PRELIMINARY STEADY-STATE SIMULATION OF GROUND-WATER FLOW IN HINDS, MADISON, AND RANKIN COUNTIES, CENTRAL MISSISSIPPI

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INTRODUCTION

In 1987 an investigation was begun by the U. S. Geological Survey (USGS) in cooperation with the Mississippi Department of Natural Resources, Bureau of Land and Water Resources to describe the aquifer systems underlying Hinds, Madison, and Rankin Counties in central Mississippi. Intensive development of these aquifers, primarily within the Jackson Metropolitan area, has resulted in significant water-level declines. Data made available by the Gulf Coast Regional Aquifer-System Analysis (GC RASA) project for the Mississippi embayment aquifer system and the coastal lowland aquifer system was refined and utilized within the three-county study area in developing a coarse-grid ground-water model of the regional flow system. The areal extent of the data from the GC RASA's Mississippi embayment aquifer system and the coastal lowland aquifer system was reduced to parts of Mississippi, Arkansas, and Louisiana and to geologic units of Paleocene to Miocene age. This report presents the preliminary results from the coarse-grid ground-water flow model of the regional flow system in Mississippi, northeast Louisiana, and southeast Arkansas (fig. 1). The study includes six aquifers of Tertiary and younger sediments.

Figure 1: Regional Study Area

The purpose of this investigation is to better understand the ground-water flow in and around the Jackson Metropolitan area. Results from a ground-water flow model of the area will be used to determine the effects of future development on the flow system and ground-water resources of the area. The purpose of this preliminary report is to describe the regional geohydrologic framework and ground-water flow in the aquifers present in the three-county area in central Mississippi. The results of this six layer coarse-grid multi-state flow model will be utilized to determine the areal extent, aquifer characteristics, and layering scheme for a fine-grid ground-water flow management model of the three-county area.

The coarse-grid ground-water flow model describing the regional flow system was constructed and calibrated on the basis of both pre- and post-development conditions. Although the primary area of concern is the three-county area in central Mississippi, the model study area includes a larger area of Mississippi, northeast Louisiana, and southeast Arkansas. The larger area was modeled to consider the regional flow system affecting the area of Hinds, Madison, and Rankin Counties. Information from the regional study area will be discussed with special emphasis on the principal aquifers in the three-county area.

DESCRIPTION OF STUDY AREA

The regional study area for this report includes about 87,000 mi.^{2} in parts of Mississippi, Louisiana, and Arkansas in the Mississippi embayment. The major area of concern, Hinds, Madison, and Rankin Counties in central Mississippi, covers an area of 2,428 mi.^{2} in the south-central part of the Mississippi embayment in the eastern Gulf Coastal Plain physiographic province (fig. 2).

WATER USE

Several urban areas in Arkansas, Louisiana, and Mississippi experience heavy pumpage from at least one of the aquifers in this study. Drawdowns resulting from stress to the aquifers have created cones of depression in the potentiometric surfaces in the respective aquifers. Concern for the aquifer system's ability to meet the increasing demand for water in the three-county area prompted this investigation.

Figure 2. Major Area of Concern: Hinds, Rankin, and Madison Counties in Central Mississippi

The first large-capacity well in the three-county area was drilled in the city of Jackson in 1896, although many domestic wells existed prior to that year. A surface-water pumping station and treatment plant on the Pearl River at Jackson were constructed in 1914 and have been in continuous operation since that time. The Pearl River is the principal source of water for Jackson with wells serving as supplemental sources. All towns in the area, except Jackson, depend totally on wells for their water supplies. Municipal wells were drilled in Edwards, Bolton, Utica, and Flora in Hinds and Madison Counties shortly after 1900, and other towns developed ground-water supplies at later dates. Tremendous growth in the Madison-Ridgeland area in Madison County during the past few years has increased water use in that area and, consequently, water-level declines. In 1980, about 26 million gallons per day (Mgal/d) of water was pumped from the Cockfield and Sparta aquifers in the three-county area.

Major water users in the three-county area with the exception of the city of Jackson utilize only ground-water, and most of the water problems are related to the availability and quality of groundwater supplies. Some shallow aquifers do not yield enough water for major industrial users. High iron concentrations (greater than 0.3 milligrams per liter) are found especially near the outcrop area of the Cockfield Formation. Downdip in the Cockfield and Sparta aquifers, excessive color in water is the result of water in the aquifer coming in contact with organic substances such as lignite. In the Jackson Metropolitan area, the Jackson dome may have an influence on the distribution of colored water in these deposits. The occurrence of saline water is a problem in deeper aquifers such as the Meridian-upper Wilcox, middle Wilcox, and lower Wilcox.

MAJOR WATER-BEARING UNITS

The aquifer system in the regional study area comprises six major aquifers of Paleocene to Miocene age. Within the system, three confining units separate the upper four aquifers, while the lower two aquifers are separated by the discontinuous clay layers of the Wilcox Group.

The regional flow movement is from the outcrop areas on the western and eastern flanks of the Mississippi embayment downdip into the aquifers and toward the axis of the embayment. As the flow moves downdip, it moves vertically upward through the overlying layers to its regional discharge area, mainly the Mississippi River Valley alluvial aquifer. The balance of the upward movement of flow is shifted westward of the embayment axis due to the higher outcrops elevations on the east flank of the embayment.

In descending order the major aquifers are the Miocene-Oligocene aquifer system, Cockfield aquifer, Sparta aquifer, Meridian-upper Wilcox aquifer, middle Wilcox aquifer, and lower Wilcox aquifer. The main aquifers for municipal and industrial supply in the three-county area are the Cockfield and Sparta aquifers.

MODEL DEVELOPMENT

Data Assimilation

Data from many sources and information from earlier reports were assembled to help define the geohydrologic framework of the study area. Outside the three-county area, data were utilized from the GC RASA project data base. In the GC RASA project area one geophysical well log was selected for approximately every 320 $mi.^2$. In some localities, more than one geophysical well log was required to represent the entire vertical section.

In the area of Hinds, Madison, and Rankin Counties in central Mississippi, at least one well log was selected every 25 $mi.^2$. The logs were analyzed to determine thicknesses of aquifers and confining units. Sand beds more than 20 feet in thickness were aggregated into the aquifers previously defined. Where more than one geophysical well log was available in a 25 $mi.^2$ area, thicknesses of the sand beds were averaged. These data along with the GC RASA Mississippi embayment subproject well-log data were used as a major source of information for defining the geohydrologic framework of the study area. Initial values for hydraulic characteristics of the aquifers and confining units for the flow model were obtained from results presented in the GC RASA Mississippi embayment subproject.

Model Description

The regional flow patterns in the study area were simulated by a numerical model that solved the ground-water flow equation subject to imposed boundary conditions. The USGS modular three-dimensional finite-difference ground-water flow model (McDonald and Harbaugh, 1984) was used to simulate the ground-water flow system of the study area.

To allow for a numerical solution of the equations describing a ground-water flow system, the system must be discretized or gridded. The model area is composed of 3,500 cells in an array of 50 rows by 70 columns. Each mell (area of spatial resolution) is 5 miles on a side or 25 mi.^{2}. Vertical discretization of the model is controlled by the six aquifer layers. The grid was orientated west-east to parallel the flow lines in the main area of concern Hinds, Madison, and Rankin Counties in central Mississippi. Predevelopment ground-water flow in this area is approximately east to west as shown by Reed (1972) and Arthur and Taylor (1988). Even under stressed conditions the genera1 flow pattern parallels the grid system (Arthur and Taylor, 1988).

The model simulates in descending order, (1) Miocene-Oligocene aquifer system, (2) Cockfield aquifer, (3) Sparta aquifer, Meridian-upper Wilcox aquifer, (5) middle Wilcox aquifer, and (6) lower Wilcox aquifer. Each model layer is separated from the layer beneath it by a vertical resistance to flow term. Hydraulic connection between aquifers is represented by vertical conductance (vertical conductance equals vertical hydraulic conductivity of confining unit divided by thickness of the confining unit) between each pair of aquifer layers. The confining unit thickness is defined as the sum of the clay bed thickness in the confining unit plus one-half the sum of the clay bed thickness in the two aquifers that the confining unit separates. A vertical conductance is computed between all vertically-adjacent cells. The hydraulic gradient within confining layers is assumed to be linear.

Boundary Conditions

Specification of boundary conditions is required to describe ground-water flow by a second-order partial-differential equation. The types of boundaries applied in the McDonald-Harbaugh model are: specified head, specified flux, or head-dependent flux. Choice of a boundary type depends on the particular hydrologic situation under consideration.

The lower boundary of the model is a specified flux where flux is equal to zero representing a no-flow boundary. This boundary represents the thick clay beds of the Midway Group that separate the overlying aquifers from the upper Cretaceous aquifers. The no-flow boundary was chosen as the lower boundary even though a negligible amount of water passes through the thick, relatively impermeable clay beds of the Midway Group. This flow is insignificant compared to the total flow of the system. The no.flow boundary at the edge of each aquifer layer represents either an area where the layer does not exist (landward of outcrop area) or an area where the flow of water into or out of the model area is assumed to be negligible.

Head-dependent flux components establish the upper boundary of the model. These components act as a source-sink layer providing flow into and out of the system. Hydraulic connection between the aquifers and surface environment provides recharge-discharge flow to the system. This condition is represented by high conductance values between the outcropping aquifer layers and the source-sink layer. This representation essentially provides for a near constant-head simulation in the aquifer outcrop areas and makes water-table elevations the driving head for each layer.

A no-flow boundary represents the northern extent of the study area. The northern extent south of Memphis, Tennessee, was located at the transition zone where the Zilpha Clay and clay beds of the Tallahatta Formation undergo a facies change to become a sand unit. With the absence of this confining unit, the Sparta aquifer and Meridian-upper Wilcox aquifer are continuous without appreciable vertical separation. Model runs conducted by the GC RASA project indicate that ground-water withdrawals north of the transition zone have negligible effects in the three-county area. Even if there is a slight effect, the amount is probably too small to influence water levels almost 200 miles to the south in the three-county area and minor compared to the effects local stresses have on the system.

The southern extent of the model area is represented by a no-flow boundary at 31 degrees N. latitude. The assumption for using this boundary condition is that south of the three-county study area (1) withdrawal from the principal aquifers under consideration does not occur; (2) shallower, irregular, and discontinuous fresh-water aquifers are utilized; (3) the distance from the area of concern to the boundary is sufficient that any effects from pumpage are negligible; and (4) the principal aquifers contain saline water.

The downdip boundary of each aquifer layer is a no-flow boundary. This was established at the extent of the aquifer that is beyond the 10,000 mg/L (milligrams per liter) total dissolved solids limit. At the 10,000 mg/L total dissolved-solids interface no flow is assumed into or out of the model area. This assumption is considered reasonable since pumpage in each layer is significantly updip from the fresh water-salt water interface. Even if there is a slight flow at these extreme downdip locations, the amount is probably too small to affect the areas of maximum usage.

Hydraulic Characteristics

Hydraulic conductivity and transmissivity are hydraulic parameters that describe the ability of an aquifer to transmit water. The GC RASA data were initially used in selecting the range of values for these parameters. The values were based on published reports of selected aquifer tests. Since aquifer tests generally are conducted in the "best" sand beds, the values obtained are not indicative of the entire sand section. The mean values of horizontal hydraulic conductivity from the aquifer tests ranged from 11 ft/d in the Meridian-upper Wilcox aquifer in Louisiana to 172 ft/d in the Sparta aquifer in Arkansas. The model simulations in this study used a constant horizontal hydraulic conductivity value for each state for an individual layer ranging from 10 ft/d in Layer 5 (middle Wilcox aquifer) in Arkansas, Louisiana, and Mississippi to 45 ft/d in Layer 2 (Cockfield aquifer) in Arkansas and Mississippi.

The horizontal hydraulic conductivity value for each state by layer is summarized in the following table:

Horizontal Hydraulic Conductivity Values (ft/d)
Used In Model Simulations

Layer	Aquifer	Arkansas	Louisiana	Mississippi
1	Miocene-Oligocene	20	20	20
2	Cockfield	45	40	45
3	Sparta	20	10	20
4	Meridian-upper Wilcox	20	15	20
5	Middle Wilcox	10	10	10
6	Lower Wilcox	30	10	20

Transmissivity is a measure of the ability to transmit water through a unit width of the aquifer in response to a hydraulic gradient. Transmissivity values for each well were computed by multiplying the layer sand thickness by the horizontal hydraulic conductivity. The layer sand thicknesses were determined from information obtained from geophysical well logs.

Common vertical hydraulic conductivity values for confining clay layers range from 10^{-6} to 10^{-3} ft/d. The larger values (10^{-3} ft/d) are used when the clay is not uniform. The smaller values (10^{-6}ft/d) represent tight, marine clays that allow very little vertical flow of water. Vertical hydraulic conductivity values for modeled confining units range from 10^{-6} to 10^{-5} ft/d. Vertical conductance values were computed between cells in adjacent layers by dividing the product of the cell area and the vertical conductivity by the sum of the clay bed thickness between cells. Clay bed thickness was determined from geophysical well logs.

PRELIMINARY 1980 MODEL SIMULATION RESULTS

A steady-state model simulation utilizing 1980 pumpage data was made starting with the hydraulic values and geohydrologic framework from the GC RASA project and then refinement of those data, especially within the three-county area. Because of the magnitude of the differences in observed and simulated 1980 water levels in the Cockfield aquifer in the three-county area, additional modifications to the model are required. The differences between observed and simulated water levels in the Sparta aquifer are much less than those in the Cockfield aquifer and may improve with the fine-grid model spacial discretization. As the project effort continues and the understanding of the flow system improves, additional refinements will be made to the model. Results from the 1980 model simulation will be discussed and compared to observed 1980 water levels and to results from the predevelopment simulation.

Miocene-Oligocene Aquifer System

The 1980 potentiometric map of the Miocene-Oligocene aquifer system representing model generated heads is shown in figure 3. Pumpage from the aquifer system in 1980 was about 6.40 million ft^3/d (47.87 Mgal/d) in the regional study area. Applying 1980 pumpage to the aquifer system induces recharge in the outcrop areas and increases the downward vertical flow from the alluvium in subcrop areas. Under 1980 pumpage conditions about 5.79 million ft^3/d (43.31 Mgal/d) enters the system in the outcrop areas and 0.87 million ft^3/d (6.51 Mgal/d) enters the system in the aquifer subcrop areas.

Cockfield Aquifer

The 1980 potentiometric map of the Cockfield aquifer representing model generated heads is shown in figure 4. Pumpage from the aquifer is about 6.24 million ft^3/d (46.68 Mgal/d) in the regional study area. In the two major pumping areas of Greenville and Jackson, Mississippi, the model reasonably simulates the measured 1980 water levels. The area in northeastern Louisiana, where the Cockfield aquifer subcrops under the alluvium, represents a good simulation. In the Greenville area, the model produces head values slightly lower than the measured heads (about 20 feet). In the three-county area, the model generated heads are higher than the measured heads. The difference in simulated versus measured water levels in the three-county area indicates the need for the development of a fine-grid ground-water flow model. The fine-grid model would provide better definition of the geohydrologic environment and ground-water flow in this area of heavy pumpage.

Pumpage from the aquifer produces water-level declines, induces more recharge in outcrop areas, and allows less discharge in subcrop areas. Pumpage results in reversal of vertical flow between the Cockfield aquifer and the Miocene-Oligocene aquifer system. Vertical movement of flow with pumpage is about 0.26 million ft^3/d (1.94 Mgal/d) from the Miocene-Oligocene to the Cockfield aquifer. Pumpage results in a flow of 3.88 million ft^3/d (29.02 Mgal/d) from the alluvium to the Cockfield aquifer. Without pumpage 9.62 million ft^3/d (71.96 Mgal/d) flows to the alluvium from the Cockfield aquifer. In the three-county area, as much as 0.8 in/yr flows downward in the outcrop area overlying the Jackson dome with pumpage versus 0.2 in/yr without pumpage.

Sparta Aquifer

The 1980 potentiometric map of the Sparta aquifer representing the model generated heads is shown in figure 5. Pumpage from the Sparta aquifer in the regional study area is about 39.66 million ft^3/d (296.66 Mgal/d). Major areas of drawdown are the Pine Bluff, Arkansas, area and the Bastrop and Monroe, Louisiana, areas. In Mississippi, the major pumping centers are located in the Jackson, Yazoo City, and Cleveland areas. The model generated heads in these areas are representative of measured heads.

Simulated drawdowns are greater in the Sparta aquifer than any of the other aquifers in the regional study area. The greatest drawdown from simulated predevelopment conditions is in the Pine Bluff area. Significant drawdowns have also occurred in the Bastrop, Monroe, and Jackson areas since predevelopment time.

Pumpage from the Sparta aquifer causes the net flow in subcrop areas to be downward from the alluvium, as opposed to upward to the alluvium under predevelopment conditions. The flow from the alluvium under 1980 pumpage conditions is 1.15 million ft^3/d (8.60 Mgal/d). Vertical movement of water upward to the Sparta from the Meridian-upper Wilcox aquifer is less than 0.1 in/yr except in the Pine Bluff area (0.2 in/yr). In the study area, vertical flow from the Meridian-upper Wilcox aquifer upward to the middle Claiborne aquifer is about 0.71 million ft^3/d (5.31 Mgal/d).

Pumpage from the Sparta aquifer also results in a reversal of vertical flow with the Cockfield aquifer. Vertical flow from the Cockfield downward to the Sparta is about 14.14 million ft^3/d (105.77 Mgal/d) under 1980 pumpage conditions, as compared to 8.47 million ft^3/d (63.36 Mgal/d) upward from the Sparta to the Cockfield under predevelopment conditions.

Meridian-Upper Wilcox Aquifer

The 1980 potentiometric map of the Meridian-upper Wilcox aquifer representing model generated heads is shown in figure 6. Pumpage from the aquifer in the regional study area is about 6.92 million ft^3/d (51.76 Mgal/d). The main pumping center in the regional study area is in the Greenwood-Indianola area, Mississippi. In this area, 1980 simulated heads are slightly lower than measured heads. At the pumping center in the middle of the Greenwood-Indianola area, the model-simulated drawdown from simulated predevelopment conditions is about 110 feet.

In Arkansas where the Meridian-upper Wilcox aquifer subcrops under the alluvium, the vertical flow is reversed under 1980 pumpage conditions. The flow upward to the alluvium under predevelopment conditions is about 0.15 million ft^3/d (1.12 Mgal/d) as compared to flow downward from the alluvium under 1980 pumping conditions of 0.06 million ft^3/d (0.45 Mgal/d).

Vertical flow to the Meridian-upper Wilcox from the middle Wilcox aquifer under predevelopment conditions generally is less than 0.1 in/yr over the majority of the areal extent of the aquifer. Vertical movement from the middle Wilcox aquifer upward through the upper Wilcox confining unit under 1980 pumping conditions is about 0.86 million ft^3/d (6.43 Mgal/d).

Middle Wilcox Aquifer

The 1980 potentiometric map of the middle Wilcox aquifer representing model generated heads is shown on figure 7. Pumpage from the middle Wilcox aquifer in the regional study area is about 3.28 million ft^3/d (24.53 Mgal/d). The main pumping centers in the regional study area are in south-central Arkansas, northwest Louisiana, and north-central Mississippi.

In most of the study area less than 0.1 in/yr of flow moves upward into the middle Wilcox aquifer through the interbedded clay layers in the Wilcox Group from the lower Wilcox aquifer. The middle Wilcox aquifer subcrops under the alluvium in Arkansas. The amount of upward movement to the alluvium is reduced under 1980 pumpage conditions from about 0.96 million ft^3/d (7.18 Mgal/d) under predevelopment conditions to about 0.20 million ft^3/d (1.50 Mgal/d) with 1980 pumpage.

Lower Wilcox Aquifer

The 1980 potentiometric map of the lower Wilcox aquifer representing model generated heads is shown on figure 8. Pumpage under 1980 conditions in the regional area is about 2.78 million ft^3/d (20.79 Mgal/d). Most of the pumpage from the aquifer is in and adjacent to its outcrop area in Mississippi and northeast Arkansas. The model-simulated drawdown from predevelopment conditions using 1980 stresses generally is less than 50 feet in most of the regional study area.

The thick clay beds of the Midway Group underlie the lower Wilcox aquifer. The model simulates the Midway as a no-flow boundary, which allows no vertical flow into or out of the lower Wilcox aquifer through the Midway Group. Flow does occur through the interbedded clays between the lower Wilcox aquifer and middle Wilcox aquifer due to the pumpage occurring in the lower Wilcox under 1980 pumpage conditions. Downward vertical flow to the lower Wilcox aquifer is about 1.92 million ft^3/d (14.36 Mgal/d), which represents a reversal in vertical flow movement from predevelopment conditions.

A summary of model-simulated flow between aquifers in the regional study area, assuming predevelopment are 1980 pumpage conditions, is shown on figures 9 and 10.

SUMMARY

The aquifer system present in the regional study area consists of six major aquifers ranging from Paleocene to Miocene age. The hydrologic system was simulated using the U. S. Geological Survey's modular three-dimensional, finite-difference ground-water flow model. The model has six layers with each layer representing the following aquifers in descending order: (1) Miocene-Oligocene aquifer system, (2) Cockfield aquifer, (3) Sparta aquifer, (4) Meridian-upper Wilcox aquifer, (5) middle Wilcox aquifer, and (6) lower Wilcox aquifer. The model has 50 rows and 70 columns and each cell is 5 miles on a side.

Model simulations indicate that groundwater flow in the regional study area moves downdip from the outcrop area and upward through the confining units as it traverses toward the Mississippi embayment axis. Regions of recirculation exist in the outcrop areas where flow enters the system and is discharged within a short distance. This interactive flow is caused by the undulating water table that reflects land-surface relief. Under stressed conditions using 1980 pumpage rates, model-simulated vertical flow between aquifers ranges from 0.26 million ft^3/d (1.94 Mgal/d) from the Miocene-Oligocene aquifer system downward to the Cockfield aquifer to 14.14 million ft^3/d (105.77 Mgal/d) from the Cockfield aquifer downward to the Sparta aquifer.

Water-level measurements made in 1980 indicate that the Sparta aquifer is the most severely stressed. The other aquifers have significant drawdown only in localized areas of heavy pumpage.

Stress to the aquifer system in Hinds, Madison, and Rankin Counties in central Mississippi due to pumpage is evident in the Cockfield and Sparta aquifers. The simulations completed by this regional analysis have shown a need to develop a fine-grid ground-water flow model of this area. Model generated heads of the Sparta aquifer in the three-county area are representative of measured heads. However, the model generated heads of the Cockfield are too high when compared to 1980 measured heads. This difference is not only attributed to the heavy and widely distributed pumpage, but also to the structural influence of the Jackson dome on the aquifer. With the development of a three layer fine-grid ground-water flow model of this area, better definition of the geohydrologic environment and ground-water flow will be available. The results of the fine-grid model analysis will provide water managers with a tool incorporating more usable information to better understand the ground-water flow system, analyze the effects of ground-water use, and to evaluate pumpage scenarios for future ground-water development in Hinds, Madison, and Rankin Counties, Mississippi.

SELECTED REFERENCES

Arthur, J. K., and Taylor, R. E., 1988, Personal communication.

Baughman, W. T., 1971, Rankin County geology and mineral resources: Mississippi Geological Survey Bulletin 115, 226 p.

Callahan, J. A., 1983, Water use in Mississippi, 1980: U. S. Geological Survey Open-File Report 83-224, 1 sheet.

Harvey, E. J., and Lang, J.W., 1958, Ground-water resources of the Jackson area, Mississippi: Mississippi Board Water Commissioners Bulletin 58-1, 35 p.

Harvey, E. J., Callahan, J. A., and Wasson, B. E., 1961, Ground-water resources of Hinds, Madison, and Rankin Counties, Mississippi, pt. 2, Basic data: Mississippi Board of Water Commissioners Bulletin 61-2, 146 p.

McDonald, M. G., and Harbaugh, A. W., 1984, Amodular three-dimensional finite-difference ground-water flow model: U. S. Geological Survey Open-File Report 83-875, 528 p.

Moore, W. H., 1965, Hinds County geology and minera1 resources: Mississippi Geological Survey Bull. 105, 244 p.

Payne, J. N., 1968, Hydrologic significance of the lithofacies of the Sparta Sand in Arkansas, Louisiana, Mississippi, and Texas: U. S. Geological Survey Professional Paper 569-A, 17 p.

Payne, J. N., 1970, Geohydrologic significance of lithofacies of the Cockfield Formation of Louisiana and Mississippi and of Yegua Formation of Texas: U. S. Geological Survey Professional Paper 569-B, 14 p.

Priddy, R. R., 1960, Madison County geology: Mississippi Geological Survey Bull. 88, 123 p.

Reed, J. E., 1972, Analog simulation of water-level declines in the Sparta Sand, Mississippi embayment: Hydrologic Investigations Atlas HA-434, 1 sheet.

Wasson, B. E., 1980, Potentiometric map of the Sparta aquifer system, fall 1980: U. S. Geological Survey Water-Resources Investigations Map 81-1051, 1 sheet.

Wasson, B. E., 1981, Potentiometric map of the Cockfield aquifer in Mississippi: U. S. Geological Survey Water-Resources Investigations Map 81-1053, 1 sheet.

EXPLANATION

— 200 — SIMULATED POTENTIOMETRIC CONTOUR - - Shows Altitude of Potentiometric Surface.

Contour interval 25 Feet.

National Geodetic Vertical Datum of 1929.

FIGURE 3. Potentiometric Map of Miocene-Oligocene Aquifer System Using Model - Generated Heads Representing 1980 Pumpage Conditions.

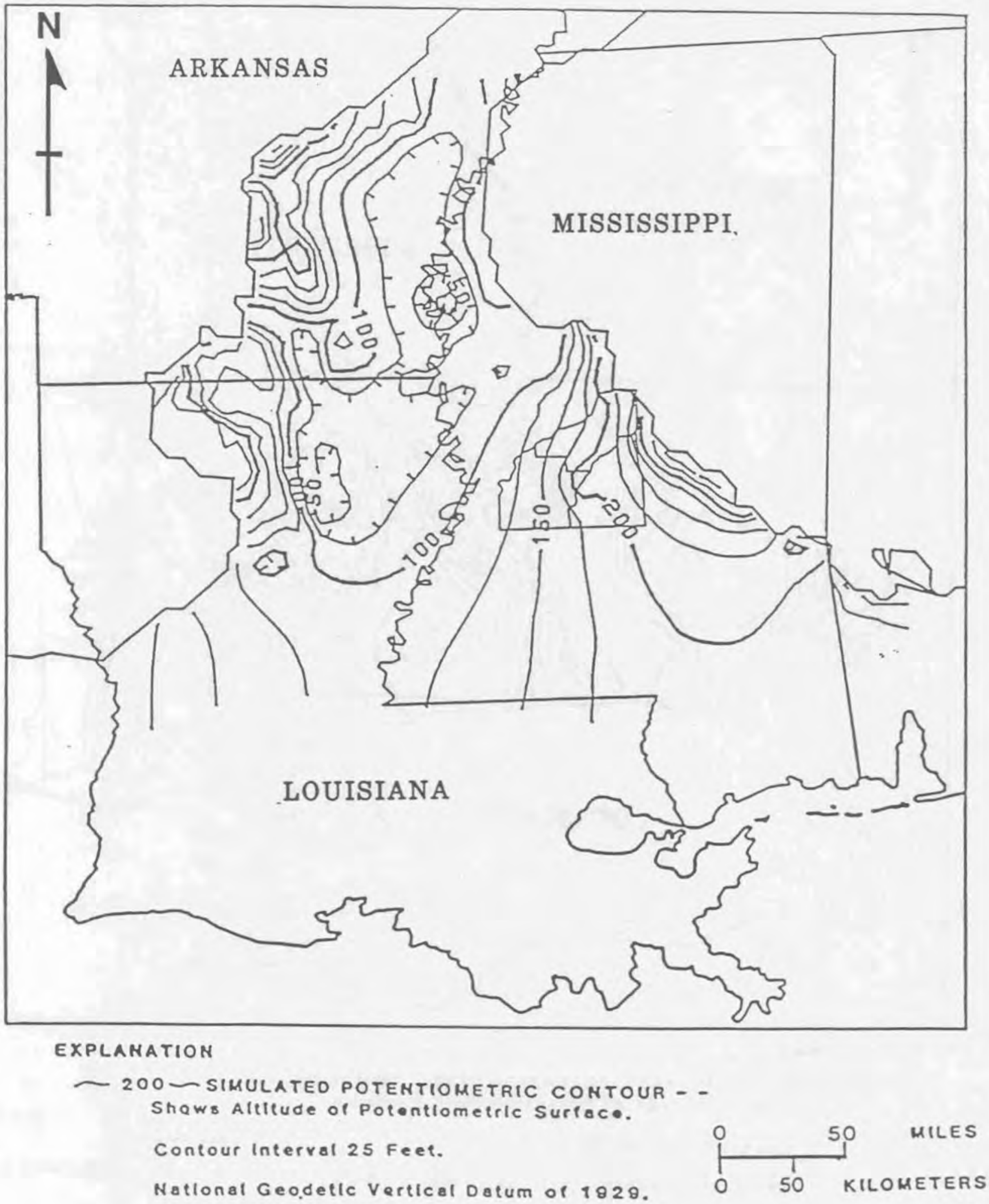


FIGURE 4. Potentiometric Map of Cockfield Aquifer Using Model - Generated Heads Representing 1980 Pumpage Conditions.

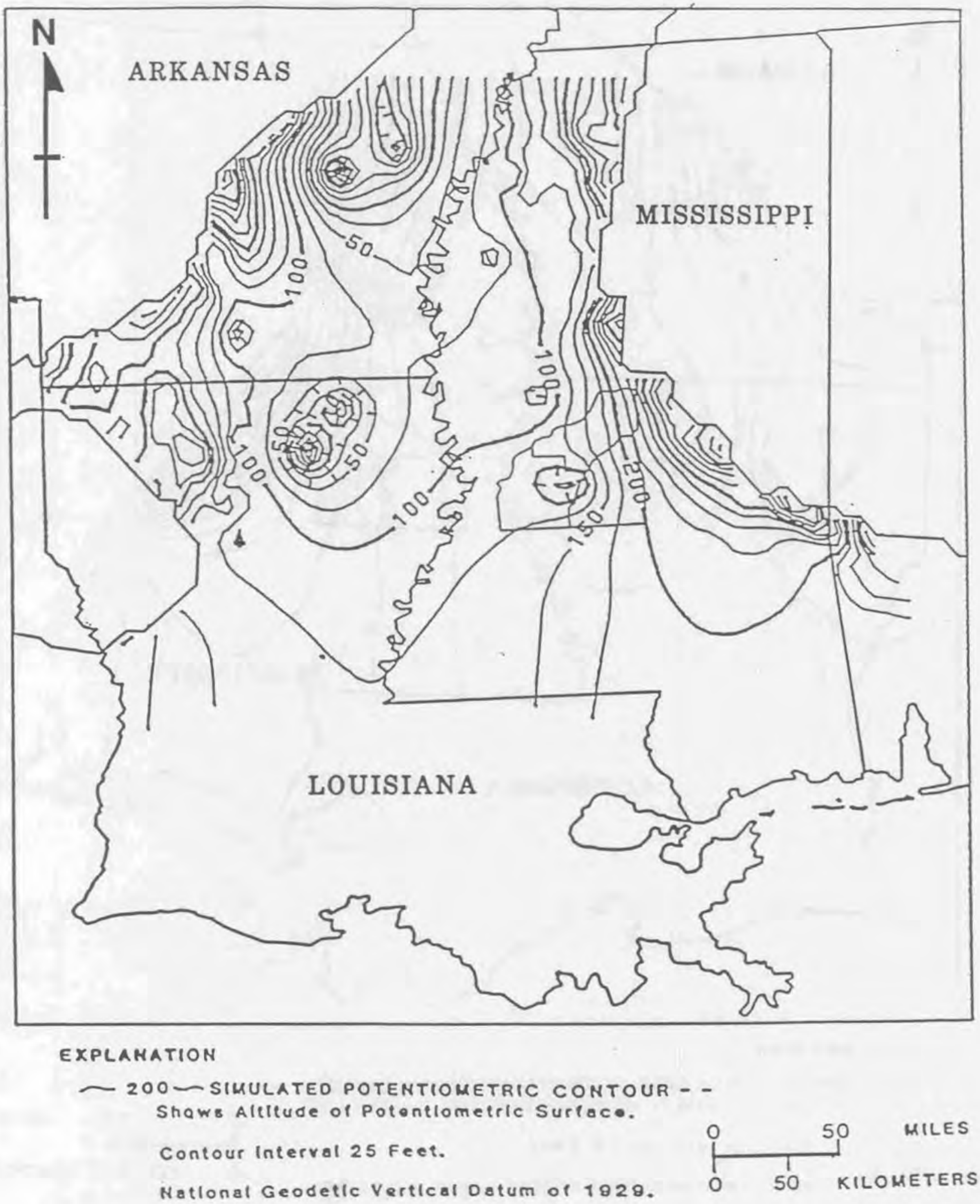
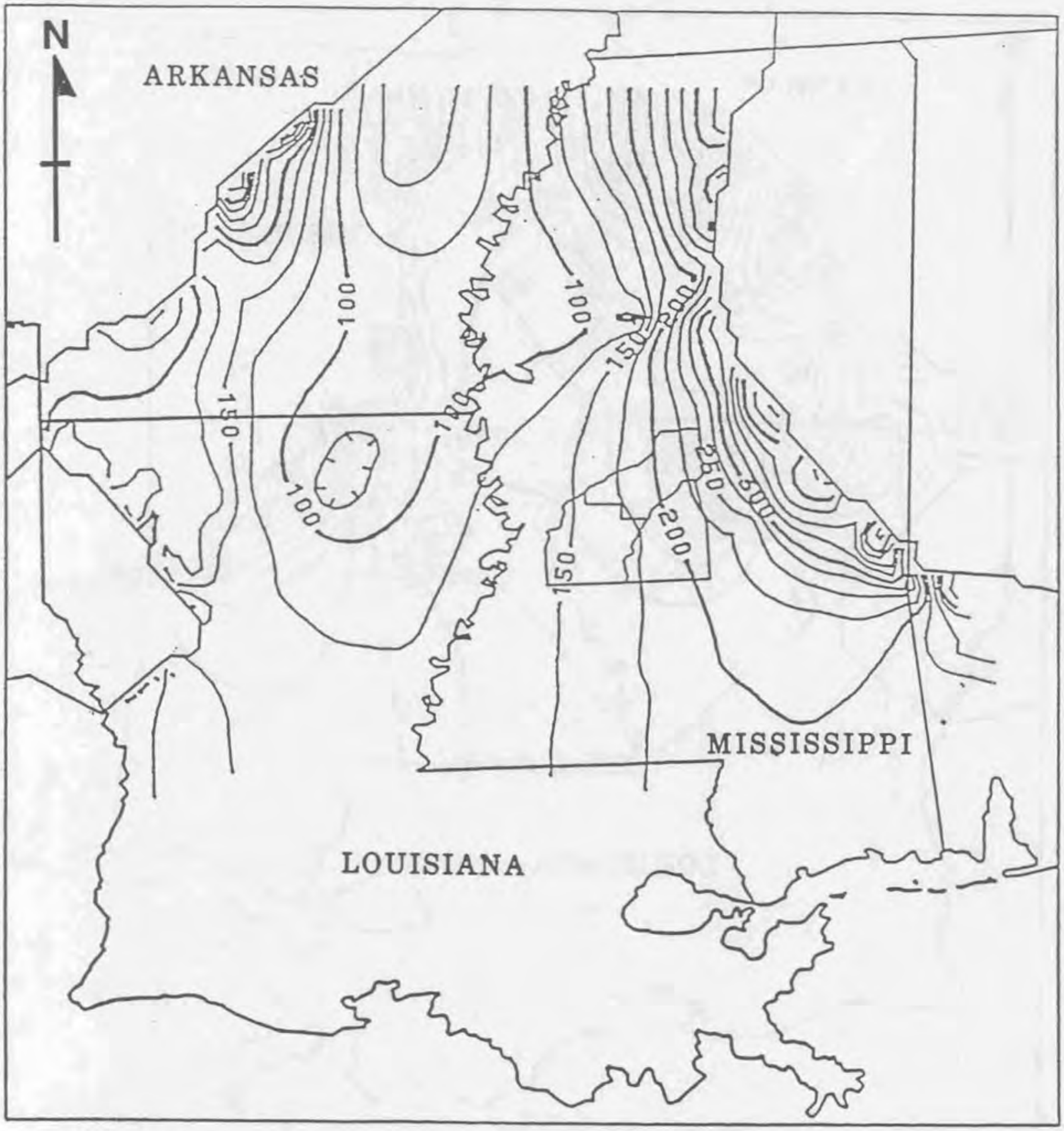


FIGURE 5. Potentiometric Map of Sparta Aquifer Using Model - Generated Heads Representing 1980 Pumpage Conditions.



EXPLANATION

— 200 — SIMULATED POTENTIOMETRIC CONTOUR - - Shows Altitude of Potentiometric Surface.

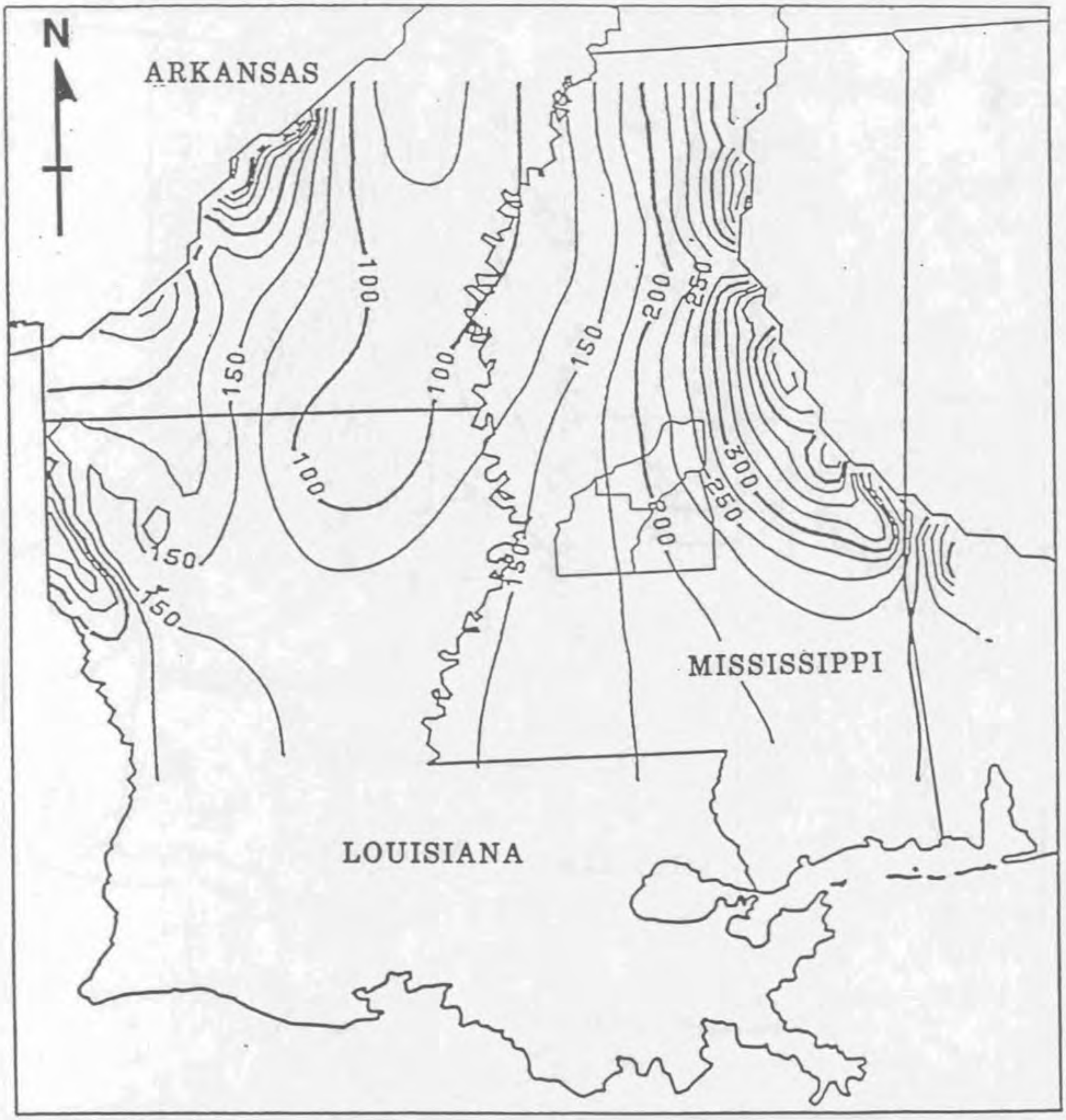
Contour Interval 25 Feet.

National Geodetic Vertical Datum of 1929.

0 50 MILES

0 50 KILOMETERS

FIGURE 6. Potentiometric Map of Meridian-Upper Wilcox Aquifer Using Model - Generated Heads Representing 1980 Pumpage Conditions.



EXPLANATION

— 200 — SIMULATED POTENTIOMETRIC CONTOUR - -
Shows Altitude of Potentiometric Surface.

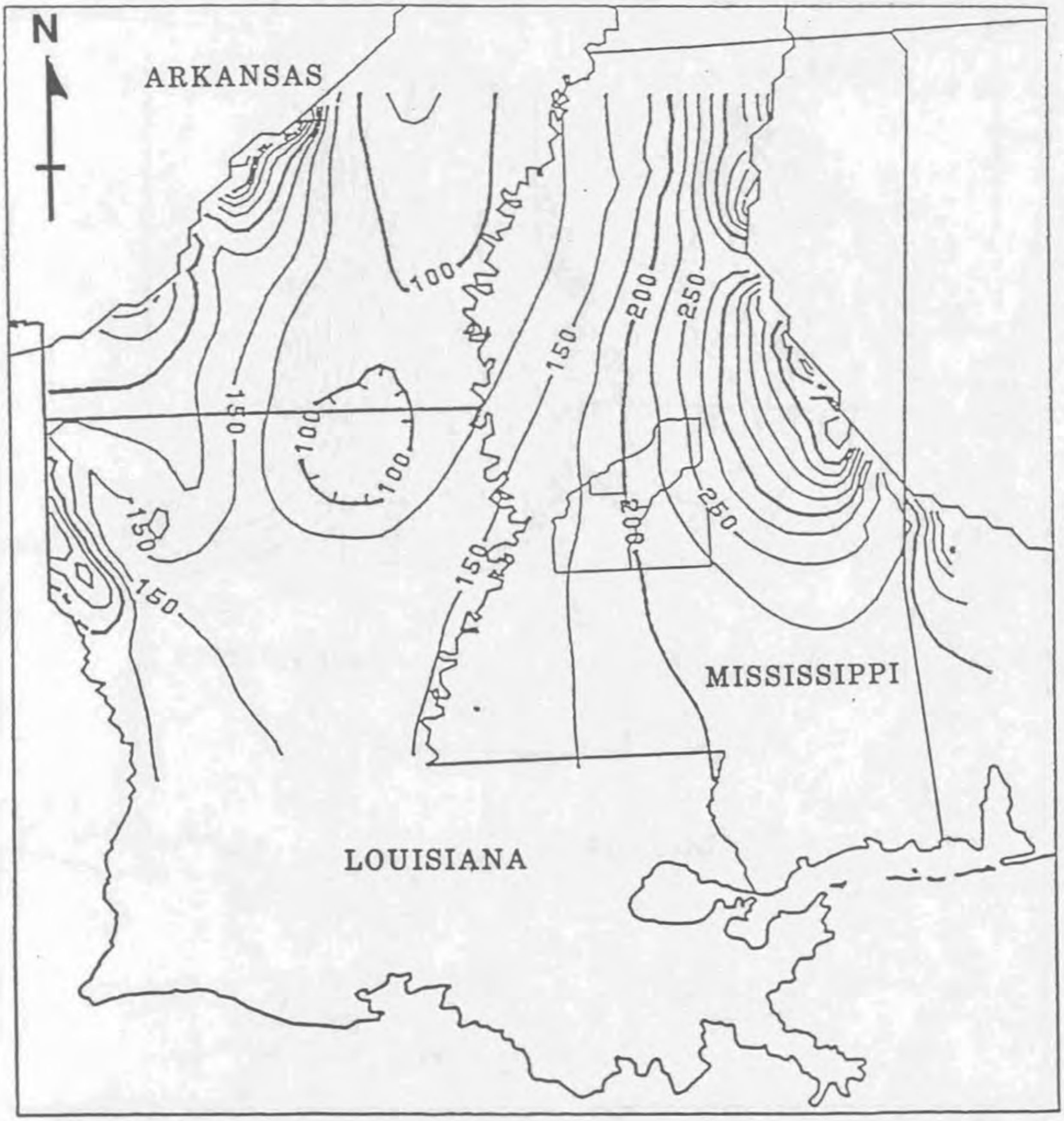
Contour Interval 25 Feet.

National Geodetic Vertical Datum of 1929.

0 50 MILES

0 50 KILOMETERS

FIGURE 7. Potentiometric Map of Middle Wilcox Aquifer Using Model - Generated Heads Representing 1980 Pumpage Conditions.



EXPLANATION

— 200 — SIMULATED POTENTIOMETRIC CONTOUR - - Shows Altitude of Potentiometric Surface.

Contour interval 25 Feet.

National Geodetic Vertical Datum of 1929.

0 50 MILES

0 50 KILOMETERS

FIGURE 8. Potentiometric Map of Lower Wilcox Aquifer Using Model - Generated Heads Representing 1980 Pumpage Conditions.

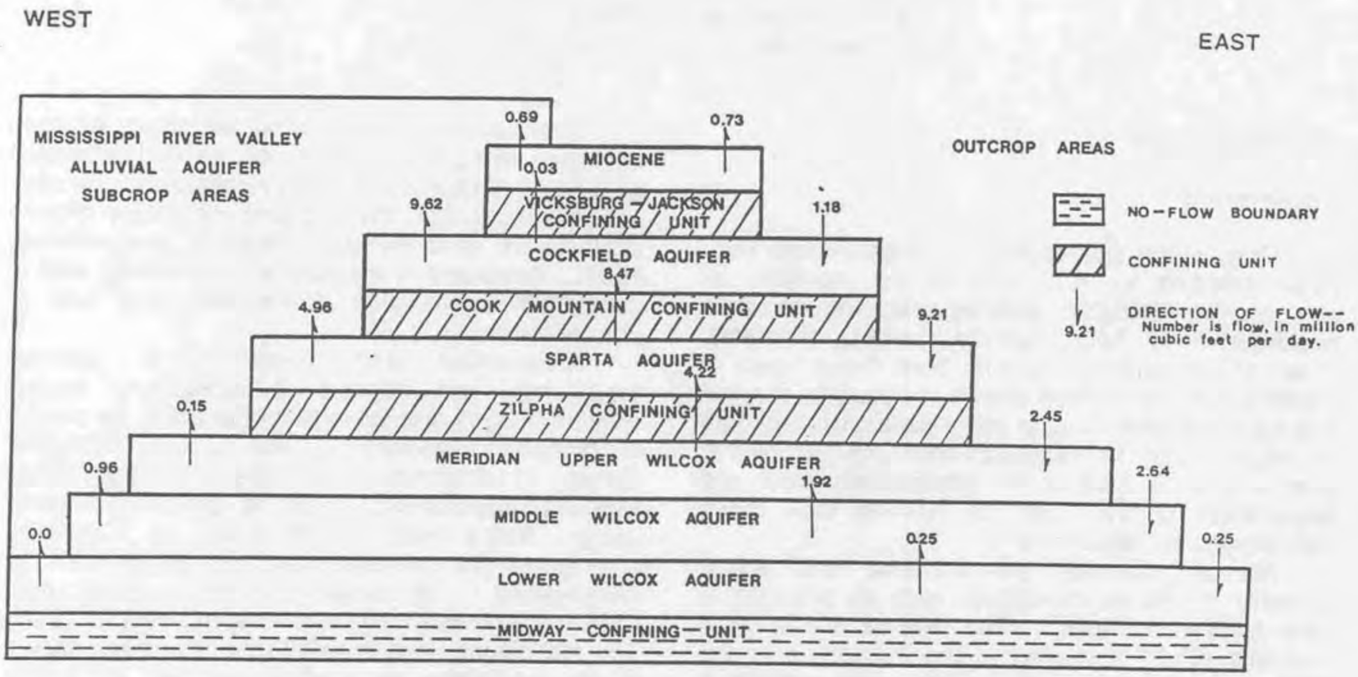


FIGURE 9. SUMMARY OF MODEL SIMULATED FLOW ASSUMING PREDEVELOPMENT CONDITIONS.

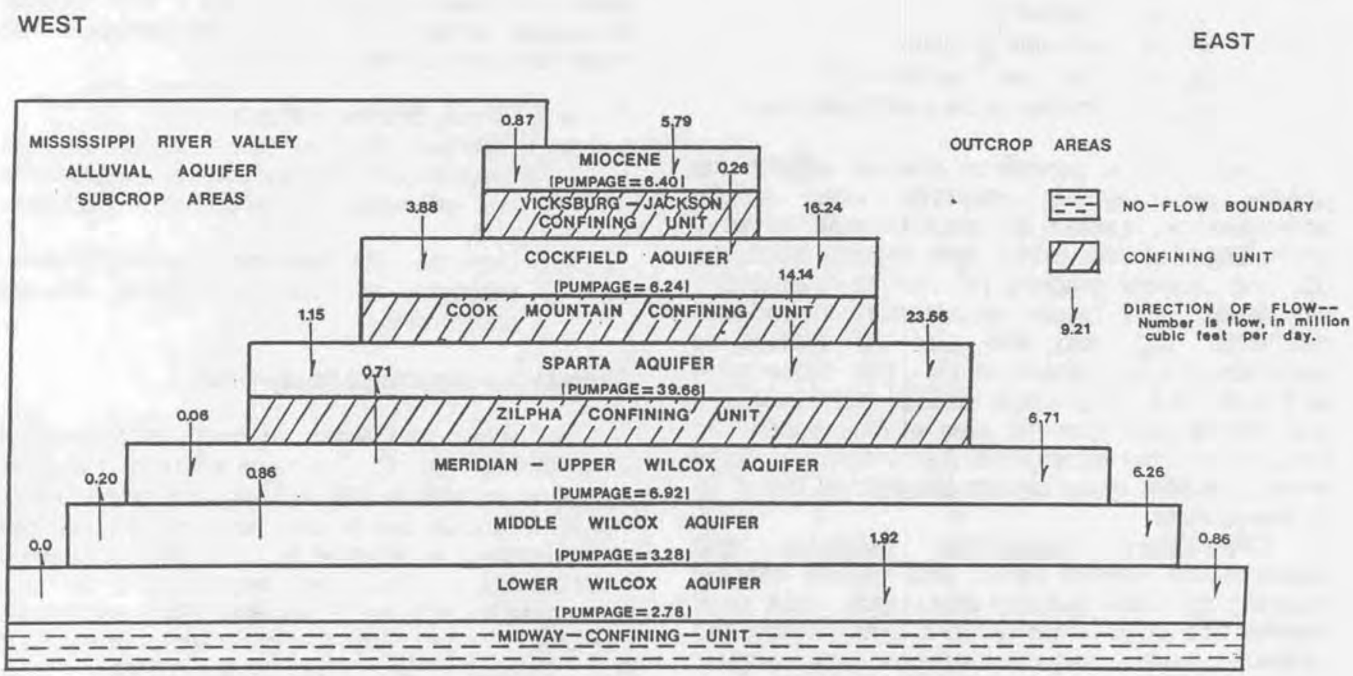


FIGURE 10. SUMMARY OF MODEL SIMULATED FLOW ASSUMING 1980 PUMPAGE CONDITIONS.