Ground-Water Potential of the Alluvium of the Arkansas River Between Little Rock and Fort Smith, Arkansas

By M. S. BEDINGER, L. F. EMMETT, *and* H. G. JEFFERY

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1669-L

Prepared in cooperation with the U.S. Army Corps of Engineers

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GROUND-WATER POTENTIAL OF THE ALLUVIUM OF THE ARKANSAS RIVER BETWEEN LITTLE ROCK AND FORT SMITH, ARKANSAS

By M. S. Bedinger, L. F. Emmett, and H. G. Jeffery

ABSTRACT

Alluvium along 200 miles of the Arkansas River from Fort Smith, Ark., on the western border of the State, to Little Rock in the approximate geographic center of the State, is potentially the most important aquifer in the Interior Highlands of Arkansas. The flood plain of the river generally is 1 to 3 miles wide, but in places its width is 5 miles. The flood plain is underlain by alluvial sand, gravel, silt, and clay which ranges in thickness from about 40 feet near Fort Smith to about 80 feet near Little Rock. Wells tapping the alluvium yield between 300 and 700 gpm (gallons per minute). Wells tapping the sandstone and shale of Mississippian and Pennsylvanian age, which border the alluvium, generally yield less than 50 gpm.

Generally, ground water in the alluvium is under water-table conditions. Movement of ground water is from the valley wall to the river, and the river acts as a drain throughout most of the year.

The alluvium is recharged primarily by infiltration of rainfall. On the average, the aquifer is recharged at the rate of 10 inches per year or approximately 130 mgd (million gallons per day). Pumpage from the alluvium is about 3.2 mgd. The amount of recharge to the aquifer can be increased many times over the natural recharge rate by constructing wells that will induce recharge from the river.

Median values of the principal constituents in water from the alluvium indicate that it is a calcium magnesium bicarbonate water. Local high concentrations of sulfate, chloride, or nitrate are probably the result of water moving from other formations into the alluvium. High concentrations of chloride in the water however, can be the result of influent seepage of river water.

The quality of water in the alluvium generally is suitable for domestic and irrigation purposes. The hardness and high content of iron and nitrate, however, makes the water undesirable for some industrial uses.

INTRODUCTION

An average of about 1 billion gallons of water per day is drawn from the ground-water reservoirs of Arkansas. Most of this water is pumped from wells in unconsolidated rocks in the Coastal Plain of Arkansas. Many of these wells yield at least 1,000 gpm (gallons per minute). Generally, only small quantities of water can be obtained from wells in consolidated rocks of the Interior Highlands. The alluvium along the Arkansas River between Little Rock and Fort Smith is the most important aquifer in the Interior Highlands. This aquifer is capable of yielding 300 to 700 gpm of water for irrigation and for municipal and industrial supplies. Factors contributing to the importance of the alluvial aquifer are its strategic position along the Arkansas River (which is being developed for navigation), its nearness to sources of fuel, and its location in an area of rich farmland.

PURPOSE AND SCOPE OF THE INVESTIGATION

This report is part of a comprehensive study of ground-water conditions along the Arkansas River in Arkansas and Oklahoma that is being made by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers. The study begun in 1957, is planned to continue for 10 or more years and is based on information collected as a part of the statewide program of ground-water studies made cooperatively by the Gelogical Survey, the Arkansas Geological and Conservation Commission, and the University of Arkansas. The report provides information on the occurrence, availability, and chemical quality of ground water in the alluvium with special emphasis on the potential yield of the alluvial aquifer.

METHODS OF INVESTIGATION

The field and laboratory data for this report were collected from 1957 through 1959. To obtain subsurface and hydrologic information about the alluvial aquifer, most irrigation wells and selected domestic wells in the alluvial area were inventoried and a program of test drilling, water-level observations, and water sampling was set up. The grain size, permeability, and porosity of some of the samples collected during test drilling were determined in the hydrologic laboratory of the Geological Survey at Denver, Colo. Pumping tests to determine the transmissibility and storage coefficients of the alluvial aquifer were made at eight locations.

Measurements of water-level fluctuations were made monthly in certain selected wells and quarterly in all wells. Continuous records of fluctuations were collected at eight large-diameter wells.

Quality-of-water data were compiled by collection and chemical analysis of water from wells during the study and by assembly of the results of previous analyses.

ACKNOWLEDGMENTS

The authors wish to thank the many residents, well drillers, well owners, and municipal officials in the area and the representatives of State and Federal agencies who provided information and assistance.

SYSTEM USED IN NUMBERING WELLS AND TEST HOLES

The well-numbering system used in this report is based on the Federal land-survey system as used in Arkansas (fig. 1). The component parts of a well number are the township number, range number, section number, and three lower-case letters which indicate, respectively,

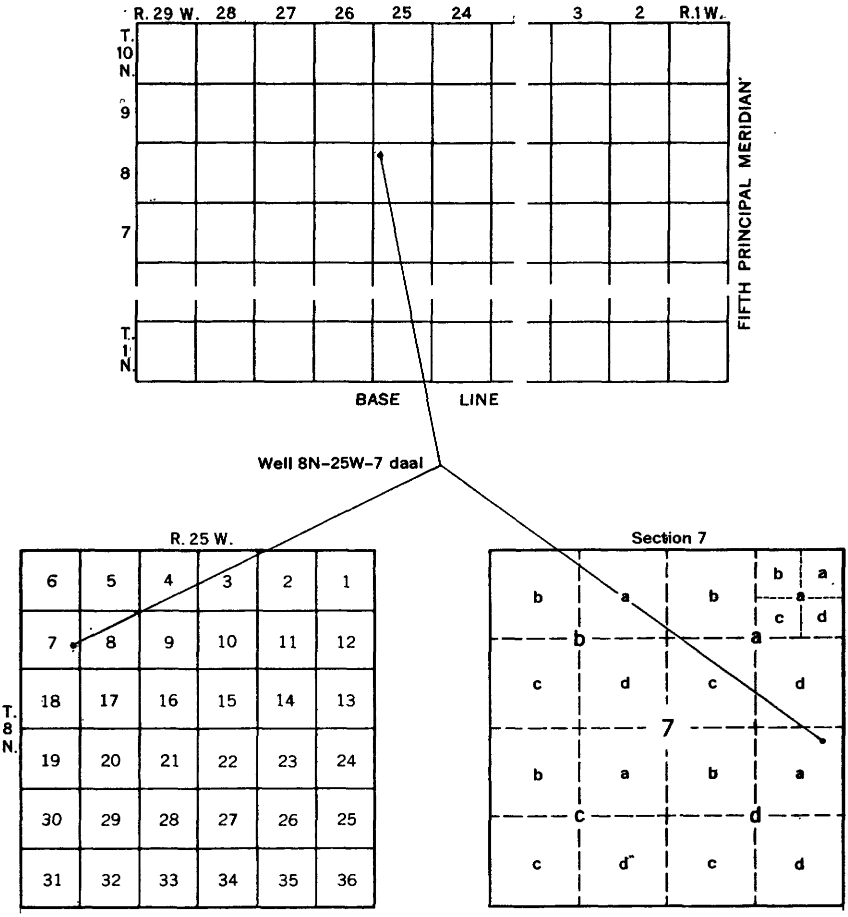


FIGURE 1.—Well-numbering system.

the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section in which the well is located. Serial numbers are also included in all well numbers, because two or more wells are located in many of the quarter-quarter-quarter sections.

Directions of township and range were not shown on the geologic sections of plate 1, as all townships in the report area are north of the base line and all ranges are west of the principal meridian.

GENERAL DESCRIPTION OF THE REPORT AREA

According to Croneis (1930), Arkansas can be divided into two topographic areas of nearly equal size. The northwestern half, which is hilly to mountainous, is the Interior Highlands physiographic province. The southeastern half of the State is nearly flat or rolling and is part of the Gulf Coastal Plain (fig. 2).

The area studied in this report is the part of the flood plain of the Arkansas River that crosses the Interior Highlands for a distance of

200 miles from Fort Smith to Little Rock. The total area of the flood plain is about 280 square miles.

The flood plain consists of alluvium, which occurs along the river in discontinuous segments about 3 to 43 miles long. The flood plain generally is 1 to 3 miles wide, but in some places is 5 miles wide. In places, terraces, which are older deposits of alluvium, border the flood plain. In a few places the alluvium and terrace deposits are absent, and the river is bordered on both sides by the consolidated rocks of the Interior Highlands.

The largest tributaries of the Arkansas River in the area are south of the river, and most of them run parallel to the ridges which trend eastward. North of the river the tributaries are smaller and generally flow southward.

Most of the precipitation falls as rain, which is normally abundant and well distributed throughout the year. The mean annual precipitation at Fort Smith is about 42 inches; at Little Rock it is about 48 inches. The mean annual temperature at both locations is 62°F.

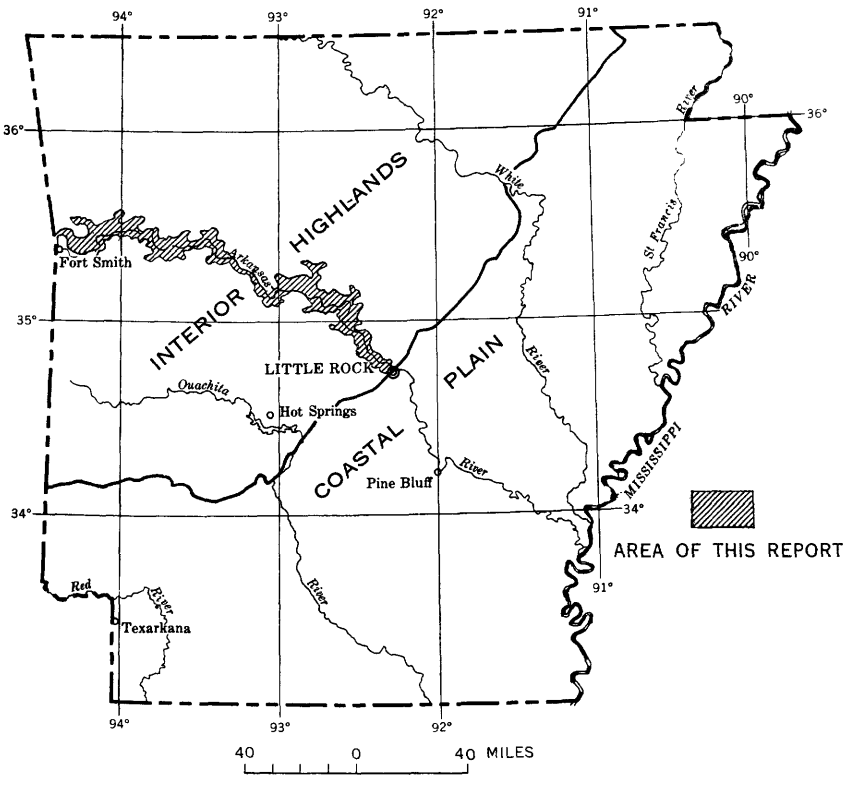


FIGURE 2.—Index map of Arkansas showing report area.

GEOLOGY

BEDROCK

Consolidated rocks of Mississippian and Pennsylvanian age border and underlie the alluvial and terrace deposits of the Arkansas River between Little Rock and Fort Smith. The bedrock includes the Stanley Shale and Jackfork Sandstone of Mississippian age and the Atoka Formation, Hartshorne Sandstone, McAlester Shale, Savanna Sandstone, and Boggy Shale, of Pennsylvania age. The bedrock consists chiefly of well-indurated thin- to massive-bedded sandstone, shale, sandy shale, and siltstone. These rocks are described in reports by Croneis (1930) and Hendricks and Parks (1950).

TERRACE DEPOSITS

The terrace deposits adjacent to the alluvium of the Arkansas River can be differentiated into (1) older rock-defended terrace deposits, whose bases are above the surface of the adjacent alluvium, and (2) younger terrace deposits, whose bases are below the surface of the alluvium. Hydrologically, the presence of these two types of terrace deposits is significant. The water in the older terrace deposits is not connected hydraulically with the water in the alluvium, whereas the water in the younger terrace deposits is.

The older rock-defended terrace deposits generally are composed of gravel, sand, silt, and clay. One such terrace has been observed near Van Buren at a height of 150 feet above the Arkansas River. A lower terrace lies about 50 feet above the flood plain of the Arkansas River. This lower terrace has been mapped in the western part of the valley by Hendricks and Parks (1950). The lower terrace deposits have a maximum thickness of about 50 feet.

The younger terrace deposits occur in the vicinity of Oppello and Roland. At Oppello they consist of clay underlain by sand and lie at several levels 30 feet or more above the flood plain of the Arkansas River. At Roland they are composed chiefly of silt and clay and lie about 30 feet above the flood plain of the river. The deposits at Oppello have not been definitely correlated with those at Roland.

ALLUVIUM

The alluvium underlying the flood plain of the Arkansas River is composed of sand, gravel, silt, and clay and grades generally from fine grained at the surface to coarse grained at the base. It ranges in thickness from an average of about 40 feet near Fort Smith to about 80 feet near Little Rock.

At the surface the alluvium can be divided into several types of alluvial deposits—point bar, swale, channel fill, natural levee, and back swamp—which can be distinguished on the basis of lithologic

690-423—63——2

character and topographic expression (Waterways Experiment Station, 1951; Bedinger and Reed, 1960).

In places, the alluvium underlying the flood plains of the tributary streams exhibits rudiments of the aforementioned types or deposits, but, areally, no distinction of the various types can be made. Consequently, the deposits of tributary streams are referred to in this report as tributary alluvium. Test holes show that where alluvium is present in the various tributary streams, it is generally composed of clay and silt. At Plummerville and Perry, however, the tributary alluvium contains relatively well-sorted gravel.

The lower part of the alluvium generally is composed of sand and gravel. Locally, beneath some channel-fill deposits and tributary alluvium, the sand and gravel is absent. In most places, however, 30 to 60 feet of saturated sand and gravel is present, the thickness generally increasing with distance downstream from Fort Smith.

Logs of representative test holes in the alluvium are given in table 1. Geologic sections of the alluvium are shown in plate 1.

TABLE 1.—*Logs of selected test holes*

6N-15W-30bbc1

[Conway County. Log by U.S. Geol. Survey. Surface alt, 287.1 ft. Depth to water, 13.8 ft., Apr. 27, 1959]

	Thickness (feet)	Depth (feet)
Silt, clayey, brown	4	4
Sand, very fine, light-brown	5	9
Sand, very fine, clayey, light-brown	10	19
Sand, very fine to fine, clayey, light-brown	10	29
Sand, medium, light-brown; contains some fine sand	5	34
Sand, medium to coarse, light-brown; contains some fine and some very coarse sand	20	54
Bedrock at 54 ft		

6N-17W-6caa2

[Conway County. Log by U.S. Geol. Survey. Surface alt, 303.0 ft]

	Thickness (feet)	Depth (feet)
Clay, silty, black	4	4
Sand, medium, tan; contains some fine sand	12	16
Sand, medium, tan; contains some coarse sand	6	22
Sand, medium to coarse, tan; contains trace of very coarse sand	29	51
Sand, very coarse, tan; contains some coarse to medium sand and a trace of very fine to medium gravel	9	60
Bedrock at 60 ft is black shale		

9N-31W-32ccb1

[Crawford County. Log by U.S. Geol. Survey. Driller: Troy Mullens. Surface alt, 396 ft. Depth to water, 11 ft, Apr. 27, 1960]

	Thickness (feet)	Depth (feet)
Sand, fine; fairly well cemented with clay	1	1
Sand, fine to medium	1	2
Clay, brown	1	3
Sand, fine	4	7
Silt and very fine sand; contains a thin stringer of blue-gray clay at 13 ft	13	20
Sand, very fine, and brown silt	5	25
Sand, coarse; contains much medium sand, some very coarse sand, and some very fine gravel	5	30
Sand and gravel; sand is coarse; gravel is very fine to fine	5	35
Gravel and sand; gravel is generally very fine to fine, but there is a trace of medium gravel; sand is coarse and contains some medium and some very coarse sand	5	40
Bedrock at 40 ft is blue-gray shale		

TABLE 1.—*Logs of selected test holes*—Continued

	Thickness (feet)	Depth (feet)
4N-15W-24cad2 [Faulkner County. Log by U.S. Geol. Survey. Surface alt, 270 ft]		
Soil, clayey, silty, black	2	2
Sand, very fine, silty, light-brown	19	21
Sand, fine, grayish-brown	4	25
Sand, medium, brown; contains some coarse sand	7	32
Sand, coarse, brown; contains much medium sand	11	43
Sand, coarse; contains much medium sand, some very coarse sand, and a trace of very fine gravel	19	62
Sand, coarse; contains some medium sand and much very fine to fine gravel in last 7 ft	12	74
Bedrock at 74 ft is dark-blue-gray to black shale		
8N-26W-15dab2 [Logan County Log by U.S. Geol. Survey. Surface alt, 361.9 ft. Depth to water, 21.3 ft., Apr. 16, 1958]		
Silt, clayey, dark-brown	12	12
Sand, very fine, silty, reddish-brown	7	19
Sand, fine and medium, silty, reddish-brown	5	24
Sand, medium and coarse, silty, reddish-brown	5	29
Sand, coarse and very coarse, silty, reddish-brown; contains some gravel	25	54
Bedrock at 54 feet		
2N-13W-16bbb3 [Pulaski County. Log by U.S. Geol. Survey. Surface alt, 259.3 ft. Depth to water, 23.2 ft, Apr. 9, 1959]		
Sand, very fine, dark-brown	2	2
Sand, very fine to fine, light-brown	5	7
Sand, fine, silty	10	17
Sand, very fine, silty, dark-brown	5	22
Sand, fine, brown; contains a trace of medium sand at 37 ft and some medium sand at 42 ft	25	47
Sand, medium, brown; contains some coarse sand, a trace of very fine gravel at 57 ft, a trace of very coarse sand at 57 ft, and boulders at 65 ft	20	67
Sand, coarse to very coarse, dark-brown; contains some very fine gravel	5	72
Sand, very coarse, gray-brown; contains a trace of very fine to fine gravel	12	84
Bedrock at 84 ft; no sample		
6N-20W-35bbc2 Yell County. Log by U.S. Geol. Survey. Driller: Troy Mullens. Surface alt, 316 ft. Depth to water 17 ft, Apr. 20, 1960]		
Soil, sandy	1.3	1.3
Sand, fine, brown; contains a trace of medium to coarse sand	6.7	8
Clay, silty, brown	2	10
sand, fine, brown; contains some very fine sand	10	20
Sand, medium, brown; contains much fine sand, some very coarse sand, and some very fine gravel	10	30
Sand, coarse; contains much medium sand, some very coarse sand, and some very fine gravel	5	35
Gravel and sand, brown; contains much fine gravel, some medium sand, and some very coarse sand	24	59

GROUND-WATER HYDROLOGY

HYDROLOGIC PROPERTIES OF THE ALLUVIAL AQUIFER

The quantity of water that an aquifer will yield and the rate at which water will move through it depend, in part, on its ability to transmit and store water. These two properties commonly are measured in terms of the coefficients of transmissibility and storage.

The coefficient of transmissibility is the field coefficient of permeability multiplied by the thickness, in feet, of the saturated part of an aquifer. Thus, the coefficient of permeability is a characteristic of the water-bearing material, and the coefficient of transmissibility is a characteristic of the aquifer as a whole.

Permeability is the capacity of a porous material to transmit water through its interstices. The standard coefficient of permeability used by the Geological Survey is defined as the rate of flow of water at 60°F, in gallons per day, through a cross section of 1 square foot, under a hydraulic gradient of 100 percent. A related coefficient, the field coefficient of permeability, is defined as the rate of flow of water, in gallons per day at the prevailing temperature, through each foot of thickness of a given aquifer 1 mile wide, under a hydraulic gradient of 1 foot per mile.

The factors that determine the permeability of a material, other than grain size and packing, are the sorting and shape of the grains. Poorly sorted material has a smaller permeability than well-sorted material, because the interstices between the large grains are filled with smaller grains which reduce the pore space.

The coefficient of storage is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. For nonartesian aquifers, the coefficient of storage approximates the specific yield.

The coefficients of transmissibility and storage of the alluvial aquifer, determined from pumping tests, are given in table 2. The pumping-test sites are shown in figure 3.

TABLE 2.—*Summary of results of pumping tests in the alluvium between Little Rock and Fort Smith*

Location	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per sq ft)	Coefficient of storage
Conway County:			
6N–15W–30bbc2	90, 000	2, 700	1.5×10^{-3}
6N–17W–6caa7	130, 000	3, 000	3.8×10^{-3}
Crawford County: 9N–29W–10add	60, 000	2, 300	4.1×10^{-3}
Faulkner County: 4N–15W–24cad1	120, 000	2, 100	9.0×10^{-3}
Logan County:			
8N–25W–17ccc2	40, 000	1, 300	1.0×10^{-4}
8N–26W–15dab1	90, 000	2, 800	7.0×10^{-2}
Pulaski County: 2N–13W–16bbb1	160, 000	3, 000	5×10^{-2}
Yell County: 6N–20W–35bbc2	120, 000	3, 000	3.8×10^{-3}

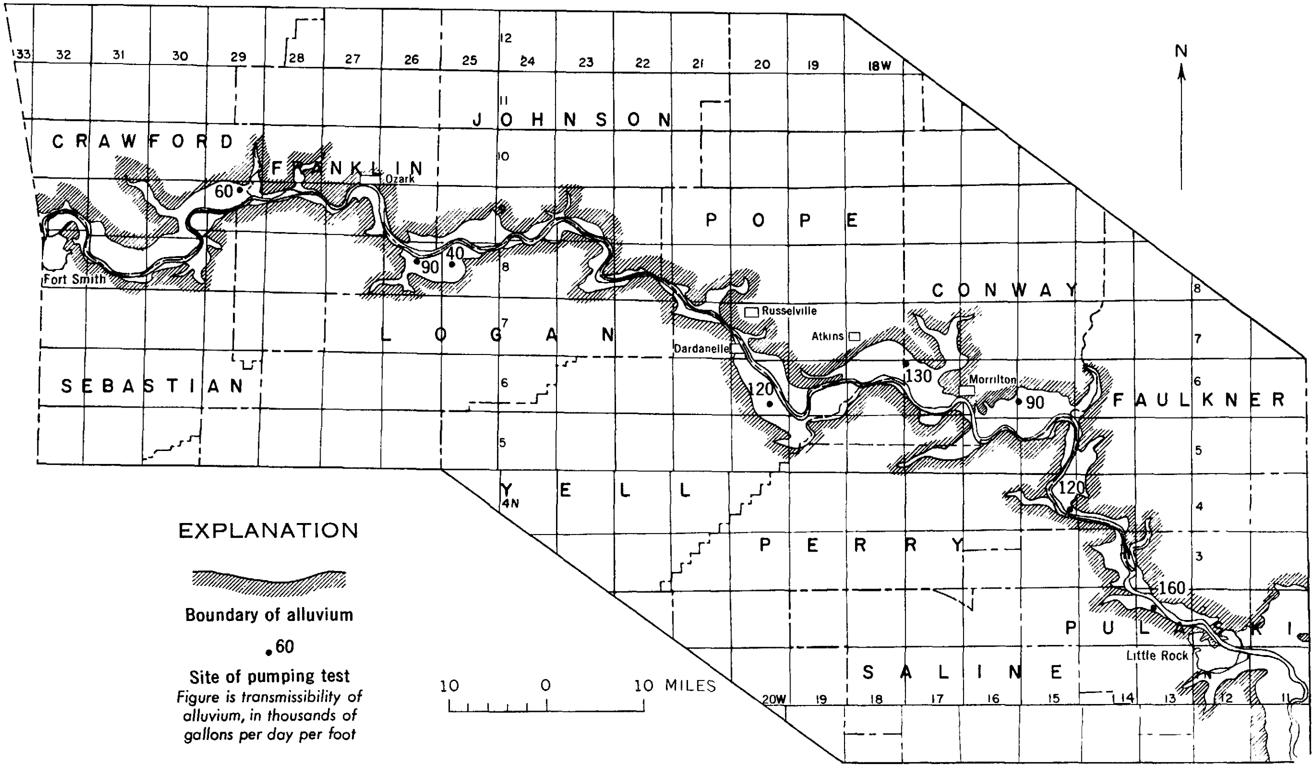


FIGURE 3.—Pumping-test sites and transmissibility determinations in the alluvium of the Arkansas River between Little Rock and Fort Smith.

The relation between grain size of the material composing the aquifer and yield of wells (table 3) in the aquifer was established by (1) determining graphically a relation between grain size and permeability and (2) determining well yields from permeabilities based on information obtained from pumping tests and well and test-hole records.

TABLE 3.—*Relation of grain size of aquifer material to yield of a well in alluvium of the Arkansas River between Fort Smith and Little Rock*

Type of material	Grain size (millimeters)		Yield (gpm per ft of thickness) of a fully penetrating 12-in-diameter well operating at 100 percent efficiency	
	From—	To—	From—	To—
Sand, very coarse	1.0	2.0	30	75
Sand, coarse and very coarse	.5	2.0	12	18
Sand, coarse	.5	1.0	7	10
Sand, medium and coarse	.25	1.0	2.5	4
Sand, medium	.25	.5	1.5	2.5
Sand, medium and fine	.125	.5	.75	1.5
Sand, fine	.125	.25	.5	1

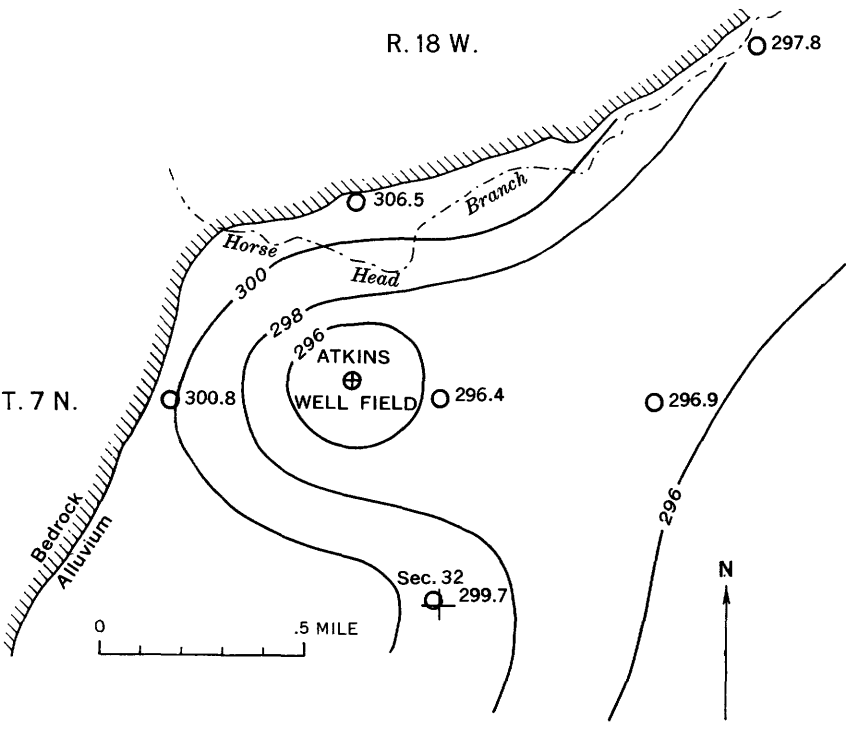
Table 3 can be used to estimate the potential yield of a well, as follows: (1) From a log or sample, determine the thickness of the saturated material having the same grain size, (2) assign a figure for yield to the material, (3) multiply the yield figure by the thickness of the material in feet, and (4) add the figures obtained in (3) for each type of material. This figure is the yield that can be expected from the well.

RECOVERY OF GROUND WATER

When water is withdrawn from a well, the water level in the vicinity of the well declines and assumes a form similar to that of an inverted cone known as the cone of depression. As pumping continues, the drawdown increases and the cone of depression becomes larger. The water level declines rapidly at first and then more slowly. If the aquifer is not receiving recharge or if discharge from the aquifer is greater than recharge to the aquifer, the cone of depression will eventually extend to the limits of the aquifer. If, however, recharge to the aquifer is greater than discharge from the aquifer an equilibrium gradient will be established wherein water will be transmitted to the well in approximately the amount that is being pumped.

Water-level measurements of the water table in the vicinity of the Atkins well field show that a condition of equilibrium has been reached (fig. 4). This means that the cone of depression has reached its approximate maximum extent and ground water is diverted toward the wells at the same rate that the wells are being pumped. Under natural conditions this water would discharge into the Arkansas River; therefore, water pumped from this well field is salvaged natural discharge.

The drawdown in a well is affected when the cone of depression reaches the boundaries of an aquifer. The aquifer boundaries in the report area are of two types—a boundary formed by the relatively



EXPLANATION

——296——

Contour (line) on the water table. Contour interval is 2 feet. Datum is mean sea level

O 306.5

Observation well showing altitude of the water table, in feet above mean sea level

⊕

City of Atkins wells

FIGURE 4.—Water table in the vicinity of the Atkins well field, April 1959.

impermeable bedrock and a boundary formed by the Arkansas River and its tributaries. When the cone of depression reaches an impermeable boundary, the drawdown increases because the impermeable material contributes no water. When the cone of depression reaches a river or other body of surface water, the drawdown in the pumped well decreases because water is contributed to the well from the river. The relations between cones of depression and these two types of boundaries are shown in figure 5.

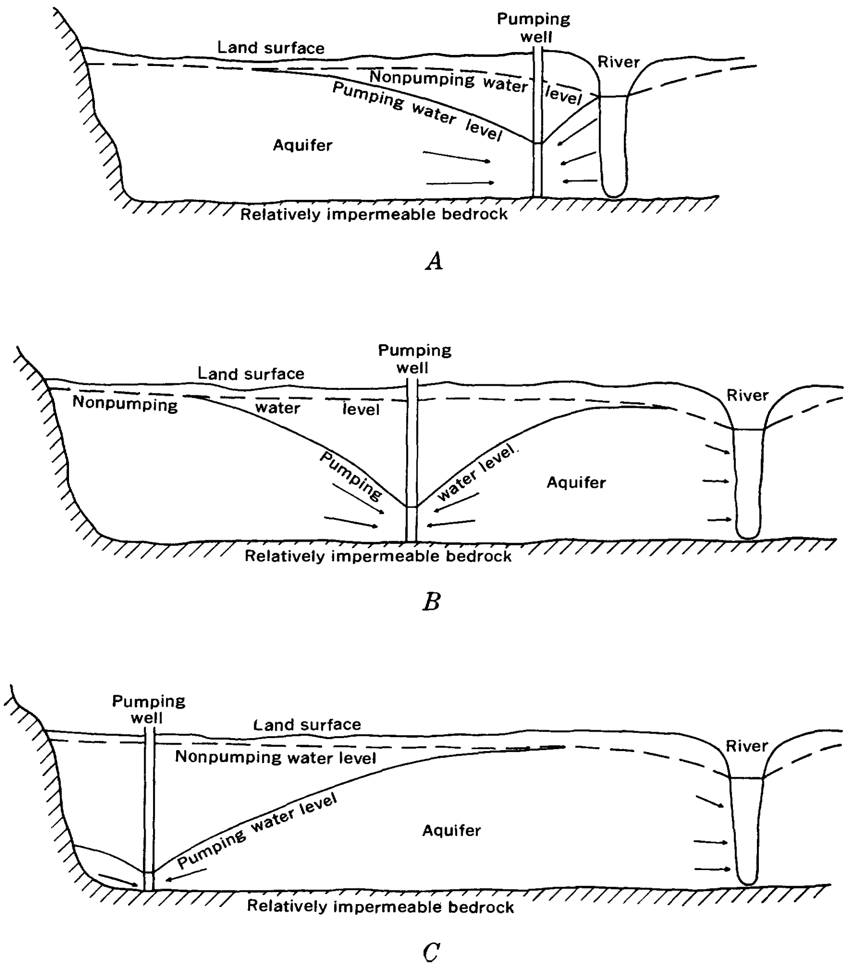


FIGURE 5.—Relation of well locations to hydrologic and geologic boundaries and to the cone of depression (pumping water level). *A*, Pumping well induces recharge from the river; drawdown is relatively small. *B*, Pumping well diverts natural ground-water flow to well at a rate equal to pumping rate; drawdown is moderate. *C*, Pumping well causes cone of depression to reach boundary of impermeable bedrock; drawdown is relatively large.

FLUCTUATIONS OF THE WATER TABLE

The water in the alluvial aquifer bordering the river between Little Rock and Fort Smith is largely under water-table conditions. Fluctuations of the water table caused by changes in atmospheric pressure and other load-imposed causes are insignificant. Barometrically induced fluctuations have been recorded in a few wells where the aquifer is overlain by fine-grained material. The largest fluctuations of the water table however, are those caused by changes in river stage and recharge from precipitation.

Water-table fluctuations due to variations in the rate of recharge from precipitation and of discharge by evapotranspiration may be considered as fluctuations due to variations in the rate of accretion of water to the aquifer. These fluctuations generally are difficult to identify on hydrographs of water levels in wells, because they are of small magnitude and frequently obscured by fluctuations caused by changes in river stage. At great distances from the river, where effects of river-stage variations are small, some fluctuations of the water level in wells can be correlated with precipitation.

Comparison of the hydrograph of the water level in well 8N–25W–7daa2, which is about 1,300 feet from the Arkansas River, with the hydrograph of the river stage at Ozark shows the relation between fluctuations of river stage and the water table (fig. 6).

The hydrograph of well 8N–25W–17ccc2 (fig 6), which is 8,800 feet from the river, shows the small magnitude of water-level fluctuations at great distance from the river. Most of the fluctuations shown in this well are caused by changes in the rate of accretion of water to the aquifer.

The diminishing effect of changes in river stage with increasing distance from the river and its tributaries is also shown by hydrographs of water levels in wells along lines perpendicular to the river (pl. 2).

CONFIGURATION OF THE WATER TABLE

The shapes of the water table in the alluvial segments from Little Rock to Fort Smith are similar. During normal and low river stages, the surfaces slope toward the river and larger tributary streams. Mounds on the water table are common beneath the more permeable surface materials. During high river stages, the ground-water gradient is reversed near the river, and troughs are formed in the water table along each side of the river.

Locally, pumping modifies the shape of the water table. Pumping for irrigation has little pronounced effect, because irrigation wells are widely spaced and pumpage is small. Pumping for municipal

690–423—63——3

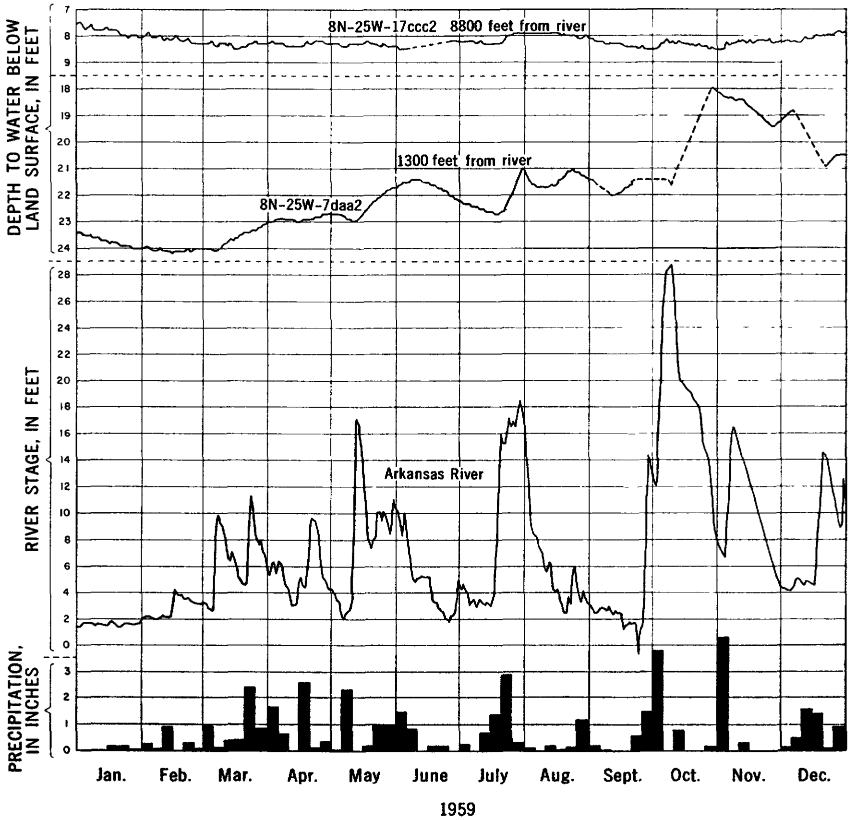


FIGURE 6.—Hydrographs of the stage of the Arkansas River at Ozark and the water level in wells 8N–25W–7daa2 and 8N–25W–17ccc2, Logan County, and graph showing precipitation at Paris, Arkansas.

use is practically continuous and is concentrated in small areas. At the Atkins municipal well field (fig. 4) pumping has a pronounced effect on the water table. The well fields of Ozark and Dardanelle are near the river. Pumping has extended the cones of depression at these well fields to the river, from which recharge is being induced.

RECHARGE AND DISCHARGE

Recharge to the alluvium is derived from infiltration of rainfall, underflow from adjacent bedrock and terrace deposits, infiltration or irrigation water, and influent seepage and recharge induced from the river. Infiltration of rainfall is the most important source of recharge, and is greatest in areas that are underlain by the highly permeable point-bar and natural-levee deposits. There is less recharge from rainfall in areas underlain by backswamp and channel-fill deposits. The amount of underflow from adjacent terrace deposits and bedrock is small, but in places sufficient quantities of water are added to alter the chemical character of water in the alluvium. Infiltration of irrigation water is of local importance where large amounts of water are applied to crops in permeable soils. Throughout most of the area, recharge by influent seepage from the river occurs only for short periods of time during high river stages. In places where large quantities of ground water are withdrawn, the natural hydraulic gradient may be reversed and significant amounts of recharge induced from the river.

Recharge to the alluvium in the vicinity of the Atkins well field was determined to be about 3 inches per year. Determination of the recharge rate was made by constructing flow lines on a map of the water table to outline the area of recharge that supplies the Atkins wells and by applying pumpage figures to this area. The fact that the area is underlain largely by backswamp deposits explains the relatively low rate of recharge.

The average rate of recharge to the McLean Bottoms, 122 miles upstream from Little Rock, was about 10 inches per year as determined from the water-table map for February 1958. On the basis of the recharge rate of 10 inches per year, recharge to the 280-square-mile area of alluvium between Little Rock and Fort Smith was estimated to be about 130 mgd (million gallons per day).

The quantity of ground water discharged by evapotranspiration is not known but is probably large. Dense growths of plants, several species of which are known to draw water from the zone of saturation or capillary fringe, are present in the area.

There is no discharge from the alluvium to bedrock or terrace deposits in the area. Water levels in the rocks adjacent to the alluvium are higher than water levels in the alluvium and indicate that any movement of water is from the adjacent rocks to the alluvium.

UTILIZATION OF GROUND WATER

In 1959 about 3.2 mgd of water was pumped from the alluvium. Approximately half was used for irrigation and half for public supplies. A small amount of water drawn from privately owned wells was used by households, stock, and self-supplied industries.

IRRIGATION USE

Almost all water pumped for irrigation is used for cultivation of row crops. Although precipitation in the area is about 48 inches per year and normally is well distributed throughout the year, droughts of short duration are frequent during the growing season.

Gattis (1950) reports that supplemental irrigation of row crops is profitable in 3 out of 4 years owing to the irregular distribution of rainfall during the growing season.

Cotton and soybeans are the principal crops that receive supplemental irrigation. Other crops receiving supplemental irrigation are vegetables, which are grown chiefly in Crawford and Pope Counties for nearby canneries.

In 1959 about 1,110 acres of rice was grown in Conway, Faulkner, and Perry Counties. Because the soils of the area are generally sandy, rice probably is not grown extensively.

In 1959 about 1.8 mgd of ground water was used for irrigation in the area (table 4).

TABLE 4.—*Use of ground water for irrigation in the alluvium between Little Rock and Fort Smith in 1959*

County	Pumpage (acre-ft.)	County	Pumpage (acre-ft.)
Conway	240	Perry	-----
Crawford	600	Pope	50
Faulkner	440	Pulaski	100
Franklin	20	Sebastian	60
Johnson	-----	Yell	500
Logan	30		
		Total	2, 040

PUBLIC AND INDUSTRIAL USE

In 1959 the combined public-water-supply pumpage from wells in the alluvium at Atkins, Dardenelle, Morrilton, and Ozark amounted to about 1.4 mgd. (See table 5.) Most of the water was pumped for domestic use, and some was supplied to small industries. One industry at Dardenelle was supplied, in part, from privately owned wells.

TABLE 5.—*Municipal pumpage (1959) of ground water from the alluvium between Little Rock and Fort Smith*

City	Pumpage (mgd)[1]	City	Pumpage (mgd)[1]
Atkins	0. 16	Morrilton	0. 68
Dardanelle	. 22	Ozark	. 30
		Total (rounded)	1. 4

[1] Million gallons per day.

ATKINS

The Atkins municipal well field is about 2 miles south of the city in Pope County. About 1,300 inhabitants of Atkins are supplied with water from three wells. Two of these wells reportedly yield about 250 gpm each. The third well yields about 75 gpm. The pumpage during 1959 was 59 million gallons, or an average of about 162,000 gpd (gallons per day), about half of which was used by a pickle-processing plant.

At a filtration plant the water is aerated, treated with chlorine, lime, and aluminum sulfate, and pumped into a settling basin. The water is then recarbonated, filtered, and pumped to a 100,000-gallon elevated steel tank for distribution in the city water mains. The capacity of the filtration plant is about 1,000 gpm.

DARDANELLE

Dardanelle, whose population is about 1,800, is supplied with water from three wells within the city. These wells yield about 300 gpm each. The water is chlorinated and stored in a 140,000-gallon elevated steel tank. In 1959 the pumpage was 82 million gallons, or an average of about 225,000 gpd.

MORRILTON

Morrilton, whose population is about 5,500, is supplied with water from four wells about 1 mile southwest of the town. Their yields range from about 200 to 500 gpm. The water is aerated, treated with lime and chlorine, settled, and filtered. The water is then stored in a 150,000-gallon ground tank and in a 200,000-gallon elevated tank. Pumpage in 1959 was 249 million gallons, or an average of about 681,000 gpd.

OZARK

Ozark, whose population is about 1,800, has five wells in a field near town on the south bank of the Arkansas River. Storage facilities for the water are a 100,000-gallon elevated steel tank west of town and a 500,000-gallon concrete tank east of town. Annual pumpage for 1959 was about 110 million gallons, or an average of about 300,000 gpd.

POTENTIAL YIELD

The potential yield of the aquifer depends upon the amount of natural recharge from precipitation and the amount of recharge that can be induced from the river.

NATURAL RECHARGE

If one assumes that the natural recharge to the aquifer by infiltration of rainfall is about 10 inches per year, the total for the area would be about 130 mgd. Theoretically, it would be possible to pump 130 mgd from the aquifer without an overdraft of ground-water storage or induction of recharge from the river. In 1959 ground water was pumped at an average rate of about 3.2 mgd, or less than 3 percent of the amount available from natural recharge. Although in practice development of all natural recharge without inducing recharge from the river is not feasible, it is apparent that only a very small part of the potential yield has been developed.

INDUCED RECHARGE

Generally under natural conditions the hydraulic gradient in the area is toward the river; this fact indicates that ground water is discharging into the river. Withdrawal of ground water through wells near the river will, if the cone of depression reaches the river, reverse the hydraulic gradient and induce recharge from the river. At the present time (1960) pumping at the city well fields of Dardanelle and Ozark has induced infiltration of river water into the aquifer. Induced infiltration of river water is practiced at many places and is discussed in a number of papers, including those by Rorabaugh (1948a, 1948b, and 1951) and Kazmann (1948a, 1948b, and 1949). References to other papers concerning induced infiltration can be found in a bibliography by Todd (1959).

Ground-water supplies developed near the river will derive part of the water by induced infiltration from the river and part from natural ground-water recharge (Theis, 1941). The percentage of induced river water in water pumped from a well depends upon distance of the well from the river, hydrologic properties of the aquifer, rate of pumping, amount of natural recharge to the aquifer, direction of natural ground-water movement, river stage, and temperature of the river water.

Development of ground-water supplies by induced infiltration of river water has certain advantages over some surface-water supplies. Water from the Arkansas River generally is, especially during low-flow periods, of poor quality and requires extensive treatment for municipal and most industrial uses. The temperature of the water in the summer exceeds 80° F., which makes the water unsuitable for cooling purposes. Ground-water supplies developed by inducing recharge from the river are intermediate in chemical quality and in temperature between the river water and ground water.

The percentages of ground water and river water pumped by a given well can be computed, if the necessary hydrologic data are available. The resulting water however, will not be a simple mixture of river and ground water. As the river water enters the aquifer, heat exchange will take place between the river water and the aquifer materials. Chemically, the river water will undergo change by dissolving materials from the aquifer. Also chemical reactions may take place between the river water and aquifer materials, further altering the original character of the river water.

For ground-water supplies near the Ohio River Rorabaugh (1951, p. 171) reports that

Apparently, objectionable odors and tastes, which have been a major problem in treating of surface water, are removed or diluted by an induced percolation system. Data are lacking to prove this point definitely. However, evidence that users of such supplies have not been troubled by odors and tastes has been cited by Jeffords (1945, p. 151) and Kazmann (1948b, p. 419).

In an induced infiltration system, the fluctuations of ground-water temperature follow temperature fluctuations of the river, but the temperature range and the time lag of fluctuations of water pumped depend upon the hydrologic properties of the aquifer, rate of pumping, distance of the well from the river, and heat exchange between the aquifer and induced water.

The advantages of an induced-infiltration supply over a common ground-water supply also include the availability of more water and reduced drawdown. These conditions in turn, result in more economical pumping costs.

Induced infiltration of water from the river increases many times the ground-water potential of the alluvial aquifer that is available from natural recharge alone. For example, in a representative part of the alluvium, 264 wells spaced 200 feet apart in a line parallel to and 100 feet from the river would be capable of pumping 200 mgd. Although this amount does not represent the maximum possible ground-water development along a 10-mile length of river, it is about twice the amount available from natural recharge in the entire area and indicates the potential available by induced infiltration.

CHEMICAL QUALITY OF GROUND WATER

GENERAL STATEMENT

Ground water from the Arkansas River alluvium principally is of the calcium magnesium bicarbonate type and is characterized by wide variations in the dissolved-solids content. The variations in dissolved-solids content and percentage composition are related more to the movement of water from adjacent or underlying formations into the alluvium than to the movement of ground water within the alluvium.

The maximum, minimum, and median concentrations of the principal constituents determined are shown in table 6. The median values emphasize the calcium magnesium bicarbonate type of water and indicate that the maximum concentrations of the other constituents are not common throughout the area. The high maximum values for chloride in Franklin and Yell Counties are the result of influent river water at the Ozark and Dardanelle municipal wells. Other high concentrations of sulfate, chloride, and nitrate are probably the result of water moving from other formations into the alluvium.

TABLE 6.—*Summary of analyses of water from the alluvium*

[Chemical analyses in parts per million]

County	Iron (Fe)		Bicarbonate (HCO_3)		Sulfate (SO_4)		Chloride (Cl)		Nitrate (NO_3)		Calcium, magnesium		Specific conductance (micromhos at 25°C)	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Pulaski	30	0.15	382	106	34	2.0	130	3.0	27	0.4	349	127	1,020	255
Faulkner	18	.00	558	190	64	.8	53	1.5	84	.2	448	172	937	333
Conway	49	.00	698	11	119	.4	69	1.8	292	.0	630	30	1,250	161
Yell	51	.09	526	23	132	1.0	208	2.0	270	.0	688	35	1,320	101
Pope	29	.08	508	31	150	.8	187	2.2	148	.0	510	42	1,450	108
Johnson	21	.09	426	136	71	1.0	32	4.0	6.4	.2	840	140	1,420	311
Logan	19	.00	632	94	45	.0	53	2.0	20	.0	546	95	973	148
Franklin	25	.02	215	19	58	2.0	225	2.2	37	.8	370	21	931	64
Crawford	21	.00	622	95	187	2.0	164	2.0	146	.0	538	120	1,230	234
Sebastian	56	.01					75	5.5			634	178	1,250	362
Median for area	1.4		245		18		11		5.2		253		510	

Specific conductance, expressed as micromhos at 25° C, is a measure of the capacity of the water to conduct an electrical current. Conductance varies with the quantities of dissolved mineral constituents, the degree of ionization of these constituents, and the temperature of the water. The specific conductance is useful in indicating the approximate dissolved-solids content of a water. The relation between specific conductance and the dissolved-solids content of water from the alluvium is shown in figure 7 (Hem, 1959, p. 40–41). Specific-conductance determinations were made on 618 samples from the project area. The distribution of these conductance values and the estimated dissolved-solids content (from fig. 7) are summarized in the following table:

Percent of samples having a specific conductance equal to or less than that shown

Percent of samples	1	10	25	50	75	90	99
Specific conductance...micromhos at 25° C	151	259	375	510	620	880	1,200
Dissolved solids [1]...p.p.m.	115	170	232	315	390	560	768

[1] Estimated from fig. 7.

Although the specific conductance values for the area ranged from 64 to 1,450 micromhos, the table shows that for 50 percent of the samples (from 25 to 75 percent) the specific conductance was between 375 and 620 micromhos and that for 90 percent of the samples the specific conductance was 880 micromhos or less.

The concentration of constituents given in a chemical analysis of water may be expressed in terms of equivalents per million, as well as in parts per million. When the results of a chemical analysis are expressed in equivalents per million, the sum of the cations (calcium, magnesium, sodium, and potassium) is equal, except for small errors in the analysis, to the sum of anions (carbonate, bicarbonate, sulfate, chloride, fluoride, and nitrate). This means of expression shows the chemical relations between the various ions in the water.

Figures 8 and 9 show the relation of the cations and the alkalinity to the total concentration, in equivalents per million, respectively. The total concentration is the sum of the ionized constituents. In figure 8 the concentrations of calcium plus magnesium and sodium plus potassium have been plotted against the total concentration. The figure shows that, as the total concentration increases, about 90 percent of the increase in cation concentration is due to calcium and magnesium. The increase in sodium and potassium is much less.

Alkalinity is caused principally by carbonates and bicarbonates. In figure 9 the alkalinity is plotted as carbonate plus bicarbonate. The plots of alkalinity for those analyses that show a nitrate content greater than 10 ppm (parts per million) have been adjusted using F. H. Rainwater's method (Sneigocki, 1955). (See arrows, fig. 9.)

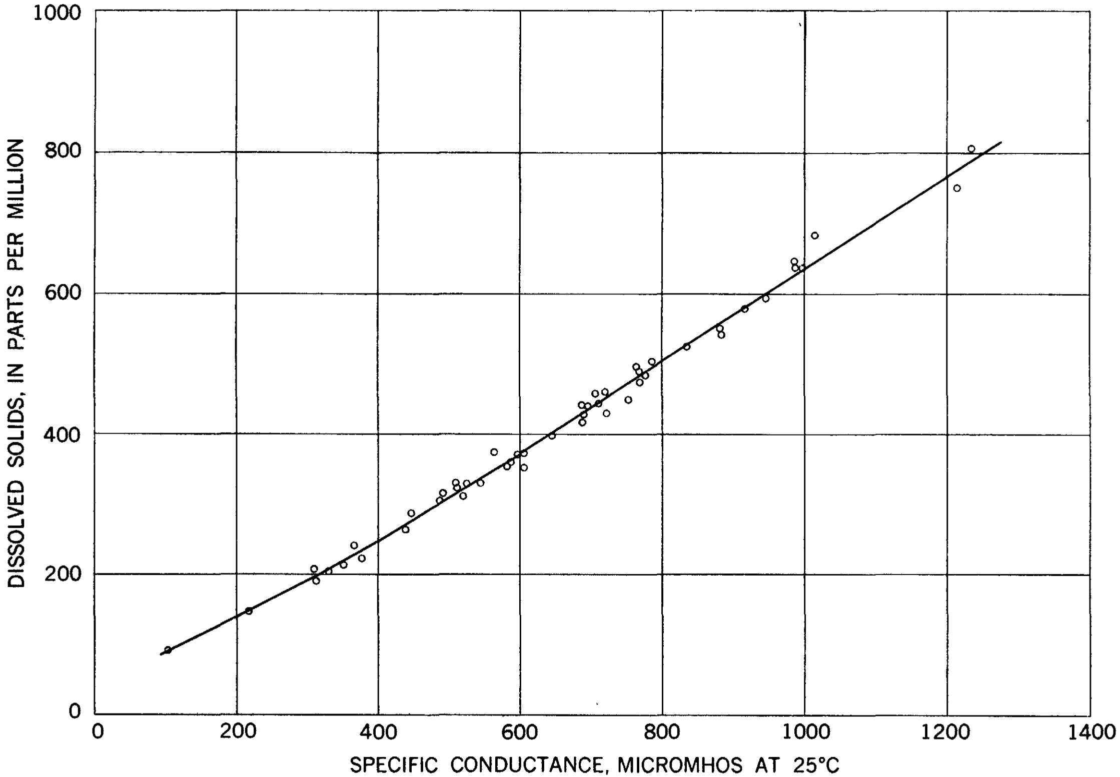


FIGURE 7.—Relation between specific-conductance values and dissolved-solids content.

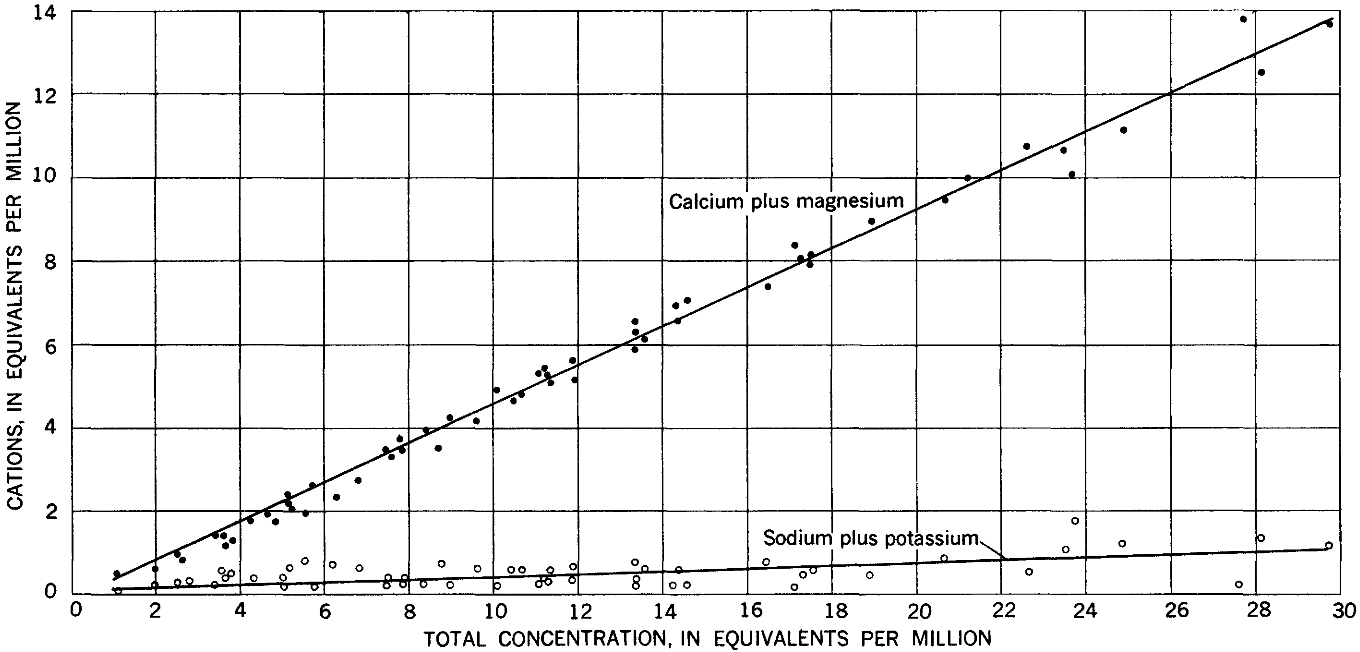


Figure 8.—Relation of cations to total concentration.

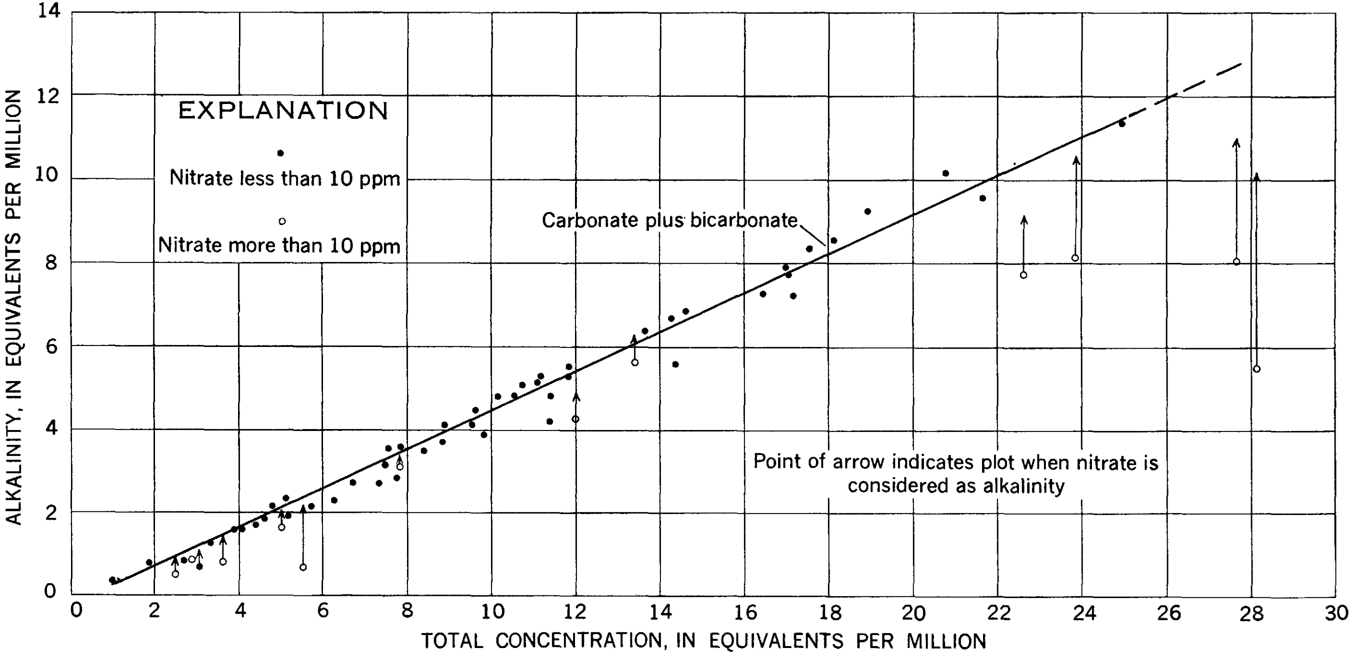


FIGURE 9.—Relation of alkalinity to total concentration.

The lack of correlation at the higher concentrations is presumed to be a result of water from adjacent or underlying formations moving into and mixing with water in the alluvium. The samples that had the higher nitrate content also had a higher percentage of sulfate and chloride than that normally found in water from the alluvium. A comparison of figures 8 and 9 shows that an increase in total concentration is due mainly to calcium, magnesium, and alkalinity. The fact that the slopes of the calcium plus magnesium and the carbonate plus bicarbonate are almost equal indicates that these constituents increase in almost equivalent proportions.

CHEMICAL QUALITY OF GROUND WATER IN RELATION TO USE

DOMESTIC AND INDUSTRIAL USES

Many cities and towns that have public water supplies chemically treat the water before distribution is made to the public. Treatment of most privately owned supplies is not feasible. Four cities in the project area use water from the alluvium for municipal supplies. The types of water treatment used are outlined in the section, "Utilization of ground water." The U.S. Public Health Service (1946, 1961) has recommended maximum limits on some constituents of water for drinking and culinary uses on interstate carriers. The limitations and the chemical analyses data (abridged) of municipal water supplies from the alluvium are shown in table 7. Some samples collected from the treatment plant or distribution system may be a composite sample of treated water from several wells; therefore, the analyses of these samples may not compare with the raw-water analyses. With the exception of iron plus manganese content in the water from the Ozark system, all the constituents are below the maximum concentrations recommended by the U.S. Public Health Service standards. At times, pumping of the Ozark and Dardanelle wells induces recharge from the Arkansas River, which is reflected by the high chloride content shown in the analyses of water from these wells.

Hardness of the water and concentrations of iron, fluoride, silica, and nitrate are important to domestic and industrial users of water. Hardness of water is the property attributable to the presence of alkaline earths (Hem, 1959, p. 145–148). Calcium and magnesium are the principal alkaline earths in natural water. Hardness is recognized by the amount of soap required to produce a lather and also by the formation of an insoluble curd which is objectionable in washing processes. The use of hard water in boilers, water heaters, radiators, and pipes is objectionable because of formation of scale. Generally, water having a hardness of less than 60 ppm is regarded as soft, and water having a hardness of more than 200 ppm is regarded

TABLE 7.—*Results of analyses of water from municipal supplies*

[Results in parts per million; analyses by Arkansas State Board of Health. Date of collection: At Atkins and Dardanelle, May 1957; at Morrilton, August 1957; at Ozark, September 1957]

Constituent	Maximum limits recommended by U.S. Public Health Service	Atkins		Dardanelle		Morrilton		Ozark	
		Wells 2 and 3	Plant	Well 2	System	Wells	Plant	Well 1	System
Iron (Fe)	0.3	3.9	0.02	0.02	0.08	5.2	0.02	1.1	6.0
Manganese (Mn)	.05	.00	.00	.00	.00	.20	.00	2.2	1.4
Aluminum (Al)		.0	.0	.0	.0				.0
Calcium (Ca)		54	39	68	68	73	21	96	58
Magnesium (Mg)	125	9.8	11	18	17	9.8	9.8	24	21
Chloride (Cl)	250	6.5	8.0	208	206	16	18	225	175
Sulfate (SO_4)	250	8.0	14	28	28	10	9.5	17	12
Fluoride (F)	[1] 0.8–1.7	.3	.3	.3	0	.2	.2	.4	.3
Total Solids	[2] 500	230	179	690	690	290	151	817	570
Total Hardness as $CaCO_3$		176	141	243	239	222	92	338	230
Total Alkalinity as $CaCO_3$		178	132	129	126	202	83	206	136
pH		7.3	8.7	6.9	6.9	7.2	8.6	7.0	6.9

[1] Dependent on annual average of maximum daily air temperatures °F.
[2] 1,000 ppm permitted when water of better quality is not available.

as very hard. The fact that the median value for hardness in the project area was 253 ppm indicates that the hardness of most of the water would be undesirable for domestic use.

A high iron content—more than 0.3 ppm—is undesirable in water for domestic use because the iron stains fabrics and porcelain or enameled fixtures. Most industrial users require water that is practically free of iron. The median value for iron in the area was 1.4 ppm.

A small amount of fluoride in drinking water is beneficial in reducing tooth decay, although large amounts cause mottling of tooth enamel. Fluoride was determined on 20 samples from the area. The concentrations ranged from 0.0 to 0.7 ppm, which are well below the maximum limit permitted by the U.S. Pacific Health Service (1961).

A silica content of water higher than 1 ppm can be troublesome, if the water is used in high-pressure boilers and steam turbines (Hem, 1959, p. 254). Silica contributes to the formation of hard boiler scale and is also deposited on steam turbine blades. In 19 samples from the project area, the silica concentration ranged from 5.8 to 35 ppm.

The U.S. Public Health Service (1961) standards recommend that the nitrate concentration be no higher than 45 ppm in water used in infant feeding. About 12 percent of the nitrate determinations show a concentration higher than 45 ppm. The median value for nitrate was 5.2 ppm—well below the 45 ppm limit.

Quality-of-water requirements for industry are as varied as the types of industry. Interested water users are referred to a publication by the California State Water Pollution Control Board (1952).

IRRIGATION

In rating a water for irrigation use, factors other than quality of the water must be considered. Among these are soil composition, permeability, drainage, and irrigation practices. Wilcox (1948) rates water for irrigation with respect to total concentration and percent sodium, assuming that conditions with respect to the factors just listed are average. Specific conductance is used to indicate total concentration, and percent sodium is calculated by dividing the equivalents per million of sodium by the total equivalents per million of the cations and multiplying the quotient by 100. When classified by this method, most of the water from the alluvium rates excellent to good. Because of a high total concentration, about 10 percent of the samples would be rated good to permissible.

CONCLUSIONS

Along the Arkansas River the alluvium ranges in thickness from about 40 feet near Fort Smith to about 80 feet near Little Rock. The saturated part of the alluvium normally ranges from 30 to 60 feet.

This saturated part, capable of supporting wells yielding in most places from 300 to 700 gpm, constitutes the most important aquifer in the Arkansas valley between Fort Smith and Little Rock. Ground water in the alluvium along this part of the Arkansas River generally is under water-table conditions, the surface of the water table sloping from the valley wall to the river throughout most of the year. Fluctuations of this surface are caused largely by changes in river stage and recharge from precipitation.

The amount of recharge available from precipitation for this area is about 10 inches per year or approximately 130 mgd; the rate of pumping is about 3.2 mgd, which is a small fraction of the amount available from natural recharge.

The amount of water potentially available by induced recharge from the river is many times the amount available from natural recharge.

Ground water in the Arkansas River alluvium is principally of the calcium magnesium bicarbonate type and is characterized by a wide variation in dissolved-solids content. As the dissolved-solids content increases, calcium and magnesium bicarbonates make up about 90 percent of the increase in the ionized constituents. In some areas the dissolved-solids content and percentage composition are affected by the movement of water from adjacent or underlying formations into the alluvium.

Generally the water is suitable for domestic use and for some industrial uses; however, the iron and nitrate contents and the hardness may make the water undesirable for some industrial uses. All the water is suitable for irrigation. Most of the water is rated as excellent to good and the rest as good to permissible.

SELECTED BIBLIOGRAPHY

Bartholomew, R. P., Kapp, L. C., and Nelson, Martin, 1945, Irrigation of arable crops on a rice soil: Arkansas Univ. Agr. Expt. Sta. Bull. 455, 20 p.

Bedinger, M. S., and Reed, J. E., 1960, Geology and ground-water resources of Desha and Lincoln Counties, Arkansas: Arkansas Geol. and Conserv. Comm., Water Resouces Circ. 6, 70 p.

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

Croneis, Carey, 1930, Geology of the Arkansas Paleozoic Area: Arkansas Geol. Survey Bull. 3, 457 p.

Gattis, J. L., 1950, Supplemental irrigation in Arkansas: Arkansas Univ. Ext. Service, leaflet 130, 1 p.

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

Hendricks, T. A., and Parks, Bryan, 1950, Geology of the Fort Smith District, Arkansas: U.S. Geol. Survey Prof. Paper 221–E, 94 p.

Jeffords, R. M., 1945, Recharge to water-bearing formations along the Ohio Valley: Am. Water Works Assoc. Jour., v. 37, p. 144–154.

Kazmann, R. G., 1948a. The induced infiltration of river water to wells: Am. Geophys. Union Trans., v. 29, p. 85–89, p. 928–929.

——— 1948b, River infiltration as a source of ground water supply: Am. Soc. Civil Eng. Trans., v. 113, p. 404–420.

——— 1949, The utilization of induced stream infiltration and natural aquifer storage at Canton, Ohio: Econ. Geology, v. 44, p. 514–524.

Maxcy, K. F., 1950, Report on the relation of nitrate concentrations in well waters to the occurrence of methemoglobinemia: Natl. Research Council Bull., Sanitary Engineer, p. 265.

Rorabaugh, M. I., 1948a, The induced infiltration of river water to wells: Am. Geophys. Union Trans., v. 29, p. 90–92.

——— 1948b, Ground-water resources of the northeastern part of the Louisville area, Kentucky: U.S. Geol. Survey open-file report, 77 p. (duplicated).

——— 1951, Stream-bed percolation in development of water supplies: Trans. Internat. Assoc. Sci. Hydrology, Gen. Assembly at Brussels, p. 165–174.

——— 1956, Ground water in Northeastern Louisville, Kentucky: U.S. Geol. Survey Water-Supply Paper 1360–B, 169 p.

Slichter, C. S., 1899 Theoretical investigation of the motion of ground waters: U.S. Geol. Survey 19th Ann. Rept., p. 295–384.

Sniegocki, R. T., 1955, Ground-water resources of the Prairie Creek unit of the lower Platte River basin, Nebraska, with a section on the chemical quality of the ground water, by F. H. Rainwater: U.S. Geol. Survey Water-Supply Paper 1327, 133 p.

Theis, C. V., 1941, The effect of a well on the flow of a nearby stream: Am. Geophys. Union Trans., v. 22, p. 734–738.

Todd, D. K., 1959, Annotated bibliography on artificial recharge of ground water through 1954: U.S. Geol. Survey Water-Supply Paper 1477, 115 p.

U.S. Public Health Service, 1946, Drinking Water Standards: Public Health Service repts., v. 61, no. 11, p. 371–384.

U.S. Public Health Service, 1961, Drinking water standards, 1961: Am. Water Works Assoc. Jour., v. 53, p. 935–945.

Waterways Experiment Station, 1951, Geology of the lower Arkansas River alluvial valley, Pine Bluff, Ark., to mouth: U.S. Army, Corps of Engineers, Tech. Memo. 3–332.

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.

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