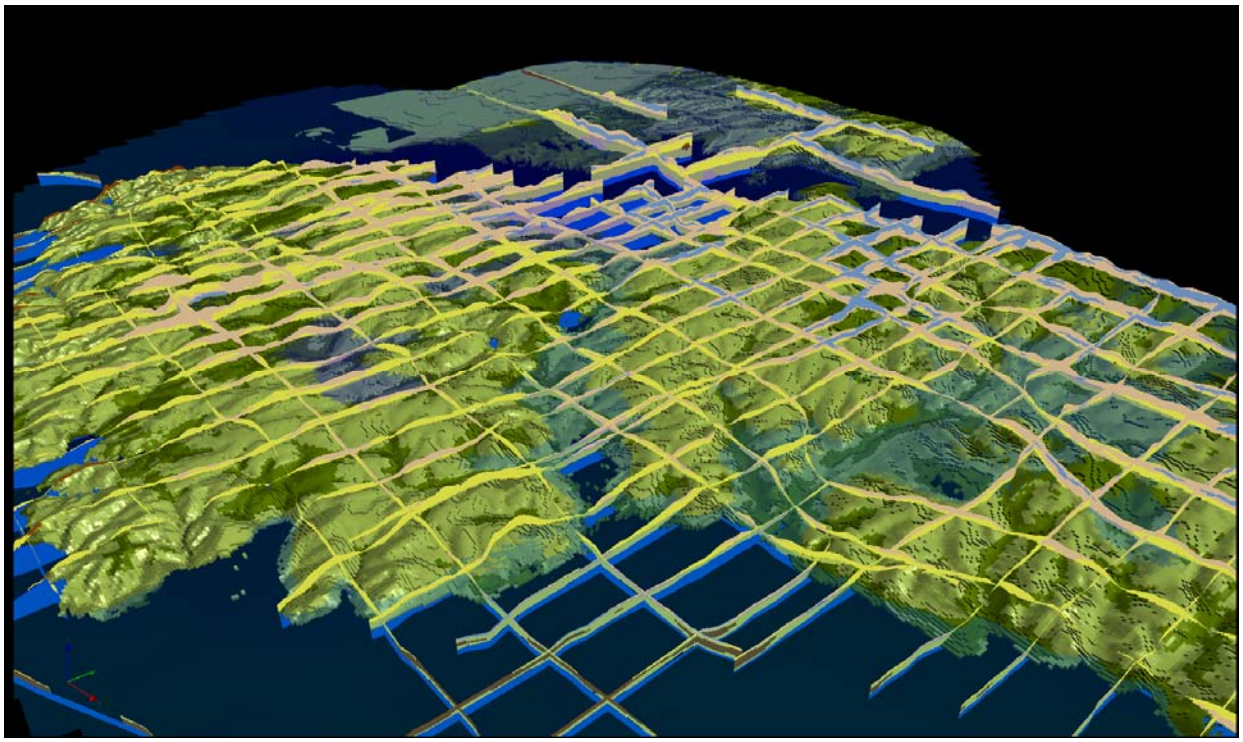
Hydrogeologic Framework of Selected Areas in Sarpy County, Nebraska



***Prepared for*:**

Papio-Missouri River Natural Resources District

8901 S 154th St
Omaha, NE 68138

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Aqua Geo Frameworks, LLC.

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8901 S 154th St
Omaha, NE 68138

Submitted by:

Aqua Geo Frameworks, LLC
130360 County Road D
Mitchell, NE 69357
Phone: (308) 641-2635

James C. Cannia, P.G.
jcannia@aquageoframeworks.com

Jared D. Abraham, P.G.
jabraham@aquageoframeworks.com

Theodore H. Asch, P.G.
tasch@aquiageoframeworks.com







Executive Summary

Aqua Geo Frameworks, LLC. (AGF) is pleased to submit this report titled "*Hydrogeologic Framework of Selected Areas in Sarpy County, Nebraska*". The Papio-Missouri River Natural Resources District (P-MRNRD) desired a better understanding of the hydrogeological framework in the Sarpy County survey area in order to assist in resource management. AGF entered into an agreement with P-MRNRD to collect, process, and interpret airborne electromagnetic (AEM) data, in conjunction with other available background information, to develop a 3D hydrogeologic framework of the Sarpy County AEM survey area and to recommend future work to enhance groundwater management activities.

The scope of work for this project was as follows:

1. SCOPE OF WORK

1.1 An AEM survey utilizing the SkyTEM304M system was flown over the Sarpy County AEM survey area. These flights have been provided as preliminary AEM data on July 30, 2016 and the final AEM data are included as a product attached to this data report.

1.2 AGF began project planning upon signing of the project between the parties. This work included flight plans, database development, and review of hydrogeologic and geologic work for the area. The P-MRNRD assisted in providing information such as power line maps, a test hole database, and related aquifer characteristic studies to AGF. In addition, various public power districts in eastern Nebraska including the cities of Gretna, Lincoln, and Springfield, plus the Metropolitan Utilities District and the Sarpy County Sanitary Improvement District provided utility locations.

At the conclusion of the design process the Sarpy County block flight lines were approximately 10-12 miles in length (east-west) and 8-10 miles (north-south) and were separated by approximately 0.60 miles (1 km) in the east-west direction and approximately 0.11-0.14 miles (200 m-250 m) in the north-south directions. The reconnaissance AEM flight lines in the Gretna area were separated by approximately 1.10 miles (1.77 km) in the east-west direction and approximately 1.0 miles (1.62 km) in the north-south direction. Approximately 631 line-miles (1022 line-km) of AEM survey were flown, in total, over the area.

1.4 AGF acquired AEM data over the Sarpy County area, commencing 27 July 2016 and finishing on 29 July 2016, to support development of the hydrogeological framework. Status reports of the flying were provided to the Contract Representative of P-MRNRD on a daily basis, including the areas flown, production rates, and flight plan for the following day.

1.5 AGF processed and conducted quality assurance and quality control (QA/QC) procedures on all data collected from the acquisition system. AGF delivered preliminary data and inversions on July 30, 2016.

1.6 AGF inverted the AEM data. These final inverted georeferenced data are delivered to the P-MRNRD with this report. After inversion, AGF derived 2D sections, 3D electrical and litho-stratigraphic models, and interpreted geologic and hydrogeologic surfaces of the surveyed area.

1.7 AGF is providing a hydrogeologic framework report that includes maps of aquifer(s), maps of aquifer materials relationships to current test holes and production groundwater wells, estimates of groundwater storage capacity, and maps of estimated potential recharge areas. This report, as mentioned above, also includes all data (acquired, processed, developed) files. The report is delivered in PDF digital format and the data in ASCII and native formats.

2. KEY FINDINGS

2.1 **Boreholes** - As discussed above, borehole information was used to analyze the AEM inversion results. These included CSD (Within the Sarpy County AEM survey area, a total of 18 CSD holes contained lithology information, 15 holes contained stratigraphy information, and 7 holes contained geophysical information), NE-DNR (A total of 922 registered wells contained usable lithology information), local water well drillers (73 wells contained limited and discontinuous lithology and stratigraphic information) , and 32 municipal wells (containing only lithology information) were utilized in the analysis of the AEM inversion results.

2.2 **Merging 2015 and 2016 AEM Databases** - The Sarpy County AEM survey area analysis encompassed an additional 37.2 line-miles (60.3 line-km) of AEM data collected in 2015 in the Sarpy County area. The 2015 AEM data contains valuable information that can be utilized in the interpretation of the larger Sarpy County AEM survey data. The 2015 AEM results were combined with the 2016 AEM data. Note that this combination did not include reinverting the 2015 data, but rather included merging the 2015 inversion results into the 2016 database and interpretation.

2.3 **Digitizing Interpreted Geological Contacts** - Characterization and interpretation of the subsurface was performed in cross-section and derived surface grid formats. Contacts between the geologic units were digitized in 2D including: Quaternary (***Q***), Cretaceous Dakota (***Kd***), and undifferentiated Pennsylvanian (***IP***). The interpretive process benefited from the use of CSD, NE-DNR, local water well driller, and municipal borehole logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including Quaternary aquifer material mapping and Cretaceous Dakota sandstone/sand dominant zones are included as appendices as well as the interpretative surface grids.

2.4 **Resistivity/Lithology Relationship** - Assessment of the sediment character in both the ***Q*** and the ***Kd*** aquifer systems was conducted to determine the overall composition of the major categories used to define the aquifer and aquitards in eastern Nebraska. For the ***Q*** aquifer systems, a numerically robust assessment of the resistivity thresholds was used to characterize non-aquifer (<12 ohm-m), marginal (12-20 ohm-m), and aquifer (20-50 ohm-m), including coarse sand-rich intervals (>50 ohm-m). A similar process was applied to the ***Kd*** and a resistivity threshold of 27 ohm-m was determined to separate sandstone/sand dominant zones from shale/clay dominant zones. This allowed for the characterization of the ranges of resistivities present in the major geologic units described in this report.

2.5 **Hydrogeological Framework of the Sarpy County AEM Survey Area** - The AEM reveals considerable variability in the ***Q***, ***Kd***, and undifferentiated ***IP*** deposits across Sarpy County AEM survey area. The subsurface distribution of materials can generally be characterized into three somewhat overlapping, but distinct, areas with smaller localized depositional features distributed at various locations within the survey area. These areas include the ***Q*** alluvium, ***Q*** glacial, and the ***Kd*** bedrock area. The ***Q*** alluvium aquifer area of the Sarpy County AEM survey area is predominantly composed of ***Q*** unconsolidated aquifer and coarse aquifer materials composed of alluvial sediments. Marginal and non-aquifer materials are present, but they are isolated and limited in geographic area. The combined alluvium system overlies the ***Kd*** and ***IP***. The ***Q*** alluvium is eroded into the surfaces of the ***Kd*** and ***IP*** and is seen mostly in the Platte River, Buffalo, and Springfield creeks. The ***Kd*** can act both as an aquifer and an aquiclude. Water from the alluvium or ***Kd*** can move between the units. The coarse aquifer and aquifer materials are most likely to have this connection and interaction.

Q glacial deposits (tills and outwash) cover much of the Sarpy County AEM survey area and thicken to the north-northeast and thin to the south-southwest. They lie unconformably upon the ***Kd*** and ***IP***. There is a separation or erosional channel between the north block of ***Kd*** and the south block of the ***Kd*** that is filled with the thickest sequence of ***Q*** materials.

The ***Kd*** is characterized by a combination of sandstone/sand dominant and shale/clay dominant units. The ***Kd*** is covered by ***Q*** alluvium and till although there are some outcrops along the bluffs near the Platter River to the south in the study area. The ***Kd*** varies in thickness from approximately 0 feet to over approximately 150 feet. The ***Kd*** occurs as erosional remnants and lies unconformably on the ***IP***. The patterns that define the shape of present day ***Kd*** are related to many erosional episodes including glaciation and fluvial processes. Recent erosion has occurred in the drainages of the Platte River, Buffalo, and Springfield Creeks. Many areas of ***Kd*** have sufficient saturated thickness to provide water to water supply wells.

2.6 **Sarpy County Estimation of Aquifer Volume and Water in Storage –** Estimations were calculated for both ***Q*** and ***Kd*** aquifer materials. The ***Q*** non-aquifer material has an estimated aquifer volume of 11,027 acre-ft and contains 4,411 acre-ft of groundwater in storage, marginal aquifer material has an estimated aquifer volume of 452,774 acre-ft and contains 158,471 acre-ft groundwater in storage, aquifer material has an estimated aquifer volume of 4,691,635 acre-ft and contains an estimated volume of 938,327 acre-ft of groundwater in storage. The ***Q*** coarse aquifer material contains an estimated aquifer volume of 358,390 acre-ft for a total of 89,598 acre-ft of groundwater in storage. The amount of groundwater in storage for all material groups is 605,799 acre-ft. Non-aquifer materials in the Sarpy County AEM survey area will yield approximately 88 acre-ft, marginal aquifer materials will yield approximately 7,924 acre-ft, aquifer materials will yield 35,332 acre-ft, and the coarse aquifer material will yield approximately 13,440 acre-ft. A total of 56,783 acre-ft is available from the combined ***Q*** aquifer and coarse aquifer materials.

The ***Kd*** sandstone/sand dominant material has an estimated aquifer volume of 2,155,817 acre-ft and contains 754,536 acre-ft of groundwater in storage, the ***Kd*** shale/clay dominant material has an estimated aquifer volume of 1,395,427 acre-ft and contains 558,171 acre-ft of groundwater in storage. The ***Kd*** sandstone/sand dominant material has an extractable volume of groundwater of 37,727acre-ft and the shale/clay dominant material has an extractable volume of groundwater of 11,163 for a total of 48,890 acre-ft.

2.7 **Potential Recharge Zones within the Sarpy County AEM Survey Area** - 3D representations of the subsurface resulting from the Sarpy County AEM investigation illustrate areas of aquifer

materials from the bedrock up to the land surface. From these interpretations a series of near-surface maps were constructed to display the ***Q*** aquifer materials in the first 10 ft. These indicate that while there is some heterogeneity in the aquifer materials, it is easy to identify the areas of aquifer materials that will transmit the most (aquifer and coarse aquifer materials), and the least (non-aquifer and marginal aquifer materials), amounts of water from the surface down to the groundwater system. The greatest possibility for recharge in the Sarpy County AEM survey area is the Platte River alluvial valley floor where coarse aquifer and aquifer materials are near the land surface. On the table lands, the best possible locations for recharge would be along the southwestern edge of the survey area and in the Buffalo and Springfield Creek drainages.

3. Recommendations

Recommendations provided to the P-MRNRD in this section are based on the interpretation and understanding gained from the addition of the AEM data to existing information and from discussions with the P-MRNRD about their management challenges.

3.1 **Additional AEM Mapping** - The aquifer maps provided in this report represent the detailed framework developed for the Sarpy County AEM survey area.

The detail provided in the hydrogeological interpretation of the Sarpy County AEM survey area allowed for confident development of hydrogeologic framework. The interpretations match well with the CSD and NE-DNR test holes. If additional high resolution information is needed within Sarpy County to resolve questions of resource management, it is recommended that additional areas of closely spaced lines or “block flights” be collected in order to develop detailed frameworks.

It should be noted that the ability to effectively map erosional remnants of the ***Kd*** can only happen with block flights. Thus, if ***Kd*** remnants are suspected and are targets of interest within an area designated for investigation, then block flights are required for effective characterization.

For example, the detailed hydrogeologic frameworks presented in this report have provided estimates of groundwater storage capacity. This is done by using existing aquifer characteristic information and calculating groundwater in storage and effective yield. It is recommended that additional closely spaced flight lines for collection of AEM data and interpretation be considered in critical areas of Sarpy County and the P-MRNRD. This will supply the P-MRNRD with information on aquifer sustainability, depletion to streams, well interference, groundwater withdrawal, and other management considerations.

3.2 **Update the Water Table map** - The groundwater data used in the analyses presented in this report use the 1995 CSD water table data (Nebraska CSD, 1995). 22 years is a long time in the evolution of a groundwater system and, in many areas, the water table used for this report was found not to be inconsistent with other recent borehole data. This is especially true on the southwest side of the AEM survey area.

3.3 **Siting new test holes and production wells** – The AEM framework maps and profiles provided in this report provide insight in 3D on the relationship between current test holes and production groundwater wells. At the time of this report, the currently available lithology data for the Sarpy County AEM survey area was used in building the framework maps and profiles. It is recommended that the results from this report be used to site new test holes and monitoring wells. Often test holes are sited based on previous work that is regional in nature. By utilizing the maps in this report new drilling locations can be sited in optimal locations.

The location of new water supply wells for communities can also use the results in this report to guide development of new water supply wells. Planners should locate wells in areas of greatest saturated thickness with the least potential for non-point source pollution.

3.4 **Aquifer testing and borehole logging** - Additional aquifer tests are recommended to improve estimates of aquifer characteristics. No aquifer properties were available outside the larger cities in the survey area. A robust aquifer characterization program is highly recommended at the state, regional (NRD's), and smaller municipal levels. Aquifer tests can be designed based on the results of AEM surveys and existing production wells could be used in conjunction with three or more installed water level observation wells.

Additional test holes with detailed, functional, and well calibrated geophysical logging for aquifer characteristics are highly recommended. The few test holes with geophysical logs in the area of the Sarpy County AEM survey were inadequate. None were calibrated and several had apparent hardware malfunctions. The borehole geophysical logs provided for this investigation demonstrate that additional calibrated and verified geophysical logs are required in the P-MRNRD.

Examples of additional logging would be flow meter logs and geophysical logs including gamma, neutron, electrical, and induction logs. Detailed aquifer characteristics can be accomplished with nuclear magnetic resonance logging (NMR). This is a quick and effective way to characterize porosity and water content, estimates of permeability, mobile/bound water fraction, and pore-size distributions with depth. This is very cost effective when compared to traditional aquifer tests.

3.5 **Recharge Zones** - The Sarpy County AEM survey hydrogeologic framework provides areas of recharge from the ground surface to the groundwater aquifer. The block flights of AEM data acquisition provide the most detailed information for understanding recharge throughout the Sarpy County AEM survey area. It is recommended that additional AEM data be collected and interpreted utilizing closely-spaced flight lines using an AEM system that has near-surface resolution. It is further recommended that future work integrate new soils maps with the results of this study to provide details on soil permeability, slope, water retention to provide a more complete understanding of the transport of water from the land surface to the groundwater aquifer.

4. Deliverables

In summary, the following are included as deliverables:

- Raw AEM Mag data Geosoft database and ASCII *.xyz's
- Raw Data Files - SkyTEM files *.geo, *skb, *.lin
- SCI inversion Geosoft database and ASCII *.xyz's
- Borehole Geosoft databases and ASCII *.xyz's
- Interpretations Geosoft database and ASCII *.xyz's
- ESRI ArcView files – surface, topo, etc
- 3D voxel model Geosoft databases and ASCII xyz's
- KMZs for the Sarpy County AEM survey including "As-Flown" flight lines, retained inversion data locations, profile interpretations, ***Q*** and ***Kd*** aquifer properties, and near-surface recharge areas
- Pitney-Bowes Discover PA sessions for the Profiles and 3D voxels

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List of Abbreviations

2D	Two-dimensional
3D	Three-dimensional
A*m^2	Ampere meter squared
AEM	Airborne Electromagnetic
AGF	Aqua Geo Frameworks, LLC
dB/dt	Change in amplitude of magnetic field with time
cm	centimeters
CSD	Conservation and Survey Division
DEM	Digital Elevation Model
DOI	Depth of Investigation
DGPS	Differential global positioning system
em, EM	Electromagnetic
ENWRA	Eastern Nebraska Water Resources Assessment
ft	Feet
FM	Geological Formation
GIS	Geographic Information System
GP	Geological Group
GPM	Gallon per minute
HEM	Helicopter Electromagnetic
Hz	Hertz (cycles per second)
IGRF	International Geomagnetic Reference Field
Km/km	Kilometers
Kmz	Google Earth Keyhole Markup language Zipped file
Kd	Cretaceous Dakota Group
MAG	Magnetic (data); Magnetometer (instrument)
MCG	Minimum curvature gridding
m	Meters
mg/L	Milligrams per liter
mi	Miles
µS/cm	MicroSiemens per centimeter
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NRD	Natural Resources Districts
Ohm-m	Unit of Electrical resistivity
OM	Geosoft Oasis montaj
***IP* or [P**	Undifferentiated Pennsylvanian formations
Pcg	Permian Council Grove Group
Pd	Pennsylvanian Douglas Group
Pkc	Pennsylvanian Kansas City Group
Pl	Pennsylvanian Lansing Group
PFC	Primary Field Compensation
PLNI	Power Line Noise Intensity

Pm	Pennsylvanian Marmaton Group
P-MNRD	Papio-Missouri River Natural Resources District
Ps	Pennsylvanian Shawnee Group
Q	Quaternary
Rx	Receiver
SCI	Spatially-Constrained Inversion
STD	Standard Deviation
TEM	Transient Electromagnetic
TDEM	Time-Domain Electromagnetic
TDS	Total dissolved solids
Tx	Transmitter
UNL	University of Nebraska Lincoln
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
V/m^2	Volts per meter squared
XRI	Exploration Resources International

1 Introduction

1.1 Purpose of Current Project

The Sarpy County airborne electromagnetic (AEM) survey area lies in eastern Nebraska and encompasses approximately 129 square miles or 82,748 acres. The Sarpy County AEM survey area is outlined in red in Figure 1-1. Sarpy County lies within the Papio-Missouri River Natural Resource District (P-MRNRD). The area is in two of the Nebraska groundwater regions, Region 10, Glacial Drift, and Region 2, the Platte River Valley (Pederson et al., 1986). As of 2010, approximately 3,500 people obtain their drinking water through domestic wells in western Sarpy County near the towns of Springfield and Gretna Nebraska. P-MRNRD desired an improved understanding of the hydrogeological framework to assist in resource management and to protect drinking water supplies in this increasingly populated area. An AEM survey was selected to assist in the development of a 3D hydrogeologic framework of the project area and recommend future work to enhance groundwater management activities.

The Sarpy County AEM survey area was identified as an area of concern by the P-MRNRD for water quantity and quality in the Quaternary alluvial/glacial (***Q***) and Cretaceous Dakota (***Kd***) aquifers. The P-MRNRD will use the AEM data and subsequent hydrogeological framework to help quantify the amount and location of the groundwater, its connection amongst aquifer units, and the impact this may have on ground water quality in the Sarpy County AEM survey area.

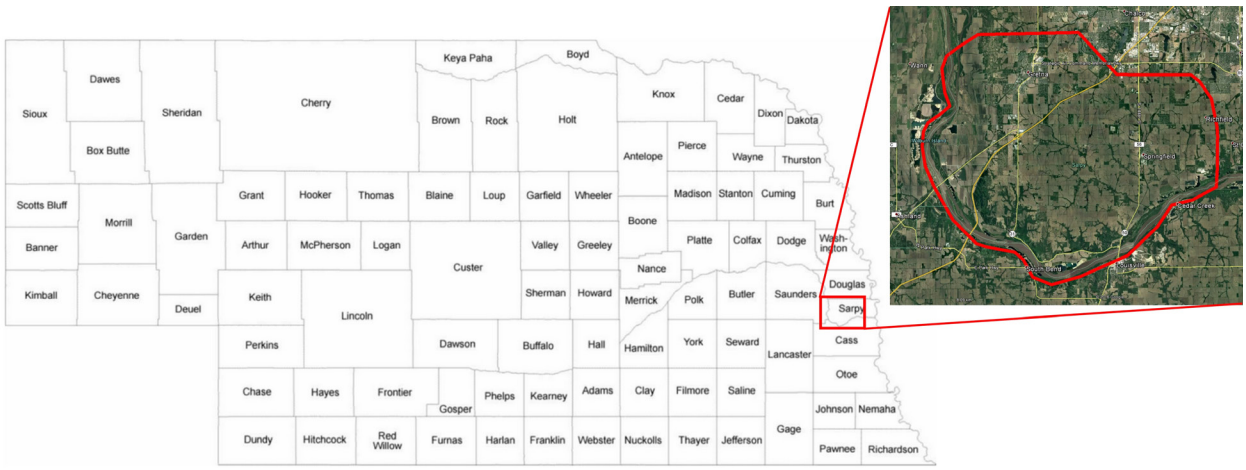


Figure 1-1: Map of Nebraska counties, indicating the location of the Sarpy County airborne electromagnetic (AEM) survey with an inset of the project area.

1.2 Background

Use of AEM technology to map and evaluate groundwater resources has gained momentum over the last 20 years in the United States and abroad. The state of Nebraska has been on the forefront of implementing AEM for water resources management over the last decade with projects across the state in a variety of geologic settings. In recent years, the Eastern Nebraska Water Resources Assessment (ENWRA) has coordinated efforts between area Natural Resources Districts (NRDs), Conservation and Survey Division (CSD), the U.S. Geological Survey (USGS), and Aqua Geo Frameworks, LLC (AGF) in support of several projects designed to characterize the hydrogeology across the state.

The ENWRA project was formed in 2006 with sponsors from six Natural Resources Districts (Lewis and Clark, Lower Elkhorn, Papio-Missouri River, Lower Platte North, Lower Platte South, and Nemaha) and cooperating agencies including the CSD and the USGS. The long-term goal of the project is to develop a geologic framework and water budget for the glaciated portion of eastern Nebraska.

In the following years, individual reports utilizing AEM data collected in 2007 were released by the USGS and CSD. In 2009, a multi-faceted investigation incorporating the 2007 AEM data and 2009 ground-based geophysical techniques was conducted by the USGS to characterize the hydrogeologic setting near Oakland, Nebraska (Abraham et al., 2011). In 2009, the Lower Platte North NRD funded the USGS and CSD for the development of a 3D hydrostratigraphic framework of the subsurface near Swedeburg, Nebraska based on an AEM survey (Smith et al., 2009; Divine and Korus, 2013). Also in 2009, the Lower Platte South NRD funded the USGS and CSD for a similar investigation of the hydrostratigraphy near Sprague, Nebraska (Smith et al., 2009; Divine and Korus, 2012). In 2013, the Lower Elkhorn NRD funded Exploration Resources International, LLC (XRI) to conduct an AEM survey near the towns of Clarkson and Howells, Nebraska in order to characterize the extent of the Quaternary aquifer beneath the area following the drought of 2012 (Abraham et al., 2014; Abraham et al., 2013). At the same time the City of Madison also funded XRI for a small scale AEM study in and around the City of Madison (Carney et al., 2014a). Also in 2013, XRI completed an AEM survey covering over 800 line-miles in Butler and Saunders counties northwest of the city of Lincoln, Nebraska (Carney et al., 2014b). This survey, funded by the Lower Platte South Natural Resources District, revealed extensive, buried paleovalley aquifers beneath thick sequences of till. Additionally, intervals of Cretaceous bedrock units were revealed in the survey. The Lower Elkhorn Natural Resources District began to map their district with three-mile AEM grids in the fall of 2014 (Exploration Resources International, 2015). In 2014-2015 the ENWRA funded XRI for a large-scale reconnaissance airborne electromagnetic survey over the glaciated portion of Nebraska. The AEM survey, composed of approximately 2,200 line-km of approximately 32 km spaced lines (Abraham et al., 2015; Carney et al., 2015a; Carney et al., 2015b). In 2016, a study led by the CSD showed the details gained from the AEM survey in around the Firth and Sprague area provided unique details that assisted in the management of the groundwater resources (Korus et al., 2016). In 2017, A study led by AGF provided information to improve the understanding of the hydrogeologic framework including areas of recharge to the aquifer and details for well head protection areas in the Bazile Creek Groundwater Management area (AGF, 2017). Thus, AEM surveys of the glacial terrain of Nebraska have

followed a progressive, long-term plan spanning nearly 10 years. This body of work shows continuing advancements in the science and application of AEM to support groundwater management.

In addition to the AEM and Magnetic Total Field data acquired during this investigation, multiple resources were used to develop the presented hydrogeologic framework and subsequent recommendations for potential recharge areas and well locations. Data and findings from previous studies, along with geologic descriptions and geophysical data were utilized to develop the hydrogeologic framework presented herein. A location map showing the Sarpy County AEM survey flight area and flight lines is presented in Figure 1-2. A Google Earth kmz of the "As-Flown" flight lines is also included in Appendix 3/KMZ.

1.3 Description of the Sarpy County Project Area

The project area is in eastern Nebraska near the towns of Springfield and Gretna and lies within the Valleys, Bluffs and Escarpments, and Rolling Hills topographic regions of Nebraska (Elder, 1951). The area investigated by the AEM reconnaissance surveys within northwest Sarpy County in eastern Nebraska spans approximately 44 square miles (mi^2) or 28,262 acres (Figure 1-2). The larger, more detailed, block-like survey in Sarpy County covered approximately 85 mi^2 or 54,486 acres. The total area of the study was 129 mi^2 or 82,747 acres.

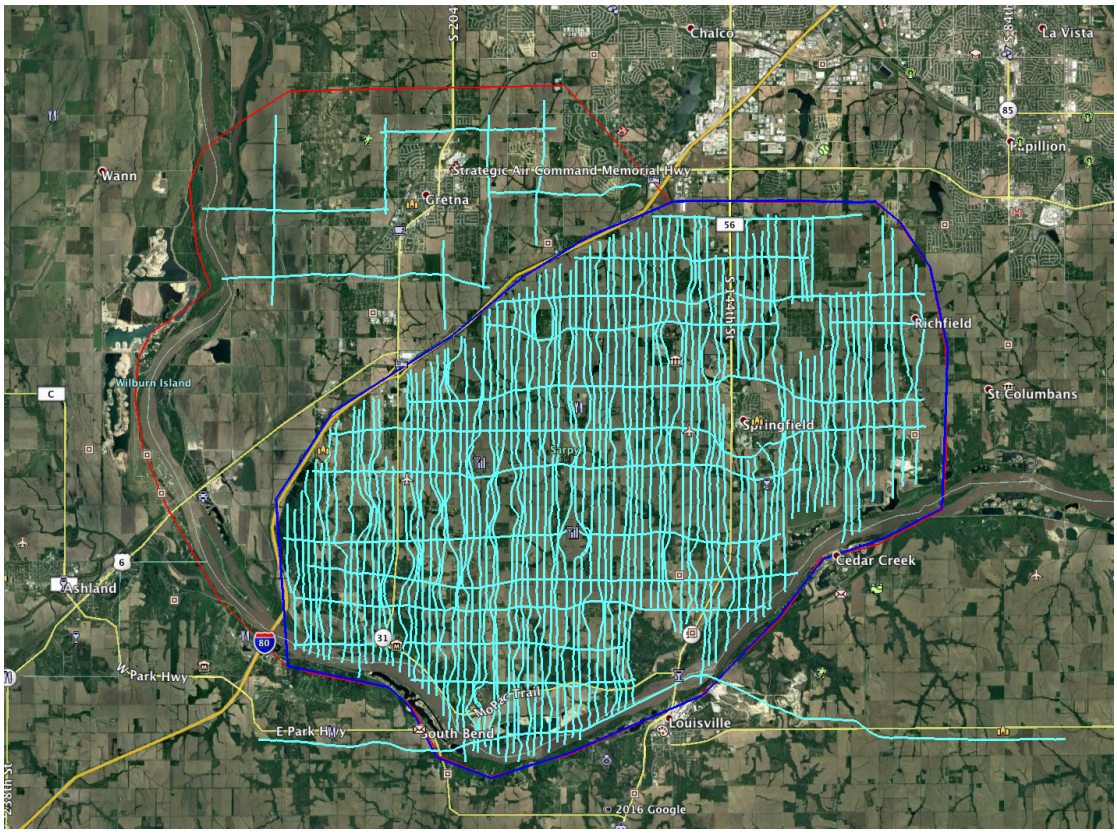


Figure 1-2. Outline of the Sarpy County AEM survey area including county lines and major roads (Interstate 80). The Sarpy County AEM survey area is outlined in red. The block flight area is outlined in dark blue. The "As-flown" flight lines are in light blue.

2 Project Area Hydrogeology

2.1 Geologic Setting

Geologic exposures in Sarpy County consist, generally, of soil, loess, glacial till and alluvium (clay, silt, sand, and gravel) and small areas of bedrock. These materials overlie deposits of loess (wind-deposited silt), till (a glacial deposit consisting of clay, silt, sand, and gravel), alluvium (clay silt, sand, gravel), Cretaceous Dakota (***Kd***) formation (sandstone, sand, clay, shale) or Pennsylvanian (***IP***) age limestone (Figure 2-1). The Quaternary-age materials are less than 1.7 million years old. These unconsolidated materials lay on consolidated bedrock that consists of sedimentary rocks of Cretaceous and Pennsylvanian age. These bedrock units may outcrop along valley sides and other various places in the county. The Cretaceous-age rocks consist primarily of sandstone and shale and are 66 to 138 million years old. The Pennsylvanian age rocks range from 290 to 300 million years old. Unexposed older sedimentary rocks of Mississippian, Devonian, Ordovician, and Cambrian ages consist mostly of dolomite, limestone, shale, and sandstone occur in the subsurface of the Sarpy County AEM survey area. The basement units consist of metamorphic rocks (gabbro or basalt) (Korus and Joeckel, 2011).

Structurally, Sarpy County lies within the Eastern Nebraska Uplift. There are two structurally high areas, one in the western and one in the northeastern part of the county. Rocks on these structures dip in several directions. A northern extension of the Humbolt Fault Zone cuts across the eastern part of the county (Burchett, 1981).

The Cretaceous deposits are not deformed by folding and faulting. Outcrops of these rocks are present in the project area within the valleys along the north and west areas of the project area.

2.1.1 Surficial Geology

The complex Pleistocene and Holocene Quaternary geology in eastern Nebraska consists of sequences of clay, silt, till, sand, and gravel overlying bedrock units. These materials are capped by loess deposits in many locations. Figure 2-2 (Burchett, undated, personal comm. Dana Divine, CSD January 20, 2017) and Figure 2-3 (Korus & Joeckel, 2011) display the geologic time scale with CSD's lithostratigraphic sequence that underlies the state of Nebraska. The surficial geology of the project area is typical of western mid-continental glaciated areas of North America where buried ***Q*** sand and gravel glacial outwash deposits or paleovalleys, comprised of unconsolidated Plio-Pleistocene sand and gravel units, underlie extensive areas of glacial till.

CSD test holes and drillers logs obtained from NE-DNR indicate glacial till units are prevalent across most of the project area. These deposits are thick in the channel between the 2 large ***Kd*** deposits seen in Figure 2-1 and thin to the south near the Platte River.

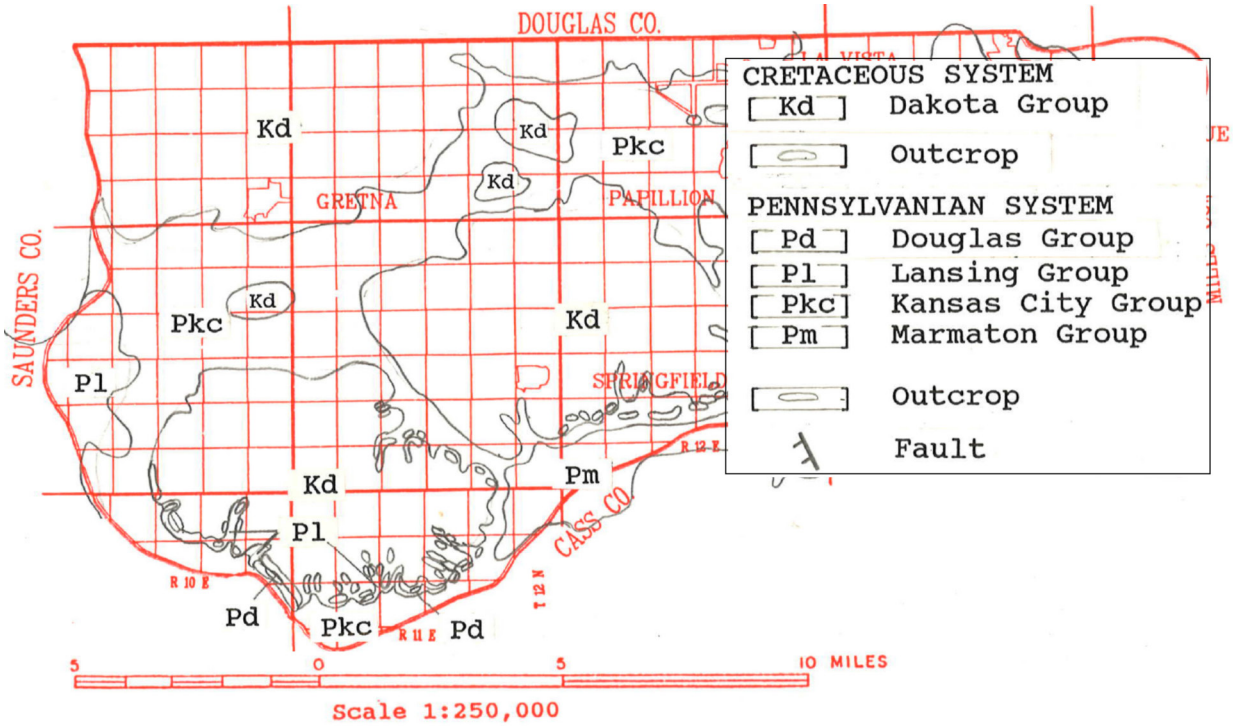


Figure 2-1. Bedrock map of western Sarpy County, Nebraska, modified from Burchett (undated, personal comm. Dana Divine, CSD January 20, 2017). Unknown projection.

2.1.2 Cretaceous Geology

There are deposits within the area from the Lower Cretaceous Dakota Gp (***Kd)***. The ***Kd*** lies upon the ***IP*** bedrock. Figure 2-1 shows the highly-eroded nature of the ***Kd*** which has left erosional remnants of the formation, one near Gretna to the north and one near Springfield and the Platte river to the south. Figure 2-4 shows the bedrock made up of the ***Kd*** lying upon the ***IP*** overlain with the topography of the area (Burchett et al., 1975). As seen on the map, the ***Kd*** forms a resistive erosional topographic high area. These two large sections of ***Kd*** make up the bulk of the remaining formation in Sarpy County. The ***Kd*** is comprised primarily of massive to interbedded sandstone/sand with ironstone and shale, some zones are argillaceous to slightly sandy (Condra and Reed, 1959). The sandstone in the Dakota Group typically has low permeability and storage compared to unconsolidated units overlying it. A hydraulic connection can exist in locations where the Dakota is in contact with overlying saturated ***Q*** deposits (Gutentag et al., 1984), which can be seen in the project area.

System	Series	Group	Formation	Thickness, Ft.	General Characteristics	Geologic Age in Million Years
Quaternary	Recent			0 to 300+	Alluvium (silt, sand and gravel)	
	Pleistocene				Loess and glacial till (clay, silt, sand and gravel)	1.7
Tertiary				Absent		66
Cretaceous	Lower Cretaceous	Dakota	Omadi	0 to150+	Buff to rusty sandstone	
			Fuson		Varicolored shale	
			Lakota		Gray sandstone	138
Jurassic				Absent		205
Triassic				Absent		240
Permian				Absent		290
Pennsylvanian	Virgil	Wabaunsee		Absent		
		Shawnee		Absent		
		Douglas		Less than 50	Shale and Limestone	
	Missouri	Lansing		0 to 200+	Limestone and shale	
		Kansas City			Limestone and shale	
	Des Moines	Marmaton		Less than 100 to 300+	Shale, limestone, and coal	
		Cherokee			Shale, sandstone, and coal	330
Mississippian				0 to 200+	Limestone, dolomite, and shale	360
Devonian				100 to 500+	Dolomite, limestone, and shale	410
Silurian				Less than 100 to 100+	Cherty dolomite	435
Middle and Upper Ordovician				Over 600	Dolomite, shale, and sandstone	
Lower Ordovician Cambrian				0 to 200+	Dolomite and sandstone	
Precambrian					Metamorphic and sedimentary rocks	570

Figure 2-2. Generalized geologic chart of Sarpy County, Nebraska. Shaded rock units are exposed on the ground surface. Modified from Burchett (undated, personal comm. Dana Divine, CSD January 20, 2017).

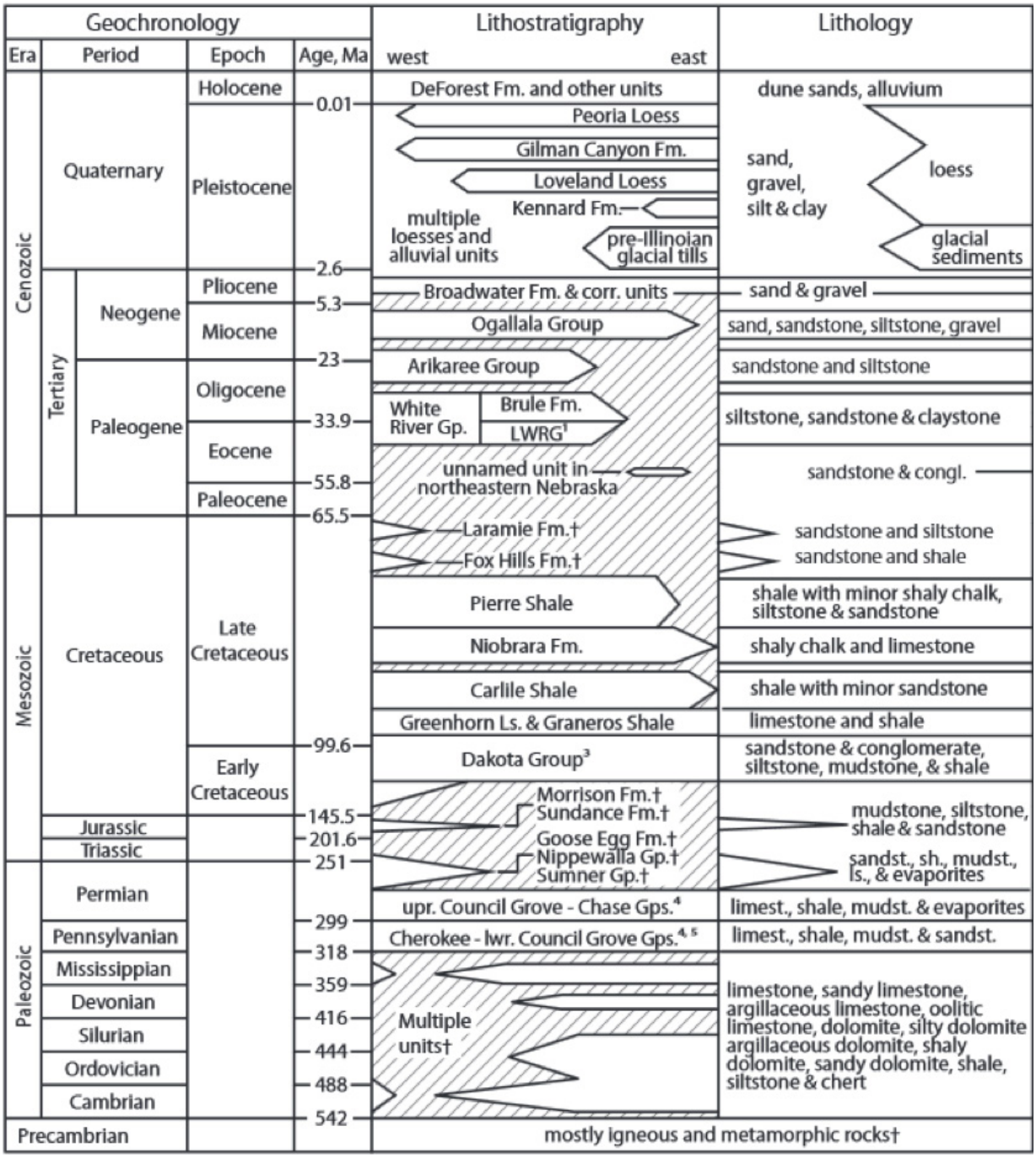


Figure 2-3. Geologic time scale with lithostratigraphic sequence underlying Nebraska, modified from Korus and Joeckel (2011).

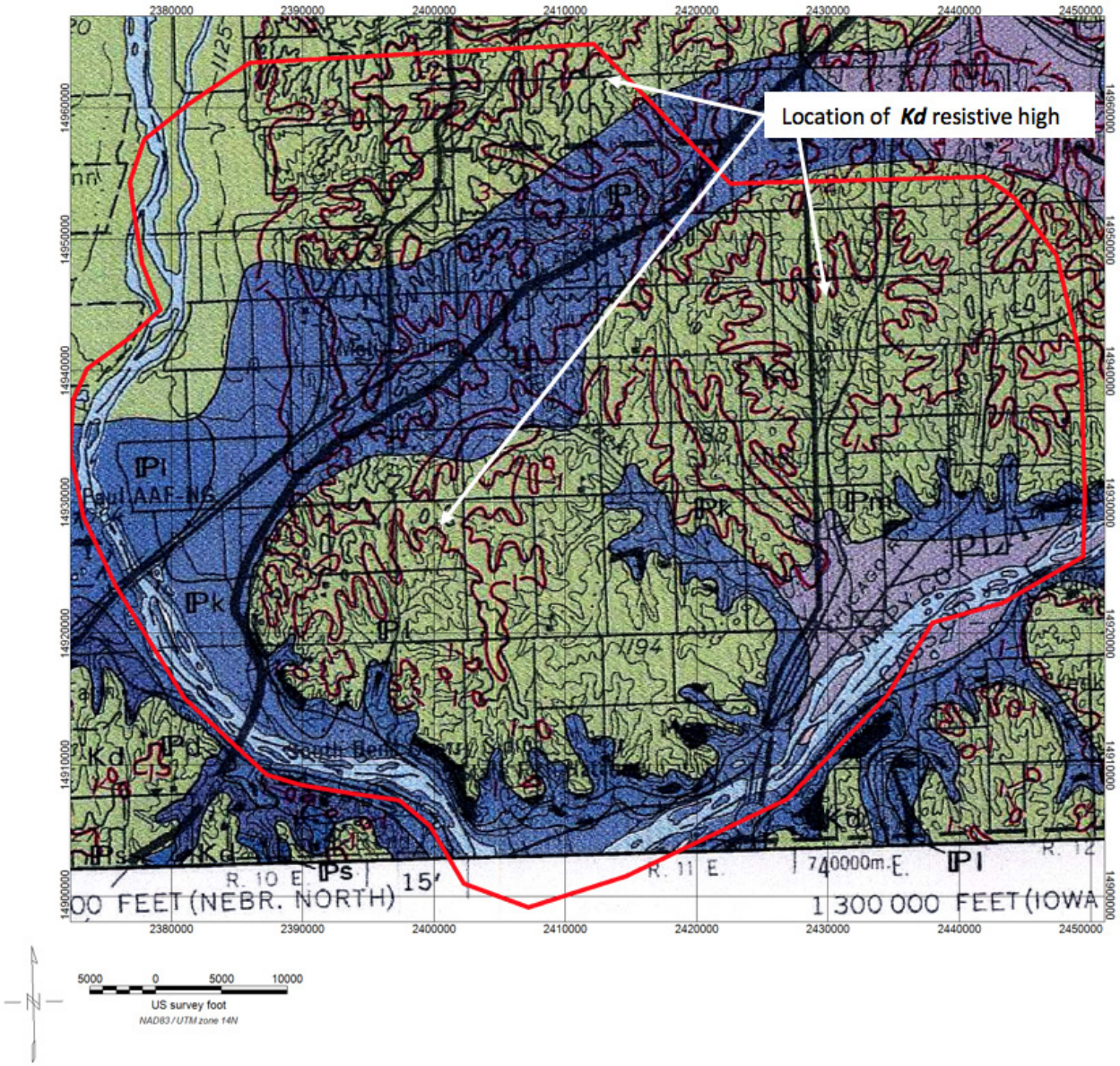


Figure 2-4. Map displaying the *Kd* lying upon the *IP* in the Sarpy County AEM survey area. The topography is overlain on the geology showing the areas of resistive *Kd* materials that lie beneath the topographic highs (modified from Burchett et al., 1975). Projection is NAD83, UTM 14 North (feet).

2.2 Sarpy County AEM Survey Area Hydrogeologic Characteristics in the Quaternary and Cretaceous Dakota Systems

2.2.1 Quaternary

A map showing the major streams and rivers within the project area is shown in Figure 2-5. Three surface water divides exist between the Elkhorn, Platte and Missouri Rivers with the divide point for all three near Gretna. The largest surface-water system in the project area is the Platte River (U.S. Geological Survey, 2015) which flows south to east along the border of the project area to its confluence with the Missouri River south of Omaha, NE. The next most important drainages are Buffalo and Springfield Creeks which drain south out of the project area and to the Platte River.

The overall elevation of the water table within the project area is shown in Figure 2-6. It was derived from the 1995 CSD statewide map (Nebraska CSD, 1995) and represents the general shape of the groundwater surface; actual water levels will be different. The contour interval in the uplands is 50 feet and the interval in the Platte River plain is 10 feet. There is a groundwater high at approximately 1100 feet elevation south of Buffalo Creek. The area north of the high has no contours due to limited groundwater level information. Where groundwater contours exist, the groundwater flow is generally to the Platte River. Due to limited water level information, a revised groundwater divide(s) was not developed for this report.

Groundwater locally can be hydraulically connected to surface water. Groundwater levels are located at shallower depths in the alluvial valleys and deeper under glaciated areas. Groundwater levels can be effected by the amount of groundwater withdrawal which is generally highest in warm weather months and typically return to shallower, pre-stress levels in the March to June timeframe. Annual depths of drawdown and recharge of aquifers are highly dependent on the type of aquifer (e.g., confined, semi-confined, or unconfined), proximity of the aquifer to the land surface, and the magnitude of stress exhibited on the system during the pumping season, combined with the amount of recharge available to the aquifer.

Groundwater under confined systems, such as in some of the aquifers beneath glacial till or clay layers, typically exhibits more drawdown than groundwater in unconfined systems that are present in alluvial settings.

Potentiometric gradients show groundwater movement from upland areas toward stream valleys. Hilly topography and complex heterogeneity within the glacial-drift terrain can create local flow systems (Gates et al., 2014). Contrasts of hydraulic conductivity within the principal aquifers of eastern Nebraska, can commonly cause significant vertical groundwater flow gradients.

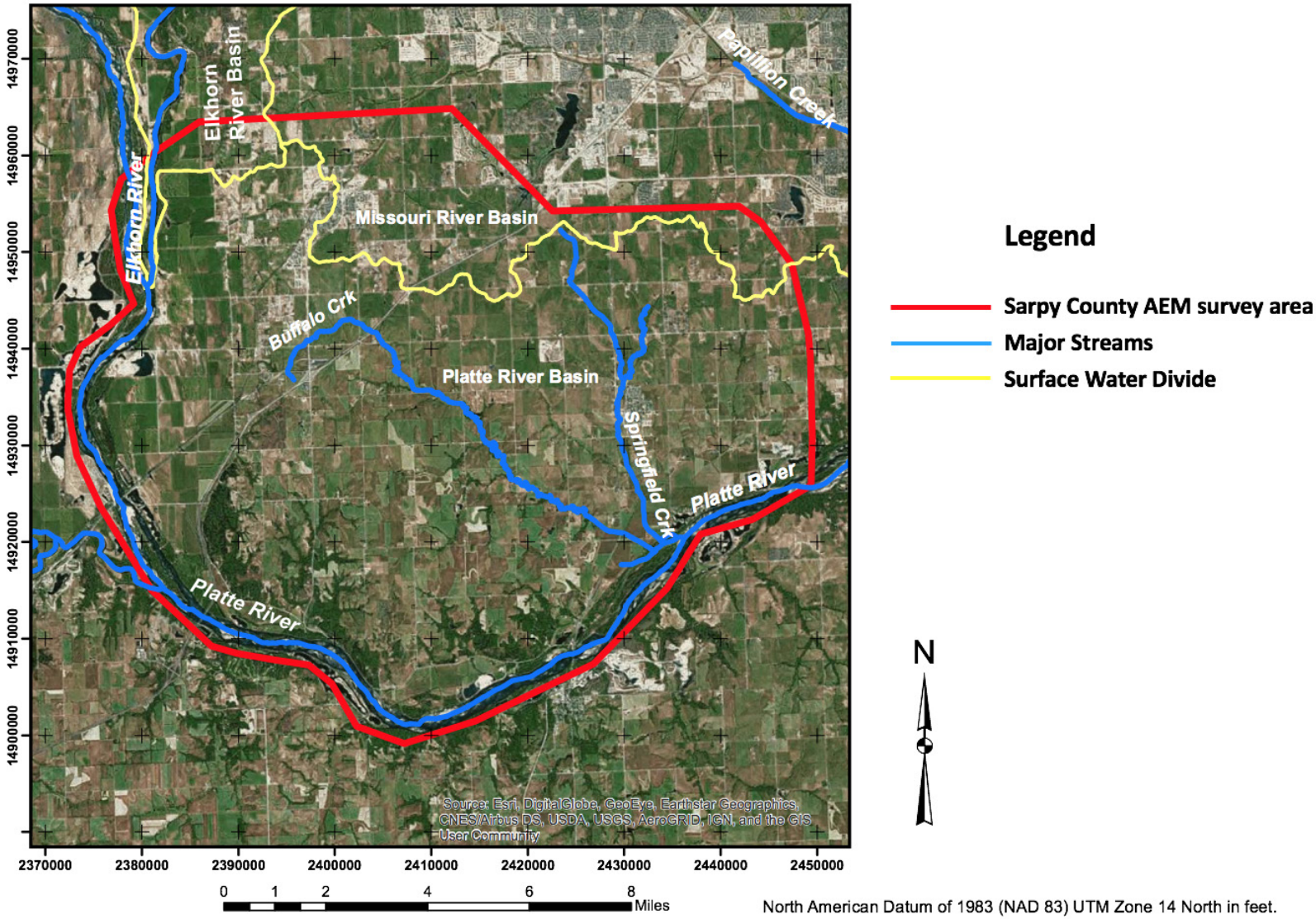


Figure 2-5. Map displaying the major streams and rivers within the Sarpy County AEM survey area. The surface water divide point between the Elkhorn, Platte, and Missouri rivers is near the town of Gretna in the northwest corner of the map. Projection is NAD83, UTM 14 North (feet). (NE-DNR, 2016c)

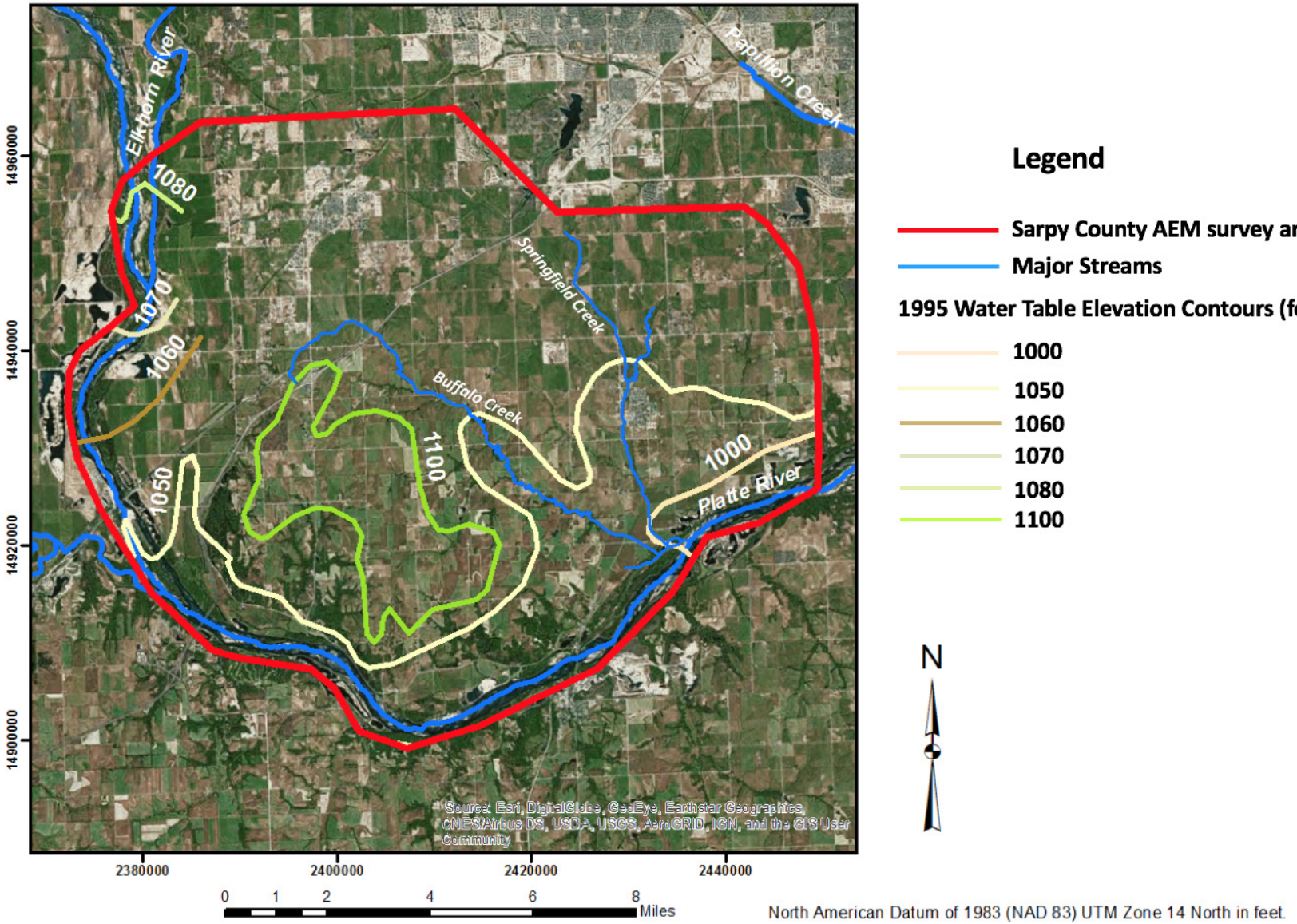


Figure 2-6. Elevation of groundwater surface in the Sarpy County AEM survey area. The limited groundwater elevation contours show a groundwater flow direction towards the Platte River (NE-CSD, 1995). Projection is NAD83, UTM 14 North (feet).

There are two principal ***Q*** hydrogeologic units within the Sarpy County AEM survey area boundary. The first are saturated alluvial deposits and the second are the glacial drift deposits that make up the stream-valley (valley fill) and upland aquifers. These aquifers are considered one unit for this report. Saturated ***Q*** alluvial deposits in eastern Nebraska are a complex mixture of unconsolidated, saturated sand, and gravel deposits. These saturated deposits can be confined to unconfined, deep to shallow, and/or regional and local, and, in places, interbedded with glacial till (Bentall, 1971; Miller and Appel, 1997; Flowerday et al, 1998; Stanton et al., 2007). Stream-valley and glacial-drift systems locally can be hydraulically connected with other, similar systems. The glacial-drift aquifers which are outwash alluvial and paleo-alluvial or paleo-glacial deposits of Plio-Pleistocene age that underlie till and loess deposits in the uplands in the project area.

Table 2-1 contains summary information for each known aquifer (***Q*** through ***Kd***) within the area (adapted from Carney et al., 2015a). Included in this table are the geologic system hosting the aquifer, aquifer thickness, and a general discussion regarding the aquifer framework, groundwater flow system characteristics, and aquifer parameters.

Table 2-1. Aquifers in Quaternary and Cretaceous Age stratigraphic units.

System	Series	Hydrologic unit	Maximum thickness (ft)
Quaternary	Holocene, Pleistocene	Aquifer in undifferentiated alluvial deposits	Generally less than 100 ft
Undifferentiated sand and gravel units in stream-valley systems. Stream-aquifer systems can be intermixed with older glacial sand and gravel making the deposits difficult to distinguish from older glacial outwash. Hydraulic head is typically unconfined. Recharge is principally from local precipitation and is rapid if the source area is primarily sand and gravel. Wells can yield up to several thousand gpm.			
Quaternary	Holocene, Pleistocene	Aquifer in undifferentiated glacial-drift deposits	Up to 300 ft
Undifferentiated sand and gravel units in glacial-drift aquifers. Hydraulic head under confined conditions and unconfined conditions. Thickness of glacial-drift aquifers vary greatly. Comprised largely of sand and gravel from ancestral river channels or glacial outwash that became capped by till or loess. Recharge mostly from precipitation infiltration or inflow from adjacent hydraulically connected aquifers. Well yields are highly variable; some capable of greater than a thousand gallons per minute but vary greatly by location. Isolated aquifers are capable of sustaining potable quality water for domestic or stock purposes.			
Cretaceous	Lower	Aquifer in sandstone/sand of the ***Kd***	Total thickness variable. Up to 300 ft in the project area
Locally, the ***Kd*** serves as an aquifer or as a confining unit. The aquifer is generally located in loosely-cemented, medium- to fine-grained sandstone/sand. Hydraulic head typically confined with local unconfined conditions encountered. Groundwater is often potable in eastern part of the state, where the ***Kd*** underlies saturated Quaternary deposits. Where ***Kd*** units lie within near proximity to the land surface, recharge is primarily from local precipitation, otherwise largely from inflow from adjacent hydrologically-connected aquifers. ***Kd*** Sandstones/sand can produce potable water to irrigation and municipal wells with variable yields.			

2.2.1.1 Aquifer Characteristics

A CSD map of the Generalized Hydrogeologic Areas in Figure 2-7 shows the aquifer characteristics classes in the project area (Olafsen-Lackey et al., 2005a; Summerside et al., 2005a). The aquifer characteristic areas present are alluvial aquifer, confined and glaciated. The glaciated area is the largest with the alluvial aquifer being next in geographic area and the confined is a very small area near the confluence of Salt Creek and the Platte River. These maps were produced to show a general understanding of the aquifers and their hydrologic connections to the streams and rivers. The alluvial aquifers have the greatest hydrologic connection, the glacial aquifers have limited hydrologic connection where the coarse-grained portions of the glacial materials are in contact with the streams and rivers, and the confined aquifers which have no connection to surface water.

Historic specific yield values in the project area (Figure 2-8) for the ***Q*** materials range from 0.5 to 0.20 based on Olafsen-Lackey et al. (2005b) and Summerside et al. (2005b). As noted on the map in Figure 2-9, there are extensive areas with the aquifer being absent or very thin in the upland areas. Specific yields are approximately 0.10 where the aquifer materials are made of mostly silt size particles. Specific yields from aquifer materials made up of sand and gravel size particles range from approximately 0.10 to 0.20. This work is regional in nature and is used in calculations for this report in later sections.

Lower and upper ranges of transmissivity were reported between 20 to 200 gpd/ft in Olafsen-Lackey et al. (2005c) and Summerside et al. (2005c). As noted on the map in Figure 2-9, there are extensive areas with the aquifer being absent or very thin in the upland areas. Overall, most transmissivity values within the project area likely range from 20 gpm/ft in wells open to the ***Q*** uplands glacial aquifer materials and up to 200 gpm/ft in wells screened in ***Q*** alluvium and glacial-drift sand and gravel.

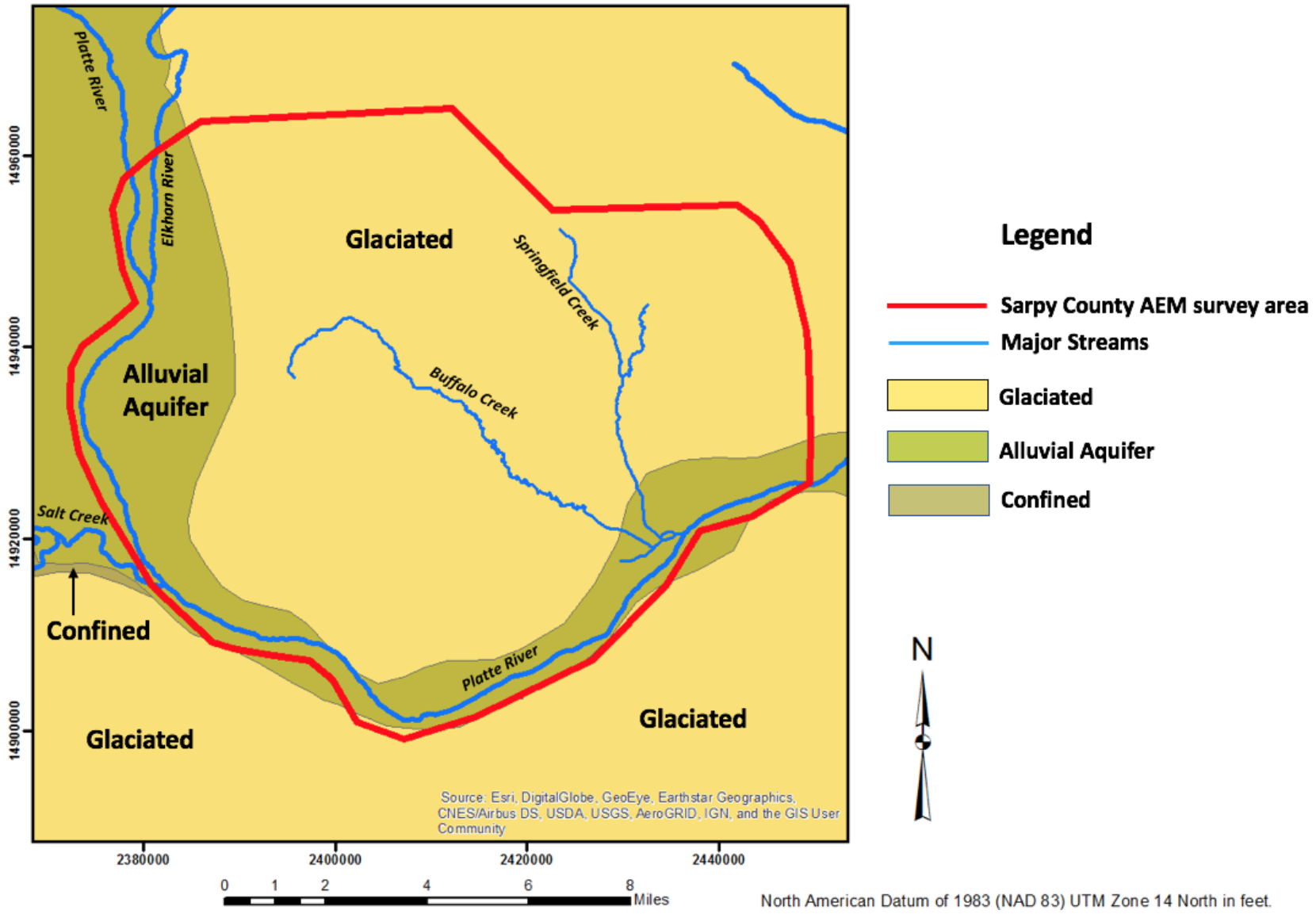


Figure 2-7. Generalized Hydrogeologic Areas within the Sarpy County AEM survey area (Olafsen-Lackey et al., 2005a; Summerside et al., 2005a). These maps show generalized hydrologic connections to the streams and rivers.

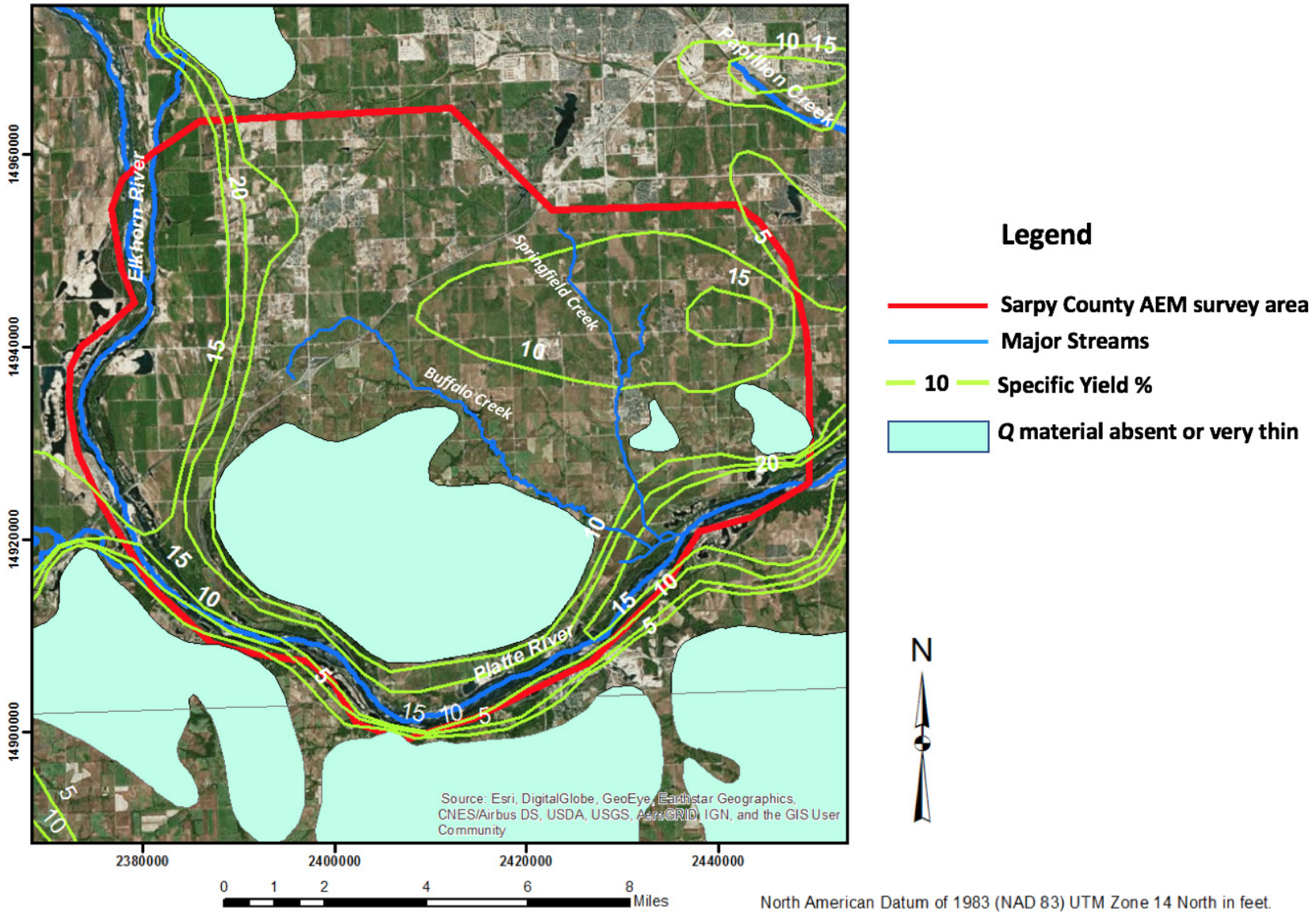


Figure 2-8. Specific yield values within the Sarpy County AEM survey area (Olafsen-Lackey et al., 2005b; Summerside et al., 2005b). Note the large areas of the uplands that have aquifer materials that are absent or very thin.

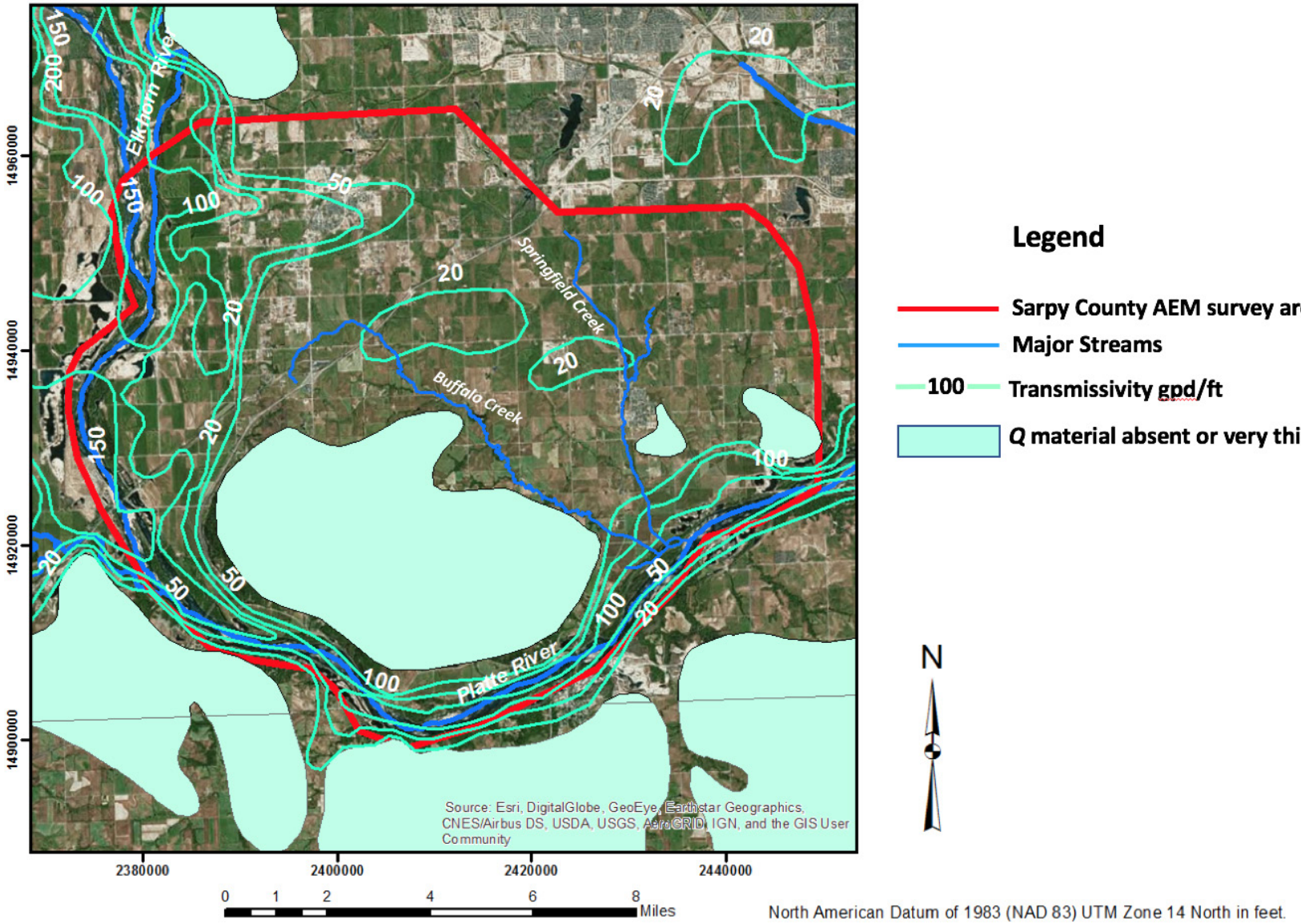


Figure 2-9. Transmissivity values within the Sarpy County AEM survey area (Olafsen-Lackey et al., 2005c; Summerside et al., 2005c). Note the large areas of the uplands that have aquifer materials that are absent or very thin.

2.2.1.2 *Connectivity to Surface Water*

Groundwater flow connectivity to surface water features is largely undocumented in the glaciated Sarpy County AEM survey area. However, there appears to be a possible connection where the Elkhorn or Platte River and other tributaries come in contact with the glaciated areas of the uplands. It can be safely assumed that there is a strong connection to the streams and the alluvium that the stream lies upon. Often stream flow measurements indicate changes in flow due to contributions from base flow or losses from the stream to the groundwater system are completed to assess this potential. There were no records found in this area to indicate these conditions.

2.2.1.3 *Connectivity to other Aquifers*

Locally, ***Q*** and ***Kd*** deposits are hydraulically connected to shallower aquifers and streams. The deeper aquifers can discharge into the shallow groundwater system or into the streams. The reverse is also true. Detailed studies are not available for precise estimates of groundwater-surface water relationships or where they occur. It is thought that temporal communication changes with increased pumping during the irrigation season (June to September). During this time groundwater gradients change and communication between the two systems can be enhanced. Areal communication is variable as it is possible that a glacial-drift aquifer (such as a paleovalley aquifer) could be in communication with an aquifer or stream at one location and not another. There is limited connection from the glacial aquifers to the streams when tills or clays are present.

2.2.1.4 *Water Quality*

McGuire et al. (2012) reported water quality results from groundwater samples that included specific conductance in microsiemens per centimeter (µS/cm) as part of the field parameters collected during a sampling event. The samples from these wells were analyzed for major ions and other constituents including nitrates and agricultural chemicals. Specific conductance is an indicator of saline water. During the sampling period from 1992 to 2009 the range of specific conductance was from 484 to 1200 µS/cm. In the Sarpy County AEM survey area, the water is fresh. With the AEM system used in this survey, it is not possible to discern the differences between the clay-containing material and variations in the specific conductance of the fresh water. In any case, the presence of saline water, let alone brackish water, is not present in this area.

2.2.2 Cretaceous Dakota

The ***Kd*** in the Sarpy County AEM survey area, shown in Figure 2-4**,** reveals the resistive eroded surface of this formation. In certain areas where the ***Kd*** is dominated by sandstone/sand, it is an important aquifer. In other areas where the ***Kd*** is dominated by shale/clay, it acts as an aquitard. Nearly all information on the ***Kd*** is from borehole lithology logs along with limited outcrops in the project area. Most of the aquifer characteristic information for the project area comes from O'Connor (1987), with limited information from the U.S. Geological Survey on selected wells in Sarpy County. The geologic map in Figure 2-4 shows ***Kd*** in direct contact with the ***Q*** Platte River alluvium. This is a strong hydrogeologic connection that has potential for water to move to and from both formations. There may be other small areas of hydrologic connection in the other tributaries to the Platte, Elkhorn, and Missouri Rivers.

Specific yield for the ***Kd*** aquifer materials can only be provided by generic published results. However, O'Connor (1987), made some estimates on specific capacity, hydraulic conductivity, and transmissivity for three high capacity wells in Sarpy County These are presented in Table 2-2.

Table 2-2. Aquifer Characteristics for the Cretaceous Dakota (*Kd*) Fm (O'Connor, 1987)

Well Location: Section-Township-Range	Discharge Rate	Specific Capacity Gpm/ft	Hydraulic Conductivity ft/d	Transmissivity ft^2/day
NE $^1/_4$, S18-T14N-R12E	1,800	74	300	21,500
NW$^1/_4$, NE $^1/_4$, S35-T14N-R10E	400	26.7	110	7440
NE ¼, SW ¼, S 18-T13N-R12E	1,000	13.5	62	3,720

Water quality in the ***Kd*** is similar to ***Q*** values (O'Connor, 1987) with the wells tested in Sarpy county for total dissolved solids being less than 500 mg/l or 782 µS/cm.

3 Additional Background Information

Various sources of background information were used to interpret the AEM data, which is discussed in Section 5.

3.1 Borehole Data

Borehole data for this project consisted of a combination of lithologic, stratigraphic, and downhole geophysical logs. The borehole information was gathered from four sources: 1) CSD Nebraska Statewide Test Hole Database (UNL, 2016) accessed January 28, 2017, which contains information from boreholes drilled between 1930 and 2016 by the CSD and other cooperating agencies.; 2) NE-DNR (Nebraska Department of Natural Resources, 2016b) accessed September 22, 2016; 3) local water-well driller records provided by the Papio-Missouri River Natural Resources District (P-MRNRD) Area (personal comm. Paul Woodward, P-MRNRD January 18, 2017); and 4) municipal wells provided by the Eastern Nebraska Water Resources Assessment (ENWRA) (personal comm. Kathleen Cameron, ENWRA October 2016).

The locations of the CSD boreholes utilized in the Sarpy County AEM survey are indicated in Figure 3-1. A total of 18 CSD holes contained lithology information, 15 holes contained stratigraphic information, and 7 holes contained geophysical information. The locations of the NE-DNR registered wells used in the Sarpy County Survey Area are indicated in Figure 3-2. A total of 922 DNR-registered wells contained usable lithology information. The locations of the local water-well driller records wells used in the Sarpy County Survey Area survey are indicated in Figure 3-3. A total of 73 wells contained limited and discontinuous lithology and stratigraphic information. The location of the municipal wells provided by ENWRA are not indicated on the map due to security concerns. A total of 32 municipal wells contained lithology information.



Figure 3-1: Locations of the Conservation Survey Division boreholes (blue dots) and the airborne electromagnetic survey flight lines (gray lines) in the Sarpy County AEM survey area (red line). Projection is NAD83, UTM 14 North.

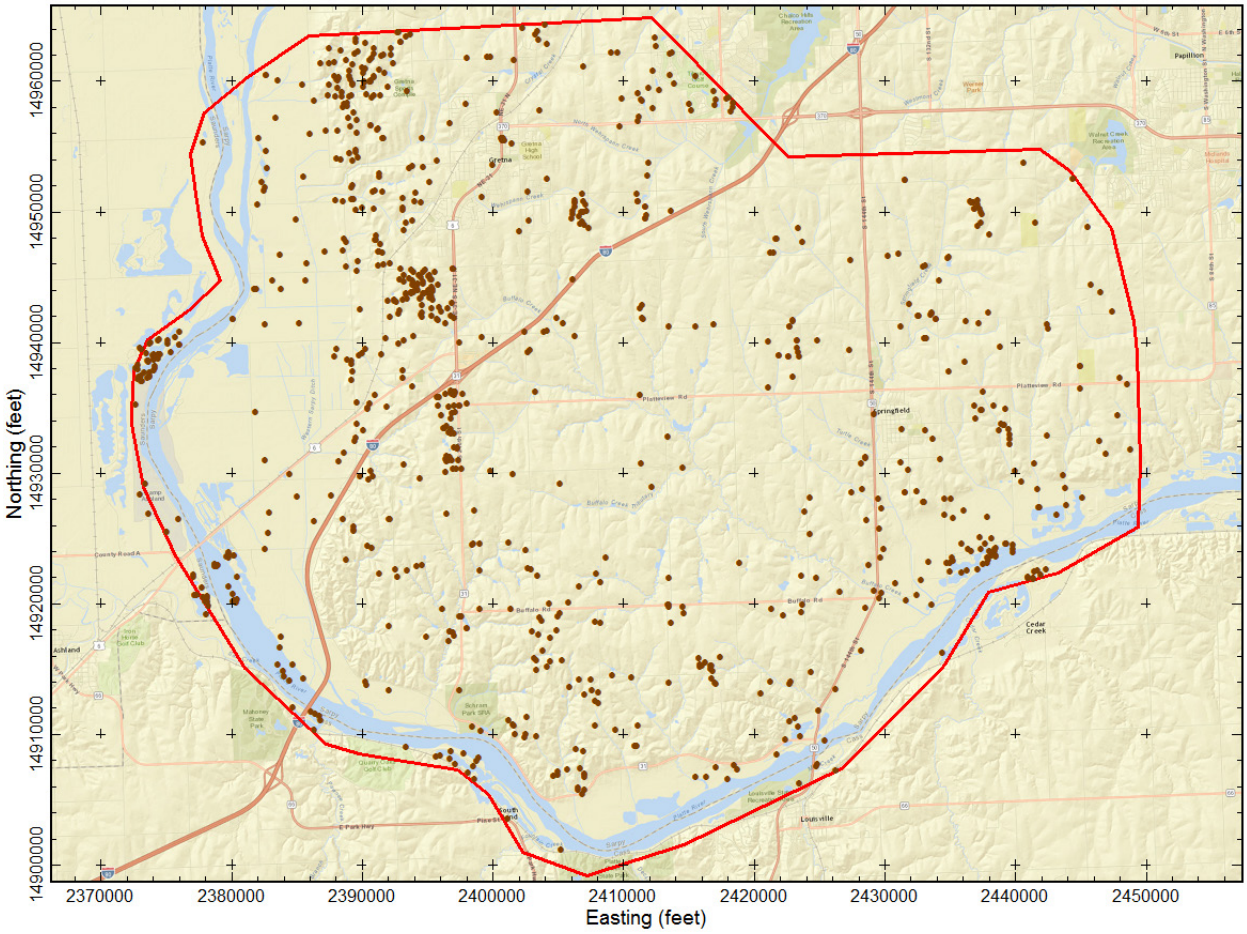


Figure 3-2: Locations of the Nebraska Division of Natural Resources Registered wells (brown dots) and the airborne electromagnetic survey flight lines (gray lines) in the Sarpy County AEM survey area (red line). Projection is NAD83, UTM 14 North.

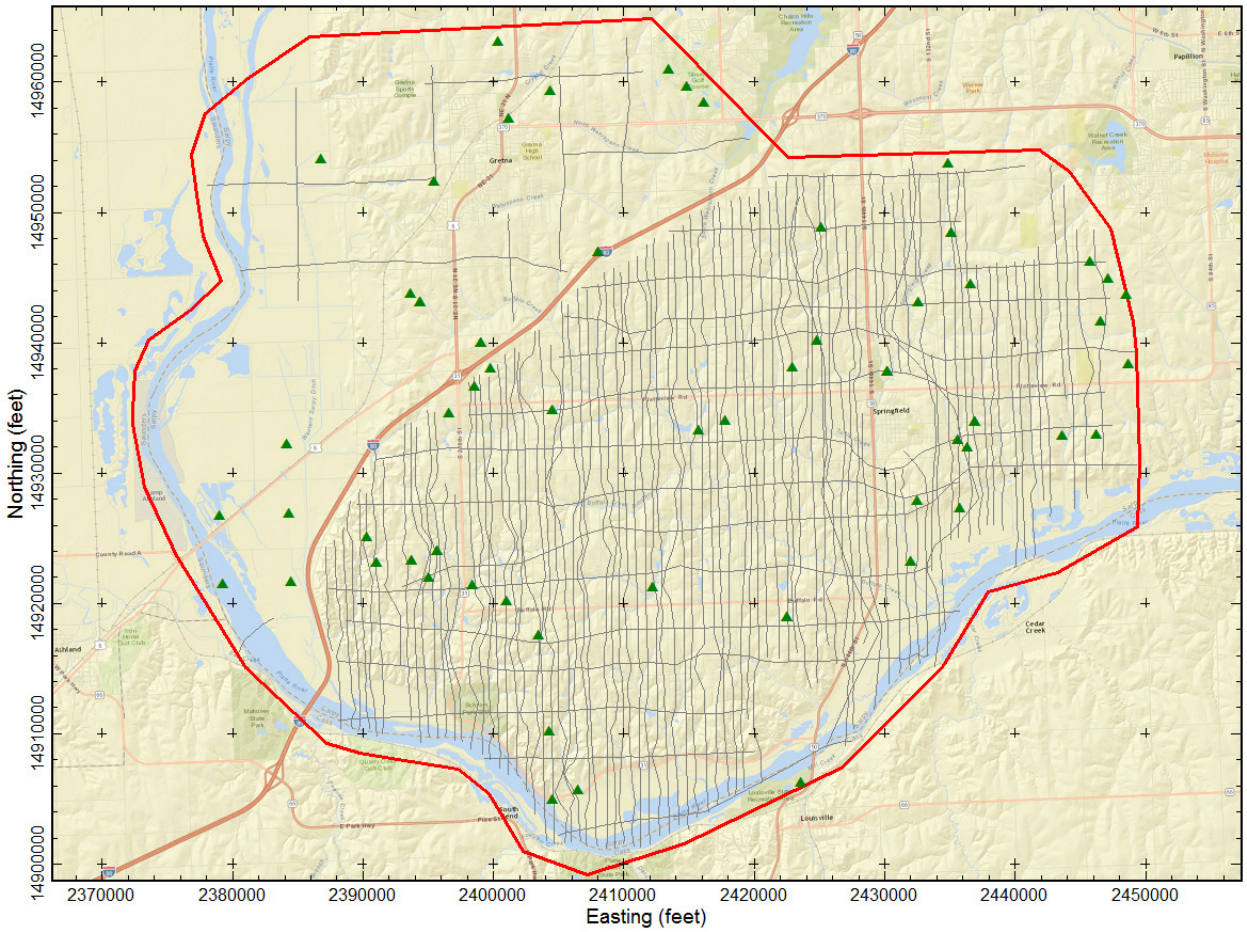


Figure 3-3: Locations of the Papio-Missouri River NRD local water-well driller records (green triangles) and the AEM flight lines (gray lines) in the Sarpy County AEM survey area (red line). Projection is NAD83, UTM 14 North.

3.2 2007 Ashland AEM Investigation

In March 2007, ENWRA funded a study where AEM methods were implemented by the USGS to characterize the hydrogeologic conditions in the Platte River valley near Ashland, as well as in areas underlain by glacial till near Firth and Oakland, Nebraska (Abraham et al., 2011; Hanson et al., 2012; Korus et al., 2013). A helicopter electromagnetic and magnetic survey was conducted in three 93-square-kilometer (36-square-mile) areas of eastern Nebraska, including the Ashland area (Figure 3-4), as part of a joint State of Nebraska and U.S. Geological Survey study (Smith et al., 2008). The objective of the survey was to improve the understanding of the relationship between surface-water and ground-water systems critical to developing water resource management programs. The electromagnetic equipment consisted of six different coil-pair orientations that measured electrical resistivity at separate frequencies from about 400 hertz to about 115,000 hertz. The electromagnetic data were converted to electrical resistivity geo-referenced grids and maps, each representing different approximate depths of

investigation for each area. The range of the subsurface investigation was comparable to the depth of the shallow aquifers.

The three areas selected for the 2007 AEM study, Ashland, Firth, and Oakland, have glacial terrains and bedrock that typify different hydrogeologic settings for surface water and ground water in eastern Nebraska which was periodically glaciated from approximately 2.5 million to 600,000 years ago (Hanson et al., 2012). The repeated advance and retreat of glaciers resulted in a complex framework of largely Quaternary (***Q***) Pleistocene-aged sediments overlying the bedrock surface. Locally, Pleistocene-aged sediments overlie Pliocene-Pleistocene buried valley deposits to form paleovalleys. The uppermost bedrock units are Cretaceous- and Pennsylvanian-aged rocks. The stratigraphy of these rocks is somewhat complex due to their origins in mixed marine and near-shore marine depositional environments. The Cretaceous rocks are primarily of the Dakota Formation, the lithology of which varies from claystone and shale to sandstone. In locations where the lithology is sandstone, the Dakota may be used as an aquifer, though the water quality is variable and not always potable. The Pennsylvanian units are primarily shales with limestones that act as regionally important aquitards. The Platte River and Quaternary aquifer are apparently hydrologically connected throughout the AEM study area and the Quaternary and Dakota aquifers are apparently hydrologically connected except where the discontinuous Cretaceous Dakota aquitard separates them. More information on the geological background is presented in Section 2.1.

Relatively large quantities of groundwater exist in the paleovalley deposits and coarse-grained alluvium associated with modern streams, such as the Platte and Elkhorn Rivers. Groundwater resources below the region's glaciated uplands are locally limited, but are often adequate for domestic purposes. Domestic wells in the region may be found in saturated coarse-grained sediments within or underlying clay-rich glacial tills. Perched aquifers are also an important source of water for domestic wells that are associated with the glaciated deposits of eastern Nebraska (Divine et al., 2009). Perched aquifers are created when downward moving water infiltrates through silt-rich loess, but not through the underlying clay-rich till, leaving saturated sediments above the regional water table (Gosselin et al., 1996).

Interpretive surfaces from Hanson et al. (2012) were used in the interpretation of the geological contacts and surfaces where they overlapped with the Sarpy County AEM survey area. The AEM data were not reinverted nor were the resistivity values integrated into the database for the Sarpy County AEM survey area database utilized in this study.

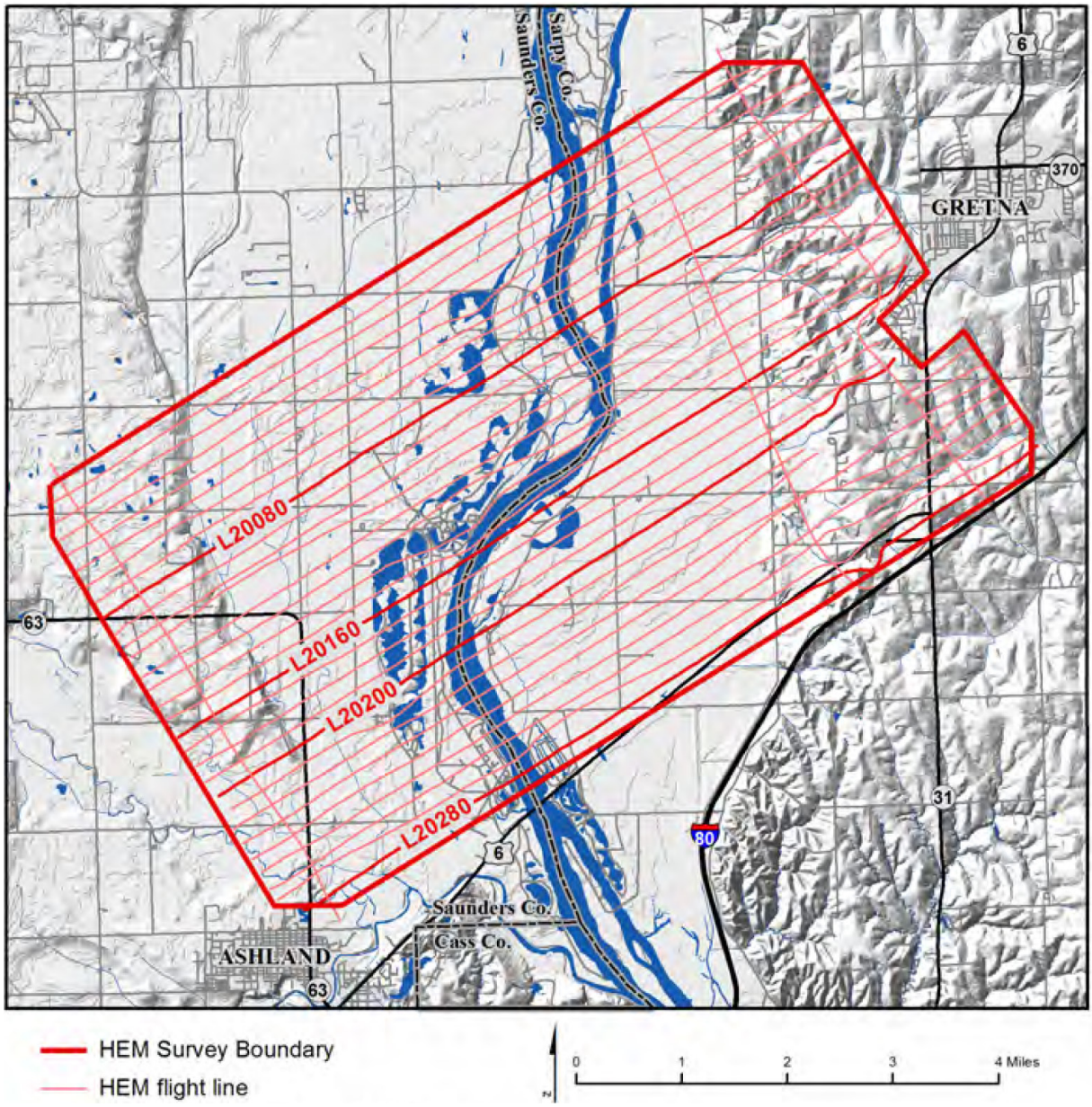


Figure 3-4. Ashland 2007 HEM survey. The flight lines are spaced approximately 890 feet (270 m) apart and soundings were acquired approximately every 10 ft (3 m). From Hanson et al. (2012)

4 Geophysical Methodology, Acquisition and Processing

4.1 Geophysical Methodology

Airborne Transient Electromagnetic (TEM) or airborne Time-Domain Electromagnetic (TDEM), or generally AEM, investigations provide characterization of electrical properties of earth materials from the land surface downward using electromagnetic induction. Figure 4-1 gives a conceptual illustration of the airborne TEM method.

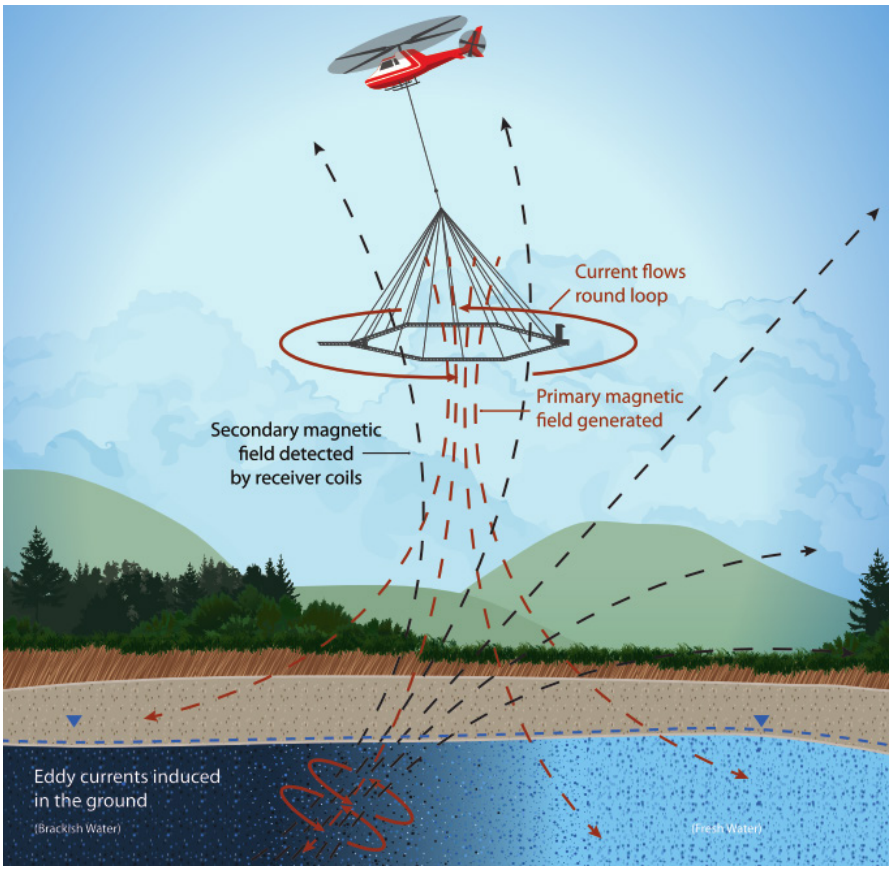


Figure 4-1: Schematic of an airborne electromagnetic survey, modified from Carney et al. (2015a).

To collect TEM data, an electrical current is sent through a large loop of wire consisting of multiple turns which generates an electromagnetic (EM) field. This is called the transmitter (Tx) coil. After the EM field produced by the Tx coil is stable, it is switched off as abruptly as possible. The EM field dissipates and decays with time, traveling deeper and spreading wider into the subsurface. The rate of dissipation is dependent on the electrical properties of the subsurface (controlled by the material composition of the geology including the amount of mineralogical clay, the water content, the presence of dissolved solids, the metallic mineralization, and the percentage of void space). At the moment of turnoff, a secondary EM field, which also begins to decay, is generated within the subsurface. The decaying secondary EM field generates a current in a receiver (Rx) coil, per Ampere's Law. This current is measured at several different moments in time (each moment being within a time band called a "gate"). From the induced current, the time rate of decay of the magnetic field, B, is determined (dB/dt). When compiled in time,

these measurements constitute a “sounding” at that location. Each TEM measurement produces an EM sounding at one point on the surface.

The sounding curves are numerically inverted to produce a model of subsurface resistivity as a function of depth. Inversion relates the measured geophysical data to probable physical earth properties. Figure 4-2 shows an example of a dual-moment TEM dB/dt sounding curve and the corresponding inverted electrical resistivity model.

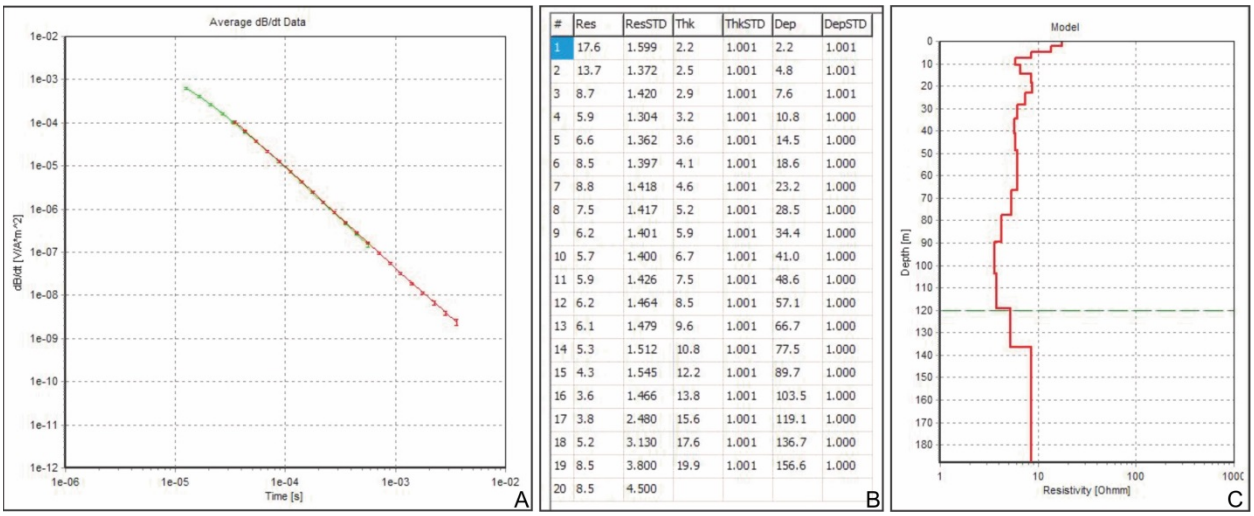


Figure 4-2: A) Example of a dB/dt sounding curve. B) Corresponding inverted model values. C) Corresponding resistivity earth model.

4.2 Flight Planning/Utility Mapping

The primary source of noise in geophysical electromagnetic surveys are other electromagnetic devices that are part of a typical municipal utility infrastructure. These include, for example, power lines, railroads, pipelines, and water pumps. Prior to AEM data acquisition in the Sarpy County AEM survey area, three types of utilities (pipelines, railroads, and power lines) were located. Various public power districts in Eastern Nebraska including the cities of Gretna, Lincoln, and Springfield, plus the Metropolitan Utilities District and the Sarpy County Sanitary Improvement District provided, through ENWRA, power line locations in Google Earth “kmz” format that were then converted to a Geographic Information Systems (GIS) Arc shapefile format. Some areas did not have coverage available for power line locations and were mapped by inspection from Google Earth imagery.

A GIS Arc shapefile of railroads in Nebraska was downloaded from the United States Department of Agriculture’s Natural Resource Conservation Service (US Dept Agriculture, 2014) and a shapefile of the pipelines in Nebraska was provided by the ENWRA group. Maps of the utilities were exported in GeoTIFF and Google Earth kmz formats and were used during data processing and interpretation.

The locations of the flight lines were converted from a regularly spaced grid to one with flight lines optimized in order to avoid electromagnetic coupling with the previously mentioned utilities. This was done by moving along each flight line in Google Earth to inspect the path for visible power lines, radio

towers, railroads, highways and roads, confined feeding operations and buildings, and any other obstructions that needed to be avoided during flight.

At the conclusion of the design process the Sarpy County block flight lines were approximately 10-12 miles in length (east-west) and 8-10 miles (north-south) and were separated by approximately 0.60 miles (1 km) in the east-west direction and approximately 0.11-0.14 miles (200 m-250 m) in the north-south directions (Figure 1-2 and Figure 4-5). The reconnaissance AEM flight lines in the Gretna area were separated by approximately 1.10 miles (1.77 km) in the east-west direction and approximately 1.0 miles (1.62 km) in the north-south direction.

4.3 AEM Survey Instrumentation

AEM data were acquired using the SkyTEM304M (304M) airborne electromagnetic system (SkyTem Airborne Surveys Worldwide, 2016). The 304M is a rigid frame, dual-magnetic moment (Low and High) TEM system. The area of the 304M Tx coil is 337 m^2 and the coil contains four (4) turns of wire. A peak current of nine (9) amps is passed through one turn of wire in the Tx for Low Moment measurements and a peak current of 120 amps is passed through the four turns of wire for High Moment measurements. This results in peak Tx Low and High magnetic moments of ~3,000 Ampere-meter-squared ($A*m^2$) and ~160,000 $A*m^2$, respectively.

The SkyTEM304M system utilizes an offset Rx positioned slightly behind the Tx resulting in a 'null' position which is a location where the intensity of the primary field from the system transmitter is minimized. This is desirable as to minimize the amplitude of the primary field at the Rx to maximize the sensitivity of the Rx to the secondary fields. The SkyTEM304M multi-turn Rx coil has an effective area of 105 m^2. In addition to the Tx and Rx that constitute the TEM instrument, the SkyTEM304M is also equipped with a Total Field magnetometer (MAG) and data acquisition systems for both instruments. The SkyTEM304M also includes two each of laser altimeters, inclinometers/tilt meters, and differential global positioning system (DGPS) receivers. Positional data from the frame mounted DGPS receivers are recorded by the AEM data acquisition system. The magnetometer includes a third DGPS receiver whose positional data is recorded by the magnetometer data acquisition system. Figure 4-3 gives a simple illustration of the SkyTEM304M frame and instrument locations. The image is viewed along the +z axis looking at the horizontal x-y plane. The axes for the image are labeled with distance in meters. The magnetometer is located on a boom off the front of the frame (right side of image). The Tx coil is located around the octagonal frame and the Rx Coil is located at the back of the frame (left side of image).

The coordinate system used by the 304M defines the +x direction as the direction of flight, the +y direction is defined 90 degrees to the right and the +z direction is downward. The center of the transmitter loop, mounted to the octagonal SkyTEM frame is used as the origin in reference to instrumentation positions. Table 4-1 lists the positions of the instruments (in feet) and Table 4-2 lists the corners of the transmitter loop in feet (whereas units of meters are presented in Figure 4-3).

The DGPS and magnetometer mounted on the frame of the SkyTEM304M require the use of base stations, which are located on the ground and are positioned in an area with low cultural noise. Data from the magnetometer and DGPS base stations were downloaded each day after the end of the day's

AEM flights. The DGPS and magnetometer base stations were placed at the Universal Transverse Mercator (UTM) coordinate system location, the Plattsmouth airport, listed in Table 4-3. The horizontal geodetic reference used is North American Datum of 1983 (NAD83 in feet). All elevations are from USGS's National Elevation Dataset, referenced to the North American Vertical Datum of 1988; with feet as the unit of measurement.

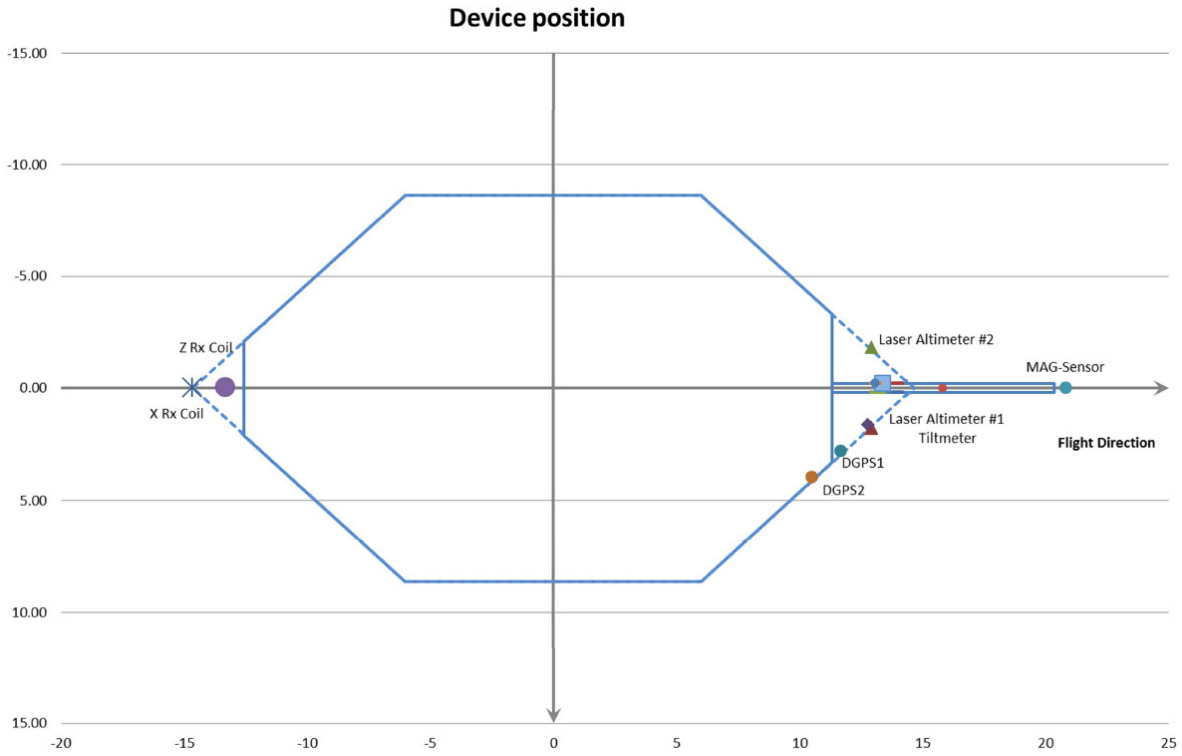


Figure 4-3: SkyTEM304M frame, including instrumentation locations and X and Y axes. Distances are in meters. Instrumentation locations listed in Table 4-1.



Figure 4-4: Photo of the SkyTEM304M system in suspension beneath the helicopter.

For this project, the 304M was flown at an average speed of 62 mi/hr (100.5 kilometers/hr) at an average flight height of 36.4 m above land surface, using the sling-load cargo system of a Eurocopter AS350BA FX2 helicopter. Figure 4-4 displays an image of the 304M in operation.

Table 4-1: Positions of instruments on the SkyTEM304M frame, using the center of the frame as the origin, in feet.

	DGPS 1	DGPS 2	Inclinometer 1	Inclinometer 2	Altimeter 1	Altimeter 2	Magnetic Sensor	Rx Coil
X	38.31	34.47	41.95	41.95	42.44	42.44	67.24	-43.46
Y	9.15	12.96	5.38	-5.38	5.87	-5.87	0.00	0.00
Z	-0.52	-0.52	-0.39	-0.39	-0.39	-0.39	-1.71	-6.56

Table 4-2: Positions of corners of the SkyTEM304M transmitter coil, using the center of the frame as the origin in feet.

Tx Corners	1	2	3	4	5	6	7	8
X	-41.46	-20.17	18.83	36.51	36.51	18.83	-20.17	-41.46
Y	-6.99	-28.18	-28.18	-10.46	10.46	28.18	28.18	6.99

Table 4-3: Location of DGPS and magnetic field base station instruments.

Instrument	Easting (ft)	Northing (ft)	UTM Zone
Magnetometer Base Station	-95.914780	40.951054	14 N
DGPS Base Station	-96.0803917°	41.2155623	14N

4.4 Data Acquisition

All SkyTEM systems are calibrated to a ground test site in Lyngby, Denmark prior to being used for production work (HydroGeophysics Group Aarhus University, 2010; HydroGeophysics Group Aarhus University, 2011; Foged et al., 2013). The calibration process involves acquiring data with the system hovering at different altitudes, from 16 ft to 164 ft, over the Lyngby site. Acquired data are processed and a scale factor (time and amplitude) is applied so that the inversion process produces the model that approximates the known geology at Lyngby.

For these surveys, installation of the navigational instruments in the helicopter and assembly of the SkyTEM304M system commenced at the beginning of the project. The helicopter and the SkyTEM304M system were located at the Plattsmouth airport. Calibration test flights were flown to ensure that the equipment was operating within technical specifications. Survey set-up procedures included measurement of the transmitter waveforms, verification that the receiver was properly located in a null position, and verification that all positioning instruments were functioning properly. A high altitude test, used to verify system performance, was flown prior to the beginning of the survey's production flights. In the field, quality control of the operational parameters for the EM and magnetic field sensors including current levels, positioning sensor dropouts, acquisition speed, and system orientation were conducted with proprietary SkyTEM software following each flight.

Approximately 636 line-miles (1,031 line-kilometers) were acquired over the Sarpy County AEM survey area July 27-29, 2016. The Sarpy County Fairgrounds in Springfield, Plattsmouth airport, and Millard

airport were used for landing and refueling between production flights. A data acquisition map is presented in Figure 4-5 with the flight lines grouped by acquisition date.

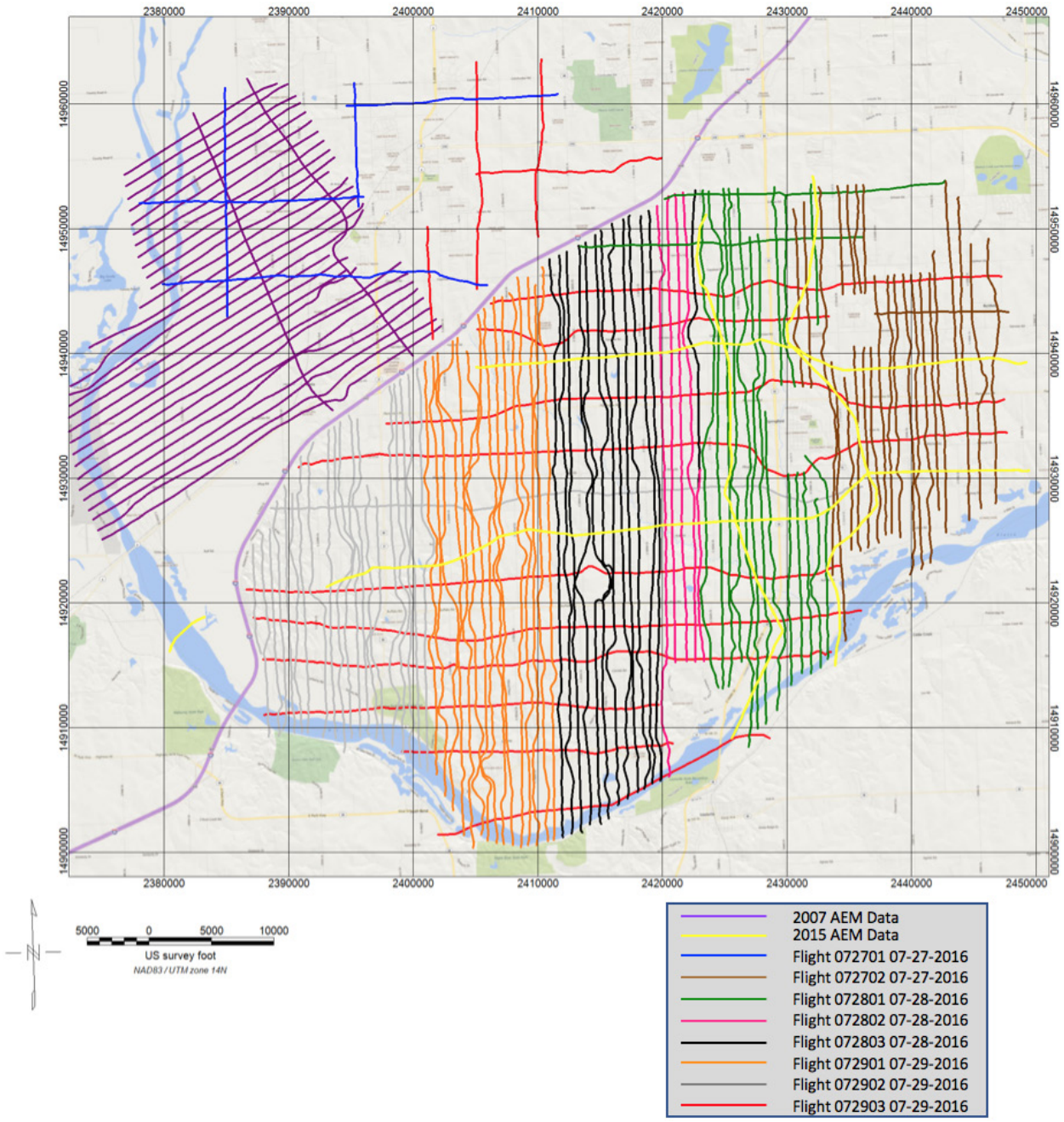


Figure 4-5: Sarpy County AEM survey area flight lines grouped by acquisition date. The map also displays previously-acquired AEM data from 2007 and 2015.

4.4.1 Primary Field Compensation

A standard SkyTEM data acquisition procedure involves review of acquired raw data by SkyTEM in Denmark for Primary Field Compensation (PFC) prior to continued data processing by AGF (Schamper et al., 2014). The primary field of the transmitter affects the recorded early time gates, which in the case of the Low Moment, are helpful in resolving the near surface resistivity structure of the ground. The Low Moment uses a saw tooth waveform which is calculated and then used in the PFC correction to correct the early time gates.

4.4.2 Automatic Processing

The AEM data collected by the 304M were processed using Aarhus Workbench version 5.2.0.0 (at Aarhus Geosoftware (http://www.aarhusgeosoftware.dk/aarhus-workbench-ib3ao) described in HydroGeophysics Group, Aarhus University (2011).

Automatic processing algorithms provided within the Workbench program are initially applied to the AEM data. DGPS locations were filtered using a stepwise, second-order polynomial filter of nine seconds with a beat time of 0.5 seconds, based on flight acquisition parameters. The AEM data are corrected for tilt deviations from level and so filters were also applied to both of the tilt meter readings with a median filter of three seconds and an average filter of two seconds. The altitude data were corrected using a series of two polynomial filters. The lengths of both eighth-order polynomial filters were set to 30 seconds with shift lengths of six (6) seconds. The lower and upper thresholds were 1 and 100 meters, respectively.

Trapezoidal spatial averaging filters were next applied to the AEM data. The times used to define the trapezoidal filters for the Low Moment were $1.0x10^{-5}$ sec, $1.0x10^{-4}$ sec, and $1.0x10^{-3}$ sec with widths of 8, 10, and 12 seconds. The times used to define the trapezoid for the High Moment were $1.0x10^{-4}$ sec, $1.0x10^{-3}$ sec, and $1.0x10^{-2}$ sec with widths of 10, 12, and 20 seconds. The trapezoid sounding distance was set to 2.5 seconds and the left/right setting, which requires the trapezoid to be complete on both sides, was turned on. The spike factor and minimum number of gates were both set to 25 percent for both soundings. Lastly, the locations of the averaged soundings were synchronized between the two moments.

4.4.3 Manual Processing and Laterally-Constrained Inversions

After the implementation of the automatic filtering, the AEM data were manually examined using a sliding two-minute time window. The data were examined for possible electromagnetic coupling with surface and buried utilities and metal, as well as for late time-gate noise. Data affected by these were removed. Examples of locating areas of EM coupling with pipelines or power lines and recognizing and removing coupled AEM data in Aarhus Workbench are shown in Figure 4-6 and Figure 4-7, respectively. Examples of two inversions, one without EM coupling and the other with EM coupling, are shown in Figure 4-8.

The AEM data were then inverted using a Laterally-Constrained Inversion (LCI) algorithm (HydroGeophysics Group Aarhus University, 2011). The profile and depth slices were examined, and any remaining electromagnetic couplings were masked out of the data set.

After final processing, 493.8 line-miles (799.9 line-km) of data were retained for the final inversions for the Sarpy County area. This amounts to a data retention of 78% for the Sarpy County area. This high rate is the result of careful flight line planning and design.

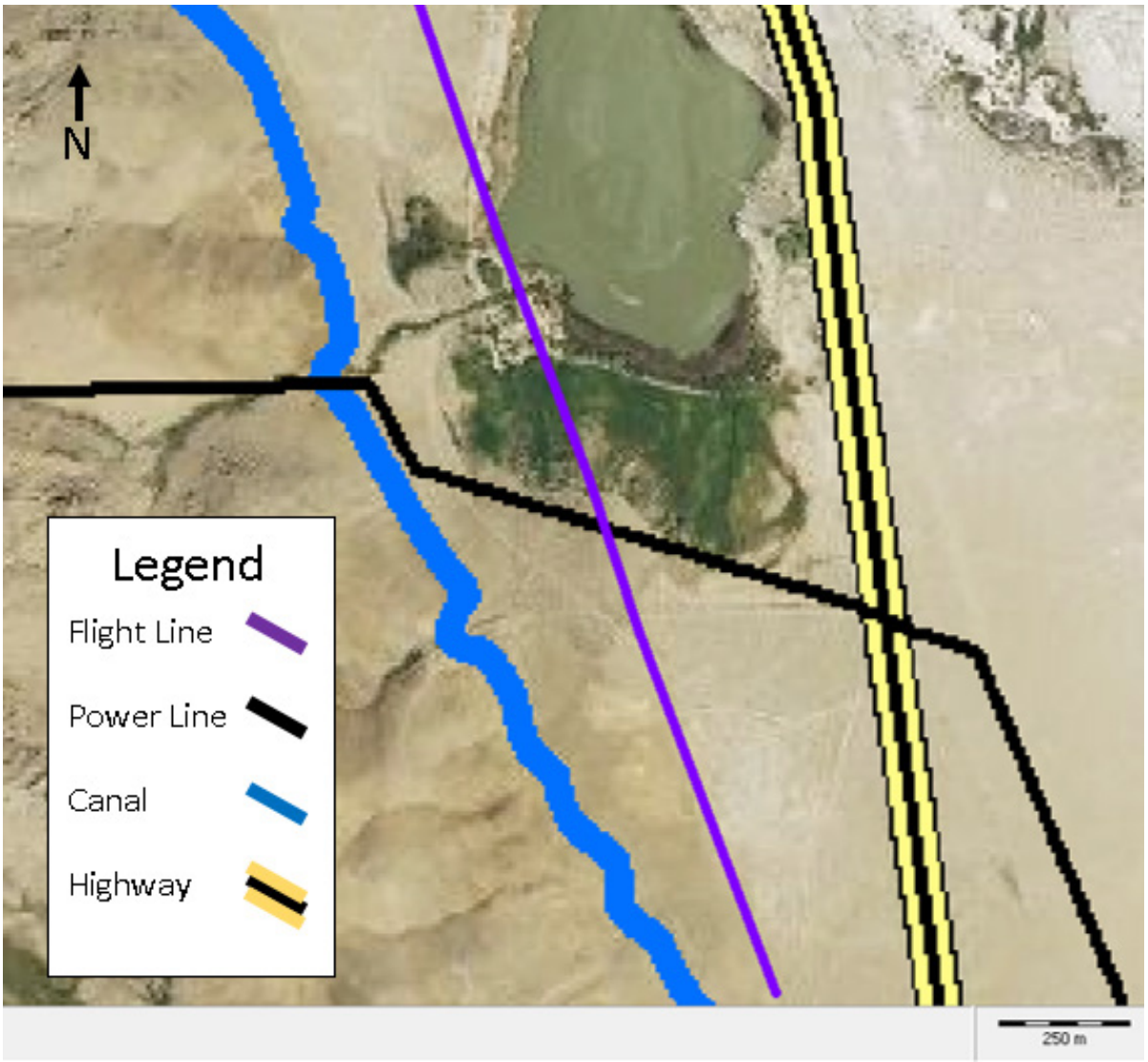


Figure 4-6: Example locations of electromagnetic coupling with pipelines or power lines.

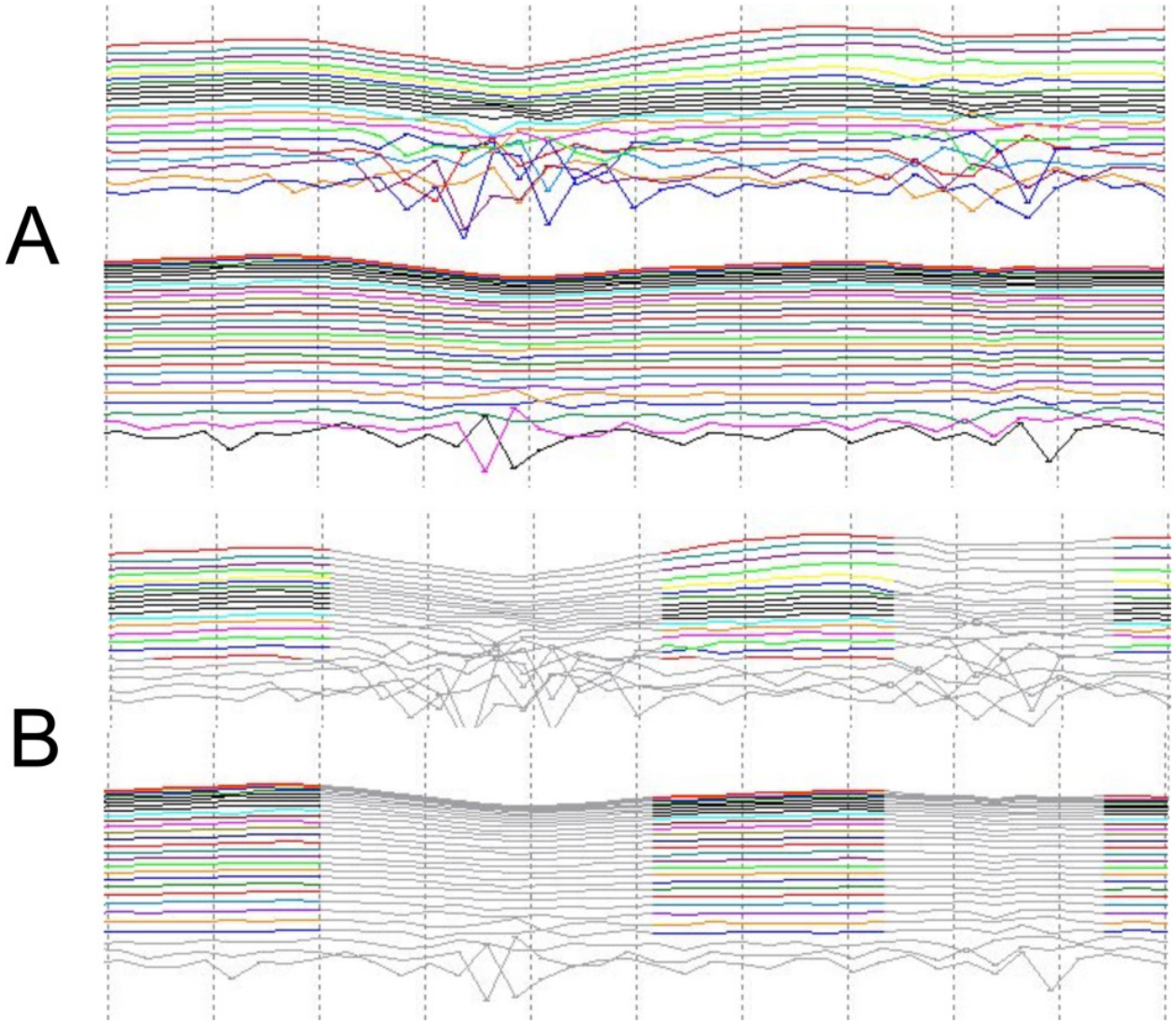


Figure 4-7: A) Example of AEM data from the Sarpy County AEM survey affected by electromagnetic coupling in the Aarhus Workbench editor. The top group of lines is the unedited data with the Low Moment on top and the High Moment on the bottom. The bottom group shows the same data after editing.

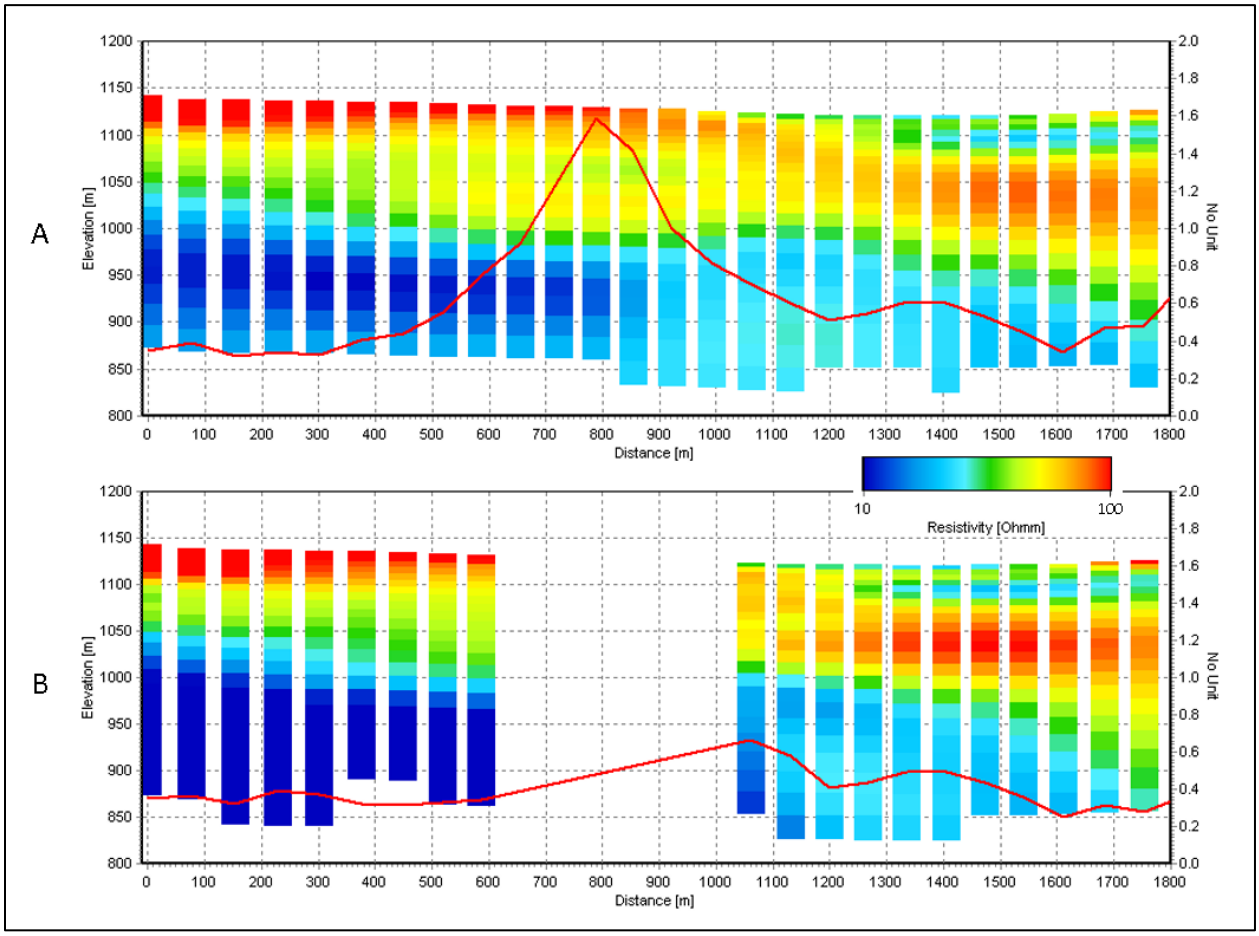


Figure 4-8: A) Example of Laterally-Constrained inversion results where AEM data affected by coupling with pipelines and power lines were not removed. B) Inversion results where AEM data affected by coupling were removed.

4.4.4 Power Line Noise Intensity (PLNI)

The Power Line Noise Intensity (PLNI) channel assists in identifying possible sources of noise from power lines. Pipelines, unless they are cathodically-protected, are not mapped by the PLNI. The PLNI is produced by performing a spectral frequency content analysis on the raw received Z-component SkyTEM data. For every Low Moment data block, a Fourier Transform (FT) is performed on the latest usable time gate data. The FT is evaluated at the local power line transmission frequency (60 Hz) yielding the amplitude spectral density of the local power line noise. The PLNI data for the Sarpy County survey are presented in Figure 4-9. The Sarpy County AEM-flight lines with blue colors representing data retained for inversion and red lines representing data removed due to infrastructure and late time noise are presented in Figure 4-10.

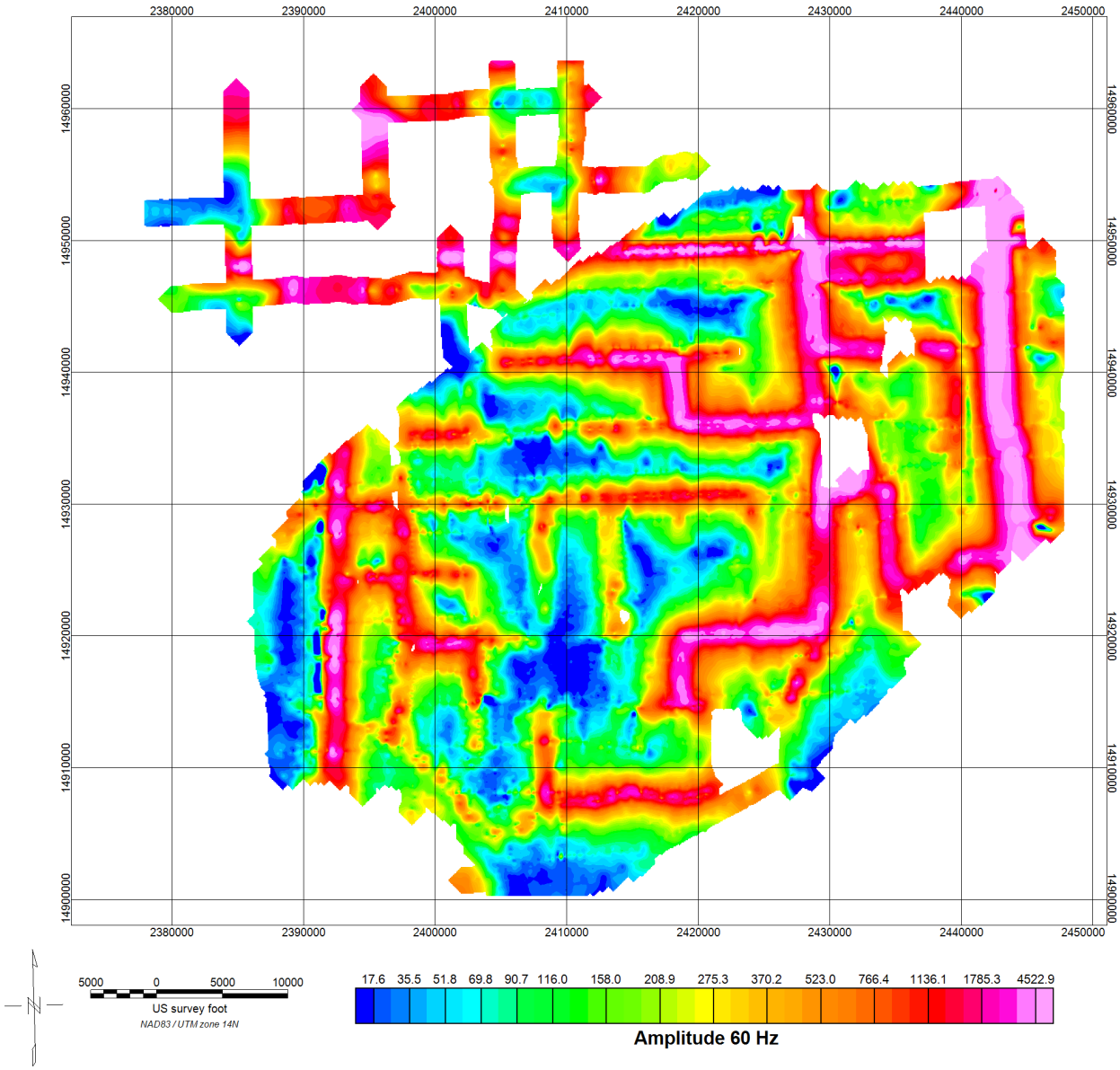


Figure 4-9: Power Line Noise Intensity (PLNI) map of the Sarpy County AEM survey area.

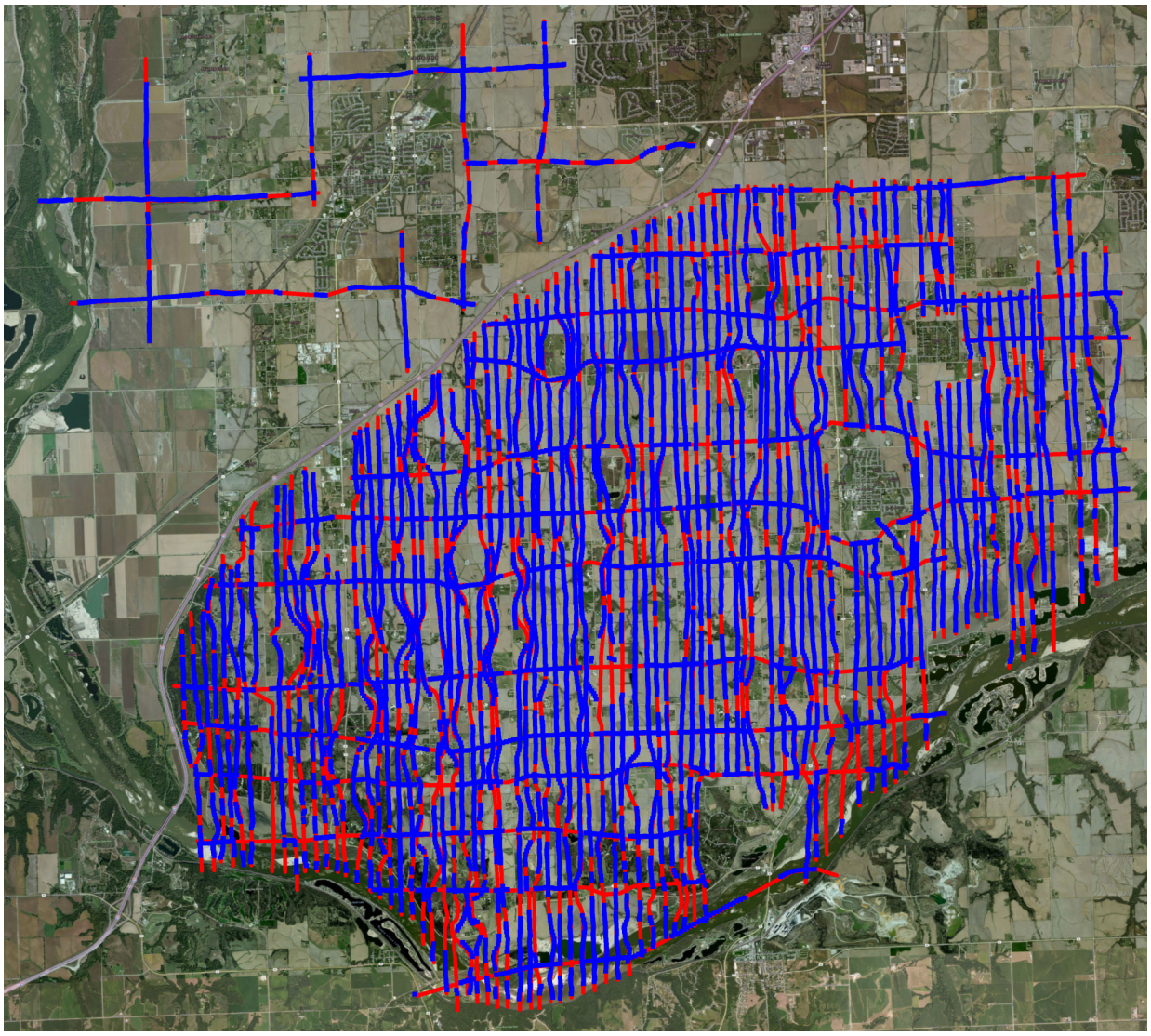


Figure 4-10: Locations of inverted data (blue lines) along the AEM flight lines (red lines) in the Sarpy County survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the flight lines are included in Appendix 3\KMZ.

4.4.5 Magnetic Field Data

As discussed above, the SkyTEM 304M includes a Total Field magnetometer. The magnetic Total Field data can yield information about infrastructure as well as geology. Figure 4-11 shows the magnetic Total Field intensity data for the Sarpy County survey area after correcting for diurnal drift and removing the International Geomagnetic Reference Field (IGRF). This data is used in decoupling efforts.

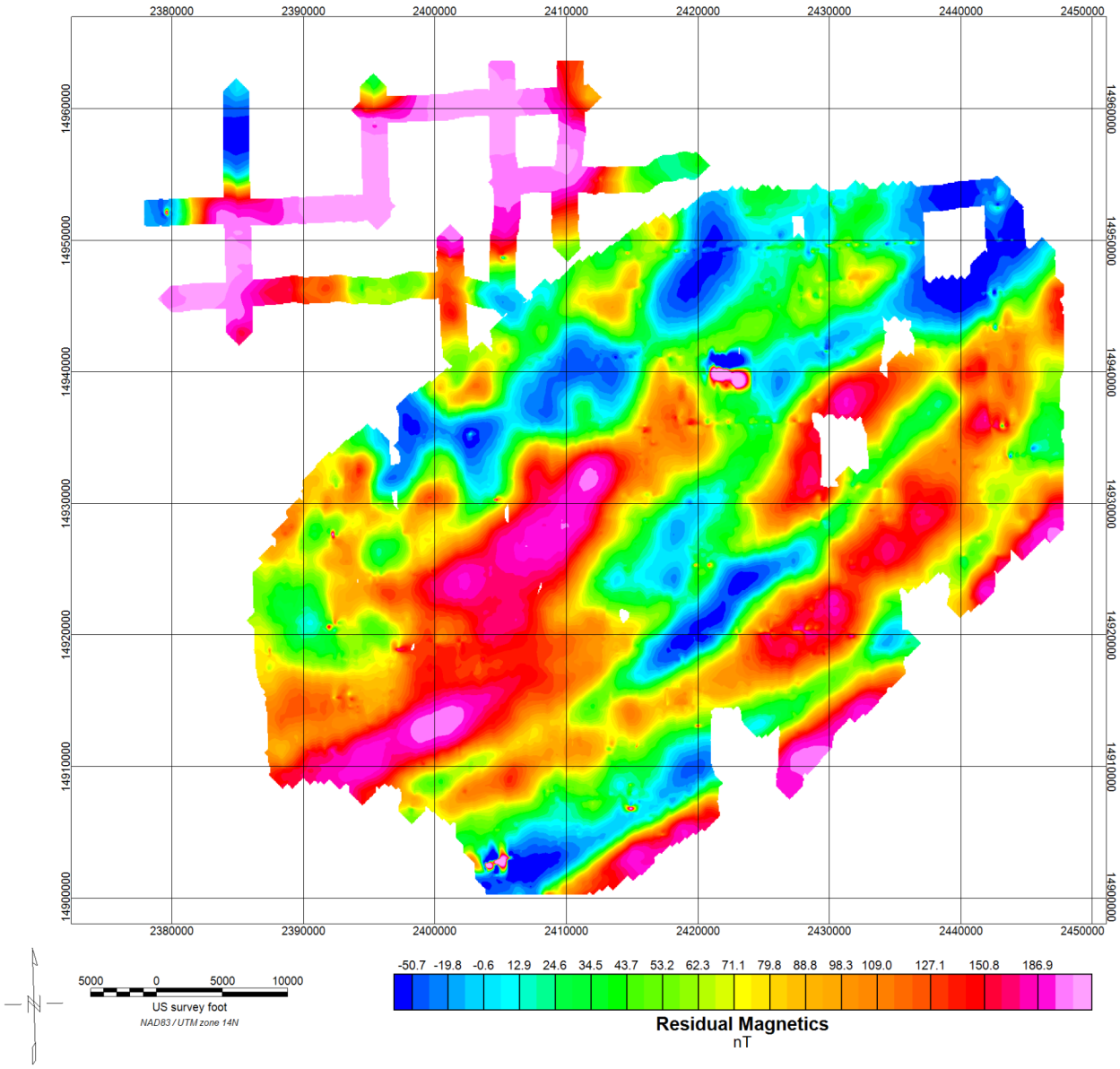


Figure 4-11: Magnetic Total Field intensity data for the Sarpy County survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed.

For comparison purposes, an image of magnetic Total Field data collected by the USGS (Sweeney and Hill, 2005) are presented in Figure 4-12. The USGS data were collected over a much larger reconnaissance grid spacing (5-mile line separation) than was collected in the present survey over Sarpy County and then the USGS data were "upward continued" to a 1000 ft elevation. Even so the comparison between the two data sets is quite good – especially the large high amplitude anomaly in

the northwestern region of the survey area and the smaller high amplitude anomaly in the center of the area.

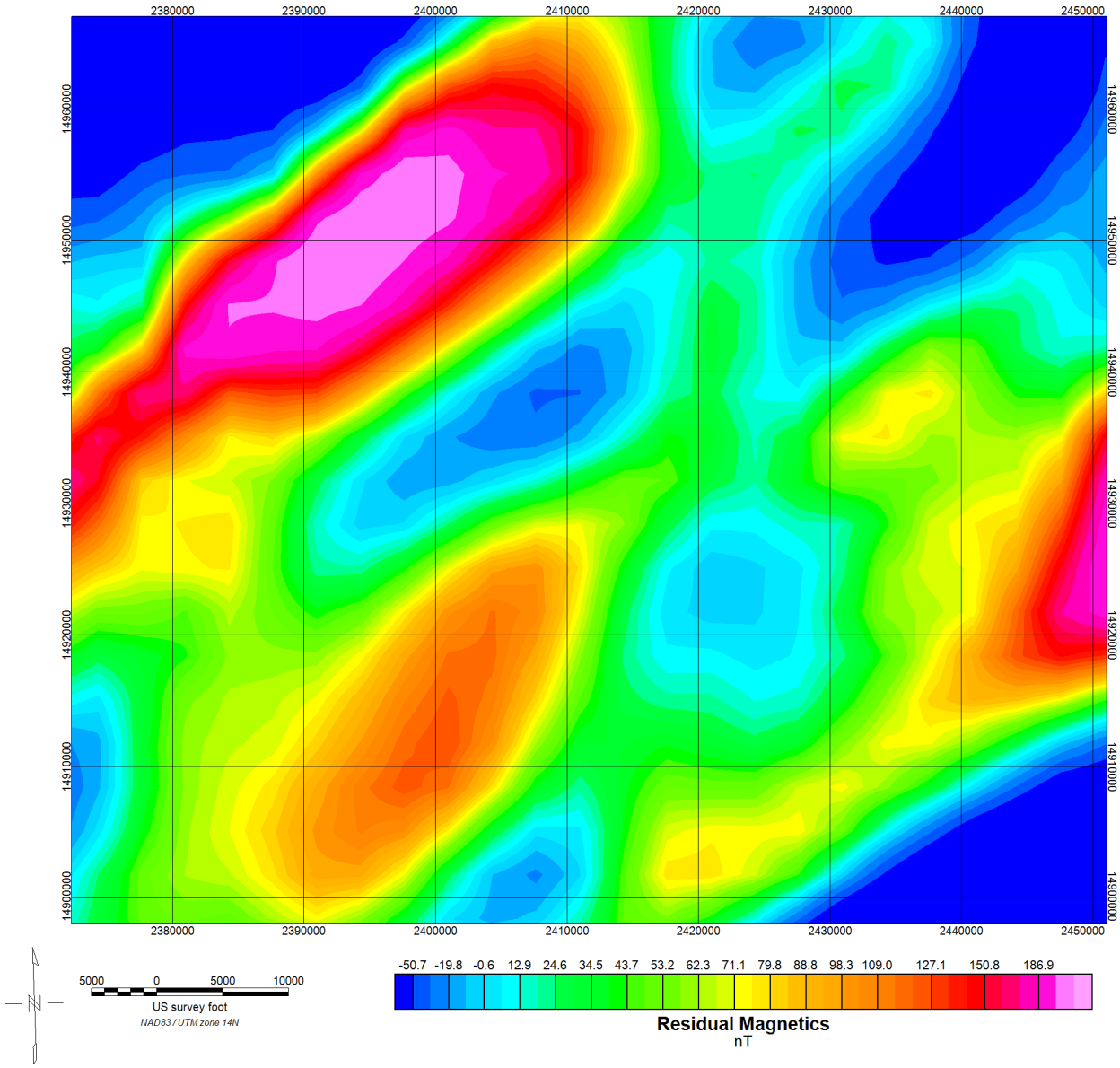


Figure 4-12: USGS magnetic Total Field intensity data for the Sarpy County AEM survey area corrected for diurnal drift, with IGRF removed (Sweeney and Hill, 2005). The data were collected on an approximately 5-mile line spacing and upward continued to a reference elevation of 1000 ft.

4.5 Spatially-Constrained Inversion

Following the initial decoupling and LCI analysis, Spatially-Constrained Inversions (SCI) were performed. SCIs use EM data along, and across, flight lines within user-specified distance criteria (Viezzoli et al., 2008).

The Sarpy County AEM data were inverted using SCI smooth models with 29 layers, each with a starting resistivity of 10 Ohm-m (equivalent to a 10 ohm-m halfspace). The thicknesses of the first layers of the models were about 10 ft with the thicknesses of the consecutive layers increasing by a factor of 1.08. The depths to the bottoms of the 28th layers were set to 1,023 ft, with thicknesses up to about 85 ft. The thicknesses of the layers increase with depth (Table 4-4 and Figure 4-13) as the resolution of the technique decreases. The spatial reference distance, ***s***, for the constraints were set to 328 ft with power laws of 0.75. The vertical and lateral constraints, ***ResVerSTD*** and ***ResLatStD***, were set to 2.0 and 1.3, respectively, for all layers. Figure 4-14 presents a histogram of the Sarpy County SCI inversion data/model residuals.

In addition to the recovered resistivity models the SCIs also produce data residual error values (single sounding error residuals) and Depth of Investigation (DOI) estimates. The data residuals compare the measured data with the response of the individual inverted models (Christensen et al., 2009; SkyTEM Airborne Surveys Worldwide, 2012). The DOI provides a general estimate of the depth to which the AEM data are sensitive to changes in the resistivity distribution at depth (Christiansen and Auken, 2012). Two DOI's are calculated: an "Upper" DOI at a cumulative sensitivity of 1.2 and a "Lower" DOI set at a cumulative sensitivity of 0.6. A more detailed discussion on the DOI can be found in Asch et al. (2015).

Table 4-4: Thickness and depth to bottom for each layer in the Spatially Constrained Inversion (SCI) models. The thickness of the model layers increase with depth as the resolution of the AEM technique decreases.

Layer	Depth to Bottom (ft)	Thickness (ft)	Layer	Depth to Bottom (ft)	Thickness (ft)
1	9.8	9.8	16	298.4	31.2
2	20.5	10.6	17	332.1	33.7
3	31.9	11.5	18	368.5	36.4
4	44.3	12.4	19	407.8	39.3
5	57.7	13.4	20	450.3	42.5
6	72.2	14.5	21	496.2	45.9
7	87.8	15.6	22	545.7	49.5
8	104.7	16.9	23	599.2	53.5
9	122.9	18.2	24	657.0	57.8
10	142.5	19.7	25	719.4	62.4
11	163.8	21.2	26	786.8	67.4
12	186.7	22.9	27	859.5	72.8
13	211.5	24.8	28	938.1	78.6
14	238.3	26.8	29	1023.0	84.9
15	267.2	28.9			

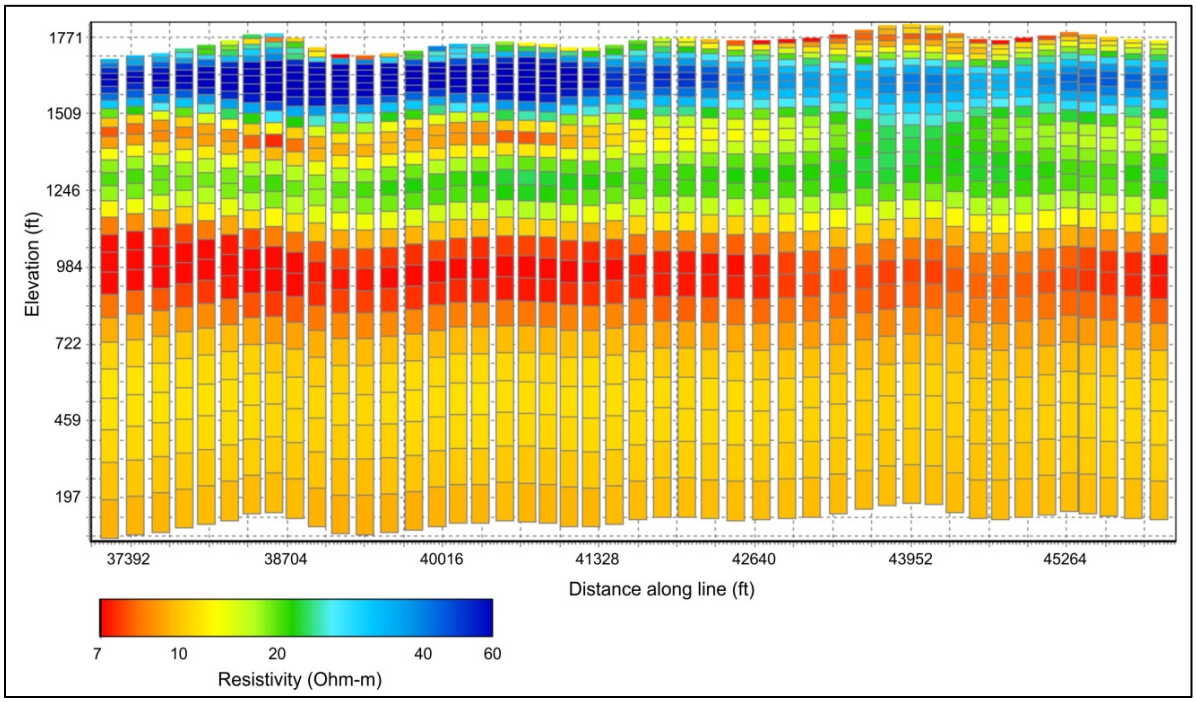


Figure 4-13: An example of an AEM profile illustrating increasing model layer thicknesses with depth.

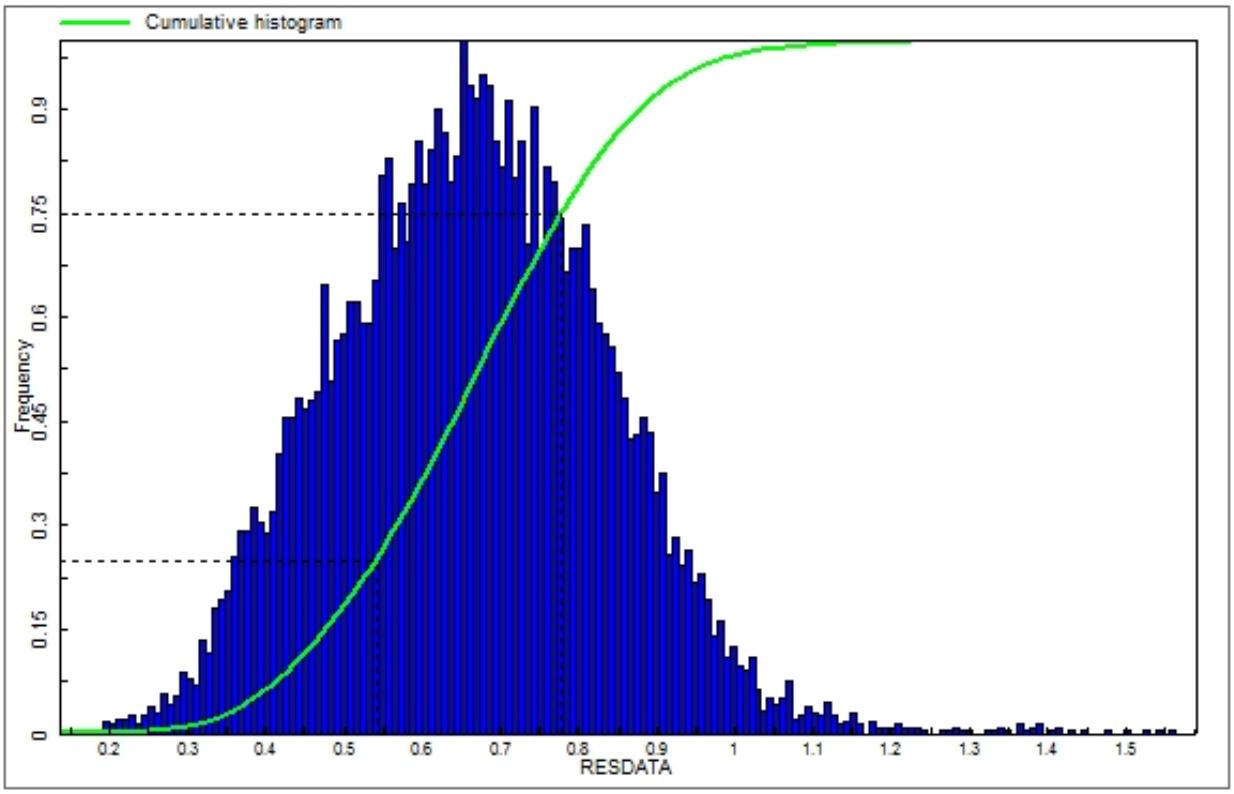


Figure 4-14: Data/model residual histogram for the Sarpy County SCI inversion results.

5 AEM Results and Interpretation

This section provides the details on the process involved in the interpretation of the Sarpy County AEM survey data and inversion results.

5.1 Interpretive Process

This section provides the details on the process involved in the interpretation of the Sarpy County AEM data and inversion results.

5.1.1 Merge AEM Databases from Different Flights

After the inversion process several short lines were combined to form continuous lines within the survey area. These continuous lines allow for improved viewing and interpretation of the AEM inversions results. Table 5-1 lists the original flight lines and the new combined lines. The Sarpy County Survey Area encompassed an additional 37.19 line-miles of AEM data collected in 2015 by ENWRA (Carney et al. 2015a) (Figure 5-1). The 2015 AEM data contains valuable information that can be utilized in the interpretation. The 2015 AEM data was combined with the 2016 AEM data. This combination did not include reinverting the 2015 data, but included merging the 2015 inversions into the 2016 database. Details on the inversion of the 2015 AEM data can be found in Carney et al. (2015a).

Table 5-1. Combination of flight lines within the Sarpy County AEM 2016 survey

Original Source Lines	Direction	New Line
L161201, and L161202	North-South	L16120201
L165401, and L165601	North-South	L16550000
L165801, and L166001	North-South	L16590000
L166201, and L166401	North-South	L16630000
L166601, and L166801	North-South	L16670000
L138901, and 139101	East-West	L13900000

Table 5-2. Combination of 2015 AEM data (Carney et al. 2015a) flight lines within the 2016 Sarpy County AEM survey database

2015 Lines	Direction
L100202	East-West
L100401	East-West
L100402	East-West
L201001	North-South
L201101	North-South

Table 5-2 summarizes the 2015 AEM data that were combined with the 2016 P-MRNRD AEM data (Figure 5-1). When looking at the combination of the two separate data sets that were collected by different systems at different times and inverted separately, it is important to note that both data sets were properly calibrated and any system bias was removed prior to inversion. This is illustrated in Figure

5-2 which presents inverted resistivity data for a 2015 flight line, L100402 (Table 5-2), and two subparallel flight lines from 2016, L139701 and L139901.

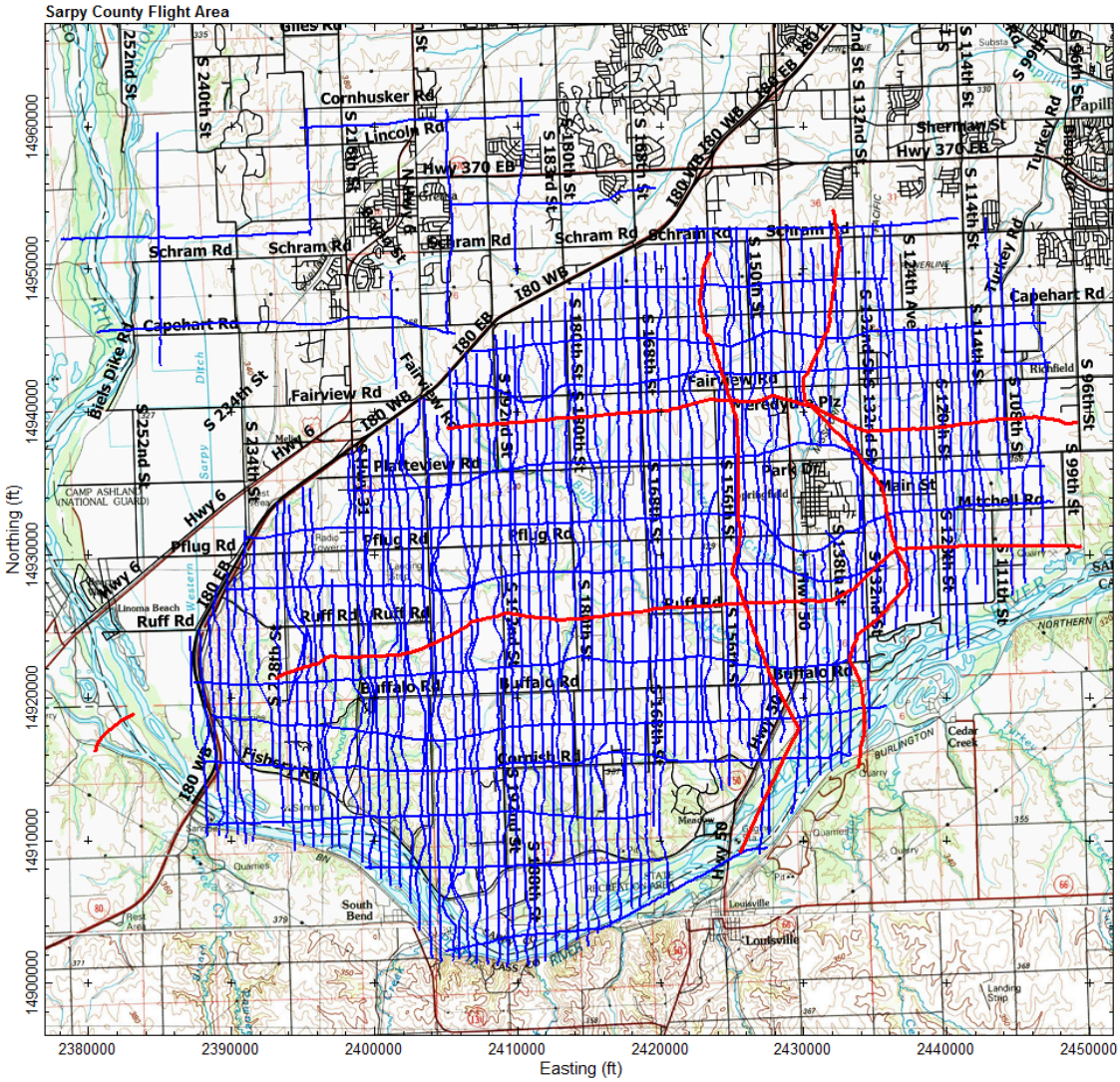


Figure 5-1. Map showing AEM data acquired in 2015 within the 2016 Sarpy County AEM survey area. Blue lines are 2016 data and red lines are 2015 data.

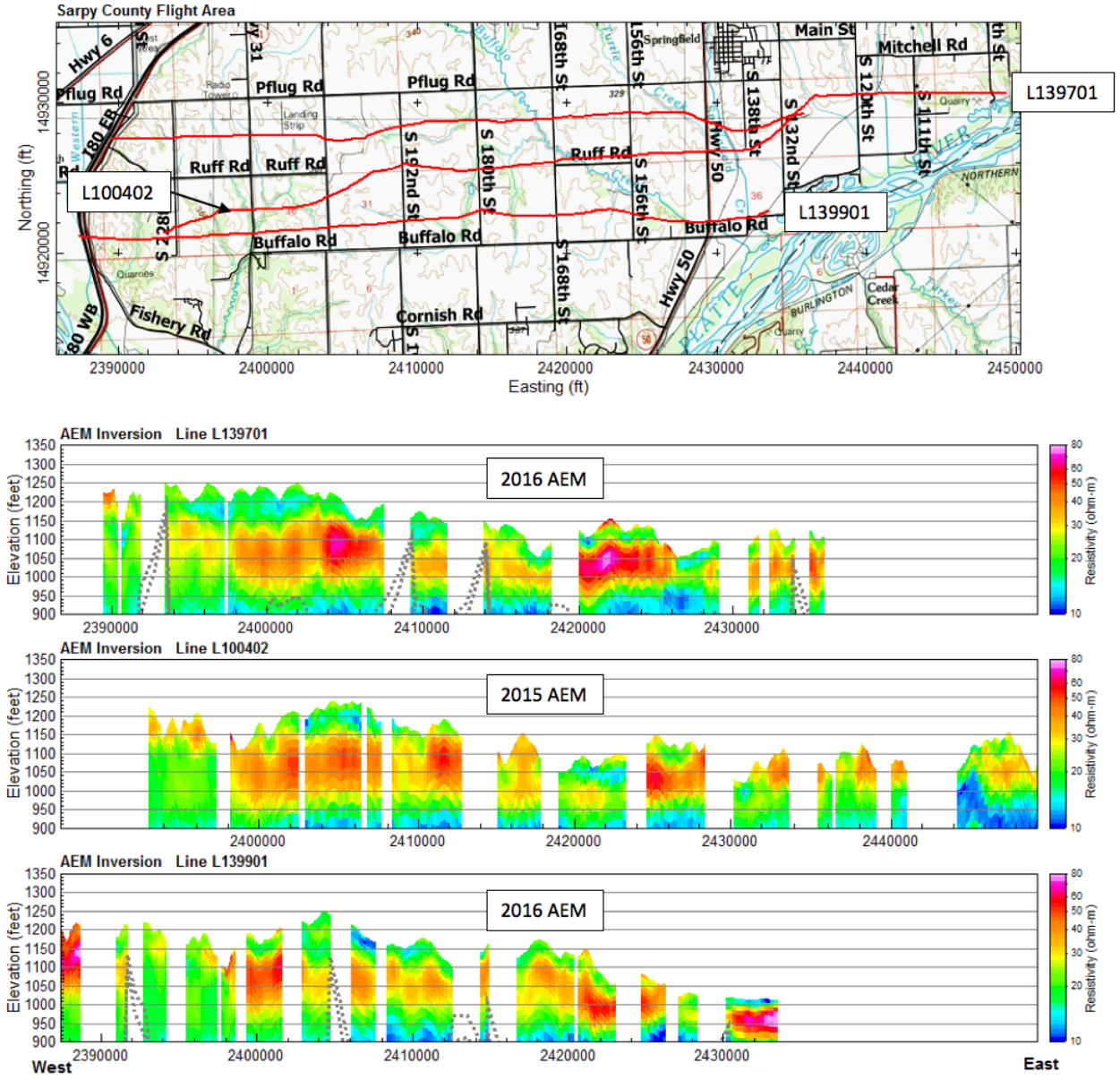


Figure 5-2. Comparison of subparallel 2015 and 2016 AEM flight lines inversion results. Top map shows the location of the flight lines (red lines) on the 100K USGS topo map. The three profiles show the inverted resistivity values for the three lines. The similarity of the inverted profiles illustrates the value of utilizing calibrated acquisition systems. Coordinate projection is NAD83, UTM14N, feet.

5.1.2 Construct the Project Digital Elevation Model

To ensure that the elevation used in the project is constant for all the data sources (i.e. Boreholes, 2015 ENWRA AEM, and 2016 Sarpy County AEM) a Digital Elevation Model (DEM) was constructed for the Sarpy County AEM survey area. The data was downloaded from the National Elevation dataset (NED) located at the National Map Website (U.S. Geological Survey, 2016) at a resolution of 1 arc-second or approximately 100 ft. The geographic coordinates are North American Datum of 1983 (NAD 83) and the elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88). The 100 ft

grid cell size was used throughout the project and resulting products. Figure 5-3 is a map of the DEM showing a vertical relief of 327 ft with a minimum elevation of 978 ft and a maximum elevation of 1,305 ft. This DEM was used to reference all elevations within the AEM datasets.



Figure 5-3. Map of the Digital Elevation Model for Sarpy County AEM survey area. Data source is the one (1) arc-second National Elevation Dataset (U.S. Geological Survey, 2016). The projection is North American Datum of 1983 (NAD 83) in feet and the elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88).

5.1.3 Create Interpretative 2D Profiles

After final combination of the AEM data, characterization of the subsurface was performed in cross-section format using Pitney-Bowes Discover PA (pbEncom, 2016). During interpretation, the horizontal

and vertical scale of the profiles were adjusted to facilitate viewing. The color scale of the resistivity data was also adjusted to illuminate subtle differences in the resistivity structure within the inverted AEM resistivity data related to the area being interpreted. The first step in the interpretation is digitizing the contacts between the geologic units including: Quaternary (***Q***), Cretaceous Dakota (***Kd***), and undifferentiated Pennsylvanian (***IP***). The interpreted geological units included the ***Q, Kd,*** and the top of the undifferentiated ***IP*** from the upper surface to the DOI. The interpretive process benefited from the use of CSD, NE-DNR, municipal wells, and the P-MRNRD local water-well drillers logs, which provided lithologic, stratigraphic, and geophysical information. The interpretations were simultaneously checked against the CSD's Nebraska bedrock geology map (Burchett, 1986) and other geological maps in the project area (Burchett et al., 1975) and (Mason and Joeckel, 2001). In the north-western section of the survey area, the 2007 ENWRA Ashland AEM survey overlapped with the 2016 Sarpy County Survey (Smith et al, 2009; Hanson et al., 2012). See Section 3.2, the 2007 Ashland AEM Investigation, for more information. The surfaces as interpreted by (Hanson et al., 2012) were incorporated into the interpretations of the 2016 Sarpy County AEM survey area where the lines overlapped. The data from the 2007 AEM system was not reinverted nor was the data reinterpreted in this study. The interpretive surfaces were converted to feet and sampled along the 2016 flight lines.

The interpretation began with picking the top of the ***IP*** contact with the ***Kd*** and the ***Q***, then the top of the ***Kd*** *and the* ***Q*** *contact*. The process was iteratively around the eroded ends of the ***Kd***.

The interpretation of the ***Kd*** included examining the AEM profile section for an electrical resistivity contrast that was collocated with the bottom of the NE-DNR borehole logs. Many of the CSD as well as the NE-DNR borehole logs stop at the ***IP*** due to that stratigraphic unit's not being considered an aquifer composed predominantly of shale and limestone. Many of the CSD boreholes have stratigraphic calls that assist in the location of the ***Kd***. For the profiles, the clipping distance from the flight line was set independently for the CSD boreholes, NE-DNR /Municipal boreholes, and the P-MRNRD wells. Typically, the CSD clipping distance was set to 2,500 ft, and the remaining boreholes were set to 1,000 ft. The inversion DOI was also inspected during interpretation of the profiles, but was almost always below the top of the ***IP*** in the Sarpy County AEM survey area.

Figure 5-4 is a six-mile-long segment of the east-west line L140501 on the southwestern extent of the Sarpy County AEM survey area. Figure 5-4 illustrates the interpretation of the top of the ***IP,*** top of the ***Kd,*** and the ***Q***. Figure 5-4 also indicates the variable resistivity contrast between the ***Q , Kd***, and the ***IP*** in this area of the Sarpy County. The NE-DNR boreholes typically end at the ***IP*** surface or just slightly penetrate the surface with lithology indicated as limestone or shale. The borehole information is critical to the determination of the top of the ***Kd***. The following characteristics were used to locate the ***Kd*** top: 1) ***Kd*** indicated on the CSD borehole stratigraphic logs; 2) indication of sandstone or shale in the lithology logs; and 3) a generally higher electrical resistivity than the overlying ***Q*** alluvial deposits. The area of the Platte River Alluvium indicates resistive sediments, which contrasts with the areas deposited on the highlands.

Figure 5-5 is a 6.25-mile segment of line L165001. The line is oriented north-south on the east side of Springfield, NE. This line intersects several CSD test holes with both lithology and stratigraphy. The

typical pattern of the area of Sarpy County is a conductive cover of ***Q*** sediments overlaying a resistive layer of ***Kd*** that is deposited on a relatively conductive IP. The area of the Platte River Alluvium is indicated by resistive materials. It is important to note that there are lateral changes in the ***Kd*** along the profile indicating more shale/clay dominant sediments.

Figure 5-6 is a 9.5-mile segment of flight line L124900 that runs just north of Springfield, NE. In this segment, while there is one CSD borehole utilized in the interpretation, several NE-DNR lithology logs exist. As seen above in the previous examples, the interpretation of the ***Q*** , ***Kd,*** and ***IP*** display variability in the resistivity. However, a change can be interpreted with the aid of the boreholes indicating the top and bottom of the ***Kd***. In this profile the DOI is indicated (dashed gray line) closer to the surface, but doesn't interfere with the interpretation of the ***Kd*** along the profile.

Figure 5-7 is a 3.5-mile segment of line L141301 that is north and west of the Gretna, NE area. The ***Q*** Platte River Alluvium is apparent on the western side of the east-west profile. The ***Kd*** changes character throughout the area and thins both to the west and the east. However, the boreholes help to indicate the ***Kd*** with the sandstone and shale lithology. Contrasting with the southern sections of the Sarpy County AEM survey area, the area around Gretna, NE has substantially thicker ***Q*** glacial deposits.

Figure 5-8 is a seven-mile segment of line 155201 that is flown over an outcrop of the Kd as mapped by Burchett et al. (1975). Some of the data was removed in the area of the outcrop due to EM coupling from a power line along the roadway, but the resistivity indicates that the ***Kd*** is resistive and is out cropping in the area. As in the previous examples, the ***Kd*** is distinguished by a resistive material relative to the ***Q*** and ***IP***. Boreholes are key to providing confidence in the interpretation. The AEM data also indicate that the ***Kd*** is further north than Burchett et al. (1975) indicated.

The above examples illustrate the interpretive process that was used on the profiles provided within this report. Each flight line with interpretation including the ***Q*** aquifer material mapping and ***Kd*** aquifer material (Section 5.2.1) are included as profiles in Appendix 1.

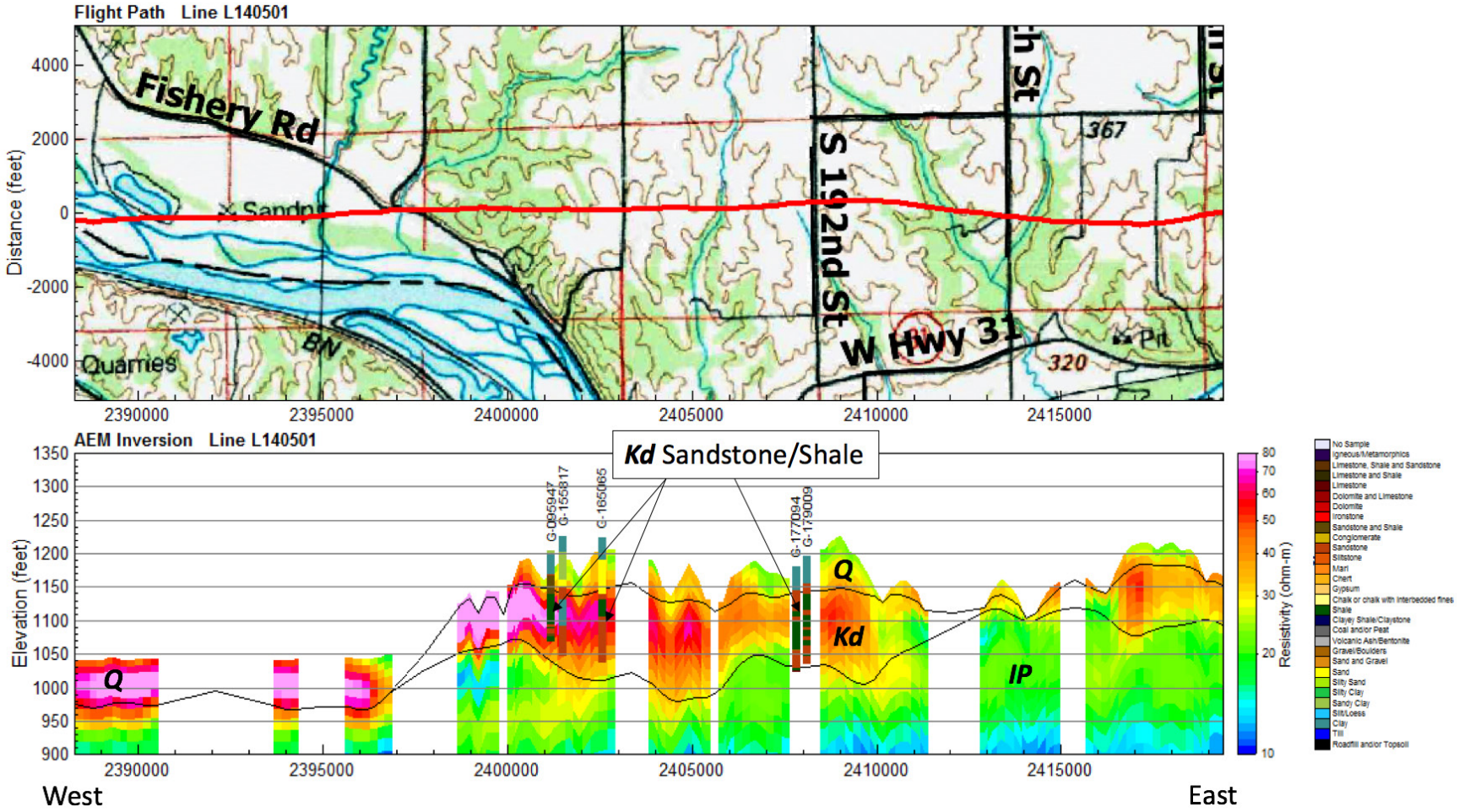


Figure 5-4. East-west flight line L140501 AEM inversion displaying resistivity and interpretations of geologic units on the south-western end of the Sarpy County AEM survey area. Top map indicates the flight path of the survey line as a red line on the 100K USGS Topo Map. Bottom profile shows the Nebraska DNR borehole lithology logs within 1,000 ft indicated on the AEM inverted resistivity models. Geologic interpretations (*Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian) are indicated by black-lines labeled with stratigraphic names.

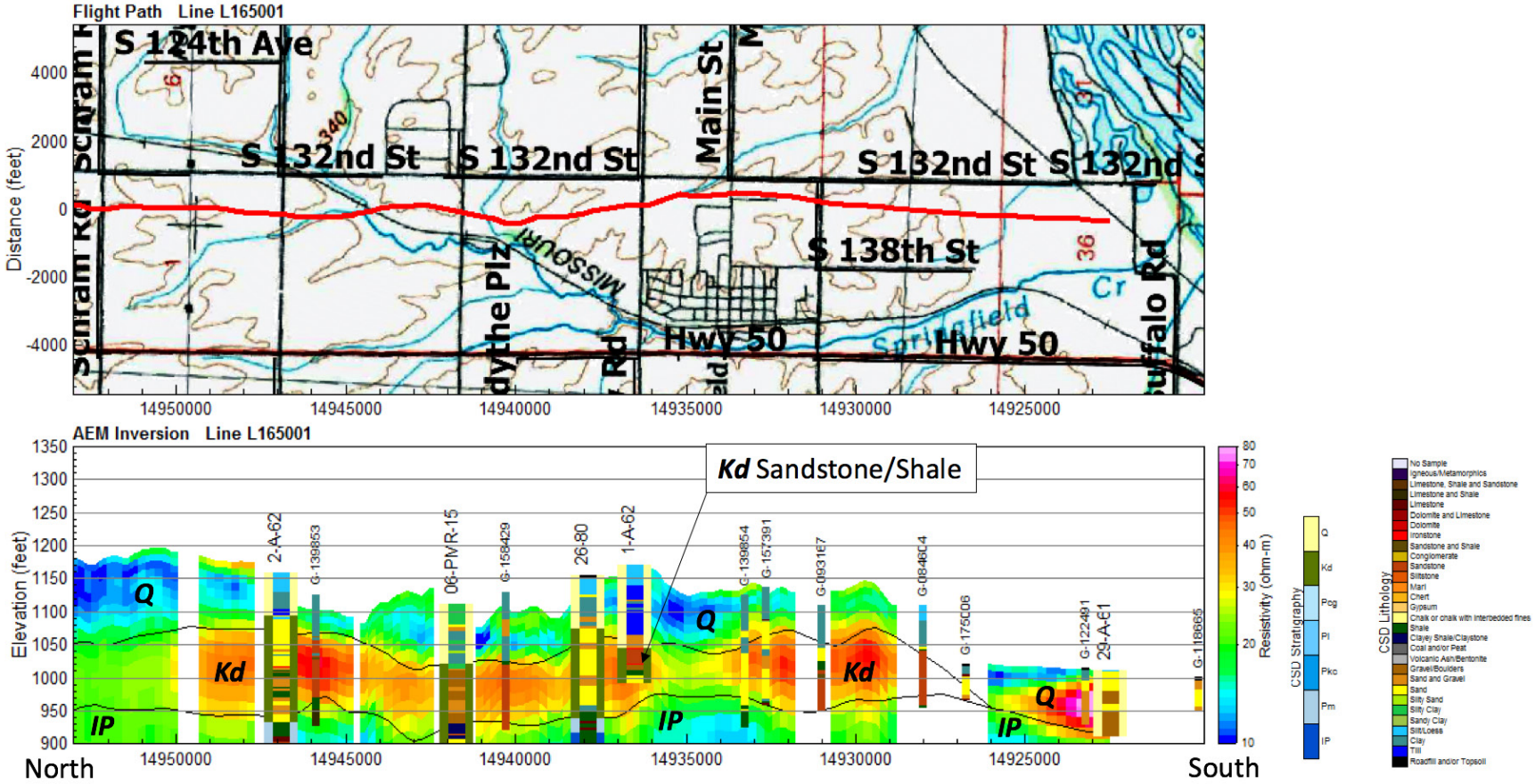


Figure 5-5. North-south flight line L165001 AEM inversion displaying resistivity and interpretations of geologic units on the eastern side of Springfield, NE in the Sarpy County AEM survey area. Top map indicates the flight path of the survey line as a red line on the 100K USGS Topo Map. Bottom profile shows the CSD (within 2,500 ft) and Nebraska DNR (within 1,000 ft) borehole lithology and stratigraphy logs indicated on the AEM inverted resistivity models. Geologic interpretations (*Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian) are indicated by black-lines labeled with stratigraphic names.

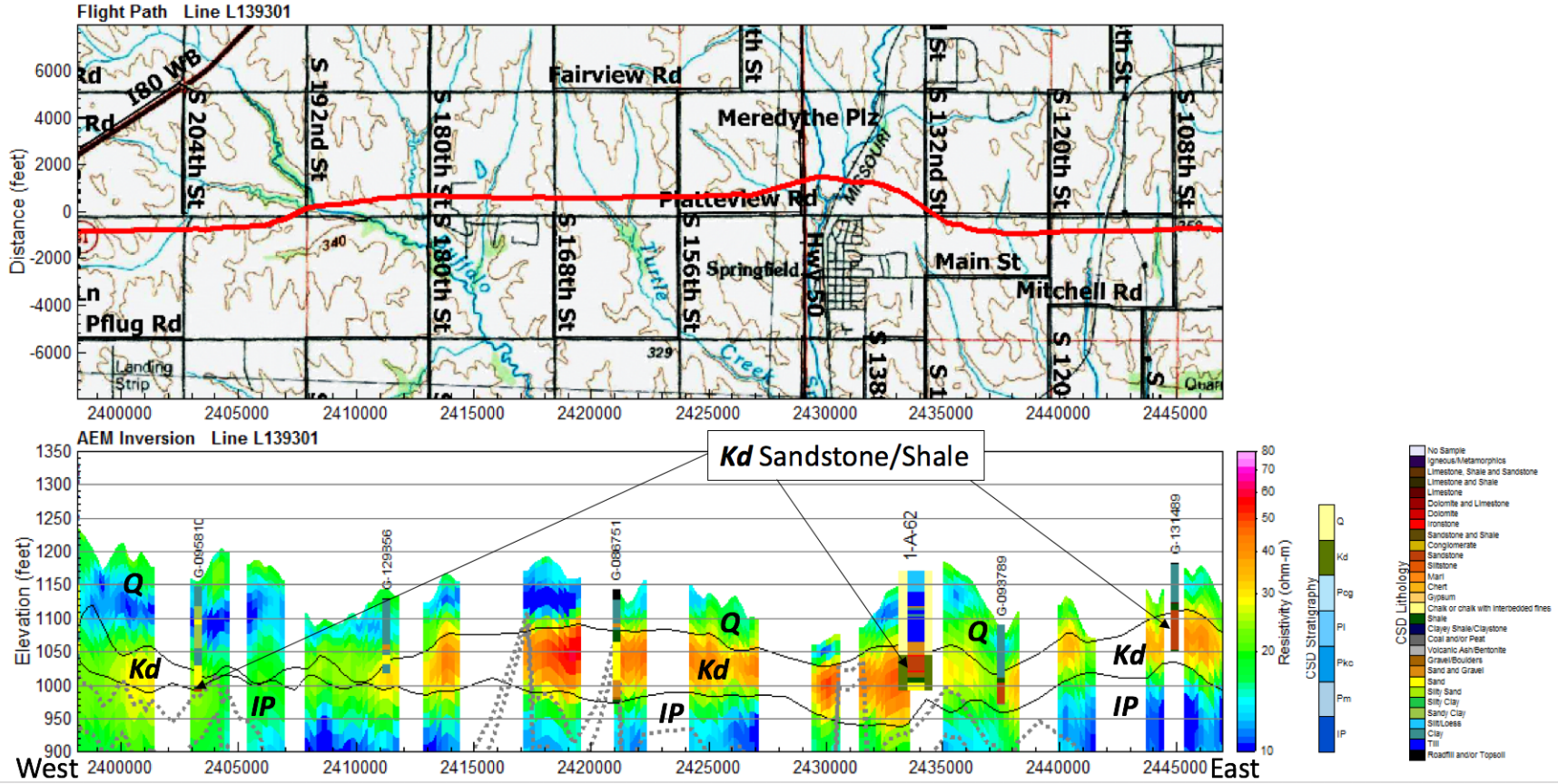


Figure 5-6. East-west Line L139301 AEM resistivity inversion displaying resistivity and interpretations of geologic units north of Springfield, NE within the Sarpy County AEM survey area. Top map indicates the flight path of the survey line as a red line on the 100K USGS Topo Map. Bottom profile shows the CSD (within 2,500 ft) and Nebraska DNR (within 1,000 ft) borehole lithology and stratigraphy logs indicated on the AEM inverted resistivity models. Geologic interpretations (*Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian) are indicated by black-lines labeled with stratigraphic names. Dashed-gray lines indicate the Depth of Investigation (DOI).

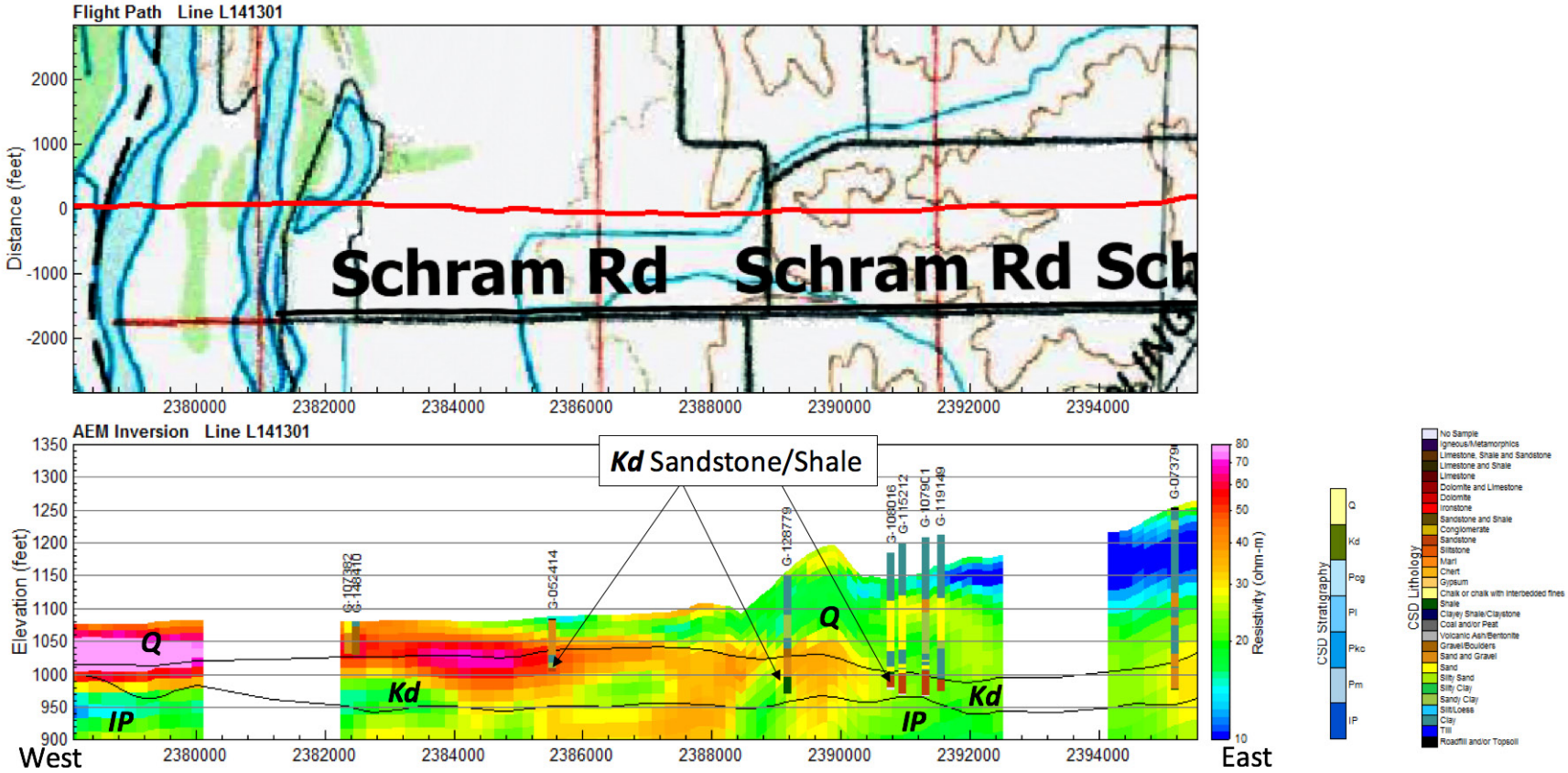


Figure 5-7. East-west flight line L141301 AEM resistivity inversion displaying resistivity and interpretations of geologic units north-west of Gretna, NE within the Sarpy County AEM survey area. Top map indicates the flight path of the survey line as a red line on the 100K USGS Topo Map. Bottom profile shows the Nebraska DNR borehole lithology logs within 1,000 ft indicated on the AEM inverted resistivity models. Geologic interpretations (*Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian) are indicated by black-lines labeled with stratigraphic names.

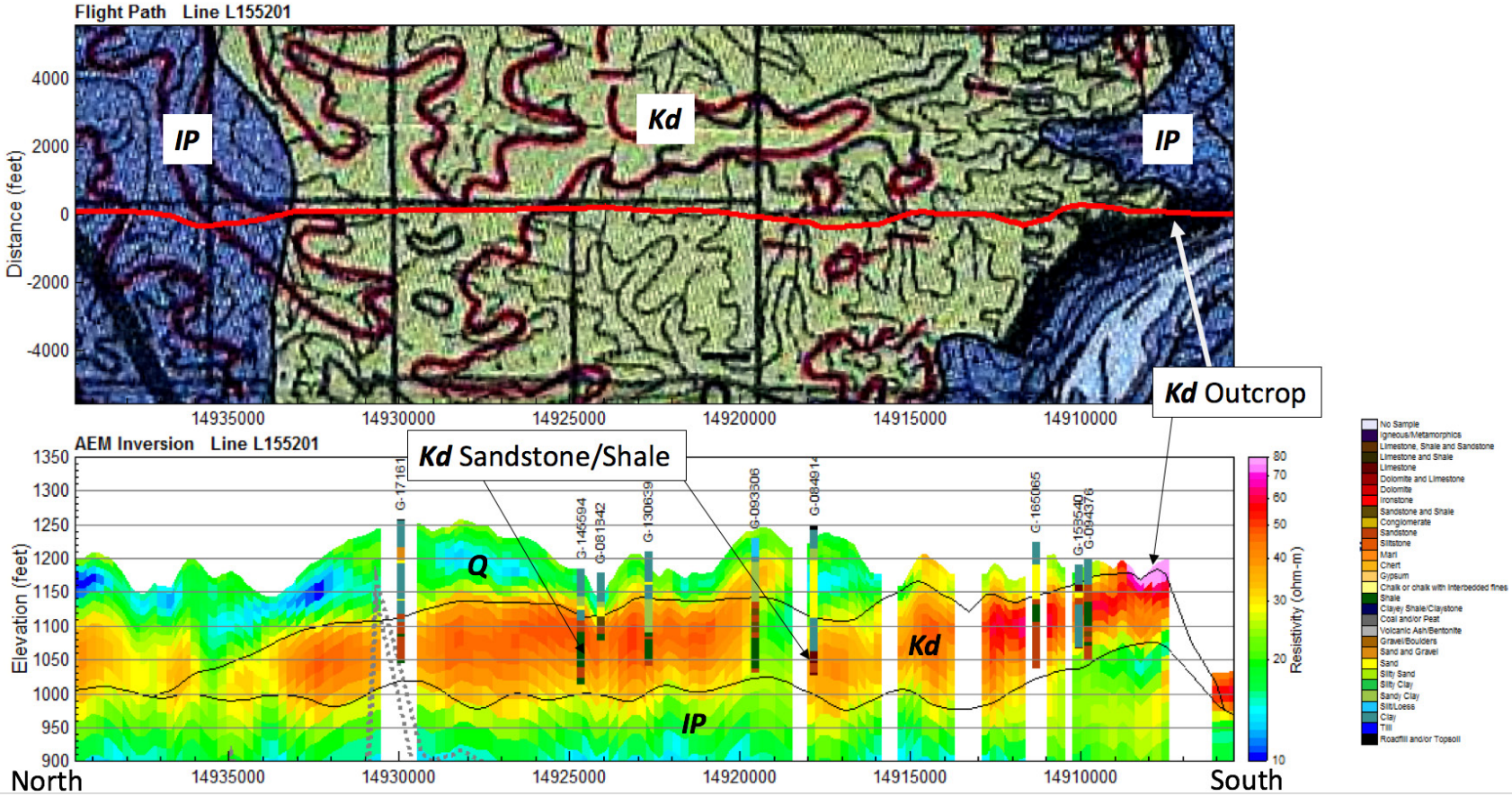


Figure 5-8. North-south flight line L155201 AEM resistivity inversion displaying resistivity and interpretations of geologic units within the Sarpy County AEM survey area. Top map indicates the flight path of the survey line as a red line on a Geologic map (Burchett et al., 1975). The green areas of the map indicate Cretaceous Dakota (*Kd*) and the Blue areas indicate Pennsylvanian (*IP*). The dark area of the top map indicates *Kd* outcrop. Bottom profile shows the CSD (within 2,500 ft) and Nebraska DNR (within 1,000 ft) borehole lithology and stratigraphy logs indicated on the AEM inverted resistivity models. Geologic interpretations (*Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian) are indicated by black-lines labeled with stratigraphic names.

5.1.4 Create Interpretative Surface Grids

Sarpy County surface grids of geologic formations were produced for the top of the ***Kd*** and the top of the ***IP***. To create these grids, the elevations of the AEM-interpreted top of the formation as well as data from CSD and NE-DNR holes were imported to a Geosoft Oasis montaj (OM) database. The interpreted elevation data were then gridded for each formation independently using the OM minimum curvature gridding (MCG) algorithm with a 100 ft cell size, a blanking distance of 2,500 ft, and the 'cells to extend beyond' set to 20.

For the ***Kd*** top or the bottom of the ***Q*** surface, six CSD boreholes, 55 NE-DNR holes, and eight municipal wells were used in addition to the 3,600 2015 and 2016 AEM picks. Using the above gridding specifications all other parameters were either left as the default or blank. The large blanking distance was required to fill in between the broadly spaced areas. An additional 8,000 AEM picks from the 2007 Ashland survey (Hanson et al., 2012) were added to the ***Kd*** picks. This was a large number due to the dense spacing of the data points in the frequency domain survey that were used to sample the interpreted surface of the ***Kd*** from Hanson et al. (2012). Using the geological maps from Burchett et al. (1975) and Mason and Joeckel (2001), 1,200 surface outcrop picks were added to the top of the ***Kd*** control points. The location of the outcrop was digitized for the X and Y location and then that location was then used to sample the DEM to provide an outcrop elevation. The surface was then regridded at a 100 ft cell size and compared with the surface DEM which was also at a 100 ft cell size. Where the ***Kd*** surface was higher in elevation than the DEM, the ***Kd*** surface as set to the DEM. The grid was then clipped to the outline of the ***Kd***. The outline of the ***Kd*** was determine by sampling the location where the ***Kd*** and the ***IP*** were at the same location. A 5x5 cell smoothing filter was used on the completed grid to remove gridding artifacts. Figure 5-9 is a map of the elevation of the top of the ***Kd*** within the Sarpy County AEM survey area.

To define the ***IP*** top surface, five CSD boreholes and 367 NE-DNR holes were used in addition to the 2,834 AEM picks. Using the above specifications listed in the previous paragraph all other parameters were either left as the default or blank. The 100 ft cell size preserved the spatial resolution obtained from the AEM data but minimized artifacts from the MCG routine. The grid was then clipped to the Sarpy County AEM survey area. A 5x5 cell smoothing filter was used on the completed grid to remove gridding artifacts. Figure 5-10 is a map of the elevation of the top of the ***IP*** within the Sarpy County Survey Area.

The bedrock or the base of the ***Q*** throughout the Sarpy County AEM survey area is a combination of the tops of the ***Kd*** and ***IP*** surfaces. In some of the literature it is titled the "pre-Pleistocene" surface. In this region, specifically around the Platte River, Buffalo Creek, and Springfield Creek, the ***Kd*** and the ***IP*** may have gone through subsequent erosion after the Pleistocene due to the outcrops and the proximity of the formations to the surface. We have elected to use the name of bedrock in the area. To construct the top of bedrock the two surfaces were combined into one (Figure 5-11) at a 100 ft grid cell size. The grid was then clipped to the Sarpy County AEM survey area.

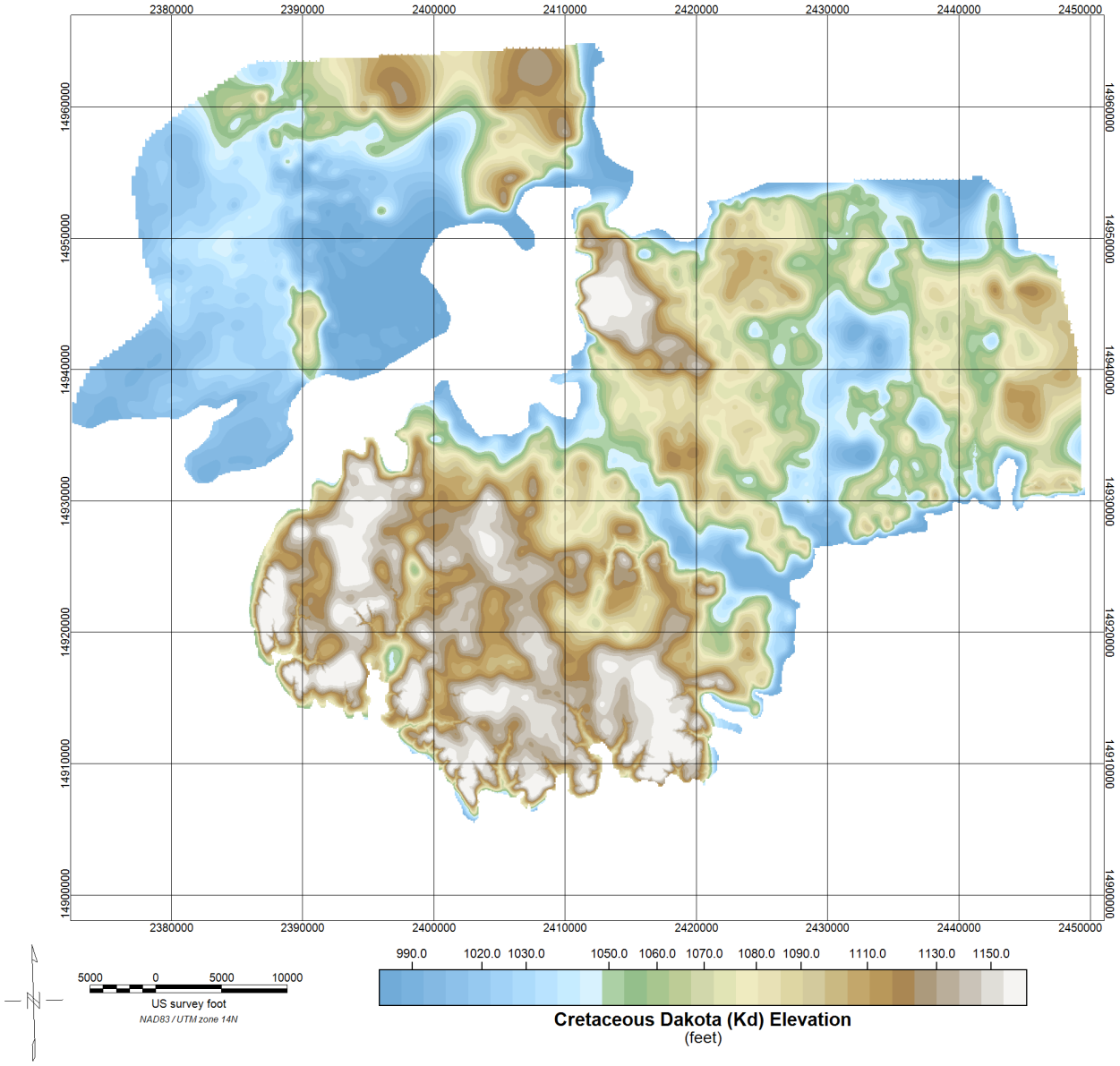


Figure 5-9. Map of the elevation of the top of the Cretaceous Dakota (*Kd*) within the Sarpy County AEM survey area. The projection is NAD83 UTM Zone 14 North (feet) and the elevation values are referenced to NAVD 88 (feet).

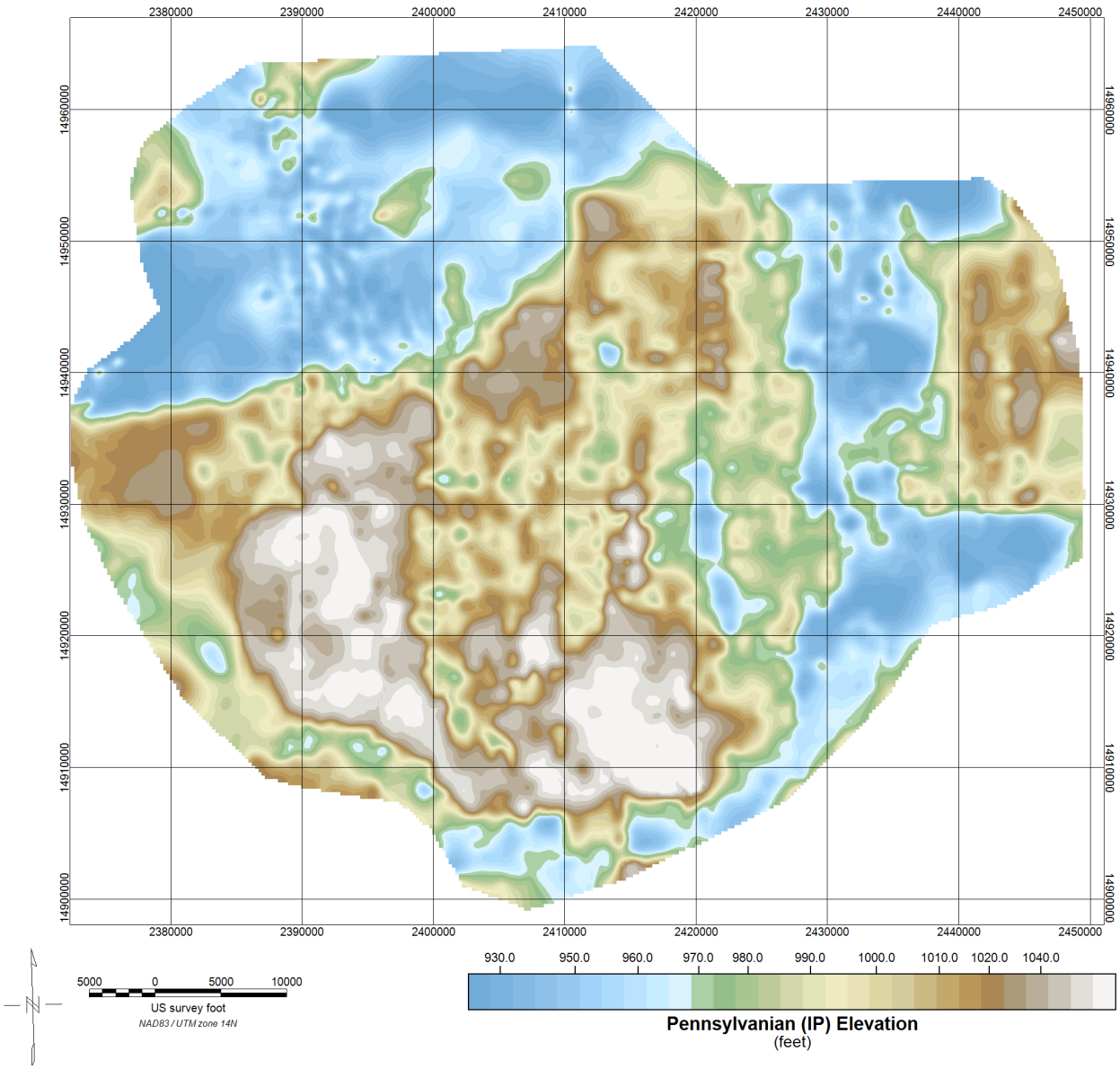


Figure 5-10. Map of the elevation of the top of the undifferentiated Pennsylvanian *(IP)* and the reconnaissance flight lines within the Sarpy County AEM survey area. The projection is NAD83 UTM Zone 14 North (feet) and the elevation values are referenced to NAVD 88 (feet).

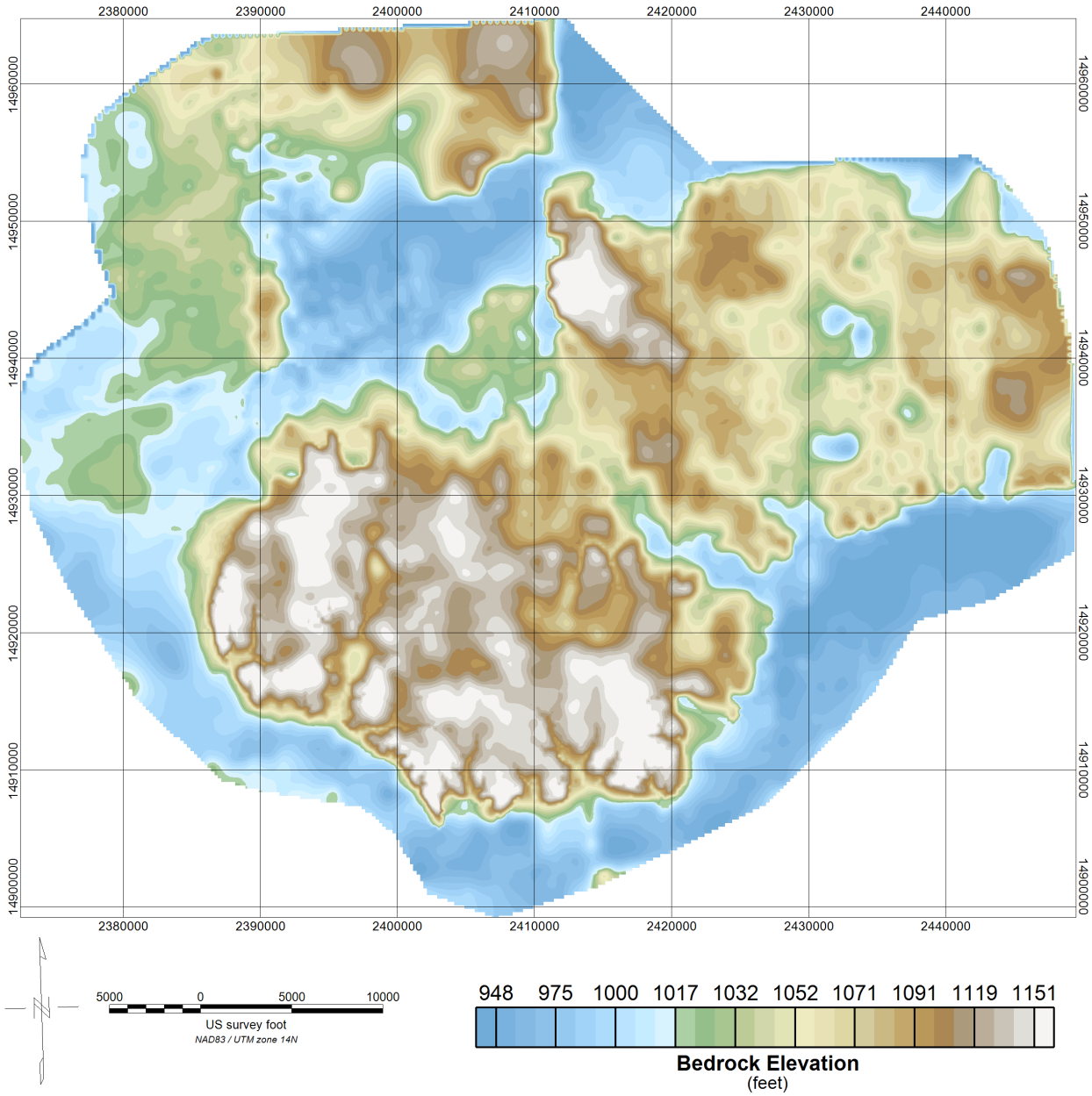


Figure 5-11. Map of the elevation of the top of the bedrock or the base of the Quaternary (*Q*). The map surface is composed of the Cretaceous Dakota (*Kd*) and undifferentiated Pennsylvanian *(IP*) within the Sarpy County AEM survey area. The projection is NAD83 UTM Zone 14 North (feet) and the elevation values are referenced to NAVD 88 (feet).

Following construction of the bedrock surface, the consolidated and unconsolidated deposits were isolated within the AEM resistivity inversions. The aquifer and non-aquifer materials in the Quaternary system were separated by four major resistivity thresholds. These ranges include less than 12 ohm-m, representing non-aquifer materials ("aquitard"- primarily glacial till, loess), 12-20 ohm-m, representing marginal aquifer deposits with potential for interlayered silt and clay, 20-50 ohm-m, indicating the Quaternary system's principal aquifer, and an interval of 50 ohm-m or greater, indicating the coarsest, sand-rich intervals within the principal aquifer (further discussion regarding the selection of these

threshold ranges is provided in the following section regarding the selection of these threshold ranges and in Carney et al. (2015a). Results of these interpretations can be found in Appendix 1.

To assist in the approximation of the saturated materials along the surveyed AEM flight lines, the 1995 CSD statewide water table (Nebraska CSD, 1995) was mapped into the cross-sections. It should be noted that this inclusion provides only a generalized characterization of the saturated thickness of the aquifer as the CSD's dataset is two decades old at the time of the 2016 Sarpy County AEM survey area and local conditions have likely deviated in areas with variable topography. The water table in the Sarpy County AEM survey area is close to the surface in some of the area. To this end a topographic correction was required to adjust the water table height to be below the surface topography. The original water table contour lines were gridded at a 1,000 ft cell size using the OM MCG and a blanking distance of 5,000 ft. The cells were set 'to extend beyond' to 50. The resulting grid was then regridded at a 100 ft cell size and compared with the DEM of the Sarpy County AEM survey area. In areas where the water table elevation was greater than the topography, the water table was set to an elevation of the topography minus 3 feet except in the surface water areas. The grid was then clipped to the Sarpy County AEM survey area. The result is presented in Figure 5-12.

A voxel grid was prepared for the Sarpy County AEM survey area. The voxel grid was made using a 100 ft grid cell size and the model layer thickness (Table 4-4 in the previous section). A minimum curvature method with a smoothing factor of five (5) cells was used within Pitney-Bowes Discover PA (pbEncom, 2016). All layers were referenced to their depth from the surface. After the voxel grids were calculated, they were clipped to the Sarpy County AEM survey area. The resulting grid can be sliced by the geological surfaces of the ***Kd***, ***IP***, bedrock, and water table. A consequence of the vertical cell size of the voxel cell is encountered when slicing the voxel volume by the interpreted surfaces. An algorithm was used that includes a cell if greater than (>) 60% is within the area of the surface. This can sometimes cause rough surfaces that are based on the voxel vertical cell sizes and not the interpreted surfaces. Table 5-3 lists the independent voxels that were created for the Sarpy County AEM survey area. These voxels can be found in Appendix 3\Voxel.

Table 5-3. Voxels

Voxel Description	Horizontal Cell Size
Quaternary	**100 feet**
Cretaceous Dakota	**100 feet**

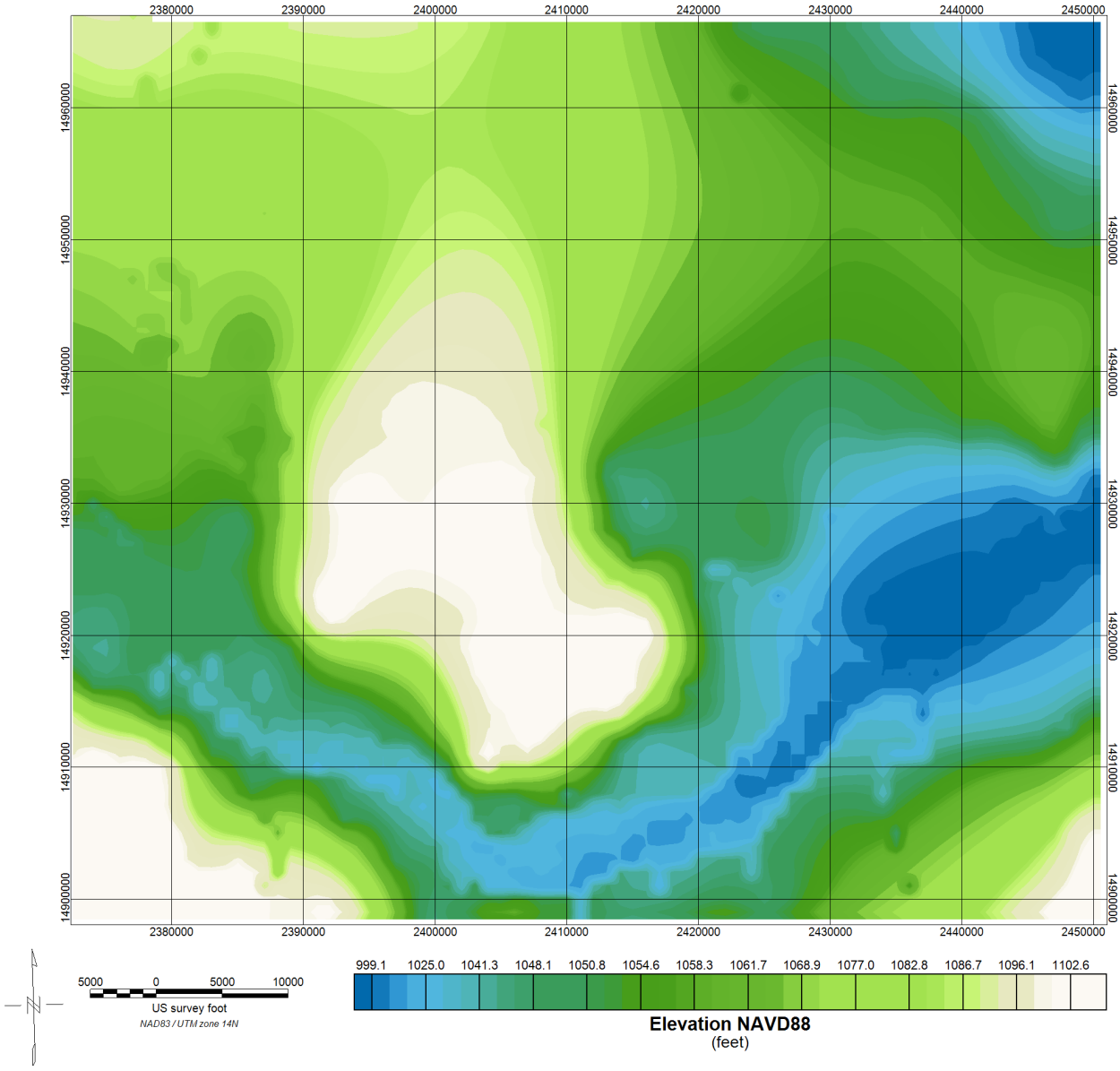


Figure 5-12. Map of the elevation of the water table (Nebraska CSD, 1995) within the Sarpy County AEM survey area. The projection is NAD83 UTM Zone 14 North (feet), and the elevation values are referenced to NAVD 88 (feet).

5.2 Resistivity-Lithology Relationship

5.2.1 Quaternary Aquifer System

A critical aspect of a geophysical survey is assessing the nature of the material detected by the geophysical method applied in the investigation. Regarding the Sarpy County AEM survey area, assessment of the sediment character in the Quaternary (***Q***) aquifer system was conducted to determine the overall composition of the major categories used to define the aquifer and aquitards in eastern Nebraska. A numerically robust assessment of the resistivity thresholds used to characterize non-aquifer, marginal, and aquifer, including sand-rich intervals, was calculated. This allows for the characterization of the ranges of resistivities present in the ***Q*** units described in this report. It should be noted that this analysis encompasses all Quaternary/Tertiary Ogallala (***Q***/***To***) aquifer systems from the ENWRA project area (Carney et al., 2015a). The original analysis that was completed as part of Carney et al. (2015a) included the area within the Sarpy County AEM survey area. This analysis has been used in the current report for the categorization of the Quaternary aquifer system.

Data for this analysis was utilized from locations across the ENWRA reconnaissance flight line area (Carney et al., 2015a and Carney et al., 2015b). The relationship between resistivity and lithology type was assessed by performing an association function that linked nine lithologic descriptor codes for ***Q*** sediments used in the CSD test hole lithologic characterization with the resistivity values across that depth interval as indicated in the 58 high-graded resistivity logs applied in the AEM data inversion (25 from the southern area, 33 from the northern area). With this approach, several thousand points became available for each lithologic description in the test holes used in this analysis. From this list of associated resistivity levels and pre-categorized lithologies, statistical analyses were performed to aide in defining the various thresholds used to determine the aquifer material type in the project area subsurface. Details of the analysis can be found in Carney et al. (2015a). A summary of the resistivities and the color scale is shown in Figure 5-13.

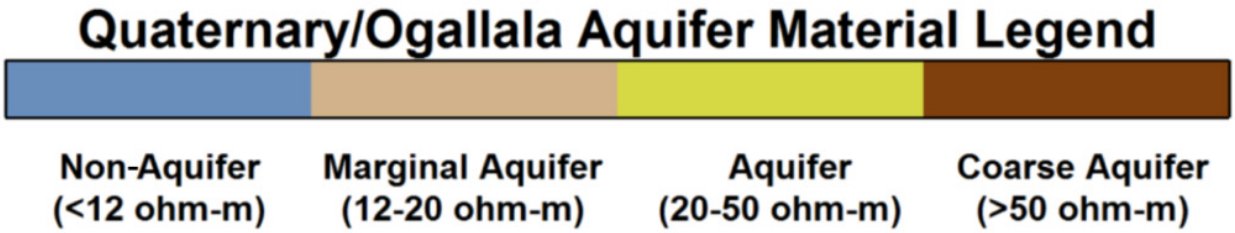


Figure 5-13. Plot displaying the relation between resistivities and major aquifer material color categories (blue- non-aquifer material, tan- marginal aquifer, yellow- aquifer, brown- sand-rich, coarse intervals of the aquifer material) and color legends for aquifer materials, stratigraphy, and lithology used in succeeding figures.

5.2.2 Bedrock Resistivity Thresholds

The bedrock in the Sarpy County AEM survey area analyzed in this study includes the Cretaceous Dakota (***Kd***) and undifferentiated Pennsylvanian (***IP***). Carney et al. (2015a) provided a distribution of the ***Kd*** and the undifferentiated Paleozoic units, of which the undifferentiated Pennsylvanian (***IP***) was a part, from an examination of the bedrock resistivity values from the CSD test holes. The ***Kd*** has a median resistivity of approximately 20 ohm-m as the ***Kd*** is predominately a sandstone, but can contain shale and electrically conductive clay minerals. The undifferentiated Paleozoic strata also have resistivity characteristics, with a median value around 16 ohm-m. The undifferentiated Paleozoic units show a wide range in detected resistivities, which should not be unexpected as this sequence contains resistive limestone and conductive shale units. Additionally, the Paleozoic and the ***Kd*** can be saturated with saline waters, which will lower the bulk resistivity. Figure 5-14 is a figure out of Carney et al. (2015a) showing the distribution of the bedrock units within the ENWRA area.

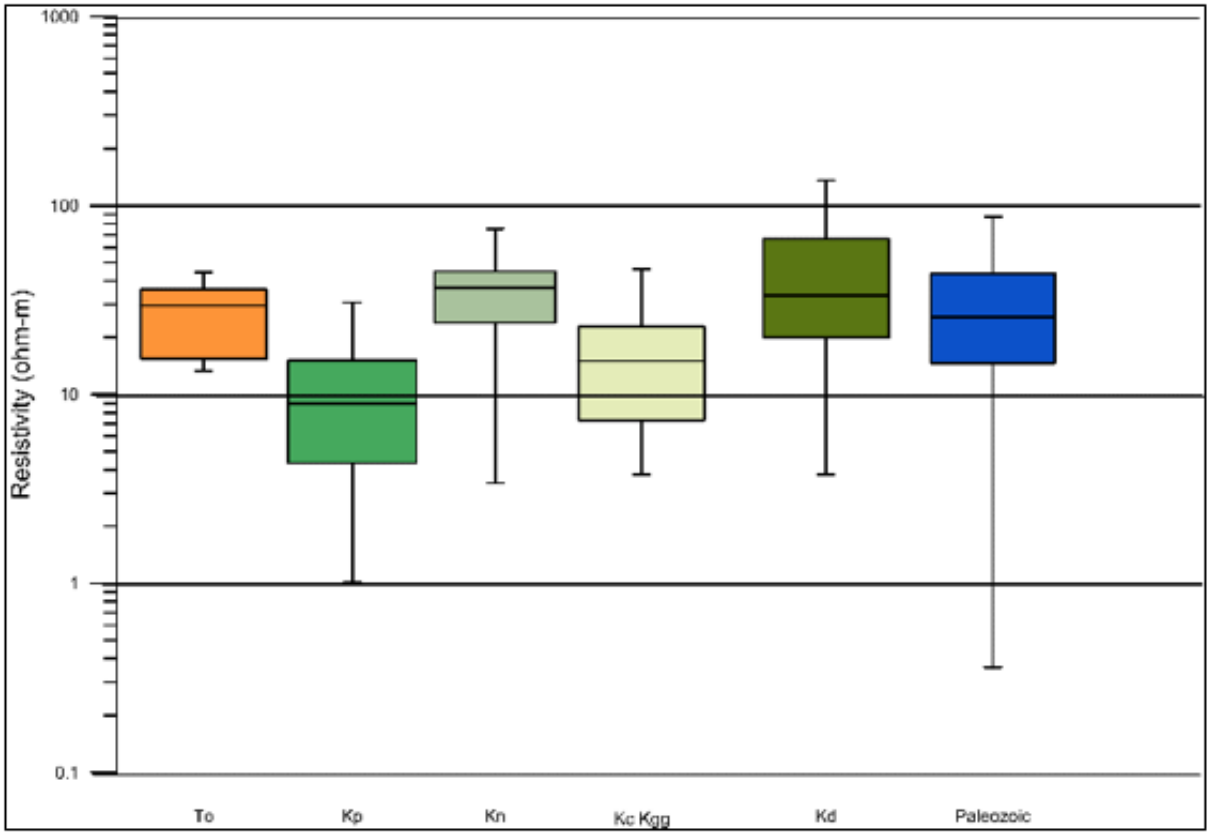


Figure 5-14. Box and whiskers plot of the resistivity distribution of the Tertiary, Cretaceous, and Paleozoic bedrock units discussed in the interpretation of the AEM data (Carney et al., 2015a).

Carney et al. (2015a) also looked at the ***Kd*** throughout the ENWRA to characterize the variability in the ***Kd***'s resistivity distribution. The relationship of lithology and resistivity was evaluated using the same method applied in associating unconsolidated ***Q*** lithologies to resistivity. Borehole geophysical log resistivities were associated with each lithologic description in the CSD test holes that contained

information on the ***Kd.*** As described above in Section 2 the ***Kd*** is typically known as a sandstone and shale, but contains intervals of unconsolidated lithologies as noted in the CSD test hole descriptions. Figure 5-15 (Carney et al., 2015a) shows a breakdown of textural size and nature of consolidation (unconsolidated (clay/silt) and consolidated fines (shale)), unconsolidated (sand and gravel) and consolidated coarse (sandstone). The distributions for the coarse categories are similar, with the 25th quartile for each greater than 50 ohm-m and median values over 70 ohm-m. Distributions for the fine textured materials are also similar, with the median values ranging from 25 to 30 ohm-m. Carney et al. (2015a) illustrated that shale has a wider range of values detected in comparison to unconsolidated fines and grouped unconsolidated and consolidated fines as one group and coarse-textured unconsolidated and consolidated materials as another group. The objective of this analysis in Carney et al. (2015a) was to determine if any natural breaks in the resistivity distribution were evident on which to base selection of categorical ranges for showing the variation in resistivity within the ***Kd***.

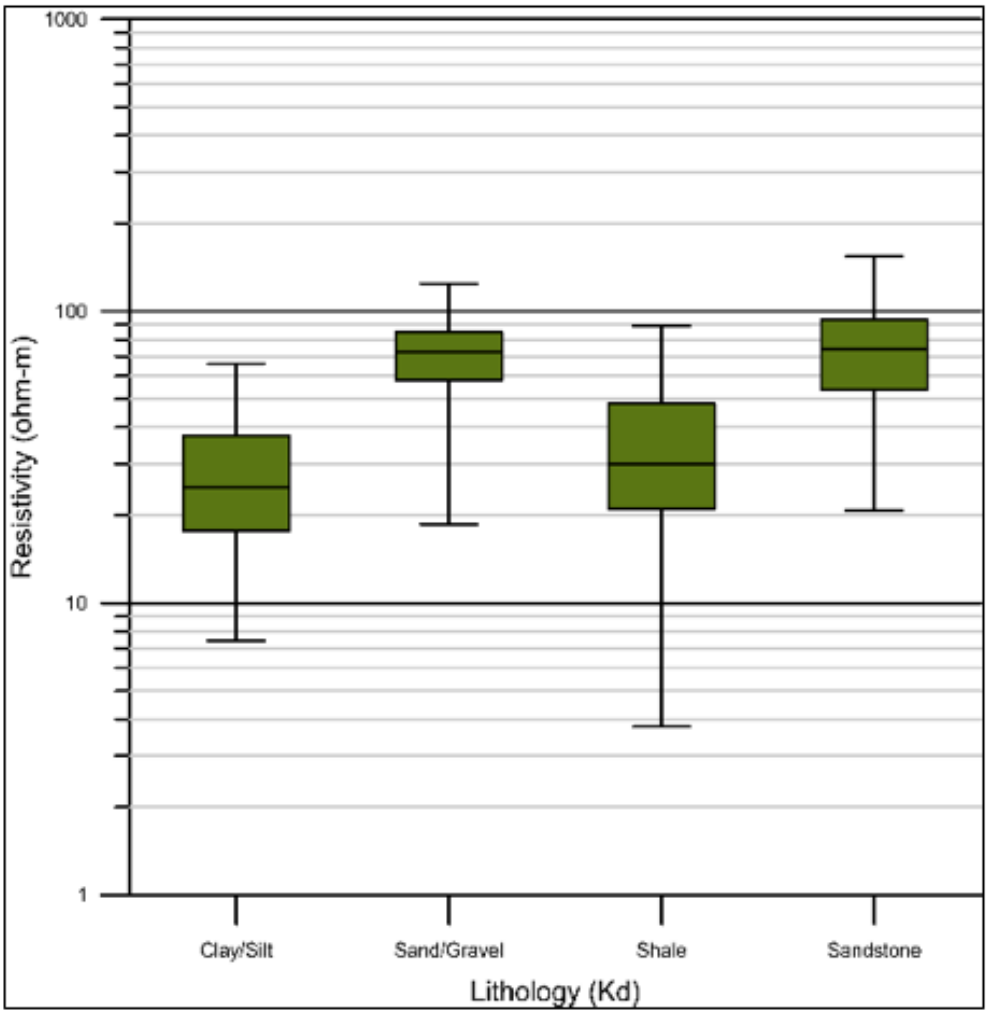


Figure 5-15. Box and whisker plot for the major lithologic texture categories within the *Kd* from CSD E-logs located across the entire ENWRA project area (Carney et al., 2015a).

Carney et al. (2015a) examined the distribution of resistivity for coarse materials (sandstone/sand) and fine materials (shale/silt/clay). From this distribution Carney et al. (2015a) concluded that the bulk of fine textured materials are generally below 40 ohm-m, and that the bulk of the coarse textured distribution is above 30 ohm-m, with overlap of the two groups in the 30 to 40 ohm-m range. The fine textured materials indicated bimodal distribution. The distribution below 10 ohm-m was attributed to brackish/saline water in the ***Kd***, and the distribution greater than 10 ohm-m is related to lithologic character. Carney et al. (2015a) grouped the ***Kd*** into three general categories: 1) 0-20 ohm-m, representing zones of the ***Kd*** predominately consisting of fines or high TDS pore water; 20-40 ohm-m, representing intervals of interbedded fine and coarse materials, and zones of 40 ohm-m or greater, which are intervals of the ***Kd*** where coarse textured deposits comprise the bulk of the material in that interval.

For the Sarpy County AEM survey area the availability of reliable borehole resistivity logs was a problem. The seven resistivity logs in the study area showed severe issues with calibration and scale offsets typical of CSD logs within ENWRA. Still, these logs have value in that they clearly show the changes in the resistivity at geological and lithologic contacts, but cannot be used in a quantified manner. One important issue with the ***Kd*** in the Sarpy County AEM survey area is that there is no evidence of saline waters associated with ***Kd*** wells (Section 2.2.1.4, Hydrogeologic Character-Water Quality). This would reduce the range of the ***Kd*** resistivities in the Sarpy County AEM survey area by increasing the minimum resistivities over the ranges that were reported in Carney et al. (2015a) and Carney et al. (2015b).

Without the availability of calibrated geophysical logs, an empirical inspection was used to characterize the ***Kd*** aquifer materials within the Sarpy County AEM survey area. To accomplish this characterization, the NE-DNR lithology logs as well as the limited CSD lithology logs were plotted on the AEM profile sections. Then the ***Kd*** resistivity range was adjusted to maximize the correlation of the sandstones/sand sections with the lithology logs. A value of 27 ohm-m was determined to be the best empirical cut-off for the shale/clay versus the sandstone/sand dominant ***Kd*** aquifer materials. Figure 5-16 is a five-mile segment of Line L1390000 showing the NE-DNR lithology logs overlaid on the interpretation of the ***Kd***. The NE-DNR logs are masked to be within 1,000 ft of the flight line. There is a good agreement with the resistivity in the AEM inversions and the lithology. Figure 5-16 also shows a sandstone/sand dominant zone in the ***Kd***. This is also indicated by the presence of wells in the area. Figure 5-17 is a three-mile segment of Line 140101 illustrating two sandstone/sand dominant areas separated by a shale/clay dominant zone. The NE-DNR wells within 1,000 ft of the flight line also indicate the zones of shale/clay dominant versus sandstone/sand dominant.

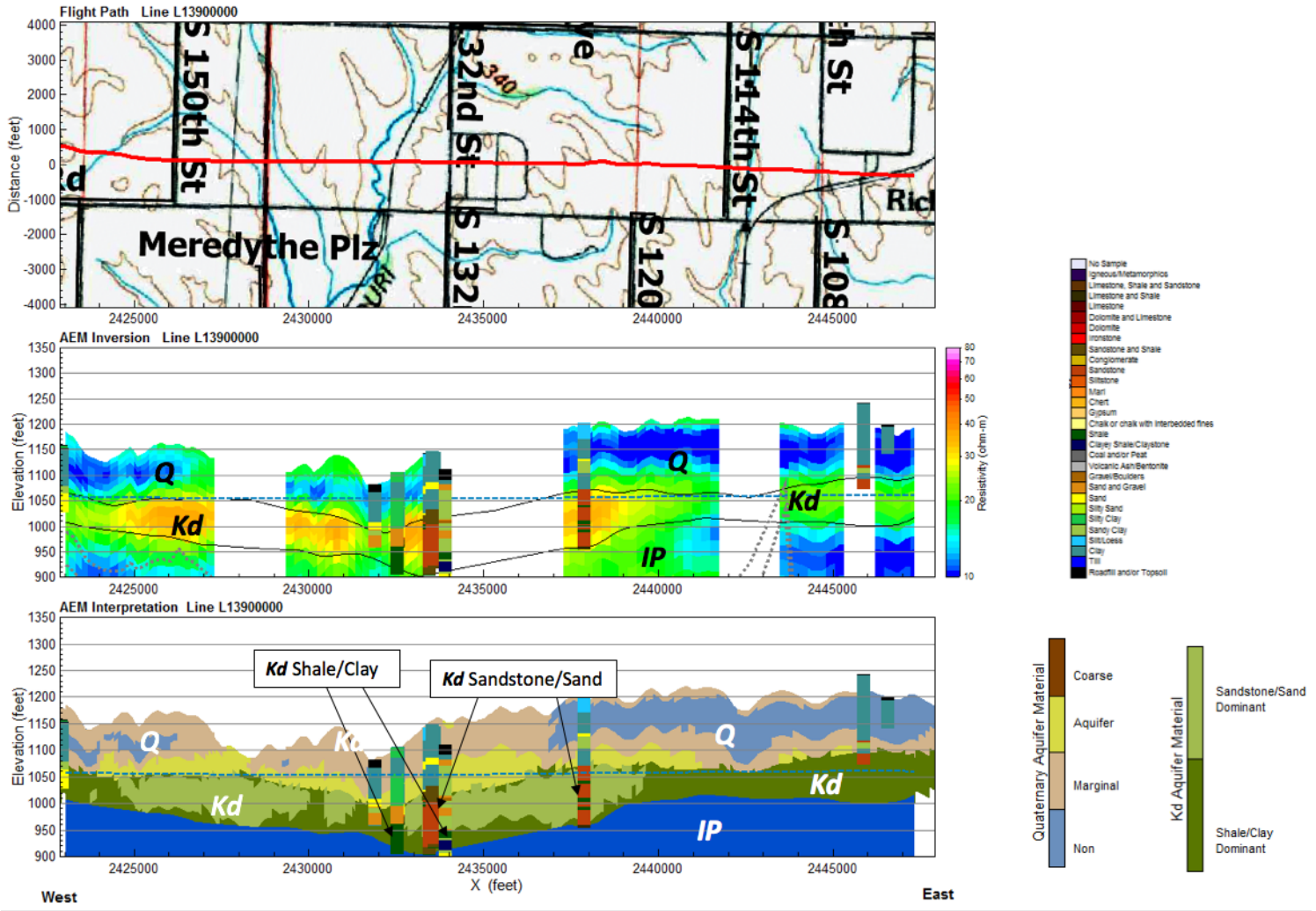


Figure 5-16. Interpretation of east-west segment of Line L13900000. Upper map showing the location of the flight path as a red line on the 100K USGS Topo Map. Middle profile shows the AEM resistivity inversion and interpretations of geologic units indicated by black-lines labeled with stratigraphic names. The middle and bottom profiles also indicate the Nebraska DNR borehole lithology logs within 1,000 ft of flight line. Bottom profile shows the interpreted *Q* aquifer material and the *Kd* aquifer material. Geologic interpretations: *Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian.

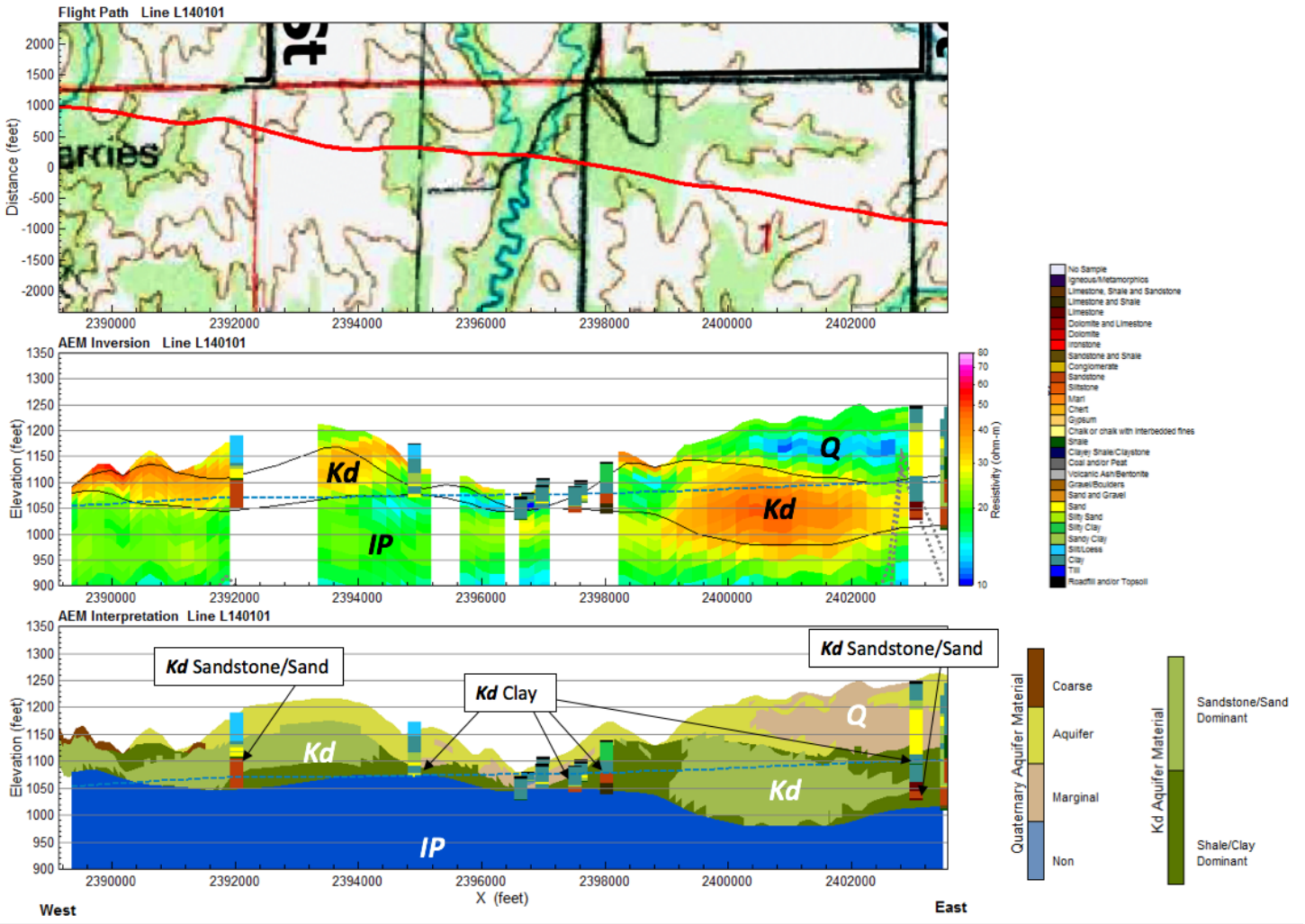


Figure 5-17. Interpretation of east-west segment of Line L140101. Upper map showing the location of the flight path as a red line on the 100K USGS Topo Map. Middle profile shows the AEM resistivity inversion and interpretations of geologic units indicated by black-lines labeled with stratigraphic names. The middle and bottom profiles also indicate the Nebraska DNR borehole lithology logs within 1,000 ft of flight line. Bottom profile shows the interpreted Q aquifer material and the *Kd* aquifer material. Geologic interpretations: *Q*= Quaternary, *Kd* = Cretaceous Dakota, *IP* = undifferentiated Pennsylvanian.

5.2.3 Comparison of AEM Inversion Resistivity to Borehole Geophysical Resistivity Logs

Three CSD borehole geophysical resistivity logs were selected from the Sarpy County AEM survey area for comparison with the AEM inversions: Test holes ***25-80***, ***26-80***, and ***06-PMR-15***. Since the resistivity logs within the CSD database are of various vintages and conducted by various staff with differing equipment, a critical examination of the absolute values of the resistivity needs to include an awareness of errors in calibration and in the proper operation of the equipment. This was introduced above in Section 5.2.2. There has been a long-standing issue with using geophysical logs as ground truths when comparing to AEM inversions that are well calibrated using modern techniques. Throughout much of the geophysical logging at the time it was acquired, the relative deflections of the resistivity measurements were all that was required or expected from a geophysical log. Operators were seldom trained in recognizing the proper operation of a calibrated sonde or in the ability to recognize high contact resistances of a cable head. This has led to many geophysical logs that are uncalibrated within the CSD database. Note that these logs still have scientific merit in their ability to relatively indicate an increase or a decrease in the formation resistivity. Not accurately, but relatively. Thus, the logs used herein are for qualitative comparison to the AEM because detailed calibration and corrections would need to be carried out for the resistivity values in the logs to be directly used as numerical constraints in the inversion of the AEM data (Ley-Cooper and Davis, 2010).

Figure 5-18 is a plot of the resistivity borehole geophysical log from test hole ***25-80*** with the 16-inch short normal resistivity log plotted over the inverted AEM resistivity for line L165601. The AEM and the geophysical log are plotted on the same resistivity scale. Test hole ***25-80*** is located 881 ft from line L165601. The agreement in the resistivity is fair in the area with the geophysical log containing more detail as would be expected, but is suffering from poor calibration. The resistivity borehole geophysical log indicates a relative increase in the resistivity associated with two thin beds. One area is a thin bed of approximately 10 ft of sand and some sand and gravel at approximately 90 ft in depth. There is also a thin (approximately 5 ft) sand and gravel bed at approximately 50 ft. The AEM does not illuminate these thin units within the ***Q*** and the zone would be classified as marginal and non-aquifer materials. The AEM is showing the ***Kd*** as slightly more resistive than the overlaying ***Q*** sediments, but the ***Kd*** would be classified as shale/clay dominant. As these are thin units and may not be laterally extensive the AEM is correctly depicting the hydrogeology.

Figure 5-19 is a plot of the resistivity borehole geophysical log from test hole ***26-80*** with the 16-inch short normal resistivity log plotted with the inverted AEM resistivity for line L168401. The AEM and the geophysical log are plotted at the same resistivity scale. Test hole ***26-80*** is located 725 ft from line L168401. The agreement in the resistivity is poor in the area with the geophysical log containing more detail as would be expected, but clearly showing calibration issues and truncating issues at the top of the log and in the high resistivity areas. The borehole resistivity log shows two small high resistivity units within the ***Q***. The lithology log indicates thin layers of sand/sand and gravel. The AEM is indicating the ***Q*** sediments are conductive and would be classified as marginal and non-aquifer materials. The borehole resistivity log and the AEM show the ***Kd*** in this log is more resistive than the ***Q***. The uncalibrated borehole resistivity log is indicating a resistivity that is greater than 70 ohm-m. The borehole log is indicating the location of the sand/sand and gravel, but the resistivities are substantially higher than the

AEM that is indicating, greater than 20 ohm-m. The ***Kd*** here would be classified as sandstone/sand dominant. The AEM is correctly depicting the hydrogeology in this area.

Figure 5-20 is a plot of the resistivity borehole geophysical log from test hole ***06-PMR-15*** with the 16-inch short normal resistivity log plotted with the inverted AEM resistivity for line L165001. The AEM and the geophysical log are plotted at the same resistivity scale. Test hole ***06-PMR-15*** is located 1,099 ft from line L165001. The comparison of the AEM and the borehole resistivity log is poor with the borehole resistivity log showing impacts of drift from the surface and too-high resistivity readings approaching 200 ohm-m. The test hole is greater than 1,000 ft from the AEM data and there could be lateral changes in the area, but the very high resistivity area is anomalous in this part of eastern Nebraska. The borehole geophysical log does show a relative inflection associated with a sand and gravel/gravel/boulder area of the ***Kd***. The borehole geophysical log also shows the clayey shale/claystone section of the ***Kd*** at approximately 180 ft and then a sand zone at approximately 210 ft. The AEM data show ***Q*** sediments as being conductive and subsequently that they are composed of non-and marginal aquifer materials. The AEM shows a thinner zone than the borehole log of the sandstone/sand dominant ***Kd*** with areas of shale/clay-dominant ***Kd*** above and below. The AEM is providing a model of the hydrogeology, but in this example the ***Kd*** is changing within the approximately 1,000 feet between the AEM data and the test hole.

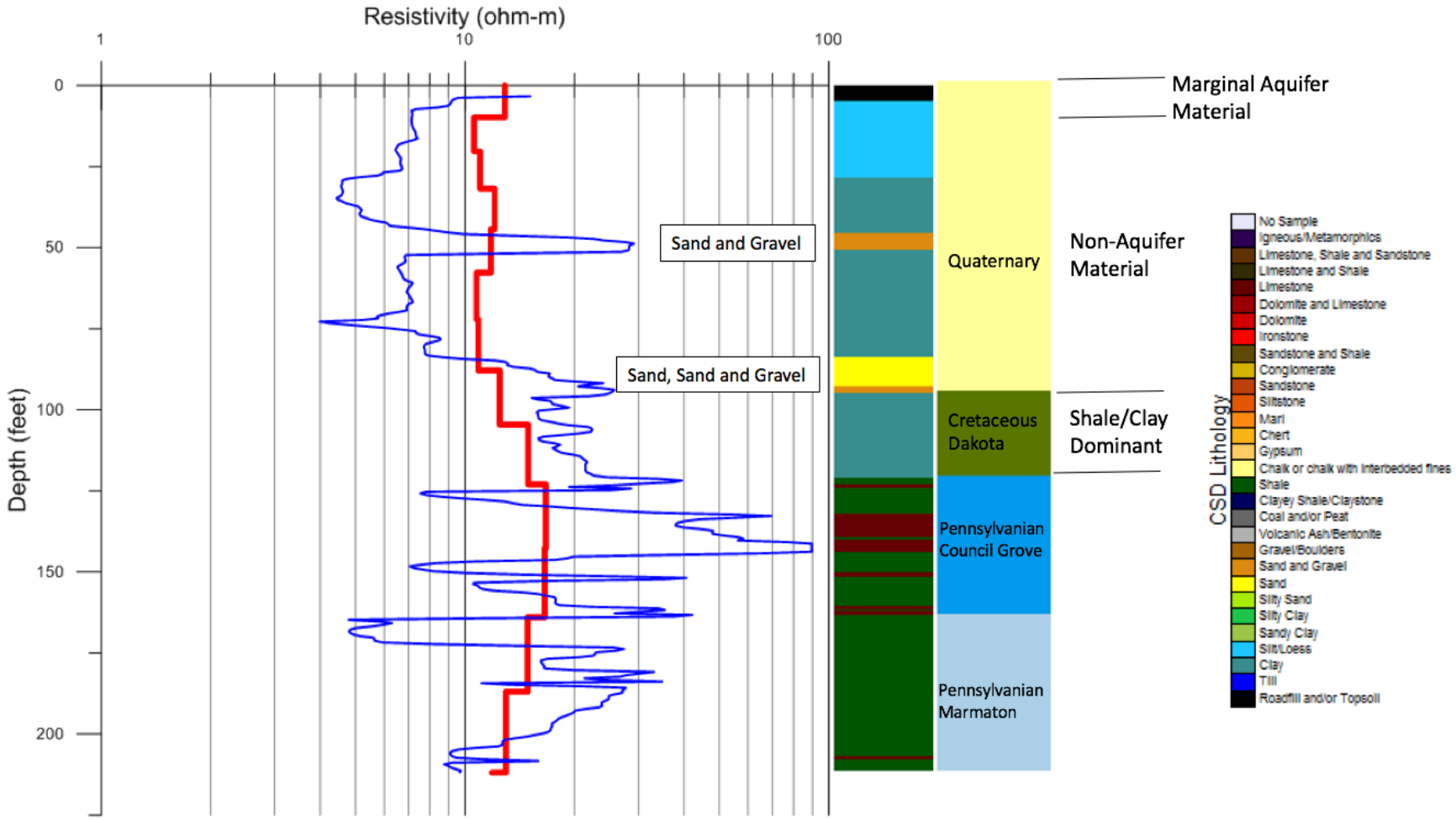


Figure 5-18. Graph of the 16-inch short normal resistivity log values (blue line) for test hole *25-80* and the inverted airborne electromagnetic resistivity values (red line). Also indicated is the lithology and stratigraphy log from *25-80* as well as the Quaternary aquifer material categories and the Cretaceous Dakota aquifer material categories derived from the AEM.

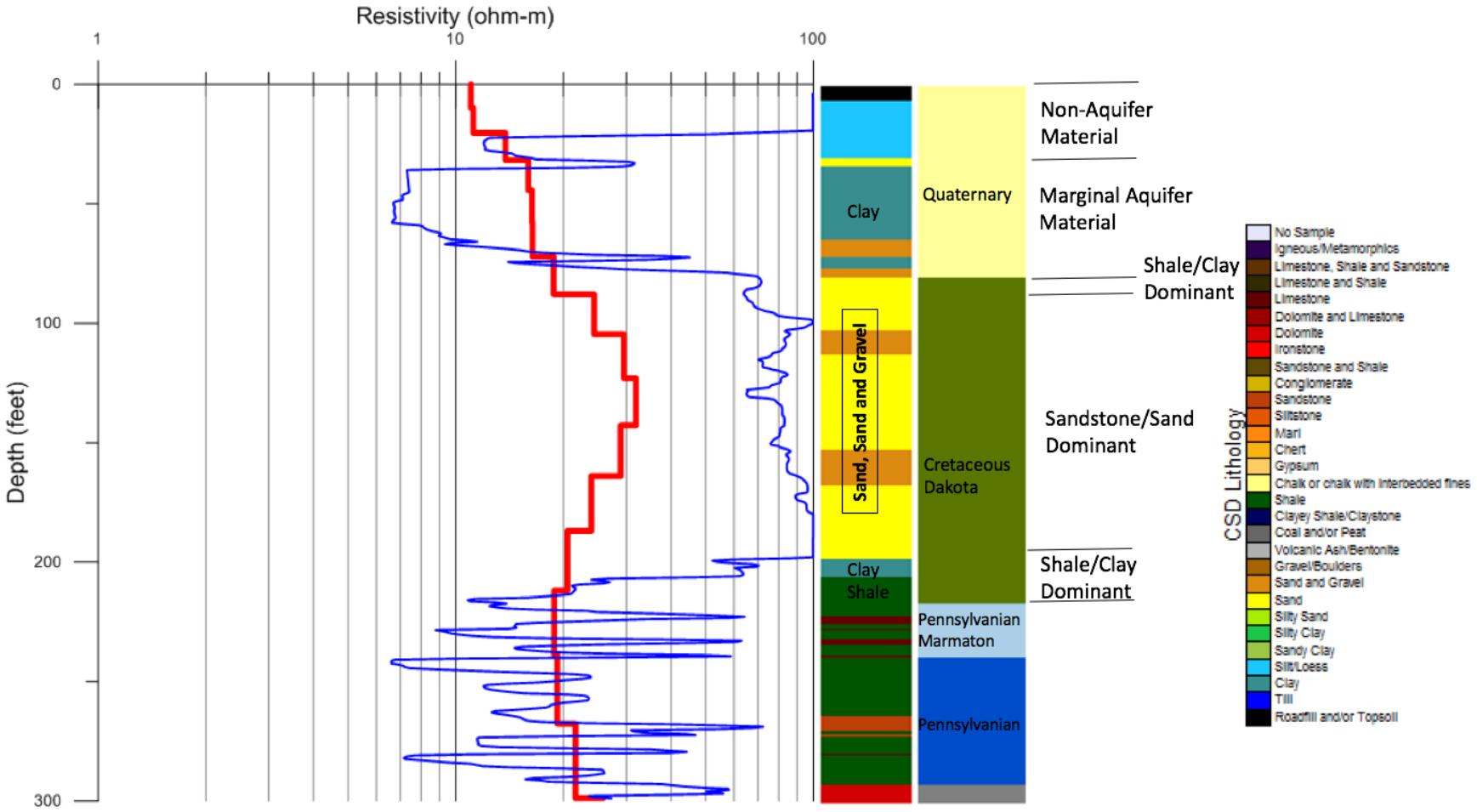


Figure 5-19. Graph of the *16*-inch short normal resistivity log values (blue line) for test hole *26-80* and the inverted airborne electromagnetic resistivity values (red line). Also indicated is the lithology and stratigraphy log from *26-80* as well as the Quaternary aquifer material categories and the Cretaceous Dakota aquifer material categories derived from the AEM.

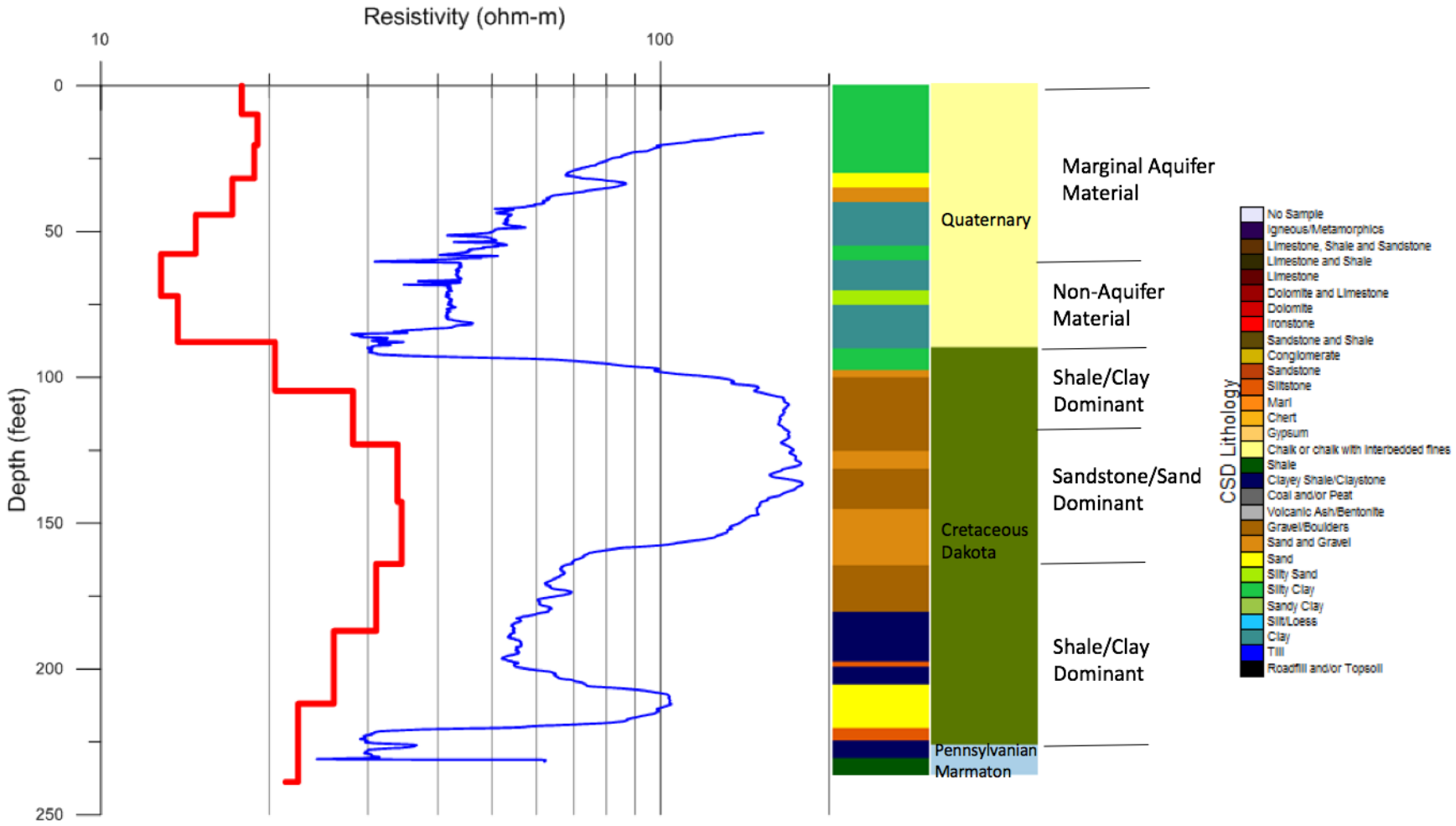


Figure 5-20. Graph of the 16-inch short normal resistivity log values (blue line) for test hole *06-PMR-15* and the inverted airborne electromagnetic resistivity values (red line). Also indicated is the lithology and stratigraphy log from *06-PMR-15* as well as the Quaternary aquifer material categories and the Cretaceous Dakota aquifer material categories derived from the AEM.

5.3 Hydrogeological Framework of the Sarpy County AEM Survey Area

The AEM reveals the variability in the Quaternary and Cretaceous deposits which make up the aquifers across the Sarpy County AEM survey area. "***Q***" and "***Kd***" are terms used in the interpretative section of this report to describe all unconsolidated, semi-consolidated and consolidated materials overlying the ***IP***, thus including aquifer and non-aquifer material alike. The 3D fence diagram displayed in Figure 5-21 presents interpreted profiles showing the overall distribution of ***Q***, ***Kd*** and ***IP*** materials (interpreted as described in Section 5.2) across the Sarpy County AEM survey area. The subsurface distribution of materials can generally be characterized into three somewhat overlapping, but distinct, areas with smaller localized depositional features distributed at various locations within the survey area. These areas include the Quaternary alluvium, Quaternary glacial, and the ***Kd*** bedrock area. Figure 5-22 presents a combined 3D fence diagram of the ***Q*** and ***IP*** and a 3D voxel model of the ***Kd*** interpreted in the Sarpy County AEM survey area. Figure 5-23 show the Thickness of the ***Q*** materials across the project area. The thickness ranges from less than 10 feet to over 200 feet with the thickest sequence of materials in the northern part of the project area east of the Platte River alluvial plain.

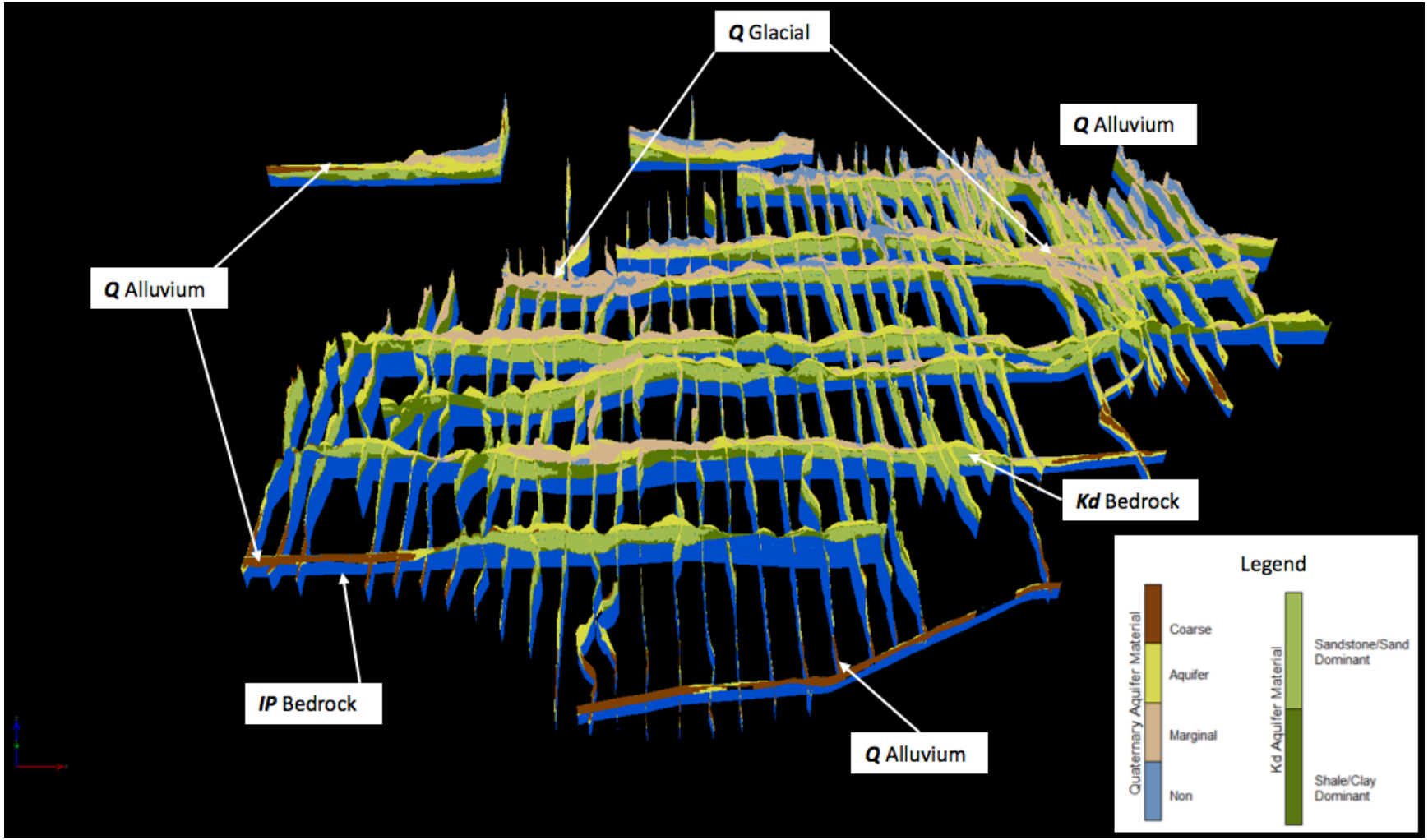


Figure 5-21. 3D fence diagram (showing 50 % of the flight lines) looking to the north of the interpreted distributions of aquifer material within the Sarpy County AEM survey area. Geological units include Quaternary deposits (*Q*) and Cretaceous Dakota (*Kd*) described in the legend at the bottom right and the dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 10x.

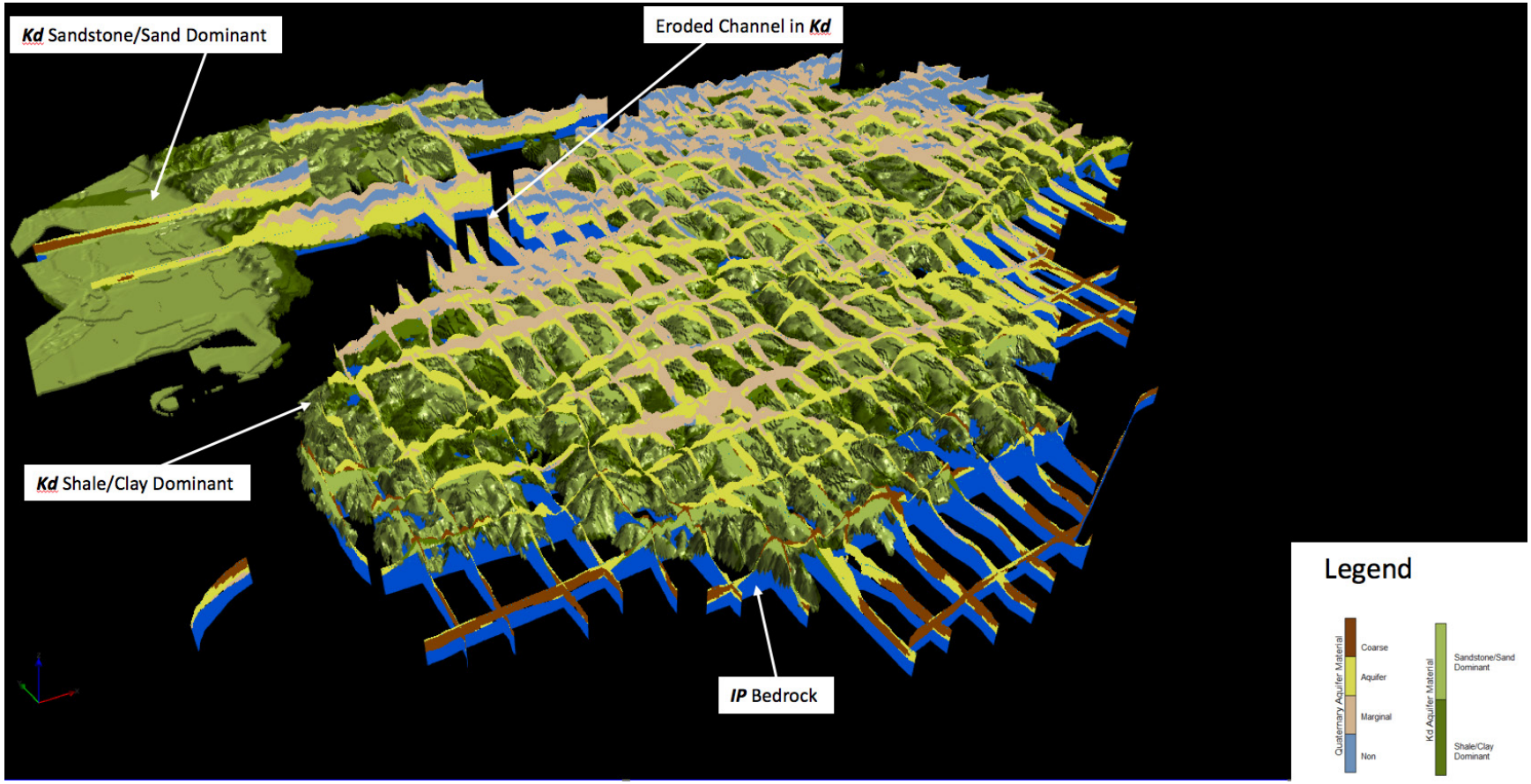


Figure 5-22. 3D fence diagram (showing 50 % of the flight lines) and voxel of the *Kd* looking to the north of the interpreted distributions of aquifer material within the Sarpy County AEM survey area. Geological units include Quaternary deposits (*Q*) and Cretaceous Dakota (*Kd*) described in the legend at the bottom right and the dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 5x.

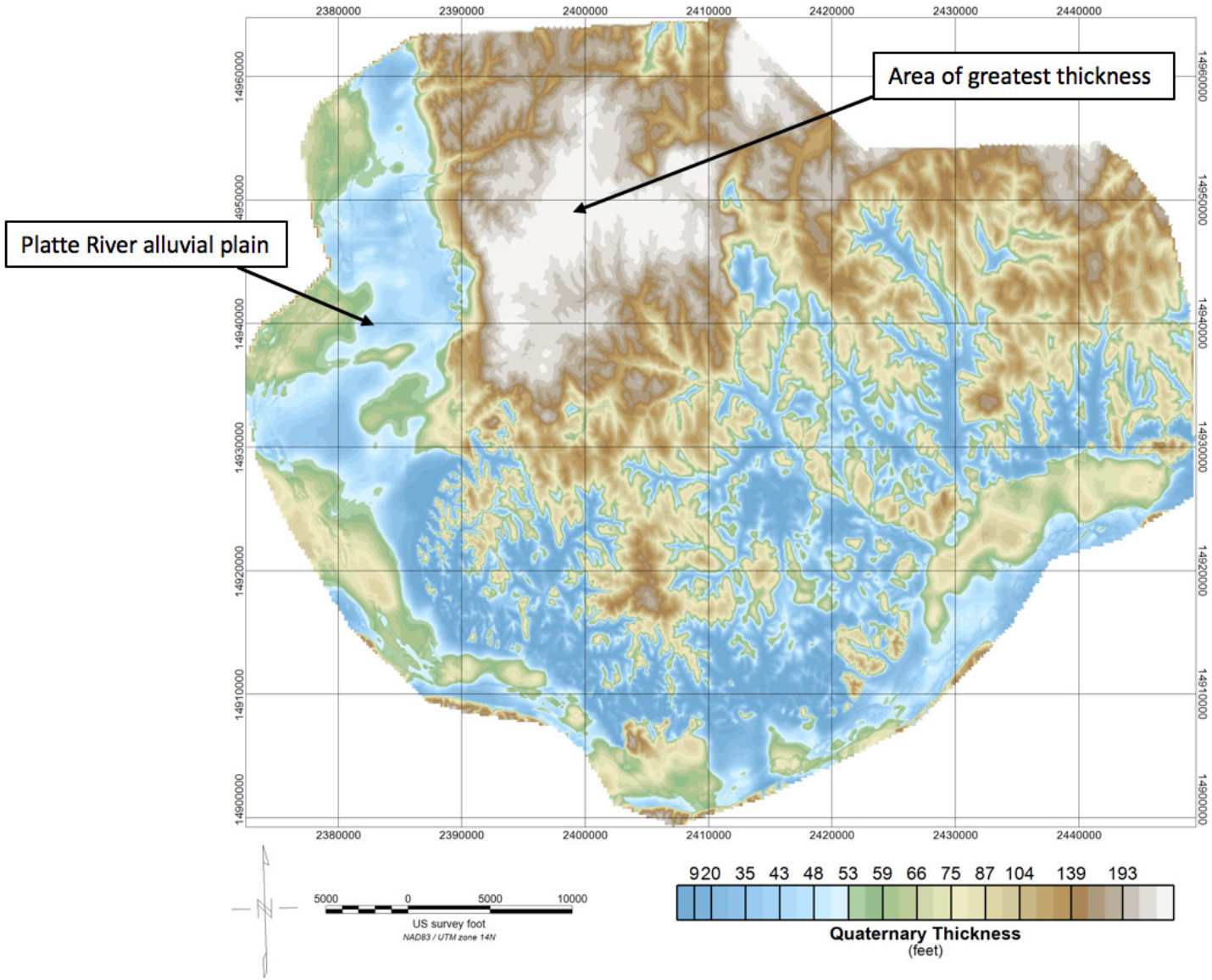


Figure 5-23. Thickness of the Quaternary materials across the Sarpy County AEM survey area. Thickest sequence of materials is in the northern part of the project area west of the Platte River alluvial plain. Map projection is NAD83, UTM14N, feet.

5.3.1 The Quaternary Alluvium and Glacial Aquifer Areas

The ***Q*** alluvium aquifer area of the Sarpy County AEM survey area is predominantly composed of unconsolidated aquifer and coarse aquifer materials composed of alluvial sediments (yellow and brown color zones in the interpretive figures, respectively). The alluvial sediments also contain marginal aquifer (tan color) and non-aquifer (blue color) materials but they are isolated and limited in geographic area. Most alluvial materials in the Platte River plain are saturated from the near surface down. The alluvium aquifer overlies the ***Kd*** and ***IP***. The approximate locations of these areas are given in Figure 5-24.

The ***Q*** alluvium is eroded into the surfaces of the ***Kd*** and ***IP*** and is seen mostly along the Platte River, Buffalo, and Springfield creeks. There can be strong groundwater-surface water communication between ***Q*** and ***Kd***. The ***Kd*** can act both as an aquifer and an aquiclude, Figure 5-25 shows sandstone/sand dominant aquifer of the ***Kd*** where water from the alluvium can move to the ***Kd*** or change flow depending on the hydraulic gradient at the time. This is also the configuration that was indicated in the Ashland area by Hanson et al. (2012). The coarse aquifer and aquifer materials are most likely to have this connection and interaction. The aquiclude portion of the ***Kd*** (shale/clay dominant) and the ***IP***, act as barriers to groundwater flow similar to non-aquifer and marginal aquifer materials of the alluvium. The map of the elevation of the top of the ***IP*** is considered the base of ***Q*** and ***Kd*** aquifer and can be found in Figure 5-10 in Section 5.1.3. Within the alluvial aquifer system there are areas of non-aquifer and marginal aquifer materials. These areas are typically confined to near surface deposits and basal silts and clays. These layers are localized and can act as an aquiclude and prevent recharge or serve as local confining units. Figure 5-26 is a 3D image of several of these layers of marginal and non-aquifer materials found in the Sarpy County AEM survey area. Figure 5-27 is a profile view of line L158001 showing the north-south flight line near the center of the Sarpy County AEM survey area. Within the profile there is an area that shows coarse aquifer material that is deposited above aquifer material lying on the ***IP*** contact. It also shows marginal to non-aquifer material lying directly on the ***IP*** that limits the hydrologic connection from the uplands to the stream. This trend is interpreted as deposits from alluvial channel systems (Figure 5-26). Figure 5-28 is a profile of flight line L142901 which traces the Platte River channel and illustrates the coarse aquifer material's southernmost portion of the Sarpy County AEM survey area (Figure 5-26) and is an area of strong hydrologic connection between stream and aquifer. Flight line L141301 (Figure 5-29), which is a reconnaissance-type line in the Gretna area, shows a combination of the different deposits described above with all the complexity of the different hydrologic communication. There are ***Q*** coarse aquifer and aquifer materials deposits lying upon ***Kd*** sandstone/sand dominant material on the west side which has a strong hydrologic connection. There are also isolated deposits of ***Kd*** shale/clay dominant material below the ***Kd*** sandstone/sand dominant aquifer which lies upon the ***IP***. In the center of the profile, ***Q*** aquifer material lies under a small areas of marginal aquifer material which shows a location of weak hydrologic connection. On the east side of the profile ***Q*** marginal and non-aquifer materials cover the aquifer materials above the water table reducing the amount of recharge from the surface and creating a semiconfined to confined conditions.

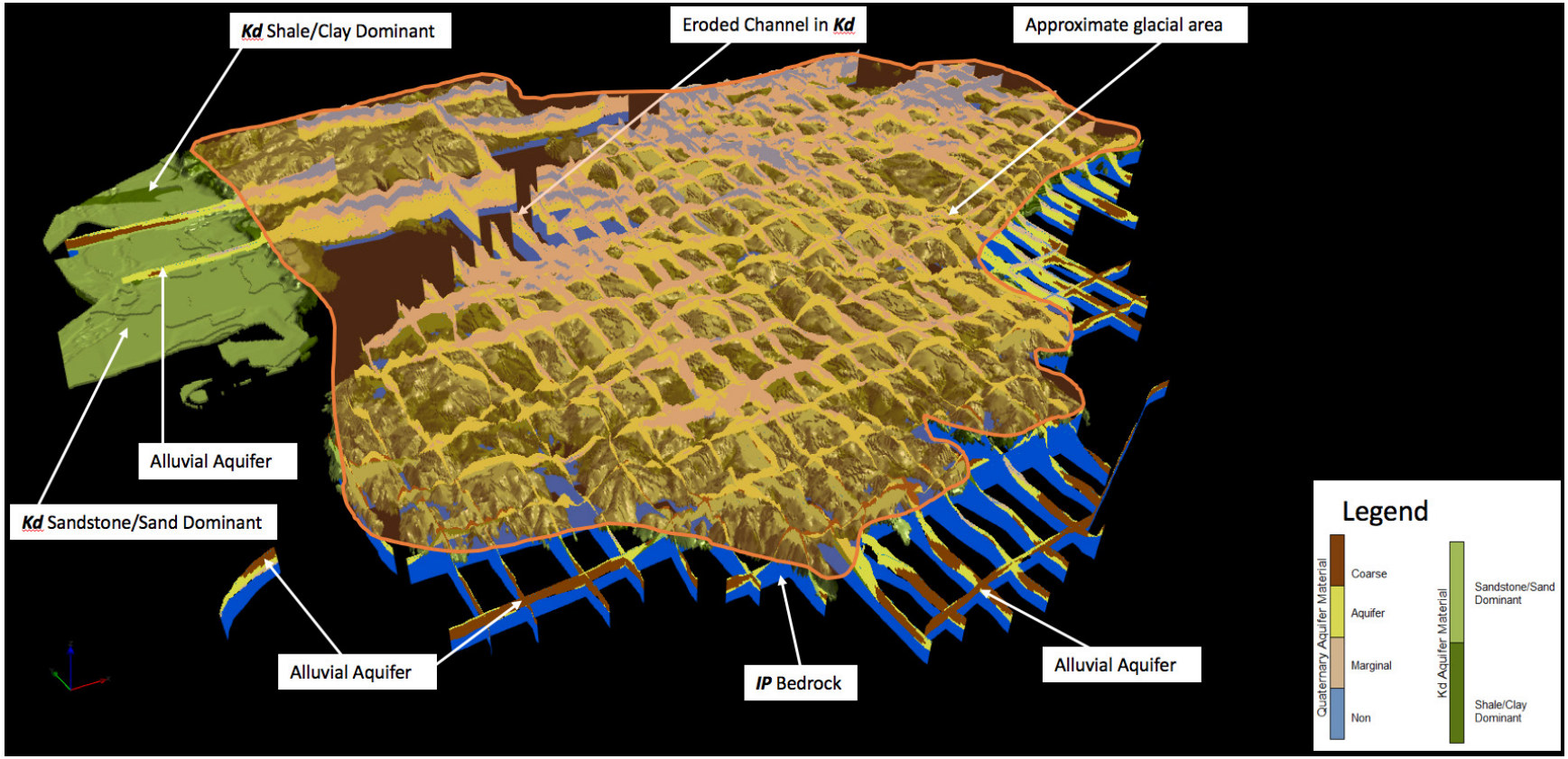


Figure 5-24. 3D fence diagram (showing 50 % of the flight lines) and voxel of the *Kd* map looking to the northeast of the Sarpy County AEM survey area illustrating where combined alluvium and glacial systems overlies the *Kd* and *IP*. Geological units include Quaternary deposits (*Q*) and Cretaceous Dakota (*Kd*) described in the legend at the bottom right and the dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 5x

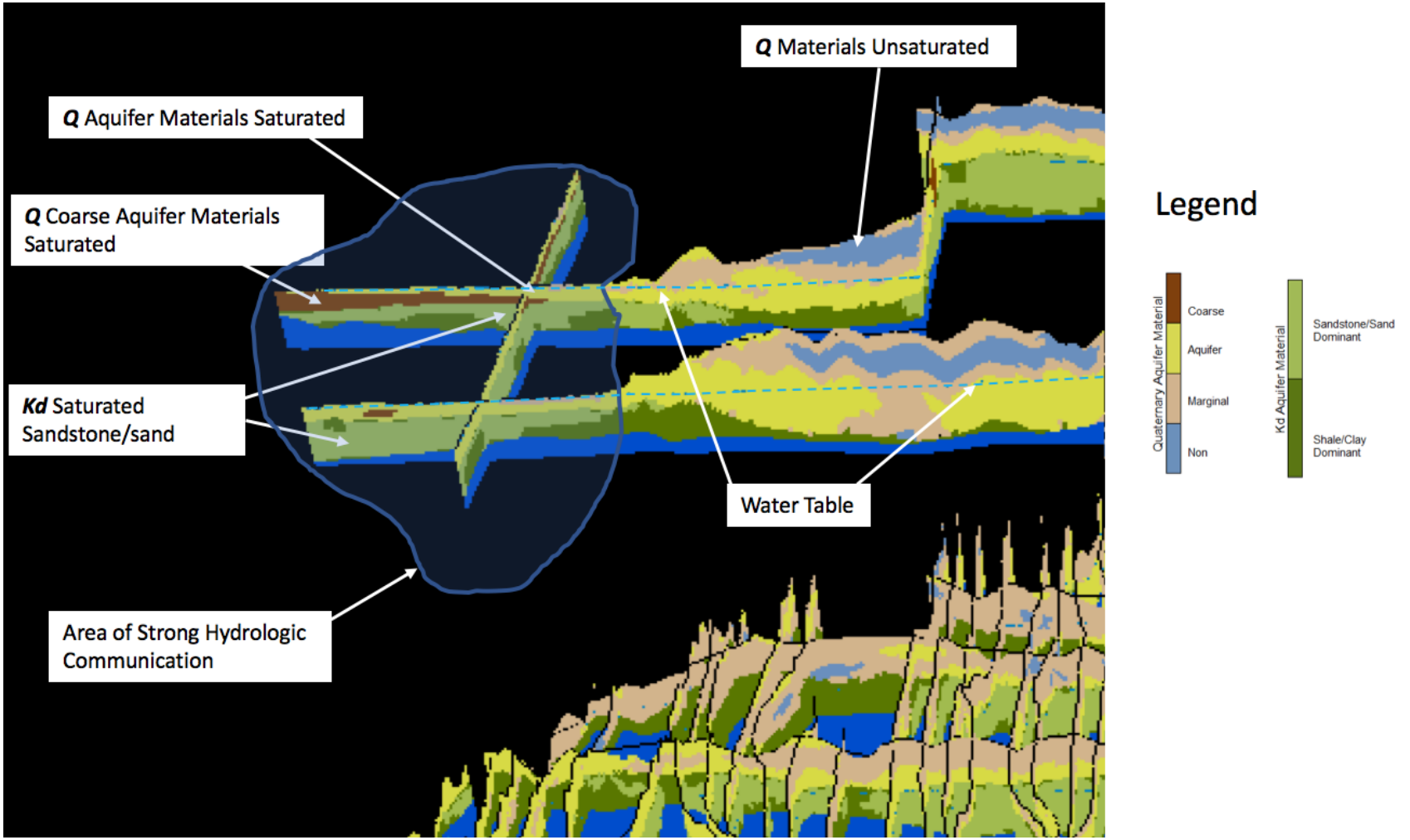


Figure 5-25. Close-up 3D fence diagram map of the northwest corner of project area presenting examples of sandstone/sand dominant units of the *Kd* where they are connected to the coarse aquifer and aquifer parts of the alluvium allowing water to move between lithological units within the Sarpy County AEM survey area. These are areas of strong hydrologic connection between the *Q* and *Kd* where saturated. Areas of shale/clay dominant units of the *Kd* and *Q* non-aquifer and marginal aquifer materials are shown (see legend colors) where water movement is restricted. Geological units include Quaternary deposits (*Q*) and Cretaceous Dakota (*Kd*) described in the legend on the right and the dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 10x

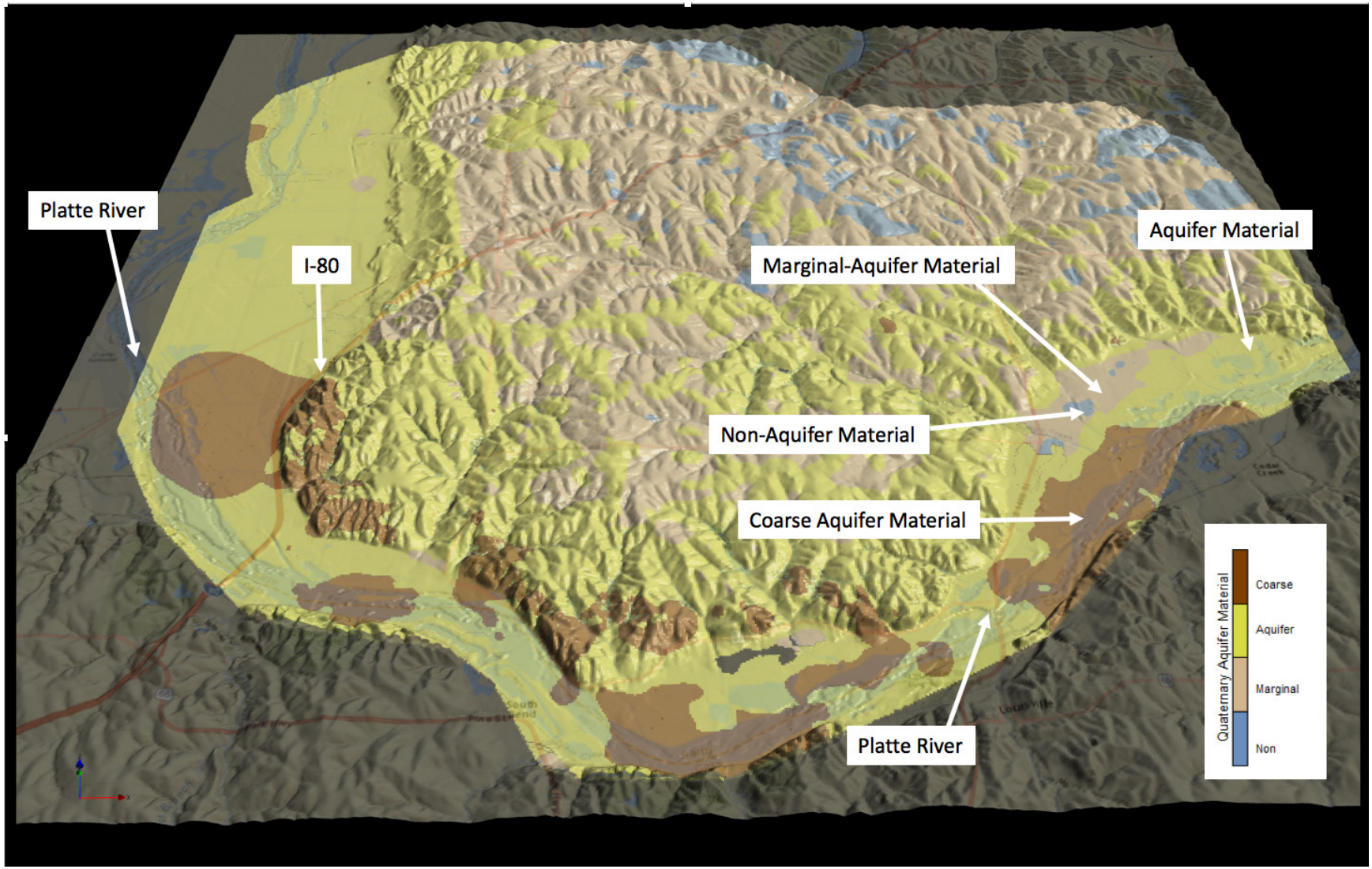


Figure 5-26. 3D voxel image of all the Quaternary materials in the project area. Note the marginal and non-aquifer materials overlying the aquifer and coarse aquifer material in the Platte River plain. This is an area of limited extent but does affect hydrologic connection and recharge in the immediate area.

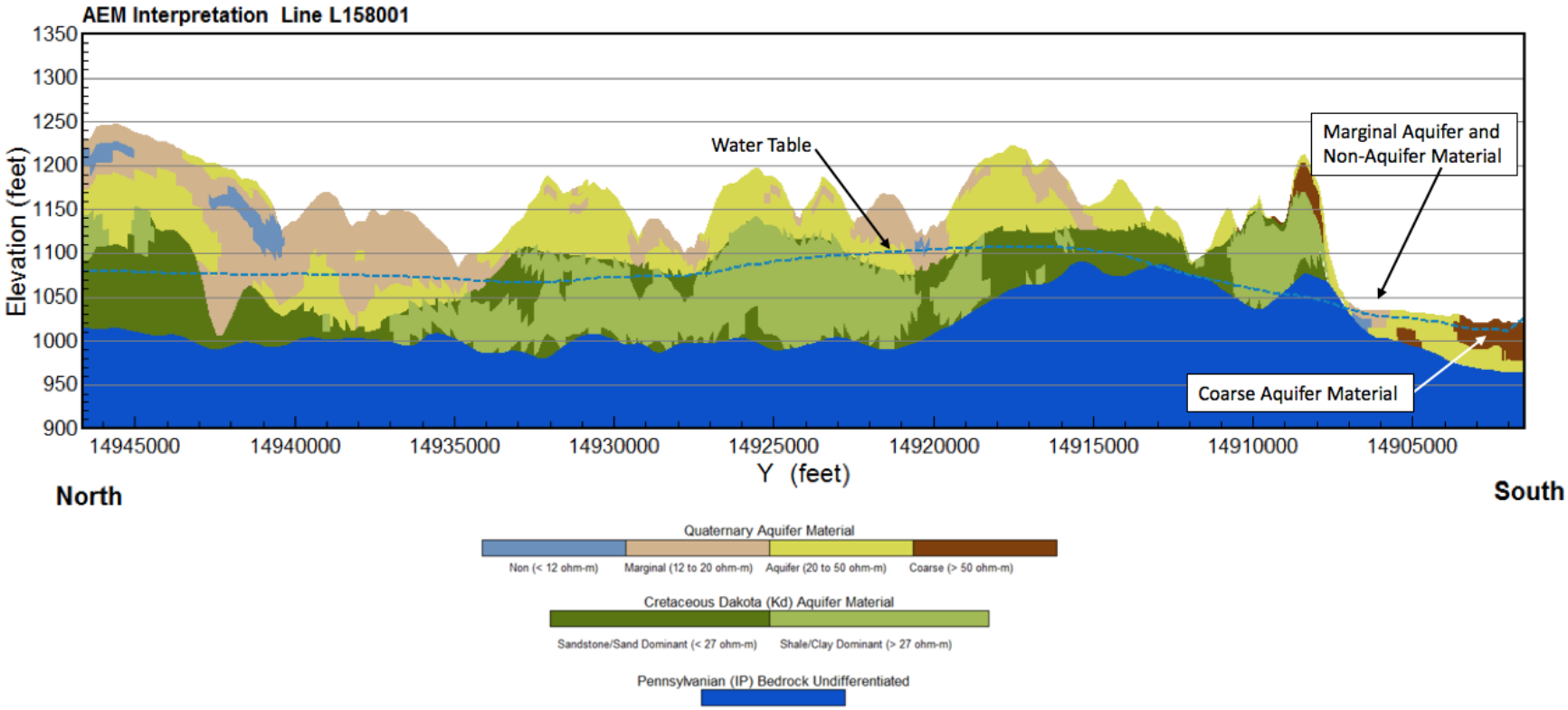


Figure 5-27. Profile L158001 showing the north-south flight line near the center of the Sarpy County AEM survey area which aligns with the 3D image in Figure 5-26.FThis shows coarse aquifer material that is deposited above aquifer material lying on the undifferentiated Pennsylvanian contact. It also shows marginal to non-aquifer material lying directly on the *IP* that limits the hydrologic connection to the stream. Projection is NAD83, UTM14N, feet.

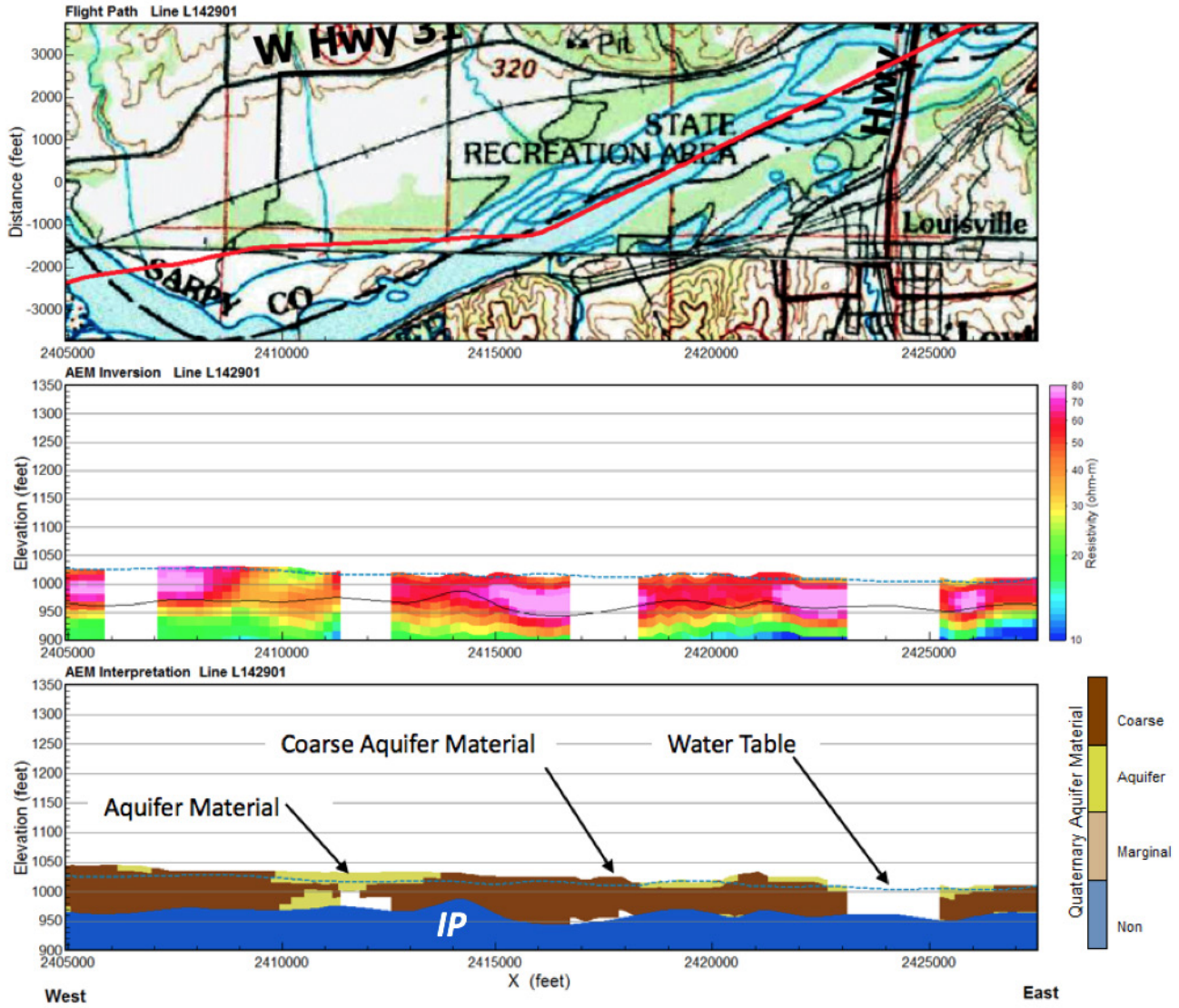


Figure 5-28. A profile view of line L142901 which traces the Platte river channel, illustrating the coarse aquifer material's southernmost portion of the Sarpy County AEM survey area. Within the aquifer system there is an area that shows *Q* coarse aquifer and aquifer materials that are deposited on the *IP* contact. Projection is NAD83, UTM14N, feet.

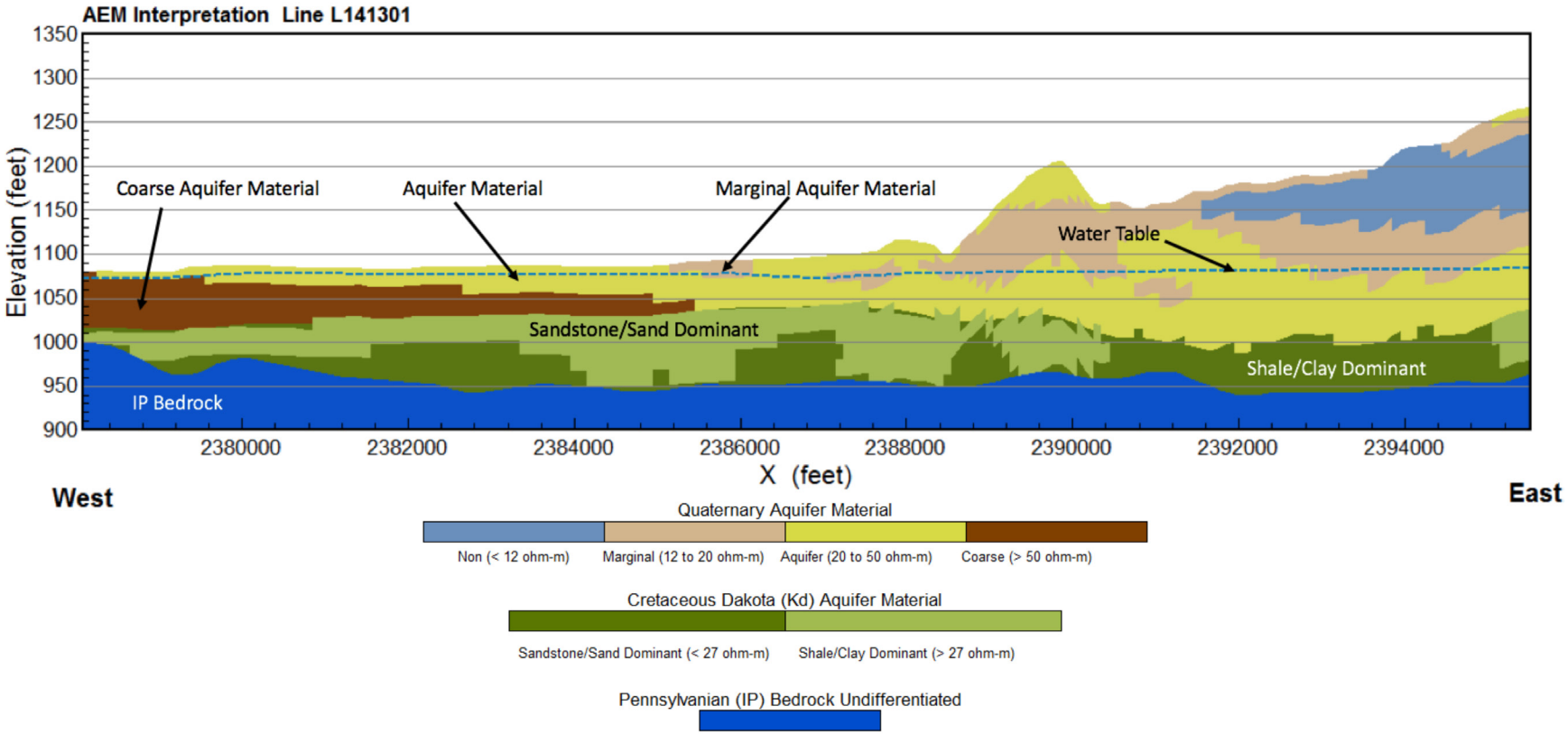


Figure 5-29. Profile L141301 is a reconnaissance-type flight line in the Gretna area, shows a combination of the different deposits described above with all the complexity of the different hydrologic communication between aquifers and stream and internally between aquifers. Projection is NAD83, UTM14N, feet.

The connection can be traced from east to west without interruption by any material change. Detailed examination of the profiles can show where the hydrologic connection between streams and groundwater aquifers is strong, weak or nonexistent.

A disadvantage of the reconnaissance lines is that they have only identified deposits along the AEM flight line and the complete extent of these deposits cannot be determined expediently without further AEM acquisition or exhaustive interpretation from added boreholes or ground EM surveys.

Q glacial deposits cover much of the Sarpy County AEM survey area and thicken to the north-northeast and thin to the south-southwest (Figure 5-30). These materials are a combination of tills and outwash deposits. They lie unconformably upon the ***Kd*** and ***IP***. There is a separation or erosional channel between the north block of ***Kd*** and the south block of the ***Kd*** within the study area and is filled with the thickest sequence of ***Q*** materials. These materials are interpreted to be glacial in origin (McGuire et al., 2012). Within the glacial sequence there are probable multiple advances of moraines as well as multiple occurrences of tunnel valleys or outwash deposits (Carney et al., 2015a). Hydrogeologically, the key to the area is the presence of separated zones of aquifer materials and how those zones are connected to surface water and subsequently compartmentalized by zones of marginal or non-aquifer materials. These zones of marginal aquifer material still can yield water to a water well but are typically composed of interlayered fine sands or thin sand layers and have abundant fine grained material composed of silt, clay, and till. Figure 5-30 is a 3D map view looking to the east displaying the distribution of aquifer materials within the glacial deposits. Within Figure 5-31 there are several zones that indicate that the glacial deposits contain coarse aquifer material zones near the land surface. These areas can be seen in the south-southwest. Glacial coarse aquifer materials exist elsewhere in the glacial deposits. These deposits of coarse aquifer material are finite zones that are separated by extensive zones of aquifer, marginal aquifer, and non-aquifer materials. Figure 5-32 provides a view from the east looking west across the project area showing distribution and thickness of ***Q*** aquifer materials. In particular the northeast is where the thickest sequence of marginal to non-aquifer material can be seen while the rest of the area is mostly aquifer material. Most of the aquifer and coarse aquifer materials that are saturated is very limited and can be seen on Figure 5-33. The saturated aquifer deposits range in thickness from absent to greater than 120 feet with the thickest units lying to the Northwest of the project area. Figure 5-34 is a profile of the east-west line L138701 showing that all deposits above the ***Kd*** are of glacial origin and are mostly unsaturated. The steep erosional channel wall on the west end of the profile would have been difficult to detect by the CSD drilling alone unless they had been lucky enough to site a borehole in the right location.

Appendix 1 contain interpreted profiles that illustrate the details of the ***Q*** and ***Kd*** aquifer areas of the Sarpy County AEM survey. Appendix 2 contains 3D images of the Sarpy County AEM survey area that have been rotated to allow viewing of the overall distribution of materials.

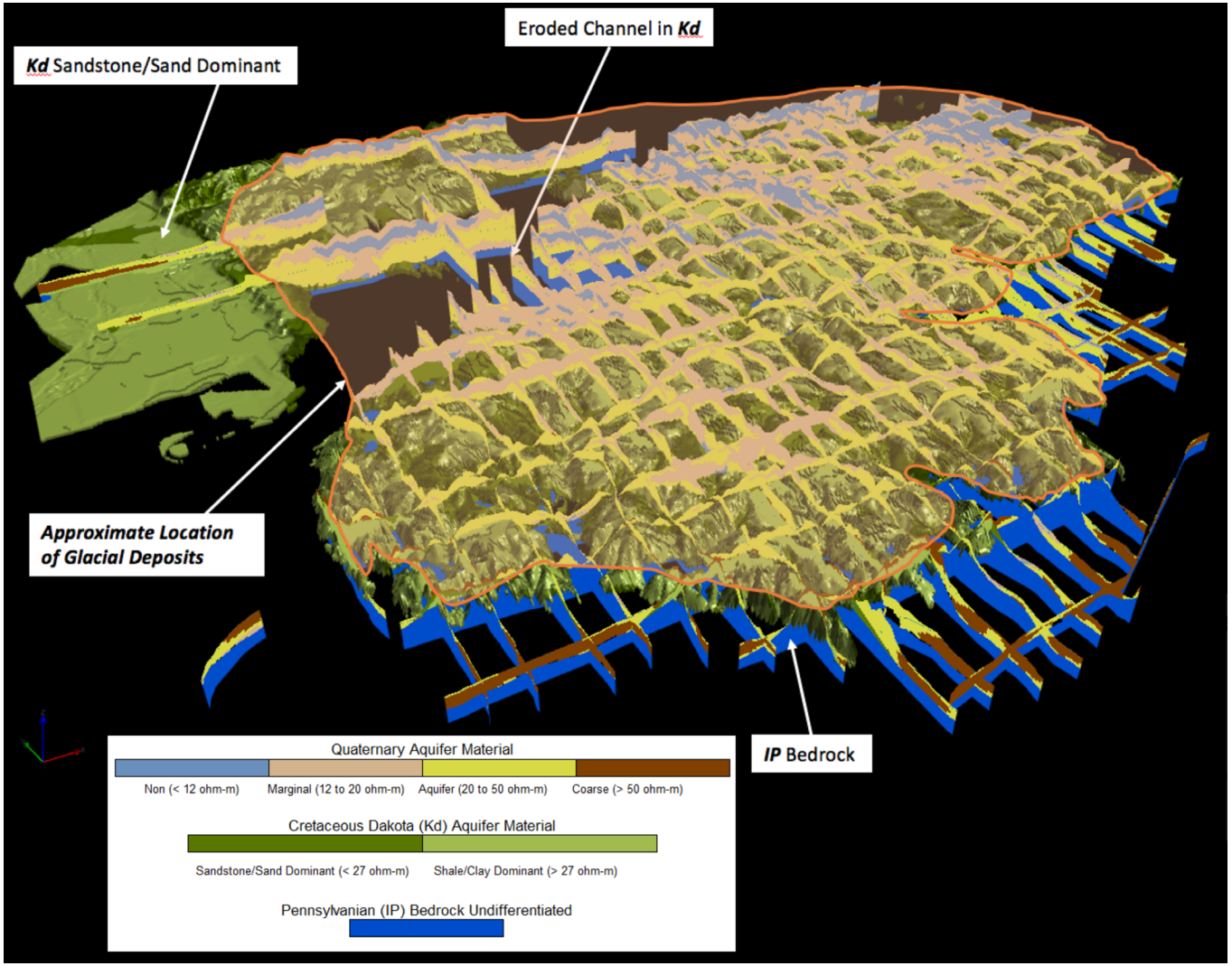


Figure 5-30. Quaternary glacial deposits are shown in the 3D fence diagram (showing 50 % of the flight lines) and voxel of the *Kd* and cover much of the Sarpy County AEM survey area and thicken to the north-northeast and thin to the south-southwest. They lie unconformably upon the *Kd* and the *IP* which is shown as a 3D voxel surface. Geological units include Quaternary deposits (*Q*) and Cretaceous Dakota (*Kd*) described in the legend at the bottom right and the dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 10x

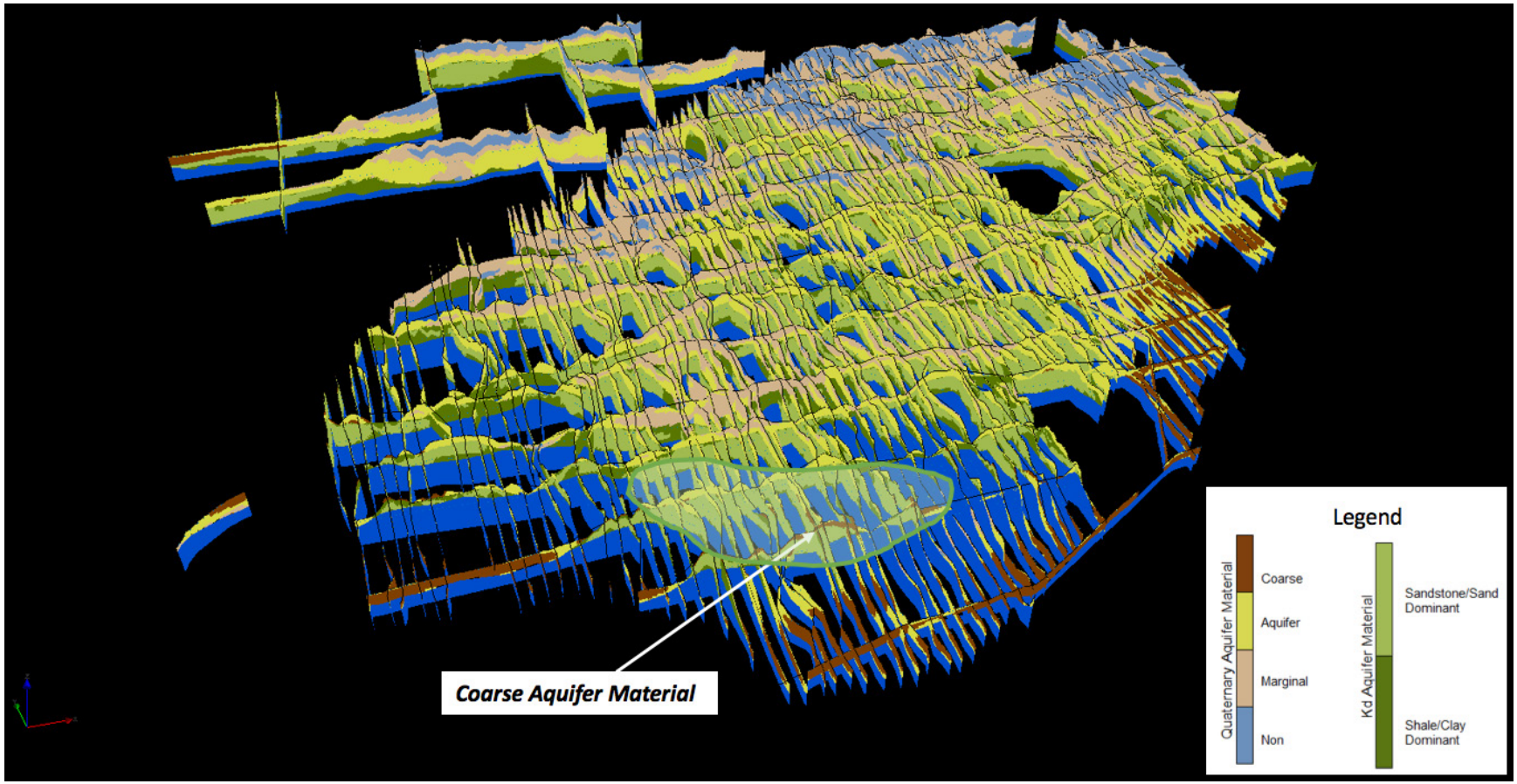


Figure 5-31. 3D fence diagram (showing 50 % of the flight lines) indicates several zones in the Quaternary glacial deposits that contain coarse aquifer material. Although they exist throughout the glacial deposits in small areas, only zones near the land surface are highlighted. These areas can be seen in the south-southwest. The dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 10x.

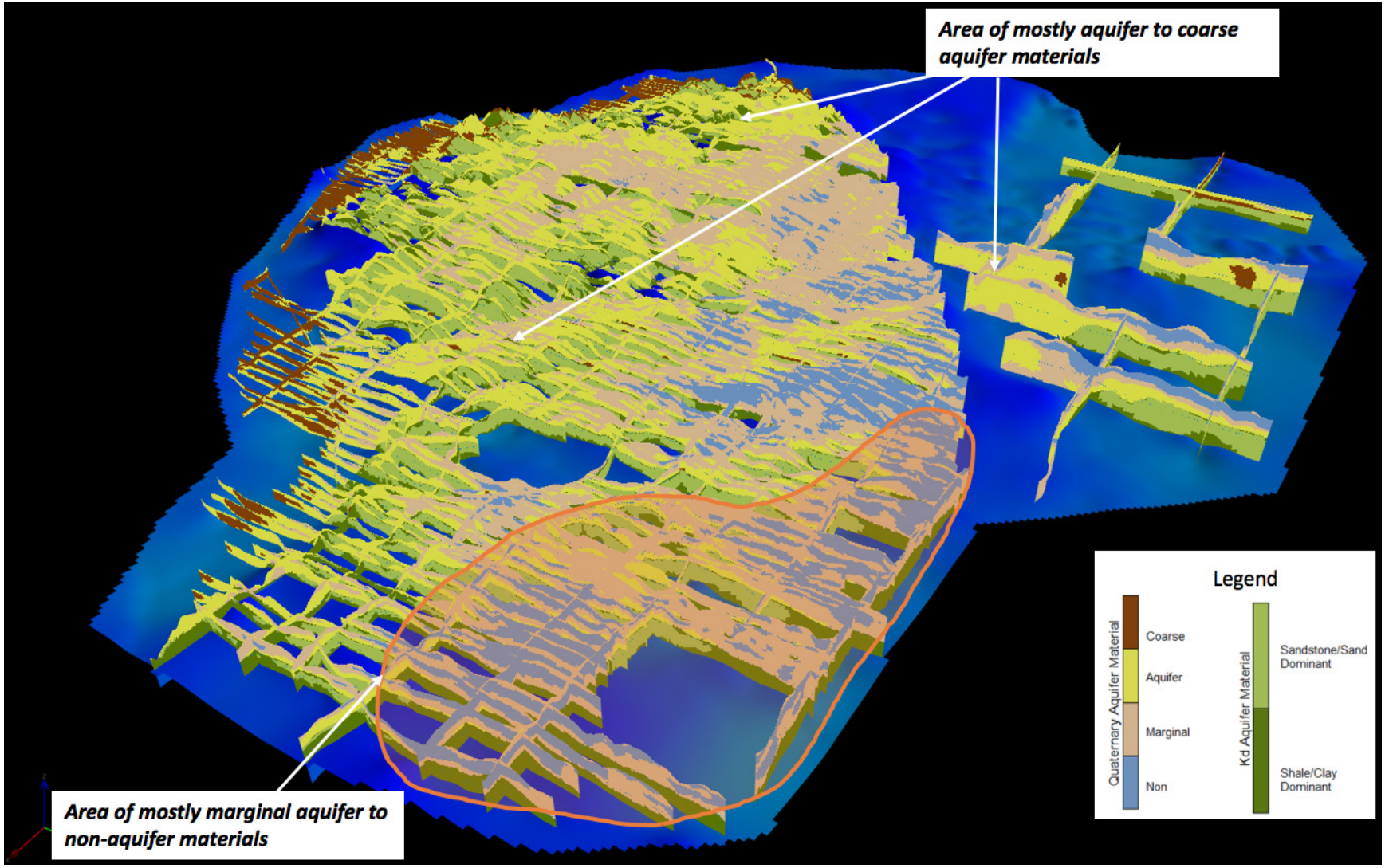


Figure 5-32. View from the east looking west across the project area showing distribution and thickness of Quaternary aquifer materials in a 3D fence diagram. In the northeast is the thickest sequence of marginal to non-aquifer material and the rest of the area is mostly aquifer material. The dark blue base is undifferentiated Pennsylvanian (*IP*). Vertical exaggeration is 5x.

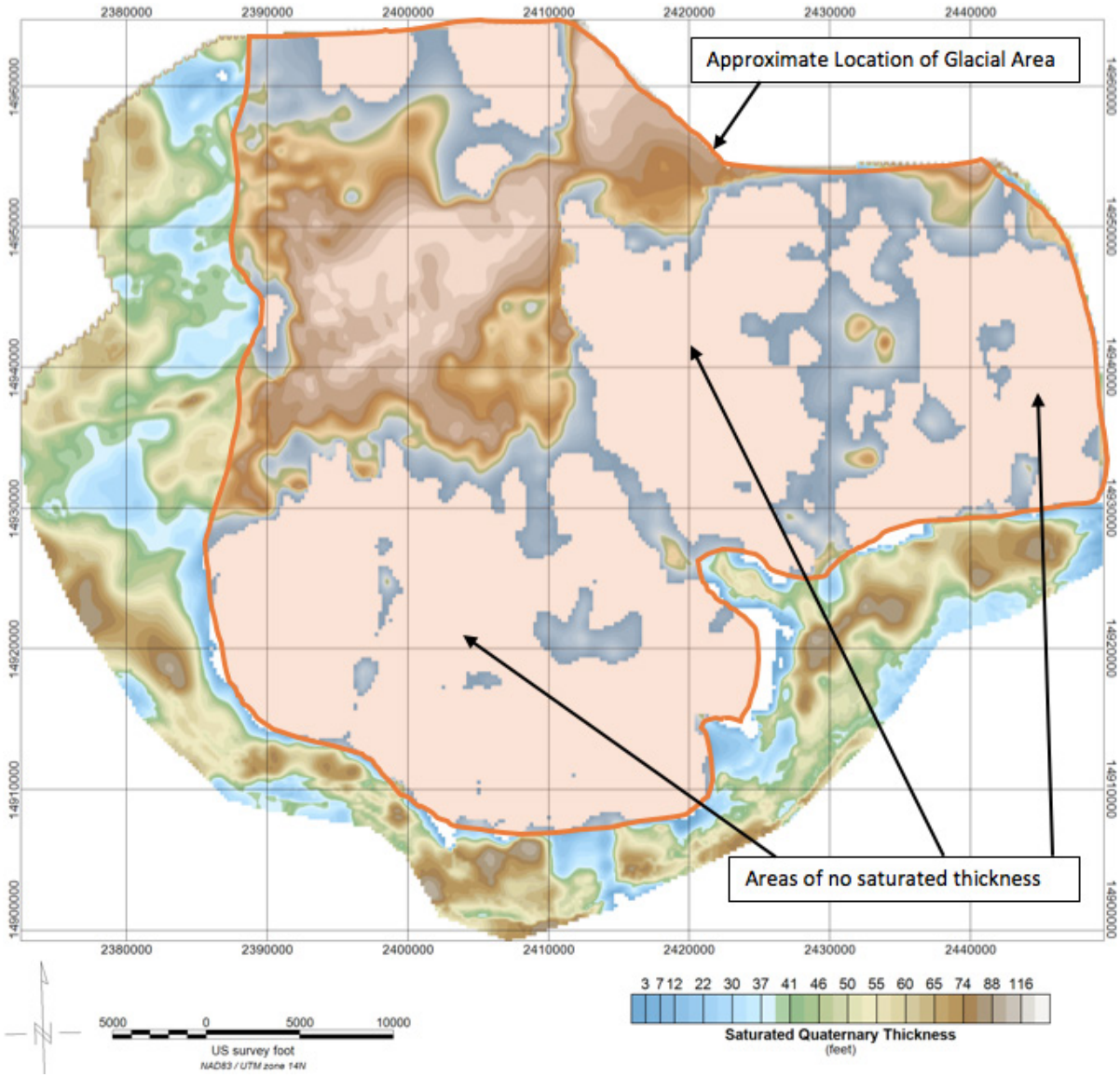


Figure 5-33. Saturated Quaternary aquifer and coarse aquifer materials are limited in extent. They range in thickness from absent to greater than 120 feet and are thickest in the northwest portion of the project area. Map projection is NAD83, UTM14N, feet.

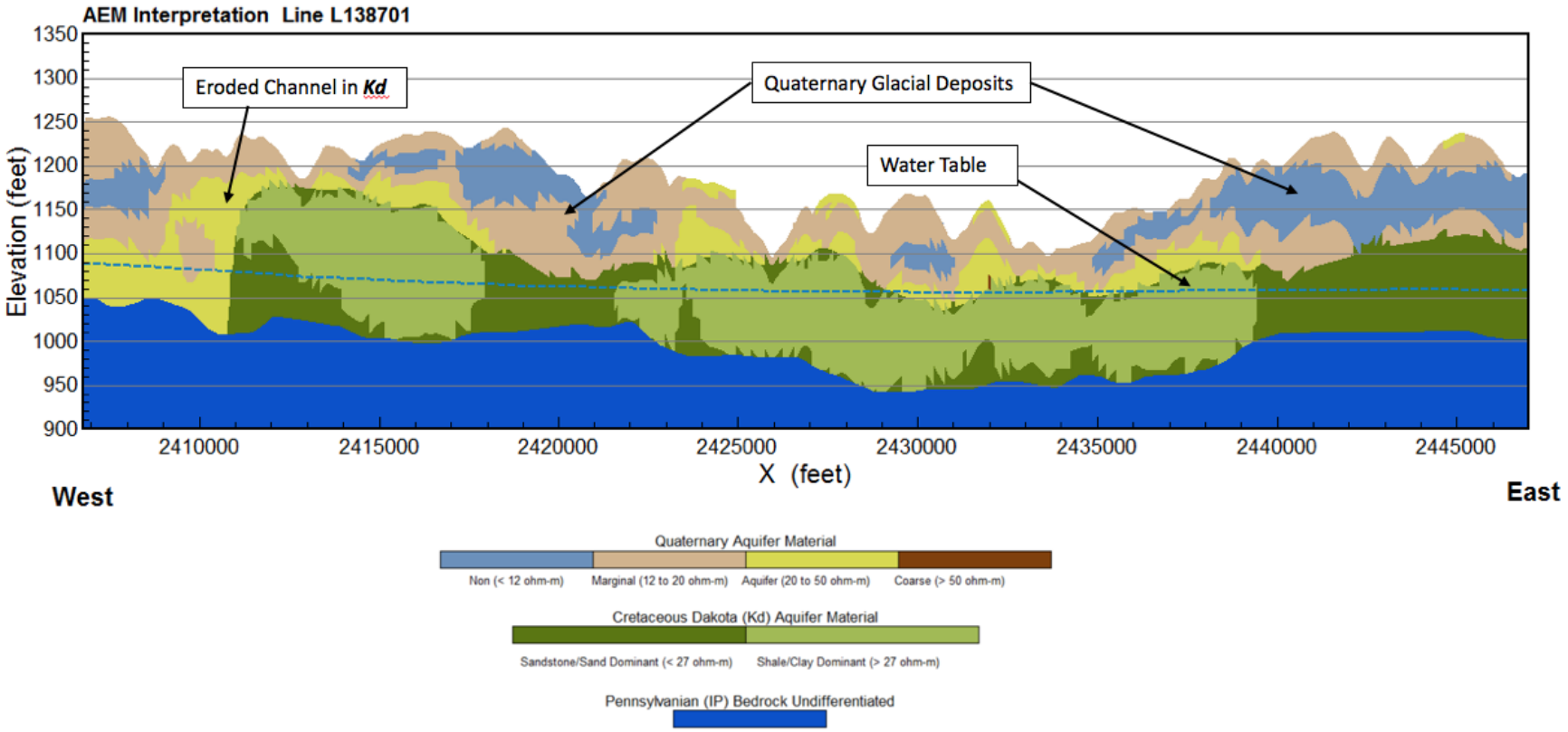


Figure 5-34. Profile L138701 is an east-west line showing that all deposits above the *Kd* are of glacial origin and are mostly unsaturated. The steep erosional channel wall on the west end of the profile would have been difficult to detect by drilling alone. Projection is NAD83, UTM14N, feet.

5.3.2 The Cretaceous Dakota

The ***Kd*** is a bedrock unit located in the central part of Sarpy County AEM survey area and is characterized by a combination of sandstone/sand dominant and shale/clay dominant units. The ***Kd*** is covered by ***Q*** alluvium and glacial deposits although there are some outcrops along the bluffs near the Platter River to the south in the study area. The ***Kd*** varies in thickness from absent to over approximately 150 feet (Figure 5-35). The ***Kd*** is a combination of an erosional surface with remnants of the original surface and lies unconformably on the ***IP***. The patterns that define the shape of present day ***Kd*** are related to erosion over many episodes of glaciation and fluvial processes in addition to recent erosion by the Platte River, Buffalo, and Springfield Creeks. The sandstone/sand dominant portion of the ***Kd*** is the aquifer material and the shale/clay dominant portion is the aquitard. Many areas of ***Kd*** have sufficient saturated thickness to be an effective water supply to wells. Figure 5-36 shows the location and thickness of the saturated sandstone/sand dominant portion of the ***Kd.*** Selection of drilling sites based on the greatest ***Kd*** thickness improves the chances of a successful water supply. Thickness does not take into account the effect of cementation of the pore space of the sandstone/sand unit, which would lead to lower yield and transmissivity. Figure 5-37 shows the combination of the saturated ***Q*** saturated aquifer and coarse aquifer materials overlying the ***Kd*** sandstone/sand aquifer. Where the ***Q*** and ***Kd*** are in contact is an area of good hydrologic connection. Figure 5-38 shows the effect of the water table on saturated thickness and the extent of hydrologically connected aquifers highlighting the complexity of the ***Kd*** sandstone/sand dominant areas in relation to the shale/clay dominant areas. This figure also highlights the hydrologic connection between the sandstone/sand dominant aquifer of the ***Kd*** and the ***Q*** aquifer materials above.

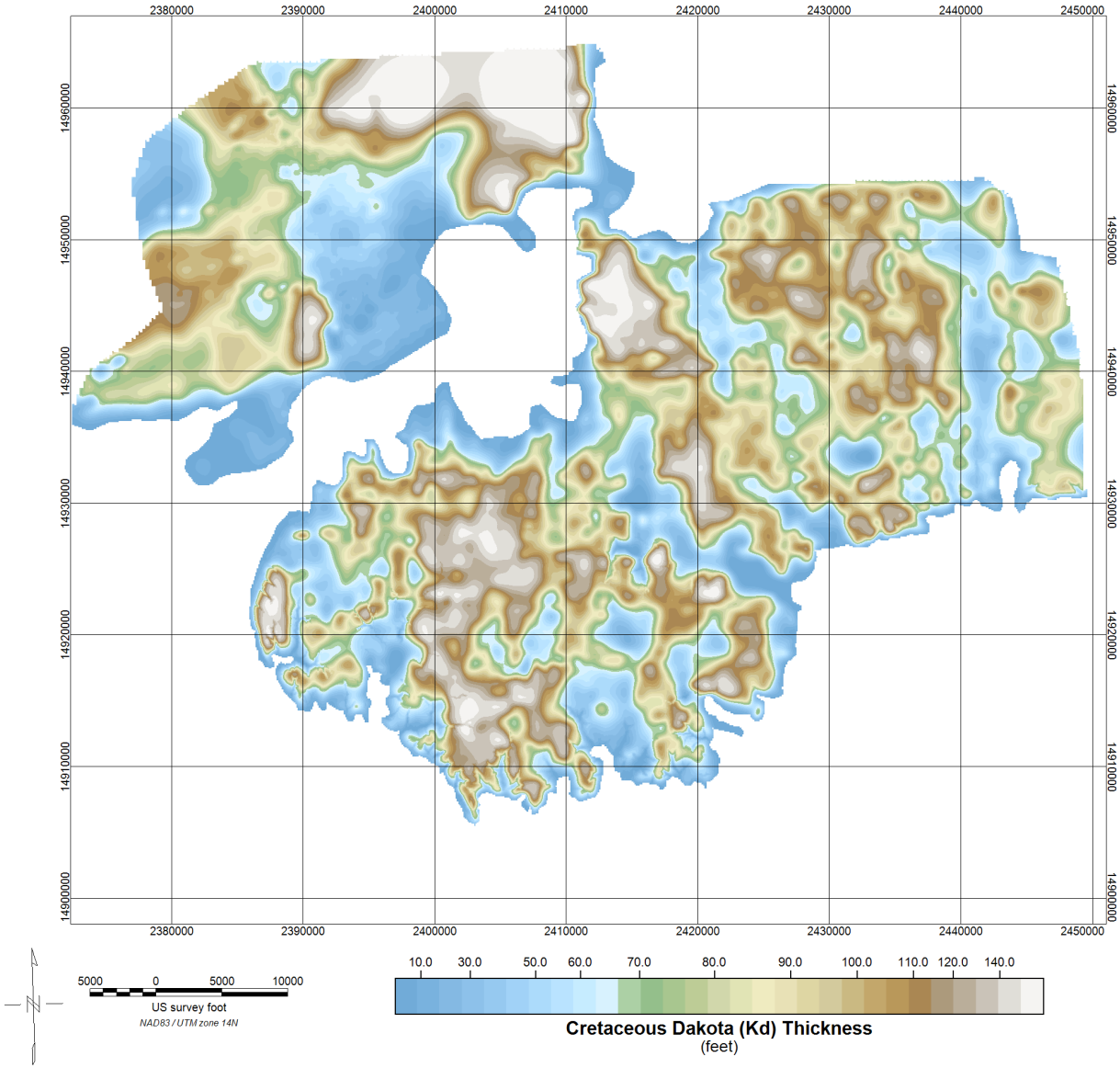


Figure 5-35. The Cretaceous Dakota (*Kd*) varies in thickness from absent to over approximately 150 feet. Note the erosional channel trending east-west between the two large blocks of *Kd*. Projection is NAD83, UTM14N, feet.

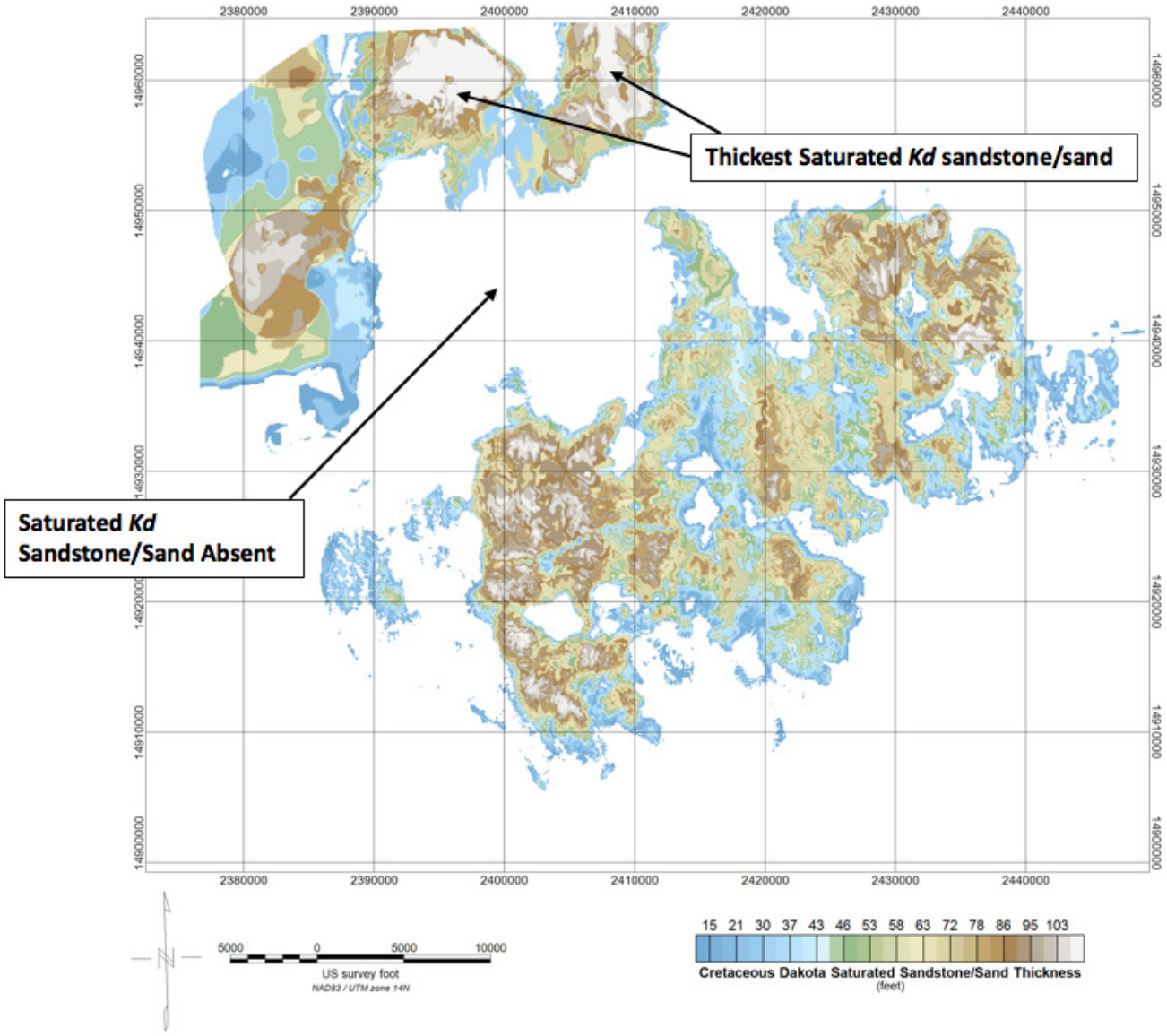


Figure 5-36. Location and thickness of the saturated sandstone/sand dominant portion of the Cretaceous Dakota. Careful examination of this map and the profiles will help guide the siting of potential new wells. Projection is NAD83, UTM14N, feet.

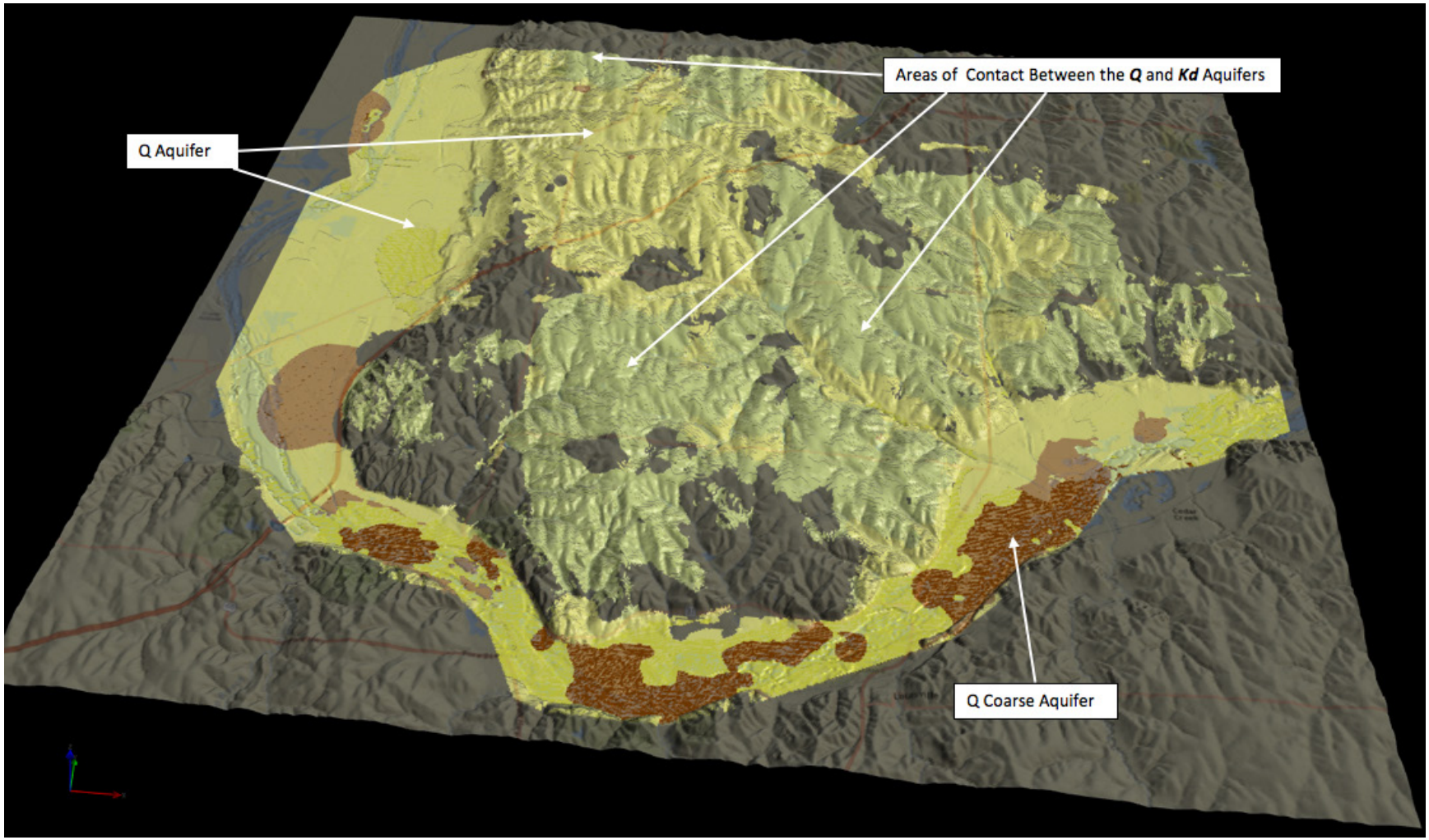


Figure 5-37. Map shows the combination of the saturated Quaternary (*Q*) saturated aquifer and coarse aquifer materials overlying the Cretaceous Dakota (*Kd*) sandstone/sand aquifer. Where the *Q* and *Kd* are in contact is an area of good hydrologic connection.

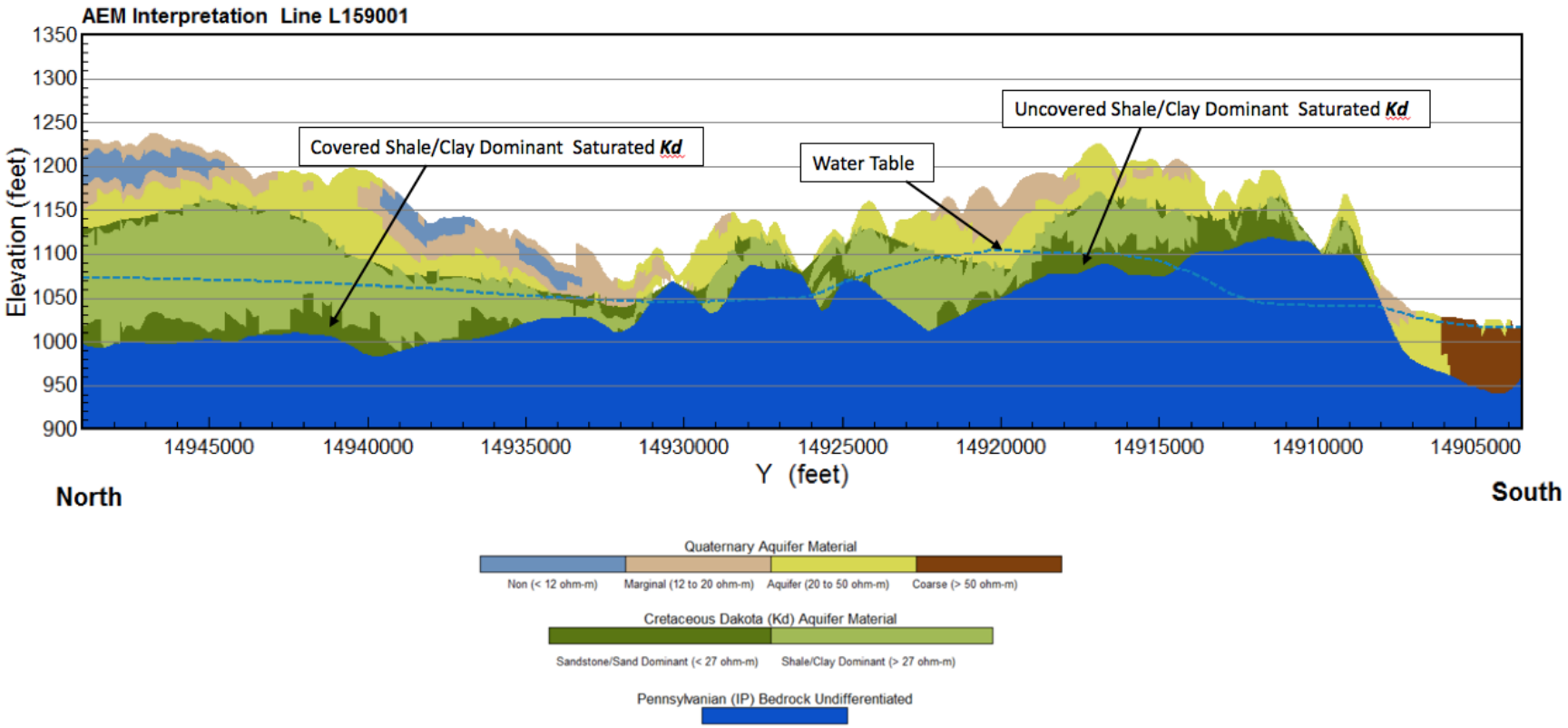


Figure 5-38. Profile L159001 shows the complex nature of this area. The effect of the water table on saturated thickness. The complexity of the *Kd* sandstone/sand dominant in relation to the shale/clay dominant faction of the *Kd,* highlights the hydrologic connection between the sandstone/sand dominant aquifer of the *Kd* and the *Q* aquifer materials. Projection is NAD83, UTM14N, feet.

5.3.3 The IP Bedrock Area

The undifferentiated Pennsylvanian (***IP***) age bedrock surface is considered the base of aquifer for ***Q*** and the ***Kd***. The heavily eroded upper surface of the ***IP*** is shown in Figure 39. There is approximately 120 feet of relief in the erosional surface with the highest elevation to the southwest and the lowest elevations to the north and east portions of the Sarpy County AEM survey area. The ***IP*** subcrops along the ridge which follows the trace of the Platte River. Some of the local quarries have exposures of ***IP***. There are channels cut into the ***IP*** surface the most notable is the wide east-west trending feature in the northwest corner and is probably of glacial origin. There are two other prominent channels, one trends north-south on the east side and is most likely of glacial origin and the other follows the trend of the Platte River along the south edge of the Sarpy County AEM survey area and is most likely the result of fluvial erosion. Some of the channels have nearly flat bottoms which terminate in abrupt channel walls at their boundaries. Two examples of this are the north side wall and the south-west side wall. The resistive nature of the limestone of the ***IP*** has influenced the location of the Platte River and the channel on the north side of the Sarpy County AEM survey area.

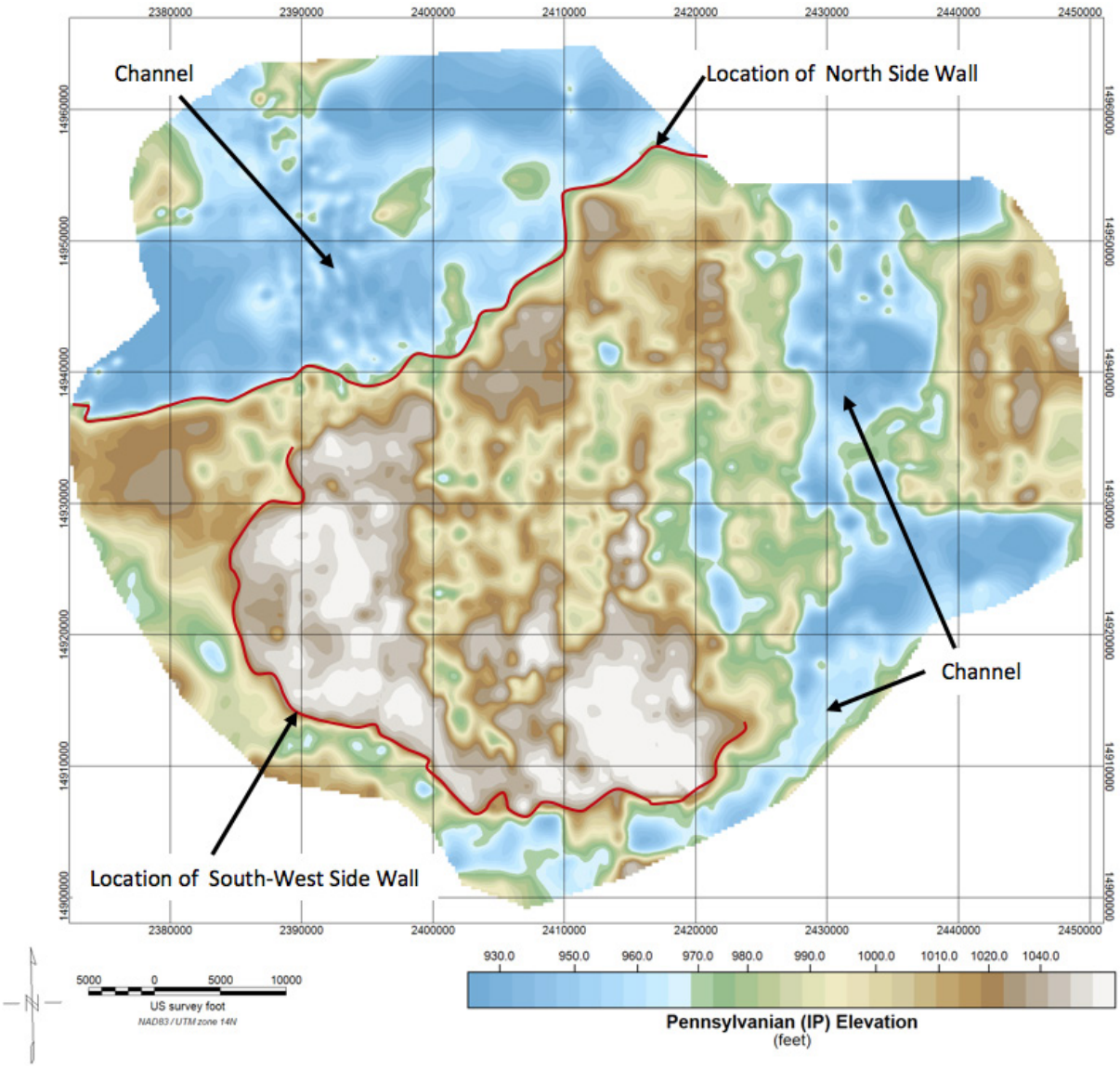


Figure 5-39. Elevation map of the undifferentiated Pennsylvanian bedrock surface which is considered the base of aquifer. Prominent channels in the surface are marked on the map and they are a result of fluvial and glacial erosion on the *IP* surface. Projection is NAD83, UTM14N, feet.

5.4 Estimation of Aquifer Volume and Water in Storage for the Sarpy County AEM Survey Area

A 3D representation of the subsurface derived from the AEM imaging provides users the ability to more accurately identify the total unsaturated and saturated aquifer volumes for the ***Q*** and the ***Kd***. The saturated zones of the ***Q*** and ***Kd*** materials can be analyzed to estimate the amount of groundwater in storage and the amount of extractable water present. Approximately 129 square miles (approximately 82,748 acres) of AEM data were collected and interpreted (Figure 1-2).

The criteria for determining the basis for the range of resistivity values used in calculating the volumes of interpreted aquifer material are provided in Section 5.2.1. The resistivity ranges for interpreted ***Q*** non-aquifer (<12 ohm-m), marginal aquifer (12-20 ohm-m), aquifer (20-50 ohm-m), and coarse aquifer materials (>50 ohm-m) are presented in Figure 5-13. The resistivity threshold between ***Kd*** sandstone/sand dominant and shale/clay dominant units, discussed in Section 5.2.2, has been determined to be 27 ohm-m.

Figure 5-40 shows a 3D fence diagram from the water table down to the top of the undifferentiated Pennsylvania of saturated Quaternary aquifer materials (including non-aquifer, marginal aquifer, aquifer, and coarse aquifer materials) through the Cretaceous Dakota sandstone/sand dominant and shale/clay dominant material. This illustrates the complex nature and interconnections between the saturated Quaternary and Cretaceous Dakota materials of the area. Figure 5-41 shows only saturated Quaternary aquifer and coarse aquifer materials and ***Kd*** sandstone/sand dominant materials as a voxel. This map shows these aquifers to be limited in extent, both vertically and horizontally. Understanding this complexity in the area and within the sedimentary deposits shows that estimated average values for porosity and specific yield are the best values to use in making volume and groundwater storage calculations. Note that the images in figures were created in pbEncom Discover PA, version 2015, Release Build 15.0.13 (pbEncom, 2016). They can be examined in greater detail by opening the PA sessions provided in Appendix 3\PA_Sessions.

All aquifer materials within the ***Q*** sediments, including non-aquifer material, marginal aquifer material, aquifer material, and coarse aquifer material are used for calculating the groundwater in storage volume and the extractable water volumes for the survey area. Reported values of the average porosity for sand making up the aquifer material and sand and gravel making up coarse aquifer material are based on values from Freeze and Cherry (1979). Clay ranges from 40%-70%, silt ranges from 35%-50%, sand ranges from 25%-50%, and gravel is from 25%-40%. Conservative estimates for the porosity values used in these calculations within the survey area are 40% for non-aquifer material, 35% for marginal aquifer material, 20% for the aquifer material, and 25% for the coarse aquifer material.

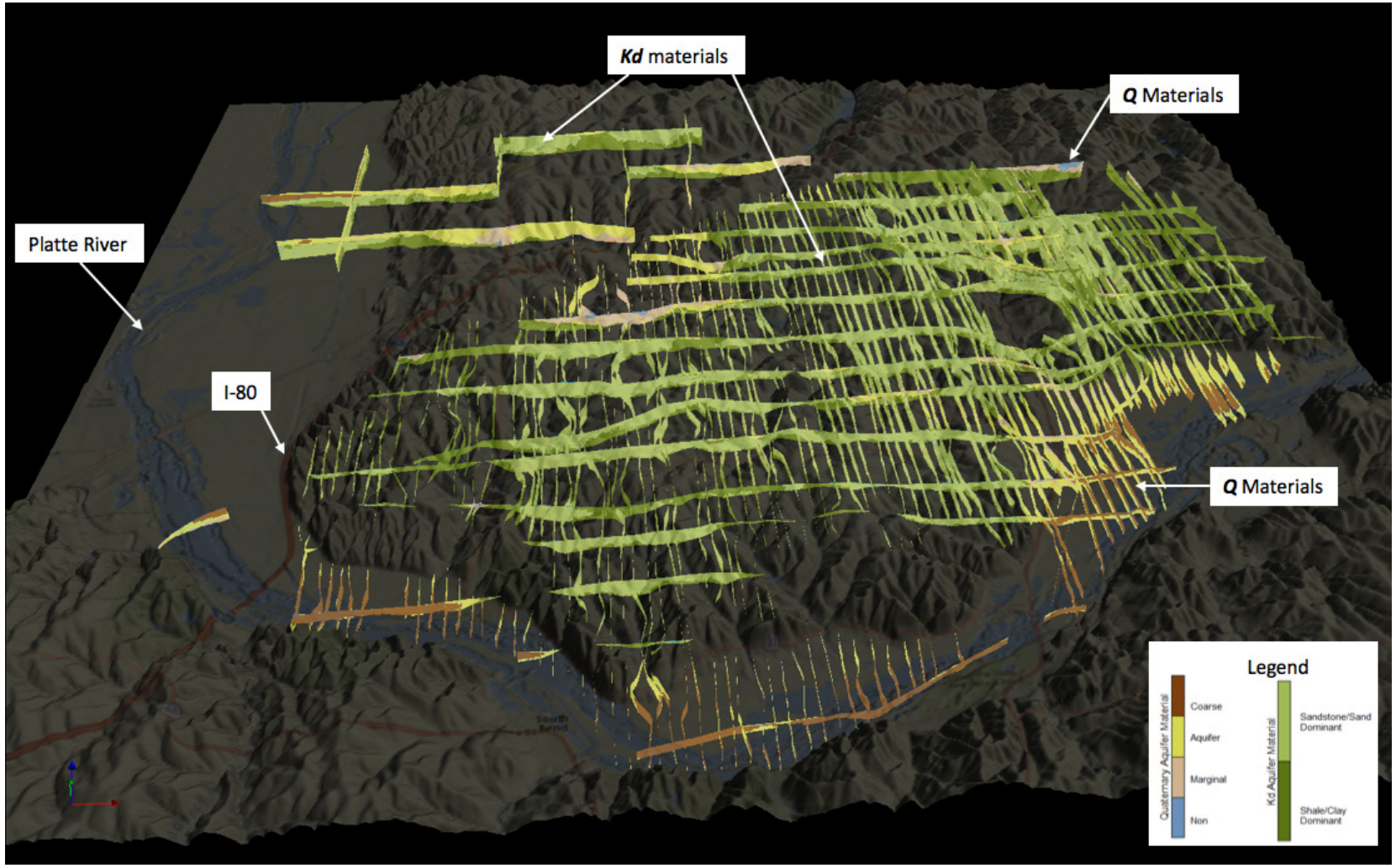


Figure 40. 3D fence diagram looking to the north of all flight lines, cutting out everything above the water table and above the Pennsylvanian surface, showing the complex relationship between the Cretaceous Dakota sandstone/sand dominant saturated materials and all of the overlying saturated Quaternary aquifer materials (coarse aquifer, aquifer , marginal aquifer, and non- aquifer). Vertical exaggeration is 10x.

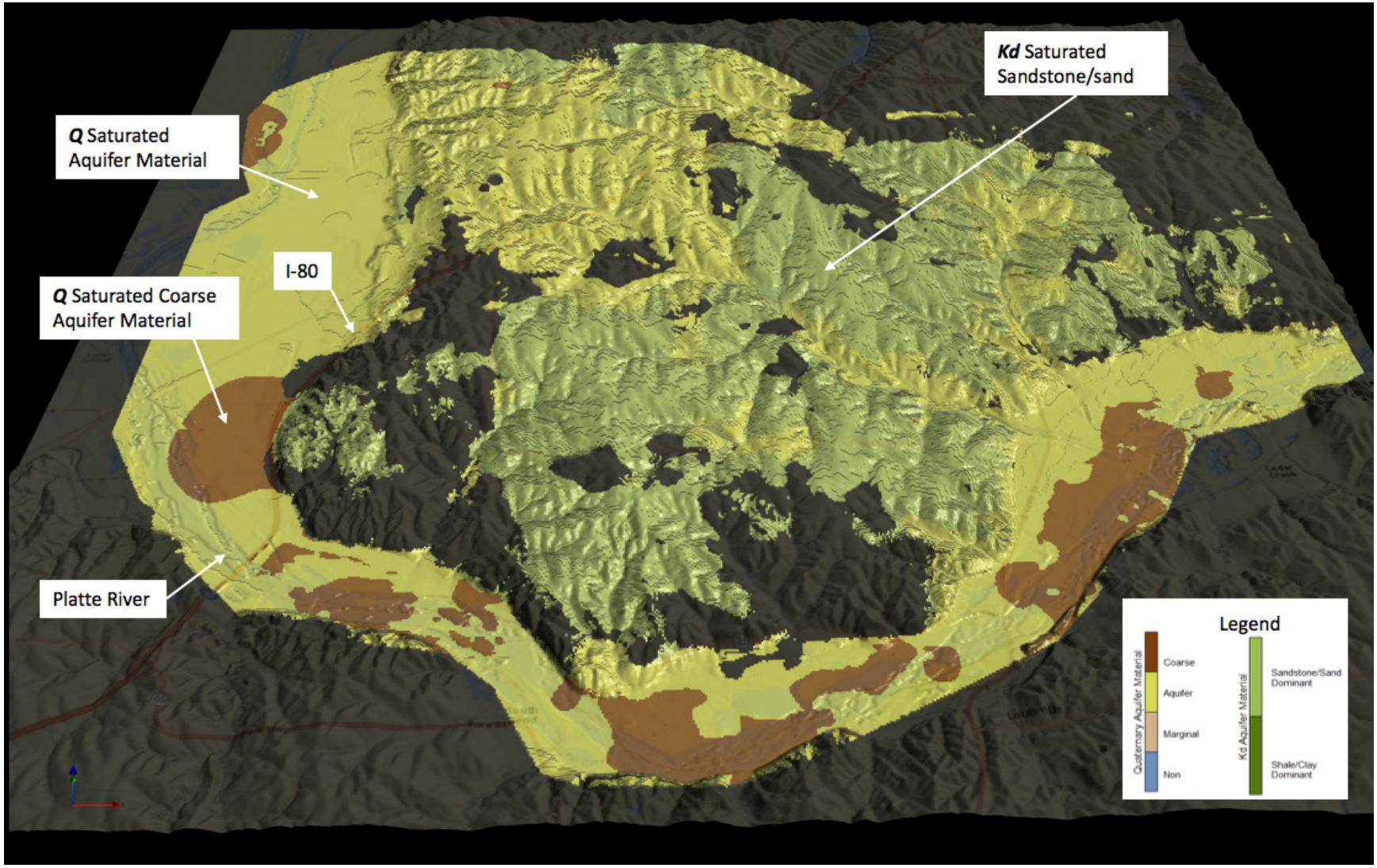


Figure 5-41. Presenting a subset of the data in Figure 5-40, this is a north-looking voxel showing only the saturated Cretaceous Dakota sandstone/sand dominant materials and only the overlying saturated Quaternary aquifer materials (aquifer and coarse aquifer). This image shows these aquifers to be limited in extent both vertically and horizontally, and their relationship to each other. Vertical exaggeration is 5x.

No aquifer test information was available for this investigation from the survey area. Specific yield values for all ***Q*** aquifer materials were selected by estimating values (Figure 2-8) from Olafsen-Lackey et al. (2005b) and Summerside et al. (2005b). Specific yield for non-aquifer materials was chosen at 0.02 (Heath, 1983) and for marginal aquifer materials a value of 0.05 was selected (Heath, 1983). The specific yield for the aquifer material ranges from 0.05 to 0.2 with an average of 0.10. While coarse aquifer materials exist as localized deposits in the survey area, estimates of specific yield for the coarse aquifer material ranges from 0.13 to 0.17 with an average of 0.15 (Olafsen-Lackey et al., 2005b; Summerside et al., 2005b). Figure 2-8 provides a map from CSD that has identified areas having none to very thin amounts of aquifer materials present. When compared to Figure 5-42, the complexity of the ***Q*** saturated aquifer thickness is apparent - there are much less saturated ***Q*** materials. Specific yield maps the area would be improved if new maps were produced using this new information plus the addition of aquifer tests or other methods of gaining new data on aquifer characteristics

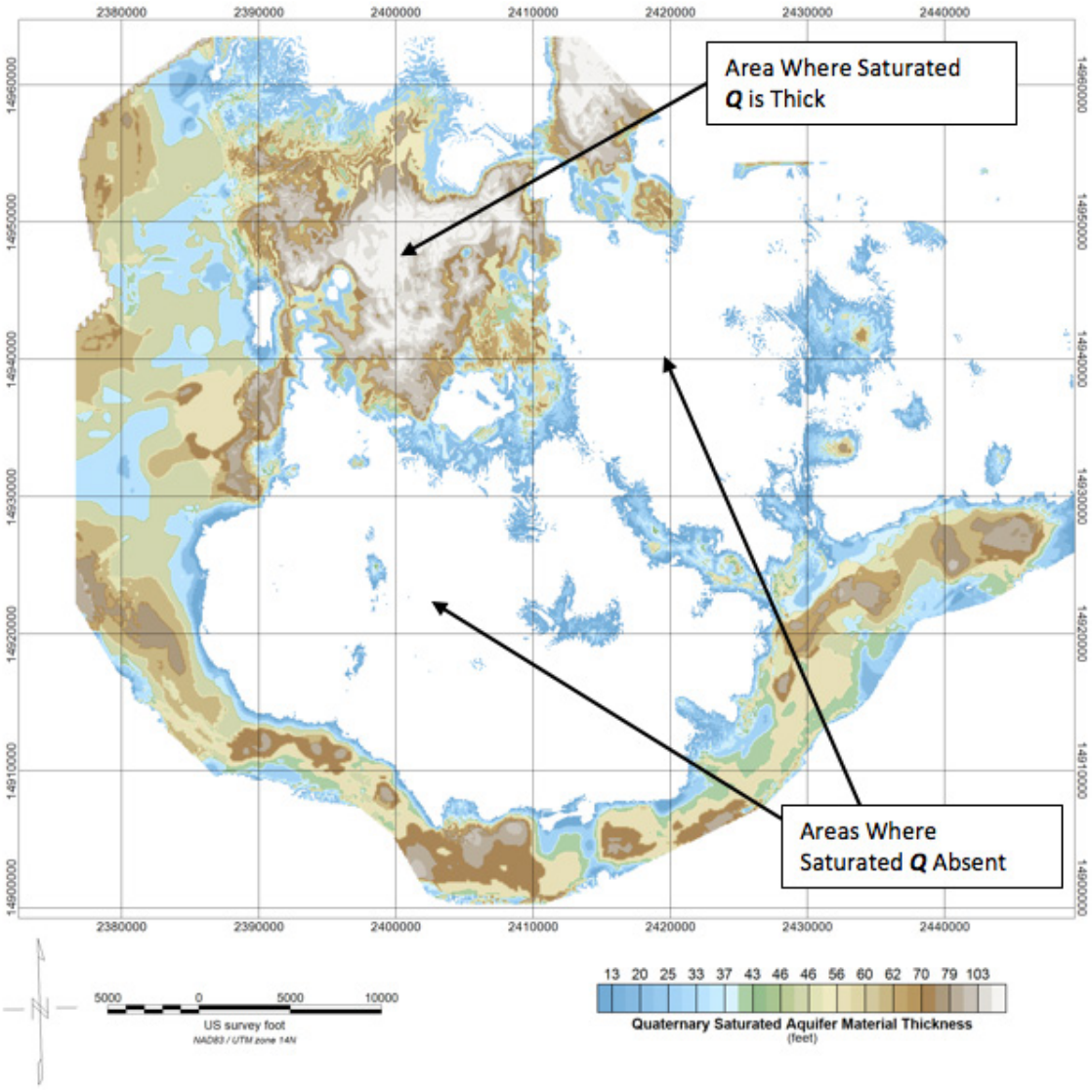


Figure 5-42. Quaternary saturated aquifer material thickness map for Sarpy County AEM survey area. Areas of thin to absent materials are seen in greater detail than Figure 2-8.

Table 5-4 shows the results of calculations for the amount of groundwater in storage calculated by volume of all aquifer materials below the water table then multiplied by the estimated porosity. The following calculation from values in the table shows the non-aquifer material has an estimated aquifer volume of 11,027 acre-ft and contains 4,411 acre-ft of groundwater in storage, marginal aquifer material has an estimated aquifer volume of 452,774 acre-ft and contains 158,471 acre-ft groundwater in storage, aquifer material has an estimated aquifer volume of 1,766,600 acre-ft and contains an estimated volume of 353,320 acre-ft of groundwater in storage. The coarse aquifer material contains an estimated aquifer volume of 358,390 acre-ft for a total of 89,598 acre-ft of groundwater in storage. The amount of groundwater in storage for all material groups is 605,799 acre-ft.

The estimate of extractable volume of water is calculated by taking the amount of groundwater in storage times the specific yield. Non-aquifer materials in the Sarpy County AEM survey area will yield approximately 88 acre-ft, marginal aquifer materials will yield approximately 7,924 acre-ft, aquifer materials will yield 35,332 acre-ft, and the coarse aquifer material will yield approximately 13,440 acre-ft. A total of 56,783 acre-ft is available from the combined aquifer and coarse aquifer materials.

These estimates are based on the CSD 1995 water table map. Also, these volumetric estimates consider only the volume of water assumed in the pore spaces of the aquifer material defined by the resistivity threshold levels and do not account for the amount of the possible “confined or semi-confined” water under pressure (head above the aquifer). This volume of water would add to the values reported in Table 5-4. However, too much uncertainty exists in developing an average level of head above the top of the aquifer across the entire project area, as well as defining a representative storativity term for the confined or semi-confined aquifers. Thus, the volumes listed in Table 5-4 are conservative estimates and the amounts released from the decline in pressure are not considered.

Porosity and Specific Yield values for the ***Kd*** sandstone/sand dominant and the shale/clay dominant materials were taken from published values by Heath, 1983. The values for sandstone/sand dominant materials are modified from Heath (1983) to account for the cemented nature of the ***Kd*** are a porosity of 0.35 of volume and specific yield of 0.05 percent. The ***Kd*** shale/clay dominant materials have values for porosity of 0.40, and specific yield of 0.02. These values will be used for calculating groundwater storage/yield for the ***Kd*** sandstone/sand dominant and shale/clay dominant materials. The results are contained in Table 5-5. The following calculations from values in the table show the ***Kd*** sandstone/sand dominant material has an estimated aquifer volume of 2,155,817 acre-ft and contains 754,536 acre-ft of groundwater in storage, the ***Kd*** shale/clay dominant material has an estimated aquifer volume of 1,395,427 acre-ft and contains 558,171 acre-ft of groundwater in storage. The ***Kd*** sandstone/sand dominant material has extractable volume of groundwater of 37,727acre-ft and the shale/clay dominant material has extractable volume of groundwater of 11,163 for a total of 48,890 acre-ft.

It should be noted that all values are very conservative in nature and are estimates based on published values for porosity and specific yield. The actual amount of extractable water will vary due to many things such as sediment grain size, sorting, cementation and other considerations. Actual values from the various sediment packages in the ***Q*** and ***Kd*** would greatly help the estimates of groundwater in storage and extractable water volume.

5.5 Recharge Areas within the Sarpy County AEM Survey Area

3D representations of the subsurface resulting from AEM investigations illustrate areas of aquifer materials from the bedrock up to the land surface. From these interpretations a new series of near-surface maps were constructed that include the interval from 0 to10 feet (about 3 m). The interval of 0-10 feet is noteworthy because this is the first layer of the inverted AEM earth model. Remember from the discussion around Table 4-4 that each model layer represents an average of the earth's resistivities within those depths, based on the physics of the electromagnetic exploration technique. These first layer maps show all aquifer materials including non-aquifer material, marginal aquifer material, aquifer material, and coarse aquifer material and indicate the areas at the land surface that can potentially transmit water to the groundwater aquifers in the area. The coarse aquifer material is able to transmit the largest volume of water and the non-aquifer material being the least able to transmit water.

The results of the interpretation of the aquifer materials of the Sarpy County AEM survey area are explained in detail in Section 5.2 and Section 5.3. The interpreted aquifer materials for the first model layer (0 – 10 ft) are presented in Figure 5-43 as a color from the ***Q*** material legend (Figure 5-13). Areas of coarse aquifer material (brown colored material) will have the highest potential to transmit the largest amount of water to the groundwater system with the aquifer material (yellow colored material) potentially transmitting slightly less precipitation downward as both units are permeable and transmissive. The marginal aquifer material (tan colored material) has a very low potential to transmit some water downward and the non-aquifer material (blue colored material) will transmit minimal to no water to the groundwater aquifer. Figure 5-44 shows only the ***Q*** coarse aquifer and aquifer material at the land surface making these areas the best recharge zones in the survey area.

However, since the amount of slope of the land surface plays a large role in the amount of residence time that water will spend in an area, the greater the length of time spent at a location, the greater the amount of infiltration potential. The greatest possibility for recharge in the Sarpy County AEM survey area is the Platte River alluvial valley floor where coarse aquifer and aquifer materials are near the land surface (Figure 5-44). On the table lands, the best possible location for recharge would be along the southwestern edge of the survey area and in the Buffalo and Springfield Creek drainages (Figure 5-44). Vaccaro and Olsen (2007) discuss how to calculate recharge when including topographic effects.

Google Earth kmz's of the Sarpy County recharge materials and locations are presented in Figure 5-45 (***Q*** aquifer material and coarse aquifer material (same as Figure 5-44, but in Google Earth), Figure 5-46 (***Q*** aquifer material only), Figure 5-47 (***Q*** coarse aquifer material only). These kmzs' are included in Appendix 3\KMZ\SarpyCounty_Recharge.

Table 5-4. Estimates of groundwater in storage and extractable water content in all Saturated Quaternary aquifer materials underlying the Sarpy County AEM survey area.

Aquifer Material Type	Aquifer Volume (ft^3)	Aquifer Volume (acre-ft)	Average Porosity	Groundwater in Storage Volume (acre-ft)	Average Specific Yield	Extractable Water Volume (acre-ft)
Non-Aquifer	480,317,422	11,027	0.4	4,411	0.02	88
Marginal	19,722,834,475	452,774	0.35	158,471	0.05	7,924
Aquifer	76,953,105,041	1,766,600	0.2	353,320	0.1	35,332
Coarse	15,611,484,510	358,390	0.25	89,598	0.15	13,440
TOTAL	112,767,741,448	5,177,582		605,799		56,783

Table 5-5. Estimates of groundwater in storage and extractable water content in all Saturated Cretaceous Dakota aquifer materials underlying the Sarpy County AEM survey area.

Aquifer Material Type	Aquifer Volume (ft^3)	Aquifer Volume (acre-ft)	Average Porosity	Groundwater in Storage Volume (acre-ft)	Average Specific Yield	Extractable Water Volume (acre-ft)
Shale/clay	60,784,808,389	1,395,427	0.4	558,171	0.02	11,163
Sandstone/sand	93,907,386,203	2,155,817	0.35	754,536	0.05	37,727
TOTAL	154,692,194,592	3,551,244		1,312,707		48,890

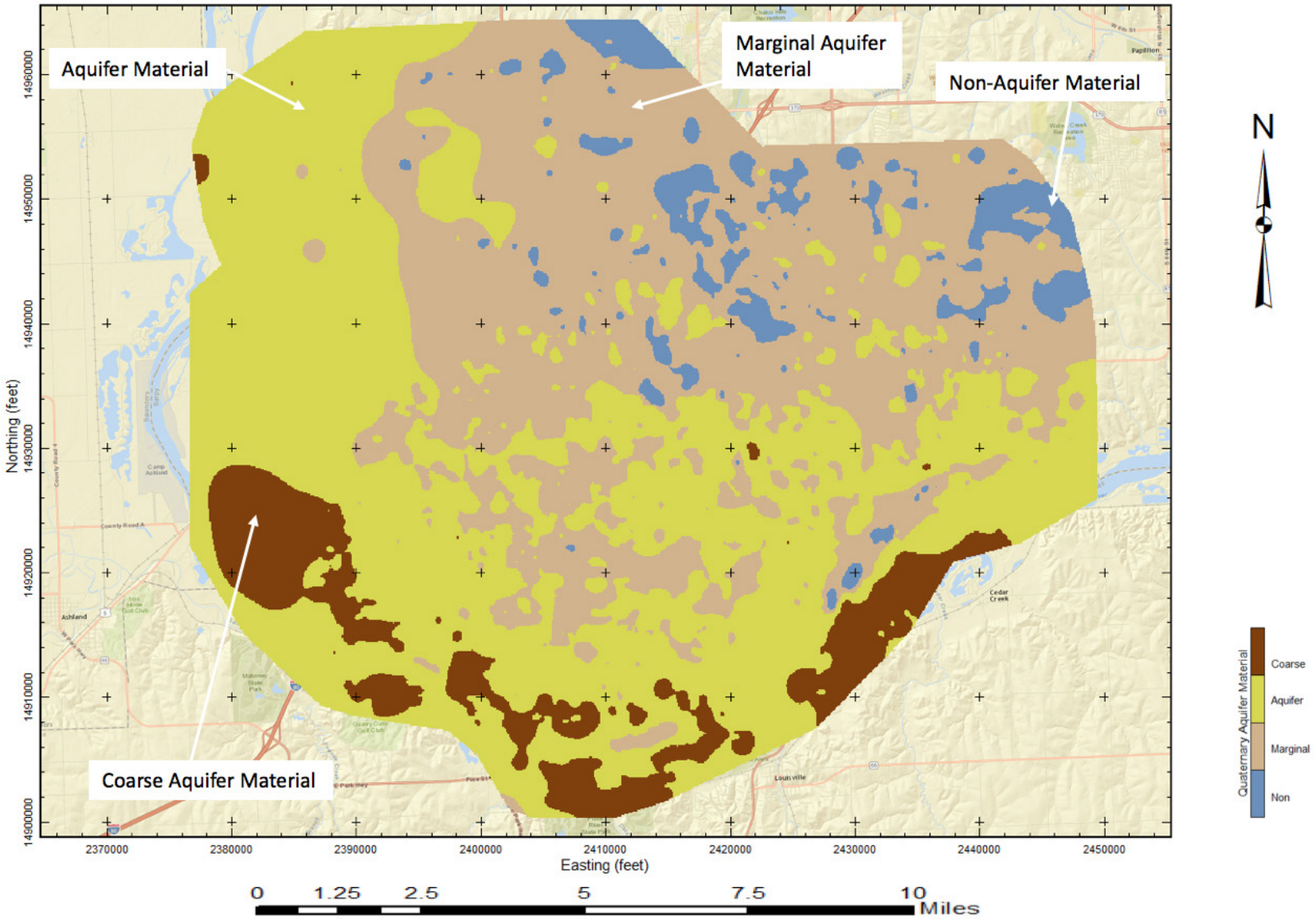


Figure 5-43. Map of <u>all</u> aquifer materials for the first 0 to 10 feet displayed over the Sarpy County AEM survey area. The material color legend indicates that different colors relate to different aquifer material types. Map projection is NAD 83, UTM Zone 14 North, feet.

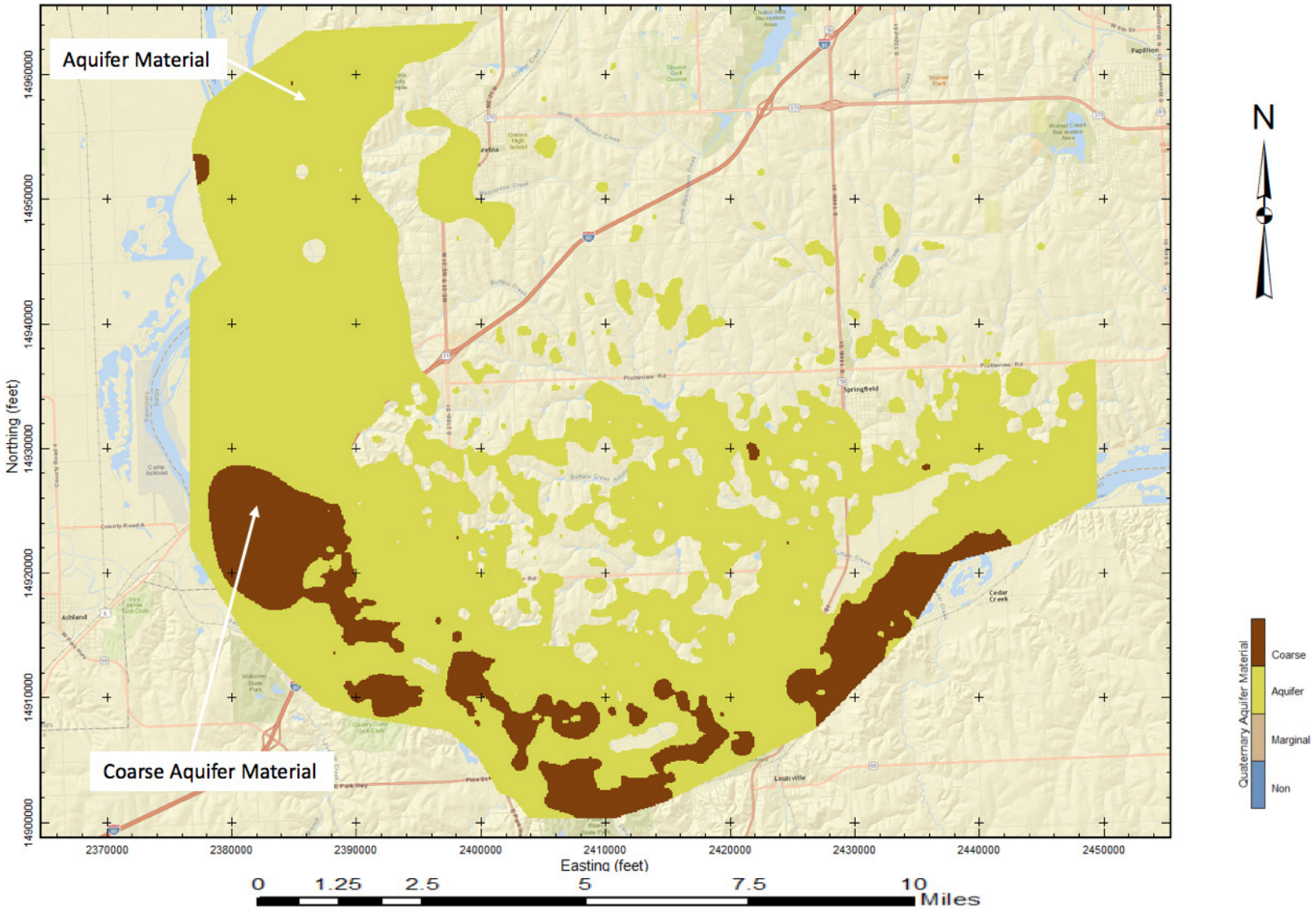


Figure 5-44. Map of the coarse aquifer materials and aquifer materials for the first 0 to 10 feet displayed over the Sarpy County AEM survey area. Material color legend shows different colors related areas to different aquifer material types. The brown and yellow areas are the areas of greatest potential recharge. Map projection is NAD 83, UTM Zone 14 North, feet.

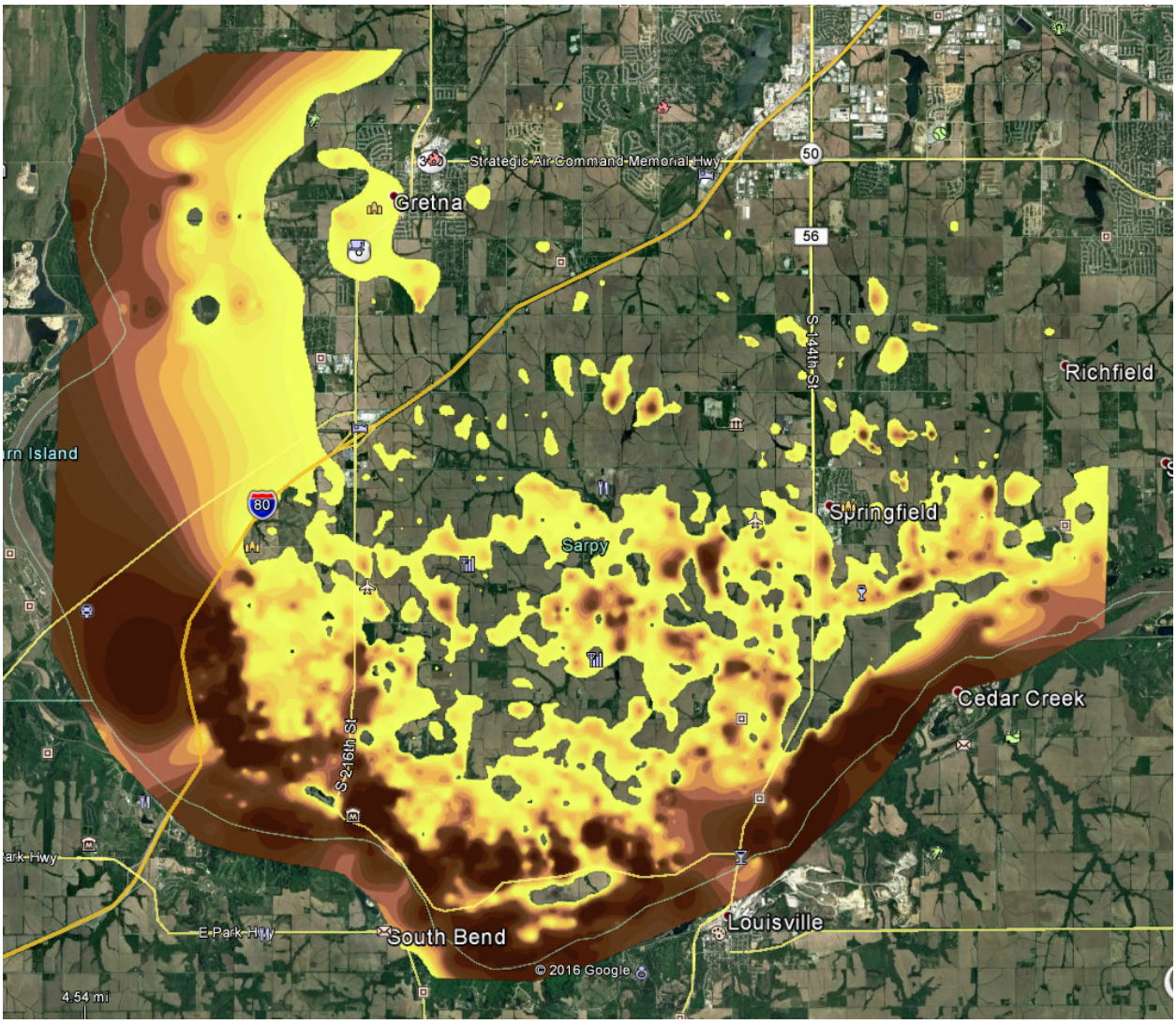


Figure 5-45. Google Earth recharge kmz of aquifer material and coarse aquifer material.

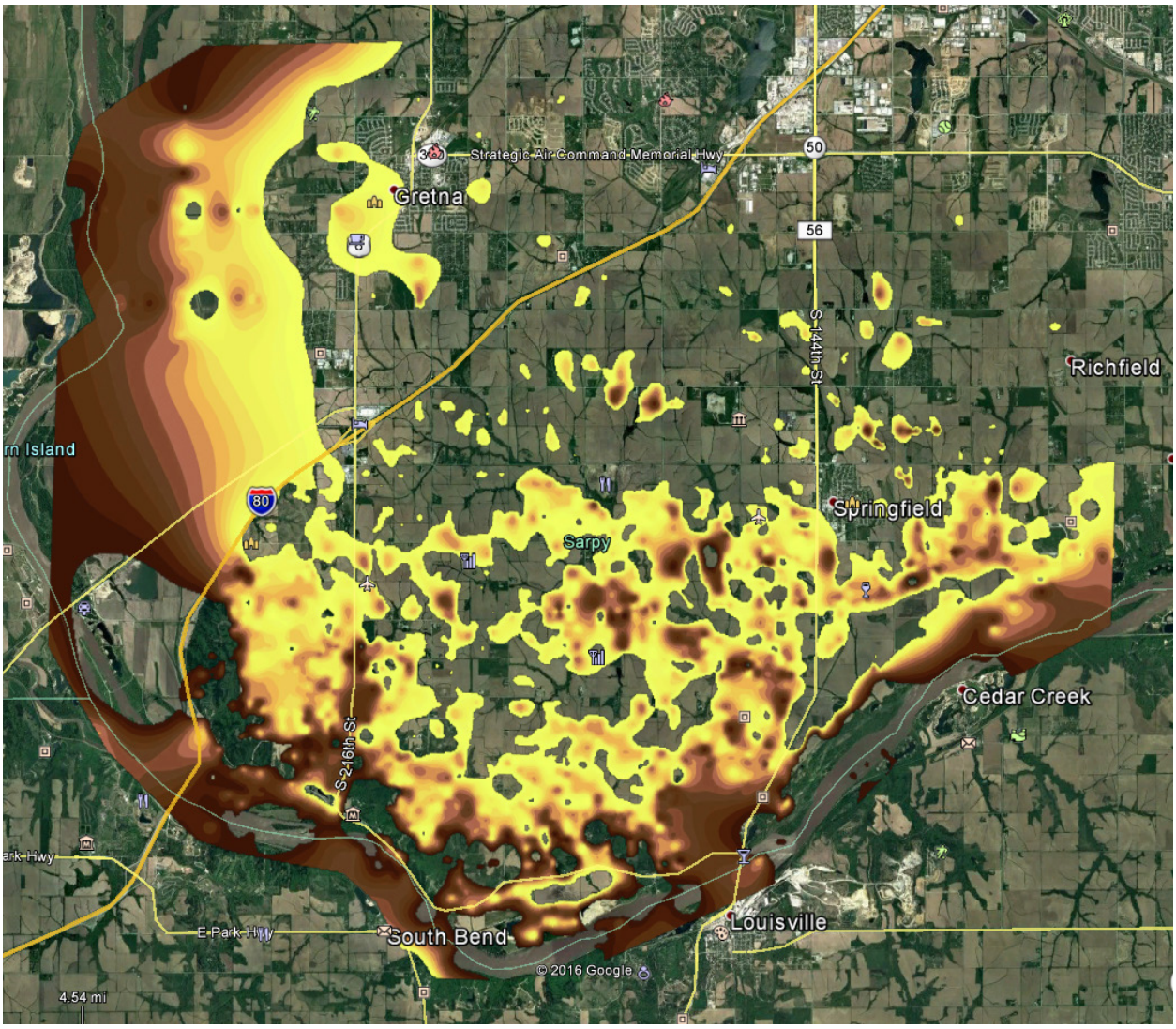


Figure 5-46. Google Earth recharge kmz of aquifer material only.

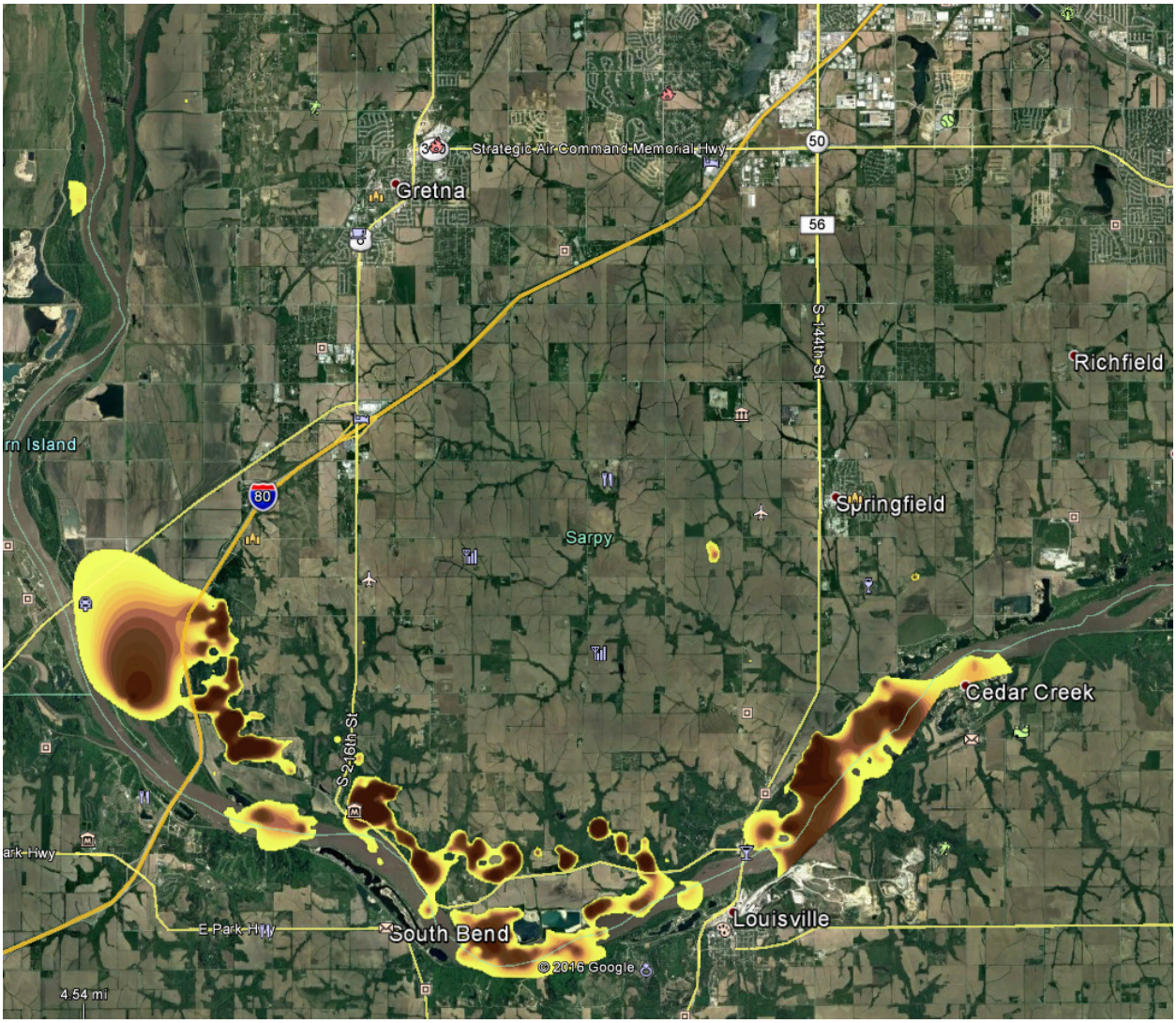


Figure 5-47. Google Earth recharge kmz of coarse aquifer material only.

5.6 Key AEM Findings

5.6.1 Boreholes

As discussed above, borehole information was used to analyze the AEM inversion results. These included CSD (Within the Sarpy County AEM survey area, a total of 18 CSD holes contained lithology information, 15 holes contained stratigraphy information, and 7 holes contained geophysical information), NE-DNR (A total of 922 registered wells contained usable lithology information), local water well drillers (73 wells contained limited and discontinuous lithology and stratigraphic information) , and 32 municipal wells (containing only lithology information) were utilized in the analysis of the AEM inversion results.

5.6.2 Merging 2015 and 2016 AEM Databases

The Sarpy County AEM survey area analysis encompassed an additional 37.2 line-miles (60.3 line-km) of AEM data collected in 2015 in the Sarpy County area. The 2015 AEM data contains valuable information that can be utilized in the interpretation of the larger Sarpy County AEM survey data. The 2015 AEM results were combined with the 2016 AEM data. Note that this combination did not include reinverting the 2015 data, but rather included merging the 2015 inversion results into the 2016 database and interpretation.

5.6.3 Digitizing Interpreted Geological Contacts

Characterization and interpretation of the subsurface was performed in cross-section and derived surface grid formats. Contacts between the geologic units were digitized in 2D including: Quaternary (***Q***), Cretaceous Dakota (***Kd***), and undifferentiated Pennsylvanian (***IP***). The interpretive process benefited from the use of CSD, NE-DNR, local water well driller, and municipal borehole logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including Quaternary aquifer material mapping and Cretaceous Dakota sandstone/sand dominant zones are included as appendices as well as the interpretative surface grids.

5.6.4 Resistivity/Lithology Relationship

Assessment of the sediment character in both the ***Q*** and the ***Kd*** aquifer systems was conducted to determine the overall composition of the major categories used to define the aquifer and aquitards in eastern Nebraska. For the ***Q*** aquifer systems, a numerically robust assessment of the resistivity thresholds was used to characterize non-aquifer (<12 ohm-m), marginal (12-20 ohm-m), and aquifer (20-50 ohm-m), including coarse sand-rich intervals (>50 ohm-m). A similar process was applied to the ***Kd*** and a resistivity threshold of 27 ohm-m was determined to separate sandstone/sand dominant zones from shale/clay dominant zones. This allowed for the characterization of the ranges of resistivities present in the major geologic units described in this report.

5.6.5 Hydrogeological Framework of the Sarpy County AEM Survey Area

The AEM reveals considerable variability in the ***Q***, ***Kd***, and undifferentiated ***IP*** deposits across Sarpy County AEM survey area. The subsurface distribution of materials can generally be characterized into three somewhat overlapping, but distinct, areas with smaller localized

depositional features distributed at various locations within the survey area. These areas include the ***Q*** alluvium, ***Q*** glacial, and the ***Kd*** bedrock area. The ***Q*** alluvium aquifer area of the Sarpy County AEM survey area is predominantly composed of ***Q*** unconsolidated aquifer and coarse aquifer materials composed of alluvial sediments. Marginal and non-aquifer materials are present, but they are isolated and limited in geographic area. The combined alluvium system overlies the ***Kd*** and ***IP***. The ***Q*** alluvium is eroded into the surfaces of the ***Kd*** and ***IP*** and is seen mostly in the Platte River, Buffalo, and Springfield creeks. The ***Kd*** can act both as an aquifer and an aquiclude. Water from the alluvium or ***Kd*** can move between the units. The coarse aquifer and aquifer materials are most likely to have this connection and interaction.

Q glacial deposits (tills and outwash) cover much of the Sarpy County AEM survey area and thicken to the north-northeast and thin to the south-southwest. They lie unconformably upon the ***Kd*** and ***IP***. There is a separation or erosional channel between the north block of ***Kd*** and the south block of the ***Kd*** that is filled with the thickest sequence of Q materials.

The ***Kd*** is characterized by a combination of sandstone/sand dominant and shale/clay dominant units. The ***Kd*** is covered by ***Q*** alluvium and till although there are some outcrops along the bluffs near the Platter River to the south in the study area. The ***Kd*** varies in thickness from approximately 0 feet to over approximately 150 feet. The ***Kd*** occurs as erosional remnants and lies unconformably on the ***IP***. The patterns that define the shape of present day ***Kd*** are related to many erosional episodes including glaciation and fluvial processes. Recent erosion has occurred in the drainages of the Platte River, Buffalo, and Springfield Creeks. Many areas of ***Kd*** have sufficient saturated thickness to provide water to water supply wells.

5.6.6 Sarpy County Estimation of Aquifer Volume and Water in Storage

Estimations were calculated for both ***Q*** and ***Kd*** aquifer materials. The ***Q*** non-aquifer material has an estimated aquifer volume of 11,027 acre-ft and contains 4,411 acre-ft of groundwater in storage, marginal aquifer material has an estimated aquifer volume of 452,774 acre-ft and contains 158,471 acre-ft groundwater in storage, aquifer material has an estimated aquifer volume of 4,691,635 acre-ft and contains an estimated volume of 938,327 acre-ft of groundwater in storage. The ***Q*** coarse aquifer material contains an estimated aquifer volume of 358,390 acre-ft for a total of 89,598 acre-ft of groundwater in storage. The amount of groundwater in storage for all material groups is 605,799 acre-ft. Non-aquifer materials in the Sarpy County AEM survey area will yield approximately 88 acre-ft, marginal aquifer materials will yield approximately 7,924 acre-ft, aquifer materials will yield 35,332 acre-ft, and the coarse aquifer material will yield approximately 13,440 acre-ft. A total of 56,783 acre-ft is available from the combined ***Q*** aquifer and coarse aquifer materials.

The ***Kd*** sandstone/sand dominant material has an estimated aquifer volume of 2,155,817 acre-ft and contains 754,536 acre-ft of groundwater in storage, the ***Kd*** shale/clay dominant material has an estimated aquifer volume of 1,395,427 acre-ft and contains 558,171 acre-ft of groundwater in storage. The ***Kd*** sandstone/sand dominant material has an extractable volume of groundwater of 37,727acre-ft and the shale/clay dominant material has an extractable volume of groundwater of 11,163 for a total of 48,890 acre-ft.

5.6.7 Potential Recharge Zones within the Sarpy County AEM Survey Area

3D representations of the subsurface resulting from the Sarpy County AEM investigation illustrate areas of aquifer materials from the bedrock up to the land surface. From these interpretations a series of near-surface maps were constructed to display the ***Q*** aquifer materials in the first 10 ft. These indicate that while there is some heterogeneity in the aquifer materials, it is easy to identify the areas of aquifer materials that will transmit the most (aquifer and coarse aquifer materials), and the least (non-aquifer and marginal aquifer materials), amounts of water from the surface down to the groundwater system. The greatest possibility for recharge in the Sarpy County AEM survey area is the Platte River alluvial valley floor where coarse aquifer and aquifer materials are near the land surface. On the table lands, the best possible locations for recharge would be along the southwestern edge of the survey area and in the Buffalo and Springfield Creek drainages.

5.7 Recommendations

Recommendations provided to the P-MRNRD in this section are based on the interpretation and understanding gained from the addition of the AEM data to existing information and from discussions with the P-MRNRD about their management challenges.

AGF is providing a hydrogeologic framework report that includes maps of aquifer materials and their relationships to current test holes and production groundwater wells, estimates of water storage capacity and water availability, and maps of estimated potential recharge areas.

5.7.1 Additional AEM Mapping.

The aquifer maps provided in this report represent the detailed framework developed for the Sarpy County AEM survey area.

The detail provided in the hydrogeological interpretation of the Sarpy County AEM survey area allowed for confident development of hydrogeologic framework. The interpretations match well with the CSD and NE-DNR test holes. If additional high resolution information is needed within Sarpy County to resolve questions of resource management, it is recommended that additional areas of closely spaced lines or "block flights" be collected in order to develop detailed frameworks.

It should be noted that the ability to effectively map erosional remnants of the ***Kd*** can only happen with block flights. Thus, if ***Kd*** remnants are suspected and are targets of interest within an area designated for investigation, then block flights are required for effective characterization.

For example, the detailed hydrogeologic frameworks presented in this report have provided estimates of groundwater storage capacity. This is done by using existing aquifer characteristic information and calculating groundwater in storage and effective yield. It is recommended that additional closely spaced flight lines for collection of AEM data and interpretation be considered in critical areas of Sarpy County and the P-MRNRD. This will supply the P-MRNRD with information on aquifer sustainability, depletion to streams, well interference, groundwater withdrawal, and other management considerations.

5.7.2 Update the groundwater table map

The groundwater data used in the analyses presented in this report use the 1995 CSD water table data (Nebraska CSD, 1995). 22 years is a long time in the evolution of a groundwater system and, in many areas, the water table used for this report was found not to be inconsistent with other recent borehole data. This is especially true on the southwest side of the AEM survey area.

5.7.3 Siting new test holes and production wells.

The AEM framework maps and profiles provided in this report provide insight in 3D on the relationship between current test holes and production groundwater wells. At the time of this report, the currently

available lithology data for the Sarpy County AEM survey area was used in building the framework maps and profiles. It is recommended that the results from this report be used to site new test holes and monitoring wells. Often test holes are sited based on previous work that is regional in nature. By utilizing the maps in this report new drilling locations can be sited in optimal locations.

The location of new water supply wells for communities can also use the results in this report to guide development of new water supply wells. Planners should locate wells in areas of greatest saturated thickness with the least potential for non-point source pollution.

5.7.4 Aquifer testing and borehole logging.

Additional aquifer tests are recommended to improve estimates of aquifer characteristics. No aquifer properties were available outside the larger cities in the survey area. A robust aquifer characterization program is highly recommended at the state, regional (NRD's), and smaller municipal levels. Aquifer tests can be designed based on the results of AEM surveys and existing production wells could be used in conjunction with three or more installed water level observation wells.

Additional test holes with detailed, functional, and well calibrated geophysical logging for aquifer characteristics are highly recommended. The few test holes with geophysical logs in the area of the Sarpy County AEM survey were inadequate. None were calibrated and several had apparent hardware malfunctions. The borehole geophysical logs provided for this investigation demonstrate that additional calibrated and verified geophysical logs are required in the P-MRNRD.

Examples of additional logging would be flow meter logs and geophysical logs including gamma, neutron, electrical, and induction logs. Detailed aquifer characteristics can be accomplished with nuclear magnetic resonance logging (NMR). This is a quick and effective way to characterize porosity and water content, estimates of permeability, mobile/bound water fraction, and pore-size distributions with depth. This is very cost effective when compared to traditional aquifer tests.

5.7.5 Recharge Zones.

The Sarpy County AEM survey hydrogeologic framework provides areas of recharge from the ground surface to the groundwater aquifer. The block flights of AEM data acquisition provide the most detailed information for understanding recharge throughout the Sarpy County AEM survey area. It is recommended that additional AEM data be collected and interpreted utilizing closely-spaced flight lines using an AEM system that has near-surface resolution. It is further recommended that future work integrate new soils maps with the results of this study to provide details on soil permeability, slope, water retention to provide a more complete understanding of the transport of water from the land surface to the groundwater aquifer.

6 Description of Data Delivered

6.1 Tables Describing Included Data Files

Table 6-1 describes the data columns in the ASCII *.xyz file P-MRNRD_EM_MAG_UTM14n_feet.xyz as well as the Geosoft database file P-MRNRD_EM_MAG_UTM14n_feet.gdb. This file contains the electromagnetic data, plus the magnetic and navigational data, as supplied directly from SkyTEM.

The result of the SCI is included in SarpyCounty_AEM_SCI_INV.gdb files and SarpyCounty_AEM_SCI_INV.xyz and the data columns of these databases are described in Table 6-2.

The borehole data used to constrain the SCI inversion and to assist in the interpretation of the inversion results are included in the files listed in Table 6-3. Each type of borehole information has both a collar file containing the location of each of the wells, and a second file containing the borehole data for the individual wells. The data column descriptions for the collar files are listed in Table 6-4. A description of the channels in all the borehole data files as well as which type of data contains each channel Table 6-5.

The various interpretation results are included in data files P-MRNRD_SarpyCo_Interpretation_v1.gdb and P-MRNRD_SarpyCo_Interpretation.xyz. Table 6-6 describes the data columns of those files.

Table 6-7 describes the raw data files included in Appendix 3 – Deliverables\RawData. As discussed above, eight (8) flights were required to acquire the Sarpy County AEM data (Figure 4-5). Grouped by flight date, there are four (4) data flies included in Appendix 3 for each flight. These files have extensions of "*.sps" and "*.skb". The "*.sps" files include navigation and DGPS location data and the "*.skb" files include the raw AEM data that has been PFC-corrections (discussed in Section 4.4.1). Two additional files are used for all the flights. These are the system description and specifications file (with the extension "*.gex") and the 'mask' file (with the extension "*.lin") which correlates the flight dates, flight numbers, and assigned line numbers.

ESRI Arc View Binary Grids of the surfaces that were used in the interpretation (DEM, water table) and derived from the interpretation (top of geological units) of the AEM and borehole are listed in Table 6-8.

Voxel grids were completed for the Sarpy County AEM survey area including Sarpy_County_Quaternary_voxel2.* and Sarpy_County_Dakota_voxel2.*xyz and *.gdb. The voxel grids were made using a 100 ft grid cell size and the model layer thickness (Table 4-4). Table 6-9 is a list of the channel names in both ASCII *.xyz and Geosoft *.gdb format for the Sarpy County AEM survey voxels.

In summary, the following are included as deliverables:

- Raw EM Mag data Geosoft database and xyz
- Raw Data Files - SkyTEM files *.geo, *skb, *.lin
- SCI inversion Geosoft database and xyz
- Borehole Geosoft databases and xyz
- Interpretations Geosoft database and xyz
- ESRI ArcView files – surface, topo, etc
- 3D voxel model Geosoft databases and ASCII xyz's
- KMZs for the Sarpy County AEM survey area including "As-Flown" flight lines, retained inversion data locations, profile interpretations, ***Q*** and ***Kd*** aquifer properties, and near-surface recharge areas (Discussed in Section 6.2)
- Pitney-Bowes Discover PA sessions for the Profiles and 3D voxels for (Discussed in Section 6.3)

Table 6-1: Channel name, description, and units for P-MRNRD_EM_MAG_UTM14n_feet.gdb and P-MRNRD_EM_MAG_UTM14n_feet.xyz with EM, magnetic, DGPS, Inclinometer, altitude, and associated data.

Parameter	Description	Unit
Fid	Unique Fiducial Number	
Line	Line Number	
Flight	Name of Flight	yyyymmdd.ff
DateTime	DateTime Format	Decimal days
Date	DateTime Format	yyyymmdd
Time	Time UTC	hhmmss.sss
AngleX	Angle (in flight direction)	Degrees
AngleY	Angle (perpendicular to flight direction)	Degrees
Height	Filtered Height Measurement	Meters [m]
Lon	Longitude, WGS84	Decimal Degrees
Lat	Latitude, WGS84	Decimal Degrees
E_UTM14N	Easting, NAD83 UTM Zone 14N	Meters [m]
N_UTM14N	Northing, NAD83 UTM Zone 14N	Meters [m]
DEM	Digital Elevation	Meters [m]
Alt	DGPS Altitude above sea level	Meters [m]
GDSpeed	Ground Speed	Kilometers/hour [km/h]
Curr_LM	Current, Low Moment	Amps [A]
Curr_HM	Current, High Moment	Amps [A]
LMZ_G01	Normalized (PFC-Corrected) Low Moment Z-RxCoil value	$pV/(m^4*A)$
HMZ_G01	Normalized (PFC-Corrected) High Moment Z-RxCoil value	$pV/(m^4*A)$
LMX_G01	Normalized (PFC-Corrected) Low Moment X-RxCoil value	$pV/(m^4*A)$
HMX_G01	Normalized (PFC-Corrected) High Moment X-RxCoil value	$pV/(m^4*A)$
_60Hz_IntenSity	Power Line Noise Intensity monitor	
Bmag_f	Raw Base Station Mag Data filtered	nanoTesla [nT]
Diurnal	Diurnal Mag Data	nanoTesla [nT]
MA1_orig	Raw Mag Data	nanoTesla [nT]
Mag_fil	Mag filtered	nanoTesla [nT]
Mag_CD	Mag Data Corrected for Diurnal Drift	nanoTesla [nT]
RMF	Residual Magnetic Field	nanoTesla [nT]
IGRF	International Geomagnetic Reference Field	nanoTesla [nT]
X_ft	Easting, NAD83 UTM Zone 14N	Feet [ft]
Y_ft	Northing, NAD83 UTM Zone 14N	Feet [ft]
Z_ft	Elevation, 100 ft grid of NED DEM NAVD88	Feet [ft]

Table 6-2: Channel name, description, and units for SarpyCounty_AEM_SCI_Inv.gdb and SarpyCounty_AEM_SCI_Inv.xyz with EM inversion results.

Parameter	Description	Unit
X_FT	Easting NAD83, UTM Zone 14	Feet [ft]
Y_FT	Northing NAD83, UTM Zone 14	Feet [ft]
X_M	Easting NAD83, UTM Zone 14	Meters [m]
Y_M	Northing NAD83, UTM Zone 14	Meters [m]
DEM_M	DEM from survey	Meters [m]
DEM_FT	DEM from 100 ft grid NED NAVD88	Feet [ft]
FID	Unique Fiducial Number	
LINE	Line Number	
TIME	Date Time Format	Decimal days
ALT_M	Altitude of system above ground	Meters [m]
INVALT	Inverted Altitude of system above ground	Meters [m]
INVALTSTD	Inverted Altitude Standard Deviation of system above ground	Meters [m]
DELTAALT	Change in Altitude of system above ground	Meters [m]
RESDATA	Residual of individual sounding	
RESTOTAL	Total residual for inverted section	
DOI_LOWER_M	Less conservative estimate of DOI	Meters [m]
DOI_UPPER_M	More conservative estimate of DOI	Meters [m]
DOI_LOWER_FT	Less conservative estimate of DOI	Feet [ft]
DOI_UPPER_FT	More conservative estimate of DOI	Feet [ft]
RHO_I_0 THROUGH RHO_I_28	Inverted resistivity of each later	Ohm-m
SIGMA_I_0 THROUGH SIGMA_I_28	Conductivity	S/m
DEP_BOT_0_M THROUGH DEP_BOT_28_M	Depth to the bottom of individual layers	Meters [m]
DEP_TOP_0_M THROUGH DEP_TOP_28_M	Depth to the top of individual layers	Meters [m]
DEP_BOT_0_FT THROUGH DEP_BOT_28_FT	Depth to the bottom of individual layers	Feet [ft]
DEP_TOP_0_FT THROUGH DEP_TOP_28_FT	Depth to the top of individual layers	Feet [ft]
THK_0_M THROUGH THK_28_M	Thickness of individual layers	Meters [m]
THK_0_FT THROUGH THK_28_FT	Thickness of individual layers	Feet (ft)

Table 6-3: Files containing borehole information.

Database (*.xyz, *.gdb)	Description
NE-DNR2015lith_Collar.	Geophysical logs from NE-DNR registered wells along the 2015 AEM survey lines
NE-DNR2015lith_Data.	
ENWRASouthLith_Collar.	Lithology logs from CSD boreholes in the southern section of ENWRA
ENWRASouthLith_Data.	
ENWRASouthStrat_Collar.	Stratigraphy logs from CSD boreholes in the southern section of ENWRA
ENWRASouthStrat_Strat.	
PMRNRDDNRLith2016_Collar.	Lithology logs from P-MRNRD DNR Wells
PMRNRDDNRLith2016_Lith.	
SarpyCOElogs1_Collar.	Geophysical Logs from CSD that were digitized from paper logs in the Sarpy County
SarpyCOElogs1_Data.	
SarpyCOElogs2_Collar.	Digital Geophysical Logs from CSD that were digital logs in the Sarpy County
SarpyCOElogs2_Data.	
PMRNRDLith_Collar.	Lithology logs from local water-well driller records in the P-MRNRD
PMRNRDLith_Data.	
PMRNRDStrat_Collar.	Stratigraphy Data from local water-well driller records in the P-MRNRD
PMRNRDStrat_Strat.	

Table 6-4: Channel name, description, and units for borehole collar files.

Parameter	Description	Unit
DH_Hole	Name of individual boreholes	
DH_East	Easting of boreholes, NAD83, UTM Zone 14	Feet [ft]
DH_North	Northing of boreholes, NAD83, UTM Zone 14	Feet [ft]
DH_RL	Elevation of top of borehole	Feet [ft]
DH_Dip	Dip of borehole	Degrees
DH_Azimuth	Azimuth of borehole	Degrees
DH_Top	Depth to top of borehole	Feet [ft]
DH_Bottom	Depth to bottom of borehole	Feet [ft]
DH_ZMin	Minimum elevation in borehole	Feet [ft]
DH_ZMax	Maximum elevation in borehole	Feet [ft]

Table 6-5: Channel name description and units for borehole data.

Parameter	Description	Unit	Type of Log
DH_East	Easting of boreholes, NAD83, UTM Zone 14	Feet [ft]	All
DH_North	Northing of boreholes, NAD83, UTM Zone 14	Feet [ft]	All
DH_RL	Elevation of top of borehole	Feet [ft]	All
DH_From	End of interval	Feet[ft]	Strat, Lith
DH_To	Start of interval	Feet [ft]	Strat, Lith
DH_Strat_Code	Code used to indicate type of stratigraphy		Strat
DH_Soil_Code	Code used to indicate type of lithology		Lith
DH_Lith_Number	1 of 30 numbers assigned to reference lithology		
Lithcode	Lithology description associated with 30 categories		
StratCode	Formation designation (e.g. "***Q***", "***Kd***")		
DH_Description/DH_Des	Description of stratigraphy or lithology		Strat, Lith
DH_Depth	Depth	Feet [ft]	GP
DH_SP	Self Potential	milliVolt [mV]	GP, E, Geo
DH_SN	Short Normal Resistivity	Ohm-m	GP
DH_SFL	Spherically Focus Log	Ohm-m]	GP
DH_ILD	Induction Log Deep	Siemens/m [S/m]	GP
DH_ILM	Induction Log Medium	Siemens/m [S/m]	GP
DH_LAT	Laterolog	Ohm-m	GP
DH_Res	Resistivity	Ohm-m	Constrain, E
DH_Nat_Gam	Natural Gamma	Counts	Geo
DH_Res_SnglPt	Resistivity Single Point	Ohm-m	Geo
DH_Res_16	Resistivity 16in	Ohm-m	Geo
DH_Res_64	Resistivity 65in	Ohm-m	Geo
DH_Res_Lat	Res Laterolog	Ohm-m	Geo
DH_SP_Cond	Self Potential Induction	milliVolt [mV]	Geo
DH_Res_FL	Resistivity of the fluid	Ohm-m	Geo
DH_Tmp_FL	Temperature of the fluid	Degrees F	Geo
DH_Del_Tmp	Change in temperature of the fluid	Degrees F	Geo

Table 6-6: Channel name description and units for the interpretation results file PMRNRD_SarpyCo_Interpretation_v1.gdb and PMRNRD_SarpyCo_Interpretation.xyz.

Parameter	Description	Unit
Line	Flight Line Number	
X_ft	Easting NAD83, UTM Zone 14	Feet [ft]
Y_ft	Northing NAD83, UTM Zone 14	Feet [ft]
Z_ft	Topography at 100ft sampling (NAVD 1988)	Feet [ft]
RHO[0] through RHO[28]	Array of Inverted model resistivities of each later	Ohm-m
RHO_STD[0] through RHO_STD[28]	Array of standard deviations of inverted model resistivities of each layer	
RESDATA	Inversion model residuals of each individual sounding	
RESTOTAL	Average of all model inversion residuals	
DEP_TOP_ft[0] through DEP_TOP_ft[28]	Depth to the top of individual layers	Feet [ft]
DEP_BOT_ft[0] through DEP_BOT_ft[28]	Depth to the bottom of individual layers	Feet [ft]
DOI_UPPER	More conservative estimate of DOI from Workbench	Feet [ft]
DOI_LOWER	Less conservative estimate of DOI from Workbench	Feet [ft]
DEP_TOP_ELEV	Elevation of top of each inversion model layer	Feet (ft)
WaterTable_1995	Elevation of the top of the water table from the Nebraska School of Natural Resources Configuration Report, 1995.	Feet [ft]
AquiferMaterialType[0] through AquiferMaterialType[28]	Array of Aquifer Material types: 0 - Bedrock; 1 - Non-Aquifer Material; 2 - Marginal Aquifer Material; 3 - Aquifer Material; 4 - Coarse Aquifer Material	Integer Array
Top_AqMat	Elevation of top of Aquifer Material (20 - 50 ohm-m)	Feet [ft]
Bot_AqMat	Elevation of bottom of Aquifer Material (20 - 50 ohm-m)	Feet [ft]
Top_CoarseAqMat	Elevation of top of Coarse Aquifer Material (>50 ohm-m)	Feet [ft]
Bot_CoarseAqMat	Elevation of bottom of Coarse Aquifer Material (>50 ohm-m)	Feet [ft]
Bedrock	Elevation of interpreted bedrock surface	Feet [ft]
Kd	Elevation of the top of the Cretaceous Dakota Formation.	Feet [ft]
SandDomTop	Top of Sand-dominant zone in the ***Kd***	Feet [ft]
SandDomBot	Bottom of Sand-dominant zone in the ***Kd***	Feet [ft]
Penn	Elevation of the top of the Pennsylvanian units.	Feet [ft]
*	No data or unit not detected	

Table 6-7: Raw SkyTEM data files

Folder	File Name	Description
Data	..NavSys.sps, …PaPc.sps, ...RawData_PFC.skb, …DPGS.sps	Raw data files included for each flight used in importing to Aarhus Workbench
Geo	20160815_337m2_Cal_DualWaveform_60Hz.gex	304M System Description
Mask	20160706_Linefile_PMRNRD.lin	Production file listing dates, flights, and assigned line numbers

Table 6-8: Files containing ESRI ArcView Binary Grids *.flt and Geosoft Grids *.grd (NAD83 UTM Zone 14 North, feet)

Grid File Name	Description	Grid Cell Size (feet)
Sarpy_DEM.*	Grid of the Digital Elevation Model (DEM) downloaded from the National Elevation Dataset (NED) August 2016 NAVD88 (feet)	100
Sarpy_ Bedrock_Top_elevation.*	Grid of the elevation of the bedrock. This is both Cretaceous Dakota (***Kd***) and undifferentiated Pennsylvanian (***IP***) NAVD88 (feet)	100
Sarpy_Kd_Sandstone_belowWT_Bottom_elevation.*	Grid of the elevation of the bottom of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material below the CSD 1995 water table NAVD88 (feet)	100
Sarpy_Kd _Sandstone_Bottom_elevation.*	Grid of the elevation of the bottom of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material NAVD88 (feet)	100
Sarpy_Kd_Bottom_elevation.*	Grid of the elevation of the bottom of the Cretaceous Dakota (***Kd***) NAVD88 (feet)	100
Sarpy_Q_AquiferMaterial_BelowWT_Bottom_Elevation.*	Grid of the elevation of the bottom of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material below the CSD 1995 water table NAVD88 (feet)	100
Sarpy_Q_AquiferMaterial_Bottom_elevation.*	Grid of the elevation of the bottom of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material NAVD88 (feet)	100
Sarpy_Q_Bottom_elevation.*	Grid of the elevation of the bottom of the Quaternary (***Q***) NAVD88 (feet)	100
Sarpy_IP_top_elevation.*	Grid of the elevation of the top of the undifferentiated Pennsylvanian (***IP***) NAVD88 (feet)	100
Sarpy_Kd_Sandstone_BelowWT_Top_elevation.*	Grid of the elevation of the top of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material below the CSD 1995 water table NAVD88 (feet)	100
Sarpy_Kd_Sandstone_Top_elevation.*	Grid of the elevation of the top of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material NAVD88 (feet)	100
Sarpy_Kd_Top_elevation.*	Grid of the elevation of the top of the Cretaceous Dakota (***Kd***) NAVD88 (feet)	100
Sarpy_ _Q_AquiferMaterial_BelowWT_Top_elevation.*	Grid of the elevation of the top of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material below the CSD 1995 water table NAVD88 (feet)	100
Sarpy_ Q_AquiferMaterial_Top_elevation.*	Grid of the elevation of the top of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material NAVD88 (feet)	100
Sarpy_Q_Top_elevation.*	Grid of the elevation of the top of the Quaternary (***Q***) NAVD88 (feet)	100

Sarpy_Q_AquiferMaterial_BelowWT_thickness.*	Grid of the thickness of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material below the CSD 1995 water table (feet)	100
Sarpy_Q_AquiferMaterial_thickness.*	Grid of the thickness of the Quaternary (***Q***) Aquifer and Coarse Aquifer Material (feet)	100
Sarpy__Kd_Sandstone_BelowWT_thickness.*	Grid of the thickness of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material below the CSD 1995 water table (feet)	100
Sarpy__Kd_Sandstone_thickness.*	Grid of the thickness of the Cretaceous Dakota (***Kd***) sandstone/sand dominant aquifer material (feet)	100
Sarpy__Kd_thickness.*	Grid of the thickness of the Cretaceous Dakota (***Kd***) (feet)	100
Sarpy__Q_thickness.*	Grid of the thickness of the Quaternary (***Q***) (feet)	100
Sarpy_Saturated_thickness.*	Grid of the thickness of the saturated material (feet)	100
Sarpy_WT_elevation.flt	Elevation of the Conservation and Survey Division (CSD) 1995 Statewide water table NAVD88 (feet)	100

Table 6-9. Channel name, description, and units for Sarpy_County_Quaternary_voxel2.* and Sarpy_County_Dakota_voxel2.*xyz and *.gdb.

Parameter	Description	Unit
X	Easting NAD83, UTM Zone 14	Feet [ft]
Y	Northing NAD83, UTM Zone 14	Feet [ft]
Z	Elevation of Voxel Node	
Quaternary or Dakota Resistivity	Voxel cell resistivity value	Ohm-m
Elevation	Ground Surface Elevation NAVD 88 100 ft grid	Feet [ft]

6.2 Description of Included Google Earth KMZ Data and Profiles

In addition to the data delivered in .xyz format, several Google Earth .kmz files were created to view the geophysical AEM flight line locations and interpreted hydrogeological data. Unique .kmz files were also created for each individual flight line, as well as a .kmz file for all flight lines "as flown" and another kmz indicating the data retained for inversion. In addition, kmz's were developed for ***Q*** and ***Kd*** aquifer properties, and the near-surface recharge areas.

The Sarpy County AEM survey area as-flown and retained flight lines are located in *Appendix_3-Deliverables\ KMZ\ SarpyCounty FlightLines*.

Within the specialized interpretation kmz files, the AEM flight line is shown as well as place marks at each location where there are interpreted geologic results. The attribute data for each unique place mark contains location information (in meters and feet) plus the elevations of tops and bottoms of Quaternary aquifer material and coarse aquifer material as well as the top and bottom of sand-dominant zones within the ***Kd***. Also included are the water table elevation derived from 1995 data (the most recent compilation) and the top of the Pennsylvanian formations in the bedrock. These .kmz files are located within the "P-MRNRD Report/*Appendix_3-Deliverables/ KMZ/ P-MRNRD_Interpretation/ Sarpy_Profiles*" folder. Also in this folder is a "GoogleEarth.pdf" readme file that provides instructions in regards to the "Settings" changes that need to be made in Google Earth, and how to use the .kmz files in Google Earth including a legend of what attributes are displayed when an AEM sounding location is clicked. This file is repeated below as a convenience. An example of the P-MRNRD Interpretation kmz is presented in Figure 6-1.

In addition to the P-MRNRD interpretation kmz there are two other Google Earth kmz files dealing with aquifer properties that have been provided with the deliverables ("*Appendix 3-Deliverables\KMZ\SarpyCounty_Aquifer_Materials"*). These files (***SarpyCo_Q_AquiferMaterials_v2.kmz*** and ***SarpyCo_Kd_Sandstone_v2A.kmz***) present the locations and tops and bottoms of Quaternary aquifer material and coarse aquifer material and the sandstone/sand zone within the ***Kd*** within the Sarpy County AEM survey area. Example images from these two kmz's are presented in Figure 6-2 and Figure 6-3.

Finally, three recharge zone kmz's based on the Sarpy County AEM survey area near-surface (first 10 ft) ***Q*** aquifer materials are included in "*Appendix_3-Deliverables\ KMZ\ SarpyCounty_Recharge*". The more general kmz presents both ***Q*** aquifer material and coarse aquifer material. Then there are kmz's each for just the ***Q*** aquifer material and for the ***Q*** coarse aquifer material.

6.2.1 Included "GoogleEarth.pdf" README for "PMRNRD_Interpretation_v2.kmz"

Data Files - Please copy the folder *Sarpy_Profiles* to your C:\ drive. Do not rename any of the images within the folder.

Google Earth Instructions:

STEP 1: In Google Earth, click "Tools", then "Options".

STEP 2: In the Google Earth Options box, click the "General" tab.

STEP 3: Under "Placemark balloons", make sure the box is checked to allow access to local files and personal data.

STEP 4: Under "Display", make sure the box is checked to show web results in external browser.

STEP 5: The P-MRNRD_v2.kmz file within the folder named *Sarpy_Profiles* can now be opened and viewed in Google Earth (Figure 6-1).

Data:

East (m) – Easting coordinate in NAD83, UTM 14N, in meters

North (m) – Northing coordinate in NAD83, UTM 14N, in meters

East (ft) – Easting coordinate in NAD83, UTM 14N, in feet

North (ft) – Northing coordinate in NAD83, UTM 14N, in feet

Elev (ft) – DEM elevation in feet

WaterTable1995 Elev (ft) – 1995 Water Table elevation, in feet

Top_Quat_AquiferMaterial (ft) – Elevation of Top of Quaternary Aquifer Material zone, in feet

Bot_Quat_AquiferMaterial (ft) – Elevation of Bottom of Quaternary Aquifer Material zone, in feet

Top_Quat_Coarse_AqMat (ft) – Elevation of Top of Coarse Aquifer Material zone, in feet

Bot_Quat_Coarse_AqMat (ft) – Elevation of Bottom of Coarse Aquifer Material zone, in feet

Bedrock (ft) – Elevation of Bedrock surface, in feet

Elev Kd (ft) – Elevation of Top of Cretaceous Dakota Formation, in feet

Kd Sand Dominant Top – Elevation of Top of sand-dominant zone within the ***Kd***, in feet

Kd Sand Dominant Bot – Elevation of Bottom of sand-dominant zone within the ***Kd***, in feet

Elev Penn – Elevation of Top of Pennsylvanian formations, in feet

Profile – Link to Interpreted AEM profile images

Legend – Link to this write-up describing data channels listed here

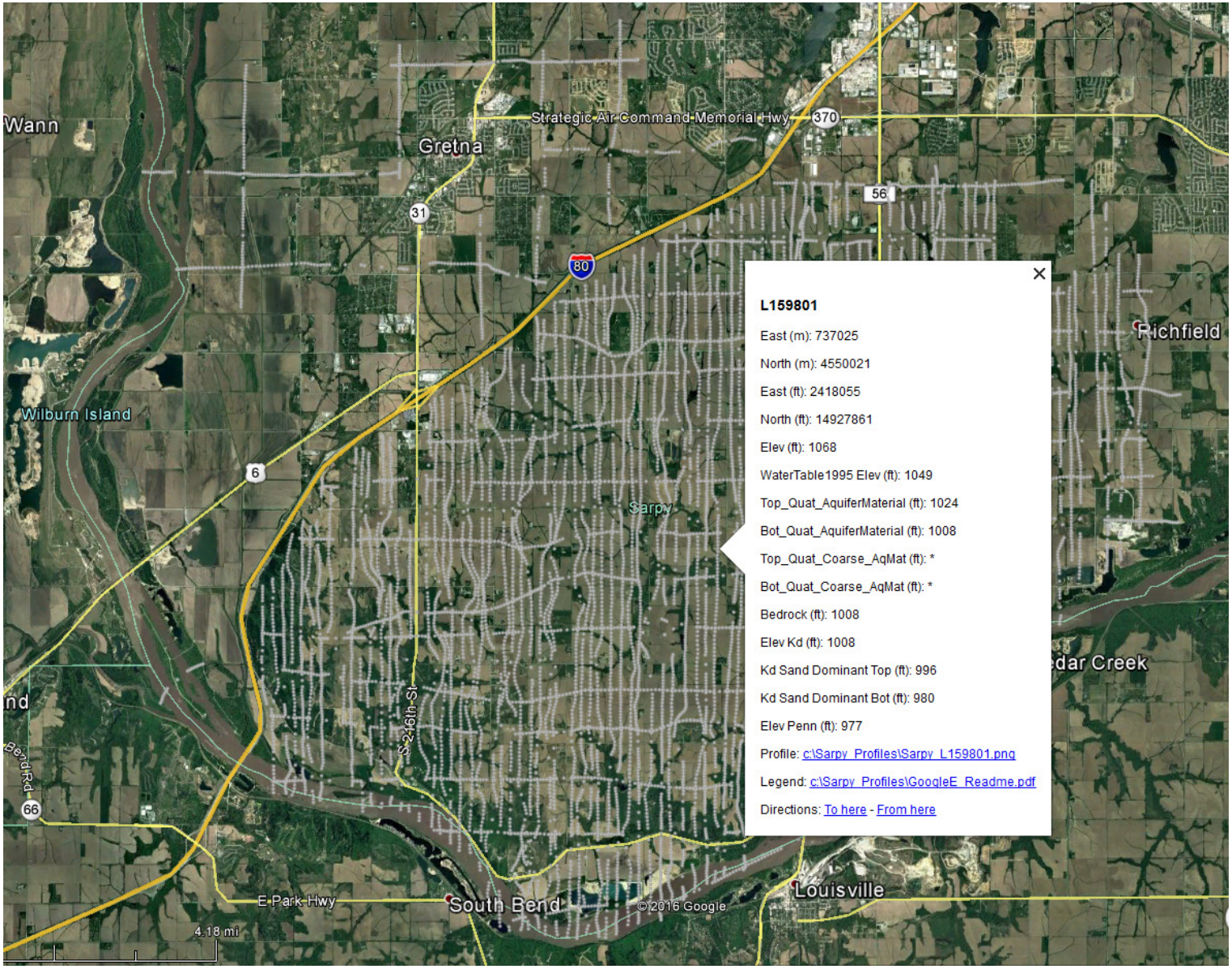


Figure 6-1. Example of Google Earth image for Sarpy County AEM survey area Interpretation kmz.

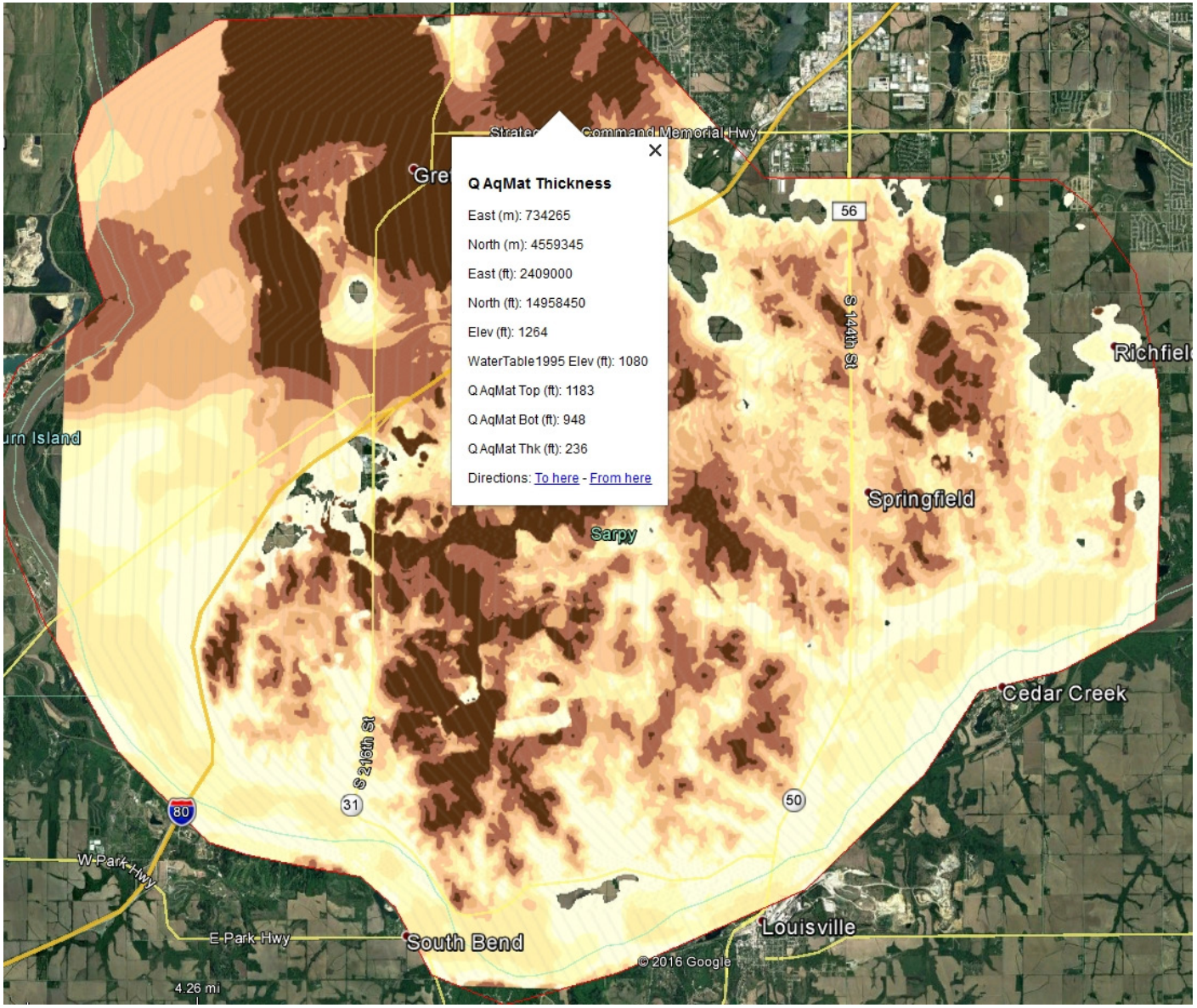


Figure 6-2. Example of Google Earth image from the Sarpy County AEM survey area Quaternary aquifer material kmz.

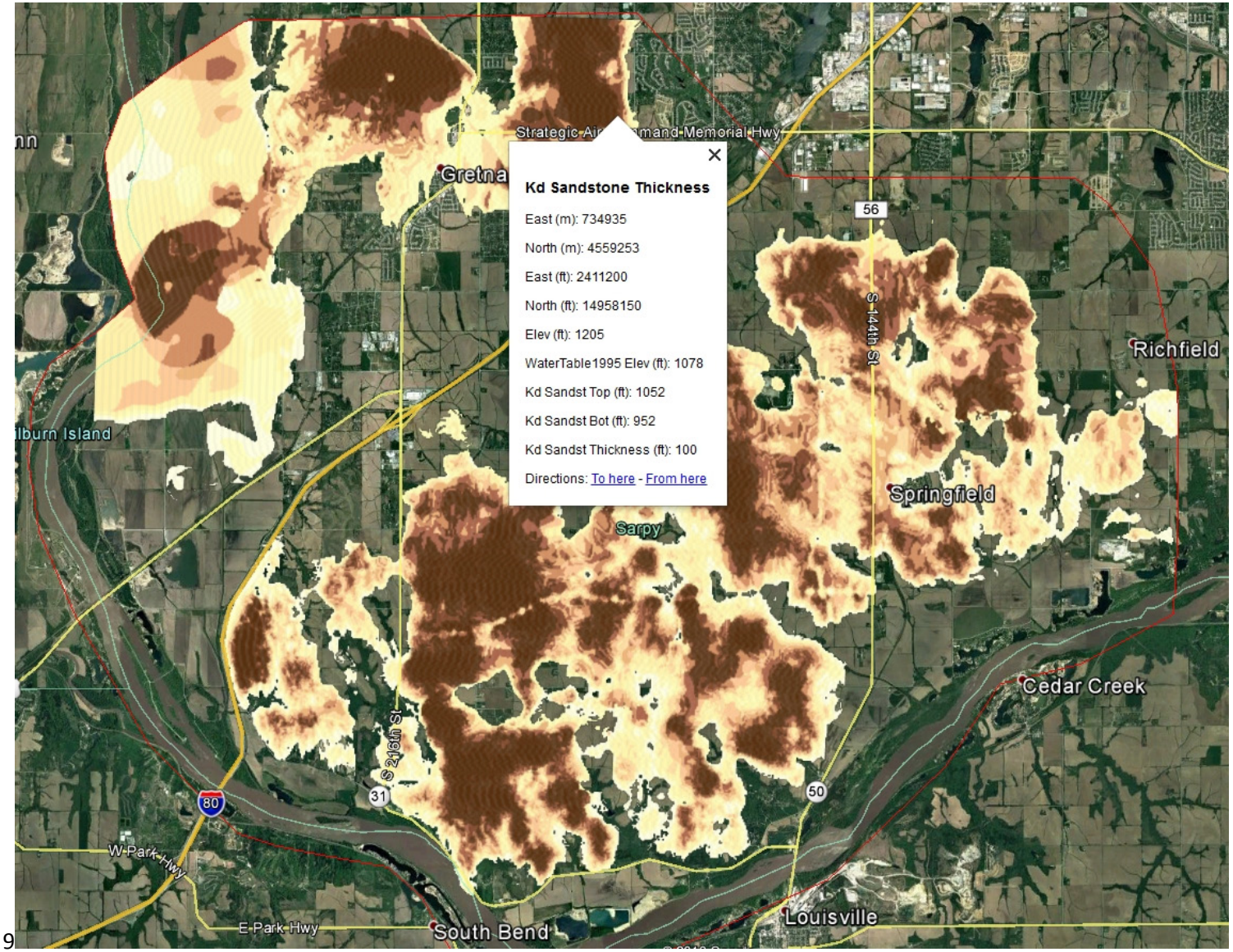


Figure 6-3. Example of Google Earth image for Sarpy County AEM survey area *Kd* sandstone/sand zones kmz.

6.3 Description of Included Profile Analyst (PA) Session Material

As discussed above PitneyBowes pbEncom Discover PA Version 2015 Release Build 15.0.13 (pbEncom, 2016) was used to create the 3D volumes and the profiles used in the interpretation within this report. In order to allow the future use of the information imported into the PA platform, PA Session Package files were created and are included within this report. A free viewer is available from the pbEncom Discover PA website: http://web2.encom.com.au/downloads/discover_3D/Discover_Viewer_2015.exe

The files located in the Appendix 3\PA_Sessions need to be unzipped and copied to a directory and then the Session file needs to be opened within Discover PA. Details on the function of Discover PA can be accessed from the pbEncom website and the help functions within Discover PA. The Session files that are included with the project deliverables are summarized in Table 6-10.

Table 6-10. Pitney-Bowes Discover PA Session Files

Area Covered	View Format	File name
Sarpy County AEM Survey Area	2D	Sarpy_Profiles.egs
Sarpy County AEM Survey Area	3D	Sarpy_3D.egs

7 References

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