HYDROGEOLOGY OF THE SOUTHEASTERN COASTAL PLAIN AQUIFER SYSTEM IN PARTS OF EASTERN MISSISSIPPI AND WESTERN ALABAMA

REGIONAL AQUIFER-SYSTEM ANALYSIS

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Hydrogeology of the Southeastern Coastal Plain Aquifer System in Parts of Eastern Mississippi and Western Alabama

By MICHAEL J. MALLORY

REGIONAL AQUIFER-SYSTEM ANALYSIS—SOUTHEASTERN COASTAL PLAIN

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1410-G

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.

Dallas L. Peck
Director

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CONVERSION FACTORS AND ALTITUDE DATUM

Factors for converting inch-pound units to metric units (International System) and abbreviations of units

Multiply inch-pound units	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)

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.

HYDROGEOLOGY OF THE SOUTHEASTERN COASTAL PLAIN AQUIFER SYSTEM IN PARTS OF EASTERN MISSISSIPPI AND WESTERN ALABAMA

By Michael J. Mallory

ABSTRACT

The 130,000-mi^2 Southeastern Coastal Plain aquifer system in South Carolina, Georgia, Alabama, Mississippi, and adjacent areas of northern Florida and southwestern North Carolina is composed of clastic sediments of Cretaceous and Tertiary age. The clastic sediments that constitute the aquifer system have been separated regionally into seven major hydrogeologic units.

In a 32,000-mi^2 area in eastern Mississippi and western Alabama, Cretaceous clastic sediments contain the Chattahoochee River aquifer (locally the Ripley aquifer), the upper Black Warrior River aquifer (locally the Eutaw-McShan aquifer), and the lower Black Warrior River aquifer (locally the Tuscaloosa aquifer). This sequence of clastic aquifers and intervening confining clays and chalks is a part of the larger, regional Southeastern Coastal Plain aquifer system. This aquifer system is separated from overlying aquifers of Tertiary age by the extensive Pearl River confining unit in the Midway Group. There is little flow between aquifers in the Cretaceous sediments and aquifers in younger sediments. The Southeastern Coastal Plain aquifer system overlies low-permeability consolidated rocks of Paleozoic to Jurassic age in the north. In the south, the base of the aquifer system consists of clays of Early Cretaceous age that isolate underlying, very saline water (greater than 10,000 mg/L dissolved solids) from the freshwater of the overlying aquifer system. The downdip limit of the freshwater aquifer system is considered to be located where water in the aquifers becomes saline (greater than 10,000 mg/L dissolved solids). Because of the observed sharpness of the freshwater-saltwater interface, it is assumed that the interface is in dynamic equilibrium and that little or no flow crosses the interface.

Geologic structure and topography exert a profound influence on the movement of water in the aquifer system. In the northern part of the study area, the aquifer system occupies the eastern flank of the Mississippi embayment. In the southern part of the study area, the aquifer system lies on the northern flank of the Gulf Coast geosyncline. The formations that form the aquifer system dip to the west in the northern part of the study area, and the dip gradually changes to a southerly direction in the southern part of the area. Land-surface altitudes generally are highest in northern Mississippi and descend to the south to a low point about 30 mi east of the Mississippi-Alabama State line, where the Tombigbee and Black Warrior Rivers exit from the study area. From there, land-surface altitudes increase into central Alabama. Most of the recharge to the aquifer system occurs in the topographically higher parts of aquifer outcrop areas. Conversely, the low areas of the major river valleys are the primary ground-water discharge areas.

Results from a multiaquifer digital model of the ground-water flow system are used to quantify both predevelopment and 1982 conditions in the aquifer system, including the effects of development by mankind. Flow in the upper and lower Black Warrior River aquifers moves from the higher parts of their outcrops to the regional drains in the valleys of the major rivers in the aquifer outcrop areas. Water entering the regional flow system in northeastern Mississippi in these aquifers flows along a long arcuate path that leads considerably downdip into east-central Mississippi before it flows back updip to emerge as base flow in major streams in western Alabama. Discharge by upward leakage from the upper and lower Black Warrior River aquifers to overlying aquifers is not as significant as had been previously thought, and it accounts for less than 5 percent of the total flow through the two aquifers. However, interlayer leakage between the two aquifers is significant.

Flow in the Chattahoochee River aquifer in the study area is mostly isolated from both the underlying Cretaceous sediments and the overlying Tertiary sediments. Flow in this aquifer extends out of the study area to the northwest beneath the Mississippi embayment.

The amount of water that flows in the regional ground-water flow system is only a small fraction of the amount that enters the local- and intermediate-scale ground-water flow systems. Of an estimated 3,900 ft^3/s (about 7 in./yr) of water that enters the total ground-water flow system, only about 310 ft^3/s under predevelopment conditions (pre-1934), or about 390 ft^3/s under 1982 conditions, enter the regional flow system. These quantities represent about 8 percent of the total flow for predevelopment conditions and about 10 percent for 1982 conditions.

The transition from predevelopment conditions to 1982 conditions was accomplished mainly by an increase in total recharge to the regional flow system, a decrease in discharge to rivers from the regional flow system, and a slight decrease in ground-water storage. These changes balance the 1982 ground-water withdrawal rate of about 160 ft^3/s (103 Mgal/d). Of the total pumpage in 1982, about 51 percent was supplied by decreased discharge to rivers and about 43 percent was supplied by increased recharge to the regional flow system. About 3 percent was supplied by withdrawals from storage in 1982; this percentage has previously been higher for short times immediately after abrupt increases in ground-water withdrawals. The remaining 3 percent of pumpage is supplied by a variety of sources that include changes in vertical leakage from adjacent aquifer systems and decreases in the amount of flow leaving the study area from the Chattahoochee River aquifer.

INTRODUCTION

BACKGROUND

The Southeastern Coastal Plain aquifer system study is part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) Program. The Southeastern Coastal Plain aquifer system provides water over an area of about 130,000 mi^2 in the Southeastern United States. The aquifer system extends from the southwestern flank of the Cape Fear arch in North Carolina to the Mississippi embayment in Mississippi (fig. 1). The Southeastern Coastal Plain aquifer system is located among three adjacent regional aquifer systems: the Northern Atlantic Coastal Plain to the northeast, the Floridan to the south and southeast, and the Gulf Coastal Plain to the west.

The Southeastern Coastal Plain aquifer system is composed of clastic sediments of Cretaceous and Tertiary age in South Carolina, Georgia, Alabama, Mississippi, and adjacent areas of northern Florida and southwestern North Carolina. The clastic sediments that constitute the aquifer system have been subdivided regionally into seven major hydrogeologic units, some of which are hydraulically interconnected with the interfingering and locally overlying Floridan aquifer system. The composition, texture, and bedding character of the major units differ from place to place. Sand aquifers of the Southeastern Coastal Plain aquifer system are massive to thinly bedded, fine- to coarse-grained, quartzose, locally feldspathic, and, in places, include limestone beds. Chalk, clay, shale, and mudstone form the confining units that separate the major aquifers of the Southeastern Coastal Plain aquifer system. Locally, the major regional aquifers have been subdivided into smaller units of subregional extent.

PURPOSE AND SCOPE

This report is one of several chapters of Professional Paper 1410 (fig. 2) that describe different aspects of the Southeastern Coastal Plain aquifer system. This report (chap. G) presents an analysis of the hydrogeology of the clastic Cretaceous Coastal Plain aquifers in parts of eastern Mississippi and western Alabama.

Results from a multiaquifer digital model of ground-water flow are used to quantify predevelopment conditions in the aquifer system as they existed before about 1934 and conditions as of 1980, including the effects of development by mankind. The modeling section of this report documents the use of the model to simulate the regional flow system in the study area.

This report provides descriptions of (1) the hydrogeologic framework and associated ground-water flow system and (2) a calibrated digital computer model capable of assessing the effects of ground-water withdrawals or other stresses on the ground-water flow system.

The study area is about 32,000 mi^2 in western Alabama and eastern Mississippi and includes all or part of 33 counties in Mississippi and all or part of 22 counties in Alabama (fig. 3).

PREVIOUS INVESTIGATIONS

Many geologic and hydrologic studies made in the study area have been published by the U.S. Geological Survey, the Mississippi Bureau of Geology, the Alabama Geological Survey, the Mississippi Research and Development Center, other State and Federal agencies, consulting firms, and others. These studies include:

1. Investigations of the geology or hydrology of a county or group of counties (Ellison and Boswell, 1960; Knowles and others, 1963; LaMoreaux and Toulmin, 1959; Newcome, 1974; Newcome and Bettandorff, 1973; Newton and others, 1961; Paulson and others, 1962; Scott, 1957; Wahl, 1965; Wasson and Tharpe, 1975; Wasson and Thomson, 1970; Wasson and others, 1965).
2. Statewide appraisals of water resources (Averett, 1968; Crider and Johnson, 1906; Newcome, 1971; Smith, 1907; Wasson, 1980).
3. Compilations of water-use data (Callahan, 1976; Pierce, 1972).
4. Investigations of the particular aquifer systems (Cretaceous) of interest to this study throughout their extent in each of the States (Boswell, 1963; Carlston, 1944).
5. Digital computer flow model studies of smaller areas within the area of this study (Gardner, 1981; Kernodle, 1981).

One series of previous investigations is of special significance because it presents a regional overview of the water resources of virtually the entire area of this study. These reports are the various chapters of U.S. Geological Survey Professional Paper 448, "Water resources of the Mississippi embayment." Chapters of interest to this study are 448–A, "Availability of water in the Mississippi embayment" (Cushing and others, 1970); 448–B, "General geology of the Mississippi embayment" (Cushing and others, 1964); 448–C, "Cretaceous aquifers in the Mississippi embayment" (Boswell and others, 1965); and 448–I, "Low-flow characteristics of streams in the Mississippi embayment in Mississippi and Alabama" (Speer and others, 1964).

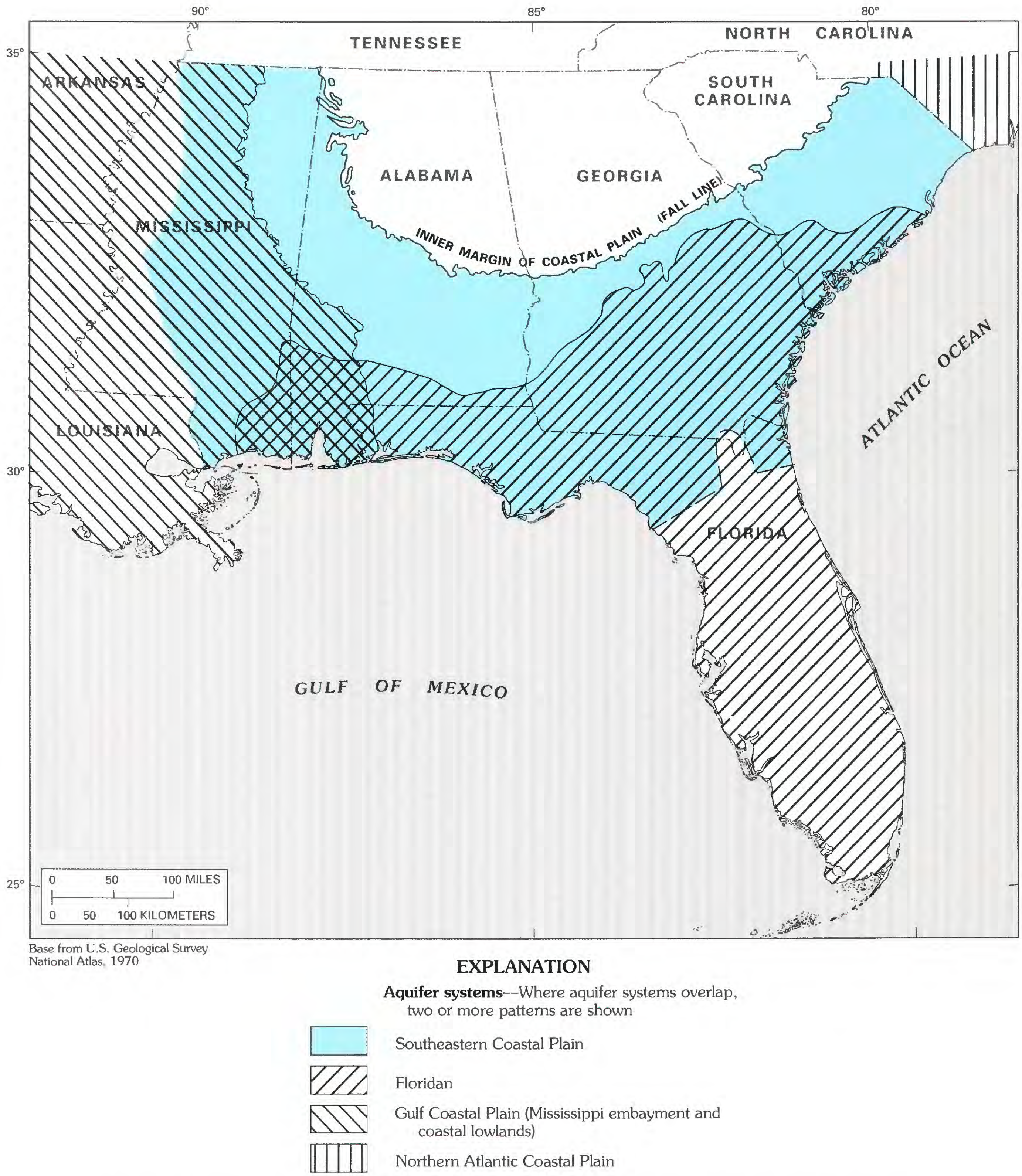


FIGURE 1.—Location of Southeastern Coastal Plain RASA study area and locations of adjacent RASA study areas.

Base modified from U.S. Geological Survey National Atlas, 1970

EXPLANATION

Boundary of regional model area

Boundary of subregional model area

Inner margin of Coastal Plain

1410-G U.S. Geological Survey Professional Paper chapter

FIGURE 2.—Location of regional and subregional model areas, and designations of U.S. Geological Survey Professional Paper chapters.

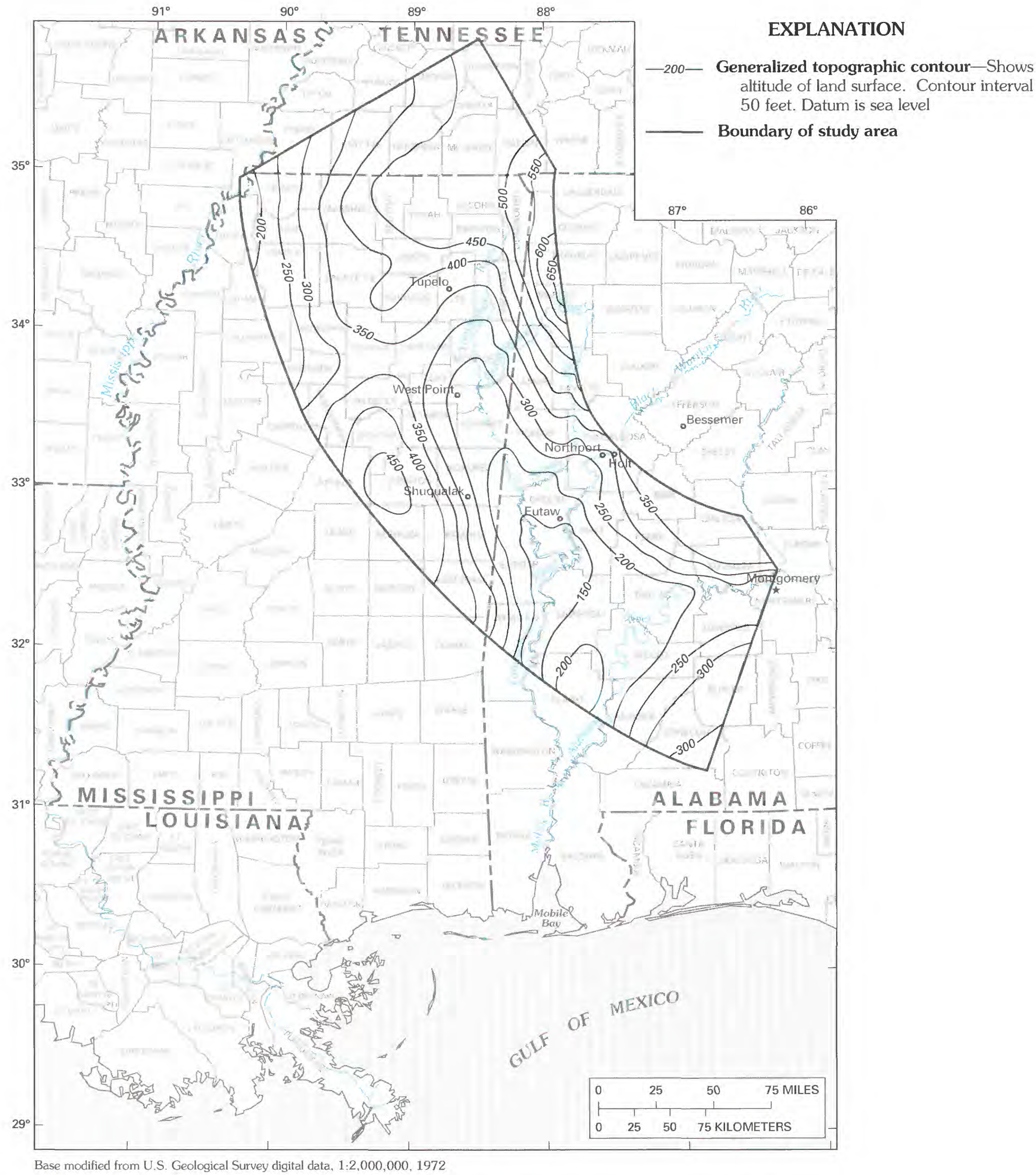


FIGURE 3.—Project area, generalized topography, and major surface drainage features.

DESCRIPTION OF THE AREA

TOPOGRAPHY AND PHYSIOGRAPHY

The study area lies in the Gulf Coastal Plain physiographic province; the part of the area in northern Mississippi is in a major subprovince of the Coastal Plain—the Mississippi embayment. Fenneman (1938) defines five physiographic subdivisions of the study area: the Fall Line Hills, Black Belt, Ripley Cuesta, Flatwoods, and Red Hills Belt (fig. 4). Locally in Mississippi, the Ripley Cuesta is known as the Pontotoc Ridge, the Black Belt is known as the Black Prairies, and the Red Hills Belt is known as the North Central Hills.

These physiographic features are the result of uplift and erosion of the generally unconsolidated coastal plain sediments. The arcuate pattern of these subdivisions reflects closely the outcrops of geologic units in the area. The Fall Line, where unconsolidated Coastal Plain sediments meet consolidated rocks of Paleozoic age, forms the northeastern boundary of the study area.

The Fall Line Hills, a broad belt ranging up to 50 mi in width, is underlain by the Upper Cretaceous sediments, including clay, sand, gravel, and chalk. The sandy and poorly consolidated material of these formations characteristically supports steep slopes, with as much as 250 ft of relief within a half mile being common near the larger streams. Altitudes of hilltops range from a maximum of 806 ft near central Tishomingo County, Miss., to about 400 ft in the southern and southwestern parts of the Fall Line Hills belt (fig. 4). The area of the belt underlain by the thinly bedded sands of the Eutaw Formation is generally somewhat higher and more deeply dissected than the area underlain by the more irregularly bedded sands and gravels of the Tuscaloosa Group to the east and north.

West and south of the Fall Line Hills lies the Black Belt, a lowland formed on the outcrop of the chalk in the Selma Group. This belt of subdued topography is up to 25 mi wide and is topographically lower than either the Fall Line Hills belt to the north and east or the Ripley Cuesta to the south and west. Altitudes between streams in the Black Belt range from 500 ft in northern Mississippi to about 200 ft in western Alabama, ascending again to about 260 ft in central Alabama. Major through-flowing rivers, the Alabama, Black Warrior, and Tombigbee, have incised their valleys as much as 60 ft lower than the level of the plain of the Black Belt.

South and west of the Black Belt, the more resistant and occasionally indurated sandy clay of the Ripley Formation supports a cuesta that rises as much as 300 ft above the adjacent Black Belt. In Mississippi, this feature, known as the Pontotoc Ridge, narrows from a width of about 12 mi at the Tennessee State line to a point about 90 mi south, where it disappears and the lowlands of the Black Belt are contiguous with the lowlands of the Flatwoods.

East of the Tombigbee River in Alabama, the Ripley Formation once again becomes resistant and forms a ridge. The absence of the cuesta in eastern Mississippi reflects a facies change from sand to chalk in the Ripley Formation. South and west of the Ripley Cuesta is another belt of lowlands, the Flatwoods, underlain by the Paleocene Porters Creek Clay of the Midway Group. South and west of this belt, another belt of hills, the Red Hills Belt, rises 200–400 ft above the Flatwoods. This belt is an expression of the outcrop of sands of the Wilcox Group.

Within each of the physiographic subdivisions described, altitudes are generally highest in northern Mississippi, descending to the south to a low point about 30 mi east of the Mississippi-Alabama State line, where the Tombigbee and Black Warrior Rivers exit from the study area. From this point, altitudes increase eastward into central Alabama. These altitude differences within the bands of each physiographic subdivision and the lithologic differences between adjacent subdivisions both influence the pattern of recharge and discharge of the Coastal Plain aquifers.

CLIMATE AND DRAINAGE

The study area has a humid subtropical to temperate climate. Climatic variations are largely governed by the presence of the extensive land mass to the north and the Gulf of Mexico to the south, which produce alternating flows of cold air moving southward and warm, moist air moving northward.

Mean annual air temperature ranges from about 62°F in the northern part of the region to about 65°F in the southern part. The average number of days per year with temperatures above 90°F ranges from 80 to 100°F, and the average number of days per year with freezing temperatures ranges from 60 to 80°F.

Mean annual precipitation ranges from a low of about 48 in. in an area on the central part of the Mississippi-Alabama border to a high of about 60 in. nearer the coast in the southern part of the area. Precipitation is unevenly distributed throughout the year. The greatest mean precipitation occurs in the winter and early spring, and the least occurs in fall. Droughts are common during summer and fall.

Major streams draining the study area include the Tombigbee, Buttahatchee, Black Warrior, and Alabama Rivers. The headwaters of the Tombigbee River are in northeastern Mississippi, where the river flows on and parallel to the outcrop of the Eutaw Formation in the

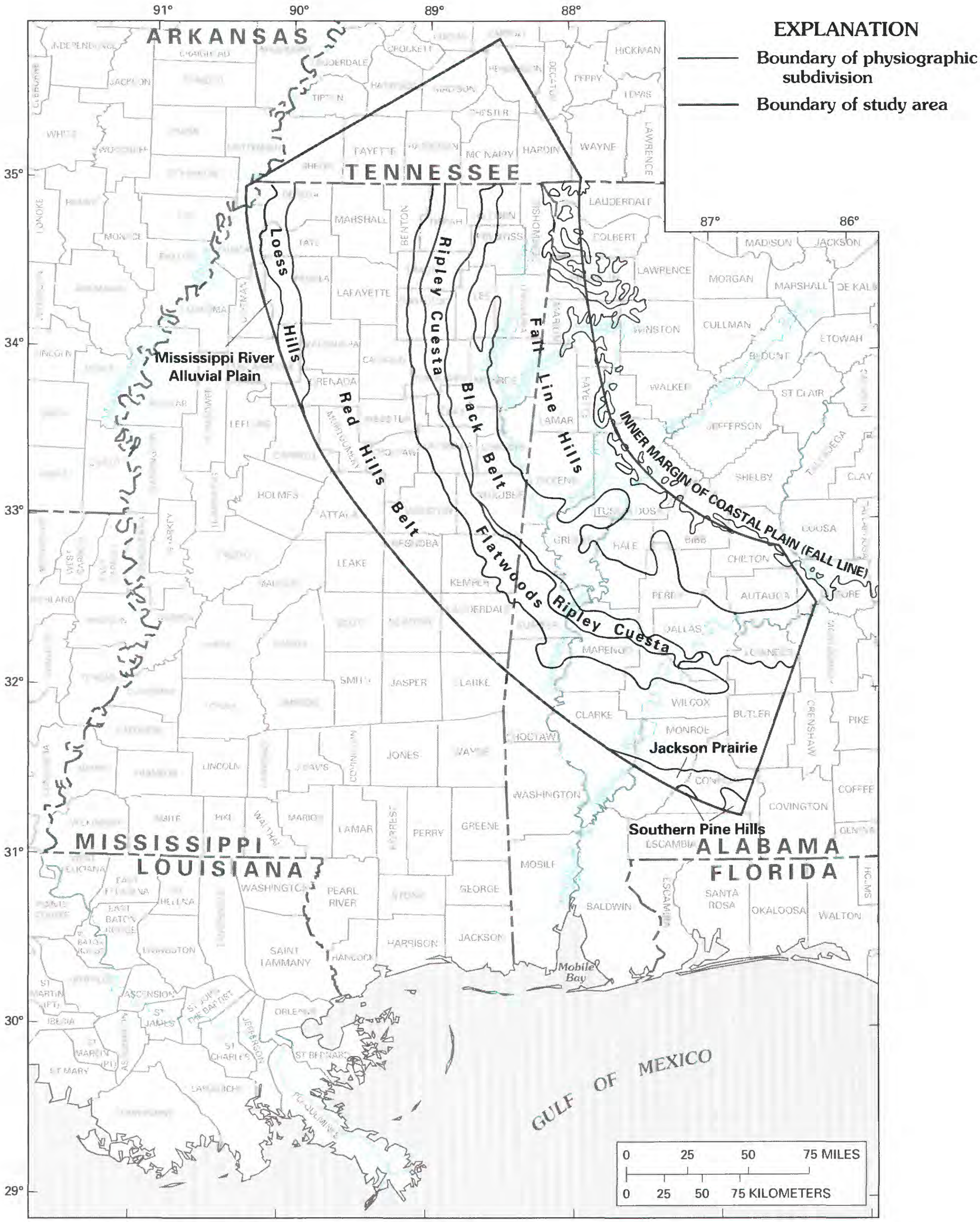


FIGURE 4.—Physiographic subdivisions of the study area.

Fall Line Hills. A short distance after entering Alabama, the Tombigbee River crosses onto the outcrop of the chalks of the Selma Group. Average runoff from the Tombigbee River basin in the study area is about 23 in/yr. Low flows are well sustained by ground-water discharge. The minimum observed runoff at four stream-gaging stations (with 199 station-years of record from 1899 to 1982) averages 0.024 (ft^3/s)/mi^2.

The headwaters of the Black Warrior River are in north-central Alabama, where the river flows over consolidated rocks of Paleozoic age. After entering the study area, the river is approximately perpendicular to the outcrop belts of the Tuscaloosa Group, the Eutaw Formation, and the Selma Group. The ability of the Cretaceous sands to sustain low flows in the rivers that cross their outcrops is illustrated by the minimum observed flows at gaging stations along the course of the Black Warrior River. At the gaging stations at Bankhead Lock and Dam, near Bessemer, Ala., and at Holt Lock and Dam near Holt, Ala., where the river flows on Paleozoic rocks, conditions of no flow have been observed, even though the drainage area of the river above Holt is 4,230 mi^2. At Northport, Ala., after the river has flowed on Tuscaloosa outcrop for only about 30 mi, the minimum observed flow is 37 ft^3/s. The drainage area above Northport is 4,828 mi^2. At Warrior Lock and Dam near Eutaw, Ala., after the river has flowed across nearly the full width of the Tuscaloosa and Eutaw outcrops, the minimum observed flow has increased to 317 ft^3/s; the drainage area above this gage is 5,800 mi^2.

The headwater tributaries of the Alabama River drain a large area of east-central Alabama that is underlain by rocks of Paleozoic age. As with the Black Warrior River, low flows for this part of the Alabama River basin are small and poorly sustained. In a drainage area of about 10,000 mi^2 upstream from the Cretaceous outcrop, the minimum observed flow is 54 ft^3/s. The major tributaries of the Alabama River flow westward on the Cretaceous deposits and join to form the Alabama River northeast of Montgomery, Ala. Near Montgomery, where discharge from the Cretaceous deposits helps sustain low flows, the minimum observed flow is 2,180 ft^3/s from a drainage area of 15,100 mi^2.

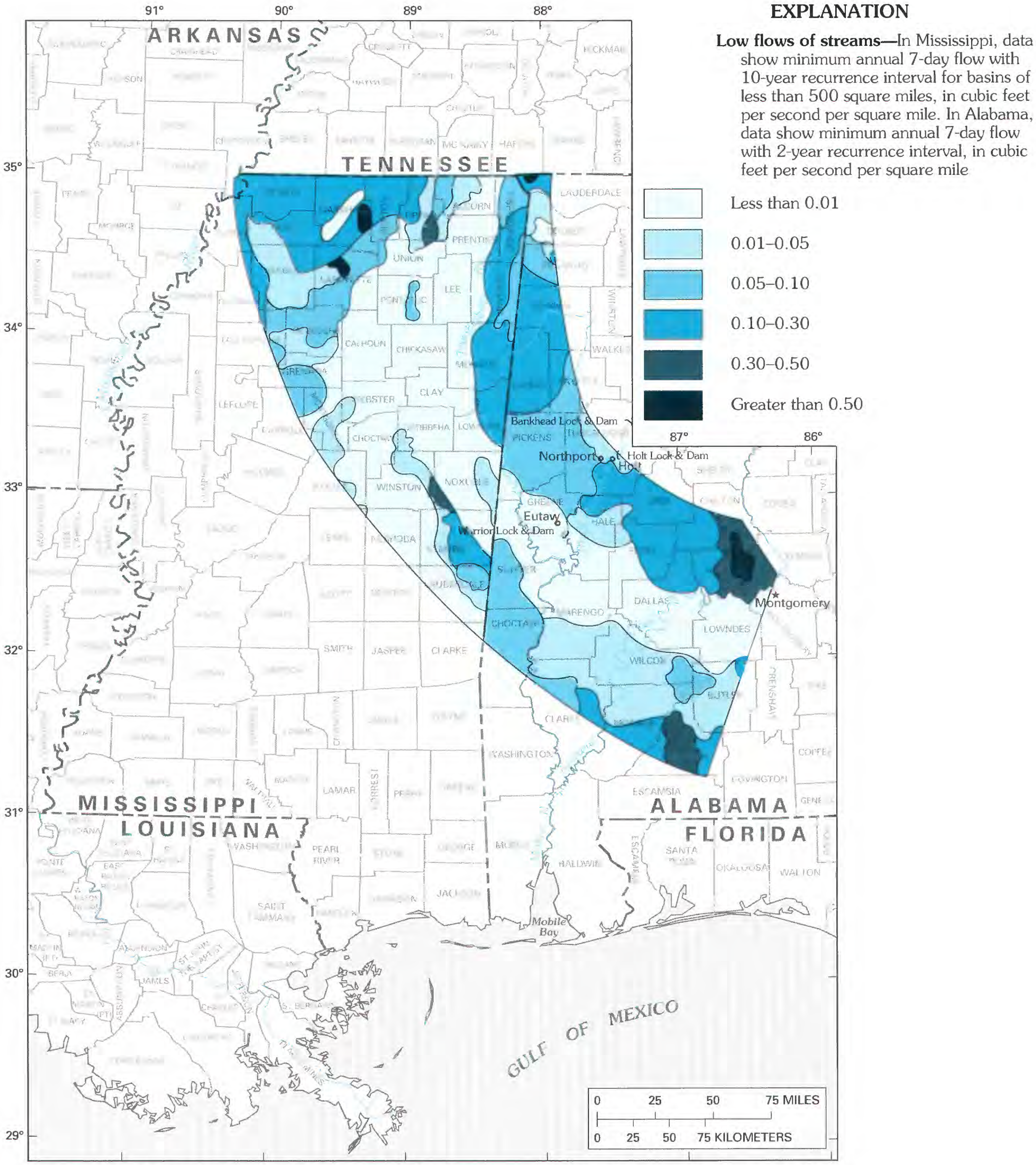
The close correlation of base flow and surface geology in Mississippi was described by Tharpe (1975) in an illustration showing the generalized geographic variation of the 7-day low flows having a 10-yr recurrence interval. Figure 5 incorporates the data from Tharpe (1975) with the data showing the geographic variation of the 7-day low flows having a 2-yr recurrence interval in Alabama (Bingham, 1979). The banded outcrop pattern of alternating sands and chalks of the Cretaceous sediments is clearly discernible (fig. 5) as distinct areas of differing base-flow characteristics. In this figure, a large area in the west-central part of the study area with minimum flows of less than 0.05 (ft^3/s)/mi^2 corresponds well with the outcrops of chalk facies in the Selma Group and the clays of the Midway Group. Sandy, more permeable facies in the Selma Group (the Ripley Formation) cause the small areas with minimum flow between 0.05 and 0.5 (ft^3/s)/mi^2 in the north-central part of the study area and the small isolated area with minimum flow between 0.01 and 0.05 (ft^3/s)/mi^2 just west of the Mississippi-Alabama border. An area with minimum flows between 0.05 and 0.3 (ft^3/s)/mi^2 marks the outcrop of the Eutaw Formation in northeastern Mississippi near the Alabama border. Correlations between surface geology and base flow in Alabama are more generalized in this figure because the shorter recurrence interval (2 yr) used in compiling that data may not exclusively reflect base-flow conditions. However, the generalized pattern of alternating bands of sands and chalks is clearly present.

HYDROGEOLOGY

GEOLOGIC FRAMEWORK

The structural setting for the deposition of the Southeastern Coastal Plain aquifer system consisted of the broad, subsiding depressions of the Gulf Coast geosyncline and the southward plunging syncline of the Mississippi embayment. Initial subsidence of these features may have occurred as early as the end of the Paleozoic era. Subsidence continued throughout the Cretaceous period, and transgressive seas reached as far north as Cairo, Ill., during Late Cretaceous time. Cyclic transgression and regression of the sea continued in this area until well into the Tertiary period, depositing the sediments that now make up the Southeastern Coastal Plain aquifer system. The nature of the sediments was controlled by the depositional environment, which in turn was governed by the fluctuations of relative sea level and the shifting of the location of the shoreline of this ancient sea. The Cretaceous sediments include gravel, sand, clay, chalk, and marls of fluvial and marine origin. Some reef-type limestones are present locally. Older units are exposed in the northern part of the region near the Fall Line, and progressively younger units occur to the west and south toward the Mississippi embayment and the Gulf of Mexico (fig. 6). The dip of these beds is generally toward the axis of the Mississippi embayment in the northern part of the study area and toward the Gulf of Mexico in the southern part. Thickness of sediments increases greatly downdip; in the south near the embayment axis (outside the area of the current study), the total thickness of post-Paleozoic deposits is about 18,000 ft.

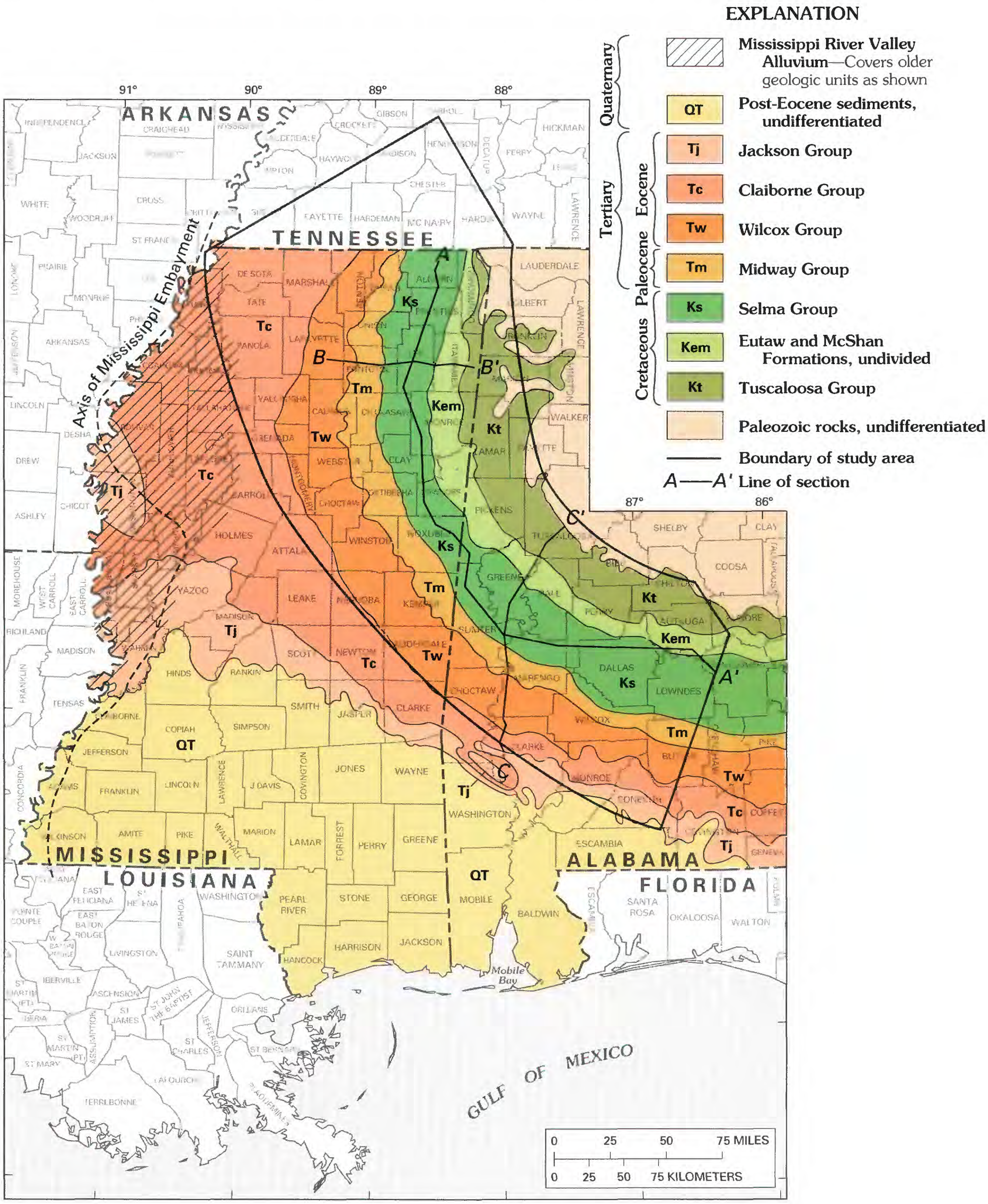
Upper Cretaceous units include, in ascending order, the Tuscaloosa Group, composed of the Coker and Gordo



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Tharpe (1975) and Bingham (1979)

FIGURE 5.—Generalized geographic variation in low flows of streams.



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Modified from Moore (1976) and Smith (1920)

FIGURE 6.—Generalized geology of the study area.

Formations; the Eutaw and McShan Formations; and the Selma Group, composed of the Mooreville Chalk, Coffee Sand, Demopolis Chalk, Ripley Formation, and Prairie Bluff Chalk.

The Coker Formation of the Tuscaloosa Group consists of thin-bedded clay, sandy clay, and medium to coarse sands. The thickness of the Coker Formation ranges from less than 1 ft at the east limit of outcrop to about 900 ft in the subsurface.

The Gordo Formation of the Tuscaloosa Group generally ranges in thickness from 100 to 400 ft in the subsurface. It is composed of thick beds of sand containing gravel in the lower part and clay and shale interbedded with sand in the upper part.

The McShan Formation crops out in Alabama and Mississippi, where it reaches a thickness of 200 ft or more in the subsurface. It consists of laminated micaceous glauconitic clay, fine sand, and lenticular beds of fine to medium glauconitic sand. The formation is overlapped by the Eutaw Formation in northern Mississippi and is absent farther north.

In the subsurface in Mississippi and Alabama, the Eutaw Formation ranges in thickness from less than 1 ft to more than 400 ft. The main body of the formation is composed of clay interbedded with fine glauconitic sand. Thin beds of fine to medium glauconitic sand are common and are fairly persistent near the base of the formation, which is normally marked by a thin bed of gravel. The sands are commonly crossbedded or show distinct stratification. A persistent sand at the top of the formation (Tombigbee Sand Member) is massive, highly glauconitic, calcareous, and fossiliferous in the upper part. The Eutaw Formation overlies the McShan Formation in Alabama and Mississippi, where the contact generally can be recognized on the outcrop. In the subsurface, however, the two units generally are mapped together. The formations together form an important aquifer in eastern Mississippi and western Alabama.

In western Alabama and eastern Mississippi, the Selma Group includes, in ascending order, the Mooreville Chalk, Coffee Sand (in Mississippi only), Demopolis Chalk, Ripley Formation, and Prairie Bluff Chalk.

The Mooreville Chalk has a maximum thickness of more than 250 ft in central and southern Mississippi and eastern Alabama. It is an impure chalk or chalky marl containing scattered thin beds of very fine sand. Some sandy zones are extremely glauconitic, especially those in the upper part of the formation.

The Coffee Sand in northern Mississippi is a facies equivalent of the Mooreville Chalk and the lower part of the Demopolis Chalk. Near its outcrop, the Coffee Sand may be more than 200 ft thick. It is made up largely of a series of stratified and crossbedded sands and clays. The sands generally are fine; in many places, they contain an abundance of mica and, in some places, glauconite and pyrite. The clays are highly carbonaceous and contain an abundance of plant remains.

The Demopolis Chalk, about 500 ft thick in central Mississippi and western Alabama, is a relatively pure chalk; the Bluffport Marl Member at the top is an impure chalk that grades into the overlying Ripley Formation. Northward, the upper 250 ft of the Demopolis Chalk becomes clayey, and the remainder becomes a part of the Coffee Sand.

The Ripley Formation in Alabama and Mississippi has a maximum thickness of about 500 ft. The formation typically consists of clay, sandy clay, sand, and thin beds of sandstone.

A transitional clay at the base of the Ripley Formation may be a lateral facies equivalent of the Bluffport Marl Member of the Demopolis Chalk. The units are lithologically similar. The transitional clay in the outcrop has an average thickness of less than 50 ft.

The Prairie Bluff Chalk is the uppermost unit of the Upper Cretaceous series in western Alabama and eastern Mississippi. The Prairie Bluff Chalk ranges from 30 to 70 ft thick. It is a slightly sandy, massive chalk that grades northward into highly fossiliferous, fine micaceous silty sand and clay. The Prairie Bluff rests unconformably on the Ripley Formation and unconformably underlies the Midway Group.

Lower Tertiary units overlie the Cretaceous system with marked unconformity. Paleocene age rocks of the Midway Group and the lower part of the Wilcox Group make up the youngest units considered in this study.

The maximum subsurface thickness of the Midway Group is about 1,000 ft at the axis of the Mississippi embayment. The thickness near the outcrop area ranges from a known minimum of 200 to about 600 ft. The Midway Group is composed predominantly of marine clay and shale but includes subordinate sand and limestone beds. Clays of the Midway Group form a layer of confinement separating the Cretaceous aquifers below from aquifers in the sandy lower parts of the overlying Wilcox Group. Younger Tertiary and Holocene sediments overlie the Wilcox Group; however, aquifers in these deposits are separated by thick layers of sediment with very low hydraulic conductivity from the Cretaceous formations and have little or no hydraulic influence on the Cretaceous aquifers. Therefore, these aquifers are not discussed in this report. The cross sections shown in figures 7 and 8 illustrate the stratigraphic and structural relations discussed above.

HYDROGEOLOGIC UNITS

The most extensive aquifers of Cretaceous age in the study area occur in the Ripley, Eutaw, and Gordo

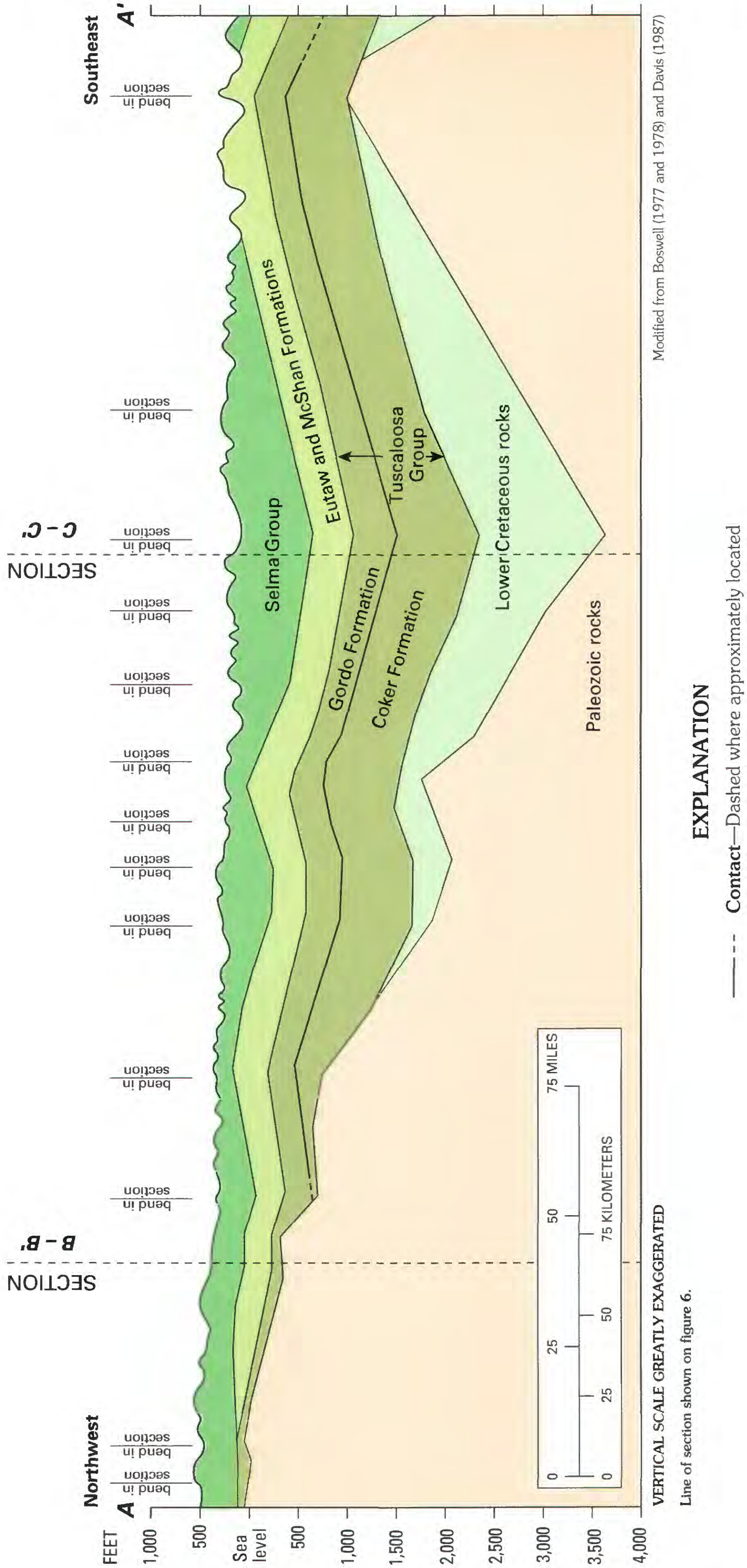


FIGURE 7.—Geologic section *A–A′*.

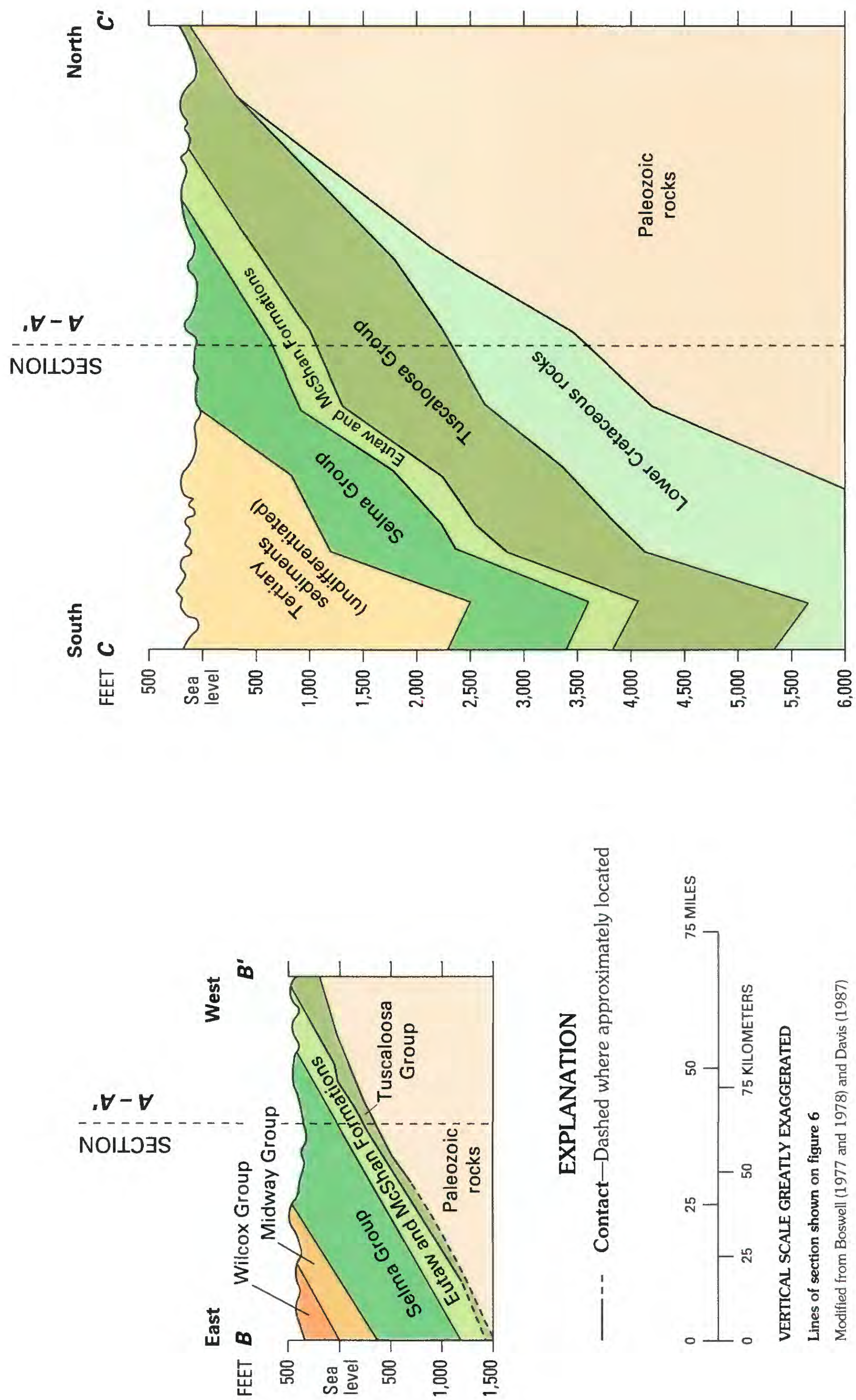


FIGURE 8.—Geologic sections B–B′ and C–C′.

Formations. In general, the aquifers are not intensively developed; the average pumpage from these aquifers is about 100 Mgal/d. In many places, only the most shallow aquifer is used, although one or more deeper aquifers are present.

This study is an integral part of the Southeastern Coastal Plain RASA study. For this large study, a hydrogeologic nomenclature was required that would transcend the many local aquifer names and the many different names used for the geologic units that extend from South Carolina to Mississippi. Furthermore, for purposes of the digital simulation of the aquifer system, it was necessary to represent the many individual permeable horizons and many confining clay horizons as a manageable number of "aquifer units," where only horizontal flow is simulated, and "confining units," where only vertical flow is simulated. In the early stages of the study, an alphanumeric nomenclature was devised that consists of an uppercase letter and a number to designate the regional aquifer and confining units. Further subdivision in the subregional areas is indicated by an additional lowercase letter and number suffix (fig. 9). This nomenclature reflects a conceptual model of the hydrogeologic framework of the regional system derived by Renken (1984) and is based primarily on permeability differences of a regional scale derived by detailed analysis of geophysical, lithologic, and paleontological data from nearly 1,000 oil, gas, and water wells in the region. Miller and Renken (1988) assigned names to these regional units, and those names are used in this report.

As shown in figure 9, this framework consists of four aquifers and three confining units in the regional system. Figure 9 shows both the regional names for these units, the alphanumeric designations by which they were identified in preliminary reports, and local aquifer and confirming unit names. In the Mississippi-Alabama study area that is described in this report, the equivalents of the regional Chickasawhay River aquifer are not simulated because they are being simulated by the adjacent Gulf Coastal Plain RASA study (fig. 1). The local equivalent of the regional Pearl River aquifer, which is also being simulated by the Gulf Coastal Plain RASA study, acts as a source-sink layer for the underlying units that are of primary interest in the study area described in this report. The regional Chattahoochee River aquifer is being actively simulated by both the Southeastern Coastal Plain RASA and the Gulf Coastal Plain RASA studies because the flow system of this hydrologic unit extends across both study areas. Inclusion of the Chattahoochee River aquifer in both projects ensures continuity of simulated ground-water flow between the models of the two studies. For purposes of this report, the regional Black Warrior River aquifer is further subdivided into two subunits, the upper Black Warrior River aquifer and the lower Black Warrior River aquifer, the division being based on a layer of reduced permeability between the aquifers that results in the two subunits having significantly different water levels in the area described by this report.

The aquifers are recharged primarily by precipitation on the outcrop; however, upward leakage accounts for a significant percentage of the recharge to the upper Black Warrior River aquifer. In the downdip parts of the aquifers, interaquifer flow through confining units is a source of significant recharge and discharge among all the aquifers. Because the aquifers are saturated, most of the streams crossing the Cretaceous outcrop area receive water from the aquifers during periods of low precipitation; therefore, most of the streams are perennial.

Analysis of aquifer test data shows that the hydrologic characteristics vary from aquifer to aquifer and from place to place within each aquifer. The lower Black Warrior River aquifer is the most productive.

The temperature of the ground water ranges from about 95°F (35°C; Boswell, 1978) to 63°F (17°C). Water from most of the aquifers is a calcium bicarbonate or sodium bicarbonate type with low dissolved solids (less than 100 mg/L). The calcium bicarbonate type is predominant in the outcrop area and at shallow depths. The higher concentrations of iron, the most troublesome chemical constituent, occur in the outcrop areas and at shallow depths. As ground water moves downgradient, the chemical properties of the water change from a calcium bicarbonate type to a sodium bicarbonate type, and the iron content decreases. The Chattahoochee River aquifer yields calcium-magnesium bicarbonate water locally. The upper Black Warrior River aquifer yields sodium chloride water in parts of Alabama and Mississippi and yields moderately hard water in places.

PEARL RIVER REGIONAL AQUIFER (LOWER WILCOX AQUIFER)

The Pearl River regional aquifer, locally called the Lower Wilcox aquifer, is composed of interconnected sand beds of Paleocene age that occur at the base of the Wilcox Group and, in some areas, includes hydraulically connected sand beds in the uppermost part of the underlying Midway Group of Paleocene age. For the purposes of this study, the Pearl River regional aquifer is of interest only because the head distribution in the aquifer affects the flow system of the underlying aquifers of Cretaceous age. The potentiometric surface of the Pearl River aquifer, in effect, establishes the upper boundary condition for the digital simulation model of the Creta-

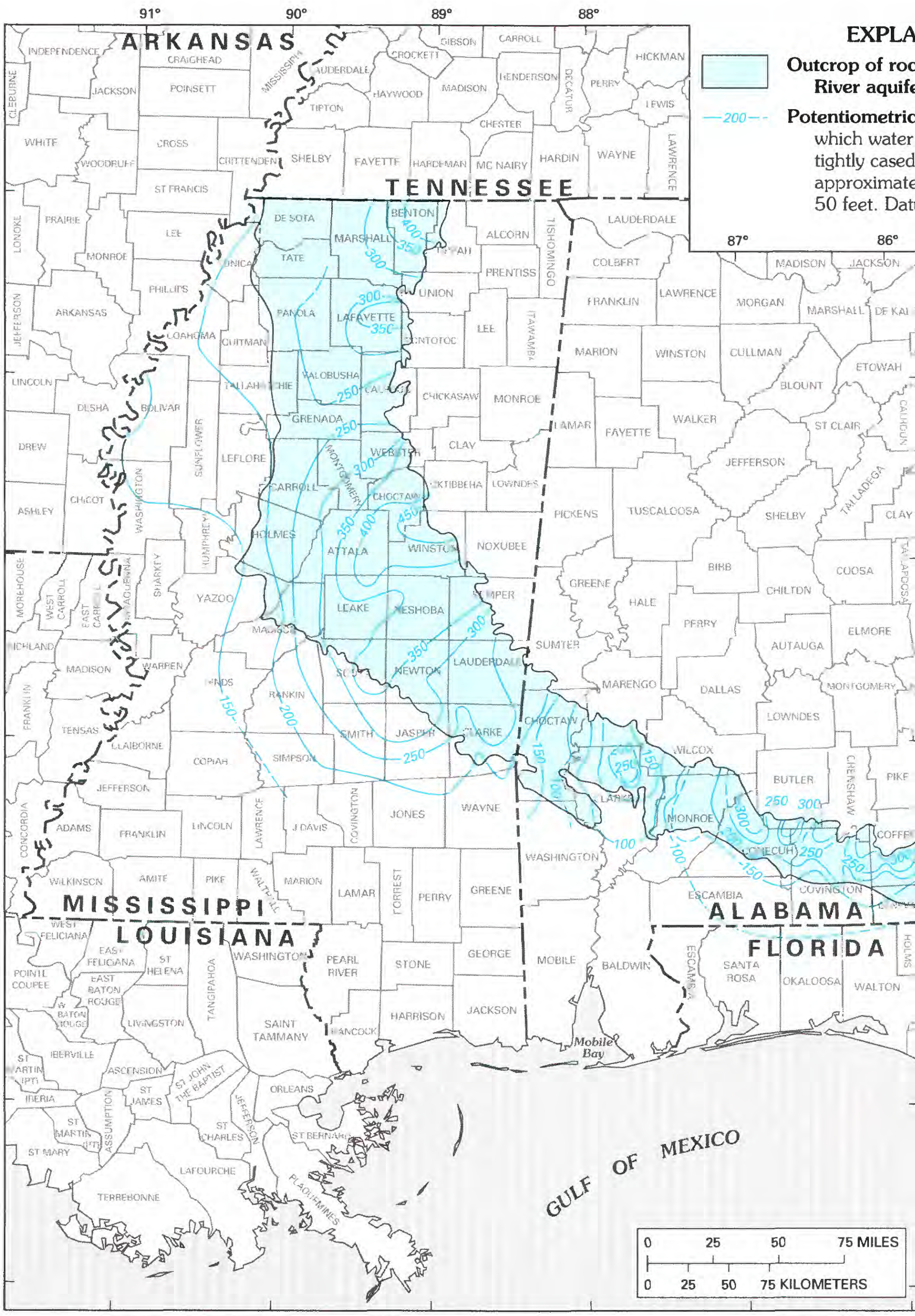
Regional hydrologic unit (Miller and Renken, 1988)	Hydrologic unit used in this report	Preliminary model unit designation	Stratigraphic units (group)	Stratigraphic units	Local aquifer and confining unit names
Chickasawhay River aquifer	Not studied	Not simulated		Catahoula Sandstone, Glendon, Marianna, Mint Springs, and Forest Hill Formations	Miocene aquifer
Pearl River confining unit	Not studied	Not simulated		Yazoo Formation	Confining unit
Pearl River aquifer	Pearl River aquifer	A2	Wilcox Group	Tuscahoma Formation Nanafalia Formation	Lower Wilcox aquifer
Chattahoochee River confining unit	Chattahoochee River confining unit	C2	Midway Group	Porters Creek Clay Clayton Formation	Confining unit
			Selma Group	Prairie Bluff Chalk	
Chattahoochee River aquifer	Chattahoochee River aquifer	A3	Selma Group	Ripley Formation	Ripley aquifer
Black Warrior River confining unit	Black Warrior River confining unit	C3	Selma Group	Demopolis Chalk	Confining unit
Black Warrior River aquifer	Upper Black Warrior River aquifer	A4a1	Selma Group	Mooreville Chalk	
				Coffee Sand Eutaw Formation McShan Formation	Eutaw-McShan aquifer
	Unnamed confining unit	A4c1	Tuscaloosa Group	Clays in the upper part of the Gordo Formation	Confining unit
	Lower Black Warrior River aquifer	A4a2	Tuscaloosa Group	Gordo Formation Coker Formation	Tuscaloosa aquifer

FIGURE 9.—Correlation of units used for regional model, subregional model, stratigraphy, and hydrology.

ceous sand aquifers, which are the primary subjects of this study. Figure 10 shows the potentiometric surface for the Pearl River aquifer before development (pre-1934) as determined by Stricker and others (1985a).

CHATTAHOOCHEE RIVER CONFINING UNIT

No direct field or laboratory test data are available to define the vertical hydraulic conductivities of the formations that make up the Chattahoochee River confining



EXPLANATION

Outcrop of rocks comprising the Pearl River aquifer

—200— Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval 50 feet. Datum is sea level

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Stricker and others (1985a)

FIGURE 10.—Predevelopment (pre-1934) potentiometric surface of the Pearl River aquifer.

unit. Lithologic data were used to make preliminary estimates of vertical hydraulic conductivity for this confining unit. In Mississippi and western Alabama, virtually the entire stratigraphic sequence represented by the Chattahoochee River confining unit consists of clays and chalks of low permeability.

The lithologically based estimates of vertical hydraulic conductivity, structural data, and the process of model calibration suggest that leakance of this confining unit is less than 1.0×10^{-8} (ft/d)/ft in the northwestern part of the Chattahoochee River confining unit and in the range of 1.0×10^{-8} to 1.0×10^{-6} (ft/d)/ft in the southeastern part (fig. 11).

CHATTAHOOCHEE RIVER REGIONAL AQUIFER (RIPLEY AQUIFER)

The Chattahoochee River regional aquifer in the study area is locally known as the Ripley aquifer and consists mostly of sand beds in the Ripley Formation, which make up a minor aquifer in northern Mississippi and central and eastern Alabama. In east-central Mississippi and westernmost Alabama, the Ripley Formation is thin and calcareous and does not constitute a significant aquifer.

Figure 12 shows the potentiometric surface before development (pre-1934) of the Chattahoochee River regional aquifer in the study area as interpreted by Stricker and others (1985b). Flow in the aquifer discharges out of the study area to the north and west. Evidence from the adjacent Gulf Coastal Plain RASA study (J.V. Brahana, oral communication, 1986) suggests that the ultimate discharge point of this flow is along the western side of the Mississippi embayment in east-central Arkansas. Size considerations prohibited extending the study area to include the entire physical boundary of this minor flow system. The Gulf Coastal Plain RASA study includes the part of the Chattahoochee River regional aquifer (called the Nacatoch aquifer in that study) north of the facies change in east-central Mississippi. Hydraulic heads generated by that study were used in this study to fix the constant-head boundary along the northwestern border of the simulation model.

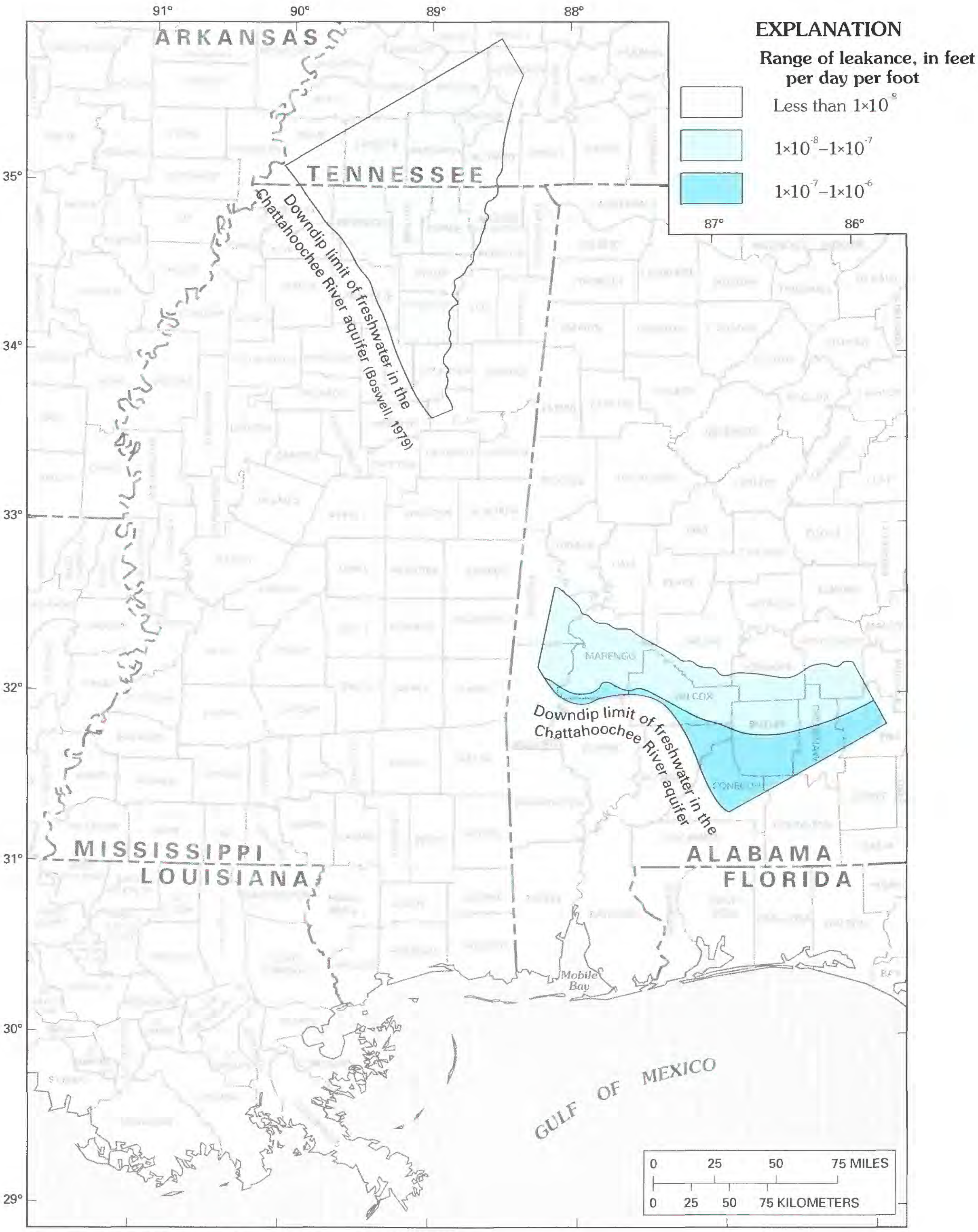
Most recharge enters the Chattahoochee River regional aquifer through precipitation in the aquifer outcrop areas and flows generally westward. A much smaller contribution to the recharge of this aquifer (about 3 percent) occurs by vertical leakage from the overlying Pearl River regional aquifer. Most of the discharge (about 80 percent) from the aquifer is to rivers in and immediately downdip from the outcrop area. The remaining recharge, about 20 percent, flows out of the boundaries of the study area toward the west side of the Mississippi embayment. A very small amount of flow (less than 1 percent of net recharge) is discharged as vertical leakage downward through the confining units to the underlying upper Black Warrior River aquifer.

Hydraulic conductivity of the Chattahoochee River aquifer, based on numerous specific-capacity tests on wells and limited aquifer test data, is about 50–75 ft/d for the northern Mississippi area and the updip and middip areas of Alabama. Transmissivity in the aquifer, based on simulation in addition to the hydraulic conductivity and aquifer thickness data, generally is in the range of 1,000–5,000 ft^2/d (fig. 13). The storage coefficient of the Chattahoochee River regional aquifer used in the calibrated model was 1.0×10^{-4}.

Quality of water in the Chattahoochee River aquifer ranges from a calcium or calcium-magnesium bicarbonate type in the updip area, where dissolved-solids concentrations are less than 100 mg/L, to a sodium bicarbonate type in the downdip areas, where concentrations of dissolved solids are as high as 500 mg/L. The most significant difference between water quality in the Chattahoochee River aquifer and that in underlying regional aquifers results from the greater mass of calcite in the calcareous sand of this aquifer that is available for dissolution (Lee, 1985). In the deeper downdip areas, the Chattahoochee River aquifer contains sodium chloride type water that is perhaps more saline than seawater (approximately 35,000 mg/L dissolved-solids concentrations), as do all of the Southeastern Coastal Plain regional aquifers at sufficient depth (Gandl, 1982). (The freshwater-saltwater interface of the Chattahoochee River aquifer is shown in fig. 37.) Iron concentration in the aquifer is variable, and the highest fluoride concentration reported for the aquifer is 4.0 mg/L (Boswell, 1979).

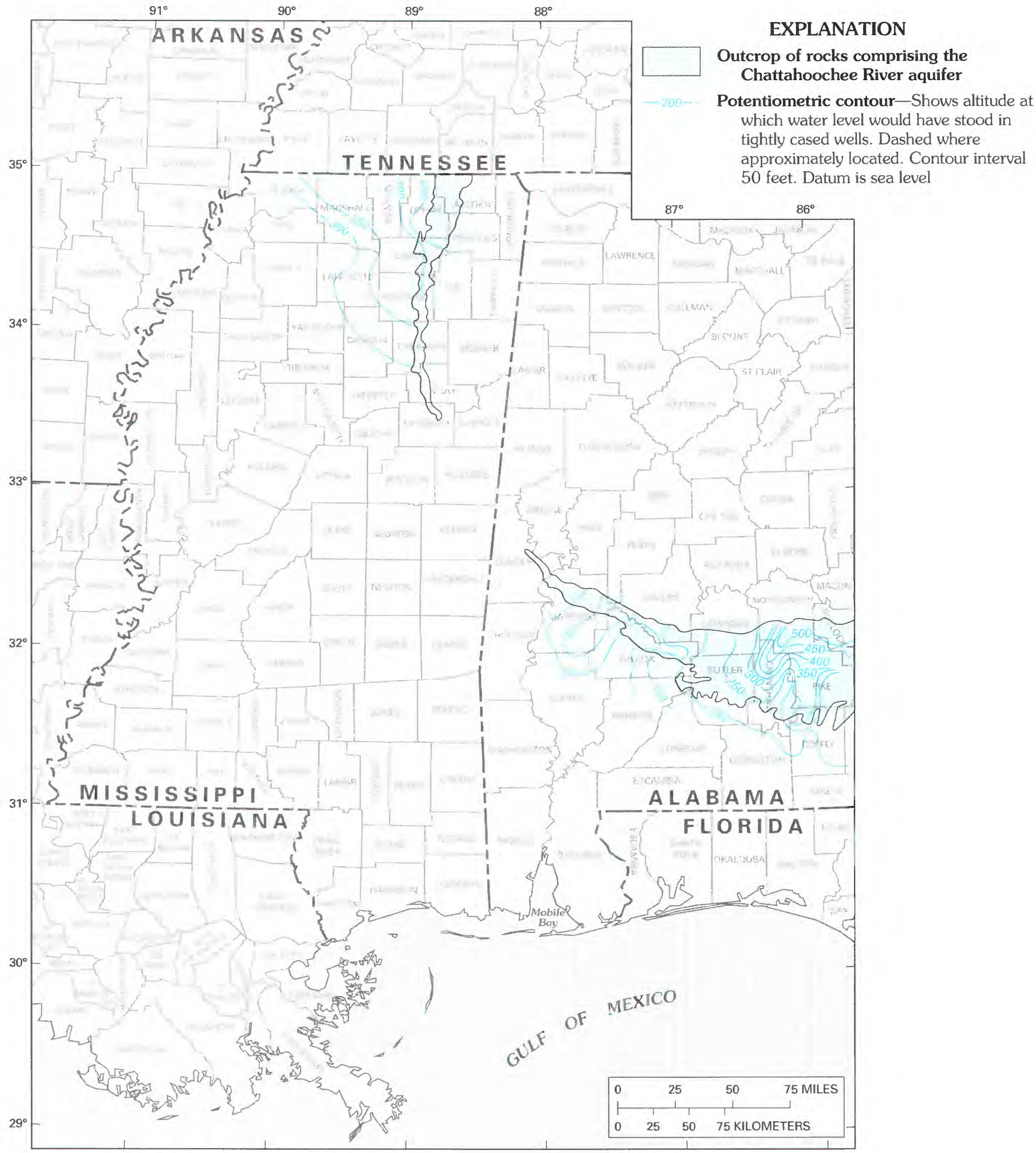
BLACK WARRIOR RIVER CONFINING UNIT

The Mooreville Chalk and Demopolis Chalk of the Selma Group form the Black Warrior River confining unit that separates the upper Black Warrior River aquifer from the Chattahoochee River aquifer (fig. 9). This confining unit is composed of massive chalk of very low hydraulic conductivity. Few values of vertical hydraulic conductivity determined by direct measurement are available for the unit. Most of the available field data on hydraulic conductivity were gathered as part of evaluations of two proposed hazardous waste disposal sites (Golder and Associates, 1983), one of which is now operational. As part of the waste disposal site study, a water-level recovery test performed on a test well in the Demopolis Chalk near Shuqualak in Noxubee County, Miss., resulted in a value of 5×10^{-4} ft/d for hydraulic conductivity. Because the design of the test caused horizontal hydraulic conductivity to be measured, it is reasonable to assume that this value represents an upper



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 11.—Leakance of the Chattahoochee River confining unit used in the calibrated model.



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Modified from Stricker and others (1985b)

FIGURE 12.—Predevelopment (pre-1934) potentiometric surface of the Chattahoochee River aquifer.

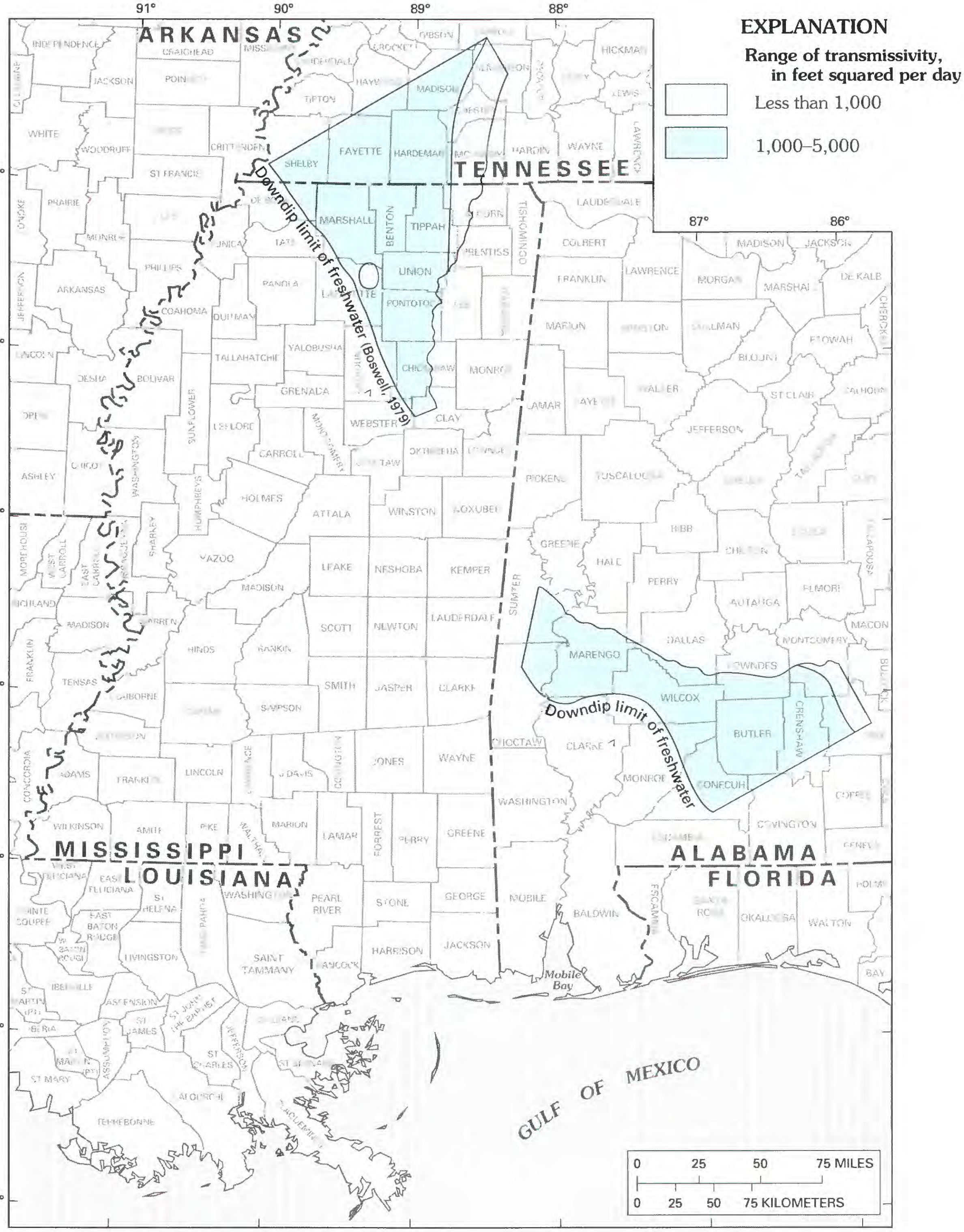

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FIGURE 13.—Transmissivity of the Chattahoochee River aquifer used in the calibrated model.

limit of vertical hydraulic conductivity at this site, since typical horizontal to vertical anisotropy ratios are generally 100 to 1 or more for most earth materials. The average thickness of the Black Warrior River confining unit is in excess of 800 ft, resulting in a range of leakance for the unit, as refined by model calibration, of 1.0×10^{-8} to 1.0×10^{-7} (ft/d)/ft.

UPPER BLACK WARRIOR RIVER REGIONAL AQUIFER (EUTAW-McSHAN AQUIFER)

Thin beds of fine to medium glauconitic sand within the Eutaw and McShan Formations make up the bulk of the upper Black Warrior River regional aquifer, locally know as the Eutaw-McShan aquifer. The Coffee Sand, which overlies the Eutaw Formation in the northern part of the area, is also included in this aquifer where present. The potentiometric surface before development for the Black Warrior River aquifer is shown in figure 14 (Stricker and others, 1985c). This map is for the entire Black Warrior River regional aquifer, which includes both the upper Black Warrior River aquifer and the underlying lower Black Warrior River aquifer (fig. 9) of this study. The Black Warrior River regional aquifer was divided into two aquifers (the upper and lower Black Warrior River aquifers) for this study because recent potentiometric maps show that in the area of this study, considerable head differentials have been developed between these aquifers under stressed conditions. In addition, limited water-level data indicate some head differential under conditions before development (pre-1934). However, a lack of historical data on conditions before development (pre-1934) precludes a separate potentiometric map for the upper and lower Black Warrior River aquifers under predevelopment conditions; therefore, a composite potentiometric map of both aquifers is shown in figure 14.

Some recharge to the upper Black Warrior River aquifer occurs as infiltration of precipitation on the outcrop area; however, this recharge is balanced by large quantities of water that are discharged to rivers and low valleys in the outcrop area. Heads in the aquifer and modeling results indicate that, before development, water entering the aquifer in its downdip area through leakage from the underlying lower Black Warrior River aquifer is the major source of recharge (more than 75 percent of total recharge) to the upper Black Warrior River aquifer. Discharge to rivers and low valleys accounts for more than 90 percent of total discharge. The remaining 10 percent of discharge is to the underlying lower Black Warrior River aquifer by vertical leakage in areas where downward hydraulic gradients exist. A nearly insignificant amount of water (less than 1 percent of total recharge) is received in the upper Black Warrior River aquifer by leakage from the overlying Chattahoochee River aquifer. In the upper Black Warrior River aquifer, 1982 potentiometric maps clearly show the effects of major river valleys as areas of aquifer discharge. Large declines in water levels have been observed in this aquifer in the Tupelo and West Point areas of Lee and Clay Counties, Miss., because of heavy pumping at these locations.

Results of 41 aquifer tests and numerous specific-capacity measurements in the upper Black Warrior River aquifer indicate a median value of hydraulic conductivity of 13.4 ft/d. This information and lithology of aquifer materials, sediment thickness, and results of model calibration show that transmissivities in the upper Black Warrior River aquifer range from less than 1,000 to more than 10,000 ft^2/d (fig. 15). The storage coefficient of the aquifer used in the calibrated model was between 1.25×10^{-4} and 2.5×10^{-4}.

Water-quality patterns in the upper Black Warrior River aquifer are similar to those in the Chattahoochee River aquifer unit. A calcium bicarbonate water type with dissolved-solids concentrations of about 120 mg/L occurs in the updip areas. Increase of dissolved-solids concentrations with distance downdip is more pronounced in the upper Black Warrior River aquifer than in the overlying Chattahoochee River aquifer. In the deeper downgradient areas, a sodium bicarbonate type water having dissolved-solids concentrations of about 1,000 mg/L is present (Lee, 1985). Dissolved iron concentrations are high, as much as 20 mg/L, near the Fall Line in Alabama (Wahl, 1965). In areas where less calcareous material is present, dissolved-solids concentrations in water from the updip parts of the aquifer are less, and a sodium bicarbonate water type dominates throughout the flow path. The freshwater-saltwater interface, as defined by Boswell (1977), is shown in figure 15.

UNNAMED CONFINING UNIT

Clay in the upper part of the Gordo Formation of the Tuscaloosa Group makes up an unnamed confining unit that separates the upper Black Warrior River aquifer from the underlying lower Black Warrior River aquifer in the study area (fig. 9). This unnamed confining unit provides significant resistance to flow between the two aquifers south of southern Lee County, Miss., but is thinner or locally missing north and northwest of Lee County. Where these clays are missing, substantial interchange of water occurs between the upper Black Warrior River aquifer and the lower Black Warrior River aquifer. Even in the southern part of the area, these dispersed clays form a confining unit that has a significantly higher vertical hydraulic conductivity than that of the Chattahoochee River confining unit and the

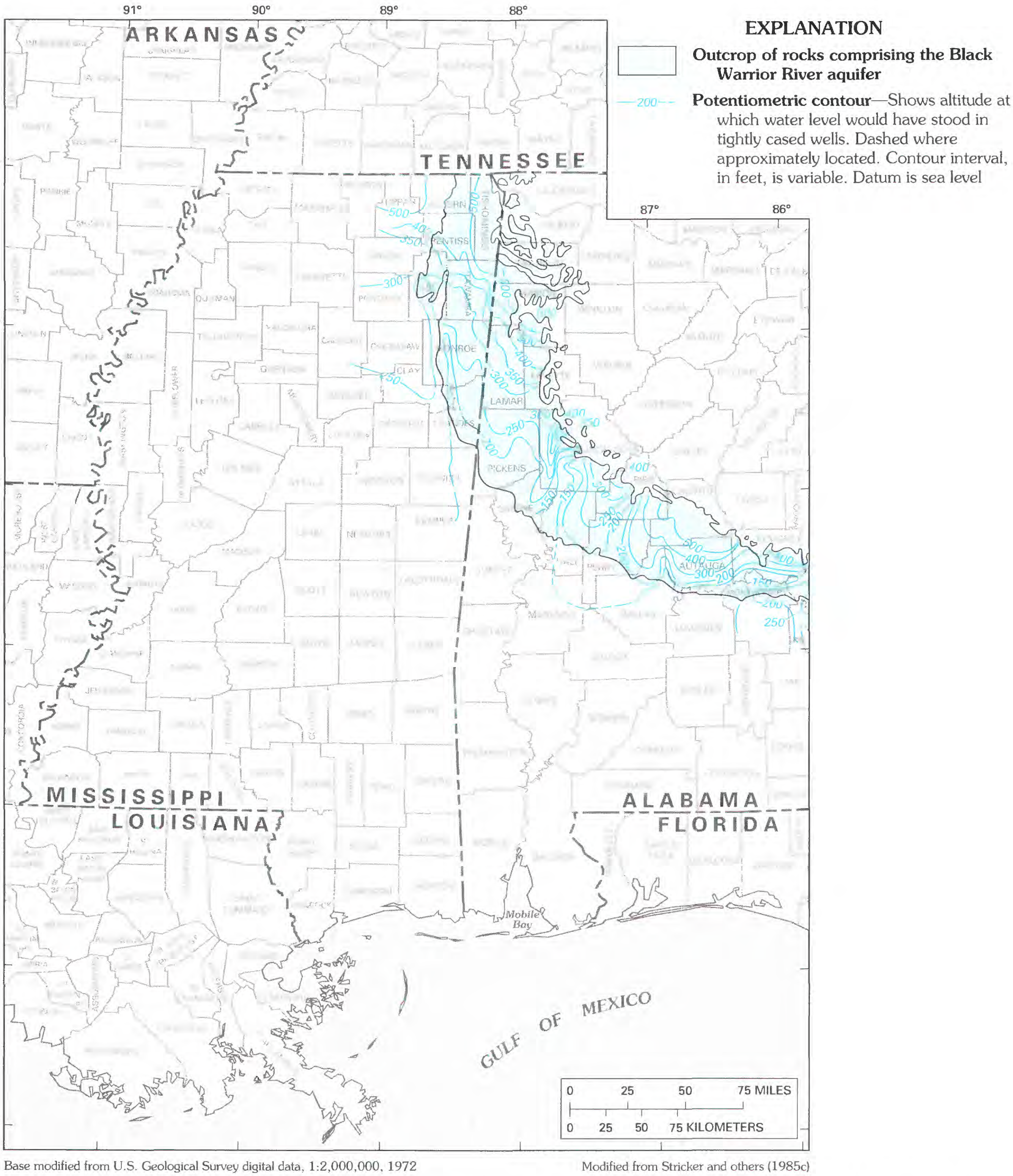

FIGURE 14.—Composite predevelopment (pre-1934) potentiometric surface of the upper and lower Black Warrior River aquifers.

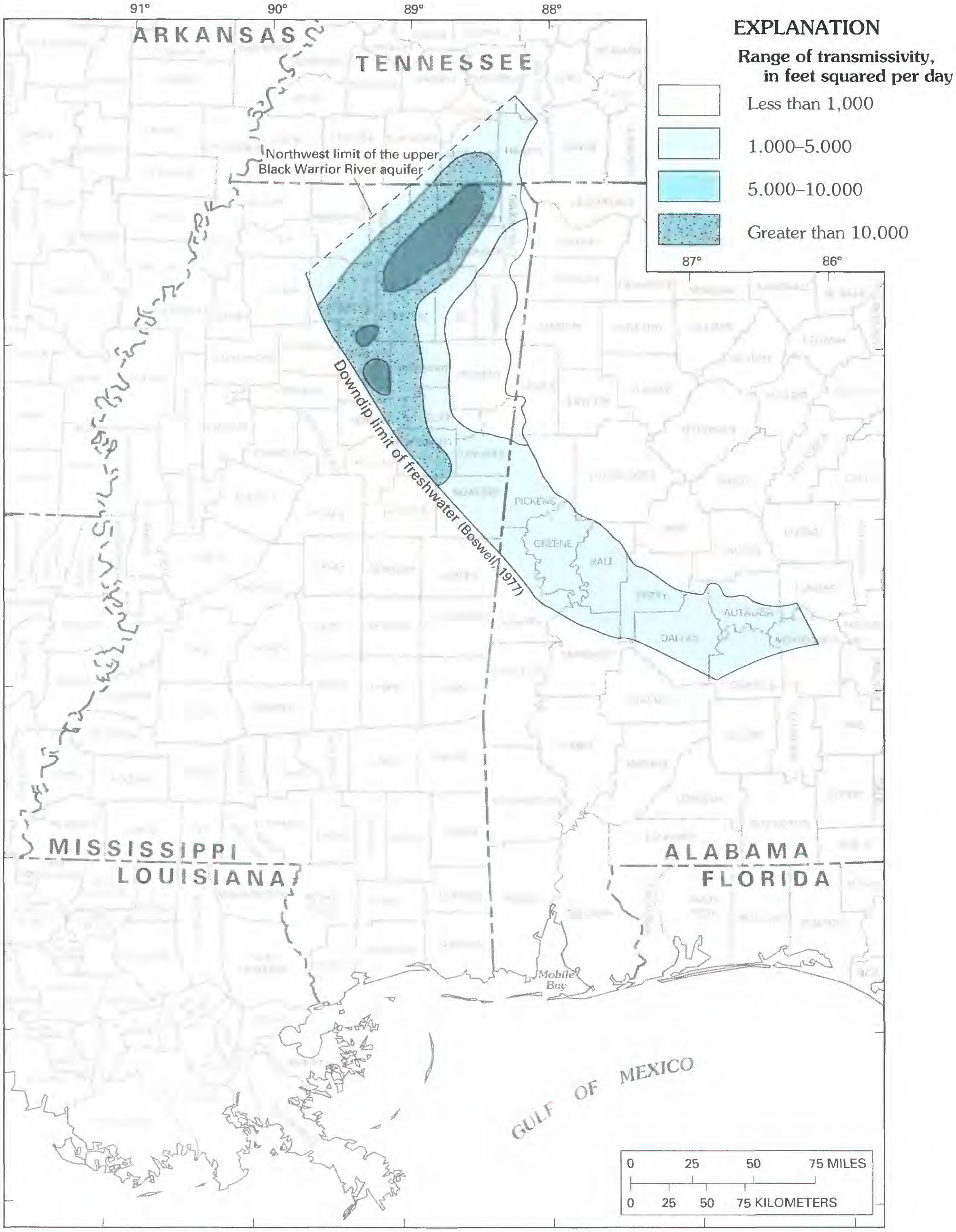

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FIGURE 15.—Transmissivity of the upper Black Warrior River aquifer used in the calibrated model.

Black Warrior River confining unit. Leakance of this unnamed confining unit in the study area ranges from 1.0×10^{-7} to 1.0×10^{-4} (ft/d)/ft (fig. 16). The potentiometric surface of the underlying lower Black Warrior River aquifer clearly shows the effects of ground-water drainage to the Tombigbee and Black Warrior Rivers despite the presence of this confining unit. A possible explanation for this phenomenon is noted by Gardner (1981, p. 11), who states, "Seismic data from the Tombigbee River were interpreted as showing extensive minor faulting of the confining bed of the Eutaw aquifer [the unnamed confining unit of this report] in the reach surveyed."

LOWER BLACK WARRIOR RIVER AQUIFER (TUSCALOOSA AQUIFER)

Permeable sand and gravel beds in the Coker and Gordo Formations of the Tuscaloosa Group make up the lower Black Warrior River aquifer. In places, some of the uppermost beds of the Lower Cretaceous series are lithologically very similar to the basal beds of the overlying Coker Formation and are included in this aquifer.

The potentiometric surface before development of the lower Black Warrior River aquifer is believed to have been similar to, but somewhat higher than, that of the overlying upper Black Warrior River aquifer. Although separate predevelopment potentiometric maps for the two aquifers could not be constructed because of a lack of historical data as previously discussed, it is not believed that differences were large between these aquifers under steady-state conditions. However, the effects of development that resulted in significant differences in the potentiometric surfaces of the two aquifers in more recent time prompted the separation of the hydrogeologic unit into two aquifers for the purposes of this study.

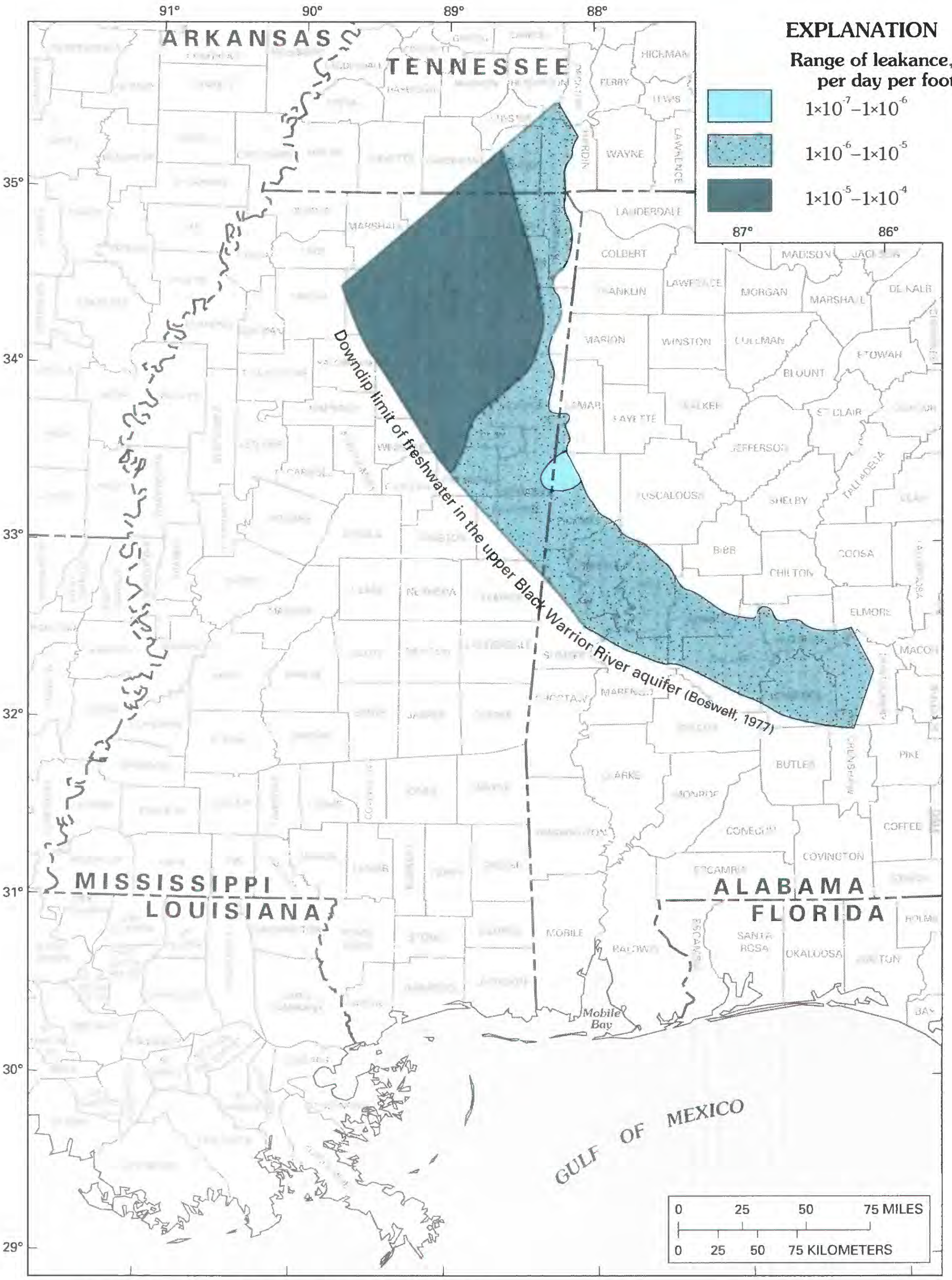
Recharge to the lower Black Warrior River aquifer occurs primarily as infiltration of precipitation in the outcrop area. In the northernmost part of the study area, some water (about 10 percent of total recharge) enters the unit by leakage downward from the overlying upper Black Warrior River aquifer. Discharge from the lower Black Warrior River aquifer is mostly (about 85 percent of total discharge) by leakage up to the overlying upper Black Warrior River aquifer. Discharge to rivers and low valleys in the outcrop area accounts for the remaining 15 percent of the total discharge from the lower Black Warrior River aquifer. In general, wells that are developed in the lower Black Warrior River aquifer are capable of larger yields and have smaller pumping lifts than wells that are developed in the overlying upper Black Warrior River aquifer. Available aquifer tests (Newcome, 1971) indicate a median hydraulic conductivity for 13 aquifer tests of 42.8 ft/d for the lower part of the lower Black Warrior River aquifer. Site-specific values of reported transmissivities ranged from 535 to 21,000 ft^2/d. Estimates of transmissivity based on four aquifer tests in the upper part of the aquifer ranged from 762 to 80,000 ft^2/d.

Total thickness of the lower Black Warrior River aquifer increases to more than 2,000 ft in the southern part of the study area. Based on thickness and hydraulic conductivity data as well as model simulation results, transmissivity values of the aquifer range from less than 1,000 to slightly over 20,000 ft^2/d (fig. 17). (The transmissivity value of 80,000 ft^2/d obtained in one aquifer test probably does not represent the aquifer on a regional scale.) Model calibration suggests a storage coefficient of about 2.5×10^{-4} for the aquifer.

Water quality in the lower Black Warrior River aquifer varies from a sodium bicarbonate water with concentrations of less than 50 mg/L dissolved solids in the updip areas to a mixed sodium chloride-bicarbonate water with greater than 1,000 mg/L dissolved-solids concentrations in the downdip areas. The increase in dissolved-solids concentrations downgradient in the lower Black Warrior River aquifer is somewhat more gradual than in the overlying aquifers. Increase in pH downgradient is also more gradual (Lee, 1985). Both of these effects may be related to the greater availability of organic material in the sediments of the lower Black Warrior River aquifer. Water in parts of the aquifer has a reported iron concentration as high as 29 mg/L (Wahl, 1965). The freshwater-saltwater interface in the aquifer, as interpreted by Wasson (1980), is shown in figure 17.

The lower Black Warrior River aquifer is the lowest aquifer in the Southeastern Coastal Plain aquifer system. In the northern part of the study area, the basal confining unit of the Southeastern Coastal Plain aquifer system consists of Paleozoic rocks. These consolidated shales, sandstones, limestones, and dolomites have much smaller permeability than the overlying Cretaceous sediments. In the extreme northern part of the study area, some secondary permeability has been developed in the Paleozoic rocks and, in these areas, they contain freshwater. However, in comparison with the Cretaceous sediments, these consolidated rock aquifers are not very productive (Boswell, 1978) and, on a regional scale, can be considered as a boundary of low permeability of the Southeastern Coastal Plain aquifer system and are represented by a no-flow boundary in the model simulation.

Farther south, the base of the flow system occurs in clays within beds of Early Cretaceous age. These clays provide a vertical resistance to flow that isolates underlying very saline water from the overlying freshwater aquifer system. Therefore, the base of the aquifer system being studied approximates the base of freshwater in these areas. Figure 18 shows the altitude of the base



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 16.—Leakance of the unnamed confining unit separating the upper and lower Black Warrior River aquifer units used in the calibrated model.

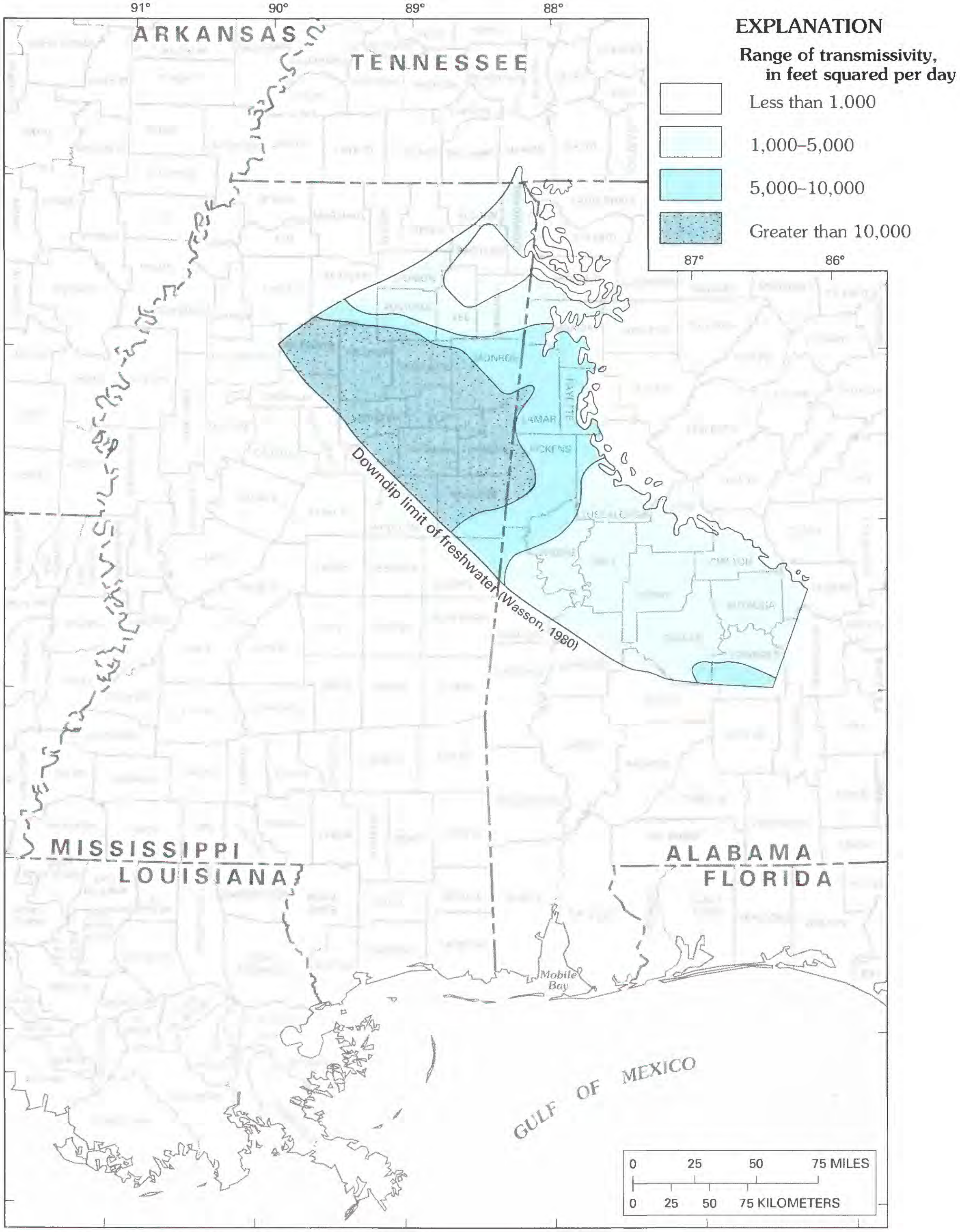


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FIGURE 17.—Transmissivity of the lower Black Warrior River aquifer used in the calibrated model.

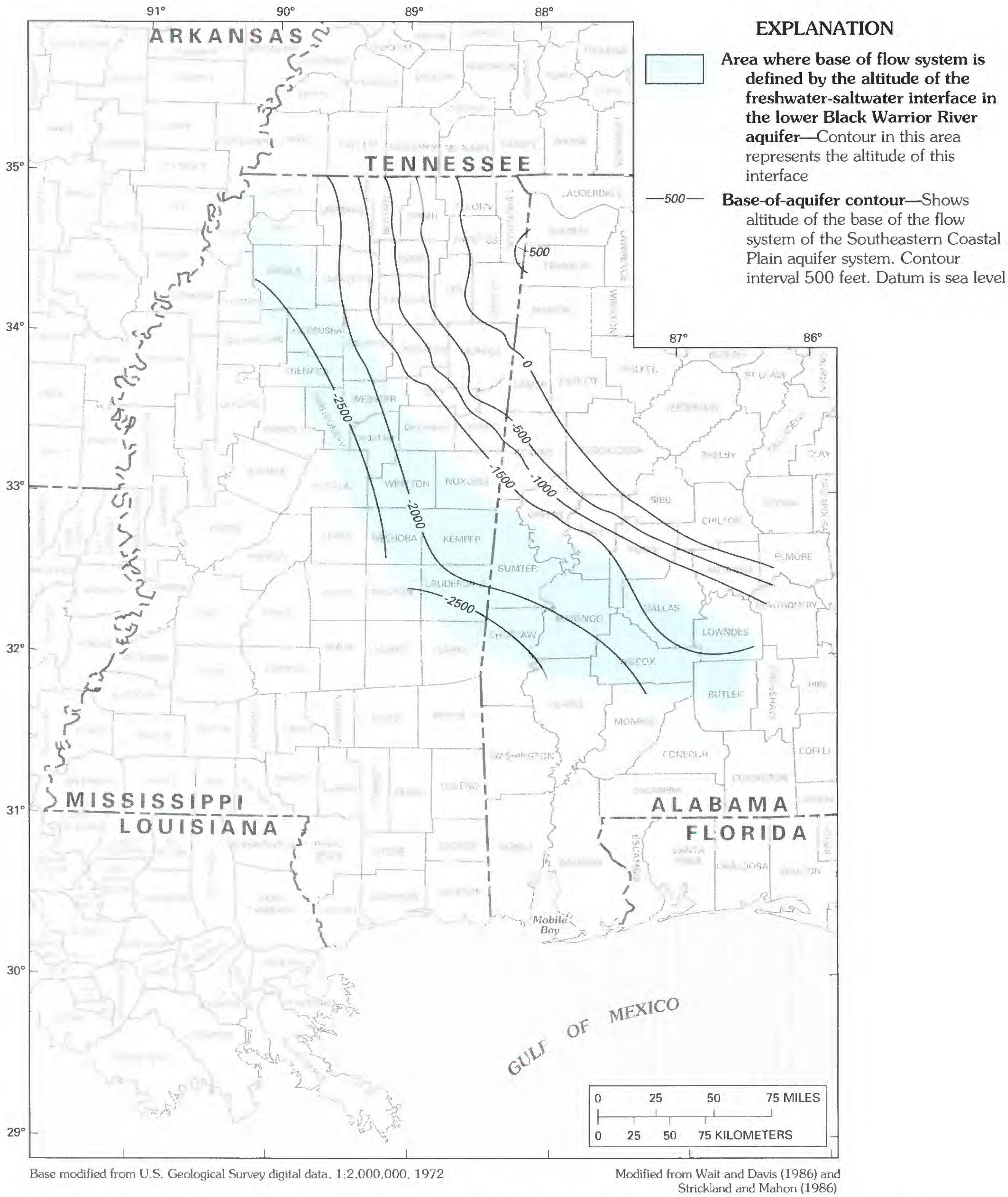


FIGURE 18.—Altitude of the base of the flow system of the Southeastern Coastal Plain aquifer system in the study area.

of the flow system of the Southeastern Coastal Plain aquifer system in the study area.

REGIONAL FLOW SYSTEM

The regional flow in the Southeastern Coastal Plain aquifer system in Mississippi and western Alabama was investigated by simulating both steady-state predevelopment conditions (pre-1934) and transient conditions when the system was subject to the stresses of historical pumpage. A digital, finite-difference model (McDonald and Harbaugh, 1988) was used to simulate both sets of conditions. This report, Professional Paper 1410–G, presents a review of the significant conclusions of the steady-state simulation as described by Mallory (written commun., 1986), as well as a complete discussion of the procedures and results of the transient simulation.

STEADY-STATE PREDEVELOPMENT FLOW SYSTEM

CONCEPTUAL MODEL OF THE SYSTEM

The primary source of recharge to the Southeastern Coastal Plain aquifer system in the Mississippi-western Alabama area is about 48–60 in/yr of precipitation on the outcrop areas. Stricker (1983) estimated that the average annual precipitation over the outcrop areas of the Southeastern Coastal Plain aquifer system in Mississippi and Alabama is 52 in. Of this total, only a small part enters the deep, confined parts of the aquifer that constitute the regional flow system. Runoff, including both direct surface runoff and ground-water base flow, in the Tombigbee River basin is about 23 in/yr and can probably be considered typical of the aquifer outcrop in the study area. Stricker (1983) reports average annual streamflows of 18 in. for Alabama and 22 in. for Mississippi, but these statewide averages may understate the streamflow from aquifer outcrop areas. Stricker (1983) also estimated the base-flow component of total runoff for 11 surface-water gaging stations in this study area using hydrograph separation techniques. These values ranged from 3 to 9 in/yr and averaged 7 in/yr.

In addition to runoff, a large part of total precipitation is returned to the atmosphere by evaporation and by transpiration by plants. Few data are available to quantify this component of the hydrologic cycle in the study area, but Barker (1986) estimated an evapotranspiration rate of about 35 in/yr for the Southeastern Coastal Plain aquifer system area as a whole.

Of the water that enters the ground-water system, only a fraction enters the regional flow system. Much of the base flow of small streams in the study area is accounted for by water that travels distances of a few miles or less in an aquifer before emerging in tributary streams. This water can be considered to be part of local ground-water flow systems. Because of the scale of this study and practical limitations on the number of nodes in the digital model, these local flow components were not investigated in detail. Model simulations for the study represent only the regional flow system; therefore, simulated recharge to the aquifers and simulated discharge to major rivers represent only a fraction of the total base flow.

The allocation of recharge between local and regional flow systems is scale dependent and continuous—a flow component that would be considered regional flow in a study covering a few counties would logically be considered local flow in a multistate aquifer study. The discretization of the finite-difference grid used in a digital model will determine the scale of the features controlling recharge and discharge that can be represented in the model. In this study, uniform cells 4 mi on a side were used in the model; consequently, only major streams are represented in the model, and the smaller perennial streams that are not simulated, in effect, define the separation of the local and regional flow systems for the model. These small streams generally act as drains for the local ground-water flow system; therefore, that fraction of total base flow that flows to them is excluded from the model computations and calculated water budgets.

Because recharge to the regional flow system had not been defined, recharge in the digital model was simulated by head-dependent flux nodes in the outcrops of the modeled aquifers; thus, a better understanding of recharge to the regional aquifer system was one of the benefits derived from the digital model calibration. Hydrographs of water-table wells in the outcrop areas (fig. 19) generally show annual water-level variations of less than 10 ft without any discernible long-term trend. This observation and the large base flows of even small streams in the outcrop areas, as previously discussed, indicate that recharge in this precipitation-rich environment is more than sufficient to provide all the recharge that the aquifers can accept and that much of the total precipitation is rejected by the aquifers and is diverted to surface runoff. In this situation, the amount of recharge accepted by an aquifer is more dependent on the ability of the aquifer to accept infiltration in the outcrop area and the rate at which the aquifer is able to move the infiltrated water downgradient out of the outcrop area than on the gross amount of precipitation available.

Predevelopment potentiometric surfaces (figs. 10, 12, and 15) show the general direction of flow within the aquifers of the Southeastern Coastal Plain aquifer system in the study area before about 1934 and indicate areas of recharge and discharge. The maps are necessarily generalized because of the very limited data collected

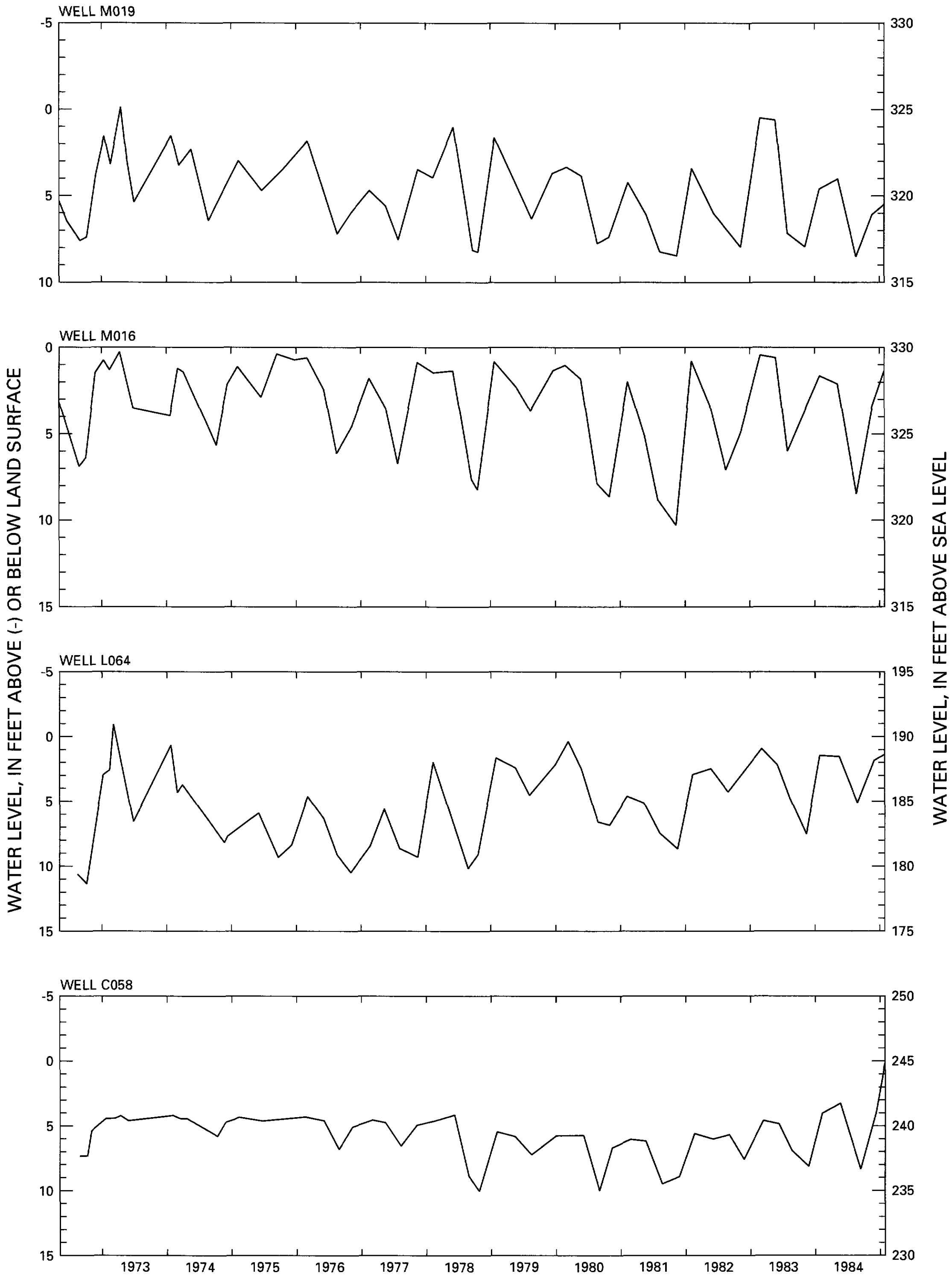


FIGURE 19.—Water levels in selected wells in aquifer outcrop areas, 1973–84.

during early days of utilization of these aquifers. These maps and the details of aquifer geometry previously described guided the delineation of the boundaries of the study area. The updip boundary is the contact between Cretaceous and Paleozoic rocks known as the "Fall Line" because the much more indurated Paleozoic rocks typically support higher physiographic relief that results in rapids and waterfalls where streams cross the contact.

The downdip boundary of flow in each aquifer is located where the aquifer becomes saline (greater than 10,000 mg/L of dissolved solids). The downdip limit of the freshwater circulation system is thought to represent a surface across which little or no flow takes place because of the observed narrow width of the freshwater-saltwater transition zone (Gandl, 1982). If substantial mixing or displacement were occurring, it would be expected that the transition zone would be more diffuse. The northwestern boundary of the study area coincides generally with the limits of permeable material in the lower two aquifer units being studied (the upper and lower Black Warrior River aquifers). However, the Chattahoochee River aquifer thickens to the north and west, and the northwestern study boundary for this aquifer is arbitrary. The formations that make up the Chattahoochee River aquifer are also included in the Gulf Coastal Plain RASA study, and conditions along the northwestern boundary were determined in conjunction with that study. The southeastern boundary of the study area was chosen to follow flow lines and to correspond to a gradual facies change from a predominantly clastic lithology in the east to a lithology dominated by chalk in central Alabama.

The locations of four hydrogeologic sections are shown in figure 20. Figures 21, 22, 23, and 24 illustrate the generalized conceptual model of the predevelopment flow system. These four hydrogeologic sections are drawn along row 27; along row 55; in an arc from row 19, column 35 to row 29, column 24 to row 55, column 24 to row 60, column 31; and along column 17.

The hydrogeologic section *D–D′* along row 27 (fig. 21) is approximately perpendicular to the strike of the outcrop of the aquifers and is located in the northern, topographically higher part of the outcrop area. Considerable recharge enters the outcrop of all three major aquifers in this area, and ground water generally flows downdip to the southwest. There is also a component of flow out of the plane of the section (to the southeast) for the lower and upper Black Warrior River aquifers and into the plane of the section (to the northwest) for the Chattahoochee River aquifer. (See the intersecting section *F–F′* shown in fig. 23.) The concentration of flow lines in the more shallow part of the aquifer system compared with the sparser flow lines in the deeper parts suggests the relatively sluggish nature of the flow in these deeper aquifers.

There is a general upward leakage from the lower Black Warrior River aquifer to the overlying upper Black Warrior River aquifer. Only a small amount of upward leakage occurs between the upper Black Warrior River aquifer and the Chattahoochee River aquifer because of the very low vertical hydraulic conductivity of the Black Warrior River confining unit that separates them. In addition, only a small amount of upward leakage occurs through the Chattahoochee River confining unit between the Chattahoochee River aquifer and the overlying Pearl River aquifer that forms the upper boundary of the aquifer system.

The geohydrologic section *E–E′* along row 55 (fig. 22) is approximately perpendicular to the generalized strike of the outcrop and through the major river valley at the confluence of the Tombigbee and Black Warrior Rivers. In this section, there is a component of flow from the deeper parts of the upper and lower Black Warrior River aquifers flowing updip toward the outcrop. This flow results from water moving toward the potentiometric low that underlies the Tombigbee–Black Warrior River valley. The upward discharge to the river valley represents the major regional drain for these aquifers. The Chattahoochee River aquifer is not prominent in this section because the formations constituting it have largely undergone a facies change to chalk.

The arcuate geohydrologic section *F–F′* (fig. 23) is approximately parallel to the strike of the outcrop and is located in the updip area near the outcrop. The denser network of flow lines illustrates the more active flow system present in the shallower, unconfined parts of the aquifers. The rather erratic flow pattern indicates the effects of “intermediate scale” flow where recharge in topographically higher areas is discharged in lower areas. As local topography affects the potentiometric surface near the outcrop, patterns of leakage are disrupted, and the general trend of upward leakage from the lower to the upper Black Warrior River aquifer is reversed in numerous smaller areas where downward leakage between these units occurs. This section is updip from the Pearl River and Chattahoochee River aquifers; consequently, those aquifers are not shown.

Flow paths at the downdip edge of the study area illustrate the assumed static nature of the interface of the saltwater-freshwater transition zone. The geohydrologic section *G–G′* along column 17 (fig. 24) is approximately parallel to the generalized strike of the outcrop and is near the downdip edge of the study area in the downdip sluggish part of the flow system in the upper and lower Black Warrior River aquifers. Here, the inability of the very tight Black Warrior River confining unit to leak enough water upward causes flow in the upper and lower Black Warrior River aquifers to be southeastward toward major regional drains in the valleys of the Tombigbee, Black Warrior, and Mobile Rivers. Flow in the the Chattahoochee River aquifer is predominantly northwestward, toward its ultimate discharge point in Missouri (Brahana and Mesko, 1987). This fact complicated the modeling of this aquifer in this study and necessitated coordinating boundary conditions with the Gulf Coastal Plain RASA study, which modeled the unit in the

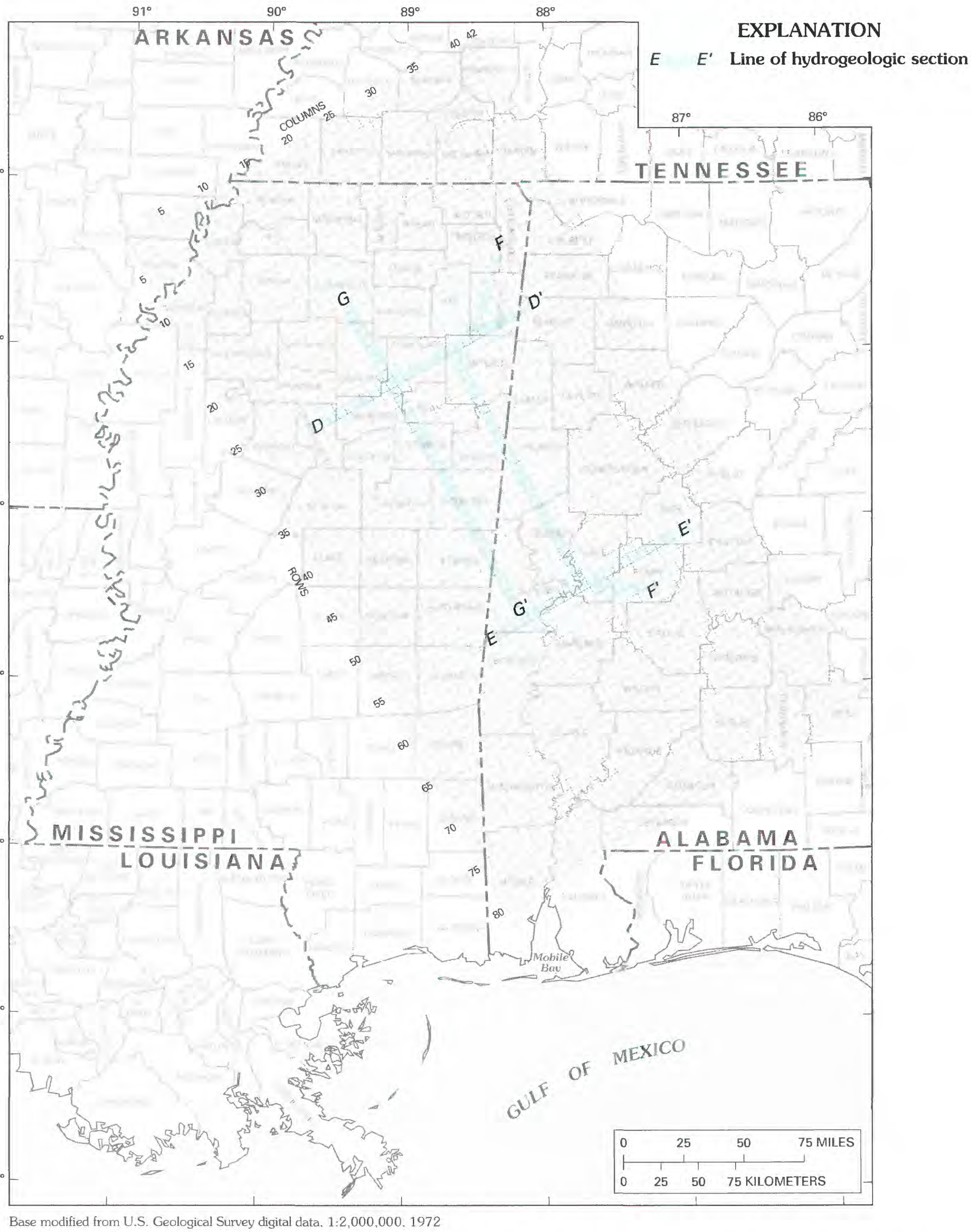


FIGURE 20.—Model area of the Southeastern Coastal Plain aquifer system in eastern Mississippi–western Alabama with finite-difference grid and lines of hydrogeologic sections.

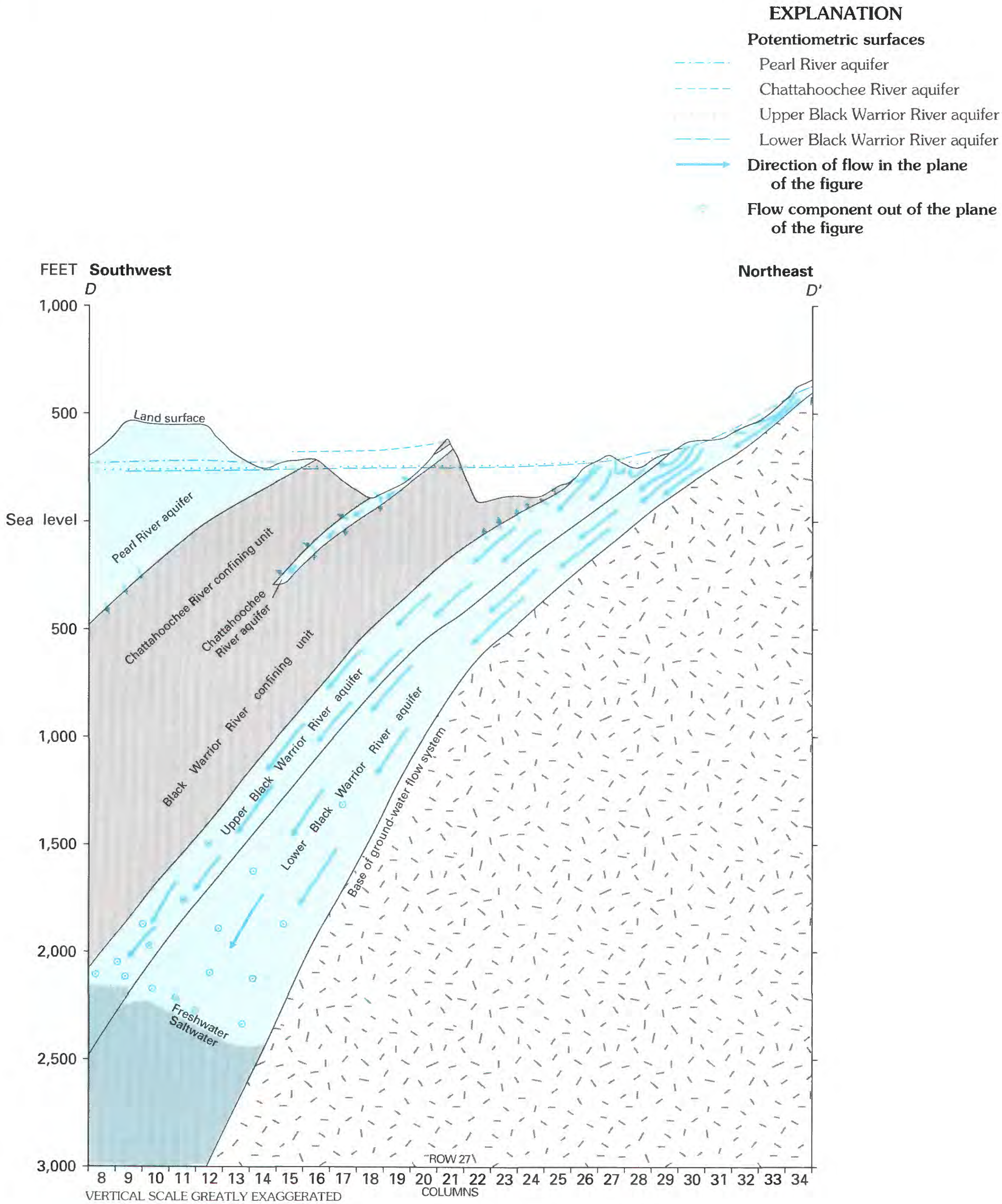


FIGURE 21.—Generalized hydrogeologic section in recharge area.

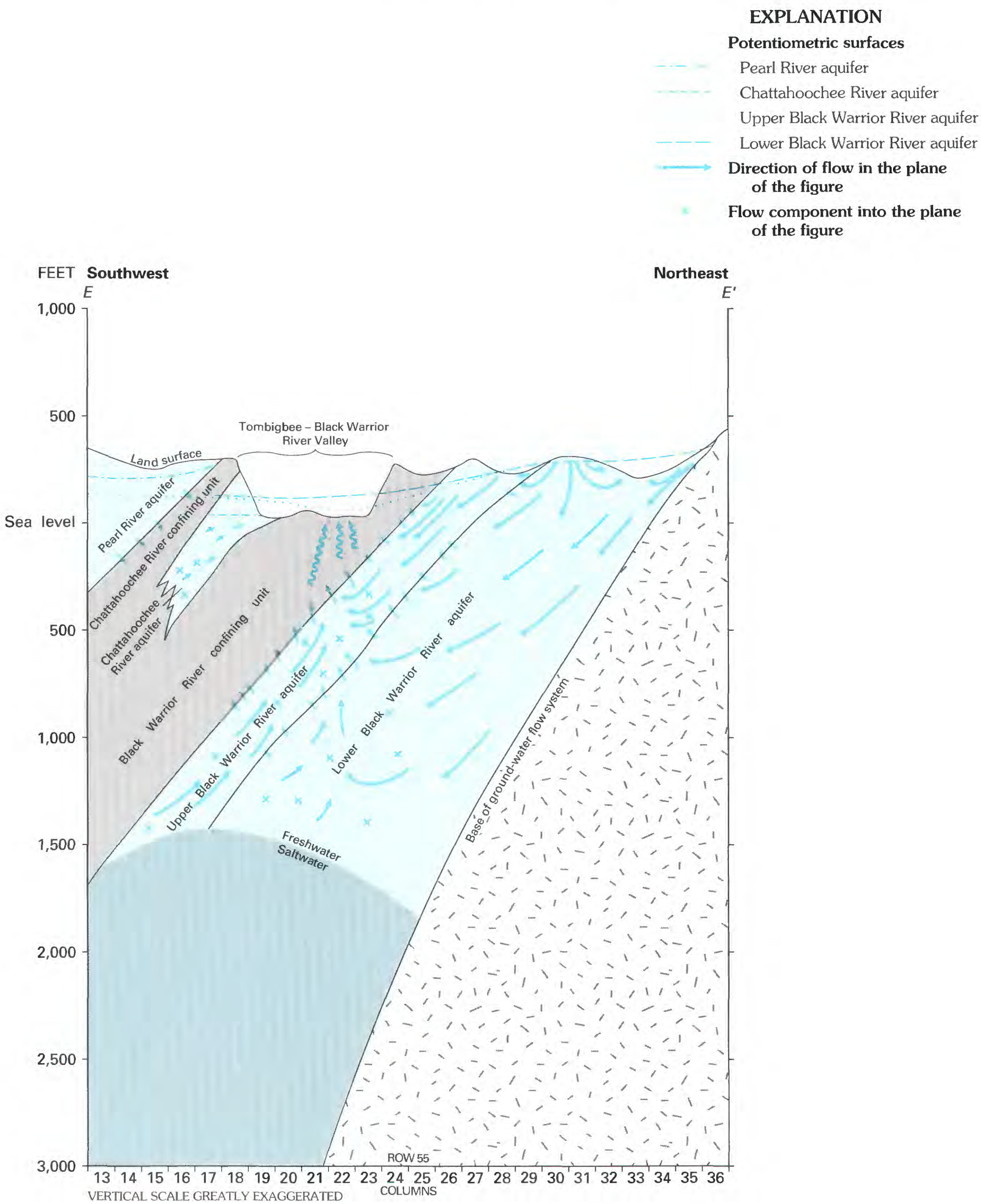


FIGURE 22.—Generalized hydrogeologic section in discharge area.

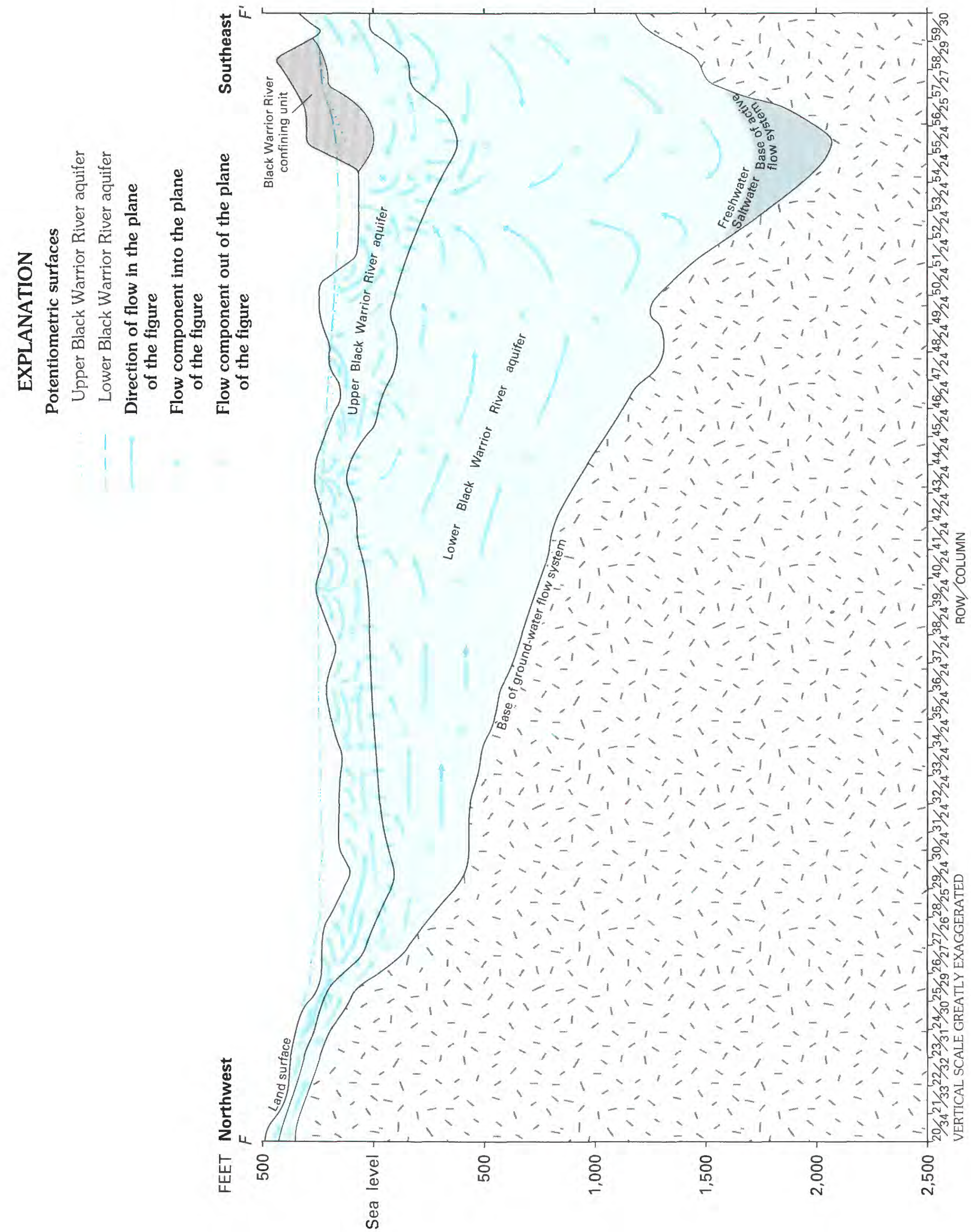


FIGURE 23.—Generalized hydrogeologic strike section F–F'.

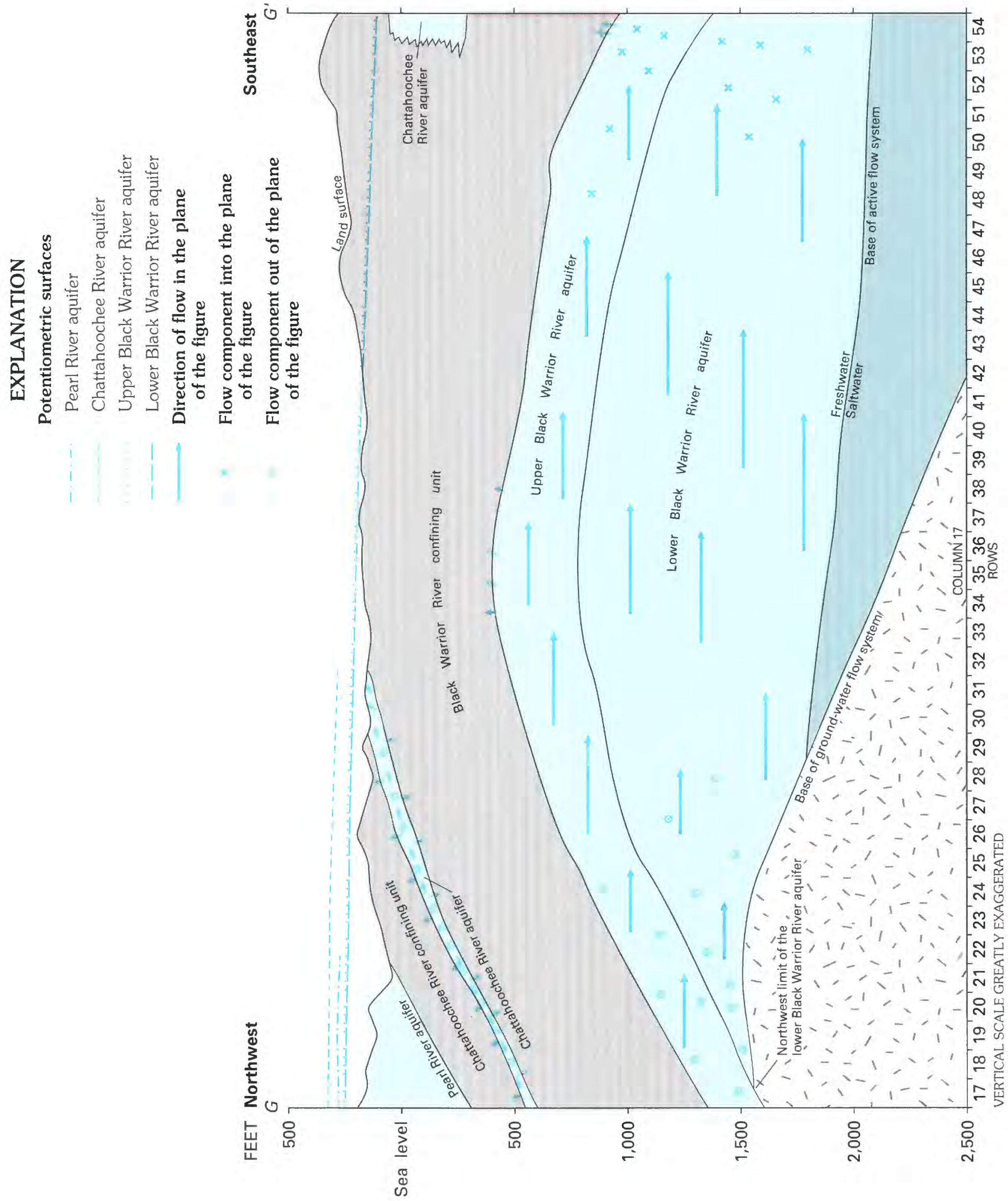


FIGURE 24.—Generalized hydrogeologic strike section G–G'.

Mississippi embayment. Potential for interaquifer leakage between the upper and lower Black Warrior River aquifers occurs in this area, although this potential is not obvious because the downdip head distribution in these two aquifers is similar under the predevelopment conditions that are shown on the section (fig. 24).

SIMULATION OF PREDEVELOPMENT CONDITIONS

The model design, boundary designations, and inherent assumptions for a preliminary, steady-state predevelopment model of the study area have been described by Mallory (written commun., 1986) and are summarized below. Figure 20 shows the finite-difference grid used to discretize the Southeastern Coastal Plain aquifer system in the Mississippi-western Alabama area. The model consisted of four layers of rectangular grid cells, each 4 mi on a side. In each layer, these cells formed a matrix of 80 rows by 42 columns (fig. 20). The top layer simulated the effects of the Pearl River aquifer and consisted entirely of constant-head flux cells where this aquifer is present. Therefore, the Pearl River aquifer was not actively simulated in the model but instead acted as a source-sink layer supplying water to and taking water from the underlying active layer based on the head differential between the layers at each node.

The Chattahoochee River aquifer, the upper Black Warrior River aquifer, and the lower Black Warrior River aquifer are simulated by the second through fourth layers. In each of these layers, head-dependent flux cells that were located to correspond with the updip edge of the aquifer outcrop supplied water to the aquifers. The downdip boundary of each of the active layers consisted of a no-flow boundary located where the aquifers become saline (greater than 10,000 mg/L dissolved solids). The northwestern and southeastern lateral boundaries of each aquifer layer were also simulated as no-flow boundaries. As discussed in the section "Conceptual Model of the System," this representation is a good approximation of the actual conditions in the upper and lower Black Warrior River aquifers where the northwestern boundaries coincide with the limits of deposition and the southeastern boundaries coincide with a facies change to chalk in these aquifers. However, the northwestern boundary for the Chattahoochee River aquifer layer, which thickens to the north and west, is arbitrary in this preliminary model. Boundary conditions used in the predevelopment model are shown in figure 25.

During transient simulation, some changes that affected steady-state calibration were made. A change to the northwestern corner of the Chattahoochee River aquifer layer was made to allow for flow out of the study area. The nodes representing the northwest and southwest boundaries of the Chattahoochee River aquifer near the corner were set to specified heads determined in consultation with the Gulf Coastal Plain RASA study, which modeled the full extent of this aquifer (J.V. Brahana, written commun., 1986).

In the preliminary predevelopment model, recharge was introduced by head-dependent flux nodes only in limited updip areas of the respective aquifer outcrops. In the transient model, head-dependent flux nodes were extended throughout the mapped extent of each aquifer outcrop. This modification produced changes in simulated heads near the downdip edge of the aquifer outcrop because of the interaction between the additional head-dependent flux nodes and the underlying aquifer layers. Simulated heads changed significantly near the downdip edge of the upper Black Warrior River aquifer outcrop, which is quite broad in some areas and has significant topographic relief across its extent.

Changes to estimates of aquifer transmissivity and vertical hydraulic conductivity of the confining unit used in the preliminary model were, in general, minor. One change that deserves discussion is that involving aquifer transmissivities in the aquifer outcrop area and the vertical hydraulic conductivity of the head-dependent flux nodes that allow recharge to enter the aquifer system. In the preliminary steady-state model, transmissivity in the outcrop areas of the modeled aquifers was not reduced to represent the pinching out of the aquifers at the land surface, and the vertical hydraulic conductivity of the head-dependent flux boundaries used to simulate recharge was set to a high value. This allowed the aquifers to accept as much recharge from the outcrop as they could transport downdip under the calibrated transmissivities used in the model; that is, the aquifers never became "starved" for recharge at the outcrop. This configuration of parameters provided a good match to the available predevelopment water-level data.

During transient simulation, however, it was discovered that in some areas subjected to heavy pumping, it was necessary to restrict the availability of recharge from the outcrop to match the pattern and distribution of observed water-level declines due to pumping. Two methods of restricting the quantity of recharge that could be captured by the aquifers were possible: either (1) reduce the vertical hydraulic conductivity of the head-dependent source nodes that simulated the entry of recharge into the aquifers or (2) reduce transmissivity in the outcrop areas to represent the beveling out of the aquifers, thereby reducing the ability of the aquifer to move water downdip from the outcrop area. The method of choosing between the two possibilities and the final parameters selected are described later in section "Simulation of Transient Conditions." However, the effects of these changes on the simulation of predevelopment con-

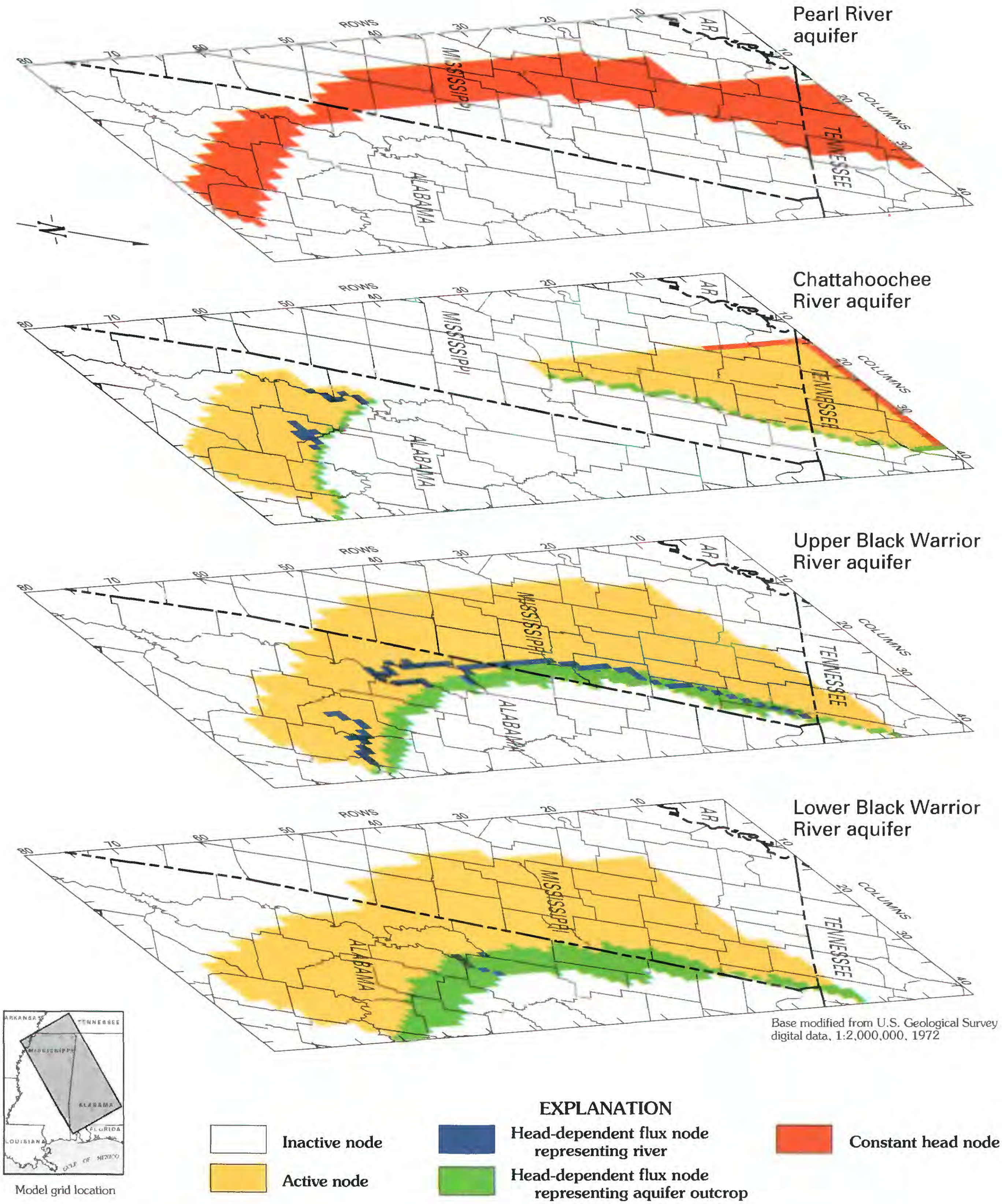


FIGURE 25.—Boundary conditions used in the predevelopment model.

ditions (where the demand for recharge was less) were not large and generally were hidden by the effects of extending the head-dependent flux boundaries throughout the mapped extent of the aquifer outcrop.

To verify that the final selection of parameters made during transient simulation continued to represent an acceptable calibration for steady-state predevelopment conditions, the model was rerun as a steady-state simulation without pumpage, and the results were analyzed using the same statistical technique used to evaluate the preliminary predevelopment model. Based on 115 control points (44 in the Chattahoochee River aquifer layer, 47 in the upper Black Warrior River aquifer layer, and 24 in the lower Black Warrior River aquifer layer), results of this analysis showed that the root-mean-square error changed from 38.6 to 47.4 ft for the Chattahoochee River aquifer, from 16.4 to 26.1 ft for the upper Black Warrior River aquifer, and from 17.8 to 37.9 ft for the lower Black Warrior River aquifer.

This statistical evaluation of the final model (after aquifer parameters had been adjusted during transient simulations) as a simulator of the predevelopment behavior of the Southeastern Coastal Plain aquifer system is obviously not as good as that of the preliminary model. However, two factors suggest that the parameter distributions of the final model should be accepted. First, the parameters used in the preliminary model consistently underestimated head declines in the study area in transient simulations for any reasonable range of values of the aquifer storage coefficient. Second and more important, the quality of the data (the hydraulic heads) available to evaluate transient simulations was better than that available to evaluate the predevelopment conditions of the preliminary model. Verification data for the preliminary predevelopment model consisted of 115 water-level measurements given in the earliest reports available (Crider and Johnson, 1906; Stephenson and others, 1928; Smith, 1907). Although these measurements were selected from a much larger number of available measurements as the most reliable, the data are questionable. The most common problem is uncertainty in the altitude of land surface at the measuring point, resulting in a corresponding uncertainty in the water-level measurement. In the late 1800's and early 1900's, when these measurements were made, accurate surveys of altitude in the study area were rare. This factor may result in errors in the verification data of 20 ft or more.

In the outcrop area of the Chattahoochee River aquifer and, to a lesser extent, in the outcrop of the upper and lower Black Warrior River aquifers, some water levels chosen for verification for the predevelopment model may actually represent perched water tables, well above the actual water table. Perched water tables are common in some parts of the study area.

The transient simulations used long-term hydrograph data for verification. (See "Simulation of Transient Conditions.") Some of the hydrographs are based on data collected over nearly 40 yr, although for most hydrographs, the period of record is shorter. The altitudes of land surface at these long-term observation wells were more accurately determined by leveling or from better topographic maps, and care was taken to select only representative wells.

Therefore, the calibration of the model for predevelopment conditions was judged to be adequate. Distributions of hydrologic parameters of aquifers and confining units used in the calibrated model are shown in figures 11, 13, 15, 16, and 17 and are discussed in the section "The Transient Flow System." Quantitative discussions of major components of the flow system for both predevelopment and transient conditions are given in the section "Summary of Flow Components."

EFFECTS OF DEVELOPMENT ON THE REGIONAL FLOW SYSTEM

MAGNITUDE AND DISTRIBUTION OF GROUND-WATER PUMPAGE

Transient simulations of the regional flow system require an accurate description of the distribution of ground-water pumpage, both areally and in time. Inventories of ground-water use were sufficiently detailed to allow disaggregation by individual aquifers for 1975 and 1980 in Mississippi (Callahan, 1976, 1983) and for 1970 in Alabama (Pierce, 1972). These data alone, however, are insufficient to determine both the spatial and temporal distributions of pumpage that are needed for simulations. Inventories of water wells that include dates of installation and measurements or estimates of their pumping capacity are fairly complete for the study area, and an attempt was made to estimate the temporal distribution of water use from these data. These comprehensive inventories are available even for the early history of ground-water development in Mississippi (Stephenson and others, 1928; Crider and Johnson, 1906; Lang and Boswell, 1960).

The first step in establishing the temporal distribution of ground-water pumpage was to determine total installed pumping capacity through time. For this purpose, the average production life of a water well was assumed to be 30 yr. Inventories of water wells were used to calculate total installed pumping capacity at the beginning of nine discrete time periods by bringing wells on line on the date that they were drilled and by retiring them 30 yr later. The discrete divisions of time were defined to give the greatest resolution from 1961 to 1982, the period when the greatest increases in pumping occurred. The time periods chosen are listed in table 1.

TABLE 1.—*Time periods used in the digital model*

Time period	Begin year	End year
1	1800	1934
2	1935	1944
3	1945	1954
4	1955	1960
5	1961	1965
6	1966	1970
7	1971	1975
8	1976	1980
9	1981	1982

Any measure of total installed pumping capacity grossly overestimates actual water use because few wells pump at full capacity 24 hours a day. A factor for percent use of the pumping capacity was calculated to give the best possible match for time periods 7 and 8 to the 5-yr water-use inventories reported in 1975 (1971–75) and 1980 (1976–80), respectively. The calculated percent-use figures were then applied to the capacity of each active well for each time period to provide the spatial distribution of pumpage for each time period.

Possible sources of error in this analysis include (1) wells not included in the available inventories, (2) an incorrect estimate of the average useful life of a production well, and (3) variation in the percent use of installed pumping capacity with time. While all these factors undoubtedly affect the generated distributions of ground-water pumpage with time, the cumulative error is believed to be small. While many smaller wells undoubtedly are omitted from inventories, their pumpage is insignificant in comparison with the pumpage by major industrial and municipal water users. It is believed that virtually all major water users are included in the inventories. If the useful life of the average water well was estimated incorrectly, a corresponding change in the calculated percent-use figure would compensate because the final totals would be preserved even though the data would be slightly shifted in time. Possible variations in percent use in time might conceivably cause the greatest distortion to the time distribution of the data; however, this factor is most likely to be reasonable for the important and heavily pumped period from 1960 to 1982.

The total pumpage determined by this analysis for each aquifer and time period is shown in table 2.

Figures 26, 27, and 28 illustrate the spatial distribution of pumpage simulated in the transient model for each aquifer and time period.

EFFECTS OF DEVELOPMENT ON WATER LEVELS

Pumping of ground water, particularly for municipal and industrial use, has caused locally severe water-level declines in the study area. In addition, less severe but more extensive regional declines occurred in some aquifers as the flow system equilibrated in response to increased ground-water withdrawals.

TABLE 2.—*Pumpage used in simulations, by aquifer and time period*
[Mgal/d, million gallons per day]

Time period	Pumpage (Mgal/d)
Chattahoochee River aquifer	
1800–1934	0.0
1935–1944	2.06
1945–1954	2.64
1955–1960	2.55
1961–1965	3.06
1966–1970	5.43
1971–1975	5.71
1976–1980	6.59
1981–1982	6.74
Upper Black Warrior River aquifer	
1800–1934	0.0
1935–1944	9.57
1945–1954	13.07
1955–1960	16.89
1961–1965	19.60
1966–1970	30.50
1971–1975	34.87
1976–1980	39.67
1981–1982	37.52
Lower Black Warrior River aquifer	
1800–1934	0.0
1935–1944	6.36
1945–1954	9.02
1955–1960	13.68
1961–1965	16.89
1966–1970	31.91
1971–1975	38.75
1976–1980	46.62
1981–1982	59.80

Eighteen observation wells (fig. 29) were used to generate long- to intermediate-term hydrographs illustrating observed water-level declines in the Chattahoochee River aquifer, upper Black Warrior River aquifer, and lower Black Warrior River aquifer. These hydrographs were also used to compare observed water-level declines with the declines simulated by the transient model (figs. 30–35). Construction features of the wells that provided the water-level measurements for these hydrographs are shown in table 3.

At the location of the two wells in the Chattahoochee River aquifer, the simulated and observed hydrographs agree well (fig. 30). At well B006, which is located in the downdip part of the aquifer, water levels have declined steadily since pumping began in 1955. At well K037, located nearer the outcrop of the unit, water levels have stabilized with no long-term downward trend because of a sufficient induced recharge.

Nine hydrographs of wells in the upper Black Warrior River aquifer are shown in figures 31–33. At well F002,

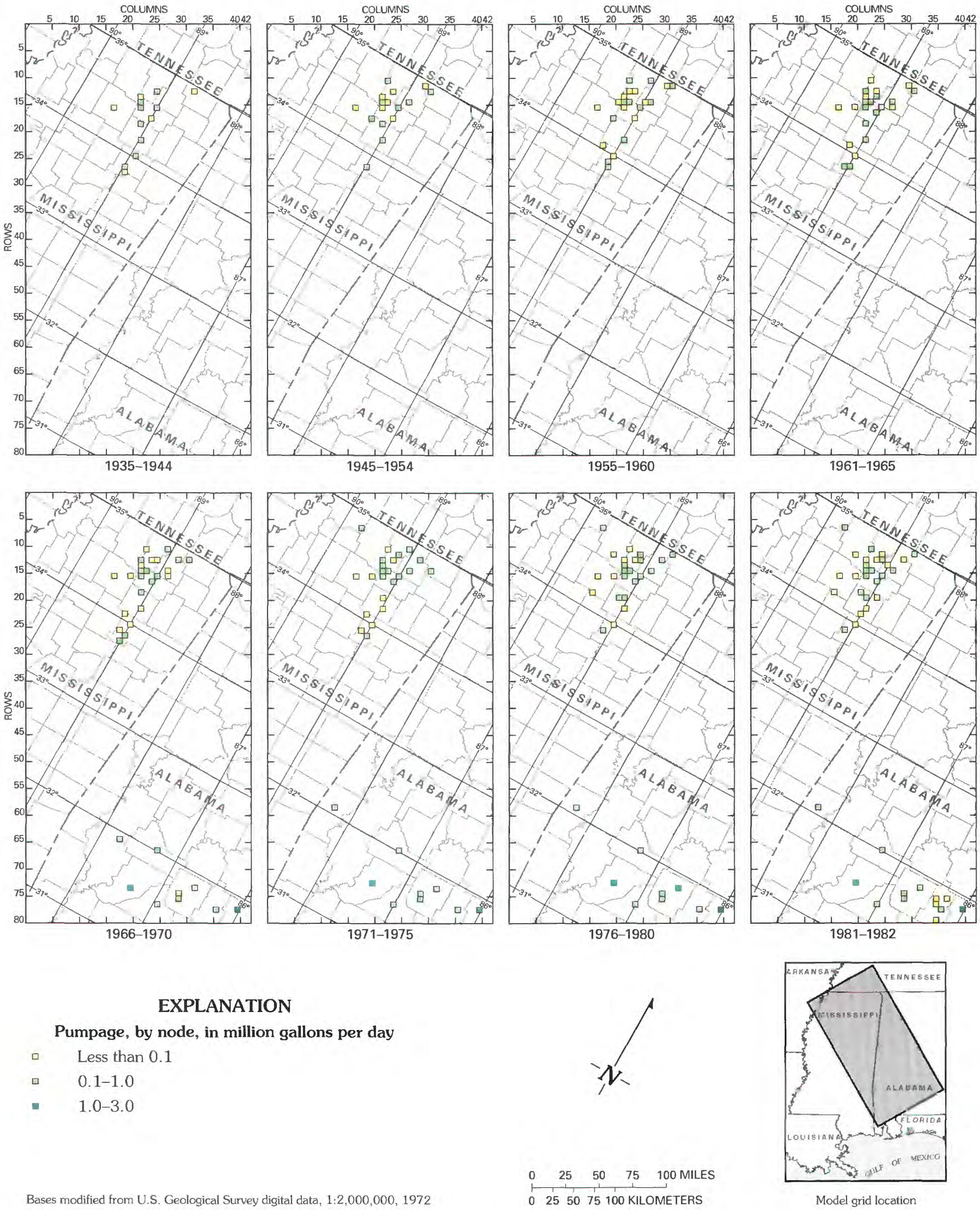


FIGURE 26.—Distribution of modeled pumpage for the Chattahoochee River aquifer.

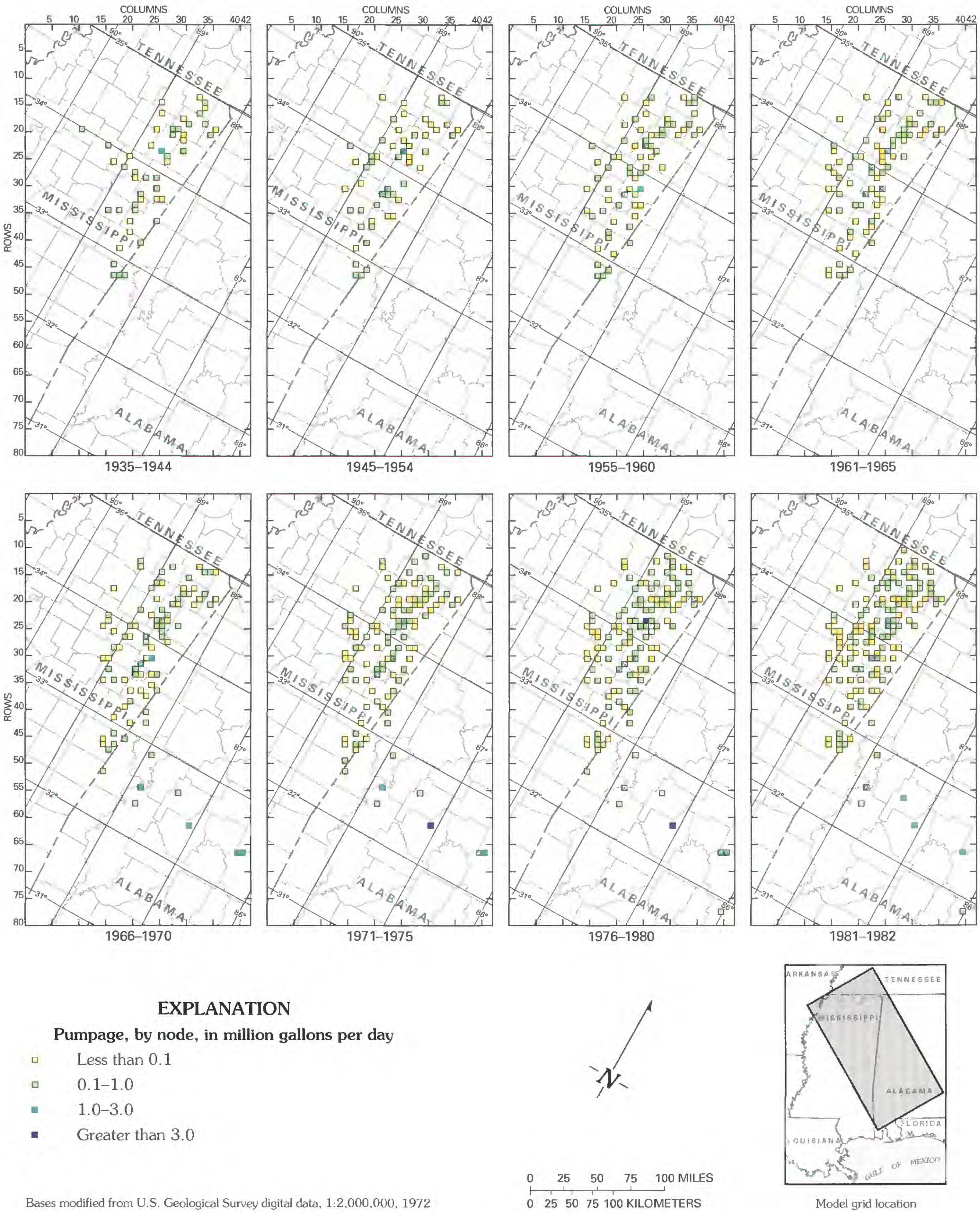


FIGURE 27.—Distribution of modeled pumpage for the upper Black Warrior River aquifer.

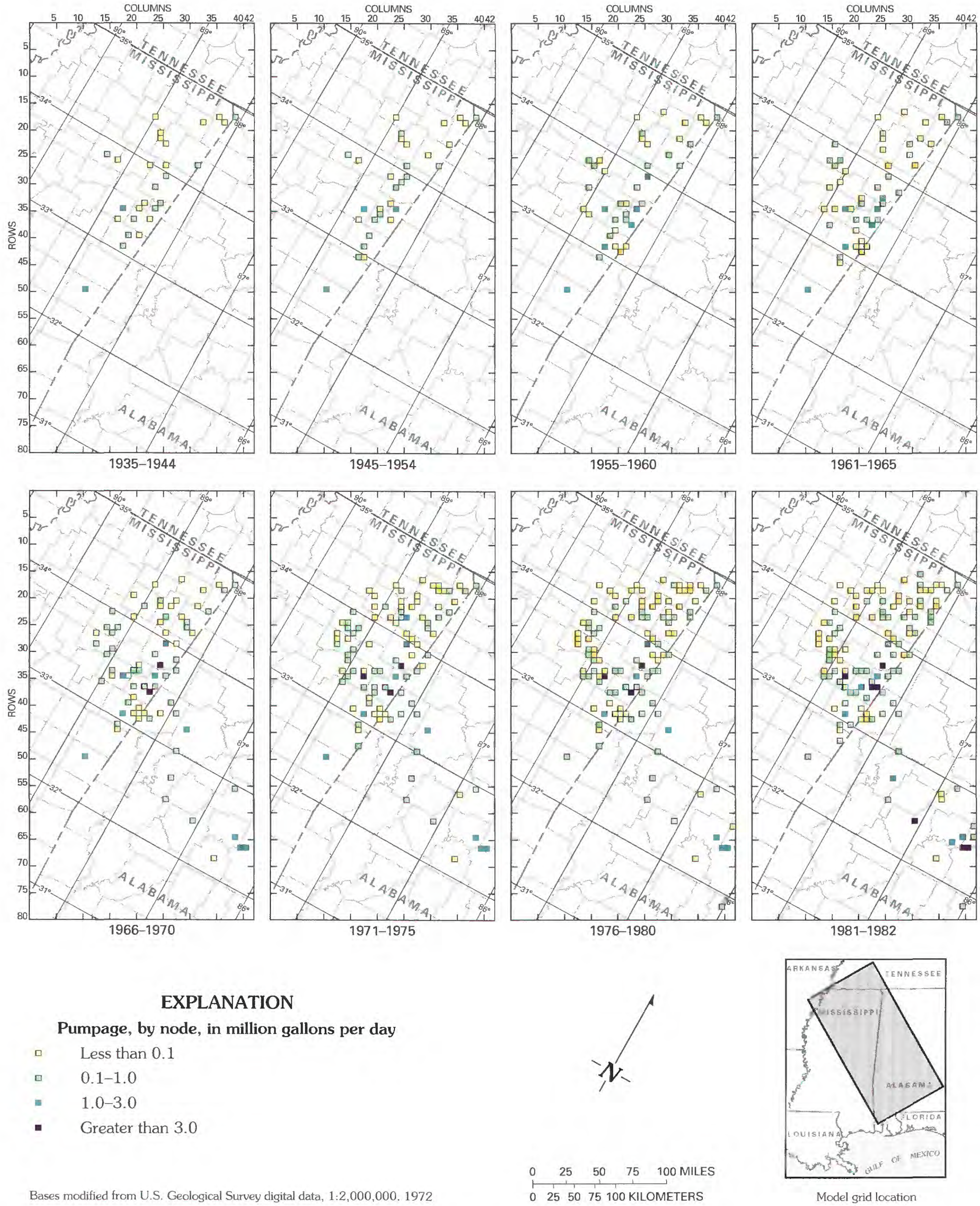
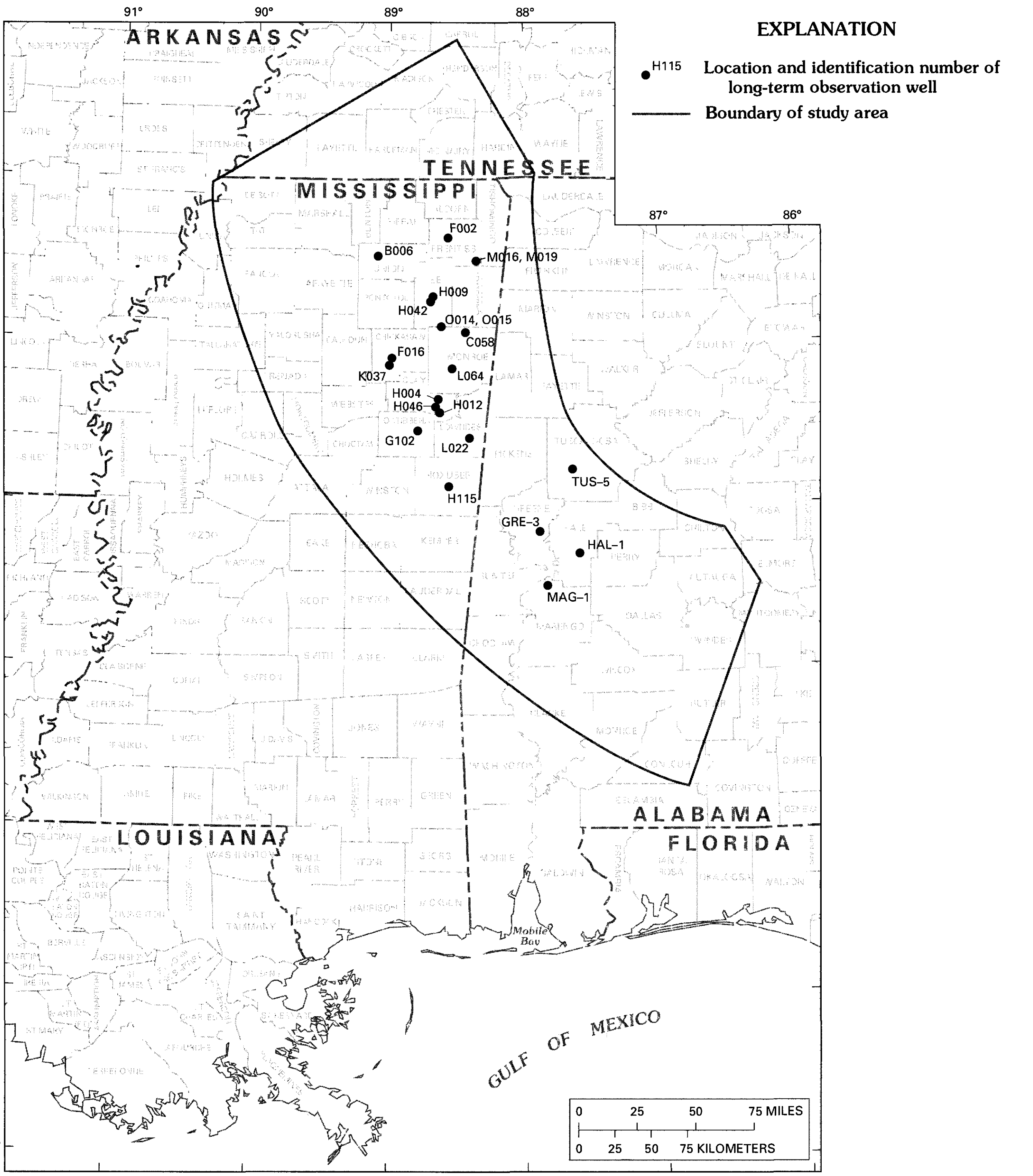


FIGURE 28.—Distribution of modeled pumpage for the lower Black Warrior River aquifer.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 29.—Location of selected long-term observation wells.

TABLE 3.—*Construction features of selected long-term observation wells*

Well number	Latitude	Longitude	Land elevation (feet above sea level)	Year drilled	Well depth (feet)	Geologic unit	Water level (feet below land surface)	Year measured	Top of screen (feet below land surface)	Location in model grid	
										Row	Column
B006	34° 32′ 00″	089° 04′ 59″	385	1955	500	Ripley	25	1955	110	17	24
F002	34° 39′ 21″	088° 33′ 41″	525	1950	491	Eutaw	183	1950	406	19	31
F016	33° 54′ 00″	088° 59′ 50″	340	1931	820	Eutaw	103	1940		27	19
G102	33° 27′ 10″	088° 47′ 17″	381		1,008	Eutaw	177	1940	968	35	18
H004	33° 36′ 20″	088° 39′ 25″	215	1953	386	Eutaw	99	1953	306	34	21
H009	34° 16′ 32″	088° 40′ 30″	285	1947	335	Eutaw	47	1947	59	24	27
H012	33° 34′ 05″	088° 39′ 32″	194	1937	800	Tuscaloosa	–11	1940	400	34	21
H042	34° 15′ 36″	088° 42′ 10″	280	1966	562	Tuscaloosa	164	1966	510	24	26
H046	33° 37′ 12″	088° 38′ 46″	237	1962	203	Tuscaloosa	28	1963		34	21
H115	33° 06′ 45″	088° 33′ 28″	185	1954	1,807	Tuscaloosa	–33	1955	1,767	42	18
K037	33° 51′ 36″	089° 00′ 53″	320		130	Ripley	64	1958		27	19
L022	33° 25′ 17″	088° 23′ 56″	178	1960	1,190	Tuscaloosa	–44	1960	1,170	38	23
O014	34° 05′ 22″	088° 37′ 17″	266	1940	612	Tuscaloosa	22	1940	587	27	26
O015	34° 05′ 23″	088° 37′ 17″	266	1956	282	McShan	20	1956	208	27	24
GRE–3	32° 50′ 05″	087° 53′ 20″	172		407	Eutaw	37	1952	395	51	
MAG–1	32° 30′ 55″	087° 50′ 41″	110		900	Eutaw	1	1953	860	56	22
HAL–1	32° 42′ 05″	087° 35′ 28″	257		278	Eutaw	43	1961	258	55	27
TUS–5	33° 13′ 40″	087° 38′ 16″	157		109	Tuscaloosa	24	1964	103	47	31

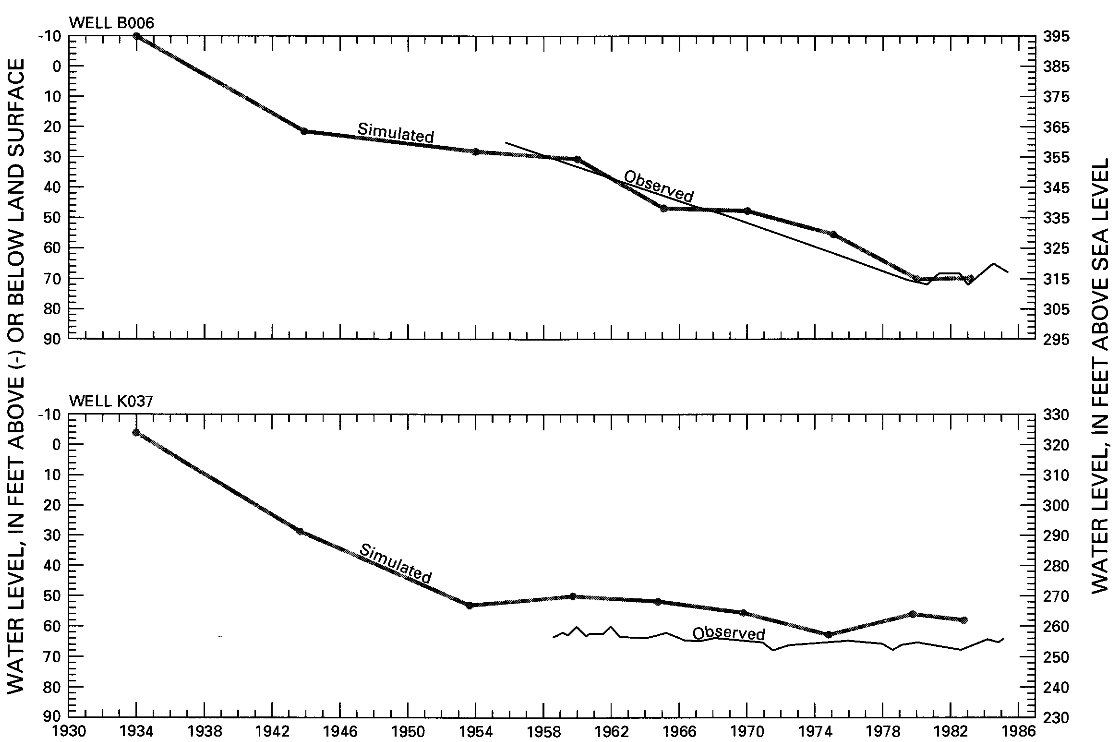


FIGURE 30.—Observed and simulated water levels in wells B006 and K037 in the Chattahoochee River aquifer.

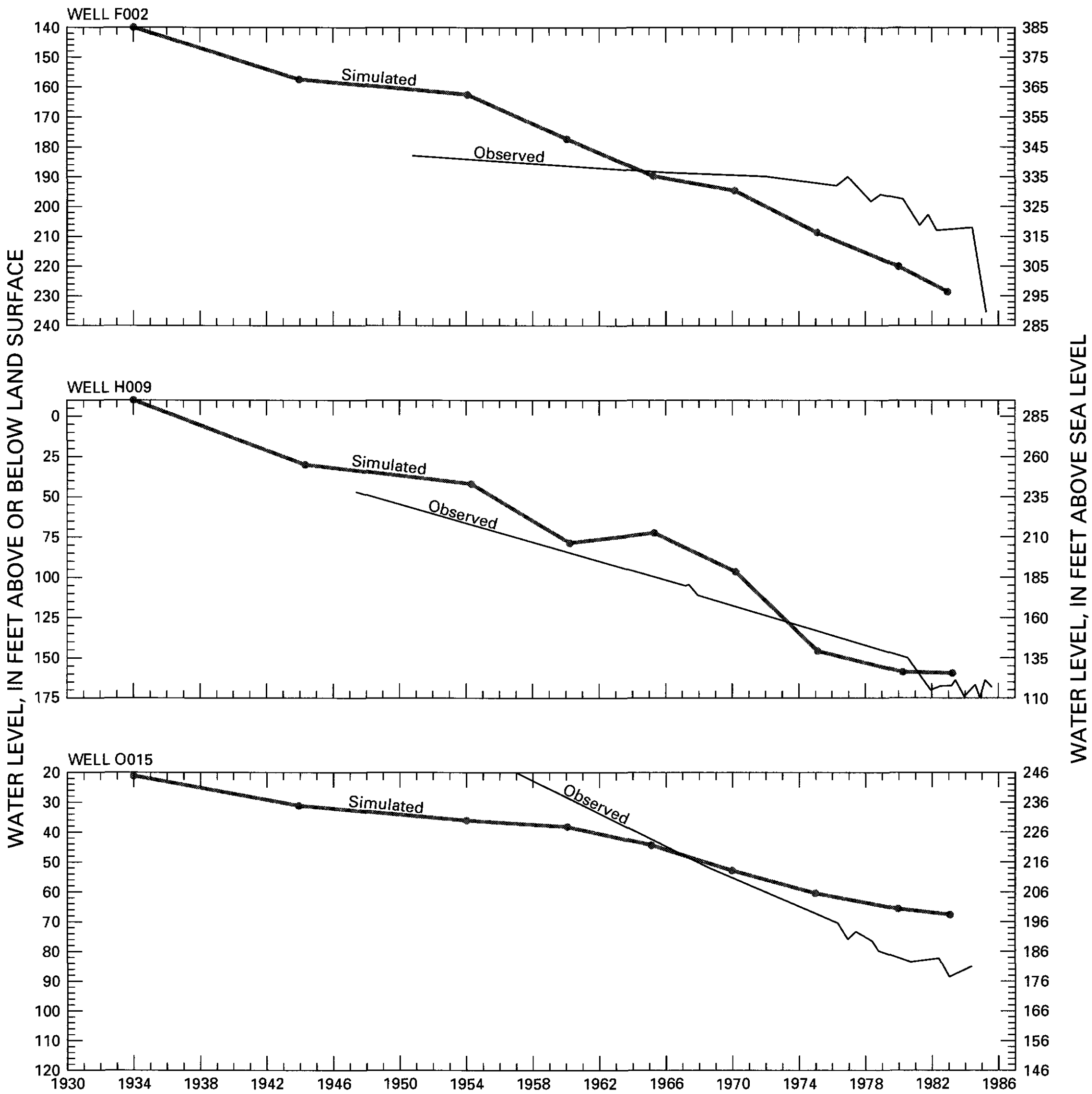


FIGURE 31.—Observed and simulated water levels in wells F002, H009, and O015 in the upper Black Warrior River aquifer.

near the northern limit of deposition of the aquifer, the match between observed and simulated hydrographs is poor. This mismatch is possibly caused by the proximity of the aquifer boundary (no flow). At well H009, located in a major drawdown center in Lee County, Miss., the agreement between observed and simulated hydrographs is good. Agreement between observed and simulated results at well O015 is only fair; however, at this well, there is some question of the accuracy of the unusually high water-level measurement reported by the driller for 1956. Because this information is the only measured water level until regular measurements were begun in 1976, if this measurement were too high, the agreement would be considerably better. Well F016 is in the downdip part of the aquifer; agreement at this site is fair. Well H004 is located near a moderate drawdown center in Clay County, Miss.; agreement at this site is somewhat poor. Well G102 is located in the downdip part of the aquifer; agreement of observed and simulated data at this site is also fair. Wells GRE–3, MAG–1, and HAL–1 are located in the major discharge area. GRE–3 and HAL–1 are near the updip edge of the aquifer, and MAG–1 is somewhat farther downdip. Agreement between the observed and simulated hydrographs at all three of these wells is good.

Seven hydrographs of wells in the lower Black Warrior River aquifer are shown in figures 34 and 35. At well H042, in the Lee County, Miss., drawdown center, agreement between observed and simulated hydrographs is good, although this well does show considerable

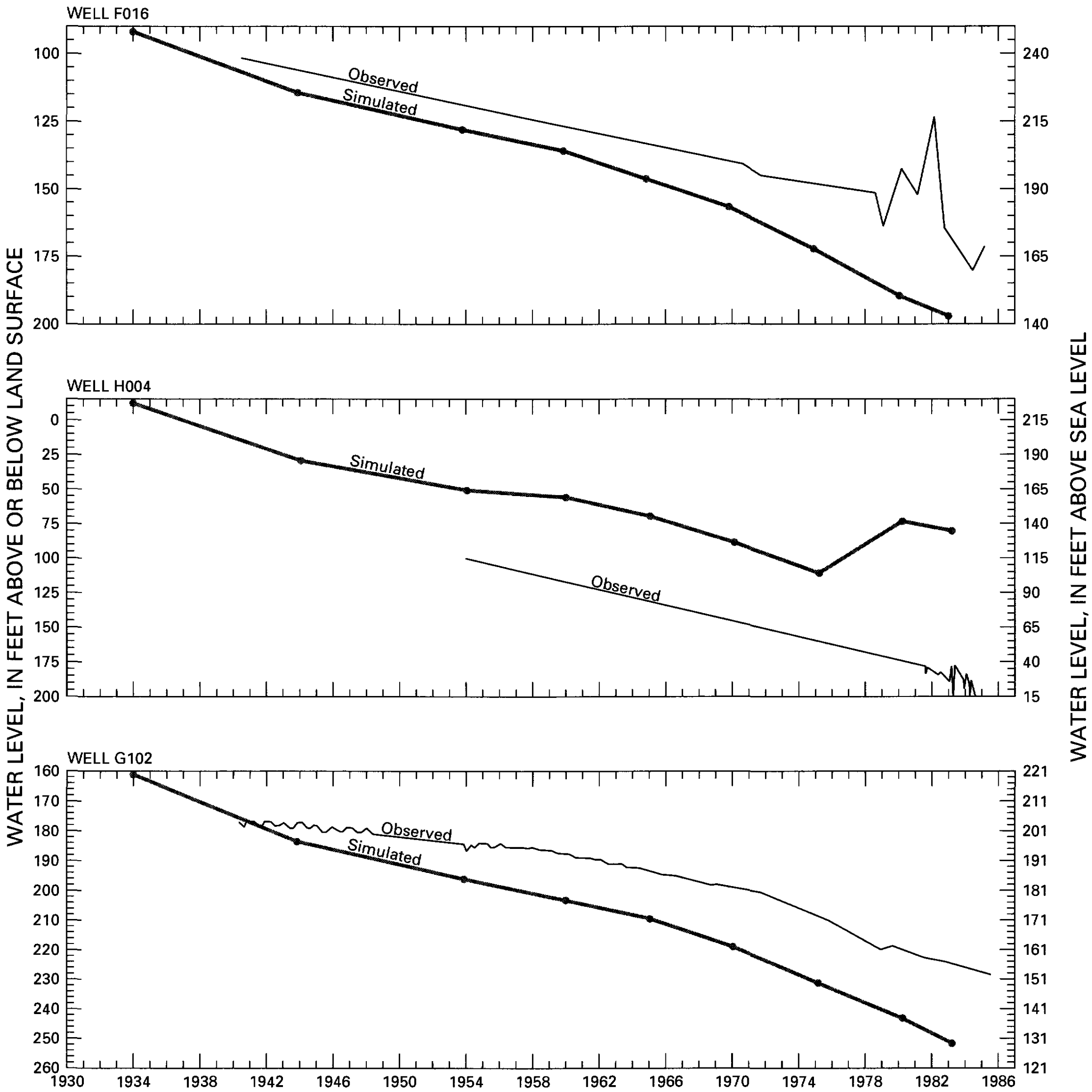


FIGURE 32.—Observed and simulated water levels in wells F016, H004, and G102 in the upper Black Warrior River aquifer.

fluctuations in water levels that are too short term to be simulated by the model time steps. Well O014 is located at the same site as well O015, which is finished in the overlying upper Black Warrior River aquifer. In the selection of wells for model calibration, an attempt was made to locate as many such pairs of wells as possible to provide information on the degree of interconnection of the aquifers. Agreement of observed and simulated water levels at this well is good. Wells H046 and H012 are located within about 3 mi of each other in a drawdown center in southeastern Clay County, Miss. The spacing between these two wells is less than one model grid unit. Results from these wells illustrate the problems inherent in discretizing a physical system into a finite-difference grid. While the match of the observed and simulated hydrographs at well H012 is one of the best of any of the control points, the match at well H046 is one of the worst. For wells this close together and for areas with hydraulic gradients this steep, significant errors are introduced because the model represents the head in a 16-mi^2 area as a single value. At well L022, in the updip part of the aquifer, agreement of observed and simulated results is fair. At well H115, in the downdip part of the unit, agreement is poor. At well TUS–5, located in the extreme updip area of the aquifer, very near the outcrop, agreement of results is also poor. Although the model grid cell that contains this well location is modeled as confined, local topographic relief or variations in deposi-

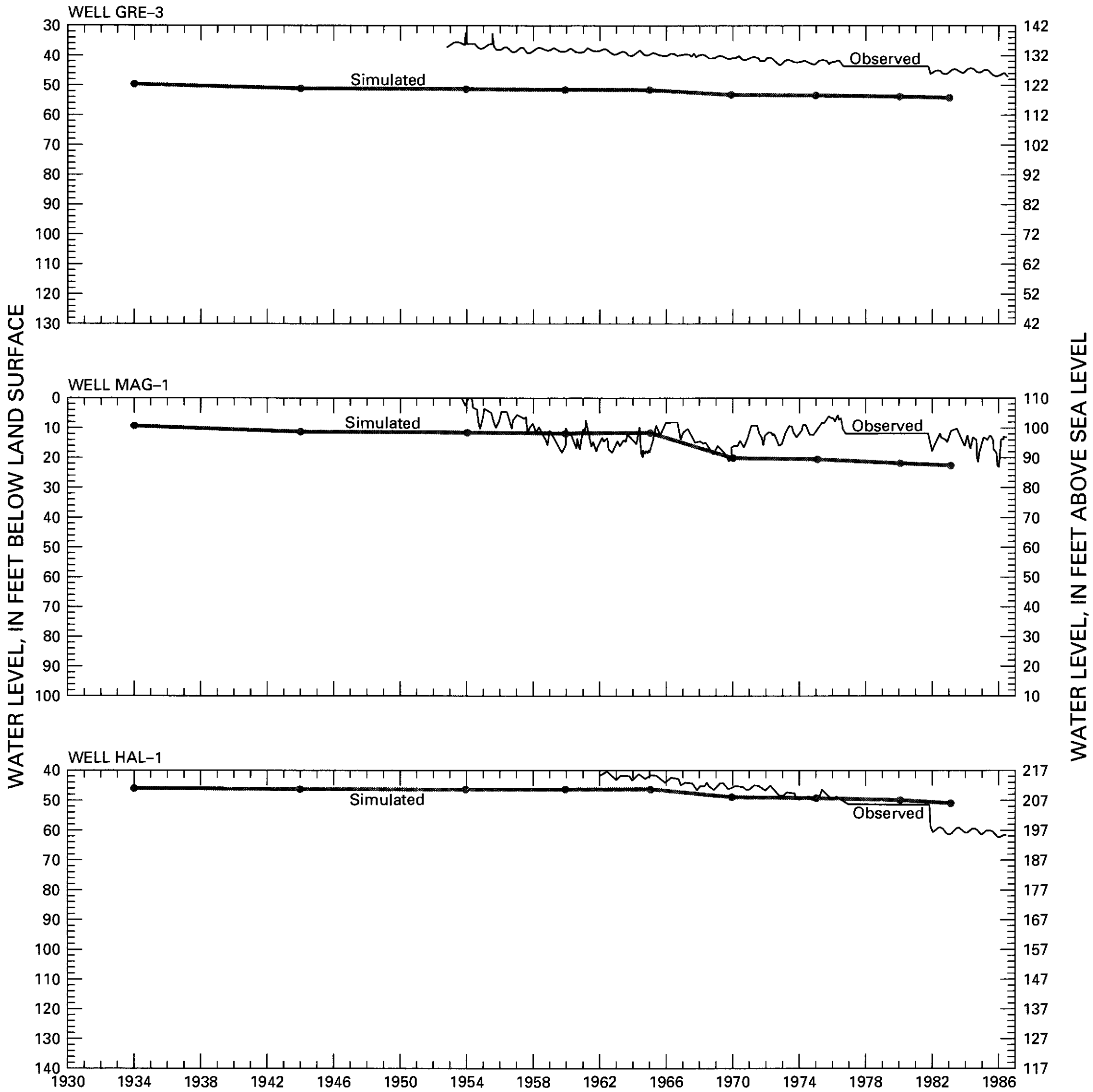


FIGURE 33.—Observed and simulated water levels in wells GRE–3, MAG–1, and HAL–1 in the upper Black Warrior River aquifer.

tional patterns may, in reality, cause the flow at this point to behave more nearly like that in an unconfined system.

THE TRANSIENT FLOW SYSTEM

In the time since pumpage from wells began in the Southeastern Coastal Plain aquifer system, the aquifer system has been in a state of change, dynamically adjusting to the effects of development. To be a useful tool in the understanding of the areal flow system, a digital computer model must be able to simulate this transient behavior of the system.

SIMULATION OF TRANSIENT CONDITIONS

The preliminary predevelopment model provided the starting point for the simulation of transient conditions. In the process of calibrating the model to reproduce observed long-term hydrographs, several changes were made in the hydrologic parameters of the preliminary model. Rerunning the predevelopment model with the final parameters calibrated under transient conditions produced results similar to the initial predevelopment conditions, and these parameters were accepted as the best calibration to represent both steady-state and transient conditions.

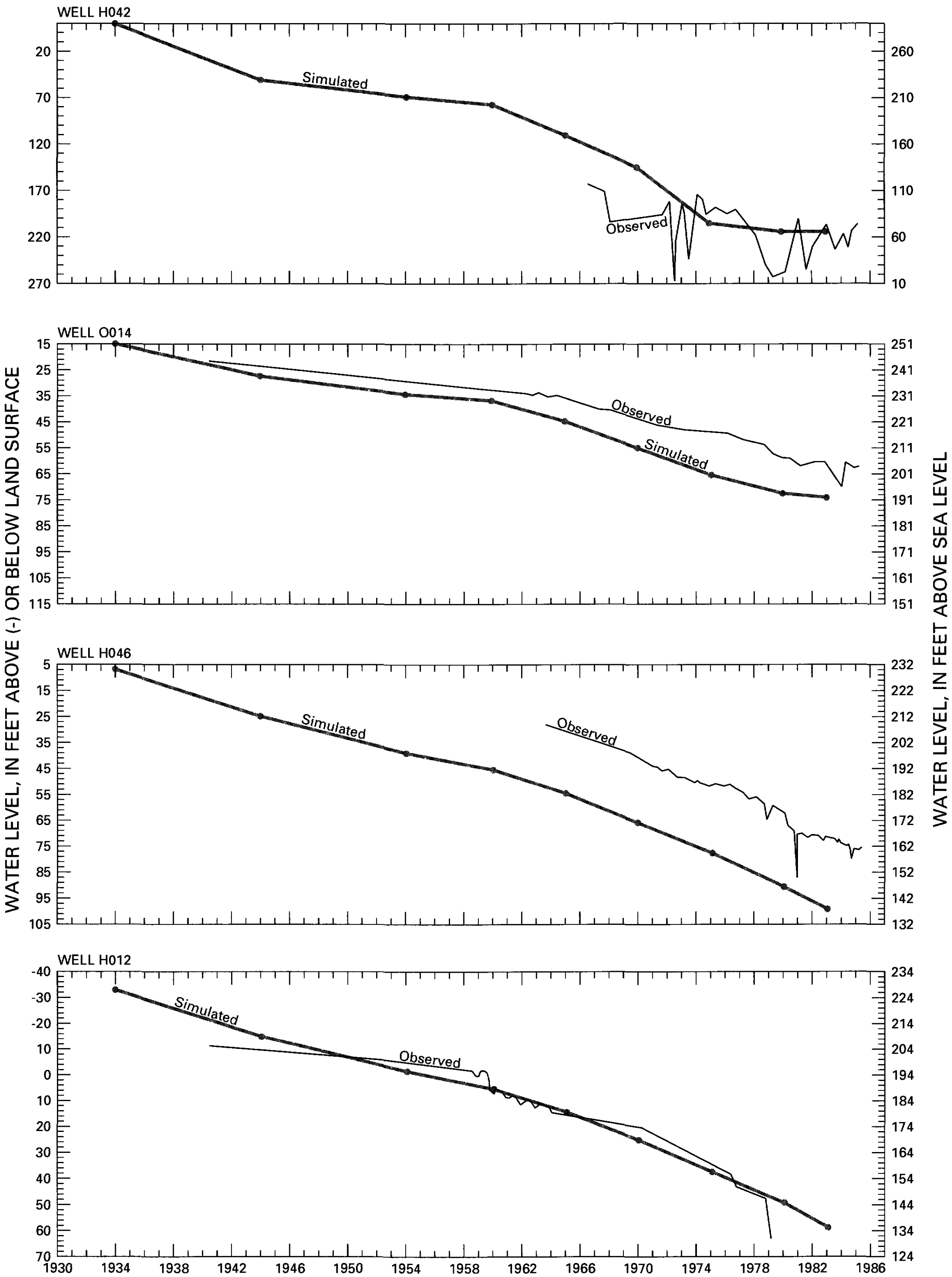


FIGURE 34.—Observed and simulated water levels in wells H042, O014, H046, and H012 in the lower Black Warrior River aquifer.

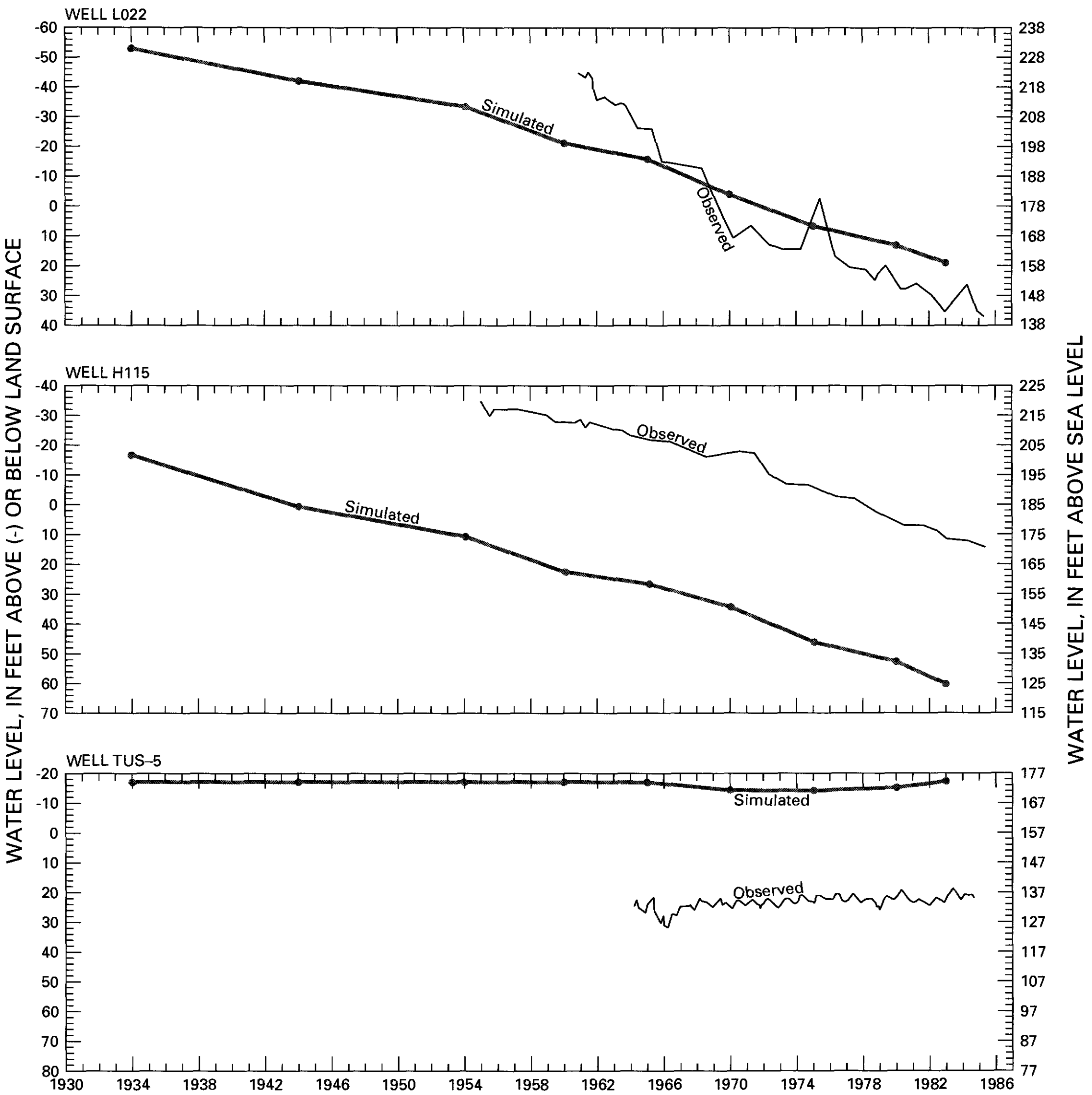


FIGURE 35.—Observed and simulated water levels in wells L022, H115, and TUS-5 in the lower Black Warrior River aquifer.

CALIBRATION

In addition to the hydrologic parameters necessary for steady-state simulation, calibration of the transient simulation model required the following.

1. The areal distribution of the value of storage coefficient—a measure of the amount of water taken into or released from an aquifer in response to a unit change of head—for each of the aquifers in the system. Only storage in aquifers was considered in this model. Although storage in the thick clays of the confining units that separate the aquifers is perhaps significant, no direct or indirect evidence is available to quantify flow derived from confining unit storage. The assumption that all of the storage in the system is from aquifer material may, therefore, result in some overestimation of the aquifer storage coefficients.
2. The historical pumpage through time from each of the aquifers. The method used to determine historical pumpage was discussed previously.
3. A record of the observed water levels through time in response to pumping. For the purposes of model calibration, this record consisted of the 18 long-term hydrographs shown in figures 30 through 35.

Initial simulations of transient conditions in many areas failed to reproduce adequately the decline in head that had been historically observed. Analysis of this inability to reproduce observed drawdowns led to a revision of an assumption made in the preliminary steady-state model, namely, that in the precipitation-rich environment of the coastal plain, sufficient recharge was available to provide all the water that the aquifer could transport out of its recharge area. While it is obvious that much potential recharge is rejected by the aquifers, the most realistic limit on the amount of recharge actually accepted by the aquifer seems to be imposed by the rate at which infiltration through the unsaturated zone of the aquifer outcrop can occur. A second factor, which limits recharge and increases hydraulic gradients in the aquifer outcrop area and which had not been incorporated into the preliminary steady-state model, is the reduction in transmissivity that occurs as the aquifer thins to a "feather edge" in its outcrop. Both of these factors will produce similar but discernible results. If resistance to infiltration predominates, the pattern of heads and gradients will be as shown in case 1 in figure 36, with lower heads near the updip edge of the aquifer outcrop and a more nearly constant hydraulic gradient downdip. If, on the the other hand, reduction of transmissivity in the outcrop area is dominant, the pattern of heads and gradients will be as in case 2 in figure 36, with higher heads in the updip edge of the outcrop and a distinct break in slope of the hydraulic gradient near the downdip edge of the outcrop area. A major part of the calibration of the transient model consisted of the adjustment of outcrop infiltration rates and transmissivities in and near the outcrop areas to achieve an accurate simulation of the observed drawdowns in the regional aquifers.

The distribution of storage coefficient values was estimated in the process of transient calibration.

Minor changes, as described in the section "Simulation of Predevelopment Conditions," were made to improve the representation of boundary conditions during the calibration of the transient model.

The process of calibrating the transient model involved minimizing the root-mean-square error at 96 points in space and time from the 18 long-term hydrographs. Calibration was made to the first eight pumping periods, simulating the time span from predevelopment to 1980. The final pumping period, simulating heads near the end of 1982, was used to check the calibration.

During calibration, root-mean-square error was reduced from 39.7 to 7.2 ft for the Chattahoochee River aquifer layer, from 46.7 to 26.0 ft for the upper Black Warrior River aquifer layer, and from 50.2 to 28.5 ft for the lower Black Warrior River aquifer layer. Comparisons of observed and simulated hydrographs for the calibrated model are shown in figures 30 through 35.

The accuracy of the calibrated transient model was checked by simulating the potentiometric surfaces of the aquifers for the fall of 1982. In the fall of 1982, as part of this study, a synoptic set of water-level measurements was made for all of the Southeastern Coastal Plain regional aquifers. Figures 37, 38, and 39 show maps of the simulated and observed water levels. The match between the simulated and observed surfaces is considered good and indicates that the model is well calibrated.

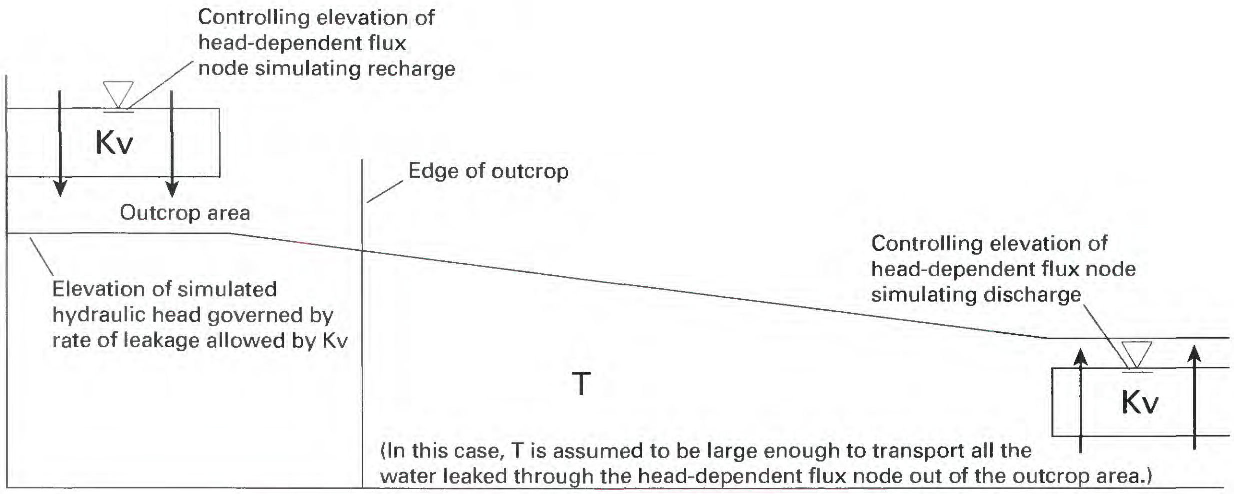
SUMMARY OF FLOW COMPONENTS

An analysis of the calibrated model indicates that before development (pre-1934), about 310 ft^3/s of water flowed through the Mississippi-Alabama part of the Southeastern Coastal Plain regional aquifers. More than 300 ft^3/s of this amount represented recharge from the aquifer outcrop areas, and the remainder, less than 10 ft^3/s, represented water flowing from vertically adjacent aquifers. In these steady-state conditions, nearly all the water flowing through the aquifer system discharged to regional drains in major river valleys. However, about 5 ft^3/s discharged to vertically adjacent aquifer systems, and about 3 ft^3/s left the study area laterally from the Chattahoochee River aquifer. Recharge to the outcrops of individual aquifers was about 20 ft^3/s to the Chattahoochee River aquifer, about 90 ft^3/s to the upper Black Warrior River aquifer, and about 190 ft^3/s to the lower Black Warrior River aquifer.

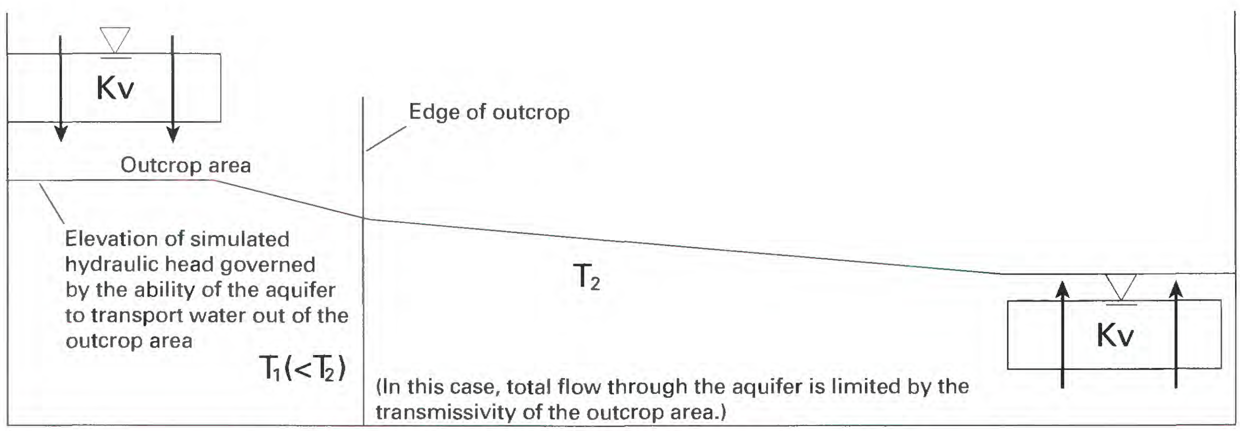
In 1982 the average pumping rate from the regional aquifer was about 160 ft^3/s. This pumping rate was balanced by (1) an increase in total recharge to about 370 ft^3/s from 300 ft^3/s, (2) a decrease in discharge to river valleys to about 220 ft^3/s from about 302 ft^3/s, (3) withdrawals of about 5 ft^3/s from aquifer storage, and (4) a slight increase in water received from vertically adjacent aquifer systems (to slightly more than 10 ft^3/s) and a slight decrease in water flowing out of the system to aquifers outside the study area (to slightly less than 5 ft^3/s). These values indicate that, of the total pumpage in 1982, about 51 percent was derived from decreased natural discharge from the aquifer, about 43 percent was derived from increased recharge in outcrop areas, and about 3 percent was being supplied from the aquifer storage. The remaining 3 percent includes all other factors, including vertical interchange with adjacent aquifers and lateral flow moving out of the study area. The cumulative numerical truncation errors present in the model also have a slight effect on these percentages.

SUMMARY AND CONCLUSIONS

Cretaceous clastic sediments in eastern Mississippi and western Alabama include the aquifers known locally



Case 1: Total recharge limited by rate of infiltration allowed by Kv.



Case 2: Total recharge limited by the ability of the aquifer to transport water out of the outcrop area.

EXPLANATION

Kv **Saturated vertical hydraulic conductivity**
T **Transmissivity**
T_1 **Transmissivity updip of edge of outcrop**
T_2 **Transmissivity downdip of edge of outcrop**

FIGURE 36.—Relative effects of transmissivity and resistance to infiltration in aquifer outcrop area on simulated hydraulic head.

as the Ripley aquifer, the Eutaw-McShan aquifer, and the Tuscaloosa aquifer. The regional Chattahoochee River aquifer is equivalent to the locally named Ripley aquifer. The upper and lower parts of the regional Black Warrior River aquifer are equivalent to the locally named Eutaw-McShan and Tuscaloosa aquifers, respectively. This sequence of clastic aquifers and intervening, confining clays and chalks is a part of the larger, regional

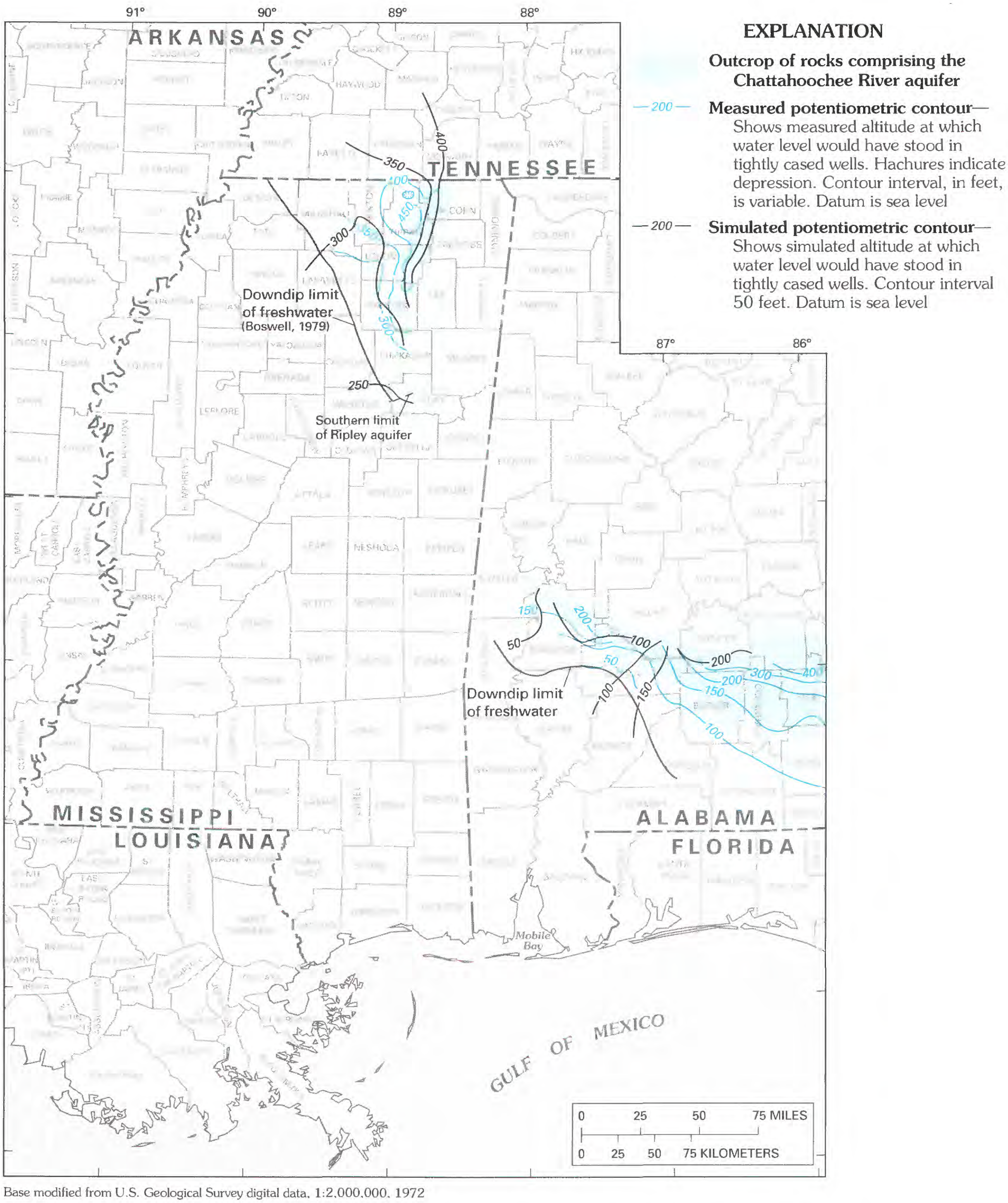
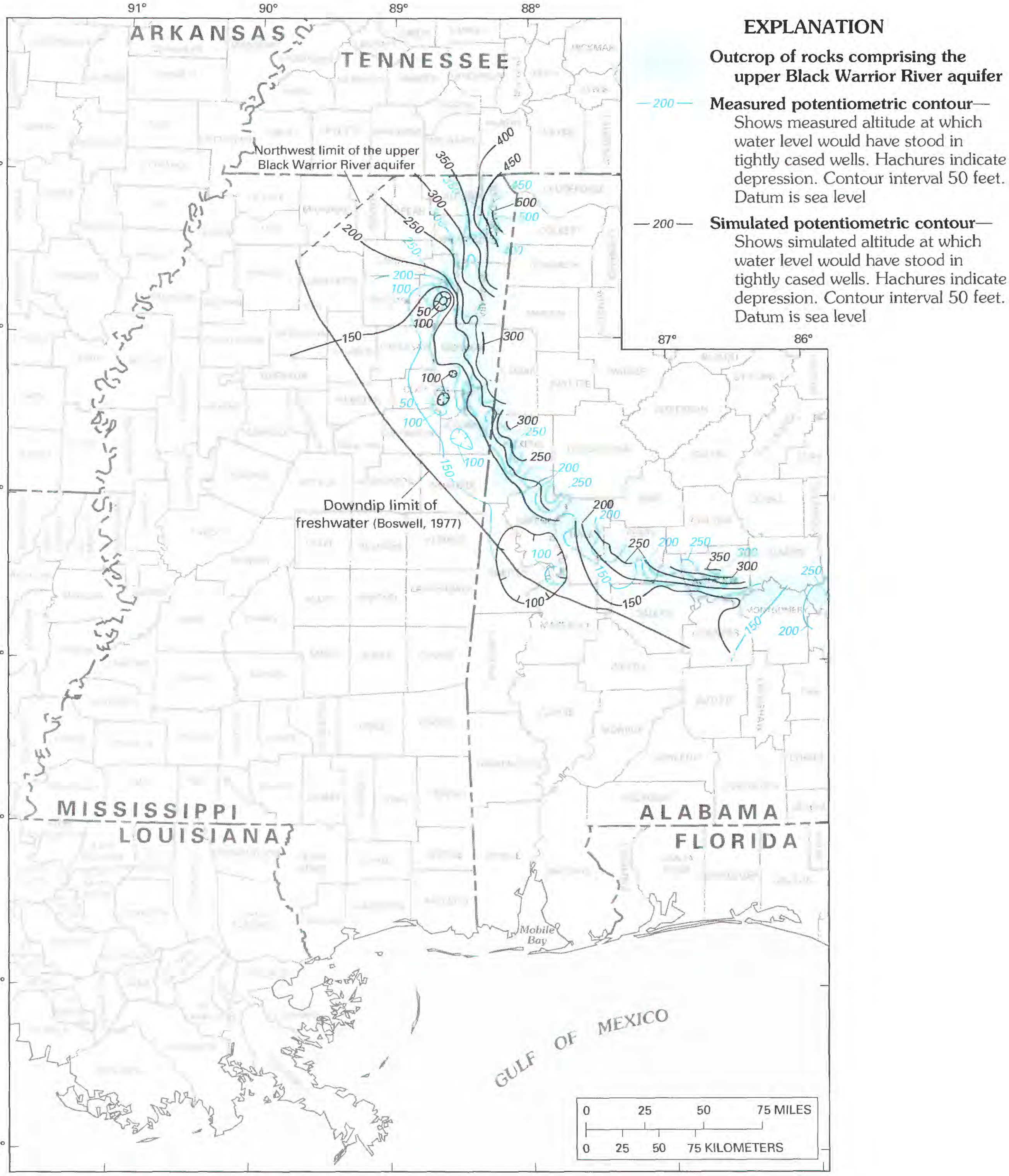
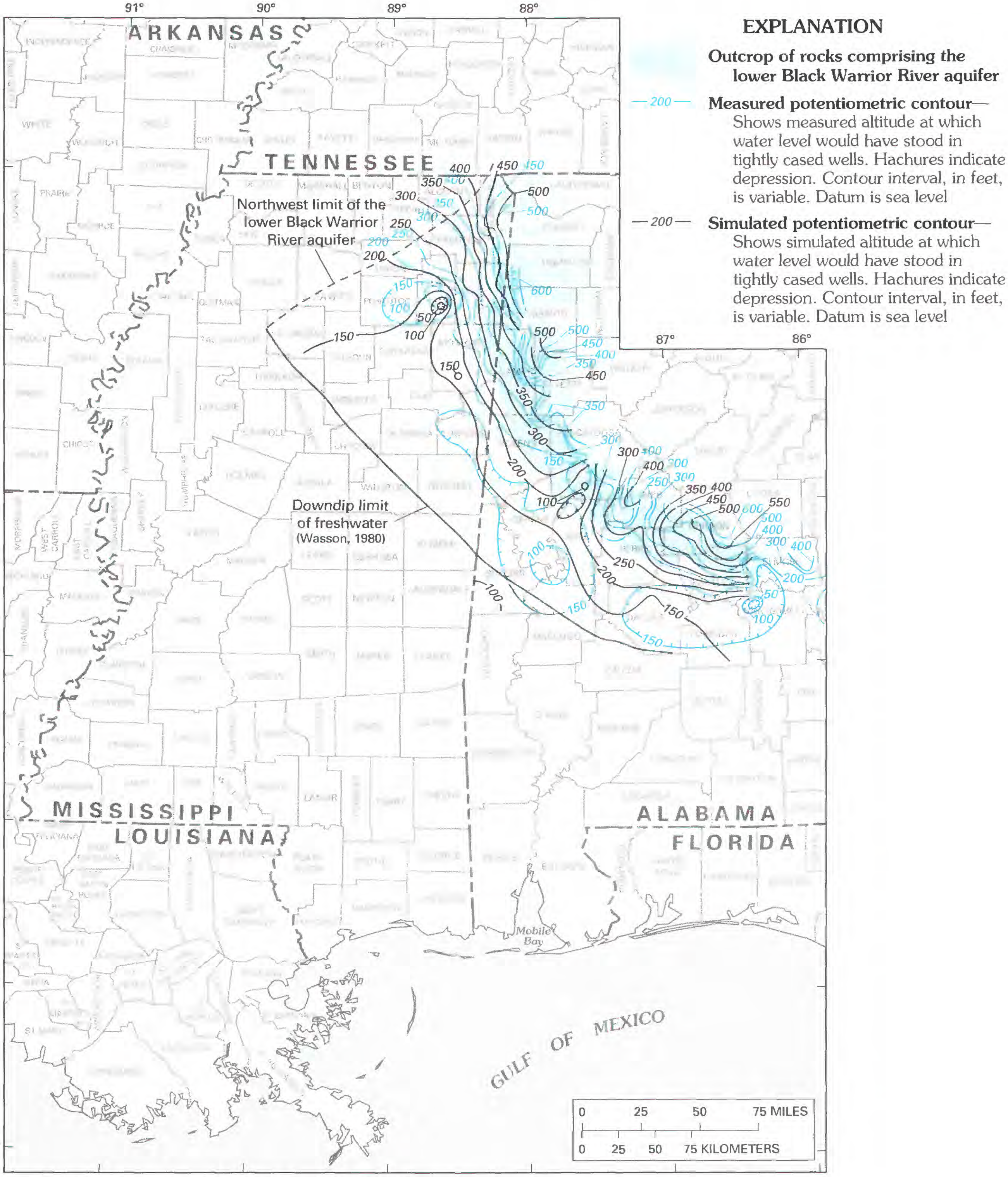


FIGURE 37.—Observed and simulated potentiometric surface for fall 1982 for the Chattahoochee River aquifer.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 38.—Observed and simulated potentiometric surface for fall 1982 for the upper Black Warrior River aquifer.



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

FIGURE 39.—Observed and simulated potentiometric surface for fall 1982 for the lower Black Warrior River aquifer.

Southeastern Coastal Plain aquifer system. This aquifer system is separated from overlying aquifers of Tertiary age by the regionally extensive Pearl River confining unit in the Midway Group, which is equivalent to the Vicksburg-Jackson confining unit of the Gulf Coastal Plain regional aquifer system. There is little interaction between the aquifers in Cretaceous sediments and aquifers in younger sediments. The Southeastern Coastal Plain aquifer system overlies poorly permeable consolidated rocks of Paleozoic to Jurassic age in the north. In the south the base of the active-flow system consists of clays of Early Cretaceous age that isolate underlying, very saline water from the freshwater of the overlying aquifers. The downdip limit of active flow in the Southeastern Coastal Plain aquifer system is located where water in the aquifers becomes saline (more than 10,000 mg/L dissolved solids). Because of the observed sharpness of the freshwater-saltwater transition zone, it is assumed that the interface of this transition is in dynamic equilibrium and that little or no flow crosses the interface.

Geologic structure and topography exert a profound influence on ground-water flow in the aquifers. In the northern part of the study area, the aquifer system occupies the eastern flank of the Mississippi embayment. In the southern part of the study area, the aquifer system lies on the northern flank of the Gulf Coast geosyncline. The formations that form the aquifer system in the study area dip to the west in the northern part of the area; however, these beds gradually change to a southerly dip in the southern part of the area. Land-surface altitudes generally are highest in northern Mississippi, descending to the south to a low point about 30 mi east of the Mississippi-Alabama State line, where the Tombigbee and Black Warrior Rivers exit from the study area. From there, land-surface altitudes increase into central Alabama. Most recharge to the aquifer system in the study area occurs in the topographically higher parts of aquifer outcrop areas. Conversely, the low areas of the major river valleys are the primary discharge areas.

Regional flow in the lower two aquifers, the upper Black Warrior River aquifer and the lower Black Warrior River aquifer, is controlled both by the hydrologic properties of the aquifer materials and by the topography within their outcrop areas. Topography within the outcrop area determines the locations of major natural recharge and discharge areas, whereas the transmissivity primarily determines the total amount of flow through the aquifers. In these aquifers, flow is from the higher outcrop areas to regional drains in the valleys of major rivers and to low-lying areas of the aquifer outcrop. The lowest parts of the outcrop of these aquifers are near the confluence of the Tombigbee and Black Warrior Rivers in western Alabama. Ground water entering the regional aquifer system in the northeastern part of Mississippi flows along a long arcuate path that carries it considerably downdip in east-central Mississippi before it flows back updip (although, of course, still downgradient) to emerge in major stream valleys in western Alabama. Discharge by upward leakage from the upper and lower Black Warrior River aquifers to overlying aquifers, while present, is not as significant as had been previously thought and accounts for less than 5 percent of the total flow through the aquifers. However, leakage between the upper and lower Black Warrior River aquifers is significant.

Flow in the Chattahoochee River aquifer (locally the Ripley aquifer) is mostly isolated, both from the underlying Cretaceous sediments and from the overlying Tertiary units. Flow in the Chattahoochee River aquifer extends out of the study area beneath the Mississippi embayment. This fact complicated the modeling of this aquifer and necessitated coordinating boundary conditions with the Gulf Coastal Plain RASA study, which modeled the unit in the Mississippi embayment.

The amount of water that flows in the deeper, regional ground-water flow system is only a small fraction of the amount that enters the local and intermediate ground-water flow systems. Of the estimated 7 in/yr or 3,900 ft^3/s of ground-water recharge in the study area, only about 310 ft^3/s under predevelopment conditions, or about 390 ft^3/s under 1982 conditions, enter the regional ground-water flow system. These amounts represent about 8 percent of the total flow infiltrating the soil for predevelopment conditions and about 10 percent for 1982 conditions.

The transition from predevelopment conditions to the 1982 pumping conditions was accomplished mainly by an increase in recharge to and a decrease in discharge from the regional flow system to rivers and lakes and by a small decrease in ground-water storage. These changes balance a pumping rate of about 160 ft^3/s (103 Mgal/d) in 1982. Of the total pumpage in 1982, about 51 percent was supplied by decreased discharge and about 43 percent was supplied by increased recharge. About 3 percent was supplied by aquifer storage. The remaining 3 percent of pumpage was supplied by a variety of sources that included changes in vertical leakage from adjacent aquifer systems and changes in lateral flow leaving the study area from the Chattahoochee River aquifer. The cumulative numerical truncation errors present in the model also have a slight effect on these percentages.

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