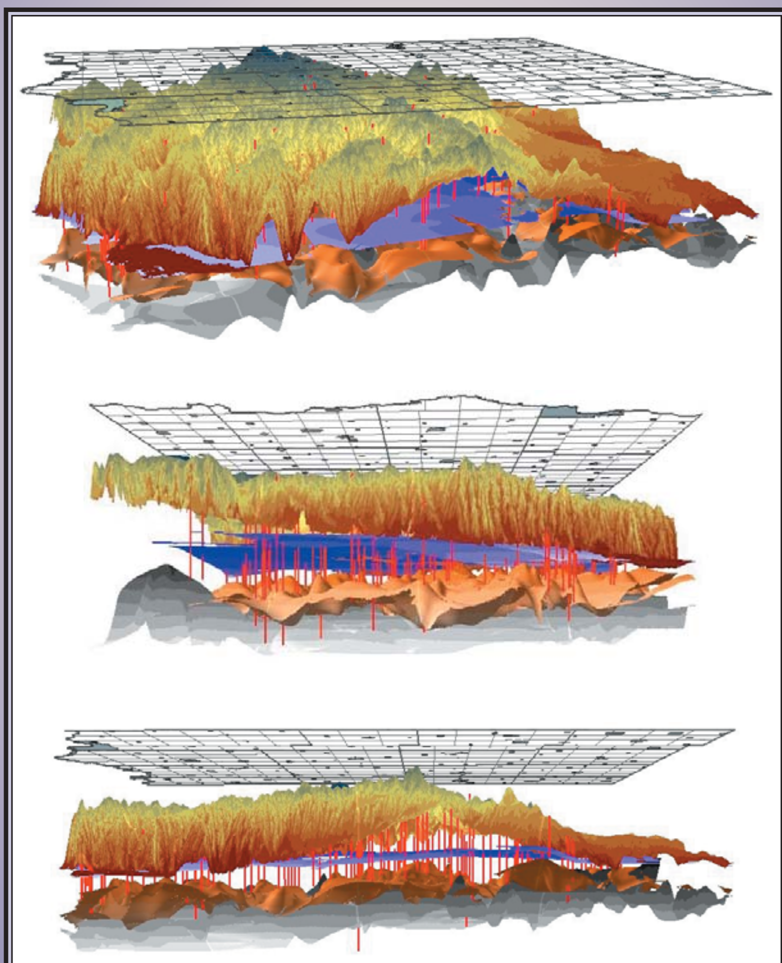
Groundwater Resource Evaluation of the Lower Dakota Aquifer in Northwest Iowa

Iowa Geological and Water Survey
Water Resources Investigation Report No. 1B



Iowa Department of Natural Resources
Richard Leopold, Director
October 2008

COVER

Three-dimensional views of the Lower Dakota Aquifer study area in northwest Iowa. Wells are shown in red, Lower Dakota Aquifer potentiometric surface in blue, top of the Lower Dakota Aquifer in brown, and top of the underlying confining layer in gray. The 16-county outline is shown above the land surface images for reference (top view is southwest to northeast, middle view is west to east, and bottom view is south to north).

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Prepared by

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Water Resources Management Program: Iowa Geological and Water Survey's Role

The Iowa Geological and Water Survey (IGWS) plans and implements programs that result in the acquisition of comprehensive information on the mineral and water resources of Iowa, with emphasis on water supply developments and monitoring the effects of environmental impacts on water quality (www.igsb.uiowa.edu/about/mission.htm).

Some of the most frequently asked questions of the IGWS are about groundwater, and since groundwater supplies 80 percent of Iowans their drinking water, an understanding of the geologic and hydrologic framework that contains Iowa's groundwater is in the best interest of Iowans and is essential when planning for better and sustainable use, protection, and management of Iowa's most valuable natural resource.

The last comprehensive state water plan for Iowa was completed in 1978 by the Iowa Natural Resources Council (www.iowadnr.com/water/files/1978waterplan1.pdf). This plan was funded by the state legislature and took three years to complete. It addressed major water problems of the time and recommended policies and programs to solve and prevent current and future problems. While some portions of the plan were implemented, the plan did not provide a mechanism for ongoing water planning. Additional plans and programs have been developed since 1978, however, these efforts were never integrated into a comprehensive plan for water management and have not created the public awareness needed to prevent degradation of groundwater and surface water resources in Iowa. The last update of the state water plan occurred in 1985.

The ability to protect and improve Iowa's natural resources, while utilizing them to benefit society, requires proactive long-range planning, based on accurate and current geologic and hydrologic information. In the past, most funding for water planning issues has come from the state general fund. Continuous reductions in general fund revenues and geologic and hydrologic staffing over the last 20 years have made it difficult for the IGWS to conduct the preemptive investigation and research necessary to create and maintain a forward looking, integrated, and comprehensive water plan.

Recently, concerns about the availability of groundwater in Iowa have come to light because of increasing demand for large quantities of water for various industries, as well as increases in demand from agricultural, industrial, and domestic uses. While Iowa is probably not facing an immediate water shortage, we currently do not have the information or resources available at the state level to answer basic questions regarding how much water can be withdrawn from Iowa's aquifers on a sustainable basis, without significantly lowering water levels and depleting very long-term groundwater storage.

Following a proposal in 2007 from the IGWS for $1.65 million for annual funding to characterize the availability, quality, use, and sustainability of Iowa's surface and groundwater resources, state legislators approved a one-time appropriation of $480,000 to support water resource studies. Currently efforts are underway to secure sustainable funding for continued study and management of Iowa's water resources through an improved water resource permitting system.

This report is part of the new Water Resources Management program work in progress to delineate the occurrence, movement, availability, use, and chemical quality of groundwater from Iowa's major aquifers for better and sustainable management of Iowa's groundwater resources. As more wells are completed in these aquifers and more stratigraphic, construction, and water-quality data are interpreted and entered into our databases, our knowledge of these valuable resources will improve and our evaluation of them will be refined.

Iowa's Geologic Framework and the Dakota Aquifer Study Area

Iowa's groundwater resources are stored in shallow unconsolidated aquifers and in five deeper bedrock aquifers that are generally separated by widespread confining beds, or aquitards, that

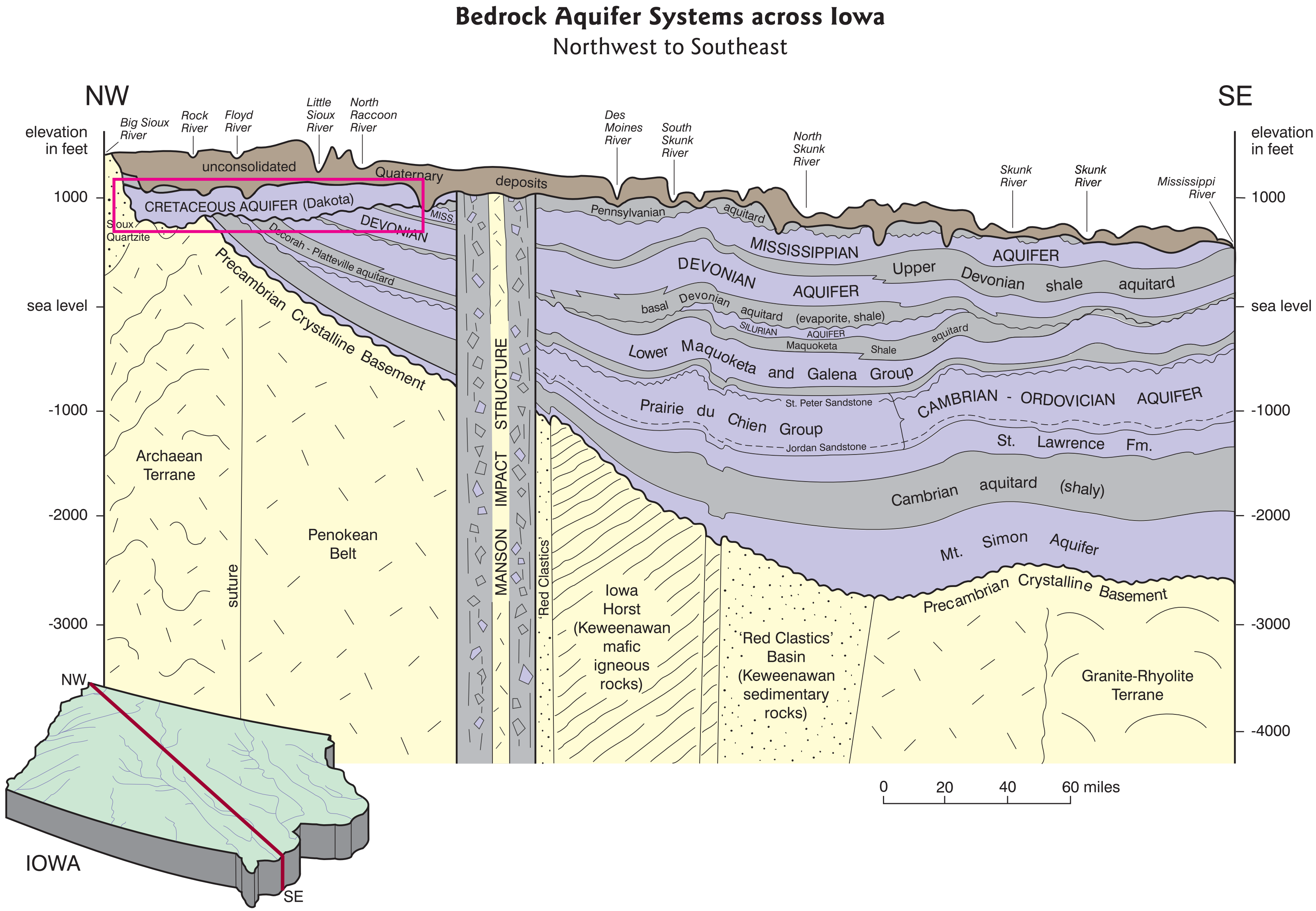


Figure 1. Cross-sectional view of Iowa's major aquifers and aquitards from northwest to southeast (modified from Iowa's Groundwater Basics by Prior, et al., 2003). Aquifers in Iowa are named according to their geologic age or the stratigraphic interval in which they occur. The Cretaceous age Dakota Aquifer is shown inside of the red rectangle.

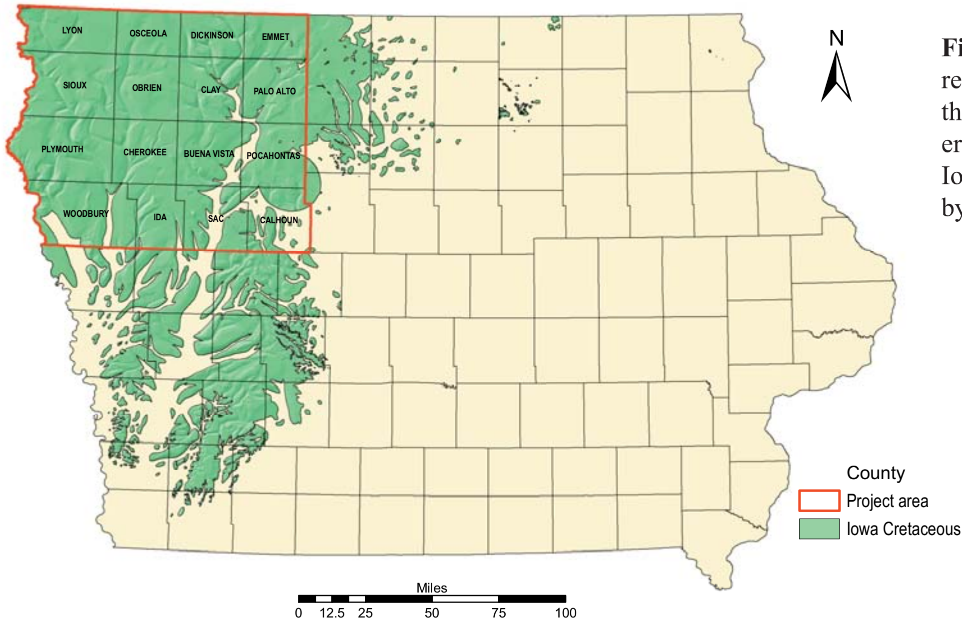


Figure 2. Area of occurrence and significant use of the Dakota Aquifer in western Iowa (modified from Iowa's Groundwater Basics by Prior, et al., 2003).

slow the movement of water between the aquifers (Figure 1). The unconsolidated aquifers include alluvial sand and gravel deposits found along stream valleys and in ancient buried river valleys, and sand and gravel deposits found within glacial drift. The bedrock aquifers are usually sandstone, siltstone, limestone, or dolomite, and sometimes are a combination of all of these rock types. The major bedrock aquifers in Iowa were deposited between 75 to 550 million years ago (mya), and include, from shallow to deep: the Cretaceous (Dakota), Mississippian, Silurian-Devonian, Cambrian-Ordovician (Jordan), and Dresbach (Mt. Simon).

The first aquifer to be studied for the new Water Resources Management plan is the Dakota, which is used for rural and public water supplies in western Iowa (Figure 2). This aquifer is composed of two members: thinly bedded and well sorted Woodbury Member shales and very fine- to fine-grained sandstones, and the underlying thickly bedded and poorly-sorted Nishnabotna Member fine- to very course-grained sandstones (Munter, et al., 1983). These deposits formed in riverine environments 100 mya. Woodbury rocks form a minor aquifer with low to moderate yields, which grades to a confining layer, while Nishnabotna rocks form a major aquifer capable of yielding greater than 1,500 gallons per minute (gpm) in some areas. Because of the greater continuous areal extent and higher yields, the initial study concentrates on the lower part of the Dakota Aquifer within the 16 counties in northwest Iowa (Gannon, et al., 2008).

In general, the lower part of the Dakota has greater yield potential, but probably poorer natural water quality (Rowden, 2008). For practical purposes, domestic supplies often use the upper portion of the aquifer because drilling costs are lower, and they do not need large yields. Public and industrial users that need greater yields must use the lower portion of the aquifer, even if the water quality is poorer.

The individual sandstone beds within the Dakota Aquifer range from less than 10 feet to more than 150 feet in thickness, and while the cumulative thickness of the sandstone also varies widely, it generally ranges from 200 to 300 feet in thickness throughout much of the study area. The sandstones are confined over most of the study area by 200 to 400 feet of clay-rich glacial till as well as by thick shale, siltstone, thin chalky limestone, and lignite (low-grade coal). Most wells developed in the aquifer range from 100 to 600 feet deep in the area. The confining beds underlying the aquifer include Dakota shales, undifferentiated Paleozoic rocks, and Precambrian crystalline rock.

Water flows through the Dakota Aquifer from the north-central part of the study area to the east, south and southwest, with recharge coming from infiltration through the land surface and confining materials (Burkart, 1984). Discharge from the aquifer is to the underlying Paleozoic aquifers and to the alluvium and glacial outwash deposits along the Missouri and Big Sioux rivers in the southwest part of the study area. Flow toward bedrock valleys may reflect discharge to Quaternary sand and gravel deposits in the valleys.

In the late 1970s, comparison of water-level data from the Dakota Aquifer with historic records on a regional scale suggested that water levels in the aquifer were not rising or falling at a detectable rate at that time (Munter, et al., 1983). A few local areas appeared to have experienced long-term water-level declines due to pumping by high-capacity wells, but the extent and magnitude of the declines were not well known. In the study area, some pumping test data were thought to have been influenced by variations in aquifer characteristics. It was suggested that shale or mudstone lenses in the aquifer may slow the response of observation wells located at relatively large distances from production wells, resulting in low estimates of how much water the aquifer can transmit, even where thickness and overall textural properties of the aquifer appear to be relatively uniform.

The water quality of the aquifer varies from a calcium-bicarbonate type to a calcium-sulfate type of water (Munter, et al., 1983). Generally, better water quality (less than 250 milligrams per liter [mg/L] of sulfate) occurs in areas that have relatively high recharge rates, mostly in the southwest part of the study area, while poorer water quality (greater than 1,000 mg/L of sulfate) occurs in areas with thick confining units such as in the north, northeast and central parts of the study area.

Methods used for Evaluation, Data Sources, and Data Dissemination

During the first year of the study, the IGWS has been designing procedures for collecting information, and developing compatible databases and geographic information system (GIS) coverages that will be used for aquifer characterizations. The data will eventually be integrated into a "Water Resources Enterprise" database that will provide content for a web-based information outlet and information for natural resource assessments, water resource planning and permitting, well forecasting, and regional and local predictive MODFLOW groundwater models that simulate three-dimensional groundwater flow through aquifers. The models will predict changes in aquifer characteristics, such as yields and areas of well interference, caused by changes in groundwater recharge and discharge. Other activities that will begin in 2008 include reestablishing a groundwater level monitoring network, possibly in cooperation with the United States Geological Survey Water Resources Division (USGS WRD) and supporting two long-term USGS stream gaging stations that would have been abandoned.

The types of data being collected for the Lower Dakota Aquifer study include:

- Well water withdrawals and pumping rates
- Aquifer properties such as storage and transmissivity
- Geologic framework characteristics like rock type, grain size, thickness, and depth to the top and bottom of the aquifer
- Groundwater quality parameters such as dissolved solids, hardness, iron, and sulfate concentrations

The data sources for the study include:

- Iowa's Geological Database (GEOSAM) and IGWS and USGS publications
- Records from DNR Water Supply and cities that use the Lower Dakota Aquifer
- Pump tests from well contractors

After reviewing all data sources for well information, 130 wells within the study area were selected as a basis for producing hydrogeologic maps. For wells with multiple static water levels, the water levels were averaged for use in constructing a potentiometric surface. An average hydraulic conductivity (K) value of 48 feet per day, and an average well function (W[u]) value of 270 were assumed for the Nishnabotna Member sandstones, based on previously collected and currently reviewed pumping test data (Munter, et al., 1983). The well point locations for the averaged constituents were then converted to a grid using a topo to raster tool, the grid was then clipped using the appropriate bedrock coverage and outline of the sixteen counties in northwest Iowa as a boundary condition, and then the grid was contoured using a raster surface contour tool.

The work in progress will delineate the occurrence, movement, availability, use, and chemical quality of groundwater from the Lower Dakota Aquifer for better and sustainable management of Iowa's groundwater resources. To be useful, this information will be made available in an understandable and accessible format, similar to the IGWS hydrologic atlas (www.iowadnr.gov/mapping/index.html) where the information can be integrated and presented on a variety of maps at appropriate scales. Web-based server applications will provide on-line access for those without desktop GIS software who want to view pre-selected GIS map layers of interest. For those who have desktop GIS software, the new series of map layers, known as coverages or themes, will also be accessible from the Iowa Geological and Water Survey's Natural Resources GIS (NRGIS) Library at www.igsb.uiowa.edu/nrgislibx/.

Making Maps with GIS

GIS software stores geographically indexed information in layers and allows users to analyze spatial relationships and map them. The information can be represented in two dimensions as points, lines, polygons, and grid cells, or in three dimensions as triangular irregular network (TIN) data with x,y, and z values, and a series of edges connecting these points to form triangles. Like grids, TINs are used to represent continuous surfaces such as a landscape, but unlike grids, TINS have a vertical component such as thickness or elevation. GIS software tools allow the user to create three-dimensional layers and perform mathematical calculations on them. The following maps were constructed with desktop GIS software using data from wells completed in the Lower Dakota Aquifer. The map layers can be related to one another employing a few simple hydrologic equations using data from geologic field observations and pumping tests. The map layers were made sequentially by using earlier constructed layers to calculate the succeeding layers.

Figure 3 is an isopach or thickness map that shows the areal distribution and thickness variation of the Lower Dakota Aquifer. This map was made by contouring the thickness of the thicker bedded and poorly-sorted, fine- to course-grained sandstone interval found in wells completed in the Lower Dakota Aquifer in northwest Iowa. The aquifer is thin or absent in the southeastern portion of the study area, and thicker toward the west.

Determining the depth to the top of an aquifer is one of the first steps in planning a water supply. Well depth is a determining factor in calculating drilling and construction costs, as well as pump and well design. Figure 4 was made by subtracting the elevation of the top of the Lower Dakota Aquifer from the elevation of the overlying land surface. The top of the aquifer is more deeply buried in the northwest portion of the study area, and closer to the land surface in the southwest, southeast and eastern portions of the area, and in areas where the current drainage network has eroded valleys into the land surface.

Determining the depth to the bottom of an aquifer is also important in planning a water supply. Aquifer thickness is a determining factor in figuring drilling and construction costs, as well as pump and well design, and well yield. Figure 5 was made by subtracting the ispoach thickness of the Lower Dakota Aquifer from the elevation of the top of the aquifer, then subtracting the result

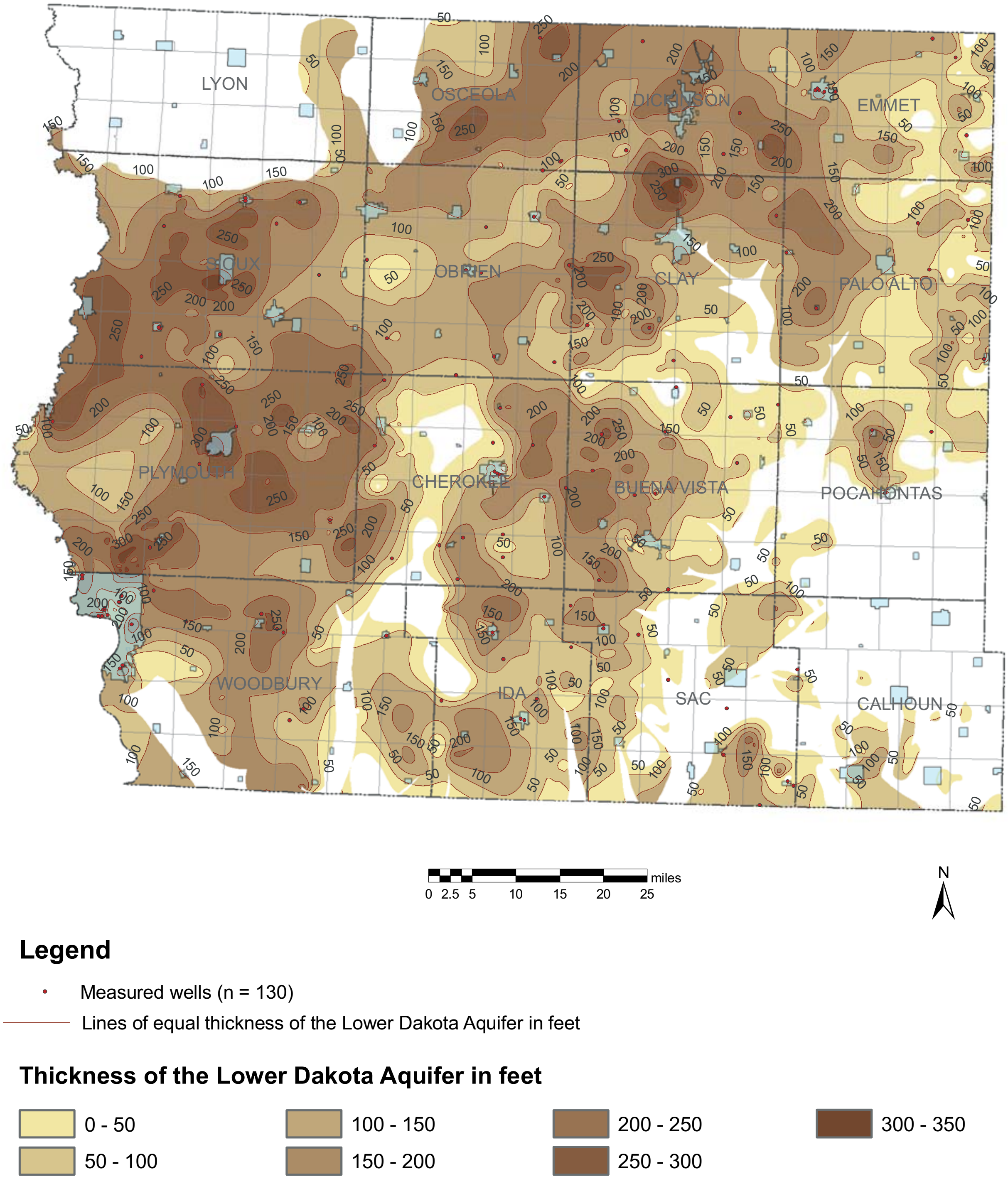


Figure 3. Distribution and isopach thickness, in feet, of the Lower Dakota Aquifer.

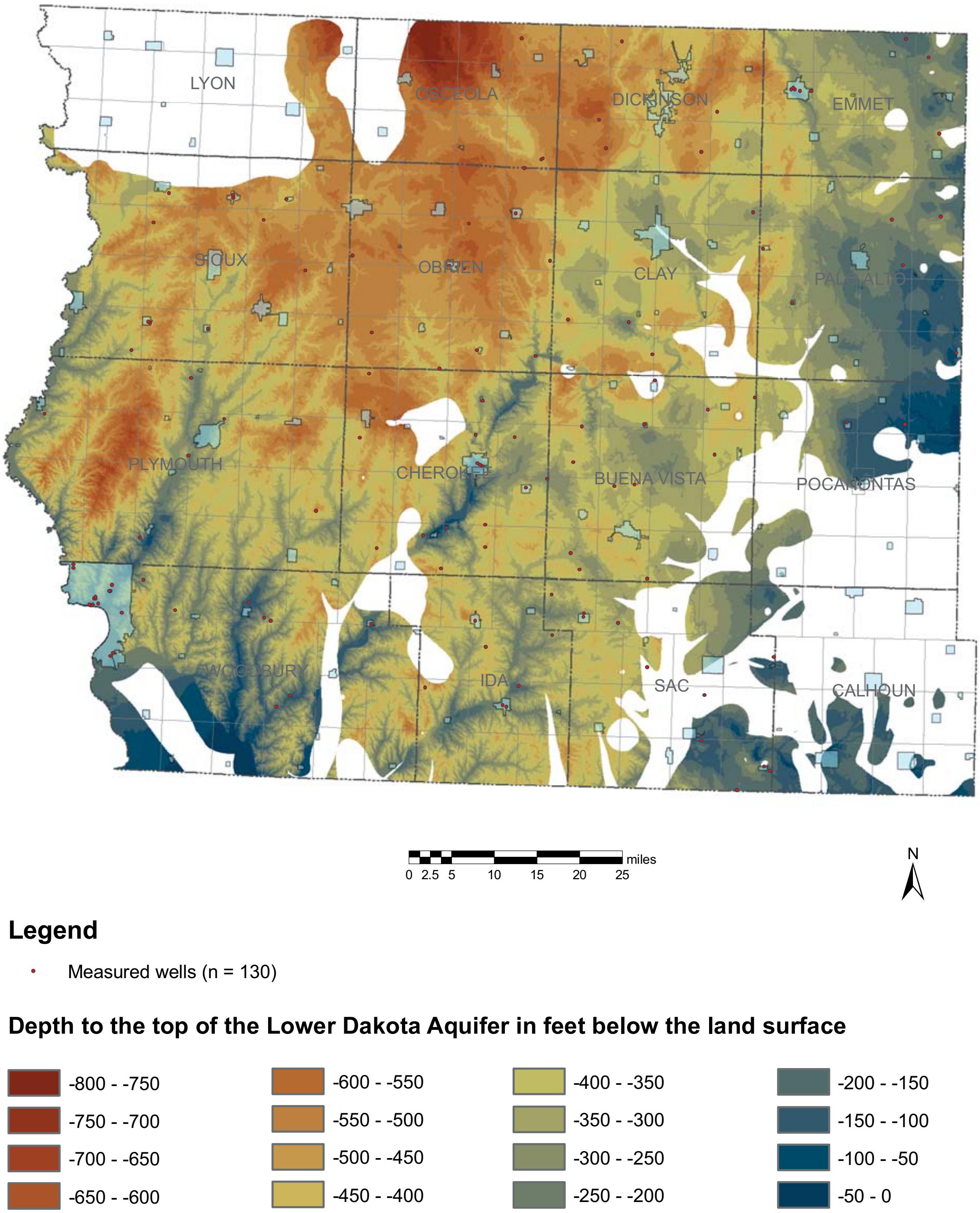


Figure 4. Depth to the top of the Lower Dakota Aquifer in feet below the land surface.

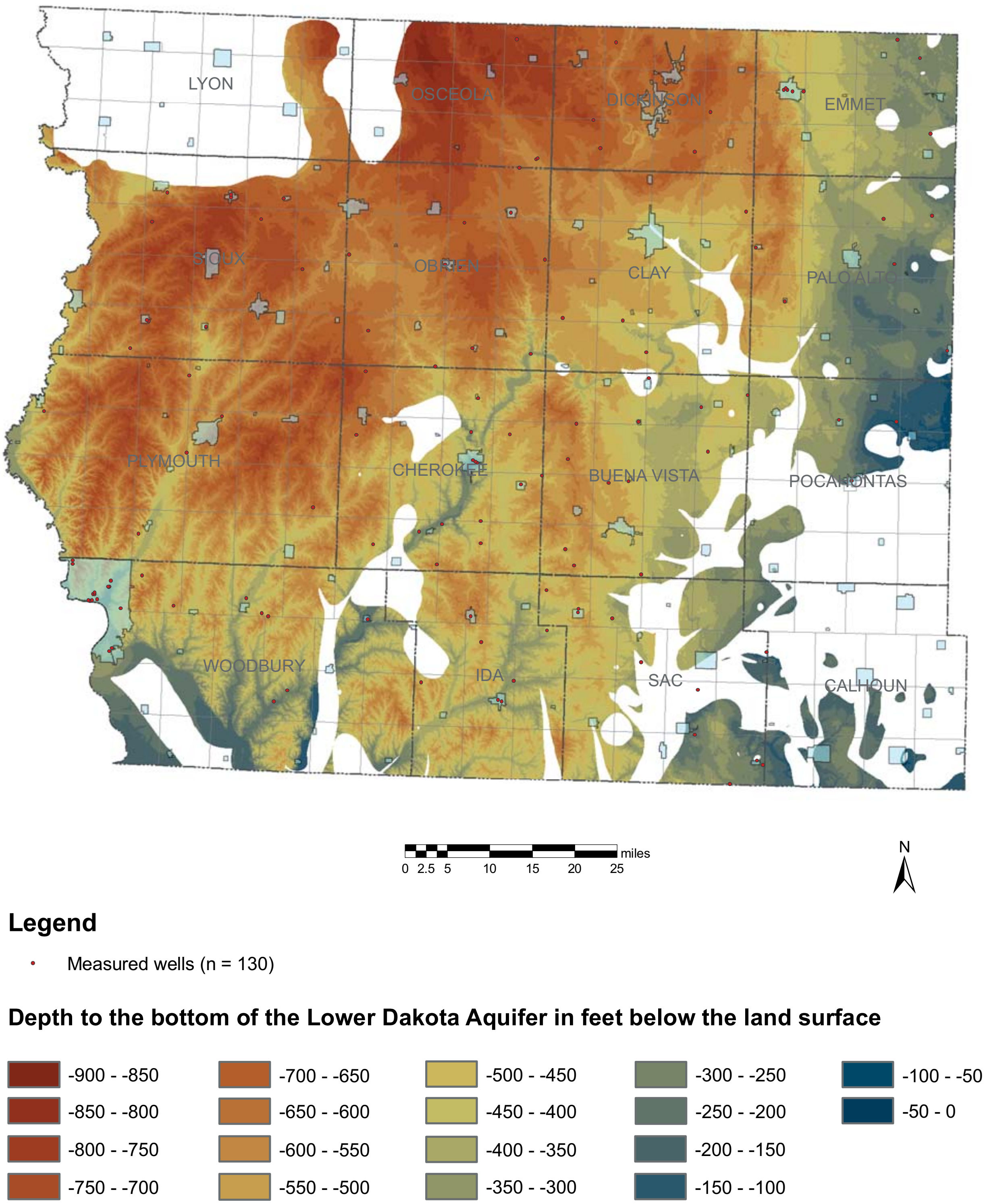


Figure 5. Depth to the bottom of the Lower Dakota Aquifer in feet below the land surface.

from the elevation of the overlying land surface. The bottom of the aquifer is deeper in the northwest part of the study area, and shallower toward the southeast, and in areas where streams have eroded the land surface.

The Lower Dakota Aquifer is underlain by Precambrian rocks deposited 2,910 to 542 mya and Paleozoic rocks deposited 542 to 142 mya. These rocks dip about 18 feet/mile to the south-southwest and form a confining layer that slows but does not prevent the flow of water between adjacent aquifers. Figure 6 was made by subtracting the elevation of the top of sub-Cretaceous rocks from the elevation of the overlying land surface. Sub-Cretaceous rocks are generally more deeply buried in northwest half of the study area, and shallower toward the southeast, and in areas underlying stream valleys.

By using elevation, rather than depth, the structure of the top of the aquifer is better represented, because it is shown relative to the flat surface of mean sea level, rather than as a depth below the uneven surface of the landscape above it. In addition, the top of the aquifer can be compared with the land surface, screened well intervals, and groundwater levels in wells in a less biased framework. Figure 7 was made by subtracting the depth to the top of the Lower Dakota Aquifer from the elevation of the overlying land surface. The highest elevations generally occur in the southeastern half of the study area, and the lowest elevations generally occur in the northwestern half of the area.

Structural trends are better represented using elevations rather than depth, since elevations are not biased by the overlying topography as depth is. The previously shown depth maps illustrate the bias introduced by the drainage network that has shaped the overlying land surface. Figure 8 was made by subtracting the depth to the bottom of the Lower Dakota Aquifer from the elevation of the overlying land surface. The highest elevations occur in the southeastern half of the study area, while the lowest elevations occur in Sioux and Plymouth counties in the western part of the area.

By using elevations, rather than depth, the structures of the top of the sub-Cretaceous rocks and the bottom of the Lower Dakota Aquifer can be compared and related to screened intervals and groundwater levels in wells in a framework unbiased by surface topography. Figure 9 was made by subtracting the depth to the top of sub-Cretaceous rocks from the elevation of the overlying land surface. The highest elevations occur in the southeastern part of the study area and in Lyon County, while the lowest elevations occur in Sioux, Plymouth, Lyon, and Woodbury counties.

A potentiometric surface is an imaginary surface formed by measuring the level to which water will rise in wells of a particular aquifer. In a confined aquifer, like the Lower Dakota, this surface is above the top of the aquifer, whereas in an unconfined aquifer, it is the same as the water table. Figure 10 was made by contouring mean static water levels collected from 1912 to 1996 from wells completed in the Lower Dakota Aquifer in northwest Iowa. Since the static water levels span a large range of time, the potentiometric surface is representative of average water levels during the time of collection. For areas where water use has remained relatively constant, the map is probably representative of current water levels. For areas where water use has increased significantly, current water levels may be lower than those represented by the map.

Since water moves from higher to lower elevations or pressure areas, lateral water movement in the aquifer is from the uplands in the north-central part of the study area to the Missouri and Big Sioux river valleys in the southwest, and bedrock valleys toward the south and east.

Transmissivity (T) is a measure of how much water an aquifer can transmit horizontally to a pumping well. $T = Kb$, where K = hydraulic conductivity and b = aquifer thickness.

K is a measure of the rate of flow of water through a cross-sectional area of the aquifer and is expressed in units of length/time. Units of T are length^2/time, since units of b are length, and units of K are length/time. Figure 11 was made by multiplying the Lower Dakota Aquifer's thick-

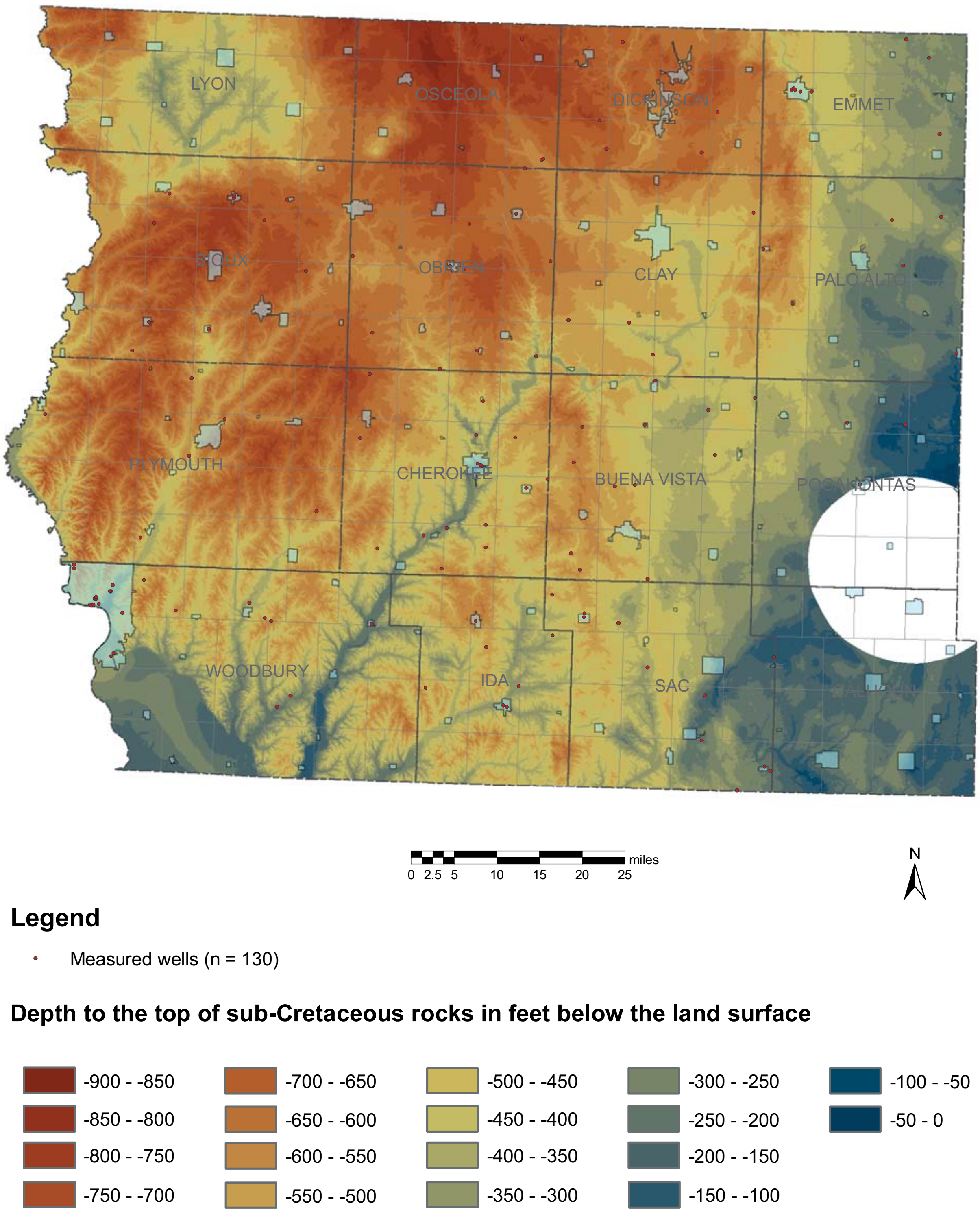


Figure 6. Depth to the top of sub-Cretaceous rocks in feet below the land surface.

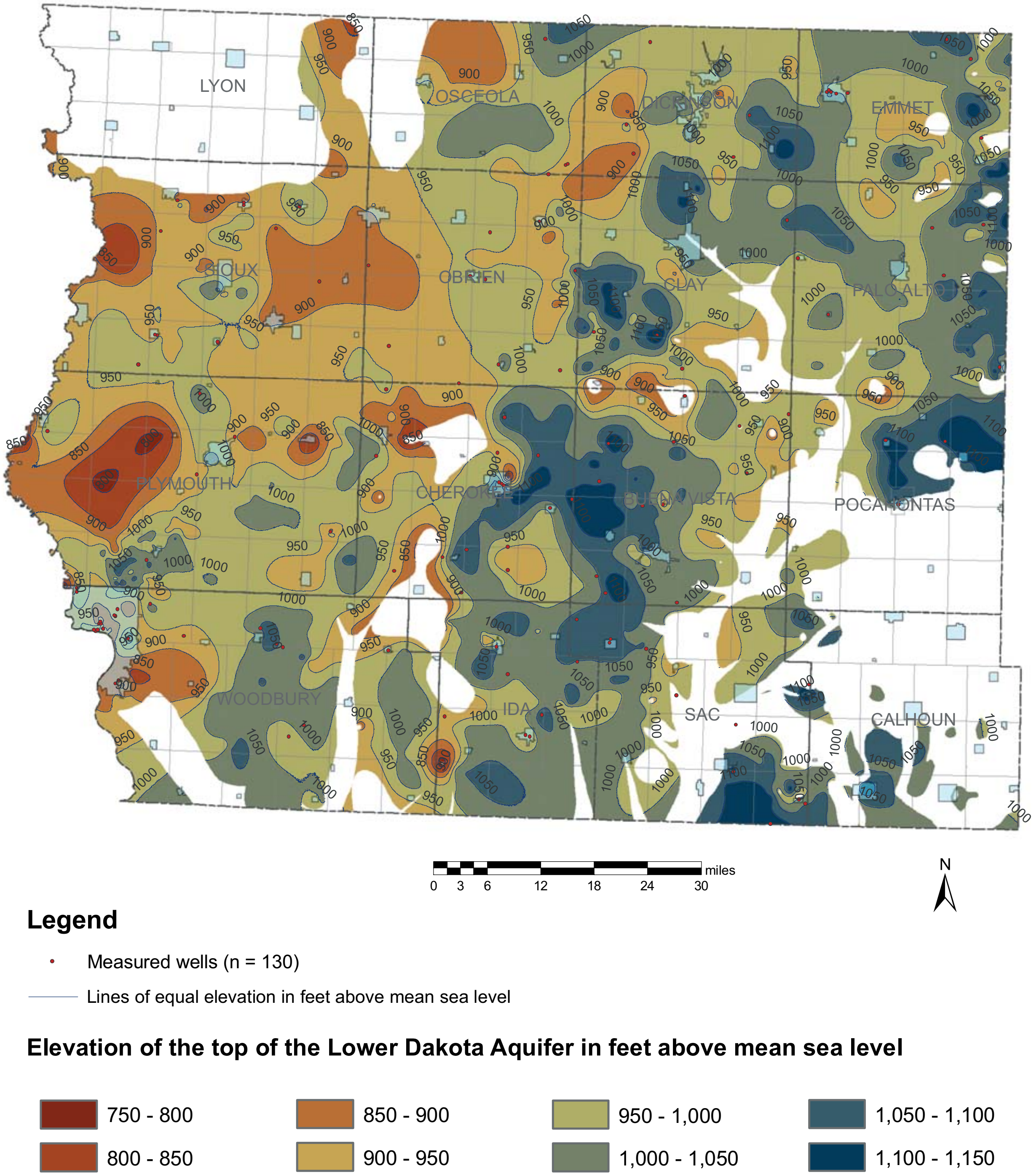


Figure 7. Elevation of the top of the Lower Dakota Aquifer in feet above mean sea level.

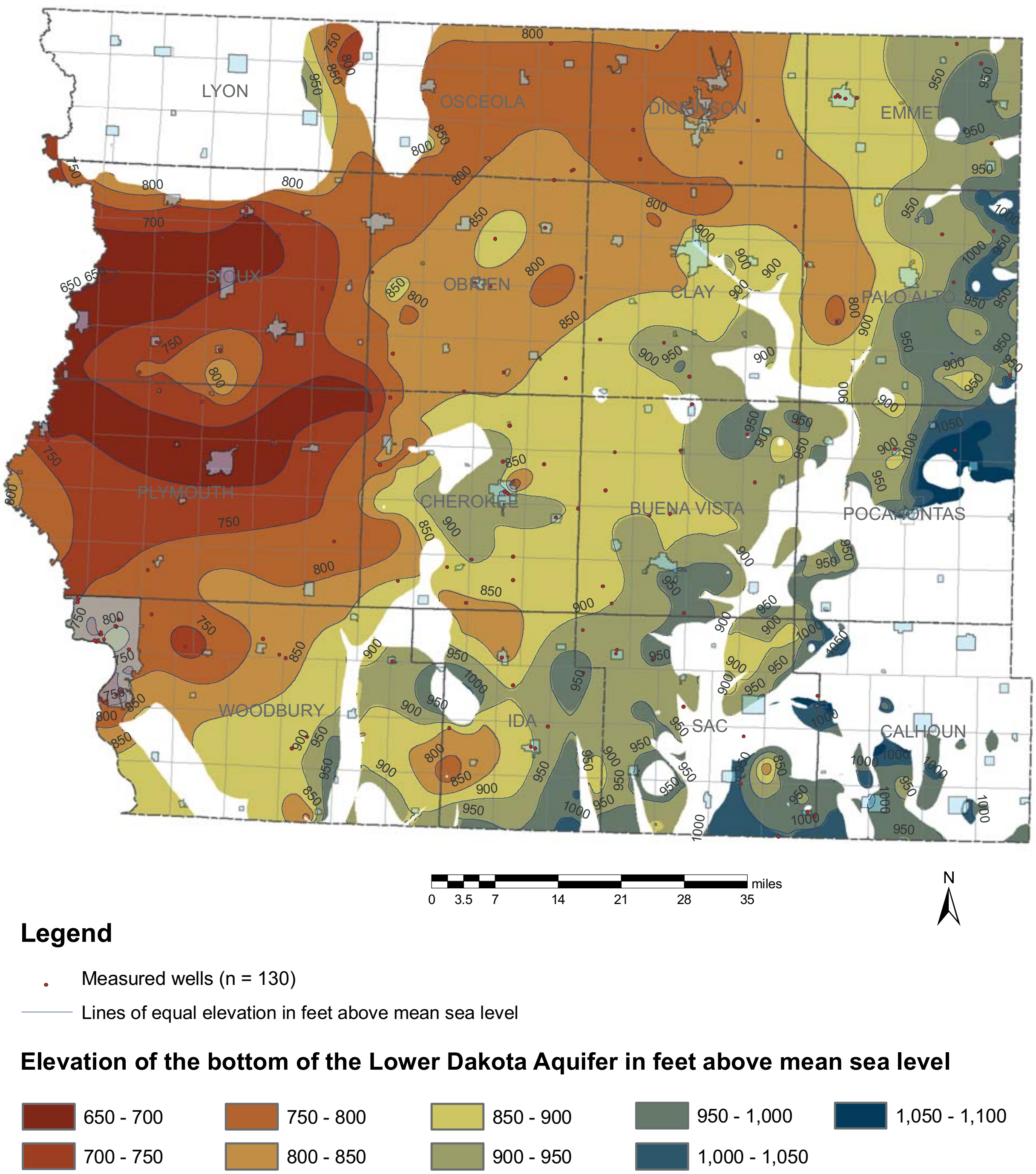
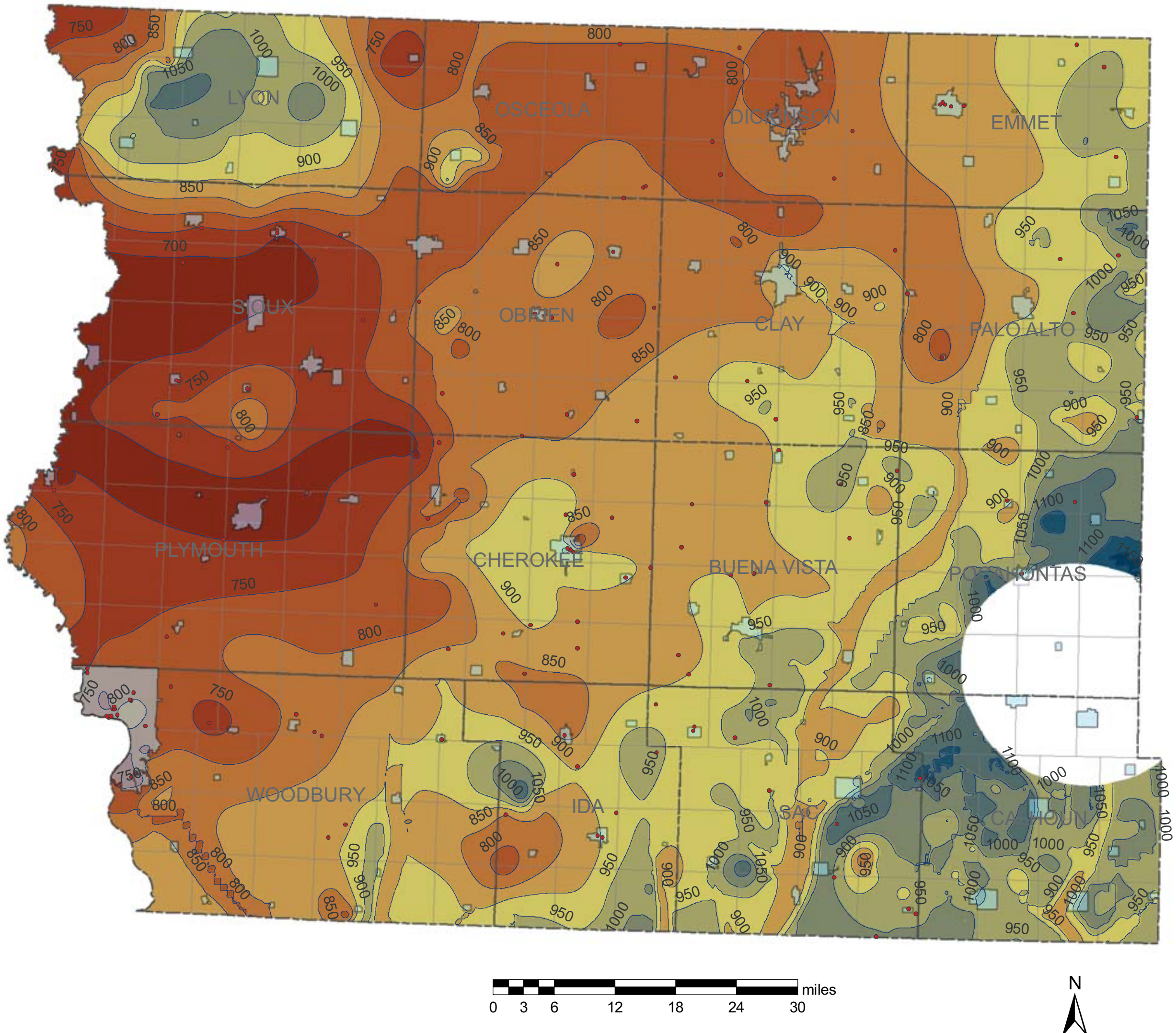


Figure 8. Elevation of the bottom of the Lower Dakota Aquifer in feet above mean sea level.



Legend

Measured wells (n = 130)

Lines of equal elevation in feet above mean sea level

Elevation of the top of sub-Cretaceous rocks in feet above mean sea level

- 650 - 700
- 700 - 750
- 750 - 800
- 800 - 850
- 850 - 900
- 900 - 950
- 950 - 1,000
- 1,000 - 1,050
- 1,050 - 1,100
- 1,100 - 1,150
- 1,150 - 1,200

Figure 9. Elevation of the top of sub-Cretaceous rocks in feet above mean sea level.

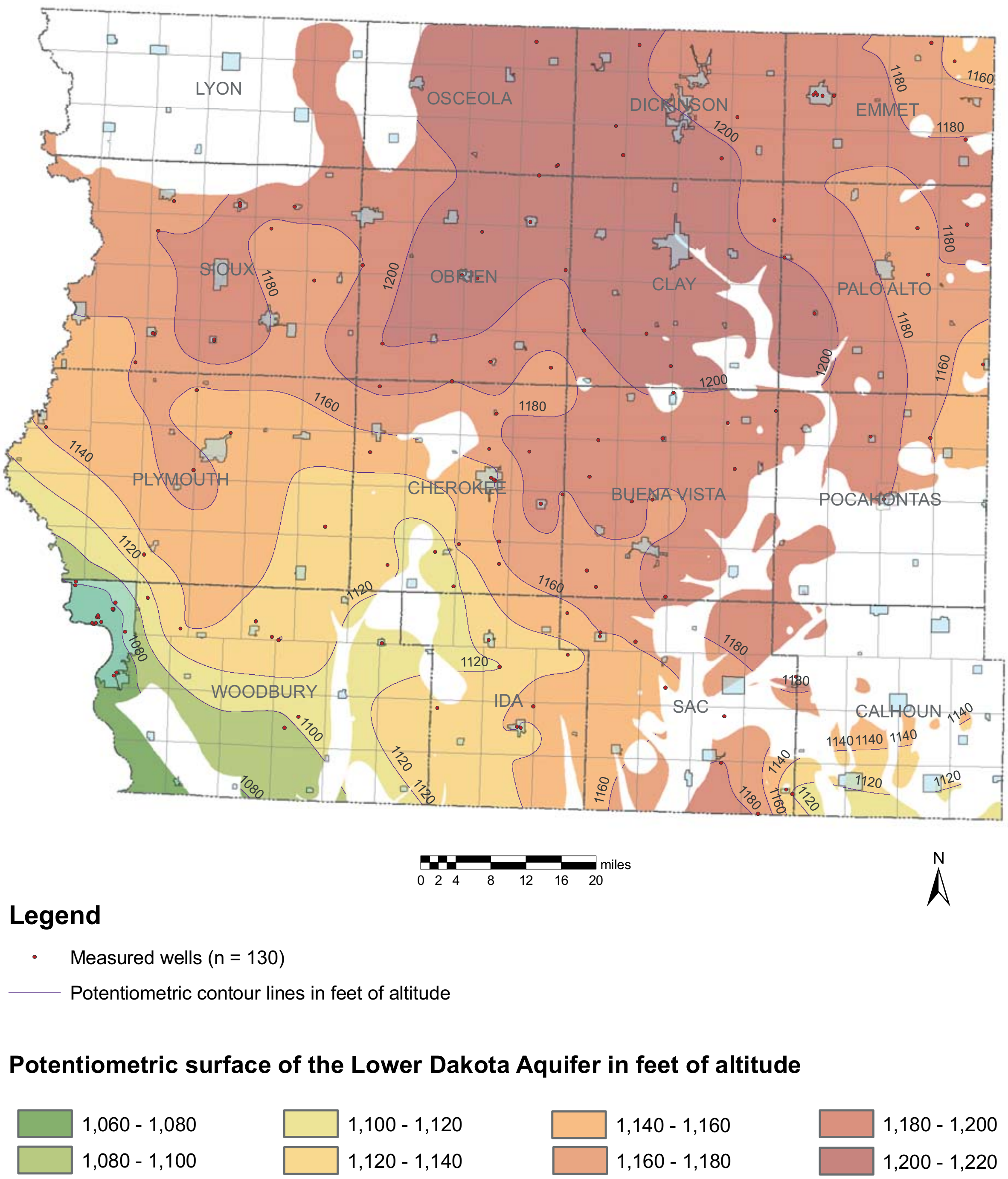


Figure 10. Potentiometric surface of the Lower Dakota Aquifer in feet above mean sea level.

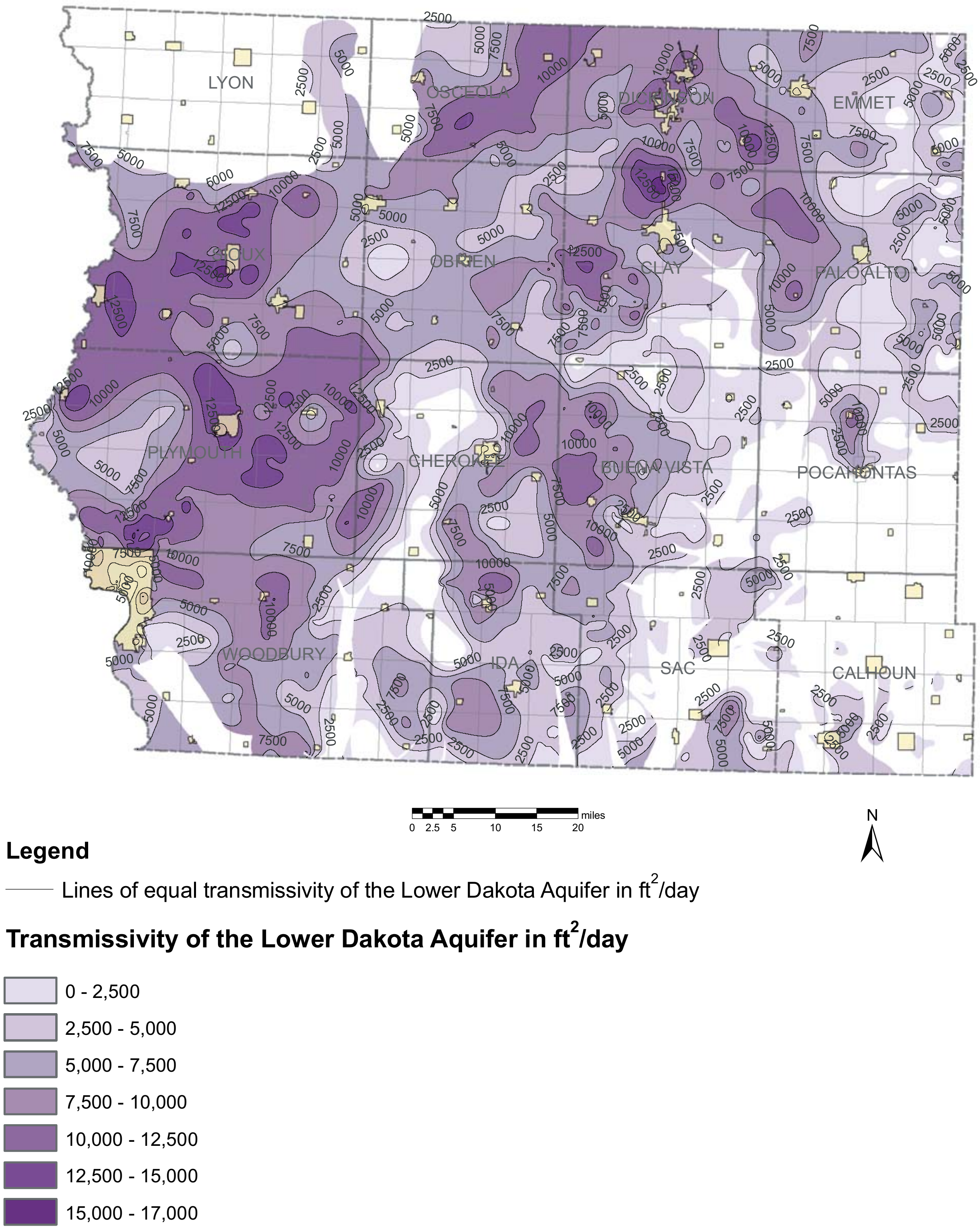


Figure 11. Transmissivity of the Lower Dakota Aquifer in ft^2/day.

ness by the aquifer's average hydraulic conductivity of 48 feet/day. Assuming that K is constant, the transmissivity is greatest where the aquifer is thickest.

Transmissivity can also be expressed as [volume/time]/length, or gallons/day/foot, since one cubic foot contains 7.481 gallons of water. For example, an aquifer with a K of 10 feet/day that has a saturated thickness of 25 feet would have a transmissivity as follows:

T = Kb, or T = 10 x 25, so T = 250 $feet^2$/day, or 250 x 7.481 = 1,870 gpd/ft.

Figure 12 was made by multiplying the previous transmissivity map layer by 7.481.

Specific capacity (C) is a measure of well performance, usually in gpm per foot. $C = Q/\Delta h$, where Q = well pumping rate or yield and Δh = well drawdown (the drop in water level in the well when it is pumped). Well function, $W(u) = r^2S/4Tt$, where r is radial flow, S is storativity, T is transmissivity, and t is time. T = well function x $Q/\Delta h$, so C = T/well function. Since the average well function for the Lower Dakota Aquifer is 270, Figure 13 was made by dividing the transmissivity map layer (in ft^2/day) by 270. Assuming that $W(u)$ is constant the specific capacity is greatest where T is greatest.

Drawdown (Δh) is the drop in the water level in a well when it is pumped, measured in feet or meters. Typically, drawdown increases with the length of pumping time, producing a cone of depression. Well yield (Q) or the amount of water that can be pumped is limited by the amount of drawdown produced. Since specific capacity (C) = $Q/\Delta h$, $Q = C \times \Delta h$, and well yields can be determined from specific capacity (C) and drawdown. Figure 14 was made by subtracting the elevation of the top of the Lower Dakota Aquifer from the elevation of the aquifer's potentiometric surface.

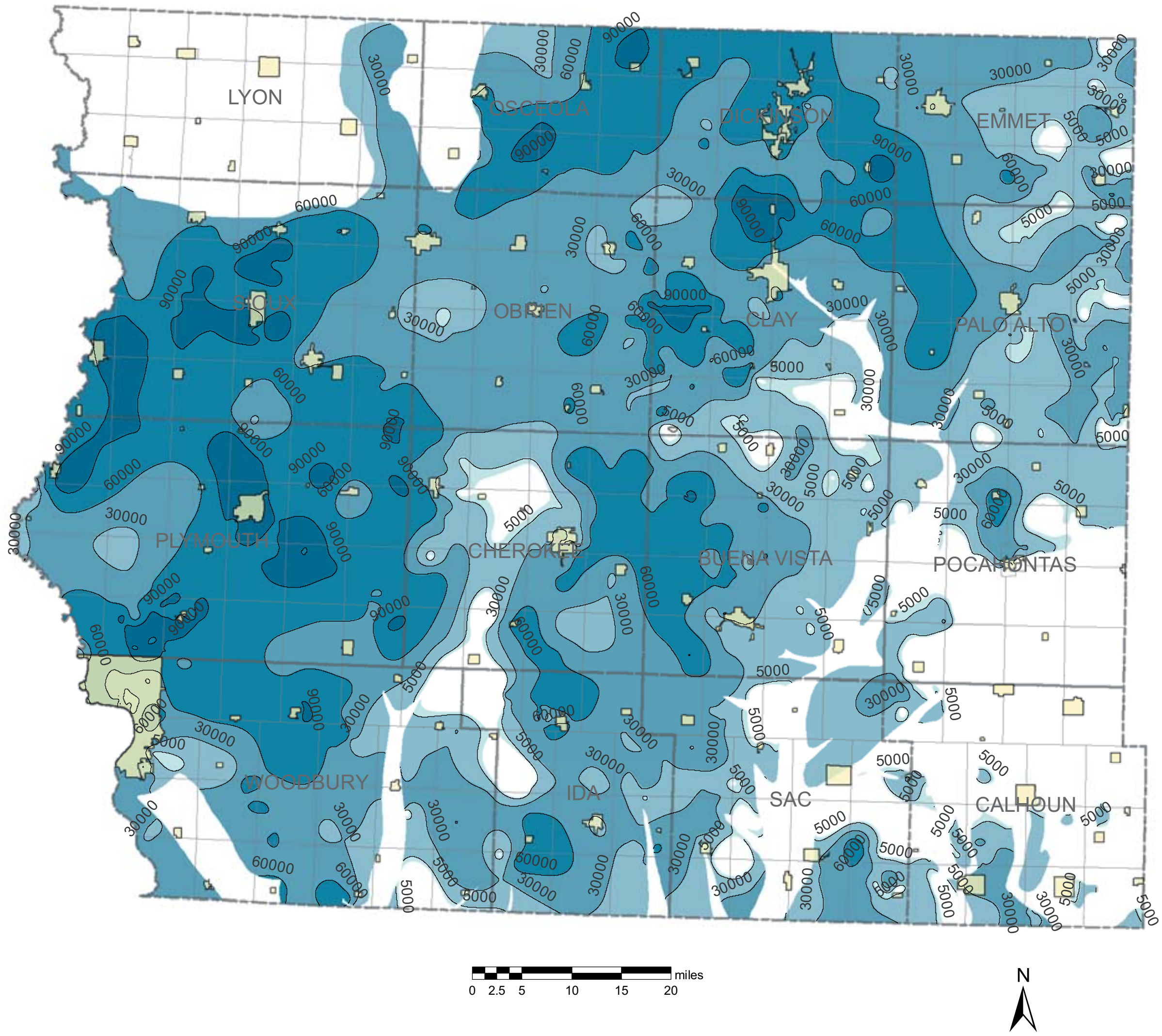
The amount of drawdown (Δh) that occurs in a well is determined by an aquifer's ability to replace water that is being pumped. If there is a lot of water in an aquifer that can move freely to the well, the drawdown will be low. If water cannot move through an aquifer quickly, the drawdown will be high and unsustainable. By using 50% of the potential drawdown to calculate potential well yields, a margin of safety is added that assures that withdrawals from the Lower Dakota Aquifer will be sustainable. Figure 15 was made by dividing the previous potential drawdown map layer by 2.

Well yield (Q) is a measure, usually in gpm, of how quickly and how much water can be withdrawn from an aquifer over a period of time. A sustainable well yield is that which can be maintained during periods of extended drought. Since specific capacity (C) = $Q/\Delta h$, $Q = C \times \Delta h$, and well yields can be determined from specific capacity (C) and drawdown (Δh). Actual well yields may vary due to well loss, or the inability of the well to produce at 100% efficiency. Figure 16 was made by multiplying the specific capacity map layer by 50% of potential drawdown, then multiplying by a 50% well efficiency.

Three-Dimensional Mapping

Figure 17 shows three-dimensional representations of the study area, with wells (in red) extruded from the land surface down through the lower Dakota's potentiometric surface (in blue) and into the Lower Dakota Aquifer (top brown, bottom confining layer gray).

The use of three dimensional mapping, rather than two, allows for enhanced visualization of spatial data by providing a more realistic perspective of the data. Patterns and trends appear in three dimensions that might not be discovered in a flat, two-dimensional view. The relationship between wells and the underlying unconsolidated materials, rock layers, and the land surface is much more easily seen in a three-dimensional view. With desktop GIS software, these layers can be tilted and rotated for better analysis of the map layers at different angles. In the future, the use of three dimensional mapping and display for data from many applications will increase.



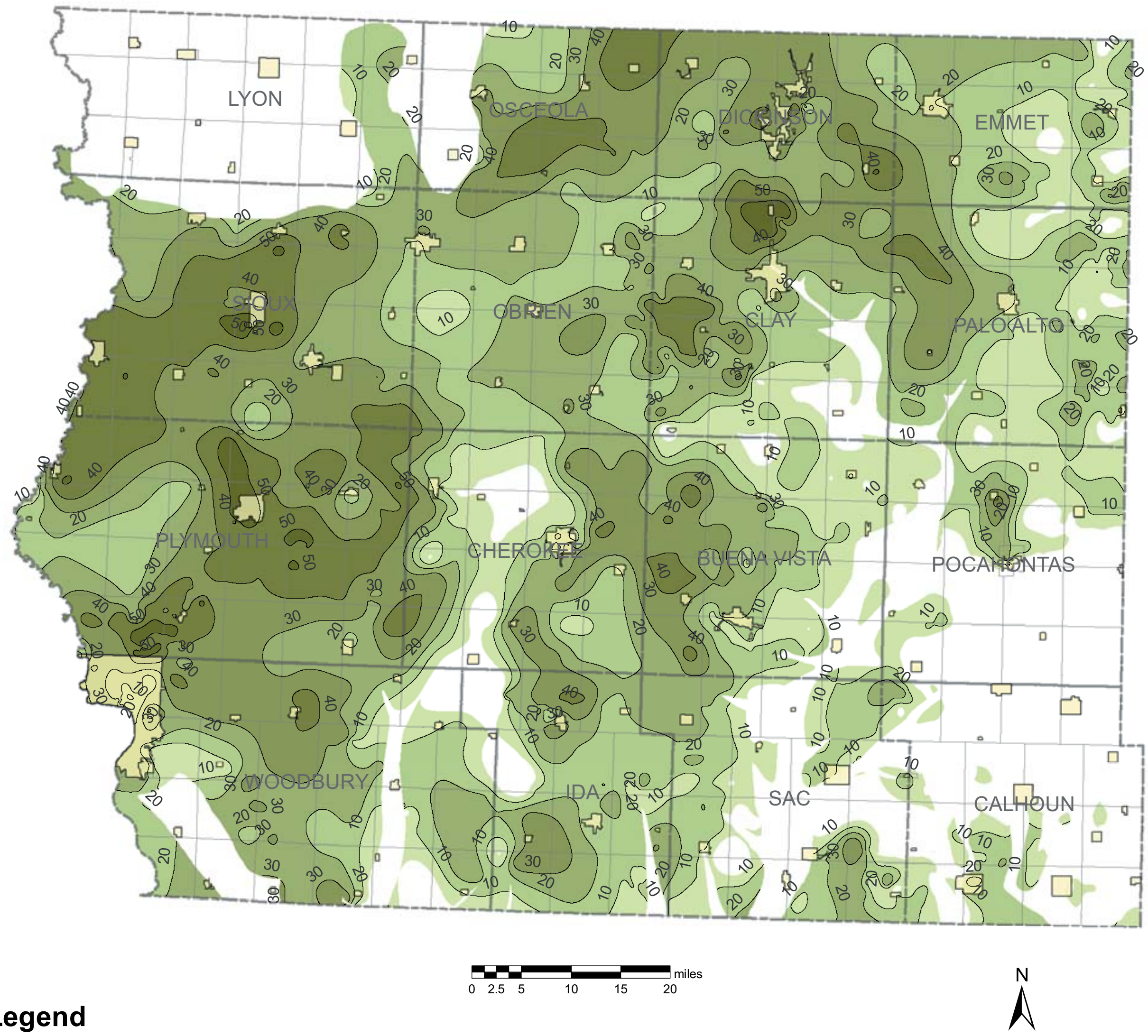
Legend

Lines of equal transmissivity of the Lower Dakota Aquifer in gpd/ft

Transmissivity of the Lower Dakota Aquifer in gpd/ft

- 0 - 5,000
- 5,000 - 30,000
- 30,000 - 60,000
- 60,000 - 90,000
- 90,000 - 127,000

Figure 12. Transmissivity of the Lower Dakota Aquifer in gpd/ft.



Legend

—— Lines of equal specific capacity of the Lower Dakota Aquifer in gpm/ft

Specific capacity of the Lower Dakota Aquifer in gpm/ft

- 0 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60

Figure 13. Specific capacity of the Lower Dakota Aquifer in gpm/ft.

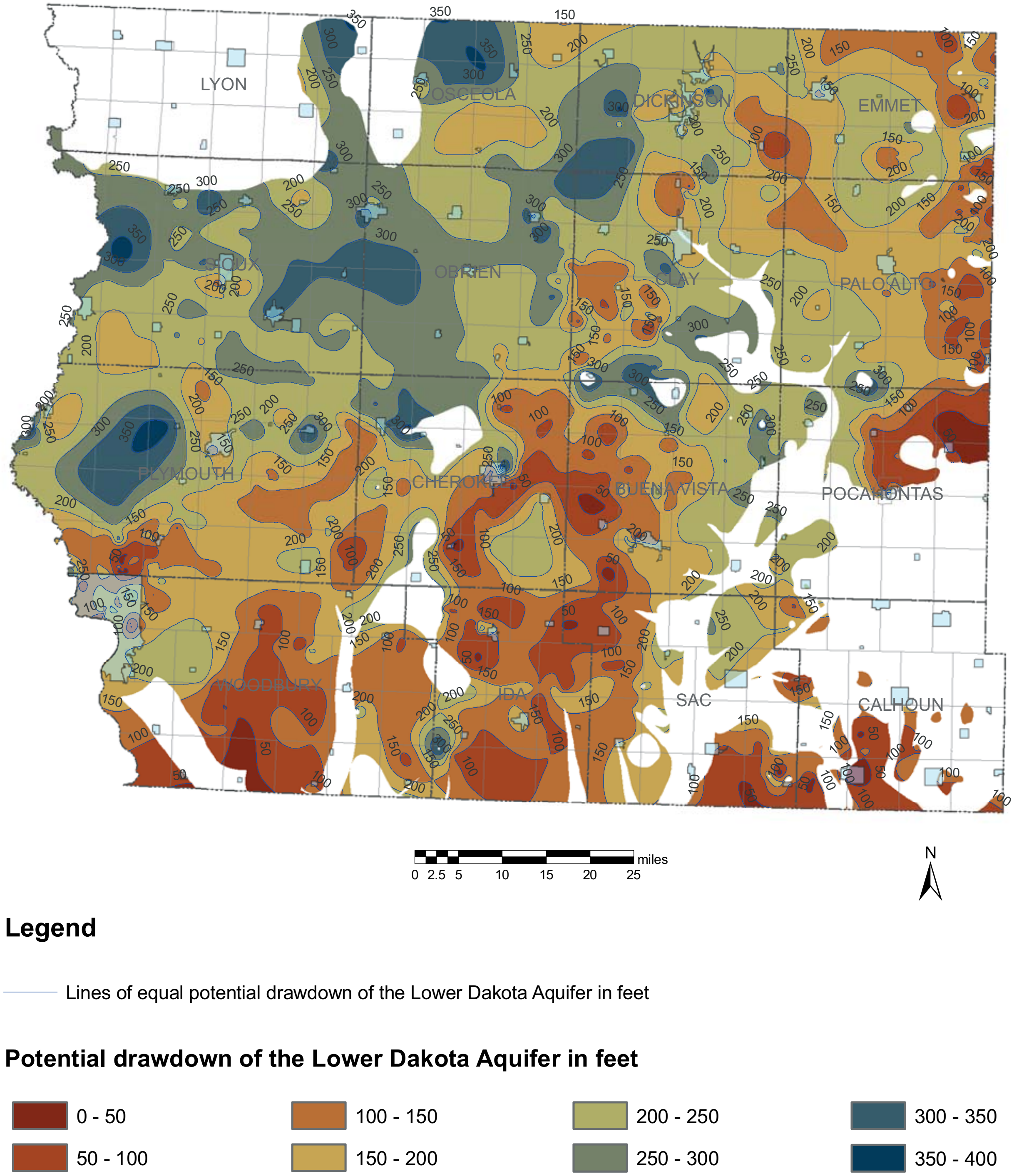
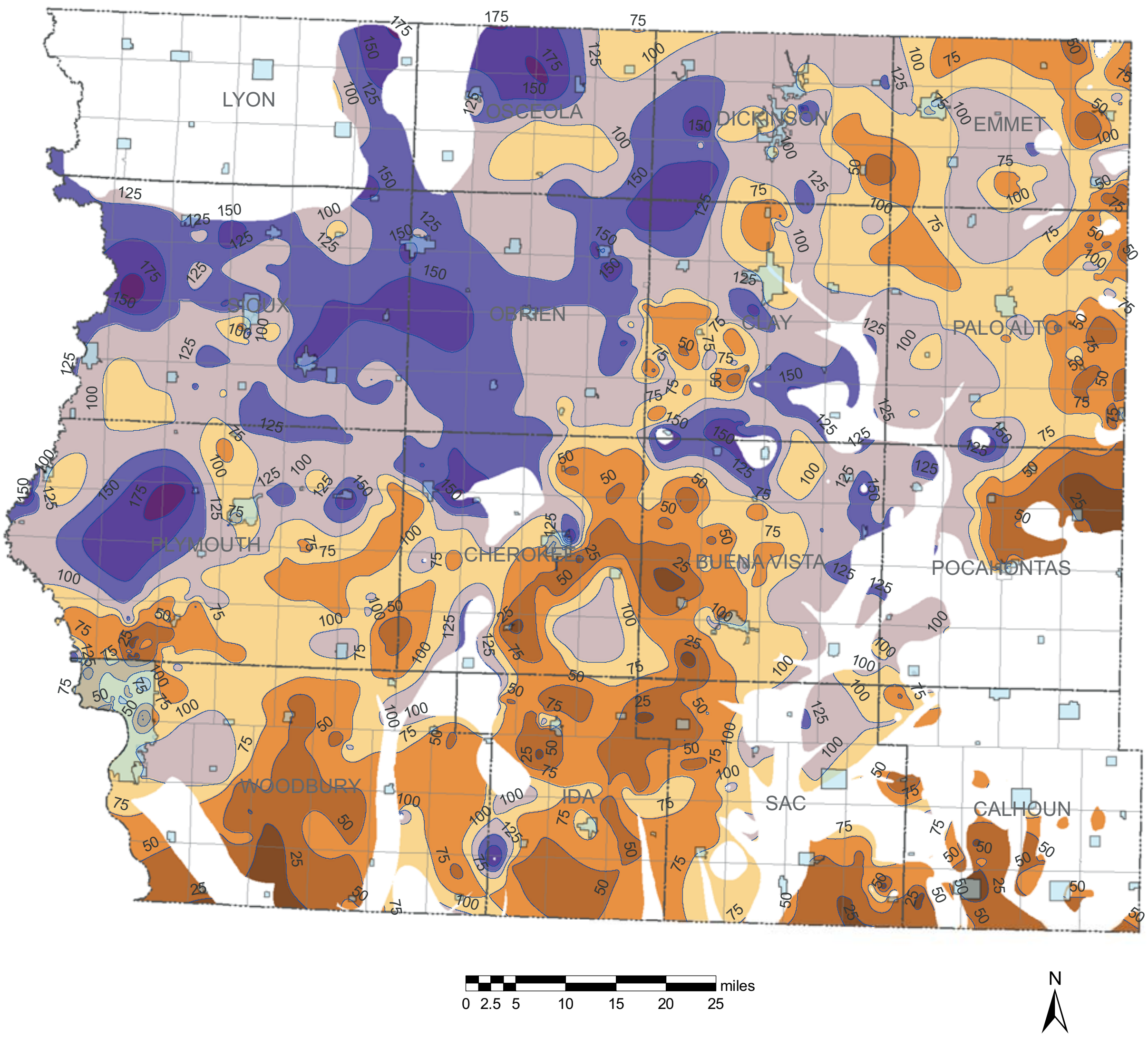


Figure 14. Potential drawdown of the Lower Dakota Aquifer in feet.



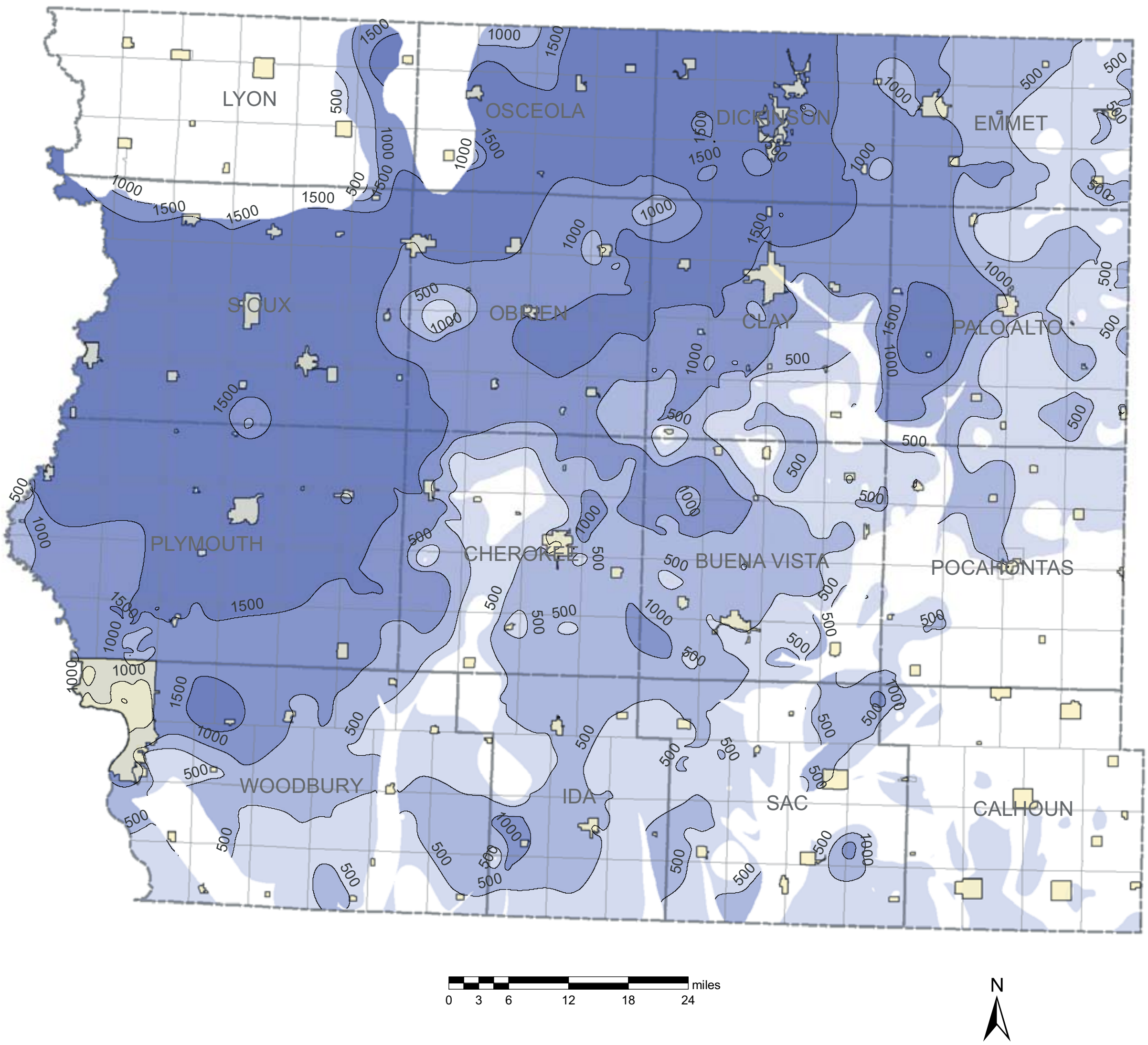
Legend

Lines of equal potential drawdown of the Lower Dakota Aquifer in feet

50% of potential drawdown of the Lower Dakota Aquifer in feet

0 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200

Figure 15. Fifty percent of potential drawdown of the Lower Dakota Aquifer in feet.



Legend

—— Lines of equal potential well yield of the Lower Dakota Aquifer in gpm

Potential well yields from the Lower Dakota Aquifer in gpm

- 0 - 500
- 500 - 1,000
- 1,000 - 1,500
- >1,500

Figure 16. Potential well yields from the Lower Dakota Aquifer in gpm.

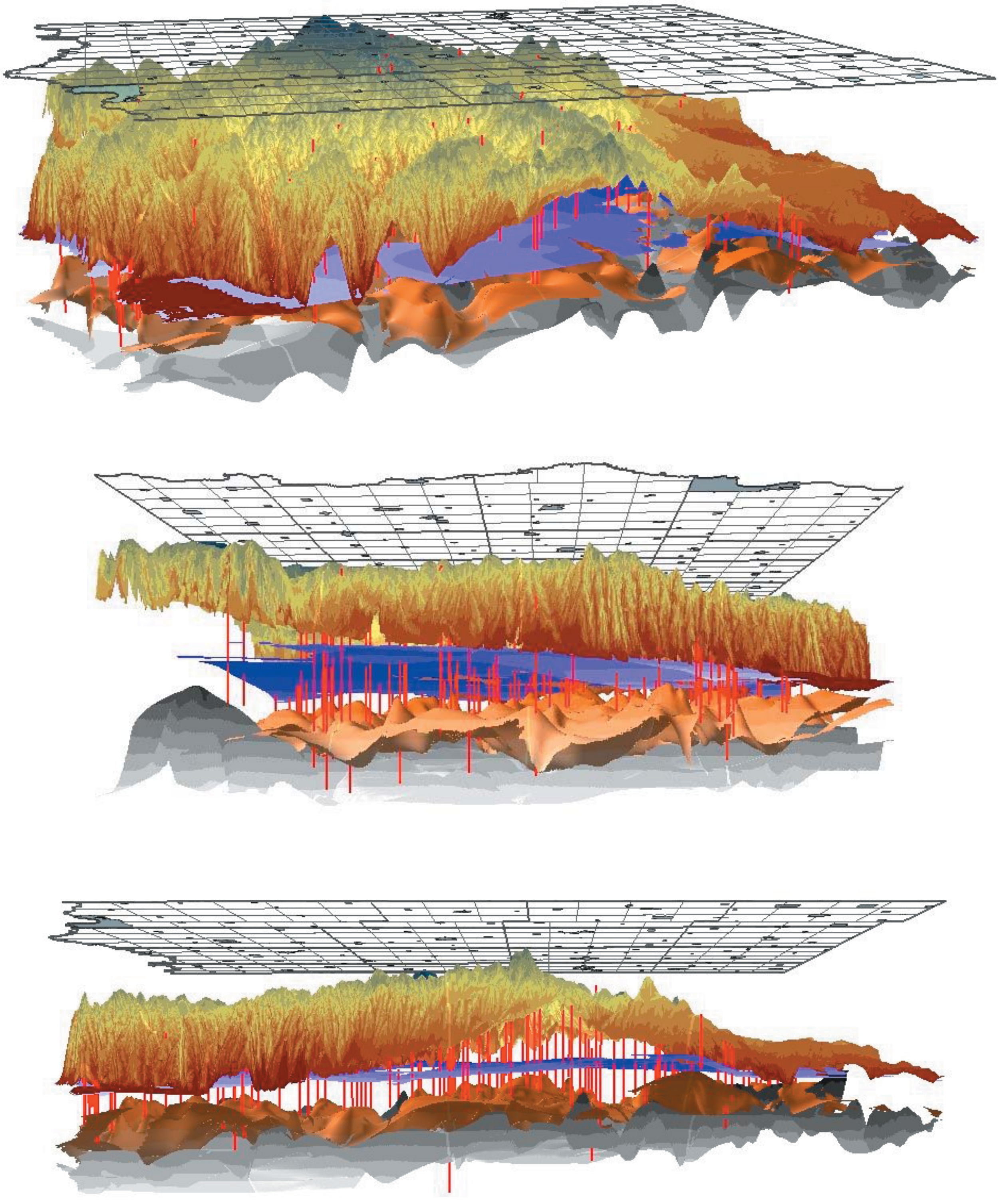


Figure 17. Three-dimensional views of the Lower Dakota Aquifer study area in northwest Iowa. Wells are shown in red, Lower Dakota Aquifer potentiometric surface in blue, top of the Lower Dakota Aquifer in brown, and top of the underlying confining layer in gray. The 16-county outline is shown above the land surface images for reference (top view is southwest to northeast, middle view is west to east, and bottom view is south to north).

Final Comments

The Dakota Aquifer is the most extensive source of large quantities of groundwater in northwest Iowa. The lower part of the Dakota, the Nishnabotna Member, has greater yield potential, but probably poorer natural water quality than the upper part of the aquifer, the Woodbury Member. Domestic supplies often use the upper portion of the aquifer because drilling costs are lower, and they do not need large yields. Public and industrial users that need greater yields must use the lower portion of the aquifer, even if the water quality is poorer.

Individual sandstone beds within the Lower Dakota Aquifer range from less than 10 feet to more than 150 feet in thickness, while the cumulative thickness of the sandstone is greater than 200 feet throughout much of the western and north-central portions of the study area. The sandstones are confined over most of the study area by 200 to 400 feet of clay-rich glacial till as well as by thick shale, siltstone, thin chalky limestone, and lignite. The confining beds underlying the aquifer include Dakota shales, undifferentiated Paleozoic rocks, and Precambrian crystalline rock. In general, the aquifer is thin or absent in the extreme northwestern and southeastern portions of the study area, and thicker toward the west and north-central parts of the area.

Lateral water movement through the aquifer is from the uplands in the north-central part of the study area to the Missouri and Big Sioux rivers in the southwest, and bedrock valleys toward the south and east. The aquifer is confined throughout most of the study area, but is under water-table conditions in the extreme southwest, near the Missouri and Big Sioux rivers. The aquifer is recharged throughout the study area by downward infiltration through the land surface and confining materials, and by lateral flow from southern Minnesota. Discharge from the aquifer is to the underlying Paleozoic aquifers and to the alluvium and glacial outwash deposits along the Missouri and Big Sioux rivers in the southwest part of the study area. Regional water level gradients suggest that flow also occurs toward South Dakota beneath a segment of the Big Sioux River.

The map layers in this report were made sequentially by using earlier constructed layers to calculate the succeeding layers. Based on previously collected and currently reviewed pumping test data, an average hydraulic conductivity value of 48 feet per day, and an average well function value of 270 were assumed for the Nishnabotna Member sandstones. An aquifer thickness map was made by contouring the thickness of the thicker bedded and poorly-sorted, fine- to course-grained sandstone interval found in wells completed in the Lower Dakota Aquifer. A potentiometric surface map was made by contouring the mean static water levels collected from 1912 to 1996 from wells completed in the Lower Dakota Aquifer. The average hydraulic conductivity was multiplied by the cumulative thickness of the Lower Dakota Aquifer to produce a transmissivity map layer. The transmissivity map layer was then divided by the average well function to produce a specific capacity map layer. A potential drawdown map was made by subtracting the elevation of the top of the Lower Dakota Aquifer from the elevation of the aquifer's potentiometric surface. An additional drawdown map depicting 50% of potential drawdown was made by dividing the previous potential drawdown map layer by 2. The potential yield map was made by multiplying the specific capacity map layer by 50% of the potential drawdown, then multiplying by a 50% well efficiency.

Estimated potential yields to wells completed in the Lower Dakota Aquifer exceed 500 gpm throughout much of the study area, and yields of greater than 1,500 gpm are possible in much of the western and north-central portions of the study area. Greater yields may be possible if more than 50% of potential drawdown is acceptable.

Previous work has shown that some pumping test data may be influenced by variations in aquifer characteristics. It was suggested that shale or mudstone lenses in the aquifer may slow the response of observation wells located at relatively large distances from production wells, resulting in low estimates of how much water the aquifer can transmit, even where thickness and overall textural properties of the aquifer appear to be relatively uniform. This heterogeneity of aquifer materials may limit the usefulness of existing pumping-test data, and suggests that the location of observation wells should be carefully considered when designing future pumping tests.

The water level records used to generate maps for this report are probably not adequate for evaluating long-term water level changes in the Lower Dakota Aquifer. Comparison of water-level data from the Lower Dakota Aquifer in this report, with data from the Dakota Aquifer collected in the late 1970s suggests that generally, water levels are similar. Comparison of the 1970s data with historic records on a regional scale suggested that water levels in the aquifer were not rising or falling at a detectable rate at that time, although a few local areas appeared to have experienced long-term water-level declines due to pumping by high-capacity wells. The extent and magnitude of the declines were not well known. As discussed, the potentiometric map presented in this report is representative of average water levels collected from 1912 to 1996. For areas where water use has remained relatively constant, the map is probably representative of current water levels, but for areas where water use has increased significantly, water levels may be lower than those shown on the map. The establishment of a comprehensive long-term monitoring network would be useful for identifying significant long-term changes in water levels in the aquifer brought about by future increases in water production.

The intensity and patterns of water demand in Iowa have changed over the last 20 years and will probably change much more in the next 20 years. Currently about 80 percent of Iowans depend on groundwater for their drinking water supplies. An updated comprehensive water resource evaluation is needed to produce accurate forecasts of water availability, quantity and quality, and to avoid long-term water shortages and prevent conflicts between water users in the future. The revised evaluation will quantify what is currently available in Iowa's aquifers, show water level trends over time, document current levels of use, and most importantly, make it possible to create reliable projections for sustainable water use into the future.

In recent years, watershed assessments have become the preferred approach to natural resource management and addressing water quality problems. It should be understood that watersheds extend below the land surface and include the movement of groundwater beneath them. To improve water quality within a watershed, one first needs to understand how the water moves through the watershed over the land and through the underlying geologic framework of soil and rock. It is essential that watershed assessments extend below the land surface and include the movement of groundwater through time because contaminants can travel with groundwater beneath the land surface and eventually be delivered back into streams and lakes.

Everything we do on the land affects the quality and quantity of our water resources and the natural systems around us. As a result, our natural resources and the quality of our lives are directly affected by the way we plan for and manage our land and waters. A better understanding of groundwater within its geologic framework and its interaction with surface water will lead to better use, protection, and management of Iowa's most valuable natural resource.

The geologic container that holds Iowa's waters may seem static, yet it is rather dynamic. The quantity and quality of water that is continually added and removed from it are constantly changing, as are demographic and climatic trends. One of the few certainties in life is the continual need for clean water. The key to a comprehensive and integrated Water Resources Management program is to update the plan regularly to accommodate demographic and climatic trends, and account for changing patterns of land and water use as they emerge. An updated Water Resources Management plan will help us make well informed, proactive decisions about how we our use our water resources as our knowledge of them improves.

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The geologic samples, water levels, and pumping tests that the maps in this report are based on were collected over many years by numerous individuals from private, public, and government sectors from public and private wells across northwest Iowa. Most of the information is from public water supply wells, but data from a variety of projects, including aquifer and water studies are also included in the map layers. Most geologic samples are collected by well drillers during well construction, and while fewer in number, outcrop observations provide important information that can not be derived from well cuttings.

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This report is a component of the new Water Resources Management program, which is being funded by legislative approval of a one-time appropriation of funding to support water resource studies in Iowa. Currently, efforts are underway to secure sustainable funding for continued study and management of Iowa's water resources through an improved water resource permitting system.

Iowans are responsible for influencing their legislators to fund natural resource programs and associated studies. They are often important cooperators involved in these studies, and hopefully they are the main benefactors of the research. Many thanks to those who have granted us access over the years, and allowed us to study their natural resources.

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