Geology and Ground-Water Resources of Bradley Calhoun, and Ouachita Counties, Arkansas

By DONALD R. ALBIN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF BRADLEY, CALHOUN, AND OUACHITA COUNTIES, ARKANSAS

By Donald R. Albin

ABSTRACT

Bradley, Calhoun, and Ouachita Counties comprise an area of approximately 2,000 square miles in south-central Arkansas. The area is in the Coastal Plain physiographic province, and is characterized by heavily timbered flatlands and low hills.

The geologic units at the surface in the counties are of Eocene, Pleistocene, and Recent age. Water for domestic and small-farm use can be obtained in and at short distances downdip from the outcrop areas of each of the formations. However, only the Sparta Sand, the Cockfield Formation, the terrace deposits, and the alluvium are major fresh-water aquifers.

The total ground-water use in the counties is approximately 6.1 mgd (million gallons per day). Of this total, about 5.0 mgd is withdrawn from the Sparta Sand, about 0.1 mgd is withdrawn from the Cockfield Formation, and about 1.0 mgd is withdrawn from the terrace deposits and alluvium. Most of the pumpage is concentrated in the vicinity of the major towns and cities. Each of the aquifers is capable of yielding larger quantities of water than presently are being withdrawn from them. However, in a small area near Camden the total pumpage from the Sparta Sand is almost the maximum sustained yield.

The ground water in Bradley, Calhoun, and Ouachita Counties primarily is of the sodium bicarbonate type. Water from the Sparta Sand and the Cockfield Formation is suitable for most municipal, industrial, agricultural, and domestic uses.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to describe the occurrence, availability, and quality of ground water in deposits of Tertiary and Quaternary age in Bradley, Calhoun, and Ouachita Counties. Records were made of 396 wells, water-level fluctuations were measured in 206 wells and water samples from 194 wells were chemically analyzed. Several maps and geologic sections are included to show the location of wells and test holes, the depth to the fresh water-brackish water contact, and the general geology and geologic structure of the area. Fieldwork for this report began in January 1958 and continued until June 1961. Test drilling in the area of this report was done primarily in November and December of 1958 and 1960. Electric logs of oil-test wells and lithologic logs of test holes and water wells have been used extensively in describing the geology of the counties.

Bradley, Calhoun, and Ouachita Counties comprise an area of approximately 2,000 square miles in south-central Arkansas (fig. 1). The area is in the Mississippi embayment part of the Coastal Plain physiographic province and is characterized by heavily timbered flatlands and low hills. The land surface generally slopes eastward away from the Fall Line. The highest altitude in the area is about 400 feet in western Ouachita County, and the lowest is about 65 feet near the junction of the Saline and Ouachita Rivers in southern Bradley County. The area is drained by the Ouachita River and its tributaries.

This report is one of a series of ground-water reports prepared by the U.S. Geological Survey in cooperation with the Arkansas Geological Commission. Areas where ground-water studies have been completed or are in progress are shown on figure 1.

Other more general reports giving information about ground water in Arkansas are Baker (1955), Hale and others (1947), Branner (1937), Stephenson and Crider (1916), and Veatch (1906).

LOCATION AND WELL-NUMBERING SYSTEM

The location and well-numbering system used in this report is based upon the Federal land-survey system as used in Arkansas. The component parts of a location or well number are the township number, the range number, the section number, and three lowercase letters that indicate, respectively, the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section in which the well or point of interest is located. The lowercase letters are assigned in counterclockwise order beginning with "a" in the northeast quarter. Serial numbers are appended where more than one well is located in a 10-acre tract. This system of locating and numbering wells and features of interest is illustrated in figure 2.

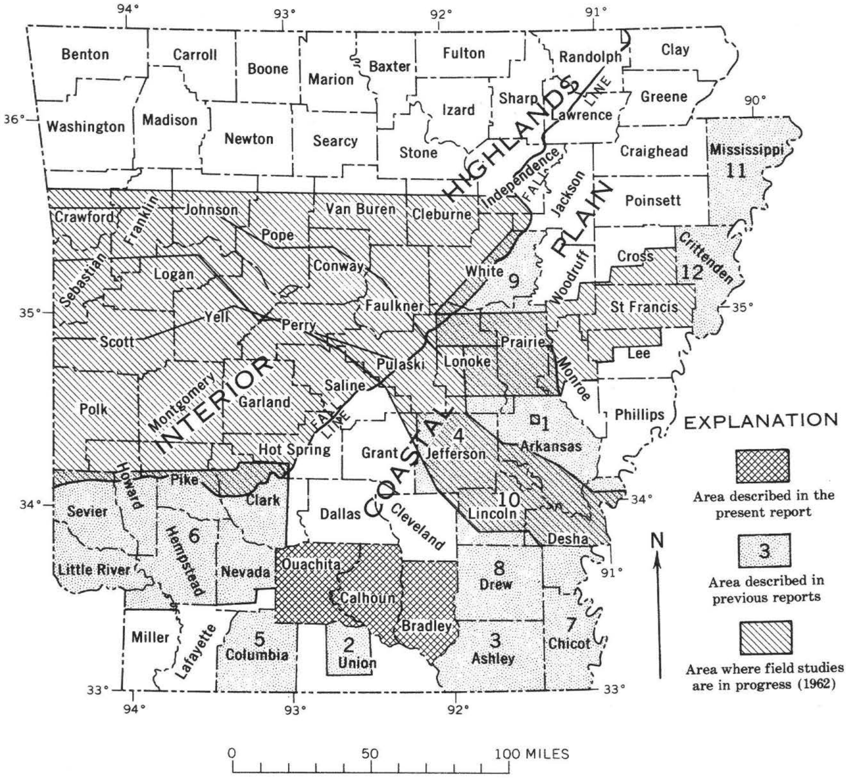

FIGURE 1.—Areas of ground-water investigations in Arkansas. (1) Engler and others (1945), (2) Baker and others (1948), (3) Hewitt and others (1949), (4) Klein and others (1950), (5) Tait and others (1953), (6) Counts and others (1955), (7) Onellion and Criner (1955), (8) Onellion (1956), (9) Counts (1957), (10) Bedinger and Reed (1960), (11) Ryling (1960), (12) Plebuch (1961).

ACKNOWLEDGMENTS

The writer is grateful for the aid given by Mr. G. H. King, superintendent of the Warren Municipal Water Works, and by the water-well drillers and oil companies who furnished information and permitted logging of test holes and wells that were being drilled in the area.

GENERAL GEOLOGY OF DEPOSITS OF CENOZOIC AGE

Published reports by Harris (1892), Veatch (1906), Spooner (1935), and Wilbert (1953) give information about the geology of Bradley, Calhoun, and Ouachita Counties. Deposits older than Cenozoic do not contain fresh water and therefore are not discussed in this report.

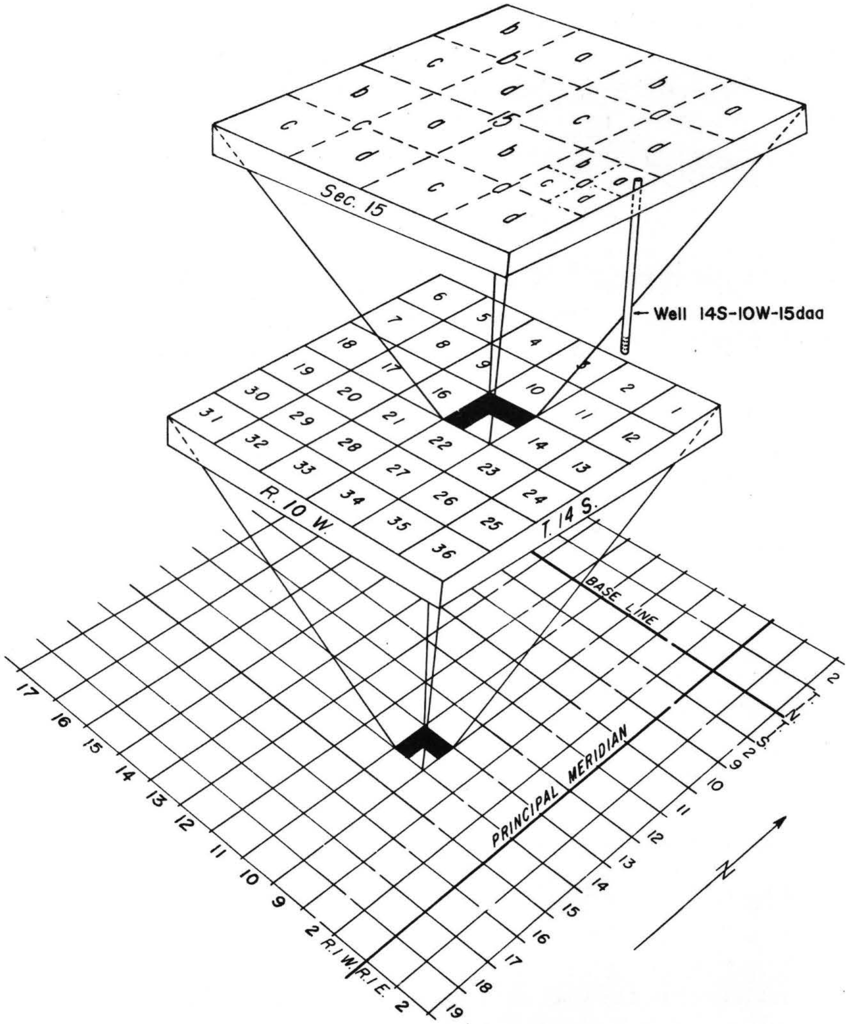

FIGURE 2.—Sketch showing location- and well-numbering system.

The rocks of Cenozoic age in Bradley, Calhoun, and Ouachita Counties were deposited in the shallow Mississippi embayment part of the Coastal Plain physiographic province. A map showing the major structural features in the embayment is shown in figure 3. The embayment was formed by a gentle downwarping of the earth's crust that began in Cretaceous time and continued, sporadically, through Tertiary time (Spooner, 1935, p. 127). The sea alternately advanced and retreated over the land surface, reaching its northernmost point in the vicinity of Cairo, Ill., during Paleocene time (Stearns, 1957, p. 1097). The elevation in Miocene time of the Sabine uplift in northwestern Louisiana and the Monroe uplift in northeastern Louisiana and southeastern Arkansas marked the permanent withdrawal of the Gulf waters from the Mississippi embayment (Spooner, 1935, p. 126). The outcrop position of each successively younger series of rocks in the Tertiary System is progressively nearer the present shoreline of the Coastal Plain (Murray, 1947, p. 1825), and, because of this, no deposits of Tertiary age younger than Eocene are present in Bradley, Calhoun, and Ouachita Counties. Table 1 is a generalized geologic column showing the formations in the counties.

During the Paleocene Epoch deep-water marine clay and marl were deposited in the counties. Early and middle Eocene times were characterized by deltaic deposition of sand, silt, clay, and lignite. Deltaic sedimentation was the dominant feature of Tertiary deposition in the counties (Murray, 1947, p. 1829), and most of the Tertiary sediments are of this type. During late Eocene time moderately deep-water clay and marl were deposited. The Quaternary Period was characterized by the deposition and reworking of fluviatile sediments.

Plate 1 is a structure contour map showing the configuration of the top of the Arkadelphia Marl of the Upper Cretaceous Series, which is the base of the Tertiary System. This map shows a gradual change in direction of dip from southeasterly in Ouachita County to easterly in Calhoun County and to northeasterly in Bradley County. This change in dip reflects the local influence of the Desha basin (fig. 3), but the regional dip is toward the axis of the Mississippi embayment.

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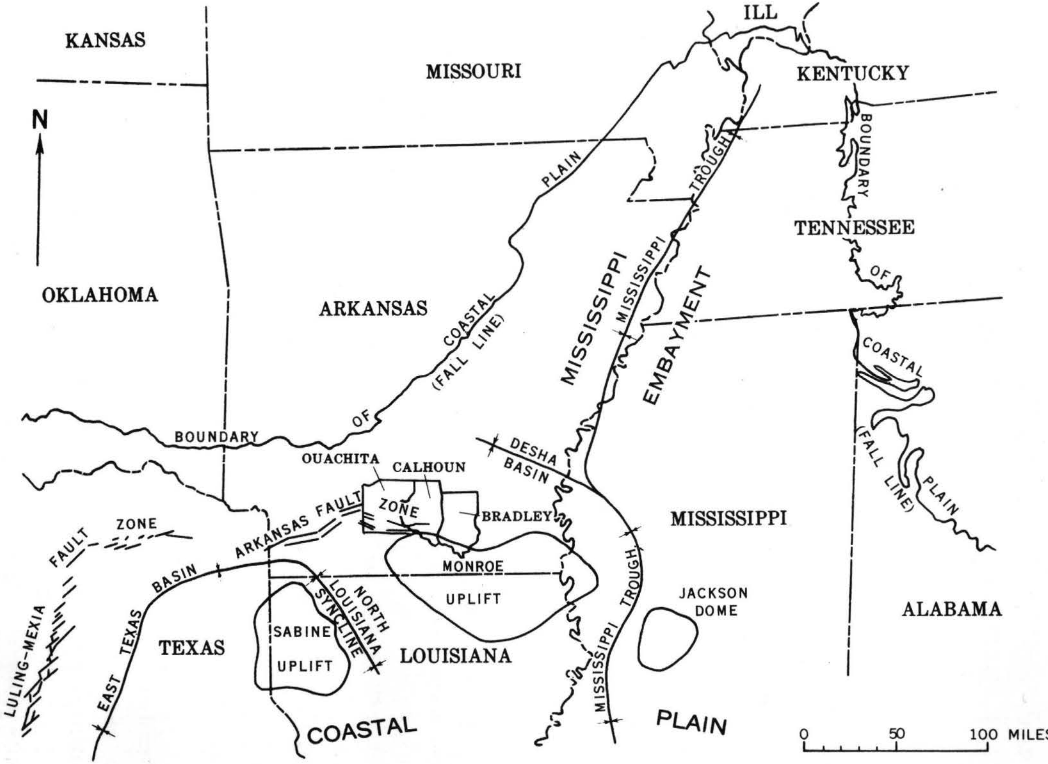

Figure 3.—Location of major structural features in the Mississippi embayment. (Modified after U.S. Geol. Survey and the Am. Assoc. Petroleum Geologists, 1961; Fisher, Kirkland, and Burroughs, 1949; and others.)

TABLE 1.—*Generalized geologic column of Bradley, Calhoun, and Ouachita Counties*

Era	System	Series	Group	Formation or Subdivision
Cenozoic	Quaternary	Recent		Alluvium
				——?——?——?——
		Pleistocene		Terrace deposits
	Tertiary	Eocene	Jackson	
			Claiborne	Cockfield Formation
				Cook Mountain Formation
				Sparta Sand
				Cane River Formation
				Carrizo Sand
			Wilcox	
		Paleocene	Midway	Porters Creek Clay
				Clayton Formation
Mesozoic	Cretaceous	Gulf		Arkadelphia Marl

Plate 1 also shows a system of grabens extending in a general east-west direction across the southern part of Ouachita and Calhoun Counties. Spooner (1935, p. 132) designated these faults the Arkansas fault zone and considered them a result of the flexure on the basement rocks. The faults probably are an eastward continuation of the Balcones and Luling-Mexia fault zones of Texas (Eardley, 1951, p. 548).

Although the grabens are delineated by a single pair of faults on plate 1, several faults may be involved, especially in the largest graben which extends from southeastern Ouachita County across most of southern Calhoun County. Either smaller blocks in this graben have not been displaced, or a complex hinging effect caused downdropping of only parts of the fault block. This hinging effect may also have formed in the two smaller grabens in southwestern Ouachita County. The faults that bound each graben are 2 to 6 miles apart, and the downthrown block between them has been displaced as much as 300 feet in Ouachita County. Most of the displacement in the Arkansas fault zone was in late Oligocene or early Miocene time, although some movement continued into the Quaternary Period (Eardley, 1951, p. 549–551).

Plate 2 is a geologic section across Bradley, Calhoun, Ouachita, and part of Nevada Counties. The section was constructed from lithologic logs of the city supply wells at Chidester and Hampton, from an industrial supply well at the Southern Kraft Division of the International Paper Co. at Camden, and from 23 test holes drilled under contract for the U.S. Geological Survey. Plate 3, a geologic section across Bradley, Calhoun, and Ouachita Counties, was constructed from electric logs of oil-test wells. Plate 4 is a geologic section across the grabens in Ouachita County; it was constructed from electric logs of oil-test wells.

TERTIARY SYSTEM

The Tertiary System includes five series; deposits of each series occur within the central Gulf Coastal Plain (Murray, 1947, p. 1829). However, deposits of only two series, the Paleocene and Eocene, are represented in Bradley, Calhoun, and Ouachita Counties, Ark.

Plate 5 is a geologic map showing the general distribution of the deposits of Tertiary age at the surface or beneath the alluvium and terrace deposits of Quaternary age. The map was drawn primarily by interpreting electric logs of oil-test wells.

PALEOCENE SERIES

MIDWAY GROUP

The Midway Group of Paleocene age is the most widespread of the deposits of Tertiary age. It underlies most of the Mississippi embayment and crops out in Arkansas in a narrow band near the Fall Line. The group includes two formations—a basal sandy marl known as the Clayton Formation and a dark-gray to black silty clay known as the Porters Creek Clay. These marine deposits range in thickness from about 400 feet in northwestern Ouachita County to about 600 feet in northeastern Bradley County.

In most electric-log correlations, the base of the first sand above the typical Porters Creek Clay has been used as the top of the Midway Group. This sand is part of a transition zone above the clay which has been included in the Midway Group by some authors and in the Wilcox Group by others. Murray (1947, p. 1835) points out that "upper Midway deposits are normally grouped with the Wilcox because of their lithologic and faunal similarity." The sandy transition zone is included in the Wilcox Group in this report, and the top of the Porters Creek Clay is considered the top of the Midway Group.

EOCENE SERIES

WILCOX GROUP

The Wilcox Group is conformable on the underlying Midway Group and has almost as great an areal distribution (Stearns, 1957, p. 1092). The group is about 250 feet thick near its outcrop in northwestern Ouachita County, and increases in thickness to about 750 feet in northeastern Bradley County. Drill cuttings from test holes in Ouachita County indicate that the Wilcox Group primarily consists of dark-gray to dark-brown swamp or back-beach lignitic clay and lignite, light-gray to gray and brown shallow-marine sand and clay, and green, moderately deep-water glauconitic clay. These deposits were laid down in a deltaic environment where the land surface was alternately inundated and exposed. The strand line evidently moved rapidly over Bradley, Calhoun, and Ouachita Counties during Wilcox time, because there is no widespread beach-sand deposit in the area comparable to the "1,400-foot" sand of the Wilcox Group in northeastern Arkansas.

CLAIBORNE GROUP

In south-central Arkansas the Claiborne Group of middle Eocene age includes, from oldest to youngest, the Carrizo Sand, Cane River Formation, Sparta Sand, Cook Mountain Formation, and Cockfield Formation. This group is unconformable on the underlying Wilcox Group (Stearns, 1957, p. 1092), and ". . . represents a transitional depositional stage between the underlying deltaic Wilcox and the overlying marine Jackson sediments" (Murray, 1947, p. 1836). All formations in this group, whether deposited under subaerial or submarine conditions or both, are composed of near-shore deposits. In Bradley, Calhoun, and Ouachita Counties the Claiborne Group ranges in thickness from 0 to about 1,500 feet.

CARRIZO SAND

The Carrizo Sand is the basal unit of the Claiborne Group. It underlies Bradley and Calhoun Counties and all but the northwest corner of Ouachita County (pl. 5). Because this formation was deposited on the irregular Wilcox erosional surface, its thickness varies considerably in short distances. However, it generally ranges in thickness from about 70 feet near its outcrop area in northwestern Ouachita County to about 150 feet in Bradley County. The formation is a beach deposit, and although it contains some lignite and shallow-water clay, it consists mainly of gray and brown very fine to medium sand.

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CANE RIVER FORMATION

The Cane River Formation overlies the Carrizo Sand and crops out in northwestern Ouachita County (pl. 5). The formation was deposited under much the same environmental conditions as the Wilcox Group, but during Cane River time the strand line apparently was more stable. The formation consists mainly of shallow-water dark-gray to dark-brown silt and silty clay, but fluctuation of the strand line is evidenced by (1) lignite and lignitic clay, which indicate back-beach deposition; (2) clean sand, which is probably a remnant of the beach itself; and (3) glauconite, which indicates marine deposition.

The Cane River Formation ranges in thickness from about 125 feet near the outcrop area in northwestern Ouachita County to about 500 feet in northeastern Bradley County.

SPARTA SAND

The Sparta Sand underlies Bradley and Calhoun Counties and all but the northwest corner of Ouachita County (pl. 5). The formation crops out over most of Ouachita County and consists mainly of gray, very fine to medium sand and brown and gray sandy clay. Most of the formation was deposited as the beach of an advancing sea. Shallow-water clay and back-beach lignitic clay and lignite in Ouachita and Calhoun Counties indicate that the shore line fluctuated somewhat in that area.

In the northwestern part of Ouachita County (11S–18W–20baa), a quartzose sandstone in the basal part of the Sparta crops out that may be one of the sedimentary quartzites described by Murray (1947, p. 1836). The outer surface of the sandstone is hard and apparently has been formed by case hardening because softer, less-consolidated sand can be exposed by breaking off small pieces of the rock. This case-hardened sandstone is the only outcrop of consolidated rock, other than thin ironstones, in the area of this report.

The Sparta Sand ranges in thickness from about 300 feet in western Calhoun County to about 600 feet in Bradley County.

COOK MOUNTAIN FORMATION

The Cook Mountain Formation underlies Bradley County, most of Calhoun County, and southern Ouachita County (pl. 5). The formation consists of moderately deep-water marine clays in most of the Mississippi embayment. In Bradley, Calhoun, and Ouachita Counties, however, the near-shore shallow-water dark-gray to dark-brown silty clays are prevalent. The formation is about 150 feet thick and contains some silt, sand, and lignitic clay that probably were deposited in a back-beach environment.

COCKFIELD FORMATION

The Cockfield Formation underlies Bradley County and all but the western part of Calhoun County (pl. 5). The formation consists mainly of gray and brown, very fine to fine sand and silt and dark-gray, dark-brown, and green lignitic silty clay. Most of the sand, silt, and clay is lignitic, and lignite commonly is present as thin interbeds; this composition indicates that the formation was deposited primarily under subaerial conditions. Some of the sand lenses probably are beach deposits, for they are free of silt but contain small amounts of glauconite. The Cockfield Formation is about 250 feet thick in Bradley and Calhoun Counties.

JACKSON GROUP

The Jackson Group underlies a small part of eastern Calhoun County and all but the southwest quarter and the northwest corner of Bradley County (pl. 5). The geologic section (pl. 2) and sub-crop pattern (pl. 5) indicate that the group has a considerably greater thickness and areal extent than that proposed by Wilbert (1953, p. 64).

The Jackson Group is about 295 feet thick in Bradley County. It was deposited primarily under marine conditions and consists mainly of gray, brown, and green silty clay and some lignite. Its contact with the predominantly continental sands of the underlying Cockfield Formation is placed at a definite break in lithology as shown on plate 2. This position of the contact, determined by the interpretation of lithologic logs, agrees with a projection of the contact from electric logs of oil-test wells east of Bradley County.

The interpretation shown on plates 2 and 5 is suggested also by a zone of *Globigerina* observed in several test holes between 20 and 30 feet above the contact. More paleontological data are necessary to substantiate the placing of the Cockfield-Jackson contact at the horizon shown. However, the presence of the marine micro-fossils indicates that the contact probably is not significantly higher than shown on plate 2.

QUATERNARY SYSTEM

Deposits of the Quaternary System are divided into two series, the Pleistocene and the Recent. Deposits of this age have the largest areal distribution of any of the deposits at the surface in Bradley, Calhoun, and Ouachita Counties.

PLEISTOCENE SERIES

TERRACE DEPOSITS

Terrace deposits of Pleistocene age cover most of soutnern Bradley County, most of Calhoun County, and the northeastern part of Ouachita County. In addition, isolated remnants of terrace deposits cap several of the hills in northwestern Ouachita County. Altitude contours of the base of the terrace gravel exposed in many pits indicate that the gravel in the counties may be part of a single terrace that slopes southward at approximately 10 feet per mile. However, the isolated terrace remnants in northwestern Ouachita County are at altitudes of approximately 300 feet and are less than 6 miles from other terraces at altitudes of approximately 100 feet. Therefore, these remants probably represent the oldest and highest of a series of three terraces in the counties. The middle terrace, primarily in Calhoun and southern Bradley Counties, gently slopes southward from altitudes of about 250 feet to about 150 feet, and the lowest and youngest terrace is at altitudes of approximately 100 feet, directly above the flood plain of the major streams in the area. Each of the terraces may slope southward, but such a slope is not apparent in the highest and lowest terraces because of their limited distribution.

The deposits average 35 to 40 feet in thickness and consist mainly of gravel, poorly sorted sand, and some clay.

RECENT SERIES

ALLUVIUM

Alluvium of Recent age underlies the stream valleys in Bradley, Calhoun, and Ouachita Counties. Some of the alluvium may be of Pleistocene age. It mainly consists of sandy clay, poorly sorted sand, and gravel derived from the older terrace deposits and averages 35 to 40 feet in thickness in the major stream valleys. The alluvium generally is somewhat finer in overall grain size than the terrace deposits.

GROUND WATER

OCCURRENCE AND MOVEMENT

Only a brief discussion of the principles of occurrence and movement of ground water is given in this report. A comprehensive description of these principles is published in reports by Meinzer (1923) and Wenzel (1942).

Almost all ground water originates as precipitation, part of the precipitation runs off in streams, part returns to the atmosphere by evaporation and by transpiration from plants, and part filters downward into the zone of saturation in which all the openings of the rocks are filled with water.

After percolating downward to the top of the zone of saturation (the water table), the water continues to move slowly under the influence of gravity to areas of discharge such as springs, streams, and pumping wells. In the more permeable rocks, such as coarse sand, gravel, and porous sandstone, the water moves with comparative freedom through the interconnected pore spaces between the individual rock particles. Such rocks are capable of yielding abundant supplies of water to wells. However, the rate of movement, even in these highly permeable rocks, is slow compared to the flow of a stream and generally does not exceed a few hundred feet per year. In less permeable rocks, such as shale or clay, molecular attraction and surface-tension forces in the extremely small pore spaces greatly retard the movement of the water. These fine-grained rocks yield little or no water to wells.

A rock formation that yields water to wells is known as an aquifer. Aquifers have been divided into two general types—water table and artesian, and the ground-water reservoir in an area may be composed of either or both types. The water-table aquifer is characterized by a free or unconfined water surface and commonly is found at shallow depths in unconsolidated rocks such as sand and gravel. The ground water in this type of aquifer generally has infiltrated from the surface directly to the water table and has not moved far from that area. Artesian aquifers commonly are found at greater depths and in more consolidated rocks. The ground water in this type of aquifer is confined in a porous layer between beds of relatively impermeable material and may have moved a considerable distance from where it entered the aquifer. The water generally is under hydraulic pressure and will rise in wells to a level above the top of the aquifer. If the water in an artesian aquifer is under sufficient hydraulic pressure to rise in a well to a level above the land surface, the well will flow.

Water levels in most wells continuously fluctuate, primarily as a result of changes in the amount of water in storage in the ground-water reservoir. A change in storage is caused by a variation in the relative rates of ground-water recharge and discharge. Water levels in shallow water-table wells generally respond to changes in precipitation with only a moderate time lag. In these shallow wells the water level may rise several feet soon after a period of heavy rainfall and decline to such a level during prolonged drought that the wells may go dry. Water levels in artesian wells are not affected immediately by seasonal or yearly changes in precipitation.

The variations in the amount of precipitation are averaged out because of the slow movement of the water through the rocks, and the magnitude of the resulting fluctuations is smaller than in water-table wells. After several uncommonly wet or dry years, a large pressure change in an artesian aquifer may be observed; however, most large fluctuations in artesian wells are caused by withdrawals of ground water in the vicinity. Minor fluctuations, generally of short duration, can be caused by barometric-pressure changes, earth and ocean tides, earthquakes, passing railroad trains, and other changes in the load upon the aquifer.

The depth to water was measured periodically in 199 wells in Bradley, Calhoun, and Ouachita Counties. The measurements in the shallow dug, driven, or bored wells show that the water table is not declining and generally is less than 30 feet below land surface. The seasonal fluctuation of the water level is as little as 2 to 5 feet in some shallow wells and as much as 15 to 20 feet in others.

The measurements show also that water levels in the deep drilled wells generally are less than 200 feet below the land surface and are not declining except in areas of heavy pumping. The seasonal fluctuation of the water levels in the deep wells generally is less than 10 feet. Because artesian pressure varies between aquifers and from place to place within each aquifer, the depth to water in the deep wells depends upon the location of the well and the particular aquifer in which the well is screened. In the areas where the formations listed below contain fresh water, the water levels generally fall within the following ranges:

Geologic unit	*Depth to water (feet)*
Jackson Group	0–140
Cockfield Formation	10–180
Sparta Sand	0–170
Cane River Formation	15–75
Carrizo Sand	50–75
Wilcox Group	50–100

Continuous-recording water-level gages were installed on wells in Warren, Fordyce, Stephens, and El Dorado. Hydrographs of the water-level fluctuations in these wells, all screened in the Sparta Sand, are shown on plate 6. These hydrographs show that the water level in the Sparta Sand is (1) declining at a rate of approximately 2.0 feet per year in the vicinity of Warren, (2) declining at a rate of approximately 2.5 feet per year in the vicinity of Fordyce, (3) declining at a rate of approximately 12.5 feet per year in the vicinity of El Dorado, and (4) is not declining in the vicinity of Stephens.

Declining water levels, such as those near Warren, Fordyce, and El Dorado, are a natural result of the development of ground-water supplies. When a well is pumped or allowed to flow, the water level in the well and in the aquifer surrounding the well declines, a hydraulic gradient is developed, and water in the aquifer flows toward the well. The declining water level (piezometric surface in artesian wells) assumes the shape of an inverted cone centered on the well. In general, the greater the drawdown the greater the amount of water that will enter the well. Each well, however, has a definite limit on the amount of drawdown available, depending on the thickness of the aquifer, the depth of the well, and the static water level in the well. Wells screened in highly permeable aquifers generally have relatively little drawdown because ground water moves through such aquifers so readily that large drawdowns cannot develop. Conversely, wells screened in less permeable rocks may develop such large drawdowns that they are temporarily, and for all practical purposes, pumped dry. Even though the larger drawdown produces a steeper hydraulic gradient toward the well, the water cannot move freely and quickly through the smaller pore spaces in the more fine-grained rocks. In general, the cone of depression will expand and deepen until a state of equilibrium is reached when as much recharge water is flowing toward the well as is being pumped from it. Water levels may decline over large areas before equilibrium is reached, but this decline generally is not serious. If the total pumpage in an area continues to exceed the amount of recharge, however, water levels will decline until increasing pumping lifts and declining well yields exceed the economic limit or until the aquifer is dewatered.

Factors controlling the amount of water that can be pumped from a well or a system of wells on a long-term basis depend on the amount of water stored in the ground-water reservoir and the location of the wells with respect to areas of natural recharge and discharge. Under natural conditions, recharge to an aquifer balances discharge from it. Any artificial discharge, such as pumping from wells, superimposed upon this natural system upsets the balance, and ground water is then withdrawn from storage. Equilibrium can be restored if natural recharge to the reservoir is increased and (or) if natural discharge is decreased by an amount equal to the pumpage. If the pumpage cannot be balanced by increased natural recharge or decreased discharge, the water pumped will continue to come from stoarge and water levels will continue to be lowered.

AVAILABILITY AND UTILIZATION

Most of the drilled domestic wells in Bradley, Calhoun, and Ouachita Counties are between 2 and 4 inches in diameter and generally are equipped with jet pumps which yield 5 to 30 gpm (gallons per minute). The drilled irrigation, industrial, and public supply wells in the counties generally range from 6 to 18 inches in diameter and are equipped with turbine pumps which yield as much as 1,000 gpm.

The maximum depth at which fresh water can be obtained ranges from less than 200 feet in northwestern Ouachita County to about 1,050 feet in northeastern Bradley County. In most of the area the Sparta Sand is the deepest fresh-water aquifer, but deposits of Tertiary age older than the Sparta Sand contain fresh water in northwestern Ouachita County. The approximate depth to the base of fresh water and the lowermost geologic unit that contains fresh water are shown on plate 7. Only one well, in the town of Reader, is known to be screened in deposits of the Midway Group. This well yields brackish water that generally is unsuitable even for domestic use. The Wilcox Group, Carrizo Sand, Cane River Formation, and Cook Mountain Formation furnish sufficient water for domestic supplies in the outcrop areas and for distances between 5 and 10 miles downdip. Farther downdip the water in these formations generally becomes too highly mineralized to be useful. A few small domestic supplies are obtained from the Jackson Group in Bradley County, but most water from these deposits is highly mineralized. The principal fresh-water aquifers in the area are the Sparta Sand and Cockfield Formation of Eocene age and the terrace deposits and alluvium of Quaternary age.

SPARTA SAND

The Sparta Sand is the most important aquifer in Bradley, Calhoun, and Ouachita Counties. It generally is capable of furnishing large quantities of good-quality water to wells in all the area except the northwest corner of Ouachita County. The formation furnishes water to most of the municipalities and industries in the area that utilize ground water. Yields of wells screened in the Sparta range from about 300 gpm in the outcrop area to about 1,000 gpm in Bradley County. Most wells outside areas of heavy pumping yield 500 to 700 gpm. The total pumpage from the aquifer in the counties is approximately 5.0 mgd (million gallons per day). Of this total, approximately 3.7 mgd is used by industries, 0.8 mgd by municipalities, and 0.5 mgd for domestic and agricultural purposes. In a small area near Camden, the total pumpage from the Sparta Sand is almost the maximum sustained yield. Additional wells in this area would result in excessive drawdowns and declining well yields.

Aquifer tests made at Camden and Warren indicate that average values of the coefficients of transmissibility and of storage for the Sparta Sand are 35,000 gpd per ft and 0.0002, respectively. Figure 4 has been constructed using these values to show the theoretical drawdown at various distances from a well pumping 700 gpm for several periods of time. A system of wells probably could be installed in any part of the area from central Calhoun County eastward through Bradley County that would yield as much water as is being produced by all the present wells in the three counties combined. The wells in such a system probably should be spaced about 2,000 feet apart to prevent excessive interference Even so, a large drawdown cone would be developed, and continuous checking of water levels versus total pumpage would be required to insure that the aquifer was not being overdeveloped.

COCKFIELD FORMATION

Although the Cockfield Formation yields as much as 500 gpm to wells in Bradley and eastern Calhoun Counties, pumpage from the formation is small. Wells at the Banks and Hermitage schools and a few small industrial supply wells obtain water from this aquifer, but the formation is used primarily as a source for domestic supplies. One irrigation well screened in the aquifer pumps at a rate of 400 gpm, but it is used only during severe droughts. The total pumpage from the Cockfield Formation in the area of this report is about 0.1 mgd. This pumpage could be increased at least tenfold.

TERRACE DEPOSITS AND ALLUVIUM

Many shallow wells, generally from 15 to 70 feet deep, have been dug, driven, or bored into the terrace deposits and the alluvium of Quaternary age in Bradley, Calhoun, and Ouachita Counties. Approximately 1.0 mgd is withdrawn from these deposits, primarily for rural domestic uses and livestock. Although there are no large-yield wells in the counties screened in the deposits, such wells could be developed in alluvium hydraulically connected with the major streams of the area.

QUALITY

Samples of ground water were collected for chemical analysis from 79 selected drilled wells and from 115 selected dug, driven, or bored wells in Bradley, Calhoun, and Ouachita Counties. The analyses were made by procedures described by Rainwater and Thatcher (1960). Table 2 summarizes the analyses, except those of

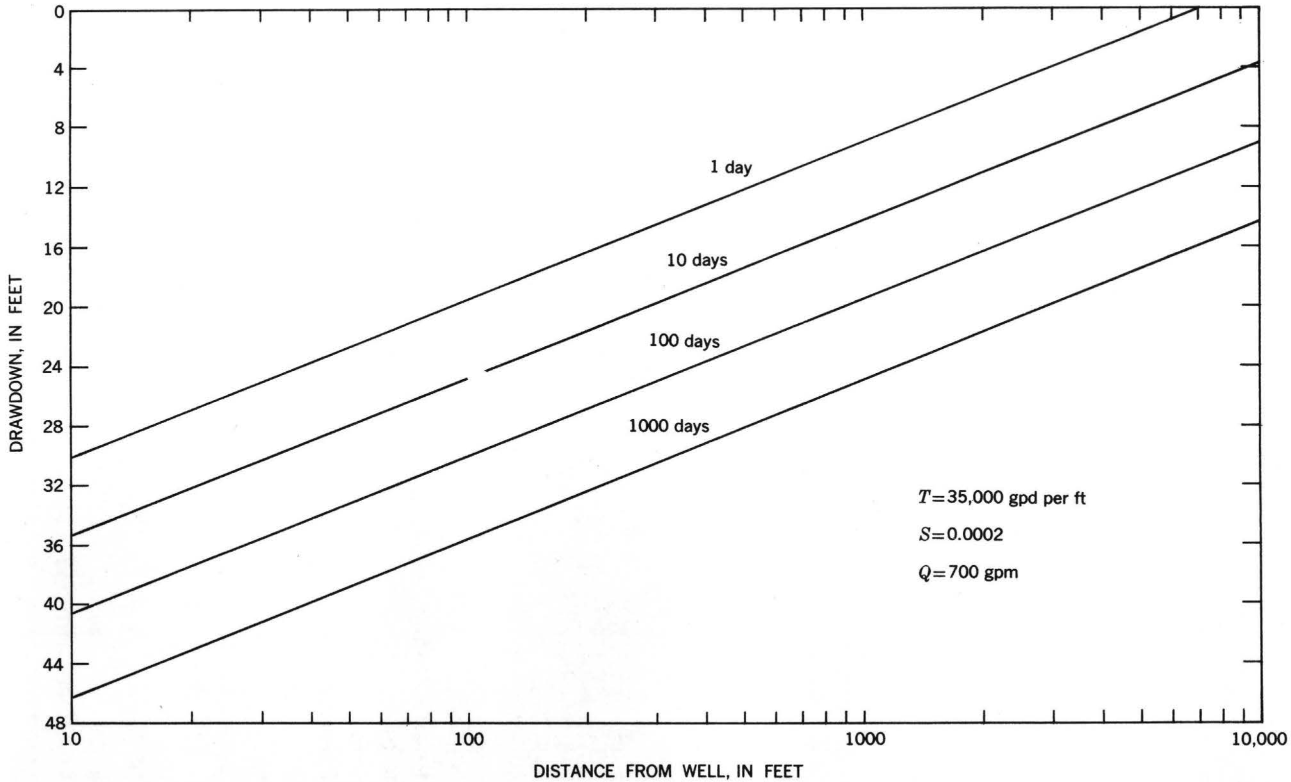

FIGURE 4.—Diagram illustrating drawdown at various distances after various periods of pumping from a well of constant discharge. T, coefficient of transmissibility; S, coefficient of storage; Q, pumping rate.

water from shallow wells in the outcrop areas of the formations of Tertiary age. Water from shallow wells in these formations is not representative of water in the formations at depth. The summary has been prepared by listing the minimum, maximum, and most representative concentrations of the various mineral constituents and physical properties of water from each formation sampled. The most representative concentration, as used here, is either the mode or the average of the modal range in values. The analyses may be used to determine the chemical suitability of the water for various uses without reference to its bacteriological content or sanitary quality.

Table 3 summarizes the significance of the mineral constituents and physical properties of natural waters. The standards used to determine the chemical suitability of water for various uses are listed in numerous publications and, therefore, are not discussed in detail in this report. Reports by Wilcox (1948), California State Water Pollution Control Board (1952), American Society for Testing Materials (1954), and Hem (1959) contain further information on water-quality standards.

Most of the constituents listed in table 3 are objectionable in drinking water only when they are present in concentrations high enough to be noticeable to the taste. However, Hem (1959, p. 239) points out that several investigations seem definitely to link nitrate in domestic water supplies with methemoglobinemia, or cyanosis, in infants whose feeding formulas are mixed with water having a high nitrate content. This so-called "blue-baby" disease apparently is a hazard, sometimes fatal, with waters containing more than 45 ppm (parts per million) nitrate.

The analyses of the 115 samples from shallow wells in the counties (some of which are not included in table 2) show that the chemical composition of water from shallow wells is relatively consistent, regardless of the formation from which the water came. This similarity in chemical composition can be attributed primarily to two facts; (1) the deposits of Tertiary age contain much sand in the outcrop areas and mineralogically resemble the alluvium and terrace deposits of Quaternary age, and (2) the water at shallow depths is recharged frequently by rainfall and has been in contact with the rocks such a short time that little solution of minerals has taken place. Therefore, water from shallow wells in the outcrop areas of deposits of Tertiary age generally will be similar in chemical content to that summarized in table 2 for water from the alluvium and terrace deposits.

Almost all the water from the shallow wells is used for small domestic or farm supplies. Probably the most important constitu-

TABLE 2.—*Summary of chemical analyses of water from selected wells in Bradley, Calhoun, and Ouachita Counties, Ark.*

[Results in parts per million except as indicated. Min., minimum concentration; Max., maximum concentration; M.R., most representative concentration (either the mode or the average of the modal range). Figures in parentheses indicate number of water samples analyzed; silica and fluoride concentrations for Sparta Sand based on seven water samples]

Mineral constituent or property	Geologic units																				
	Alluvium and terrace deposits (57)			Jackson Group (4)			Cockfield Formation (27)			Sparta Sand (34)			Cane River Formation (9)			Carrizo Sand (3)			Wilcox Group (1)	Midway Group (1)
	Min.	Max.	M.R.	Min.	Max.	M.R.	Min.	Max.	M.R.	Min.	Max.	M.R.	Min.	Max.	M.R.	Min.	Max.	M.R.	M.R.	M.R.
Temperature (°F)	63	74	67	68	73	74	65	74	70	65	83	66	66	71	69	65	65	65	------	64
Silica (SiO_2)	------	------	------	------	------	------	------	------	------	3.9	53	20	------	------	------	------	------	------	6.6	------
Iron (Fe)	.00	7.5	.90	.06	.62	.09	.04	62	.35	.00	23	.30	.04	3.6	.40	.04	.77	.30	.00	.07
Calcium (Ca)	------	------	------	14	45	26	1.9	117	7.5	1.0	24	5.2	4.9	65	12	4.0	20	5.6	17	13
Magnesium (Mg)	------	------	------	3.6	13	5.0	.0	38	1.9	.0	6.3	2.3	1.7	18	3.7	1.2	7.0	1.5	2.6	3.1
Sodium (Na)	------	------	------	29	153	75	1.2	182	54	2.3	132	18	3.4	964	490	18	1,050	35	427	842
Potassium (K)	------	------	------	4.1	8.2	6.0	.7	11	3.2	.7	5.6	3.5	.6	16	9.3	.6	11	2.0	13	8.4
Bicarbonate (HCO_3)	0	341	15	204	272	237	8	428	181	0	334	110	44	400	268	58	518	100	254	320
Carbonate (CO_3)	0	0	0	0	0	0	0	0	0	0	2	0	0	4	0	0	10	0	10	0
Sulfate (SO_4)	1.0	68	2.0	4.8	152	100	.0	470	3.9	.2	25	4.1	.2	31	1.6	.4	6.0	4.9	8.8	6.2
Chloride (Cl)	3.0	1,190	10	7.0	15	11	2.2	58	8.2	3.5	84	5.8	4.0	1,410	870	5.8	1,350	7.3	540	1,120
Fluoride (F)	------	------	------	------	------	------	------	------	------	.1	1.2	.1	------	------	------	------	------	------	.9	------
Nitrate (NO_3)	.5	198	8.8	.8	3.8	2.2	.0	9.5	.6	.0	2.1	.4	.2	1.9	1.2	.8	4.7	.9	.1	1.5
Dissolved solids	------	------	------	196	482	400	27	958	197	42	362	147	55	2,720	1,450	90	2,820	134	1,170	2,260
Hardness as $CaCO_3$:																				
Calcium, Magnesium	6	399	30	51	153	100	5	448	22	4	84	30	22	236	44	15	79	20	53	45
Noncarbonate	0	399	5	0	0	0	0	300	0	0	20	0	0	26	0	0	0	0	0	0
Percent sodium	------	------	------	28	85	69	23	97	75	15	97	34	69	94	90	60	96	78	------	97
Sodium adsorption ratio	------	------	------	1.0	9.3	3.0	.2	29	3.2	.2	24	1.2	2.8	34	24	1.6	51	25	------	55
Specific conductance (micromhos at 25° C)	46	4,130	141	336	734	535	25	1,180	310	43	584	210	83	4,610	2,400	127	4,680	194	1,820	3,970
pH	4.5	7.9	6.5	7.3	8.0	7.9	5.8	8.2	7.6	4.30	8.4	7.6	7.4	8.3	8.2	7.2	8.4	7.7	8.6	8.0

ents related to domestic use are iron, sulfate, chloride, nitrate, and calcium magnesium hardness. The upper limit of concentration for each of these constituents, especially nitrate, ideally should be the same as those suggested in table 3. The analyses of samples from the 115 shallow wells showed that in 20 samples iron exceeded 0.3 ppm, in 4 samples chloride exceeded 250 ppm, in 20 samples nitrate exceeded 45 ppm, and in 15 samples calcium magnesium hardness exceeded 100 ppm.

The 20 wells yielding water having a high nitrate content are randomly distributed over the counties, and show no apparent relation to a particular stream, agricultural area, municipality, or industrial site. However, the wells generally are in rural areas, close to barnyards. These wells were resampled to determine whether nitrogen might be present as ammonium (NH_4) or nitrite (NO_2) rather than as nitrate (NO_3). The analyses of the second set of samples showed only traces of ammonium and nitrite, and confirmed the presence of nitrogen as nitrate. The analyses of the second set of water samples also showed that the nitrate concentration had increased in 8 samples, had decreased in 13 samples, and had remained constant in 2 samples. The random areal distribution, the proximity to barnyards, and the changing nitrate concentration indicate that pollution from the land surface is the primary source of the nitrate in these waters. However, of the 115 water samples from the shallow dug, driven, and bored wells, 40 contained nitrate concentrations of 20 ppm or greater. This widespread occurrence of uncommonly high nitrate concentrations may be caused by factors other than surface contamination. The decay of plant debris, the action of bacteria, and the leaching of nitrate from various soil horizons can be important factors in causing ground waters to have a high nitrate content (Hem, 1959, p. 116–117). It is probable that one or more of these factors are operative in the heavily timbered counties, and, when combined with surface contamination, cause nitrate concentrations to exceed the recommended limit. Therefore, care should be taken to prevent surface contamination of shallow groundwater supplies and, before infants are fed water from these sources, a sample of the water should be analyzed to determine whether a methemoglobinemia hazard is present.

Analyses of samples from deep drilled wells screened in the Jackson Group show that water from these deposits is harder than water from the other formations in the counties. The mineral constituents in the most significant concentrations are sodium and bicarbonate, although minor concentrations of calcium and sulfate are present also.

TABLE 3.—*Significance of dissolved mineral constituents and physical properties of natural waters*

Item	Constituent or physical property	Source or cause	Significance
1	Temperature		Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. In general, temperatures of shallow ground water show some seasonal fluctuation, whereas temperatures of ground water from moderate depths remain near the mean annual air temperature of the area (about 65°F in Bradley, Calhoun, and Ouachita Counties). In very deep wells, the water temperature generally increases about 1°F for each 60-foot increment of depth.
2	Silica (SiO_2)	Dissolved from practically all rocks and soils, generally in small amounts from 1 to 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
3	Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 to 2 ppm of soluble iron in surface water generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. U.S. Public Health Service drinking water standards recommend that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
4	Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities commonly associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark brown or black stain. U.S. Public Health Service drinking water standards recommend that manganese should not exceed 0.05 ppm.

5	Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Causes most of the hardness and scale-forming properties of water; soap consuming (see item 13). Waters low in calcium and magnesium are desired in electroplating, tanning, dyeing, and in textile manufacturing.
6	Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. High sodium content commonly limits use of water for irrigation. Sodium salts may cause foaming in steam boilers.
7	Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
8	Sulfate (SO_4)--------	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Large amounts have a laxative effect on some people and, in combination with other ions, gives a bitter taste. Sulfate in water containing calcium forms a hard scale in steam boilers. U.S. Public Health Service drinking water standards recommend that the sulfate content should not exceed 250 ppm.
9	Chloride (Cl)--------	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	Large quantities increase the corrosiveness of water and, in combination with sodium, give a salty taste. U.S. Public Health Service drinking water standards recommend that the chloride content should not exceed 250 ppm.

TABLE 3.—*Significance of dissolved mineral constituents and physical properties of natural waters*—Continued

Item	Constituent or physical property	Source or cause	Significance
10	Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, the amount of drinking water consumed, and the susceptibility of the individual. The maximum concentration of fluoride recommended by the U.S. Public Health Service for areas having an annual average of maximum daily air temperatures between 63.9° F and 70.6° F, as in southern Arkansas, is 1.2 ppm, with 0.9 ppm considered the optimum concentration.
11	Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soil.	Nitrate encourages growth of algae and other organisms that produce undesirable tastes and odors. Concentrations much greater than the local average may suggest pollution. U.S. Public Health Service drinking water standards recommend that nitrate content should not exceed 45 ppm, for there is evidence that higher concentrations may cause methemoglobinemia in infants, the so-called "blue-baby" disease that is sometimes fatal. Nitrate has been shown to be helpful in reducing intercrystalline cracking of boiler steel.
12	Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	U.S. Public Health Service drinking water standards recommend that the dissolved solids should not exceed 500 ppm. Water containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
13	Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form, and deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. In general, water of hardness of as much as 60 ppm is considered soft; 61 to 120 ppm, moderately hard; 121 to 180 ppm, hard; more than 180 ppm, very hard.

14	Percent sodium and sodium adsorption ratio.	See item 6	Values for these properties are used with specific conductance values to determine the suitability of a water for irrigation use.
15	Specific conductance micromhos at 25°C.	Mineral content of the water	Specific conductance is a measure of the capacity of the water to conduct an electric current. This property varies with concentration and degree of ionization of the constituents and with temperature (therefore reported at 25°C).
16	Hydrogen ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

Analyses of samples from deep wells screened in the Cockfield Formation, the Sparta Sand, and the Carrizo Sand show that sodium and bicarbonate are the principal mineral constituents in water from these formations. The Cockfield Formation and the Sparta Sand generally contain water that is suitable for most municipal, industrial, agricultural, and domestic uses. Water in the Carrizo Sand, however, becomes unsuitable for most uses at only short distances downdip from the outcrop area because of increasing mineralization with depth.

Deep wells screened in the Cane River Formation, Wilcox Group, and Midway Group yield water containing high concentrations of sodium and chloride. Although these waters are utilized for a few small domestic and livestock supplies, they are unsuitable for most uses.

Because of the wide distribution of the Sparta Sand and the generally good-quality water at shallow depths, ground water having a chemical quality suitable for most uses generally can be obtained everywhere in Bradley, Calhoun, and Ouachita Counties.

POSSIBILITIES FOR FUTURE DEVELOPMENT

Each of the aquifers in Bradley, Calhoun, and Ouachita Counties is capable of yielding larger quantities of water than presently are being withdrawn from them. Only in the vicinity of the major towns or cities is there any significant pumpage, and only in a small area near Camden has the total pumpage from a single aquifer, the Sparta Sand, approached the maximum sustained yield. A system of properly spaced wells probably could be screened in the Sparta Sand almost anywhere in the area from central Calhoun County eastward through Bradley County that would yield more water than all the existing wells in the counties combined. Before such a system is contemplated, however, several factors which control the amount of water that can be pumped from an area on a long-term basis must be considered. These factors were discussed on pages G12–G15.

In general, both the quantity and the quality of the ground-water resources of the counties are satisfactory for the needs of most users.

LITHOLOGIC LOGS

Table 4 contains lithologic logs of representative test holes and water wells in Bradley, Calhoun, and Ouachita Counties.

TABLE 4.—*Lithologic logs of representative test holes and water wells in Bradley, Calhoun, and Ouachita Counties, Ark.*

Well W

[Location, Bradley County, 13S–9W–6acb. Owner, City of Warren. Drilled by B. F. Edington Drilling Co. Inc. Log by U.S. Geological Survey. Surface altitude, 250 feet]

	Thickness (feet)	*Depth (feet)*
Tertiary-Eocene:		
Jackson Group:		
Road-fill material	10	10
Clay, silty, light-gray and buff	5	15
Clay, sandy, dark-gray, lignitic	8	23
Clay, sandy, brownish-gray, lignitic; contains some interbedded greenish-gray and green clay and lignite	47	70
Clay, green, hard	10	80
Lignite	3	83
Clay, green, hard; contains interbedded lignitic gray and gray-brown silty clay, and lignite	43	126
Clay, silty, gray and gray-brown, lignitic; contains interbedded lignite and very fine sand	20	146
Sand, fine to medium, rounded, gray; contains much black and green chert	21	167
Sand, fine to medium, subrounded to subangular, gray; contains much black and green chert and streaks of lignite	20	187
Sand, medium to coarse, subrounded to subangular, gray; contains much black and green chert and streaks of lignite	59	246
Lignite	8	254
Clay, silty, green, greenish-gray, gray, and brown, the brown clay is very lignitic; contains streaks of lignite and some silt and very fine to fine sand	143	397
Cockfield Formation:		
Sand, silt to fine, brownish-gray	16	413
Sand, medium to coarse, subrounded, gray; contains a few thin streaks of lignite	20	433
Sand, medium to coarse, subrounded, gray, increasingly more "dirty"; contains streaks of green clay, lignitic brown clay, and lignite	21	454
Clay, silty, green, greenish-gray, and brown; contains a few stringers of silt and fine to medium sand and lignite	84	538
Sand, very fine to fine, gray; contains some green, greenish-gray, and brown clay, and lignite	55	593
Cook Mountain Formation:		
Clay, green, greenish-gray, brown, and buff; contains interbedded lignite, silt, and very fine sand	76	669
Sand, silt to very fine, some medium, gray, and interbedded lignite	31	700
Clay, green, greenish-gray, brown, and buff, and lignite; contains interbedded silt and very fine sand	41	741
Lignite	7	748
Sand, fine, gray-brown	7	755
Lignite	6	761
Clay, green, greenish-gray, gray, and brown, and lignite	46	807
Sparta Sand:		
Sand, fine to medium, subrounded to subangular, gray-brown; contains muscovite flakes and black chert	16	823
Sand, medium, subrounded to subangular, brownish-gray; contains black chert	37	860
Clay, green, greenish-gray, brown, and some almost white, and lignite	106	966
Sand, fine to medium, some coarse, brownish-gray; contains interbedded green, greenish-gray, gray, and brown clay, and lignite	103	1,069

TABLE 4.—*Lithologic logs of representative test holes and water wells in Bradley, Calhoun, and Ouachita Counties, Ark.*—Continued

Test hole 25

[Location, Bradley County, 15S–9W–25aca. Augered by U.S. Geological Survey. Log by U.S. Geological Survey. Surface altitude, 150 feet]

	Thickness (feet)	*Depth (feet)*
Tertiary-Eocene:		
Jackson Group:		
Clay, silty, grayish-brown, greenish-brown, and brown; contains some medium sand	22	22
Sand, very fine to fine, clayey; contains some gray clay	10	32
Clay, green, hard	5	37
Clay, sandy, gray, brown, and green	53	90
Cockfield Formation:		
Silt, gray, lignitic	2	92
Sand, fine clayey, gray, lignitic	25	117

Well H

[Location, Calhoun County, 14S–13W–6aaa. Owner, City of Hampton. Drilled by Layne-Arkansas Co. Log by Layne-Arkansas Co. Surface altitude, 203 feet]

	Thickness (feet)	*Depth (feet)*
Quaternary:		
Terrace deposits:		
Soil	12	12
Gravel	23	35
Tertiary-Eocene:		
Cockfield Formation:		
Clay	30	65
Soft rock	2	67
Gumbo and sandy shale	78	145
Fine sand	4	149
Sand and shale	6	155
Fine sand	5	160
Sandy shale	20	180
Fine sand	4	184
Gumbo	16	200
Shale	20	220
Gumbo	25	245
Gumbo and 3-inch rock	5	250
Rock	1	251
Cook Mountain Formation:		
Gumbo	3	254
Soft rock	1	255
Gummy shale	61	316
Hard gumbo	10	326
Shale and sand	6	332
Sandy clay	42	374
Gumbo	23	397
Sparta Sand:		
Fine-packed sand	19	416
Gumbo	13	429
Fine gray water sand	21.5	450.5
Sandy shale	20.5	471

TABLE 4.—*Lithologic logs of representative test holes and water wells in Bradley, Calhoun, and Ouachita Counties, Ark.*—Continued

Well C

[Location, Ouachita County, 12S–19W–14aaa. Owner, Town of Chidester, Ark. Log from the surface to 178 feet is modified from a driller's log supplied by the Carloss Well Supply Co. Log from 178 feet to total depth is from a test hole drilled by the Childers Drilling Co. and logged by the U.S. Geological Survey. Surface altitude, 286 feet]

	Thickness (feet)	*Depth (feet)*
Tertiary-Eocene:		
Sparta Sand:		
Sand, reddish-brown	8	8
Sand, brown; contains streaks of red clay	12	20
Sand, white to light-tan	10	30
Sand; contains streaks of soft white clay	21	51
Sand, light-brown to tan, water-bearing	47	98
Sand, hard-packed, water-bearing; contains 5 feet of coarse sand	20	118
Cane River Formation:		
Clay, hard	7	125
Clay, sandy, soft	4	129
Clay, black, very hard [lignite?]	12	141
Sand, streaks	4	145
Sand; contains streaks of clay	10	155
Clay, black, very hard [lignite?]	22	177
Rock, hard	1	178
Clay, and lignite, dark-brown	63	241
Sand, medium, light-gray	13	254
Sand, medium, clayey, brown; contains lignite	12	266
Shale, brown	13	279
Carrizo Sand:		
Sand, fine to medium, gray; contains blue to almost black clay	26	305
Sand, very fine to medium, brown; contains streaks of shale, clay, and some gravel	24	329
Sandstone, fine-grained, brown	2	331
Sand, fine to medium, gray, contains streaks of brown siltstone and some lignite	22	353
Wilcox Group:		
Lignite	13	366
Clay, sandy, gray; lignite streak at 374 feet	28	394
Siltstone, brown	2	396
Clay, sandy, gray	19	415

TABLE 4.—*Lithologic logs of representative test holes and water wells in Bradley, Calhoun, and Ouachita Counties, Ark.*—Continued

Test hole 24

[Location, Ouachita County, 14S–19W–4caa. Drilled by H. E. Cutter and Dad Drilling Co. Log by U.S. Geological Survey. Surface altitude, 300 feet]

	Thickness (feet)	*Depth (feet)*
Tertiary-Eocene:		
Sparta Sand:		
Clay, sandy, gray and light-brown; contains numerous small ironstone concretions	6	6
Clay, silty, chocolate-brown; contains some lignitic gray clay	9	15
Clay, silty, gray, lignitic; contains small ironstone concretions	5	20
Clay, silty, gray and brown; contains interbedded silt and lignite	20	40
Sand, fine, gray; contains interbedded lignite	5	45
Clay, silty, gray and brown, lignitic	30	75
Sand, fine, brownish-gray; contains interbedded silt, gray clay, and lignite	30	105
Sand, fine to medium, brownish-gray; contains interbedded silt, gray clay, and lignite	70	175
Sand, fine to very coarse, brownish-gray; contains some interbedded lignite	35	210
Lignite	5	215
Sand, fine to very coarse, brownish-gray; contains interbedded dark-brown and gray clay, and lignite	15	230
Cane River Formation:		
Clay, silty, dark-chocolate-brown and gray, interbedded with brown very fine to fine sand	15	245
Clay, dark-chocolate-brown and gray, glauconitic	5	250
Clay, silty, dark-chocolate-brown and gray; contains some brown siltstone	20	270

SELECTED REFERENCES

American Society for Testing Materials, 1954, Manual on industrial water: Philadelphia, Pa., Am. Soc. for Testing Materials.

Arkansas Geological Survey, 1929, Geologic map of Arkansas: U.S. Geol. Survey, scale 1:500,000.

Baker, R. C., Hewitt, F. A., and Billingsley, G. A., 1948, Ground-water resources of the El Dorado area, Union County, Arkansas: Arkansas Univ. Bur. Research, Research Ser. 14, 39 p., 6 figs.

Baker, R. C., 1955, Arkansas' ground-water resources: Arkansas Geol. Conserv. Comm. Water Resources Circ. 1, 16 p.

Bedinger, M. S., and Reed, J. E., 1961, Geology and ground-water resources of Desha and Lincoln Counties, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 6, 129 p., 19 pls., 23 figs.

Branner, G. C., 1937, List of Arkansas water wells: Arkansas Geol. Survey Inf. Circ. 11, 142 p., 22 pls., 4 figs.

California State Water Pollution Control Board, 1952, Water-quality criteria: California State Water Pollution Control Board Pub. 3.

Counts, H. B., 1957, Ground-water resources of parts of Lonoke, Prairie, and White Counties, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 5, 65 p., 7 pls., 8 figs.

Counts, H. B., Tait, D. B., Klein, Howard, and Billingsley, G. A., 1955, Ground-water resources in a part of southwestern Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 2, 35 p., 6 pls., 8 figs.

Cushing, E. M., Speer, P. R., and Schroeder, M. E., 1960, Progress report on study of the geohydrology of the Mississippi embayment area: U.S. Geol. Survey open-file report, 20 p., 9 figs.

Eardley, A. J., 1951, Structural geology of North America: New York, Harper & Bros., 624 p.

Engler, Kyle, Thompson, D. G., and Kazman, R. G., 1945, Ground-water supplies for rice irrigation in the Grand Prairie region, Arkansas: Arkansas Univ. Agr. Expt. Sta. Bull. 457, 56 p., 1 pl., 10 figs.

Fenneman, N. M., 1949, Physical divisions of the United States: U.S. Geol. Survey map.

Fisher, R. L., Kirkland, R. A., and Burroughs, B. B., 1949, Distribution of pre-Upper Cretaceous formations in south Arkansas and north Louisiana: Shreveport Geol. Soc. Guidebook, 17th Ann. Field Trip.

Fisk, H. N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: War Dept., U.S. Army, Crops of Engineers, 78 p., 33 pls., 80 figs.

Hale, Harrison, Baker, R. C., Walling, I. W., Parrish, D. M., and Billingsley, G. A., 1947, Public water supplies of Arkansas: Arkansas Univ. Bur. Research, Research Ser. 11, 104 p.

Harris, G. D., 1892, The Tertiary geology of southern Arkansas: Arkansas Geol. Survey Ann. Rept., v. 2, p. 1–207.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p., 2 pls., 40 figs.

Hewitt, F. A., Baker, R. C., and Billingsley, G. A., 1949, Ground-water resources of Ashley County, Arkansas: Arkansas Univ. Inst. Sci. Technology Research Ser. 16, 35 p., 6 figs.

Klein, Howard, Baker, R. C., and Billingsley, G. A., 1950, Ground-water resources of Jefferson County, Arkansas: Arkansas Univ. Inst. Sci. Technology Research Ser. 19, 44 p., 8 figs.

Meinzer, O. E., 1923, The occurrence of ground water in the United States with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p., 31 pls., 110 figs.

Murray, G. E., 1947, Cenozoic deposits of central Gulf Coastal Plain: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 10, p. 1825–1850.

Onellion, F. E., 1956, Geology and ground-water resources of Drew County, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 4, 43 p., 10 figs.

Onellion, F. E., and Criner, J. H., Jr., 1955, Ground-water resources of Chicot County, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 3, 32 p., 8 figs.

Plebuch, R. O., 1961, Fresh-water aquifers of Crittenden County, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 8, 65 p., 19 figs.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p., 17 figs.

Ryling, R. W., 1960, Ground-water potential of Mississippi County, Arkansas: Arkansas Geol. Conserv. Comm. Water Resources Circ. 7, 87 p., 21 figs.

Spooner, W. C., 1935, Oil and gas geology of the Gulf Coastal Plain in Arkansas: Little Rock. Parke-Harper, 516 p., 22 pls., 95 figs.

Stearns, R. C., 1957, Cretaceous, Paleocene, and lower Eocene geologic history of the northern Mississippi embayment: Geol. Soc. America Bull., v. 68, no. 9, p. 1077–1100.

Stephenson, L. W., and Crider, A. F., 1916, Geology and ground waters of northeastern Arkansas, with a discussion of the chemical character of the waters, by R. B. Dole: U.S. Geol. Survey Water-Supply Paper 399, 315 p., 11 pls., 4 figs.

Tait, D. B., Baker, R. C., and Billingsley, G. A., 1953, The ground-water resources of Columbia County, Arkansas, a reconnaissance: U.S. Geol. Survey Circ. 241, 25 p., 1 pl., 6 figs.

U.S. Geological Survey and the American Association of Petroleum Geologists, 1961, Tectonic map of the United States: U.S. Geol. Survey.

U.S. Public Health Service, 1962, Drinking water standards: Federal Register, Mar. 6, p. 2152–2155.

Veatch, A. C., 1906, Geology and underground water resources of northern Louisiana and southern Arkansas: U.S. Geol. Survey Prof. Paper 46, 422 p., 51 pls., 33 figs.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p., 6 pls., 17 figs.

Wilbert, L. J., Jr., 1953, The Jacksonian stage in southeastern Arkansas: Arkansas Resources and Devel. Comm., Div. Geol. Bull. 19, 125 p.

Wilcox, L. B., 1948, The quality of water for irrigation use: U.S. Dept. Agriculture Tech. Bull. 962.