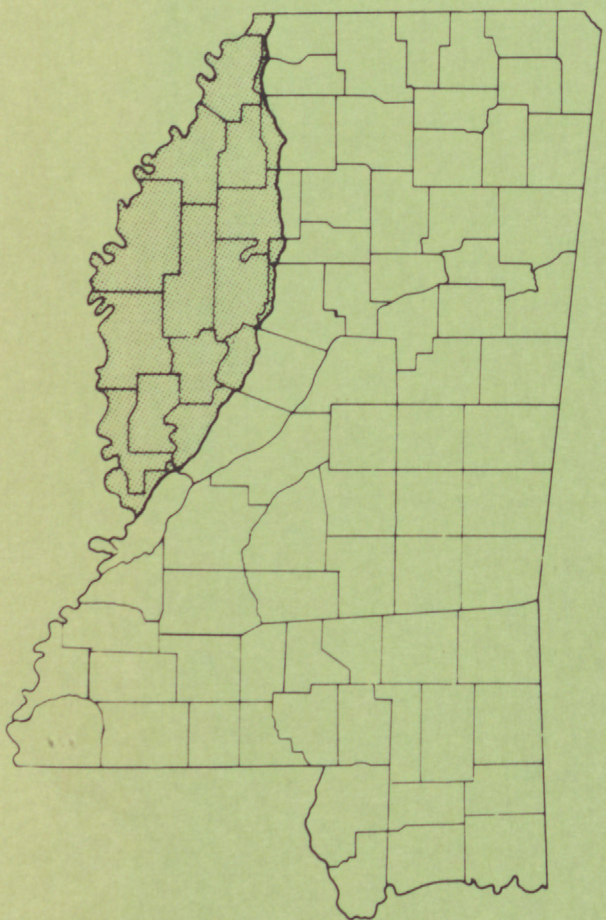
(200)
R290
no. 84-822

# GEOHYDROLOGY AND SIMULATED EFFECTS OF LARGE GROUND-WATER WITHDRAWALS ON THE MISSISSIPPI RIVER ALLUVIAL AQUIFER IN NORTHWESTERN MISSISSIPPI



UNITED STATES
GEOLOGICAL SURVEY
OPEN-FILE REPORT
84-822

U. S. GEOLOGICAL SURVEY
RESTON, VA.
APR 4 1985
LIBRARY

PREPARED IN
COOPERATION WITH THE
MISSISSIPPI DEPARTMENT
OF NATURAL RESOURCES
BUREAU OF LAND AND
WATER RESOURCES

# GEOHYDROLOGY AND SIMULATED EFFECTS OF LARGE GROUND-WATER WITHDRAWALS ON THE MISSISSIPPI RIVER ALLUVIAL AQUIFER IN NORTHWESTERN MISSISSIPPI

by

D. M. Sumner and B. E. Wasson

Hydrologists

U. S. Geological Survey

USGS LIBRARY-RESTON
3 1818 00061827 0

Open-file report (Geological Survey (U.S.))

U. S. GEOLOGICAL SURVEY
OPEN-FILE REPORT 84-822

Prepared in cooperation with the
MISSISSIPPI DEPARTMENT OF NATURAL RESOURCES
BUREAU OF LAND AND WATER RESOURCES

Jackson, Mississippi
1984

## UNITED STATES DEPARTMENT OF THE INTERIOR

**WILLIAM P. CLARK, *SECRETARY***

## GEOLOGICAL SURVEY

**Dallas L. Peck, *Director***

---


**For additional information write to:**

**District Chief**
**U.S. Geological Survey**
**Water Resources Division**
**100 West Capital Street, Suite 710**
**Jackson, Mississippi 39269**
**Telephone: (601) 960-4600**



**Copies of this report can be purchased from:**

**Open-File Services Section**
**Western Distribution Branch**
**U.S. Geological Survey**
**Box 25425, Federal Center**
**Lakewood, Colorado 80225**
**Telephone: (303) 234-5888**

CONTENTS

## ILLUSTRATIONS

Page

TABLES

FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS
TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert inch-pound units published herein to the International System of Units (SI):

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Flow | |
| cubic foot per day ($ft^3/d$) | 0.02832 | cubic meter per day ($m^3/d$) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3/s$) |
| | Gradient | |
| foot per mile (ft/mi) | 18.9 | centimeter per kilometer (cm/km) |
| | 0.189 | meter per kilometer (m/km) |
| | Hydraulic conductivity | |
| foot per day (ft/d) or $(ft^3/d)/ft$ | 0.3048 | meter per day (m/d) |
| | Transmissivity | |
| foot squared per day ($ft^2/d$) or $(ft^3/d)/ft$ | 0.0920 | meter squared per day ($m^2/d$) |
| | Riverbed conductance | |
| foot squared per day ($ft^2/d$) or $(ft^3/d)/ft$ | 0.0929 | meter squared per day ($m^2/d$) |
| | Leakance | |
| per day ($d^{-1}$) or $[(ft^3/d)ft^2]/ft$ | 1 | per day ($d^{-1}$) |

GEOHYDROLOGY AND SIMULATED EFFECTS OF LARGE GROUND-WATER WITHDRAWALS ON THE MISSISSIPPI RIVER ALLUVIAL AQUIFER IN NORTHWESTERN MISSISSIPPI

by D. M. Sumner and B. E. Wasson

ABSTRACT

The 7,000 square mile Mississippi River alluvial plain in northwestern Mississippi (the Delta) is underlain by a prolific aquifer that currently (1983) yields about 1,100 Mgal/d (million gallons per day) of water to irrigation wells. Commonly about 20 feet of clay underlying the Delta land surface is underlain by about 80 to 180 feet of sand and gravel that forms the Mississippi River alluvial aquifer. This study of the alluvial aquifer was prompted by recent declines of water levels. The study was designed to better define the hydrology of the aquifer and to quantify availability of water from the aquifer.

The Mississippi River is in good hydraulic connection with the alluvial aquifer. Generally, smaller streams are less likely to recharge the aquifer than larger streams. Direct vertical recharge to the alluvial aquifer from the 52 inches of precipitation is small, especially in the central part of the Delta.

A two-dimensional finite-difference computer model of the alluvial aquifer was constructed, calibrated, and verified using water levels observed for five dates between April 1981 and to September 1983. The values of some of the calibration-derived parameters are: hydraulic conductivity, 400 feet per day; specific yield, 0.30; and infiltration of precipitation to the aquifer, 0.5 inch per year.

The model shows that the aquifer had a net loss in storage of about 360 Mgal/d for the 2 years from April 1981 to April 1983. During this period, pumpage was about 1,100 Mgal/d (1,270,000 acre feet per year) and the net inflows from the sources of recharge were: Mississippi River, 390 Mgal/d; recharge along east edge of the Delta, 170 Mgal/d; streams within the Delta, 57 Mgal/d; areal recharge from infiltration, 180 Mgal/d; and oxbow lakes, 24 Mgal/d.

The effects of several levels of pumpage by wells--0; 670; 1,100; 1,900; and 4,000 Mgal/d--were projected 20 years into the future. In 2003 the 1,100-Mgal/d pumping rate, about average for the early 1980's, would take 46 percent of the water withdrawn from storage, water levels would be lowered more than 20 feet in a large area in the central part of the Delta, and ground-water levels would continue to decline in future years.

## INTRODUCTION

Most of the water pumped in the Delta is used for irrigation and comes from the Mississippi River alluvial aquifer. In recent years catfish farming has become a major user of ground water, second only to irrigation. Increasing use of water from the alluvium and decreasing water levels in the early 1980's prompted this study. Use of water from the alluvial aquifer increased from about 200 Mgal/d in the early 1970's to about 1,100 Mgal/d in the early 1980's.

The Mississippi River Alluvial Plain, a convex lens-shaped part of the Gulf Coastal Plain, includes part of the Yazoo basin in northwestern Mississippi (Fenneman, 1938). Locally known as the Delta, the alluvial plain slopes about one-half foot per mile from about 220 feet above sea level at the upper end near Memphis, Tenn., to about 80 feet near Vicksburg, Miss., a distance of 200 miles. The Delta has an area of about 7,000 square miles. The Mississippi River forms the western edge of the Delta, or study area (figs. 1 and 14). An escarpment, the Bluff Hills, which are about 100 to 200 feet higher than the alluvial plain forms the eastern edge of the Delta. The Yazoo-Tallahatchie-Coldwater River system drains the eastern edge of the plain and collects water from many streams that enter the plain from the hills to the east (fig. 14).

Precipitation in the Delta averages about 52 inches annually. Seasonal distribution of precipitation is approximately: winter, 17 inches; spring, 15 inches; summer, 11 inches; and fall, 9 inches. Average annual temperature ranges from 62°F near Memphis to 66°F near Vicksburg. The normal frost-free growing season extends from early April to early November.

Before 1800, all of the Delta was covered with hardwood forest. By 1930, about half of the Delta had been cleared and was in row crops--mostly in cotton. In 1984, only small areas of the hardwood forest remain, except for the Delta National Forest in Sharkey and Issaquena Counties and the floodway area between the levees of the Mississippi River.

The purpose of this study was to better understand and define the hydrology of the Mississippi River alluvial aquifer in northwestern Mississippi and to quantify the effects of future withdrawals of water for irrigation, catfish farming, and other uses. This report describes the geohydrology of the Mississippi River alluvial aquifer as determined by field investigations and digital modeling of the aquifer. The report was prepared by the U.S. Geological Survey in cooperation with the Mississippi Department of Natural Resources, Bureau of Land and Water Resources. The Mississippi Research and Development Center also provided financial support. Water use in the Delta was studied in cooperation with the U.S. Soil Conservation service. The authors wish to acknowledge several people within the U.S. Geological Survey who made significant contributions to the study and report. R. E. Taylor did most of the computer-related work and aided

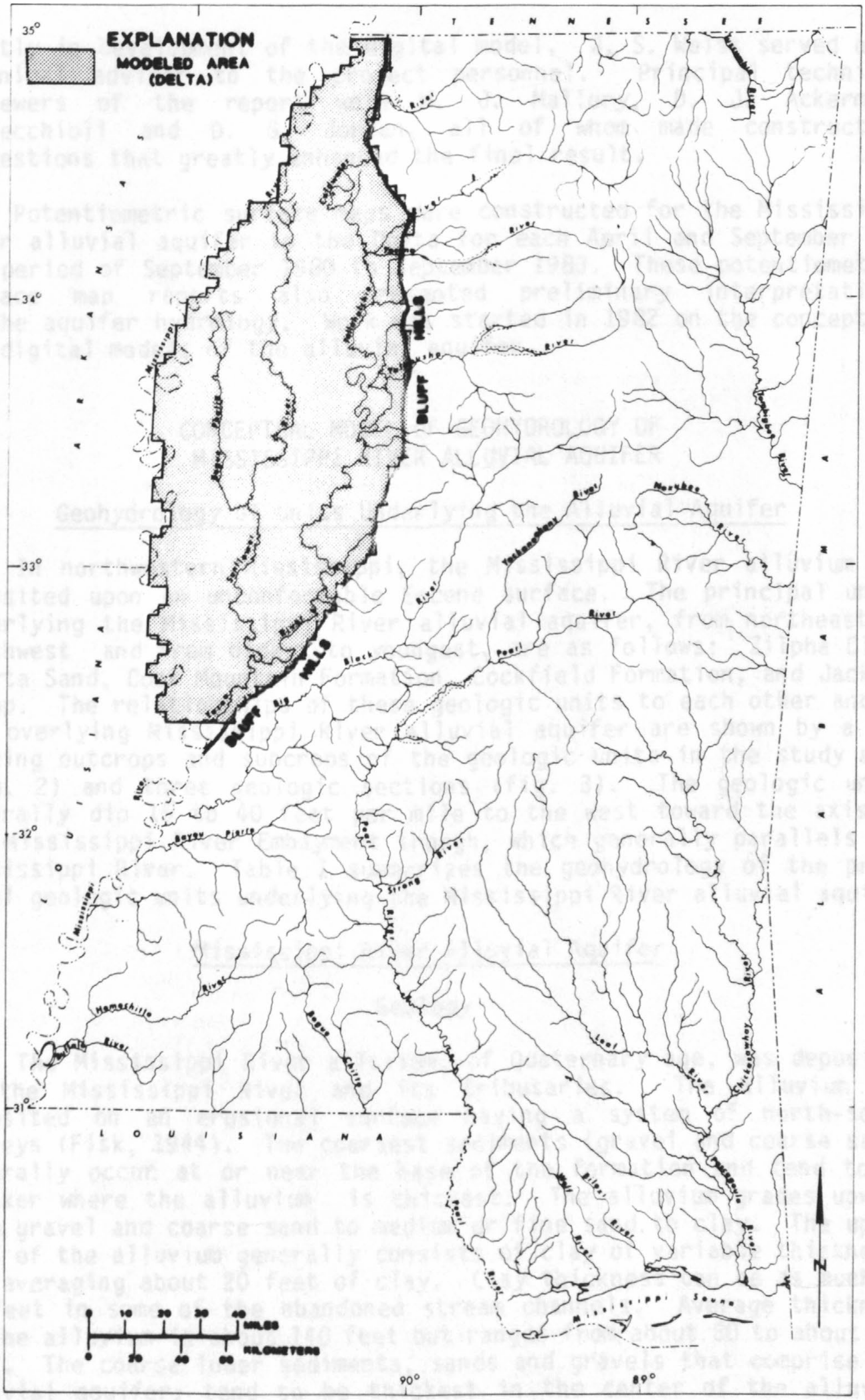



Figure 1.--Location of the study area (Delta) in northwestern Mississippi.

greatly in development of the digital model. J. S. Weiss served as a technical advisor to the project personnel. Principal technical reviewers of the report were M. J. Mallory, D. J. Ackerman, J. Vecchioli and D. G. Jordan, all of whom made constructive suggestions that greatly enhanced the final result.

Potentiometric surface maps were constructed for the Mississippi River alluvial aquifer in the Delta for each April and September for the period of September 1980 to September 1983. These potentiometric surface map reports also presented preliminary interpretations of the aquifer hydrology. Work was started in 1982 on the conceptual and digital models of the alluvial aquifer.

## CONCEPTUAL MODEL OF GEOHYDROLOGY OF MISSISSIPPI RIVER ALLUVIAL AQUIFER

### Geohydrology of Units Underlying the Alluvial Aquifer

In northwestern Mississippi, the Mississippi River alluvium was deposited upon an unconformable Eocene surface. The principal units underlying the Mississippi River alluvial aquifer, from northeast to southwest and from oldest to youngest, are as follows: Zilpha Clay, Sparta Sand, Cook Mountain Formation, Cockfield Formation, and Jackson Group. The relationships of these geologic units to each other and to the overlying Mississippi River alluvial aquifer are shown by a map showing outcrops and subcrops of the geologic units in the study area (fig. 2) and three geologic sections (fig. 3). The geologic units generally dip 15 to 40 feet per mile to the west toward the axis of the Mississippi River Embayment trough, which generally parallels the Mississippi River. Table 1 summarizes the geohydrology of the principal geologic units underlying the Mississippi River alluvial aquifer.

### Mississippi River Alluvial Aquifer

#### Geology

The Mississippi River alluvium, of Quaternary age, was deposited by the Mississippi River and its tributaries. The alluvium was deposited on an erosional surface having a system of north-south valleys (Fisk, 1944). The coarsest sediments (gravel and coarse sand) generally occur at or near the base of the formation and tend to be thicker where the alluvium is thickest. The alluvium grades upward from gravel and coarse sand to medium or fine sand to clay. The upper part of the alluvium generally consists of clay of variable thickness, but averaging about 20 feet of clay. Clay thickness can be as much as 70 feet in some of the abandoned stream channels. Average thickness of the alluvium is about 140 feet but ranges from about 80 to about 240 feet. The coarse lower sediments, sands and gravels that comprise the alluvial aquifer, tend to be thickest in the center of the alluvial plain and thinner towards the periphery of the Delta (fig. 4). The alluvium thins to a feather edge along the eastern side of the Delta.

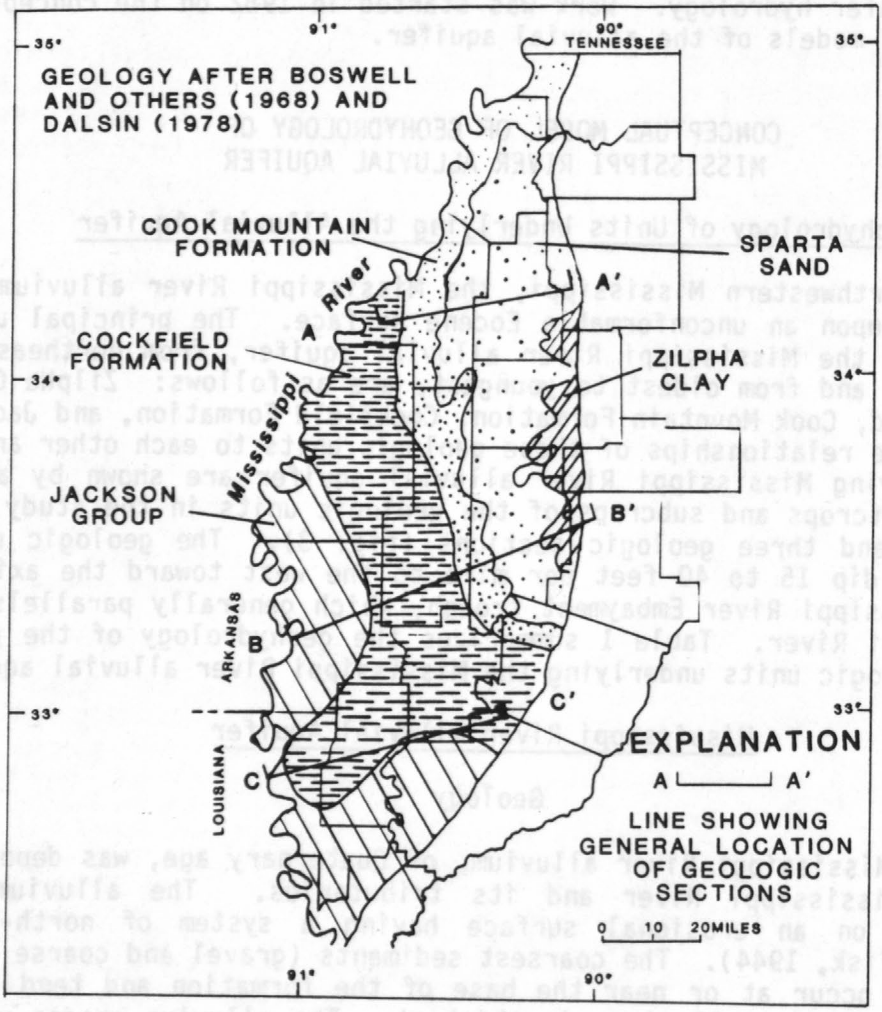



Figure 2.--Geologic units subjacent to the Mississippi River alluvium and general location of geologic sections.

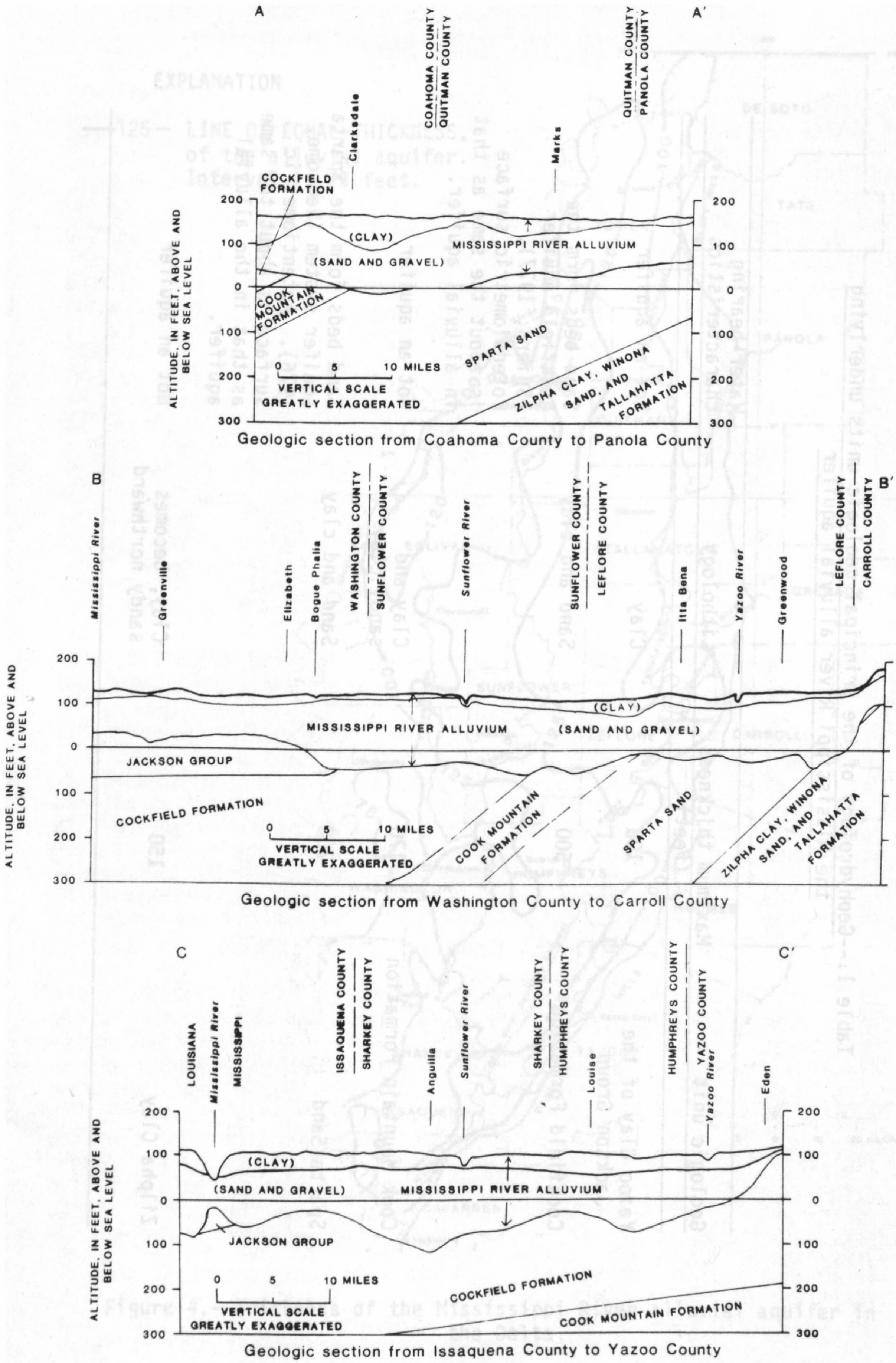



Figure 3.--Geologic sections east-west across the Delta.

Table 1.--Geohydrology of the principal geologic units underlying the Mississippi River alluvial aquifer

| Geologic unit | Maximum thickness (feet) | Lithology | Water-bearing characteristics |
|---|---|---|---|
| Yazoo Clay of the Jackson Group | 100 | Clay | Not an aquifer |
| Cockfield Formation | 500 | Sand and clay | Sand beds form the Cockfield aquifer (Spiers, 1977). Potentiometric surface is about the same as that in alluvial aquifer. |
| Cook Mountain Formation | 170 | Clay and sandy clay | Not an aquifer |
| Sparta Sand | 700 | Sand and clay | Sand beds form the Sparta aquifer system (Newcome, 1976). Potentiometric surface is about the same as that in the alluvial aquifer. |
| Zilpha Clay | 150 | Clay; becomes sandy northward | Not an aquifer |

EXPLANATION

—125— LINE OF EQUAL THICKNESS, of the alluvial aquifer. Interval is 25 feet.

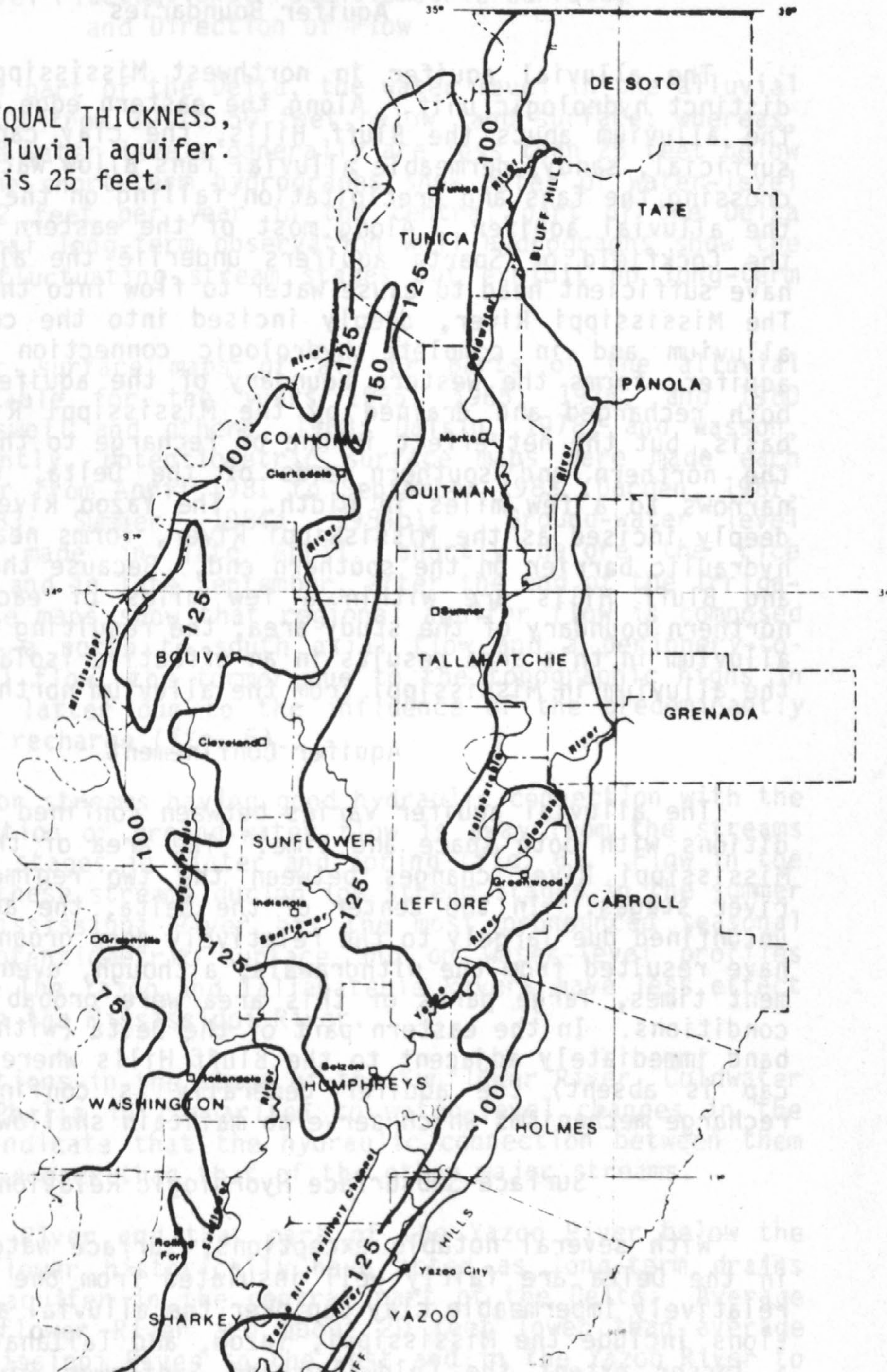



Figure 4.--Thickness of the Mississippi River alluvial aquifer in the Delta.

## Aquifer Boundaries

The alluvial aquifer in northwest Mississippi is a relatively distinct hydrologic unit. Along the eastern edge of the Delta, where the alluvium abuts the Bluff Hills, the clay cap is lacking. The surficial, sandy, permeable alluvial fans allow water from the streams crossing the fans and precipitation falling on the fans to infiltrate the alluvial aquifer. Along most of the eastern edge of the Delta, the Cockfield or Sparta aquifers underlie the alluvial aquifer and have sufficient head to cause water to flow into the alluvial aquifer. The Mississippi River, deeply incised into the coarser part of the alluvium and in complete hydrologic connection with the alluvial aquifer, forms the western boundary of the aquifer. The aquifer is both recharged and drained by the Mississippi River on a seasonal basis, but the net effect is one of recharge to the aquifer. On both the northern and southern ends of the Delta, the alluvial plain narrows to a few miles in width. The Yazoo River, although not as deeply incised as the Mississippi River, forms nearly as effective a hydraulic barrier on the southern end. Because the Mississippi River and Bluff Hills are within a few miles of each other along the northern boundary of the study area, the resulting narrow width of the alluvium in this area results in an effective isolation of the bulk of the alluvium in Mississippi from the alluvium north of the area.

## Aquifer Confinement

The alluvial aquifer varies between confined and unconfined conditions with both space and time. The area of the aquifer near the Mississippi River changes between the two regimes with changes in river stages. In the center of the Delta, the aquifer generally is unconfined due largely to the relatively deep ground-water levels that have resulted from the withdrawals, although, even during predevelopment times, large parts of this area were probably under unconfined conditions. In the eastern part of the Delta (with the exception of a band immediately adjacent to the Bluff Hills where the clay confining cap is absent) the aquifer generally is confined due to several recharge mechanisms which serve to maintain shallow water levels.

## Surface-Subsurface Hydrologic Relationships

With several notable exceptions, surface water and ground water in the Delta are fairly well insulated from one another due to the relatively impermeable clay cap over the alluvial aquifer. The exceptions include the Mississippi, Yazoo, and Tallahatchie Rivers and to a lesser extent the Coldwater and Sunflower Rivers and the Bogue Phalia. These streams have completely or partially penetrated the clay cap; therefore, the streams are in hydraulic contact with the aquifer. The amount of ground water-surface water interflow along a river stretch varies both areally (degree of stream-aquifer connection varies with areal variation in clay thickness) and temporally (large seasonal fluctuations in stream stages change both magnitude and direction of interflow).

## Water-Level Fluctuations, Potentiometric Surface, and Direction of Flow

In the central part of the Delta, the water level in the alluvial aquifer generally is from 30 to 50 feet below land surface; whereas, in other areas, the water levels generally are less than 25 feet below land surface. Some short-term hydrographs show rates of water-level decline of about 2 feet per year in the central part of the Delta since 1980. Several long-term observation well hydrographs show the effect of nearby fluctuating stream stages but exhibit no long-term changes.

Potentiometric surface maps of all or parts of the alluvial aquifer are available for the years 1955, 1965, 1976, and 1980 (Harvey, 1956; Boswell and others, 1968; Dalsin, 1978; and Wasson, 1980b). Subsequently, potentiometric surface maps were made each April and September from April 1981 to September 1983 (Darden, 1981, 1982a, 1982b, 1983; Sumner, 1984a, 1984b). Ground-water level measurements were made in late April, shortly before the rice irrigation season, and in late September, after the end of the irrigation season. These maps show that regional aquifer flow is composed of two components--a north to south axial flow and a periphery-to-interior transaxial flow, the former due to the topographic highs in the north and the latter due to the influence of the predominantly peripheral aquifer recharge (fig. 5).

Along the major streams having good hydraulic connection with the aquifer, the direction of ground-water flow is away from the streams during high stream stages in winter and spring (fig. 6). Flow in the aquifer is toward these streams during low stream stages in the summer and fall. The Mississippi River has the most pronounced seasonal effects on the potentiometric surface and on water-level profiles (figs. 7, and 8). The Yazoo and Tallahatchie Rivers have less effect on the aquifer than the Mississippi River.

Large fluctuations in the stage of the Sunflower River, Coldwater River, and Bogue Phalia in comparison to water-level changes in the alluvial aquifer indicate that the hydraulic connection between them and the aquifer is poorer than that of the other major streams.

The Sunflower River and that part of the Yazoo River below the mouth of the Sunflower historically have acted as long-term drains from the alluvial aquifer in the central part of the Delta. Average stages in the Sunflower River are about 20 feet lower than average stages in the Mississippi River to the west and in the Yazoo River to the east. This difference in head has influenced the configuration of the potentiometric surface in the alluvial aquifer. Historically, the potentiometric surface of the aquifer has sloped toward the Sunflower River from the north, west, and east (fig. 5) even though hydraulic connection is poor. Pumpage for irrigation and catfish ponds since 1980 has caused a general decline of 1 to 2 feet per year in the potentiometric surface in the central part of the Delta. As a result, in some reaches of the Sunflower River, the potentiometric surface has declined slightly below the level of the lower stages in the river, and the river may now recharge the aquifer in these areas the year round as indicated in the profiles of figure 8.

EXPLANATION

—120— POTENTIOMETRIC CONTOUR--Shows altitude in feet at which water level would have stood in tightly cased wells. Contour interval is 10 feet. Datum is sea level.

←— FLOW LINE--Shows direction of ground-water flow.

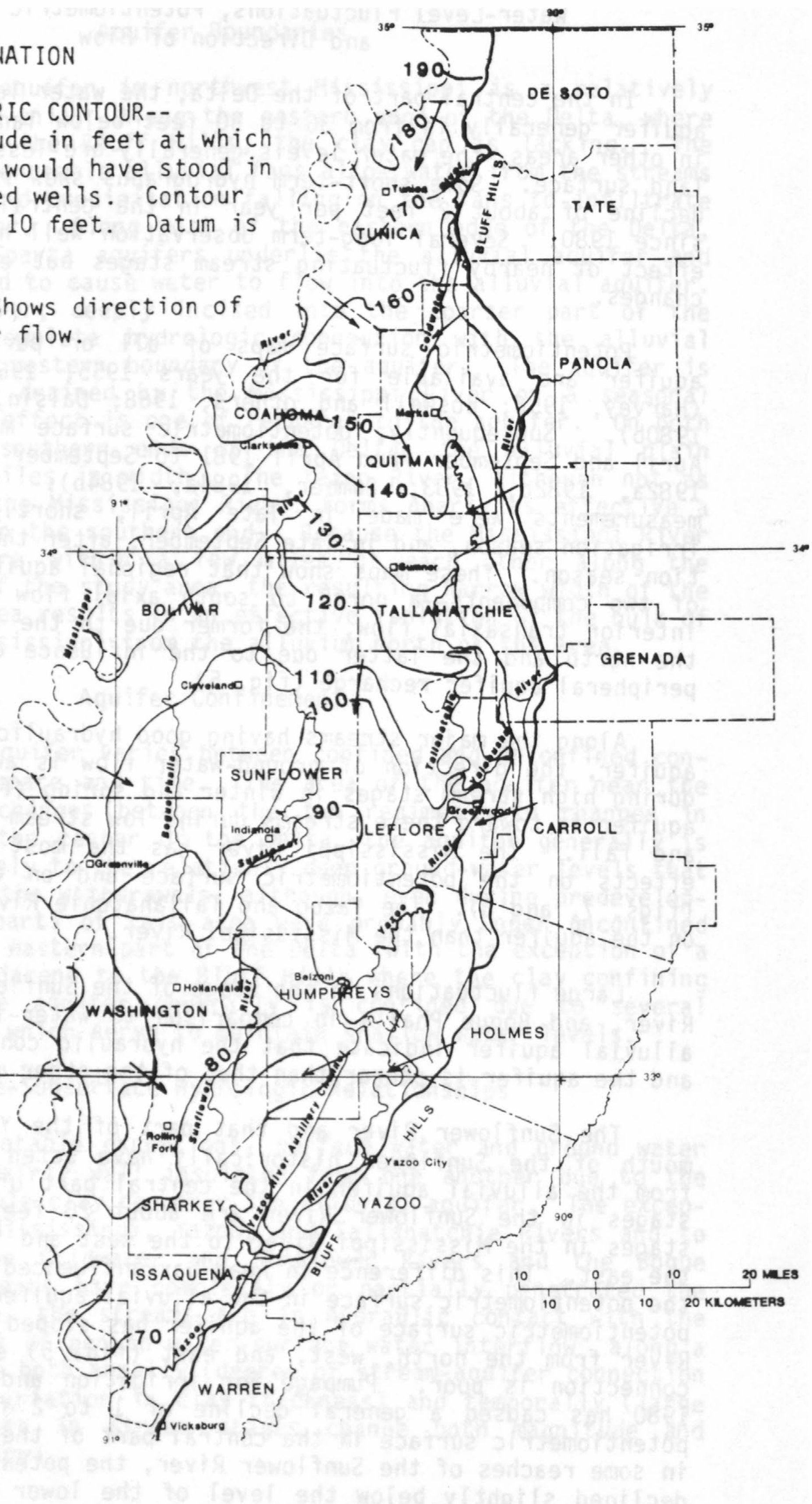



Figure 5.--Potentiometric surface of the alluvial aquifer in the Delta for April 1981.

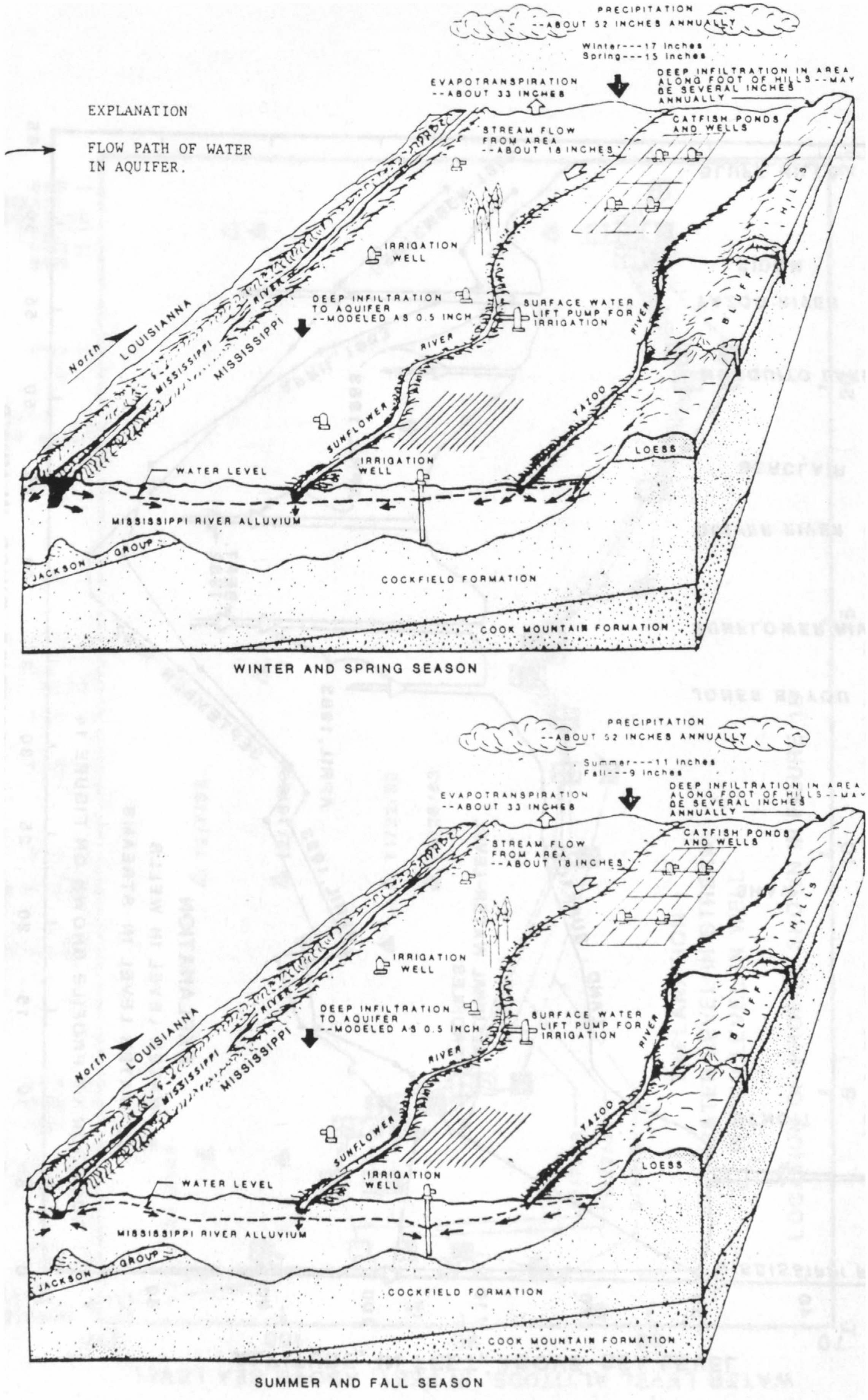



Figure 6.--Schematic diagram of relationships among geologic, hydrologic, and climatic processes in the Delta. (Shows seasonal change in flow.)

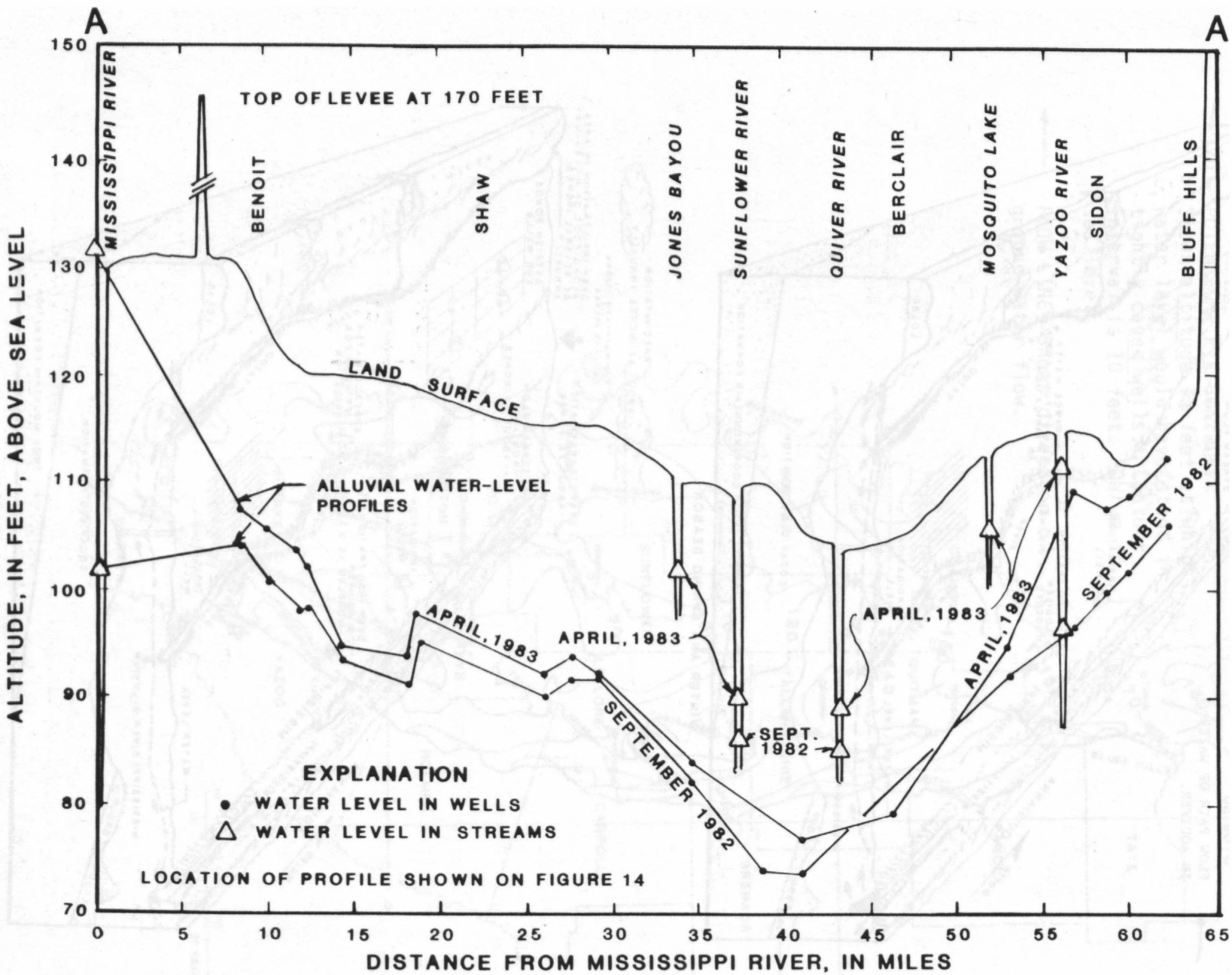



Figure 7.--Water-level profile (A-A') across the Delta, from Benoit in Bolivar County to Sidon in Leflore County.

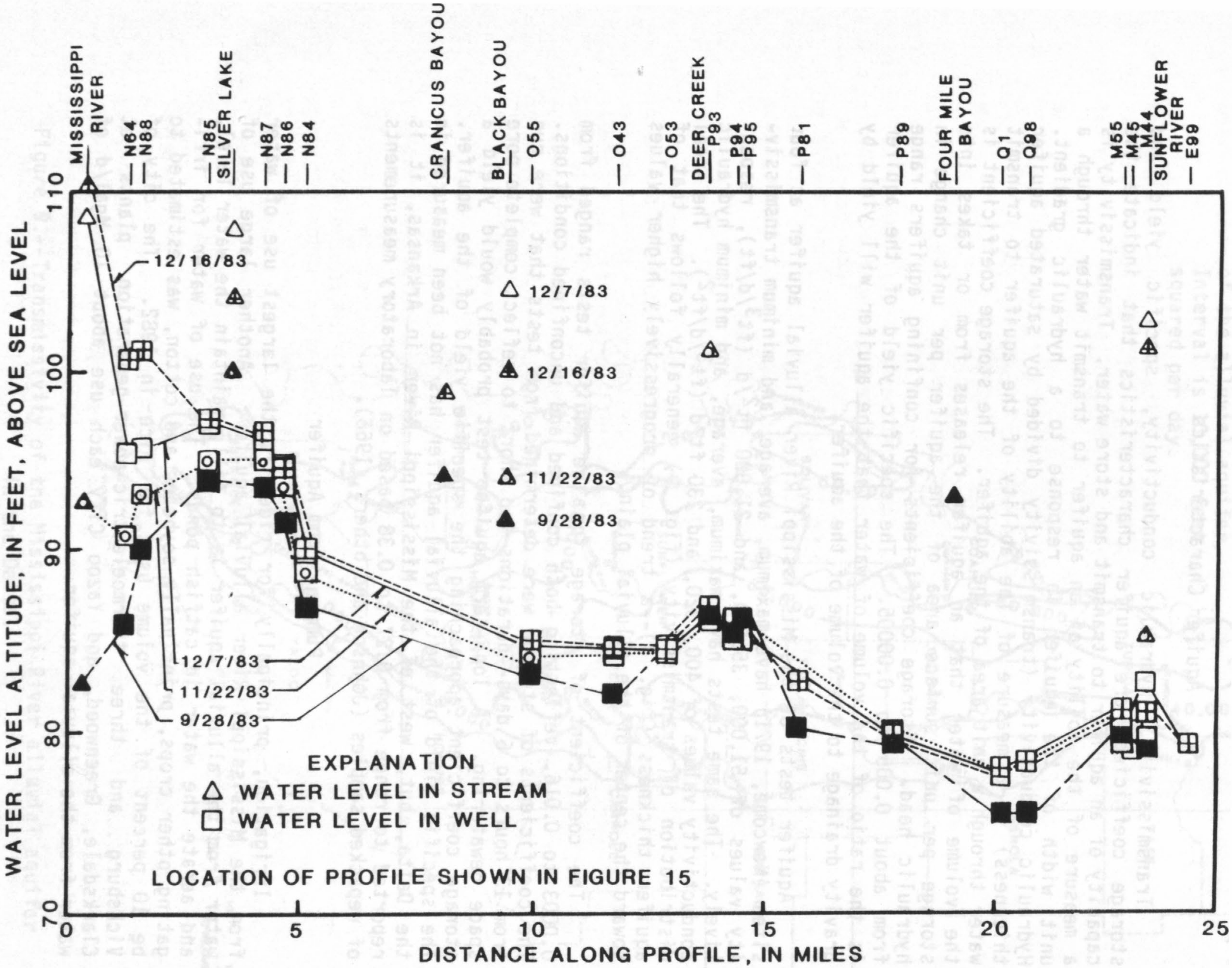



Figure 8.--Water-level profile (B-B') along State Highway 12 through Hollandale showing effect of water-level change in the Mississippi River on the water level in the alluvial aquifer.

Water also enters the alluvial aquifer areally as direct infiltration of precipitation. However, as determined by simulation studies, this infiltration is only a small fraction of the total precipitation.

## Aquifer Characteristics

Transmissivity, hydraulic conductivity, specific yield and storage coefficient are aquifer characteristics that indicate the capacity of an aquifer to transmit and store water. Transmissivity is a measure of the ability of an aquifer to transmit water through a unit width of the aquifer in response to a hydraulic gradient. Hydraulic conductivity (transmissivity divided by saturated aquifer thickness) is a measure of the ability of the aquifer to transmit water through a unit area of the aquifer. The storage coefficient is the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head. Storage coefficients for confining aquifers range from about 0.005 to 0.00005. The specific yield of the aquifer is the ratio of the volume of water that the aquifer will yield by gravity drainage to the volume of the aquifer.

Aquifer tests of the Mississippi River alluvial aquifer at four sites (Newcome, 1971) have maximum, average, and minimum transmissivity values of 51,000, 35,000, and 21,000 $ft^2/d$ ($ft^3/d/ft$), respectively. The same tests have maximum, average, and minimum hydraulic conductivity values of 400, 320, and 230 ft/d ($ft^3/d/ft^2$). The areal distribution of transmissivity (fig. 9) generally follows that of aquifer thickness (fig. 4)--a trend of progressively higher values toward the center of the alluvial plain.

The coefficient of storage for the aquifer tests ranged from 0.0003 to 0.016, reflecting both confined and unconfined conditions. The coefficients of storage were determined from tests that were run from 13 hours to 6 days--durations too short to reflect complete pore space dewatering. A long-term aquifer test probably would yield a storage coefficient approaching the specific yield of the aquifer. The specific yield of the alluvial aquifer has not been measured in the Delta, but, west of the Mississippi River in Arkansas, it is reported to range from 0.27 to 0.38 based on laboratory measurements of repacked samples (Johnson and others, 1966).

## Pumpage from Aquifer

Irrigation, principally for rice, is the largest use of water from the Mississippi River alluvial aquifer. Another large use of water from the alluvial aquifer is to fill, maintain the water level, and aerate the water in catfish ponds. The use of water for irrigating other crops, principally soybeans and cotton, was estimated to be 10 percent of the volume used for rice in 1982. The city of Vicksburg and three thermoelectric-power-generation plants at Clarksdale, Greenwood, and Yazoo City each use about 10 Mgal/d of water from the alluvial aquifer.

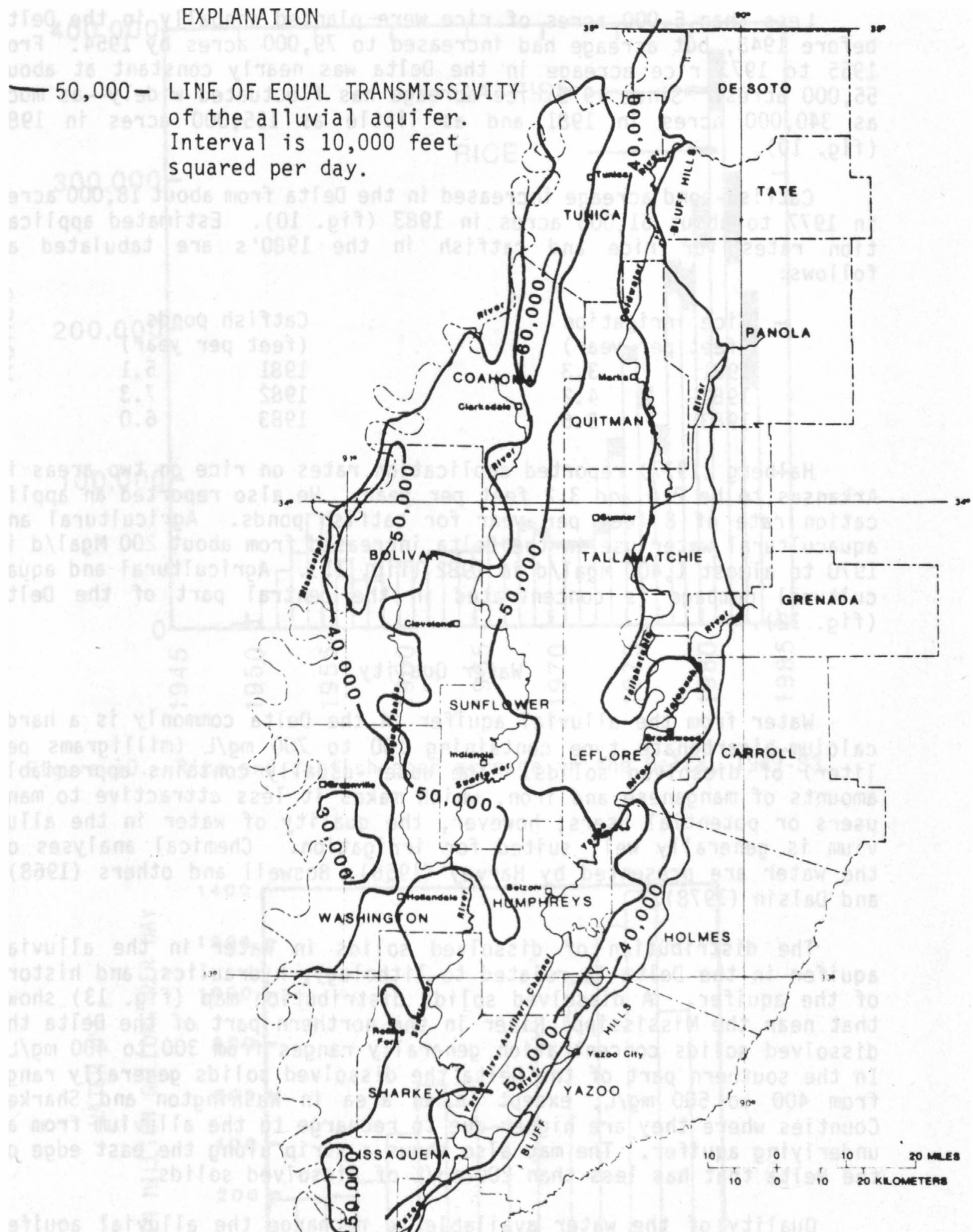



Figure 9.--Transmissivity of the Mississippi River alluvial aquifer in the Delta.

Less than 5,000 acres of rice were planted annually in the Delta before 1948, but acreage had increased to 79,000 acres by 1954. From 1955 to 1973 rice acreage in the Delta was nearly constant at about 55,000 acres. Since 1973 rice acreage has fluctuated widely--as much as 340,000 acres in 1981 and as little as 155,000 acres in 1983 (fig. 10).

Catfish-pond acreage increased in the Delta from about 18,000 acres in 1977 to about 61,000 acres in 1983 (fig. 10). Estimated application rates for rice and catfish in the 1980's are tabulated as follows:

| Rice irrigation (feet per year) | | Catfish ponds (feet per year) | |
|---|---|---|---|
| 1981 | 3.3 | 1981 | 5.1 |
| 1982 | 4.2 | 1982 | 7.3 |
| 1983 | 3.6 | 1983 | 6.0 |

Halberg (1977) reported application rates on rice on two areas in Arkansas to be 2.6 and 3.2 feet per year. He also reported an application rate of 8 feet per year for catfish ponds. Agricultural and aquacultural water use in the Delta increased from about 200 Mgal/d in 1970 to almost 1,400 Mgal/d in 1982 (fig. 11). Agricultural and aquacultural pumpage is concentrated in the central part of the Delta (fig. 12).

## Water Quality

Water from the alluvial aquifer in the Delta commonly is a hard, calcium-bicarbonate type containing 100 to 700 mg/L (milligrams per liter) of dissolved solids. The water usually contains appreciable amounts of manganese and iron, which makes it less attractive to many users or potential users; however, the quality of water in the alluvium is generally well suited for irrigation. Chemical analyses of the water are presented by Harvey (1956), Boswell and others (1968), and Dalsin (1978).

The distribution of dissolved solids in water in the alluvial aquifer in the Delta is related to lithology, hydraulics, and history of the aquifer. A dissolved solids distribution map (fig. 13) shows that near the Mississippi River in the northern part of the Delta the dissolved solids concentration generally ranges from 300 to 400 mg/L. In the southern part of the Delta the dissolved solids generally range from 400 to 500 mg/L, except in an area in Washington and Sharkey Counties where they are higher due to recharge to the alluvium from an underlying aquifer. The map also shows a strip along the east edge of the Delta that has less than 200 mg/L of dissolved solids.

Quality of the water available to recharge the alluvial aquifer varies with space and time. Dissolved solids concentrations in the Mississippi River commonly ranged from 170 to 270 mg/L between 1973 and 1981. Water in streams along the eastern edge of the Delta commonly contains between 25 and 125 mg/L of dissolved solids. Precipitation in the Delta commonly contains less than 10 mg/L dissolved solids. But as the water percolates to and through the

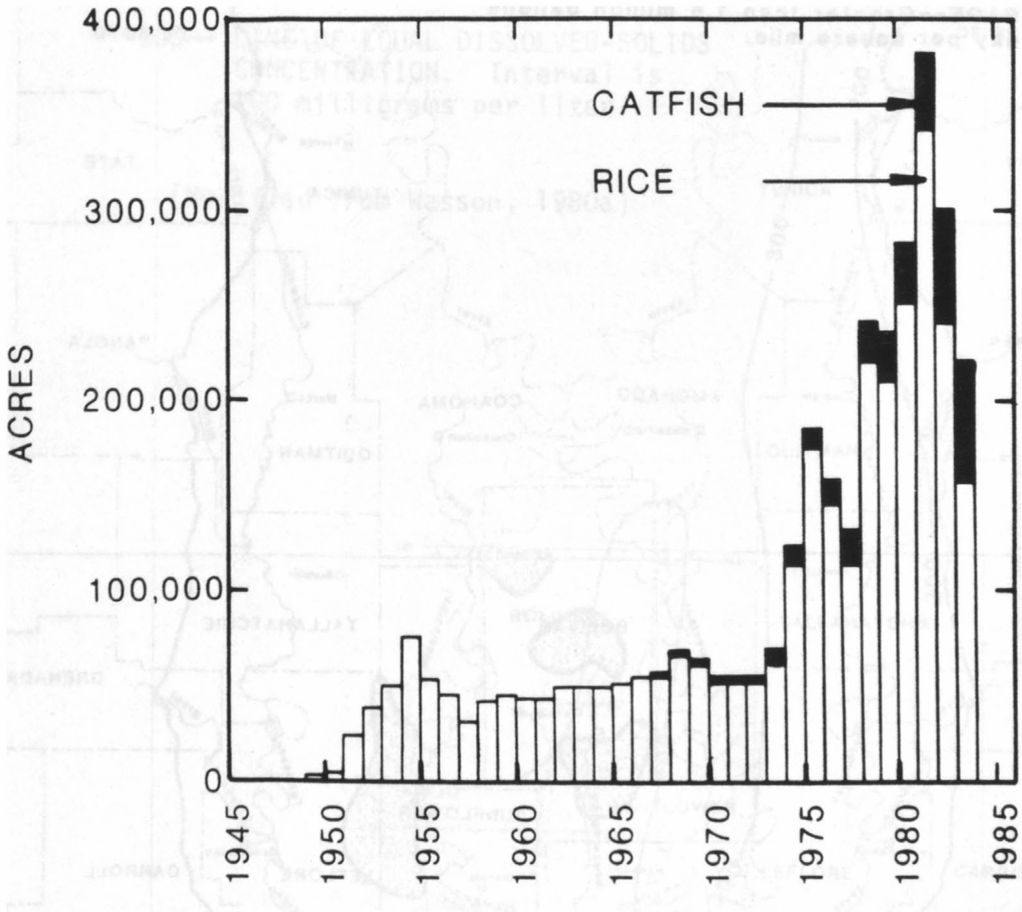



Figure 10.--Rice and catfish-pond acreage in the Delta, 1949-83.

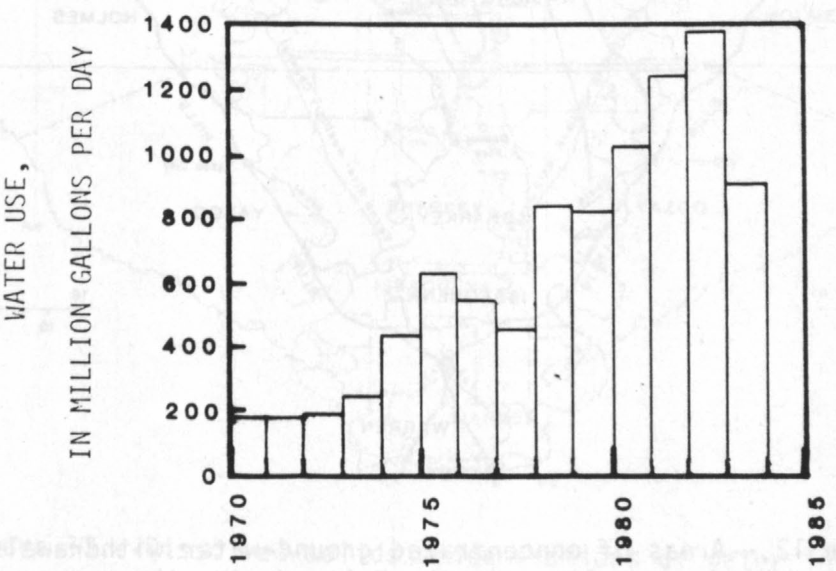



Figure 11.--Agricultural and aquacultural water use in the Delta 1970-83.

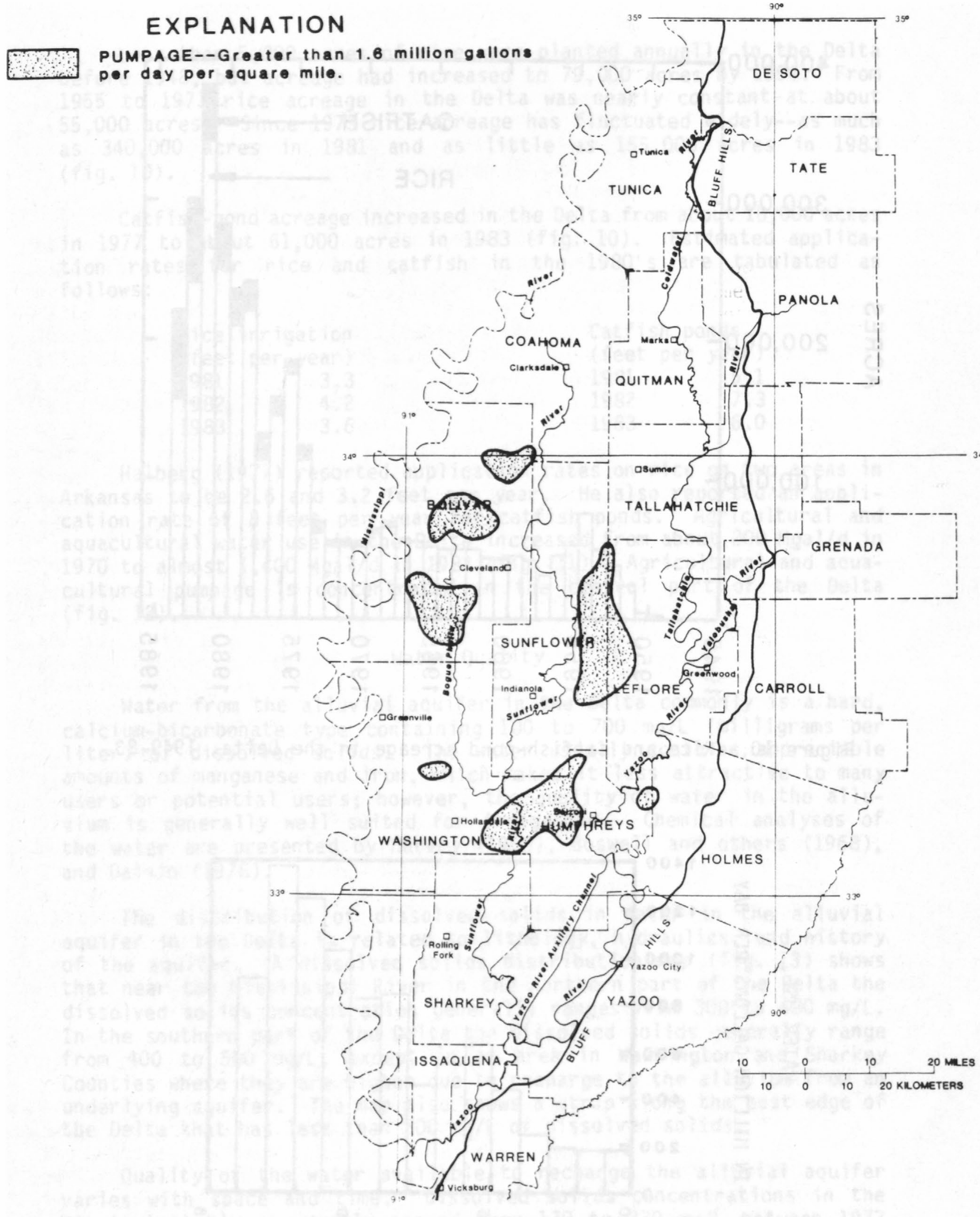



Figure 12.--Areas of concentrated ground-water withdrawals for agriculture and aquaculture in the Delta during the summer of 1982.

EXPLANATION

—300— LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION. Interval is 100 milligrams per liter.

(Modified from Wasson, 1980a)

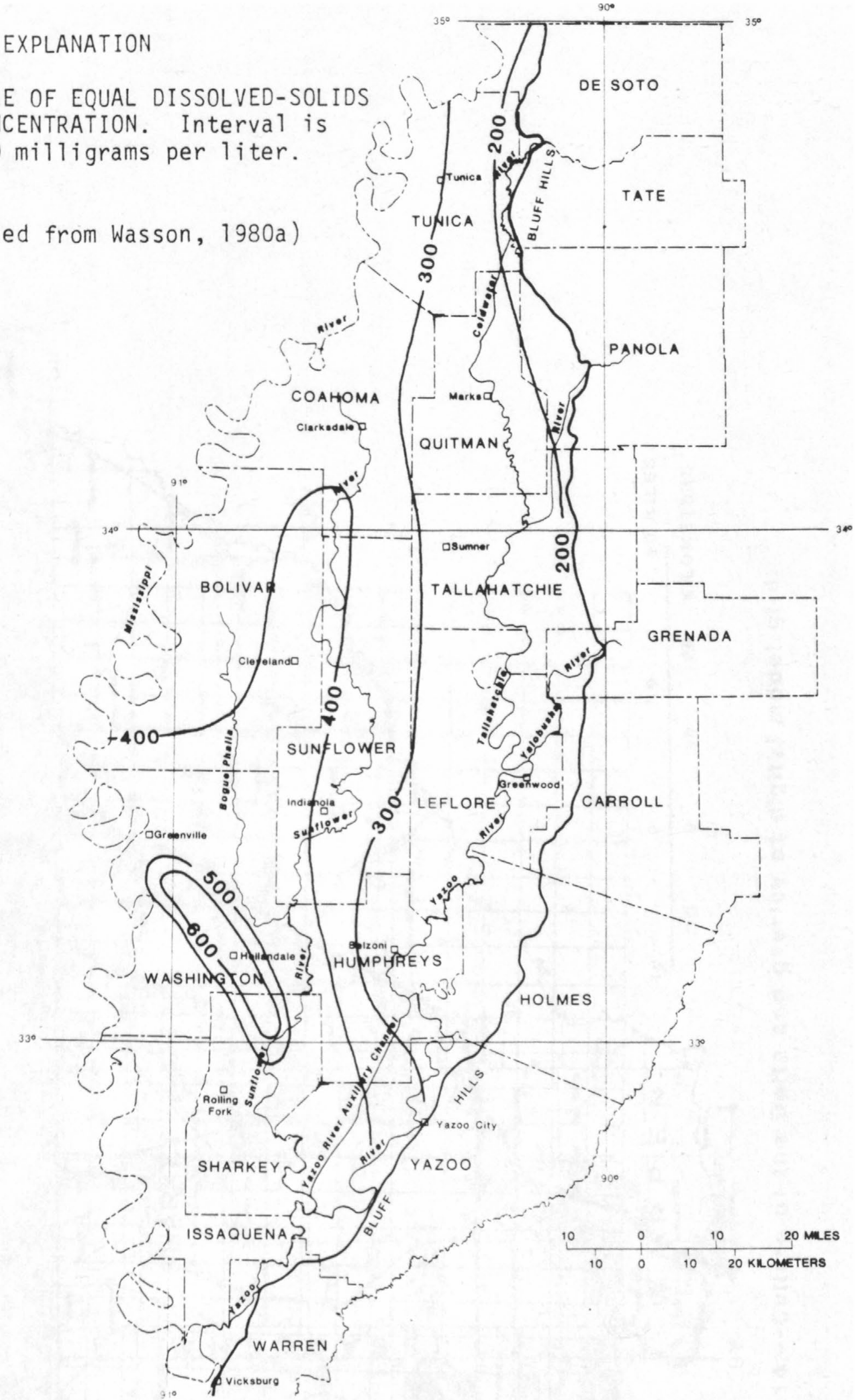



Figure 13.--Dissolved-solids concentrations of water in the alluvial aquifer in the Delta.

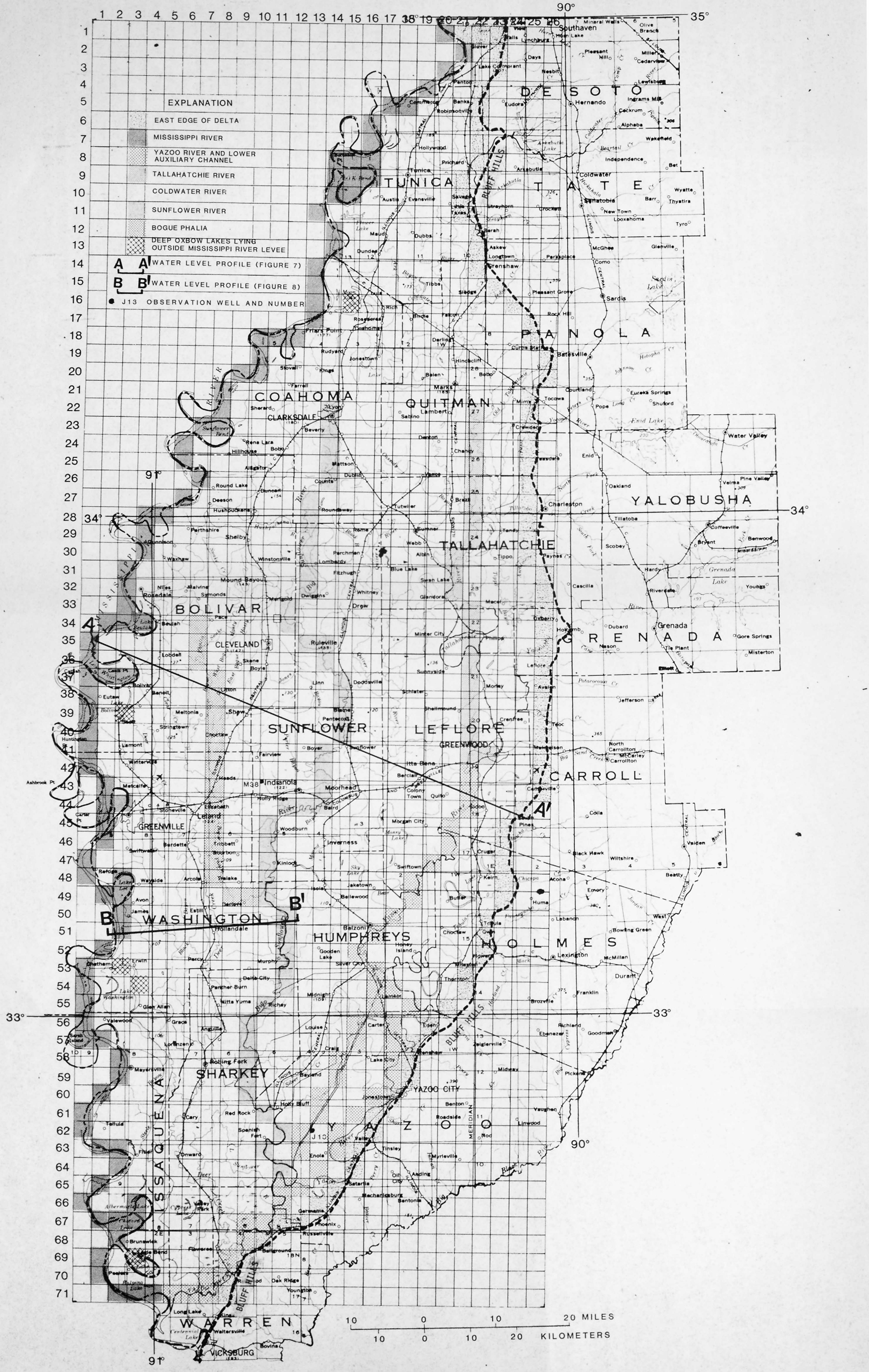



Figure 14.--Culture of the Delta and overlay of digital model grid.

aquifer the dissolved solids concentration increases, depending on the soil and rock through which it moves. Water in aquifers immediately underlying the alluvial aquifer commonly has a lower dissolved solids concentration than that in the alluvial aquifer, except in a part of Washington and Sharkey Counties where the Cockfield aquifer may contain water with more than 1,000 mg/L dissolved solids. The levees along the Mississippi River now prevent annual flooding of the Delta by water from the river and may contribute to a long-term change in water quality in the alluvial aquifer.

## COMPUTER MODEL CONSTRUCTION AND CALIBRATION

A finite-difference digital model (McDonald and Harbaugh, 1984) was selected to simulate ground-water flow in the alluvial aquifer in northwestern Mississippi. The steps in the evolution and application of the model are outlined below:

1) Development of conceptual model of aquifer system (discussed in previous part of report).
2) Finite-difference discretization of conceptual model of aquifer system.
3) Calibration of digital model.
4) Sensitivity analysis.
5) Model verification.
6) Application of model for predictive purposes.

### Model Construction

Finite-difference models require input and produce output in descretized form, both spatially and temporally. Thus, an initial step in the transition from the conceptual model to the finite-difference model involves determining the form of spatial discretization; that is, a grid system. Figure 14 illustrates the grid system used in this study. Nodes (points of spatial resolution) are squares having sides of 4 kilometers (2-1/2 miles). The grid is composed of 1,846 nodes in an array of 71 rows by 26 columns. Only those nodes within the alluvial aquifer of northwestern Mississippi (1,211 nodes) were used within the model.

Ground-water flow is described by a second-order partial-differential equation which requires specification of either head or flux along the aquifer boundaries. The boundaries of the alluvial aquifer are quite distinct. The Mississippi River is in nearly complete hydraulic connection with the aquifer, producing an aquifer head along the western boundary of the aquifer that is virtually equal to the river stage and specified as such in the aquifer model. The location of the eastern boundary was chosen to coincide with the western edge of the Bluff Hills. In this area, the hydrologic environment is rather complex. The absence of the clay confining cap here allows for much greater rainfall recharge than elsewhere, allows for recharge from a multitude of streams, and makes evapotranspiration an important factor in the hydrologic budget. Also, leakage from the underlying Tertiary aquifers is important near the Bluff Hills. To the west of the Bluff Hills, water levels in aquifers of Tertiary age have declined to near those in the alluvium, and inter-aquifer leakage is not important to the water budget. Rather than attempt to simulate this complex system, aquifer heads along the Bluff Hills were specified in the flow model based upon observed head values. A linear change in head between observations was assumed.

Similarly, the relatively short north and south boundaries of the aquifer were simulated by specified head boundaries. All specified head boundaries were simulated by means of head dependent flux nodes in which the hydraulic conductance was set sufficiently high ($10^9$ $ft^2/d$) such that a negligible difference existed between the specified head (Mississippi River stages along the western boundary and observed heads along the other boundaries) and the aquifer head along these boundaries.

In modeling the alluvial aquifer, the assumption was made that the deposits consist of two distinct layers--a lower highly permeable aquifer consisting of gravel and sand and an overlying nearly impermeable confining layer of clay. The altitude of the aquifer base was discretized from contour maps of the top of the Tertiary age rocks (Smith, 1979). Assuming that the surficial clay layer is 20 feet thick, the elevation of the discretized aquifer top was generated from the discretized land surface elevation described by 5-foot interval topographic maps. A provision is made in the McDonald-Harbaugh model for conversion from water-table to confined conditions, or vice versa, based on the relation of the potentiometric head to the base of the confining layer. Under water-table conditions, the model recomputes transmissivity values as changes occur in saturated aquifer thickness.

## Model Calibration

The aquifer responds to stress (pumpage, river leakage, rainfall recharge, and others) to produce a response in the form of a particular distribution of head and discharge values; therefore, if the aquifer system can be defined, the aquifer response to any stress can be determined. Some of the parameters that define the aquifer system, as well as some of the aquifer stresses, are unknown or poorly known. The aquifer model was used to determine these unknowns by means of model calibration.

Model calibration can be accomplished with either steady-state or transient simulations. In steady-state calibration, observed heads at equilibrium (usually predevelopment) conditions are used as the known aquifer response. Steady-state calibration of the alluvial model was not considered acceptable for three reasons:

1) Even in predevelopment time, water levels in many parts of the aquifer were highly seasonal, never approaching equilibrium conditions.

2) The seasonal average predevelopment potentiometric surface was not determinable within sufficient accuracy because of the large temporal head variations relative to the spatial head variations upon which steady-state calibration is based (that is, model noise due to measurement error would overshadow model parameter sensitivity).

3) In those areas where equilibrium conditions might have been approximated, neither the head distribution, nor aquifer discharges are known to sufficient accuracy for model calibration.

Calibration of the alluvial aquifer model was based on transient simulations. Transient simulations more realistically model the non-equilibrium conditions now occurring in the alluvial aquifer and allow for simulation of flow conditions for a date for which the potentiometric surface is well defined. The simulation period chosen for calibration was April 1981 to April 1983. This time period was selected because of the availability of water-use and potentiometric-surface data. The basis for model calibration was four potentiometric maps for September 1981, April 1982, September 1982, and April 1983 (figs. 15-18). Initial model heads were provided by an April 1981 potentiometric surface map (fig. 5).

As with space, time was broken into discrete steps. The time-step length chosen for use in model calibration was 30.4 days. A simulation made with 10 times this temporal resolution produced a negligible difference in model-generated heads; therefore, a time step of 30.4 days is sufficient to avoid significant temporal truncation error. The length of each stress period (time periods during which aquifer stresses are simulated as constant) was set equal to the time-step length. Thus, pumpage, rainfall recharge, and river stages were updated every 30.4 days of the calibration simulation period.

## Aquifer Stresses

Pumpage--Agricultural and aquacultural pumpage is the dominant stress on the alluvial aquifer; therefore, a major effort was expended to determine the distribution and magnitude of this pumpage. Rice and catfish farming account for most of the alluvial ground-water withdrawals. The spatial pumpage distribution was determined through the use of Agricultural Stabilization and Conservation Service photographs made of the study area in the summer of 1982. Values of rice (fig. 19) and catfish (fig. 20) were recorded for each model node. The two resulting acreage arrays provided the base for generation of pumpage arrays (fig. 21). In accordance with farming practices of the area, pumpage for rice was uniformly concentrated within the May to August growing season of each simulated year. Three-fourths of catfish pumpage was placed within this same period, the remaining one-fourth being spread evenly from September through the following April. Total rice acreage within the alluvial plain of northwestern Mississippi was 340,000 acres in 1981, 240,000 acres in 1982, and 155,000 acres in 1983. To account for ground-water withdrawals for row crop (cotton, soybeans, and corn) irrigation, rice acreage values were increased by 5 percent in 1981, 10 percent in 1982, and 15 percent in 1983 to produce effective rice acreage values of 360,000, 250,000, and 180,000 acres in 1981, 1982, and 1983, respectively. This scheme was used because row crop irrigation is generally found in areas of rice cultivation, due to the availability of wells in these areas. The percentage increase in actual rice acreage is related to observations of the degree of row crop irrigation during 1981, 1982, and 1983. The 1983 effective rice acreage array was generated by

EXPLANATION

——140— OBSERVED WATER-LEVEL CONTOUR--

— —140— SIMULATED WATER-LEVEL CONTOUR--

altitude at which water-level would stand in tightly cased wells. Contour intervals are 10 feet. Datum is sea level.

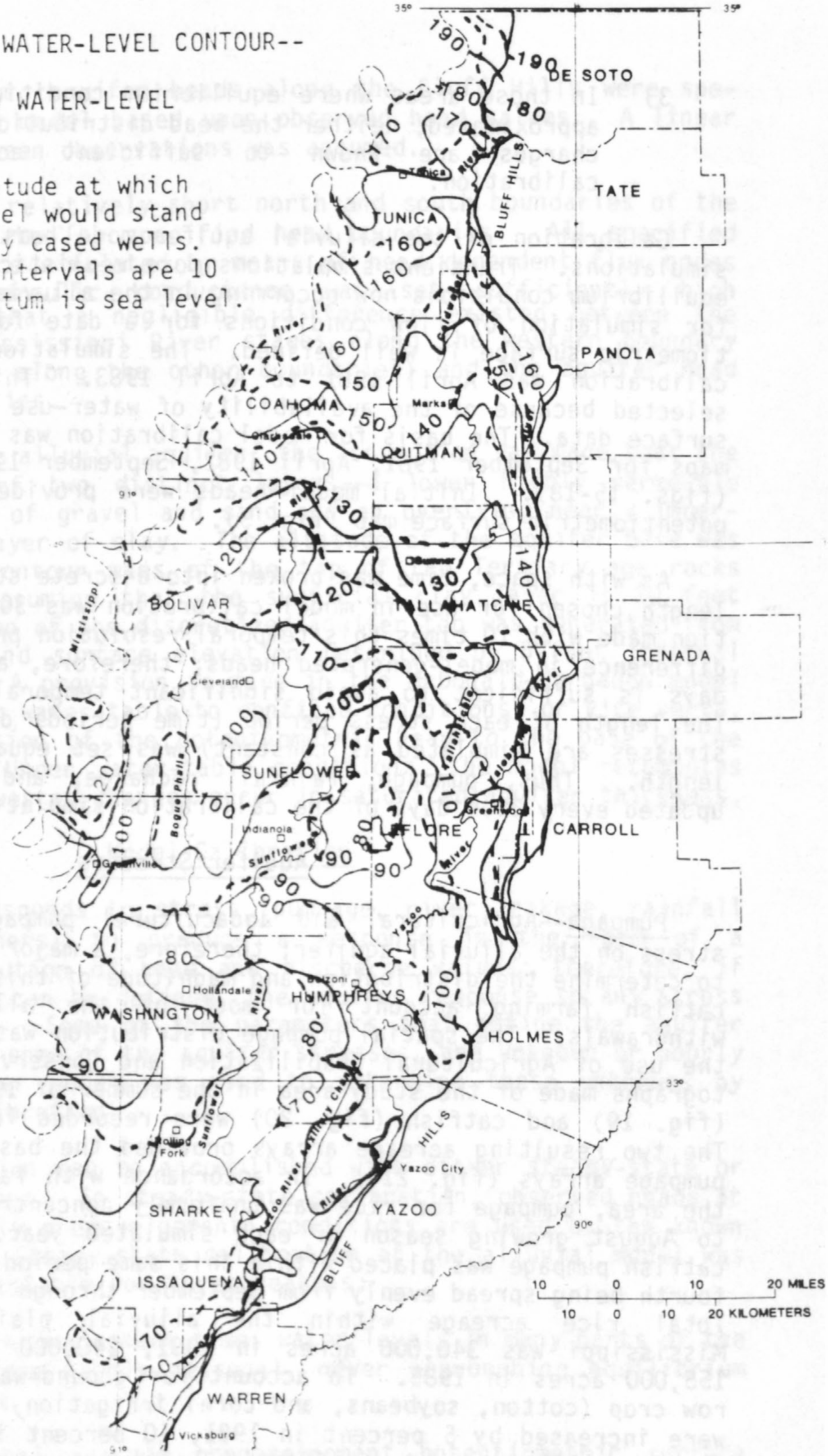



Figure 15.--Observed and model generated potentiometric surfaces of the alluvial aquifer in the Delta for September 1981.

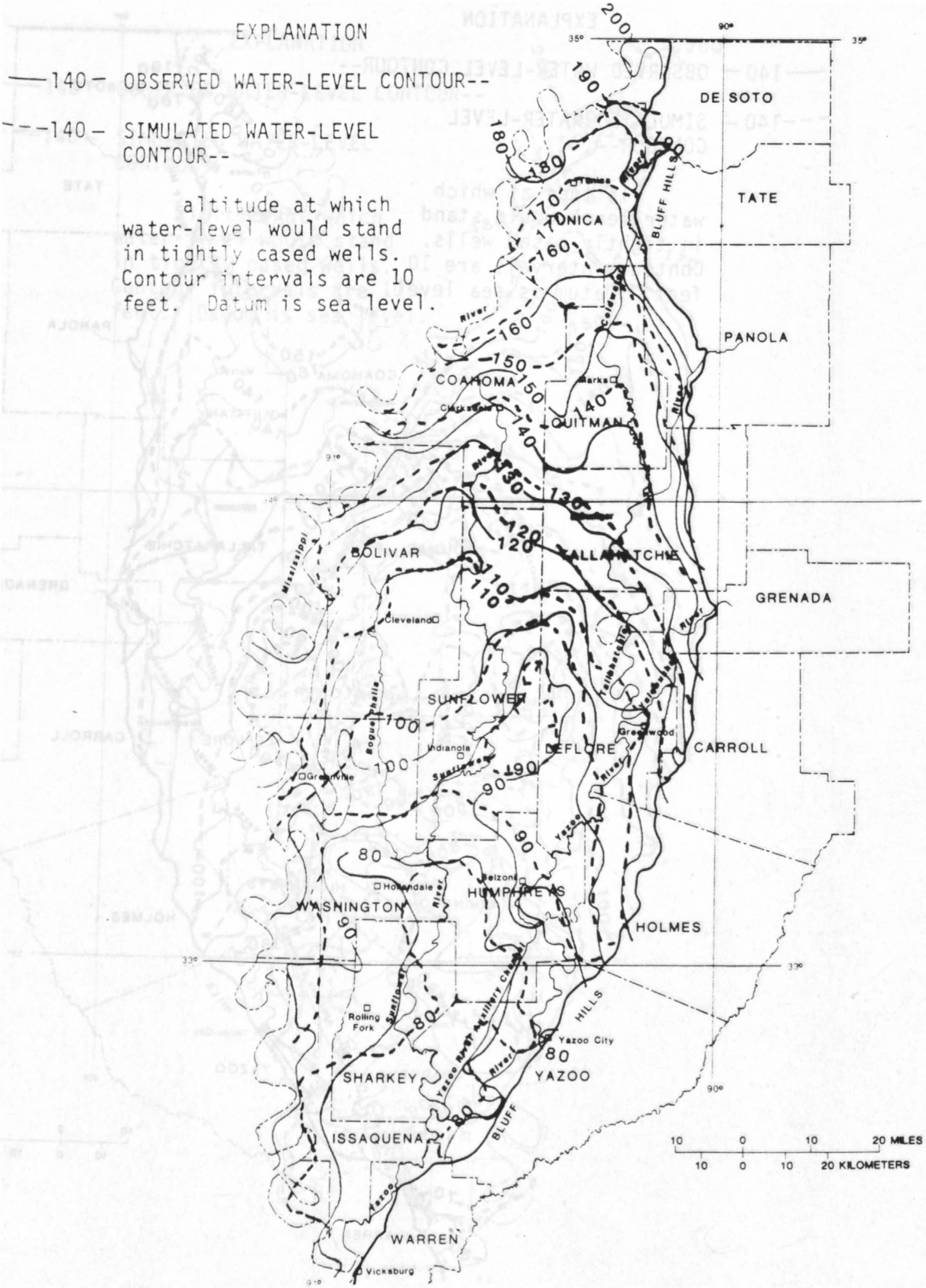



Figure 16.--Observed and model generated potentiometric surfaces of the alluvial aquifer in the Delta for April 1982.

EXPLANATION

—140— OBSERVED WATER-LEVEL CONTOUR--

- - -140 - SIMULATED WATER-LEVEL CONTOUR--

altitude at which water-level would stand in tightly cased wells. Contour intervals are 10 feet. Datum is sea level.

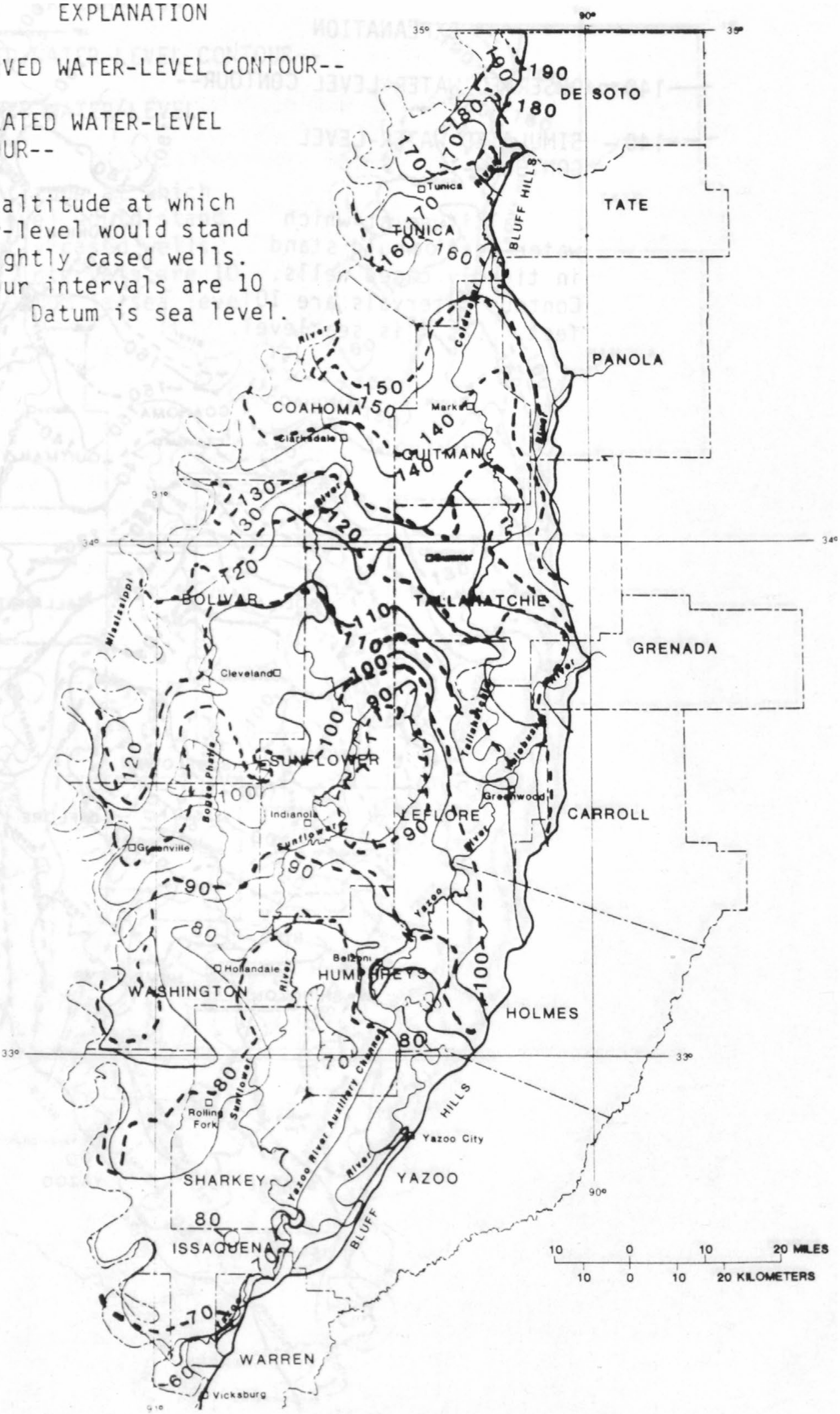



Figure 17.--Observed and model generated potentiometric surfaces of the alluvial aquifer in the Delta for September 1982.

EXPLANATION

——140— OBSERVED WATER-LEVEL CONTOUR--

- - -140— SIMULATED WATER-LEVEL CONTOUR--

altitude at which water-level would stand in tightly cased wells. Contour intervals are 10 feet. Datum is sea level.

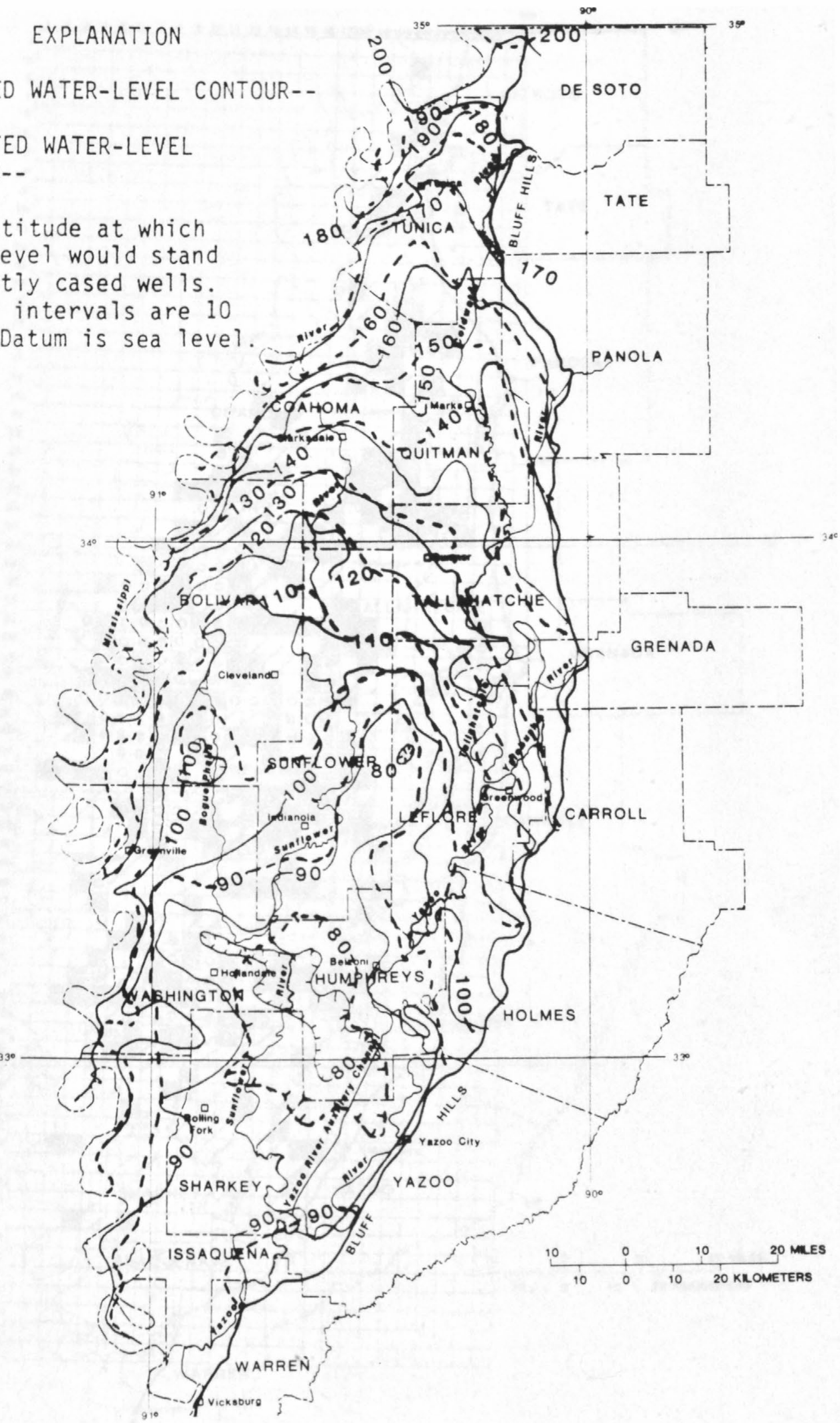



Figure 18.--Observed and model-generated potentiometric surfaces of the alluvial aquifer in the Delta for April 1983.

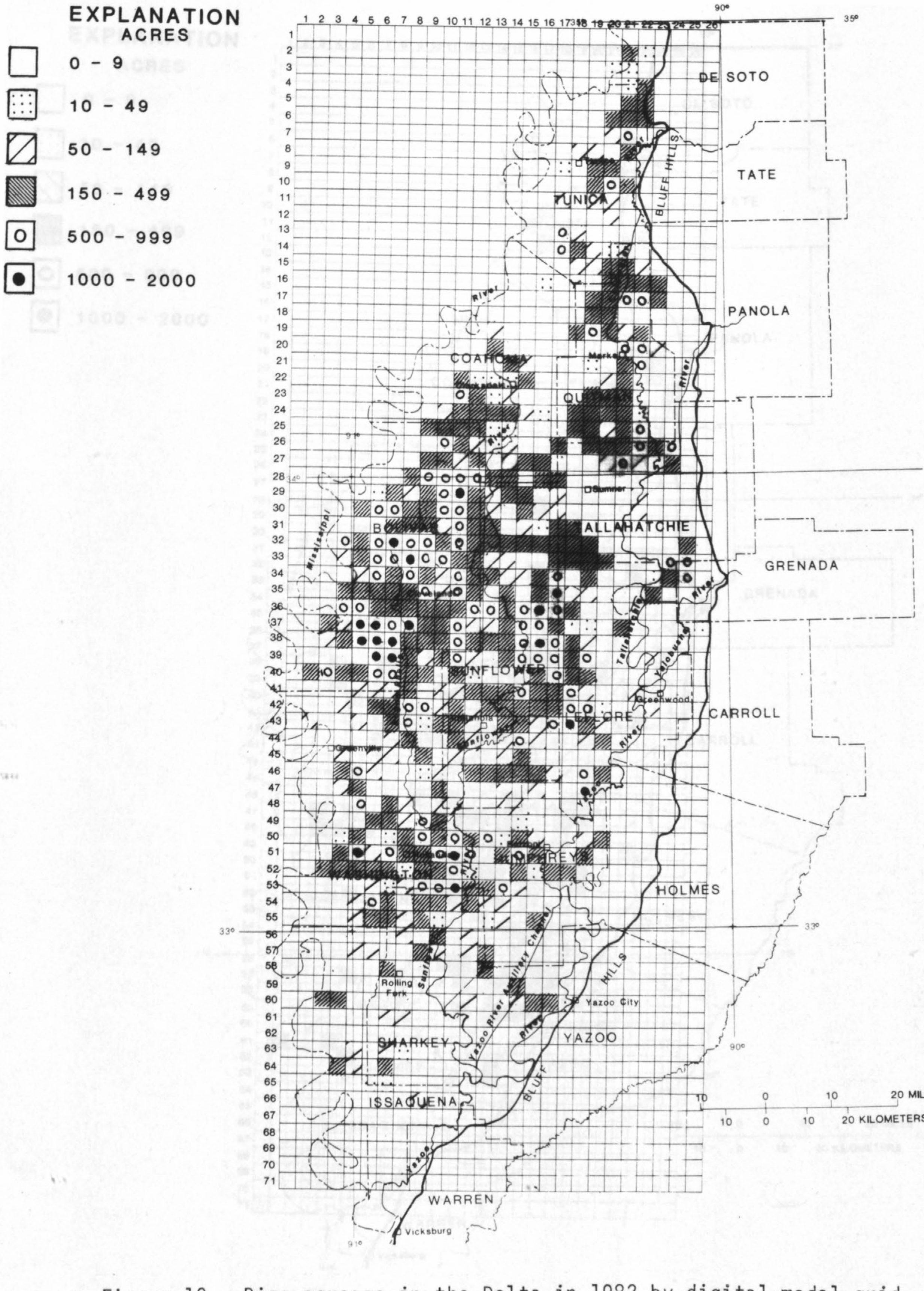



Figure 19.--Rice acreage in the Delta in 1982 by digital-model grid.

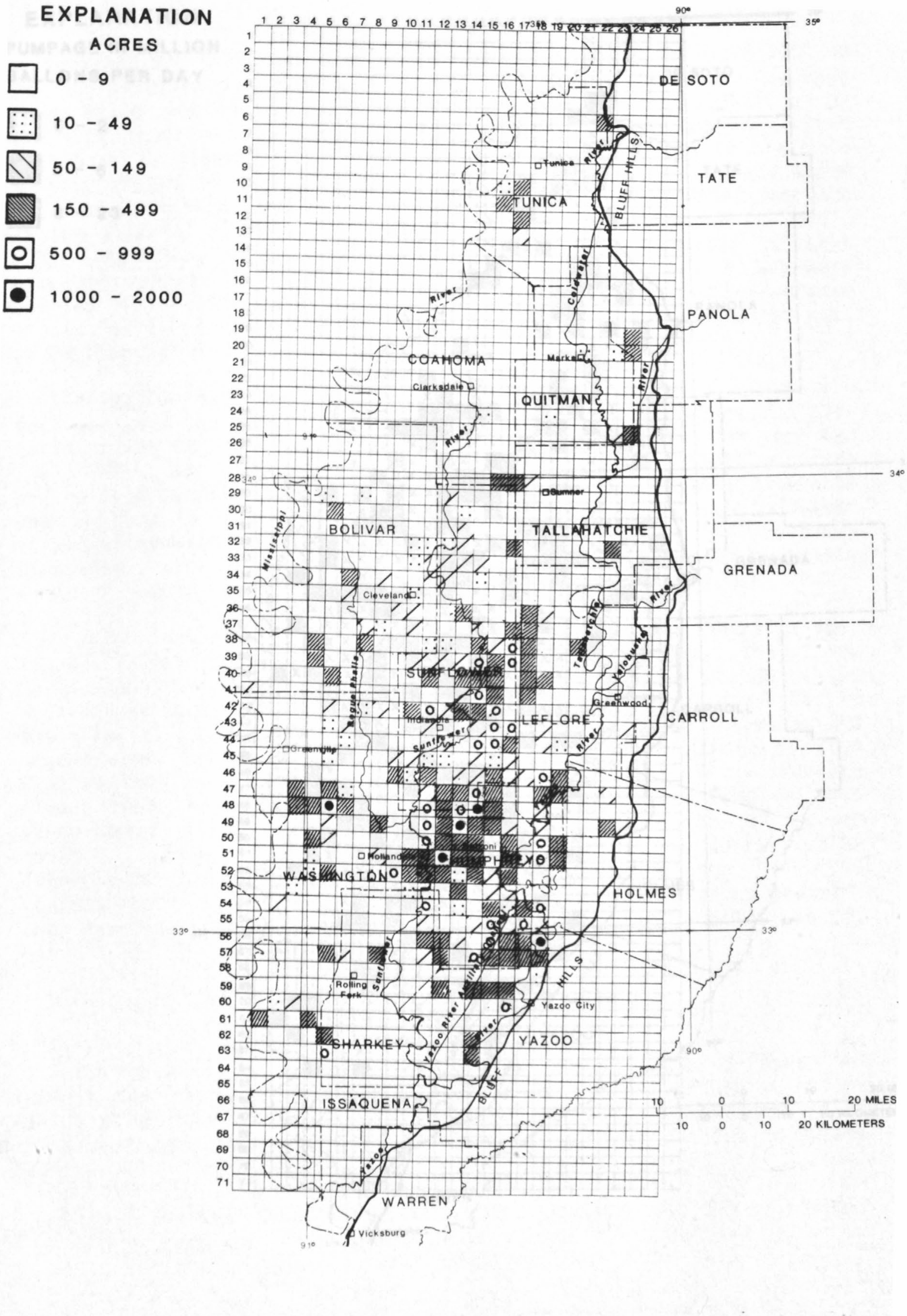



Figure 20.--Catfish-pond acreage in the Delta in 1982 by digital-model grid.

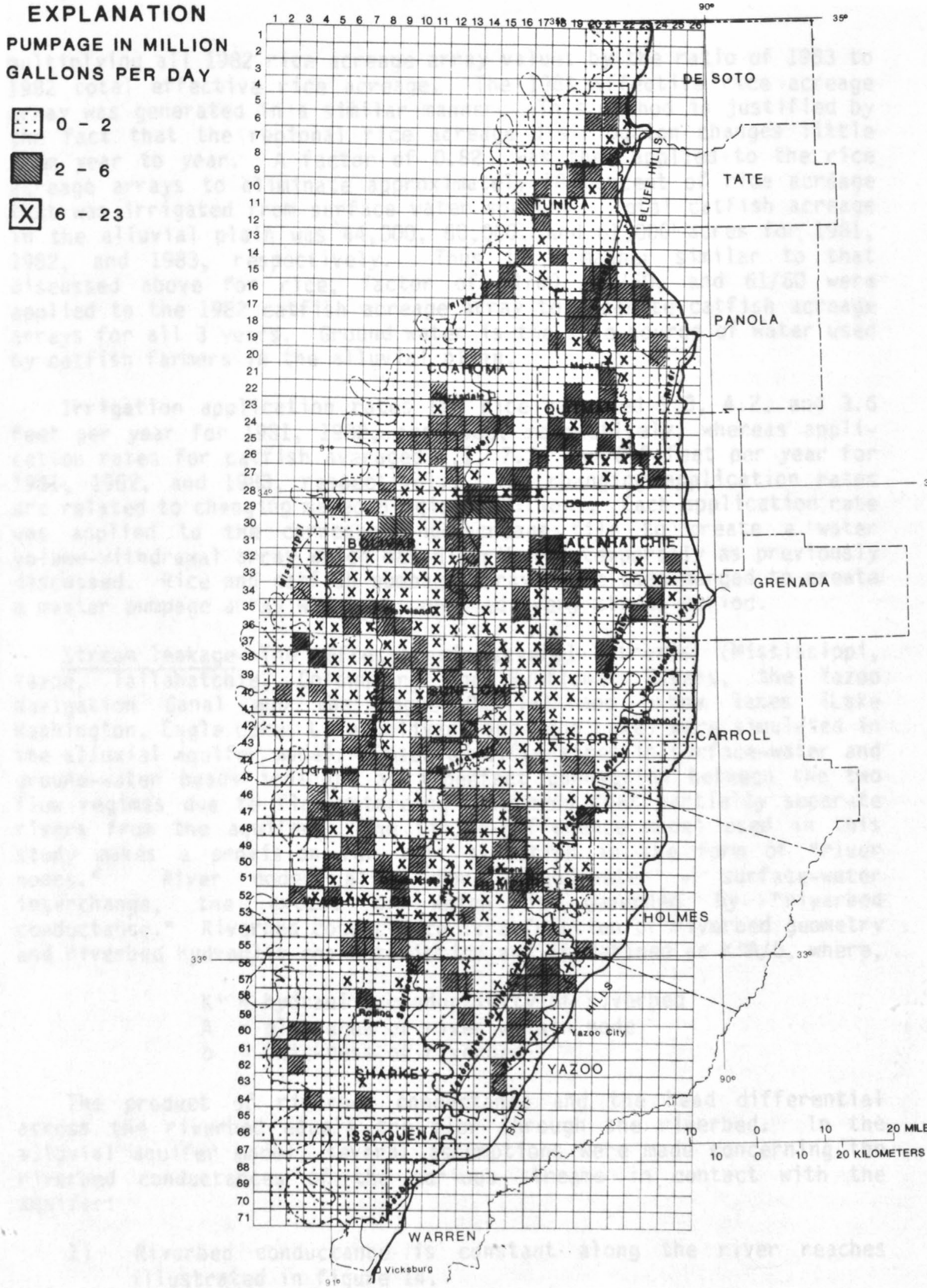



Figure 21.--Rate of pumpage in the Delta, by model grid, during summer months of 1982.

multiplying all 1982 rice acreage array values by the ratio of 1983 to 1982 total effective rice acreage. The 1981 effective rice acreage array was generated in a similar manner. This method is justified by the fact that the regional rice acreage distribution changes little from year to year. A factor of 0.82 was then applied to the rice acreage arrays to eliminate approximately 18 percent of rice acreage that was irrigated from surface water sources. Total catfish acreage in the alluvial plain was 44,000, 60,000, and 61,000 acres for 1981, 1982, and 1983, respectively. Thus in a manner similar to that discussed above for rice, factor of 44/60, 60/60, and 61/60 were applied to the 1982 catfish acreage array to generate catfish acreage arrays for all 3 years. Ground water is the sole source of water used by catfish farmers in the alluvial plain.

Irrigation application rates for rice averaged 3.3, 4.2, and 3.6 feet per year for 1981, 1982, and 1983, respectively, whereas application rates for catfish averaged 5.1, 7.3, and 6.0 feet per year for 1981, 1982, and 1983, respectively. The changing application rates are related to changing meteorologic conditions. Each application rate was applied to the corresponding acreage file to create a water volume-withdrawal array which was distributed temporally as previously discussed. Rice and catfish pumpage arrays were then merged to create a master pumpage array which was updated every stress period.

Stream leakage--The effects of several streams (Mississippi, Yazoo, Tallahatchie, Coldwater, and Sunflower Rivers, the Yazoo Navigation Canal and the Bogue Phalia) and oxbow lakes (Lake Washington, Eagle Lake, Lake Bolivar, and Moon Lake) were simulated in the alluvial aquifer model. Observed differences in surface-water and ground-water heads indicate an imperfect connection between the two flow regimes due to flow-retarding riverbeds that partially separate rivers from the aquifer. The finite-difference model used in this study makes a provision for this situation in the form of "river nodes." River nodes allow for ground-water - surface-water interchange, the extent of which is governed by "riverbed conductance." Riverbed conductance is a function of riverbed geometry and riverbed hydraulic characteristics and is defined as K'A/b, where,

K' = hydraulic conductivity of riverbed
A = plan area of river within node
b = thickness of riverbed

The product of riverbed conductance and the head differential across the riverbed equals the flow through the riverbed. In the alluvial aquifer model, several assumptions were made concerning the riverbed conductances of the various streams in contact with the aquifer:

1) Riverbed conductance is constant along the river reaches illustrated in figure 14.

2) A 1:2:3 relationship was assumed for the riverbed conductances of the upper, middle, and lower reaches, respectively of the Yazoo-Tallahatchie-Coldwater River system. This relationship is based upon a continual increase in river width and depth from upstream to downstream. The riverbed conductance of the Yazoo Navigation Canal was assumed to be equal to that of the lower reach of the Yazoo-Tallahatchie-Coldwater River system.

3) A 3:10 relationship was assumed for the riverbed conductances of the Bogue Phalia and Sunflower River, respectively.

4) The Mississippi River riverbed conductance and the "lakebed" conductance of several oxbow lakes were assumed to be very high ($10^9$ $ft^2/d$) to reflect the negligible difference in river/lake and aquifer head.

Rainfall recharge--Rainfall on the alluvial plain of northwestern Mississippi averages 52 inches per year. Only a small amount of this precipitation enters the alluvial aquifer because of the relatively impermeable surficial clay. Most of the rainfall goes into surface runoff and evapotranspiration. Unlike pumpage, for which magnitude and distribution are known approximately during the calibration period, rainfall recharge was an unknown factor to be determined through model calibration. In the calibration period simulations, rainfall recharge was assumed to be areally uniform and to be concentrated uniformly within the heavy rainfall months of December-April.

Underlying aquifers--The effects on the alluvial aquifer of the underlying Tertiary aquifers were assumed to be negligible for the following reasons:

- The Zilpha Clay, Yazoo Clay, and Cook Mountain Formation are effective barriers to interflow in areas other than the Sparta and Cockfield subcrop areas (fig. 2). In the subcrop areas the differences between alluvial and Tertiary aquifer predevelopment heads probably were less than 10 feet. With distance from the subcrop areas of the Tertiary aquifers the head differences generally increased and were greater than 50 feet in places in and near the Delta.

- The transmissivity values of the Tertiary aquifers are almost an order of magnitude less than those found in the alluvial aquifer.

- In 1980 there was not a significant head difference (generally less than 10 feet) between the alluvial and the shallow Tertiary aquifers in the subcrop areas. Thus, inter-aquifer flow is currently negligible.

- Continued heavy irrigation pumpage could significantly lower water levels in the alluvial aquifer and indirectly in the Tertiary aquifers; however, the alluvial aquifer is becoming largely unconfined, whereas the Tertiary aquifers are confined. The volume of water released from the confined Tertiary aquifers will be insignificant compared with release from storage by dewatering pore space within the alluvial aquifer.

- To further investigate the possible influence of the subcropping confined aquifers on the alluvial aquifer, a two-layer model was constructed. Actually, another layer representing the Sparta and Cockfield aquifers was added to the calibrated, 24-month, two-dimensional model (to be described later) of the alluvial aquifer. In the second layer of the three-dimensional model the Sparta aquifer was assigned a uniform transmissivity of 7,000 $ft^2/d$ in the area where it underlies the alluvial aquifer and a transmissivity of 5,000 $ft^2/d$ in an area where the Sparta aquifer is overlain by the Cook Mountain Formation. West of the 5,000 $ft^2/d$ transmissivity area of the Sparta, a line of nodes was assigned zero horizontal transmissivity to separate the Sparta aquifer from the Cockfield aquifer. The Cockfield aquifer was assigned a transmissivity of 6,000 $ft^2/d$ in its subcrop area and a value of 5,000 $ft^2/d$ in the area where it is overlain by the Jackson Group. Layer two consisted of active nodes surrounded by no-flow nodes. Initial heads in layer two were set equal to those in layer one. A storage coefficient of 0.0001 was assigned to layer two. No pumpage was assigned to layer two although pumpage is actually about 20 Mgal/d from the Sparta and Cockfield aquifers in the Delta, an insignificant volume when compared to pumpage estimates for the alluvial aquifer.

  The degree of connection between two aquifers separated by a semi-permeable layer is a function of the thickness and hydraulic conductivity of the semi-permeable layer. Even where the alluvial aquifer is shown directly overlying the Sparta and Cockfield aquifers (figs. 2, 3), driller's logs and electrical logs generally show at least some clay or silt separation of the aquifers. On this basis, it was assumed that at least 1 foot of fine-grained sediment always separates the aquifers. The hydraulic conductivity of the sediments separating the two layers of the model was varied through a wide range in several simulations made using the two-layer model and the resulting potentiometric surface in the alluvial layer was compared to that produced by the one-layer model. In all cases, the difference in the heads and flow terms in the alluvial aquifer produced by the two models was insignificant. The results of this analysis are summarized as follows:

| | | | |
|---|---|---|---|
| Selected values of hydraulic conductivity of sediment separating layer one (alluvium) from layer two (Sparta and Cockfield) in feet per day | $10^{-7}$ | $10^{-5}$ | $10^{-3}$ |
| Maximum difference (feet) between heads in the single layer model and heads in layer one of the two-layer model | | | |
| (a) Among ten most extreme values | -1.6 | -2.3 | -2.3 |
| (b) Other 1,201 nodes | - .4 | - .5 | - .5 |
| Flux up through confining layer (Mgal/d) | 3.1 | 8.2 | 11 |
| Flux down through confining layer (Mgal/d) | 6.2 | 17 | 21 |

Evapotranspiration--The rate of ground-water loss to evapotranspiration is a function of the depth to saturation within the water-bearing strata. As the level of saturation becomes lower, fewer plants are able to access the water and losses decrease. The effects of evapotranspiration were neglected in modeling flow in the alluvial aquifer for two reasons:

1) Water levels in the alluvial aquifer are below the depth of plant root penetration over most of the alluvial plain.

2) In those areas of the alluvial aquifer where the potentiometric surface is above the depth of plant root penetration, the water itself is usually confined near the bottom of the clay cap, well below the root zone, because the clay greatly inhibits vertical water movement.

## Calibration Strategy and Results

The unknowns in the alluvial aquifer system to be determined by means of model calibration included hydraulic conductivity, specific yield, storage coefficient, riverbed conductances (Yazoo-Tallahatchie-Coldwater, Sunflower, and Bogue Phalia), and rate of areal recharge. Calibration was facilitated by identifying areas of the aquifer in which water levels are predominantly sensitive to only a few of the several unknowns. These areas are delineated in figure 22. For the short calibration period being used, the three areas can be considered virtually isolated one from another. Thus, the original calibration problem can be reduced to a number of smaller problems, which have fewer unknowns and are thus easier to calibrate than the original problem.

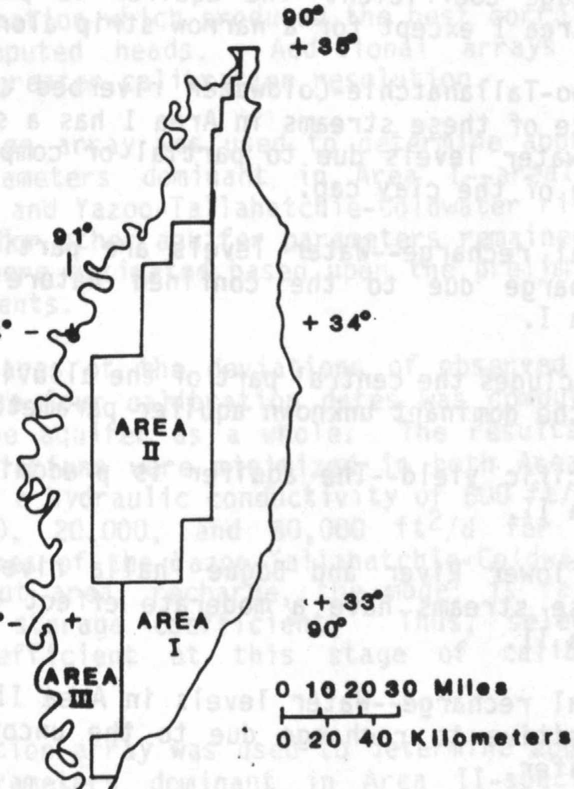



Figure 22.--Delineation of three aquifer areas in the Delta as used for model calibration.

Area I includes the area adjacent to the Yazoo-Tallahatchie-Coldwater River system and the Bluff Hills. The dominant unknown aquifer parameters in this area are assumed to be:

- Hydraulic conductivity--Transport of ground water is important due to the steep hydraulic gradients in Area I.
- Storage coefficient--The aquifer is predominantly confined in Area I except for a narrow strip along the Bluff Hills.
- Yazoo-Tallahatchie-Coldwater riverbed conductance--The presence of these streams in Area I has a significant influence on water levels due to partial or complete stream penetration of the clay cap.
- Areal recharge--Water levels are particularly sensitive to recharge due to the confined nature of the aquifer in Area I.

Area II includes the central part of the alluvial plain. Here, it is assumed that the dominant unknown aquifer parameters are:

- Specific yield--The aquifer is predominantly unconfined in Area II.
- Sunflower River and Bogue Phalia riverbed conductances -- These streams have a moderate effect upon water levels in Area II.
- Areal recharge--Water levels in Area II are only moderately sensitive to recharge due to the unconfined nature of the aquifer.

  (Hydraulic conductivity is only of minor importance due to the low hydraulic gradients in Area II.)

Area III includes that part of the aquifer adjacent to the Mississippi River. Here, the dominant unknown aquifer parameters are assumed to be:

- Hydraulic conductivity--Transport of water is important due to the high hydraulic gradients in Area III.
- Specific yield and storage coefficient--The aquifer in Area III has both confined and unconfined zones.
- Areal recharge--Water levels in Area III are moderately sensitive to recharge.

The general calibration chronology proceeded as follows:

Preliminary to the more systematic calibration to follow, about 10 simulations were made in order to arrive at approximations for all model parameters. Further model calibration was accomplished through multi-dimensional arrays of simulations. That is, each unknown aquifer parameter was allowed to take on discrete values within a reasonable range and an array of simulations involving all of the resulting possible parameter combinations was then constructed. The best approximation to the unknown aquifer parameter was then taken to be that parameter combination which produced the best correlation between observed and computed heads. Additional arrays were then constructed to provide greater calibration resolution.

The first calibration array was used to determine approximations for those aquifer parameters dominant in Area I--areal recharge, hydraulic conductivity, and Yazoo-Tallahatchie-Coldwater riverbed conductances. The values for other aquifer parameters remained constant within this array and were estimated based upon the preliminary model runs and field measurements.

The sum of the squares of the deviations of observed heads from calculated heads for the four calibration dates was computed for the three areas and for the aquifer as a whole. The results (table 2) indicate that head deviations were minimized in both Area I and the aquifer as a whole with a hydraulic conductivity of 600 ft/d, riverbed conductances of 10,000, 20,000, and 30,000 $ft^2/d$ for the upper, middle, and lower reaches of the Yazoo-Tallahatchie-Coldwater, and no areal recharge. Without areal recharge, the model is fairly insensitive to changes in storage coefficient. Thus, selection of a value for storage coefficient at this stage of calibration was arbitrary.

The second calibration array was used to determine approximations for those aquifer parameters dominant in Area II-specific yield, Sunflower and Bogue Phalia riverbed conductances, and areal recharge. The values for hydraulic conductivity and Yazoo-Tallahatchie-Coldwater riverbed conductances determined from the previous array of model runs were assumed to be known parameters for this stage of calibration. A value of 0.0001 was assumed for storage coefficient.

Because of the extremely poor fit obtained with high areal recharge rates in the previous calibration array, recharge was varied between 0 and 1 in/yr in this stage of calibration. The results (table 3) indicated that specific yield values of 0.30 and 0.35 produce nearly equally good fits, while that produced with a value of 0.25 is relatively poor. A value of 0.30 is closer to the generally accepted values for specific yield and was chosen over a value of 0.35 for this reason.

An areal recharge rate of 1 in/yr produced a relatively poor head match in Areas I and III. Because of the importance of Area II, the central drawdown region, an areal recharge rate of 0.5 in/yr was chosen over no recharge, because of the better head match in this area with that rate of recharge.

Table 2.--First calibration array -- shows the sum of the squares of the differences between observed and computed head values for various values of the model parameters dominant in area I, (areas I, II, and III, figure 22) -- Continued--

| | | | | Sum of squares of head residuals | | | |
|---|---|---|---|---|---|---|---|
| S | K | R | K' | Total | Area I | Area II | Area III |
| | 600 | 0 | .1C | 78,248 | 26,318 | 13,020 | 38,910 |
| | | | C | 74,947 | 23,451 | 13,021 | 38,475 |
| | | | 10 C | 83,115 | 32,293 | 13,028 | 37,794 |
| | | 2 | .1C | 229,132 | 137,593 | 13,851 | 77,688 |
| | | | C | 202,117 | 115,101 | 13,493 | 73,523 |
| | | | 10 C | 165,954 | 87,100 | 12,924 | 65,930 |
| | | 4 | .1C | 1,579,583 | 1,019,570 | 154,880 | 405,133 |
| | | | C | 1,145,725 | 717,081 | 120,933 | 307,711 |
| | | | 10 C | 700,741 | 327,571 | 63,812 | 309,358 |
| 0.005 | 200 | 0 | .1C | 119,871 | 48,910 | 13,585 | 57,376 |
| | | | C | 110,369 | 40,190 | 13,583 | 56,596 |
| | | | 10 C | 108,625 | 39,432 | 13,574 | 55,619 |
| | | 2 | .1C | 138,727 | 72,655 | 15,346 | 50,726 |
| | | | C | 139,202 | 73,020 | 15,301 | 50,881 |
| | | | 10 C | 152,025 | 85,922 | 15,267 | 50,836 |
| | | 4 | .1C | 1,088,033 | 643,199 | 92,972 | 351,862 |
| | | | C | 946,596 | 516,846 | 87,742 | 342,008 |
| | | | 10 C | 795,060 | 385,181 | 80,514 | 329,365 |
| | 400 | 0 | .1C | 92,271 | 32,682 | 12,876 | 46,713 |
| | | | C | 86,292 | 27,309 | 12,872 | 46,111 |
| | | | 10 C | 89,792 | 31,721 | 12,854 | 45,217 |
| | | 2 | .1C | 123,006 | 67,351 | 12,726 | 42,929 |
| | | | C | 122,721 | 67,628 | 12,710 | 42,383 |
| | | | 10 C | 129,695 | 75,525 | 12,682 | 41,488 |
| | | 4 | .1C | 774,396 | 494,954 | 61,912 | 217,530 |
| | | | C | 665,360 | 400,330 | 56,087 | 208,943 |
| | | | 10 C | 496,884 | 258,016 | 45,050 | 193,818 |
| | 600 | 0 | .1C | 79,589 | 26,190 | 12,941 | 40,458 |
| | | | C | 76,168 | 23,074 | 12,943 | 40,151 |
| | | | 10 C | 82,194 | 29,734 | 12,944 | 39,516 |
| | | 2 | .1C | 122,397 | 70,164 | 12,681 | 39,552 |
| | | | C | 118,432 | 66,863 | 12,644 | 38,925 |
| | | | 10 C | 118,029 | 67,733 | 12,609 | 37,687 |
| | | 4 | .1C | 618,874 | 404,121 | 51,879 | 162,874 |
| | | | C | 536,218 | 333,766 | 46,411 | 156,041 |
| | | | 10 C | 380,867 | 205,557 | 34,219 | 141,091 |

Table 2.--First calibration array. Show the sum of the squares of the differences between observed and computed head values for various values of the model parameters dominant in area I (areas I, II, and III, figure 22)

<u>S</u>, storage coefficient; <u>K</u>, hydraulic conductivity of alluvial aquifer (ft/d); <u>R</u>, areal recharge (in/yr); <u>K'</u>, Yazoo riverbed conductance (ft /d); and <u>C</u>, riverbed conductance = 10,000, 20,000, and 30,000 ft /d for upper, middle, and lower reaches, respectively, of the Yazoo-Tallahatchie-Coldwater River system.

| | | | | Sum of squares of head residuals | | | |
|---|---|---|---|---|---|---|---|
| <u>S</u> | <u>K</u> | <u>R</u> | <u>K'</u> | Total | Area I | Area II | Area III |
| 0.0001 | 200 | 0 | 0.1C | 118,095 | 48,324 | 13,684 | 56,087 |
| | | | C | 107,743 | 38,836 | 13,684 | 55,223 |
| | | | 10 C | 109,238 | 41,389 | 13,668 | 54,181 |
| | | 2 | .1C | 706,371 | 334,741 | 23,868 | 347,762 |
| | | | C | 595,034 | 251,003 | 23,173 | 320,858 |
| | | | 10 C | 530,714 | 210,062 | 22,843 | 297,809 |
| | 400 | 0 | .1C | 89,997 | 31,982 | 12,970 | 45,045 |
| | | | C | 84,662 | 27,309 | 12,968 | 44,385 |
| | | | 10 C | 92,287 | 35,629 | 12,952 | 43,706 |
| | | 2 | .1C | 364,272 | 209,270 | 14,622 | 140,380 |
| | | | C | 305,364 | 162,276 | 14,208 | 128,880 |
| | | | 10 C | 249,549 | 118,592 | 13,510 | 117,447 |
| | 600 | 0 | .1C | 77,700 | 26,377 | 13,037 | 38,286 |
| | | | C | 74,512 | 23,609 | 13,037 | 37,866 |
| | | | 10 C | 83,494 | 33,107 | 13,046 | 37,341 |
| | | 2 | .1C | 291,472 | 174,868 | 14,676 | 101,928 |
| | | | C | 246,836 | 138,696 | 14,021 | 94,119 |
| | | | 10 C | 189,260 | 95,028 | 13,049 | 81,183 |
| 0.001 | 200 | 0 | .1C | 118,558 | 48,440 | 13,675 | 56,443 |
| | | | C | 108,399 | 39,130 | 13,675 | 55,594 |
| | | | 10 C | 109,190 | 40,953 | 13,661 | 54,576 |
| | | | .1C | 425,695 | 212,984 | 20,239 | 192,472 |
| | | | C | 382,687 | 178,605 | 19,860 | 184,222 |
| | | | 10 C | 357,199 | 162,822 | 19,741 | 174,636 |
| | | 4 | .1C | 5,442,521 | 3,264,100 | 514,321 | 1,664,100 |
| | | | C | 3,807,368 | 1,881,040 | 394,708 | 1,531,620 |
| | | | 10 C | 2,664,815 | 986,593 | 280,212 | 1,398,010 |
| | 400 | 0 | .1C | 90,549 | 32,100 | 12,955 | 45,494 |
| | | | C | 84,935 | 27,201 | 12,953 | 44,781 |
| | | | 10 C | 91,705 | 34,713 | 12,932 | 44,060 |
| | | 2 | .1C | 270,367 | 155,301 | 13,859 | 101,207 |
| | | | C | 241,127 | 131,561 | 13,665 | 95,901 |
| | | | 10 C | 208,858 | 106,936 | 13,272 | 88,650 |
| | | 4 | .1C | 2,608,111 | 1,657,090 | 251,860 | 699,161 |
| | | | C | 1,892,962 | 1,066,270 | 191,538 | 635,154 |
| | | | 10 C | 1,132,717 | 481,431 | 107,578 | 543,708 |

Table 3.--Second calibration array. Shows the sum of the squares of the differences between observed and computed head values for various values of the model parameters dominant in area II (areas I, II, and III shown on figure 22)

<u>SY</u>, specific Yield; <u>R</u>, areal recharge (in/yr); <u>K'</u>, Sunflower riverbed conductance (ft /d); and <u>C</u>, riverbed conductance = 10,000 ft /d for Sunflower River and 3,000 ft /d for Bogue Phalia.

| | | | Sum of squares of head residuals | | | |
|---|---|---|---|---|---|---|
| SY | R | K' | Total | Area I | Area II | Area III |
| 0.25 | 0 | .1C | 78,357 | 24,532 | 14,253 | 39,572 |
| | | C | 77,928 | 24,335 | 14,121 | 39,472 |
| | | 10 C | 75,838 | 23,384 | 13,599 | 38,855 |
| | .5 | .1C | 77,214 | 28,058 | 13,437 | 35,719 |
| | | C | 77,004 | 27,977 | 13,322 | 35,705 |
| | | 10 C | 75,997 | 27,491 | 12,953 | 35,553 |
| | 1 | .1C | 99,622 | 44,673 | 12,746 | 42,203 |
| | | C | 98,137 | 43,897 | 12,649 | 41,591 |
| | | 10 C | 93,775 | 41,739 | 12,409 | 39,627 |
| .30 | 0 | .1C | 75,759 | 24,126 | 13,315 | 38,318 |
| | | C | 75,113 | 23,715 | 13,234 | 38,164 |
| | | 10 C | 73,534 | 22,786 | 13,021 | 37,727 |
| | .5 | .1C | 74,908 | 27,607 | 12,826 | 34,475 |
| | | C | 74,753 | 27,530 | 12,759 | 34,464 |
| | | 10 C | 73,986 | 26,984 | 12,631 | 34,371 |
| | 1 | .1C | 94,105 | 42,567 | 12,406 | 39,132 |
| | | C | 93,062 | 42,026 | 12,352 | 38,684 |
| | | 10 C | 90,159 | 40,563 | 12,320 | 37,276 |
| .35 | 0 | .1C | 75,477 | 24,186 | 13,090 | 38,201 |
| | | C | 74,509 | 23,608 | 13,036 | 37,865 |
| | | 10 C | 72,517 | 22,466 | 12,973 | 37,078 |
| | .5 | .1C | 73,965 | 27,503 | 12,764 | 33,698 |
| | | C | 73,953 | 27,449 | 12,727 | 33,777 |
| | | 10 C | 73,388 | 26,914 | 12,724 | 33,750 |
| | 1 | .1C | 91,899 | 41,836 | 12,499 | 37,564 |
| | | C | 91,068 | 41,380 | 12,468 | 37,220 |
| | | 10 C | 88,514 | 40,000 | 12,547 | 35,967 |

The model is relatively insensitive to changes in the riverbed conductance values for the Sunflower River and Bogue Phalia. Because of field observations which indicate that the aquifer is less sensitive to changes in the stage of these streams than to stage changes in the Yazoo River, conductance values lower than that determined for the Yazoo River were assumed.

A third calibration array (table 4) was constructed in order to arrive at new estimates for those unknown parameters dominant in Area I (with the exception of areal recharge for which a value of 0.5 in/yr was assumed based upon the second array of model runs). Of those values tested, riverbed conductance values of 30,000, 20,000, and 10,000 $ft^2/d$ for the lower, middle, and upper reaches of the Yazoo-Tallahatchie-Coldwater River system, respectively, were found to produce the optimal head match in Area I and the aquifer as a whole.

In Areas I and II, the head match is relatively poor for values of hydraulic conductivity less than 400 ft/d and is relatively insensitive to changes in this parameter greater than 400 ft/d. Because a value of 400 ft/d is more in keeping with the generally accepted value of hydraulic conductivity in the alluvial aquifer, it was chosen over higher values which produced similar head fits. Area III indicates an apparent need for a higher value of hydraulic conductivity primarily due to a poor head match along the Mississippi River in April 1983. The authors believe that this situation is due to conceptual error in some of the simplifying assumptions used in model construction. Direct vertical recharge from precipitation may be greater in some areas adjacent to the Mississippi River than is included in the model, due to sandy areas near the river. Another likely error is the assumption of a distinct upper confining layer of 20 feet thickness. Because the aquifer in the area near the Mississippi River alternately is recharged and then drained by the river, changing the aquifer from the unconfined to the confined regime and back, correct placement of the clay confining layer is essential because of the drastically different aquifer responses under the two regimes. Because of the complex nature of alluvial geology, precise placement of this confining layer is virtually impossible. Also, distinctiveness of the clay-aquifer interface in this continuously stratified formation is questionable. Thus, it is possible that the transition from unconfined to confined conditions is not abrupt, but rather that a transition period exists, during which time both pore space saturation-desaturation and elastic deformation play an important role in changes in aquifer storage. These effects would be most important during periods of intense aquifer stress (April 1983, near the Mississippi River, for example). The long-term error in head prediction in the area of primary interest, the central drawdown region, caused by not including the above-mentioned model embellishments is probably negligible because of, (1) the short-term nature of the extreme events which make the conceptual errors most evident and (2) the remoteness of the central drawdown region from the rapidly-stressed area.

A slightly better overall head match was obtained with a storage coefficient of 0.0001 than with the other values tested in those simulations with the preferred values of hydraulic conductivity and riverbed conductance.

Table 4.-- Third calibration array. Shows the sum of the squares of the differences between observed and computed head values for various values of the model parameters dominant in area I (areas I, II, and III shown on figure 22)

S, storage coefficient; K', Yazoo-Tallahatchie-Coldwater riverbed conductance (ft /d); K, hydraulic conductivity (ft/d); and C, riverbed conductance = 10,000, 20,000, and 30,000 ft /d for upper, middle, and lower reaches, respectively, of the Yazoo-Tallahatchie-Coldwater River system.

| | | | Sum of squares of head residuals | | | |
|---|---|---|---|---|---|---|
| S | K' | K | Total | Area I | Area II | Area III |
| 0.001 | 0.1C | 200 | 98,336 | 37,618 | 13,592 | 47,126 |
| | | 300 | 85,516 | 30,926 | 12,954 | 41,636 |
| | | 400 | 78,199 | 27,518 | 12,700 | 37,981 |
| | | 500 | 74,507 | 26,979 | 12,640 | 34,888 |
| | | 600 | 73,149 | 26,821 | 12,752 | 33,576 |
| | C | 200 | 94,791 | 34,410 | 13,591 | 46,790 |
| | | 300 | 83,782 | 29,658 | 12,954 | 41,170 |
| | | 400 | 77,266 | 26,748 | 12,702 | 37,816 |
| | | 500 | 73,880 | 26,434 | 12,640 | 34,806 |
| | | 600 | 72,354 | 26,089 | 12,751 | 33,514 |
| | 10 C | 200 | 97,663 | 37,748 | 13,586 | 46,329 |
| | | 300 | 87,196 | 33,584 | 12,952 | 40,660 |
| | | 400 | 81,729 | 31,322 | 12,714 | 37,693 |
| | | 500 | 77,678 | 30,299 | 12,645 | 34,734 |
| | | 600 | 75,867 | 29,608 | 12,765 | 33,494 |
| 0.0005 | .1C | 200 | 97,998 | 37,567 | 13,599 | 46,832 |
| | | 300 | 85,450 | 31,272 | 12,972 | 41,206 |
| | | 400 | 78,550 | 27,947 | 12,715 | 37,888 |
| | | 500 | 75,107 | 27,553 | 12,658 | 34,896 |
| | | 600 | 74,304 | 27,524 | 12,755 | 34,025 |
| | C | 200 | 94,713 | 34,596 | 13,598 | 46,519 |
| | | 300 | 83,983 | 30,241 | 12,970 | 40,772 |
| | | 400 | 77,772 | 27,336 | 12,716 | 37,720 |
| | | 500 | 74,596 | 27,122 | 12,660 | 34,814 |
| | | 600 | 73,520 | 26,824 | 12,753 | 33,943 |
| | 10 C | 200 | 98,020 | 38,374 | 13,597 | 46,049 |
| | | 300 | 87,850 | 34,523 | 12,965 | 40,362 |
| | | 400 | 82,453 | 32,125 | 12,724 | 37,604 |
| | | 500 | 78,548 | 31,125 | 12,661 | 34,762 |
| | | 600 | 76,964 | 30,308 | 12,774 | 33,882 |
| 0.0001 | .1C | 200 | 97,700 | 37,546 | 13,602 | 46,252 |
| | | 300 | 85,601 | 31,758 | 12,979 | 40,874 |
| | | 400 | 79,055 | 28,430 | 12,723 | 37,902 |
| | | 500 | 76,058 | 28,163 | 12,665 | 35,230 |
| | | 600 | 75,555 | 28,224 | 12,761 | 34,570 |

Table 4.--Third calibration array -- shows the sum of the squares of the differences between observed and computed head values for various values of the model parameters dominant in area I (areas I, II, and III shown on figure 22) -- Continued --

| | | | Sum of squares of head residuals | | | |
|---|---|---|---|---|---|---|
| S | K' | K | Total | Area I | Area II | Area III |
| | C | 200 | 94,651 | 34,791 | 13,601 | 46,259 |
| | | 300 | 84,410 | 30,943 | 12,979 | 40,488 |
| | | 400 | 78,333 | 27,903 | 12,724 | 37,706 |
| | | 500 | 75,612 | 27,792 | 12,662 | 35,158 |
| | | 600 | 74,750 | 27,528 | 12,759 | 34,463 |
| 10 | C | 200 | 98,214 | 38,858 | 13,598 | 45,758 |
| | | 300 | 88,639 | 35,421 | 12,973 | 40,245 |
| | | 400 | 83,123 | 32,840 | 12,731 | 37,552 |
| | | 500 | 79,700 | 31,929 | 12,667 | 35,104 |
| | | 600 | 78,103 | 30,952 | 12,786 | 34,365 |

A summary of calibration-derived values for alluvial aquifer parameters and a comparison of these values with previous estimates follows:

Hydraulic conductivity - The value of 400 ft/d determined by means of model calibration is reasonably close to the value of 320 ft/d based upon four aquifer tests (Newcome, 1971).

Specific yield - The value of 0.30 determined by means of model calibration is the same value used in a model of the alluvium in Arkansas (Broom and Lyford, 1981) and falls within the range of laboratory measurements of specific yield mentioned earlier.

Storage coefficient - The relatively high value of 0.001 determined by means of model calibration is reasonable in light of the fact that shallow unconsolidated aquifers are often more compressible than more consolidated, deeper aquifers. Any uncertainty in this parameter is relatively unimportant, particularly in the central drawdown region, because of the lack of model sensitivity to storage coefficient.

Areal recharge - The value of 0.5 in/yr determined by means of model calibration is reasonably close to the value of 0.36 in/yr reported for some areas of the alluvial aquifer in Arkansas (Broom and Lyford, 1981).

Riverbed conductance - No previous estimates for this parameter have been made on any stream within the study area. The calibration-derived values are as follows:

| | Riverbed conductance ($ft^2/d$) | Riverbed leakance ($d^{-1}$) |
|---|---|---|
| Mississippi River includes oxbow lakes[1/] | 1,000,000,000 | |
| Yazoo-Tallahatchie-Coldwater River system | | |
| Upper Reach | 10,000 | 0.008 |
| Middle Reach | 20,000 | 0.008 |
| Lower Reach | 30,000 | 0.008 |
| Sunflower River | 10,000 | 0.004 |
| Bogue Phalia | 3,000 | 0.002 |

[1/] Conductance value assumed to be very high in order to give near perfect hydraulic connection between river and alluvial aquifer.

NOTE: Riverbed conductance is a function of the grid system chosen. Thus, the above mentioned values for riverbed conductance should be linked with the grid system used in this study. In order to make these values transferable to other grid systems, riverbed leakance values were calculated for each river reach based upon average values for the plan area of the river within a node.

Figures 15-18 show observed potentiometric maps and potentiometric surface maps generated by the calibrated model. Comparison of these observed and model-generated water-level maps shows that the alluvial aquifer model has successfully simulated ground-water levels within reasonable accuracy for the four periods of significant aquifer stress. More than 95 percent of the model-generated head values for the calibrated dates (with the exception of April 1983) were within 8 feet of the observed head values, as shown by figure 23, which presents the distribution of error in histogram form. Only 87 percent of the model-generated head values for April 1983 were within 8 feet of the observed head values, due to the head mismatch near the Mississippi River discussed earlier.

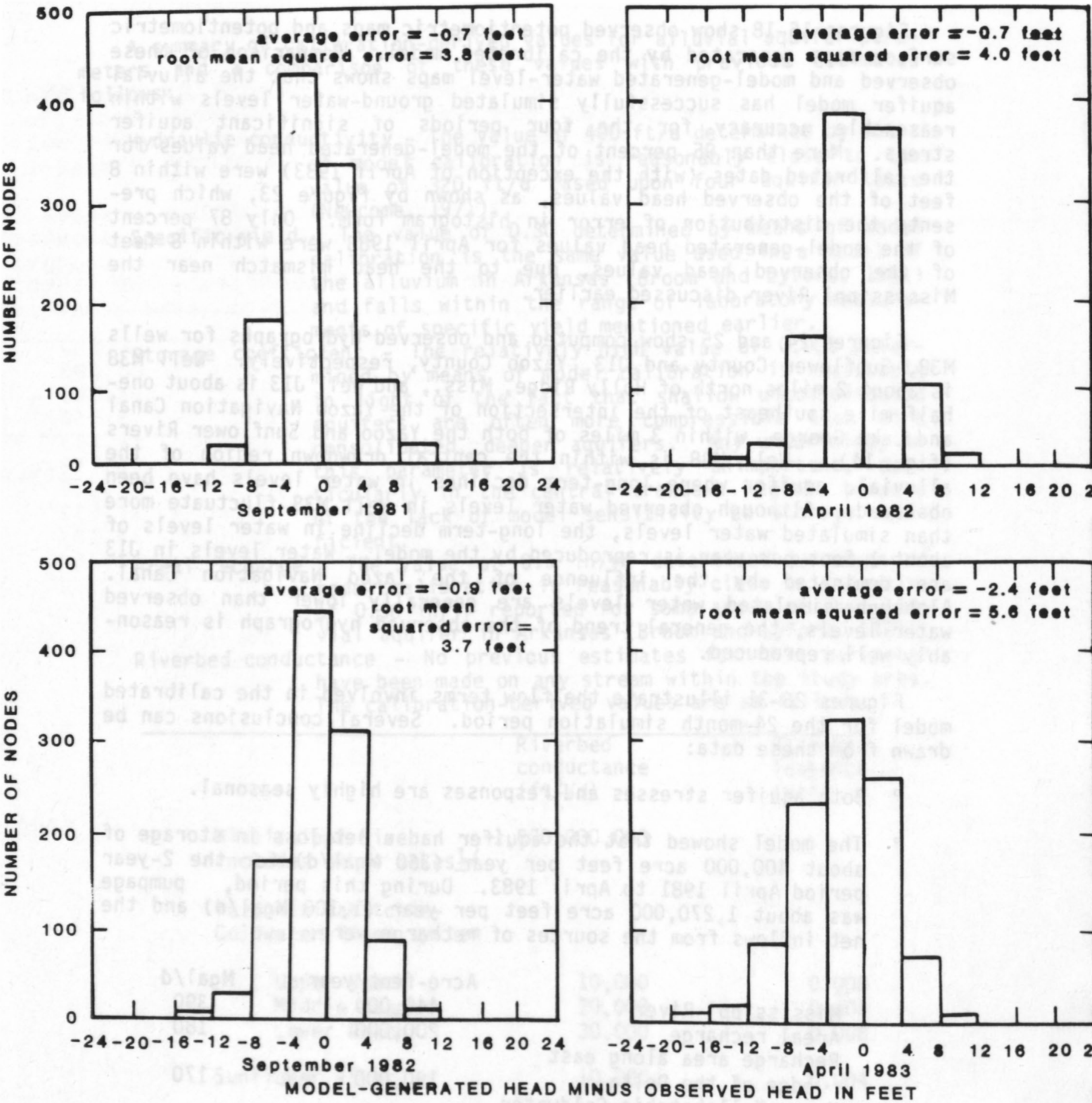
Figures 24 and 25 show computed and observed hydrographs for wells M38, Sunflower County and J13, Yazoo County, respectively. Well M38 is about 2 miles north of Holly Ridge, Miss., and well J13 is about one-half mile southeast of the intersection of the Yazoo Navigation Canal and Lake George, within 3 miles of both the Yazoo and Sunflower Rivers (fig. 14). Well M38 is within the central drawdown region of the alluvial aquifer where long-term declines in water levels have been observed. Although observed water levels in well M38 fluctuate more than simulated water levels, the long-term decline in water levels of about 1 foot per year is reproduced by the model. Water levels in J13 are dominated by the influence of the Yazoo Navigation Canal. Although simulated water levels are generally lower than observed water levels, the general trend of the observed hydrograph is reasonably well reproduced.

Figures 26-31 illustrate the flow terms involved in the calibrated model for the 24-month simulation period. Several conclusions can be drawn from these data:

- Both aquifer stresses and responses are highly seasonal.

- The model showed that the aquifer had a net loss in storage of about 400,000 acre feet per year (360 Mgal/d) for the 2-year period April 1981 to April 1983. During this period, pumpage was about 1,270,000 acre feet per year (1,100 Mgal/d) and the net inflows from the sources of recharge were:

| | Acre-feet/year | Mgal/d |
|---|---|---|
| Mississippi River | 440,000 | 390 |
| Areal recharge | 200,000 | 180 |
| Recharge area along east edge of the Delta | 190,000 | 170 |
| Yazoo-Tallahatchie-Coldwater River System | 51,000 | 45 |
| Oxbow lakes | 27,000 | 24 |
| Sunflower River | 12,000 | 11 |
| Bogue Phalia | 1,100 | 1 |




$$\text{average error} = \sum_{i=1}^{N} \frac{(h_{cal_i} - h_{obs_i})}{N}$$

$$\text{root mean squared error} = \sqrt{\sum_{i=1}^{N} \frac{(h_{cal_i} - h_{obs_i})^2}{N}}$$

,where $h_{cal}$ = model-generated head
$h_{obs}$ = observed head
N = number of nodes used in error computations (non-specified nodes)

Figure 23.--Distribution of head error for the September 1981 through April 1983 calibration simulations.

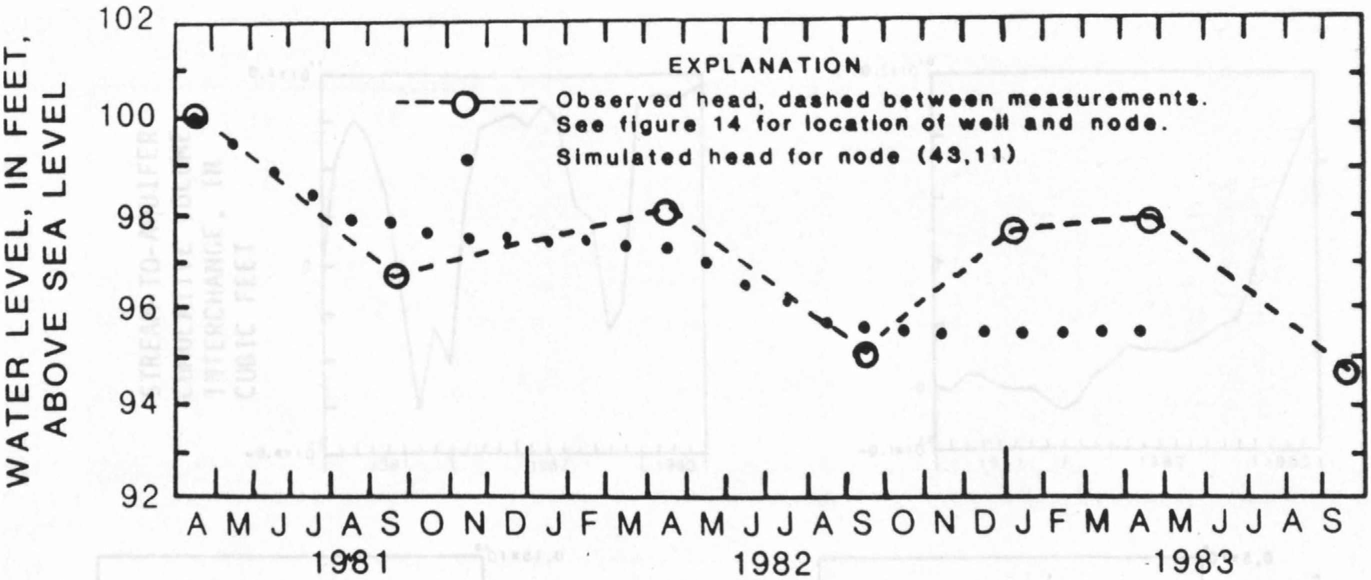



Figure 24.--Hydrographs (observed and model-generated) for well M38, Sunflower County.

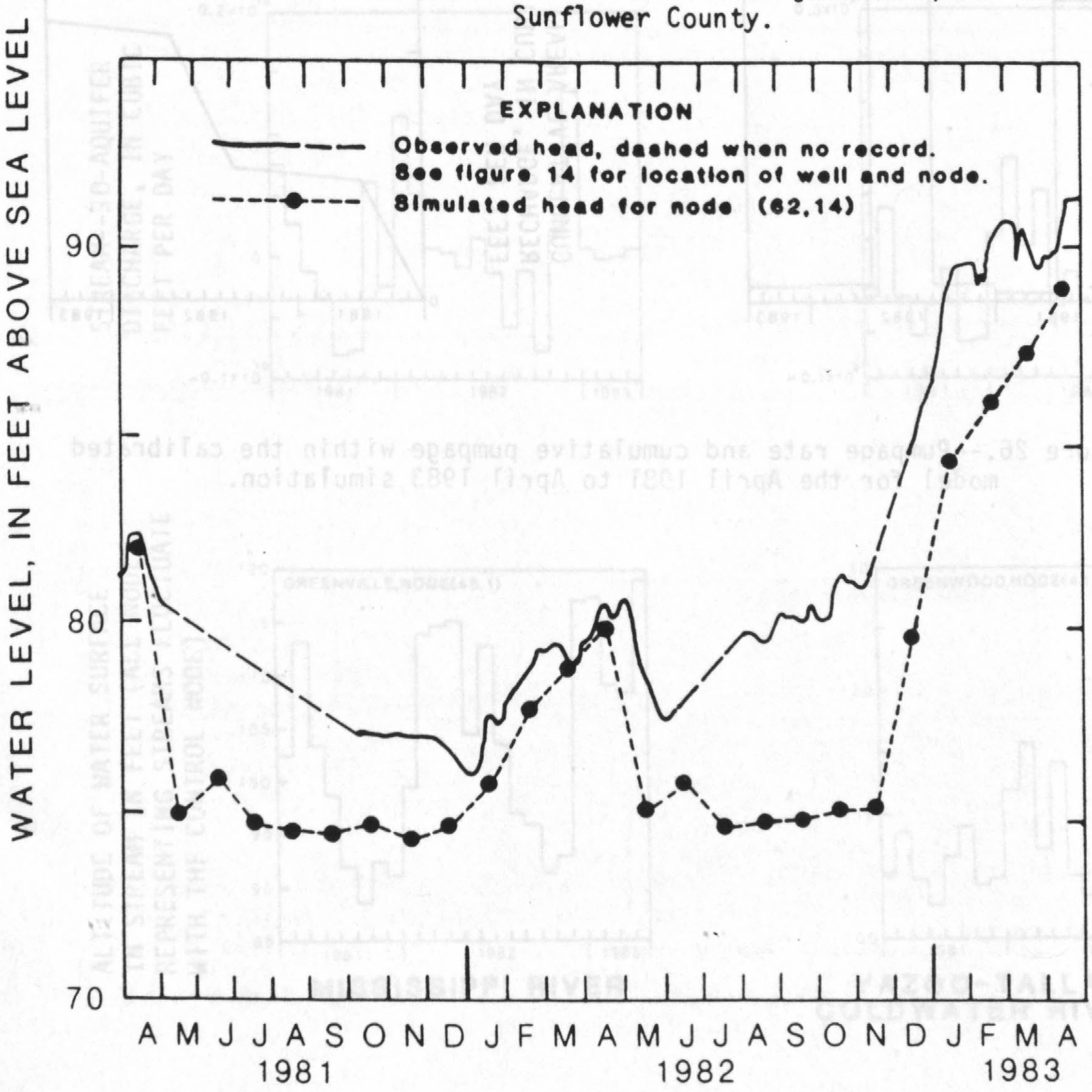



Figure 25.--Hydrographs (observed and model-generated) for well J13, Yazoo County.

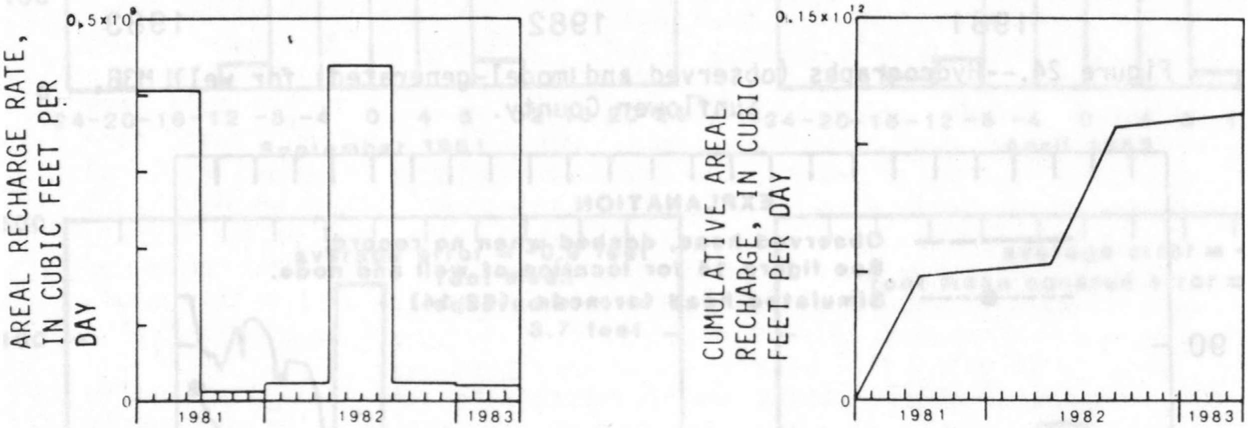



Figure 26.--Pumpage rate and cumulative pumpage within the calibrated model for the April 1981 to April 1983 simulation.

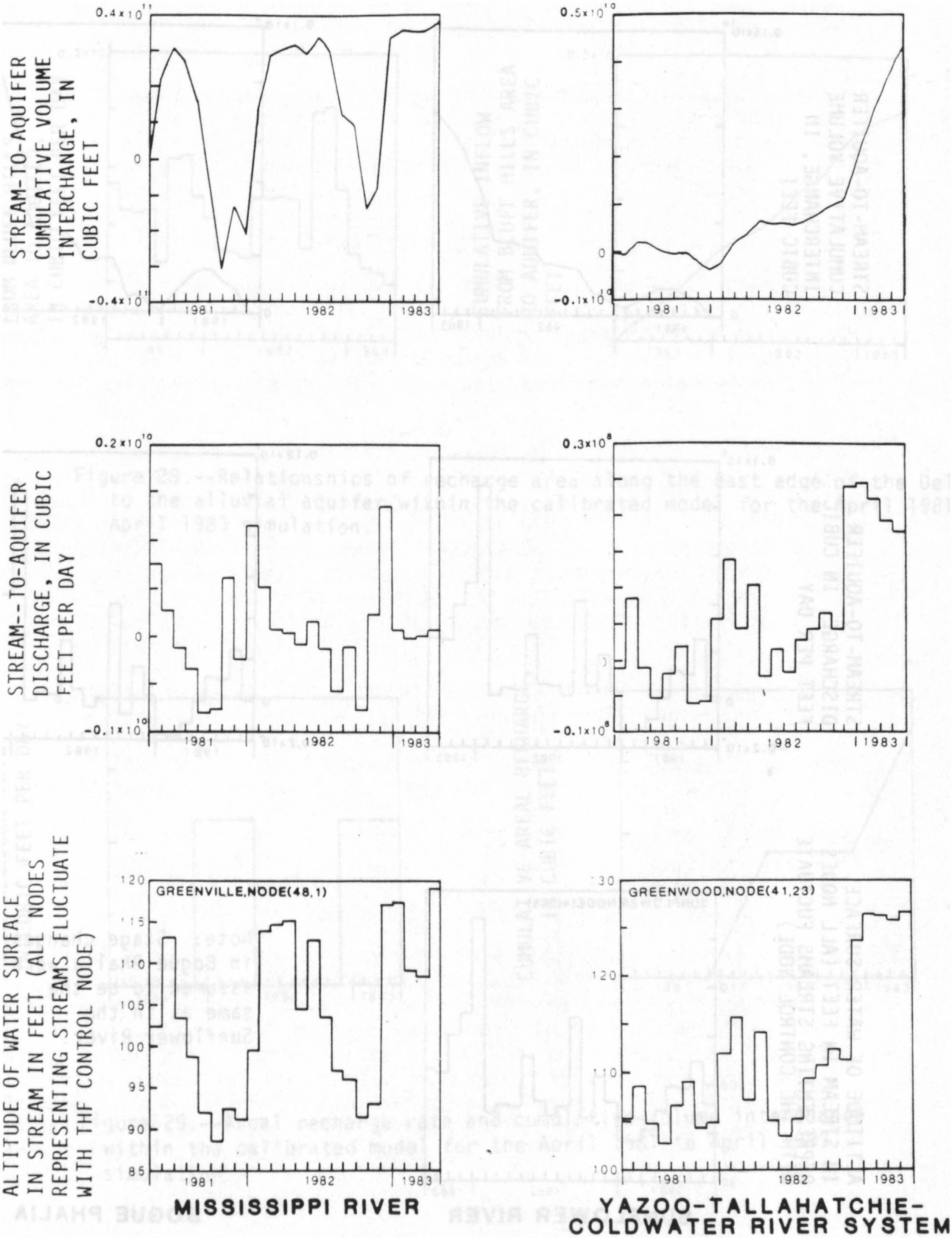



Figure 27. Relationships of streams to the alluvial aquifer within the calibrated model for the April 1981 to April 1983 simulation.

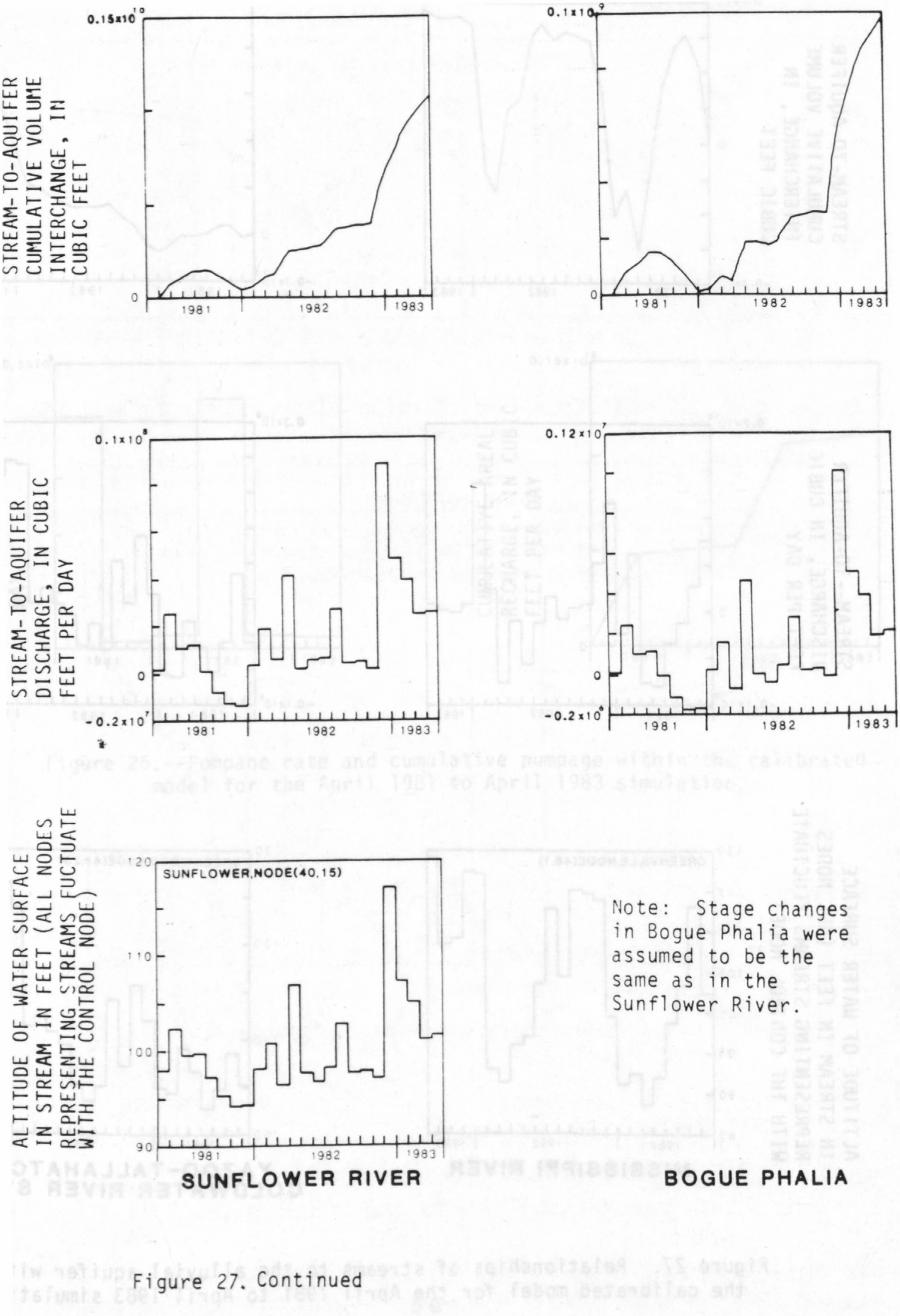



Figure 27. Continued

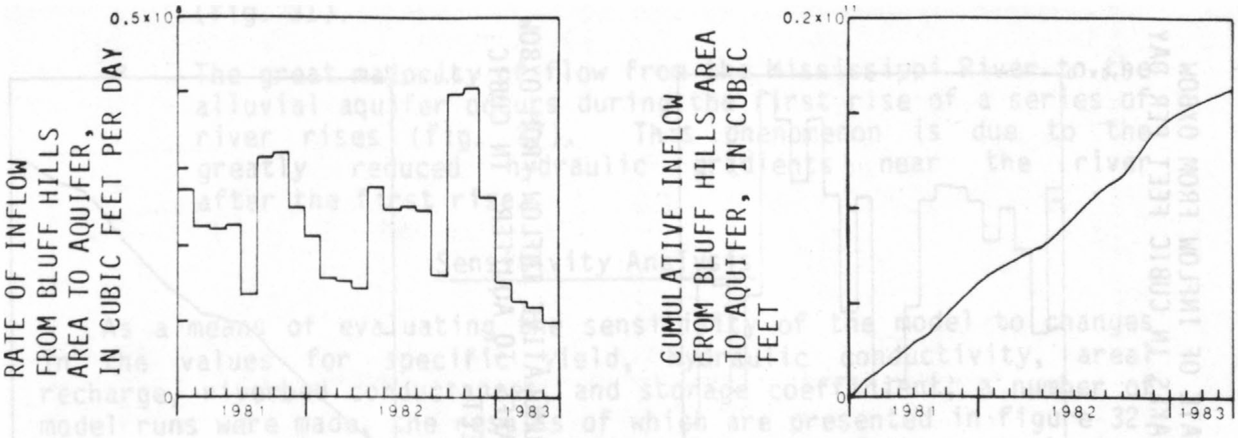



Figure 28.--Relationships of recharge area along the east edge of the Delta to the alluvial aquifer within the calibrated model for the April 1981-April 1983 simulation.

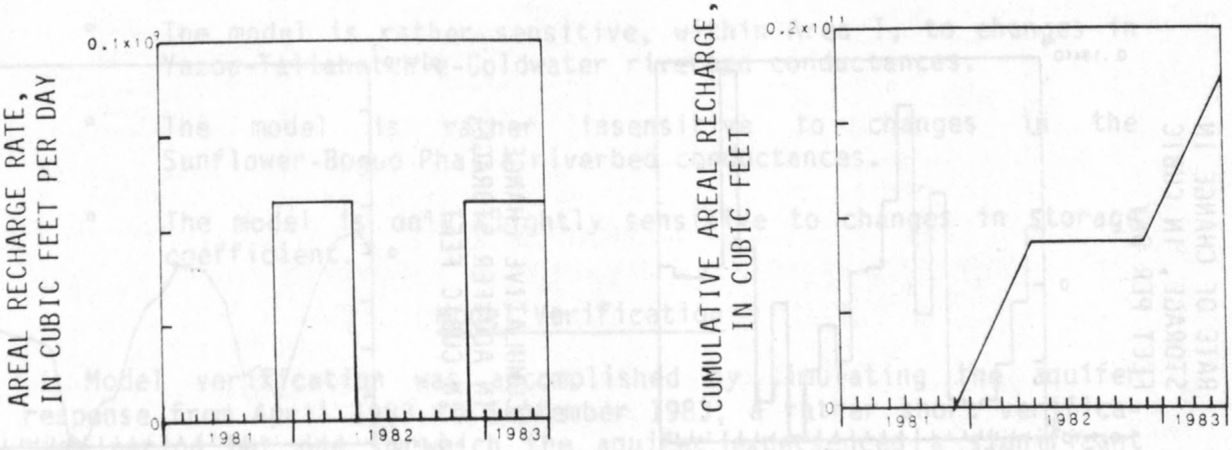



Figure 29.--Areal recharge rate and cumulative-volume interchange within the calibrated model for the April 1981 to April 1983 simulation.

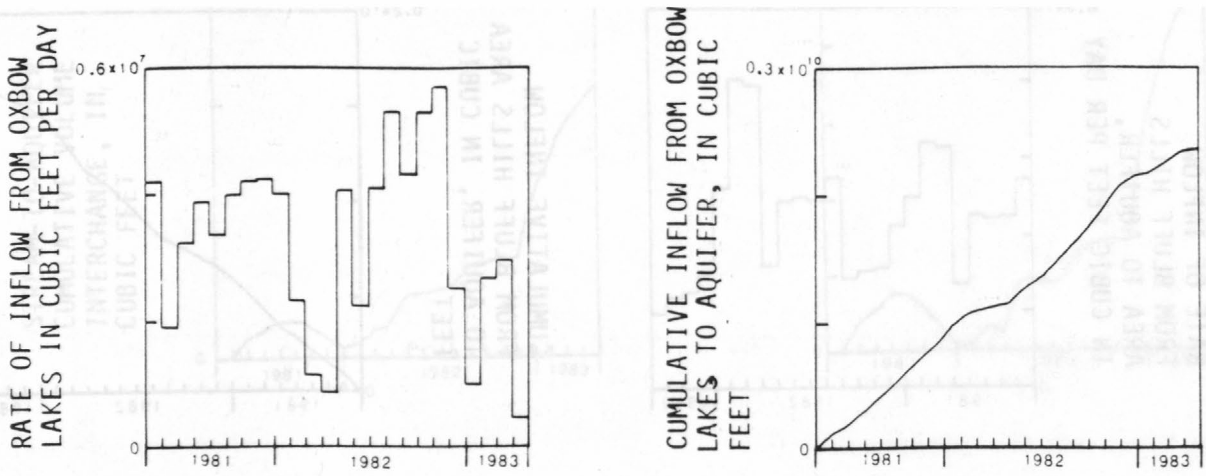



Figure 30.--Relationship of oxbow lakes to alluvial aquifer within the calibrated model for the April 1981 to April 1983 simulation.

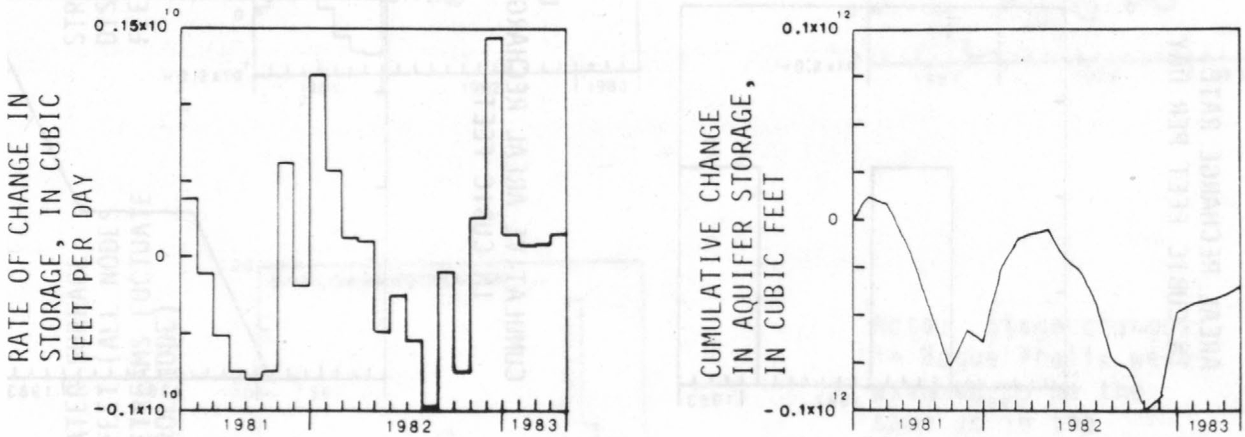



Figure 31.--Rate and cumulative-volume interchange of water added to aquifer storage within the calibrated model for the April 1981-April 1983 simulation.

- Almost $0.35 \times 10^{11}$ $ft^3$ or 0.8 million acre-feet was removed from aquifer storage during the 24-month simulation period (fig. 31).

- The great majority of flow from the Mississippi River to the alluvial aquifer occurs during the first rise of a series of river rises (fig. 27). This phenomenon is due to the greatly reduced hydraulic gradients near the river after the first rise.

## Sensitivity Analysis

As a means of evaluating the sensitivity of the model to changes in the values for specific yield, hydraulic conductivity, areal recharge, riverbed conductances, and storage coefficient, a number of model runs were made, the results of which are presented in figure 32. Several conclusions can be drawn from examination of these graphs.

- The model is relatively insensitive to changes in hydraulic conductivity and specific yield for values higher than 400 ft/d and 0.30 for these parameters, respectively.

- The model is quite sensitive, within Areas I and III to areal recharge rate. Because of this sensitivity, future field work in the area would be most profitably applied to the further definition of magnitude and distribution of areal recharge.

- The model is rather sensitive, within Area I, to changes in Yazoo-Tallahatchie-Coldwater riverbed conductances.

- The model is rather insensitive to changes in the Sunflower-Bogue Phalia riverbed conductances.

- The model is only slightly sensitive to changes in storage coefficient.

## Model Verification

Model verification was accomplished by simulating the aquifer response from April 1983 to September 1983, a rather short verification period but one in which the aquifer experienced a significant stress as agricultural pumpage began and the rivers fell from their higher than normal spring stages. As the error histogram indicates the model simulated the aquifer reasonably well during this period. About 96 percent of the nodes had computed head values within 8 feet of observed heads (fig. 33). Figure 34 illustrates both observed and computed water levels.

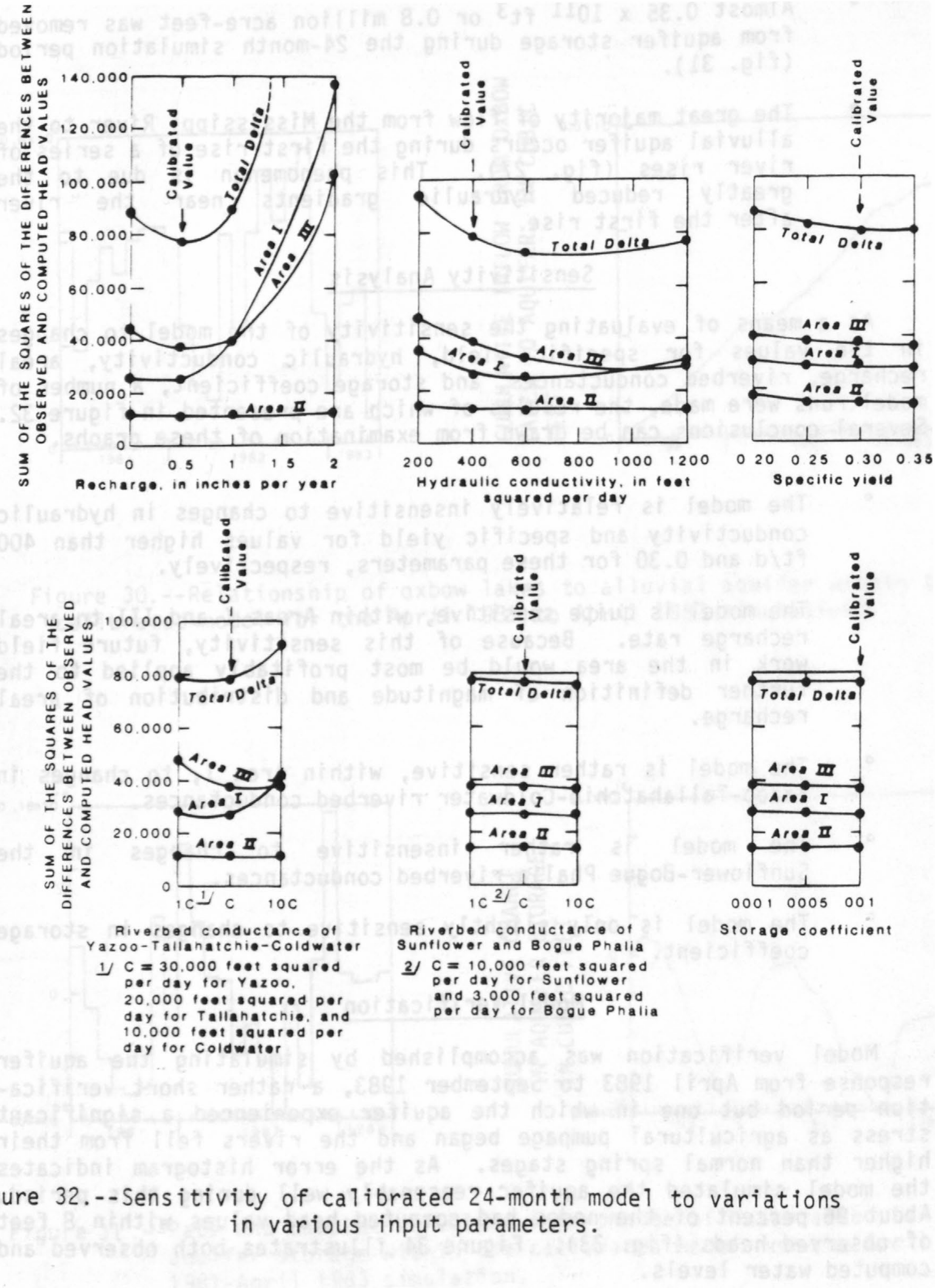



Figure 32.--Sensitivity of calibrated 24-month model to variations in various input parameters.

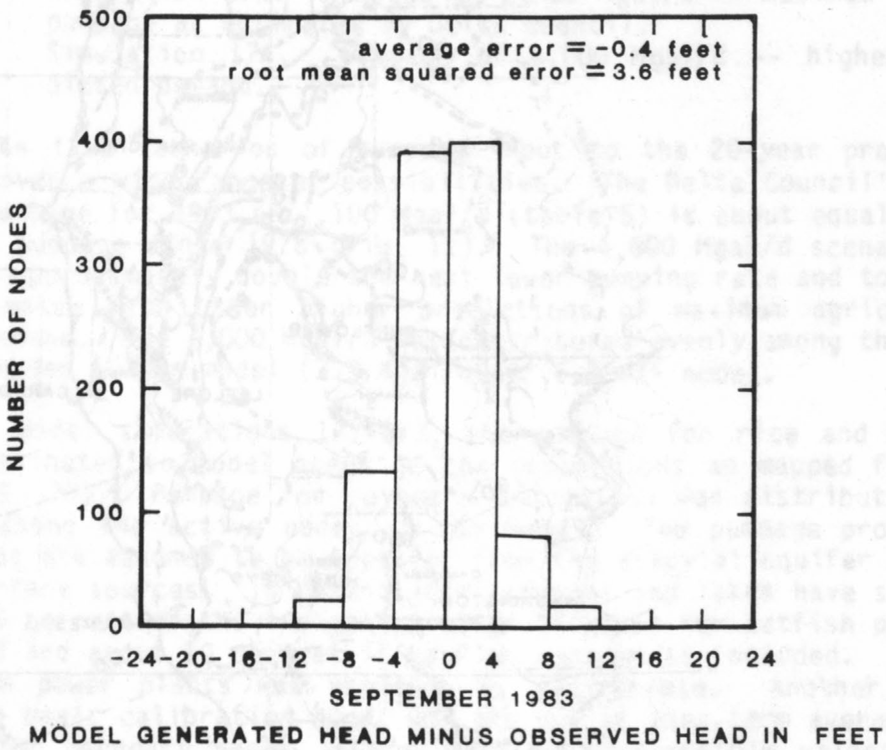



Figure 33.--Distribution of head error for April 1983 to September 1983 simulation.

EXPLANATION

—140— OBSERVED WATER-LEVEL CONTOUR--

---140- SIMULATED WATER-LEVEL CONTOUR--

altitude at which water-level would stand in tightly cased wells. Contour intervals are 10 feet. Datum is sea level.

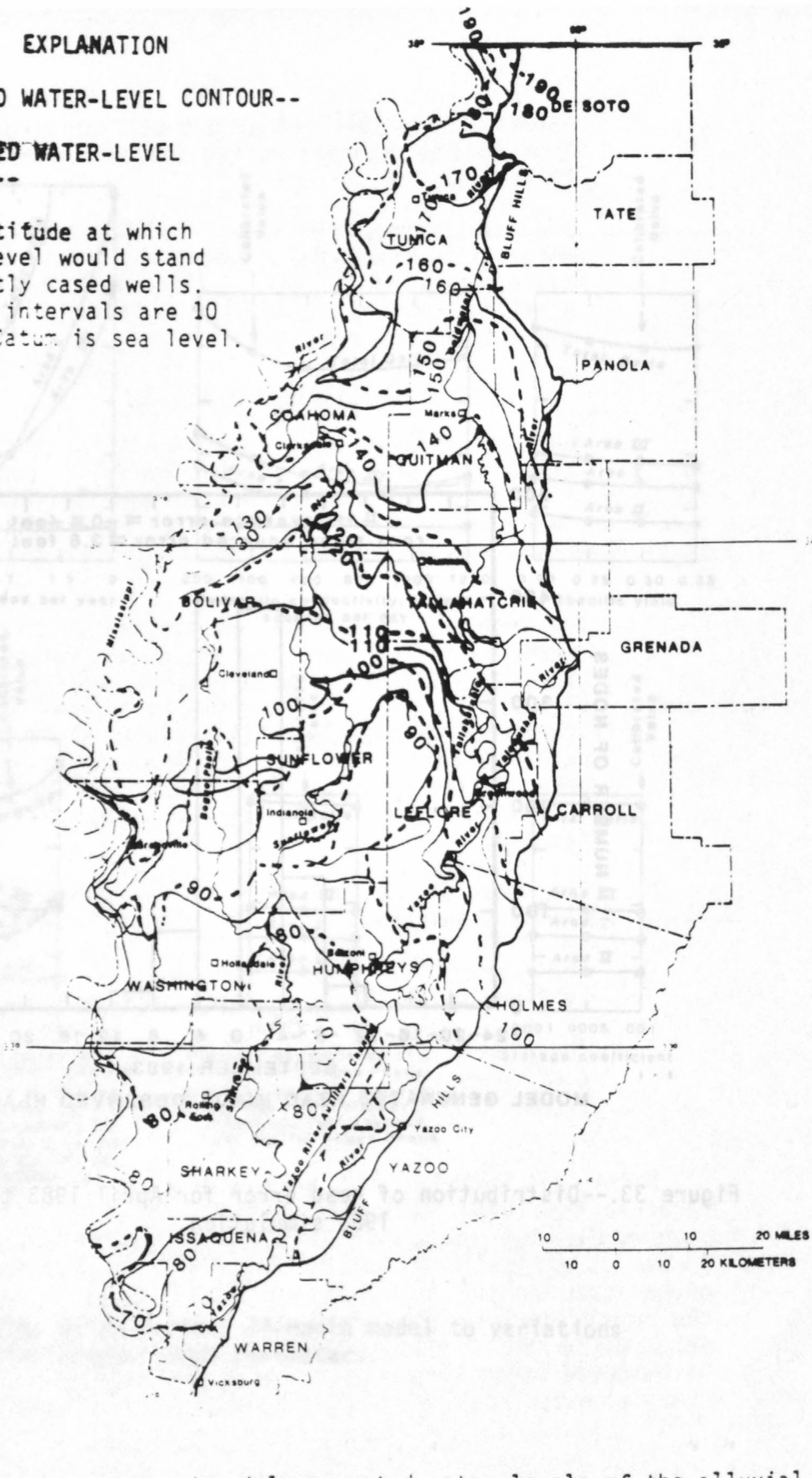



Figure 34.--Observed and model-generated water levels of the alluvial aquifer in the Delta for September 1983.

The calibrated and verified model of the alluvial aquifer, as previously described, is used herewith to estimate aquifer responses in the future. The following pumping stresses were simulated for the 20-year period beginning September 1983.

- Simulation 170. No pumpage.
- Simulation 171. Pumpage of 670 Mgal/d -- minimum average pumpage during next 20 years as estimated by Delta Council (oral commun., 1983).
- Simulation 173. Pumpage of 1,100 Mgal/d -- 1983 pumpage as estimated by Delta Council.
- Simulation 172. Pumpage of 1,900 Mgal/d -- maximum average pumpage as estimated by Delta Council.
- Simulation 174. Pumpage of 4,000 Mgal/d -- highest predicted demand.

These five scenarios of pumpage input to the 20-year projection model cover a wide range of possibilities. The Delta Council's estimated pumpage for 1983 of 1,100 Mgal/d (table 5) is about equal to the average pumpage since 1978 (fig. 11). The 4,000 Mgal/d scenario was used to approximately double the next lower pumping rate and to have a closer match with other higher predictions of maximum agricultural water demand. The 4,000 Mgal/d was distributed evenly among the 1,211 active nodes of the model (3.3 Mgal/d per 6.3 $mi^2$ node).

For model simulations 171-173, the pumpage for rice and catfish was distributed to model nodes in the proportions as mapped for 1982 (fig. 19, 20). Pumpage for soybeans and cotton was distributed uniformly among the active nodes of the model. The pumpage projection scenarios are assumed to be supplied from the alluvial aquifer and not from surface sources. In recent years streams and lakes have supplied about 15 percent of the irrigation water if water for catfish ponds is excluded and about 10 percent if catfish pumpage is included. Pumpage at three power plants was assigned as appropriate. Another change from the basic calibration model was the use of long-term average head values for boundary nodes, rather than updated monthly values. The time-step length was changed from monthly for the calibration simulations to 2 years for the predictive simulations (170-174).

Results of the predictive model (simulations 170-174), are presented in table 6 and in a series of illustrations. Water budgets (table 6) for the ending stress period for each of the simulations show various shifts in flow as pumpage is increased or as pumpage is redistributed.

A schematic diagram illustrating the flow budget for the 1,900 Mgal/d pumping rate is shown in figure 35. The predictive simulations have constant-stress stream stages and pumping rates. With increasing pumpage rates from wells (table 6), increases occur in withdrawals of water from aquifer storage, percentage of pumpage

Table 5.--Delta Council estimates of minimum, 1983, and maximum agricultural pumpage -- used to simulate aquifer conditions during the next 20 years

DELTA COUNCIL ESTIMATES[1] -- December 2, 1983

| Crop | Acres | Feet of water applied | Acre-feet |
|---|---|---|---|
| MINIMUM ACREAGE PROJECTION | | | |
| Cotton | 150,000 | x 0.5 x 2/5[2] = | 30,000 |
| Soybeans | 300,000 | x 0.5 x 4/5[3] = | 120,000 |
| Rice | 100,000 | x 3 = | 300,000 |
| Catfish | 60,000 | x 5 = | 300,000 |
| | | | 750,000 = 670 Mgal/d |
| 1983 ACREAGE ESTIMATE | | | |
| Cotton | 150,000 | x 0.5 = | 75,000 |
| Soybeans | 300,000 | x 0.5 = | 150,000 |
| Rice | 155,000 | x 4 = | 620,000 |
| Catfish | 60,000 | x 7 = | 420,000 |
| | | | 1,265,000 = 1,100 Mgal/d |
| MAXIMUM ACREAGE PROJECTION | | | |
| Cotton | 450,000 | x 0.5 x 2/5 = | 90,000 |
| Soybeans | 900,000 | x 0.5 x 4/5 = | 360,000 |
| Rice | 400,000 | x 3 = | 1,200,000 |
| Catfish | 100,000 | x 5 = | 500,000 |
| | | | 2,150,000 = 1,900 Mgal/d |

1/ Staff and several members participated in making estimates.

2/ Expect to irrigate cotton 2 out of 5 years.

3/ Expect to irrigate soybeans 4 out of 5 years.

Table 6.--Water budget for entire model at end of each 20-year simulation

| Simulation number | 170 | 171 | 173 | 172 | 174 |
|---|---|---|---|---|---|
| Approximate pumpage in Mgal/d | 0 | 670 | 1,100 | 1,900 | 4,000 |
| | Flow rates, in Mgal/d | | | | |
| FLOW TO AQIFER FROM: | | | | | |
| Storage | 0 | 229 | 539 | 1,079 | 2,106 |
| Wells | 0 | 0 | 0 | 0 | 0 |
| Recharge | 178 | 178 | 178 | 178 | 178 |
| River leakage | 26 | 220 | 317 | 455 | 1,208 |
| Specified head | 44 | 124 | 171 | 248 | 533 |
| Total in | 248 | 751 | 1,205 | 1,960 | 4,025 |
| FLOW FROM AQUIFER TO: | | | | | |
| Storage | 70 | 0 | 0 | 0 | 0 |
| Wells | 0 | 705 | 1,166 | 1,929 | 4,013 |
| Recharge | 0 | 0 | 0 | 0 | 0 |
| River leakage | 134 | 33 | 26 | 19 | 0 |
| Specified head | 29 | 1 | 1 | 0 | 0 |
| Total out | 234 | 739 | 1,193 | 1,948 | 4,013 |
| Percent discrepancy of in-out calculations | 6.04 | 1.58 | 1.00 | 0.60 | 0.30 |
| Percentage of water pumped that comes from storage | | 32 | 46 | 56 | 52 |

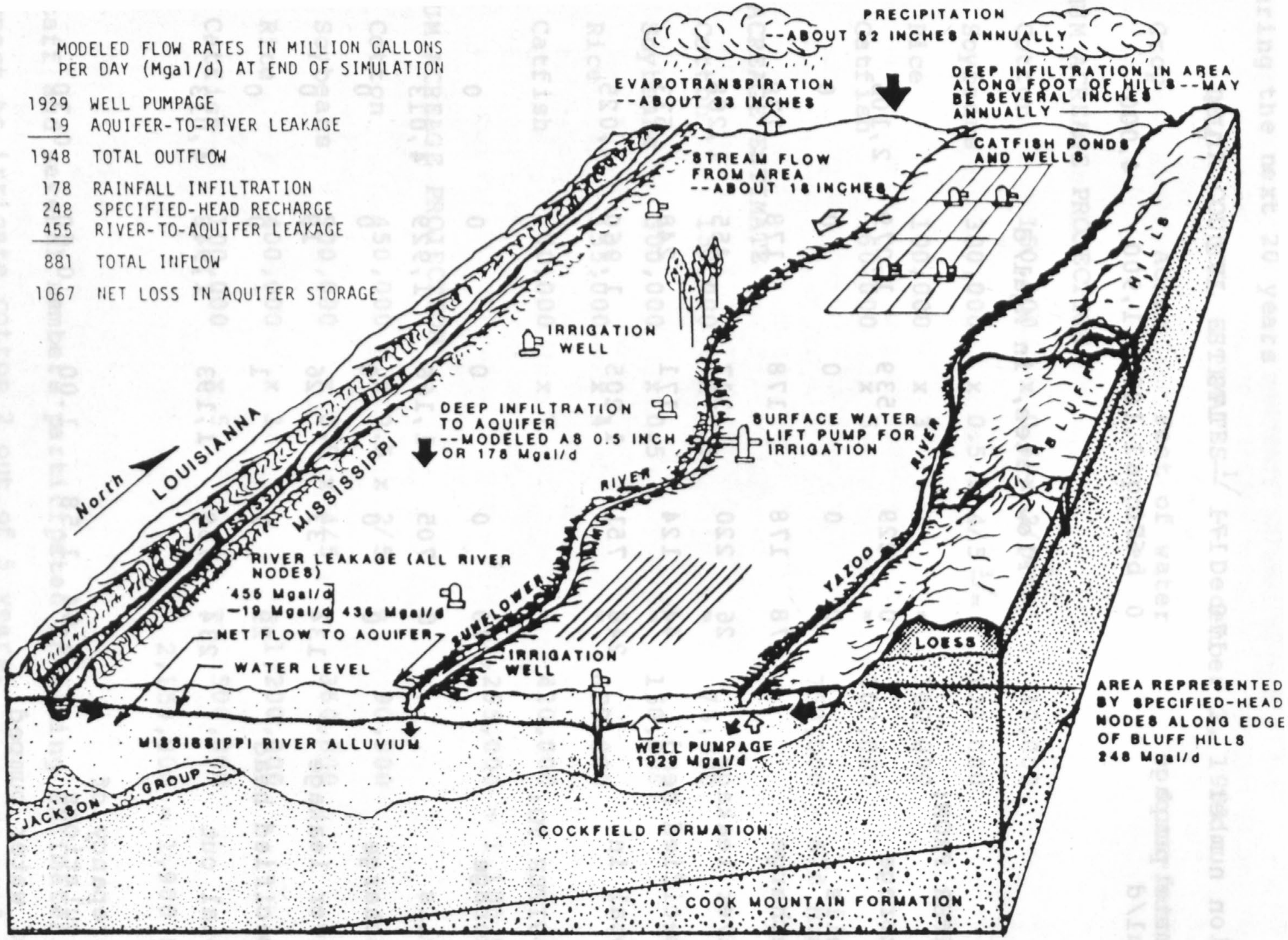



Figure 35.--Simulated flow diagram for the alluvial aquifer for a 1,900 million gallons per day pumping rate for the year 2003.

derived from storage, eastern recharge area-to-aquifer flow, and stream-to-aquifer leakage. At 670 Mgal/d the percentage of pumpage coming from storage is 32 percent; at 1,100 Mgal/d, 46 percent; and at 1,900 Mgal/d, 56 percent. However, for 4,000 Mgal/d pumpage the percentage of water from storage is only 52 percent because pumpage for this scenario is uniformly distributed.

A series of five maps (figs. 36-40) shows the simulated potentiometric surface for the year 2003 for the different pumping scenarios. With each increase in pumpage, the simulated potentiometric surface maps show a lower water surface and enlargement of the depressed potentiometric surface in the central part of the Delta compared to the September 1983 potentiometric surface map. Pumpage more than doubles between the 1,900 and 4,000 Mgal/d pumpage scenarios, but, because areal distribution is different, the maximum drawdowns or minimum heads are about the same for the two simulations. However, the 4,000 Mgal/d causes a much larger area of water-level depression in the aquifer.

Another series of maps (figs. 41-45) shows the drawdown or recovery that occurs during the 20-year projections. The no-pumpage simulation shows a maximum of about 30 feet of recovery (fig. 41) from 1983 water levels. With increasing pumping rates the magnitude and extent of drawdown increase (figs. 42-45).

A third series of maps (figs. 46-50) shows the remaining saturated thickness of the alluvial aquifer after 20 years of continuous pumpage at specified rates. As water levels decline and the saturated thickness of the aquifer becomes less, it will become more difficult to obtain large yields from wells. Presently large-capacity irrigation wells in the Delta are constructed with 20 to 60 feet of screen and have 20 to 50 feet of drawdown space above the screens. As saturated thickness diminishes, the average yields of wells will be smaller and water-supply problems are likely to occur.

The first map (fig. 46) in this series shows the areal variation in saturated aquifer thickness at the end of the 20-year simulation period if no pumpage occurs during the period. This map shows that most of the Delta would have more than 100 feet of saturated aquifer and some large areas of the Delta would have greater than 150 feet of saturated aquifer. The saturated aquifer thickness map (fig. 47) resulting from the 670 Mgal/d pumping rate simulation shows several small areas in the Delta where no more than 75 feet of the alluvial aquifer is saturated. The largest area having less than 75 feet of saturated aquifer is in the part of Washington County where the total thickness of the alluvial aquifer tends to be less than in most of the Delta. The 1,100 Mgal/d simulation (fig. 48) shows that several large areas will have less than 75 feet of saturated aquifer and some small areas will have less than 50 feet of saturated aquifer. The 1,900 Mgal/d simulation (fig. 49) shows that a large part of the central Delta would have less than 75 feet of saturated aquifer and two small areas in Bolivar and Sunflower Counties would have less than 25 feet. The 4,000 Mgal/d pumpage scenario (fig. 50) is more than twice the

EXPLANATION

--140-- SIMULATED WATER-LEVEL CONTOUR--shows altitude, in feet, at which water level would stand in tightly cased wells. Contour interval is 10 feet. Datum is sea level.

AREA WHERE POTENTIOMETRIC SURFACE ALTITUDE IS LESS THAN:

200 FEET

100 FEET

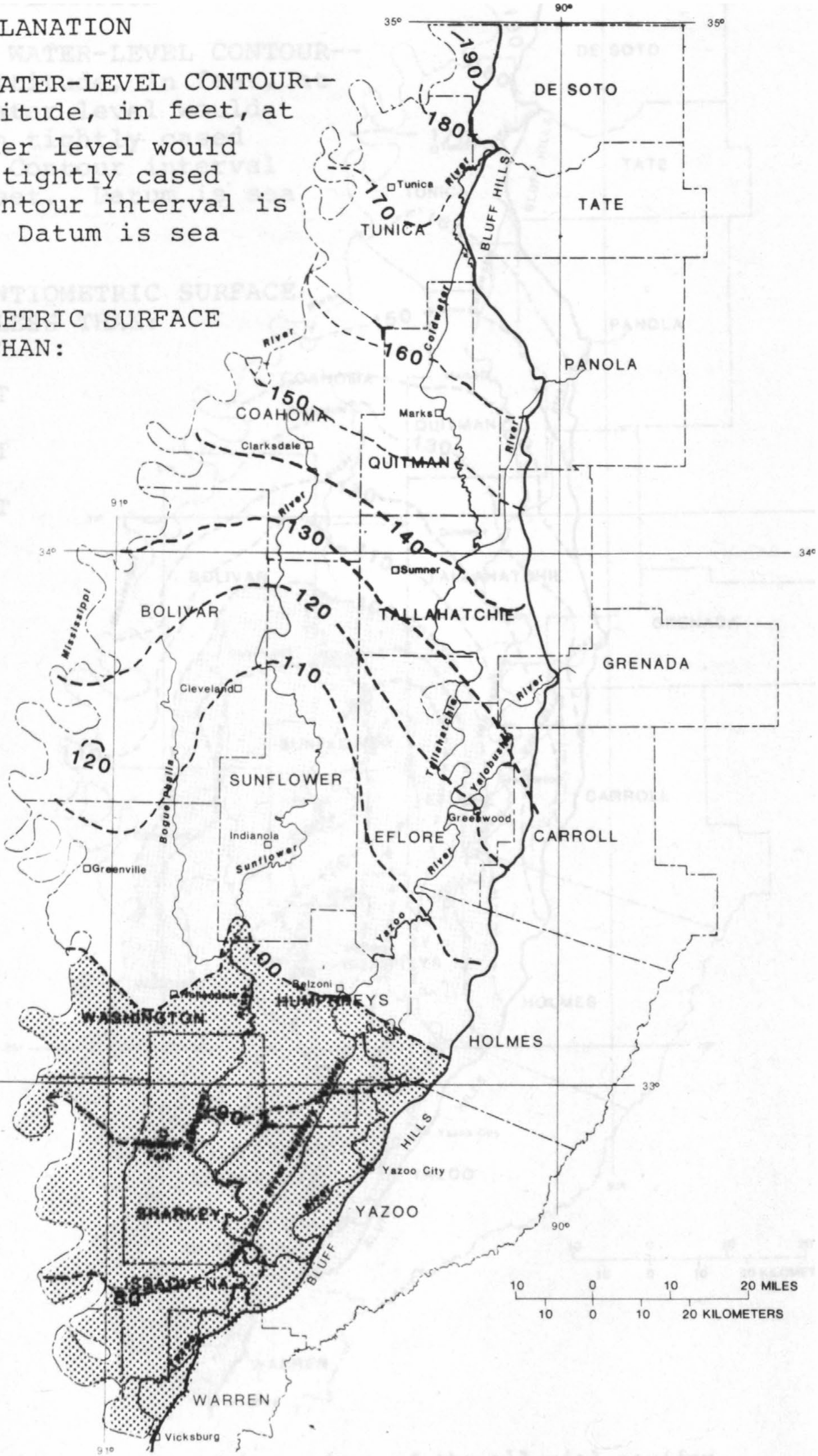



Figure 36.--Simulated potentiometric surface of the alluvial aquifer in the Delta for the year 2003 assuming no pumpage.

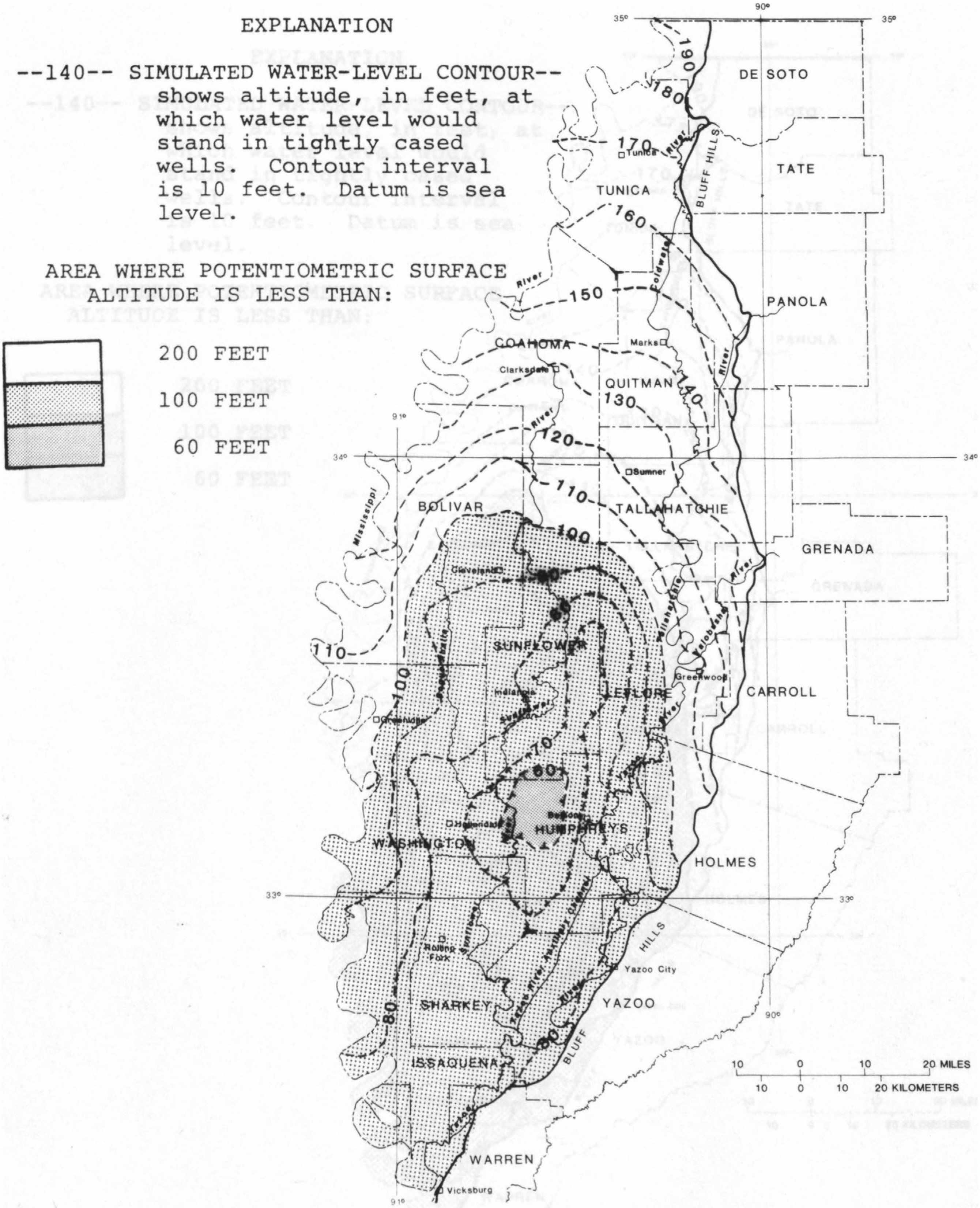



Figure 37.--Simulated potentiometric surface of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 670 million gallons per day.

EXPLANATION

--140-- SIMULATED WATER-LEVEL CONTOUR--shows altitude, in feet, at which water level would stand in tightly cased wells. Contour interval is 10 feet. Datum is sea level.

AREA WHERE POTENTIOMETRIC SURFACE ALTITUDE IS LESS THAN:

200 FEET

100 FEET

60 FEET

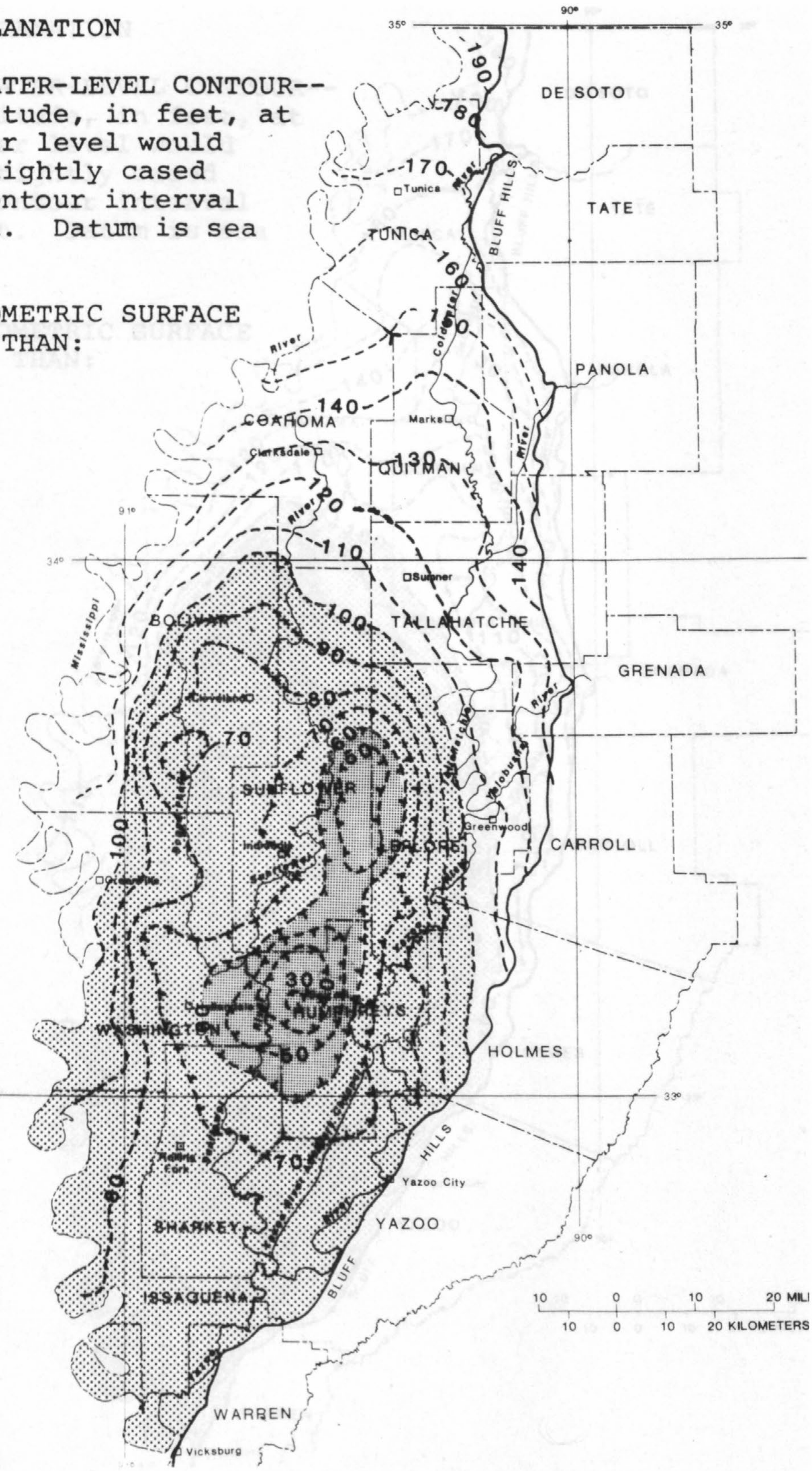



Figure 38.--Simulated potentiometric surface of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 1,100 million gallons per day.

EXPLANATION

--140-- SIMULATED WATER-LEVEL CONTOUR--shows altitude, in feet, at which water level would stand in tightly cased wells. Contour interval is 10 feet. Datum is sea level.

AREA WHERE POTENTIOMETRIC SURFACE ALTITUDE IS LESS THAN:

200 FEET

100 FEET

60 FEET

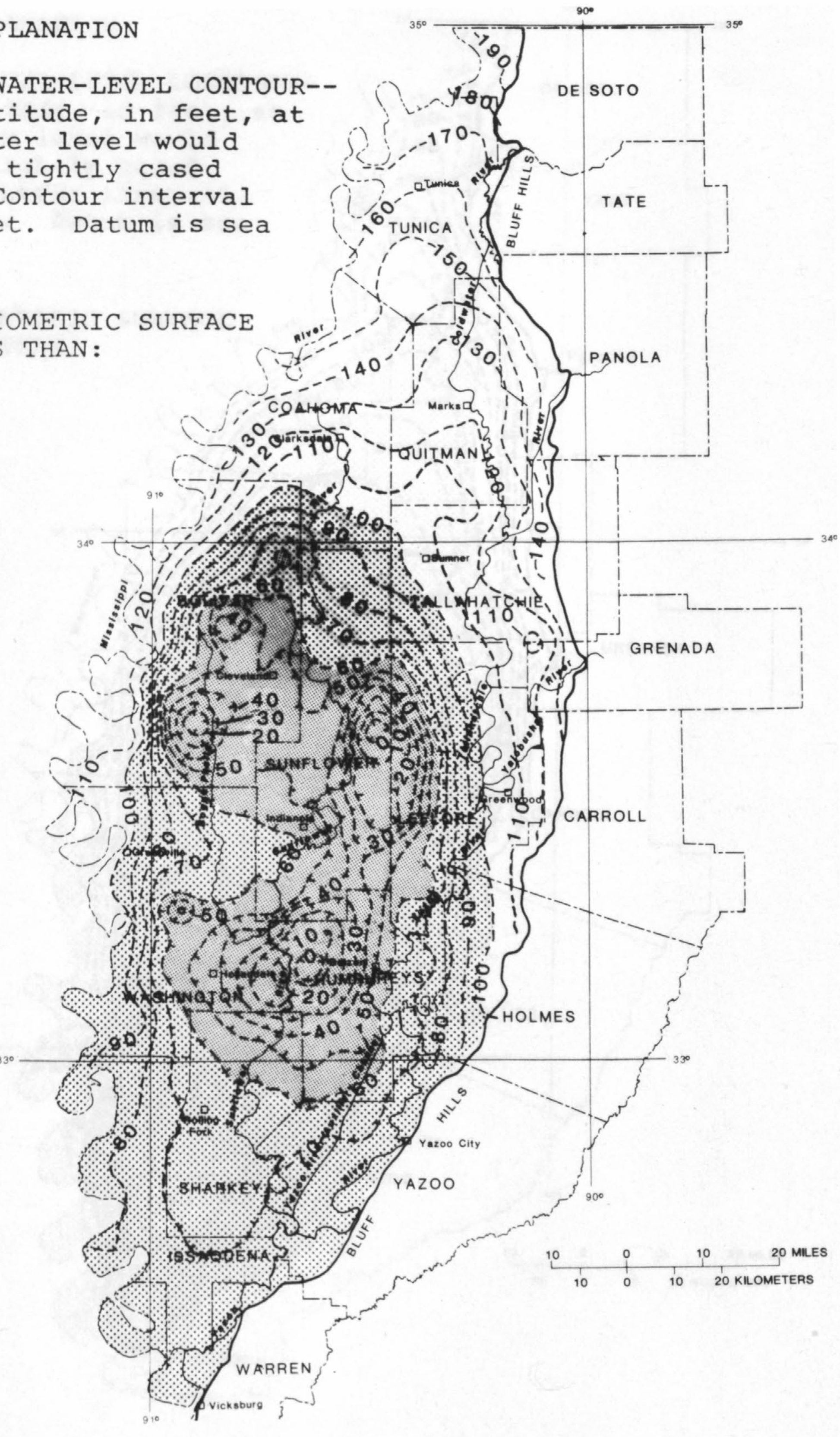



Figure 39.-- Simulated potentiometric surface of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 1,900 million gallons per day.

EXPLANATION

--140-- SIMULATED WATER-LEVEL CONTOUR--shows altitude, in feet, at which water level would stand in tightly cased wells. Contour interval is 10 feet. Datum is sea level.

AREA WHERE POTENTIOMETRIC SURFACE ALTITUDE IS LESS THAN:

200 FEET

100 FEET

60 FEET

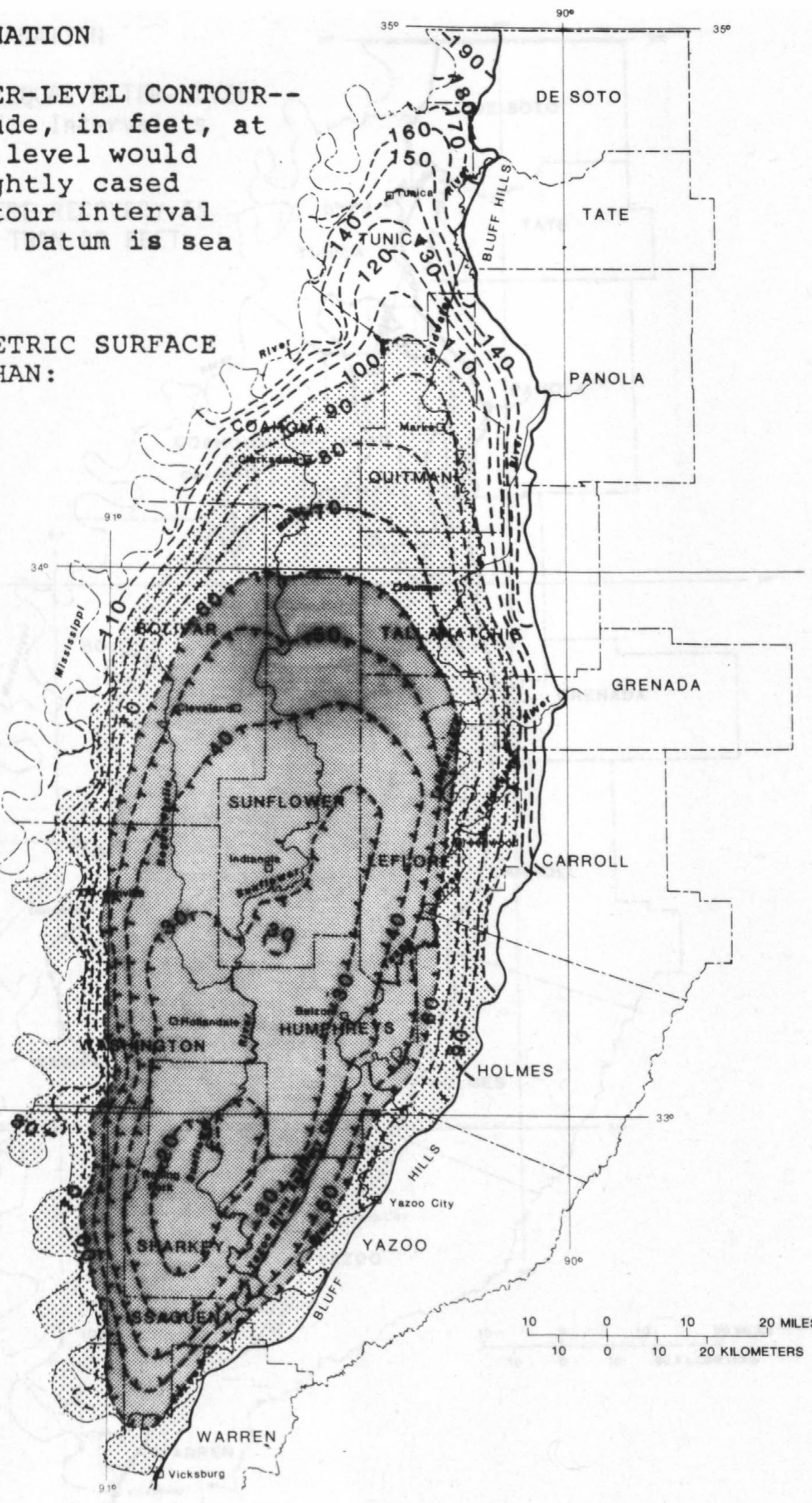



Figure 40.--Simulated potentiometric surface of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 4,000 million gallons per day and is uniformly distributed.

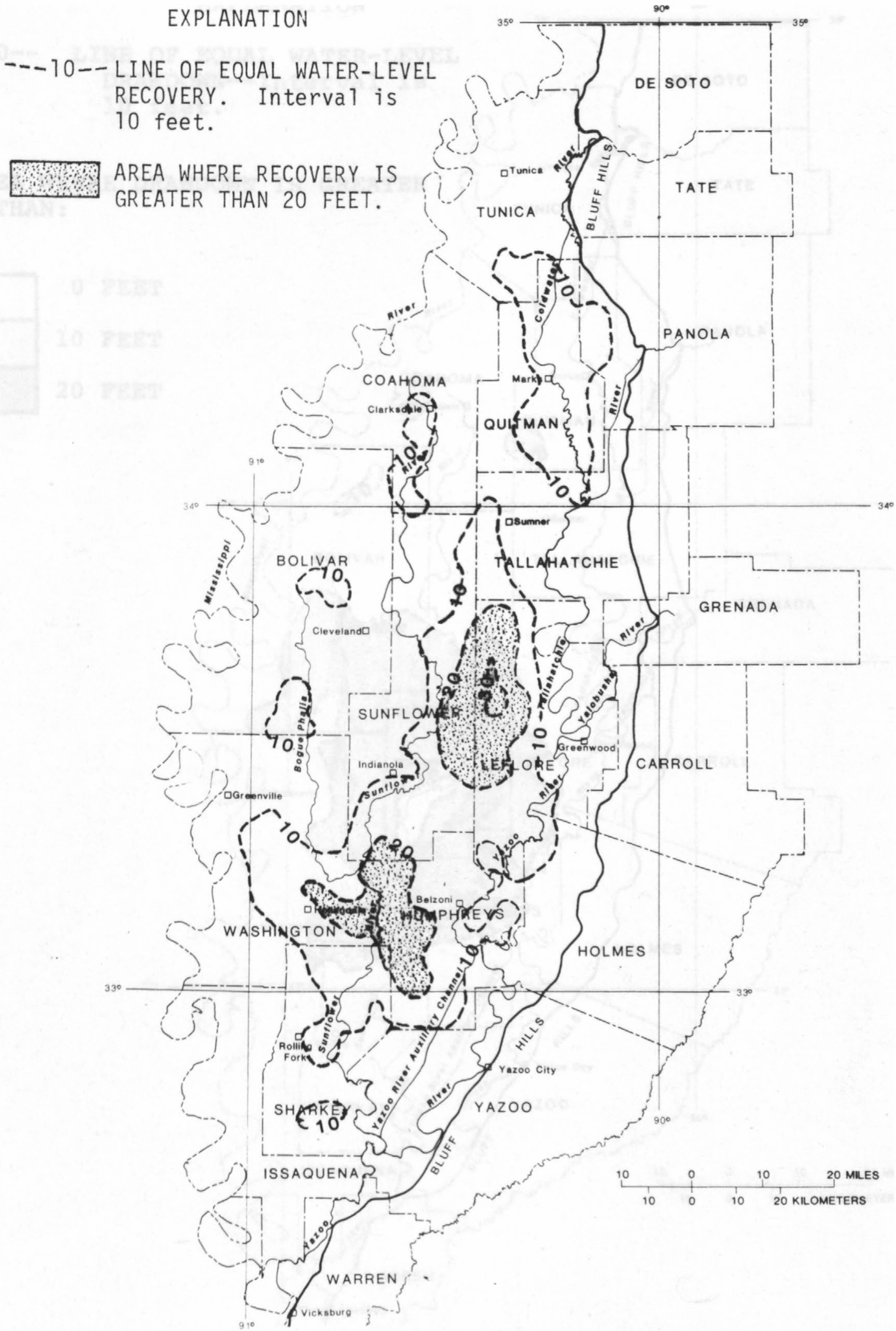



Figure 41.--Simulated recovery of water levels in the alluvial aquifer in the Delta for the period September 1983 to September 2003 assuming no pumpage.

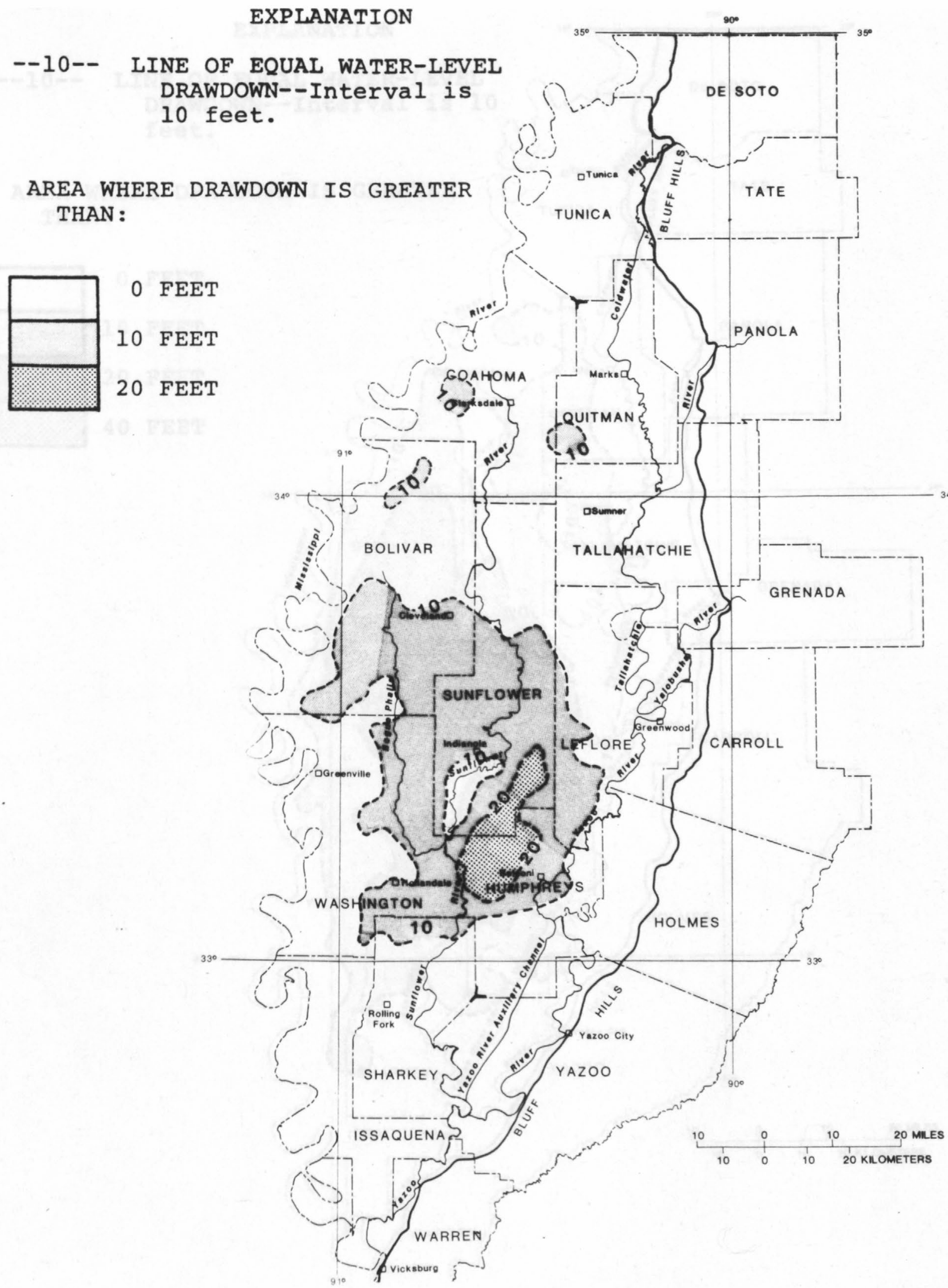



Figure 42.--Simulated drawdown of water levels in the alluvial aquifer in the Delta for the period September 1983 to September 2003 assuming pumpage is 670 million gallons per day.

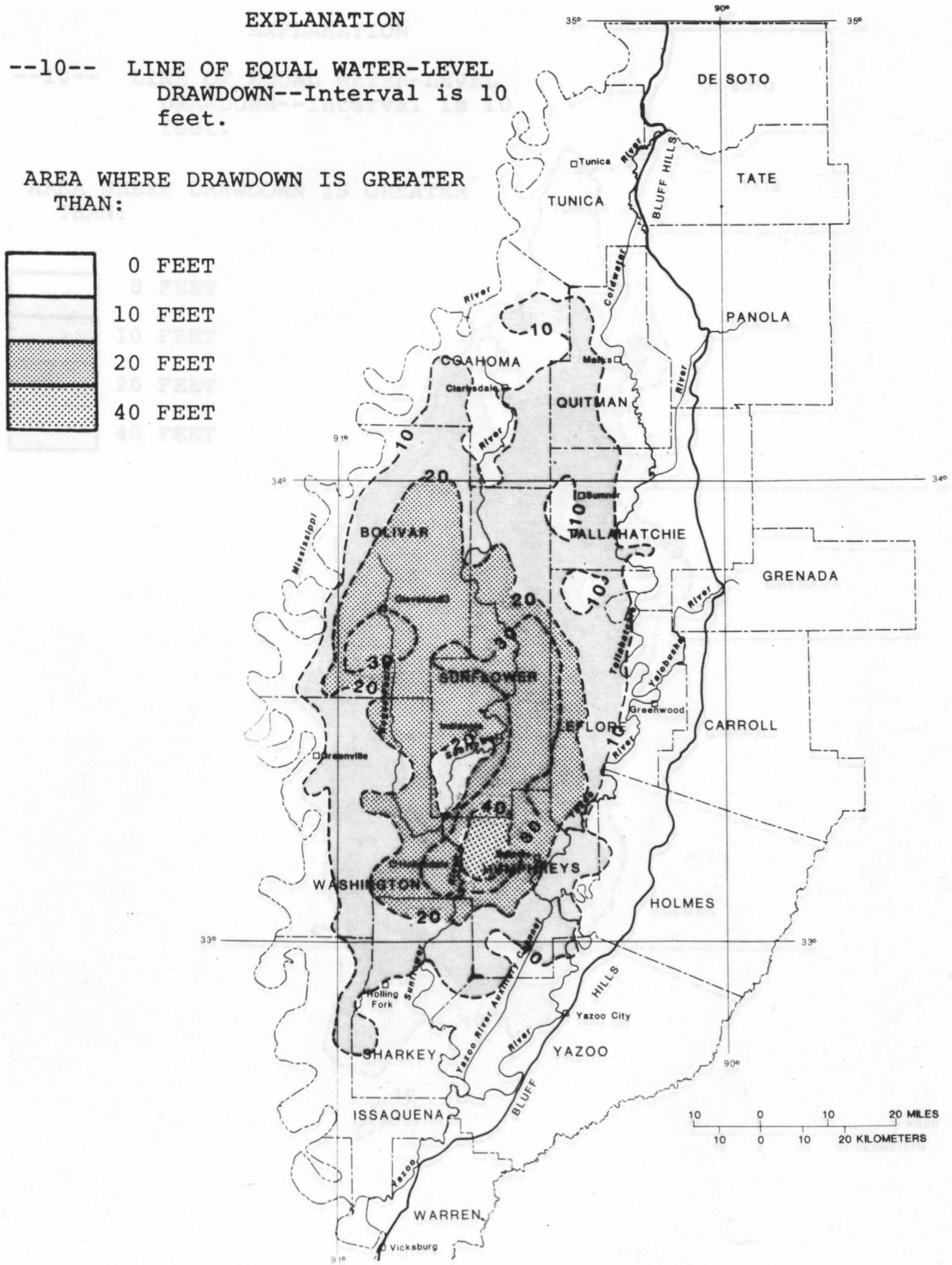



Figure 43.--Simulated drawdown of water levels in the alluvial aquifer in the Delta for the period September 1983 to September 2003 assuming pumpage is 1,100 million gallons per day.

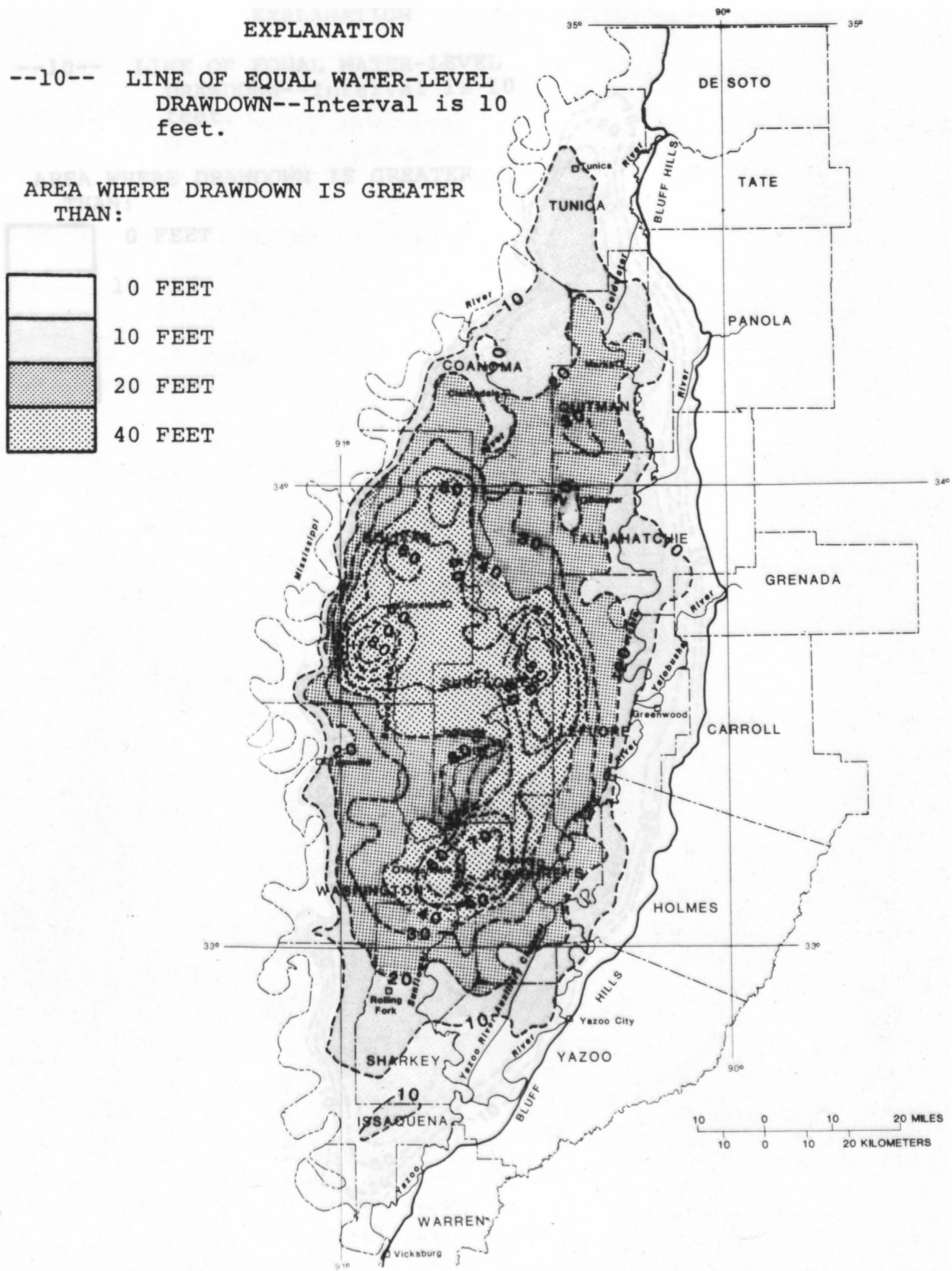



Figure 44.--Simulated drawdown of water levels in the alluvial aquifer in the Delta for the period September 1983 to September 2003 assuming pumpage is 1,900 million gallons per day.

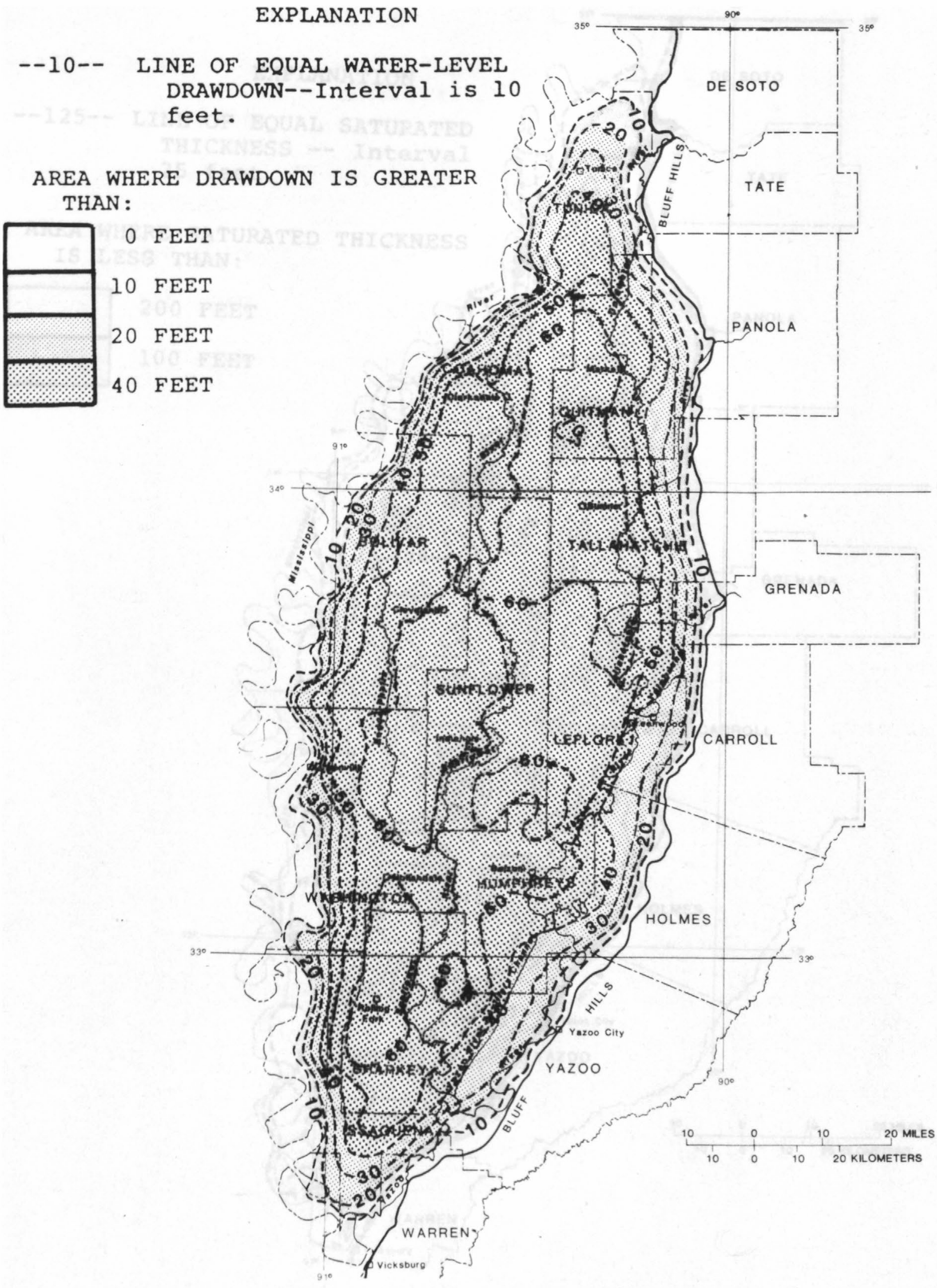



Figure 45.--Simulated drawdown of water levels in the alluvial aquifer in the Delta for the period September 1983 to September 2003 assuming pumpage is 4,000 million gallons per day and is uniformly distributed.

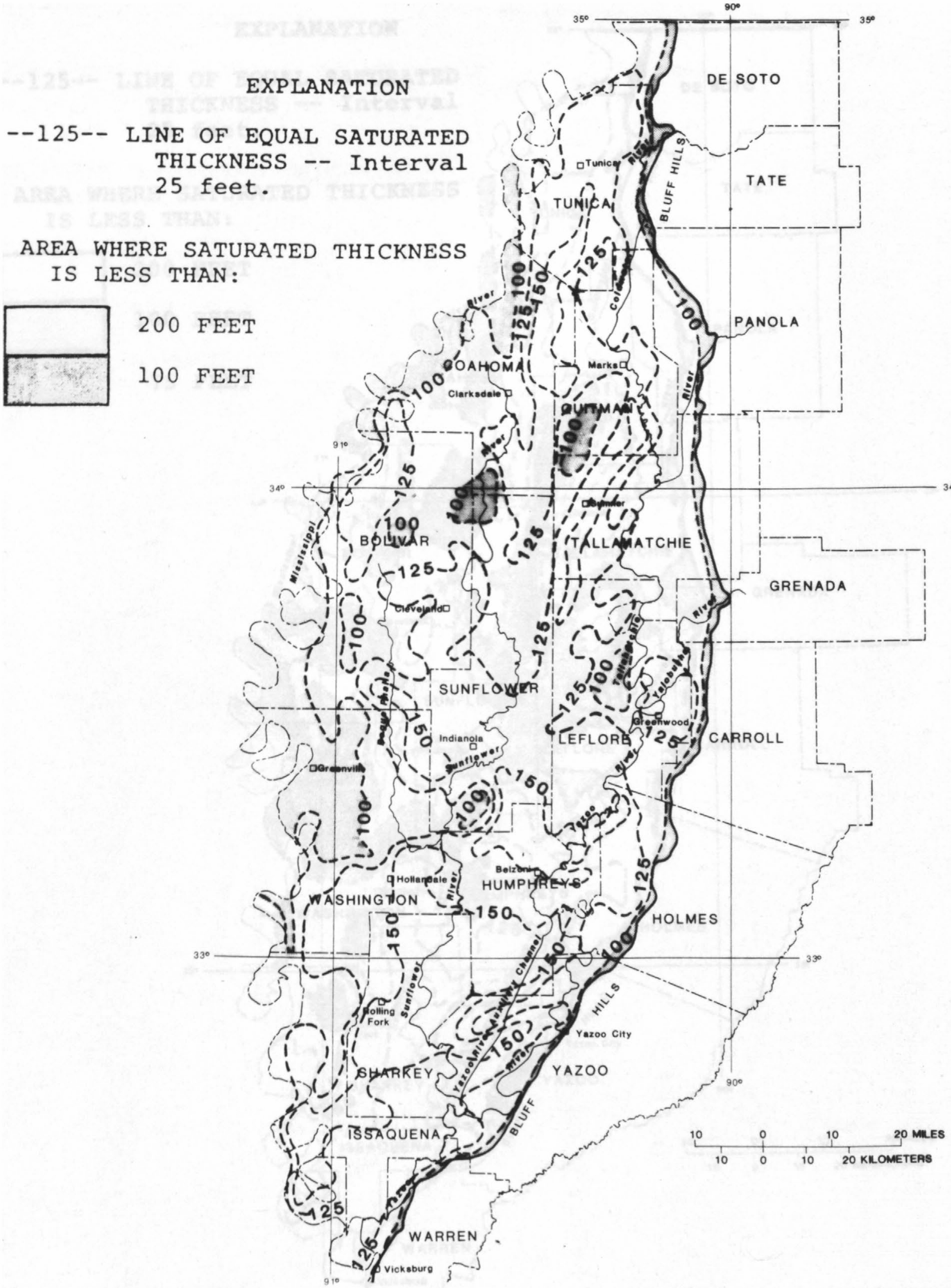



Figure 46.--Simulated saturated thickness of the alluvial aquifer in the Delta for the year 2003 assuming no pumpage.

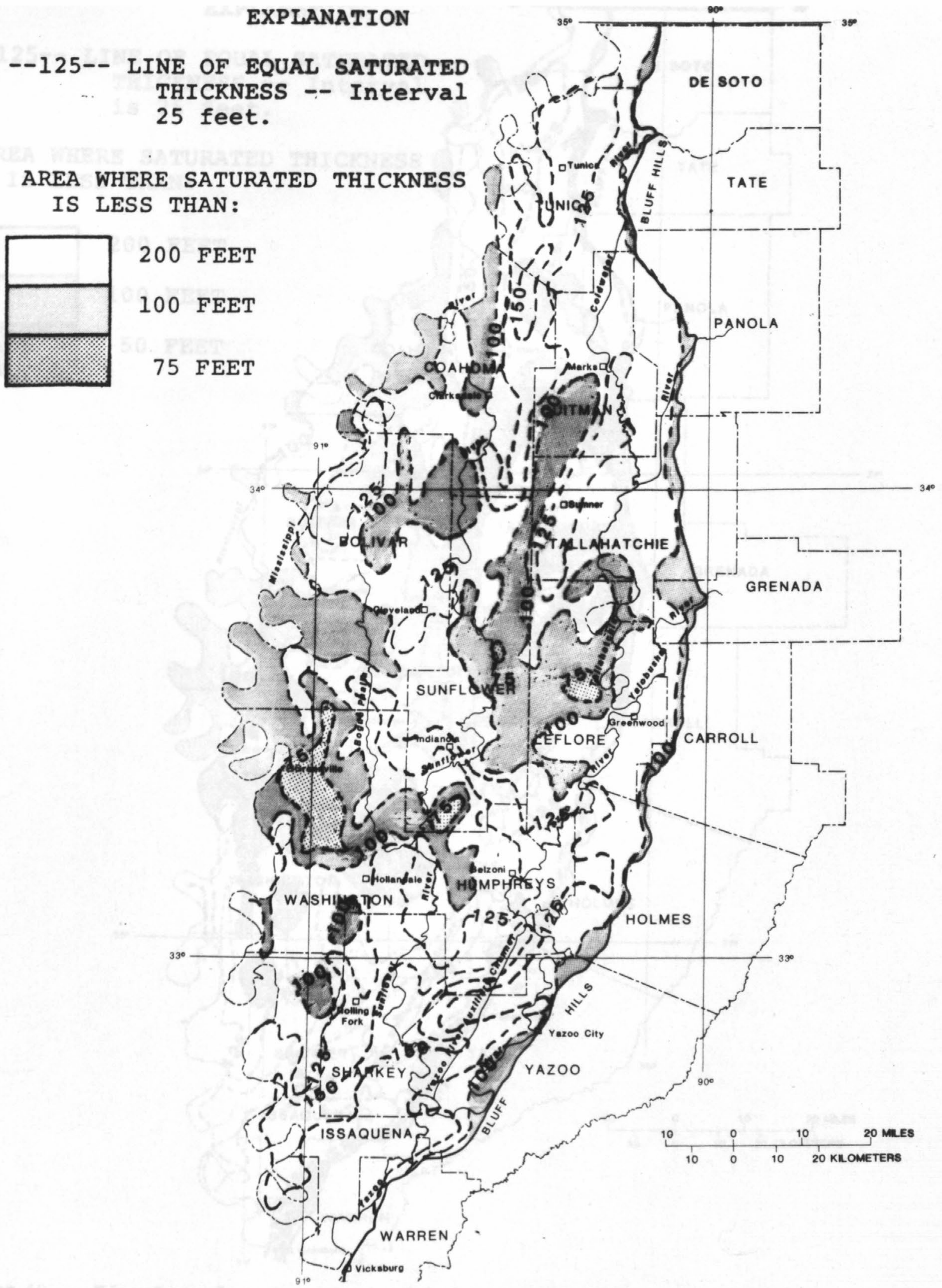



Figure 47.--Simulated saturated thickness of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 670 million gallons per day.

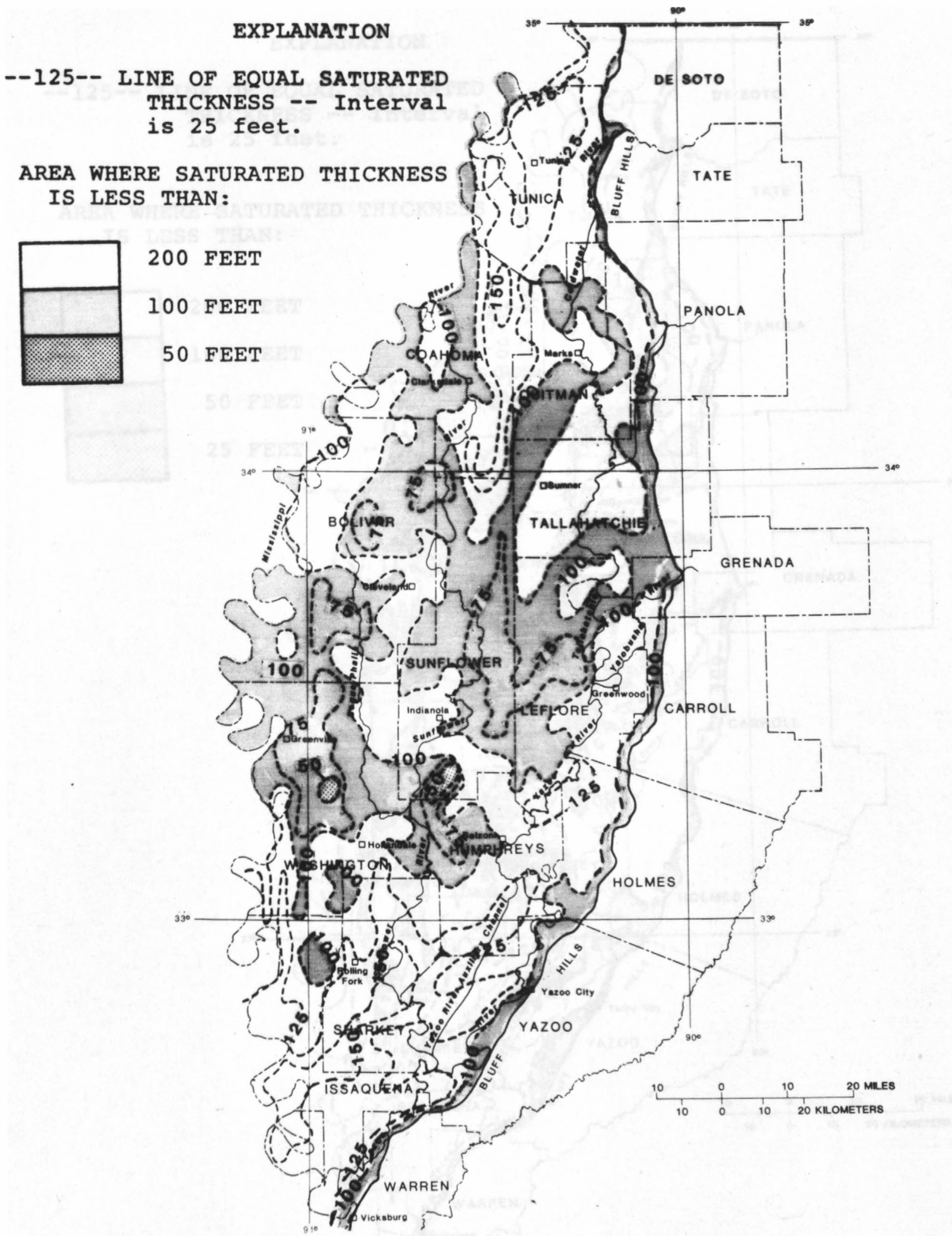



Figure 48.--Simulated saturated thickness of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 1,100 million gallons per day.

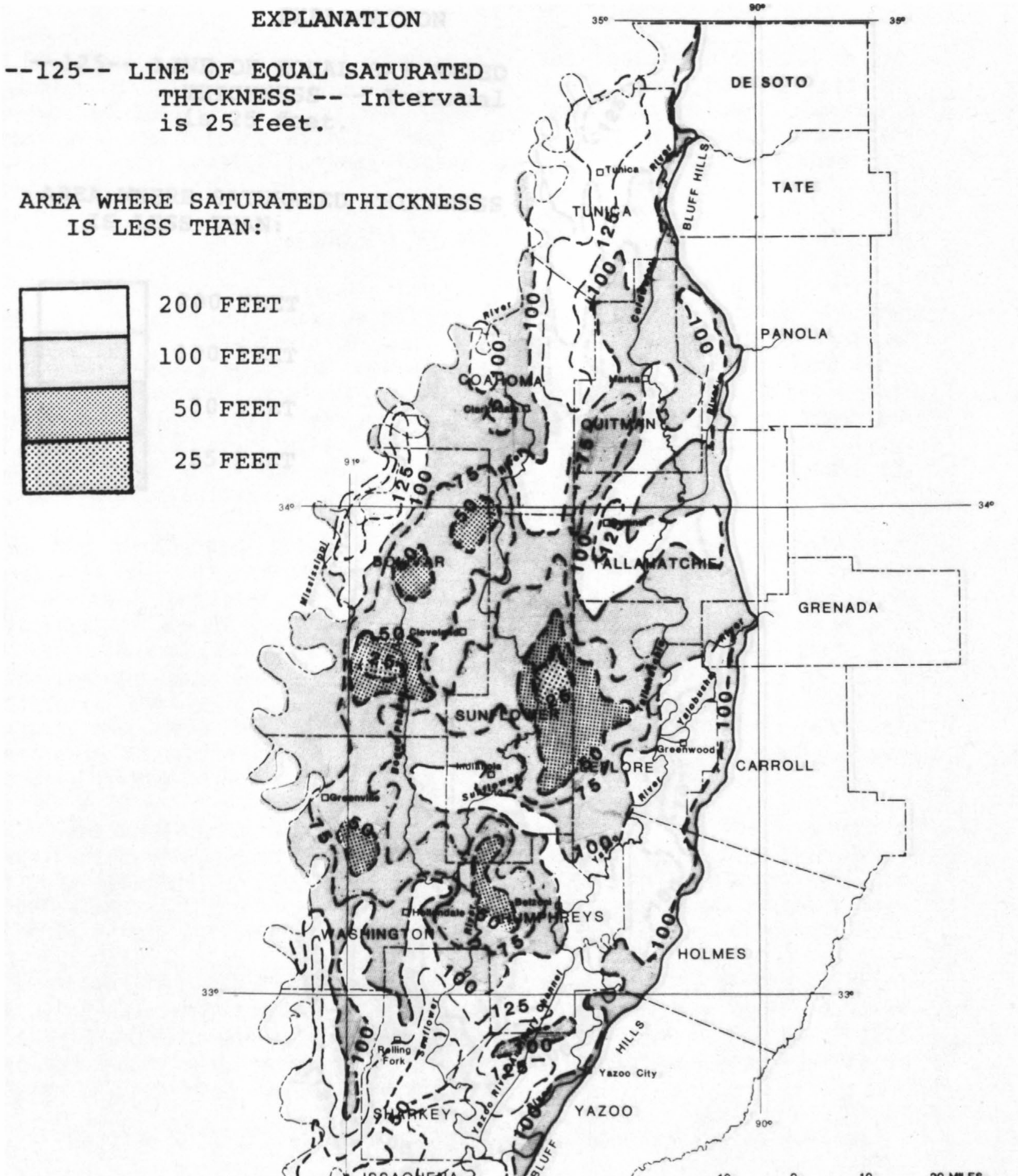



Figure 49.--Simulated saturated thickness of the alluvial aquifer in the Delta for the year 2003 assuming pumpage is 1,900 million gallons per day.

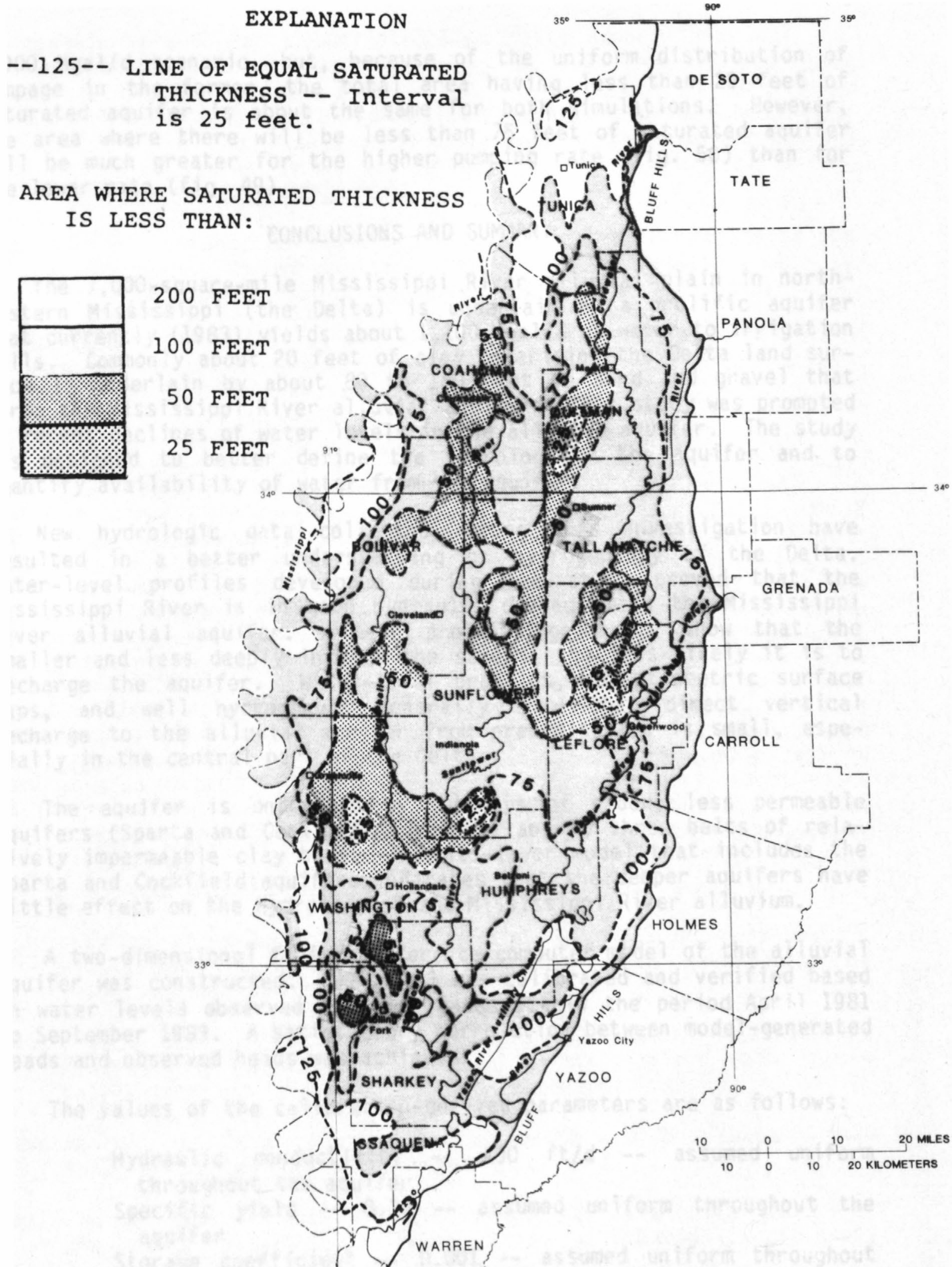



Figure 50.--Simulated saturated thickness of the alluvial aquifer in The Delta for the year 2003 assuming pumpage is 4,000 million gallons per day and is uniformly distributed.

1,900 Mgal/d scenario, but, because of the uniform distribution of pumpage in the former, the total area having less than 25 feet of saturated aquifer is about the same for both simulations. However, the area where there will be less than 75 feet of saturated aquifer will be much greater for the higher pumping rate (fig. 50) than for the lower rate (fig. 49).

## CONCLUSIONS AND SUMMARY

The 7,000-square-mile Mississippi River alluvial plain in northwestern Mississippi (the Delta) is underlain by a prolific aquifer that currently (1983) yields about 1,100 Mgal/d of water to irrigation wells. Commonly about 20 feet of clay underlying the Delta land surface is underlain by about 80 to 180 feet of sand and gravel that forms the Mississippi River alluvial aquifer. This study was prompted by recent declines of water levels in the alluvial aquifer. The study was designed to better define the hydrology of the aquifer and to quantify availability of water from the aquifer.

New hydrologic data collected during this investigation have resulted in a better understanding of hydrogeology of the Delta. Water-level profiles developed during the study proved that the Mississippi River is in good hydraulic contact with the Mississippi River alluvial aquifer. These profiles generally show that the smaller and less deeply incised the stream, the less likely it is to recharge the aquifer. Water-level profiles, potentiometric surface maps, and well hydrographs generally show that direct vertical recharge to the alluvial aquifer from precipitation is small, especially in the central part of the Delta.

The aquifer is underlain by subcrops of older, less permeable aquifers (Sparta and Cockfield aquifers) and by three belts of relatively impermeable clay beds. A multi-layer model that includes the Sparta and Cockfield aquifers indicates that the deeper aquifers have little effect on the hydrology of the Mississippi River alluvium.

A two-dimensional finite-difference computer model of the alluvial aquifer was constructed. The model was calibrated and verified based on water levels observed for five dates within the period April 1981 to September 1983. A satisfactory correlation between model-generated heads and observed heads was achieved.

The values of the calibration-derived parameters are as follows:

- Hydraulic conductivity -- 400 ft/d -- assumed uniform throughout the aquifer
- Specific yield -- 0.30 -- assumed uniform throughout the aquifer
- Storage coefficient -- 0.001 -- assumed uniform throughout the aquifer
- Areal recharge -- 0.5 inch per year -- assumed uniform throughout the area of aquifer
- Riverbed leakance --
  - Yazoo-Tallahatchie-Coldwater River system - 0.008 $d^{-1}$
  - Sunflower River - 0.004 $d^{-1}$
  - Bogue Phalia - 0.002 $d^{-1}$

The model showed that the aquifer had a net loss in storage of about 400,000 acre feet per year (360 Mgal/d) for the 2-year period April 1981 to April 1983. During this period, pumpage was about 1,270,000 acre feet per year (1,100 Mgal/d) and the net inflows from the sources of recharge were:

| | Acre-feet/year | Mgal/d |
|---|---|---|
| Mississippi River | 440,000 | 390 |
| Areal recharge | 200,000 | 180 |
| Recharge area along east edge of the Delta | 190,000 | 170 |
| Yazoo-Tallahatchie-Coldwater River system | 51,000 | 45 |
| Oxbow lakes | 27,000 | 24 |
| Sunflower River | 12,000 | 11 |
| Bogue Phalia | 1,100 | 1 |

The simulated effects of rates of pumpage by wells -- 0, 670, 1,100, 1,900, and 4,000 Mgal/d -- were projected 20 years into the future. The pumping rate of 1,100 Mgal/d is about average for the early 1980's. For this pumping rate 46 percent of the water pumped would be coming from storage at the end of 20 years and declining ground-water levels would continue. Increasing the pumping rate to 1,900 Mgal/d for the same 20-year period increases the percentage of water coming from storage to 56 percent (table 6). Simulated water levels for a pumping rate of 1,100 Mgal/d for the year 2003 show water levels to be more than 40 feet lower than in 1983 in part of Humphreys County and more than 20 feet lower in a large area in the central part of the Delta (fig. 43). It is not possible to simulate steady-state water levels for the aquifer for a 1,100 Mgal/d pumping rate because parts of the aquifer become unsaturated at some time exceeding 20 years, but before equilibrium of flow in the aquifer is reached.

## SELECTED REFERENCES


Boswell, E. H., Cushing, E. M., and Hosman, R. L., 1968, Quarternary aquifers in the Mississippi embayment, with a discussion of quality of water by H. G. Jeffery: U. S. Geological Survey Professional Paper 448-E, 15 p.

Broom, M. E., Lyford, F. P., 1981, Alluvial aquifer of the Cache and St. Francis River basins, northeastern Arkansas: U. S. Geological Survey Open-File Report 81-476, 48 p.

Brown, G. F., 1947, Geology and artesian water of the alluvial plain in northwestern Mississippi: Mississippi Geological Survey Bulletin 65, 424 p.

Callahan, J. A., 1977, Irrigation in the alluvial plain of northwestern Mississippi, 1975: Mississippi Board of Water Commissioners Bulletin 77-1, 62 p.

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

Dalsin, G. J., 1978, The Mississippi River valley alluvial aquifer in Mississippi: U. S. Geological Survey Water-Resources Investigations Report 78-106, 1 sheet.

Darden, Daphne, 1981, Water-level map of the Mississippi Delta alluvium in northwestern Mississippi, April 1981: U. S. Geological Survey Water-Resources Investigations Open-File Report 81-1123, 1 sheet.

_____ 1982a, Water-level maps of the alluvial aquifer, northwestern Mississippi, September 1981: U. S. Geological Survey Water-Resources Investigations Report 82-574, 1 sheet.

_____ 1982b, Water-level maps of the alluvial aquifer, northwestern Mississippi, April 1982: U. S. Geological Survey Water-Resources Investigations Report 82-4061, 1 sheet.

_____ 1983, Water-level maps of the alluvial aquifer, northwestern Mississippi, September 1982: U. S. Geological Survey Water-Resources Investigations Report 83-224, 1 sheet.

Fenneman, N. M., 1938, Physiography of eastern United States: New York and London, McGraw-Hill Book Co., 714 p.

Fisk, H. N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: U. S. Department of Army, Mississippi River Commission, 78 p.

Halberg, H. N., 1977, Use of water in Arkansas, 1975: Arkansas Geological Commission Water Resources Summary Number 9, 28 p.

Harbeck, G. E., Jr., Golden, H. G., and Harvey, E. J., 1961, Effect of irrigation withdrawals on stage of Lake Washington, Mississippi: U. S. Geological Survey Water-Supply Paper 1460-I, 29 p.

Harvey, E. J., 1956, Records of wells in the alluvium in northwestern Mississippi: Mississippi Board of Water Commissioners Bulletin 56-1, 130 p.

Holand, T. W. and Ludwig, A. H., 1981, Use of water in Arkansas, 1980: Arkansas Department of Commerce and Arkansas Geological Commission: Water Resources Summary No. 14, 30 p.

Johnson, A. I., Mosten, R. P., and Versaw, S. F., 1966, Laboratory study of aquifer properties and well design for an artificial-recharge site: U. S. Geological Survey Water-Supply Paper 1615-H, 42 p.

Krinitzsky, E. L., and Wire, J. C., 1964, Groundwater in alluvium of the lower Mississippi Valley (upper and central areas): U. S. Department of Army, Corps of Engineers Technical Report No. 3-658, v. 1 and 2, 100 p.

Lamonds, A. G., 1971, Hydrology of Horseshoe Lake, Arkansas: U. S. Geological Survey Open-File Report, 77 p.

Lobmeyer, D. H., and Sauer, C. G., 1974, Water Resources of Hamilton County, southwestern Kansas: U. S. Geological Survey Hydrologic Investigations Atlas HA-516, 2 sheets.

Lohman, S. W., 1972, Ground-water hydraulics: U. S. Geological Survey Professional Paper 708, 70 p.

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

Mississippi Agricultural Statistics, Mississippi Crop and Livestock Reporting Service, Annual and summary reports 1949-83: Jackson, Mississippi.

Newcome, Roy, Jr., 1971, Results of aquifer tests in Mississippi: Mississippi Board of Water Commissioners Bulletin 71-2, 44 p.

_______, 1976, The Sparta aquifer system in Mississippi: U. S. Geological Survey Water-Resources Investigations Report 76-7, map.

Smith, F. L., 1979, Geological investigation of the Yazoo Basin, Lower Mississippi Valley: U. S. Army Corps of Engineers, Waterways Experiment Station, Technical Report No. 3-480.

Sniegocki, R. T., 1964, Hydrogeology of a part of the Grand Prairie region, Arkansas: U. S. Geological Survey Water-Supply Paper 1615-B, 72 p.

Speer, P. R., Golden, H. G., Patterson, J. F., and others, 1964, Low-flow characteristics of streams in the Mississippi embayment in Mississippi and Alabama, with a section on quality of water by W. J. Welborne: U. S. Geological Survey Professional Paper 448-I, 47 p.

Spiers, C. A., 1977, The Cockfield aquifer in Mississippi: U. S. Geological Survey Water-Resources Investigations Report 77-17, map.

Sumner, D. M., 1984a, Water-level maps of the alluvial aquifer, Mississippi, April 1983: U. S. Geological Survey Water-Resources Investigations Report 83-4285, 1 sheet.

______ 1984b, Water-level maps of the alluvial aquifer, northwestern Mississippi, September 1983: U. S. Geological Survey Water-Resources Investigations Report 84-4346, 1 sheet.

Turcan, A. N., Jr., and Meyer, R. R., 1962, Alluvial aquifer in northeastern Louisiana--A large source of water: U. S. Geological Survey Water-Supply Paper 1619-V, 28 p.

Wasson, B. E., 1980a, Sources for water supplies in Mississippi: Mississippi Research and Development Center Bulletin, 112 p.

______ 1980b, Water-level map of the Mississippi Delta Alluvium in northwestern Mississippi, September 1980: Bureau of Land and Water Resources Map 80-1, 1 sheet.

______ 1981a, Potentiometric map of the Cockfield aquifer in Mississippi, 1980: U. S. Geological Survey Water-Resources Investigations Open-File Report 81-1053, 1 sheet.

______ 1981b, Potentiometric map of the Sparta aquifer system in Mississippi, Fall 1980: U. S. Geological Survey Water-Resources Investigations Open-File Report 81-1051, 1 sheet.

Whitfield, M. S., 1975, Geohydrology and water quality of the Mississippi River alluvial aquifer, northeastern Louisiana: Louisiana Department Public Works Water Resources Technical Report No. 10, 29 p.

Sumner, Wasson

Geohydrology and Simulated Effects of Large Ground-Water Withdrawals on the Mississippi River Alluvial Aquifer in Northwestern Mississippi

OFR 84-822

USGS LIBRARY-RESTON
3 1818 00061827 0