GENERALIZED DESCRIPTION AND ANALYSIS OF GROUND-WATER FLOW IN THE COCKFIELD AND SPARTA AQUIFERS IN HINDS, MADISON, AND RANKIN COUNTIES, MISSISSIPPI

By J. Kerry Arthur

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
foot per day	0.3048	meter per day
foot per year	0.3048	meter per year
foot per mile	0.1894	meter per kilometer
inch	25.4	millimeter
inch per year	25.4	millimeter per year
mile	1.609	kilometer
million gallons per day	0.04381	cubic meter per second
cubic foot per second	0.02832	cubic meter per second
million cubic feet per day	0.3278	cubic meter per second
quare mile	2.590	square kilometer
foot squared per day	0.0929	centimeter squared per day

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: °C = (°F-32)/1.8.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness. In this report, the mathematically reduced form, foot squared per day, is used for convenience.

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ABSTRACT

The Cockfield and Sparta aquifers supply more than 95 percent of the ground water pumped in Hinds, Madison, and Rankin Counties, Mississippi. In 1990, about 27 million gallons per day was pumped from the two aquifers in the three-county study area, most from the Sparta aquifer. From 1960 to 1990, pumping in the Jackson area caused water levels in observation wells to decline as much as 60 feet in the Cockfield aquifer and 80 feet in the Sparta aquifer.

The Cockfield Formation crops out in northeastern Madison County and in a small area above the Jackson Dome adjacent to the Pearl River. The Cockfield Formation has a regional dip of 20 feet per mile to the southwest. The Sparta Sand crops out entirely outside the three-county study area. The Sparta Sand has a regional dip of 24 feet per mile. Throughout most of the study area, the total sand thickness ranges from 200 to 400 feet for the Sparta Sand and from 100 to 300 feet for the Cockfield Formation. The average horizontal hydraulic conductivity of the Sparta aquifer in the study area is 60 feet per day. The average horizontal hydraulic conductivity of the Cockfield aquifer in the study area is 39 feet per day.

Simulated predevelopment potentiometric surface in the Jackson area ranged from 200 to 240 feet above sea level in the Cockfield aquifer and from 200 to 220 feet above sea level in the Sparta aquifer. Simulated predevelopment net areal recharge in outcrop areas averaged about 0.12 inch per year to the Cockfield aquifer and about 0.27 inch per year to the Sparta aquifer in the model area. Over the crest of the Jackson Dome, predevelopment recharge from land surface to the Cockfield was about 0.25 inch per year. Flow analysis indicates that, from predevelopment to 1990, water levels in the Jackson area declined as much as 120 feet in the Cockfield aquifer and as much as 140 feet in the Sparta aquifer. Average net areal recharge during 1990 was about 0.22 inch per year in outcrop areas to the Cockfield aquifer and about 0.57 inch per year to the Sparta aquifer. During 1990, recharge over the Jackson Dome to the Cockfield aquifer was as much as 3 inches per year.

With a uniform 25-percent pumpage increase from the Cockfield and Sparta aquifers from 1990 through 2000, analysis indicates water levels in the Jackson area would decline about 30 feet and 20 feet, respectively. With a uniform 50-percent pumpage increase, analysis indicates water levels in the Cockfield and Sparta would decline as much as 60 feet and 50 feet, respectively.

INTRODUCTION

The Cockfield and Sparta aquifers are principal sources of water supply in Hinds, Madison, and Rankin Counties, supplying more than 95 percent of the ground water pumped in the area. During 1990, about 27 million gallons per day of fresh ground water was pumped from the two aquifers in the three-county area. During the period 1960-90, pumping in the Jackson area has resulted in water-level declines of as much as 60 feet in the Cockfield aquifer and 80 feet in the Sparta aquifer. Because of concerns of State and local officials about the future adequacy of the ground-water supply in the three counties, the U.S. Geological Survey and the Mississippi Department of Environmental Quality, Office of Land and Water Resources, began a cooperative study in 1987 of the Cockfield and Sparta aquifers in the three-county area in west-central Mississippi (fig. 1).

Hydrogeologic information on the Cockfield and Sparta aquifers is needed by State and local officials to assist them in managing the ground-water resources of the three-county area. A major component of the USGS study is the development and documentation of a digital ground-water flow model of the two aquifers. The model can serve as a tool for managers to acquire a better understanding of the flow dynamics and regional water-yielding capability of the two aquifers in the three-county area.

Purpose and Scope

This report presents a description of the study area, a generalized description of the Cockfield and Sparta aquifers, a detailed description of the ground-water flow model, and an analysis of the results of simulation of ground-water flow in the Cockfield and Sparta aquifers in the study area. The terms "study area" and "three-county area" are used interchangeably in this report. The term "model area" refers to a much larger area that is inclusive of the Hinds, Madison, and Rankin Counties study area.

Previous Investigations

Numerous earlier reports present information concerning the hydrogeology and ground-water resources of all or parts of the three-county area. The names Cockfield aquifer and Sparta aquifer were given to the water-bearing sand beds of the Cockfield Formation and Sparta Sand by Boswell and others (1970, p. 8) to emphasize their water-bearing character. Spiers (1977a) and Newcome (1976) described the Cockfield and Sparta aquifers, respectively, in Mississippi. Spiers and Dalsin (1979), and Harvey and others (1964) described the water resources in the three-county area. Monroe (1954), described the geology in the Jackson area. Geologic reports of the three counties (Priddy, 1960; Moore and others, 1965; and Baughman and others, 1971) discussed geologic framework and ground-water resources. The findings of regional water-resources investigations involving these counties are in reports by Cushing and others (1964); and by Hosman and others (1968). Payne described the regional hydrology of the Sparta Sand (1968), Cane River Formation (1972), and Cockfield Formations (1970). Oakley (1984) reported on the ground-water resources in the Ross Barnett Reservoir area. The three-county area was included in two ground-water flow modeling reports (Reed, 1972; Arthur and Taylor, 1990). Harvey and Grantham (1963), Wasson (1981a; 1981b), and Darden (1986; 1987) presented potentiometric maps of the Cockfield and Sparta aquifers in Mississippi. Wasson (1980a) described sources of ground-water supplies in Mississippi.

Description of the Study Area

The Hinds, Madison, and Rankin Counties study area is located in west-central Mississippi and occupies 2,428 square miles. Jackson, the major population center, is located in about the geographic center of the three-county area. The population of the study area increased from about 288,000 in 1970 to about 400,000 in 1990. In addition to the Jackson area, Bolton, Clinton, Edwards, Raymond, and Utica in Hinds County; Canton, and Flora in Madison County; and Brandon in Rankin County are major population centers in the study area (Spiers and Dalsin, 1979) (fig. 1).

The climate in the area is humid-subtropical. Mean annual precipitation is about 54 inches. December is the wettest month, averaging about $5^1/2$ inches, and October the driest month, averaging about $2^1/4$ inches. The mean annual temperature is 65 °F. January, the coldest month, averages about 48 °F, and July, the hottest month, averages about 82 °F (Spiers and Dalsin, 1979).

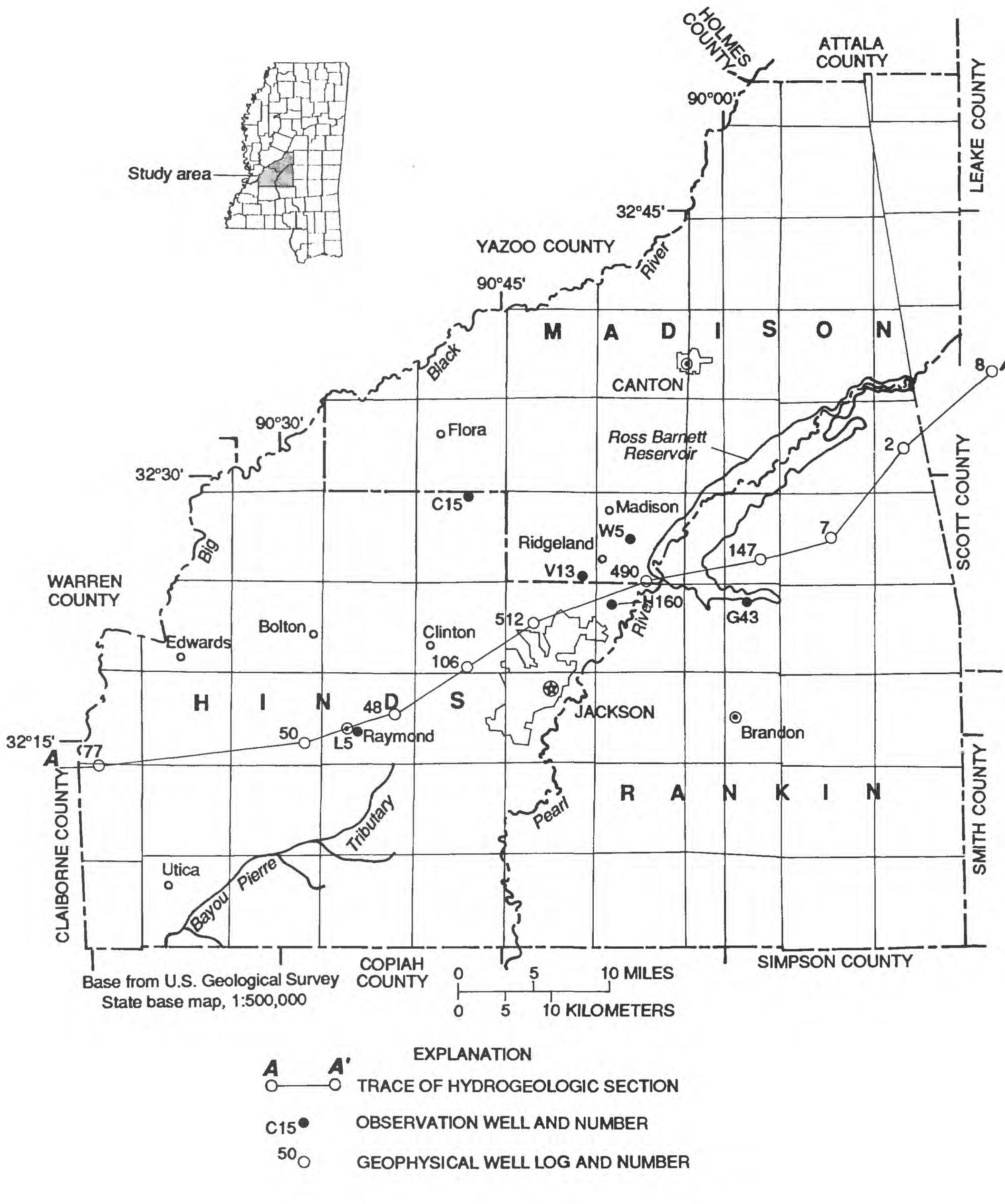


Figure 1.--Location of study area, trace of hydrogeologic section, and selected observation wells.

The Pearl River, which flows through the center of the three-county area, and the Big Black River, which is the western boundary of Hinds and Madison Counties, are the major surface drains. A small area in southwestern Hinds County is drained by upstream tributaries of the Bayou Pierre (fig. 1). The Pearl River drains all of Rankin County, the eastern one-third of Hinds County, and a narrow area of eastern Madison County. The Big Black River drains most of Madison County and about two-thirds of Hinds County. The 32,000-acre Ross Barnett Reservoir, located several miles northeast of Jackson, impounds flow in the Pearl River for water supply and recreation.

Topography

The four physiographic districts of the Gulf Coastal Plain that characterize the geology and topography in the three-county study area are: (1) the North-Central Plateau in northern Madison County, (2) the Jackson Prairie in northeastern Hinds, southern Madison, and northern Rankin Counties, (3) the Southern Pine Hills in south-central Hinds and southern Rankin Counties, and (4) the Loess Hills in western Hinds County (Fenneman, 1938) (fig. 2).

The North-Central Plateau is developed on the outcrop areas of the Cook Mountain and Cockfield Formations in northeastern Madison County. Land-surface altitudes in these outcrop areas generally range from 200 to 400 feet above sea level (fig. 3). Most of the North-Central Plateau District is drained by the Big Black River.

The Jackson Prairie, developed on the Yazoo Clay, is characterized by gently rolling hills. The Jackson Prairie District includes most of the central part of the study area. Land-surface altitudes generally range from 200 feet above sea level in the Big Black River flood plain to the west, to about 500 feet above sea level in eastern Rankin County.

The Southern Pine Hills District lies to the south of the Jackson Prairie in the southern one-half of Hinds and Rankin Counties. The Southern Pine Hills District is developed on sediments of the Vicksburg Group of Oligocene age and undifferentiated deposits of Miocene age. Most of the Southern Pine Hills District is drained by the Pearl River and tributaries of Bayou Pierre, and land-surface altitudes generally range from 200 feet above sea level in southwestern Hinds County to 400 feet above sea level in eastern Rankin County.

The Loess Hills District in the extreme western part of Hinds County is characterized by nearly vertical bluffs of weathered, wind-blown material. The loess deposits are thickest along the western edge of the study area adjacent to the Big Black River flood plain. The deposits decrease in thickness to the east and are about 20 feet thick near Edwards, near the eastern extent of the physiographic district. The Loess Hills District, though having hilly terrain, includes the lowest land-surface altitudes in the study area.

Geologic Framework

The three-county area (fig. 3) lies on the eastern flank of the Mississippi embayment syncline, a large trough-like structure whose axis generally is coincident with the present Mississippi River (Arthur and Taylor, 1991). The embayment was filled with sedimentary deposits during the cyclic invasion of the sea during the Cretaceous and Tertiary Periods. These deposits form the aquifers and confining units that consist of gravel, sand, silt, clay, marl, and limestone and underlie the study area to a depth of more than 10,000 feet. The Cockfield and Sparta aquifers are in deposits of Tertiary age. The geologic units and stratigraphy in the study area are listed in table 1.

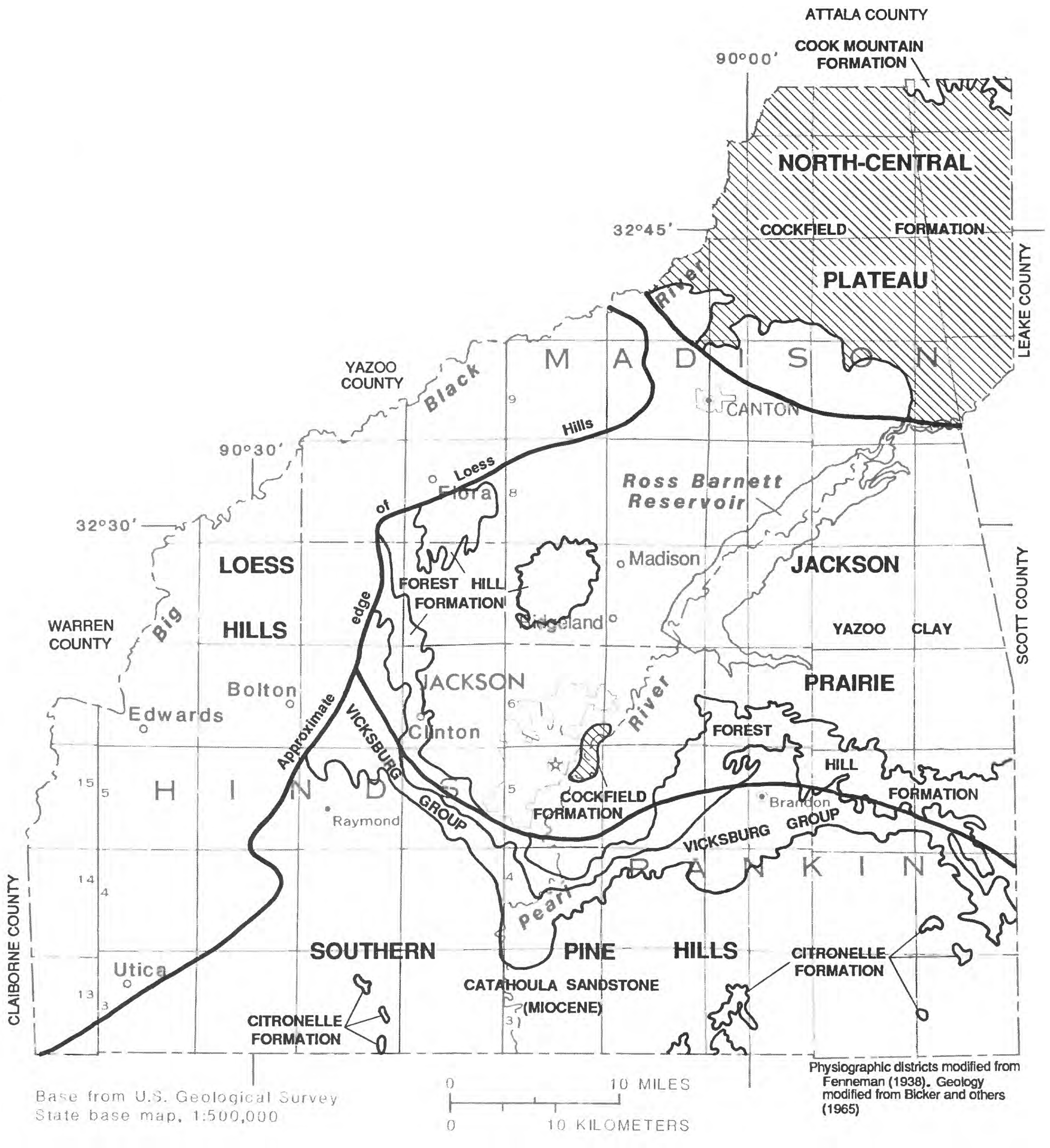
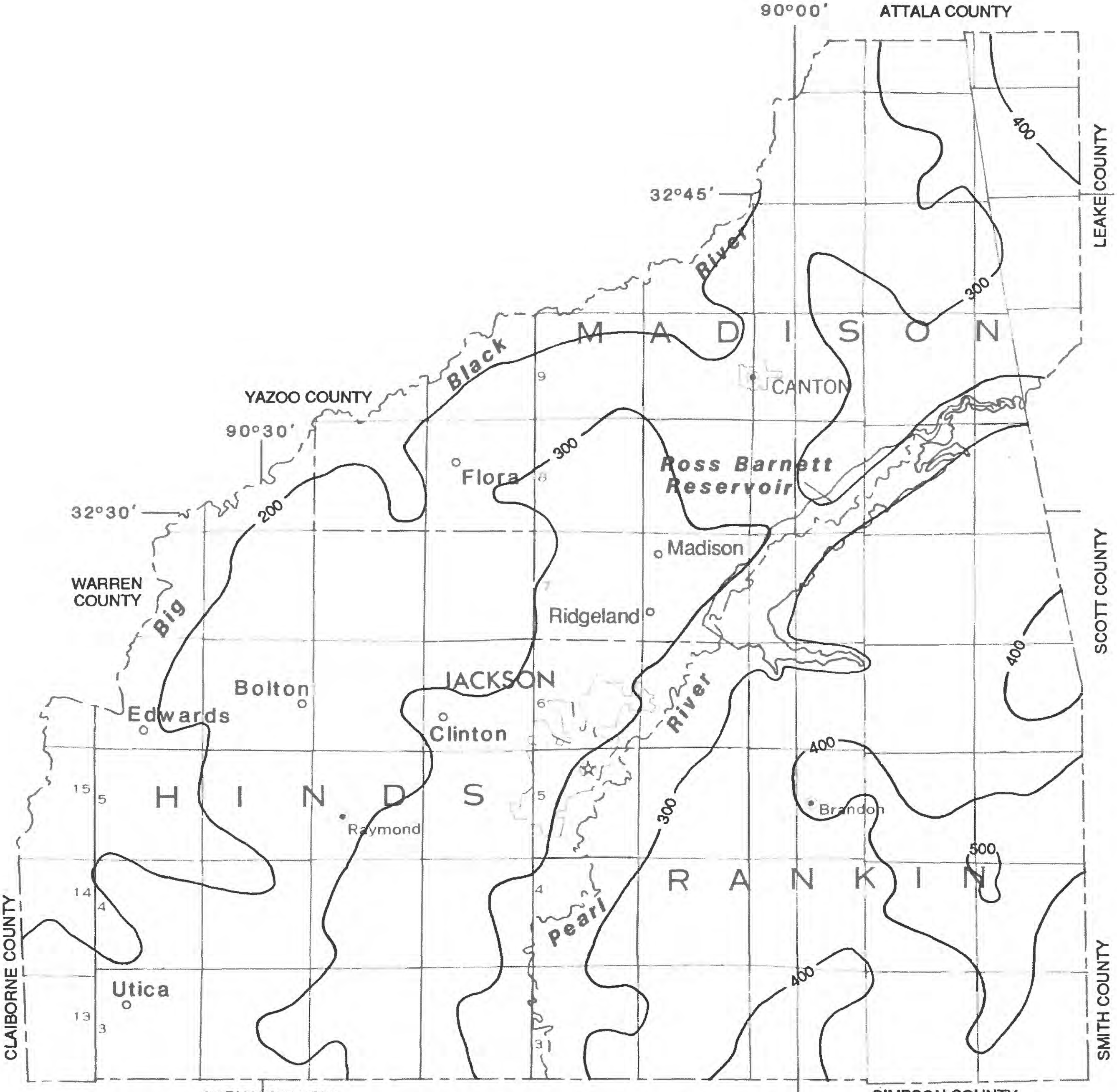


Figure 2.--Generalized surficial geology and location of physiographic districts.



Base from U.S. Geological Survey State base map, 1:500,000

Land surface data from U.S. Geological Survey digital elevation model 1970-73

EXPLANATION

— 300 — TOPOGRAPHIC CONTOUR--Shows altitude of land surface. Contour interval 100 feet. Datum is sea level

Figure 3.--Land-surface altitude in the three-county study area.

Table 1.--Geologic units and principal aquifers in Mississippi
[Modified from Slack and Darden, 1991]

Erathem	System	Series	Group	Geologic unit	Principal aquifer or aquifer system
Cenozoic	Quaternary	Holocene and Pleistocene		Quaternary alluvium	
				Mississippi River valley alluvium	Mississippi River alluvial aquifer
		Pleistocene		Loess Terrace deposits	
	Tertiary	Pliocene		Citronelle Formation Graham Ferry Formation	Citronelle aquifers
		Miocene		Pascagoula Formation Hattiesburg Formation Catahoula Sandstone, upper part Catahoula Sandstone, lower part Deposits of Miocene age	Miocene aquifer system
		Oligocene	Vicksburg Group	Bucatunna Formation of Waynesboro sand lentil	
				Byram Formation Glendon Limestone Marianna Formation Mint Spring Formation	Oligocene aquifer system
				Forest Hill Formation	
		Eocene	Jackson Group	Yazoo Clay Moodys Branch Formation	
			Claiborne Group	Cockfield Formation	Cockfield aquifer
				Cook Mountain Formation	
				Sparta Sand	Sparta aquifer
				Zilpha Clay	
				Winona Sand Tallahatta Formation Neshoba Sand Member, Basic City Shale Member, and Meridian Sand Member	Winona-Tallahatta aquifer
				Meridian Sand Member and Wilcox Group, upper part	Meridian-upper Wilcox aquifer
			Wilcox Group	Wilcox Group, upper part Hatchetigbee Formation	
		Paleocene		Tuscahoma Formation Wilcox Group, middle part	
				Nanafalia Formation Fearn Springs Member Wilcox Group, lower part	Lower Wilcox aquifer
			Midway Group	Naheola Formation Porters Creek Clay Matthews Landing Marl Member Clayton Formation	

Geologic units at land surface in the study area range in age from Quaternary to Tertiary. Western Hinds and southwestern Madison Counties are underlain by as much as 30 feet of Quaternary loess deposits that form the Loess Hills (Bicker and others, 1965). Alluvial deposits of Quaternary age, consisting of clay, silt, sand, and gravel, are adjacent to rivers and streams, predominantly along the Pearl and Big Black Rivers. Deposits of Miocene age consisting mostly of sand, shale, and sandstone underlie the southern one-half of Hinds and Rankin Counties. The Vicksburg Group of Oligocene age, consisting of clay, marl, limestone, and sand, crops out in the central part of Hinds and Rankin Counties (fig. 2). The massive marine Yazoo Clay crops out in northern Hinds, southern Madison, and northern Rankin Counties (in the central part of the study area). The Cockfield Formation crops out in northeastern Madison County. The oldest stratigraphic unit exposed in the study area, the Cook Mountain Formation, crops out in a small area in extreme northeastern Madison County (fig. 2).

The Tertiary formations dip southwestward toward the Mississippi embayment axis from outcrop areas in the northern and central parts of Mississippi. Corresponding units crop out in belts on the western side of the embayment in northern Louisiana and southeastern Arkansas (Arthur and Taylor, 1991). The oldest units of Tertiary age crop out farthest from the embayment axis. In Mississippi, progressively younger units are at land surface toward the west and southwest. The regional dip of the geologic units in the study area ranges from 15 to 25 feet per mile.

The Jackson Dome causes the regional dip of the geologic units to be interrupted and to vary substantially in the Jackson area (fig. 4). The crest of the dome, which is about 6 miles south of the Hinds-Madison County boundary and centered under the city of Jackson, causes the geologic units to be displaced about 600 to 700 feet upward over the crest of the dome. The upward displacement decreases radially from the crest of the dome, but some displacement is indicated over about 100 square miles in the Jackson area. The uplift effect of the dome causes a large area in northeastern Hinds and western Rankin Counties to be in the outcrop area of the Yazoo Clay, and a small area along the Pearl River over the crest of the dome to be in the Cockfield Formation outcrop area (fig. 2). If the dome were not present and the regional dip prevailed, the outcrop belt of the Yazoo Clay would lie northeast of the Jackson area outside of Hinds County; the Cockfield Formation would not crop out along the Pearl River in Hinds and Rankin Counties. The Cockfield would only crop out in northeastern Madison County in the study area. Harvey and others (1964) presented six geologic sections for the Jackson area that show the effects of the Jackson Dome on the dip and thickness of stratigraphic units.

The Cockfield Formation, the upper part of the Claiborne Group of Eocene age, is overlain by the Jackson Group and underlain by the Cook Mountain Formation (table 1). In the subsurface, the Cockfield Formation consists of sand, silt, clay, shale, and lignite. Lignite is common in the clay and shale and as lenses in the sand beds. The overlying, nearly impermeable Yazoo Clay of the Jackson Group restricts recharge and vertical flow between more permeable sediments throughout most of the three-county area. The total clay thickness of the Jackson Group is as much as 500 feet in southwestern Hinds County (fig. 5); in the subsurface the clay isolates the Cockfield Formation from overlying units (fig. 4). The Cook Mountain Formation consists of shale, clay, thin beds of sand, and limestone and, though not as impermeable as the Yazoo Clay, the Cook Mountain impedes vertical flow between the sands of the Cockfield Formation and the underlying Sparta Sand. In the subsurface, the average total clay thickness of the Cook Mountain Formation is about 100 feet in the study area (fig. 6).

The dip of the Cockfield Formation across the study area averages about 20 feet per mile to the southwest (Spiers and Dalsin, 1979). The base of the Cockfield Formation dips from about 200 feet above sea level in northeastern Madison County to 1,600 feet below sea level in southwestern Hinds County (fig. 7). In western Hinds County the dip is less, but on the southwestern flank of the Jackson Dome the dip is as much as 130 feet per mile.

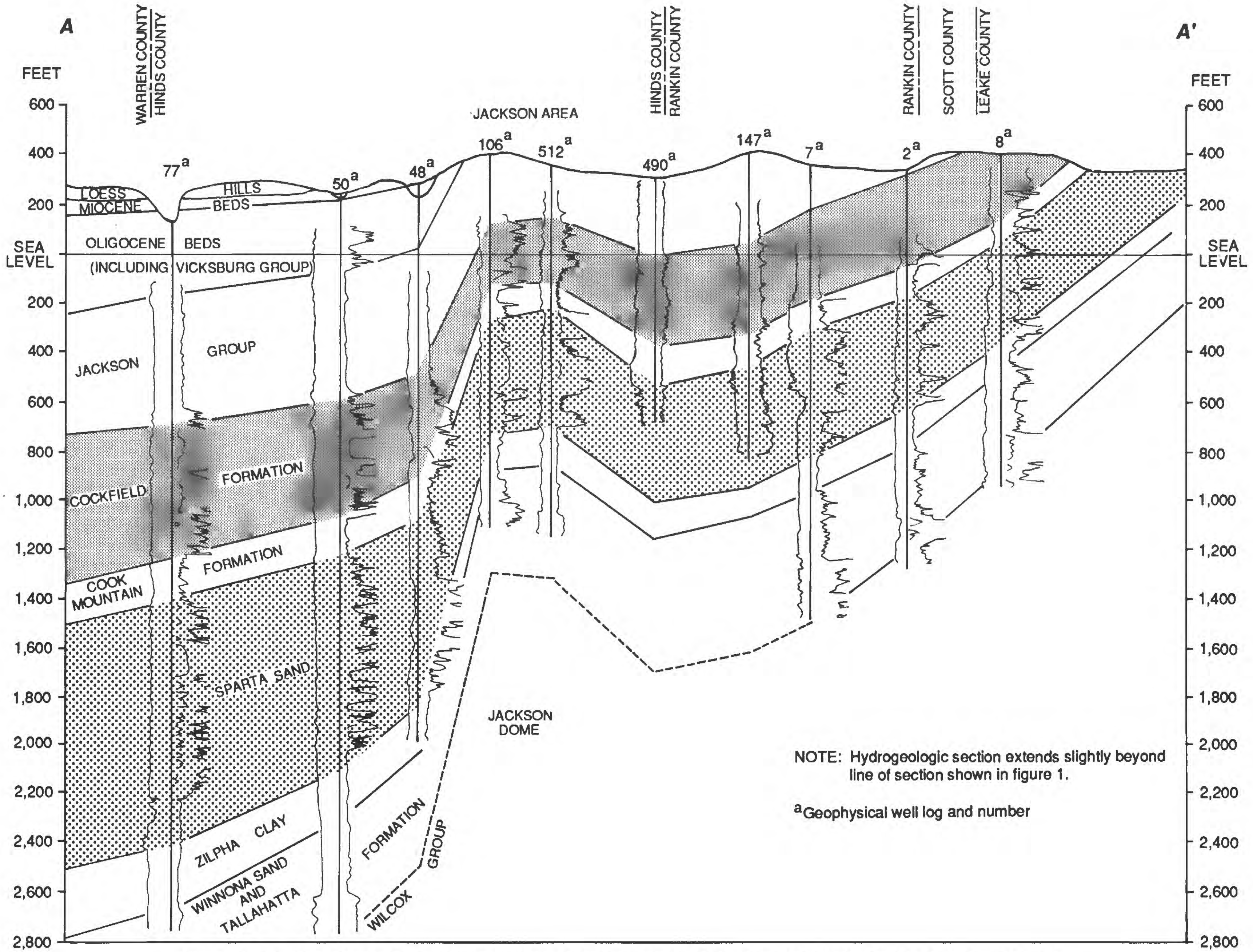


Figure 4.--Hydrogeologic section through study area from southeast Warren County to southwest Leake County (modified from Newcome, 1976).

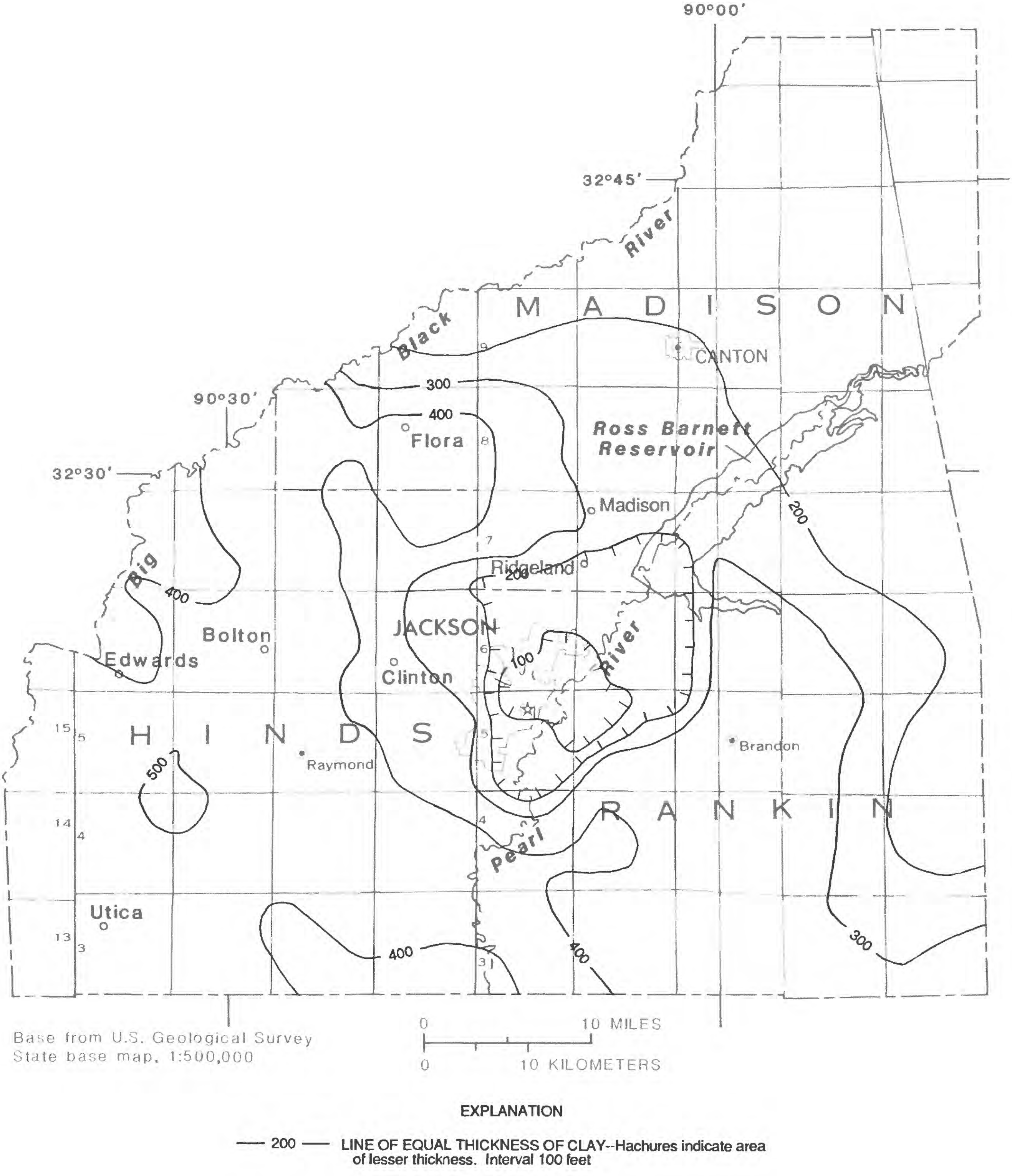
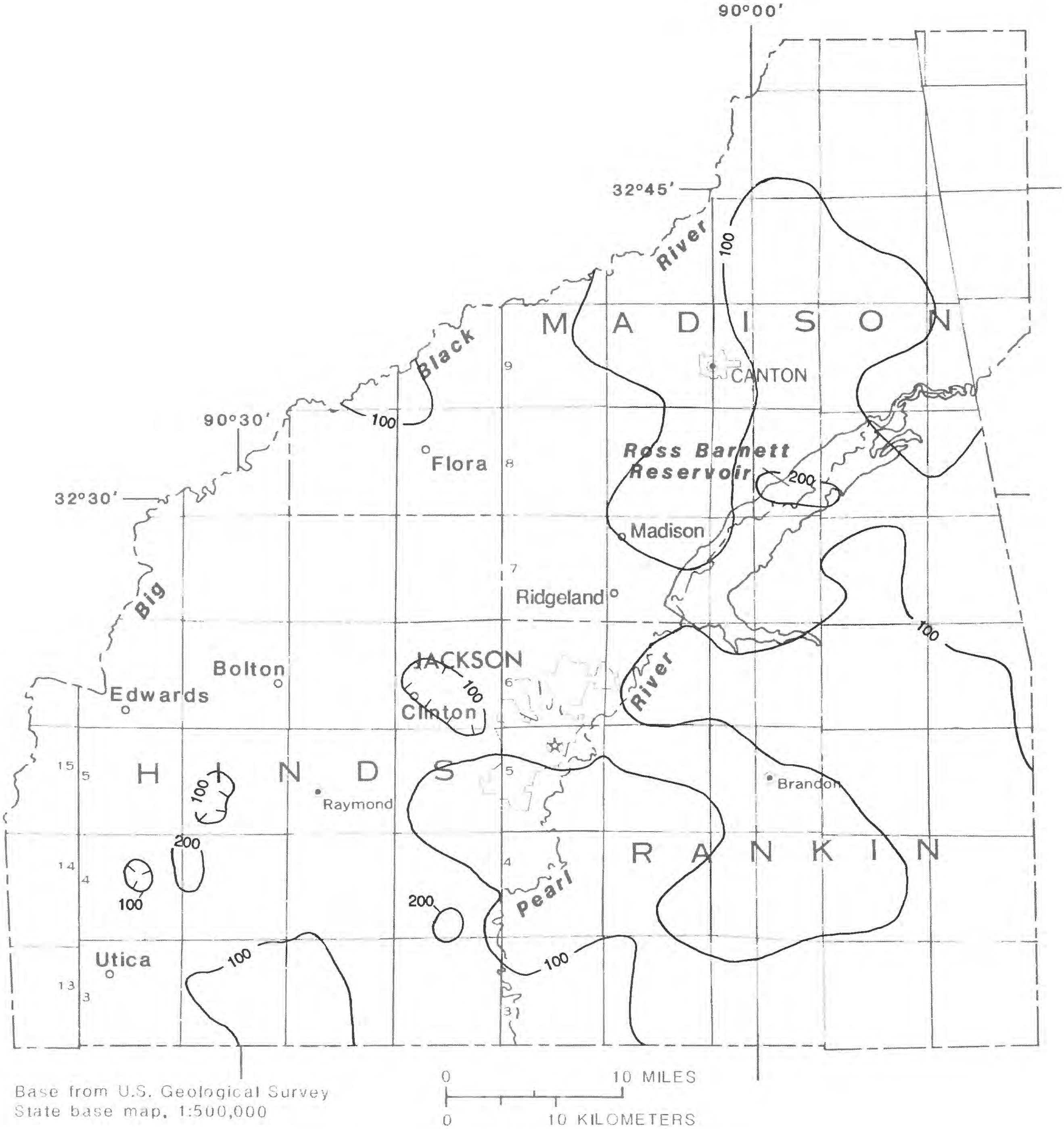


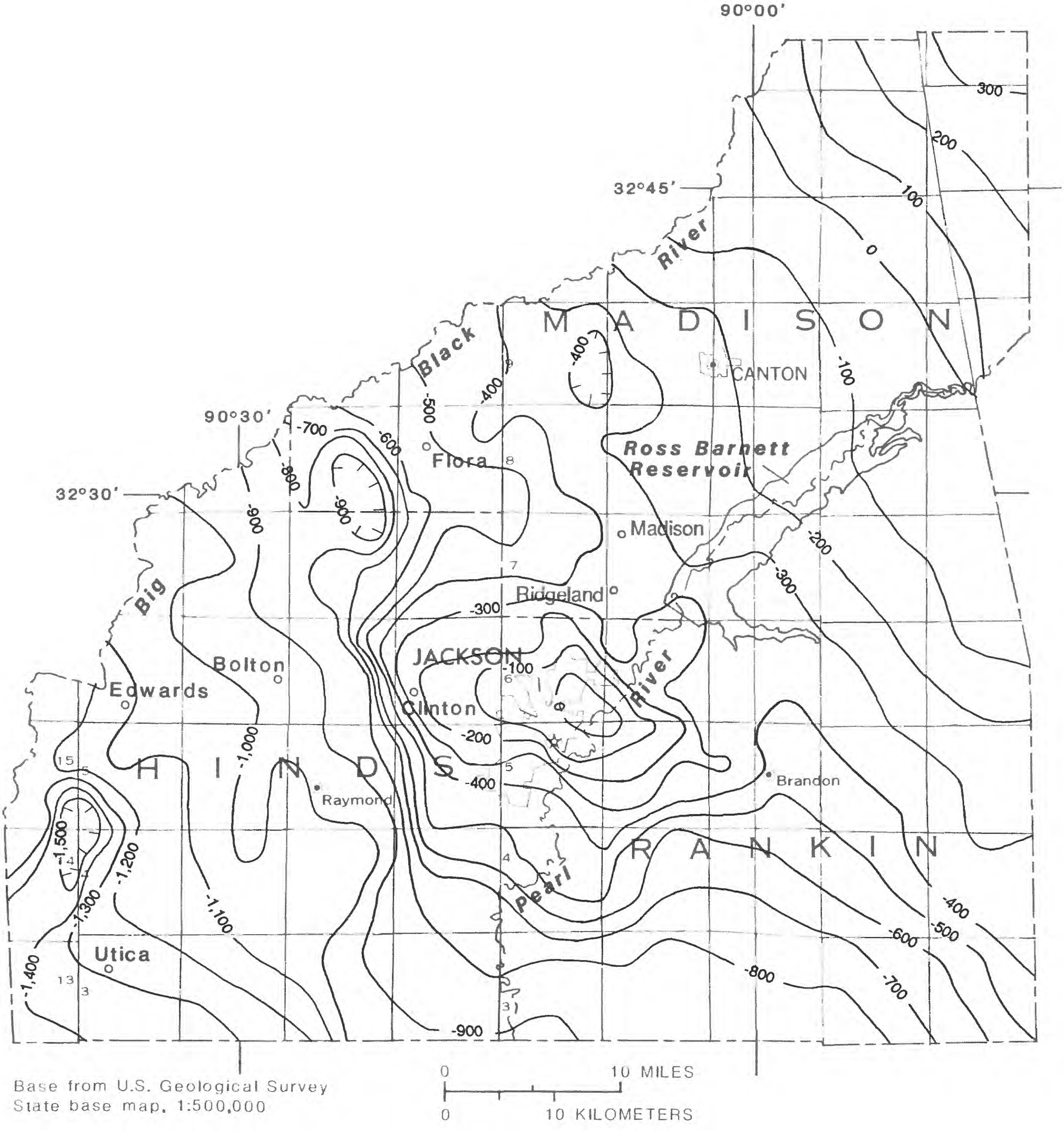
Figure 5.--Total clay thickness of the Jackson Group in the three-county study area.



EXPLANATION

—— 100 —— LINE EQUAL THICKNESS OF CLAY--Hachures indicate area of lesser thickness. Interval 100 feet

Figure 6.--Total clay thickness of the Cook Mountain Formation in the three-county study area.



EXPLANATION

— 100 — LINE OF EQUAL ALTITUDE--Hachures indicate a depression. Interval 100 feet. Datum is sea level

Figure 7.--Altitude of the base of the Cockfield Formation in the three-county study area.

The Sparta Sand is composed mostly of sand and contains more sand than any other formation of comparable thickness in Mississippi. It consists of alternating beds of sand and clay with lenses of lignite. The sand grain size varies from fine to medium with fair uniformity. The Sparta Sand is present in the upper middle part of the Claiborne Group of Eocene age (table 1). The Cook Mountain Formation is a confining layer between the Cockfield Formation and the Sparta Sand. The Sparta Sand is underlain by the Zilpha Clay, which hydraulically separates the Sparta aquifer from deeper geologic units. The thickness of the Zilpha Clay generally ranges from about 100 feet in northeastern Madison County to 300 feet in southwestern Hinds County (fig. 8). The Sparta Sand is in the subsurface throughout the three-county area. The base of the unit dips southwest from about 200 feet below sea level in northeastern Madison County to more than 2,400 feet below sea level in southwestern Hinds County (fig. 9). The average regional dip of the Sparta is about 24 feet per mile, but in the Jackson area the Jackson Dome displaced the units upward and the Sparta Sand dips about 140 feet per mile between Jackson and Raymond in Hinds County.

GENERALIZED DESCRIPTION OF AQUIFERS

The Cockfield and Sparta aquifers are two of the major aquifers in Mississippi. They supply most of the fresh ground water used in the Hinds, Madison, and Rankin Counties area, and to an area extending from Wayne County in the southeastern part of Mississippi to the Mississippi-Tennessee border in the northwestern part of the State. The two aquifers are described in statewide reports--the Cockfield aquifer by Spiers (1977a) and the Sparta aquifer by Newcome (1976).

Cockfield Aquifer

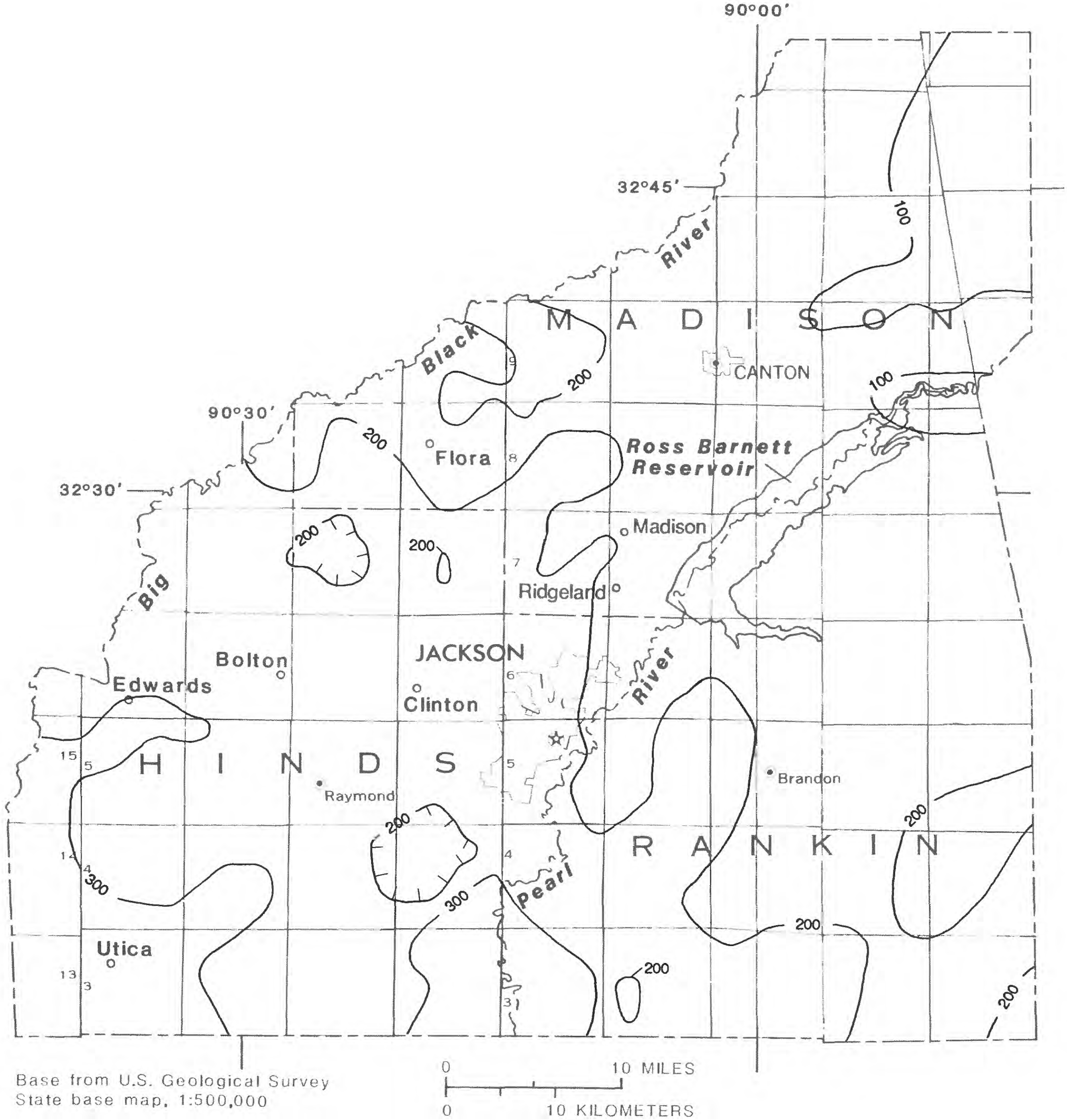
The Cockfield aquifer is composed of interbedded fine sand, silt, and clay of the Cockfield Formation. Thicker sand beds commonly occur in the lower part of the aquifer in the study area. The aquifer is confined above by the Yazoo Clay throughout most of the three-county area. Vertical flow between the underlying Sparta aquifer and the Cockfield aquifer is restricted by the intervening fine-grained sediments of the Cook Mountain Formation.

The Cockfield aquifer, a source of freshwater in about 30 percent of Mississippi and throughout the three-county area, is exposed at land surface in the study area in northeastern Madison County (fig. 2). Outside the study area in Mississippi, the outcrop of the Cockfield aquifer extends from Clarke County (at the Mississippi-Alabama State boundary) northwest through the study area into Yazoo and Holmes Counties. The aquifer subcrops the Mississippi River alluvial aquifer in northwestern Mississippi throughout about one-third of the Mississippi Alluvial Plain (Arthur and Taylor, 1991).

The sand beds that form the Cockfield aquifer generally range in total thickness from 100 feet in and near the outcrop area in northeastern Madison County and over the crest of the Jackson Dome to 500 feet in southwestern Hinds County (fig. 10). Over most of the study area, sand thickness ranges from 100 to 300 feet. The total sand-bed thickness generally increases from northeast to southwest in the three-county area. Sand thickness in the study area was determined by analysis of geophysical logs.

Hydraulic Properties

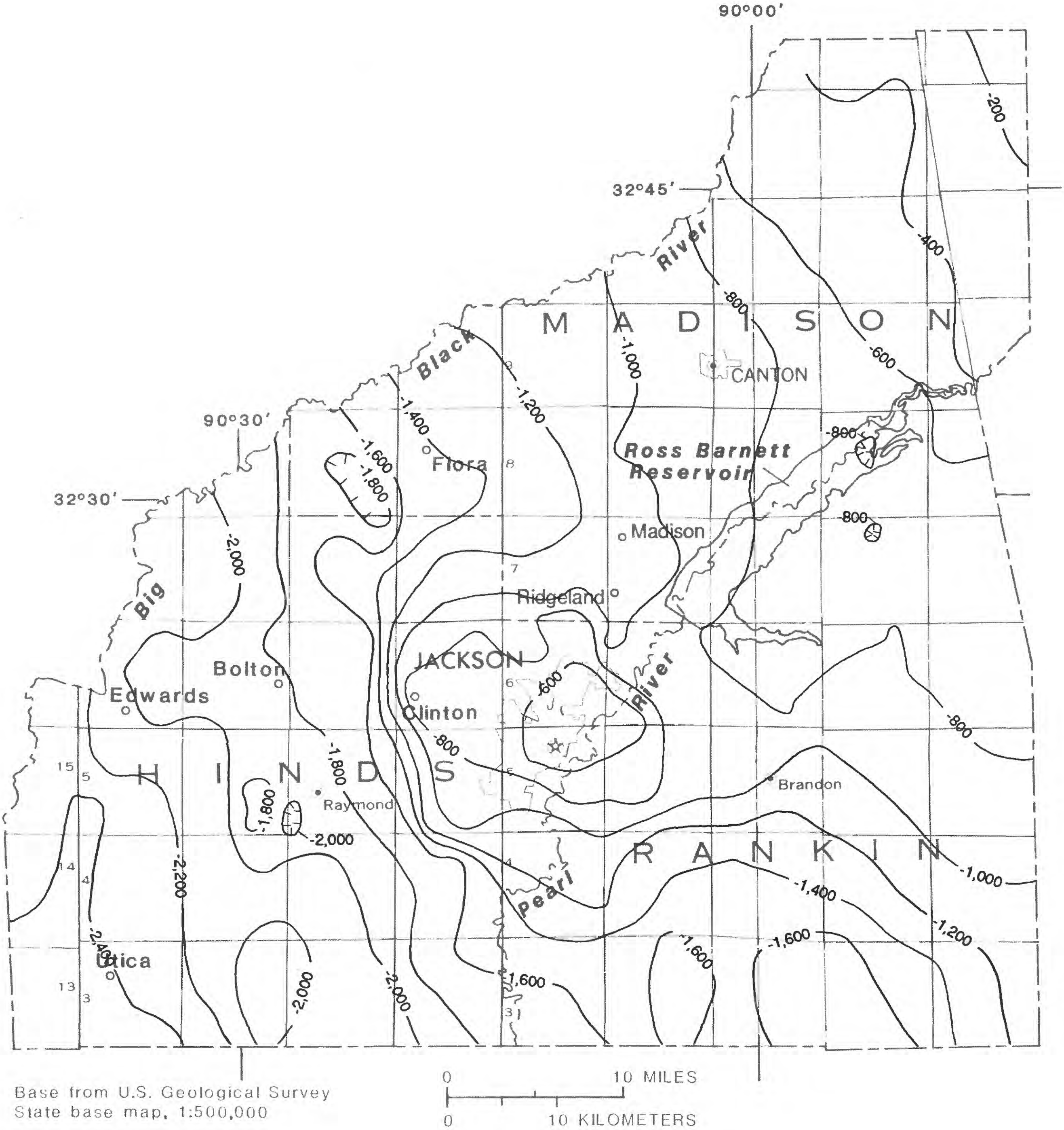
Horizontal hydraulic conductivity and storage coefficient are aquifer properties that indicate the capacity of an aquifer to transmit and store water. Hydraulic conductivity is a measure of the ability of the aquifer to transmit water through a unit area of the aquifer. Storage coefficient is the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head.



EXPLANATION

— 100 — LINE OF EQUAL THICKNESS OF CLAY--Hachures indicate area of lesser thickness. Interval 100 feet

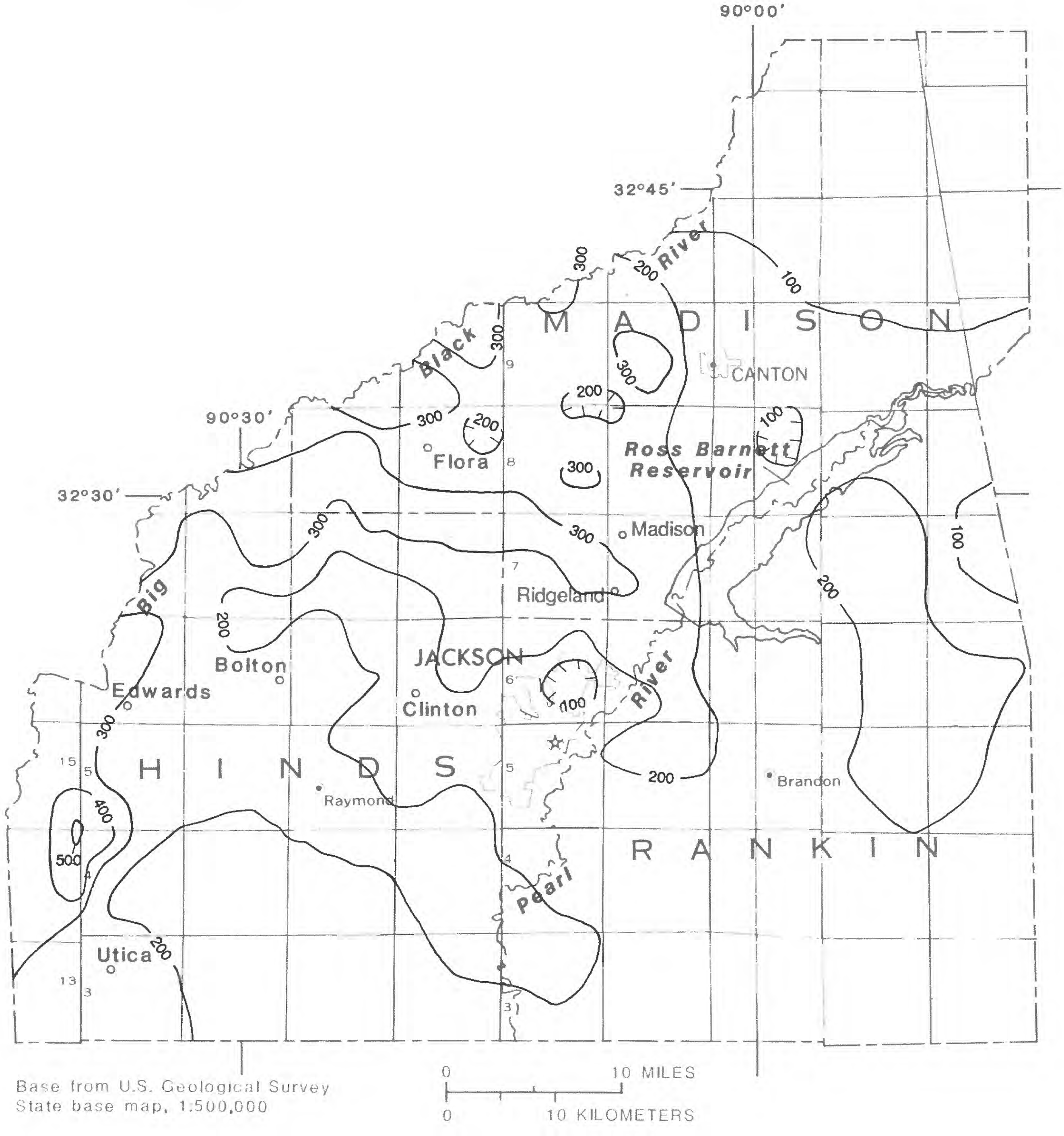
Figure 8.--Total clay thickness of the Zilpha Clay in the three-county study area.



EXPLANATION

—— -800 —— LINE OF EQUAL ALTITUDE--Hachures indicate a depression. Interval 200 feet. Datum is sea level

Figure 9.--Altitude of the base of the Sparta Sand in the three-county study area.



EXPLANATION

—— 200 —— LINE OF EQUAL THICKNESS OF SAND--Hachures indicate area of lesser thickness. Interval 100 feet

Figure 10.--Total sand thickness of the Cockfield Formation in the three-county study area.

Hydraulic properties of the Cockfield aquifer were determined from analysis of aquifer tests at 17 wells in the three-county area (Slack and Darden, 1991). Tests were made at four wells in Hinds County, four wells in Madison County, and nine wells in Rankin County. Horizontal hydraulic conductivity ranged from 5 to 100 feet per day and averaged 39 feet per day. Storage coefficients ranged from 7.0×10^{-5} to 8.0×10^{-4}.

Pumpage

Pumpage from the Cockfield aquifer in the three-county area has increased steadily from about 2.0 million gallons per day during 1965 to about 8.4 million gallons per day during 1990 (fig. 11). Rankin County had the greatest pumpage from the aquifer during 1990 with about 4.0 million gallons per day. Most of the pumpage in Rankin County was from the west-central part of the county (fig. 12). Hinds and Madison Counties had 2.2 and 2.1 million gallons per day pumpage, respectively, during 1990. In Hinds County, most of the pumping was concentrated in the central part of the county in the Clinton-Raymond area. In Madison County, most of the pumping was concentrated in the Madison-Ridgeland area in the southeastern part of the county. Most of the pumping from the aquifer is concentrated in a belt about 6 to 8 miles wide encircling the Jackson Dome.

Water Levels

Water levels are highest in the eastern and northeastern part of the three-county area near the outcrop area of the Cockfield aquifer (Darden, 1986). Water levels have declined an average of as much as 2 feet per year since 1960 in observation wells completed in the Cockfield aquifer in heavily pumped parts of the study area (fig. 13). In the small area where the Cockfield Formation crops out along the Pearl River at Jackson, the Yazoo Clay is absent and water levels are substantially higher in the Cockfield aquifer than in the surrounding area. The fine-grained sediments in the upper part of the Cockfield Formation are more permeable than the Yazoo Clay and they transmit water more readily to the deeper sands that make up the Cockfield aquifer. The increased recharge to the Cockfield aquifer along the Pearl River, where the Yazoo Clay is absent, disrupts the west-southwest regional slope of the potentiometric surface. In this area, water levels generally are higher than the regional slope of the potentiometric surface would indicate. A water-level depression south of this area, extending from east-central Hinds County eastward across the Pearl River into west-central Rankin County, was reported by Wasson (1981b) and Darden (1986). Minimum water levels in the depression were about 40 feet lower than water levels in the surrounding area. The lowest regional water levels in the Cockfield aquifer in the study area are in western and southwestern Hinds County. West of the three-county area, the potentiometric surface decreases toward the west-northwest where the Cockfield aquifer underlies the Mississippi River alluvial aquifer.

Water Quality

Generally, the quality of water from the Cockfield aquifer in the three-county area meets Federal and State drinking-water standards. In the outcrop area in northeastern Madison County, the aquifer contains moderately hard calcium-magnesium bicarbonate type water (Spiers and Dalsin, 1979). Down the dip from the outcrop area, the dissolved-solids concentrations increase and the water becomes a sodium bicarbonate type (Spiers and Dalsin, 1979), but throughout the study area the aquifer contains freshwater.

Two water-quality properties whose values do not meet Federal and State drinking-water standards in water from the Cockfield aquifer in several parts of the study area are color and dissolved iron. Water with color values more than 50 platinum-cobalt units is present in southern Hinds and Rankin Counties and in the area underlying the upper part of the Ross Barnett Reservoir (fig. 14). Water with dissolved-iron concentrations of more than 0.3 milligram per liter is present in

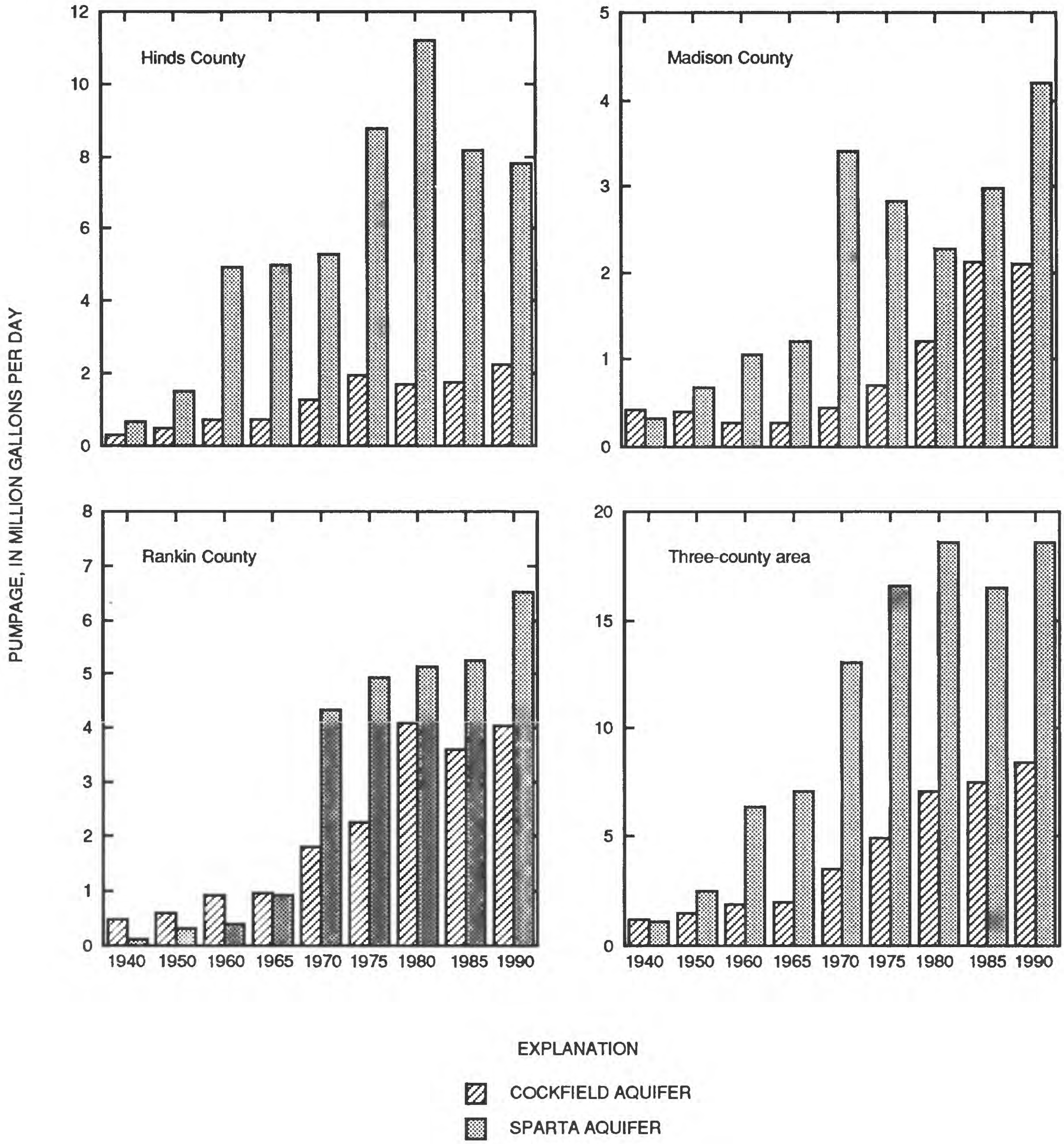
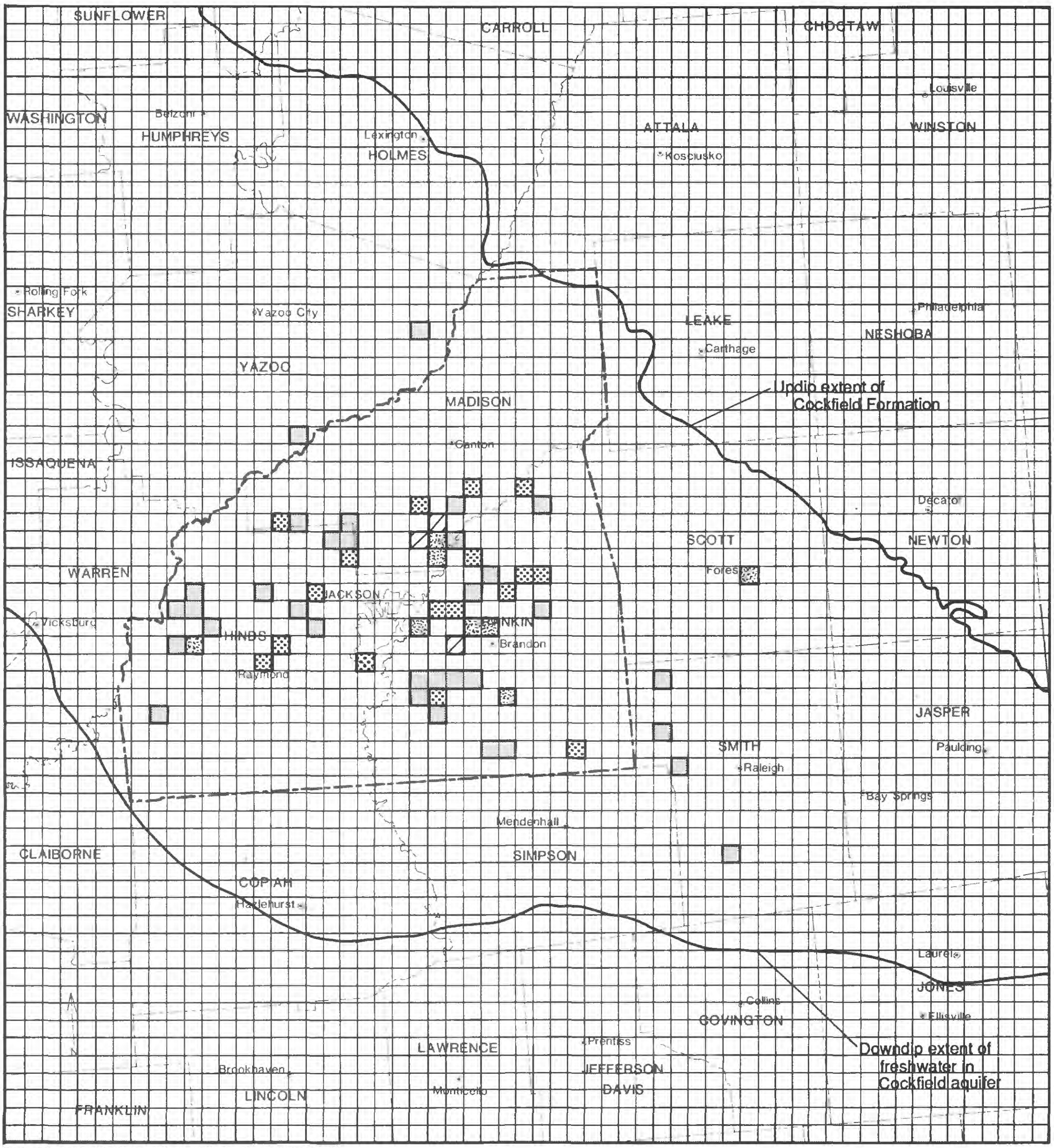


Figure 11.--Pumpage from the Cockfield and Sparta aquifers in Hinds, Madison, and Rankin Counties and in the three-county area.



Base from U.S. Geological Survey State base map, 1972

0 10 20 MILES
0 10 20 KILOMETERS

EXPLANATION

PUMPAGE IN 4-SQUARE-MILE AREA, IN GALLONS PER DAY
(Pumpage less than 25,000 gallons per day not shown)

- 25,000 to 100,000
- 100,000 to 250,000
- 250,000 to 500,000
- 500,000 to 720,000

Figure 12.--Estimated pumpage from the Cockfield aquifer during 1985-90.

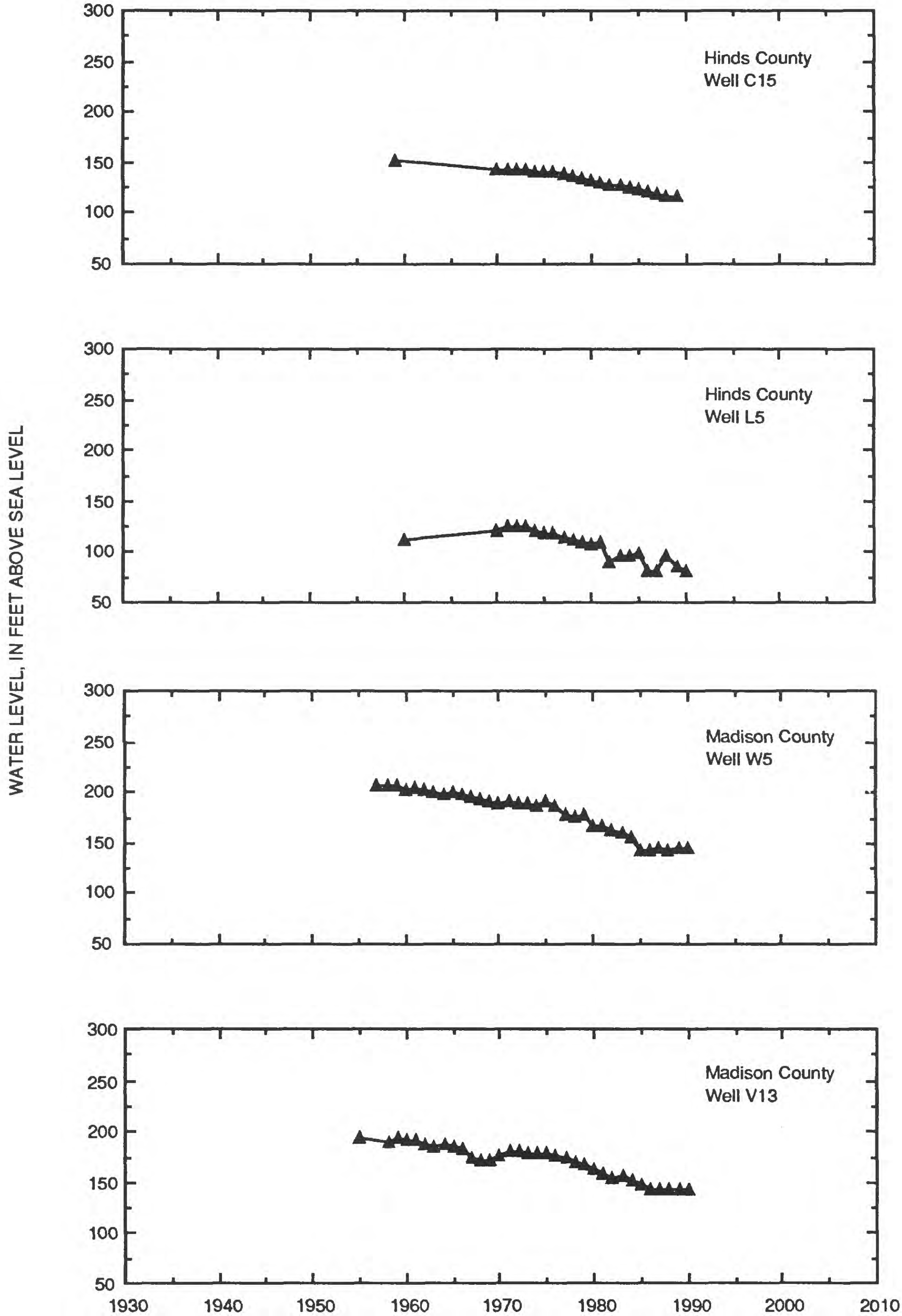


Figure 13.--Measured water levels in selected observations wells completed in the Cockfield aquifer.

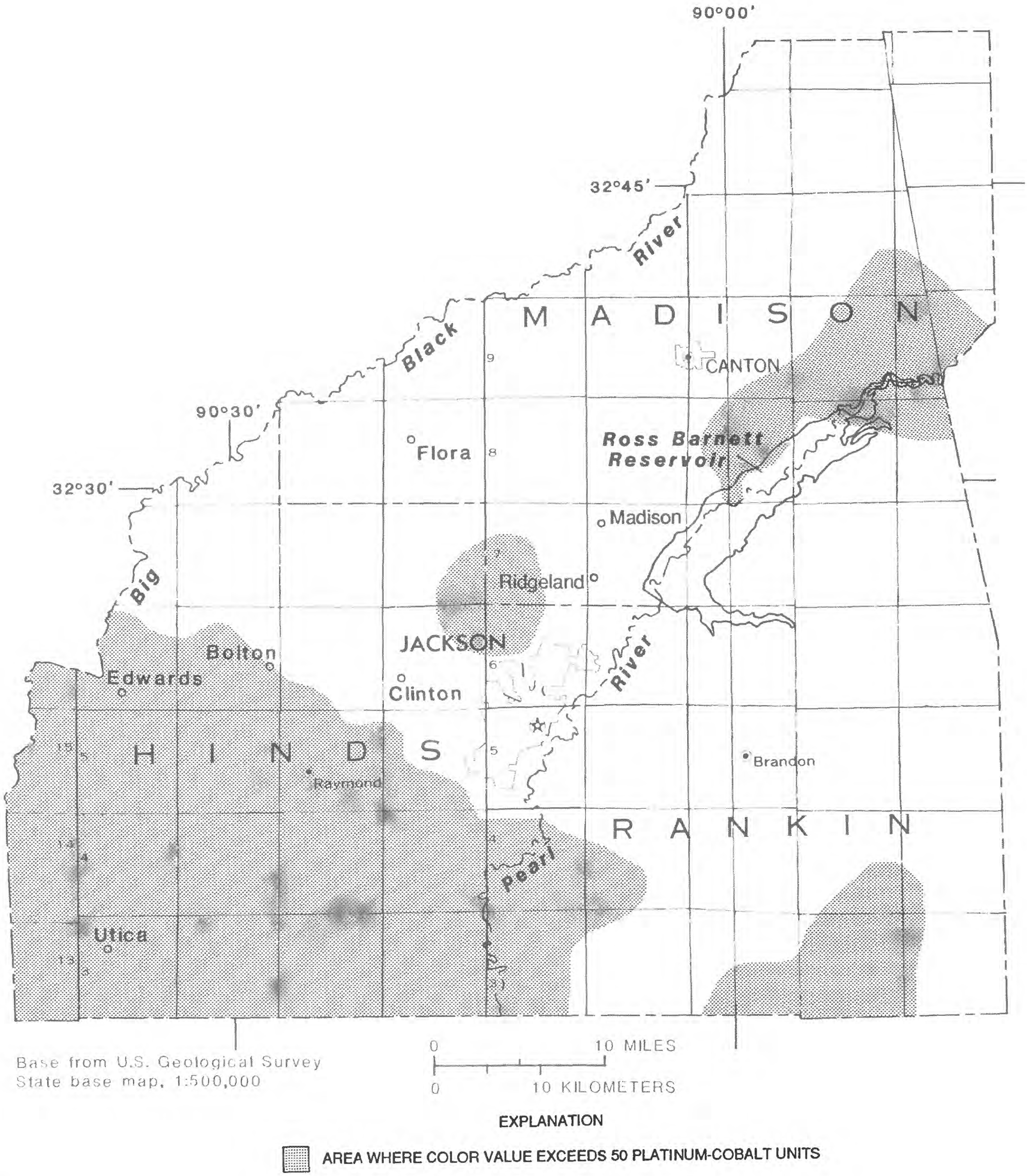


Figure 14.--Generalized area where color value in water from the Cockfield aquifer exceeds 50 platinum-cobalt units in the three-county study area.

southeastern Hinds County, in most of Madison County, and in northeastern and southwestern Rankin County (fig. 15). Water with the highest iron concentrations generally is in and near the outcrop area of the aquifer.

Sparta Aquifer

The Sparta aquifer generally consists of two or more sand beds separated by discontinuous clay beds and is an existing or potential water-supply source throughout the study area. The Sparta aquifer contains freshwater throughout the three-county area and in more than 40 percent of the entire State. The Sparta aquifer is exposed at the surface outside the study area in a band extending from Clarke County (at the Mississippi-Alabama State boundary) northwestward through central Mississippi into southwestern Tennessee. The Sparta aquifer subcrops the Mississippi River alluvial aquifer in the northeastern part of the Mississippi Alluvial Plain in Mississippi (Arthur and Taylor, 1991).

Generally, the Sparta aquifer contains more sand and is more permeable than the Cockfield aquifer. In the study area, total sand thickness of the Sparta is less than 200 feet in northeastern Madison County and in a small area in west-central Rankin County, and more than 500 feet in southwestern Madison and western Hinds Counties. Throughout most of the three-county area, total sand thickness of the Sparta ranges from 200 to 400 feet (fig. 16). The total sand thickness of the Sparta aquifer generally is 100 to 200 feet greater than the total sand thickness of the Cockfield aquifer.

Hydraulic Properties

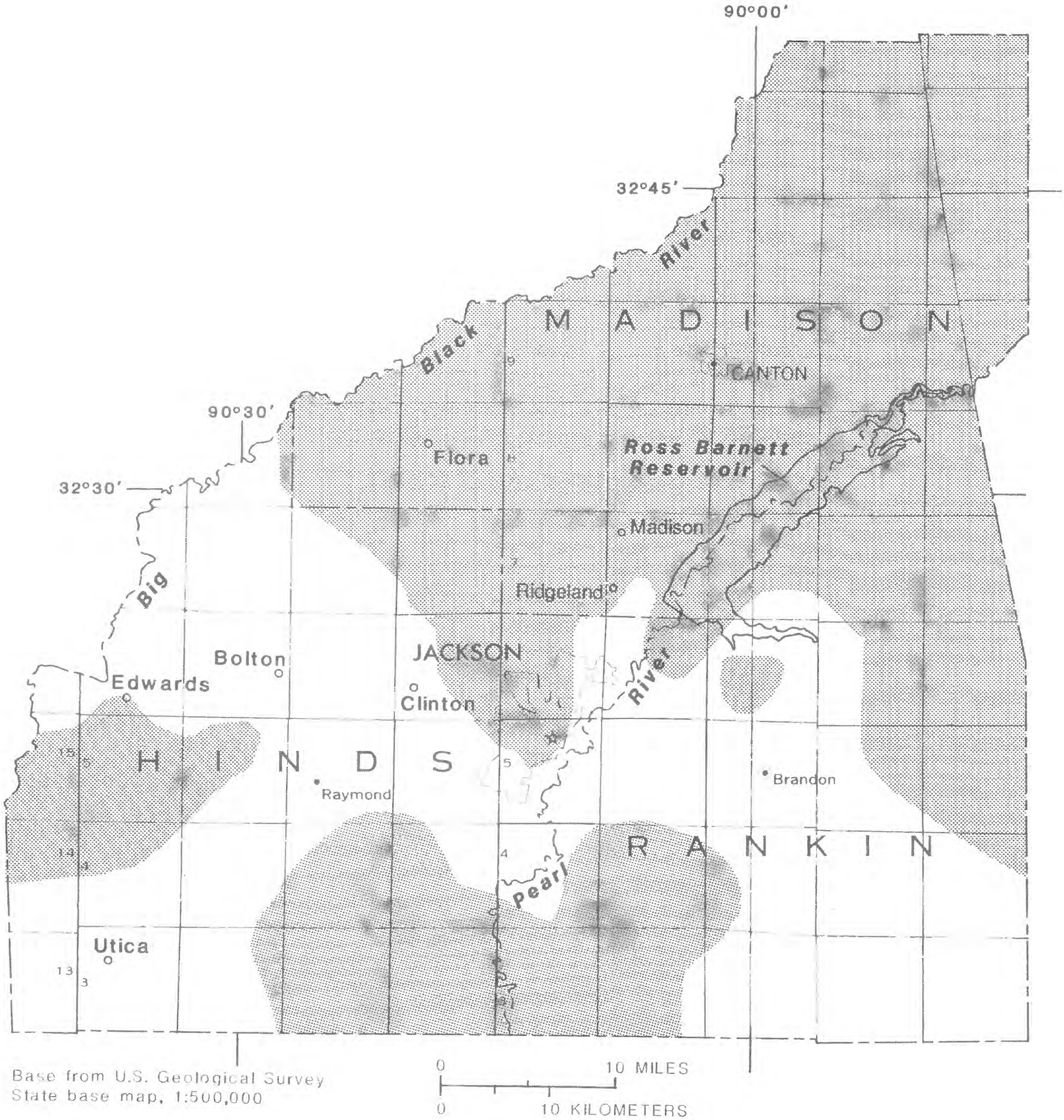
Hydraulic properties of the Sparta aquifer determined from aquifer test analyses at 27 wells in the three-county area were reported by Slack and Darden (1991). Horizontal hydraulic conductivity at 17 wells in Hinds County, 2 in Madison County, and 8 in Rankin County ranged from 25 to 100 feet per day and averaged 60 feet per day. Storage coefficients for the Sparta aquifer ranged from 3×10^{-5} to 1×10^{-4}.

Pumpage

The Sparta aquifer is the most heavily pumped aquifer in the study area. During 1990, pumpage from the Sparta aquifer in the three-county area was about 18.5 million gallons per day, more than double the rate pumped from the Cockfield aquifer. Pumpage from the Sparta aquifer in the study area increased from about 7.1 million gallons per day during 1965 to 18.5 million gallons per day during 1990 (fig. 11). Hinds County had the greatest pumpage from the Sparta aquifer during 1990, about 7.8 million gallons per day. Most of the pumpage in Hinds County was from the east-central part of the county (fig. 17). Madison and Rankin Counties had 4.2 and 6.5 million gallons per day pumpage, respectively, during 1990 from the Sparta aquifer. Most of the pumping in Rankin County was concentrated in the west-central part of the county, whereas most of the pumping in Madison County was in the Canton area.

Water Levels

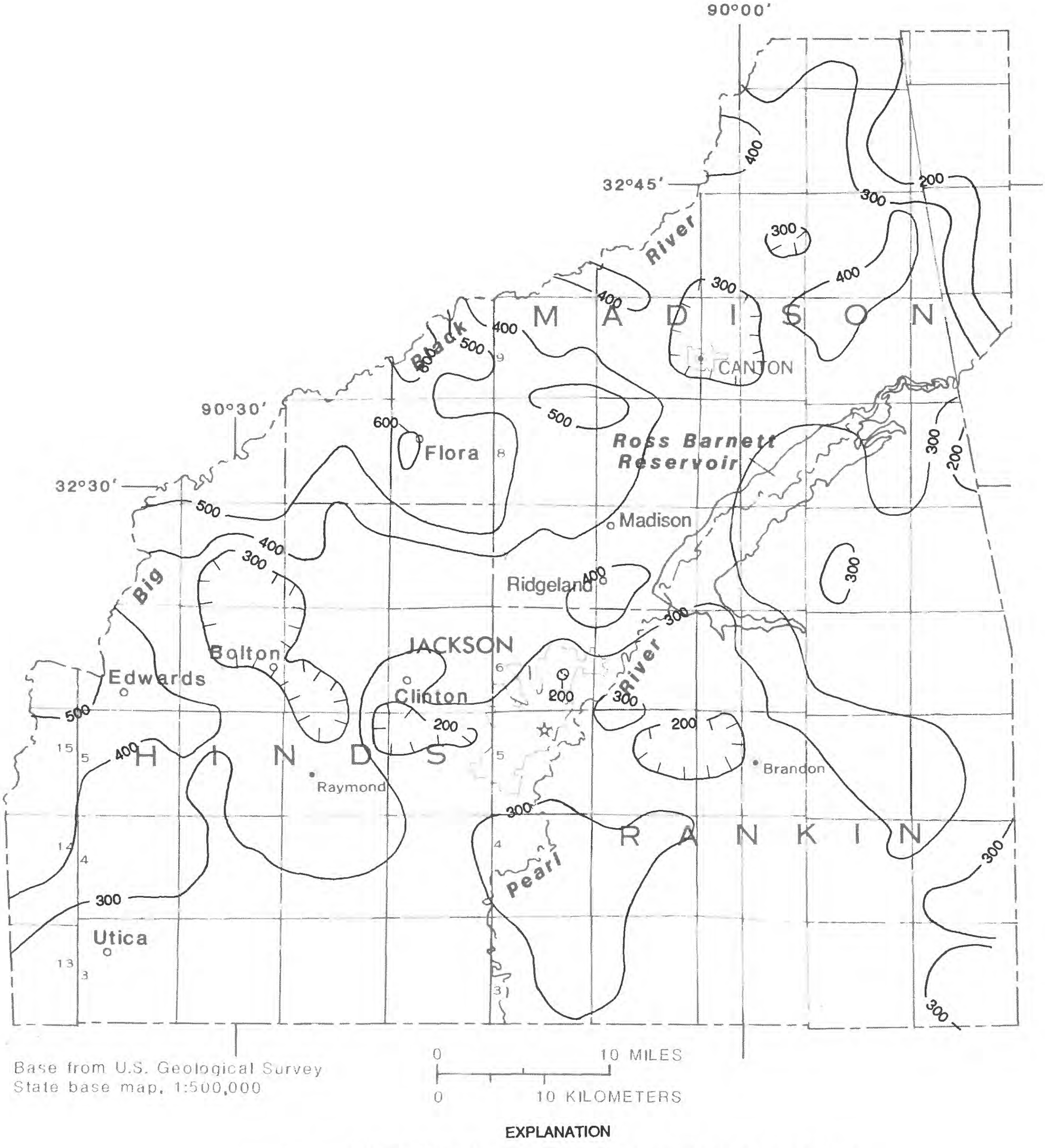
Water levels in the Sparta aquifer are highest in the northeastern part of the study area near the outcrop area where water levels are more than 200 feet above sea level. Water levels declined in the Sparta aquifer as much as $2^1/2$ feet per year from 1960 to 1990 in selected observation wells in heavily pumped areas (fig. 18). Down the dip from the outcrop area, water levels slope west-southwestward toward the heavily pumped Jackson area and toward the regional discharge area under the Mississippi Alluvial Plain (Darden, 1987).



EXPLANATION

AREA WHERE DISSOLVED-IRON CONCENTRATION EXCEEDS 0.3 MILLIGRAM PER LITER

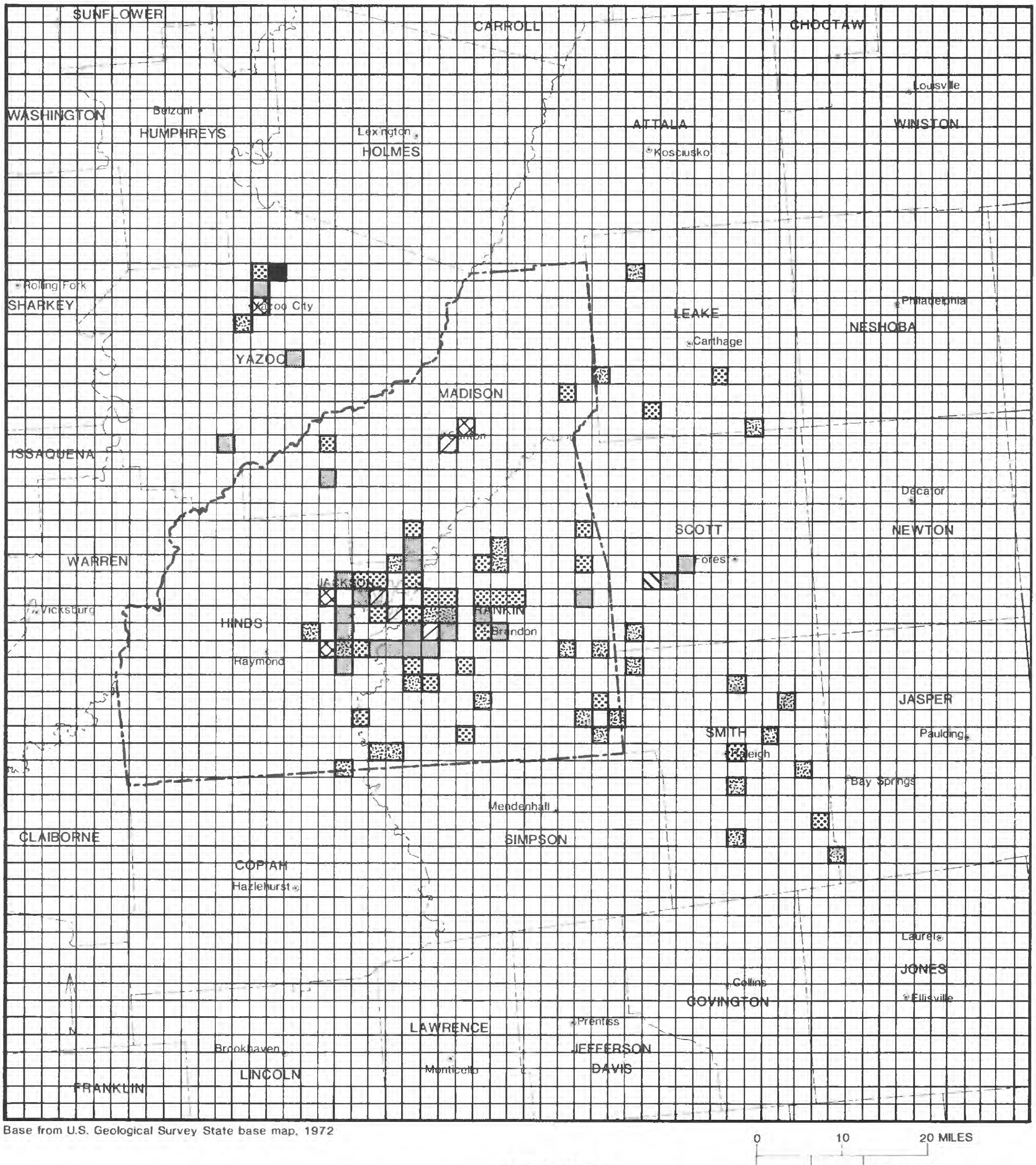
Figure 15.--Generalized area where dissolved-iron concentration in water from the Cockfield aquifer exceeds 0.3 milligram per liter in the three-county study area.



EXPLANATION

—— 500 —— LINE OF EQUAL THICKNESS OF SAND--Hachures indicate area of lesser thickness. Interval 100 feet

Figure 16.--Total sand thickness of the Sparta Sand in the three-county study area.



EXPLANATION

PUMPAGE IN 4-SQUARE-MILE AREA, IN GALLONS PER DAY
(Pumpage less than 25,000 gallons per day not shown)

- 25,000 to 100,000
- 100,000 to 250,000
- 250,000 to 500,000
- 500,000 to 750,000
- 750,000 to 1,000,000
- 1,000,000 to 2,500,000
- 7,500,000 to 9,300,000

Figure 17.--Estimated pumpage from the Sparta aquifer during 1985-90.

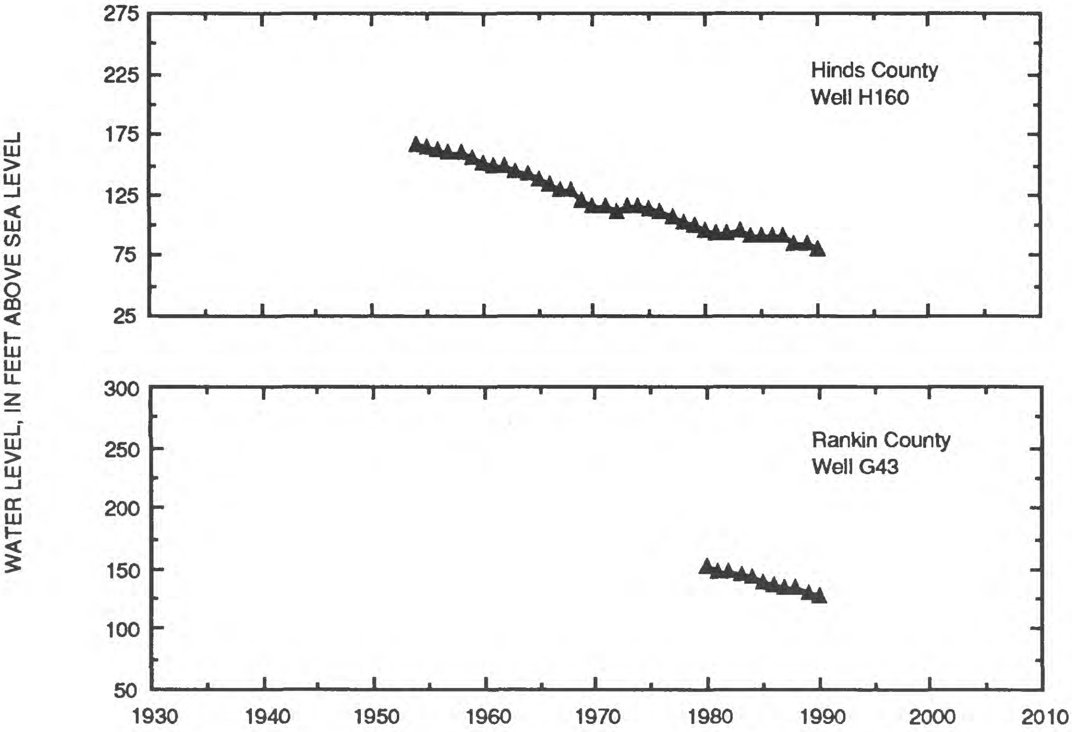


Figure 18.--Measured water levels in selected observation wells completed in the Sparta aquifer.

A substantial water-level depression in the Sparta aquifer centered in the Jackson area in east-central Hinds County was defined by Wasson (1981a) and Darden (1987). Water-level measurements reported by Darden (1987) in observation wells completed in the aquifer indicated that the water level at the center of the depression at Jackson was about 60 feet above sea level during 1984. Water levels adjacent to the depression toward the east and northeast were 60 to 80 feet higher than water levels in the depression. West and southwest of Jackson, in the direction of regional water-level slope, water levels in 1984 were about 40 feet higher than levels in the center of the depression at Jackson.

Water Quality

Water from the Sparta aquifer in the study area generally is suitable for most uses. The aquifer contains freshwater throughout the three-county area. Dissolved-solids concentrations in the water, a sodium bicarbonate type, increase in the downdip, or southwest direction.

Chemical analyses of water from wells completed in the Sparta aquifer indicate color and dissolved iron generally are the only two properties for which values do not meet the Federal and State drinking-water standards. The excessive color and high dissolved-iron concentrations occur in several localized areas. The aquifer contains water having excessive color (more than 50 platimum-cobalt units) in southern Hinds County and southwestern Rankin County, and in northern Rankin County and north and west-central Madison County to near the upper part of the Ross Barnett Reservoir (fig. 19). The aquifer contains water having dissolved-iron concentrations of more than 0.3 milligram per liter in nearly all of Madison County, and in northeastern and southeastern Rankin County (fig. 20). Generally, iron concentrations in water from the aquifer decrease downdip from the outcrop area.

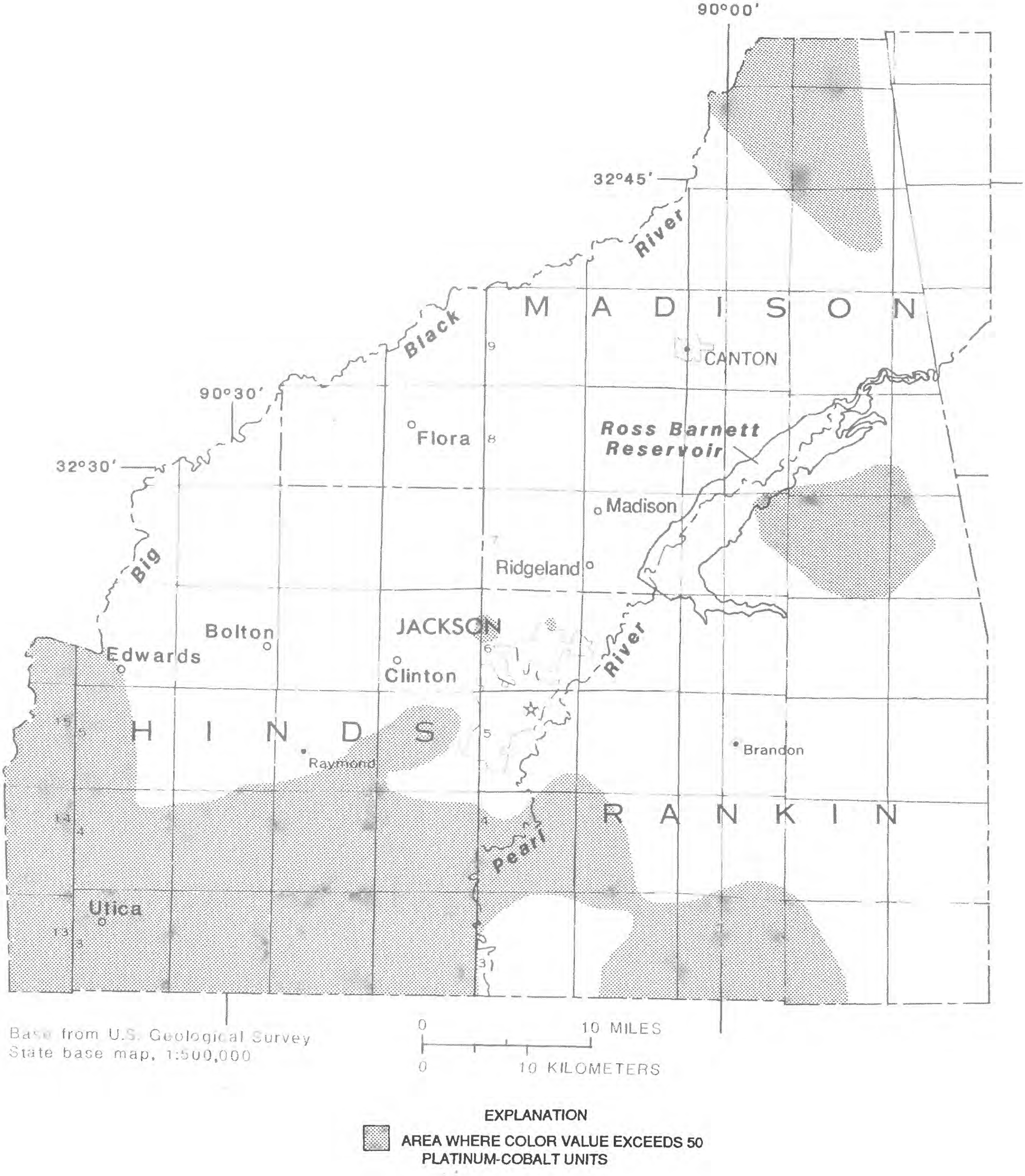
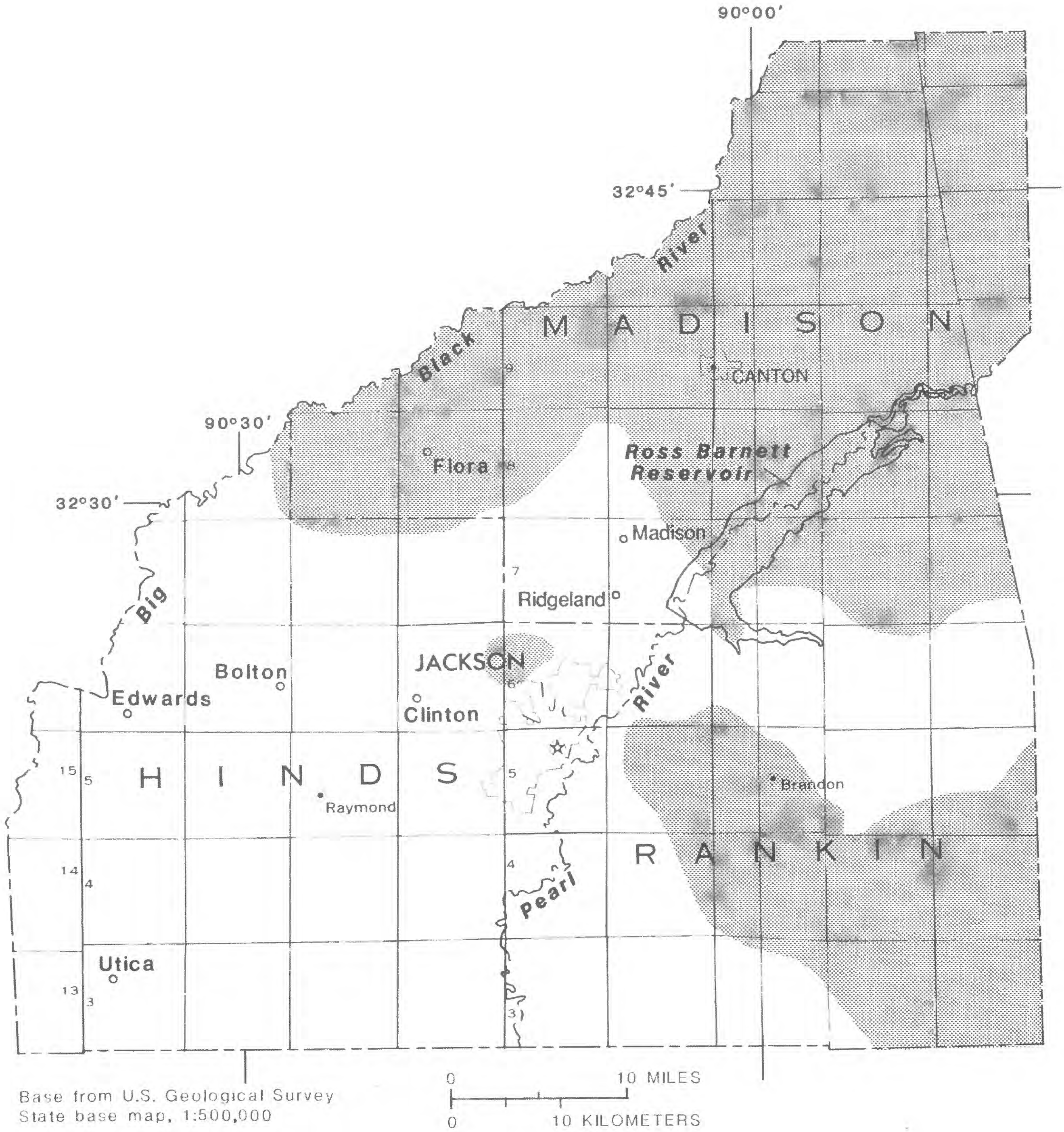


Figure 19.--Generalized area where color value in water from the Sparta aquifer exceeds 50 platinum-cobalt units in the three-county study area.



EXPLANATION

AREA WHERE DISSOLVED-IRON CONCENTRATION EXCEEDS 0.3 MILLIGRAM PER LITER

Figure 20.--Generalized area where dissolved-iron concentration in water from the Sparta aquifer exceeds 0.3 milligram per liter in the three-county study area.

SIMULATION OF GROUND-WATER FLOW

Description of Model

The U.S. Geological Survey's modular three-dimensional finite-difference ground-water flow model (McDonald and Harbaugh, 1988) was used to simulate flow in the Cockfield and Sparta aquifers in the Hinds, Madison, and Rankin Counties area. The model program uses a finite-difference method to numerically solve partial differential equations that describe ground-water flow. The model-generated solutions to the equations provide simulated heads (water levels) and flow budgets for the individual aquifers for the specified boundary conditions, hydraulic characteristics, and stresses.

Model Grid and Layers

The model grid covers 15,600 square miles in west-central Mississippi (fig. 21). The grid extends beyond the three-county area in all directions to include adjacent areas that could affect the potentiometric surface and availability of water in the Cockfield and Sparta aquifers within the study area. The lateral extent of the model area was positioned to minimize, as much as practicable, horizontal flow into and out of the model area. The southwestern corner of the model grid is located at latitude 31°30' and longitude 91°00'. The model grid is oriented north-south with 65 rows and 60 columns with each block-centered flow cell 2 miles on a side. The western edge of the model is about 2 miles west of Vicksburg. The eastern edge is about 12 miles west of Meridian. The southern edge is about 10 miles north of Hattiesburg, and the northern edge is about 15 miles north of Kosciusko.

The Cockfield aquifer is represented as layer 1 (fig. 22) in the model, and the Sparta aquifer is represented as layer 2 (fig. 23). A third layer represents the water-bearing units below the Sparta aquifer. The model extent includes not only the outcrop area of the Cockfield Formation in northeast Madison County in the three-county area but the outcrop and subcrop areas throughout the west-central part of the State (fig. 24). The Sparta Sand crops out entirely outside the three-county area, but the model extends eastward and northward to include most of the Sparta Sand outcrop in the central part of the State. The cell-by-cell representation of all outcrop areas in the model area is shown in figure 25.

Model Boundaries

The selection and location of the lateral, upper, and lower boundaries in the flow model determine, to a large extent, the model response to applied stresses. To minimize the effect of pumpage in the study area at the lateral boundaries, the model extent was extended beyond the three-county area. In the freshwater zone of the Cockfield (layer 1) and Sparta (layer 2) aquifers, the lateral boundaries at the model extent of the aquifers are represented with head-dependent flux nodes using the general head package in the modular model. At locations beyond the freshwater extent of the aquifer (where dissolved-solids concentrations in water exceed 10,000 milligrams per liter), the lateral boundaries of both aquifers were designated no-flow boundaries. At these boundary cells, horizontal flow is not "allowed" to enter or leave the model. A no-flow condition at the saltwater interface may not be an entirely valid assumption, but the assumption is reasonable because all major pumping from the Cockfield and Sparta aquifers is substantially up the dip from the freshwater-saltwater interface (figs. 12 and 17). In addition, there has been no indication of a change in location of the interface since investigated by Gandl (1982).

Aquifer heads at the lateral boundaries for the head-dependent flux nodes represent water levels in the aquifer one cell width (2 miles) from the center of the adjacent cell. The heads were determined from potentiometric maps by Harvey and Grantham (1963), Wasson (1980b, 1981a, 1981b), and Darden (1986, 1987). Aquifer heads at lateral boundaries for predevelopment conditions (figs. 26 and 27) were estimated using a predevelopment potentiometric map by Reed (1972) and published water

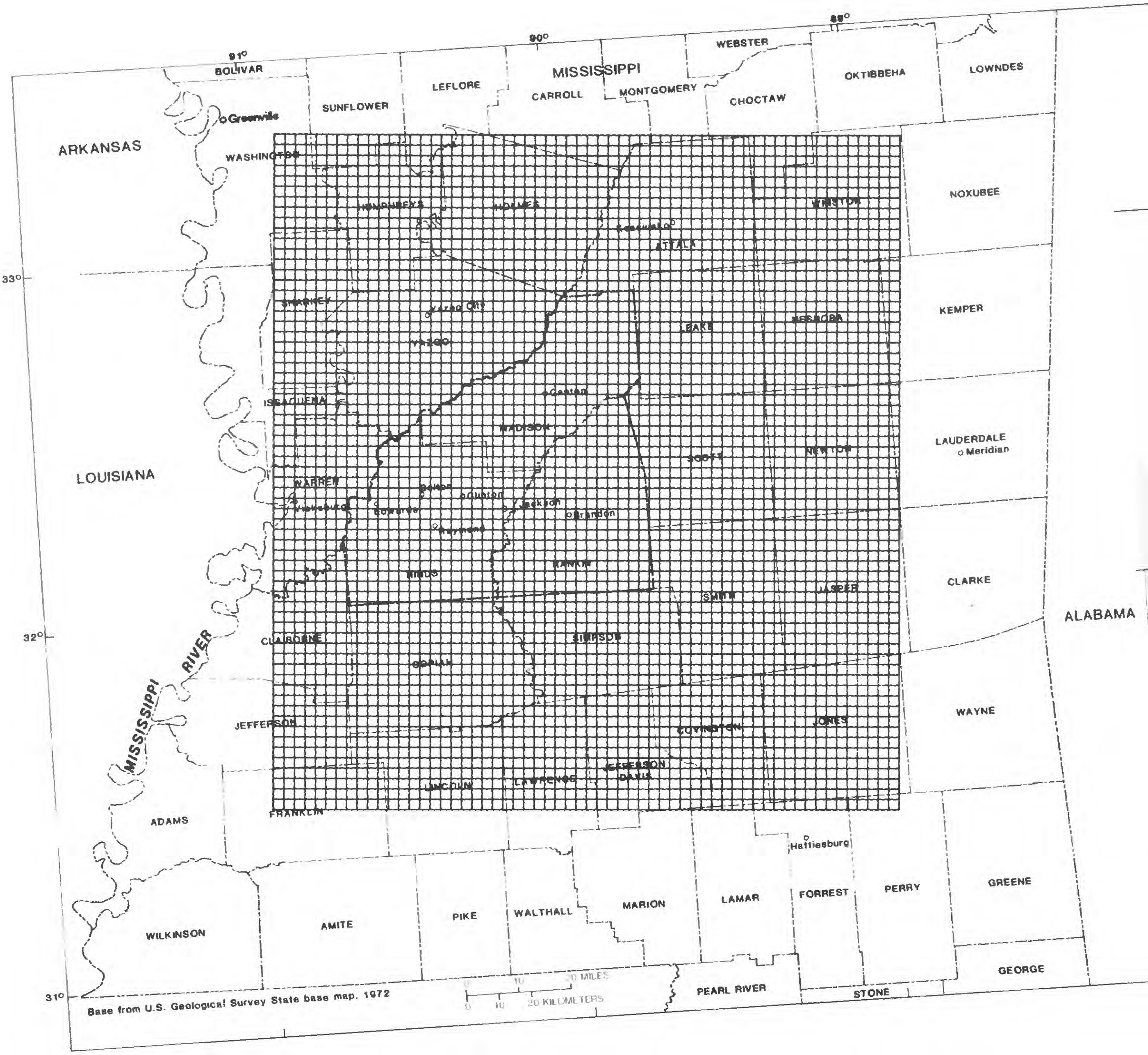


Figure 21.--Model grid extent.

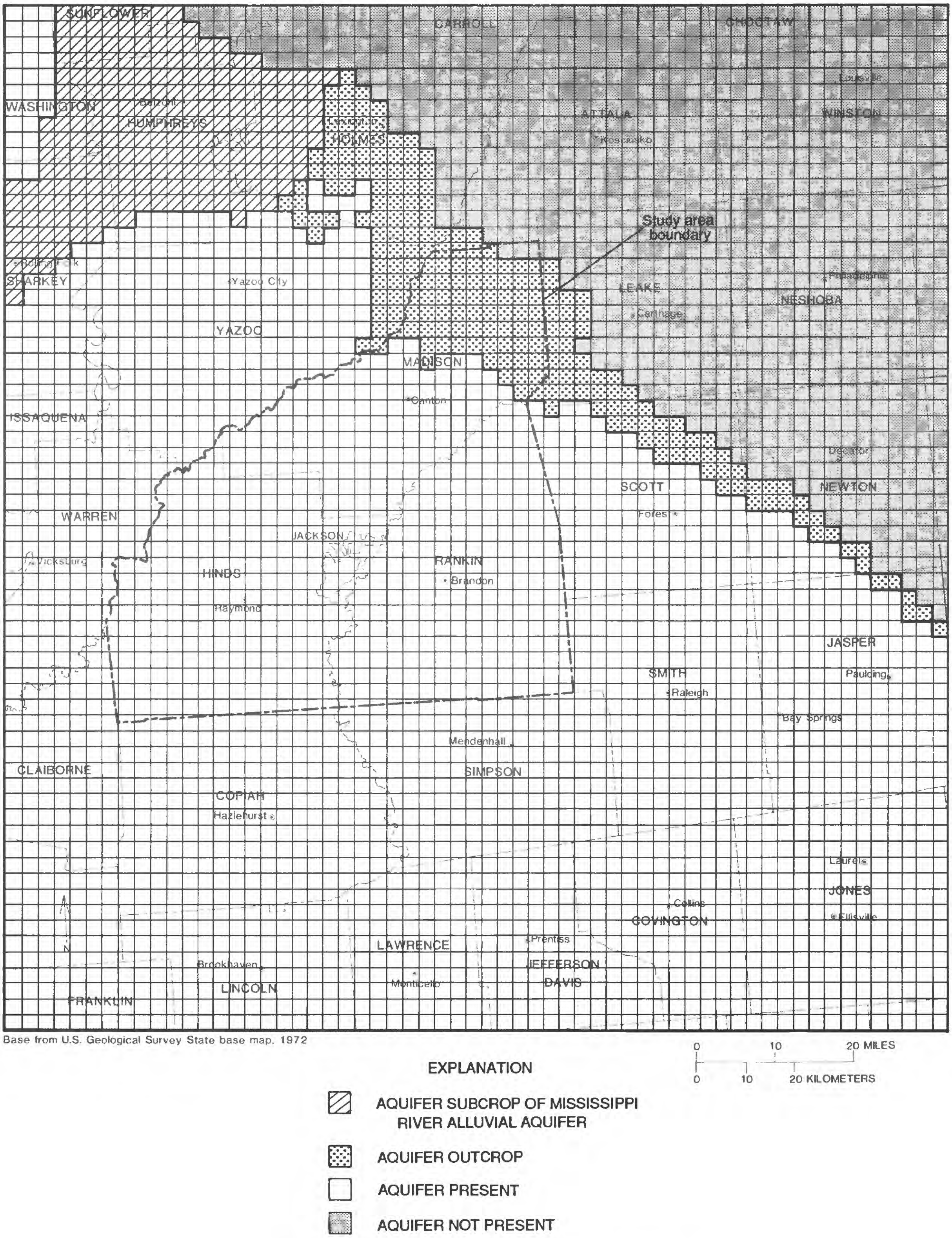


Figure 22.--Extent of Cockfield aquifer (layer 1) in model area.

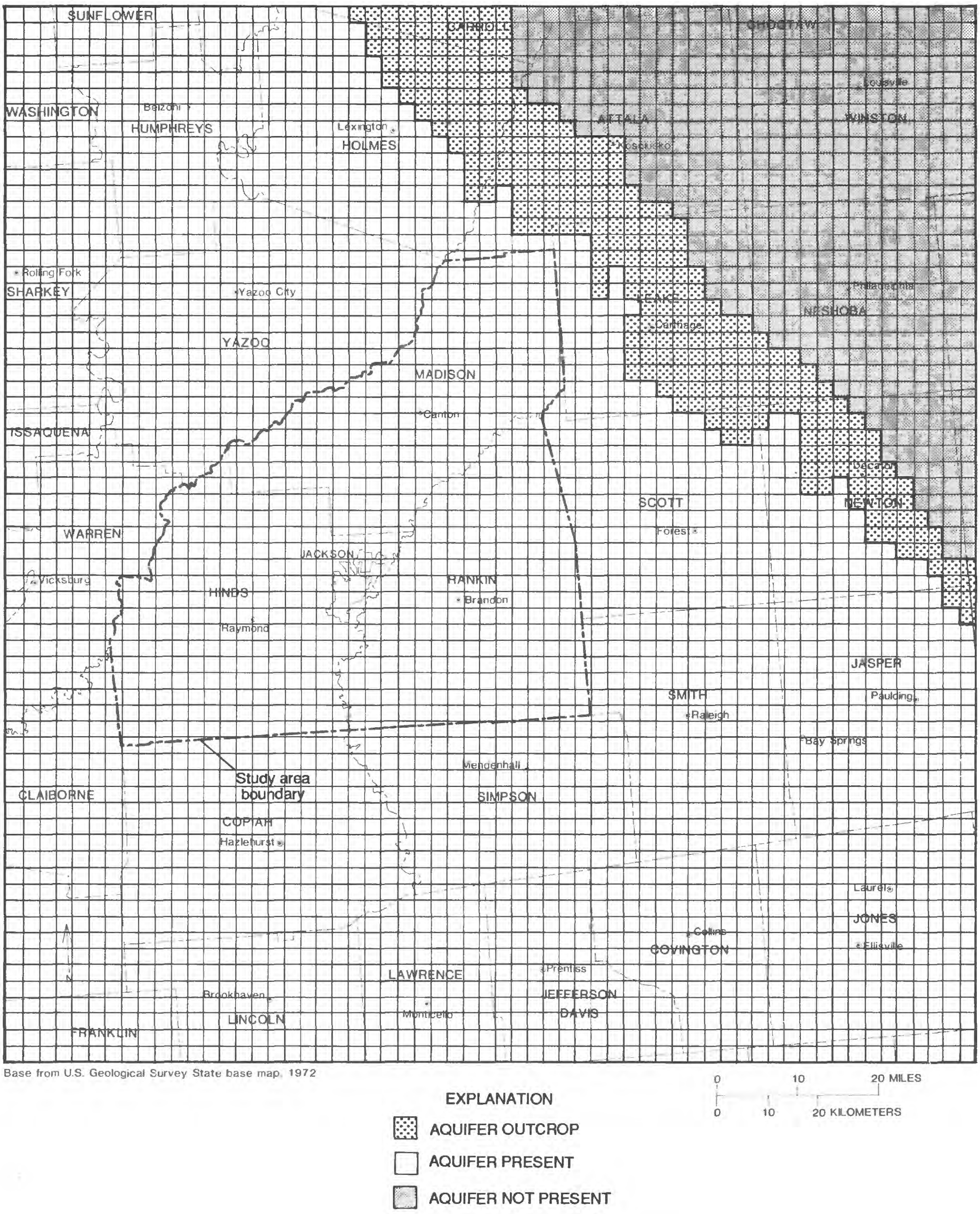


Figure 23.--Extent of Sparta aquifer (layer 2) in model area.

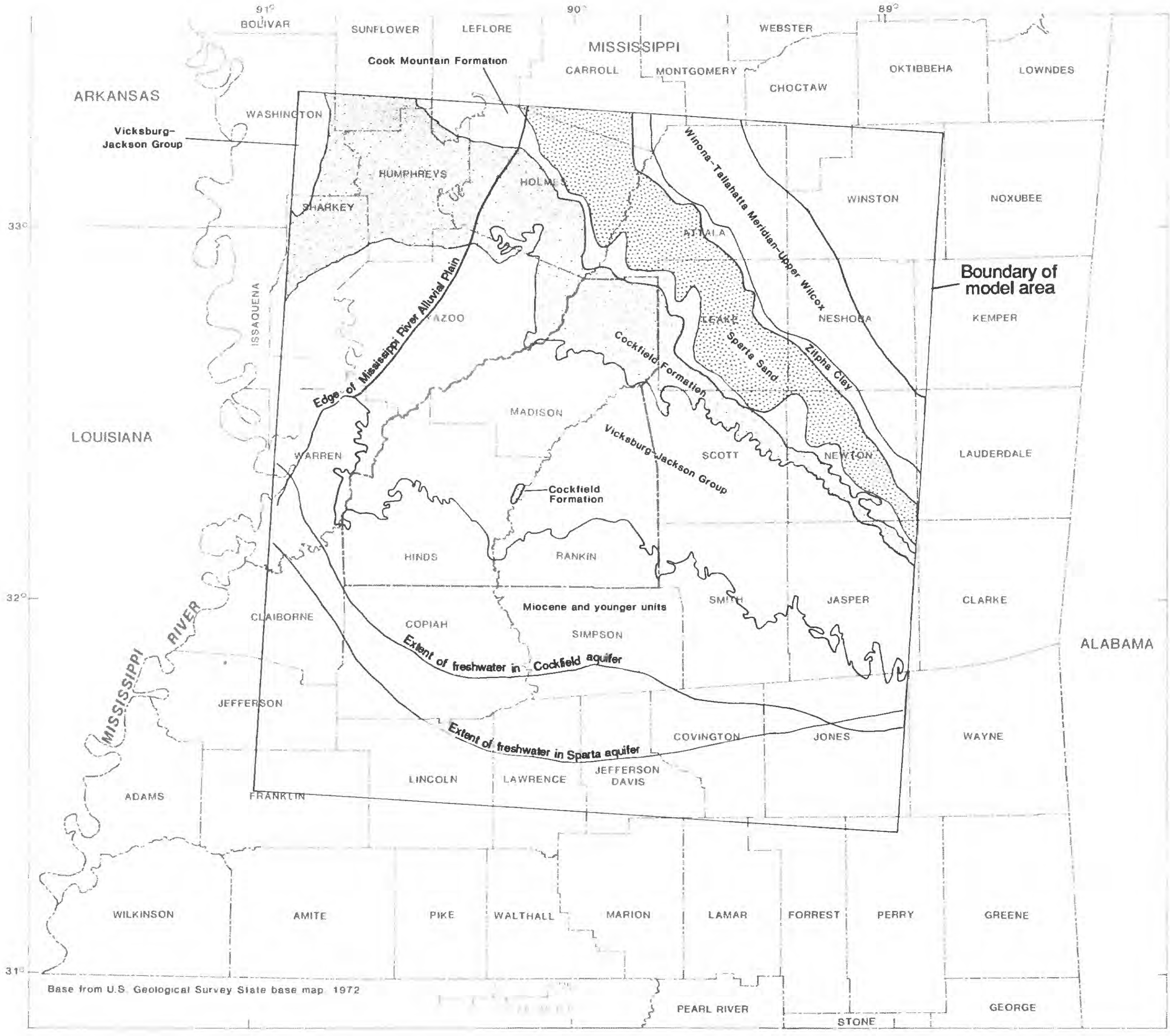
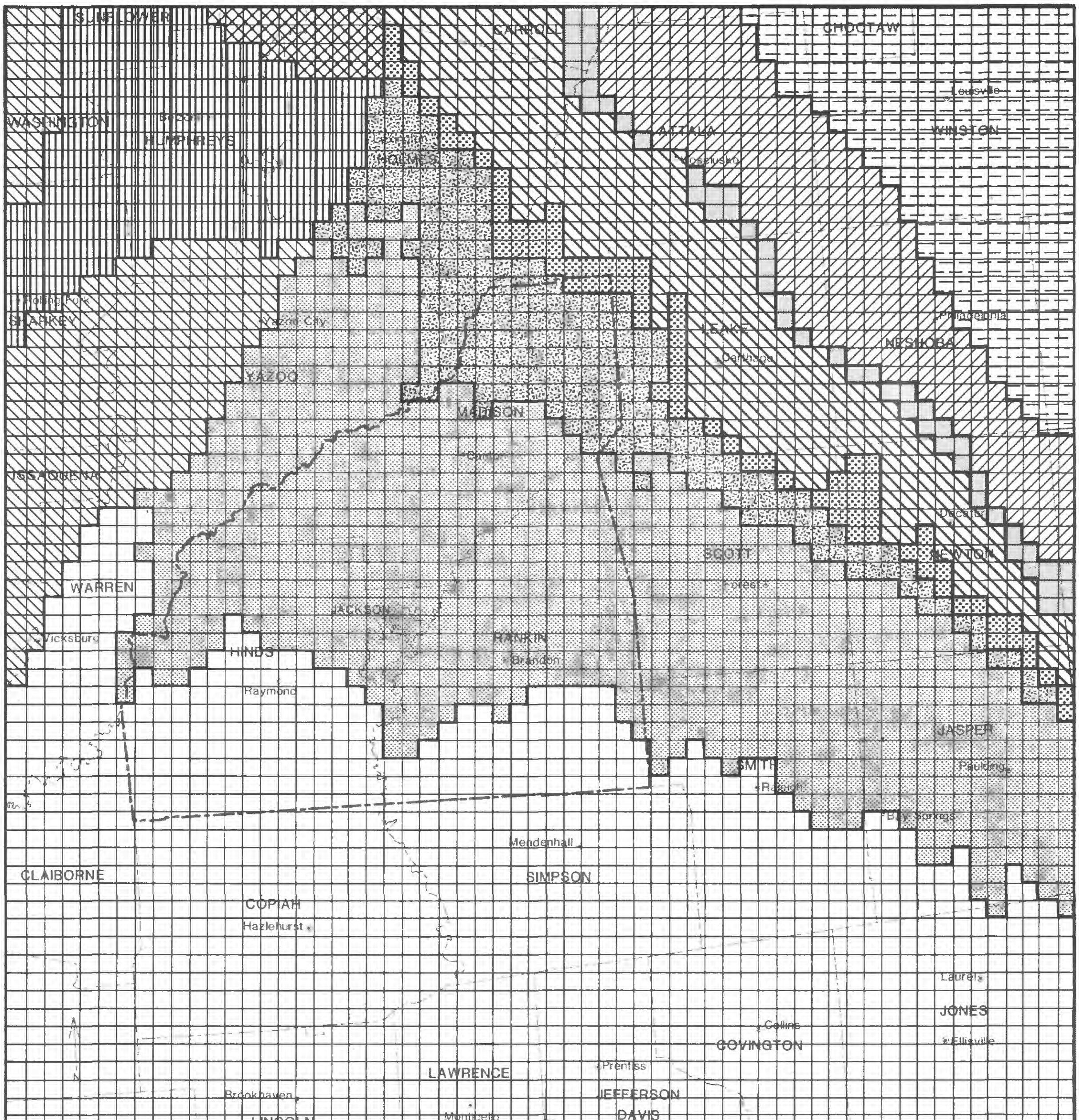


Figure 24.--Outcrop units and downdip extent of freshwater in the Cockfield and Sparta aquifers in the model area.



Base from U.S. Geological Survey State base map, 1972

0 10 20 MILES
0 10 20 KILOMETERS

EXPLANATION

- OUTCROP OF COCKFIELD FORMATION
- OUTCROP OF SPARTA SAND
- OUTCROP OF WINNONA-TALLAHATTA MERIDIAN-UPPER WILCOX
- OUTCROP OF MIOCENE AND YOUNGER UNITS
- OUTCROP VICKSBURG-JACKSON GROUPS
- OUTCROP OF COOK MOUNTAIN FORMATION
- OUTCROP OF ZILPHA CLAY
- SUBCROP OF COCKFIELD FORMATION
- SUBCROP OF VICKSBURG-JACKSON GROUPS
- SUBCROP OF COOK MOUNTAIN FORMATION
- NOT SIMULATED-INACTIVE CELLS

Figure 25.--Generalized outcrop and subcrop areas of geologic units in the model area.

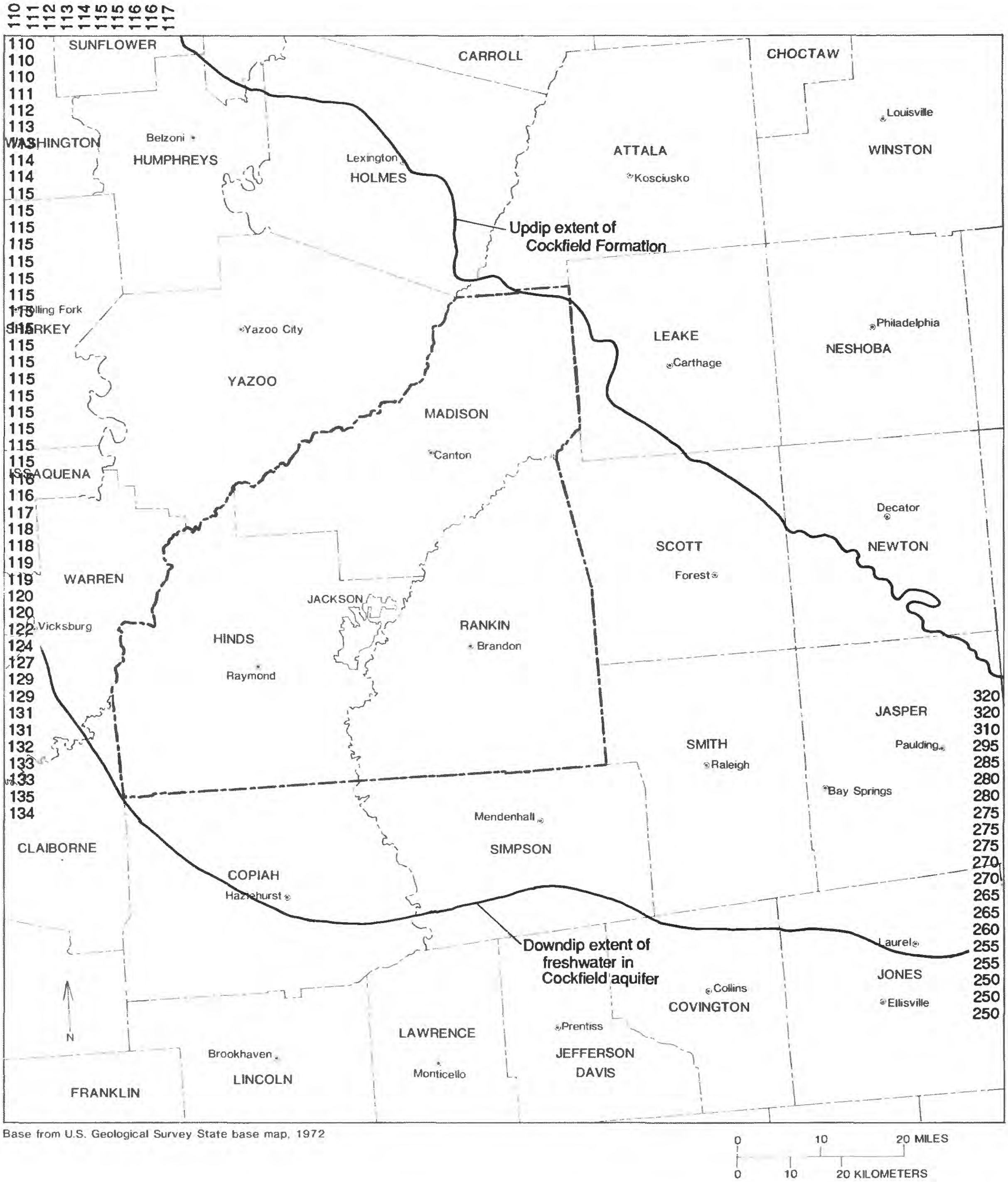


Figure 26.--Predevelopment specified heads (in feet above sea level) in the Cockfield aquifer at the lateral head-dependent flux boundary.

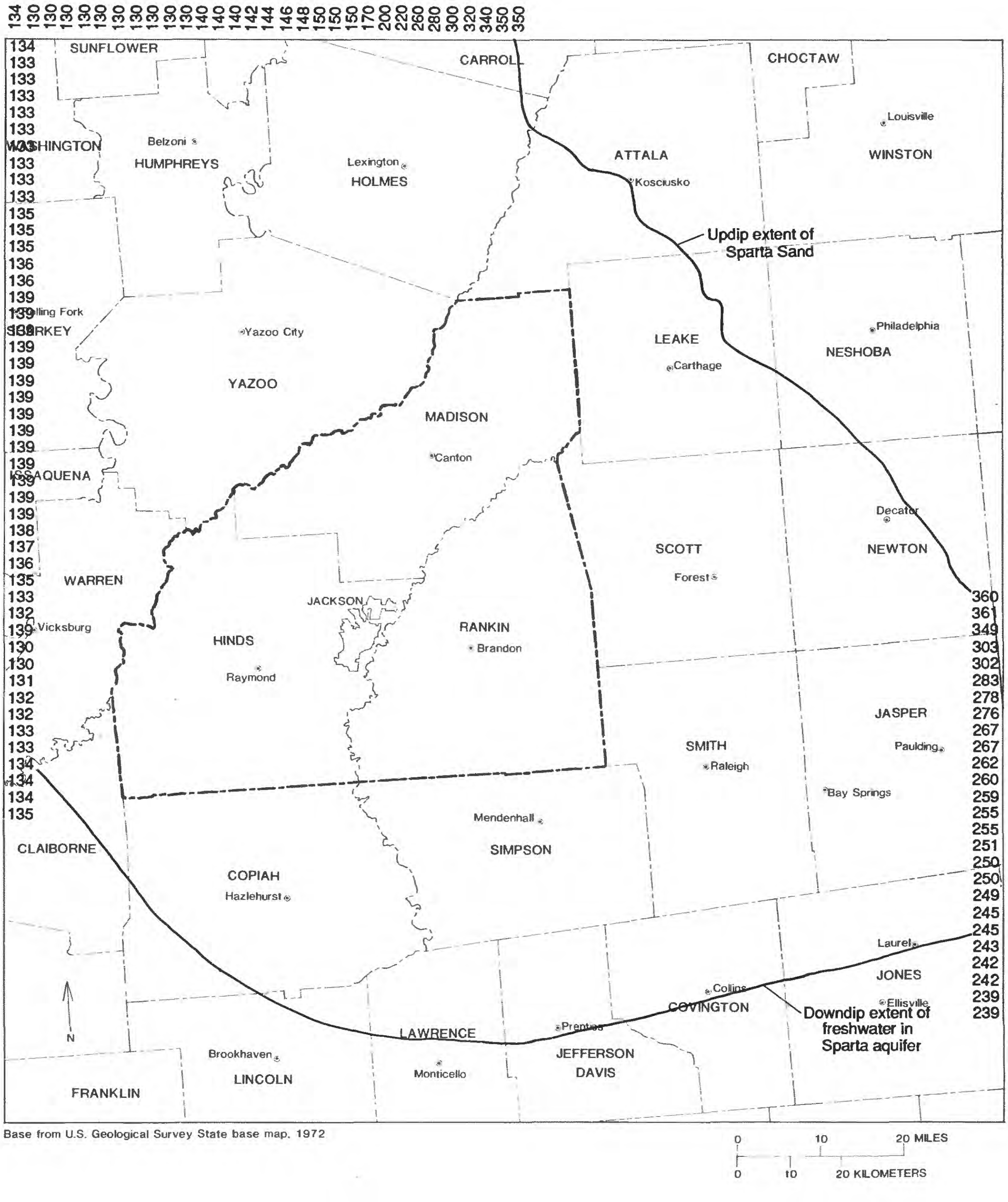


Figure 27.--Predevelopment specified heads (in feet above sea level) in the Sparta aquifer at the lateral head-dependent flux boundary.

levels by Brown (1947), Stephenson and others (1928), Logan and Perkins (1905), Hilgard (1860), and Crider and Johnson (1906). Heads at lateral boundaries for time periods with no published water levels were estimated based on a constant rate of water-level decline or rise for individual cells. Heads at lateral boundaries were held constant at 1990 levels for scenarios projecting conditions to 2000 (figs. 28 and 29). Hydraulic conductance at the lateral boundaries was set equal to the conductance of the adjacent cell.

The upper boundary of the model is simulated by head-dependent flux components functioning as a source-sink layer that extends throughout the active area of the model. This boundary is implemented using the river package in the modular model. The upper boundary simulates recharge and discharge in the aquifer outcrop areas and simulates leakage in areas where the Cockfield or Sparta aquifer underlies another aquifer. The water-table heads in the modeled area were used as the driving heads for the upper boundary head-dependent flux components (fig. 30).

Water-table altitudes were assumed constant with time except in the Mississippi River alluvial aquifer. Large withdrawals of ground water for agriculture since 1960 have caused substantial water-level declines in the alluvial aquifer. Water-level measurements made in the alluvial aquifer from 1960 to 1990 were used to determine the heads for the individual stress periods (pumping periods) for the upper model boundary. Predevelopment heads reported by Sumner and Wasson (1990) were used to represent water levels in the alluvial aquifer before 1960. Outside the Mississippi Alluvial Plain, no changes in water-table altitudes, except for seasonal variations, have been reported.

The resistance to vertical flow at the upper boundary is greatest in areas where thick clay overlies the Cockfield and Sparta aquifers. The largest area of high resistance to vertical flow is down the dip from the Yazoo Clay outcrop and subcrop areas. Smaller areas of high resistance to vertical flow are in the Cook Mountain Formation and Zilpha Clay outcrop areas. In the aquifer outcrop areas, total clay thickness usually is small, resulting in less resistance to vertical flow into the aquifer than in areas where the aquifer is confined and overlain with many feet of clay.

The lower boundary simulates vertical flow into and out of the Sparta aquifer (layer 2) from underlying units. The lower boundary is simulated using a third layer representing the underlying water-bearing units and extends throughout the areal extent of the Sparta aquifer. The Zilpha Clay, a dense marine clay, underlies the Sparta (layer 2) throughout the model area and averages about 200 feet in thickness. The thickness and low permeability of the clay preclude substantial flow into or out of the aquifer from underlying water-bearing units, but the simulation of an additional layer below the Zilpha Clay quantifies any leakage between the Sparta and water-bearing units underlying the aquifer. Heads generated by the third layer for each stress period are used by the model to compute vertical flow through the Zilpha Clay. The potentiometric surfaces representing heads for the lower boundary for predevelopment and 1990 conditions are shown in figures 31 and 32.

Model Calibration

Because most of the hydrologic information available concerning the Cockfield and Sparta aquifers represent the period 1960-90, when pumpage was steadily increasing, model calibration was based on transient simulations. The calibration strategy consisted of varying the unknown or poorly known hydraulic values that affect the ground-water flow and holding constant the known values until the model responded with the best-fit head distribution for each aquifer and stress period. After the best-fit head distribution was determined under transient conditions, the calibrated values were used to simulate steady-state conditions with no pumpage. The steady-state, no pumpage scenario simulated predevelopment conditions where long-term dynamic equilibrium is reached and recharge is balanced by natural discharge from the modeled area. The potentiometric head generated by the steady-state

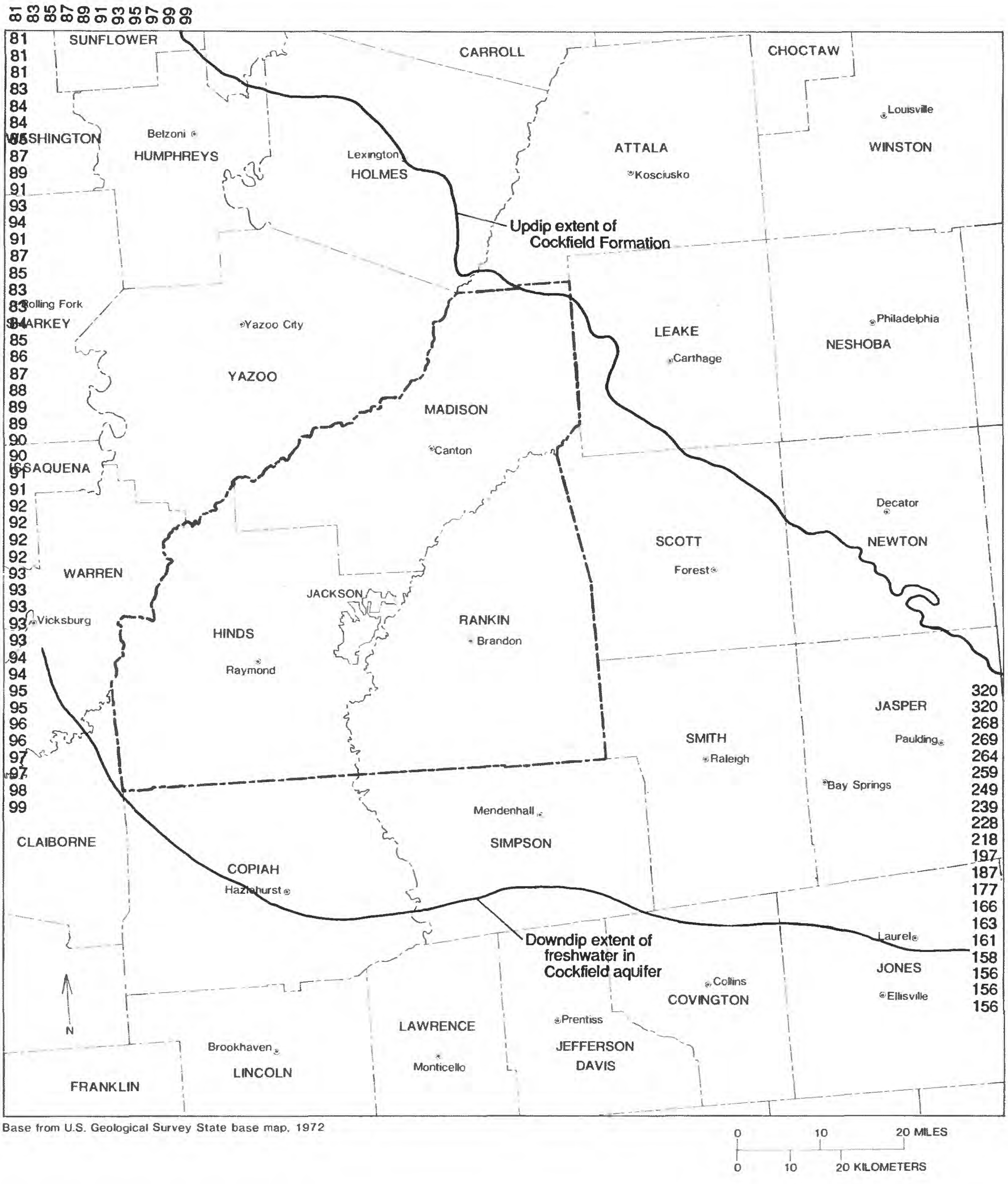


Figure 28.--Specified heads (in feet above sea level) for 1990 in the Cockfield aquifer at the lateral head-dependent flux boundary.

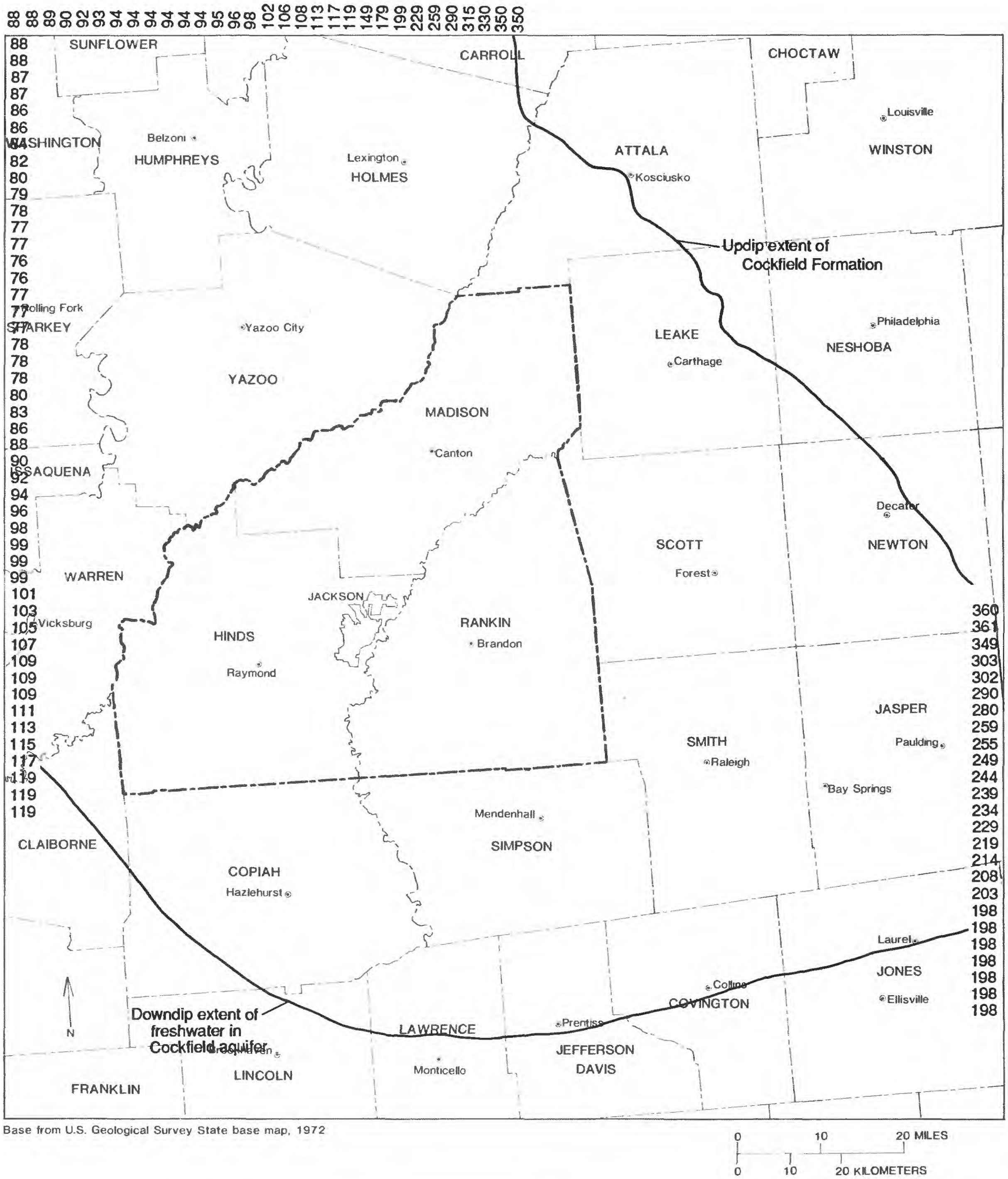
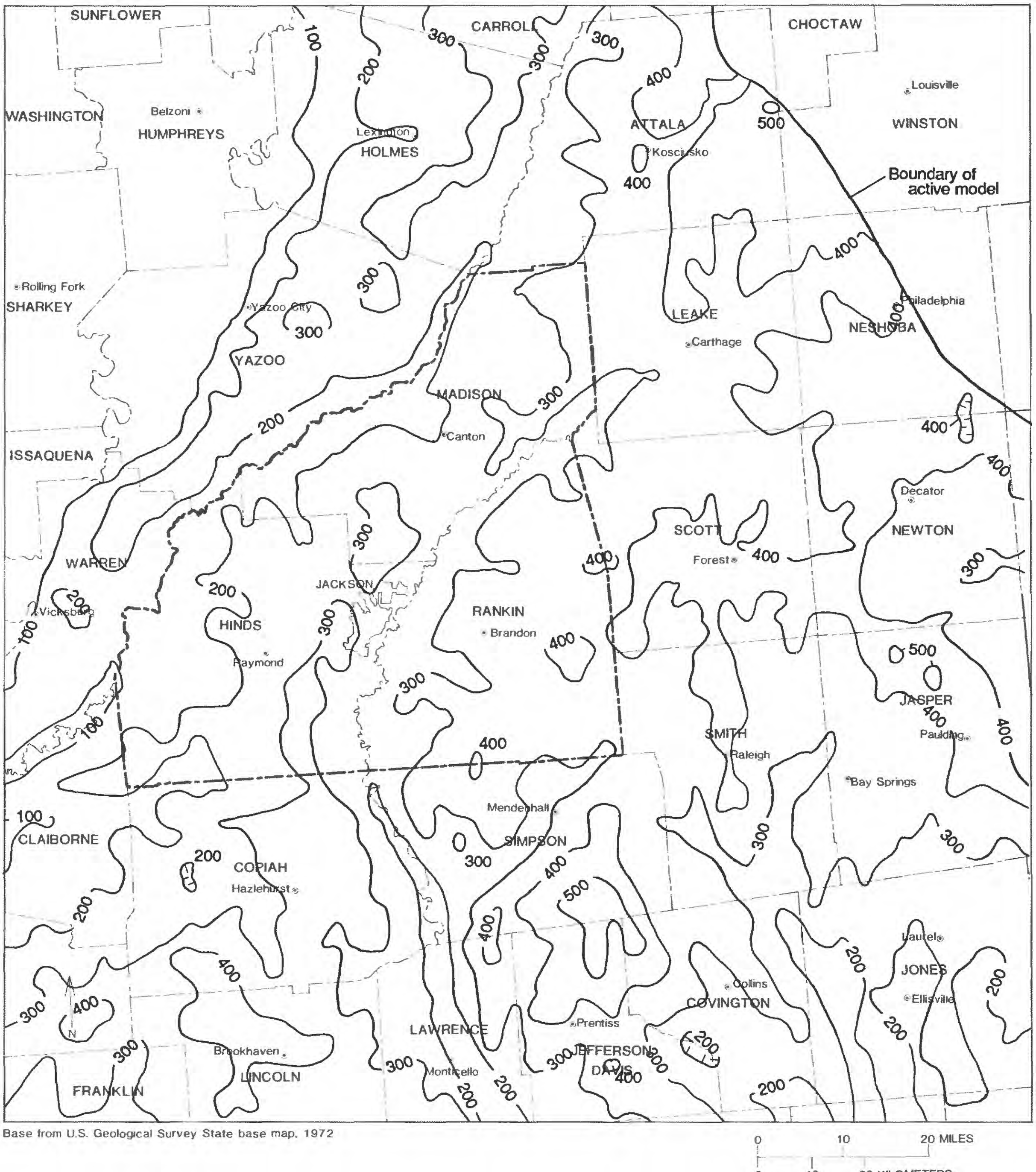


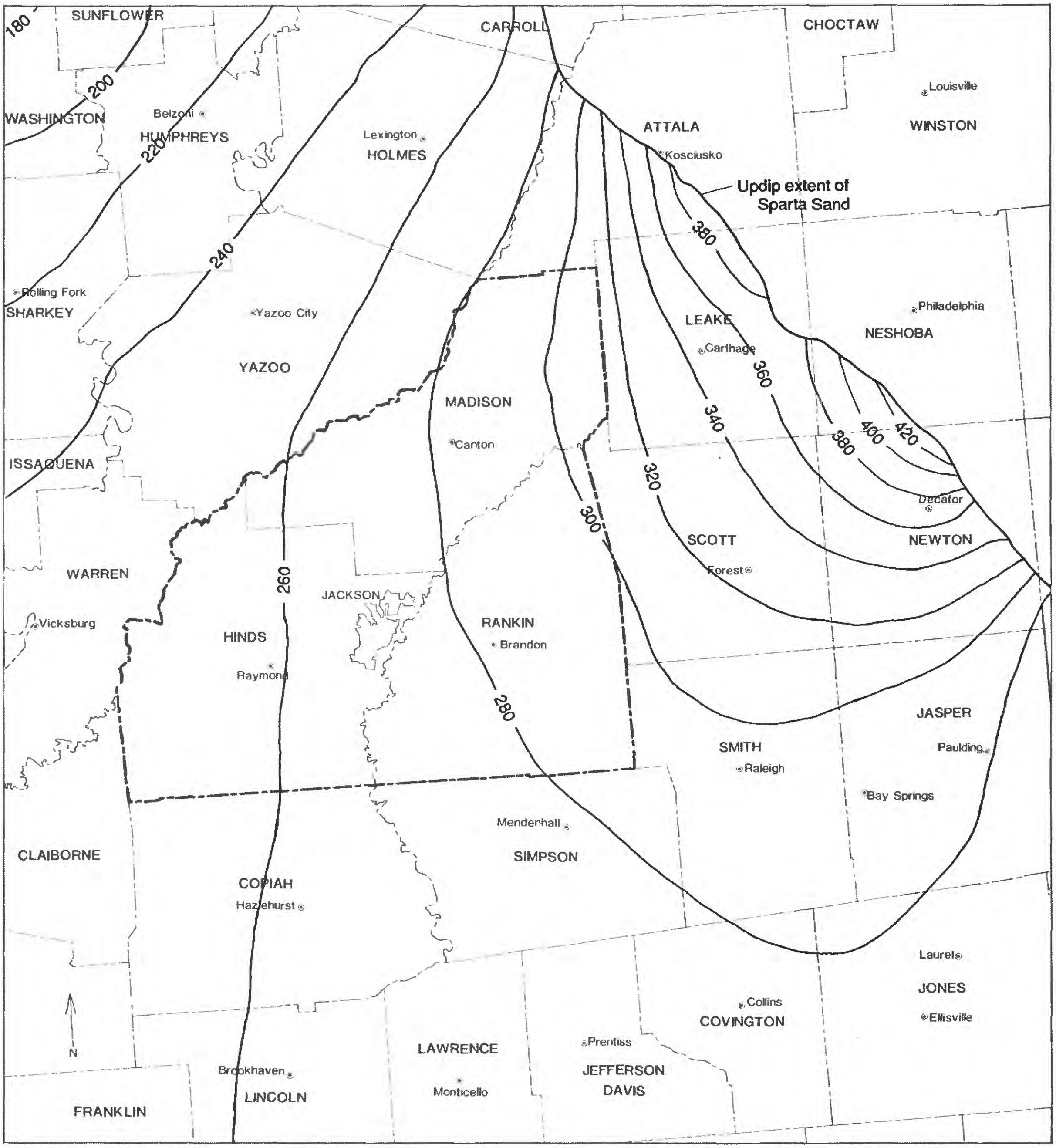
Figure 29.--Specified heads (in feet above sea level) for 1990 in the Sparta aquifer at the lateral head-dependent flux boundary.



EXPLANATION

—— 100 —— **POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate a depression. Interval 100 feet. Datum is sea level**

Figure 30.--Water-table altitudes used for the upper boundary in the model area.



Base from U.S. Geological Survey State base map, 1972

EXPLANATION

— 300 — **POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Interval 20 feet. Datum is sea level**

Figure 31.--Simulated predevelopment potentiometric surface of the lower boundary in the model area.

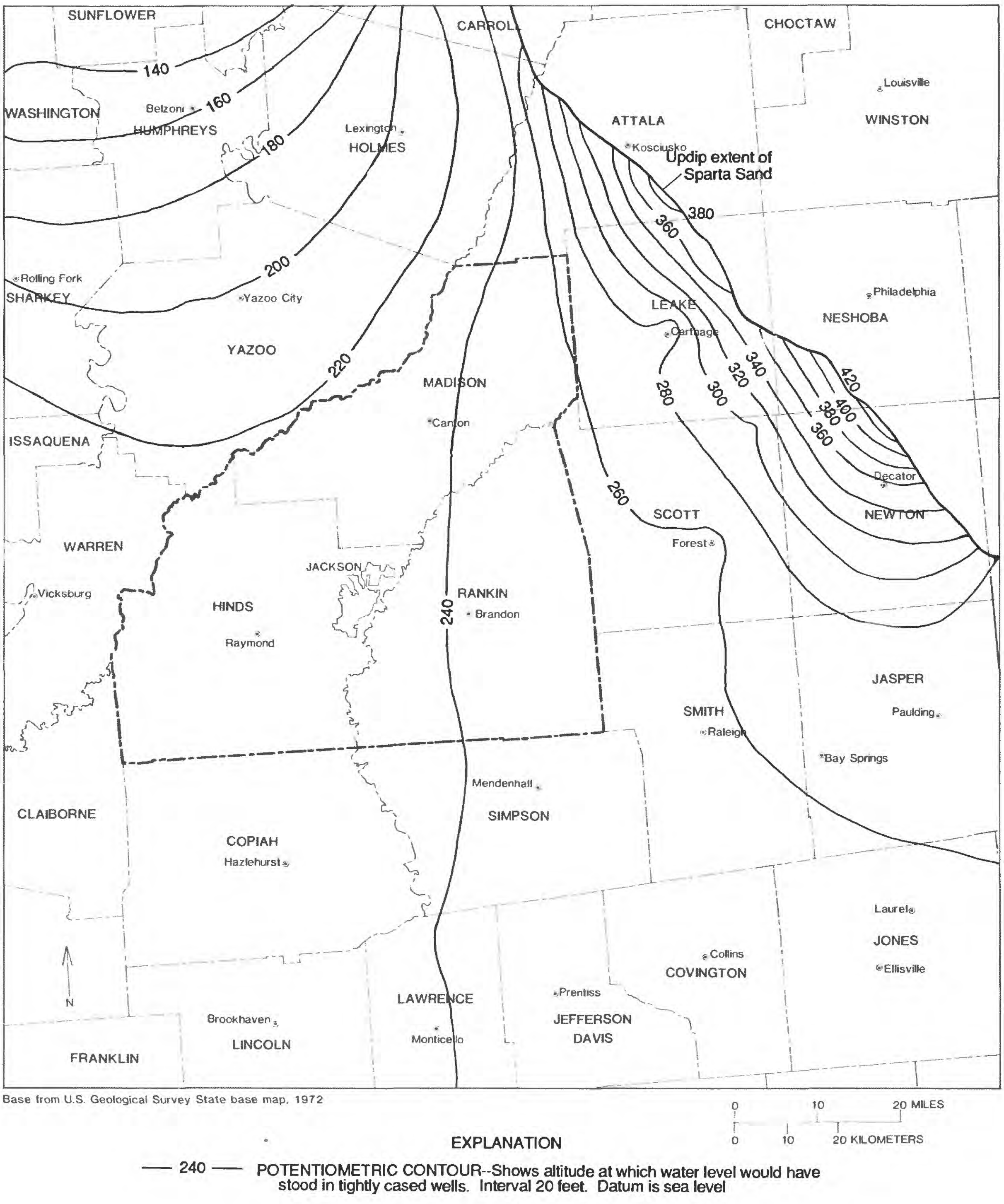


Figure 32.--Simulated 1990 potentiometric surface of the lower boundary in the model area.

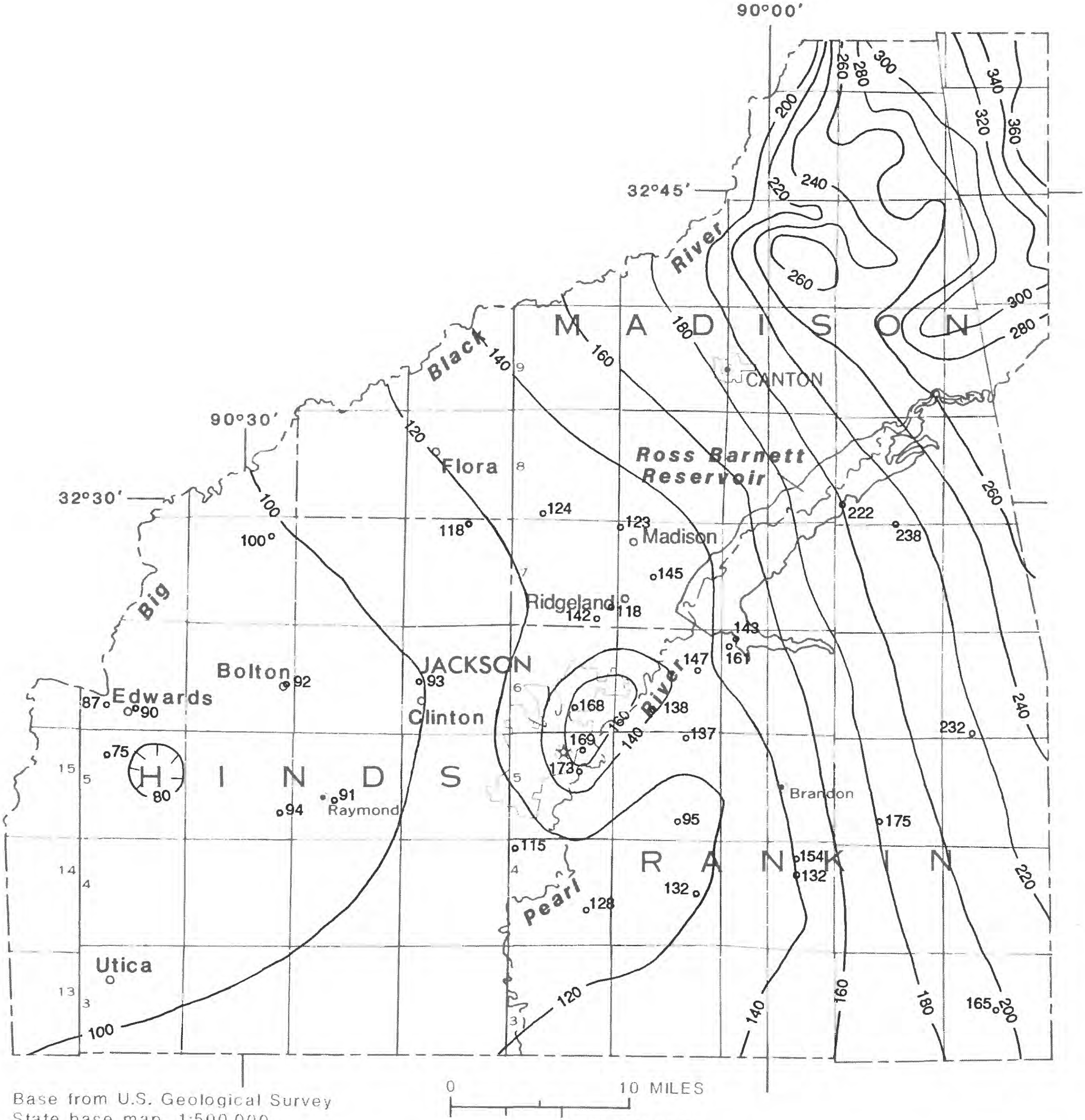
predevelopment simulation were compared to historical water-level measurements and simulated flow budgets were analyzed to verify that the model response was reasonable considering climate, hydrologic setting of the area, and hydrogeologic characteristics of the two aquifers.

Initial simulations of the Cockfield and Sparta aquifers were made under stressed conditions for nine pumping periods from 1920 through 1990. The first pumping period was 20 years, the next two were 10 years each, and the last six were 5 years each. Flow characteristics were evaluated at the end of each stress period, and model-generated heads were compared with measured water levels and hydrographs of long-term observation wells. Transient calibration was accomplished using the last three stress periods and was based on water-level measurements used to construct potentiometric maps of the Cockfield and Sparta aquifers by Wasson (1981a, 1981b), Darden (1986, 1987) and D.E. Burt (U.S. Geological Survey, written commun., 1992). The root-mean-square error of model-simulated heads from measured water levels for the last three stress periods (1975-90) for wells located in the three-county area and in the model area is shown in table 2. The simulated head error for both aquifers for stress period nine (1985-90) was between 12 and 13 feet. The simulated 1990 potentiometric surface and measured 1989 water levels for the two aquifers are shown in figures 33 and 34. Historical water-level measurements and the simulated predevelopment potentiometric surfaces of the Cockfield and Sparta aquifers are shown in figures 35 and 36. The historical measurements represent water levels from 1848-1935, but the water levels should be a reasonable approximation of potentiometric surfaces of the aquifers in the study area before heavy pumping.

Table 2.--Root-mean-square error of simulated head in the Cockfield and Sparta aquifers

	3-County area		Model area	
	Number of water-level measurements	Root-mean-square error of simulation, in feet	Number of water-level measurements	Root-mean-square error of simulation, in feet
		1980		
Cockfield	53	17.0	90	18.8
Sparta	37	13.9	107	15.0
		1985		
Cockfield	34	13.6	54	16.6
Sparta	33	11.8	87	12.0
		1990		
Cockfield	23	12.6	33	12.5
Sparta	19	12.3	53	12.7

Long-term hydrographs from six observation wells representing measured water levels in the Cockfield and Sparta aquifers and simulated water levels at the observation well locations are shown in figures 37 and 38. The difference between measured and simulated water levels is least after 1970. Before 1970, simulated water levels were consistently higher than measured water levels. The lack of pumpage information before 1970 and the small water-level declines generated by the model indicate that pumping rates may be underestimated.

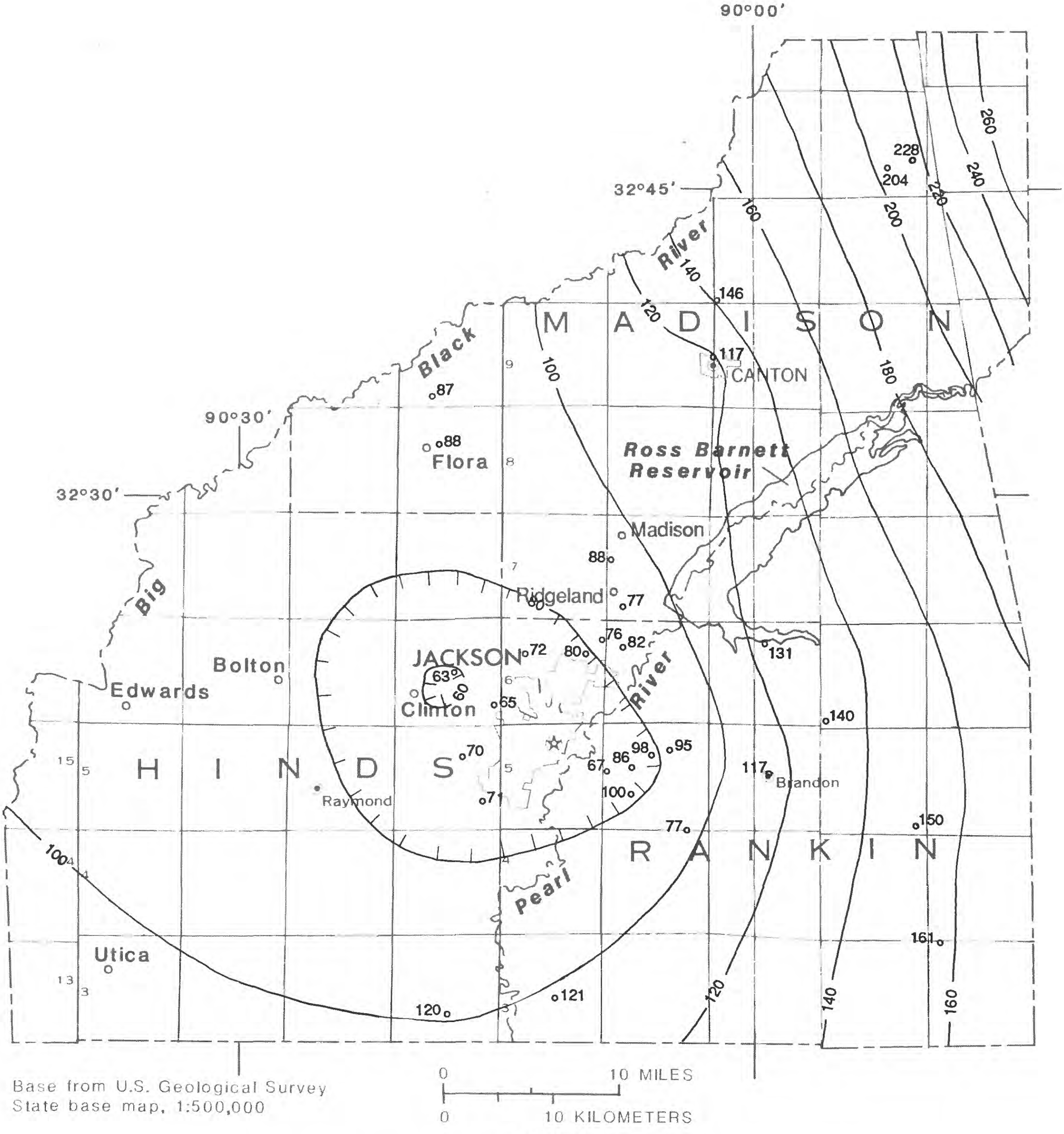


EXPLANATION

— 100 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate a depression. Interval 20 feet. Datum is sea level

o100 LOCATION OF WELL AND MEASURED WATER LEVEL, IN FEET ABOVE SEA LEVEL

Figure 33.--Simulated 1990 potentiometric surface and measured 1989 water level representing the Cockfield aquifer in the three-county study area.

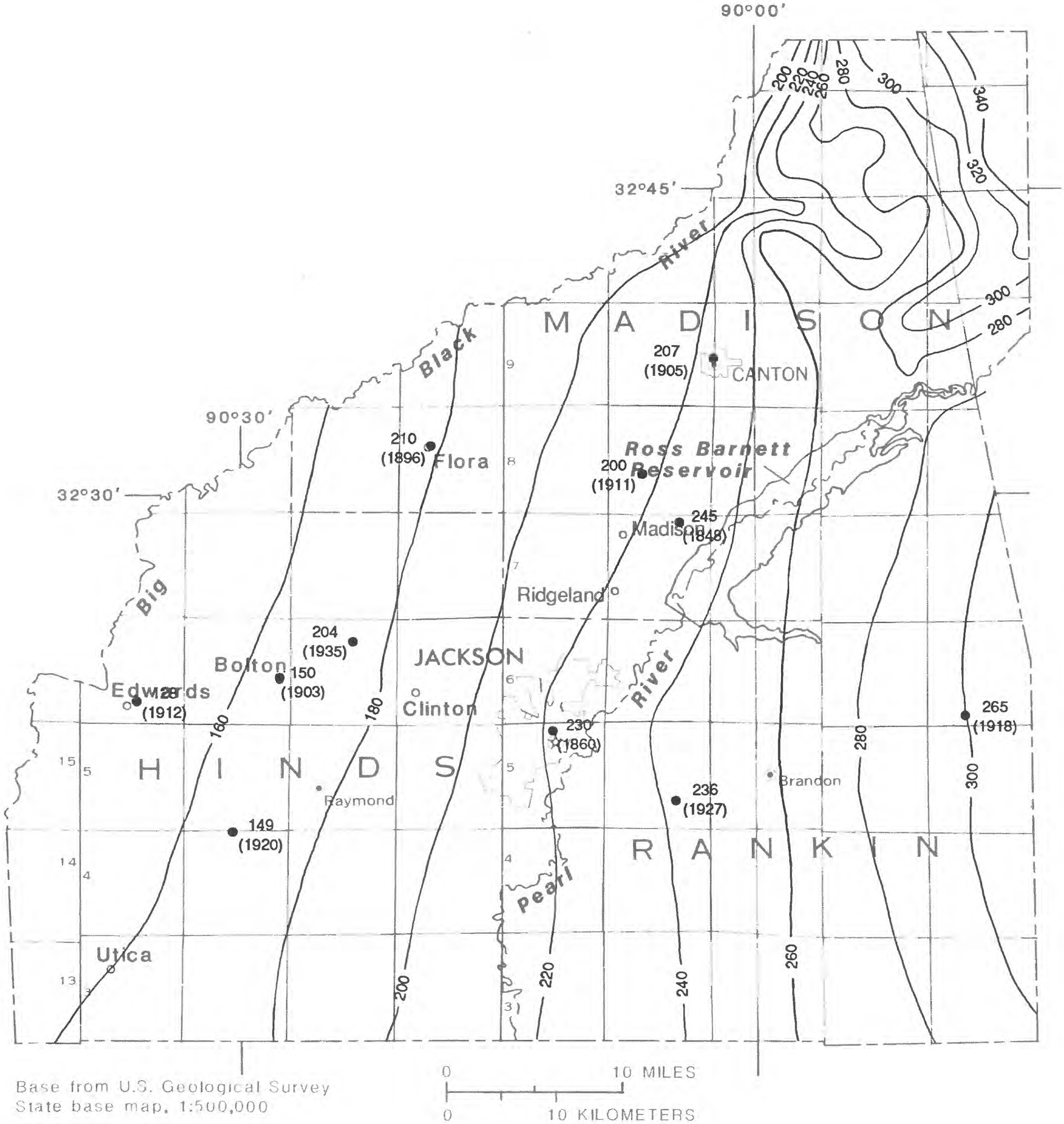


EXPLANATION

—— 100 —— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate a depression. Interval 20 feet. Datum is sea level

o88 LOCATION OF WELL AND MEASURED WATER LEVEL, IN FEET ABOVE SEA LEVEL

Figure 34.--Simulated 1990 potentiometric surface and measured 1989 water levels representing the Sparta aquifer in the three-county study area.



EXPLANATION

— 200 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Interval 20 feet. Datum is sea level

● 149 (1920) LOCATION OF WELL, WATER LEVEL IN FEET ABOVE SEA LEVEL, AND YEAR OF MEASUREMENT

Figure 35.--Simulated predevelopment potentiometric surface of the Cockfield aquifer and selected water-level measurements in the three-county study area.

EXPLANATION

—— 200 —— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate a depression. Interval 20 feet. Datum is sea level

215 ● (1901) LOCATION OF WELL, WATER LEVEL IN FEET ABOVE SEA LEVEL, AND YEAR OF MEASUREMENT

Figure 36.--Simulated predevelopment potentiometric surface of the Sparta aquifer and selected water-level measurements in the three-county study area.

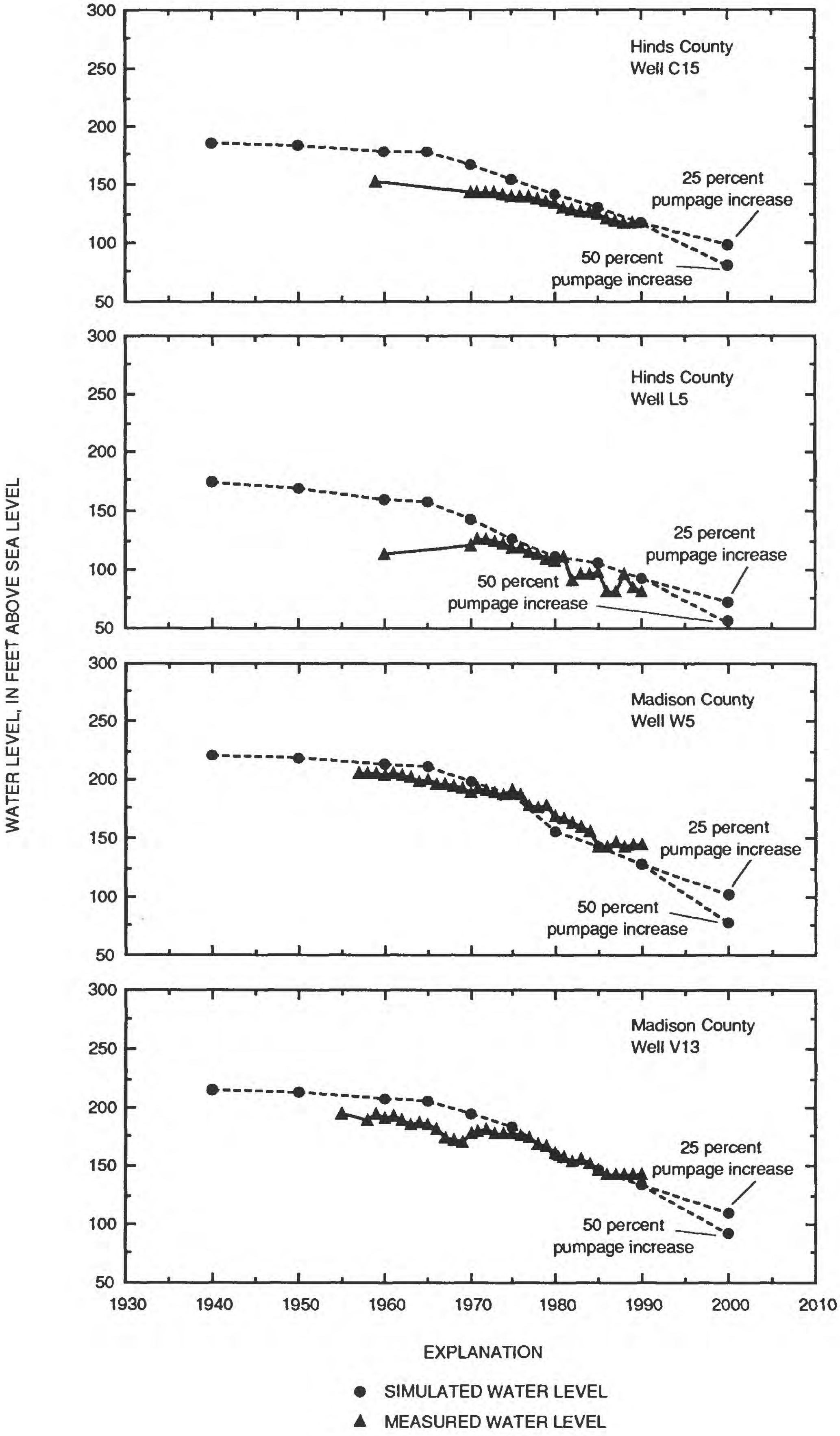


Figure 37.--Simulated and measured water levels in selected observation wells completed in the Cockfield aquifer.

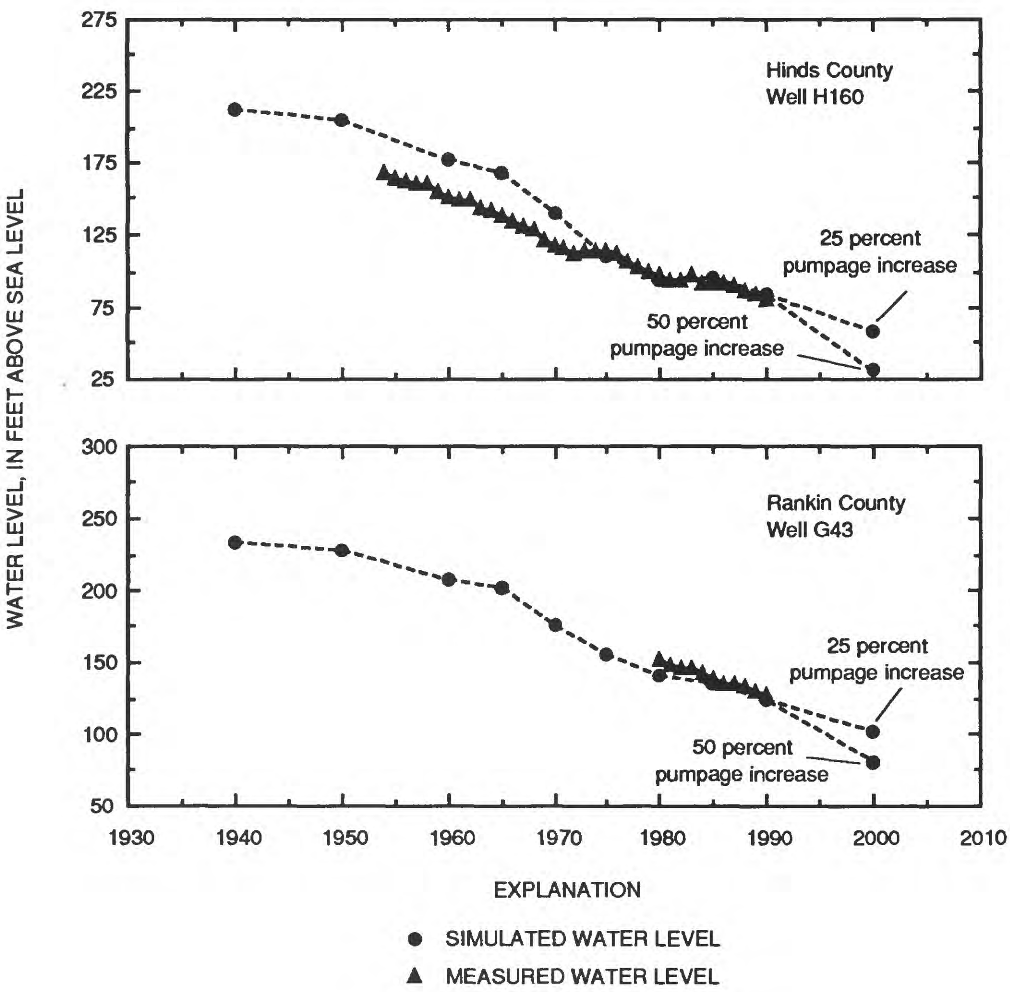
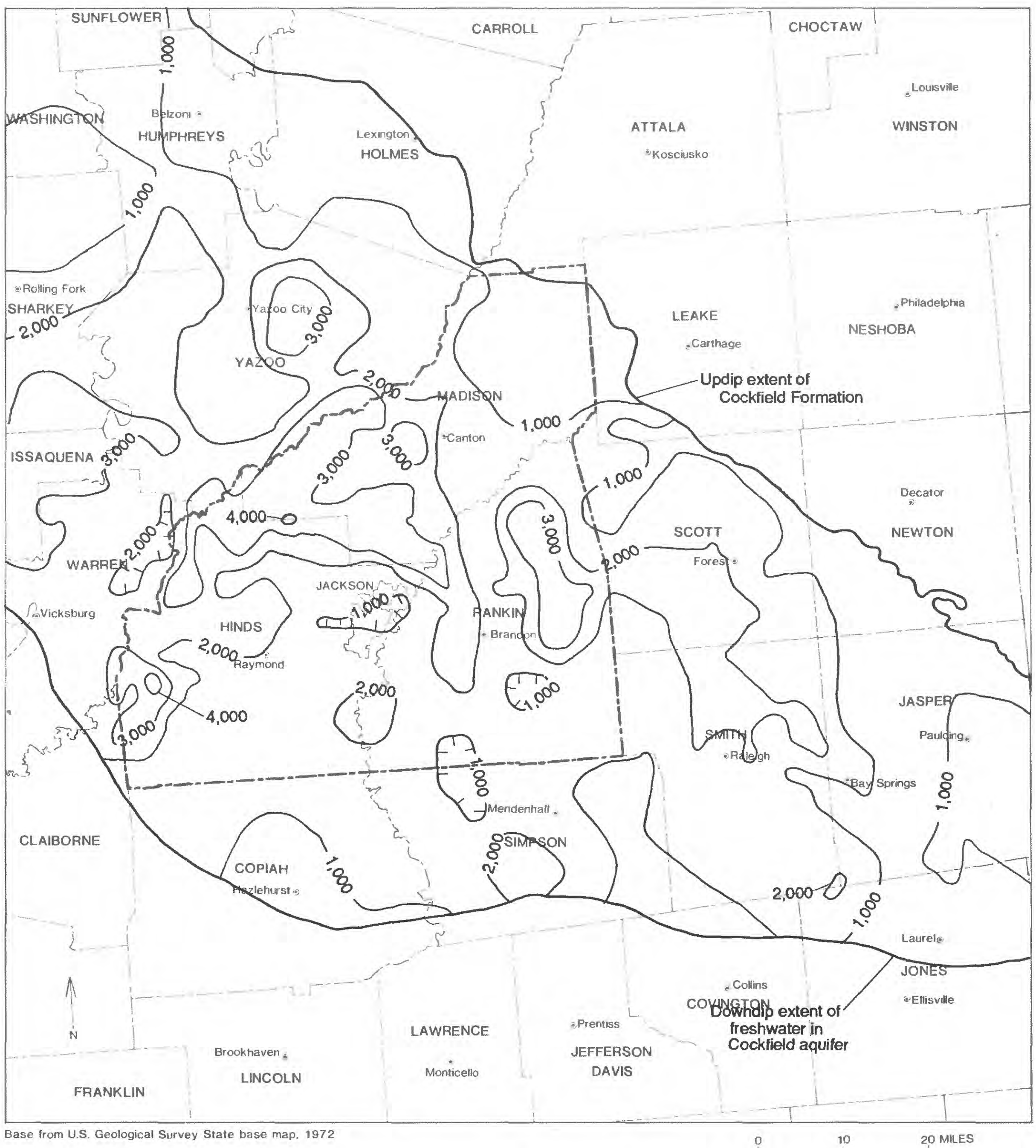


Figure 38.--Simulated and measured water levels in selected observation wells completed in the Sparta aquifer.

Model Hydraulic Properties

The hydraulic properties that determine the transmissive, storage, leakage, and recharge capabilities of the Cockfield and Sparta aquifers were tested through a range of values to generate the best-fit head distribution for each aquifer. The tested values for a given property were constrained to within a range generally considered reasonable. The capacity of the aquifers to transmit water from recharge areas to discharge areas, either naturally or as a result of pumping at wells, is determined to a large degree by aquifer transmissivity.

The areal variation of simulated transmissivity for the Cockfield aquifer in the calibrated model is shown in figure 39. The transmissivities used in the model were computed by multiplying total sand thickness times horizontal hydraulic conductivity. The transmissivity values used in the model represent a 4-square-mile area with a uniform hydraulic conductivity for the entire sand thickness. Water wells are selectively completed in sand beds that produce the most water, and as a result, the hydraulic conductivity values computed from aquifer tests generally are larger than the values used in the model. In the three-county area, the transmissivity of the Cockfield aquifer is greatest in southwestern Hinds and Madison Counties. In these two areas, the transmissivity for the calibrated model generally ranges from 3,000 to 4,000 feet squared per day. In west-central Rankin County, the transmissivity is greater than 3,000 feet squared per day. The Cockfield aquifer transmissivity is less than 1,000 feet squared per day in the outcrop area in northeastern Madison County, over the Jackson Dome in Hinds County, and in two small areas in southern Rankin County. Throughout most of the three-county area, the simulated transmissivity of the Cockfield aquifer is between 1,000 and 3,000 feet squared per day.



EXPLANATION

—— 1,000 —— LINE OF EQUAL TRANSMISSIVITY--Hachures indicate decrease in transmissivity. Interval 1,000 feet squared per day

Figure 39.--Simulated transmissivity of the Cockfield aquifer in the model area.

The simulated transmissivity of the Sparta aquifer in the calibrated model in the three-county area is about three to five times the transmissivity of the Cockfield aquifer (fig. 40). The greater transmissivity of the Sparta aquifer is attributed not only to larger sand thickness, but also to greater horizontal hydraulic conductivity. The simulated transmissivity is greatest for the three-county area in southwestern Madison and northwestern Hinds Counties. In both these areas transmissivity of the Sparta aquifer in the calibrated model is greater than 14,000 feet squared per day. In contrast, the smallest simulated transmissivities used in the calibrated model are in northeastern Madison, southern Hinds, and west-central Rankin Counties. In these areas, transmissivities in the calibrated model generally range from 4,000 to 6,000 feet squared per day. Throughout most of the study area, the simulated transmissivities of the Sparta aquifer in the calibrated model ranged from 6,000 to 10,000 feet squared per day.

A uniform storage coefficient of 8×10^{-5} was used in the calibrated model in the confined part of the Cockfield aquifer. A storage coefficient value of 3×10^{-4} was used in the confined part of the Sparta aquifer. In the outcrop areas, a specific yield of 0.15 was used in the calibrated model to simulate storage in the unconfined parts of both aquifers.

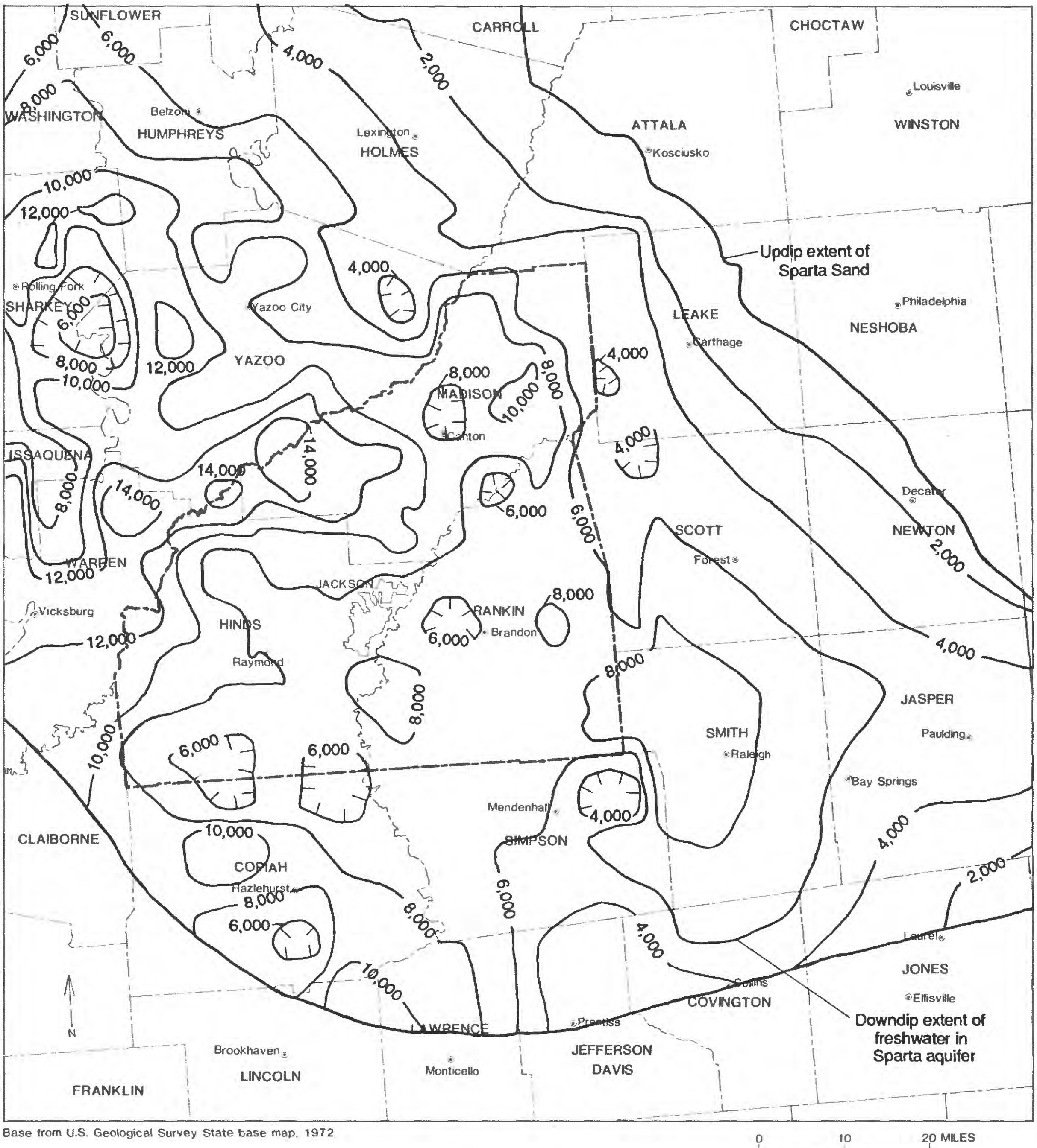
Recharge and discharge through the upper head-dependent flux boundary are determined not only by the magnitude of the head difference between the water table and potentiometric surface of the Cockfield or Sparta aquifer, but also by the thickness and vertical conductivity of the deposits between the water table and the underlying aquifer. No field determinations of vertical hydraulic conductivity for the confining units were available. During the calibration process, the vertical conductivity values were varied within the range of values given by Heath (1983) for similar materials and lithologies. Vertical hydraulic conductivity in the calibrated model for the upper boundary ranges from 1×10^{-2} feet per day in aquifer outcrop areas and subcrop areas of the Mississippi River alluvial aquifer to 1×10^{-6} feet per day in areas where the Cockfield is overlain by the Yazoo Clay. Leakance (vertical hydraulic conductivity divided by clay thickness) values, which determine vertical flow, for the upper head-dependent boundary for the calibrated model are shown in figure 41.

The Cook Mountain Formation separates the Cockfield and Sparta aquifers hydraulically and lithologically. The clay beds and other less conductive materials in the Cook Mountain Formation impede vertical leakage between the two aquifers. The resistance to vertical flow between the Cockfield and Sparta aquifers was estimated using a vertical hydraulic conductivity of 5×10^{-6} feet per day. The vertical conductance varied areally with the sum of the total clay thickness in the Cook Mountain Formation and half of the sum of the total clay thicknesses in Cockfield and Sparta aquifers. The ranges of leakance used in the calibrated model between the two aquifers are shown in figure 42.

Vertical leakage between the Sparta aquifer and underlying water-bearing units is controlled by the lower head-dependent flux boundary. The lower model boundary simulates flow through the Zilpha Clay confining unit between the Sparta aquifer and underlying water-bearing units. The vertical conductivity of the Zilpha Clay used in the calibrated model is 1×10^{-6} feet per day. Leakance values for the lower boundary for the calibrated model are shown in figure 43.

Model Sensitivity

The sensitivity of the model response to a range of hydraulic values is determined largely by the conceptual representation in the model of the aquifer boundary conditions and hydrogeologic framework. Because aquifer water levels are the best known aquifer characteristic, they are used as the basis for assessing the sensitivity of the model to a particular range of hydraulic parameter values. The degree to which simulated heads differ from the calibrated simulation model heads while using multiples of the parameter values used in the calibrated model is one measure of model sensitivity.



EXPLANATION

—— 2,000 —— LINE OF EQUAL TRANSMISSIVITY--Hachures indicate decrease in transmissivity. Interval 2,000 feet squared per day

Figure 40.--Simulated transmissivity of the Sparta aquifer in the model area.

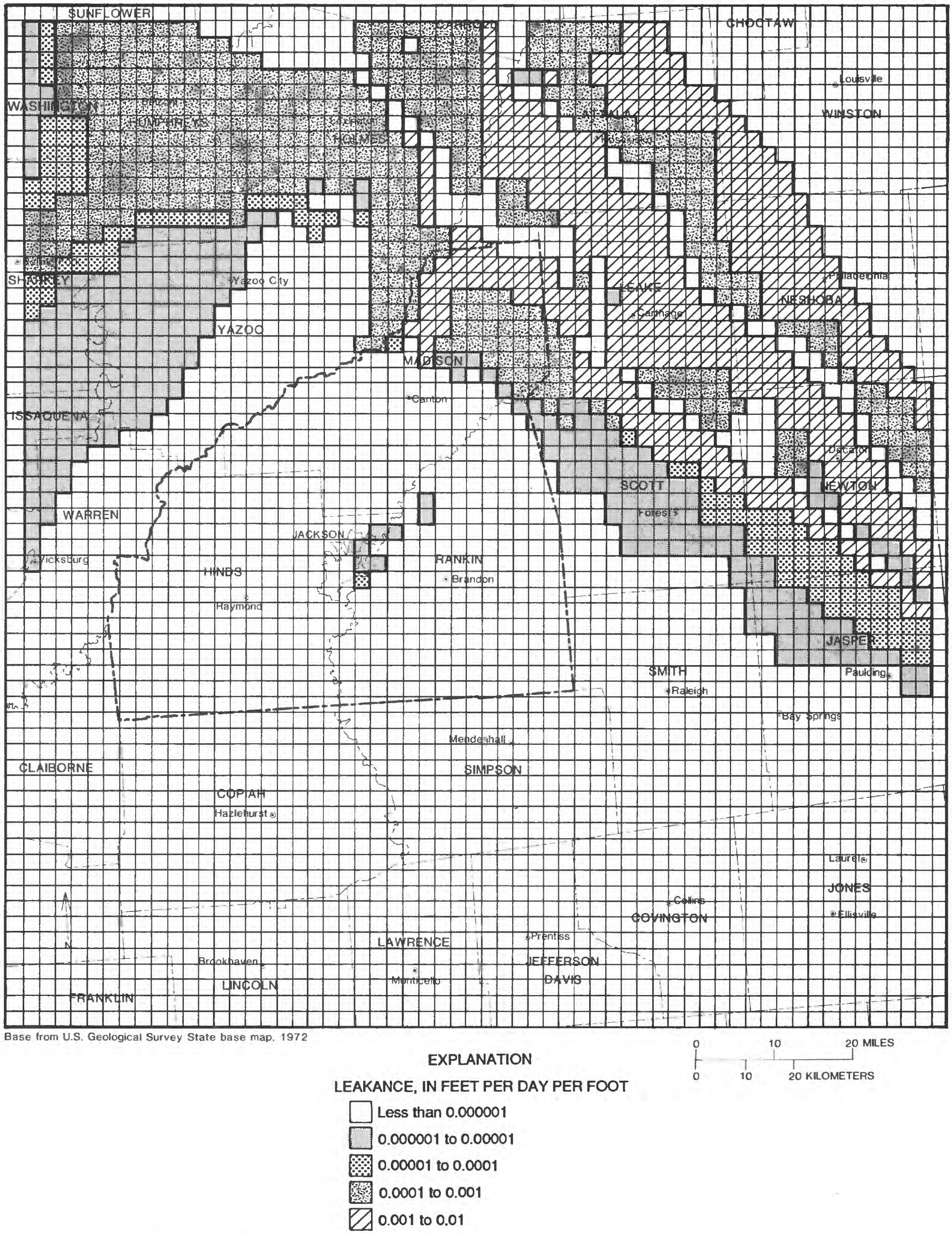


Figure 41.--Leakance values (vertical conductivity divided by clay thickness) for upper head-dependent flux boundary of the model.

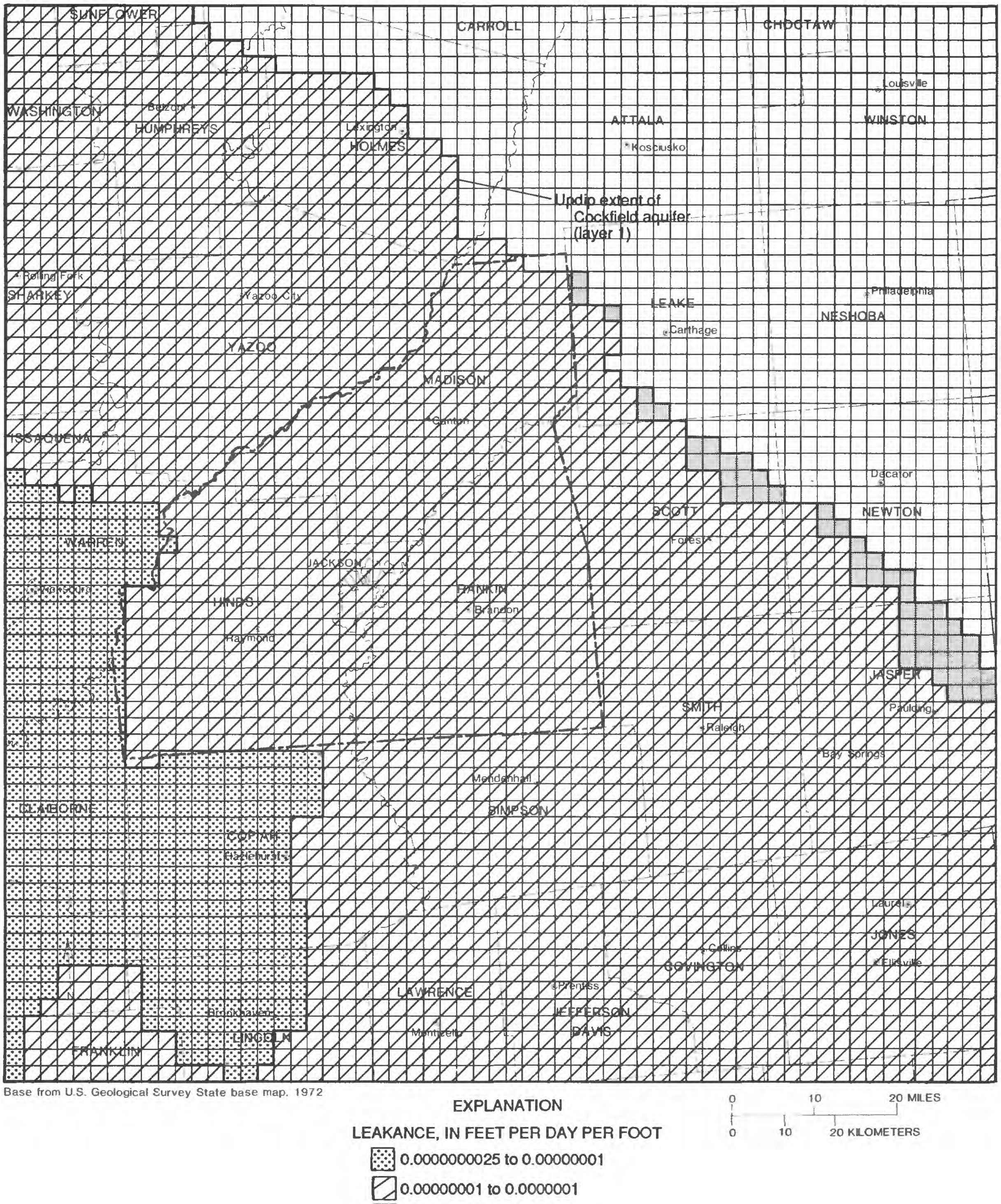


Figure 42.--Leakance values (vertical conductivity divided by clay thickness) representing hydraulic connection between the Cockfield (model layer 1) and Sparta (model layer 2) aquifers.

EXPLANATION

LEAKANCE, IN FEET PER DAY PER FOOT

- Less than 0.0000000025
- 0.0000000025 to 0.00000001
- 0.00000001 to 0.0000001
- 0.0000001 to 0.000001

Figure 43.--Leakance values (vertical conductivity divided by clay thickness) for lower head-dependent flux boundary of the model.

To illustrate the sensitivity of the model generated heads to changes in known and estimated hydraulic values, pumpage and transmissivity values for the Cockfield and Sparta aquifers were varied from 0.1 to 2.0 times the values used in the calibrated model (fig. 44). The root-mean square error of simulated heads increased much greater when transmissivity was decreased from calibrated values than when transmissivity was increased. The model's response to equal increases and decreases in pumpage was about the same, but the model was more sensitive to an increase in pumpage than to an increase in transmissivity. During the calibration process, error analysis of heads (water levels) indicated that the model was least sensitive to variations in storage coefficients and most sensitive to changes in vertical hydraulic conductivity of the confining units. Arthur and Taylor (1990) concluded that the trough shape of the Mississippi embayment, combined with the natural upward regional discharge near the axis of the embayment in all the confined aquifers, may contribute to the increased sensitivity of the model to vertical hydraulic conductivity.

Limitations of Model Application

The proper use of any model is limited by the cell size, the accuracy of the calibration, the assumptions made in the model construction, and the sensitivity of the model to selected parameters. The model developed and calibrated in this study may be used for analyzing ground-water flow and for evaluating the effects of withdrawals form the Cockfield and Sparta aquifers on an areal scale (uniform hydraulic parameters over a 4-square-mile cell in the three-county area). The cell size limits the model's ability to provide detailed results of site-specific withdrawals and to predict heads in individual wells or well fields. Well fields are usually smaller, and the area of influence of individual pumping wells are usually much smaller, than the area of a model cell. The head calculated by the model represents the head at the node and is a good approximation of the average head for the area indicated by the cell, but may not be a good approximation of the water level in a particular well or small well field. Thus, the model limitations need to be considered when using simulation results to formulate water-supply decision.

GROUND-WATER FLOW ANALYSIS

To evaluate the current flow conditions in the aquifers, the following sequence of steps was taken. Results of simulations made using the calibrated model for the stress period representing the 1990 conditions were analyzed in detail. Next, predevelopment (no pumpage) steady-state conditions were simulated in the calibrated model, the results analyzed, and the heads were compared with historical water-level measurements for the aquifers. Finally, to test the calibrated model responses to increased stresses, two hypothetical transient scenarios were simulated, both projecting conditions to 2000. One scenario had a uniform 25-percent pumpage increase from 1990 rates in both aquifers for the period 1990-2000, and the other scenario had a uniform 50-percent pumpage increase for that period.

The ground-water flow analyses using calibrated model simulation results for simulations representing predevelopment conditions, 1990 conditions, and the two hypothetical scenarios projecting conditions to 2000, are presented in the following section. The analysis of flow for each condition consists of discussions concerning potentiometric surfaces, recharge and discharge, flow at lateral boundaries, vertical flow between aquifers, and ground-water flow budgets.

Predevelopment Flow Conditions

After transient calibration, the model was modified to represent steady-state, predevelopment conditions (no pumpage) using the hydraulic parameter values from the calibrated transient simulation. The predevelopment simulation results could not be verified precisely because historical water-level information for the two aquifers is sparse and the available information mostly represents conditions after initial development of the two aquifers. As a result, the predevelopment model results are subjective and illustrate only general trends and relative comparisons with stressed conditions.

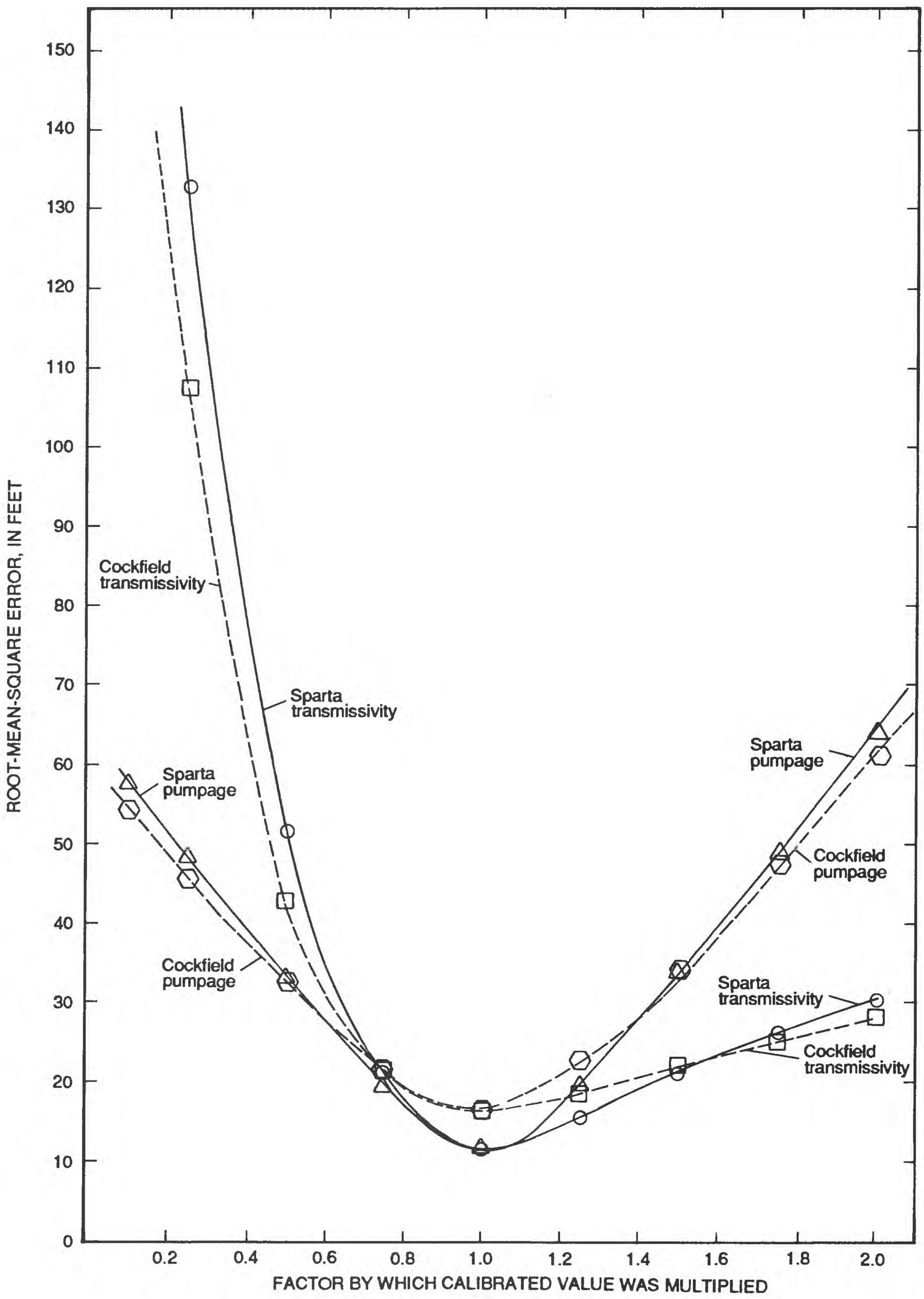


Figure 44.--Model sensitivity to changes in aquifer transmissivity and pumpage.

Potentiometric Surfaces

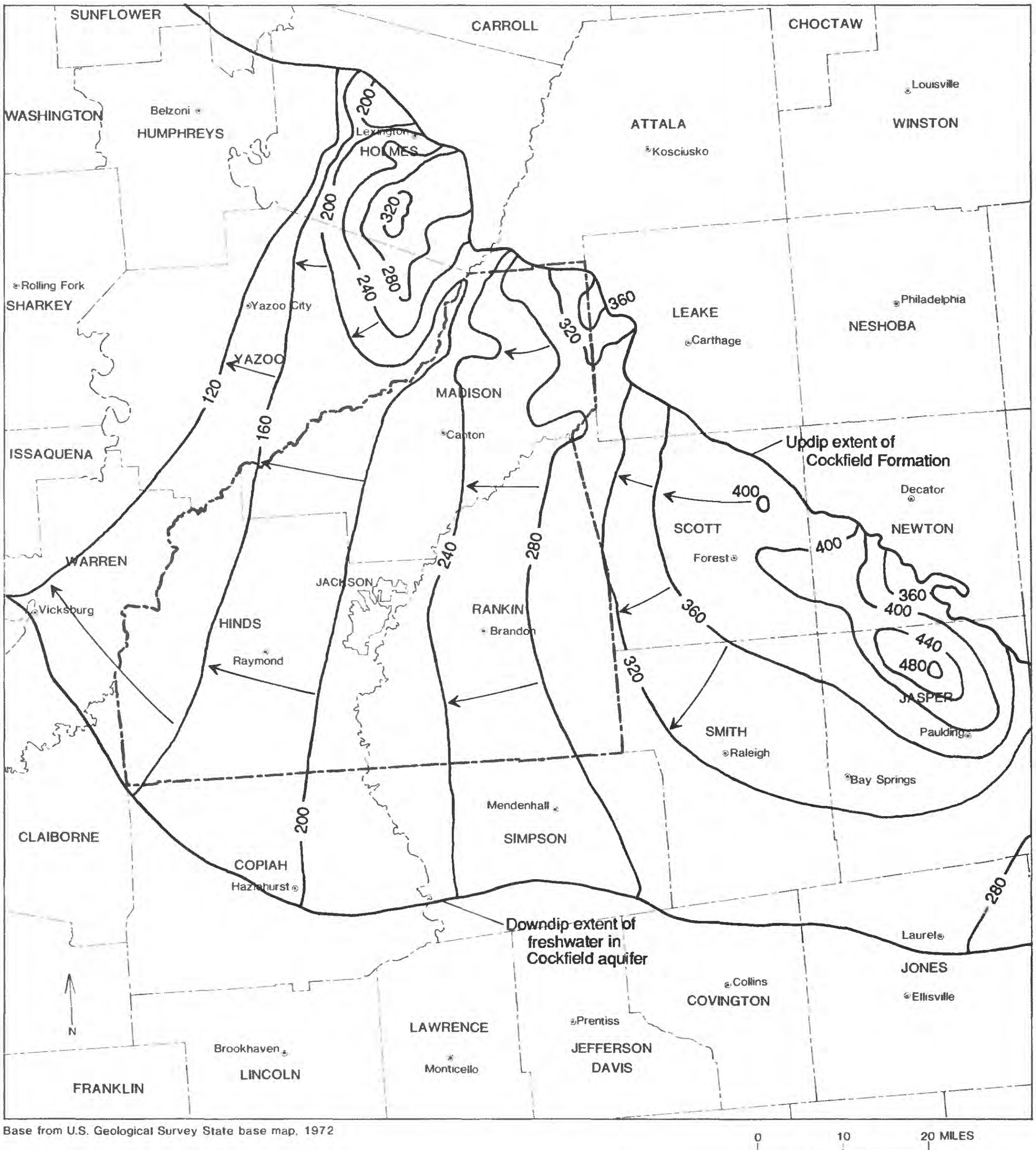
The potentiometric surface of the Cockfield aquifer representing water levels generated by the steady-state, no-pumpage model simulation indicates that predevelopment water levels are highest in southwestern Newton-northern Jasper Counties in the aquifer outcrop area. In this area, simulated predevelopment water levels are more than 400 feet above sea level (fig. 45). The potentiometric surface slopes to the south-southwest in the eastern part of the model area and to the west-northwest in the central and western part of the model area. In the three-county area, the altitude of the predevelopment potentiometric surface of the Cockfield decreases westward in the confined part of the aquifer. In the Cockfield outcrop area in northeastern Madison County, the water table represents the predevelopment potentiometric surface of the aquifer. The water table generally parallels land surface in areas of little relief, and in hilly areas the water table reflects a subdued image of the topography. In northeastern Madison County, the water-table altitude decreases westward toward the Big Black River. The regional predevelopment flow in the Cockfield aquifer is west-northwest toward the Mississippi Alluvial Plain. The Cockfield subcrop area of the Mississippi River alluvial aquifer is the regional predevelopment discharge area for the Cockfield aquifer in Mississippi.

In the Jackson area, simulated predevelopment water levels in the Cockfield aquifer generally ranged from 200 to 240 feet above sea level. Hilgard (1860, p. 190) reported that in a well bored at the State Penitentiary at Jackson, the water level rose to within 70 feet of land surface from sand 111 feet below land surface. The sand referenced is part of the Cockfield aquifer, and the water level referenced would be at an altitude of about 230 feet above sea level (fig. 35), which is slightly lower than the stream bed of the Pearl River in the Jackson area. Other water levels shown on the simulated predevelopment potentiometric surface map of the Cockfield aquifer are from Stephenson and others (1928) and Harvey and others (1961).

In the three-county area, simulated predevelopment water levels in the confined part of the Cockfield aquifer generally range from 300 feet above sea level at the eastern edge of Rankin County to less than 160 feet above sea level along the Big Black River in western Hinds County. The east-to-west gradient of the predevelopment potentiometric surface is about 3.3 feet per mile.

The drawdown available for a confined aquifer before the aquifer would begin to be dewatered, is the distance from the potentiometric surface of the aquifer to the top of the aquifer. The simulated predevelopment water levels in the Cockfield aquifer are slightly below the top of the formation in and near the formation outcrop area but more than 900 feet above the top of the formation in southwestern Hinds County (fig. 46). In the Jackson area, over the crest of the Jackson Dome, the simulated predevelopment Cockfield aquifer water level is at or below the top of the Cockfield Formation, but above the top of the sand beds of the aquifer, in about a 25-square-mile area. The distance between the potentiometric surface and the top of the Cockfield Formation increases with distance away from the crest of the Jackson Dome, especially westward, where, in a distance of about 8 miles the predevelopment potentiometric surface is about 700 feet above the top of the Cockfield Formation (fig. 46).

Predevelopment water levels in the Sparta aquifer generated from the steady-state, no-pumping model simulation are highest in northwestern Newton County in the aquifer outcrop area (fig. 47). In this area, water levels are more than 400 feet above sea level. Predevelopment water levels decrease to the south-southwest in the eastern part of the model area and to the west in the central and western part of the model area. The regional direction of simulated predevelopment flow is westward in most of the model area. In the three-county area, the predevelopment potentiometric surface slopes from east to west. The highest simulated water levels in the three-county area are in northeastern Madison County, where water levels are about 280 feet above sea level. The lowest simulated water levels in the Sparta aquifer in the three-county area are in extreme southwestern Hinds County, where water levels are about 160 feet above sea level. In Jackson, Stephenson and

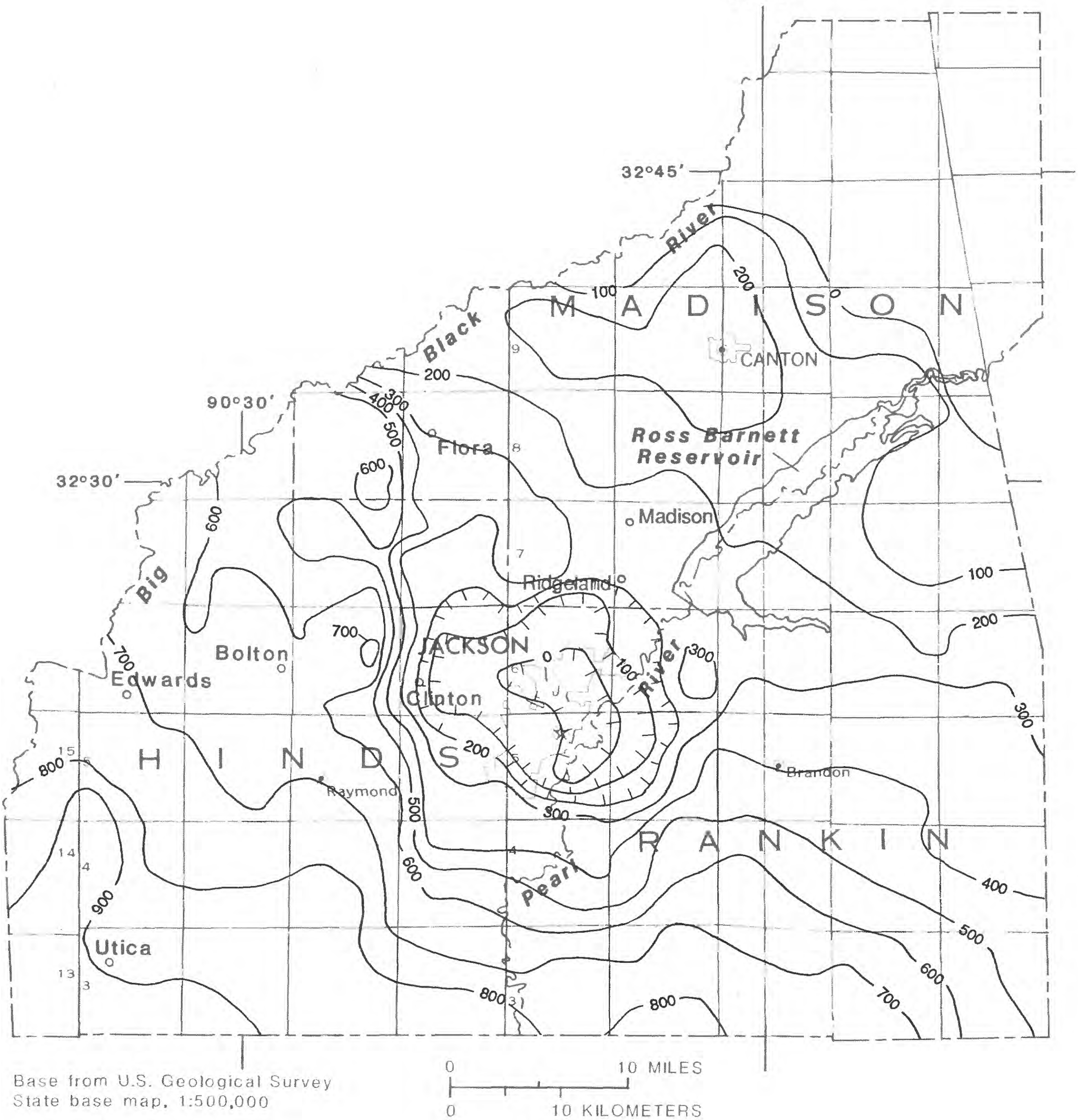


EXPLANATION

— 120 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Interval 40 feet. Datum is sea level

← DIRECTION OF REGIONAL GROUND-WATER FLOW

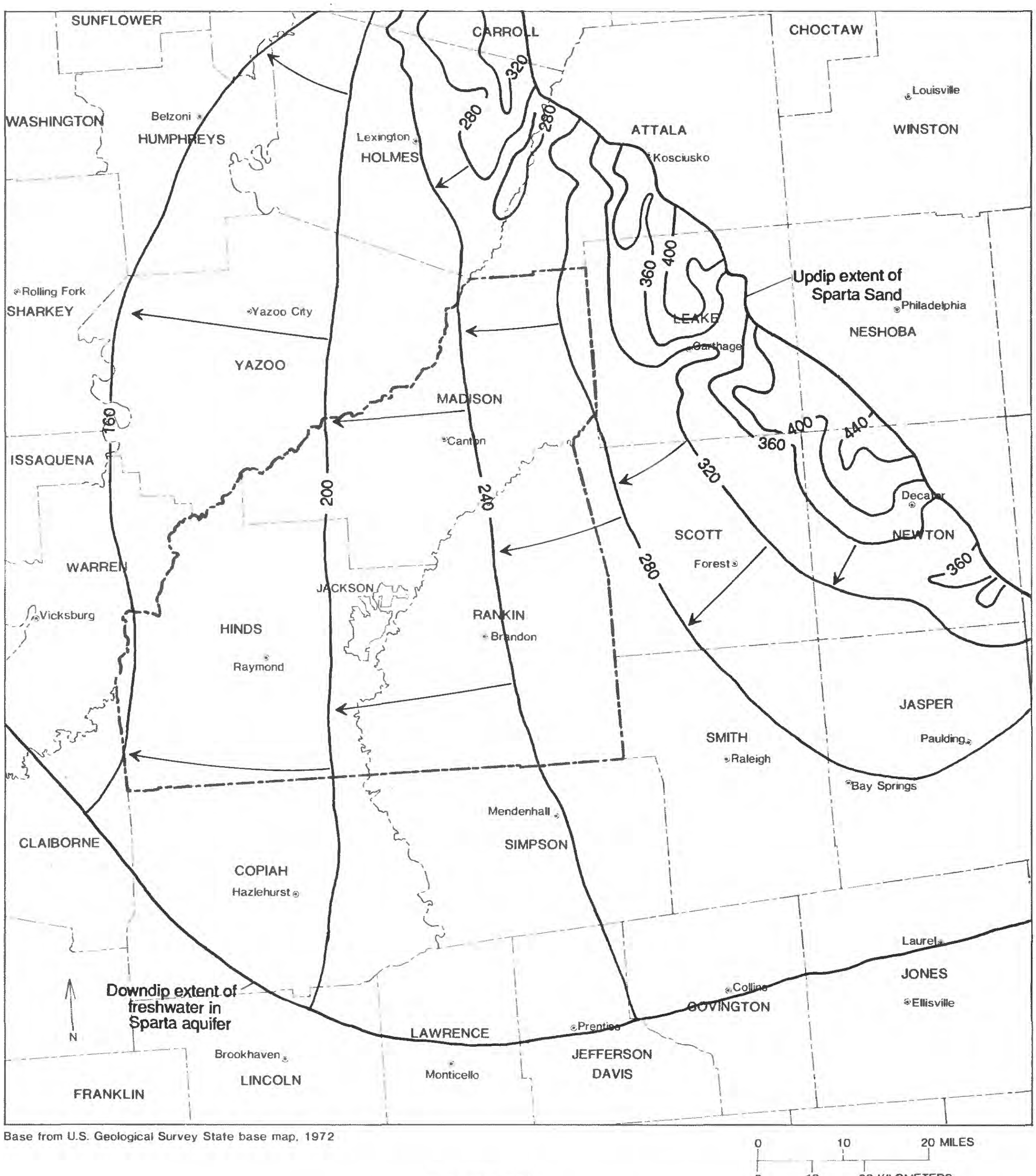
Figure 45.--Simulated predevelopment potentiometric surface of the Cockfield aquifer in the model area.



EXPLANATION

— 100 — LINE OF EQUAL DISTANCE BETWEEN TOP OF COCKFIELD FORMATION AND SIMULATED PREDEVELOPMENT POTENTIOMETRIC SURFACE--Hachures indicate area of lesser distance. Interval 100 feet

Figure 46.--Distance between simulated predevelopment potentiometric surface of the Cockfield aquifer and top of the Cockfield Formation in the three-county study area.



EXPLANATION

—— 200 —— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Interval 40 feet. Datum is sea level

←—— DIRECTION OF REGIONAL GROUND-WATER FLOW

Figure 47.--Simulated predevelopment potentiometric surface of the Sparta aquifer in the model area.

others (1928) and Harvey and others (1961) reported a 1911 water level in the Sparta aquifer of 225 feet above sea level (fig. 36). In the Jackson area, the simulated predevelopment water levels range from 200 to 220 feet above sea level. The simulated predevelopment potentiometric surface of the Sparta aquifer decreases about 1.9 feet per mile from east to west across the three-county area.

The Sparta aquifer predevelopment water levels generally range from 300 feet above the top of the Sparta Sand in northeastern Madison County and in a small area along the Pearl River near Jackson, to 1,900 feet above the top of the Sparta Sand in southwestern Hinds County (fig. 48). Predevelopment water levels are nearer the top of the formation over the Jackson Dome than in areas adjacent to the dome. Distance between the potentiometric surface and top of the Sparta Sand increases rapidly west of the dome (fig. 48), and predevelopment Sparta water levels are as much as 1,200 feet above the top of the Sparta Sand within 15 miles west and southwest of the Jackson area.

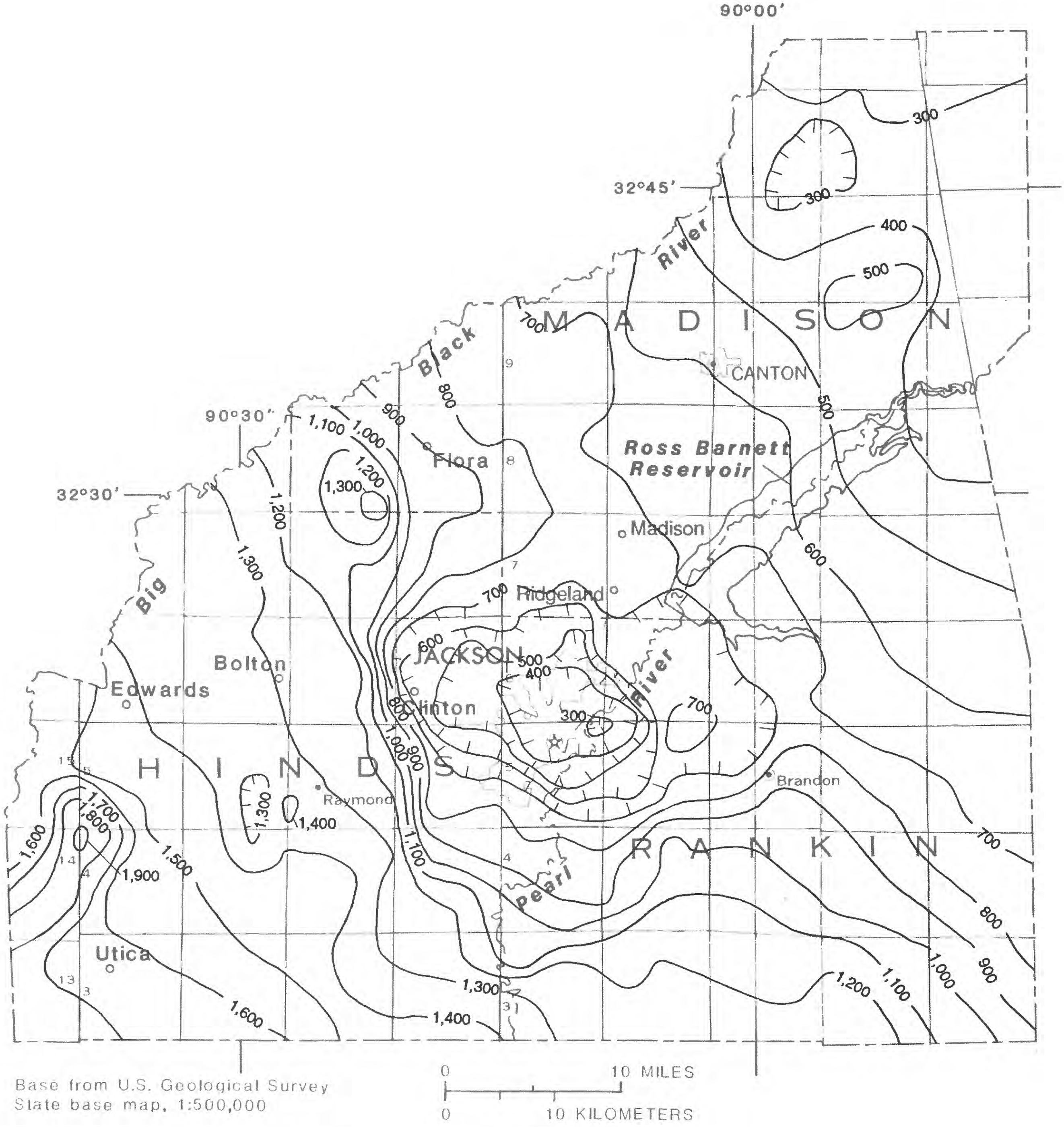
Recharge and Discharge

Simulation of predevelopment conditions indicate that most of the recharge to the Cockfield and Sparta aquifers in the model area was predominantly by direct infiltration of rainfall in and near aquifer outcrop areas. Predevelopment discharge from the Cockfield and Sparta aquifers in the model area was to streams, springs, and seeps in and near the aquifer outcrop areas, and upward leakage to the Mississippi River alluvial aquifer.

Simulated predevelopment areal net recharge in the outcrop area of the Cockfield aquifer in the model area was about 8.02 cubic feet per second (fig. 49), which is equivalent to about 0.12 inch per year. About 12.2 cubic feet per second entered the Cockfield aquifer from the Yazoo Clay outcrop area. The Yazoo Clay has a low vertical permeability, but the Yazoo Clay outcrop in the model area is about seven times larger than the Cockfield Formation outcrop area. Most of the recharge to the Cockfield aquifer in the Yazoo Clay outcrop area was near the updip extent of the Yazoo Clay where the clay is thin and land surfaces are greater than 400 feet above sea level. Throughout the entire Yazoo Clay outcrop area, predevelopment recharge to the Cockfield aquifer averaged less than 0.05 inch per year. In the three-county area, the greatest simulated predevelopment recharge rate to the Cockfield was in the outcrop area in northeastern Madison County where as much as 5.0 inches per year entered the aquifer (fig. 50). Throughout most of the outcrop area in northeastern Madison County where recharge occurs, the rate of recharge ranged from 0.25 to 2 inches per year. In the Cockfield Formation outcrop area along the Pearl River near the crest of the Jackson Dome, predevelopment recharge to the aquifer was about 0.25 inch per year. Throughout the entire three-county area, except along the Big Black River and its tributaries in northern Madison County and along the Pearl River in northern Rankin County and eastern Madison County, predevelopment simulation results indicate that the aquifer was recharged from land surface; however, throughout most of the area the recharge rate was less than 0.01 inch per year.

The Sparta aquifer crops out outside the study area in Attala, Holmes, Leake, Neshoba, and Newton Counties (fig. 24). Predevelopment net recharge to the Sparta in the aquifer outcrop in the model area was about 21.9 cubic feet per second, which is equivalent to 0.27 inch per year (fig. 49). About 1.30 cubic feet per second entered the aquifer from the Cook Mountain Formation outcrop area. No substantial flow entered the Sparta aquifer from the water table in the three-county area because the Cockfield and Cook Mountain Formations lie above the Sparta.

Under simulated predevelopment conditions, water from the Cockfield aquifer discharged to the Mississippi River alluvial aquifer in the Mississippi Alluvial Plain west of the three-county area. Water also discharged locally to streams from the Cockfield and Sparta aquifers in and near the aquifer outcrop area (fig. 51). Simulation results indicate that in the model area, about 18.6 cubic feet per second was discharged to the Mississippi River alluvial aquifer from the Cockfield aquifer. The Mississippi River alluvial aquifer also is the regional discharge area for the Sparta aquifer. The Sparta



EXPLANATION

— 700 — LINE OF EQUAL DISTANCE BETWEEN TOP OF SPARTA SAND AND SIMULATED PREDEVELOPMENT POTENTIOMETRIC SURFACE--Hachures indicate areas of lesser distance. Interval 100 feet

Figure 48.--Distance between simulated predevelopment potentiometric of the Sparta aquifer and top of the Sparta Sand in the three-county study area.

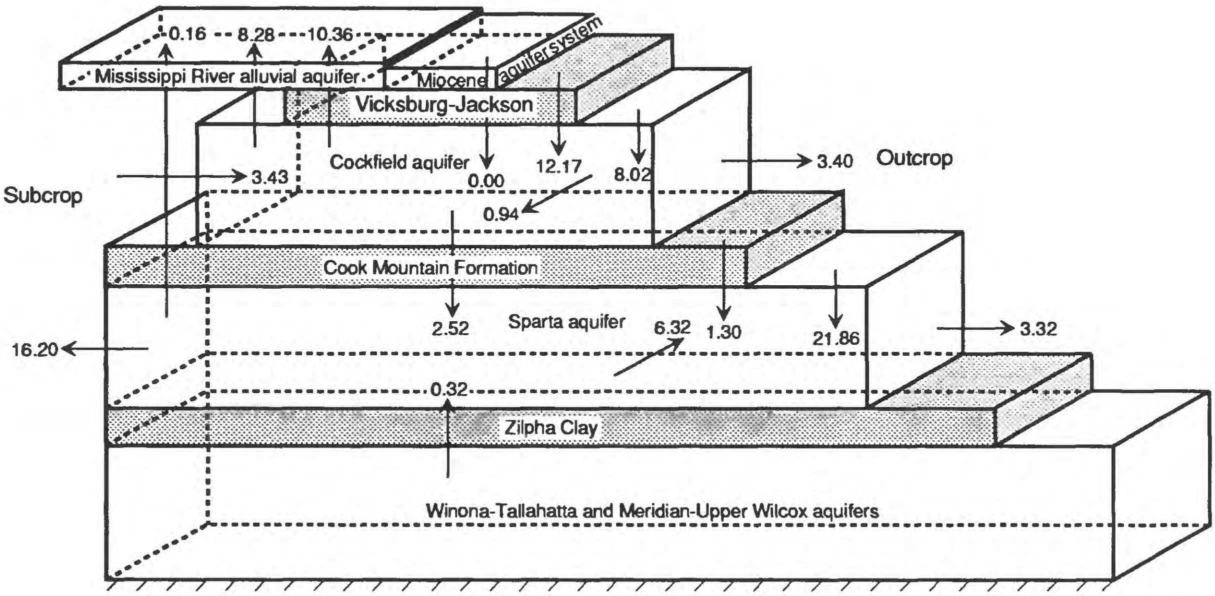


Figure 49.--Simulated predevelopment vertical and horizontal flow for the model area. Numbers indicate flow in cubic feet per second.

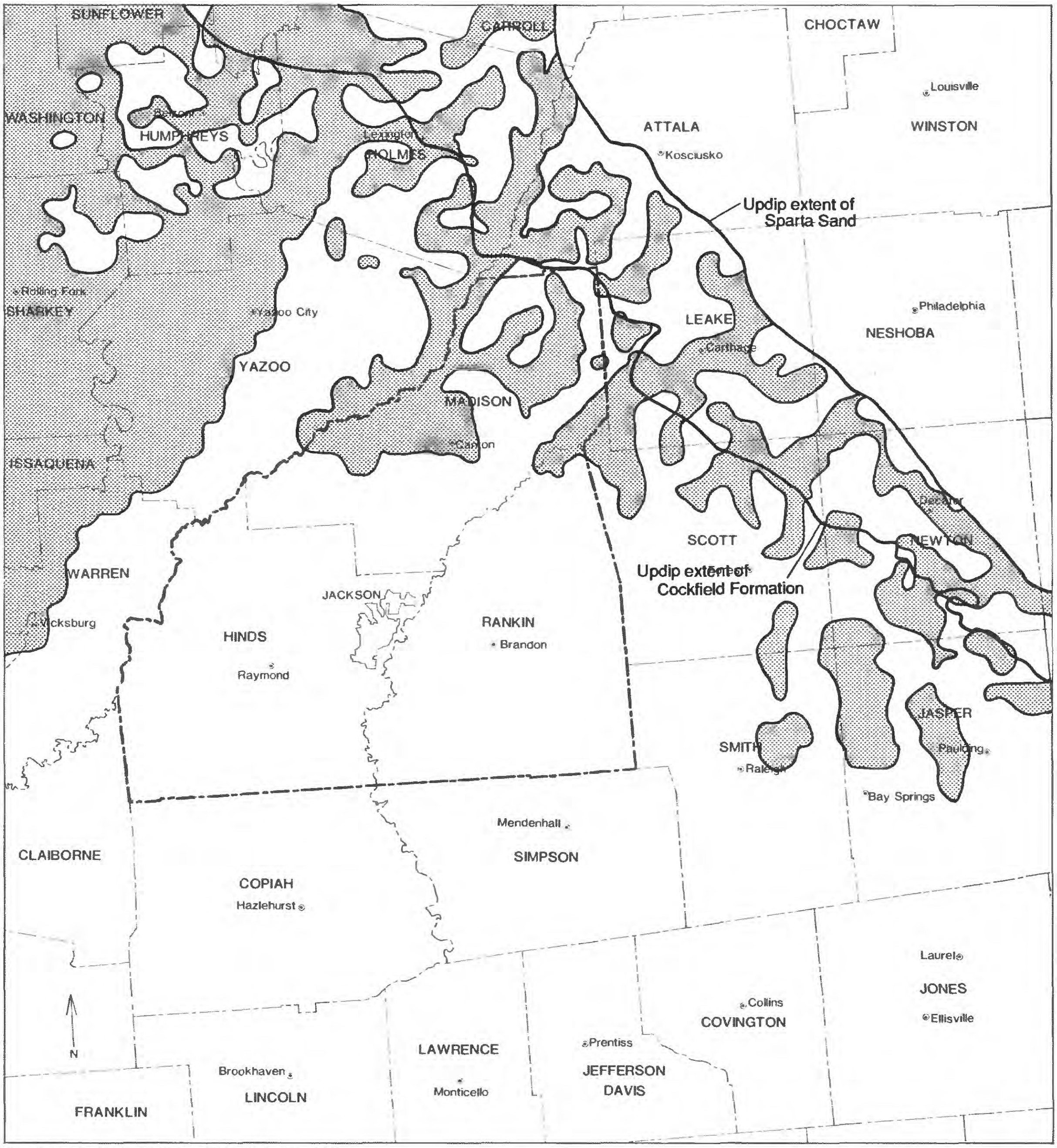
EXPLANATION

AREA OF DISCHARGE

AREA OF RECHARGE

—— 1 —— LINE OF EQUAL RECHARGE--Interval inches per year is variable

Figure 50.--Simulated predevelopment surficial recharge in area of outcrop and vertical flow from overlying units to the Cockfield aquifer in the three-county study area.



Base from U.S. Geological Survey State base map, 1972

0 10 20 MILES

0 10 20 KILOMETERS

EXPLANATION

AREA OF DISCHARGE

AREA OF RECHARGE

Figure 51.--Simulated areas of discharge from and recharge to the Cockfield and Sparta aquifers before ground-water development in the model area.

Sand subcrops the alluvial aquifer outside of the model area, but predevelopment model simulation indicates that about 0.16 cubic foot per second flowed upward through the Cook Mountain Formation into the alluvial aquifer in the model area (fig. 49).

Flow at Lateral Boundaries

The area modeled does not represent the entire freshwater extent of the Cockfield and Sparta aquifers. Freshwater discharge and recharge occur both inside and outside the area modeled in the two aquifers, and as a result, flow into and out of the model area occurs at the extent of the model grid. The model simulates the freshwater part of the Cockfield and Sparta aquifers, and no flow is assumed into or out of the model beyond the downdip extent of freshwater.

The largest simulated predevelopment lateral flow in the Cockfield was that flow across the west head-dependent flux lateral boundary, where about 3.43 cubic feet of water per second flowed eastward into the model area (fig. 49). Most of this flow probably moved from the Cockfield outcrop area in Arkansas to the regional discharge area in the Mississippi Alluvial Plain in Mississippi. About 3.40 cubic feet per second moved eastward in the Cockfield aquifer out of the model area across the east head-dependent flux boundary. Most of the lateral flow at the east boundary probably was from the high altitude Cockfield outcrop area in northeastern Jasper County where shallow ground-water flow moved toward the Chickasawhay River Valley. The northern head-dependent flux boundary for the Cockfield lies entirely in the Mississippi Alluvial Plain. Lateral flow of about 0.94 cubic foot per second moved southward into the model area in the Cockfield across the north lateral boundary toward the aquifer subcrop of the Mississippi River alluvial aquifer.

Simulated predevelopment lateral flow in the Sparta aquifer was greatest at the west head-dependent flux lateral boundary where about 16.20 cubic feet per second flowed westward out of the model area into southeastern Arkansas and northeastern Louisiana (fig. 49). An estimated lateral flow of 6.32 cubic feet per second moved northward out of the model area in the Sparta across the north model boundary toward the aquifer subcrop in the east-central part of the Mississippi Alluvial Plain. At the east boundary, predevelopment lateral flow of about 3.32 cubic feet per second in the Sparta aquifer moved eastward out of the model area.

Vertical Flow between Aquifers

The magnitude and direction of vertical flow between aquifers is determined by the head difference between the aquifers, the vertical conductivity of the intervening confining unit, the hydraulic conductivity of the aquifers, and the overlapping area of the aquifers. The greatest simulated predevelopment vertical flow in the model area was between the Cockfield aquifer and the Mississippi River alluvial aquifer. In the model area, the Cockfield underlies about 1,800 square miles of the alluvial aquifer. In about one-half of this area the Cockfield lies directly under the alluvial aquifer. In the remainder of the area where the alluvial aquifer and the Cockfield are present, they are separated by as much as 500 feet of Yazoo Clay. Predevelopment simulation indicates that about 18.64 cubic feet per second moved upward into the Mississippi River alluvial aquifer from the Cockfield aquifer in the model area. The Sparta directly subcrops the alluvial aquifer outside the model area, but within the model area predevelopment simulation indicates that about 0.16 cubic foot per second moves upward through the Cook Mountain Formation from the Sparta aquifer into the alluvial aquifer (fig. 49).

The Miocene aquifer system overlies the southern third of the model area and is at land surface (fig. 24). The Cockfield aquifer is separated from the overlying Miocene aquifer system by as much as 500 feet of Yazoo Clay. This thick layer of tight marine clay offers little opportunity for substantial interchange of water between the Miocene aquifer system and the Cockfield aquifer (fig. 50).

The Cockfield and Sparta aquifers are separated by the Cook Mountain Formation. Predevelopment model simulation indicates that about 2.52 cubic feet per second flowed downward from the Cockfield aquifer into the Sparta aquifer in the model area (fig. 49). This flow rate is equivalent to 0.002 inch per year in the model area. In the eastern half of the three-county area, simulated predevelopment vertical flow was downward from the Cockfield into the Sparta and was reversed in the western half of the three-county area (fig. 52). The flow downward in the eastern half ranges from zero to about 0.010 inch per year. The upward flow from the Sparta to the Cockfield in the western one-half of the study area is less and ranges from zero to about 0.005 inch per year. The reversal of vertical flow between the two aquifers in the three-county area is the result of a reversal in vertical hydraulic head gradient between the two aquifers as distance increases from the recharge area to the regional discharge area in the Mississippi Alluvial Plain.

The quantity of predevelopment vertical flow between the Sparta aquifer and underlying water-bearing units was small. Model simulation results indicate that in the model area about 0.32 cubic foot per second flowed upward from underlying water bearing units into the Sparta under predevelopment conditions (fig. 49). In the three-county area, predevelopment vertical flow between the Sparta and water-bearing units below the Sparta is consistent with conditions throughout the entire model area. Vertical flow was upward from the underlying units into the aquifer throughout the entire three-county area (fig. 53). Predevelopment simulation results indicate that flow from underlying units into the Sparta aquifer ranges from less than 0.001 to less than 0.002 inch per year and averaged about 0.001 inch per year in the study area.

Flow Budget

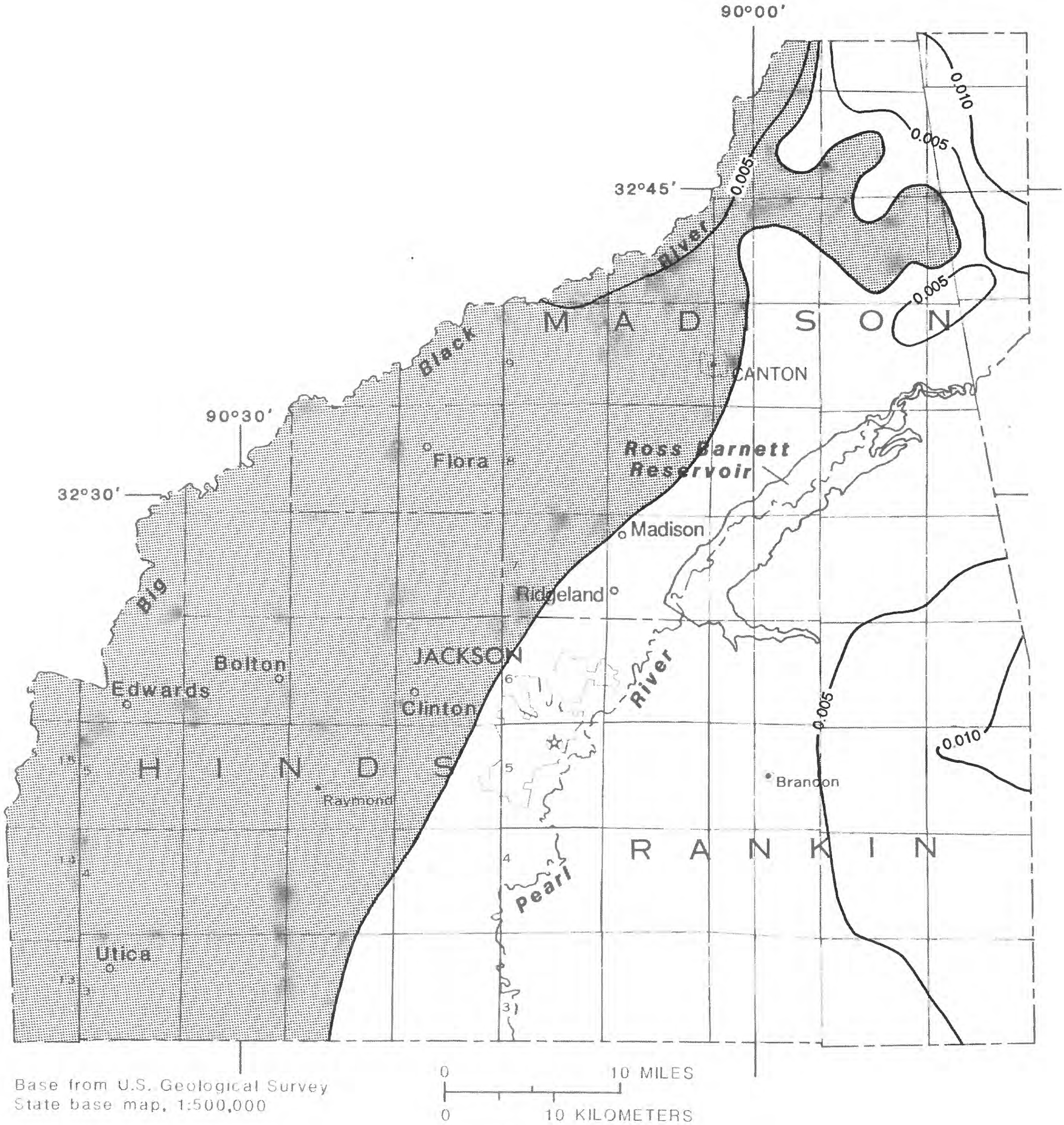
Model simulation indicates that total net predevelopment flow was greater through the Sparta than through the Cockfield aquifer in the model area (fig. 54). About 26 cubic feet per second moved through the Sparta as compared to about 24 cubic feet per second through the Cockfield. Greater average transmissivity in the Sparta results in more flow through the aquifer; however, in the northwestern part of the model area where the Cockfield crops out in the hills (recharge area) adjacent to the aquifer subcrop of the Mississippi River alluvial aquifer (discharge area), there was substantial flow in the Cockfield aquifer. The short flow path from recharge area to discharge area and steep hydraulic gradients enhance flow in the Cockfield aquifer in this area.

The major recharge components of predevelopment flow in the Cockfield aquifer in the model area are recharge in the Cockfield outcrop area and leakage from overlying units through the Yazoo Clay. The vertical flow through the clay mainly is in topographically high areas at the updip extent of the formation, where the clay is thin and is incised by streams. The dominant predevelopment discharge component of the Cockfield in the model area was flow to the Mississippi River alluvial aquifer in the Cockfield and the Yazoo Clay subcrop areas.

The major predevelopment source of water for the Sparta aquifer in the model area was recharge in the outcrop area, where about 23.2 cubic feet per second entered the aquifer. The greatest predevelopment net discharge from the aquifer in the model area was at the lateral boundaries, where about 26 cubic feet per second moved out of the model area. Most of the lateral flow was westward and northward toward the Sparta subcrop of the Mississippi River alluvial aquifer.

Simulation of 1990 Flow Conditions

Current (1990) conditions in the three-county study area were simulated in the final pumping period (1985-90) of the transient model simulation. The results from the transient simulation show the cumulative effects of 70 years of pumpage from the Cockfield and Sparta aquifers. The 1990 ground-water flow analysis of the Cockfield and Sparta aquifers, based on model simulation results, is presented in the following section.



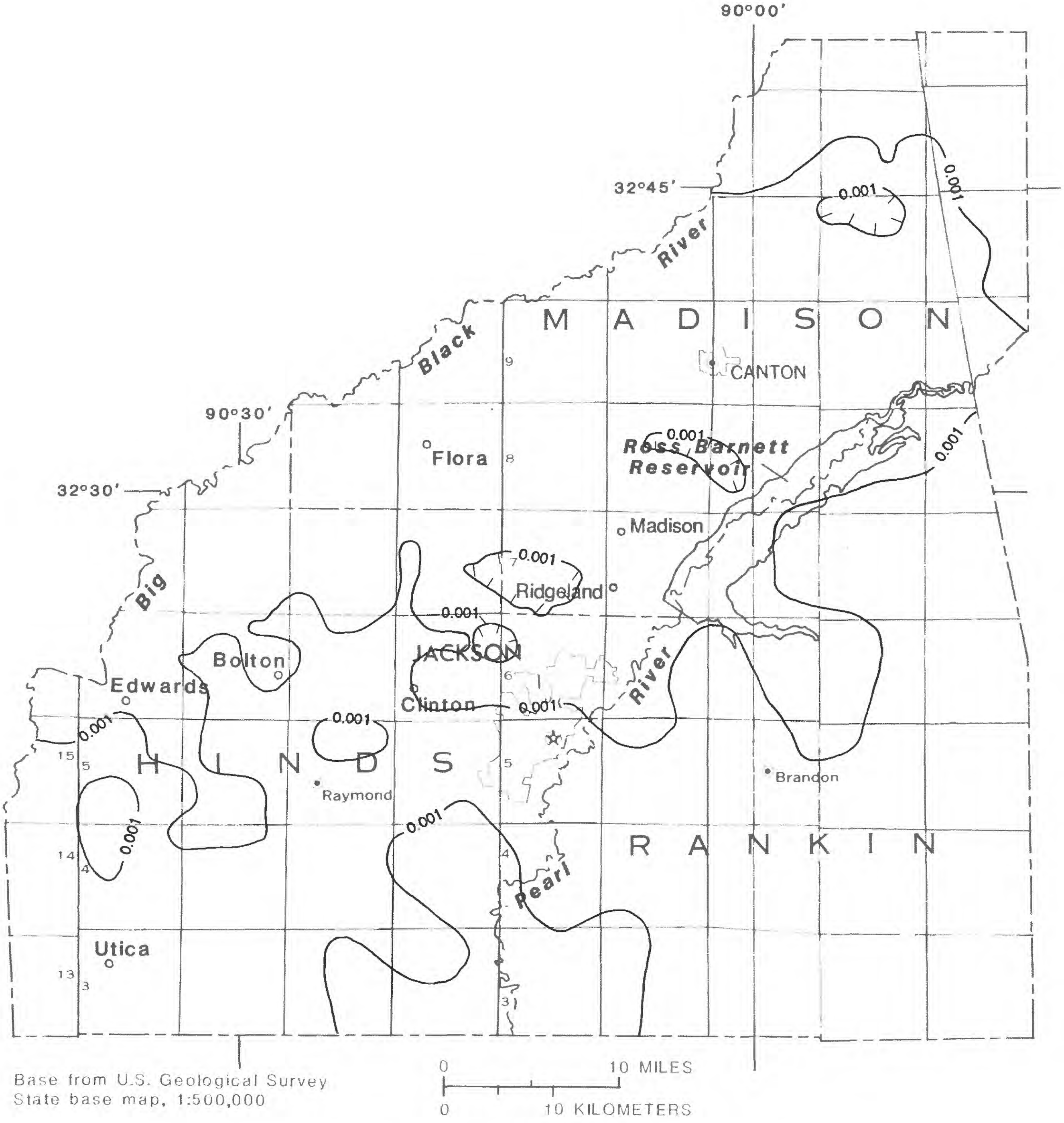
EXPLANATION

AREA IN WHICH FLOW IS FROM THE COCKFIELD AQUIFER TO THE SPARTA AQUIFER

AREA IN WHICH FLOW IS FROM THE SPARTA AQUIFER TO THE COCKFIELD AQUIFER

—0.005— LINE OF EQUAL VERTICAL FLOW--Interval 0.005 inch per year

Figure 52.--Simulated predevelopment vertical flow between the Cockfield and Sparta aquifers in the three-county study area.



EXPLANATION

—— 0.001 —— LINE OF EQUAL VERTICAL FLOW--Hachures indicate area of lesser flow. Interval 0.001 inch per year

Figure 53.--Simulated predevelopment vertical flow to the Sparta aquifer from underlying units in the three-county study area.

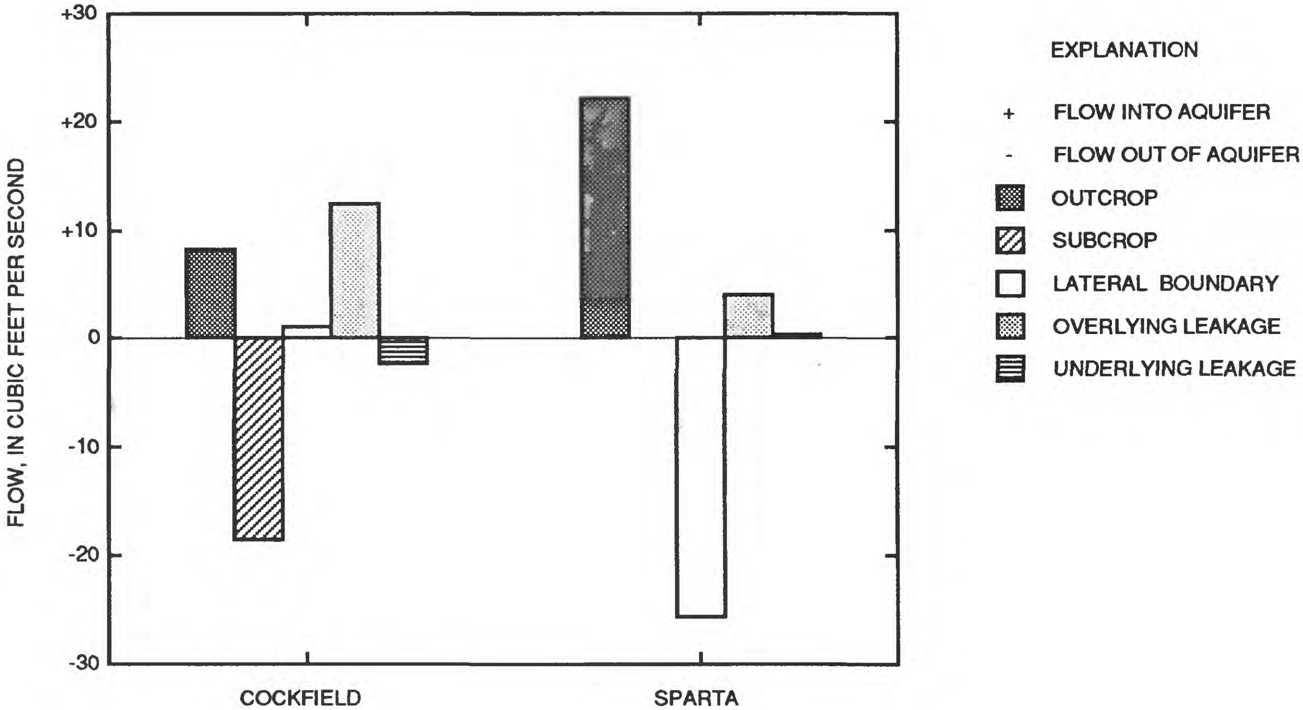
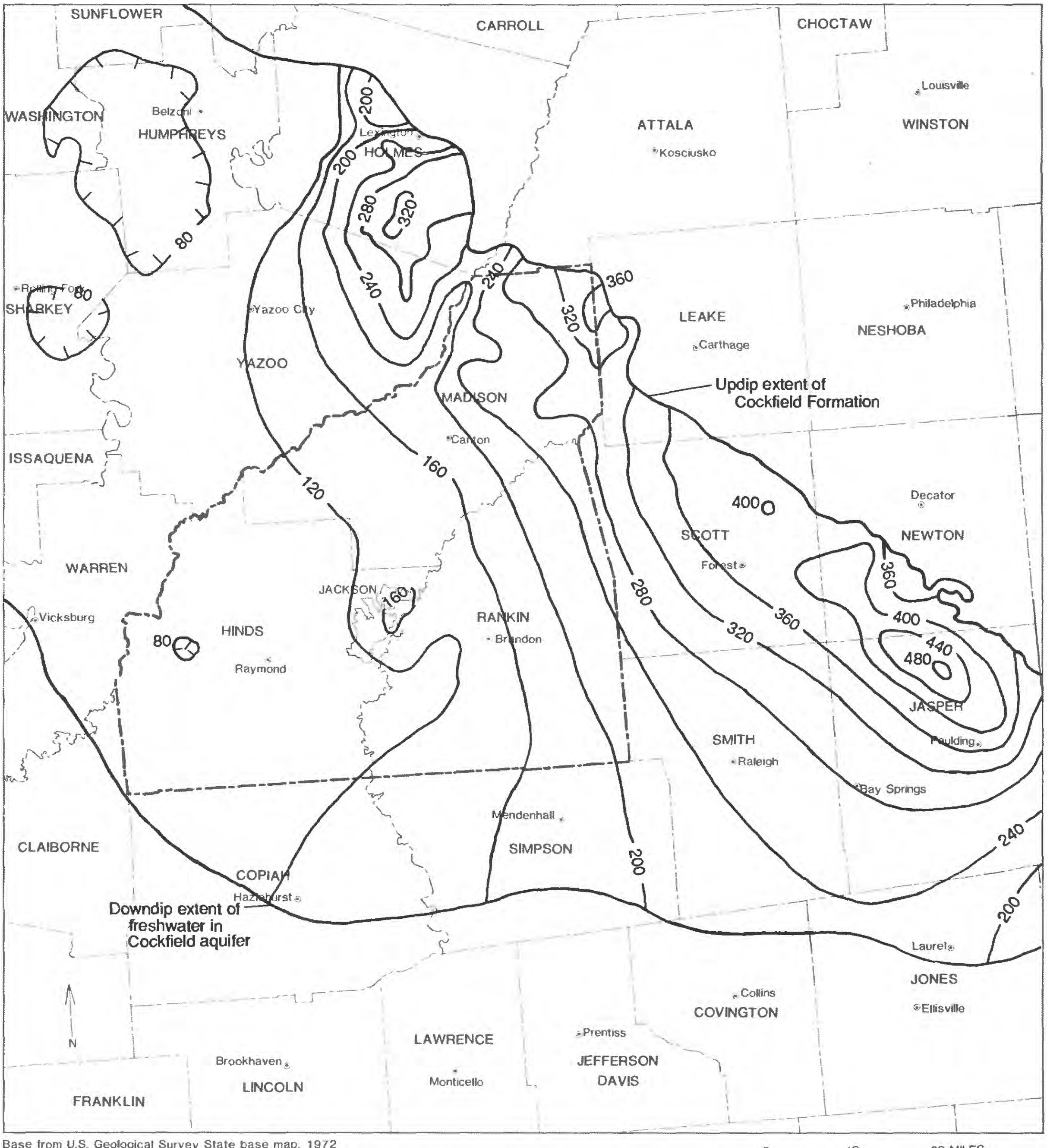


Figure 54.--Simulated predevelopment flow budget for the Cockfield and Sparta aquifers in the model area.

Potentiometric Surfaces

As a result of pumping in the model area, the potentiometric surfaces of the confined parts of the Cockfield and Sparta aquifers have declined from predevelopment levels. The simulated 1990 potentiometric surface for the Cockfield in the model area is shown in figure 55. The configuration of the regional potentiometric surface of the aquifer representing simulated 1990 water levels generally conforms to that of the simulated predevelopment potentiometric surface of the Cockfield aquifer, except in the Jackson area where pumping has caused water-level declines (fig. 33). In the Jackson area east of the Pearl River, simulation results indicate that water levels were drawn down as much as 120 feet in the aquifer (fig. 56). Over the Jackson Dome, however, water levels in the aquifer declined less because of recharge from land surface. In most of the three-county area in the confined part of the aquifer, simulated water levels are 40 to 100 feet lower than simulated predevelopment water levels.

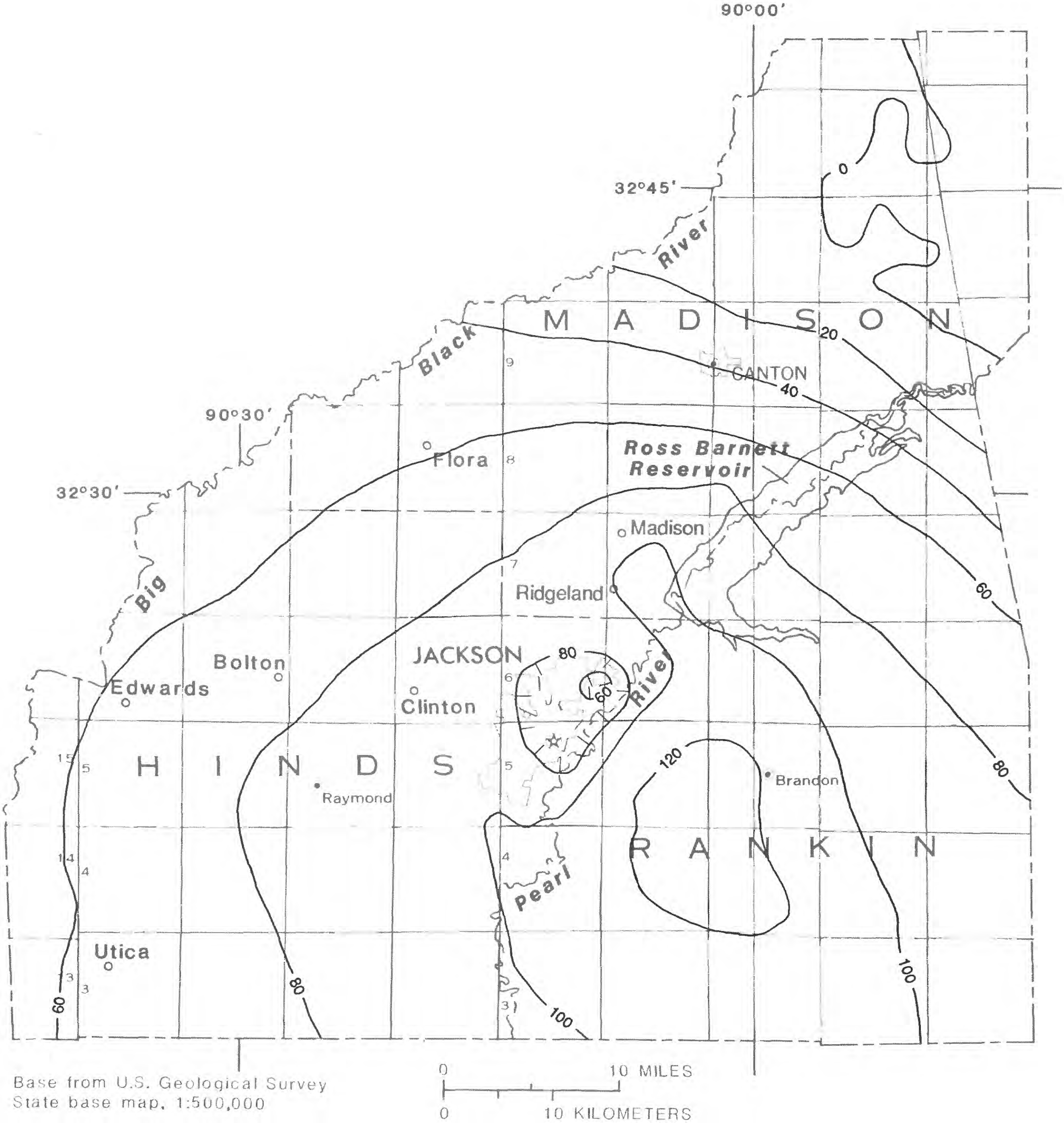
The decline in water levels in the Cockfield aquifer has decreased the distance between the potentiometric surface and the top of the Cockfield Formation (fig. 57). However, water levels remain above the top of the Cockfield aquifer. The sand beds that constitute the aquifer are in the deeper part of the formation. In a small area (about 3 square miles) above the Jackson Dome, simulated 1990 water levels in the aquifer are more than 100 feet below the top of the Cockfield Formation but remain above the top of the Cockfield aquifer. For most of Jackson and extending several miles eastward across the Pearl River, simulated 1990 Cockfield aquifer water levels are at or below the top of the Cockfield Formation but above the top of the Cockfield aquifer. The combined effect of stratigraphic uplift caused by the Jackson Dome and water-level declines has resulted in decreased distance between the Cockfield potentiometric surface and the top of the Cockfield Formation in the Jackson area. The distance between the potentiometric surface and the top of the formation increases with distance from the dome, but the increase is greatest to the west-southwest.



EXPLANATION

—— 80 —— POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate water level depression. Interval 40 feet. Datum is sea level

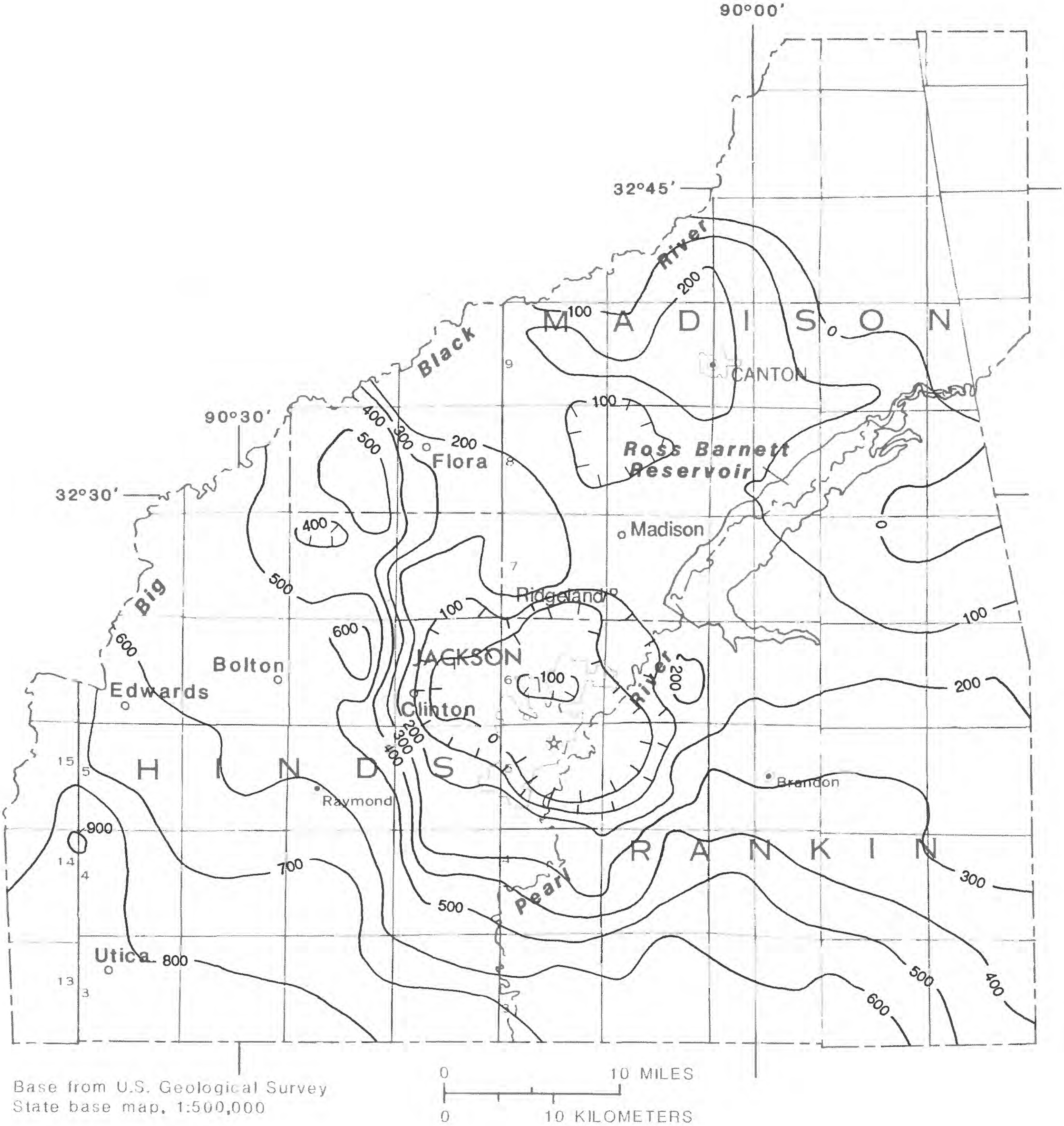
Figure 55.--Simulated 1990 potentiometric surface of the Cockfield aquifer in the model area.



EXPLANATION

— 60 — LINE OF EQUAL DRAWDOWN IN FEET--Hachures indicate area of lesser drawdown. Interval 20 feet

Figure 56.--Simulated drawdown of water levels in the Cockfield aquifer from predevelopment to 1990 conditions in the three-county study area.



EXPLANATION

—— 100 —— LINE OF EQUAL DISTANCE BETWEEN THE TOP OF THE COCKFIELD FORMATION AND THE SIMULATED 1990 POTENTIOMETRIC SURFACE--Positive value indicates potentiometric surface is above the top of the formation. Negative value indicates potentiometric surface is below the top of the formation. Hachures indicate area of lesser value. Interval 100 feet

Figure 57.-- Distance between simulated 1990 potentiometric surface of the Cockfield aquifer and top of the Cockfield Formation in the three-county study area.

The configuration of the potentiometric surface of the Sparta aquifer has changed substantially since predevelopment. Heavy pumping from the aquifer in the Jackson area and at Yazoo City, outside the three-county area in the northwestern part of the model area, has resulted in large depressions in the potentiometric surface (fig. 58). The regional slope of the potentiometric surface down the dip from the Sparta outcrop increased from about 1.9 feet per mile westward before development to about 13.5 feet per mile southwestward during 1990.

In the three-county area, the 1990 simulated Sparta aquifer depression is centered in west Jackson, where the aquifer water levels are less than 60 feet above sea level (fig. 34). The potentiometric surface in southwestern Madison County indicates not only the effect of pumping in Jackson but also the effect of pumping in the Yazoo City area. As pumping from the aquifer increases, the two depressions will probably expand, and the effects of pumping at Yazoo City outside the study area would then extend farther into the three-county area.

Simulated 1990 water-level declines in the Sparta aquifer from predevelopment conditions in the three-county area are greatest in the Jackson area, where water levels were about 140 feet below simulated predevelopment levels (fig. 59). Water-level declines in the aquifer are smaller to the northeast and southwest of the Jackson area, but large declines extend to the northwest because of the influence of the pumping at Yazoo City. The smallest declines in the three-county area are in northeastern Madison County, where 1990 water levels were about 20 feet below predevelopment levels.

Water-level declines in the Sparta aquifer have caused a corresponding decrease in the distance between the potentiometric surface of the aquifer and the top of the Sparta Sand (fig. 60). Simulation results for 1990 indicate that in the three-county area the least distance between the potentiometric surface of the aquifer and the top of the formation occurs above the Jackson Dome. In a 4-square-mile area above the dome, the simulated 1990 water level is less than 200 feet above the top of the formation. The combined effect of large water-level declines in the aquifer in the Jackson area and the uplift of the stratigraphic units above the Jackson Dome has resulted in the decreased distance between the potentiometric surface and the top of the Sparta Sand in this area. The distance of the potentiometric surface from the top of the Sparta Sand increases rapidly away from the Jackson area, particularly toward the west-southwest, where within about a 4-mile reach, the distance between the potentiometric surface and the top of the formation increases to as much as 700 feet. Outside the Jackson area the simulated 1990 potentiometric surface of the aquifer ranged from about 300 feet above the top of the Sparta Sand in northeastern Madison County to more than 1,700 feet above the top of the Sparta Sand in southwestern Hinds County.

Recharge and Discharge

Simulation results for 1990 indicate that areal recharge to the Cockfield and Sparta aquifers has increased from predevelopment rates as a direct result of pumping from the two aquifers. Regional discharge from the Cockfield and Sparta to the Mississippi River alluvial aquifer and local discharge in and near aquifer outcrop areas to springs, seeps, and streams probably have decreased with increased pumping and corresponding lowering of the potentiometric surfaces.

Simulated average areal recharge during 1990 in the area modeled to the Cockfield aquifer in the outcrop area in the model area was about 14.30 cubic feet per second, or 0.22 inch per year, a 78-percent increase over the predevelopment rate (fig. 61). Recharge in the model area to the Cockfield aquifer in the Yazoo Clay outcrop area almost doubled to about 23.22 cubic feet per second.

In the three-county area in and near the Cockfield outcrop area in northeastern Madison County, the maximum rate of recharge to the aquifer increased very little from predevelopment; however, the size of the recharge area increased substantially after development (fig. 62). The increase in recharge

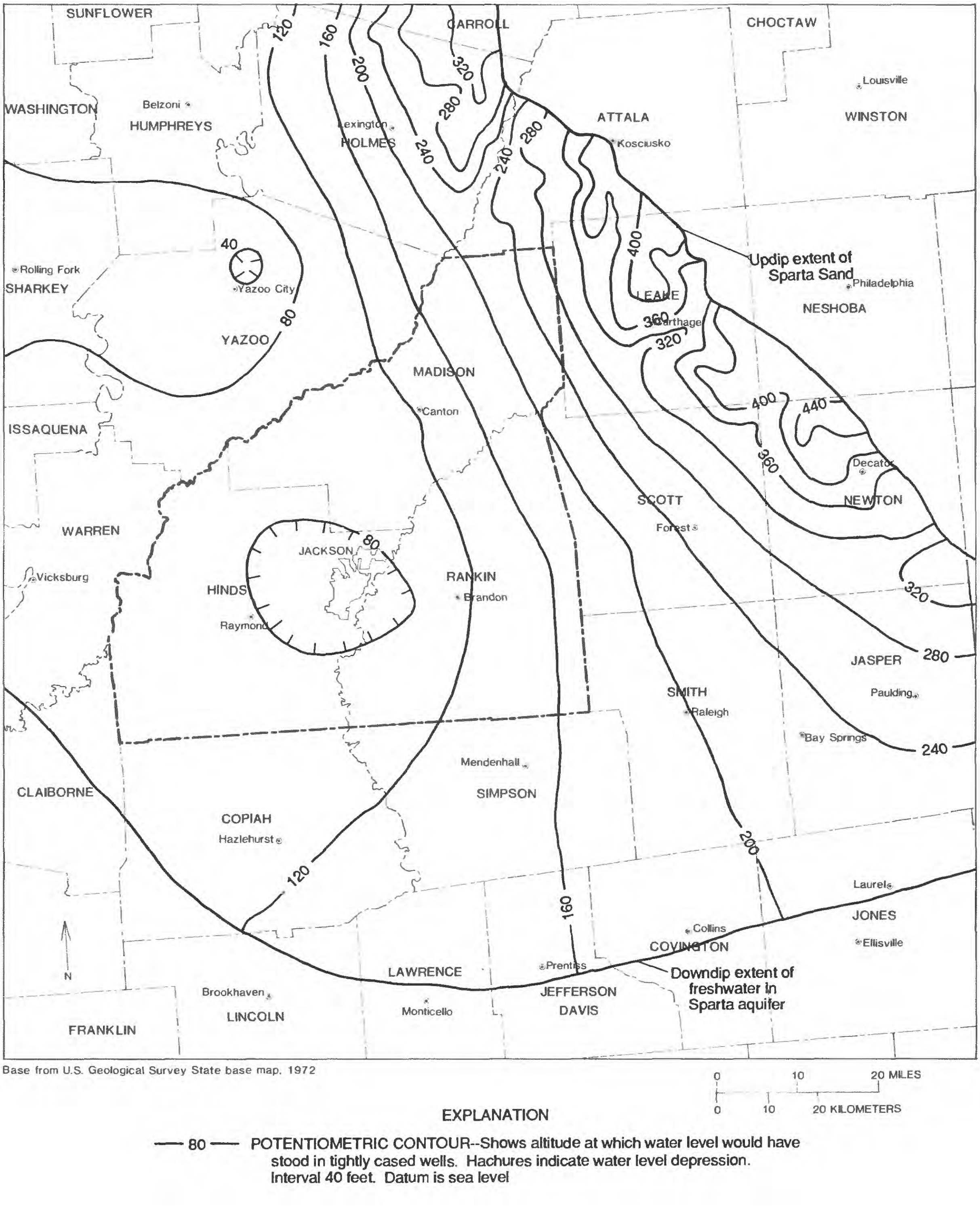
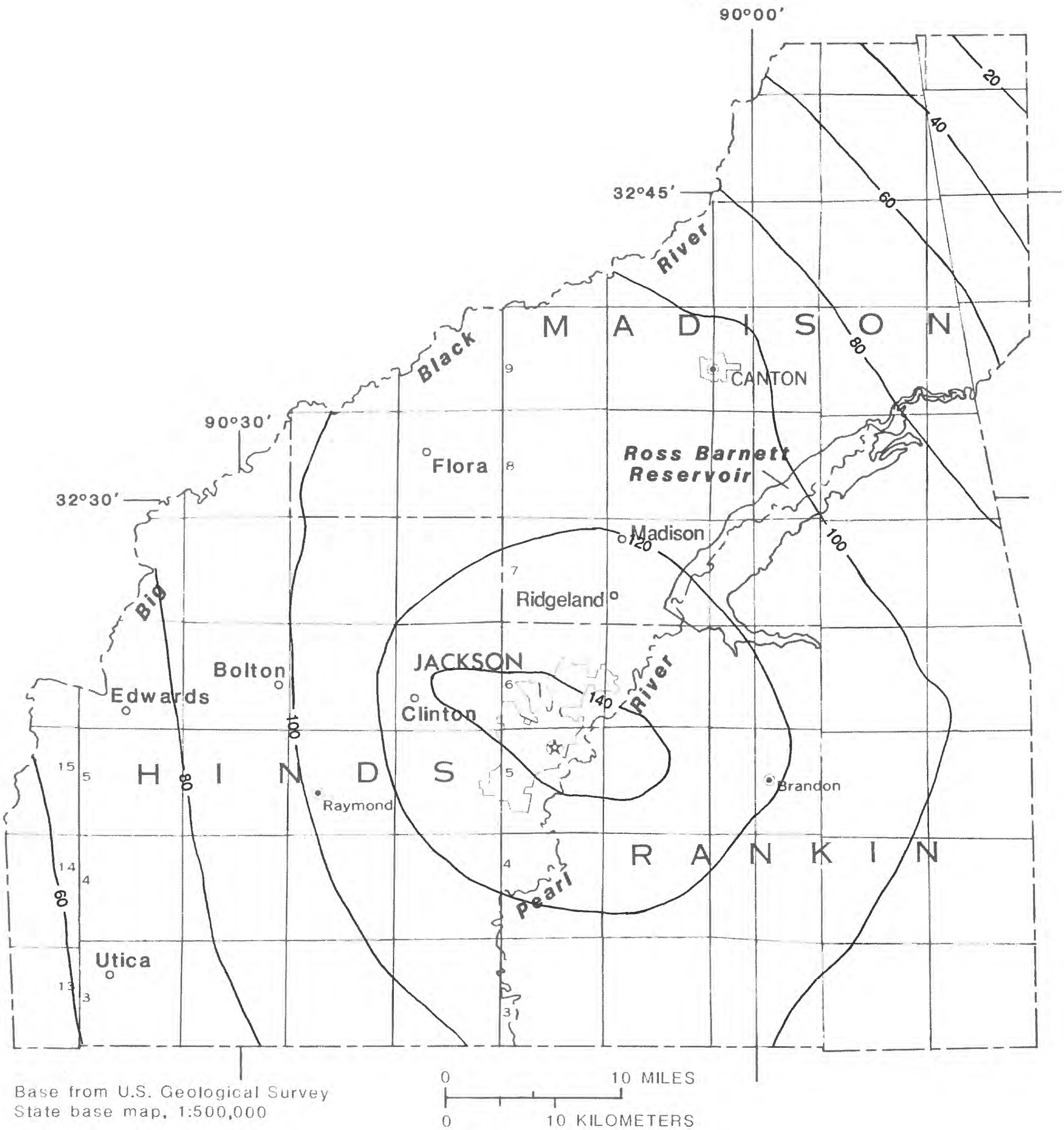


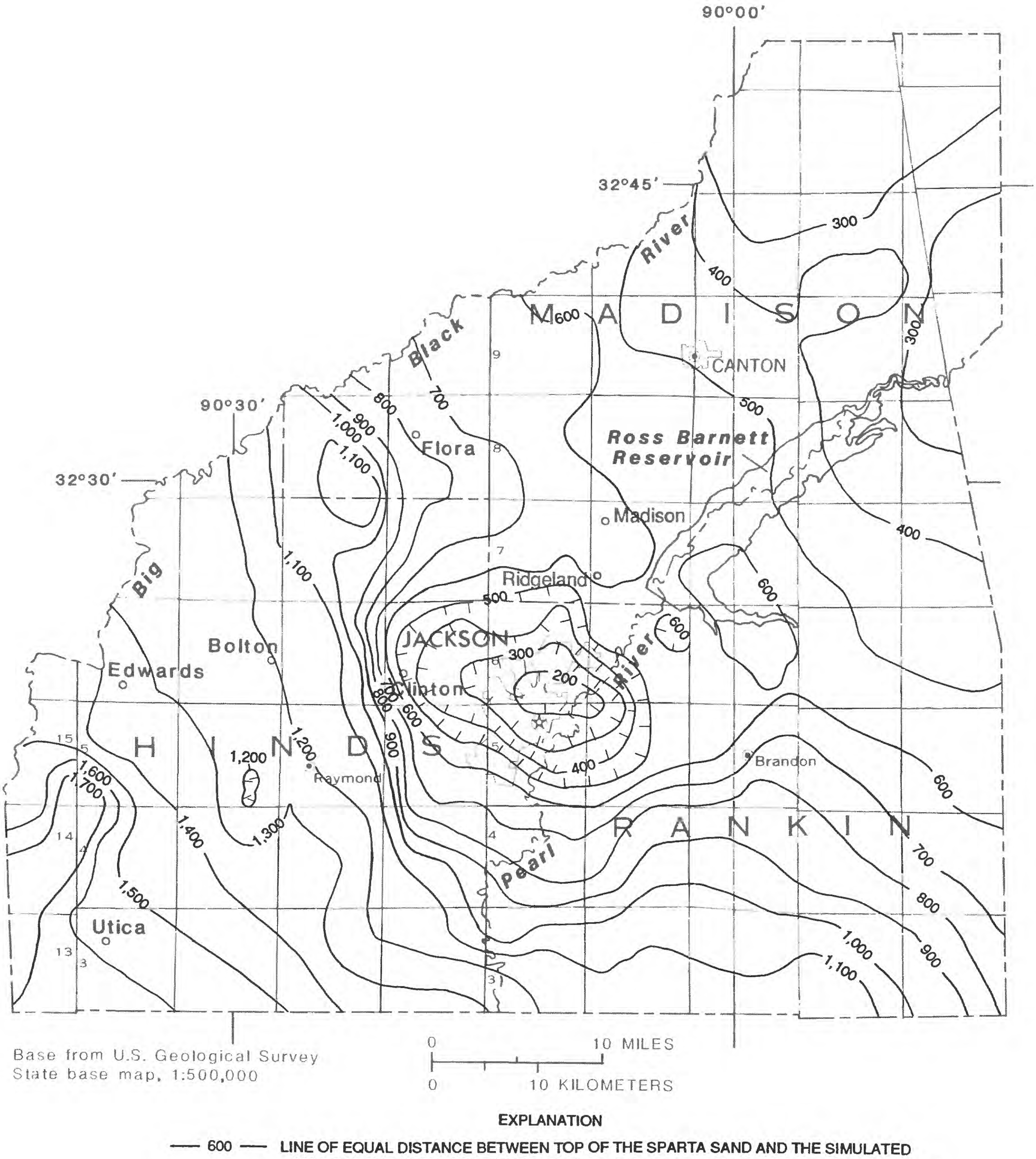
Figure 58.--Simulated 1990 potentiometric surface of the Sparta aquifer in the model area.



EXPLANATION

—— 100 —— LINE OF EQUAL DRAWDOWN, IN FEET--Interval 20 feet

Figure 59.--Simulated drawdown of water levels in the Sparta aquifer from predevelopment to 1990 conditions in the three-county study area.



EXPLANATION

—— 600 —— LINE OF EQUAL DISTANCE BETWEEN TOP OF THE SPARTA SAND AND THE SIMULATED 1990 POTENTIOMETRIC SURFACE--Hachures indicate area of lesser distance. Interval 100 feet

Figure 60.--Distance between simulated 1990 potentiometric surface of the Sparta aquifer and top of the Sparta Sand in the three-county study area.

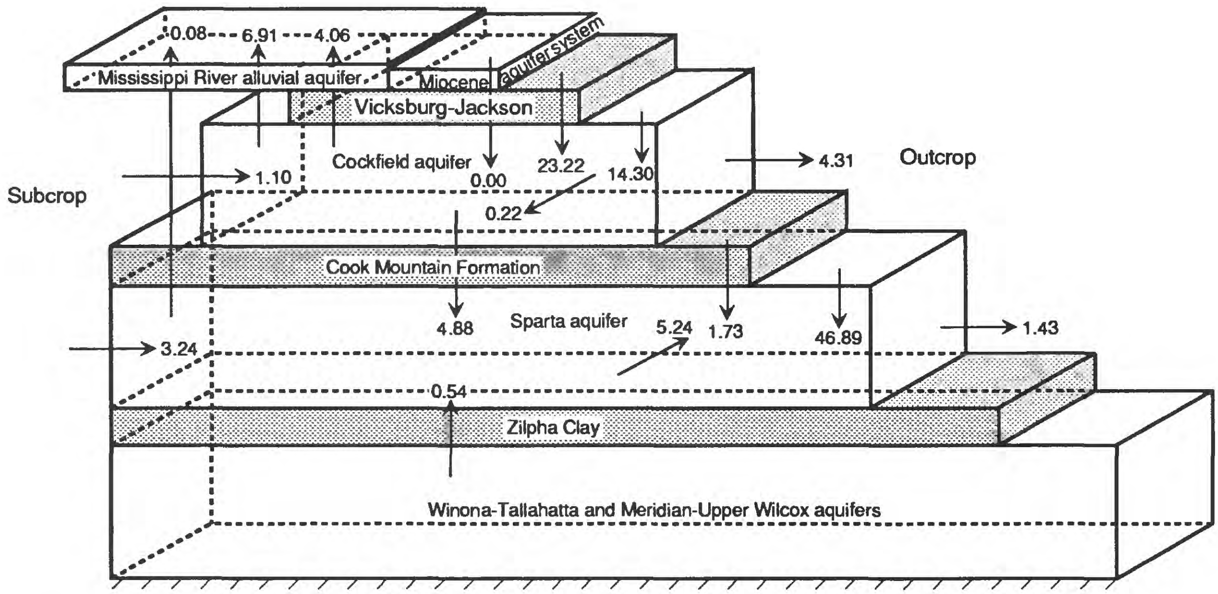
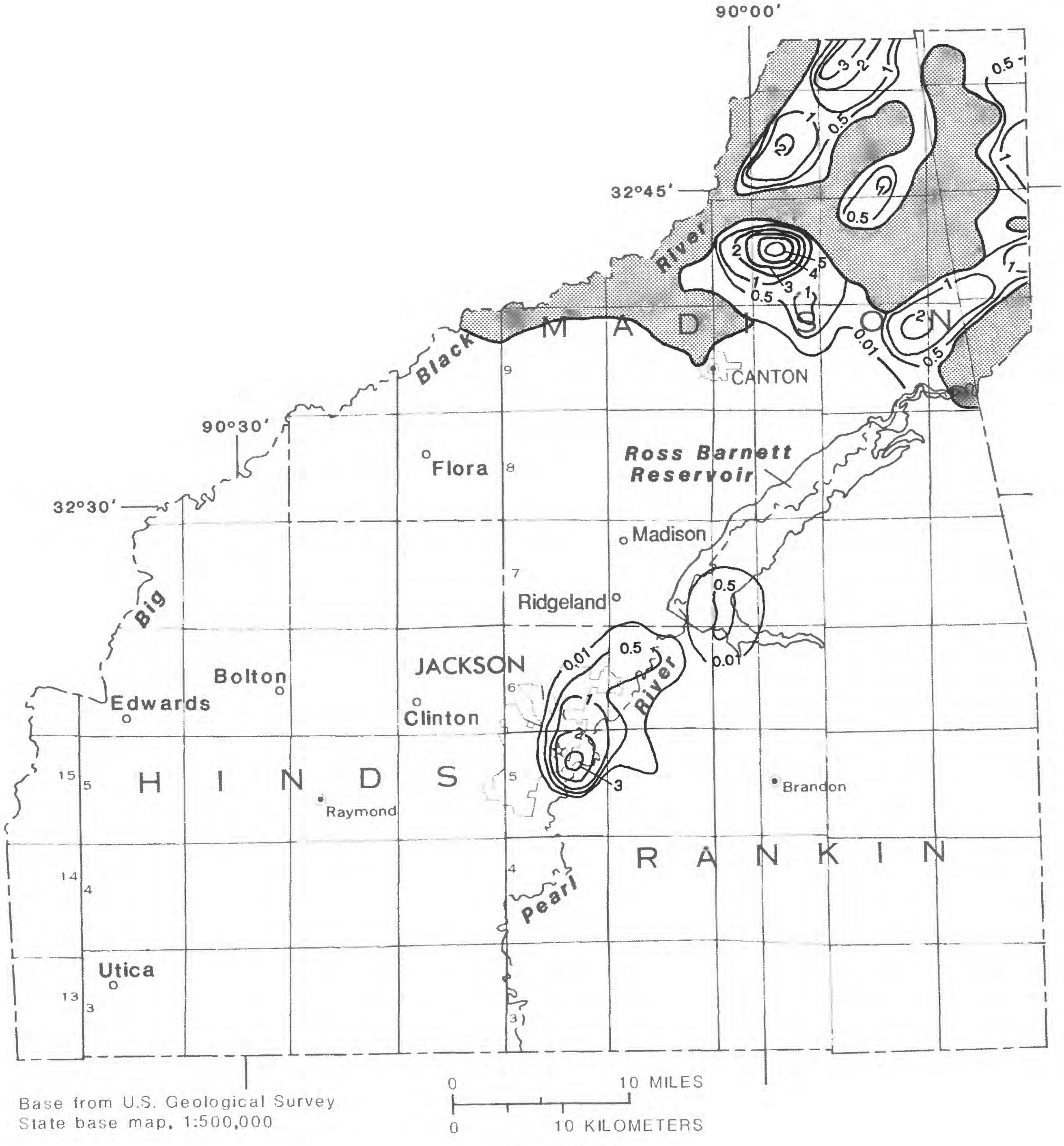


Figure 61.--Simulated 1990 vertical and horizontal flow for the model area. Numbers indicate flow in cubic feet per second.



EXPLANATION

AREA OF DISCHARGE

AREA OF RECHARGE

0.01 LINE OF EQUAL RECHARGE--Interval in inches per year is variable

Figure 62.--Simulated surficial recharge in area of outcrop and vertical flow from overlying units to the Cockfield aquifer during 1990.

reaching the confined part of the aquifer may have resulted in a decreased local discharge in the outcrop area. Simulated 1990 recharge to the Cockfield aquifer increased substantially in the Jackson area in and near the formation outcrop area along the Pearl River (fig. 62). During 1990 as much as 3 inches per year of recharge entered the Cockfield aquifer from land surface in a small area along the Pearl River over the Jackson Dome. The recharge rate decreased away from the outcrop area in the confined part of the aquifer as a result of the thickening of the overlying Yazoo Clay. Away from the crest of the Jackson Dome and the Cockfield outcrop area, less than 0.01 inch per year flowed downward through the Yazoo Clay into the aquifer during 1990.

Pumping from the Cockfield aquifer has decreased the natural regional discharge from the aquifer to the Mississippi River alluvial aquifer (fig. 63). Simulation results for 1990 indicate that in the model area, about 6.91 cubic feet per second was discharged from the Cockfield to the alluvial aquifer in the Cockfield aquifer subcrop area (fig. 61). The 1990 discharge rate is about 16 percent less than the predevelopment discharge rate, indicating that pumping from the Cockfield is capturing some of the water that would naturally be discharged to the alluvial aquifer. Flow discharge through the subcropping Yazoo Clay from the Cockfield to the Mississippi River alluvial aquifer was substantially decreased in 1990 to about 4.06 cubic feet per second, less than half of the predevelopment discharge rate (fig. 61).

Simulated 1990 recharge in the model area to the Sparta aquifer in the outcrop area more than doubled the predevelopment rate to about 46.89 cubic feet per second, or 0.57 inch per year (fig. 61). During 1990 about 1.73 cubic feet per second entered the aquifer through the Cook Mountain Formation outcrop area.

Because the Sparta aquifer does not subcrop the Mississippi River alluvial aquifer in the model area, only a small amount of water moves upward into the alluvial aquifer from the Sparta. Simulation results indicate that during 1990 only about 0.08 cubic foot per second moved upward from the Sparta through the Cook Mountain Formation into the alluvial aquifer (fig. 61). The 1990 discharge rate to the alluvial aquifer is a 50-percent decrease from the predevelopment discharge rate.

Flow at Lateral Boundaries

During 1990 simulated lateral flows at all the lateral boundaries in the Cockfield and Sparta aquifers were the same direction as before development, except at the west boundary of the Sparta (figs. 49 and 61). Lateral flow eastward into the model area at the west boundary in the Cockfield decreased from predevelopment to about 1.10 cubic feet per second during 1990. Flow southward into the model area at the north boundary of the aquifer decreased from 0.94 to 0.22 cubic feet per second (fig. 49, 61). The decreased inflow at the west and north boundaries during 1990 was the result of decreased heads in the Cockfield aquifer at the west and north boundaries. Extensive development of the Cockfield aquifer northwest of the model area near Greenville, Miss., caused water-level declines over a large area in Washington County. During 1990 flow eastward at the east boundary out of the model area in the Cockfield aquifer was about 4.31 cubic feet per second, a small increase over the predevelopment rate.

Simulation results indicate that all predevelopment flow westward from the Sparta aquifer out of the model at the west boundary was reversed by pumping, and during 1990, about 3.24 cubic feet per second flowed eastward into the model area at the west boundary. During 1990, lateral flows at the north and east boundaries out of the model in the Sparta were 5.24 and 1.43 cubic feet per second, a decrease of 1.08 and 1.89 cubic feet per second from simulated predevelopment rates (figs. 49, 61).

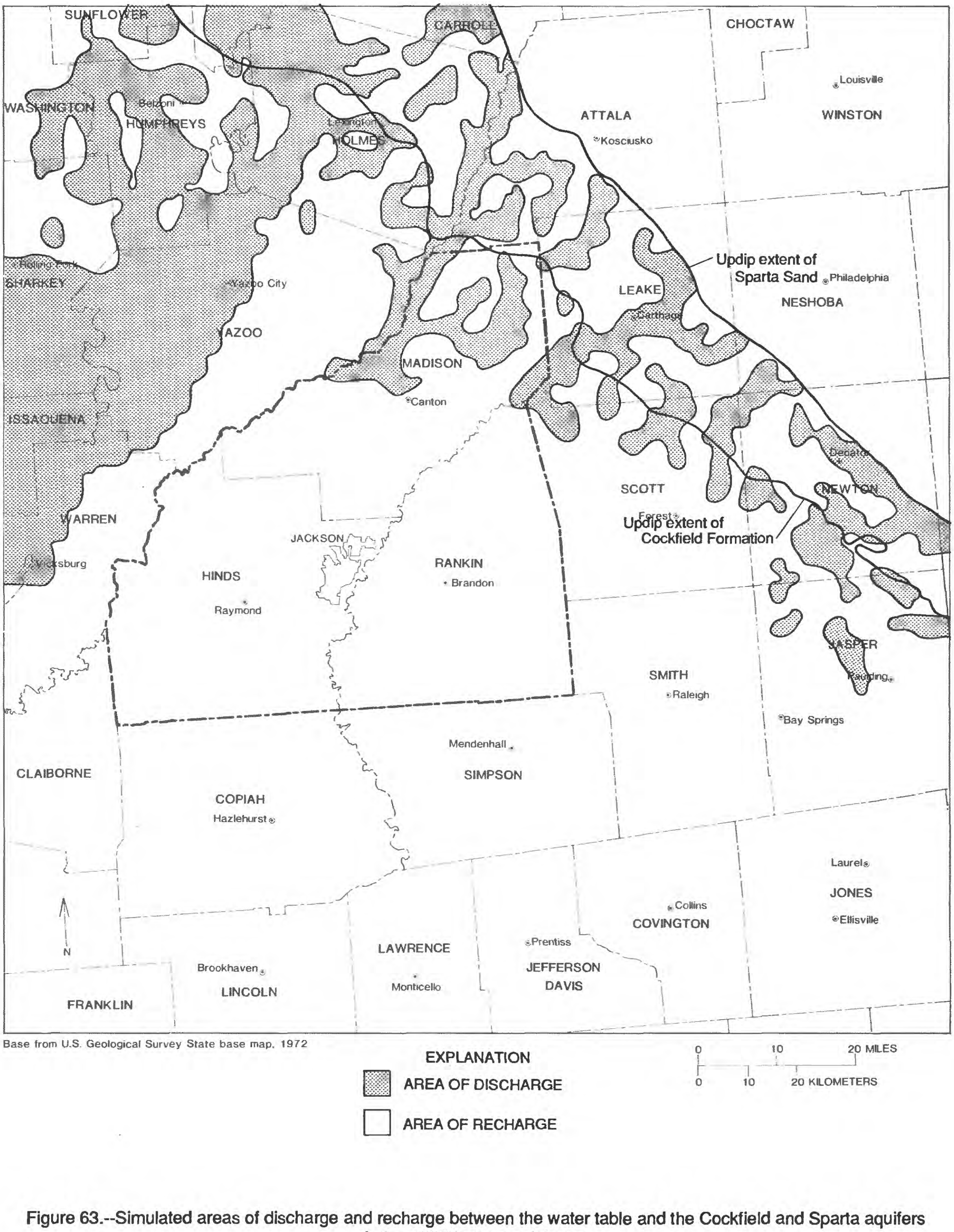


Figure 63.--Simulated areas of discharge and recharge between the water table and the Cockfield and Sparta aquifers during 1990 in the model area.

Vertical Flow between Aquifers

Model simulation results indicate that pumping does affect vertical flow between aquifers in the model area. Before development, 18.64 cubic feet per second flowed upward from the Cockfield aquifer into the Mississippi River alluvial aquifer in the model area; however, during 1990, upward flow decreased to 10.97 cubic feet per second (figs. 49, 61). Similarly, during 1990, less flow moved upward from the Sparta through the Cook Mountain Formation into the alluvial aquifer. During 1990, pumping had little effect on leakage between the Cockfield and the Miocene aquifer system, as the thick Yazoo Clay allows only trace quantities of water to move downward (fig. 62).

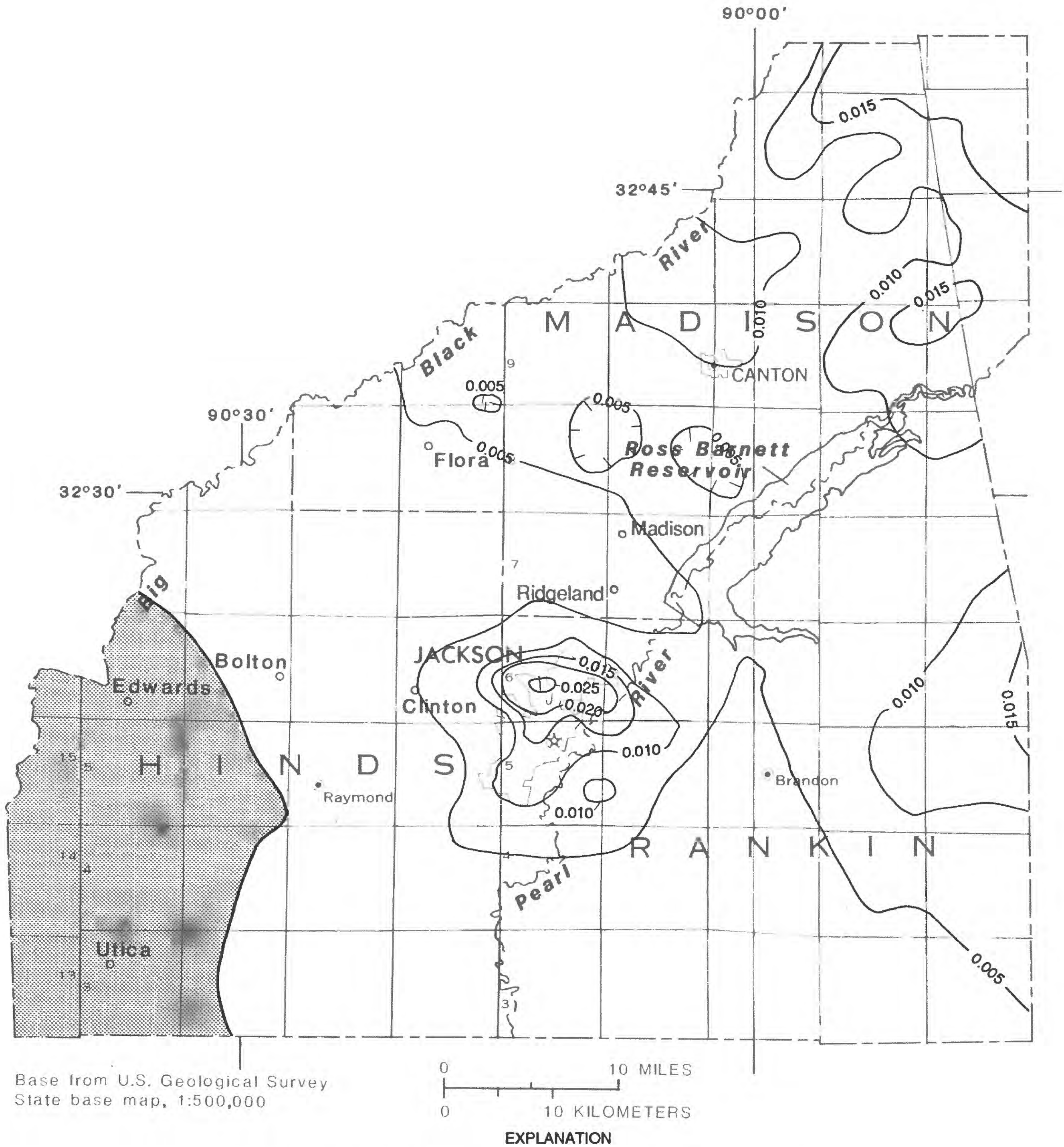
During 1990, pumpage from the Sparta aquifer was more than twice the pumpage from the Cockfield aquifer; hence, water-level declines since predevelopment are larger in the Sparta than in the Cockfield. The larger water-level declines in the Sparta have resulted in leakage downward from the Cockfield into the Sparta. Simulation results indicate that during 1990 about 4.88 cubic feet per second (about twice the predevelopment rate) moved downward from the Cockfield through the Cook Mountain Formation into the Sparta in the model area (fig. 61). In the three-county area, 1990 simulation results indicate that the highest rate of flow downward from the Cockfield into the Sparta occurs over the Jackson Dome, where as much as 0.025 inch per year entered the Sparta (fig. 64). Heavy pumping from the Sparta in the Jackson area, along with the thinning of the confining unit over the dome, contribute to the increased downward leakage in the Jackson area. Outside the Jackson area, leakage downward to the Sparta increases to the east and northeast with a maximum rate as much as 0.015 inch per year in northeastern Madison County. In southwestern Hinds County, 1990 simulation results indicate that leakage reverses, and flow is upward from the Sparta into the Cockfield (fig. 64). The trend of upward flow increases in both aquifers to the west and southwest toward the regional discharge areas in the Mississippi River alluvial aquifer.

During 1990, pumpage from the Sparta aquifer resulted in more upward flow through the Zilpha Clay from water-bearing units underlying the Sparta. Total flow upward into the Sparta in the model area during 1990 was small, about 0.54 cubic foot per second (fig. 61). Throughout most of the three-county area during 1990, vertical flow into the Sparta from underlying units was less than 0.003 inch per year; however, in the Jackson area, flow was slightly larger because of the combined effect of heavy pumping from the Sparta and thinner confining unit (fig. 65).

Flow Budget

Total net flow through the Cockfield aquifer in the model area increased more than 50 percent from predevelopment rates to about 40 cubic feet per second during 1990 (fig. 66). Recharge to the Cockfield in the outcrop areas increased 78 percent from predevelopment to about 14.3 cubic feet per second, and recharge to the aquifer from leakage through the Yazoo Clay almost doubled from predevelopment conditions to about 23.22 cubic feet per second. About 2.20 cubic feet per second was released from storage in the Cockfield aquifer. Pumpage during 1990 from the Cockfield aquifer in the model area was about 20.88 cubic feet per second. Leakage downward from the Cockfield aquifer to the Sparta aquifer during 1990 almost doubled to 4.88 cubic feet per second, and flow to the Mississippi River alluvial aquifer decreased about 41 percent from the predevelopment rate to about 10.97 cubic feet per second.

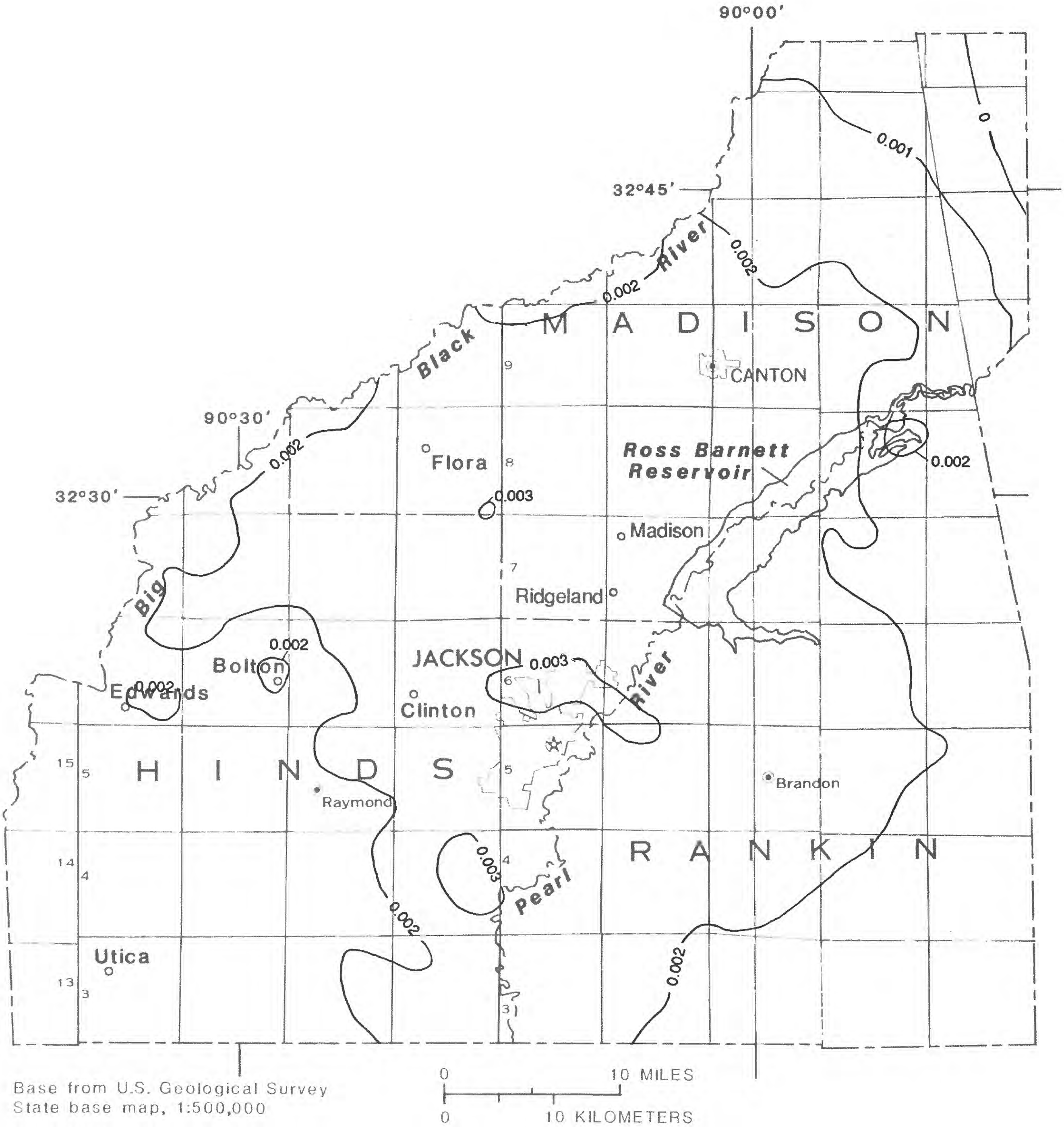
Simulation results indicate that total flow through the Sparta aquifer during 1990 in the model area more than doubled from the predevelopment rate to about 57 cubic feet per second. Recharge to the Sparta from the outcrop area increased from about 21.92 cubic feet per second during predevelopment to 46.89 cubic feet per second during 1990. Combined leakage into the Sparta from the Cockfield and from land surface through the Cook Mountain Formation almost doubled from predevelopment rates in the model area to 6.61 cubic feet per second. Upward leakage to the Sparta aquifer from underlying units increased slightly to about 0.54 cubic foot per second during 1990, and



EXPLANATION

- AREA OF FLOW FROM THE COCKFIELD AQUIFER TO THE SPARTA AQUIFER
- AREA OF FLOW FROM THE SPARTA AQUIFER TO THE COCKFIELD AQUIFER
- 0.010 — LINE OF EQUAL VERTICAL FLOW--Hachures indicate area of lesser vertical flow. Interval 0.005 inch per year

Figure 64.--Simulated vertical flow between the Cockfield aquifer and the Sparta aquifer during 1990 in the three-county study area.



EXPLANATION

— 0.003 — LINE OF EQUAL VERTICAL FLOW--Interval 0.001 inch per year

Figure 65.--Simulated vertical flow to the Sparta aquifer from underlying units during 1990 in the three-county study area.

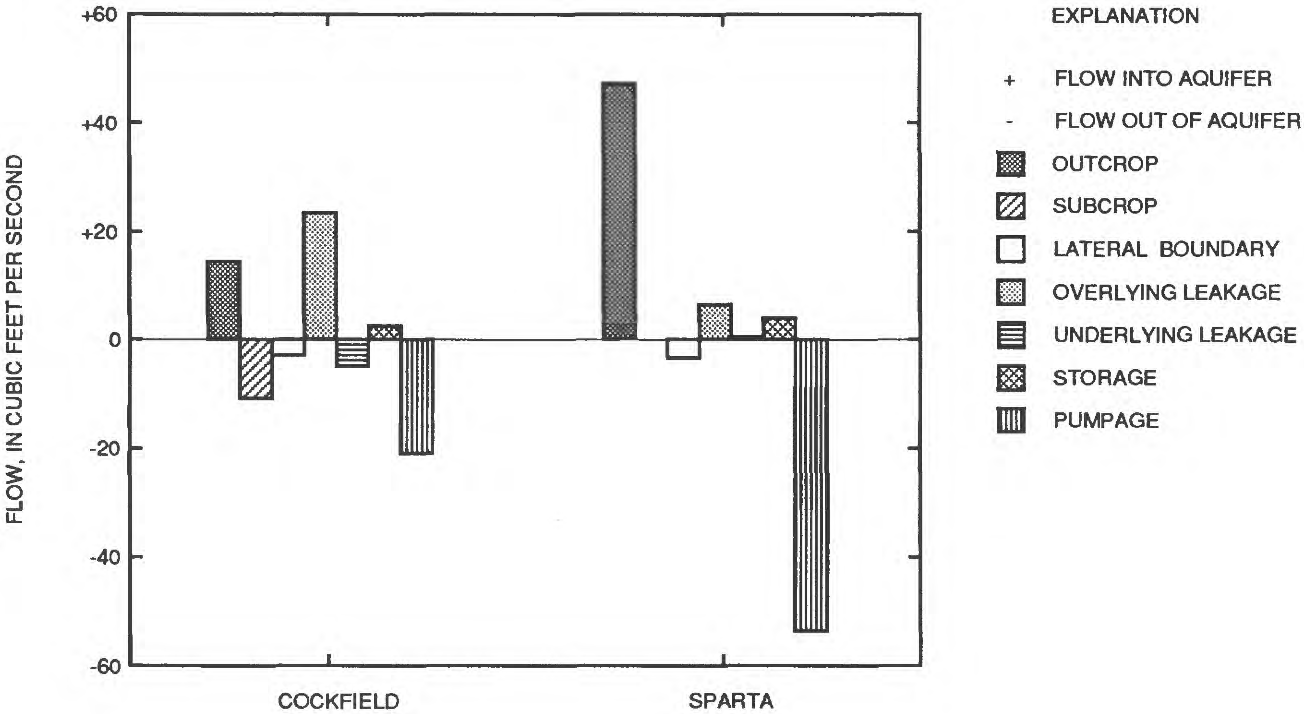


Figure 66.--Simulated 1990 flow budget for the Cockfield and Sparta aquifers in the model area.

about 3.84 cubic feet per second was released from storage in the Sparta aquifer. Pumpage from the aquifer in the model area during 1990 was about 53.94 cubic feet per second. Flow out of the model area across the lateral boundaries decreased from about 25.84 cubic feet per second before development to 3.43 cubic feet per second during 1990. During 1990, most of the water that flowed out of the model area at the lateral boundaries in the Sparta probably flowed to pumping centers outside the model area and to the Mississippi River alluvial aquifer.

Simulation of 2000 Flow Conditions

The calibrated model, which represents flow conditions from 1920 through 1990, was used to make two transient model simulations projecting flow conditions in the Cockfield and Sparta aquifers through 2000. In one simulation, a hypothetical uniform 25-percent pumpage rate increase from 1990 rates was applied throughout the model area for both aquifers for 1990 through 2000; in the other simulation, a hypothetical uniform 50-percent pumpage increase for both aquifers was applied throughout the model area for the same period.

The scenarios simulated were not designed to represent estimates of future withdrawals from the two aquifers, but rather to provide insight into possible areal changes in water levels and ground-water flow. The simulations also are examples of how the two aquifers could remain viable sources of water for the three-county area.

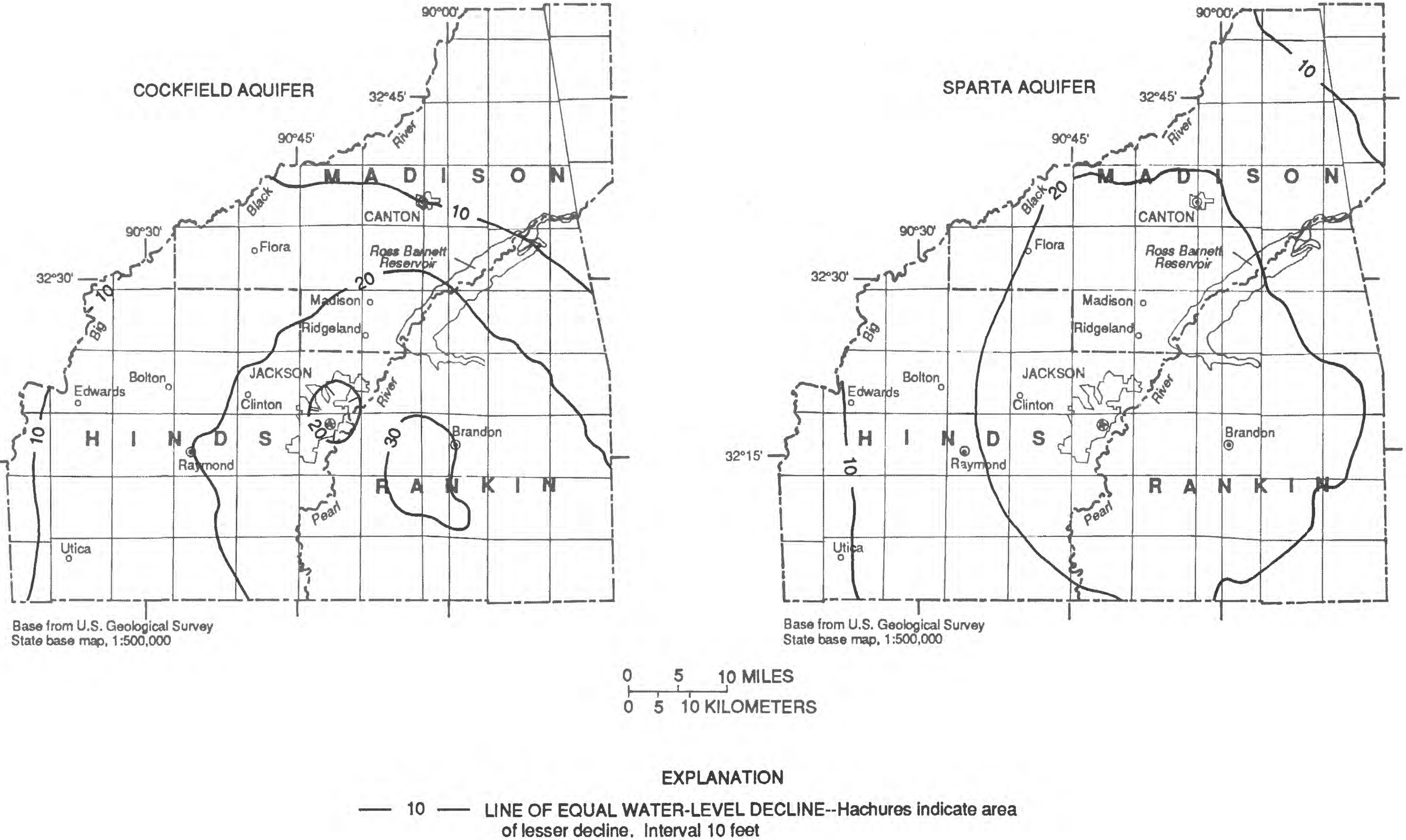


Figure 67.--Simulated water-level declines in the Cockfield and Sparta aquifers from 1990 through 2000 in the three-county study area assuming a uniform 25-percent pumpage increase in the model area.

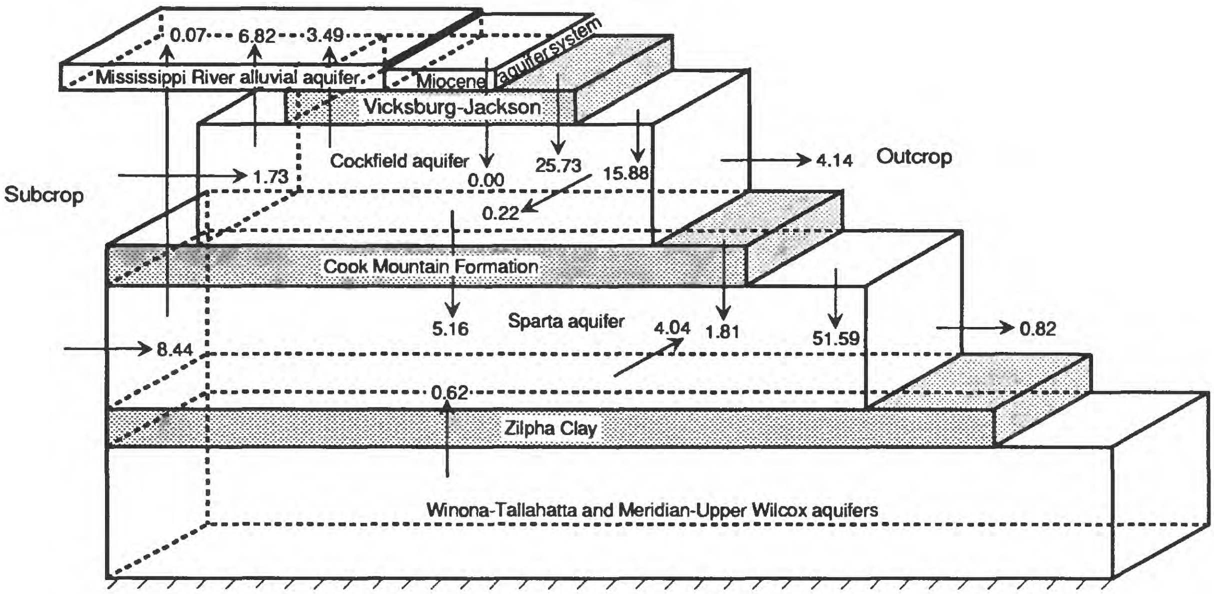
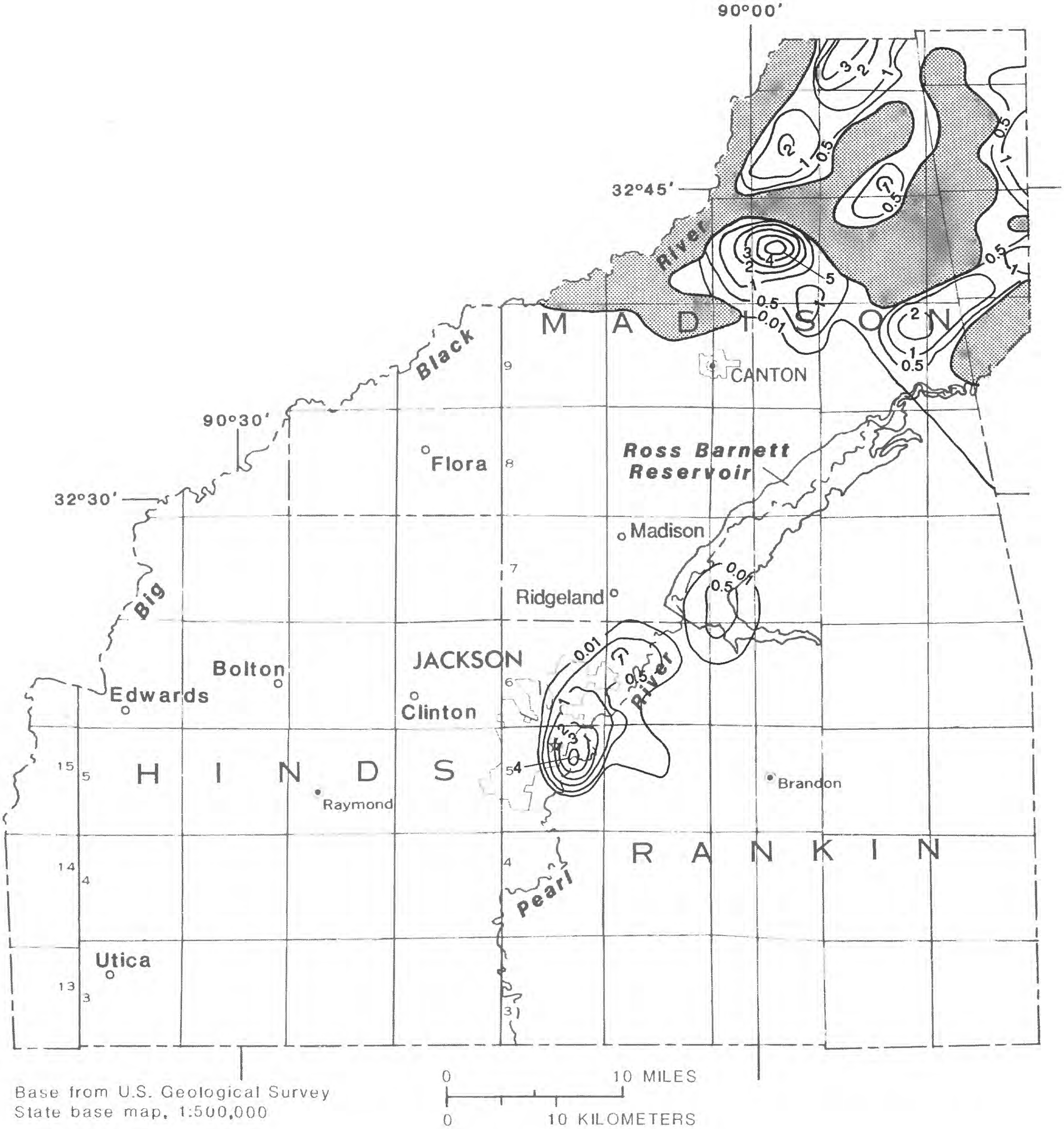


Figure 68.--Simulated 2000 vertical and horizontal flow for the model area assuminga uniform 25-percent pumpage increase in the model area. Numbers indicate flow in cubic feet per second.

Uniform 25-Percent Pumpage Increase from 1990 Rates

Increasing pumpage 25 percent from the 1990 rate for the Cockfield aquifer resulted in a withdrawal rate from the aquifer of 16.9 million gallons per day in the model area and 10.5 million gallons per day in the three-county area. The Sparta pumpage with the uniform 25-percent increase was 43.6 million gallons per day in the model area and 23.1 million gallons per day in the three-county area.

Model simulation results indicate that, with the 25-percent pumpage increase during 1990 to 2000 in the Cockfield aquifer, water levels would decline from 2 to 3 feet per year at observation well locations in heavily pumped areas (fig. 13). The largest water-level declines in the study area in the Cockfield were in western Rankin County, adjacent to Jackson, where water levels were about 30 feet below 1990 levels (fig. 67). Over the crest of the Jackson Dome, Cockfield water levels declined less than 20 feet, whereas in the area surrounding the crest, declines were greater than 20 feet. The smaller declines over the crest of the dome were because of recharge to the Cockfield from land surface. Most of the recharge from land surface probably came from the Pearl River. Declines were smaller toward the Cockfield outcrop in northeastern Madison County area and westward outside the Jackson area.



EXPLANATION

AREA OF DISCHARGE

AREA OF RECHARGE

— 0.5 — LINE OF EQUAL RECHARGE--Interval in inches per year is variable

Figure 69.--Simulated surficial recharge in area of outcrop and vertical flow from overlying units to the Cockfield aquifer during 2000 in the three-county study area assuming a uniform 25-percent pumpage increase in the model area.

Model simulation results indicate that with the 25-percent pumpage increase during 1990 to 2000, the Sparta aquifer generally had declines similar to those in the Cockfield aquifer of about 2 to $2^{1}/2$ feet per year in the heavily pumped areas (fig. 18). The largest declines in the Sparta aquifer would occur at Jackson, with smaller declines extending northward to include Canton (fig. 67). Within the area of largest decline, water levels were more than 20 feet below 1990 levels and throughout most of the area outside the area of largest decline, the simulation indicated water levels in the aquifer would be 10 to 20 feet below 1990 levels.

The simulated uniform 25-percent pumpage increase resulted in increased recharge to the Cockfield aquifer in the outcrop area and a decrease in discharge from the Cockfield to the Mississippi River alluvial aquifer (fig. 68). In the Cockfield aquifer and Yazoo Clay outcrop areas, recharge to the Cockfield would increase from 37.52 cubic feet per second during 1990 to 41.61 cubic feet per second during 2000. Total net discharge in the model area from the Cockfield aquifer to the Mississippi River alluvial aquifer would decrease slightly from 10.97 cubic feet per second during 1990 to 10.31 cubic feet per second during 2000. The simulated 25-percent pumpage increase would result in total recharge to the Sparta aquifer in the model area to increase in outcrop areas from 48.62 cubic feet per second during 1990 to 53.40 cubic feet per second during 2000 (fig. 68).

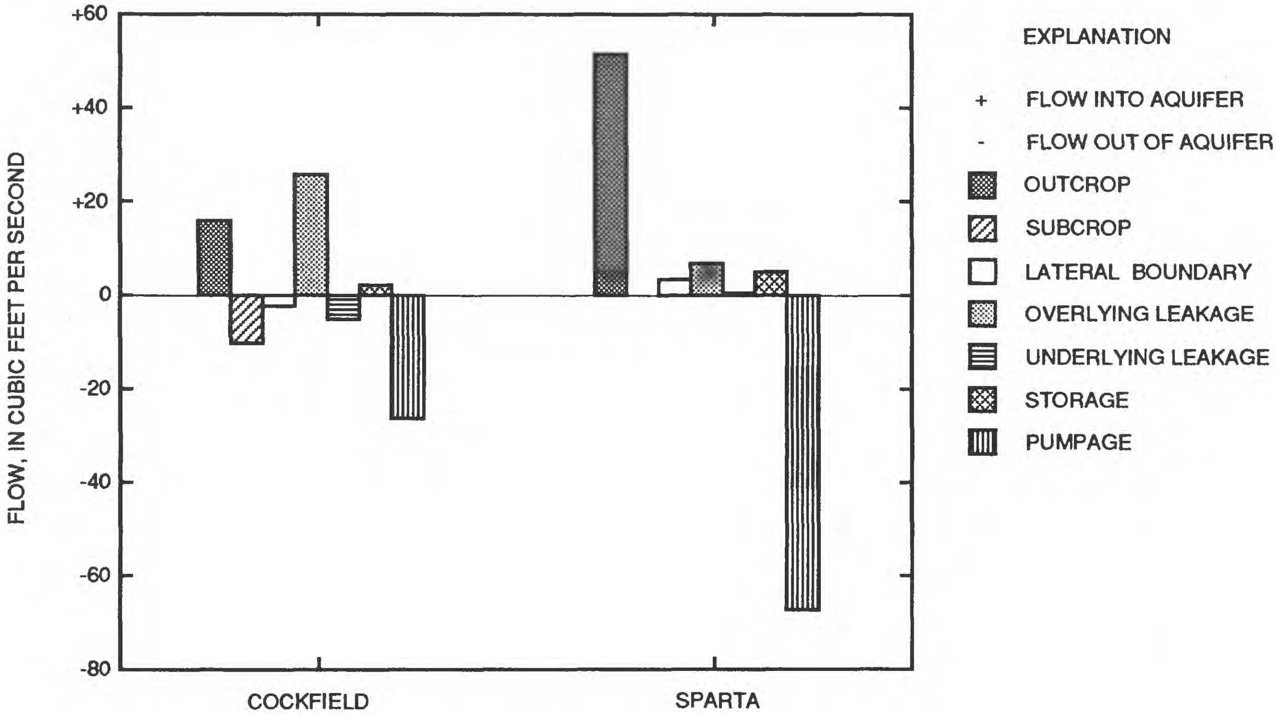


Figure 70.--Simulated 2000 flow budget for the Cockfield and Sparta aquifers in the model area assuming a uniform 25-percent pumpage increase in the model area.

In the three-county area, recharge in the Cockfield outcrop area in northeastern Madison County would increase slightly from 1990 through 2000 with the 25-percent pumpage increase, whereas recharge in the outcrop area over the Jackson Dome would increase substantially (fig. 69). A small area along the Pearl River over the Jackson Dome would have as much as 4 inches per year recharge to the aquifer during 2000 (fig. 69). In northeastern Madison County, in and adjacent to the outcrop area, recharge during 2000 would increase slightly, and the area of discharge would decrease.

Model simulation indicates that with the 25-percent pumpage increase, net lateral flow at the west boundary into the model area in the Cockfield aquifer would increase from 1.10 cubic feet per second during 1990 to 1.73 cubic feet per second during 2000. Net lateral flow at the north boundary into the model area in the Cockfield remained about the same, but net lateral flow at the east boundary out of the model area in the Cockfield would decrease from 4.31 cubic feet per second during 1990 to 4.14 cubic feet per second during 2000. Net lateral flow at the west boundary into the Sparta would increase substantially from 3.24 cubic feet per second during 1990 to 8.44 cubic feet per second during 2000. Net lateral flow at the north and east boundaries, out of the model area in the Sparta, would decrease to 4.04 and 0.82 cubic feet per second, respectively, during 2000 (fig. 68).

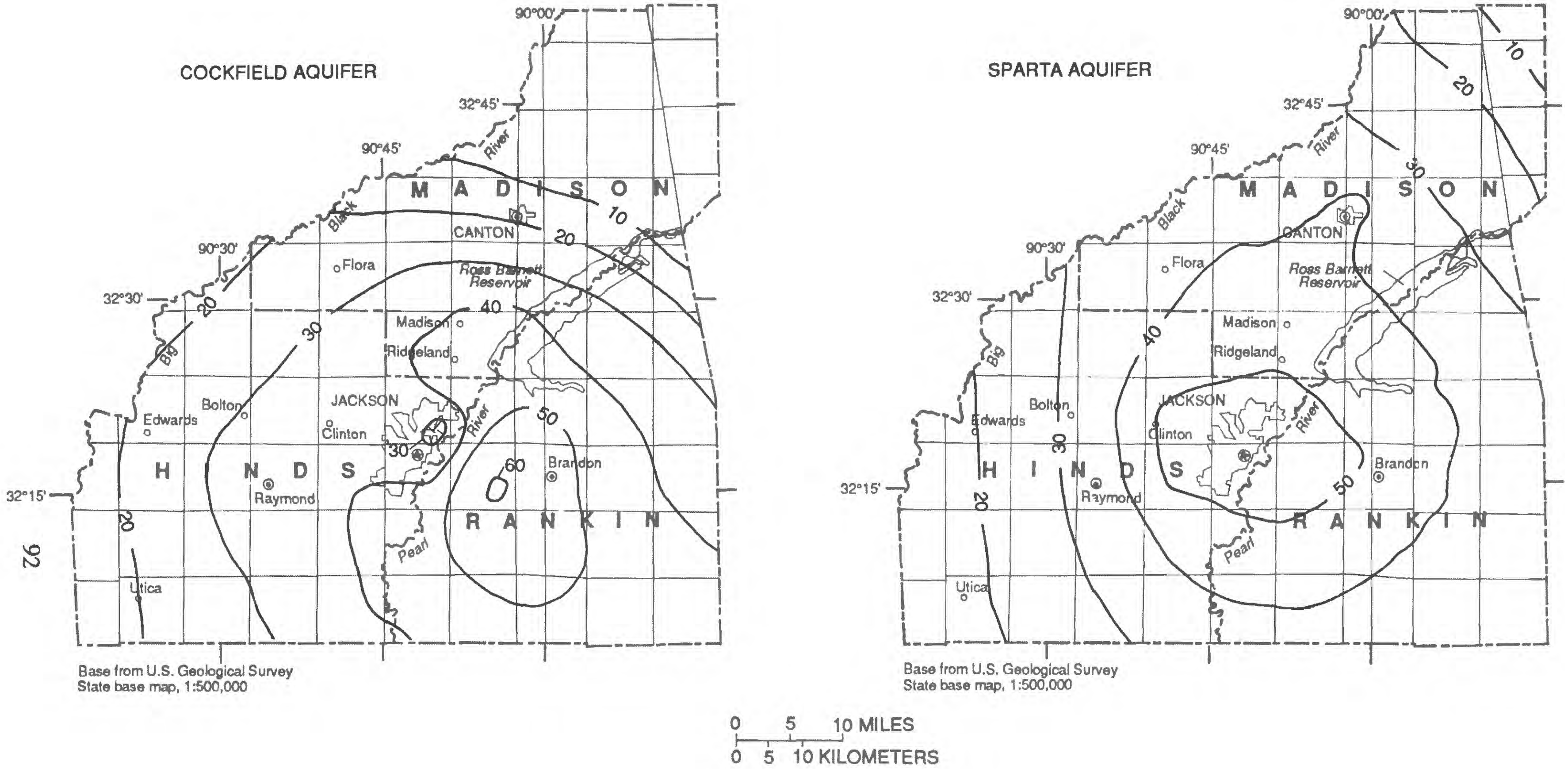
The 25-percent pumpage increase would result in additional leakage downward into the Sparta aquifer from the Cockfield aquifer and upward into the Sparta from underlying water-bearing units. Leakage downward from the Cockfield aquifer into the Sparta aquifer would increase from 4.88 cubic feet per second during 1990 to 5.16 cubic feet per second in the model area during 2000, whereas upward flow into the Sparta from underlying units would increase from 0.54 cubic foot per second during 1990 to 0.62 cubic foot per second during 2000 (fig. 68).

In terms of percentage change of flow in the Cockfield and Sparta from 1990 to 2000 with a uniform 25-percent pumpage increase, the net flow at the lateral boundaries was the flow component most affected by the increased pumpage (fig. 66 and 70). During 1990, a net of 2.99 cubic feet per second flowed out of the model area across the lateral boundaries in the Cockfield aquifer; however, during 2000, a net of 2.19 cubic feet per second would flow out. Net flow at the lateral boundaries in the Sparta aquifer would change from 3.43 cubic feet per second out of the model area during 1990 to 3.58 cubic feet per second into the model area during 2000 with the 25-percent pumpage increase. The dominant flow components in the 2000 simulation (as well as in the 1990 simulation), in terms of magnitude in the Cockfield, were recharge in the aquifer outcrop area (15.88 cubic feet per second), leakage from land surface at and near the updip extent of the Yazoo Clay outcrop (25.73 cubic feet per second), pumpage (26.10 cubic feet per second), and discharge to the Mississippi River alluvial aquifer (10.31 cubic feet per second). The largest flow components in the Sparta during 2000 would be pumpage (67.43 cubic feet per second) and recharge in the aquifer outcrop area (51.59 cubic feet per second).

Uniform 50-Percent Pumpage Increase from 1990 Rates

Increasing pumping 50 percent from the 1990 rate in the Cockfield aquifer would result in withdrawal rates of 20.2 million gallons per day in the model area and 12.6 million gallons per day in the three-county area. Increasing pumping 50 percent in the Sparta aquifer would result in withdrawal rates of 53.3 million gallons per day in the model area and 27.8 million gallons per day in the three-county area.

Model results from the 50-percent pumpage increase scenario for 1990 to 2000 indicate that simulated water levels in the Cockfield in the Jackson area would decline about 4 to 6 feet per year, or about double the rate of the 25-percent pumpage increase (fig. 37). The largest water-level declines from 1990 levels in the aquifer probably would occur in west-central Rankin County, where simulated water levels during 2000 would be as much as 60 feet below simulated 1990 water levels (fig. 71). As was indicated in the 25-percent pumpage increase scenario, water-level declines in the Cockfield aquifer would be less over the crest of the Jackson Dome than in the surrounding area. Recharge from



EXPLANATION

— 10 — LINE OF EQUAL WATER-LEVEL DECLINE--Hachures indicate area of lesser decline. Interval 10 feet

Figure 71.--Simulated water-level declines in the Cockfield and Sparta aquifers from 1990 through 2000 in the three-county study area assuming a uniform 50-percent pumpage increase in the model area.

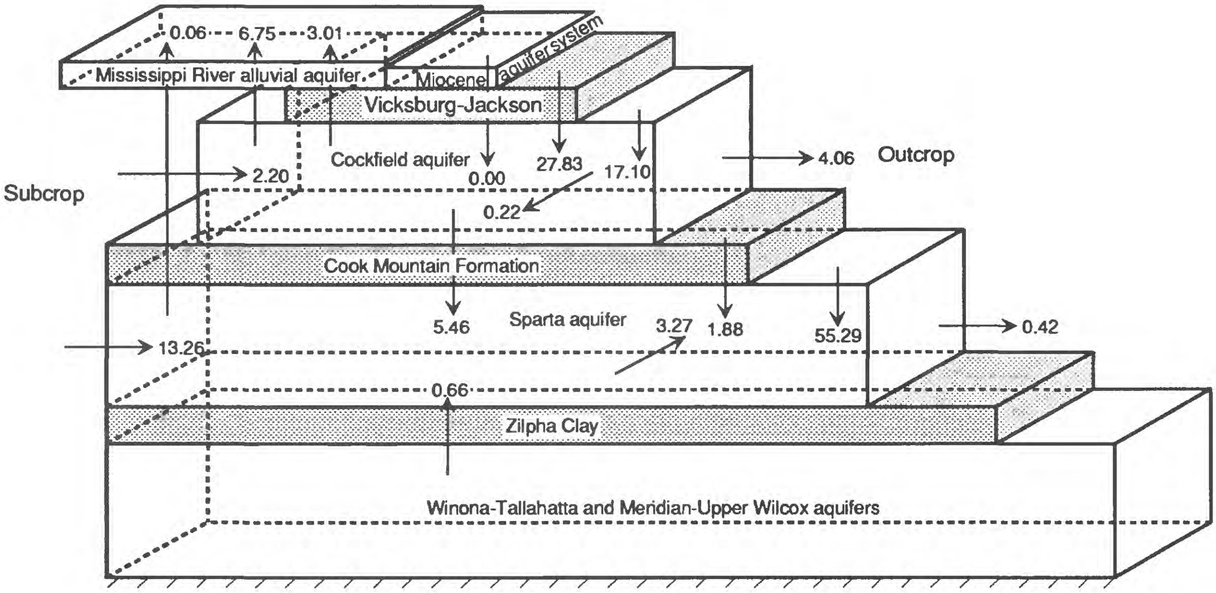
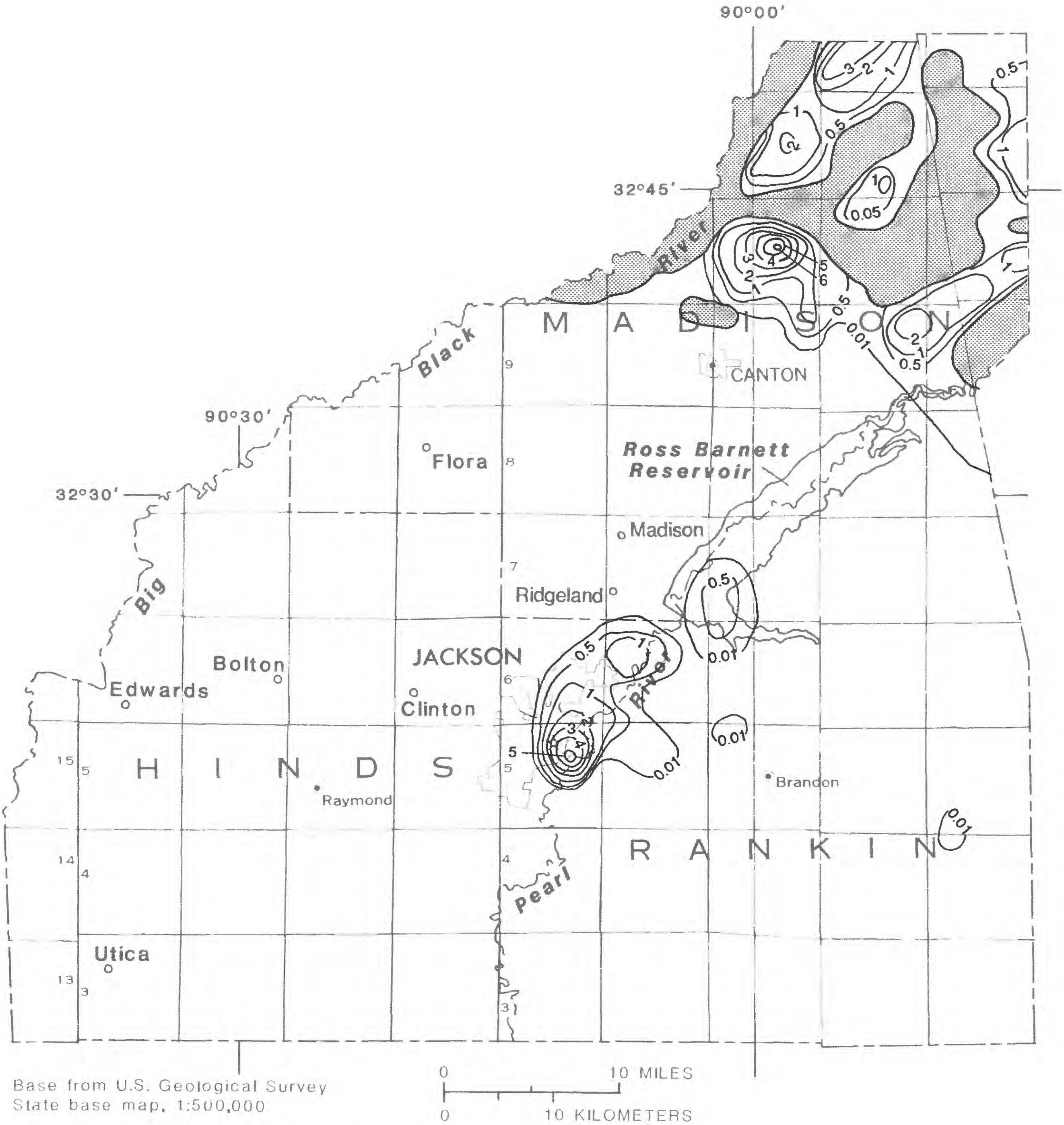


Figure 72.--Sketch showing simulated 2000 vertical and horizontal flow for the model area assuming a uniform 50-percent pumpage increase in the model area. Numbers indicate flow in cubic feet per second.



EXPLANATION

AREA OF DISCHARGE

AREA OF RECHARGE

— 0.01 — LINE OF EQUAL RECHARGE--Interval inches per year is variable

Figure 73.--Simulated surficial recharge in area of outcrop and vertical flow from overlying units to the Cockfield aquifer during 2000 in the three-county study area assuming a uniform 50-percent pumpage increase in the model area.

land surface over the dome probably would lessen the water-level declines in the aquifer to about 30 feet from 1990 through 2000 for the 50-percent pumpage increase. Outside the Jackson area, water-level declines in the aquifer probably would not be as large. In northeastern Madison County near the aquifer outcrop area, water levels would be less than 10 feet below 1990 levels.

Simulated water levels in observation wells completed in the Sparta aquifer in the Jackson area declined from 4½ to 5½ feet per year during 1990 through 2000, with a 50-percent pumpage rate increase from the 1990 rate (fig. 38). In the three-county area, simulated water-level declines in the aquifer were largest in Jackson, where water levels during 2000 would be more than 50 feet below 1990 levels (fig. 71). At Canton, in central Madison County, water levels would be 40 feet below 1990 levels; however, northeast of Canton in extreme northeastern Madison County, simulated water-level declines would decrease rapidly and would be about 10 feet below 1990 levels. Heavy pumping from the Sparta, not only in Jackson but also in Scott and Yazoo Counties (fig. 16), would produce water-level declines from 30 to 40 feet that extended northeastward and westward of the Jackson area beyond the three-county area.

The simulated uniform 50-percent pumpage increase resulted in an increase in recharge to the Cockfield aquifer in the outcrop areas and a decrease in discharge to the Mississippi River alluvial aquifer (figs. 61 and 72). In the Cockfield aquifer and Yazoo Clay outcrop areas, simulated net areal recharge to the Cockfield aquifer would increase from 37.52 cubic feet per second during 1990 to 44.93

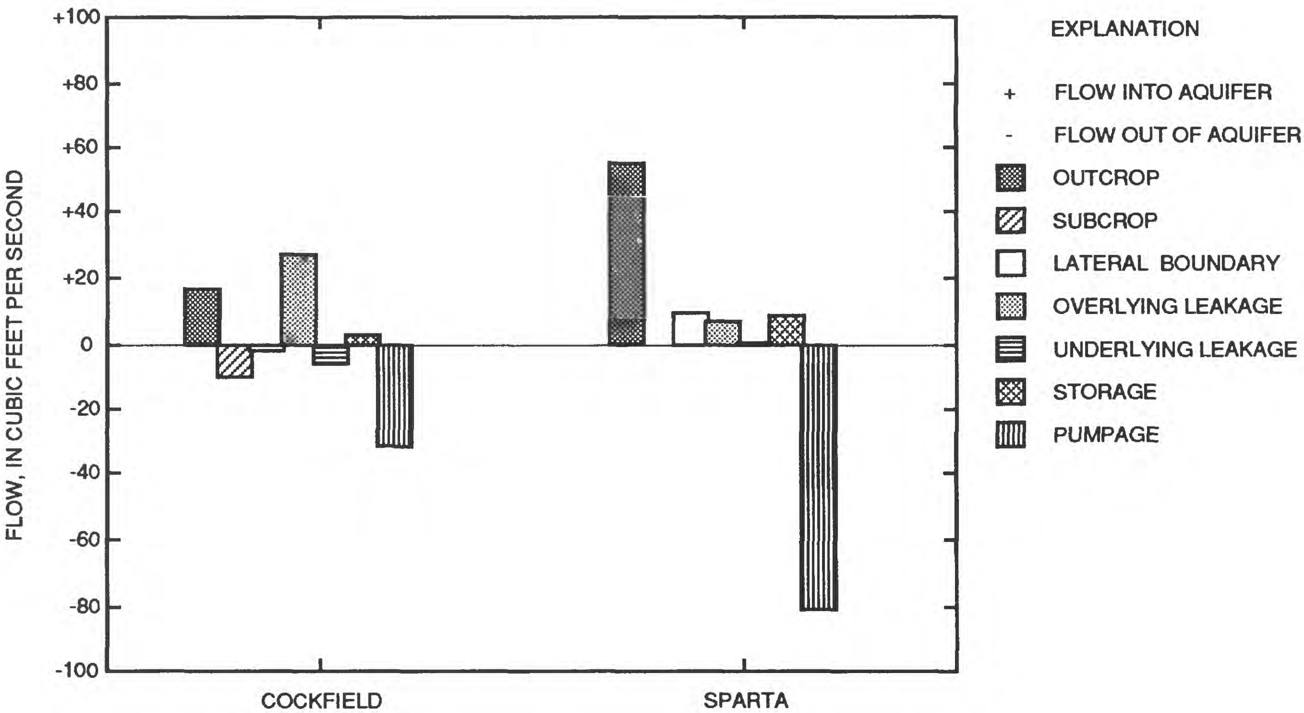


Figure 74.--Simulated 2000 flow budget for the Cockfield and Sparta aquifers in the model area assuming a uniform 50-percent pumpage increase in the model area.

cubic feet per second during 2000. Total net discharge in the model area from the aquifer to the alluvial aquifer would decrease from 10.97 cubic feet per second during 1990 to 9.76 cubic feet per second during 2000. The simulated 50-percent pumpage increase caused total net recharge to the Sparta in outcrop areas to increase from 48.62 cubic feet per second during 1990 to 57.17 cubic feet per second during 2000 (fig. 72).

In the three-county area, the simulated 50-percent pumpage increase during 1990 through 2000 resulted in a maximum recharge rate of about 6 inches per year in a small area of the Cockfield outcrop in northeastern Madison County (fig. 73). In this area of the outcrop, near the confined part of the aquifer, sand beds are thickest and land surface and water levels are high, resulting in high recharge rates. In other recharge areas in northeastern Madison County, maximum rates of recharge ranged from 1 to 3 inches per year. Simulated recharge rates to the Cockfield aquifer during 2000 increased substantially from 1990 rates in the Jackson area. Over the crest of the Jackson Dome in a small area along the Pearl River recharge to the aquifer was about 5 inches per year. The recharge rate decreased rapidly away from the crest of the Jackson Dome where the top of the formation dips into the subsurface.

The simulated 50-percent increase in pumpage increased the lateral flow into the model area across the western boundary in the Cockfield aquifer from 1.10 cubic feet per second during 1990 to 2.20 cubic feet per second during 2000 (fig. 72). The simulated lateral flow out of the model area across the eastern boundary of the Cockfield decreased from 4.31 to 4.06 cubic feet per second. Simulated lateral flow into the model area at the western boundary in the Sparta aquifer increased 10.02 cubic feet per second from 1990 through 2000, resulting in 13.26 cubic feet per second lateral flow into the model area at the western boundary during 2000. Simulated lateral flow out of the model area across the northern and eastern boundaries of the Sparta decreased from 1990 rates to 3.27 cubic feet per second and 0.42 cubic foot per second, respectively, during 2000 (fig. 72).

Vertical flow into the Sparta aquifer from the Cockfield aquifer and from underlying water-bearing units increased as a result of the simulated 50-percent pumpage rate increase. Simulation results indicate that during 2000, 5.46 cubic feet per second would flow downward from the Cockfield into the Sparta in the model area. During 2000, 0.66 cubic foot per second would flow upward into the Sparta from underlying water-bearing units in the model area (fig. 72).

Total net lateral flow at the lateral boundaries is the flow component most affected (in percentage flow change from 1990 through 2000) by the simulated uniform 50-percent pumpage increase in the two aquifers; however, the flows at the lateral boundaries during 2000 were a small part of the flow budget, accounting for only about 3 percent of the total Cockfield aquifer flow budget and about 12 percent of the Sparta aquifer flow budget (fig. 74). One possible contributing factor to the substantial percentage change in flow at the lateral boundaries is that heads at the lateral boundaries were assumed to remain at 1990 levels for the pumping interval 1990 through 2000. This assumption was based on pumping outside the model area remaining at or near 1990 rates during 1990 to 2000. As was the case during 1990, most of the 2000 flow budget for the Cockfield aquifer consisted of recharge from the outcrop (17.10 cubic feet per second), leakage into the aquifer from land surface through the Yazoo Clay (27.83 cubic feet per second), and pumpage (31.32 cubic feet per second). Simulation results for the Sparta aquifer indicate that of the 80.92 cubic feet per second pumped from the aquifer during 2000 about 68 percent would come from recharge in the outcrop area within the model area. The balance of the water came from the combined contribution of flow across the lateral boundaries from outside the model area (9.57 cubic feet per second), from aquifer storage (8.73 cubic feet per second), and from downward leakage from the Cockfield aquifer through the Cook Mountain Formation (7.34 cubic feet per second).

SUMMARY

The Cockfield and Sparta aquifers, the principal sources of ground water in Hinds, Madison, and Rankin Counties in west-central Mississippi, supply more than 95 percent of the ground water pumped in the three-county study area. During 1990, about 27 million gallons per day of freshwater was pumped from the Cockfield and Sparta aquifers in the three-county area.

The Cockfield Formation crops out in the study area in northeastern Madison County and in a small area in Hinds and Rankin Counties over the crest of the Jackson Dome along the Pearl River. The geologic units are displaced about 600 to 700 feet upward over the crest of the dome. The Cockfield Formation dips about 20 feet per mile to the southwest across the study area. Total thickness of sand in the Cockfield aquifer generally ranges from 100 feet in and near outcrop areas to 500 feet in southwestern Hinds County. The average horizontal hydraulic conductivity of the Cockfield aquifer in the study area is 39 feet per day. Pumpage from the aquifer in the three-county area increased from about 2.0 million gallons per day during 1965 to about 8.4 million gallons per day during 1990. Water levels declined an average of as much as 2 feet per year from 1960 to 1990 in selected observation wells in heavily pumped parts of the area. Throughout the three-county area, generally the Cockfield contains freshwater that meets drinking-water standards; however, in parts of the study area, color and dissolved iron values do not meet the drinking-water standards.

The Sparta Sand crops out outside the study area and is in the subsurface throughout the three-county area. The Sparta Sand dips regionally about 24 feet per mile to the southwest across the study area. Total sand thickness of the Sparta aquifer ranges from 200 to 400 feet throughout most of the study area. The average horizontal hydraulic conductivity of the Sparta aquifer in the study area is 60 feet per day. Pumpage from the Sparta in the study area increased from about 7.1 million gallons per day during 1965 to 18.5 million gallons per day during 1990, resulting in water-level declines averaging as much as $2^1/2$ feet per year from 1960 to 1990 in selected observation wells in the Jackson area. The Sparta aquifer contains freshwater that generally meets drinking-water standards throughout the three-county area; locally, however, excessive color and dissolved iron may cause water to be unsuitable for domestic and some industrial uses.

A two-layer three-dimensional finite-difference digital ground-water flow model was used to simulate the flow system in the Cockfield and Sparta aquifers in the three-county area. The model was calibrated under transient conditions with pumpage varying with time, using nine stress periods from 1920 through 1990. After calibration, the model was modified to simulate steady-state predevelopment conditions. Finally, a stress period was added to the transient model representing 1990 through 2000. Two hypothetical pumping scenarios were tested in the added stress period. The first scenario assumed a uniform 25-percent pumpage increase from 1990 rates in both aquifers; in the second scenario, a uniform 50-percent pumpage increase was assumed.

The simulated predevelopment potentiometric surface of the Cockfield aquifer decreases to the south-southwest in the eastern part of the model area and to the west-northwest in the central and western part of the area. In the smaller three-county area, the simulated predevelopment surface of the Cockfield decreases to the west in the confined part of the aquifer. In the Jackson area, the simulated Cockfield potentiometric surface generally ranges from 200 to 240 feet above sea level. In a 25-square-mile area over the Jackson Dome, simulated predevelopment water levels in the Cockfield aquifer were at or below the top of the Cockfield Formation but above the top of the sand beds of the Cockfield aquifer.

The simulated predevelopment potentiometric surface of the Sparta aquifer decreases to the south-southwest in the eastern part of the model area and decreases to the west in the central and western part of the area. In the three-county area, the simulated predevelopment potentiometric surface of the aquifer slopes from east to west. In the Jackson area, the simulated predevelopment potentiometric surface of the Sparta ranges from 200 to 220 feet above sea level.

Simulated predevelopment areal net recharge to the Cockfield aquifer in the outcrop area was about 0.12 inch per year in the model area. In the three-county area, simulated predevelopment recharge to the Cockfield in the outcrop area in northeastern Madison County ranges from 0.25 to 2 inches per year, and in the formation outcrop area over the crest of the Jackson Dome along the Pearl River, recharge was about 0.25 inch per year. Simulated predevelopment areal recharge in the model area to the Sparta in the outcrop was about 0.27 inch per year.

Simulated predevelopment horizontal flow at the lateral boundaries in Cockfield aquifer was largest at the west boundary, where about 3.43 cubic feet per second flowed eastward into the model area. In the Sparta aquifer the largest lateral flow also was at the west boundary, where about 16.20 cubic feet per second flowed westward out of the model area.

Simulation of predevelopment conditions indicates that about 18.64 cubic feet per second moved upward into the Mississippi River alluvial aquifer from the Cockfield aquifer in the model area. The Sparta aquifer subcrops the alluvial aquifer outside the model area, but within the model area, simulation of predevelopment conditions indicates that 0.16 cubic foot per second moved upward from the aquifer through the Cook Mountain Formation into the alluvial aquifer. Predevelopment vertical flow between the Cockfield and Sparta in the model area was downward from the Cockfield into the Sparta at a rate of about 2.52 cubic feet per second. Predevelopment leakage between the Sparta and underlying water-bearing units was negligible; about 0.32 cubic foot per second flowed upward into the aquifer in the model area.

Simulations of transient conditions indicate that during 1990, water levels in the Cockfield aquifer were as much as 120 feet below predevelopment levels in the Jackson area east of the Pearl River. Over the Jackson Dome, water-level declines in the Cockfield are not as great because of recharge from land surface. Simulated 1990 water levels in the Sparta in the Jackson area were about 140 feet below simulated predevelopment levels.

Simulation results indicate that, as a result of pumping from the Cockfield aquifer in the model area, the average areal recharge in the aquifer outcrop area during 1990 increased about 78 percent over the predevelopment rate to about 0.22 inch per year. Simulated recharge to the aquifer over the Jackson Dome was as much as 3 inches per year during 1990. During 1990, simulated recharge in the model area to the Sparta in the aquifer outcrop was about 0.57 inch per year, more than double the predevelopment rate. Pumpage from the Cockfield aquifer decreased discharge from the aquifer to the Mississippi River alluvial aquifer. During 1990, about 6.91 cubic feet per second flowed to the alluvial aquifer from the Cockfield aquifer in the model area, about 16 percent less than the predevelopment rate. Leakage downward from the Cockfield into the Sparta during 1990 was about 4.88 cubic feet per second, about double the predevelopment rate. In the Jackson area, downward leakage into the Sparta from the Cockfield during 1990 was as much as 0.025 inch per year over the Jackson Dome. During 1990, vertical flow into the Sparta from underlying water-bearing units was small, about 0.54 cubic foot per second in the model area.

Increasing the pumpage by a uniform 25 percent from the 1990 rate in the Cockfield and Sparta aquifers from 1990 to 2000 would cause water levels to decline about 30 feet in the Cockfield aquifer in heavily pumped areas and about 20 feet in the Sparta aquifer. Over the crest of the Jackson Dome, Cockfield water-level declines would not be as large because of recharge from land surface.

The simulated 25-percent pumpage increase would result in an increase in recharge from 1990 simulated rates in outcrop areas of the Cockfield and Sparta aquifers. In the Cockfield Formation outcrop area along the Pearl River at Jackson over the Jackson Dome, as much as 4 inches per year recharge would be entering the aquifer from the land surface by 2000. Total net discharge from the Cockfield aquifer to the Mississippi River alluvial aquifer would decrease slightly from 10.97 cubic feet per second in 1990 to 10.31 cubic feet per second by 2000. Simulated net lateral flow into the Sparta aquifer at the west boundary would increase substantially from 3.24 cubic feet per second in 1990 to 8.44 cubic feet per second by 2000. The simulated 25-percent pumpage increase from 1990 through 2000 would result in an increase of vertical flow from the Cockfield aquifer to the Sparta aquifer from 4.88 cubic feet per second to 5.16 cubic feet per second in the model area, whereas vertical flow into the Sparta from underlying water-bearing units would increase from 0.54 to 0.62 cubic foot per second.

Increasing pumping by a uniform 50 percent from the 1990 rates in the Cockfield and Sparta aquifers from 1990 to 2000 would cause water levels to decline about 60 feet in west-central Rankin County in the Cockfield aquifer. Over the Jackson Dome, simulated water levels in the Cockfield aquifer would decline about 30 feet from 1990 through 2000. Water levels would decline more than 50 feet below 1990 levels in the Sparta aquifer in the Jackson area by 2000. Areal net recharge in the model area to the Cockfield and Sparta in outcrop areas would increase to 44.93 cubic feet per second and 57.17 cubic feet per second, respectively, during 2000. Over the Jackson Dome along the Pearl River, recharge to the Cockfield from land surface would be about 5 inches per year during 2000. Simulated lateral flow in the Cockfield out of the model area at the west boundary would decrease to 4.06 cubic feet per second, and lateral flow into the model area at the west boundary in the Sparta would increase to 13.26 cubic feet per second during 2000. Simulated vertical flow into the Sparta from the Cockfield and from water-bearing units underlying the Sparta would increase to 5.46 cubic foot per second and 0.66 cubic feet per second, respectively, during 2000.

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