Geologic Evaluation of the Buried Sand and Gravel Aquifers in Western Iowa

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ABSTRACT

Due to the recurrence of drought in western Iowa, water users have increasingly been looking for additional sources of water. Buried sand and gravel aquifers associated with three bedrock channels were investigated as potential sources. Due to low data density, two primary study areas were chosen for a more detailed analysis. Point coverage was not sufficient to generate isopach maps or perform statistical analysis, but the production of cross-sections aided in the understanding of the sand and gravel bodies.

Valley fills, where present, are likely to be laterally continuous, but not all valleys will have a significant thickness of sand and gravel. Sand sheets also have the potential to be laterally continuous, but their margins will not be as predictable as a valley fill since they are not bounded by a valley wall. This study demonstrates the complexity of glacial till sequences and predicting the presence of sand and gravel bodies within or between till sheets.

On a local (community or township) scale, it appears that general trends can be established if the data density is sufficient. However, there is less confidence in using this data as a predictive tool on a regional scale. Several areas, such as the Glenwood Chute, have thick and continuous sand and gravel bodies. In many other areas, the data is not sufficient to map the sand and gravel. In many cases, one or two highly productive wells are identified, but their lateral distribution cannot be established.

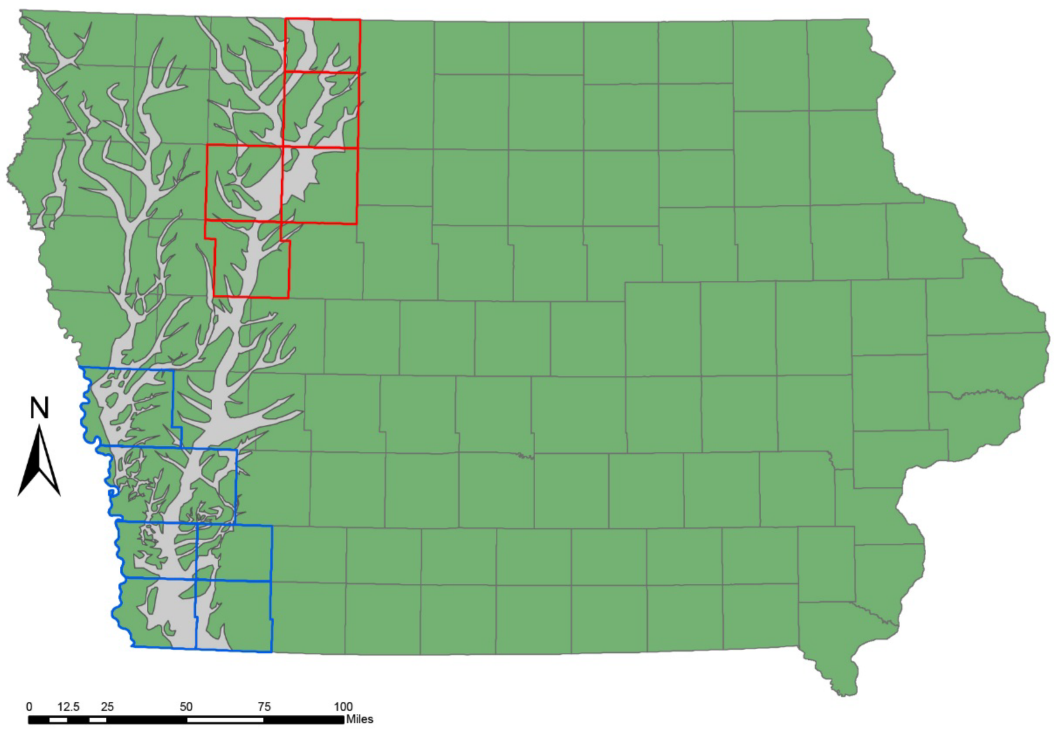

Figure 1. Study area in western Iowa. Buried bedrock channels are shown in gray. The Fremont Channel (east) is the deepest of these valleys. The northwest study area is outlined in red, and the southwest study area is outlined in blue.

INTRODUCTION

Droughts have been reoccurring in western Iowa since 2011. This has left many public water utilities and private well owners actively looking for alternative sources of water. Based on this demand for additional water, users in western Iowa are looking at buried sand and gravel aquifers as a primary or secondary water supply. Due to increased interest in these aquifers, the Iowa Department of Natural Resources (IDNR) contracted with the Iowa Geological Survey (IGS) to characterize buried sand and gravel aquifers found within three extensive bedrock valleys in western Iowa (Figure 1). These channels underlie a sizeable portion of western Iowa. The primary purpose of the investigation was to evaluate existing geologic data thereby characterizing the lateral and vertical extent of various sand and gravel units. In addition to the geologic characterization, a limited estimation of well yields was also made. The complex nature of the sand and gravel deposits, and poor distribution of data, prevented the characterization of the entire study area. Two refined areas, which were more data rich than the overall study area, were chosen for in-depth study. In northwestern Iowa, Buena Vista, Emmet, Palo Alto, Pocahontas, and Sac counties were selected. Fremont, Harrison, Mills, Montgomery, Page, and Pottawattamie counties were selected in southwestern Iowa.

GEOLOGY

The basic geology of the study area consists of Quaternary deposits on top of Mesozoic and Paleozoic strata. The Paleozoic units dip to the southwest while the Mesozoic units overlie them with a relatively shallow dip.

Landforms

Five landform regions are present in the study area: the Des Moines Lobe, the Northwest Iowa Plains, the Southern Iowa Drift Plain, the Loess Hills, and the Missouri River Alluvial Plain (Figure 2).

The Des Moines Lobe landform region was most recently glaciated during the Wisconsin Episode. A lobe of the Laurentide Ice Sheet moved into Iowa 15,000 years ago and reached its furthest southern extent at 13,500 years ago (Bettis et al., 1996; Ruhe, 1969). The Des Moines Lobe represents the southernmost extension of the Prairie Pothole Region (PPR), a region that extends from Alberta, Canada, and occupies more than 700,000 km^2. The PPR is dominated by hummocky topography and contains thousands of small, shallow closed depressions that formed as the Wisconsin ice

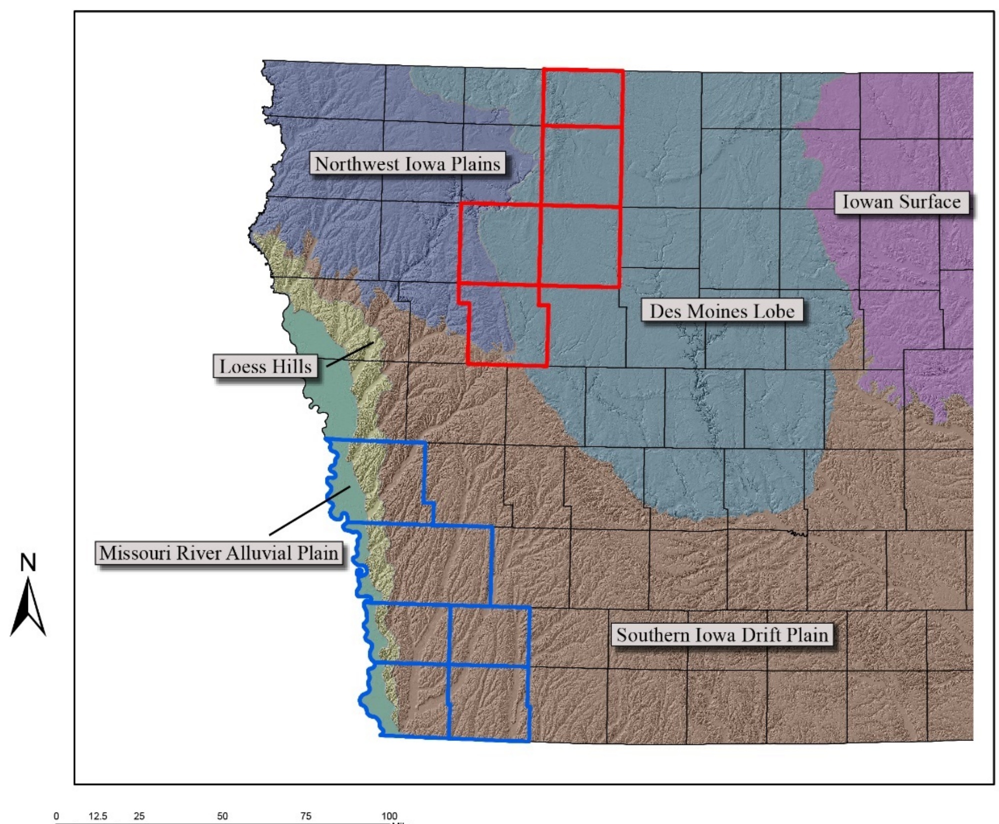

Figure 2. Landform regions of Iowa (Prior, 1976) showing the northwest (red) and southwest (blue) study areas.

sheet melted (Miller et al., 2009; Sloan, 1972). Poor natural drainage is characteristic of a relatively young glacial landscape (Prior, 1976).

The western portion of the Northwest Iowa Plains (NIP) was last glaciated during the Pre-Illinoian. The eastern half is covered by younger glacial deposits associated with the Sheldon Creek advance which occurred earlier in the Wisconsin, between 40,000 and 26,000 years ago. The NIP exhibit characteristics similar to the Iowan Surface in northeastern Iowa, as it was affected by processes associated with a periglacial environment during the most recent ice advance (Des Moines Lobe). This area was subject to intense freeze-thaw cycles, strong winds, and solifluction (Prior, 1976; Walters, 1996). Erosion erased many features of earlier glaciations, and modern stream networks started to develop. Unlike the Iowan Surface, loess (predominantly wind-blown silt) covers much of the NIP.

The Southern Iowa Drift Plain (SIDP) is a heavily eroded landscape. Numerous glacial advances between 2.6 and 0.5 million years ago (Ma) deposited thick packages of sediment. Since the last glacial advance, a long period of erosion and landscape development has resulted in a well-developed drainage network. Loess covers most upland areas, except in steep drainage divides where till outcrops.

The Loess Hills stand to the east of the Missouri River and were formed from wind-blown particles originating from the Missouri River Alluvial Plain. These hills can stand over 200 feet higher than the Missouri River flood plain. Loess thickness reaches greater than 150 feet near the Missouri River, and thins to the east in the direction of the SIDP landform region.

The Missouri River Alluvial Plain is composed of alluvial sediments (sand and fine-grained materials) deposited by flooding along the Missouri River (Prior, 1976). This landform region was not considered part of the study area.

Quaternary Geology

The thickness of Quaternary materials in the study area is highly variably and closely related to the location of buried bedrock channels (Figure 3). The primary Quaternary deposits in the study area consist of fine-grained alluvium, sand and gravel outwash deposits, loess, and glacial till (Figure 4), ranging in age from modern (Holocene) to several million years old (Pre-Illinoian). Each of these materials has specific implications for water resources in terms of whether or not it behaves as an aquifer or confining unit. Understanding the origin of these materials and their relationships with each other allows for better predictions of where buried sand and gravel deposits occur.

Holocene Alluvium

Holocene deposits consist of recently deposited river sediments along major rivers and streams. Modern river deposits in

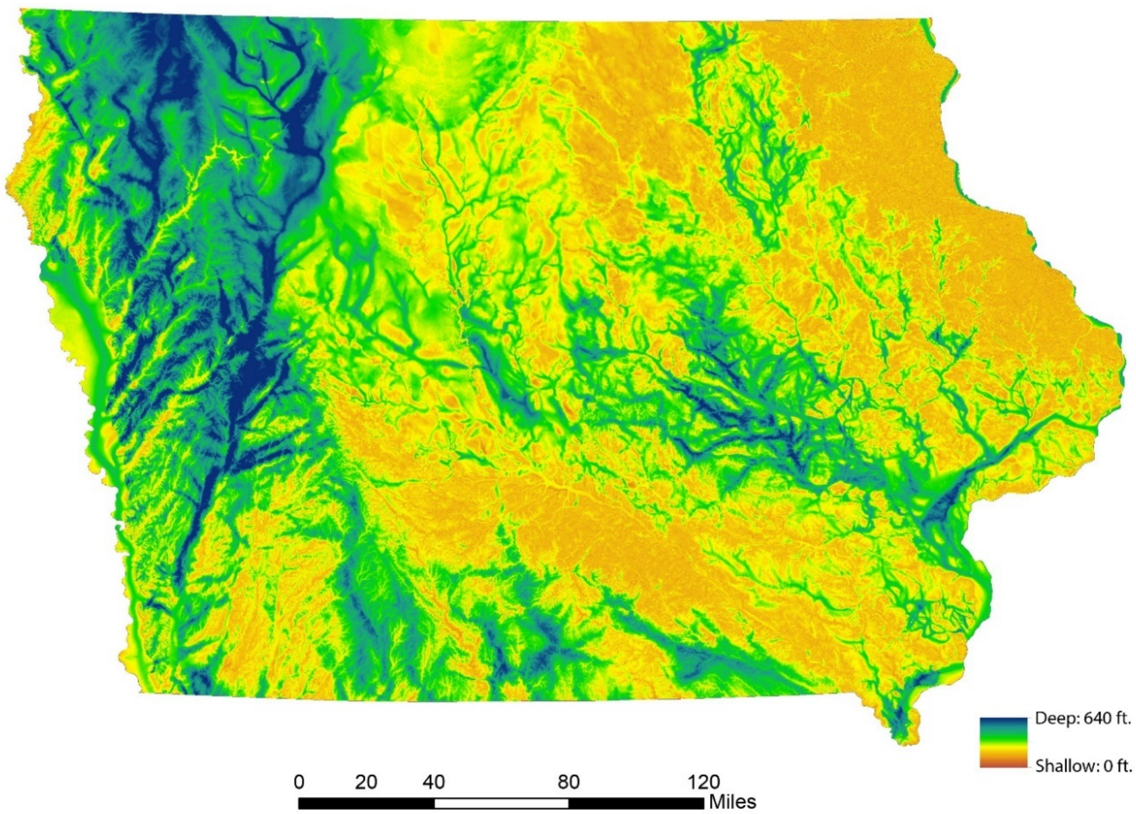

Figure 3. Map showing the thickness of unconsolidated Quaternary materials. Blue represents thicker packages of sediment which are usually found in paleo channels in the bedrock surface.

western Iowa consist of accumulations of gravel, sand, silt, and clay of the DeForest Formation. These sediments were deposited in flood plains and in river channels. Fine-grained materials dominate the composition, reflecting their formation from erosion of loess and glacial till. Holocene alluvium is generally too fine-grained to be considered a productive aquifer.

Missouri River Alluvium

The Missouri River forms the western boundary of the study area. The current channel of the Missouri River was likely established during the Pleistocene Pre-Illinoian Episode (0.5-2.6 Ma) after glaciation buried the Fremont channel. The current river channel has carried large volumes of glacial melt water and drained large areas of the United States. Missouri River alluvium can be up to 200 feet thick and is one of the most prolific aquifers in Iowa.

Loess

Loess is wind-blown sediment composed primarily of silt and fine sand. These materials were deposited in floodplains, then transported via the prevailing westerly wind onto adjacent landscapes. Loess generally has a low permeability and a high water holding capacity, but is not normally used as

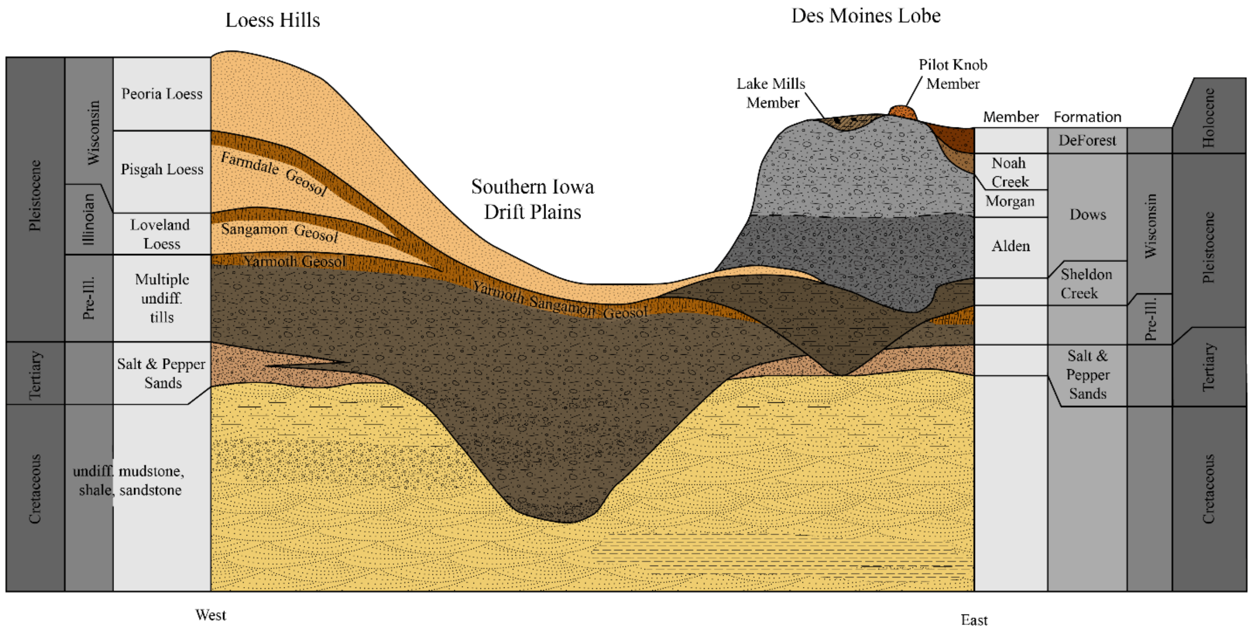

Figure 4. Generalized stratigraphy and associated materials in the study area. Modified from Gannon et al., 2008.

an aquifer. Loess is normally considered a confining or semi-confining bed.

Glacial Deposits

Glacial deposits may consist of basal till, supraglacial till, moraine materials, glacial lake deposits, and outwash. Tills are composed of nearly equal amounts of clay, silt, and sand with smaller amounts of pebbles, gravels, cobbles, and boulders. These materials are eroded by the glacier from areas up ice and are carried and reworked until being deposited. Rocks not found in Iowa bedrock, like granite and basalt, are entrained in glacial till. Till can be deposited underneath glacial ice by lodgment (basal) or from the debris left in ice as it melts (supraglacial and englacial). By having a large percentage of fine materials, glacial tills are generally impervious to water movement and are considered confining units. However, due to their heterogeneous deposition, they can have pockets of sand and gravel units that were deposited by subglacial or melt-out processes. These materials may be local aquifers, but are usually laterally discontinuous.

Terminal moraines are features that form at the terminus of glaciers. They consist of the same materials as glacial tills, but frequently include larger sand and gravel bodies. Terminal moraines mark the farthest extent of a glacier and are often influenced by fluvial processes.

Glacial lakes form when ice or moraines constrict glacial streams. Lakes also form in depressions left when large ice blocks are left on the landscape melt. Lake deposits are generally fine grained and may include isolated sand lenses. Glacial lake deposits generally act as confining units that slow the movement of water.

Outwash is generally coarse sand and gravel that was deposited in front of the glacier as it advanced, as fluvial plains related to subglacial melting, or as large floods when glacial lakes emptied catastrophically. These deposits may be found far from the glacial margin along river valleys. These sediments are usually fairly well sorted and normally transmit or store water readily. Outwash can be either a local or regional scale aquifer.

Quaternary Stratigraphy

Quaternary stratigraphic units include, from youngest to oldest: Holocene DeForest Formation; Wisconsin Noah Creek, Dows, and Sheldon Creek formations; Pleistocene loess; and Pre-Illinoian glacial materials (till and outwash); buried bedrock valley fill deposits; and Tertiary "Salt and Pepper" sands (Figure 4). Quaternary sediments are difficult to evaluate as a regional aquifer due to their varying distribution, thickness, and limited well data.

DeForest Formation

The DeForest Formation consists of fine-grained alluvium, colluvium, and pond sediments found in stream valleys. These materials occur at the land surface in stream valleys, closed depressions, and hillslopes throughout Iowa. Their thickness is highly variable and is based on landscape position. The DeForest Formation may be as old at 14,000 radiocarbon years before present (RCYBP). The DeForest Formation is not a focus of this study and therefore, its seven members will not be discussed in detail.

Noah Creek Formation

The Noah Creek Formation consists of coarse-grained sand and gravel deposits associated with stream valleys and outwash plains of the Des Moines Lobe glacial advance. The Noah Creek Formation ranges in age from 14,000 to 11,000 RCYBP. These deposits are typically 20 feet thick, but may have a much greater thickness depending on the proximity to the source and the valley morphology.

Dows Formation

The Wisconsin-age Dows Formation is the most recent glacial deposit in Iowa, and was deposited between 15,000-12,000 RCYBP (Johnson, 1986). The ice sheet was a surging front from the main Laurentide ice sheet that then thinned and stagnated. Work done by Hooyer and Iverson (2000) places the thickness of the glacier at around 820 feet (250 meters). Strip logs show that deposits in the study areas can be over 200 feet (61 meters) thick. The Dows Formation is subdivided into four members: the Alden Member is a dense basal till unit with a uniform loam matrix texture; the Morgan Member is highly variable, consisting of interbedded loamy till deposits and sorted sediments with common inter-till sand bodies; the Lake Mills Member is composed of glacial lake sediments; and the Pilot Knob Member is an upland sand and gravel unit occurring as irregularly shaped hummocks on the land surface (Bettis et al., 1996). The Dows Formation is not present in the southwest study area.

Sheldon Creek Formation

Earlier Wisconsin-age glacial deposits are recognized as the Sheldon Creek Formation. There may be two undifferentiated advances included in this formation, which date from approximately 40,000 to 26,000 years ago (Bettis et al., 1996; Bettis, 1997). These tills and glaciofluvial deposits are much more variable in thickness than the Dows Formation due to erosional processes. The Sheldon Creek Formation can have a thin mantle of loess. In the eastern part of the northern study area the Dows Formation is deposited on the Sheldon Creek. These deposits are not present in the southwest study area.

Pleistocene Loess

Three separate loess sequences are identified in Iowa (youngest to oldest): the Peoria, Pisgah, and Loveland formations. The Peoria Formation was formed during the last glacial period, 25,000-12,000 years ago, and constitutes the majority of near surface loess in Iowa. The two older formations are much thinner and were deposited during earlier glacial advances. The Early Wisconsin Pisgah/Gilman Canyon Formation was deposited between 44,000 and 27,000 RCYBP. This unit is found discontinuously throughout Iowa. The older Loveland Formation is related to the Illinoian-age ice advance and is found only in western Iowa. Thermoluminescence ages from the Loveland reference locality (Forman et al., 1992) range from 165,000 to 125,000 calendar years before present.

Pre-Illinoian

Iowa was glaciated numerous times before the Wisconsin-age events. (Boellstorff, 1978a, b; Hallberg, 1980, 1986). The most recent studies place the number of glacial advances at seven, though a higher number is possible. These ice advances occurred between 0.5 and 2.6 Ma (Boellstorff, 1978a, b; Hallberg, 1980). Boellstorff (1978a and b) subdivided the Pre-Illinoian tills in western Iowa into the A, B, and C tills based on pebble lithology, remnant magnetism, and volcanic ash deposits as marker beds. The stratigraphy established for eastern Iowa (Hallberg, 1980) identified two formations, the Wolf Creek and older Alburnett, based primarily on texture, clay mineralogy, and calcite-dolomite ratios. These deposits extend as far south as Kansas and Missouri. Based on well-drilling records, Pre-Illinoian-age materials can be up to 500 feet thick when encountered in a buried bedrock channel. There was considerable time between glacial advances during the Pleistocene, which allowed for extended periods of erosional down-cutting and landscape development. Paleosols formed during these interglacial periods mark the boundaries between till units.

Salt and Pepper Sands

Unconsolidated sands composed of quartz and dark volcanic materials are located within the study areas in isolated patches. Drillers around Iowa named them ‘Salt and Pepper’ sands. The sands are commonly found beneath the Pre-Illinoian materials but, in some cases, may be above some of the

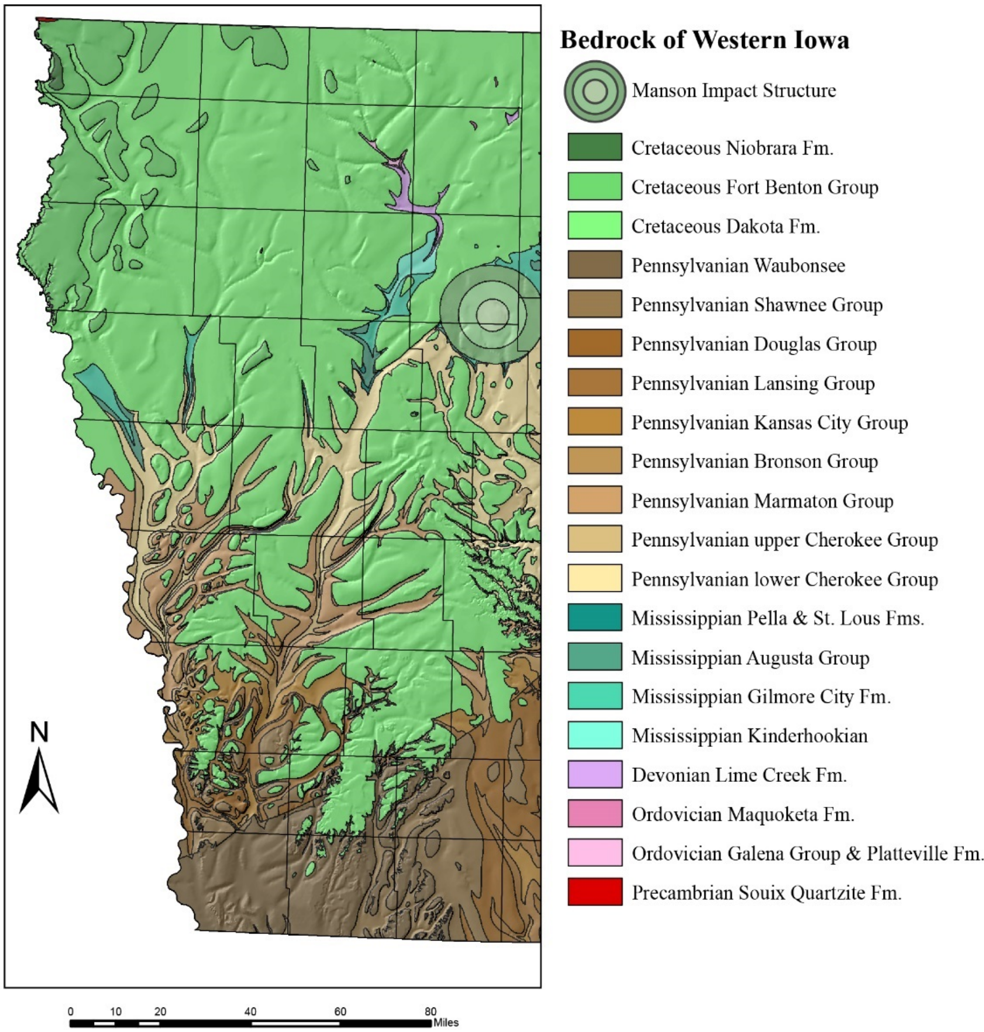

Figure 5. Bedrock geologic map of Iowa (Witzke et al., 2010). Cretaceous units are shown in green. Pennsylvanian groups are tan to brown.

oldest of these till deposits. The deposition of these sands is thought to be alluvial and represents a paleo east-to-west drainage pattern. These sands are thought to be the eastern extension of the Tertiary-Quaternary aged Ogallala Formation of Nebraska (Gannon et al., 2008). Certain wells pump from these sands, though yields are generally low.

Bedrock

The bedrock surface in western Iowa is predominantly Cretaceous and Pennsylvanian age deposits (Figure 5). The Cretaceous is underlain by Pennsylvanian, Mississippian, Devonian, and Ordovician aged bedrock. Where the Cretaceous is absent, the Pleistocene is underlain by Pennsylvanian, Mississippian, Devonian, Ordovician, and Precambrian units.

The Cretaceous sequence in western Iowa includes the Dakota Formation, outliers of the Greenhorn and Graneros formations, and the Manson Impact Structure (Witzke et al., 2010). The Dakota Formation is the most extensive stratigraphic unit at the bedrock surface in the northwest Iowa study area and is comprised of the older Nishnabotna and younger Woodbury members. The Nishnabotna is primarily a quartz-dominated sandstone that locally grades into mudstone. The texture of the sandstone ranges from very fine to very coarse with basal gravels at some localities (Munter et al., 1983; Witzke and Ludvigson, 1994). The Woodbury Member is generally dominated by gray and red mudstones. It can also contain incised channels filled with fine sandstone. Episodes of soil development are also present in some of the finer sediments. The top of the Dakota Formation is composed of shallow marine shale which formed when the Western Interior Seaway encroached eastward (Gannon et al., 2008).

The Lower and Middle Pennsylvanian groups are primarily composed of rocks deposited in terrestrial (non-marine) environments. The lithologies include deep sea phosphatic shale, sandstone, coal, shallow marine shale, limestone, terrestrial mudstone, and paleosols (ancient soil). If buried sand and gravel deposits are in direct contact with bedrock, there may be an influence in terms of available water quantity and/or quality.

Bedrock Channels

Bedrock in western Iowa has been incised into valleys or channels (Figure 6). The Fremont Channel is the largest bedrock channel in both study areas. This channel was likely formed from glacial meltwater eroding the bedrock during one of the first glacial advances. The Fremont Channel is cut deeper

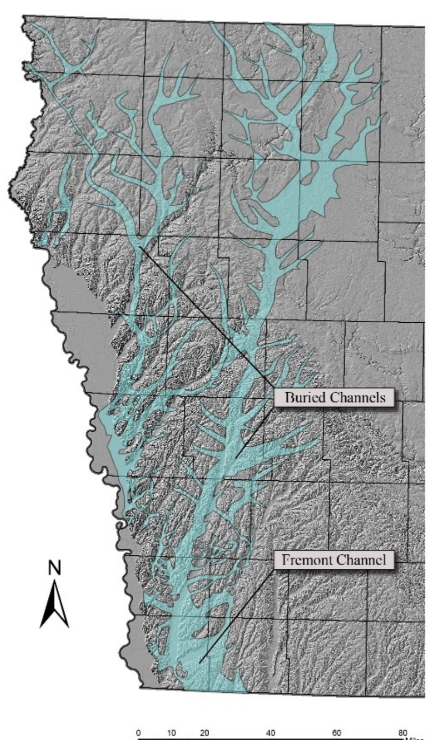

Figure 6. Buried bedrock channels in the study area.

into bedrock than the modern Missouri River and can be up to 250 feet deeper than the surrounding bedrock (Gannon et al., 2008). Many different materials can be found in these channels: original alluvial deposits, bodies of sand and gravel deposited by glaciers, till, outwash, and in isolated locations salt and pepper sands. When found, these sand and gravel bodies can be used as aquifers.

Figure 7 shows a generalized model of how glacial deposits can accumulate in these channels and the complexity of trying to identify and map individual sand units. Following the initial channel cutting, alluvial

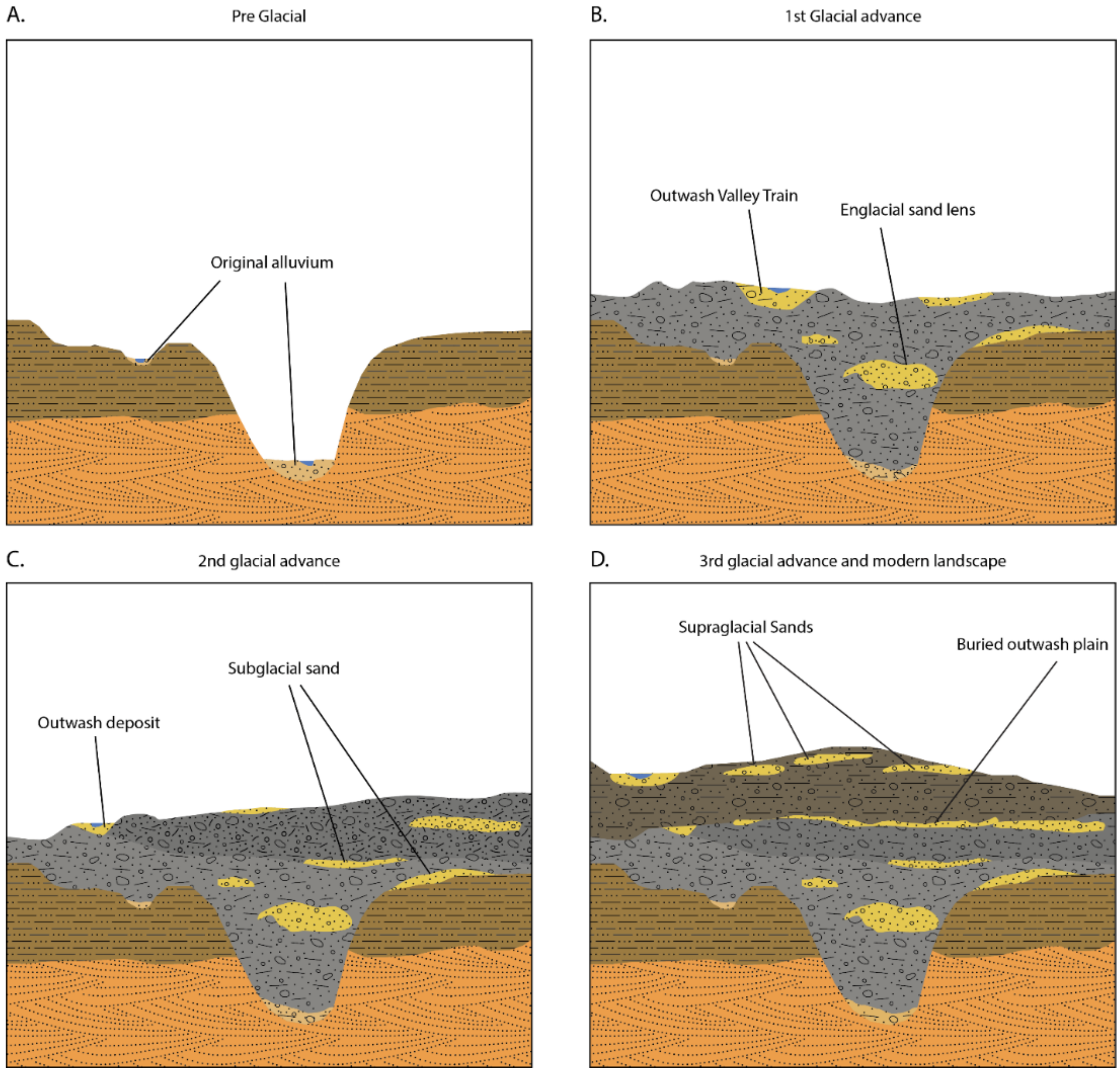

Figure 7. Generalized model of bedrock channel infilling and types of sand and gravel deposits associated with glacial deposition. Frame A shows bedrock channels pre glaciation. Frame B shows bodies of sand within till and a river forming on top of the deposited till. In this case, the river formed in a large body of outwash left by the retreating glacier. In frame C, the second glacial advance eroded the river channel and deposited englacial (within) and subglacial (below) sands. Frame D shows a buried outwash plain formed in front of the advancing glacier. This connects hydraulically to the englacial sand and gravel deposited by the second advance. Supraglacial sands, laid down as the glacier melted, are shown as well. These sand and gravel deposits are not necessarily laterally continuous.

or outwash deposits may have been deposited (Figure 7A). As the first glacier advanced, the channel was partially or completely filled with glacial till and possibly englacial sands, as outwash channels downcut into the surface (Figure 7B). A subsequent advance may have eroded the earlier surface materials and deposited another till sheet (Figure 7C). If an outwash plain associated with this advance wasn't completely eroded by the next till sheet, it could become a buried outwash plain (Figure 7D). Outwash channels and plains have the greatest likelihood of being laterally continuous and providing a sustainable water supply. Englacial and subglacial sand and gravel bodies are probably only able to provide a local private water source.

DATA AND METHODS

Data Sources

The IGS maintains a wide collection of geological information in its database, GeoSam. The database includes information on water wells drilled in Iowa, geologic exposures, drill core, and drill cuttings. Since the 1930s, the IGS has collected samples sent in voluntarily from well drillers across the state. Drillers document geologic information and send in driller's logs and samples from five foot increments. Samples are processed, assigned W-numbers, and shelved so they can later be retrieved for study. Samples are described by geologists on strip logs that record detailed information about lithology, mineralization, fossils, and other information that would be considered key stratigraphic data. They are then added to GeoSam. These data points were used as the primary data set for this report as they provide the most detailed geologic information. However, for a large percentage of wells drilled in the study areas, samples were not collected and a strip log could not be produced. Many of these wells have driller's logs. These logs provide useful information like depth and thickness of geologic units, though the quality of the data is variable. Driller's logs usually provide information on sand and gravel unit depth and thickness, but differentiating till units and the difference between till and loess is very difficult. Water production and well casing information may also be included for some data points. Approximately 2,600 GeoSam data points were available for the study area, including 830 strip logs.

Additional data was available from the Private Well Tracking Database (PWTS) managed by the IDNR. PWTS may have driller's logs and pumping information not available in GeoSam. Over 1,500 records were available for the study area, and 200 to 300 records had useful information. County sanitarians were contacted, but the response did not result in any new data. All available data were compiled and assessed to evaluate the predictability of sand and gravel deposits.

Data Compilation

To construct the data set used in this study, strip logs and driller's logs were intensively analyzed to look for sand bodies above bedrock. Data points were initially considered if they met the following criteria:

- Wells were located within one mile of a bedrock channel (digitized from the 2010 bedrock topography map).
- Geologic materials were differentiated (eg clay, till, sand, gravel, limestone, etc.).
- Bedrock was not within 50 feet of the surface.
- The location confidence of the well point was within one section.

A shapefile was created using data points that met the minimum criteria listed above. The sand and gravel unit needed to be overlain by a confining unit to be included in the coverage. The following features were recorded in the table:

- Presence or absence of sand and gravel
- Total sand and gravel thickness
- Number of sand and gravel units encountered
- Thickness of the thickest sand and gravel unit
- Depth to the top of the thickest sand and gravel unit
- Depth to the bottom of the thickest sand and gravel unit
- Elevation of the top of the thickest sand and gravel unit (calculated from the DEM)
- Elevation of the bottom of the thickest sand and gravel unit (calculated from the DEM)

Data Analysis

Isopach (thickness) maps require a sufficient distribution and quality of data. The current evaluation lacked both an adequate distribution of points and had insufficient quality of data to produce a regional isopach map. The distribution of data averaged less than 1 point per 10 square miles. This lack of data was confounded by natural horizontal and vertical spatial variability of sand and gravel within glacial till. In many instances, complete sand and gravel packages were not characterized by drillers, often stopping short of identifying the maximum thickness. These issues with data coverage led us to refine our study area to two groups of counties (Figure 1) which were more data rich. The new localized study areas averaged no less than one point per two square miles. This new dataset allowed for a more confident summary of the presence of sand and gravel units. However, point coverage was still too sparse for an accurate isopach map.

Cross-Sections

Cross-sections were constructed using GeoSam points. Cross-section line criteria were:

- Located in or across a buried bedrock valley
- Cross-section locations including public wells were given higher priority
- Priority was given in areas with denser data and/or points with greater depth
- Cross-section locations are perpendicular or parallel to the bedrock valley

The criteria used to select data points for the cross-sections were:

- Points considered were within a two mile buffer from the cross-section line
- Points used had a similar surface and/or bedrock elevation to the axis of the bedrock channel

Upland points were included to assess the potential for englacial sand or outwash bodies that were not associated with the bedrock valley.

Estimated Potential Well Yields

The estimated potential well yields in the various buried sand and gravel units were estimated using the available specific capacity data from the source water public well geographic information system (GIS) coverage. The public well coverage, unlike the private well data set, generally tries to maximize water production. No attempt was made to identify which sand and gravel unit the estimated well yield represented.

The estimated potential well yield point data is shown in Figure 8, and ranges from less than 50 gallons per minute (gpm) to over 300 gpm. Approximately 61 public wells are located within the bedrock channel extent, and approximately 86 wells are found outside the bedrock valley extent. Some of this

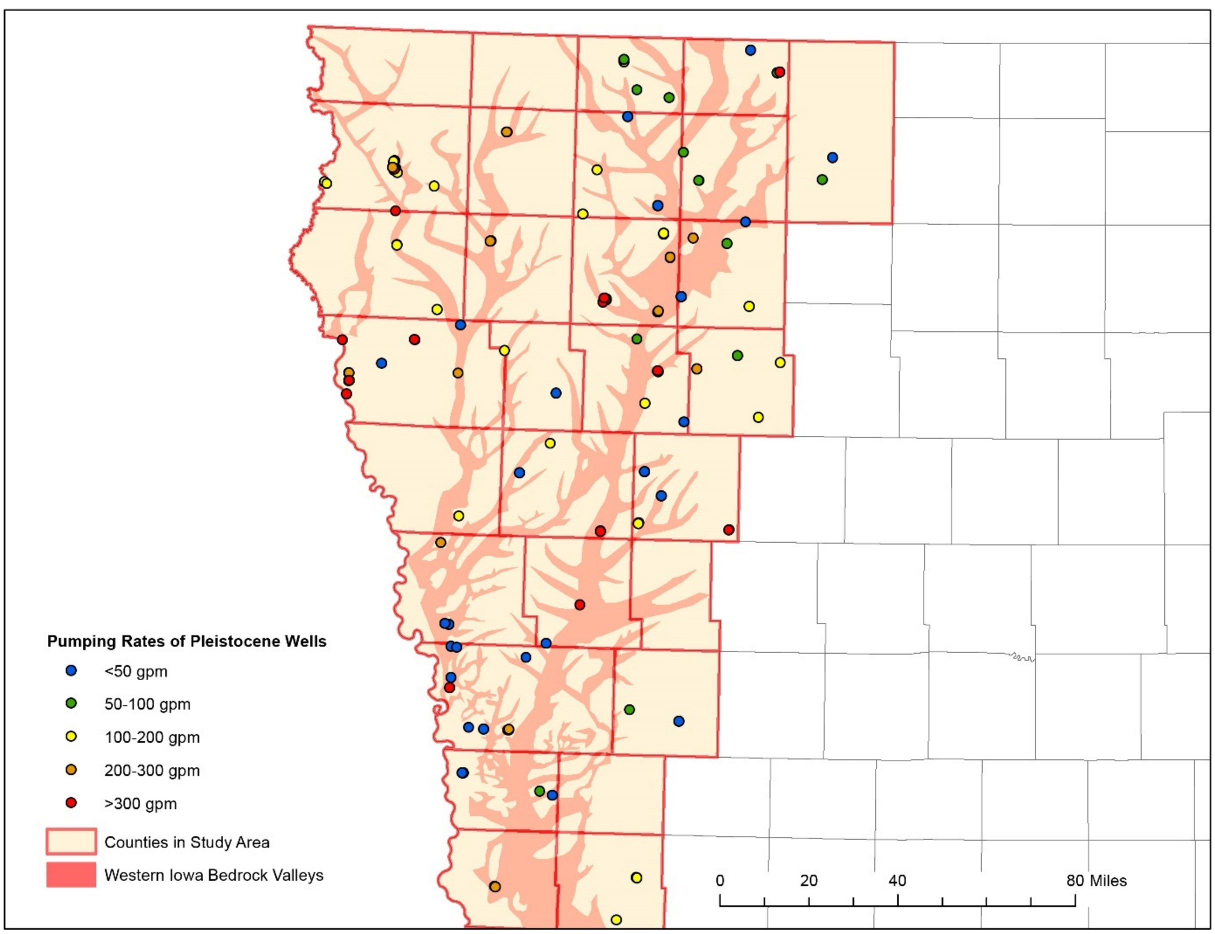

Figure 8. Pumping rates of public wells screened in Pleistocene aquifers.

discrepancy may be the result of errors within the bedrock topography map and our bedrock valley coverage, but many of the wells are screened in a buried sand and gravel unit that is likely located outside the bedrock valleys.

DISCUSSION

Due to the nature of this project, several data limitations must be recognized and considered in the final analysis. As discussed previously, the point coverage density is very low. The lack of complete penetrations of drilling records makes it challenging to evaluate the deepest parts of the bedrock valley. Although identifying sand and gravel on the strip logs and driller's logs is possible, determining stratigraphy from strip logs is difficult, and very doubtful from driller's logs. Knowing the till stratigraphy is not necessary to evaluate the nature of the sand and gravel resources, but limits the ability to correlate units. Driller's logs in particular are even more problematic. It is often impossible to determine the difference between loess and weathered till from a driller's log. Descriptions of sand bodies rarely include details such as sorting, shape, etc. though sometimes size is included.

Initial Data Review

Analysis of over 2,800 data points (Figure 9) in the initial study area did not reveal any striking patterns. Graded point coverages were created from available data (Appendix A) due to insufficient data to confidently produce an isopach. Deficiencies in the data set likely led to this result. The lateral density of points was low, averaging one point per 10 square miles. Due to the low point density, two study areas were chosen for a more detailed analysis. Five counties in northwestern Iowa (Buena Vista, Emmet, Palo Alto, Pocahontas, and Sac) were chosen and had a point density of one point per square mile. In Southwest Iowa, a six county area (Fremont, Harrison, Mills, Montgomery, Page, and Pottawattamie) was selected based on a one point per two square mile point density. Additional data points were added that were excluded in the initial analysis due to overlapping proximity.

Focus on Northwest and Southwest Study Areas

Although the point density was higher in the northwest and southwest study areas, the data was still not dense enough to perform statistical analysis. A lack of complete penetrations of the entire unconsolidated thickness, multiple sand and gravel penetrations, and/or limited need for large quantities of water at a given locality were all potential problems in trying to derive a statistically valid approach to map the sand and gravel bodies throughout the entire region. In areas with a shallow sand and gravel unit, there was no need to drill to a deeper source, limiting the number of full penetrations. A graphical approach (isopach) to identify the 'first occurrence' of sand and gravel or the 'total thickness' of sand and gravel proved to be problematic in wells with multiple sand and gravel units. Graded point coverages were created for the northwest and southwest study areas showing the minimum thickness of the thickest drift, the depth to the top of the thickest drift, and the elevation of

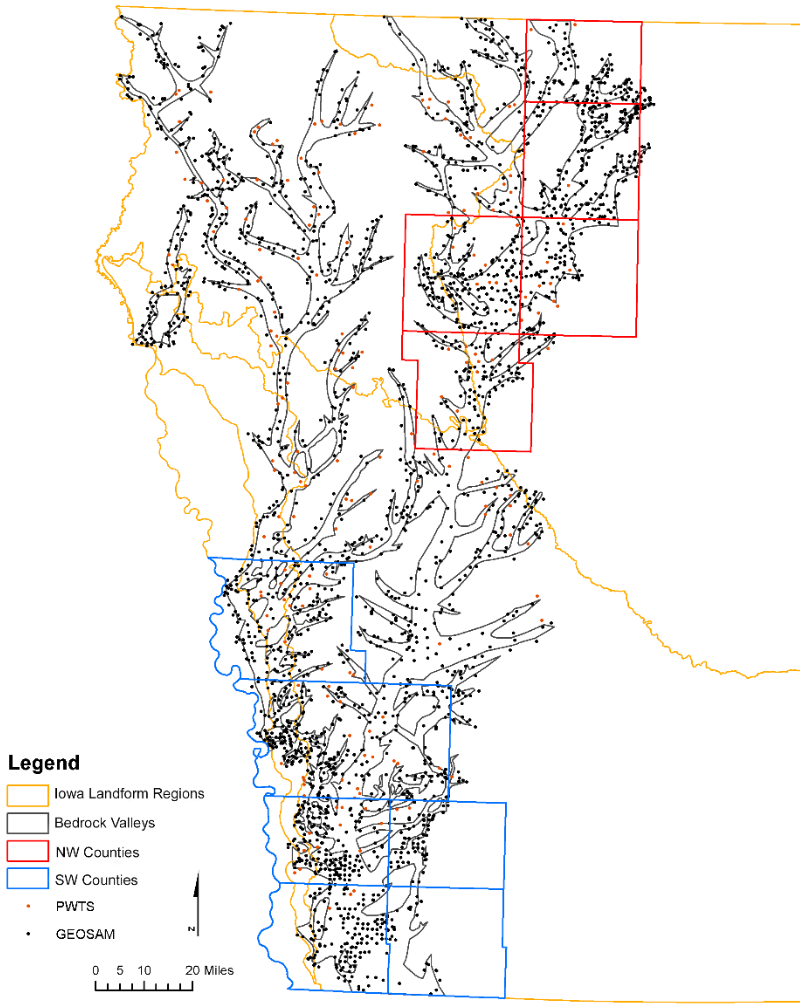

Figure 9. GEOSAM and PWTS points used in evaluation.

the top of the thickest unit (Appendix A). Based on these graphical methods, correlations and predictions of sand and gravel bodies was not possible.

Cross-Sections

The final, and most instructive, approach to mapping the sand and gravel bodies for this project was to produce cross-sections which allowed a visual representation of the depth at which the sand and gravel bodies occur, and a better understanding of their lateral continuity. The cross-sections also illustrate the complexity and difficulty involved in correlating the various sand and gravel units. The sands shown could represent alluvial sands, englacial bodies, outwash plains, subglacial deposits, supraglacial deposits, or colluvial sediments. Cross-sections perpendicular to the bedrock valleys allowed for the assessment of potential sand and gravel resources included within the till, but occurring outside of the bedrock valleys. These points may have been excluded in the initial analysis by using the one-mile buffer.
It should be noted that the surface elevation and bedrock depth on the geologic logs may

not match the surface and bedrock profile lines on the cross-sections. The data points do not always fall directly on the cross-section line and may be up or down slope creating a perceived offset. The bedrock surface profile was generated from the statewide bedrock contour map that has a 50 foot contour interval. Well records are described at five foot intervals and therefore have more accurate data. Additionally, new data points are available since production of the current bedrock topography map. The location of the data points in GeoSam are used to establish the surface elevation; the location accuracy may also create a discrepancy with the bedrock depth. Discrepancies between the surface elevation of data points and surface profile of the cross-section may also be offset due to differences in actual elevation (upslope or downslope). In all cases, the well point was hung on the true elevation regardless of the surface elevation of the cross-section line.

A total of eight cross-sections were produced (Figure 10 and Appendix B), five in the northwest project area (Figure 11) and three in the southwest project area. The locations, units encountered, and the relationship with the stratigraphy and landform regions for each is discussed below. Due to the difficulty in separating loess, oxidized till, and unoxidized till from driller's logs, stratigraphy was grouped into 'confining layers' and 'sand, sand and gravel' bodies. Specific units are not likely to be mapped and correlated based on the existing data, but generalized 'potential sand bodies' were outlined on the cross-sections. In these areas there is shown to be an increased probability of locating a sand and gravel aquifer when compared with nearby unproductive areas.

Northwest Study Area

Cross-section A-A' (Appendix B) is located in central Buena Vista and Pocahontas Counties. It is perpendicular to the channel axis and is contained almost entirely within the bedrock valley. The western edge of the cross-section is located at the town of Pocahontas, which pumps most of its water out of bedrock aquifers. Cross-section A-A' has a limited number of complete penetrations in the bedrock valley, and no full penetration in the deepest part of the valley. The western flank of the bedrock valley has several wells with a sand and gravel unit near or on bedrock. The eastern side of the valley has a relatively consistent sand and gravel body approximately 250 to 300 feet below the surface. Estimating this aquifer's well yield potential is difficult due to the lack of pumping information. These are private wells with pumping rates that range from seven to 24 gpm. The average is around 16 gpm. This estimate was based on four wells on the cross-section line and two that likely pumped water from the same body. The average drawdown is 3 feet. The lack of wells penetrating deeper in this area makes it difficult to evaluate the maximum water production of the aquifer. Wells in the side valley and located outside of the bedrock valley have limited and discontinuous sand and gravel units.

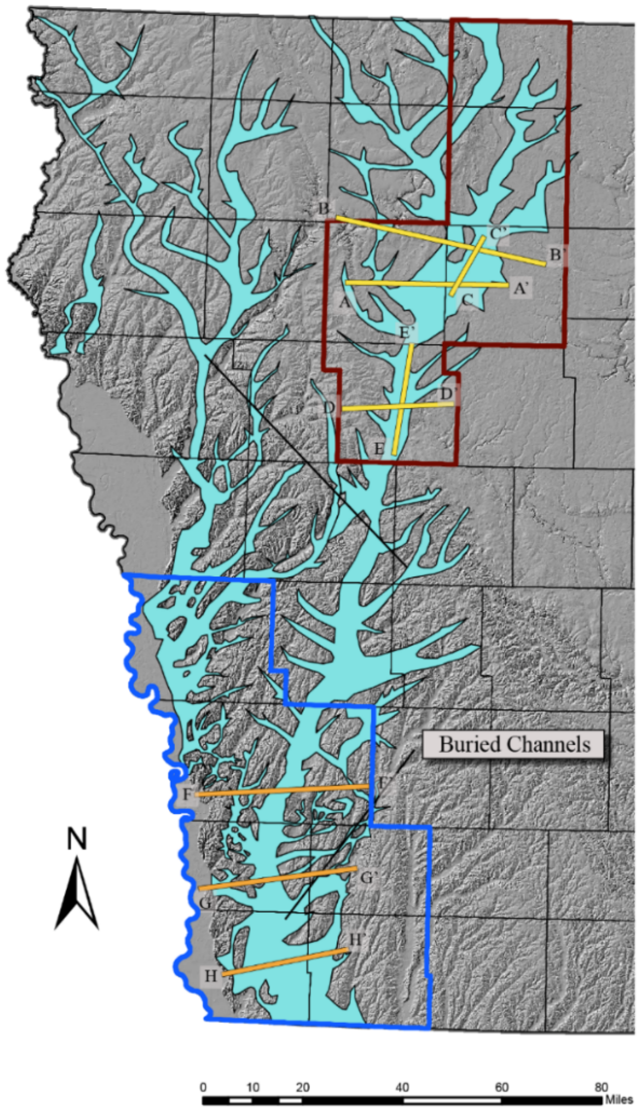

Figure 10. Cross-section locations in relation to the buried channels.

Cross-section B-B' (Appendix B) starts in southwest Clay County and crosses northern Buena Vista County and most of Pocahontas County. This section is also perpendicular to the bedrock valley, but includes an upper portion of the same side channel found in A-A', upland, and the main channel. Borings that reach, or nearly reach, bedrock typically have a significant sand and gravel unit, especially in the central and eastern portion of the bedrock valley. The western side of the bedrock valley has very few complete penetrations, presumably due to relatively consistent, but discontinuous sand bodies in the upper 100 feet. This area coincides with the margin of the Des Moines Lobe landform region (Figure 11), and likely represents moraine and supraglacial deposits. Also, unlike the side valley in cross-section A-A', this location appears to contain sand and gravel units. Five out of the six towns that lie on this cross-section line, Hancock, Laurens, Marathon, Sioux Rapids, and Peterson, pump water from the Dakota Aquifer. The other town, Linn Grove, pumps water from the alluvium of the Little Sioux River. No consistent sand and gravel body was identified on this cross-section.

Cross-section C-C' (Appendix B) runs roughly parallel with the deepest part of bedrock valley, connecting cross-sections A-A' and B-B'. It is entirely within Pocahontas County. This cross-section illustrates the connectivity between the sands and gravels at depth in the center of the channel in the first two cross-sections. Cross-section C-C' shows two potential sand bodies. One is shared with A-A' and shows generally thinner penetrations in comparison with the second. This body is within 200 to 250 feet below the land surface. Well yields vary from 8 to 35 gpm with an average of 19 gpm. The second body is further north, and approximately 250 to 300 feet below the land surface. Wells in this body show 50 feet or more of sand. Well yields range from 3 to 80 gpm, with an average of 40 gpm. There are few complete penetrations suggesting reasonable potential for private wells, but public wells would likely exhaust the aquifer. Relatively shallow sand and gravel units are also noted in the northern part of the cross-section.

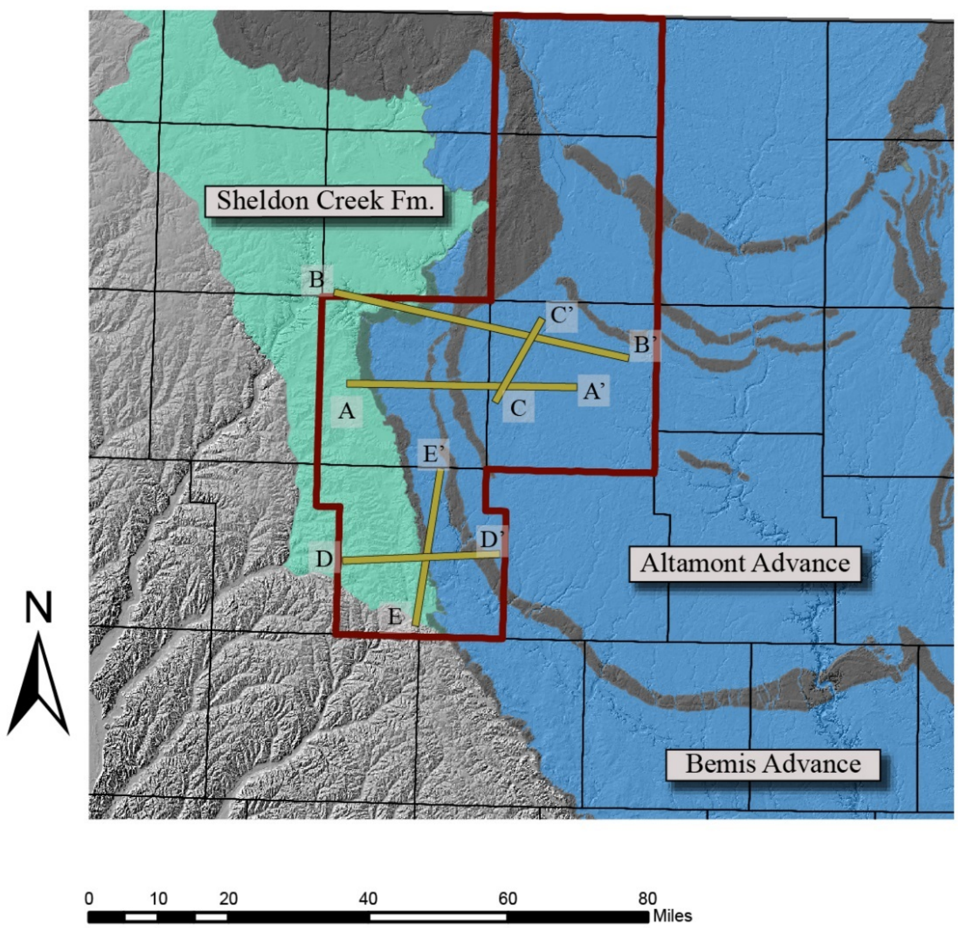

Figure 11. Northwest study area showing the Sheldon Creek till plain, DML boundary and moraines (dark gray), and cross-section lines.

Cross-section D-D’ (Appendix B) is oriented east-west in central Sac County and runs perpendicular to the bedrock valley. Sand and gravel units are distributed discontinuously throughout the valley. Correlation of these units is difficult without complete penetrations. Also noted are the presence of relatively shallow sand and gravel bodies on the east side of the cross-section. These are probably related to their location on the edge of the Des Moines Lobe landform region and related to moraine materials (Figure 11). No consistent sand and gravel body was identified on this cross-section.

Cross-section E-E’ (Appendix B) is nearly perpendicular to D-D’ and is parallel with the bedrock valley. Sand and gravel at or near the bedrock surface is common. A shallow sand and gravel body present near the surface on the southern side of the cross-section is related to the modern Boyer River channel. A body of sand is located in the northern part of the cross-section roughly 300 feet below surface, though it may not be continuous over the course of the valley. The wells on this cross-section are private and range from 16 to 55 gpm with an average of 34 gpm. This cross-section does not include any cities or towns.

Southwest Study Area

Cross-section F-F’ (Appendix B) spans all of Pottawattamie County, perpendicular to the bedrock valley axis, and includes two side valleys. The central point of the bedrock valley contains a significant sand and gravel unit that could be up to 50 feet, but nearby well points do not reach bedrock, which would have provided information on the lateral extent. Holes outside of the bedrock valley to the east contain only thin and discontinuous sand and gravel bodies. However, the scarcity of data hinders the ability to conclude that these units are isolated. The western third of the cross-section, out of the bedrock valley, contains a unique sequence. Sand and gravel is noted at the bedrock surface from the Missouri River margin all the way to the edge of the bedrock valley. The lack of sand and gravel at shallower depths can be attributed to these wells being located in the loess hills landform region with loess thicknesses exceeding 180 feet. In the majority of the strip logs in this area, the sand and gravel is overlain directly by loess, without an intervening till unit. Differentiating loess from weathered till on driller’s logs is problematic, as both are often described as ‘yellow clay’. It also appears from the available drilling records that the sand and gravel package is very close to or directly on top of bedrock. This raises the question of whether or not this was a former position of the Missouri River before it down-cut to its current elevation. If so, deposits may be locally or regionally continuous. Pumping information from the wells used to make the cross-section shows tests ranging from six to 125 gpm (City of Treynor) with an average of 18 gpm. The majority of the wells are private wells.

Cross-section G-G’ (Appendix B) crosses all of Mills County and extends across part of Montgomery County. The location for G-G’ was chosen due to the seemingly large number of data points in the bedrock valley. Upon further review, these points were either of poor quality or limited depth. The wells with shallow depth appear to be related to a loess-mantled terrace on the western side of the valley (Tassier-Surine et al., 2012). This terrace has no pumping information. Limited data is present east of the bedrock valley. The town of Red Oak lies on the eastern edge of the cross-section. The town wells are set in the Dakota aquifer. The west side of the cross-section contains a significant valley fill from a bedrock tributary (Glenwood Chute) to the main valley. The Glenwood Chute is related to the ancestral Missouri River Valley and corresponds to the Platte River Valley on the Nebraska side of the Missouri River (Burchett and Dreezen, 1964; Stone, 1971). Although not shown on the cross-section, thick (100 feet or greater) sand and gravel deposits are present the length of the tributary valley (Glenwood Chute). Pump tests in wells screened in the buried sand and gravel units within the Glenwood Chute have wells yields ranging from 8 to 150 gpm, with a median of 8 gpm. The higher well yields found within the Glenwood Chute suggest the possible use of these sand and gravel units for public wells.

Cross-section H-H' (Appendix B) is contained almost entirely within the bedrock valley, and includes all of Fremont County and part of Page County. Two continuous sand and gravel zones appear to be present at this location. One occurs at depth, sitting on top of bedrock in the deepest part of the valley. This sand body was only found on logs from oil exploration wells; there were no pump tests. The other is shallower, ranging from less than 50 to more than 200 feet below the land surface, but at a relatively uniform elevation (approximately 950 feet). Pumping data from the shallow sand body show pumping rates from 12 to 250 gpm, with the average being 188 gpm (with the outlier of 12 gpm being excluded). The town of Sydney uses this sand unit as a water source, as does the Freemont County Golf Course. Unlike the other cross-sections, this sand and gravel unit occurs both within the bedrock valley and outside on the bedrock 'upland', indicating that it may be related to a younger glacial advance or outwash plain. The limited number of available strip logs makes correlation of this sand and gravel unit difficult to the west of the bedrock valley.

CONCLUSIONS

Due to the recurrence of drought in western Iowa, water users have increasingly been looking for additional sources of water. Buried sand and gravel aquifers associated with three bedrock channels were investigated as potential sources. Due to low data density, two primary study areas were chosen for a more detailed analysis. Point coverage was not sufficient to generate isopach maps or perform statistical analysis, but the production of cross-sections aided in the understanding of the sand and gravel bodies.

The cross-sections (Appendix B) help to illustrate the nature of the sand and gravels units in identifying whether or not they are isolated englacial bodies, sand sheets (subglacial or outwash), or valley fills (Figure 7). Englacial bodies will be the most difficult to predict, both in terms of location and extent. Valley fills, where present, are likely to be laterally continuous, but not all valleys will have a significant thickness of sand and gravel. Sand sheets also have the potential to be laterally continuous, but their margins will not be as predictable as a valley fill since they are not bounded by a valley wall. This study demonstrates the complexity of glacial till sequences and predicting the presence of sand and gravel bodies within or between till sheets.

On a local (community or township) scale, it appears that general trends can be established if the data density is sufficient. However, there is less confidence in using this data as a predictive tool on a regional scale. Several areas, such as the Glenwood Chute, have thick and continuous sand and gravel bodies. In many other areas, the data is not sufficient to map the sand and gravel. In many cases, one or two highly productive wells are identified, but their lateral distribution cannot be established.

ACKNOWLEDGMENTS

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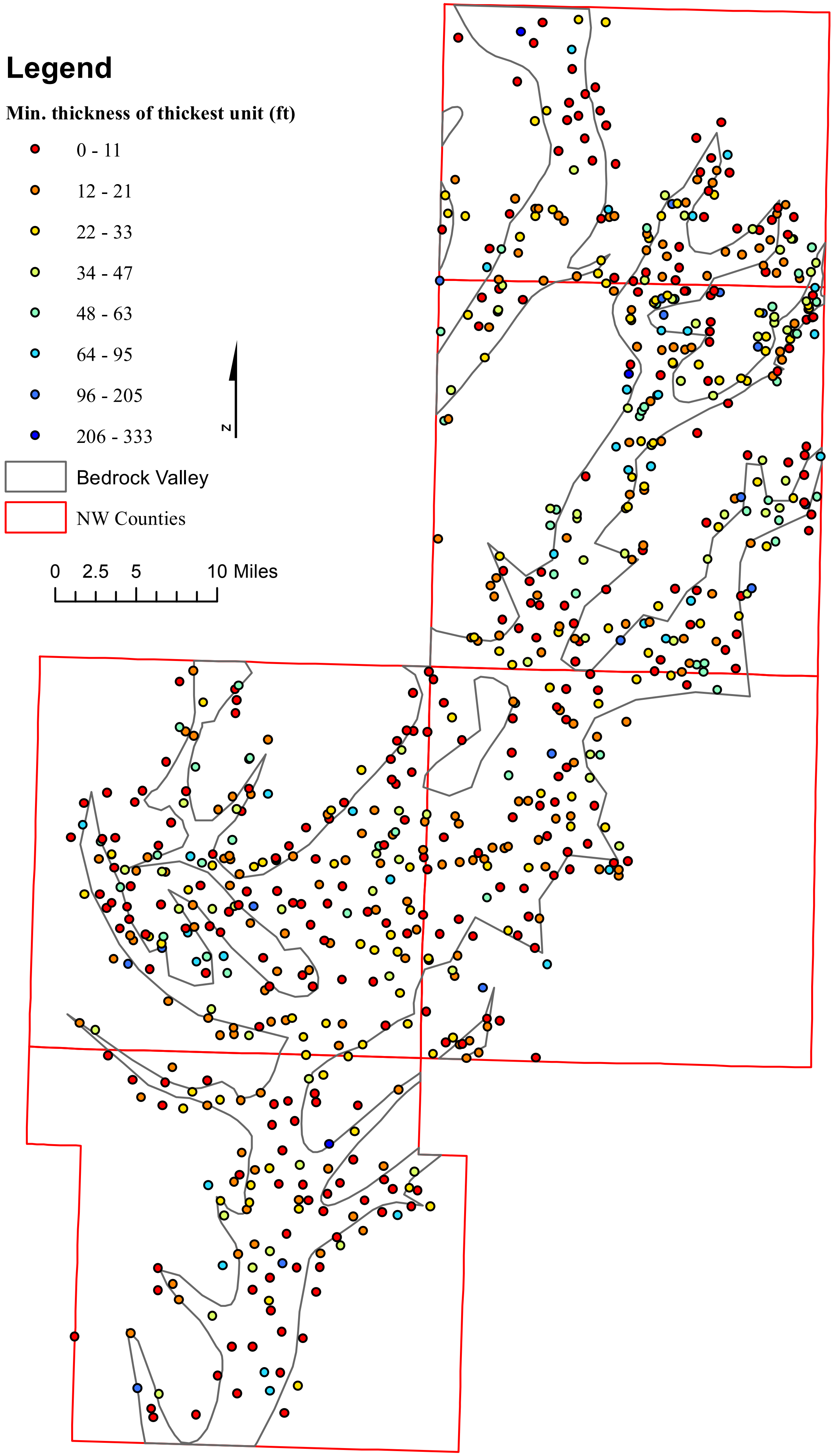
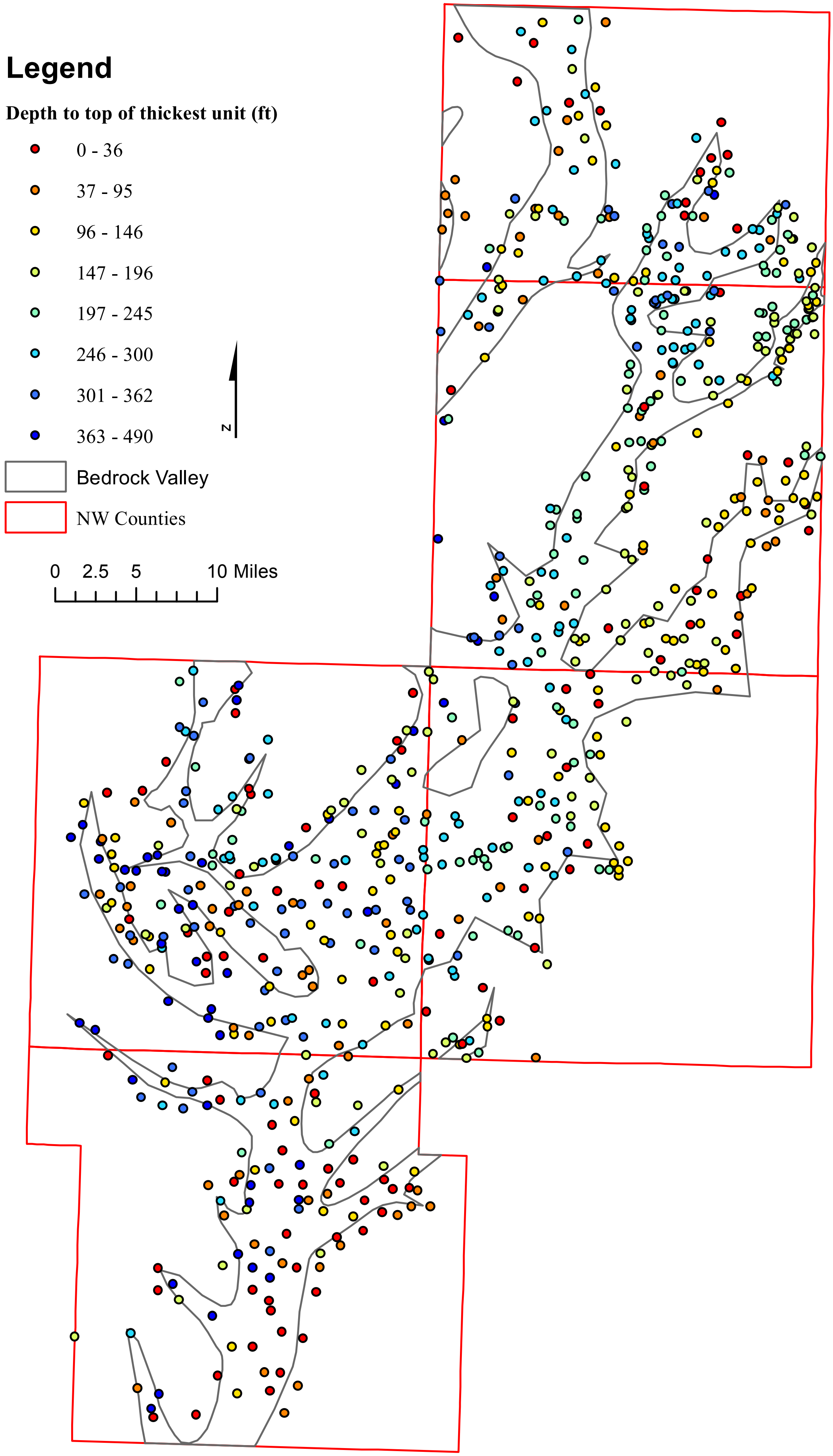
APPENDIX A

Graded point coverages for the northwest and southwest study areas showing the minimum thickness of the thickest unit, depth to the top of the thickest unit, and elevation of the top of the thickest unit for each region.

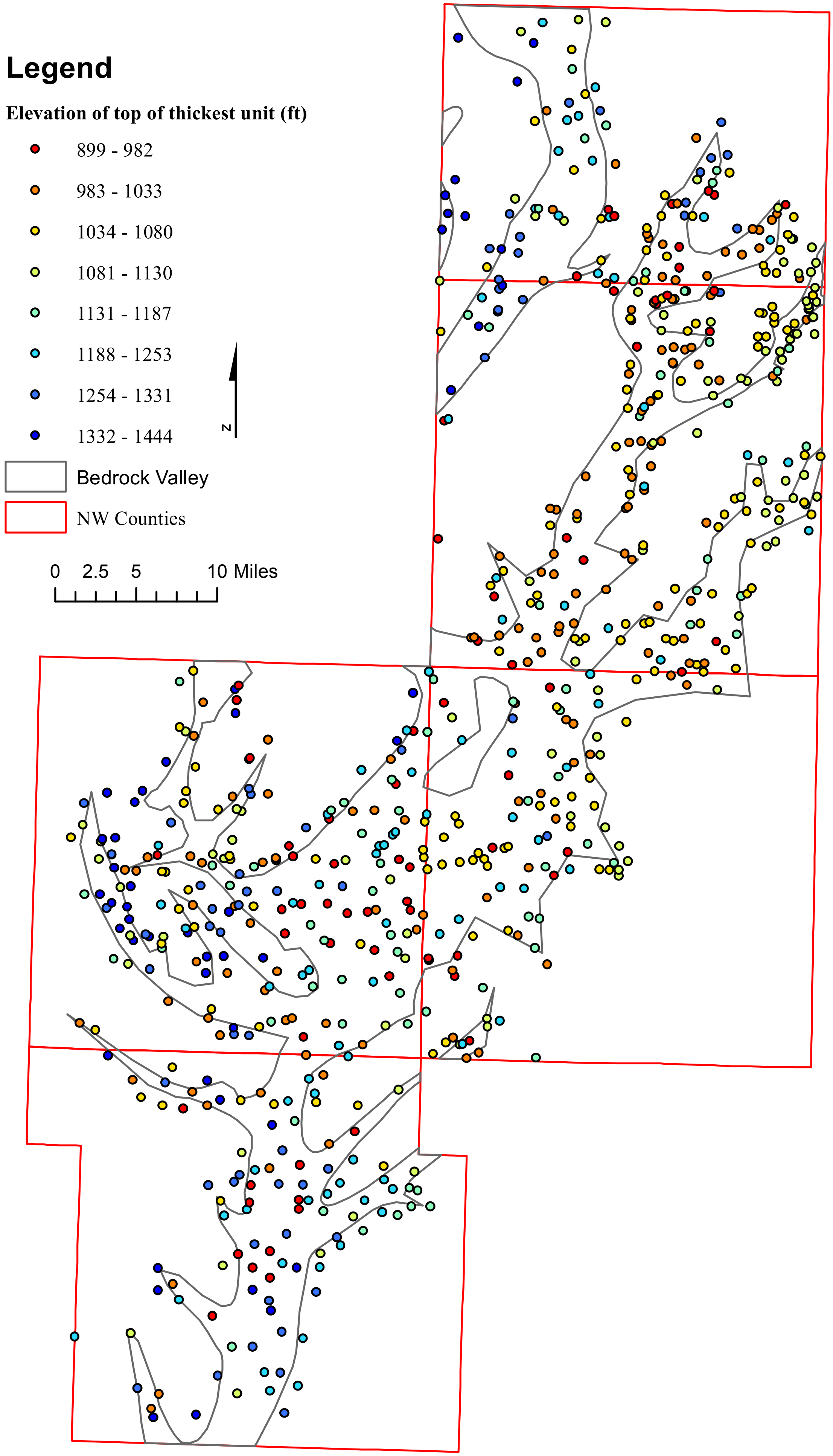
Northwest Study Area- Minimum Thickness of the Thickest Sand and Gravel Unit



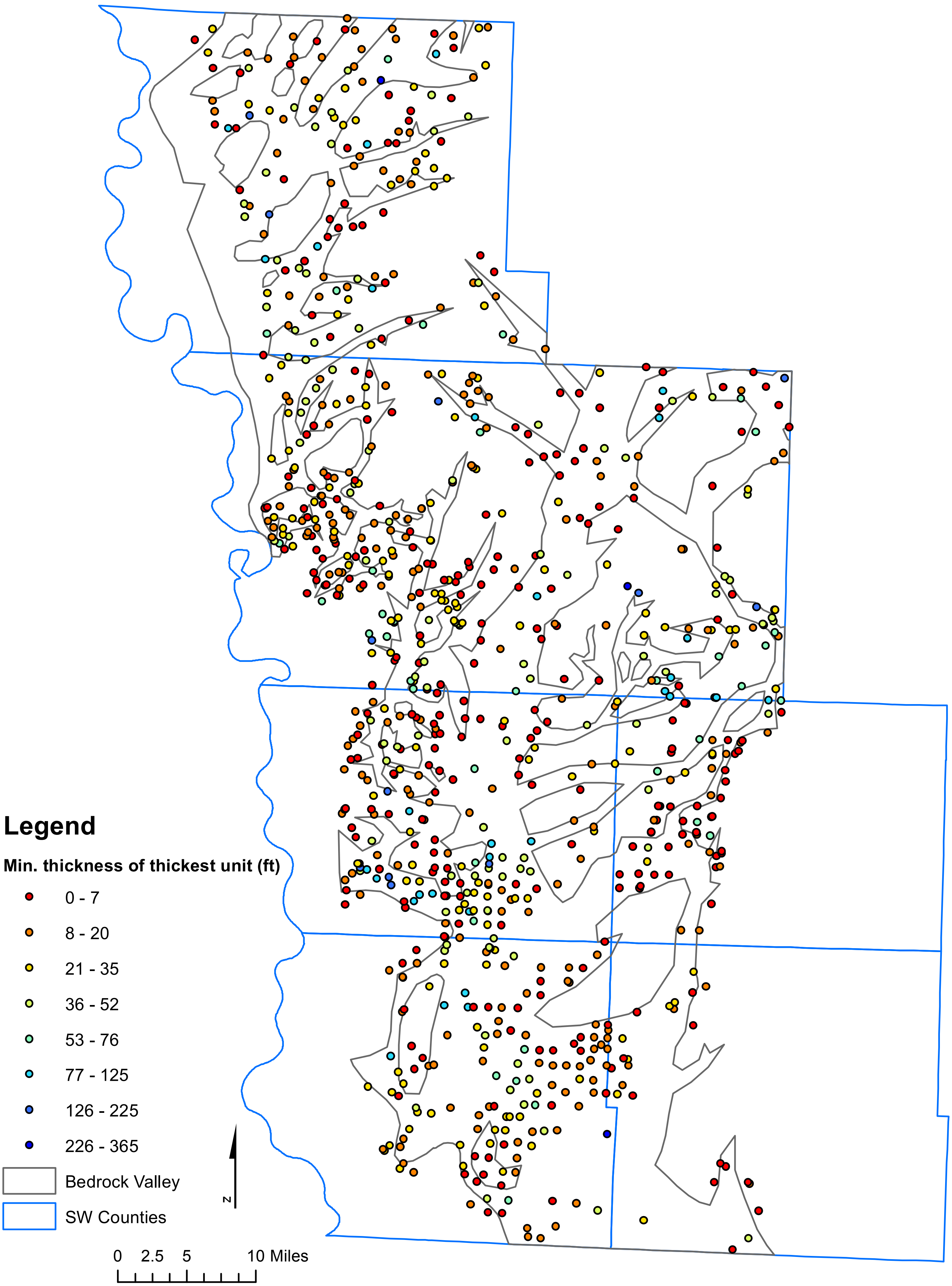
Northwest Study Area- Depth to the Top of the Thickest Sand and Gravel Unit



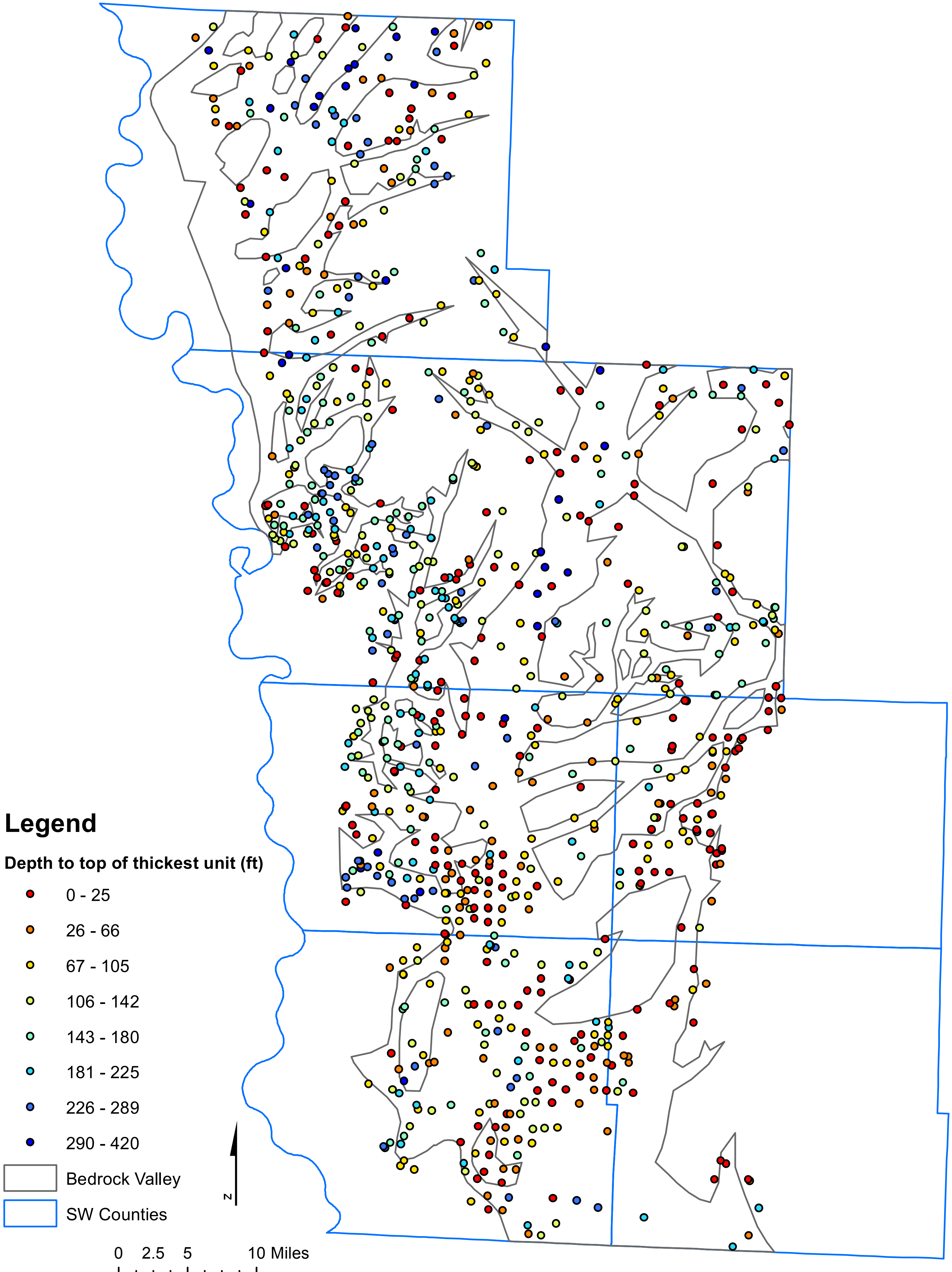
Northwest Study Area- Elevation of the Top of the Thickest Sand and Gravel Unit



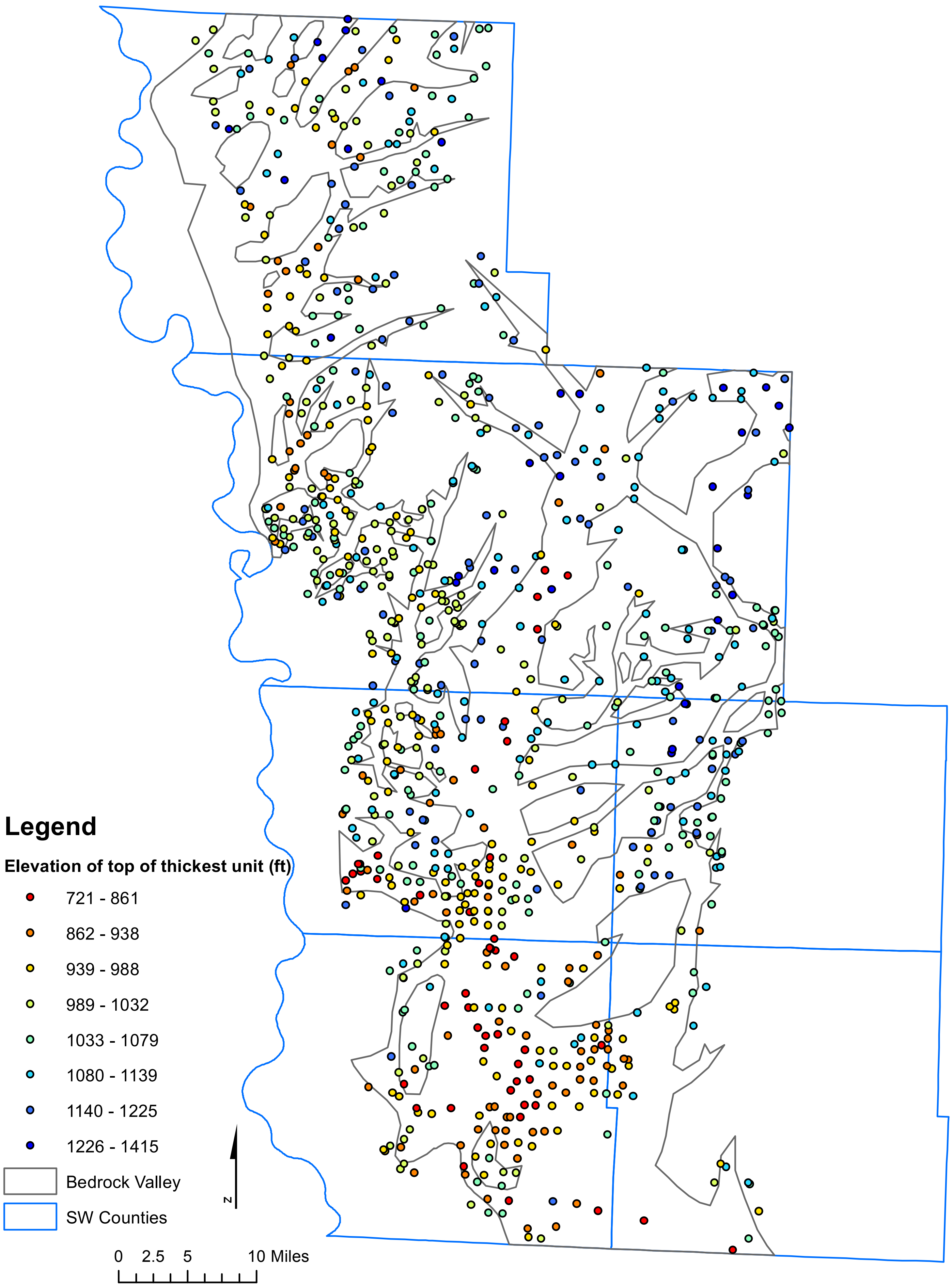
Southwest Study Area- Minimum Thickness of the Thickest Sand and Gravel Unit



Southwest Study Area- Depth to the Top of the Thickest Sand and Gravel Unit



Southwest Study Area- Elevation of the Top of the Thickest Sand and Gravel Unit

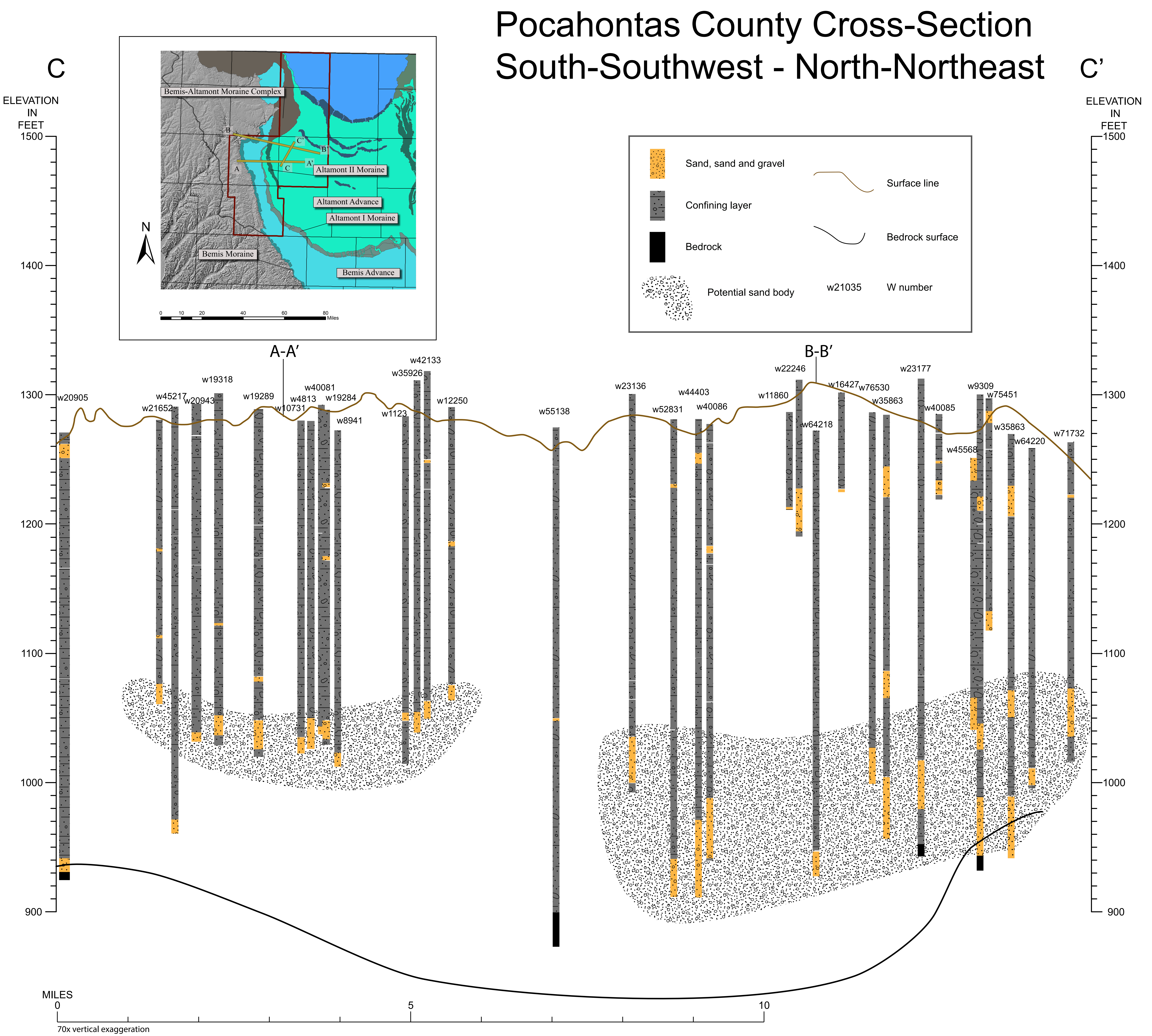


APPENDIX B

Geologic cross-sections illustrating the subsurface geology and location of potential sand and gravel bodies in the northwest and southwest study areas.

Beuna Vista and Pocahontas Counties Cross-Section West-East

B
B'
Clay, Beuna Vista, and Pocahontas Counties Cross-Section
West-Northwest - East-Southeast
Des Moines Lobe
Bemis Moraine
Bemis-Altamont Moraine Complex
Altamont Moraine
C-C'
ELEVATION IN FEET
1500
1400
1300
1200
1100
1000
900
800
MILES
0
5
10
15
20
70x vertical exaggeration
Sand, sand and gravel
Confining layer
Bedrock
Sample Gap
Surface line
Bedrock surface
w21035
W number
Potential sand body
Bemis-Altamont Moraine Complex
Altamont II Moraine
Altamont Advance
Altamont I Moraine
Bemis Moraine
Bemis Advance
N



Pocahontas County Cross-Section
South-Southwest - North-Northeast
C
C'
ELEVATION IN FEET
1500
1400
1300
1200
1100
1000
900
Bemis-Altamont Moraine Complex
Altamont II Moraine
Altamont Advance
Altamont I Moraine
Bemis Moraine
Bemis Advance
N
0 10 20 40 60 80 Miles
Sand, sand and gravel
Confining layer
Bedrock
Potential sand body
Surface line
Bedrock surface
w21035 W number
A-A'
B-B'
w20905
w21652
w45217
w20943
w19318
w19289
w10731
w4813
w40081
w19284
w8941
w1123
w35926
w42133
w12250
w55138
w23136
w52831
w44403
w40086
w11860
w22246
w64218
w16427
w76530
w35863
w23177
w40085
w45568
w9309
w75451
w35863
w64220
w71732
MILES
0
5
10
70x vertical exaggeration

Sac County Cross-Section
West - East


E
E'
Sac County Cross-Section
South - North
ELEVATION IN FEET
1500
1400
1300
1200
1100
1000
900
800
Sand, sand and gravel
Confining layer
Bedrock
Sample Gap
Surface line
Bedrock surface
w21035
W number
Potential sand body
Bemis Moraine
D-D'
Altamont II Moraine
Altamont Advance
Altamont I Moraine
Bemis Moraine
Bemis Advance
N
MILES
0
5
10
15
20
70x vertical exaggeration
w39425
w22995
w54431
w22437
w57997
w16756
w72502
w7545
w57997
w75456
w75255
w31334
w21647
w21214
w19789
w76730
w13001
w48296
w17060
w39031
w55272
w11012
w20953
w23244
w19724
w55259
w17378
w23034
w15136
w48293
w9668
w57408
w65334
w21412
w34712
w73978
w15222
w50987
w62475
w45076
w9885
w52390

Pottawattamie County Cross-Section
West - East


G
G'
Mills and Montgomery Counties Cross-Section
West - East
ELEVATION IN FEET
1300
1200
1100
1000
900
800
700
MILES
0
5
10
15
20
70x vertical exaggeration
w49565
w44021
w45731
w52634
w71481
w71482
w39642
w49534
w71546
w71480
w42931
w53819
w27841
w54663
w54323
w52111
w21839
w71457
w12929
w54334
w61294
w71454
w25364
w71511
w25365
w71450
w71449
w71451
w71512
w40007
w53033
w18893
w7423
w55423
w40406
N
0 6.25 12.5 25 50 Miles
Sand, sand and gravel
Confining layer
Bedrock
Sample Gap
Surface line
Bedrock surface
w21035 W number
Potential sand body


H
H'
Fremont and Page Counties Cross-Section
West - East
ELEVATION IN FEET
1300
1200
1100
1000
900
800
700
ELEVATION IN FEET
1300
1200
1100
1000
900
800
700
N
F
F'
G
G'
H
H'
0 6.25 12.5 25 50 Miles
w17844
w39410
w58828
w52912
w39447
w42395
w52913
w22573
w18910
w27709
w42458
w18920
w53573
w71276
w56586
w50683
w71270
w71326
w71330
w38736
w71273
w71328
w71310
w71311
w71302
w71309
w71303
w71313
w71304
w71308
w71305
w71301
w71307
w535
w71299
w563
w7477
w547
w7407
w43518
w11422
w28118
Sand, sand and gravel
Confining layer
Bedrock
Potential sand body
Surface line
Bedrock surface
w21035
W number
MILES
0
5
10
15
20
70x vertical exaggeration