Tertiary Aquifers in the Mississippi Embayment

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Tertiary Aquifers in the Mississippi Embayment

By R. L. HOSMAN, A. T. LONG, T. W. LAMBERT, *and others*

With discussions of QUALITY OF THE WATER

By H. G. JEFFERY

WATER RESOURCES OF THE MISSISSIPPI EMBAYMENT

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TERTIARY AQUIFERS IN THE MISSISSIPPI EMBAYMENT

By R. L. Hosman, A. T. Long, T. W. Lambert, and others

ABSTRACT

The aquifers of Tertiary age contain water having less than 1,000 parts per million dissolved solids in an area of about 75,000 square miles and are used as sources of water supply in almost all this area. The total withdrawal from Tertiary aquifers is about 500 million gallons per day. In much of the area, two or more Tertiary aquifers are available for development, although generally only the shallowest aquifer is used. Most of the Tertiary aquifers are areally extensive, and some contain fresh water at depths in excess of 2,000 feet.

The aquifers are recharged by precipitation on the outcrop and by downward percolation of water from overlying alluvium where the outcrops are covered by Quaternary deposits.

Although analysis of test data shows that the hydraulic characteristics of the Tertiary aquifers differ from aquifer to aquifer and vary within any given aquifer, the permeabilities of the lower Wilcox aquifer are generally more consistent and higher than for other Tertiary aquifers. However, a hydrologic unit of the Claiborne Group, the Memphis aquifer–Sparta Sand, is the most productive.

The temperature of the water from the Tertiary aquifers ranges from about 62°F to 97°F. All the Tertiary aquifers contain water of good quality, but the quality generally deteriorates with depth as mineralization increases. Excessive mineralization occurs at depths of a few hundred feet to more than 3,000 feet. Generally, water in the Tertiary aquifers at shallow depths or where recharge occurs from overlying Quaternary alluvium is a calcium bicarbonate type with varying amounts of magnesium and iron; downdip, the water changes to a sodium bicarbonate–sodium chloride type with varying amounts of magnesium and sulfate. Iron is the most troublesome chemical constituent; the content generally decreases with depth. Locally, saline water occurs in aquifers that are shallower than other aquifers containing fresh water. The Sparta Sand contains mineralized water at shallow depths in an area both updip and downdip from fresh water.

Flowing wells can be obtained from Tertiary aquifers in a few low-lying areas associated with major streams. Although unrestricted flow from wells has contributed to water-level declines, most declines are the result of pumping, and no regional overdevelopment is indicated. Only one aquifer, the Sparta Sand, shows signs of pending or possible local overdevelopment. Collectively, the Tertiary aquifers are capable of sustaining more extensive development, and some aquifers are untapped by wells in large areas where they contain fresh water.

INTRODUCTION

This report is one of a series describing the aquifers in the Mississippi embayment (fig. 1). The aquifers are grouped according to geologic age into pre-Cretaceous, Cretaceous, Tertiary, and Quaternary. The Tertiary aquifers are defined and described in this chapter.

Sediments of the Tertiary System occur on the surface (fig. 2) or in the subsurface of about 75 percent of the Mississippi embayment and have a maximum aggregate thickness of about 7,000 feet. Much of the Tertiary outcrop, especially that west of the Mississippi River and north of the Arkansas River, is covered by Quaternary deposits. Many of the Tertiary sands are thick and extensive and contain fresh (less than 1,000 parts per million dissolved solids) water in areas of many thousands of square miles and form regional aquifers. Other sands that are not extensive or contain fresh water in limited areas are, nevertheless, locally productive aquifers. The principal Teritary aquifers are in the Wilcox Group (Formation) and the Claiborne Group; most are in the Claiborne.

The Tertiary System contains the most extensive aquifers in the Mississippi embayment, and most of the water is under artesian pressure. Areas of use, where producing wells tap the aquifers, are shown on plates 3–8, as are areas of potential use, where the aquifers contain fresh water but wells have not been drilled into the aquifer. The areas of use can also be considered as areas of potential use because the aquifers in these areas are generally capable of supporting much heavier withdrawals.

Stratigraphic relations of the Tertiary units are shown by nine geologic sections (pls. 1, 2), and table 1 lists the oil tests and wells used in the sections. Table 2 shows the geologic columns used by the U.S. Geological Survey and the units that are or include aquifers.

Temperature of the water from the Tertiary aquifers ranges from about 62°F to about 97°F (fig. 3).

Data used in the preparation of the maps showing top of unit, thickness, percentage of sand, and areal extent of fresh water were obtained from the interpretation of electric logs of water wells and oil-test wells. Chemical analyses were used to verify the areas of fresh and mineralized water. Drillers' logs were used in areas where electric logs were not available, and

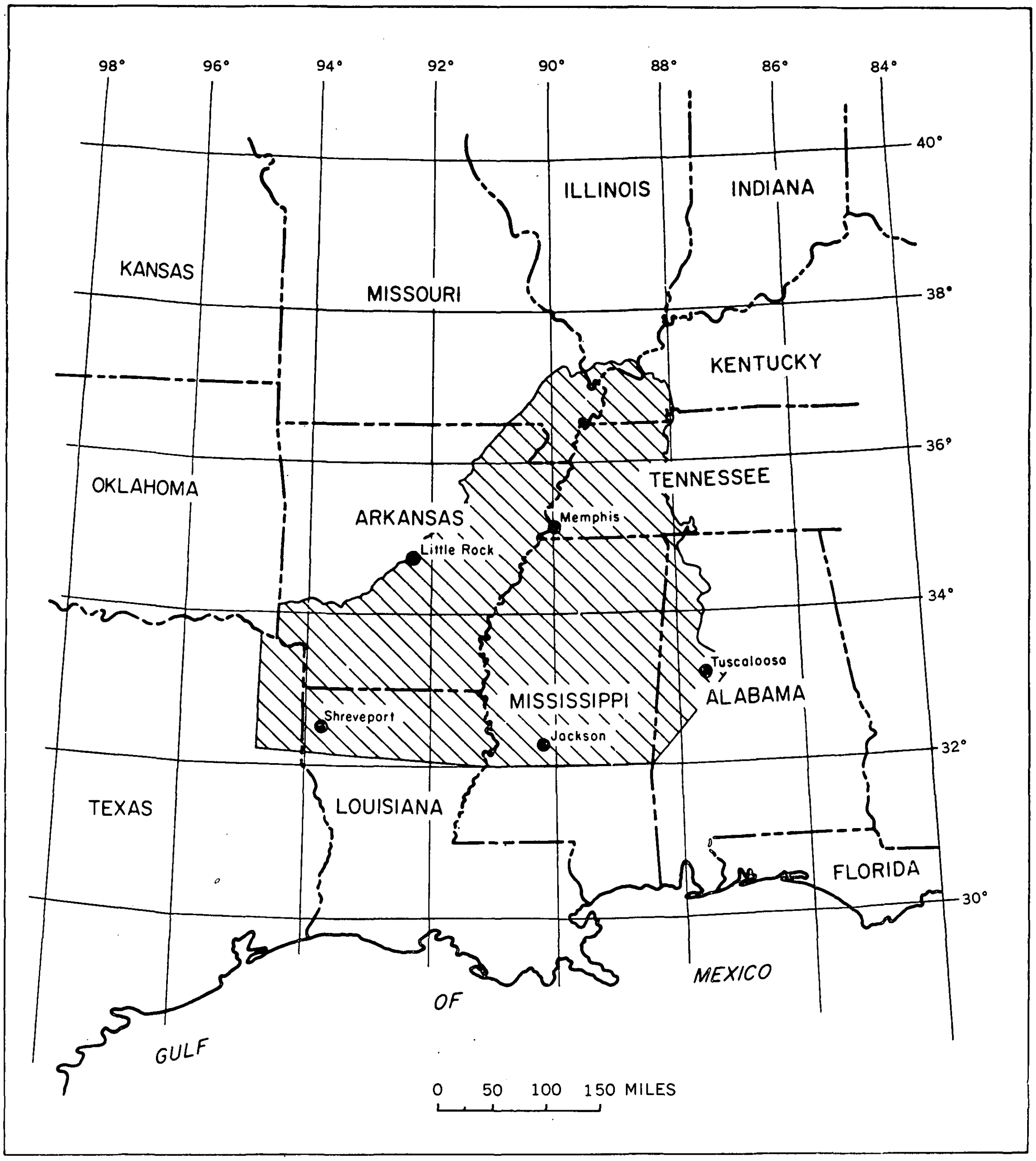

FIGURE 1.—Area of embayment study.

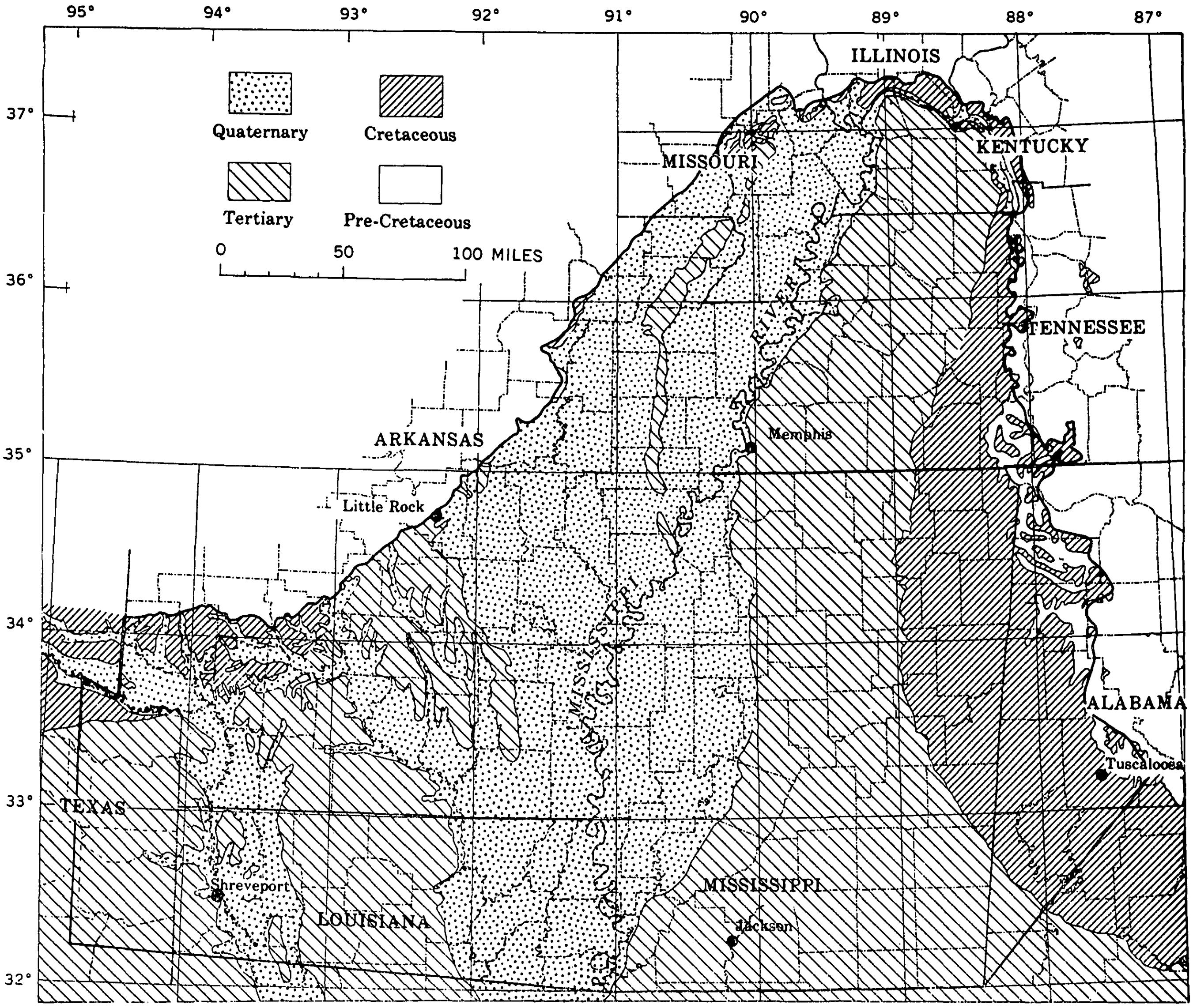

FIGURE 2.—Generalized geology of the Mississippi embayment.

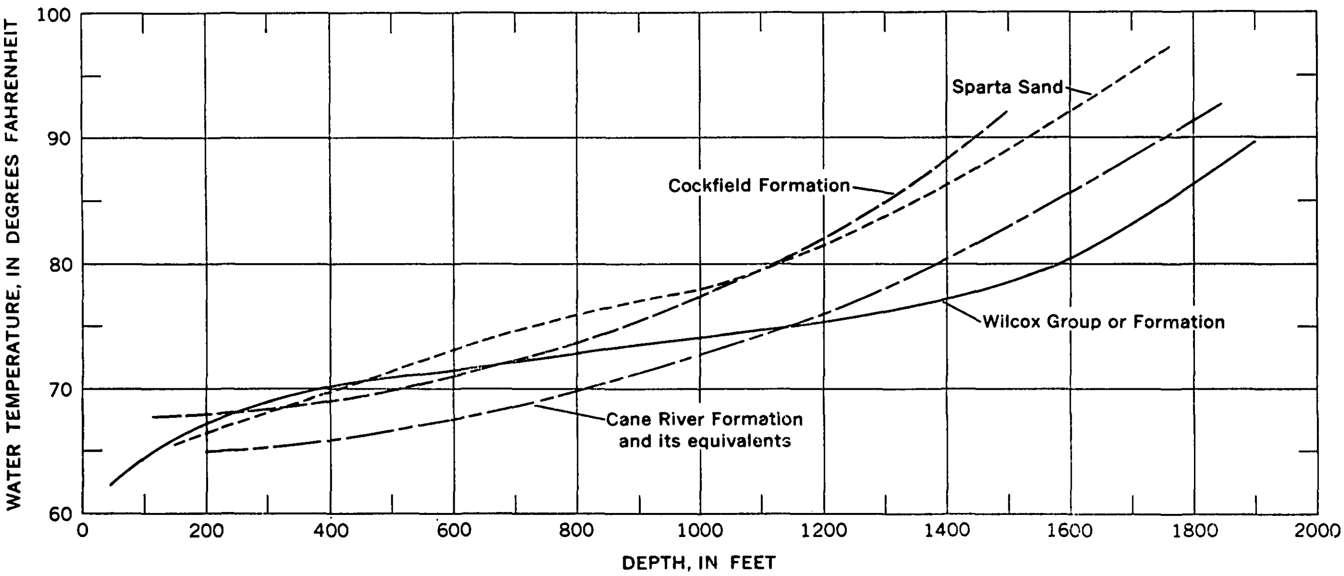

FIGURE 3.—Average temperature gradients of water from Tertiary aquifers.

some microscopic and micropaleontologic examinations of well cuttings were made to verify the geologic interpretations. Maps showing the percentage of sand generally indicate the water-bearing potential of each unit; the higher percentages are associated with the more favorable areas.

This investigation and the preparation of this report were under the direction of E. M. Cushing. Fieldwork and data synthesis and analysis for the report were done by J. G. Newton for Alabama, R. L. Hosman for Arkansas, T. W. Lambert and L. M. MacCary for Kentucky, Illinois, and Missouri, E. H. Boswell for Mississippi, G. K. Moore for Tennessee, and A. T. Long for Texas and Louisiana. Interpretation of quality-of-water data was done by H. G. Jeffery. Lithologic and micropaleontologic studies were done by S. M. Herrick.

TABLE 1.—*Oil tests and wells shown on geologic sections*

State and county or parish	Well	Company or driller	Name
Arkansas			
Calhoun	28	Lion Oil Co	Core hole C-4.
Do	49	Garland Anthony	Brazil 1.
Cleveland	48	G F G Oil Co	C. E. Young 1.
Do	45	Frank and George Frankel.	Ulna Edwards 1.
Do	46	Carter Oil Co	Foster-Grayson B-1.
Craighead	16	Tennark, Inc	Ruby Martin 1.
Crittenden	70	M. E. Davis	De Mange 1.
Do	71	Stanley Oil Corp	Danner 1.
Cross	14	Cross Oil Co	Newman Bros. 1.
Do	15	Seaboard Oil Co	F. S. Tilley 1.
Do	69	Ramsey Petroleum Co.	Singer 1.
Dallas	6	H. M. Mills	Sparkman Lumber Co. Horne 1.
Do	7	I. F. Stone	Herbert E. Walsh 1.
Desha	63	Hunt Oil Co	J. B. Thornton 1.
Do	64	Honolulu Oil Corp	Anderson Tully 1.
Do	65	Delta Caribbean Oil Corp.	Grief Brothers 1.
Do	90	W. Shannon	S. A. Banks 1.
Grant	8	Connelly and Froderman.	Ashcraft 1.
Do	47	Stratton Drilling Co	J. Stupka 1.
Jefferson	9	F. R. Jackson, and others.	David N. Ford 1.
Lafayette	3	Barnsdall Oil Co	Bond S-1.
Lee	1	U.S. Geological Survey.	U.S. Forest Service 1.
Do	3	City of Marianna, Ark.	Water well.
Do	97	Cockburn Oil Co	L. W. Robinson 1.
Do	54	Curtis Kinard	Payne Estate 1.
Lonoke	10	Seaboard Oil Co	S.A. Hovis 1.
Miller	1	Barnsdale Oil Co	Nichols 1.
Do	2	Carter Oil Co	H. B. Carroll 3.
Monroe	2	Seaboard Oil Co	E. L. Medford 1.
Do	12	Sohio Products Co	D. Gann 1.
Nevada	4	Barney Dunlap	Ervin Hart 1.
Ouachita	5	Hunt Oil Co	Mollie Purifoy 1.
Phillips	3	Ambassador Oil Corp.	Thompson Unit 1.
Do	61	McAlester Fuel Co	Welch 1.
Do	62	Plymouth Oil Co	J. R. Bush 1.
Prairie	2	M. W. Martin	Steward 1
Do	11	Victory Development Co.	Clayton 1.
Do	73	R. E. Smith	Stewart 1.
St. Francis	13	Barnwell Drilling Co	Thombaugh 1.
Union	50	R. T. Adams	Winn 1.
Woodruff	68	Magnolia Petroleum Co.	Roy Sturgis 1.
Kentucky			
Fulton	S946. 1- 92. 3	Mt. Carmel Drilling Co.	Florence Smith 1.
Do	S988. 3-105. 7	Layne-Central Co	City of Hickman.
Do	S1038. 0- 96. 9	Clemens Exploration Co.	Floyd R. Naylor.
Do	S1081. 5- 78. 2	Illinois Central	Illinois Central Railroad.
Graves	S1127. 8- 82. 2	Clemens Exploration Co.	Jess Walker.
Hickman	S1021. 1-170. 3	U.S. Geological Survey.	Jack Roberts 2.

TABLE 1.—*Oil tests and wells shown on geologic sections*—Con.

State and county or parish	Well	Company or driller	Name
Louisiana			
Bienville	36	Atlantic Refining Co	H. C. Cook 1.
Do	37	Hurley, Cummins, & Lohman.	Longbell Lumber Co. 1.
Do	38	Pierce & Crow	E. W. Merritt 2.
Bossier	10	A. J. Hodges Industries, Inc.	Skannal C-3.
Caddo	6	Arkansas-Louisiana Gas Co.	Bell A-1.
Do	32	C. P. Porter & Naro Oil Co.	Turner 1.
Jackson	42	The Texas Co	Tremont Lumber Co. 1.
Do	43	Shell Oil Co., Inc	Tremont 2.
Do	44	Brown Paper Mill Co.	Fee 3.
Lincoln	39	Arkansas-Louisiana Gas Co.	Hays 1.
Madison	29	V. S. Parham	Kathan-Johnson 1.
Do	46	Victor P. Grage	W. R. Gilfoil 1.
Ouachita	21	The California Co	Walter Maxey 1.
Do	45	Stanolind Oil Co	Tina S. Parker 1.
Richland	27	Atlantic Refining Co	Mrs. Birdie S. Franklin 1.
Union	19	H. J. Heartwell	Griffin 1.
Do	40	Phillips Petroleum Co.	Hamilton 1.
Do	41	Pan American Petroleum Corp.	T. L. James Co., Inc.
Webster	12	Hunt Oil Co	Jacinta Sales 1.
Do	33	Kin Ark Oil Co	M. Braswell 1.
Do	34	George Belchic, Jr., and others.	Prather 1.
Do	35	Sunray-Midcontinent Oil Co.	Gleason 1.
Mississippi			
Bolivar	8	Seaboard Oil Co	Chicago Mill and Lbr. Co. 1.
Calhoun	22	Layne-Central Co	Slate Springs Water Assn.
De Soto	1	Union Producing Co	Withers Estate 1.
Grenada	11	Adams Oil & Gas	J. K. Avent 1.
Hinds	28	Pure Oil Co	Gaddis Farms 1.
Do	41	Kingwood Oil Co. and George E. Shaw.	Lewis 1.
Do	48	Plains Production Co.	J. S. Taylor 1.
Do	1206	Leonard Jones	La Rue 1.
Issaquena	38	Pres Cochrane	Anderson-Tully 1.
Lauderdale	16	C. L. Higgason and L. L. Chapman.	Malone-Thigpen 1.
Do	18	American Liberty Oil Co.	Flintkote Corp. 1.
Marshall	6	Shell Oil Co	Paul F. Johnson, and others.
Newton	6	Sun Oil Co	Hilma Wall 1.
Do	7	Fred Mellen, James Hattox, and others.	Gordon Holroyd 1.
Rankin	11	Monsanto Chemical Co.	Leon 1.
Do	85	Layne-Central Co	City of Brandon.
Scott	31	Honolulu Oil Corp	Board of Supervisors 1.
Do	1009	Pan American Producing Co.	School Land 1.
Sharkey	10	Harold K. Boysen	A. Y. Keith 1.
Sunflower	2	J. L. Ryan and T. J. Townsend.	J. R. Cooper 1.
Tallahatchie	12	Gulf Refining Co	T. P. Cason et al. 1.
Tate	2	Johnson-Perry Co	Prichard Estate 1.
Tunica	2	Layne-Central Co	Tunica County Vocational High School.
Warren	43	Frontier Oil Ref. Corp.	F. C. Martin 1.
Do	58	Union Producing Co	C. J. Harlen 1.
Washington	1	Roeser & Pendleton, Inc.	Conn. Gen. Life Ins. Co. 1.
Do	9	Lee Raines	R. N. Aldrich 1.
Yazoo	40	E. P. Thomas and J. A. Morgan.	Callie Smith 1.
Do	92	Sells Petroleum Co	Faulkner 1.
Missouri			
Dunklin	1	Thomas C. Knight	John Stewart 1.
New Madrid	6809	Cordova-Union Oil Corp.	E. Phillips 1.
Do	8882	U.S. Bureau of Mines.	R. B. Oliver, Jr. 1.
Tennessee			
Fayette	Fa: J-1	Lazarov-Robillio Oil Co.	Beasley 1.
Do	Fa: 0-32	Barnwell Drilling Co	Shinault 1.
Do	Fa: S-7	Texas Gas Trans. Corp.	Matthews 7003.

TABLE 1.—*Oil tests and wells shown on geologic sections*—Con.

State and county or parish	Well	Company or driller	Name
Tennessee—Con.			
Fayette	Fa: W-1	Layne-Central Co.	U.S. Geol. Survey and Tennessee Div. Geology.
Lake	Lk: E-17	Jack W. Frazier & Carl Benz.	Sam Hays 1.
Lauderdale	Ld: F-4	U.S. Geological Survey.	Sullivan 1.
Shelby	Sh: U-12	Lion Oil and Refining Co.	L. Bateman 1.
Texas			
Cass	DB-1664404	Arkla Oil Co.	Brooks Brothers 1.
Do	DB-3505502	Max Agress	Clark and Boise Lumber Co. 1.
Do	DB-3506303	Joe G. Strahan	Mrs. Sloan Taylor 1.
Harrison	LK-3511802	Grelling and Ellison	H. P. McGaughey 1.
Do	LK-3535203	The Texas Co.	R. E. Latham 1.
Do	LK-3536204	Paul Scott and R. E. Kennedy.	C. A. Bell 1.
Do	LK-3537103	H. J. Strief	A. White 1.
Do	LK-3538403	Stanolind Oil & Gas Co.	Hattie Cole 1.
Do	LK-3540403	Bert Fields	E. Vance 1.
Marion	SX-3512102	Magnolia Petroleum Co.	S. L. Orr 1.

TABLE 2.—*Stratigraphic columns of the Tertiary System in the Mississippi embayment*

NORTHEASTERN TEXAS

[Bowie, Cass, Marion, and Harrison Counties]

- Eocene Series
  - Claiborne Group
    - Sparta Sand [1]
    - Weches Greensand
    - Queen City Sand [1]
    - Reklaw Formation [1]
    - Carrizo Sand [1]
    - Wilcox Formation [1]
- Paleocene Series
  - Midway Group
    - Wills Point Formation
    - Kincaid Formation

NORTHERN LOUISIANA

[North of 32d parallel]

- Oligocene Series
  - Vicksburg Formation
- Eocene Series
  - Jackson Group
    - Yazoo Clay
    - Moodys Branch Formation
  - Claiborne Group
    - Cockfield Formation [1]
    - Cook Mountain Formation
    - Sparta Sand [1]
    - Cane River Formation [1]
    - Carrizo Sand [1]
- Eocene and Paleocene Series
  - Wilcox Group [1,2]
    - Dolet Hills Formation [1]
    - Naborton Formation [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay
    - Clayton Formation

ARKANSAS

- Pliocene(?) deposits [1]
- Eocene Series
  - Jackson Group undifferentiated [1]
  - Claiborne Group
    - Cockfield Formation [1]
    - Cook Mountain Formation
    - Sparta Sand [1]
    - Cane River Formation [1]
    - Carrizo Sand [1]
    - Wilcox Group undifferentiated [1,3]

See footnote at end of table.

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TABLE 2.—*Stratigraphic columns of the Tertiary System in the Mississippi embayment*—Continued

- Paleocene Series
  - Midway Group [4]
    - Porters Creek Clay
    - Clayton Formation [1]

MISSOURI

- Pliocene(?) deposits [1]
- Eocene Series
  - Claiborne Group undifferentiated [1]
  - Wilcox Formation [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay [1]
    - Clayton Formation

ILLINOIS

- Pliocene(?) deposits [1]
- Eocene Series
  - Wilcox Group undifferentiated [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay
    - Clayton Formation

KENTUCKY

- Pliocene(?) deposits [1]
- Eocene Series
  - Claiborne Group undifferentiated [1]
  - Wilcox Group undifferentiated [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay
    - Clayton Formation [1]

TENNESSEE

- Pliocene(?) deposits [1]
- Eocene Series
  - Jackson(?) Formation
  - Claiborne Group undifferentiated [1]
  - Wilcox Group undifferentiated [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay [1]
    - Clayton Formation [1]

NORTHERN MISSISSIPPI

Northern Part

- Pliocene(?) deposits [1]
- Eocene Series
  - Jackson Group undifferentiated
  - Claiborne Group
    - Cockfield Formation [1]
    - Cook Mountain Formation
    - Sparta Sand [1]
    - Zilpha Clay
    - Winona Sand [1]
    - Tallahatta Formation [1]
  - Wilcox Formation [1]
- Paleocene Series
  - Midway Group
    - Porters Creek Clay
      - Tippah Sand Lentil [1]
    - Clayton Formation [1]

Southern Part

- Pliocene(?) deposits [1]
- Eocene Series
  - Jackson Group undifferentiated
  - Claiborne Group
    - Cockfield Formation [1]
    - Cook Mountain Formation
    - Sparta Sand [1]
    - Zilpha Clay
    - Winona Sand [1]
    - Tallahatta Formation [1]
  - Wilcox Formation [1]
- Paleocene Series
  - Midway Group
    - Naheola Formation [1]
    - Porters Creek Clay
    - Clayton Formation [1]

TABLE 2.—*Stratigraphic columns of the Tertiary System in the Mississippi embayment*—Continued

CENTRAL MISSISSIPPI

- Pliocene(?) deposits[1]
- Oligocene Series
  - Forest Hill Sand[1]
- Eocene Series
  - Jackson Group
    - Yazoo Clay
      - Shubuta Member
      - Pachuta Marl Member
      - Cocoa Sand Member
      - North Twistwood Creek Member
    - Moodys Branch Formation
  - Claiborne Group
    - Cockfield Formation[1]
    - Cook Mountain Formation
      - Gordon Creek Shale Member
      - Potterchitto Sand Member
      - Archusa Marl Member
    - Sparta Sand[1]
    - Zilpha Clay
    - Winona Sand[1]
    - Tallahatta Formation
      - Neshoba Sand Member[1]
      - Basic City Shale Member
      - Meridian Sand Member[1]
    - Wilcox Formation[1]
      - Bashi Marl Member
      - Fern Springs Member
- Paleocene Series
  - Midway Group
    - Naheola Formation[1]
    - Porters Creek Clay
      - Matthews Landing Marl Member
    - Clayton Formation[1]

WESTERN ALABAMA

- Eocene Series
  - Claiborne Group
    - Tallahatta Formation
      - Meridian Sand Member[1]
  - Wilcox Group[1]
    - Hatchetigbee Formation[1]
      - Bashi Marl Member
    - Tuscahoma Sand[1]
      - Bells Landing Marl Member
      - Greggs Landing Marl Member
    - Nanafalia Formation[1]
      - Grampian Hills Member
      - Middle member
      - Gravel Creek Sand Member[1]
- Paleocene Series
  - Midway Group
    - Naheola Formation[1]
      - Coal Bluff Marl Member
      - Oak Hill Member
    - Porters Creek Formation
      - Matthews Landing Marl Member
    - Clayton Formation
      - McBryde Limestone Member
      - Pine Barren Member

[1] Unit is fresh-water aquifer or contains fresh-water aquifer(s).
[2] Wilcox Group (Eocene Series) undifferentiated. Wilcox Group (Paleocene Series): upper part is undifferentiated; Dolet Hills and Naborton Formations are lower two units.
[3] In ascending order Wilcox Group in Arkansas bauxite area composed of Berger Formation, Saline Formation, and Detonti Sand.
[4] In ascending order Midway Group in Arkansas bauxite area composed of Kincaid Formation and Wills Point Formation.

The cooperation of the following State officials and members of their staffs is gratefully appreciated: Philip E. LaMoreaux, State Geologist, Geological Survey of Alabama; Norman F. Williams, State Geologist, Arkansas Geological Commission; Wallace W. Hagan, Director and State Geologist, Kentucky Geological Survey; Jack W. Pepper, Engineer, Mississippi Board of Water Commissioners; Thomas R. Beveridge, former Director and State Geologist, and William C. Hayes, Jr., Director and State Geologist, Missouri Geological Survey; William D. Hardeman, State Geologist, Tennessee Division of Geology; Joe D. Carter, Chairman, Texas Water Commission; James H. Gill, Commissioner, Louisiana Department of Conservation; Leo W. Hough, State Geologist, Louisiana Geological Survey; and Claude Kirkpatrick, Director, Louisiana Department of Public Works. These officials furnished geologic and hydrologic information, many electric logs, and sets of well cuttings for this study. The pumping and water-level information supplied by well drillers in the area is appreciated.

TERTIARY AQUIFERS

MIDWAY GROUP

By R. L. Hosman, T. W. Lambert, and G. K. Moore

The Midway Group of the Paleocene Series overlies the rocks of the Cretaceous System. In most of the embayment the group is predominantly made up of dark clay. It includes, however, three locally used aquifers: the Clayton Formation (Kincaid Formation in bauxite area of Arkansas), the subordinate sand beds of limited extent including the Tippah Sand Lentil of the Porters Creek Clay in extreme northern Mississippi, and the Naheola Formation in Mississippi and Alabama.

The Clayton Formation, basal unit of Paleocene age, is mostly composed of limestone, calcareous sand, and sandstone, all of marine origin. The formation is generally about 35 feet thick in the subsurface, but in some places in the outcrop area it is much thinner.

The Porters Creek Clay overlies the Clayton and ranges in thickness from about 180 feet to about 1,000 feet. It is a dark clay in most of the embayment but locally contains sand beds that are water bearing in western Kentucky, western Tennessee, and extreme northern Mississippi.

The Naheola Formation is the upper unit of the Midway Group in western Alabama and eastern Mississippi. The thickness generally ranges from 100 feet in Mississippi to about 200 feet in Alabama. Sandy beds in the Naheola Formation are water bearing in western Alabama and the adjacent areas of Mississippi. In this report these beds are considered as part of the lower Wilcox aquifer.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Aquifers in the Midway Group receive recharge from precipitation in the outcrop area. The aquifers probably receive additional recharge locally where underlying Cretaceous rocks are permeable. The limited extent of the sand beds generally impedes ground-water movement except near the outcrop areas, and local conditions determine the direction of this movement.

The use of ground water from the Midway Group is generally confined to the outcrop areas of the aquifers in Arkansas, Kentucky, Tennessee, Mississippi, and Alabama. The aquifers crop out in a narrow belt on the east side of the embayment along the Tertiary-Cretaceous contact shown in figure 2. On the west side of the embayment the aquifers crop out and are used where the Tertiary outcrop area is adjacent to the periphery of the embayment. Wells tapping these aquifers are designed for small capacity, and the yields are adequate only for domestic and stock use. Some wells, tapping the Clayton Formation near the outcrop area in Arkansas, flow, but their yields are small and the hydrostatic pressure is low. The withdrawal of water from the Clayton is probably less than 0.1 mgd (million gallons per day).

AQUIFER CHARACTERISTICS

Data pertaining to aquifer characteristics of the Midway aquifers are not available, but well yields are generally small.

QUALITY OF THE WATER

Utilization of water is governed to a large extent by the chemical and physical properties of the water. The source and significance of many of these properties are given in table 3. Water from wells drilled near the outcrop of the Clayton Formation in Arkansas is moderately mineralized. The dissolved-solids content of six samples ranges from 184 to 437 ppm (parts per million) and averages 256 ppm. Calcium, magnesium, and bicarbonate generally are the predominant constituents where the dissolved-solids content is low; increases in dissolved solids are caused primarily by increases in sodium, bicarbonate, and chloride.

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

Constituent or physical property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 ppm. Higher concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam from high-pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. Waters having a low pH tend to be corrosive and may dissolve iron in objectionable quantities from pipe, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacturing, brewing, and other processes. Large quantities cause unpleasant taste and favor the growth of iron bacteria. On exposure to air, iron in ground water usually is oxidized and forms a reddish-brown precipitate. "Public Health Service Drinking Water Standards" (1962) [1] recommend that iron in water supplies not exceed 0.3 ppm.
Manganese (Mn)	Dissolved from some rocks and soils. Not as common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark-brown or black stain. Maximum concentration recommended by the drinking-water standards is 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all rocks and soils, 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.	Cause most of the hardness and scale-forming properties of water; soap consuming. (See 'Hardness.") Waters low in calcium and magnesium are desired in electroplating, tanning, and dyeing, and in textile manufacturing.
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. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium content may limit the use of water for irrigation.
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 they cause carbonate hardness.
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, give a bitter taste. Sulfate in water containing calcium forms a hard scale in steam boilers. The drinking-water standards recommend that sulfate in water supplies not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial wastes.	Large quantities increase the corrosiveness of water and, in combination with sodium, give a salty taste. The drinking-water standards recommend that chloride in water supplies not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, 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 drinking-water standards varies with the annual average maximum daily air temperatures and ranges downward from 1.7 ppm for an average maximum daily temperature of 50.0°F to 0.8 ppm for an average maximum daily temperature of 90.5°F. Optimum concentrations for these ranges are from 1.2 to 0.7 ppm.
Nitrate (NO_3)	Decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soil.	Nitrate encourages growth of algae and other organisms that cause undesirable tastes and odors. Concentration much greater than the local average may indicate pollution. The drinking-water standards recommend that the nitrate content not exceed 45 ppm, as there is evidence that higher concentrations may cause methemoglobinemia (an often fatal disease in infants).
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Include any organic matter and some water of crystallization.	The drinking-water standards recommend that the dissolved solids not exceed 500 ppm. Waters containing more than 1,000 ppm dissolved solids are unsuitable for many purposes.
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, waters of hardness as much as 60 ppm are considered soft; 61–120 ppm, moderately hard; 121–180 ppm, hard; more than 180 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water	Indicates degree of mineralization and 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).
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.

[1] "Public Health Service Drinking Water Standards", revised 1962, apply to drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations.

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

Constituent or physical property	Source or cause	Significance
Color	Usually caused by organic matter	Refers to the appearance of water that is free of suspended matter. Color of 10 units or less usually goes unnoticed. The drinking-water standards recommend that color not exceed 15 units. Color in water is objectionable in food and beverage processing and in many manufacturing processes.
Temperature		Affects usefulness of water for many purposes. Most users desire water of uniformly low temperature. In general, temperatures of shallow ground waters show some seasonal fluctuation, whereas temperatures of ground waters from moderate depths remain near the mean annual air temperature of the area. In deep wells the water temperature generally increases 1°F for each 60–80 feet of depth.

The dissolved-solids content of water from five wells in the Clayton Formation in Tennessee ranges from 86 to 2,550 ppm; the dissolved-solids content of water from two of these wells is 1,060 and 2,550 ppm, and that of water from the other three wells ranges from 86 to 156 ppm. The water with the highest dissolved-solids content is a calcium magnesium sulfate type and may be representative of water from the Clayton where the Owl Creek Formation of Cretaceous age acts as an aquiclude between the Clayton and the McNairy Sand Member of the Ripley Formation.

Water from sandy zones in the outcrop of the Porters Creek Clay in Tennessee is generally low in dissolved solids. The analyses of water from eight wells show that the dissolved-solids content ranges from 80 to 533 ppm. Calcium, magnesium, and sulfate are generally the predominant constituents. In Missouri, the dissolved-solids content of water from sandy zones in the Porters Creek Clay is higher than it is in Tennessee. The range in dissolved solids of water from five wells in Missouri ranges from 200 to 1,080 ppm. However, two higher values, 797 and 1,080 ppm, may not be representative of water in these sands; these values include 268 and 200 ppm of nitrate, which indicate that the waters are probably polluted.

Analyses of water from three wells in Mississippi indicate that water from the Naheola Formation is generally of good chemical quality. The water is a sodium bicarbonate type, and the dissolved-solids content ranges from 128 to 418 ppm.

POTENTIAL USE

The interpretation of electric logs indicates that the Clayton Formation and local sand beds in the Porters Creek Clay contain fresh water in an area of about 2,800 square miles in Tennessee. Fresh water in these aquifers is generally restricted to the outcrop areas in Arkansas, Missouri, and Kentucky. The sand beds are thin and of small areal extent; therefore, only small yields of water may be expected. These sands are not extensively developed, however, because larger supplies of water of good quality are available from other aquifers in most of the region. Additional small supplies for domestic and stock use can be developed from the Midway.

CONCLUSIONS

Subordinate sand beds in the Clayton Formation and Porters Creek Clay contain fresh water near their outcrop areas in Arkansas, Missouri, Kentucky, Tennessee, and Mississippi. The aquifers yield small quantities of water and are the source of domestic and stock supplies. The water in the outcrop area is generally of good quality.

LOWER WILCOX AQUIFER

By E. H. BOSWELL, R. L. HOSMAN, and G. K. MOORE

The Wilcox Group (Formation) crops out in an area about 100 miles wide in the southwest corner of the embayment, and in belts 10–25 miles wide in the eastern part of the embayment (pl. 3). The outcrop area narrows in the northern part of the embayment, because the Wilcox thins and may be overlapped by the Claiborne Group in places. The Wilcox dips about 20 feet per mile toward the axis of the embayment in the northern part; the dip increases to more than 50 feet per mile in the southern part of the embayment. The unit is more than 3,000 feet thick in the southeastern part of the embayment (pl. 3).

The Wilcox contains thick extensive sands in the subsurface of northeastern Arkansas, southeastern Missouri, southwestern Kentucky, western Tennessee, and northwestern and central Mississippi. Although the exact stratigraphic and hydrologic relations of the sands cannot be determined by interpretation of available data, correlation of electric logs suggests that the Wilcox may contain as many as three major sand units in the northern and eastern parts of the embayment. These sands, which include the aquifer known in the Memphis area as the "1,400-foot" sand, are collectively referred to as the lower Wilcox aquifer in this report and are treated as one aquifer on the maps (pl. 4). The sands occupy similar stratigraphic positions within the Wilcox in that they are generally in the lower part, in some places forming the basal unit. In much of the area the base of the lower Wilcox aquifer is also the base of fresh water.

The maximum thickness of the lower Wilcox aquifer, where it contains fresh water, is 300 feet in Arkansas, 340 feet in Tennessee, 400 feet in Missouri, and 450 feet in Mississippi (pl. 4).

In most of the northern half of the embayment, more than 80 percent of the lower Wilcox aquifer is composed of sand (pl. 4). The aquifer is generally composed of fine to medium sand, but it is composed of coarse sand in places in Tennessee and Kentucky and of coarse sand and fine gravel in places in Mississippi.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The main source of recharge is precipitation in the outcrop area. Leakage from overlying sandy beds may be a major source of recharge in the northern part of the embayment, where the lower Wilcox aquifer is overlain by outcropping sands of the Claiborne Group and the water is under water-table conditions.

The regional movement of ground water is toward the axis of the embayment. Large withdrawals of ground water, mainly for municipal and industrial use, result in large cones of depression in the piezometric surface near Memphis and Jackson, Tenn. (pl. 4). The ground-water withdrawals for municipal and industrial use are 15 mgd in Mississippi, 23 mgd in Tennessee (13 mgd in Memphis and 7 mgd in Jackson), 9 mgd in northeastern Arkansas, and 1 mgd in Missouri.

The area of use is small in Kentucky, Illinois, and Missouri; but in Tennessee it is about 1,500 square miles, mostly in a belt 8–16 miles wide adjacent to the outcrop and in the Memphis area. The aquifer is utilized in a large part of northeastern Arkansas and northwestern Mississippi, but the withdrawal is small.

Additional withdrawals of ground water result from uncontrolled flowing wells in northwestern Mississippi and in western Alabama. The piezometric surface in these areas shows changes imposed on the aquifer by the flowing wells. The amount of water wasted by flowing wells is not known. The piezometric surface is below land surface in the area of use in Tennessee, but it is probably above the land surface in a few of the major stream valleys where flowing wells may be drilled. The piezometric surface is below land surface in Missouri and Arkansas.

AQUIFER CHARACTERISTICS

Moderate yields from wells tapping the lower Wilcox aquifer are generally obtainable. Wells yielding from 500 gpm (gallons per minute) to more than 2,000 gpm can be constructed at many locations underlain by the aquifer. The results of pumping tests and aquifer tests using wells in the lower Wilcox aquifer are summarized (averages by county) in the following table:

[Number in parenthesis denotes number of tests used to compute average

County	State	Coefficient			Specific capacity [4] (gpm per ft of drawdown)
		Transmissibility [1] (gpd per ft)	Storage [2]	Permeability [3] (gpd per sq ft)	
Mississippi	Arkansas	(1) 160,000	(1) 0.0002	(1) 1,300	(3) 30
Ballard	Kentucky				(2) 12
Lauderdale	Mississippi	(3) 122,000	(2) .0001	(3) 1,250	(2) 14
Winston	do	(1) 80,000	(1) .0001	(1) 890	(1) 39
Madison	Tennessee	(4) 75,000	(3) .0015	(2) 510	(1) 12
Shelby	do	(20) 98,000	(20) .0002		

[1] The worth of an aquifer as a fully developed source of water depends largely on two hydraulic characteristics—the capacity of the aquifer to transmit water (the coefficient of transmissibility) and the capacity of the aquifer to store water (the coefficient of storage).

The coefficient of transmissibility (*T*) is the rate of flow of water, in gallons per day, at the prevailing temperature, through a vertical strip of an aquifer 1 foot wide extending the full saturated height of the aquifer, under a hydraulic gradient of 100 percent. (A hyrdaulic gradient of 100 percent means a 1-foot drop in water level or head in a 1-foot flow distance.) For example, an aquifer has a coefficient of transmissibility of 26,400 gpd per ft. If the hydraulic gradient were 100 percent, 26,400 gallons of water would move through each vertical strip of the aquifer 1 foot wide in each 24-hour period. Assuming a line 100 feet in length perpendicular to the direction of flow in the aquifer, 26,400 gpd per ft multiplied by 100 feet, or 2,640,000 gpd, would move past the line. If the hydraulic gradient were only 10 feet per mile, then only 5,000 gpd $(26{,}400\times\frac{10}{5{,}280}\times100)$ would move past the line in a day.

[2] The coefficient of storage (*S*) is the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The coefficient can be expressed as the quantity of water, in cubic feet, that is discharged from each vertical prism of the aquifer having a basal area of 1 square foot and a height equal to that of the aquifer, when the water level falls 1 foot. For an artesian aquifer, the water released from or taken into storage in response to a change in water level is attributed to the compressibility of the aquifer material and of the water. The volume of water thus released or stored, divided by the product of the water-level change and the area of the aquifer surface over which it is effective, is the coefficient of storage of the aquifer. For artesian aquifers the storage coefficients range from about 0.00001 to about 0.001, and for water-table aquifers they range from about 0.05 to 0.3.

When the coefficients of transmissibility and storage are known, the theoretical drawdown for any time at any point in an area of pumping for any given rate and distribution of pumping from wells can be computed (fig. 4).

[3] The coefficient of permeability is the rate of flow of water, in gallons per day, at the prevailing temperature through a cross section of 1 square foot of an aquifer under a hydraulic gradient of 100 percent. It is equal to the coefficient of transmissibility divided by the saturated thickness (in ft) of the aquifer.

[4] Specific capacity defines the capacity of a well to yield water. It is defined as the yield per unit of drawdown for a given period of pumping and is generally expressed as gallons of water discharged in 1 minute for each foot of decline in the water level in the well. If it were not for many extraneous factors—the size of well, the depth of penetration of the well into the aquifer, the length of screen, the size of screen openings and the relation of the size of these openings to size and assortment of aquifer materials, and the amount of development of the well—specific capacity would be a measure of the capacity of the aquifer in the vicinity of the well to transmit water.

Specific capacity is used to compare the yields of wells and as a means of determining how deep in the well the pump bowls (turbine) should be set. For example, if a well has a specific capacity of 5 gpm per ft and is capable of yielding 500 gpm, then the drawdown for this discharge will be about 100 feet $(\frac{500}{5})$, and the pump bowls must be set at least 100 feet below the static water level in the well in order to pump 500 gpm.

QUALITY OF THE WATER

Water in the lower Wilcox aquifer is generally a sodium bicarbonate type and has a low, fairly uniform dissolved-solids content. At a few places in the outcrop area, the water is a calcium bicarbonate type; and in extreme downdip areas it is a sodium bicarbonate chloride type. The dissolved-solids content of the water is lower in the outcrop areas, and it increases gradually as the water moves west and southwest from these areas (pl. 4). Calcium, magnesium, and sulfate are generally low, but at some locations they compose a large part of the dissolved solids. The chloride content of the water varies with the dissolved solids, and when the dissolved solids are less than about 500 ppm, the chloride content is generally low. Increases in dissolved solids in excess of about 500 ppm are mainly sodium, bicarbonate, and chloride. At many places, when dissolved solids are about 1,200 ppm, chloride and bicarbonate are present in about equal amounts. Small amounts of fluoride and nitrate are present in the water. Larger amounts of fluoride are present in extreme downdip areas. The larger amounts of nitrate are in water from shallow wells in the outcrop area and are probably the result of contamination. The iron content of the water generally decreases with depth. The ranges in concentration of the various constituents are shown in table 4. The median values in this table are representative of the quality of water over a large part of the area. The maximum values for most constituents are for water in downdip areas.

TABLE 4.—*Summary of chemical analyses of water from the lower Wilcox aquifer*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	44	0.0	11
Iron (Fe)	15	.00	.58
Calcium (Ca)	34	.0	2.9
Magnesium (Mg)	8.4	.0	.9
Sodium (Na)	704	1.5	36
Potassium (K)	16	.3	2.1
Carbonate plus bicarbonate (CO_3+HCO_3)	661	6	110
Sulfate (SO_4)	37	.0	3.0
Chloride (Cl)	725	.0	3.7
Fluoride (F)	1.8	.0	.1
Nitrate (NO_3)	13	.0	.3
Dissolved solids	1,810	13	120
Hardness as $CaCO_3$	112	1	11
Specific conductance (micromhos at 25°C)	3,520	19	176
pH	8.6	5.2	7.5
Color	90	0	8

POTENTIAL USE

Interpretation of electric logs indicates that the area of potential use of water from the lower Wilcox aquifer is large in Arkansas, Missouri, Tennessee, and Mississippi (pl. 4), where overlying aquifers contain adequate supplies of water. The area of potential use (about 8,000 sq mi) in Tennessee is more than five times the area of use (about 1,500 sq mi). The area of potential use also includes all or parts of several counties in Kentucky, where only a small quantity of water is withdrawn from the aquifer, and a small area in Illinois near Cairo. Areas where the contours in the piezometric surface are closely spaced (pl. 4) are probably unfavorable areas for potential largescale ground-water development of this aquifer.

CONCLUSIONS

The lower Wilcox aquifer is one of the largest sources of ground water in the Mississippi embayment. Wells yielding 500 gpm or more are possible in many places. Moderate yields are generally obtainable, and yields exceeding 2,000 gpm are possible in some places. The water is generally a sodium bicarbonate type and contains a fairly uniform amount of dissolved solids. Wells tapping the sand yield about 48 mgd. The area of potential use is larger than the area of use. A detailed study of the geohydrology of the thick extensive sands in the lower part of the Wilcox may be needed to provide information for future development.

MINOR WILCOX AQUIFERS

By R. L. HOSMAN, A. T. LONG AND E. H. BOSWELL

In addition to the thick sands, the Wilcox deposits contain aquifers consisting of thin sand beds interbedded with clay. The individual sands are not areally extensive but are locally used aquifers, which are collectively used in an area of several thousand square miles. These minor aquifers are in the upper part of the Wilcox in the northern part and in the southeastern part of the embayment and occur throughout the Wilcox in the southwestern part.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Overlying clay confines the water in the minor sand beds a few miles downdip from the outcrop of the beds. In the southwestern part of the embayment the Wilcox receives recharge from precipitation on the outcrop and from overlying sandy Quaternary beds. The natural discharge is in the major stream valleys or toward points of heavy withdrawals in this area. Downdip, the water probably moves toward the axis of the embayment.

Withdrawal of ground water from the minor Wilcox aquifers is about 5 mgd in Mississippi, about 5 mgd in Louisiana and Texas, and about 2 mgd in southwestern Arkansas. More than half of the withdrawals is for municipal supply, and the rest is for industrial use and supplemental irrigation. Cones of depression in the piezometric surface show the effect of the withdrawals, and significant declines in the water level have accompanied the development of public supplies from the minor sand beds in the Wilcox.

AQUIFER CHARACTERISTICS

The aquifer characteristics of the minor Wilcox aquifers are shown (averages by county or parish) in the following table:

[Number in parenthesis denotes number of tests used to compute average]

County or parish	State	Coefficient			Specific capacity (gpm per ft of drawdown)
		Transmissibility (gpd per ft)	Storage	Permeability (gpd per sq ft)	
Hot Spring	Arkansas	(1) 18, 000	(1) 0. 00002	(1) 450	
Bossier	Louisiana	(2) 6, 800	(1) . 0005	(2) 95	
Webster	do	(2) 9, 000	(1) . 0002	(2) 100	
Lauderdale	Mississippi	(1) 26, 000		(1) 200	(1) 11
Cass	Texas	(2) 7, 200		(2) 100	(2) 4
Harrison	do	(3) 3, 300		(3) 65	(3) 2
Marion	do	(1) 10, 000		(1) 140	(1) 4

QUALITY OF THE WATER

Water in the area of use of the minor Wilcox aquifers in southwestern Arkansas, northwestern Louisiana, and northeastern Texas is generally a sodium bicarbonate type when dissolved solids are low and a sodium bicarbonate chloride type when they are high. The ranges in concentrations of the various constituents and the median values are given in table 5. The median values indicate that sodium, bicarbonate, and chloride are the principal constituents in the water. Maximum amounts of calcium and magnesium occur in the water locally but are not representative of any area. The maximum amount of sulfate is in water from an area in the central part of Caddo Parish, La., and Harrison County, Tex. (pl. 4). The maximum amount of nitrate is in water from a shallow well, and the nitrate is probably a result of contamination.

TABLE 5.—*Summary of chemical analyses of water from the minor Wilcox aquifers in Arkansas, Louisiana, and Texas*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	66	7. 9	17
Iron (Fe)	55	. 00	. 24
Calcium (Ca)	134	. 0	7. 4
Magnesium (Mg)	155	. 0	3. 4
Sodium (Na)	849	1. 0	110
Potassium (K)	13	. 5	2. 2
Carbonate plus bicarbonate (CO_3+HCO_3)	910	0	256
Sulfate (SO_4)	300	. 0	3. 7
Chloride (Cl)	985	1. 0	50
Fluoride (F)	4. 8	. 0	. 2
Nitrate (NO_3)	156	. 0	. 5
Dissolved solids	2, 120	17	347
Hardness as $CaCO_3$	956	3	38
Specific conductance (micro mhos at 25°C)	2, 470	16	588
pH	8. 6	4. 8	7. 6
Color	1, 000	0	8

The patterns of chemical analyses of water from the minor Wilcox aquifers (pl. 4) show the variations in the chemical characteristics of the water. The patterns show that along the outcrop area in Arkansas the water is low in dissolved solids. Comparison of these patterns with the one for Ouachita County, Ark., indicates that the water farther downdip rapidly increases in dissolved-solids content and changes to a sodium chloride type.

In Louisiana and Texas, the chemical characteristics of the water vary more when the dissolved-solids content is low, and as the dissolved-solids content increases, sodium, bicarbonate, and chloride become the principal constituents. The general distribution of dissolved solids in this area (pl. 4) is related to the geologic structure. Locally, the distribution of dissolved solids is irregular; an extreme example of the irregularity is shown by the two patterns (pl. 4) for water from wells in Marion County, Tex. The two wells, at about the same location and depth (925 and 950 ft), yield water containing 80 and 909 ppm dissolved solids. These local variations in dissolved solids are probably related to variations in the physical character of the deposits.

Water in minor Wilcox aquifers in Mississippi is generally a sodium bicarbonate type in the northern part of the area of use and a calcium bicarbonate type in the southern part of the area of use ,pl. 4). The dissolved-solids content of the water ranges from 56 to 436 ppm (table 6). The iron content of the water is generally lower in areas where sodium and bicarbonate are the principal constituents. In areas where the water is a calcium bicarbonate type, the calcium content of the water in most instances will exceed the median value shown; and in areas where the water is a sodium bicarbonate type, the sodium content will exceed the median value for sodium.

TABLE 6.—*Summary of chemical analyses of water from the minor Wilcox aquifers in Mississippi*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	42	2.8	14
Iron (Fe)	15	.00	.25
Calcium (Ca)	48	2.5	13
Magnesium (Mg)	19	.4	2.5
Sodium (Na)	177	.8	18
Potassium (K)	4.0	1.0	1.5
Carbonate plus bicarbonate (CO_3+HCO_3)	364	9	137
Sulfate (SO_4)	36	.6	6.5
Chloride (Cl)	70	2.2	5.5
Fluoride (F)	.5	.0	.2
Nitrate (NO_3)	6.3	.0	.2
Dissolved solids	436	56	151
Hardness as $CaCO_3$	199	10	50
Specific conductance (micromhos at 25°C)	--------	73	-------
pH	8.7	5.5	7.3

POTENTIAL USE

Minor sand beds in the upper part of the Wilcox in Mississippi are of potential use locally, particularly in Grenada, Leflore, Holmes, and Madison Counties (pl. 3). Fresh water in the Wilcox is virtually untapped in a belt east of the Red River and underlying the Sparta Sand outcrop in Louisiana. In local areas in Texas, electric-log data indicate that sand beds of variable thickness and areal extent are potential aquifers. They are not used because water is available in overlying aquifers. The area of potential use in southwestern Arkansas is small, as the minor Wilcox aquifers are utilized in almost all the area where they contain fresh water. However, the total withdrawal is small and could be increased.

CONCLUSIONS

Discontinuous sands in the Wilcox are used as aquifers in many places in the embayment. The yields of wells and the chemical quality of the water differ widely. In the southwestern part of the embayment the iron content is commonly high, and the aquifers are chiefly used where other aquifers are not available or contain water of poorer chemical quality.

CARRIZO SAND AND MERIDIAN–UPPER WILCOX AQUIFERS

By R. L. HOSMAN, E. H. BOSWELL, and A. T. LONG

The Carrizo Sand is the basal unit of the Claiborne Group in Arkansas, Louisiana, and Texas, and unconformably overlies the Wilcox Group. It is overlain by the Cane River Formation in Arkansas and Louisiana. In Texas, where the Reklaw Formation, Queen City Sand, and Weches Greensand are equivalents of the Cane River Formation, the Carrizo is overlain by the Reklaw Formation. In northeastern Texas the Carrizo Sand crops out in two narrow bands, one on either side of the East Texas basin (pl. 5). The northern band extends northeastward into Arkansas, and the southern band extends southeastward into Louisiana.

In Arkansas and Louisiana, water in the Carrizo Sand is confined by the Cane River Formation above and the Wilcox below. The Cane River Formation becomes increasingly sandy updip near the outcrop, and, in places, sand in the Cane River apparently rests on and is hydraulically connected with the Carrizo. Interfingering middle Cane River sands in northwestern Louisiana and southwestern Arkansas merge to become the thick Queen City Sand in northwestern Texas and extreme southwestern Arkansas. The underlying Reklaw Formation is sandy in northeastern Texas. The Carrizo, Reklaw, and Queen City are apparently hydraulically connected, have similar hydrologic properties, and may be treated as a single hydrologic unit in this area. This sand unit ranges in thickness from about 200 feet to about 500 feet, the maximum thickness being in the trough of the East Texas basin. The beds dip southeast and northeast toward the axis of the basin and dip northeast to east in northwestern Louisiana. The dip ranges from about 15 to 50 feet per mile. The water-bearing sands underlie small parts of northern Caddo and Bossier Parishes, La., and about half (1,600 sq mi) of the northeast corner of Texas.

The Carrizo Sand is present in the subsurface of the Coastal Plain in south-central Arkansas south of about lat 35° N. North of this latitude the overlying Cane River Formation becomes sand, and the Carrizo becomes the basal part of a thick sand unit. The Carrizo dips southeastward from its outcrop in southwestern Arkansas at a rate of 20–40 feet per mile (pl. 5). The thickness in the subsurface ranges from about 60 feet near the outcrop to about 300 feet in south-central Arkansas (pl. 5).

In Mississippi the Meridian Sand Member of the Tallahatta Formation is equivalent to the Carrizo Sand and is the basal unit of the Claiborne Group. Generally, sands are present in the upper part of the Wilcox either in contact with the Meridian Sand or separated from it by discontinuous clay beds. Interpretation of piezometric data and chemical analyses of the water indicate that the Meridian Sand and the upper sands in the Wilcox are hydraulically connected and may be considered a single aquifer in much of the embayment in Mississippi.

The sands forming the Meridian–upper Wilcox aquifer are not represented by a continuous exposure on the outcrop; even the Meridian Sand, although it apparently overlaps the upper and middle parts of the

Wilcox in northern Mississippi, is irregular in thickness and is discontinuous. In extreme northern Mississippi, the entire Meridian–upper Wilcox aquifer and the lower part of the Claiborne form the major Memphis aquifer.

The Meridian–upper Wilcox aquifer ranges in thickness from 50 feet to about 400 feet (pl. 5) and contains fresh water in an area of about 17,500 square miles. It is one of the most widely used aquifers for municipal, industrial, domestic, and farm water supplies in Mississippi.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Recharge to the Carrizo Sand and to the Meridian–upper Wilcox aquifer comes from rainfall on the outcrop, seepage from overlying Quaternary deposits in the northern part of the embayment, and underflow from the Memphis aquifer.

Withdrawals from the Carrizo Sand are extremely small, about 0.5 mgd, considering that the sand contains fresh water in an area of several thousand square miles. Most of the wells tapping the Carrizo are for domestic and stock supplies; only a few are for municipal, industrial, and irrigation supplies. The yields range from about 30 to 100 gpm. Flowing wells of low yield can be obtained in major stream valleys in southwestern Arkansas and possibly in northwestern Louisiana.

Withdrawals from the Meridian–upper Wilcox aquifer are distributed over the area of use (pl. 5) and are not large in any locality, although the total withdrawal is about 27 mgd. More water is probably wasted from flowing wells in the Meridian–upper Wilcox aquifer than is used at present (1965). The largest withdrawals are for municipal and industrial use in northeastern Leflore County, Miss. A large depression in the piezometric surface has formed in northwestern Mississippi (pl. 5) owing to discharge from uncontrolled flowing wells and, to a lesser extent, to withdrawals for use.

Water in the Carrizo Sand and in the Meridian–upper Wilcox aquifer moves downdip except in west-central Mississippi, where movement is toward an area of withdrawal delineated by the 150-foot contour (pl. 5). South of this area the water levels are higher, and wells drilled into the aquifer flow. The water level in wells in Yazoo County is about 125 feet above land surface.

AQUIFER CHARACTERISTICS

The aquifer characteristics of the Carrizo Sand and the Meridian–upper Wilcox aquifer are summarized (averages by county) in the following table:

[Number in parenthesis denotes number of tests used to compute average]

County	State	Coefficient: Transmissibility (gpd per ft)	Coefficient: Storage	Coefficient: Permeability (gpd per sq ft)	Specific capacity (gpm per ft of drawdown)
Carrizo Sand					
Hot Springs	Arkansas	(1) 4,100		(1) 100	(1) 2
Cass	Texas	(1) 2,400		(1) 50	(1) 1
Harrison	do	(1) 1,300		(1) 35	
Meridian–upper Wilcox aquifer					
Attala	Mississippi	(2) 32,000	(1) 0.0002		(2) 15
Holmes	do	(2) 54,000	(2) .003	(2) 480	
Leflore	do	(2) 86,000	(1) .0001	(2) 1,000	(1) 20
Montgomery	do	(1) 56,000	(1) .0002	(1) 910	(1) 24
Sunflower	do	(1) 18,000	(1) .0001	(1) 200	
Tallahatchie	do	(1) 11,000		(1) 200	

QUALITY OF THE WATER

Water from the Carrizo Sand is generally soft, low in iron, and a sodium bicarbonate type; but the type of water varies with the dissolved-solids content. The dissolved-solids content ranges from 90 to 2,820 ppm; the maximum amount is in water from a faulted zone. Where the dissolved-solids content is low (pl. 5), the water is either a calcium magnesium bicarbonate type or a sodium bicarbonate type. Increases in dissolved-solids content, up to about 400 ppm, are primarily due to increases in sodium and bicarbonate; increases in excess of about 400 ppm are due to increases in sodium, bicarbonate, and chloride. The sodium and chloride contents increase at a faster rate than the bicarbonate.

The dissolved solids increase as the water moves downdip, but this increase is probably small. For example, water from two wells that are 332 and 346 feet deep contains 90 and 178 ppm dissolved solids (pl. 5), and water from two downdip wells that are 1,406 and 2,050 feet deep contains 822 and 654 ppm dissolved solids.

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Water from the Carrizo Sand is generally of good quality and is suitable for most uses, but in places treatment for iron removal would be desirable for some uses. In downdip areas, the chloride content makes the water unsuitable for some industrial uses.

Water in the Meridian–upper Wilcox aquifer in most of the area of use is soft and a sodium bicarbonate type and contains less than 500 ppm dissolved solids. The amounts of calcium, magnesium, and sulfate in the water are low; the larger amounts of these constituents are in water from wells in the outcrop area. The iron content of the water is usually low, but larger amounts occur locally throughout the area. The highly colored waters are generally found at considerable depths in the aquifer. The ranges in concentration and the median values of the various constituents and properties of the water are shown in table 7. The maximum amounts of most constituents are in water from wells in the extreme downdip area of use. The median values emphasize the sodium bicarbonate character of the water, and they are indicative of the quality of the water in a large part of the area of use.

TABLE 7.—*Summary of chemical analyses of water from the Meridian–upper Wilcox aquifer*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	41	0.0	13
Iron (Fe)	8.7	.00	.15
Calcium (Ca)	38	.0	2.5
Magnesium (Mg)	12	.0	.7
Sodium (Na)	1,060	2.0	82
Potassium (K)	15	.9	3.7
Carbonate plus bicarbonate (CO_3+HCO_3)	1,960	10	225
Sulfate (SO_4)	46	.0	4.2
Chloride (Cl)	860	.0	6.1
Fluoride (F)	7.0	.0	.1
Nitrate (NO_3)	17	.0	.7
Dissolved solids	2,680	24	238
Hardness as $CaCO_3$	134	0	11
Specific conductance (micromhos at 25°C)	4,490	48	-------
pH	8.9	5.2	7.7
Color	90	0	11

Water in the outcrop of the Meridian–upper Wilcox aquifer contains smaller amounts of dissolved solids and has more variable chemical characteristics than water from downdip locations (pl. 5). As the water moves downdip from the outcrop, the dissolved-solids content gradually increases, up to about 500 ppm; most of the calcium and magnesium present in water in the outcrop is removed by base exchange, and sodium and bicarbonate become the principal constituents. Increases in dissolved solids up to about 600 ppm are principally an increase in sodium bicarbonate, and increases in excess of about 600 ppm are usually increases in sodium, bicarbonate, and chloride; the rate of increase of chloride varies from area to area.

Because of the fairly uniform character and low dissolved-solids content of the water, the Meridian–upper Wilcox aquifer is an excellent source of water supply for municipalities and industries. The type and degree of treatment required for water from this unit depends largely on the intended use. The water would be suitable for some uses, such as cooling, with little or no treatment; but for other uses it would require, depending upon the location, treatment for corrosion control and for the removal of iron and color.

POTENTIAL USE

The limit of the area of potential use of the Carrizo Sand and the Meridian–upper Wilcox aquifer is the downdip limit of fresh water (pl. 5). In much of the present area of use the full potential of the aquifers is not approached; in Mississippi, the Meridian–upper Wilcox aquifer contains fresh water in an area of about 17,500 square miles, some of the better parts of the aquifer are in the area of potential use. The data indicate that the yields of future wells drilled in the Carrizo in northeastern Texas and northwestern Louisiana will be within the range of yields of existing wells; yields exceeding about 100 gpm probably cannot be expected. Although the Carrizo Sand contains fresh water in an area of more than 5,000 square miles in Arkansas, it is largely unproven and unused as an aquifer. It is used in an area of less than 400 square miles in southwestern Arkansas where the hydrology and potential of the unit are virtually the same as in the northwestern Louisiana area. However, in south-central Arkansas, where the unit is much thicker, it is composed of slightly coarser sand than it is to the southwest and contains fresh water at depths exceeding 2,000 feet, and the potential appears large. As there are no wells tapping the Carrizo in this area (except for a deep exploratory test), the hydrostatic head is high, and large well yields can probably be expected.

CONCLUSIONS

The principal aspect of the Carrizo Sand and Meridian–upper Wilcox aquifer is that in their present undeveloped state they represent a huge reserve of ground water in nearly one-fourth of the Mississippi embayment. In Mississippi, where the withdrawal from the Meridian–upper Wilcox aquifer is about 27 mgd for all purposes, exclusive of the water lost from uncontrolled flowing wells, the potential of the aquifer is far greater than the present development. Large areas remain where the sands have not been tapped by water wells, although in some places the aquifer characteristics preclude large ground-water developments. In south-central Arkansas, where the hydrology of the Carrizo Sand is the most favorable for future development in that State, the unit is untapped. In the southwestern Arkansas–northeastern Texas–northwestern Louisiana area, data indicate that, although the aquifer yields water to only a few large-capacity wells, additional large withdrawals may overdevelop the aquifer unless the withdrawals cause increased recharge.

CANE RIVER FORMATION AND EQUIVALENTS

By R. L. Hosman, E. H. Boswell, and A. T. Long

The Cane River Formation in Louisiana and Arkansas is equivalent to the Reklaw Formation, Queen City Sand, and Weches Greensand in Texas and to the Tallahatta Formation (exclusive of the Meridian Sand Member, which is equivalent to the Carrizo Sand), Winona Sand, and Zilpha Clay in Mississippi. Above the Meridian Sand Member, the Tallahatta Formation also includes the Basic City Shale and Neshoba Sand Members; north of lat 34° N., the upper part of the Tallahatta is undifferentiated.

The top of the Cane River Formation or its equivalents is defined in this report on the basis of a micropaleontologic and lithologic examination of drill cuttings from wells in Arkansas and Mississippi and a correlation of electric logs of these wells with electric logs of wells elsewhere in the embayment.

The Cane River Formation or its equivalents ranges from about 200 feet to about 500 feet in thickness (pl. 6), and the formation dips toward the axis of the embayment (pl. 6) at 5–40 feet per mile.

In the subsurface of Louisiana and Arkansas the Cane River Formation is a marine clay. However, in the updip section on the west side of the embayment the Cane River becomes increasingly sandy; the predominant and more persistent sands generally occur in the middle part of the formation. In northwestern Louisiana this middle part contains interfingering sands which merge updip in northeastern Texas to form the Queen City Sand. The sandy middle part of the Cane River extends a short distance northeastward into Arkansas, beyond which the Cane River generally contains from two to four principal sands. In northeastern Texas the Reklaw is also sand, and it and the underlying Carrizo Sand and the overlying Queen City Sand form an aquifer. In places in and near the outcrop area in southwestern Arkansas, the lower part of the Cane River Formation is sand or very sandy clay and provides hydraulic connection between the Carrizo and the overlying Cane River sands.

Sands of the Cane River Formation are sources of water for small domestic wells in an area of about 4,000 square miles in south-central and southwestern Arkansas. Only in about one-fourth of this area do wells tap the Cane River.

Updip the Cane River undergoes a facies change northward at about lat 35° N., and the marine clays become sand. The transitional zone of interfingering sands and clays is narrow. The northern sand facies of the Cane River is the middle part of the Memphis aquifer.

The Tallahatta Formation of Mississippi includes the Meridian Sand, Basic City Shale, and Neshoba Sand Members. North of lat 34° N., the upper part of the Tallahatta is undifferentiated. The Meridian Sand Member was discussed in this report with its equivalent, the Carrizo Sand. The Basic City Shale is not an aquifer in its type locality, but it does include water-bearing sands northward and is a locally used aquifer in some areas. The Neshoba Sand Member, apparently a facies of the Basic City Shale Member, and the overlying Winona Sand form an extensive aquifer in northwestern Mississippi. Although the Cane River in Arkansas is not subdivided, the Winona Sand and overlying Zilpha Clay are recognizable on electric logs in eastern Arkansas, chiefly in Lee and Phillips Counties. The marine clays in the Tallahatta and Zilpha Formations like those in the Cane River, change to a sand facies at approximately lat 35° N.

Several miles north of Memphis a clay reappears in the Claiborne section in the same stratigraphic position as that occupied by the Zilpha Clay and the corresponding part of the Cane River Formation to the south. Although this clay has not been identified as the Zilpha, its stratigraphic position and the overall thickness of the Claiborne section suggest that it probably is the Zilpha. If this clay is the Zilpha, its absence in many places at about the latitude of Memphis is possibly not due to a facies change but to removal by erosion and subsequent replacement by Sparta Sand. This replacement could have been accomplished by two or three major streams entering the embayment in this area, probably from the northeast.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The outcrop is the principal recharge area for the Reklaw–Queen City aquifer and for sands of the Cane River Formation, and it forms uplands in the western part of the embayment. Wells in the outcrop area generally yield 5–10 gpm. Downdip, larger capacity wells tap the aquifer. Several industrial and irrigation wells in eastern Cass County, Tex., and a municipal well in Bossier Parish, La., yield 50–100 gpm and these pumpage figures are included with those for the Carrizo, as the Carrizo and the sands in the Cane River form one aquifer. Withdrawals from the Cane River in Arkansas are about 3 mgd in an area of about 1,000 square miles, mostly in the southwestern part of the State. In this area flowing wells of low yield can be obtained in major stream valleys.

The outcrop belt of the sands of the Tallahatta Formation is in an area of rugged topography, and recharge conditions are good. The water moves westward except in the central part of the Mississippi alluvial plain, where long-term withdrawals have caused a large cone of depression. This cone is a result of withdrawals beginning in 1896 (Brown, 1947, p. 27), when the first flowing artesian well in the alluvial plain was developed in the Winona–Tallahatta aquifer. Because this aquifer is shallow, is artesian, and yields water of good chemical quality, it has been the source of many flowing wells. As a result, the artesian pressure has declined, and the present trend in well drilling is to drill deeper and develop wells in the Meridian–upper Wilcox aquifer.

AQUIFER CHARACTERISTICS

Aquifer characteristics of the Cane River Formation and its equivalents are not known for most of the area. The results of one aquifer test in the Neshoba Sand in Carroll County, Miss. (pl. 6) show a coefficient of transmissibility of 4,800 gpd per ft, a coefficient of storage of 0.0005, and a coefficient of permeability of 60 gpd per sq ft. The specific capacity of the pumped well was 3 gpm per foot of drawdown.

QUALITY OF THE WATER

Water in the Reklaw–Queen City aquifer and in sands of the Cane River Formation is generally soft and has a fairly high iron content; the chemical characteristics generally vary with the dissolved-solids content. Where the dissolved-solids content of the water is low, calcium and sodium may both be present in about equal amounts or either may predominate. Bicarbonate is the principal anion. As the dissolved-solids content increases, sodium and bicarbonate become the principal constituents; a continued increase in dissolved solids results in the water changing to a sodium bicarbonate chloride type and then to a sodium chloride type.

The ranges in concentration and the median values of the various constituents are given in table 8. The maximum amounts of iron and nitrate are unusually high; but, excluding these anomalous amounts, the maximum amounts would be only 6.6 and 3.2 ppm, respectively. The dissolved-solids content of the water generally increases with depth, and most of the larger amounts are in water from wells deeper than 200 feet. The dissolved-solids content, however, does not necessarily increase because of an increase in depth. Some wells that are deeper than 200 feet yield water containing less than 350 ppm dissolved solids. The maximum amounts of dissolved solids are in water from a faulted zone in Arkansas.

TABLE 8.—*Summary of chemical analyses oj water from the Reklaw–Queen City aquifer and the sands in the Cane River Formation*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Iron (Fe)	55	0.02	0.50
Calcium (Ca)	65	.8	7.5
Magnesium (Mg)	20	.0	2.8
Sodium (Na)	964	.8	119
Potassium (K)	16	.4	5.0
Carbonate plus bicarbonate (CO_3+HCO_3)	708	0	212
Sulfate (SO_4)	81	.0	1.8
Chloride (Cl)	1,410	1.8	59
Fluoride (F)	1.8	.0	.1
Nitrate (NO_3)	29	.0	1.0
Dissolved solids	2,720	29	306
Hardness as $CaCO_3$	236	2	31
Specific conductance (micromhos at 25°C)	4,610	43	500
pH	8.3	4.7	-------

Patterns of the variations in the chemical characteristics of water from several locations are shown in plate 6. Except for the patterns for the southernmost two Texas wells, the patterns are representative of the chemical characteristics of water at different locations in the formation. In Texas, the water containing 29 ppm nitrate and 96 ppm of dissolved solids is not representative of the formation. This water is from a 30-foot-deep well, and the high nitrate content probably results from surface contamination. The chemical characteristics shown by the pattern of the southernmost well (452 ppm dissolved solids) are neither similar to the chemical characteristics of water in other areas nor to those of water at shallower depths in the same area. The factors that caused these characteristics are not known.

Except in the faulted zone in Arkansas, the dissolved-solids content of water from sands in the Cane River Formation and its equivalents is less than 1,000 ppm. The median value for iron indicates that the iron content is generally high in much of the area; consequently, for many uses treatment for iron removal would be desirable. The silica content of the water ranges from 9.1 to 23 ppm, and the concentration of this constituent would need to be reduced if the water were to be used in high-pressure steam boilers.

Water from the Tallahatta Formation is generally soft and a sodium bicarbonate type (pl. 6). At a few locations, calcium and magnesium are in sufficient quantities to cause the water to be moderately hard or hard. The water commonly has a low iron content and is colored.

The dissolved-solids content ranges from 59 to 1,590 ppm (table 9). It is lowest in the water from the outcrop or recharge area, and increases with depth into the formation and with distance traveled by the water downdip. The increase in dissolved-solids content results mainly from an increase in the sodium and bicarbonate contents (pl. 6).

TABLE 9.—*Summary of chemical analyses of water from the Tallahatta Formation*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	51	0.4	19
Iron (Fe)	4.3	.00	.12
Calcium (Ca)	40	.0	1.9
Magnesium (Mg)	18	.0	.4
Sodium (Na)	651	7.4	152
Carbonate plus bicarbonate (CO_3+HCO_3).	1,710	52	332
Sulfate (SO_4)	42	.0	1.0
Chloride (Cl)	56	.0	5.6
Fluoride (F)	4.0	.0	.3
Dissolved solids	1,590	59	382
Hardness as $CaCO_3$	174	0	8
pH	8.6	7.0	-------
Color	120	5	-------

The median values in table 9 are indicative of the chemical characteristics of water in the Tallahatta Formation. The median concentrations of constituents other than silica, sodium, and bicarbonate rarely exceed 10 ppm. Calcium and magnesium ions are evidently either unavailable in the aquifer material or are removed from solution by ion exchange; near maximum amounts of calcium and magnesium ions are unusual and occur only locally in the water. The median value of 0.12 ppm for iron indicates that the iron content is usually low. Maximum and near maximum amounts of sulfate and chloride also are unusual and occur only locally in the water. The coloring material in the water is probably derived from organic material in the deposits, and the amount or degree of coloration generally increases with depth.

Water in the Tallahatta Formation is generally of good chemical quality, and in much of the area it is suitable for many uses without treatment. With treatment it can be made suitable for most uses. The particular treatment depends upon the area and the intended use of the water. It could include iron and color removal for domestic, municipal, and industrial supplies; reduction of alkalinity for some industrial uses; reduction of the silica content of water used in high-pressure steam boilers; and the addition of stabilizers or inhibitors for corrosion control.

Water in the Winona Sand is generally soft and a sodium bicarbonate type. At a few locations calcium is present in sufficient quantities to make the water moderately hard, but the percentage of calcium is not great enough to change the type of water. The available information on iron content of the water is inconclusive.

The dissolved-solids content of the water ranges from 33 to 977 ppm (table 10). It is less in water from wells in the outcrop area and increases with depth and the downdip movement of the water. The median values in table 10 and the patterns on plate 6 show that increases in dissolved solids are primarily in sodium and bicarbonate. A comparison of the median dissolved-solids values of water from the Winona Sand (619 ppm) with those from the Tallahatta Formation (382 ppm) and from the Sparta Sand (256 ppm) in Mississippi indicates that water in the Winona Sand is more mineralized than water from the underlying and overlying formations.

The maximum and minimum values in table 10 show the range in concentration of the various constituents; and the median values, except those for sodium and bicarbonate, are representative of the concentrations of these constituents in the water throughout the area of use. Near maximum amounts of calcium are unusual and occur only locally in the water. The calcium content of the water in 89 percent of the analyses was 11 ppm or less, and in 67 percent of the analyses it was 5 ppm or less. Sodium and bicarbonate increase with downdip movement of water. The maximum and minimum amounts of fluoride (table 10) are in water from the deepest (1,550 ft) and the shallowest (6 ft) wells, respectively. Fluoride generally is in water from wells deeper than 1,200 feet; the fluoride content of water at depths less than 1,200 feet is not known.

TABLE 10.—*Summary of chemical analyses of water from the Winona Sand*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	42	0.3	21
Iron (Fe)	1.5	.05	-------
Calcium (Ca)	33	.9	2.5
Magnesium (Mg)	3.0	.3	.9
Sodium (Na)	415	5.6	244
Potassium (K)	13	.4	3.5
Carbonate plus bicarbonate (CO_3+HCO_3)	1,110	15	650
Sulfate (SO_4)	11	.9	1.3
Chloride (Cl)	24	1.0	4.6
Fluoride (F)	2.7	.2	-------
Dissolved solids	977	33	619
Hardness as $CaCO_3$	92	4	8

Although water in the Winona Sand generally contains more dissolved solids than water in the Tallahatta Formation, the major chemical characteristics of water from both formations are similar. Thus, water from the Winona Sand would generally be suitable for the same uses, and subject to the same requirements of treatment, as water from the Tallahatta Formation.

POTENTIAL USE

The area of potential use of sands in the Cane River Formation (pl. 6) in Arkansas is about 3,000 square miles in the south-central and southwestern parts of the State. This area is about three times as large as the area of use. The area of potential use is limited by the downdip extent of the sands and the downdip limit of fresh water in them.

The present area of use of water from the Winona-Tallahatta aquifers is nearly the maximum potential area of development. However, the aquifers are sparsely developed, particularly in areas where they underlie the Sparta Sand. In other areas wells are drilled to the underlying Meridian–upper Wilcox aquifer to obtain higher water levels and greater artesian flows.

CONCLUSIONS

Aquifers of the Cane River Formation and its equivalents are underdeveloped. These aquifers are not used in large areas, and most wells provide small domestic supplies. A few large-capacity wells have been drilled in these aquifers in Mississippi, but the total withdrawal has been small, although the area in which fresh water occurs is large. The Winona equivalent is not tapped in eastern Arkansas.

As the sand beds in the Cane River Formation are updip sand facies of marine clays, water in them is confined not only by clays above and below, but also by the subsurface termination of the sand downdip. Thus, movement of water in these aquifers is naturally restricted to vertical leakage. Withdrawals by pumping would accordingly be the principal means of increasing the recharge in the outcrop.

Although not within the scope of this report, a detailed study of the stratigraphic relations, areal extent, and hydrologic nature of the sands of the Cane River Formation on the west side of the Mississippi embayment would be valuable to future development of the aquifers in this area.

SPARTA SAND

By R. L. Hosman, E. H. Boswell, and A. T. Long

The Sparta Sand overlies the Cane River Formation in most of the western part of the embayment, and the Zilpha Clay in the eastern part. It is correlative with the upper part of the Memphis aquifer. The Sparta crops out on both the west and east sides of the embayment and dips toward the axis of the embayment and southward toward the gulf (pl. 7). The thickness near the outcrop areas ranges from about 400 feet, in western Louisiana, to about 100 feet, in southeastern Mississippi; the maximum thickness in the subsurface is about 1,100 feet near the axis of the embayment at the south limit of the region (pl. 7).

The Sparta has been removed by erosion in places under the flood plain of the Mississippi River near the north boundary of Mississippi, and the truncated edge of the Sparta underlies the alluvium in other parts of the area. The Sparta occurs only as outliers in northeastern Texas.

The Sparta consists chiefly of beds of fine to medium sand in the lower half of the formation, and of beds of sand, clay, and lignite in the upper half. In parts of the embayment, clay beds separate the Sparta into two or more hydrologic units.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The sources of recharge to the Sparta Sand are precipitation on the outcrop, leakage from overlying alluvium, and underflow from the Memphis aquifer. Recharge from streams is negligible except in areas where the streams are directly connected to the aquifer.

The areas of heavy withdrawals of water by wells, indicated by the depressions in the piezometric surface (pl. 7), are in south-central Arkansas, in north-central Louisiana, and at Jackson, Yazoo City, and Clarksdale, Miss. Withdrawals for industrial, irrigation, and municipal use are about 125 mgd in Arkansas, about 53 mgd in Louisiana, and about 37 mgd in Mississippi. The major withdrawals are for industrial use in Louisiana, for industrial and municipal use in Arkansas, and for municipal use in Mississippi. Larger capacity wells screened in the Sparta yield from a few hundred to more than 2,000 gpm. The piezometric surface has declined below the land surface everywhere in the lowlands, except in the southern part of the region in Mississippi, as a result of pumping and discharge from flowing wells. Water levels have declined more than 200 feet in south-central Arkansas and in north-central Louisiana and may be below the top of the Sparta Sand in parts of these areas.

The regional movement of ground water in the Sparta is toward the axis of the embayment. In the outcrop area the ground water discharges into streams or alluvium.

AQUIFER CHARACTERISTICS

The aquifer characteristics for the Sparta Sand are summarized (averages by county or parish) in the following table:

[Number in parenthesis denotes number of tests used to compute average]

County or parish	State	Coefficient: Transmissibility (gpd per ft)	Coefficient: Storage	Coefficient: Permeability (gpd per sq ft)	Specific capacity (gpm per ft of drawdown)
Arkansas	Arkansas	(2) 130,000			
Columbia	do	(8) 28,000	(3) 0.0008	(1) 830	(7) 9
Dallas	do	(1) 24,000	(1) .0003		
Desha	do	(1) 20,000	(1) .0024		
Drew	do	(1) 13,500		(1) 140	
Grant	do	(2) 38,000			(1) 12
Jefferson	do	(5) 100,000	(5) .0002		
Lafayette	do	(1) 49,000	(1) .0005		
Ouachita	do	(1) 29,000	(1) .0002	(1) 660	(1) 7
Prairie	do	(1) 55,000	(1) .0002		
Union	do	(6) 32,900	(2) .0004	(6) 80	(3) 14
Bienville	Louisiana	(2) 18,000	(1) .0012	(2) 170	
Claiborne	do	(2) 26,000		(2) 210	
Ouachita	do	(1) 24,000	(1) .0002	(1) 300	
Union	do	(2) 19,500	(2) .0004	(2) 270	
Webster	do	(1) 40,000	(1) .0001	(1) 400	
Coahoma	Mississippi	(1) 50,000	(1) .0005	(1) 850	
Hinds	do	(10) 43,000	(7) .0004	(10) 550	(5) 16
Humphreys	do	(1) 94,000	(1) .0002	(1) 1,000	
Leflore	do	(1) 140,000		(1) 1,300	

QUALITY OF THE WATER

Water in the Sparta Sand is generally soft and is a sodium bicarbonate type (pl. 7). The dissolved-solids content ranges from 20 to 1,510 ppm (table 11), but the median value of 218 ppm indicates that generally the water is moderately mineralized. The median values also indicate that concentrations of all constituents except sodium and bicarbonate are low. Greater amounts of calcium and magnesium occur in water in areas of Arkansas and Mississippi where recharge to the Sparta Sand is from overlying Quaternary deposits. Nearly maximum amounts of sulfate are unusual and occur only locally in the water in Madison County, Miss., and Jackson Parish, La. Larger amounts of fluoride are present in water from the downdip areas, and the higher iron content is generally in water in and near the areas of outcrop. Larger amounts of chloride occur in water in downdip areas and in parts of Monroe and Lee Counties, Ark.

The patterns of chemical analyses on plate 7 show that the dissolved-solids content of the water is less in the outcrop and that it increases as the water moves downdip; calcium, magnesium, and iron contents, however, generally decrease with the movement of water downdip. The downdip increase in dissolved solids is mainly due to increases in sodium and bicarbonate. In extreme downdip areas the increase in dissolved solids is mainly due to increases in sodium, bicarbonate, and chloride.

The median values indicate that water in the Sparta Sand is generally of good quality. Except in the area of highly mineralized water in Monroe and Lee Counties, Ark., and in the extreme downdip locations, the water is suitable for most uses; but some treatment, such as iron removal or softening, may be desirable in places.

TABLE 11.—*Summary of chemical analyses of water from the Sparta Sand*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	62	0.0	17
Iron (Fe)	23	.00	.21
Calcium (Ca)	79	.0	3.3
Magnesium (Mg)	29	.0	.9
Sodium (Na)	598	2.6	70
Potassium (K)	11	.6	3.0
Carbonate plus bicarbonate (CO_3+HCO_3)	991	0	193
Sulfate (SO_4)	216	.0	3.7
Chloride (Cl)	638	1.0	7.4
Fluoride (F)	5.4	.0	.2
Nitrate (NO_3)	14	.0	.8
Dissolved solids	1,510	20	218
Hardness as $CaCO_3$	288	0	13
Specific conductance (micromhos at 25°C).	2,710	42	338
pH	9.0	4.3	8.0
Color	240	0	14

The high dissolved-solids content and the sodium chloride type of water in parts of Monroe and Lee Counties, Ark., are uncommon. Water in the Memphis aquifer to the north of this area contains less dissolved solids and is generally a calcium magnesium bicarbonate type. Water in the Sparta Sand south of this area also contains less dissolved solids but is a calcium magnesium bicarbonate or a sodium bicarbonate type. This anomalous situation may be due to the upward movement of mineralized water from lower aquifers. The occurrence of mineralized water in the Sparta in this area coincides with the zone of transition (pl. 7) where the marine clays of the Cane River undergo a facies change to sand. In this zone the clays are sandy and are probably less confining than the marine clays. This apparent increase in vertical permeability and the facts that in this area the Carrizo Sand contains saline water and has about a 10-foot higher hydrostatic head than the Sparta could account for the mineralized water in the Sparta at shallow depths.

POTENTIAL USE

The Sparta Sand is extensively utilized in areas of south-central Arkansas and north-central Louisiana. Large depressions in the piezometric surface (pl. 7) in these areas indicate an overdraft from the aquifer, and the proximity of a deep cone of depression in northeastern Louisiana to the area in which the Sparta contains saline water indicates that this overdraft may eventually result in a deterioration of the quality of the water in the area of heavy withdrawals.

Increased withdrawal near the outcrop area in Arkansas and Louisiana may increase the recharge to the Sparta and increase the available supply. The Sparta is capable of sustaining increased withdrawals in much of Mississippi and in southeastern Arkansas.

CONCLUSIONS

The Sparta Sand is one of the major sources of water in much of the embayment and is generally capable of yielding at least a few hundred gallons per minute. It is extensively utilized in large areas of Arkansas and Louisiana, and heavy pumping in part of the area may result in deterioration of the quality of the water. The water from the Sparta is of good quality and is suitable for most uses, except in some areas near the axis of the embayment. The water has a high iron content and is hard near the outcrop. Potential areas for larger yields from the Sparta are near the outcrop in Louisiana, much of Mississippi, and southeastern Arkansas.

MEMPHIS AQUIFER

By R. L. Hosman, G. K. Moore, and T. W. Lambert

The Memphis aquifer is a major aquifer in western Tennessee, southwestern Kentucky, southeastern Missouri, and northeastern Arkansas north of about lat 35° N. It is known locally in the Memphis, Tenn., area as the "500-foot" sand, and is the principal aquifer from which Memphis obtains its water supply.

The sand rests unconformably upon clay of the Wilcox, and the top of the unit near the latitude of Memphis appears to correlate with the top of the Sparta. In this area marine clays of the lower part of the Claiborne are not present but are represented by sand facies, and the entire section of sand from the top of the Wilcox to the top of the Sparta constitutes a single aquifer several hundred feet thick. North of the Memphis area a clay is present in the upper part of the Memphis aquifer which divides it into two aquifers, the lower being several times thicker than the upper. This clay occupies approximately the same stratigraphic position as the Zilpha Clay of Mississippi. The zone of transition, or facies change, which marks the southern limit of the Memphis aquifer, is shown on plate 7. To the south in Arkansas the interval occupied by the Memphis aquifer farther north includes the Carrizo Sand, Cane River Formation, and Sparta Sand, and in Mississippi the Tallahatta Formation, Winona Sand, Zilpha Clay, and Sparta Sand.

The Memphis aquifer thickens southward and toward the axis of the Mississippi embayment, which is marked approximately by the present course of the Mississippi River. The thickness ranges from about 400 feet to about 870 feet (pl. 7). The unit crops out on both the east and west sides of the northern part of the embayment, but in Illinois and Missouri it is overlapped by younger beds. The top of the unit dips about 12 feet per mile toward the axis of the embayment (pl. 7).

The area of outcrop of the Memphis aquifer comprises about 2,000 square miles in Tennessee, about 600 square miles in Kentucky and Missouri, and about 2,000 square miles in Arkansas. The Memphis aquifer is covered by Quaternary deposits west of the Mississippi River except in parts of Craighead, Green, and Clay Counties, Ark., where a part of the aquifer crops out as a segment of Crowleys Ridge.

The Memphis aquifer is principally made up of sand, but contains some argillaceous, micaceous, and lignitic materials. The sand is thick bedded, very fine to gravelly, and generally well sorted. Clay layers constitute only a small part of the total thickness, but layers as much as 20 feet thick may be extensive enough locally to separate the sand hydraulically.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The principal sources of recharge to the Memphis aquifer are precipitation on the outcrop area on the east side of the embayment and leakage from Quaternary alluvium and terrace deposits on the west side.

The major area of use of the Memphis aquifer is in the northeastern part of the embayment (pl. 7). Flowing wells can result from drilling in the major stream valleys east of the Mississippi River. The withdrawals from wells in 1960 were estimated to be about 160 mgd in Tennessee, 15 mgd in Arkansas, and 1 mgd in Missouri and Kentucky. The major part, about 140 mgd, was withdrawn in the Memphis area.

The regional movement of ground water in the Memphis aquifer is toward the axis of the embayment, and near the axis the movement has a southward component.

The large depression in the piezometric surface centered at Memphis results from the heavy withdrawal of ground water (pl. 7).

AQUIFER CHARACTERISTICS

The following table summarizes (averages by county) the aquifer characteristics for the Memphis aquifer:

[Number in parenthesis denotes number of tests used to compute average]

County	State	Coefficient			Specific capacity (gpm per ft of drawdown)
		Transmissibility (gpd per ft)	Storage	Permeability (gpd per sq ft)	
St. Francis	Arkansas	(1) 55,000	(1) 0.0009		
Graves	Kentucky	(1) 300,000	(1) .0002	(1) 2,000	(1) 54
Crockett	Tennessee	(1) 42,000	(1) .0005		(1) 11
Dyer	do	(3) 140,000	(3) .0004		
Fayette	do	(1) 20,000			
Gibson	do	(3) 89,000			
Haywood	do	(1) 200,000	(1) .0001		
Lake	do	(1) 130,000	(1) .0003		
Lauderdale	do	(2) 93,000	(1) .0003		(1) 4
Madison	do	(1) 150,000	(1) .011	(1) 600	
Obion	do	(4) 66,000	(3) .0006	(2) 265	(2) 23
Shelby	do	(60) 250,000	(52) .001		
Tipton	do	(1) 220,000			(1) 43
Weakley	do	(1) 54,000	(1) .0006		

QUALITY OF THE WATER

Water in the Memphis aquifer is generally a mixed type where the dissolved-solids content is low, and a calcium magnesium bicarbonate type when the dissolved-solids content is high (pl. 7). The maximum and minimum values in table 12 show a wide range in concentration for most constituents. The larger amounts of chloride, nitrate and dissolved solids and the higher values for specific conductance are in water from shallow wells and are not representative of water in the Memphis aquifer. The maximum values for calcium, magnesium, and bicarbonate are indicative of the concentrations of these constituents where recharge to the Memphis aquifer is from Quaternary deposits. The iron content of the water is generally low, but amounts in excess of 1 ppm are found locally.

TABLE 12.—*Summary of chemical analyses of water from the Memphis aquifer*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	43	3.3	13
Iron (Fe)	60	.00	.24
Calcium (Ca)	79	.5	7.0
Magnesium (Mg)	31	.3	2.6
Sodium (Na)	57	1.9	7.4
Potassium (K)	12	.0	.8
Carbonate plus bicarbonate (CO_3+HCO_3).	402	0	36
Sulfate (SO_4)	98	.0	3.1
Chloride (Cl)	174	.0	4.8
Fluoride (F)	2.0	.0	.1
Nitrate (NO_3)	439	.0	1.4
Dissolved solids	848	16	78
Hardness as $CaCO_3$	398	4	27
Specific conductance (micromhos at 25°C).	1,460	23	102
pH	8.5	4.7	6.3
Color	20	0	4

The patterns of chemical analyses (pl. 7) show that in the eastern part of the area of use, where the sand crops out, the water generally contains less than 100 ppm dissolved solids. Bicarbonate is the principal anion, and either calcium or sodium is the predominant cation. In a few places calcium, magnesium, and sodium are present in about equal amounts. In Missouri and parts of Arkansas and western Tennessee, where recharge to the Memphis aquifer is from Quaternary deposits, the water contains more dissolved solids and is a calcium magnesium bicarbonate type. Two exceptions are in southern Missouri, where the water contains less dissolved solids and is a sodium bicarbonate type. One of the samples from southern Missouri also contained an unusually high amount of iron.

Downdip from the area where a part of the sand forms a segment of Crowleys Ridge in northeastern Arkansas (pl. 7), the water is low in dissolved solids and is a sodium bicarbonate type. North and south of this segment of the ridge, where the outcrop of the aquifer is overlain by Quaternary deposits, the water has a higher dissolved-solids content and is a calcium magnesium bicarbonate type.

Water in the Memphis aquifer is generally of good quality and is suitable for most uses. However, in some places treatment for removal of iron and softening would be desirable for municipal and some industrial uses.

POTENTIAL USE

The Memphis aquifer is relatively undeveloped in the area of use except at Memphis. Large-capacity wells tap only the upper part of the aquifer. All the area of potential use where wells have not been drilled into the aquifer is in northeastern Arkansas and southeastern

Missouri. The Memphis aquifer is several hundred feet thick in this area and represents a large ground-water reserve.

CONCLUSIONS

The Memphis aquifer is a major aquifer in the northern part of the Mississippi embayment and is the principal source of water supply for Memphis. The aquifer is the sandy facies of the Claiborne Group below the top of the Sparta Sand. Large yields can be obtained from wells in most of the area of use, but the thickest sand is in the vicinity of Memphis, where the withdrawal of ground water is largest. The water from the sand is generally of good quality, but treatment for excessive iron and for hardness is desirable in places. Where the outcrop of the aquifer is overlain by Quaternary deposits, recharge from these deposits affects the chemical quality of the water, making it higher in dissolved-solids content and of a different chemical type. Most of the wells tap only the upper part of the aquifer. It offers excellent prospects for future development on the west side of the embayment, where it now is largely unused.

COCKFIELD FORMATION

By R. L. Hosman, A. T. Long, and E. H. Boswell

The Cockfield Formation crops out over large areas on both the east and west sides of the embayment. The truncated Cockfield underlies thick Quaternary alluvial deposits in the Mississippi River valley. The formation is missing in some areas of the western part of the valley in northern Louisiana. The Cockfield underlies the marine clay of the Jackson Group near the axis of the embayment at the extreme south limit. The lower part of the Jackson Group contains beds of fine sand in contact with the Cockfield in south-central Arkansas; these sands and the Cockfield together form one hydrologic unit. The thickness of the Cockfield near its outcrop area generally ranges from 100 feet to 400 feet; in the subsurface the thickness increases to about 700 feet (pl. 8). The Cockfield dips southward and toward the axis of the embayment (pl. 8).

The Cockfield Formation generally consists of fine to medium sand in the basal part, and silt, clay, and lignite in the upper part. The beds are discontinuous and contain carbonaceous material throughout.

Plate 8 does not show the Cockfield Formation north of lat 35° N., because positive identification of Cockfield deposits has not been established in this area. However, the Cockfield may be present in the northern part of the embayment east of the axis where the land surface is at a higher altitude.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The recharge to the Cockfield Formation is from precipitation on the outcrop and seepage from the Quaternary alluvium. The excess or rejected recharge on the outcrop contributes to the base flow of streams.

The regional movement of water in the Cockfield as shown by contours on the piezometric surface (pl. 8) is westward in Mississippi, southward in Arkansas, and southwestward in Louisiana. The irregular shape of some of the contours may be partly due to the fact that the wells may be screened in different sands within the Cockfield. The degree of hydraulic connection between the sands is not known, but slightly different piezometric pressures apparently do exist where they are affected by pumping.

The Cockfield is used for water supply in an area of about 20,000 square miles in Mississippi, 10,000 square miles in Arkansas, and 3,000 square miles in Louisiana. Where the water is confined by the Jackson Group at the south limit of the region, the piezometric surface is above the land surface and wells flow. The water in the Cockfield is saline in much of the area where it is confined by the Jackson Group.

The withdrawal of water by wells for municipal and industrial use is about 10 mgd in Arkansas, 2 mgd in Louisiana, and 20 mgd in Mississippi. The largest local withdrawal, 10 mgd, is at Greenville, Miss. The withdrawal by wells is small compared with the natural discharge. Large withdrawals are confined to local areas where water cannot be obtained from deeper aquifers. The water in the Cockfield is withdrawn only for domestic and stock use in much of the area.

AQUIFER CHARACTERISTICS

The following table summarizes (averages by county or parish) the aquifer characteristics for the Cockfield Formation.

[Number in parenthesis denotes number of tests used to compute average]

County or parish	State	Coefficient			Specific capacity (gpm per ft of drawdown)
		Transmissibility (gpd per ft)	Storage	Permeability (gpd per sq ft)	
Chicot	Arkansas	(1) 51,000	(1) 0.0008	(1) 850	
Caldwell	Louisiana	(1) 29,000			
East Carroll	do	(1) 33,000	(1) .0003	(1) 330	(4) 7
West Carroll	do				(2) 8
Hinds	Mississippi	(2) 22,500	(2) .0001	(2) 230	(1) 4
Rankin	do	(3) 25,000	(1) .0008	(2) 370	(2) 8
Scott	do	(2) 63,000	(1) .0004	(2) 480	(2) 16
Washington	do	(3) 72,000	(3) .0004	(3) 910	(1) 28

QUALITY OF THE WATER

Water in the Cockfield Formation is generally soft and a sodium bicarbonate type (pl. 8). The dissolved-solids content ranges from 25 to 4,870 ppm (table 13), but the median value of 303 ppm indicates that in most of the area the water is moderately mineralized. The median values also indicate that the concentration of all the constituents except sodium and bicarbonate is low. Larger amounts of calcium and magnesium are present in water in parts of Arkansas and in Louisiana where the Cockfield Formation is recharged from Quarternary deposits. Larger amounts of sulfate occur in water from wells in Jefferson County and from a few wells in Drew County, Ark., where the aquifer is continuous with sand in the overlying Jackson Group. Higher-than-normal sulfate contents also occur in water in most of Madison, Rankin, and Hinds Counties, Miss. The iron values are irregularly distributed over the area but generally the larger amounts are in water in or near areas of outcrop. Large amounts of fluoride are in water from deep wells in the downdip part of the area of use. The maximum amount of chloride is in water from a deep well in the extreme downdip area. Most of the larger amounts of chloride are in water from wells in an east-west belt extending from southern Ashley County, Ark., across central Chicot County, Ark., and into Washington County, Miss. The amount of coloration is probably related to the amount of carbonaceous material in the formation. The more highly colored water is in wells in the downdip areas.

TABLE 13.—*Summary of chemical analyses of water from the Cockfield Formation*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	53	2.0	13
Iron (Fe)	62	.00	.21
Calcium (Ca)	125	.0	3.2
Magnesium (Mg)	36	.0	1.1
Sodium (Na)	1,910	1.2	105
Potassium (K)	13	.2	3.2
Carbonate plus bicarbonate (CO_3+HCO_3)	1,590	8	249
Sulfate (SO_4)	464	.0	2.4
Chloride (Cl)	2,380	2.0	16
Fluoride (F)	4.4	.0	.3
Nitrate (NO_3)	10	.0	1.0
Dissolved solids	4,870	25	303
Hardness as $CaCO_3$	440	0	13
Specific conductance (micromhos at 25°C)	8,430	25	455
pH	8.9	5.8	8.2
Color	1,200	0	11

The patterns of chemical analyses (pl. 8) are representative of areal variations in the chemical characteristics of water in the Cockfield Formation. These patterns show that the dissolved-solids content increases, principally in sodium and bicarbonate, with the downdip movement of water. These patterns also indicate that as water moves downdip, the concentrations of calcium, magnesium, and sulfate decrease.

Water in the Cockfield Formation is generally of good chemical quality and is suitable for most uses. In places, however, softening and iron and color removal would be desirable for municipal and many industrial uses.

POTENTIAL USE

The area of use coincides with the area of potential use in the southern part of the embayment, but in much of the area the aquifer has not been fully developed. An increase in withdrawals will eventually result in a decrease in the base flow of streams in the area and available water in the overlying Quaternary alluvium. In Arkansas, few wells tap the Cockfield north of the Arkansas River. In much of the area of potential use, yields will be adequate only for domestic and stock use.

CONCLUSIONS

The sandy basal part of the Cockfield Formation is a major aquifer locally. It contains fresh water in about 33,000 square miles, generally where the Quaternary alluvium directly overlies the sand of the Cockfield. The Cockfield contains saline water in some areas near the axis of the embayment. The Cockfield yields small to moderate quantities of water and is the source of domestic and several public and industrial water supplies. The water is generally of good quality, but treatment for iron and color removal and softening may be desirable in places.

Withdrawals from the Cockfield Formation can be increased in much of the area, but use will generally be limited by small yields. The present withdrawal is about 30 mgd.

FOREST HILL SAND

By E. H. Boswell

In Mississippi, south of the Cockfield outcrop (pl. 8) and near the south limit of the embayment, the Forest Hill Sand of Oligocene age crops out in a narrow band. This outcrop extends southeastward from just west of Jackson to about the 89th meridian of longitude. Although the Forest Hill Sand does not supply water in a large enough area to be of regional importance as an aquifer, it is used locally. Thus, some information about the sand is included in this report. However, because the area within the embayment is small, maps like those prepared for the other aquifers were not made.

The Forest Hill Sand is composed of gray clay and thin-bedded very fine sand and averages about 100 feet in thickness. The formation generally contains less than 40 percent sand, although in a few places it is predominantly sand. The Forest Hill is underlain by the Yazoo Clay and overlain by the Vicksburg Group; large areas of the outcrop are covered by surficial sand, gravel, and clay, which are terrace deposits or remnants of the Citronelle Formation.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Forest Hill Sand is recharged by precipitation on the outcrop. Ground water in the sand moves southwestward.

Withdrawals of water from the Forest Hill Sand for all purposes are estimated to total about 1 mgd. Most of this water is for domestic and farm use.

AQUIFER CHARACTERISTICS

Results of an aquifer test in the Forest Hill Sand in Rankin County, Miss., show a coefficient of transmissibility of 900 gpd per ft, a coefficient of storage of 0.0001, and a coefficient of permeability of 26.

QUALITY OF THE WATER

Water in the Forest Hill Sand is slightly alkaline; generally it is soft, has a low iron content, and is a sodium bicarbonate type. The dissolved-solids content (table 14) ranges from 270 to 791 ppm; generally, it is lower in the outcrop and increases downdip, but large amounts occur throughout the area. Most constituents have a fairly wide range in concentration, but near maximum concentrations of most constituents are unusual and occur only locally. The large amounts of calcium and magnesium, and usually sulfate and chloride, are in water from the shallower wells in the area. This indicates that water in the upper part of the formation has chemical characteristics different from those in the lower part, or that part of the water pumped from these shallower wells is derived from an overlying formation. The larger amounts of fluoride and the greater coloration generally occur in water from deeper wells in the downdip part of the area.

The median values in table 14 indicate that water in the Forest Hill Sand is generally of good chemical quality and is suitable for most uses. However, in areas where the hardness of the water is high, softening treatment would be desirable. In the downdip area the fluoride content and color of the water may be high enough to make the water undesirable as a municipal or domestic supply.

TABLE 14.—*Summary of chemical analyses of water from the Forest Hill Sand*

[Constituents in parts per million]

Constituent or property	Maximum	Minimum	Median
Silica (SiO_2)	35	5.5	8.9
Iron (Fe)	9.0	.03	.16
Calcium (Ca)	74	.6	2.8
Magnesium (Mg)	24	.3	3.0
Sodium (Na)	289	47	142
Potassium (K)	11	2.6	4.6
Carbonate plus bicarbonate (CO_3+HCO_3)	724	154	386
Sulfate (SO_4)	214	.0	17
Chloride (Cl)	109	3.5	9.2
Fluoride (F)	4.0	.0	.4
Nitrate (NO_3)	4.8	.0	2.2
Dissolved solids	791	270	443
Hardness as $CaCO_3$	226	2	21
Specific conductance (micromhos at 25°C)	1,130	297	698
pH	8.7	7.0	8.3
Color	320	0	35

POTENTIAL USE

The Forest Hill Sand is, in general, used for domestic and farm water supplies in the area of outcrop and for about 20 miles downdip. The total withdrawal is small, and the aquifer is capable of sustaining further development by low-yield wells.

CONCLUSIONS

The Forest Hill is a locally used aquifer because the next source of water is at least 600 feet deeper, in the Cockfield Formation. Farther downdip and southeastward along the strike the sand percentage decreases, and hydrologic conditions are not conducive to the development of ground-water supplies. Although the Forest Hill aquifer will be used for some small public and industrial water supplies, it will be used mostly for domestic and farm supplies.

PLIOCENE(?) DEPOSITS

Scattered deposits of gravel of Pliocene(?) age occur in the embayment, generally underlying loess in prominent ridges and bluffs along the Mississippi River. These isolated gravels are generally water bearing and are of only local value as aquifers. Thickness of the gravels ranges from a few feet to about 50 feet. Yields of as much as 400 gpm have been reported, but most wells are used for domestic and farm water supplies.

SIGNIFICANCE OF RESULTS

By R. L. HOSMAN and E. M. CUSHING

This report defines and describes the Tertiary aquifers within the embayment only where they contain water having a dissolved-solids content of less than 1,000 ppm. Determination of the manner in which these aquifers will behave when manmade changes are imposed upon them is beyond the scope of this investigation and the adequacy of available data. More information is needed to provide definitive answers to meet the needs of regional water management. However, some aspects of the areal relations, characteristics, and utilization of the aquifers are now known:

1. The water-bearing units in the Tertiary System that contain fresh water underlie an area of about 75,000 square miles (about three-fourths of the Mississippi embayment), and they are used as sources of supply in almost all this area. In most of the embayment two or more aquifers are available for use. Individually, the areas of use and of potential use of the aquifers are, in square miles:

Aquifer	*Area of use*	*Area of potential use*	*Total*
Wilcox Group or Formation	23, 000	19, 000	42, 000
Carrizo Sand and Meridian–upper Wilcox aquifer	17, 000	9, 000	26, 000
Cane River Formation and its equivalents	17, 000	3, 000	20, 000
Sparta Sand	37, 000	0	37, 000
Memphis aquifer	12, 000	6, 500	18, 500
Cockfield Formation	[1] 23, 000	[1] 5, 500	[1] 28, 500

[1] Possibly more, pending positive identification and mapping of Cockfield in northern part of embayment.

2. Parts of all Tertiary aquifers underlie the States in the embayment. The total withdrawal from those units is about 500 mgd. Most of this amount is withdrawn in the southern half of the embayment, and the largest areas of potential use are in the northern half. The largest single local withdrawal, about 140 mgd, is at Memphis, Tenn. In most areas where they are utilized, the aquifers are capable of sustaining much larger withdrawals.
3. Water from the Tertiary aquifers is generally of good chemical quality and is suitable for many uses without treatment. For some industrial and municipal uses treatment may be desirable. Iron is the most common troublesome chemical constituent.
4. In east-central Arkansas, mineralized water occurs at shallow depths in the Sparta Sand. This condition is anomalous and seems to coincide with a zone of transition (pl. 7) where the underlying Cane River Formation changes from clay to sand. The increasing amount of sand in the Cane River in this area causes an increase in vertical permeability, and thus reduces the effectiveness of the Cane River as a confining bed for mineralized water in the underlying Carrizo Sand. Water in the Carrizo in this area has about a 10-foot higher hydrostatic head than does water in the Sparta, and this head provides the pressure differential necessary to induce the upward movement of water from the Carrizo into the Sparta.

   North of this zone of transition where the Cane River Formation is predominantly sand, the water in the Sparta section, as well as in the Carrizo and Cane River (Memphis aquifer), is fresh.

   Towns in the vicinity of this zone of transition have difficulty in obtaining water supplies that do not require expensive treatment. A comprehensive report of the hydrology and geology in this area could give suggested solutions to the quality problems and provide knowledge of the principles of the movement of water through these zones of transition which would be applicable to hydrologically and geologically similar areas.
5. Chemical-quality changes in water from the Memphis aquifer on the west side of the embayment indicate the effects of recharge. In this area the Memphis aquifer crops out in a segment of Crowleys Ridge and receives recharge. Downdip from this segment of the ridge (pl. 7), water in the Memphis aquifer is low in dissolved solids and is a sodium bicarbonate type. However, north and south of this area Quaternary alluvium overlies and recharges the Memphis aquifer. Downdip from these areas water in the Memphis aquifer has a higher dissolved-solids content and is a calcium magnesium bicarbonate type.
6. Although flowing wells can be developed in some low-lying areas, chiefly stream valleys, water levels in the Tertiary aquifers are generally too low to produce natural flow from wells on a regional basis.
7. Most general water-level declines in the Tertiary aquifers are the result of pumping and are not indicative of overdevelopment. Only one aquifer, the Sparta Sand, shows water-level declines that are becoming regional (pl. 7); the cones of depression in the piezometric surface in some local areas have coalesced, and the coalescence of others is impending. Although the Sparta is capable of sustaining more development on a regional basis, local overdevelopment may be imminent.

8. Most wells tapping Tertiary aquifers are small-capacity domestic wells, but most withdrawal is by municipal, industrial, and irrigation wells. Wells yielding as much as 200 gpm can probably be developed in the Tertiary aquifers throughout the area where the aquifers contain fresh water, and in many areas wells yielding as much as 2,000 gpm have been and can be developed.
9. The lower Wilcox aquifer is widely used in the northern and eastern parts of the embayment. Electric logs indicate the aquifer is probably composed of two, or possibly three, major sands. These sands are areally extensive, occur in the lower to middle parts of the Wilcox, and seem to be interconnected so that, in effect, they constitute one aquifer. More data and study are needed to determine the extent, relations, and hydraulic characteristics of these sands.
10. The stratigraphic relations of the massive Claiborne sand section north of lat 35° N., the Memphis aquifer, can now be tentatively assigned as a result of electric log correlations and drill-cutting analyses. The top of the Memphis aquifer seems to correlate with the top of the Sparta, and the Memphis aquifer makes up the entire Claiborne section between the top of the Wilcox and the top of the Sparta.
11. Although the Cockfield Formation has not been definitely recognized in the northern part of the embayment, observations made while mapping the top of the Memphis aquifer indicate that it may occur in areas of higher land-surface altitude near the axis of the embayment, where the Tertiary section is thicker.

APPLICATION OF RESULTS

By E. M. Cushing and R. L. Hosman

On the basis of the data in this report, the water-bearing units that are sources of water supply anywhere in the Tertiary area can be determined, and the following approximations can be made: (1) The range in depth of the wells, (2) the water-bearing potential of each unit, (3) the water level, (4) the direction of flow of the water, (5) the yield and specific capacity of the well, and (6) the temperature and quality of the water. In some areas the amount of lowering of the water level due to the pumping of wells in that area (time-distance-drawdown) can be estimated.

To show how this information is used, we will pose a hypothetical question and then, in subsequent paragraphs, apply the information to answer the question. The problem is: What are the alternatives in developing a water supply of at least 300 gpm from an artesian aquifer in the southeast corner of Dallas County, Ark.?

From the contour maps showing the configuration of the tops of the aquifers within the embayment (pls. 3–8), one sees that four aquifers are available—the Carrizo, Cane River, Sparta, and Cockfield. A topographic map shows that the land-surface altitude of the southeast corner of Dallas County is about 250 feet above mean sea level.

The Cockfield Formation crops out in the area and is the shallowest aquifer. As the southeast corner of Dallas County lies near the outer edge of the outcrop (pl. 8), the Cockfield will be thin and will probably be suitable only for supplying small amounts of water to shallow wells. Consequently, the Cockfield is not a possible source of water in the amount of 300 gpm.

The top of the next aquifer, the Sparta Sand (pl. 7), is about 100 feet below sea level, or about 350 feet below the land surface. The Sparta is about 500 feet thick and should be 61–80 percent sand (pl. 7). To penetrate the entire Sparta a well should be drilled about 850 feet deep. The water level should be about 160 feet above sea level, or about 90 feet below land surface; the direction of movement of the water is south (pl. 7). The quality of the water (pl. 7) would probably be:

Constituent	*Epm*	*Ppm*
Ca	0.8	16
Mg	.4	5
Na+K	1.0	23
Fe	----------	Trace
HCO_3+CO_3	1.3	80
SO_4	.3	15
Cl	.5	18
$F+NO_3$	----------	Trace
Dissolved solids (sum)	----------	About 120

The temperature of the water should be 68°–76°F (fig. 3). Analysis of an aquifer test made in the same general area gives values of about 24,000 gpd per ft for the coefficient of transmissibility and 0.0003 for the coefficient of storage. A yield of about 300 gpm should be easily obtainable. The time-distance-drawdown relation for a discharge of 300 gpm is shown in figure 4.

The top of the Cane River Formation (pl. 6) is about 600 feet below sea level, or about 850 feet below land surface. It is about 450 feet thick and should be about 21–40 percent sand (pl. 6). To penetrate all the sands in the Cane River a well should be drilled about 1,300 feet deep. Quantitative hydrologic information such as water levels or aquifer characteristics pertaining to the sands of the Cane River in this area is not available. However, water levels should be high, probably slightly higher than those in the Sparta. Most wells tapping the sands of the Cane River are small-capacity domestic wells, and the maximum yield of

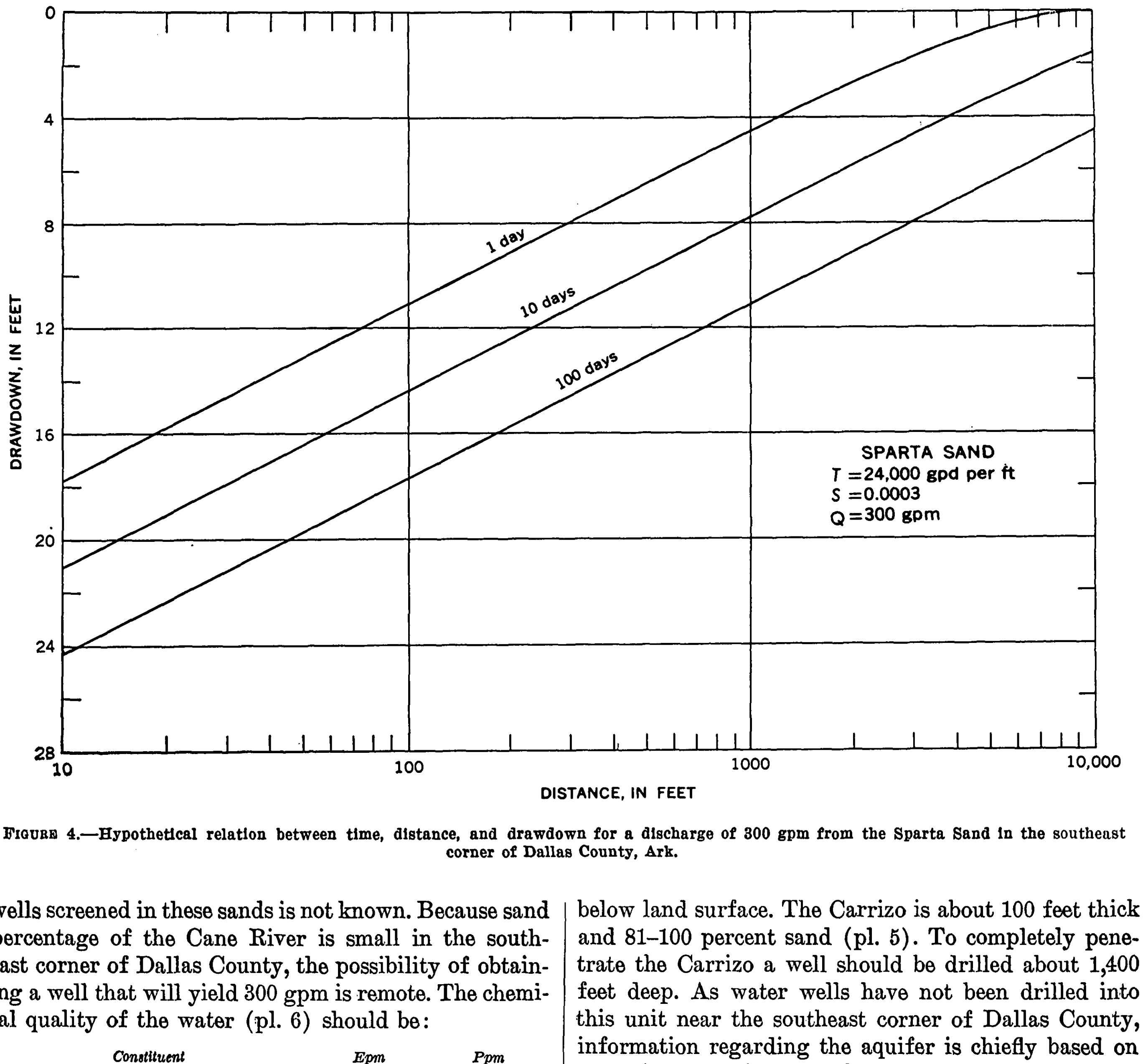

FIGURE 4.—Hypothetical relation between time, distance, and drawdown for a discharge of 300 gpm from the Sparta Sand in the southeast corner of Dallas County, Ark.

wells screened in these sands is not known. Because sand percentage of the Cane River is small in the southeast corner of Dallas County, the possibility of obtaining a well that will yield 300 gpm is remote. The chemical quality of the water (pl. 6) should be:

Constituent	*Epm*	*Ppm*
Ca	0.5	10
Mg	.1	1
Na+K	14.0	322
Fe	----------	Trace
HCO_3+CO_3	4.2	256
SO_4	.1	5
Cl	10.6	160
$F+NO_3$	----------	Trace
Dissolved solids (sum)	----------	About 620

The temperature of the water should be about 70°–78°F (fig. 3).

The deepest aquifer in the southeast corner of Dallas County is the Carrizo Sand. The top of the unit (pl. 5) is about 1,050 feet below sea level, or about 1,300 feet below land surface. The Carrizo is about 100 feet thick and 81–100 percent sand (pl. 5). To completely penetrate the Carrizo a well should be drilled about 1,400 feet deep. As water wells have not been drilled into this unit near the southeast corner of Dallas County, information regarding the aquifer is chiefly based on analysis of electric logs in the area.

The dissolved-solids content of the water from the Carrizo Sand will probably be between 900 and 1,000 ppm, and the principal constituents will be sodium, bicarbonate, and chloride. The temperature of the water should be about 78°F. Water levels should be higher than those in the Sparta Sand, and wells should yield at least 300 gpm.

The reader should remember that the above determinations are estimates based upon the available information. By drilling and testing a particular site, more exact data can be obtained.

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