SIMULATED RESPONSE TO FUTURE PUMPING IN THE SPARTA AQUIFER, UNION COUNTY, ARKANSAS

By John M. Kilpatrick

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch per year (in/yr)	2.54	centimeter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.0438	cubic meter per second

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

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ABSTRACT

Water levels in the basal aquifer of the Sparta Sand have declined more than 320 feet in the El Dorado, Arkansas, area since ground-water development began about 1920. Previous ground-water flow-model results have indicated that a 25 to 50 percent increase in pumpage above 1984 rates would lower water levels below the top of the aquifer by 2005. The model results and local saltwater intrusion problems have raised serious doubts about the viability of the aquifer as the source of additional freshwater needed for future economic expansion and growth in the El Dorado area.

Because of these concerns, an existing U.S. Geological Survey ground-water flow model of the Sparta aquifer was updated and used to evaluate the effects of changes in the magnitude or location of pumping on the potentiometric surface of the aquifer in the El Dorado area. In addition, an attempt was made to evaluate the effects of changes in the magnitude of pumpage in the Magnolia, Arkansas, and West Monroe, Louisiana, areas on water levels in the Sparta aquifer in the El Dorado area.

The results of model simulations with specified variations in pumping indicated that even with a major redistribution of municipal pumpage, a 25 percent increase in total pumpage during a 30-year period would result in at least 25 feet of additional drawdown. The results of other simulations indicated that although pumping in the Magnolia and West Monroe areas affects water levels in the Sparta aquifer in the El Dorado area, the effect of pumping at these locations is small in comparison to the effects of pumping in the El Dorado area.

INTRODUCTION

The Sparta aquifer is a major source of water supply in east-central and southern Arkansas, northern Louisiana, and northwestern Mississippi. Approximately 157 Mgal/d were withdrawn in 1985 from the aquifer in Arkansas (Holland, 1987, p. 24). Most of the water withdrawn from the aquifer is utilized for public supply and industrial use. In the Grand Prairie, water from the Sparta aquifer also is used for irrigation in substantial amounts.

Pumping from the Sparta aquifer has resulted in large, deep cones of depression in the potentiometric surface of the aquifer in several areas, including Magnolia, El Dorado, and Pine Bluff, Arkansas, and West Monroe, Louisiana. Drawdown in the El Dorado area has exceeded 320 ft since development began in this area about 1920. Water-level declines in the Magnolia, El Dorado, and West Monroe areas have been so great that individual cones of depression in these areas have coalesced across the Arkansas-Louisiana State line.

Since the early 1960's chloride concentrations have increased in water from the aquifer in the El Dorado area. The likely source of the saltwater is a part of the aquifer located in a graben a few miles southeast of El Dorado. Chloride concentrations in water from the graben have been estimated to be as much as 2,500 mg/L (milligrams per liter). Pumpage in the El Dorado area has reversed the natural flow direction and induced the flow of saltwater from the graben toward the cone of depression in the El Dorado area. Any additional pumping in El Dorado with the current distribution of withdrawals could increase the rate of saltwater flow toward the center of the cone of depression (Broom and others, 1984).

Declining water levels and saltwater intrusion in the El Dorado area have caused doubt about the viability of the Sparta aquifer as the source of additional water needed for future economic expansion and growth. In 1985, as a result of increasing concerns about water-level declines and increasing chloride concentrations in the aquifer, a hydrologic study that included the development of a digital ground-water flow model was begun by the U.S. Geological Survey (Fitzpatrick and others, 1990; McWreath and others, 1991). Simulation results from that study indicated that a 25 to 50 percent increase in pumpage above 1984 rates would lower the potentiometric surface below the top of the aquifer by 2005.

In 1990, a study was begun by the U.S. Geological Survey (USGS) in cooperation with the Arkansas Soil and Water Conservation Commission (ASWCC), to update the ground-water flow model developed by Fitzpatrick and others (1990) and to use the updated model to evaluate several possible future pumping scenarios in the El Dorado area.

Purpose and Scope

This report presents the details of how the existing model was updated, along with an evaluation of several potential future pumping scenarios developed jointly by the USGS, ASWCC, and the city of El Dorado. These scenarios were designed to evaluate three questions:

1. What effect will the anticipated reduction of pumpage in the Magnolia area have on water levels in the El Dorado area?
2. What effect will future increases in pumpage in the West Monroe area have on water levels in the El Dorado area?
3. What effect would changes in the location of city of El Dorado public supply wells have on the depth of the cone of depression in the El Dorado area?

Evaluations of these questions are presented in this report.

Description of the Study Area

The study area (fig. 1) encompasses much of southern and east-central Arkansas, northern Louisiana, and northwestern Mississippi. It extends into the Mississippi Alluvial Plain, which has little or no relief, and the West Gulf Coastal Plain, characterized by rolling terrain with low to moderate relief. Land-surface altitudes in the study area range from approximately 50 ft above sea level near the Mississippi River at the southern end of the study area to more than 500 ft at the northwestern boundary. The principal streams in the study area include the Mississippi, Arkansas, Saline, Ouachita, and Red Rivers, Bayou Dorcheat and Bodcau Creek. These streams generally flow to the southeast following the regional topographic gradient. Average annual rainfall ranges from 48 to 56 in/yr (Freiwald, 1985).

GEOHYDROLOGY OF THE STUDY AREA

The study area is underlain by Quaternary deposits and older Tertiary units. Quaternary deposits unconformably overlie Tertiary units in the Mississippi Alluvial Plain along the Mississippi River, and in stream valleys that cross outcrops of Tertiary units. The thickness of these deposits can be as much as 200 ft in the Mississippi Alluvial Plain, although thicknesses of less than 100 ft are more common in the valleys of the Red, Ouachita, and Saline Rivers (Petersen and others, 1985, p. 4). The uppermost aquifer in the study area is comprised of the basal sand and gravel unit of the Quaternary deposits and is called the Mississippi River Valley alluvial aquifer.

The Tertiary units underlying the study area dip from their outcrop and subcrop areas along the western and eastern edges of the study area toward the axis of the Mississippi embayment, which approximately follows the present course of the Mississippi River. These Tertiary sediments contain several regionally extensive and significant aquifers and confining units, the youngest of which is the Cockfield aquifer in the Cockfield Formation. The Cockfield aquifer is separated from the underlying Sparta aquifer by the Cook Mountain confining unit, which consists of clays in the Cook Mountain Formation and typically is 100 to 150 ft thick. The underlying Sparta aquifer in the Sparta Sand is confined except in its outcrop areas. The aquifer ranges in thickness from 200 to 600 ft. In the El Dorado area (fig. 2), a clay confining unit divides the Sparta aquifer into upper and lower aquifers locally known as the "Greensand" and "El Dorado" aquifers (fig. 3) (Broom and others, 1984, p. 14). The sources of recharge to the aquifer are precipitation on the outcrop, inflow from rivers in the outcrop, leakage from the alluvial aquifer where the Sparta aquifer subcrops, and leakage from adjacent aquifers where the hydraulic gradient is toward the Sparta aquifer. Most natural discharge is to rivers in the outcrop and to adjacent units with lower hydraulic heads. The regional movement of water in the aquifer before development generally was downdip toward the south and toward the axis of the Mississippi embayment. The Sparta aquifer is confined below by the Cane River confining unit that consists of 300 to 600 ft of tight marine clay of the Cane River Formation. The geohydrology of the area is described in more detail by Fitzpatrick and others (1990) and McWreath and others (1991).

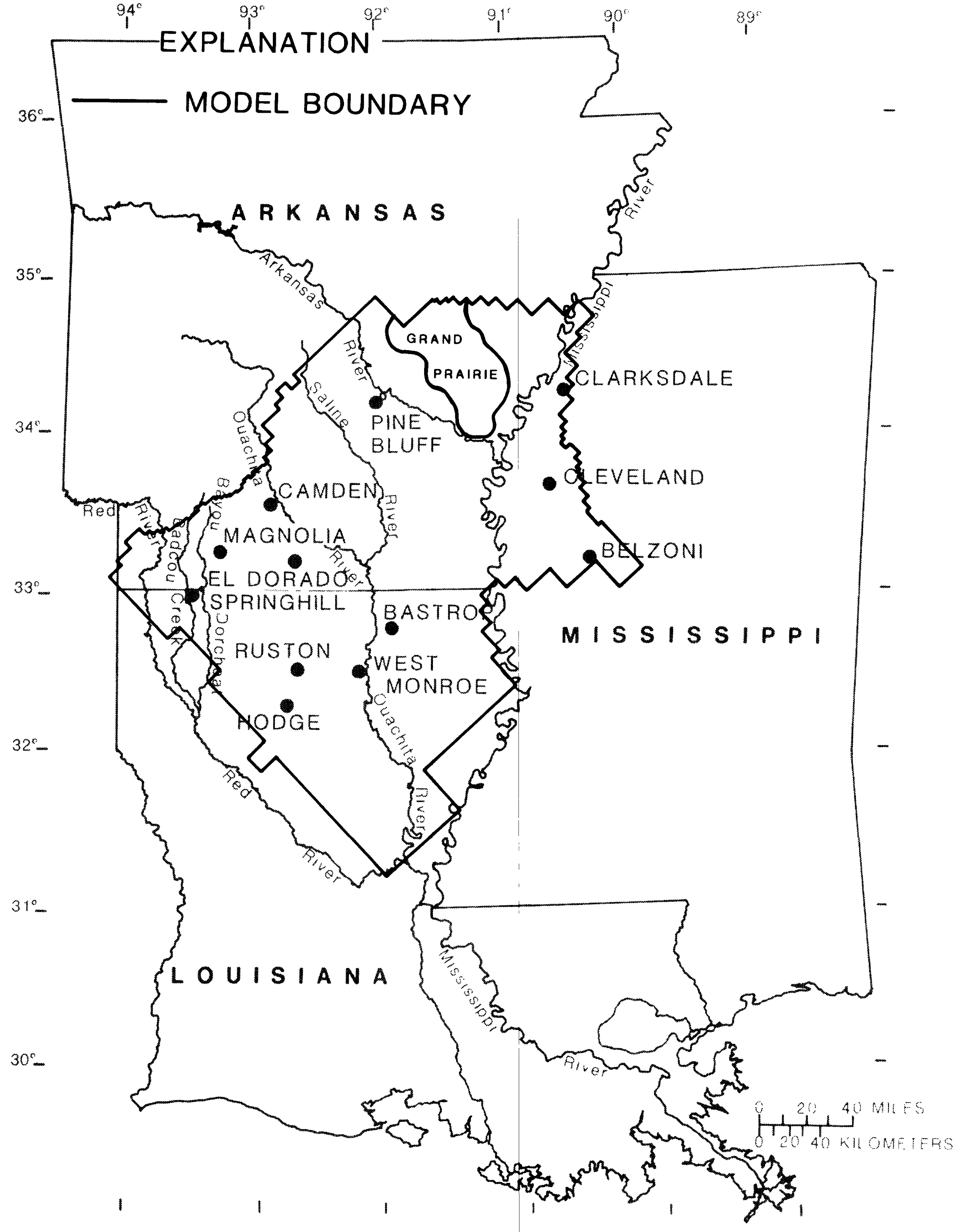

Figure 1.--Location of study and model area.

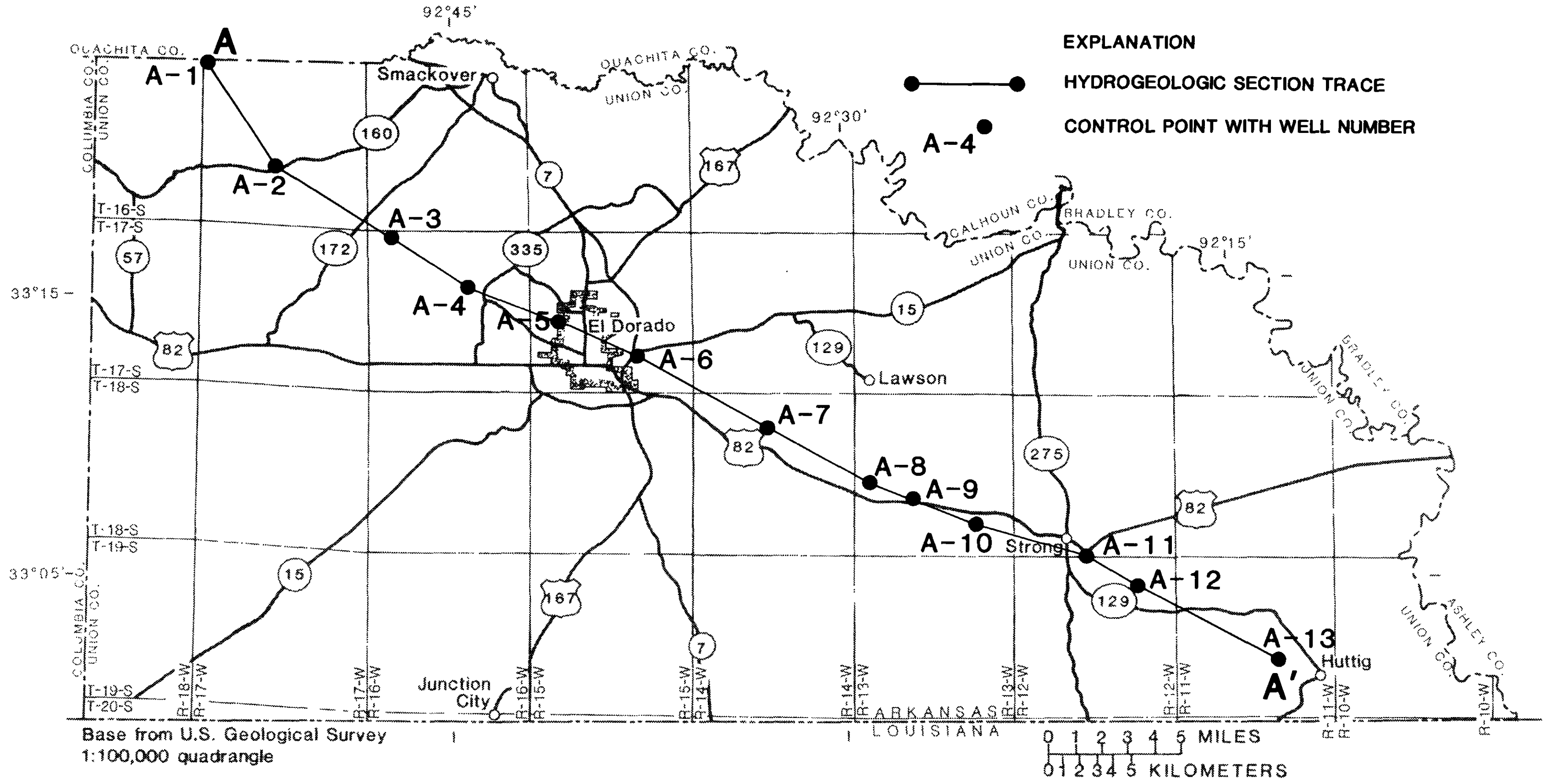

Figure 2.--Location of hydrogeologic section A-A'.

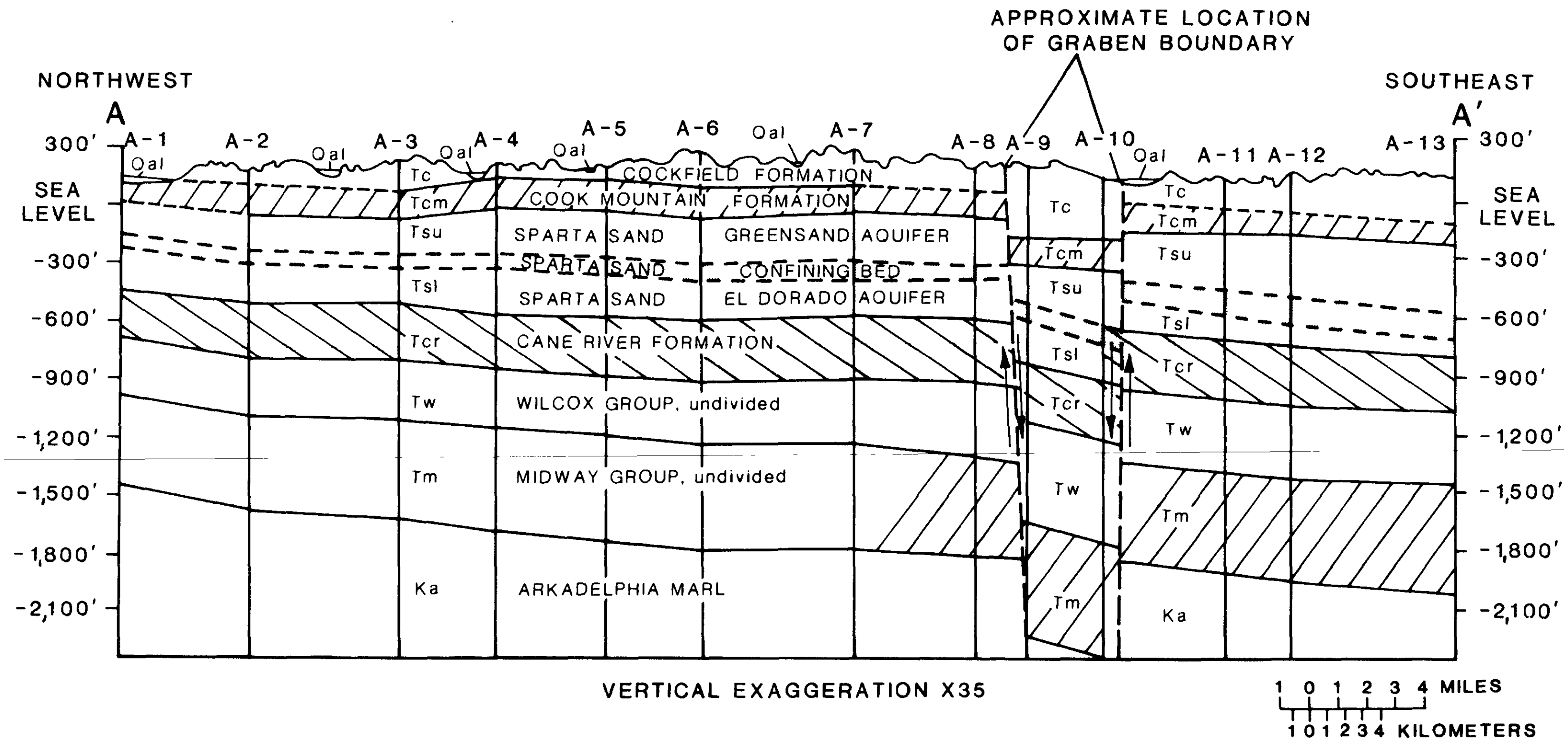

Figure 3.--Geologic section A-A′. Line of section shown on figure 2.

DESCRIPTION OF THE GROUND-WATER FLOW MODEL

Between 1985 and 1989, the USGS developed a computer model of the Sparta aquifer in central and southern Arkansas, northern Louisiana, and northwestern Mississippi to simulate the effects of ground-water withdrawals on the Sparta aquifer (Fitzpatrick and others, 1990; McWreath and others, 1991). The digital model code used in the study was the modular finite-difference ground-water flow model (MODFLOW) developed by McDonald and Harbaugh (1988). The variably spaced model grid consisted of 113 rows and 95 columns. Cell dimensions ranged from 1 mi by 1 mi in areas of large withdrawals to 10 mi by 23 mi in areas where little if any water is withdrawn. The model consisted of two layers, with hydraulic heads calculated only in the lower layer representing the Sparta aquifer. The upper layer representing the Cockfield aquifer was modeled as a constant head boundary. The base of the Sparta aquifer was modeled as a no-flow boundary. The model boundaries to the north, south, and east into Mississippi were represented by specified head, whereas boundaries to the west and east in Louisiana were represented as no flow boundaries. The model period of 1898 through 1984 was divided into 25 stress periods, and appropriate aquifer withdrawals were assigned to each stress period. Calibrated hydraulic conductivities used for computation of transmissivity of the Sparta aquifer ranged from 1 to 35 ft/d. Calibrated vertical hydraulic conductivities of the Cook Mountain confining unit ranged from $9x10^{-6}$ to $3x10^{-3}$ ft/d. The calibrated storage coefficient of the Sparta aquifer was $1x10^{-4}$. A more complete description of the development, calibration, and acceptance testing of the model is provided by Fitzpatrick and others, 1990.

UPDATING WITHDRAWALS

A significant part of this study involved the compilation of aquifer withdrawals between 1985 and 1989 and the addition of these values to the appropriate well datasets used previously (Fitzpatrick and others, 1990), in order to extend simulation of the response of the aquifer to pumping during this period. Aquifer-stream interaction and recharge in the outcrop area were assumed to be the same as in the previous simulation period because there have been no known significant changes in amounts of precipitation or streamflow conditions in the study area. Withdrawals from wells during this period were input into the well dataset based on withdrawal and well location information available in water-use data bases for 1985, 1989, or 1990.

CHECKING MODEL CALIBRATION

After withdrawals from the Sparta aquifer were added to the model for the period 1985 to 1989, simulated hydraulic heads in the aquifer at the end of the last stress period were compared with the spring 1990 observed water levels to check the calibration of the model. It was important to verify that the model was still accurately simulating flow in the aquifer. This was verified first by comparing the observed spring 1990 potentiometric surface with the simulated potentiometric surface for the same time. This comparison indicated that the model was properly calibrated and accurately simulating the response of the aquifer to 1985-89 pumpage.

The second, more objective, method of verifying model calibration was an error analysis of simulated and observed water levels at nodes representing control points. The root mean square error (RMSE) was used to judge the goodness of fit. The RMSE is given by

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (hs-ho)^2}{n-1}},$$

where hs is the simulated potentiometric head in feet;
ho is the observed potentiometric head in feet; and
n is the number of observations.

The results of error analyses for 1985 and 1990 data sets are listed below:

Statistic	1985	1990
Number of wells checked	233	113
Mean absolute error (ft)	17.07	18.29
Maximum absolute error (ft)	78.19	68.40
Minimum absolute error (ft)	0.00	0.53
Standard deviation of the differences	14.22	15.38
Variance of the differences	202.30	236.58
Sum of the squares of the differences	114,809.56	64,299.13
Sum of absolute value of the differences (ft)	3,976.83	2,066.81
Root mean square error (ft)	22.25	23.96

Although fewer observed water levels were available for 1990 than for 1985, the RMSE for both years is similar and verifies that the model is still properly calibrated.

SIMULATED RESPONSE TO FUTURE PUMPING

After adding 1985-89 withdrawals to the model and rechecking the calibration, the model was used to simulate the effects on water levels of several pumping scenarios for 1990 to 2019. The pumpages applied in these scenarios are specified in the same areas and are of a similar magnitude as those for which the model was calibrated. The 30-year predictive simulation period (1990 to 2019) was divided into six 5-year stress periods. For all of these simulations, pumpage in the entire model area remained constant at 1985 through 1989 rates throughout the simulation period except where specific changes are noted in the text.

Baseline Scenario

To provide a baseline for the purpose of comparison, a model simulation was made for the period 1990-2019 with pumpage in the aquifer held constant at 1985 through 1989 rates. The resulting simulated potentiometric surface for spring 2020 (fig. 4) was used for comparison with simulations described later in this report. The results of this simulation indicate that 30 years of additional pumpage at 1985 through 1989 pumping rates will cause water levels in the Sparta aquifer to decline only slightly. This suggests that, at 1985 through 1990 pumping rates, the aquifer is at or near equilibrium.

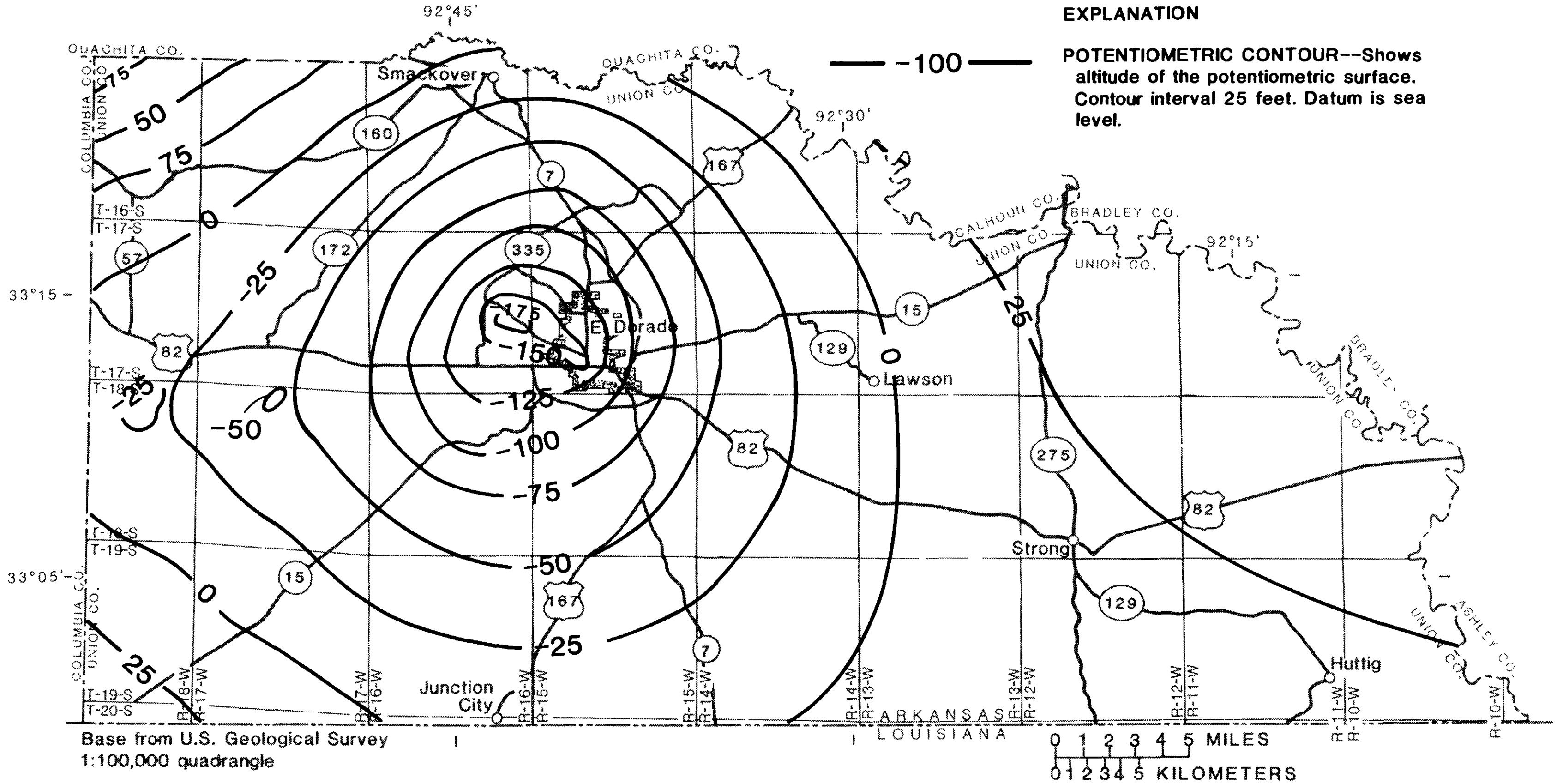

Figure 4.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for the baseline scenario.

Scenarios 1A and 1B

The purpose of these scenarios and associated model simulations is to determine the effect an anticipated reduction of pumpage in the Magnolia area will have on the potentiometric surface of the Sparta aquifer in the El Dorado area. The city of Magnolia has recently (1991) constructed a surface water reservoir capable of providing as much as 5 Mgal/d of water for public supply (A.H. Ludwig, U.S. Geological Survey, oral commun., 1991). The city of Magnolia is expected to have the capability to treat only approximately 1 Mgal/d of this water in 1991. Both of these scenarios were based on the admittedly optimistic assumption that during the 30-year simulation period the city will expand or add treatment facilities to fully utilize this new surface-water resource. A further extension of this assumption was that local industrial users of the Sparta aquifer gradually will switch from private wells completed in the aquifer to the local municipal surface-water supply.

Two slightly different scenarios were simulated based on the assumptions described. The first of these (scenario 1A) was based on the pumpage values illustrated in figure 5. Pumpage in the Magnolia area gradually was reduced while pumpage in the El Dorado area and the remainder of the model area was unchanged from 1985 through 1989 rates. The resulting simulated potentiometric surface of the Sparta aquifer in Union County in the spring of 2020 (fig. 6) is only slightly higher in the El Dorado area than that for the baseline scenario (fig. 4). In the Magnolia area (fig. 1) the results were far more dramatic. The drawdown cone that dominated the potentiometric surface in the Magnolia area in 1990 is absent in 2020.

For scenario 1B, pumpage in the El Dorado area was increased by 25 percent from 1990 to 2019, while pumpage in the Magnolia area was decreased in the same manner as scenario 1A (fig. 7). The resulting simulated potentiometric surface for the spring of 2020 (fig. 8) showed that water levels would decline to a level at or near the top of the "El Dorado" aquifer (local name for the lower Sparta aquifer) in the El Dorado area. A decline of this magnitude (more than 75 ft) during the simulation period would likely aggravate the existing saltwater intrusion problem in the area.

Scenarios 2A and 2B

The purpose of these scenarios and associated model simulations is to determine the effect of future increases in pumpage in the West Monroe, Louisiana, area on water levels in the Sparta aquifer in the El Dorado area. Both of these scenarios were based on an incremental increase of pumpage in the West Monroe area by 25 percent and a gradual decrease in pumpage in the Magnolia area.

For the first of these scenarios (2A), pumpage in the El Dorado area remained unchanged from 1985 through 1989 rates (fig. 9). The resulting potentiometric surface of the Sparta aquifer in Union County for the spring of 2020 (fig. 10) is only slightly lower than that for scenario 1B (fig. 4), which simulated identical conditions, except pumpage in the West Monroe area was not increased during the simulation period. For the second of these scenarios (2B), pumpage in the El Dorado area was also gradually increased (fig. 11). The resulting simulated potentiometric surface (fig. 12) is once again only slightly lower than that resulting from a similar simulation (scenario 1B), made with West Monroe area pumpage unchanged from the previous stress period (fig. 8).

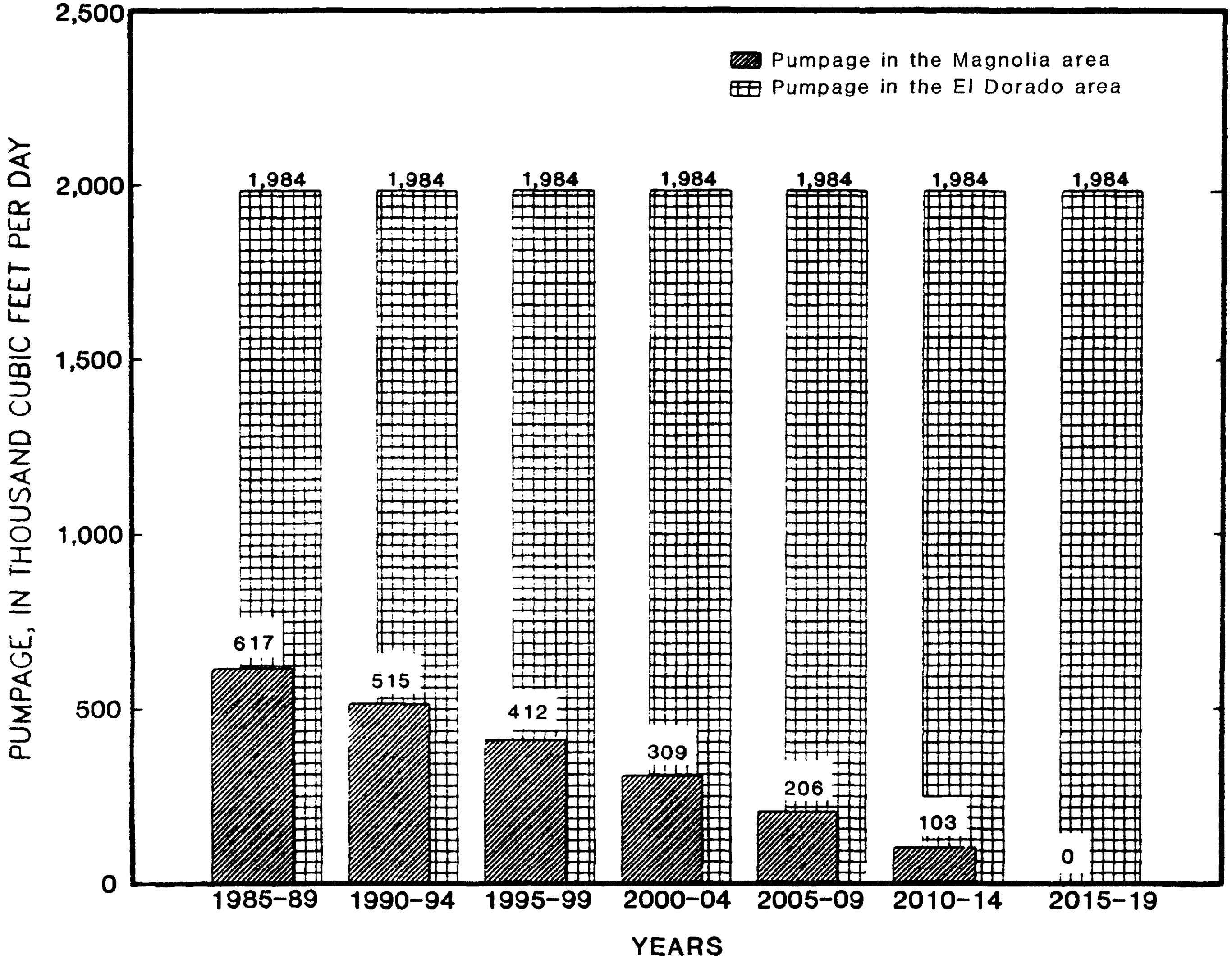

Figure 5.--Histogram of pumpage for scenario 1A.

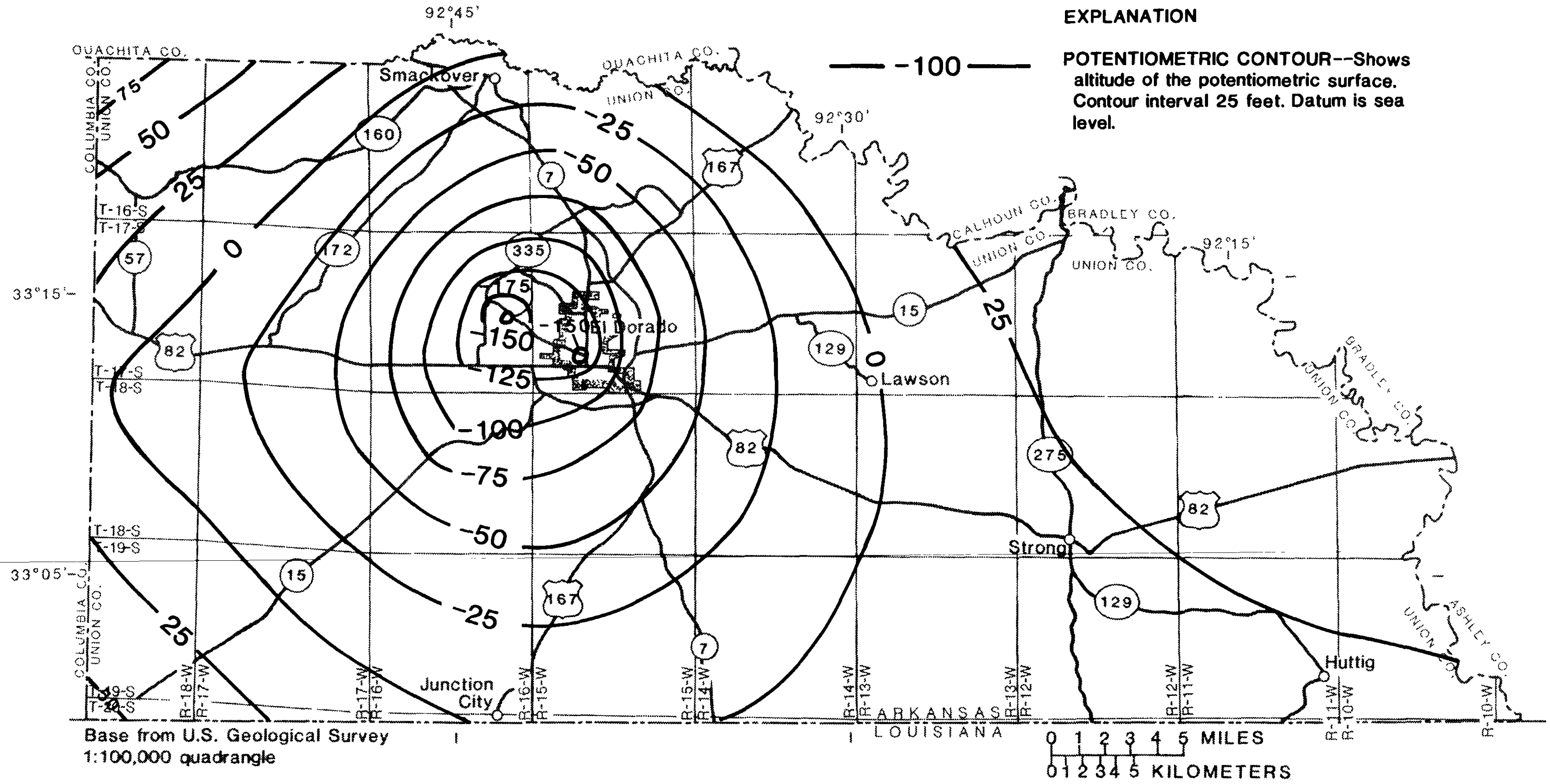

Figure 6.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 1A.

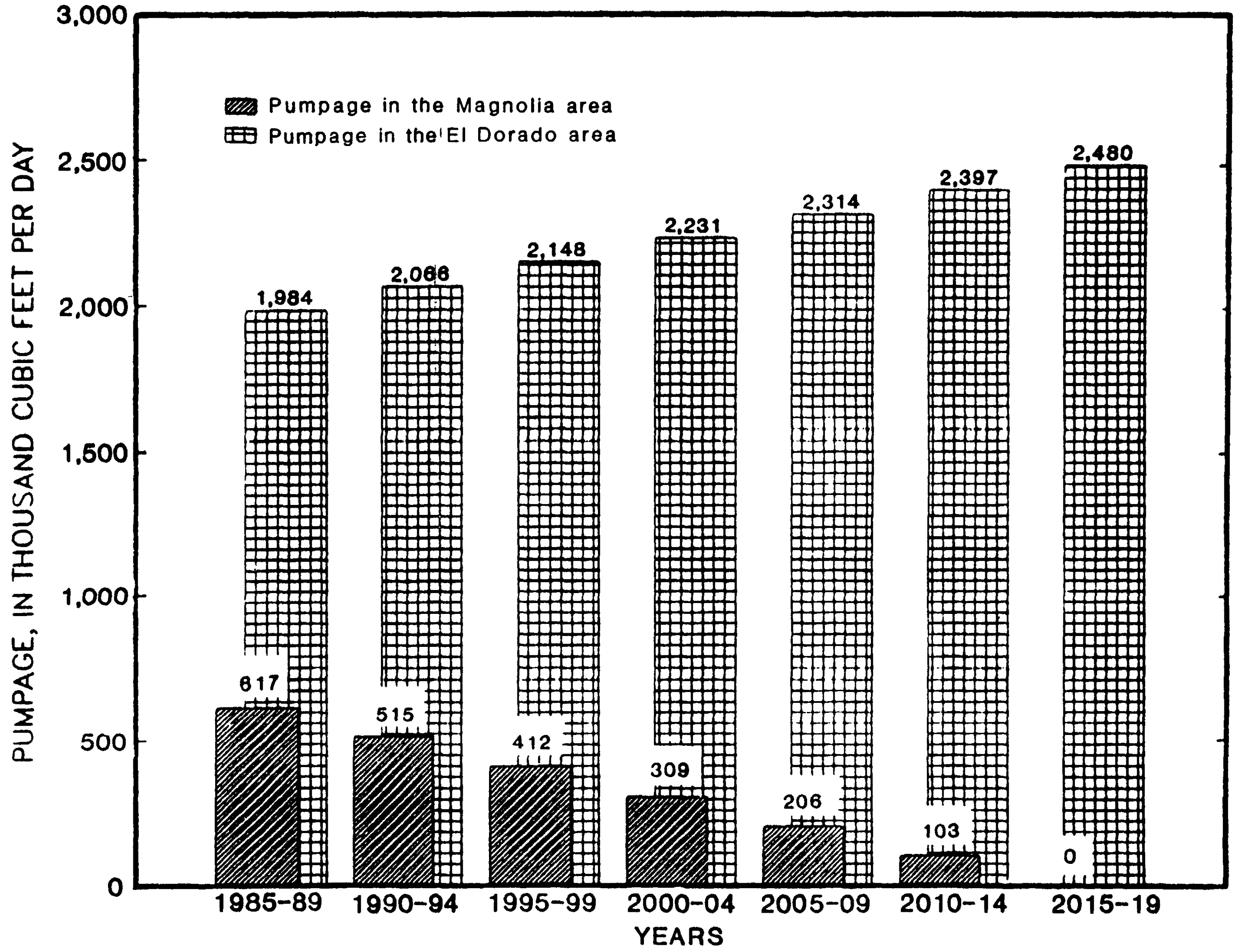

Figure 7.--Histogram of pumpage for scenario 1B.

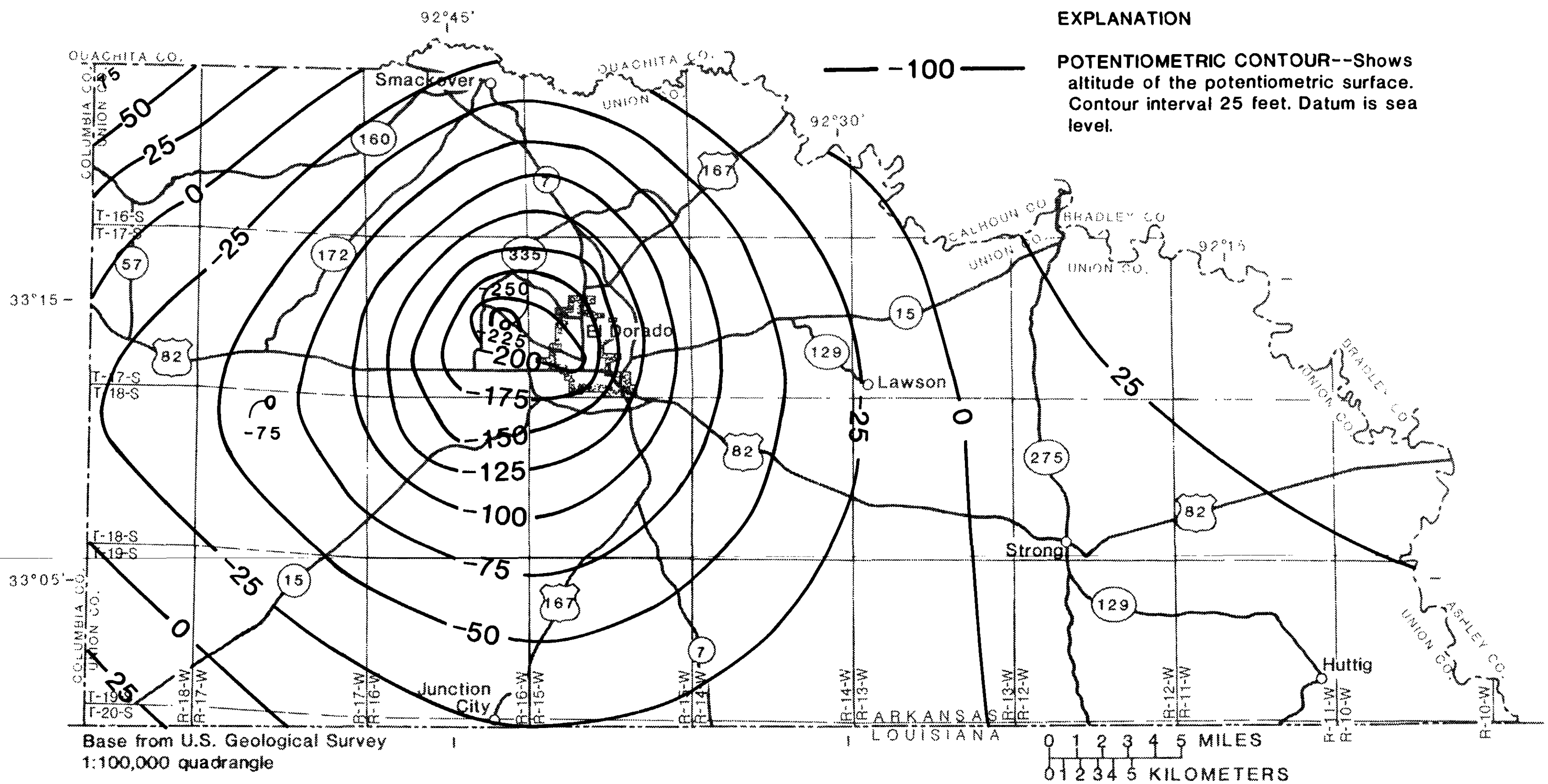

Figure 8.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 1B.

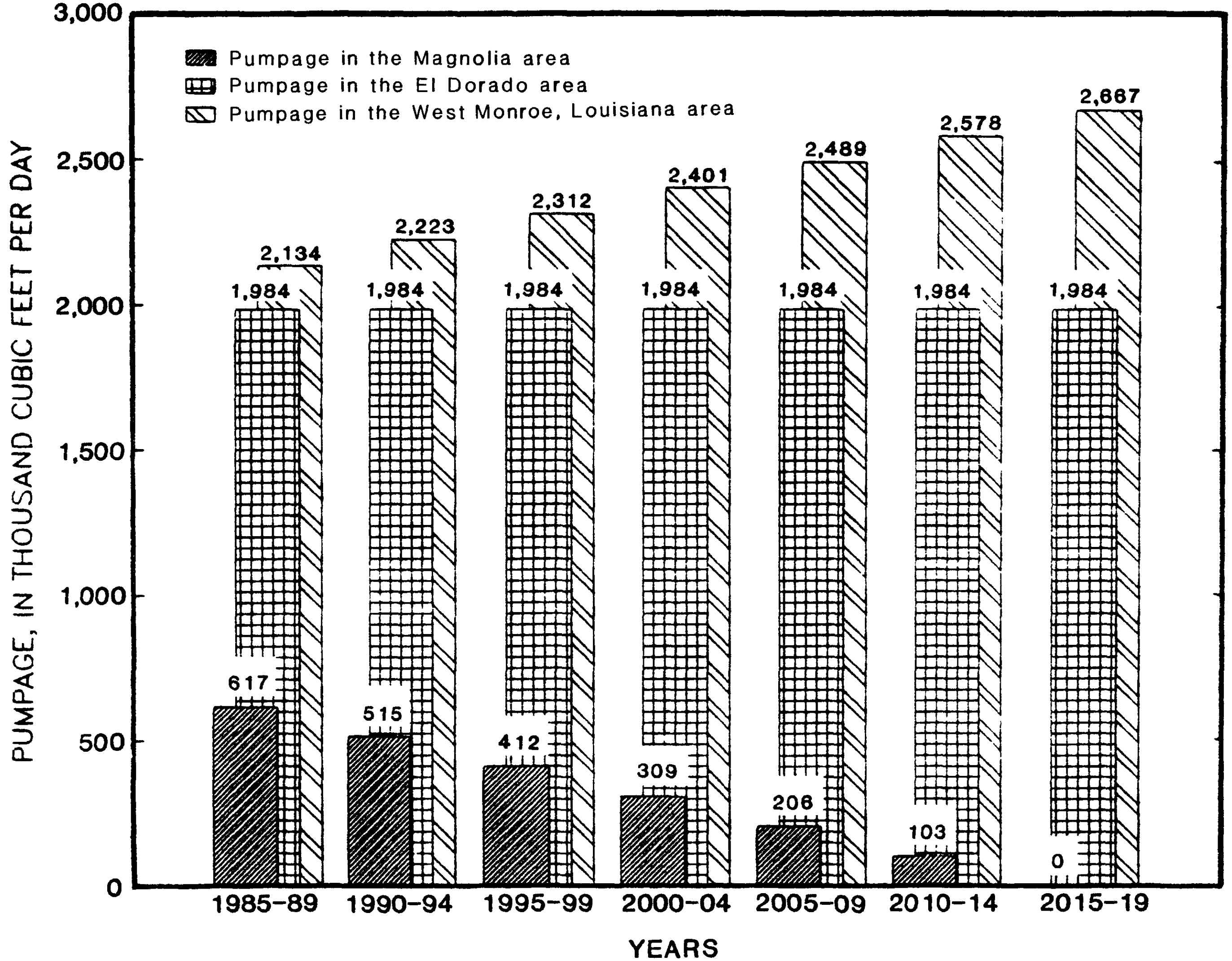

Figure 9.--Histogram of pumpage for scenario 2A.

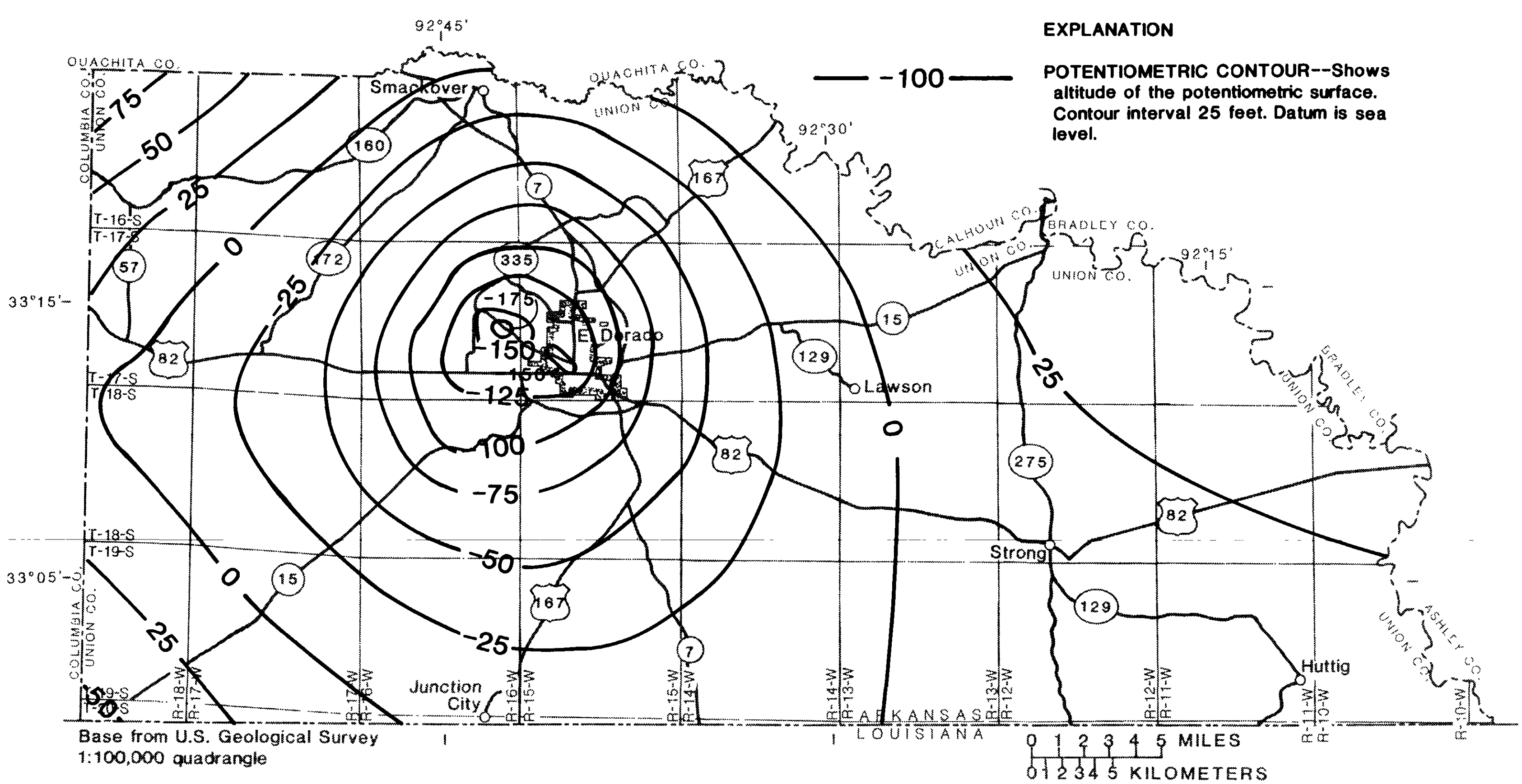

Figure 10.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 2A.

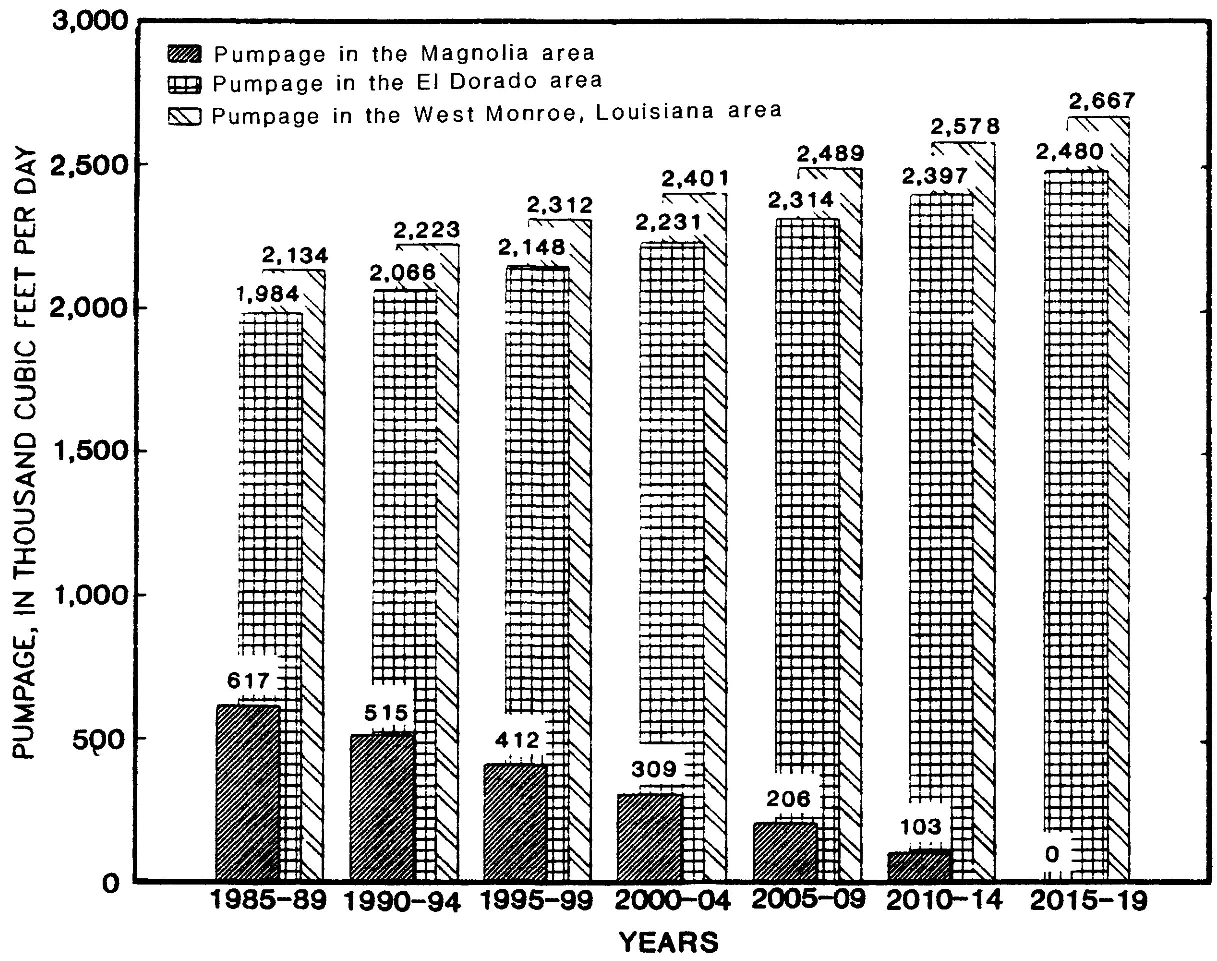

Figure 11.--Histogram of pumpage for scenario 2B.

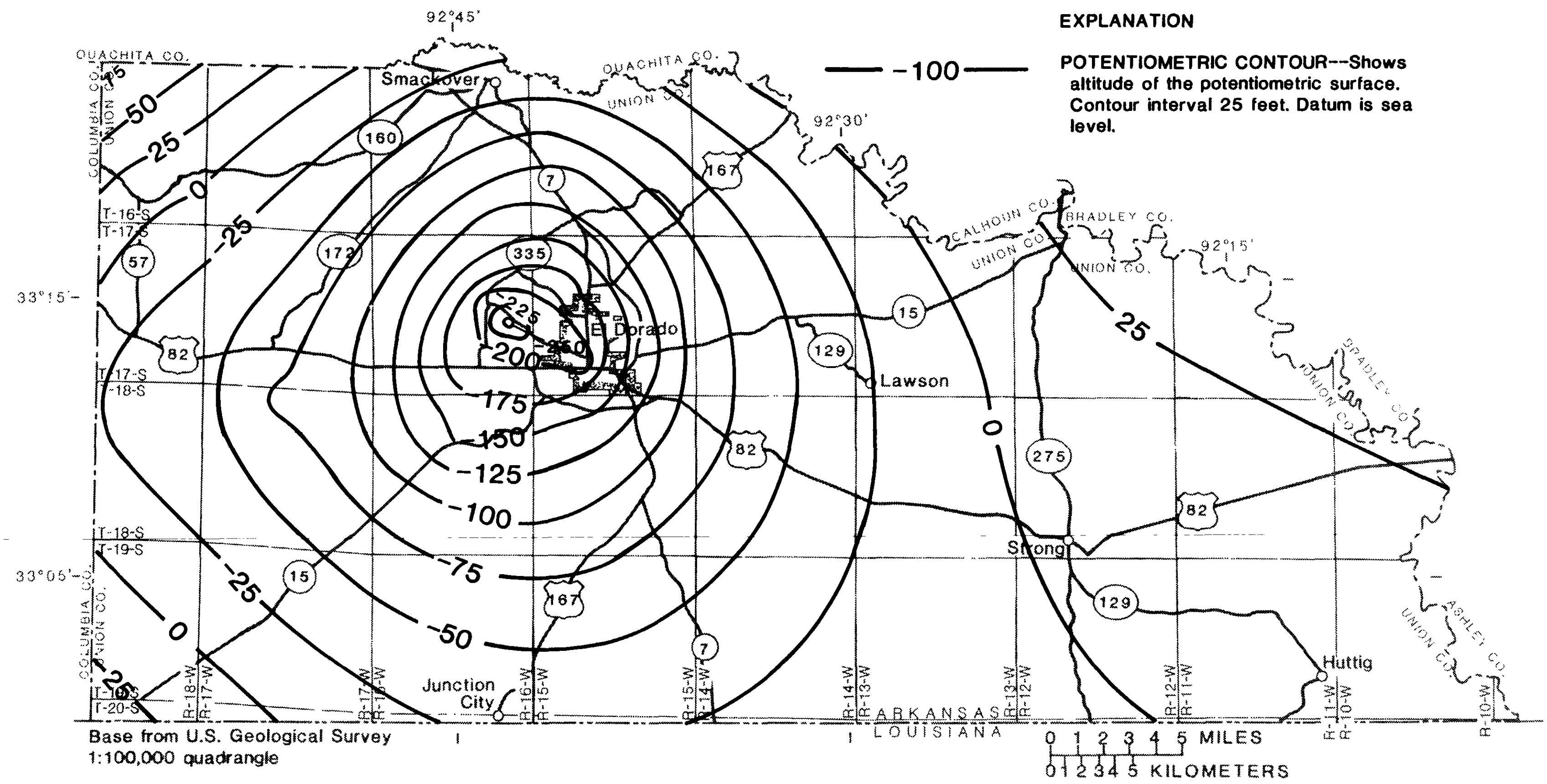

Figure 12.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 2B.

Scenarios 3A and 3B

The purpose of scenarios 3A and 3B and associated model simulations is to determine the effect of future changes in the location of city of El Dorado public supply wells on the depth of the drawdown cone in the potentiometric surface of the Sparta aquifer in the El Dorado area. Both of these scenarios were based on the following conditions or assumptions:

- -- Pumpage in the West Monroe, Louisiana, and El Dorado areas is incrementally increased a total of 25 percent over the simulation period.
- -- Pumpage is gradually decreased in the Magnolia area as described for scenarios 1A and 1B.
- -- Pumpage in the El Dorado area was gradually redistributed over the predictive simulation period (1990 through 2019) by decreasing pumpage at nodes simulating city pumpage for the period 1985 through 1989 and increasing or adding pumpage at nodes that had no city pumpage during this period. All pumpage increases above 1985 through 1989 values in the area were assigned to nodes that had no city pumpage for the period 1985 through 1989.

The two scenarios simulated different redistributions of pumpage. For the first of these scenarios (3A) withdrawal sites were moved from 1985 through 1989 locations in the center of the cone of depression to locations north and west of the city (fig. 13). For the second scenario (3B), withdrawal sites were moved from 1985 through 1989 locations in the center of the cone of depression to locations around the outside of the city in all directions (fig. 14). Pumping locations were redistributed for both of these scenarios in a gradual manner, over the simulation period, to simulate the likely situation where, as older wells and pumps are shut down due to problems related to age and heavy use, new wells are drilled farther away from the center of the cone to replace them.

Only a slight difference in the simulated potentiometric surfaces (fig. 15 and 16) resulted from these two scenarios. Both of the scenarios resulted in 40 ft less drawdown than scenario 2B, a simulation with identical conditions where pumpage was not redistributed. The effects of the redistributions were not more dramatic because pumpage by the city of El Dorado accounts for only 38 percent of the pumpage in the area. The other 62 percent remained in or near the center of the drawdown cone throughout each simulation.

At the end of both of the scenarios simulated, water levels in the center of the cone of depression had been drawn down an additional 30 ft below spring 1990 levels and simulated spring 2019 levels for the baseline scenario. This indicates that despite a complete redistribution of pumpage by the city of El Dorado, even a modest increase in pumpage (25 percent over a 30-year period) will result in substantial additional drawdown in the center of the cone of depression. As mentioned previously, any additional drawdown will only serve to further induce the flow of saltwater toward the cone of depression in the potentiometric surface of the aquifer.

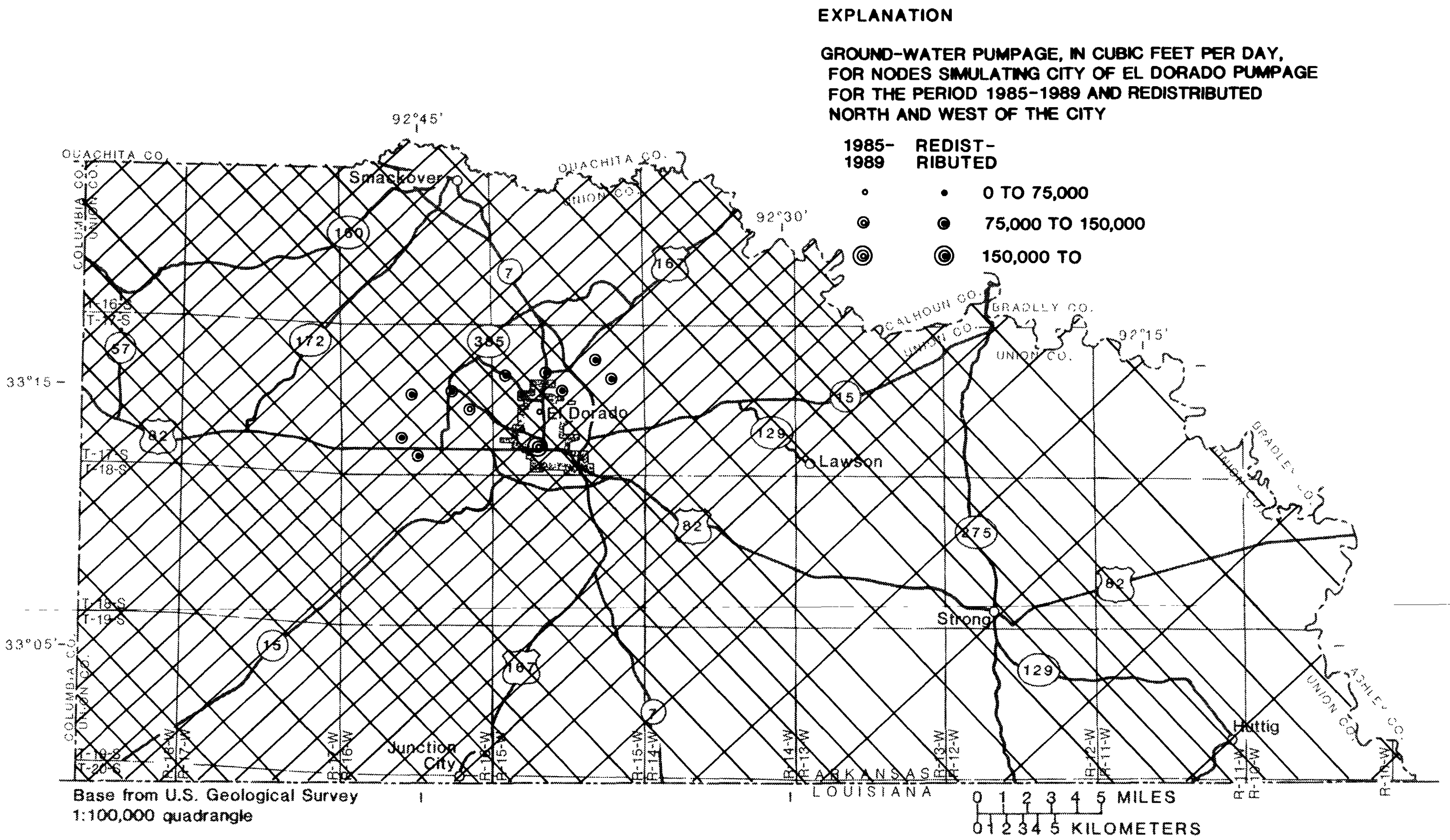

Figure 13.--City of El Dorado ground-water pumpage simulated for scenario 3A.

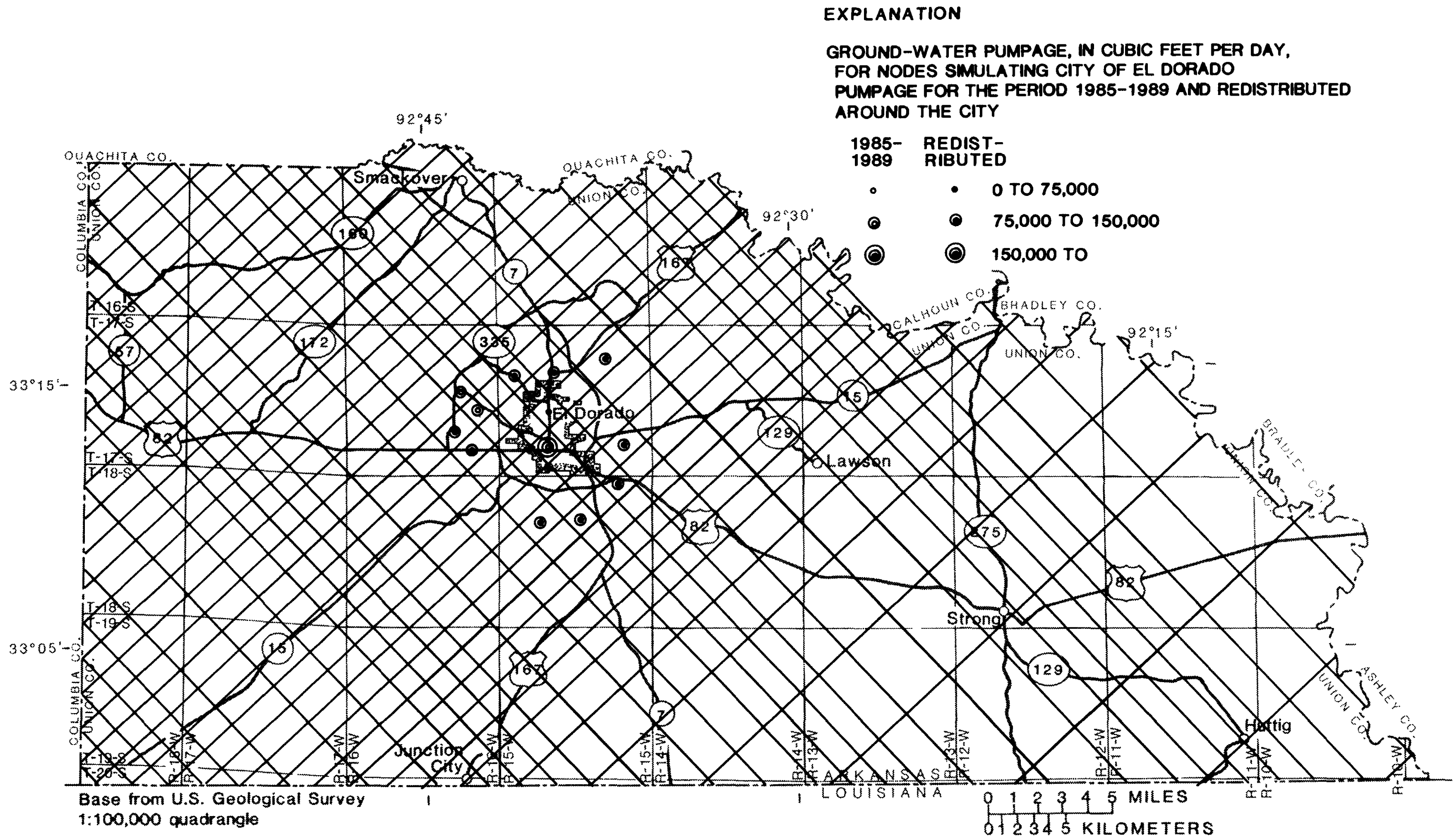

Figure 14.--City of El Dorado ground-water pumpage simulated for scenario 3B.

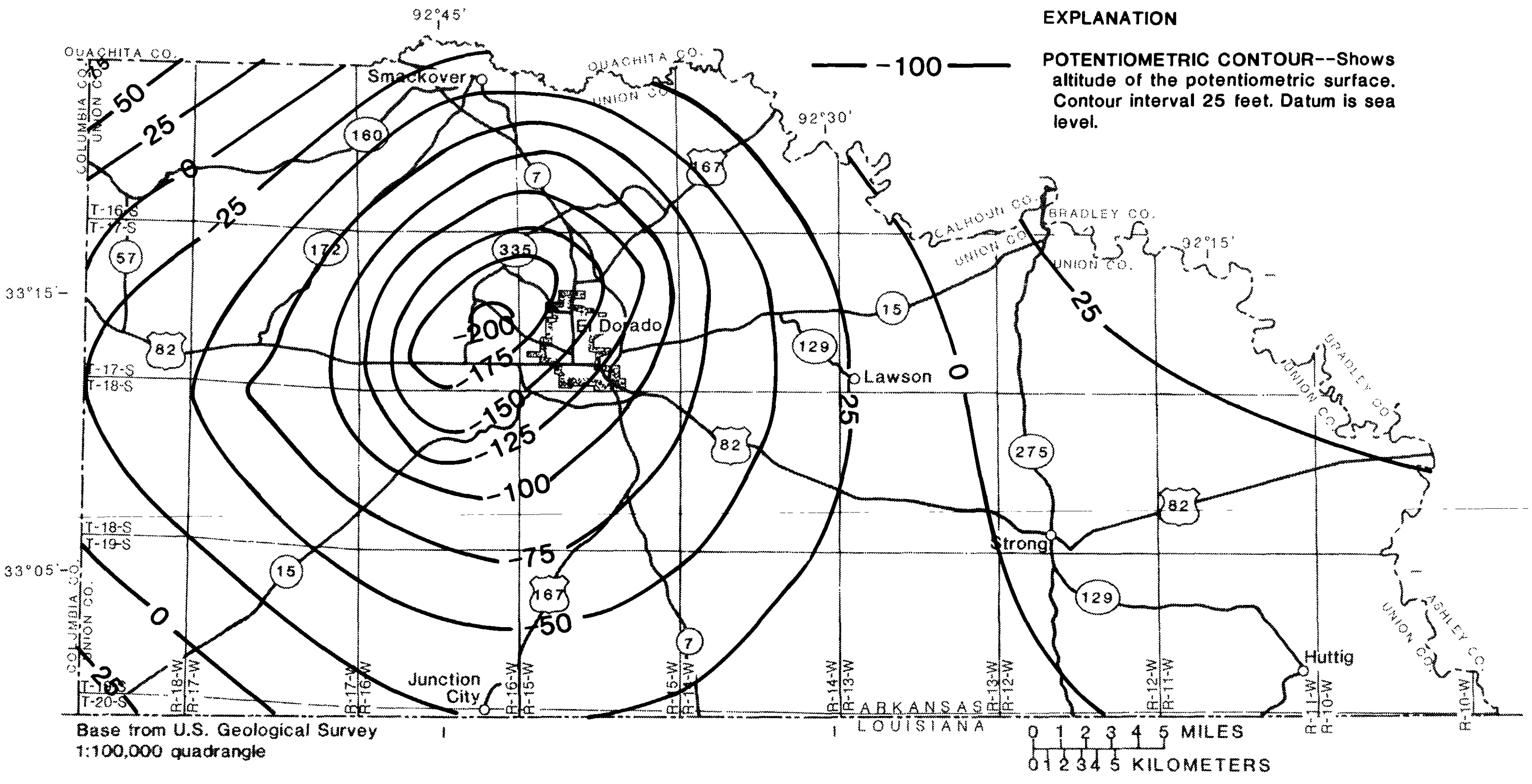

Figure 15.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 3A.

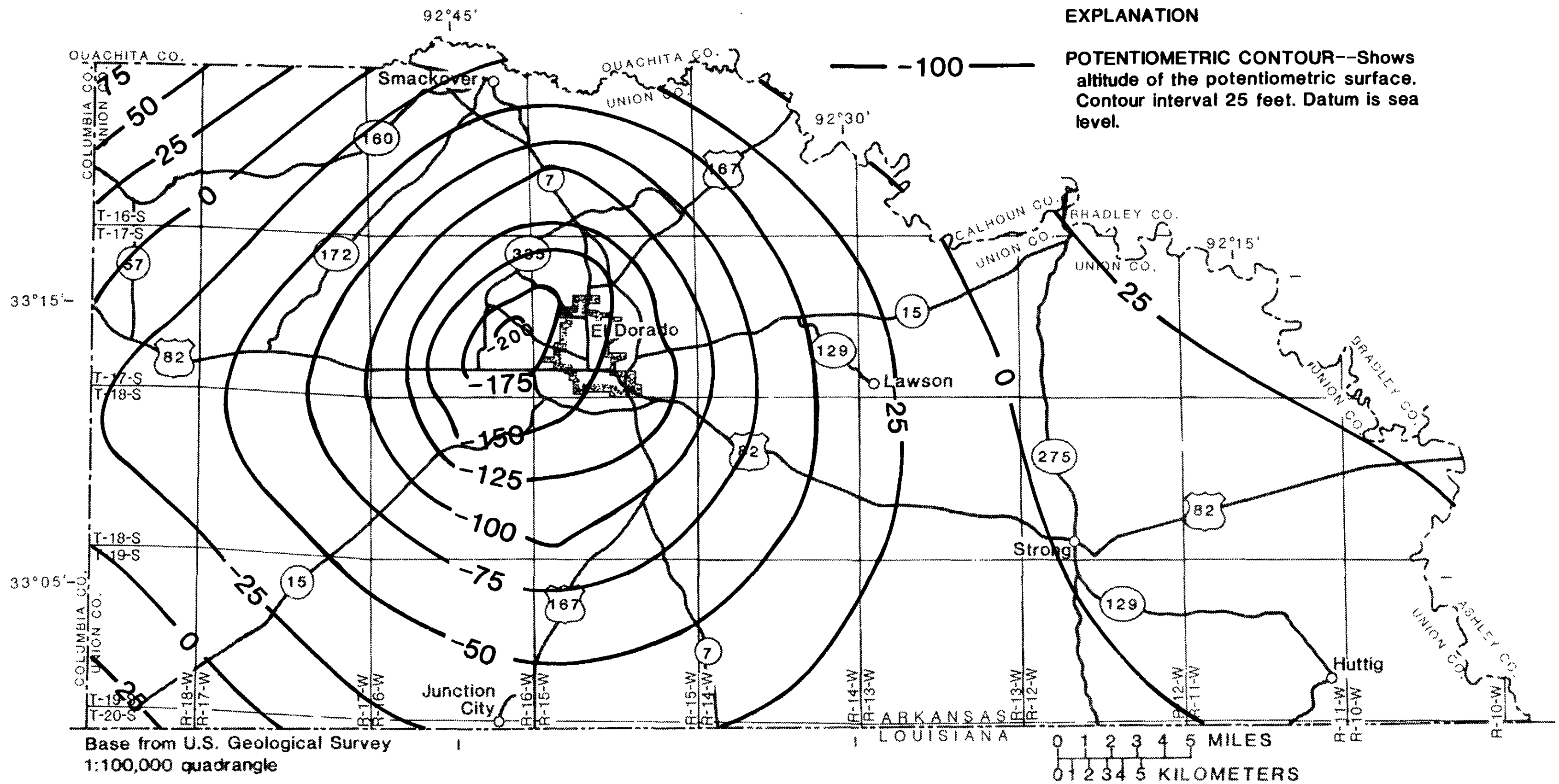

Figure 16.--Simulated potentiometric surface of the Sparta aquifer in Union County in spring 2020 for scenario 3B.

SUMMARY AND CONCLUSIONS

In 1990, a study was initiated by the USGS in cooperation with the Arkansas Soil and Water Conservation Commission to update the ground-water flow model of the Sparta aquifer previously developed and to use the updated model to evaluate several potential future pumping scenarios in the El Dorado area.

Withdrawals from wells for the period between 1985 and 1989 were added to the previously developed model which simulated flow in the aquifer from 1898 through the end of 1984. Discharge to and recharge from streams and recharge as a result of rainfall infiltration were assumed to be the same as in the previous simulation period. Withdrawals from wells during this period were input based on withdrawal and well location information obtained from data bases for 1985, 1989, or 1990.

The calibration of the updated model including the additional simulation time was checked qualitatively by comparing simulated and observed potentiometric surfaces of the Sparta aquifer in the spring of 1990, and was checked quantitatively by comparing the root mean square errors of the original model and the updated model. Both comparisons indicated that the updated model was still properly calibrated.

After updating stresses and rechecking model calibration, the updated model was used to simulate the effects on water levels of several pumping scenarios for the period 1990 to 2019. The following conclusions can be reached from the results of the six scenarios simulated:

--Future decreases in pumpage from the Sparta aquifer in the Magnolia area will allow water levels to rise in the aquifer in the El Dorado area only slightly.

--Future increases in pumpage from the aquifer in the West Monroe, Louisiana, area will result in only slightly lower water levels in the aquifer in the El Dorado area.

--Despite a complete redistribution of pumpage by the city of El Dorado, which would move pumpage away from the center of the cone of depression, even a modest increase in pumpage (25 percent over a 30-year period) will result in substantial additional drawdown in the center of the cone of depression. Any additional drawdown will further induce the flow of saltwater toward the cone of depression in the potentiometric surface of the Sparta aquifer in the El Dorado area.

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*U.S. Government Printing Office: 1992 — 654-193/40006