GROUND-WATER MODELS OF THE MIOCENE AQUIFER SYSTEM IN JONES COUNTY, MISSISSIPPI

Raymond Sturdivant, Jr.
Delta Environmental Consultants, Inc., Tampa, Florida
and Department of Geology, The University of Southern Mississippi

David M. Patrick
Department of Geology, University of Southern Mississippi

Introduction

Purpose and Scope

The objectives of this research were to develop a better understanding of the Miocene aquifer system in Jones County, Mississippi; to document the historic drawdown of potentiometric surfaces in this region; and to develop three-dimensional, numerical simulation models of the aquifers. Particular attention was given to the population centers at Laurel, Ellisville, and Sandersville. The Paleogene and deeper aquifers, and the shallow Citronelle aquifer were not a part of this study. This research was a part of a more comprehensive regional investigation dealing with the Miocene aquifers in Forrest and Lamar, as well as Jones County (Patrick and Zhao 1989; Patrick and others 1989).

Previous Investigations

There have been a number of earlier investigations of the geology and ground-water hydrology of Jones County, in particular, and southern Mississippi, in general, which have contributed to our studies. Among the regional studies are those of Shows and others (1966), Taylor and others (1968), Callahan (1971 and 1975), Newcome (1971 and 1975), Boswell (1979) and Colson and Boswell (1985). A ground-water model was developed for the Miocene aquifers along the Mississippi Gulf Coast (Sumner and others 1987), and Boswell and others (1987) studied this aquifer in the Laurel area. This latter study addressed hydraulic and geologic characteristics, historic water level changes, water quality, and long term extraction effects. A number of unpublished MS theses have contributed significantly to our understanding of the Miocene sediments at the surface and in the subsurface (Dooley 1983; Gerald 1986; and Day 1987).

Aquifer Framework

The Miocene aquifers of Jones County are a part of a thick body of southerly dipping, fluvial, fine-and coarse-grained clastics which outcrop several miles south of Jackson and extend to the south where, along the coast, they exhibit thicknesses of several thousand feet. Both surface and subsurface data have shown that these sediments are highly non-uniform, and regionally, they exhibit considerable lateral and vertical variability, or facies changes. From oldest to youngest, the formation names of Catahoula (Miocene), Hattiesburg (Miocene), Pascagoula (a facies of the Hattiesburg), and Citronelle (Plio-Pleistocene?) have been given to these clastics. Locally, these formation names may be difficult to apply due to facies changes, and the term Neogene may be more appropriate as it would include aquifers in the Citronelle Formation which is, in regions downdip from Jones County, difficult or impossible to distinguish from the Miocene formations. The principal aquifers in Jones County lie in the Catahoula Formation.

Methodology

Data Acquisition

The data used in this investigation consisted of published information describing pumping test and water level (potentiometric surface measurements) and unpublished information such as drillers and borehole geophysical logs. These unpublished water well data were obtained from the U.S.Geological Survey (USGS), the Mississippi Bureau of Land and Water Resources, and the Mississippi Bureau of Geology. Pumping test, drilling, and water level data provided temporal information on well location, elevation of screened interval, water level, and drawdown. The borehole geophysical logs provided information on the nature of the sediments in which the water wells were constructed. Data from approximately 10 percent had borehole geophysical logs. Potentiometric surface data were taken from original driller's logs rather than from existing data bases. All water wells were plotted on USGS 7 1/2 minute topographic maps for the purpose of verifying the accuracy of the location, for determining ground elevation, and latitude and longitude (geographic coordinates) of the well.

Development of the Data Base

A LOTUS data base was used to store the water well data from approximately 1,000 wells (Lotus Development Corp. 1986). The information entered into the data base for each water well included: geographic coordinates, depths of screens, potentiometric surface elevation, transmissivity and storage coefficient (if known), and year the potentiometric surface was determined (date of drilling). The data stored in the data base could be sorted on the basis of year, depth, location, or other parameter of interest. During this phase of the investigation, the well location data given by geographic coordinates were converted by computer to Universal Transverse Mercator (UTM) grid system using the USGS program J-380 and then storing the UTM coordinates in the data base (U.S. Geological Survey). The water well data base is interactive with the software SURFER (Golden Software 1986) which plots potentiometric surface maps, and the software INTERSAT, the numerical simulation program (HydroSoft 1985); the data base is available on diskette at the Water Resources Research Institute (WRRI) office.

Geologic Cross-Sections

Two north-south and two east-west geologic cross-sections were prepared using the borehole geophysical logs for the purpose of defining and understanding the framework and boundary conditions of the aquifer system. These sections are also on file and available in the WRRI office. The lithologies or sediment types encountered in this system are diverse in composition and are usually not lithified. Generally, fine to medium quartz sand is the most common sediment type present and this material is that in which most of the water wells are constructed. Somewhat subordinate in distribution to these sands is lutite, a moderately graded mixture of clayey silt with minor sand. These data also showed that the Catahoula Formation was dipping to the southwest and that the formation was thickest in the western part of the county.

Hydrogeologic Setting

Aquifer Boundary Conditions

The analysis of the data from the water wells and information derived from the geologic cross-sections showed that the Neogene sediments could be subdivided into three hydrogeologic units: one lower, one middle, and one upper, conforming to two massive and continuous Catahoula Formation sands, termed the lower and middle aquifers, and the overlying sands of the Citronelle Formation which formed the upper aquifer. There were so few water wells in the upper aquifer, and their spatial distribution was so poor, that this aquifer was excluded from further study. Figures 1 and 2, respectively, show the distribution of water wells in the lower and middle aquifers. The Catahoula Formation contains fresh ground water throughout Jones County with the total depth of fresh water lying significantly below the formation base. Both confined and unconfined conditions are present. Unconfined conditions exist where Miocene beds outcrop in the county and are not overlain by impermeable units. Down dip, these aquifer will usually become confined due to lateral and vertical facies changes and the occurrence of impermeable strata above and below them. Ground water that occurs in the unconfined aquifers are capable of supplying potable sources for small domestic needs, but large municipal and industrial water supplies must use the deeper confined aquifers. The geologic data suggest that the deeper confined aquifer bodies are, more-or-less, continuous with minor hydraulic interconnection; however, these data also indicate that there is increasing interconnection in down-dip areas in the southern part of the county and beyond (Patrick and others 1989).

Aquifer Performance Tests

The results of aquifer tests indicate that these aquifers are among the most permeable ones in the state (Newcome 1971). The average hydraulic conductivity for 21 aquifer tests performed on wells in Jones County was about 90 feet per day (680 gallons per day per foot squared) - near the average for the Miocene aquifers in Mississippi. In the Laurel areas, the average hydraulic conductivity values are 85 feet per day (640 gallons per day per foot squared), slightly lower than average. Transmissivity values range from 600 feet squared per day to 10,000 feet squared per day and average about 6,000 feet squared per day. There have been few pumping tests performed in the middle and upper Catahoula aquifers. Most pumping tests are performed in wells screened in high producing sands. These sands may possess hydraulic properties that are not representative of the various sand units in the formation, both laterally and vertically. The highest yielding wells are screened in the upper Catahoula aquifer with wells capable of producing about 1,600 gallons per minute. These wells, located in the southwestern part of the county, are screened in the upper Catahoula aquifer whereas large wells in the central and northern parts of the county are screened in the middle and lower Catahoula aquifers. Wells in the Laurel area commonly produce 400 to 800 gallons per minute from the middle and lower Catahoula aquifers (Boswell and others 1987).

Historic Potentiometric Surfaces

Pre-Development Potentiometric Surface

Prior to ground-water withdrawal, the aquifers were in a state of dynamic equilibrium. In this condition, the aquifer would reflect seasonal water level responses to variations in precipitation, but year to year, water levels would remain generally the same. Before stresses were applied to the Miocene aquifer system, ground-water flow followed the dip of the beds to the south southwest. This pre-development, groundwater flow concept was determined by Sumner and others (1987) for Jones County as part of their study of the ground water conditions along the Mississippi Gulf Coast.

Historic Potentiometric Surfaces

The historic lowering of potentiometric surfaces was studied and documented by analyses of computer-generated potentiometric surface contour maps which were plotted for specific time periods for each aquifer. Time periods rather than specific years were used in order to maximize the spatial and temporal distribution of water well data points. The time periods for the lower aquifer were: 1960-1966, 1970-1973, 1980-1984, and 1985-1987; and those for the middle aquifer were: 1966-1969, 1970-1972, 1980-1983, and 1984-1987. These maps reflect the stress conditions in the aquifer during that period of time, and they show the cones of depression existing at major pumping centers for that period. In addition, the maps were used in the calibration of the numerical models. These contour maps were evaluated in terms of regional drawdowns; that is, the comparison of maximum and minimum potentiometric surface elevations (or relief), occurring over the entire county area, and local drawdown occurring at population centers. The relief or pressure differences, regionally or locally, is a measure of the stress to which the aquifer has been subjected. These contour maps were developed using SURFER (Golden Software 1986). The strategy for the development of these contour maps included the following techniques. Some water wells were so closely spaced that they would appear to be co-located at the scale of these maps; in such instances, water elevations were averaged. The regional historic drawdowns are summarized and given in Table 1, and the local historic drawdowns are in Tables 2 and 3, respectively, for the lower and middle aquifers.

Numerical Simulation

General

The evaluation of the quantity and availability of groundwater resources on a regional basis is a complex problem and would be difficult to accomplish without the use of computer-driven, mathematical simulation models. The numerical model will solve the groundwater flow equation subject to imposed boundary and initial conditions which express the conservation of mass and momentum and describe the hydraulic head over the region of interest (Mercer and Faust 1981). The validity of the model will depend upon: the adequacy of the geologic boundary conditions, the spacing of the finite-difference grid over the area, and the quality and quantity of the hydraulic data for the aquifer; generally, these factors are mutually interdependent.

Software Selection

The software used in this study was INTERSAT and is executable on a variety of personal IBM-compatible personal computers, as well as mainframe systems (HydroSoft 1985). Interactive operation is provided through the use of a tree structure of menus which provides the user with complete control of all phases of the operation. Time required for the input of basic model is reduced approximately one order of magnitude over batch type codes owing to its interactive operation. Finite-difference equations are solved by the method of Prickett and Lonnquist (1971). Pumping/injection data may be entered by a data file or interactively. The program allows for variation in grid spacing and interactive observation of changes made to a given grid.

Model Grid

The study area was overlain by a rectangular grid system with the majority of squares or "cells" having dissimilar dimensions for the purpose of discretization in order to perform finite-difference calculations of the groundwater flow equations. Grid systems may be either face-centered or block-centered; this model is face-centered in which the nodal points are located at the intersection of grid lines. Grid systems may be either uniform or variable in terms of the dimensions of the grid; this software allows for variable grid spacing to provide more detail in the more populous areas where there is more hydraulic data. The modeled area is 243,000 feet in the north-south direction and 468,000 feet in the east-west direction; and there are 16 rows (east-west) and 20 columns (north-south). Vertical discretization was based upon the two-aquifer model previously discussed.

Model Boundaries

The boundary conditions of a groundwater flow model describe the relations between the region being modeled and adjacent regions. In Jones County, the eastern and western boundaries were described as a no-flow or barrier boundaries because of the lack of influence of the major pumping centers on these boundaries and because these boundaries are, more-or-less, parallel to the regional groundwater flow paths. The base of the grid system was modeled as a no-flow boundary in order to simulate the contact between the Miocene aquifers and underlying Oligocene aquifer system. The northern and southern boundaries were described as constant-head because they are, more-or-less, normal to the regional flow paths.

Model Parameters

The model parameters are the hydraulic parameters at each node (for each aquifer) which describe the characteristics of the aquifers, these are: elevation of the control potentiometric surface (pre-development or other defined surface), elevations of top and base of aquifer, hydraulic conductivity, porosity, storage coefficient, model grid spacing and dimensions, and pumping rates at pumping centers. The control potentiometric surface was the 1970-1973 surface, and there were three pumping centers, all located in the Laurel area. The transmissivity is calculated by the program. Many of these parameters, particularly hydraulic conductivity and storage coefficient, are determined from field pumping tests; porosity may be determined from geophysical logs or by laboratory tests. There are data from 18 pumping tests in the lower aquifer and 1 pumping test in the middle aquifer; of the 18 pumping tests in the lower aquifer, only 8 resulted in determination of the storage coefficient. Additionally, most of these aquifer tests were conducted at major pumping centers. Thus, the adequacy of the hydraulic data in this area is marginal.

Model Set-Up and Calibration

The models for the lower and middle aquifers were set up using historic potentiometric elevation data for the period 1970-1973. With these surfaces as the starting points, pumping rates, hydraulic conductivity, storage coefficient, and porosity values were changed within the model grid until the simulation program could produce potentiometric surface maps which were similar to the historic maps developed for the periods 1980-1984 for the lower aquifer and 1980-1983 for the middle aquifer. This activity required many iterations before the simulated and observed potentiometric surface maps were similar in appearance. Many iterations were necessary because of lack of measured data at the grid nodes; for example, at many nodes, average values of hydraulic conductivity and storage coefficient had to be used because pumping tests had not been conducted in these areas. Also, pumping rates were not known in some areas and, therefore, estimates of pumping rates had to be used. The similarity between simulated and observed surfaces indicated that the data values assigned to each, or at least most, of the nodes was meaningful and that the model could be used to simulate other surfaces, in the past or in the future, by decreasing or increasing, respectively, the pumping rates. Figures 3 and 4 show both simulated and observed surfaces for the lower and middle aquifers, respectively.

Results of Numerical Simulation Studies

Simulated potentiometric surfaces for both aquifers were computed on the basis of 2, 4, and 6 percent annual increases in pumping for the years 1995, 2005, and 2015. Potentiometric surface maps were calculated for all rates and years. These maps were evaluated by the same technique used to study the historic drawdown, namely, the determination of maximum and minimum potentiometric surface elevations within the county. The simulated surface maps may contain an artificiality in that a surface will be calculated and drawn even if that surface elevation is below the top of the aquifer. The calculated elevation of such a surface would have no analytical meaning; however, the fact that the surface is below the top of the aquifer indicates that the aquifer is probably overstressed. Minimally, this condition would suggest that the aquifer has been overpumped. Table 4 shows the maximum and minimum potentiometric surface elevations for both aquifers. An asterisk is used in the table to indicate a computed surface elevation which is below the top of the aquifer. The minimum elevation is the drawdown of the cone of depression centered near Laurel. Overall, these simulated data suggest that both aquifers will probably safely sustain a 4 percent annual increase in pumping rate through the early years of the next century; however, a 6 percent increase will probably overstress both aquifers.

Conclusions And Recommendations

The lower aquifer appears to be capable of sustaining 4 percent annual increases in pumping rates in the Laurel area through the first decade of the next century; however, the development of new pumping centers with similar extraction rates in near-by regions may adversely interfere with the cone of depression at Laurel. In regard to the middle aquifer, both the drawdown history as well as the numerical simulations indicate that the number of wells and the extraction rates in this aquifer should be limited.

The significance and reliability of numerical simulations are highly dependent upon the accuracy and availability of the geologic and hydraulic data upon which the model is constructed. We have indicated that there are limited pumping tests in this area and, therefore, limited number of values of hydraulic conductivity, storage coefficient, and other parameters which are necessary to develop the model. Thus, there is a need to conduct additional pumping tests in this region and to monitor more wells. One must conclude, therefore, that the simulated surfaces calculated by our model are approximate ones and that the predicted elevations only indicate the trends that may occur in the future.

The geologic data upon which the boundary conditions were established are considered to be reasonably reliable, particularly in the Laurel area; however, these data are less abundant beyond Laurel. Furthermore, the data indicate that the stratigraphy and, consequently, the boundary conditions of these aquifers are more complex and less well defined in southern Jones County and in the counties lying to the south and west. The geologic uncertainties in Jones County, and other areas where the Miocene aquifers are used, could be lessened by additional borehole geophysical logs and by continuous cores in strategic locations in the region.

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TABLES

Table 1. Regional and local historic potentiometric surface elevations in feet.

	Lower Aquifer		Middle Aquifer	
Year	1960's	1980's	1960's	1980's
Regional	240/140	240/60	260/80	240/120

Table 2. Local historic maximum/minimum potentiometric surface elevations in feet for the lower Catahoula aquifer at Laurel, Ellisville, and Sandersville.

Years	Maximum/Minimum Elevation (Feet)		
	Laurel	Ellisville	Sandersville
1960-1966	120/90	180/160	160/160
1970-1973	130/90	160/140	200/160
1980-1984	80/60	140/100	200/160
1985-1987	90/80	80/70	160/140

Table 3. Local historic maximum/minimum potentiometric surface elevations in feet for the middle Catahoula aquifer at Laurel, Ellisville, and Sandersville.

Years	Maximum/Minimum Elevation (Feet)		
	Laurel	Ellisville	Sandersville
1966-1969	180/80	200/180	260/260
1970-1973	220/200	200/190	260/240
1980-1983	140/120	160/140	-
1984-1987	220/200	220/200	240/220

Table 4. Simulated maximum/minimum potentiometric surface elevations in feet. * indicates that the simulated surface is below top of aquifer.

	Lower Aquifer			Middle Aquifer		
Year	1995	2005	2015	1995	2005	2015
2 Percent	240/60	240/40	240/20	240/120	240/120	240/100
4 Percent	240/60	240/20	220/*	240/100	240/100	240/80
6 Percent	240/20	240/*	240/*	240/100	240/*	240/*

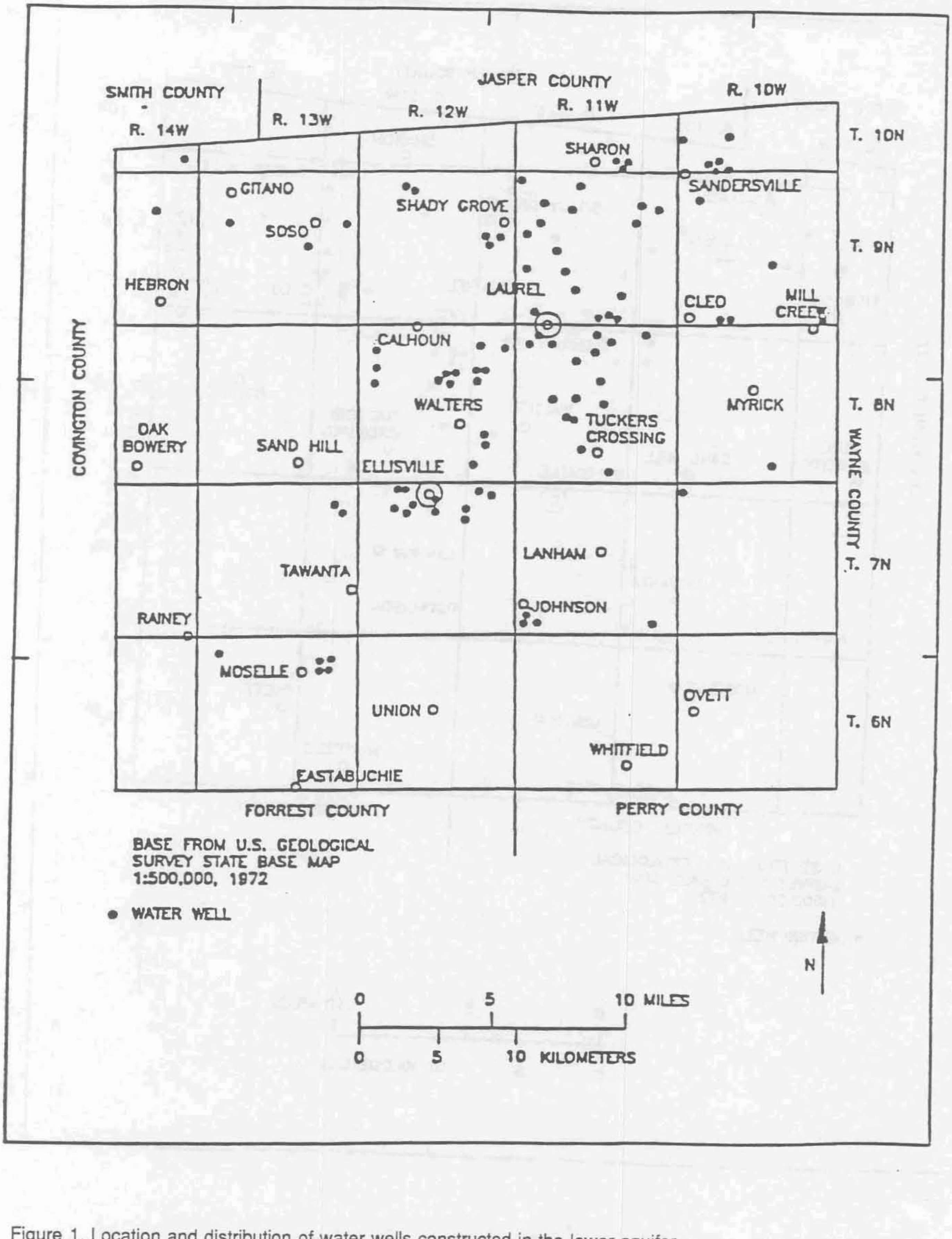

Figure 1. Location and distribution of water wells constructed in the lower aquifer.

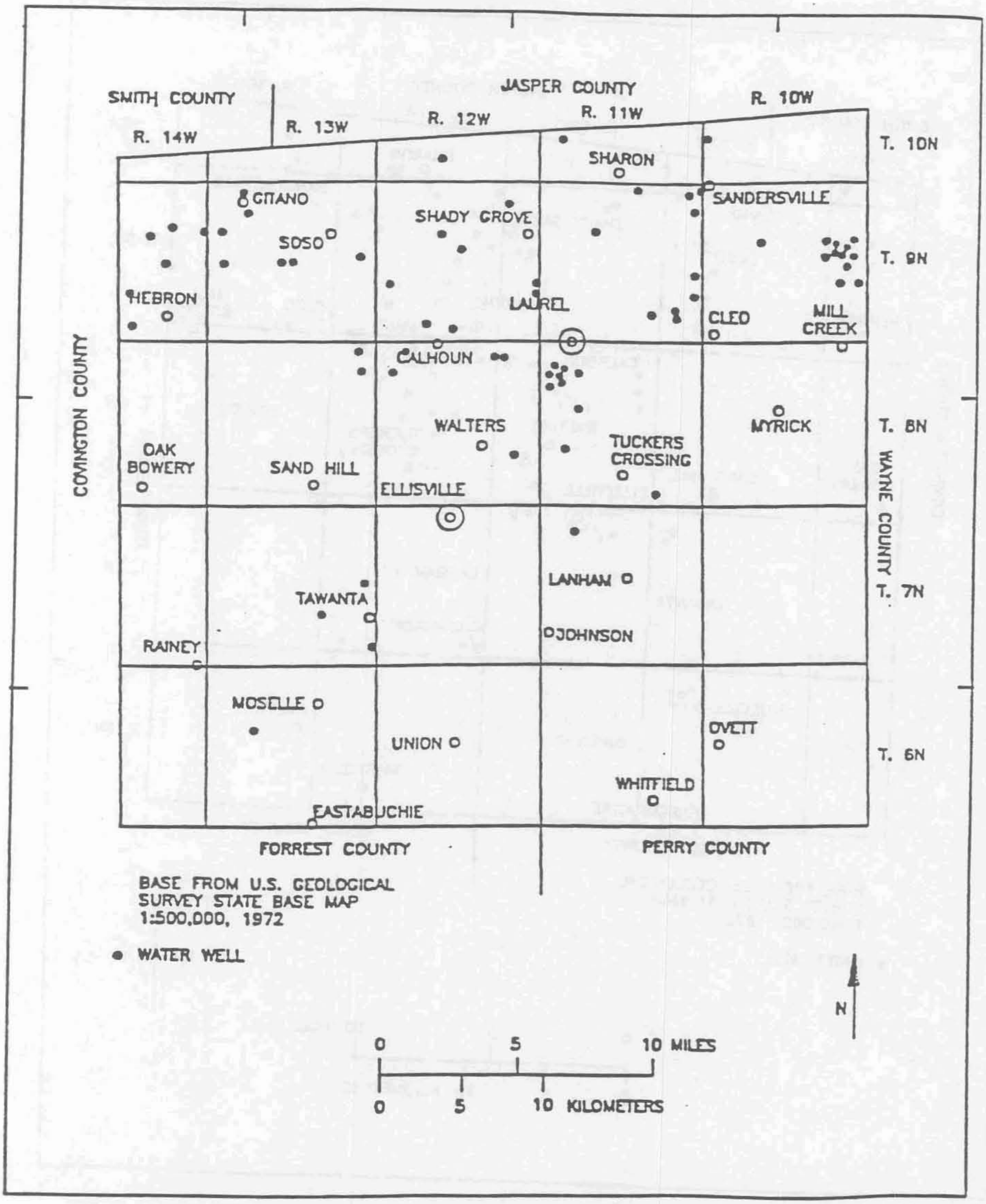

Figure 2. Location and distribution of water wells constructed in the middle aquifer.

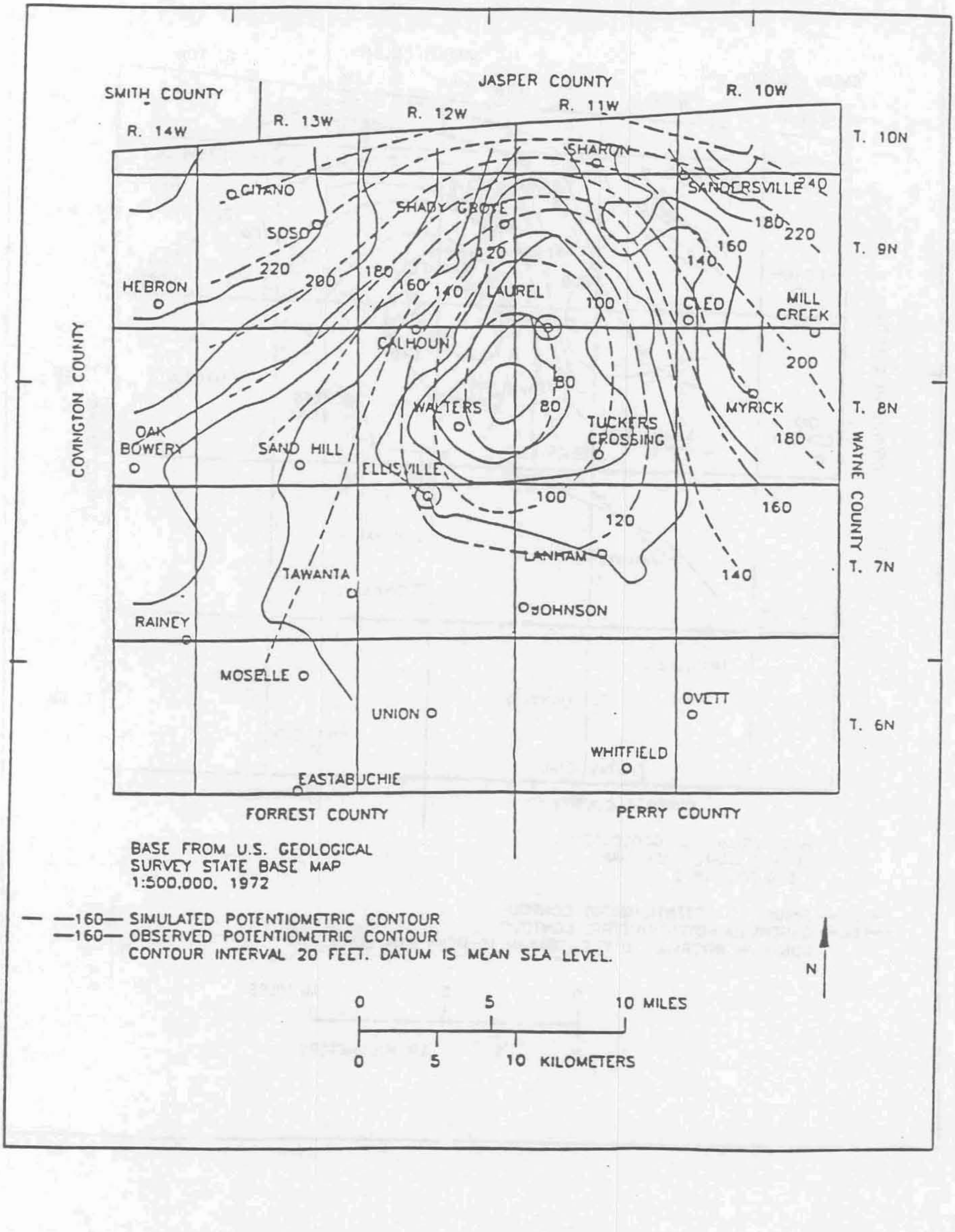

Figure 3. Potentiometric surface contour map for lower aquifer showing observed (solid) and simulated (dashed) elevations (feet).

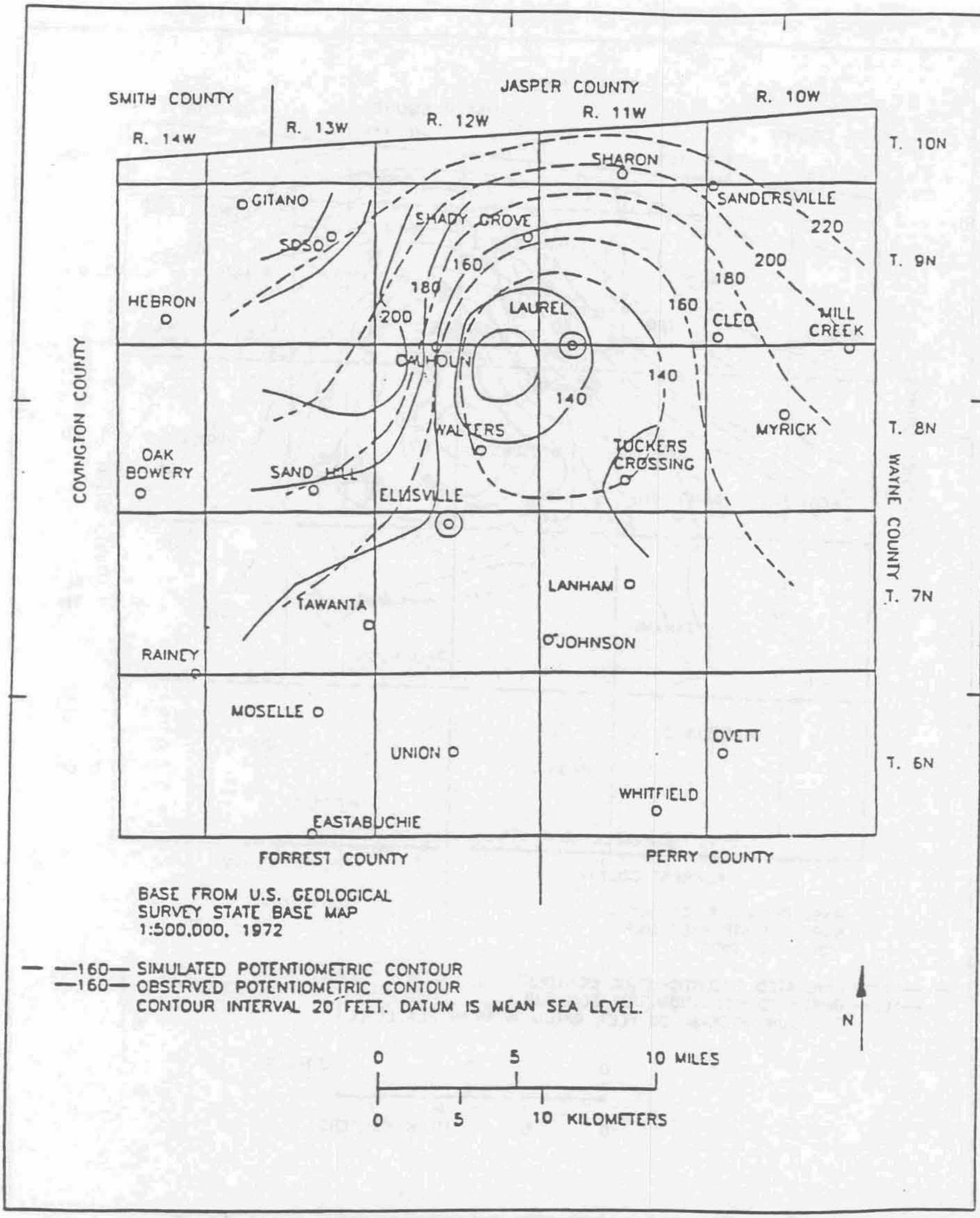

Figure 4. Potentiometric surface contour map for middle aquifer showing observed (solid) and simulated (dashed) elevations (feet).