Number of samples	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25° C)	pH
The Knobs	Mississippian rocks		1	0.09	189	1.0	4.5	0.0	5.1	160	320	7.9
Cumberland Plateau section	Lee formation	2	1	.04	20	2.3	1.5	.1	.3	10	32.9	
Do	Mississippian rocks		4	.18	117	28	2.5	.1	.4	124	243	7.6
Kanawha section	Conemaugh formation; Breathitt formation.	1	4	.17	249	113	5.2	.2	.5	216	604	7.3
Do	Breathitt formation	2	4	.08	20	28	2.0	.1	1.2	37	98	6.7
Cumberland Mountain section	Lee formation		1	.18	39	7.2	38	.1	3.2	45	204	7.1
Do	Mississippian rocks		1	.18	59	6.1	1.2	.1	.5	53	112	7.6

[1] Median values are shown where there are more than two samples.

fossil sea water trapped in the rocks when they were deposited and chemically modified and concentrated by processes not yet completely understood.

Salty water is found at shallow depths where the ground-water circulation in sedimentary rocks of marine origin has been poor, or in strata of continental origin into which salty water has migrated naturally or has been introduced artificially through wells. Salty water in the region is most common in the marine sedimentary rocks of Mississippian age (22 percent of the wells inventoried yield salty water) and less common in the predominantly continental sedimentary rocks of the Lee formation (6 percent of the wells inventoried yield salty water) and younger Pennsylvanian rocks (6 percent of the wells inventoried yield salty water). Lower Mississippian rocks, which consist predominantly of shale, yield salty water to more than half the wells inventoried. Upper Mississippian rocks, mostly limestone, yield salty water to only a few wells because solution cavities in limestone cannot develop without free circulation of ground water. A few marine beds, however, are present in the predominantly continental Pennsylvanian rocks, and some salty water probably was trapped in the marine sediments during deposition. It is possible that the massive sandstones of the Lee formation may be of marine origin (Mitchum, 1954); if so, this would account for the prevalence of salt water in the Lee formation at depth.

Salty water occurring at shallow depth (less than 100 feet) is restricted generally to the lower parts of the principal drainage basins of the region (pl. 9) probably because the circulation of ground water at depths beneath major drainageways is slow or negligible. Rocks in the headwater areas, such as in the extreme southeastern part of the Kanawha section and in the Cumberland Mountain section, generally do not contain salty water at shallow depth. Figure 12 illustrates another reason why wells drilled along the lower courses of principal streams bordered by thick alluvial deposits may be more likely to yield salty water than wells drilled at the base of hills or on hillsides. Wells drilled on the valley bottoms generally are not only deep, but are cased through most of their length, thereby excluding fresh water at shallow depth.

At least one area where salty water occurs at shallow depth in the Eastern Coal Field coincides with the principal gas and oil fields of the region. The Big Sandy gas field, shown on an oil and gas map of Kentucky (Wood and Walker, 1954) occupies a large part of the Levisa Fork drainage basin which includes many shallow wells that yield salty water. Salty water under high head may

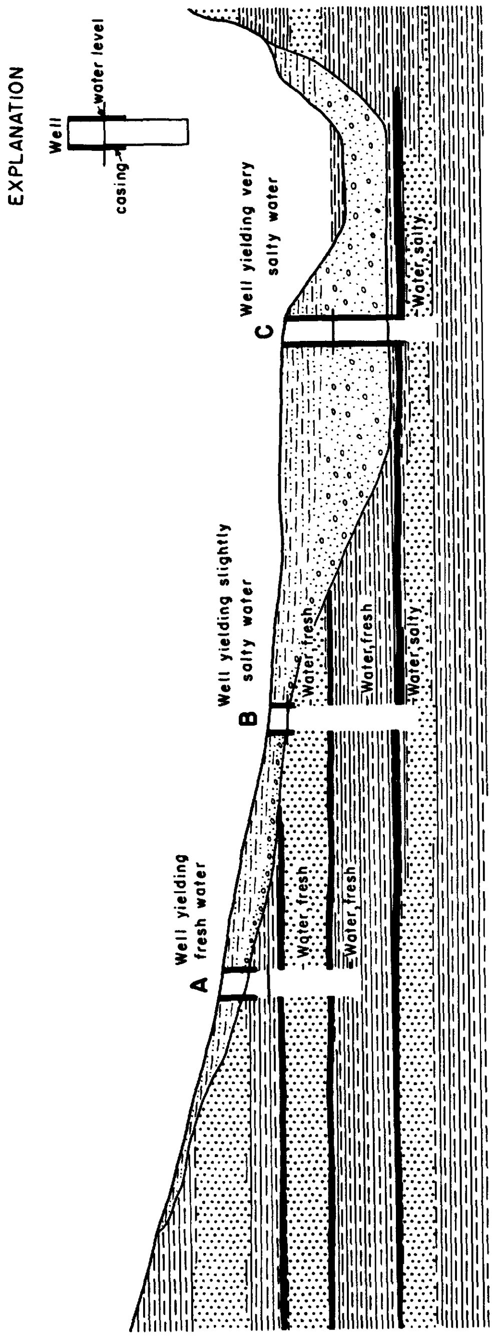

FIGURE 12.—Section showing hypothetical relation of topography to wells yielding salty water in the Eastern Coal Field region, Kentucky.

have migrated through improperly plugged or abandoned gas, oil, or test wells, or may have migrated upward during the drilling. Water wells that penetrate salt-water zones also may be responsible for contamination of shallow bodies of fresh water.

In the parts of the region where large structural disturbances such as the Irvine-Paint Creek uplift and Cumberland Mountain section overthrust have occurred, the rocks generally contain fresh water at shallow depth. Structural movements tend to increase ground-water circulation by fracturing the rocks, elevating them, and exposing permeable beds such as the Lee formation.

Iron is the second constituent most often found in objectionable amounts in ground water in the Eastern Coal Field. Iron is present in noticeable quantities in the water from wells and springs in all the formations of the region. Acidic water from coal mines may contain very large quantities of iron; for example, a water sample from a coal mine in the Prestonsburg quadrangle contained 233 ppm of iron (Price, 1956). Judging by analyses made of ground water in the Paintsville area (Baker, 1955) and Prestonsburg quadrangle (Price, 1956) water from drilled wells in the alluvium of the tributary valleys may contain the largest quantities of iron in the region (table 7).

The sources of the iron are iron-bearing minerals found in all rocks of the region, and probably the casings of some wells. Coals and black shales commonly contain an iron disulfide mineral, either pyrite or marcasite. Oxidation of the disulfides produces iron sulfate, iron hydroxide, and free acid in mine water. Iron hydroxide, a reddish-brown sediment, is commonly found in well water of the region. Water that contains the sediment is locally called red or sulfur water. Acidic water, if in contact with the casing of the well, may dissolve iron from it.

Areas in which vadose water drains through beds of black shale or coal, or areas in which acidic mine drainage recharges the ground water, probably will have water of poor quality and of a high iron and sulfate content. Under these circumstances, the iron-bearing water will occur at shallow depth and may be cased off. Water of better quality commonly can be found at greater depth.

Table 10 shows the source and significance of dissolved mineral constituents in natural water.

In addition to the dissolved constituents certain other properties of water are reported in tables 7–9. These properties are hardness, specific conductance, and pH. Hardness may be defined as the sum of all the hardness-causing constituents expressed as equivalent calcium carbonate. The specific conductance of water meas-

TABLE 10.—*Source and significance of dissolved mineral constituents in natural water*

Constituent	Source	Significance
Silica (SiO_2)	Siliceous minerals present in virtually all formations.	Forms hard scale in pipes and boilers. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	The common iron-bearing minerals present in most formations.	Oxidizes to a reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown, is objectionable for food processing and beverages; larger quantities impart taste and favor the growth of iron bacteria.
Manganese (Mn)	Manganese-bearing minerals	Rarer than iron; in general has same objectionable features; brown to black stain.
Calcium (Ca) and magnesium (Mg)	Minerals that form limestone and dolomite and occur in some amount in almost all formations. Gypsum also a common source of calcium.	Cause most of the hardness and scale-forming properties of water; soap consuming.
Sodium (Na) and potassium (K)	Feldspars and other common minerals; ancient brine, sea water; industrial brine and sewage.	In large amounts cause foaming in boilers and other difficulties in certain specialized industrial water uses.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate minerals.	Decompose on application of heat with attendant release of corrosive carbon dioxide gas. Carbonates of calcium and magnesium form scale.
Sulfate (SO_4)	Gypsum, iron sulfides, and other rarer minerals; common in water from coal-mining operations and many industrial wastes.	Sulfates of calcium and magnesium form hard scale.
Chloride (Cl)	Found in small to large amounts in all soils and rocks; natural and artificial brine, sea water, sewage.	Chloride salts in large enough amounts give salty taste; objectionable for various specialized industrial uses of water.
Fluoride (F)	Various minerals of widespread occurrence, in minute amounts.	In water consumed by children, about 1.5 ppm and more may cause mottling of tooth enamel, but about 1.0 ppm reduces incidence of tooth decay (Maier, 1950).
Nitrate (NO_3)	Decayed organic matter, sewage, nitrate fertilizers, nitrates in soil.	Values higher than the local average may suggest pollution. There is evidence that more than about 45 ppm NO_3 may cause methemoglobinemia (infant cyanosis) which is sometimes fatal. Water of high nitrate content should not be used for baby feeding (Maxcy, 1950).

ures its ability to conduct electricity. It varies with the concentration and the degree of ionization of minerals in solution and with the temperature. Variations in specific conductance show changes in the concentrations of dissolved minerals in water. The hydrogen-ion concentration of water is expressed in pH units; pH may be defined as the logarithm of the reciprocal of the hydrogen-ion concentrations in moles per liter. The pH indicates the relative acidity or alkalinity of water. Pure water of pH 7.0 is neutral; however, for practical purposes water is reported as having no actual acidity unless its pH is less than 4.5. Some alkaline water has a pH higher than 8.0, and some water containing free mineral acids has pH values of less than 4.5.

SUGGESTIONS FOR FUTURE INVESTIGATIONS

More detailed investigations of the availability of ground water in the Eastern Coal Field region will be needed in additional 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. Future industries generally will be established in areas where an adequate supply of water is known to be available. Crop irrigation, which is becoming more important in Kentucky, will also be stimulated by information on the availability of ground water.

Studies to determine accurately the potential yield of the rocks in the region are needed badly. Many more specific-capacity tests should be made on existing wells to determine their yield. Studies are needed also to determine the effects of long-term pumping and drought on the quantity of water stored in the rocks. In the Corbin area, W. F. Guyton and D. J. Jones (written communication, 1944) concluded that reduction of recharge to the aquifers pumped by the city wells during the summer growing season probably cut the yield of the wells by half. The feasibility of making quantitative studies, using the drainage basin as a unit, should also be determined.

Quality of water studies should be made, particularly to learn more about the occurrence of salty water and to delineate more accurately the areas in which it occurs. The water from more wells should be sampled and analyzed for chloride content. Wells yielding salty water should be sampled at various depths to determine the horizon or horizons at which the salty water enters. The relation of high-chloride water to existing or abandoned gas, oil, or test wells also should be determined. A study should be made of the effects of coal-mine drainage on the quality of the ground water. Some work is being done on this in connection with the Beaver Creek project (W. E. Price, Jr., written communication, 1960).

Expansion and reëvaluation of the present observation-well program should be undertaken primarily to learn more about the seasonal effects of precipitation on the water levels in wells that differ as to topographic location, depth, and aquifer penetrated, and to gain a better understanding of the hydrologic characteristics of wells in the Eastern Coal Field region.

Additional test augering should be done in the alluvium of the valleys which are tributary to the Ohio River, especially along the Big Sandy River and its Levisa Fork. One or more test wells should be put down, screened, developed, and pumped to field test the potential yield of the alluvium.

Lithofacies studies are needed to determine the probable extent of sandstones and other favorable water-bearing beds. These studies would involve in part the collection of core-drill records, records of carefully logged gas, oil, and test wells, and the measurement of sections.

Compilation mapping of the Upper and Lower Mississippian strata, possibly breaking down the Upper Mississippian into rocks of Chester and Meramec age, should be done. Not only would this complete the geologic maps in this report, but would enable a more detailed and useful water-availability map of the Mississippian rocks to be constructed.

The collection and examination of more water-well samples should be made to determine more accurately the lithology of the water-bearing beds.

In the future detailed ground-water studies should be made in the following areas:

1. Jenkins-Whitesburg area. The reconnaissance indicated that this is one of the most favorable areas in the upper Kentucky River basin for the development of ground-water supplies from wells in the bedrock.
2. Middlesboro-Pineville area. To determine if possible the reasons for artesian conditions in the area, the depth and character of the alluvium in the Middlesboro basin, and the effects of faulting on well yields and the availability of ground water.
3. Ashland-Greenup area. Ground water is available in moderate to large amounts in the alluvium in this area. Expansion of the industrial use of ground water requires further information on its availability.
4. South part of the Paint Creek uplift. The Lee formation yields 30 to 140 gpm for waterflooding and public supply, and the Breathitt formation in this area may yield as much as 100 gpm. A study of this area also might reveal the principles which control the occurrence of salty water in the basins of the Big Sandy, and Licking Rivers.

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