Geology of the Lower Dakota Aquifer

Iowa's Water Resources Management Program

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. Since groundwater supplies 80 percent of Iowans with 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 and vulnerable natural resource.

The last comprehensive state water plan for Iowa was completed in 1978 by the Iowa Natural Resources Council. Additional plans and programs have been developed since 1978, however, these efforts were never integrated into a complete 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.

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 do not have sufficient information or resources available at the state level to answer basic questions regarding how much water can be withdrawn from Iowa's aquifers on a sustainable basis, without significantly lowering water levels and depleting very long-term groundwater storage.

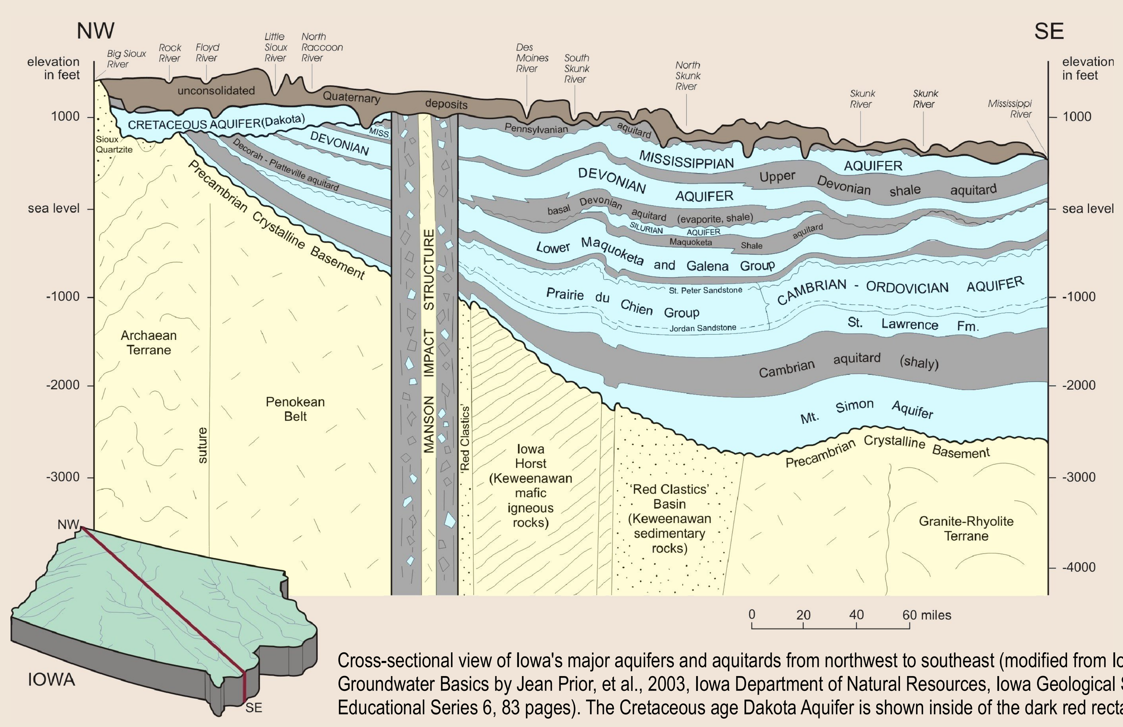
Following a proposal in 2007 from the Iowa Geological and Water Survey (IGWS) to characterize the availability, quality, use, and sustainability of Iowa's surface and groundwater resources, the Iowa legislature funded a comprehensive Water Resources Management program.

To be useful, the information from the water resource investigations 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 with the ability 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 IGWS Natural Resources GIS (NRGIS) Library at www.igsb.uiowa.edu/nrgislibx/. Water resources investigation reports and miscellaneous map series maps will be available from the IGWS in hard copy or downloadable PDF format at www.igsb.uiowa.edu/gsbpubs/.

The Dakota Aquifer is the first aquifer to be studied under the auspices of the 2008 Water Resources Management program. The geologic and hydrologic evaluations concentrate on the Lower Dakota Aquifer. The water-quality evaluation focuses on the entire Dakota Aquifer.

This miscellaneous map series, or hydrologic atlas, is the first of a new series of investigations to delineate the occurrence, movement, availability, use, chemical quality, and vulnerability of groundwater from Iowa's major aquifers. 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.

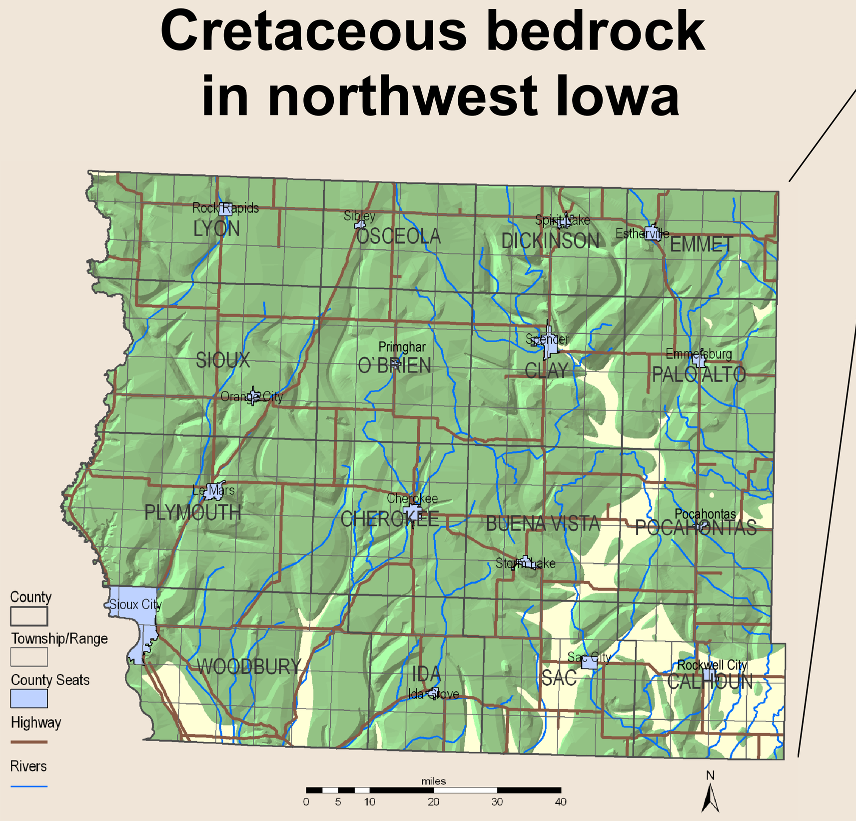
Aquifer systems of Iowa



Cross-sectional view of Iowa's major aquifers and aquitards from northwest to southeast (modified from Iowa's Groundwater Basics by Jean Prior, et al., 2003, Iowa Department of Natural Resources, Iowa Geological Survey Educational Series 6, 83 pages). The Cretaceous age Dakota Aquifer is shown inside of the dark red rectangle.

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 slow the movement of water between the aquifers. 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).

Cretaceous bedrock in northwest Iowa



Area of occurrence of Cretaceous bedrock within the 16-county Dakota Aquifer study area in western Iowa.

Much of the study area is underlain by Cretaceous bedrock, which is buried beneath relatively thick Quaternary sediments over most of the region. The Dakota Aquifer is part of a sequence of sandstone, limestone, and shale deposited during the Cretaceous Period by five major transgressive-regressive marine cycles that inundated Minnesota, Iowa, and western Wisconsin from the west. The rocks were deposited on an irregular erosional surface as fluviodeltaic deposits on crystalline and sedimentary rocks of Precambrian and Paleozoic ages. Following deposition, the bedrock surface was deeply eroded prior to glaciation, and the Cretaceous rocks were removed completely in some areas. Similarly, the rocks are thin or missing over highs on the underlying unconformity, such as the Sioux Quartzite Ridge in northwest Lyon County.

The Dakota Aquifer is composed mainly of sandstone and provides water for domestic and public water supplies in western Iowa. The initial study concentrates on the lower part of the Dakota Aquifer within the 16 counties in northwest Iowa.

Cretaceous stratigraphy in northwest Iowa

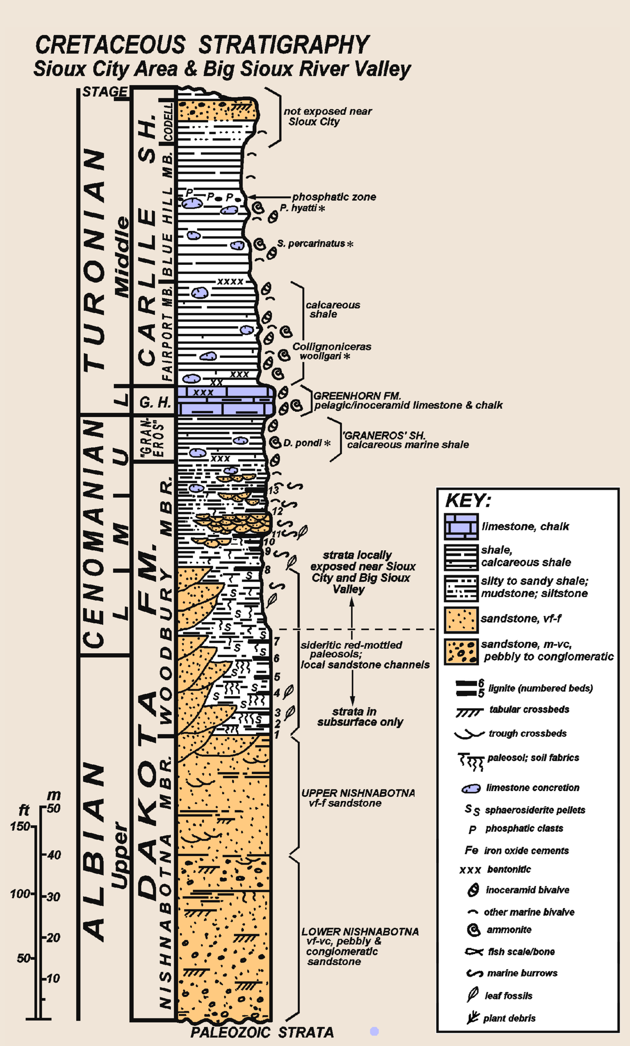
The Dakota Formation is characterized by a succession of poorly consolidated sandstones, which are best developed in the lower part of the formation, and mudstones or shaly strata, which typically dominate the upper portion. Where overlain by younger Cretaceous strata, the Dakota Formation reaches a maximum thicknesses of about 500 feet in northwestern Iowa. Formation thickness is highly variable due to the relief of the underlying sub-Cretaceous surface and the significant sub-Quaternary erosional truncation of Dakota strata across most of the area. Where the Dakota Formation forms the bedrock surface in northwest Iowa, it ranges from less than 50 feet to about 450 feet in thickness.

The Dakota Aquifer is used for rural, industrial and public water supplies in western Iowa. The 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. These deposits formed in riverine environments 100 mya. Sediments of the Nishnabotna Member were aggraded in large, mostly braided river systems that drained westward across Iowa into the nearby Western Interior Seaway. Most sandstone and mudstone strata of the Nishnabotna Member represent fluvial and floodbasin deposits, but estuarine sediments are locally recognized in the lower part of the member. The Woodbury Member was also deposited primarily in aggrading large rivers, but mostly by meanderbelt systems with extensive floodbasins and overbank deposits.

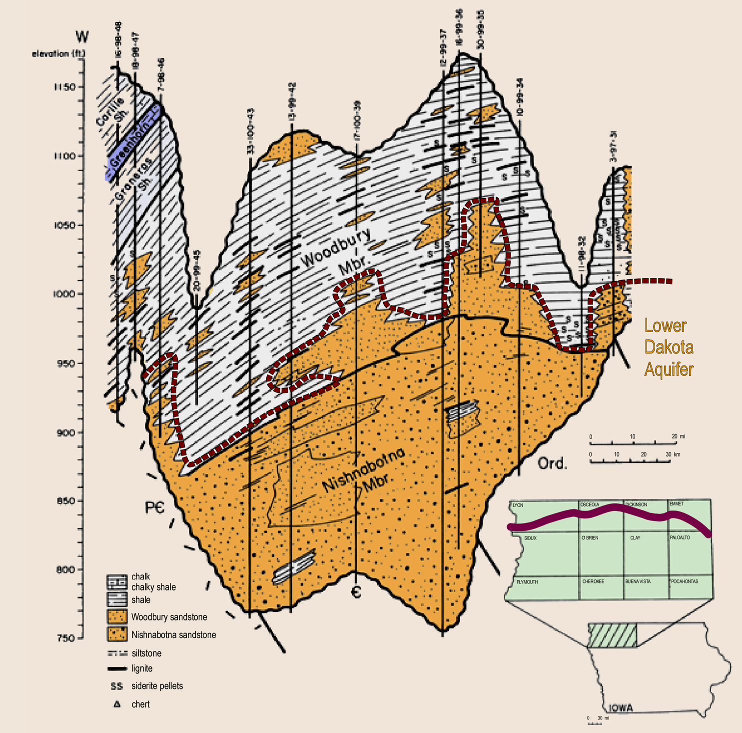
Woodbury rocks form a minor aquifer with low to moderate yields, which grades to a confining layer, while Nishnabotna rocks form a major aquifer capable of yielding greater than 1,500 gallons per minute (gpm) in some areas. Because of the greater continuous areal extent and higher yields, the initial study concentrates on the lower part of the Dakota Aquifer within the study area in northwest Iowa.

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. The confining beds underlying the aquifer include Dakota shales, undifferentiated Paleozoic rocks, and Precambrian crystalline rock.

In areas where the aquifer is overlain by a thick sequence of Quaternary material, primarily glacial till and upper Cretaceous shale, it is less vulnerable to contamination from the land surface.



Geologic cross section through Cretaceous strata in northwest Iowa



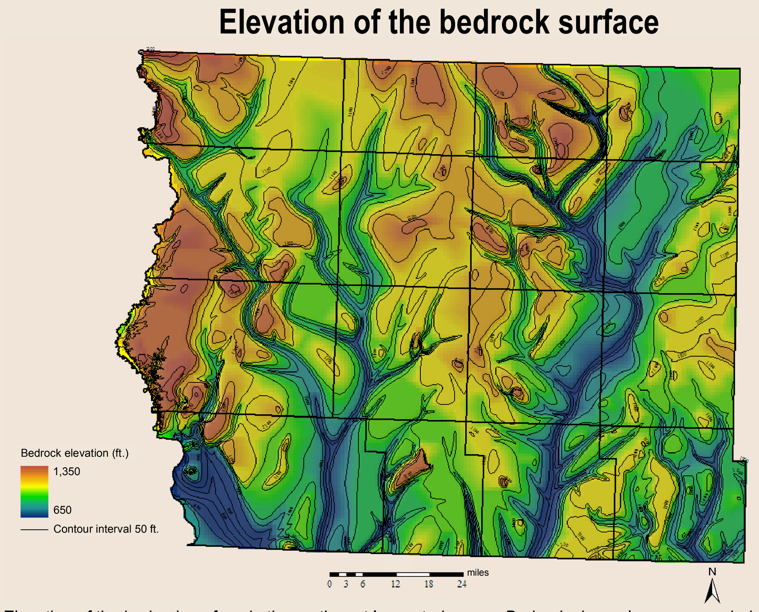
Cretaceous marine strata, primarily shale, overlie the Dakota Formation in areas of northwest Iowa, especially in the western part. Most of these strata are included within the Fort Benton Group, an interval comprising, in ascending order, the "Graneros" Shale, Greenhorn Formation, and Carlile Shale. This interval reaches maximum thicknesses of about 200 feet in the study area. Outliers of the Niobrara Formation have recently been recognized in western Lyon County, and Cretaceous-aged rocks of the Manson Impact Structure are found in the southeastern part of the study area.

The upper, Woodbury Member of the Dakota Formation is lithologically variable, but is generally dominated by gray- and red-mottled mudstones at most localities, often with some subsidiary sandstone or siltstone beds. Locally the Woodbury contains thick but discontinuous sandstone channel bodies. These sandstones are generally very fine- to fine-grained and regionally comprise less than 20 to 30% of the Woodbury interval. Because of the local prominence of these sandstone bodies, especially in the lower part of the member, it can be difficult to differentiate these sandstones from those of the underlying Nishnabotna Member. The Woodbury is erosionally truncated across much of northwest Iowa, where it forms the Cretaceous bedrock surface. It reaches maximum thickness of 150 to 230 feet in the area, where covered by younger Cretaceous strata. Woodbury strata overstep the Nishnabotna edge to directly overlie Precambrian and Paleozoic rocks in portions of the study area, including parts of Lyon, Osceola, Emmet, Palo Alto, Pocahontas, and Calhoun counties.

The Nishnabotna Member forms a continuous sandstone across much of the study area. The sheet-like geometry of porous and permeable sandstone forms the primary and most productive portion of the Dakota Aquifer in Iowa. The member ranges from 0 to over 300 feet in thickness in northwest Iowa, reaching its maximum thicknesses in parts of Woodbury and Plymouth counties. In general, the Nishnabotna is thickest within a broad southwestward-trending topographic low developed across the eroded sub-Cretaceous surface, and it is overstepped by upper Dakota strata eastward onto the elevated Paleozoic bedrock surface and northwestward onto elevated areas of Precambrian bedrock.

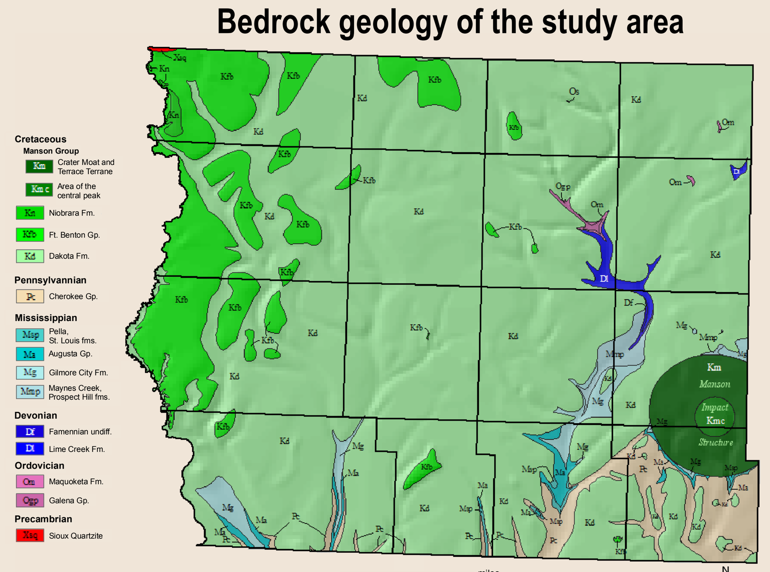
The Lower Dakota Aquifer is comprised of the contiguous sandstones of the Nishnabotna and Woodbury members.

Elevation of the bedrock surface



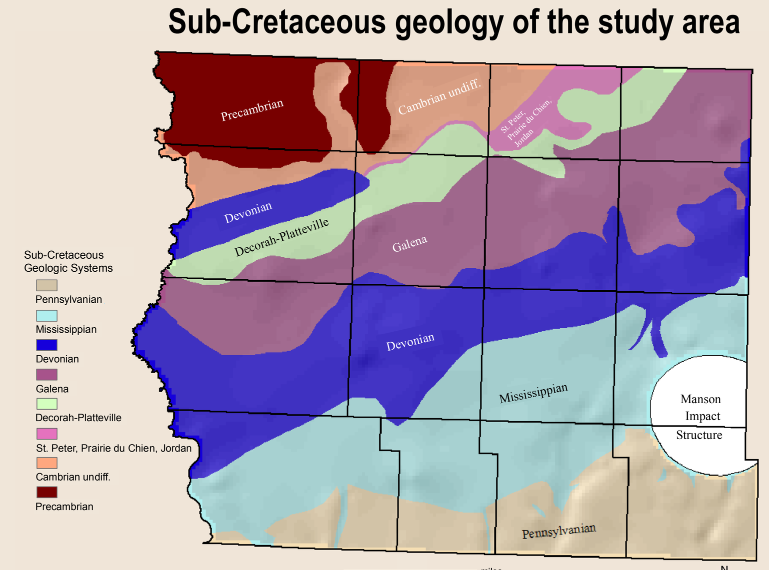
Elevation of the bedrock surface in the northwest Iowa study area. Bedrock channels appear as dark green and blue linear features

Bedrock geology of the study area



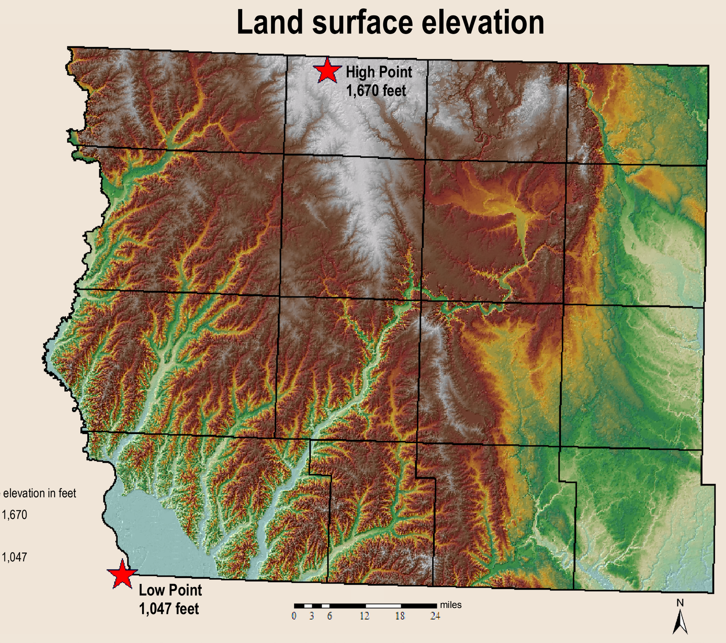
Bedrock geology of the northwest Iowa study area. Bedrock topography shown as shaded background.

Sub-Cretaceous geology of the study area



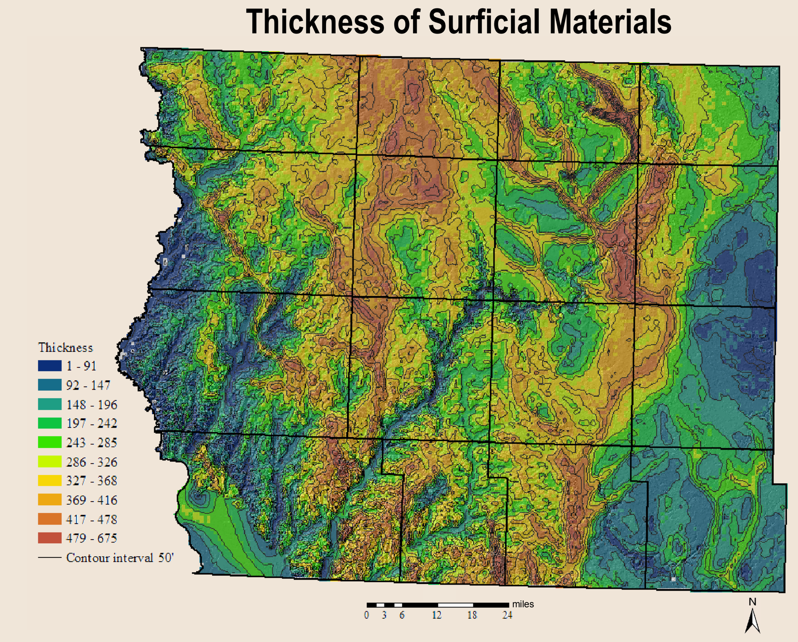
Geology of the sub-Cretaceous surface in the northwest Iowa study area.

Land surface elevation



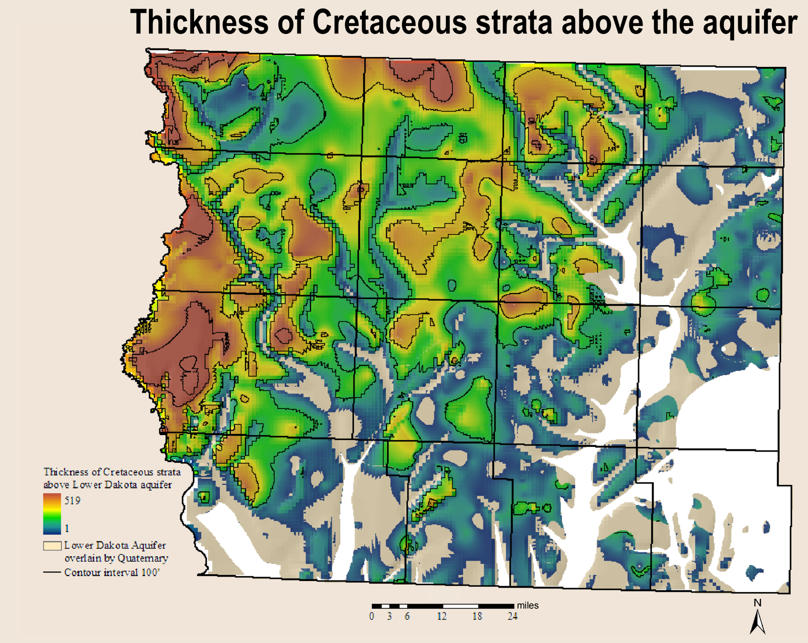
Land surface elevation in feet above sea level within the 16-county study area in northwest Iowa. The northwest quarter of the area consists of gently rolling to nearly flat plains of the Northwest Iowa Plains landform region. The south central portion of the area includes the gently rolling Southern Iowa Drift Plain. The southwest quadrant of the area includes the northern end of the high relief Loess Hills region and the moderately high relief Southern Iowa Drift Plains. The eastern portion of the area includes the moderately low relief Des Moines Lobe region and the southwestern corner includes the extremely flat Missouri River Alluvial Plain.

Thickness of Surficial Materials



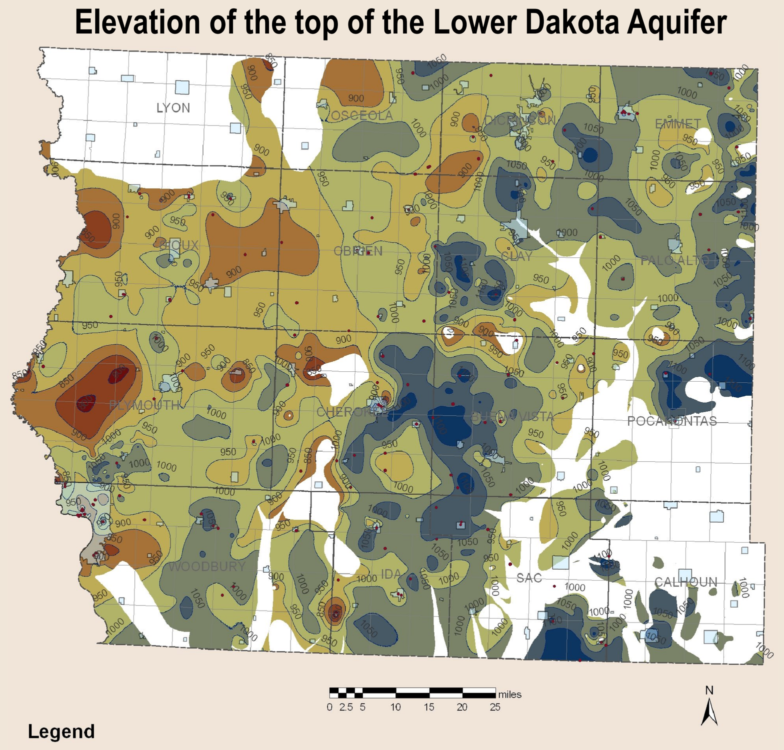
Isopach or thickness map of unconsolidated Quaternary materials in northwest Iowa. These materials include glacial till, alluvium, loess, and various inter-till and sub-till sediments. Although most of these materials are of Quaternary age, it is likely that some sediments may be of Pliocene, or possibly Miocene age. The materials may include from youngest to oldest: Holocene (modern) river deposits, Pleistocene loess (wind-blown silt), Pleistocene glacial materials (including glacial till and related deposits), buried bedrock valley fill materials, and Tertiary "Salt and Pepper" sands.

Thickness of Cretaceous strata above the aquifer



Isopach or thickness map of Cretaceous strata above the Lower Dakota Aquifer in northwest Iowa. This interval is dominated by shale and mudstone, but locally may include thin and discontinuous sandstone units of the Woodbury Member that are not directly connected to the Lower Dakota Aquifer, but are physically separated from it by intervening mudstone strata. The lateral extent of these upper Dakota sandstones is limited, and most appear to be less than a mile or two in cross-sectional dimensions. However, these sandstone bodies may extend as elongate channels within the surrounding mudstone, and some could possibly extend in their long dimension distances spanning one or two counties

Elevation of the top of the Lower Dakota Aquifer



Legend

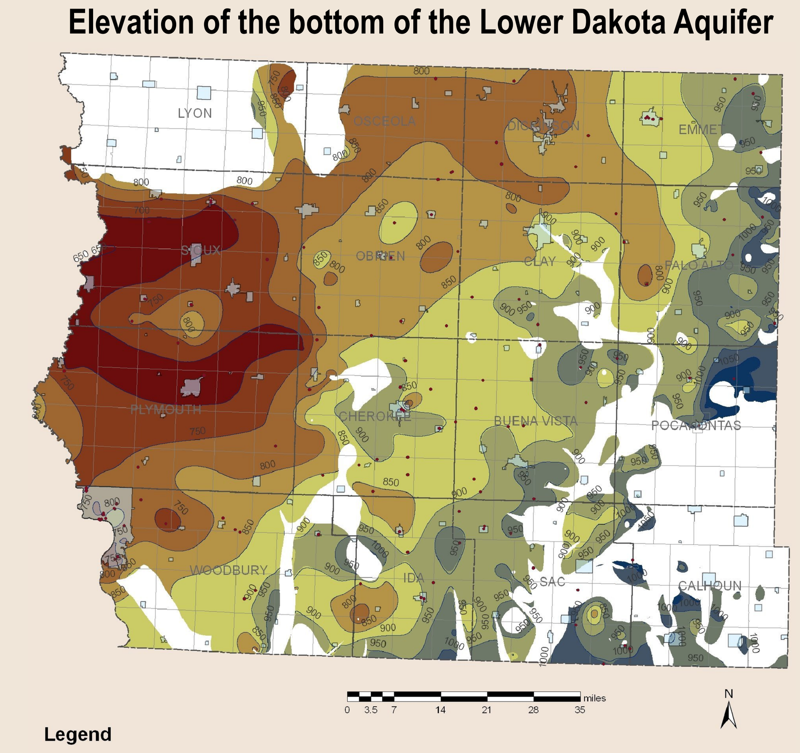
- Measured wells (n = 130)
- Lines of equal elevation in feet above mean sea level

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

750 - 800; 800 - 850; 850 - 900; 900 - 950; 950 - 1,000; 1,000 - 1,050; 1,050 - 1,100; 1,100 - 1,150

Elevation of the top of the Lower Dakota Aquifer in feet above mean sea level. 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. The upper surface of the aquifer forms a highly irregular surface which is defined by the complex arrangement of contiguous sandstone and mudstone lithofacies within the Dakota Formation. 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.

Elevation of the bottom of the Lower Dakota Aquifer



Legend

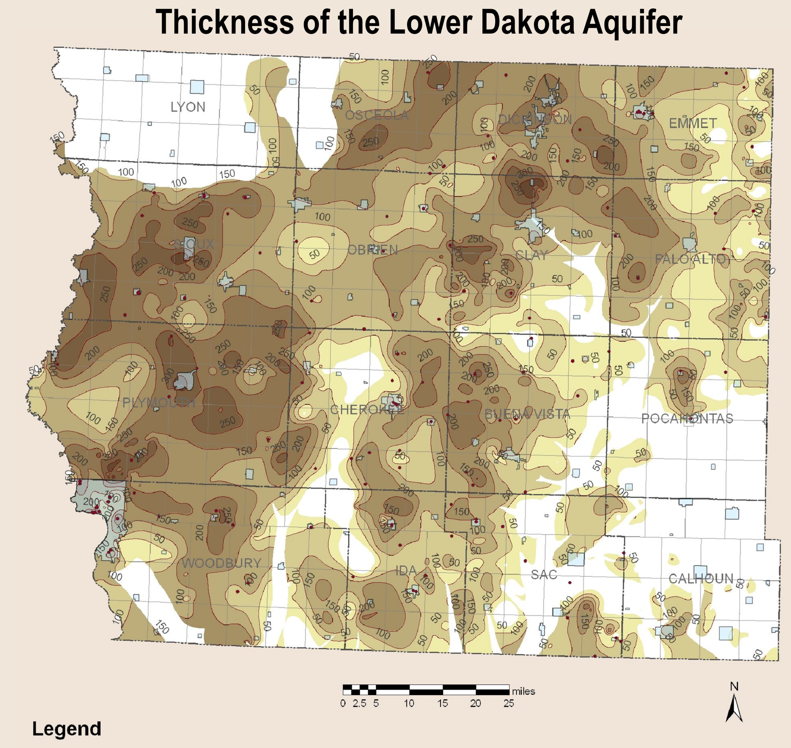
- Measured wells (n = 130)
- Lines of equal elevation in feet above mean sea level

Elevation of the bottom of the Lower Dakota Aquifer 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

Elevation of the bottom of the Lower Dakota Aquifer in feet above mean sea level. Paleocurrent data suggest that the surface formed by the unconformity at the base of the Cretaceous system is a drainage or stream-dissected surface with net transport of Dakota-age sediment to the southwest. The highest elevations occur in the southeastern half of the study area, and 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 the topography of the overlying land surface.

Thickness of the Lower Dakota Aquifer



Legend

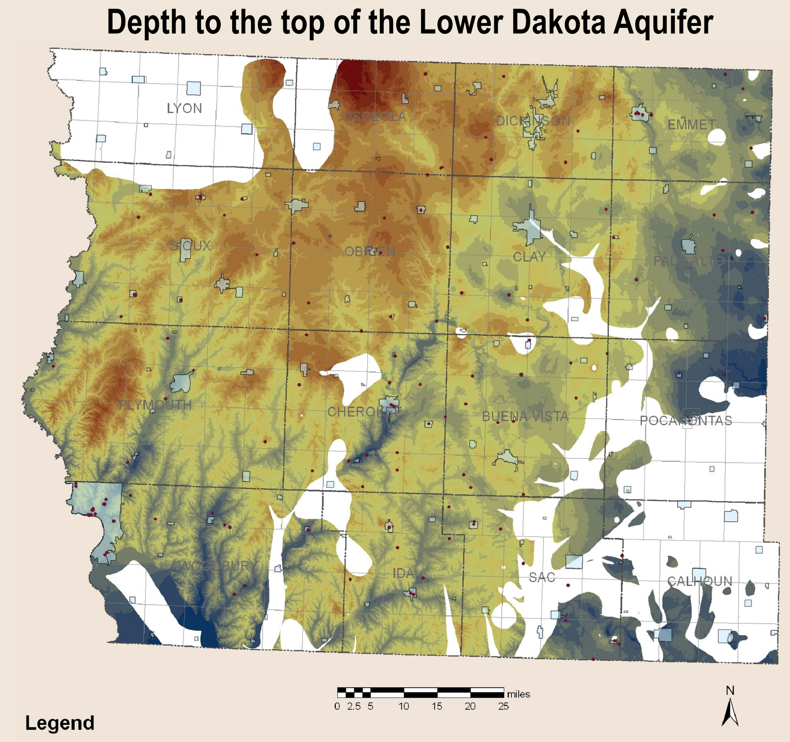
- Measured wells (n = 130)
- Lines of equal thickness of the Lower Dakota Aquifer in feet

Thickness of the Lower Dakota Aquifer in feet

0 - 50; 50 - 100; 100 - 150; 150 - 200; 200 - 250; 250 - 300; 300 - 350

Isopach or thickness map showing the areal distribution and thickness of the Lower Dakota Aquifer. The great relief of the bounding surfaces of the aquifer result in a highly variable sandstone thickness. 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 contiguous sandstones of the Nishnabotna and Woodbury members that comprise 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. Because there is no direct hydrologic connection between the isolated sandstone bodies of the Woodbury Member that are separated from the Lower Dakota Aquifer by mudstones, they are not represented on this map.

Depth to the top of the Lower Dakota Aquifer



Legend

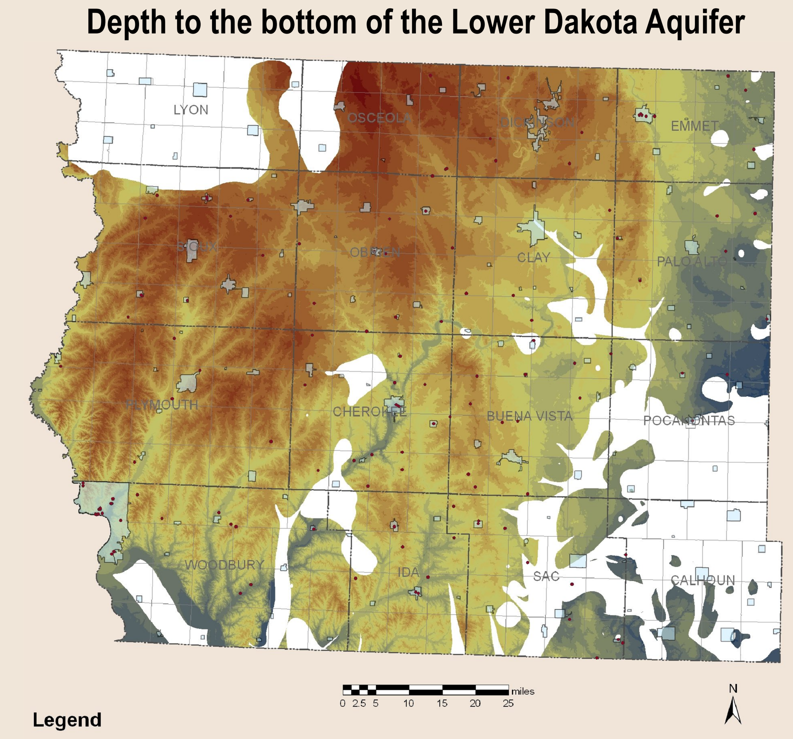
- Measured wells (n = 130)

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

800 - 750; 750 - 700; 700 - 650; 650 - 600; 600 - 550; 550 - 500; 500 - 450; 450 - 400; 400 - 350; 350 - 300; 300 - 250; 250 - 200; 200 - 150; 150 - 100; 100 - 50; 50 - 0

Depth from the land surface to the top of the Lower Dakota Aquifer. 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. 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. In areas where well records showed basal mudstone/shale intervals to be below earlier iterations of the top of the aquifer, the elevation of the top of the aquifer needed to be modified to be no higher than the base of that particular well. This modification produced the third of four iterations of the top of the Lower Dakota Aquifer. In areas where much of the Dakota Formation is dominated by mudstones, particularly parts of Sioux, northwest Plymouth, Lyon, and Osceola counties, this procedure significantly increased the depth to the top of the aquifer.

Depth to the bottom of the Lower Dakota Aquifer



Legend

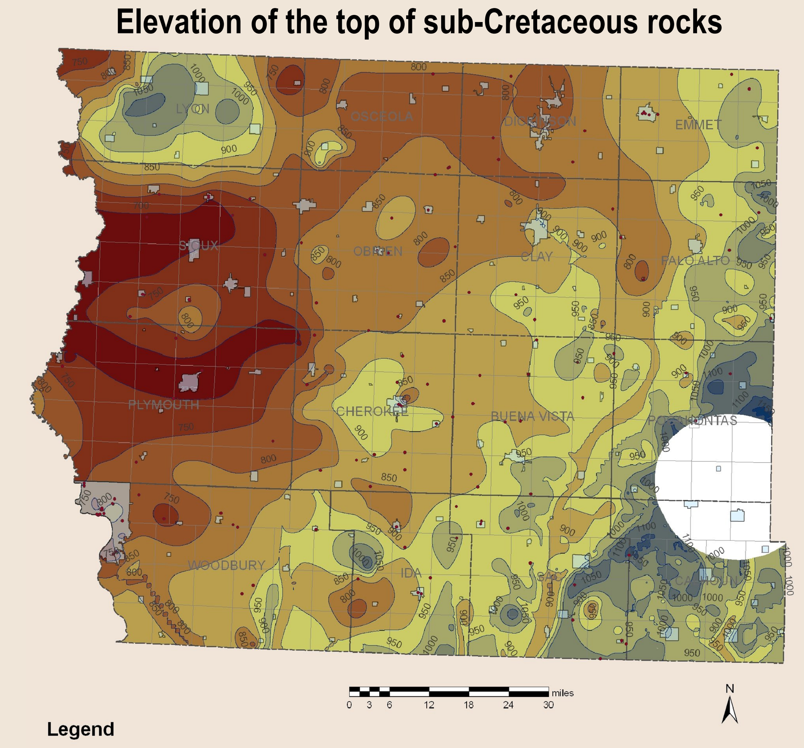
- Measured wells (n = 130)

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

900 - 850; 850 - 800; 800 - 750; 750 - 700; 700 - 650; 650 - 600; 600 - 550; 550 - 500; 500 - 450; 450 - 400; 400 - 350; 350 - 300; 300 - 250; 250 - 200; 200 - 150; 150 - 100; 100 - 50; 50 - 0

Depth from the land surface to the bottom of the Lower Dakota Aquifer. Determining the depth to the bottom of an aquifer is important in planning a water supply. Aquifer thickness is a determining factor in calculating drilling and construction costs, as well as pump and well design, and well yield. The bottom of the aquifer is more deeply buried in the northwest portion of the study area, and closer to the land surface in the southeast, and in areas where the current drainage network has eroded valleys into the land surface. The rock units underlying the Cretaceous strata in northwest Iowa range from Precambrian to Pennsylvanian in age. The geologic mapping associated with this project combined these rock units into nine map units. These depositional packages represent periods of marine transgressions into Iowa, and each of these units is erosionally beveled and truncated to the northwest beneath the Cretaceous strata. The nine mapping units were chosen because they share hydrologic relationships with overlying Cretaceous strata, they form identifiable lithologic packages, and they are of mappable scale.

Elevation of the top of sub-Cretaceous rocks



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

Elevation of the top of sub-Cretaceous rocks in feet above mean sea level. Within the study area, several sub-Cretaceous units comprise additional bedrock aquifers that are in direct hydrologic connection with the Lower Dakota Aquifer. Some of these sub-Cretaceous aquifers are being used locally as groundwater sources in areas of northwest Iowa, including Galena, Devonian, and Mississippian strata. The specific hydrologic relationships between the sub-Cretaceous units and the Lower Dakota Aquifer are currently not clear. However, probable head relationships and flow directions between the various sub-Cretaceous and Cretaceous aquifers were previously interpreted as primarily downward recharge and flow from the Lower Dakota Aquifer into the sub-Cretaceous aquifers over most of the study area. However, upward ground-water gradients from sub-Cretaceous rocks into the Lower Dakota Aquifer were observed in areas near the Big Sioux River in Lyon and Plymouth counties and near Le Mars in Plymouth County.

Summary and Conclusions

The first aquifer to be studied for the 2008 Water Resources Management program is the Dakota, which is used for most water supplies in western Iowa. 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. 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.

The Lower Dakota Aquifer is comprised of the contiguous sandstones of the Nishnabotna and Woodbury members. The individual sandstone beds within the 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 aquifer is thickest and most productive in the west-central and north-central parts of the study area, and thin or absent in the northwest and south-eastern portions of the 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. Most wells developed in the aquifer range from 100 to 600 feet deep. The confining beds underlying the aquifer include Dakota shales, and undifferentiated Paleozoic rocks and Precambrian crystalline rocks which have angular unconformity with the overlying younger strata.

Although the interval immediately overlying the Lower Dakota Aquifer is dominated by shale and mudstone, locally it may include thin and discontinuous sandstone units of the Woodbury Member that are not directly connected to the aquifer, but are physically separated from it by intervening mudstone strata. The lateral extent of these upper Dakota sandstones is limited, and most appear to be less than a mile or two in cross-sectional dimensions. However, these sandstone bodies may extend as elongate channels within the surrounding mudstone, and some could possibly extend in their long dimension distances spanning one or two counties. These sandstones are much less productive than the lower aquifer, however, they are locally important sources of water, particularly for domestic or farm use. Unfortunately, the distribution of subsurface data in northwest Iowa is insufficient to accurately predict the stratigraphic and geographic distribution of the sandstone bodies within the upper Dakota Formation.