Ground-Water Geology of the Dickson, Lawrenceburg, and Waverly Areas in the Western Highland Rim Tennessee

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1764

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

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By M. V. MARCHER, R. H. BINGHAM, *and* R. E. LOUNSBURY

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By M. V. Marcher, R. H. Bingham, and R. E. Lounsbury

ABSTRACT

Ground-water supplies in the Dickson, Lawrenceburg, and Waverly areas are obtained from wells and springs in limestone and chert formations of Mississippian age. In the Dickson area most of the wells and springs are in Warsaw Limestone. In the Lawrenceburg and Waverly areas, ground-water supplies are obtained from Fort Payne Chert and from residuum. In all three areas a few wells obtain small amounts of water from gravel stringers in the residuum.

Yields of wells range from a few to 300 gpm (gallons per minute). Wells having the largest yields obtain water from residual material (colluvium) in the valley of Trace Creek in the Waverly area. Fewer than 10 percent of all wells inventoried yield more than 25 gpm. Springs are common in all the areas studied and yield as much as 1,000 gpm.

The quality of water from wells and springs in the areas studied generally is good. The water is of the calcium bicarbonate type, and most of it is moderately hard to hard. The constituents in water from springs and from wells are about the same, although water from springs tends to be softer and slightly lower in dissolved-solids content.

Springs constitute the largest potential source of water in the three areas. Twenty-one of the large springs discharge approximately 12 million gallons per day, or about 8,000 gpm. Another potential source of water is residuum underlying the valley of Trace Creek in the Waverly area. Wells yielding as much as 500 gpm probably could be developed in this aquifer.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The western part of the Highland Rim province in Tennessee is underlain principally by limestone and chert formations from which ground water is available in adequate quantities for domestic and moderate municipal and industrial uses. The occurrence of ground water in a consolidated-rock terrane is intimately related to the lithology and structure of the geologic formations. A knowledge of the geologic and hydrologic conditions therefore is essential in determining the quantity and quality of the ground water available and in providing information with which to plan maximum and orderly development of the ground-water supply.

The Dickson, Lawrenceburg, and Waverly areas (fig. 1) were selected for study because they are representative of the western part of the Highland Rim province and because each is an area of potential industrial development and urbanization. The present study was undertaken to appraise the ground-water resources of these areas and to increase the knowledge of the principles of ground-water occurrence in limestone terranes.

To accomplish these objectives, the geology of the Dickson, Lawrenceburg, and Waverly areas was studied, emphasis being put on the water-bearing properties of the formations and the depth and areal extent of the principal aquifers. Water-level data were collected for use in constructing contour maps of the ground-water surface and in determining the source and direction of movement of ground water in each area. Water samples from 19 wells and 3 springs were collected and analyzed to determine the suitability of the water for potential uses. In addition, field tests for hardness, pH, and iron content were made on samples from 121 wells and 21 springs.

This report and the accompanying geologic maps have been prepared by the U.S. Geological Survey as a part of the cooperative water-resources investigations program with the Tennessee Division of Water Resources and the cooperative geologic mapping program with the Tennessee Division of Geology.

PHYSICAL FEATURES OF THE WESTERN HIGHLAND RIM

LANDFORMS AND RELIEF

Central Tennessee is included in the Interior Low Plateau physiographic province (Fenneman, 1938, p. 415–417; 431–434) and is subdivided into the Highland Rim and Nashville Basin sections or subprovinces (fig. 1). The Nashville Basin is a rolling plain having an average altitude of about 700 feet above sea level. Surrounding the Nashville Basin on all sides and standing about 200 feet above it is the Highland Rim, a gently rolling to highly dissected plateau. The most highly dissected part of the plateau is in the Western Highland Rim where the local relief is between 200 and 300 feet. From high points in the southeastern part, the Western Highland Rim surface slopes westward and northwestward at a rate of 15 to 20 feet per mile. The most extensive areas of rolling uplands form the major drainage divides south of the Duck River in the southern part of the Rim and between the Cumberland and Tennessee Rivers in

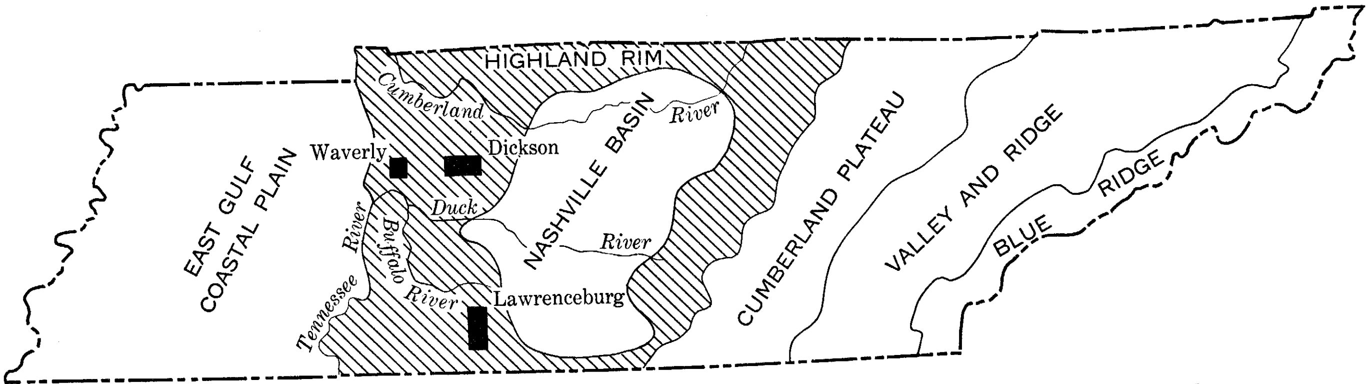


FIGURE 1.—Map showing physiographic provinces of Tennessee and location of the Dickson, Lawrenceburg, and Waverly areas.

the northern part. North of the Cumberland River the Highland Rim plateau is a gently rolling karst plain formed on highly soluble limestone of Mississippian age.

Away from the major drainage divides and toward the streams, the Highland Rim plain is represented only by the crests of narrow sinuous ridges separating equally narrow steep-walled valleys. Many of the smaller valleys occupy shallow synclines, most of which may have been formed in part by subsurface sapping by ground water (White, 1960, p. 2029).

The larger streams of the Western Highland Rim, such as the Buffalo, Duck, and Cumberland Rivers (fig. 1), occupy steep-walled valleys and have narrow flood plains, rarely as much as a mile wide. Both the Duck and Buffalo Rivers have rather winding courses preserved by entrenchment from a previous cycle of erosion. The Cumberland River, on the other hand, has a relatively straight course except in the north-central part of the Highland Rim where it follows a broadly meandering valley entrenched about 150 feet below the general level of the adjacent uplands.

Terraces are conspicuous landforms, especially along the Duck and Buffalo Rivers. In the southwestern part of the Highland Rim, terraces are well defined along the east side of the Tennessee River, but farther north well-defined terraces are present only along the west side of the Tennessee River. Terraces are absent along the Western Highland Rim segment of the Cumberland River although some terrace gravels are present on the uplands in this general area. Several terrace levels can be distinguished, particularly along the Duck and Buffalo Rivers. In these areas the terraces stand from a few feet to more than 100 feet above the flood plains.

DRAINAGE

Approximately half of the Western Highland Rim is drained by the Tennessee River and its major tributary, the Duck River. The northern part of the Rim is drained by the Cumberland River. About one-fourth of the area is drained by southward-flowing tributaries of the Elk River in Alabama; this river in turn flows into the Tennessee River.

CLIMATE

Throughout the Western Highland Rim the climate is quite uniform and temperate. Mean annual precipitation ranges from 48 inches in the extreme northern part of the Rim to as much as 56 inches in the southwestern part. Over most of the area the mean annual precipitation is about 50 inches (Dickson, 1960, p. 6), occurring mostly during late winter and spring. The wettest month is

January, when the average rainfall is 6.2 inches; and the driest is October, when the average rainfall is 2.6 inches.

The mean temperature in the area is 59.8°F. July is the warmest month and has an average temperature of 79.1°F, and January is the coldest, having an average of 41°F.

PREVIOUS INVESTIGATIONS

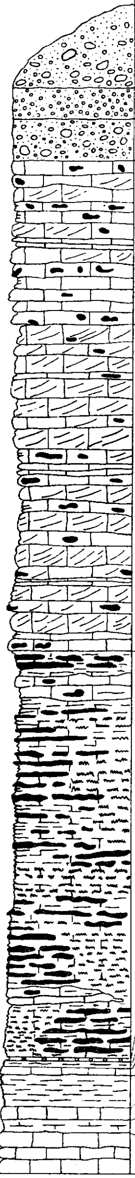
Prior to this study no investigation had been made that dealt exclusively with the geology or ground-water resources of the Dickson, Lawrenceburg, and Waverly areas. The first significant study of the geology of the Western Highland Rim was made in 1851 by Safford. More detailed information was given by Safford in his report "Geology of Tennessee" (1869). The rocks in various parts of the Rim and adjacent areas were studied subsequently by Hayes and Ulrich (1903), Wade (1914), Miser (1921), Jewell (1931), and Bassler (1932). Ground-water studies by Piper (1932), Theis (1936), and Smith (1962) describe briefly the ground-water conditions in the Western Highland Rim and present some data on wells, springs, and municipal water supplies in the Dickson, Lawrenceburg, and Waverly areas.

ACKNOWLEDGMENTS

The residents and drilling contractors in the Dickson, Lawrenceburg, and Waverly areas cooperated in the study by granting permission for the use of their wells for tests and water-level measurements and by providing well construction data and general information on ground-water conditions. Their cooperation and assistance is gratefully acknowledged. Municipal water plant operators also generously furnished information on ground-water pumpage and customers served. Dr. C. W. Wilson, Vanderbilt University, O. L. Smith, Tennessee Division of Water Resources, and R. A. Miller, Tennessee Division of Geology, were helpful in providing information on the geology and hydrology of parts of the areas.

GENERAL GEOLOGY

The Western Highland Rim is underlain mainly by limestone and chert formations ranging in age from Ordovician through Mississippian (fig. 2). Locally the ridges and uplands are veneered with a varying thickness of Tuscaloosa Gravel of Late Cretaceous age. Terrace gravel and alluvial deposits underlie the terraces and floodplains along most of the larger stream valleys in the region. In most of the province the oldest formations exposed at the surface are the Fort Payne Chert and Warsaw and St. Louis Limestones of Mississippian age.



AGE	MAXIMUM THICKNESS, IN FEET	FORMATION	LITHOLOGY
QUATERNARY	50	Alluvium	Unsorted gravel and sand
	20	Terrace gravel	Rounded and iron-stained chert and quartz pebbles in a sandy matrix
CRETACEOUS	25	Tuscaloosa Gravel	Rounded chert pebbles in an ashen gray sandy clay matrix
MISSISSIPPIAN	100	St. Louis Limestone	Dark-yellowish-brown, fine- to coarse-grained, fossil-fragmental cherty limestone
	200	Warsaw Limestone	Yellowish-brown, coarse-grained, fossil-fragmental limestone
	250	Fort Payne Chert	Mutually intergrading lithofacies of bedded chert, scraggy chert, and shaly chert. Bedded chert consists of layers of chert 4 to 8 inches thick intercalated with silty dolomitic limestone. Scraggy chert consists of very rough irregular plates of chert in a limy matrix. Shaly chert consists of dolomitic, very cherty, platy siltstone
DEVONIAN	1.5	Maury Formation	Greenish-gray mudstone containing abundant phosphatic nodules
	4.5	Chattanooga Shale	Grayish-black fissile shale
SILURIAN	5	Brassfield Limestone	Gray medium-grained glauconitic limestone
ORDOVICIAN	20	Mannie Shale	Dark-bluish-gray shale
	8	Fernvale Limestone	Tan to reddish-gray very coarse-grained limestone
	8	Sequatchie Formation	Bluish-green calcareous mudstone
	25	Leipers Limestone	Dark-bluish-gray coarse-grained shaly limestone

FIGURE 2.—Composite stratigraphic section of formations cropping out in the Dickson, Lawrenceburg, and Waverly areas.

In the three areas studied, rocks of Ordovician, Silurian, and Devonian age crop out only in the Lawrenceburg area, and the descriptions of these formations given in this report apply only to that area. Ordovician rocks include the Leipers Limestone, western tongue of the Sequatchie Formation, Fernvale Limestone, and Mannie Shale. Rocks of Silurian and Devonian age are represented by the Brassfield Limestone and the Chattanooga Shale, respectively.

STRATIGRAPHY

ORDOVICIAN SYSTEM

LEIPERS LIMESTONE

The oldest formation exposed in the areas studied is the Leipers Limestone, of Late Ordovician age, which crops out at only a few localities in the southern part of the Lawrenceburg area (pl. 1). At these localities the formation is represented by as much as 25 feet of massive coarse-grained dark-blue silty limestone and thin- to medium-bedded nodular shaly, silty limestone. This lithology corresponds with that of the granular facies of the Leipers described by Wilson (1949, p. 187).

WESTERN TONGUE OF THE SEQUATCHIE FORMATION

The Leipers Limestone is unconformably overlain by a massive bluish-green mudstone as much as 8 feet thick. This mudstone forms the basal unit of the Richmond Group in this area and may be equivalent to the western tongue of the Sequatchie Formation (Wilson, 1949, p. 209) which is present several miles east of the Lawrenceburg area.

FERNVALE LIMESTONE

Above the mudstone is the Fernvale Limestone (Wilson, 1949, p. 208), which consists of massive very coarse grained tan to reddish-gray limestone. The formation is about 8 feet thick and is well exposed in the valley of Shoal Creek southwest of Lawrenceburg.

MANNIE SHALE

Conformably overlying the Fernvale Limestone in the Lawrenceburg area is the Mannie Shale (Wilson, 1949, p. 215), a dark-bluish-gray silty shale containing a few beds of greenish-gray very silty limestone. Approximately 20 feet of Mannie Shale is exposed along Shoal Creek. In the southeastern part of the Lawrenceburg area, both this formation and the Fernvale Limestone have been stripped away by post-Richmond pre-Chattanooga erosion.

SILURIAN SYSTEM

BRASSFIELD LIMESTONE

Rocks of Silurian age, which are exposed only in the Lawrenceburg area, consist of a single formation, the Brassfield Limestone. It is a massive medium-grained gray slightly silty glauconitic limestone. The formation is preserved in discontinuous patches about 5 feet thick in the southwestern part of the Lawrenceburg area but is absent in the southeast. The Brassfield is unconformably overlain by the Chattanooga Shale and conformably underlain by the Mannie Shale.

DEVONIAN SYSTEM

CHATTANOOGA SHALE

Rocks of Devonian age are represented only by the Chattanooga Shale, which is exposed in the valleys of Shoal Creek and East Fork Sugar Creek in the southern part of the Lawrenceburg area. At these localities the formation is about 4½ feet thick and consists of fissile grayish-black carbonaceous shale and a basal fine-grained sandstone bed about 1 foot thick.

MISSISSIPPIAN SYSTEM

In the three areas studied, rocks of Missippian age are widespread and are the only ones significant as sources of ground water. Mississipian formations represented include the Maury Formation, Fort Payne Chert, Warsaw Limestone, and St. Louis Limestone.

In many parts of the areas, Mississipian rocks are represented only by residual chert and soil. Certain cherts from each formation are sufficiently distinctive, however, so that gelogic contacts can be mapped even where bedrock exposures are scarce or nonexistent. Some intermediate varieties of chert are difficult to identify with certainty, and interbedding of lithologies near formational boundaries results in mixed suites of chert. Slumping of the residuum also adds to the difficulty of mapping, but in most parts of the areas residuum contacts can be supplemented with sufficient bedrock outcrops to provide a reasonably accurate map.

MAURY FORMATION

The Maury Formation is exposed only in the Lawrenceburg area, and there the unit is approximately 1½ feet thick. It consists of very shaly grayish-green siltstone and contains scattered phosphatic nodules near its base. The Maury is conformably overlain by the Fort Payne Chert.

FORT PAYNE CHERT

The Fort Payne Chert is widely exposed in the three areas, especially in the Lawrenceburg (pl. 1) and Waverly areas (pl. 2). For field purposes the Fort Payne is subdivided into three distinctive lithofacies (Marcher, 1962, p. 111–113) which include "bedded chert," "scraggy chert," and "shaly chert." All three of these lithofacies are found in the areas studied.

The bedded-chert lithofacies is well represented in both the Lawrenceburg and Waverly areas and, although it is mostly in the lower part of the Fort Payne, it is present throughout the formation. When fresh this type of rock consists mainly of dark very silty, slightly dolomitic, cherty limestone and highly calcareous siltstone. Chert, which occurs in beds 1 to 8 inches thick, is very dense, dark, and brittle. When weathered this lithofacies is represented by layers of buff punky chert separated by seams of tripolitic clay and siliceous shale.

Scraggy chert is well exposed along State Highway 13 between Pumpkin Creek and Blue Creek in the Waverly area, in the northern part of the Lawrenceburg area, and along Piney River in the southwestern part of the Dickson area (pl. 3). This lithology consists of very rough, irregular plates and chips of chert in a matrix of fine-grained very silty and siliceous limestone (pl. 4). Both chert and limestone are dark-yellowish-brown, but locally the chert is darker than the matrix. When fresh, the rock resembles massive coarse-grained limestone; but as the lime is leached from the rock, the plates of chert stand out in relief so that from a distance the rock has a rather shaly appearance.

Shaly chert is best exposed in the Dickson area although it is present also in both the Waverly and Lawrenceburg areas. Typically the shaly-chert lithofacies of the Fort Payne is a highly calcareous, dolomitic, very cherty siltstone (pl. 4). When fresh, the rock is almost invariably some shade of brown such as pale- or dark-yellowish-brown. Fresh exposures in roadcuts show the rock to be rather massive, but as it weathers its inherent platy and shaly structure is emphasized. Most of the chert, which is extremely abundant in this lithofacies, is grayish brown to dusky brown, very hard, dense, and brittle. The chert occurs as rough irregularly shaped nodules or as fairly persistent beds 6 to 10 inches thick. Both chert and siltstone become soft and tripolitic when weathered, and because of its yellowish-brown or orange color, it is referred to frequently as "yellow rock." Small siliceous geodes 1 to 2 inches in diameter are common in the shaly facies of the Fort Payne. Fossils are rather rare in the shaly Fort Payne, but in roadcuts east of Will Hall Creek in the Dickson area and at a number of points in both the Lawrenceburg and Waverly areas, the rock contains an abundance of crinoid stems and large fragments of bryozoans.

In each of the three areas, the shaly facies of the Fort Payne contains massive beds of medium- to coarse-grained very silty fossil-fragmental limestone (pl. 4). Crinoids, bryozoans, brachiopods, and horn corals are common in these beds, especially in the Lawrenceburg area. The limestone usually ranges from light-olive-gray to dark-yellowish-brown, the latter color predominating in the siltier beds. Chert, which is locally abundant, is light colored, dense, and hard and consists largely of replaced fossils. This type of chert is very similar to that in the overlying Warsaw Limestone. The chert in the Warsaw, however, does not contain the great abundance of large crinoid columnals that are present in the chert derived from limestones in the Fort Payne.

In the Lawrenceburg area, green and bluish-green silty calcareous shale is associated with the fossil-fragmental limestone. In an abandoned quarry about 1 mile southwest of Lawrenceburg, dark-olive-brown shale is interbedded with the limestone.

No borings completely penetrate the Fort Payne Chert in the Dickson area, but in an oil-test well just south of the area, the formation is known to be 265 feet thick. In another oil-test well west of the Dickson area, the formation is only 56 feet thick. This unusual thinness reflects local thickening of the overlying Warsaw at the expense of the Fort Payne. In most of the Dickson area and adjacent areas, the Fort Payne is about 250 feet thick. Outcrops in the vicinity of Lawrenceburg indicate that the total thickness of the formation in that area is at least 250 feet and may be as much as 300 feet. A few miles northeast of Lawrenceburg, however, the formation thins to about 200 feet, as indicated by a driller's log of a water well. The thickness of the Fort Payne in the Waverly area is about 250 feet, as determined from a driller's log of a water well in the City of Waverly and by measurements of nearby surface outcrops.

Bedrock contacts between the Fort Payne Chert and the Warsaw Limestone are well exposed at a number of points in the Dickson area. Along Piney River and Jones Creek, the contact is very sharp and irregular (pl. 3). Along Jones Creek it is marked by a massive bed of porous fossiliferous chert of secondary origin. Bedding-plane seeps are common at the contact, and the irregularity probably is due to interstratal solution rather than to post-Fort Payne pre-Warsaw erosion. Along Beaverdam Creek in the east-central part of the Dickson area, the Fort Payne grades upward from typical siltstone into very silty Warsaw Limestone, and the contact is conformable.

WARSAW LIMESTONE

Bedrock outcrops of Warsaw Limestone are nonexistent in the Lawrenceburg and Waverly areas, and the formation is represented only by massive blocks and beds of porous fossiliferous chert and dark-red clayey soil.

Outcrops of Warsaw Limestone are present throughout much of the Dickson area (pl. 3). Some of the better and more extensive exposures are along Nails and Beaverdam Creeks in the southeastern part of the area and along West and East Piney Rivers in the western part.

In much of the Dickson area, the Warsaw is between 150 and 200 feet thick. Toward the south, however, it thins considerably and in the southwestern part of the area appears to be only about 100 feet thick. In this part of the area, weathering and slumping preclude accurate determination of the thickness. Furthermore, draping of the Tuscaloosa Gravel down valley walls makes it doubly difficult to pick the Warsaw-St. Louis contact with accuracy. Cuttings from an oil-test well about 1½ miles west of the area mapped indicate that the Warsaw is 310 feet thick. The cuttings appear to be badly mixed, however, and the upper 50 feet may be St. Louis Limestone. Thus, the total thickness of the Warsaw may be only 260 feet. This unusual thickness reflects thickening of the Warsaw at the expense of the Fort Payne Chert.

In the Dickson area the Warsaw is primarily a medium-grained to very coarse grained fossil-fragmental limestone (pl. 4). Colors range from pale yellowish brown to dark yellowish brown and light olive gray. Bedding is generally massive, although many beds weather platy or even shaly. Cross bedding is common, especially in the coarser grained layers. Stylolitic zones are locally well defined in many of the coarse-grained beds. Locally the Warsaw contains an abundance of light-colored dense fossiliferous chert which weathers to porous blocks 1 to 3 feet in diameter. Such chert beds are well exposed at the base of the formation in the eastern part of the Dickson area.

In some parts of the Dickson area, the Warsaw contains beds that are almost identical with the shaly facies of the Fort Payne. These beds consist of very cherty, calcareous, dolomitic siltstone or extremely silty limestone, and they contain numerous small siliceous geodes. Individual beds are usually thick and massive but, similar to those of the Fort Payne, they commonly weather shaly and platy.

On Baker Branch, in the east-central part of the Dickson area, typical coarse-grained fossil-fragmental limestone is interbedded with highly oolitic calcarenite and fine-grained very cherty siltstone.

This is the only known locality in the Dickson area where the Warsaw is oolitic, but the formation is known to contain oolitic zones elsewhere in the Western Highland Rim.

The contact between Warsaw and St. Louis bedrock is well exposed near the upper end of Bruce Hollow in the southwestern part of the Dickson area and at a number of localities in the south-central part of that area. At most of these localities the contact is sharp and irregular, but some of the irregularity, as in the Fort Payne–Warsaw contact, may be due to interstratal solution.

ST. LOUIS LIMESTONE

The St. Louis Limestone exposed in the Waverly and Lawrenceburg areas is represented only by residual chert and soil. In the Lawrenceburg area, residuum derived from the St. Louis is included in the Warsaw Limestone (pl. 1). In the Waverly area, the St. Louis residuum is approximately 80 feet thick.

Residuum derived from the St. Louis is present on most of the hills throughout the Dickson area and St. Louis bedrock is well exposed in the southwestern, northwestern, and south-central parts of the map (pl. 3).

The original thickness of the St. Louis in the Dickson area is unknown. The thickness of the residuum derived from the St. Louis, however, is more than 250 feet at a number of points in the area.

Along Yellow Creek in the northwestern corner of the Dickson area, the St. Louis is a fine- to coarse-grained fossil-fragmental limestone. Beds of semioolitic limestone and calcareous siltstone also are present. These beds range from pale to dark yellowish brown. *Lithostrotion proliferum*, considered to be a guide fossil to the St. Louis, is present at this locality.

In Bruce Hollow in the southwestern corner of the Dickson area, the St. Louis is mainly a fine-grained very silty dark-yellowish-brown limestone (pl. 4). There the formation also contains about 25 feet of coarse-grained silty olive-gray limestone. Both the fine- and coarse-grained beds contain an abundance of dense dark chert.

In the south-central part of the area and adjacent parts of the quadrangles to the south, the lower St. Louis beds consist of pale- to moderate-yellowish-brown calcareous siltstone as much as 30 feet thick. Locally these beds are extremely cherty. The siltstone is overlain by medium- to coarse-grained fossil-fragmental limestone very similar to the Warsaw. These beds differ from the Warsaw, however, in that they generally contain an abundance of silt and are more brownish.

Chert derived from the St. Louis is typically dark, very dense, hard, and brittle. The medium- to coarse-grained calcarenite, however, yields chert that is almost identical with that from much of the Warsaw.

At a number of points in the western part of the Dickson area, large blocks of very hard quartzitic chert 3 to 4 feet in diameter are scattered through the residuum. Presumably these rather unusual cherts are derived from the St. Louis Limestone although they have not been observed in place anywhere in the Western Highland Rim.

In many places in the mapped areas, the St. Louis residuum is characterized by round chert "cannonballs" 3 to 6 inches in diameter. The exterior of the "cannonballs" is usually weathered to a tripolitic material, but the interior, usually brownish black, is very dense and hard. Many "cannonballs" have concentric layering.

CRETACEOUS SYSTEM

TUSCALOOSA GRAVEL

Tuscaloosa Gravel in the Waverly and Lawrenceburg areas is found mixed with residuum in a few small widely scattered outcrops (pls. 1–3).

In the Dickson area, Tuscaloosa Gravel is well exposed in roadcuts on U.S. Highway 70 west of Dickson and on some of the ridges in the southwestern part of the area (pl. 3).

The thickness of the Tuscaloosa Gravel cannot be determined accurately because of slumping and mixing with residuum. In a gravel pit on U.S. Highway 70 about 4 miles west of Dickson, about 25 feet of Tuscaloosa is exposed. Farther west, in the Tennessee City quadrangle, about 40 feet of Tuscaloosa is exposed.

In the Dickson area and over most of the Western Highland Rim, the Tuscaloosa consists of an unsorted mixture of chert gravel, sand, silt, and clay. The chert gravel, largely derived from the Camden Chert of Devonian age or from the local Mississippian rocks, is composed of well-rounded fragments that range from one-fourth inch to 6 inches in diameter. The sand and silt fraction consists mainly of angular fragments of chert and some quartz. The clay fraction is made up of both kaolinite and montmorillonite; the kaolinite is most abundant (Marcher and Stearns, 1962, p. 1374).

At the previously mentioned gravel pit west of Dickson and in a number of roadcuts in the same general area, the Tuscaloosa consists of beds of well-sorted heavy-mineral-bearing quartz sand containing well-rounded pebbles of vein quartz. At the same locality the Tuscaloosa also contains beds of well-indurated siltstone or very fine grained sandstone mineralogically identical with the fine fraction of the main mass of Tuscaloosa. These siltstone beds contain poorly preserved fragmentary plant fossils which are the only fossils found thus far in the Tuscaloosa in Tennessee.

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QUATERNARY SYSTEM

TERRACE GRAVEL

Well-defined terraces along the Duck River in the Waverly area are capped with as much as 20 feet of poorly sorted water-worn chert gravel. Well-rounded pebbles of vein quartz and ironstone also are common. The size of particles ranges from silt to cobbles more than 1 foot in diameter. Except where highly weathered the terrace deposits have a characteristic reddish-brown color caused by iron staining. The color, abundance of quartz, rounded ironstone pebbles, and topographic position of the terrace gravel serve to distinguish it from the Tuscaloosa Gravel.

Terrace gravel is present at three levels along the Duck River (pl. 2). The lowest level is about 420 feet above sea level, the middle level about 500 feet above sea level, and the upper level about 600 feet above sea level. The 600- and 500-foot terraces are correlative in altitude with terraces along the Tennessee River which are believed to be of Pleistocene age (Wade, 1917, p. 71–74).

ALLUVIUM

The Duck River in the Waverly area and the Piney River in the Dickson area, as well as some of the larger creeks in all three areas studied, are bordered by flood plains underlain by deposits of silt, sand, and gravel of varying thickness. The pebbles in these relatively modern sediments are less rounded than those composing the older terrace deposits.

The alluvium is probably not more than 20 feet thick along the smaller streams, but it is known to be as much as 40 feet thick along the Duck River and 30 to 50 feet thick along Piney River.

GEOLOGIC STRUCTURE

The Lawrenceburg area lies on the southern flank of the Nashville dome. The strata underlying the area dip south-southwestward at an average rate of 15 feet per mile. The relative thinness of the Fort Payne Chert in the northeastern part of the area may be due to slight uplift of the dome during the deposition of the units. Dips of as much as 10° in the area are associated with small local structures.

In the Waverly area the rocks of Mississippian age dip northwestward at an average rate of 15 feet per mile. The regional dip is northward into the Tennessee lobe of the Illinois basin, but this attitude is not apparent in the Waverly area. Dips as great as 29° were measured in the area, but these are local exceptions. Near the confluence of Blue and Pumpkin Creeks, an exposure of a local angular unconformity in the Fort Payne Chert shows that the upper beds are dipping south-southwestward at 5° and that the lower beds are nearly horizontal.

In the three areas only one fault has been mapped, and that, southwest of Waverly in the vicinity of Cold Branch Bridge (pl. 2). Here the fault strikes N. 87° W. and closely parallels a segment of the valley of the Duck River. The dominant set of joints in the vicinity of the fault strikes N. 75°–85° W., and a minor set strikes N. 8°–15° E.

The rocks in the Dickson area dip gently toward the north, reflecting regional dip into the Tennessee lobe of the Illinois basin. The northeastern part of the area is dominated by a structural high (pl. 4) having approximately 150 feet of closure.

SUMMARY OF GEOLOGIC HISTORY

Prior to Mississippian time, the Western Highland Rim was primarily a submarine open shelf on which calcareous sediments and varying amounts of silt and clay were deposited. The area was intermittently exposed to subaerial erosion owing to positive structural movement of the Nashville dome. Erosion during these periods of uplift resulted in some formations being partly stripped away before the succeeding sediments were deposited.

During Early Mississippian time, the Tennessee lobe of the Illinois basin was depressed; and silty, siliceous, calcareous ooze, now composing the Fort Payne Chert, was deposited. From its lithology and fossil content, the Fort Payne is interpreted as having been deposited in deep tranquil water. Areas of shallow water where various marine organisms, particularly crinoids, could thrive were present locally, and large crinoidal bioherms or reefs formed. Erosion of the reefs resulted in the winnowing and abrasion of the fossil fragments and the accumulation of coarse-grained fossil-fragmental limestone.

Gradual cessation of subsidence, perhaps coupled with filling of the basin, produced an open-shelf shoal environment in which sediments now composing the Warsaw Limestone accumulated. This environment was characterized by warm, shallow, turbulent water in which various marine organisms were abundant. The sea in which the Warsaw was deposited had local areas of deeper, quieter water, and in these areas highly calcareous siltstone was deposited.

Shoal conditions, like those in which the Warsaw was deposited, continued to exist during the deposition of the St. Louis Limestone. Again local areas on the shelf were sites of deposition of calcareous siltstone.

The record of post-St. Louis Mississippian deposition is very meager. From the presence of scattered remnants of Ste. Genevieve Limestone and possibly Bethel Sandstone, it is inferred that these formations at one time may have covered part of or all the Western Highland Rim.

In the absence of any direct record, it is inferred that the Western Highland Rim was above sea level and subject to erosion until Late Cretaceous time. During Late Cretaceous, however, the Rim was mostly blanketed with gravel, sand, and clay that were derived mainly from the west and now constitute the Tuscaloosa Gravel. Paleogeographic reconstruction (Marcher, 1961, p. 90–93) suggests that the Dickson and Lawrenceburg areas were near the strand line during deposition of the Tuscaloosa. The unsorted chert gravel in the western part of the Dickson area is interpreted as being nonmarine, and the sand containing quartz pebbles and heavy minerals, as well as the plant-bearing siltstone, are believed to be at least partly marine.

Uplift of the Western Highland Rim during late Tertiary and Pleistocene time resulted in entrenchment of the larger streams and the local formation of terraces. This uplift also initiated the present cycle of erosion and the accompanying weathering and solution of limestones underlying the Highland Rim plateau.

GROUND WATER

SOURCE

Subsurface water in the areas studied is derived from precipitation falling on the immediate areas. Little, if any, ground water moves into the Western Highland Rim from adjacent areas. Weathering of the soluble carbonate rocks in the Western Highland Rim has produced a layer of residuum, commonly as much as 125 feet thick, which soaks up, stores, and eventually transmits the water to streams or to openings in the underlying bedrock.

The average annual precipitation in the Western Highland Rim is about 50 inches; hence approximately 2,600 acre-feet of water falls on each square mile segment of the Highland Rim each year. Part of this flows off almost immediately as surface runoff, and part percolates into the soil. The proportion of water entering the soil depends on the slope of the land surface, permeability of the soil, character and amount of vegetation, and climatic conditions. Precipitation entering the soil first replaces previously depleted soil moisture and is then evaporated or transpired by plants. Water entering the soil in excess of that needed to replace depleted soil moisture percolates downward through the soil and enters the zone of saturation.

During periods of no rainfall, streams draining the Western Highland Rim are maintained entirely by ground water. This fact, coupled with measurements of streams draining parts of the areas studied or nearby geologically and topographically similar areas, provide a means of estimating the minimum amount of recharge for a given period. These estimates range from about 1.5 inches in the drainage basin of Trace Creek in 1932 to nearly 5 inches in the basin of Piney River in 1960. It must be emphasized that these are minimum estimates, and the actual amount of annual recharge may be several times greater. A further discussion of the amounts of recharge in the individual areas is given in the sections on the hydrology of those areas.

OCCURRENCE

In the Dickson, Lawrenceburg, and Waverly areas, most ground water is obtained from bedrock, zones of chert concentration at the bedrock-residuum contact, and gravel stringers in the residuum (fig. 3). Springs also are major sources of ground water and constitute the largest undeveloped potential source in the Highland Rim. Although the water-yielding properties of the alluvium are not known at present, it also is a possible source of large ground-water supplies along the larger streams of the areas.

Where water-bearing beds are overlain by beds of lower permeability, the water is free to move laterally but not vertically. Because the water is confined and under pressure, it will rise above the level at which it is penetrated in a well. The height to which the water will rise in a well depends on the amount of pressure, which, in turn, depends on the height at which the water enters the aquifer.

By definition, artesian water is ground water that is under sufficient pressure to rise above the level at which it is tapped in a well, but it does not necessarily rise to or above the land surface (Sayre, 1936, p. 33). On the basis of this definition, ground water in limestones underlying the Western Highland Rim occurs under artesian conditions in most places. In the areas studied, many wells penetrate considerable thicknesses of bedrock or residuum before reaching a water-bearing zone, and the water from these zones invariably rises a few feet in these wells. Generally water in the bedrock rises to near the top of bedrock. Water from permeable zones at or near the bedrock-residuum contact rises variable distances which are perhaps related to the height of nearby bedrock highs.

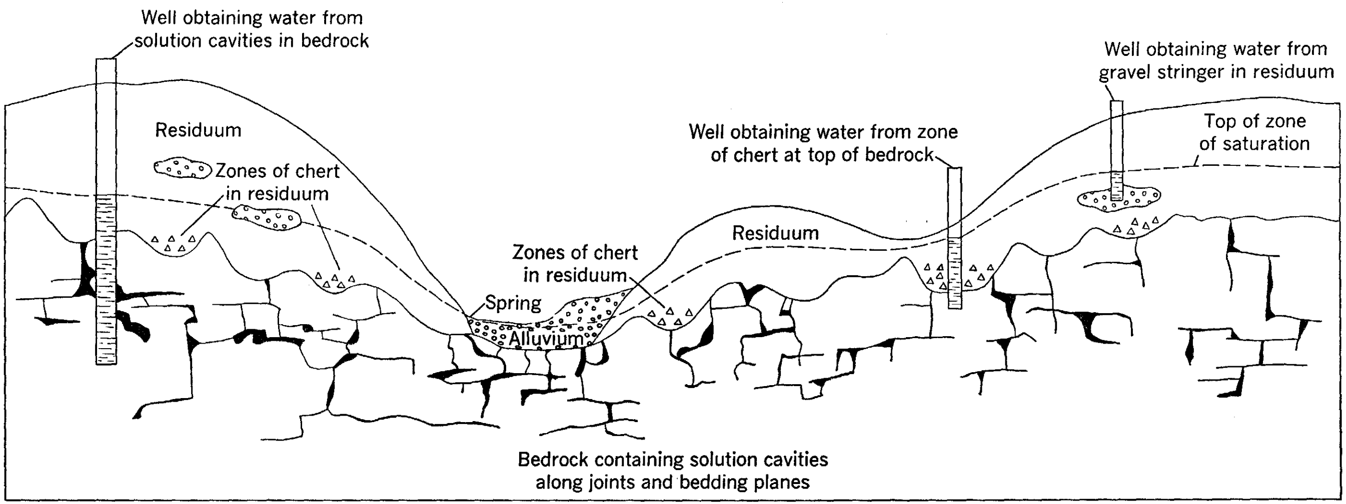

FIGURE 3.—Schematic diagram illustrating occurrence of ground water in the Western Highland Rim.

The degree of hydraulic interconnection between the bedrock and the overlying residuum apparently varies in different areas, depending on the local differences in permeability of the two aquifers. Water-level data suggest that in some parts of the Dickson and Lawrenceburg areas the bedrock and residuum are hydraulically semi-independent. For example, water levels in wells in residuum generally stand slightly higher than do those in wells in bedrock, even where the two types of aquifers are in similar topographic positions. In addition, water-level fluctuations in wells obtaining water from bedrock generally are smaller than those in wells obtaining water from residuum, thus indicating that the storage capacity of the bedrock is less than that of the residuum. Finally, in several pairs of closely adjacent wells which obtain water from different aquifers, the water level in the well in residuum invariably stands a few inches to as much as 3 feet higher than that in a well in bedrock.

Water-level measurements in both bedrock and residuum wells were used in preparing the composite water-level contour maps of the three areas studied (pls. 5, 6, 7). Although the bedrock and residuum may be hydraulically semi-independent, water levels in the two aquifers rarely differ as much as 3 feet, which is well within the limits of standard map accuracy. Furthermore, the maps are intended only to show the general pattern of ground-water levels and their relationship to topography, areas of recharge and discharge, and the general direction of ground-water movement and not the exact altitude of the water level at any given point other than that measured in wells.

MOVEMENT OF GROUND WATER

TOPOGRAPHIC CONTROL

The general direction of ground-water movement is from points of recharge to points of discharge. As indicated by the water-level contour maps, the main areas of recharge are the residuum blanketed uplands. Water entering the residuum moves downward where it can enter the bedrock or flow along the bedrock-residuum contact. In either place the dominant direction of movement is laterally toward the valleys where it is discharged through springs or by seepage into streams. Subsurface sapping under valley walls and floors indicate greater development of solution openings in these areas. For example, subsurface sapping probably is responsible for the formation of as much as 115 feet of residuum in the valley of Trace Creek in the Waverly area. This thick highly permeable zone is an excellent aquifer yielding as much as 300 gpm (gallons per minute) to individual wells.

GEOLOGIC CONTROL

The lithologic character and structural attitude of the rocks control the development of solution passages and thus the movement of ground water. Tilted rocks facilitate the entry of water by exposing numerous bedding planes and partings along which water can move downdip for considerable distances.

Beds of differing permeability in the various formations also control the movement of ground water. For example, in the Dickson area the Warsaw Limestone contains beds of cherty siltstone which are much less permeable and soluble than underlying or overlying beds, and springs and seeps are common at the top or bottom of these cherty beds.

Beds of chert also may localize and control the movement of ground water. In a number of wells in the Dickson area, water is reported to come from just above or below a layer of chert.

MOVEMENT IN LIMESTONE

The original porosity, or percentage of open pore spaces, of limestone depends mainly on its mode of origin. Limestone precipiated from sea water is usually dense and fine grained and has a very low porosity. On the other hand, calcarenite—limestone which was deposited as sand-sized particles of fossils or of preexisting rock—may have a high original porosity. Postdepositional cementation and recrystallization may reduce the porosity considerably. Most of the pores remaining open are too small and too poorly interconnected to transmit water freely.

Limestones are brittle rocks and postdepositional structural movements cause them to break along numerous fracture planes or joints. Joints are particularly significant in that they permit more rapid vertical movement of ground water. However, joints are relatively insignificant as sources of water to wells because they are vertical, or nearly so, and the likelihood of a well striking such a vertical crevice is very small.

Original openings in the form of bedding planes or partings between the rock layers are of great significance because they transmit water laterally and because they are the main sources of water obtained from wells drilled into bedrock. However, the importance of both bedding planes and joints as means of transmitting water depends largely on the degree of solution that has taken place along their walls.

Although limestone is nearly insoluble in pure water, it is readily dissolved by water containing only small amounts of acids. Water seeping through soil and residuum picks up carbon dioxide and forms carbonic acid. Additional amounts of organic acid derived from decaying vegetation are absorbed by the water. The total amount of acid in solution is small and the rate at which it dissolves the limestones is very slow, but in the leisurely course of geologic time the total volume of rock dissolved is great.

Water moving downward through the residuum eventually reaches bedrock and because of the bedrock's low permeability, flows laterally along the bedrock-residuum contact. Solution during lateral movement of the ground water dissolves deep and irregular channels on the top of the bedrock and leaves irregularly spaced pinnacles protruding upward into the residuum. Continued solution at the base of the pinnacles may completely remove the lower part, leaving boulders of limestone "floating" in the residuum. The insoluble components of the limestone, such as chert and clay, are also left behind.

In moving laterally along the bedrock-residuum contact, the water enters joints, bedding planes, fractures, and other openings and enlarges them by solution. The result is an irregular network of openings of various sizes and shapes that extend both vertically and laterally. The depth to which this network can and does occur is limited only by the depth at which ground-water circulation can take place. Analysis of data from 75 wells penetrating bedrock in the Dickson area shows that 25 percent of the wells reach water-bearing crevices above a depth of 115 feet, 50 percent above a depth of 162 feet, and 75 percent above a depth of 204 feet. One of the deeper wells in the Dickson area penetrated a water-bearing zone, presumably a solution opening, at a depth of 349 feet.

An additional influential factor in the formation of solution openings is the volume of water and the rate of its movement through the rock. If other factors are equal, more and larger solution passages are formed where the volume and movement of the water is greatest—that is, in the valleys. Thus the resulting pattern of solution passages is more or less adjusted to the topography. That the greatest amount of solution takes place beneath the valley walls and floors is shown by the close relation between geologic structure and surface drainage in some parts of the Western Highland Rim. In Wayne County, for example, most of the streams occupy synclines, and the uplands are underlain by anticlines (Miser, 1921, pl. 1). White (1960, p. 2029) summarized evidence which strongly suggests that these synclines may be the result of subsurface sapping beneath the valley floors rather than of structural warping.

MOVEMENT IN CHERT

Except for bedding planes and partings between the rock layers, chert is essentially devoid of original porosity. Because of its brittleness, however, chert is subject to fracturing during structural movements, and these fractures are the main avenues through which water enters and is transmitted.

In cherty formations that are calcareous, such as the Fort Payne of the Western Highland Rim, leaching and solution of the rock plays a leading role in creating secondary permeability. In cuts on U.S. Highway 70 near the east edge of the Dickson area, the Fort Payne is completely weathered to a platy or shaly, very cherty siltstone. The maximum depth to which this completely leached zone extends is not known, but cuttings from a water well in the northeast part of the Dickson area show that the rock contains leached zones nearly 100 feet below the land surface. These leached zones may be significant sources of water to wells in local areas.

MOVEMENT IN RESIDUUM

Movement of ground water in residuum probably takes place by slow seepage except in local areas where chert particles rather than clay are the main component of the rock. Locally, thin beds of chert fragments derived by weathering of the underlying limestone, and containing little clay, occur at the residuum-bedrock contact. The origin of these beds is not fully understood, but one possible explanation is that some of the fine clay particles may have been washed away by the lateral movement of ground water along the top of the bedrock.

Stringers of chert and quartz gravel in the residuum above the top of bedrock may serve locally as good aquifers for small supplies of water. These stringers apparently represent fillings of solution channels in limestone which has since decomposed.

QUALITY OF WATER

All ground water contains substances dissoved from air, soil, and rock. The amount of these substances is related to their solubility, the temperature and chemical character of the water, and the length of time the water is in contact with the air, soil, or rock. High concentrations of dissolved substances may restrict the use of ground water for domestic and industrial purposes. In general, the dissolved-solids content of ground water increases with depth in the Western Highland Rim; and even at shallow depths, where the water has been in contact with the Chattanooga Shale, sulfide content may restrict the water's use for most purposes.

Standards for drinking water used on interstate-commerce carriers have been established by the U.S. Public Health Service (1962, p. 2154). Although, except for fluorides, these standards are not mandatory even on common carriers, they are generally accepted as a basis for evaluating drinking-water supplies. The standards for some of the chemical constituents are given in the following table:

Constituent	*Maximum concentration recommended (ppm)*
Iron	0.3
Manganese	.05
Sulfate	250
Chloride	250
Fluoride	1.5
Dissolved solids	[1] 500

[1] 1,000 ppm may be permitted if water of better quality is not available.

HARDNESS

Calcium and magnesium are the principal alkaline earth elements in natural water. Hard water is objectionable because of its scale-forming properties and because it necessitates the use of large amounts of soap. Water having a hardness of less than 60 ppm (parts per million) is considered to be soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; and more than 180 ppm, very hard.

Hardness is one of the more significant and restrictive characteristics of ground water in the Highland Rim. Of the 19 samples of water from wells that were analyzed for this study (table 1), 3 are classed as soft, 5 as moderately hard, 5 as hard, and 6 as very hard. As shown in table 1, hardness of ground water from both the Fort Payne Chert and the residuum is extremely variable, although, in general, ground water from the residuum is usually softer. However, high hardness of some samples from residuum suggests that the water has been in contact with bedrock. Water from unweathered limestone generally is harder than that from residuum.

HYDROGEN ION CONCENTRATION

The pH, or hydrogen ion concentration, is a measure of the acidity or alkalinity of the ground water. Water having a pH of 7 is neutral; progressive values above 7 indicate increasing alkalinity and progressive values below 7 indicate increasing acidity.

Field and laboratory determinations of pH show that the pH value of water from residuum ranges from 6.0 to 7.5 and, in general, increases as the hardness increases. (See table 1.) The pH of water from the Warsaw and St. Louis Limestones has about the same range of values as does that from residuum. However, of 33 samples tested, only 6 had a pH lower than 7. Water from the Fort Payne Chert tends to have a consistently high pH; of 34 samples tested, only 2 had a pH of 7 or lower, but none had a pH higher than 7.8.

TABLE 1.—*Chemical analyses of ground water from Dickson, Lawrenceburg, and Waverly areas*

[Results in parts per million. All analyses made by the U.S. Geol. Survey]

Analysis [1]	Owner or name	Depth of well (feet)	Date of collection	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (NCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Ph	Geologic source of water
														Noncarbonate	Total		
1	J. M. Mobbs	105	10-23-59	0.06	2.7	1.8	2.4	0.4	10	0.4	4	7.4	36	6	14	6.3	Residuum.
2	E. Cross	66	do	.04	14	1.2	1.1	.1	43	1.2	2.5	4.8	56	0	39	6.9	Do.
3	A. Grice	150	6- 8-60	.09	32	4.1	1.9	.2	112	1.9	1.0	.2	107	4	96	7.1	Do.
4	C. Griffin	34	do	.40	31	5.4	1.8	1.3	112	5.2	2.0	1.1	112	7	99	7.1	Do.
5	T. L. Simms	63	10-23-59	.06	36	8.5	1.4	.8	144	1.2	3.0	4.0	139	8	126	7.5	Do.
6	W. Law	75	6- 8-60	.12	49	3.4	1.8	.1	160	1.4	2.0	.8	144	4	136	7.2	Do.
7	R. Spann	128	do	.07	53	4.9	1.7	.2	184	1.3	1.0	0	161	1	152	7.5	Do.
8	O. W. Fielder	115	6- 9-60	.09	54	5.0	1.5	.2	186	.6	2.0	0	160	4	156	7.4	Do.
9	F. Parchment	200	6- 8-60	.67	34	5.6	4.1	.1	136	1.5	4.0	4.8	135	0	108	7.4	Warsaw or St. Louis Limestone.
10	Redden Spring	(Spring)	7- 7-60	0	41	5.5	1.5	.4	142	2.0	4.0	2.5	133	8	124	7.5	Do.
11	City of Dickson	(Spring)	do	0	49	6.2	1.6	.1	172	1.4	2.0	.7	151	6	147	7.6	Do.
12	W. Jackson	(Spring)	6- 9-60	.06	55	6.4	1.5	.9	188	2.8	1.0	3.9	172	9	163	7.4	Do.
13	R. C. Brown	175	do	.72	65	4.7	3.2	.2	216	2.2	5.0	3.9	202	4	180	7.7	Do.
14	E. G. Baker	72	7- 7-60	0	68	4.4	2.4	.1	220	3.9	1.0	0	196	6	187	7.2	Do.
15	I. Armstrong	256	do	0	68	4.7	2.3	.1	226	1.1	2.0	1.7	199	4	189	7.4	Do.
16	J. Markus	71	10-23-59	.06	11	4.0	1.2	.1	46	.4	1.5	6.4	59	6	44	6.9	Fort Payne Chert.
17	C. R. Purcell	83	do	.04	29	5.3	1.6	.4	99	1.1	4.0	4.1	108	12	93	7.6	Do.
18	H. Oaks	120	do	.03	36	6.1	1.4	.3	130	1.7	2.5	4.1	128	9	116	7.6	Do.
19	W. C. Brown	102	6- 9-60	.02	53	12	3.7	1.0	208	1.2	6.0	6.4	195	12	182	7.3	Do.
20	L. Register	328	do	.43	47	22	1.9	.3	208	29	2.0	.3	220	36	206	7.8	Do.
21	I. Greer	217	do	.58	61	19	1.3	.3	270	12	1.0	2.5	238	10	232	7.6	Do.
22	D. Cooley	163	6- 8-60	.67	61	9.6	16	1.1	260	6.1	4.0	.1	238	0	192	7.7	Pre-Chattanooga formations.

[1] Analysis number is shown on plates 5, 6, and 7.

IRON

When present in concentrations greater than 0.3 ppm, iron and manganese can cause stains on laundry, enamel, and cooking utensils; in concentrations of 0.5 to 1.0 ppm, it can be tasted. Generally, water from formations underlying the Western Highland Rim has a low iron content. Of 115 samples analyzed, only 10 had an iron content greater than 0.3 ppm. Seventy-three samples had an iron content of 0.1 ppm or less.

DISSOLVED SOLIDS

Theoretically, dissolved solids are the anhydrous residues of the dissolved constituents, including any organic matter that may be present. Water containing less than 500 ppm of dissolved solids generally is satisfactory for most domestic and industrial uses. However, even though the total dissolved mineral content may be less than 500 ppm, the presence of iron or other undesirable constituents or excessive hardness may render the water unsuitable for some purposes.

The dissolved solids in ground water from the three areas studied ranged from 36 to 238 ppm. Generally, the dissolved-solids content is related to the depth from which the water is obtained—that is, the deeper the well the greater the likelihood that the water will have a higher dissolved-solids content. Locally, however, water associated with the Chattanooga Shale and formations immediately underlying it may have a high dissolved-solids content regardless of depth.

GENERAL CHARACTER OF GROUND WATER

Concentrations of chemical constituents in ground water may be expressed as equivalents per million or as parts per million. By converting parts per million to equivalents per million and plotting according to a method devised by Stiff (1951, p. 15, 16), the gross chemical characteristics of ground water can be compared visually (fig. 4). Diagrams of analyses of water samples from the areas studied show that the general character of the ground water from different water-bearing units varies considerably. Ground-water samples from the Fort Payne Chert and the overlying limestones generally are similar except in those areas where the Fort Payne is dolomitic, as in the Dickson area. Water obtained from dolomitic Fort Payne contains more magnesium and sulfate than does water from non-dolomitic beds. Thus, when analyses of water from these rocks are plotted, the cation curve is displaced to the left (fig. 4), and the anion curve is displaced to the right. The source of the sulfate may be gypsum and iron sulfide minerals which are common locally in the Fort Payne.

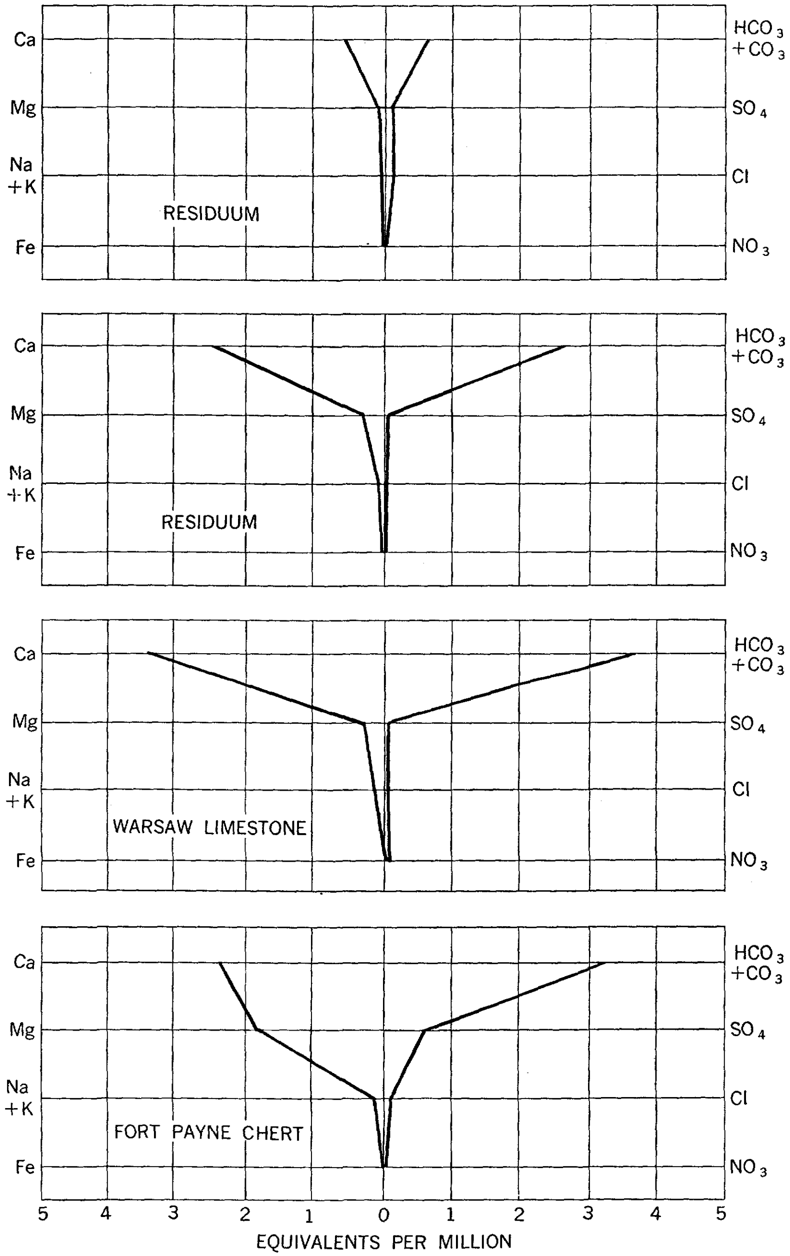

FIGURE 4.—Diagrams illustrating general chemical character of ground water in the Western Highland Rim.

The chemical pattern for ground water from the Warsaw Limestone is that of calcium bicarbonate water (fig. 4). It is generally consistent regardless of the depth of the well or even if the water issues from springs.

The pattern shown for ground water from residuum near the top of limestone is very similar to that for water from limestone (fig. 4) and indicates that the water has been in contact with limestone during its movement through the rock. The slightly lower calcium and bicarbonate contents indicate that the water from residuum was in contact with limestone for a shorter period of time than was the water from the bedrock.

Ground water from thoroughly leached residuum or from gravel stringers in the residuum has an even smaller calcium and bicarbonate content (fig. 4).

GROUND-WATER HYDROLOGY OF SELECTED AREAS

DICKSON AREA

LOCATION AND GENERAL FEATURES OF THE AREA

The Dickson area, as referred to in this report, covers about 118 square miles in the south-central part of Dickson County (fig. 5). Lying between lat 36°00′ and 36°07′30″ N. and long 87°15′ and 87°30′ W., the area is entirely within the Burns and Dickson 7½-minute quadrangles.

The city of Dickson (population 5,028 in 1960) is in the central part of the area and is about 40 miles west of Nashville.

The Dickson area is near the center of the Western Highland Rim plateau. Local relief is nearly 300 feet, and the maximum and minimum elevations in the area are about 960 and 560 feet, respectively. The drainage divide between the Tennessee and the Cumberland River basins trends northwestward across the area, forming a continuous rolling highland. Other nearly flat ridges divide the area into a number of smaller drainage basins. The generally accordant summits of these ridges are remnants of the former Highland Rim plain.

GEOLOGIC CONDITIONS RELATING TO GROUND-WATER OCCURRENCE

Except for small exposures of Tuscaloosa Gravel in the western part of the area and of alluvium along the stream valleys, formations of Mississippian age underlie the entire Dickson area (pl. 3). The uplands throughout the area are blanketed with as much as 125 feet of residuum derived from the Warsaw and St. Louis Limestones.

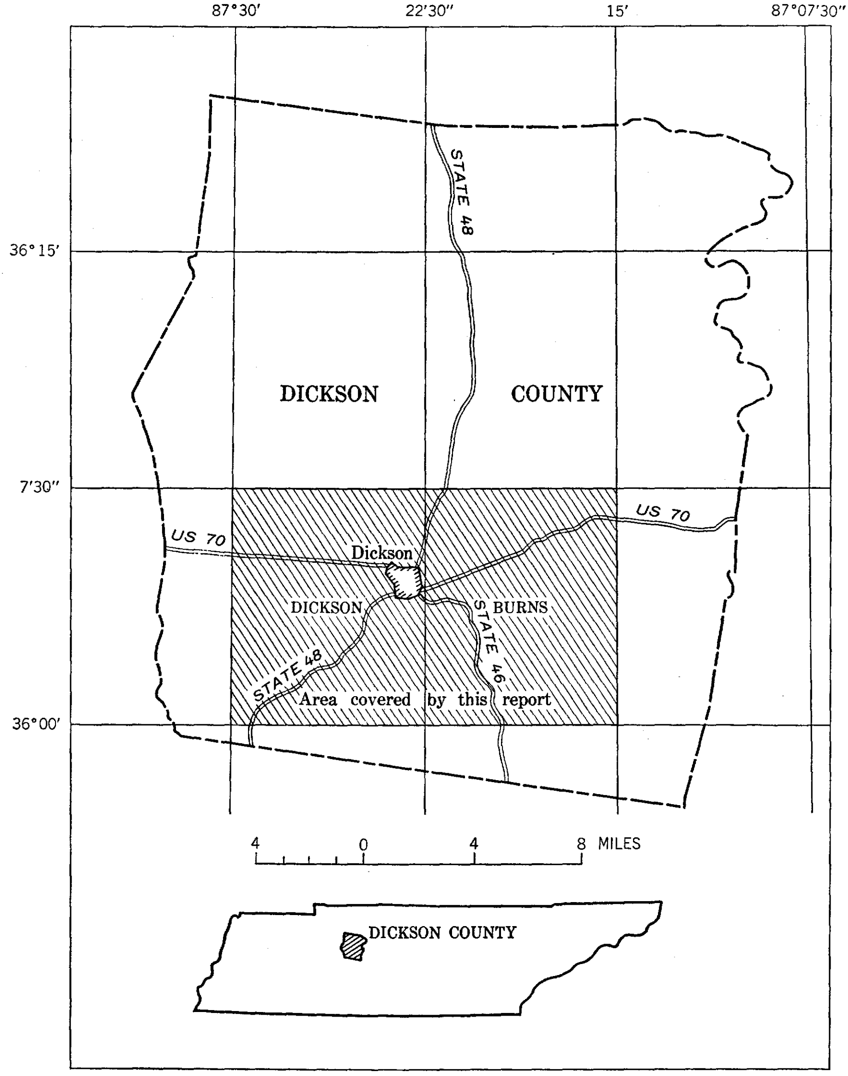

FIGURE 5.—Location of the Dickson area.

Most of the wells in the Dickson area (about 70 percent of those inventoried) obtain water from bedrock. Wells in bedrock are about evenly divided between Warsaw Limestone and Fort Payne Chert. About 20 percent of the wells obtain water from residuum at or near the top of bedrock. The formation of solution openings in the Warsaw and St. Louis Limestones is controlled in part by the presence of impermeable chert layers and beds of cherty siltstone. Beds of relatively soluble limestone in the Fort Payne may serve as water-bearers in some parts of the area, but most wells in the Fort Payne Chert apparently obtain water from weathered zones or from openings along bedding planes at depth.

Data collected from well owners and well drillers show that water generally can be obtained at depths of less than 300 feet. Presumably, water could be obtained from even greater depths in the western part of the area, but there is a definite possibility that such water may contain excessive amounts of dissolved minerals. In the eastern part of the area where the Fort Payne Chert is at or near the land surface, wells deeper than 300 feet or perhaps less would penetrate the Chattanooga Shale, which commonly yields highly mineralized water.

HYDROLOGIC CONDITIONS

During the study of the Dickson area, data on 115 wells and 12 springs were collected, and many of these data are incorporated in the hydrologic map (pl. 5). In addition the map shows contours on the water surface throughout the area. In most of the area the contours show the water levels accurately, but along the steep valley walls and narrow ridges it is impractical to draw the contours to fit the topography. In some parts of the area, therefore, the water level indicated by the contours may appear to stand above land level. Even if the contours were fitted accurately to the topography, the resulting pattern would be exceedingly intricate and would be difficult to interpret. Furthermore, the map would show little more than is intended to be shown by the contours as they are drawn.

RECHARGE

Estimates of the minimum amount of ground-water recharge in the Dickson area are based on rainfall records and on records of the minimum discharge of Piney River, a southward flowing tributary of Duck River which drains about one-half of the area. The drainage basin lying outside the Dickson area is geologically and topographically similar to that lying within the area. Hence it is assumed that the minimum amount of recharge over the entire drainage basin is of the same order of magnitude as that within the Dickson area.

On the basis of U.S. Weather Bureau records, total precipitation in the Piney River basin is estimated to have been about 40 inches during 1960, or about 10 inches less than the average precipitation in the Western Highland Rim region. Therefore, about 2,100 acre-feet of precipitation fell on each square mile of the Piney River basin. In 1960, minimum discharge of Piney River, which drains 193 square miles, was 68 cfs (cubic feet per second), all of which rep-

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resents water being discharged from the ground-water reservoir. If the minimum discharge of 68 cfs did not change throughout the year, then a total of 260 acre-feet of ground water was discharged from each square mile of the basin. This amount represents about 12 percent, or about 5 inches, of the total precipitation. Thus the minimum amount of recharge to the underground aquifers was about 5 inches, and the actual amount of recharge may have been considerably more. Furthermore, rainfall was deficient during 1960; so in a normal year the actual amount of recharge would be even greater.

As shown by the water-level contour map (pl. 5), the areas of recharge, which are areas of highest water levels, coincide closely with the major drainage divides. Because these drainage divides are nearly flat or rolling and are thickly blanketed with residuum, rain falling on the surface is retained long enough that a part can be absorbed by the soil and residuum. The thick layer of residuum soaks up, stores, and gradually releases the water to the rocks below or discharges it through springs.

DISCHARGE

The water-level contour map (pl. 5) shows that the water level is not a uniformly-sloping surface. Irregularities in the direction of movement and gradient are related to topography and to areas of recharge and discharge.

Ground water moves in the general direction of the slope of the water surface or at right angles to the contour lines. Thus from areas of recharge on the uplands, ground water moves downward and outward into the valleys. Where the slope of the land is steep or the permeability of the aquifer is greater than in other areas, the ground water moves more rapidly and the contours are closely spaced. Conversely, the spacing of the contours is wider in areas where the topography is nearly flat or where the aquifers have a lower permeability, thus slowing the movement of ground water.

In contrast to the upland areas of recharge, the valleys are areas of discharge from the ground-water reservoir. As previously stated, the flow of water from the ground-water reservoir maintains the flow of streams through the dry part of the year. Most of the natural discharge in the Dickson area is through springs which are common in all the valleys of the area. Discharge by pumping from wells is negligible and has no significant effect on the overall shape and slope of the water surface.

WATER-LEVEL FLUCTUATIONS

Long term records of water-level fluctuations in the Dickson area are not available. Figure 6, however, is a nearly continuous record

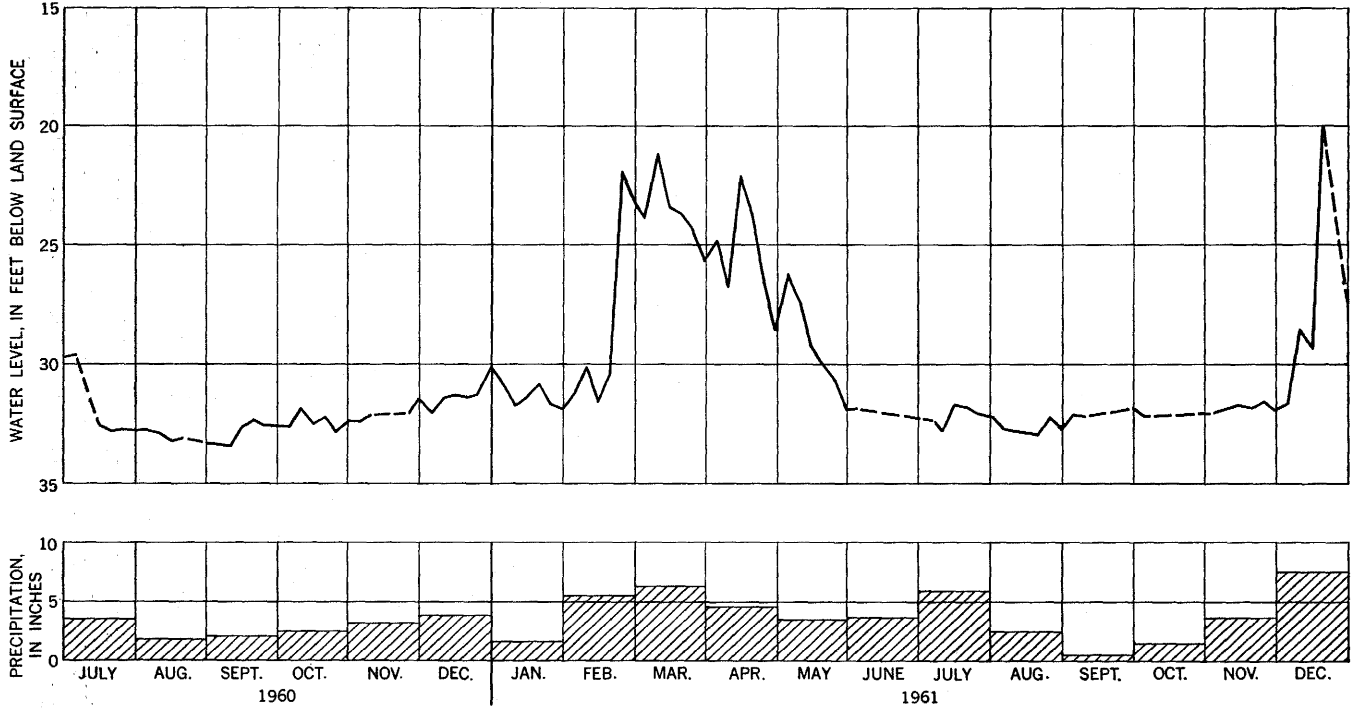

Figure 6.—Hydrograph of well Di: F–19 in Dickson, Dickson County, Tenn.

of water level in a well owned by the city of Dickson; the period covered is July 1, 1960, through December 1961. This graph shows seasonal fluctuations that are believed to be typical for the area. The hydrograph shows also a fairly close correlation between rainfall and the water level. During the drier parts of the year, the water level is low and fairly stable. Intermittent rains of an inch or so produce only a slight temporary rise in the water level. Major rises in water level shown by the hydrograph result from the cumulative effects of rainfall during the late winter and early spring rainy season.

YIELDS OF WELLS

Wells in the Dickson area are rarely tested to determine accurately their maximum yield. Reported yields commonly are based on 1-hour or shorter bailing tests made at the time the wells were drilled, so it is probable that, in some wells, use of larger pumps and adequate development would yield much more than the amount reported by the well owners or by well drillers. Although the reported yields vary greatly, about three-fourths of the wells inventoried for this study yield 10 gpm or less. Of 44 wells for which yield data are available, 2 yield less than 1 gpm, 32 yield from 1 to 10 gpm, 4 yield 10 to 20 gpm, and only 6 yield more than 20 gpm. The maximum reported yield is 70 gpm. Well data show that of the 15 wells which yield 10 gpm or more, only 3 are more than 200 feet deep. One of these, whose depth is 349 feet, obtains part of its water from a depth of 85 feet. The well data suggest that yields ranging from about 10 to 100 gpm are most likely to be obtained between depths of about 75 and 200 feet.

Most of the wells in the area which obtain water from residuum are shallow dug or bored wells equipped with hand buckets or pumps, and no information as to yield is available. The yield of most such wells probably is very small. Locally, drilled wells which obtain water from residuum at or near the top of bedrock may yield fairly large volumes of water. Of the 15 wells which yield 10 gpm or more, 5 are in residuum (pl. 5).

Yields of wells in bedrock are extremely variable, ranging from 0.3 gpm to as much as 70 gpm. Yields of wells in both the Fort Payne Chert and the Warsaw Limestone have about the same range of variability. The presence of springs that discharge several hundred gallons per minute from the Warsaw Limestone, and the general absence of such large springs in the Fort Payne, indicate that openings capable of transmitting large volumes of water are best formed in the Warsaw. With the limited data now available, it is impossible to predict where or at what depth such openings could be penetrated by wells.

SPRINGS

Springs are numerous in several parts of the Dickson area, especially along the Piney River and Nails Creek (pl. 5). They are sources of the water which helps to maintain the base flow of the perennial streams of the area, and through them most of the natural ground-water discharge takes place. Most of the larger springs—such as Fielder, Bruce, Hall, and Redden (pl. 5)—issue from several openings in alluvium and colluvium at the foot of hills where solution passages in bedrock discharge into the overlying material. Baker Spring and a number of small springs along Nails and Jones Creeks issue from openings along bedding planes in limestone which have been enlarged by solution. No springs of significant size have been observed issuing from joints. However, the location and size of solution-enlarged openings through which some springs emerge is in part controlled by joints.

Long term records are required to determine the average discharge or the ranges in yield of springs. The only spring for which more than one or two measurements are available is Fielder Spring in the southwestern part of the area (pl. 5). The discharge of Fielder Spring and the date of measurement are given below.

Based on the measurements made during 1952 and 1953, the average discharge was about 880 gpm. If the discharges determined during 1961 are included, the average discharge was about 950 gpm. The latter figure probably is more nearly correct. On the basis of these average discharges, Fielder Spring can be classed as a third-magnitude spring (Meinzer, 1923, p. 53).

Date of measurement	*Discharge (gpm)*	*Date of measurement*	*Discharge (gpm)*
8- 6-31	930	4-29-53	880
10-29-31	770	5-26-53	990
7-17-52	970	6-23-53	930
8-12-52	850	6- 2-54	870
9-23-52	840	7- 7-61	1,300
10-22-52	910	8- 9-61	1,400
11-20-52	770	9- 7-61	940
12- 8-52	730	10- 4-61	930
1-20-53	780	11- 2-61	820
2-24-53	890	12- 4-61	710
3-18-53	980		

Springs also can be classified according to their variability (Meinzer, 1923, p. 53)—that is, the ratio of the spring's fluctuation to its average discharge. Variability is expressed quantitatively by the formula $V=100\left(\frac{a-b}{c}\right)$ in which V is the variability, in percentage; a is the maximum discharge; b is the minimum discharge; and c is the average discharge. Although long-term records are essentail in determining the absolute variability of a spring, it is permissible to speak of the variability of a spring within a designated period. On this basis, Fielder Spring can be classified as subvariable (having a variability of more than 25 but not more than 100 percent) during the period 1952 to 1953 and during 1961.

Discharge measurements made of springs in August 1960 show that yields ranged from 50 to more than 1,000 gpm (pl. 5). Records of the U.S. Weather Bureau show that rainfall was deficient during the preceding month; hence the yields indicated on plate 5 may be less than the average for August.

WATER USE AND POTENTIAL DEVELOPMENT

At present (1960) the city of Dickson obtains its water supply from a spring-fed lake having a capacity of 65 million gallons. The amount of water supplied by the city to its customers in 1960 was about 375,000 gpd (gallons per day). This amounts to approximately 75 gpd (gallons per day) per person in the city of Dickson.

The amount of water discharged from the ground-water reservoir through wells is insignificant in comparison with the total amount of water available. The population of the Dickson area outside the limits of the municipal water supply is estimated to be about 4,500. Assuming that each person uses 50 gpd, the total amount used is about 225,000 gpd, most of which is derived from wells, although springs are commonly used for domestic purposes in some parts of the area.

Although at present there are no large capacity wells in the Dickson area, it is probable that wells having moderate yields could be developed in some parts of the area. Crevices in bedrock are almost invariably partly plugged with clay and sand-sized chert particles. Removal of these particles by well development enlarges the effective area drained by a well and may increase the yield considerably. One of the easiest methods of removing the fine particles from the crevices and one that has been used very effectively in some areas underlain by limestone aquifers is the step-pumping method. This consists of pumping a well at a given rate for several hours until the water has become clear. Then the rate of pumping is increased and continued until the water has again become clear. Periodic increase in the rate of pumping may be continued until the maximum yield is obtained. Other methods of developing wells include reaming, acidizing, dynamiting, and using dry ice or calgon. The method used should depend mainly on geologic conditions at the well site.

The largest potential source of ground water in the Dickson area is springs. On the basis of measurements made in August 1960, it is estimated that the seven largest springs in the area discharge a total of more than 4 million gpd. Water from springs has a low dissolved-solids content (between 124 and 163 ppm in three samples tested), is moderately hard to hard, and has a temperature of 55° to 60° F.

QUALITY OF WATER

The quality of water from formations underlying the Dickson area is generally good. During this study, samples of water from 76 wells were tested for hardness. Of these, 8 were soft, 27 were moderately hard, 31 were hard, and 10 were very hard. (See hardness classification, p. 23). The maximum hardness was about 1,030 ppm, the minimum was 34 ppm, the average was 152 ppm, and the median was 137 ppm. Of the same number of samples tested for pH, 20 had a pH of 7 or less, and the remainder from 7.0 to 7.8. Practically all the samples tested contained from 0.1 to 0.3 ppm iron, and only four samples contained 0.5 ppm or more.

"Sulfur" water was reported from two wells in the Dickson area. One of these, owned by the city of Dickson, apparently obtains water from, or near the top of, the Chattanooga Shale. The other well, in the east-central part of the area, is 96 feet deep and obtains water from very near the top of the Fort Payne Chert.

The overall quality of water from springs is about the same as that from wells, but, in general, the hardness and the dissolved-solids content of water issuing from springs in the Warsaw Limestone are slightly less than those of water from wells in the same formation.

LAWRENCEBURG AREA

LOCATION AND GENERAL FEATURES OF THE AREA

The Lawrenceburg area consists of the Lawrenceburg and Ethridge 7½-minute quadrangles in Lawrence County (fig. 7). The Ethridge quadrangle is directly north of the Lawrenceburg quadrangle, the two forming a north-south oriented rectangle of approximately 122 square miles. The area lies between lat 35°07′30″ and 35°22′30″ N. and long 87°15′ and 87°22′30″ W. The city of Lawrenceburg (population 8,042 in 1960) in near the center of the area studied.

The Lawrenceburg area is in the southwestern part of the Highland Rim of Tennessee. In this area the Highland Rim is a gently rolling to highly dissected plateau which has an average elevation of about 980 feet. The lowest and highest elevations in the area are approximately 680 and 1,040 feet, respectively, and the total relief is about 360 feet.

About 70 percent of the area is in a youthful to late youthful stage of physiographic development; it has a local relief of less than 60

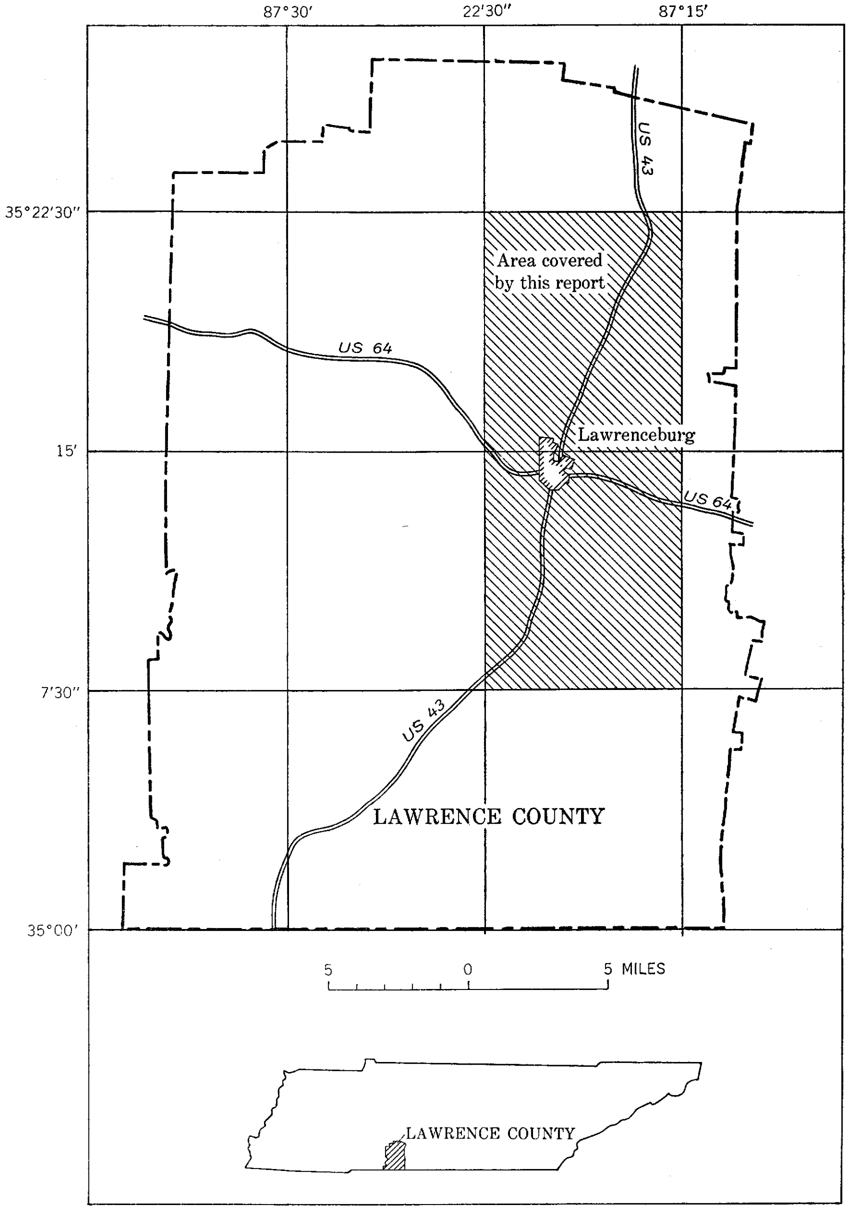

Figure 7.—Location of the Lawrenceburg area.

feet. Much of the Lawrenceburg area is submaturely dissected, having broad ridges separating the stream valleys. Along Shoal Creek the plateau is highly dissected, and the short tributaries of this creek have advanced headward, producing narrow sinuous ridges which rise from the creek and merge toward the relatively undissected plateau.

GEOLOGIC CONDITIONS RELATING TO GROUND-WATER OCCURRENCE

The Fort Payme Chert and residuum derived from it are the only hydrologically significant rock units in the Lawrenceburg area. Rocks older than Fort Payne Chert have limited surface expression, and no wells are known to have been drilled in the outcrop area of these formations; nor do any wells obtain potable water from these formations elsewhere in the area. The Chattanooga Shale acts as a barrier to the downward movement of water into underlying formations, and therefore there is little likelihood that significant quantities of water could be obtained from them. Furthermore, water which has been in contact with the Chattanooga Shale is commonly rather highly mineralized for most purposes.

Of the 63 wells inventoried for this study, 23 are known to obtain water from the Fort Payne Chert. Water in the Fort Payne occurs in solution channels and in weathered zones along bedding planes and fractures. Success in obtaining water from Fort Payne bedrock depends on intercepting one or more of these channels or zones. The chances of intercepting water-bearing channels or crevices decreases with depth. Of the 23 wells known to obtain water from bedrock in the area, 15 were drilled through less than 60 feet of bedrock. Six of the eight wells which penetrate more than 60 feet of bedrock before intercepting water-bearing cavities yield water high in sulfide. In the southern half of the area, all the producing wells inventoried reached water-bearing crevices before penetrating more than 50 feet of bedrock.

Residuum is composed chiefly of clay and silt and varying amounts of chert and gravel. Where it consists mainly of silt and clay, the residuum has a very low permeability and yields little or no water. Where large chert particles and gravel are concentrated in zones within the residuum, water moves freely. Discontinuous beds of cherty residuum containing little clay are common at the top of bedrock in some parts of the area. This is an important water-producing zone locally, as it yields water to 24 of the 63 drilled wells inventoried for this study.

Stringers of chert and quartz gravel enclosed in the residuum well above bedrock locally serve as good aquifers. These stringers represent fillings of solution channels by chert and quartz particles. Decomposition of the surrounding limestone has left the chert and quartz particles as narrow discontinuous stringers surrounded by residuum. Two wells inventoried for this study are known to obtain water from such stringers, and it is probable that 10 other wells drilled in the residuum also may obtain water from these stringers.

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HYDROLOGIC CONDITIONS

RECHARGE

Shoal Creek, a tributary of the Tennessee River, drains about one-half the Lawrenceburg area. The remainder is drained by tributaries of the Elk and Buffalo Rivers. Although the Lawrenceburg area differs topographically from much of the Shoal Creek drainage basin, estimates of the minimum amount of recharge in the Lawrenceburg area are based on minimum flow of that stream because no other data are available.

U.S. Weather Bureau records show that, in 1960, rainfall at Lawrenceburg, and presumably over the entire Shoal Creek basin, was about 46 inches. This amounts to about 2,400 acre-feet of rainfall per square mile per year. Minimum discharge of Shoal Creek, which has a drainage area of about 350 square miles, was 98 cfs on September 7 and 8, 1960. Assuming that the minimum discharge was not less than 98 cfs during the entire year, then a total of 200 acre-feet was discharged from each square mile in the basin during 1960. This means that a minimum of approximately 8 percent of the total rainfall, or about 4 inches, entered and left the ground-water reservoir over the entire drainage area of Shoal Creek. However, the Lawrenceburg area is less dissected than most of the Shoal Creek basin, and consequently the amount of recharge in that area may be somewhat greater.

In the Lawrenceburg area the main areas of recharge are the residuum-blanketed uplands, as indicated by the water-level contour map (pl. 6). Water levels stand highest in the northeast corner of the map area where the land surface reaches an elevation of 1,040 feet. Another ground-water high or area of recharge is just southeast of Lawrenceburg.

DISCHARGE

From the ground-water high in the northeast corner of the area, the water-level surface slopes northwest toward tributaries of the Buffalo River and southwest toward Shoal Creek, indicating that discharge is taking place in those areas. The slope of the water-level contours around the ground-water high southeast of Lawrenceburg indicates that ground water in this part of the area flows toward points of discharge along Shoal Creek on the west and along Sugar Creek on the southeast.

The area of low-ground-water level centered near Lawrenceburg (pl. 6) may be caused by discharge from Hope Spring, which furnishes the municipal water supply for Lawrenceburg. This ground-water low coincides generally with a slight structural sag (pl. 4), which may cause the water to flow into this part of the area from all sides except the west. Thus a direct relationship is indicated between geologic structure, the occurrence and location of Hope Spring, and the direction of ground-water movement and hydraulic gradient.

WATER-LEVEL FLUCTUATIONS

Figure 8, a hydrograph of a drilled well 227 feet deep in the Lawrenceburg area, is presented to show the control exerted by geology on water-level fluctuations. The well obtains water from Fort Payne Chert and pre-Chattanooga limestone; hence, during some parts of the year, the hydrograph is a composite of water levels from the two water-bearing units. From well data and the hydrograph, it is apparent that during the wet period of the year water is supplied to the well mainly by the Fort Payne Chert. During this period the water level responds quickly to short local rains. As the water level falls, however, the openings in the Fort Payne supplying the well are drained, and the water level is stabilized and maintained solely by inflow from pre-Chattanooga limestone. The stability of the water level from about the middle of July to about the end of October suggests that recharge to the pre-Chattanooga limestone is not affected by local rains and probably moves into the area from a considerable distance.

YIELDS OF WELLS

Yields of wells in the Lawrenceburg area range from less than 1 gpm to more than 35 gpm (pl. 6). These quantities, reported by well owners and drillers, generally are based on 1-hour bailing tests at the time the wells were drilled. Sustained yields may be somewhat less than those reported. Maximum yields of the larger capacity wells are rarely determined, and some wells may be capable of yielding considerably more water than is reported. Some wells in the Lawrenceburg area are perhaps capable of yielding 50 gpm or more, but bailing tests are not suitable for accurately measuring yields of this magnitude.

The average yield of all wells for which data are available is 10 gpm, and the average yield of wells deriving water from residuum is about 10 gpm. Analysis of well-yield data show that 40 percent of the wells in the Lawrenceburg area which yield 10 gpm or more obtain water for bedrock. The average yield of wells completed in bedrock is about 8 gpm, but this figure is greatly influenced by a few wells of relatively large yield.

Wells yielding moderately large supplies of ground water are rare in the Lawrenceburg area; however, moderately large supplies probably could be obtained in some parts of the area if wells are adequately developed by one of the procedures previously described.

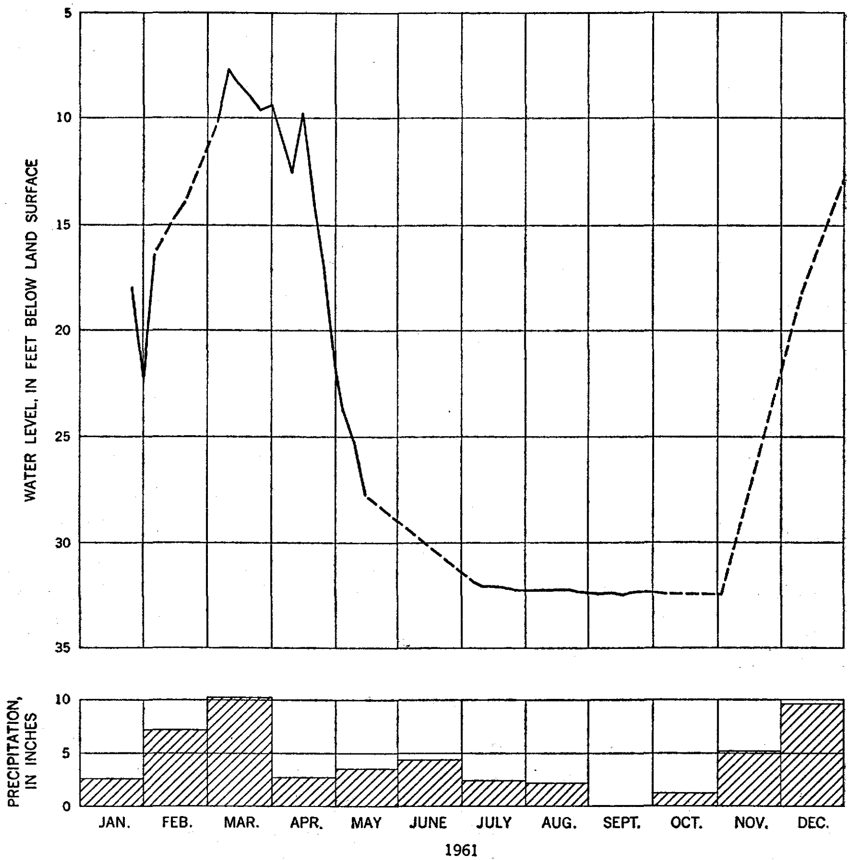

FIGURE 8.—Hydrograph of well Ln: N–39 near Lawrenceburg, Lawrence County, Tenn.

SPRINGS

Springs are common in the Lawrenceburg area, and many domestic water supplies are obtained from them. Most of the springs discharge from residuum or solution openings in the Fort Payne Chert in valleys (pl. 6). Many small springs and seeps in the valley of Shoal Creek are at the contact between the Chattanooga Shale and the overlying Fort Payne Chert. As far as is known, none of the springs along Shoal Creek are in use, and the water is probably rather highly mineralized because of its close association with the Chattanooga Shale.

QUALITY OF WATER

During this study, chemical analyses were made of samples of water from six wells in the Lawrenceburg area. In addition, the pH, hardness, and iron content of water from 23 wells were determined in the field. Many of these data are shown on plate 6.

Ground water in the Lawrenceburg area is soft to moderately hard. (See hardness classification, p. 23.) In general, water from the residuum is softer than that from bedrock. Water from the deeper wells in bedrock generally is harder than that from the shallower bedrock wells.

Of the 23 samples of water field tested for iron, only 2 contained more than 0.3 ppm, and both of these samples were taken from wells that obtain water from residuum.

Hydrogen sulfide, a gas that has a disagreeable odor and taste, is reported in water from some wells in the Lawrenceburg area. The presence of sulfide apparently is related to the depth at which the water is obtained. With increasing depth, circulation is restricted, and the water is in contact with the rock for a longer period of time. Thus, in theory, more mineral matter can be dissolved. Six wells in the area were reported to yield sulfide water. Four of these wells penetrated more than 80 feet of bedrock before obtaining water, and two wells penetrated 60 feet of bedrock before obtaining water. All these wells are in the central part of the area.

No complete analyses of water from springs in the Lawrenceburg area are available. Field tests show, however, that water from springs is moderately hard (60–120 ppm), has a pH of 6.5 to 7.3, and contains little iron.

WATER USE AND POTENTIAL DEVELOPMENT

The rural population of the Lawrenceburg area is estimated to be about 4,500. Assuming that each person uses 50 gpd, the total amount of water used outside the limits of the city water system is estimated to be about 220,000 gpd.

The municipal system of Lawrenceburg obtains water from Hope Spring and Shoal Creek just west of the city. The city water plant supplied approximately 1,700,000 gpd during the period June 1960 through June 1961. Of this amount, about 75 percent or about 1,300,000 gpd was obtained from Hope Spring. Approximately 70 percent of the total amount supplied by the city is for industrial use. Excluding water used for industry, the per capita use of water in Lawrenceburg is approximately 75 gpd.

As in the Dickson area, the largest potential source of ground water in the Lawrenceburg area is springs. Excluding Hope Spring, which is used by the city, six of the largest springs in the area (pl. 6) yield more than 3.5 million gpd. This estimate is based on measurements made during the months of October and December, the driest part of the year, and thus is considered to be conservative.

WAVERLY AREA

LOCATION AND GENERAL FEATURES OF THE AREA

The Waverly area is entirely within Humphreys County (fig. 9), in the west-central part of the Highland Rim plateau, and covers an area of about 60 square miles. The area lies between lat 36°00′ and 36°07′30″ N. and long 87°45′ and 87°52′30″ W. The city of Waverly (population 2,891 in 1960) is near the center of the area and is served by U.S. Highway 70 and State Highway 13.

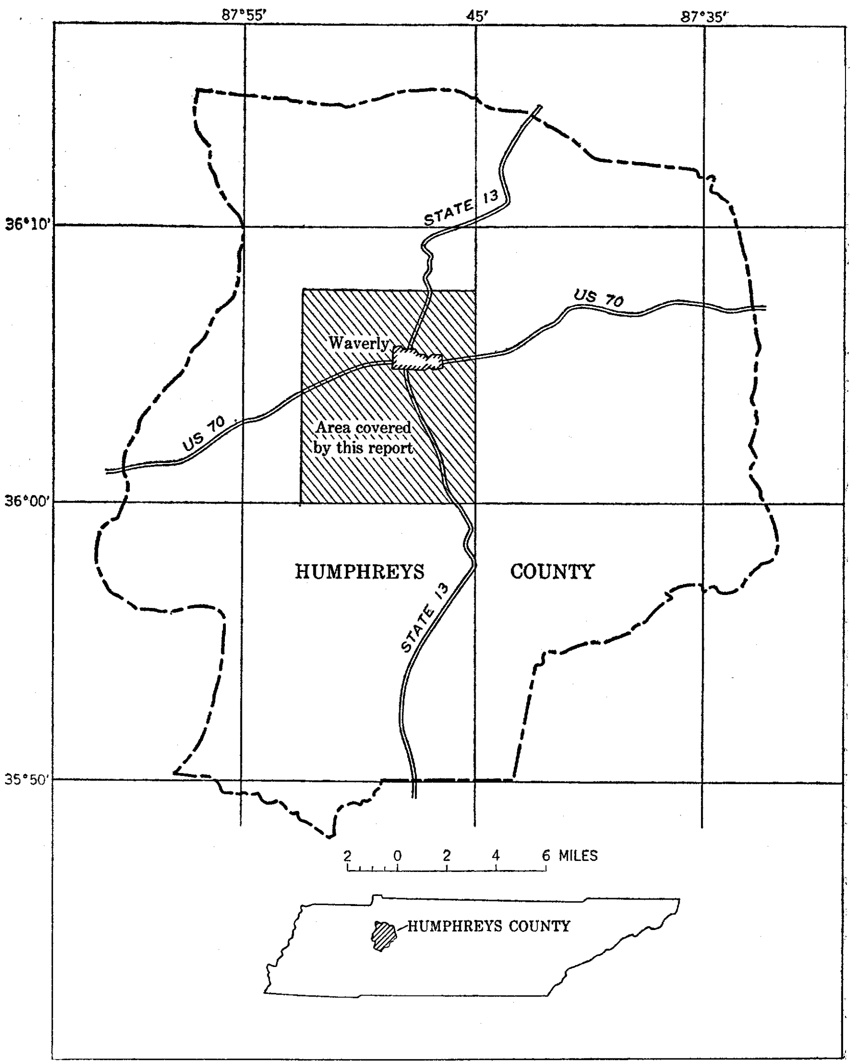

FIGURE 9.—Location of the Waverly area.

Except for the floodplains along the Duck River and its tributaries, the area is deeply dissected and rugged. Interstream areas are narrow though fairly level. The highest parts of the ridges are remnants of the Highland Rim plain.

Duck River, a major tributary of the Tennessee River, enters Kentucky Lake in the southwestern part of the area. The flood plain of the Duck River ranges in width from a few tenths of a mile to 1½ miles. Above the flood plain there are at least three terraces which indicate levels at which the river once flowed.

The total relief in the area is about 400 feet. The highest point, 760 feet above sea level, is on Stephany Ridge in the northeast corner of the quadrangle. The lowest point is 359 feet above sea level at the surface of Kentucky Lake. Local relief throughout most of the area is about 200 feet.

Approximately 60 percent of the area is drained by tributaries of the Duck River. The remaining part is drained by small streams such as Trace and Little Richland Creeks that flow directly into the Tennessee River.

GEOLOGIC CONDITIONS RELATING TO GROUND-WATER OCCURRENCE

Residuum derived from the Fort Payne Chert is the most widely used aquifer in the Waverly area. Weathering of the Fort Payne produces a layer of residuum and colluvium consisting largely of angular chert particles in a silty clay matrix. In the valley of Trace Creek, this zone of residuum and colluvium is known to be at least 115 feet thick and may be as much as 150 feet thick. Locally the residuum is highly permeable and is capable of yielding large amounts of water to wells. Three wells yielding 300 gpm each have been drilled into this aquifer in the immediate vicinity of Waverly.

Weathering of the scraggy-chert lithofacies of the Fort Payne produces residuum which locally serves as a good source of small to moderate supplies of water. Small to moderate supplies can also be obtained locally from near the bedrock-residuum contact, especially where the top of bedrock is more than 50 feet below the land surface.

Of the 46 wells inventoried for this study, probably less than 50 percent obtain all or most of their water from Fort Payne Chert bedrock. This percentage is not necessarily an indication of the potential of the Fort Payne as an aquifer, because in most places water in sufficient amounts for local needs is obtained from the overlying residuum. However, probably only small supplies of water can be obtained from wells which extend very far below the weathered zone.

The Warsaw and St. Louis Limestones are represented in the Waverly area only by residuum, which is limited to the highest ridges (pl. 2) and is not particularly significant as a source of water. Locally, however, the residuum contains stringers of chert gravel which may serve as aquifers. As in the Lawrenceburg area, these stringers represent fillings of solution channels in limestone which has since been decomposed by weathering. Similar gravel stringers also are known to occur in residuum derived from the Fort Payne Chert.

Although a few dug wells are known to obtain water from alluvium in the valleys of Trace, Blue, and Pumpkin Creeks, no information on the yields of these wells is available. However, small to moderate supplies probably could be derived from the alluvium, particularly in parts of Trace Creek valley where its thickness is as much as 20 feet and where the ground-water level remains near the land surface throughout the year.

The flood plain along the Duck River is subject to periodic flooding. For this reason, the alluvium, which is as much as 40 feet thick, has not been used as a source of ground water in that area.

HYDROLOGIC CONDITIONS

Because of extremely rugged topography in the Waverly area, the water-level contours shown on the hydrologic map (pl. 7) are necessarily highly generalized. The map is useful, however, in showing the general altitude and movement of ground water in the area.

RECHARGE

Although Trace Creek, a tributary of the Tennessee River, drains only about one-fourth of the Waverly area, discharge measurements made in 1932 and 1933 are used in estimating the amount of minimum recharge because no other data are available. However, the topography and geology of the Waverly area are nearly identical with that of the entire drainage basin, and it is believed that recharge within the area is of the same order of magnitude as that of the entire basin.

In 1932 and 1933, rainfall at Johnsonville, about 9 miles west of Waverly, was about 65 and 56 inches, respectively. Thus in 1932 the rainfall per square mile was 3,500 acre-feet, and in 1933 it was 3,000 acre-feet. In 1932 the minimum discharge of Trace Creek was 2.3 cfs; and if this rate continued throughout the year, about 80 acre-feet per square mile was discharged from the ground-water reservoir. In 1933, the minimum discharge was 2 cfs. Thus the amount of ground water discharge was about 70 acre-feet per square mile per year. In spite of the variation in rainfall, which amounted to 9 inches, the amount of ground-water runoff was about 2 percent of the total rainfall. Thus during 1932 and 1933 a minimum of between 1 and 2 inches of rainfall entered the aquifers as recharge.

The estimate of 1 to 2 inches of recharge is undoubtedly much too low because, although the topography is rugged and therefore conducive to a high proportion of surface runoff, the area is thickly blanketed with pervious residuum capable of absorbing and storing large amounts of water.

DISCHARGE

On May 12, 1960, the discharge of Trace Creek was measured at the east and west edges of the Waverly quadrangle. At the time of measurement there was no inflow from the small tributaries of Trace Creek along the reach measured, and, as there had been no precipitation for several days, the measured discharge was assumed to be derived entirely from ground-water storage. The discharge at the upstream measuring point was 6.2 cfs, and that at the downstream point was 12.7 cfs. The area of the Trace Creek drainage basin above the upstream measuring point is about 12,730 acres, and the area of the basin between the two measuring points is about 7,120 acres. The ratio of discharge to area drained at the upstream measuring point is about 0.5 cfs per 1,000 acres. The ratio of discharge to the area between the measuring points is 0.9 cfs per 1,000 acres. Thus the amount of ground water per 1,000 acres supplied to the stream from ground-water storage in the Waverly area is nearly twice that in the headwaters east of the area. As shown by the water-level contour map (pl. 7), ground water in the northern part of the area moves toward the valley of Trace Creek; there it is discharged from the residuum, colluvium, and alluvium that underlie the valley. This ground-water runoff constitutes a potential source of water that could be readily obtained by properly developed wells.

In the southern part of the area, ground water flows toward the valley of Blue Creek and thence southwest toward the valley of Duck River. Much of the subsurface flow may be discharging into the alluvium underlying the flood plain of the Duck River and into the river itself.

WATER-LEVEL FLUCTUATIONS

The hydrograph of a well 129 feet deep which obtains water from residuum in the valley of Trace Creek (fig. 10) shows that, although the water level in this well is affected by nearby pumpage, the major variations in depth to water are seasonal. During late winter and early spring when rainfall is heaviest and vegetation is dormant, the water level stands high. As the weather becomes

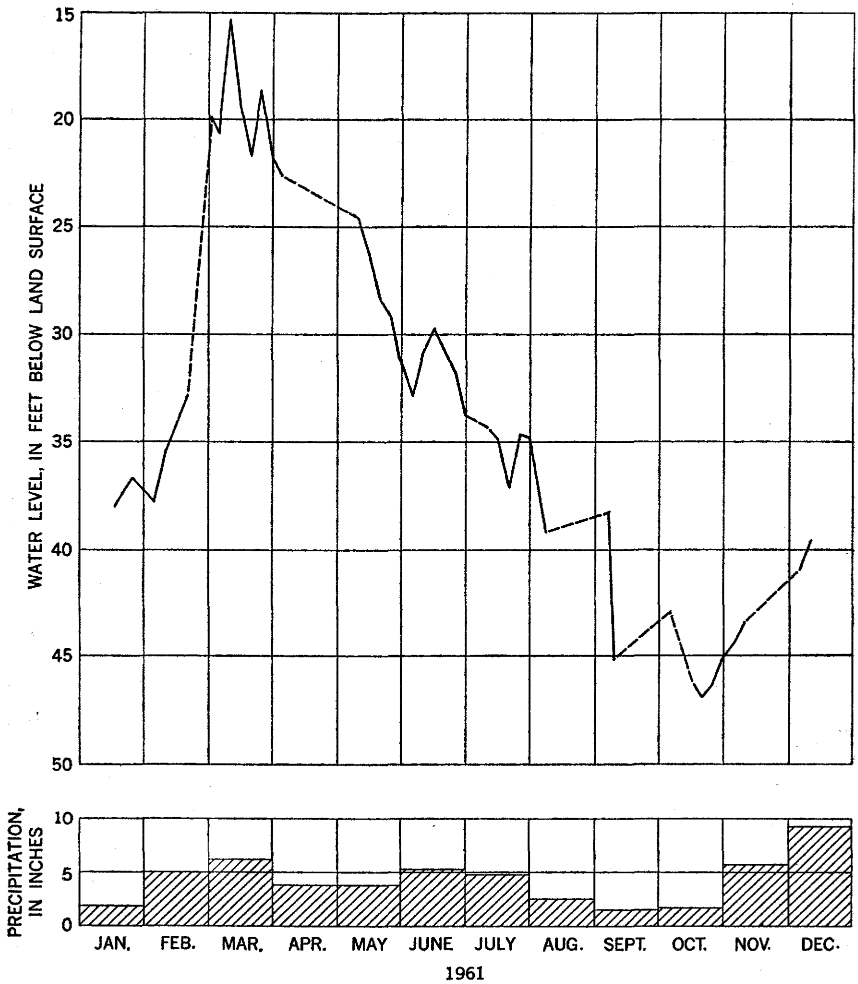

FIGURE 10.—Hydrograph of well Hs: J-47 obtaining water from residuum in the Waverly area.

warmer, evaporation and transpiration gradually increase, causing a corresponding decline in water level until a low is reached during the autumn dry season. During the summer and early fall, rainfall has little effect on the overall downward trend in depth to water.

In contrast to the water level of the well in residuum, which fluctuates widely, the water level in a well obtaining water from pre-Chattanooga limestone or chert is quite stable, as shown in figure 11. The total fluctuation in this well was less than 2 feet in 1961. This hydrograph also shows that major rises in the water level do not occur until several days after rainfall, suggesting that the aquifer tapped by the well is not recharged locally.

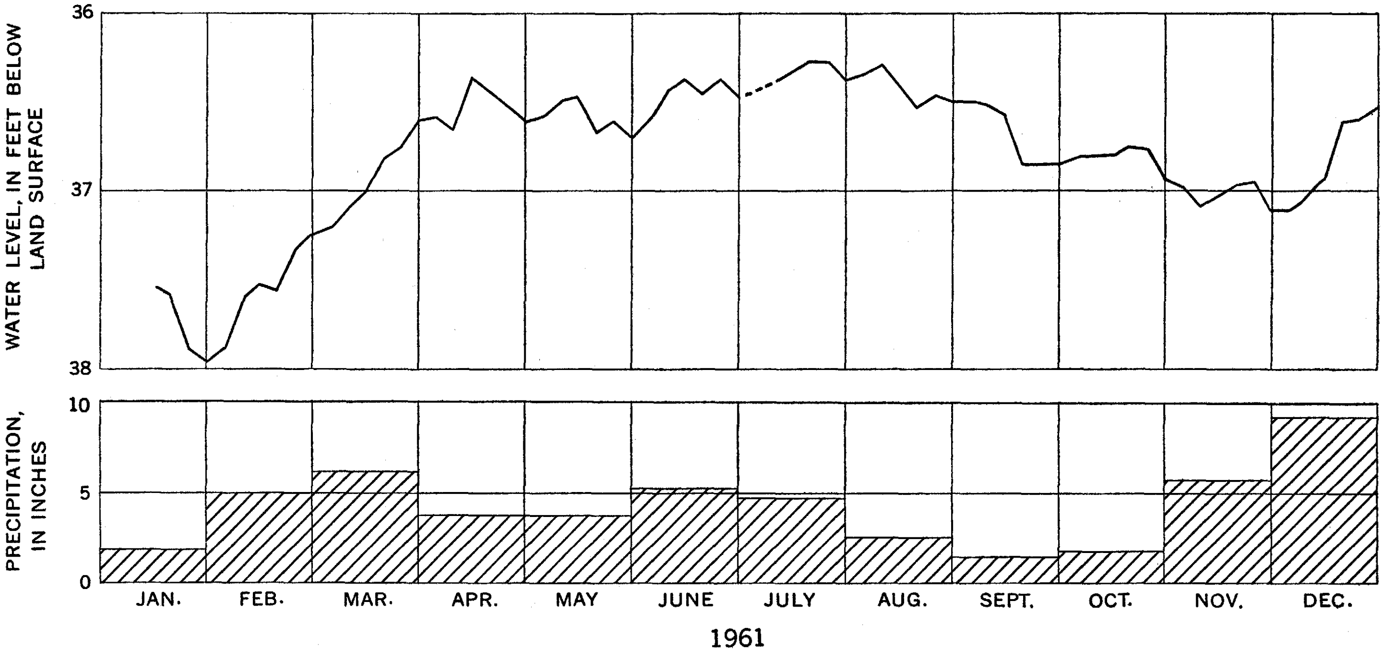

FIGURE 11.—Hydrograph of well Hs: J–33 obtaining water from pre-Mississippian limestone or chert in the Waverly area.

YIELDS OF WELLS

Accurate information as to the yields of wells in the Waverly area is scant because few wells have been tested adequately. Two municipal wells and one industrial well are reported to yield 300 gpm each from deposits underlying the valley of Trace Creek (pl. 7). Both municipal wells obtain water from the same two water-bearing zones at about 42 and 114 feet below the surface. The deeper water-bearing zone is near the top of the bedrock, which is reported to be at a depth of 124 feet. The industrial well is reported to obtain water from zones at 220 and 234 feet below the surface. The top of bedrock in this well is reported to be at a depth of 130 feet.

The specific capacity of one of the Waverly municipal wells was determined to be about 15 gpm per foot of drawdown when pumped for 5 hours at a rate of 300 gpm.

Most of the domestic wells in the area yield from 5 to 20 gpm (pl. 7). Excluding the high-yielding wells mentioned above, the average yield of 17 wells for which information is available is 13 gpm.

SPRINGS

Springs are common in the Waverly area, particularly along Blue Creek (pl. 7). Most of them discharge from colluvium at the edges of valleys, and only a few discharge directly from bedrock. The scarcity of springs in the valley of Trace Creek may be due to the fact that the bedrock is deeply buried by residuum, and the ground-water flow is directly through the residuum to the bed of the stream itself.

The largest spring in the area, Carnell Spring, has been measured periodically since August 1961. The dates of measurement and the amounts of discharge are given below.

Date of measurement	*Discharge (gpm)*
8-8-61	610
9-7-61	640
10-5-61	530
11-3-61	580
12-5-61	440

Based on these measurements, the average discharge of Carnell Spring was 560 gpm, and the spring can be classed as subvariable for the period of record.

QUALITY OF WATER

Ground water in the Waverly area ranges from soft to hard. The hardness and the number of samples in each category tested are given below:

Hardness (ppm)	*Number of samples*
0–60 (soft)	11
60–120 (moderately hard)	14
120–200 (hard)	6

The pH of water from wells field tested for this study ranged from 5.2 to 8.0, and the pH of water from springs in the area ranged from 7.0 to 7.2.

Dissolved iron ranged from 0.07 to 0.67 ppm in the samples analyzed. Forty-four percent of the water samples analyzed contained iron in quantities undesirable for some industrial uses. However, the relative ease with which iron can be removed from ground water would permit economical treatment and use for most purposes. Water from springs contained 0.10 ppm iron or less.

In four samples analyzed, sulfate ranged from 1.9 to 6.1 ppm. The water having the highest sulfate content was obtained from water-bearing zones beneath the Chattanooga Shale, and the relatively high sulfate content probably is due to the water having been in contact with that formation.

PRESENT AND POTENTIAL GROUND-WATER DEVELOPMENT

Ground-water use in the Waverly area is concentrated in and around the town of Waverly where about 300,000 gpd is pumped from two municipal wells 134 feet and 260 feet deep, respectively. The source of water in the suburban area beyond the municipal water lines is from drilled domestic wells, and in rural areas mostly from dug wells and springs.

The population of the rural area covered by this report is about 1,000. If the average rural per capita consumption is 50 gpd, the total amount of ground water used by rural residents is about 50,000 gpd. An unknown but perhaps significant quantity is used for livestock, irrigation of gardens, and minnow-rearing ponds.

The population supplied by the Waverly municipal water system is about 3,100, and the per capita consumption therefore is about 100 gpd. Since there is no qualification as to domestic and industrial or commercial use, this amount represents the total per capita use for all purposes. It is therefore somewhat higher than the per capita use determined for the Dickson and Lawrenceburg areas.

The most significant potential sources of ground water in the Waverly area are springs and the residuum and colluvium underlying the valley of Trace Creek. As previously stated, the yields of springs in the area range from about 100 to more than 600 gpm. Most of these springs are remote from the area where development of large water supplies is most likely to occur. Large water supplies probably can be obtained from residuum close to the city of

Waverly and adjacent to lines of transportation. Yields of as much as 500 gpm. and perhaps more could be obtained in this part of the area from properly drilled and adequately developed wells.

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