

Depletion of the Ogallala Aquifer Water Reserves in Western Kansas

By

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B.S., University of Kansas, 1993

Submitted to the Department of Geography and the Faculty of the Graduate
School of the University of Kansas in partial fulfillment of the requirements
for the degree of Master of Arts

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Abstract

Western Kansas is a dry environment that places its dependence for irrigation water upon wells that extract the groundwater from the High Plains Aquifer. The most important constituent of the High Plains Aquifer is the Ogallala Aquifer, a fresh water-bearing interval in permeable sediments of the Pliocene Ogallala Formation. The United States Geological Survey (USGS) collected water level data until 1997, at which time the Kansas Geological Survey (KGS) became responsible for data acquisition. Although the KGS has published an online web Atlas of the High Plains Aquifer that includes projections of remaining aquifer lifetime, these forecasts do not consider possible climatic variation. Precipitation data will be used to compensate for the influence of local weather conditions upon irrigation demand. These data will be used to create maps depicting the state of the Ogallala Aquifer, including yearly levels and change in water levels to help provide a detailed view of the depletion of the aquifer. Using these data, a model will be created to predict the future water levels of the aquifer considering the effects of precipitation upon climatic variation. To examine the impact of climatic variation upon well drawdown, three scenarios of the future will be modeled: a period of higher than average precipitation, a period of lower precipitation, and a period of average precipitation. Future trends in the water levels of the Ogallala Aquifer were mapped by examining the outcome of these possible future scenarios.

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I. Significance and Importance



Fig. 1

Extent of the Ogallala Aquifer

The Ogallala Aquifer stretches from Nebraska to Texas and is one of the largest groundwater reservoirs in the world (Figure 1). Over 74,000 square miles in surface area, in places it is over 500 feet thick. Today, in places the aquifer's water reserves primarily to support agricultural irrigation are being withdrawn at rates that exceed recharge rate. Water levels in the aquifer are declining at an increasing and unmaintainable rate (Peterson et al.; 2003).

Two conditions must exist if an aquifer is to yield a dependable supply of water over many years. First, the rate of withdrawal must not exceed the transmissibility of the aquifer; otherwise, the water is pumped out faster than it can be supplied to the well, and the safe well yield will soon be exceeded. Safe well yield is defined as the maximum pumping rate that can be supplied by a well without lowering the water level below the pump intake. Second, the rate of total withdrawal should not exceed the aquifer's recharge rate; otherwise the water level in the aquifer will fall. When an aquifer declines significantly, the safe aquifer yield has usually been exceeded, and if the overdraft is sustained for many years, the aquifer will be depleted.

The first manmade well was dug in the Ogallala Aquifer in early 1900s. Early wells were artesian in nature and it was only later that farmers resorted to pumping the water. Since then, thousands of wells have been drilled into the aquifer. As more water was pumped from the aquifer, wells had to be drilled deeper and deeper. At current rates of irrigation in western Kansas, the aquifer is being depleted faster than it can be recharged, and in some areas the aquifer is dry.

This is a serious threat to the economy of the region, which is

dependent upon the aquifer for irrigation. Estimates of the economic impact from loss of irrigation water to the area predict a possible loss of \$300 million dollars in gross annual revenue (Kansas State University, 1998). Former Kansas Governor Bill Graves set a goal of zero depletion of the aquifer levels in Kansas (U.S. Water News Online, 2003), but this measure was opposed by farmers and their lobbyists who regarded it as too extreme.

II. Study Area

Kansas has divided the oversight of groundwater resources into several Groundwater Management Districts (GMD). The study area for this project is a region of the Ogallala Aquifer in southwestern Kansas, consisting of GMD #3 which includes Ford, Gray, Haskell, Grant, Stanton, Morton, Stevens, Seward, Hamilton, Kearny, Finney, and Meade Counties (Figure 2). Although the Kansas Geological Survey (KGS) and the Division of Water Resources (DWR) take measurements from observation wells throughout Kansas, this study will evaluate only those observations in the specified counties.

Kansas High Plains Aquifer

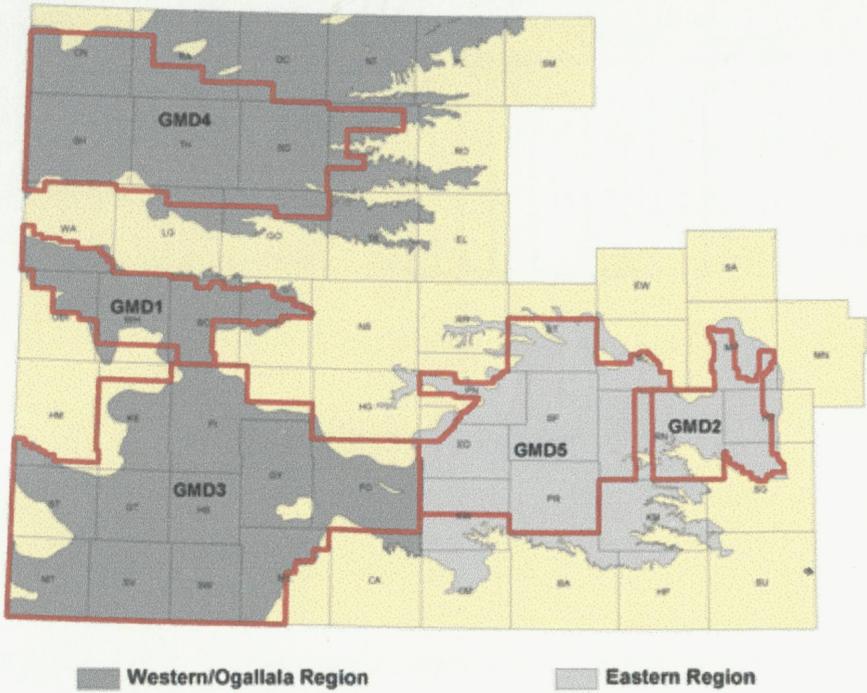


Fig. 2

Kansas High Plains Aquifer Groundwater Management Districts

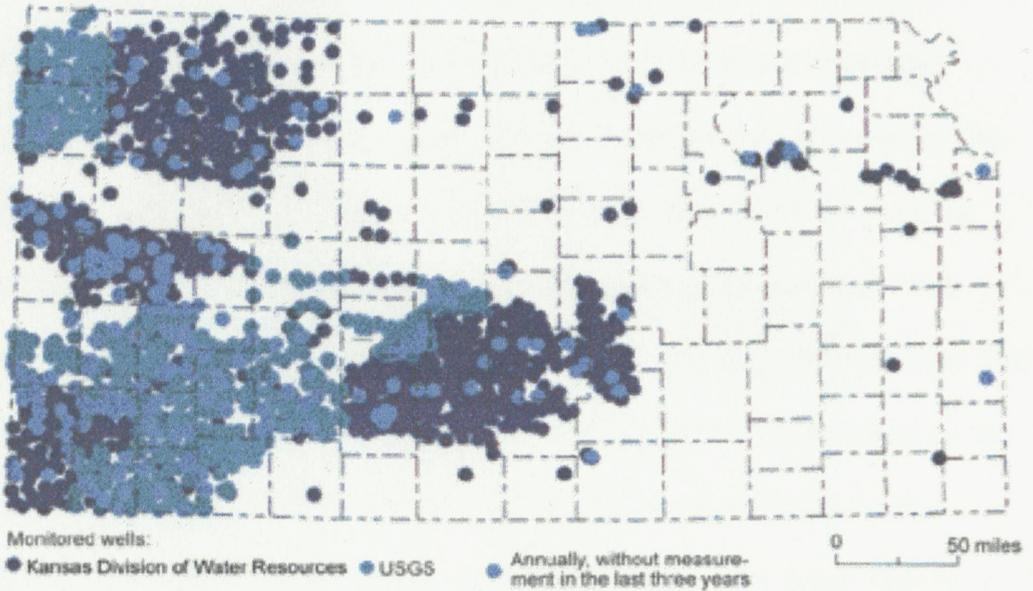


Fig. 3

Monitored well locations

III. Background

The KGS and the DWR are the primary sponsors of a statewide water level measurement program that samples approximately 1500 wells in Kansas annually (Figure 3). These annual measurements are normally taken during the months of January and February in stock wells, irrigation wells, abandoned wells, household wells, and monitor wells. Data acquired during these yearly measurements are tabulated by the KGS to establish trends and provide data for effective water resource management.

When the responsibility for acquiring annual water levels fell to the KGS in 1997, a significant effort was made to improve the accuracy, quality, quantity, cost benefit, and regional public service/support of the data and program. By eliminating previous basic problems, such as measuring the wrong wells, a substantial increase in accuracy was achieved over previous years. The physical acquisition methodology had been basically unchanged for the past 40 years, and is a function of the surface and the interior conditions of the well casings (Miller et al., 1997b). The wells to be measured are located by their legal Township and Range description (given in the well permit) and the use of a Global Positioning System (GPS). Access to the water level surface in most measured wells is through access tubes, threaded plug holes, or open slits in the wellhead base (Figure 4). Water level measurements are taken with a steel tape lowered down into the well shaft. A lead weight is attached to the tape with copper wire to prevent the tape from binding inside the well. The tape is 500 foot long and is divided into one-foot intervals. Prior to inserting the tape into the well, blue carpenters chalk is used to coat the first 15 feet of the tape and slowly lowered down the wellbore to a depth which has been determined from a combination of the depth of the last measurement and measured depths in nearby

wells. When the tape is extracted the chalk will have washed away creating a “cut” which shows the water level.



Fig. 4
Typical wellhead

A simple spreadsheet template system is used on a laptop computer that queries the user for each data point. This program helps the user to determine if the measurement is accurate by comparing the new measurement to a database of previous measurements and the current depths to water in nearby wells. If the measurement is outside of a calculated window the measurer is notified that there is a problem and is instructed to measure the well again.

Depth to water is the main variable measured in the observation well program. Three other secondary variables of the well are involved: the ground elevation, north-south coordinate, and east-west coordinate. The primary variable, depth to water, varies with differences in topography and geographic location. However, the influence of these variables can be cancelled out by considering the change in water level, that is, the difference between the depth to water in one year and the depth to water in the same well in the next year.

IV. Objective

Water levels in the Ogallala Aquifer have been declining rapidly during the period that records have been collected by Kansas agencies. Demand for ground water in Western Kansas remains high with the large amount of agricultural activity in the region. While most water-level data are available to the public, it is in a tabular format that does not provide much insight into general trends throughout the region. Creating graphics from these data allows a view that is easily understood by the layman. It is also a good vehicle to express the possible future state of the Ogallala Aquifer.

Kansas Geological Survey (KGS) and the Division of Water Resources (DWR) data will be used to create maps depicting changes in water levels in the Ogallala Aquifer in GMD #3. Data used will be from 1984 though the most recent readings for 2003. Many wells were not measured throughout this period; some were only sampled for a few years and then abandoned for various reasons and other new wells introduced as these older ones were dropped. This study uses only those wells that remained in use throughout the study period to evaluate yearly changes in aquifer levels. The local communities are not populous and have little industry, so they do not place any great demand upon the aquifer. The water used in this region is primarily for agricultural purposes. Generally, water table levels within the Ogallala Aquifer have been getting lower with each successive yearly measurement. This scenario is expected to continue for the foreseeable future with current farming methods. It is possible to forecast future changes in the aquifer by extending this historical trend of declining water levels. This regular trend in drawdown may be perturbed by temporary conditions-specifically, climate changes which may increase or reduce the demand for irrigation water.

Demand for irrigation water is logically linked to local climate,

because the amount of water needed for irrigation is reduced if rainfall is adequate for crop production. Local precipitation data was used as a variable to help determine the significance of local rainfall conditions upon the demand for irrigation water and the consequent changes in aquifer level. Since precipitation is highly localized it may seem that recording station measurements are not representative of overall county precipitation. Yet this study will demonstrate that localized precipitation events, extrapolated out on a yearly basis, are consistent across large areas. By using the historical record of water levels and precipitation within the GMD#3, a model will be created to map the future water table levels in the aquifer. The effects of changing climatic conditions will be illustrated with different future scenarios showing the impact upon well drawdown of different amounts of annual precipitation.

V. Methodology

a. Data Collection

Water level data for the study were collected by the Kansas Geological Survey and are compiled into an electronic format which is available online. This information can be accessed on the Kansas Geological Survey's web site through an online program called WIZARD, whose interface allows a user to select data by a variety of criteria: Public

Land Survey System (Township, Range and Sections), Latitude and Longitude Coordinates, County Name, GMD#, Date Range, USGS Identification Code, or KGS Local Well Number. By using this interface it was possible to download a tab-delimited text file containing all measurements and notations for each well monitored during the years 1984-2003 in GMD#3 in a few minutes. Another file containing the well locations in latitude and longitude format was obtained from the WIZARD site manager (Wilson, 2003).

Precipitation data are available from a variety of sources. The National Climatic Data Center (NCDC) archives data collected by the National Oceanic and Atmospheric Administration (NOAA) on their web site (<http://dipper.nws.noaa.gov>). This data is available in an hourly format through the year 1999. Additional precipitation data can be found from the State Climatologist through the Kansas State University Research and Extension Office, which has the most recent precipitation data. However, this data goes back only to 1999 in a monthly and yearly total format. Earlier data has been compiled into thirty year averages that are updated every ten years. These are referred to either as “normal,” which is the thirty year average from 1961-1990, or as “new normal,” which is the average from 1971-2000. Both these sources contain

useful data, but they lack certain information. It would be ideal to have the latitude and longitude of each precipitation recording station in order to create a gridded buffer around each station for subsequent combination with water level data. Unfortunately, precipitation data is listed only with the name of the recording station, along with the county name. Another problem is that the 1984-2002 NCDC data is in an hourly format, resulting in a file that is large and difficult to manage. Data from the State Climatologist's Office is in a yearly format that is directly compatible with the yearly water level data, but it is only available back to 1999. Monthly precipitation for every observation station in Kansas for the 1984 through 2001 seasons also can be obtained through the Data Access Support Center (DASC), a data-distribution service sponsored by the Kansas Water Office. This data is in a tab-delimited text file and contains the monthly precipitation measurements and recording station name with the county names. Following the acquisition of data on aquifer water levels and precipitation, two additional pieces of data were required. The first is an ESRI ArcInfo shape-file that contains a Kansas county border polygon file to use as a background for the maps. This is a file that contains to-and-from nodes and right-and-left polygon information. The second is another ESRI ArcInfo shape-file but containing a border line file for GMD#3. These were obtained from the KGS (Ross, 2003).

b. Data Processing

The well monitoring data is a tab-delimited text file containing a large amount of information for each well every year a measurement was recorded. Much of this information is irrelevant to this study and was removed after using Microsoft Excel to change the format to a Dbase IV format that would be compatible with ESRI ArcView 3.2. The only fields required are: USGS_ID, Sequence Number, Measurement Date and Time, and Depth to Water. Also, the Measurement Date and Time field is provided in the format of Month-Day-Year. In order to have consistent data input for GIS processing on a yearly basis, the Month and Day portions of this field were parsed into different fields. After splitting apart this field the Month and Day records were deleted from the final data file.

Since the well monitoring data file contains each well's measurement level for all years, it was necessary to split the data file into separate files for each year so that yearly comparisons could be made. This was done using the ArcView 3.2 Query Function. The Query Function Builder can select records based upon the data contained within any field of the records. By setting the query to search for records in which the Measurement Year field equals a year within the study period, 1984-2003, the program selects all records that match. These records can then be grouped together at the top of the database file through the Arc Promote

function and that year's group of records saved to a separate file using the Export function. This is repeated until each year is saved as a separate database file.

In order to geocode the well monitoring data it must be combined with the well site location file which contains the latitude and longitude coordinate data for each monitored well in GMD#3. After removing extraneous data with Excel and saving as a Dbase IV formatted file, the well site location file must be converted into a geographic information file within ArcView 3.2. The file is first added as a table to the Arc project window, and then, using the View window, it is added as an Event Theme having a latitude and longitude-based coordinate scheme. Then, in the Theme window, it can be converted into an Arc shape file, which actually consists of a set of five files including the well site data file.

ArcView 3.2 is then used to join this data file with the well monitoring data file. Both the well site location file and the well monitoring data file contain the USGS Identification Number for each record. ArcView 3.2 can join the two together using this common identifier to match like records in both files. After joining, the resulting file

is converted to a shape file. After saving the geocoded shape file for each year, the annual well monitoring data file is removed from the well site location file using the ArcView 3.2 command, Remove All Joins. This prepares the well location file to be joined to the successive monitoring data file.

The Spatial Analyst Extension for grid data is turned on in ArcView 3.2, allowing additional geographic analysis functions to be used. The shape file containing borders of GMD#3 are added to the project as a new theme. This file acts as a geographic boundary, limiting Arc to processing data only within the study area. If analysis is not limited to the area within this boundary, the surrounding areas (which have no well measurements) would influence the outcome.

After setting the Analysis Properties to be the same as the GMD#3 shape file, a surface is created for each yearly well measurement using the Interpolate Grid function of ArcView 3.2. In order to permanently save this surface it must then be converted to a shape file. The resulting shape file is an isoplethic representation of the well data that uses darker shades of blue to represent deeper water surface levels. These files are then used in the next step to create a map depicting the differences

between successive years. To aid in interpretation of these maps, a contour line map was created to overlay the surface. This was done for visual enhancement only and is simply a different representation of the same data.

ArcView 3.2 has an analysis tool called Map Calculator that can perform functions using data included in its View window. By subtracting one year's surface from the previous year's surface, a grid of well drawdown for each year is created. These grids were saved as shape files and their legends created to depict positive drawdowns in red and negative drawdowns in blue.

Each well location within the study region is identified by both a USGS identification number and a County Code identifier. By using the ArcView 3.2 Query Function Builder, the well locations and measurements for each county can be separated from the GMD#3 file. By exporting the data from the main well file in ArcView 3.2, separate county files can be created for each year of the study period. Data for each year within each county can be joined together into a county-wide file that contains all years from 1984-2003.

The precipitation data file for Kansas can be opened with ArcView 3.2 and each county name separated using the Query Function Builder. Individual county data is then exported to separate files. The average water level drawdown was then calculated for each county by averaging the individual well drawdowns. Since Excel will treat any field with no data as though it was a zero value, it can return misleading values if this problem is not addressed. If in 1985 a particular well's depth to water was not measured, but in 1984 a measurement of 65 feet was recorded, the result would be a value of -65 feet. This would incorrectly appear to be a dramatic increase in water level when in fact the true value is not known. To counter this problem a logic function within Excel can be used so only wells with observations for both years are used. After drawdowns for all wells in each county are calculated, an average is found for the entire county. The final result is a file for each county, containing a record for each year's average well drawdown and precipitation.

c. Prediction Model

A linear regression analysis was used to relate the change in water table elevation to yearly precipitation through time. This linear regression uses two predictor variates: year and precipitation. It assumes there is a linear change in water level through time occurring

at a constant rate, perturbed by the variable of precipitation. The resulting regression equation can be used to predict the future drawdown for specified years and amounts of precipitation. A prediction of the future drawdown of the Ogallala Aquifer can be created for each county using this model.

The linear regression model is based upon the least squares method, which fits a line to the observed data points so that the sum of the squared deviations between the observations and the fitted line is the minimum possible for any line. This is the line around which there is the smallest possible variance, and which provides the "most likely" estimates (Draper and Smith, 1998). Using the individual county data files created in the previous step this computation was performed using the statistical program, JMP v. 5.0 (SAS Institute, 2002). The resulting statistics include parameter estimates that can be used in a prediction model to estimate future scenarios.

$$\text{Drawdown} = \beta + \alpha(\text{Year}) + \delta(\text{Precipitation})$$

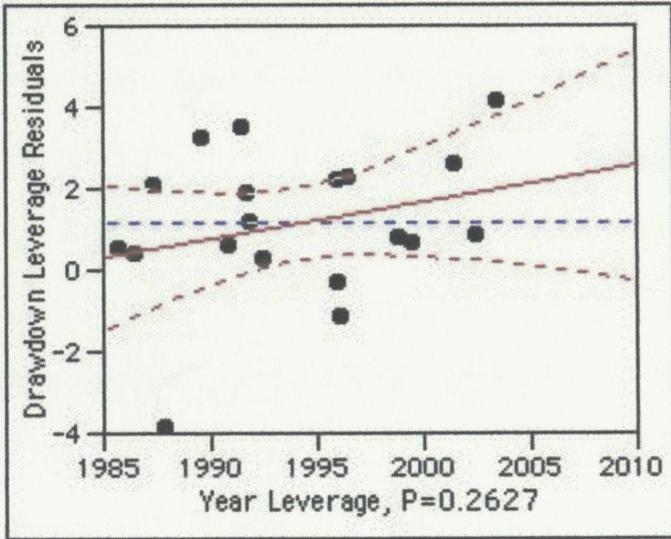
β = Regression Coefficient (Intercept)

α = Time Coefficient

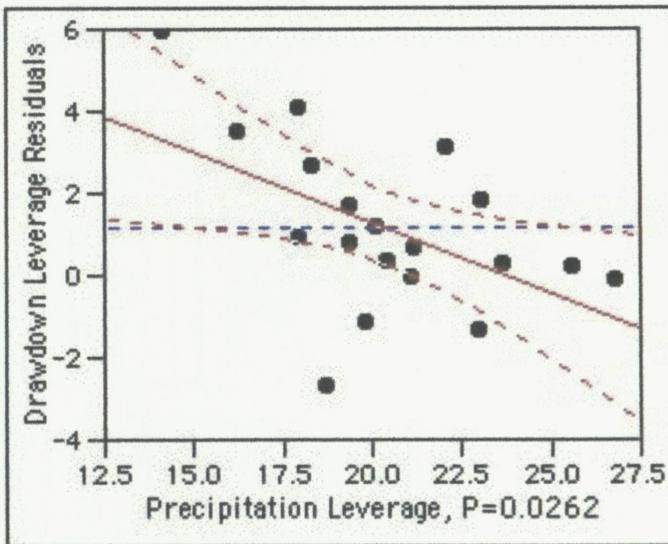
δ = Precipitation Coefficient

This equation assumes that there is a significant relationship between well drawdown, time and precipitation. The significance of

these relationships is demonstrated in the Leverage Plots (Figures 5 and 6) that show the Drawdown Leverage Residuals along the Y axis and the Year Leverage and Precipitation Leverage along the X axis. The diagonal line in each plot represents the effect of the specified variable on the regression; that is, the line represents the partial regression of a specific variable, holding any other variables constant. The horizontal line in each plot represents the mean. The distance from the point to the horizontal line reflects what the residual would be without that variable in the model. If a point is close to the diagonal line, the specific predictor variable is highly effective in predicting that observation. The curved dashed lines represent 95 percent confidence limits around the fitted model. If the confidence limits include the horizontal line representing the mean, the regression model is not statistically significant at the 95 percent level, although it may be significant at lower levels (SAS Institute, 2002). In the example shown, the confidence limits on the Leverage plot for Year enclose the mean line, indicating that the annual trend in drawdown is not statistically significant (Figure 5). However, the confidence limits on the Precipitation Leverage plot do cross the mean line, indicating a significant statistical relationship between these two variables (Figure 6).

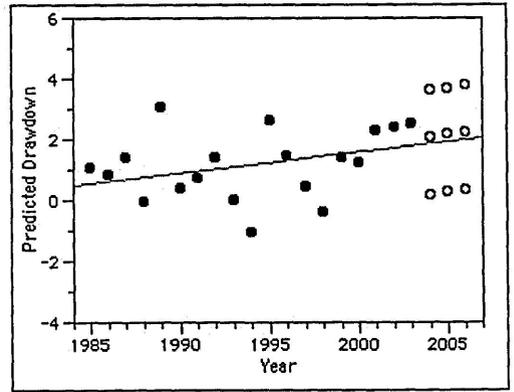
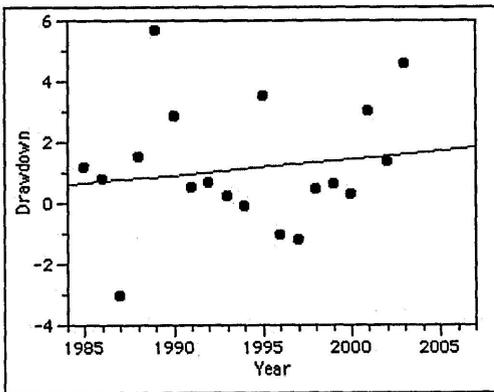


Year vs. Drawdown Leverage Plot
Figure 5



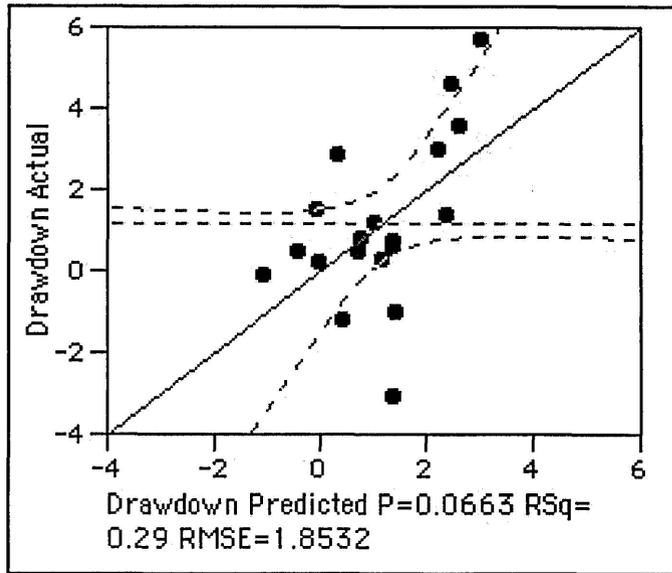
Precipitation vs. Drawdown Leverage Plot
Figure 6

Although a partial regression may not be statistically significant, this does not mean that there is no relationship, or that the model cannot be used for predictive purposes. The lack of significance simply means that the uncertainty attached to an estimate is large, usually because of excessive scatter in the observations or because the observations are limited in number. The predictions made from the model are still the "best possible" in a minimum variance sense, even if the predictions are not statistically distinguishable from naïve predictions based on the mean alone. To elaborate upon this fact a comparison can be made between the actual values calculated for yearly well drawdown to the predicted values (Figure 7), and the linear regression leverage plot showing the statistical relationship between the actual and calculated drawdown (Figure 8).



Drawdown vs. Predicted Drawdown

Figure 7.



Actual vs. Predicted Drawdown Leverage Plot

Figure 8.

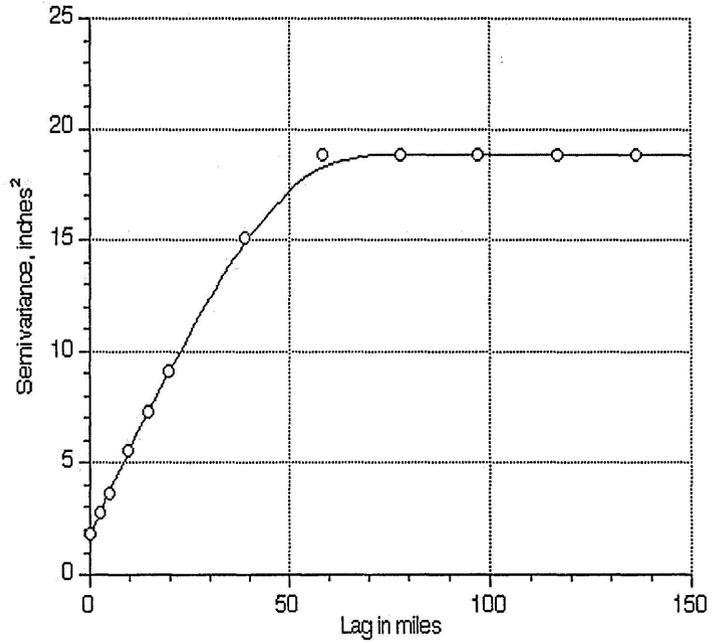
d. Precipitation Semi-Variance

The nature of precipitation within the study area is such that a meteorological event can be a very localized occurrence. It may rain several inches at one precipitation recording station while a neighboring station has no rain at all. A fast moving storm can easily bypass the widespread network of recording stations in this area. While some counties may have two or three recording stations, many only have one.

A semi-variance can be used to address the localized nature of precipitation in the region. A model was created to show the semi-

variance of the yearly precipitation throughout the study area using county average and recording station measurements. This semi-variance model was created using the yearly precipitation values from each county's recording stations within GMD#3 during all years of the study period. The semi-variance of each year was then combined to create the model. On the semi-variogram (Fig. 9), the lag shown is in miles. The lag is the distance from the measurement points where it can be assumed that the precipitation measurements are legitimate. As the average county in the GMD#3 is six townships, or thirty-six miles wide, the semi-variogram shows that we can legitimately assume that the annual values are consistent across the entire area. This means that individual, local precipitation events do not statistically have any influence upon, or add any significant error to yearly county measurements.

Model semivarlogram



Model semi-variogram

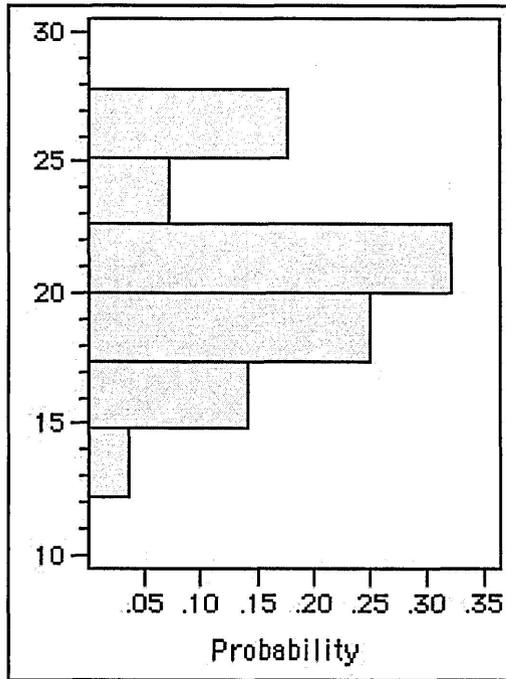
Figure 9

e. Prediction Scenarios

Three sets of three different future scenarios will be investigated using each of the created models. The sets represent time: one year, two years, and three years in the future:

1. The first scenario in each set uses trends in drawdown established in the past to model the future.
2. The second scenario envisions a period of severe drought.
3. The third scenario shows a future level of the aquifer during a period of increased precipitation.

To establish the proper levels of precipitation for each of these scenarios the data file for each county's yearly precipitation was used to produce empirical distributions of annual precipitation (Figure 10). The mean value of yearly precipitation for each county was used to model the first scenario of continuation of current trends. The lower 10th percentile of the precipitation distribution was used to model the second scenario of drought conditions. Increased precipitation modeled in the third scenario used the upper 90th percentile as the input value.



Annual Precipitation Probability Distribution

Figure 10.

By putting these precipitation variables into the model along with each year, 2004 or 2005, files were created that were used in conjunction with the water level surfaces previously made in ArcView. Since the result of this model was a single value for each individual county, they had to be integrated with the ArcView yearly well monitoring data file. First, the predicted well drawdowns from the model were subtracted from the last monitoring year's water level readings from each well in each county. The results for each county were then joined together with all other counties in GMD#3. ArcView 3.2 was used to create a surface grid and

contour map for the year 2004. This operation was repeated for the following years, 2005 and 2006.

VI. Product

The result is a set of maps portraying the recent historical water levels of the Ogallala Aquifer and the change, through time, in these levels. The maps show the water level surface interpreted from depth-to-water measurements taken during the period, 1984-2003 (Figures 12-31). A second set of maps show the year-to-year well drawdown for the twenty years (Figures 32-50). Additionally, a set of maps that portray the predicted future levels of the Ogallala Aquifer considering the relationship between precipitation and well drawdown established through a linear regression have been made. Three different projections of these future levels are modeled through the next two years: the first scenario takes an average of the past and continues that average into the future (Figures 52-53), the second portrays the result of a long drought (Figures 54-56), and the last shows the future level of the aquifer after a period of increased precipitation (Figures 57-59).

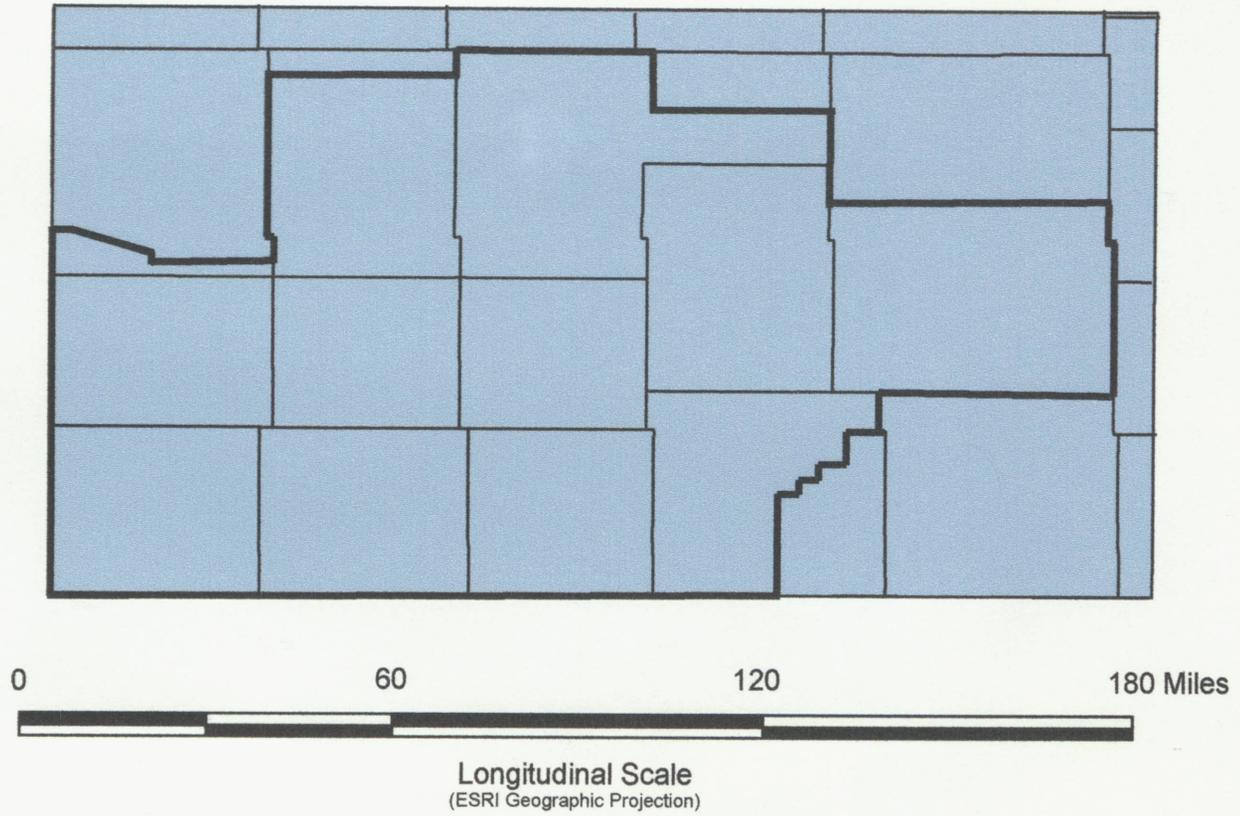


Figure 11. Boundary of Groundwater Management District No. 3

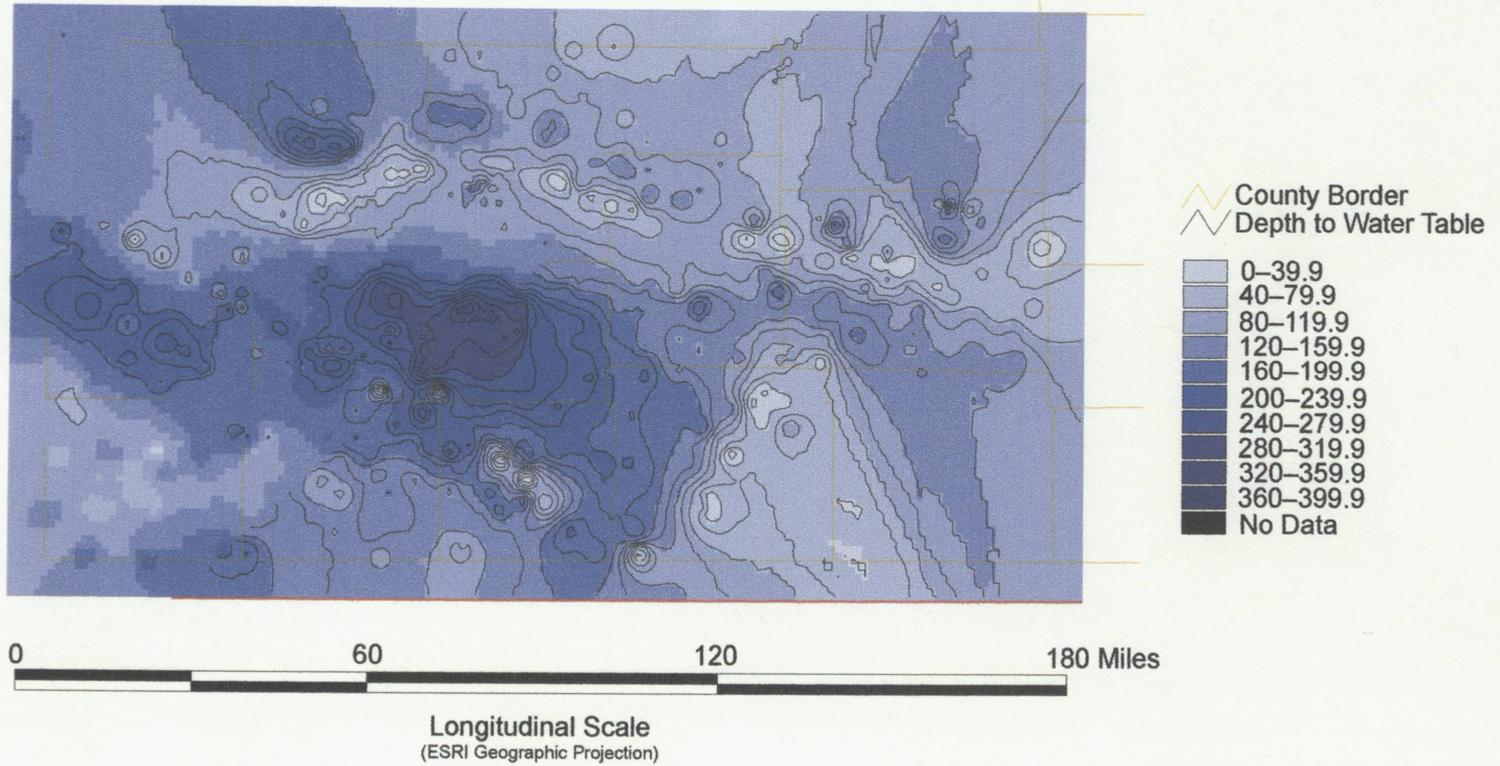
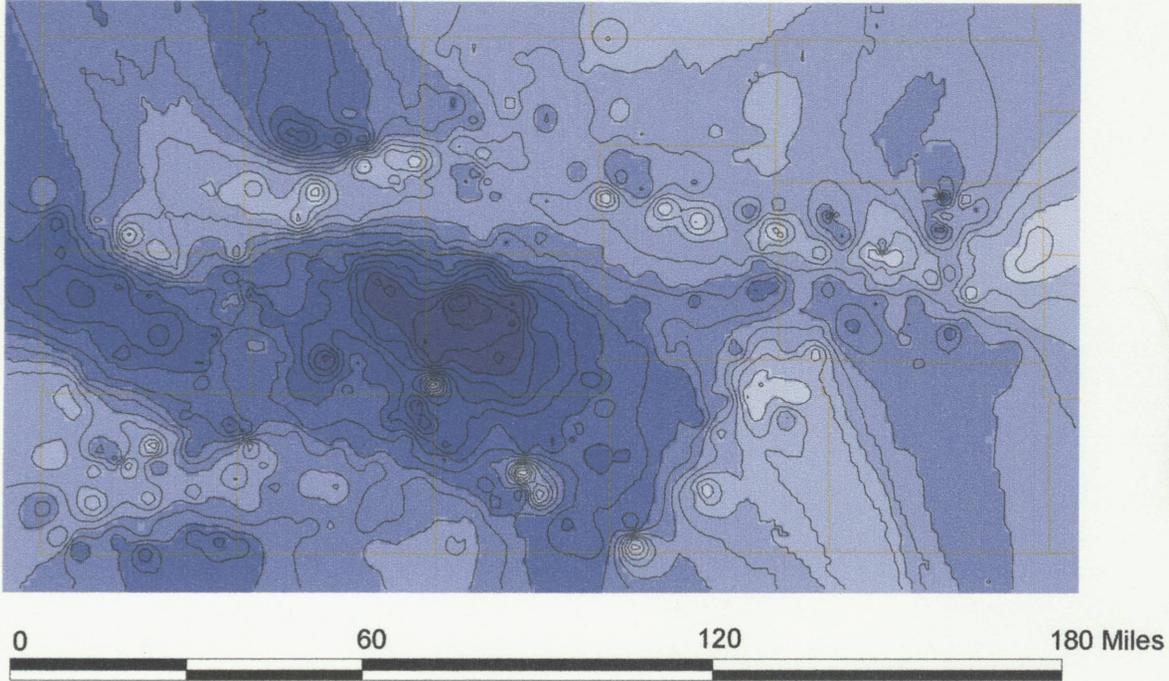
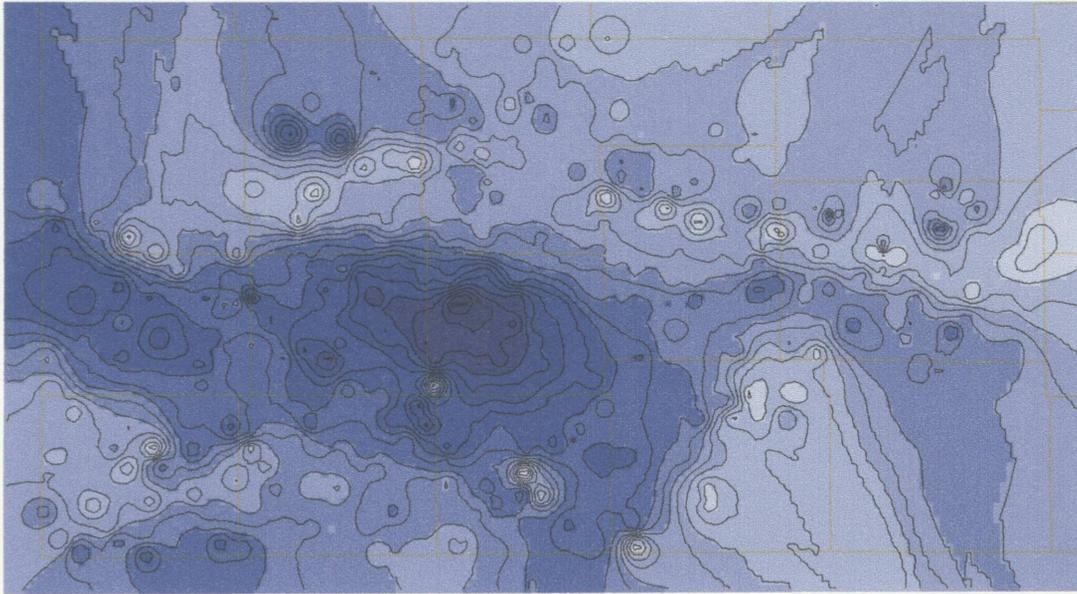


Figure 12. Depth to water table in 1984



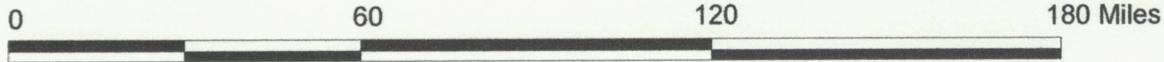
Longitudinal Scale
(ESRI Geographic Projection)

Figure 13. Depth to water table in 1985



County Border
Depth to Water Table

- 0-39.9
- 40-79.9
- 80-119.9
- 120-159.9
- 160-199.9
- 200-239.9
- 240-279.9
- 280-319.9
- 320-359.9
- 360-399.9
- No Data



Longitudinal Scale
(ESRI Geographic Projection)

Figure 14. Depth to water table in 1986

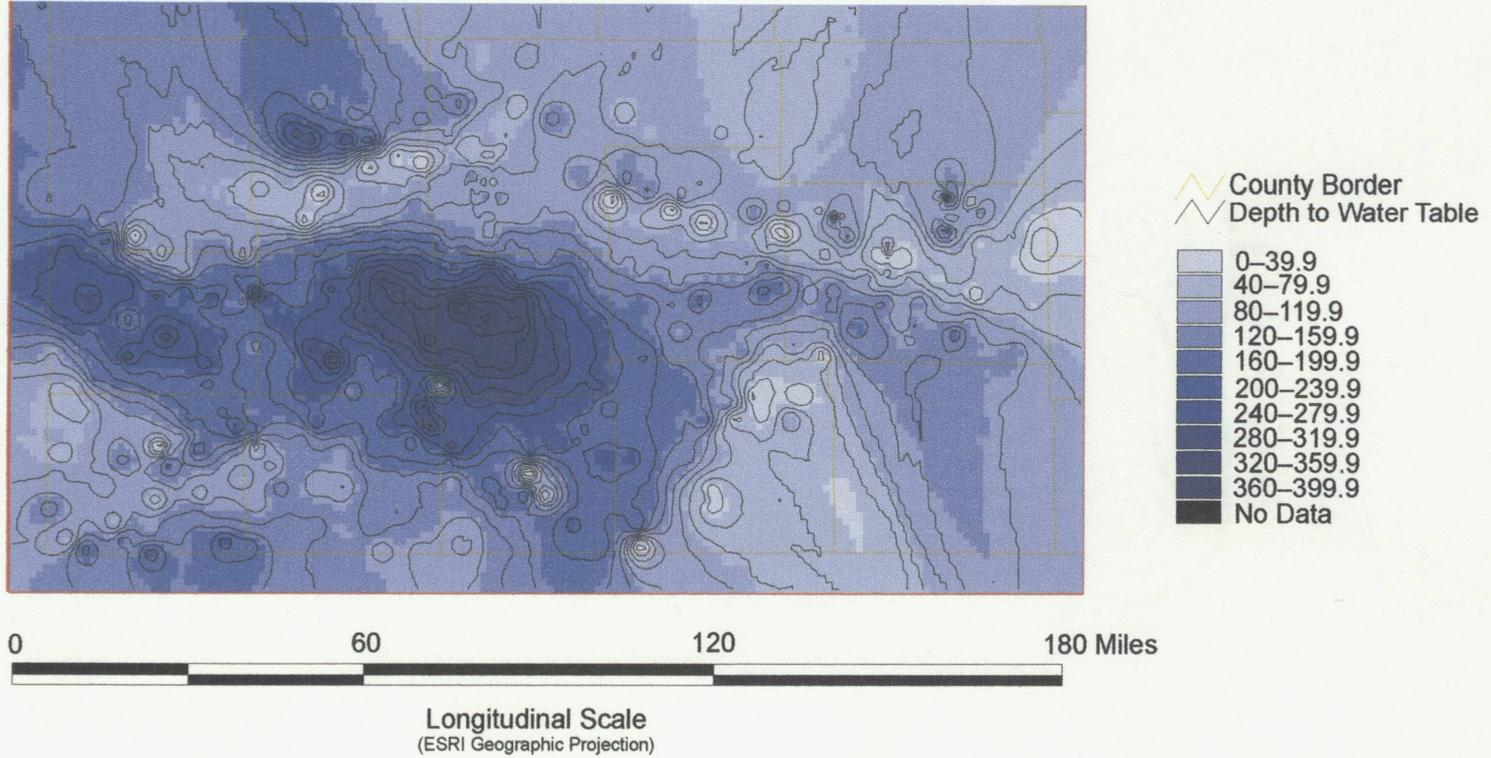


Figure 15. Depth to water table in 1987

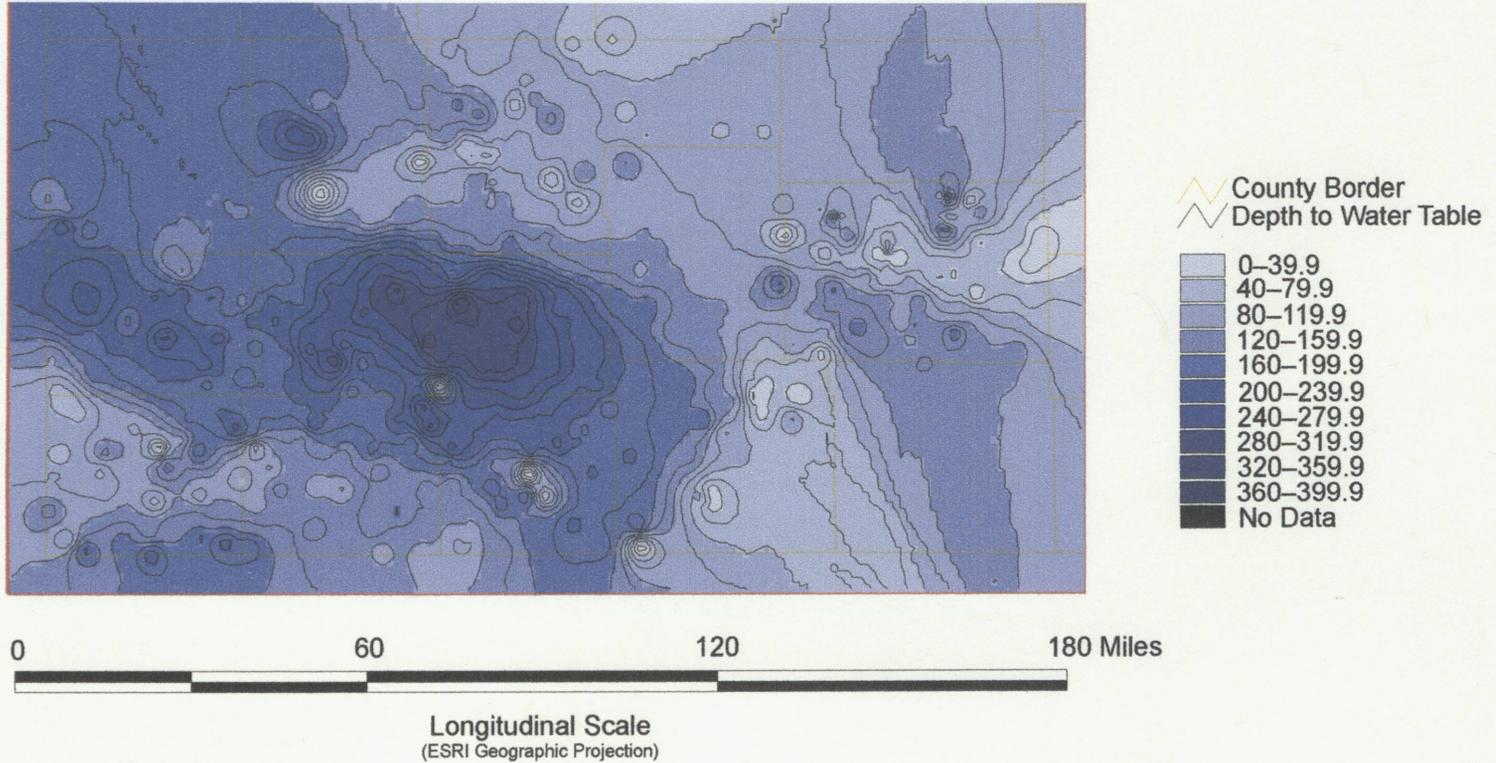
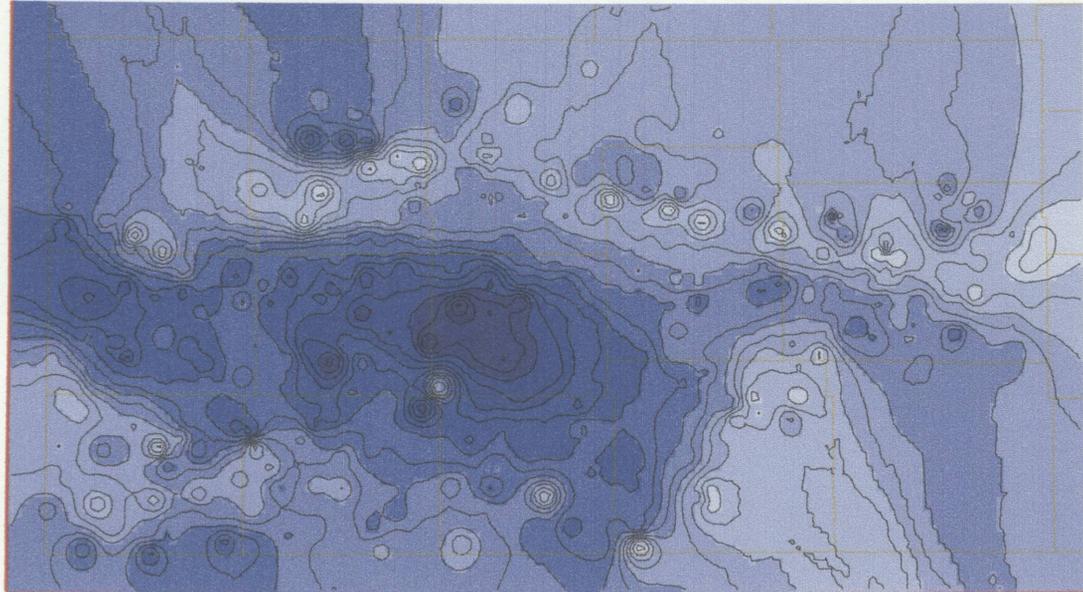


Figure 16. Depth to water table in 1988



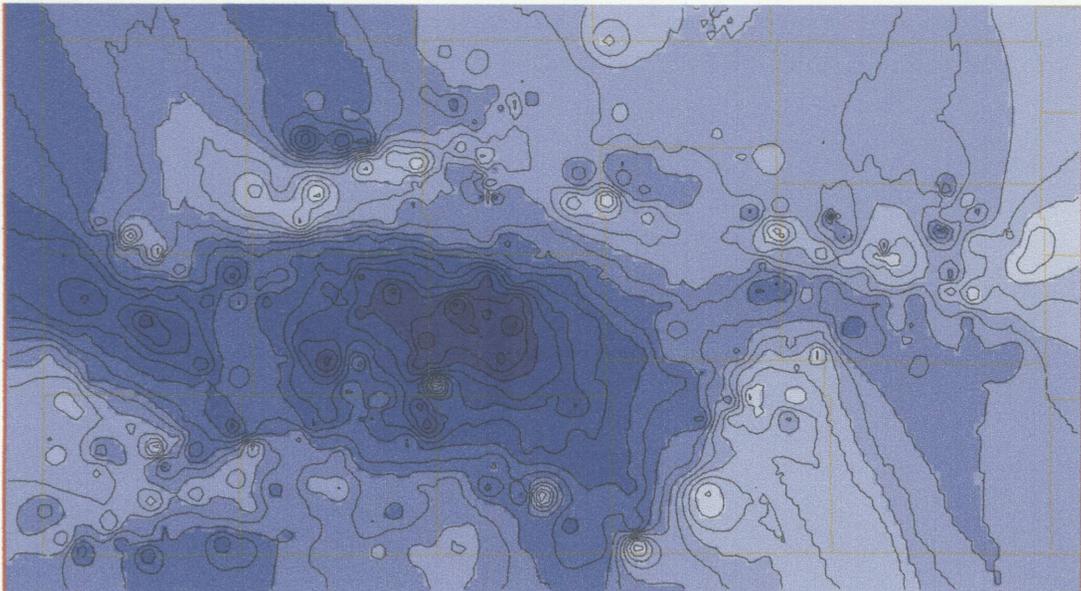
County Border
Depth to Water Table

- 0-39.9
- 40-79.9
- 80-119.9
- 120-159.9
- 160-199.9
- 200-239.9
- 240-279.9
- 280-319.9
- 320-359.9
- 360-399.9
- No Data



Longitudinal Scale
(ESRI Geographic Projection)

Figure 17. Depth to water table in 1989



County Border
Depth to Water Table

- 0-39.9
- 40-79.9
- 80-119.9
- 120-159.9
- 160-199.9
- 200-239.9
- 240-279.9
- 280-319.9
- 320-359.9
- 360-399.9
- No Data

0 60 120 180 Miles

Longitudinal Scale
(ESRI Geographic Projection)

Figure 18. Depth to water table in 1990

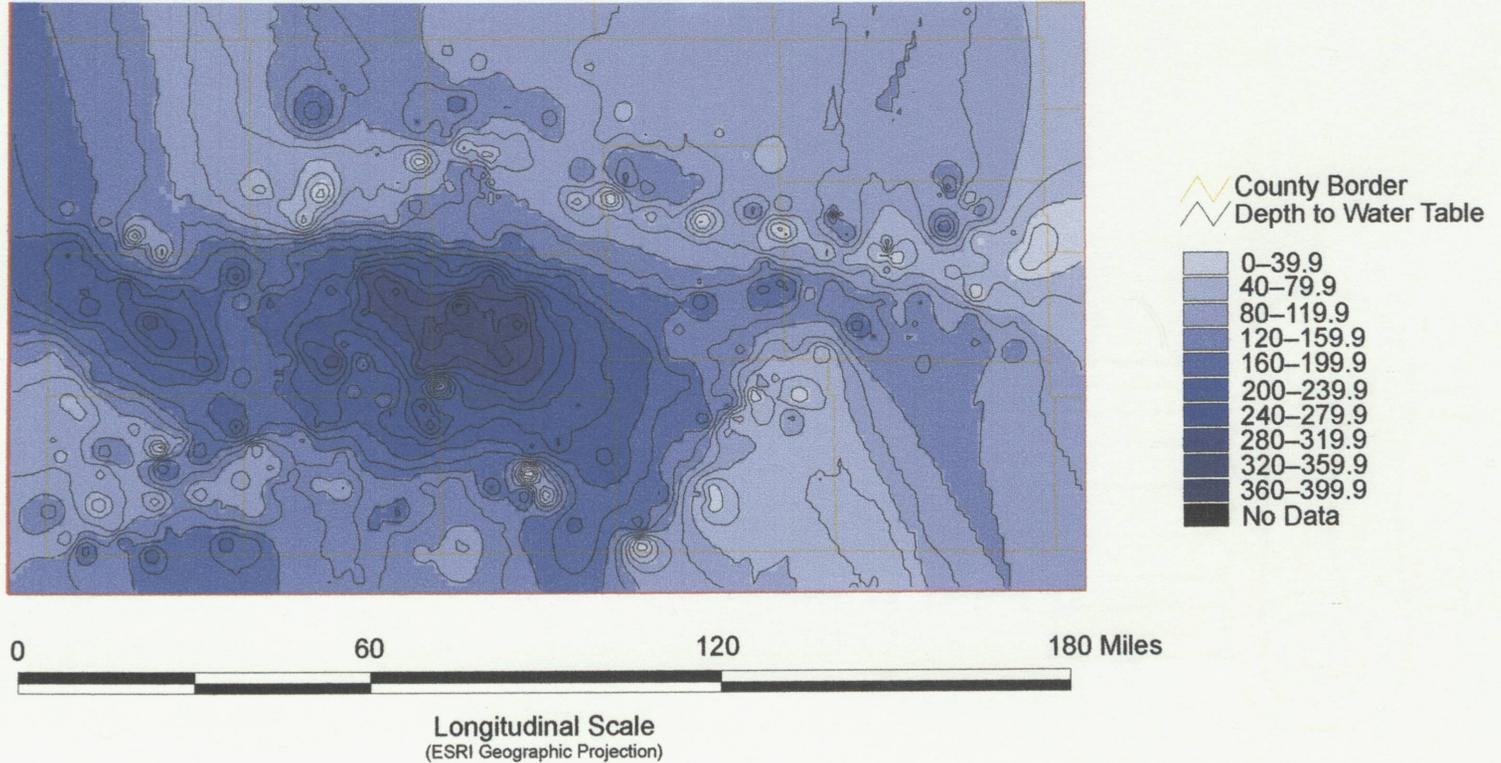


Figure 19. Depth to water table in 1991

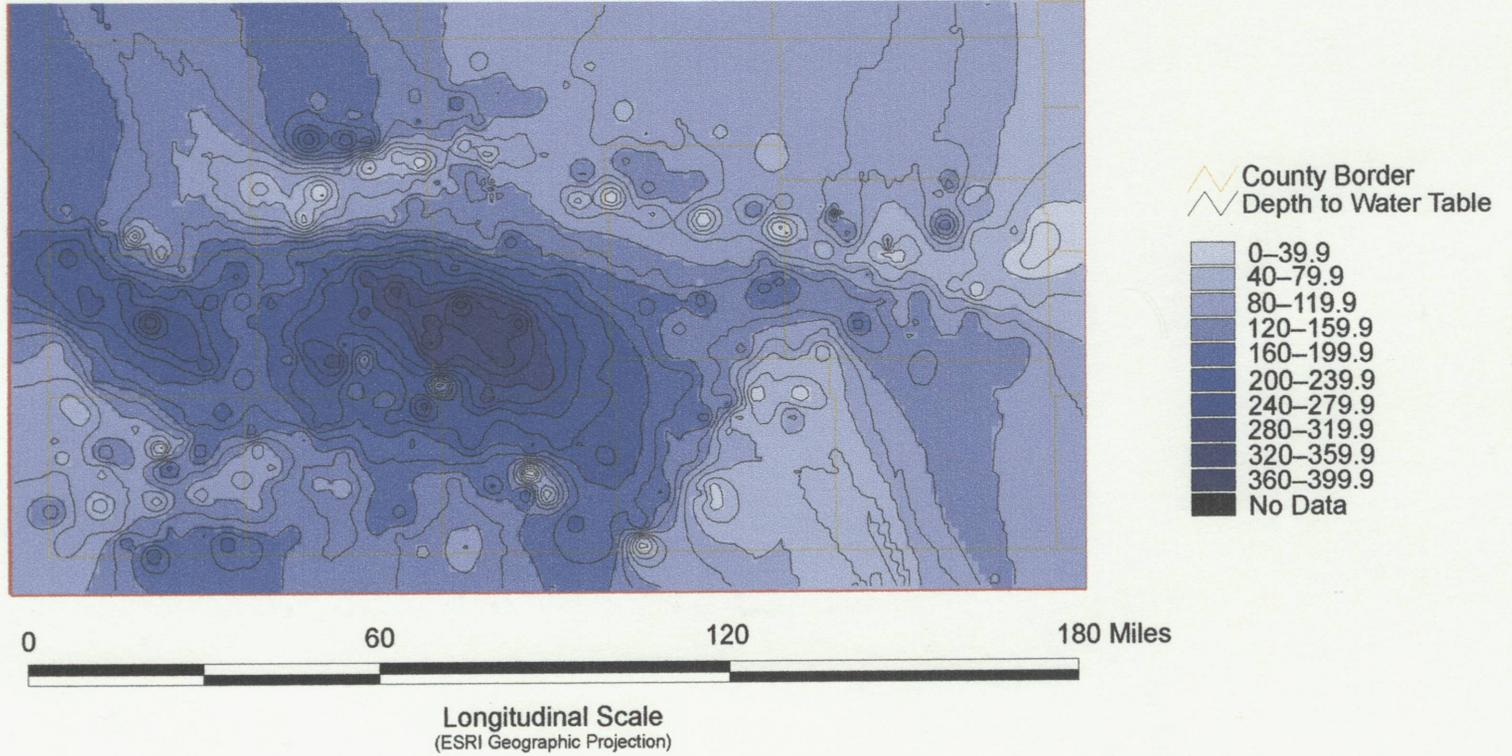


Figure 20. Depth to water table in 1992

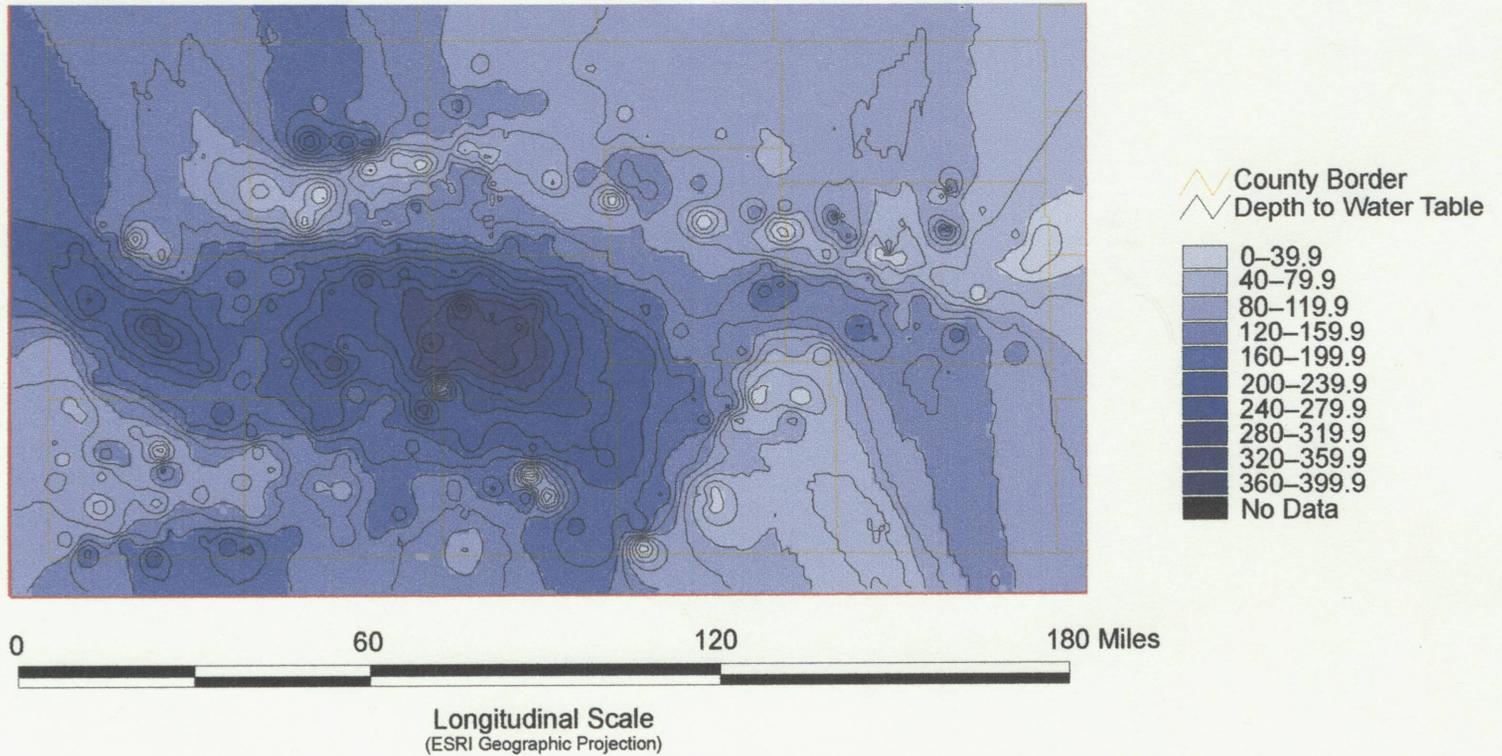
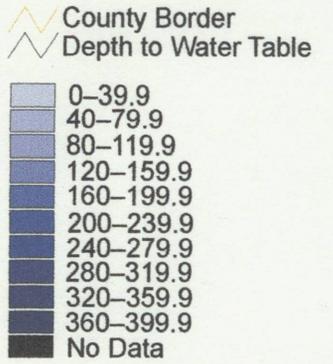
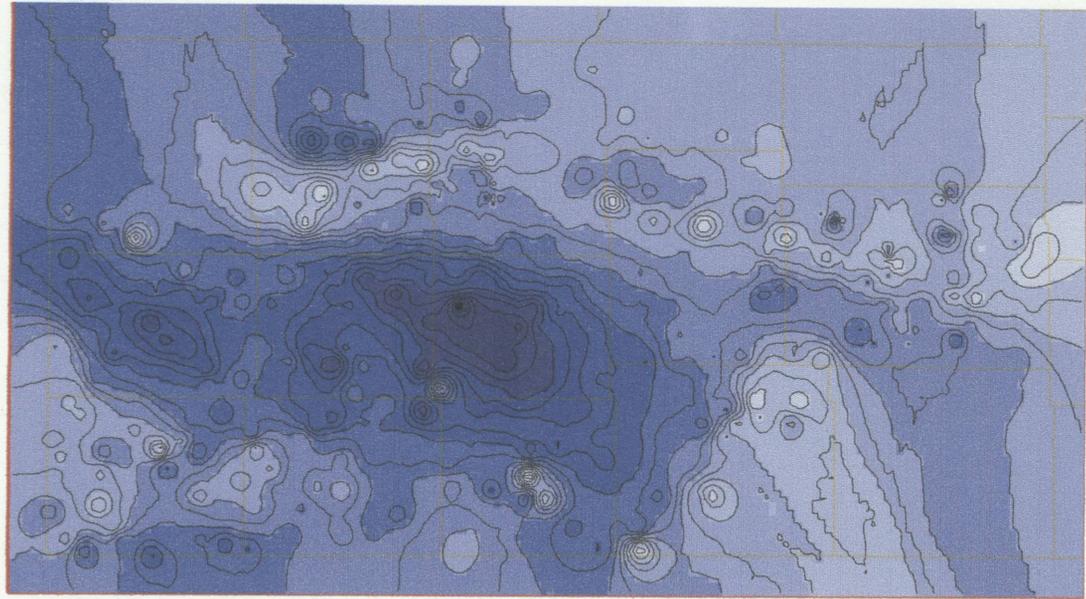


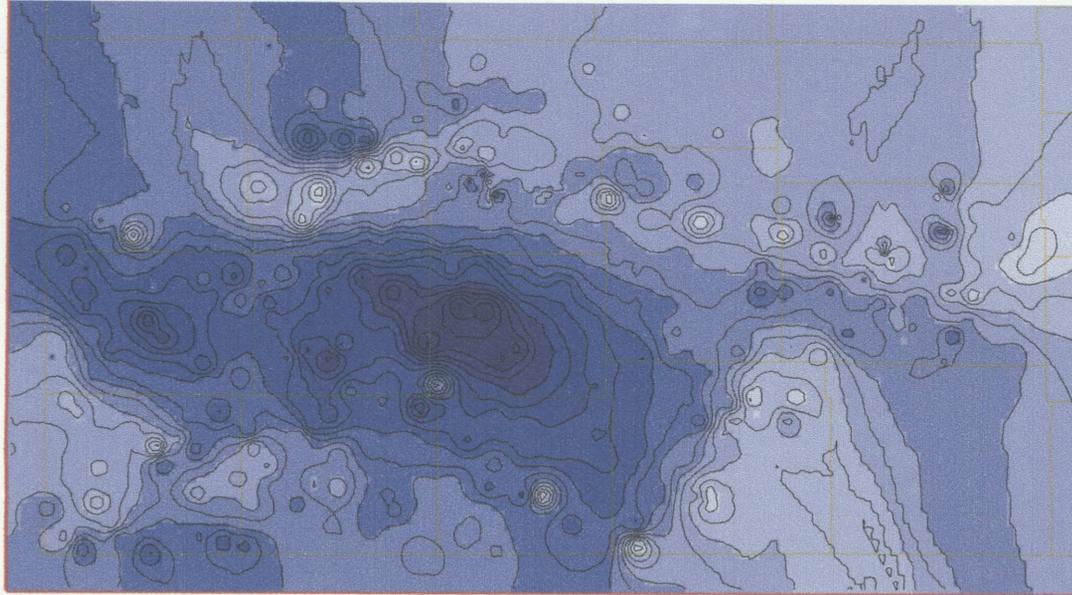
Figure 21. Depth to water table in 1993



Longitudinal Scale
(ESRI Geographic Projection)

Figure 22. Depth to water table in 1994

40



0 60 120 180 Miles

Longitudinal Scale
(ESRI Geographic Projection)

Figure 23. Depth to water table in 1995

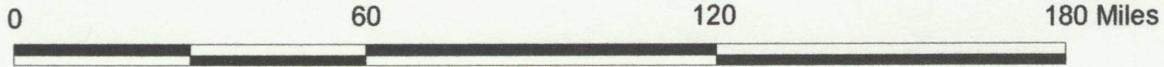
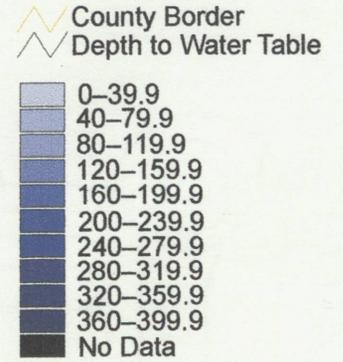
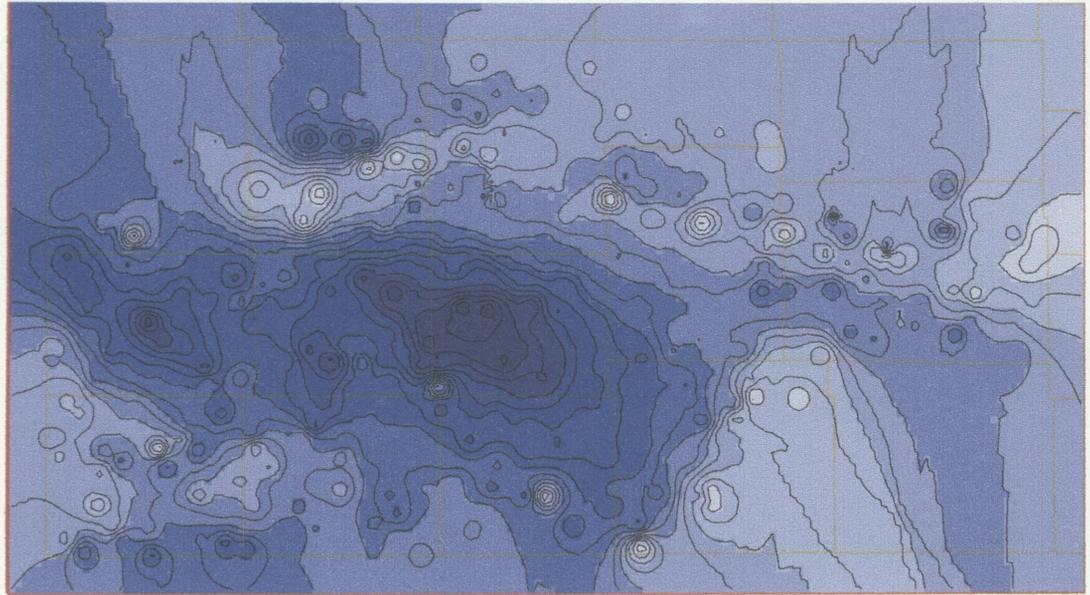


Figure 24. Depth to water table in 1996

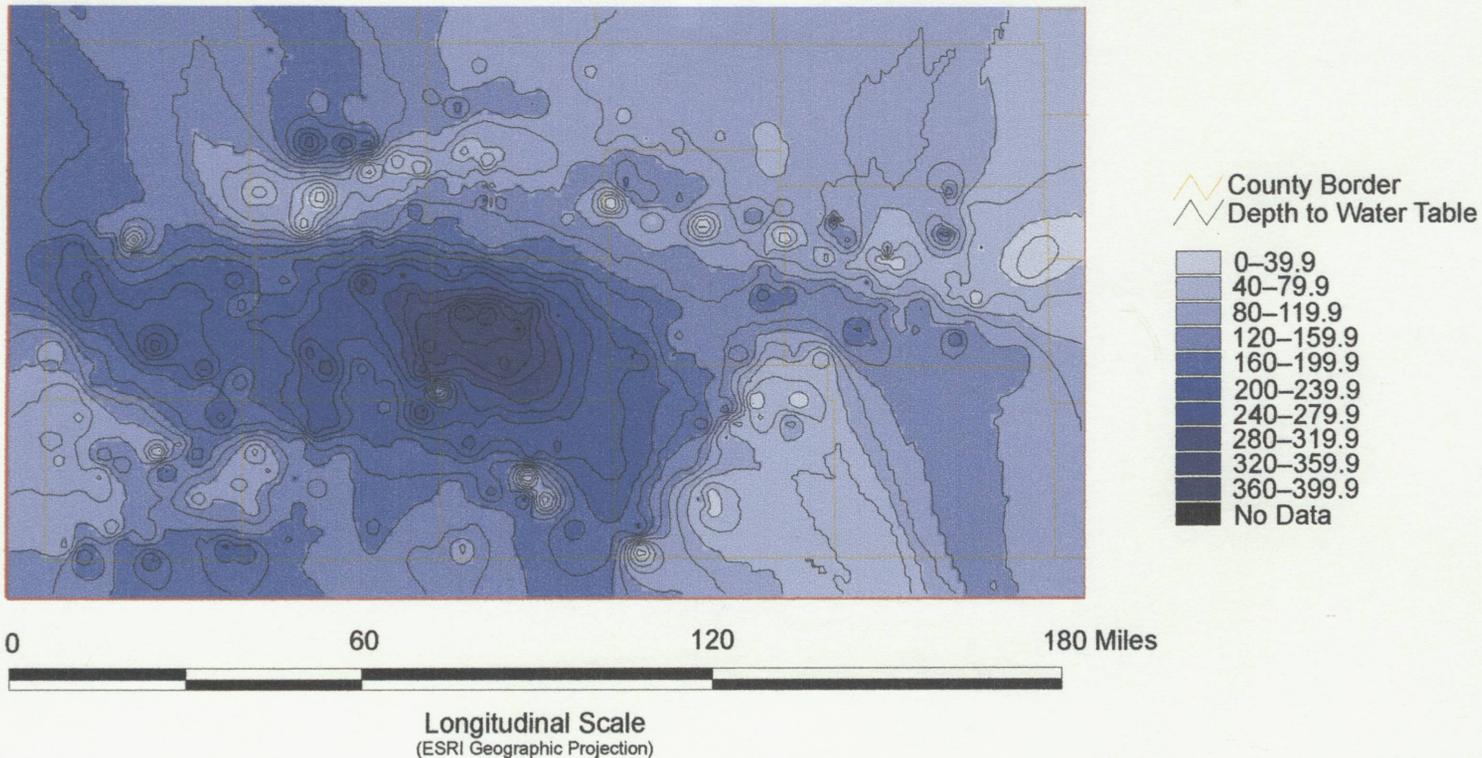


Figure 25. Depth to water table in 1997

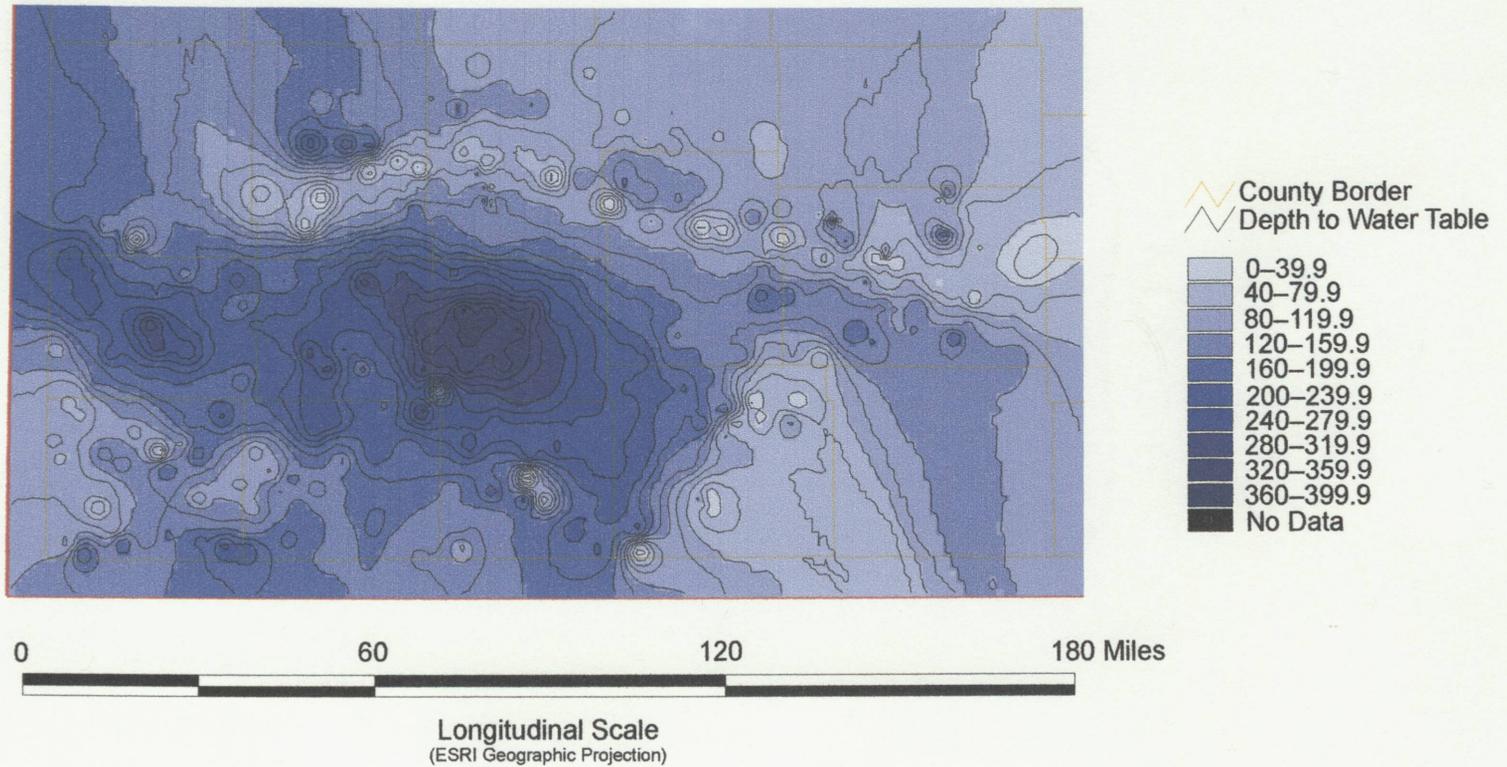


Figure 26. Depth to water table in 1998

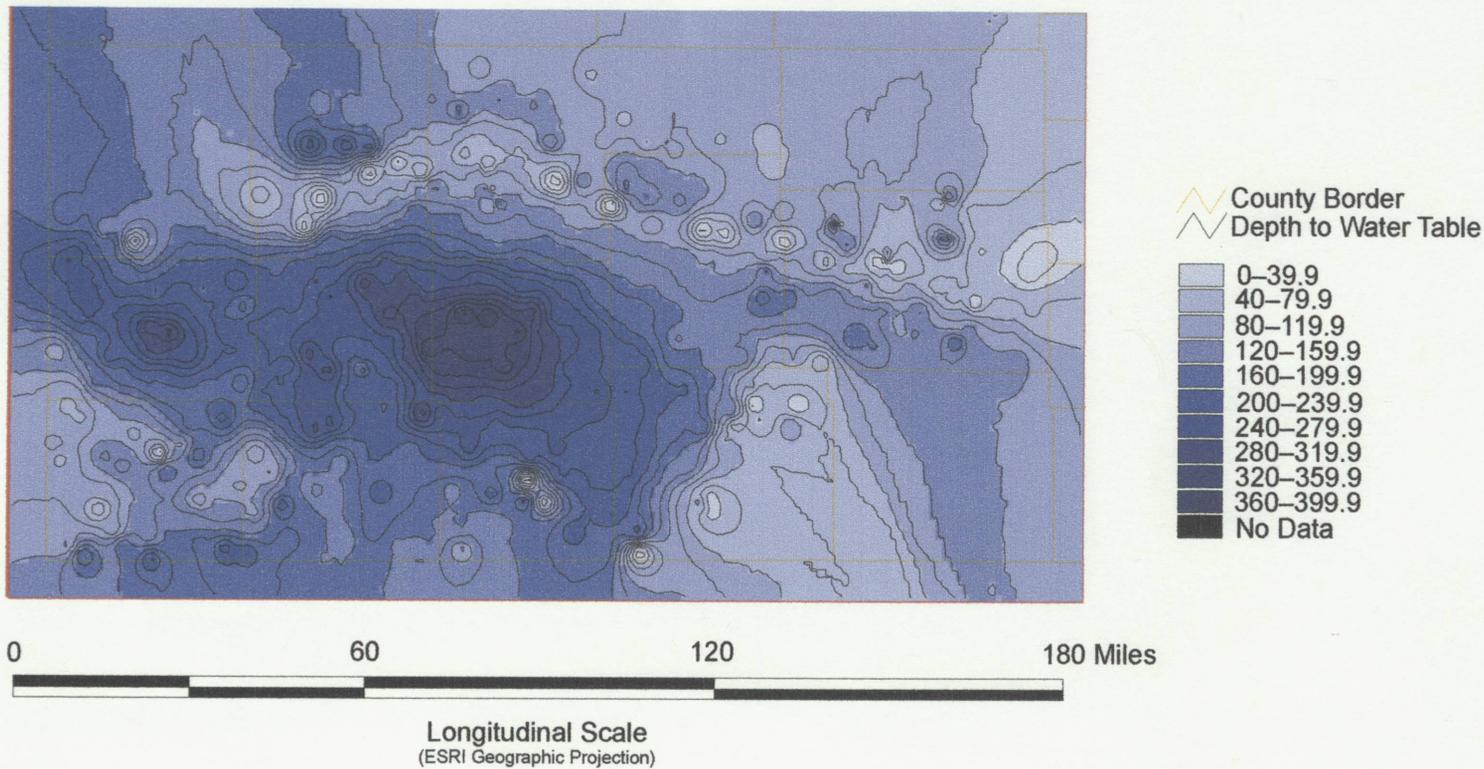


Figure 27. Depth to water table in 1999

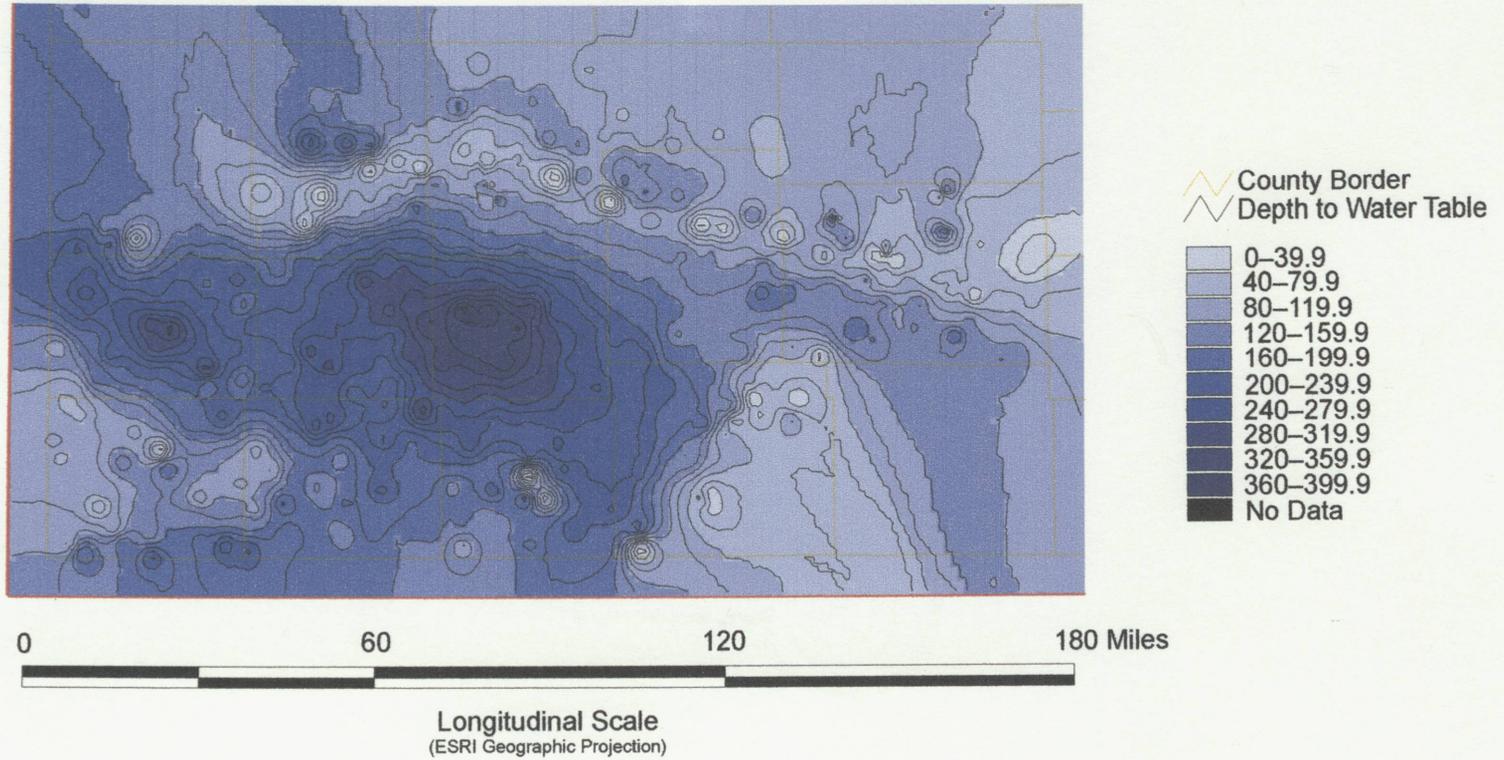


Figure 28. Depth to water table in 2000

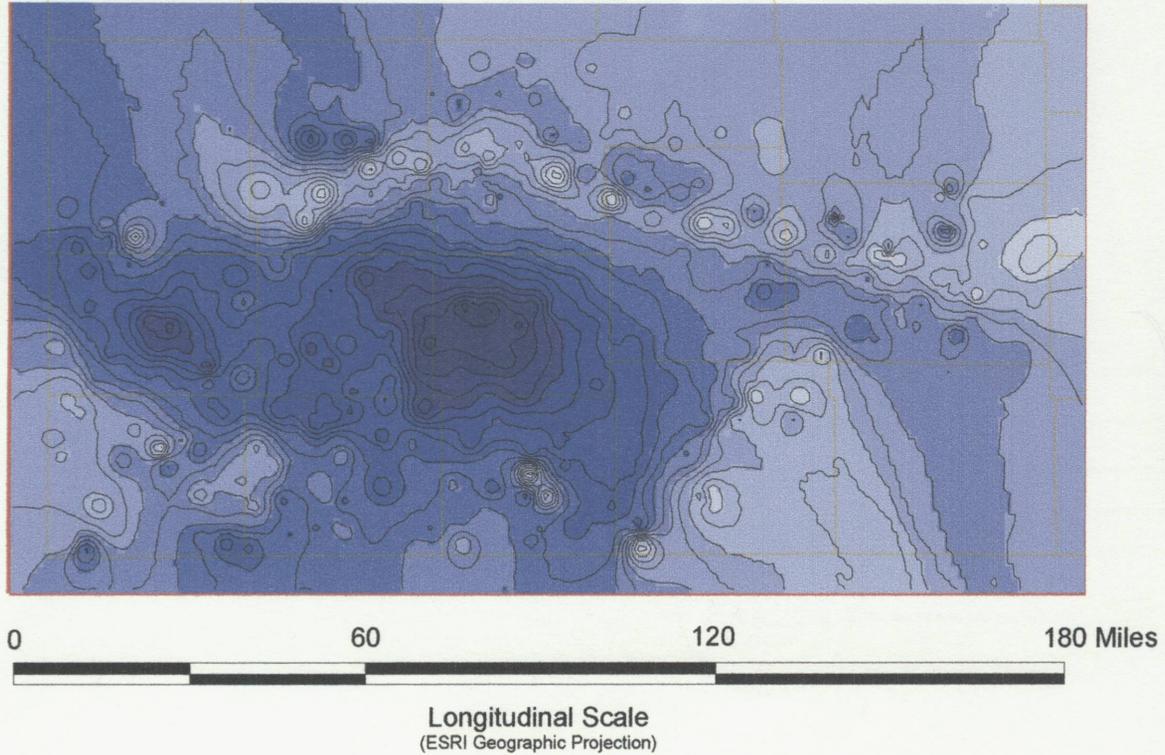


Figure 29. Depth to water table in 2001

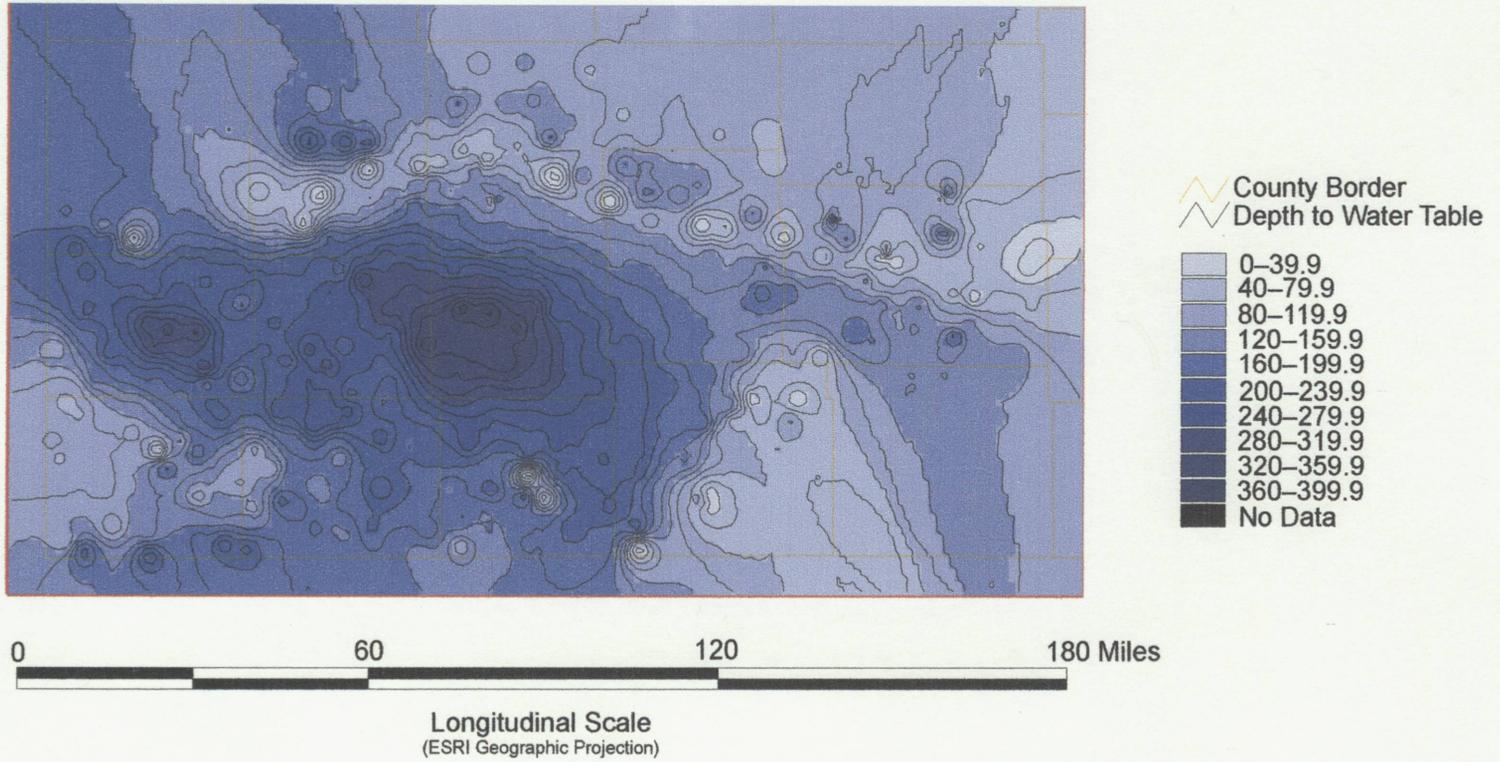


Figure 30. Depth to water table in 2002

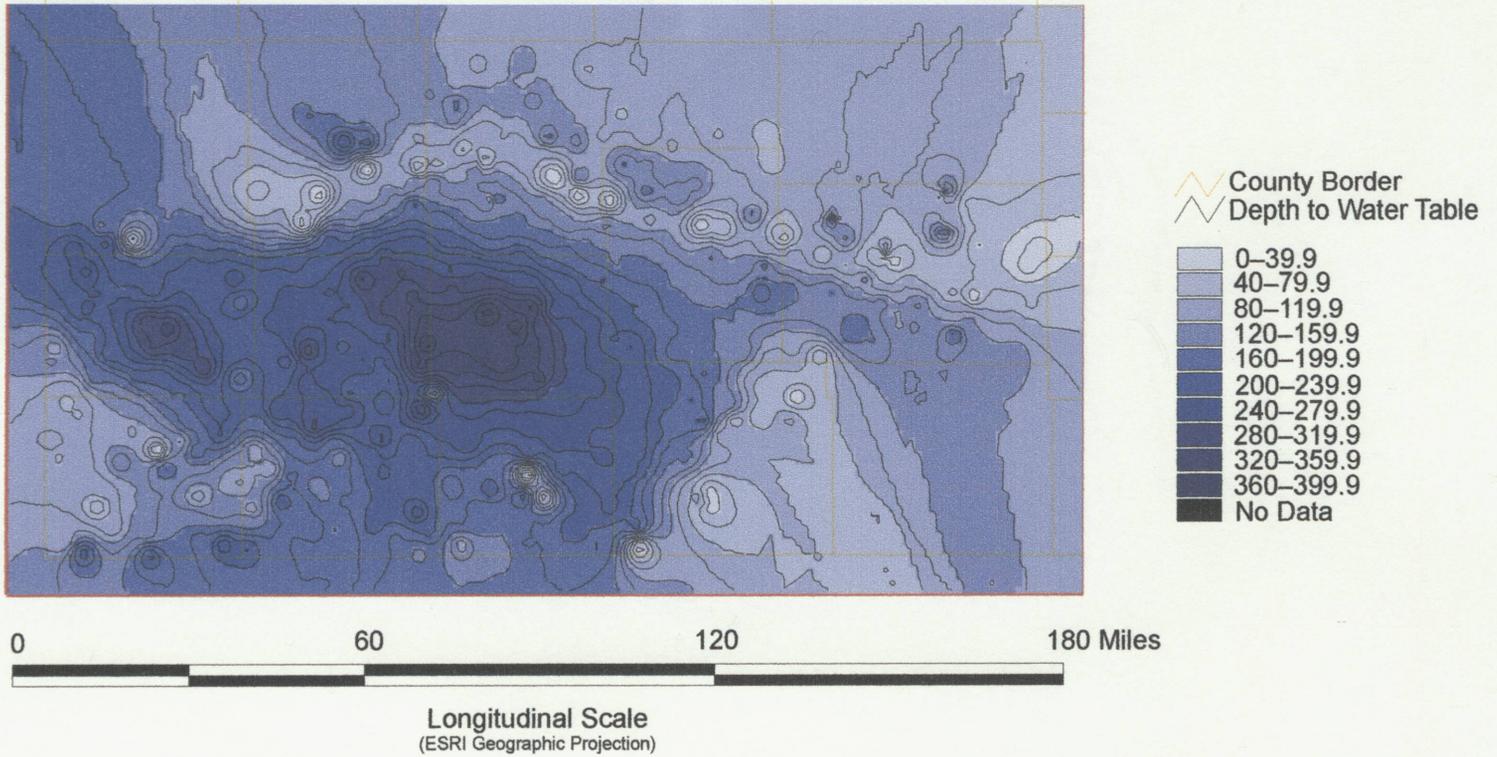


Figure 31. Depth to water table in 2003

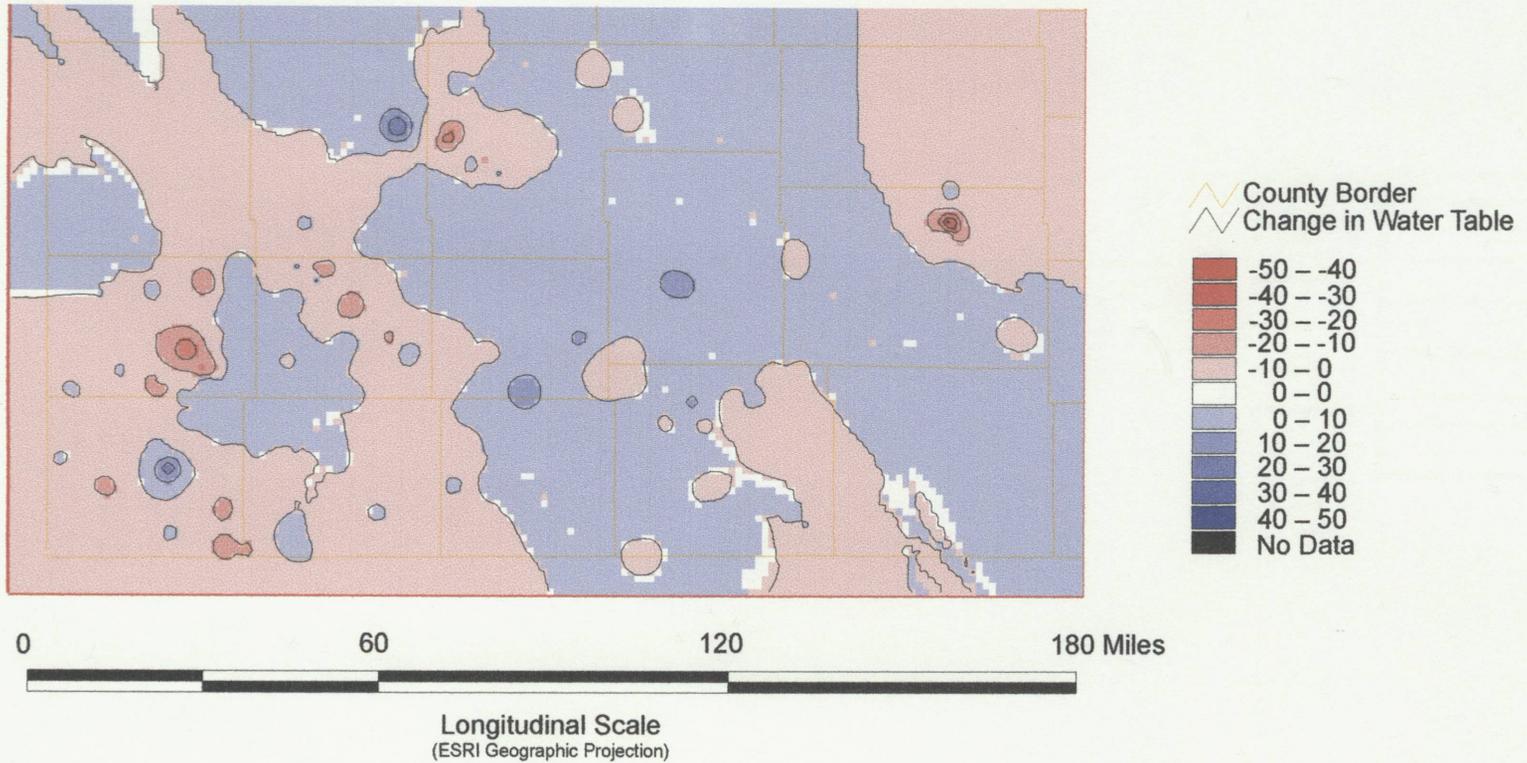
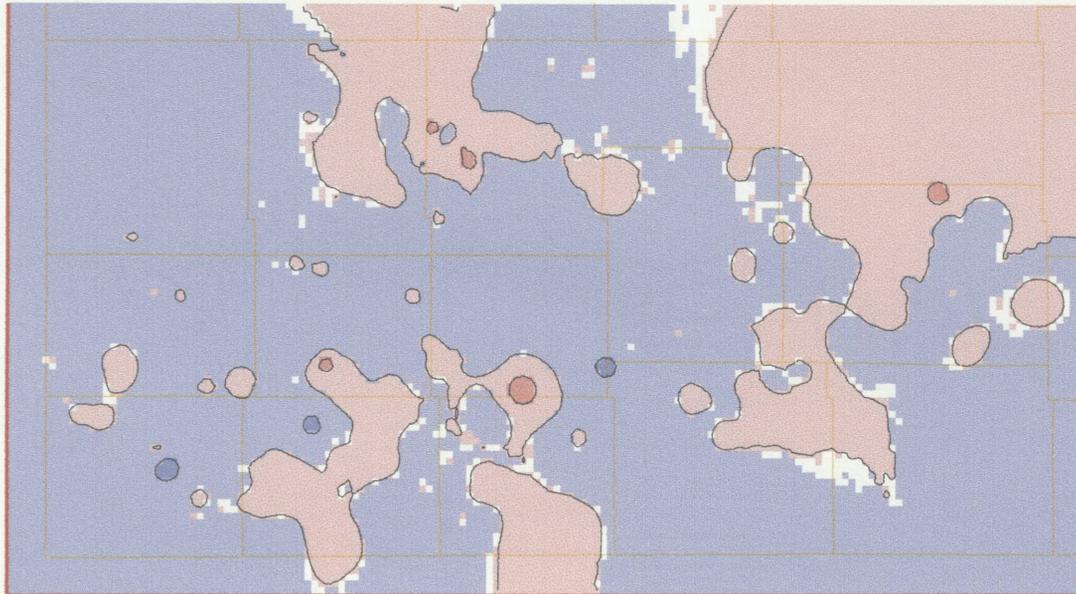
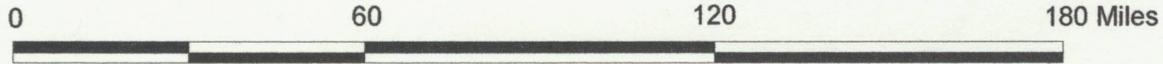
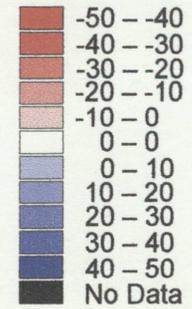


Figure 32. Change in water table, 1984 to 1985

50



County Border
Change in Water Table



Longitudinal Scale
(ESRI Geographic Projection)

Figure 33. Change in water table, 1985 to 1986

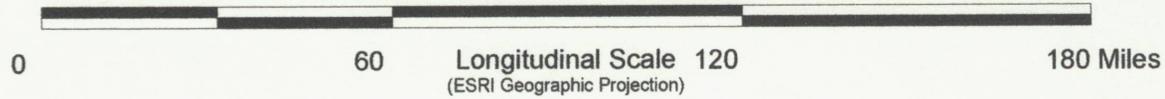
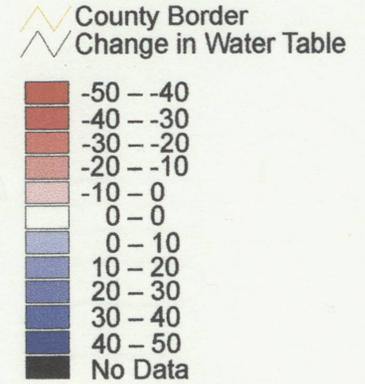
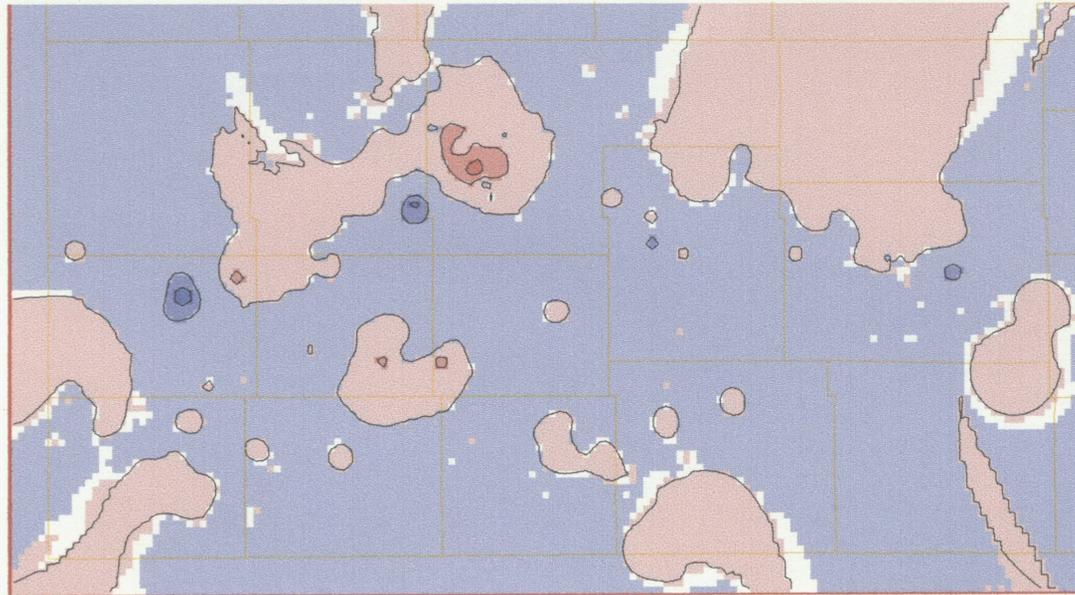


Figure 34. Change in water table, 1986 to 1987

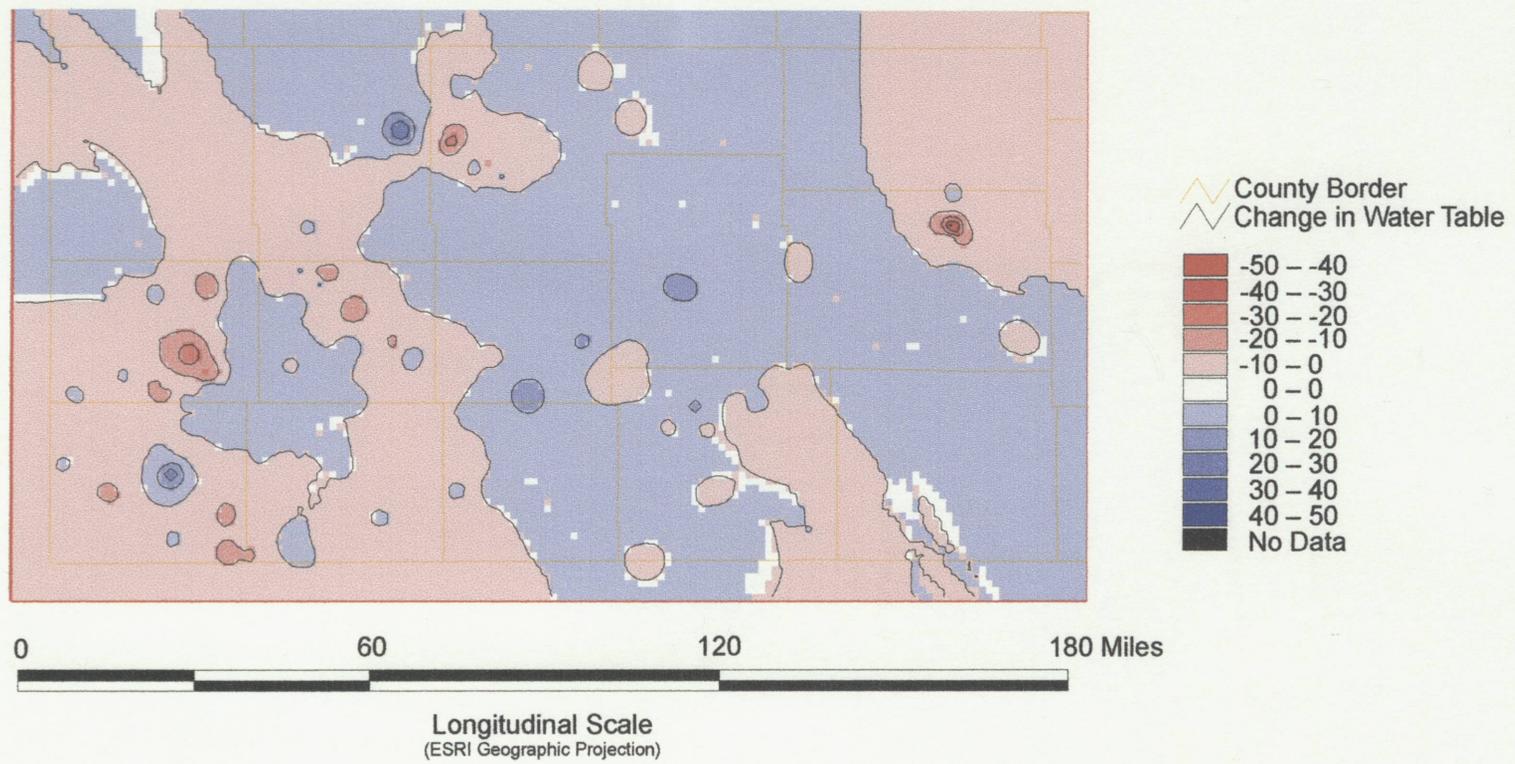


Figure 35. Change in water table, 1987 to 1988

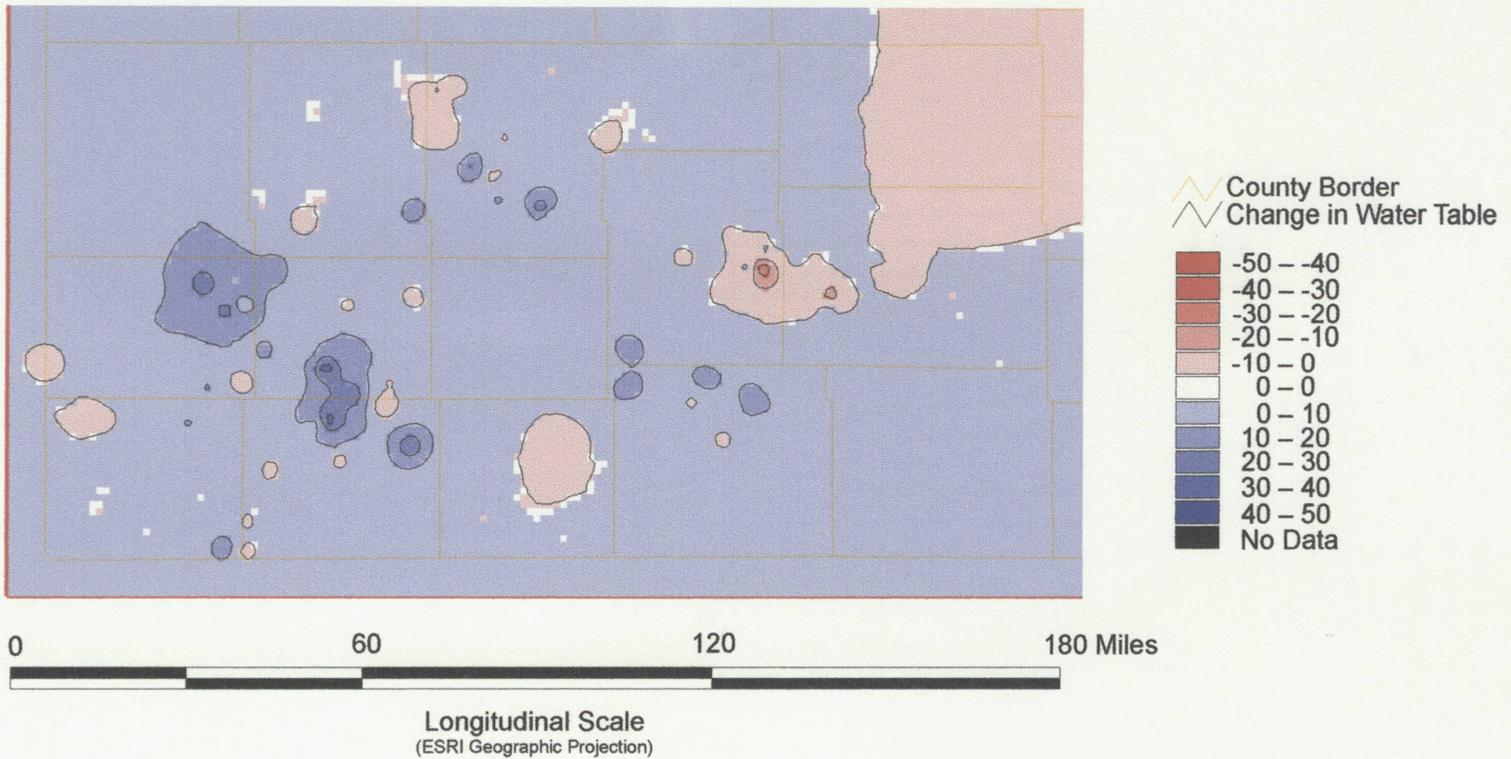


Figure 36. Change in water table, 1988 to 1989

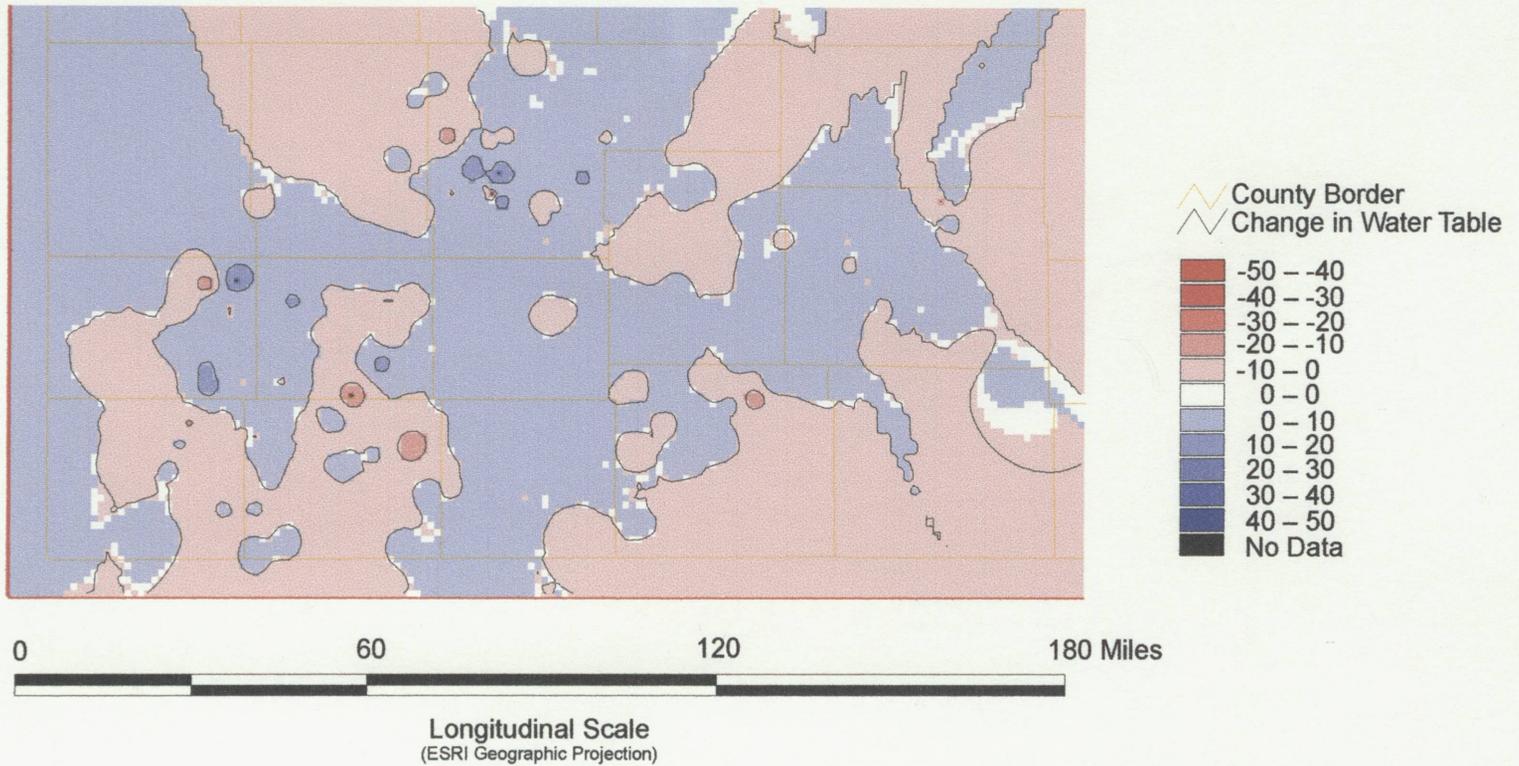


Figure 37. Change in water table, 1989 to 1990

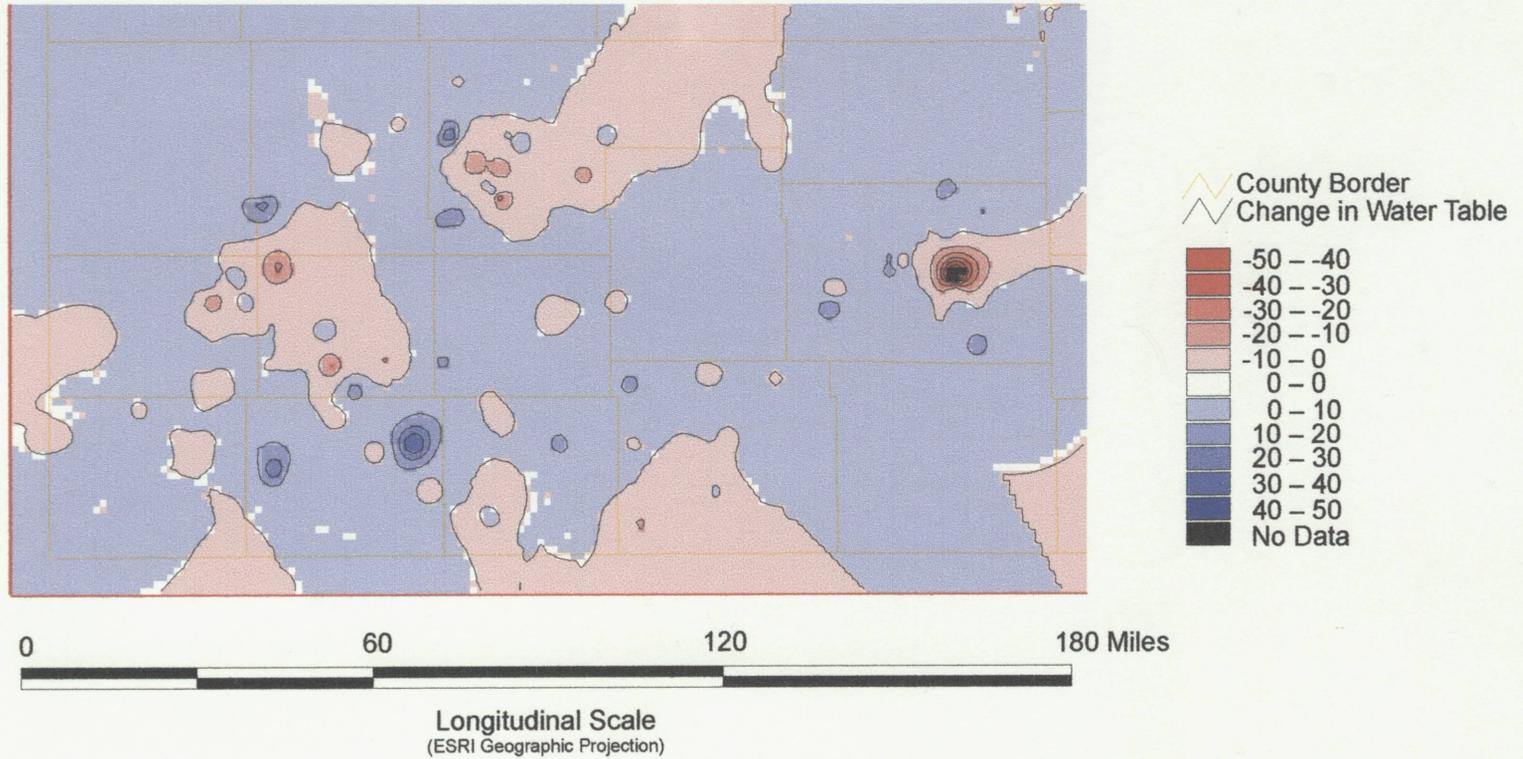
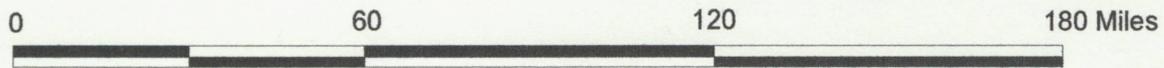
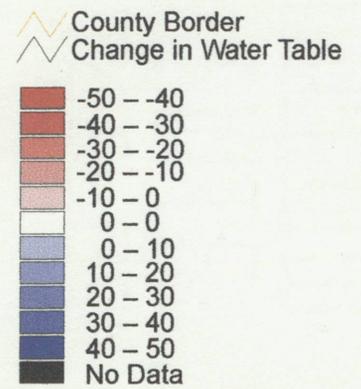
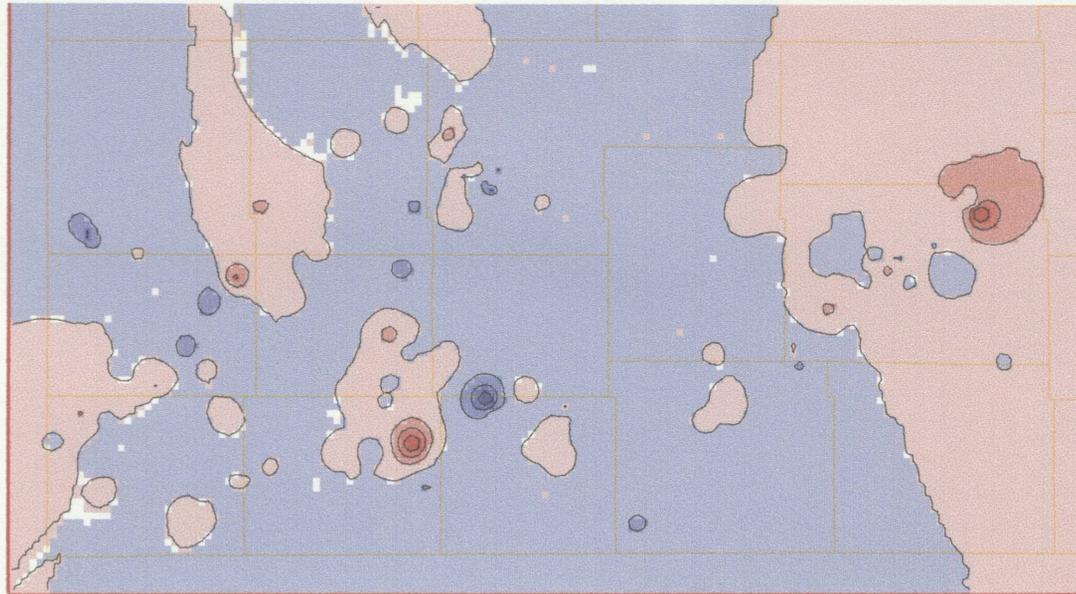


Figure 38. Change in water table, 1990 to 1991



Longitudinal Scale
(ESRI Geographic Projection)

Figure 39. Change in water table, 1991 to 1992

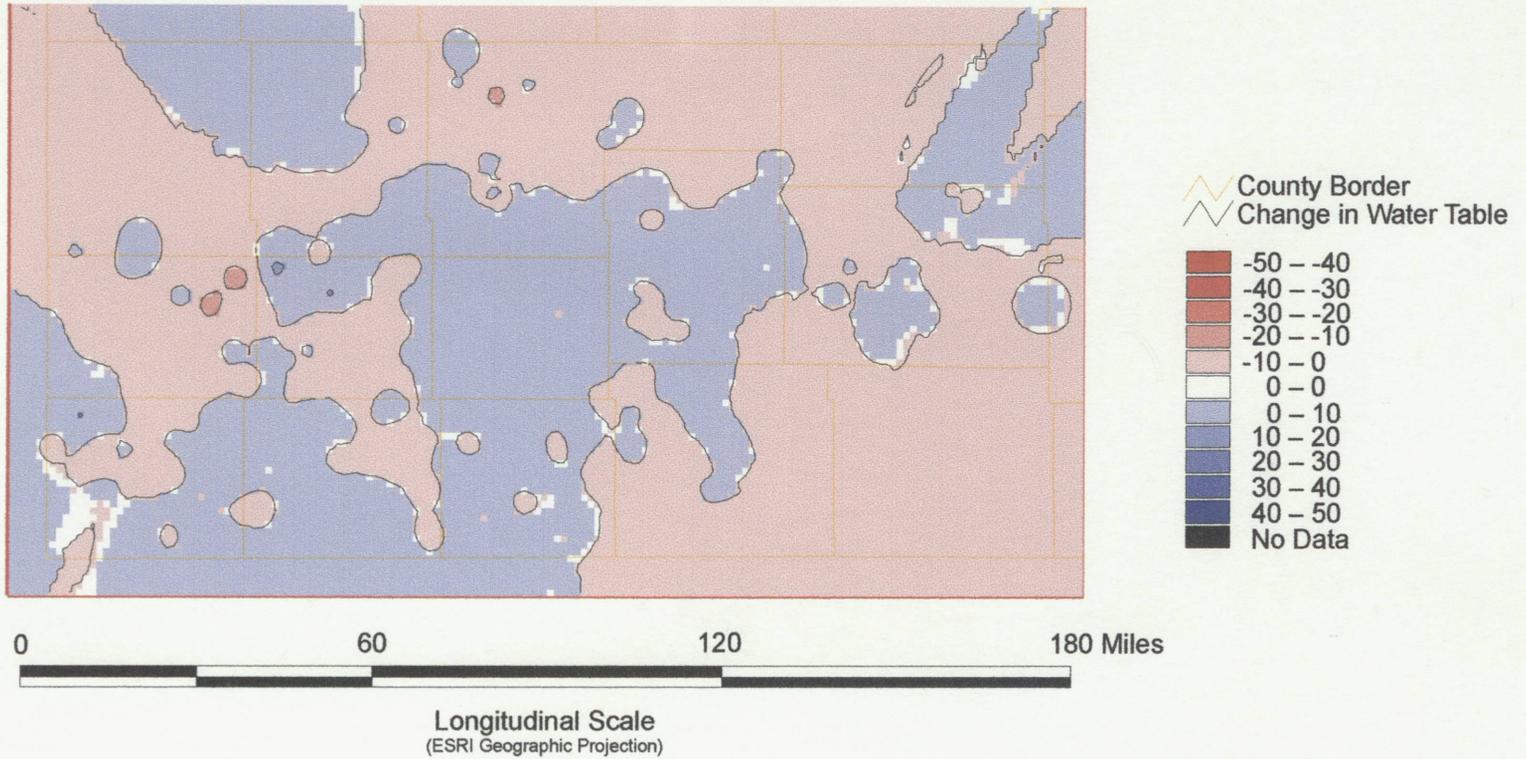


Figure 40. Change in water table, 1992 to 1993

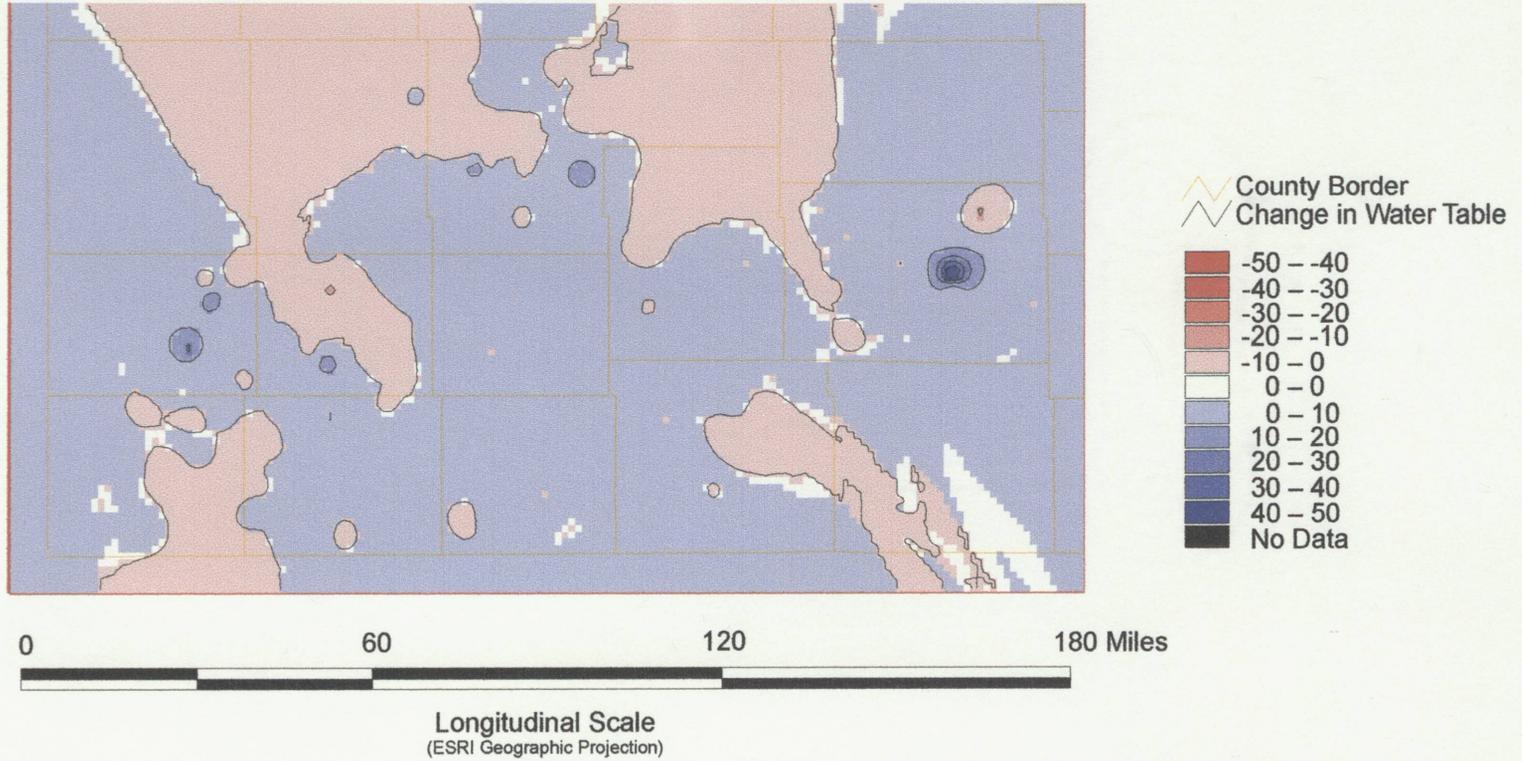


Figure 41. Change in water table, 1993 to 1994

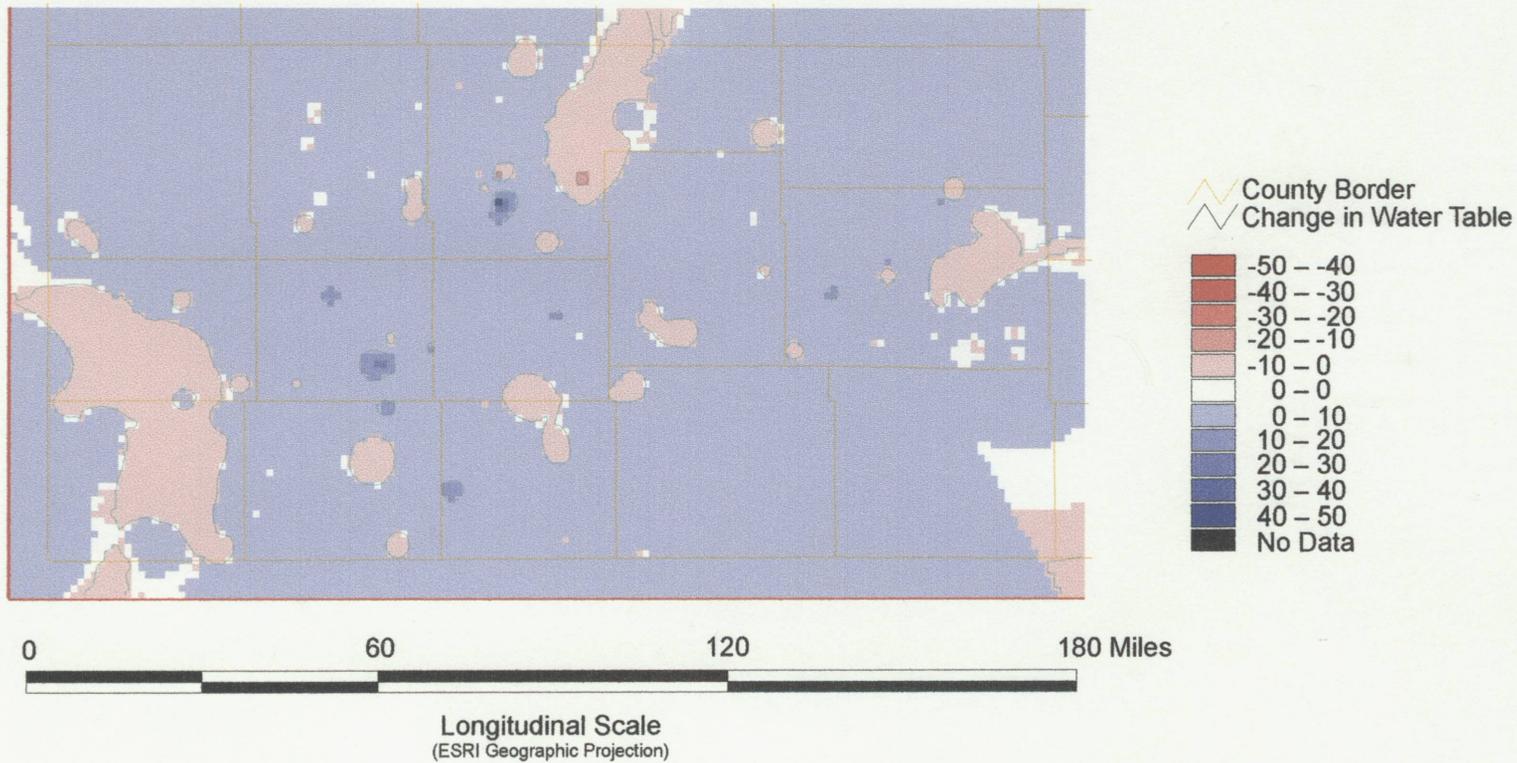


Figure 42. Change in water table, 1994 to 1995

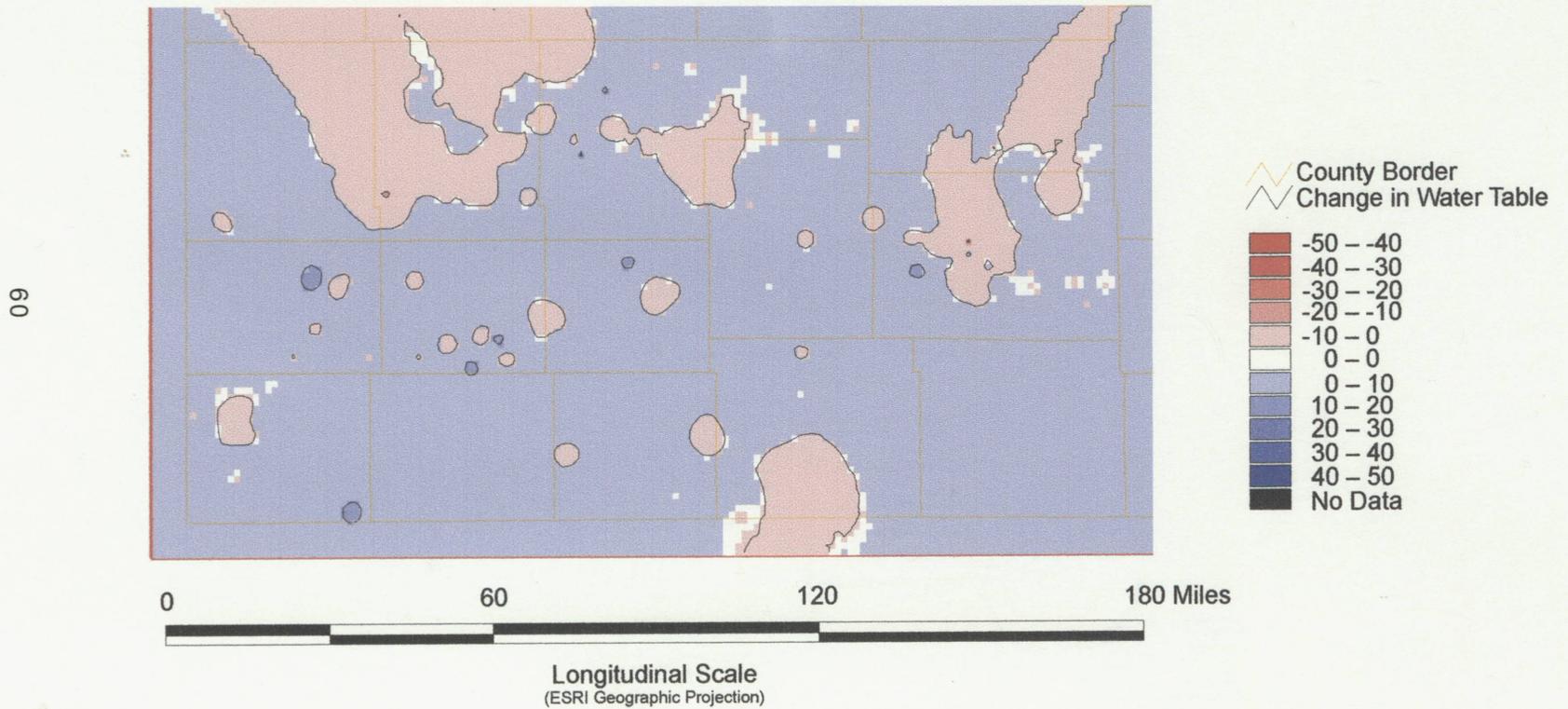


Figure 43. Change in water table, 1995 to 1996

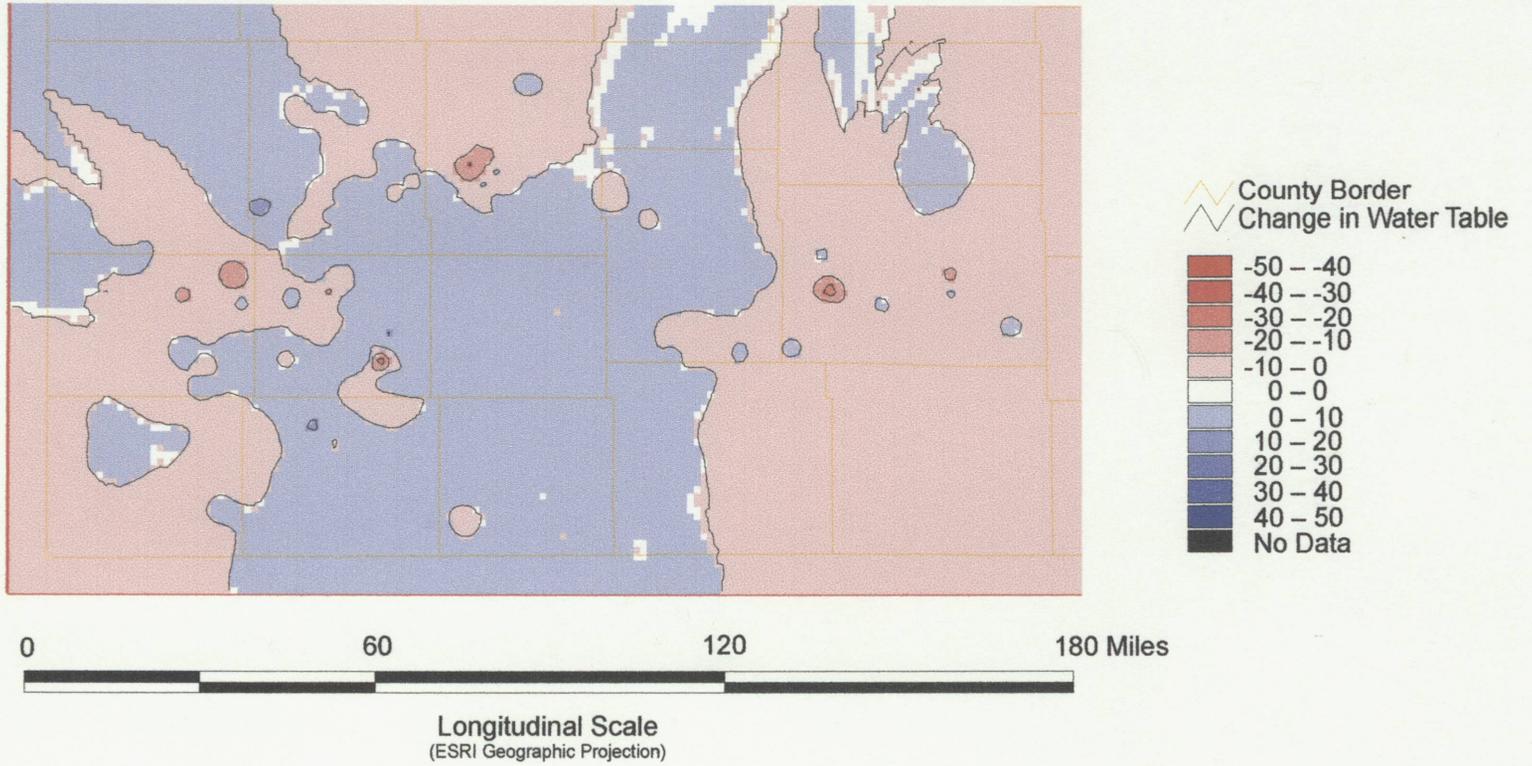


Figure 44. Change in water table, 1996 to 1997

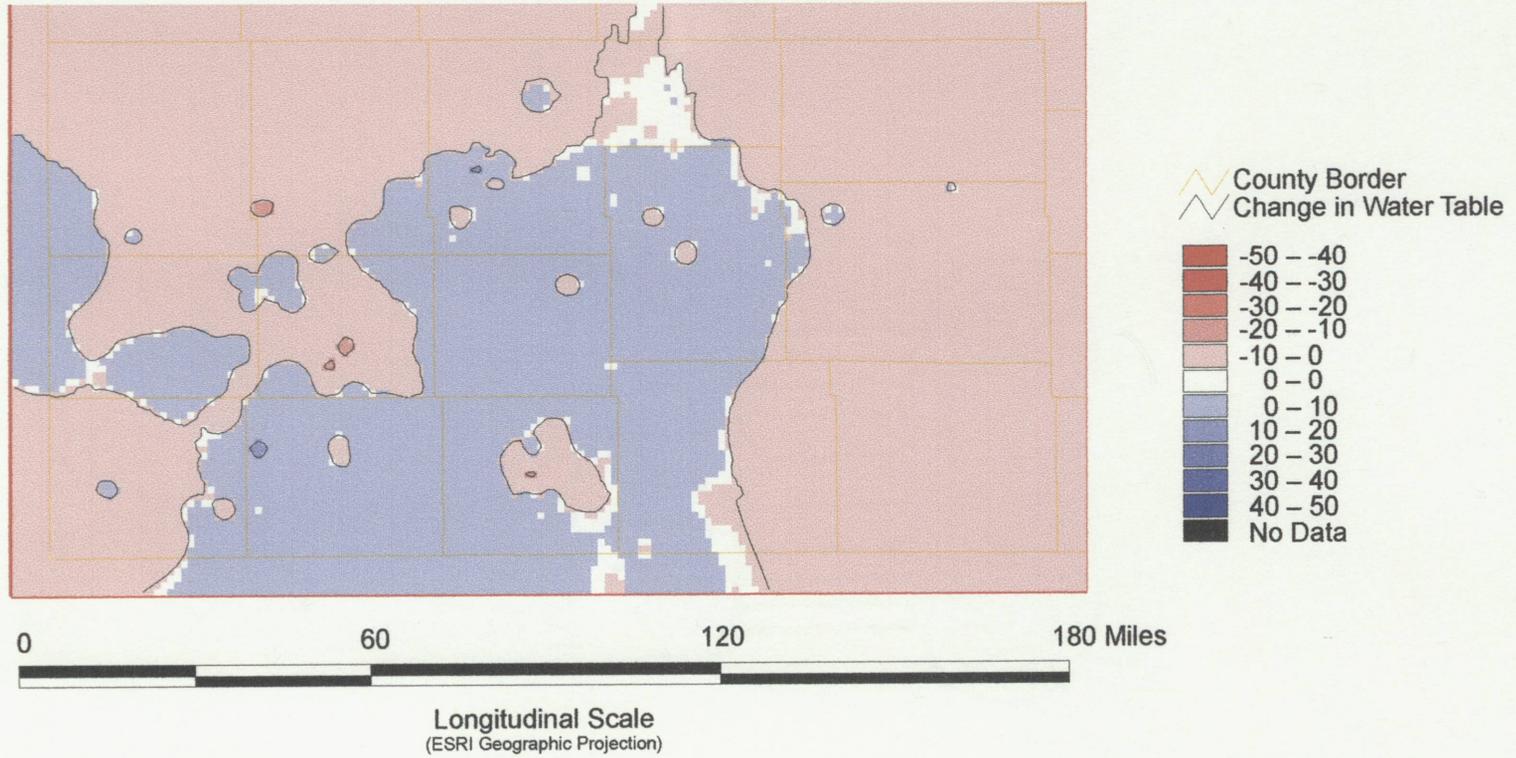


Figure 45. Change in water table, 1997 to 1998

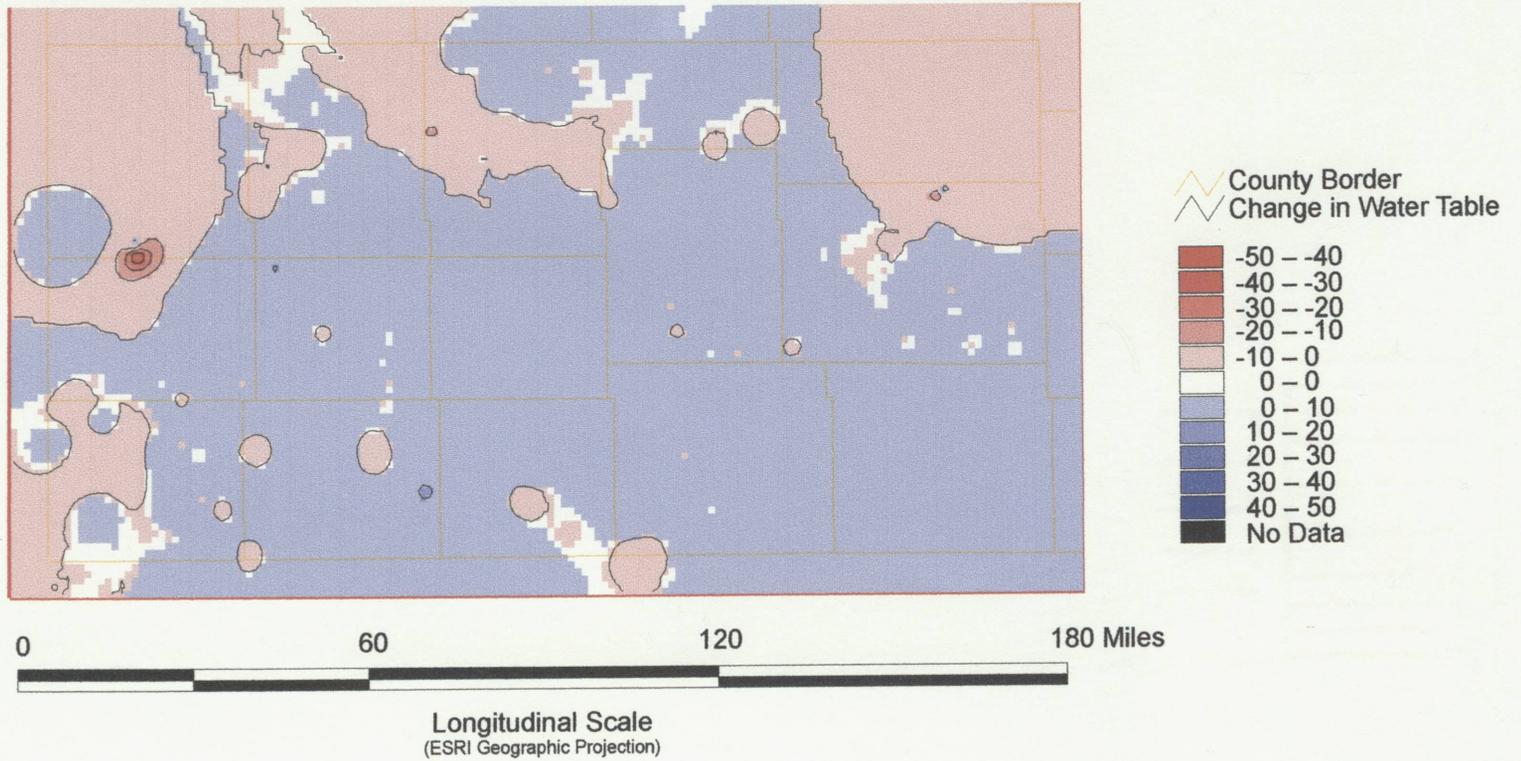


Figure 46. Change in water table, 1998 to 1999

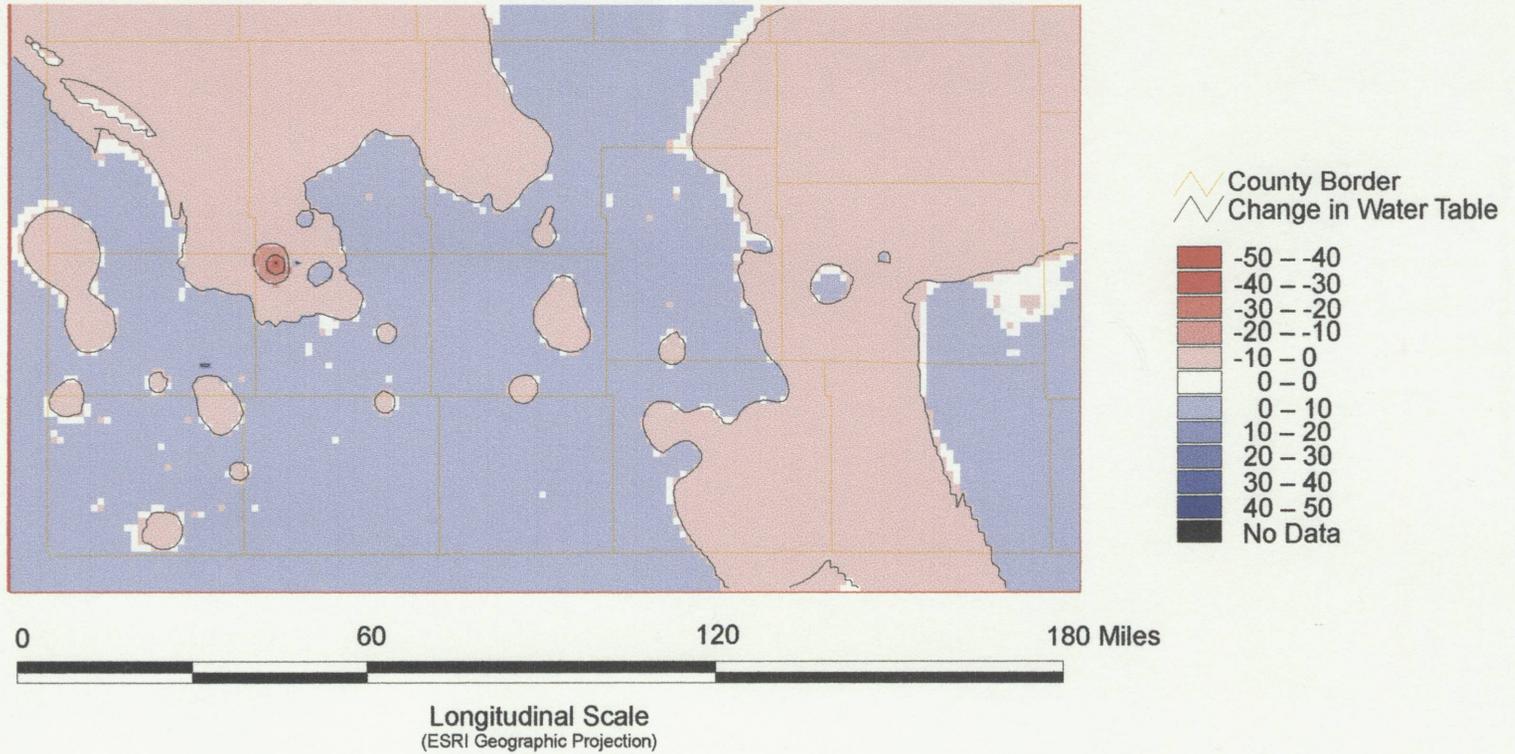


Figure 47. Change in water table, 1999 to 2000

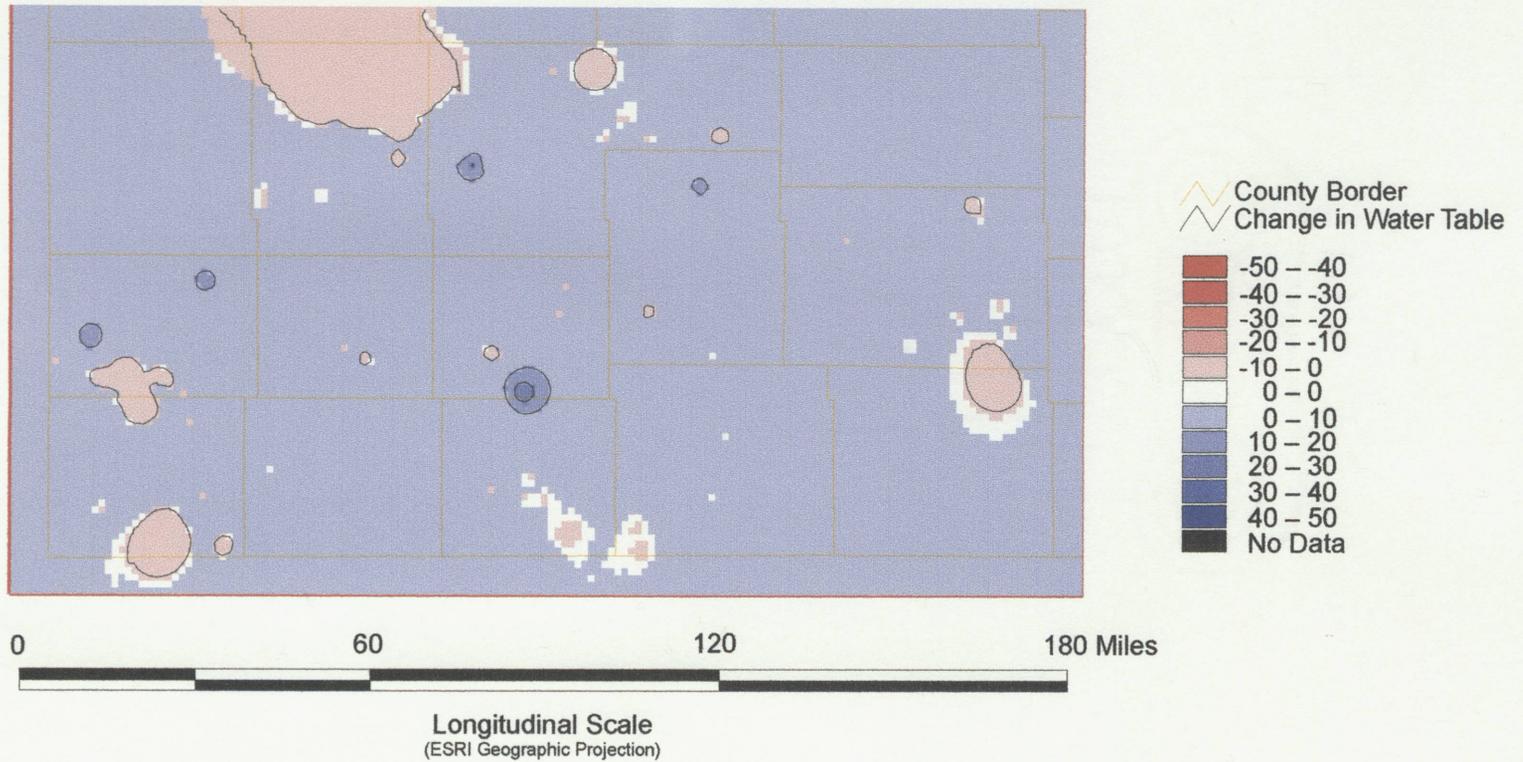


Figure 48. Change in water table, 2000 to 2001

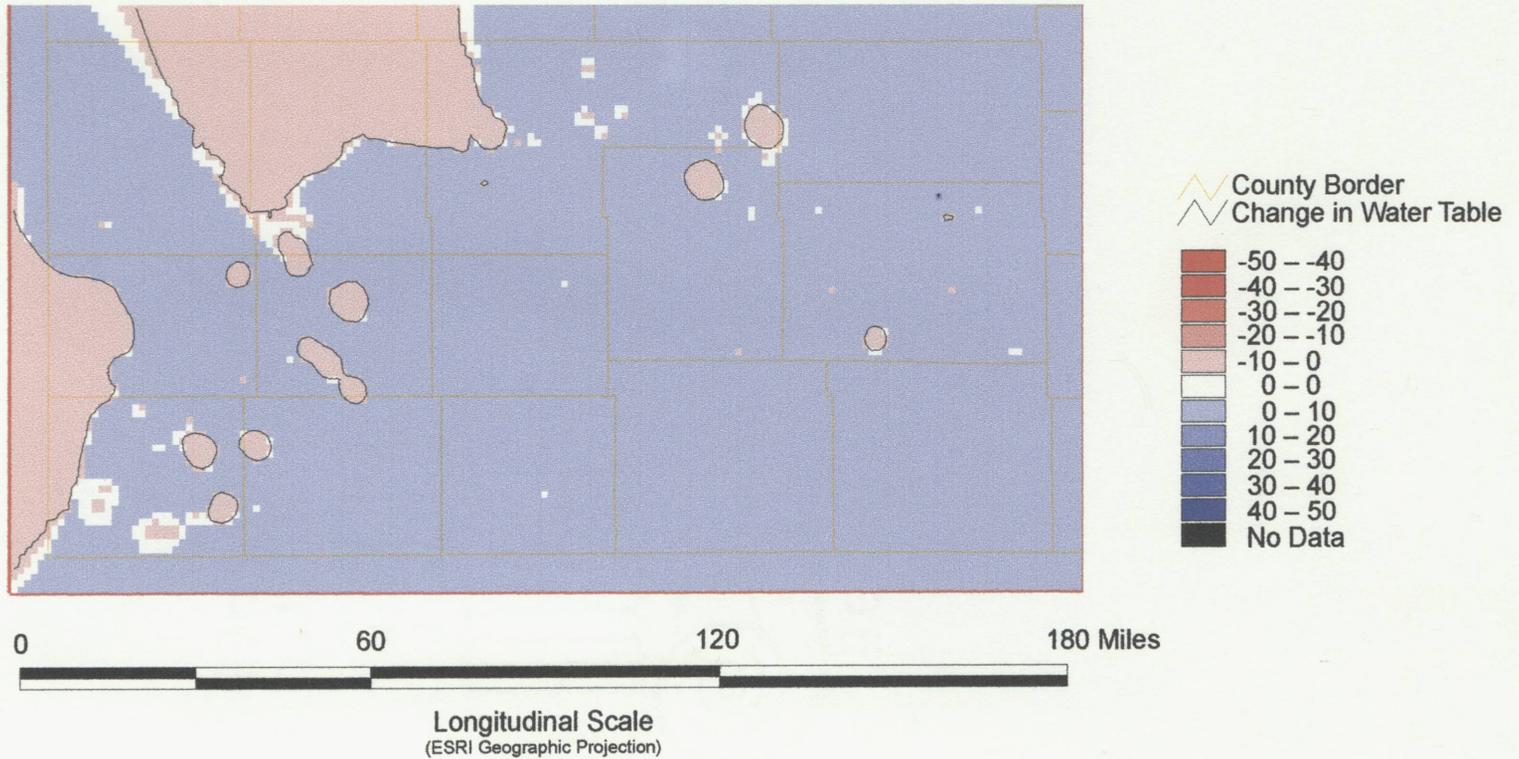


Figure 49. Change in water table, 2001 to 2002

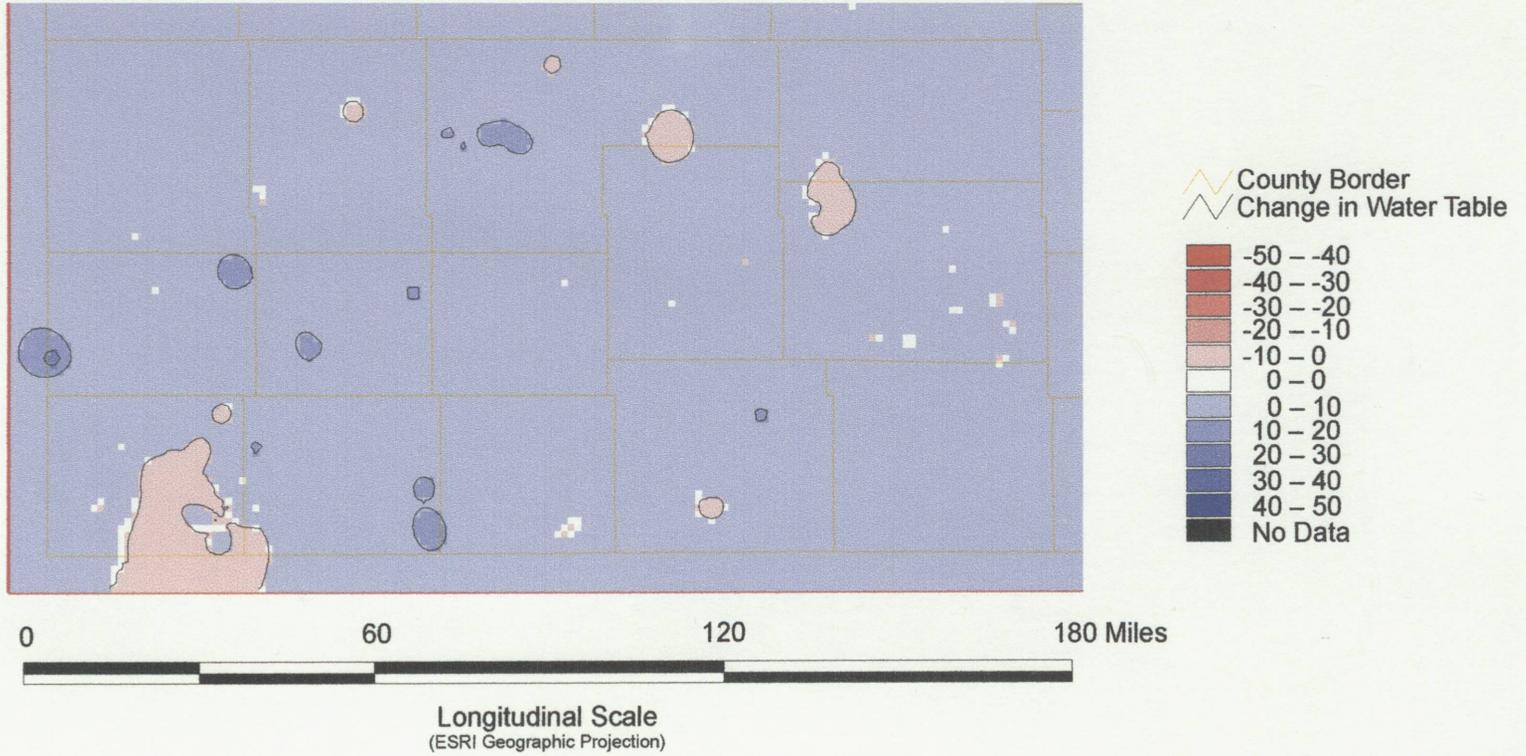


Figure 50. Change in water table, 2002 to 2003

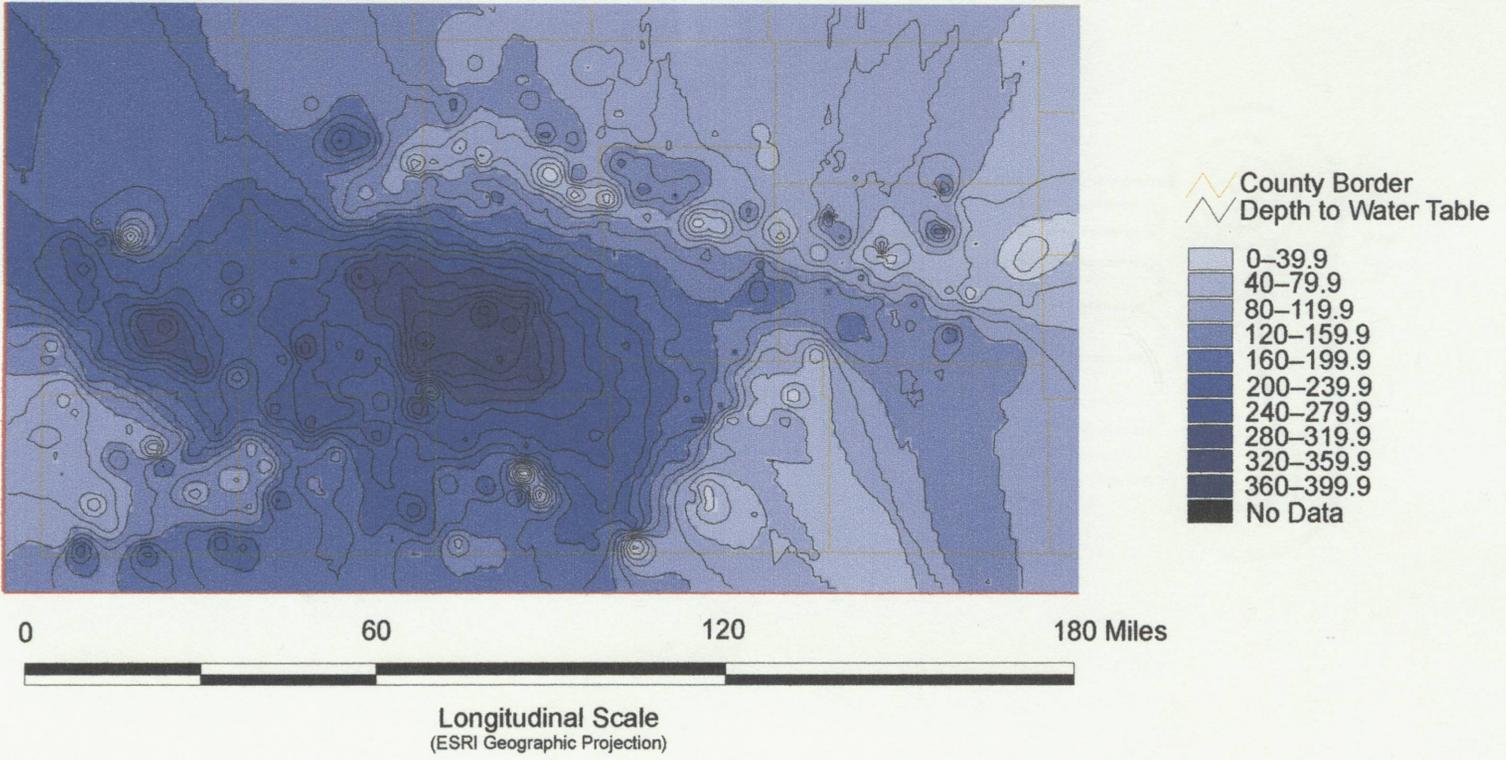


Figure 51. 2004 predicted depth to water table following average precipitation

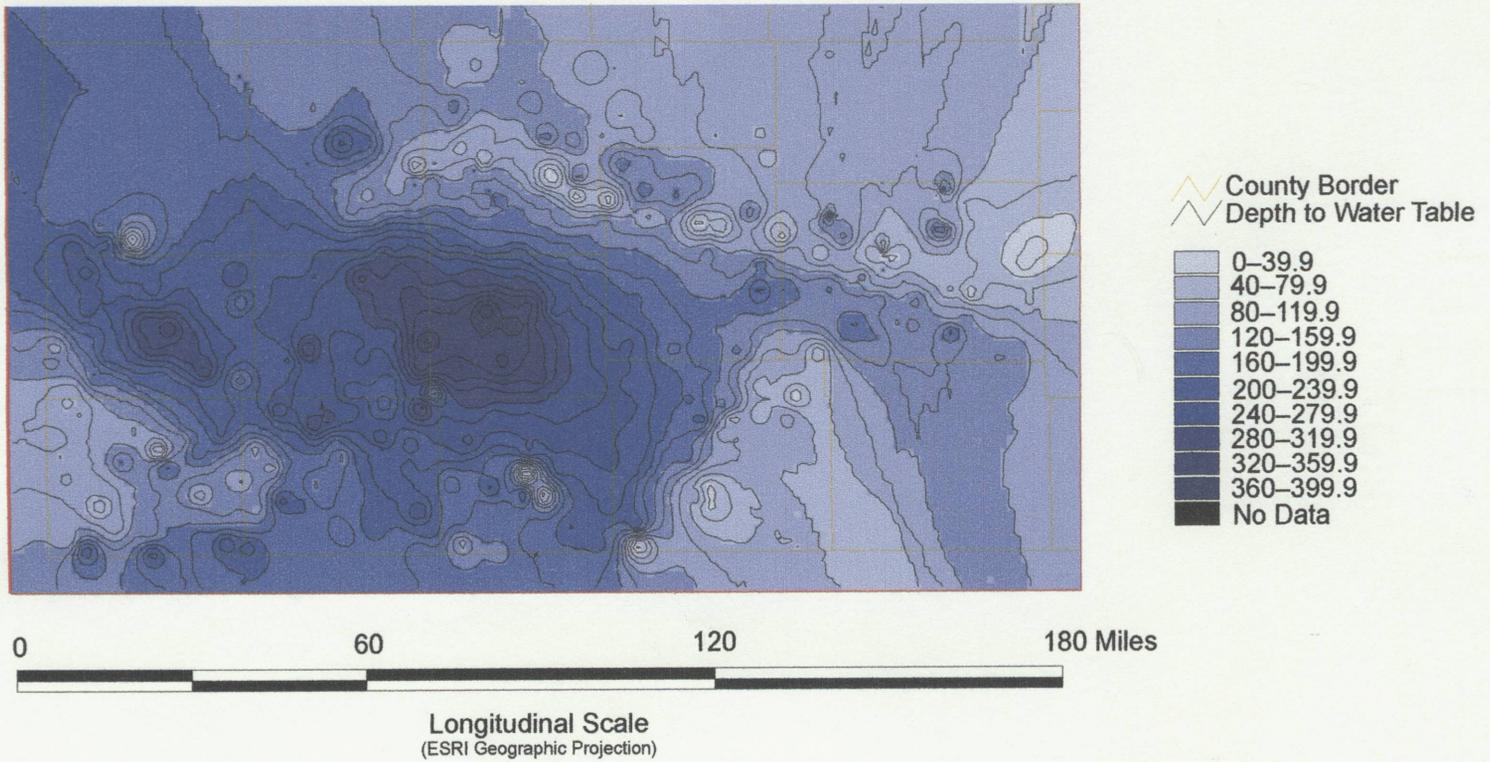
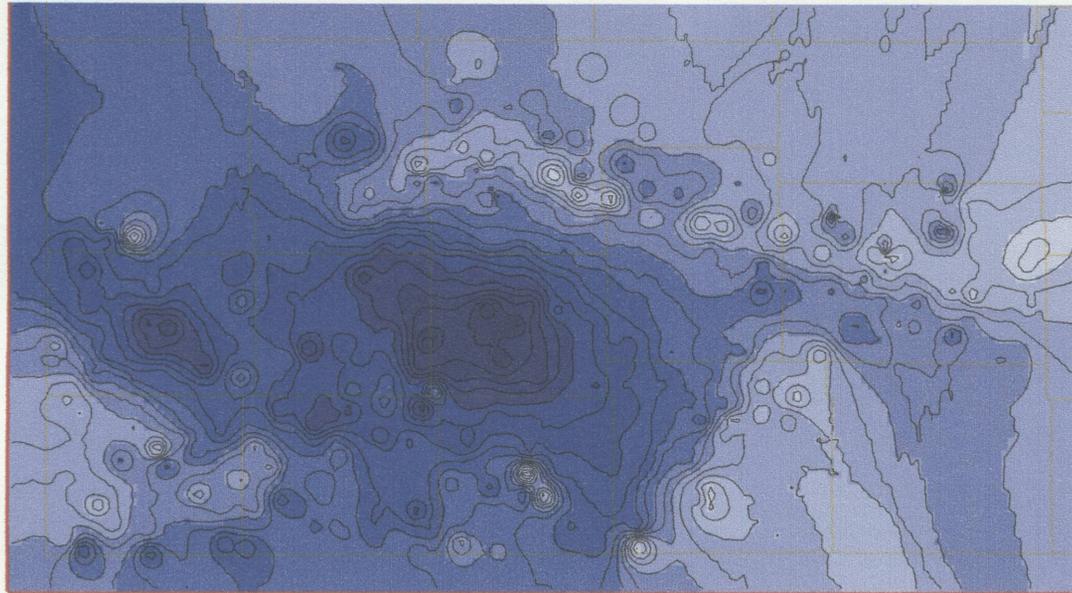
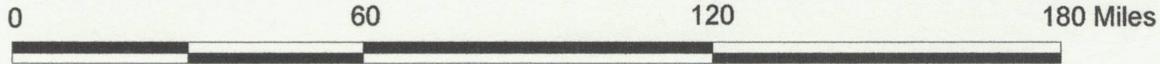
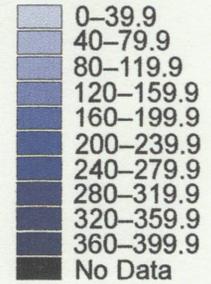


Figure 52. 2005 predicted depth to water table following average precipitation

70



County Border
Depth to Water Table



Longitudinal Scale
(ESRI Geographic Projection)

Figure 53. 2006 predicted depth to water table following average precipitation

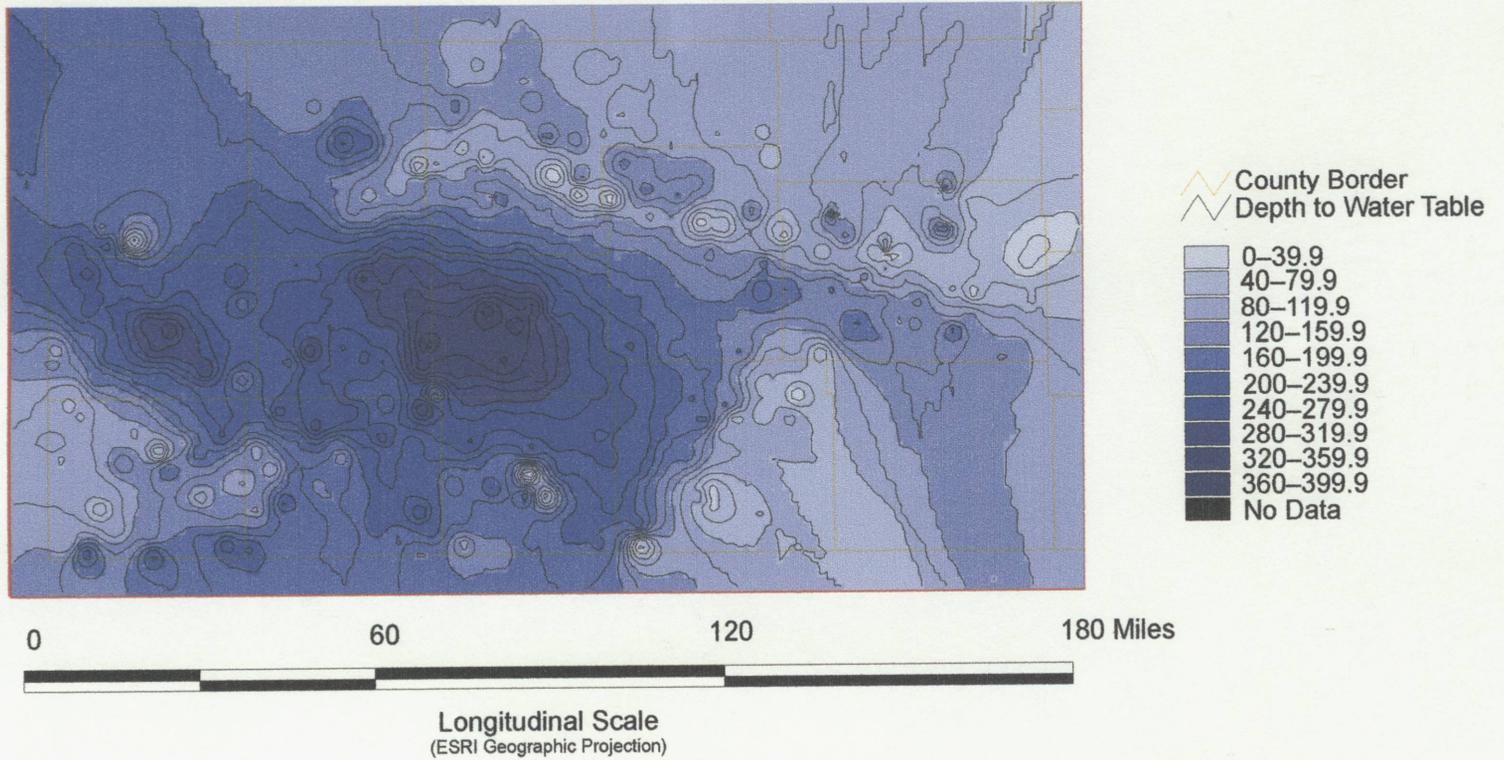


Figure 54. 2004 predicted depth to water table following low precipitation

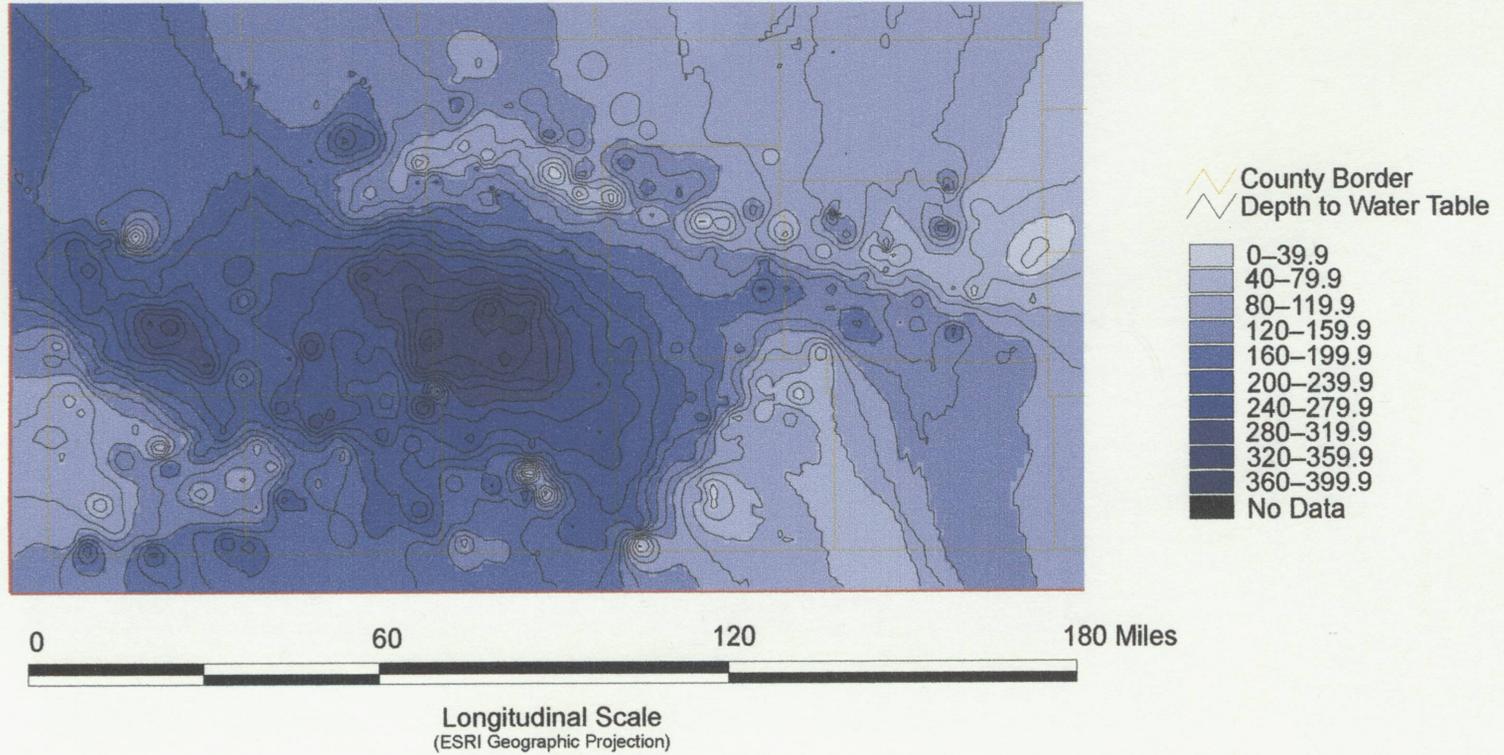


Figure 55. 2005 predicted depth to water table following low precipitation

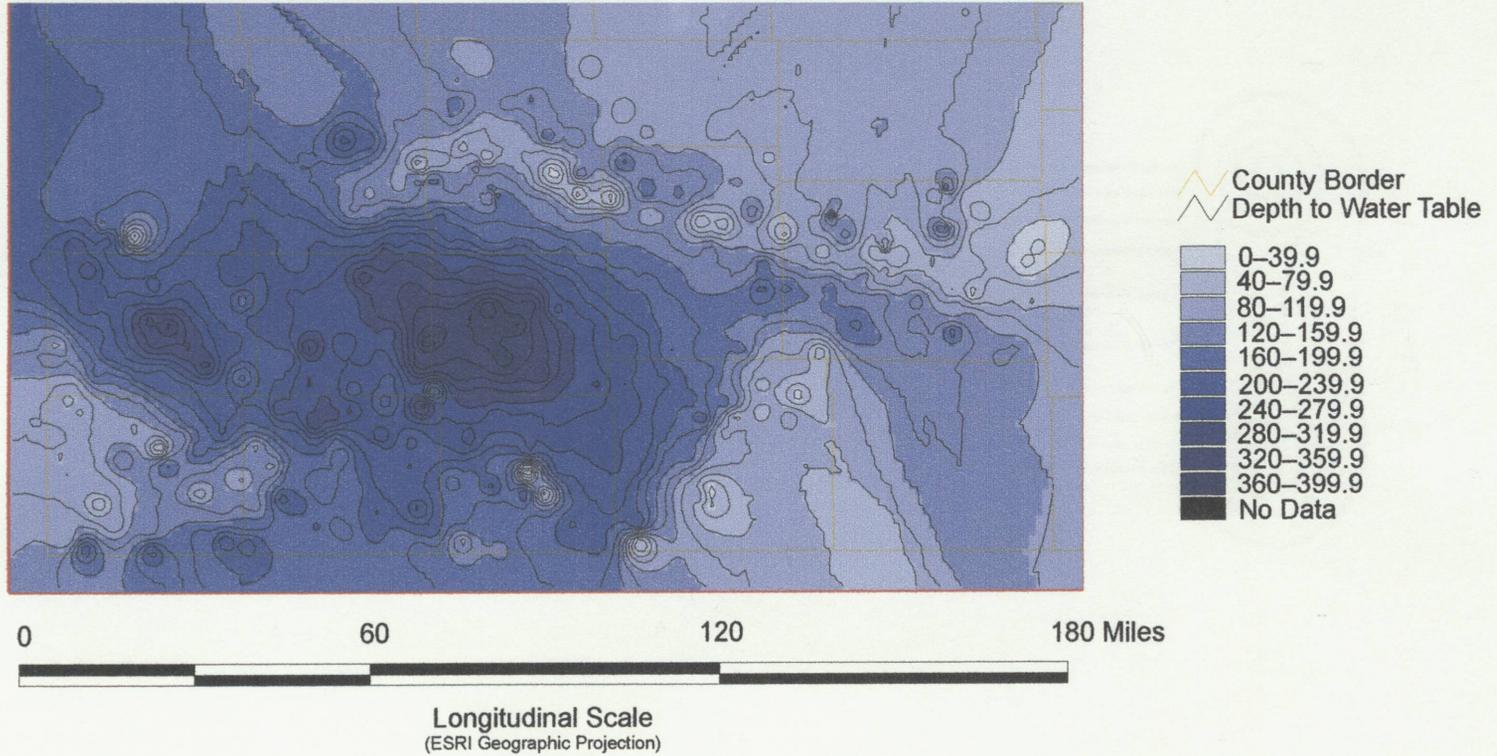


Figure 56. 2006 predicted depth to water table following low precipitation

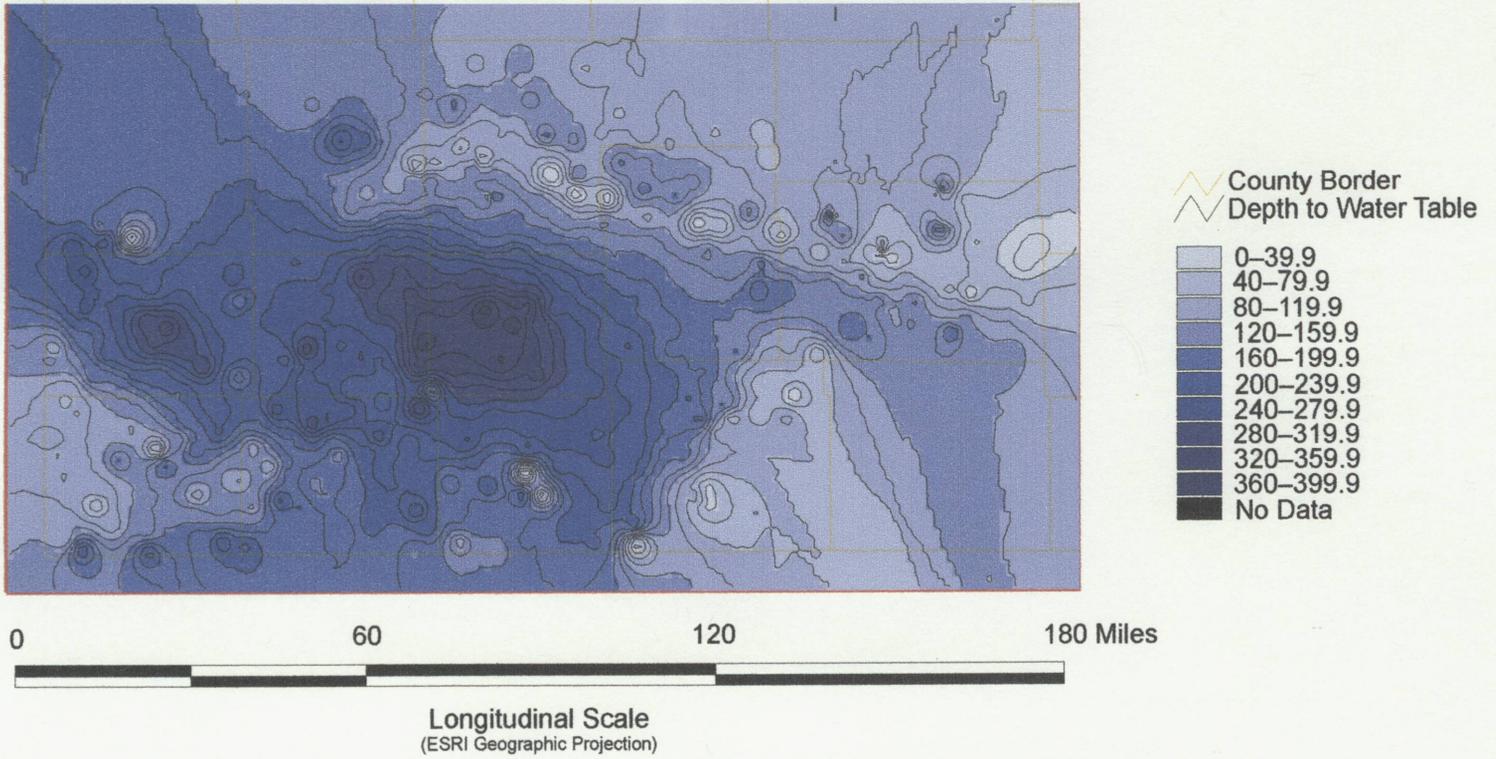


Figure 57. 2004 predicted depth to water table following high precipitation

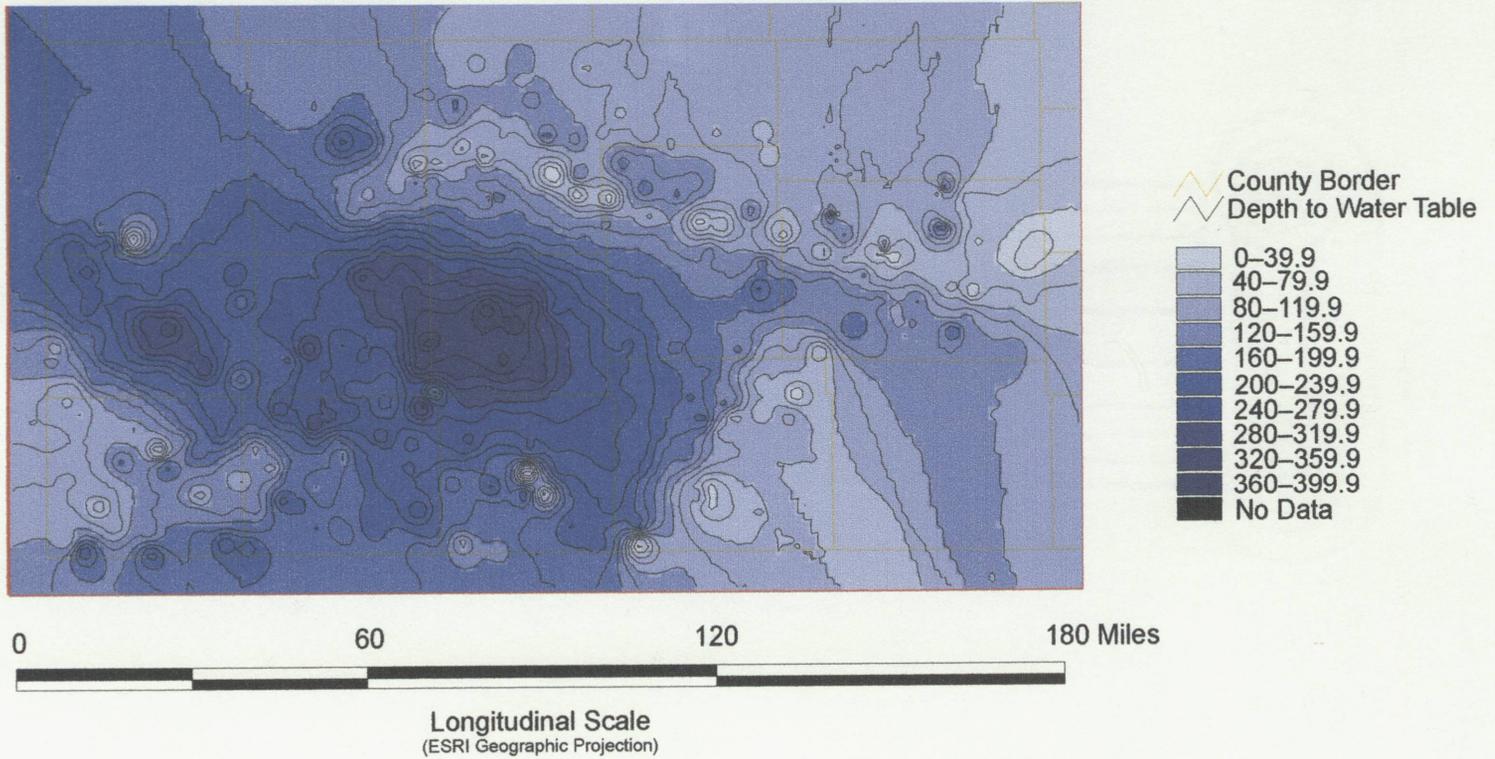


Figure 58. 2005 predicted depth to water table following high precipitation

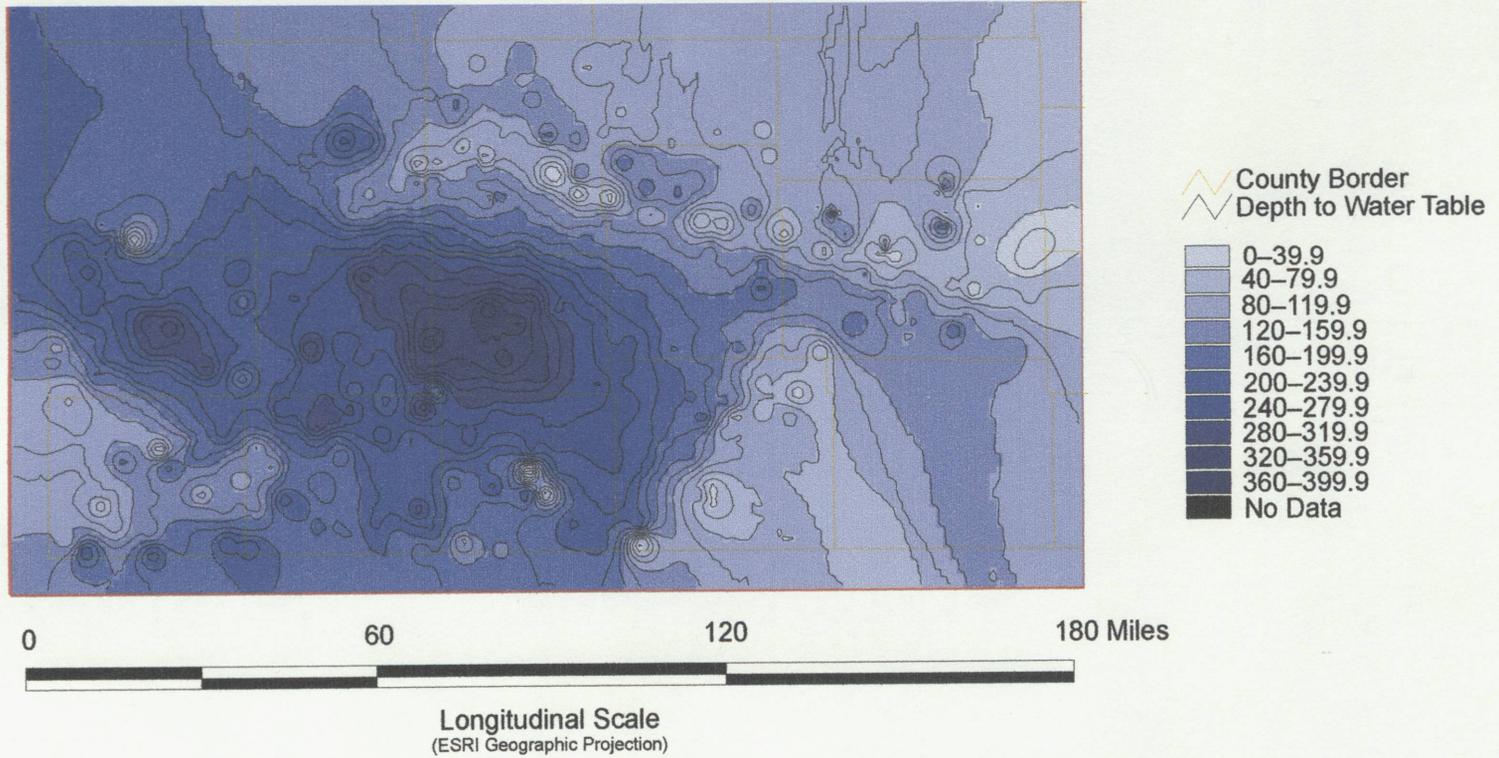


Figure 59. 2006 predicted depth to water table following high precipitation

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