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SAND-DISTRIBUTION MODEL

By

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	LINCOLN COUNTY Sand and gravel	LINCOLN COUNTY Lake	LINCOLN COUNTY Till	PIPESTONE COUNTY Sand and gravel	PIPESTONE COUNTY Lake	PIPESTONE COUNTY Till
Post-glacial	al	hl		al	hl	
Late Wisconsinan sediment, undifferentiated		sc				
New Ulm Formation, undifferentiated	nuo	nul		nuo	nul	
New Ulm Formation, Dovray Member			nd			
New Ulm Formation, Ivanhoe Member	*nio2*		ni (1-2)	*nio (1-2)*		ni (1-2)
New Ulm Formation, Verdi Member	nvo (1-2)		nv (1-2)	*nvo2*		nv (1-2)
Pre-Wisconsinan, undifferentiated				oo	ol	
Hatfield till						hf
Cazenovia till	*czo*		*cz*	*czo*		cz
Magnolia till	*mgo*		*mg*	*mgo*		*mg*
Unknown Riding Mountain sediment	*urmo*		*urm*			
Unknown Riding Mountain/Winnipeg sediment			*urw*			
Unknown Rainy sediment				*qo4*		*qd4*
Unknown Winnipeg sediment				*qo5*		*qd5*
Undifferentiated sediment	*uno (1-2)*		*un*	*uno*		*un*

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- Post-glacial sand and gravel
- Post-glacial silt and clay
- Sand and gravel
- Silt and clay
- Riding Mountain provenance
- Riding Mountain/Winnipeg provenance
- Winnipeg provenance
- Rainy provenance
- Unknown provenance

Figure 1. Correlation of stratigraphic units depicted on cross sections in Lincoln County and adjacent Pipestone County (Conrad and others, in press).

INTRODUCTION

The Quaternary sand and gravel deposits of Minnesota are products of a complex history of multiple glacial events that makes mapping of these potential aquifers challenging. However, establishing the location and characteristics of sand and gravel aquifers is an essential step toward their wise use and protection. In Lincoln County, this project employed a process that combined the understanding of a geologist and the expertise of a geologic information specialist with the data-handling capabilities of a geographic information system (GIS) to create three-dimensional models showing the distribution of Quaternary sand and gravel deposits that may be aquifers. The three-dimensional models relate sand and gravel bodies to the glacial events that formed them. Although the models and interpretations are based on the best available data, they are unavoidably incomplete due to a lack of data in some areas, particularly at depth.

Sand and gravel deposits at the land surface are mapped by a geologist from exposures, shallow drill holes, soil maps, and landforms. In contrast, mapping sand and gravel deposits in the subsurface relies primarily on water-well records, supplemented with engineering boring logs, scientific drill core, and drill cuttings. Each well record or drill log describes the vertical sequence of earth materials at one location. It falls to the geologist to predict what materials occur in the areas between wells or at depths not penetrated by the wells. That prediction is based on an assessment of the available data and an understanding of the glacial history and processes that created the glacial sediment. The distribution of data greatly affects the resolution and accuracy of our models. For example, if the wells are widely spaced, there will not be enough that intersect deposits of limited extent to support accurate mapping of those features. In a similar manner, bodies of sand and gravel at greater depths are typically intersected by fewer wells because shallower bodies of sand and gravel are adequate to supply water and there is no need to continue drilling.

The unconsolidated Quaternary sediments that overlie the bedrock in Lincoln County vary greatly in character and thickness. On average, the Quaternary sediments are 525 feet (160 meters) thick (Plate 6, *Depth to Bedrock*). These deposits are largely the result of many distinct glacial-ice advances during the Pleistocene Epoch (Plate 4, *Quaternary Stratigraphy*, Fig. 2), and therefore most of the Quaternary aquifers within Lincoln County consist of sand and gravel beds laid down by meltwater that flowed from these glaciers, forming deposits along rivers and in lakes. Layers of unsorted sediment (diamicton) composed of clay to boulder-sized particles deposited directly from the ice, termed till, and fine-grained clay- and silt-rich bedded sediment deposited in ponded meltwater in front or on top of the glaciers, form aquitards that enclose the aquifers. The till layers left by each ice sheet tend to be more laterally persistent than the sand and gravel layers because ice typically spreads across a given area, whereas meltwater streams that deposited the sand and gravel were generally confined to drainages occupying lower elevations of the evolving landscape. Sand and gravel may be deposited by both an advancing glacier and a retreating glacier of the same cycle, thus till from an ice advance may bury its own sand and gravel, as well as material deposited during a previous glacial event. In this report, the depicted sand and gravel bodies have been named after the underlying till (except for those at the land surface [units *al*, *nuo*] and those that overlie undifferentiated sediment [units *uno*, *uno2*]).

Glacial ice and meltwater not only deposited sediments but also eroded older, underlying sediments, creating a very disturbed "layer cake" stratigraphy. A new layer of sand or till could fill a void eroded into an older layer or could completely take the place of an older layer given sufficient erosion. The net effect of this depositional and erosional activity is that sand and gravel bodies that provide water to wells in Lincoln County tend to be discontinuous. Over relatively short distances in most directions, the extent and thickness of any given aquifer is difficult to predict. To address this, 49 closely spaced (0.6 mile [1 kilometer]) cross-section lines were generated in an east–west direction (see Plate 4, Fig. 1). Along these lines, water-well records, records of scientific and engineering test holes, and descriptions of exposures (Plate 1, *Database Map*) were used by a geologist to identify contacts between units in the subsurface. Final interpretations along five of these cross sections are shown on Plate 4; all additional cross sections are available in the supplementary files.

Till is generally described as "clay" by well drillers. Although sand and gravel deposits can occur within a till, they occur more commonly and tend to be thicker and more continuous at the contact between two till sheets. Where two clay (till) layers related to different depositional events are not separated by a sand and gravel layer, their contact may be recognized by a change in the driller's description of the clay's texture (for example clay/sandy clay/clay and gravel), density, or color. Using the available data, contact lines were drawn along each cross section, with each line representing the base of a unit of sand and gravel or till. Coordinates and elevations from the geologic unit contacts are extracted from the cross sections in GIS and interpreted into a unit surface. The resulting rasters represent the distribution of the geologic units over the county in three dimensions. The till and sand surfaces were iteratively modified until the geologist was confident that they adequately represented the stratigraphic interpretation for most water-well data. When the till and sand-surface rasters representing the base of each unit were final, they were processed through GIS raster calculations to create top and bottom surfaces and a thickness for each geologic unit. The result is a three-dimensional geologic model of tills and sand and gravel deposits for the county. All model outputs are available digitally as raster datasets in the supplementary files accompanying this plate.

The stratigraphic order of the sand and till units in Lincoln County are illustrated in Figure 1. The sand and gravel deposits portrayed by the geologic model are shown in Figures 2 through 9. Undifferentiated sediment (unit *unk*) is portrayed in Figure 10, indicating areas where the characteristics of deeper deposits cannot be differentiated due to the lack of data. Figure 11 illustrates that several areas in Lincoln County are underlain by multiple sand bodies, while areas in white represent where there are no mapped sand units. However, many of the areas lacking delineated sands also have few or no well records (see Plate 4, Fig. 1).

Several factors determine whether the sand and gravel units depicted here are usable aquifers. To be an aquifer, the units must be saturated and able to readily transmit water to a well. Their capacities for water storage and transmission depend on their extent and thickness, as well as factors such as texture, degree of sorting, consolidation, and connectivity between sand and gravel units. In many places, two or more sand and gravel units may connect to form a single aquifer if there is no intervening till layer. Water quality also determines whether an aquifer is suitable as a source of drinking water. Maps and reports included in Part B of the Lincoln County Atlas, produced by the Minnesota Department of Natural Resources, will describe aquifer characteristics including chemistry, pollution sensitivity, and groundwater flow direction.

The geologic model should be considered a probability map for the occurrence and approximate thickness of major sand and gravel deposits. The model does not guarantee sand and gravel will be found at all places shown, nor does it preclude them from being found in areas where they are not shown. Sand and gravel deposits that were too thin or did not extend to neighboring cross sections commonly were eliminated by the processing that created the multiple surfaces. Because wells typically do not penetrate the complete thickness of a sand and gravel layer, drillers' logs commonly underreport sand-deposit thickness. As a result, some of the sand and gravel deposits may be thicker and more widespread than portrayed. At increasing depths in the stratigraphic section, data availability diminishes, and delineated sand and gravel deposits could be more or less discontinuous than shown. The older, deeper sand and gravel in some areas are portrayed as bar-shaped in an east–west direction. The true shape of the sand body is likely distorted due to the low density of well logs across Lincoln County, especially at depth, and the nature of the mapping of these deposits along cross sections in an east–west direction. Despite these constraints, the geologic model provides a realistic interpretation of where and what kind of geologic units would be encountered in the subsurface of Lincoln County. However, given the limits of the data, as noted above, the model should be used as a guide and should not preclude further site-specific investigations or inspection of individual well logs.

REFERENCE

Conrad, D.R., Gowan, A.S., and Van Berkel, J.T., in press, Quaternary stratigraphy, pl. 4 of Retzler, A.J., project manager, Geologic atlas of Pipestone County, Minnesota: Minnesota Geological Survey County Atlas C-59, 6 pls., scale 1:100,000.

CONTOURS FOR FIGURES 2 THROUGH 9

Thickness of a sand and gravel unit contoured at 20-foot (6-meter) intervals.

- 20
- 40
- 60
- 80
- 100
- 120
- 140 and greater

Note: Contour lines may not close at the edges of mapped areas. This is an artifact of the digital processing.

DEPTH FOR FIGURES 3 THROUGH 10

- 0–50
- 51–100
- 101–150
- 151–200
- 201–250
- 251–300
- 301-350
- 351–400
- 401 and below

Depth in feet from the land surface to the top of a sand and gravel unit (depth from the land surface to the top of undifferentiated sediment is shown on Figure 10).

SCALE 1:300 000
5 0 5 10 MILES
5 0 5 10 KILOMETERS

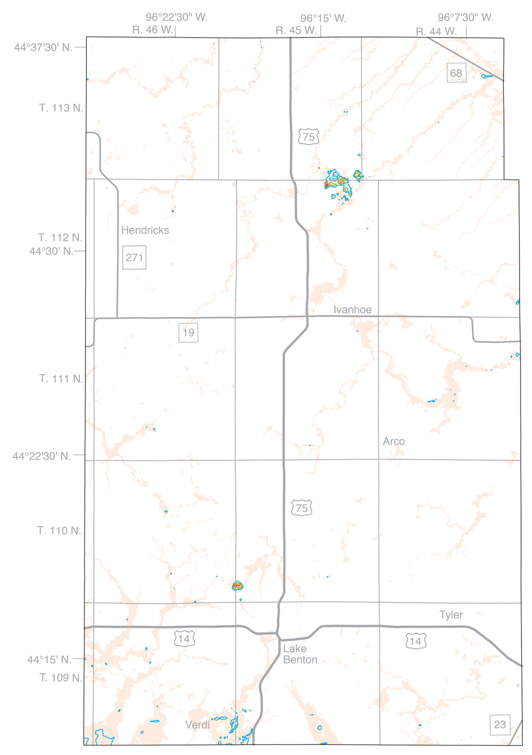

Figure 2. Surficial sand and gravel—Model-generated map showing the extent and thickness of sand and gravel bodies generally occurring at or near the land surface. Includes units *al* and *nuo* from Plate 3, *Surficial Geology*. Varies in cumulative thickness from 0 to 100 feet (0 to 30.5 meters), averaging 7 feet (2.1 meters).

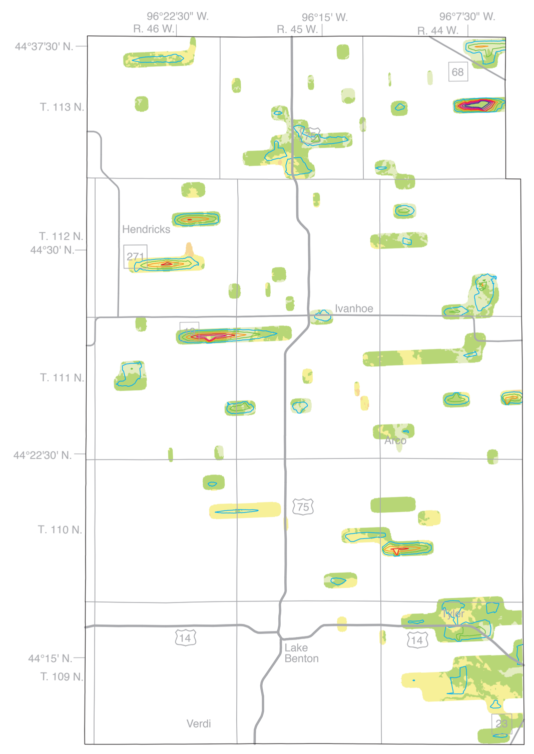

Figure 3. Sand and gravel unit *nio2*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit ni2 and below till of unit nv. This unit is generally discontinuous and may overlie older, deeper sand and gravel units in places. It was deposited by meltwater from a late Wisconsinan ice advance of Riding Mountain provenance. It may also include sand and gravel associated with an overlying ice advance of Riding Mountain provenance. Modeled to a maximum depth from the land surface of 190 feet (57.9 meters) and varies in cumulative thickness from 0 to 194 feet (0 to 59.1 meters), averaging 16 feet (4.9 meters).

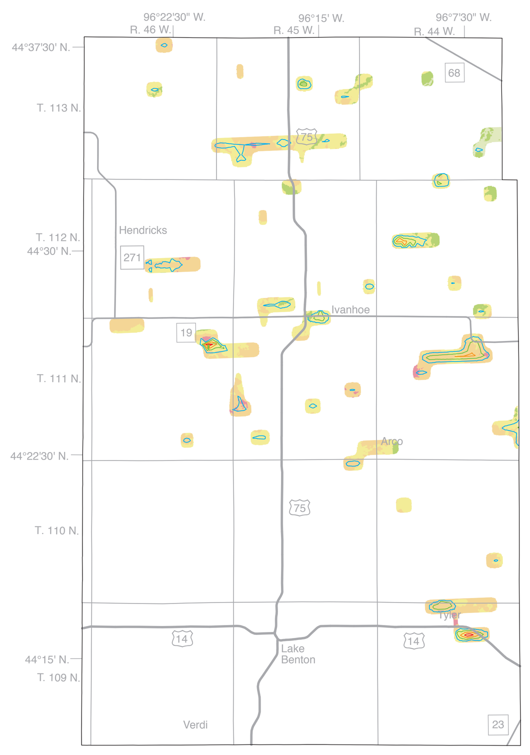

Figure 4. Sand and gravel unit *nvo*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit nv and below till of either unit ni and/or unit ni2. This unit is generally discontinuous. It was deposited by meltwater from a middle Wisconsinan ice advance of mixed Winnipeg and Riding Mountain provenance. It may also include sand and gravel associated with an overlying ice advance of Riding Mountain provenance. Modeled to a maximum depth from the land surface of 226 feet (68.9 meters) and varies in cumulative thickness from 0 to 93 feet (0 to 28.3 meters), averaging 13 feet (4.0 meters).

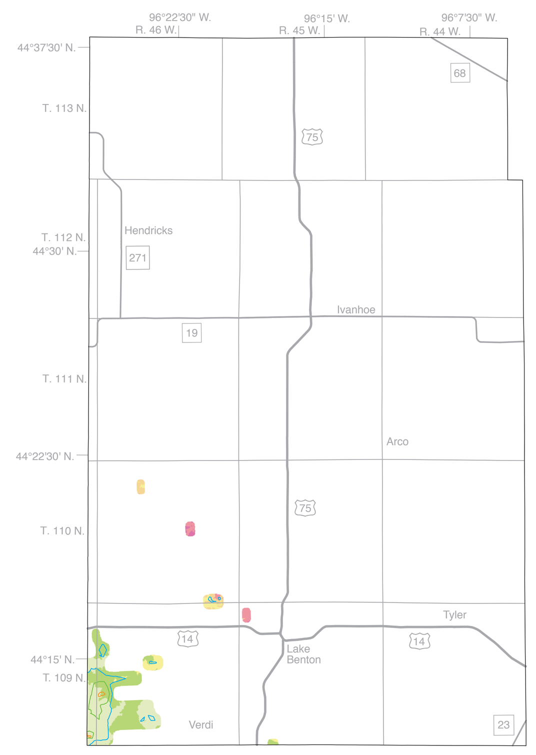

Figure 5. Sand and gravel unit *nvo2*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit nv2 and below till of unit nv. This unit is generally discontinuous. It was deposited by meltwater from a middle Wisconsinan ice advance of mixed Winnipeg and Riding Mountain provenance. It may also include sand and gravel associated with an overlying ice advance of Riding Mountain provenance. Modeled to a maximum depth from the land surface of 268 feet (81.7 meters) and varies in cumulative thickness from 0 to 63 feet (0 to 19.2 meters), averaging 17 feet (5.2 meters).

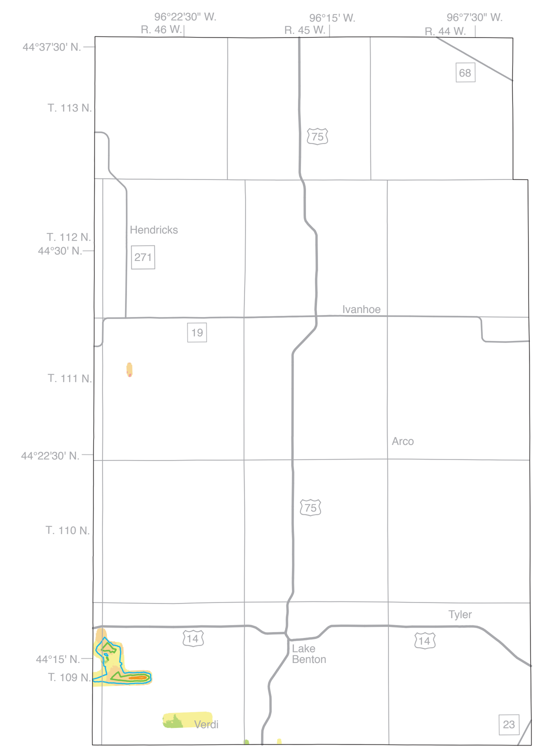

Figure 6. Sand and gravel unit *czo*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit *cz* and below till of either unit nv and/or unit nv2. This unit is generally discontinuous. It was deposited by meltwater from a pre-Wisconsinan ice advance of Rainy provenance. It may also include sand and gravel associated with the overlying ice advance of mixed Winnipeg and Riding Mountain provenance. Modeled to a maximum depth from the land surface of 205 feet (62.5 meters) and varies in cumulative thickness from 0 to 68 feet (0 to 20.7 meters), averaging 18 feet (5.5 meters).

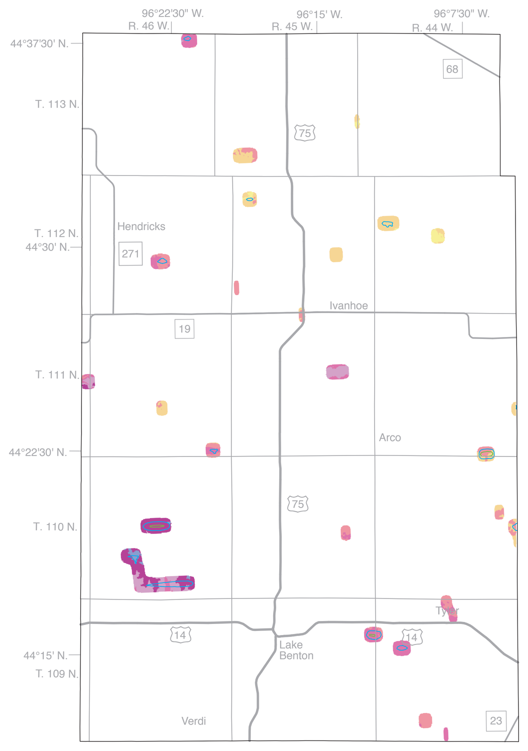

Figure 7. Sand and gravel unit *mgo*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit *mg* and below till of either unit *cz* and/or unit nv. This unit is generally discontinuous. It was deposited by meltwater from a pre-Wisconsinan ice advance of Riding Mountain provenance. It may also include sand and gravel associated with the overlying ice advance of Rainy provenance. Modeled to a maximum depth from the land surface of 410 feet (125.0 meters) and varies in cumulative thickness from 0 to 60 feet (0 to 18.3 meters), averaging 10 feet (3.0 meters).

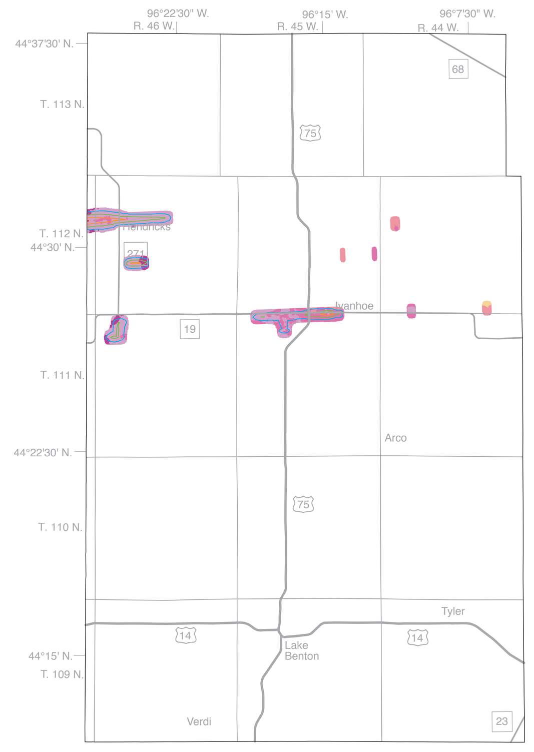

Figure 8. Sand and gravel unit *urmo*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above till of unit *urm* and below till of unit *mg*. This unit is generally discontinuous and may overlie older, deeper sand and gravel units in places. It was deposited by meltwater from a pre-Wisconsinan ice advance of Riding Mountain provenance. It may also include sand and gravel associated with an overlying ice advance of Riding Mountain provenance. Modeled to a maximum depth from the land surface of 372 feet (113.4 meters) and varies in cumulative thickness from 0 to 80 feet (0 to 24.4 meters), averaging 23 feet (7.0 meters).

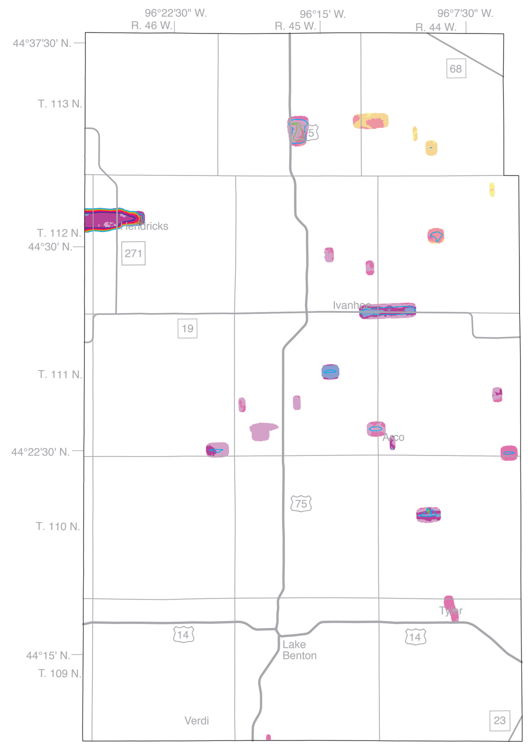

Figure 9. Sand and gravel units *uno* and *uno2*—Model-generated map of the extent, depth from the land surface, and thickness of sand and gravel bodies stratigraphically immediately above unit *un* and/or *unk*. This unit is generally discontinuous. It was deposited by meltwater from a pre-Wisconsinan ice advance of unknown provenance. Unit *uno* is modeled to a maximum depth from the land surface of 424 feet (129.2 meters) and varies in cumulative thickness from 0 to 297 feet (0 to 90.5 meters), averaging 44 feet (13.4 meters). Unit *uno2* is modeled to a maximum depth from the land surface of 558 feet (170.1 meters) and varies in cumulative thickness from 0 to 68 feet (0 to 20.7 meters), averaging 13 feet (4.0 meters).

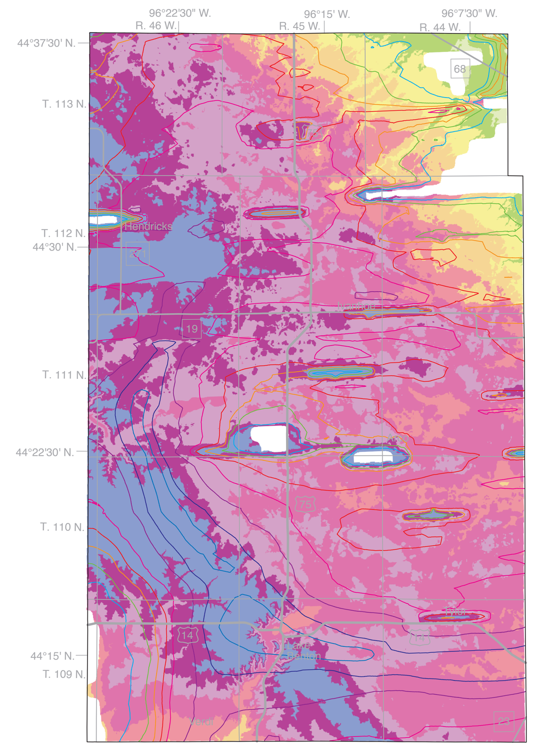

Figure 10. Undifferentiated sediment, unit *unk*—Model-generated map of the extent, depth from the land surface, and thickness of Quaternary sediment for which no descriptive data are available, contoured at 50-foot (15-meter) intervals. Unit *unk* is modeled to a maximum depth from the land surface of 663 feet (202.1 meters) and varies in cumulative thickness from 0 to 434 feet (0 to 132 meters), averaging 232 feet (70.7 meters).

CONTOURS FOR FIGURE 10

Thickness of undifferentiated sediment.

- 50
- 100
- 150
- 200
- 250
- 300
- 350
- 400

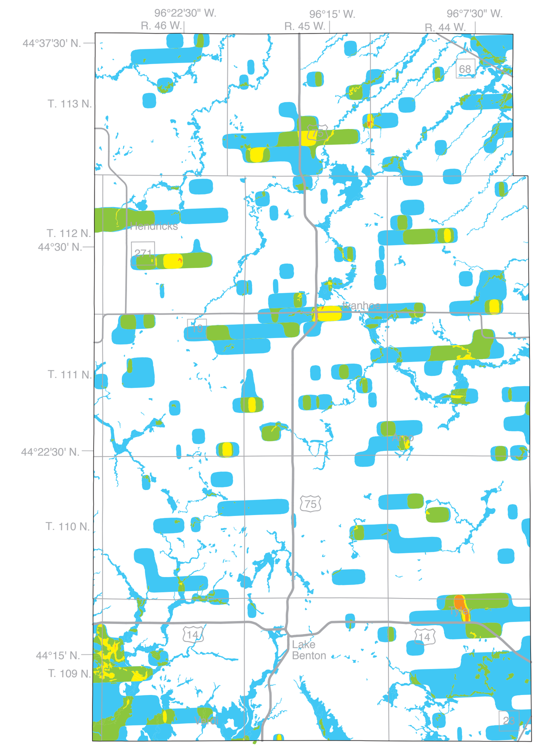

Figure 11. Number of sands bodies—Model-generated map of the extent and number of Quaternary sand bodies (as defined in the model) encountered between the land surface and bedrock. The individual sand bodies are not necessarily interconnected. Uncolored areas have no mapped sand units. Maximum overlapping sand bodies is 4.

NUMBER OF SAND UNITS
- 1
- 2
- 3
- 4

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