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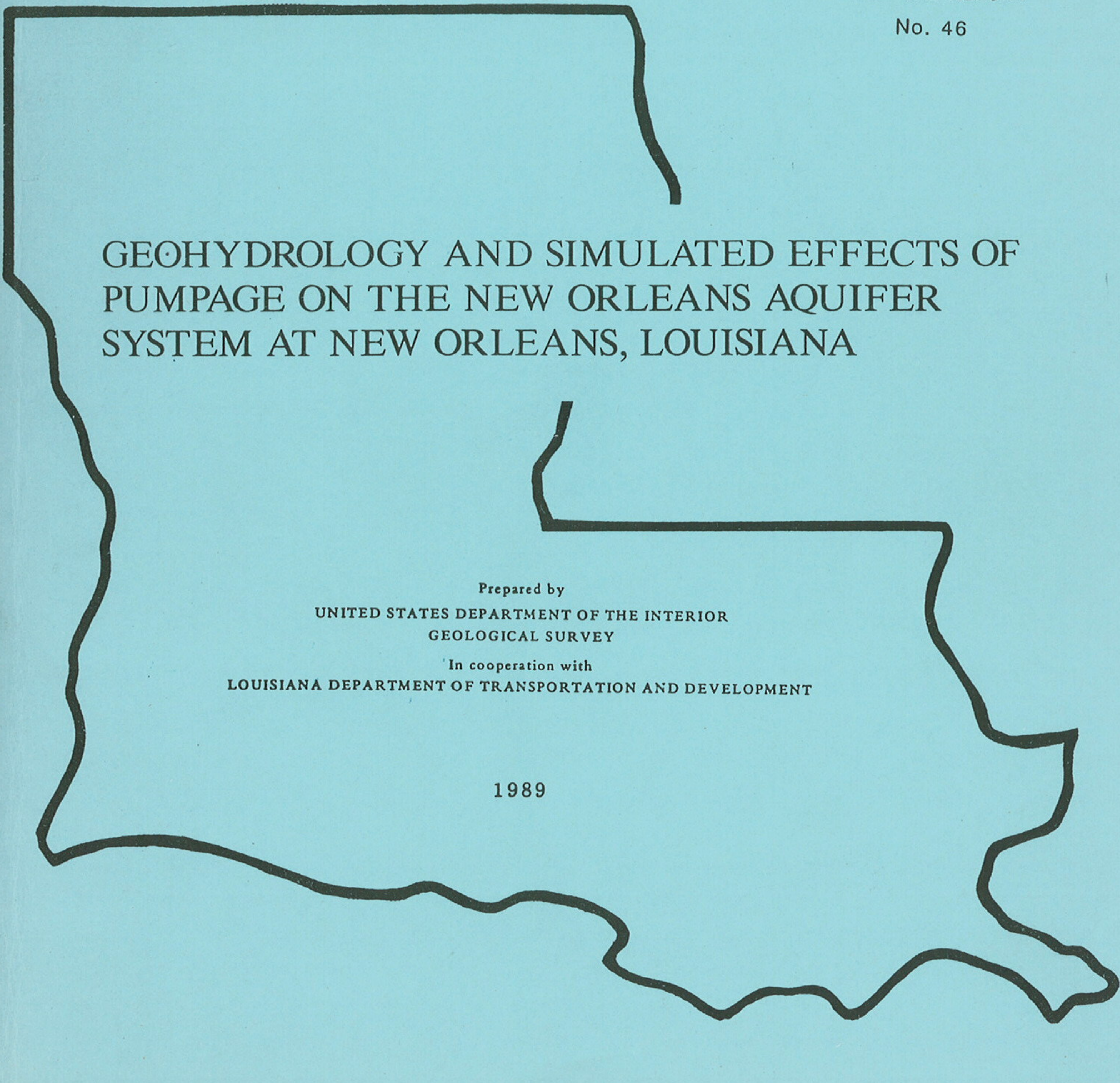
TECHNICAL REPORT
No. 46



GEOHYDROLOGY AND SIMULATED EFFECTS OF PUMPAGE ON THE NEW ORLEANS AQUIFER SYSTEM AT NEW ORLEANS, LOUISIANA

Prepared by
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
In cooperation with
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

1989

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By

D.C. Dial and D.M. Sumner

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BUDDY ROEMER, Governor

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NEIL L. WAGONER, Secretary

Cooperative projects with the

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

Darwin Knochenmus
District Chief
U.S. Geological Survey
P.O. Box 66492
Baton Rouge, LA 70896-6492

Telephone: (504) 389-0281

Z. "Bo" Bolourchi
Chief, Water Resources Section
Louisiana Department of
Transportation and Development
P.O. Box 94245
Baton Rouge, LA 70804-9245
Telephone: (504) 379-1434

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound units	By	To obtain metric units
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
square foot (ft^2)	0.0929	square meter (m^2)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
gallon per minute (gal/min)	3.785	liter per minute (L/min)
million gallons per day (Mgal/d)	3,785	cubic meter per day (m^3/d)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)

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

GEOHYDROLOGY AND SIMULATED EFFECTS OF PUMPAGE ON THE NEW ORLEANS AQUIFER SYSTEM AT NEW ORLEANS, LOUISIANA

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ABSTRACT

The New Orleans aquifer system was evaluated as an alternative public-supply source for New Orleans. It is the only aquifer system that contains a large volume of freshwater beneath the city. The geohydrologic framework of the New Orleans aquifer system consists of a series of alternating beds of sand and clay that deepen southward toward the Gulf of Mexico. The aquifer system in this investigation includes the Gramercy, Norco, Gonzales-New Orleans, and "1,200-foot" aquifers, and the intervening clay beds. Transmissivities of the aquifers range between 9,000 and 32,000 feet squared per day. Hydraulic conductivities range from 100 to 130 feet per day and storage coefficients average about 0.0005, based on aquifer-test results. Aquifer-test data are unavailable for the "1,200-foot" aquifer. Confining-unit hydraulic conductivities were based on their depth of burial.

A three-dimensional finite-difference ground-water flow model was used to evaluate the New Orleans aquifer system. The model was calibrated by comparing observed and computed water levels for the period 1900 to 1981. Differences of 20 feet or less were observed for most of the modeled area. The model was used to predict the effects of pumping on water levels and saltwater encroachment. Flow within the aquifer system was simulated for the period 1987-2006 at the 1986 pumping rate of 40 Mgal/d (million gallons per day) and with an increase of 130 Mgal/d over the 1986 rate. The first simulation showed a gradual recovery over the 20-year period. The lowest water level at the end of 20 years was 90 feet below sea level near Michoud. The second simulation showed a maximum decline of 410 feet below sea level near the lakefront at Lake Pontchartrain. Dewatering of the aquifer could possibly occur as a result of increased pumping, but its effect is of little significance.

The increased pumpage required to supply New Orleans (130 Mgal/d superimposed on the present pumpage of 40 Mgal/d) would cause saltwater to move more rapidly toward the areas of pumping. The rate of encroachment in the Industrial Canal area would be about 500 feet per year and in the Michoud area about 250 feet per year. The Gonzales-New Orleans aquifer has the capability to supply the needs of New Orleans but certain problems need to be addressed such as the effect of water-level decline on subsidence and the control of saltwater encroachment.

INTRODUCTION

The impetus for this study was a growing public concern over the deteriorating quality of drinking water from the Mississippi River. At present (1986), the river is the sole source of public water supply for the residents of the city of New Orleans and the surrounding five-parish area. Previous occurrences of surface-water-quality degradation, such as the spillage of hazardous chemicals into the river and saltwater encroachment from the Gulf of Mexico during periods of low river flow, focused attention on the need for an alternative public drinking-water source. The New Orleans aquifer system in the New Orleans area is a possible alternative source. In 1981, the U.S. Geological Survey, in cooperation with the Louisiana Department of Transportation and Development, began an investigation to determine the effects of past, present, and projected future pumping stresses on the New Orleans aquifer system. The study area includes the city of New Orleans and most of Orleans Parish (fig. 1).

Purpose and Scope

The purposes of this report are to: (1) describe the geohydrologic setting and analyze the movement of ground water in the New Orleans aquifer system, and (2) determine the effect of pumping on water levels and saltwater encroachment in the Gonzales-New Orleans aquifer.

The study consisted of two phases. The first phase involved the compilation and publication of a ground-water data report that included information on water levels, ground-water withdrawals, and water quality of the aquifers in the five-parish greater New Orleans area (Dial, 1983). Other information included the status of saltwater encroachment in the New Orleans aquifer system as of 1981 and test drilling and installation of observation wells.

The second phase involved the construction and calibration of a numerical flow model that simulated ground-water flow conditions in the New Orleans aquifer system. Model input was derived from several sources including the data report, areal ground-water reports, well records, and geophysical logs. The calibrated model was used to simulate the effects of past, present, and projected future pumping from the aquifer. Simulations were made to estimate future water levels and determine the direction and the rate of saltwater movement.

Previous Investigations

Information on ground-water levels and water quality of aquifers in southeastern Louisiana was described by Harris (1904). The aquifers in the New Orleans area were described first by Eddards and others (1956). Rollo (1966) did an interpretive study of ground-water resources in the New Orleans area. Cardwell and others (1963) summarized well data of all the Mississippi River parishes south of Baton Rouge. Dial (1983) completed an updated data report of the greater New Orleans area. Reports that describe ground-water investigations of the Mississippi River parishes between New Orleans and Baton

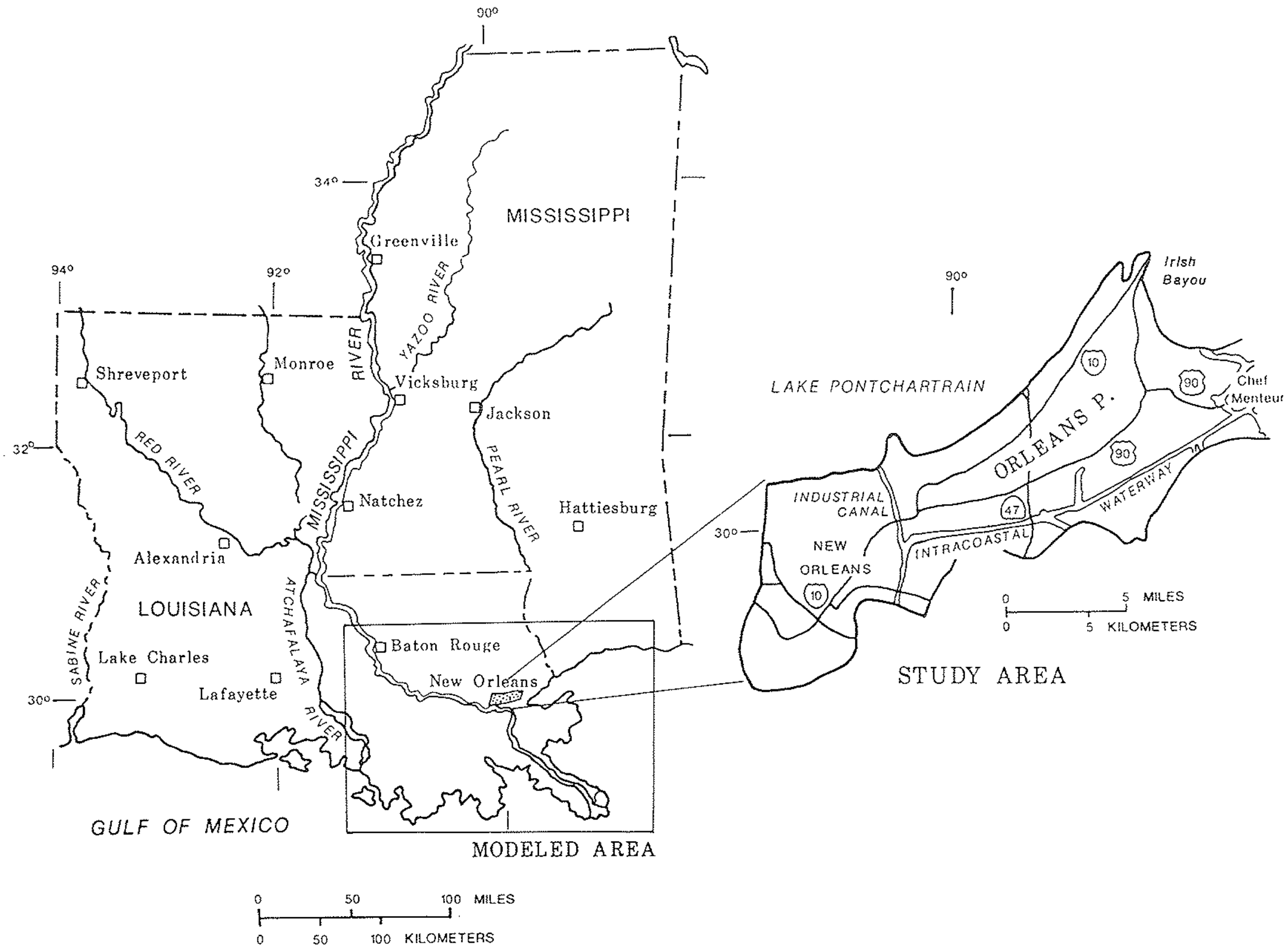


Figure 1.--Locations of study and modeled areas.

Rouge are: Norco area (Hosman, 1972), Gramercy area (Dial and Kilburn, 1980), Geismar-Gonzales area (Long, 1965), and Plaquemine-White Castle area (Whiteman, 1972). Other reports include the Lake Pontchartrain area (Cardwell and others, 1967), Tangipahoa and St. Tammany Parishes (Nyman and Fayard, 1978), and Washington Parish (Case, 1979).

GEOHYDROLOGY OF THE NEW ORLEANS AQUIFER SYSTEM

In the study area, ground water is present in a complex series of alternating beds of sand and clay. The beds dip gently southward (on the order of 25 ft/mi, feet per mile) as a result of downwarping on the southern flank of the Southern Mississippi uplift (Fisk, 1944, p. 65). The dip increases progressively toward the coast as a result of subsidence caused by sediment deposition in the Gulf of Mexico. The Southern Mississippi uplift and the Mississippi structural trough, a downwarp that parallels the present Mississippi River valley (Fisk, 1944, p. 64), are the geologic structures that affect the regional ground-water flow patterns (fig. 2). The alternating beds of sand are aquifers, and the beds of clay are confining units between the aquifers. A geohydrologic summary of the aquifers is shown in table 1, and generalized geohydrologic sections showing the aquifers and intervening clay beds are shown in figure 3.

Aquifers and Confining Units

The New Orleans aquifer system is defined as the succession of beds of sand and clay from the land surface to the base of the "1,200-foot" aquifer. The major aquifers in this succession, from youngest to oldest, are the Gramercy, Norco, Gonzales-New Orleans, and "1,200-foot" aquifers. Also, a part of the aquifer system, but of little importance to the New Orleans area, includes the shallow aquifers and the Mississippi River alluvial aquifer (table 1). The aquifer outcrop areas (fig. 4) define the northern boundary of the aquifers in this study. The aquifers become shallower toward the outcrop areas and either pinch out or merge with shallow sand beds near land surface.

The surficial deposits in each aquifer outcrop area consist of clay and interbedded thin beds of sand. The confining unit between the surficial deposits and the underlying aquifers gradually thickens southward and the underlying aquifers become more deeply buried. In areas where the Gramercy and Norco aquifers are absent, this confining unit may be more than 400 ft (feet) in thickness (fig. 5). The confining units between each of the aquifers consist mostly of clay with some interbedded silty or sandy lenses. The thickness of these confining units, shown in figures 6-8, ranges from a few feet to over 200 ft.

The shallow aquifers in New Orleans consist of point-bar deposits, distributary-channel deposits, and discontinuous near-surface beds of sand. The Mississippi River alluvial aquifer is not present in New Orleans but is included in table 1 because of its hydraulic connection with the Mississippi River and with the Gramercy aquifer ("200-foot" sand), Norco aquifer ("400-foot" sand), Gonzales-New Orleans aquifer ("700-foot" sand), and the "1,200-

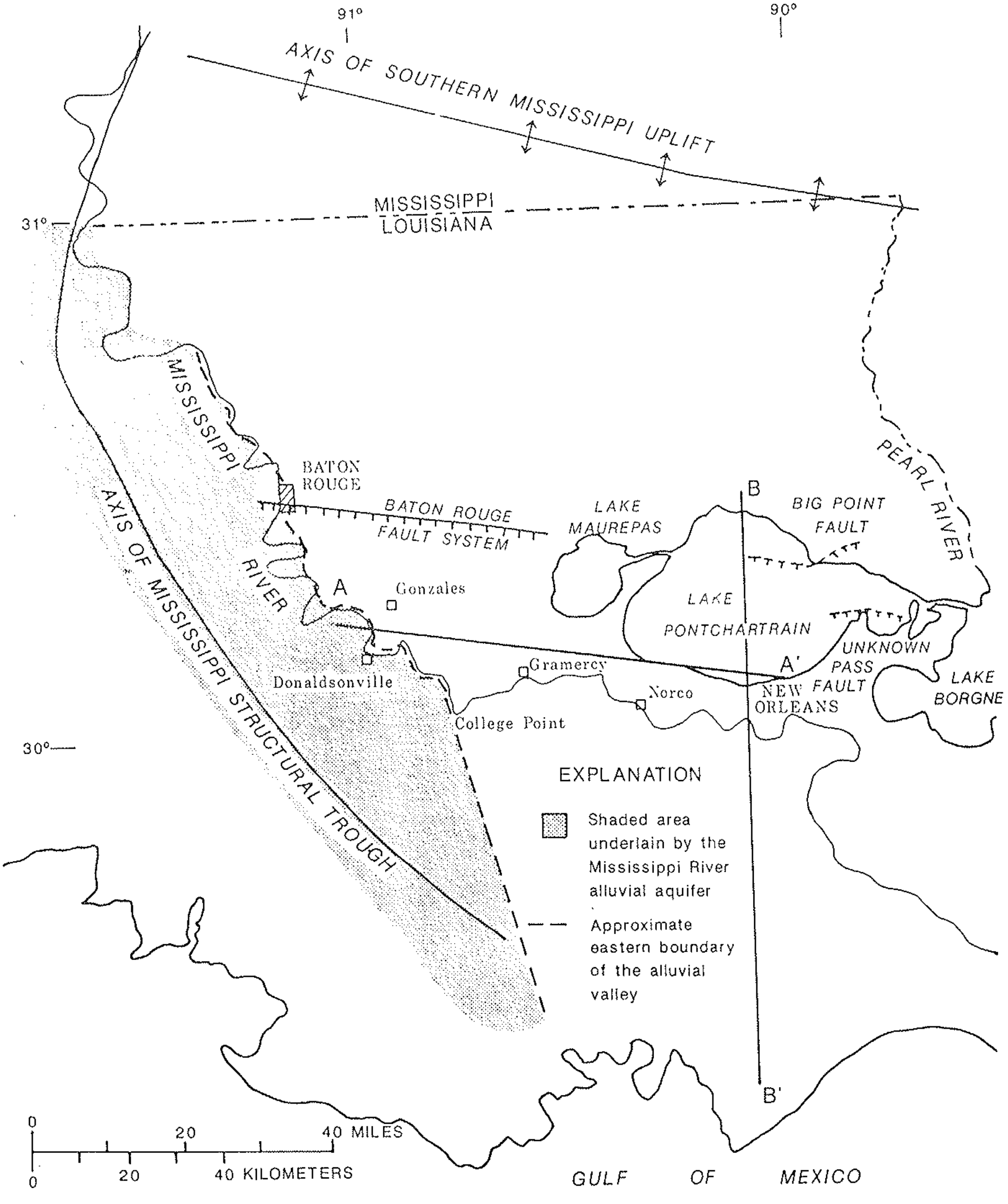


Figure 2.--Structural features affecting prepumping ground-water movement in southeastern Louisiana and southern Mississippi.

Table 1.--Geohydrologic summary of aquifers in the New Orleans area

[ft/d, feet per day; mg/L, milligrams per liter;
µg/L, micrograms per liter]

System	Series		Aquifer	Thickness (feet)	Description and remarks (depth of top, in feet)	Aquifer properties	Water quality[1]
Quaternary	Holocene	Shallow aquifers	Point-bar deposits	Variable; maximum 150	Fine to very fine sand and silt. Bars accumulate on inside of river bends. (10-60)	No aquifer test results.	Generally very hard with high iron concentrations.
	Pleistocene		Distributary-channel deposits	Maximum 100	Fine sand. May contain organic debris. (5-10)	No aquifer test results.	Generally very hard with high iron concentrations.
			Discontinuous isolated near surface beds of sand	Variable; maximum 180	Variable lithology. Sands occur locally and pinch out in short distances.	No aquifer test results.	Variable depending on location. Generally contains salty, very hard water.
			Mississippi River alluvial aquifer	60-120	Fine to medium sand at top; grading to coarse sand and gravel in lower part. (75-130) Not present downstream from College Point.	Estimated hydraulic conductivity 200 ft/d or more in coarse sand and gravel.	Hard to very hard with high iron concentrations.
		New Orleans aquifer system	Gramercy ("200-foot" sand)	0-150	Fine to coarse sand. Discontinuous with variable thickness. Hydraulically connected with the Mississippi River. (125-225)	Estimated hydraulic conductivity 100 ft/d. Estimated storage coefficient 0.0005.	Generally salty water except in northwest corner of Jefferson Parish.
			Norco ("400-foot" sand)	0-275	Fine to medium sand. Variable thickness; pinches out in eastern Orleans Parish. (300-400)	Estimated hydraulic conductivity 130 ft/d. Estimated storage coefficient 0.0005.	Generally salty water except in northwest corner of Jefferson Parish and western part of St. Charles Parish. Where fresh, water has low hardness with pH between 7.5 and 8.0 standard units.
			Gonzales-New Orleans ("700-foot" sand)	150-300	Mostly fine to medium sand of uniform texture. Continuous throughout the area. (400-800)	Estimated hydraulic conductivity 110 ft/d based on tests in Jefferson and Orleans Parishes. Estimated storage coefficient 0.0005.	Contains salty water in part of area. Freshwater is soft and low in iron and manganese concentrations; pH averages about 8.0 standard units.
			"1,200-foot" aquifer	50-130	Fine to medium sand. (800-1,200)	Estimated hydraulic conductivity 100 ft/d. Estimated storage coefficient 0.0005.	Contains salty water except in northeast corner of Orleans Parish.

[1] The U.S. Geological Survey (Hem, 1985, p. 159) classifies hardness as follows: Water having a hardness of 0-60 mg/L is considered soft, 61-120 mg/L is moderately hard, 121-180 mg/L is hard, and more than 180 mg/L is very hard.
Iron concentration equal to or greater than 300 µg/L is considered high; a concentration less than 300 µg/L is considered low.
Chloride concentration greater than 250 mg/L is considered salty.

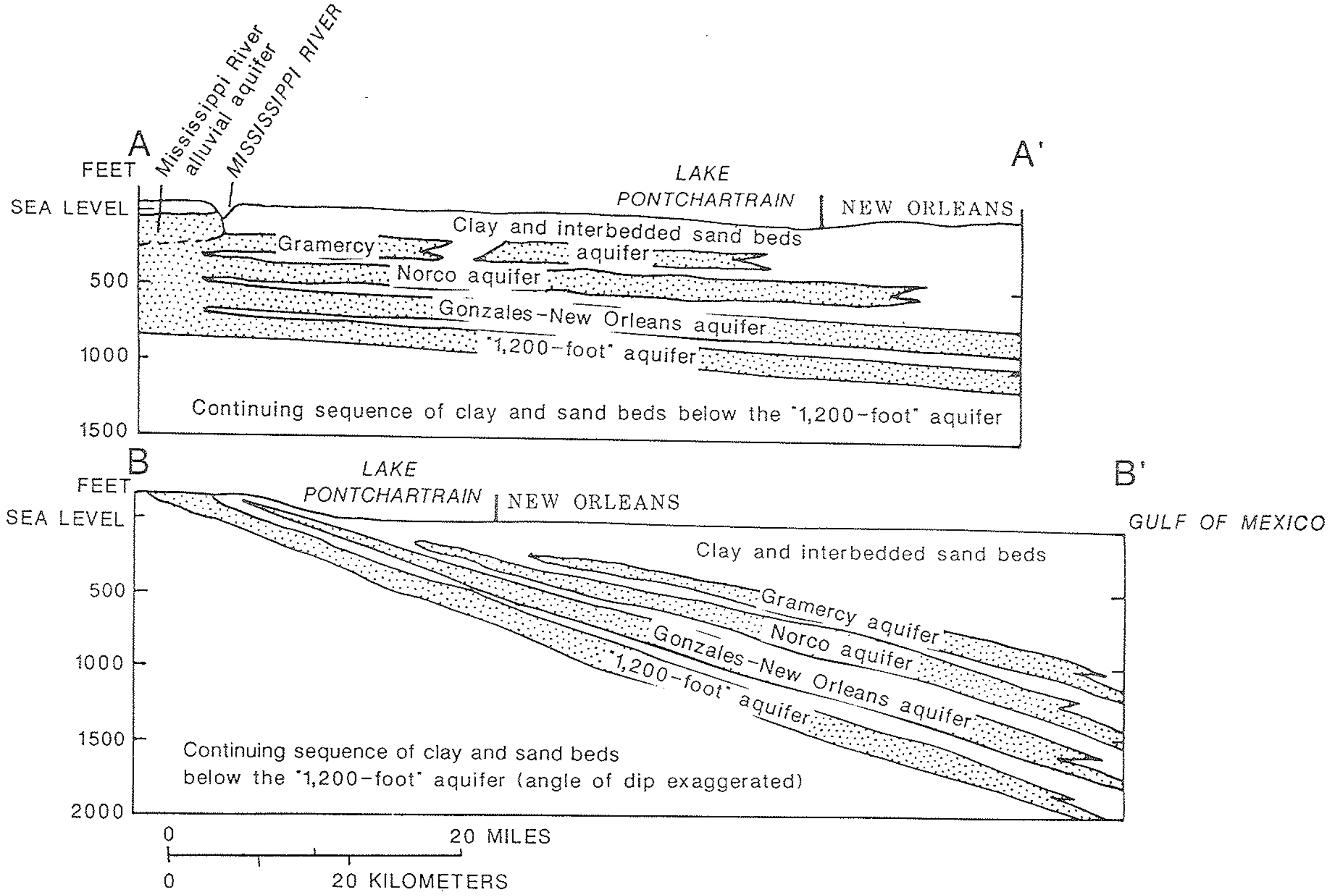
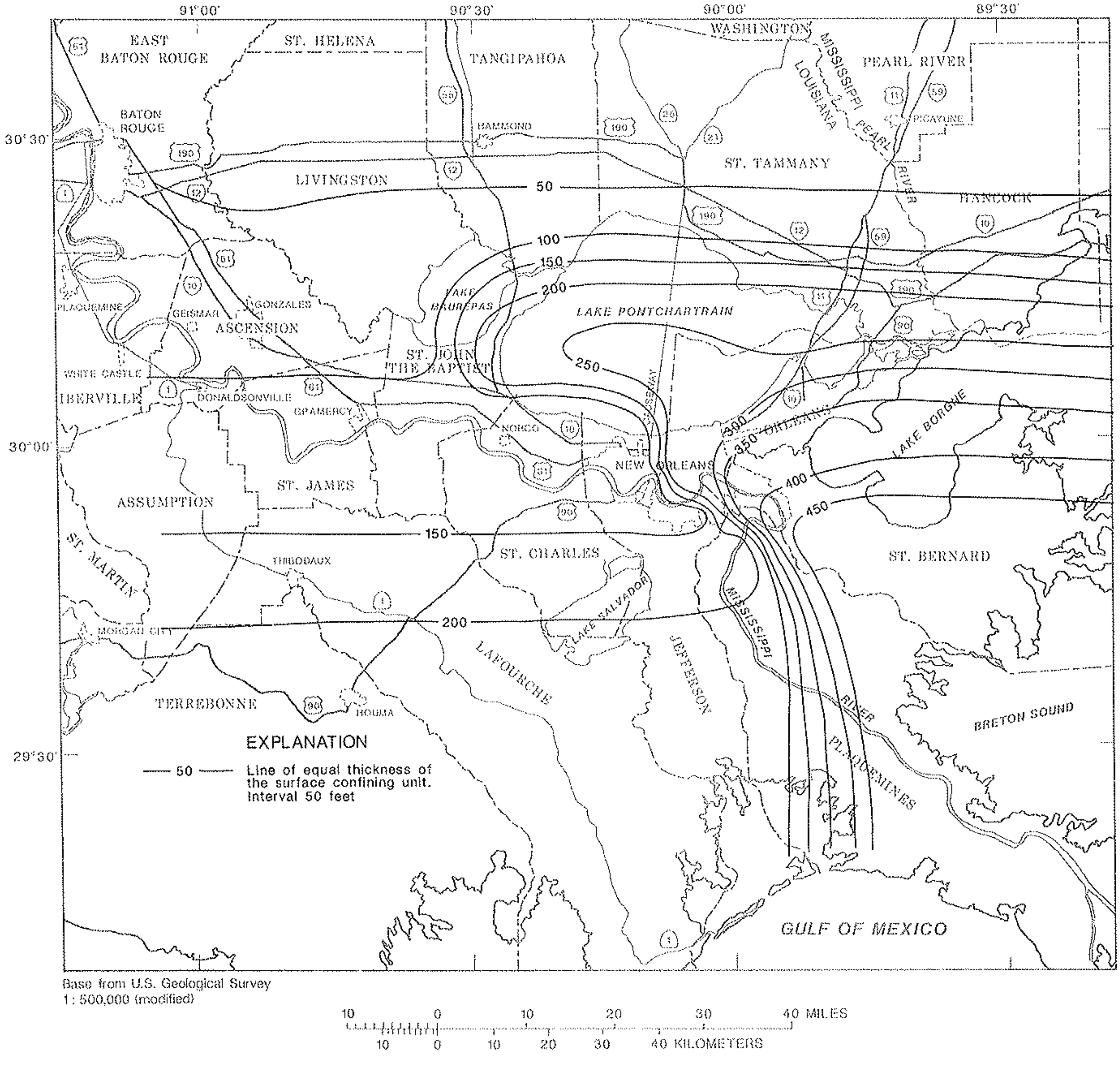


Figure 3.--Geohydrologic sections of the aquifers in the New Orleans area.



Base from U.S. Geological Survey
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Figure 5.--Thickness of the surface confining unit.

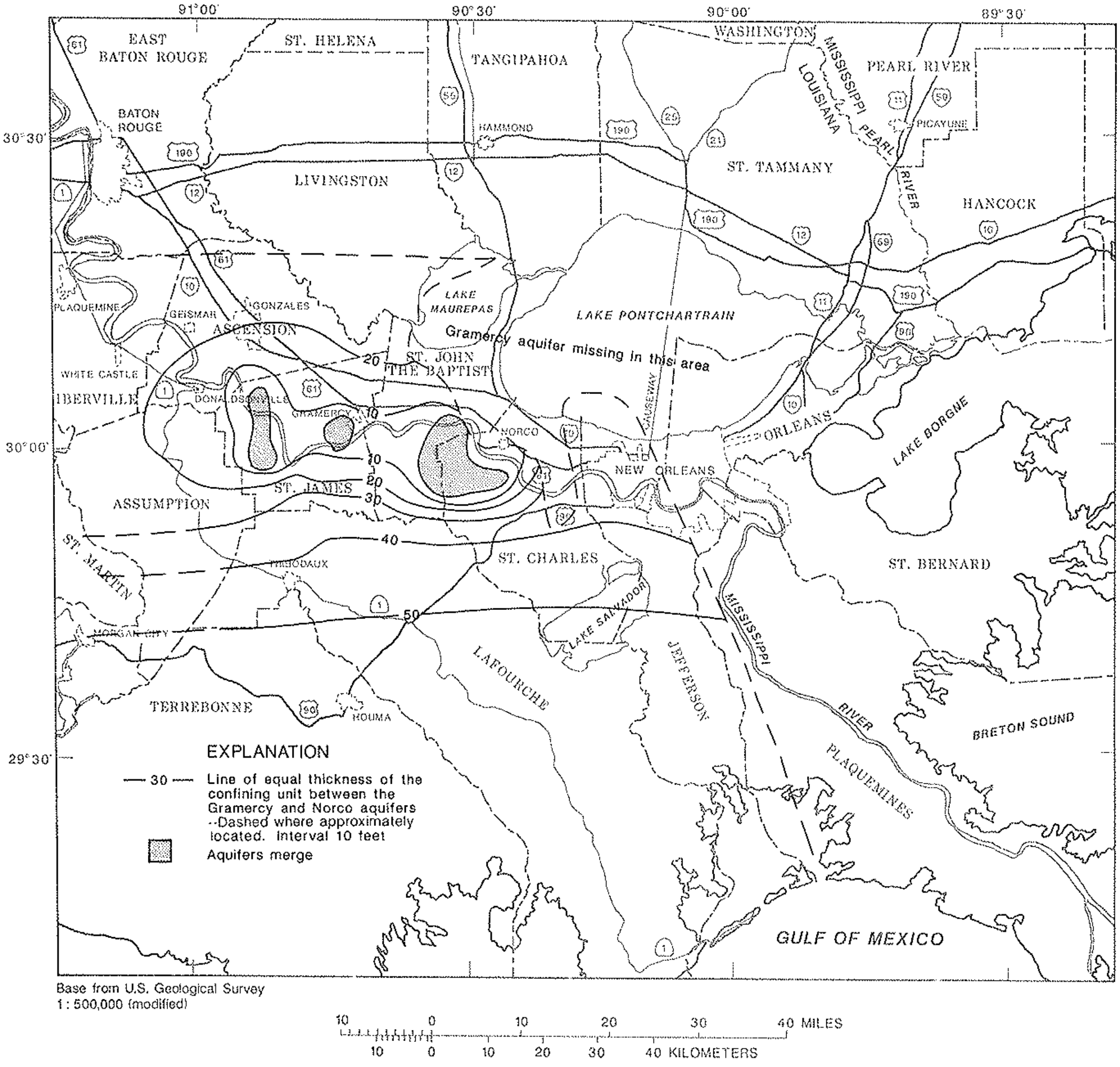

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Figure 6.--Thickness of the confining unit between the Gramercy and Norco aquifers.

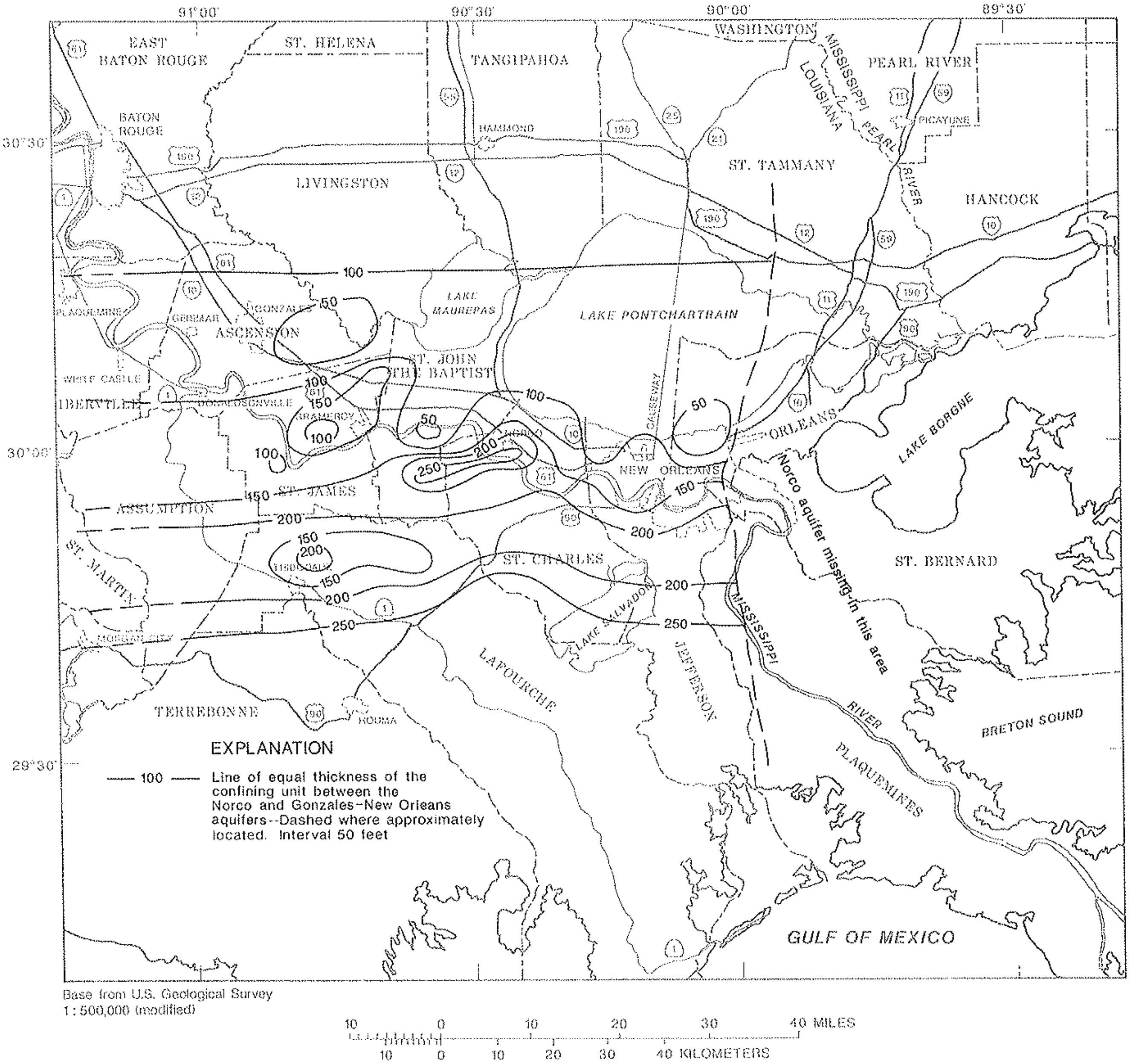

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Figure 7.--Thickness of the confining unit between the Norco and Gonzales-New Orleans aquifers.

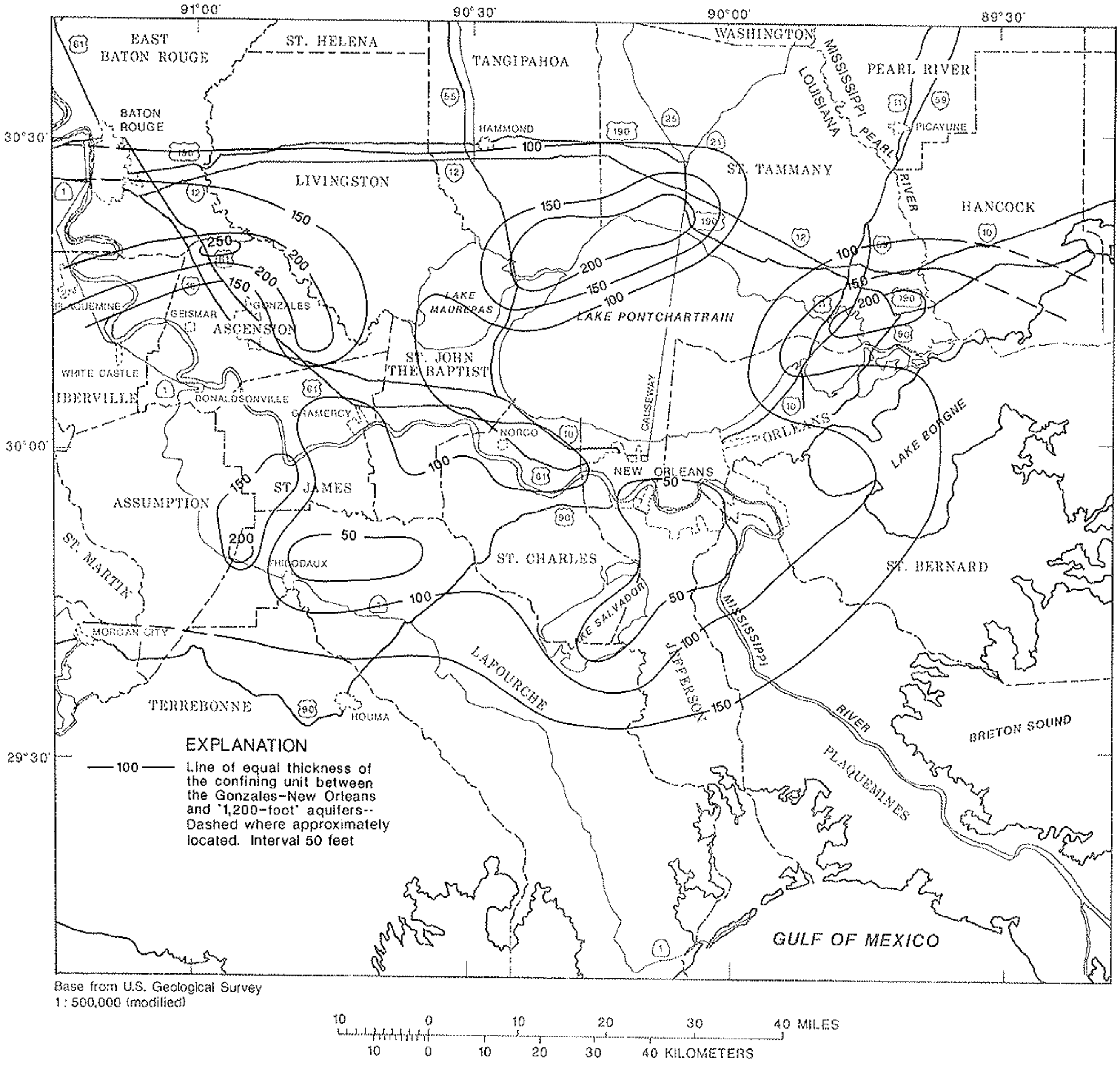

Figure 8.--Thickness of the confining unit between the Gonzales-New Orleans and "1,200-foot" aquifers.

foot" aquifer along the alluvial valley, where they tend to merge and become a single unit (figs. 2-3).

The Gramercy aquifer is not present in much of Orleans Parish (figs. 4 and 9). Where present, it contains saltwater and is pumped very little. Saltwater is defined as water having a chloride concentration greater than 250 mg/L (milligrams per liter). The Gramercy aquifer is separated from the underlying Norco aquifer by a thin bed of clay of variable thickness (10-50 ft). In some areas, the clay is missing, and the two aquifers merge into a single unit; this occurs in St. Charles, St. John the Baptist, and St. James Parishes (Hosman, 1972, p. 32; Dial and Kilburn, 1980, pl. 3).

The Norco aquifer is generally widespread in western Orleans Parish and in the Mississippi River parishes west of Orleans Parish (figs. 4 and 10) but pinches out in eastern Orleans Parish (Rollo, 1966, pl. 4). Like the Gramercy aquifer, it contains saltwater and is almost unused in the study area. The Norco aquifer is separated from the underlying Gonzales-New Orleans aquifer by a thick (up to 200 ft) clay bed.

The Gonzales-New Orleans aquifer is the only aquifer containing significant quantities of freshwater beneath New Orleans (fig. 4). Because of its areal distribution, thickness (fig. 11), and the availability of freshwater, it is the only practical choice for consideration as a public-supply source. Much information is already available on its aquifer properties and water quality. The Gonzales-New Orleans aquifer is separated from the "1,200-foot" aquifer by a clay bed of variable thickness. The thickness of the clay bed is not well defined in Orleans Parish because very few wells have penetrated below the Gonzales-New Orleans aquifer. The clay probably thins out in some areas, and a direct hydraulic connection with the "1,200-foot" aquifer exists (Rollo, 1966, p. 48). Water-level measurements made by the U.S. Geological Survey since the 1960's support Rollo's conclusion.

Like the Gonzales-New Orleans aquifer, the "1,200-foot" aquifer is present throughout Orleans Parish (figs. 4 and 12). Information on the "1,200-foot" aquifer is sparse in the study area because of almost no ground-water development in the aquifer. The aquifer contains saltwater in most of Orleans Parish, except near Irish Bayou in the northeastern part of the parish (fig. 1). Water levels in the "1,200 foot" aquifer are affected by pumping from the Gonzales-New Orleans aquifer, as indicated by water-level and pumping records of both aquifers.

The Mississippi River alluvial valley is the western boundary of the aquifers in this study. The present course of the river and its location with respect to the alluvial valley are shown in figure 2. In the alluvial valley, an almost unbroken sand interval may have a thickness of several hundred feet (Whiteman, 1972, pls. 2-3). Water levels in wells screened in the alluvial aquifer as well as the underlying aquifers near the alluvial valley (fig. 2) are closely correlated with Mississippi River stages. The hydrograph of well An-2, screened in the Gonzales-New Orleans aquifer at Gonzales, Louisiana, is affected by river stage though it is more than 6 mi from the river (fig. 13). Pumping in the New Orleans area has had no effect on water levels in the Gonzales-New Orleans aquifer in the Gonzales area, and water levels in wells

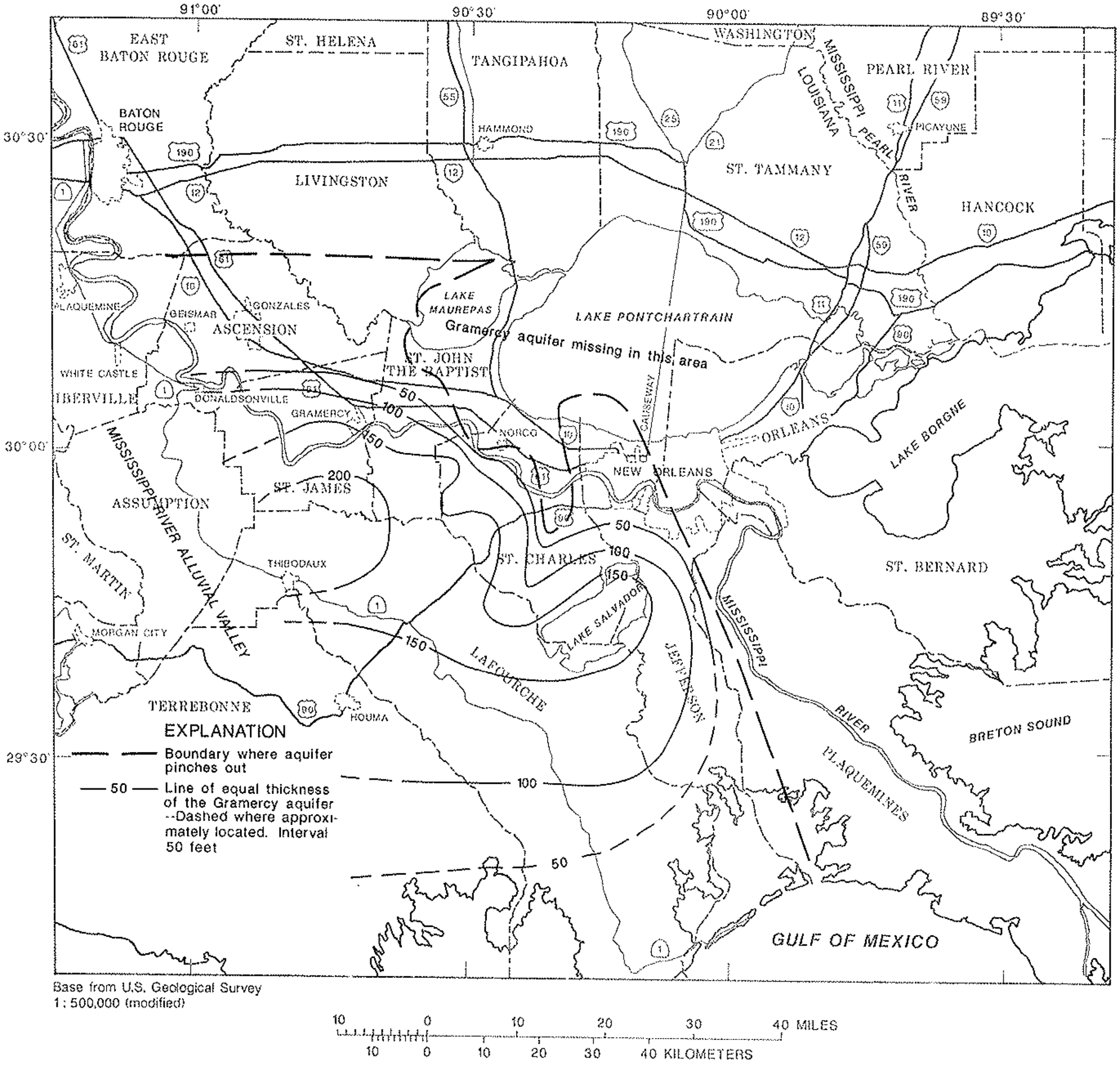

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Figure 9.--Thickness of the Gramercy aquifer.

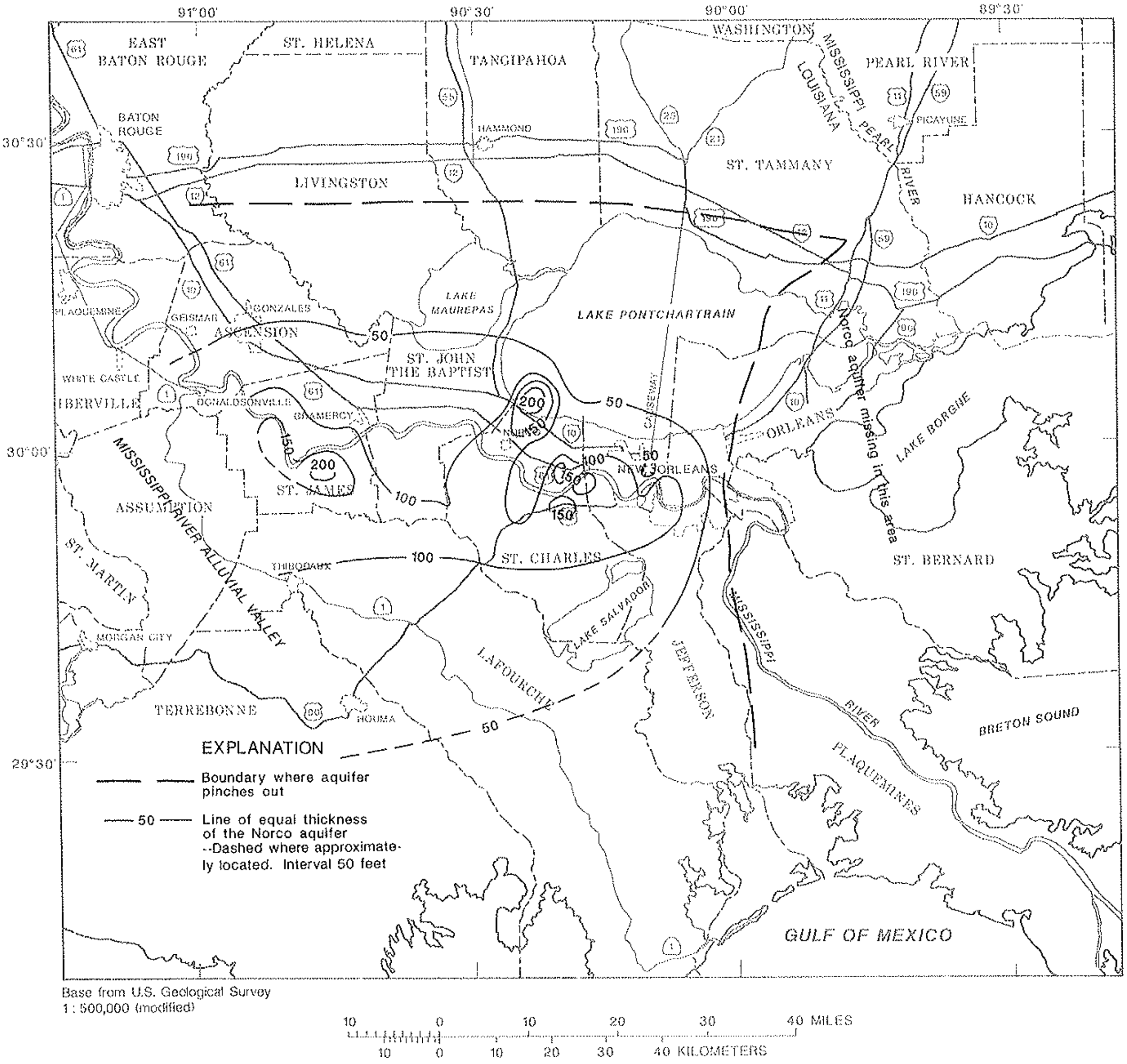

Figure 10.--Thickness of the Norco aquifer.

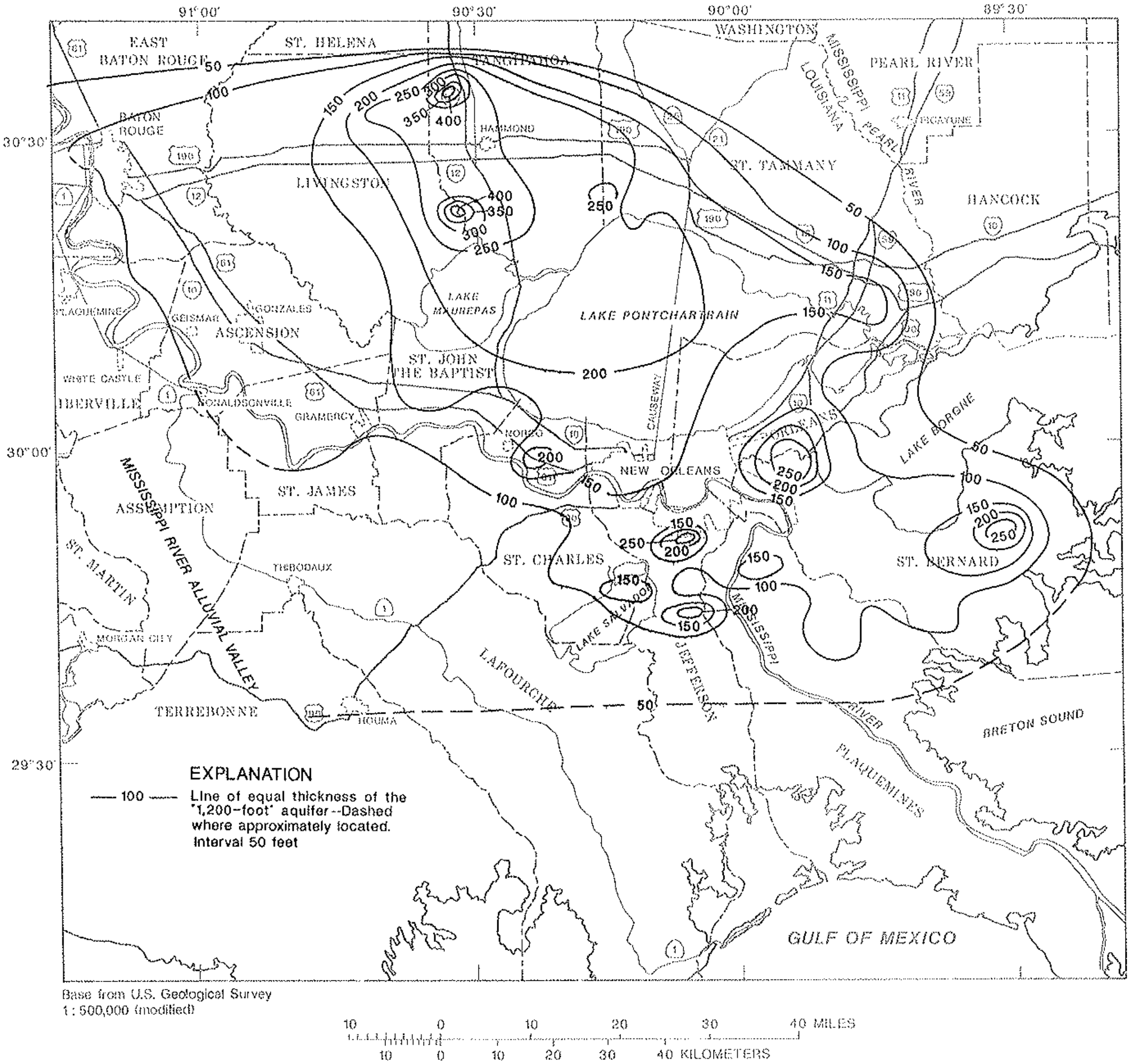

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Figure 12.--Thickness of the "1,200-foot" aquifer.

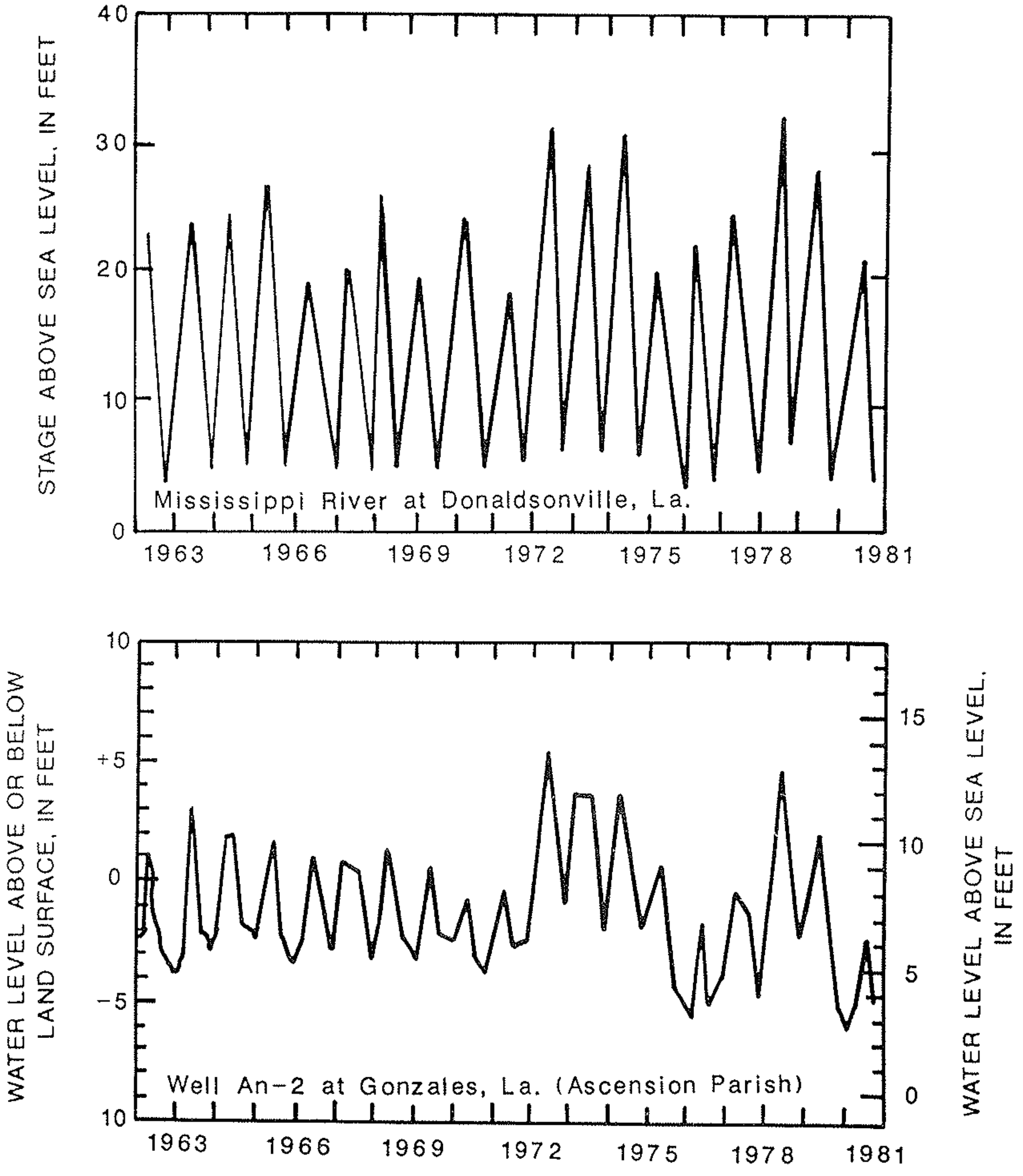


Figure 13.--Relation between stages of the Mississippi River and water levels in well An-2.

near the alluvial valley can be expected to be maintained by the Mississippi River. In the New Orleans area, however, the Mississippi River alluvial aquifer is absent, and hydraulic connection between the river and underlying aquifers is lacking.

The southern boundary of the aquifers in this study is beneath the Gulf of Mexico where the sands diminish in thickness and appear to pinch out altogether. The eastern boundary of the aquifers is also beneath the Gulf of Mexico, off the coast of southern Mississippi. The Gramercy and Norco aquifers pinch out in eastern Orleans Parish. The Gonzales-New Orleans and "1,200-foot" aquifers are assumed to pinch out farther east beneath the coastal waters.

Ground-Water Movement

Ground-water movement in the surficial hydrologic environment involves a complex interrelation between rainfall, runoff, infiltration, and evapotranspiration. Most of the rainfall discharges to local streams that flow southward to the gulf coast. The surficial deposits over most of the outcrop areas are generally impermeable to infiltration, and only a small amount of the rainfall recharges the ground-water system.

Average precipitation over the outcrop areas is about 60 in/yr (inches per year). The aquifers are recharged directly by precipitation and by percolation downward through the overlying surficial sediments. Recharge from precipitation is sufficient to maintain relatively constant long-term water levels in the aquifers at the outcrop areas. Observations of water levels in shallow wells near outcrop areas indicate that the long-term water levels are not affected by ground-water pumping.

Ground-water movement in all of the aquifers in this study (Gramercy, Norco, Gonzales-New Orleans, and "1,200-foot") is part of the regional flow system similar to that shown in figure 2. Prepumping directions of ground-water flow were largely controlled by the geologic structures referred to earlier. Water moved southerly to southwesterly from the outcrop areas to areas of discharge. Water in the aquifers in this study discharged into the Mississippi River alluvial aquifer, which generally had a lower head. During short periods of time, however, the river stage was higher than the artesian head in the aquifers, and ground-water flow near the river was temporarily reversed. At present, the flow system along the alluvial valley remains essentially the same as it was under prepumping conditions. In other areas where the aquifers were not in contact with the Mississippi River alluvial aquifer, ground-water discharge moved upward through confining units to the surface.

Ground-water movement from recharge to discharge areas flushed out the original salty water in the aquifers (Morgan, 1963, p. 12). The irregularity of the freshwater-saltwater contacts in the aquifers is an indication that the rate of flushing varied spatially. The areas containing freshwater and salty water for each aquifer are indicated in figure 4. Unlike the typical coastal aquifer where freshwater overlies very salty water (chloride concentration

19,000 mg/L), the transition from freshwater to salty water for aquifers in this study is gradual. For example, most of the chemical analyses of water from wells in areas mapped as containing saltwater have chloride concentrations less than 1,000 mg/L.

Development of the Gonzales-New Orleans aquifer in the New Orleans area altered the prepumping flow direction as water moved radially toward the area of lowered head. Pumping induced leakage into the pumped aquifer through confining units above and below, and also affected the position of the freshwater-saltwater interface in the Gonzales-New Orleans aquifer. The prepumping interface in the aquifer extended northeastward from downtown New Orleans (fig. 4) (Rollo, 1966, pl. 13). Early development was close to the interface, and pumping in the downtown area intercepted most of the saltwater that was moving toward the pumping center. However, in the 1970's ground-water withdrawal in the downtown area declined, and saltwater began moving toward other pumping centers in the areas of the Industrial Canal, the lakefront at Lake Pontchartrain, and Michoud.

Although two active faults (Big Point and Unknown Pass) are known in the Lake Pontchartrain area (fig. 2), their effect on ground-water movement is considered minimal. Two arguments support this conclusion: (1) Geophysical logs of oil- and water-test boreholes in the Lake Pontchartrain area indicate a considerable amount of sand in the first few hundred feet below land surface. These sand beds are not sufficiently displaced across the faults to seal off ground-water flow. (2) Water-level data from observation wells nearest the area of faulting show no evidence of significant head differences across the faults.

Ground-Water Pumpage

Pumpage information prior to 1953 is not available for the New Orleans area. Because water users generally kept no records, estimates of pumpage were based on well information such as well diameter, reported well yield, number of years the well was in service, and pump horsepower or rated pump capacity. Eddards and others (1956) inventoried ground-water pumpage of the New Orleans area for the year 1953, and Rollo (1966) conducted an inventory for 1963. In addition to these studies, Federal-State cooperative water-use inventories have been conducted at 5-year intervals since 1960. The results of these studies are reported in Snider and Forbes, (1961), Bieber and Forbes (1966), Dial (1970), Cardwell and Walter (1979), and Walter (1982).

Ground-water withdrawal in New Orleans is almost entirely from the Gonzales-New Orleans aquifer. The major areas of pumping at present (1986) are the University of New Orleans, the Industrial Canal area north of U.S. Highway 90, the Michoud area, and downtown New Orleans (fig. 14). Pumpage from the Gonzales-New Orleans aquifer in Orleans Parish reached a maximum of about 43 Mgal/d (million gallons per day) in 1969 and declined to about 35 Mgal/d in 1980. As of 1986, pumpage had declined to about 30 Mgal/d. Outside of Orleans Parish, pumping from the aquifer is confined mostly to Jefferson, St. Charles, and Ascension Parishes.

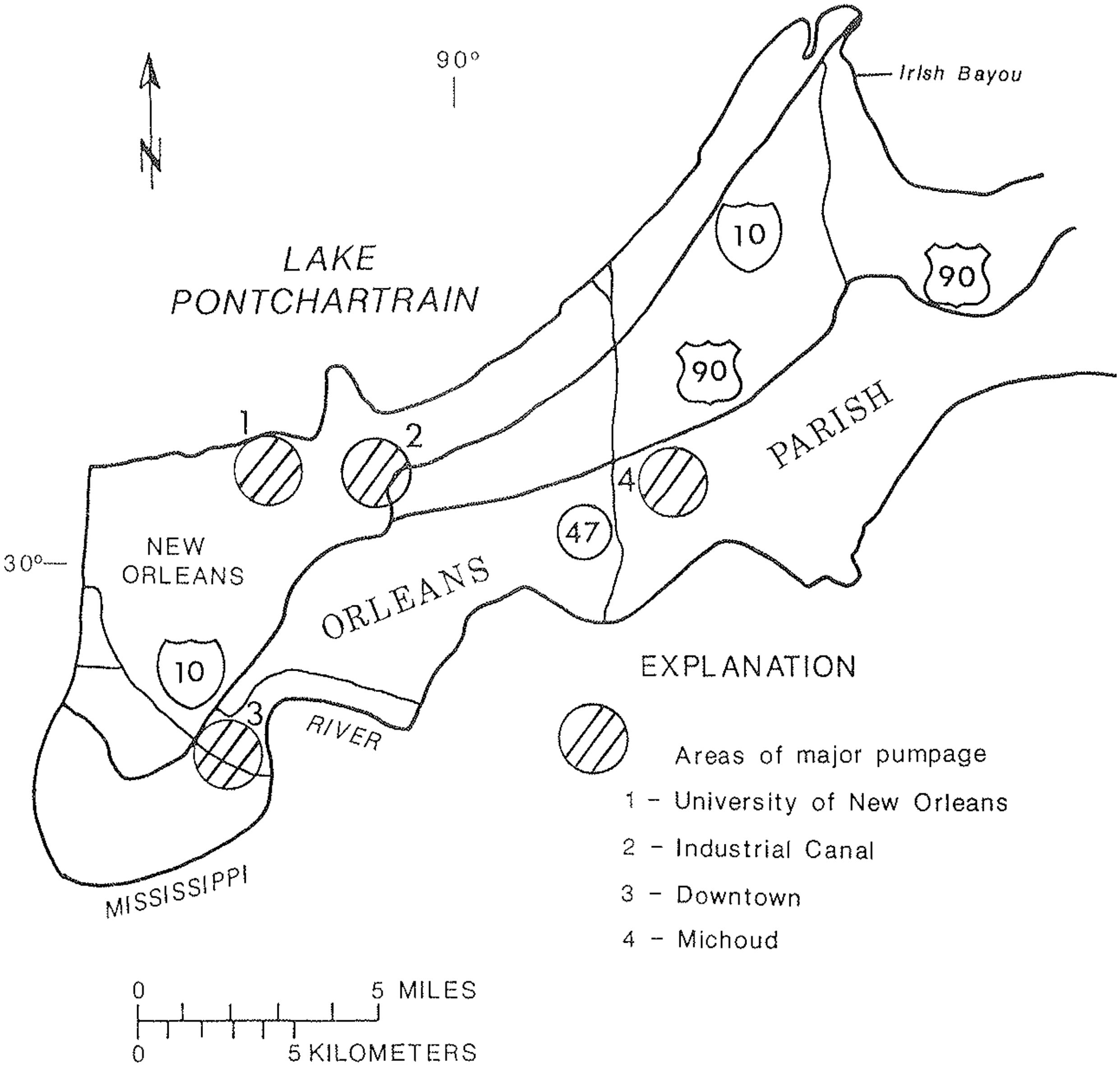


Figure 14.--Areas of major pumpage in the study area.

Pumping from the Gramercy, Norco, and "1,200-foot" aquifers is minimal in New Orleans. For the Gramercy aquifer, pumping is confined mostly to St. James Parish (fig. 9) where it reached a maximum of about 10 Mgal/d in the early 1960's and has not changed appreciably since then. Pumpage from the Norco aquifer, which is confined mostly to St. Charles Parish (fig. 10), reached a maximum of about 15 Mgal/d in 1960. By 1980, pumpage from the Norco aquifer had declined to 8 Mgal/d. No pumping has been reported from the "1,200-foot" aquifer in New Orleans since 1969.

SIMULATION OF THE GROUND-WATER FLOW SYSTEM

Simulation of ground-water flow involved the construction and calibration of a numerical model of the aquifer system in New Orleans and the surrounding area. The preparation of the model included conceptualization of the aquifer system, model construction, model calibration, and application of the model for predictive purposes. The conceptual model has been described in the preceding section on "Geohydrology of the New Orleans aquifer system." The simulation model was constructed on the framework of the ground-water flow model documented by McDonald and Harbaugh (1984). The calibration procedure included modifications to improve the comparison between observed and computed water levels in each aquifer. Application of the model involved the use of alternative pumping stresses to predict future water levels and estimate rates of saltwater encroachment.

Model Development

A three-dimensional finite-difference ground-water flow model simulated the hydrologic relation between the Gonzales-New Orleans aquifer, the underlying "1,200-foot" aquifer, and the overlying Norco and Gramercy aquifers. A layered conceptualization of the aquifers was developed for modeling purposes. The model incorporated four aquifer layers representing the Gramercy, Norco, Gonzales-New Orleans, and "1,200-foot" aquifers. The effect of clay confining units on inter-aquifer leakage was also simulated. A diagram relating the aquifer system to the model is shown in figure 15.

The modeled area includes most of southeastern Louisiana and a part of southern Mississippi, and covers a surface area of about 23,000 mi^2 (square miles) (pl. 1). A finite-difference grid consisting of 31 rows and 45 columns was superimposed on the modeled area. The smallest grid blocks (cells) were given dimensions of 1.0 mi^2 (1 mi on a side) in the New Orleans area where detailed model resolution was desired. The block size was expanded outward toward the model boundaries to a maximum area of 281 mi^2 (25 mi X 11.25 mi). Orientation of the grid approximates the strike of the aquifer outcrops (fig. 4).

Boundary Conditions

The effects of the surficial deposits on the deeper aquifers were accounted for in the model by means of a head-dependent flux boundary. The head distribution in the surficial deposits was specified to remain constant. The flux to the underlying aquifers was determined by the following relation:

$$q = K \frac{(H-h)}{b}$$

where q = flux, in feet per day;
K = vertical hydraulic conductivity of the clay separating the surficial deposits and underlying aquifers, in feet per day;
b = thickness of clay, in feet;
H = specified head in surficial sediments, in feet; and
h = model-computed head in underlying aquifer, in feet.

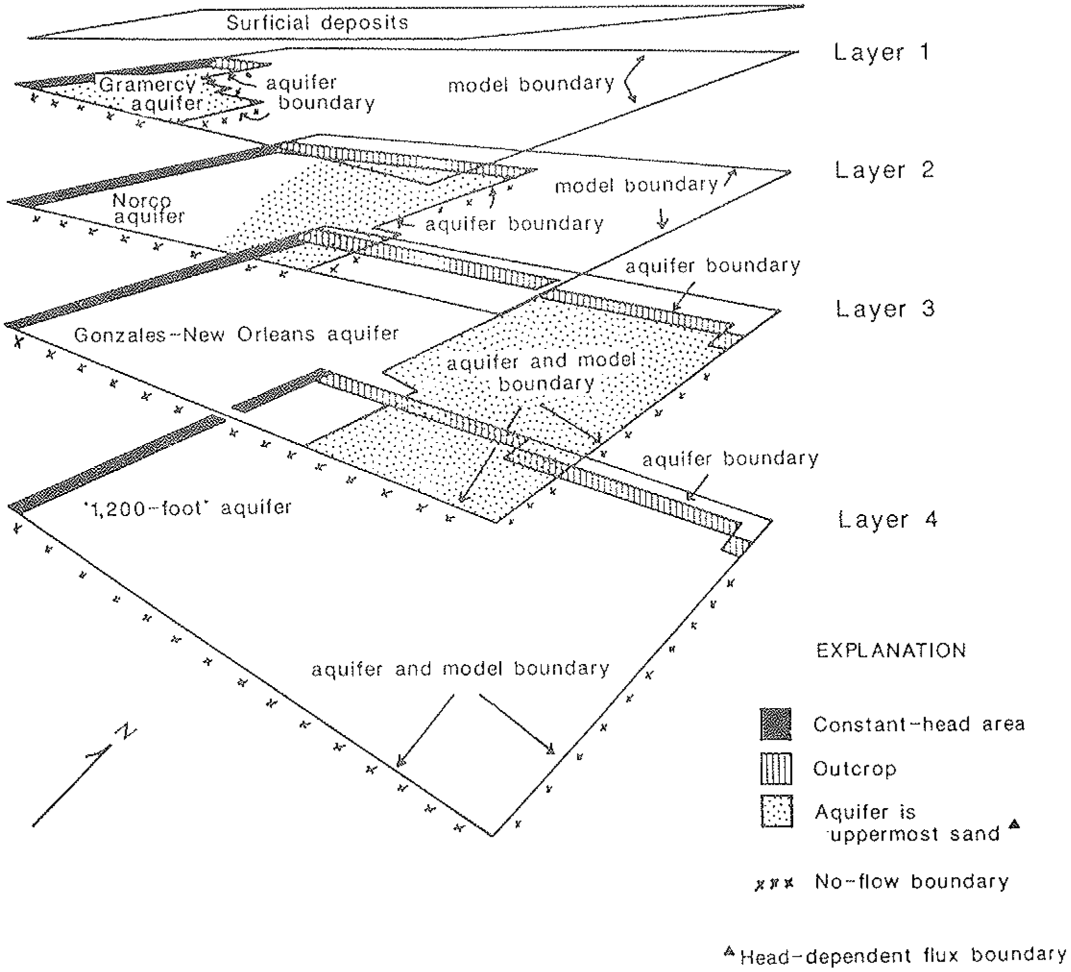
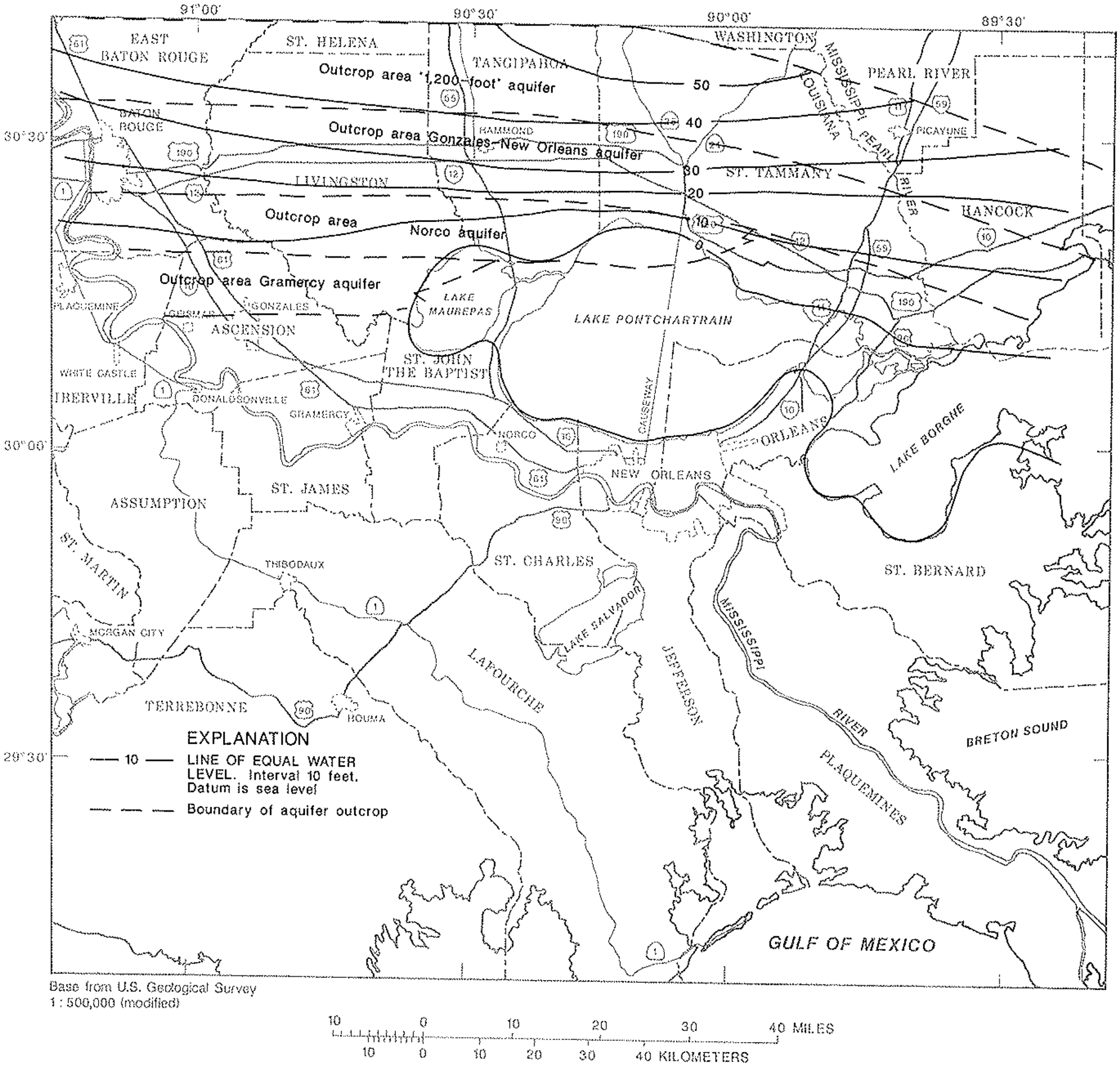


Figure 15.--The four-layered model showing model and aquifer boundaries.

This head-dependent flux boundary provides recharge from the surficial hydrologic environment. Water can enter or leave through the stratigraphic subcrop of a given layer beneath the surficial deposits. Also, in those parts of layers two and three, where the stratigraphic equivalent of the Gramercy aquifer is clay (fig. 15), water enters or leaves these layers through the overlying clays. The thickness distribution of the clay separating the surficial deposits from underlying aquifers (fig. 5) and the head distribution within the surficial deposits (fig. 16) were used as model input. The hydraulic conductivity of the clay separating the surficial and underlying aquifers was computed on the basis of its burial depth, and is discussed in the section "Confining-Unit Properties."

The western boundary of the model corresponds to the area of mergence of all aquifers with the Mississippi River alluvial aquifer and is designated a constant-head boundary. Because hydraulic connection exists between the Mississippi River, the alluvial aquifer, and the Gramercy, Norco, Gonzales-New



Base from U.S. Geological Survey 1:500,000 (modified)

Figure 16.--Estimated altitude of the water-level surface in the surface confining unit in 1900.

Orleans, and "1,200-foot" aquifers along portions of the alluvial valley, the long-term water-level averages in the river-aquifer system are assumed to be constant.

The southern and eastern extent of each layer coincides with the estimated location of the sand-to-clay facies change for that layer and is designated a no-flow boundary (fig. 15). For the Gonzales-New Orleans and "1,200-foot" aquifers, these sand-to-clay facies changes, and the model boundaries are at the same location. Hydrologic information for stratigraphic units below the "1,200-foot" aquifer, determined mainly from geophysical logs of the area, indicates a fairly thick clay bed between the "1,200-foot" aquifer and the next underlying aquifer. Leakage across the clay bed is assumed to be negligible.

Aquifer Properties

The hydraulic properties of an aquifer determine its capacity to transmit and store water. Information about aquifer properties is available from aquifer-test results and from published ground-water reports in the section "Previous Investigations" (p. 13). On the basis of a few aquifer tests, estimated hydraulic conductivity is 100 ft/d (feet per day) for the Gramercy aquifer and 130 ft/d for the Norco aquifer. Transmissivities of the Gramercy and Norco aquifers range from 9,000 to 30,000 ft^2/d (square feet per day). The hydraulic conductivity determined from aquifer tests of the Gonzales New Orleans aquifer averages 110 ft/d. The transmissivity of the Gonzales-New Orleans aquifer in the greater New Orleans area ranges from 12,000 to 24,000 ft^2/d and has been reported as high as 32,000 ft^2/d in the Gonzales area (Long, 1965). Aquifer properties of the "1,200-foot" aquifer are unavailable in the greater New Orleans area. An estimated hydraulic conductivity of 100 ft/d is based on aquifer lithology that is about the same as that of the Gonzales-New Orleans aquifer. Thickness maps for each aquifer are shown in figures 9 through 12. Storage coefficients range between 0.0001 and 0.001 and average about 0.0005 for the Gramercy, Norco, and Gonzales-New Orleans aquifers. Information on storage coefficient is unavailable for the "1,200-foot" aquifer, but an average of 0.0005 is assumed. Table 1 summarizes hydraulic properties of the aquifers.

Confining-Unit Properties

The confining-unit properties include vertical hydraulic conductivity and specific storage. In contrast to the relative abundance of aquifer-property data, a lack of information exists on confining-unit properties. Because of insufficient measurements of the vertical hydraulic conductivity of clays, generalizations that considered the fundamental processes controlling hydraulic conductivity were necessary to define this property spatially. As noted by Muskat (1946, p. 17), one of the variables of importance in determining the hydraulic conductivity of fine-grained sediments is the degree of compaction, which is related to burial depth. Bredehoeft and others (1983) have observed the pronounced effect of compaction on shale hydraulic conductivity in South Dakota.

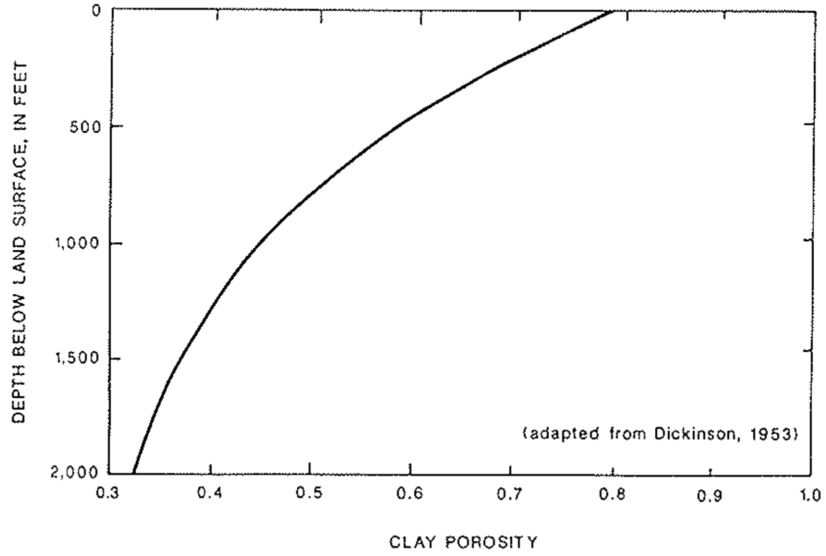
The porosity of clays in the sediments of Tertiary age in the Gulf Coastal Plain (Dickinson, 1953, p. 420) declines logarithmically from about 80 percent at land surface to about 32 percent at a depth of 2,000 ft (fig. 17). Muskat (1946, p. 17) suggested that hydraulic conductivity decreases at a rate even greater than that of porosity with depth. The relation between porosity and depth along with structure contour maps showing the areal distribution of average burial depth by clay layer were used to define the spatial distribution of clay porosity.

The approach for quantifying hydraulic conductivity of clay links Dickinson's (1953) expression for clay porosity as a function of burial depth to work which defined the nature of the relation of void ratio of clay to hydraulic conductivity. Taylor (1948) and Abelev and Tsytovich (1964) report a linear relation between void ratio and log-transformed hydraulic conductivity in clays and cohesive soils. With this assumption, an equation of the form

$$K = K_{ref} e^{C(v-v_{ref})}$$

where K = hydraulic conductivity for a given void ratio, in feet per day;
K_{ref} = hydraulic conductivity at a burial depth of 1,000 ft, in feet per day;
C = slope of log-transformed hydraulic conductivity versus void ratio relation, dimensionless;
v = void ratio, defined by $v = n/(1-n)$, dimensionless;
v_{ref} = void ratio at a burial depth of 1,000 ft, dimensionless; and
n = porosity, dimensionless

can be used to define the spatial distribution of clay hydraulic conductivity if the two parameters K_{ref} and C can be determined. Because of a complete lack of data on K_{ref} and C, calibration of the flow model appears as the only viable means of inferring these two clay parameters.



(adapted from Dickinson, 1953)

Figure 17.--Relation of clay porosity to depth.

Variable-Density Considerations

Concentration of dissolved solids in water from the aquifer system ranges from less than 10 mg/L in the outcrop area to greater than 10,000 mg/L downgradient. Accompanying the downgradient increase in dissolved solids is a corresponding increase in water density, introducing the effect of gravity forces on the flow system. Meisler (1986) and Wait and others (1986) have considered water having a dissolved-solids concentration of less than 10,000 mg/L to have essentially the same density as freshwater. The water having a dissolved-solids concentration greater than 10,000 mg/L is considered to be stagnant, and a no-flow boundary is assigned at the surface defined by this concentration. This procedure has the advantage of producing a constant-density problem and the disadvantage of possibly neglecting the flow which might pass through this boundary. During predevelopment conditions in the New Orleans area, this conceptualization was probably valid. However, subsequent ground-water pumping in close proximity to the 10,000 mg/L surface has induced movement of salty water toward the cone of depression, violating the no-flow conceptualization.

Thus, the authors concluded that flow from the highly salty parts of the aquifer system could not be neglected. No-flow boundaries were chosen beyond any conceivable hydraulic radius of influence induced by ground-water withdrawals at New Orleans, thereby producing a variable-density problem. Lack of data to adequately describe the spatial distribution of water density in the aquifer preclude the use of a variable-density flow model. Rather, constant density is assumed throughout the system. Because the salty water is stratigraphically downdip and, therefore, at a lower altitude than the freshwater in this aquifer at New Orleans, it is thought that the gravity forces will slow the advance of the saltwater front. Thus, the model will produce a conservative solution to encroachment rates in the Gonzales-New Orleans aquifer. Both underlying and overlying aquifers contain salty water throughout much of the New Orleans area. Thus, the constant-density assumption will underestimate leakage from the overlying aquifer and overestimate leakage from the underlying aquifer to the stressed part of the Gonzales-New Orleans aquifer. The error introduced by the constant-density assumption can only be fully evaluated with additional density, pressure, and water-level information, and construction of a variable-density flow model.

Clay-Storage Considerations

The release of water from clay storage resulting from pumping stresses on the Gonzales-New Orleans aquifer was not considered in aquifer simulations. Thus, leakage between aquifers was assumed to be directly proportional to the head gradient between the two aquifers. The head gradient across confining units was assumed to be linear and to respond instantly to head changes in the adjacent aquifers. The validity of these assumptions was investigated by an analytical method which provided an estimate of the relative significance of clay storage in the flow budget of the Gonzales-New Orleans aquifer.

The analytical approach involved an idealization of the Gonzales-New Orleans aquifer as being overlain and underlain by confining units of 75-foot thickness (average clay thickness over study area). Water levels in the aquifers above and below the Gonzales-New Orleans aquifer are assumed to have remained constant because the change in water levels in these aquifers is small relative to the water-level change within the Gonzales-New Orleans aquifer. The water level in the Gonzales-New Orleans aquifer showed the greatest rate of decline from 1953-63 (about 1.5 ft/yr, feet per year, at center of drawdown cone; average rate of drawdown within a 30-mile radius of influence is less than half this rate). The ultimate average rate of drawdown within the confining units resulting from an aquifer drawdown of 1.5 ft/yr is 0.75 ft/yr; drawdown in each confining unit is half the drawdown of the aquifer assuming constant water levels above and below the Gonzales-New Orleans aquifer. Greater rates of drawdown within the Gonzales-New Orleans aquifer will increase the rate of release of water stored within the adjacent confining units. Thus, the water level in the Gonzales-New Orleans aquifer will be prescribed to fall at the maximum rate of drawdown of 1.5 ft/yr in this analysis to provide a conservative estimate of the effects of clay storage.

The volume (V) of water, released from clay storage for a given drawdown distribution within the confining unit is given by:

$$V = S_s A \int_0^b s(z)dz = S_s bA\bar{s},$$

where S_s = specific storage coefficient, in feet^{-1};
s = drawdown in confining unit, in feet;
z = vertical spatial coordinate within the confining unit;

$\bar{s}$ = average drawdown in confining unit, in feet;
b = confining unit thickness, in feet; and
A = plan area of cone of influence within the Gonzales-New Orleans aquifer = 30 mi^2 = 7.88×10^{10} ft^2 (square feet).

The rate of release of water from clay storage (q) for a given water-level decline (ΔH) in the Gonzales-New Orleans aquifer is given by (Bredehoeft and Pinder, 1970):

$$q \approx \frac{K \Delta H}{(\pi K t'/S_s)^{1/2}}$$

where K = vertical hydraulic conductivity of the clay, in feet/day; and
t' = time since decline in water level.

Assuming a succession of step-wise water-level declines in the Gonzales-New Orleans aquifer, the resulting release of water from clay storage is given by the superposition of a series of individual releases. As the time between steps, and, therefore, the water-level decline between steps, become infinitesimally small, the rate of flow from clay storage approaches that depicted in figure 18. The rate of flow increases rapidly during early time and then stabilizes to a constant level at some later time. This later time corresponds to the time (τ) at which the contribution of the first step release to

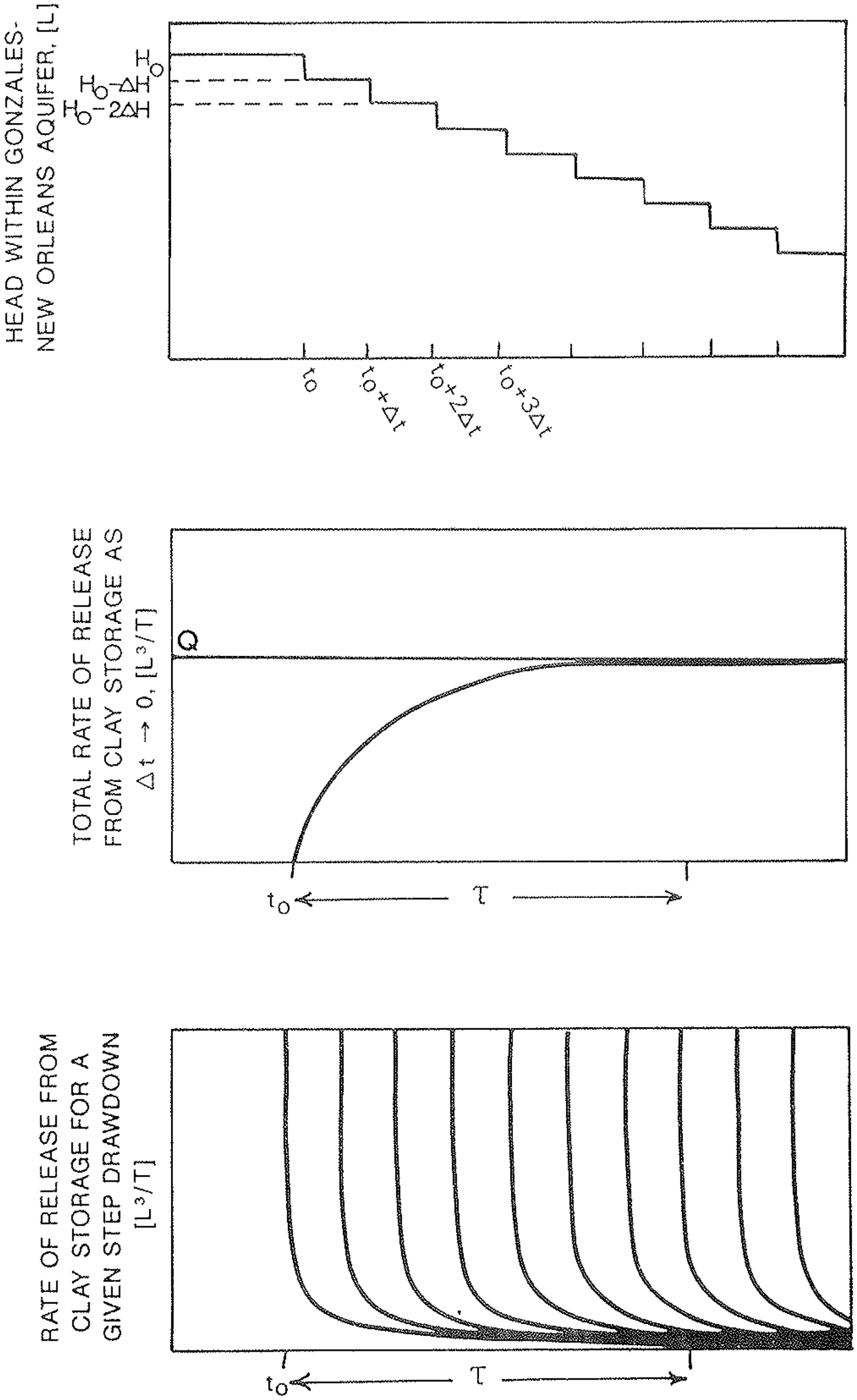


Figure 18.--Idealized step-wise drawdown within the Gonzales-New Orleans aquifer and the resulting step-wise and total release of water from the adjacent confining units.

total flow has become negligible and is given by (Bredehoeft and Pinder, 1970):

$$\tau = (S_s b^2)/2K$$

The quasi-equilibrium flow, which is attained after time (τ) is given by:

$$Q = S_s A \int_0^b \frac{ds}{dt}\, dz = S_s A b \frac{d\bar{s}}{dt}.$$

The principal unknown in the above equation is specific storage. Torak and Whiteman (1982) calibrated a ground-water flow model of the "2,000-foot" sand at Baton Rouge with a spatially uniform specific-storage value of 1.5×10^{-5} ft^{-1}, which is reasonably close to the values determined by Whiteman (1980) by means of consolidation tests of clay samples. Using this estimate of specific storage, the quasi-equilibrium release of water from clay storage when substituted into the previous equation is:

$$\begin{aligned} Q &= (1.5 \times 10^{-5})(7.88 \times 10^{10})(75)(0.75), \\ &= 66 \times 10^{6} \text{ ft}^3/\text{yr}, \\ &= 500 \text{ Mgal/yr}, \\ &= 1.36 \text{ Mgal/d}, \end{aligned}$$

or about 2.72 Mgal/d from clays above and below the Gonzales-New Orleans aquifer.

The time (τ) required to attain this flow is dependent on the vertical hydraulic conductivity (K) of the confining unit. For example,

for K = 1.0×10^{-3} ft/d, τ = 42 days,
1.0×10^{-4} ft/d, τ = 420 days, and
1.0×10^{-5} ft/d, τ = 4,200 days.

Regardless of the time involved, a flow of 2.72 Mgal/d is relatively insignificant in regard to total pumpage from the Gonzales-New Orleans aquifer, and water derived from clay storage can be assumed negligible if the assumptions inherent in this analysis are valid. The most suspect assumption in the above analysis is the assumed value of specific storage. Helm (1984) indicated that specific storage is a function of burial depth and that values for this parameter, several orders of magnitude higher than the assumed value, might be expected for shallow sediments. However, with the lack of a fully documented ground-water flow model that would consider the effects of transient leakage from clay storage, a decision was made to ignore the contribution from clay storage to the flow system.

The assumption of proportionality between inter-aquifer leakage and the head differential across a confining unit is only a reasonable approximation after a time (τ) has elapsed following a head change in one or both aquifers. A regional ground-water study (Gulf Coast Regional Aquifer System Analysis) which included the New Orleans area arrived at values of vertical hydraulic conductivity of confining units on the order of magnitude of 10^{-4} ft/d (Angel Martin, Jr., U.S. Geological Survey, oral commun., 1987). The time (τ) corresponding to a hydraulic conductivity of this magnitude is on the order of one year, a period which is small compared to the time frame under consideration in this study. Thus, the time delay involved in obtaining a linear head distribution across a clay confining unit with a head change in the adjacent aquifers is considered negligible.

Calibration Strategy and Results

Calibration of the model based on observed water levels between 1900 and 1981 provides a means of inferring the values of hydraulic properties which are not well known. Thus, as an initial calibration strategy, the aquifer properties were assumed to be known, and the confining-unit properties were determined as a solution to the inverse problem by model calibration. Time within this period was discretized into seven pumping periods. Initial heads were estimated on the basis of sparse turn-of-the-century observed water levels. A summary of pumpage from each aquifer for each pumping period is given in table 2.

Table 2.--Distribution of pumpage from each aquifer used in the model

[Values in million gallons per day]

Pumping period	Time period	Gramercy aquifer	Norco aquifer	Gonzales-New Orleans aquifer	"1,200-foot" aquifer
1	1900-19	------	------	2.17	0.04
2	1920-39	------	8.01	5.96	.10
3	1940-53	2.80	13.28	31.00	.05
4	1954-63	9.88	15.29	54.81	.24
5	1964-69	8.61	10.07	59.80	.06
6	1970-75	6.76	9.43	53.42	(a)
7	1976-81	10.33	7.13	52.49	(a)
8	1982-86	8.94	8.14	40.98	(a)

[a] No known pumpage from the aquifer.

Numerous simulations were made with various values of the two confining-unit parameters, K_{ref} and C. (See section on "Confining-Unit Properties" for definition of these parameters.) The degree to which observed water levels were simulated was quantified by root-mean-square error (fig. 19). For the special instance of uniform confining-unit hydraulic conductivity ($C = 0$) throughout the vertical section, a moderately good agreement between observed and computed water levels was achieved with a hydraulic conductivity of 2.5×10^{-4} ft/d. However, consideration of the effects of burial depth on hydraulic conductivity ($C \neq 0$) produced a significantly better correspondence.

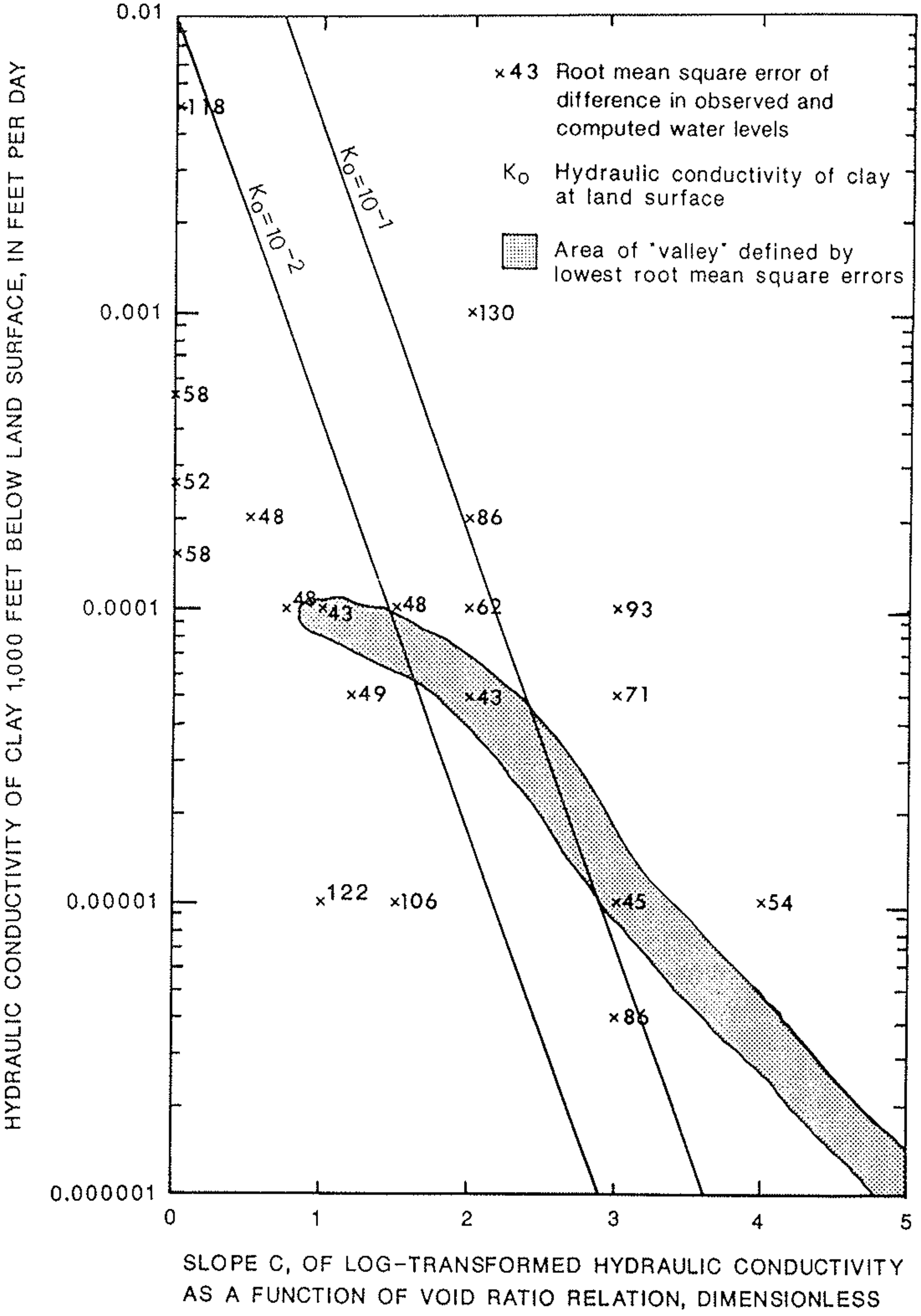


Figure 19.--Model root-mean-square error as a function of confining-unit properties.

An immediately obvious "best fit" is not apparent in figure 19 where a root-mean-square-error "valley" of comparable head matches exists. This distribution does not imply that the computed heads are necessarily comparable throughout the study area for all sets of confining-layer parameters within the "valley" although they are reasonably close in the areas of observed water levels. The difference in computed water levels for simulations within the "valley" lie in areas of sparse or absent observed water levels south and east of New Orleans and in the "1,200-foot" aquifer. As a result, the problem is insufficiently constrained and produces a root-mean-square-error "valley" rather than a "cone." Two other possible constraints are:

1. The reasonableness of the confining-unit hydraulic conductivities produced by given values of K_{ref} and C. Pairs of confining-unit parameters which will produce specified values of hydraulic conductivity at land surface are delineated in figure 19. A value of 0.01 ft/d as the hydraulic conductivity of a surficial clay is probably only marginally reasonable, and a value of 0.1 ft/d is probably unreasonable. Thus, this additional constraint indicates that confining-unit properties in the low C and high K_{ref} part of the "valley" are more reasonable.

2. Uniform weighting of head residuals was used in the computation of root-mean-square error, producing a bias toward matching the head distribution in aquifers and at times of more concentrated water-level measurements. The "1,200-foot" aquifer in particular received little weighting in that only one well, Or-156, (fig. 12) was measured. Examination of head residuals at this well indicates that the "1,200-foot" aquifer is most accurately simulated with confining-unit values of C = 1 and $K_{ref} = 1.0 \times 10^{-4}$ ft/d, which falls within that part of the "valley" indicated by the hydraulic conductivity constraint noted above. Figure 20 illustrates the resulting variation of hydraulic conductivity with burial depth.

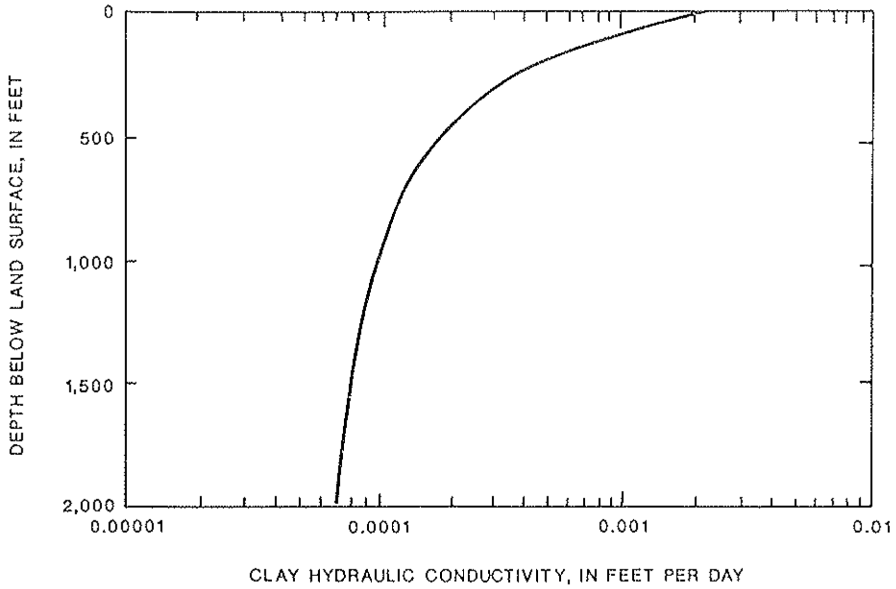


Figure 20.--Relation of clay hydraulic conductivity to depth.

Perturbation of the aquifer hydraulic properties with these assumed values of confining-unit hydraulic properties produced no significant improvement in the comparison between observed and computed changes in water level, and the originally assumed values of aquifer hydraulic conductivity and storage coefficient were retained (table 1).

Comparison of Observed and Computed Water Levels

Several observation wells in the New Orleans area were used for comparison of observed and computed water levels. The hydrographs of wells Or-78, Or-42, and Jf-65, screened in the Gonzales-New Orleans aquifer, show observed and computed water levels in Jefferson and Orleans Parishes (fig. 21). Good agreement exists except that the computed water levels do not reflect the seasonal water-level differences indicated by the observed water levels. Areal comparisons of differences between observed and computed water levels are shown as contour maps for 1963 (fig. 22) and 1981 (fig. 23). For most of the modeled area, the differences are 20 ft or less. Some error is to be expected because model-generated water levels represent the average water levels in a node and observed water levels represent point observations.

Sensitivity Analysis

A sensitivity analysis was used as a means of demonstrating the model's response to estimated values of aquifer hydraulic conductivity, storage coefficient, and pumpage. These constituents were varied over a range of values to determine the model's sensitivity to the changes. Root-mean-square errors were calculated for 1963 and 1981 from the sum of squares of differences between observed and computed water levels in the standard calibrated-model simulation and the simulation with a different value for the aquifer characteristic being tested. The results are shown graphically in figure 24. The model was sensitive to changes in hydraulic conductivity and insensitive to changes in storage coefficient. It was also fairly insensitive to changes in pumpage up to 20 percent greater or less than the modeled pumpage. The high model sensitivity to the confining-unit parameters is illustrated in figure 19.

The estimation of initial (1900) heads was based on rather limited data. In order that error introduced into model calibration as a result of possibly poor initial head estimates might be evaluated, simulations to measure model sensitivity to initial head conditions were made. A value of 20 ft was added to initial head estimates in all layers, throughout the study area, and a simulation was conducted. The value of 20 ft is the authors' estimate of maximum error in initial head estimates. As one would expect that the model would exhibit the greatest sensitivity to initial conditions during the early part of the simulation, model-generated potentiometric surfaces which correspond to the first time at which observed and computed potentiometric heads were compared within model calibration were examined in this sensitivity analysis. The increase in model-generated 1940 potentiometric water levels introduced as a result of increasing the initial heads by 20 ft is negligible in the northern part of the study area, encompassing all data points used in

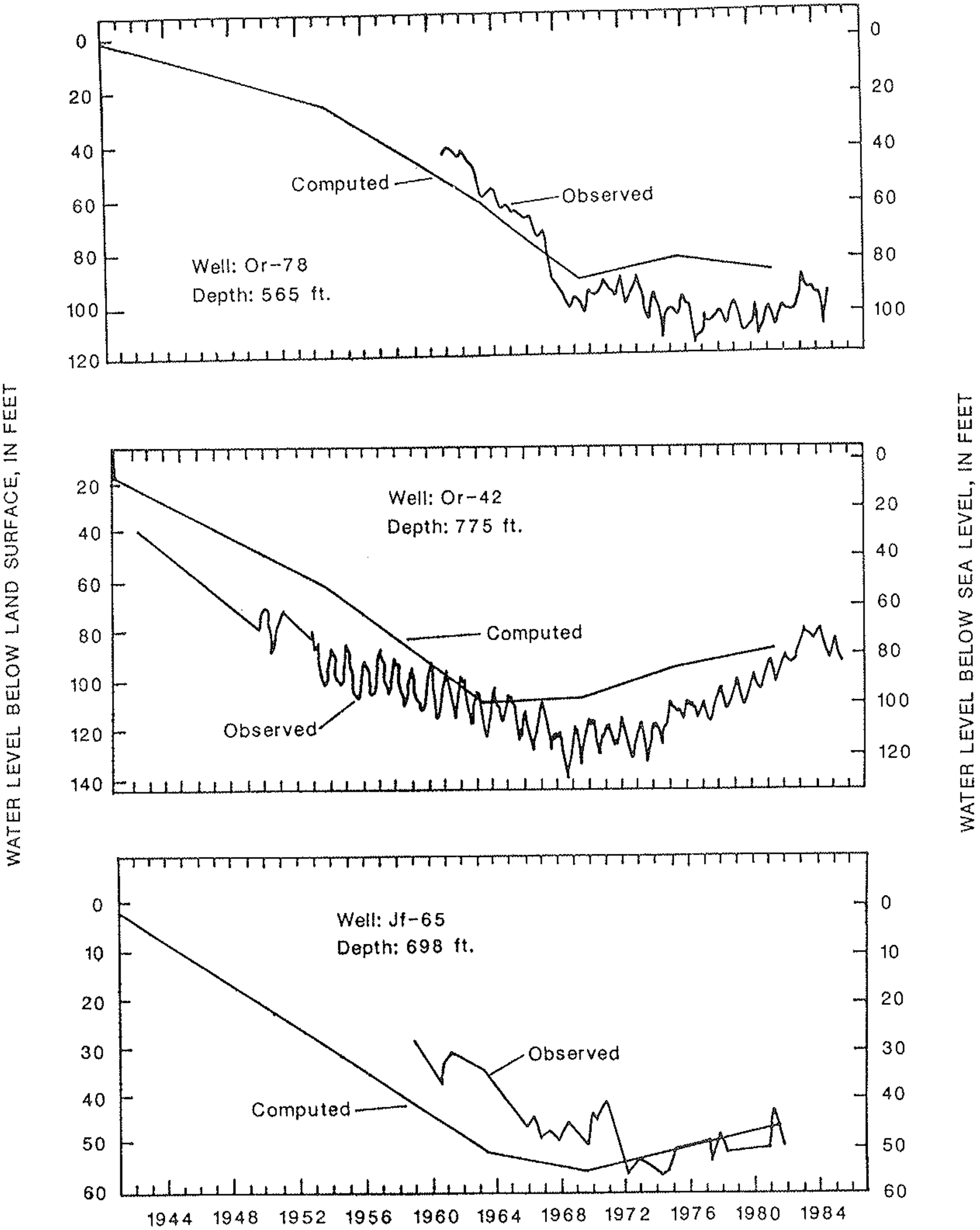


Figure 21.--Comparison of observed and computed water levels in the Gonzales-New Orleans aquifer, New Orleans area.

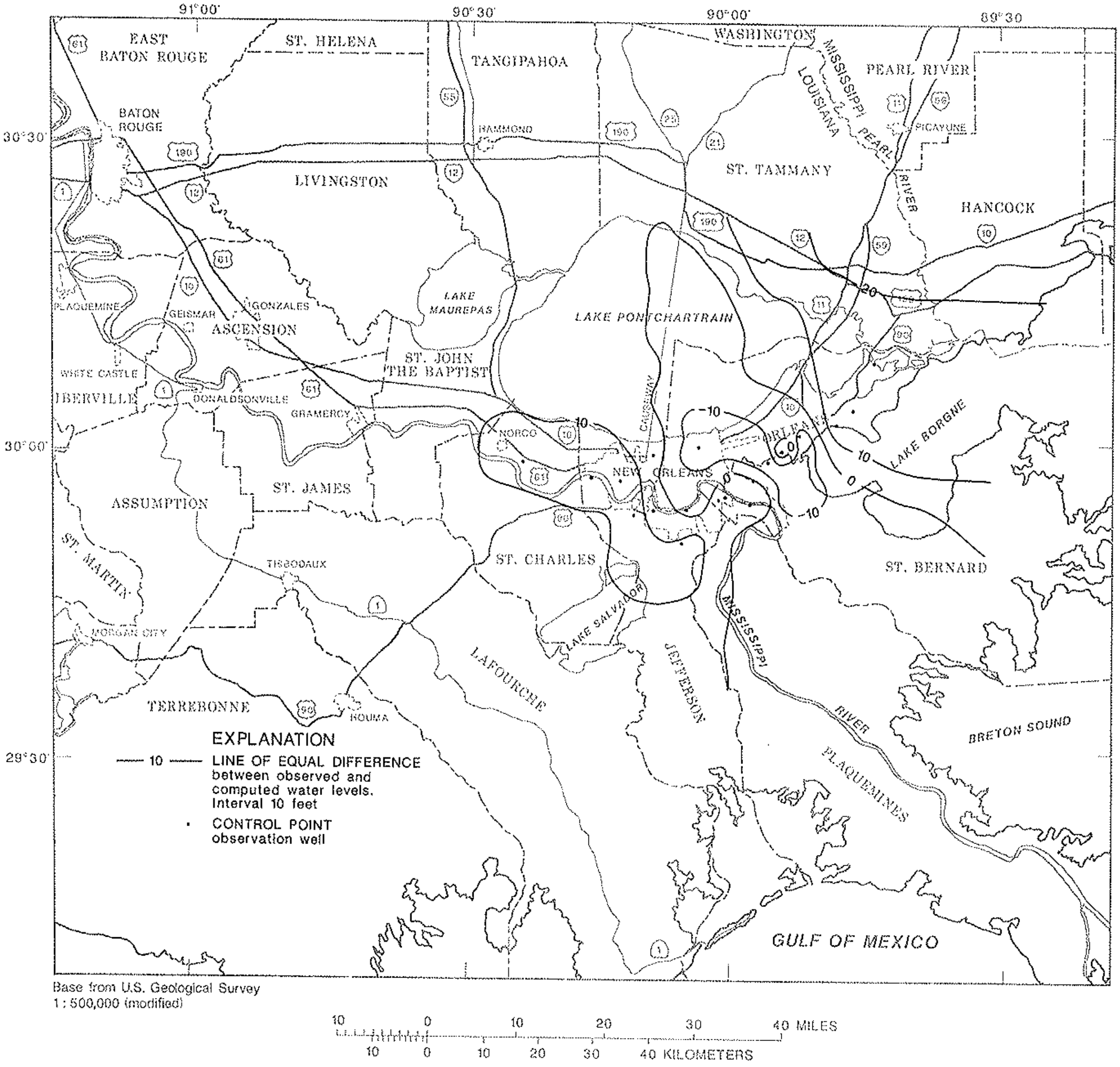


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Figure 22.--Comparison of observed and computed water levels in the Gonzales-New Orleans aquifer, 1963.

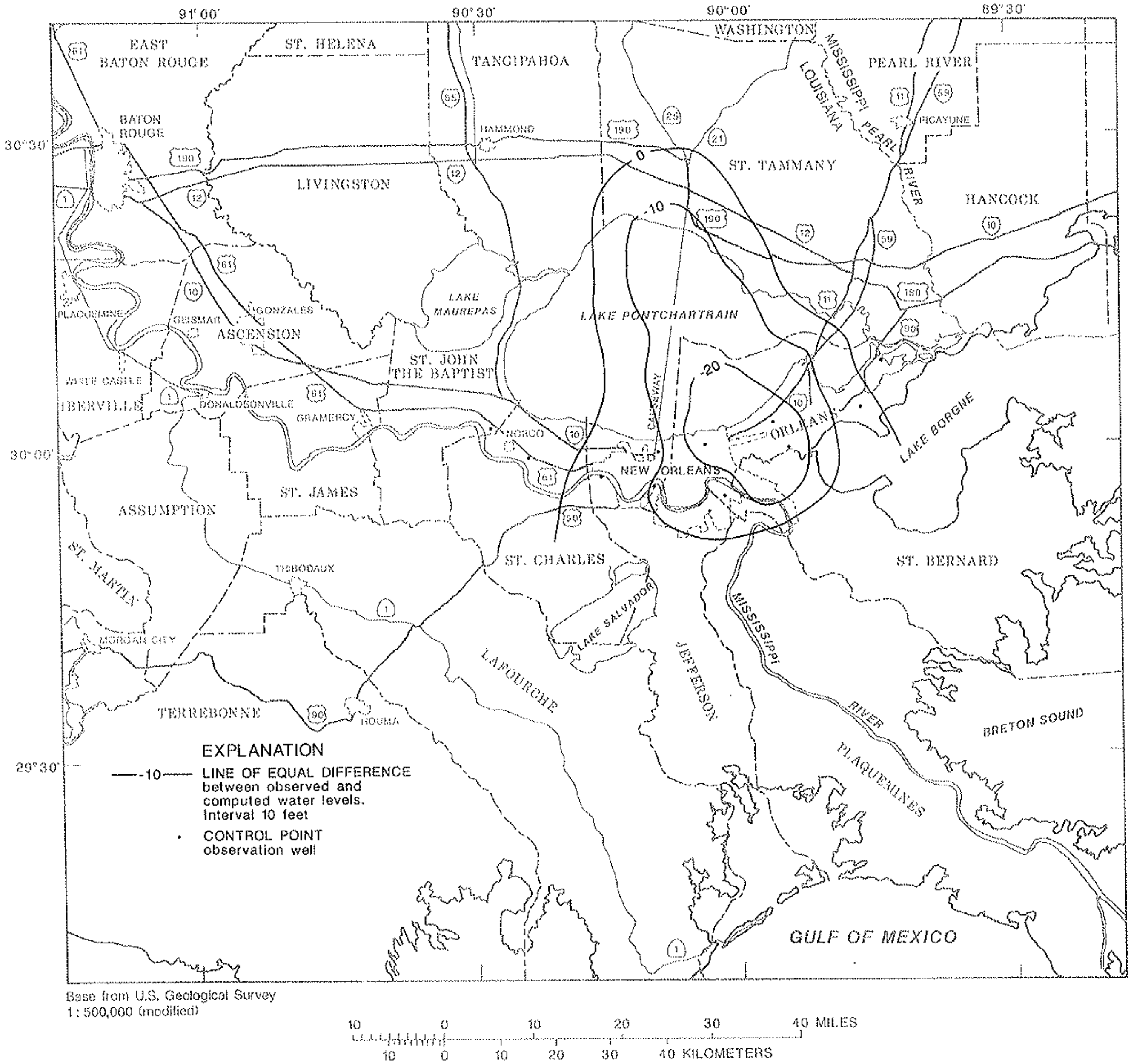

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Figure 23.--Comparison of observed and computed water levels in the Gonzales-New Orleans aquifer, 1981.

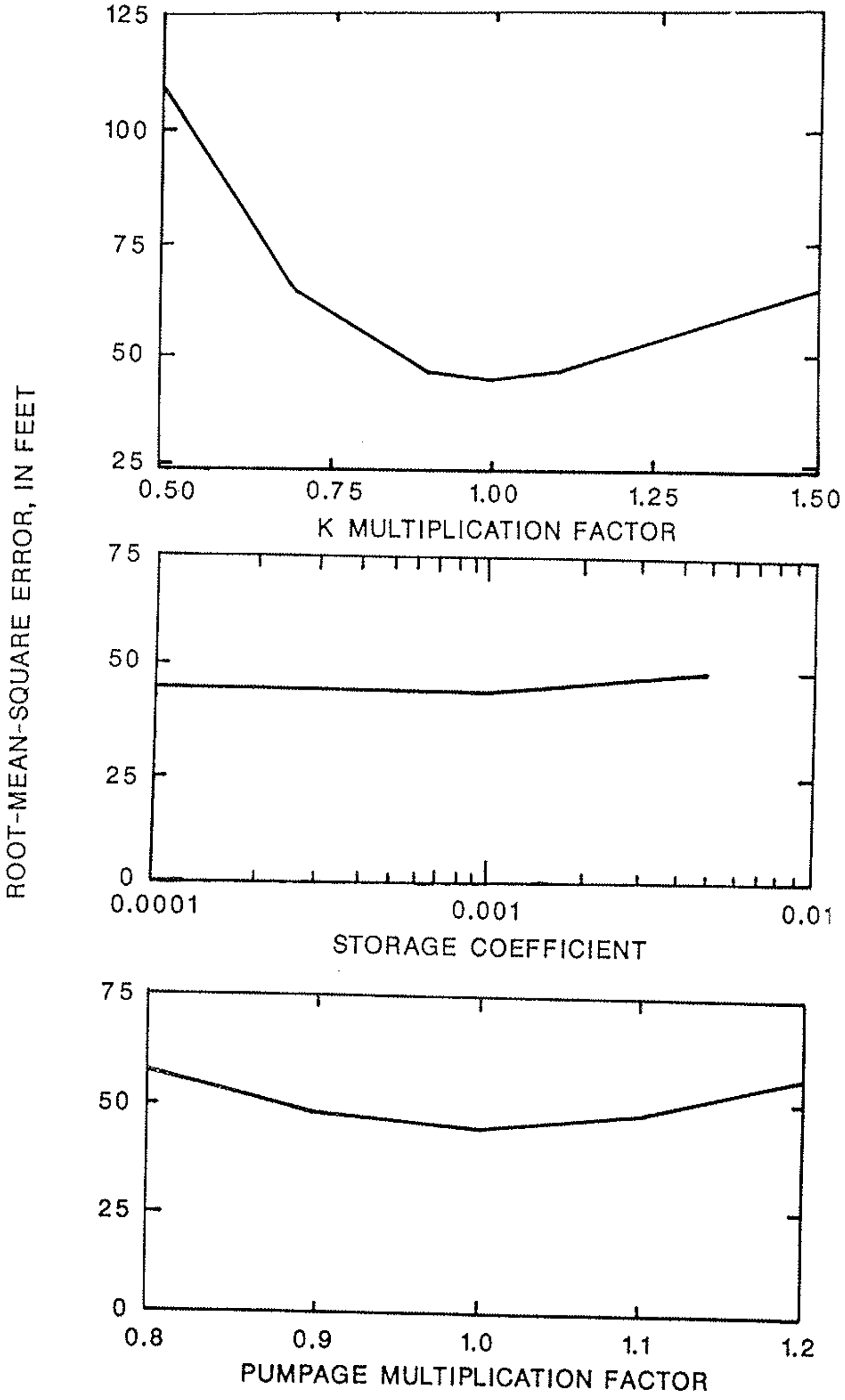


Figure 24.--Sensitivity of the model to variations in values of aquifer hydraulic conductivity (K), storage coefficient, and pumpage.

model calibration, and is small (less than 1 ft) in the southern and extreme eastern part of the study area. The "short hydraulic memory" of this aquifer system that is evident from the previous analysis indicates that error introduced into model calibration via possible error in the estimate of initial conditions is negligible.

Predevelopment Flow Simulations

A steady-state, no-pumpage simulation was conducted with the calibration-derived aquifer-system parameters. The potentiometric surfaces thus produced (figs. 25-28) are reasonably close to the authors' prior estimate of predevelopment conditions in the aquifer system. Water is seen to enter the outcrop areas, flow generally southward and then discharge vertically upward to an overlying aquifer or to the surficial system. The model-generated estimates of the steady-state flow components are shown in figure 29. A scarcity of potentiometric data prior to 1940 precludes any further refinement of model calibration based upon this simulation. Use of simulated predevelopment heads as initial conditions within the calibration simulation, rather than the authors' estimate, produced a negligible difference in simulated heads.

Water Budget of the Gonzales-New Orleans Aquifer

The water budget is an accounting of the various components of the flow system. These include constant head, leakage to or from the surficial environment, inter-aquifer leakage, aquifer storage, and pumpage. A summary of the model-simulated water budget for the period 1900 to 1981 is shown in table 3, and a historical perspective of the water budget for the period 1900 to 1981

Table 3.--Water budget for the Gonzales-New Orleans aquifer, 1900-1981

[Values in million gallons per day]

						Leakage from and to the					
		Western boundary		Surficial environment		"1,200-foot" aquifer		Norco aquifer		Storage	
Year	Pumpage	In	Out	In	Out	From	To	From	To	Taken from	Added to
1900	0.00	0.00	1.58	4.14	5.53	12.52	0.00	0.00	9.54	0.00	0.00
1920	2.17	.00	1.50	4.27	4.99	12.90	.00	.00	8.60	.12	.00
1940	5.96	.00	1.12	4.74	3.92	13.80	.00	.09	7.93	.29	.00
1953	31.00	.26	.18	9.79	1.40	18.68	.00	5.15	3.23	1.92	.00
1963	54.81	1.35	.08	18.24	.63	22.90	.19	12.44	1.75	2.52	.00
1969	59.80	1.79	.08	21.08	.49	23.04	.41	15.00	1.09	.95	.01
1975	53.42	1.58	.08	19.78	.50	21.33	.50	13.65	1.23	.06	.69
1981	52.49	2.17	.08	19.41	.53	20.95	.51	12.72	1.26	.09	.49

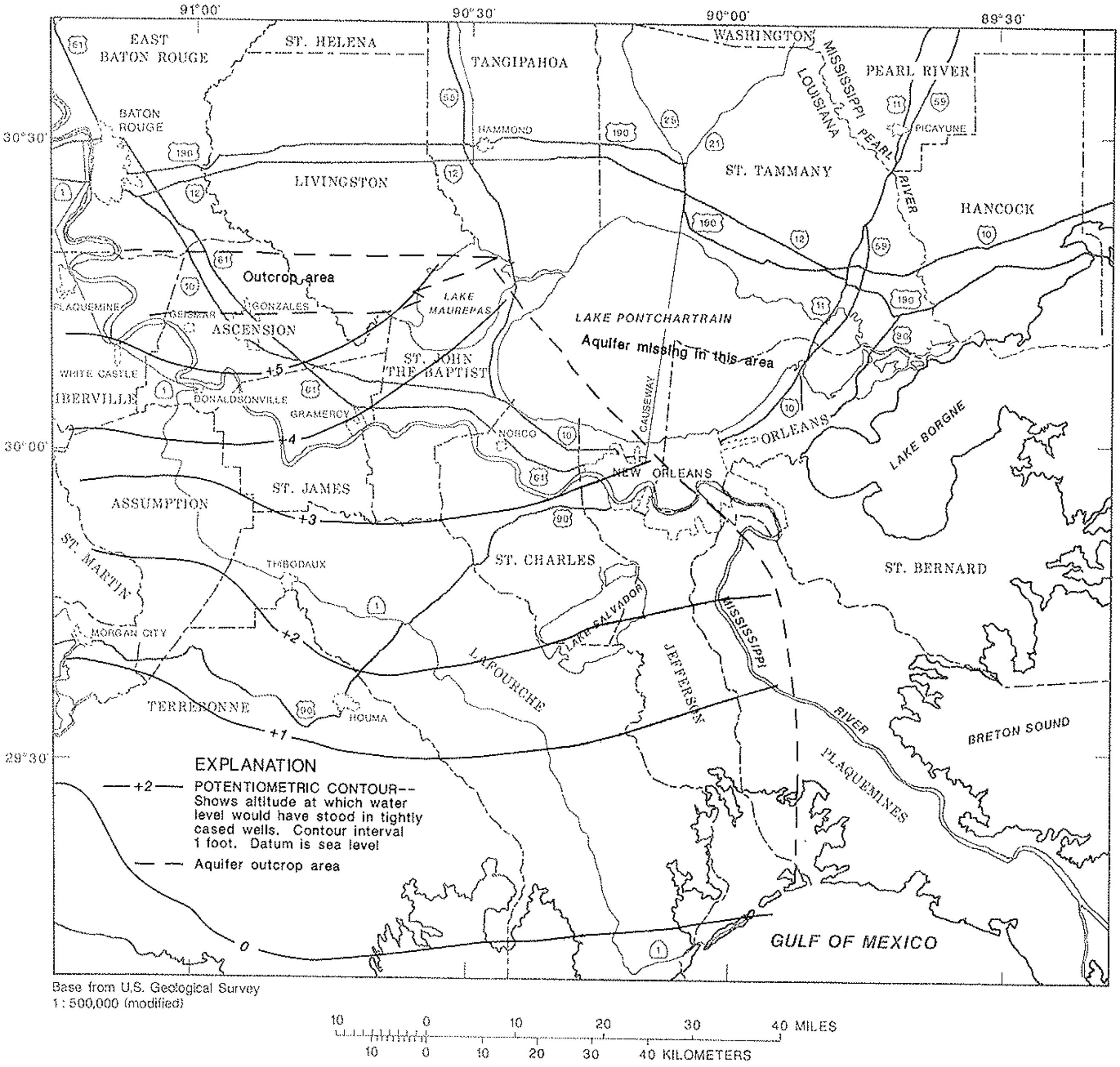
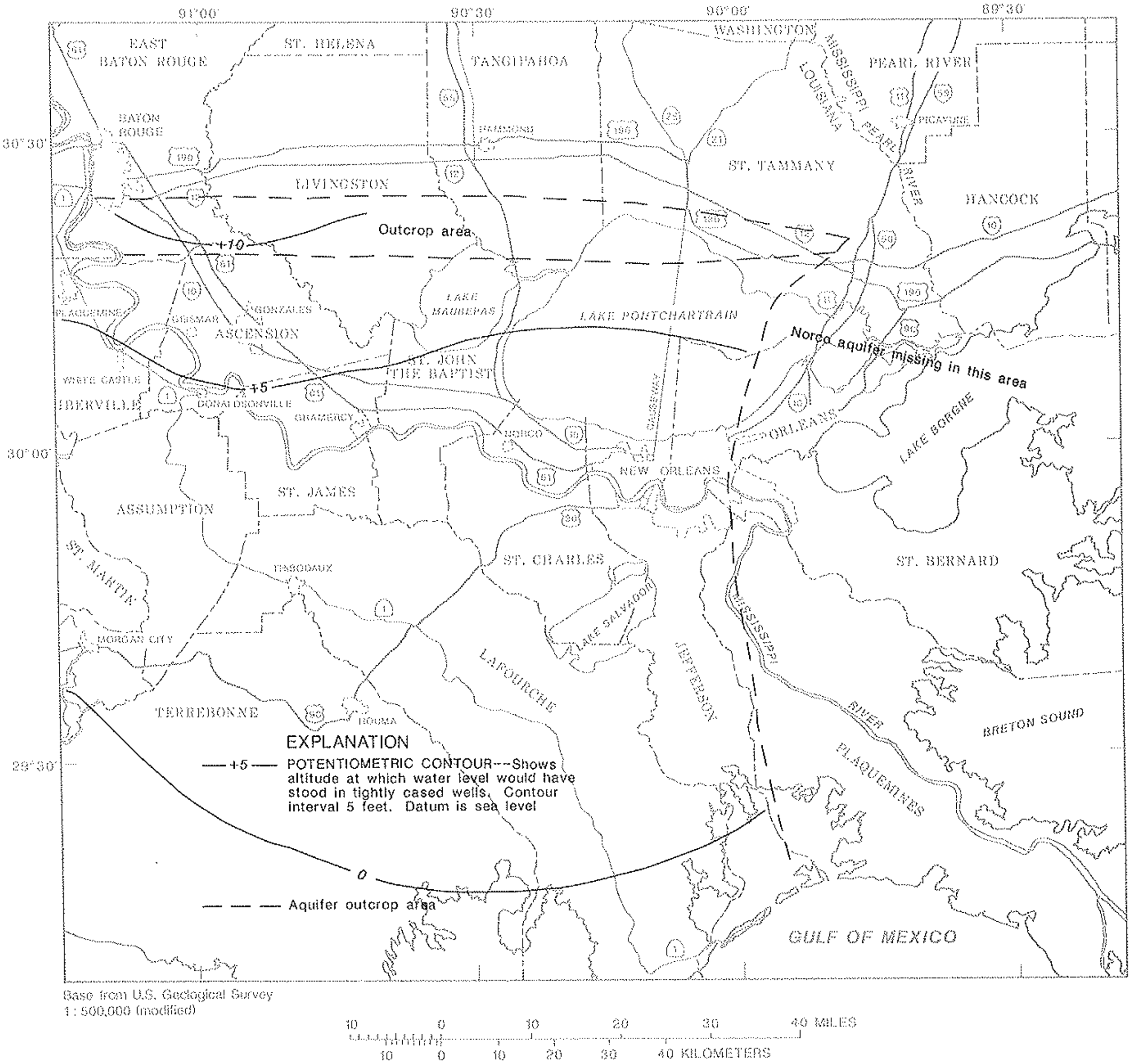


Figure 25.--Simulated steady-state potentiometric surface of the Gramercy aquifer in 1900.



Base from U.S. Geological Survey
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Figure 26.--Simulated steady-state potentiometric surface of the Norco aquifer in 1900.

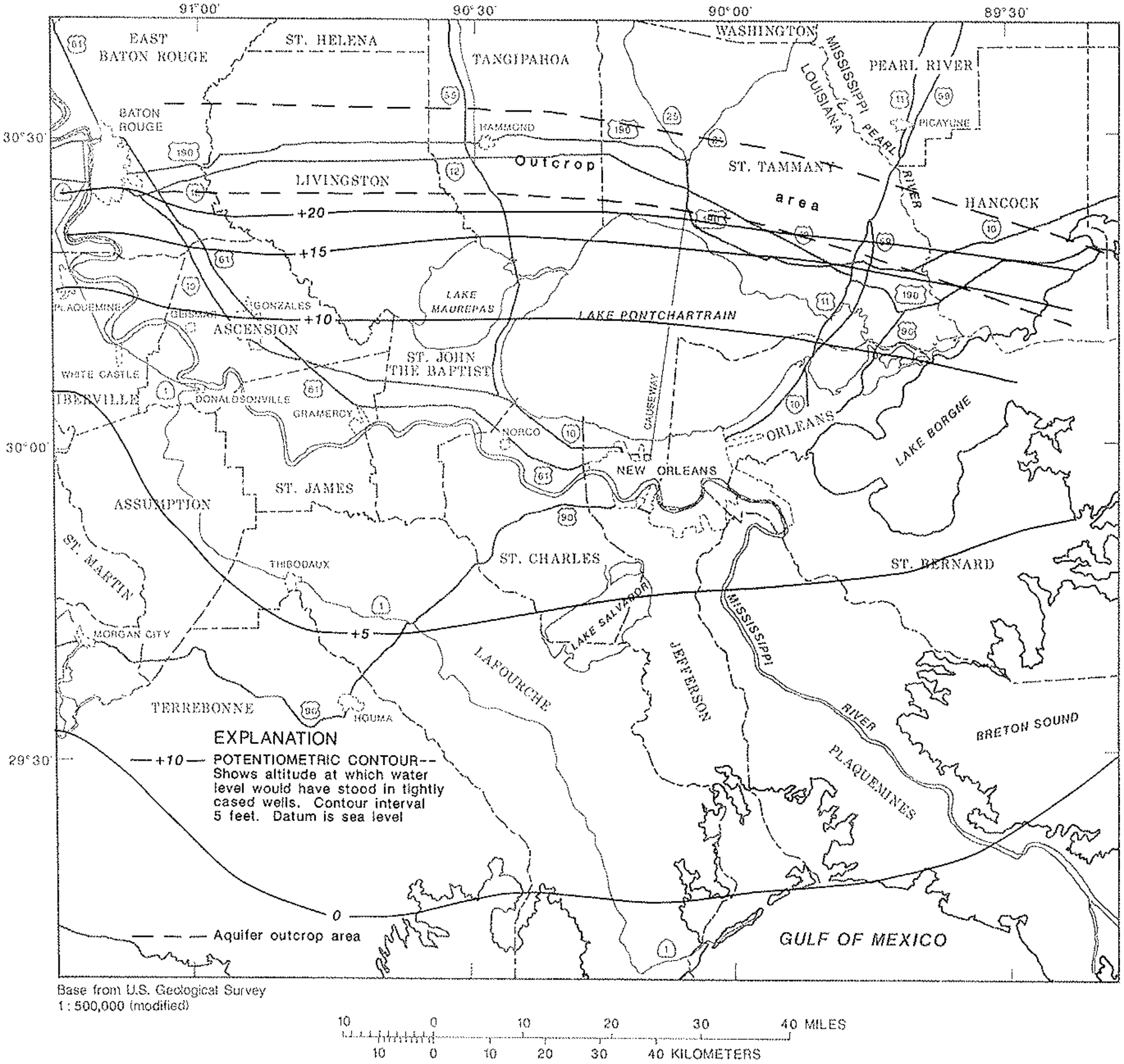

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Figure 27.--Simulated steady-state potentiometric surface of the Gonzales-New Orleans aquifer in 1900.

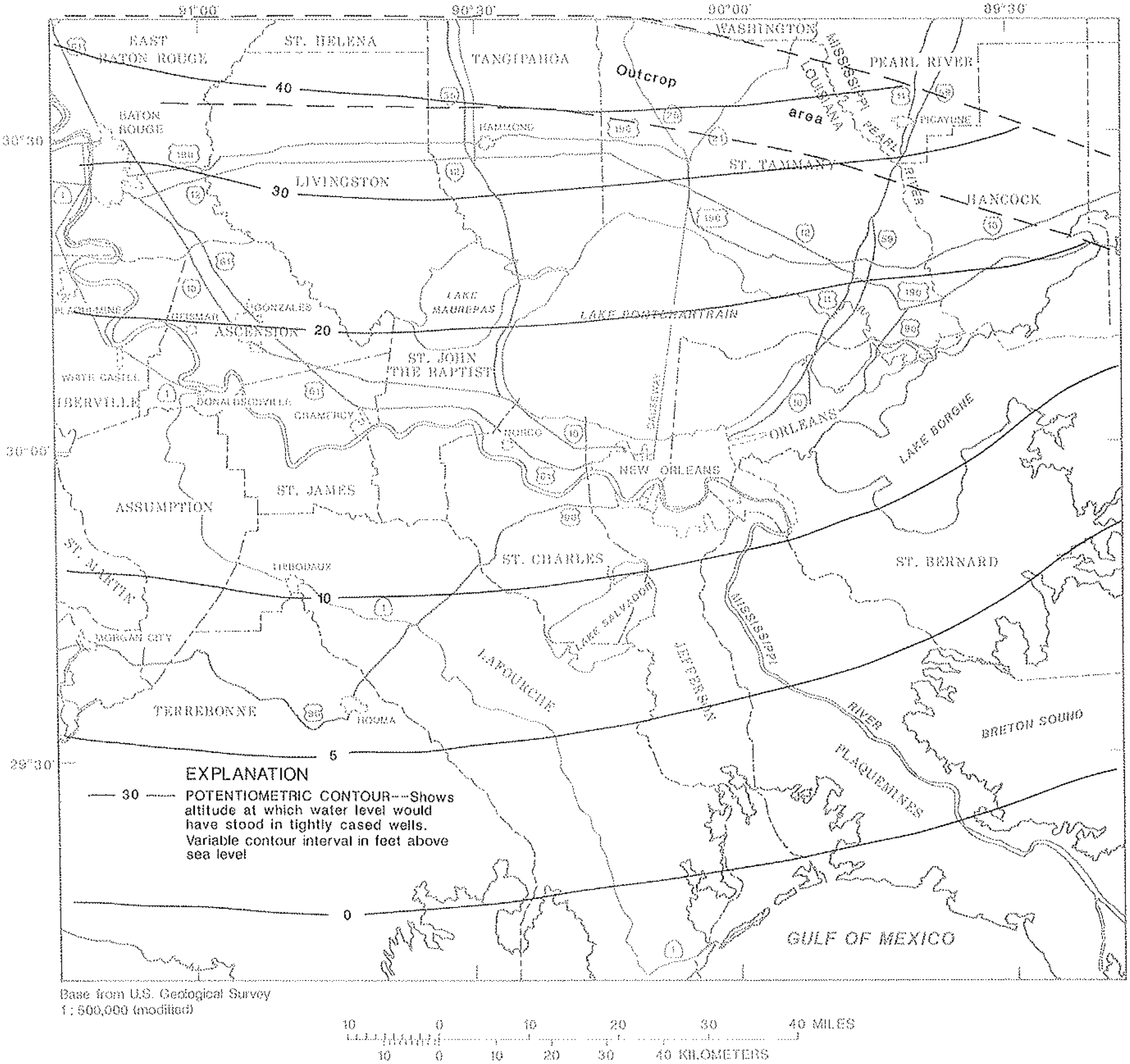

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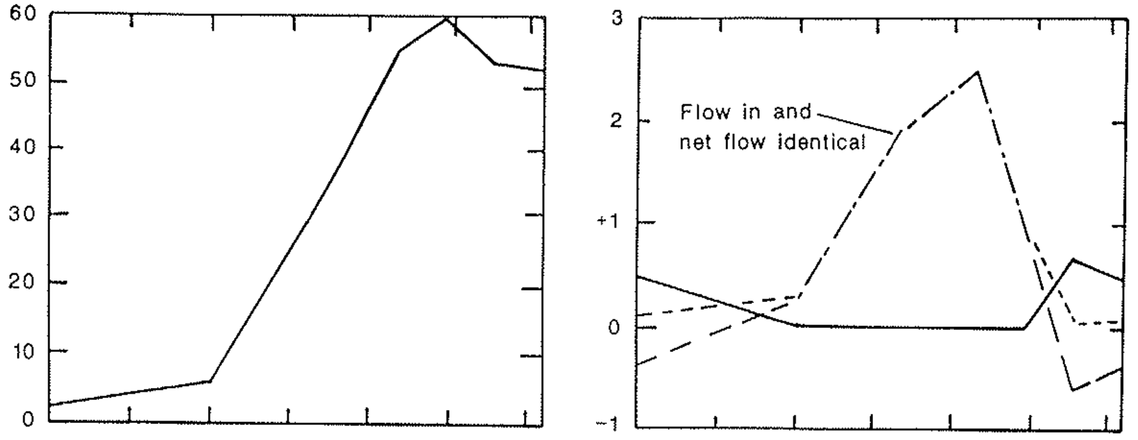
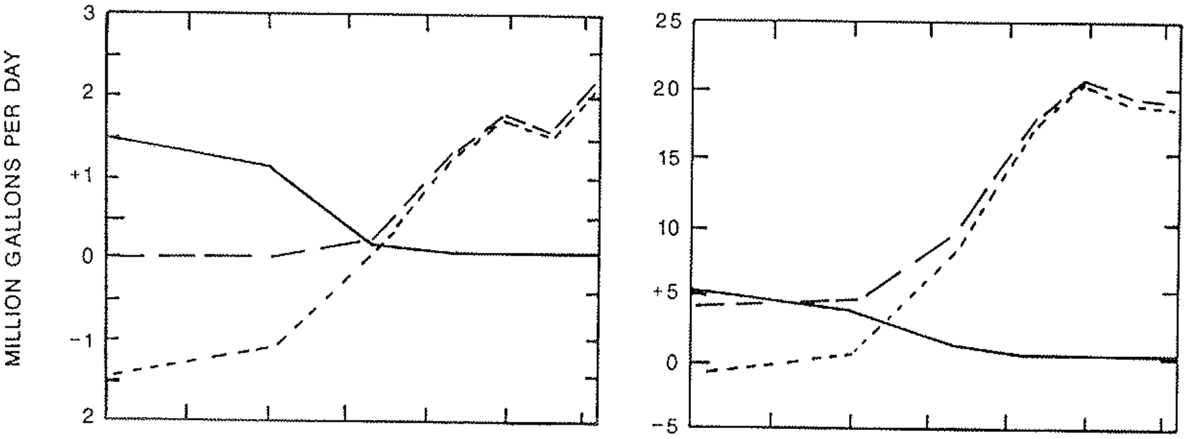
Figure 28.--Simulated steady-state potentiometric surface of the "1,200-foot" aquifer in 1900.



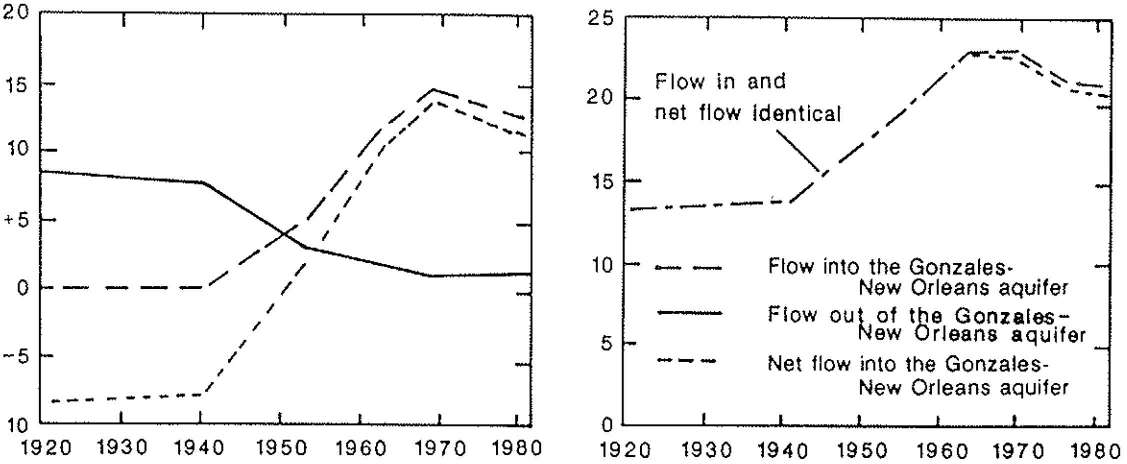
Pumpage from the Gonzales-New Orleans aquifer

Storage in the Gonzales-New Orleans aquifer



Flow at the western boundary

Leakage from the surficial environment



Leakage to and from the Norco aquifer

Leakage to and from the '1,200-foot' aquifer

Figure 29.--Relation of components of the ground-water flow system to pumpage from the Gonzales-New Orleans aquifer, 1900-81.

is shown in figure 29. The components of the flow system that are the source of most of the recharge to the Gonzales-New Orleans aquifer are inter-aquifer leakage (38 Mgal/d or 63 percent in 1969) and surface leakage (21 Mgal/d or 33 percent in 1969). Pumpage and inter-aquifer leakage reached a maximum in 1969 and decreased gradually from that time to 1981. In 1919, before heavy pumping from the aquifer began, net losses were indicated to constant head and surficial environment. As pumping increased, however, these two sources became contributory. Storage remained relatively insignificant in the water budget from 1900 to 1981 (table 3).

Because inter-aquifer leakage accounts for the largest amount of recharge to the Gonzales-New Orleans aquifer (table 3), the possibility exists for contamination of the aquifer by saltwater from leakage across the confining units above and below the aquifer. However, it should be pointed out that the overlying Norco aquifer is generally absent in eastern Orleans Parish where the Gonzales-New Orleans aquifer would be developed, and the underlying "1,200-foot" aquifer contains freshwater in the northern part of the modeled area.

SIMULATED EFFECTS OF PUMPING

Simulations were made to determine the effects of long-term stresses on the Gonzales-New Orleans aquifer for the present rate of pumpage of 40 Mgal/d and for an increase of 130 Mgal/d for a total of 170 Mgal/d. The two pumping conditions, 40 Mgal/d and 170 Mgal/d, were each simulated for a period of 20 years from 1987 to 2006. Starting heads for the 20-year simulations were determined by the model by using pumpage from the 1981 water-use inventory and continuing at that rate of pumpage to the end of stress period 8 (1982-86). The potentiometric surface of the Gonzales-New Orleans aquifer determined from 1986 model-generated water levels is shown in figure 30.

Water Levels

The potentiometric surface of the Gonzales-New Orleans aquifer, generated by the model after pumping 20 years at the 1986 rate of 40 Mgal/d, is shown in figure 31. The lowest water level for the year 2006 is about 90 ft below sea level in the Michoud area. The continuing current decline in pumpage from the Gonzales-New Orleans aquifer is reflected in a rise in water levels at the end of the 20-year period.

The simulation of an additional pumpage rate of 130 Mgal/d was based on the public-supply requirements of New Orleans as determined by the 1980 water-use survey (Walter, 1982). The required 130 Mgal/d was distributed in 12 cells near the lakefront of Lake Pontchartrain as far as possible from the freshwater-saltwater interface. Each of the cells represented either a 3- or 4-well group, with each well pumping at 2,000 gal/min (gallons per minute). There was a total of 45 wells in the 12 groups. The distribution of the well groups along the lakefront (fig. 32) was designed to obtain maximum distance between them and the freshwater-saltwater interface. The model-generated potentiometric surface after pumping 20 years at the increased rate of 170 Mgal/d is shown in figure 32.

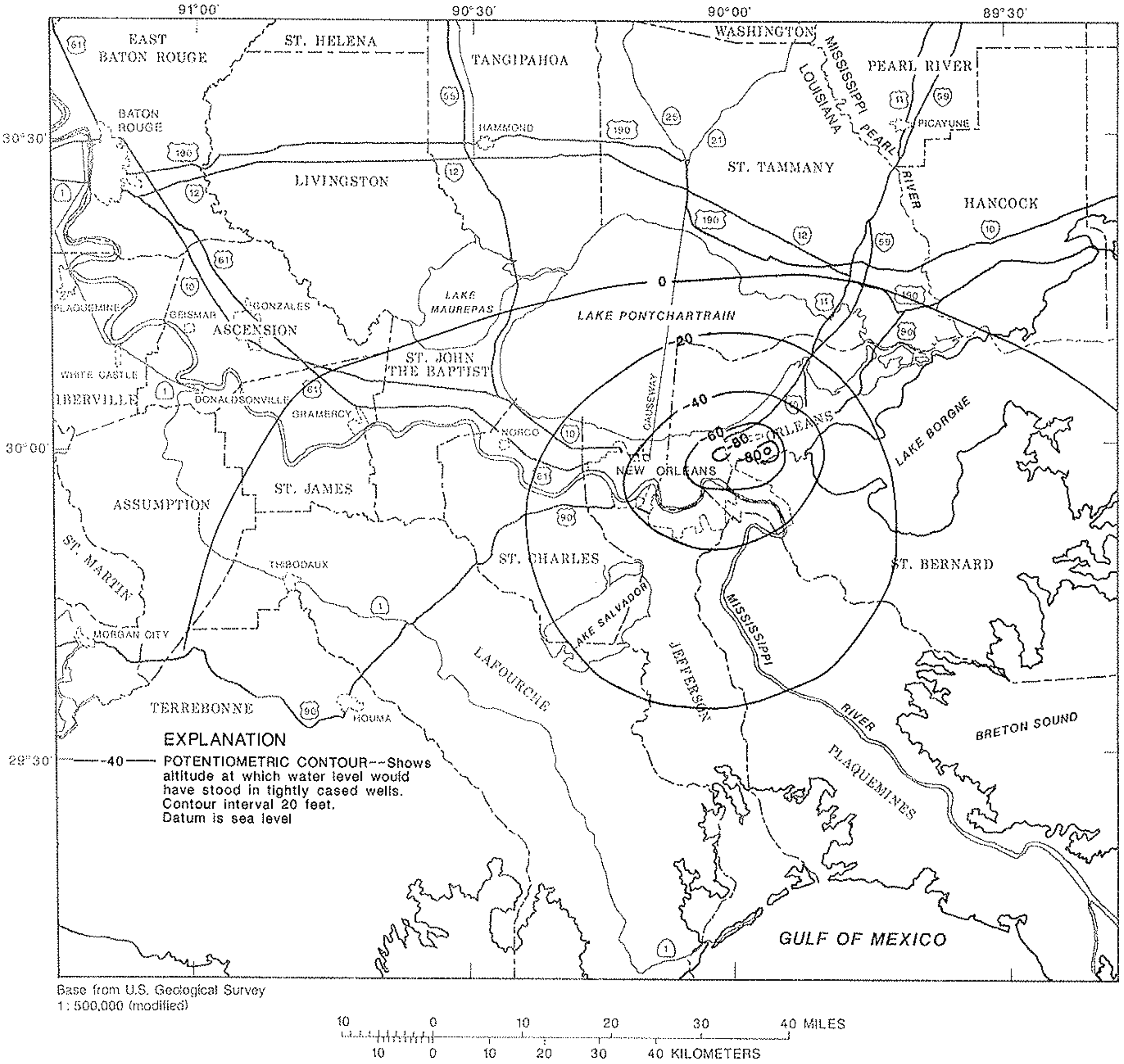
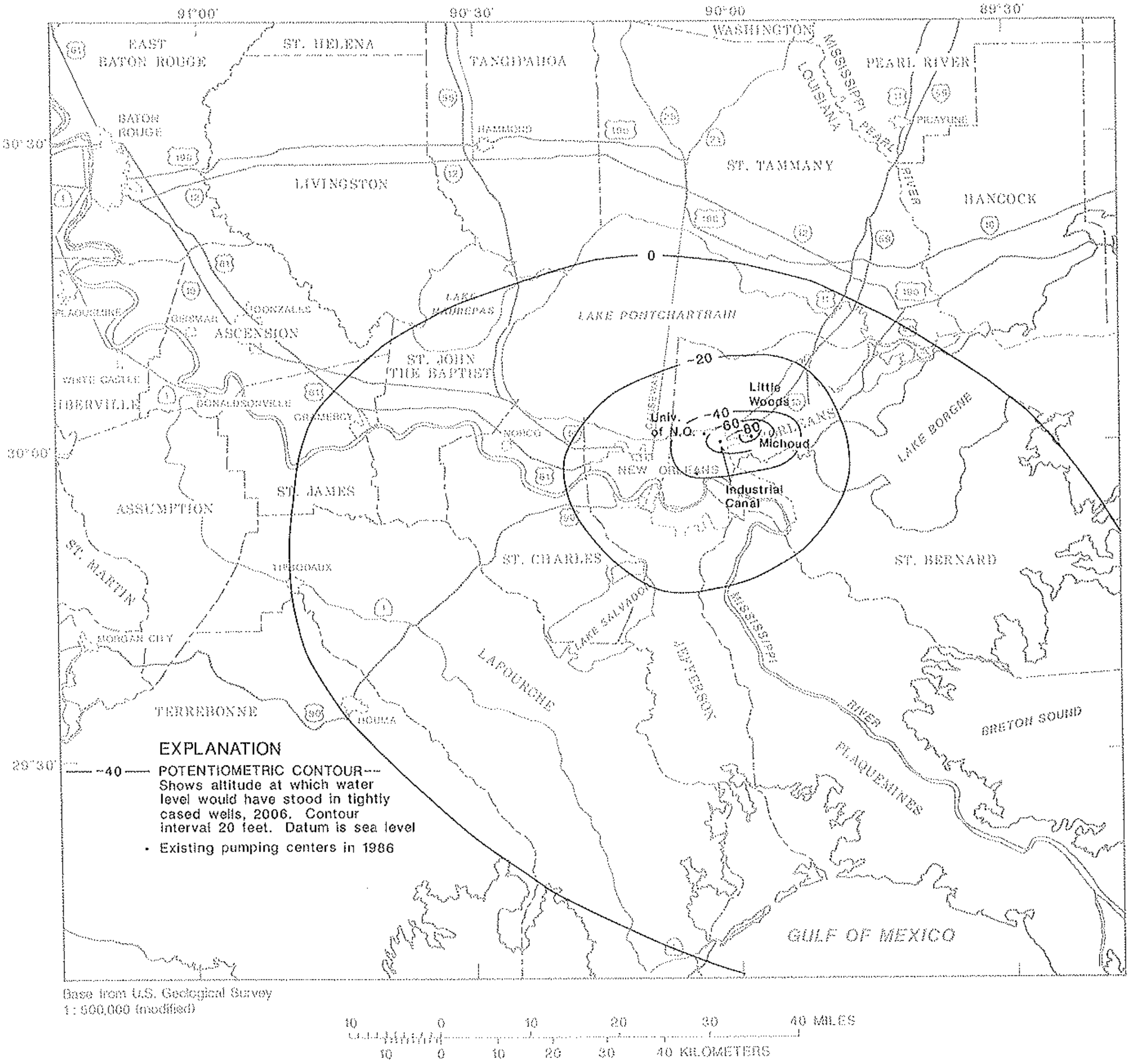


Figure 30.--Simulated potentiometric surface of the Gonzales-New Orleans aquifer in 1986.



Base from U.S. Geological Survey 1:500,000 (modified)

Figure 31.--Simulated potentiometric surface of the Gonzales-New Orleans aquifer after pumping at the 1986 rate of 40 million gallons per day for 20 years (1987-2006).

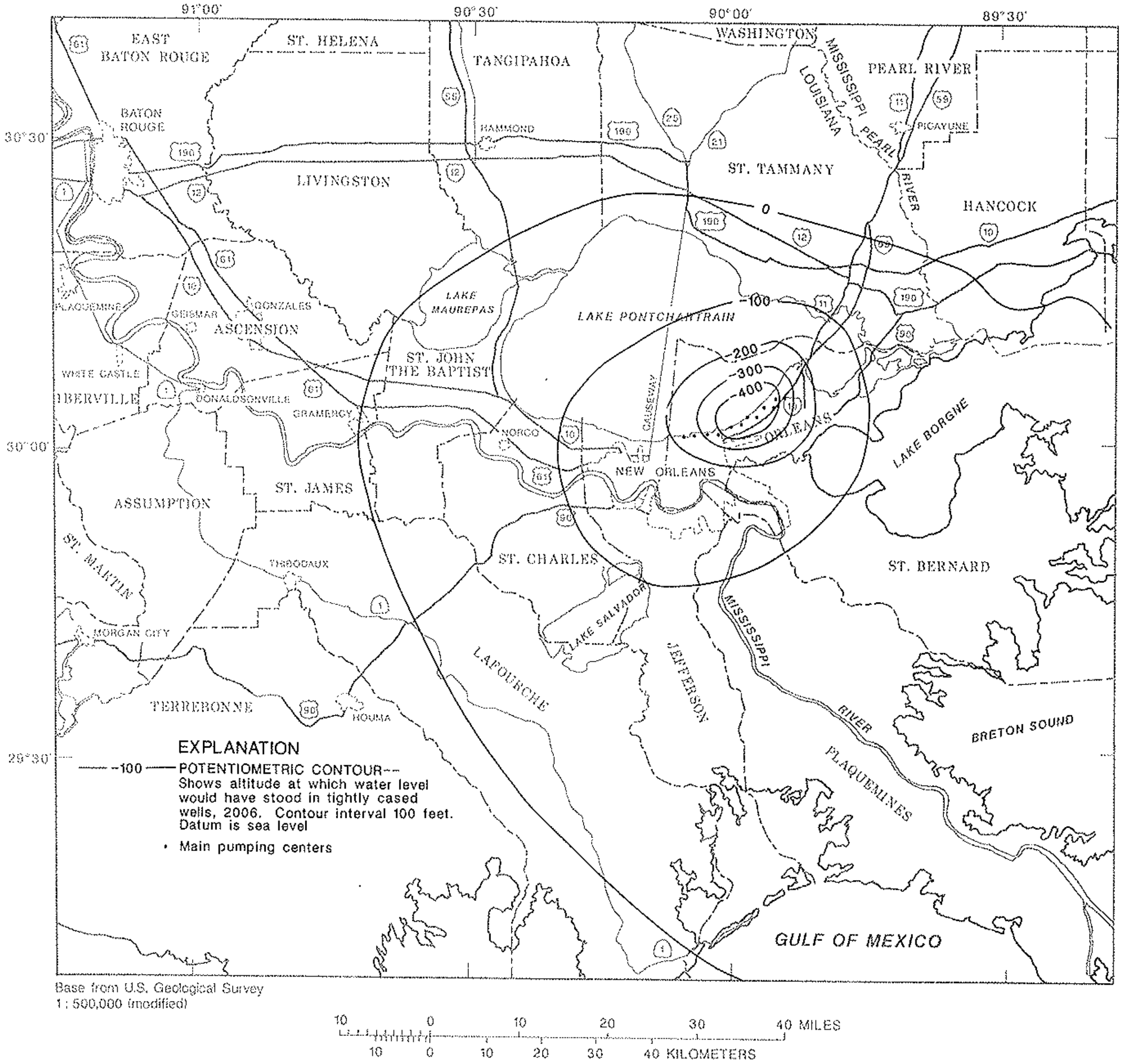


Figure 32.--Simulated potentiometric surface of the Gonzales-New Orleans aquifer after increasing the 1986 pumpage of 40 million gallons per day by 130 million gallons per day for 20 years (1987-2006).

The area of maximum water-level decline after imposing the pumpage of 170 Mgal/d on the aquifer was in the northeastern part of Orleans Parish near the shoreline of Lake Pontchartrain. The increased pumpage may lower the potentiometric surface slightly below the top of the aquifer in this area, where the top of the aquifer is about 400 to 450 ft below sea level (Rollo, 1966, pl. 8). The lowest water level simulated by the model after pumping 20 years at 170 Mgal/d was 410 ft below sea level. Thus, the effect of dewatering the aquifer, if any, at the increased pumpage is minimal. Any problem of dewatering could probably be avoided by spacing the well groups in different configurations that would lessen the amount of drawdown.

Saltwater Encroachment

The major problem associated with additional development of the Gonzales-New Orleans aquifer is saltwater encroachment. The additional pumpage of 130 Mgal/d would result in a lowering of the potentiometric surface and an increase in the hydraulic gradient toward the area of maximum water-level decline (figs. 31 and 32). Application of Darcy's law to compute saltwater encroachment rates would involve an assumption of negligible dispersion and density effects. The validity of these assumptions was tested by a comparison of historically measured encroachment rates in the Gonzales-New Orleans aquifer with those predicted by Darcy's law using estimated values of aquifer hydraulic conductivity, effective porosity (using a conservative estimate of 30 percent), and hydraulic gradient. The results indicated that Darcy's law gives a reasonable estimate of encroachment rates and, thus, will be used for the predicted encroachment rates using model-generated water levels. Darcy's law is given as:

$$v = KI/\theta,$$

where v = ground-water velocity, in feet per day;
K = hydraulic conductivity, in feet per day;
I = hydraulic gradient, dimensionless; and
θ = effective porosity, dimensionless.

Table 4 summarizes the calculated rates of saltwater encroachment. The position of the interface after 20 years of pumping was estimated from model-generated water levels. The average rate of movement of the interface projected over 20 years of pumping at the present rate was 150 ft/yr in the area of Industrial Canal (fig. 31).

The average rate of saltwater encroachment for the simulations involving a 170 Mgal/d pumpage rate was calculated to be 500 ft/yr in the Industrial Canal area and 250 ft/yr near Michoud (fig. 32). The slower calculated rate of encroachment in the Michoud area is because of the present heavy pumping south of the hypothetical well fields. Because the hydraulic gradient at the start of the 20-year simulation is south toward the pumping center at Michoud, the saltwater will not move north toward the new center of drawdown until the hydraulic gradient is reversed. On the basis of these calculations, salty water in the area of Industrial Canal would reach the well fields near the lakefront in 42 years. In the Michoud area, salty water would reach the well

Table 4.--Rate of saltwater encroachment for the year 2006

[ft/yr, feet per year; Mgal/d, million gallons per day]

	Average rate of encroachment (ft/yr) for the area near	
	Industrial Canal	Michoud
2006 (no increase in pumpage of 40 Mgal/d).......	150	---
2006 (increase pumpage by 130 Mgal/d to a total of 170 Mgal/d)......................	500	250

fields in about 63 years if the current pumpage of about 10 Mgal/d at Michoud remained constant.

The rates of saltwater encroachment in the Gonzales-New Orleans aquifer apply only to flow of saltwater within the aquifer itself. As indicated earlier, the possibility exists for leakage to occur across confining units above and below the aquifer. Because of the complexity of this problem, no attempt was made to determine the time of travel of saltwater across the intervening confining units. Because leakage is significant in the water budget, this problem needs to be addressed if the aquifer is used as an alternative drinking-water supply.

SUMMARY AND CONCLUSIONS

The New Orleans aquifer system was evaluated as a possible alternative public-supply source for New Orleans because it is the only aquifer system that contains a large volume of freshwater beneath the city. The geohydrologic setting of the New Orleans aquifer system is part of a series of alternating beds of sand and clay that deepen southward toward the Gulf of Mexico. The sands form the aquifers, and the clays form the intervening confining units. The transmissivities of the Gramercy and Norco aquifers range from 9,000 to 30,000 ft^2/d; estimated hydraulic conductivities are 100 and 130 ft/d, respectively. The transmissivity of the Gonzales-New Orleans aquifer in the greater New Orleans area ranges from 12,000 to 24,000 ft^2/d and has been reported as high as 32,000 ft^2/d; the average hydraulic conductivity is 110 ft/d. Storage coefficients range between 0.0001 and 0.001 and average about 0.0005 for the Gramercy, Norco, and Gonzales-New Orleans aquifers. Confining-unit hydraulic conductivities were estimated on the basis of depth of burial.

A three-dimensional finite-difference ground-water flow model was calibrated and used to analyze the New Orleans aquifer system. Four aquifer layers representing the Gramercy, Norco, Gonzales-New Orleans, and "1,200-foot" aquifers, and intervening clay confining units were included in the model formulation. The model was calibrated by comparing observed water levels with computed water levels for the period 1900 to 1981. For most of the modeled area, differences in observed and computed water-levels were 20 ft or less. A sensitivity analysis indicated that the model was very sensitive to aquifer hydraulic conductivity and confining-unit hydraulic conductivity, fairly sensitive to changes in the assumed magnitude of pumping, and insensitive to storage coefficient.

The model was also used to predict the effects of pumping on water levels. Saltwater encroachment was estimated from simulated results. Simulations were made for the present (1986) pumpage of 40 Mgal/d and for an increase of 130 Mgal/d for a total pumpage of 170 Mgal/d from the Gonzales-New Orleans aquifer. The aquifer was simulated for 20 years (1987 to 2006). For the present pumping conditions, the model results showed a water-level recovery after 20 years. The lowest water level was about 90 ft below sea level in the Michoud area. For the increased pumping rate of 170 Mgal/d, water levels declined to a maximum of 410 ft below sea level near the lake front at Lake Pontchartrain. The decline was not enough to cause aquifer dewatering to be a major concern although some possibility exists that water levels would be lowered below the top of the aquifer.

Saltwater encroachment is the main problem associated with additional development of the Gonzales-New Orleans aquifer. The increased pumpage required to supply New Orleans would quicken the movement of saltwater toward areas where the well fields are located. Estimates of encroachment rates were calculated for the Industrial Canal and Michoud areas. The average simulated rate of encroachment for the 20-year period at a pumping rate increased by 130 Mgal/d (total pumpage of 170 Mgal/d) from the 1986 rate was 500 ft/yr for the Industrial Canal area and 250 ft/yr for the Michoud area. The estimated time of travel from the present interface to the nearest well field is 42 years for the Industrial Canal area and 63 years for the Michoud area.

The Gonzales-New Orleans aquifer is capable of supplying the public-supply needs of New Orleans, but its successful use is dependent on control of saltwater encroachment within the aquifer and possible contamination from inter-aquifer leakage from the Norco and "1,200-foot" aquifers. Another problem arising from its use other than saltwater contamination is water-level decline, which may contribute to other problems such as land subsidence.

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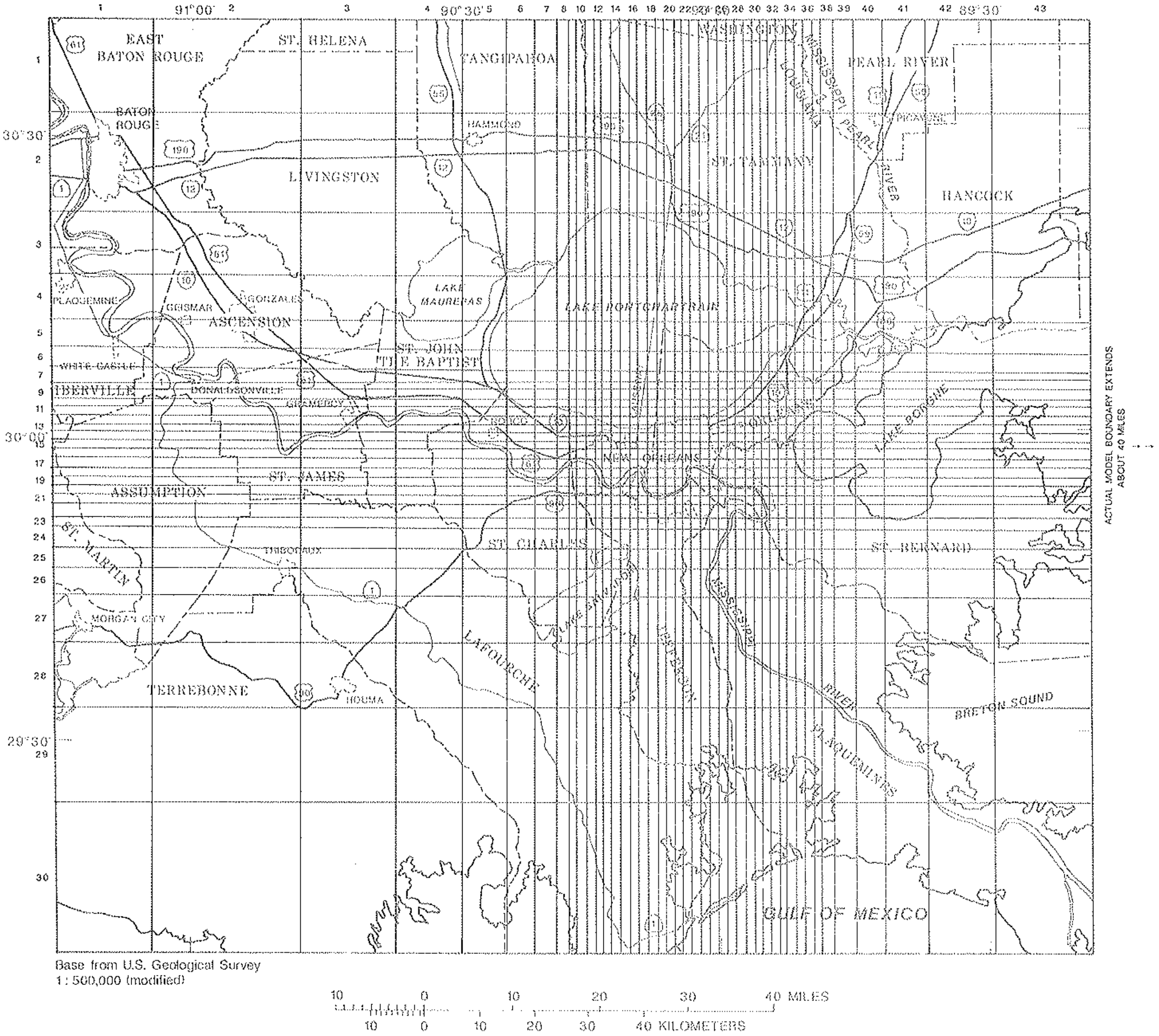
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

TECHNICAL REPORT NO. 46
PLATE 1



Base from U.S. Geological Survey
1 : 500,000 (modified)

THE AREA COVERED BY THE MODEL IN SOUTHEASTERN LOUISIANA AND SOUTHERN MISSISSIPPI.