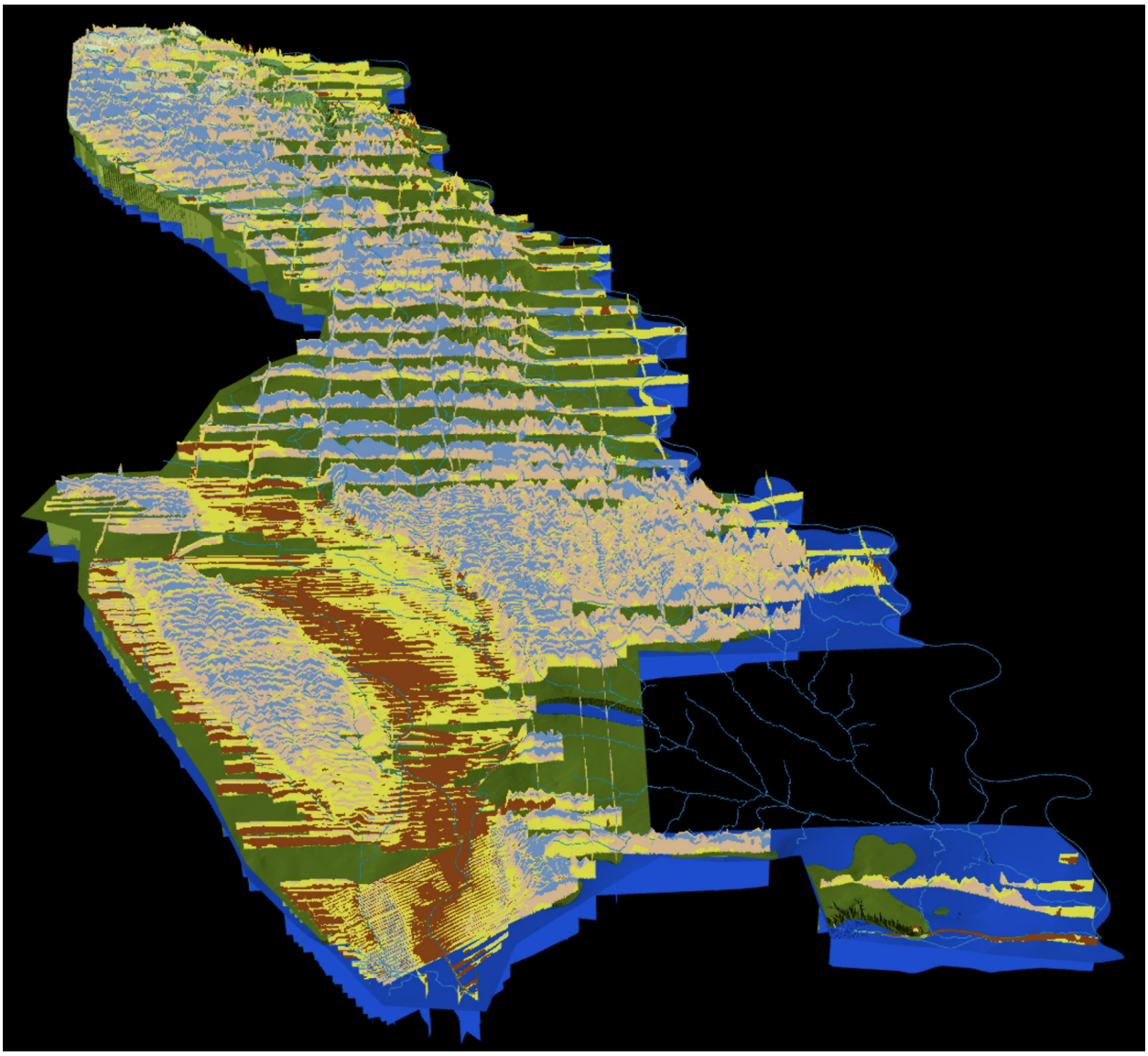
Aqua Geo Frameworks

Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Papio-Missouri River Natural Resources District



REVISED

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Executive Summary

Aqua Geo Frameworks, LLC. (AGF) is pleased to submit this report titled *"Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Papio-Missouri River Natural Resources District*.

An understanding of the hydrogeological framework in the survey area is desired to assist in resource management. AGF entered into an agreement with the Papio-Missouri River Natural Resources District (P-MRNRD) to collect, process, and interpret airborne electromagnetic (AEM) data, in conjunction with other available background information, to develop a 3D hydrogeologic framework 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 P-MRNRD project area. These flights have been provided as preliminary AEM inversions and the final AEM data and inversions are included as a product attached to this data report.

1.2 AGF began project planning upon signing of the project between AGF and the P-MRNRD. 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, test hole databases, and related aquifer characteristic studies, if available.

Upon conclusion of the design process, the P-MRNRD reconnaissance flight lines had a maximum length of approximately 41 miles (67 km) in the north-south direction and about 26 miles (43 km) at their longest in the east-west direction and were separated by approximately 3 miles (5 km) in both east-west and north-south directions. The Tekamah Block, in the north east region of the investigation area, had north-south lines about 2 miles (3.5 km) long separated by about 0.15 miles (250 m). The Southern Block, in the southern part of the 2020 AEM survey area, had predominantly east-west flight lines with a maximum length of about 22 miles (35 km) with a separation of about 0.25 miles (400 m) and a few north-south reconnaissance tie lines with a maximum length of 22 miles (35 km).

1.4 AGF acquired AEM data over the P-MRNRD, commencing 17 August 2020 and finishing on 23 August 2020, to support development of the hydrogeological framework. During this time frame, data collected over approximately 1,533 line-miles (2,484 line-kilometers) were acquired over the P-MRNRD AEM survey area. Status reports of the flying were provided to the Contract Representative of P-MRNRD daily, 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 August 18 – August 24, 2020.

1.6 AGF inverted the AEM data. Approximately 1,065 line-miles (1,725 line-kilometers) were retained for inversion, amounting to a retention rate of 69.5%. This high rate is the result of careful flight line planning and design given the infrastructure that was encountered during the acquisition. These final inverted georeferenced data are delivered to the P-MRNRD with this

report. After inversion, AGF derived 2D sections, 3D electrical models, and interpreted geologic and hydrogeologic surfaces of the surveyed area.

1.7 AGF reinverted the 2007 Ashland AEM data using the current Spatially-Constrained Inversion after recalibrating the 2007 Ashland AEM data with proximal SkyTEM data.

1.8 AGF combined the historically collected AEM data within the P-MRNRD (2007, 2014, 2015, 2016, and 2018) as well as the historical data between 3-5 miles into the Lewis and Clark, Lower Elkhorn, and Lower Platte South Natural Resources Districts. The area of Sarpy County, south of I-80, was not combined in this report. AGF integrated and/or reinterpreted the historical AEM data that was merged with the 2020 AEM data.

1.9 AGF is providing a hydrogeologic framework report that includes maps of aquifer materials and their relationships to current test holes and production groundwater wells, 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** - Information from boreholes was used to analyze the AEM inversion results and was important for all areas in the P-MRNRD. The top of the undifferentiated Pennsylvanian (***IP***) was a challenging unit to interpret due to the highly variable resistivity of the ***IP.*** Top of the bedrock for the area was developed by inspection of the borehole logs that included consolidated geologic units and CSD (Nebraska Conservation and Survey Division) bedrock contacts. The Cretaceous Carlile (***Kc***) and the Cretaceous Greenhorn Limestone and Graneros Shale ***(Kgg)*** only occurred in the northern reconnaissance lines. The CSD stratigraphic control was utilized to distinguish the Quaternary (***Q***) from the underlying ***Kc*** and ***Kgg***. Contacts between the ***Q*** and Cretaceous Dakota Group (***Kd***) often had limited or no contrast in the electrical resistivity between the different geologic formations. Use of CSD stratigraphy calls and the presence of sandstone and shale in the NE- DNR (Nebraska Department of Natural Resources) registered wells were used to pick the **Q/Kd** contact when no resistivity contrast was present. The dependence on just boreholes for geologic interpretation also has its limitations because sometimes the boreholes are wrong, improperly located, have improper stratigraphic/lithology picks, and/or other errors. These errors in the boreholes are usually encountered in the NE-DNR registered wells. Very rarely inconsistencies are encountered in the oldest of the NE- CSD wells. The limited errors in the CSD wells may very well be due to poor positioning from a time before GPS and modern survey methods. As a guide in the interpretation of the AEM, a bedrock surface was prepared using the CSD and NE-DNR borehole logs. As in all surveys of this nature the use of boreholes with AEM needs to be approached in a thoughtful and considered manner as to the value of information from an individual borehole.

2.2 **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 Group (***Kd***), and undifferentiated Pennsylvanian (***IP***). For the three northernmost flight lines the Cretaceous Carlile (***Kc***) and the Cretaceous Greenhorn Limestone and Graneros Shale ***(Kgg)*** were picked in a similar manner. The interpretive process benefited from the use of CSD and NE-DNR borehole

logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including the Quaternary aquifer material mapping is included in the appendices as well as interpretative surface grids.

2.3 **Resistivity/Lithology Relationship** - Assessment of the sediment character in the Quaternary aquifer system and the bedrock strata 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 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). This allowed for the characterization of the Quaternary ranges of resistivities present in this report. The Cretaceous Dakota Group within the P-MRNRD was split into three parts based on empirical comparisons to lithology logs. Less than 18 ohm-m was classified as Shale/Clay Dominant materials, 18 to 35 ohm-m as Siltstone/Silt Dominant materials, and 35 ohm-m and greater as Sandstone/Sand Dominant materials. This is a modification of the splits that were used in the previous P-MRNRD reports with the addition of the Siltstone/Silt Dominant class. The previous split in the Cretaceous Dakota Group was at 20 ohm-m between Shale/Clay Dominant and Sandstone/Sand Dominant material. Additional unpublished work in Eastern Nebraska using AEM data has led to a better understanding of the resistivity versus lithology within the Cretaceous Dakota Group. Lacking quality geophysical well logs in the Cretaceous Dakota Group (like those that exist in the Quaternary) makes it difficult to produce a more robust statistical distribution of the resistivity versus lithology as was done for the Quaternary materials

2.4 **Hydrogeological Framework of the P-MRNRD** - The Southern Block is dominated by the Todd Valley on the west and the central portion by the Platte River Valley and associated Elkhorn River Valley. The eastern portions of the Southern Block are dominated by loess and glacial till of the Rolling Hills. The Todd Valley and Platte Valleys are separated by an island of loess and glacial till. There are connections in the subsurface at the northern and southern ends of the Todd Valley with the Platte River. Numerous productive wells exist in the regions of the Todd Valley and the Platte Valley. The Cretaceous Dakota Group within the area contains predominantly Siltstone/Silt Dominant materials but there is a large area of Sandstone/Sand Dominant material that several wells produce out of but with lower specific yields than the overlying Quaternary. There are also a few wells screened in both the Sandstone/Sand Dominant material and the thicker Quaternary materials within the Southern Block.

The Arlington Block is bounded on the west by the Elkhorn River and trends east encompassing a previously mapped paleochannel. The area is dominated by loess and glacial Rolling Hills. Beginning at the bluffs along the Elkhorn River and continuing east southeast through the town of Arlington a package of aquifer materials exists directly on the Cretaceous Dakota Group bedrock depression. Toward Arlington there are several wells that are completed in the unit and produce well with good specific yields. Along the length of the paleochannel, the extent was revised by the AEM as several areas have little to no aquifer material. This is typical of pre-Pleistocene channels that have had Pleistocene glacial forces and other events scour the aquifer from the paleochannel. Other mapping within eastern Nebraska has also indicated this Architectural Type I channel (Korus et al., 2016). There are strong ties with the paleochannel on the western end of the Block and the Elkhorn River. The Cretaceous Dakota Group within the Arlington Block is not very productive as much of the material is Siltstone/Silt Dominant, but some wells are completed in the Dakota with lower specific capacities.

Mapping in the area of the Tekamah Block was extended to the west of the 2018 flight Block to encompass the proposed "Composite Catchment Zone" as defined by LRE (2019). This area is dominantly composed of thin unsaturated Quaternary non and marginal aquifer material overlying the shallow Cretaceous Dakota Group Siltstone/Silt and Shale/Clay Dominant materials. Very few wells exist in the area with low specific capacities. There would seem to be very low connection in the Dakota Aquifer from the west to the east side of the Tekamah Block. The eastern end of the Tekamah Block contains Dakota Sandstone/Sand Dominant material that wells produce from.

The Northern Area of the P-MRNRD is composed of reconnaissance lines only. The northern-most regions also contain Cretaceous Carlile and Cretaceous Greenhorn Limestone and Graneros Shale which are both not considered aquifers. Both of these units are heavily eroded. The Quaternary units in the area are of three general types 1) loess and glacial tills containing non- and marginal aquifer materials; 2) Missouri River alluvial deposits; and 3) small areas of paleochannel deposits of aquifer materials under the loess and glacial till. The loess and glacial tills form the backbone of the district and fall along the topographic high separating the LENRD and the P-MRNRD. There are few wells in the area and low specific capacity in the wells that are there. These materials form a strong barrier of flow across those materials. The Missouri River alluvium materials are aquifer and coarse aquifer material deposited on the underlying Cretaceous Dakota and Undifferentiated Pennsylvanian units. In the western portions of the Missouri River flood plain east of Tekamah, a clay/silt zone overlies the aquifer material forming confined aquifer conditions. Under the loess and glacial till there are selected areas of aquifer material that are not well defined by the reconnaissance lines, but may be related to paleochannels. Some of the aquifer material areas are in depressions in the bedrock and others are in areas previously identified as paleochannel systems. These areas do not look to be major aquifers or conduits to groundwater flow as they are not well defined by the specific capacity data from the NE-DNR registered well database.

2.5 Potential Recharge Zones within the P-MRNRD 2020 AEM Survey Area - The use of block flights in the Southern Area and Tekamah area illustrates the preferred method of using AEM to identify areas where the potential for recharge to the aquifer can be high and low. Locations where the flight lines are closely spaced showing either aquifer or coarse aquifer material at the land surface 0-6 feet should be considered as locations for higher likelihood for recharge because of the 2D and 3D spatial nature of the aquifer material distribution. The opposite is also true where AEM data analysis shows non-aquifer or marginal aquifer material; those areas will likely not be optimal recharge locations. These maps do not provide infiltration rates as no slopes are used and no calculations are made of the rates. The maps do provide a good indication of the silt and clay layer and boundary to recharge on the western side of the Missouri River Flood Plain.

Within the reconnaissance AEM flight area of the P-MRNRD, the highest rate of recharge can be expected along the river and stream valleys due to the presence of aquifer and coarse aquifer materials from the land surface down to the water table and beyond. Areas with aquifer and coarse aquifer materials at the surface can also become conduits for infiltration of nitrates into the groundwater system. These areas exist in the river and stream areas of the survey area where the reconnaissance lines are the basis for this determination. A potential solution for any nonpoint source water quality contamination is adding additional fresh surface water as

recharge to select areas of rangeland that can dilute any potential nitrate contaminant problem occurring from cropland. Additional work can be done to identify where the best locations are for these type of management efforts. The current recharge analysis allows for more accurate representation of the aquifer materials in the first 6 feet from the land surface downward.

2.6 Integration of historical AEM data - The reinversion of the Ashland data and the integration and merging of the historical data provide a marked enhancement in the ability to interpret the P-MRNRD AEM data. As many lines in the area were originally reconnaissance lines and/or ended at the boundaries of the NRD, the merging provided a full view of the geologic section. The ability to integrate the edges of the district provides a much more robust interpretation of the geological surfaces and extent of the geological and aquifer materials. The enhanced calibration and inversion of the Ashland Block also provided a seamless integration into the data collected in following years.

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 hydrogeologic maps provided in this report represent the completed hydrogeologic framework developed for the P-MRNRD at a reconnaissance level within the Northern Area with approximately 3-mile spacing between flight lines, and the detailed mapping of the Southern Block and the Tekamah Block flight areas. The District is virtually covered in reconnaissance level mapping. Further AEM flights should be focused on areas of well head protection and/or water development as required. Tekamah is a great example of well head protection-level data acquisition. Other areas of interest may include the mapping of the potential paleochannels that were identified under the loess and till in the Northern Area. While these areas are not the large channel systems seen in the Todd Valley, they may provide local water sources for future development. Future data collection around the metropolitan area of Omaha is limited due to the infrastructure and rapid growth within the area.

3.2 **Update the Water Table map** - The groundwater data used in the analyses presented in this report utilized the 1995 CSD water table map which is now 26 years old. Additional water level measurement locations would improve the water table map where groundwater conditions are unconfined. The areas of glacial till and loess covering the parts of the district will need great care in developing a water level map of potentiometric heads due to the confined to semiconfined nature of the area. Use of the data collected in this survey and future surveys will provide the best possible water table and conditions map for the district.

3.3 **Siting new test holes and production wells** – The AEM hydrogeological framework profiles, maps, and surfaces provided in this report provide great 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 P-MRNRD area was used in building the framework maps and profiles. Additional information from previous groundwater reports were helpful in this work. 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 more 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. A good example of this would be confined aquifers with large volumes of coarse aquifer and aquifer material with minimal sedimentary boundary conditions. The previous AEM studies have already found use by CSD and local well drillers to locate test wells and production wells within the P-MRNRD.

3.4 **Aquifer testing and borehole logging** - Aquifer tests are recommended to improve estimates of aquifer characteristics. Limited aquifer properties from previous reports 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. Examples of additional logging would be flow meter logs and geophysical logs including gamma, neutron, electrical, and induction logs. Detailing aquifer characteristics can be accomplished with nuclear magnetic resonance logging (NMR) at a reduced cost when compared to traditional aquifer tests. 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.

3.5 **Recharge Zones** - The P-MRNRD hydrogeologic framework in this report provides areas of recharge from the ground surface to the groundwater aquifer in the Block flights and along the reconnaissance lines. The area of the Missouri River would benefit from additional AEM data acquisition to define the extent and character of the silt and clay layer that is observed on the western end of the Missouri River Flood plain. As discussed above assessing the recharge area for wellhead protection would also benefit from AEM infill lines.

3.7 **Managed Aquifer Recharge** – The areas which may have potential for managed aquifer recharge (MAR) can be approximately located by the interpreted results from AEM reconnaissance line interpretations. Detailed analysis for this purpose would need to be done to determine where viable opportunities for the P-MRNRD exist and what additional information would be required for final selections of MAR sites. A detailed plan for locating and developing MAR sites would be beneficial to the P-MRNRD for storage and release of water for stream flow and other uses.

3.8 **Updating previous groundwater reports and Groundwater Management Plans** - The NRD's groundwater reports and management plans should be updated with the AEM information to make them a more comprehensive set of publications. Should future AEM work be completed, the results from that effort will help guide the future groundwater management plans for the district. The addition of estimates of groundwater in storage, recharge areas, hydrologic connection to streams and consideration of managed aquifer recharge sites will greatly improve groundwater management planning.

4. DELIVERABLES

In summary, the following are included as deliverables:

- Raw EM Mag data as ASCII *.xyz
- SCI inversion as ASCII *.xyz
- Interpretations as ASCII *.xyz
- Raw Data Files - SkyTEM files *.gex, *skb, *.lin
- ESRI ArcMapgrid files – surface, topo, *.flt
- Voxel Grid of the Tekamah and Arlington Blocks *.csv
- 2D Profiles and 3D fence diagrams of the AEM survey lines
- Relevant features and extents as ESRI Shapefiles
- Files compatible with the Nebraska Geocloud
- Google Earth KMZs for P-MRNRD AEM flight lines

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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
ASR	Aquifer Storage and Recovery
dB/dt	Change in amplitude of magnetic field with time
BMP	Best management plan
CSD	Nebraska 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
FEM	Frequency-Domain Electromagnetic
FT	Fourier Transform
FT, ft	Feet
ft^3	cubic feet
Fm	Formation
GIS	Geographic Information System
Gpm	Gallons per minute
Hr, hr	hours
Hz	Hertz (cycles per second)
IGRF	International Geomagnetic Reference Field
IP	undifferentiated Pennsylvanian units
Kc	Cretaceous Carlile Formation
Kd	Cretaceous Dakota Group
Kgg	Cretaceous Greenhorn Limestone and Graneros Shale
Km, km	Kilometers
KMZ, kmz	Keyhole Markup language Zipped file
LCI	Laterally-constrained Inversions
LCNRD	Lewis and Clark Natural Resources District
LENRD	Lower Elkhorn Natural Resources District
LPNNRD	Lower Platte North Natural Resources District
LPSNRD	Lower Platte South Natural Resources District
LRE	Leonard Rice Engineers, LLC
MAG	Magnetic (data); Magnetometer (instrument)
MCG	Minimum curvature gridding
M, m	Meters
mi^2	Miles squared
NAD83	North American Datum of 1983
MAR	Managed Aquifer Recharge
NAVD88	North American Vertical Datum of 1988
NE	Nebraska
NED	National Elevation Dataset
NE-DNR	Nebraska Department of Natural Resources

NMR	Nuclear Magnetic Resonance
NRD	Natural Resources Districts
OM	Geosoft Oasis montaj
PFC	Primary Field Compensation
PLNI	Power Line Noise Intensity
P-MRNRD	Papio-Missouri River Natural Resources District
Q	Quaternary
Rx	Receiver
recon	Reconnaissance
sec	second
SCI	Spatially-Constrained Inversion
SPCS	State Plane Coordinate System
STD	Standard Deviation
TEM	Transient, Time-Domain Electromagnetic
TDEM	Time-Domain Electromagnetic
Tx	Transmitter
UNL	University of Nebraska Lincoln
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VE	Vertical Exaggeration
V/m^2	Volts per meter squared
X, x	The x-direction in a cartesian coordinate system
XRI	Exploration Resources International
Y, y	The y-direction in a cartesian coordinate system
Z, z	The z-direction (positive is up) in a cartesian coordinate system

1 Introduction

1.1 Purpose of Current Project

Sound management of groundwater and surface water in eastern Nebraska has become increasingly important in recent years. There are expanding pressures placed on the resource by the ever growing and dynamic demands for: agricultural production, population growth and urbanization, potential contamination from natural and anthropogenic sources, industrial and commercial needs; along with ever present changing climate.

The combination of these stresses on water resources has increased the need for detailed hydrogeologic frameworks of the subsurface. Groundwater management strategies and policies implemented to address water quality concerns is another effort that can be improved with better understanding of recharge, and its relationship with the underlying aquifers. The mapping of the subsurface related to groundwater flow and hydrologic connection between different aquifers and streams is also important in understanding water quality. Geographic regions that are identified as major contributors to recharge could be areas targeted for enhanced promotion of best management practices (BMP) to reduce or eliminate future contamination events. This is best accomplished by block flights similar to Tekamah or the Southern Block in the southern part of the investigation area. Additional uses of this survey will be to determine potential areas of Managed Aquifer Recharge (MAR) to supplement current supplies of groundwater in areas if needed to replace depletions from development or supply future development. This data can be used to enhance the hydrogeologic framework for groundwater modeling for testing management scenarios at a regional level where boreholes are not sufficient or are of limited use. Where AEM block flights exist, this dense flight line data would be excellent for local groundwater models by having high resolution framework to build the model.

This report describes the general hydrogeologic conditions, assessed using data collected from this AEM survey and previous surveys. In addition to the AEM data, reports from previous studies, analysis of historic groundwater levels, and geologic descriptions from University of Nebraska-Lincoln Conservation and Survey Division (CSD) test holes, and drillers logs obtained from registered wells at the Nebraska Department of Natural Resources (NE-DNR) were used. The AEM survey data were collected along reconnaissance (recon) lines spaced approximately 3 miles (5 km) apart and the Arlington (which is part of the Southern Block), Southern, and Tekamah Block flights. The Tekamah Block had lines separated by about 800 ft (250 m) and the Southern Block had east-west lines separated by about 1300 ft (400 m). This AEM survey was planned and selected by P-MRNRD and AGF, with assistance from scientists from CSD, to assist in the development of a 3D hydrogeologic framework of this project area and to recommend future work to enhance groundwater management activities. This work was supported by the Natural Resources Commission Water Sustainability Fund, the P-MRNRD, and in-kind service from CSD.

A location map showing the P-MRNRD is presented in Figure 1-1. A Google Earth image of the "As-Flown" flight lines are presented in Figure 1-2 and also included as a kmz in Appendix 3-Deliverables

\KMZ\FlightLines. These are discussed in detail in Section 2. The main AEM flight area was between Fremont, NE and Omaha, NE and continued north to just south of Sioux City, Iowa.

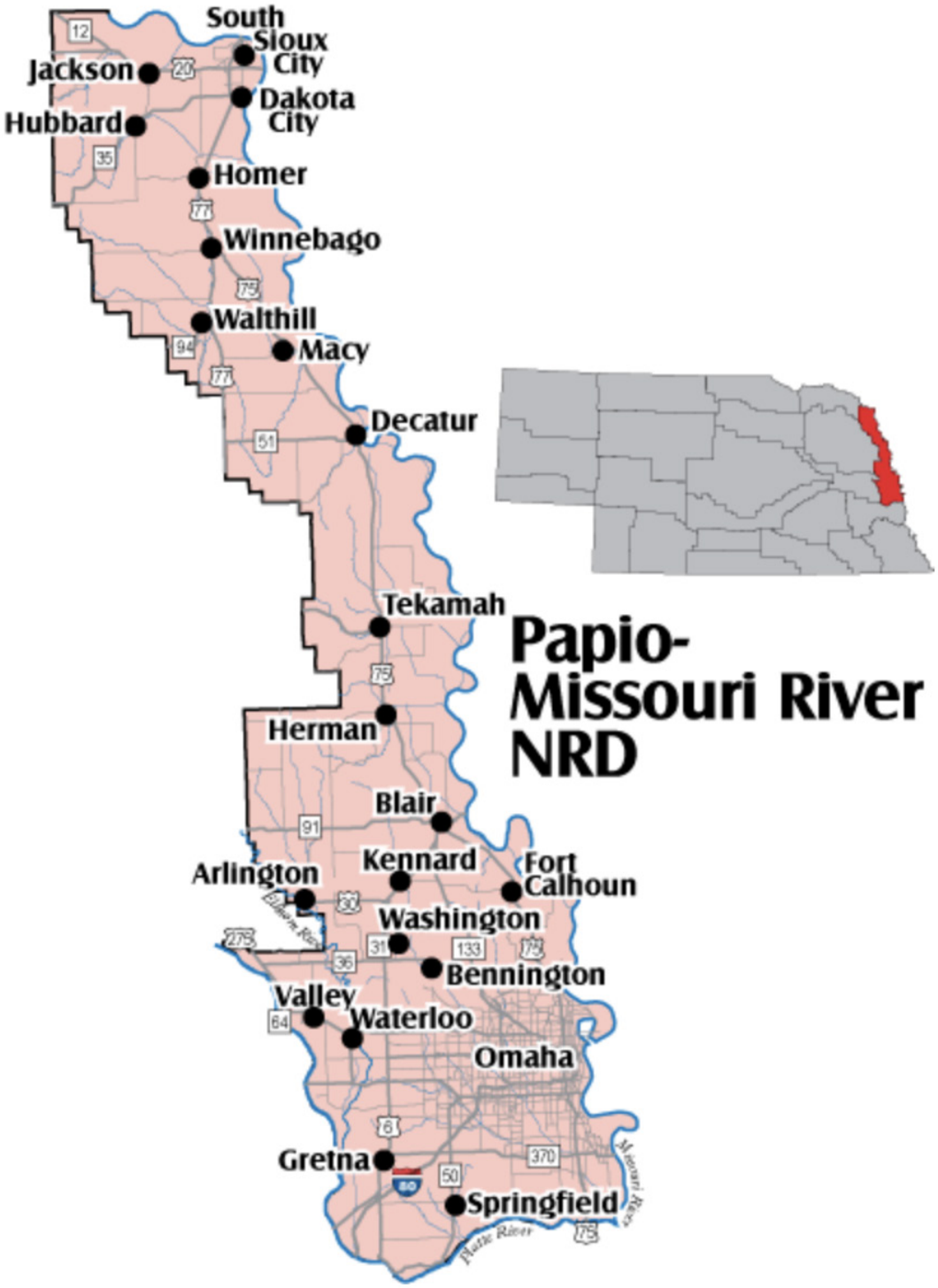


Figure 1-1. Map of the P-MRNRD in eastern Nebraska (modified from https://www.papionrd.org/).

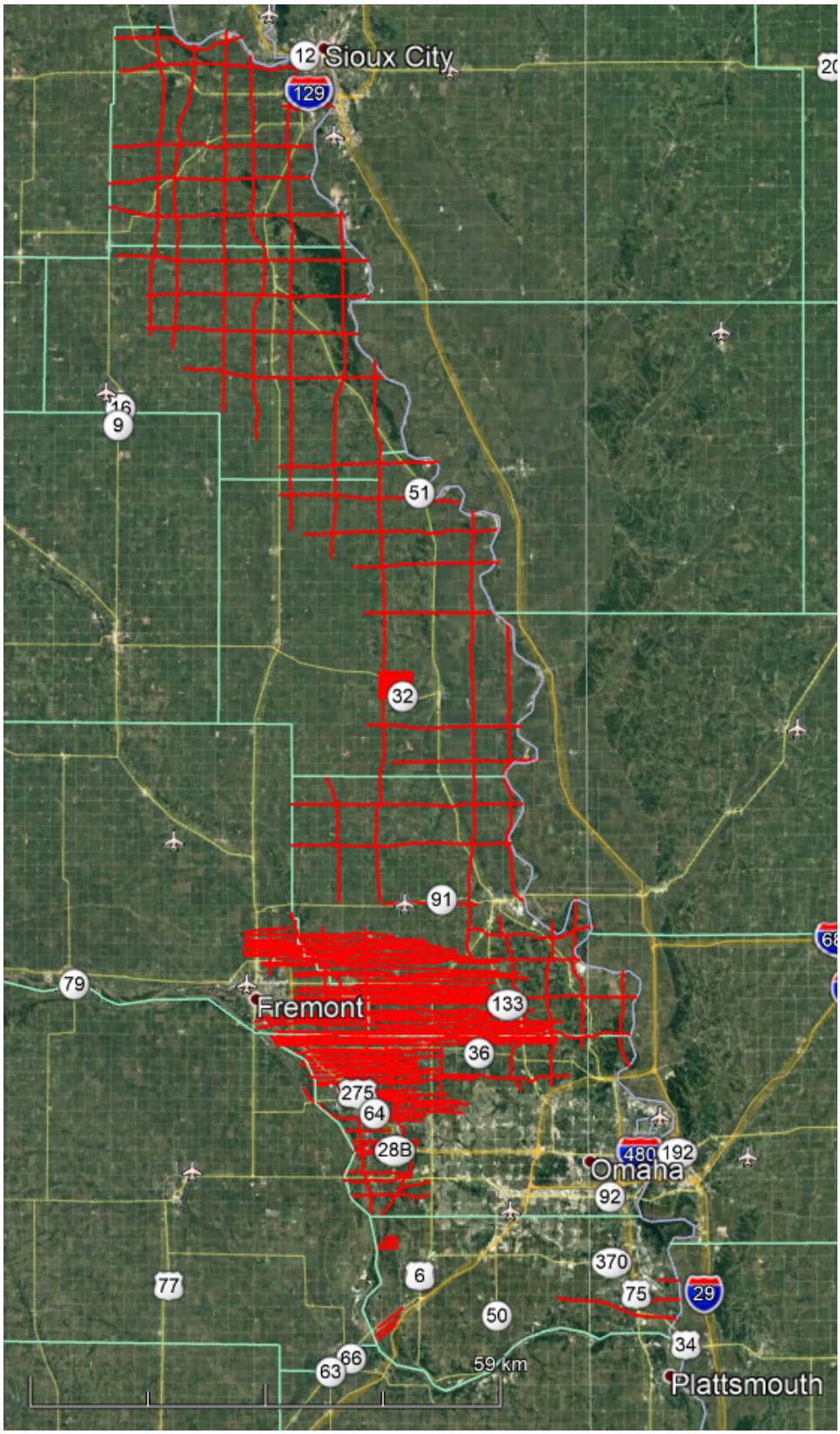


Figure 1-2. A Google Earth image of the P-MRNRD 2020 AEM survey area

1.2 Background

Under the current P-MRNRD Groundwater Management Plan, the P-MRNRD established a districtwide Groundwater Management Area, for purposes of managing groundwater quality and quantity. Figure 1-3 shows the Water Quality Phase I and Water Quantity Level I areas along with two smaller Water Quality Phase II areas near the towns of Springfield and Tekamah (modified from https://www.papionrd.org/).

The District continues to monitor groundwater quality and quantity by collecting groundwater data each year at new and repeat locations. The conclusions from these studies indicated that groundwater aquifers continue to be contaminated to varying degrees with nitrate/nitrogen and that the causes were likely related to nonpoint source contamination due to leaching of nutrient applications, both from organic and inorganic sources, and irrigation practices.

The District was also interested in understanding the framework of the paleochannels near the town of Arlington in Washington County, along with the hydrologic connection in the areas of the Platte and Elkhorn Rivers. In addition, the District was interested in the hydrologic connections of Todd Valley with the Platte River Alluvium near Fremont, Nebraska in the north and Ashland, Nebraska in the south. Additional areas of interest include the hydrologic connection to all streams and rivers along the flight lines and the framework and groundwater recharge potential of the Tekamah Block flight area is of interest for understanding water quality.

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 and more, 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. For purposes of this project, the P-MRNRD, ENWRA, and CSD are cooperating with AGF because of the shared aquifer boundaries and similar groundwater management efforts between these neighboring NRDs.

1.3 Description of the P-MRNRD 2020 AEM Project Area

The P-MRNRD spans approximately 1,790 square miles (mi^2) in eastern Nebraska. The elevation of the area ranges from 950 ft to 1520 ft above sea level**.** It is underlain by parts of two of Nebraska's eight topographic regions—Rolling Hills and Valleys (Elder et al., 1951).

Principal cities within the project area, based on 2010 population estimates, include (alphabetically) Blair (8,091), Decatur (467), Omaha (466,893), Papillion (19,539), South Sioux City (12,911), Springfield, (1,603), Tekamah (1,723), and Valley (2,271) (U.S. Census Bureau, 2013).

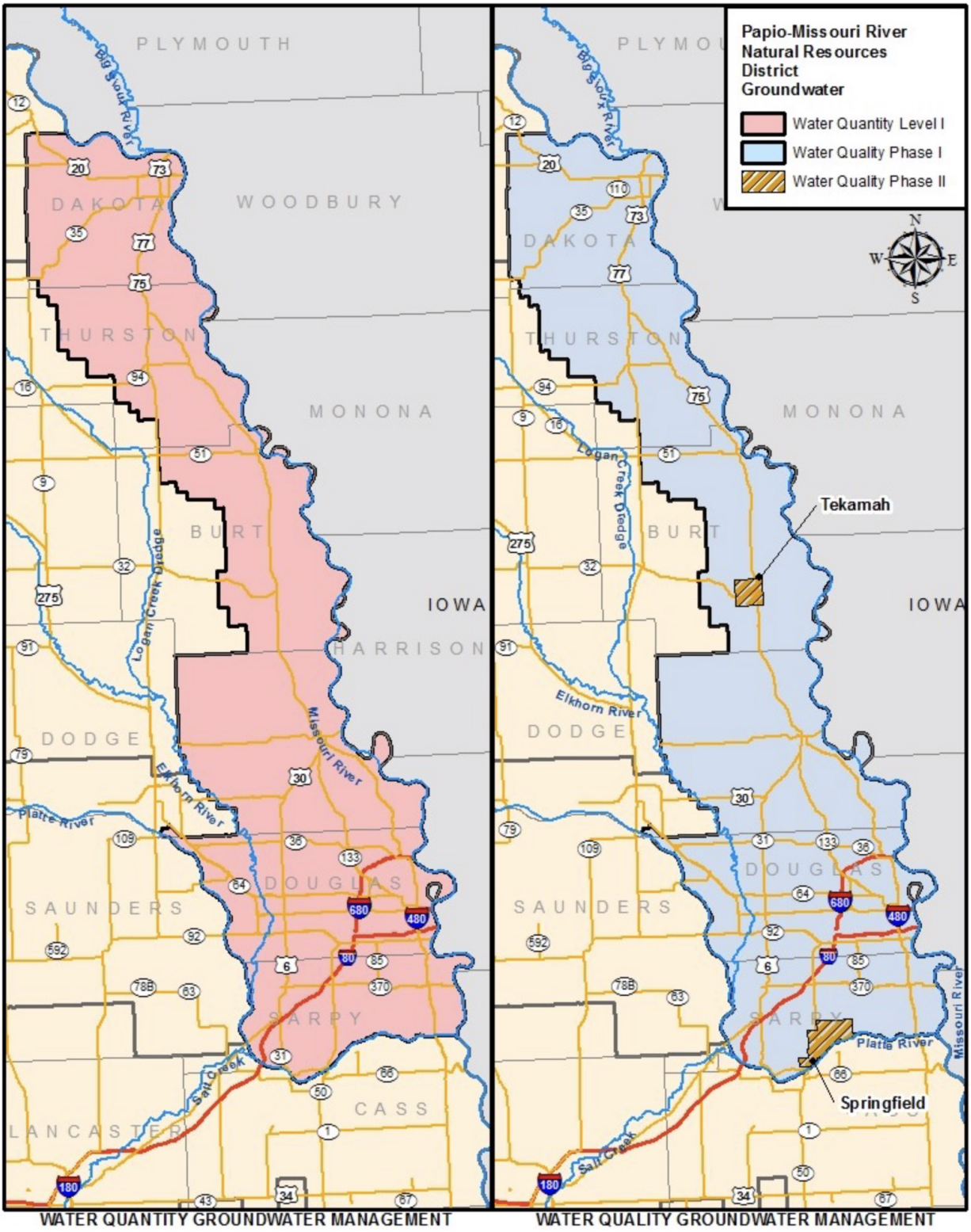


Figure 1-3. Map of the P-MRNRD groundwater management areas. The red shaded area on the left is the groundwater Quantity management area and the blue shaded area on the right along with small hatched zones are for groundwater water Quality within the boundary of the P-MRNRD (modified from https://www.papionrd.org/).

2 Hydrogeology of the Papio-Missouri River Natural Resources District

In the past decade there are have been several AEM investigations of the P-MRNRD. In the reports provided by the AGF team, there are background information sections on the geology and hydrogeology of the P-MRNRD. While these discussions will not be repeated here in order to save the reader time and space, they may be found in the following reports, listed in chronological order, which can be downloaded from the ENWRA website:

Hanson, P. R., Korus, J.T., and D. P. Divine. 2012. Three-dimensional hydrostratigraphy of the Platte River Valley near Ashland, Nebraska: Results from Helicopter Electromagnetic mapping in the Eastern Nebraska Water Resources Assessment. Bulletin 2, Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and National Resources, University of Nebraska-Lincoln. Link to PDF file: http://enwra.org/media/Ashland_ENWRA_Bull_2_2012_small.pdf

Carney, C.P., Abraham, J.D., Cannia, J.C., and Steele, G.V., 2015, Airborne Electromagnetic Geophysical Surveys and Hydrogeologic Framework Development for Selected Sites in the Lower Elkhorn Natural Resources District: prepared for the Lower Elkhorn Natural Resources District by Exploration Resources International Geophysics LLC, Vicksburg, MS. .http://www.enwra.org/LENRD2014AEMDataDownload.html

Carney, C.P., Abraham, J.D., Cannia, J.C., and Steele, G.V., 2015, Final Report on Airborne Electromagnetic Geophysical Surveys and Hydrogeologic Framework Development for the Eastern Nebraska Water Resources Assessment – Volume II, including the Lower Platte North, Lower Platte South, and Nemaha Natural Resources Districts: Prepared for the Eastern Nebraska Water Resources Assessment (ENWRA) by Exploration Resources International Geophysics LLC, Vicksburg, MS. http://www.enwra.org/aem%20data%20download.html

AGF, 2017, Hydrogeologic framework of selected areas in Sarpy County, Nebraska, Prepared for the Papio-Missouri River Natural Resources District, March 1, 2017, by Aqua Geo Frameworks, LLC, Mitchell, Nebraska. http://www.enwra.org/aem2016.html

AGF, 2019, "Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Eastern Nebraska Water Resources Assessment Area" Chapter on the Papio-Missouri River Natural Resources District: Prepared for the Papio-Missouri River Natural Resources District by Aqua Geo Frameworks, LLC, Mitchell, NE. 144p. http://www.enwra.org/aem2018.html

AGF, 2019, Summary Report on "Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Eastern Nebraska Water Resources Assessment Area" Chapters Completed for Lewis and Clark, Lower Elkhorn, Lower Platte North, Lower Platte South, Nemaha, and Papio-Missouri River Natural Resources Districts: Prepared for Eastern Nebraska Water Resources Assessment by Aqua Geo Frameworks, LLC, Mitchell, NE. 13 December 2019, 22p., http://www.enwra.org/aem2018.html

3 Additional Background Information

3.1 Boreholes

Borehole data for this project consisted of a combination of lithologic, stratigraphic, and downhole geophysical logs. The borehole information was gathered from two sources: 1) CSD Nebraska Statewide Test Hole Database (UNL, 2020), of a total of 225 wells which contains information from boreholes drilled between 1930 and 2020 by the CSD and other cooperating agencies (Figure 3-1).; 2) and the NE-DNR registered wells database of a total of 7,839 wells (Nebraska Department of Natural Resources, 2020b) (Figure 3-2). The boreholes used in this study can be found as Shape Files in the Appendix 3 Deliverables.).

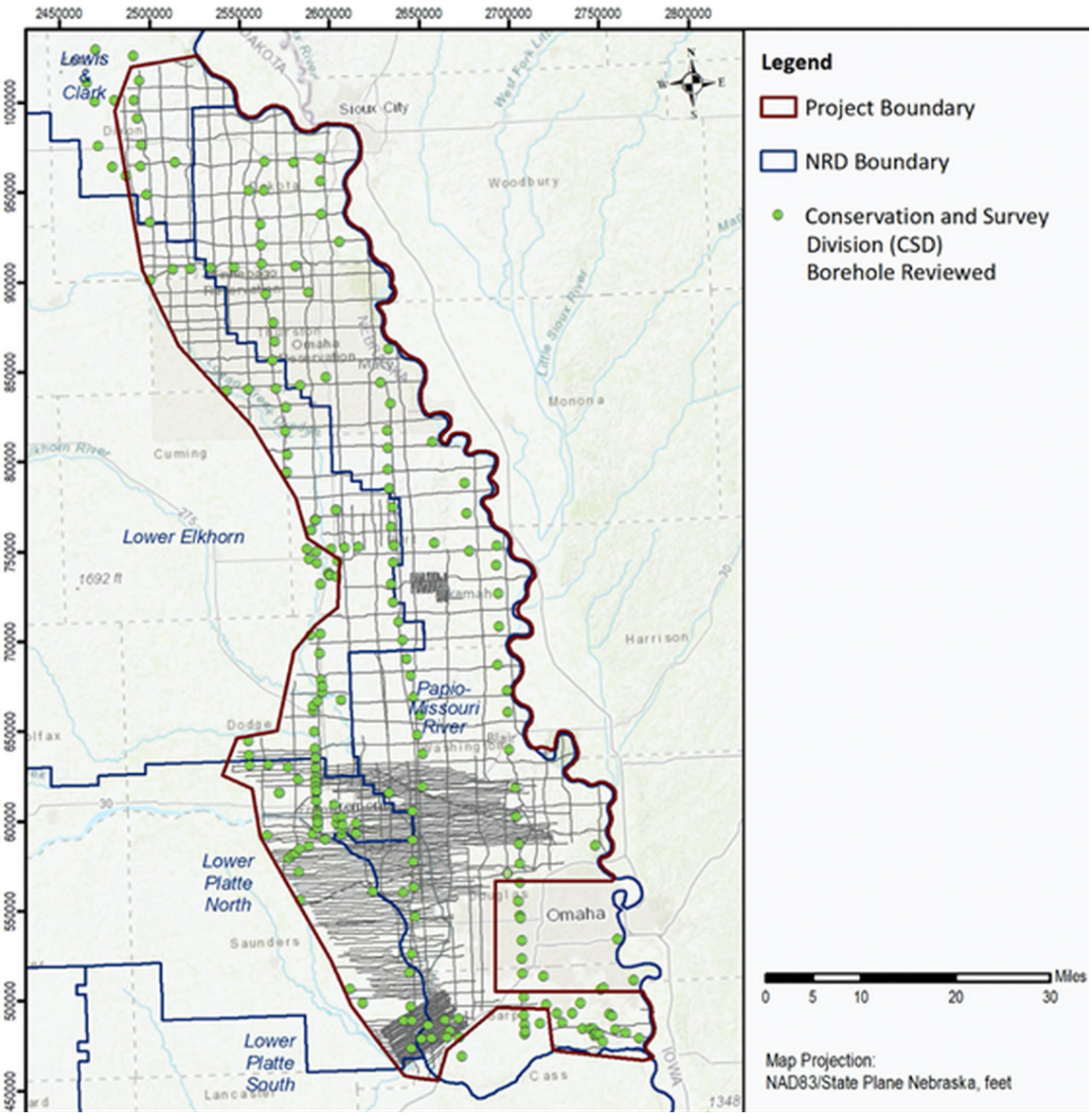


Figure 3-1. CSD borehole logs (225 within and adjacent to the project boundary) used for quality control and interpretative purposes.

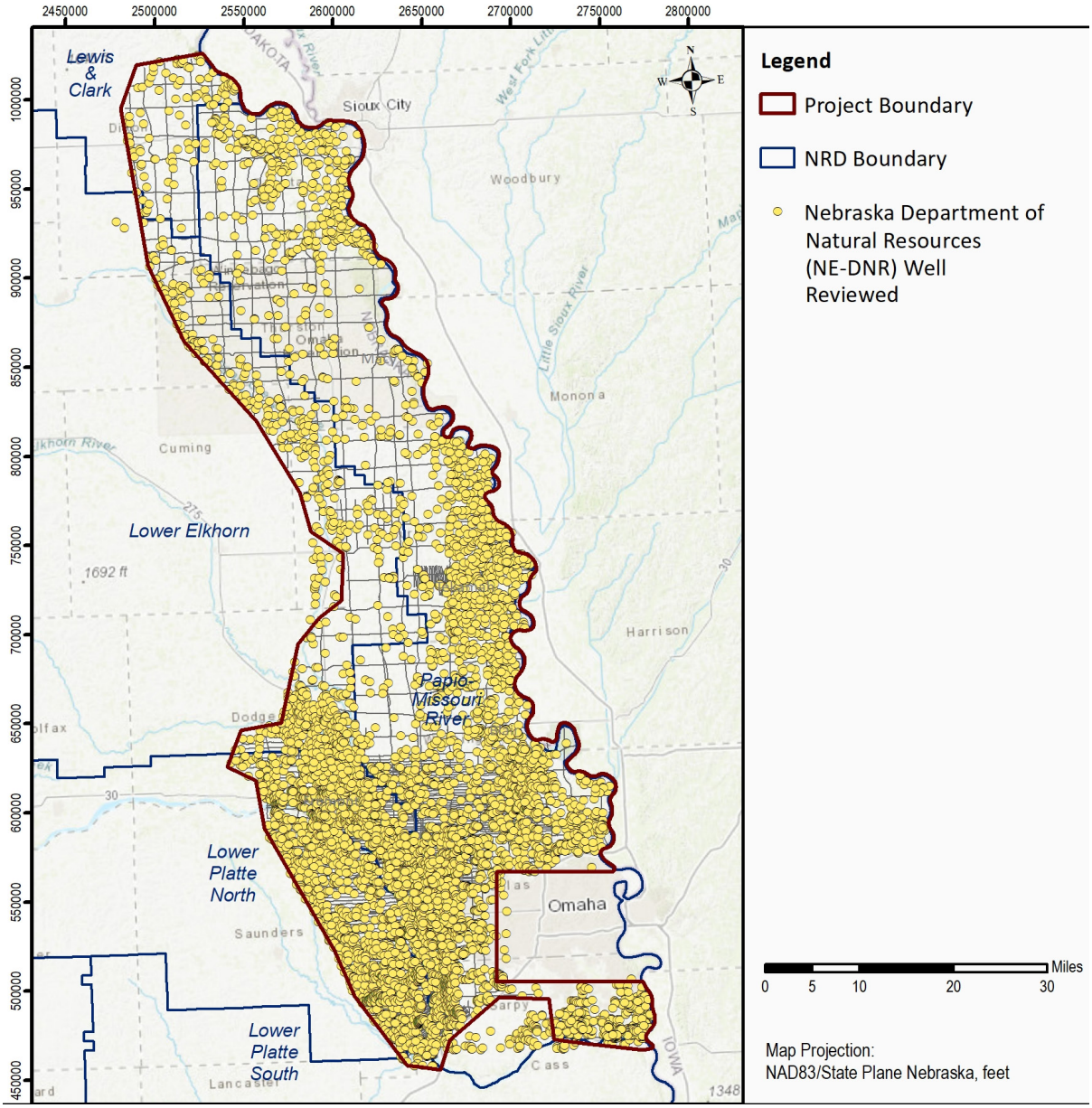


Figure 3-2. NE-DNR borehole logs (7,839 within and adjacent to the project boundary) used for quality control and interpretative purposes.

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.

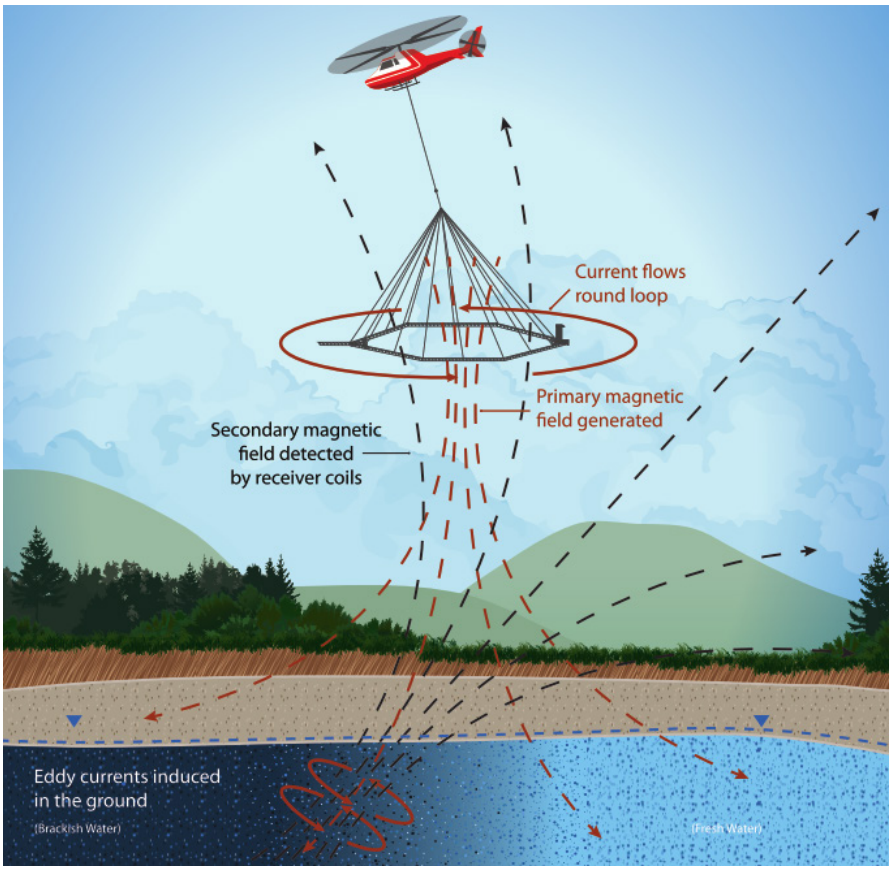
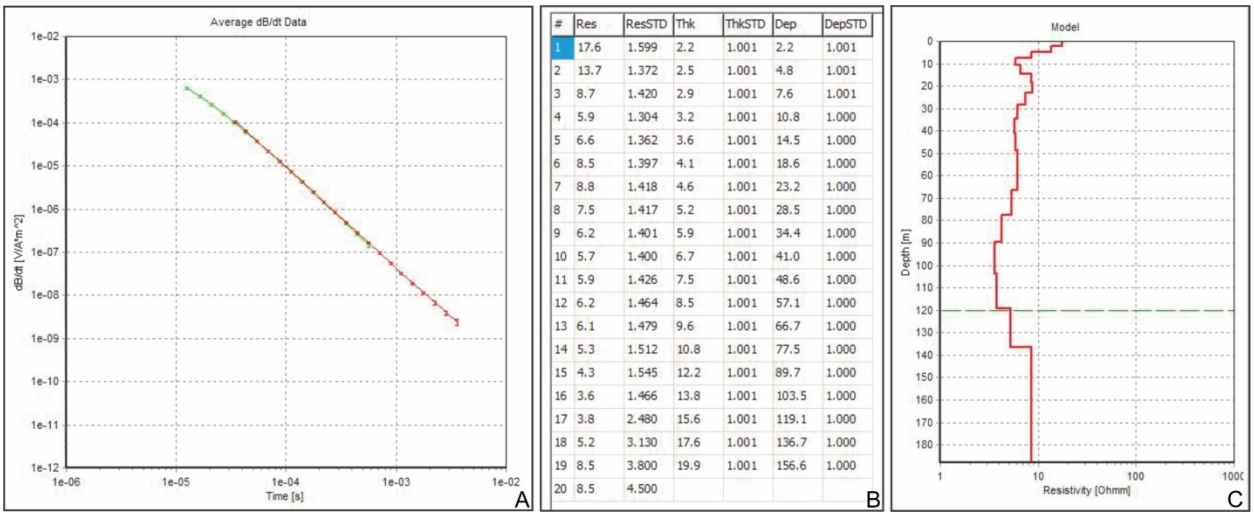


Figure 4-1: Schematic of an airborne electromagnetic survey, modified from Carney et al. (2015a).

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.



#	Res	ResSTD	Thk	ThkSTD	Dep	DepSTD
1	17.6	1.599	2.2	1.001	2.2	1.001
2	13.7	1.372	2.5	1.001	4.8	1.001
3	8.7	1.420	2.9	1.001	7.6	1.001
4	5.9	1.304	3.2	1.001	10.8	1.000
5	6.6	1.362	3.6	1.001	14.5	1.000
6	8.5	1.397	4.1	1.001	18.6	1.000
7	8.8	1.418	4.6	1.001	23.2	1.000
8	7.5	1.417	5.2	1.001	28.5	1.000
9	6.2	1.401	5.9	1.001	34.4	1.000
10	5.7	1.400	6.7	1.001	41.0	1.000
11	5.9	1.426	7.5	1.001	48.6	1.000
12	6.2	1.464	8.5	1.001	57.1	1.000
13	6.1	1.479	9.6	1.001	66.7	1.000
14	5.3	1.512	10.8	1.001	77.5	1.000
15	4.3	1.545	12.2	1.001	89.7	1.000
16	3.6	1.466	13.8	1.001	103.5	1.000
17	3.8	2.480	15.6	1.001	119.1	1.000
18	5.2	3.130	17.6	1.001	136.7	1.000
19	8.5	3.800	19.9	1.001	156.6	1.000
20	8.5	4.500				

B

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 typical municipal utility infrastructure. These include, for example, power lines, railroads, pipelines, and water pumps. Prior to AEM data acquisition in the P-MRNRD, three types of utilities (pipelines, railroads, and power lines) were located. Various public power districts in Eastern Nebraska provided power line locations in Google Earth “kmz” format that were then converted to a Geographic Information Systems (GIS) ESRI shapefile format. Some areas did not have coverage available for power line locations and were mapped by inspection from Google Earth imagery.

Public power entities that provided power line location data to ENWRA included: Burt County Power District, City of Fremont, Lincoln Electric Systems, Nebraska Public Power District, and the Omaha Public Power District.

A GIS ESRI 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 three 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 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.

Upon conclusion of the design process, the P-MRNRD reconnaissance flight lines had a maximum length of approximately 41 miles (67 km) in the north-south direction and about 26 miles (43 km) at their longest in the east-west direction and were separated by approximately 3 miles (5 km) in both east-west and north-south directions. The Tekamah Block, in the northeast region of the investigation area, had north-south lines about 2 miles (3.5 km) long separated by about 0.15 miles (250 m). The Southern Block, in the southern part of the 2020 AEM survey area, had predominantly east-west flight lines with a maximum length of about 22 miles (35 km) and a separation of about 0.25 miles (400 m) with a few north-south reconnaissance tie lines with a maximum length of 22 miles (35 km).

4.3 AEM Survey Instrumentation

AEM data were acquired using the SkyTEM304M (304M) airborne electromagnetic system (SkyTem Airborne Surveys Worldwide, 2020). The 304M is a rigid frame, dual-magnetic moment (Low and High) TEM system. The area of the 304M Tx coil is 342 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 about 110 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 ~150,000 $A*m^2$, 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). Figure 4-4 displays a couple of images of the 304M in operation.

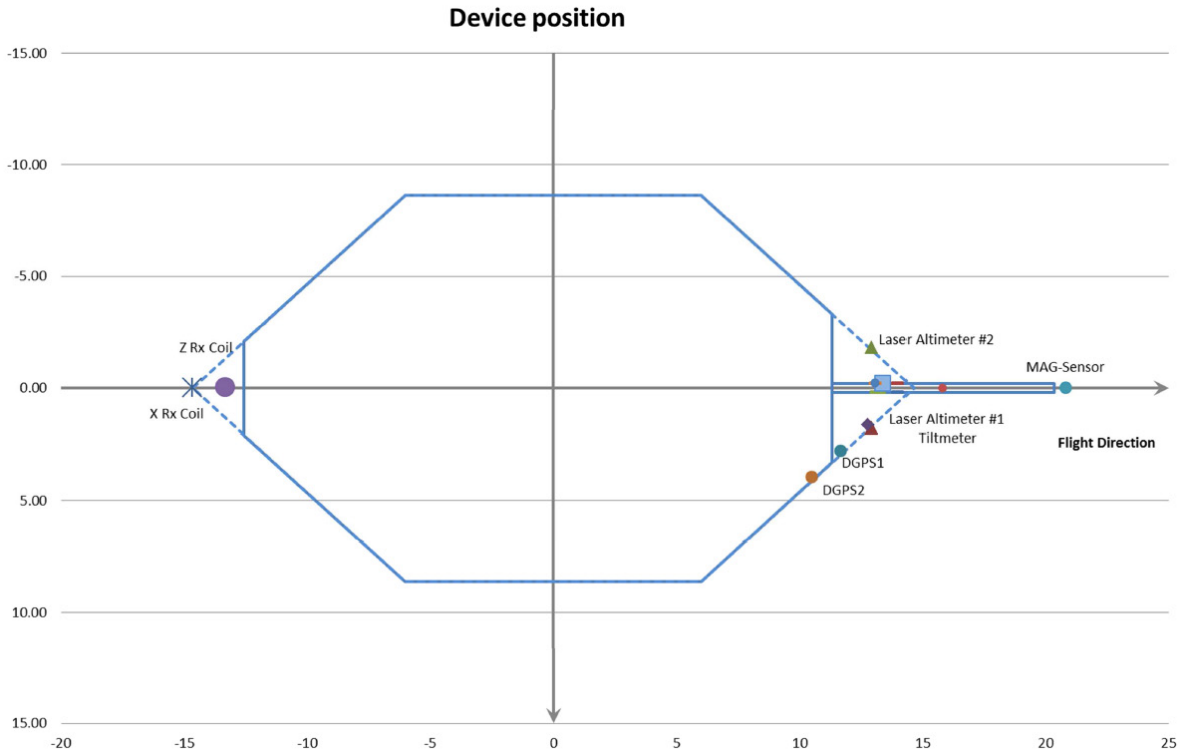


Figure 4-3: SkyTEM304M frame, including instrumentation locations and X and Y axes. Distances are in meters. Instrumentation locations listed in Table 4-1.



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

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	39.08	34.15	42.36	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	-41.16	-19.78	18.83	37.19	39.19	18.83	-19.78	-41.16
Y	-6.89	-27.98	-28.18	-10.85	10.85	28.18	27.98	6.89

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 Nebraska projects in the Middle Republican NRD on August 1, 2020. 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 1,533 line-miles (2484 line-kilometers) were acquired over the P-MRNRD AEM survey area between 17 August 2020 and finishing on 23 August 2020. The acquisition was carried out of a field on a private property within the P-MRNNRD east of Arlington, Nebraska in order to avoid crew contact with the general public due to Covid-19 restrictions. A data acquisition map for the reconnaissance flight lines is presented in Figure 4-5, for the Tekamah Block in Figure 4-6, and for the Southern Block flight lines in Figure 4-7. All flight lines are grouped by acquisition date.

For this project, the 304M was flown at an average speed of 55 mi/hr (89.8 kilometers/hr) at an average flight height of 130.3 ft (39.7 m) above land surface, using the sling-load cargo system of a Eurocopter AS350 helicopter. The average pitch (tilt angle in the +/- X direction of travel) was -3.0 degrees and the

average yaw (tilt angle perpendicular to the direction of travel) was 3.4 degrees. Images of the P-MRNRD AEM survey ground speeds are presented in Figure 4-8 (All flight lines), Figure 4-9 (Tekamah Block flight lines), and Figure 4-10 (Arlington Block flight lines). Flight heights are presented in Figure 4-11 (All flight lines), Figure 4-12 (Tekamah Block flight lines), and Figure 4-13 (Southern Block flight lines). Images of the pitch (X) angle are presented in Figure 4-14 (All flight lines), Figure 4-15 (Tekamah Block flight lines), and Figure 4-16 (Southern Block flight lines). Images of the yaw (Y) angle are presented in Figure 4-17 (All flight lines), Figure 4-18 (Tekamah Block flight lines), and Figure 4-19 (Southern Block flight lines).

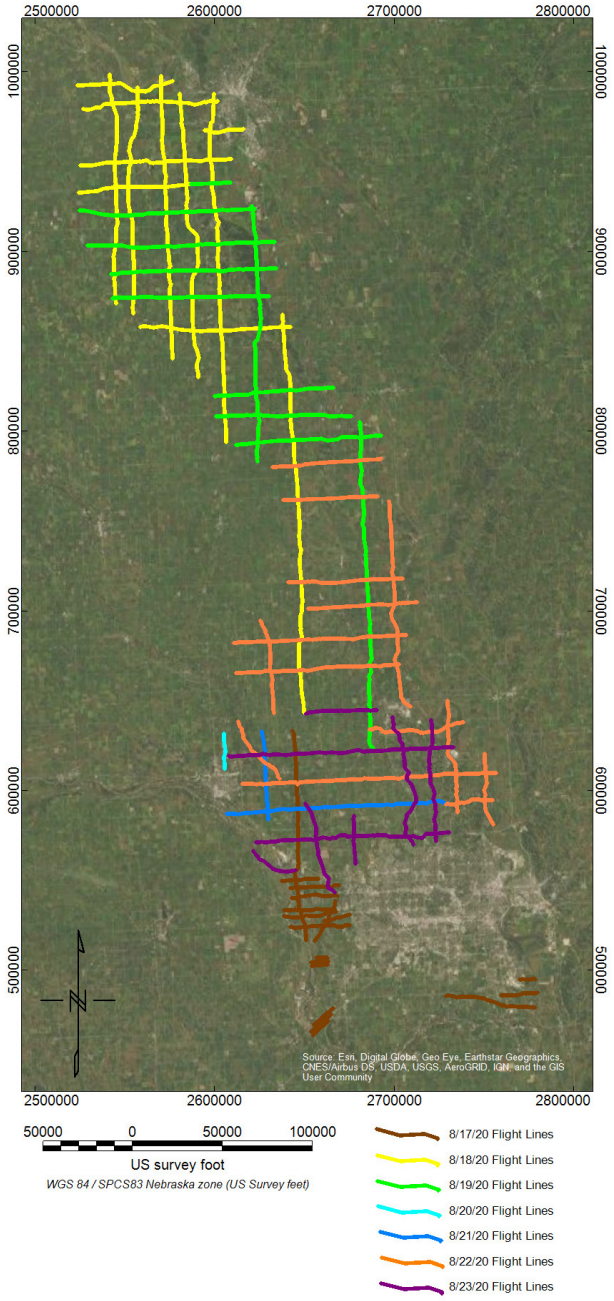


Figure 4-5. P-MRNRD 2020 Reconnaissance AEM flight lines grouped by acquisition date. Projection is Nebraska State Plane NAD83, feet.



Figure 4-6. P-MRNRD 2020 Tekamah Block AEM flight lines grouped by acquisition date. Projection is Nebraska State Plane NAD83, feet.

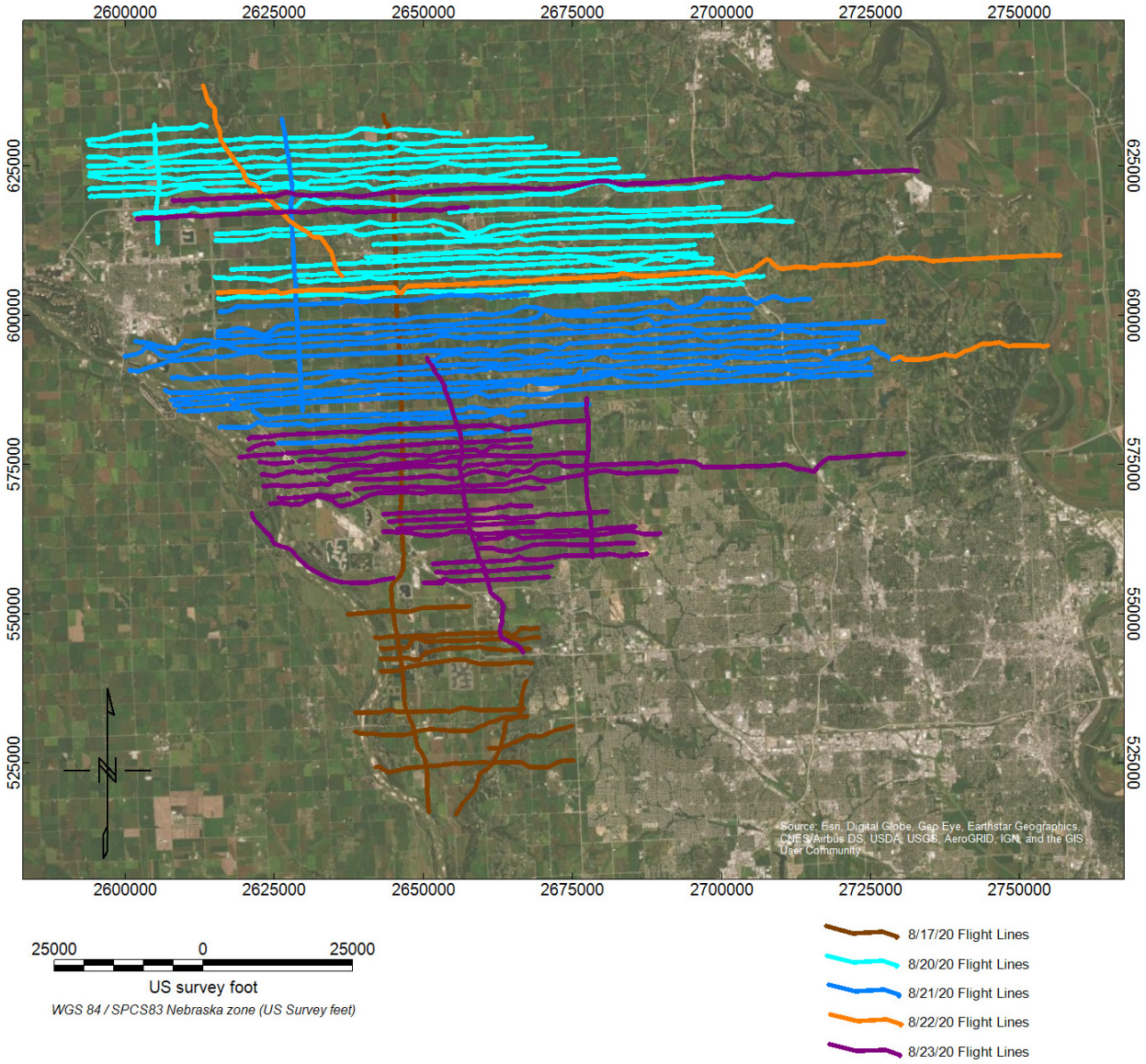


Figure 4-7. P-MRNRD 2020 Southern Block AEM flight lines grouped by acquisition date. Projection is Nebraska State Plane NAD83, feet.

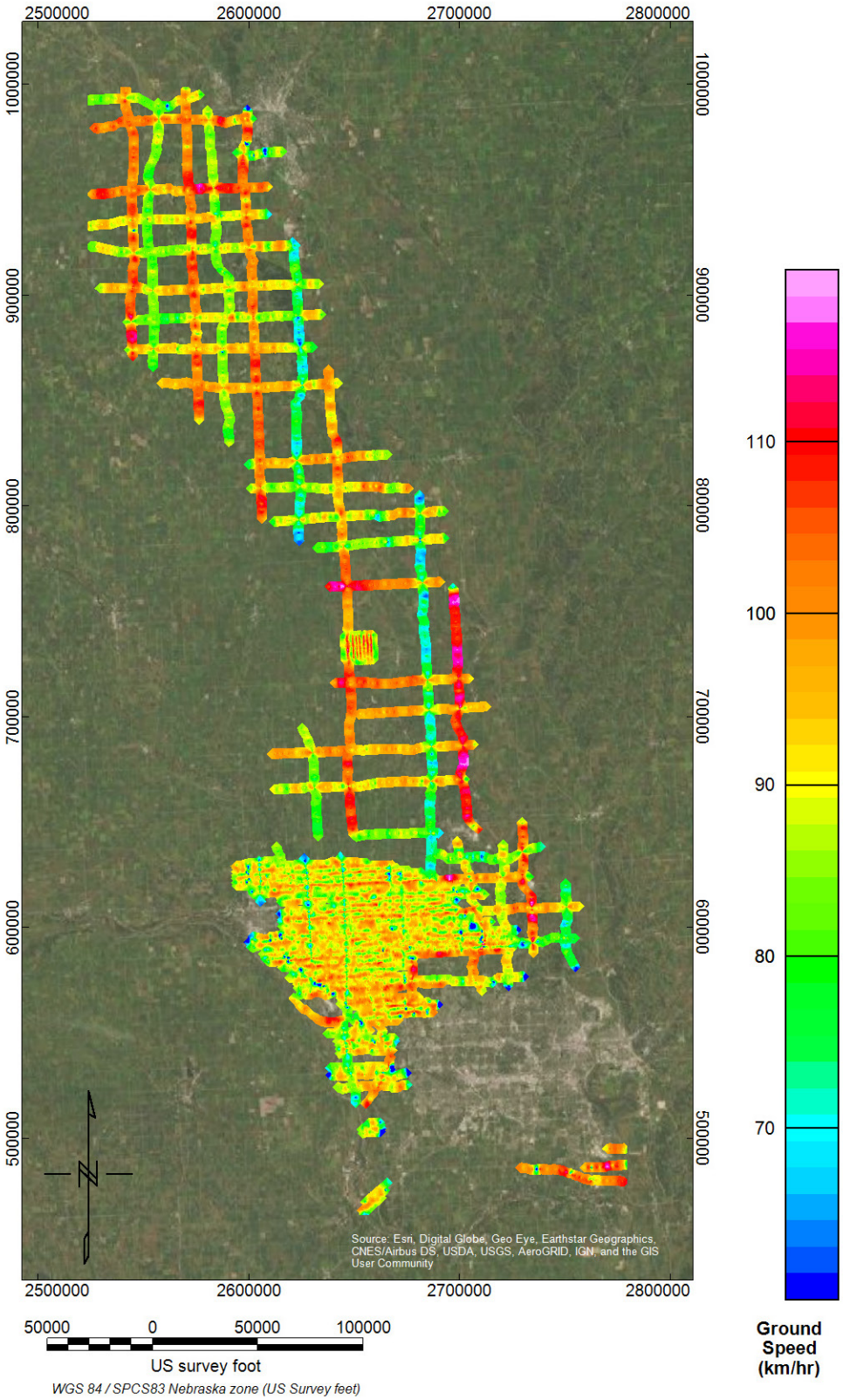


Figure 4-8. P-MRNRD 2020 AEM flight lines ground speed. Projection is Nebraska State Plane NAD83, feet.

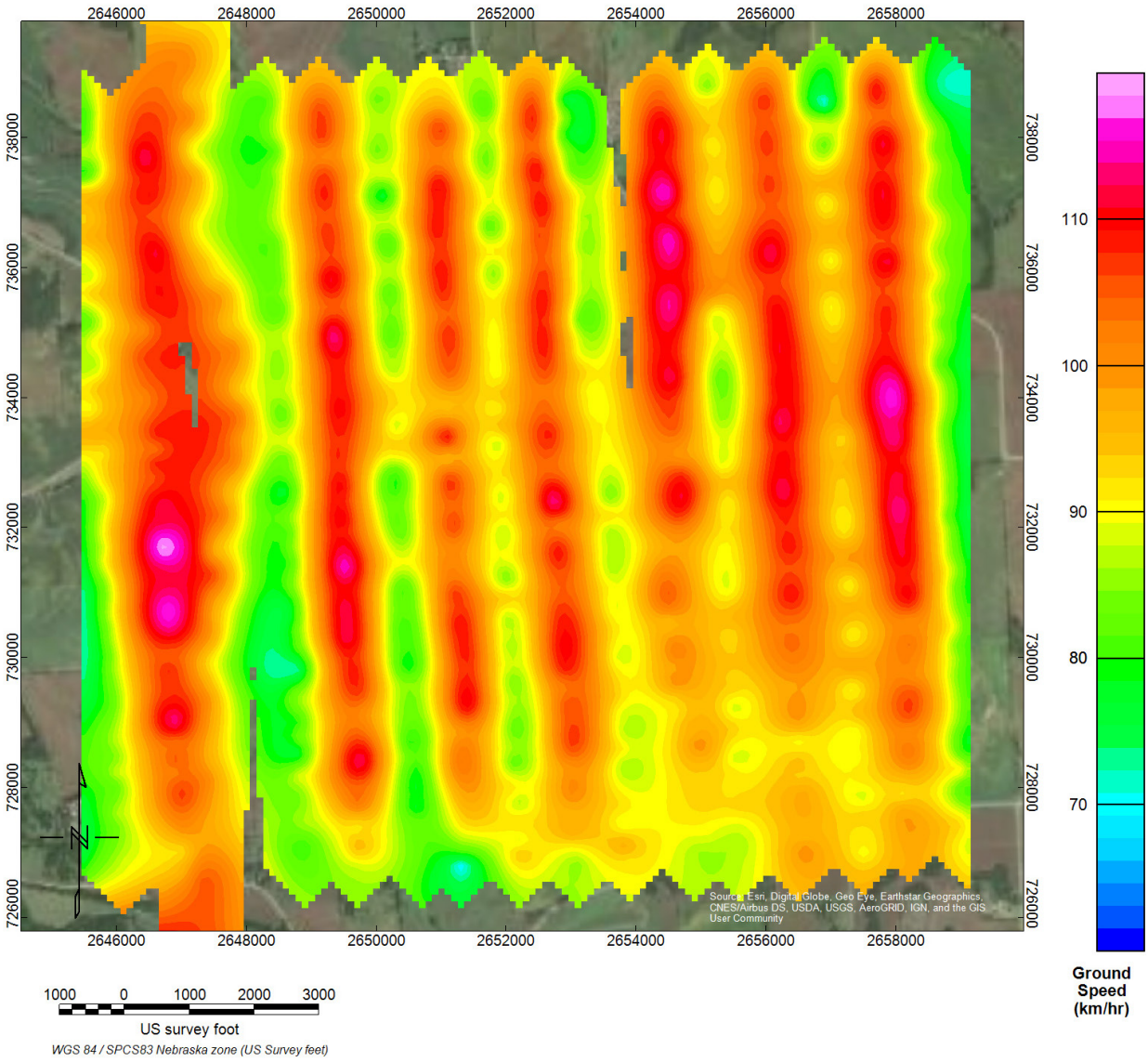


Figure 4-9. Blow up of the P-MRNRD 2020 Tekamah Block AEM flight lines ground speed. Projection is Nebraska State Plane NAD83, feet.

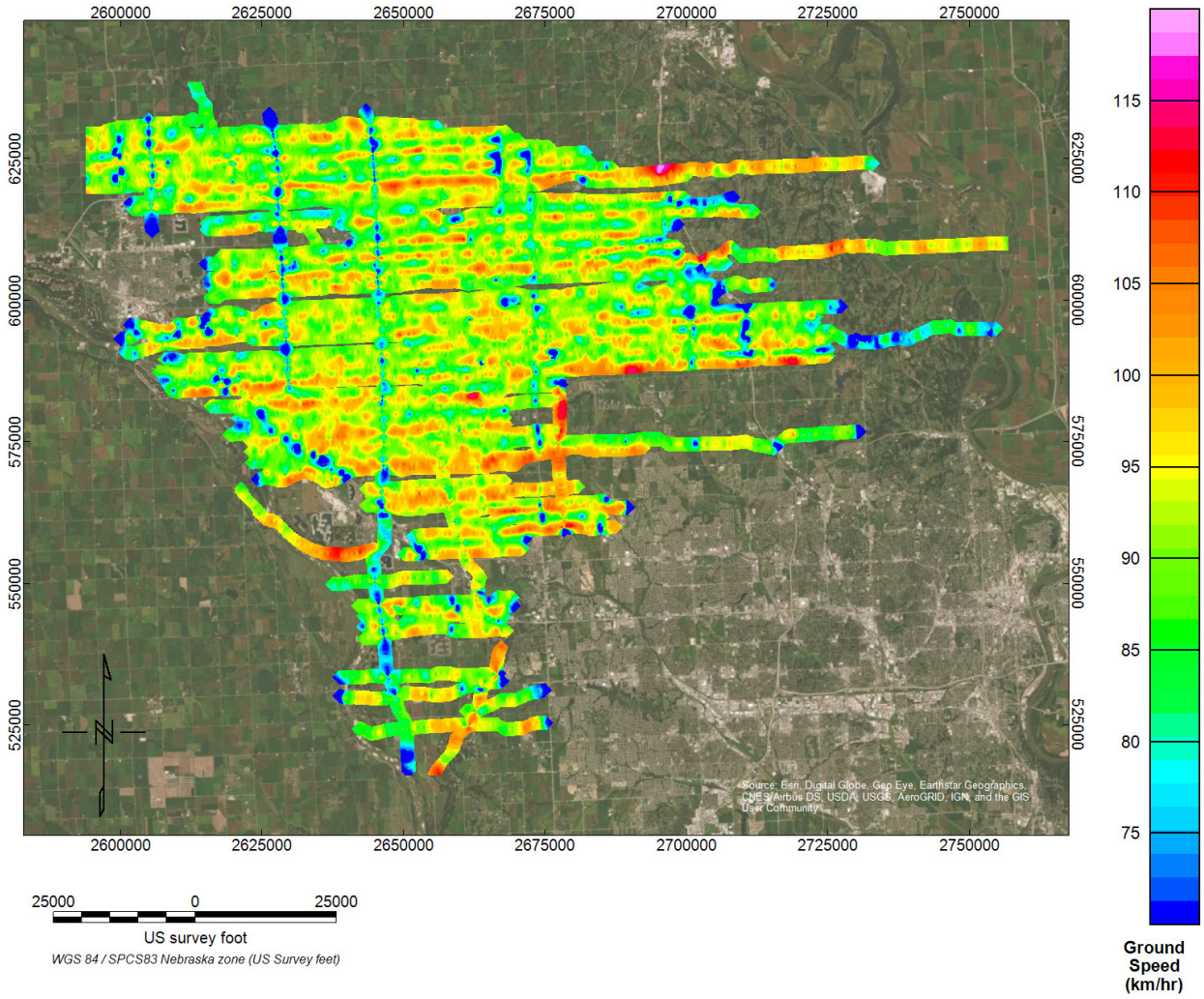


Figure 4-10. Blow up of the P-MRNRD 2020 Southern Block AEM flight lines ground speed. Projection is Nebraska State Plane NAD83, feet.

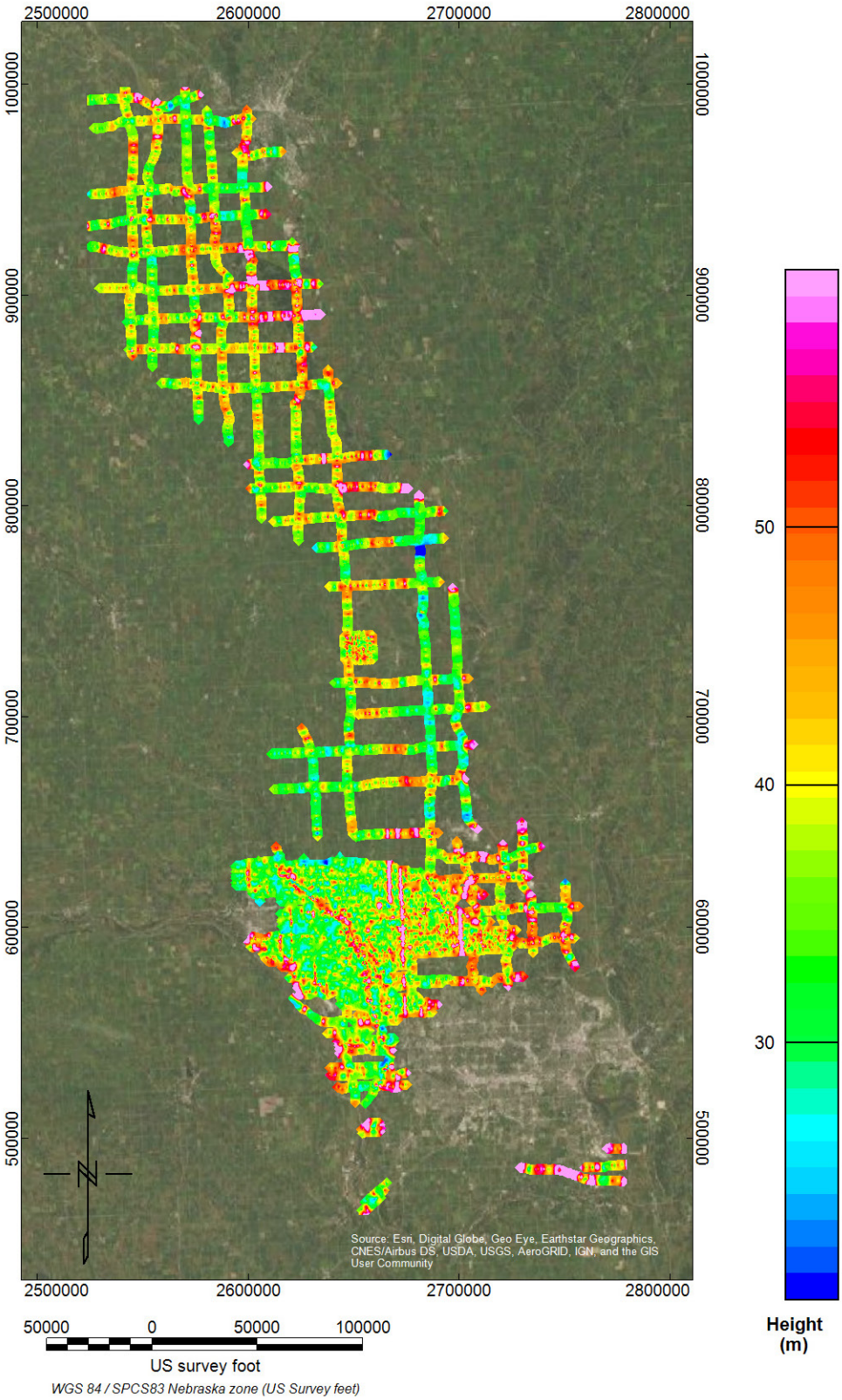


Figure 4-11. P-MRNRD 2020 AEM flight lines flight height above the ground surface. Projection is Nebraska State Plane NAD83, feet.

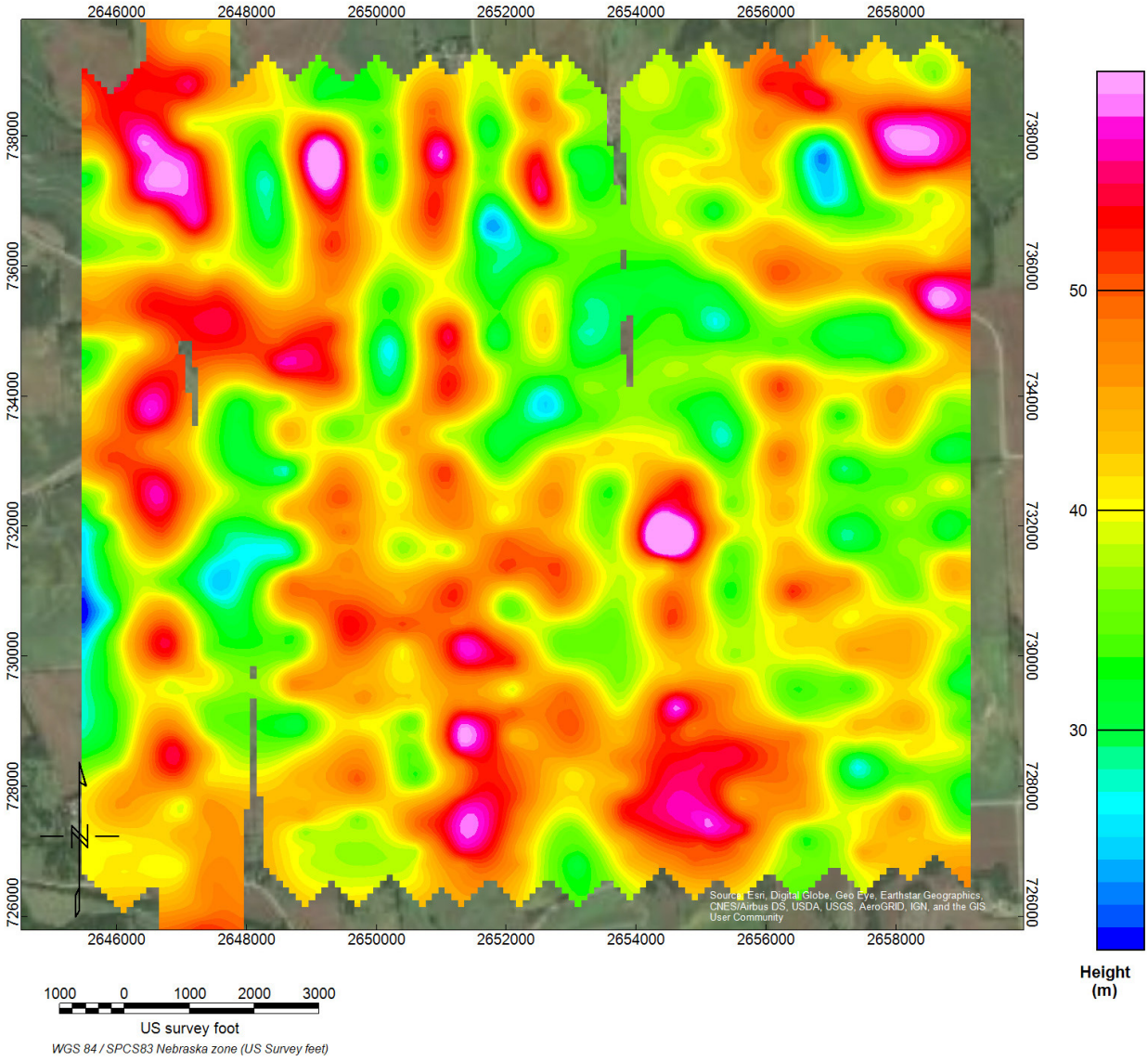


Figure 4-12. Blow up of the P-MRNRD 2020 Tekamah Block AEM flight lines flight height above the ground surface. Projection is Nebraska State Plane NAD83, feet.

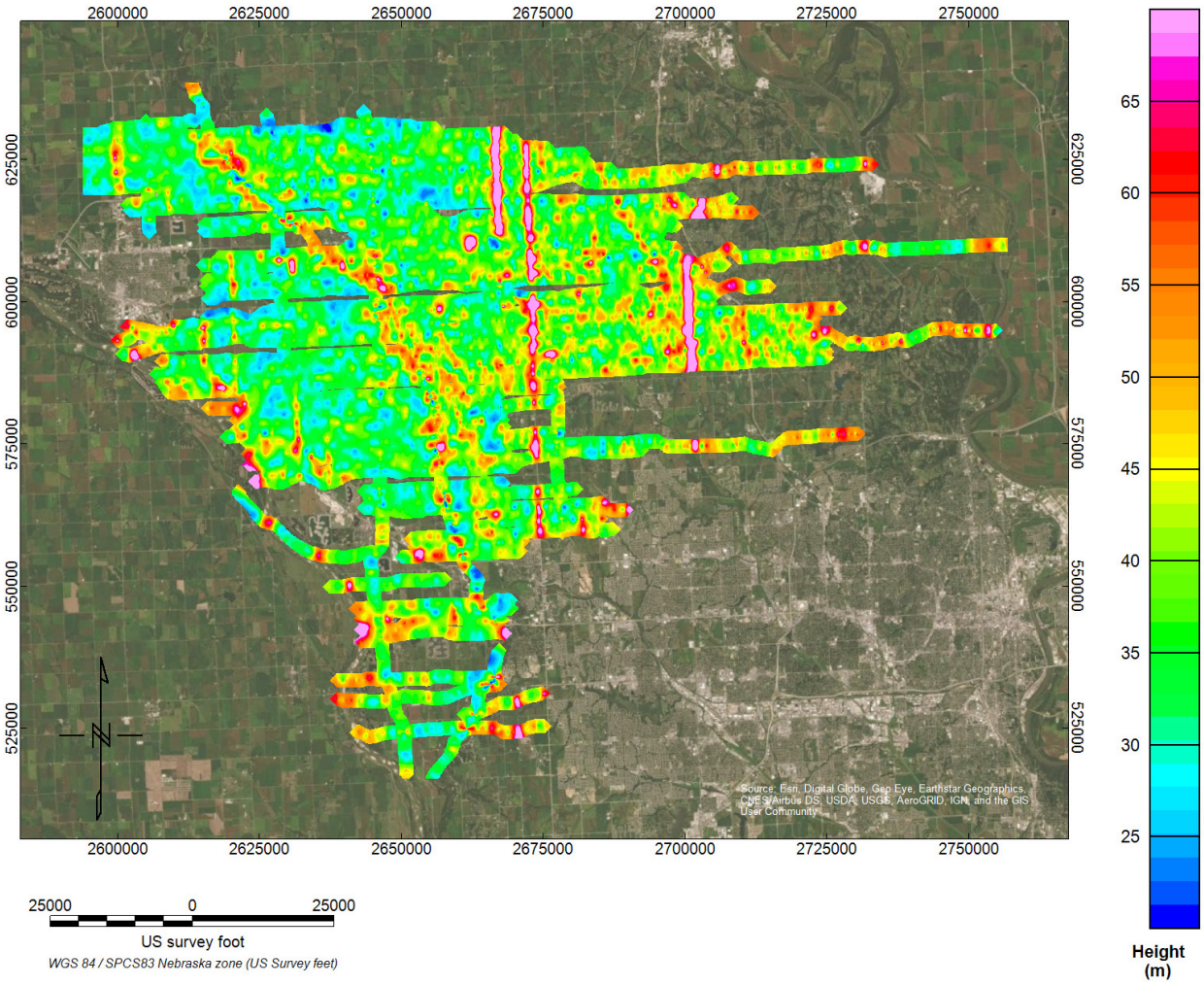


Figure 4-13. Blow up of the P-MRNRD 2020 Southern Block AEM flight lines flight height above the ground surface. Projection is Nebraska State Plane NAD83, feet.

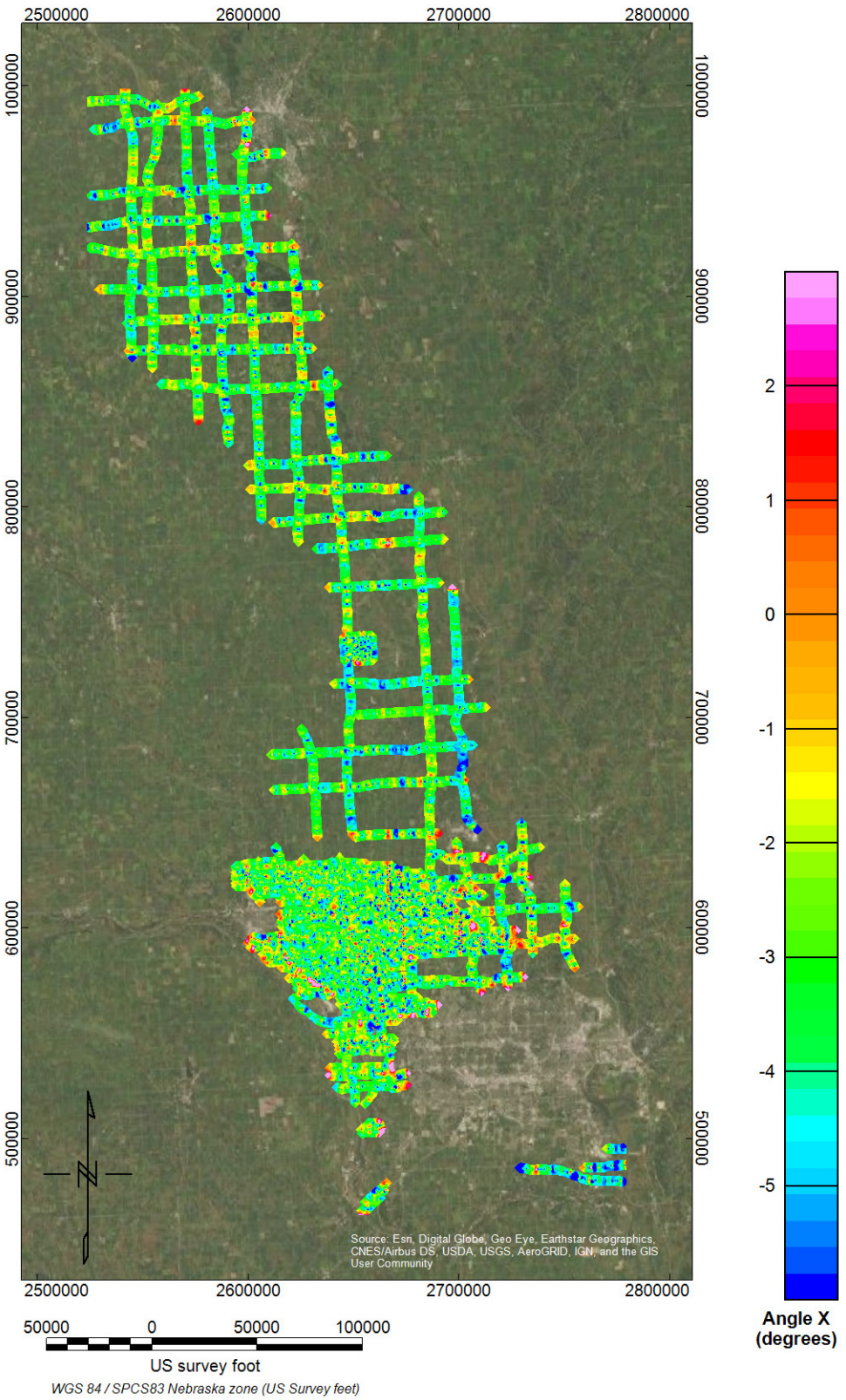


Figure 4-14. P-MRNRD 2020 AEM flight lines pitch angle in the +/-X direction of travel. Projection is Nebraska State Plane NAD83, feet.

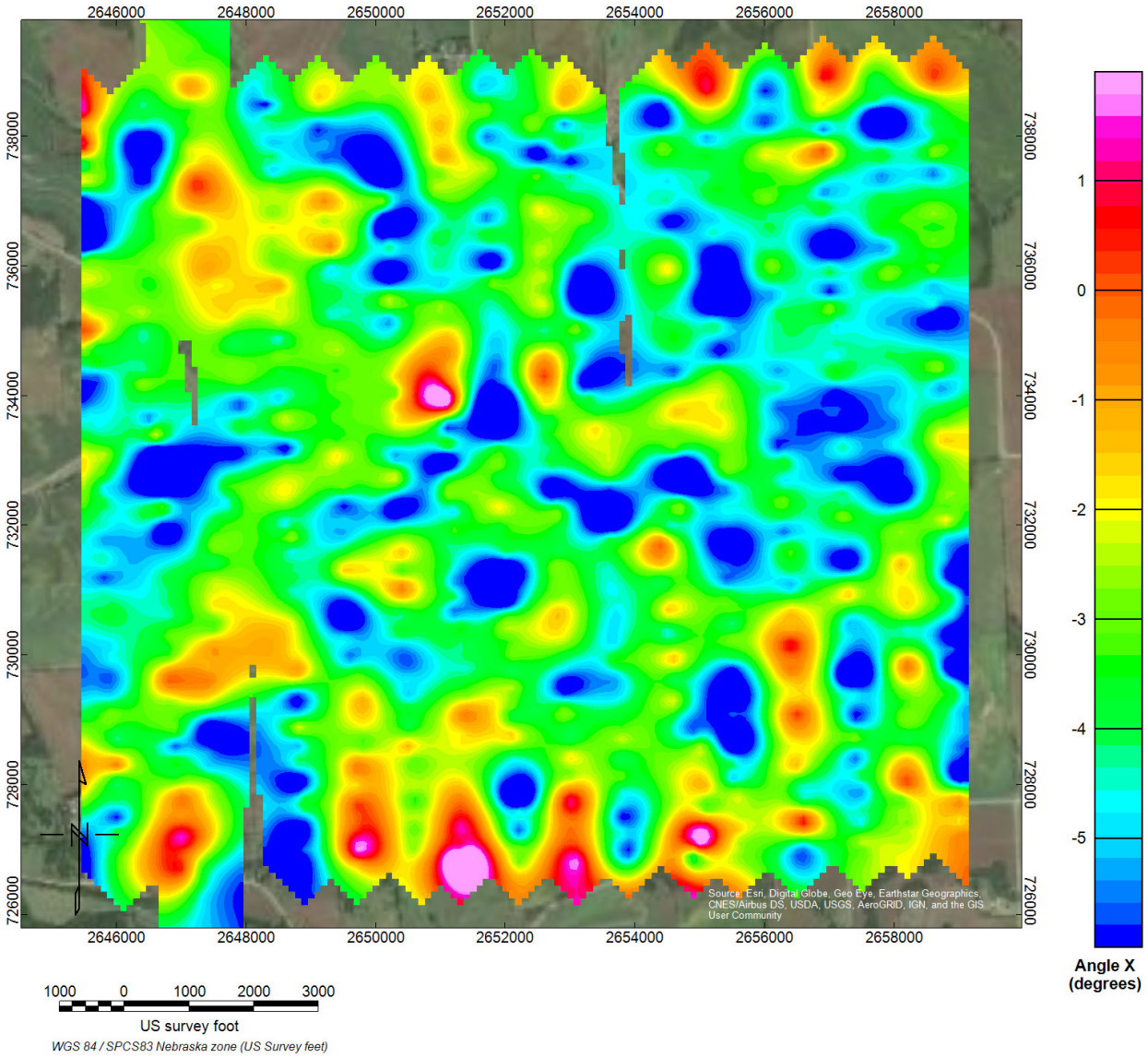


Figure 4-15. Blow up of the P-MRNRD 2020 Tekamah Block AEM flight lines pitch angle in the +/-X direction of travel. Projection is Nebraska State Plane NAD83, feet.

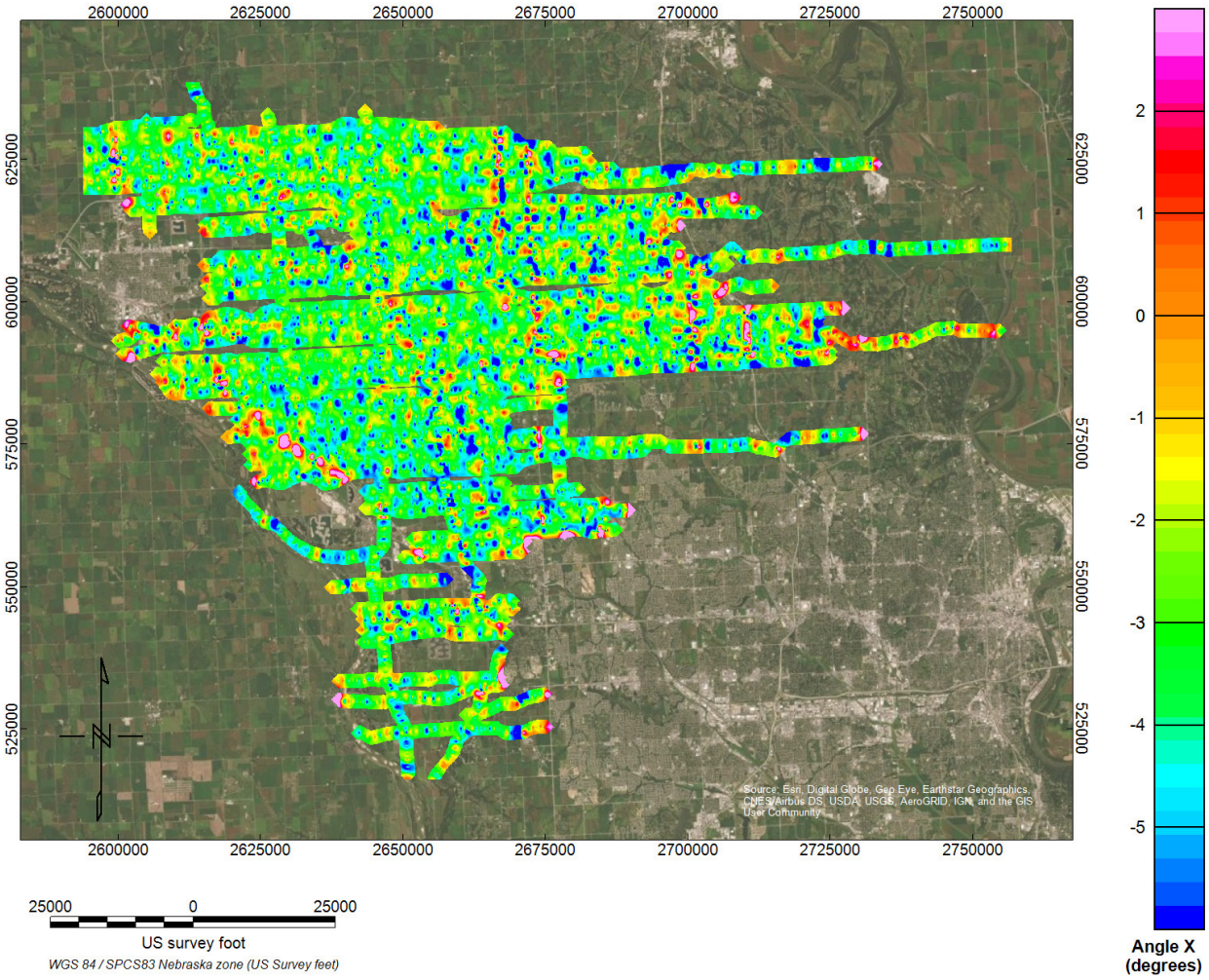


Figure 4-16. Blow up of the P-MRNRD 2020 Southern Block AEM flight lines pitch angle in the +/-X direction of travel. Projection is Nebraska State Plane NAD83, feet.

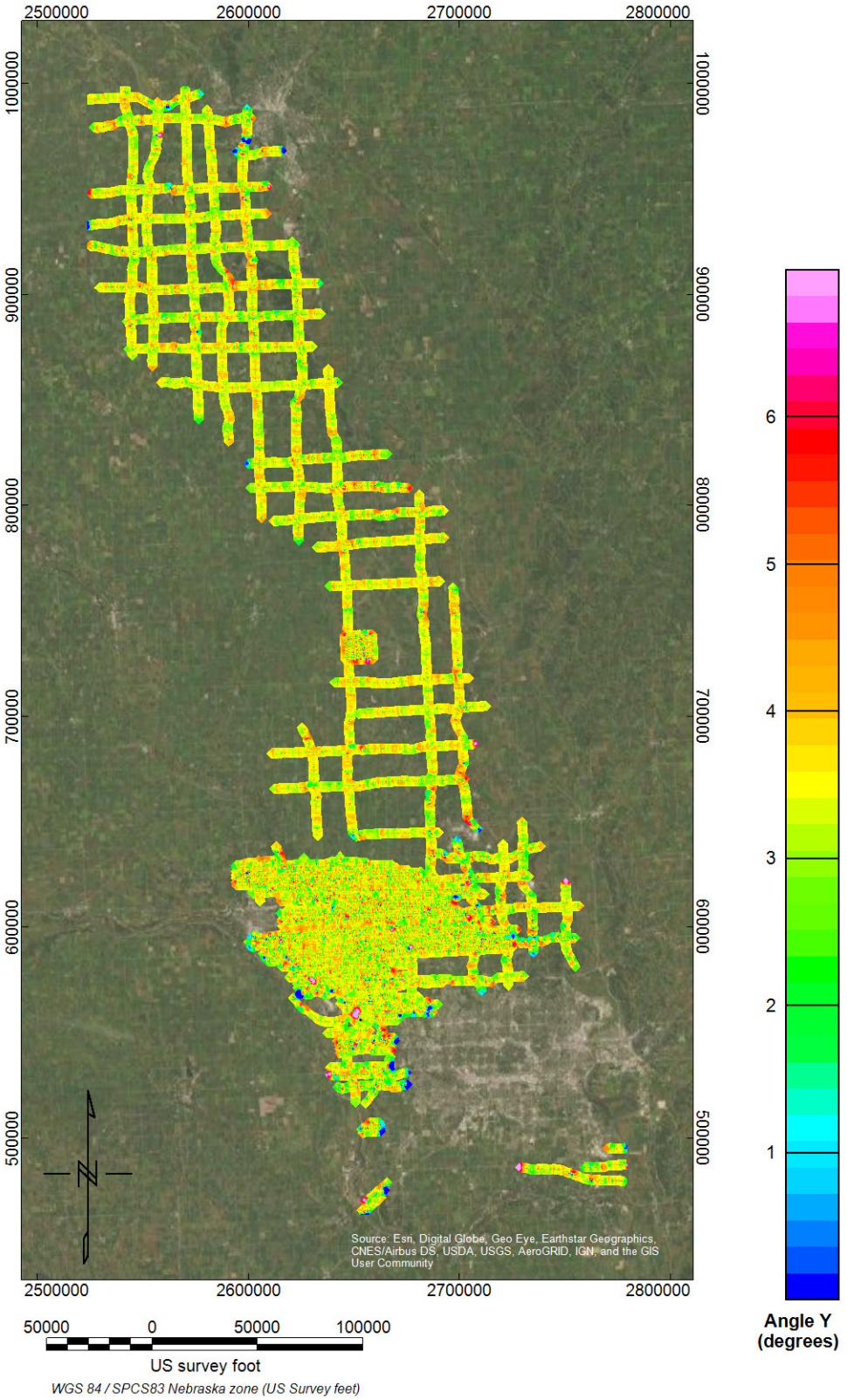


Figure 4-17. P-MRNRD 2020 AEM flight lines yaw angle perpendicular to the direction of travel. Projection is Nebraska State Plane NAD83, feet.

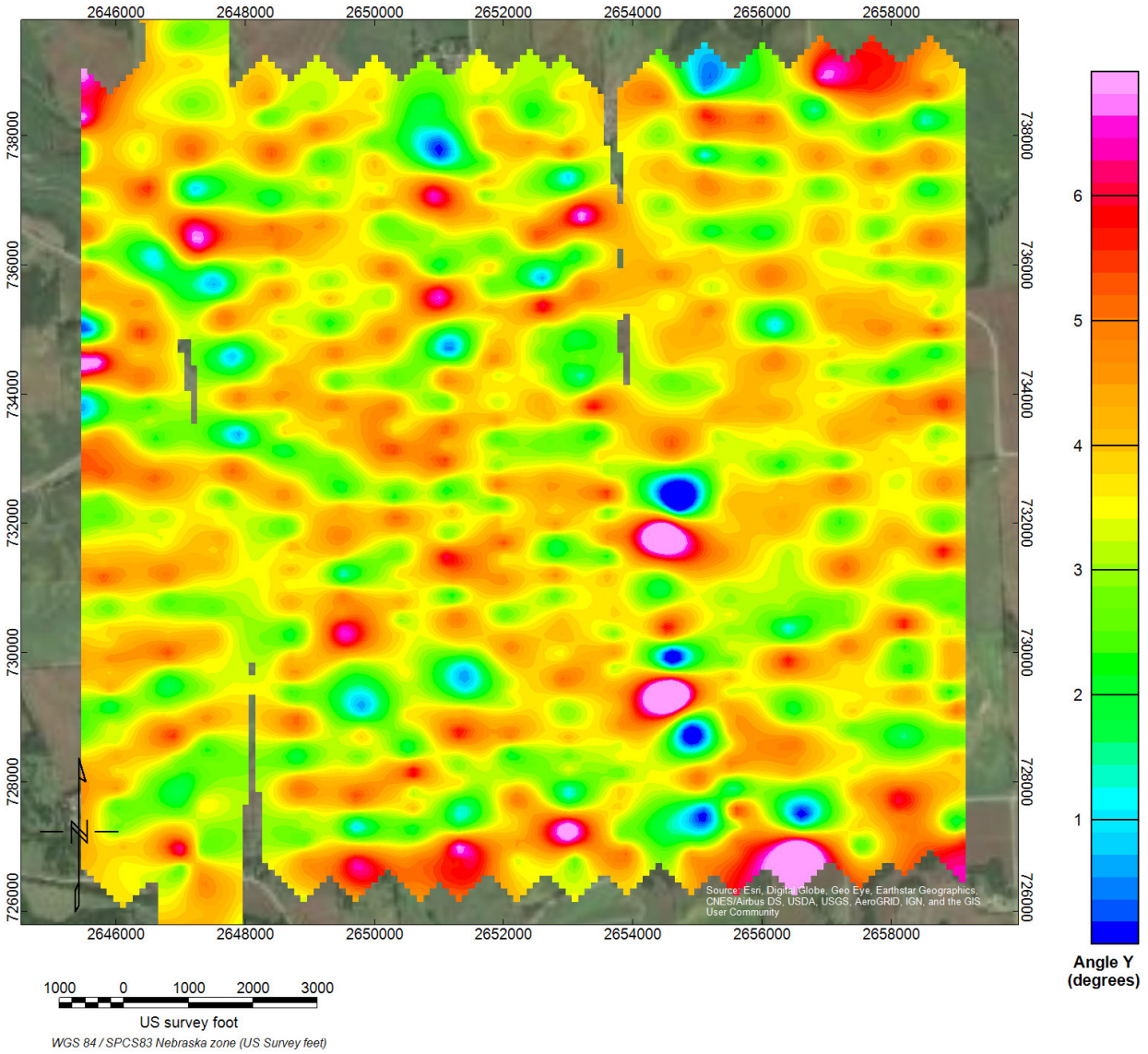


Figure 4-18. Blow up of the P-MRNRD 2020 Tekamah Block AEM flight lines yaw angle perpendicular to the direction of travel. Projection is Nebraska State Plane NAD83, feet.

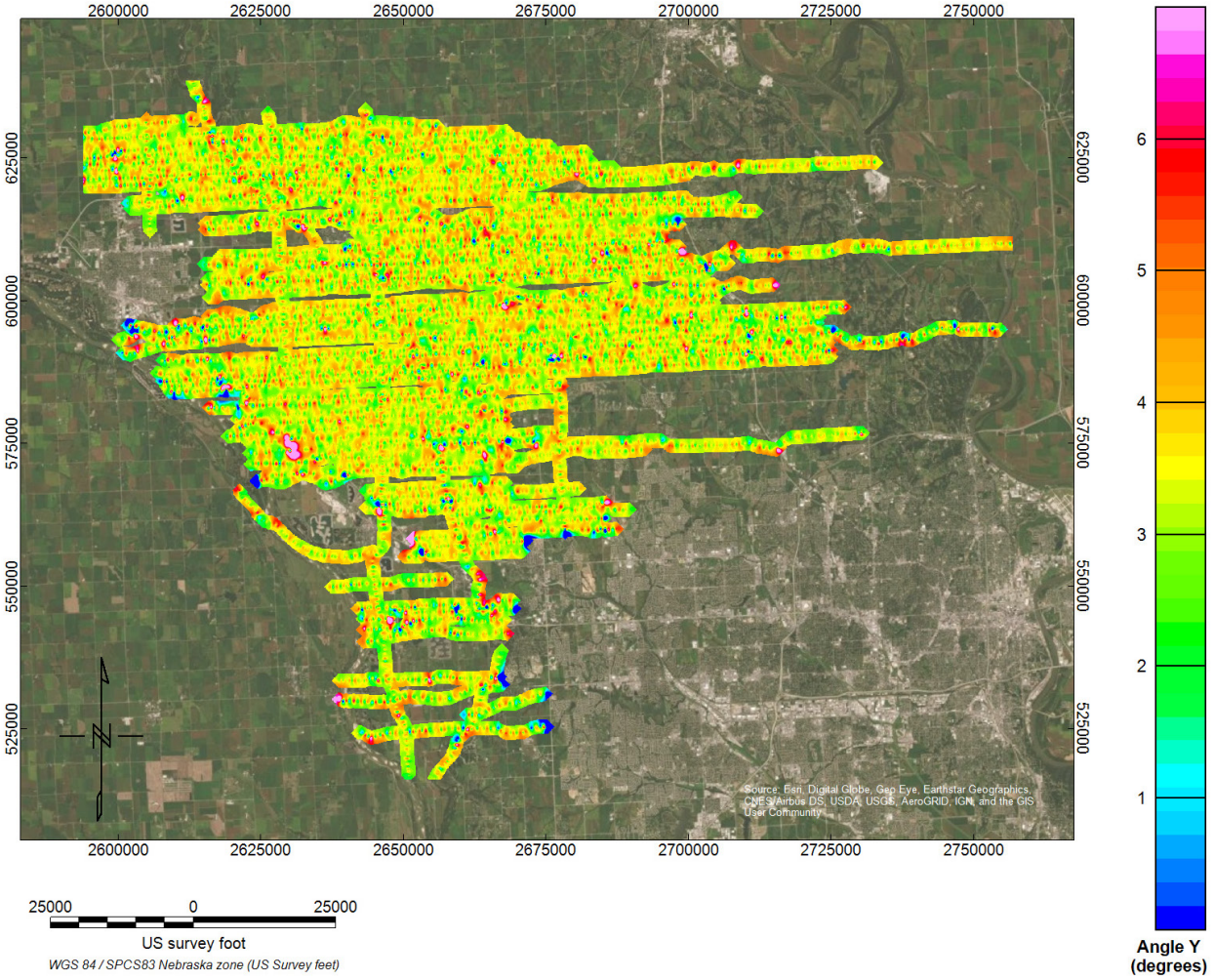


Figure 4-19. Blow up of the P-MRNRD 2020 Southern Block AEM flight lines yaw angle perpendicular to the direction of travel. Projection is Nebraska State Plane NAD83, feet.

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 6.3.1.0 (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 ten 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 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 15 seconds with shift lengths of twelve (12) seconds. The lower and upper thresholds were 1 and 6 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 3, 6, and 18 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 6, 12, and 36 seconds. The trapezoid sounding distance was set to 1.0 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 4-20 and Figure 4-21, respectively. Examples of two inversions, one without EM coupling and the other with EM coupling, are shown in Figure 4-22. Areas were also cut out where the system height was flown greater than 230 feet (70 m) above the ground surface which caused a decrease in the signal level. This problem was encountered at several locations along the major rivers and streams due to the tall cottonwood trees.

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, 1,065-line-miles (1,725-line kilometers) were retained for inversion amounting to a retention rate of 69.5%. This high rate is the result of careful flight line planning and design given the infrastructure that was encountered during the acquisition

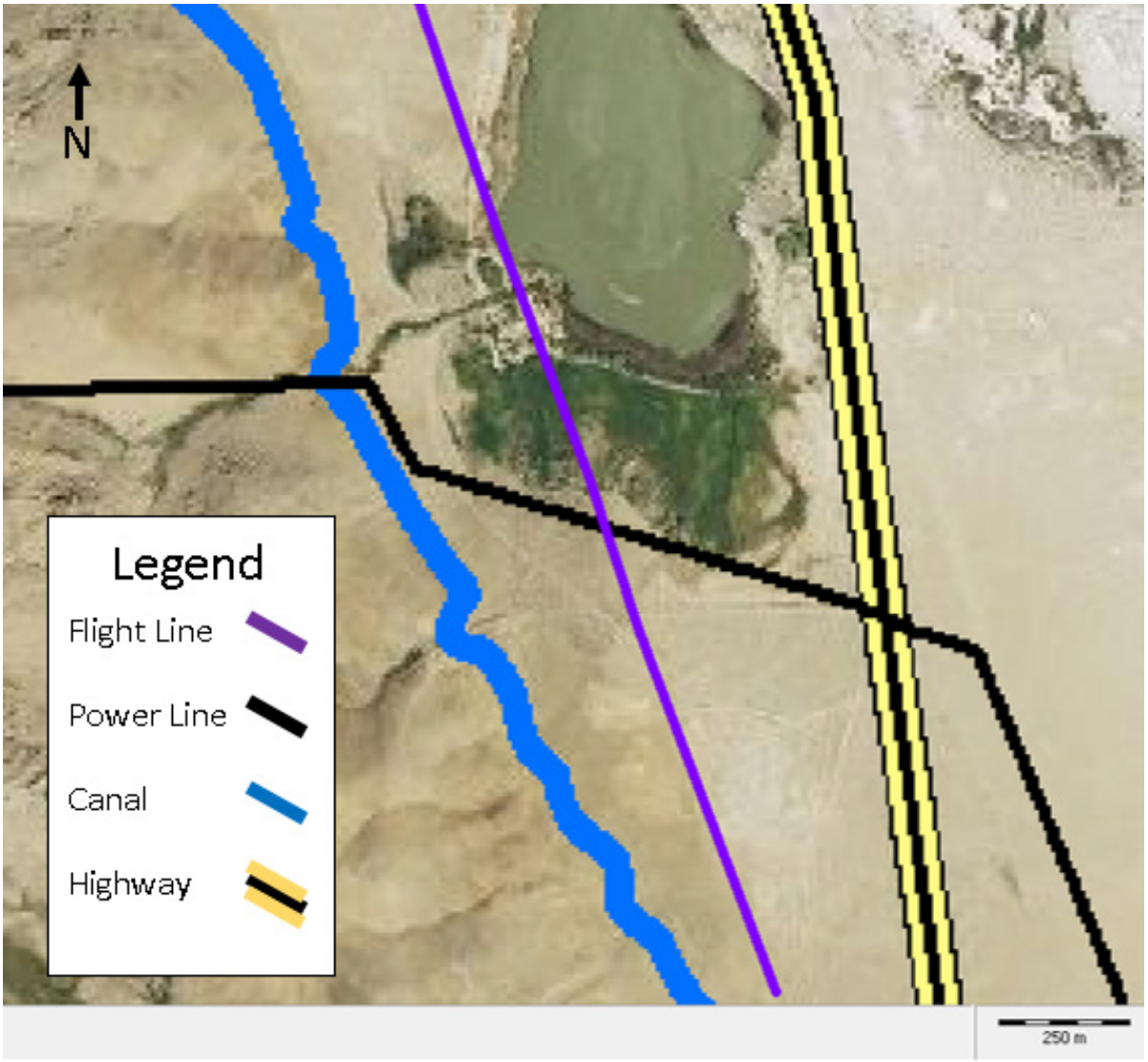


Figure 4-20: Example locations of electromagnetic coupling with pipelines or power lines.

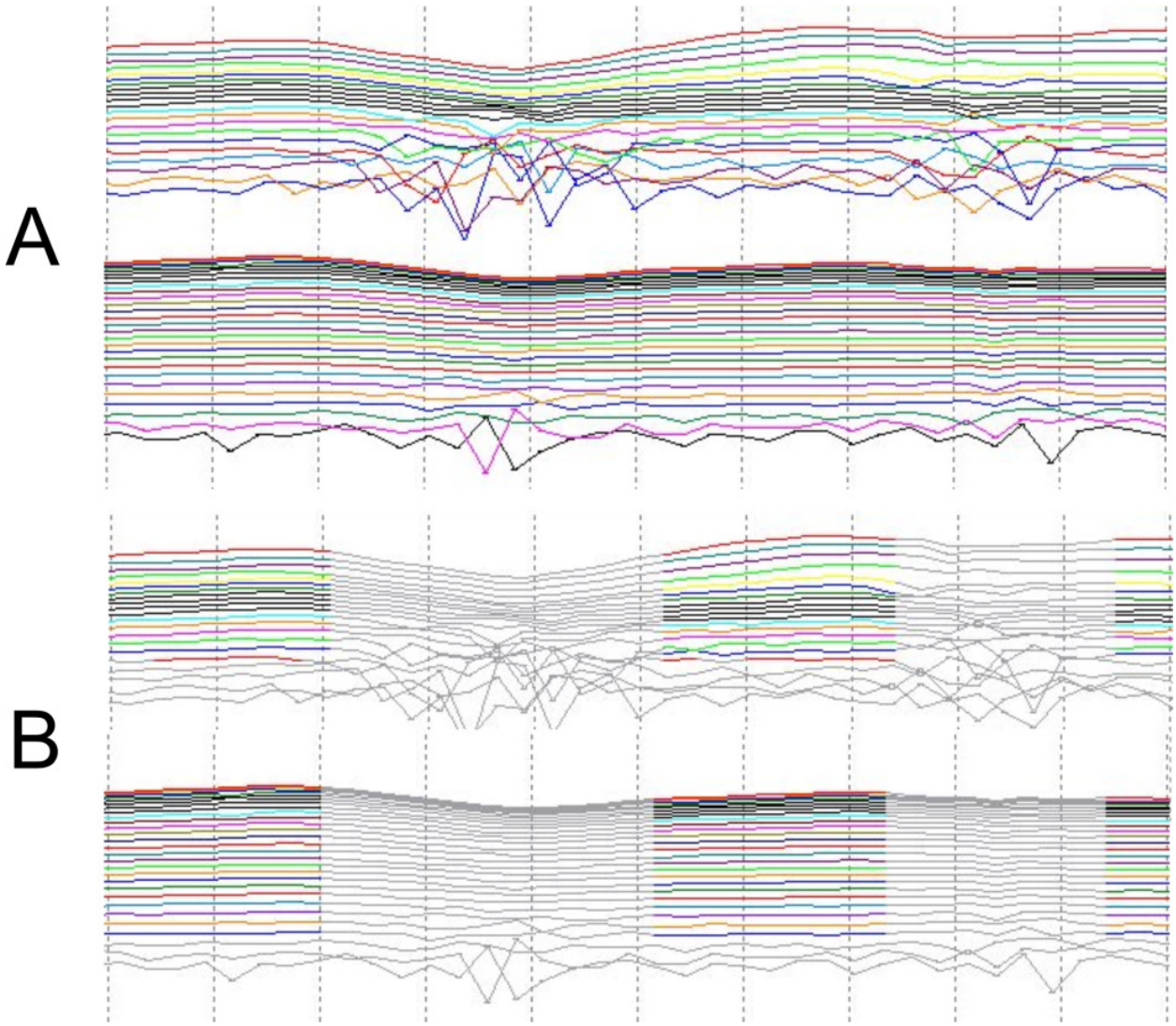


Figure 4-21: A) Example of AEM data affected by electromagnetic coupling as presented in the Aarhus Workbench editor. The top group of lines is the unedited data with the Low Moment on top and the High Moment on the bottom. The bottom group shows the same data after editing.

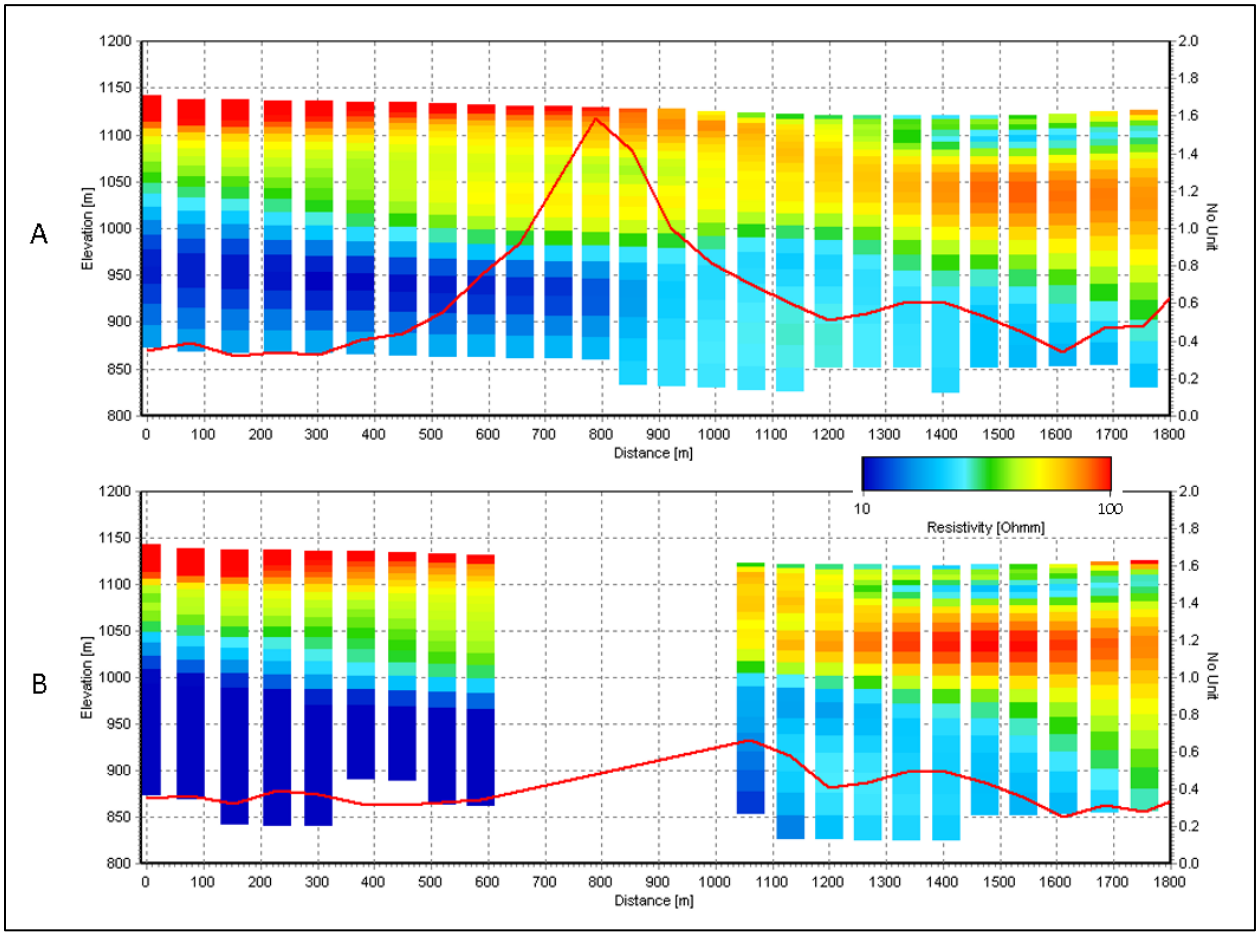


Figure 4-22: A) Example of Laterally-Constrained inversion results where AEM data affected by coupling with pipelines and power lines were not removed. B) Inversion results where AEM data affected by coupling were removed.

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 all flight lines of the P-MRNRD 2020 AEM survey are presented in Figure 4-23 and magnified images of the Tekamah Block and the Arlington Block are presented in Figure 4-24 and Figure 4-25, respectively. Images of the P-MRNRD 2020 survey As-Flown data and the data retained for inversion are presented in Figure 4-26 for the P-MRNRD 2020 reconnaissance flight lines, Figure 4-27 for the Tekamah Block flight lines, and Figure 4-28 for the Southern Block flight lines. The blue colors represent the 69.5% of data retained for inversion and red lines representing data removed due to infrastructure and late time noise.

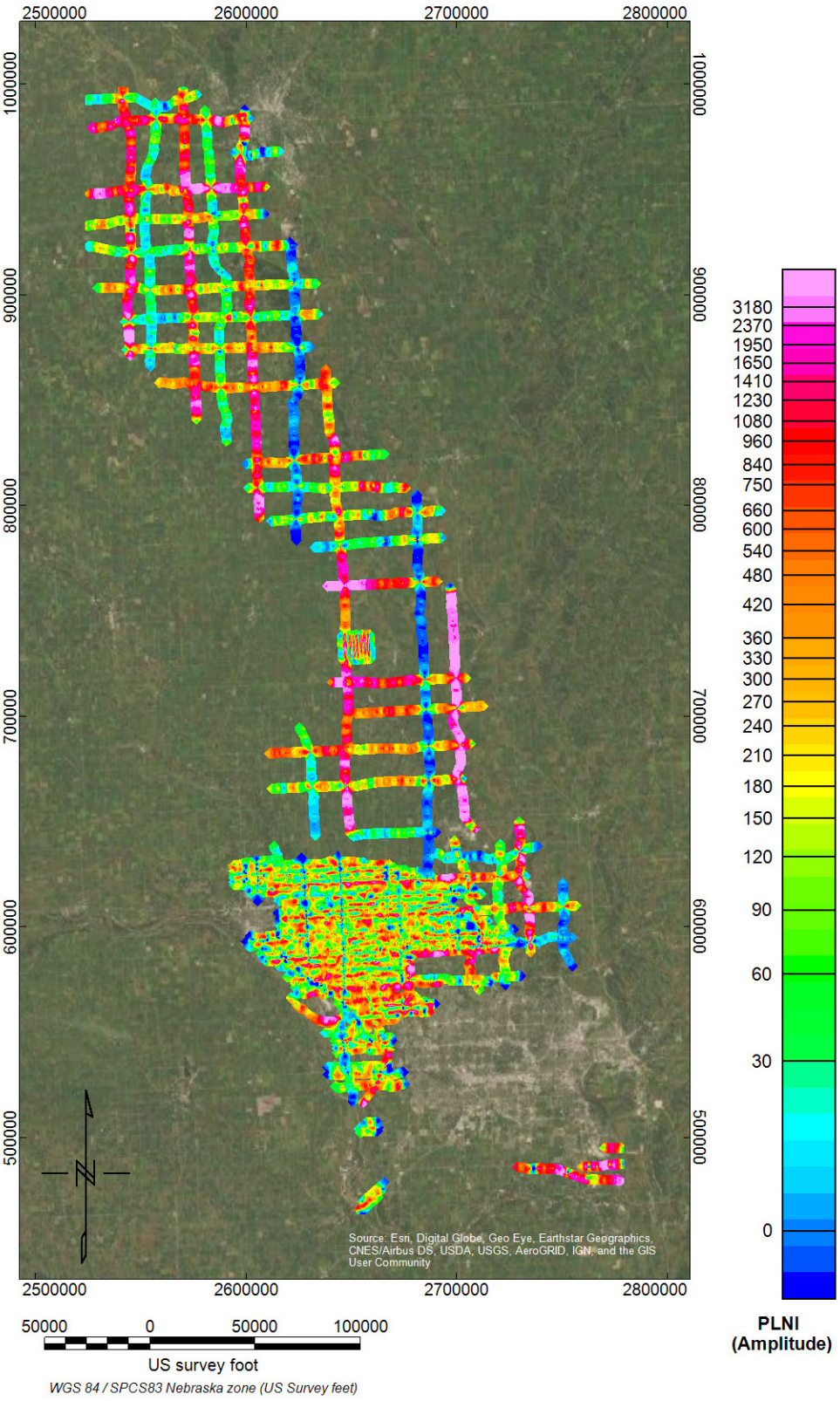


Figure 4-23: Power Line Noise Intensity (PLNI) map of the P-MRNRD 2020 project area.

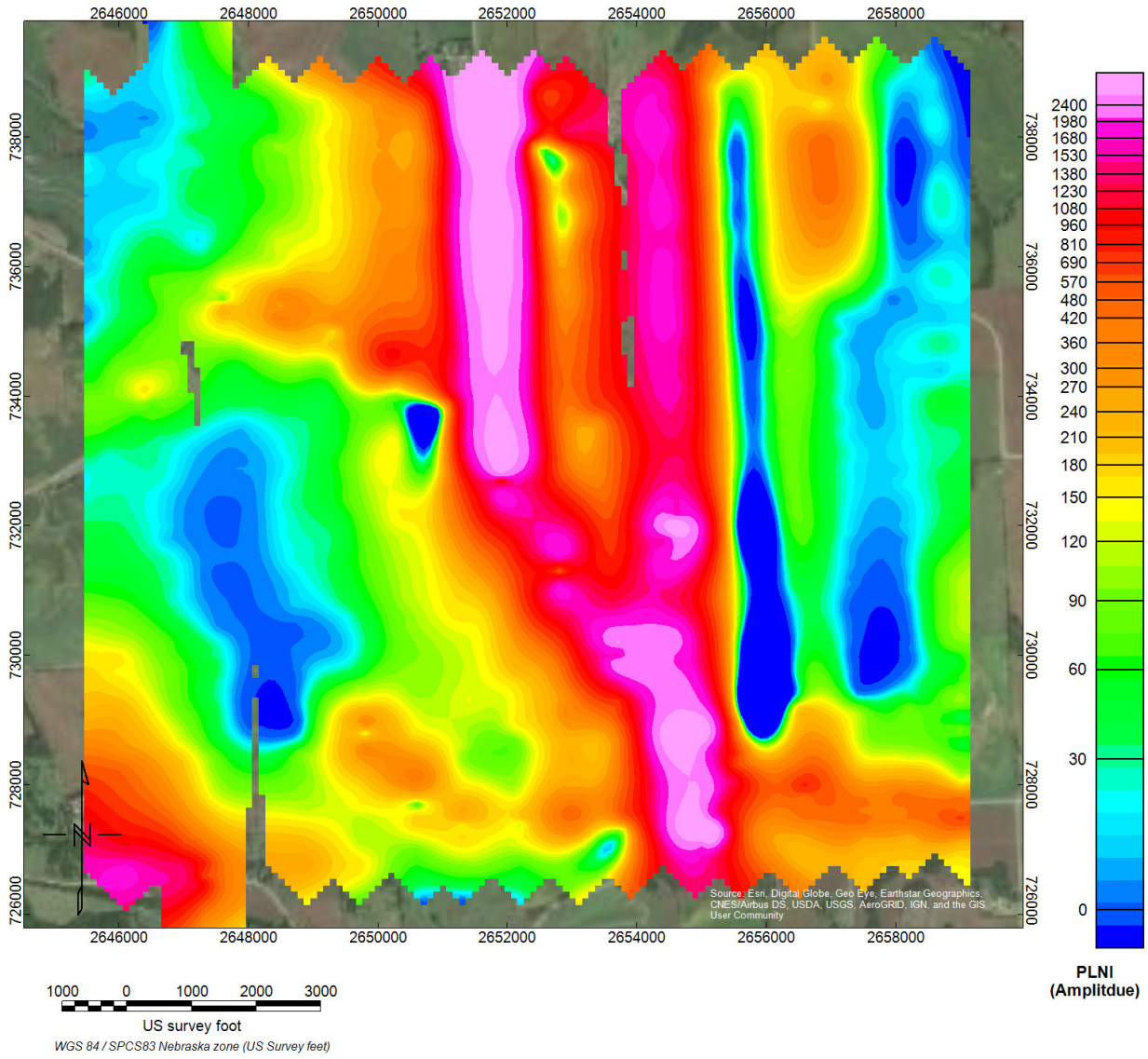


Figure 4-24: Blow up of the Power Line Noise Intensity (PLNI) map of the P-MRNRD 2020 Tekamah Block flight area.

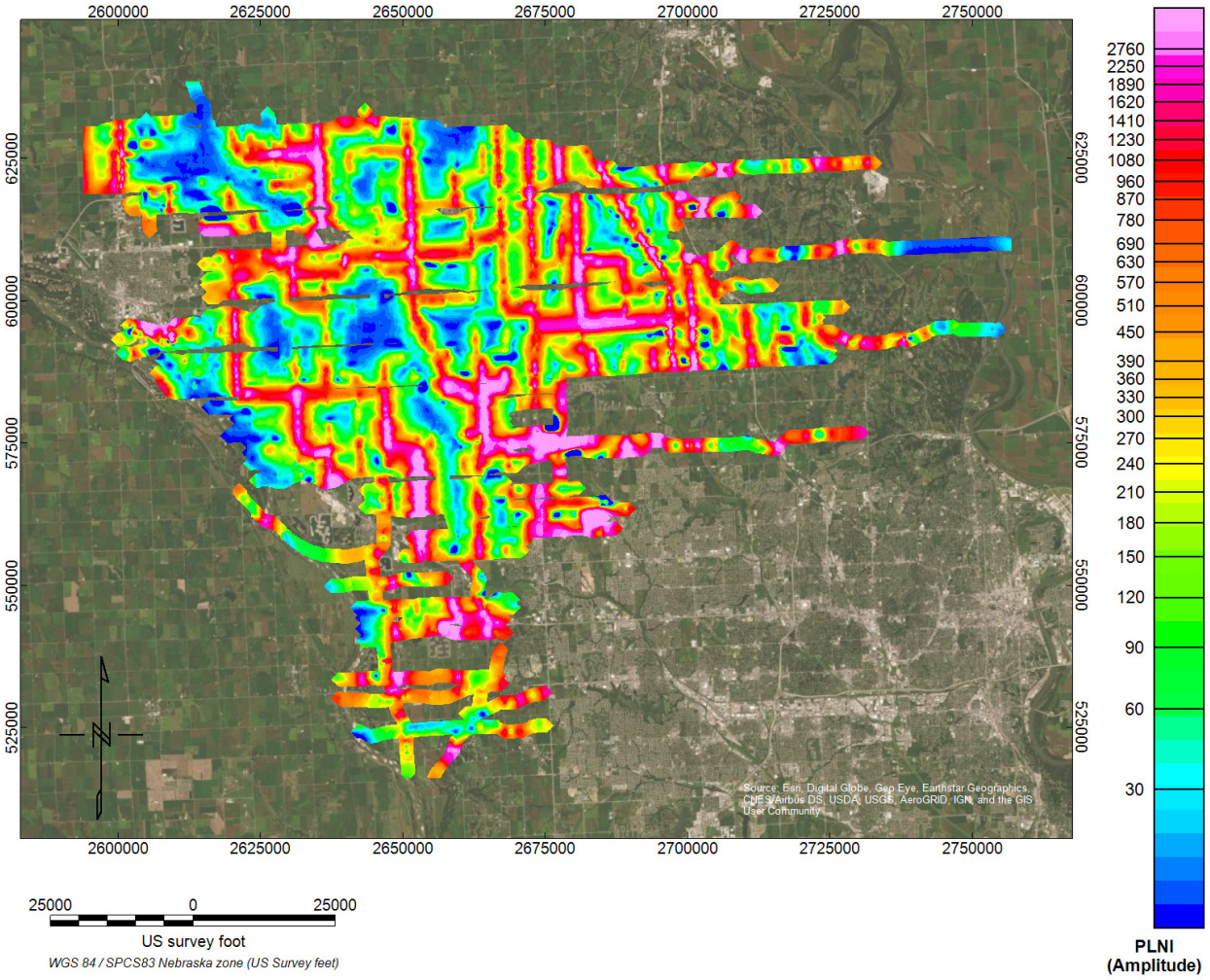


Figure 4-25: Blow up of the Power Line Noise Intensity (PLNI) map of the P-MRNRD 2020 Southern Block flight area.

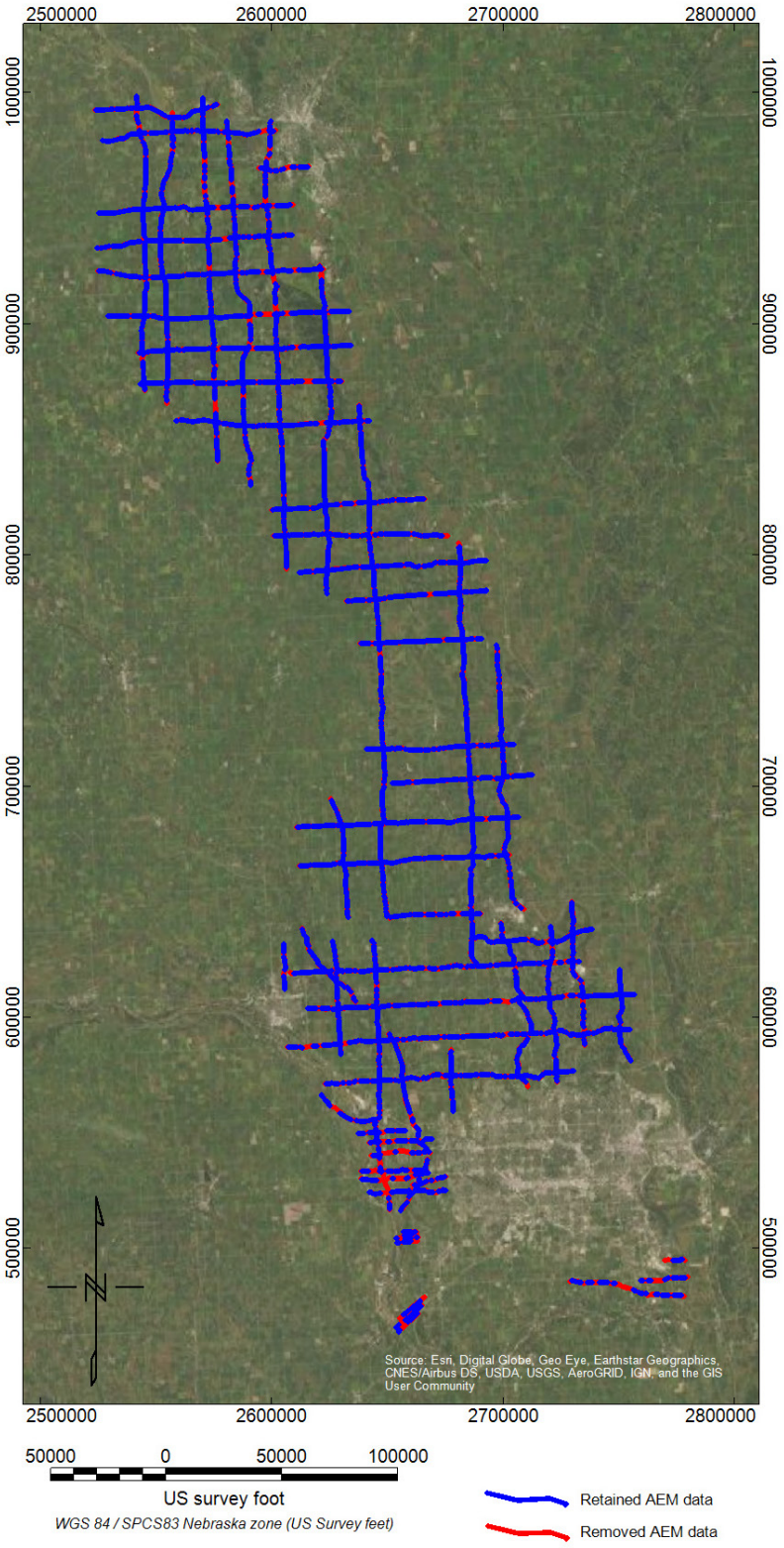


Figure 4-26. Locations of inverted data (blue lines) along the AEM flight lines (red lines) on the P-MRNRD 2020 Reconnaissance AEM survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the "as-flown" flight lines are included in Appendix 3\KMZ.

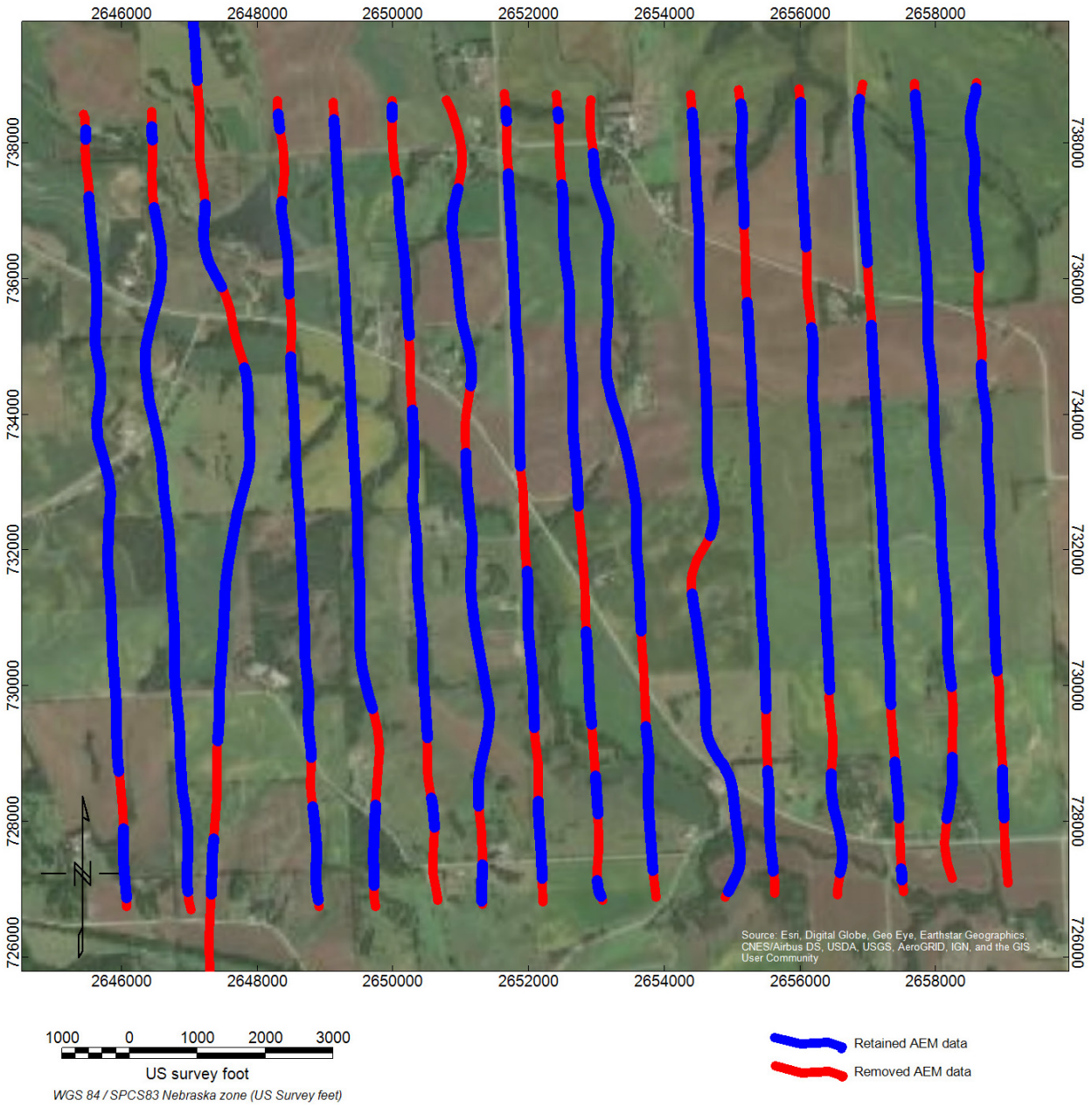


Figure 4-27. Locations of inverted data (blue lines) along the AEM flight lines (red lines) in the P-MRNRD 2020 Tekamah Block AEM survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the "as-flown" flight lines are included in Appendix 3\KMZ.

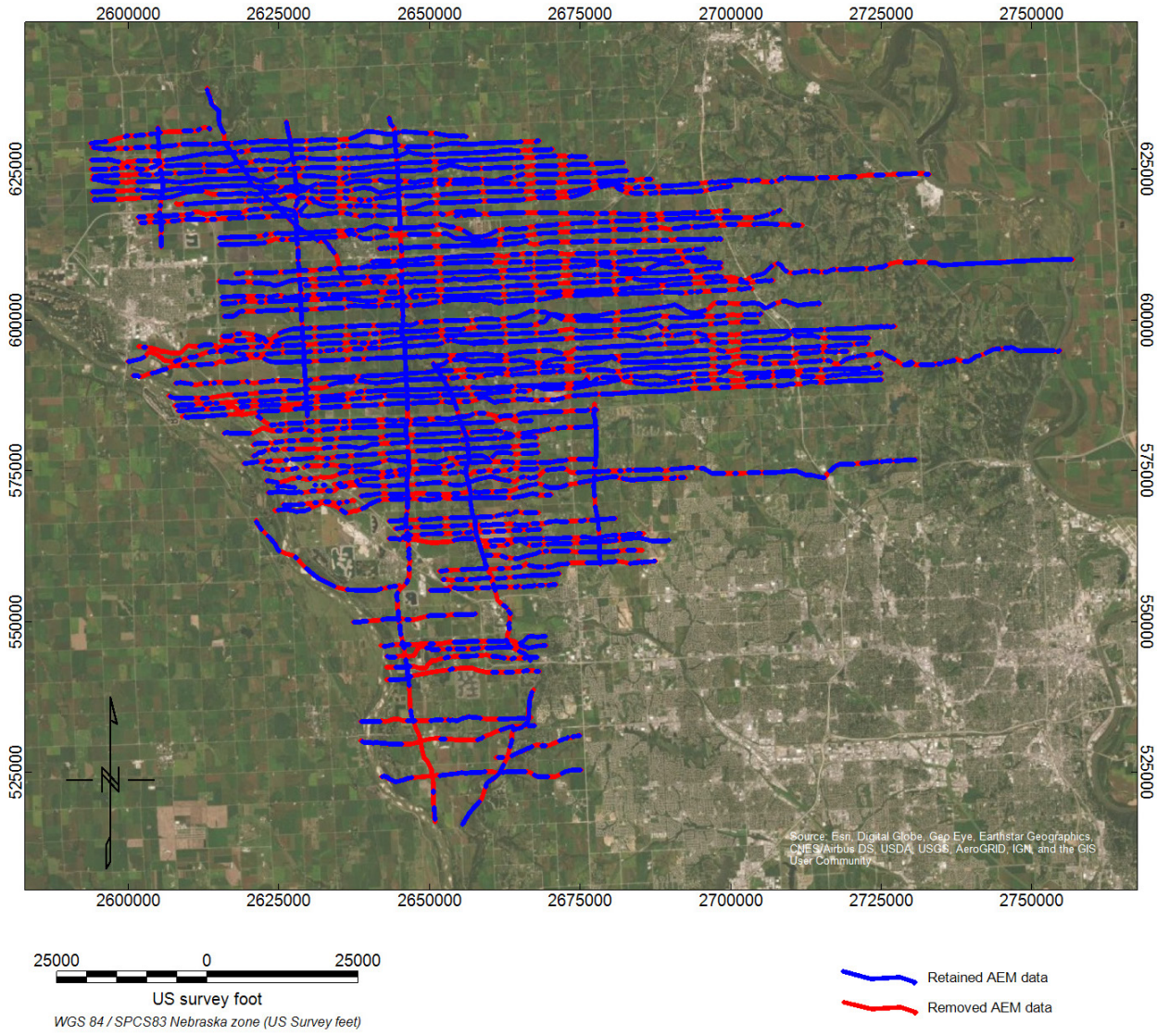


Figure 4-28. Locations of inverted data (blue lines) along the AEM flight lines (red lines) in the P-MRNRD 2020 Southern Block AEM survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the "as-flown" flight lines 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 4-29 shows the residual magnetic Total Field (RMF) intensity data for the P-MRNRD AEM survey area after correcting for diurnal drift and removing the International Geomagnetic Reference Field (IGRF). This data is used in decoupling efforts. Figure 4-30 presents a magnification of the Tekamah Block RMF and Figure 4-31 presents a magnification of the RMF for the Arlington Block AEM survey area.

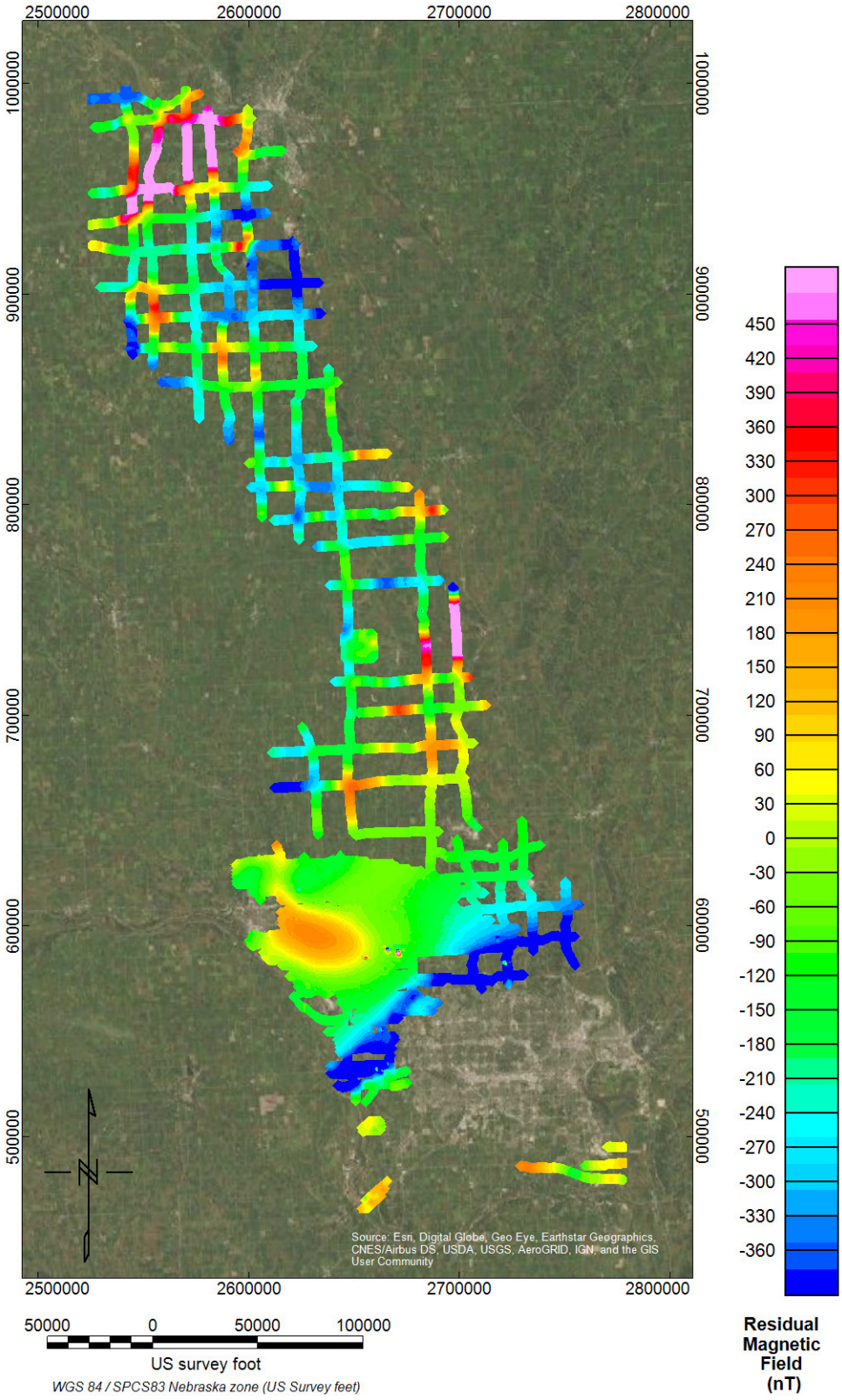


Figure 4-29. Residual magnetic Total Field intensity data for the P-MRNRD 2020 AEM survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed.

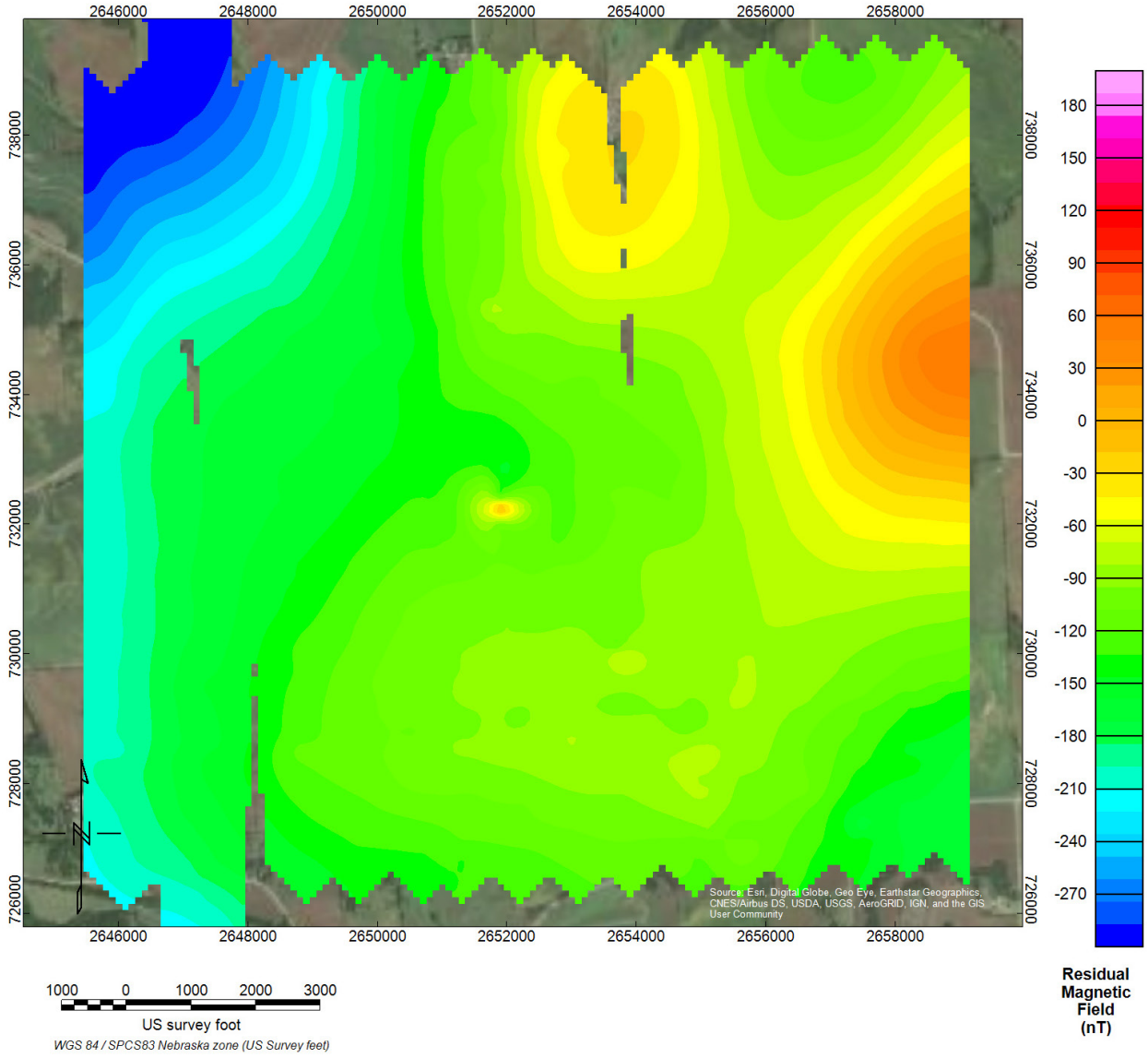


Figure 4-30. Residual magnetic Total Field intensity data for the P-MRNRD 2020 Tekamah Block AEM survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed.

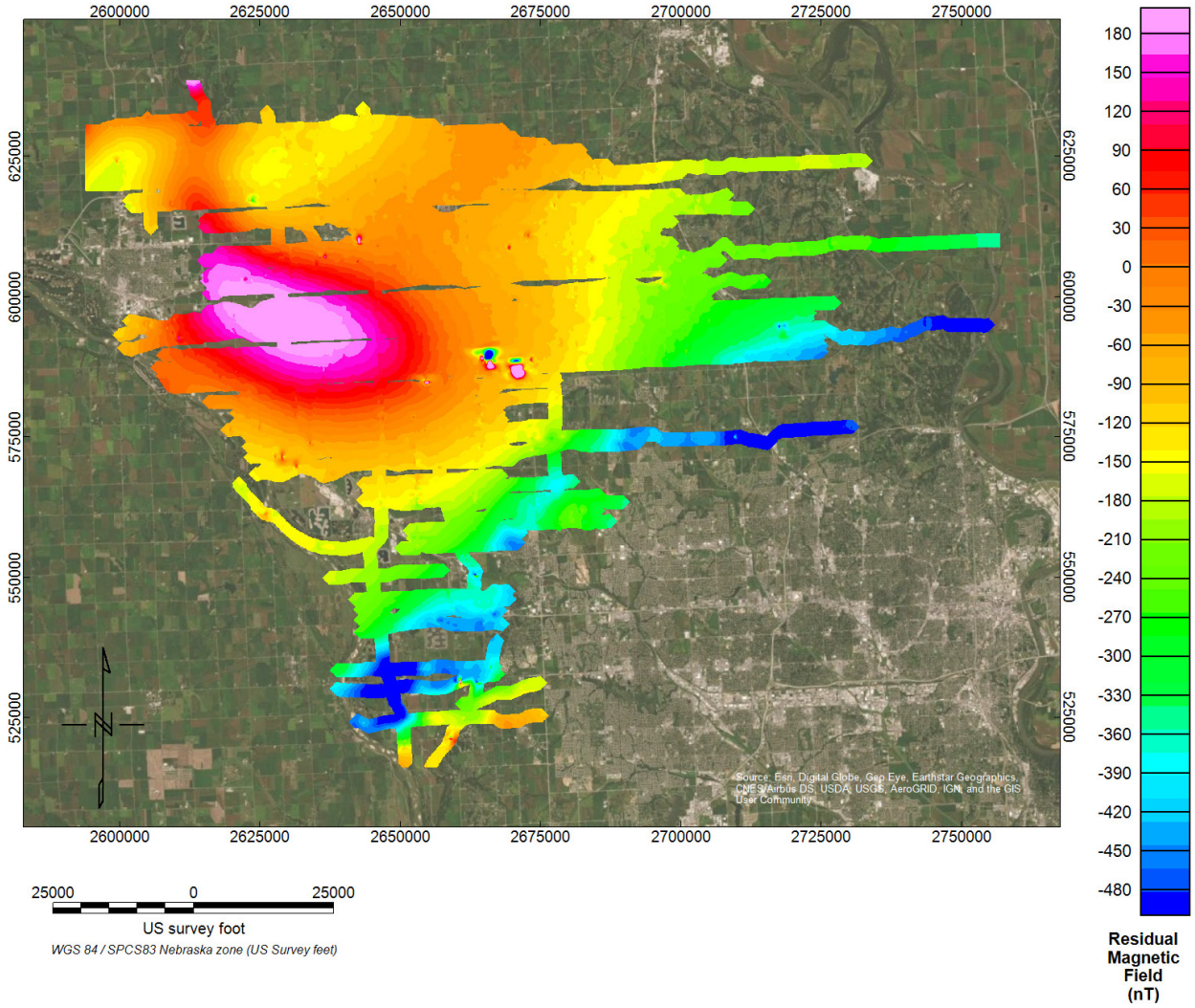


Figure 4-31. Residual magnetic Total Field intensity data for the P-MRNRD 2020 Southern Block AEM survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed.

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 P-MRNRD 2020 AEM data were inverted using a 40-layer model structure. The SCI inversions used smooth models, 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 6.6 ft (2 m) with the thicknesses of the consecutive layers increasing by a factor of 1.06. The depths to the bottoms of the 39th layers were set to 1,066 ft, with thicknesses up to about 71 ft. The thicknesses of the layers increase with depth (Table 4-3 and Figure 4-32) as the resolution of the technique decreases. The spatial reference distance, ***s***, for the constraints were set to 308 ft with power laws of 0.75. The vertical and lateral constraints, ***ResVerSTD*** and ***ResLatStD***, were set to 2.4 and 1.4, respectively, for all layers.

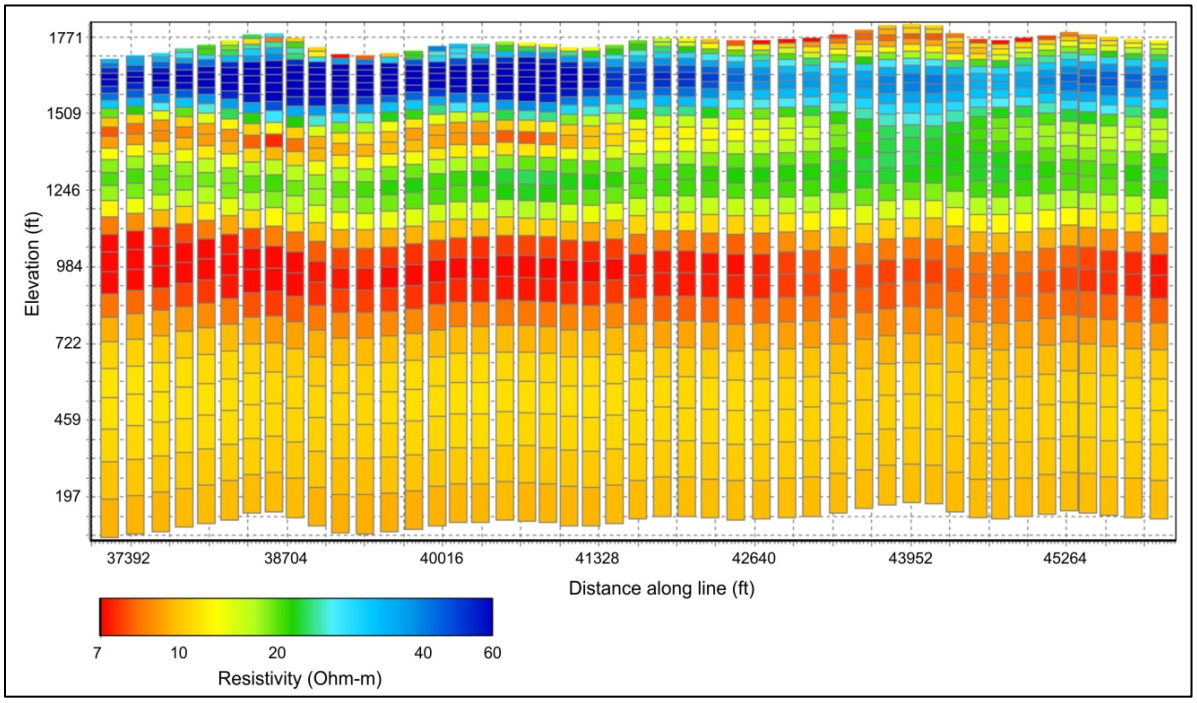


Figure 4-32. An example of an AEM profile illustrating increasing model layer thicknesses with depth.

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). 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 4-3: Thickness and depth to bottom for each layer in the Spatially Constrained Inversion (SCI) AEM earth 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)	Depth to Bottom (m)	Thickness (m)	Layer	Depth to Bottom (ft)	Thickness (ft)	Depth to Bottom (m)	Thickness (m)
1	6.6	6.6	2.0	2.0	21	276.7	23.0	84.3	7.0
2	13.5	7.0	4.1	2.1	22	301.2	24.4	91.8	7.5
3	21.0	7.4	6.4	2.3	23	327.2	26.0	99.7	7.9
4	28.9	7.9	8.8	2.4	24	354.9	27.7	108.2	8.4
5	37.3	8.4	11.4	2.6	25	384.4	29.5	117.2	9.0
6	46.3	9.0	14.1	2.7	26	415.8	31.4	126.7	9.6
7	55.9	9.6	17.0	2.9	27	449.3	33.4	136.9	10.2
8	66.0	10.2	20.1	3.1	28	484.9	35.6	147.8	10.9
9	76.9	10.8	23.4	3.3	29	522.8	37.9	159.3	11.6
10	88.4	11.5	26.9	3.5	30	563.1	40.4	171.6	12.3
11	100.7	12.3	30.7	3.7	31	606.1	42.9	184.7	13.1
12	113.7	13.1	34.7	4.0	32	651.8	45.7	198.7	13.9
13	127.7	13.9	38.9	4.2	33	700.5	48.7	213.5	14.8
14	142.5	14.8	43.4	4.5	34	752.3	51.8	229.3	15.8
15	158.2	15.8	48.2	4.8	35	807.5	55.2	246.1	16.8
16	175.0	16.8	53.3	5.1	36	866.3	58.8	264.0	17.9
17	192.9	17.9	58.8	5.4	37	928.8	62.5	283.1	19.1
18	211.9	19.0	64.6	5.8	38	995.4	66.6	303.4	20.3
19	232.2	20.3	70.8	6.2	39	1066.3	70.9	325.0	21.6
20	253.8	21.6	77.3	6.6					

Figure 4-33 presents a histogram of the P-MRNRD 2020 SCI inversion data/model residuals and a map of data to model error residuals comparison is presented in Figure 4-34.

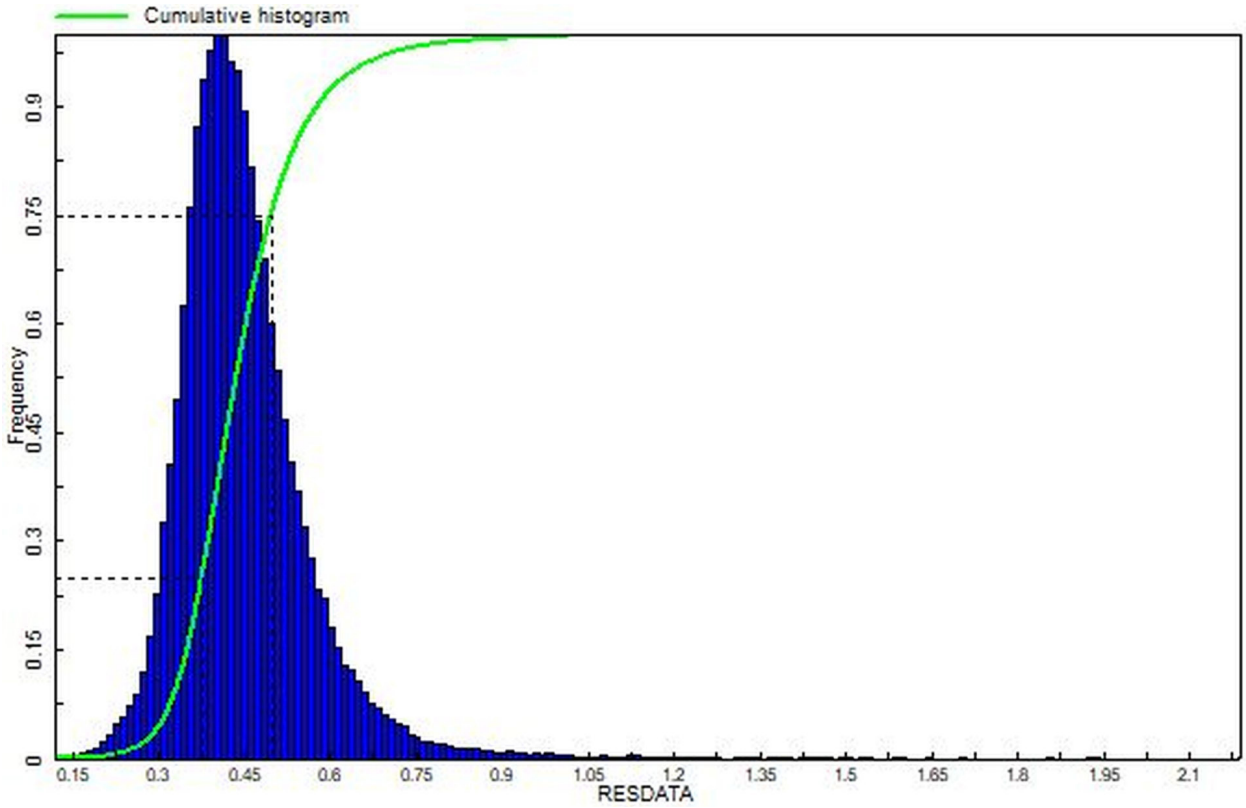


Figure 4-33. Data/model residual histogram for the P-MRNRD 2020 SCI inversion results.

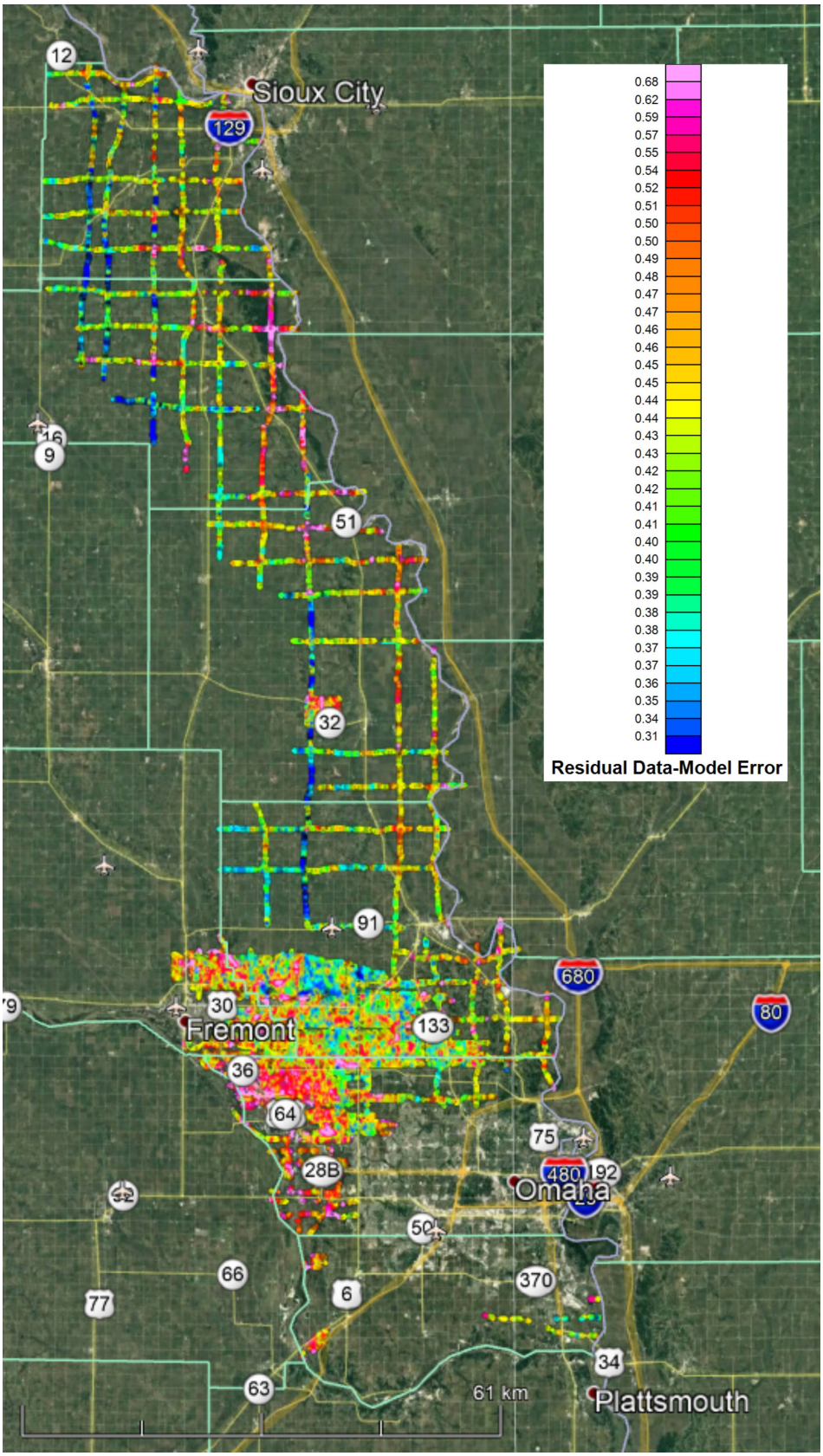


Figure 4-34. Map of data-inversion model residuals for the P-MRNRD 2020 SCI inversion results.

4.6 Re-Inversion of Ashland 2007 AEM Survey Data

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 (Fugro, 2007; Abraham et al., 2011; Hanson et al., 2012; Korus et al., 2013a). 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 4-35), 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 groundwater 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 Group (***Kd***), 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 Hanson et al. (2012).

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).

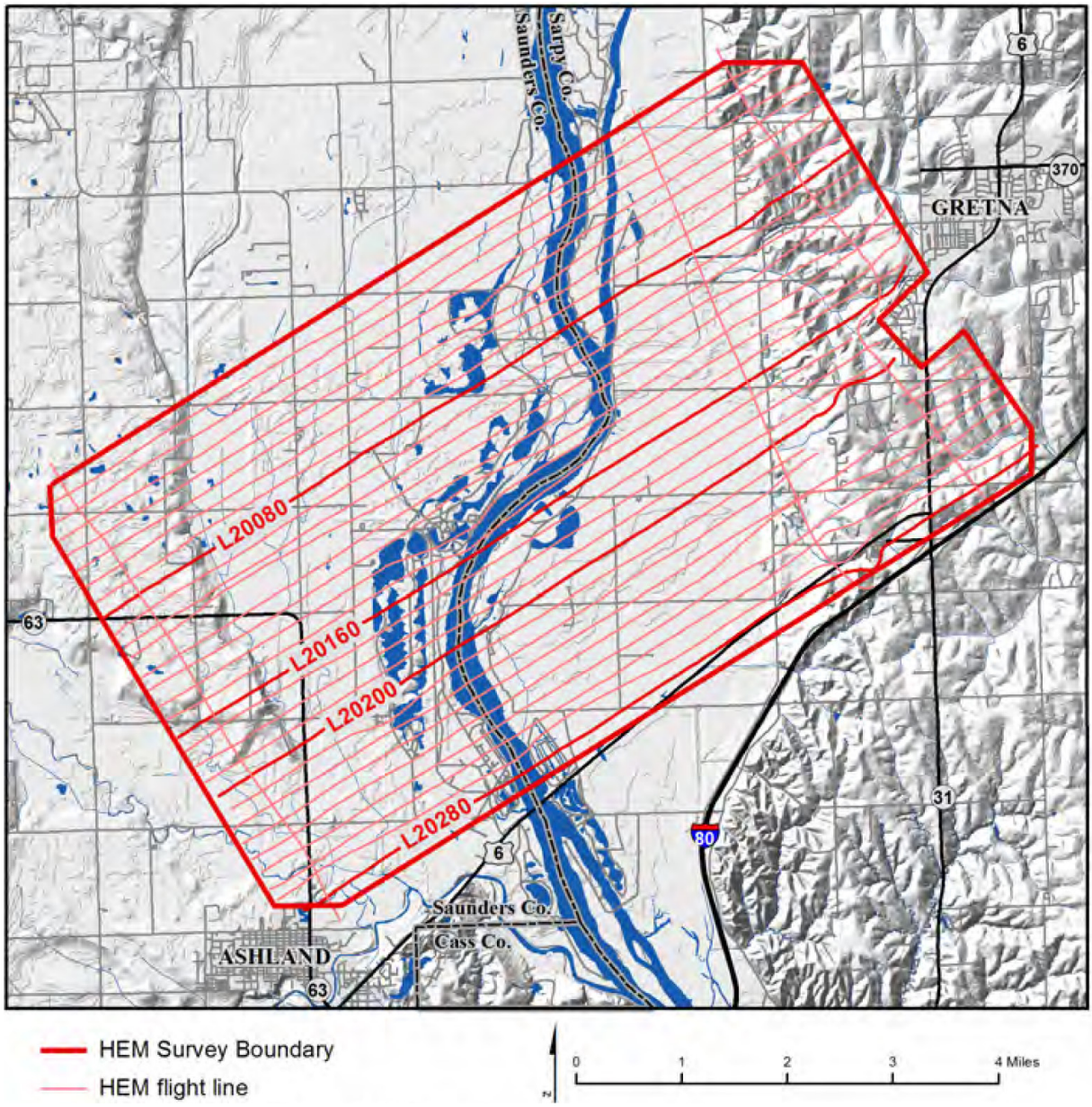


Figure 4-35. Map of the Ashland 2007 HEM survey. The flight lines are spaced approximately 890 feet (270 m) apart and soundings were acquired approximately every 10 ft (3 m). From Hanson et al. (2012)

4.6.1 Motivation for Re-Inversion of the Ashland 2007 AEM Data

As discussed in Section 2 above, additional AEM surveys have been performed across different regions of the P-MRNRD since 2007 including SkyTEM surveys in 2014, 2015, 2016, 2018, and the most recent AEM survey in 2020 (Figure 4-36). It was first noticed in the P-MRNRD inversion results after the 2015 reconnaissance-style SkyTEM survey (Carney, 2015b) that there was a difference between the SkyTEM inversion results and the 2007 Fugro RESOLVE inversion results. But since there was only one 2015 reconnaissance line crossing the Ashland survey area, the differences were just noted. However, after

both the 2016 (AGF, 2017) and 2018 (AGF, 2019a) SkyTEM AEM surveys, during which several reconnaissance flight lines crossed the Ashland survey area, the distinct differences between the inverted resistivities from the 2015, 2016, and 2018 SkyTEM AEM surveys and from the Ashland 2007 Fugro RESOLVE AEM survey (Fugro, 2007) stood out even more. Note that the SkyTEM data are time-domain-based electromagnetic (TEM) data and the RESOLVE data are frequency-domain-based electromagnetic (FEM) data. 3D Fence Diagrams of the Ashland 2007 RESOLVE inversion results integrated with the 2015, 2016, 2018, and 2020 SkyTEM inversion results are presented in Figure 4-37 and Figure 4-38.

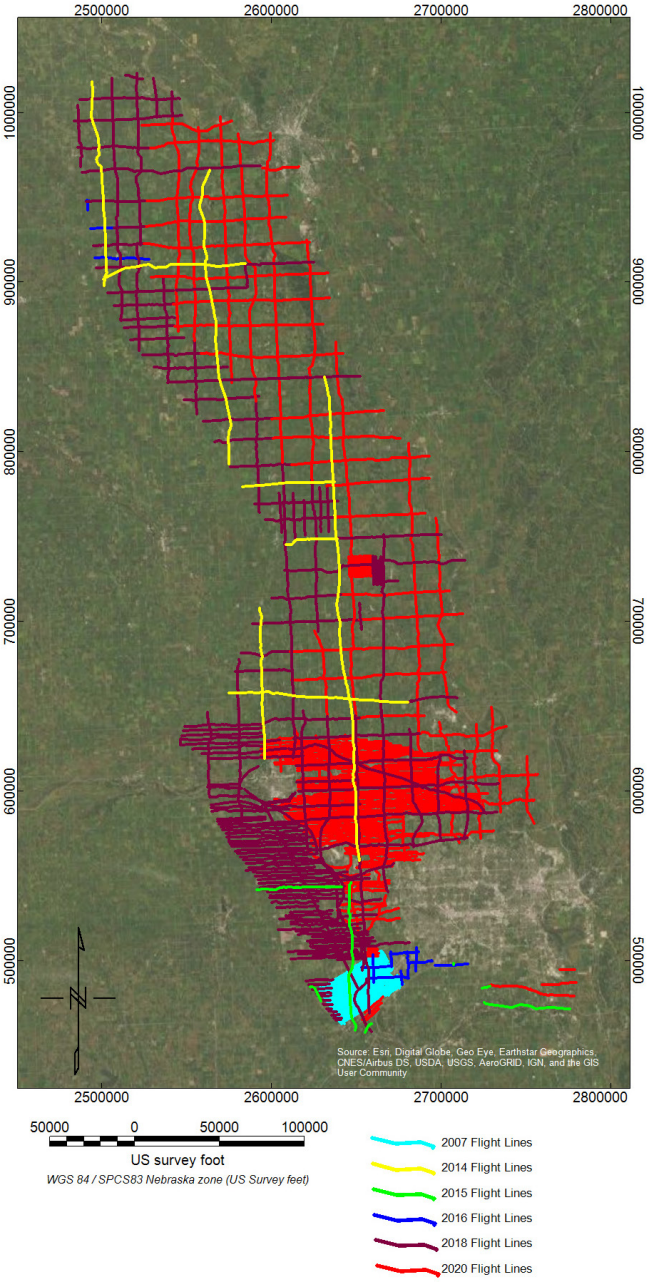


Figure 4-36. Map of AEM flight lines, grouped by year, that have surveyed portions of the Papio-Missouri River Natural Resources District.

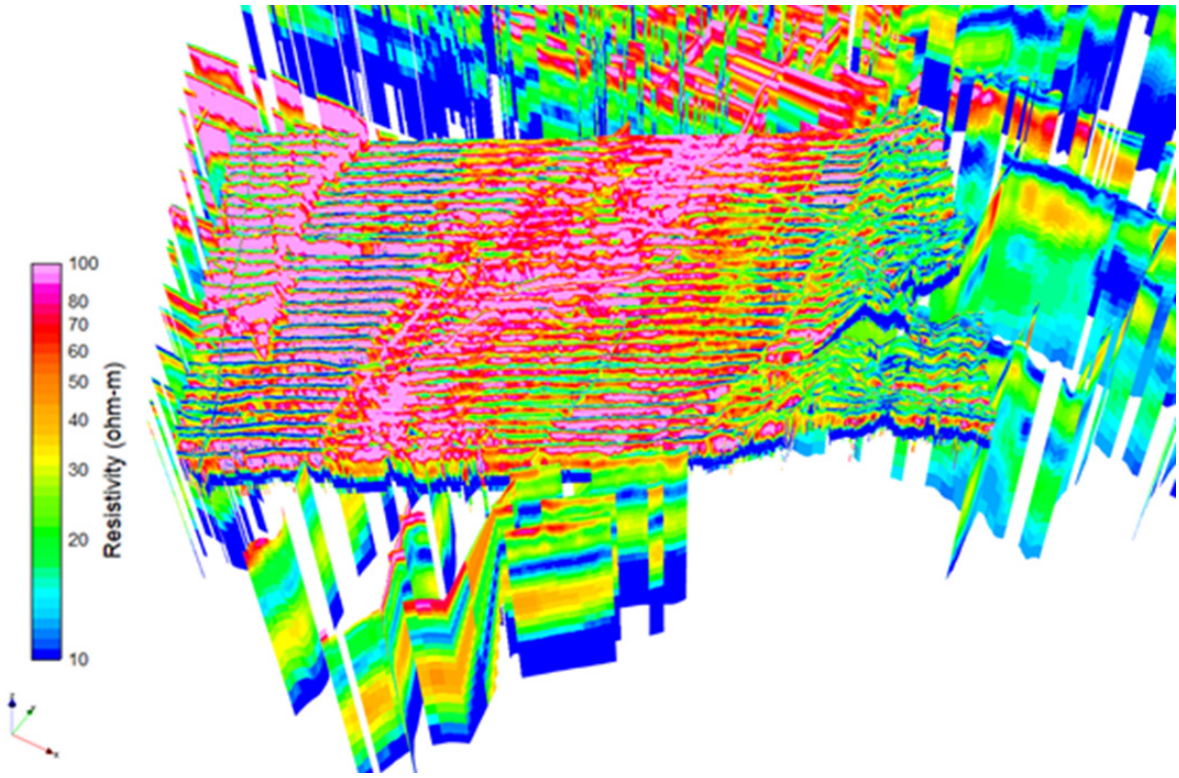


Figure 4-37. 3D Fence Diagram of the Ashland 2007 Inversion results integrated with the 2015, 2016, 2018, and 2020 SkyTEM inversion results.

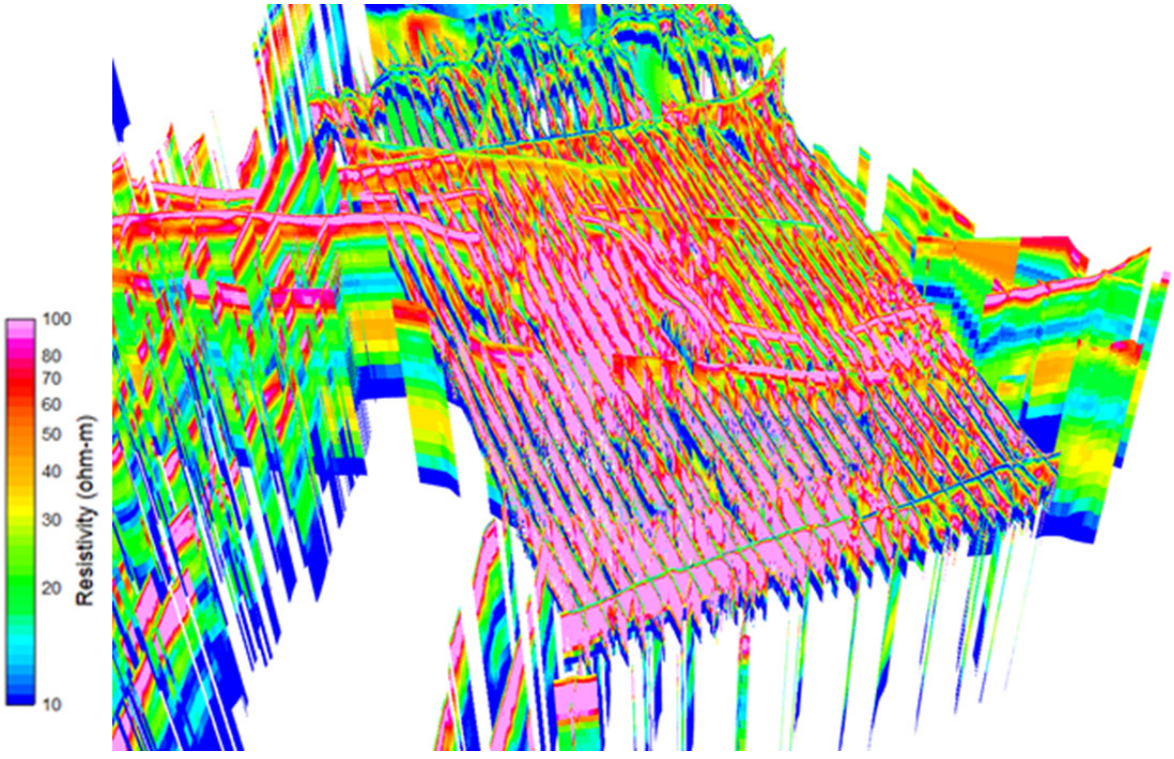


Figure 4-38. 3D Fence Diagram of the Ashland 2007 Inversion results integrated with the 2015, 2016, 2018, and 2020 SkyTEM inversion results.

4.6.2 Calibration of the 2007 Ashland AEM Data

As stated in Section 4.4 above, the SkyTEM AEM systems are calibrated at a site near Lyngby, Denmark. Over the course of many AEM surveys, the SkyTEM calibrations have been proven over the years to be very stable. Thus, utilizing the inversion results of the SkyTEM flight lines that have crossed through the 2007 Ashland FEM survey area, the Ashland data can be calibrated. The process, which will be presented in more detail below, involves first identifying several locations along the SkyTEM flight lines where they cross the Ashland RESOLVE flight lines and extracting the SkyTEM resistivity earth models. The SkyTEM models are then used to derive a forward model FEM response using the 2007 Ashland RESOLVE system specifications including frequency, transmitter-receiver coil orientations, and inter-coil distances found in the Fugro report (Fugro, 2007). The FEM forward modelling responses, based on the SkyTEM resistivity models, are then compared to the measured 2007 Ashland FEM data at the selected locations closest to where the SkyTEM and RESOLVE lines crossed. Ratios are calculated resulting in coefficients that are applied to the measured 2007 Ashland FEM data and LCI and SCI inversions are run. Further refinements to the correction factors are then developed based on the relation between the measured system altitudes and the calculated inverted altitudes. Once all correction factors were determined, a final SCI inversion was run, and the calibrated Ashland AEM inversion results were integrated with the SkyTEM AEM inversion results in the P-MRNRD.

The calibration locations used where SkyTEM flight lines crossed Ashland RESOLVE flight lines are presented in Figure 4-39 and in Table 4-4. A 2016 SkyTEM flight line will be used for the calibration.

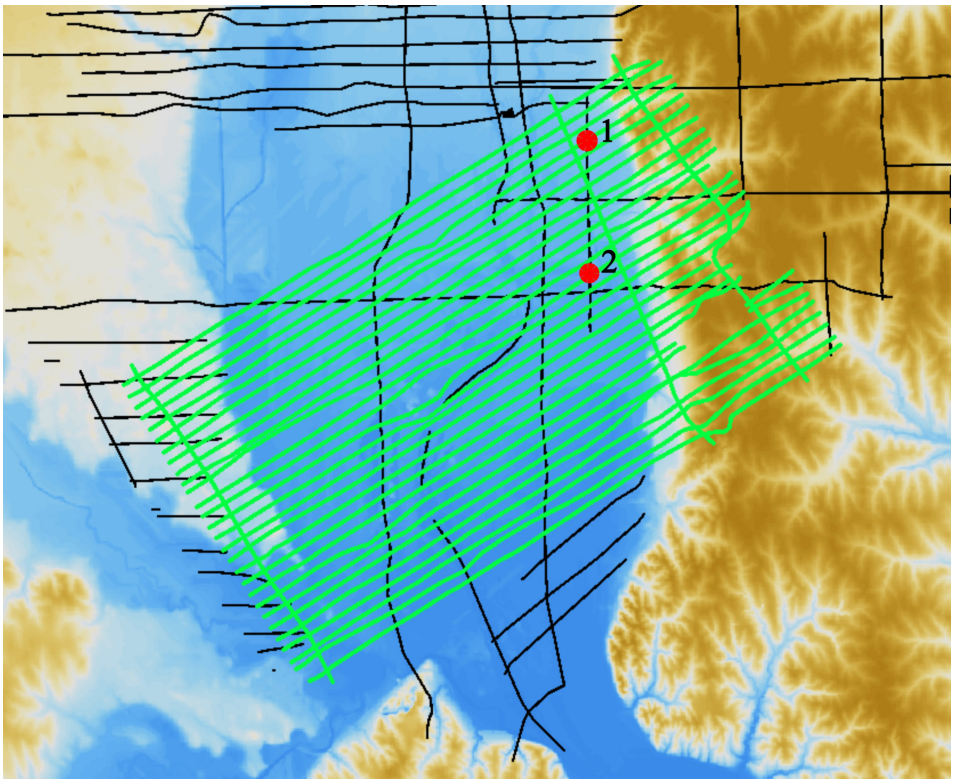


Figure 4-39. Locations (red dots), where SkyTEM flight lines (black) crossed RESOLVE flight lines (green), selected for calibration.

Table 4-4. SkyTEM-RESOLVE calibration locations (Projection Nebraska State Plane 1983, feet)

	2016 SkyTEM L169801		2007 RESOLVE L20040		2007 RESOLVE L20130	
Point	Easting	Northing	Easting	Northing	Easting	Northing
1	2659883	500645	2659861	500622	xx	xx
2	2660170	491265	xx	xx	2660111	491294

Once the calibration locations were selected, the 2016 SkyTEM inverted resistivity earth models at those locations were extracted and plotted with the closest 2007 Ashland RESOLVE data points; Point 1 in Figure 4-40 and Point 2 in Figure 4-41. The FEM forward-response to the 2016 SkyTEM models were then calculated using AarhusInv v8.11 (HGG, 2021).

One check that is made on these forward model responses is to invert the 'new' RESOLVE data at points 1 and 2 and compare the inversion results to the 'true' SkyTEM models. These inversions are presented for location Point 1 in Figure 4-42 and for Point 2 in Figure 4-43.

These forward-responses form the basis for the calibration of the Ashland RESOLVE data (Table 4-5). Initially, several more locations were selected as calibration locations. However, after the calibration factors at points 1 and 2 were determined, it was observed that the ratio of the two sets of factors (the last column in Table 4-5), was very close to 1.00 with an average of 0.97. Thus, only the two calibration points were utilized in the process.

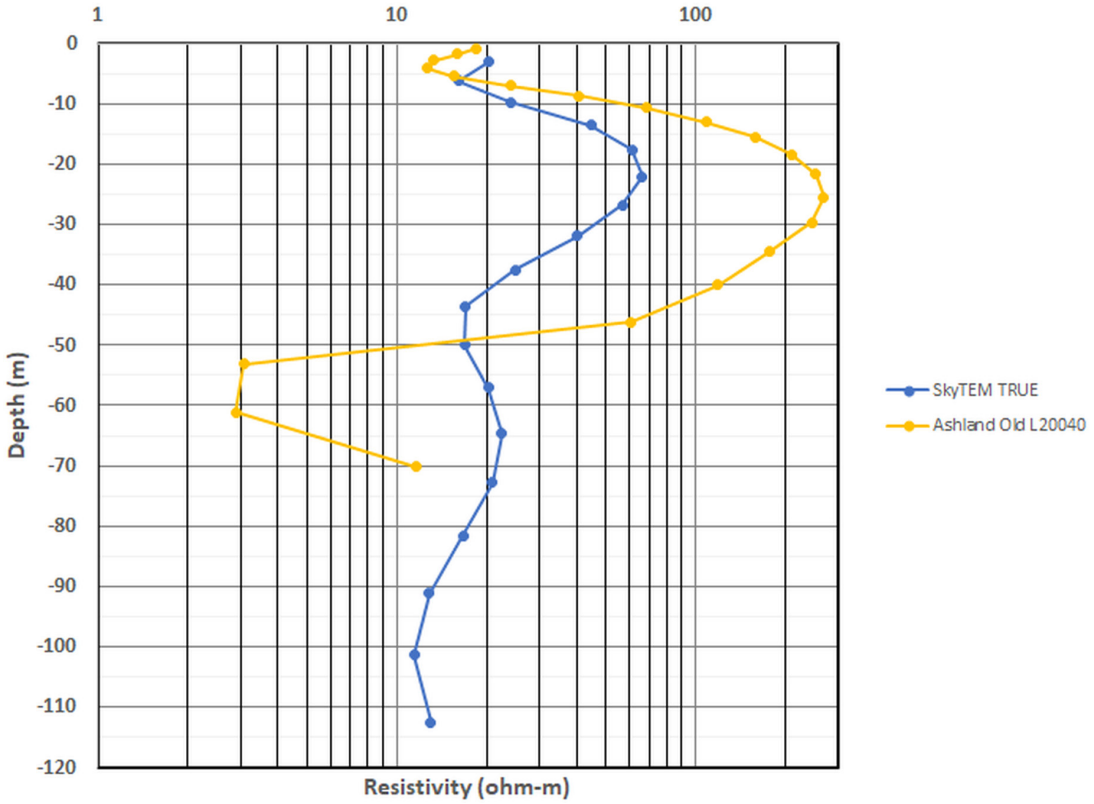


Figure 4-40. Plot of SkyTEM earth model (blue) versus the original inverted Ashland RESOLVE data (yellow) at Point 1.

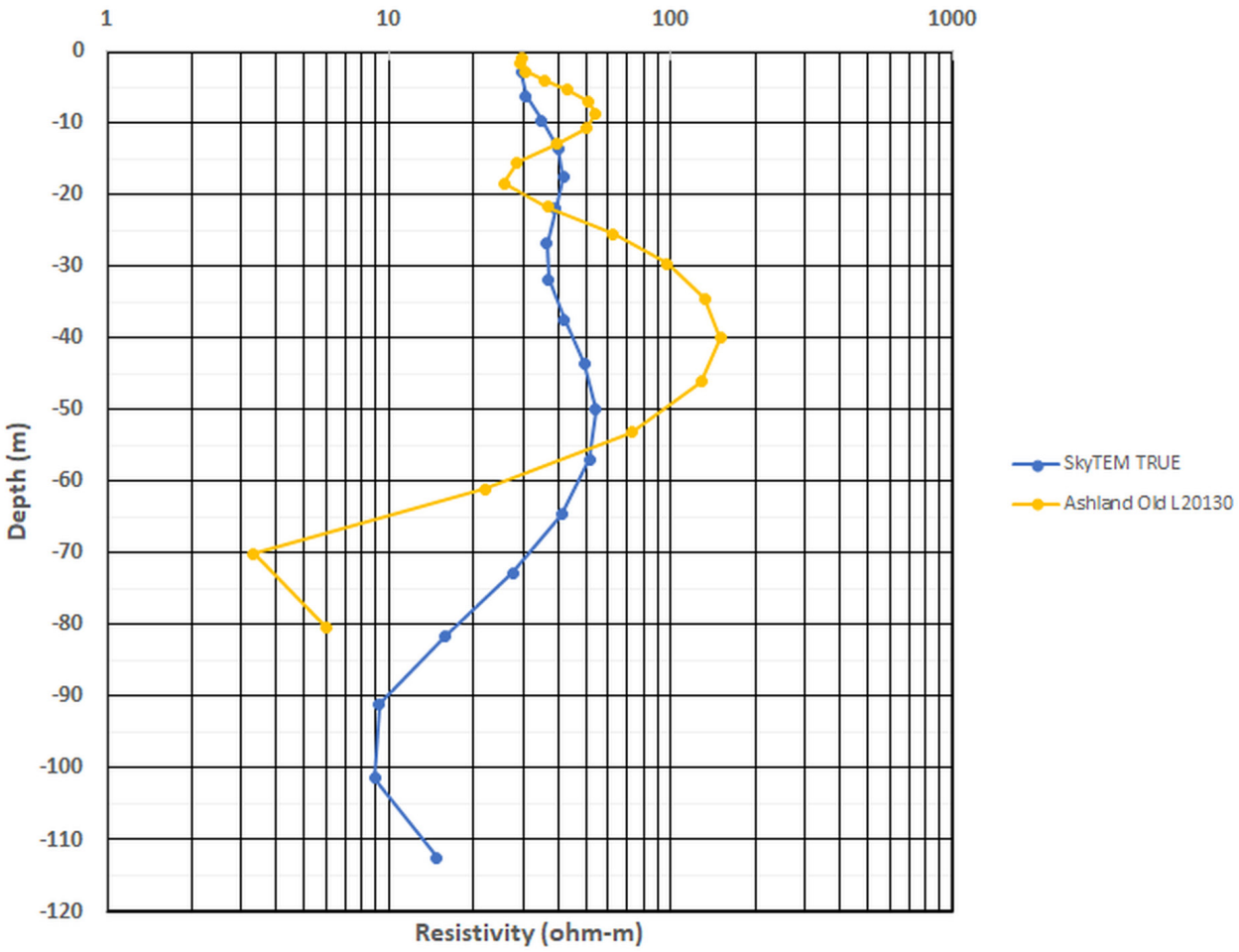


Figure 4-41. Plot of SkyTEM earth model (blue) versus the original inverted Ashland RESOLVE data at Point 2 (yellow line).

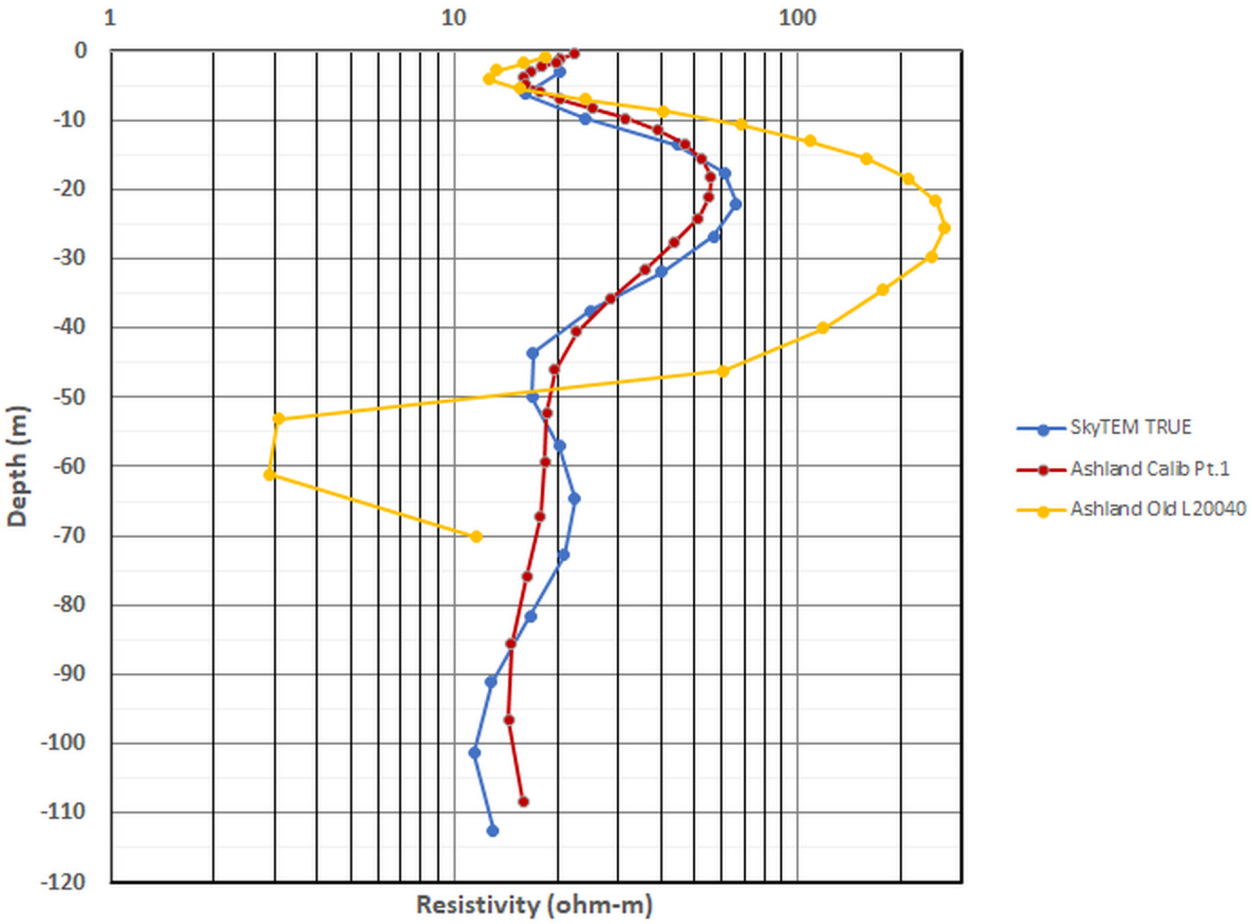


Figure 4-42. Plot of SkyTEM "true" model (blue line), the inverted FEM forward model response at Point 1 (red line), and the original 2007 RESOLVE model at Point 1 (yellow line).

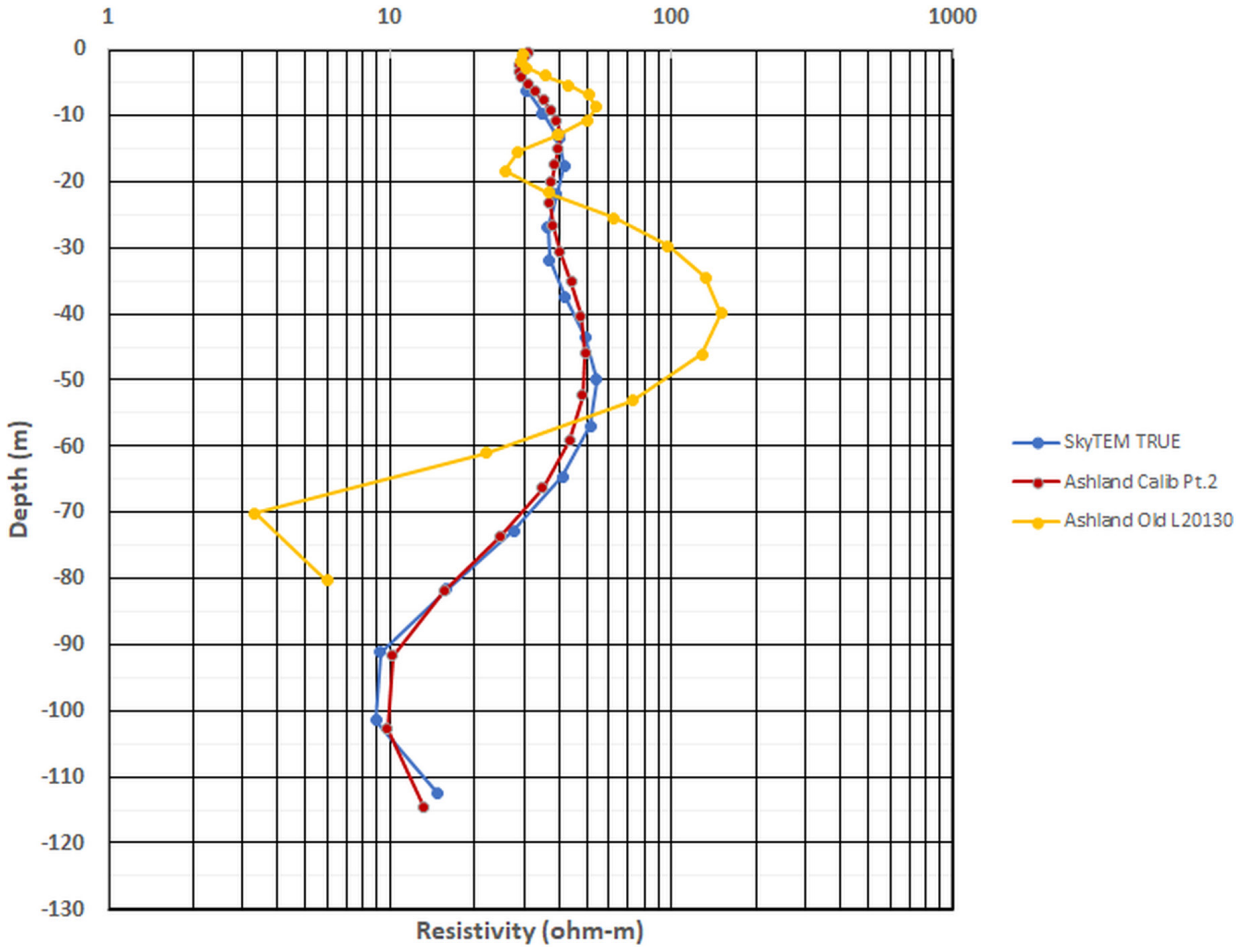


Figure 4-43. Plot of SkyTEM "true" model (blue line), the inverted FEM forward model response at Point 2 (red line), and the original 2007 RESOLVE model at Point 2 (yellow line).

Table 4-5. SkyTEM-Ashland RESOLVE calibration *preliminary* coefficients.

		L169801 at L20040		Ratio	L169801 at L20130		Ratio	Ratio of Ratios
Frequency (Hz)		AarhusInv	FEM	L20040	AarhusInv	FEM	L20130	Avg = 0.97
In-Phase	380	140	57	2.43	110	47	2.36	1.03
Quadrature	380	336	150	2.24	270	118	2.29	0.98
In-Phase	1760	564	221	2.55	430	173	2.49	1.02
Quadrature	1760	923	431	2.14	767	353	2.17	0.99
In-Phase	3270	-864	148	-5.83	-680	119	-5.72	1.02
Quadrature	3270	-1178	242	-4.87	-1012	199	-5.09	0.96
In-Phase	6520	1652	715	2.31	1362	601	2.27	1.02
Quadrature	6520	1788	919	1.95	1555	752	2.07	0.94
In-Phase	26640	3983	2139	1.86	3293	1614	2.04	0.91
Quadrature	26640	2183	1492	1.46	2036	1166	1.75	0.84
In-Phase	116400	5899	3449	1.71	5432	2899	1.87	0.91
Quadrature	116400	1360	902	1.51	1637	1132	1.45	1.04

As stated in the Table 4-5 caption, the coefficients in the table are preliminary calibration factors. This is because the forward response modeling used to develop the calibration coefficients was performed at a fixed system altitude. A refinement is necessary in order to ensure that the inverted altitudes are close to the measured altitudes (within 1 m-2 m). So, the next step in the process was to apply the preliminary calibration coefficients to the full Ashland data set and then iteratively invert the data in Aarhus Geosoftware Workbench, both as LCI's of lines L20040 and L20130, until close to the right calibration factors are calculated as indicated by the differences between the measured altitude and the inverted altitude (within 1 m-2 m). Then, SCI inversions were run. The final SCI inversions did not use the co-axial data measured at 3,270 Hz because they added too much noise to the inversion result. The final calibration factors are listed in Table 4-6. The final results at points 1 and 2 are presented in Figure 4-44 and Figure 4-45, respectively. While they don't look that close in these plots, the resistivity values are relatively close to those from the 2016 SkyTEM data. This is further demonstrated by the 3D Fence Diagrams in Figure 4-46 and Figure 4-47 which present the calibrated Ashland data plotted with the SkyTEM 2015, 2016, 2018, and 2020 inversion results.

After the calibration process was complete, the calibrated 2007 Ashland FEM data were integrated with the SkyTEM 2014, 2015, 2016, 2018, and 2020 inversion results.

Table 4-6. Final FEM calibration factors applied to the 2007 Ashland RESOLVE data.

Frequency (Hz)		Original Calib Factor	Final Calib Factor
In-Phase	380	2.430	1.215
Quadrature	380	2.241	1.120
In-Phase	1760	2.548	1.274
Quadrature	1760	2.143	1.072
In-Phase	3270	-5.834	-2.917
Quadrature	3270	-4.874	-2.437
In-Phase	6520	2.311	1.156
Quadrature	6520	1.945	0.973
In-Phase	26640	1.862	0.931
Quadrature	26640	1.463	0.732
In-Phase	116400	1.710	0.855
Quadrature	116400	1.508	0.754

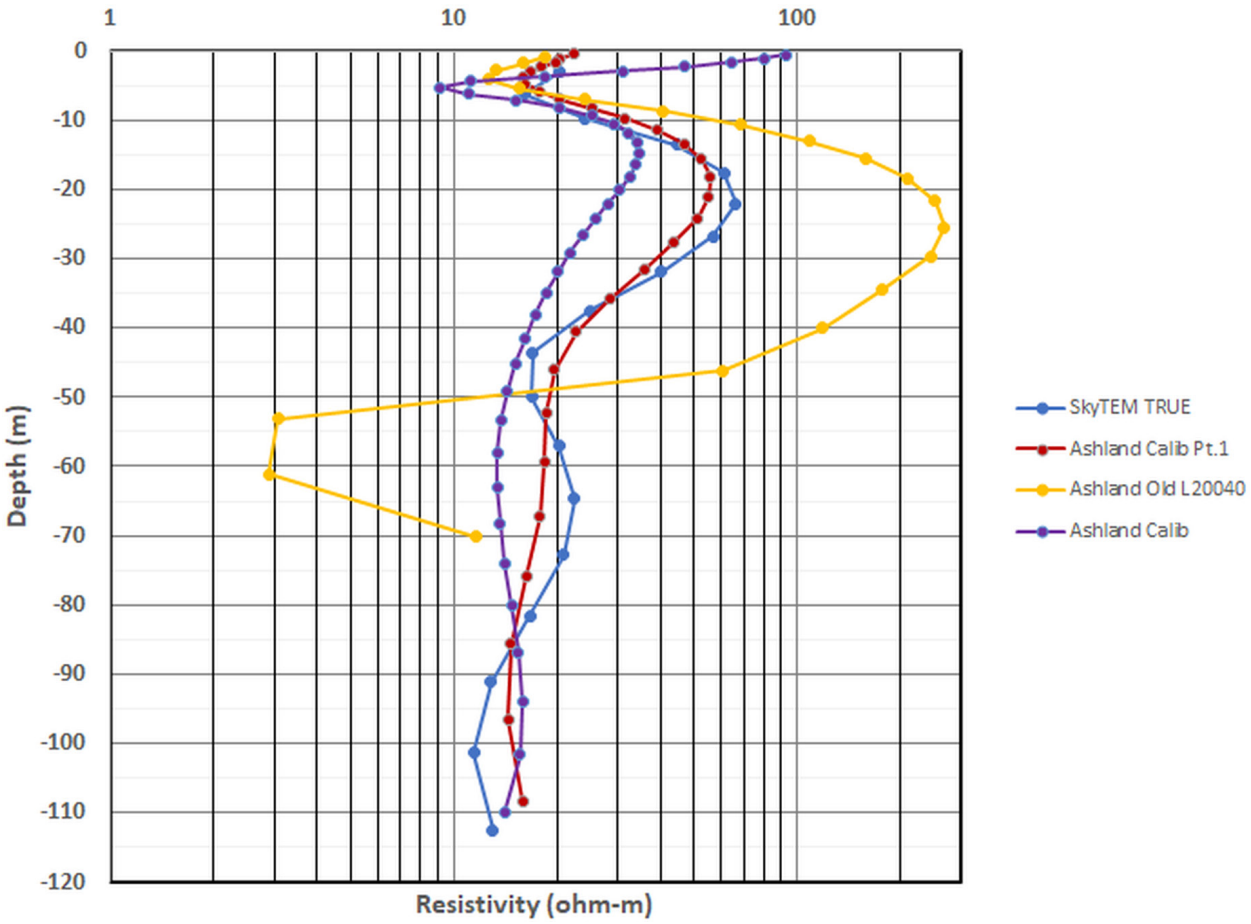


Figure 4-44. Plot of SkyTEM "true" model (blue line), the inverted FEM forward model response at Point 1 (red line), the original 2007 RESOLVE model near Point 1 (yellow), and the calibrated RESOLVE model near Point 1 (purple line).

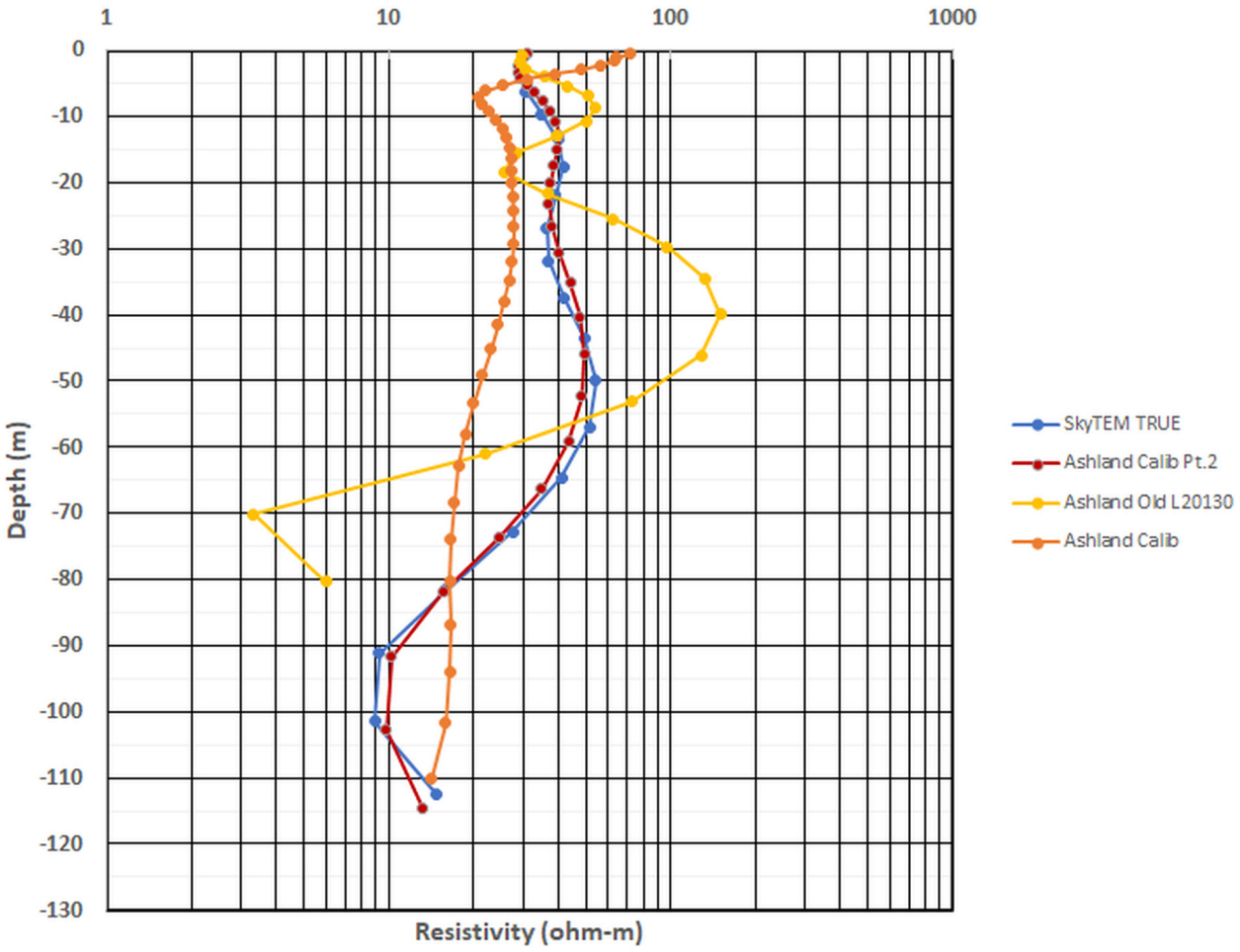


Figure 4-45. Plot of SkyTEM "true" model (blue line), the inverted FEM forward model response at Point 2 (red line), the original 2007 RESOLVE model near Point 2, and the calibrated RESOLVE model near Point 2 (purple line).

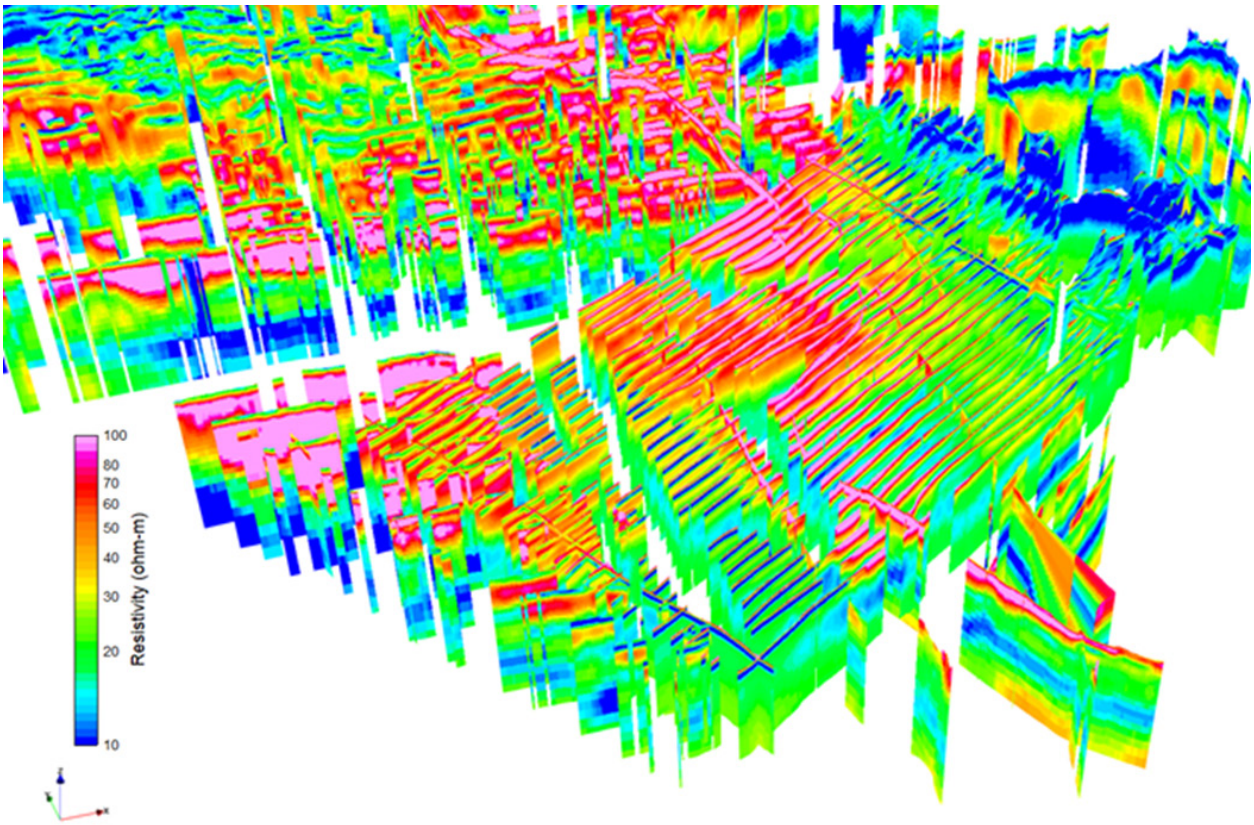


Figure 4-46. 3D Fence Diagram of the calibrated Ashland 2007 Inversion results integrated with the 2015, 2016, 2018, and 2020 SkyTEM inversion results. View is to the northeast.

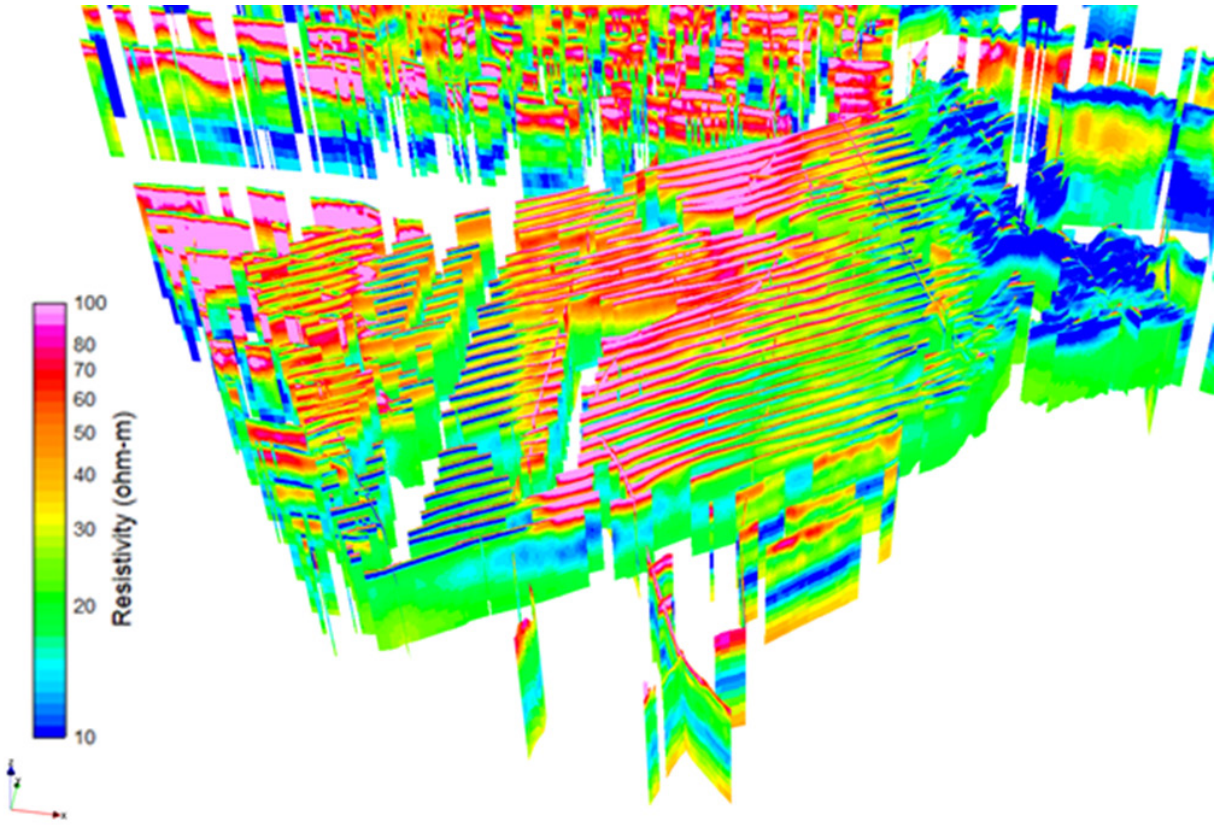


Figure 4-47. 3D Fence Diagram of the calibrated Ashland 2007 Inversion results integrated with the 2015, 2016, 2018, and 2020 SkyTEM inversion results. View is to the north.

5 AEM Results and Interpretation

This section provides the details on the process involved in the interpretation of the P-MRNRD 2020 AEM data and inversion results with previous AEM surveys within the study area.

5.1 Merge AEM Databases from Different Flights and Inversions

After the inversion process, flight lines from the P-MRNRD 2020 data set were combined with previous AEM surveys (2007, 2014, 2015, 2016, 2018) within the P-MRNRD (Figure 5-1). These surveys are discussed in Smith et al. (2008), Carney et al. (2015a, 2015b), and AGF (2017, 2019a, 2019b). This includes block flights and reconnaissance grid flight lines. These continuous lines allow for improved viewing and interpretation of the AEM inversions results across the P-MRNRD area. A compiled table listing the original flown lines and the new combined lines is included in *Appendix 3 – Deliverables/ProcessedData/Integrated_AEM_Datasets.xlsx*.

5.2 Interpretive Process

5.2.1 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 and AEM), a Digital Elevation Model (DEM) was constructed for the ENWRA area. The data was downloaded from the National Elevation dataset (NED) located at the National Map Website (U.S. Geological Survey, 2021) at a resolution of 1 arc-second or approximately 100 ft. The geographic coordinates are North American Datum of 1983 (NAD 83) State Plane Coordinate System (SPCS) Nebraska Zone (feet) 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 5-2 is a map of the DEM for the P-MRNRD 2020 survey area having a vertical relief of about 723 ft with a minimum elevation of 887 ft and a maximum elevation of 1,610 ft. This DEM was used to reference all elevations within the AEM and borehole datasets.

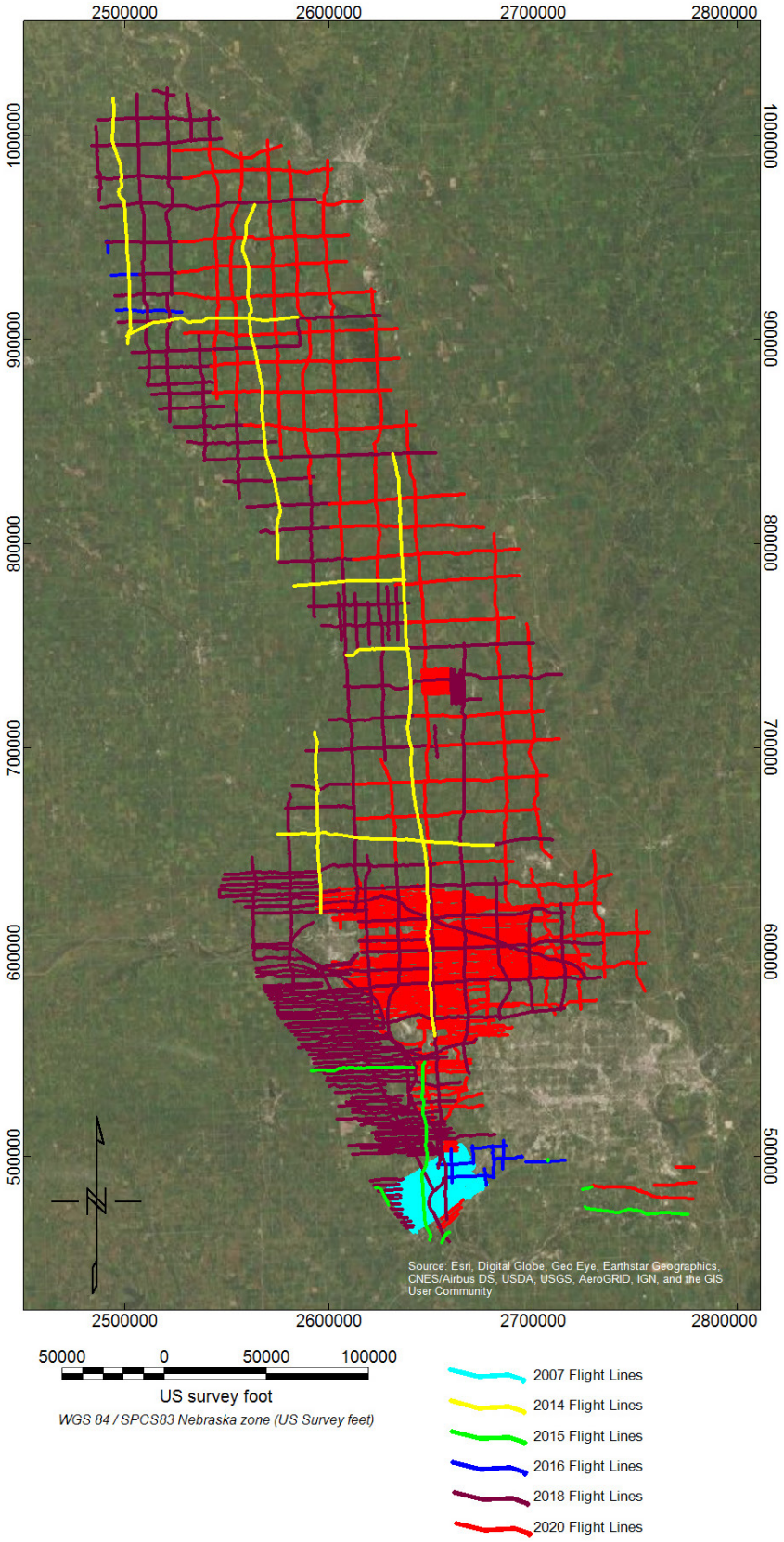


Figure 5-1. P-MRNRD combined survey lines.

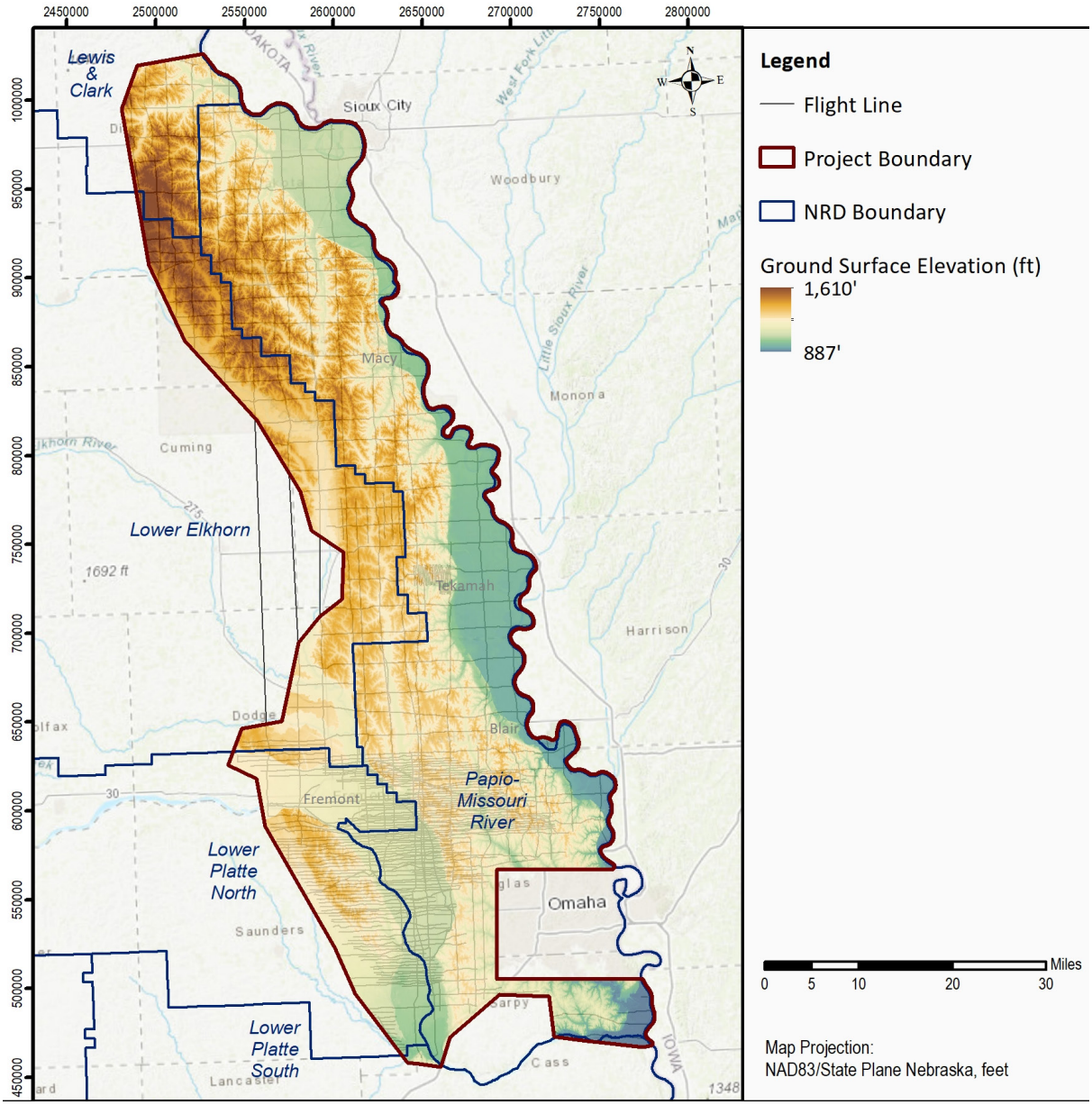


Figure 5-2. Map of the Digital Elevation Model for the P-MRNRD 2020 study area. Flight lines are indicated with light grey lines. Data source is the one (1) arc-second National Elevation Dataset (U.S. Geological Survey, 2021). North American Datum of 1983 (NAD 83) State Plane Nebraska (feet) and the elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88).

5.2.2 Borehole Derived Bedrock Surface

As a guide in the interpretation of the AEM, a bedrock surface was prepared using CSD and NE-DNR borehole logs. The interpolation process included:

- Consolidate the NE-DNR lithology tables used in previous AGF studies as well as newly compiled NE-DNR specific to this project into one comprehensive dataset.
- Categorize each borehole's lithology description as either 'Bedrock' or 'Unconsolidated' based on the description type. For example:
  - Sandstone, Shale, Siltstone, Limestone, Chalk = 'Bedrock'
  - Clay, silt, gravel/boulders, etc. = 'Unconsolidated'
- Review the dataset and flag those boreholes where an 'Unconsolidated' lithologic description was underlying a 'Bedrock' description.
- Revise categorized lithology, as needed, or flag boreholes for removal from working borehole lithology dataset.
- Extract only those NE-DNR boreholes that indicate depth to the top of bedrock into a working bedrock only borehole lithology dataset.
- Add the CSD borehole stratigraphy table to the working bedrock only borehole lithology dataset, import final dataset into ESRI's ArcCatalog, and export as a borehole point shapefile.
  - The final bedrock only borehole shapefile used for interpolation contained 3,723 data points (Shown in Figure 5-3 below).
- Extract the project's 100 ft cell size ground surface elevation DEM into the bedrock only borehole point shapefile, and calculate the top of bedrock elevation by subtracting the depth to the top of bedrock from the ground surface elevation.
- Interpolate the bedrock only borehole point shapefile into a continuous raster dataset using the kriging geostatistical model and export to a 100 ft cell size grid.
- Calculate the residuals of the actual measured top of bedrock elevation to the interpolated top of bedrock elevation.
- Review any borehole where the residual was > 30 ft or < -30 ft. The value of 30 was used because it is a general representation of the degree of error while logging a borehole with mud rotary drilling techniques as it is approximately one drill stem length. Flag those boreholes that appear to be anomalous.
  - Boreholes were flagged as an "anomaly" if the following was observed:
    - A borehole in a cluster of boreholes where the actual measured bedrock elevation varied more than ~ 75 ft from adjacent wells' actual measured bedrock elevation, or
    - a borehole's actual measured bedrock elevation varied more than ≈ 75 ft from an adjacent CSD well.
- Re-interpolate the borehole point shapefile, excluding those points flagged as "anomaly", into a continuous raster dataset using the kriging geostatistical model and exported to a 100 ft cell size grid.
- Mosaic the newly interpolated bedrock elevation raster surface with AGF's previously constructed top of bedrock surfaces within the project area and set a maximum elevation as DEM minus 3 ft.

This surface was utilized as a guide in the interpretation of the bedrock within the AEM data profiles described next.

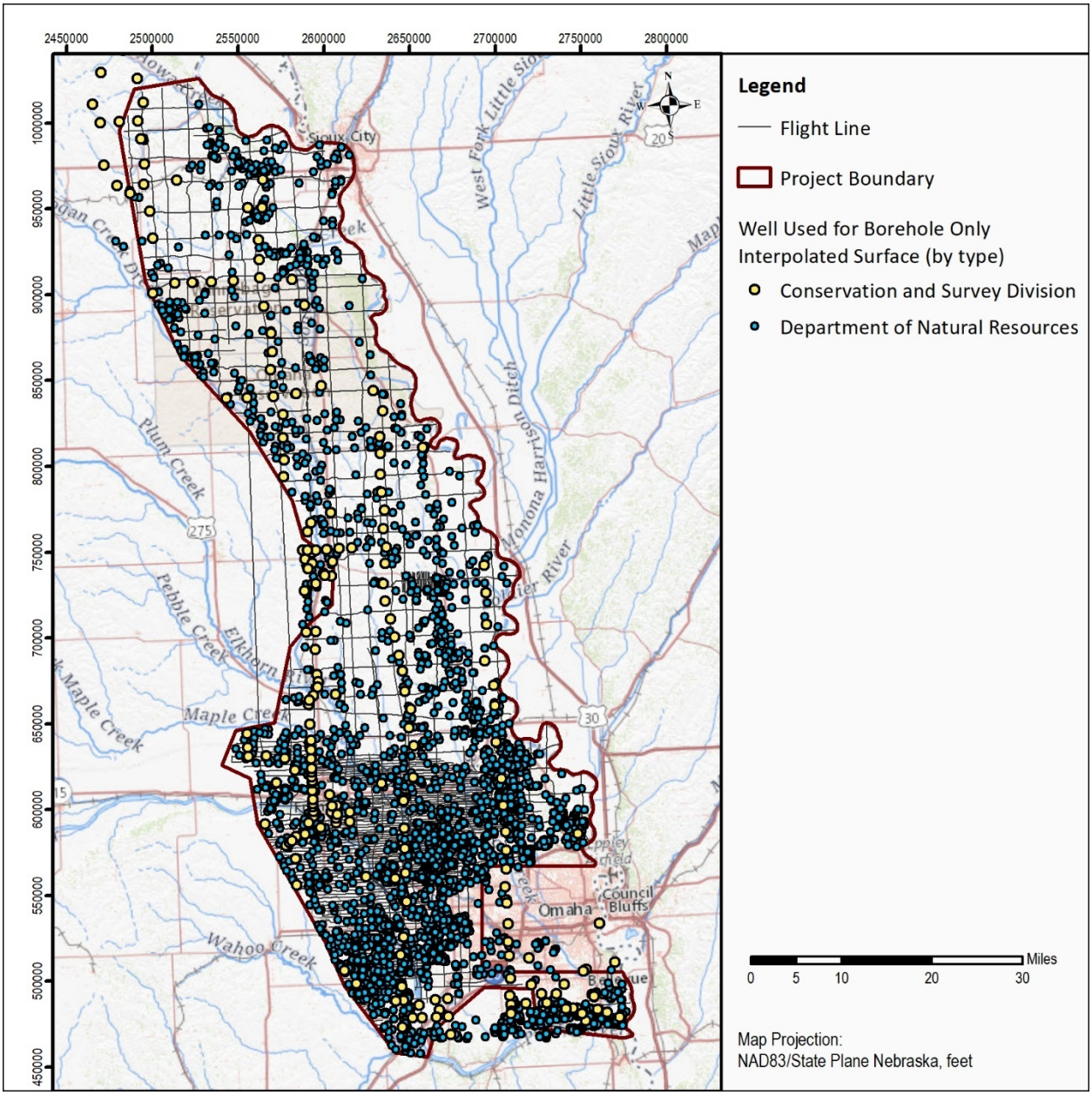


Figure 5-3. Map of the project boundary showing the data points used to interpolate the bedrock surface elevation. This "borehole only" interpolated bedrock surface was used as a guide in the interpretation of the AEM data. The project is NAD83 State Plane Nebraska (feet).

5.2.3 Create Interpretative 2D Profiles

After final combination of the AEM data (described above in Section 5.1), characterization of the subsurface was performed in cross-section format using Datamine Discover Profile Analyst (PA) (Datamine Discover, 2020). During interpretation, the horizontal and vertical scales 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 Carlile Formation (***Kc***), Cretaceous Greenhorn Limestone and Graneros Shale (***Kgg***), Cretaceous Dakota Group (***Kd***), and the undifferentiated Pennsylvanian and other potential Paleozoic units in the north in most areas of the P-MRNRD (***IP***). The interpretive process benefited from the use of CSD and NE-DNR boreholes which provided lithologic, stratigraphic, and geophysical information. The interpretations were simultaneously checked against the CSD's Nebraska bedrock geology map (Burchett et al., 1988; Burchett, 1986, and Burchett et al., 1975), but may differ due to the final interpretation. Additionally, the bedrock surface, as developed from borehole logs was used as a guide for the interpretation of the ***Kc***, ***Kgg***, ***Kd***, and ***IP*** in areas of low electrical resistivity contrast and no boreholes.

The ***Kc*** and the ***Kgg*** only occurred in the northern portions of the P-MRNRD. The CSD stratigraphic control was utilized to distinguish the ***Q*** from the underlying ***Kc*** and ***Kgg*** in addition to the geological mapping (Burchett et al., 1988; Burchett, 1986, and Burchett et al., 1975). The ***Kc*** is a marine shale and is distinguished by its electrically conductive nature. The ***Kgg*** is typically observed as an electrical resistor from the inclusion of the Greenhorn Limestone but is masked in many locations by the Graneros Shale which is a low resistivity unit.

The ***Kd*** general location is detectable when there are resistive sands/sandstones. Use of general thickness constraints can also assist in the interpretation of the ***Kd*** location. CSD wells in the area also provide stratigraphic control assisting in the location of the geologic units. When the ***Kd*** is the Cretaceous bedrock unit, much greater care needs to be taken due to the poor resistivity contrast of the ***Q*** and the ***Kd*** in many locations. Many of the holes in the area indicate sand or sand and gravel at the bottom of the ***Q*** while the ***Kd*** is sand and or sandstone. The resistivity contrast between the ***Q*** sand and the ***Kd*** sand is almost nonexistent. Use of CSD stratigraphy calls and the presence of sandstone and shale in the NE- DNR registered wells were used to pick the ***Q/Kd*** contact when no resistivity contrast was present. The borehole derived bedrock surface provided a useful interpretive tool to supplement the boreholes.

The top of the ***IP*** was a challenging unit to interpret due to the highly variable resistivity of the ***IP***. The unit goes from a resistive unit to a conductive unit based on the presence of clay minerals within the shale and limestone units. The best way to interpret the unit is to use the boreholes in the area. Many of the CSD and the NE-DNR holes have shale, chalk, or limestone indicated at the bottom. This provides a clear indication of the ***IP***. When the CSD holes contain stratigraphic information, that boundary can be confidently interpreted. In some instances, there are no indications of the ***IP*** at the bottom of the holes. Inspecting the area for the average depth of the NE-DNR holes provides another clue to the position of

the ***IP*** as many wells stop on top of the ***IP***. The following images are selected examples of the interpreted resistivity profiles that illustrate the interpretation process with the use of the boreholes.

Figure 5-4 is an approximately 24.5-mile-long line, L1102000, that is flown east-west south of South Sioux City and Goodwin, Nebraska. The line is composed of data from 2018 and 2020. Several CSD test holes are projected onto the line that are within ½ mile (2,640 feet) of the flight line. The ***Q*** sediments are composed of two basic types: glacial tills and sands in the Rolling Hills and Missouri river sediments within the Missouri river flood plain. On the western end of the line the eroded remnants of the ***Kc***, ***Kgg***, and ***Kd*** are present. The ***Kd*** occurs along the total length of the line but is thinning to the east due to erosion. CSD test hole *02-PMR-14* is off the line to the south, but does indicate the thick ***Kd*** section along the bluffs. Several NE-DNR wells within 1,500 feet of the flight line are within the Missouri river sediments and indicate a silt and clay layer overlying the sand and gravel resistive materials deposited overlying the ***Kd***.

Figure 5-5 is an approximately 24.5-mile-long line, L908600, that is flown east-west south of Burt and the Washington County Line. The line goes from the Missouri River flood plain in the east to Logan Creek in the west. The line is composed of data from 2018 and 2020. Two CSD test holes are projected onto the profile that are within ½ mile (2,640 feet) of the flight line, one on the west and one in the Missouri River flood plain. The ***Q*** sediments are composed of two basic types: glacial tills in the Rolling Hills and Missouri River sediments within the Missouri River flood plan with some small amounts of sands in the Logan Creek drainage. The ***Kd*** occurs along the majority of the line but is eroded off beneath the Missouri River sediments overlying the ***IP***. CSD test hole *04-PMR-17* indicates clays overlying sand and gravel terminating in the limestone of the ***IP***. Several NE-DNR wells within 1,500 feet of the flight line are within the Missouri River sediments and indicate a silt and clay layer overlying the sand and gravel resistive materials deposited on the ***Kd*** on the western side of the Missouri River sediments while the clay is absent on the far eastern end of the line. There are also several NE-DNR wells within the Rolling Hills. These wells indicate thick clay with sandstone and sand at the bottom within the ***Kd***.

Figure 5-6 is an approximately 23.5-mile-long line, L700901, that is flown east-west northeast of Fremont, north of Arlington and Kennard, and ending northwest of Fort Calhoun, Nebraska. The line goes from Platte River valley in the west to the Rolling Hills above the Missouri River flood plain. The line is composed of 2020 data. One CSD test hole, *24-A-62*, is projected onto the profile that is within ½ mile (2,640 feet) of the flight line within the Rolling Hills. This test hole indicates glacial till clay rich materials overlying sand materials deposited on the ***Kd*** composed of shale terminating in the ***IP*** limestone. The ***Q*** sediments are composed of three basic types: glacial tills in the Rolling Hills, paleochannel deposits, and Elkhorn and Platte River sediments. The ***Kd*** occurs along the line but is eroded thin on the eastern end overlying the ***IP***. There are several NE-DNR wells within 1,500 feet of the flight line. These are concentrated in two areas that may indicate a paleochannel system on the top of the ***Kd*** and under the thick glacial tills. There is also a few NE-DNR wells that show thick clays overlying sandstone in the center of the line.

Figure 5-7 is an approximately 10.4-mile-long line, L706300, that begins in the Missouri River flood plain and extends west into the Rolling Hills. The line is south of La Platte, Nebraska and north of the Platte

River. The line is composed of 2020 data. Several CSD wells are in the area and penetrate the ***IP***. On the far western end of the line CSD test hole *24-80* intersects a thin layer of ***Kd***. Several NE-DNR wells within 1,500 feet of the flight line are within the Missouri River sediments and indicate the sand and gravel resistive materials deposited on the ***IP***. In the center portion of the line the NE-DNR wells indicate layers of silt and clay overlaying the limestones of the ***IP***. In the far western end of the line the NE-DNR wells indicate a thin layer of sandstone of the ***Kd.***

Figure 5-8 is an approximately 34.4-mile-long north-south line, L1000801, that is on the eastern end of the P-MRNRD AEM survey area. The line goes from Missouri River flood plain in the north to the Rolling Hills in the south. The line begins in the Missouri River channel and extends south east of Tekamah and enters the Rolling Hills just west of Blair, Nebraska. The line is composed of 2020 data. The ***Q*** sediments are composed of two basic types: glacial tills in the Rolling Hills and Missouri River sediments. The ***Kd*** occurs along the line but is eroded thin along the length of the profile overlying the ***IP***. Several NE-DNR wells within 1,500 feet of the flight line are in both the glacial till and the Missouri River alluvium deposits. Along the majority of the line, a silt and clay layer is deposited on the coarse sand and gravels of the Missouri River alluvium. There are a few NE-DNR wells that show sandstone of the ***Kd***.

All of the 2D profiles along the flight lines can be found in *Appendix 1 – 2D Images*. The above profiles show examples of the interpretive process used in this P-MRNRD AEM interpretative report.

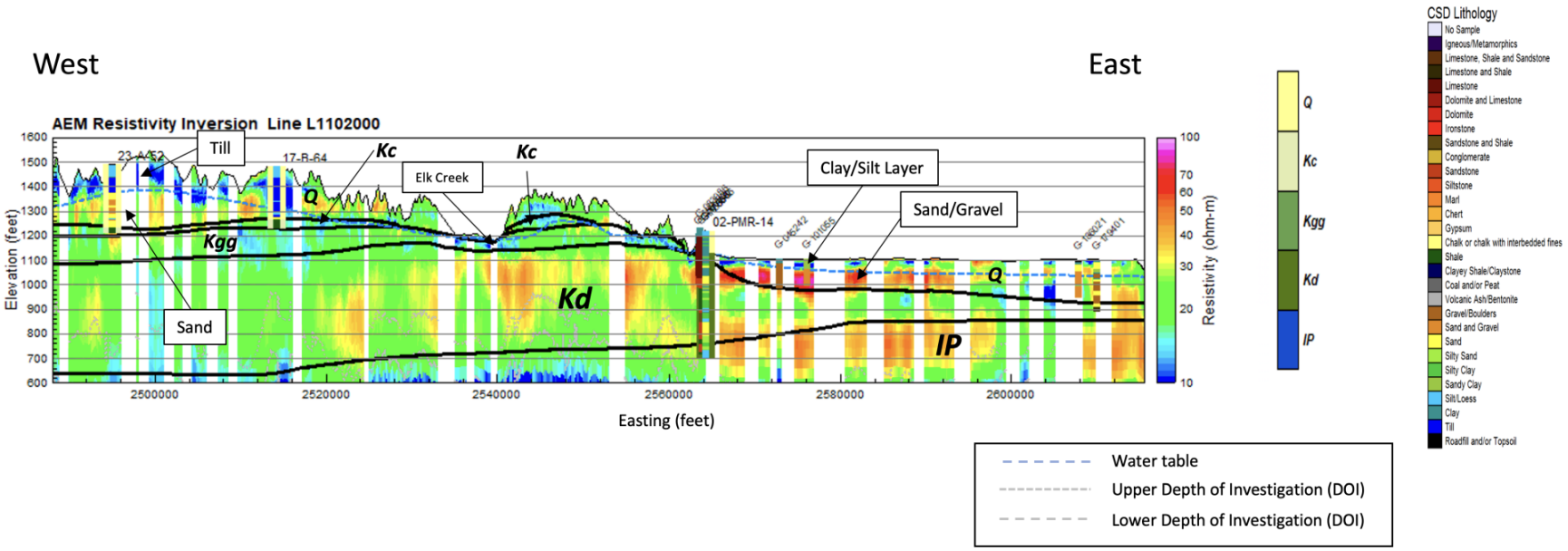


Figure 5-4. 24.5-mile line L1102000 that is flown east-west south of South Sioux City and Goodwin, Nebraska. CSD borehole lithology and stratigraphy logs are indicated on the AEM inverted earth models if they are within ½ mile (2,640 feet) of the flight line. Nebraska DNR lithology logs are indicated if they are within 1,500 feet of the flight line. Interpretations of the top of the Cretaceous Carlile (Kc), Cretaceous Greenhorn Limestone and Graneros Shale (Kgg), Cretaceous Dakota Group (*Kd*), and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines.

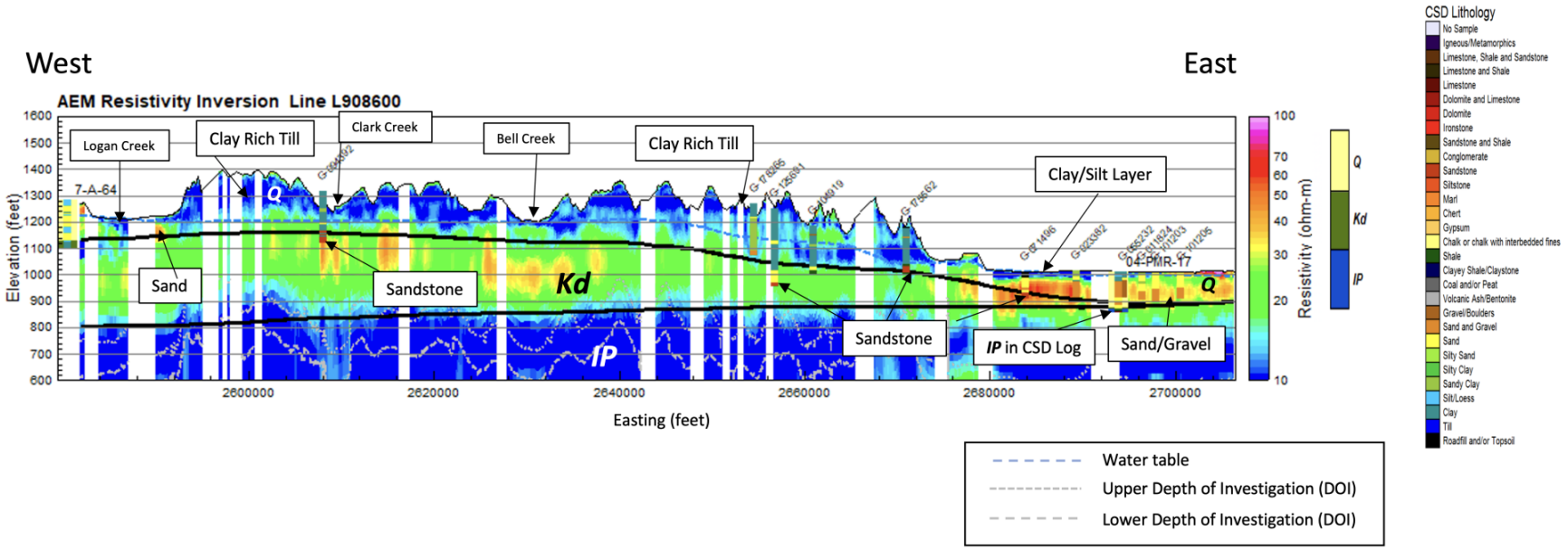


Figure 5-5. 24.5-mile-long east-west line L908600 that is flown south of the Burt/Washington county line. CSD borehole lithology and stratigraphy logs are indicated on the AEM inverted earth models if they are within ½ mile (2,640 feet) of the flight line. Nebraska DNR lithology logs are indicated if they are within 1,500 feet of the flight line. Interpretations of the top of the Cretaceous Dakota Group (*Kd*) and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

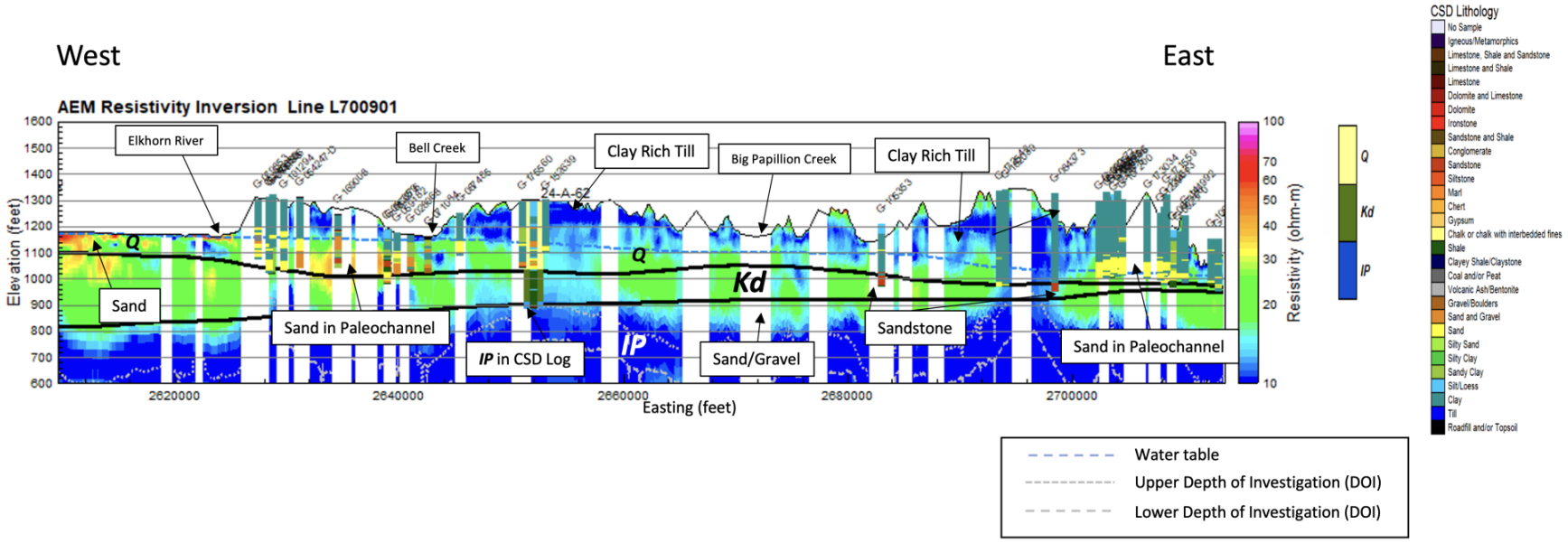


Figure 5-6. 23.5-mile-long east-west line L700901 that is flown from northwest of Fremont to northwest of Fort Calhoun, Nebraska. CSD borehole lithology and stratigraphy logs are indicated on the AEM inverted earth models if they are within ½ mile (2,640 feet) of the flight line. Nebraska DNR lithology logs are indicated if they are within 1,500 feet of the flight line. Interpretations of the top of the Cretaceous Dakota Group (*Kd*) and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

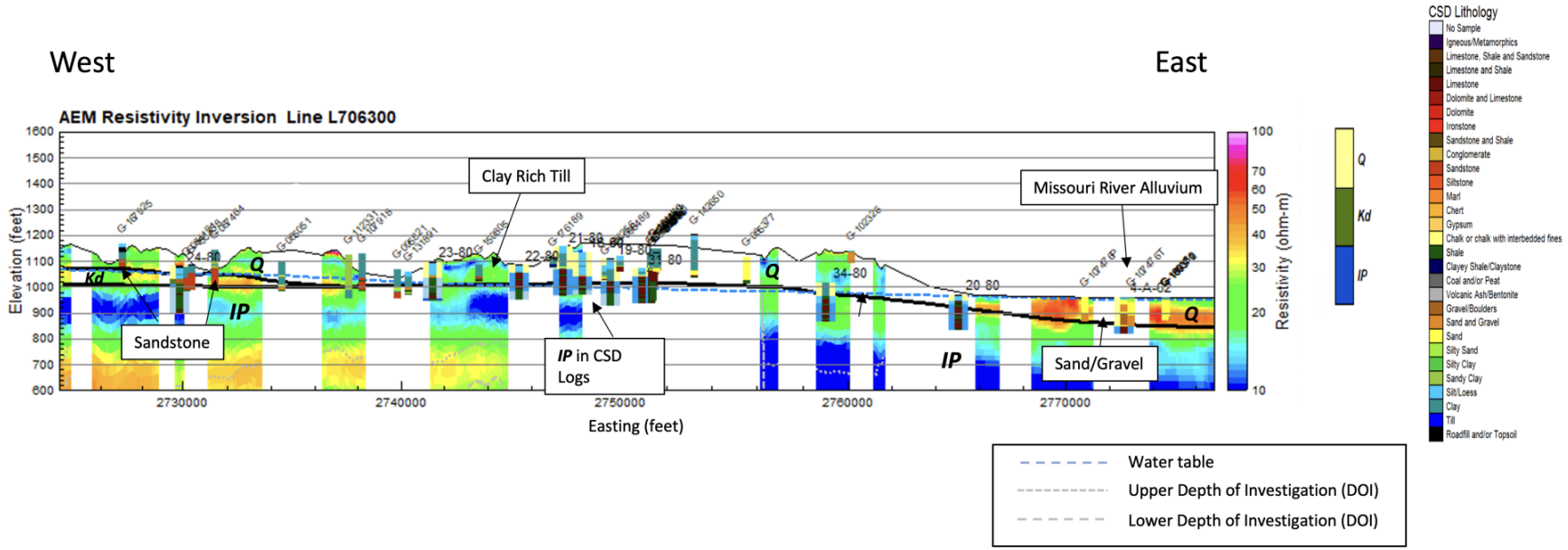


Figure 5-7. 10.4-mile-long east-west line L70603 flown south of La Platte, Nebraska and north of the Platte river. Nebraska CSD borehole lithology and stratigraphy logs are indicated on the AEM inverted earth models if they are within ½ mile (2,640 feet) of the flight line. Nebraska DNR lithology logs are indicated if they are within 1,500 feet of the flight line. Interpretations of the top of the Cretaceous Dakota Group (*Kd*) and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

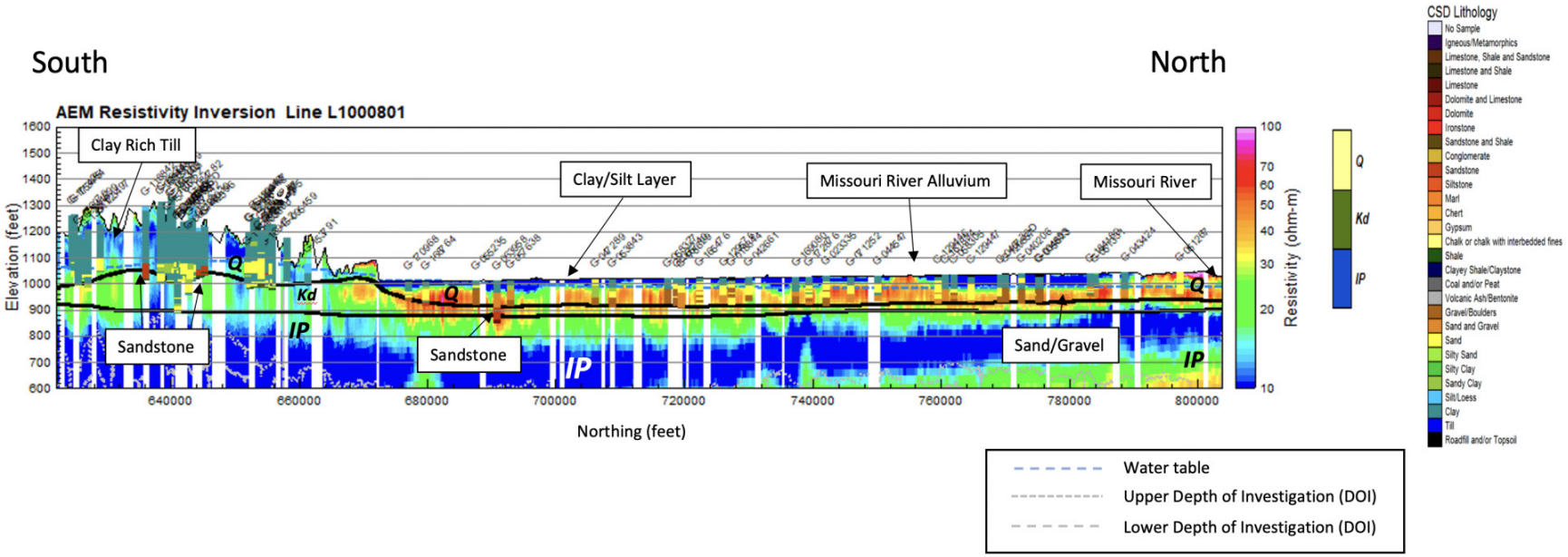


Figure 5-8. 17-mile-long north-south line L1000801 flown east of Tekamah and west of Blair, Nebraska. Nebraska CSD borehole lithology and stratigraphy logs are indicated on the AEM inverted earth models if they are within ½ mile (2,640 feet) of the flight line. Nebraska DNR lithology logs are indicated if they are within 1,500 feet of the flight line. Interpretations of the top of the Cretaceous Dakota Group (*Kd*) and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

5.2.4 Create Interpretative Surface Grids

For the P-MRNRD 2020 AEM survey area geologic unit top elevation, geologic unit thickness, and geologic unit saturated thickness grids were produced. To create these grids, data such as a ground surface digital elevation model (DEM), water table elevation, Nebraska Conservation and Survey Division (CSD) boreholes, and AEM interpreted point data of the survey area were imported and processed in ESRI's ArcMap along with the Spatial and Geostatistical Analyst extensions.

Raster grids of the elevation of the top of the Cretaceous Carlile (***Kc***), Cretaceous Greenhorn Limestone and Graneros Shale (***Kgg***), Cretaceous Dakota Group (***Kd***), and undifferentiated Pennsylvanian (***IP***) for the P-MRNRD area were produced. To create the grids, AEM data points and CSD boreholes with top elevation information were compiled for each geologic unit and input into ESRI's ArcMap for processing. In some areas, the CSD boreholes provided data control between flight lines. The number of AEM data points and CSD boreholes compiled for each geologic unit are shown in Table 5-1 below.

Table 5-1. The number of data points used to interpolate the elevation of the top of each geologic unit within the P-MRNRD project boundary.

Geologic Unit	# of AEM Data Points	# of CSD Boreholes
Kc	661	20
Kgg	1,410	16
Kd	18,053	149
IP	10,031	103

The top elevation point data were interpolated for each geologic unit into a continuous surface using the kriging geostatistical model and exported to 100 ft cell size resolution raster datasets. The surfaces were corrected with the 100 ft resolution ground surface DEM so that each surface was restrained to a maximum elevation of DEM minus 3 ft. Figure 5-9, Figure 5-10, Figure 5-11, Figure 5-12, Figure 5-13, and Figure 5-14 are maps displaying the top elevation surfaces of ***Kc, Kgg, Kd,*** and ***IP*** within the 2020 P-MRNRD AEM survey area.

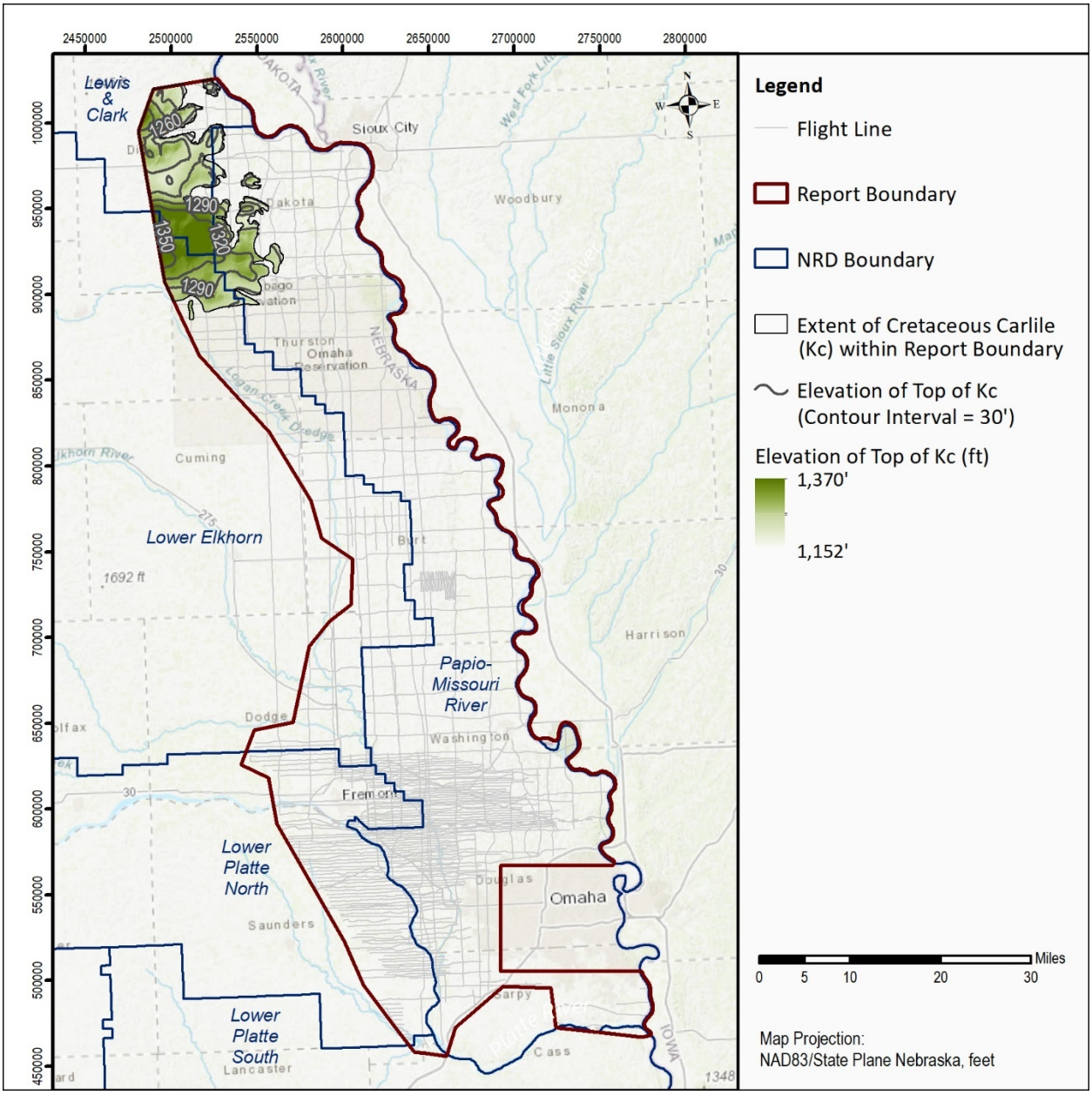


Figure 5-9. Map of the elevation of the top of the Cretaceous Carlile Formation (*Kc*) within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

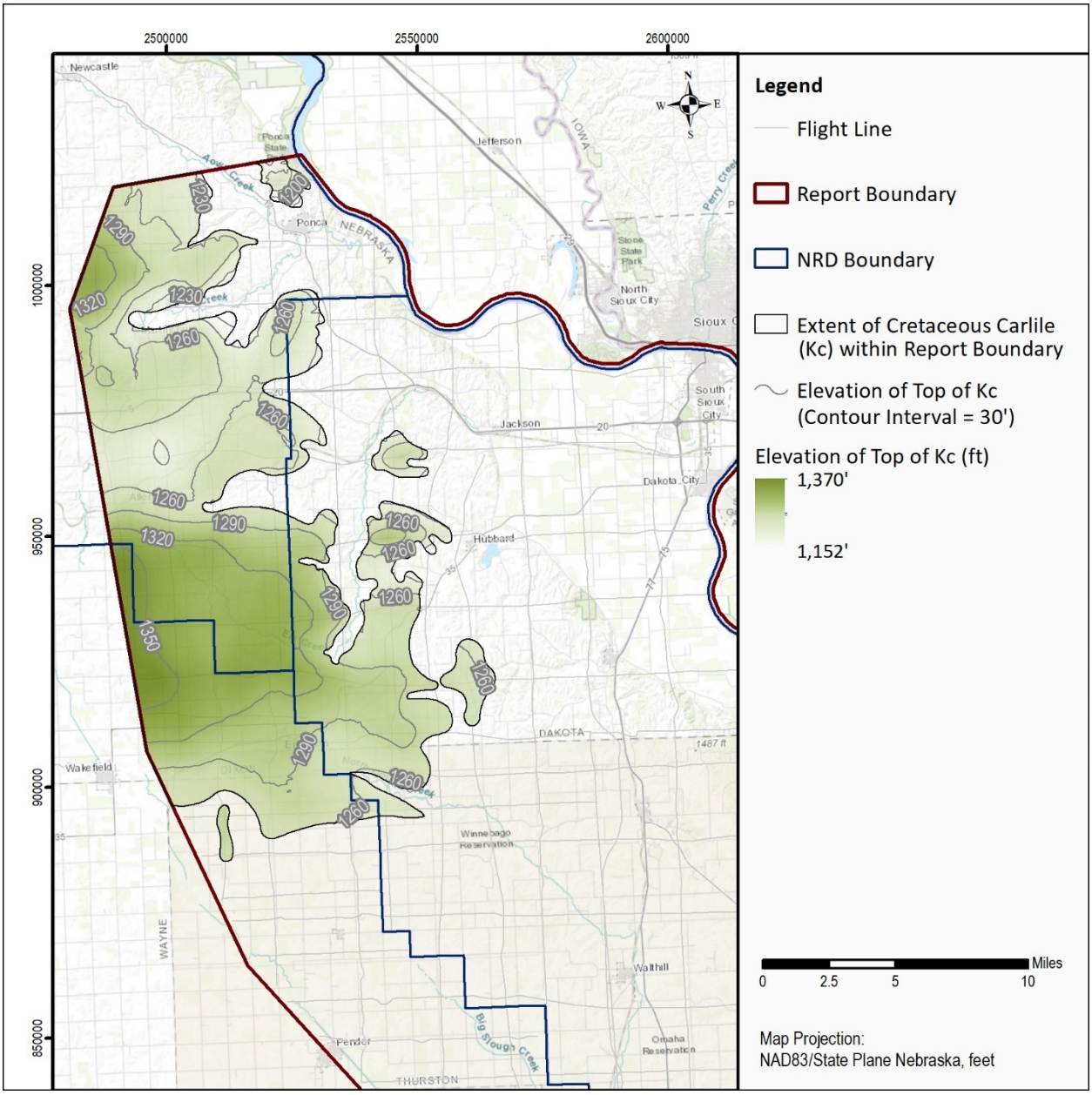


Figure 5-10. Map of the elevation of the top of the Cretaceous Carlile Formation (*Kc*) zoomed into a smaller area within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

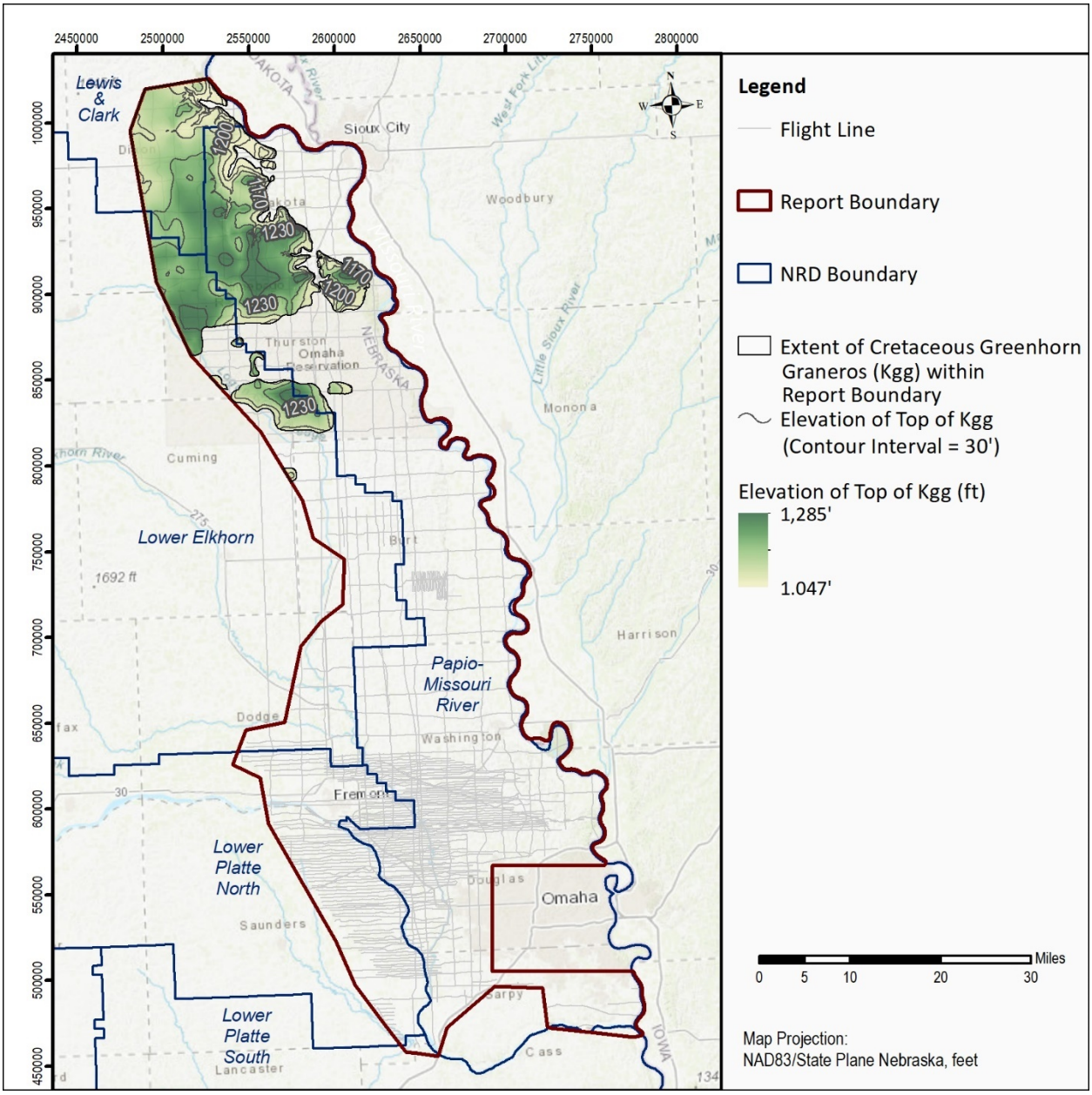


Figure 5-11. Map of the elevation of the top of the Cretaceous Greenhorn Limestone and Graneros Shale (*Kgg*) within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

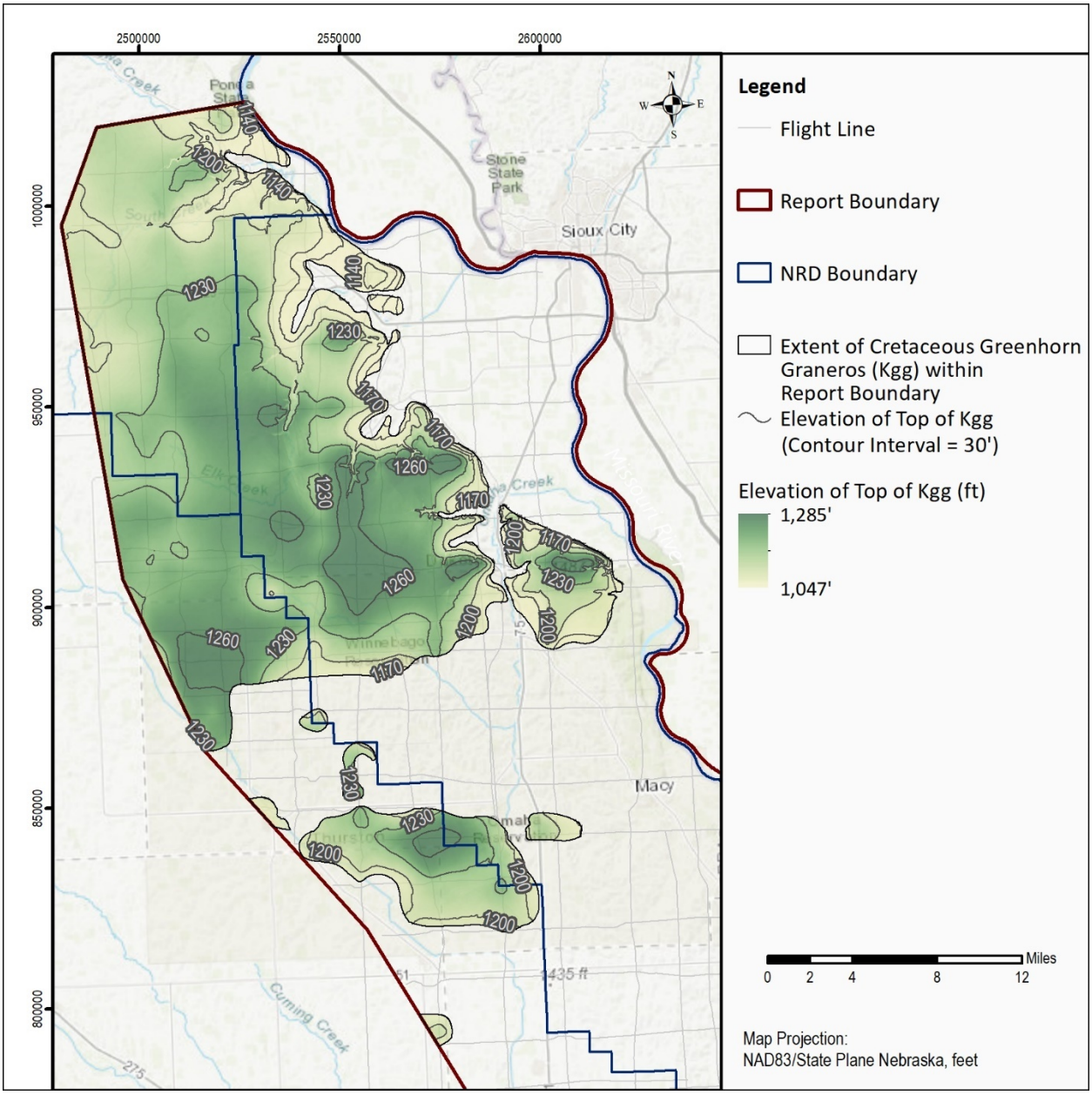


Figure 5-12. Map of the elevation of the top of the Cretaceous Greenhorn Limestone and Graneros Shale (*Kgg*) zoomed into a smaller area within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

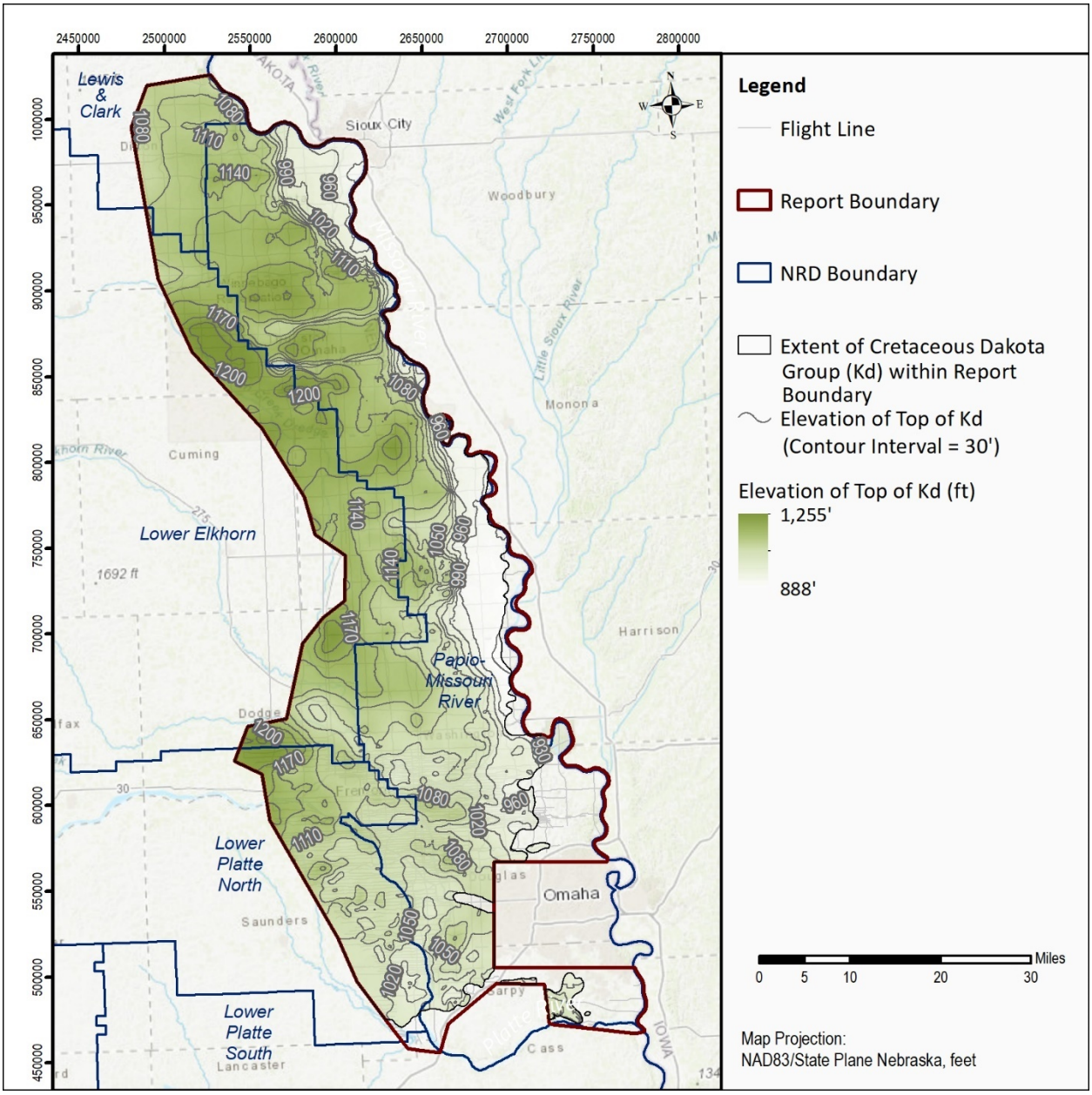


Figure 5-13. Map of the elevation of the top of the Cretaceous Dakota Group (*Kd*) within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

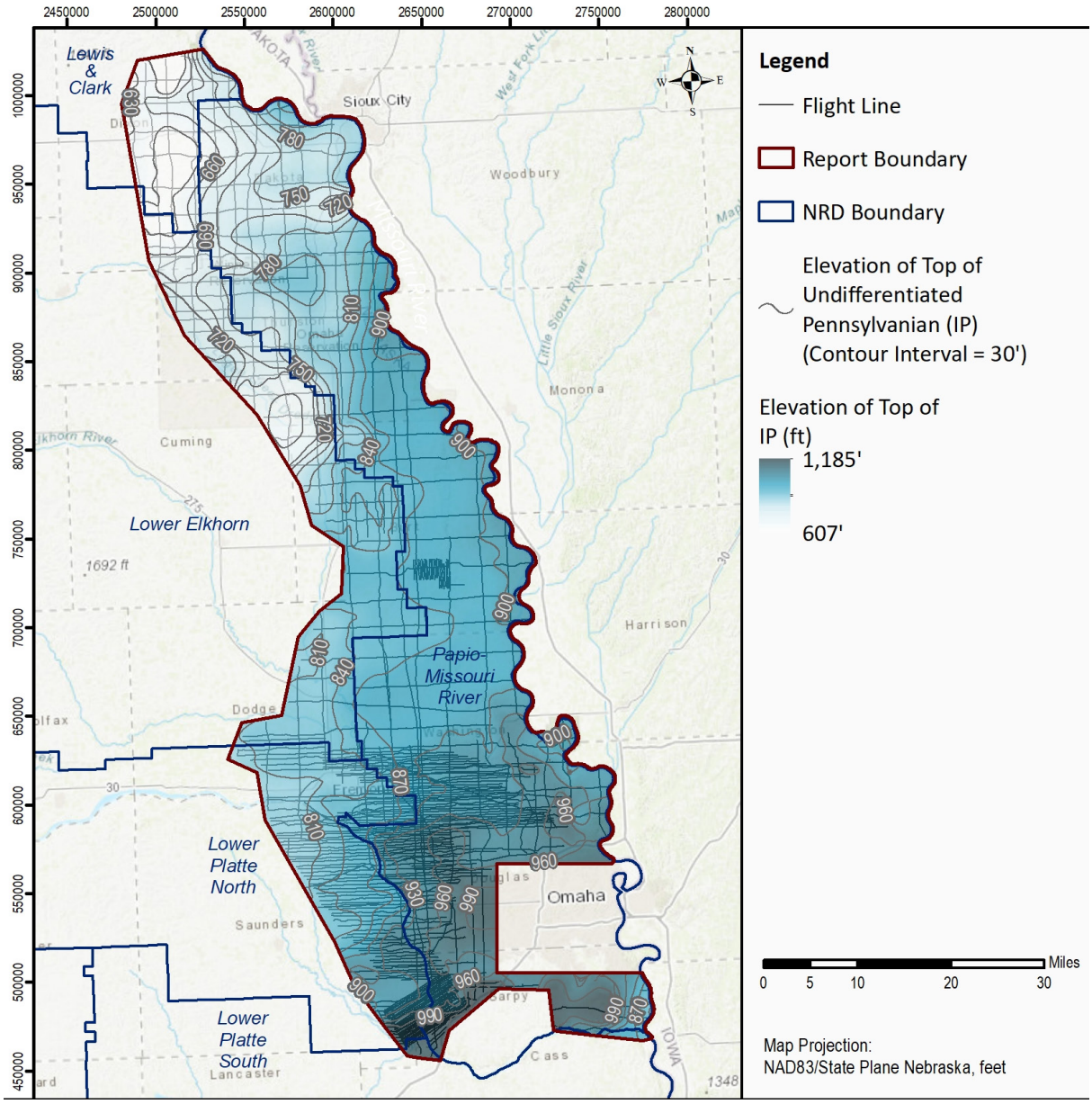


Figure 5-14. Map of the elevation of the top of the undifferentiated Pennsylvanian (*IP*) within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

Using the elevation grids for each geologic unit a top of bedrock elevation surface was produced. To create the bedrock grid, the ***Kc***, ***Kgg***, ***Kd***, and ***IP*** top elevation surfaces were mosaicked together in ArcMap. To reduce some edge effects that occur from mosaicking independently interpolated surfaces together, a smoothing factor was applied to the mosaicked surface with the Focal Statistics algorithm in ArcMap. The smoothed bedrock surface was corrected with the 100 ft resolution ground surface DEM so that it was restrained to a maximum elevation of DEM minus 3 ft. Figure 5-15 is a map of the elevation of the top of bedrock surface within the 2020 P-MRNRD AEM survey area.

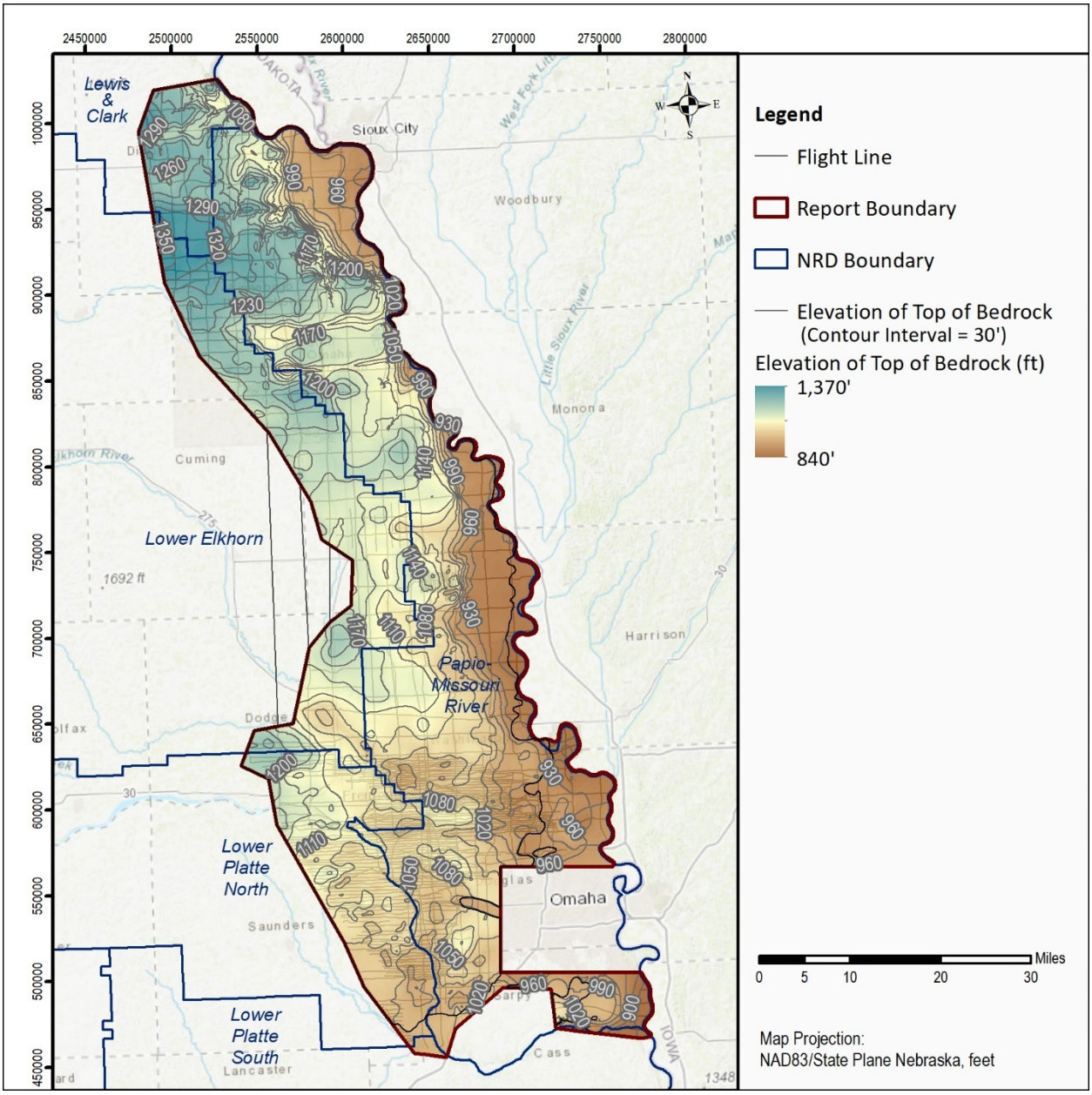


Figure 5-15. Map of the elevation of the top of the bedrock within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

Quaternary deposits (***Q***), ***Kc, Kgg,*** and ***Kd*** thicknesses were calculated for the 2020 P-MRNRD AEM survey area using the top of elevation surfaces and ArcMap's raster calculator. Table 5-2 summarizes the raster calculator input and output for each thickness calculation. The output was set to snap to the 100 ft DEM, then was clipped to each geologic unit extent.

Table 5-2. Summary of the input into ArcMap's raster calculator and the resultant output surfaces.

Raster Calculator Input	Output Result
DEM - Top of Bedrock	***Q*** **Thickness**
Top of ***Kc*** - Top of Kgg	***Kc*** **Thickness**
Top of ***Kgg*** - Top of Kd	***Kgg*** **Thickness**
Top of ***Kd*** - Top of IP	***Kd*** **Thickness**

Figure 5-16, Figure 5-17, Figure 5-18, and Figure 5-19 are maps displaying the total thicknesses of ***Q, Kc, Kgg,*** and ***Kd*** within the 2020 P-MRNRD AEM survey area, respectively.

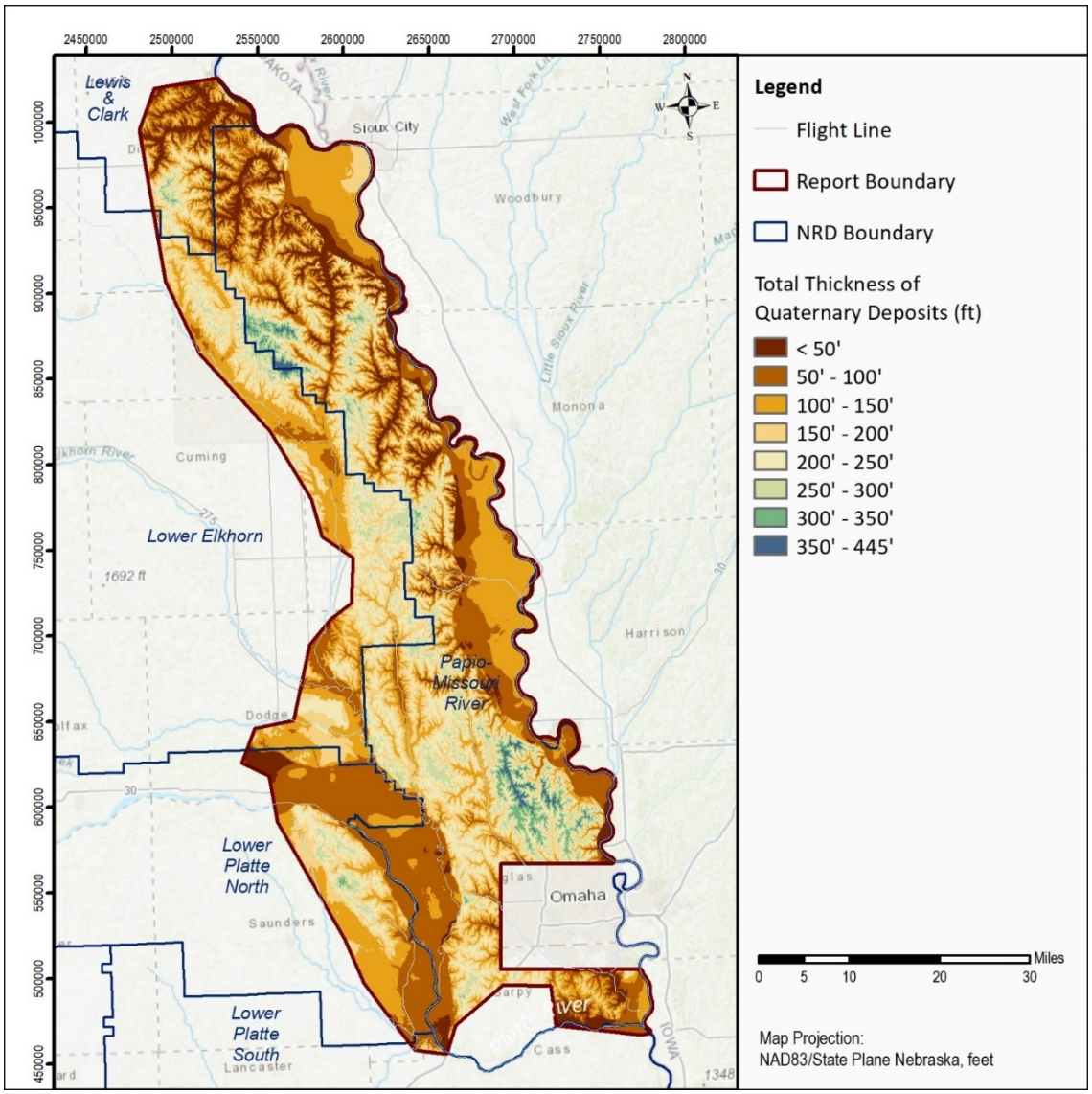


Figure 5-16. Map of the total thickness (in feet) of Quaternary (*Q*) deposits within the 2020 PMRNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

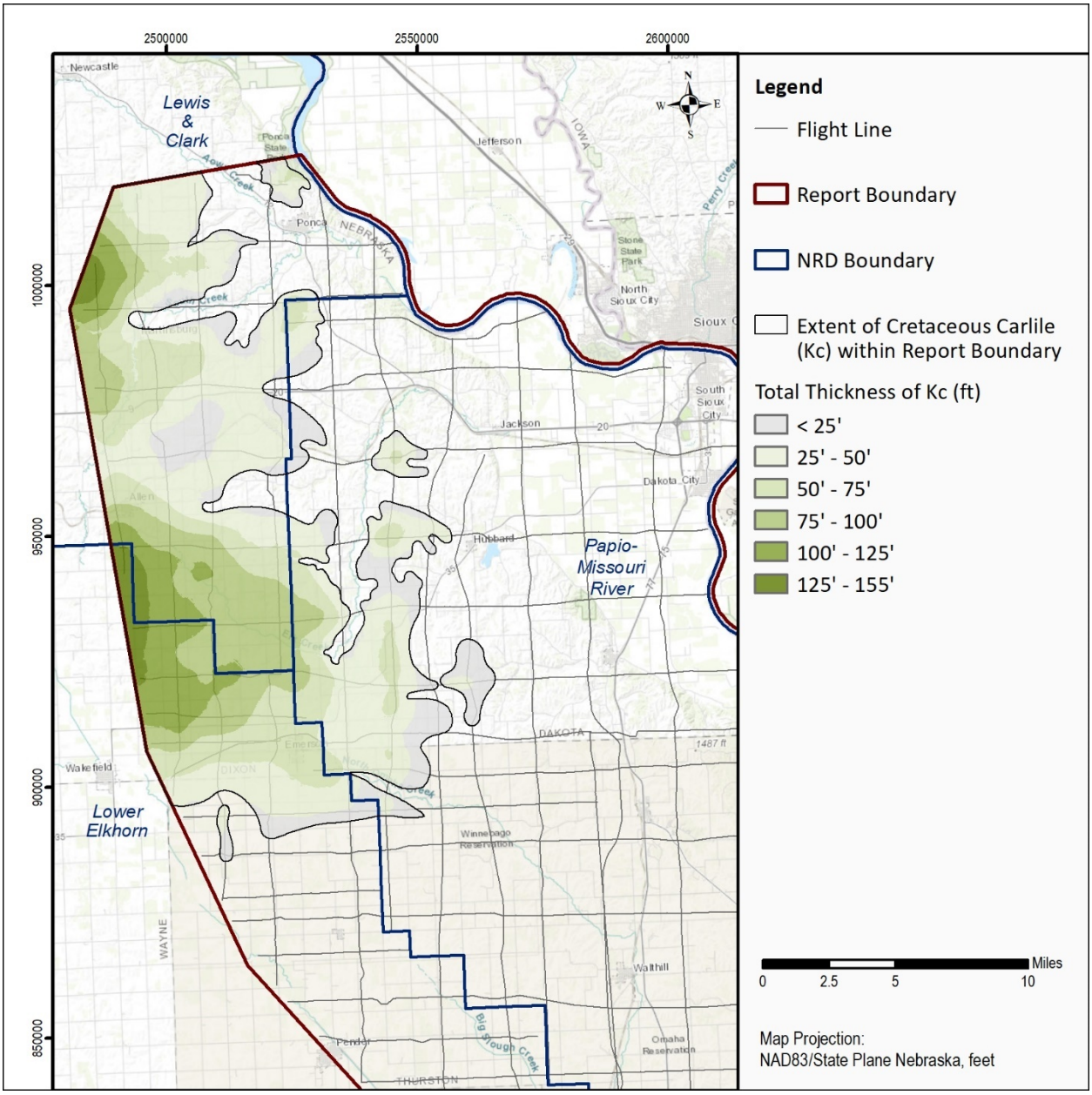


Figure 5-17. Map of the total thickness (in feet) of the Cretaceous Carlile (*Kc*) within the 2020 P-MRNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

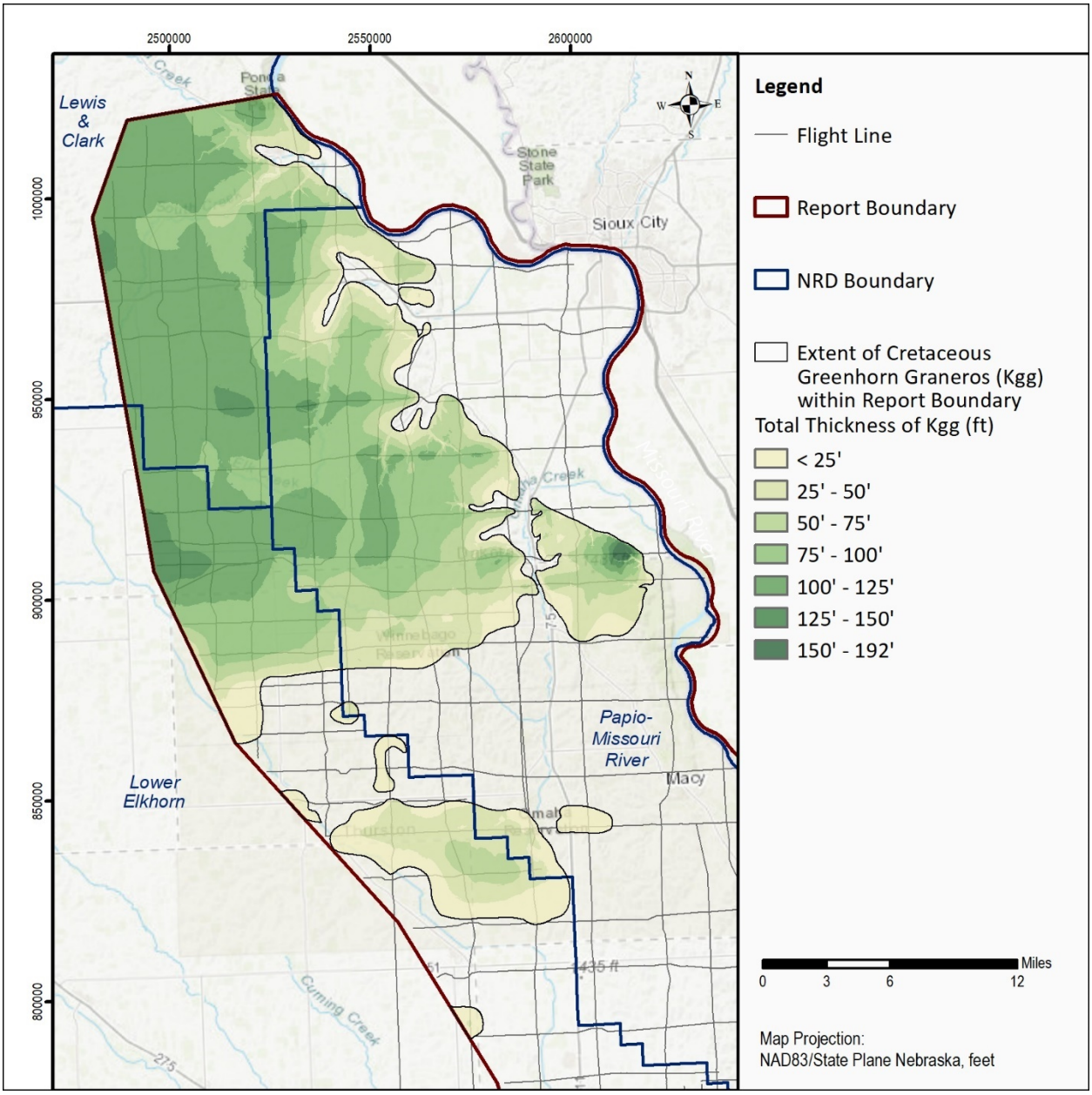


Figure 5-18. Map of the total thickness (in feet) of the Cretaceous Greenhorn Limestone and Graneros Shale (*Kgg*) within the 2020 P-MRNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

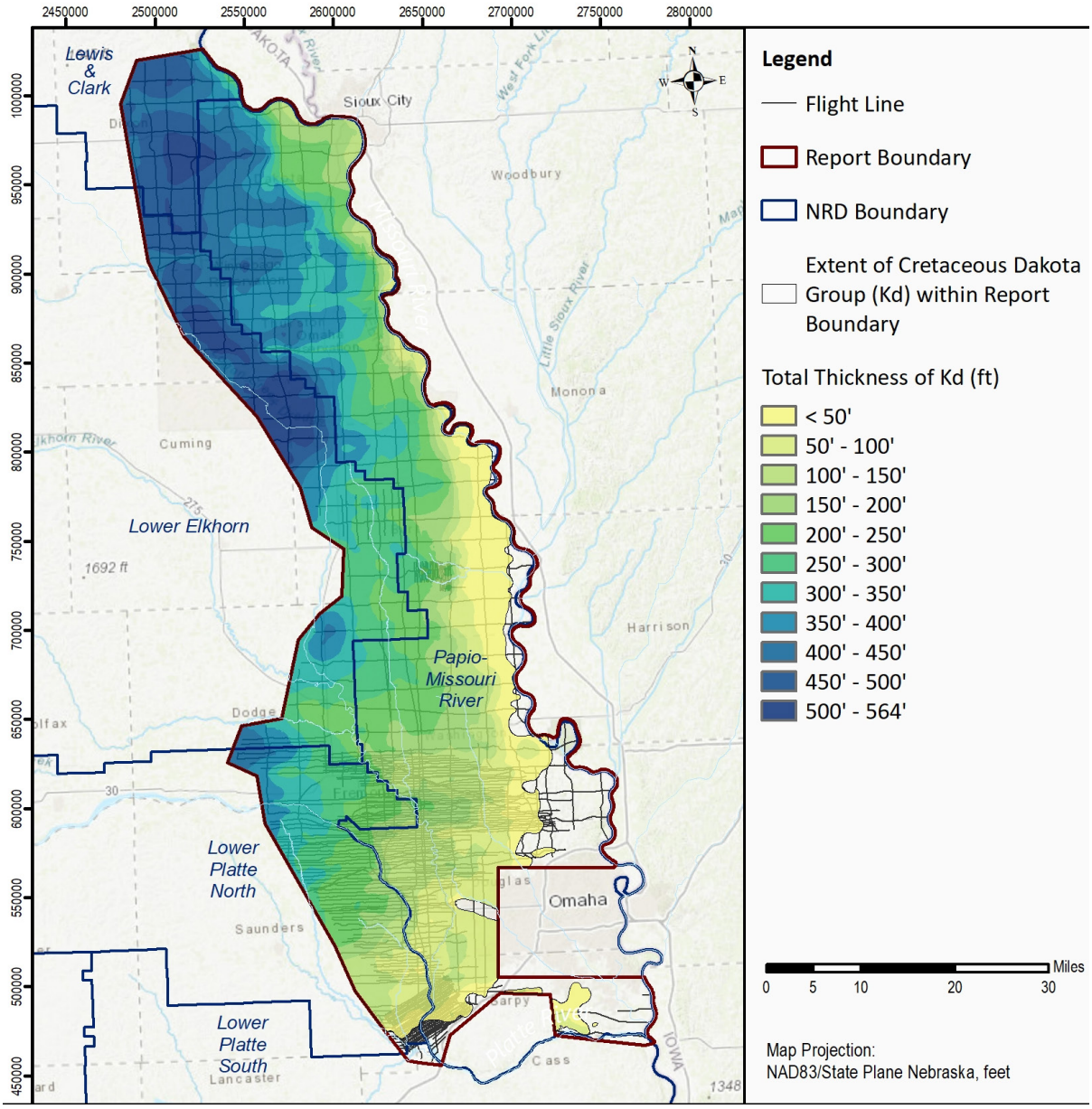


Figure 5-19. Map of the total thickness (in feet) of the Cretaceous Dakota Group (*Kd*) within the 2020 P-MRNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

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 utilized. 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 2020 P-MRNRD AEM survey and local conditions likely deviate in areas with variable topography. The original water table contour lines were gridded to a 100 ft cell size using ArcMAP's contour to raster tool. The resultant grid was corrected with the 100 ft ground surface DEM so that in areas where the water table was greater than the topography, the water table was set to the DEM elevation. The grid was then clipped to the AEM survey area. Figure 5-20 shows a map of the water table elevation surface within the P-MRNRD 2020 AEM survey area.

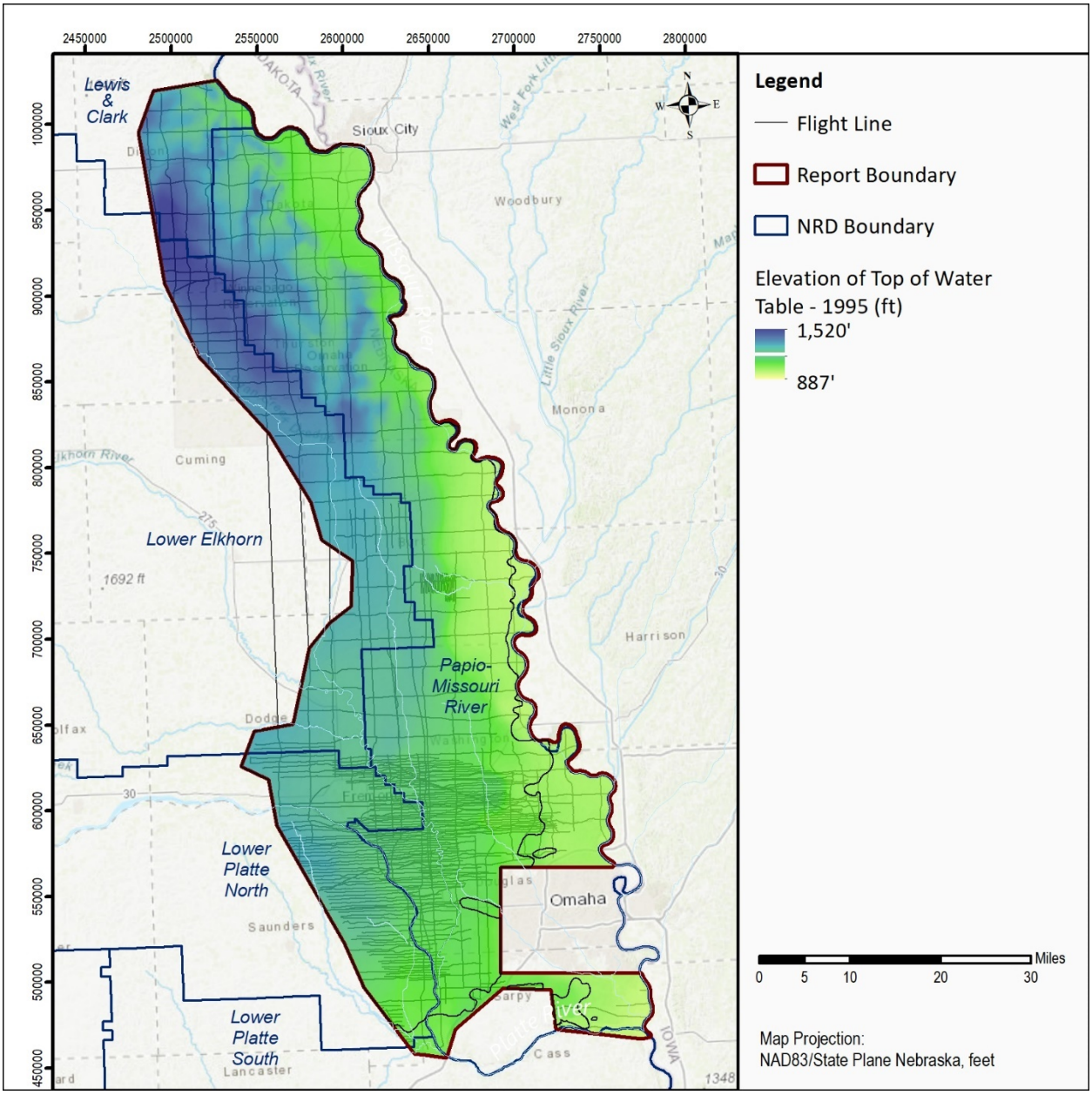


Figure 5-20. Map of the elevation (in feet) of the 1995 CSD water table within the 2020 P-MRNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

The saturated thickness of both ***Q*** and ***Kd*** were calculated for the 2020 P-MRNRD AEM survey area using the top elevation of ***Q*** and ***Kd*** and 1995 CSD water table surfaces in ArcMap's raster calculator. For the ***Q*** saturated thickness grid, the elevation of the top of bedrock was subtracted from the 1995 water table. For the ***Kd*** saturated thickness grid, the top of ***Kd*** was mosaicked with the water table in ArcMap using the 'minimum' operator, then the top of ***IP*** was subtracted from the mosaicked raster dataset. Figure 5-21 and Figure 5-22 are maps displaying the ***Q*** and ***Kd*** saturated thickness grids within the 2020 P-MRNRD AEM survey area, respectively.

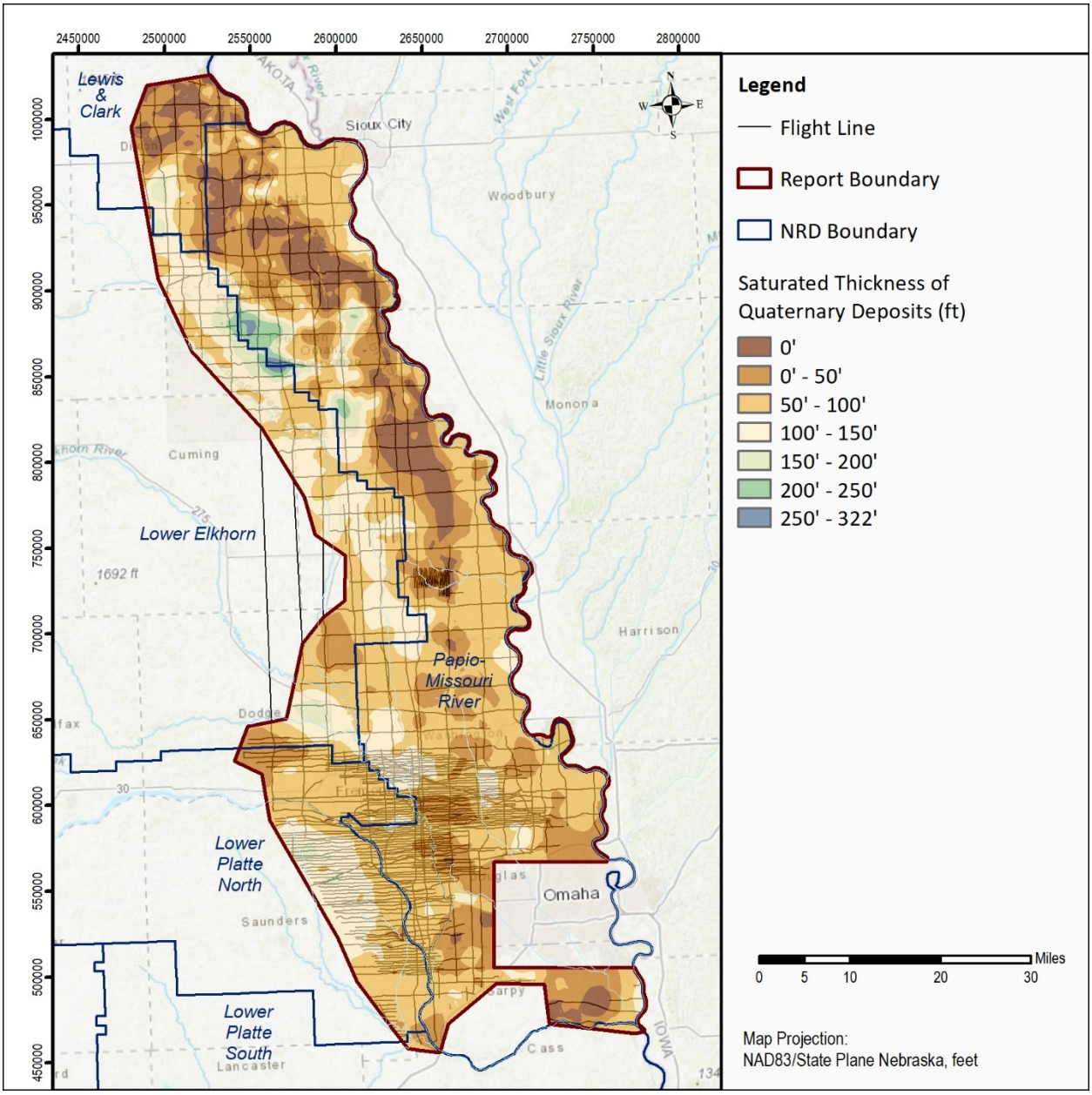


Figure 5-21. Map of the saturated thickness of Quaternary (*Q*) deposits within the 2020 P-MRNRD AEM survey area. Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

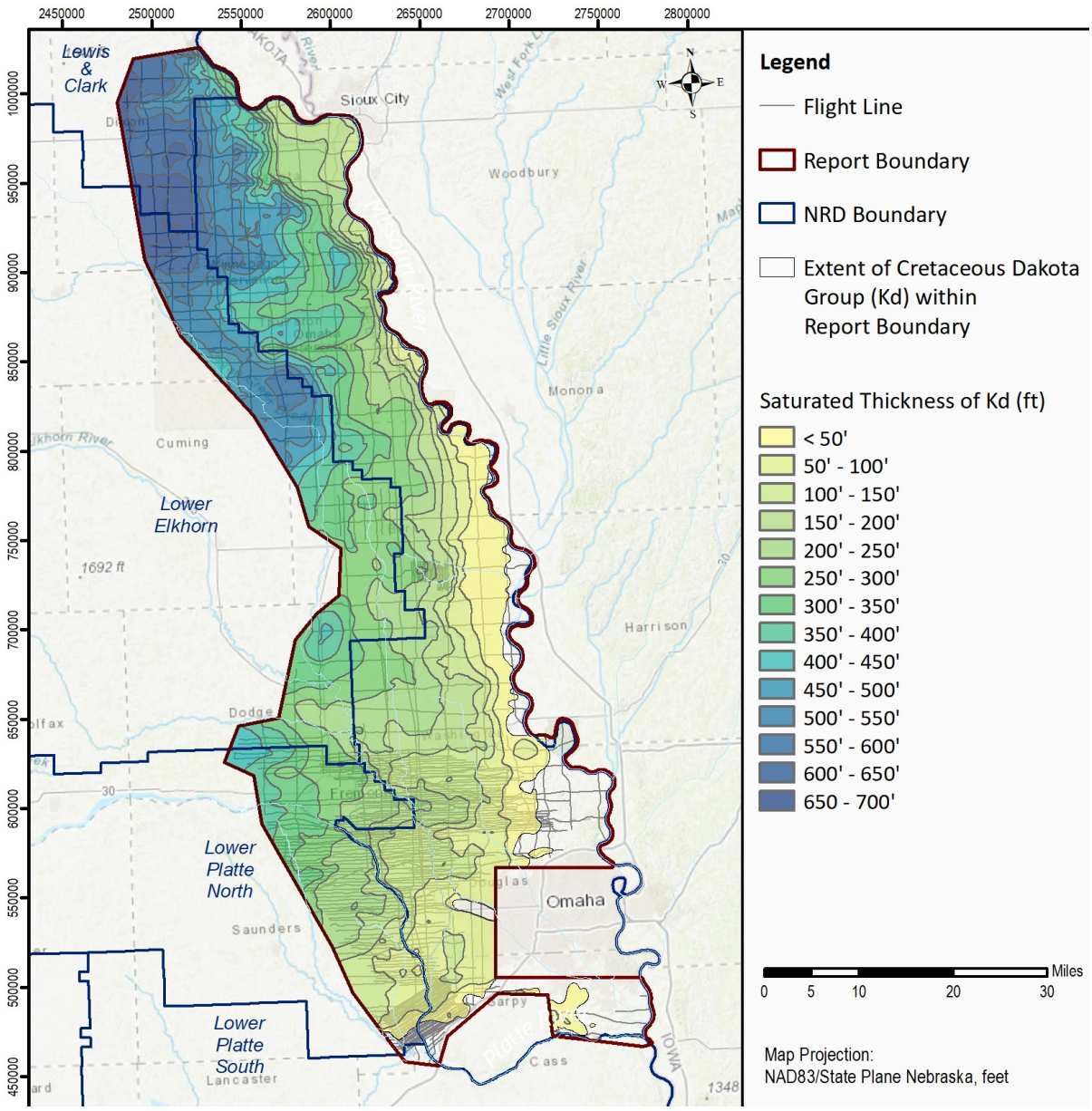


Figure 5-22. Map of the saturated thickness of Cretaceous Dakota Group (*Kd*) within the 2020 P-MRNRD AEM survey area. Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

To give a general idea of well performance within the ***Q*** and ***Kd***, NE-DNR water well specific capacity data were calculated. First, the wells were assigned to either "Quaternary well" or "Bedrock well" after an evaluation of the screen interval in which the top and bottom elevation of the well screen was compared to the bedrock elevation using the following logic (Table 5-3):

Table 5-3. Logic for assignment of a groundwater well for specific capacity estimation.

Logic	Well Type
If entire length of screen is below top of bedrock elevation	**Bedrock well**
If entire length of screen is above top of bedrock elevation	**Quaternary well**

Assignment of the wells was a conservative effort, in that if screen length/elevation data were not available and if the total well depth was not higher than the top of bedrock, then the well was not used in the specific capacity calculations. In some cases, the lithologic log was referred to in the NE-DNR database to confirm the assignment of a well within areas around the eastern edge of the ***Kd*** extent. Some wells were assigned as a "dually completed well" and this occurred when a screen interval fell within both ***Q*** and ***Kd***.

After the wells were assigned, the specific capacity was calculated, but only for those wells with readily available specific capacity data (ie. pumping rate, static water level, pumping water level) in the NE-DNR well GIS shapefile. Figure 5-23, Figure 5-24, Figure 5-25, Figure 5-26, Figure 5-27, and Figure 5-28 are maps of ***Q*** and ***Kd*** saturated thickness with NE-DNR well points displaying estimated specific capacity within the 2020 P-MRNRD AEM survey area. Figure 5-29 displays those wells that were considered dually completed.

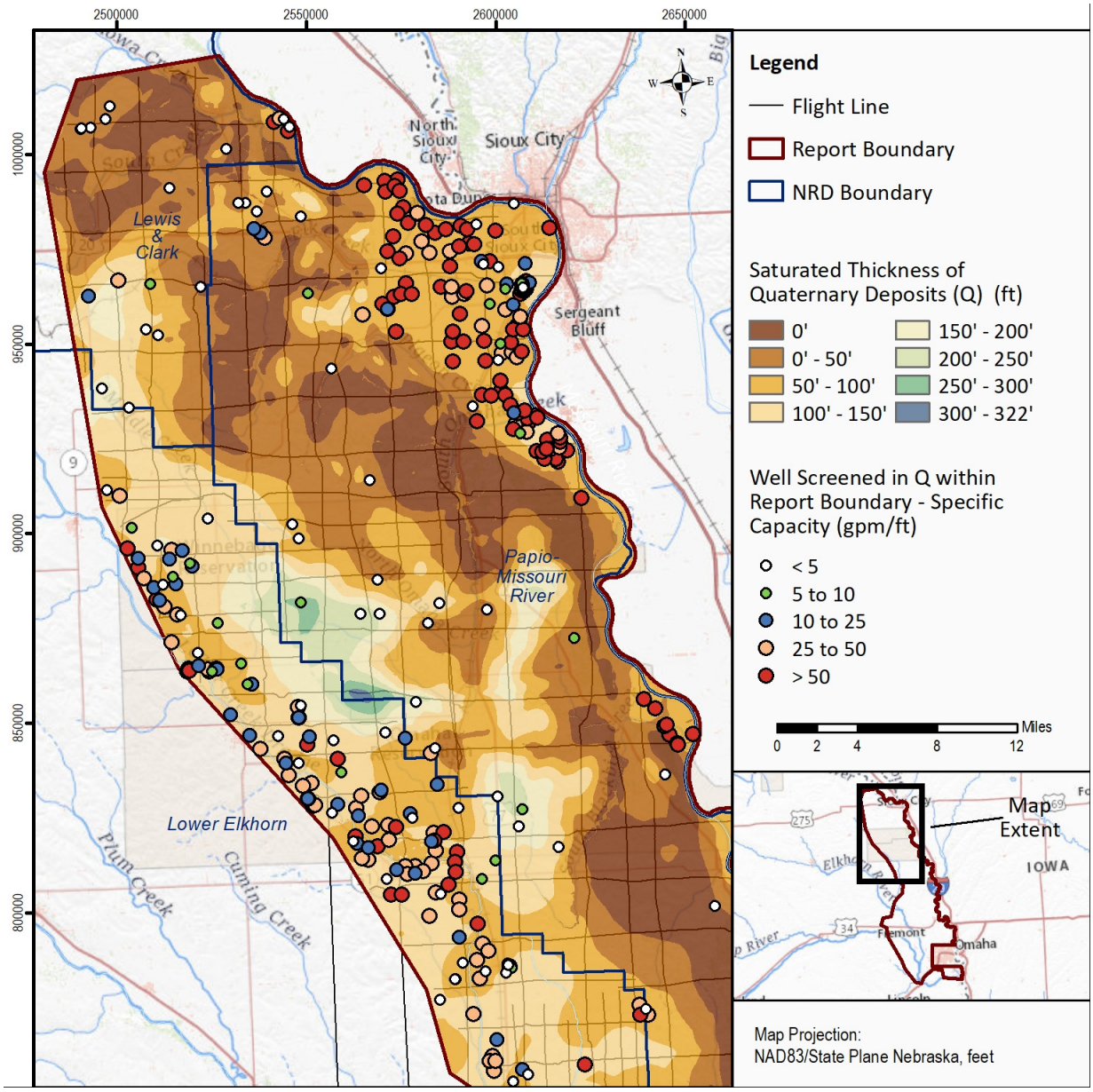


Figure 5-23. Map of the saturated thickness of the Quaternary (*Q*) materials in the northern portion of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Q* (i.e., screen interval within *Q*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

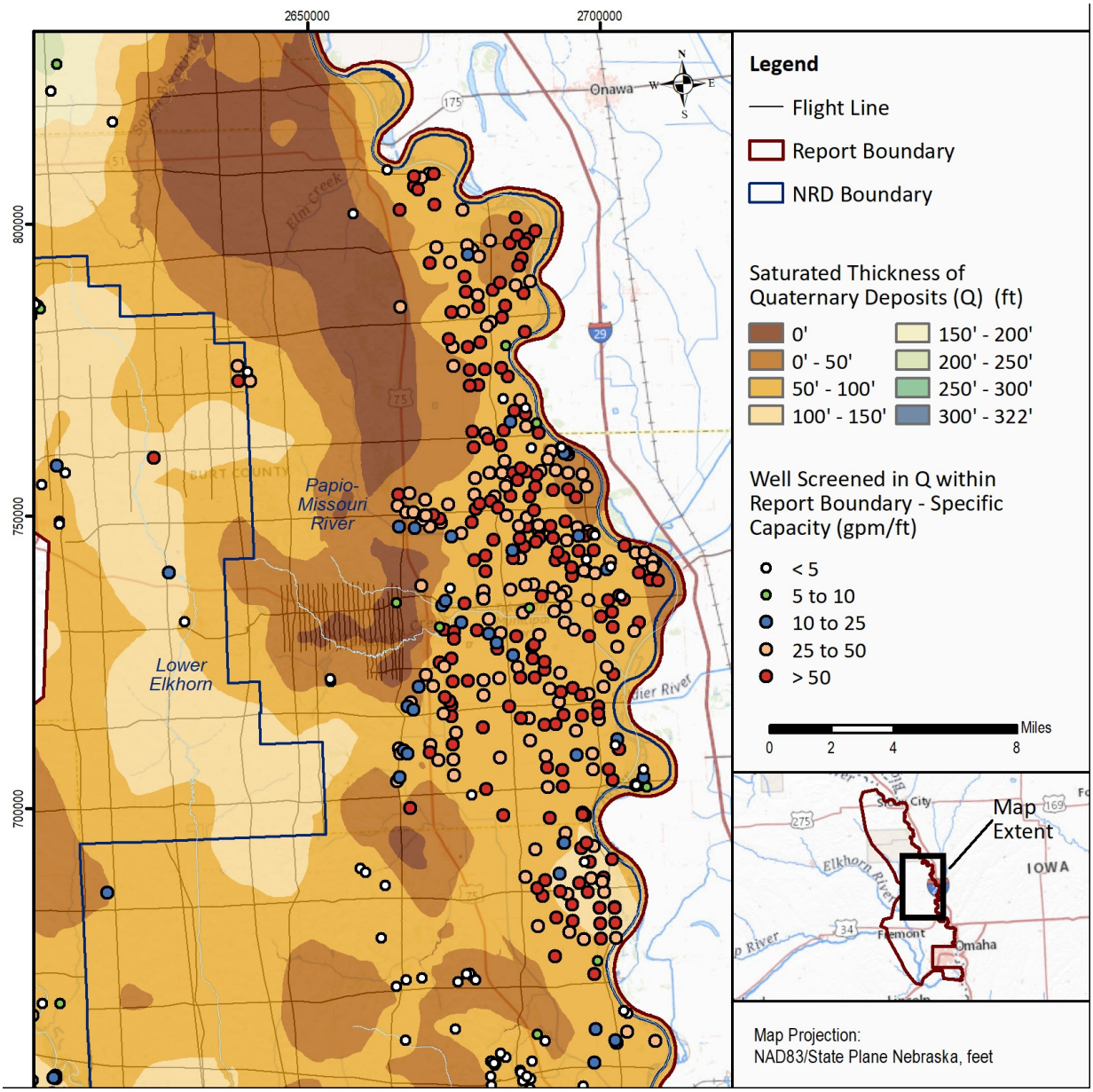


Figure 5-24. Map of the saturated thickness of the Quaternary (*Q*) materials in the eastern portion of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Q* (ie. screen interval within *Q*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

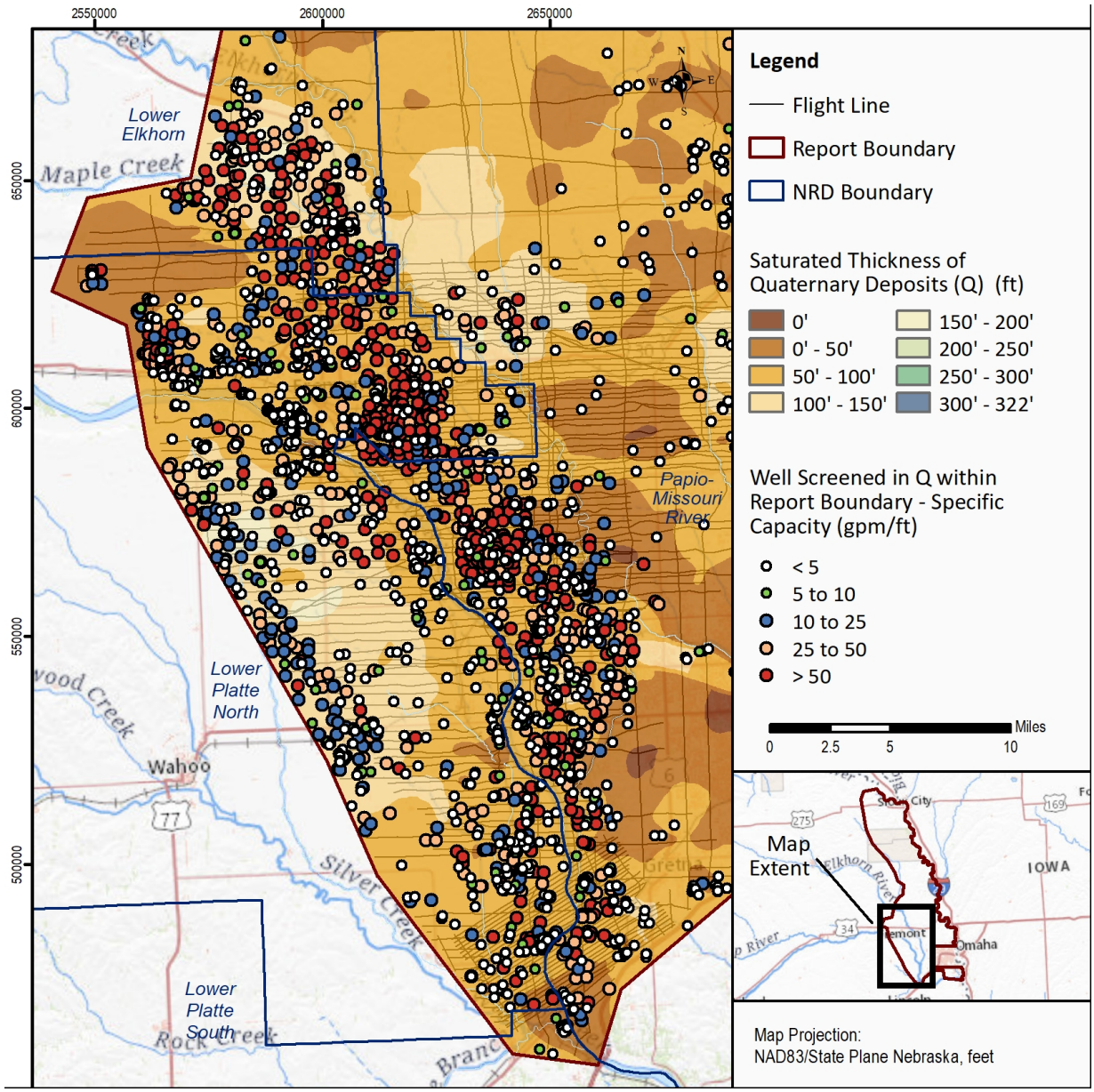


Figure 5-25. Map of the saturated thickness of the Quaternary (*Q*) materials in the Todd Valley area of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Q* (ie. screen interval within *Q*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

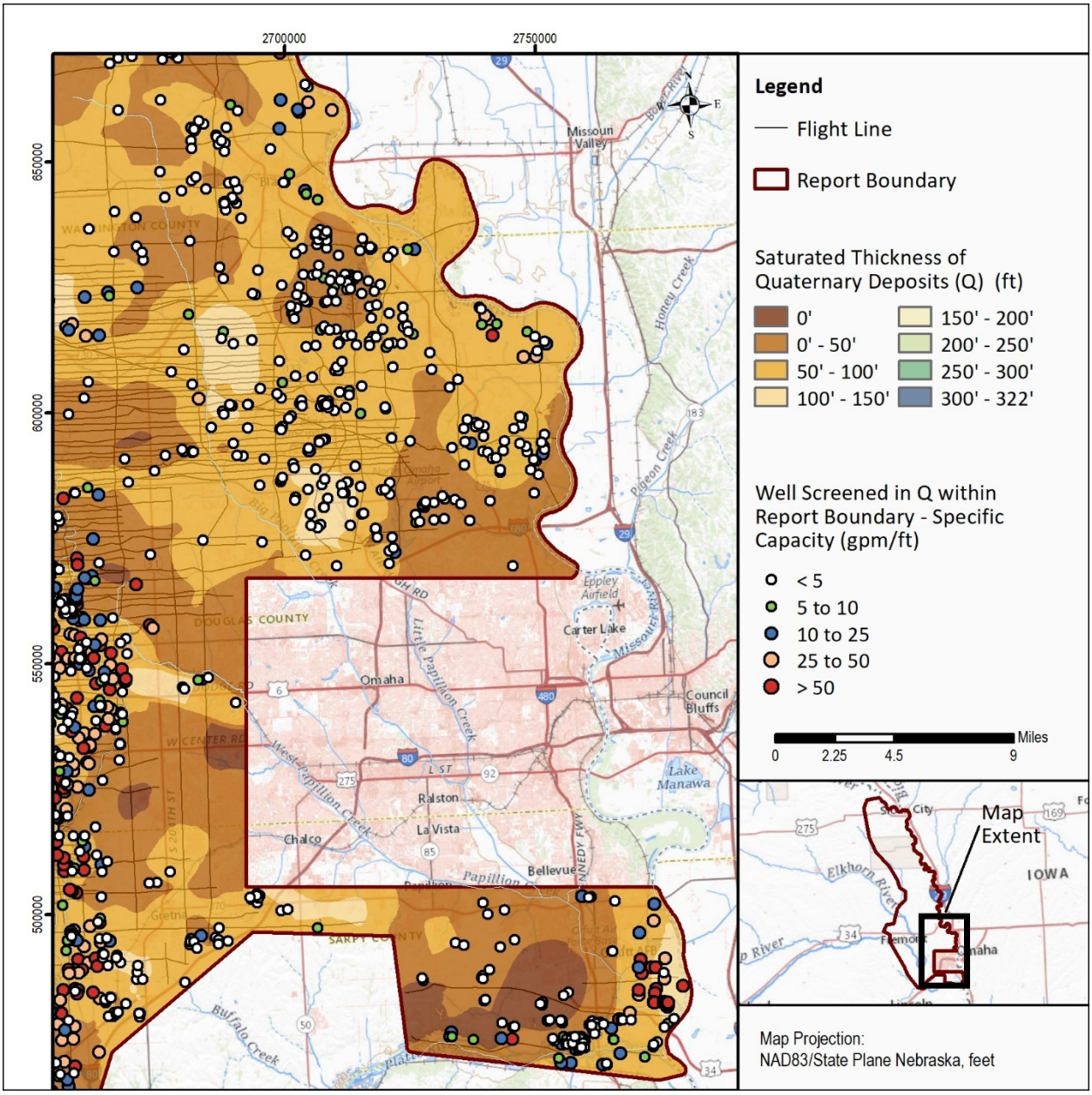


Figure 5-26. Map of the saturated thickness of the Quaternary (*Q*) materials in the Arlington area of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Q* (ie. screen interval within *Q*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

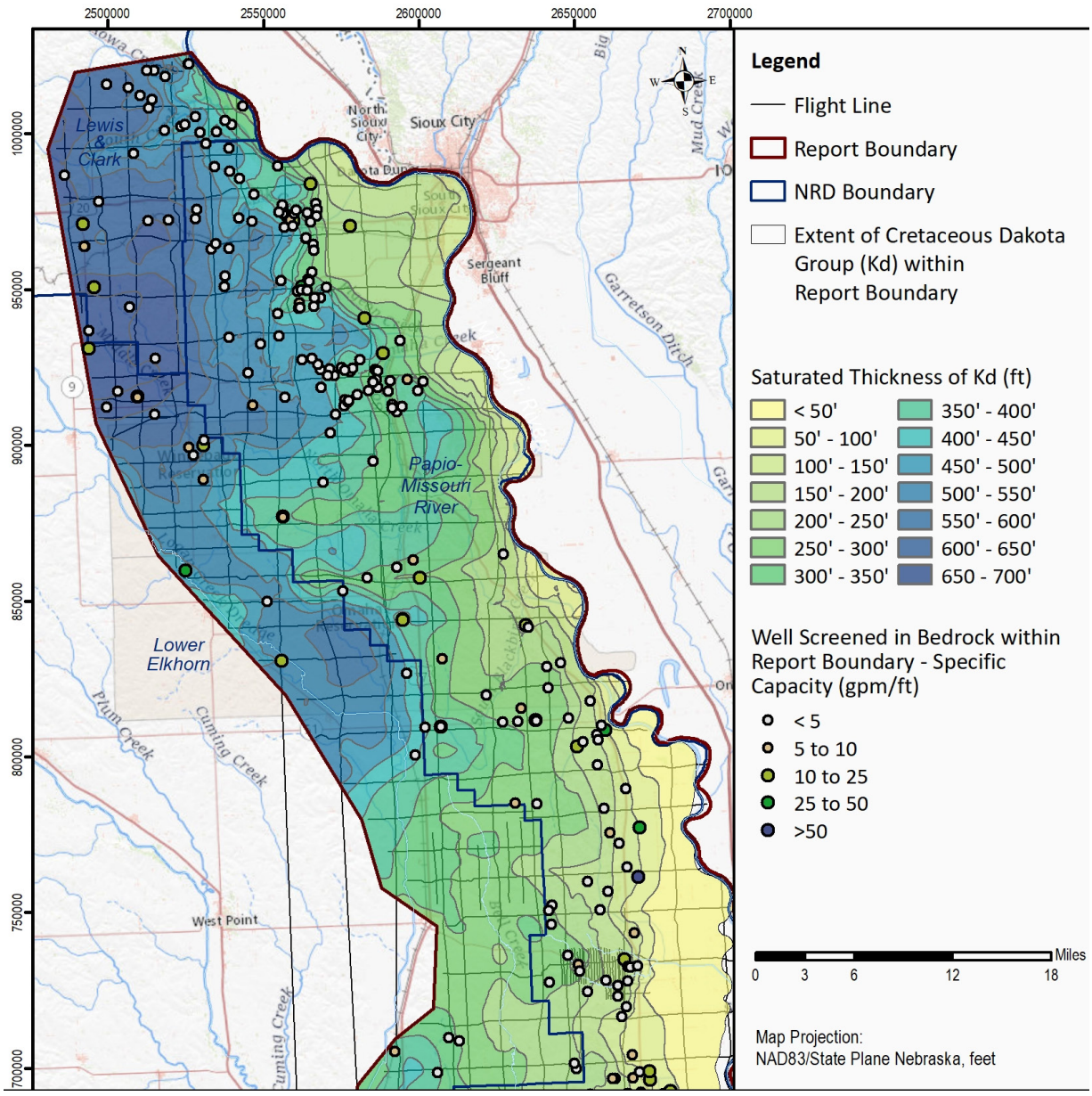


Figure 5-27. Map of the saturated thickness of the Cretaceous Dakota Group (*Kd*) in the northern portion of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Kd* (ie. screen interval within *Kd*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

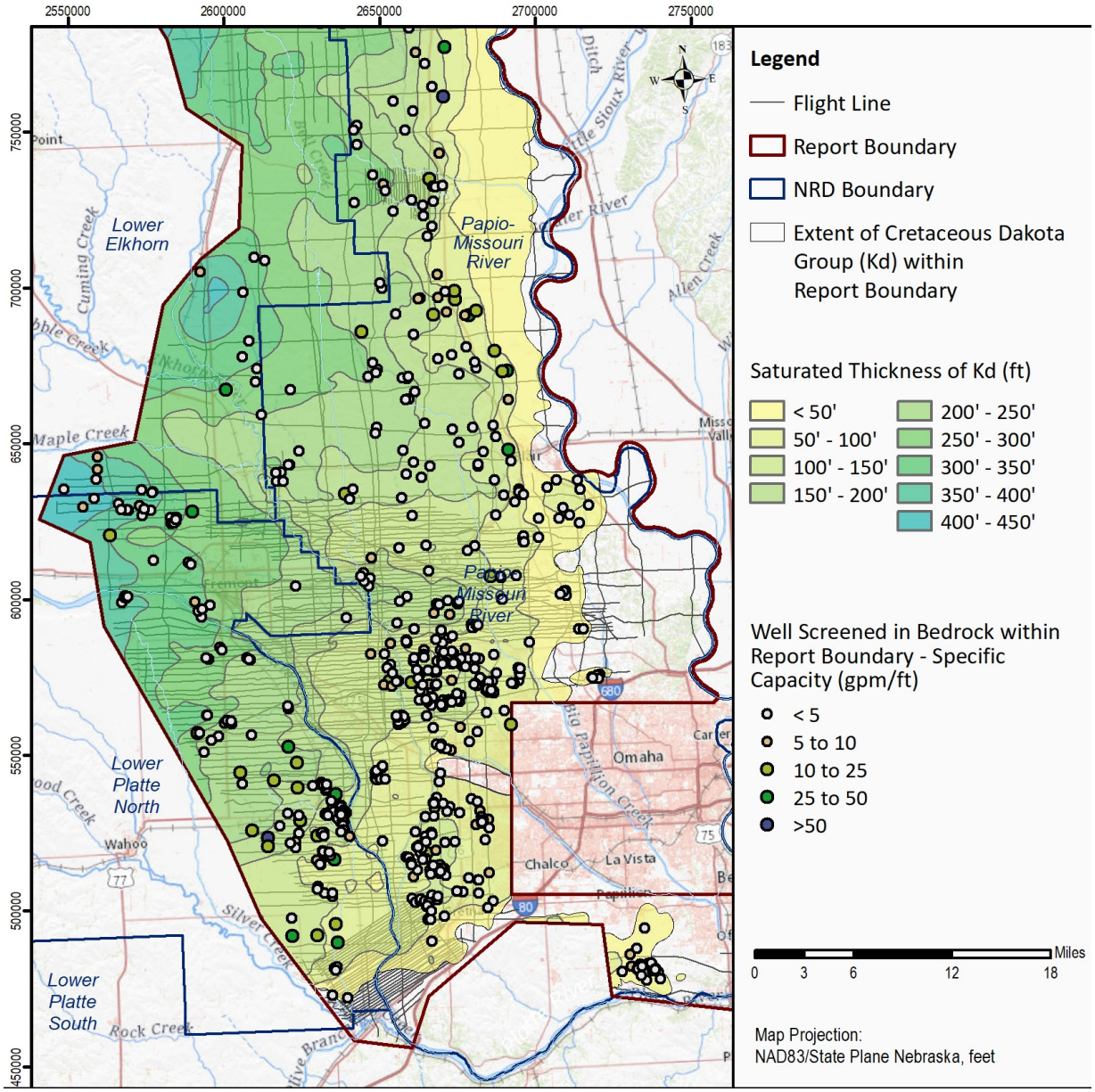


Figure 5-28. Map of the saturated thickness of the Cretaceous Dakota Group (*Kd*) in the southern portion of the 2020 P-MRNRD AEM survey area with the estimated specific capacity of wells completed in *Kd* (ie. screen interval within *Kd*). Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

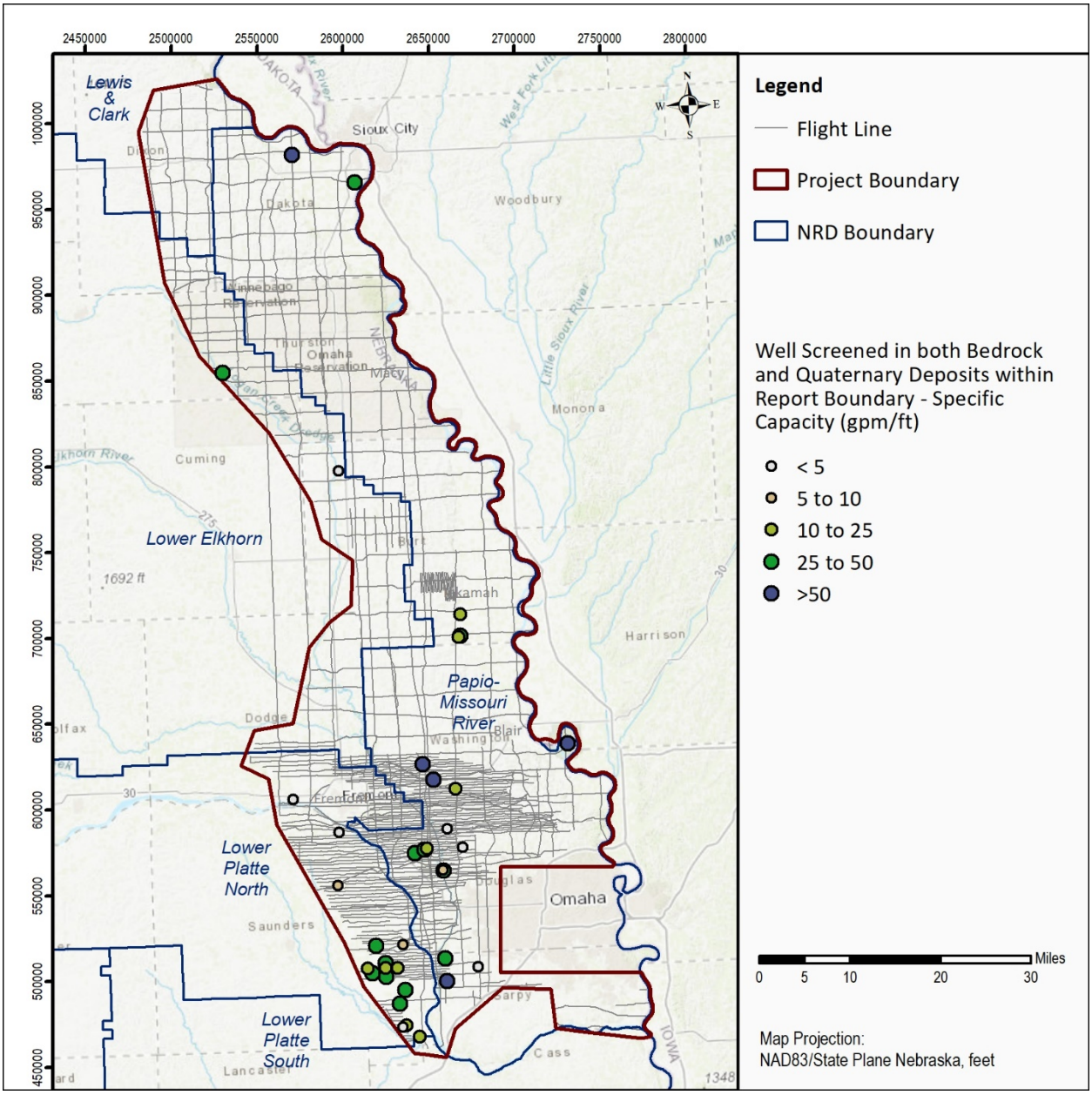


Figure 5-29. Map of estimated specific capacity of wells completed in both bedrock and Quaternary (*Q*) deposits within the P-MRNRD 2020 AEM survey area. Flight lines are indicated by the gray lines. The projection is NAD83 State Plane Nebraska (feet).

5.2.4.1 Paleochannels

Within the northern area of the project boundary, west of Macy in the area of Walthill, Nebraska, anomalously low bedrock elevations were logged in two CSD holes, *11-B-64* and *26-B-63*, at 395' and 415' below ground surface (bgs), respectively. These holes fall in line with apparent pre-Pleistocene paleochannels drawn by Burchett et al. (1988). Figure 5-30 displays the two low bedrock elevation CSD holes, split by a CSD hole (*27-B-63*) with a relatively higher bedrock elevation (245' bgs), and the AEM bedrock elevation data points overlying the Burchett et al. (1988) map. The AEM data interpreted in this area (blue points in Figure 5-30) agree with the apparent paleochannels where conductive material is seen in the AEM profiles at depths up to 400' bgs. Figure 5-31 shows a north-south AEM profile along line L201901 that crosses the Burchett et al. (1988) proposed paleochannels near CSD test holes *26-B-63*, *27-B-63*, and *11-B-64*. Note the deep low resistivity materials filling the paleochannels.

The interpolated bedrock surface, constructed from the top elevations of ***Kc, Kgg, Kd,*** and ***IP*** grids, generally follow the same spatial extent of the paleochannels shown in the Burchett et al. (1988) map (Figure 5-32).

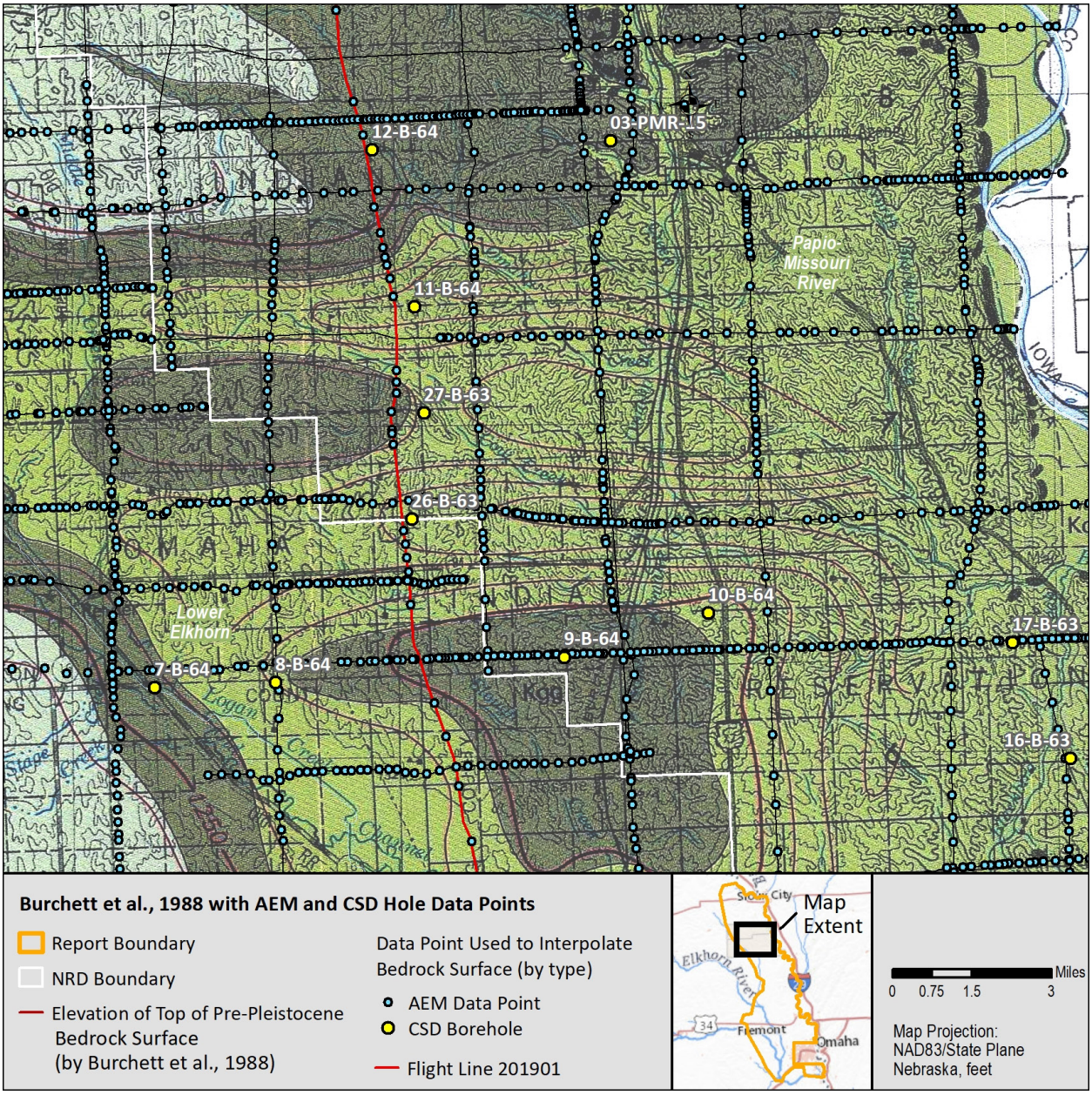


Figure 5-30. Map of the spatial distribution of the CSD holes and AEM data points within the Macy/Walthill area where pre-Pleistocene paleochannels are shown on Burchett et al. (1988). The red contours represent the top of bedrock elevation as drawn by Burchett et al., 1988. The projection is NAD83 State Plane Nebraska (feet).

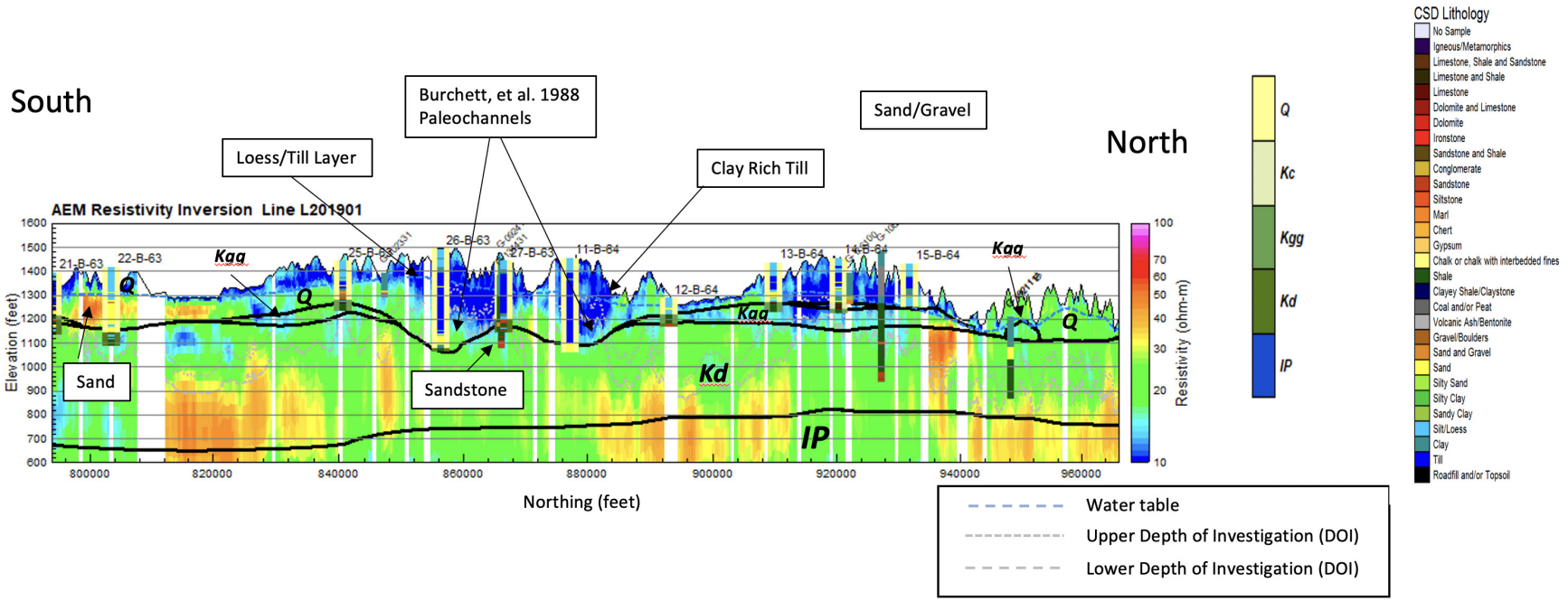


Figure 5-31. Line L201901 showing the Burchett et al. (1988) paleochannels. Cretaceous Greenhorn Limestone and Graneros Shale (Kgg), Cretaceous Dakota Group (*Kd*), and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

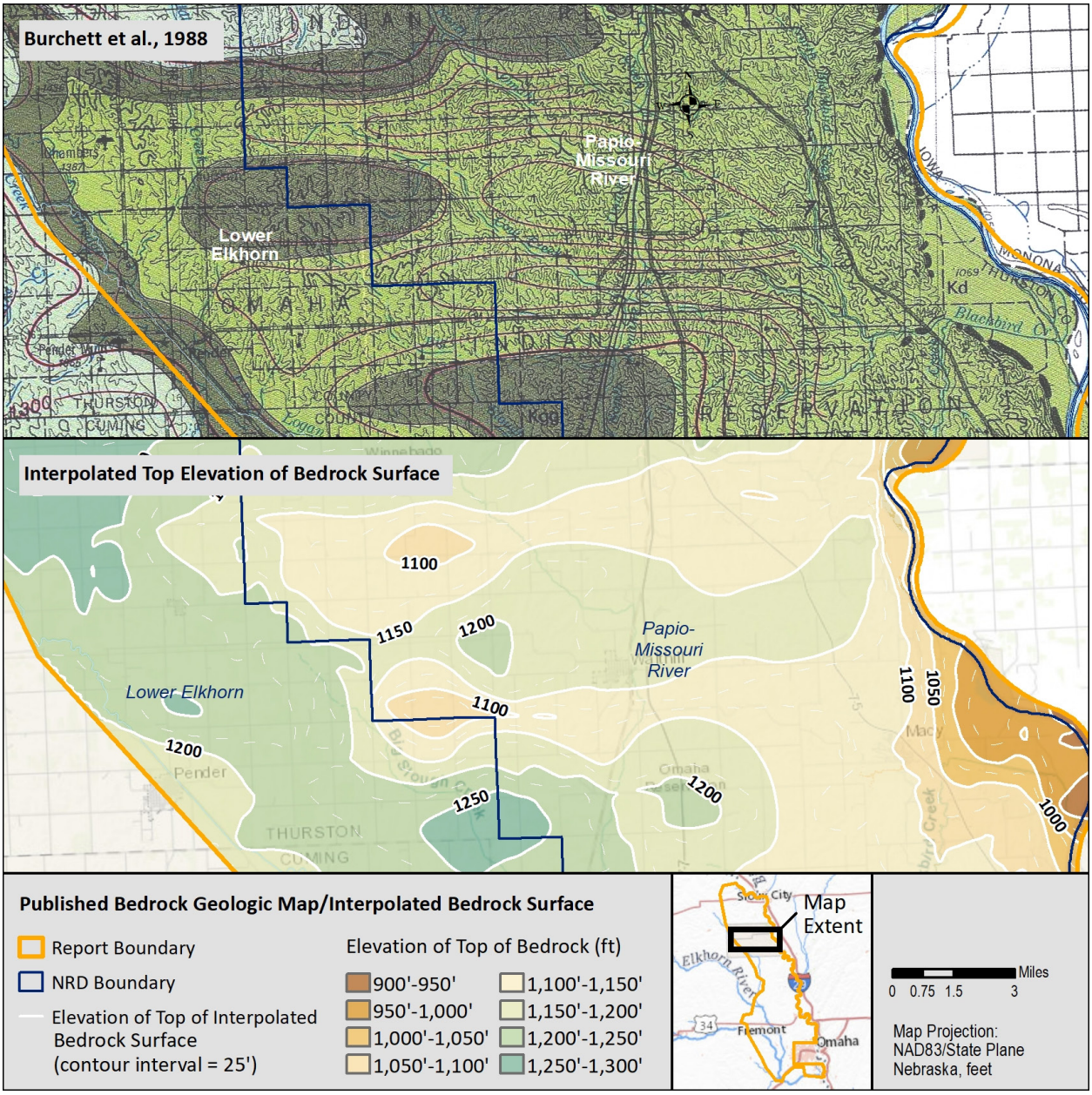


Figure 5-32. Map showing a comparison between the paleochannels drawn by Burchett et al. (1988) and the AEM/CSD interpolated paleochannels. The projection is NAD83 State Plane Nebraska (feet).

5.2.4.2 Identify Geologic Unit Outcrops

A geologic outcrop investigation was carried out to refine the top of bedrock elevation in areas where outcrops have been previously mapped, especially in areas where AEM point data were 2 or more miles apart at reconnaissance flight lines. The investigation included downloading the previously published geologic map showing the formation outcrops (Burchett et al., 1988), digitizing the outcrop extents into a GIS, then comparing and revising, as needed, the top of bedrock elevation interpolated surface. Revisions to the top of bedrock elevation surface were made to *generally* match the digitized outcrops because the scale of the Burchett et al. (1988) map was relatively small; therefore, the outcrop extents were more generalized on the map. Also, outcrops in the bedrock elevation surface may not be captured in small areas such as road cuts due to the horizontal resolution of the surface (100 ft). Outcrop areas in the bedrock elevation surface, as well as all geologic formation top elevation surfaces, were set to the ground surface DEM elevation minus 3 ft. A three-foot layer of soil was assumed to overlay most areas that are designated as outcrop.

In the example area displayed in Figure 5-33 the top panel shows the Bedrock Geologic Map Showing Configuration of the Bedrock Surface in the Nebraska Part of the Sioux City 1 x 2 Quadrangle (Burchett et al., 1988) and the corresponding digitized outcrops. The second panel in Figure 5-33 shows the digitized outcrops compared to the aerial imagery. In some cases, the outcrops appear to be in irrigated farmland as well as along drainages and treed areas. The refined interpolated outcrop areas are shown in the third panel in Figure 5-33 and generally follow the spatial pattern of the previously mapped outcrop areas in most cases.

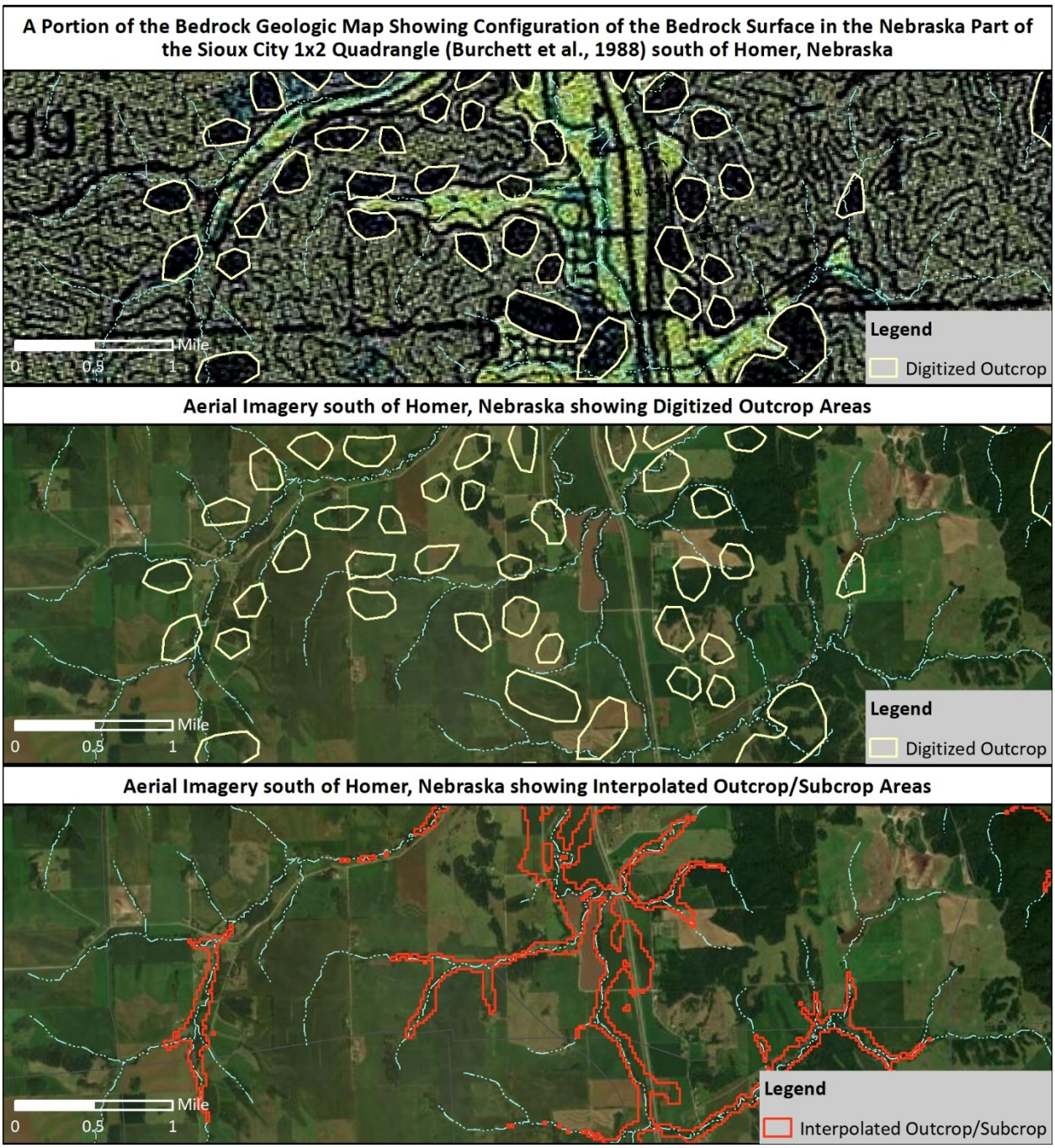


Figure 5-33. Map of an area south of Homer, Nebraska that compares the original published geologic map (Burchett et al., 1988), digitized outcrops from the geologic map, and the extent of the final outcrops after the outcrop investigation was complete. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

5.2.4.3 Revise geologic unit extents based on AEM data

Based on the AEM point data and recently drilled CSD holes, some sections of the geologic unit extents delineated in the Geologic Bedrock Map of Nebraska (Burchett, 1986) were refined. The most notable refinements were made to the Cretaceous Carlile (***Kc***) and Cretaceous Greenhorn Limestone and Graneros Shale (***Kgg***) in the northern portion of the project area as well as along the eastern edge where the Cretaceous Dakota Group (***Kd***) extent has been moved further to the east. The currently mapped geologic extents presented in the Burchett (1986) were retained in areas where an AEM survey was not conducted or where the AEM point data or CSD lithology did not explicitly vary from the published mapped extent. Figure 5-34 and Figure 5-35 below show the published geologic extents compared to the refined extents within two sections of the project area. The final Bedrock geology map for the P-MRNRD is included in *Appendix 1 – 2D Images* and is discussed in Section 5.3.

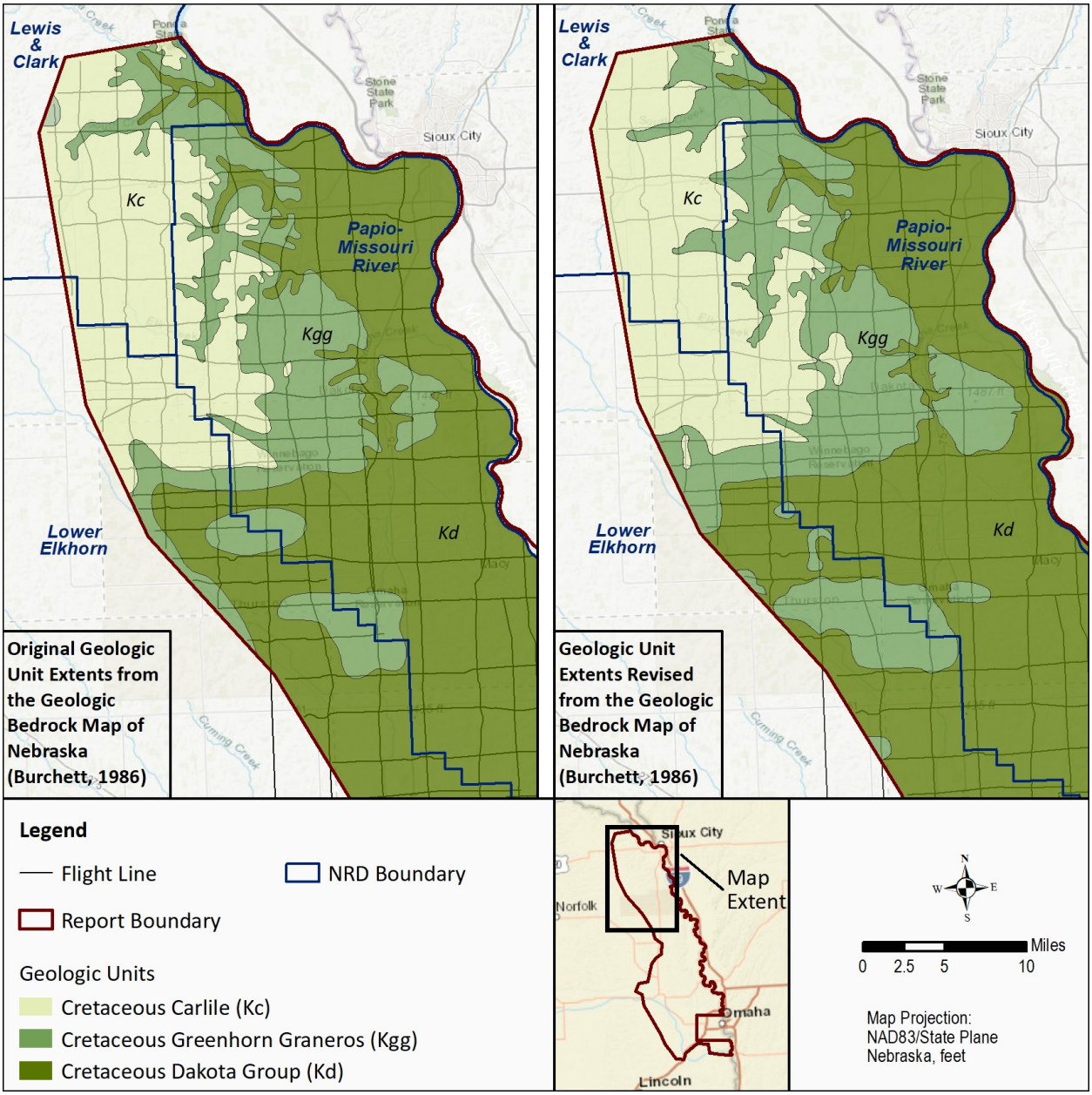


Figure 5-34. Map of the northern portion of the report boundary showing a comparison between the original extent of the mapped Cretaceous Carlile (*Kc*) and Cretaceous Greenhorn Limestone and Graneros Shale (*Kgg*) geologic units and the revised extent of the *Kc* and *Kgg* geologic units based on AEM data and recently drilled CSD holes. The project is NAD83 State Plane Nebraska (feet).

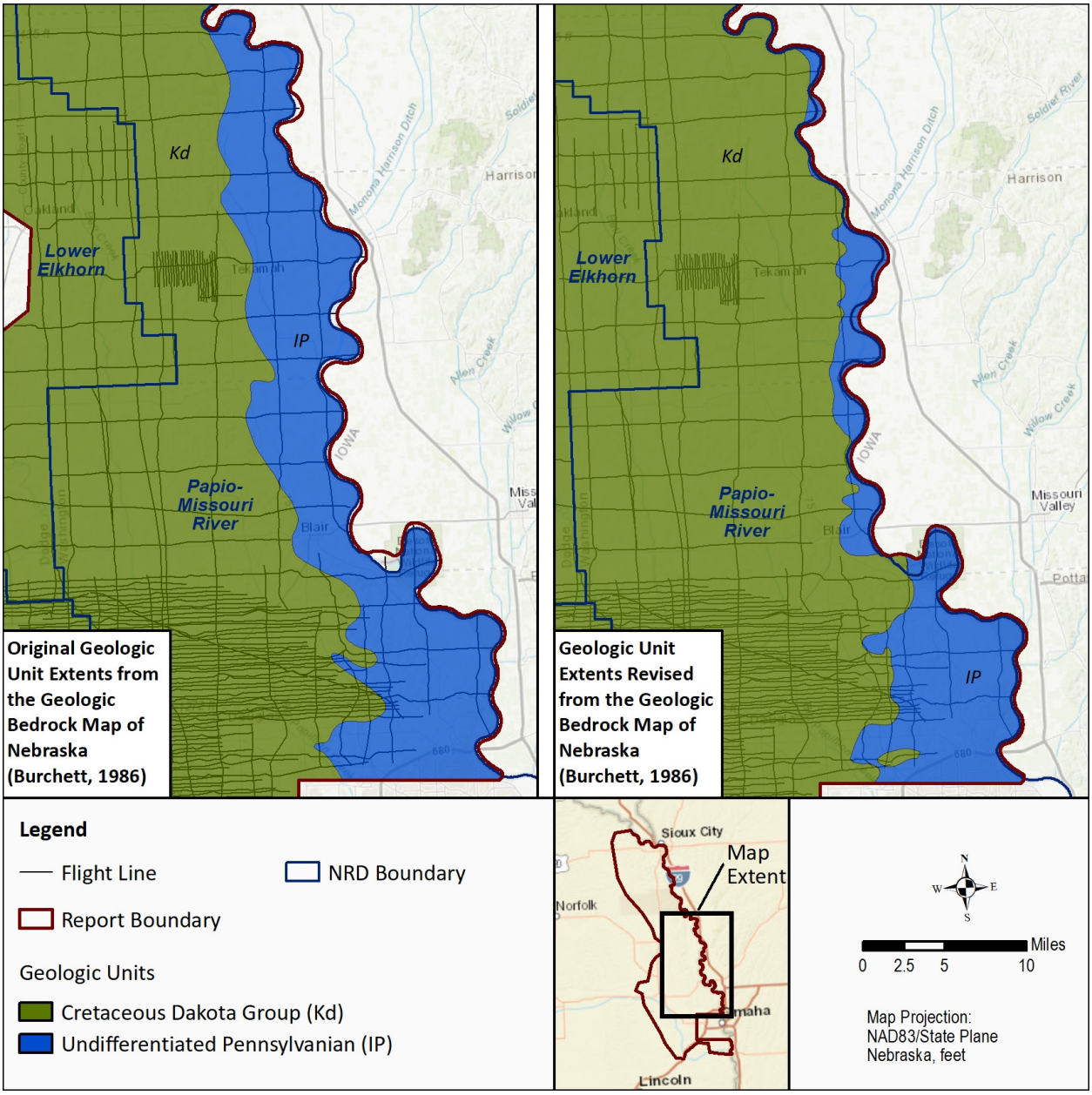


Figure 5-35. Map of the central-eastern portion of the report boundary showing a comparison between the original extent of the mapped Cretaceous Dakota Group (*Kd*) and undifferentiated Pennsylvanian (*IP)* geologic units based on AEM data and recently drilled CSD holes. The project is NAD83 State Plane Nebraska (feet).

5.2.5 Resistivity/Lithology Relationship in the Quaternary Aquifer System

A critical aspect of a geophysical survey, for whatever purpose, is assessing the nature of the material detected by the geophysical method applied in the investigation. In regard to the P-MRNRD survey, assessment of the sediment character in both the Quaternary aquifer system and the consolidated bedrock strata 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 major geologic units described in this report. It should be noted that this analysis encompasses all Quaternary/Tertiary Ogallala (***Q/To***) aquifer system and bedrock data from both the ENWRA project area (Carney et al., 2015a, 2015b). The original analysis that was completed as part of Carney et al. (2015a, 2015b) included the overall area of the P-MRND. 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 line area (Carney et al., 2015a, 2015b). The relationship between resistivity and lithology type was assessed by performing an association function that linked nine lithologic descriptor codes for ***Q/To*** 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, 2015b). A summary of the resistivities and the color scale is shown in Figure **5-36**.

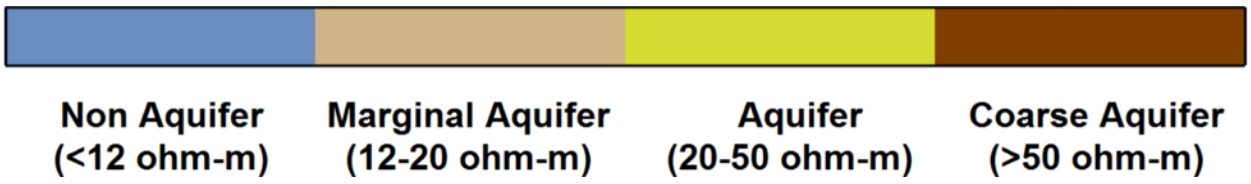


Figure 5-36. Plot displaying the resistivities by major aquifer material color categories: blue- non-aquifer materials, tan- marginal aquifer materials, yellow- aquifer materials, brown- coarse aquifer materials (Carney et al., 2015b).

5.2.6 Resistivity/Lithology Relationship in the Bedrock

The bedrock in the P-MRNRD analyzed in this study includes the ***Kc, Kgg, Kd,*** and ***IP.*** These were included to demonstrate the overall distribution in resistivity of bedrock materials across the entire P-MRNRD. The median resistivity values for each unit are 16 ohm-m for the ***Kc*** and the ***Kgg*** lumped together, the mean for the ***Kd*** is 35 ohm-m, and the mean for the ***IP*** is 16 ohm-m (Carney et al., 2015a, 2015b). ***IP*** units show the widest range in detected resistivities, which should not be unexpected as this sequence contains resistive limestone and conductive shale units. For the ENWRA study, the ***Kc*** and the ***Kgg*** were interpreted together. For this current study, the proximity of the ***Kgg*** to the surface allows for a more accurate interpretation. The low resistivity character of 3 to 9 ohm-m for the ***Kc*** made the interpretation of the ***Kc*** relatively straight forward. The ***Kgg*** showed a more resistive character on the order of 15 ohm-m. The ***Kd*** within the P-MRNRD was split into three parts based on empirical comparisons to lithology logs. 0-18 ohm-m was classified as Shale/Clay Dominate materials, 18-35 as Siltstone/Silt Dominate materials, and 35 and greater as Sandstone/Sand Dominate materials (Figure 5-37). This is a modification of the splits that were used in the P-MRNRD reports from AGF (2017, 2019a) with the addition of the Siltstone/Silt Dominant class. The previous split in the Cretaceous Dakota Group was at 20 ohm-m between Shale/Clay Dominant and Sandstone/Sand Dominant materials. Additional unpublished work in the Nebraska ***Kd*** using AEM data has led to a better understanding of the resistivity versus lithology with the ***Kd***. Lacking the quality geophysical well logs in the ***Kd*** that exist in the ***Q***, it is difficult to produce a more robust statistical distribution of the resistivity versus lithology as was done for the ***Q*** materials (Carney et al., 2015a, 2015b

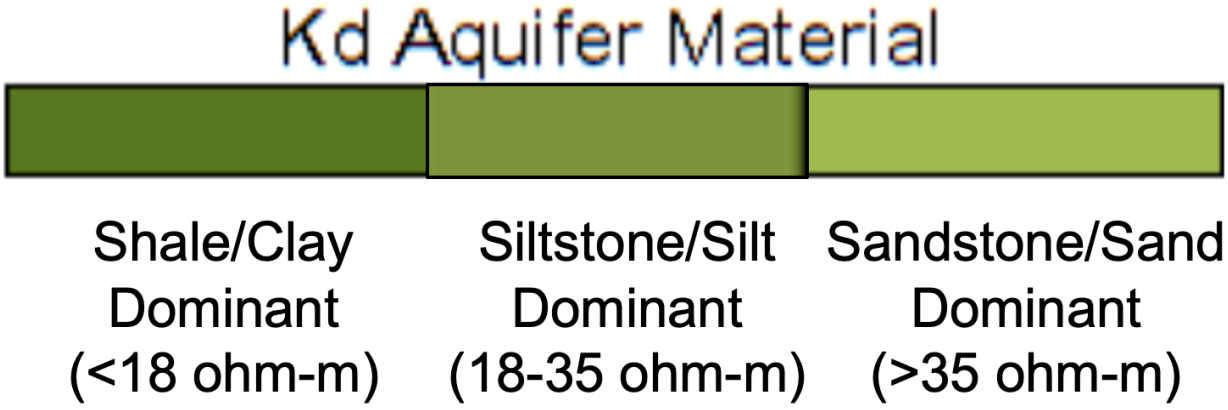


Figure 5-37. Plot displaying the resistivities of the Cretaceous Dakota Group by 0-18 ohm-m classified as Shale/Clay Dominate materials, 18-35 ohm-m as Siltstone/Silt Dominant materials, and 35 ohm-m and greater as Sandstone/Sand Dominant materials.

5.2.7 Create 3D Interpretative Voxel Grids

A voxel grid was completed for the Southern Block and Tekamah Block. Voxel grids were also used as interpretation infills in the profiles where gaps existed due to EM Coupling. The overall P-MRNRD voxel used a 300 feet grid cell size. The Arlington Block is a subset of the Southern Block. The Tekamah Block used a 100 feet cell size. The voxel grids were made using a composite model layer thickness (Table 5-4) for the overall combined dataset listed in Section 5.1. In some circumstances, the shallow imaging systems such as in the CGG Resolve used at Ashland will have the deeper parts of the layers "nulled" due to lack of data at depth. Table 5-5 is a summary of the normalized layering used in the voxels. A minimum curvature method was used within Datamine Discover PA (Datamine Discover, 2021). All layers were referenced to their depth from the surface and then projected on the area DEM. After the grid was calculated, the grid was split at the top of the Cretaceous Carlile (***Kc***), Cretaceous Greenhorn Limestone and Graneros Shale (***Kgg***), Cretaceous Dakota Group (***Kd***), and the undifferentiated Pennsylvanian (***IP***). The units were also split at the 1995 CSD water table. These resulting voxel grids can be used to explore the distribution of the aquifer materials within the area in 3D. Specifically, these grids can allow for visual inspection of the volume of materials above the ***IP*** bedrock including the ***Kd*** and the ***Q*** materials. The ***Q*** materials can also be separated by the thresholds developed above for the four lithology classes. Utilizing the voxel grids from the ***Q*** analysis, volumes of the different materials within the section can be estimated. Additionally, the ***Kd*** can be divided into three lithology classes: Sandstone/Sand-Dominant, Siltstone/Silt-dominant, and Shale/Clay-Dominant portions. Within the ***Kd*** Sandstone/Sand-Dominant zones, higher resistivities can be illustrated that are greater than 35 ohm-m. The voxel grids for the South Block, Arlington Block, and Tekamah Block can be found in *Appendix 3-Deliverables\Voxel*.

Table 5-4. Datasets combined into a single voxel. The 2018-304M was selected as the normalizing model structure.

AEM Data Year	System	No. Layers	Bottom 1st Layer	Bottom Last Layer
2007	Resolve	40	-1.6	-360.9
2014	508	30	-16.4	-1641.1
2015	508	30	-16.4	-1772.4
2016	304M	30	-9.8	-1023.7
2018	304M	40	-3.3	-1148.0
2018	312	40	-9.8	-1804.9
2020	304M	40	-6.6	-1066.3

Table 5-5. Normalized voxel depth layers.

Layer	Depth to Bottom (ft)	Thickness (ft)	Depth to Bottom (m)	Thickness (m)	Layer	Depth to Bottom (ft)	Thickness (ft)	Depth to Bottom (m)	Thickness (m)
1	-3.3	3.3	-1.0	1.0	21	-197.8	20.0	-60.3	6.1
2	-6.9	3.6	-2.1	1.1	22	-219.8	199.8	-67.0	60.9
3	-10.8	7.2	-3.3	2.2	23	-243.8	44.0	-74.3	13.4
4	-15.1	7.9	-4.6	2.4	24	-270.0	226.1	-82.3	68.9
5	-19.7	11.8	-6.0	3.6	25	-298.9	72.8	-91.1	22.2
6	-24.9	13.1	-7.6	4.0	26	-330.4	257.6	-100.7	78.5
7	-30.5	17.4	-9.3	5.3	27	-364.8	107.3	-111.2	32.7
8	-36.7	19.3	-11.2	5.9	28	-402.6	295.3	-122.7	90.0
9	-43.6	24.3	-13.3	7.4	29	-443.9	148.6	-135.3	45.3
10	-51.2	26.9	-15.6	8.2	30	-489.2	340.6	-149.1	103.8
11	-59.4	32.5	-18.1	9.9	31	-538.7	198.1	-164.2	60.4
12	-68.2	35.7	-20.8	10.9	32	-593.2	395.0	-180.8	120.4
13	-78.1	42.3	-23.8	12.9	33	-652.6	257.5	-198.9	78.5
14	-88.6	46.2	-27.0	14.1	34	-717.5	460.0	-218.7	140.2
15	-100.4	54.2	-30.6	16.5	35	-788.7	328.7	-240.4	100.2
16	-113.2	59.0	-34.5	18.0	36	-866.8	538.1	-264.2	164.0
17	-127.3	68.3	-38.8	20.8	37	-952.1	414.0	-290.2	126.2
18	-142.7	74.5	-43.5	22.7	38	-1045.6	631.6	-318.7	192.5
19	-159.4	85.0	-48.6	25.9	39	-1148.0	516.4	-349.9	157.4
20	-177.8	92.8	-54.2	28.3					

5.2.8 Comparison of Borehole Resistivity Logs to Inverted AEM Resistivity Soundings

Several previously published comparisons of the borehole geophysical resistivity logs have been done in the past for the AEM surveys within the P-MRNRD (AGF, 2017, 2019a; Carney et al., 2015a, 2015b). Regarding the 2020 data only two new lines were close to boreholes that were previously compared to the AEM. A brief comparison of the 16-inch short normal resistivity log for *01-PMR-14* to AEM inverted resistivity for Line L701301, which is in the Arlington Block, illustrates a paleochannel in the area. Line L701301 is 800 feet south of *01-PMR-14* (Figure 5-38). There is a general agreement but due to the offset in the location of the borehole versus the line, there is an elevation difference as illustrated by the difference in the elevations of the conductive glacial till. However, the ***Q*** resistive materials in the paleochannel do show up well as do the resistive sand and sandstone in the ***Kd***.

Another geophysical log that is somewhat close to a 2020 P-MRNRD AEM survey line is *03-PMR-15*. The borehole is 2,315 feet west of Line L1001301. This line is part of the reconnaissance grid collected in the northern portions of the P-MRNRD. Figure 5-39 is a plot of the AEM inverted resistivity versus the 16-inch short normal resistivity log for *03-PMR-15*. The agreement is not as compelling as the previous example from Figure 5-38 due to the distance between the flight line and the borehole.

One of the major issues with the geophysical borehole logs within the P-MRNRD area is the poor calibration and other operational issues with the logging systems. As an example of the possible biases and issues with using the geophysical logs as direct comparisons to the AEM, a historic line that was acquired in 2018 and is part of the AGF (2019a) report is Line L101600 that passes close to *01-PMR-18* and *02-PMR-18*. The 16-inch short normal resistivity log *01-PMR-18* compares well with AEM inverted resistivity but the next 16-inch short normal resistivity log from *02-PMR-18* shows elevated resistivities and looks to have a clear offset bias (Figure 5-40). The resistivities in the log from *02-PMR-18* are unreasonably high as compared with other logs and the AEM resistivity in the area. Unfortunately, this is not a unique issue with comparing borehole logs with AEM and has been published on before (Ley-Cooper and Davis, 2010).

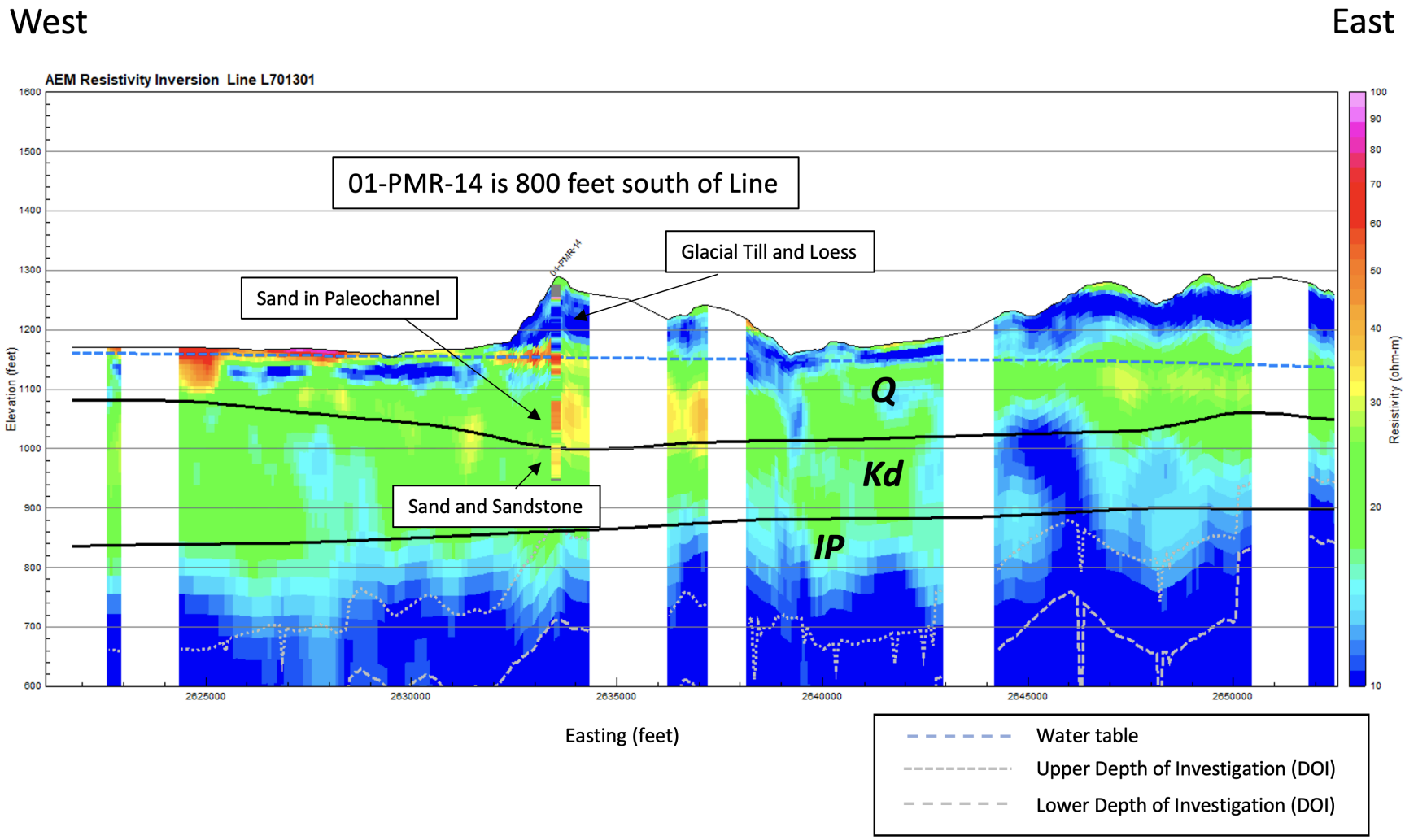


Figure 5-38. Inverted AEM resistivities for flight line L701301 with borehole 16-inch normal resistivity log of *01-PMR-14* overlaid at the same color scale. Cretaceous Dakota Group (*Kd*), and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

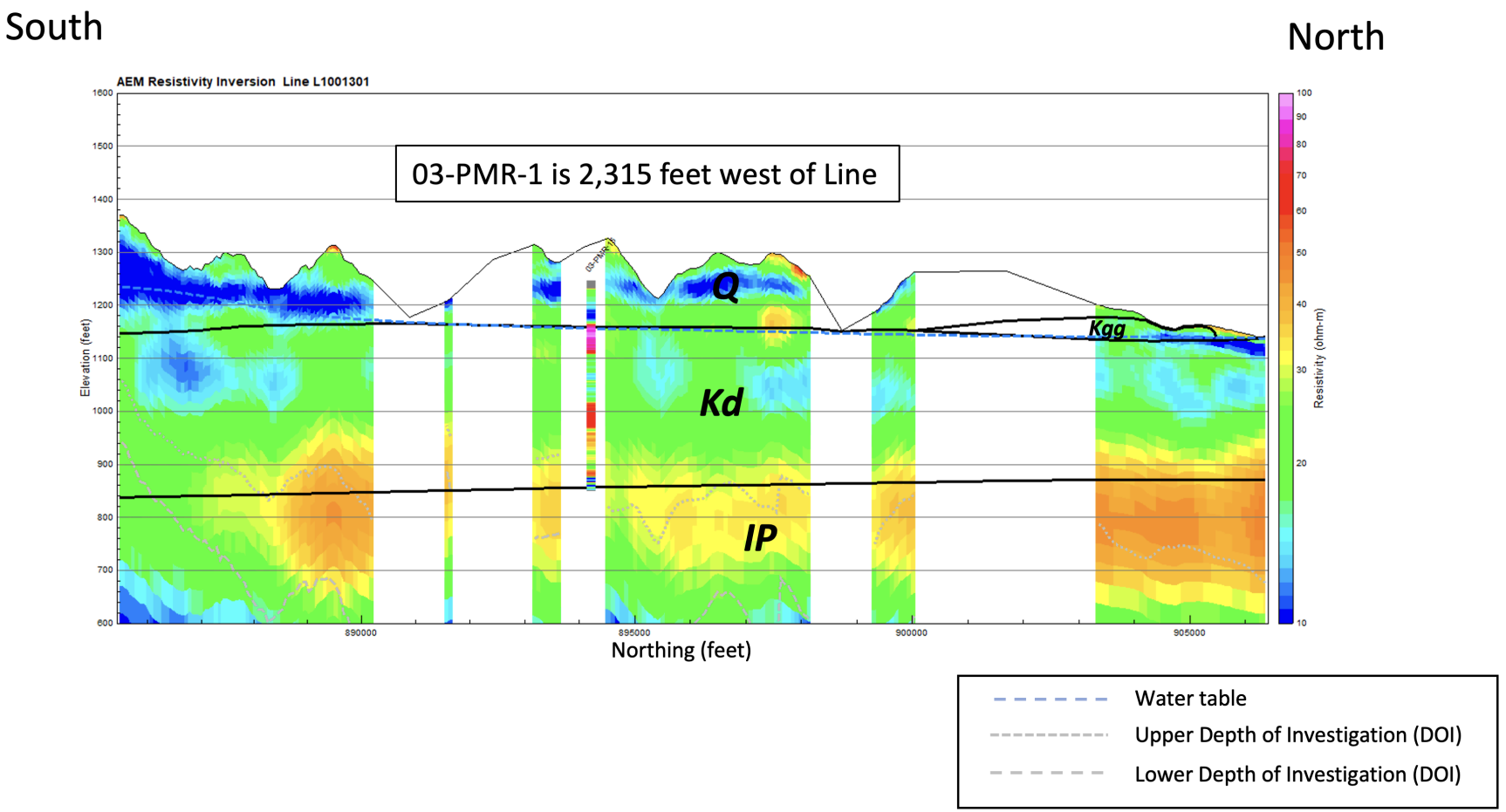


Figure 5-39. Inverted AEM resistivities for flight line L1001301 with borehole 16-inch normal resistivity log of *03-PMR-15* overlaid at the same color scale. Cretaceous Greenhorn Limestone and Graneros Shale (Kgg), Cretaceous Dakota Group (*Kd*), and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

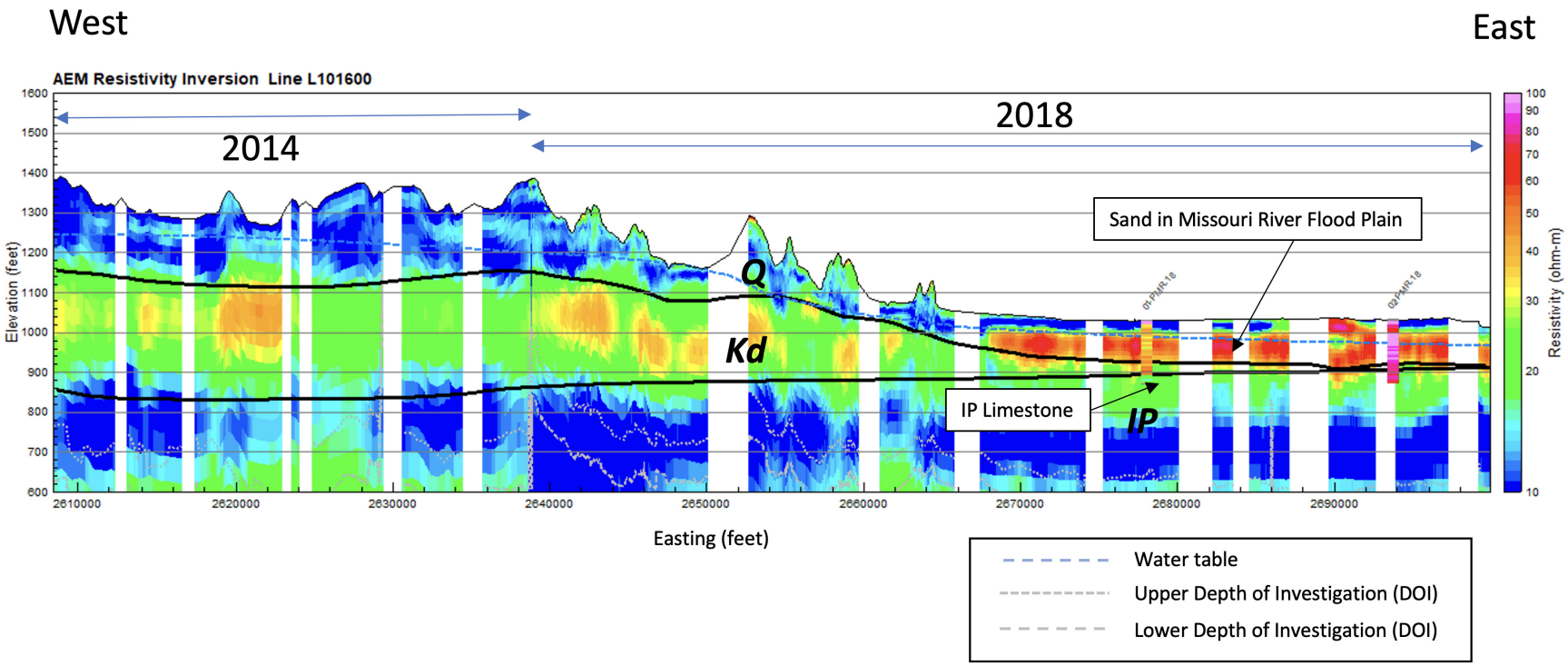


Figure 5-40. Inverted AEM resistivities for flight line L101600 a combination of 2014 and 2018 AEM data with borehole 16-inch normal resistivity logs of *01-PMR-18 and 02-PMR-18* overlaid at the same color scale. Cretaceous Dakota Group (*Kd*), and undifferentiated Pennsylvanian (*IP*) are indicated by the black lines. Gaps indicate areas removed due to coupling.

5.3 Hydrogeological Framework of the P-MRNRD 2020 AEM Survey Area

The 2020 survey compiles the bulk of the previous AEM survey efforts within P-MRNRD beginning in 2007 with the Ashland survey (Smith et al., 2008), the 2015 reconnaissance lines (Carney et al., 2015b), the Sarpy County survey (AGF, 2017), and the 2018 Tekamah Block and reconnaissance lines survey (AGF, 2019a, Section 5.1 map). Much of the Sarpy County survey was left out of this compilation. These AEM-derived results provide new information on the hydrogeology in areas that were previously unknown to the P-MRNRD or were only known to a limited extent from just the borehole information. The survey, completed in 2020 by AGF, provides the basis for this section of the report. The following highlights the areas that fill in and aggregate this portion of the current multi-year project being conducted by the P-MRNRD and ENWRA. The areas are partitioned as the Southern Block (Todd Valley, Elkhorn River, Platte Valley), Arlington Block, Tekamah Block, and the Northern Area (Figure 5-41). Figure 5-42 is a 3D fence diagram and bedrock surface image of the AEM interpretation looking to the north that shows the geologic formations and survey blocks across the survey area of P-MRNRD.

The AEM reveals variability in the Quaternary and Cretaceous deposits which make up the aquifers across the AEM survey areas. Quaternary (***Q***), Cretaceous Carlile Formation (***Kc***), Cretaceous Greenhorn Limestone and Graneros Shale ***(Kgg),*** Cretaceous Dakota Group ***(Kd)***, are terms used to describe stratigraphic units in the interpretative section of this report to describe all unconsolidated, semi-consolidated, and consolidated materials overlying the undifferentiated Pennsylvanian (***IP)*** units that may contain other Paleozoic units in the north of the P-MRNRD; thus, including aquifer and non-aquifer material alike. It is generally accepted that the ***Kc***, ***Kgg***, and ***IP*** are not aquifers in the P-MRNRD. It should be noted that in the entire survey area only the northern area contains a limited number of reconnaissance flight lines that have ***Kc*** and ***Kgg*** in the subsurface. These units are not considered aquifers. The ***Kc*** and the ***Kgg*** are heavily eroded within the P-MRNRD. Full sections of the ***Kgg*** only occur in areas with overlying ***Kc.*** There is not a full section of the ***Kc*** within this survey area. For purposes of this section the ***Q*** and ***Kd*** will be discussed concurrently.

The ***Q*** aquifer materials of the survey area are composed of unconsolidated non-aquifer (blue color in figures), marginal aquifer (tan color in figures), aquifer (yellow color in figures), and coarse aquifer (brown color in figures) materials (see Figure 5-36 in Section 5.2.5). These materials are composed predominantly of pre-glacial alluvial, glacial, loess, and alluvial deposits related to the current drainages. The ***Kd*** is broken up into three material types Shale/Clay Dominant (dark green), Siltstone/Silt Dominant (olive), and Sandstone/Sand Dominant (light green) (Figure 5-37). The Siltstone/Silt and the Sandstone/Sand Dominant ***Kd*** material may contain materials that will yield water to wells. Within these zones there will be mixtures of shale/siltstone/sandstone as well as clay/silt/sand. The electrical characterization of the ***Kd*** is used to provide a guide to the dominant material types and is by no means a definitive description of all the materials within the zone (see Section 5.2.6). The ***Kd*** materials are related to the deltaic systems that existed during the Cretaceous and are summarized in Witzke and Ludvigson (1994) as “prodelta muds”, “distributary channels”, and “delta-front sand-silt”. This is also discussed in O’Connor (1987).

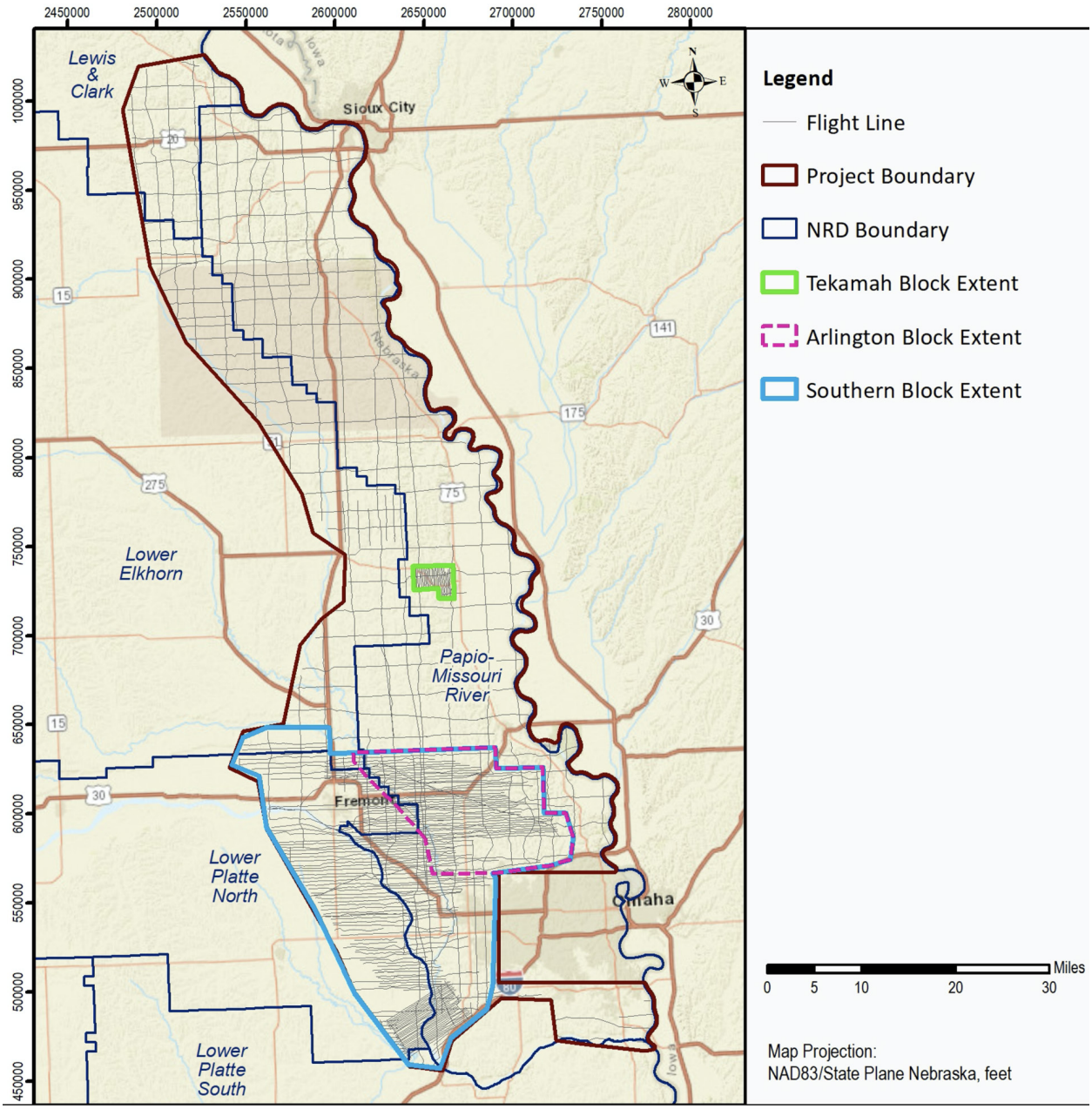


Figure 5-41. P-MRNRD Study Area with the three block areas indicated: Arlington Block, Southern Block, and the Tekamah Block. Note the Arlington Block is a subset of the Southern Block.

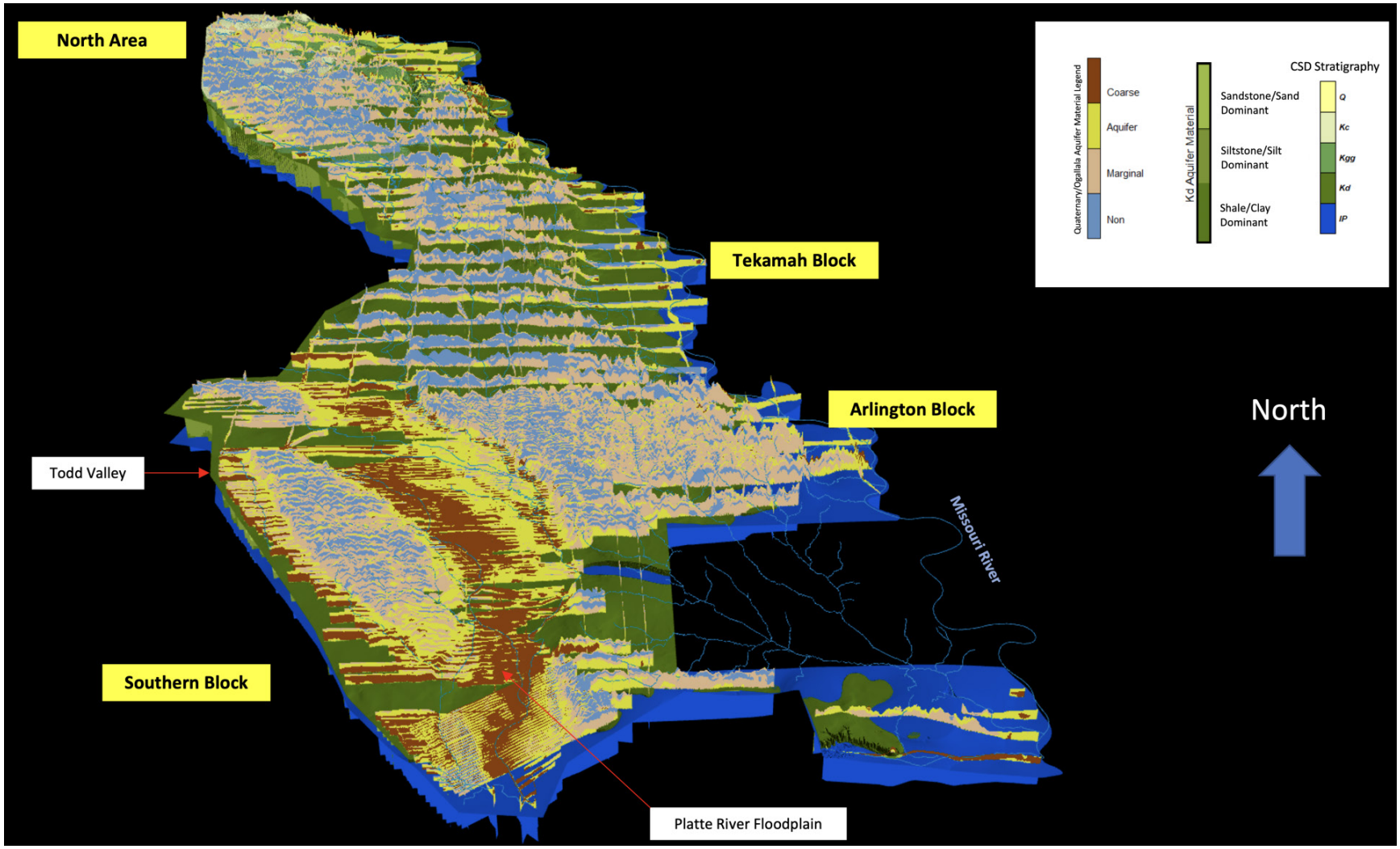


Figure 5-42. P-MRNRD regional 3D fence diagram looking to the north. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Carlie (*Kc*), Greenhorn Limestone and Graneros Shale (*Kgg*), Dakota Group (*Kd*) are shown as a surface overlaying the undifferentiated Pennsylvanian (*IP*) surface. Major streams are indicated as thin blue lines. Vertical exaggeration (VE) = 20x.

5.3.1 The Hydrogeologic Framework of the Southern Block Survey Area

The dominant hydrogeologic features that are in the southern block are ***Q*** alluvial deposits found in the modern drainages and paleochannels, the loess and till deposits which are clay and silt rich, and the ***Kd*** Sandstone/Sand Dominant deposits which are considered bedrock aquifers (AGF,2019a). The 3D P-MRNRD Southern Block model (Figure 5-43) illustrates the modern extent of ***Q*** alluvial deposits in the Platte River floodplain, the Elkhorn River course, and includes the paleochannel of the Todd Valley to the west. Glacial till and loess deposits comprising unconsolidated non-aquifer and marginal aquifer materials occupy a large area northwest of the main Platte River floodplain and Elkhorn River. A north-south trending island of this loess and glacial till separate the Todd Valley from the Platte River Valley floodplain.

The Todd Valley is characterized as an older paleochannel of the Platte River (Korus et al., 2013). The thick coarse ***Q*** alluvial deposits that comprise the Todd Valley connect hydraulically to the current day Platte River Valley at the northern and southern end of the glacial till island featured in Figure 5-44. The northern portion the present-day Platte Valley in flood stage can recharge the higher Todd Valley at the northern end convergence.

AEM interpretation Line L703200 (Figure 5-45) is a west to east profile through the P-MRNRD Southern Block from the Todd Valley, east through the thick assemblage of loess and glacial tills and east to the Platte River Valley. The entire Quaternary (***Q***) system here is underlain by the Dakota Group (***Kd***) and undifferentiated Pennsylvanian (***IP***). The ***Kd*** noticeably thickens westward and is the bedrock base to the Quaternary (***Q***) in the Southern Block. There would appear to be very little connection between the Elkhorn River and Platte River through the ***Q*** loess and tills. The glacial till island separates the Todd Valley and the Platte River Valley floodplain on the western portion of the profile. The water table gradient dips east to the Missouri River floodplain in this profile.

AEM interpretation Line L1000900 (Figure 5-46) is a south to north profile through the P-MRNRD Southern Block from the Platte River near the I-80 Bridge north to Hwy 30 north of the Elkhorn River. The profile is predominantly through the axis of the Platte River Valley and crosses the confluence of the Platte and Elkhorn Rivers before crossing the Elkhorn River on the northern end and terminating in the thick ***Q*** loess and till deposits. The ***Q*** here is underlain by the ***Kd*** and ***IP***. The ***Kd*** noticeably thins to the south where it is eroded off and the ***Q*** materials directly overlie the ***IP***. Within the ***Kd*** there are several zones of Sandstone/Sand Dominant materials. There is good agreement between the CSD test wells stratigraphy and the interpreted AEM.

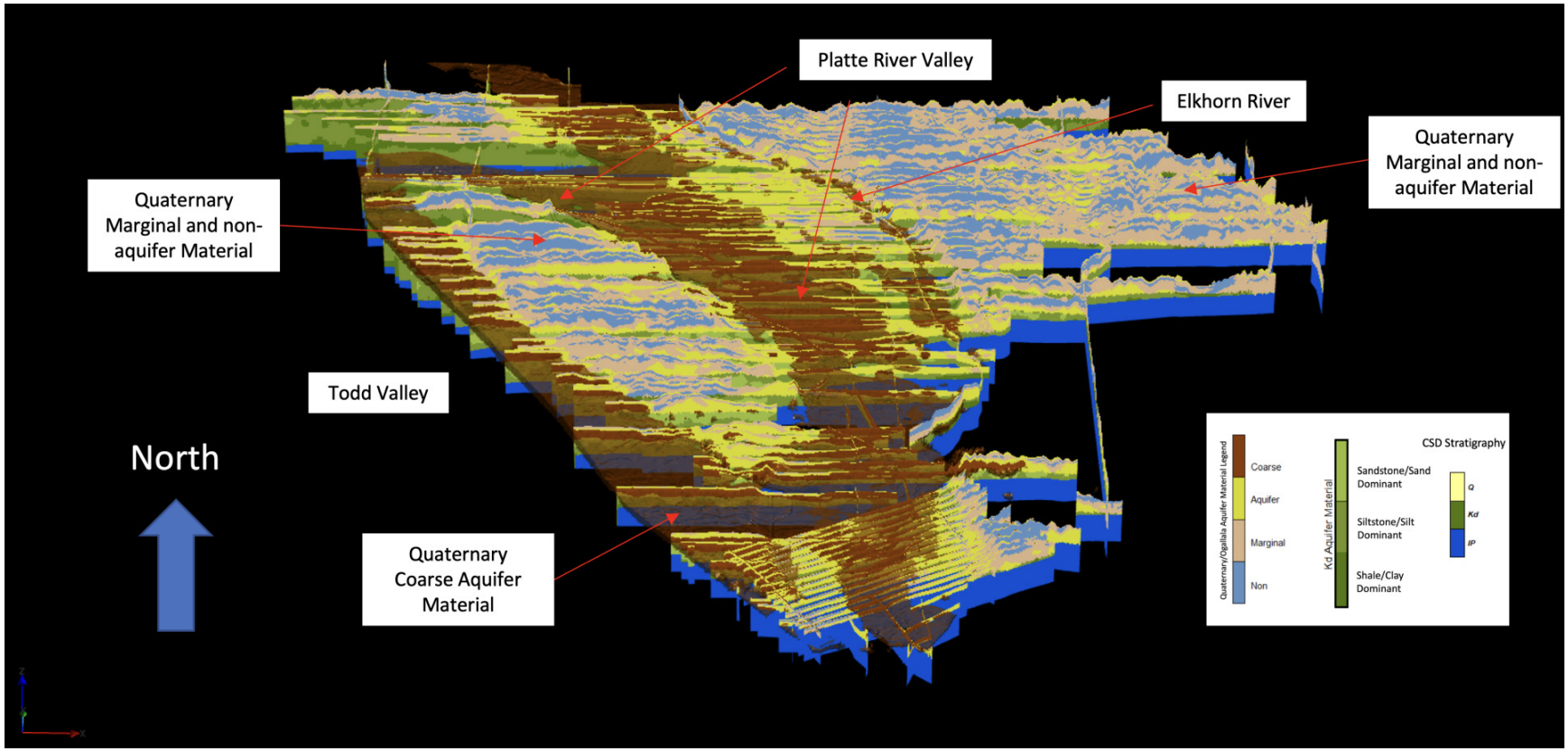


Figure 5-43. P-MRNRD Southern Block 3D Fence Diagram looking to the north of the along the Platte and Elkhorn River valleys. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials are indicated on the legend. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. The Quaternary coarse aquifer materials are indicated as a transparent voxel as the dark brown. Vertical exaggeration (VE) = 20x.

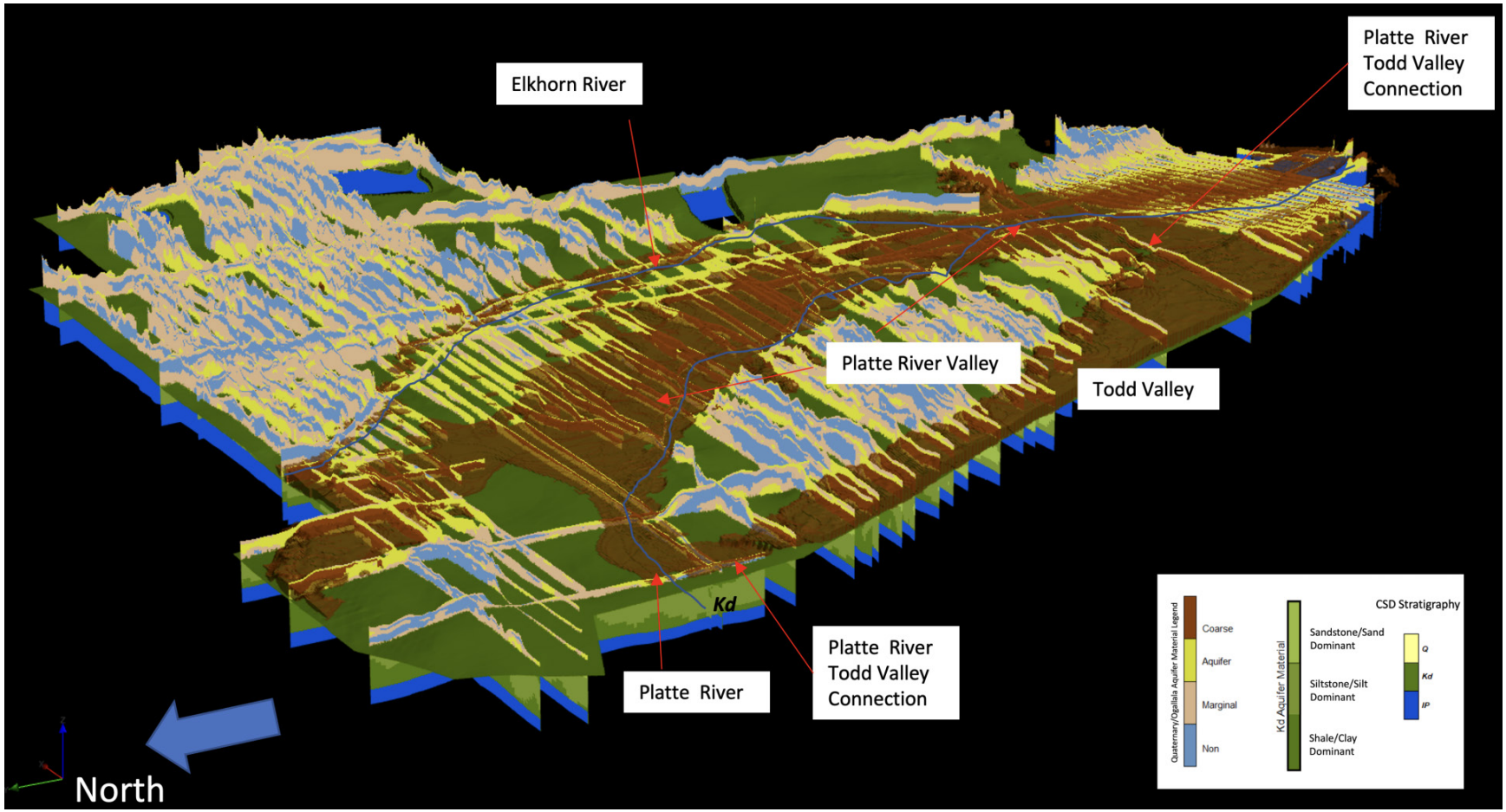


Figure 5-44. P-MRNRD Southern Block 3D Fence diagram looking toward the southeast from the northwest. *(Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials are indicated on the legend and are also represented as a surface under the Q. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. The Quaternary coarse aquifer materials are indicated as a transparent voxel as the dark brown. Connections between the Platte River and the Todd Valley can be seen at the top and bottom. Vertical exaggeration (VE) = 20x.

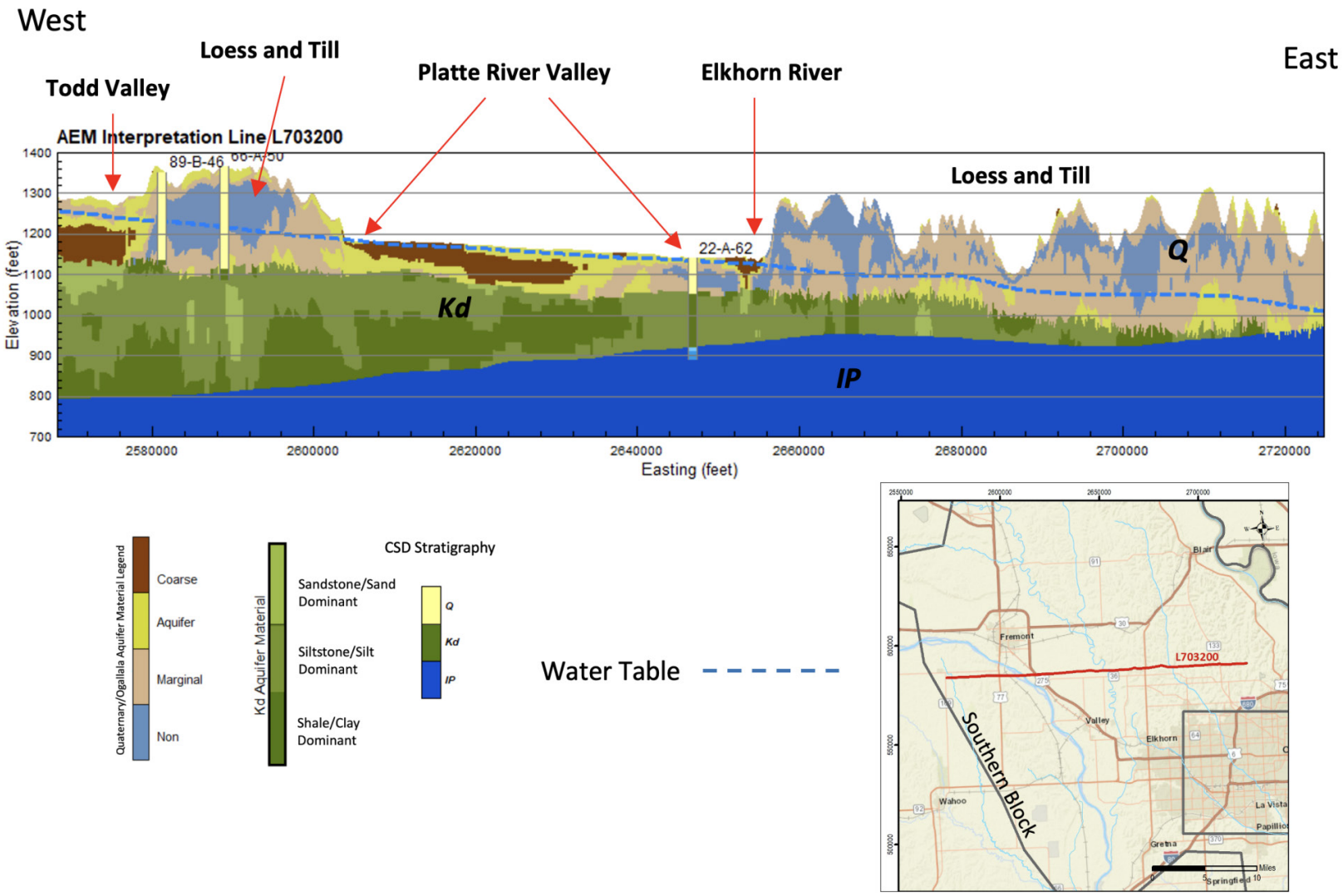


Figure 5-45. AEM interpretation profile of Line L703200 within the Southern Block of the P-MRNRD survey area. The line crosses from the Todd Valley to the Platte River Valley the Elkhorn River and into the thick loess and till north west of Omaha, Nebraska. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group, and *IP* = undifferentiated Pennsylvanian. The inset map indicates the location of the flight line within the Southern Block near Fremont, Nebraska.

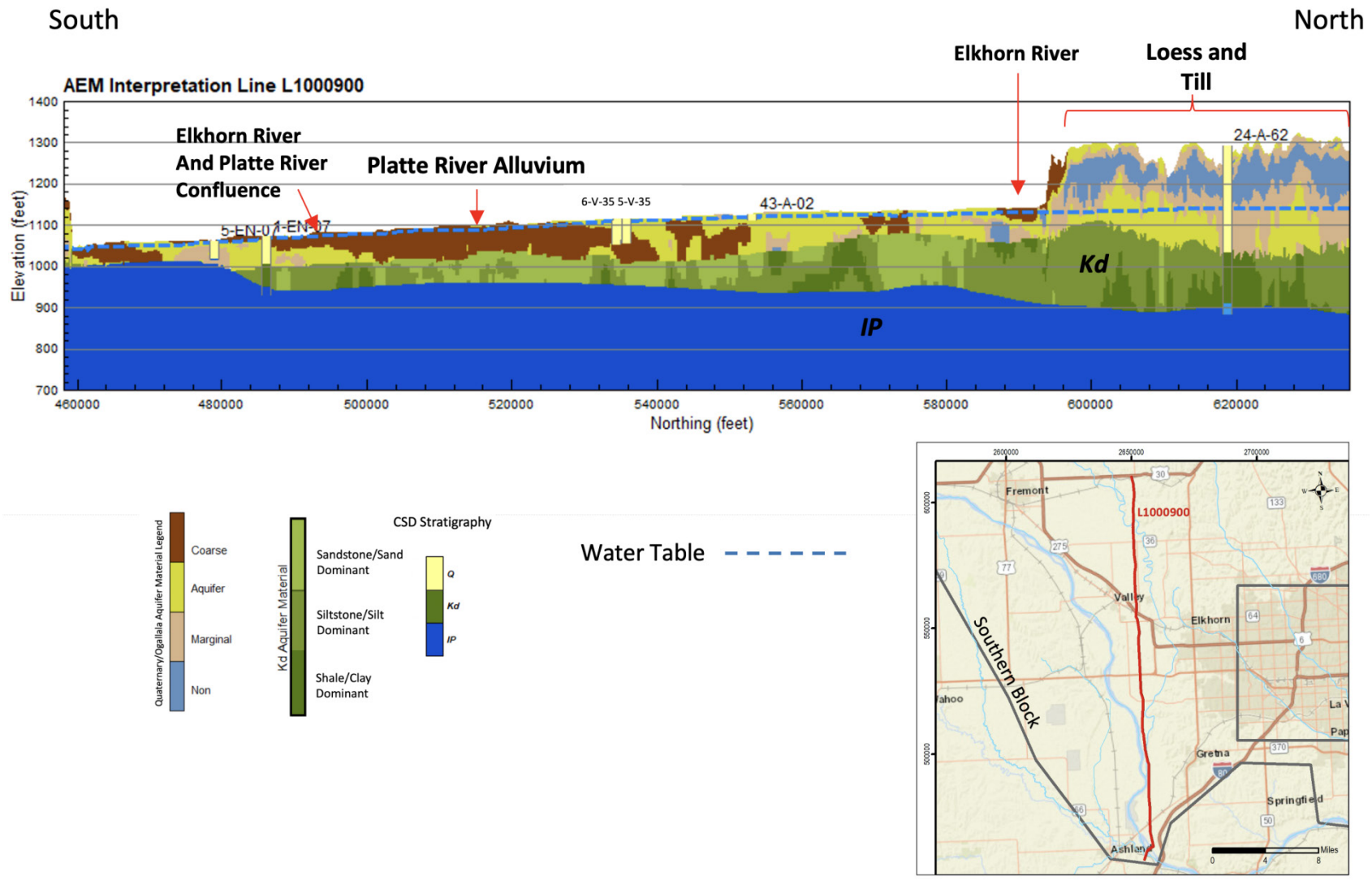


Figure 5-46. AEM interpretation profile of Line L1000900 within the Southern Block of the P-MRNRD survey area. The line crosses from the Platte River Valley the Elkhorn River and into the thick loess and till north east of Fremont, Nebraska. CSD test wells within ½ mile of the flight lines are project on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group, and, *IP* = undifferentiated Pennsylvanian. The inset map indicates the location of the flight line within the Southern Block along the Platte River.

Figure 5-47 is a 3D voxel model looking from the south to the northeast of the ***Q*** saturated aquifer and coarse aquifer material materials throughout the P-MRNRD Southern Block. The Todd Valley, Platte River Valley and Elkhorn River are represented as the predominant ***Q*** aquifer and coarse aquifer material in the P-MRNRD Southern Block. The apparent lack of aquifer and coarse aquifer material east of the Elkhorn River indicates an unlikely connection of the Elkhorn and Platte Rivers to the Missouri River Floodplain through the loess and glacial till.

The P-MRNRD Southern Block water table is represented as a surface on Figure 5-48. This illustrates that much of the ***Q*** materials are saturated within the Platte Valley. The water table is based upon the CSD 1995 regional water table (CSD, 1995). Glacial till deposits comprising unsaturated, unconsolidated non-aquifer, and marginal aquifer materials predominate above the water table in the areas east of the Elkhorn River and the island of loess and till between the Todd Valley and the Platte and Elkhorn River Valleys. The general, regional water gradient is south- southeast towards the Missouri River floodplain.

The Todd Valley ***Q*** Alluvial system converges and merges into the current Platte River alluvial valley in the southern portion of the P-MRNRD Southern Block. Figure 5-49 illustrates where the Todd Valley system joins with the younger Platte River alluvium. Coarse ***Q*** material of the upper Todd Valley converges with the Platte River alluvial floodplain, which ultimately takes a southern track into the Lower Platte South NRD and the Platte River Valley. Unfortunately, this is an area without dense AEM data collection within the Lower Platte North Natural Resources District (LPNNRD). Due to the absence of data collection the AEM data was interpolated across the area. The interpolation was justified due to the predominance of coarse materials (sand and sand and gravel) within the lithology logs of the CSD test wells and the NE-DNR registered wells in the area (Figure 5-50). AEM interpretation of east-west line L300400 profile, Figure 5-51 displays the area where the Todd Valley and Platte systems coalesce and form a hydraulic connection between the thicker elevated Todd Valley and lower Platte River floodplain.

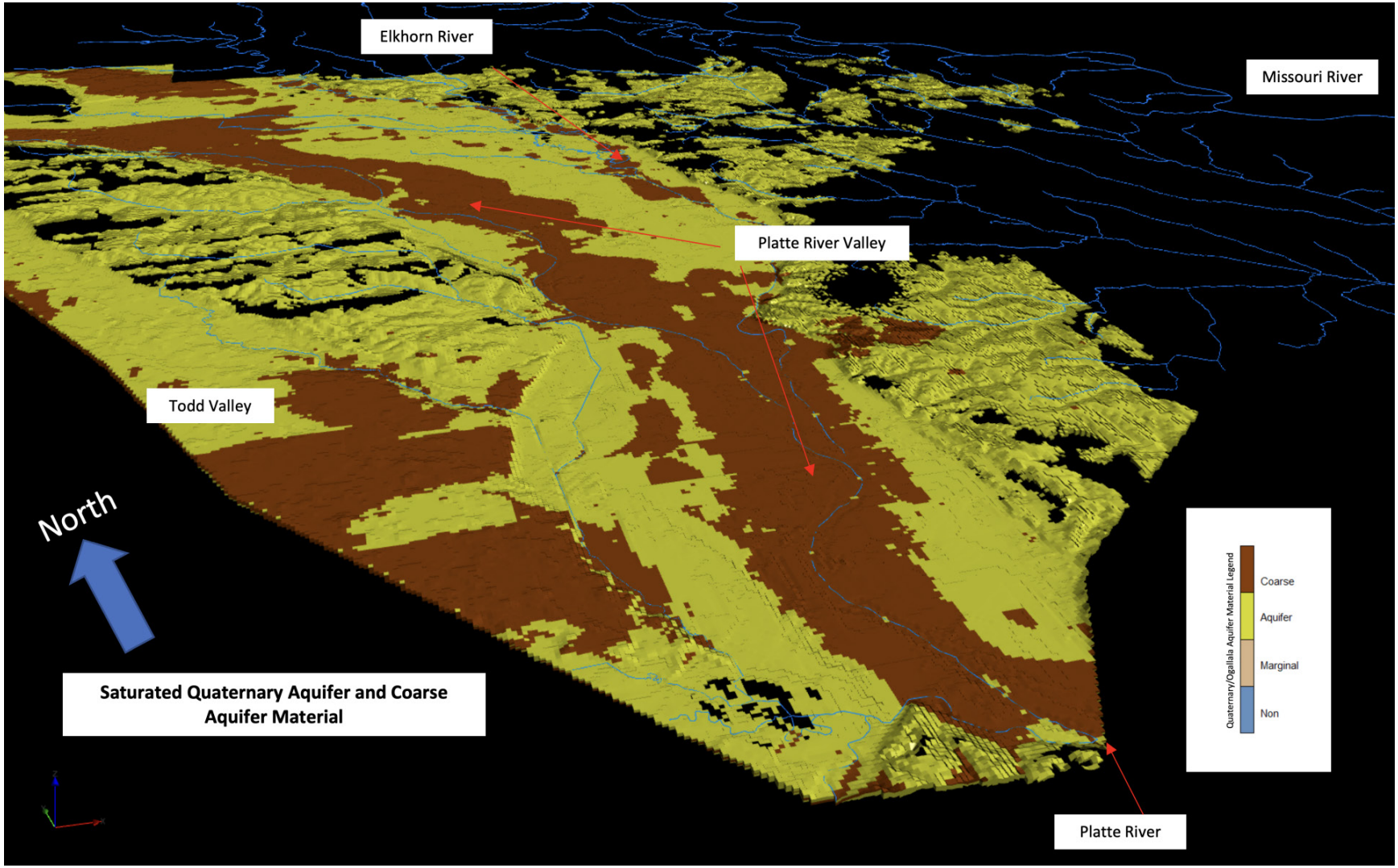


Figure 5-47. P-MRNRD Southern Block 3D voxel plot looking toward the northeast from the southwest. *(Q)* Quaternary aquifer and coarse aquifer materials colors are as indicated on the legend. The major streams in the area are indicated by thin blue lines. Vertical exaggeration (VE) = 5x.

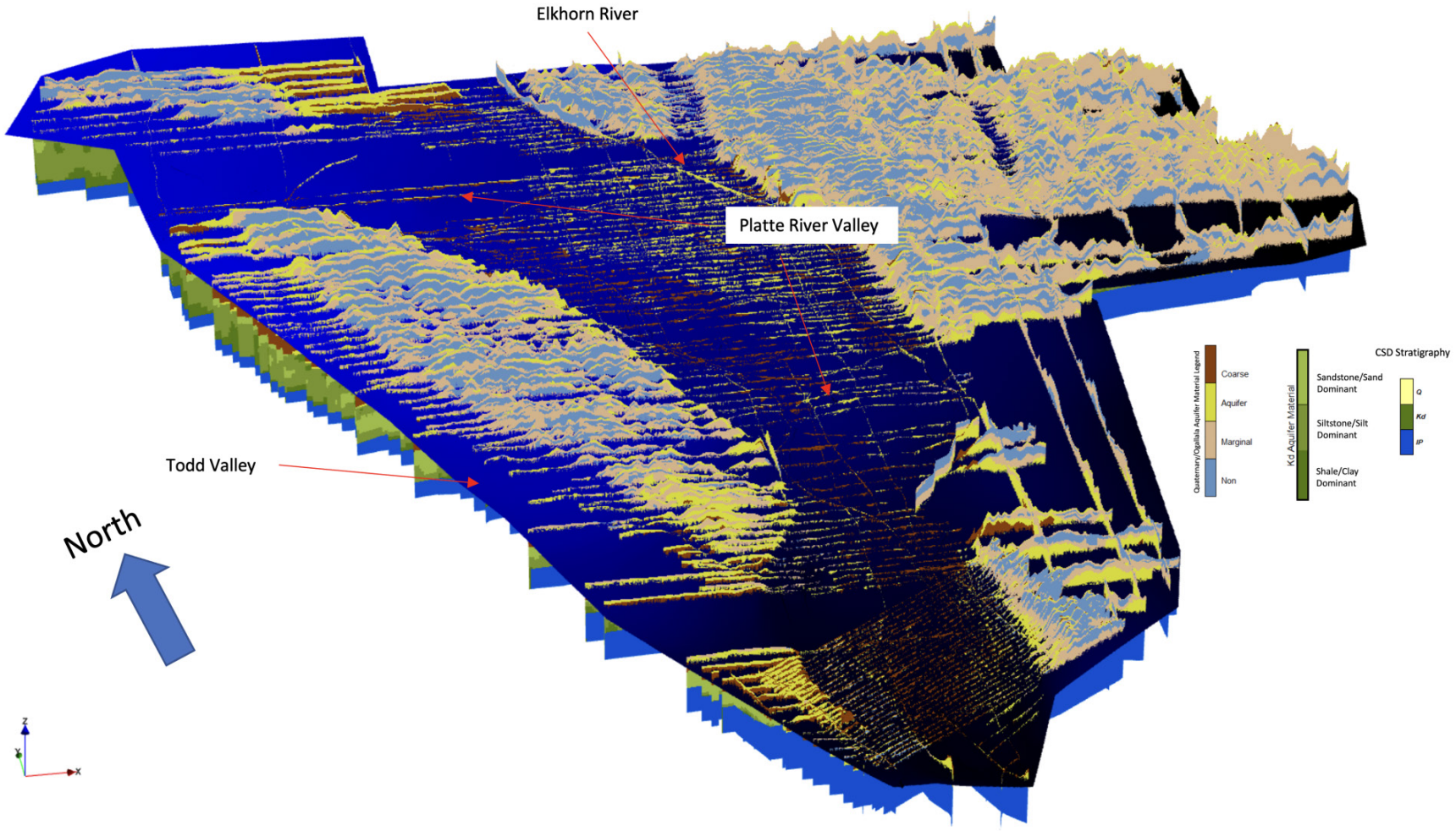


Figure 5-48. P-MRNRD Southern Block 3D Fence diagram looking toward the northeast from the southwest. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials are indicated on the legend. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. The 1995 CSD water table (CSD, 1995) is indicated as a dark blue surface. Vertical exaggeration (VE) = 20x.

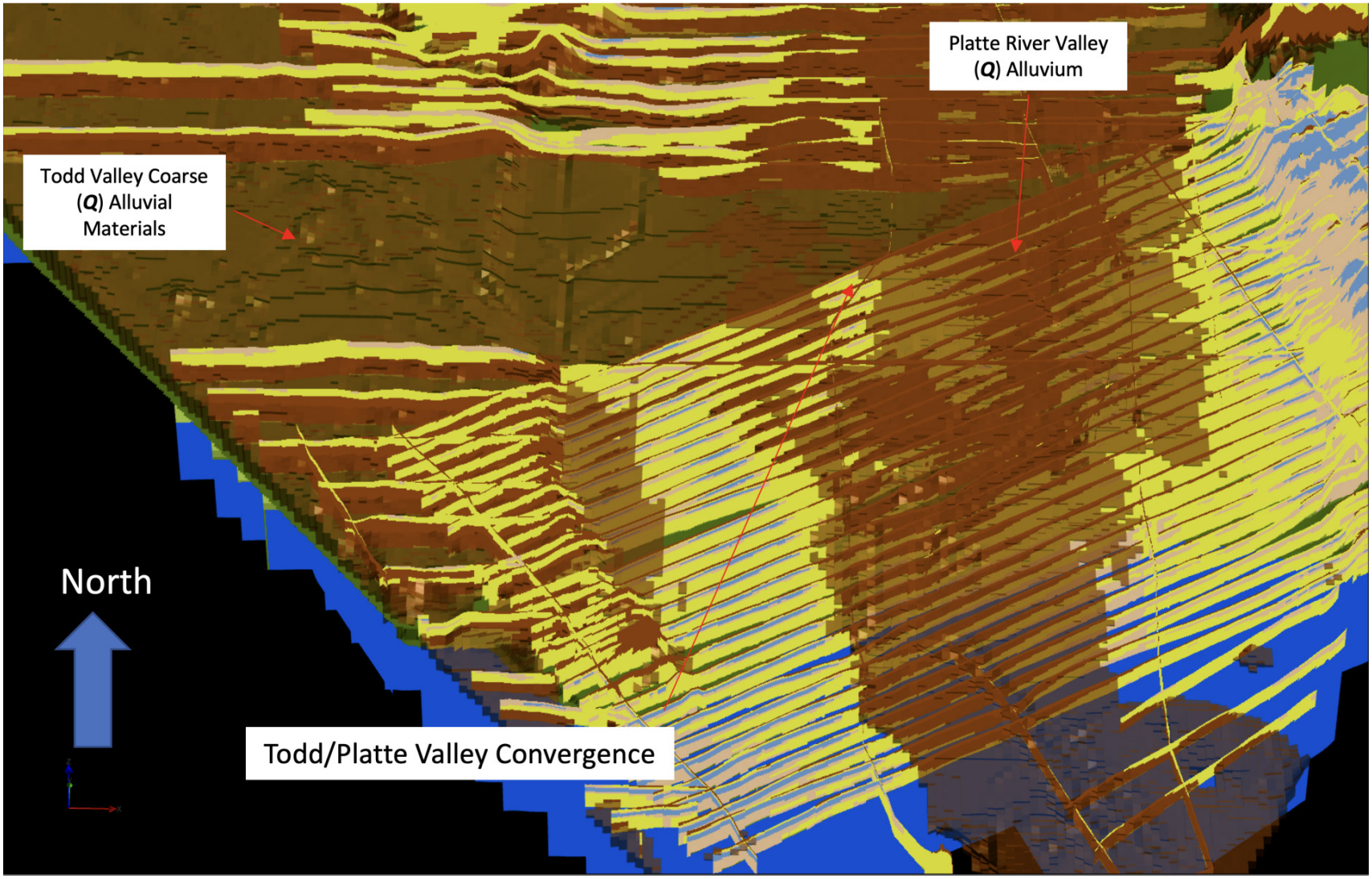


Figure 5-49. P-MRNRD Southern Block 3D Fence Diagram looking at the southern end of the Todd and Platte Valley where the two areas converge. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) is indicated by a dark green surface. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. The Quaternary coarse aquifer materials are indicated as a transparent voxel as the dark brown. Vertical exaggeration (VE) = 20x.

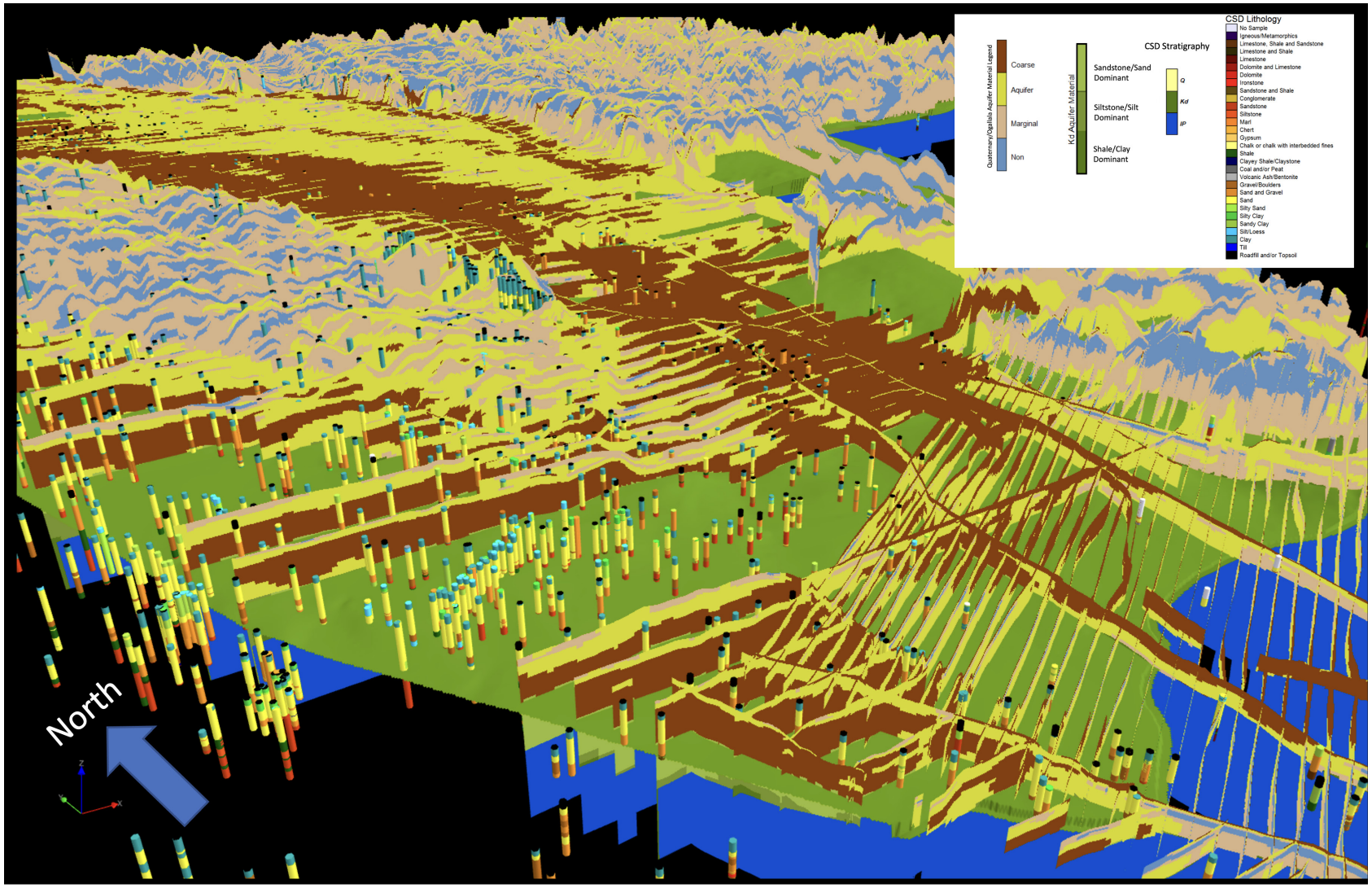


Figure 5-50. P-MRNRD Southern Block 3D Fence Diagram looking at the southern end of the Todd and Platte Valley where the two areas converge. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) is indicated by a dark green surface. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. CSD test holes and NE-DNR registered wells are shown with the lithology as indicated by the legend. Vertical exaggeration (VE) = 20x.

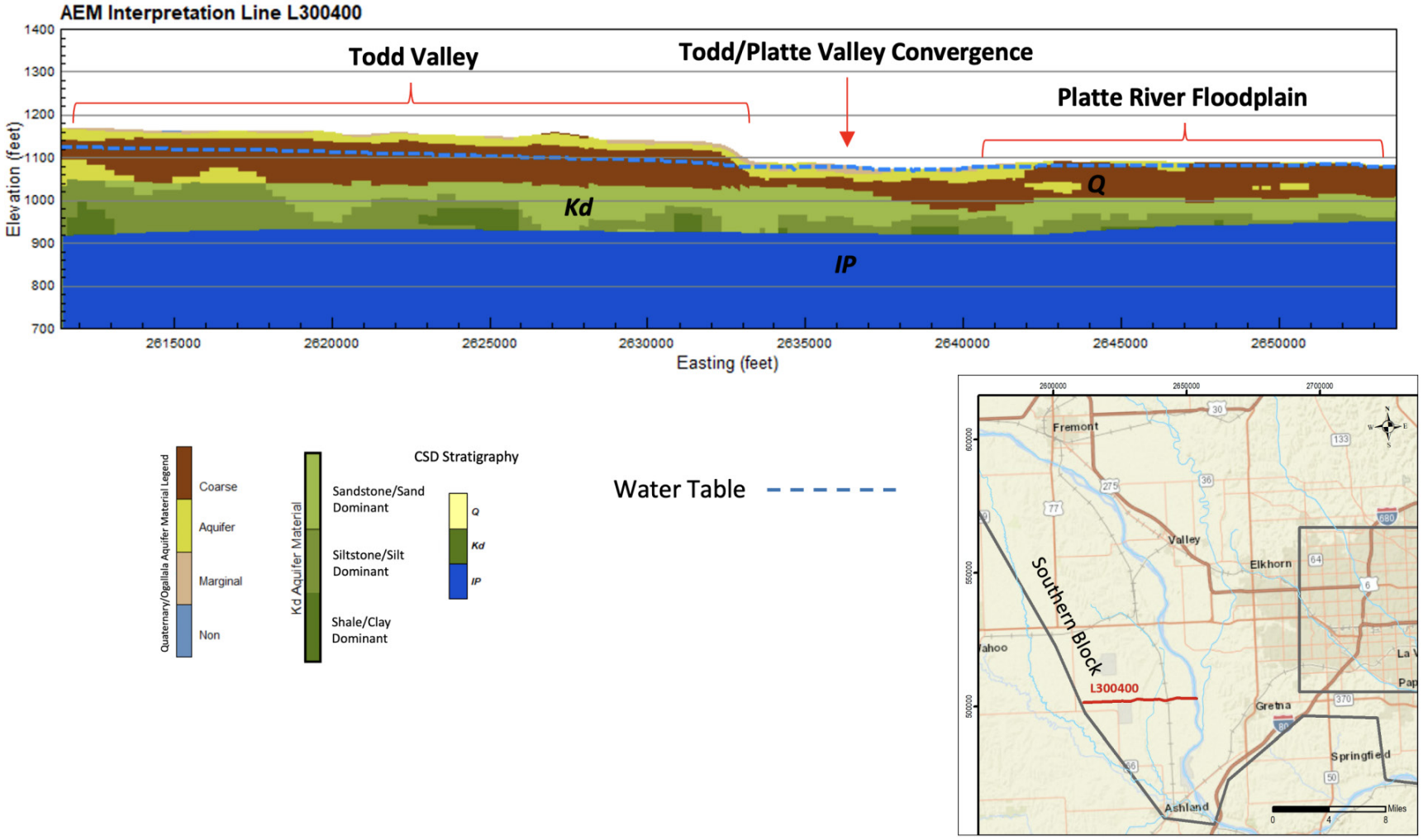


Figure 51. AEM interpretation profile of Line L300400 within the Southern Block of the P-MRNRD survey area. The line crosse from the Todd Valley the Platte River Floodplain. The profile illustrates the continuation of the aquifer and coarse aquifer material across the area. *Q*=Quaternary, *Kd*= Cretaceous Dakota Group, and *IP* = undifferentiated Pennsylvanian. The inset map indicates the location of the flight line within the Southern Block along the Platte River.

The ***Q*** coarse material total thickness and saturated thickness for the P-MRNRD Southern Block are compiled in Figure 5-52 which show the distribution and extent of productive material in the Southern Block. There is a discernable lack of these materials in the eastern third of the southern block study area. Saturated ***Q*** coarse material is 100' -154' in portions of Todd Valley while the Platte Valley has areas with saturated materials in the range of 50' to 100'. Examining the specific capacity of the wells within the ***Q*** materials (Figure 5-53) shows that the AEM interpretation is corroborated by the specific capacity values as calculated from the NE-DNR registered well database (Section 3). Within Figure 5-53 the Todd Valley and the Platte Valley are easily identified with many registered wells at greater than 50 gpm/foot. The loess/glacial till island between the Todd Valley, as well as the area east of the Elkhorn River, can also be readily identified. The area at the north of the Southern Block will be examined in detail later as part of the Arlington Block.

As discussed previously the Cretaceous Dakota Group (***Kd***) exists over much of the P-MRNRD Southern Block. The southern end of the Block and the eastern end of the Block have ***Kd*** eroded off. Also, as discussed earlier the ***Kd*** was divided into three material or lithology classifications (Section 5.2.6). Within the Southern Block there is a distinct pattern to the distribution of the ***Kd*** material types. The lithology classification at the surface of the ***Kd*** within the Southern Block is shown in Figure 5-54. There is a strong pattern showing that the south-western portions of the area have the high concentrations of the Sandstone/Sand Dominant materials. It is these areas were the largest likelihood of communication of the ***Q*** and the ***Kd*** exists.

AEM Line L202001 inversion and interpretation profiles illustrate an example of a ***Kd*** sandstone/sand dominant signature in the floodplain of the Platte River (Figure 5-55). Note the transition from the Platte River to the Elkhorn River and then the glacial till-covered bluffs, which cover the aquifer material of the paleochannel to be discussed in the Arlington Block. This aquifer geometry provides for sharp flow boundaries within the aquifer system. The paleochannel and alluvial channel deposits of the Platte and Elkhorn Rivers are in direct contact with the ***Kd***. Where the ***Q*** coarse aquifer, aquifer, and marginal aquifer material overlie the ***Kd*** Sandstone/Sand Dominant materials, you have hydrologic connection between the ***Q*** and ***Kd***. This connection includes recharge from the land surface through the ***Q*** down into the ***Kd*** *(*AGF, 2019a*)*. Examining the total ***Kd*** Sandstone/Sand distribution and total thickness throughout the Southern Block is similar to the Sandstone/Sand Dominant distribution of the surface layer (Figure 5-54). Some areas the ***Kd*** are up to 300 ft thick (Figure 5-56a). Another useful examination of the ***Kd*** is the specific capacity of the NE-DNR registered wells that are completed and screened within the ***Kd*** (Figure 5-56b). There is also a pattern of the dual completion wells that the screen extends from the ***Q*** to the ***Kd*** (Figure 5-57). This figure shows that many of the dual completion wells are in areas of both ***Kd*** Sandstone/Sand Dominant material and in areas of ***Q*** aquifer and coarse aquifer material.

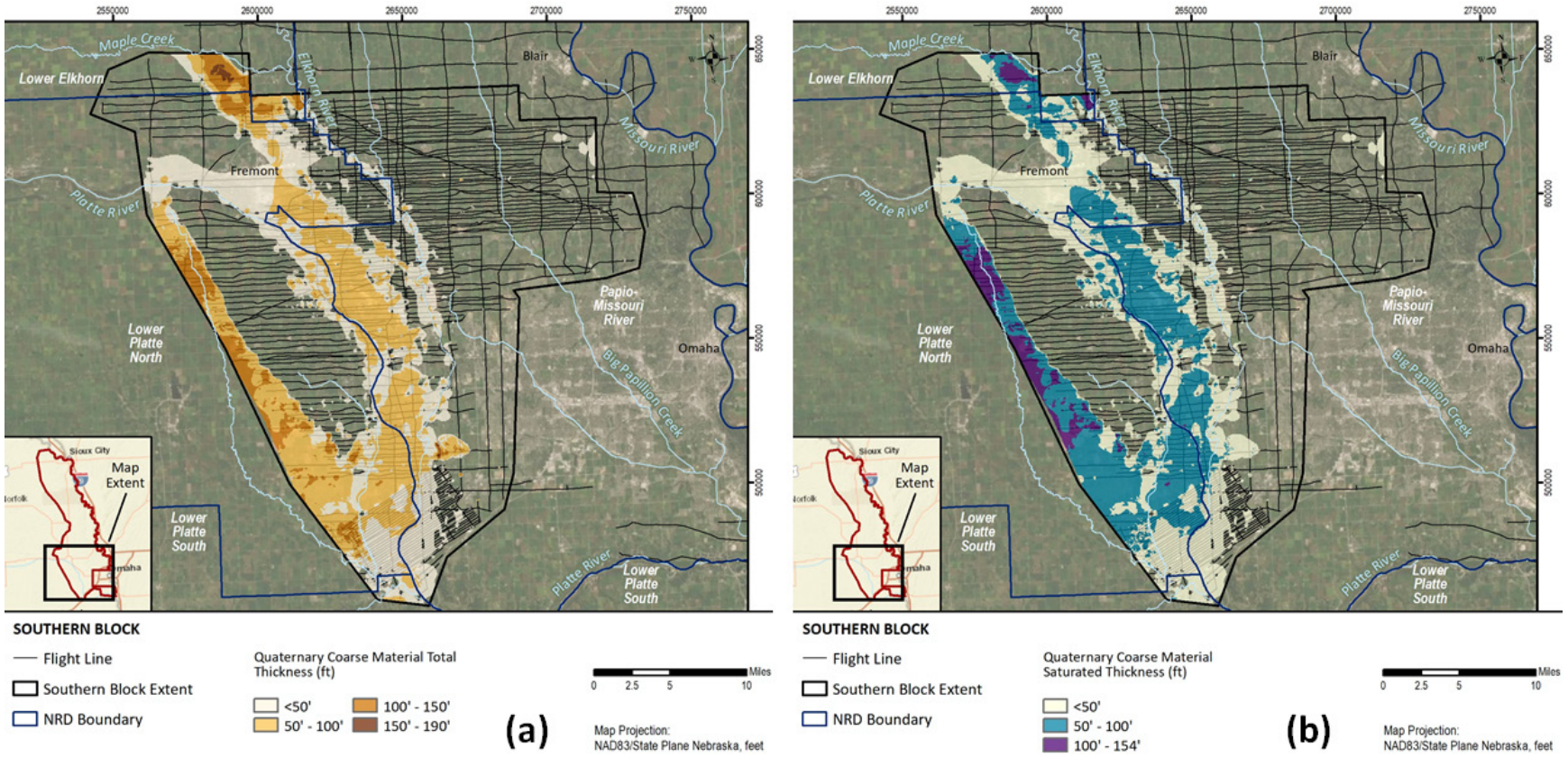


Figure 5-52. a) Quaternary (*Q*) coarse material total thickness and b) saturated thickness (ft) of the Southern Block P-MRNRD.

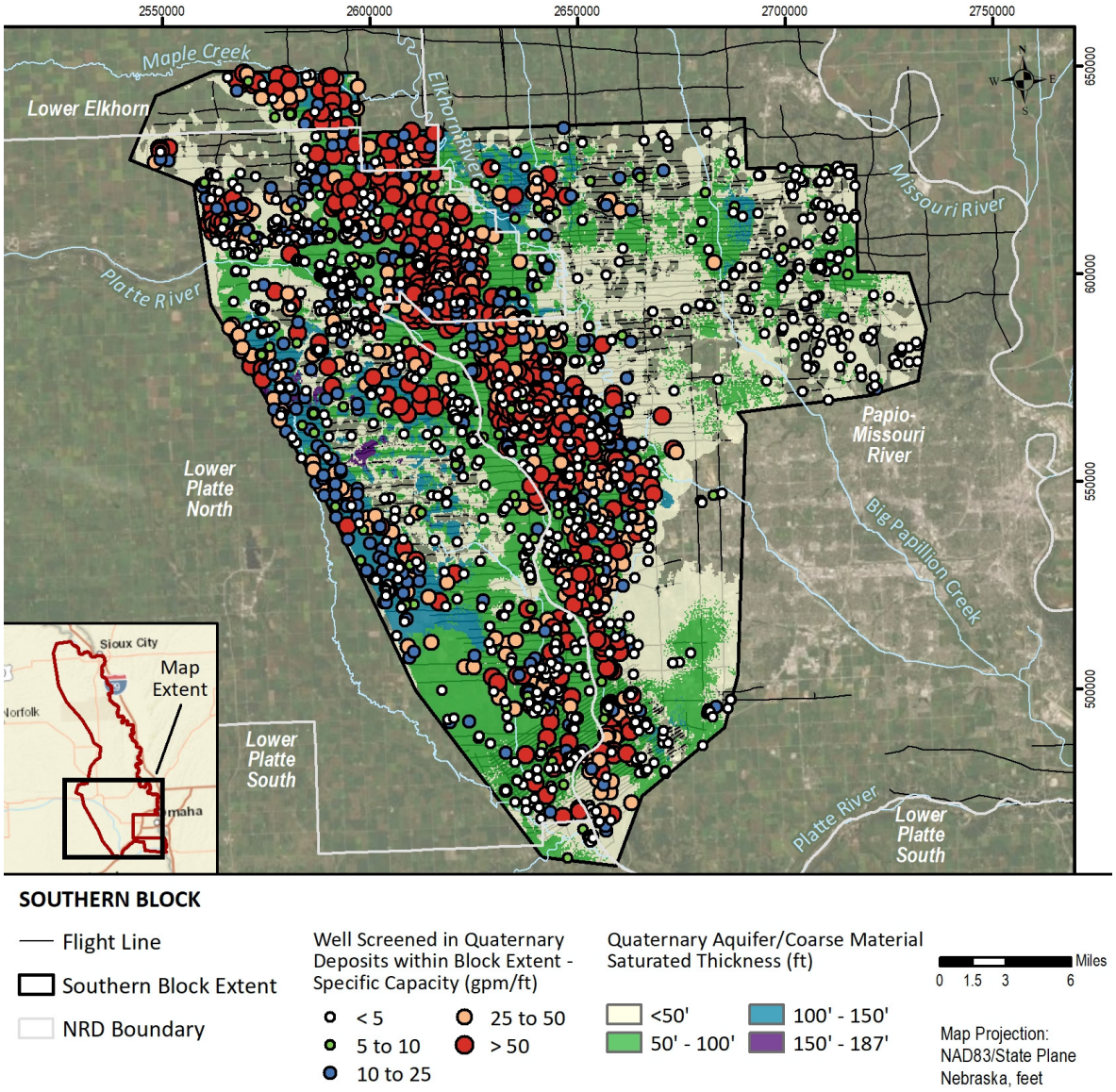


Figure 5-53. Quaternary (*Q*) saturated aquifer and coarse aquifer material thickness with the estimated specific capacity of the NE-DNR registered wells within Southern Block P-MRNRD.

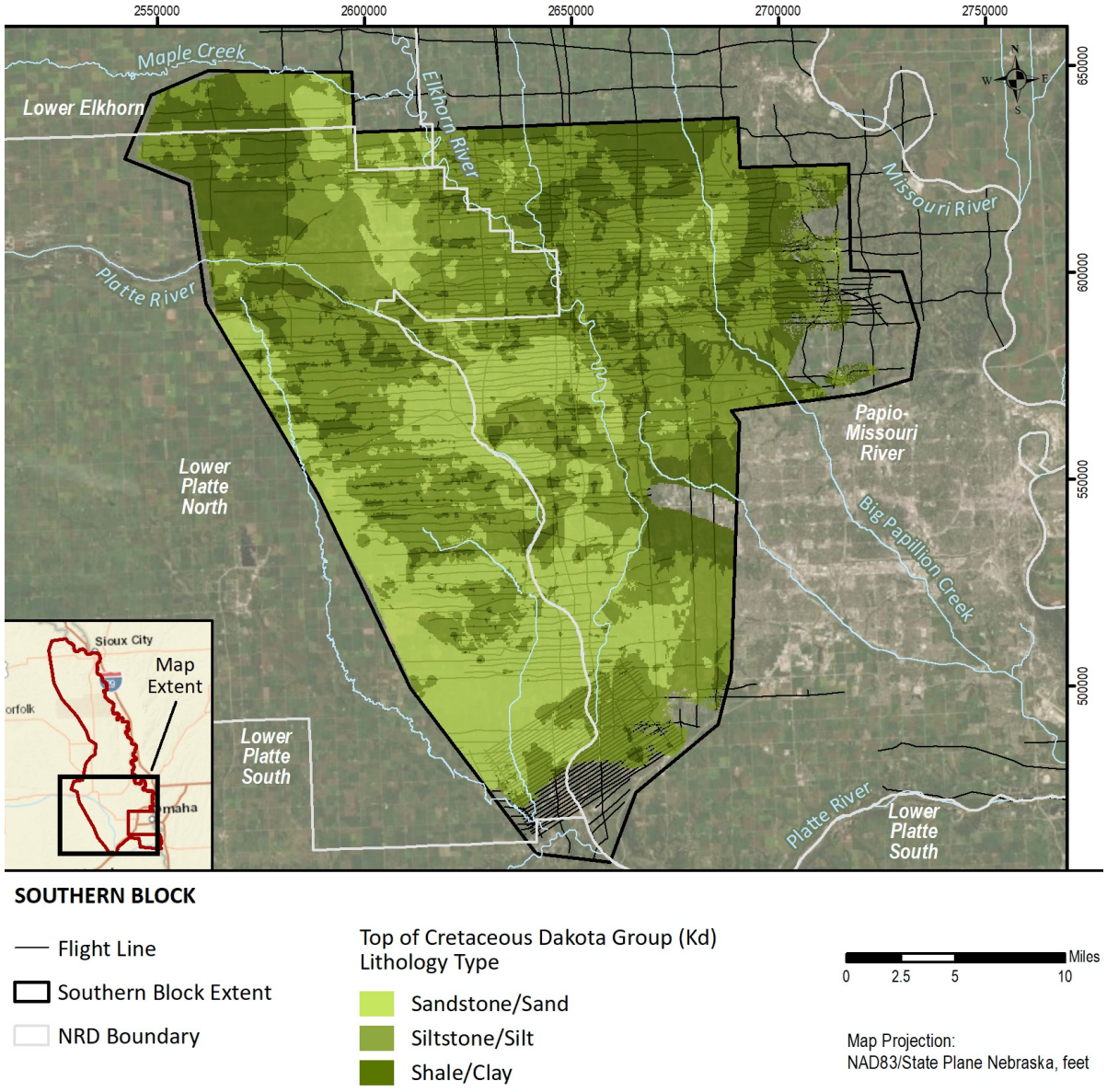


Figure 5-54. Top or surface layer of the Cretaceous Dakota Group (*Kd*) material or lithology classification for the P-MRNRD Southern Block.

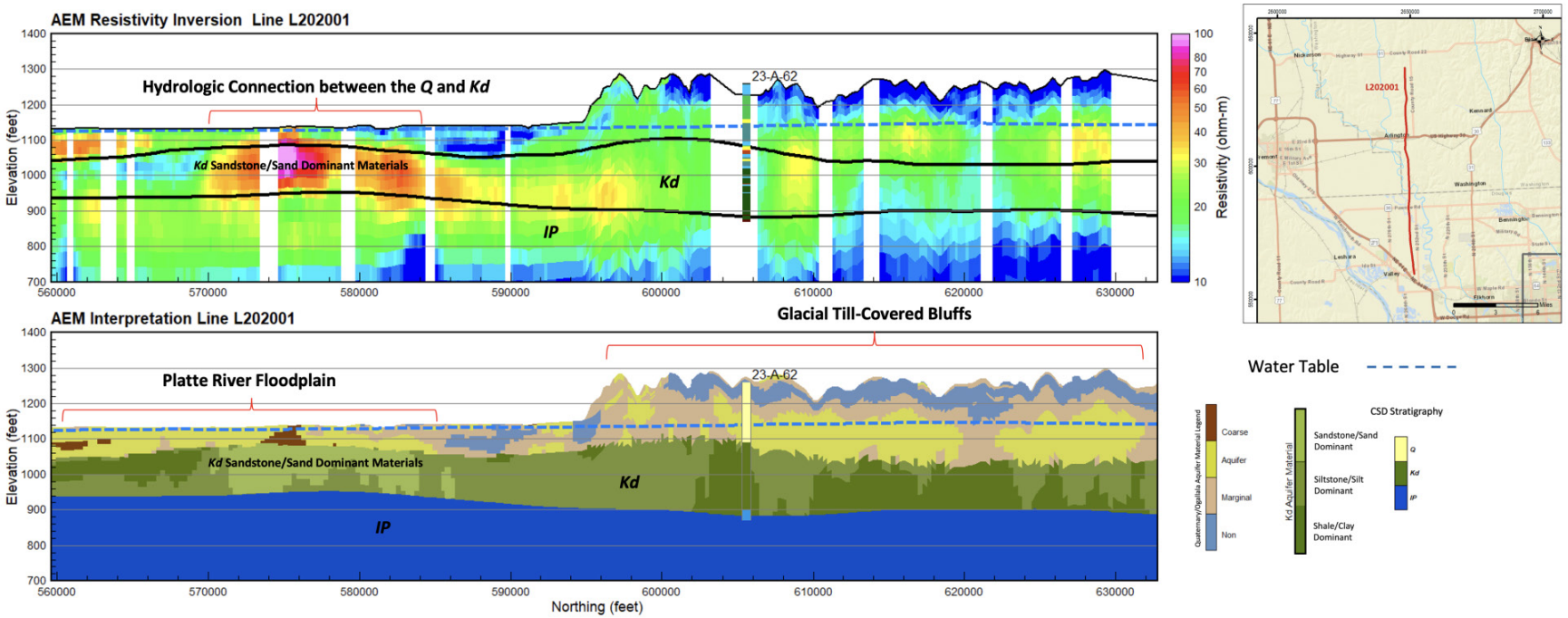


Figure 5-55. AEM interpretation of north-south line L202001 inversion and interpretation profiles within the Southern Block of the P-MRNRD survey area. The line goes from the loess and till areas north of Arlington south into the Platte and Elkhorn River valleys. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group and, *IP* = Undifferentiated Pennsylvanian. The inset map indicates the location of the flight line within the Southern Block along the Elkhorn River.

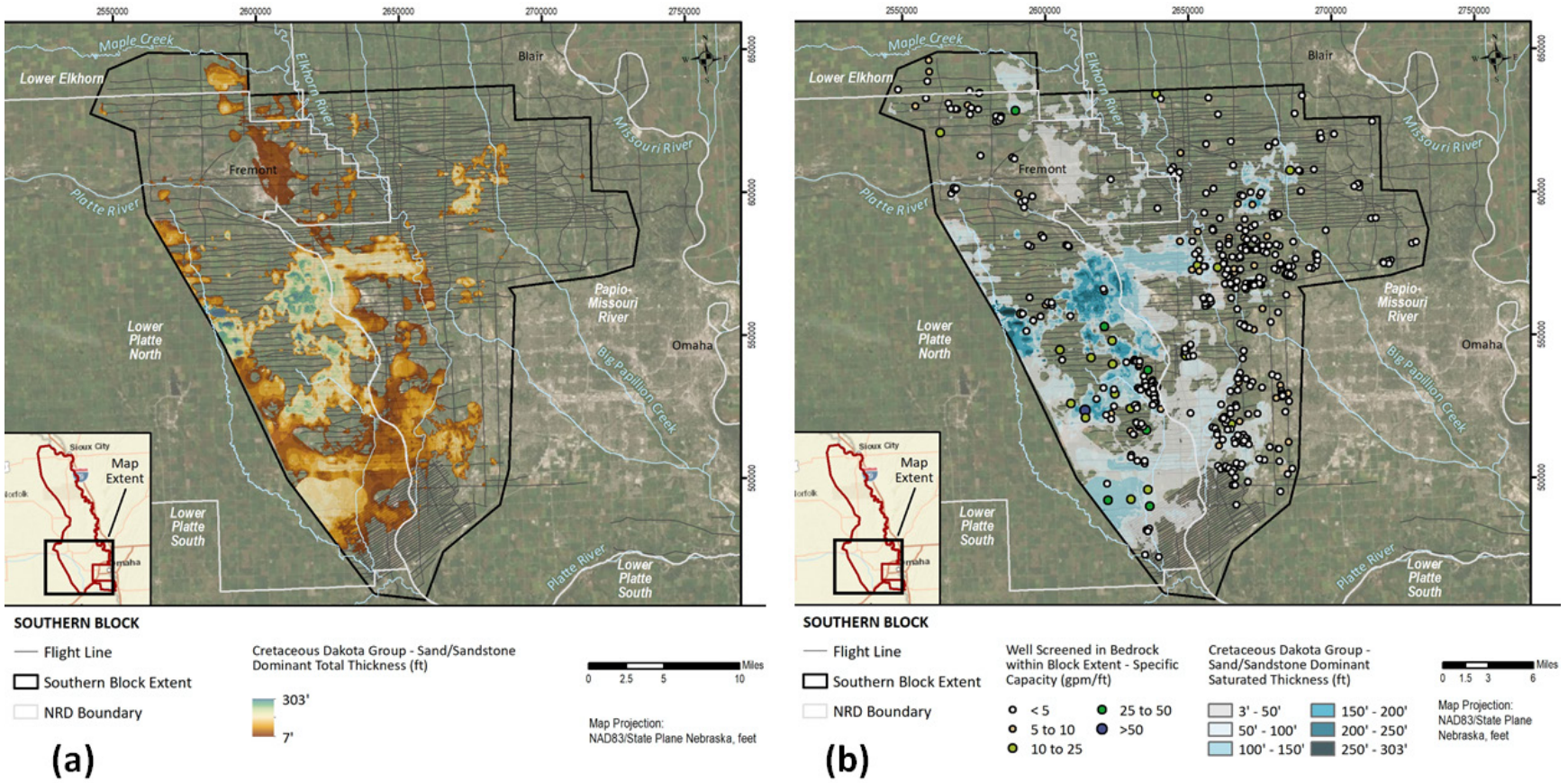


Figure 5-56. a) Cretaceous Dakota Group (*Kd*) Sandstone/Sand Dominant total thickness and b) Sandstone/Sand Dominant saturated thickness (ft) of the Southern Block P-MRNRD also indicating the estimated specific capacity of the NE-DNR wells competed in the *Kd*.

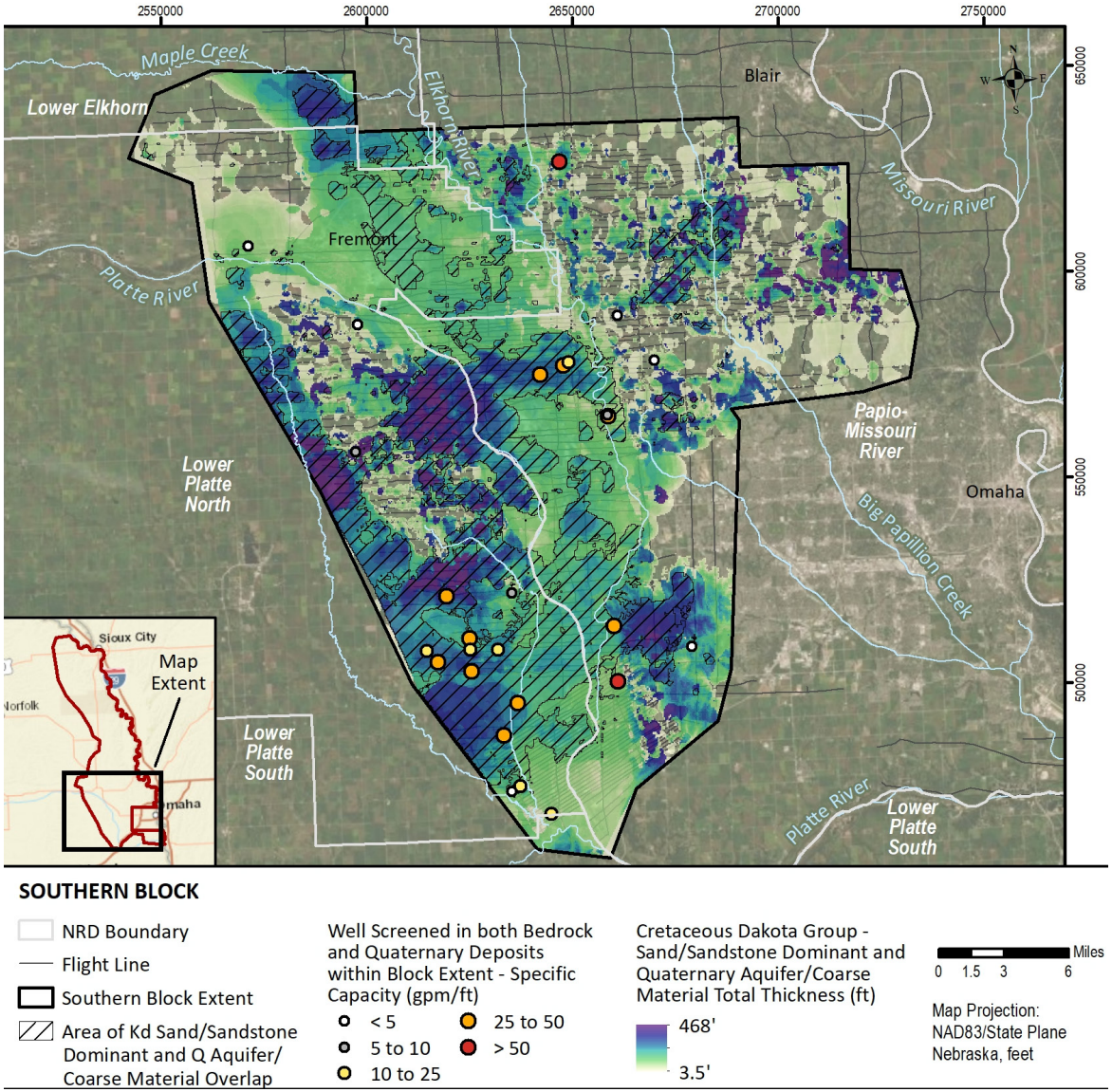


Figure 5-57. Quaternary (Q) Coarse Aquifer material presence (hatched zone) and Cretaceous Dakota Group (*Kd*) Sandstone/Sand Dominant total thickness also indicating the estimated specific capacity of the NE-DNR wells competed in the Q and *Kd*.

5.3.2 Hydrogeologic Framework of the Arlington Block Survey Area

The Arlington Block is a subset within the Southern Block as indicated by Figure 5-41. The Block was delineated to examine the AEM mapping of the paleochannel previously proposed by Korus et al., (2013b). The Block is bound on the west by the bluff of the Elkhorn River and the east by the end of the AEM block flights. The Block extends from the northern end of the Southern Block down to the south encompassing the loess and glacial till of the Rolling Hills that are east of the Elkhorn River within the Southern Block discussed above. The 3D voxel diagram in Figure 5-58 in the area just south and east of Arlington allows for examination in greater detail of the nature and extent of the eastern Platte River floodplain and Elkhorn River channel, the glacial till on its borders, and the area of the paleochannel that's been imaged with the AEM just northeast of the Elkhorn River. The Arlington Block diagram highlights the ***Q*** aquifer and coarse aquifer material on the ***Kd*** bedrock surface contour with a series of bedrock highs. What is first noted is that the aquifer materials within ***Q*** do not form a continuous paleochannel deposit to the east. The areas of marginal and non-aquifer materials are not displayed in Figure 5-58.

Figure 5-59a outlines the CSD interpretation of the paleochannel on the latest saturated ***Q*** aquifer and coarse aquifer material thickness. The adjacent map (Figure 5-59b) is the AGF interpretation of the paleochannel based on the AEM inversions, CSD test holes, and NE-DNR registered wells. As can be seen, the original CSD interpretation is very close to the AGF interpretation. Figure 5-60a combines the ***Kd*** bedrock elevation contours and the saturated ***Q*** aquifer and coarse aquifer material thickness. The ***Kd*** bedrock channel contour is readily apparent on the map, trending from northwest to southeast in the northern Arlington Block. As discussed above, the aquifer and coarse aquifer material do not extend throughout the channel, but are in zones of the channel and not others. This can be seen in the thickness of the non-aquifer and marginal aquifer thickness map (Figure 5-60b) as the thin zones in Figure 5-60a become the thicker zones in Figure 5-60b.

This channel exhibits the characteristics of the Type I Sedimentary Architectural Units as described by Korus et al., (2016). According to Korus et al. (2016), the Type I unit has a highly irregular surface representing a composite disconformity at the base of the overlying ***Q*** till. The basal surface is an approximately 7 miles wide, west-east trending bedrock depression with sides that slope less than 1 degree. The basal surface is incised into the bedrock up to 260 feet. The lower and upper surface gradually converge towards the edges of the bedrock depression. Type I units are locally absent beneath deeply incised basal surfaces of overlying materials. Figure 5-61 is a diagram from Korus et al. (2016). With the insights into the morphology of the channel system the areas absent of the aquifer and coarse aquifer material are better understood.

The extent of the Arlington/Washington County paleochannel is shown in Figure 5-62a of the ***Q*** saturated aquifer and coarse aquifer materials thickness. Using the 2020 AGF interpreted AEM Block information, the interpreted area of the paleochannel has increased with the aid of the additional AEM data. Figure 5-62b details the distribution of NE-DNR registered well specific capacity data for wells screened into the ***Q*** deposits within the Arlington Block. The thick, saturated ***Q*** Aquifer/Course Material

in the northwest paleochannel area correlate uniquely with the distribution of wells having specific capacities in the range of 25 to 50 gallons per minute per foot (gpm/ft).

Figure 5-63 reveals the position of the paleochannel in three separate profiles. AEM Interpretation lines Line L701401, L501100.1, and L702501 all identify the ***Q*** paleochannel appearing oblique to the section, on the ***Kd*** bedrock surface. Line L701401 illustrates the hydraulic connection to the Elkhorn River and adjacent Platte River Valley. In the center profile Line L501100.1 (which is down the axis of the channel) the ***Q*** paleochannel appears to have been eroded and bisected to the ***Kd*** bedrock by later glacial activity and filled with clay rich till. Line L702501 exhibits similar erosion of the ***Q*** paleochannel to the ***Kd*** bedrock and the thick assemblage of the glacial till, forming a hydraulic barrier, eastward toward the Missouri River floodplain.

AEM Interpretation lines L700701 and L700800 offer additional insight into the paleochannels architecture and hydraulic framework at the base of the ***Q*** in this area of the Arlington Block (Figure 5-64 and Figure 5-65). The hydraulic connection from the Elkhorn River to the ***Q*** the paleochannel is notable on profile lines L700701 and L700800.

The Arlington Block area, ***Q*** specific capacity is summarized in the 3D in Figure 5-66. The figure shows the variation in NE-DNR registered wells specific capacity across the Arlington Block survey, with the areas of aquifer material holding the bulk of the wells over 5 gpm/ft.

As discussed previously the Cretaceous Dakota Group (***Kd***) exists over much of the P-MRNRD Southern Block of which the Arlington Block is a sub-block. The eastern end of the Arlington block has ***Kd*** eroded off. Also, as discussed earlier the ***Kd*** was divided into three material or lithology classifications (Section 5.2.6). Within the Arlington Block there is a distinct pattern to the distribution of the ***Kd*** material types. The lithology classification at the surface of the ***Kd*** within the Arlington Block is shown in Figure 5-67. There is much less Sandstone/Sand Dominant material within the Arlington Block being composed mostly of the Siltstone/Silt materials.

The Cretaceous ***Kd*** aquifer material extent is illustrated in the 3D Arlington voxel, Figure 5-68 which shows the distribution and coverage of ***Kd*** Sandstone/Sand Dominant materials as an opaque voxel. The Shale/Clay and Siltstone/Silt Dominant materials are transparent. Additional information on the range of ***Kd*** aquifer wells and their associated specific capacities is provided in Figure 5-69. While a couple of the better wells are within the Sandstone/Sand Dominant materials, much of the wells are in the area that would fall within the Siltstone/Silt Dominant. The Specific Capacities are low, typically less than 5 gpm/ft as would be expected for ***Kd*** wells.

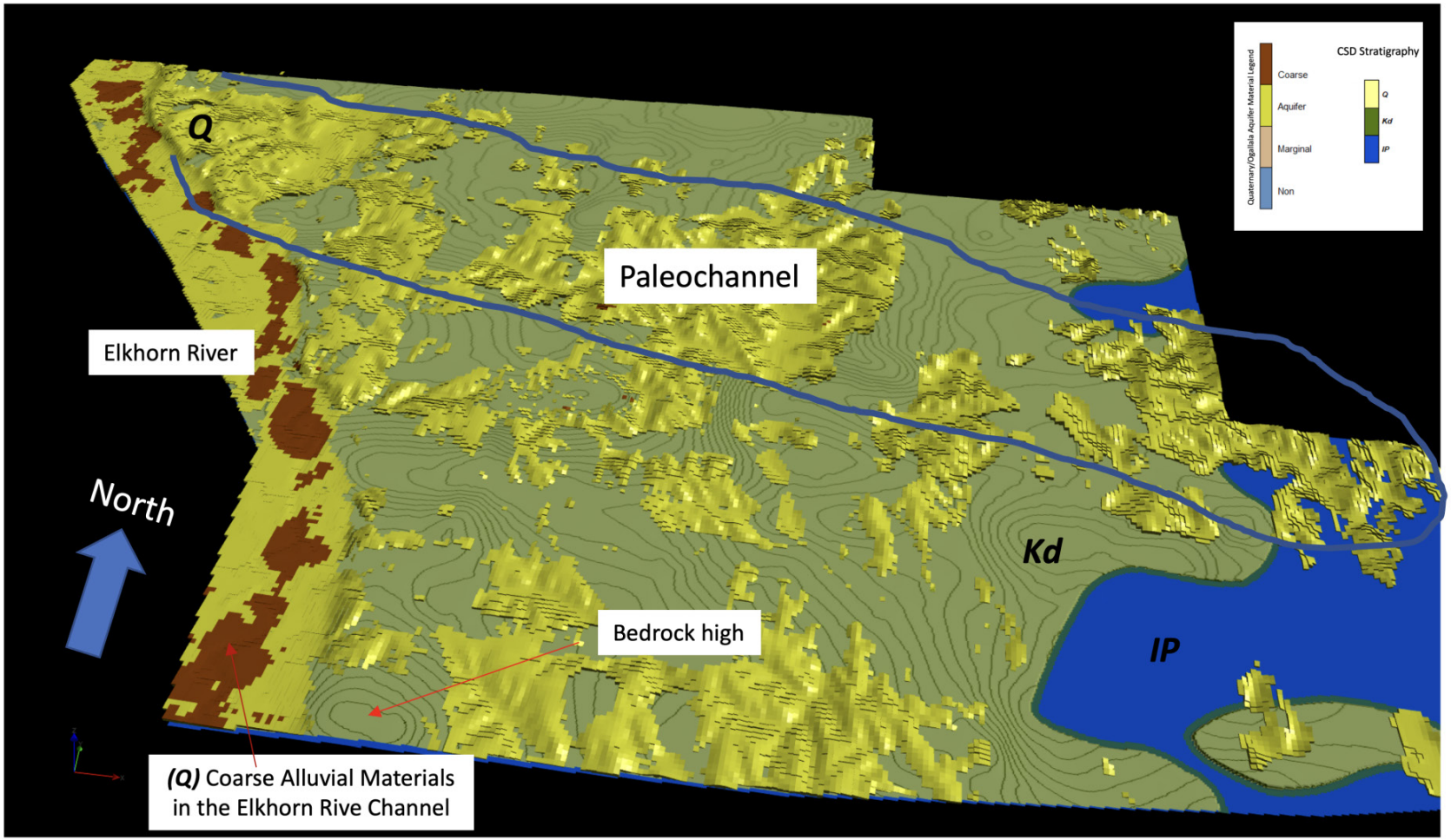


Figure 5-58. P-MRNRD Arlington Block 3D voxel plot looking toward the northeast from the south. *(Q)* Quaternary aquifer and coarse aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) surface is shown as a green contour surface. The undifferentiated Pennsylvanian (*IP*) surface is indicated by the blue. The AGF estimated Arlington/Washington County paleochannel location is shown by a blue line. Vertical Exaggeration (VE) = 5x.

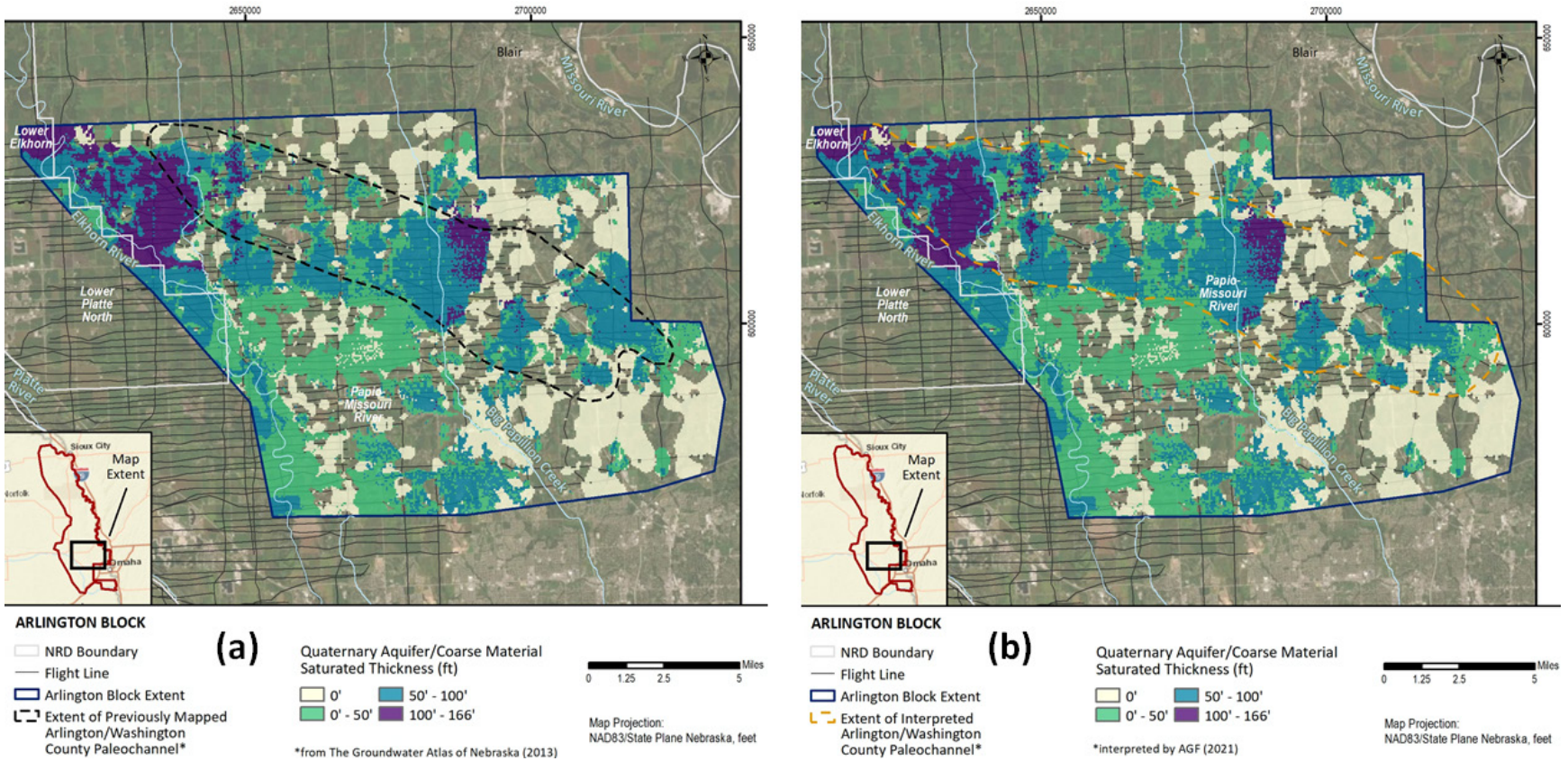


Figure 5-59. Quaternary (*Q*) saturated aquifer and coarse aquifer material thickness a) CSD paleochannel position (Korus et al., 2013b), and b) AGF revised interpretation of the paleochannel.

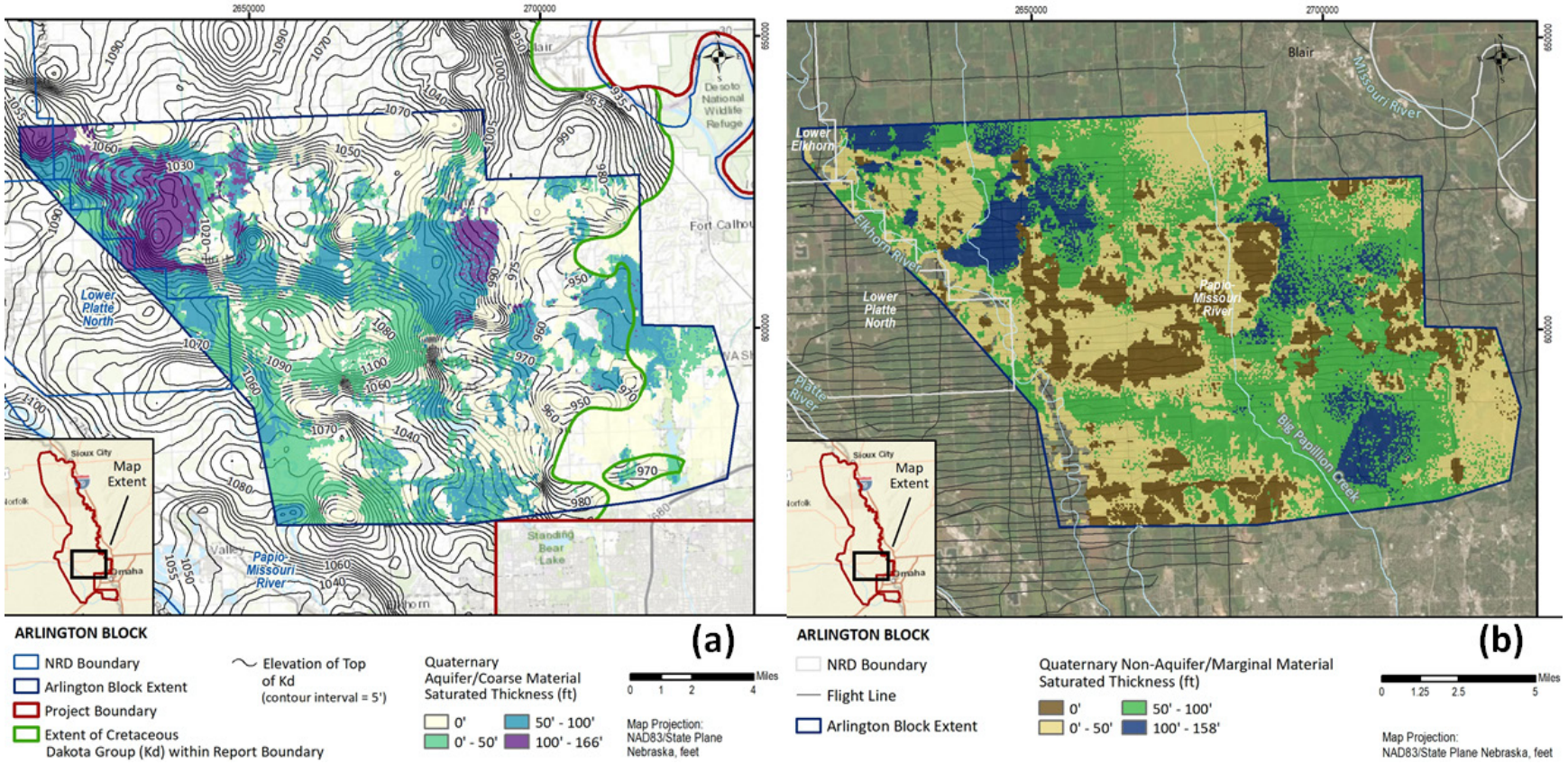


Figure 5-60. a) Quaternary (*Q*) saturated aquifer and coarse aquifer material thickness on a contour map of top surface of the Cretaceous Dakota Group (*Kd*) and b) Quaternary (Q) saturated marginal and non-aquifer material thickness.

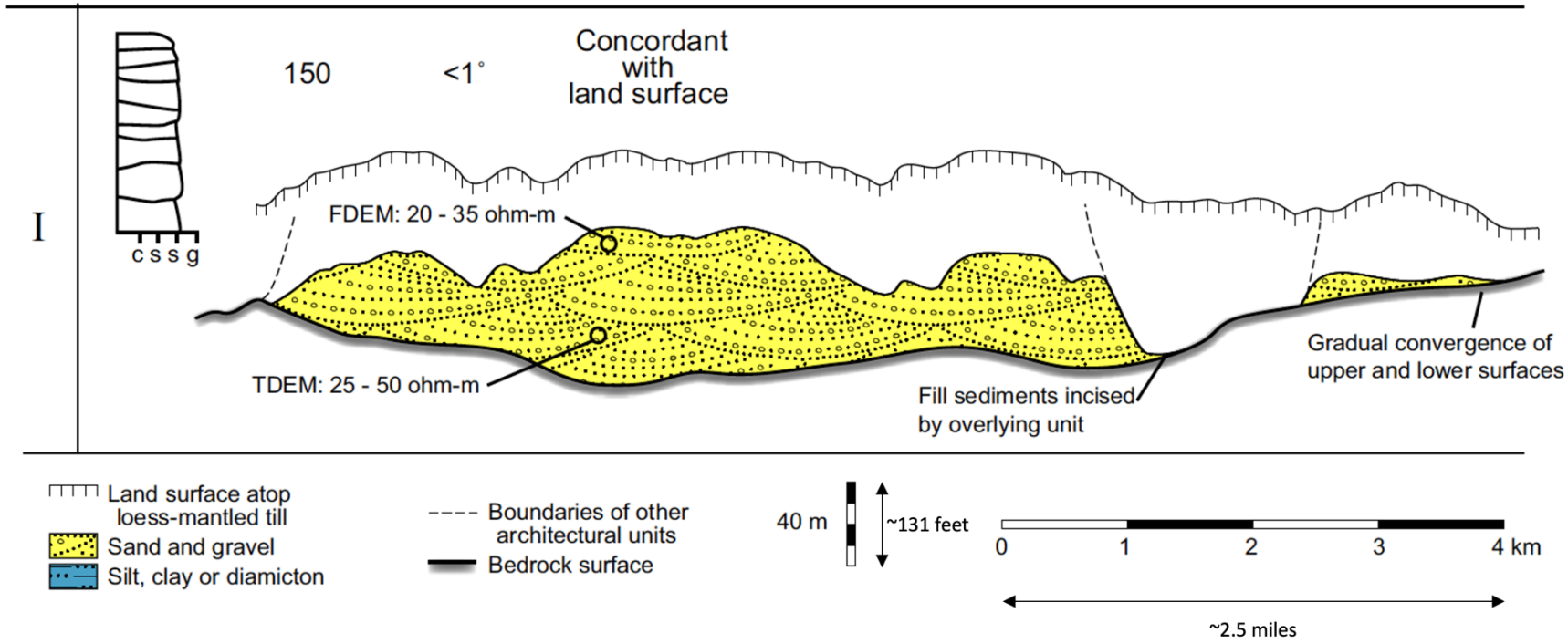


Figure 5-61. Diagram of the principle sedimentary and geophysical characteristics of the architectural unit Type I (modified from Korus et al., 2016).

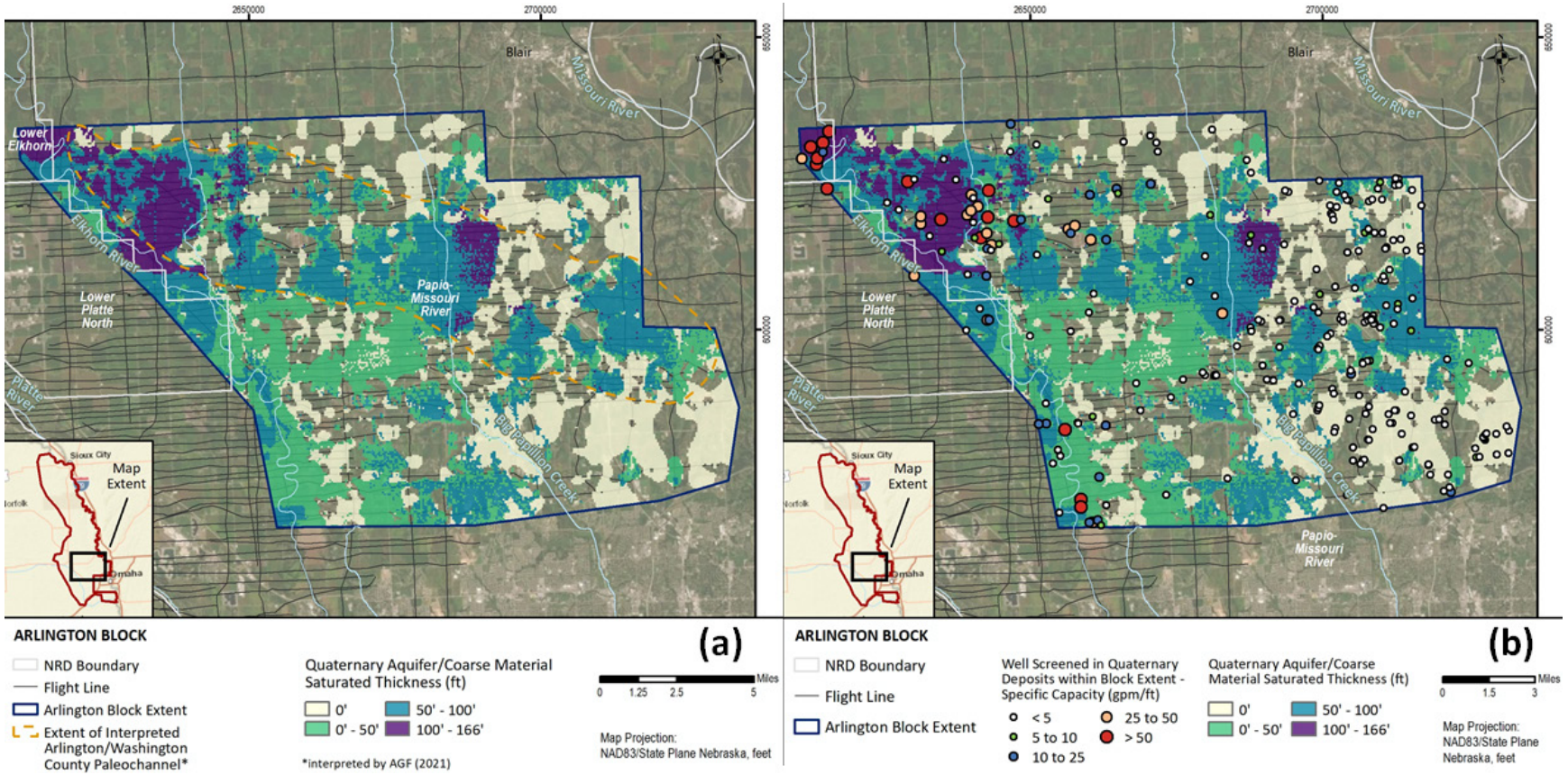


Figure 5-62. Quaternary (*Q*) saturated aquifer and coarse aquifer material thickness a) AGF interpretation of paleochannel position indicated and b) NE-DNR registered wells specific capacity of wells within the *Q*.

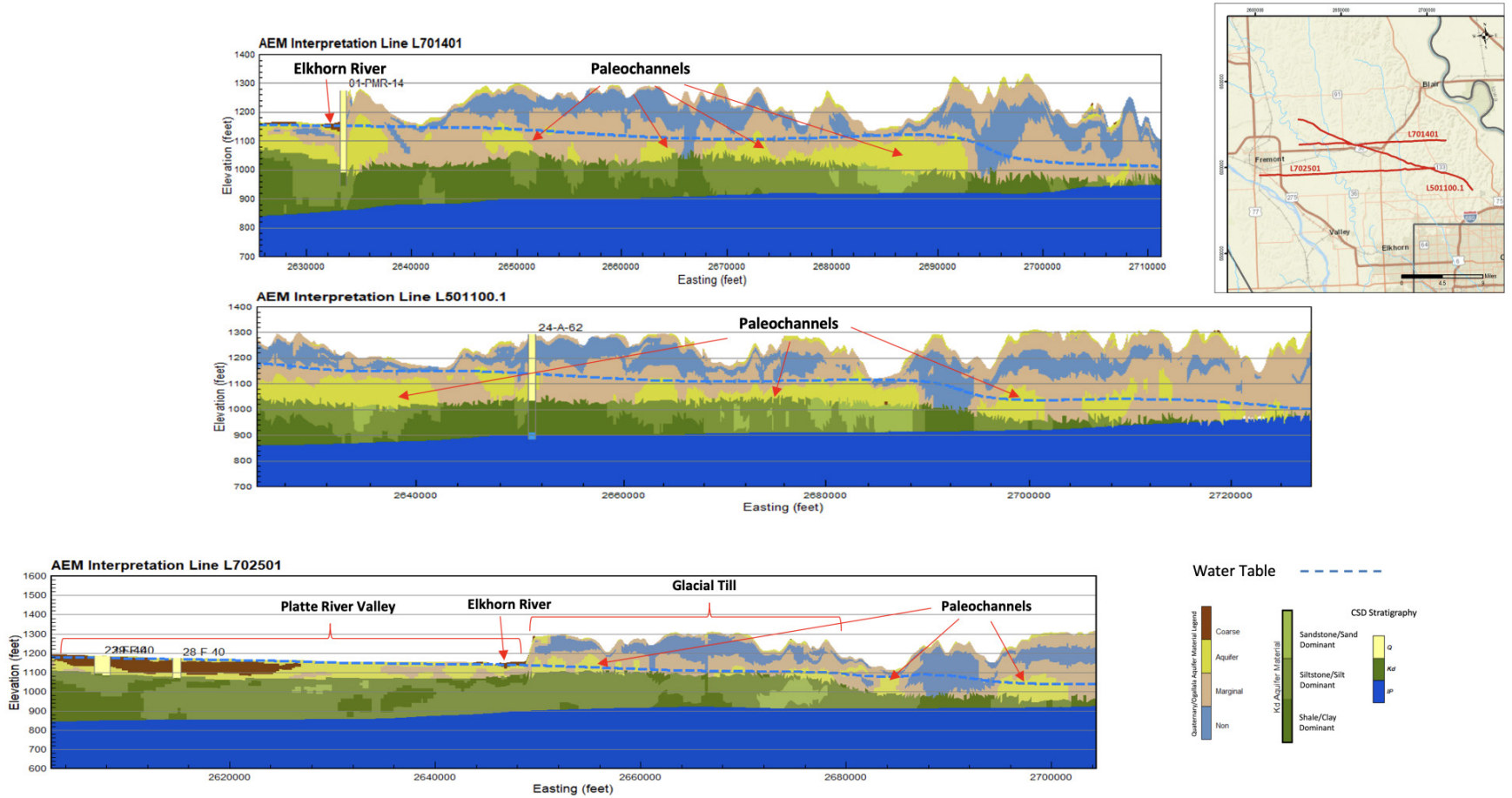


Figure 5-63. AEM interpretation of east-west line 701401, 702501 and southeast-northwest line 501100.1 profiles within the Arlington Block of the P-MRNRD survey area. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group and, *IP* = Undifferentiated Pennsylvanian. The inset map indicates the location of the flight lines within the Arlington Block along the Elkhorn River.

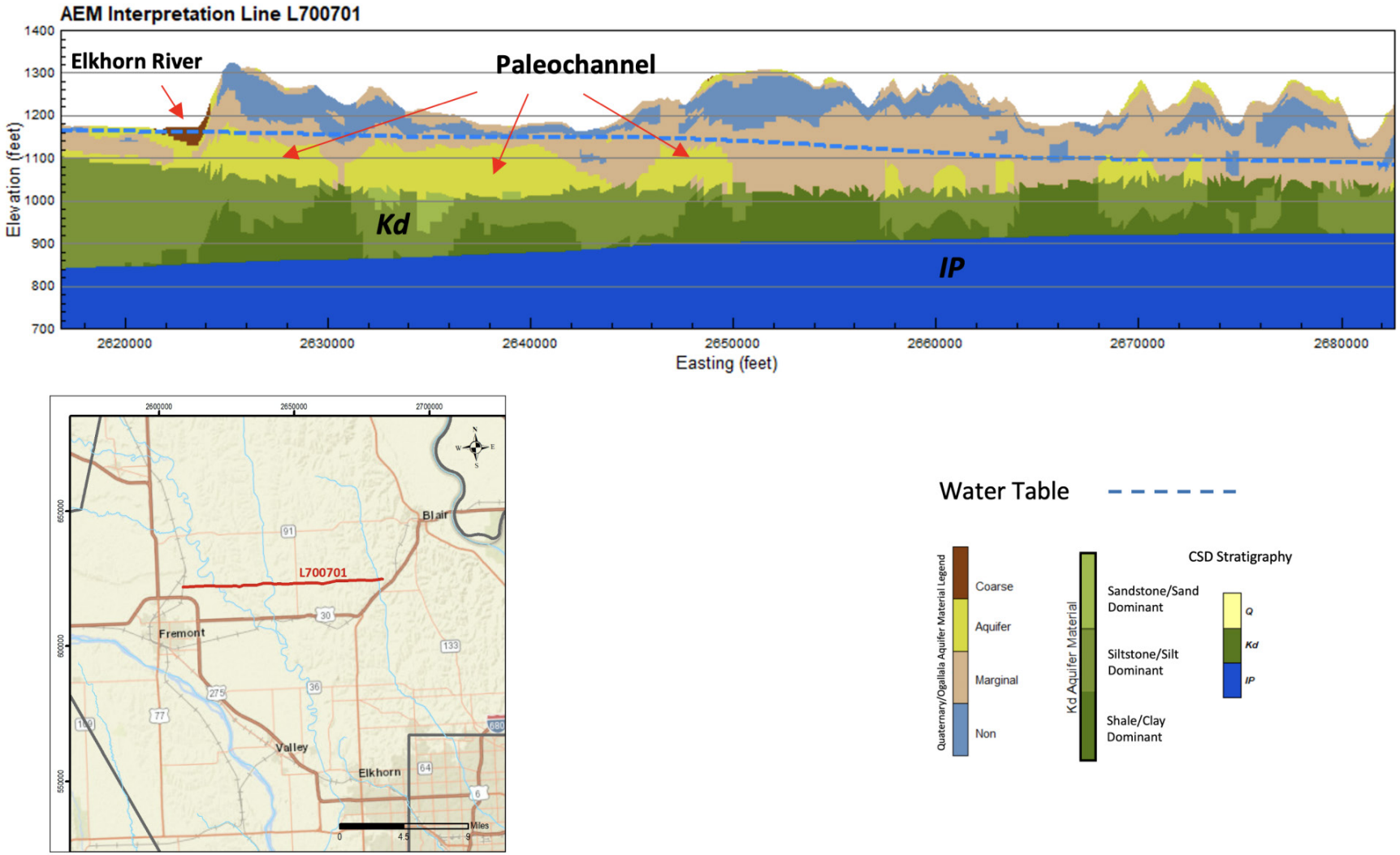


Figure 5-64. AEM interpretation of east-west line 700701 profile within the Arlington Block of the P-MRNRD survey area. The relationship of the Elkhorn River can be seen with the Arlington/Washington County Paleochannel. CSD test wells within ½ mile of the flight lines are project on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group and, *IP* = Undifferentiated Pennsylvanian. The inset map indicates the location of the flight lines within the Arlington Block along the Elkhorn River.

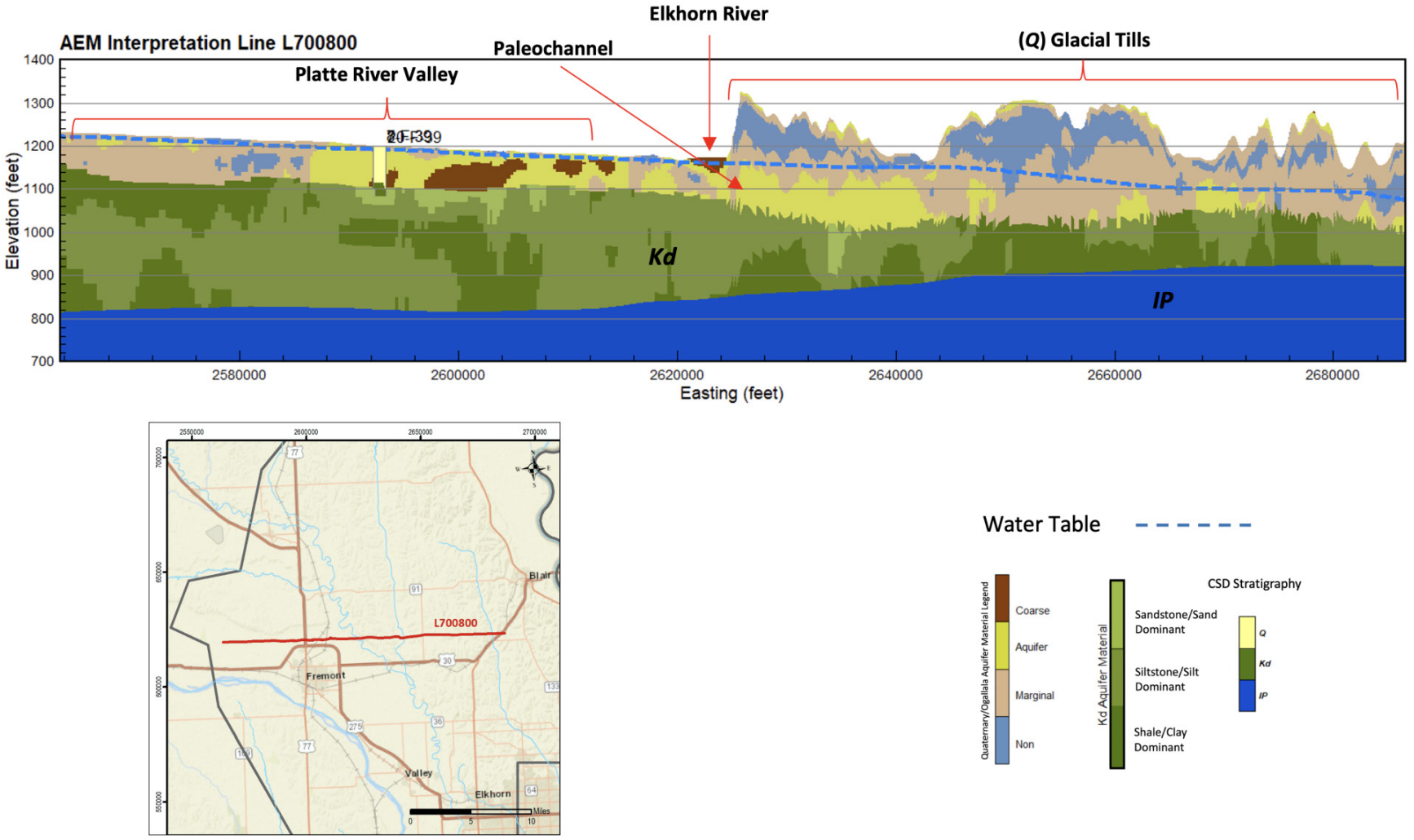


Figure 5-65. AEM interpretation of east-west line 700800 profile within the Arlington Block of the P-MRNRD survey area. The relationship of the Elkhorn River can be seen with the Arlington/Washington County Paleochannel. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy *Q*=Quaternary, *Kd*= Cretaceous Dakota Group and, *IP* = Undifferentiated Pennsylvanian. The inset map indicates the location of the flight lines within the Arlington Block along the Elkhorn River.

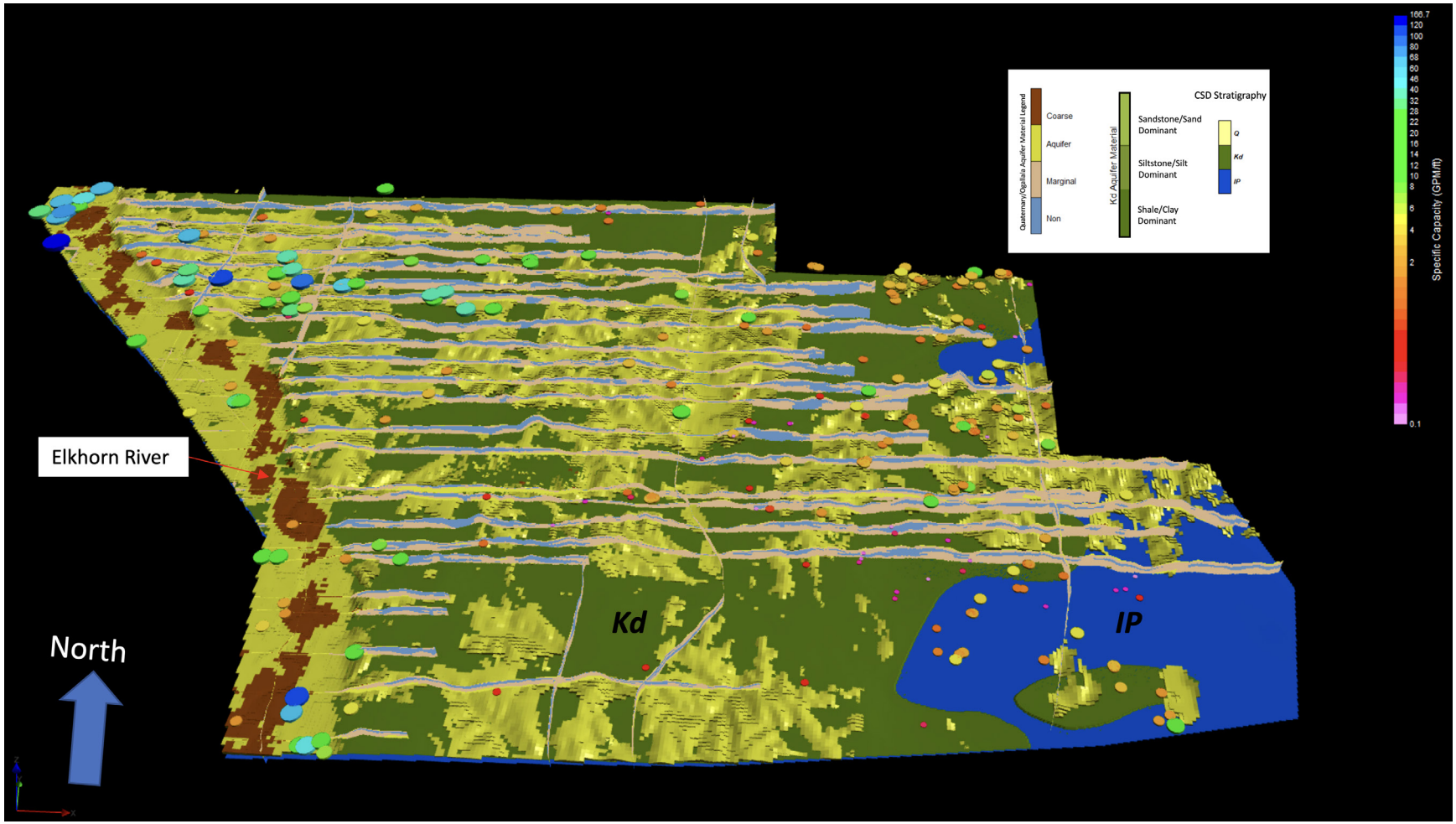


Figure 5-66. P-MRNRD Arlington Block 3D voxel plot looking north from the south. *(Q)* Quaternary aquifer and coarse aquifer materials colors are as indicated on the legend. Every third AEM profile is displayed as a 3D fence. The Cretaceous Dakota Group (*Kd*) surface is shown as a green contour surface. The undifferentiated Pennsylvanian (*IP*) surface is indicated by the blue. The NE-DNR registered wells specific capacity is shown as the point-size plot as indicated in the legend. Low specific capacity are pink-red and are the smallest points. Vertical Exaggeration (VE) = 5x.

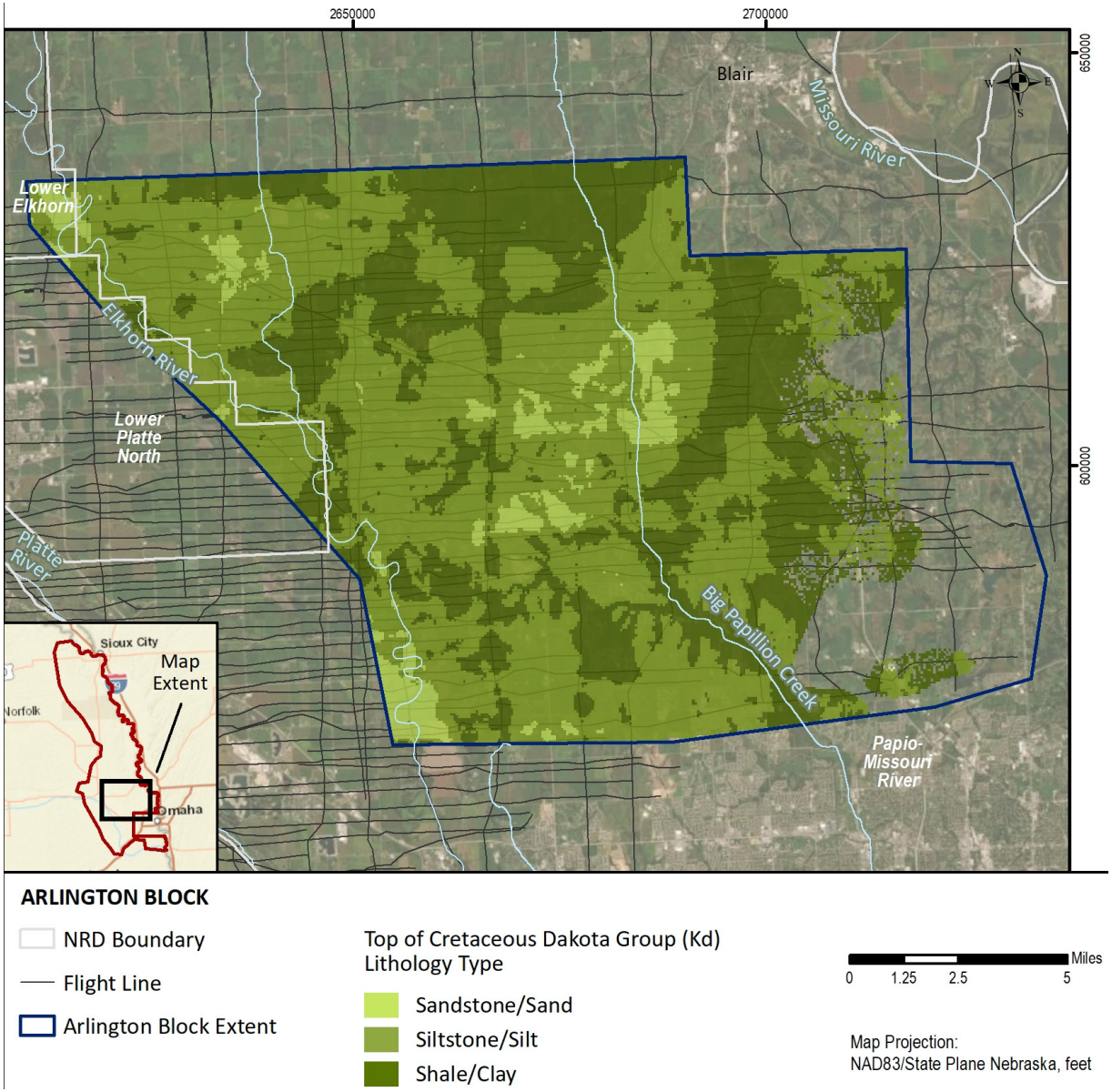


Figure 5-67. Top or surface layer of the Cretaceous Dakota Group (*Kd*) material or lithology classification for the P-MRNRD Arlington Block.

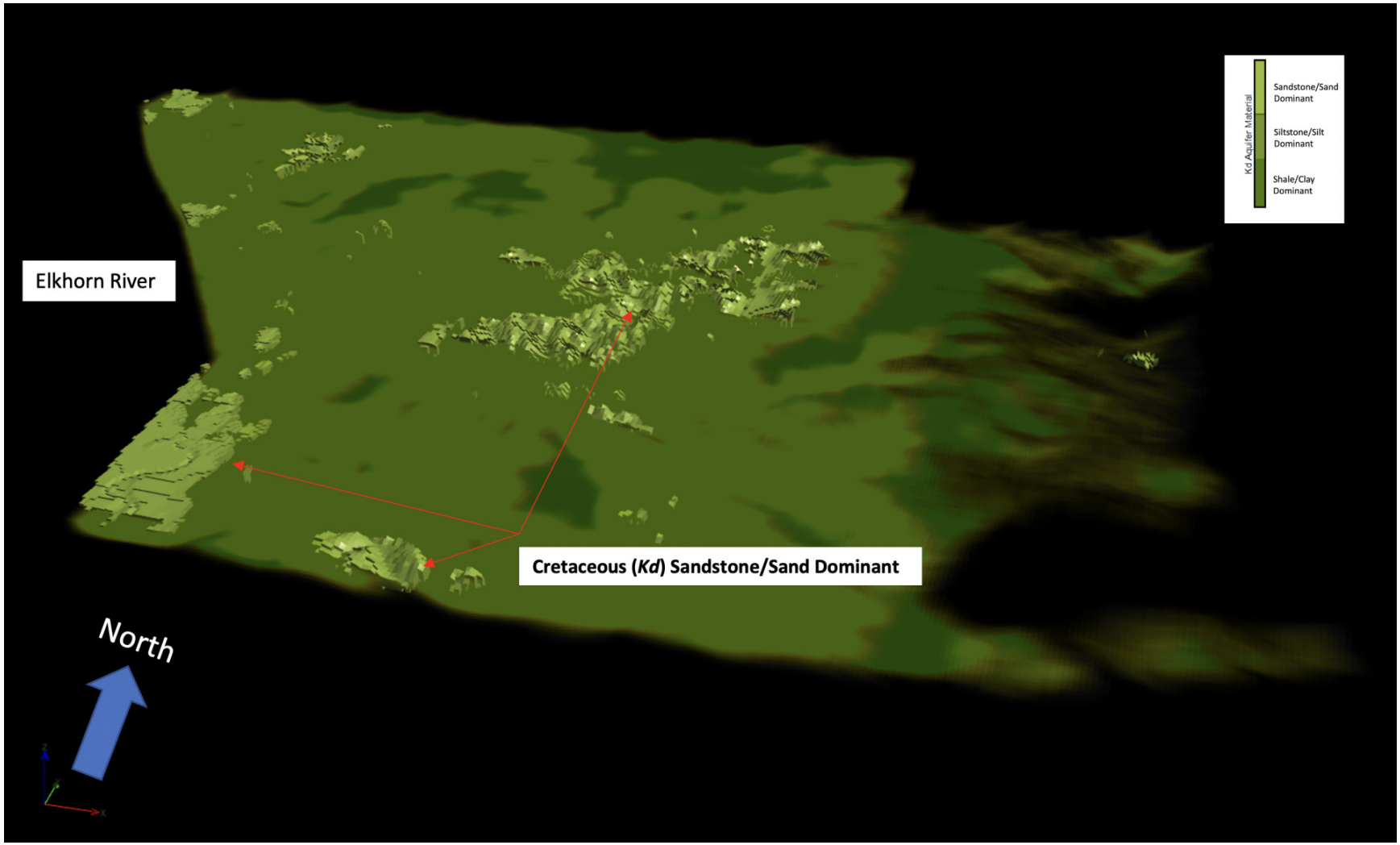


Figure 5-68. P-MRNRD Arlington Block 3D voxel plot looking toward the north/northwest from the south. The Cretaceous Dakota Group (*Kd*) is shown. The Sandstone/Sand Dominant voxel is opaque while the Siltstone/Silt and Shale/Clay Dominant material surface is shown transparent. The majority of the Arlington Block is composed of Siltstone/Silt Dominant materials. Vertical Exaggeration (VE) = 10x.

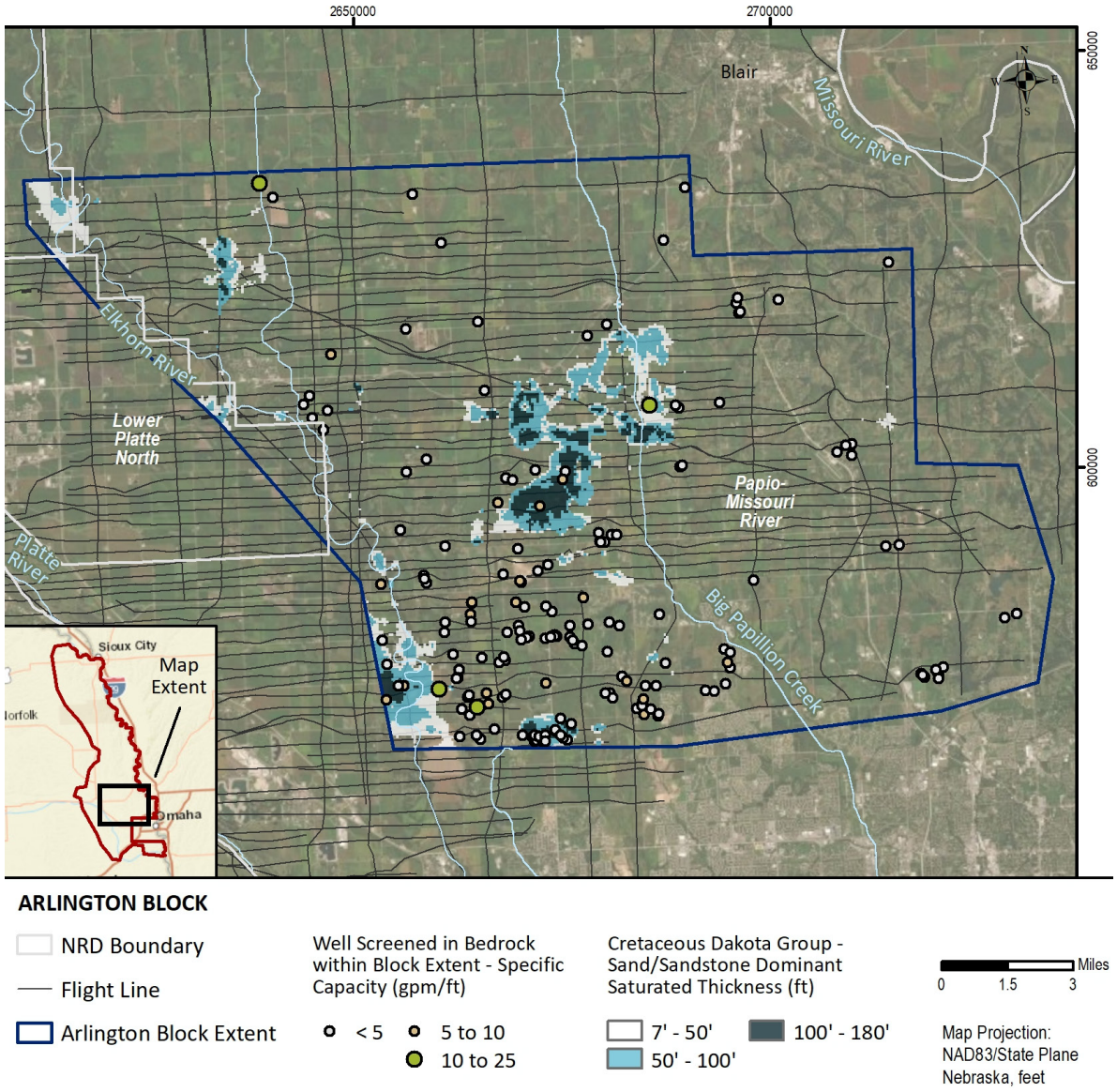


Figure 5-69. The Cretaceous Dakota Group (*Kd*) Sandstone/Sand Dominant saturated thickness is shown with the NE-DNR registered wells completed within the *Kd* specific capacity.

5.3.3 Hydrogeologic Framework of the Tekamah Block Survey Area

The 2020 AEM survey provided additional insight into the geographic distribution and extent of the unconsolidated and consolidated material identified in the 2018 Tekamah Block AEM survey area (AGF, 2019). Based on work conducted by Leonard Rice Engineers, Inc. (LRE) on the delineation of a wellhead protection area for the City of Tekamah, a "Composite Capture Zone" was identified west of the City and west of the previous AEM data collection (LRE, 2019). P-MRNRD used this information to help plan the 2020 AEM data acquisition to cover the Composite Capture Zone as defined by (LRE, 2019).

The ***Q*** material in the Tekamah Block (Figure 5-41) is identified through interpretation of the AEM data as non-aquifer, marginal aquifer, aquifer material, and coarse aquifer material. These ***Q*** deposits overlie the unconsolidated and consolidated ***Kd*** bedrock which is divided into Sandstone/Sand Dominant, Siltstone/Silt Dominant, and Shale/Clay Dominant units. Both the ***Q*** and the ***Kd*** units are portrayed in the P-MRNRD 3D fence diagram center on the Tekamah Block (Figure 5-70). The 3D fence diagram displays the Tekamah Block as well as the reconnaissance flight lines and the interpreted hydrostratigraphic profiles looking to the northwest. Generally, the 2020 flight is compiled with the previous 2018 AEM survey, with the northern and southern portions of the AEM survey area being a similar mix of ***Q*** aquifer materials and the ***Kd***. As with the 2018 AEM survey, there are no flight lines directly within the town of Tekamah due to FAA restrictions. The boreholes in the area indicate silty clay and sandy clay in much of the area with only thin layers of sand and sand and gravel in the basal areas above the ***Kd*** bedrock (LRE, 2019; AGF, 2019). In the southern and northern portions, the material is made up of mostly marginal aquifer material except for isolated bodies of coarse aquifer, aquifer, and non-aquifer materials at near surface elevations and lying on the bedrock.

The saturated thickness of the ***Q*** aquifer coarse/material and saturated thickness of the ***Q*** non-aquifer marginal materials extents are shown in Figure 5-71a. The greatest thickness of the saturated ***Q*** aquifer/coarse material is on the high ground north and south of Tekamah Creek and varies in thickness, from 0 to 56 feet. The saturated thickness of the ***Q*** non-aquifer and marginal material map reveal that this unit varies in thickness from 0 to 56 feet in the west and northwestern portion of the Tekamah Block (Figure 5-71b). There is a lack of ***Q*** wells in the western two thirds of the survey area, as the mapping confirms the lack of productive aquifer material (Figure 5-72).

The ***Kd*** has a hydrologic connection to the Missouri River ***Q*** alluvium to the east of the flight block. Figure 5-73 shows this hydrologic relationship along profile L908005. East-west Line L908005 is located just north of the town of Tekamah and the Tekamah Block AEM survey area and west of the Missouri River. The profile shows good hydrologic connection between the Cretaceous Dakota Group (***Kd***) and the Missouri River Quaternary deposits. Interpretation of undifferentiated Pennsylvanian (***IP***) is indicated by the blue area. The CSD 1995 water table is indicated with a dashed blue line. The confining layer of silt and clay (LRE, 2019) is clearly identified over the ***Q*** sands that overlie the ***Kd*** out in the Missouri River flood plain. Much of the ***Q*** deposits on the bluffs are unsaturated. The ***Kd*** is composed predominantly of Siltstone/Silt Dominant material with only a small amount of the Sandstone/Sand Dominant material indicated on this profile.

The surface layer or the top of the ***Kd*** is also revealing as only a small area on the eastern end of the Tekamah Block has Sandstone/Sand Dominant material at the surface (Figure 5-74).

Figure 5-75 is a 3D fence and voxel Tekamah Block diagram illustrating the distribution and extent of ***Kd*** Sandstone/Sand Dominant aquifer material on the undifferentiated Pennsylvanian ***IP*** bedrock basement surface. The 3D fence diagram shows that to the west of the Sandstone/Sand Dominant materials with the flight lines indicated by the fences showing the non-aquifer and marginal aquifer materials in the ***Q*** and Siltstone/Silt and Shale/Clay Dominant materials in the ***Kd***. Adding the NE-DNR registered wells to Figure 5-75 produces Figure 5-76. The area on the eastern side of the Block displays good correlation with the wells indicating sandstone as was seen in the 2018 dataset (AGF, 2019). Looking at the area added in 2020 west of the original flight block, we see very few wells with many of them only indicating shale and small amounts of sandstone and siltstone.

The thickness of the ***Kd*** Sandstone/Sand Dominant material in the Tekamah Block area varies from 8 to 231 feet. The thickest sections are on the eastern end of the flight block (Figure 5-77a). Also, indicated on this figure is the specific capacity of wells completed in the ***Kd.*** The saturated thickness of the ***Kd*** Sandstone/Sand Dominant material in the Tekamah Block varies from 0 to 197 feet (Figure 5-77b). Figure 5-77b also shows the Composite Capture Zone as draw by LRE (2019). The AEM survey indicates only a few small pods of Sandstone/Sand Dominant material west of the main Sandstone body in the ***Kd***.

The Tekamah Block AEM flight area has very little **Q** aquifer and coarse aquifer material. The main aquifer material type in the Tekamah Block is ***Kd*** Sandstone/Sand Dominant material. While these materials will produce water, the yields and specific capacity will be reduced. The western areas of the Composite Capture Zone contain very little aquifer materials in both the ***Q*** and ***Kd***.

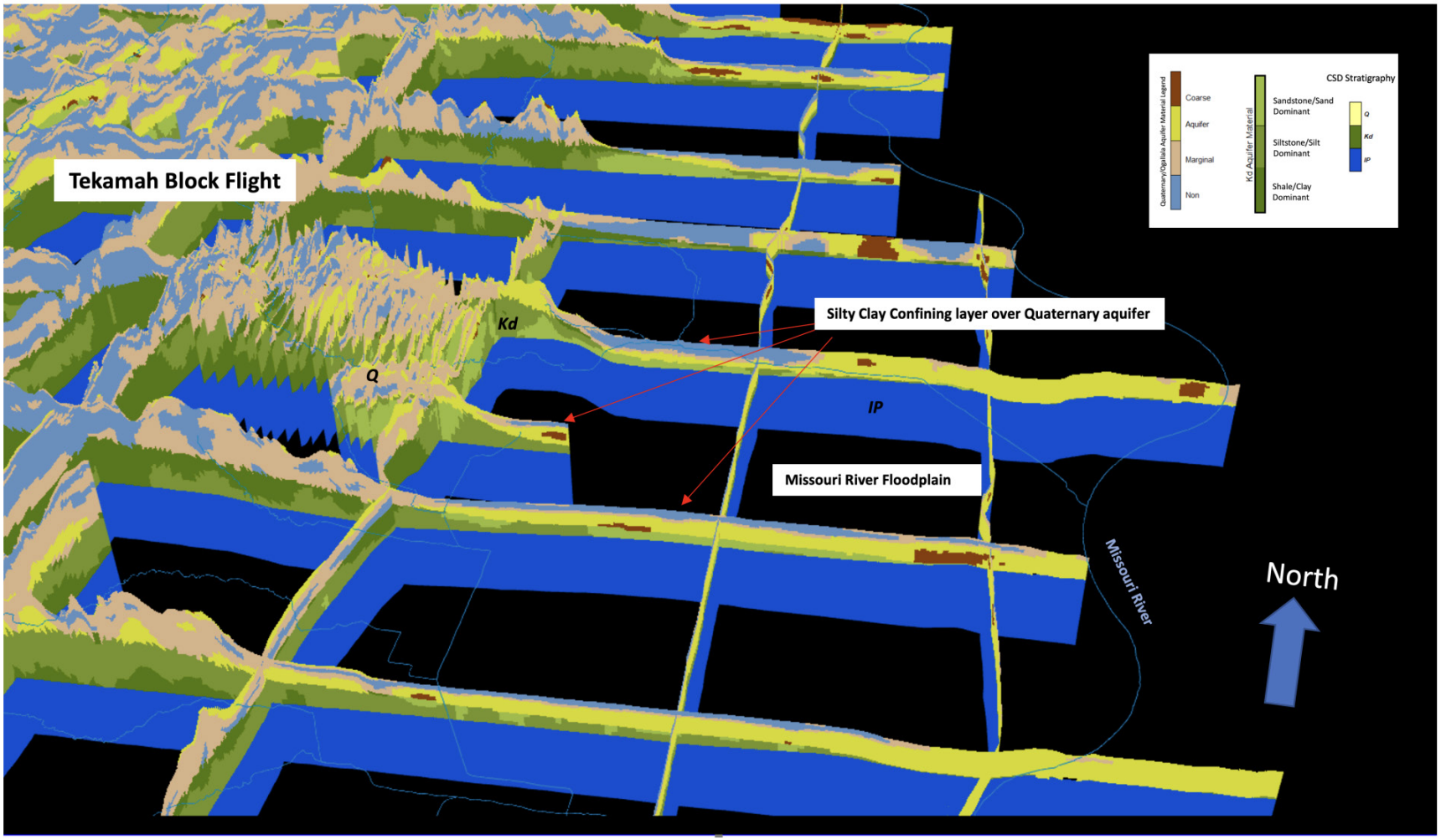


Figure 5-70. 3D Fence Diagram centered on the Tekamah area showing the Tekamah Block and the reconnaissance lines looking to the northwest. *(Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials are indicated on the legend and are also represented as a surface under the *Q*. The undifferentiated Pennsylvanian (*IP*) is also indicated on the fence diagrams. The thin blue lines are the major streams in the area. Vertical exaggeration (VE) = 20x.

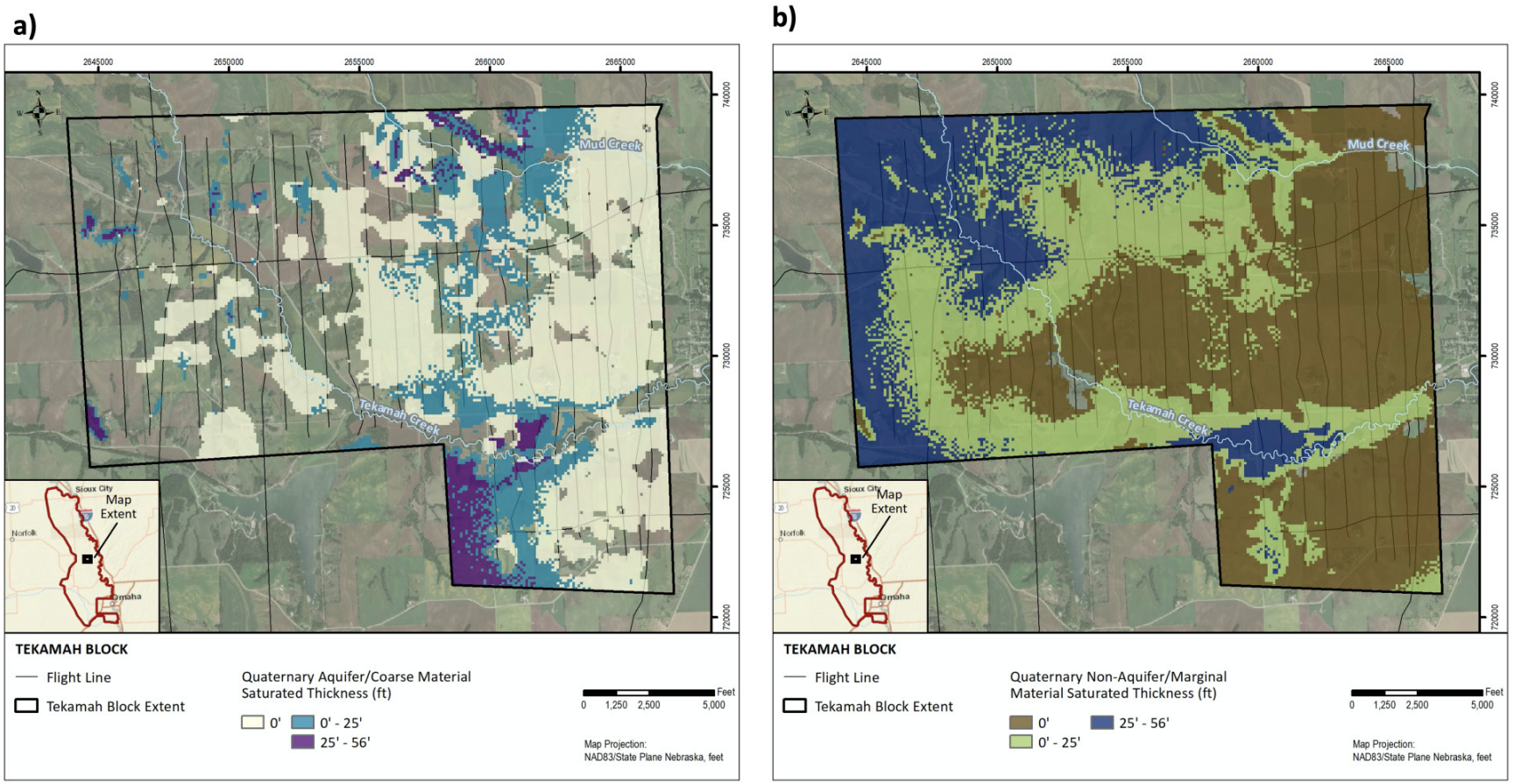


Figure 5-71. Map of the Quaternary (*Q*) aquifer and coarse aquifer material saturated thickness (a) and map of the *Q* non-aquifer and marginal aquifer material saturated thickness (b).

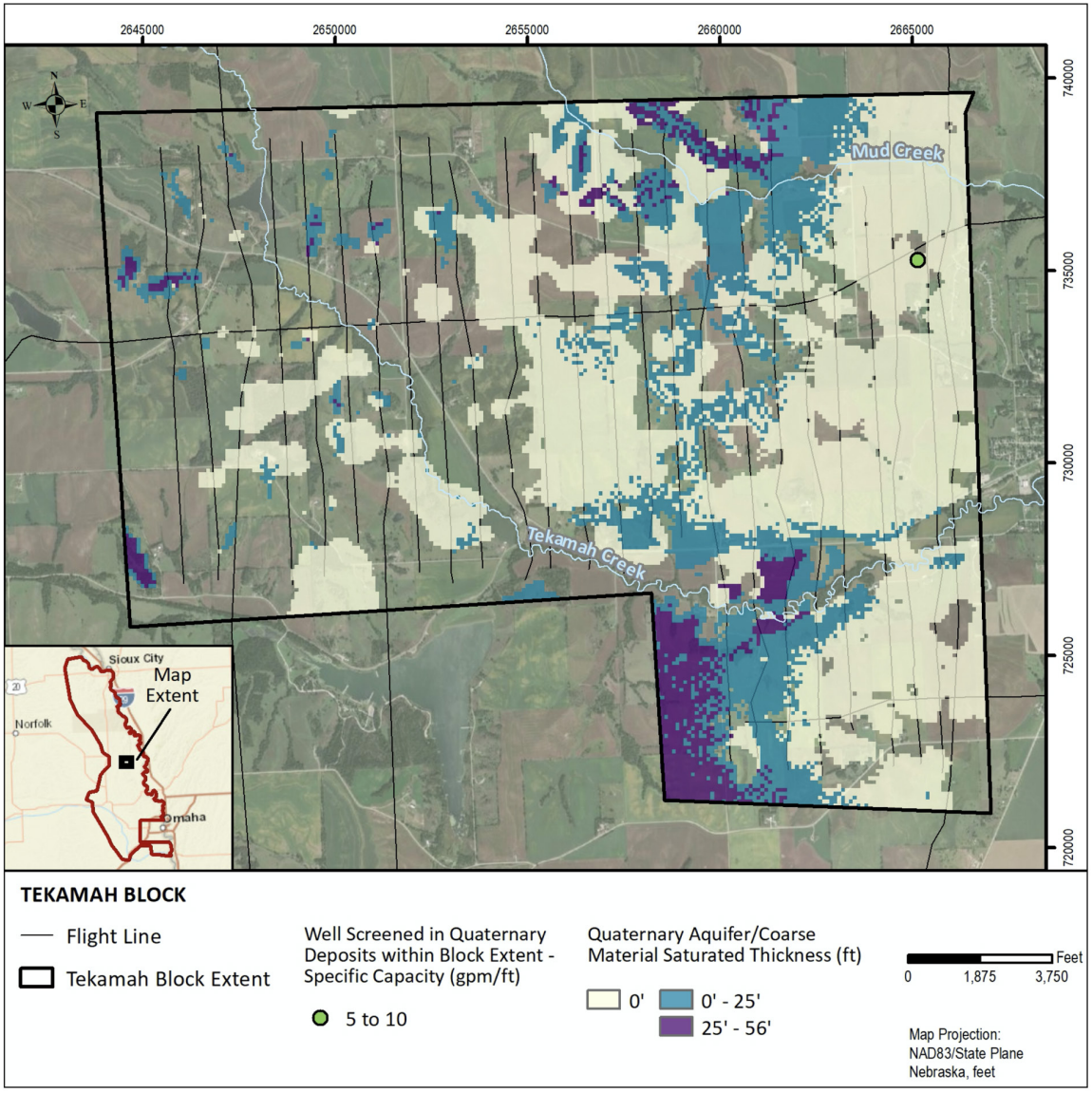


Figure 5-72. Map of the Quaternary aquifer and coarse aquifer material saturated thickness with only one NE-DNR well that has a specific yield from within the *Q*.

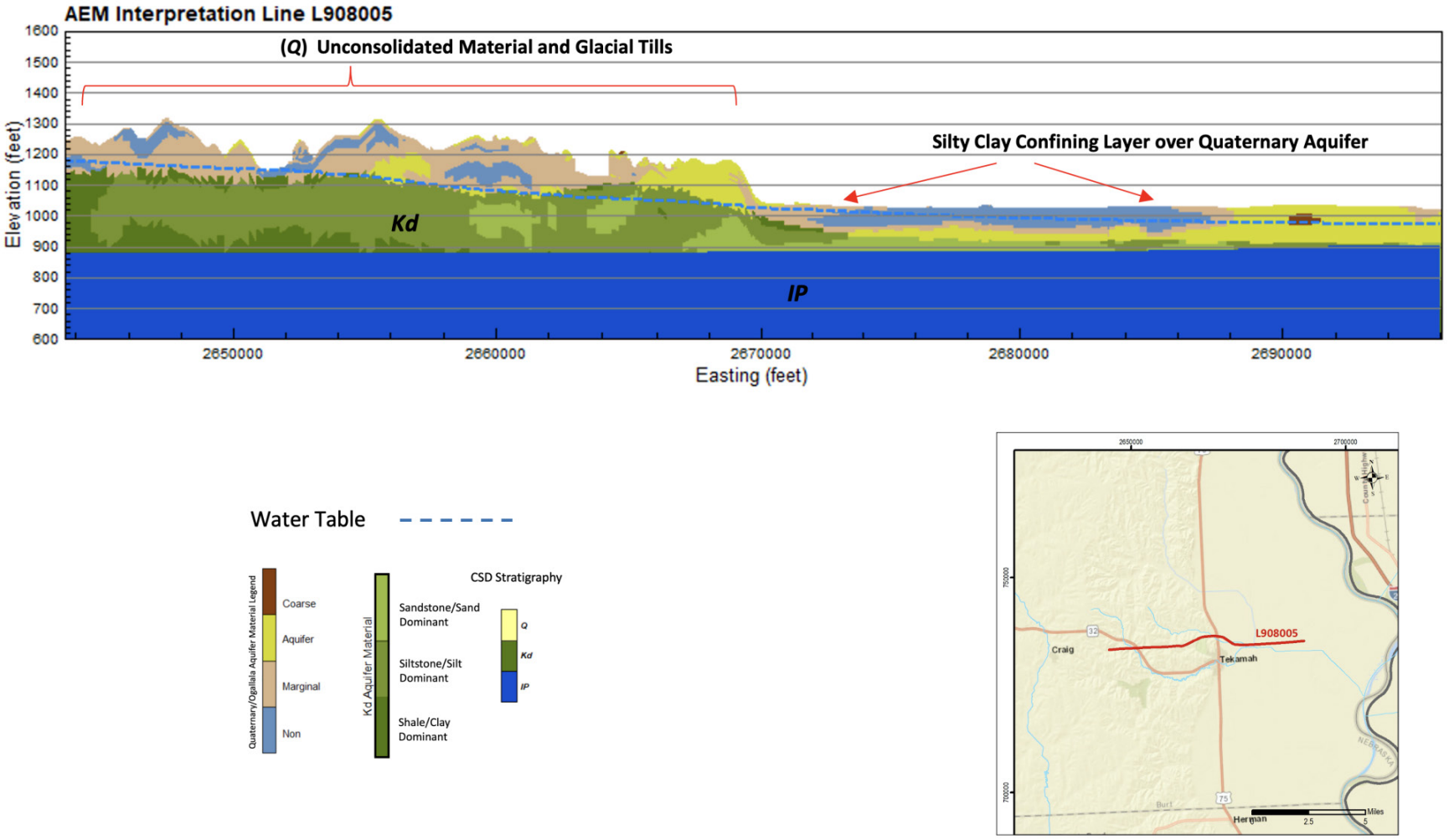


Figure 5-73. AEM interpretation profile of Line L908005 within the Tekamah Block of the P-MRNRD survey area. The line crosses from the Rolling Hills dominated with loess and till to the Missouri River flood plain. *(Q)* Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials are indicated on the legend and are also represented as a surface under the *Q*. The undifferentiated Pennsylvanian (*IP*) is indicated by the blue color.

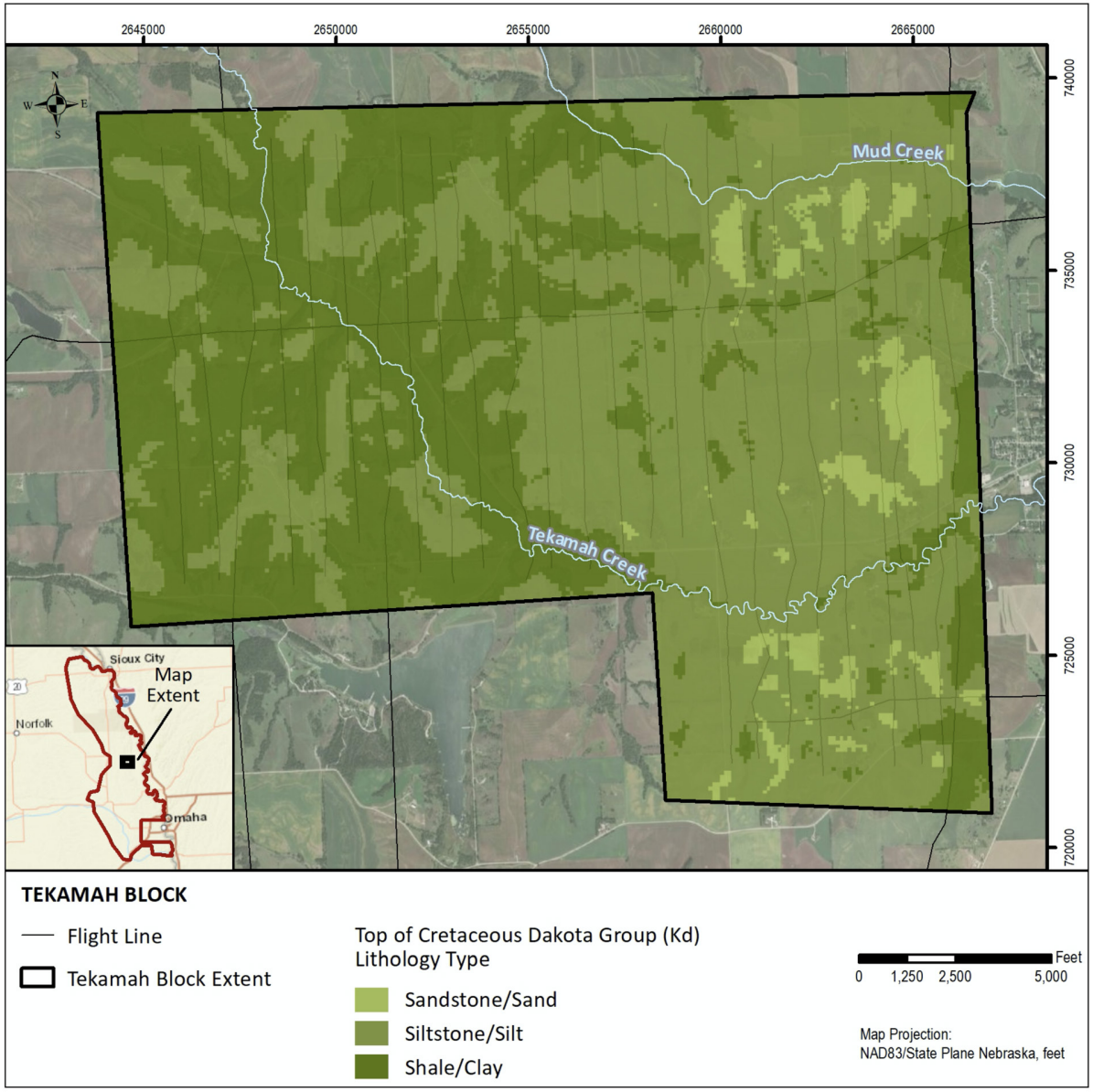


Figure 5-74. Top or surface layer of the Cretaceous Dakota Group (*Kd*) material or lithology classification for the P-MRNRD Tekamah Block.

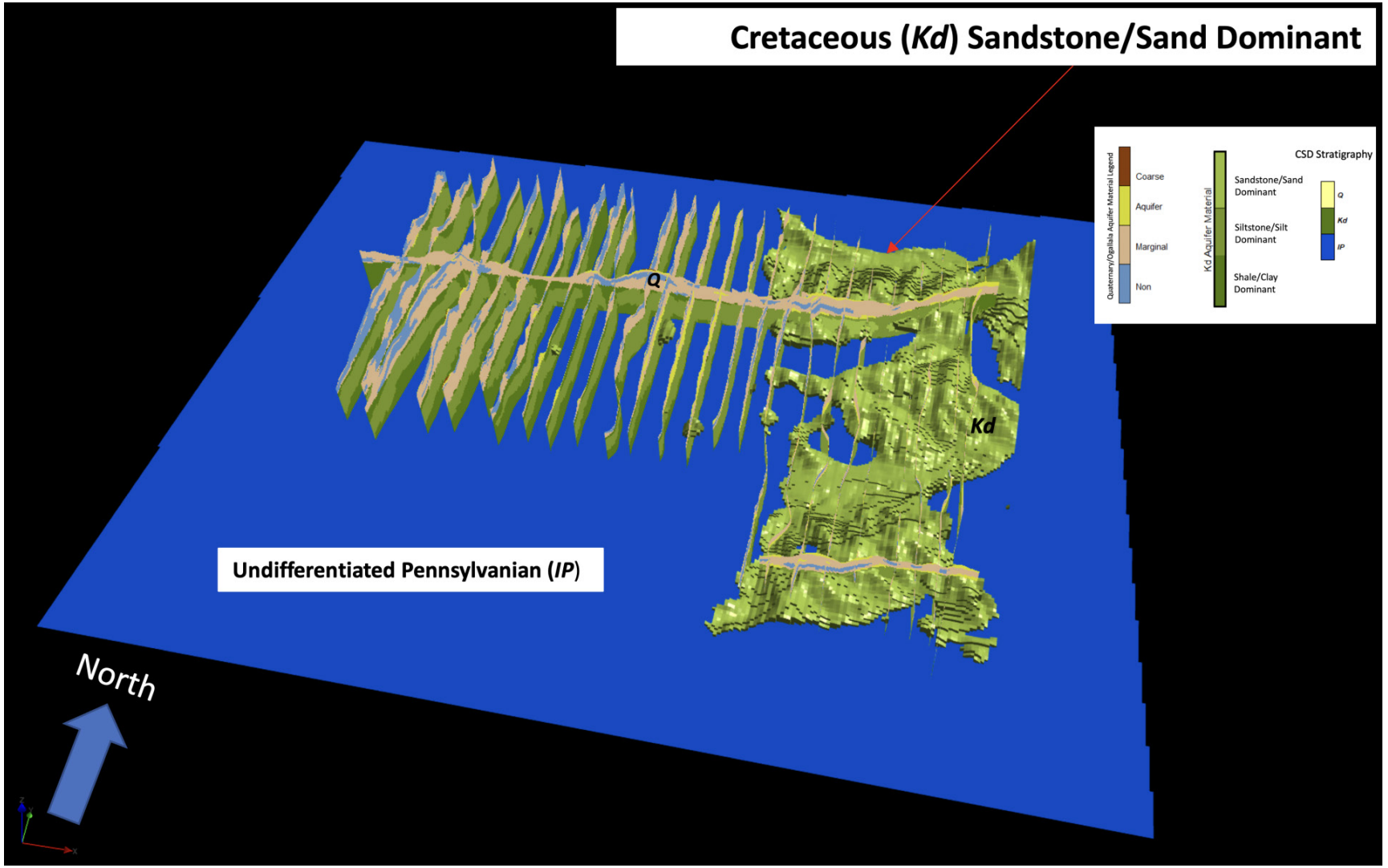


Figure 5-75. P-MRNRD Tekamah Block 3D Fence and voxel plot looking toward the northeast from the south. (*Q*) Quaternary materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials colors are as indicated on the legend. The Sandstone/Sand Dominate materials are displayed as a 3D voxel. The Undifferentiated Pennsylvanian (*IP*) surface is indicated by the blue. Vertical Exaggeration (VE) = 5.

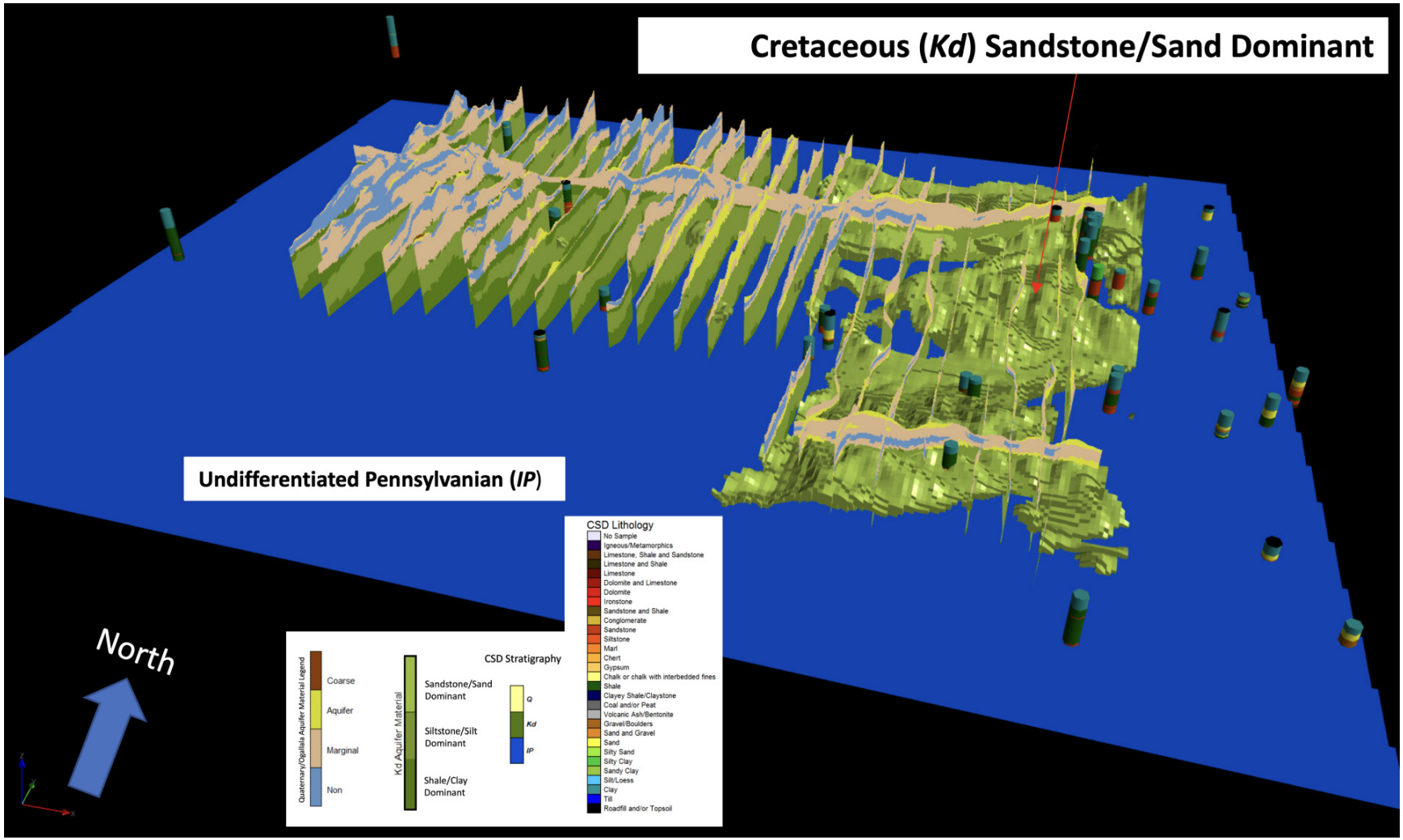


Figure 5-76. P-MRNRD Tekamah Block 3D Fence and voxel plot looking toward the northeast from the south. *(Q*) Quaternary materials colors are as indicated on the legend. The Cretaceous Dakota Group (*Kd*) materials colors are as indicated on the legend. The Sandstone/Sand Dominate materials are displayed as a 3D voxel. The Undifferentiated Pennsylvanian (*IP*) surface is indicated by the blue. The NE-DNR registered wells are indicated as colored tubes with lithology indicated in the legend. Vertical Exaggeration (VE) = 5.

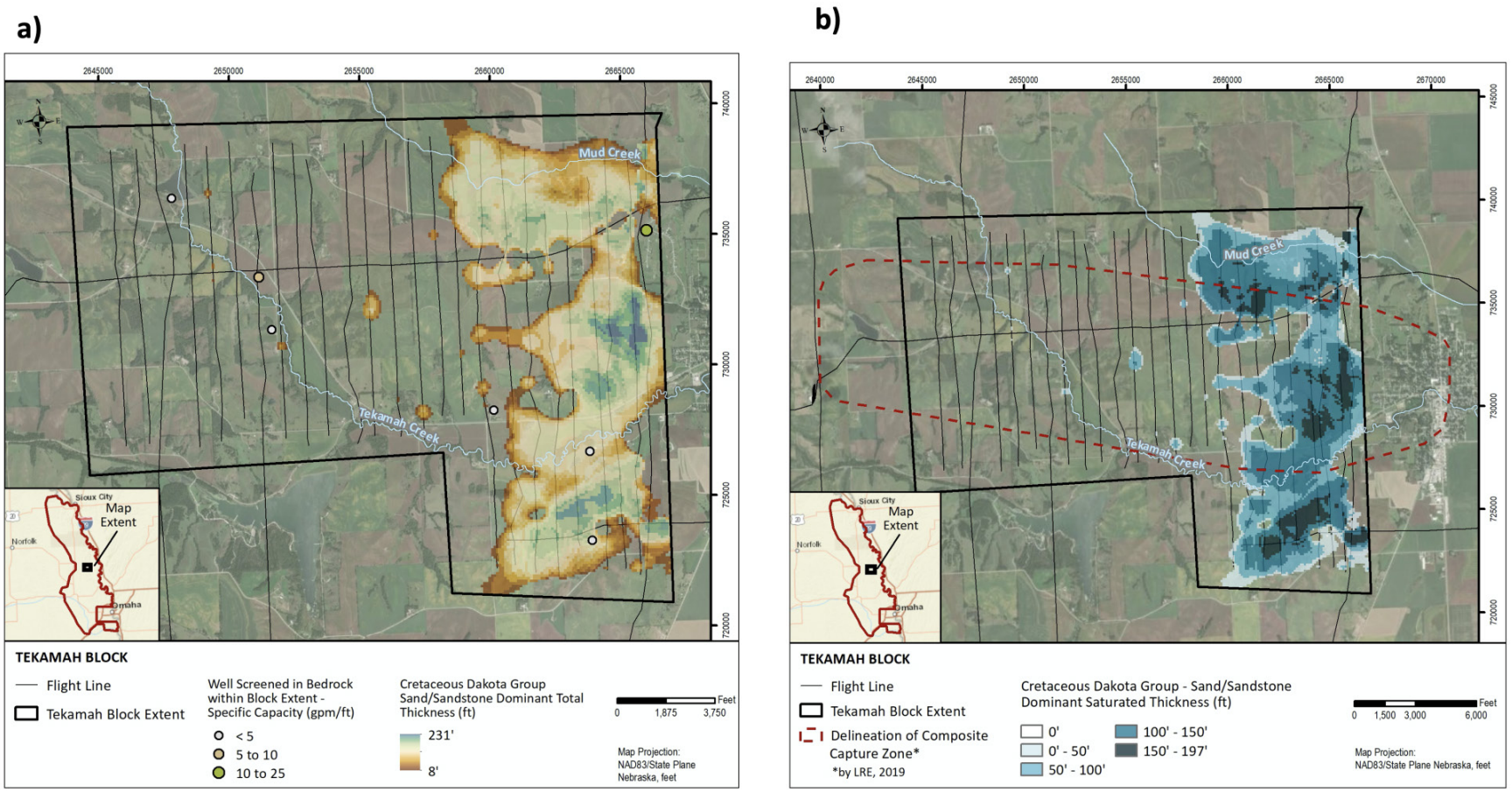


Figure 5-77. a) map of the Cretaceous Dakota Group (*Kd*) total Sandstone/Sand Dominant materials with the NE-DNR specific capacity indicated for well completed within the *Kd*. and b) map of the Cretaceous Dakota Group (*Kd*) total Sandstone/Sand Dominant materials saturated thickness. Also indicated is the Composite Capture Zone (LRE, 2019).

5.3.4 Hydrogeologic Framework of the P-MRNRD Northern Area

The Northern Area is composed of the reconnaissance lines that were collected north of the Southern Block up to the Missouri along the Nebraska and South Dakota border (Figure 5-1). This does not include the Tekamah Block that was discussed previously. The Northern Area reconnaissance lines are composed of lines from 2014, 2016, 2018, and 2019 AEM surveys (Figure 5-1, Section 5.1). The ***Q***, ***Kc***, ***Kgg***, ***Kd***, and ***IP*** all occur within the Northern Area.

In Figure 5-78 a 3D Fence diagram of the northern area looking northwest, the prominent feature is vast amounts of ***Q*** loess and glacial till composed of non-aquifer marginal aquifer material which overlies the bedrock units of the ***Kc***, ***Kgg***, and ***Kd***. This prominent feature forms a northwest to southeast trending, clay rich low transmissive backbone along the P-MRNRD district. Within the non-and marginal aquifer areas there are some scatted remnants of paleochannels or other glacial deposits containing aquifer and coarse aquifer materials. The material extends west and south of the Tekamah Block. Along the western edge of the Northern Area there are aquifer and coarse aquifer materials associated with Logan Creek. The Missouri River floodplain defines the eastern boundary of the Northern Area and is composed of aquifer and coarse aquifer materials. Some of these areas are overlain by a silt and clay layer that in some cases forms a confined aquifer.

The ***Q*** alluvial deposits in the Missouri River floodplain and upland (***Q)*** loess, glacial tills and associated aquifer materials make up the northeast edge of the Northern Area survey as seen in Figure 5-79. This view area is from roughly Tekamah to Decatur, Nebraska along the Missouri River. This area above the Missouri River floodplain is comprised of ***Q*** glacial till and marginal aquifer material and is draped in coarse Quaternary alluvial material. This material is possibly a remnant of glacial thrust sheets which formerly occupied this region in the Pleistocene (Korus et al., in preparation). They do not seem to be terrace deposits (Miller, 1964) but may also be related to other outwash deposits. The surfaces of the ***Kc***, ***Kgg*** and ***Kd*** are seen in the view with the erosional edges of the formations seen along the bluffs. Also seen in this view are the paleochannels as identified from Burchett et al. (1988) (Section 5.2.4.1).

Figure 5-80 is a profile of Line L1001301 which describes the northern, upper end of the Northern Area. The line exhibits the ***Q*** alluvial deposits in the Missouri River floodplain, the upland ***Q*** glacial tills and loess and associated aquifer materials which overlie the ***Kd*** bedrock aquifer in the northeast edge of the North Block Survey. There are also features that may represent glacial trust remnants as well as a paleochannel. The overall impression is most of the ***Q*** materials are composed of non- and marginal aquifer materials. Individual profiles of each of the lines within the Northern Area can be found in *Appendix 1 – 2D Images*.

Under the loess and glacial till of the Northern Area, some aquifer and coarse aquifer material exists. While sporadic, it may provide insight into paleochannel systems. The nature of the reconnaissance survey cannot provide the detail that a block flight can, and the difference in the resolution of the ***Q*** materials as examined in the previous sections on the South Block, Arlington Block, and Tekamah Block. However, using the information that we do have we can highlight areas that may include aquifer, and conduits for water transport. Figure 5-81 is a 3D fence diagram with only the saturated portion of the

aquifer and coarse aquifer materials plotted along the fence profiles overlain on the bedrock surfaces of the ***Kc***, ***Kgg***, ***Kd***, and ***IP***. The first step in examining this figure is to mentally remove the ***Q*** alluvial deposits of the Platte and Elkhorn Rivers, Logan Creek, and the Missouri River. Then examine the areas indicated by the yellow and brown on the 3D Fence diagram that represent the coarse and aquifer material. The paleochannels indicated by Burchett et al. (1988), as well as the channel associated with the Oakland Paleochannel (AGF, 2019b; Abraham et al., 2012), can be seen as depressions in the ***Kd*** and are also indicated by some aquifer material. Additionally, there are a few other areas that may be related to paleochannel deposits of the Type I Architectural class (Korus et al., 2016), as discussed previously in the Arlington Block, are indicated on Figure 5-81.

The character of the ***Kd*** within the Northern Area is variable with small areas of Sandstone/Sand Dominant materials. Figure 5-82 is a 3D fence diagram of the Northern area with the ***Kd*** material types highlighted overlain on the ***IP*** surface. The largest areas of Sandstone/Sand Dominate material are in the Tekamah Blocks previously discussed and the area east of Oakland in the LENRD. There are a few small areas up in the northernmost reaches of the survey area along the Missouri River within the LCNRD as well as some other areas scatted throughout the Northern Area. Some of this may be bias from the reconnaissance lines as we are seeing more Sandstone/Sand Dominant materials in the area of denser flight lines. To see the correlation of the ***Kd*** material types with the NE-DNR registered wells specific capacity values, those values are presented as color/size range points on the 3D fence diagram of the ***Kd*** (Figure 5-83). There is some correlation, but it is hard to tell with the limited data from the reconnaissance lines. One thing that is for certain is that most of the wells are not great producers.

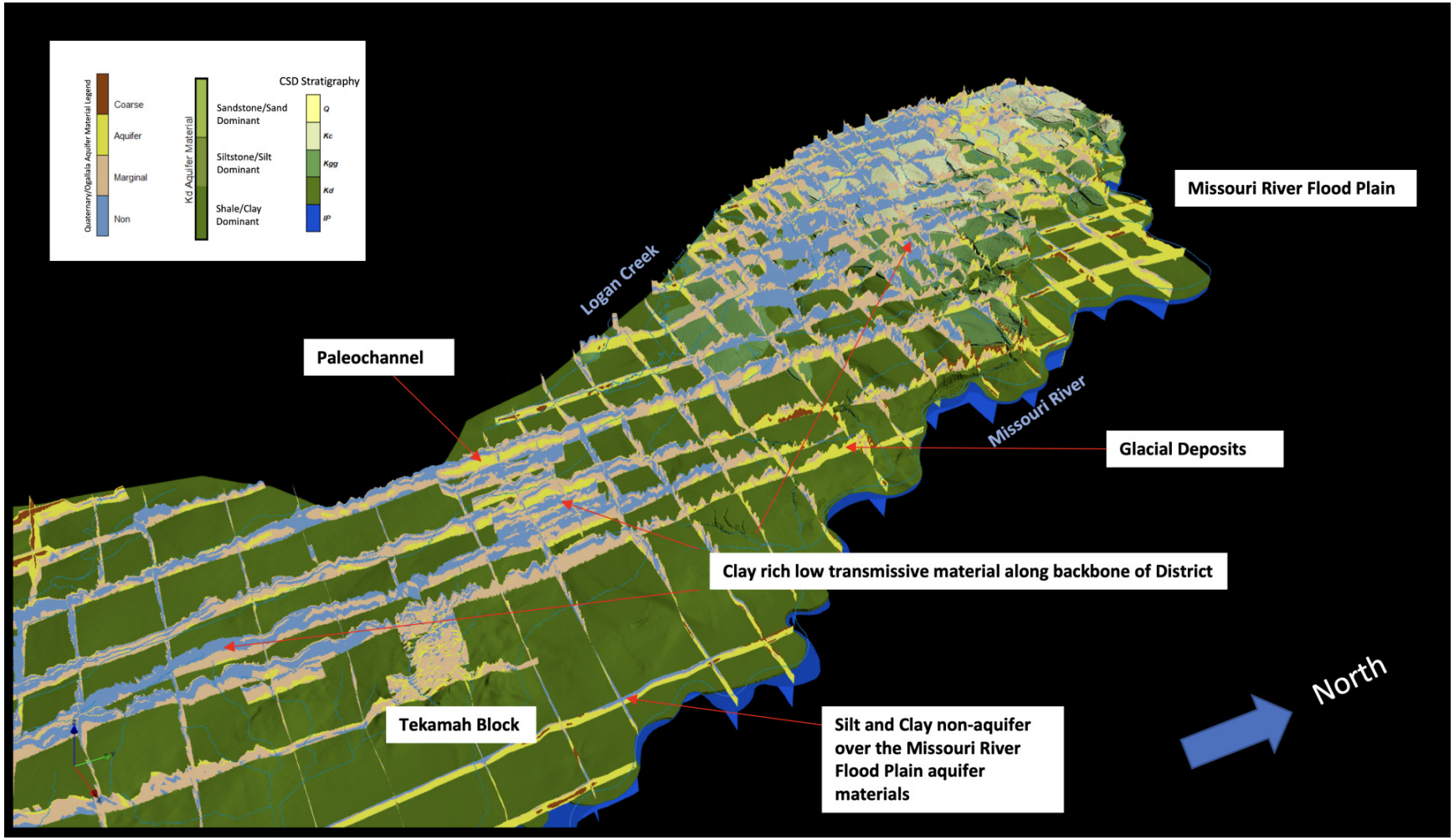


Figure 5-78. P-MRNRD North Area 3D Fence Diagram looking northwest from the southwest. Quaternary (Q) glacial tills and associated aquifer materials colors are as indicated on the legend. The Cretaceous Carlile (Kc), Greenhorn Limestone and Graneros Shale (Kgg), and Dakota Group (Kd) surface is shown as surfaces colored as indicated in the legend. The Undifferentiated Pennsylvanian (IP) surface is indicated by the blue surface. A broad area of clay rich low transmissive material appears across the backbone of the North area extending south and west of the Tekamah Block. Vertical Exaggeration (VE) = 20x.

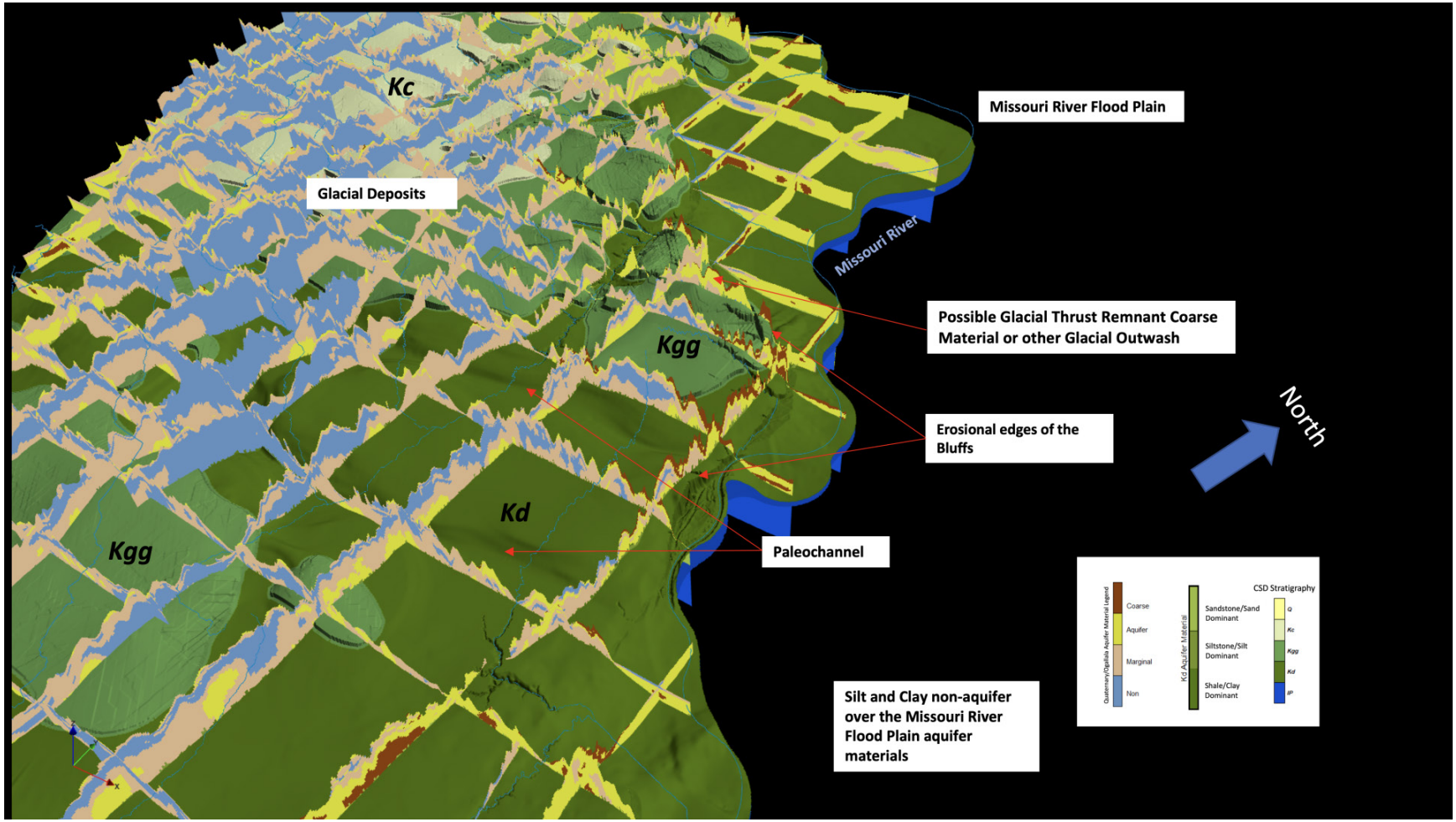


Figure 5-79. P-MRNRD North Area 3D Fence Diagram looking northwest from the southwest. Quaternary (Q) glacial tills and associated aquifer materials colors are as indicated on the legend. The Cretaceous Carlile (Kc), Greenhorn Limestone and Graneros Shale (Kgg), and Dakota Group (Kd) surface is shown as surfaces colored as indicated in the legend. The undifferentiated Pennsylvanian (IP) surface is indicated by the blue surface. Erosion remnants of the Cretaceous units are overlain by complex deposits of paleochannels, glacial till, loess, and possibly glacial trust sheets. Vertical Exaggeration (VE) = 20x.

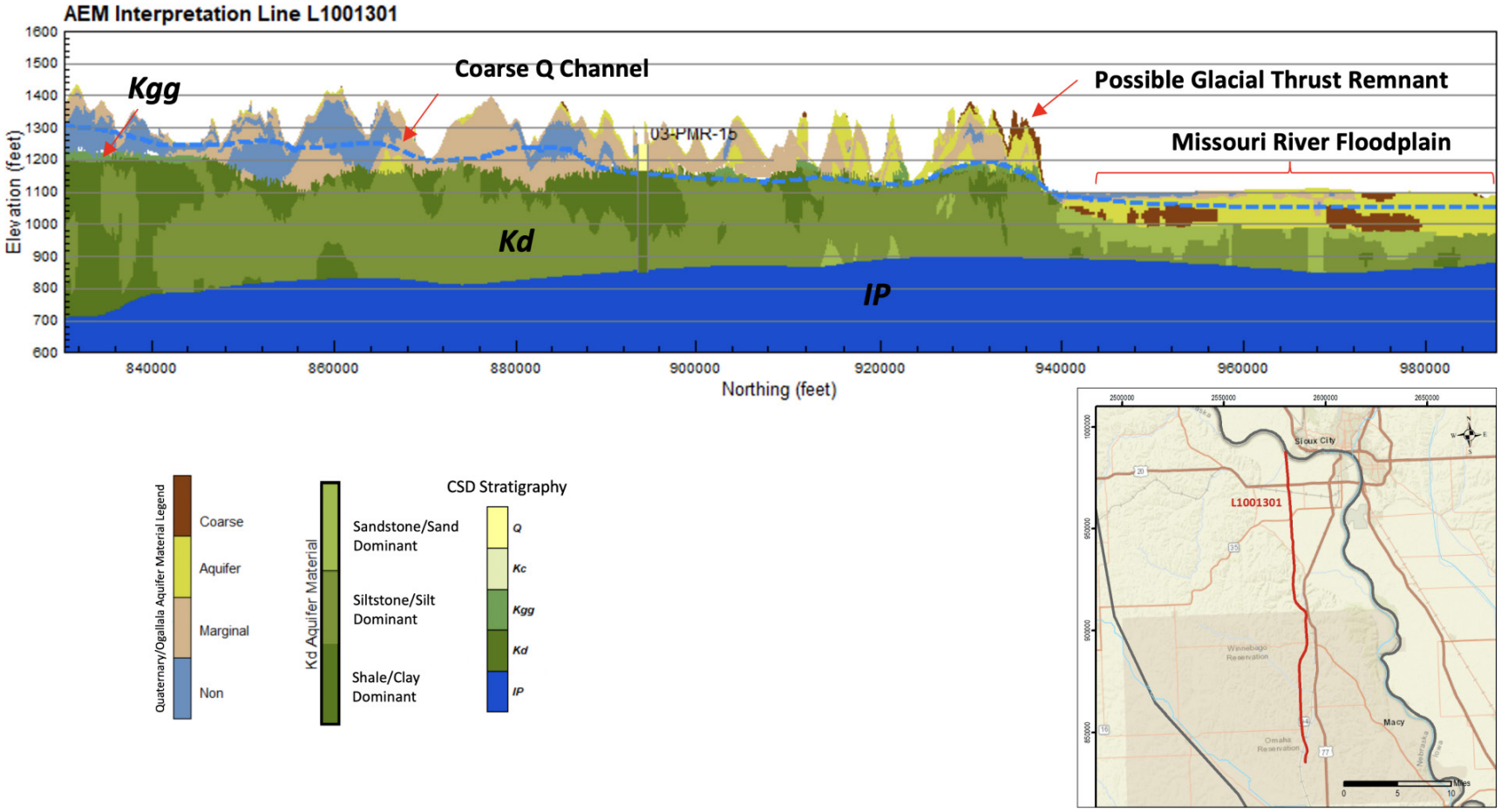


Figure 5-80. AEM interpretation of north-south line L1001301 within the North Area of the P-MRNRD survey area. The line goes from the Missouri River floodplain in the north, south into the upland Quaternary (Q) glacial tills and associated aquifer materials which overlie the Greenhorn Limestone and Graneros Shale (Kgg), Cretaceous Kd bedrock aquifer, and IP = Undifferentiated Pennsylvanian. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy. The inset map indicates the location of the flight line within the North Block south from the Missouri River.

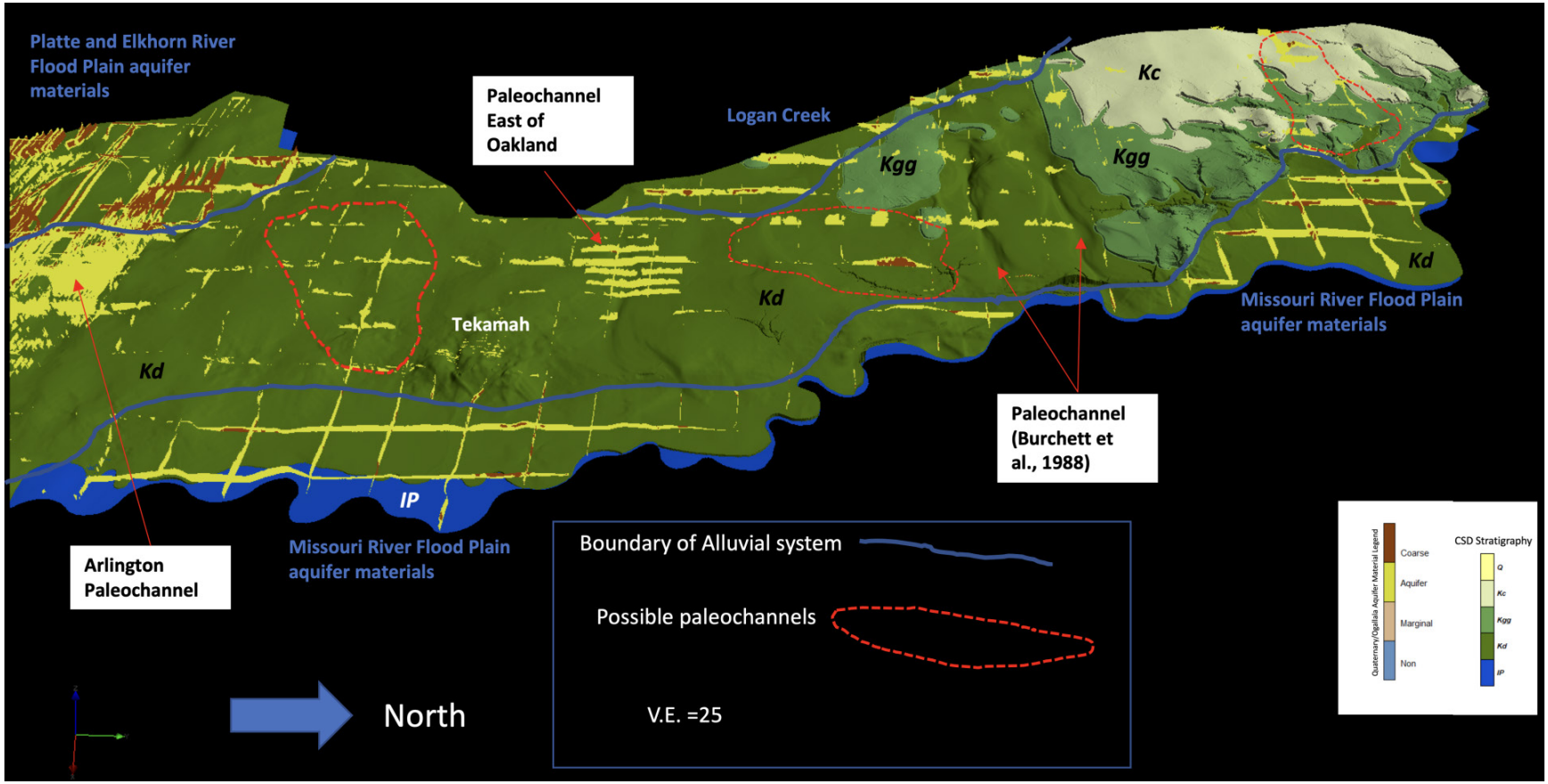


Figure 5-81. P-MRNRD North Area 3D Fence Diagram looking to the west from the east. Only displaying the saturated Quaternary (Q) coarse and aquifer materials as colors indicated on the legend. The Cretaceous Carlile (Kc), Greenhorn Limestone and Graneros Shale (Kgg), Dakota Group (Kd), and Undifferentiated Pennsylvanian (IP) surfaces are shown as indicated in the legend. Alluvial systems including the Platte and Elkhorn River, Logan Creek, and Missouri River are indicated. Historically mapped paleochannels are indicated by blue lines. Possible other paleochannels are indicated by dashed red lines. Vertical Exaggeration (VE) = 25x.

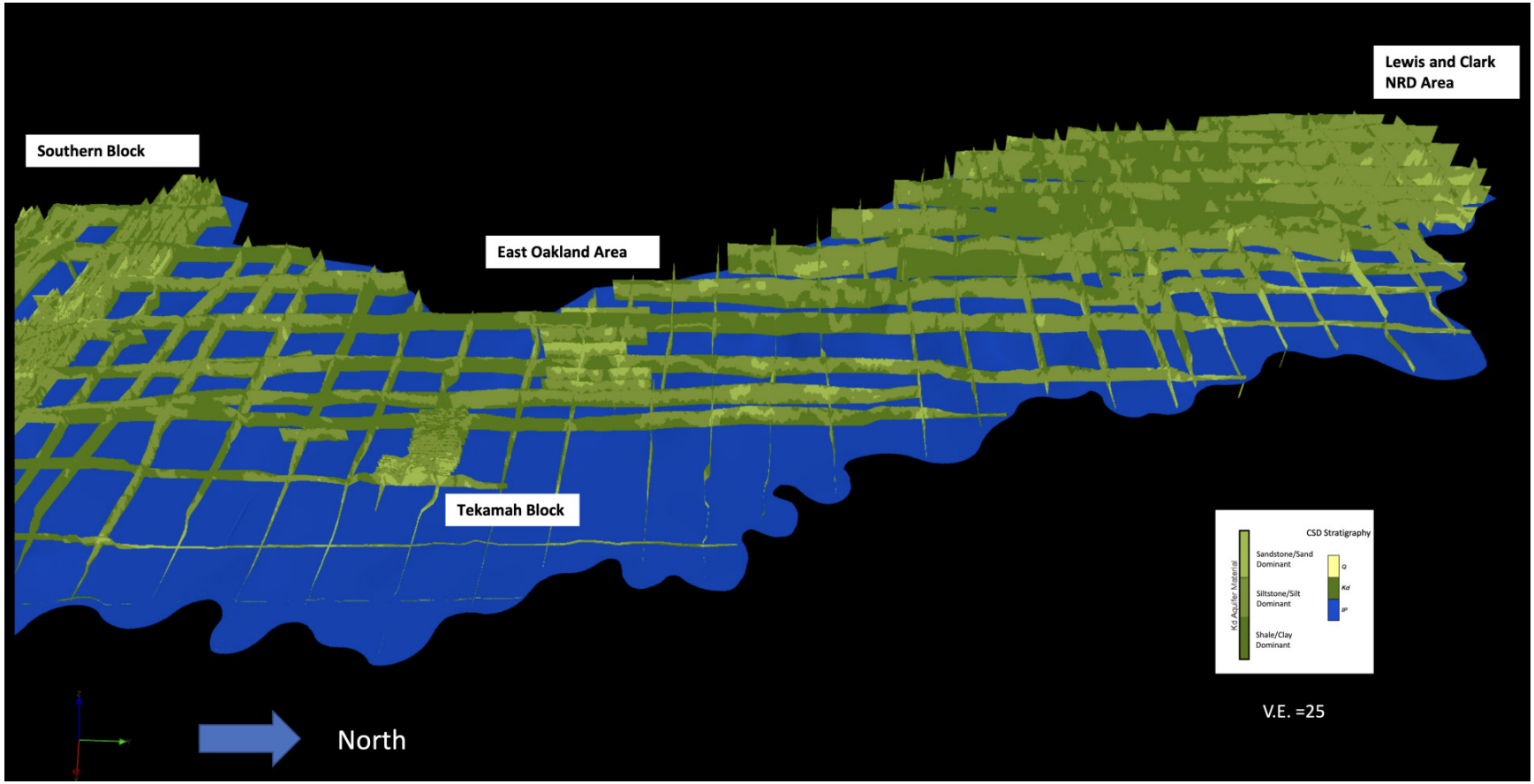


Figure 5-82. P-MRNRD North Area 3D Fence Diagram looking to the west from the east. Only displaying the Cretaceous Dakota Group (*Q*) materials as colors indicated on the legend. The Undifferentiated Pennsylvanian (*IP*) surface is shown as blue. Vertical Exaggeration (VE) = 25x.

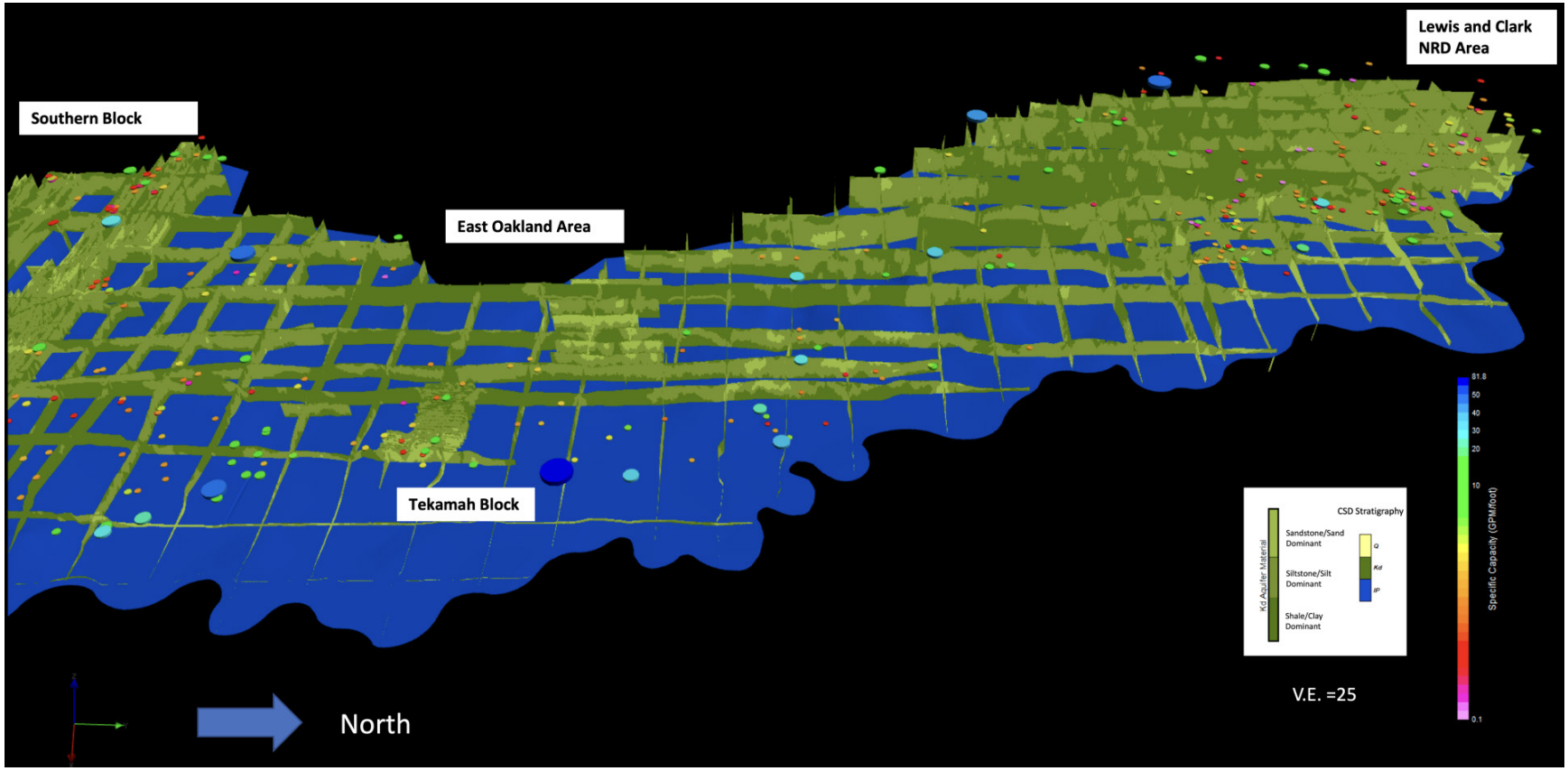


Figure 5-83. P-MRNRD North Area 3D Fence Diagram looking to the west from the east. Only displaying the Cretaceous Dakota Group (Q) materials as colors indicated on the legend. The Undifferentiated Pennsylvanian (IP) surface is shown as blue. The NE-DNR registered wells specific capacity for wells competed in the Kd are shown on the color/size points. Vertical Exaggeration (VE) = 25x.

5.3.5 Hydrogeologic Framework of the Overall P-MRNRD Study Area

The 2020 and merged P-MRNRD AEM surveys are represented in 3D regional Fence Diagrams that illustrate the overall hydraulic framework of the P-MRNRD District. Figure 5-84 is a 3D regional profile of the P-MRNRD District looking northeast and Figure 5-85 is looking to the north. Many of the feature and configurations of the ***Q*** materials can be seen in this figure that have been previously described. These include the Platte River Flood Plain, Todd Valley, Missouri River Flood Plain and the Clay and silt rich glacial till and loess that make up the backbone of the district. ***Q*** aquifer and coarse aquifer materials are thick in the southwest western part of the survey area near the Todd Valley, Platte and Elkhorn Rivers. The Tekamah Block AEM flight area has very little ***Q*** aquifer and coarse aquifer material. On the far southeastern end of the survey area, the few reconnaissance lines (south of Omaha) show the ***Q*** transitioning from marginal aquifer materials to aquifer and coarse aquifer as you enter the Missouri River Flood Plain on the thin ***Kd*** bedrock transitioning to the ***IP***. Figure 5-86 is another view from the north looking south. The eroded remnants of the ***Kc*** and ***Kgg*** are apparent. The non- and marginal aquifer material form a strong feature that extends from the Northern Area down the east of the Arlington Block. Figure5-87 is a AEM profile Line L1000900 which extends from the Missouri River floodplain (Northern Area) to the Platte River alluvial valley (Southern Block). The AEM regional profile Line L1000900 summarizes the hydrogeology of the P-MRNRD District.

Much of the configuration of the ***Kd*** has been discussed previously. However, there is value in looking at the whole of the ***Kd*** within the P-MRNRD. Figure 5-88 is a 3D fence diagram of the ***Kd*** plotted on the ***IP*** surface. What comes out of this view is an apparent pattern to the distribution of the material types within the ***Kd***. Especially the Sandstone/Sand Dominant material that is of interest as an aquifer. This image can also be compared with the diagram from (Witzke and Ludvigson, 1994) (Figure 5-89). There is a striking similarity to the “distributary channels” and “delta-front sand-silt” features to the Sandstone/Sand Dominant material. However, more work could be done on the re-creation of the Eastern Nebraska ***Kd*** depositional environment. As was done previously, an examination of the NE-DNR registered wells specific capacity values for wells competed in the ***Kd*** is useful (Figure 5-90). As seen in the previous sections, there is a good correlation in the Southern Block and a rough correlation in the Northern Area. It is important to remember the ***Kd*** wells are bias by a couple factors. They do not occur in many areas of good ***Q*** aquifer regardless of the make-up of the ***Kd*** as they are lower specific capacity. Why put a well in the ***Kd*** if the ***Q*** aquifer will provide what is required? The other bias is when there is no other aquifer available, a low specific capacity well in the ***Kd*** Siltstone/Silt Dominant material is better than nothing at all. It is clear that much more could be done to investigate the ***Kd***.

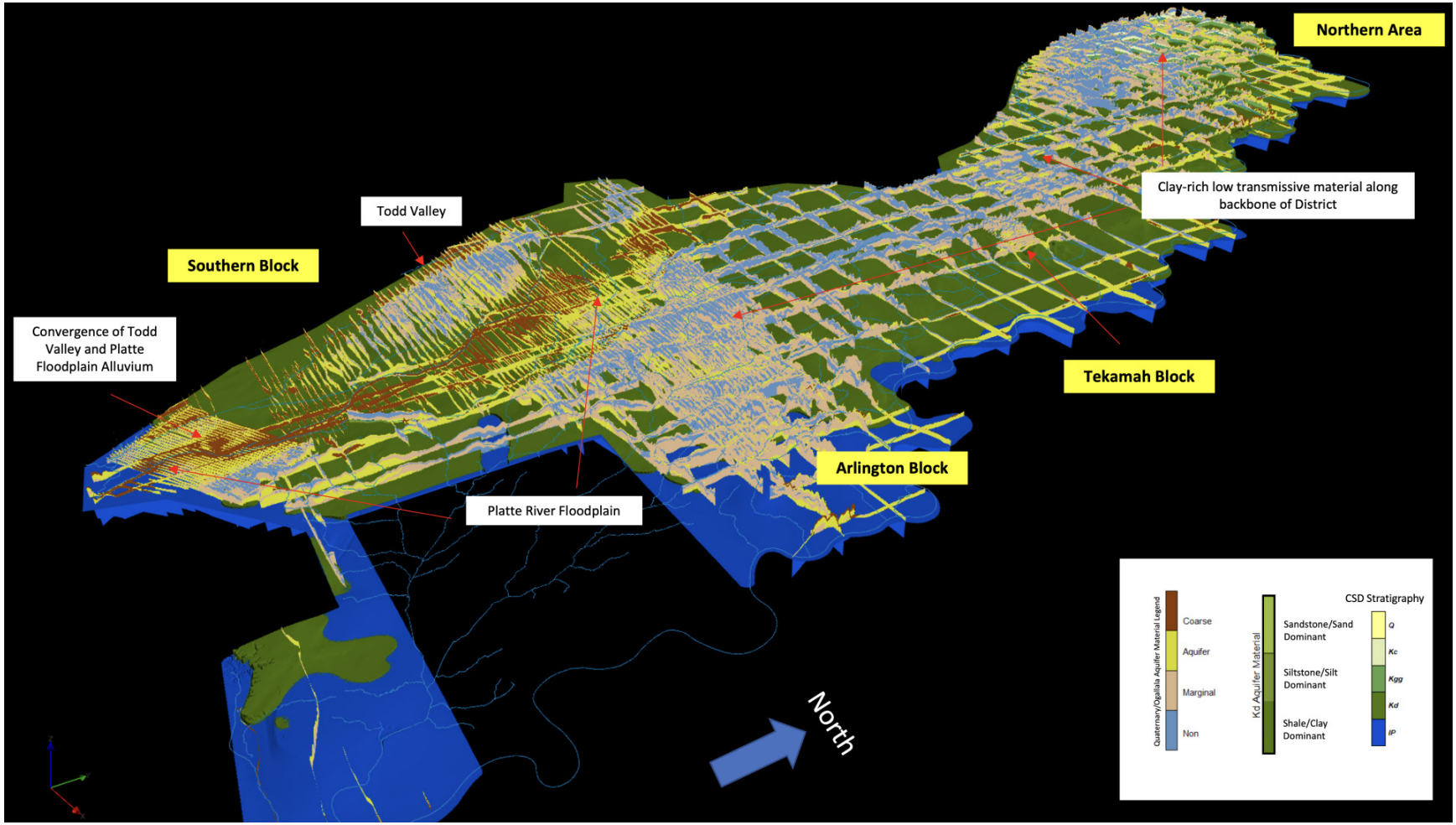


Figure 5-84. P-MRNRD Regional 3D Fence Diagram looking to the northeast. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Carlile (*Kc*), Greenhorn Limestone and Graneros Shale (*Kgg*), Dakota Group (*Kd*) are shown as a surface overlaying the undifferentiated Pennsylvanian (*IP*) surface. The Quaternary coarse aquifer materials are indicated as a transparent voxel as the dark brown. A broad area of clay rich low transmissive glacial till and loess material overlies the backbone of the district from the North Area to southeast of the Arlington Block Survey area. Major streams are indicated as thin blue lines. Vertical exaggeration (VE) = 20x.

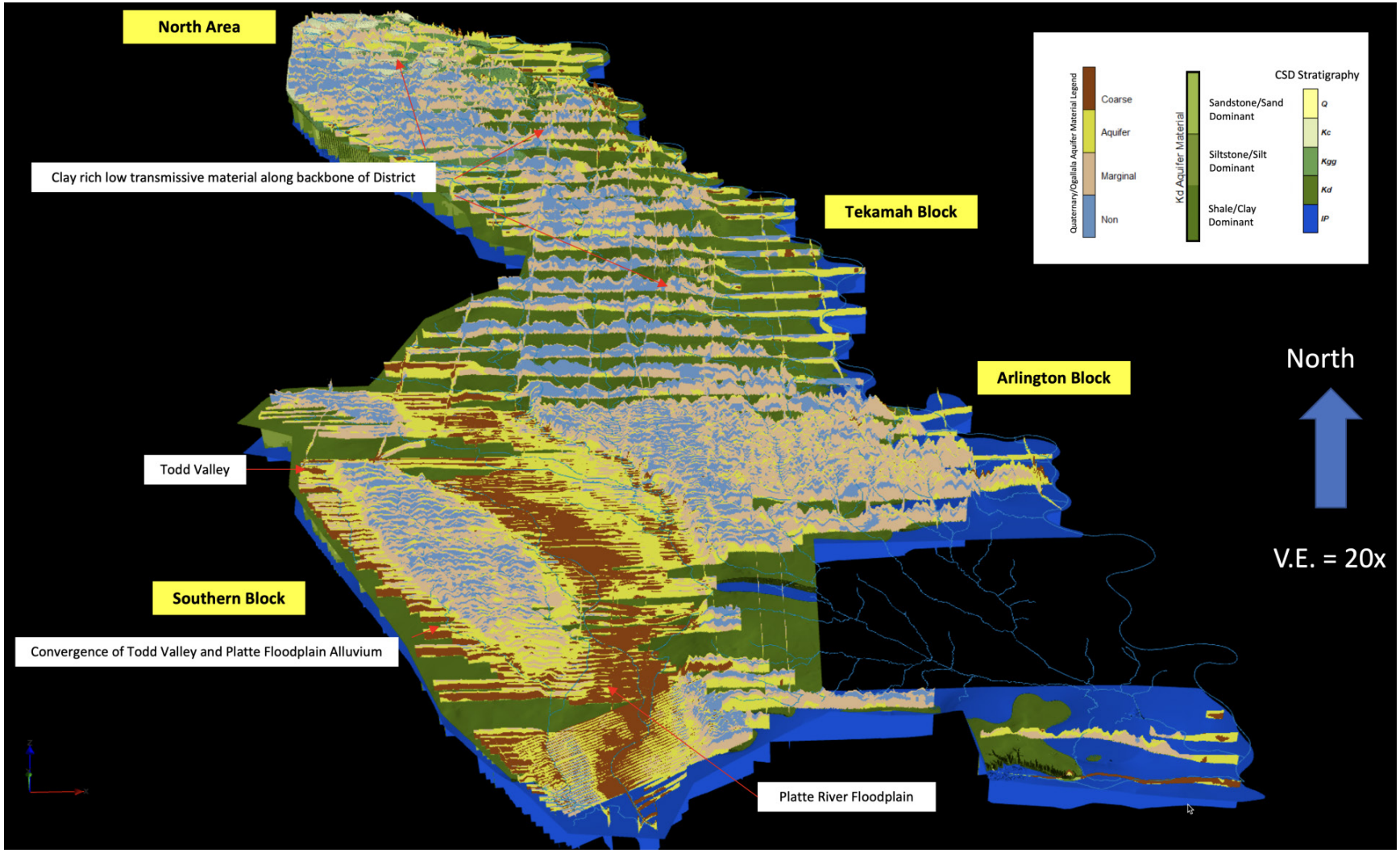


Figure 5-85. P-MRNRD Regional 3D Fence Diagram looking to the north. (*Q*) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Carlile (*Kc*), Greenhorn Limestone and Graneros Shale (*Kgg*), Dakota Group (*Kd*) are shown as surfaces overlaying the undifferentiated Pennsylvanian (*IP*) surface. The Quaternary coarse aquifer materials are indicated as a transparent voxel as the dark brown. A broad area of clay rich low transmissive glacial till and loess material overlies the backbone of the district from the Northern Area to southeast of the Arlington Block survey area. Major streams are indicated as thin blue lines. Vertical exaggeration (VE) = 20x.

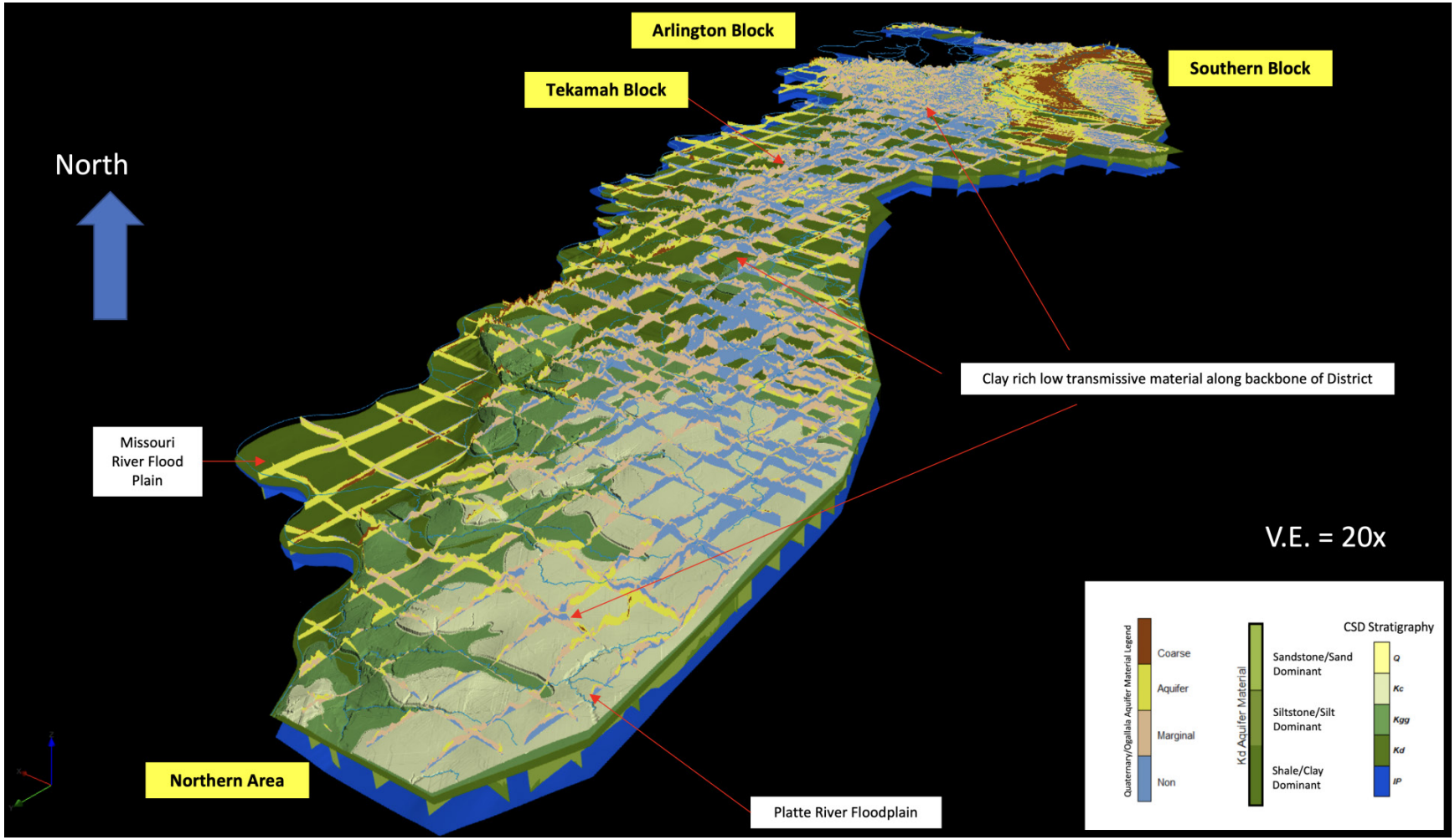


Figure 5-86. AEM Line P-MRNRD 3D Fence Diagram looking to the southeast from the north. (Q) Quaternary aquifer materials colors are as indicated on the legend. The Cretaceous Carlile (Kc), Greenhorn Limestone and Graneros Shale (Kgg), Dakota Group (Kd), and Undifferentiated Pennsylvanian (IP) are displayed as surfaces. A broad area of clay rich low transmissive glacial till and loess material overlies the backbone of the district from the Northern Area to southeast of the Arlington Block Survey area. Vertical exaggeration (VE) = 20x.

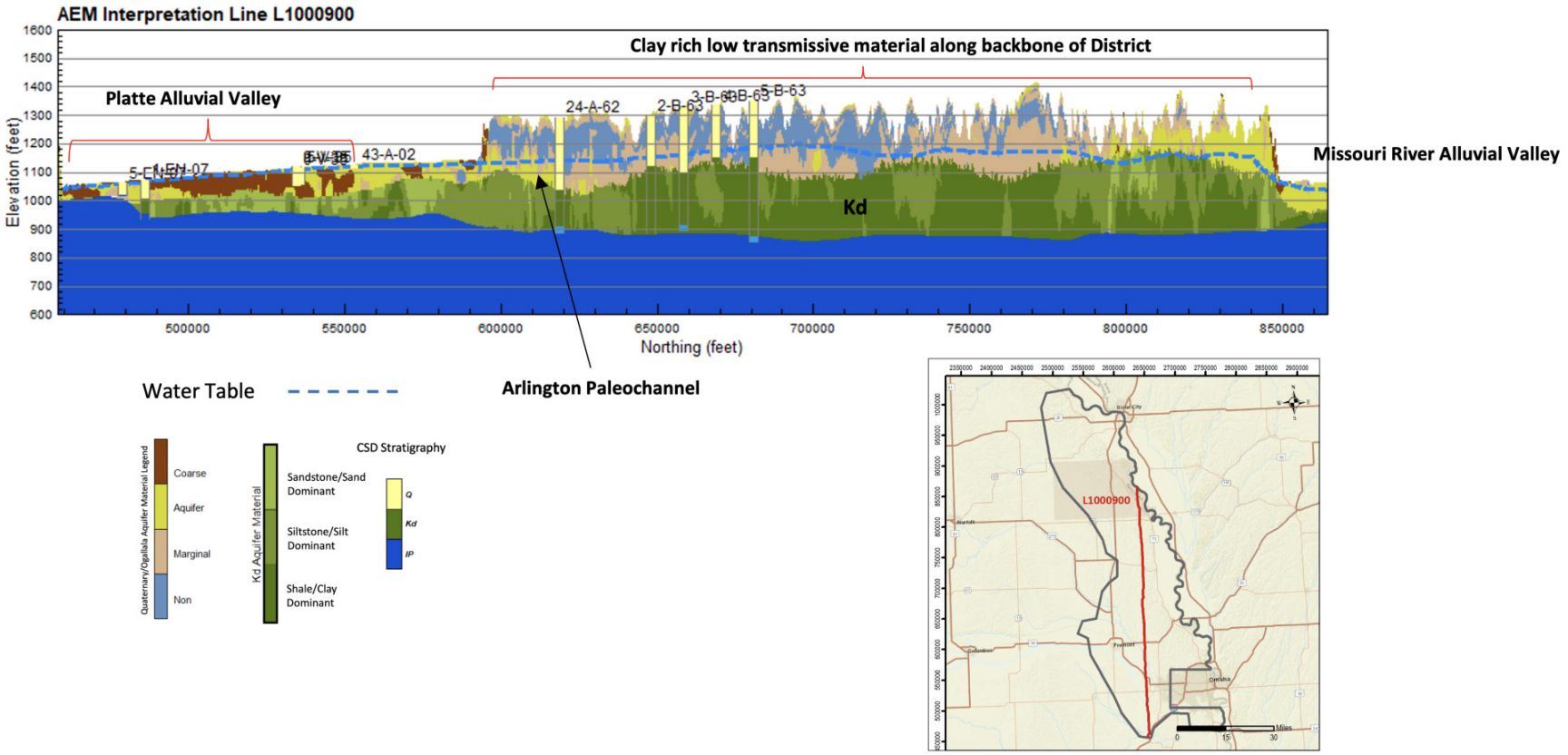


Figure 5-87. AEM interpretation of north-south line L1000900 inversion and interpretation profiles within the P-MRNRD survey area. The line goes from the Quaternary (Q) Missouri River Flood Plain through the glacial tills and loess, the Arlington Paleochannel to the Platte River Flood Plain. These Q deposits overlie the Cretaceous Dakota Group (Kd) that contains mixtures of materials types indicated in the legend and the IP = undifferentiated Pennsylvanian on the southern end. CSD test wells within ½ mile of the flight lines are projected on to the profile indicating stratigraphy. The inset map indicates the location of the flight line from the Missouri River (Northern Area) south to the end of the South Block survey area.

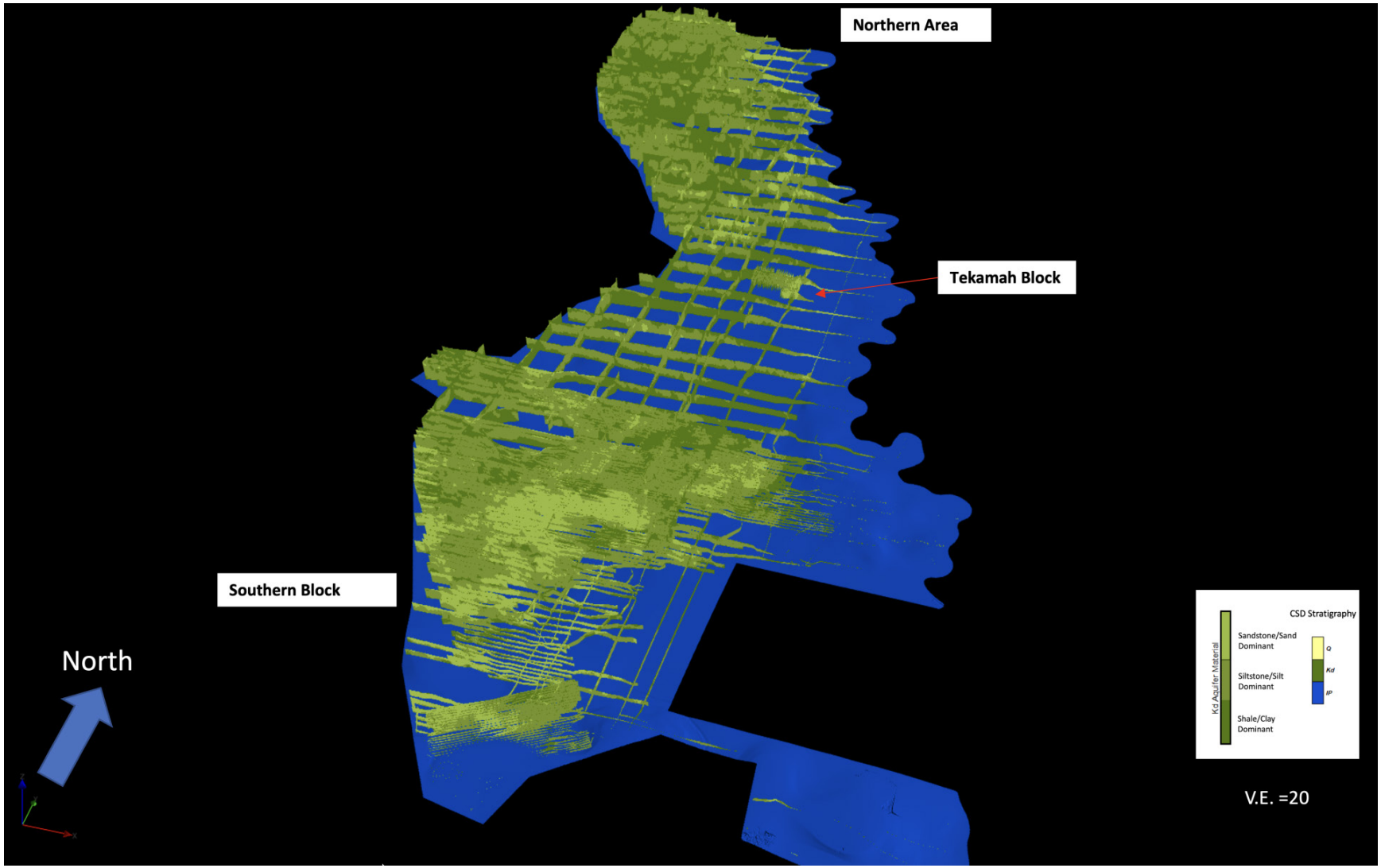


Figure 5-88. P-MRNRD North Area 3D Fence Diagram looking to the northwest from the southeast. Only displaying the Cretaceous Dakota Group (Q) materials as colors indicated on the legend. The undifferentiated Pennsylvanian (IP) surface is shown as blue. Vertical Exaggeration (VE) = 20x.

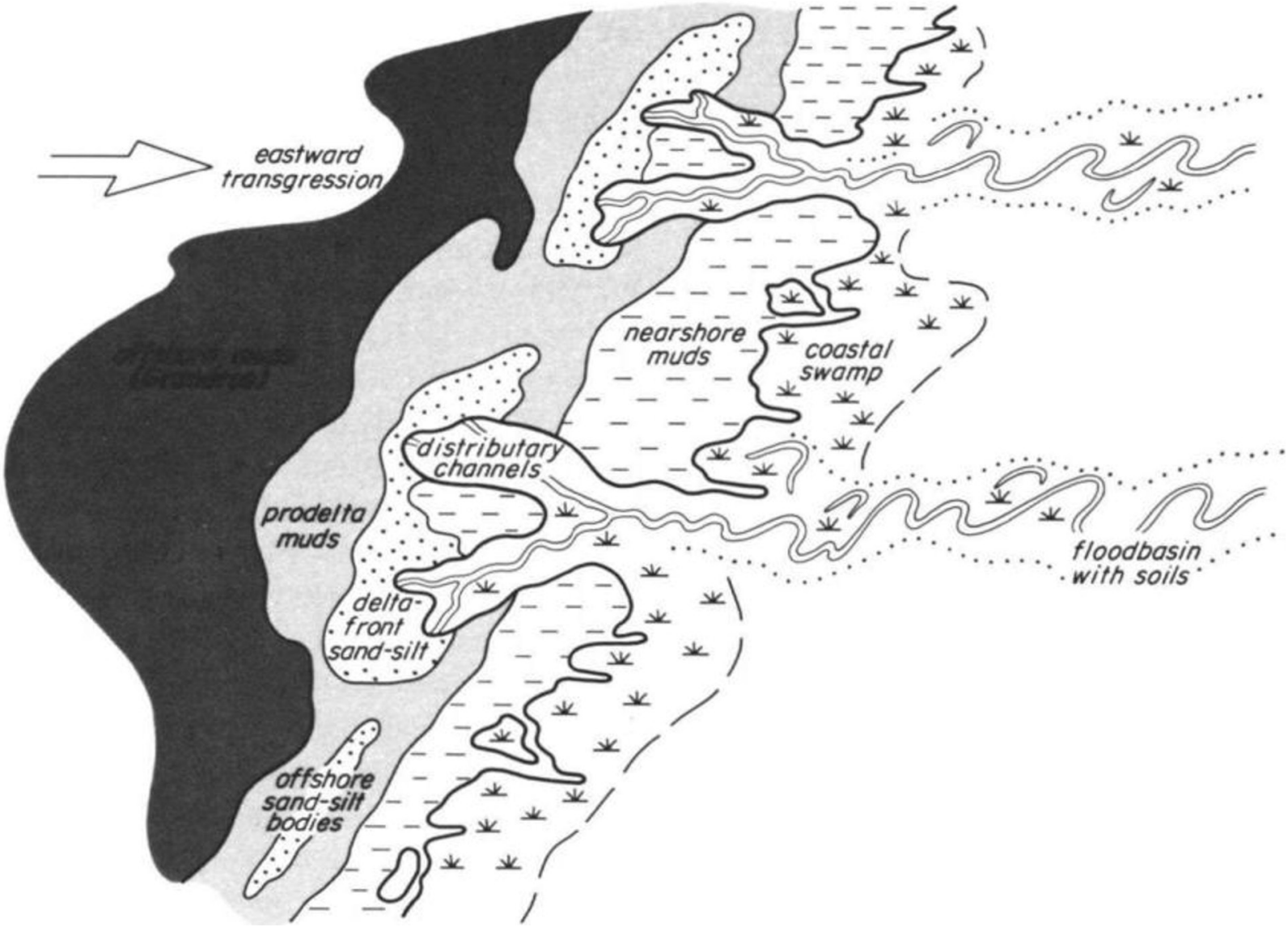


Figure 5-89. Depositional environment of the Dakota Group sediments during the Cretaceous Period in eastern Nebraska and western Iowa (modified from Witzke and Ludvigson, 1994).

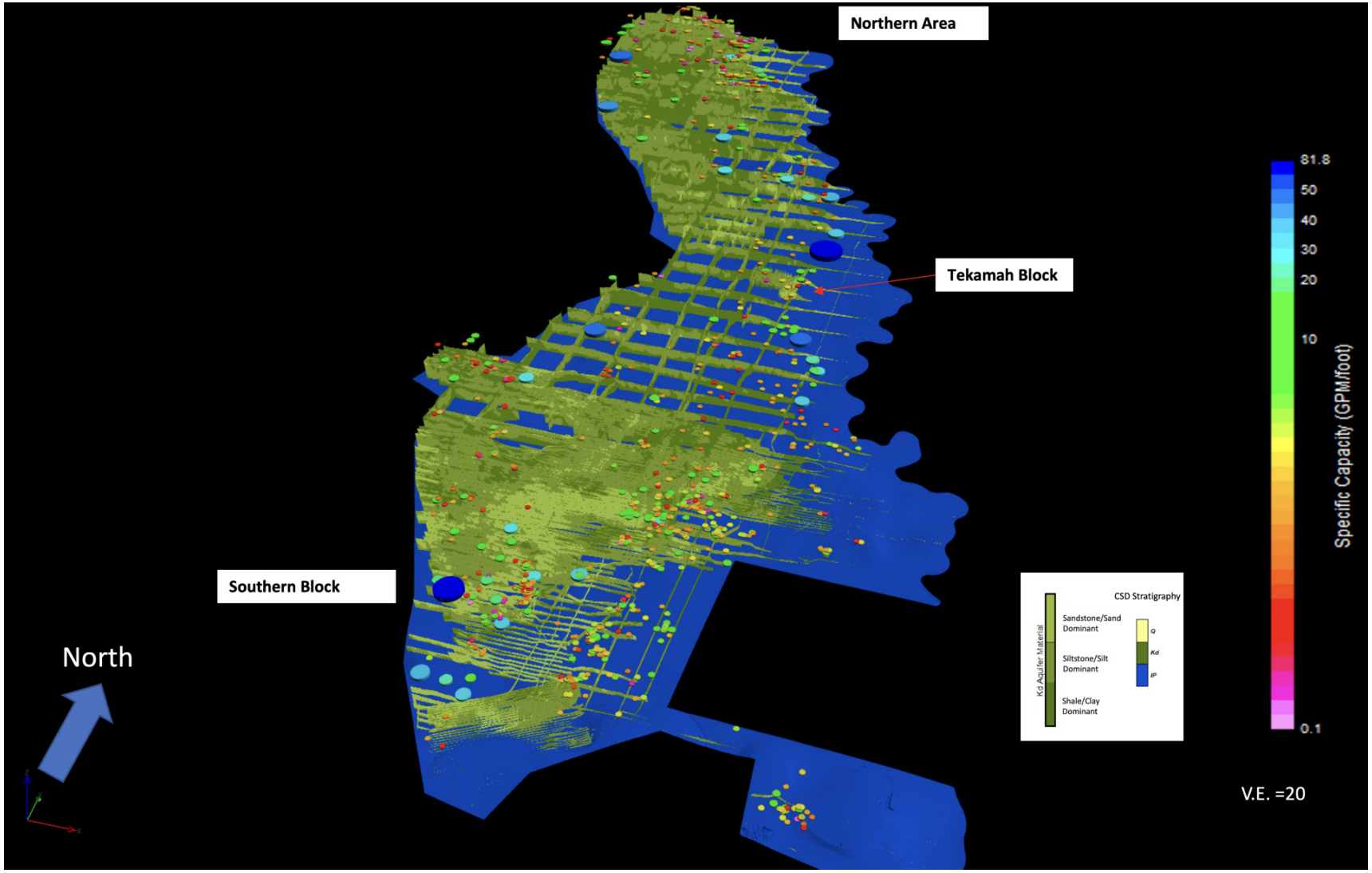


Figure 5-90. P-MRNRD Northern Area 3D Fence Diagram looking to the northwest from the southeast. Only displaying the Cretaceous Dakota Group (Q) materials as colors indicated on the legend. The undifferentiated Pennsylvanian (IP) surface is shown as blue. NE-DNR registered wells specific capacity of wells competed in the Kd are indicated by a color/size point as indicated by the legend. Vertical Exaggeration (VE) = 20x.

5.3.6 Hydrogeologic Framework of the P-MRNRD Summary Maps

Putting all the information together including the NE-DNR wells the CSD test holes, historical geological mapping, and the AEM interpretations maps can be provided that give a view of the P-MRNRD study area as a whole.

There is a North – South topographic divide between Lower Elkhorn NRD and P-MRNRD. Missouri River floodplain comprises the eastern border. A northwest to southwest topographic divide exists between the Todd Valley and the Platte River Valley. The bedrock elevation map, which is a composite of the ***Kc***, ***Kgg***, ***Kd*** and **IP**, exposes subtle contours that show historic alluvial scour and broad regional depositional pathways. Comparing the two (Figure 5-91) corroborates the well-known fact that the paleo-topography of the pre-Pleistocene environment was drastically different from the current glacially sculpted landscape. The importance in this fact is the paleochannels can typically be found in the pre-Pleistocene valleys.

The Total Thickness and Saturated Thickness of ***Q*** Deposits do not reveal much about the character of the ***Q*** aquifers at depth at depth. Much of the most productive areas of the P-MRNRD are in the relatively thinner alluvial valleys and not in the thick loess and till areas. A comparison of the total thickness of the ***Q*** to the saturated thickness of the ***Q*** does show the thick areas along the backbone of the district but do not highlight the productive aquifers (Figure 5-92). It does show the areas of high bedrock. It is much more useful to look at the fence diagrams of the ***Q*** and the thickness maps generated in the block areas to gain understanding of the aquifer material distribution.

The Total Thickness and Saturated Thickness of ***Kd*** Deposits indicates that much of the ***Kd*** is saturated in the area and the ***Kd*** thins to the south and east. As with the ***Q*** maps above it doesn't provide information on the quality of the aquifers. A comparison of the total thickness of the ***Kd*** to the saturated thickness of the ***Kd*** is presented in Figure 5-93. It is much more useful to look at the fence diagrams of the ***Kd*** and the thickness maps generated in the Block areas to gain understanding of the aquifer material distribution.

The density of well specific capacity for the NE-DNR registered wells completed within the ***Q***, dual completion dually in both ***Q*** and ***Kd***, and ***Kd*** completed wells are presented in Figure 5-94. The higher density of ***Q*** wells correlates with the Missouri River, Todd Valley, and Platte River Valley areas. The Arlington Paleochannel is also indicated in the ***Q*** image (Figure 5-94a). The dual ***Q*** and ***Kd*** wells are much less common in the area and are within areas of better ***Kd*** aquifer quality as was seen in previous sections (Figure 5-94b). The ***Kd*** wells completed in bedrock tend to occupy areas lacking in saturated (***Q***) Quaternary alluvial deposits (Figure 5-94c). This is an interesting plot as it shows the areas of poor ***Q*** production as well as the most productive areas of the ***Kd.***

One of the products of this mapping has been the revision of the bedrock geology map for the P-MRNRD. The process of the revision was covered in Section 5.2.2. The revised bedrock geology map is presented in Figure 5-95. It is important to note that the Burchett (1986) map has only been revised in areas that were better illuminated by the AEM and additional CSD test wells. That was a quality product that has been a basis of much of the work in this report.

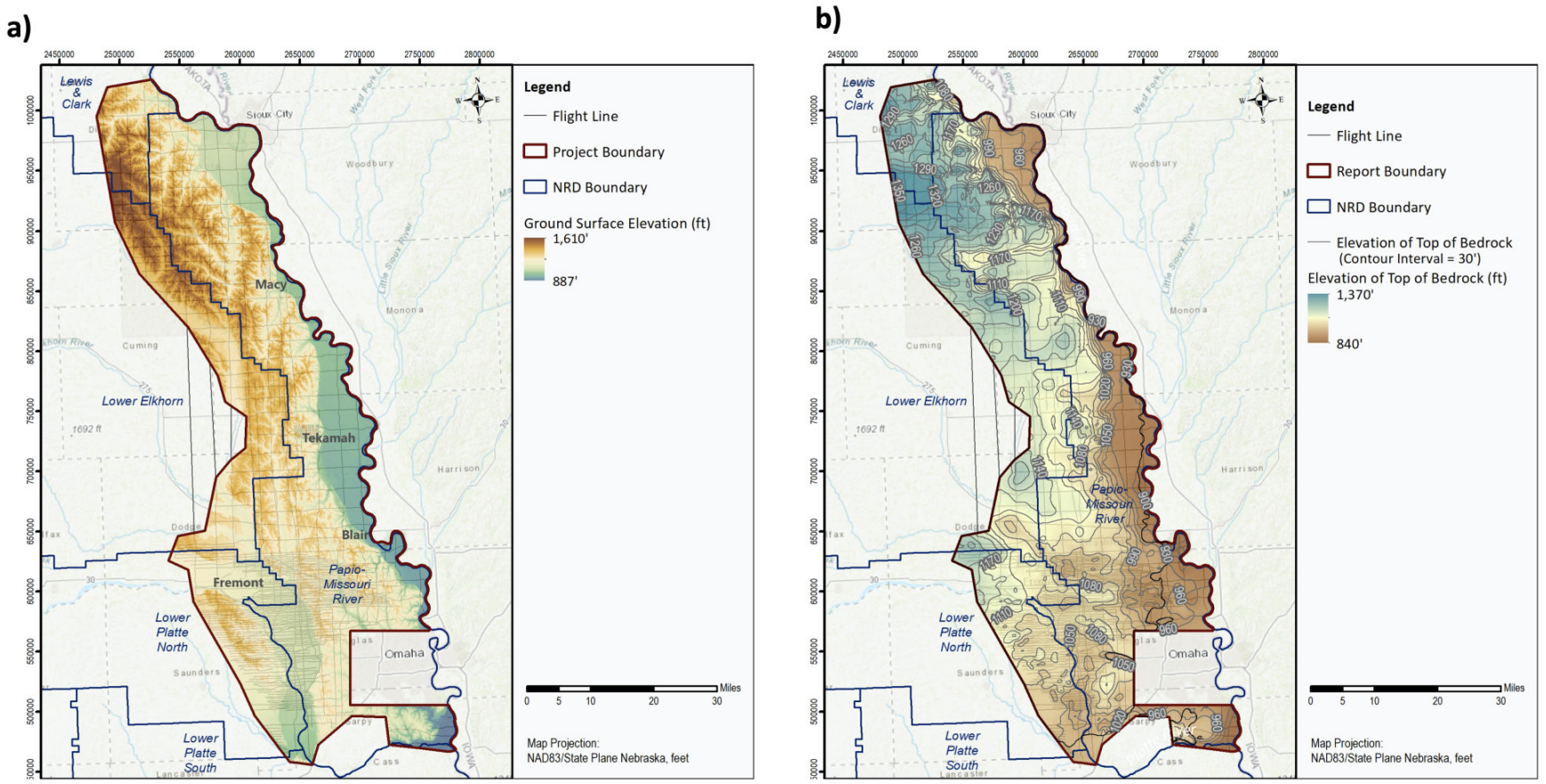


Figure 5-91. a) P-MRNRD Regional map of Ground Surface Elevation (ft) and b) Elevation of Top of Bedrock (ft) of the P-MRNRD.

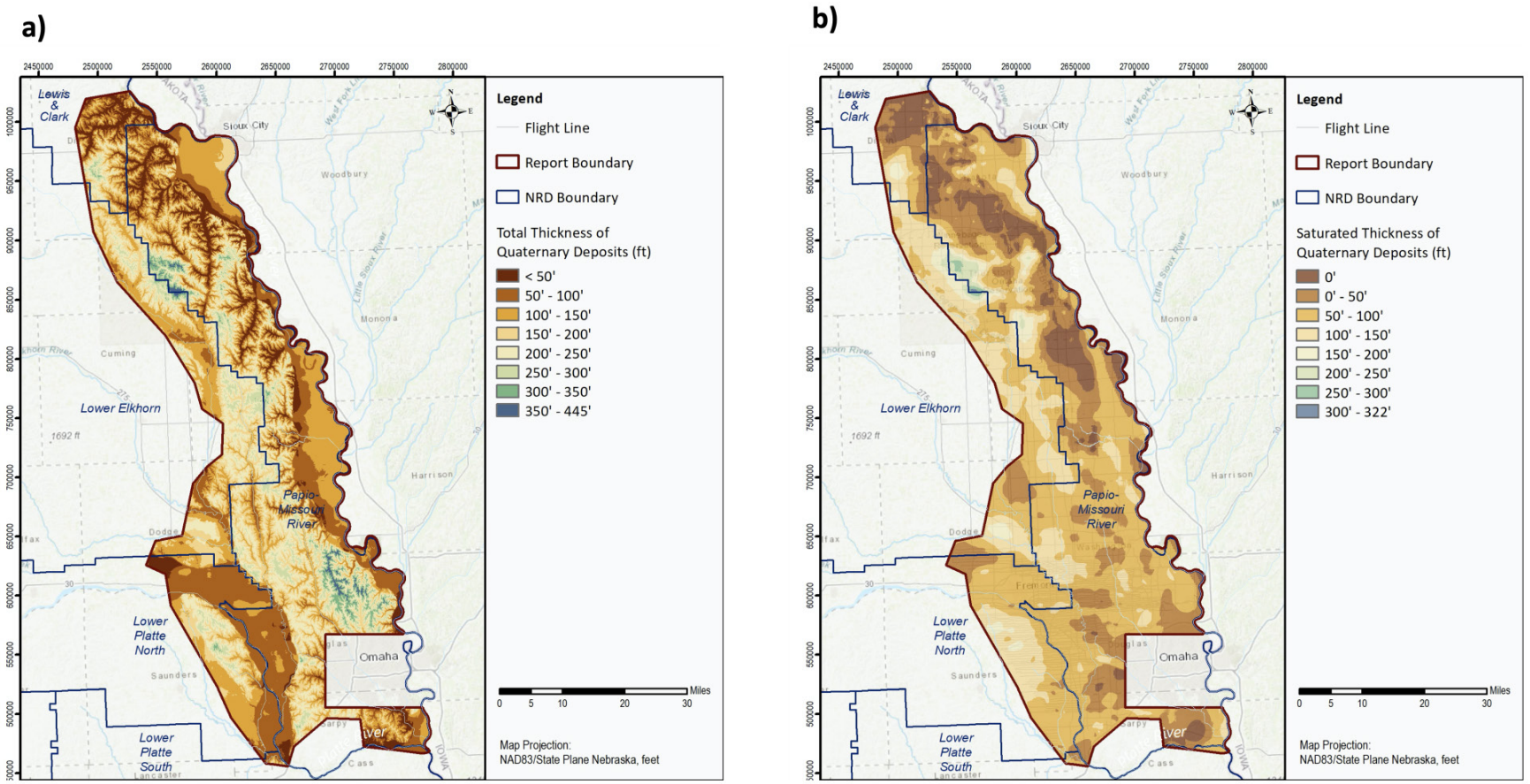


Figure 5-92. a) P-MRNRD Regional map of Total Thickness of Quaternary (Q) Deposits (ft) and b) Saturated Thickness of Quaternary Deposits (ft) of the P-MRNRD.

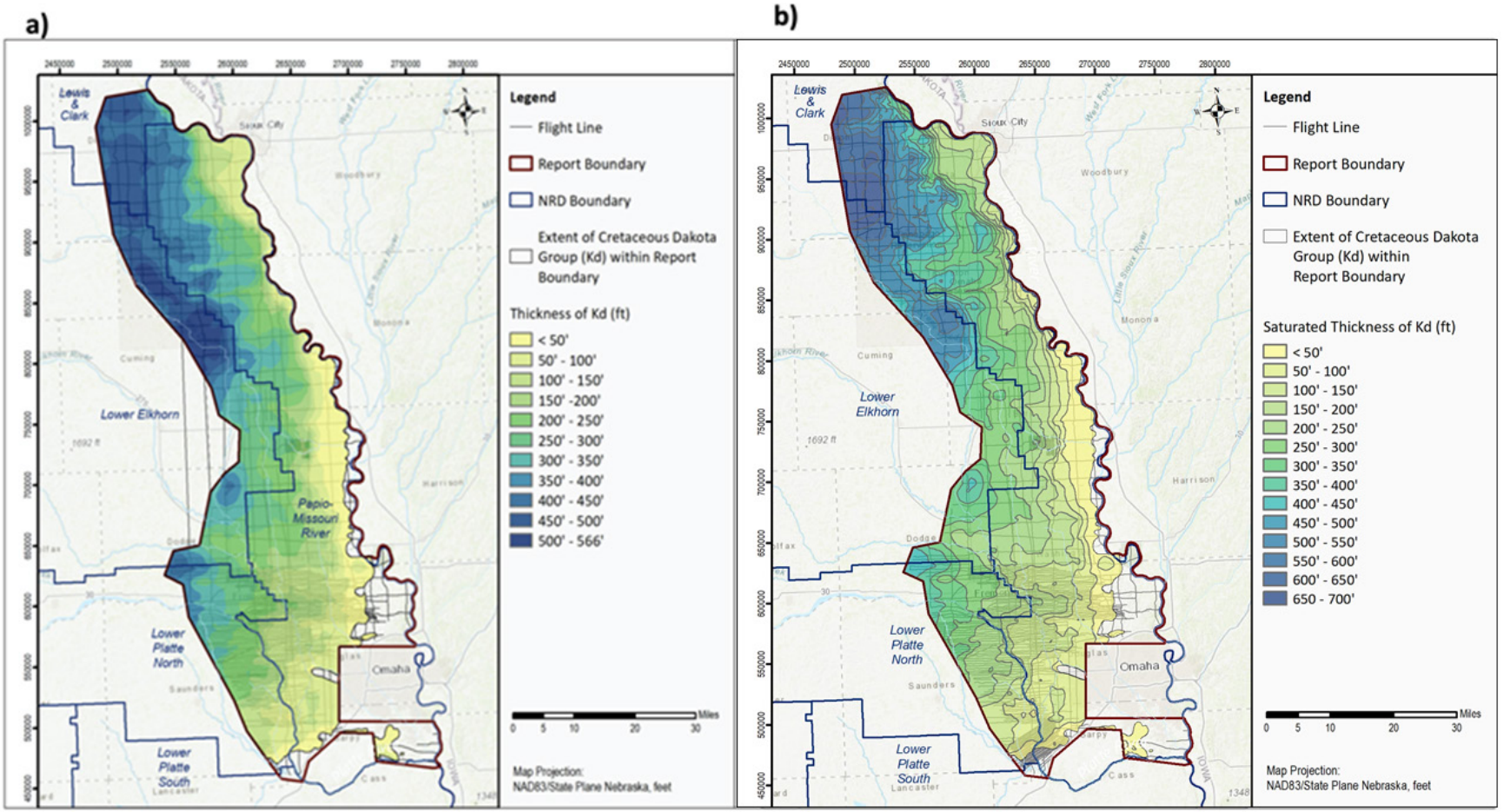


Figure 5-93. a) P-MRNRD Regional map of Total Thickness of Cretaceous Dakota Group (Kd) (ft) and b) Saturated thickness of the Kd (ft)

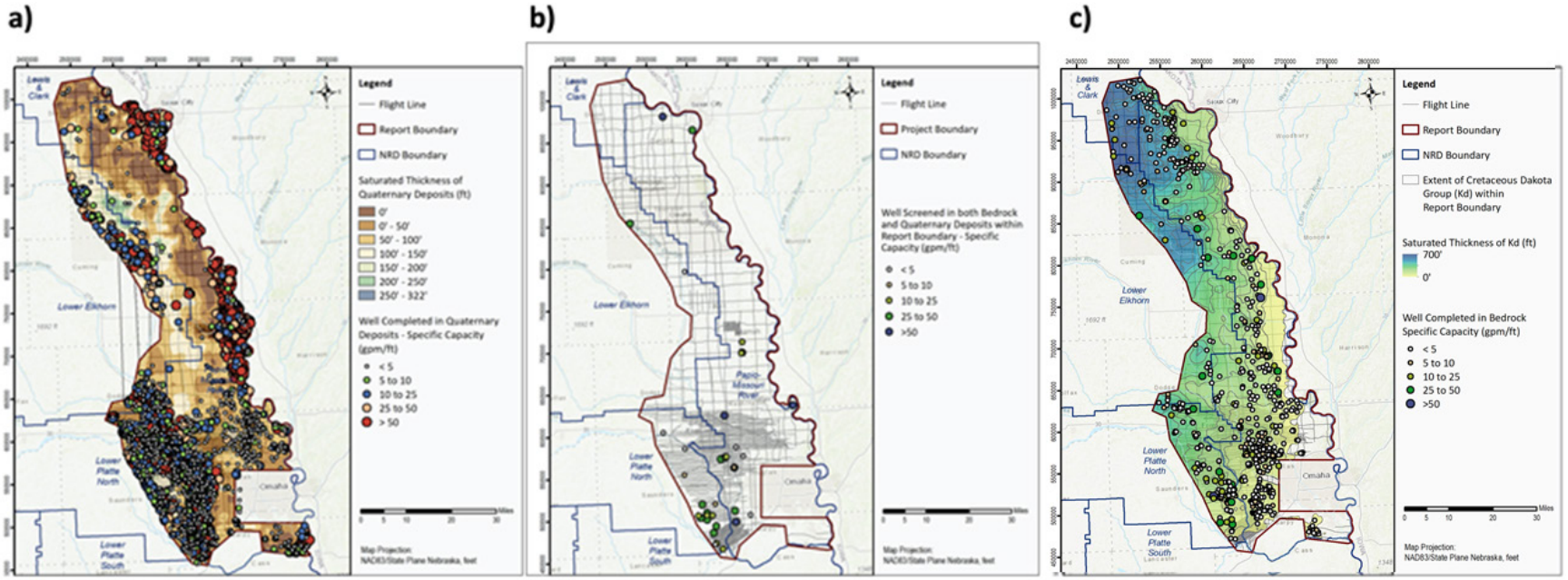


Figure 5-94. a) P-MRNRD Regional map of Saturated Thickness of Quaternary Deposits (ft) with wells completed in Quaternary Deposits - Specific Capacity (gpm/ft), b) location of the dual competed well is both the Q and the Cretaceous Dakota Group (Kd) and c) Saturated Thickness of Kd with wells completed in Bedrock -Specific Capacity (gpm/ft).

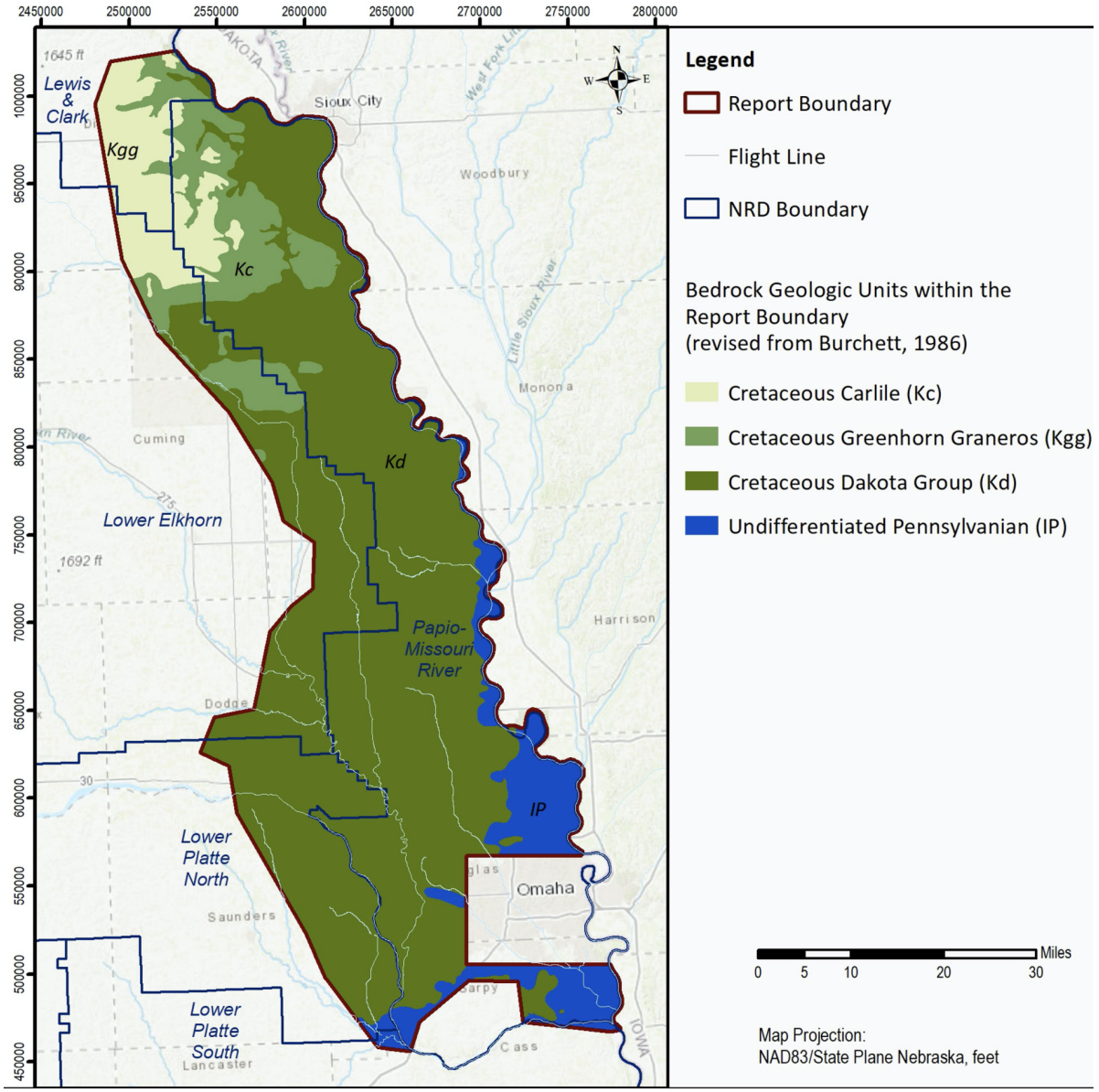


Figure 5-95. AGF Revised Bedrock Geology Map of the P-MRNRD.

5.4 Recharge Areas in the P-MRNRD 2020 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. A new 40-layer model (previous work used a 30-layer model) was developed for the layer inversions and interpretations for the P-MRNRD. From these interpretations a new series of near-surface maps were constructed for the Tekamah Block AEM flight area that include the layer intervals from 0 to 6 ft. This surface model layer is shown because it provides a visualization of whether the sediments are made up of aquifer material (brown - “good”) to coarse aquifer material (blue - “very good”). From the discussion around the inverted earth mode, each model layer represents an average of the earth’s resistivities within those depths, based on the physics of the electromagnetic exploration technique. The first layer map shows aquifer materials and indicates the areas at the land surface and just below that can potentially transmit water to the groundwater aquifers in the area. The coarse aquifer material can transmit the largest volume of water. There is not always a direct path downwards to the aquifer from the land surface. Often there is no path available for the water to move through. Figure 5-96 shows the potential for recharge in layer 1, 0 to 6 ft over the whole of the P-MRNRD merged survey area. The northern part of the merged survey area is presented in Figure 5-97, the central portion in Figure 5-98, and the southern portion, including the re-inverted Ashland area, is presented in Figure 5-99. What these maps do not do is show the slopes and the rates of possible recharge, but only show the materials within the first 6 feet. What can be seen is the clay and silt layer that is along the western area of the Missouri River Flood plain east of Tekamah.

The recharge layer shown is included as a Google Earth kmz in Appendix 3-Deliverables\KMZ\ Recharge.

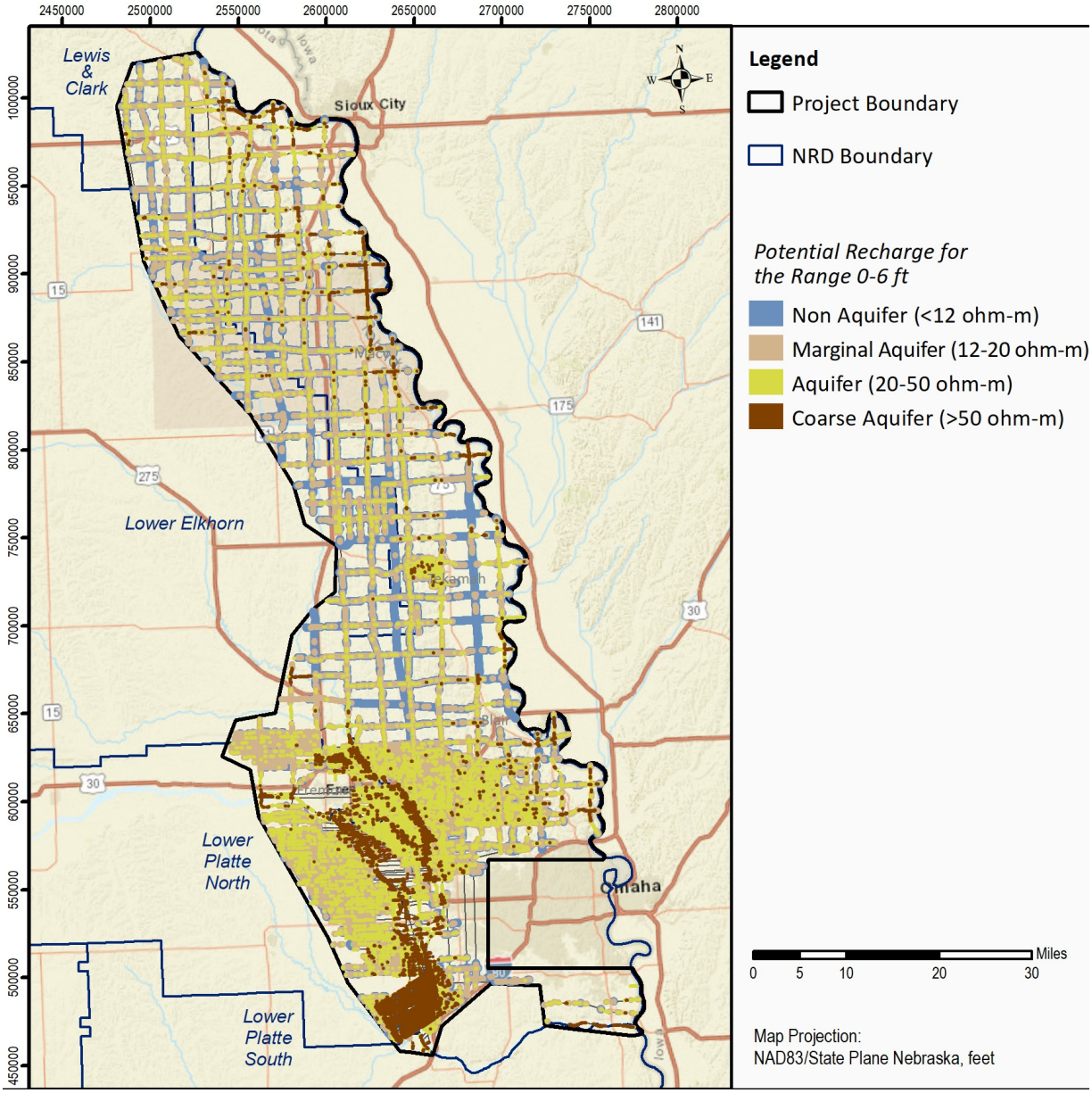


Figure 5-96. Google Earth image of potential recharge for the range 0-6 ft (AEM inversion model layer 1) within the 2020 P-MRNRD AEM flight area. This kmz included in Appendix 3-Deliverables\KMZ\Recharge.

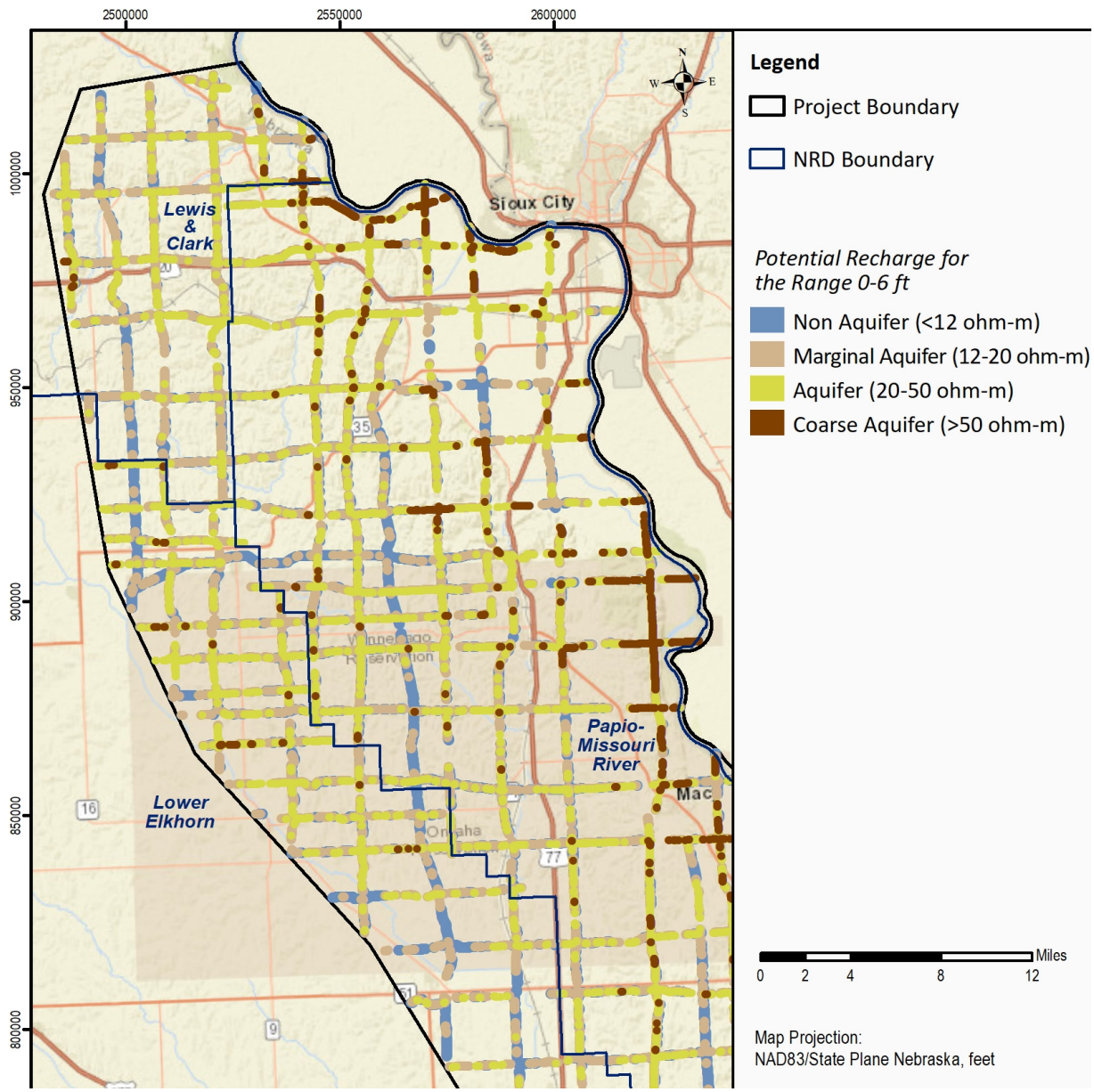


Figure 5-97. Google Earth image of potential recharge for the range 0-6 ft (AEM inversion model layer 1) within the northern portion of the 2020 P-MRNRD AEM flight area. This kmz included in Appendix 3-Deliverables\KMZ\Recharge.

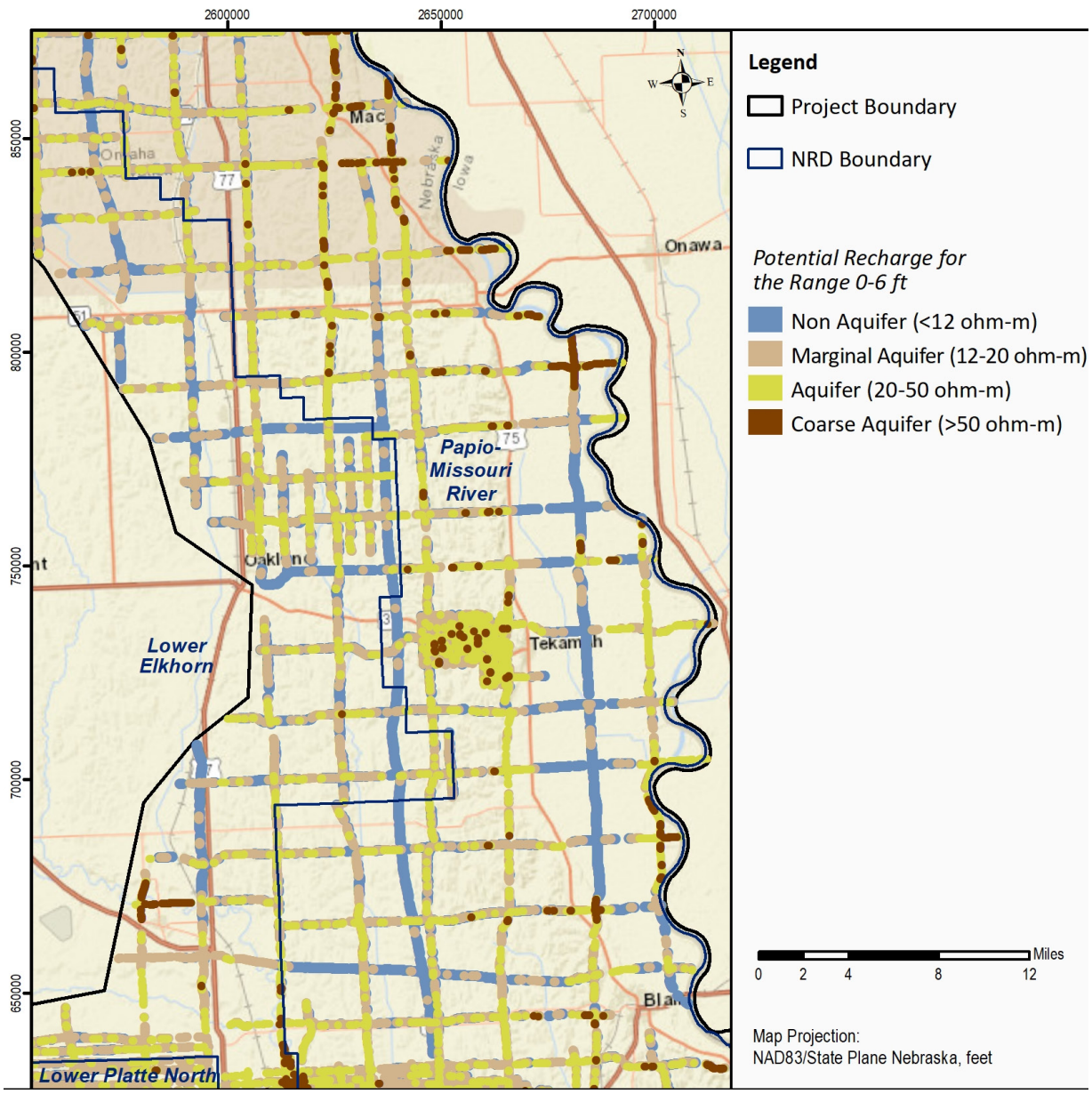


Figure 5-98. Google Earth image of potential recharge for the range 0-6 ft (AEM inversion model layer 1) within the central portion of the 2020 P-MRNRD AEM flight area. This kmz included in Appendix 3-Deliverables\KMZ\Recharge.

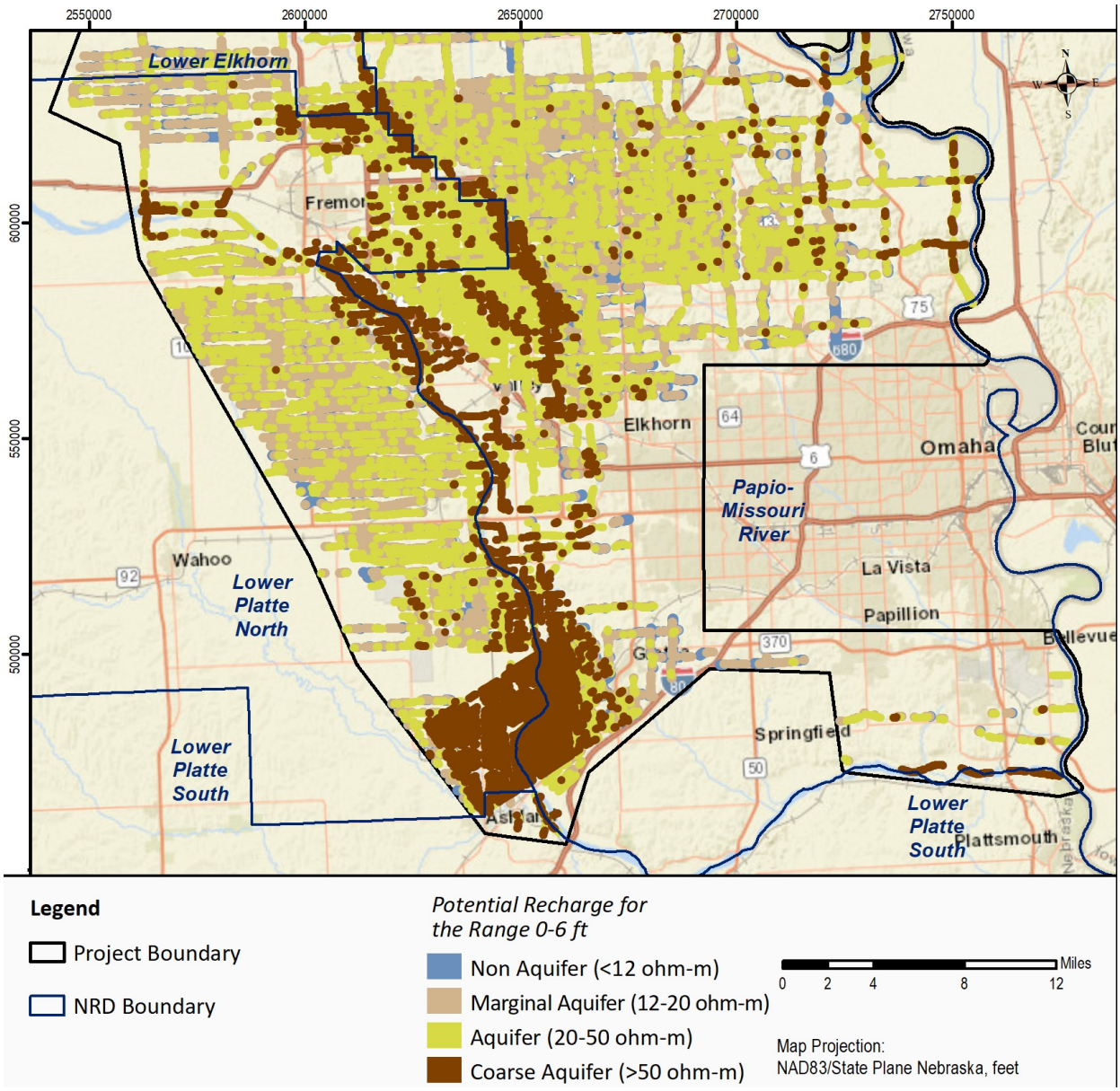


Figure 5-99. Google Earth image of potential recharge for the range 0-6 ft (AEM inversion model layer 1) within the southern portion of the 2020 P-MRNRD AEM flight area. This kmz included in Appendix 3-Deliverables\KMZ\Recharge.

5.5 Key AEM Findings

5.5.1 Boreholes

Information from boreholes was used to analyze the AEM inversion results and was important for all areas in the P-MRNRD. The top of the undifferentiated Pennsylvanian (***IP***) was a challenging unit to interpret due to the highly variable resistivity of the ***IP.*** Top of the bedrock for the area was developed by inspection of the borehole logs that included consolidated geologic units and CSD (Nebraska Conservation and Survey Division) bedrock contacts. The Cretaceous Carlile (***Kc***) and the Cretaceous Greenhorn Limestone and Graneros Shale ***(Kgg)*** only occurred in the northern reconnaissance lines. The CSD stratigraphic control was utilized to distinguish the ***Q*** from the underlying ***Kc*** and ***Kgg***. Contacts between the Quaternary (***Q***) and Cretaceous Dakota Group (***Kd***) often had limited or no contrast in the electrical resistivity between the different geologic formations. Use of CSD stratigraphy calls and the presence of sandstone and shale in the NE- DNR (Nebraska Department of Natural Resources) registered wells were used to pick the **Q/Kd** contact when no resistivity contrast was present. The dependence on just boreholes for geologic interpretation also has its limitations because sometimes the boreholes are wrong, improperly located, have improper stratigraphic/lithology picks, and/or other errors. These errors in the boreholes are usually encountered in the NE-DNR registered wells. Very rarely inconsistencies are encountered in the oldest of the NE- CSD wells. The limited errors in the CSD wells may very well be due to poor positioning from a time before GPS and modern survey methods. As a guide in the interpretation of the AEM, a bedrock surface was prepared using the of CSD and NE-DNR borehole logs. As in all surveys of this nature the use of boreholes with AEM needs to be approached in a thoughtful and considered manner as to the value of information from an individual borehole.

5.5.2 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 Group (***Kd***), and undifferentiated Pennsylvanian (***IP***). For the three northernmost flight lines the Cretaceous Carlile (***Kc***) and the Cretaceous Greenhorn Limestone and Graneros Shale ***(Kgg)*** were picked in a similar manner. The interpretive process benefited from the use of CSD and NE-DNR borehole logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including the Quaternary aquifer material mapping is included in the appendices as well as interpretative surface grids.

5.5.3 Resistivity/Lithology Relationship

Assessment of the sediment character in the Quaternary aquifer system and the bedrock strata 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 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). This allowed for the characterization of the Quaternary ranges of resistivities present in this report. The Cretaceous Dakota Group within the P-MRNRD was split into three parts based on empirical comparisons to lithology logs. Less than 18 ohm-m was classified as Shale/Clay Dominant materials, 18 to 35 as Siltstone/Silt Dominant materials, and 35 and greater as Sandstone/Sand Dominant materials. This is a modification of the splits that were used in the previous P-MRNRD reports with the of the addition of the Siltstone/silt Dominate class. Additional unpublished work in the Eastern Nebraska using AEM data has led to a better understanding of the resistivity versus lithology within the Cretaceous Dakota Group. Lacking quality geophysical well logs in the Cretaceous Dakota Group (loke those that exist in the Quaternary) makes it difficult to produce a more robust statistical distribution of the resistivity versus lithology as was done for the Quaternary materials.

5.5.4 Hydrogeological Framework of the P-MRNRD

The Southern Block is dominated by the Todd Valley on the west and the central portion by the Platte River Valley and associated Elkhorn River Valley. The eastern portions of the Southern Block are dominated by loess and glacial till of the Rolling Hills. The Todd Valley and Platte Valleys are separated by an island of loess and glacial till. There are connections in the subsurface at the northern and southern ends of the Todd Valley with the Platte River. Numerous productive wells exist in the regions of the Todd Valley and the Platte Valley. The Cretaceous Dakota Group within the area contains predominantly Siltstone/Silt Dominant materials but there is a large area of Sandstone/Sand Dominant material that several wells produce out of but with lower specific yields then the overlying Quaternary. There are also a few wells screened in both the Sandstone/Sand Dominant material and the thicker Quaternary materials within the Southern Block.

The Arlington Block is bounded on the west by the Elkhorn River and trends east encompassing a previously mapped paleochannel. The area is dominated by loess and glacial Rolling Hills. Beginning at the bluffs along the Elkhorn River and continuing east southeast through the town of Arlington a package of aquifer materials exists directly on the Cretaceous Dakota Group bedrock depression. Toward Arlington there are several wells that are completed in the unit and produce well with good specific yields. Along the length of the paleochannel, the extent was revised by the AEM as several areas have little to no aquifer material. This is typical of pre-Pleistocene channels that have had Pleistocene glacial forces and other events scour the aquifer from the paleochannel. Other mapping within eastern Nebraska has also indicated this Architectural Type I channel (Korus et al., 2016). There are strong ties with the paleochannel on the western end of the Block and the Elkhorn River. The Cretaceous Dakota Group within the Arlington Block is not very productive as much of the material is Siltstone/Silt Dominant, but some wells are completed in the Dakota with lower specific capacities.

Mapping in the area of the Tekamah Block was extended to the west of the 2018 flight Block to encompass the proposed "Composite Catchment Zone" as defined by LRE (2019). This area is dominantly composed of thin unsaturated Quaternary non and marginal aquifer material overlying the shallow Cretaceous Dakota Group Siltstone/Silt and Shale/Clay Dominant materials. Very few wells exist in the area with low specific capacities. There would seem to be very low connection in the Dakota Aquifer from the west to the east side of the Tekamah Block. The eastern end of the Tekamah Block contains Dakota Sandstone/Sand Dominant material that wells produce from.

The Northern Area of the P-MRNRD is composed of reconnaissance lines only. The northern-most regions also contain Cretaceous Carlile and Cretaceous Greenhorn Limestone and Graneros Shale which are both not considered aquifers. Both of these units are heavily eroded. The Quaternary units in the area are of three general types 1) loess and glacial tills containing non- and marginal aquifer materials; 2) Missouri River alluvial deposits; and 3) small areas of paleochannel deposits of aquifer materials under the loess and glacial till. The loess and glacial tills form the backbone of the district and fall along the topographic high separating the LENRD and the P-MRNRD. There are few wells in the area and low specific capacity in the wells that are there. These materials form a strong barrier of flow across those materials. The Missouri River alluvium materials are aquifer and coarse aquifer material deposited on the underlying Cretaceous Dakota and Undifferentiated Pennsylvanian units. In the western portions of the Missouri River flood plain east of Tekamah a clay and silt zone overlies the aquiver material forming a confined aquifer conditions. Under the loess and glacial till there are selected areas of aquifer material that are not well defined by the reconnaissance lines, but may be related to paleochannels. Some of the aquifer material areas are in depressions in the bedrock and others are in areas previously identified as paleochannel systems. These areas do not look to be major aquifers or conduits to groundwater flow as they are not well defined by the specific capacity data from the NE-DNR registered well database.

5.5.5 Potential Recharge Zones within the P-MRNRD 2020 AEM Survey Area

The use of block flights in the Southern Area and Tekamah area illustrates the preferred method of using AEM to identify areas where the potential for recharge to the aquifer can be high and low. Locations where the flight lines are closely spaced showing either aquifer or coarse aquifer material at the land surface 0-6 feet should be considered as locations for higher likelihood for recharge because of the 2D and 3D spatial nature of the aquifer material distribution. The opposite is also true where AEM data analysis shows non-aquifer or marginal aquifer material; Those areas will likely not be optimal recharge locations. These maps do not provide infiltration rates as no slopes are used and no calculations are made of the rates. The maps do provide a good indication of the silt and clay layer and boundary to recharge on the western side of the Missouri River Flood Plain.

Within the reconnaissance AEM flight area of the P-MRNRD, the highest rate of recharge can be expected along the river and stream valleys due to the presence of aquifer and coarse aquifer

materials from the land surface down to the water table and beyond. Areas with aquifer and coarse aquifer materials at the surface can also become conduits for infiltration of nitrates into the groundwater system. These areas exist in the river and stream areas of the survey area where the reconnaissance lines are the basis for this determination. It should be noted that in these areas the results shown in the recharge maps are based on actual AEM data. A potential solution for any nonpoint source water quality contamination is adding additional fresh surface water as recharge to select areas of rangeland that can dilute any potential nitrate contaminant problem occurring from cropland. Additional work can be done to identify where the best locations are for these type of management efforts. The current recharge analysis allows for more accurate representation of the aquifer materials in the first 6 feet from the land surface downward.

5.5.6 Integration of historical AEM data

The reinversion of the Ashland data and the integration and merging of the historical data provide a marked enhancement in the ability to interpret the P-MRNRD AEM data. As many lines in the area were originally reconnaissance lines and/or ended at the boundaries of the NRD, the merging provided a full view of the sections. The ability to integrate the edges of the district provides a much more robust interpretation of the geological surfaces and extent of the geological and aquifer materials. The enhanced calibration and inversion of the Ashland Block also provided a seamless integration into the data collected in following years.

5.6 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.

5.6.1 Additional AEM Mapping

The hydrogeologic maps provided in this report represent the completed hydrogeologic framework developed for the P-MRNRD at a reconnaissance level within the Northern Area with approximately 3-mile spacing between flight lines, and the detailed mapping of the Southern Block and the Tekamah Block flight areas. The District is virtually covered in reconnaissance level mapping. Further AEM flights should be focused on areas of well head protection and/or water development as required. Tekamah is a great example of well head protection-level data acquisition. Other areas of interest may include the mapping of the potential paleochannels that were identified under the loess and till in the Northern Area. While these areas are not the large channel systems seen in the Todd Valley, they may provide local water sources for future development. Future data collection around the metropolitan area of Omaha is limited due to the infrastructure and rapid growth within the area.

5.6.2 *Update the Water Table map*

The groundwater data used in the analyses presented in this report utilized the 1995 CSD water table map which is now 26 years old. Additional water level measurement locations would improve the water table map where groundwater conditions are unconfined. The areas of glacial till and loess covering the parts of the district will need great care in developing a water level map of potentiometric heads due to the confined to semiconfined nature of the area. Use of the data collected in this survey and future surveys will provide the best possible water table and conditions map for the district.

5.6.3 *Siting new test holes and production wells*

The AEM hydrogeological framework profiles, maps, and surfaces provided in this report provide great 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 P-MRNRD area was used in building the framework maps and profiles. Additional information from previous groundwater reports were helpful in this work. 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 more 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. A good example of this would be confined aquifers with large volumes of coarse aquifer and aquifer material with minimal sedimentary boundary conditions. The previous AEM studies have already found use by CSD and local well drillers to locate test wells and production wells within the P-MRNRD.

5.6.4 *Aquifer testing and borehole logging*

Aquifer tests are recommended to improve estimates of aquifer characteristics. Limited aquifer properties from previous reports 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. Examples of additional logging would be flow meter logs and geophysical logs including gamma, neutron, electrical, and induction logs. Detailing aquifer characteristics can be accomplished with nuclear magnetic resonance logging (NMR) at a reduced cost when compared to traditional aquifer tests. 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.

5.6.5 Recharge Zones

The P-MRNRD hydrogeologic framework in this report provides areas of recharge from the ground surface to the groundwater aquifer in the Block flights and along the reconnaissance lines. The area of the Missouri River would benefit from additional AEM data acquisition to define the extent and character of the silt and clay layer that is observed on the western end of the Missouri River flood plain. As discussed above assessing the recharge area for wellhead protection would also benefit from AEM infill lines.

5.6.6 Managed Aquifer Recharge

The areas which may have potential for managed aquifer recharge (MAR) can be approximately located by the interpreted results from AEM reconnaissance line interpretations. Detailed analysis for this purpose would need to be done to determine where viable opportunities for the P-MRNRD exist and what additional information would be required for final selections of MAR sites. A detailed plan for locating and developing MAR sites would be beneficial to the P-MRNRD for storage and release of water for stream flow and other uses.

5.6.7 Updating previous groundwater reports and Groundwater Management Plans

The NRD's groundwater reports and management plans should be updated with the AEM information to make them a more comprehensive set of publications. Should future AEM work be completed, the results from that effort will help guide the future groundwater management plans for the district. The addition of estimates of groundwater in storage, recharge areas, hydrologic connection to streams and consideration of managed aquifer recharge sites will greatly improve groundwater management planning.

6 Description of Data Delivered

6.1 Tables Describing Included Data Files

Table 6-1 describes the raw data files included in Appendix 3_Deliverables \Raw_Data. As discussed above, fifteen (15) flights were required to acquire the P-MRNRD AEM data (Figure 4-5). Grouped by flight date, there are four (4) data flies included in Appendix 3\Raw_Data 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 have 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") in the GEO subdirectory and the 'mask' file (with the extension "*.lin"), in the MASK subdirectory, which correlates the flight dates, flight numbers, and assigned line numbers.

Table 6-2 describes the data columns in the ASCII *.xyz file PMRNRD2020_EM_MAG_AUX.xyz. 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 PMRNRD2020_AEM_SCI_INV_v1.xyz and the data columns of these databases are described in Table 6-3.

The interpretation results are included in the data file PMRNRD2020_InterpSurfaces.xyz in ASCII format. Table 6-4 describes the data columns of those files.

A table of data has been compiled (Table 6-5) that lists, model layer by model layer, the top, middle, and bottom depths and elevations of each model cell layer along with the inverted model resistivity for that cell. The format of the voxel grids that have been created from the AEM data in the Tekamah Block, Arlington Block, and Southern Block are described in Table 6-6. The voxel grids are presented as xyz files.

ESRI ArcGIS raster grids of the surfaces (.flt format) 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 6-7. And stored in Appendix 3_Deliverables\Grids. In addition, data files with Geocloud formats are included in Appendix 3_Deliverables\Geocloud. The format is listed in Table 6-8.

In summary, the following are included as deliverables:

- Raw Data Files - SkyTEM files *.gex, *skb, *.lin (Table 6-1)
- Raw EM Mag data as ASCII *.xyz (Table 6-2)
- SCI inversion as ASCII *.xyz in array and an individual column format by model layer (Table 6-3, Table 6-5)
- Interpretations as ASCII *.xyz (Table 6-4, Table 6-9)
- ESRI ArcView files – surface, topo, flt (Table 6-7)
- Voxel Grids of the Tekamah, Arlington, and Southern Blocks, *.xyz (Table 6-6)
- 2D profiles, Surfaces, and 3D fence diagrams of the AEM survey inversion results
- Files compatible with the Nebraska Geocloud (Table 6-8)
- Shape files of relevant features and extents within the P-MRNRD (Table 6-10)
- KMZs for P-MRNRD AEM flight lines (Discussed in Section 6.2).

Table 6-1. 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	20200820_20016_PMNRD_SkyTEM304_SKB.gex 20200820_20016_PMNRD_SkyTEM304_SR2.gex 20200820_20016_PMNRD_SkyTEM304_SR2.sr2	304M System Description
Mask	20200930_Nebraska_AGF_PMNRD_Prod.lin	Production file listing dates, flights, and assigned line numbers

Table 6-2: Channel name, description, and units for PMRNRD2020_EM_MAG_AUX.xyz with DEM, 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_m	Easting, NAD83 UTM Zone 14N	Meters [m]
N_UTM14N m	Northing, NAD83 UTM Zone 14N	Meters [m]
E_NESP83_ft	Easting, NAD83 Nebraska State Plane	Feet [ft]
N_NESP83N_ft	Northing, NAD83 Nebraska State Plane	Feet [ft]
DEM	Digital Elevation	Meters [m]
Alt	DGPS Altitude above sea level	Meters [m]
GDSpeedL	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 values array	$pV/(m^4*A)$
HMZ_G01	Normalized (PFC-Corrected) High Moment Z-RxCoil values array	$pV/(m^4*A)$
HMX_G01	Normalized (PFC-Corrected) High Moment X-RxCoil values array	$pV/(m^4*A)$
PLNI	Power Line Noise Intensity monitor	V/m^2
Bmag	Raw Base Station Mag Data filtered	nanoTesla [nT]
Diurnal	Diurnal Mag Data	nanoTesla [nT]
MAG_Raw	Raw Mag Data	nanoTesla [nT]
DEC	Magnetic Declination	nanoTesla [nT]
INC	Magnetic Inclination	nanoTesla [nT]
IGRF	Magnetic IGRF regional field	nanoTesla [nT]

RMF	Residual Magnetic Field	nanoTesla [nT]
TMI	Total Magnetic Intensity	nanoTesla [nT]

Table 6-3. Channel name, description, and units for PMRNRD2020_AEM_SCI_INV_v1.xyz with EM inversion results.

/Parameter	Description	Unit
LINE	Line Number	
East_NESP83FT	Easting NAD83, Nebraska State Plane	Feet (ft)
North_NESP83FT	Northing NAD83, Nebraska State Plane	Feet [ft]
DEM_FT	DEM from 100 ft grid NED NAVD88	Feet [ft]
East_UTM_M	Easting NAD83, UTM Zone 14	Meters [m]
North_UTM_M	Northing NAD83, UTM Zone 14	Meters [m]
DEM_M	DEM from survey	Meters [m]
ALT_M	Altitude of system above ground	Meters [m]
INVALT_M	Inverted Altitude of system above ground	Meters [m]
RESDATA	Residual of individual sounding	
RESTOTAL	Total residual for inverted section	
RHO_I_0 THROUGH RHO_I_38	Inverted resistivity of each layer	Ohm-m
RHO_I_STD_0 THROUGH RHO_I_STD_38	Inverted resistivity error per layer	
SIGMA_I_0 THROUGH SIGMA_I_38	Conductivity	S/m
DEP_TOP_0_FT THROUGH DEP_TOP_38_FT	Depth to the top of individual layers	Feet [ft]
DEP_BOT_0_FT THROUGH DEP_BOT_38_FT	Depth to the bottom of individual layers	Feet [ft]
THK_0_FT THROUGH THK_38_FT	Thickness of individual layers	Feet [ft]
DEP_TOP_0_M THROUGH DEP_TOP_38_M	Depth to the top of individual layers	Meters [m]
DEP_BOT_0_M THROUGH DEP_BOT_38_M	Depth to the bottom of individual layers	Meters [m]
THK_0_M THROUGH THK_38_M	Thickness of individual layers	Meters [m]
DOI_UPPER_FT	More conservative estimate of DOI	Feet [ft]
DOI_LOWER_FT	Less conservative estimate of DOI	Feet [ft]
DOI_UPPER_M	More conservative estimate of DOI	Meters [m]
DOI_LOWER_M	Less conservative estimate of DOI	Meters [m]

Table 6-4. Channel name description and units for the interpretation results files PMRNRD2020_InterpSurfaces.xyz.

Parameter	Description	Unit
LINE	Line Number	
East_M	Easting NAD83, UTM Zone 14N	Meters (m)
North_M	Northing NAD83, UTM Zone 14N	Meters (m)
East_ft	Easting NAD83, Nebraska State Plane	Feet [ft]
North_ft	Northing NAD83, Nebraska State Plane	Feet [ft]
DEM_ft	Topography at 100ft sampling (NAVD 1988)	Feet [ft]
RHO [0] through RHO [38]	Array of Inverted model resistivities of each layer	Ohm-m
RESDATA	Inversion model residuals of each individual sounding	
RESTOTAL	Inversion model average of all residuals	
DEP_TOP_FT [0] through DEP_TOP_FT [38]	Depth to the top of 39 individual layers	Feet [ft]
DEP_BOT_FT [0] through DEP_BOT_FT [38]	Depth to the bottom of 39 individual layers	Feet [ft]
DOI_UPPER_FT	More conservative estimate of DOI from Workbench	Feet [ft]
DOI_LOWER_FT	Less conservative estimate of DOI from Workbench	Feet [ft]
SoilRecharge	1 = Surficial layer Non-Aquifer; 2 = Marginal; 3 = Aquifer; 4 = Coarse Aquifer Material	
WaterTable1995	Elevation of the top of the water table from the Nebraska School of Natural Resources Configuration Report, 1995.	Feet [ft]
NAT[0] through NAT[38]	Array of model cell top elevations of the Non-Aquifer Material (<12 ohm-m), if present	Feet [ft]
NAB[0] through NAB[38]	Array of model cell bottom elevations of the Non-Aquifer Material (<12 ohm-m), if present	Feet [ft]
ThkTot_NAq	Total Thickness of Non-Aquifer Material (<12 ohm-m) above bedrock	Feet [ft]
ThkWT_NAq	Total Thickness of Non-Aquifer Material (<12 ohm-m) below the water table and above bedrock	Feet [ft]
MAT[0] through MAT[38]	Array of model cell top elevations of the Marginal-Aquifer Material (12 - 25 ohm-m), if present	Feet [ft]
MAB[0] through MAB[38]	Array of model cell bottom elevations of the Marginal-Aquifer Material (12 - 25 ohm-m), if present	Feet [ft]
ThkTot_MAq	Total Thickness of Marginal-Aquifer Material (12 - 25 ohm-m) above bedrock	Feet [ft]
AMT[0] through AMT[38]	Array of model cell top elevations of the Aquifer Material (25 - 40 ohm-m), if present	Feet [ft]
AMB[0] through AMB[38]	Array of model cell bottom elevations of the Aquifer Material (25 - 40 ohm-m), if present	Feet [ft]

ThkTot_AqM	**Total Thickness of Aquifer Material (25 - 40 ohm-m) above bedrock**	**Feet [ft]**
CAT[0] through CAT[38]	**Array of model cell top elevations of the Coarse Aquifer Material (>40 ohm-m), if present**	**Feet [ft]**
CAB[0] through CAB[38]	**Array of model cell bottom elevations of the Coarse Aquifer Material (>40 ohm-m), if present**	**Feet [ft]**
ThkTot_CAq	**Total Thickness of Coarse Aquifer Material (>40 ohm-m) above bedrock**	**Feet [ft]**
ThkTot_Aq_CA	**Sum of Total Thicknesses of Aquifer Material (25 - 40 ohm-m) and Coarse Aquifer Material (>50 ohm-m) above bedrock**	**Feet [ft]**
ThkWT_Aq_CA	**Sum of Total Thicknesses of Aquifer Material (25 - 40 ohm-m) and Coarse Aquifer Material (>40 ohm-m) below the water table and above bedrock**	**Feet [ft]**
Elevation Bedrock	**Elevation of interpreted Bedrock surface**	**Feet [ft]**
Kc	**Cretaceous Carlile Formation**	**Feet [ft]**
Kgg	**Cretaceous Greenhorn Shale, Graneros Limestone**	**Feet [ft]**
Kd	**Cretaceous Dakota Group**	**Feet [ft]**
IP	**Pennsylvanian, Undifferentiated**	**Feet [ft]**

Table 6-5. P-MRNRD Inverted Model Structure with DEM and Layer Top-, Bottom-, and Mid-points in Depth and Elevation plus Inverted Cell Resistivities (PMRNRD2020_XYDEM_Dep_Elev_Rho.xyz).

Parameter	Description	Unit
Line	Line number	
East_ft	Easting NAD83, Nebraska State Plane	Feet [ft]
North_ft	Northing NAD83, Nebraska State Plane	Feet [ft]
DEM_ft	Topography at 100ft sampling (NAVD 1988)	Feet [ft]
Dep_Top_ft		Feet [ft]
Dep_Mid_ft		Feet [ft]
Dep_Bot_ft		Feet [ft]
Elev_Top_ft		Feet [ft]
Elev_Mid_ft		Feet [ft]
Elev_Bot_ft		Feet [ft]
RHO	Cell Resistivity	Ohm-m

Table 6-6. Channel name, description, and units for ArlingtonBlockVoxelXYZData.xyz, TekamahBlockVoxelXYZData.xyz, SouthernBlockVoxelXYZData.xyz.

Parameter	Description	Unit
X	Easting NAD83, State Plane Nebraska	feet [ft]
Y	Northing NAD83, State Plane Nebraska	feet [ft]
Z	Depth of Voxel Node	feet [ft]
Resistivity	Voxel cell resistivity value	Ohm-m

Table 6-7. Files containing ESRI ArcGIS Raster Grids *.flt (Nebraska State Plane, NAD83, feet)

Grid File Name	Description	Grid Cell Size (feet)
PMRNRD_DEM_ft	Digital Elevation Model (ground surface elevation) (NAVD88 feet) of the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_WaterTable_1995	Elevation (NAVD88 feet) of water table (1995) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TopEle_Kc	Elevation (NAVD88 feet) of top of Cretaceous Carlile (Kc) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TopEle_Kgg	Elevation (NAVD88 feet) of top of Cretaceous Greenhorn Graneros (Kgg) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TopEle_Kd	Elevation (NAVD88 feet) of top of Cretaceous Dakota Group (Kd) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TopEle_IP	Elevation (NAVD88 feet) of top of Undifferentiated Pennsylvanian (IP) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TopEle_Bedrock	Elevation (NAVD88 feet) of top of bedrock for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TotalThickness_Q	Thickness (feet) of Quaternary Deposits for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TotalThickness_Kc	Thickness (feet) of Cretaceous Carlile (Kc) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TotalThickness_Kgg	Thickness (feet) of Cretaceous Greenhorn Graneros (Kgg) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_TotalThickness_Kd	Thickness (feet) of Cretaceous Dakota Group (Kd) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_SaturatedThickness_Q	Saturated Thickness (feet) of Quaternary Deposits for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
PMRNRD_SaturatedThickness_Kd	Saturated Thickness (feet) of Cretaceous Dakota Group (Kd) for the PMRNRD survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_AquiferCoarse_SaturatedThickness	Saturated Thickness (feet) of Quaternary aquifer/coarse material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_AquiferCoarse_TotalThickness	Total Thickness (feet) of Quaternary aquifer/coarse material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Marginal_SaturatedThickness	Saturated Thickness (feet) of Quaternary marginal material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Marginal_TotalThickness	Total Thickness (feet) of Quaternary marginal material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_NonAquiferMarginal_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer/marginal material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_NonAquiferMarginal_TotalThickness	Total Thickness (feet) of Quaternary non aquifer/marginal material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_NonAquifer_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_NonAquifer_TotalThickness	Total Thickness (feet) of Quaternary non aquifer material for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Kd_SandSandstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100

TekamahBlock_Kd_SandSandstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Kd_SiltSiltstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Kd_SiltSiltstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Kd_ShaleClayDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
TekamahBlock_Kd_ShaleClayDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Tekamah Block survey area, NAD83/State Plane Nebraska, feet	100
Arlington_AquiferCoarse_SaturatedThickness	Saturated Thickness (feet) of Quaternary aquifer/coarse material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_AquiferCoarse_TotalThickness	Total Thickness (feet) of Quaternary aquifer/coarse material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Aquifer_SaturatedThickness	Saturated Thickness (feet) of Quaternary aquifer material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Aquifer_TotalThickness	Total Thickness (feet) of Quaternary aquifer material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Coarse_SaturatedThickness	Saturated Thickness (feet) of Quaternary coarse material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Coarse_TotalThickness	Total Thickness (feet) of Quaternary coarse material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_NonAquiferMarginal_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer/marginal material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_NonAquiferMarginal_TotalThickness	Total Thickness (feet) of Quaternary non aquifer/marginal material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_NonAquifer_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_NonAquifer_TotalThickness	Total Thickness (feet) of Quaternary non aquifer material for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_SandSandstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_SandSandstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_SiltSiltstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_SiltSiltstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_ShaleClayDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
Arlington_Kd_ShaleClayDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Arlington survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_AquiferCoarse_SaturatedThickness	Saturated Thickness (feet) of Quaternary aquifer/coarse material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_AquiferCoarse_TotalThickness	Total Thickness (feet) of Quaternary aquifer/coarse material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300

SouthernBlock_Aquifer_SaturatedThickness	Saturated Thickness (feet) of Quaternary aquifer material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Aquifer_TotalThickness	Total Thickness (feet) of Quaternary aquifer material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Coarse_SaturatedThickness	Saturated Thickness (feet) of Quaternary coarse material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Coarse_TotalThickness	Total Thickness (feet) of Quaternary coarse material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_NonAquiferMarginal_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer/marginal material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_NonAquiferMarginal_TotalThickness	Total Thickness (feet) of Quaternary non aquifer/marginal material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_NonAquifer_SaturatedThickness	Saturated Thickness (feet) of Quaternary non aquifer material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_NonAquifer_TotalThickness	Total Thickness (feet) of Quaternary non aquifer material for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_SandSandstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_SandSandstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group sand/sandstone dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_SiltSiltstoneDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_SiltSiltstoneDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group silt/siltstone dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_ShaleClayDominant_SaturatedThickness	Saturated Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300
SouthernBlock_Kd_ShaleClayDominant_TotalThickness	Total Thickness (feet) of Cretaceous Dakota Group shale/clay dominant for the Southern Block survey area, NAD83/State Plane Nebraska, feet	300

Table 6-8. Geocloud-import XYZ files. (3 files: *_geocloud.xyz)

LINE	Original Line Number
X_SP_FT	Easting Nebraska State Plane (feet) WGS 84
Y_SP_FT	Northing Nebraska State Plane (feet) WGS 84
ELEV_FT	Elevation above sea level (feet) from USGS Data Elevation Model
X_SP_M	Easting Nebraska State Plane (meters) WGS 84
Y_SP_M	Northing Nebraska State Plane (meters) WGS 84
ELEV_M	Elevation above sea level (meters) from USGS Data Elevation Model
INV_ALT_FT	Inverted altitude of AEM system (feet)
RESDATA	Data residual of sounding
RESTOTAL	Total data residual of inversion
RHO_01 to 39	Resistivity of layers 1 to 39 (Ohm-m)
RHO_STD_01 to 39	Standard deviation of resistivity of layers 1 to 39
DEP_TOP_FT_01 to 39	Depth to top of layer 1 to 39 (negative feet)
DEP_TOP_M_01 to 39	Depth to top of layer 1 to 39 (negative meters)
DEP_BOT_FT_01 to 39	Depth to bottom of layer 1 to 39 (negative feet)
DEP_BOT_M_01 to 39	Depth to bottom of layer 1 to 39 (negative meters)
DOI_UPPER_FT	Upper Depth of Investigation calculation (negative feet)
DOI_LOWER_FT	Lower Depth of Investigation calculation (negative feet)
DOI_UPPER_M	Upper Depth of Investigation calculation (negative meter)
DEP_LOWER_M	Lower Depth of Investigation calculation (negative meter)

Table 6-9. PMRNRD_Merged_Interp.XYZ, _2020_Interp.xyz, _2007_Ashland_Interp2020.xyz

LINE	Original Line Number
X_SP_ft	Easting Nebraska State Plane (feet) WGS 84
Y_SP_ft	Northing Nebraska State Plane (feet) WGS 84
ELEV_FT	Elevation above sea level (feet) from USGS Data Elevation Model
X_SP_M	Easting Nebraska State Plane (meters) WGS 84
Y_SP_M	Northing Nebraska State Plane (meters) WGS 84
ELEV_M	Elevation above sea level (meters) from USGS Data Elevation Model
DOI_UPPER_M	Upper Depth of Investigation calculation (negative meter)
DOI_LOWER_M	Lower Depth of Investigation calculation (negative meter)
WT_ft	Elevation of Water Table (ft)
Bedrock_ft	Elevation of interpreted bedrock surface (ft)
Kc_Top_ft	Elevation of the top of the Cretaceous Carlile Shale (ft)
Kgg_Top_ft	Elevation of the top of the Cretaceous Greenhorn Limestone and Graneros Shale (ft)
Kd_top_ft	Elevation of the top of the Cretaceous Dakota Group (ft)
IP_Top_ft	Elevation of the top of the undifferentiated Pennsylvanian (ft)

Table 6-10. Relevant features and extents as ESRI Shapefiles.

Shapefile Name	Explanation
Outcrops_DigitizedAndInterpolated_PMRNRD	Digitized and Interpolated Bedrock Outcrops/Subcrops; revised from Burchett, R.R., Dreeszen, V.L., Sounders, V.L., and Prichard, G.E., 1988 or interpreted from AEM data.
Kc_Exent_PMRNRD	AGF interpreted extent of the Cretaceous Carlile (Kc); revised from Burchett, R. R., 1986, Bedrock geology of Nebraska.
Kgg_Exent_PMRNRD	AGF interpreted extent of the Cretaceous Greenhorn Limestone and Graneros Shale (Kgg); revised from Burchett, R. R., 1986, Bedrock geology of Nebraska.
Kd_Exent_PMRNRD	AGF interpreted extent of the Cretaceous Dakota Group (Kd); revised from Burchett, R. R., 1986, Bedrock geology of Nebraska.
IP_Exent_PMRNRD	AGF interpreted extent of the Undifferentiated Pennsylvanian (IP); revised from Burchett, R. R., 1986, Bedrock geology of Nebraska.
AGF_Interpreted_ArlingtonWashington_Paleochannel	Interpretation of the Arlington/Washington County Paleochannel based on AEM data.
ProjectExtent_PMRNRD	Project Extent

6.2 Description of Included Google Earth KMZ Data and Profiles

In addition to the data delivered in XYZ format, Google Earth .KMZ files were generated to view the geophysical AEM flight line locations and interpreted geologic data. KMZ files for all "*As-Flown*" flight lines and data "*Retained*" for inversion after editing are included in the folder "*Appendix_3_Deliverables\KMZ\Flight Lines*".

Unique KMZ files were created for each individual flight line in approximately 10-mile segments or shorter. Within these specialized 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 as well as bedrock and the 1995 water table. These KMZ files are located within the "*Appendix_3_Deliverables\KMZ\Interpretation\PMR20_Profiles*" folder. In this folder is a "*GoogleE_Readme.pdf*" file that provides instructions regarding 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 P-MRNRD GoogleE_Readme.pdf file is repeated below as a convenience. The P-MRNRD interpretation KMZ has been subdivided into eight subarea KMZ's in order for ease of loading in Google Earth. An image of the subareas and the coverage of the KMZ's is presented in Figure 6-1 and examples of clicking on points are presented in Figure 6-2 (Northern portion), Figure 6-3 (Central portion), and Figure 6-4 (Southern portion).

6.2.1 Included README for the P-MRNRD Interpretation KMZ's

README for:

PMR20_Area-1.kmz
PMR20_Area-2.kmz
PMR20_Area-3.kmz
PMR20_Area-4.kmz
PMR20_Area-5.kmz
PMR20_Area-6.kmz
PMR20_Area-7.kmz
PMR20_Area-8.kmz

The PMRNRD 2020 interpretation kmz is made up of eight (8) parts (1-8), running from south to north, due to the size of the survey area and the loading time and stability of the Google Earth program.

Data Files - Please copy the folder *PMR20_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 (the profiles).

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

STEP 5: The 2020 Interpretation kmz files within the folder named *PMR20_Profiles* can now be opened and viewed in Google Earth.

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, Nebraska State Plane, in feet

North (ft) – Northing coordinate in NAD83, Nebraska State Plane, in feet

Elevation (ft) – Digital Elevation Model (DEM) elevation in feet

Soil Recharge Material – Aquifer material on the Surface: 1=Non-Aquifer Material; 2=Marginal Aquifer Material; 3=Aquifer Material; 4=Coarse Aquifer Material.

WaterTable1995 – 1995 Water Table elevation, in feet

Total Thickness Aq CAq Material (ft) – Sum of the thicknesses of Aquifer Material and Coarse Aquifer Material at the sounding location.

Total Thickness NonAq Material (ft) – Sum of thicknesses of Non-Aquifer Material at the sounding location.

Elevation Bedrock (ft) – Elevation of the Cretaceous Bedrock surface, in feet.

Elevation Kc (ft) – Elevation of Cretaceous Carlile Formation, in feet.

Elevation Kgg (ft) – Elevation of Cretaceous Greenhorn Shale and Graneros Limestone Formation, in feet.

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

Elevation IP (ft) – Elevation of undifferentiated Pennsylvanian units, in feet.

Profile – Link to Interpreted AEM profile images.

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

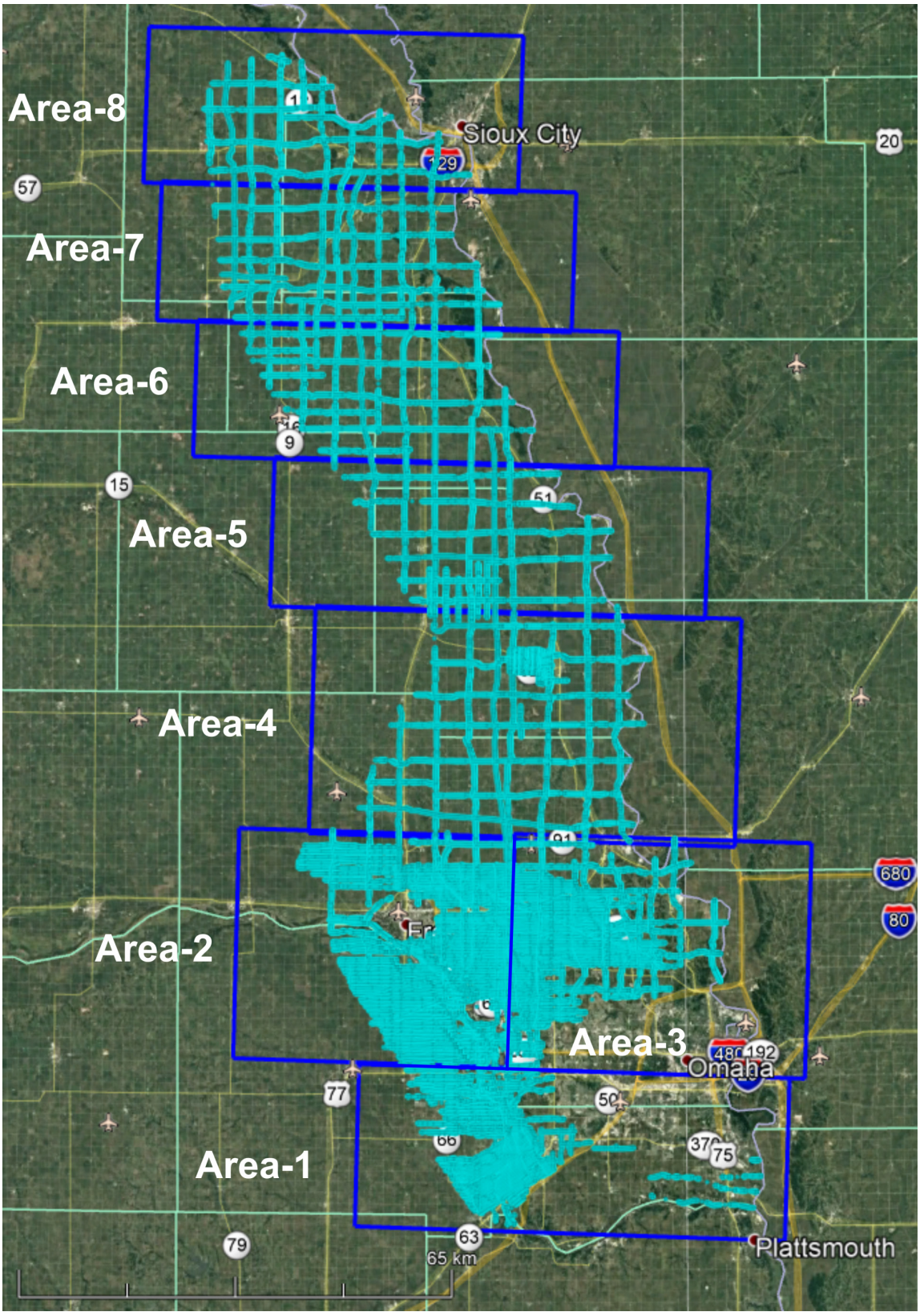


Figure 6-1. KMZ of the PMRNRD 2020 AEM survey area showing the breakup into eight (8) subarea KMZ's.

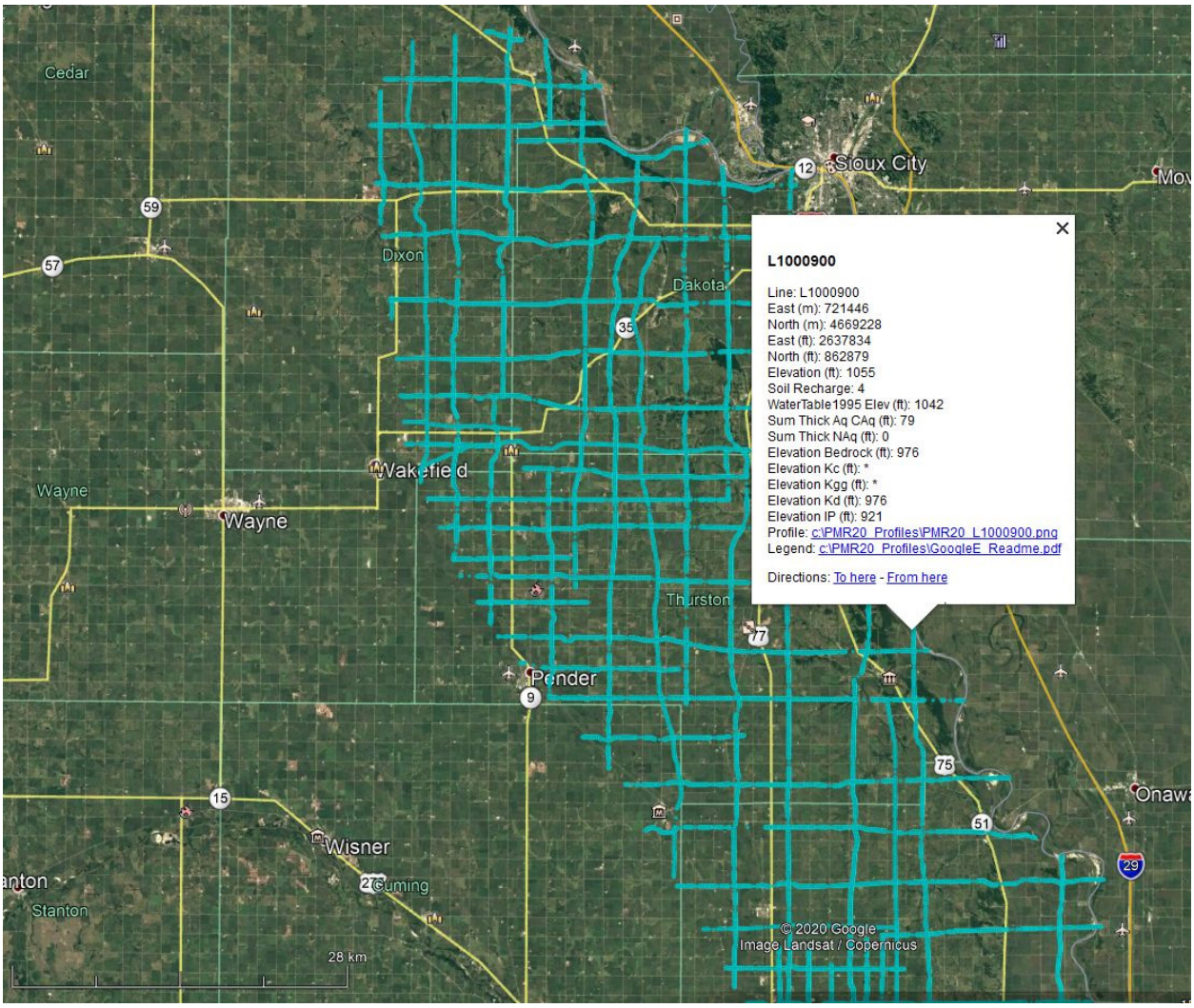


Figure 6-2. Example KMZ of the northern portion of the PMRNRD 2020 AEM survey area.

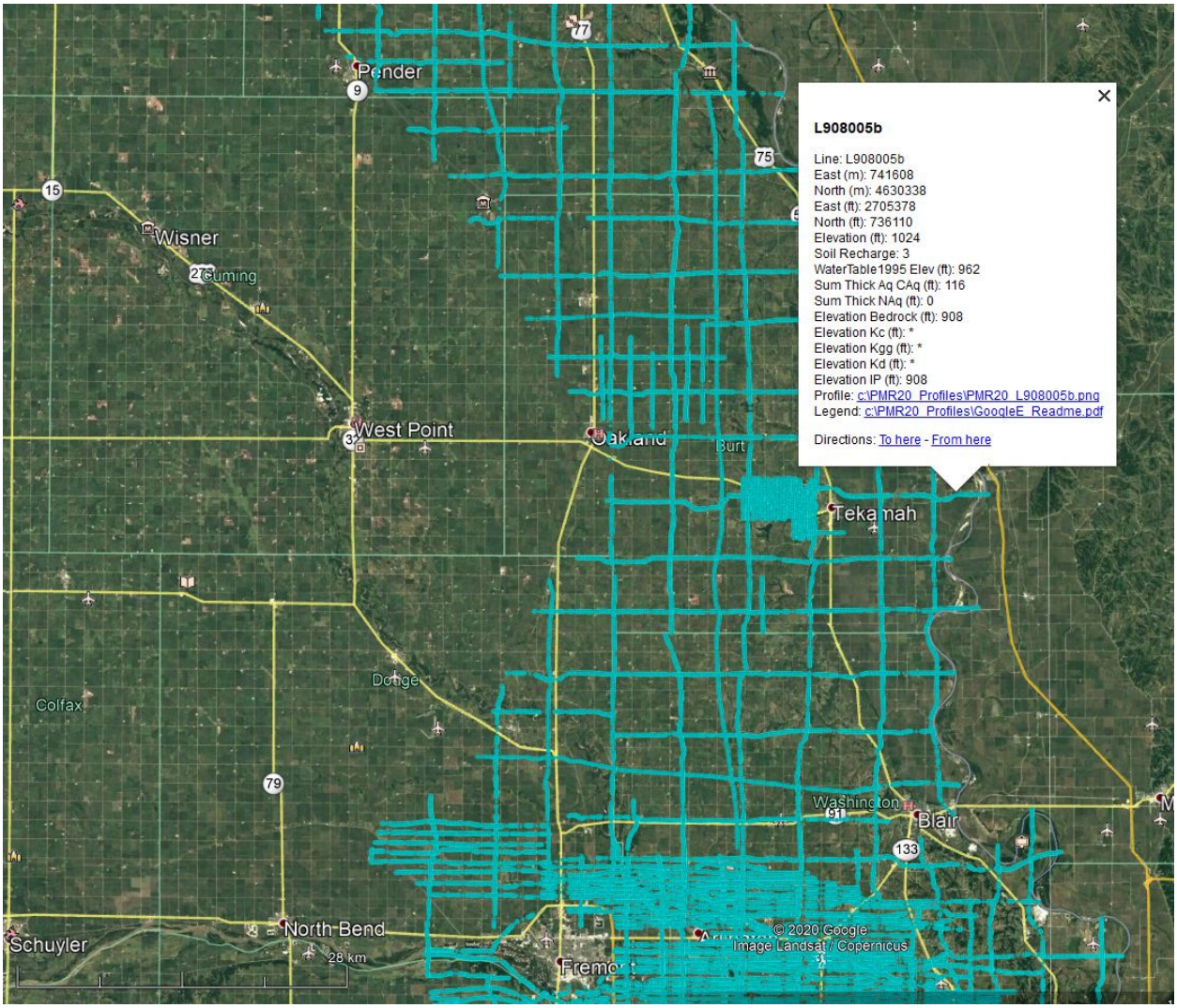


Figure 6-3. Example KMZ of the central portion of the PMRNRD 2020 AEM survey area.

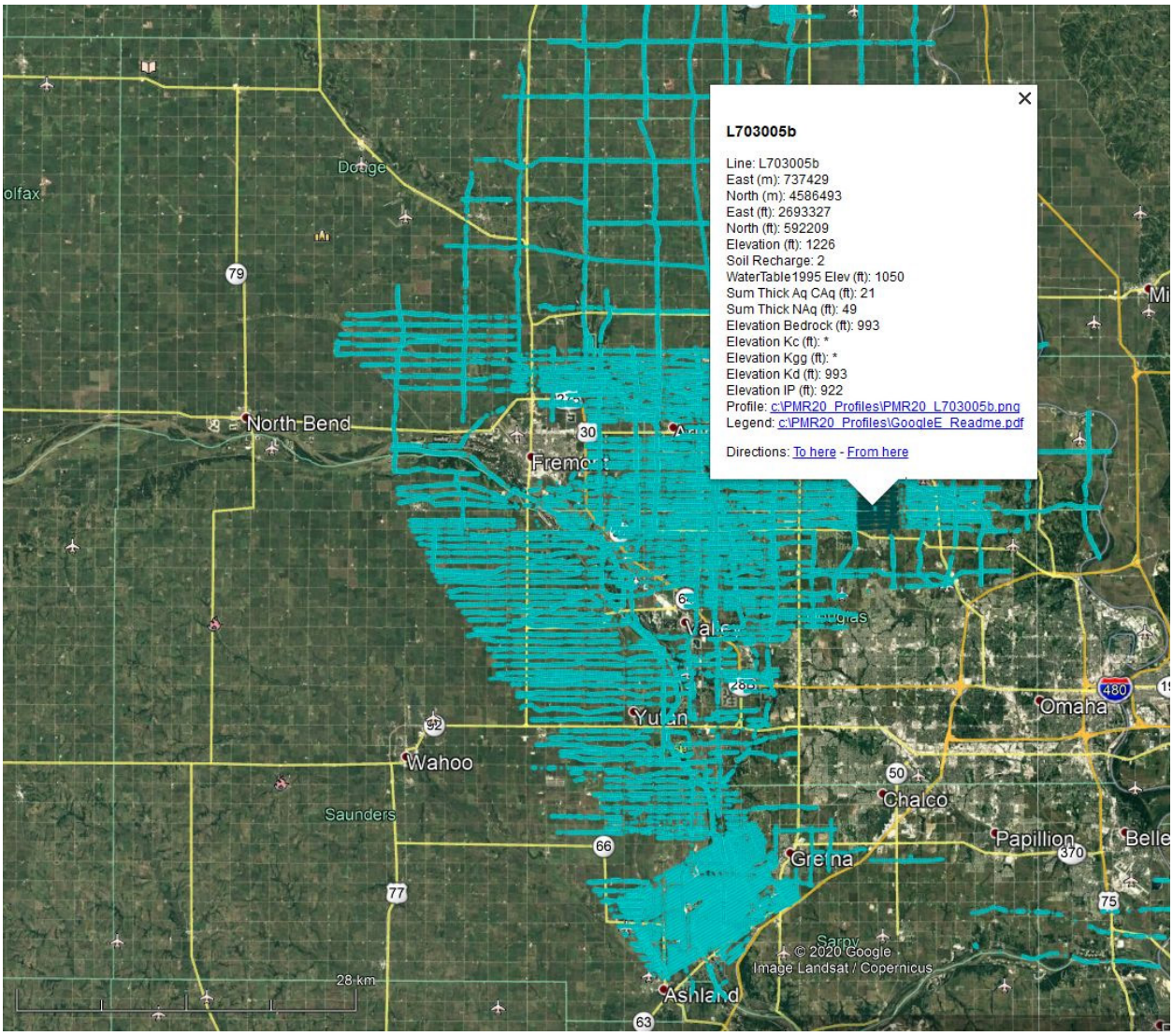


Figure 6-4. Example KMZ of the southern portion of the PMRNRD 2020 AEM survey area.

7 References

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