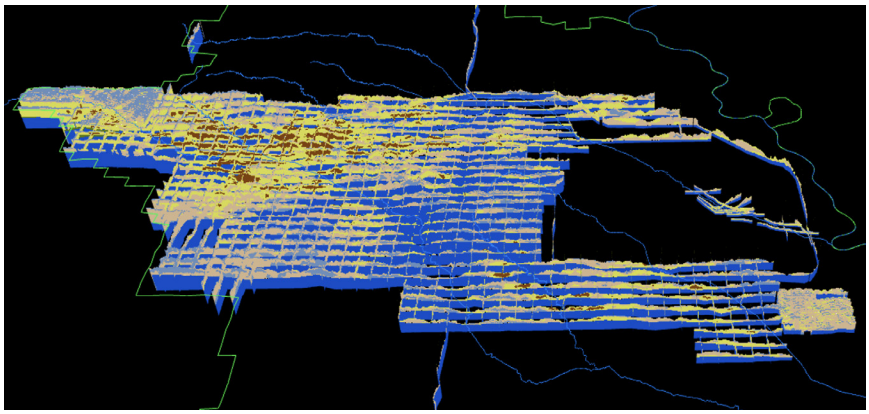
Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Areas within the Nemaha Natural Resources District



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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 Areas within the Nemaha 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 Nemaha Natural Resources District (NNRD) to collect, process, and interpret airborne electromagnetic (AEM) data, and to use it in conjunction with other available background information to develop a 3D hydrogeologic framework.

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 Nemaha NRD project area. These flights have been provided as preliminary AEM inversions and the final AEM data and inversions are included as products attached to this data report.

1.2 AGF began project planning upon signing of the contract between AGF and the NNRD. This work included flight plans, database development, and review of hydrogeologic and geologic work for the area. The NNRD assisted in providing information such as power line maps, water table measurements, irrigated acreage data, and water quality. AGF constructed a borehole only bedrock surface utilizing the Conservation and Survey Division test wells and the Department of Natural Resources Registered well databases. This bedrock surface was utilized in flight planning and interpretation.

Upon conclusion of the design process, the 2023 NNRD flight lines had a maximum length of approximately 13 miles (21 km) in the east-west direction and about 8 miles (13 km) at their longest in the north-south direction. The flight lines were separated by approximately 0.96 mile (1.5 km) in both east-west and north-south directions. Note that the 2023 NNRD flight lines filled in areas around the 2018 and 2020 NNRD AEM survey programs.

1.4 AGF acquired AEM data over the NNRD, commencing 23 June 2023 and finishing on 24 June 2023, to support development of the hydrogeological framework. During this time frame, data collected over approximately 337 line-miles (543 line-kilometers) were acquired over the NNRD AEM survey area. Status reports of the flying were provided to the NNRD 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 in the form of 2D profiles and 3D fence diagrams on June 25, 2023.

1.6 AGF inverted the AEM data. After final processing, approximately 274-line-miles (441-line kilometers) were retained for inversion amounting to a retention rate of 81.2%. 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 NNRD with this report. AGF-derived 2D sections, 3D electrical models, and interpreted geologic and hydrogeologic surfaces of the surveyed area are also delivered with this report.

1.7 AGF combined the historic AEM data that was acquired in the NNRD from 2007 until 2020 with

the 2023 data. The total combined AEM data within the NNRD is 1,910.5 line-miles (3,074.7 line-km). The historic data were not reinverted but the inversion results were combined. Lower Platte South Natural Resources District (LPSNRD) had the Firth and Sprague Block reinverted in 2022 as part of their hydrogeological framework (AGF 2022) and those new inversions were utilized for the portions of those blocks that lie within the NNRD.

1.8 AGF is providing a hydrogeologic framework report that includes maps of aquifer materials and their relationships to current test holes and production groundwater wells, estimated transmissivity maps, maps of potential water management regions, areas of potential water quality concerns, and maps of estimated potential recharge areas under the AEM flight lines. This report, as mentioned above, also includes all data (acquired, processed, and developed) files. The report is delivered in PDF digital format and the data in ASCII and native formats.

2. KEY FINDINGS

2.1 Boreholes - The interpretive process benefited from the use of Conservation and Survey Division (CSD) and Nebraska Department of Natural Resources (NE-DNR) borehole logs. Information from boreholes was used to analyze the AEM inversion results and were important for all areas in the NNRD, especially for interpreting the top of the undifferentiated Pennsylvanian and Paleozoic (***IP***). The ***IP*** was a challenging unit to interpret due to the highly variable resistivity. This unit when compared to the Quaternary (***Q***) often had limited or no contrast in the electrical resistivity between the different geologic units. The bedrock surface that was developed for this project from CSD and surrounding NE-DNR boreholes was used as a guide for the interpretation of the ***IP*** in areas of low electrical resistivity contrast and no local boreholes.

The dependence on just boreholes for geologic interpretation has its limitations because sometimes the boreholes are incorrect, improperly located, have improper stratigraphic/lithology picks, and/or have other errors. These errors in the boreholes are more often encountered in the NE-DNR registered wells. Very rarely inconsistencies are also encountered in the oldest of the CSD wells. The errors in the CSD wells, though limited, may be due to poor positioning prior to the evolution of GPS and modern survey methods. As in all surveys of this nature, the use of boreholes with AEM needs to be approached in a thoughtful, professional manner.

2.2 Merging AEM data- The historic AEM data that was acquired in the NNRD from 2007 until 2020 was merged with the 2023 data. Before the 2015 and 2018 data could be combined with the 2020 and 2023 data to create 3D voxels, the inverted earth model structures for 2015 and 2018 had to be converted into the 40-layer 2020 and 2023 inverted model layer structure with a first layer depth of -2 m (-6.6 ft) and 39th layer depth of -325 m (-1066.3 ft). The 2015 inversion models had 30 layers with a first layer depth of -5 m (-16.4 ft) and a 29th layer depth of -500.2 m (-1,641.1 ft). The 2018 inversion models had 40 layers with a first layer depth of -1 m (-3.3 ft) and a 39th layer depth of -349.9 m (-1,147.7 ft). The total combined AEM data within NNRD is 1,910.5 line-miles (3,074.7 line-km). These data were not reinverted, but the inversions were combined with the inversions of the 2023 data. Lower Platte South Natural Resources District (LPSNRD) had the Firth and Sprague Block AEM data reinverted in 2022 as part of their hydrogeological framework (AGF, 2022). Those new inversions were utilized for the portions of those blocks that lie within the NNRD. These combined data sets provided a comprehensive set of cross-sections and voxel models across the areas of the most important aquifers within the District. The well calibrated SkyTEM 304 data and stable inversions provide combined sections that displayed no breaks in the images. The exceptions were the 2007 and 2009 RESOLVE frequency domain

data that has an inherently shallower imaging ability and the 2015 SkyTEM 508 that has a much deeper imaging ability and Depth of Investigation (DOI).

2.3 Digitizing Interpreted Geological Contacts - Characterization and interpretation of the subsurface was performed in cross-section and derived 2D and 3D surface grid formats. Contacts between the geologic units were digitized in 2D profiles including: ***Q***, ***Kd***, and ***IP***. The interpretive process benefited from the use of CSD and NE-DNR borehole logs. Surface grids of the interpreted geologic units were then produced. Each flight line profile with interpretations is included in the appendices as well as the Quaternary aquifer material mapping as interpretative surface grids.

2.4 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 determined and used to characterize non-aquifer (<12 ohm-m), marginal (12-20 ohm-m), aquifer (20-50 ohm-m), and coarse sand-rich intervals (>50 ohm-m) (Carney et al., 2015a). This allowed for the characterization of the major geologic units described in this report using their ranges of resistivities. The ***Kd*** was not subdivided in this study due to the thin nature of the eroded remnant in the northwest part of the survey area and the limited flight line coverage.

2.5 Hydrogeological Framework of the NNRD - The NNRD AEM survey area reveals variability in the Quaternary (***Q***) deposits across the NNRD AEM survey area. The ***Q*** deposits make up the aquifer materials overlying the undifferentiated ***IP*** bedrock units. The aquifer material and coarse aquifer material exist in paleochannels up to approximately 200 feet thick. These are separated by ***Q*** deposits that consist of marginal to non-aquifer materials including glacial till and loess. The paleochannel systems are also apparent in the AEM-interpreted saturated aquifer and coarse aquifer thickness maps. The AEM-derived hydrogeological interpretation correlates very well with the recorded borehole Specific Capacity data across the field area. Adjustments and refinements of the paleochannel configuration have been made based on the AEM data and the use of the Specific Capacity values. Note that some of the isolated deposits of aquifer and coarse aquifer materials outside the main paleochannels also show a good match with the NE-DNR Specific Capacity values. Using the saturated thickness of the aquifer and coarse aquifer material and an estimate of the hydraulic conductivity, an estimate of the transmissivity was developed. These values compare well with the Leggette, Brashears, & Graham (LBG) values derived from using the Specific Capacity (AGF, 2021; AGF, 2019; and LBG, 2017). The coarsest and thickest areas of the saturated paleochannels have the highest transmissivity values. It is important to note that the transmissivity values were derived by only using the saturated thickness of the aquifer and coarse aquifer materials. This provides an additional view of the possible transmissive properties of the materials within the NNRD AEM survey area.

2.6 Potential Recharge Zones within the NNRD AEM Survey Area - Locations where the AEM inversion results show either aquifer or coarse aquifer material at the land surface can be considered as locations of higher likelihood for recharge due to the 2D and 3D spatial nature of the aquifer material distribution. The opposite is also true where AEM data analysis shows non-aquifer material or marginal aquifer material at the surface. Those areas will likely not be optimal recharge locations. The highest rate of recharge can be expected in the central areas in the paleochannel region due to the presence of unsaturated aquifer and coarse aquifer materials from the surface down to the water table. This determination is based on reconnaissance-type flight lines. It should be noted that in some of these areas the results shown in the recharge maps are based more on interpolation between data points and less actual AEM data.

Note that areas with aquifer and coarse aquifer materials at the surface can also become conduits for infiltration of nitrates into the groundwater system. A potential solution for any nonpoint source water quality contamination is adding 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 an accurate representation of the aquifer materials in the first ~6 feet from the land surface downward.

2.7 Auburn- Selected AEM profiles were acquired around the town of Auburn to assist in their water resources assessment. The results show a lenticular deposit of sands within the Little Blue River alluvial valley. Many DNR registered wells are within the area that are already utilizing the resources. A few new areas were identified where additional wells maybe placed, but the resource is limited with many wells already completed within the aquifer materials as detected by the AEM survey.

3. RECOMMENDATIONS

Recommendations provided to the NNRD 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 NNRD about their management challenges.

3.1 Additional AEM Mapping or Ground Based Geophysics- The hydrogeologic maps provided in this report represent the hydrogeologic framework developed for the NNRD at reconnaissance level with approximately 1-mile spacing between flight lines for much of the AEM survey area. The bulk of the aquifer areas of the NNRD have been covered. Additional AEM data would need to be targeted as infill to determine fine details of specific areas including well head protection areas or well fields. If ground access is achievable and the areas are only a section or two (640-1280 acres) in size, ground-based Time Domain Electromagnetics using a towed system maybe a feasible and economic solution. A system that is based on the SkyTEM electronics that is on the market is the TEM Company's tTEM system (TEM Company, 2024). AGF can provide these services, if required, in the future.

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 29 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 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 NNRD 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 results of this report can also be used to guide development of new water supply wells for local communities. Planners should locate wells in areas of

greatest saturated thickness with the least potential for non-point source pollution. An example of a good well location would be one located above a confined aquifer with a large volume of coarse aquifer and aquifer material surrounding it 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 NNRD.

3.4 Aquifer testing and borehole logging – Aquifer tests are recommended to improve estimates of aquifer characteristics. There were limited previous reports available on aquifer properties outside of 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. 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 NNRD hydrogeologic framework in this report provides areas of recharge from the near surface. Reconnaissance-level AEM investigations provide limited detailed information between the lines for understanding recharge throughout the survey area. For detailed recharge sites additional infill AEM can be flown or ground-based tTEM surveys can be conducted. This should be done in areas identified by the NNRD that are of priority importance for management purposes. It is further recommended that future work integrate new soils and land use maps with the results of this study to provide details on soil permeability, slope, and water retention. This will provide a more complete understanding of the transport of water from the land surface to the groundwater aquifer. A potential solution to water quality, quantity, and stream depletion is adding additional fresh surface water as recharge to select areas of rangeland or other areas. Additional work can be done to identify where the best locations are for these types of management efforts. This information can and has been used in Nebraska to improve Well Head Protection Areas by refining groundwater travel time estimates and the boundary areas.

3.6 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 NNRD exist and what additional information would be required for final selections of MAR sites. Additional AEM mapping in new block flight locations and along the streams in the NNRD is valuable for locating potential MAR locations. A detailed plan for locating and developing MAR sites would be beneficial to the NNRD for storage and release of water for stream flow and other uses. The unsaturated aquifer and coarse aquifer material maps provide information on areas that warrant further investigation.

3.7 Updating previous groundwater reports and Groundwater Management Plans - The information provided in this report should be used to update the groundwater information and management of the Nemaha Natural Resources District. Integrating data presented in this report with the historical work as well as the inclusion of future AEM mapping enhancements, a greater understanding of the District can be achieved. The addition of estimates of groundwater in storage, recharge areas, hydrologic connection to streams, and consideration of managed aquifer recharge sites will greatly improve the District's overall groundwater management plans.

4. DELIVERABLES

The following are included as deliverables:

- Raw Data Files - SkyTEM files *.gex, *skb, *.lin
- Raw EM Mag data as ASCII *.xyz
- SCI inversion as ASCII *.xyz in array and an individual column format by model layer
- Interpretations as ASCII *.xyz
- ESRI GIS files – raster grids (*.flt) and ESRI ArcGIS Pro map package (.mpkx).
- 2D profiles, Surfaces, and 3D fence diagrams of the AEM survey inversion results
- Files compatible with GeoScene3D and the Nebraska GeoCloud
- KMZs for NNRD AEM flight lines, interpretative profiles, and recharge zones.

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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
AM	Aquifer Material
ASR	Aquifer Storage and Recovery
b	Saturated thickness
bgs	below ground surface
BMP	Best Management Process
dB/dt	Change in amplitude of magnetic field with time
CA	Coarse Aquifer Material
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
IWMPP	Interrelated Water Management Plan/Program
K	Hydraulic Conductivity
Kd	Cretaceous Dakota Group
Km, km	Kilometers

KMZ, kmz	Keyhole Markup language Zipped file
LCI	Laterally-constrained Inversions
LPSNRD	Lower Platte South Natural Resources District
M, m	Meters
MAG	Magnetic (data); Magnetometer (instrument)
MCG	Minimum curvature gridding
mg/L	milligram per liter or parts per million (ppm)
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
NNRD	Nemaha Natural Resources District
NRD	Natural Resources Districts
OM	Geosoft Oasis montaj
PFC	Primary Field Compensation
PLNI	Power Line Noise Intensity
Q	Quaternary
Rx	Receiver
recon	Reconnaissance
sec	second
SC	Specific Capacity
SCI	Spatially-Constrained Inversion
SPCS	State Plane Coordinate System
STD	Standard Deviation
T	Transmissivity
TEM	Transient, Time-Domain Electromagnetic
TDEM	Time-Domain Electromagnetic
To	Tertiary Ogallala Group
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
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 resources by the ever growing and dynamic demands of: agricultural production, population growth and urbanization, potential contamination from natural and anthropogenic sources, industrial and commercial needs; along with the persistent threat of drought.

The combination of these stresses on water resources has increased the need for detailed hydrogeologic frameworks of the subsurface. These frameworks provide information on groundwater flow and hydrologic connection between different aquifers, streams, and the surface. Groundwater management strategies and policies on water use and quality can be better implemented with this additional information. Areas of recharge can be identified and used to determine best management practices (BMP) to reduce or eliminate future contamination events. These recharge areas can also be used for potential Managed Aquifer Recharge (MAR) to supplement groundwater in areas where it is depleted from development or where it is needed for future use.

Aqua Geo Frameworks (AGF) entered into an agreement with the Nemaha Natural Resources District (NNRD) to collect, process, and interpret airborne electromagnetic (AEM) data and to use it in conjunction with other available background information to develop a 3D hydrogeologic framework. Background information used included reports from previous studies, analysis of historic groundwater levels, and geologic descriptions from the University of Nebraska-Lincoln Conservation and Survey Division (CSD) test bore holes, as well as drillers logs obtained from registered wells at the Nebraska Department of Natural Resources (NE-DNR). The AEM survey data were collected along reconnaissance (recon) lines spaced approximately 0.93 miles (1.50 km) apart. This AEM survey was planned and selected by NNRD and AGF with assistance from scientists at the CSD. The goal for the AEM survey was to assist in the development of a 3D hydrogeologic framework of project areas, then to use the framework to recommend future work to enhance groundwater management activities. This work was supported by the Natural Resources Commission Water Sustainability Fund, NNRD and in-kind service from CSD.

A location map showing the NNRD is presented in Figure 1-1. A Google Earth KMZ (kmz) of the “As-Flown” flight lines are included in Figure 1-2 and in *Appendix 3 - Deliverables\KMZ\FlightLines*. The 2023 flight area was south and southeast of Tecumseh, west of Stella, northwest of Nemaha, and north of Julian. The towns of Elk Creek and Auburn are within the survey area.

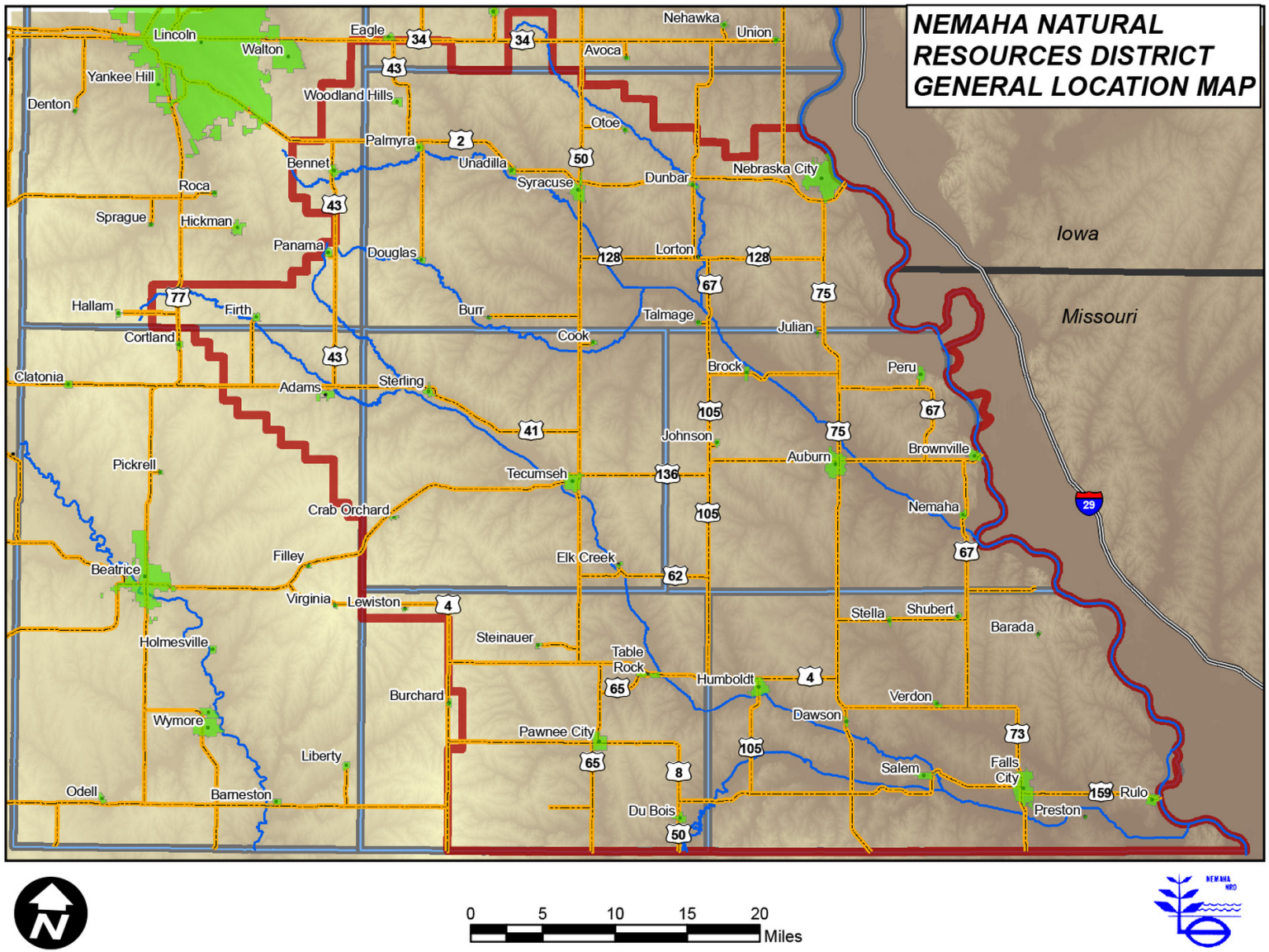


Figure 1-1. Map of the NNRD in southeastern Nebraska (https://www.nemahanrd.org/).

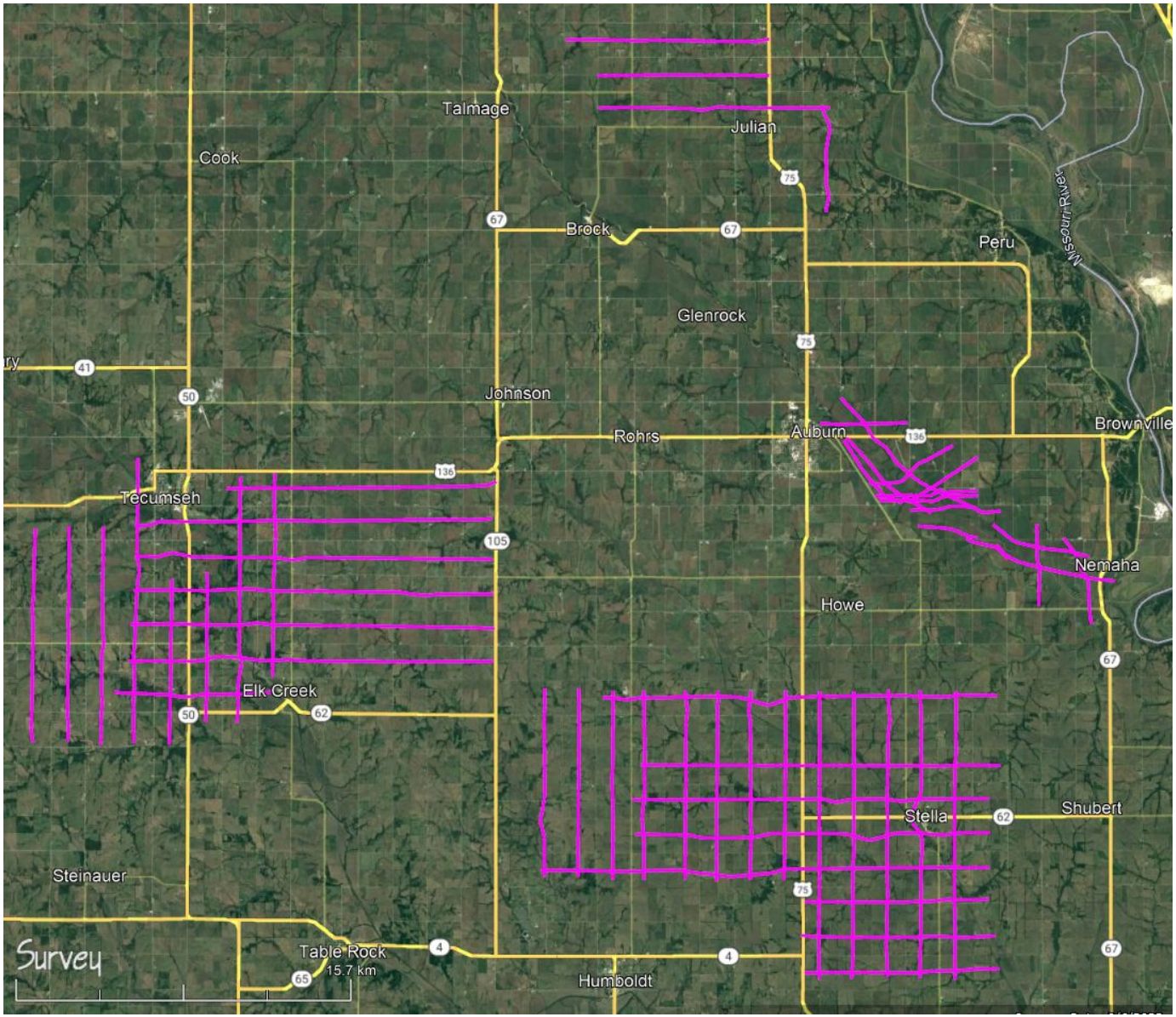


Figure 1-2. Google Earth image of the NNRD 2023 AEM survey area including major roads.

1.2 Background

In January of 1986, with the approval of the NNRD Groundwater Management Plan, the NNRD established a districtwide Groundwater Management Area, for purposes of managing groundwater quality and quantity. The initial Groundwater Management Plan was updated in 1995 and 1999 for water quality and well permitting. It was updated again in 2003 designating selected areas in the survey area for Phase II water quality management within parts of Johnson, Nemaha, and Otoe counties. Different Phases (or Action) Levels were established: Phase 1, Phase 2 and Phase 3, each containing elevated levels of requirements to address a specific level of groundwater condition.

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

Use of AEM technology to map and evaluate groundwater resources has gained momentum over the last 20 years in the United States and abroad. Over the last decade, the state of Nebraska has been on the forefront of implementing AEM for water resources management with projects across the state in a variety of geologic settings. In recent years, the Eastern Nebraska Water Resources Assessment (ENWRA) group has coordinated efforts between area Natural Resources Districts (NRDs), Conservation and Survey Division (CSD), the U.S. Geological Survey (USGS), and Aqua Geo Frameworks, LLC (AGF) in support of several projects designed to characterize the hydrogeology across the state. The Eastern Nebraska Water Resources Assessment (ENWRA) project was formed in 2006. The sponsors consist of six NRDs (Lewis and Clark, Lower Elkhorn, Papio-Missouri River, Lower Platte North, Lower Platte South, and Nemaha) formally organized by an Interlocal Cooperative Agreement. Other cooperating agencies include the: Nebraska Department of Natural Resources; Conservation and Survey Division; School of Natural Resources, University of Nebraska-Lincoln; and U.S. Geological Survey. The long-term goal of the project is to develop a geologic framework and water budget for the previously glaciated portion of eastern Nebraska. The initial funding source was a three-year Interrelated Water Management Plan/Program (IWMPP) grant. For purposes of this project, NNRD, ENWRA, and CSD are cooperating with each other and AGF due to the shared aquifer boundaries and similar groundwater management efforts between NRDs.

2 Hydrogeology of the Nemaha Natural Resources District

In the past decade there have been several AEM investigations conducted within the NNRD. The dominant hydrogeologic features in the District are the paleochannels that trend from the west to the east through the center portion of the District. Much of the District is covered by Rolling Hills composed of glacial till and loess overlaying Cretaceous Dakota (***Kd***) in the very northwestern portion of the district, with much of the bedrock composed of various Paleozoic and Pennsylvanian Units including the Permian Chase, Council Grove, and Admire Groups and the Pennsylvanian Wabaunsee and Shawnee Groups. These units are lumped into the Undifferentiated Pennsylvanian and Paleozoic units in this report (***IP***). The hydrological features within the NNRD and previous AEM surveys have been discussed in detail in many previous publications. More information can be found in the following reports, listed in chronological order:

Smith, B.D., Abraham, J.A., Cannia, J.C., Steele, G.V., and Hill, P.L., 2008, Helicopter electromagnetic and magnetic geophysical survey data, Oakland, Ashland, and Firth study areas, Eastern Nebraska, March 2007: U.S. Geological Survey Open-File Report 2008-1018. Link to PDF file: https://pubs.usgs.gov/of/2008/1018/downloads/REPORT/ofr_2008_1018_v18.pdf

Smith, B.D., Abraham, J.D., Cannia, J.C., Minsley, B.J., Ball, L.B., Steele, G.V., and Deszcz-Pan, M., 2011, Helicopter electromagnetic and magnetic geophysical survey data, Swedeburg and Sprague study areas, eastern Nebraska, May 2009: U.S. Geological Survey Open-File Report 2010–1288, 37 p. https://pubs.usgs.gov/of/2010/1288/

Divine, D.P. and Korus, J.T., 2012. Three-dimensional hydrostratigraphy of the Sprague, Nebraska Area: Results from Helicopter Electromagnetic (HEM) mapping for the Eastern Nebraska Water Resources Assessment (ENWRA). Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Conservation Bulletin 4 (New Series), 32 p.

Korus, J.T., Joeckel, R.M. and Divine, D.P., 2013a. Three-dimensional hydrostratigraphy of the Firth, Nebraska Area: Results from Helicopter Electromagnetic (HEM) mapping in the Eastern Nebraska Water Resources Assessment (ENWRA). Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska–Lincoln. Conservation Bulletin 3 (New Series), 100 p. http://www.enwra.org/media/Firth_ENWRA_Bull_3_2013_small%20red.pdf

Korus, J.T., Howard, L.M., Young, A.R., Divine, D.P., Burbach, M.E., Jess, J.M., and D.R. Hallum (with contributions from Diffendal, R.F. and Joeckel, R.M.), 2013b, The Groundwater Atlas of Nebraska: Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. 64 p. https://marketplace.unl.edu/nemaps/the-groundwater-atlas-of-nebraska-ra-4b-2013pdf.html

Carney, C.P., Abraham, J.D., Cannia, J.C., and Steele, G.V., 2015a, Final Report on Airborne Electromagnetic Geophysical Surveys and Hydrogeologic Framework Development for the Eastern Nebraska Water Resources Assessment – Volume I, including the Lewis and Clark, Lower Elkhorn, and Papio-Missouri River 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

Carney, C.P., Abraham, J.D., Cannia, J.C., and Steele, G.V., 2015b, 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

LBG, 2015, Well interference evaluation of the Village of Shubert (Village) Well No. 3: Leggette, Brashears & Graham, Saint Paul, MN, 9p.

LBG, 2017, Nemaha Natural Resources District Hydrogeologic Assessment Report-2017: Leggette, Brashears & Graham, Saint Paul, MN, 76p.

AGF, 2019, "Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Eastern Nebraska Water Resources Assessment Area" Chapter on the Nemaha Natural Resources District: Prepared for the Nemaha Natural Resources District by Aqua Geo Frameworks, LLC, Mitchell, NE. 130p. http://www.enwra.org/aem2018.html

AGF, 2021, Airborne Electromagnetic Mapping and Hydrogeologic Framework of Selected Regions of the Nemaha Natural Resources District: Prepared for Nemaha Natural Resources District by Aqua Geo Frameworks, LLC, Fort Laramie, WY, 15 March 2021, 136p., (accessed on February 13, 2024) http://www.enwra.org/aem2020.html

AGF, 2022, AGF Analysis and Calibration of 2007 Firth and 2009 Sprague RESOLVE Data: Prepared for the Lower Platte South Natural Resources District by Aqua Geo Frameworks, LLC, Fort Laramie, WY, 10 November 2022, 22p

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, 2023), including 445 wells within the NNRD boundary with information from boreholes drilled between 1935 and 2019 by the CSD and other cooperating agencies; and 2) NE-DNR registered wells database, including 2,982 wells within the NNRD boundary (Nebraska Department of Natural Resources, 2023) (Figure 3-1). These boreholes do not reflect the entirety of the NNRD NE-DNR database. Instead, they are only those boreholes that include a lithologic log in the database. Out of the 2,982 NE-DNR holes, 374 were used to interpolate a borehole-only bedrock surface (discussed below). All the CSD holes that fell within the borehole-only bedrock area (230 holes) were used for the interpolation. The boreholes used in this study can be found as ESRI shapefiles in the *Appendix 3 – Deliverables\ESRI Products*.

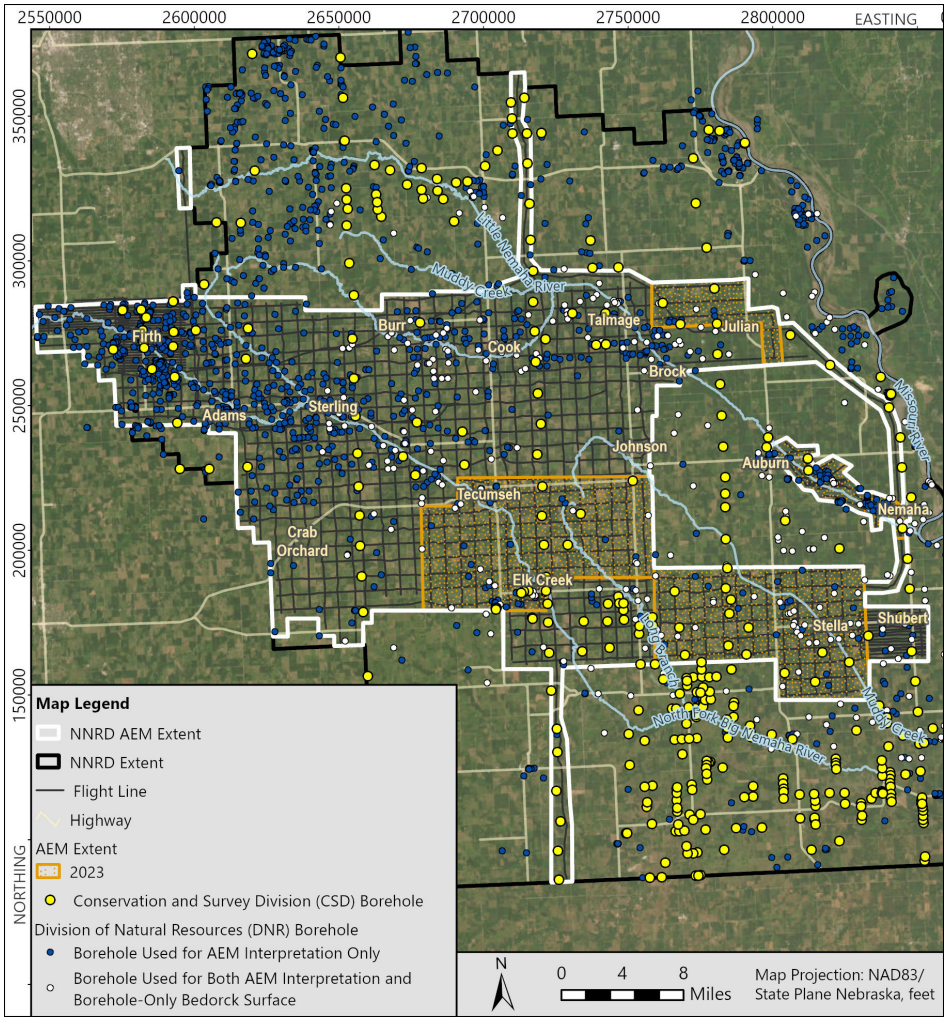


Figure 3-1. NE-CSD and DNR borehole logs used for quality control and interpretative purposes. Map projection is Nebraska State Plane NAD83, feet.

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.

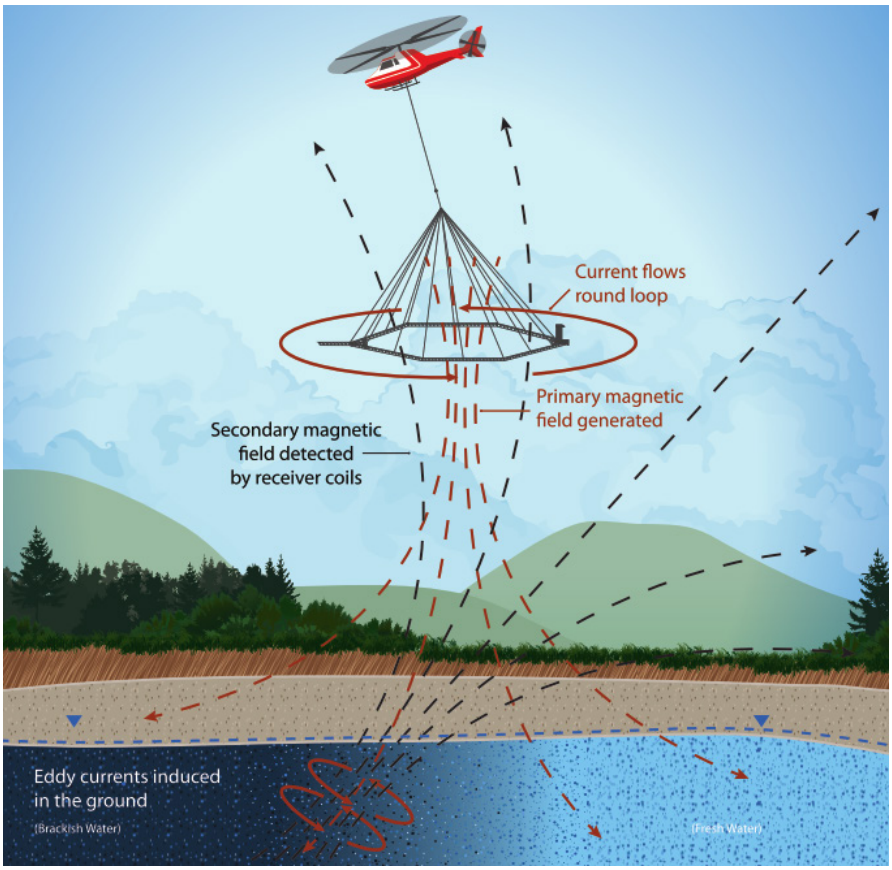


Figure 4-1: Schematic of an airborne electromagnetic survey, modified from Carney et al. (2015a).

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 in the Rx coil 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 result of the inversion, the corresponding electrical resistivity model.

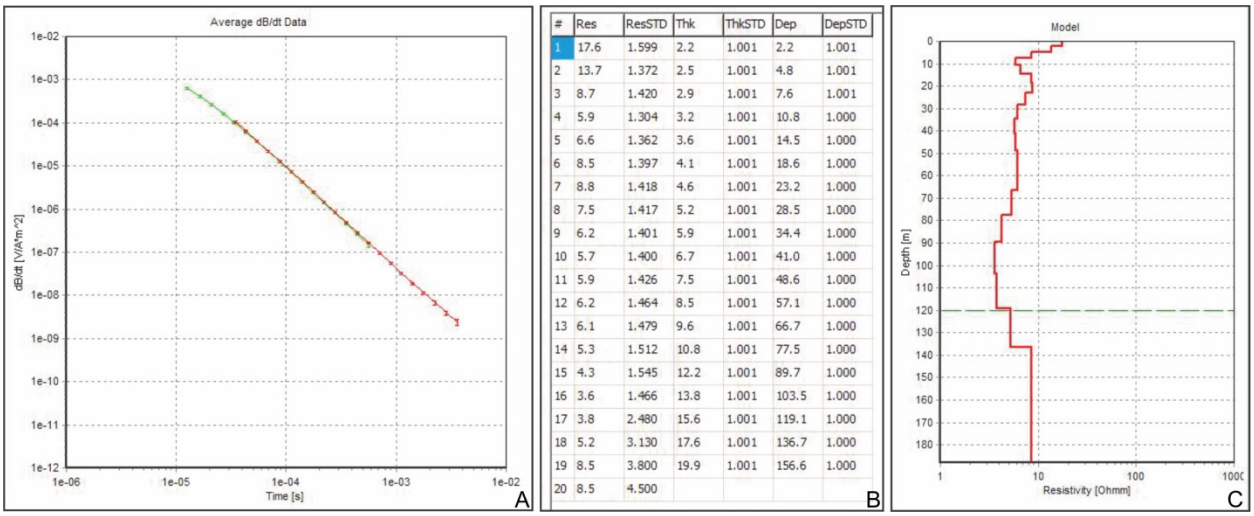


Figure 4-2: A) Example of a dB/dt sounding curve. B) Corresponding inverted model values. C) Corresponding resistivity earth model.

4.2 Flight Planning/Utility Mapping

The primary source of noise in geophysical electromagnetic surveys are other electromagnetic devices that are part of typical municipal utility infrastructure. These include, but are not limited to, power lines, railroads, pipelines, and water pumps. Prior to AEM data acquisition in the NNRD, three types of utilities (pipelines, railroads, and power lines) were located. Some areas were mapped by inspection from Google Earth imagery.

The locations of the flight lines were modified 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 ESRI ArcGIS Pro 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 NNRD 2023 flight lines had a maximum length of approximately 13 miles (21 km) in the east-west direction and about 8 miles (13 km) at their longest in the north-south direction. The flight lines were separated by approximately 0.96 mile (1.5 km) in both east-west and north-south directions. Note that the 2023 NNRD flight lines filled in areas around the 2018 and 2020 NNRD AEM surveys.

4.3 AEM Survey Instrumentation

AEM data were acquired using the SkyTEM304M (304) airborne electromagnetic system (SkyTem Airborne Surveys Worldwide, 2024). The 304 is a rigid frame, dual-magnetic moment (Low and High) TEM system. The area of the 304 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 SkyTEM304 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 SkyTEM304 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 SkyTEM304 is also equipped with a Total Field magnetometer (MAG) and data acquisition systems for both instruments. The SkyTEM304 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 SkyTEM304 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 304 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 304 in operation.

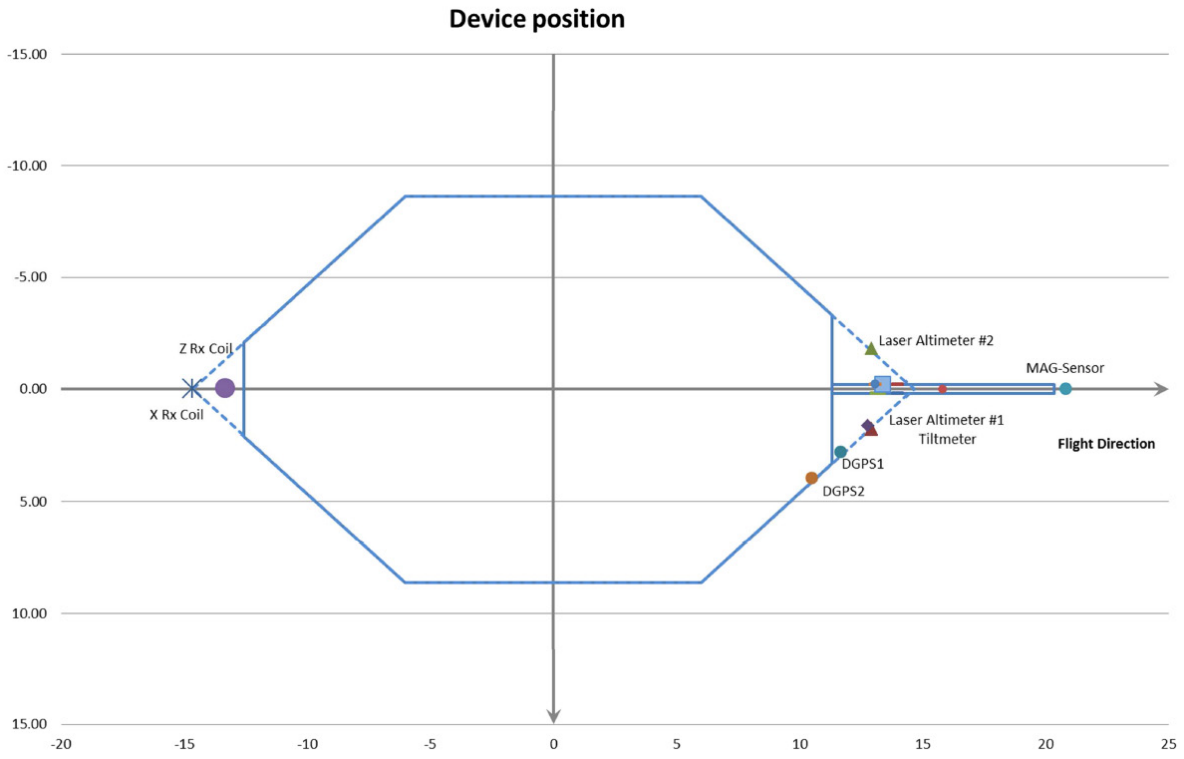


Figure 4-3: SkyTEM 304 frame, including instrumentation locations and X and Y axes. Distances are in meters. Instrumentation locations listed in Table 4-1.



Figure 4-4: Photos of the SkyTEM 304 system in suspension beneath the helicopter.

Table 4-1: Positions of instruments on the SkyTEM 304 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	0
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 SkyTEM 304 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.

Installation of the navigational instruments in the helicopter and assembly of the SkyTEM304 system commenced at the beginning of the 2023 AGF AEM project campaign in June in Colorado and the system was ferried to McCook, Nebraska and then to Beatrice, Nebraska for projects with other districts. The NNRD project was flown out of the Beatrice Municipal Airport on June 23 and 24 with refueling occurring at the Tecumseh and Auburn Municipal Airports. 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 337.3 line-miles (542.7 line-kilometers) were acquired over the NNRD AEM survey area between 23 June 2023 and finishing on 24 June 2023. A data acquisition map for the flight lines is presented in Figure 4-5, grouped by acquisition date. For this 2023 NNRD project, the SkyTEM 304M was flown at an average speed of 66.4 mi/hr (106.9 kilometers/hr) and at an average flight height of 115.3 ft (35.1 m) above land surface, using the sling-load cargo system of a Eurocopter AS350 B2 helicopter. The average pitch (tilt angle in the +/- X direction of travel) was -1.99 degrees and the average roll (tilt angle perpendicular to the direction of travel) was -0.50 degrees. Images of the NNRD AEM survey ground

speeds are presented in Figure 4-6, the flight heights are presented in Figure 4-7, and images of the pitch (X) angle and roll (Y) angle are presented in Figure 4-8 and Figure 4-9, respectively.

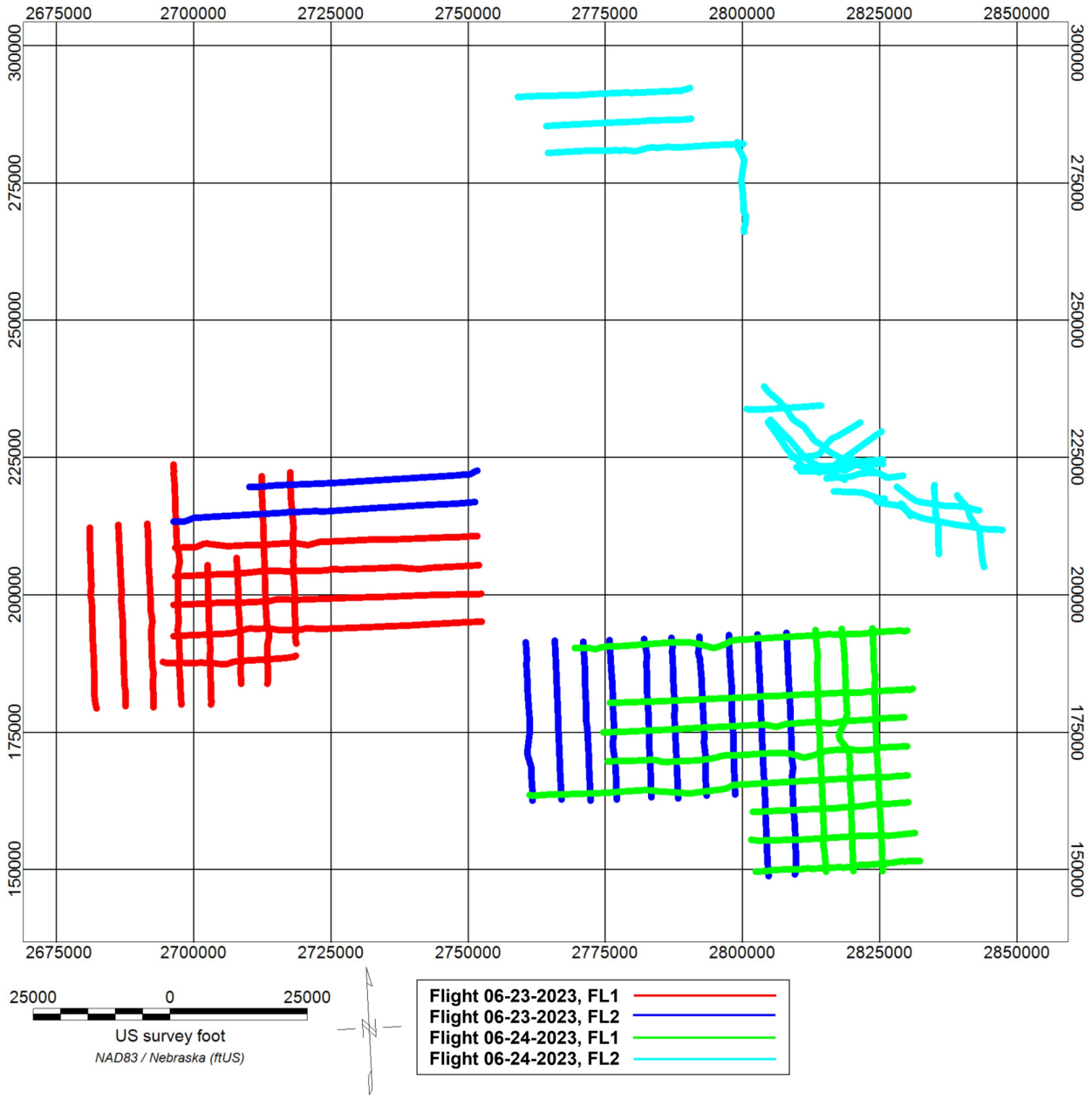


Figure 4-5. NNRD 2023 AEM flight lines grouped by acquisition date. Projection is Nebraska State Plane NAD83, feet.

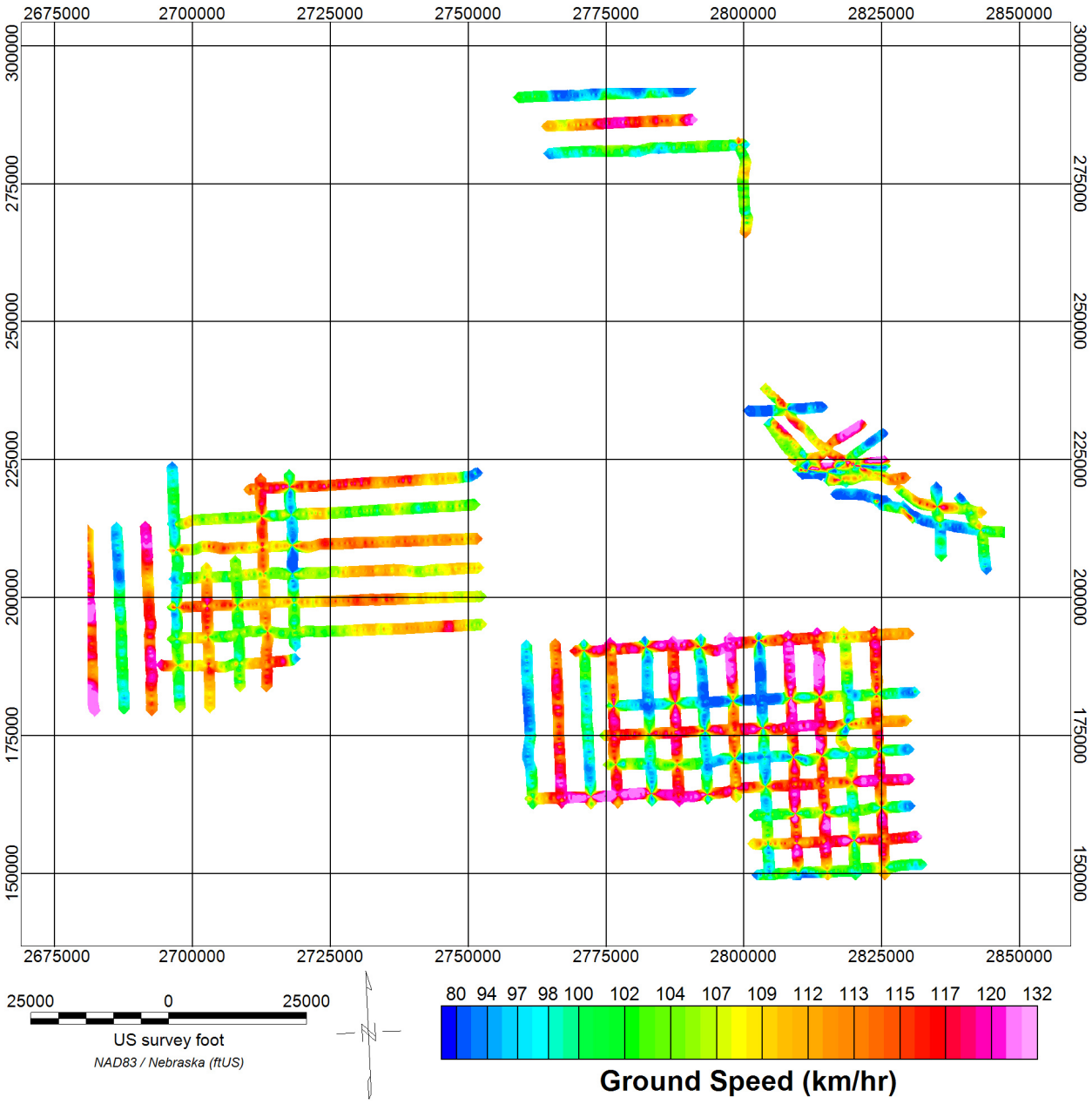


Figure 4-6. NNRD 2023 AEM flight lines ground speed. Projection is Nebraska State Plane NAD83, feet.

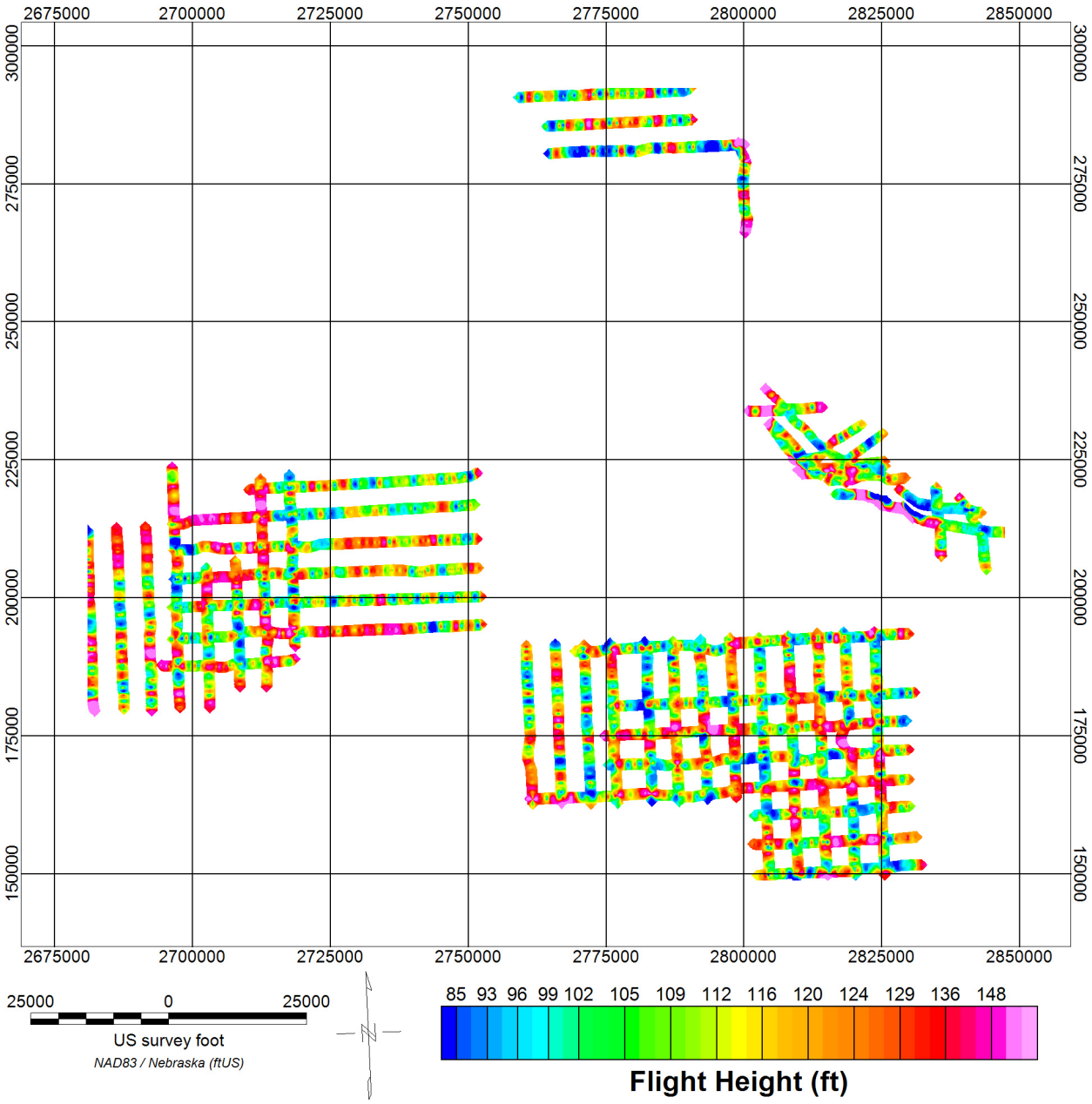


Figure 4-7. NNRD 2023 AEM flight lines flight height above the ground surface. Projection is Nebraska State Plane NAD83, feet.

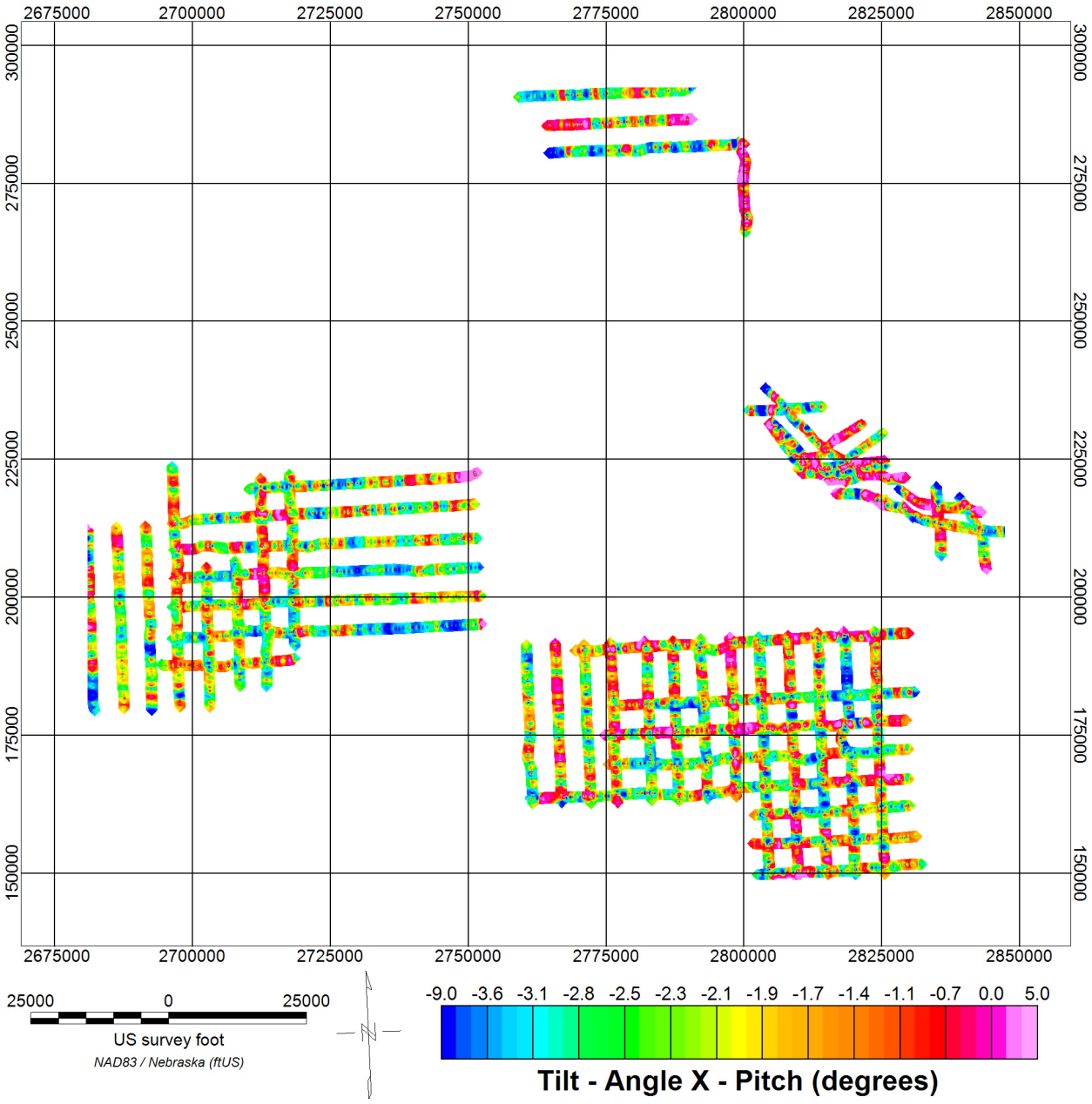


Figure 4-8. NNRD 2023 AEM flight lines pitch tilt angle in the +/-X direction of travel. Projection is Nebraska State Plane NAD83, feet.

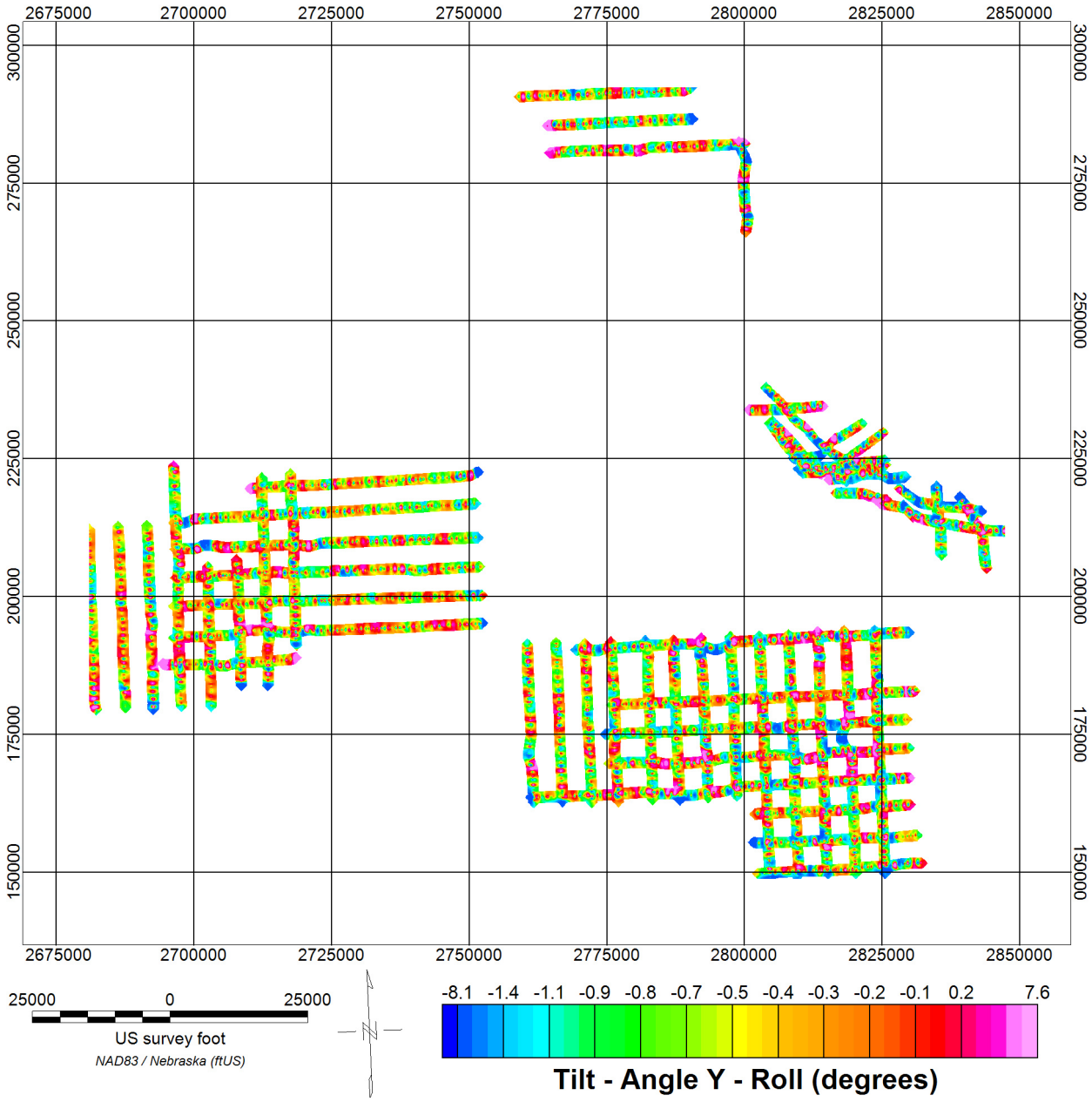


Figure 4-9. NNRD 2023 AEM flight lines Y roll angle perpendicular to the direction of travel. Projection is Nebraska State Plane NAD83, feet.

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 304 were processed using Aarhus Workbench version 6.8.0.0 (Aarhus Geosoftware (https://www.aarhusgeosoftware.dk/aarhus-workbench) 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 100 meters, respectively.

Trapezoidal spatial averaging filters were next applied to the AEM data. The times used to define the trapezoidal filters for the Low Moment were $1.0x10^{-5}$ sec, $1.0x10^{-4}$ sec, and $1.0x10^{-3}$ sec with widths of 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 moments. 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. An example of flight light passing over possible sources of EM coupling is shown in Figure 4-10 Figure 4-11 displays what an EM coupling looks like in Aarhus Workbench both before and after removal. Example inversion results with coupling and that coupling removed are shown in Figure 4-12. Data were also removed where the system height was greater than 230 feet (70 m) which causes a decrease in the signal level. This occurred at several locations due to object avoidance.

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. Once acceptable LCI results were obtained, the data were then inverted using the Spatially Constrained Inversion (SCI) discussed below.

After final processing, 273.8 line-miles (440.6 line-kilometers) were retained for inversion amounting to a retention rate of 81.2%. This high rate is the result of careful flight line planning and design to avoid the infrastructure present in the survey area.

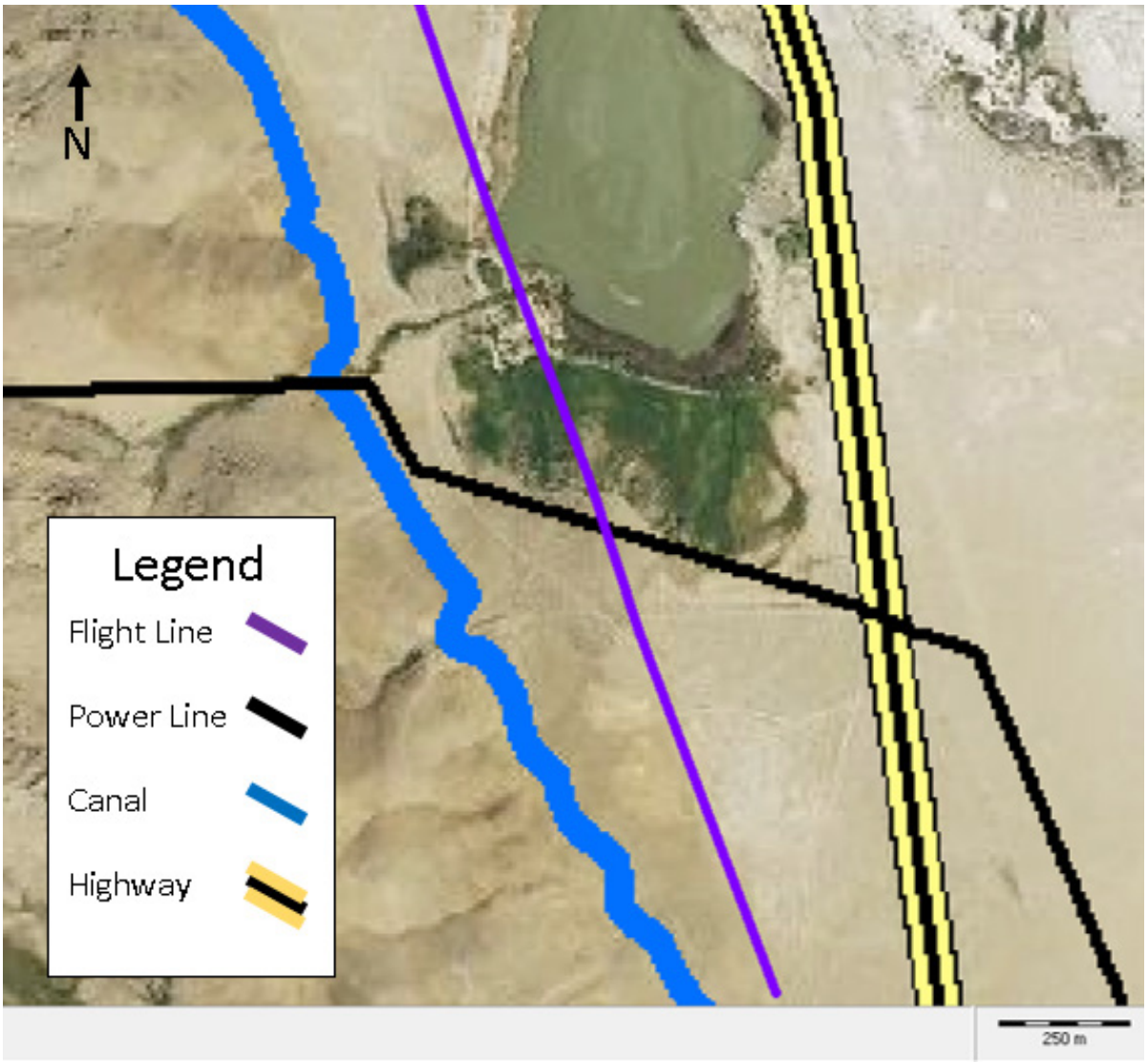


Figure 4-10: Example locations of electromagnetic coupling with pipelines or power lines.

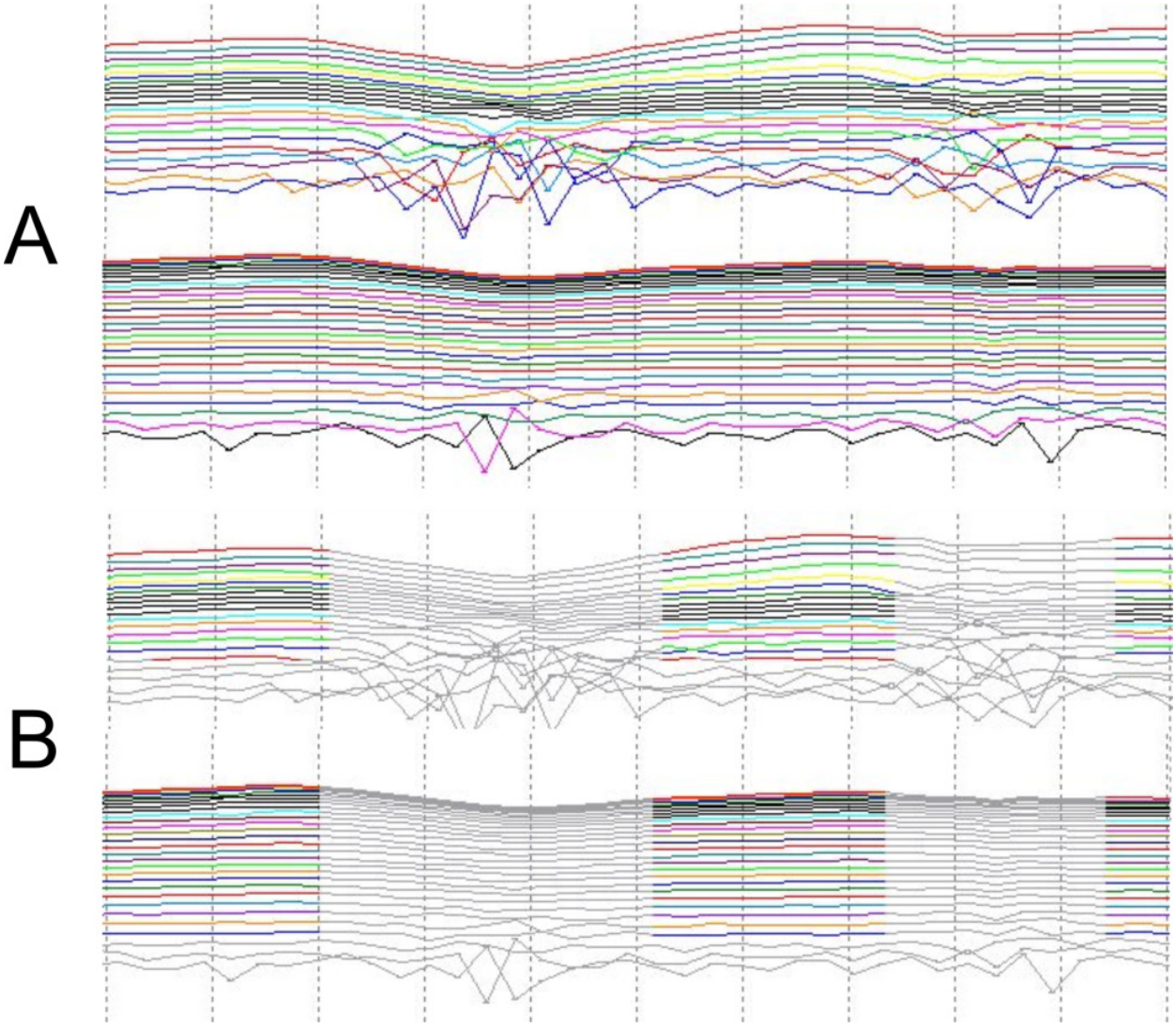


Figure 4-11: A) Example of AEM data affected by electromagnetic coupling as presented in the Aarhus Workbench editor. The top group of lines is the unedited data with the Low Moment on top and the High Moment on the bottom. The bottom group shows the same data after editing.

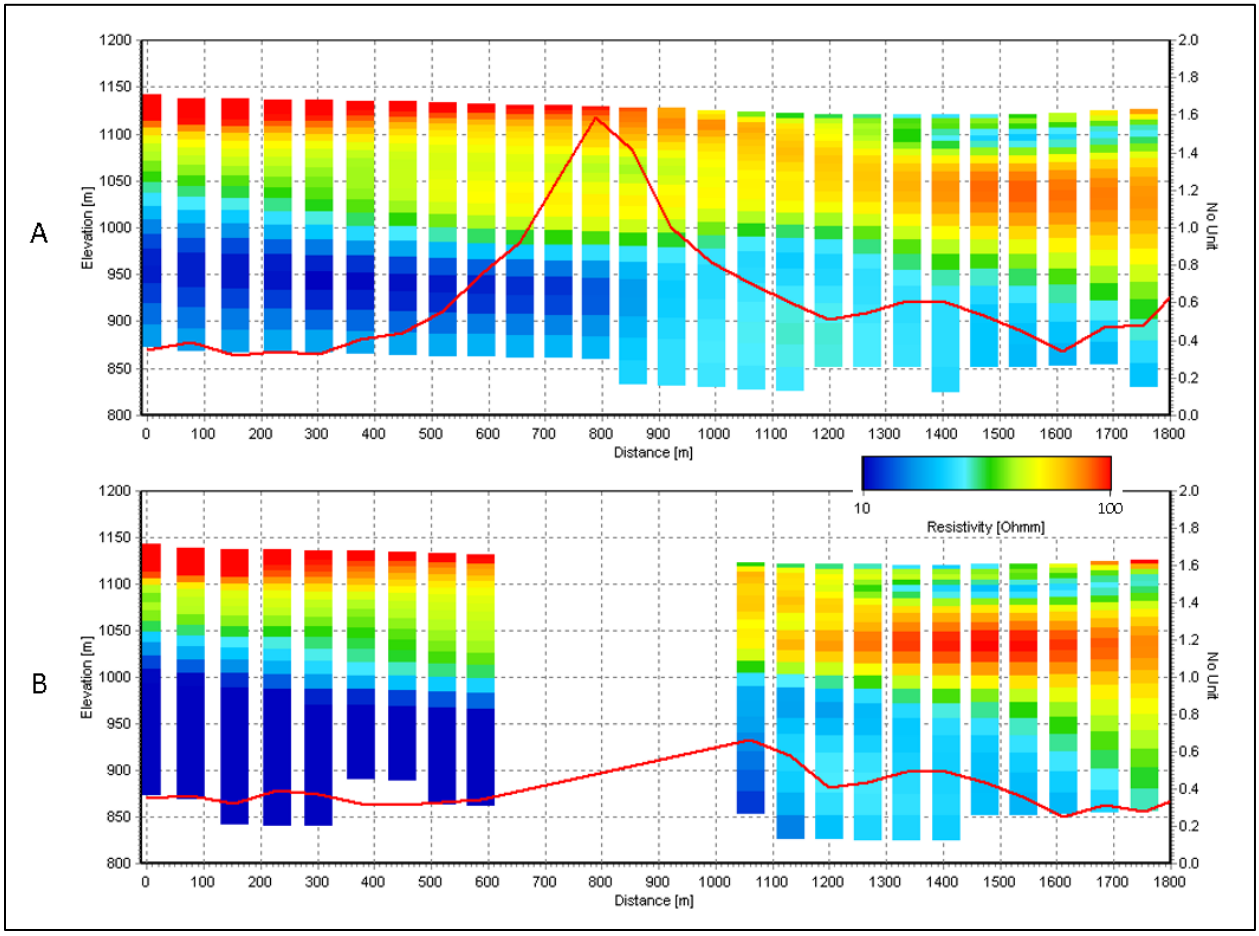


Figure 4-12: A) Example of Laterally-Constrained inversion results where AEM data affected by coupling with pipelines and power lines were not removed. B) Inversion results where AEM data affected by coupling were removed.

4.4.4 Power Line Noise Intensity (PLNI)

The Power Line Noise Intensity (PLNI) channel assists in identifying possible sources of noise from power lines. Pipelines, unless they are cathodically-protected, are not mapped by the PLNI. The PLNI is produced by performing a spectral frequency content analysis on the raw received Z-component SkyTEM data. For every Low Moment data block, a Fourier Transform (FT) is performed on the latest usable time gate data. The FT is evaluated at the local power line transmission frequency (60 Hz) yielding the amplitude spectral density of the local power line noise. The PLNI data for the NNRD 2023 AEM survey are presented as a grid in Figure 4-13. The NNRD 2023 survey As-Flown data and the data retained for inversion are presented in Figure 4-14. The blue lines represent the 81.2% of data retained for inversion and red lines representing data removed due to infrastructure and noise.

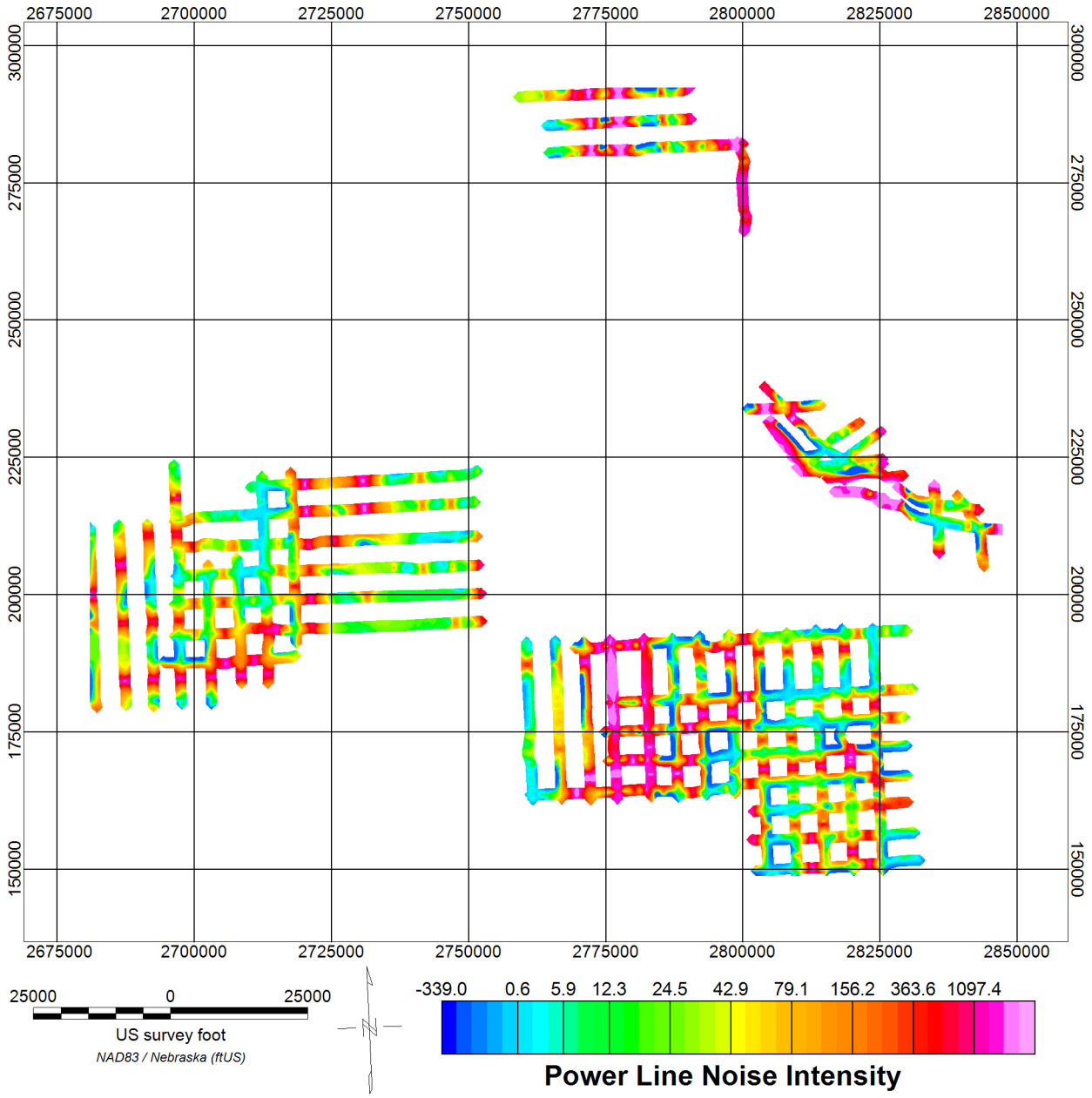


Figure 4-13: Power Line Noise Intensity (PLNI) map of the NNRD 2023 project area. Projection is Nebraska State Plane NAD83, feet.

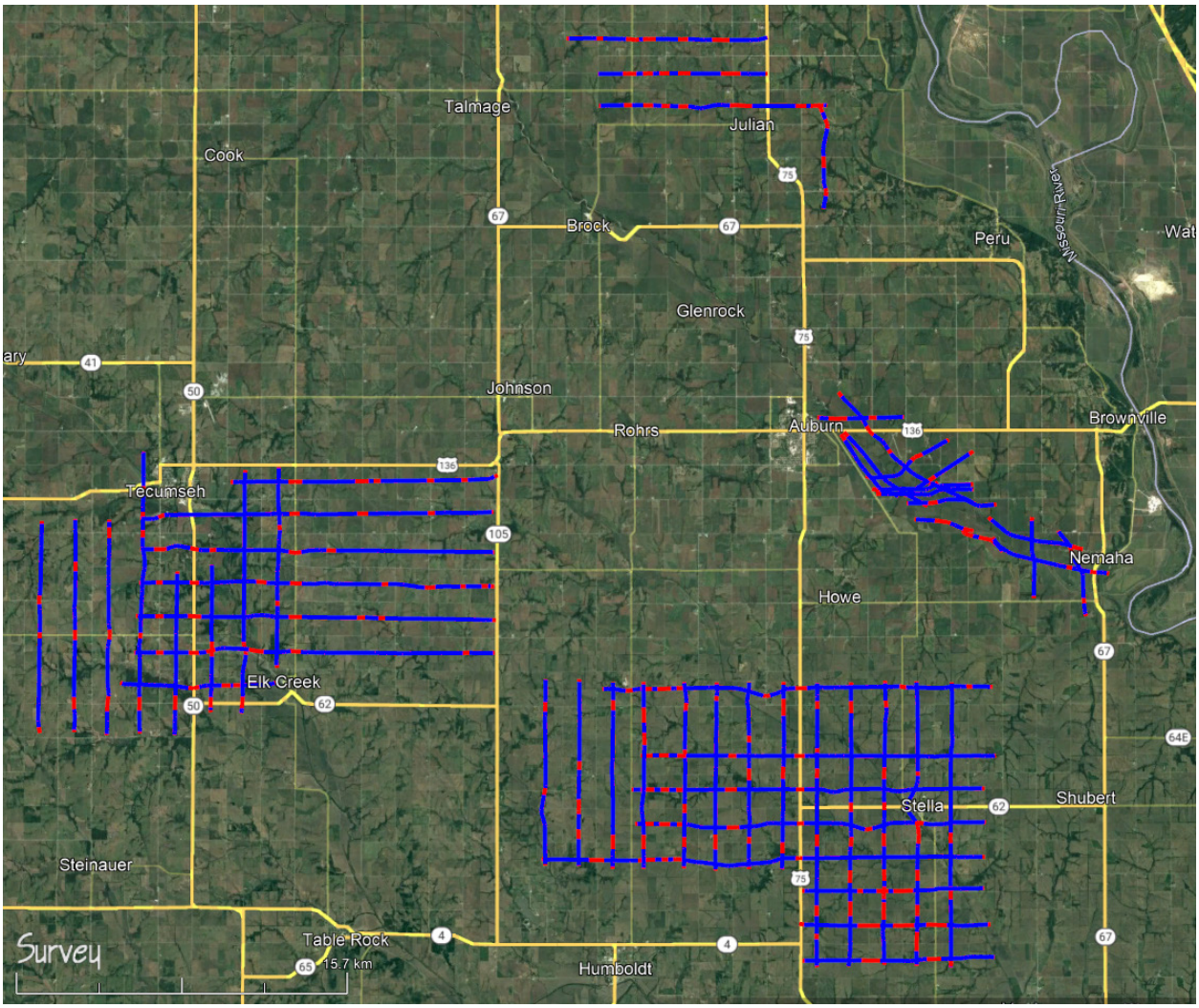


Figure 4-14. Locations of inverted data (blue lines) along the AEM flight lines (red lines) on the NNRD 2023 AEM survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the "as-flown" flight lines are included in Appendix 3\KMZ.

4.4.5 Magnetic Field Data

As discussed above, the SkyTEM 304 includes a Total Field magnetometer. The magnetic Total Field data can yield information about infrastructure as well as geology. Figure 4-15 shows the residual magnetic Total Field (RMF) intensity data for the 2023 NNRD AEM survey area after correcting for diurnal drift and removing the International Geomagnetic Reference Field (IGRF). This data is used in decoupling efforts.

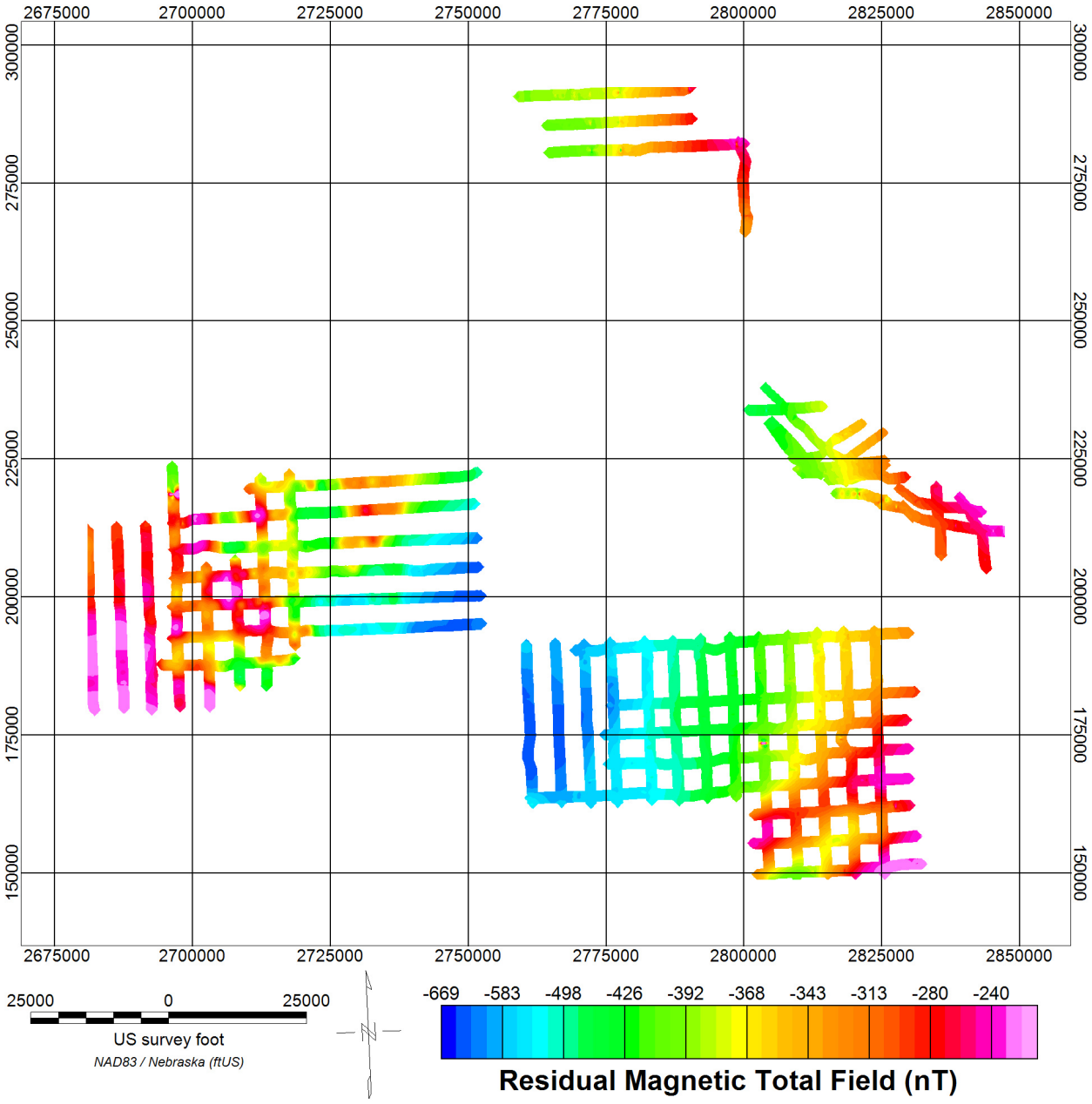


Figure 4-15. Residual magnetic Total Field intensity data for the NNRD 2023 AEM survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed. Projection is Nebraska State Plane NAD83, feet.

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 NNRD 2023 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 approximately by a factor of 1.01. The depths to the bottoms of the 39th layers were set to 325.0 ft, with thicknesses up to about 21.6 ft. The thicknesses of the layers increase with depth (Table 4-3 and Figure 4-16) as the resolution of the EM technique decreases. The spatial reference distance, ***s***, for the inversion constraints was set to 328 ft (100 m) with a power law falloff of 0.75. The vertical and lateral constraints, ***ResVerSTD*** and ***ResLatStD***, were set to 2.4 and 1.4, respectively, for all layers.

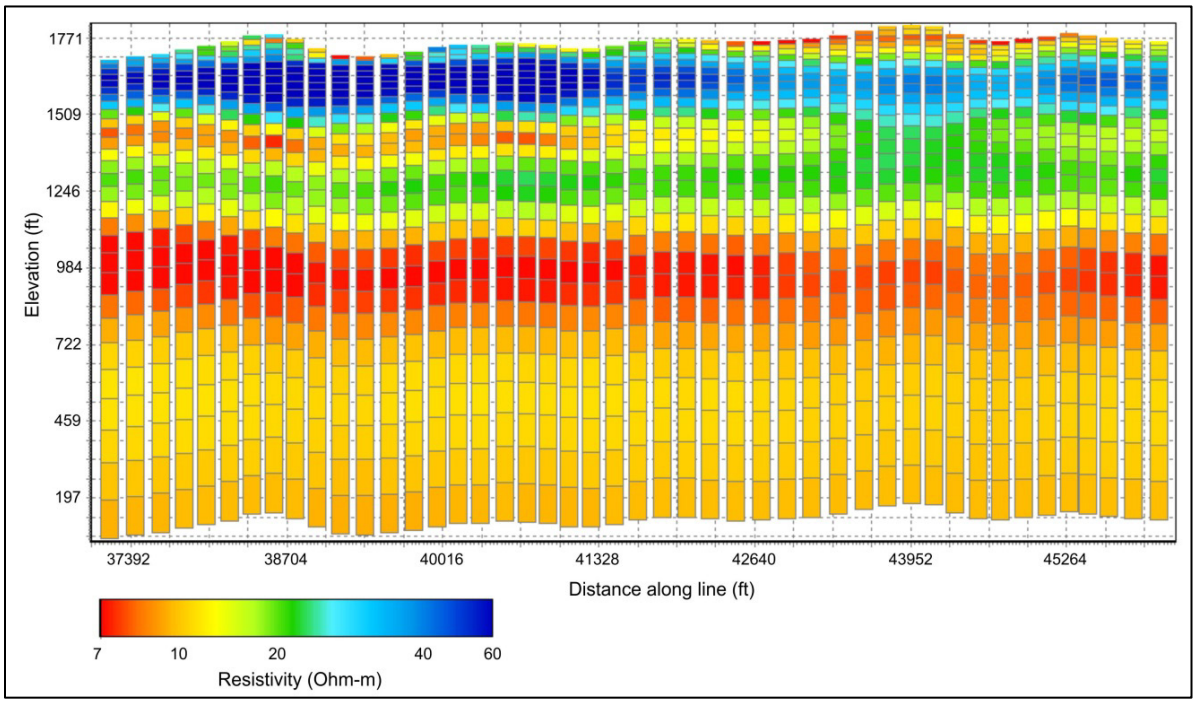


Figure 4-16. An example of an AEM profile illustrating increasing model layer thicknesses with depth.

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 forward modeled 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	276.6	23.0	84.3	7.0
2	13.5	6.9	4.1	2.1	22	301.2	24.6	91.8	7.5
3	21.0	7.5	6.4	2.3	23	327.1	25.9	99.7	7.9
4	28.9	7.9	8.8	2.4	24	355.0	27.9	108.2	8.5
5	37.4	8.5	11.4	2.6	25	384.5	29.5	117.2	9.0
6	46.3	8.9	14.1	2.7	26	415.7	31.2	126.7	9.5
7	55.8	9.5	17.0	2.9	27	449.2	33.5	136.9	10.2
8	65.9	10.2	20.1	3.1	28	484.9	35.8	147.8	10.9
9	76.8	10.8	23.4	3.3	29	522.7	37.7	159.3	11.5
10	88.3	11.5	26.9	3.5	30	563.0	40.4	171.6	12.3
11	100.7	12.5	30.7	3.8	31	606.0	43.0	184.7	13.1
12	113.9	13.1	34.7	4.0	32	651.9	45.9	198.7	14.0
13	127.6	13.8	38.9	4.2	33	700.5	48.6	213.5	14.8
14	142.4	14.8	43.4	4.5	34	752.3	51.8	229.3	15.8
15	158.1	15.7	48.2	4.8	35	807.5	55.1	246.1	16.8
16	174.9	16.7	53.3	5.1	36	866.2	58.7	264.0	17.9
17	192.9	18.0	58.8	5.5	37	928.9	62.7	283.1	19.1
18	212.0	19.0	64.6	5.8	38	995.5	66.6	303.4	20.3
19	232.3	20.3	70.8	6.2	39	1066.3	70.9	325.0	21.6
20	253.6	21.3	77.3	6.5					

Figure 4-17 presents a histogram of the NNRD 2023 SCI inversion data/model residuals and a map of data to model error residuals comparison is presented in Figure 4-18.

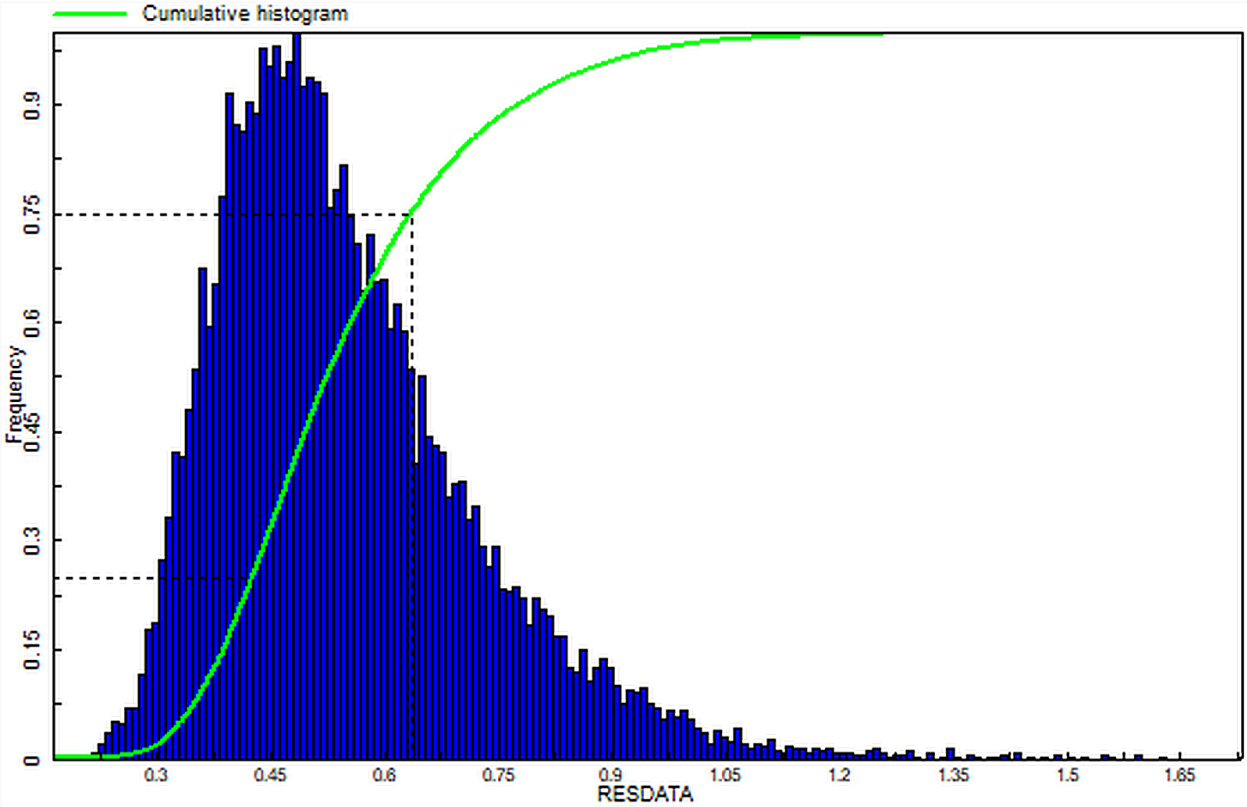


Figure 4-17. Data/model residual histogram for the NNRD 2023 SCI inversion results.

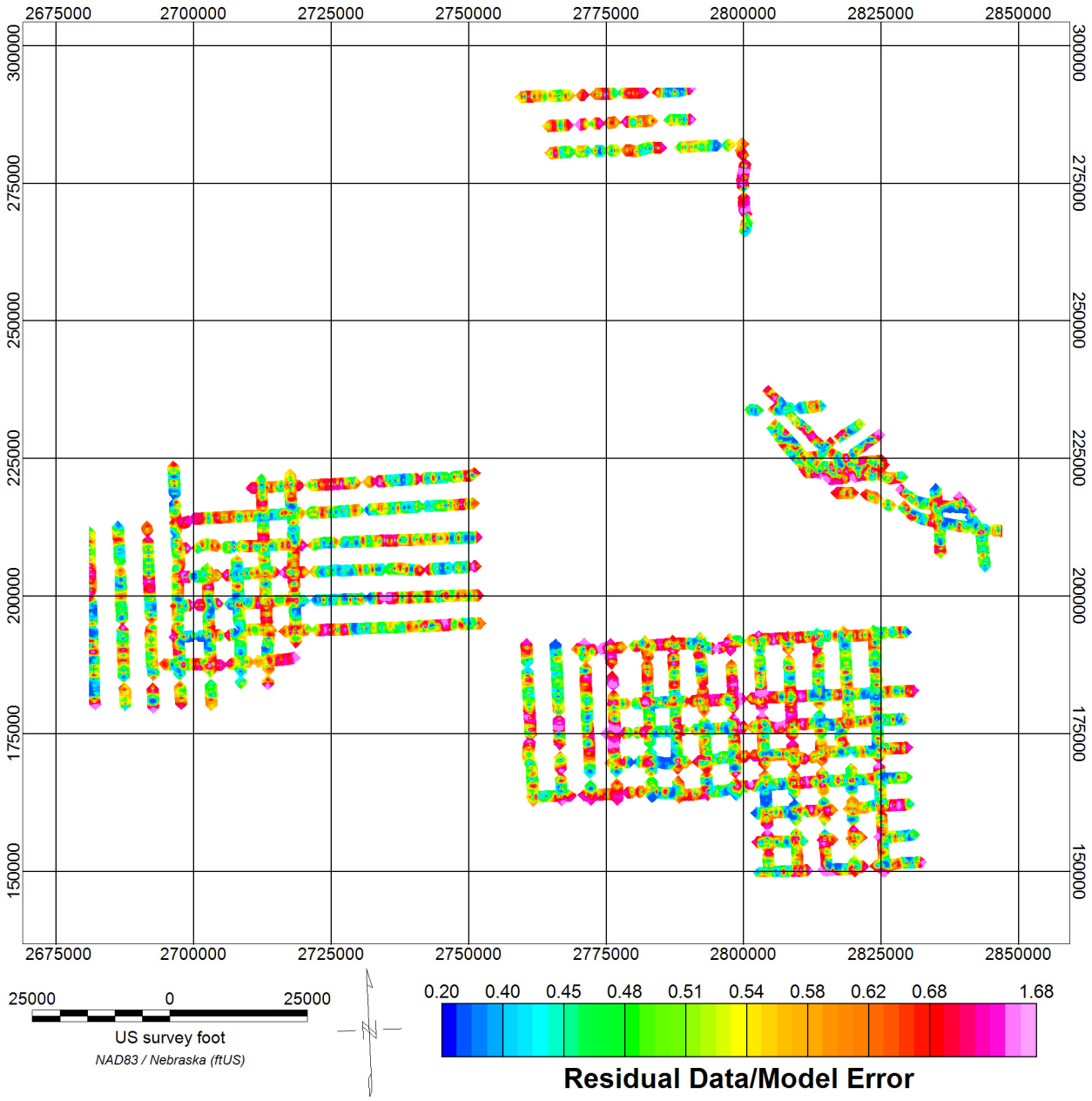


Figure 4-18. Map of data-inversion model residuals for the NNRD 2023 SCI inversion results. Projection is Nebraska State Plane NAD83, feet.

5 AEM Results and Interpretation

This section provides the details on the process involved in the interpretation of the NNRD 2023 AEM survey data and inversion results.

5.1 Merging AEM Flight Lines

After the inversion process, lines from the 2015 (Carney et al., 2015b), 2018 (AGF, 2019), 2020 (AGF, 2021), and 2023 NNRD AEM surveys plus Frequency Domain AEM RESOLVE surveys from 2007 Firth and 2009 Sprague (AGF, 2022) were merged into the area of the NNRD (Table 5-1). The resultant combined area allows for improved viewing and interpretation of the NNRD AEM inversion results. Figure 5-1 is a map of the 2023 NNRD AEM survey with the lines that were combined from the 2007, 2009, 2015, 2018, and 2020 NNRD AEM surveys.

Before the 2015 and 2018 could be combined with the 2020 and 2023 data to create 3D voxels, the inverted earth model structures for 2015 and 2018 had to be converted into the 40-layer 2020 and 2023 inverted model layer structure presented in Table 4-3 with a first layer depth of -2 m (-6.6 ft) and 39th layer depth of -325 m (-1066.3 ft). The 2015 inversion models had 30 layers with a first layer depth of -5 m (-16.4 ft) and a 29th layer depth of -500.2 m (-1,641.1 ft). The 2018 inversion models had 40 layers with a first layer depth of -1 m (-3.3 ft) and a 39th layer depth of -349.9 m (-1,147.7 ft).

5.2 Interpretative Process

5.2.1 Construction of 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 downloaded and processed for the NNRD survey. The data was downloaded from the National Elevation dataset (NED) located at the National Map Website (U.S. Geological Survey, 2023) at a resolution of 1/3 arc-second or approximately 30 ft. The native horizontal and vertical datum of the DEM was North American Datum of 1983 (NAD83) and North American Vertical Datum of 1988 (NAVD88), respectively. For this project, the DEM was projected to NAD83 Nebraska State Plane Coordinate System (SPCS), feet and the elevation values are referenced to NAVD88, feet. Figure 5-2 is a map of the DEM for the NNRD AEM survey area having a vertical relief of approximately 637 ft with a minimum elevation of 851 ft and a maximum elevation of 1,488 ft. This DEM was used to reference all elevations within the AEM and borehole datasets. The raster dataset was resampled to a 300-foot cell size grid for the voxel modeling for the complete NNRD area and a 100-foot cell size grid was used for the Auburn subset area.

Table 5-1. Merged 2015, 2018, 2020, and 2023 NNRD AEM flight lines.

	Merged Lines 2018, 2020, 2023	Final Line
EW	600801, 100101, 800101, 302201	600802
EW	600701, 100201	600702
EW	600601, 100301	600602
EW	600501, 100401	600502
EW	600401, 100500	600402
EW	800201, 302101	800202
EW	800301, 302001	800302
EW	800401, 301901	800402
EW	800501, 301801	800502
EW	800601, 301701	800602
EW	800701, 301601	800702
EW	103301, 301500	301501
EW	103201, 301400	301401
EW	103101, 301300	301301
EW	103001, 301200	301201
EW	102901, 301100	301101
EW	102801, 300900	300901
EW	102701, 300800	300801
EW	102601, 300700	300701
EW	102500, 300600	300601
EW	1100301, 102400, 300400	300401
EW	1100201, 102301, 300200	300201
EW	1100101, 102200	102201
NS	200101	402100
NS	900101, 200201, 402200	402201
NS	900201, 402300, 200301	402301
NS	900301, 402400, 200401	402401
NS	900401, 200501	200502
NS	900501, 200601	200602
NS	900601, 200801, 200701	200702
NS	900701, 201001, 200901	200902
NS	900801, 201201, 201101	201202
NS	201802, 201801	201803

	Merged/Modified Lines 2015	Final Line
NW-SE	101101	3001101a
EW	101101	3001101b
NW-SE	101101	3001101c
EW	101101	3001101d
SW-NE	101102	3001101e
EW	101201	3001201
EW	101401	3001301
EW	101501	3001501
NS	200801	4000803
NS	201101	4001101
NS	101303	4001201
NS	101201	4001302
NS	101501	4001401

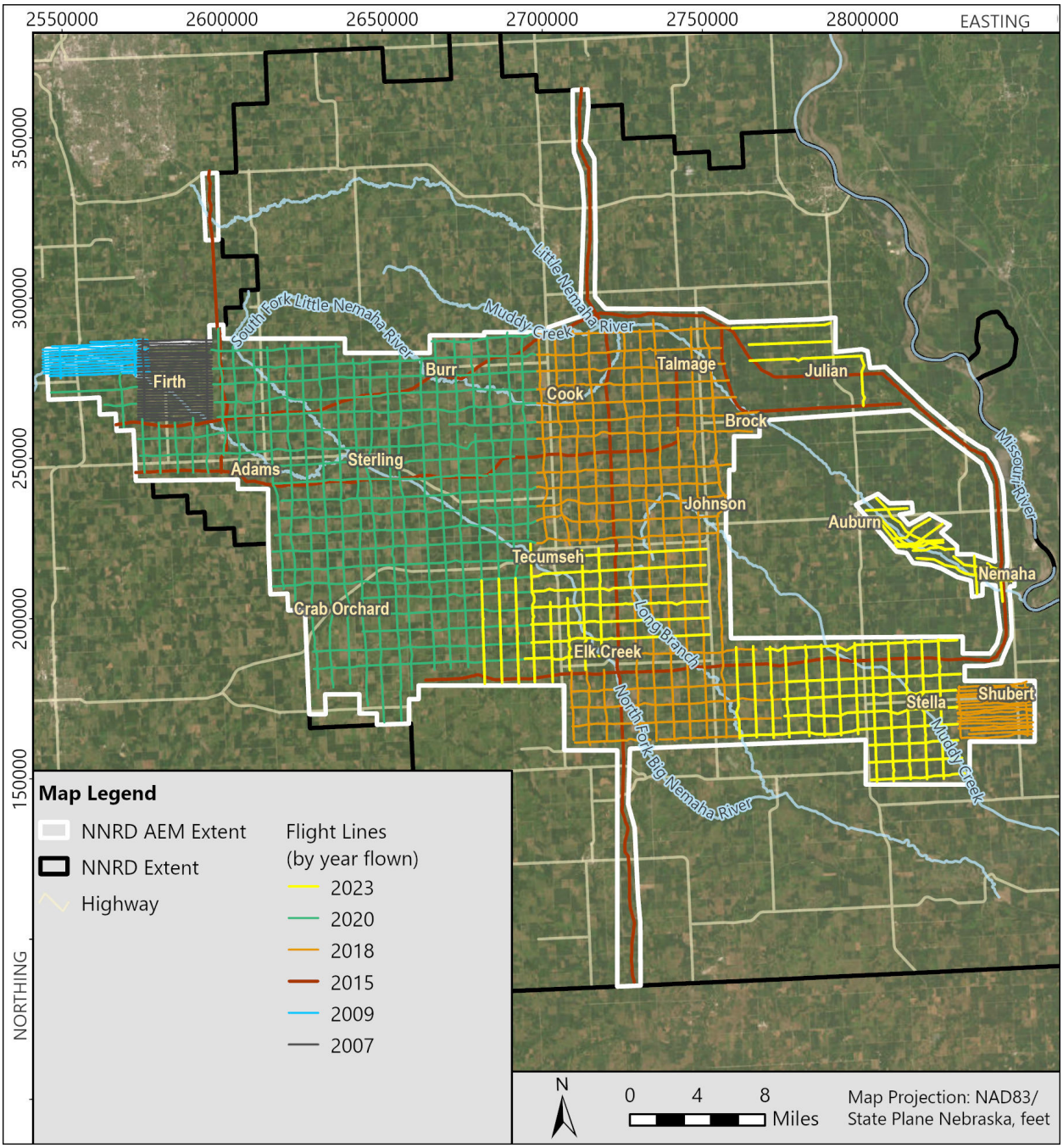


Figure 5-1. Map of the 2023 NNRD AEM survey with the flight lines that were combined from the 2007, 2009, 2015, 2018, and 2020 NNRD AEM surveys color-coded by year.

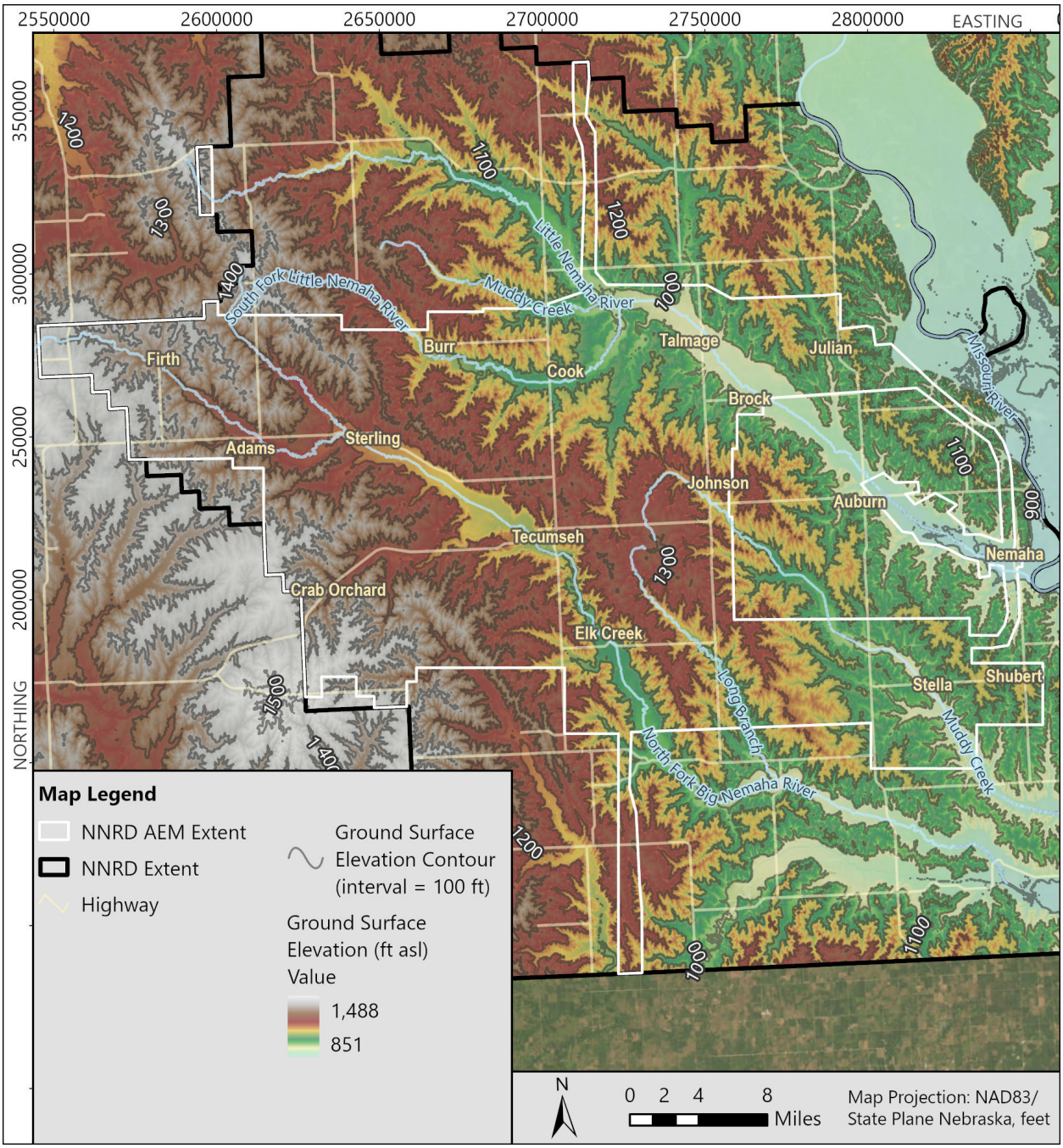


Figure 5-2. Map of the Digital Elevation Model for the NNRD AEM survey area. Data source is the one (1/3) arc-second National Elevation Dataset (U.S. Geological Survey, 2023). Projection is North American Datum of 1983 (NAD 83) State Plane Nebraska (feet) and the elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88) (feet).

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 in combination with a published geologic map. For conciseness, the bedrock surface interpolation process is described in the following bulleted list:

Data used:

- USGS Map I-2725, "Bedrock Geologic Map Showing Thickness of Overlying Quaternary Deposits, Lincoln Quadrangle and Part of Nebraska City Quadrangle, Nebraska and Kansas" by Burchett et. al. (1972) (Figure 5-3). This map shows the approximate locations of bedrock outcrops.

Most up to date DNR and CSD borehole data downloaded from GeoCloud (UNL, 2023).

DNR borehole processing:

- Extracted DNR boreholes with lithologic data information readily available in GeoCloud (UNL, 2023) within an approximately 37-mile by 47-mile area encompassing the 2023 flight lines as well as surrounding area.
    - 374 boreholes (Figure 3-1 Boreholes) were included in the dataset for analysis (dataset is referred to as 'working borehole lithology dataset' herein).
- Extracted project DEM elevation to the DNR boreholes.
- In a spreadsheet, categorized 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'
- Calculated the top of bedrock for each borehole by subtracting the first instance of 'Bedrock' lithology from the DEM elevation.

CSD borehole processing:

- Extracted project DEM elevation to the CSD boreholes.
- Calculated the top of bedrock for each borehole by subtracting the first bedrock unit from the DEM elevation.
- Added the CSD borehole stratigraphy table to the working borehole lithology dataset.
    - Number of CSD boreholes included in the working borehole lithology dataset = 230 (UNL, 2023) (Figure 3-1 Boreholes)

Borehole bedrock elevation interpolation:

- Converted the working borehole lithology dataset into a point shapefile.

  - Final borehole shapefile used for interpolation included 604 data points.

- Interpolated the borehole point shapefile into a continuous raster dataset using the kriging geostatistical model and exported raster surface to a 300 ft cell size grid.

- Calculated the residuals of the actual measured top of bedrock elevation to the interpolated top of bedrock elevation.

- Reviewed 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. Flagged those boreholes that appeared to be anomalous.
  - Boreholes are 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 ~ 100 ft from adjacent wells’ actual measured bedrock elevation, or
    - a borehole’s actual measured bedrock elevation varied more than ≈ 100 ft from an adjacent CSD well.

- Re-interpolated the borehole point shapefile excluding those points flagged as “anomaly” into a continuous raster dataset using the kriging geostatistical model and export to a 300 ft cell size grid.

- The final borehole-only bedrock surface was used as a guide in the interpretation of the bedrock within the AEM data profiles described next.

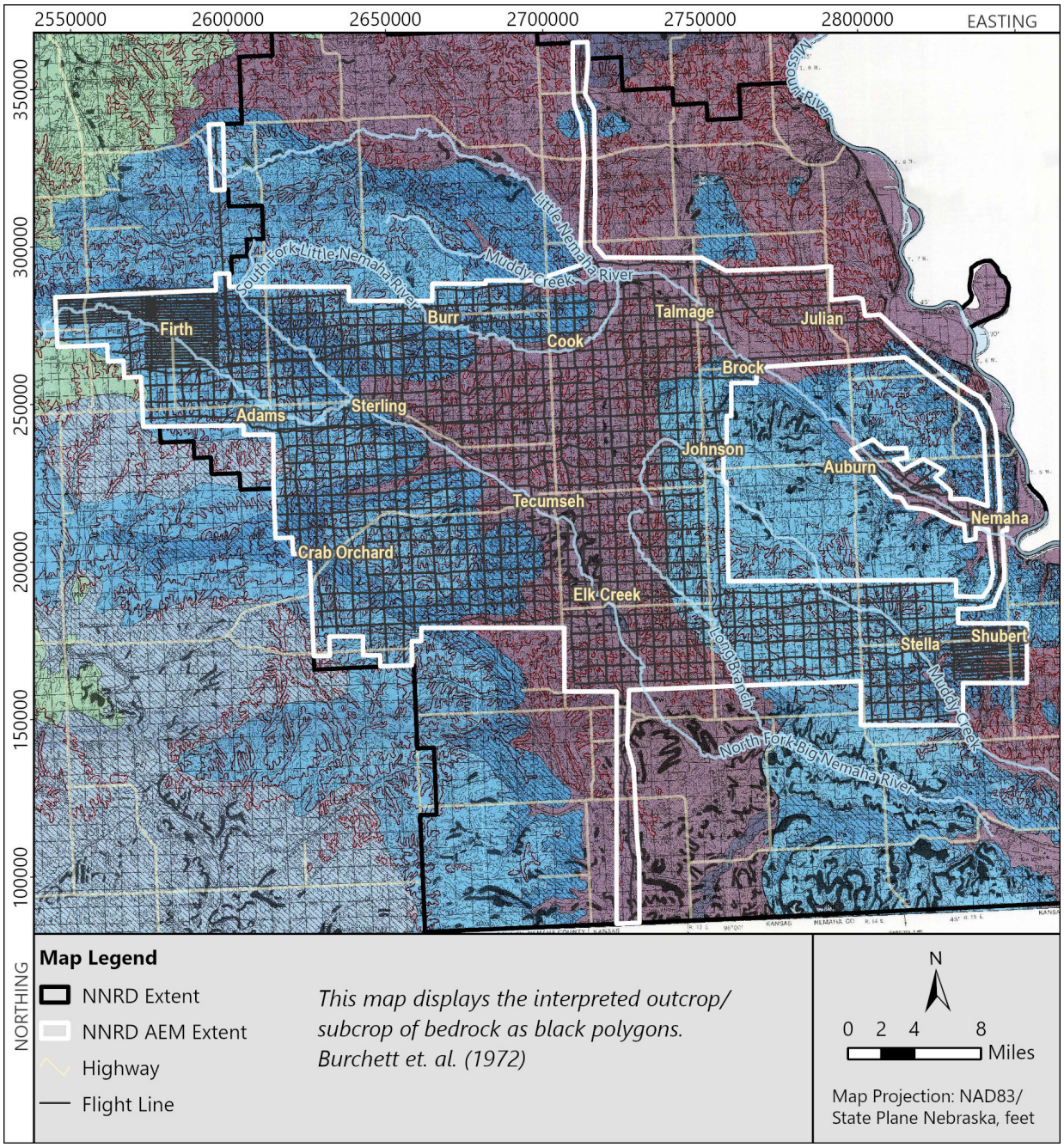


Figure 5-3. This map displays the approximate outcrop of geologic units as black polygons or shaded areas. Source of the map is Burchett et. al. (1972) and was used as a guide for the AEM interpretation throughout the NNRD AEM survey.

5.2.3 Create Interpretative 2D Profiles

After the 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, 2024). 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 highlight subtle differences in the resistivity structure within the inverted AEM data related to the area being interpreted. The first step in the interpretation is digitizing the contacts between the geologic units including: Cretaceous Dakota Group (***Kd***) and the undifferentiated Pennsylvanian and Paleozoic units (***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 maps (Burchett et al., 1972, Burchett, 1986), and the contacts and extents may differ in the final interpretation. Additionally, the bedrock surface, as developed from borehole logs, was used as a guide for the interpretation of the ***Kd*** and ***IP*** in areas of low electrical resistivity contrast and no boreholes.

The ***Kd*** only occurs in the northwestern portion of the NNRD survey area. The CSD stratigraphic control as well as the geological mapping (Burchett, 1986) were utilized to distinguish the ***Q*** from the underlying ***Kd***. The ***Kd*** general location (extent and depth) is detectable when there are resistive sands/sandstones. Use of general thickness constraints can also assist in the interpretation of the ***Kd*** position. 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 to interpret the top of the bedrock due to the poor resistivity contrast of the ***Q*** and the ***Kd*** in many locations. Some NE-DNR 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 interpretation of the highly eroded ***Kd*** in the northwestern portion of the NNRD survey was difficult due to the limited well control and limited AEM data. Estimates were made using the above procedure, but should be considered estimates. The interpretation of the ***Kd*** was not changed from the interpretation that was conducted in 2020 NNRD AEM study and was reported in AGF (2021).

The top of the ***IP*** was a challenging unit to interpret due to the highly variable resistivity of the ***IP*** and the occurrence of structural complexity within the ***IP*** units. The ***IP*** exhibits material properties from a resistive unit to a conductive unit based on the presence of clay minerals within the shale and limestone units. Additionally, there is saline water present in areas of the ***IP*** that exhibit a low resistivity signature. 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***. Thus, the ***IP*** must be deeper than the indicated NE-DNR hole that has no bedrock units indicated. The following profiles 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 4-mile-long line, L1001101, that was flown northwest to southeast on the east side of the Little Nemaha River near Auburn. Eighteen (18) NE-DNR registered wells are within 1,000 feet of the flight. The ***Q*** sediments are composed of two basic types: 1) fine grained low resistivity glacial tills, loess, and over bank deposits; and 2) possible paleochannel deposits/alluvial deposits. The coarse grained/ high resistivity materials form a lenticular deposit with the thickest and the deepest deposits in the center of the flight line. There is ***IP*** bedrock along the length of the line.

Figure 5-5 is an approximately 21-mile-long line, L800202, that was flown east-west north of Elk Creek and south of Tecumseh, Nebraska. This line is composed of 2020 and 2023 SkyTEM data. Line L800202 crosses North Fork of Big Nemaha River. One CSD test hole (*9-A-56*) is within 1,000 feet of the flight line and is shown projected onto the line. The ***Q*** sediments are composed of two basic types: glacial tills/loess with minor glacial outwash or small paleochannels. There is ***IP*** bedrock along the length of the line. The CSD test hole indicates shale within the ***IP***. Only a few NE-DNR wells are within 1,000 feet of the flight line. They do indicate the presence of small sand deposits within the ***Q***. On the eastern end of the line is a discrete resistivity anomaly. This was investigated as a potential bedrock block that was faulted in the area. However, when looking at adjacent lines it would seem to indicate an isolated sand deposit related to a paleochannel of outwash deposit. No wells are in the specific location to definitely determine the source of the high resistivity zone. This anomaly is much shallower than the Elk Creek Carbonite and is likely not related to the deposit. The majority of the line is composed of clays and silts.

Figure 5-6 is an approximately 25-mile-long portion of east-west line, L300401. The line segment is composed of 2018, 2020, and 2023 SkyTEM data. The line is just south of Talmage, Nebraska, and crosses (from east to west) Rock Creek, Little Nemaha River, Spring Creek, and the South Fork of the Little Nemaha River. The line has several NE-DNR wells within 1,000 feet of the flight line. The ***Q*** sediments are composed of two basic types: glacial tills/loess and paleochannel deposits. On the western end of the line segment a high resistivity feature indicates sand and gravel of a paleochannel deposit. Much of the deposit is unsaturated as indicated by the 1995 statewide water table (NE CSD, 1995). A similar but smaller deposit is located on the eastern side of the line segment. There is ***IP*** bedrock present along the length of the line.

Figure 5-7 is an approximately 23-mile-long east-west line, L600602. This line is composed of 2020 and 2023 SkyTEM data. The line is just north of Stella, Nebraska. The line crosses (from east to west) Muddy Creek, Little Muddy Creek, Long Branch, and the North Fork of the Big Nemaha River. One CSD test hole (*56*-78) and four NE-DNR wells are within 1,000 feet of the flight line. The ***Q*** sediments are composed of two basic types: glacial tills/loess and paleochannel deposits. The flight line indicates the edges of a large paleochannel system in the center of the flight line with much of it above the 1995 statewide water table. It also clearly shows several areas below the water table that indicate higher resistivity related to the coarse materials. The CSD test hole indicates shale within the ***IP***. The NE-DNR wells also indicate shale and limestone at depth.

Further discussion of the interpretation of the AEM data from 2007 to 2020 can be found in (Divine and Korus, 2012; Korus et al., 2013b; Carney et al., 2015b; AGF, 2019; and AGF, 2021). All of the 2D profiles along the flight lines can be found in *Appendix 1 – 2D Profiles and Surfaces*. The profiles discussed above show examples of the interpretive process used in this NNRD AEM interpretative report.

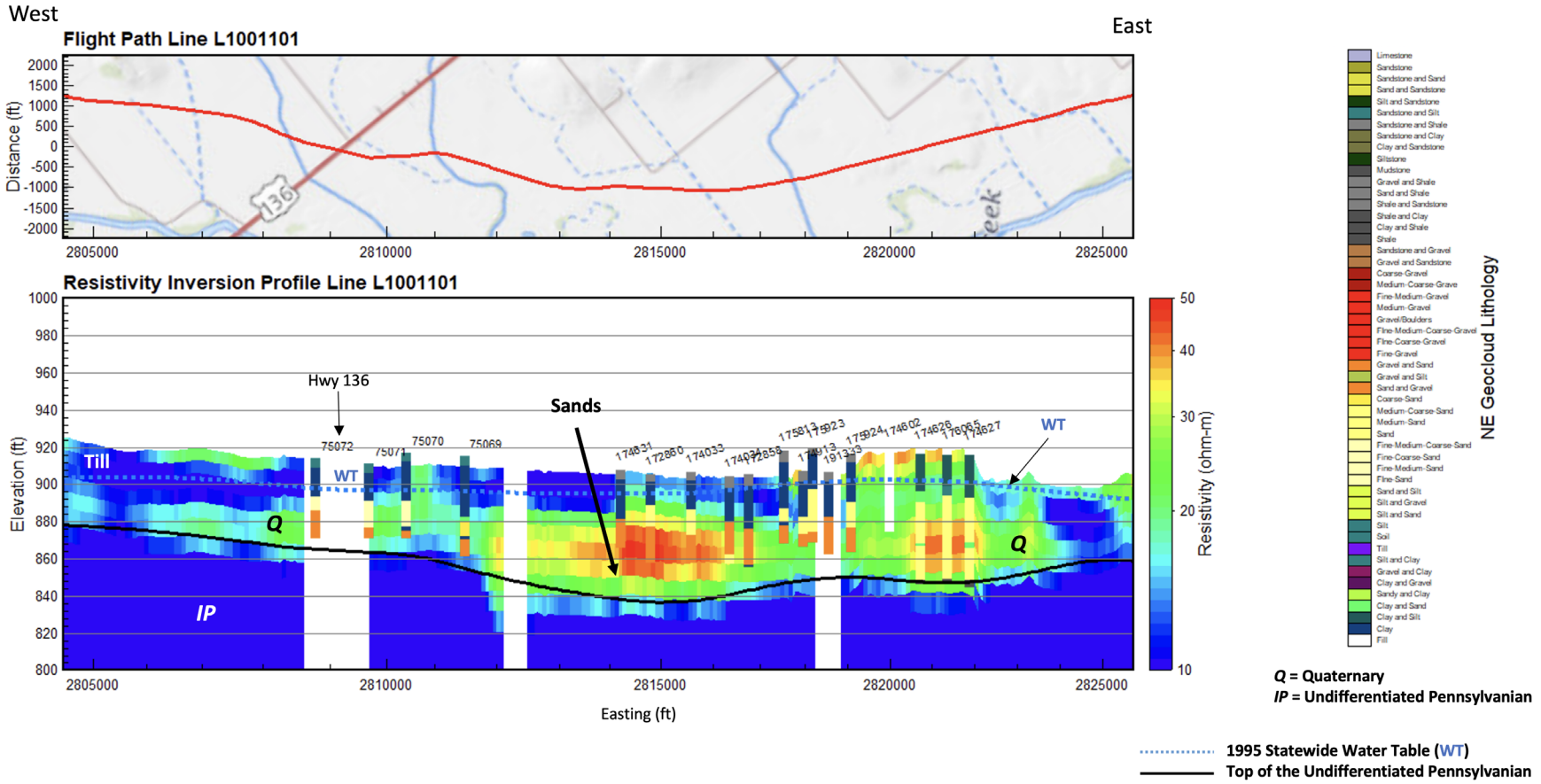


Figure 5-4. 4-mile line, L1001101, that was flown northwest-southeast, on the east side of the Little Nemaha River near Auburn, NE. NE-DNR borehole lithology is displayed on the AEM inverted earth models if they are within 1,000 feet of the flight line. Quaternary (*Q*) sediments and undifferentiated Pennsylvanian units (*IP*) are indicated. The interpretation of the top of the undifferentiated Pennsylvanian (*IP*) is indicated by the black line. The 1995 statewide water table is indicated by the dashed blue line.

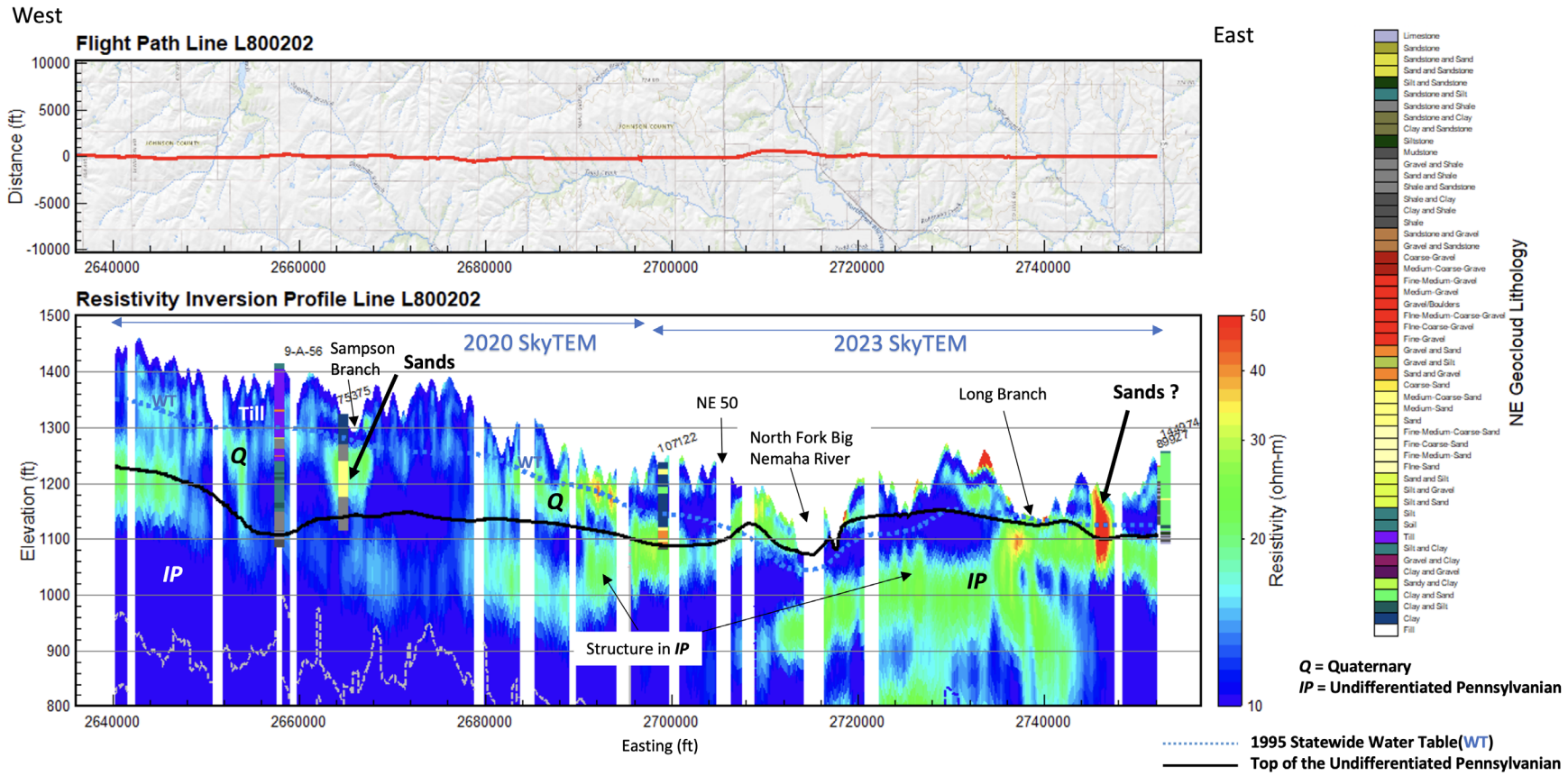


Figure 5-5. 21-mile line, L800202, that was flown east-west, north of Elk Creek, Nebraska. CSD borehole lithology and NE-DNR lithology logs are displayed on the AEM inverted earth models if they are within 1,000 feet of the flight line. Quaternary (*Q*) sediments and undifferentiated Pennsylvanian and Paleozoic units (*IP*) are indicated. The interpretation of the top of the undifferentiated Pennsylvanian (*IP*) is indicated by the black line. The 1995 statewide water table is indicated by the dashed blue line.

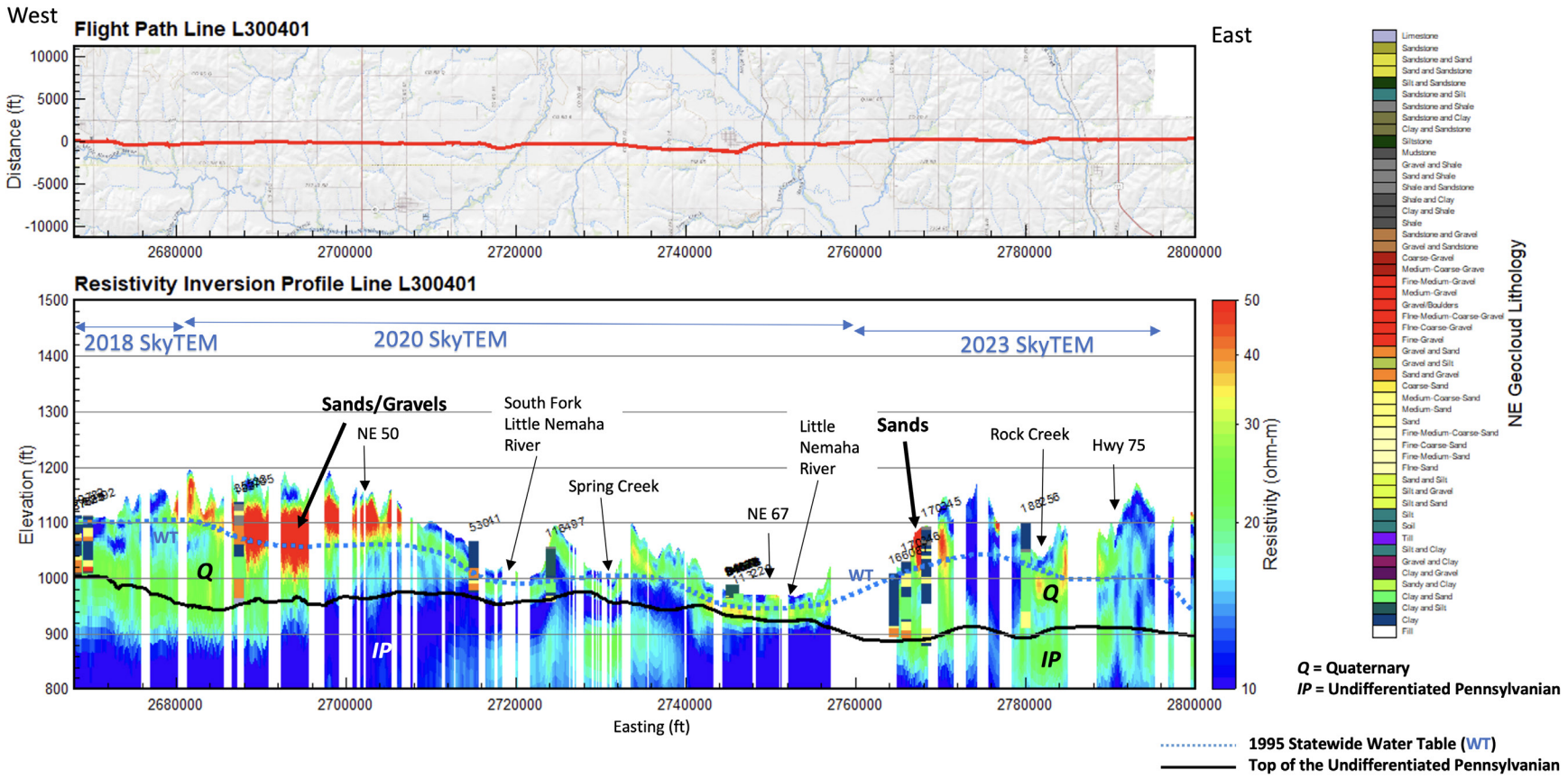


Figure 5-6. 25-mile line portion of L300401 that was flown east-west, south of Talmage, Nebraska. CSD borehole lithology and NE-DNR lithology logs are displayed on the AEM inverted earth models if they are within 1,000 feet of the flight line. Quaternary (*Q*) sediments and undifferentiated Pennsylvanian and Paleozoic units (*IP*) are indicated. The interpretation of the top of the undifferentiated Pennsylvanian (*IP*) is indicated by the black line. The 1995 statewide water table is indicated by the dashed blue line.

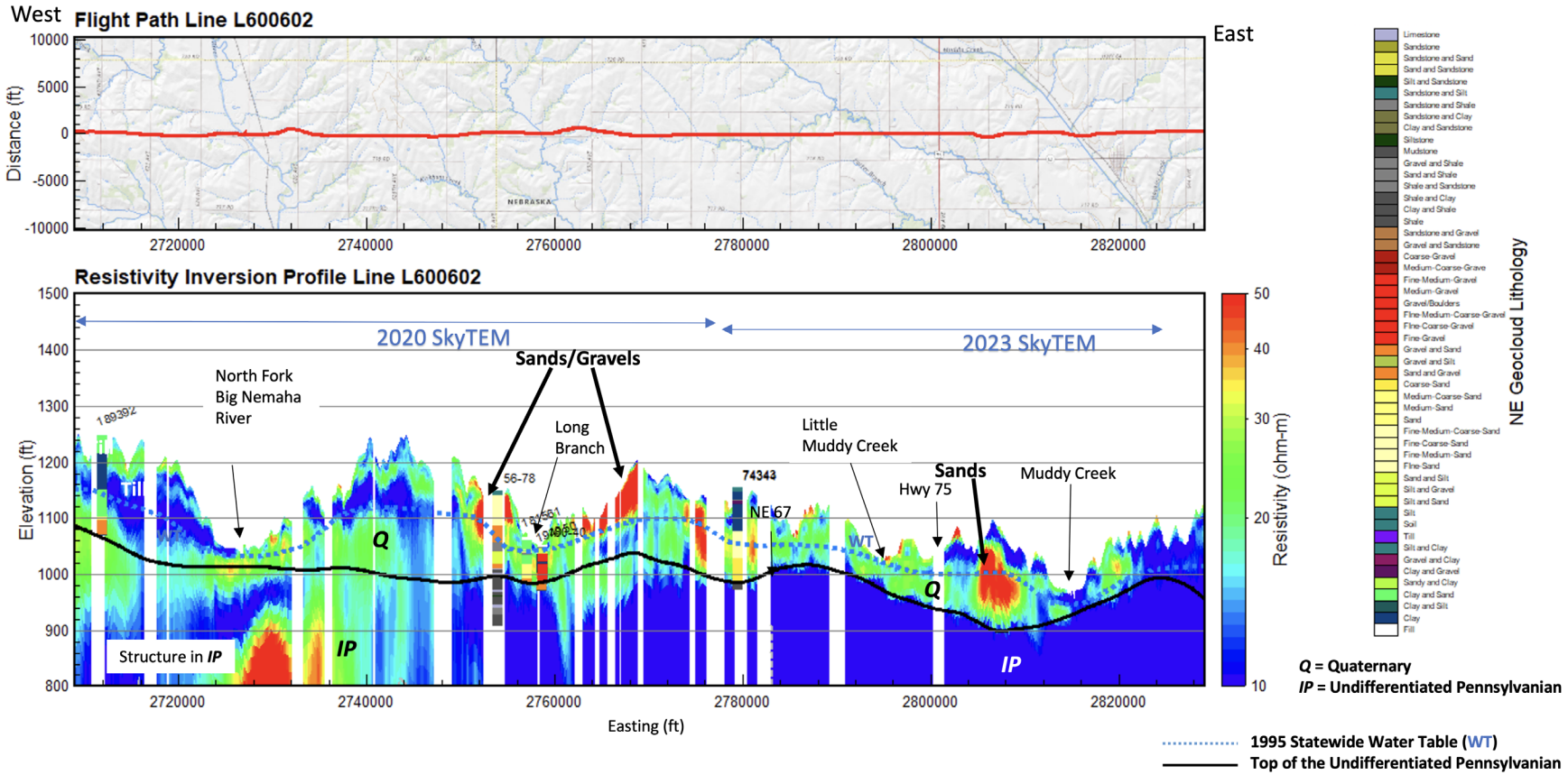


Figure 5-7. 23-mile line, L600602, that was flown east-west, north of Stella, Nebraska. CSD borehole lithology and NE-DNR lithology logs are displayed on the AEM inverted earth models if they are within 1,000 feet of the flight line. Quaternary (*Q*) sediments and undifferentiated Pennsylvanian and Paleozoic units (*IP*) are indicated. The interpretation of the top of the undifferentiated Pennsylvanian (*IP*) is indicated by the black line. The 1995 statewide water table is indicated by the dashed blue line.

5.2.4 Create Interpretative Surface Grids

After the top of bedrock was interpreted from the AEM data within the 2023 survey extent, the interpretations (i.e., points that represent the elevation of the top of bedrock) were imported and processed in ESRI's ArcGIS Pro with the Spatial and Geostatistical Analyst extensions. These interpreted points as well as CSD boreholes and some NE-DNR boreholes (within the Auburn area only) were used to interpolate the bedrock surface. Please note that the terms grid, surface, and raster dataset are used interchangeably, and all refer to a continuous dataset made up of cells (with each cell being a 300 ft by 300 ft area) where each cell contains elevation data representative of the elevation at that location.

Approximately 1,500 AEM interpretation points, 36 CSD boreholes, and 48 NE-DNR boreholes (Auburn area only) were used to interpolate the bedrock surface. The surface was interpolated using the kriging geostatistical model and exported to a 300 ft cell size resolution, snapped to the project DEM. The bedrock surface was corrected with the DEM so that the bedrock elevation was constrained to less than or equal to DEM minus 3ft. A subset area grid of 100 ft cell size was made for the Auburn area.

The 2023 AEM survey area bedrock elevation surface was mosaicked with the 2020, 2018, 2015, 2009, and 2007 bedrock elevation surfaces (Figure 5-8). Some areas where the previously interpolated surfaces came together required some hand-blending to remove tears between these surfaces as best as possible while retaining the integrity of the previous work. Hand-blending methods included revising contours at the surface interfaces or mosaicking the edges using a "blending" operator within ArcGIS Pro. The bedrock elevation surface was then subtracted from the ground surface DEM to create a depth to bedrock (feet below ground surface [bgs]) raster dataset. Figure 5-9 and Figure 5-10 display the top of bedrock elevation within the NNRD AEM survey extent and depth to bedrock within the NNRD AEM survey extent, respectively.

The bedrock surface is made up of both the Cretaceous Dakota Group (***Kd***) and the Undifferentiated Pennsylvania and Paleozoic units (***IP***) within the NNRD AEM survey area. However, the ***Kd*** is only present within a small portion on the far northwest side of the survey extent and was interpreted as part of the 2020 NNRD AEM survey project. Figure 5-11 and Figure 5-12 display the extent and elevation of the top of the ***Kd*** within the full NNRD AEM extent and zoomed into the western portion of the survey area, respectively.

The entire NNRD AEM survey area is underlain by ***IP*** and the elevation of the ***IP*** within the survey area is equal to the bedrock elevation, except where the ***Kd*** is present. Figure 5-13 displays the elevation of the top of ***IP*** within the NNRD AEM survey extent.

The total thickness of Quaternary deposits (***Q***) was calculated for the entire NNRD AEM survey area by subtracting the top of bedrock from the ground surface elevation. Figure 5-14 is a map displaying the total thickness of ***Q.***

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 almost three decades old at the time of this publication and local conditions likely deviate in areas with variable topography. The original water table contour lines were gridded at a 300 ft cell size using the topography to raster tool within ArcGIS Pro. The resultant surface was snapped to the project DEM and corrected so that all elevations are equal to or less than the DEM elevation. Figure 5-15 shows a map of the water table elevation surface within the entire NNRD AEM survey area.

The saturated thickness of ***Q*** was calculated for the NNRD AEM survey area by mosaicking the water table elevation with the bedrock elevation using the 'maximum' operator, then subtracting the top of bedrock elevation from the mosaicked dataset within ArcGIS Pro. Figure 5-16 is a map displaying the ***Q*** saturated thickness grid within the NNRD AEM survey area.

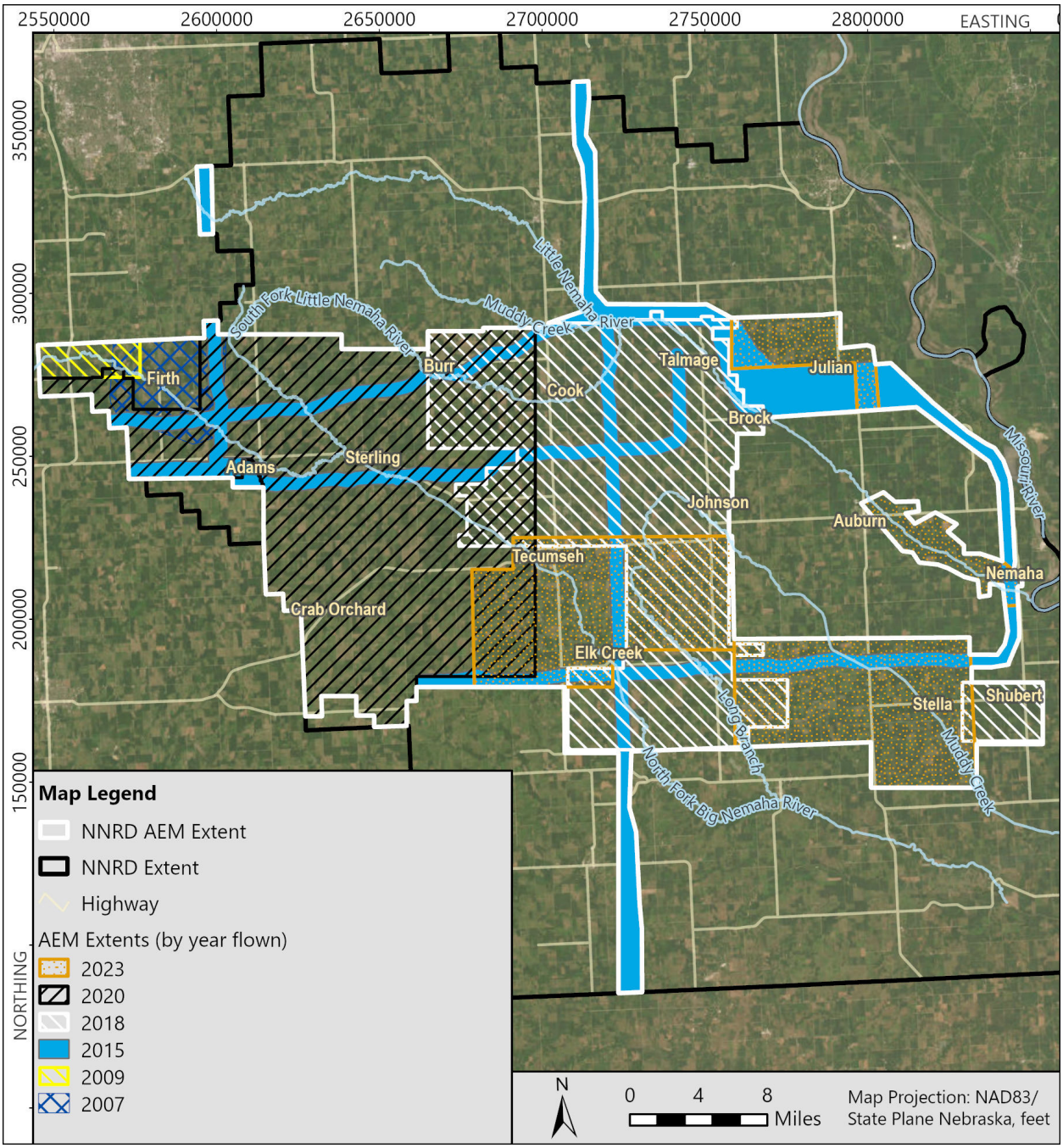


Figure 5-8. This map displays the extents of the bedrock grids by year of data acquisition within the NNRD AEM survey extent. The AEM survey extent is depicted by a white polygon. The thick black polygon is the NNRD boundary extent.

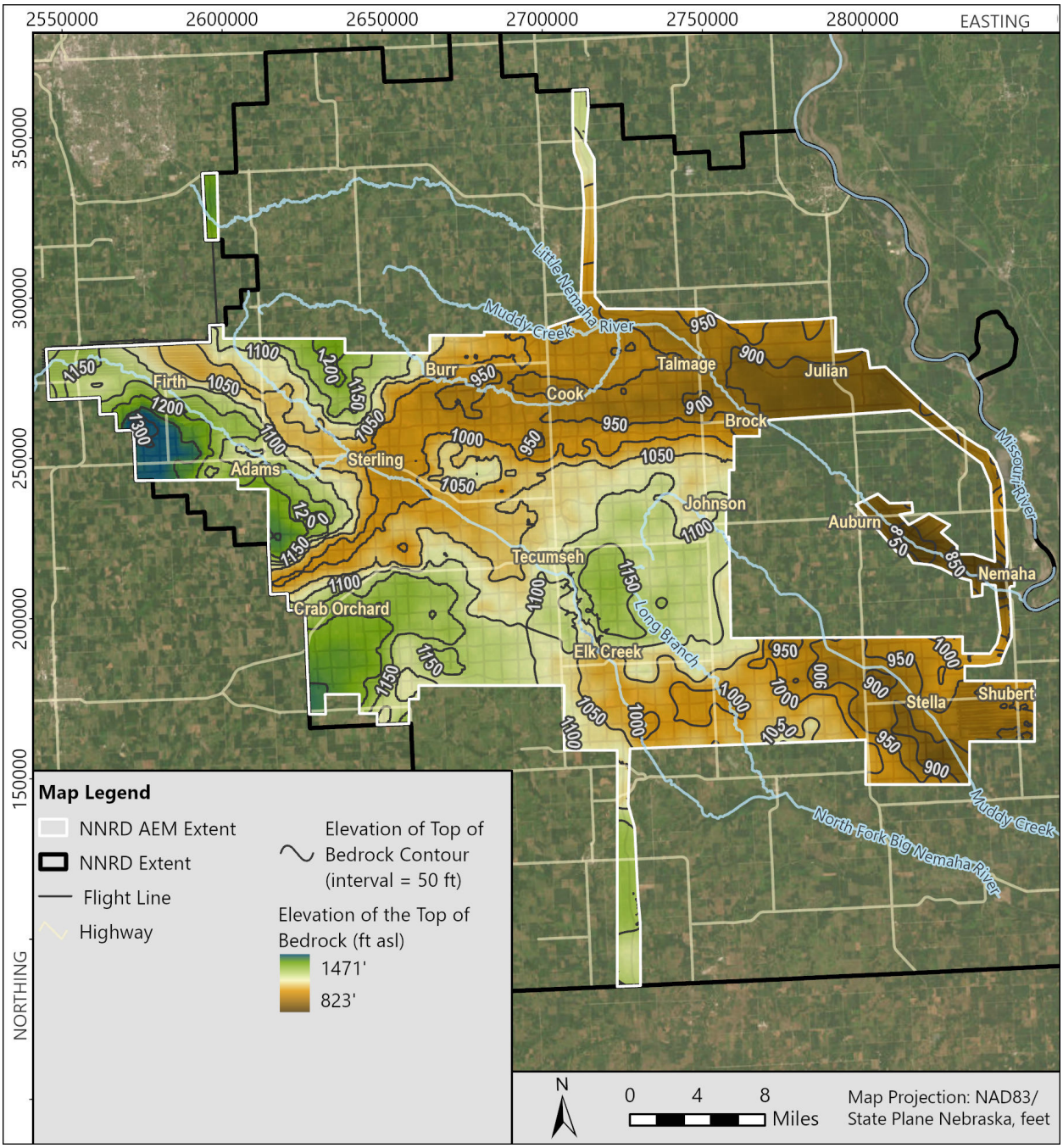


Figure 5-9. This map displays the elevation of the top of bedrock (ft asl) within the combined NNRD AEM survey extent. The AEM survey extent is depicted by a white polygon and flight lines are shown as thin black lines. The thick black polygon is the NNRD boundary extent.

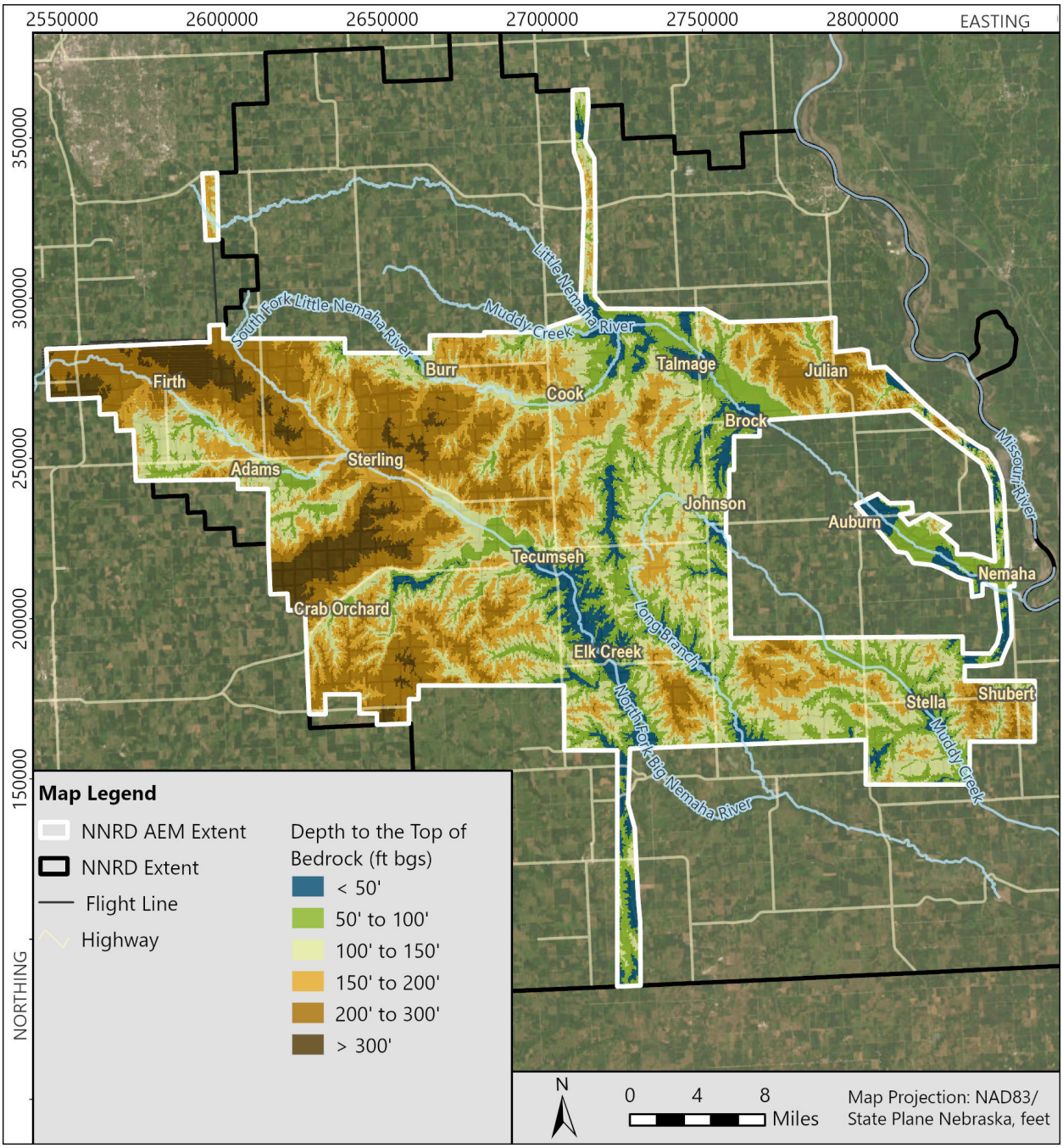


Figure 5-10. This map displays depth to the top of bedrock (ft bgs) within the combined NNRD AEM survey extent. The AEM survey extent is depicted by a white polygon and flight lines are shown as thin black lines. The thick black polygon is the NNRD boundary extent.

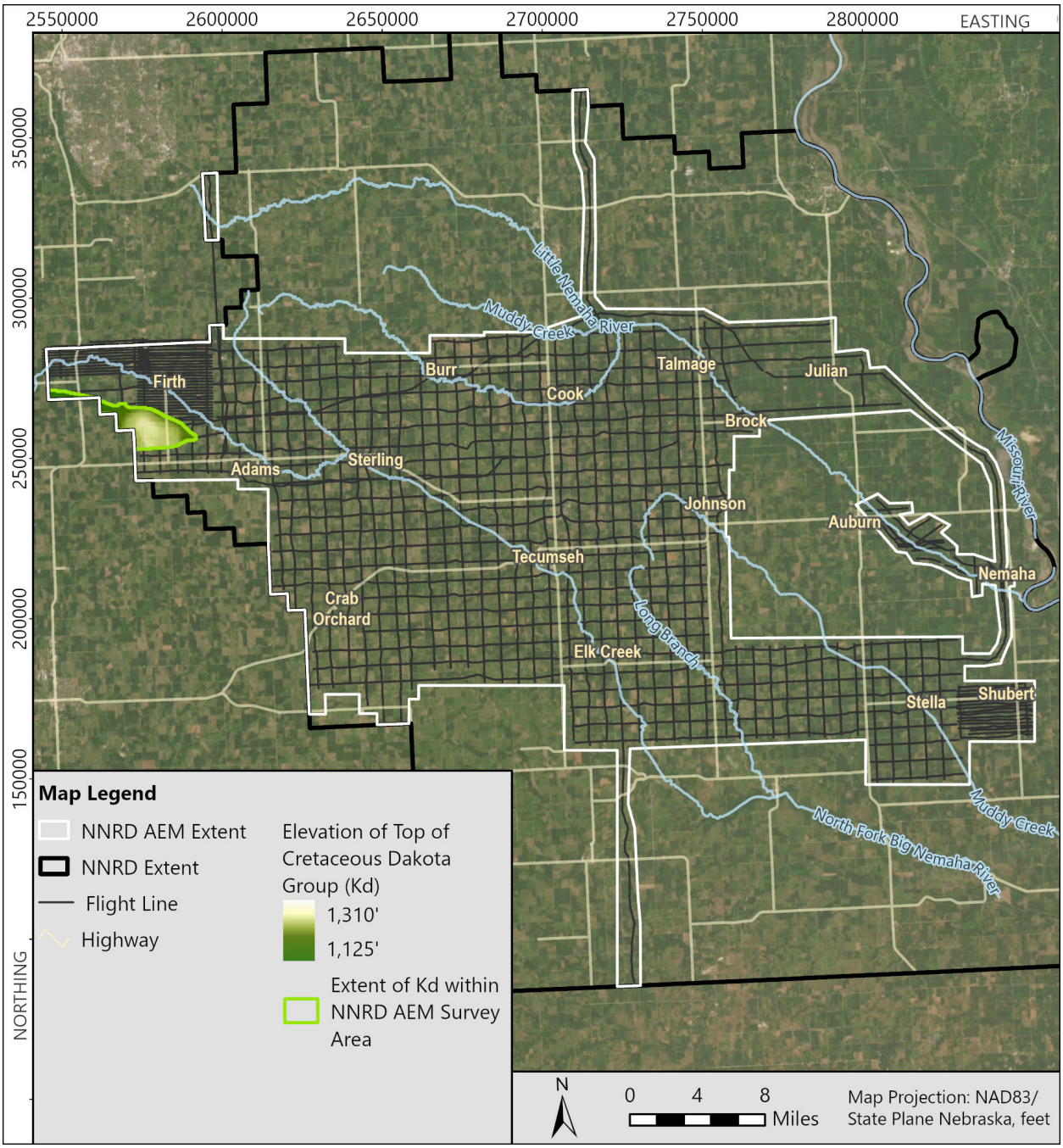


Figure 5-11. Map of the elevation of the top of the Cretaceous Dakota Group (*Kd*) within the combined NNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

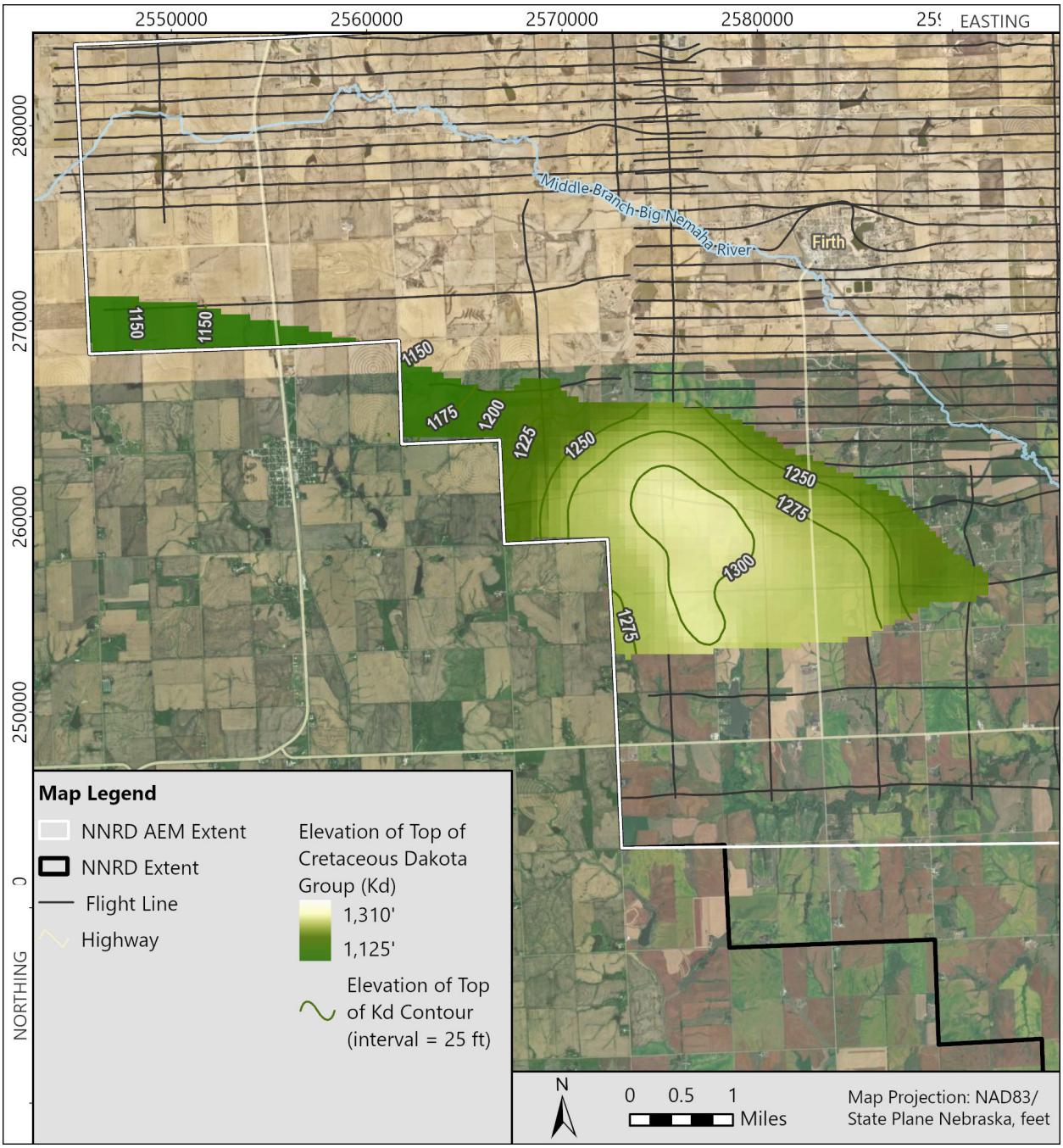


Figure 5-12. Zoomed-in map of the elevation of the top of the Cretaceous Dakota Group (*Kd*) within the combined NNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

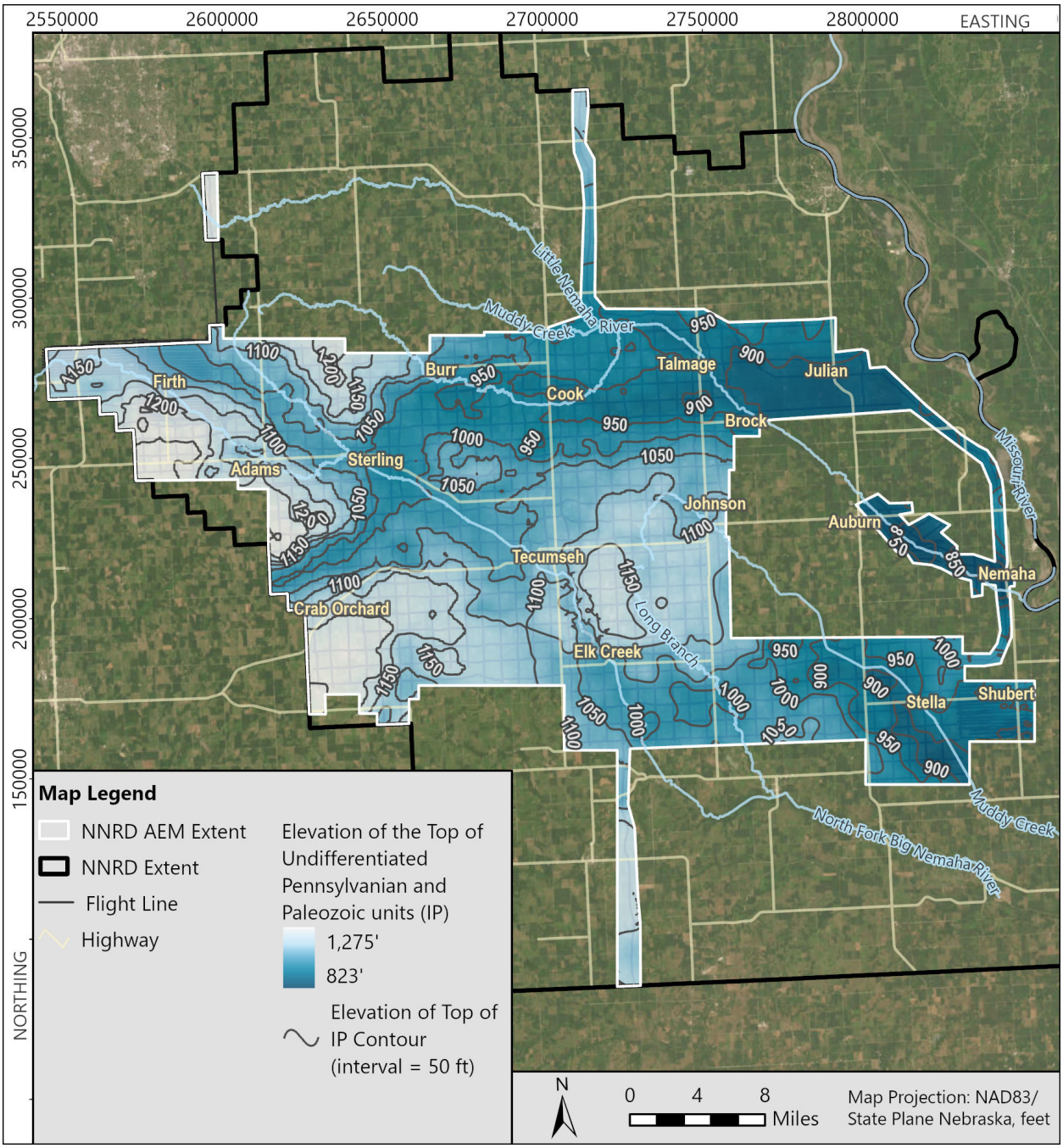


Figure 5-13. Map of the elevation of the top of the Undifferentiated Pennsylvanian and Paleozoic units (*IP*) within the combined NNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

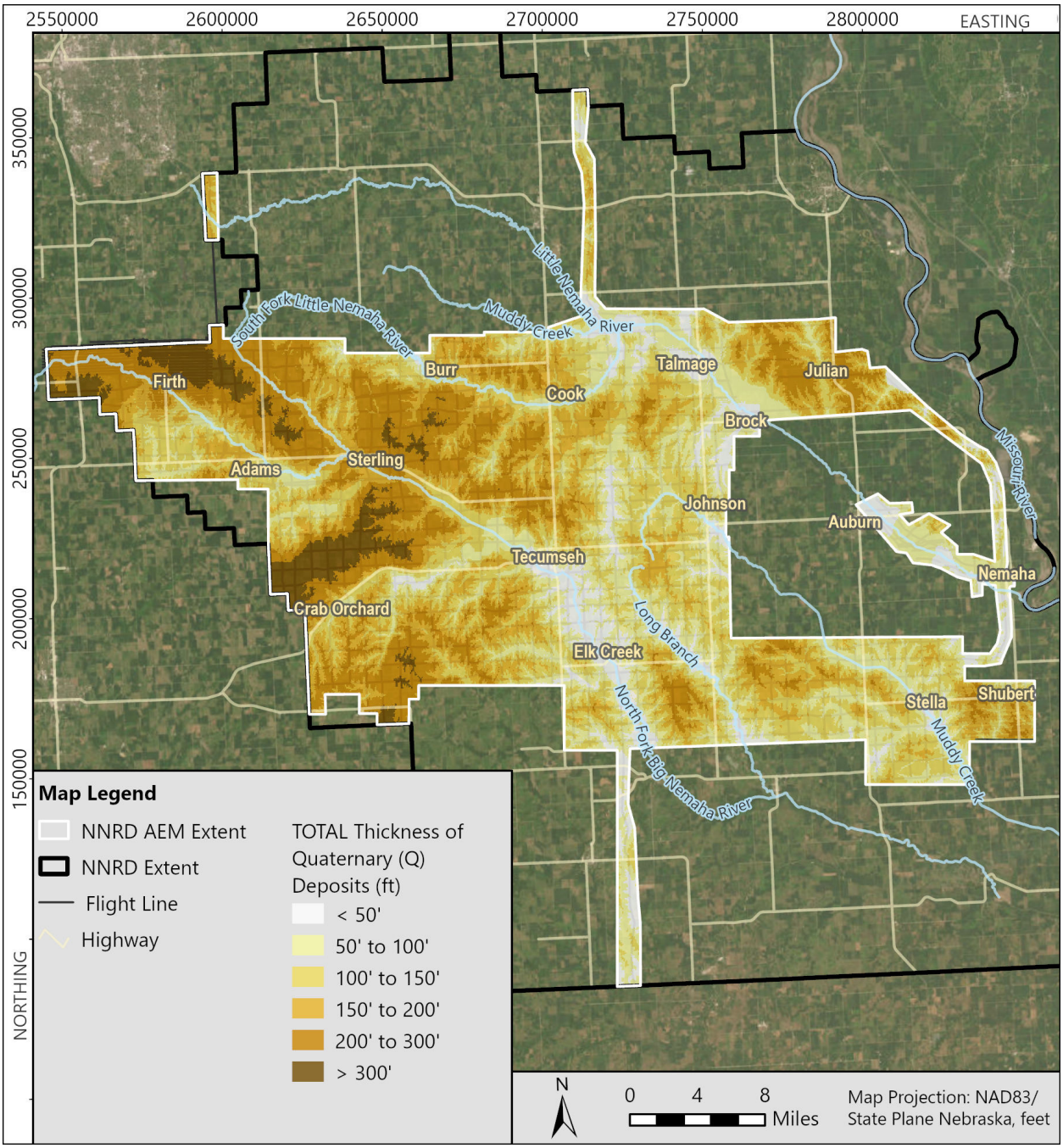


Figure 5-14. Map of the total thickness (in feet) of Quaternary (*Q*) deposits within the combined NNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

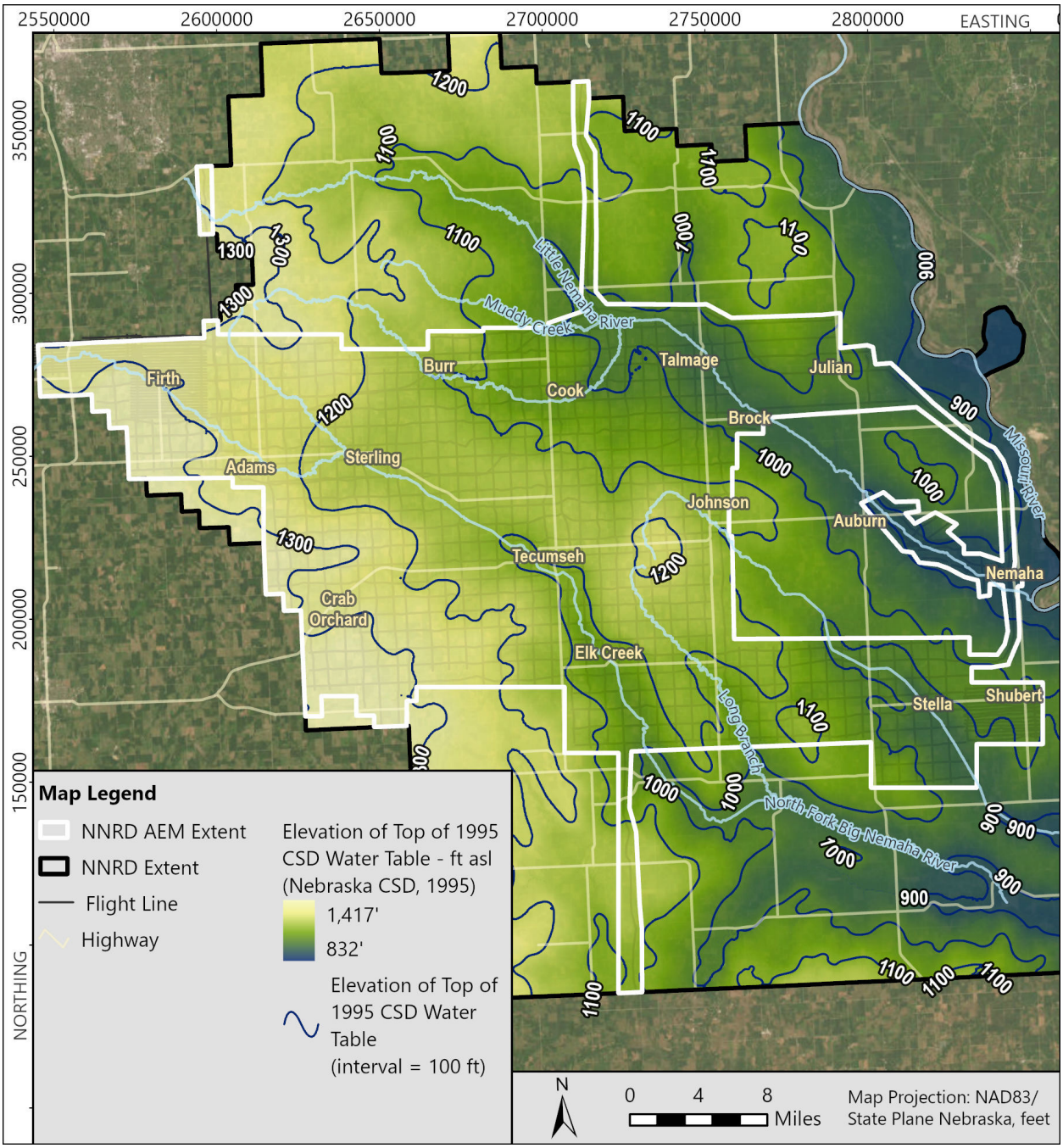


Figure 5-15. Map of the elevation (in feet) of the 1995 CSD water table (Nebraska CSD, 1995) within the combined NNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet) and the elevation values are referenced to NAVD 88 (feet).

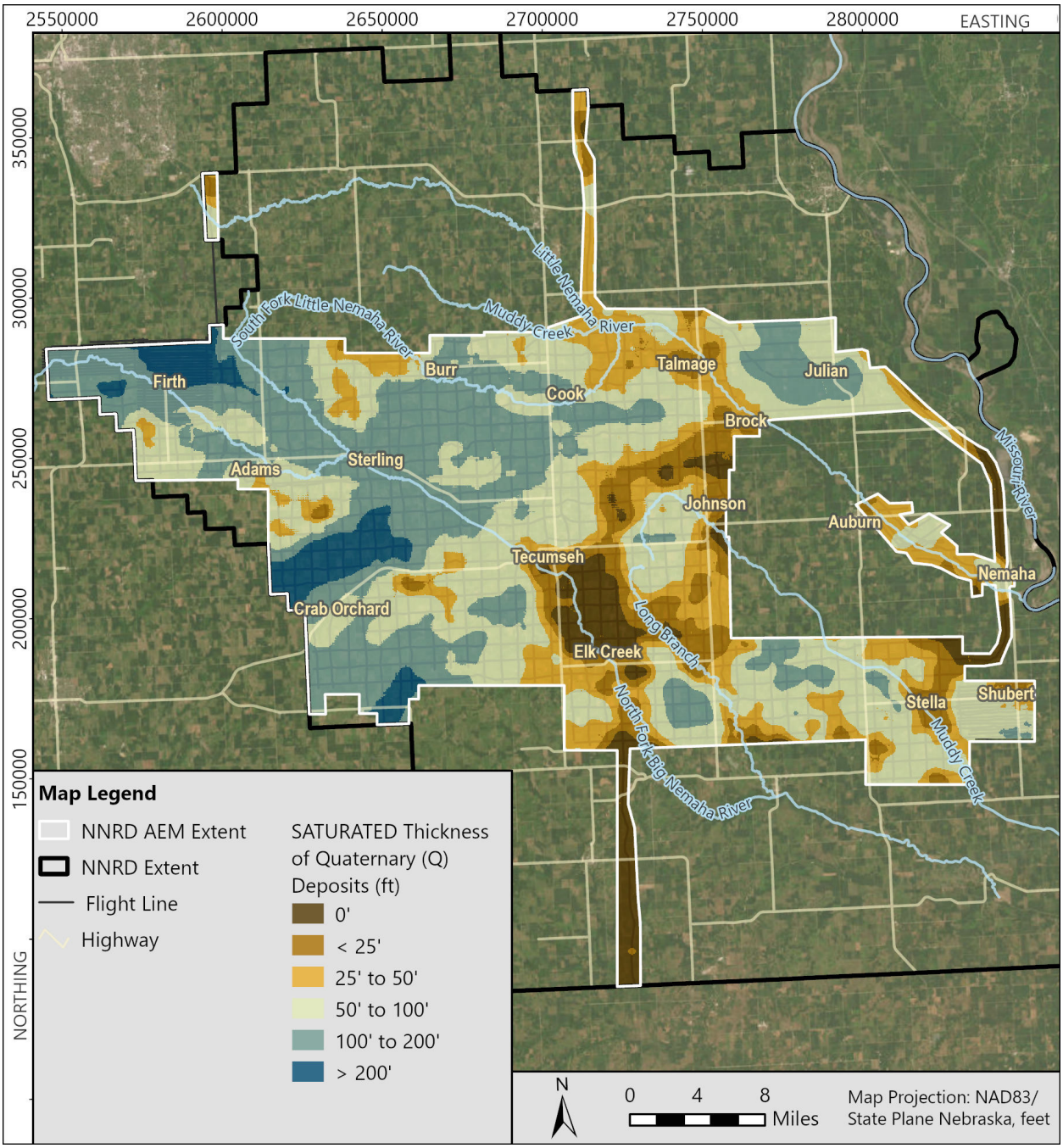


Figure 5-16. Map of the saturated thickness (in feet) of Quaternary (*Q*) deposits within the combined NNRD AEM survey area. The projection is NAD83 State Plane Nebraska (feet).

5.2.4.1 *Specific Capacity Wells*

To give a general idea of well performance within the ***Q***, NE-DNR water well specific capacity data (pumping rate, static water level, and pumping water level) were calculated. First, the wells that fell within the NNRD AEM survey area 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:

- If the entire length of screen is below top of bedrock elevation, then well is assigned a 'Bedrock well'.
- If the entire length of screen or total well depth (if no screen data available), is above top of bedrock elevation, then well is assigned 'Quaternary well'.

A 10 ft 'buffer', or degree of error, was applied to the logic so that if, for example, the majority of a well's screen was within the ***Q,*** but 10 ft or less fell below the top of bedrock, it would be assigned as 'Quaternary well'. Well screens that fell within this degree of error were hand-assigned on a case-by-case basis. If screen depths and/or total well depth data were not available, then the well was not used in the specific capacity calculations.

After the well assignment, the specific capacity was calculated, but only for those wells with readily available specific capacity data (pumping rate, static water level, pumping water level) in the NE-DNR well GIS shapefile. Figure 5-17 is a map of the saturated thickness of the aquifer material and coarse aquifer material with NE-DNR well points displaying the estimated specific capacity within the NNRD survey area.

5.2.4.2 *Transmissivity Map*

The transmissivity, or the ability of an aquifer to transmit water, of the unconsolidated saturated material was calculated. The transmissivity, **T**, was calculated using the equation:

$$\mathbf{T = K * b}$$

Where, **K** is the hydraulic conductivity (ft/sec) and **b** is the saturated aquifer thickness (ft). The saturated thickness used in the estimation for the entire NNRD survey area reflects the saturated thickness of the aquifer material (AM) and coarse aquifer (CA) materials only; marginal aquifer material was not included in the calculation. The hydraulic conductivity value used in the equation is $3.3x10^{-3}$ feet/sec and is representative of clean sand/gravel (Freeze & Cherry, 1979). The resultant grid was converted to gpd/ft using a conversion factor with ArcGIS Pro's raster calculator. Figure 5-18 is a map of the estimated transmissivity of the saturated AM and CA material within the NNRD AEM survey area.

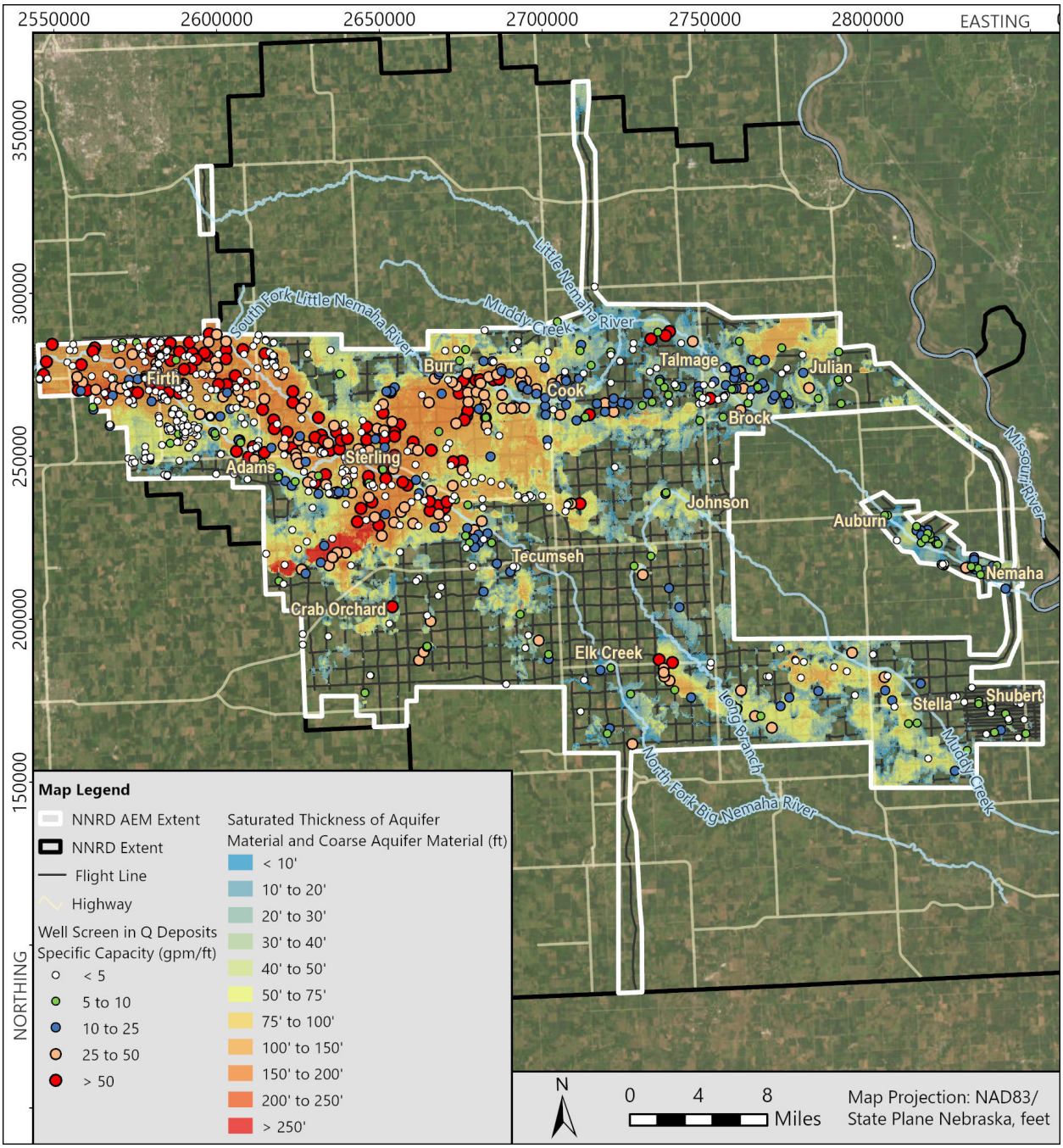


Figure 5-17. Map of the saturated thickness of Aquifer Material and Coarse Aquifer material within the combined NNRD AEM survey area with NE-DNR wells displaying estimated Specific Capacity. Flight lines are indicated by the black lines. The projection is NAD83 State Plane Nebraska (feet).

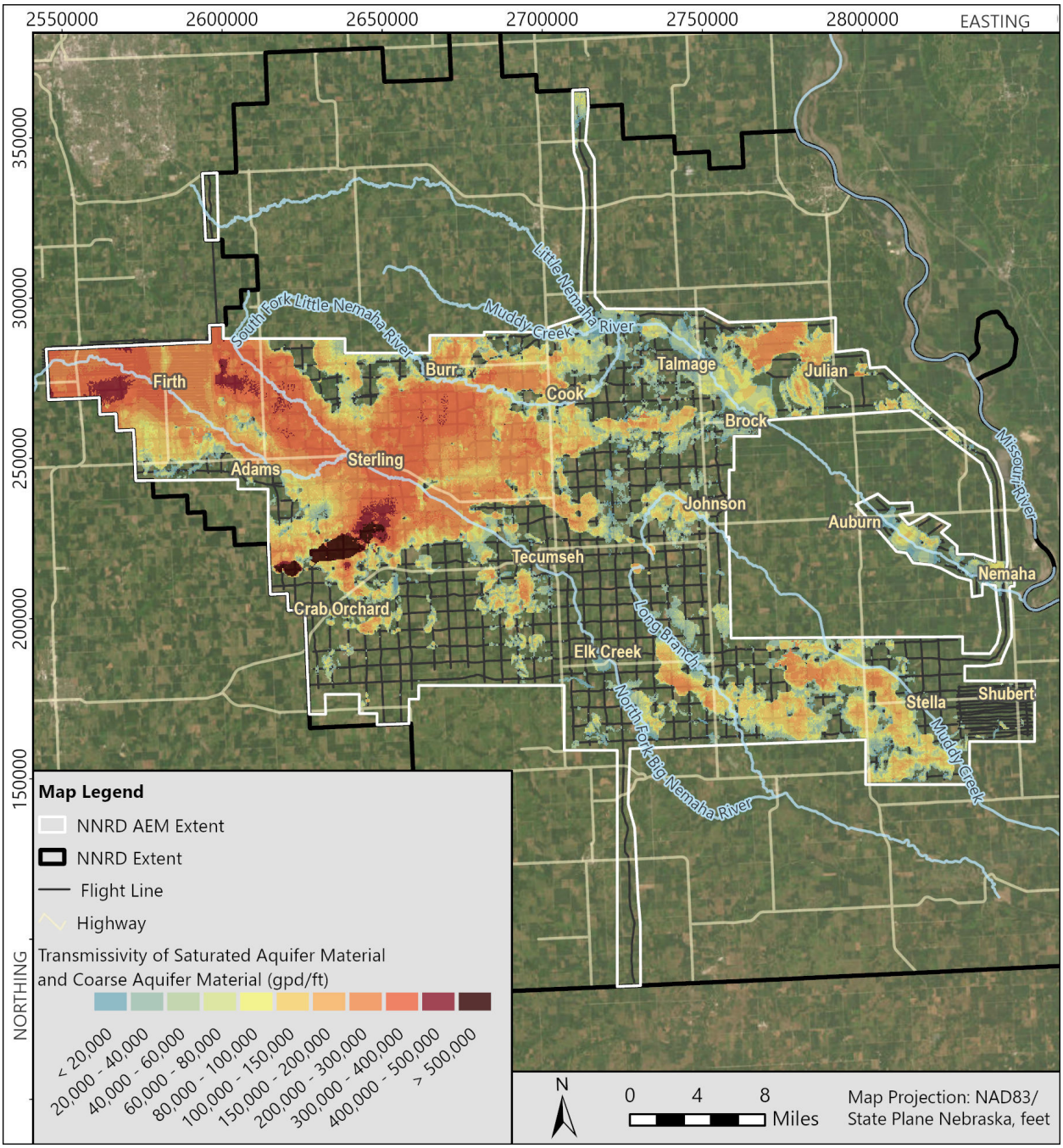


Figure 5-18. Map of the estimated Transmissivity within the combined NNRD AEM survey area. Flight lines are indicated by the black lines. The projection is NAD83 State Plane Nebraska (feet).

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. Regarding the NNRD 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., 2015b). The original analysis that was completed as part of Carney et al. (2015b) included the overall area of the NNRD. 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., 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. (2015b). A summary of the resistivities and the color scale is shown in Figure 5-19.

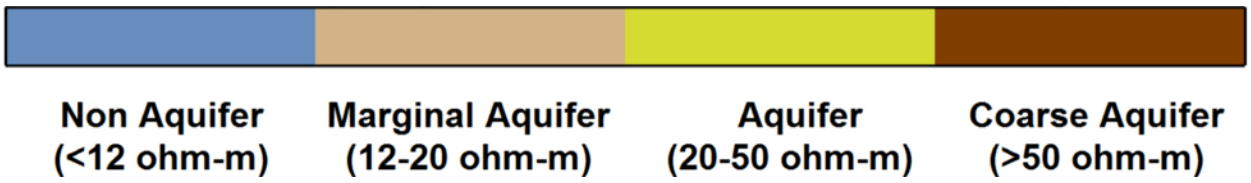


Figure 5-19. Plot displaying the resistivities by major aquifer material color categories: blue- non-aquifer materials, tan- marginal aquifer materials, yellow- aquifer materials, brown- coarse aquifer materials (Carney et al., 2015b).

5.2.5.1 *Resistivity/Lithology Relationship in the Bedrock*

The bedrock in the NNRD analyzed in this study includes the ***Kd*** and ***IP.*** These were included to demonstrate the overall distribution in resistivity of bedrock materials across the entire NNRD. The median resistivity value for the ***IP*** is 16 ohm-m (Carney et al., 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. Some of the units are also saturated with saline waters lowering the bulk resistivity. Due to the very small amount of ***Kd*** within the NNRD, there was no lithological split completed for the ***Kd*** in this region of Nebraska.

5.2.6 *Create 3D Interpretative Voxel Grids*

A voxel grid was completed for the NNRD AEM survey area. The voxel grids were made using a 300 feet grid cell size and the model layer thickness (from Table 4-3). As discussed in Section 5.1 above, the 2015 and 2018 model layer structures had to be adapted to the 2020 and 2023 inversion model layer structure (Table 4-3) before the databases could be combined into one dataset with one layer structure that could be used to create a 3D voxel. A minimum curvature method (MCM) was used within Datamine Discover PA (Datamine Discover, 2024). 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 interpreted top of the Cretaceous Dakota Group (***Kd***) and the top of the undifferentiated Pennsylvanian (***IP***) using the surface elevation grids discussed above in Section 5.2.4. The 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 bedrock as well as surface materials.

The Quaternary (***Q***) materials can also be separated by thresholds developed for four lithology classes (see Section 5.2.5). Utilizing the voxel grids of the ***Q,*** analysis can be made of the thickness of the different materials within the section. Additionally, the ***Q*** voxel can be split into unsaturated and saturated portions utilizing the CSD 1995 Statewide water table (NE CSD, 1995) (Section 5.2.4.).

Figure 5-20 is an exploded diagram of the plot of the stratigraphy of the area, including the ***Q, Kd,*** and ***IP***, looking to the north. The voxel grids can be found in *Appendix 3-Deliverables\Voxel*.

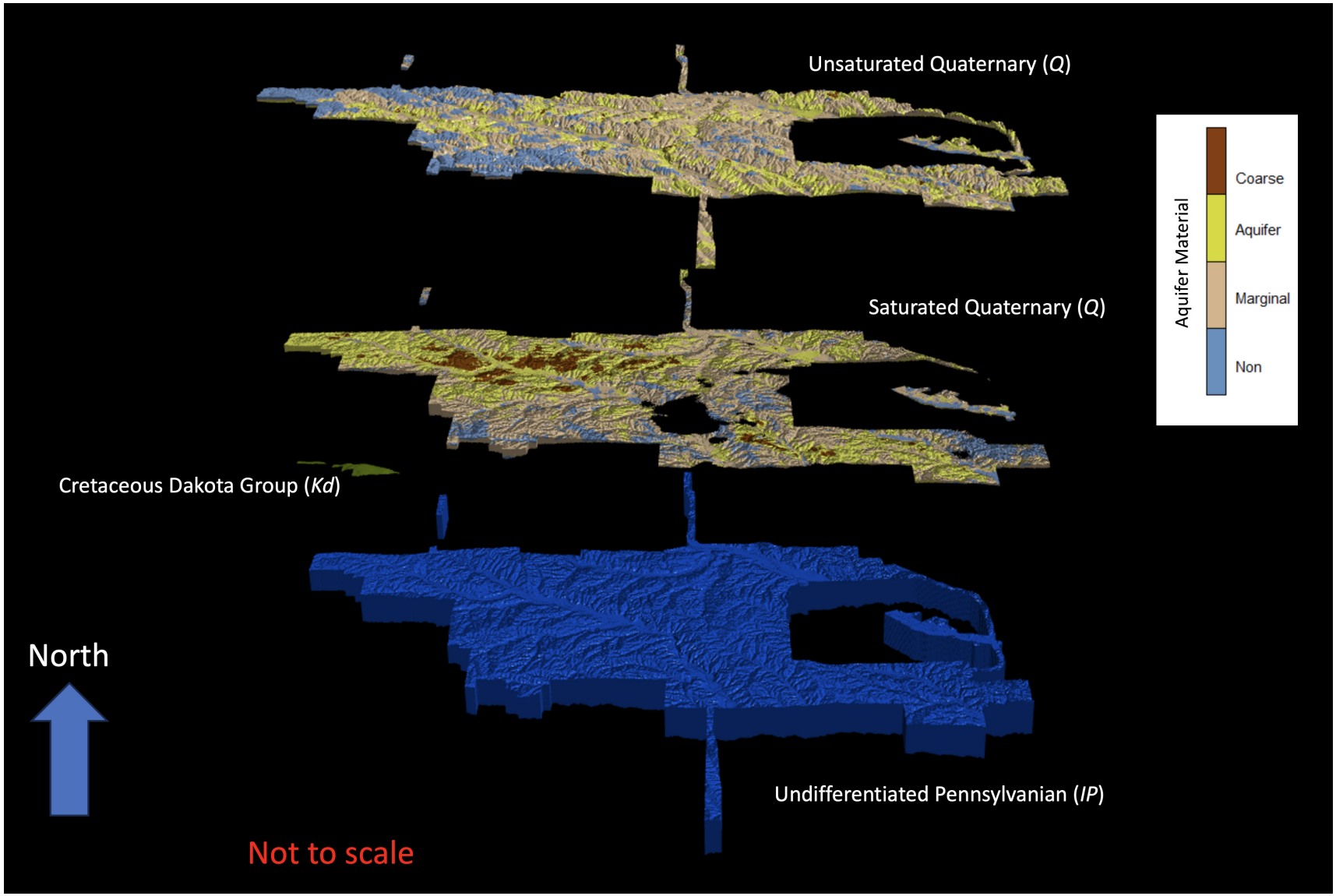


Figure 5-20. Exploded 3D Voxel model of the stratigraphy of the NNRD AEM area showing unsaturated and saturated Quaternary (*Q*) and Cretaceous Dakota Group (*Kd*) material and undifferentiated Pennsylvanian (*IP*). Not to scale.

5.2.7 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 NNRD (AGF, 2021; AGF 2019; Carney et al., 2015b). One AEM profile from 2020, L401801, has six CSD test holes with e-logs within one mile of the flight line. Figure 5-21 shows the 16-inch short normal e-logs displayed at the same color scale as the AEM data. Overall, the match is very good. These e-logs compare well with the AEM inversion earth models.

Note that one of the major issues with the geophysical borehole logs within the ENWRA area is the poor calibration and other operational issues with the logging systems. Unfortunately, this is not a unique issue with comparing borehole logs with AEM and has been published on previously (Ley-Cooper and Davis, 2010).

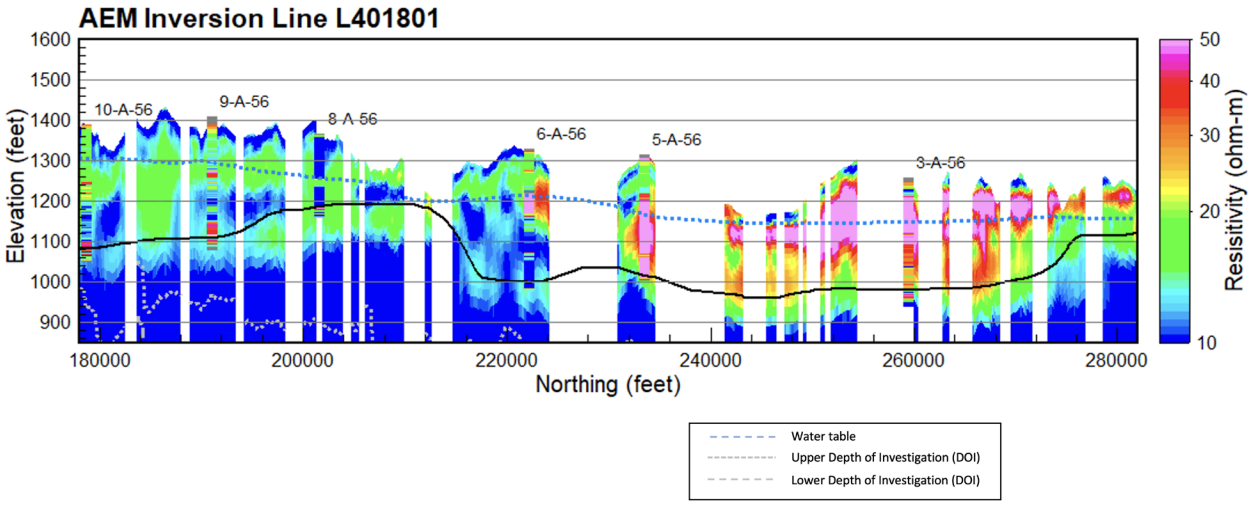


Figure 5-21. Inverted AEM resistivities for flight line L401801 with borehole 16-inch short normal resistivity logs from six CSD test holes overlaid at the same color scale within one mile of the flight line. The undifferentiated Pennsylvanian (*IP*) is indicated by the black line. Gaps indicate areas removed due to coupling.

5.2.8 Surface Materials Grid

Surface/near surface material types within the NNRD survey area, which could indicate potential areas for management of aquifer recharge and non-point source contamination, were interpolated into a raster dataset representing the depth interval 0 ft to 6.56 ft bgs or 2 meters (the first model layer in Table 4.3) The material types were separated by four major resistivity thresholds selected in Datamine Discover PA (Datamine, 2024). These ranges include less than 12 ohm-m, representing non-aquifer materials (“aquitard”- primarily glacial till, clay, loess); 12-20 ohm-m, representing marginal aquifer deposits with potential for interlayered silt and clay; 20-50 ohm-m, indicating the Quaternary system’s aquifer materials composed dominantly of sands and gravels; and an interval of 50 ohm-m or greater, indicating coarser sand-rich intervals within the aquifer. Further discussion regarding the selection of these threshold ranges is provided in the previous section, Section 5.2.5, and in Carney et al. (2015b). To create the surface/near surface material type the first voxel model layer was used and plotted in map

format. Figure 5-22 is a map of the surface/near surface material types for the interval 0 ft-6.56 ft (0 – 2 m) within the NNRD AEM survey area.

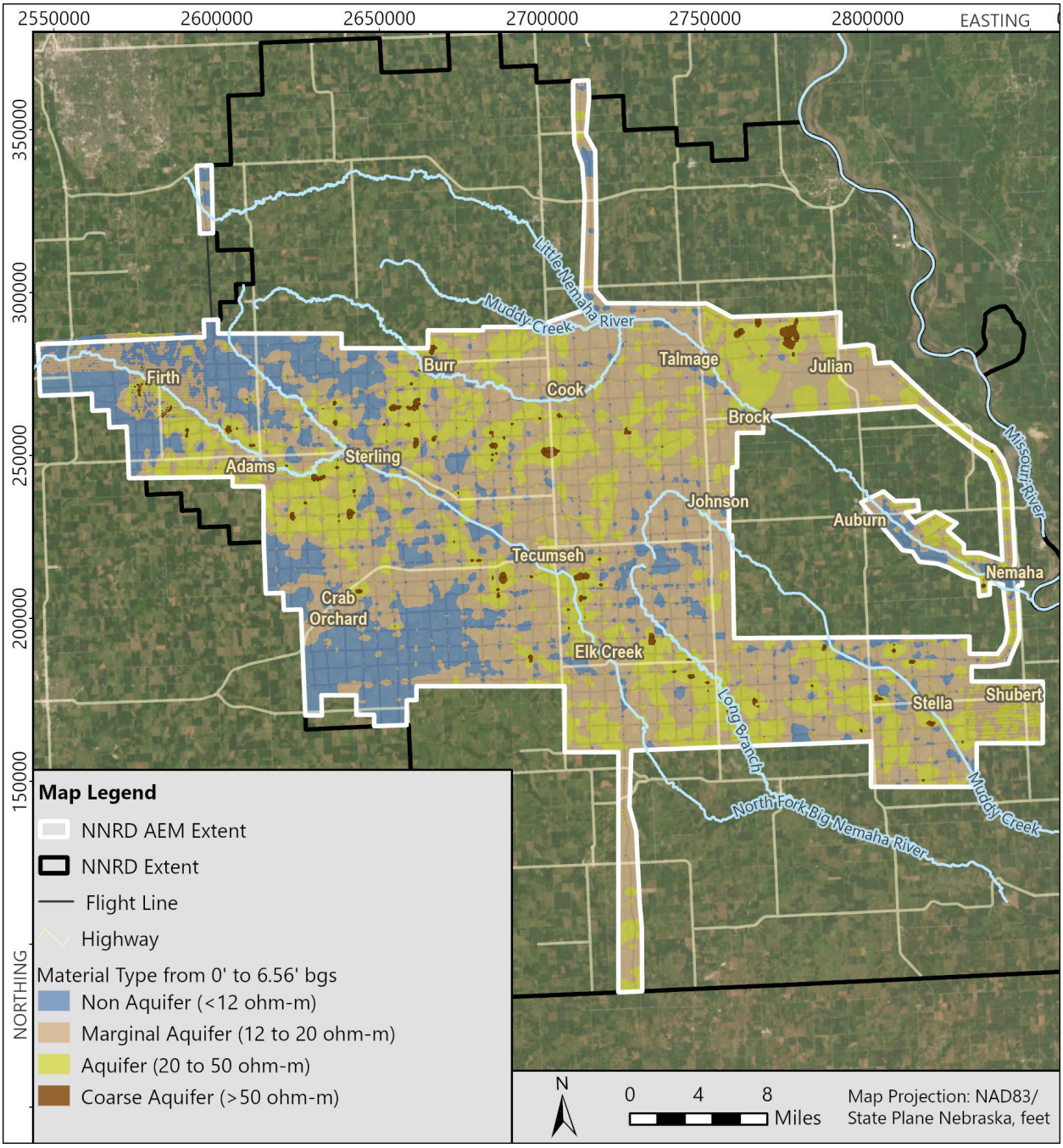


Figure 5-22. Map, illustrating surface recharge, of the material type (Non-Aquifer, Marginal Aquifer, Aquifer Material, or Coarse Aquifer) from 0 ft to 6.56 ft (2 meters) below ground surface within the NNRD AEM survey area. Black lines indicate flight lines. The projection is NAD83 State Plane Nebraska (feet).

5.3 Hydrogeological Framework of the NNRD AEM Survey Area

The NNRD 2023 survey continues to build upon the previous AEM surveys within NNRD since the Firth 2007 survey (Korus et al, 2013b; Smith et al., 2008) and 2009 Sprague survey (Divine and Korus, 2012; Smith et al., 2011), then continuing with the 2015 lines (Carney et al., 2015b), the 2018 1-mile recon lines of portions of the NNRD and detailed Shubert Block flights (AGF, 2019a), and the 2020 NNRD survey (AGF, 2021) (Figure 5-23). These AEM-derived results provide new information on the hydrogeology in areas that were previously unknown to the NNRD or were only known to a limited extent from just the borehole information. The survey completed in 2023 by AGF, combined with the other surveys in the area, provides the basis for this section of the report. The following highlights the additions to the current multi-year project being conducted by the NNRD and ENWRA.

The 2023 AEM survey and the combined datasets continue to reveal variability in the Quaternary (***Q***) deposits across the NNRD AEM survey area. The Quaternary (***Q***) materials are generally thickest in the west associated with paleochannels. The ***Q*** materials make up the aquifer materials overlying the undifferentiated Pennsylvanian and other Paleozoic bedrock units (***IP***). Figure 5-24, looking northwest, is a 3D fence diagram of the NNRD combined flight lines with the ***IP*** bedrock units indicated as a solid blue color at the base of the sections with a small Cretaceous Dakota Group (***Kd***) remnant indicated as a dark green material in a far northwestern region of the combined AEM survey area. The major streams are also indicated for spatial reference. The different ***Q*** aquifer materials are as indicated in the legend. The paleochannels can be seen in the western and northern portion of the combined NNRD AEM survey area and are indicated by the brown of the coarse aquifer material and the yellow of the aquifer material. The aquifers in this area of Nebraska are within the Quaternary materials. As in previous AEM reports, the thin remnant of ***Kd*** will not be discussed at length due to the small spatial extent and limited AEM and borehole control. However, some wells are completed within the ***Kd***. The ***IP*** units of the area are not considered as aquifer material and will not be discussed within this report.

Examining the 3D fence diagrams from other angles provides a spatial understanding of the distribution of aquifer materials within the combined NNRD AEM survey area. Figure 5-25 is another 3D fence diagram looking to the west. The coarse aquifer and aquifer material are clearly the dominant feature in the northern portion of the survey area running from the west to the east. The paleochannels and the resultant bedrock depressions in the area are the key to understanding the shape and depth of the aquifer and coarse aquifer material.

5.3.1 The Hydrogeologic Framework of the Combined NNRD AEM Survey Area

A general understanding of the hydrogeological framework of the AEM survey area can be gained by looking at select profiles throughout the survey area. Beginning in the north with east-west profile L300401 (Figure 5-26), the distribution of the aquifer materials shows that the paleochannels are within the northern portions of the AEM project area. Stratigraphy and specific capacities are indicated in boreholes along profile L300401 in Figure 5-26 where the information is available.

Profiles trending to non- and marginal-aquifer materials such as east-west profile L800202 (Figure 5-27) are in the southern part of the combined AEM project area. Again, stratigraphy and specific capacities are indicated in boreholes along profile L800202 in Figure 5-27 where the information is available. A little further south, along profile L600602 (Figure 5-28), there is very limited occurrence of aquifer materials (sands and sands and gravels) with the area predominately composed of marginal and non-aquifer materials.

Figure 5-29 presents the elevation (Figure 5-29a) and depth to top (Figure 5-29b) of the combined AEM bedrock surface including the bedrock surfaces from the Sprague area (Divine and Korus, 2012), Firth area (Korus et al., 2013a), and the 2018 (AGF, 2019), 2020 (AGF, 2021), and 2023 AEM survey-derived bedrock surfaces. Note that the depth to the top of the bedrock is from the ground surface which can have variable topography. The bedrock lows from the west to the east are easily identified in the areas of the NNRD. The depth of the paleochannel erosion is different from one channel to another as the southern channel trending from the southwest to the northeast is slightly deeper than the channel trending from the northwest to the southeast (Figure 5-29b).

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. These materials are predominantly composed of glacial, pre-glacial alluvial, and minor alluvial deposits related to the current drainages. As noted above, the dominant hydrogeologic features in the NNRD 2020 AEM survey area, the western side of the combined AEM project area, are the paleochannels. These channels have been identified in previous studies by Korus et al. (2013a), LBG (2017), AGF (2019). The CSD Nebraska Groundwater Atlas provides a general pattern to the paleochannels of the area and is in general agreement with the AEM, with the AEM results providing much more detail.

Figure 5-30a presents the total thickness of the aquifer material and coarse aquifer material in the combined NNRD AEM survey area. Figure 5-30b is an overlay of the paleochannels from Korus et al. (2013a) and the total thickness of aquifer and coarse aquifer material from the combined NNRD survey area. A general agreement can be seen between the aquifer thickness and the approximate paleochannel extent (Korus et al., 2013a); however, some realignment of the channel and refinement can be seen in the northern area, west and east of Burr, Nebraska, and along the southern boundary in the area northwest of Crab Orchard, Nebraska. This is not an unexpected result as this was the goal of the survey.

A comparison of the AEM-derived profiles to the LBG-generated cross sections as well as the AEM-derived surfaces to the LBG-generated surfaces was completed in AGF, 2019.The comparison showed a general agreement with the LBG sand thickness to the AEM-derived aquifer and coarse aquifer material total thickness with differences generally only occurring in areas that did not contain test holes and registered wells. In general, the AEM data display more consistency and less “bulls’ eyes” from the gridding artifacts of using boreholes only. A further comparison was not completed with the combined AEM data as there were no issues identified in the previous comparisons (AGF, 2019). The AEM provides enhanced resolution and fidelity to the borehole only studies.

Using the interpretive surfaces and grids that were produced as described above, an enhanced understanding of the hydrogeological framework of the combined NNRD AEM survey area can be achieved. Figure 5-31a shows the total thickness of the unsaturated aquifer materials and coarse aquifer materials and Figure 5-31b shows the total thickness of the saturated aquifer materials and coarse aquifer materials. When the 1995 CSD water table is used to separate the unsaturated from the saturated (Figure 5-31b), the paleochannel systems are apparent in the saturated aquifer and coarse aquifer thickness. The unsaturated areas may provide areas of future groundwater storage through the use of managed aquifer recharge (MAR).

Another view of all of the Quaternary (***Q***) aquifer materials and just the saturated ***Q*** aquifer materials in the combined NNRD AEM survey area are presented as 3D voxel models in Figure 5-32 and Figure 5-33, respectively. In each image, the ***Q*** is overlying the top of the interpreted bedrock surface. The saturated paleo channel coarse aquifer material clearly stands out in Figure 5-33. An exploded 3D voxel model (Figure 5-34) shows the unsaturated Quaternary (***Q***) material overlying the saturated ***Q*** material overlying the Cretaceous Dakota Group (***Kd***) (only located on the western end of the NNRD AEM survey area) and Undifferentiated Pennsylvanian (***IP***).

Maps of unsaturated thickness of the non-aquifer and marginal aquifer materials (Figure 5-35a) and the saturated thickness of the non-aquifer and marginal aquifer materials (Figure 5-35b) show the areas in the combined NNRD AEM survey area that have the most clay. Small isolated areas can be seen in the north and between the larger paleochannel systems.

Figure 5-36 is a map of the thickness of the saturated aquifer and coarse aquifer materials showing the correlation with Specific Capacity values derived from the NE-DNR registered wells as described in Section 5.2.4.1. The Specific Capacity values map out the extent of the paleochannel well. As described previously, adjustments and refinements of the paleochannel configuration can be made based on the AEM data and the use of the Specific Capacity values. Note that some of the isolated deposits of aquifer and coarse aquifer materials outside the main paleochannels also show a good match with the NE-DNR Specific Capacity values.

By using the saturated thickness of the aquifer and coarse aquifer material and an estimate of the hydraulic conductivity (Freeze and Cherry, 1979), an estimate of the transmissivity was developed (Figure 5-37). These values compare relatively well with the LBG values derived from using the Specific Capacity (AGF, 2019, LBG, 2017). The coarsest and thickest areas of the saturated paleochannel have the highest transmissivity values. It is important to note that the transmissivity values (Figure 5-37) were derived by only using the saturated thickness of the aquifer and coarse aquifer materials. However, this provides an additional view of the possible transmissive properties of the materials within the area of the combined NNRD AEM survey area.

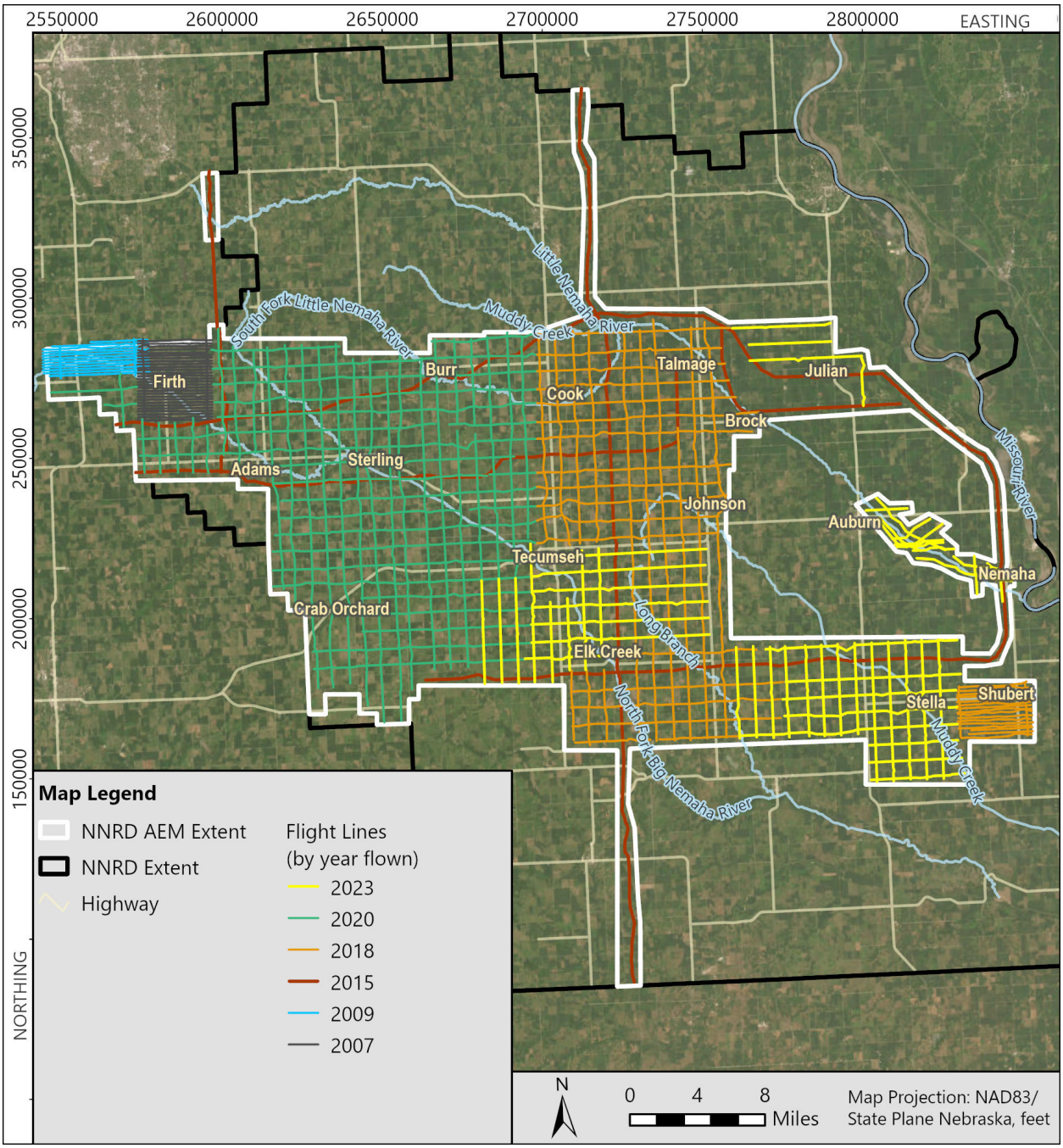


Figure 5-23. Map of the NNRD with the AEM data collection by year indicated by the legend. The projection is NAD83 State Plane Nebraska (feet).

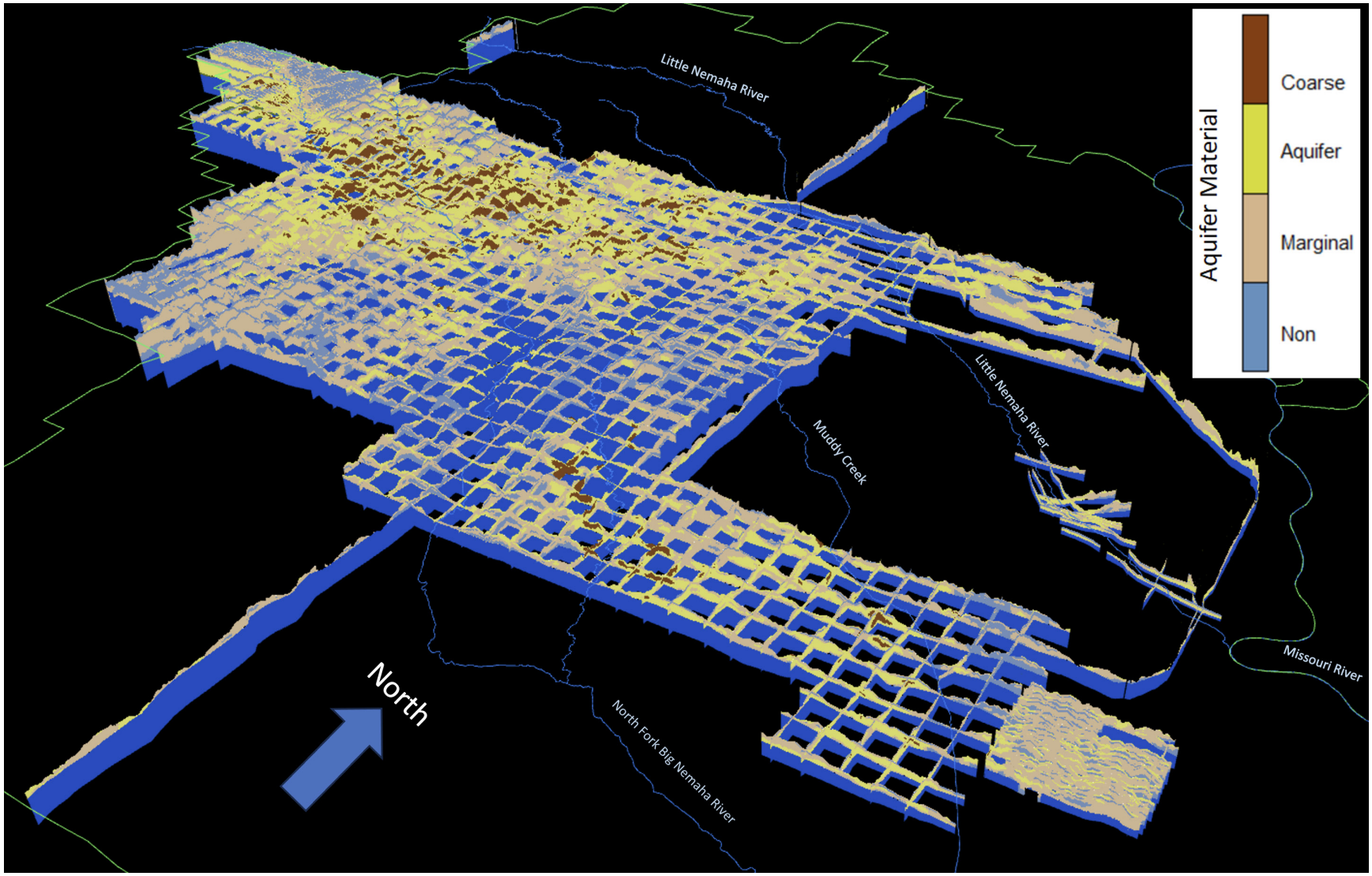


Figure 5-24. 3D fence diagram looking to the northwest of the NNRD lines. The blue basement is the undifferentiated Pennsylvanian (*IP*) and Paleozoic units and the green (in the northwest area) is the Cretaceous Dakota Group (*Kd*) bedrock. Vertical exaggeration 15x.

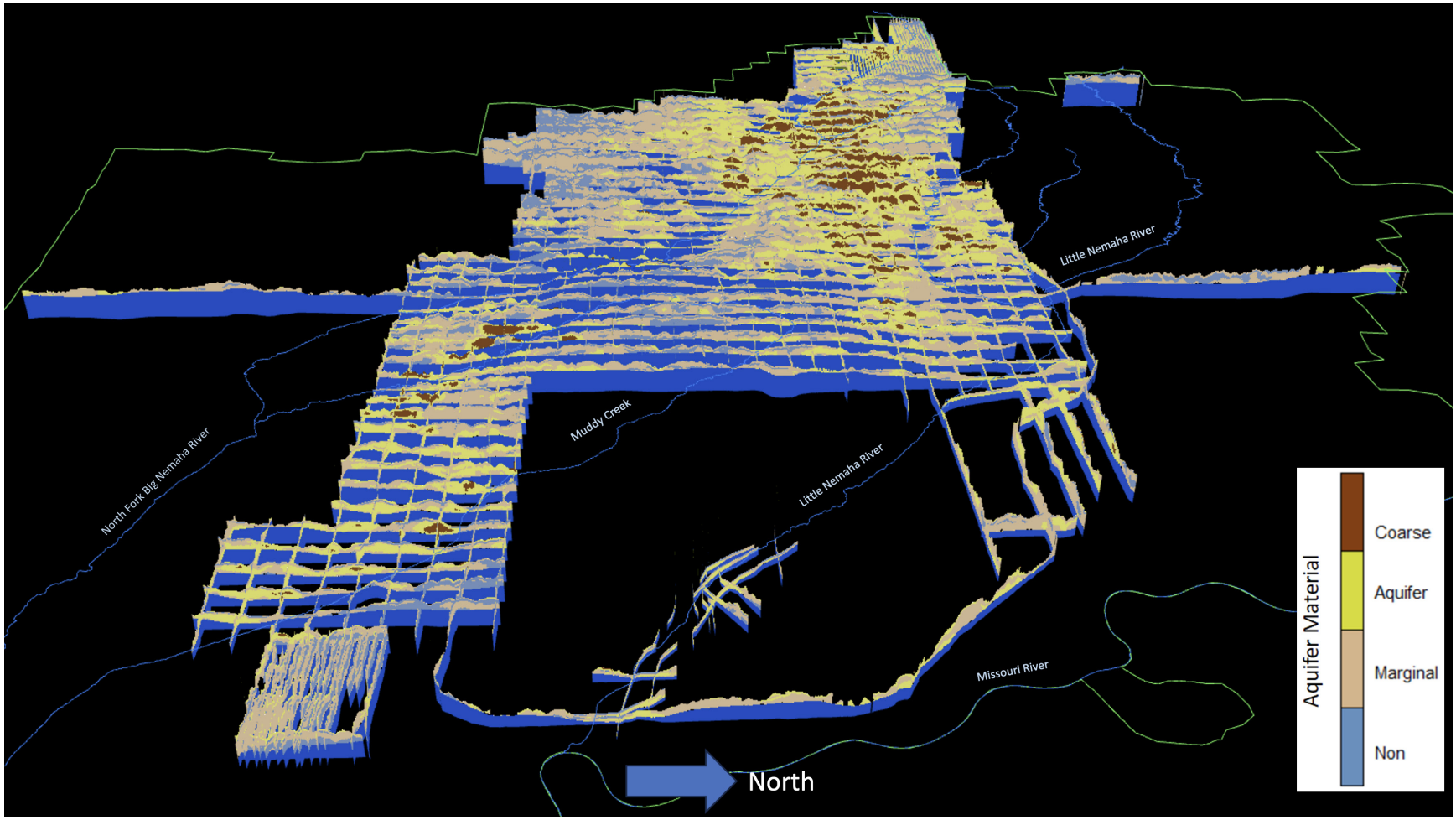


Figure 5-25. 3D fence diagram looking to the west of the combined NNRD lines. The blue basement is the undifferentiated Pennsylvanian (*IP*) and Paleozoic units and the green (in the northwest area) is the Cretaceous Dakota Group (*Kd*) bedrock. Vertical exaggeration 15x.

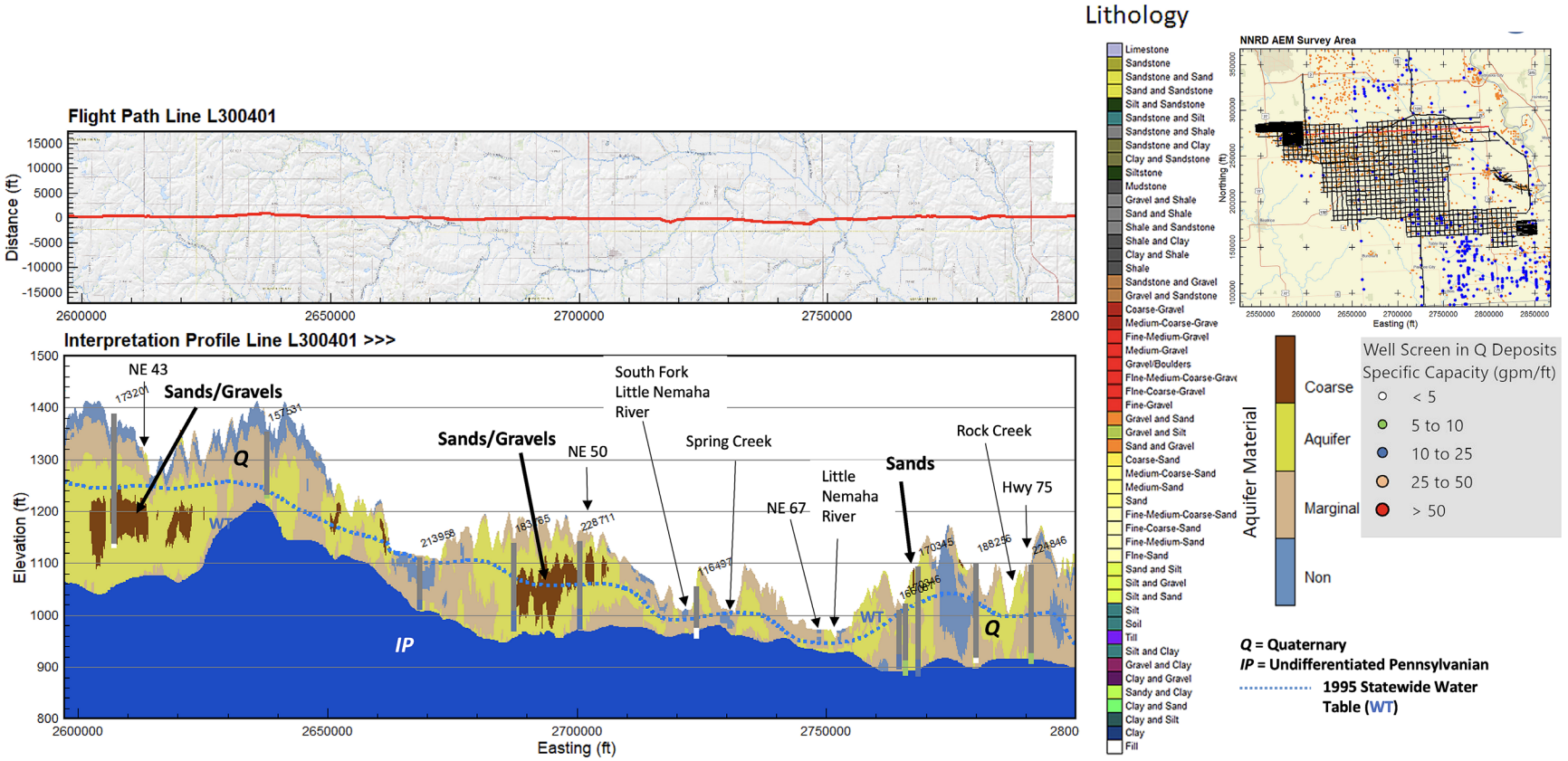


Figure 5-26. Profile of east-west line L300401 AEM interpretation. NE CSD and DNR test holes within 1000 feet are projected on the profile indicating stratigraphy and Specific Capacity (where available). Stratigraphy, Quaternary aquifer materials and Specific Capacity are indicated by the legends.

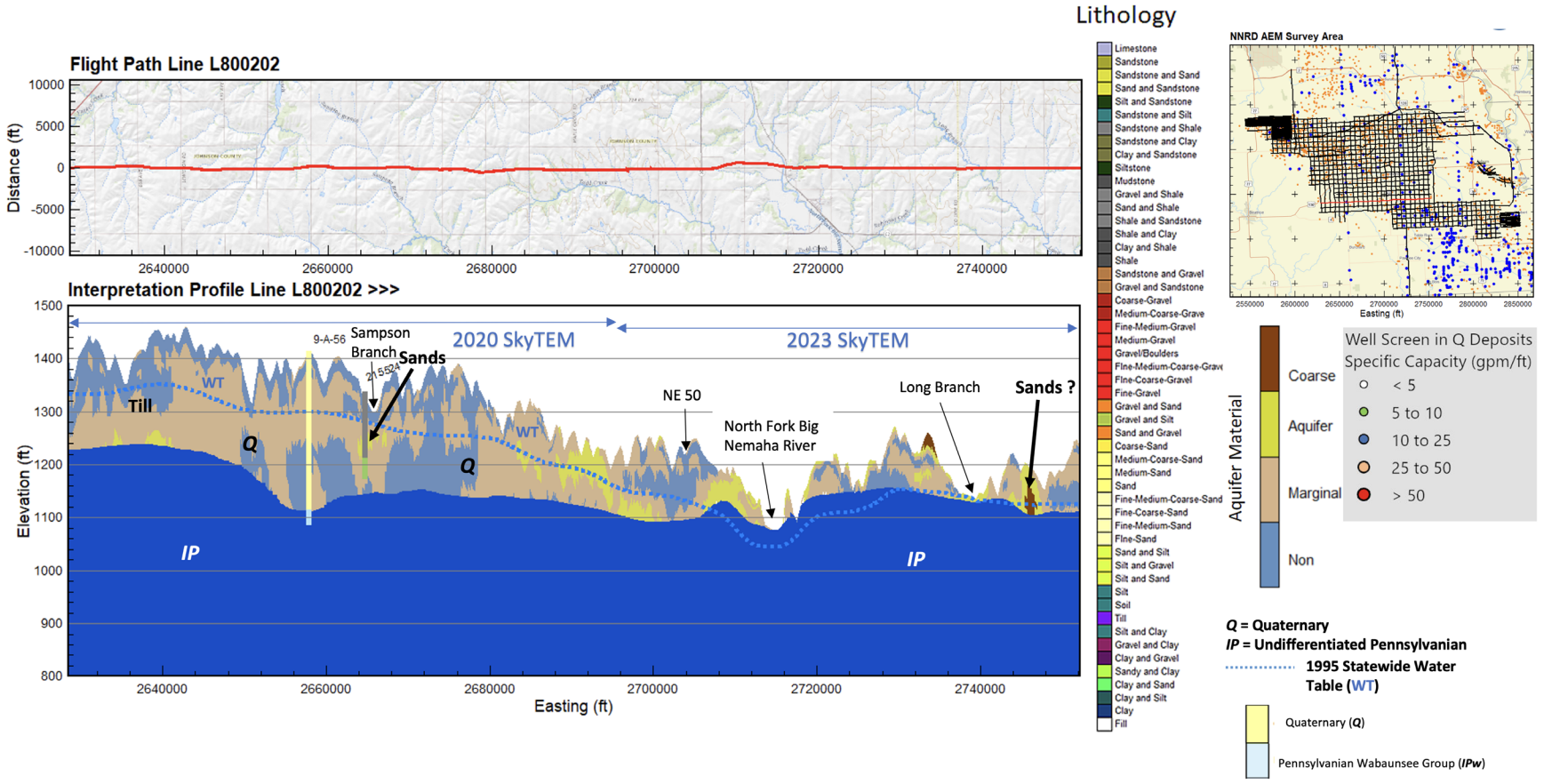


Figure 5-27. Profile of east-west line L800202 AEM interpretation. NE CSD and DNR test holes within 1000 feet are projected on the profile indicating stratigraphy and Specific Capacity (where available). Stratigraphy, Quaternary aquifer materials and Specific Capacity are indicated by the legends.

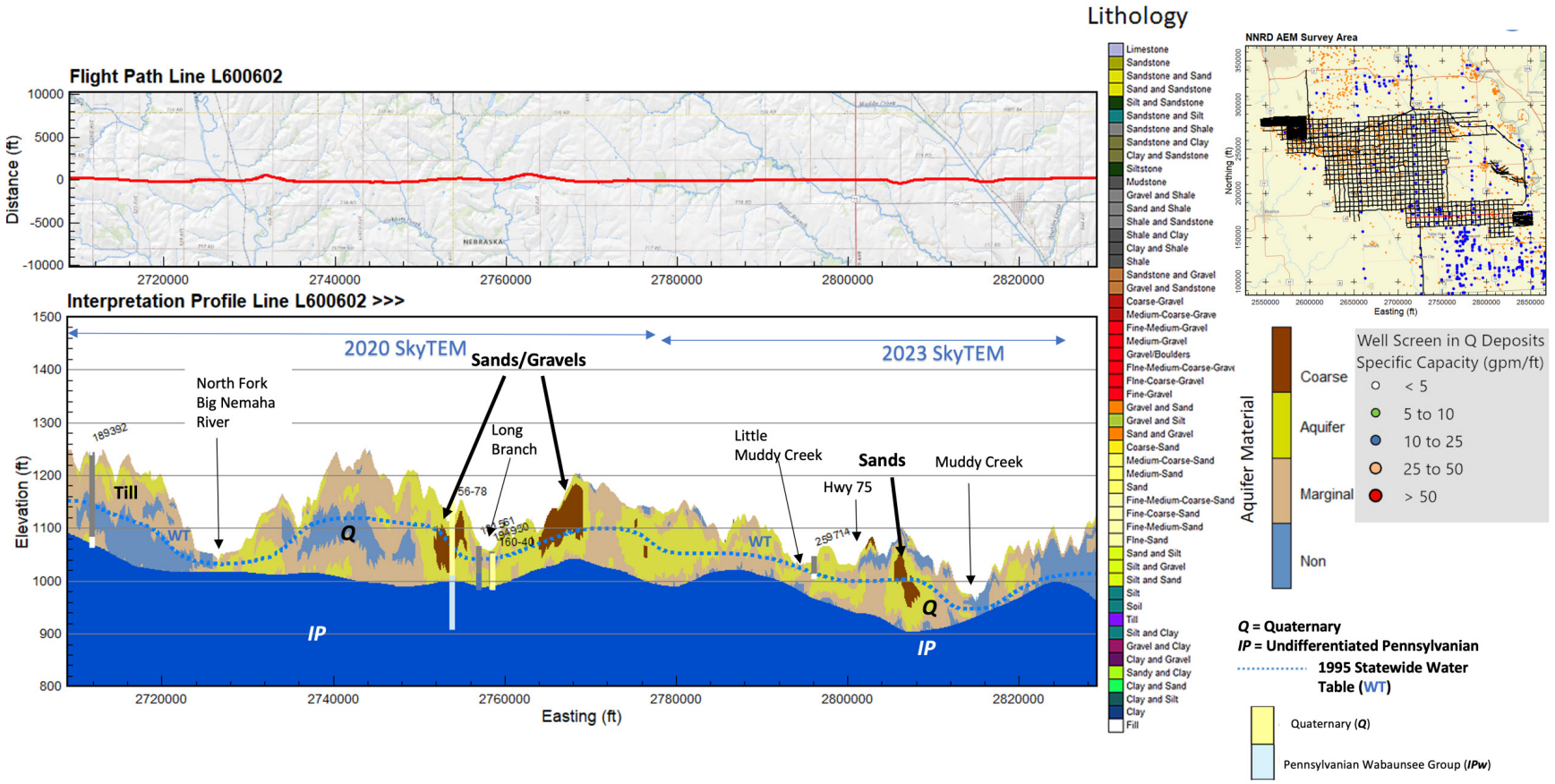


Figure 5-28. Profile of east-west line L600602 AEM interpretation. NE CSD and DNR test holes within 1000 feet are projected on the profile indicating stratigraphy and Specific Capacity (where available). Stratigraphy, Quaternary aquifer materials and Specific Capacity are indicated by the legends.

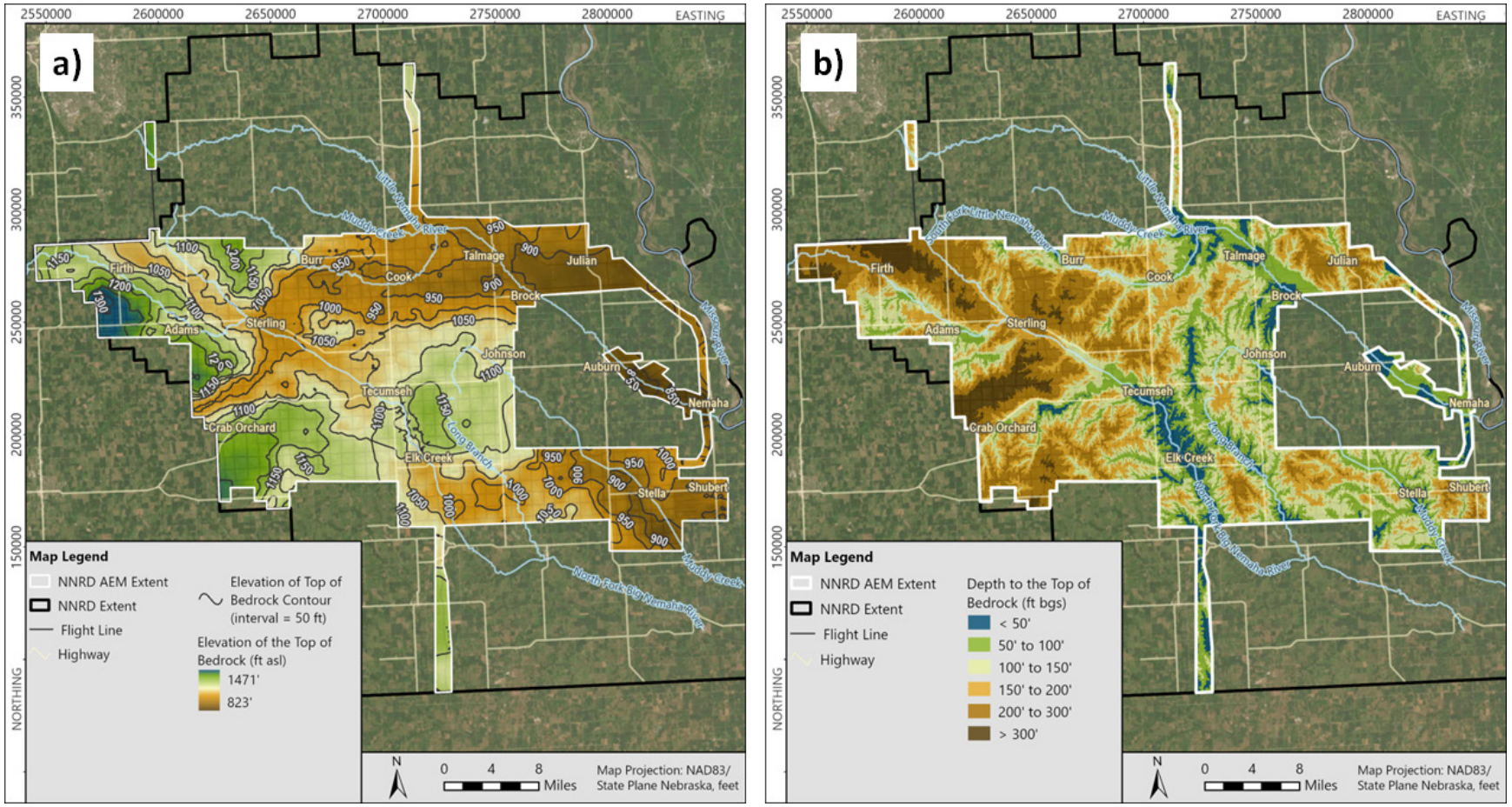


Figure 5-29. a) Map of the bedrock elevation from the combined AEM studies including 2007, 2009, 2015, 2018, 2020, and 2023. b) Map of the depth to the top of the bedrock from the combined AEM studies. The projection is NAD83 State Plane Nebraska (feet).

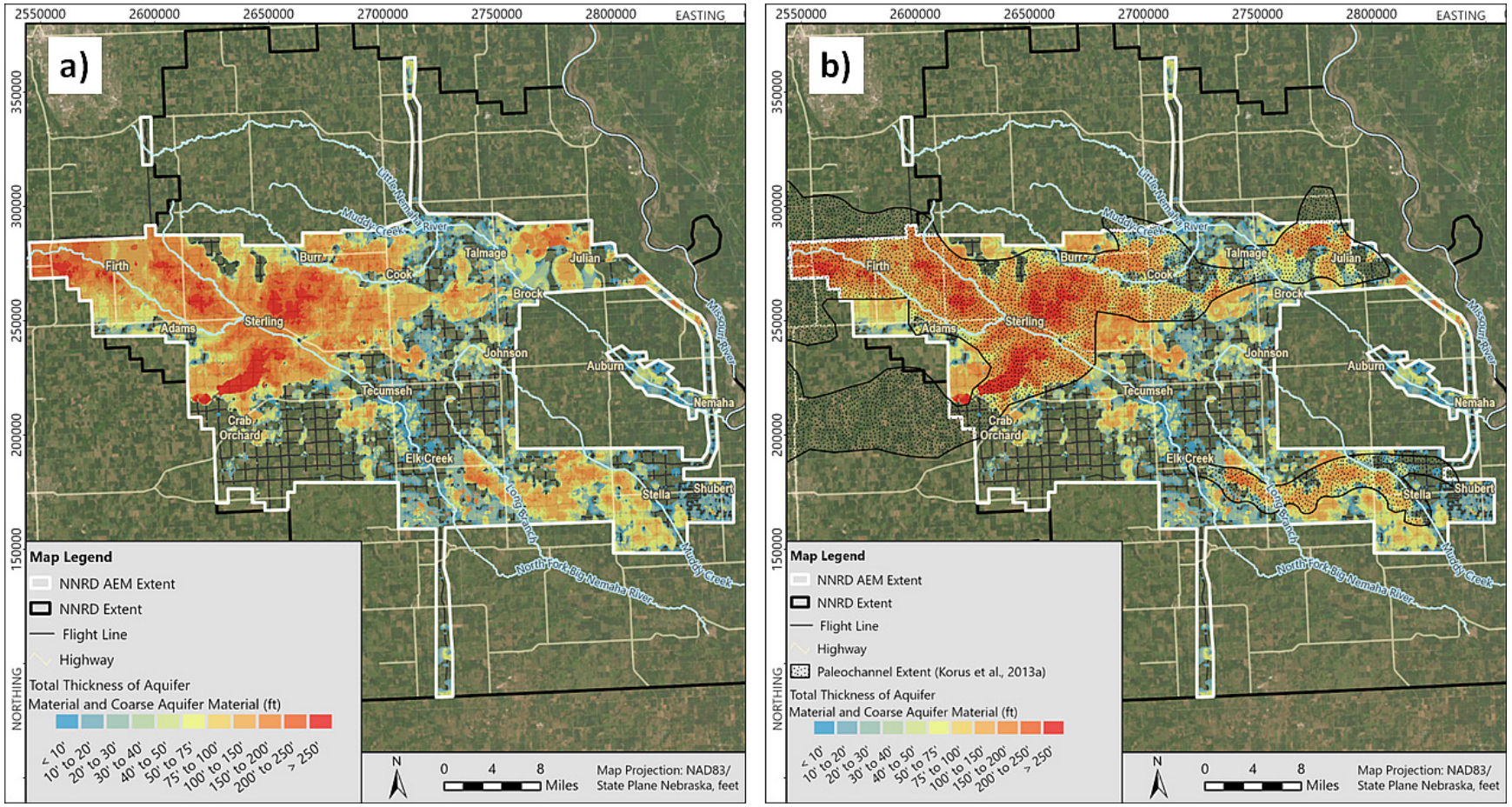


Figure 5-30. a) Map of the Total thickness of the Aquifer Material and Coarse Aquifer Material in the combined NNRD AEM survey area; b) Total thickness of the Aquifer Material and Coarse Aquifer Material compared to the paleochannels from Korus et al. (2013a). The projection is NAD83 State Plane Nebraska (feet).

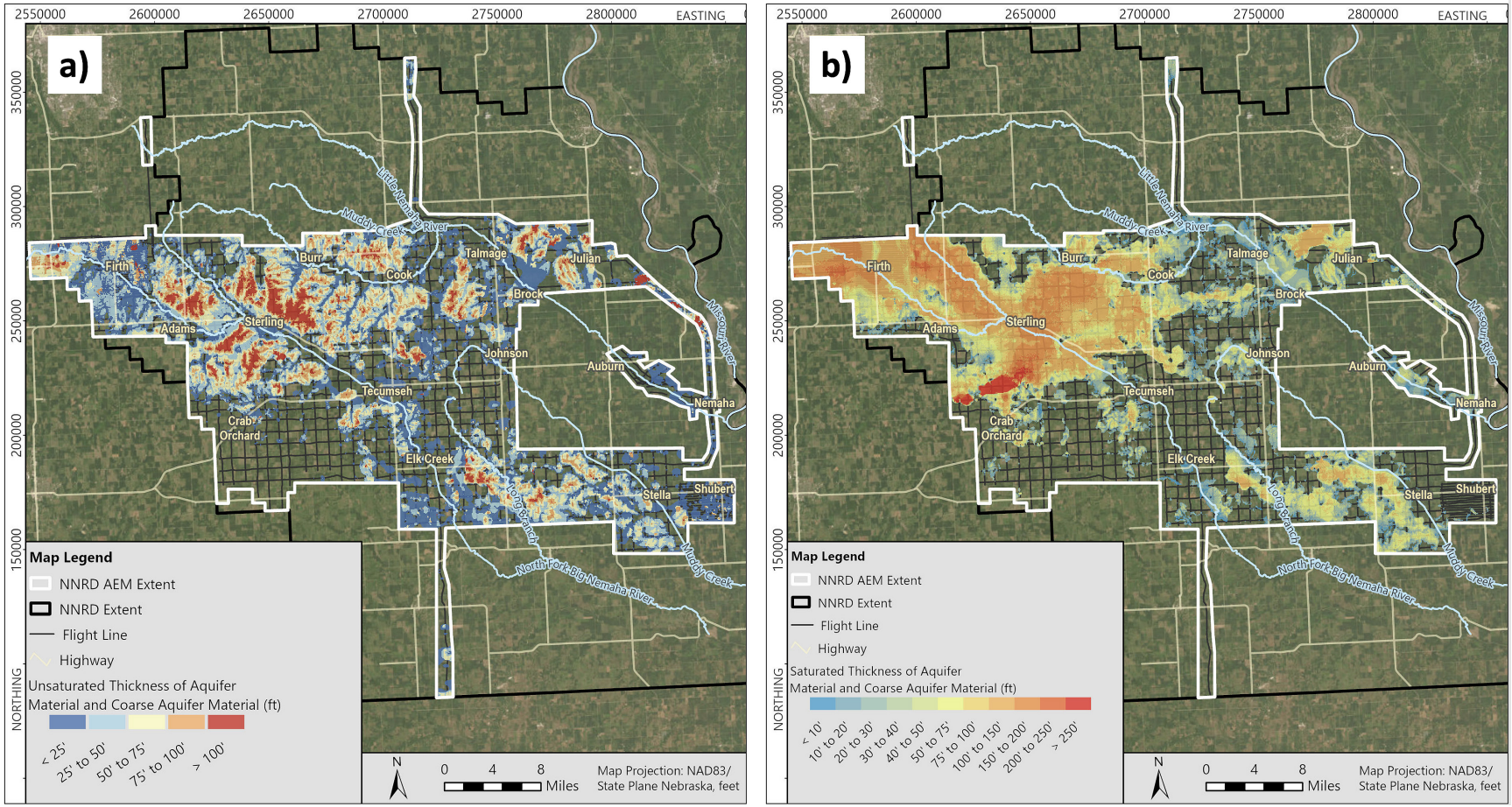


Figure 5-31. a) Map of the Unsaturated thickness of Aquifer Material and Coarse Aquifer material within the combined NNRD AEM survey area. b) Map of the Saturated thickness of Aquifer Material and Coarse Aquifer Material within the combined NNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

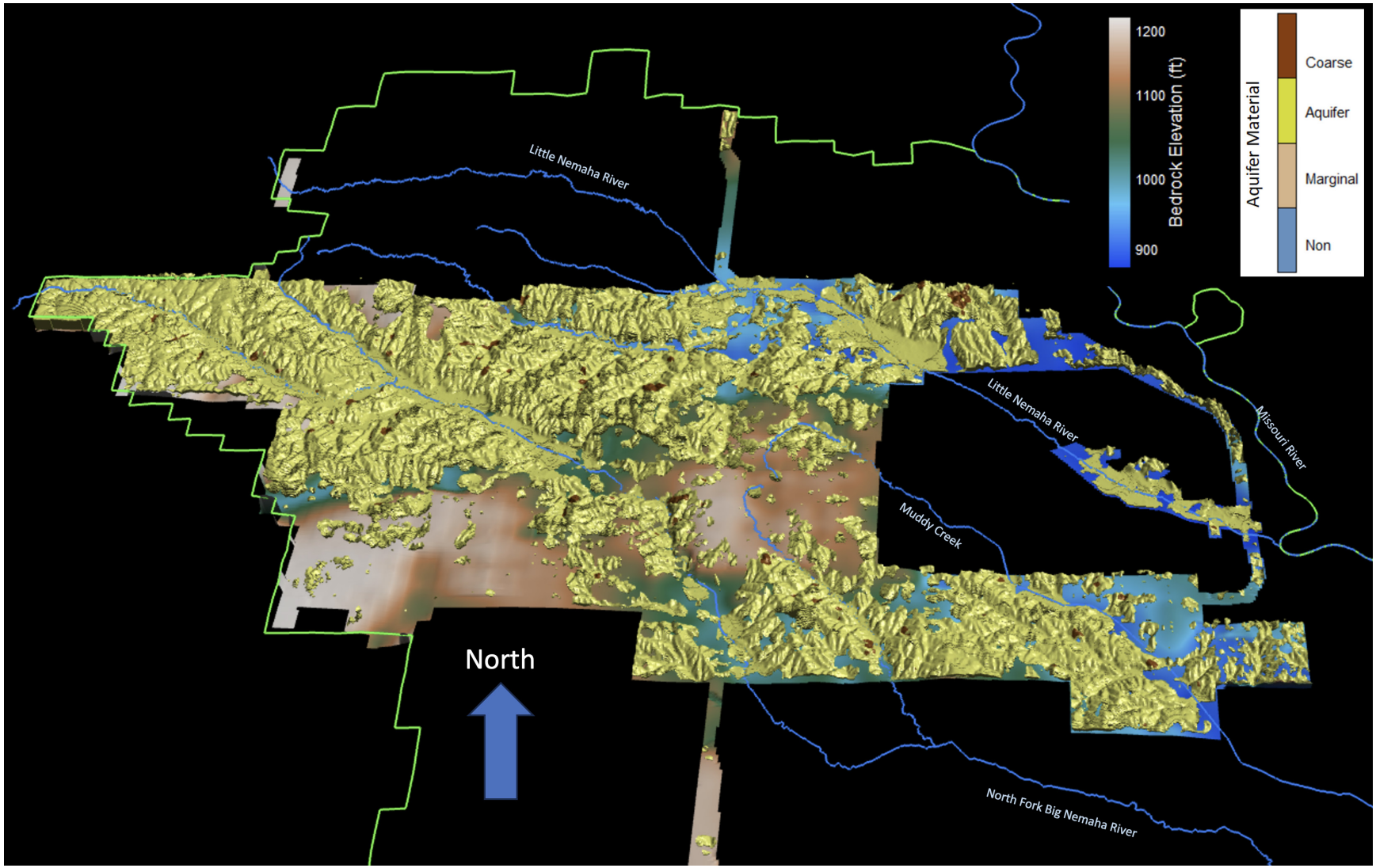


Figure 5-32. 3D voxel model of all the Quaternary (*Q*) Aquifer Material and Coarse Aquifer Material overlying the top of the bedrock surface, in elevation (feet). V.E.=15X.

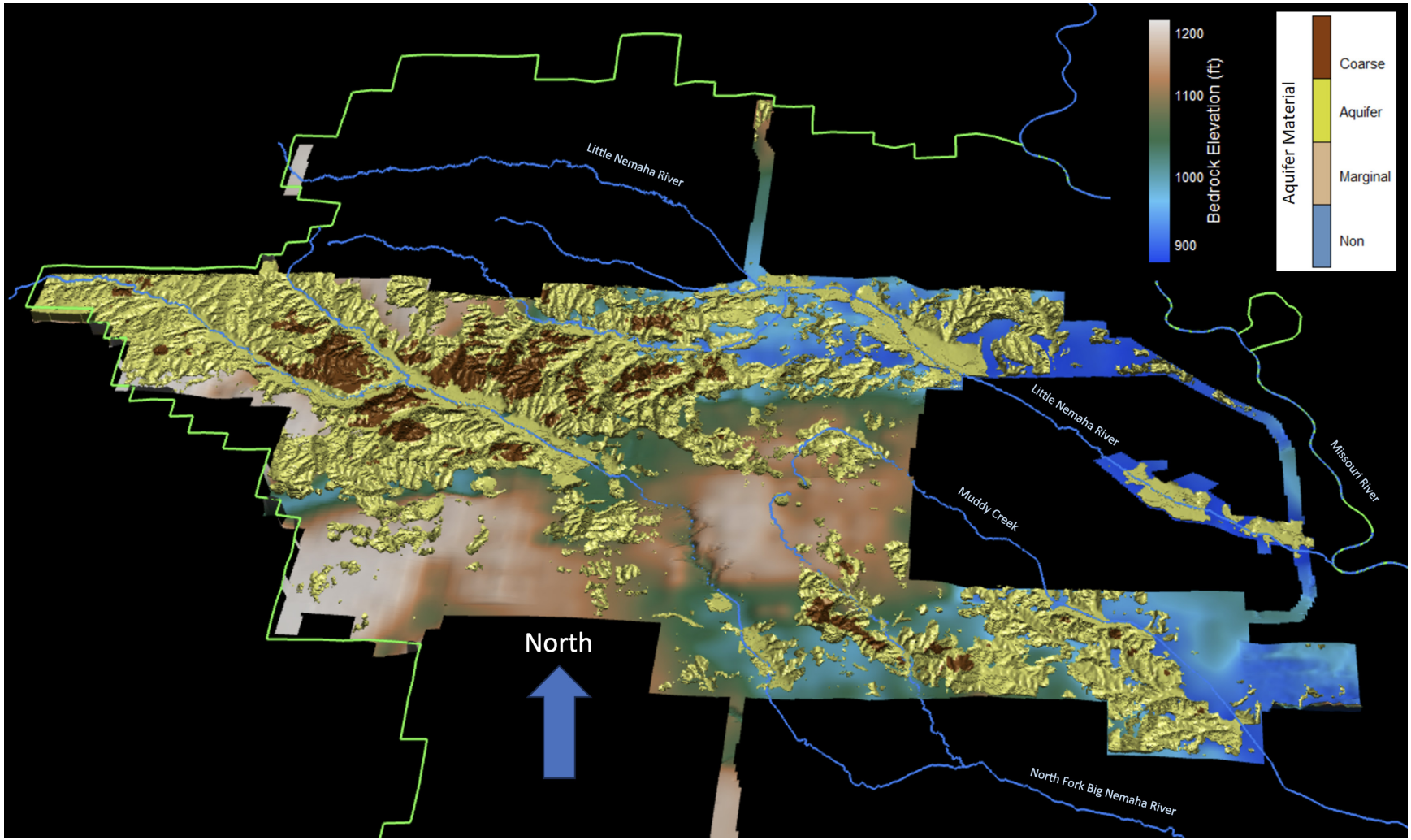


Figure 5-33. 3D voxel model of all the Saturated Quaternary (*Q*) Aquifer Material and Coarse Aquifer Material overlying the top of the bedrock surface, in elevation (feet). V.E.=15X.

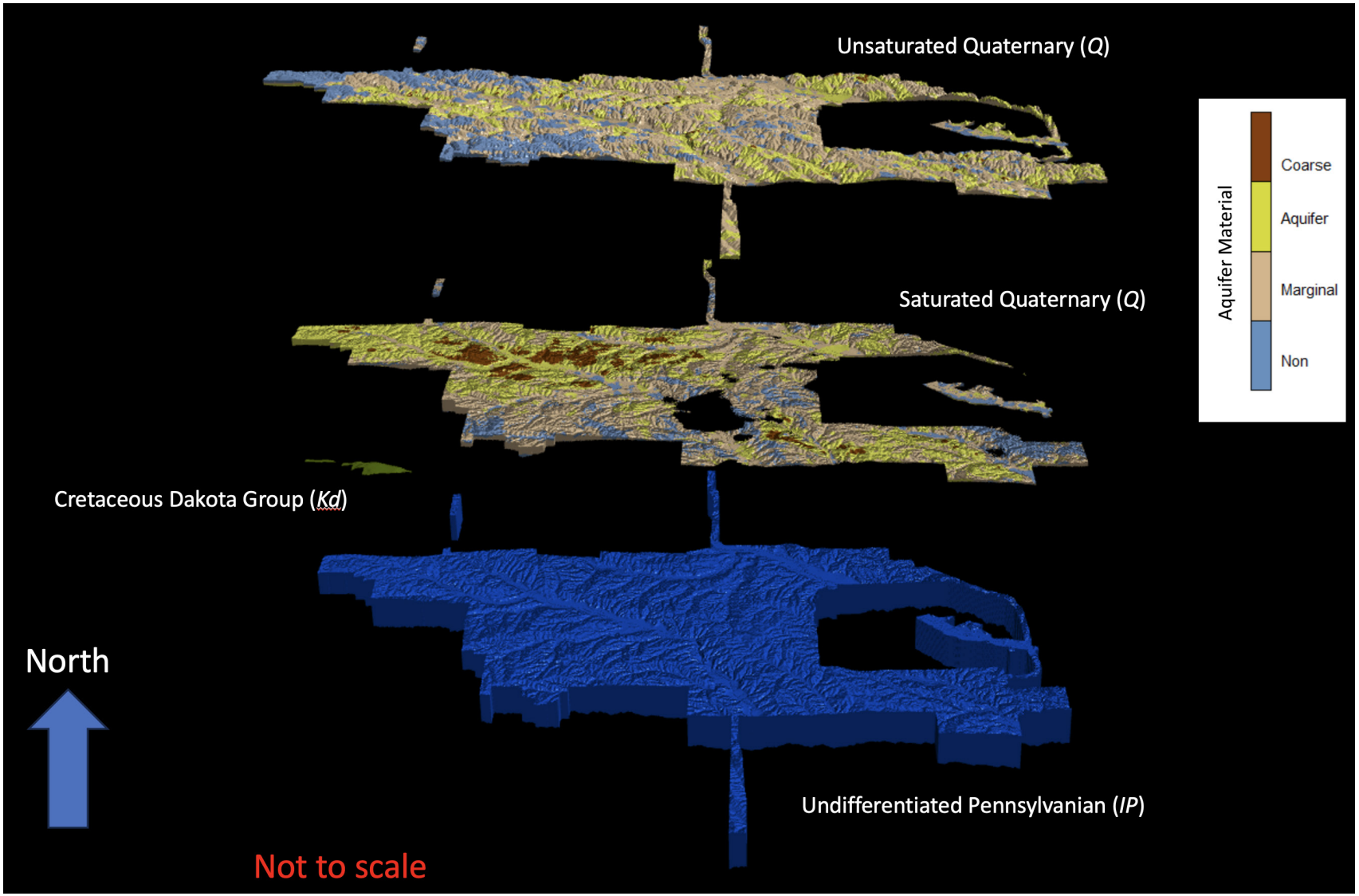


Figure 5-34. Exploded 3D voxel model showing the Unsaturated Quaternary material overlying the Saturated Quaternary (*Q*) material overlying the Cretaceous Dakota Group (*Kd*) (only on the western end of the NNRD AEM survey area) and Undifferentiated Pennsylvanian (*IP*). V.E.= 15X.

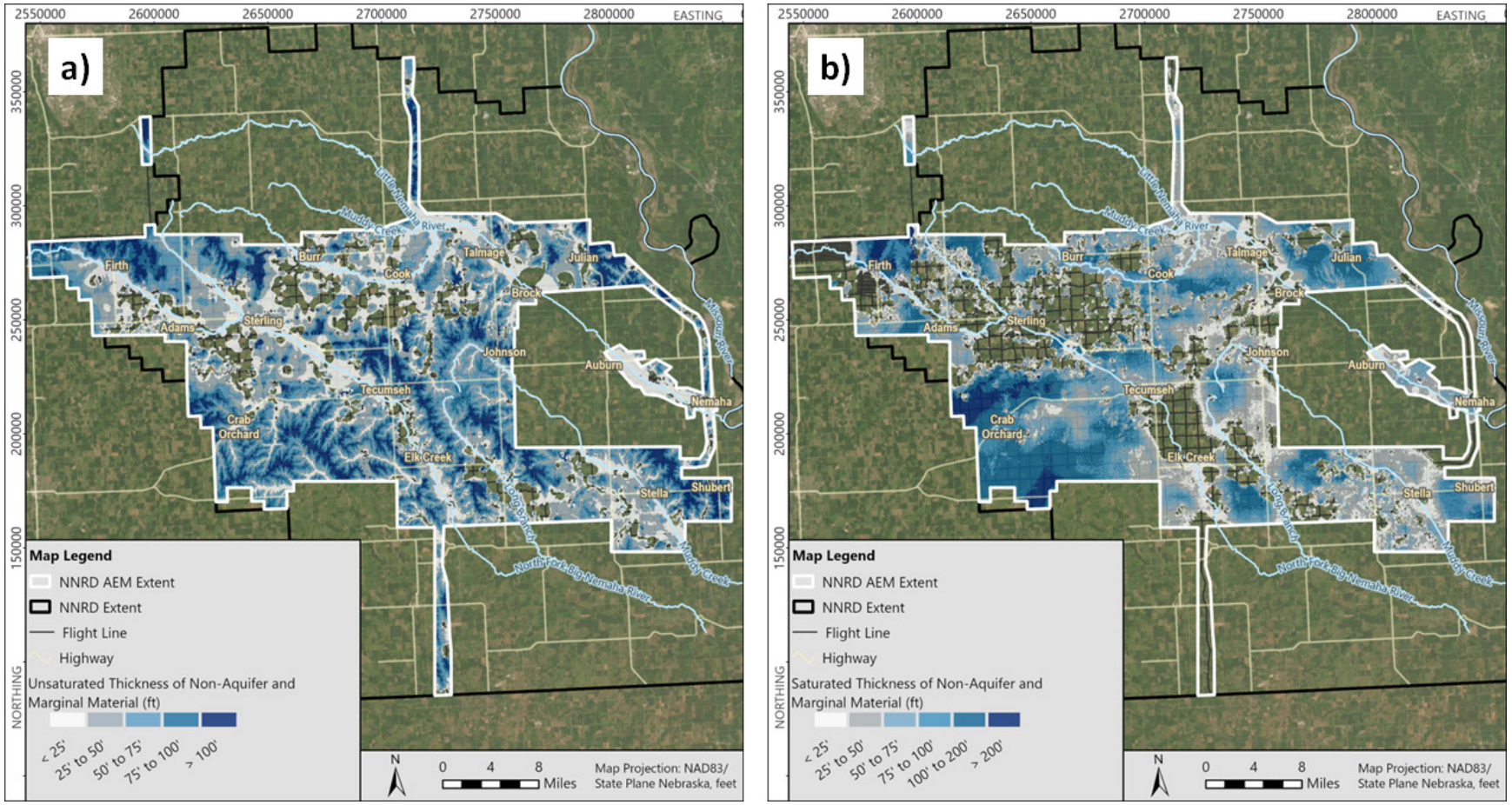


Figure 5-35. a) Map of the Unsaturated thickness of Non-Aquifer and Marginal Material within the combined NNRD survey area. b) Map of the Saturated thickness of Non-Aquifer and Marginal Material within the combined NNRD survey area. The projection is NAD83 State Plane Nebraska (feet).

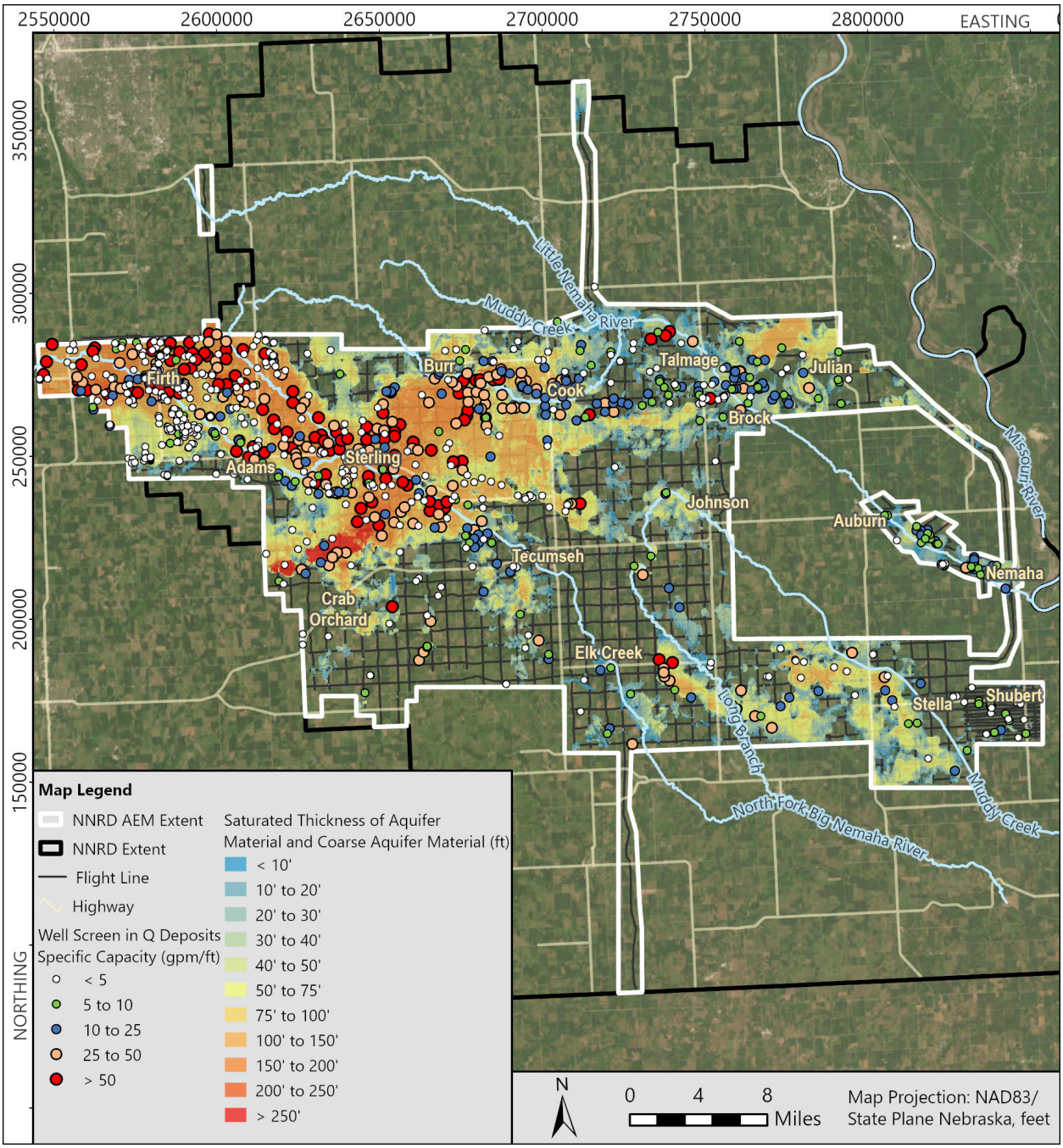


Figure 5-36. Map of the Saturated thickness of Aquifer Material and Coarse Aquifer material within the combined NNRD AEM survey area with the Specific Capacity values calculated from the NE-DNR registered wells indicated. The projection is NAD83 State Plane Nebraska (feet).

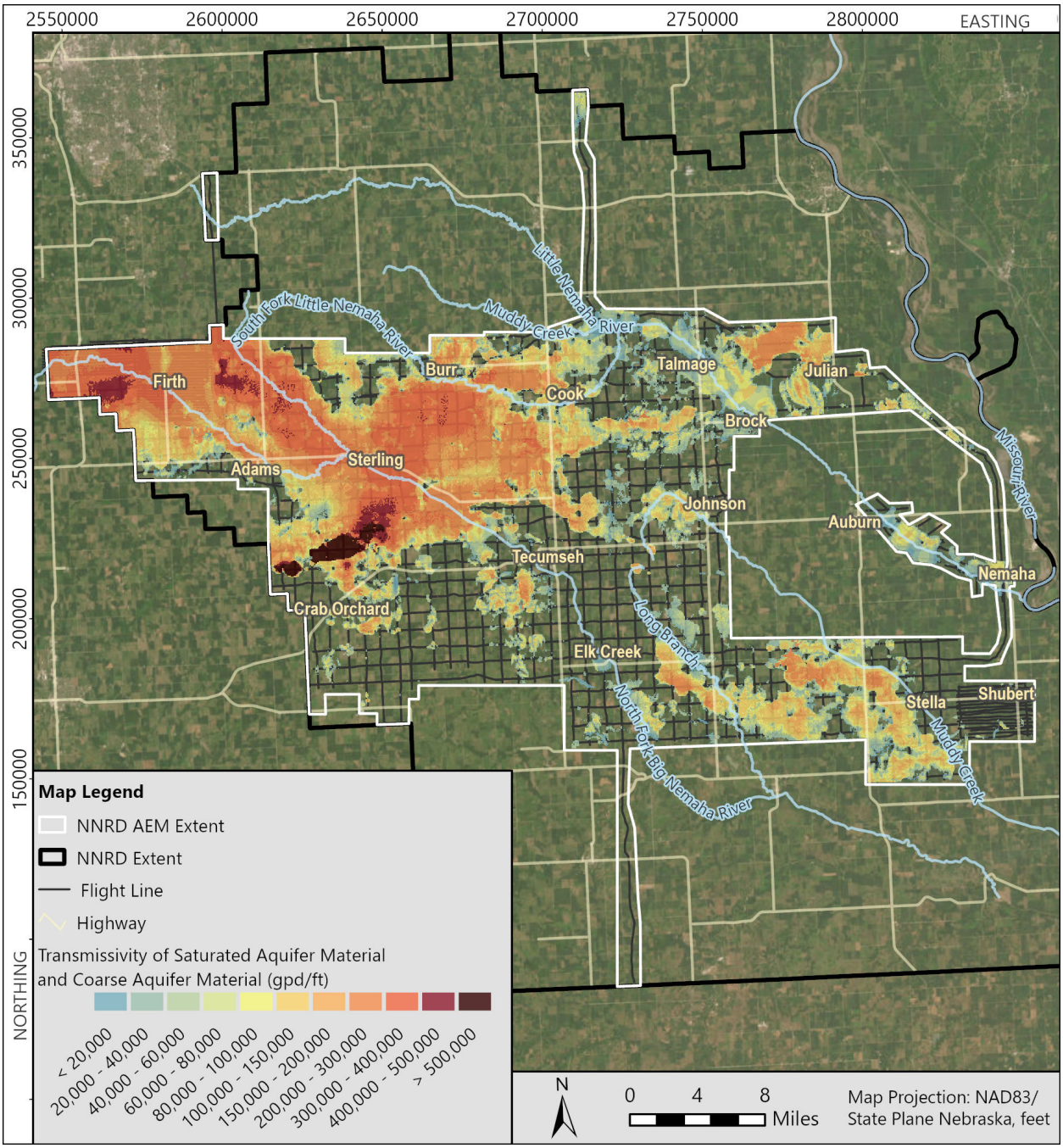


Figure 5-37. Map of the estimated Transmissivity within the combined NNRD AEM survey area for Saturated Aquifer Material and Coarse Aquifer Material. The projection is NAD83 State Plane Nebraska (feet).

5.3.2 The Hydrogeologic Framework of the Auburn AEM Survey Area

The flight line layout for the Auburn portion of the combined NNRD AEM survey area is presented in Figure 5-38. Figure 5-39 presents a map of the 1995 water table (Nebraska CSD, 1995) in the Auburn area. The Little Nemaha River, running down the middle of the AEM survey area, clearly has a strong effect on the water table in the area.

3D fence diagrams of the Auburn AEM interpretation results (with views to the northwest, west, and west-northwest) including CSD and NE-DNR lithology and stratigraphy borehole logs and the bedrock elevation surface are presented in Figure 5-40, Figure 5-41, and Figure 5-42, respectively. Note the difference in the range of the bedrock elevation in the Auburn area (820 ft to 900 ft) versus the range in elevation in the larger combined NNRD AEM survey area (about 820 ft to 1250 ft).

Examination of the profiles in the 3D fence diagrams clearly shows that the Quaternary (***Q***) aquifer materials in the Auburn area are composed of about 50% Aquifer Materials and about 50% Marginal Aquifer Materials and Non-Aquifer Materials with no apparent Coarse Aquifer Materials present in the area.

Figure 5-43 presents a combination of the 3D fence diagram view to the northwest with a 3D voxel model of Quaternary aquifer materials, CSD and NE-DNR borehole lithology and stratigraphic logs, and the bedrock elevation surface. The 3D voxel shows the spatial distribution of the Aquifer Materials across the Auburn area.

The interpretative AEM profile of Auburn east-west line L1001101 (Figure 5-44) also includes borehole lithology, stratigraphy, and Specific Capacity logs (where available). Note that the Specific Capacity wells are located in the Aquifer Materials composed of sands and show yields up to about 10-25 gpm/ft.

Figure 5-45 presents the elevation (Figure 5-45a) and depth to top (Figure 5-45b) of the bedrock surface in the Auburn area. Note that the depth to the top of the bedrock is from the ground surface which can have variable topography. Maps of the total thickness of the Quaternary (***Q***) deposits in the Auburn AEM survey area and the saturated thickness of the ***Q*** deposits are presented in Figure 5-46a and Figure 5-46b, respectively. The thickest ***Q*** deposits are located on the northern side of the survey area which is consistent with the greatest depths to the bedrock surface.

Maps of the total thickness in the Auburn AEM area of the Quaternary (***Q***) Non-Aquifer Material and Marginal Aquifer Material and the total thickness of the Aquifer Material and Coarse Aquifer Material in the Auburn area are presented in Figure 5-47a and Figure 5-47b, respectively. On the Aquifer Material and Coarse Aquifer Material map (Figure 5-47b) there appears to be about four (4) areas that are thicker than 60 ft (red-colored areas with dotted circles). Two of these four areas overlap with thicker areas of Non-Aquifer and Marginal Aquifer materials but two do not (white areas with dotted circles in Figure 5-47a).

Following up on these observations are maps of the unsaturated thickness of the Quaternary Aquifer Material and Coarse Aquifer Material in the Auburn area (Figure 5-48a) and the saturated thickness

(Figure 5-48b) of the Quaternary Aquifer Material and Coarse Aquifer Material in the Auburn AEM survey area. Note the same four (4) areas on the saturated ***Q*** Aquifer Material and Coarse Aquifer Materials map (Figure 5-48b) as are the thickest ***Q*** deposit areas in Figure 5-47b.

Continuing following up on the observations of Figure 5-47 are maps of the unsaturated thickness of the Quaternary Non-Aquifer and Marginal Aquifer material in the Auburn area (Figure 5-49a) and the saturated thickness (Figure 5-49b) of the Quaternary Non-Aquifer and Marginal Aquifer material in the Auburn AEM survey area. It can be observed that much of the Auburn AEM survey area has unsaturated Non-Aquifer and Marginal Aquifer material (Figure 5-49a) that is only 20 ft thick or less and there are several saturated areas that are greater than 60 ft thick (Figure 5-49b).

Figure 5-50 is a map of the thickness of the saturated Aquifer Material and Coarse Aquifer materials in the Auburn AEM survey area showing the correlation with Specific Capacity values derived from the NE-DNR registered wells as described in Section 5.2.4.1. The higher Specific Capacity values correlate in some locations with the interpreted thick Aquifer Material and Coarse Aquifer Material. But there is one location (dashed circle in Figure 5-50) that has higher Specific Capacity values (10-25 gpm/ft) where there shows no saturated thickness of Aquifer Material and Coarse Aquifer Material. This area is outside the AEM flight area and the extent of the voxel model. There are also areas (solid black circles in Figure 5-50) where there are greater than 60 ft areas of saturated Aquifer Material and Coarse Aquifer Material with no wells present. These could be potential locations of new production wells. Note that there are still other isolated deposits of Aquifer and Coarse Aquifer materials that also show a good match with the NE-DNR Specific Capacity values.

As with the combined NNRD AEM interpreted results, by using the saturated thickness of the aquifer and coarse aquifer material and an estimate of the hydraulic conductivity (Freeze and Cherry, 1979), an estimate of the transmissivity was developed for the Auburn AEM survey area (Figure 5-51). These values compare relatively well with the LBG values derived from using the Specific Capacity (AGF, 2019 ; LBG, 2017). The coarsest and thickest areas of the saturated Aquifer Material and Coarse Aquifer Material have the highest transmissivity values. It is important to note that the transmissivity values (Figure 5-51) were derived by only using the saturated thickness of the aquifer and coarse aquifer materials. However, this provides an additional view of the possible transmissive properties of the materials within the Auburn AEM survey area.

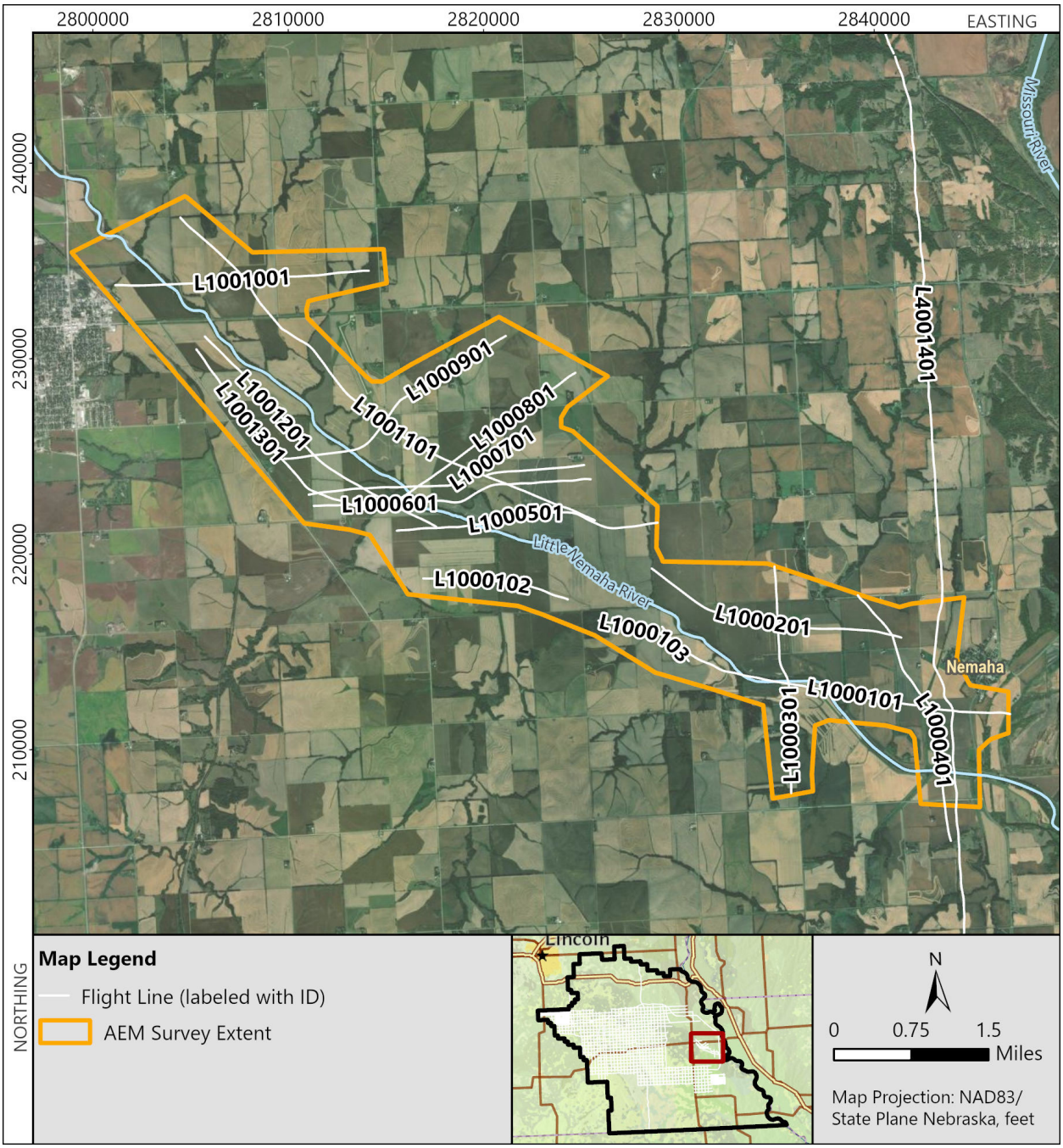


Figure 5-38. Flight line map of that portion of the NNRD AEM survey area containing the labeled Auburn area AEM flight lines. The projection is NAD83 State Plane Nebraska (feet).

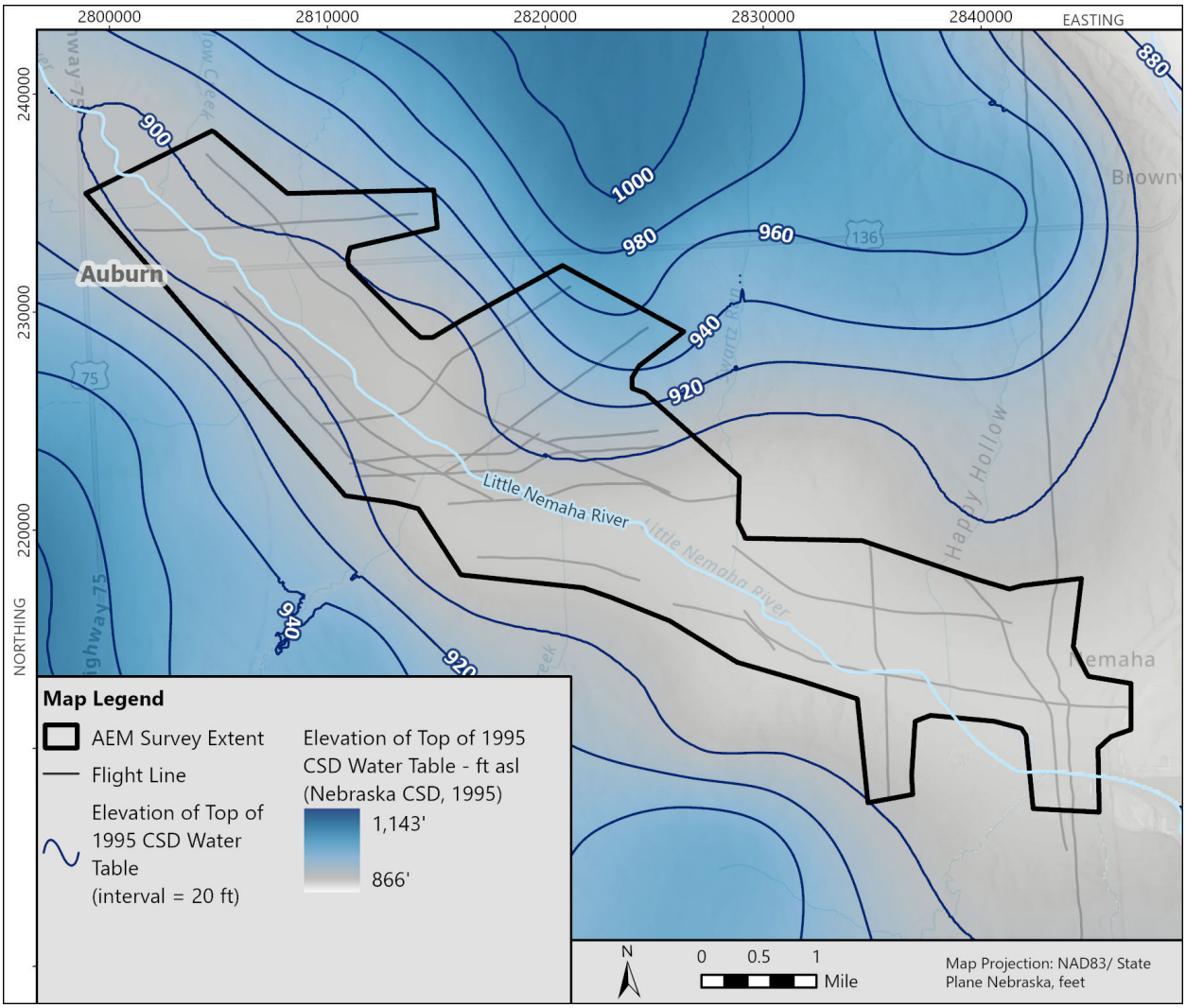


Figure 5-39. Map of the elevation of the top of the 1995 CSD water table (Nebraska CSD, 1995). Projection is Nebraska State Plane, feet.

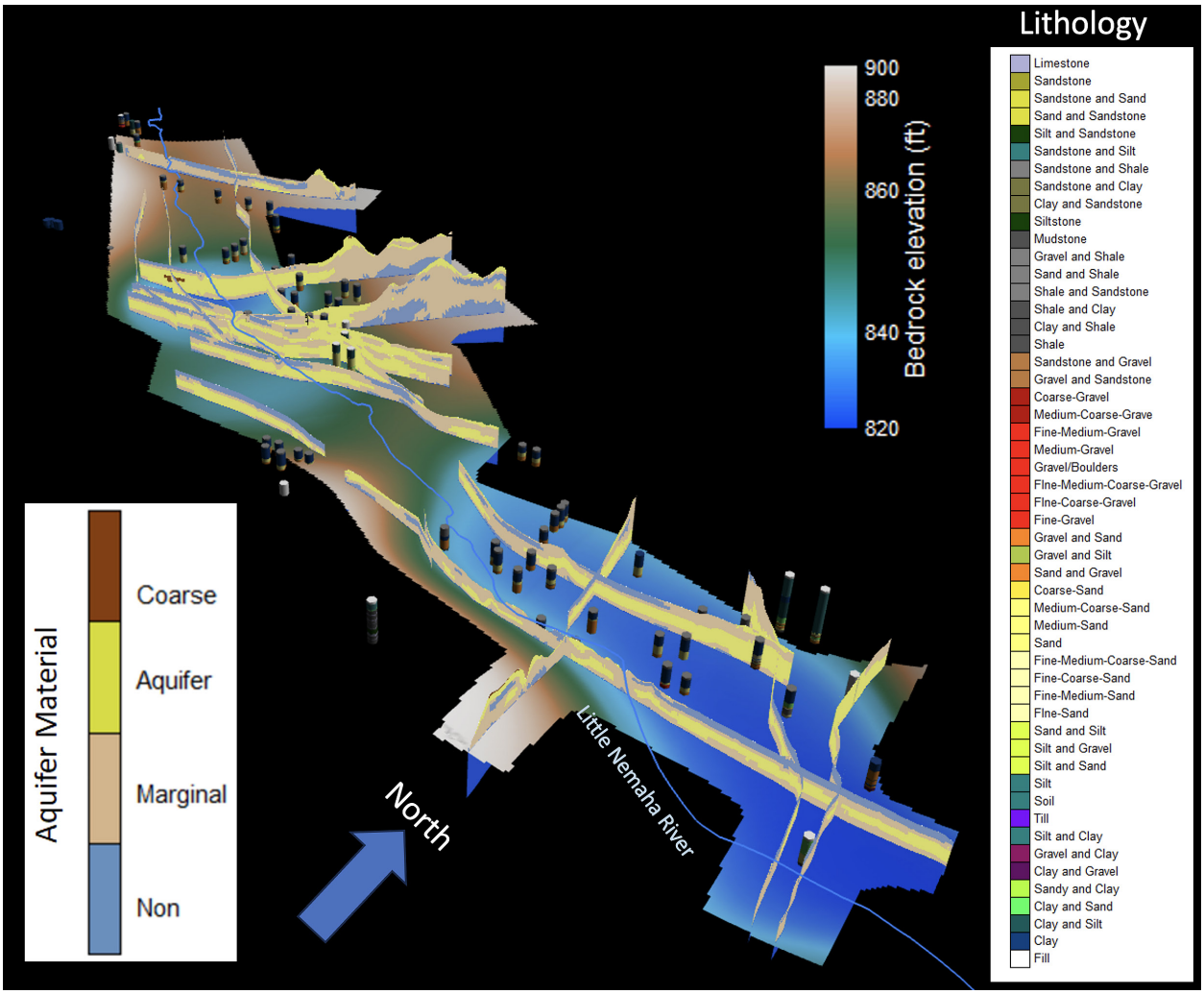


Figure 5-40. 3D fence diagram looking to the northwest of the 2023 Auburn AEM flight lines with NE CSD and NE-DNR lithology and stratigraphic borehole logs and the bedrock elevation surface. Vertical exaggeration 15x.

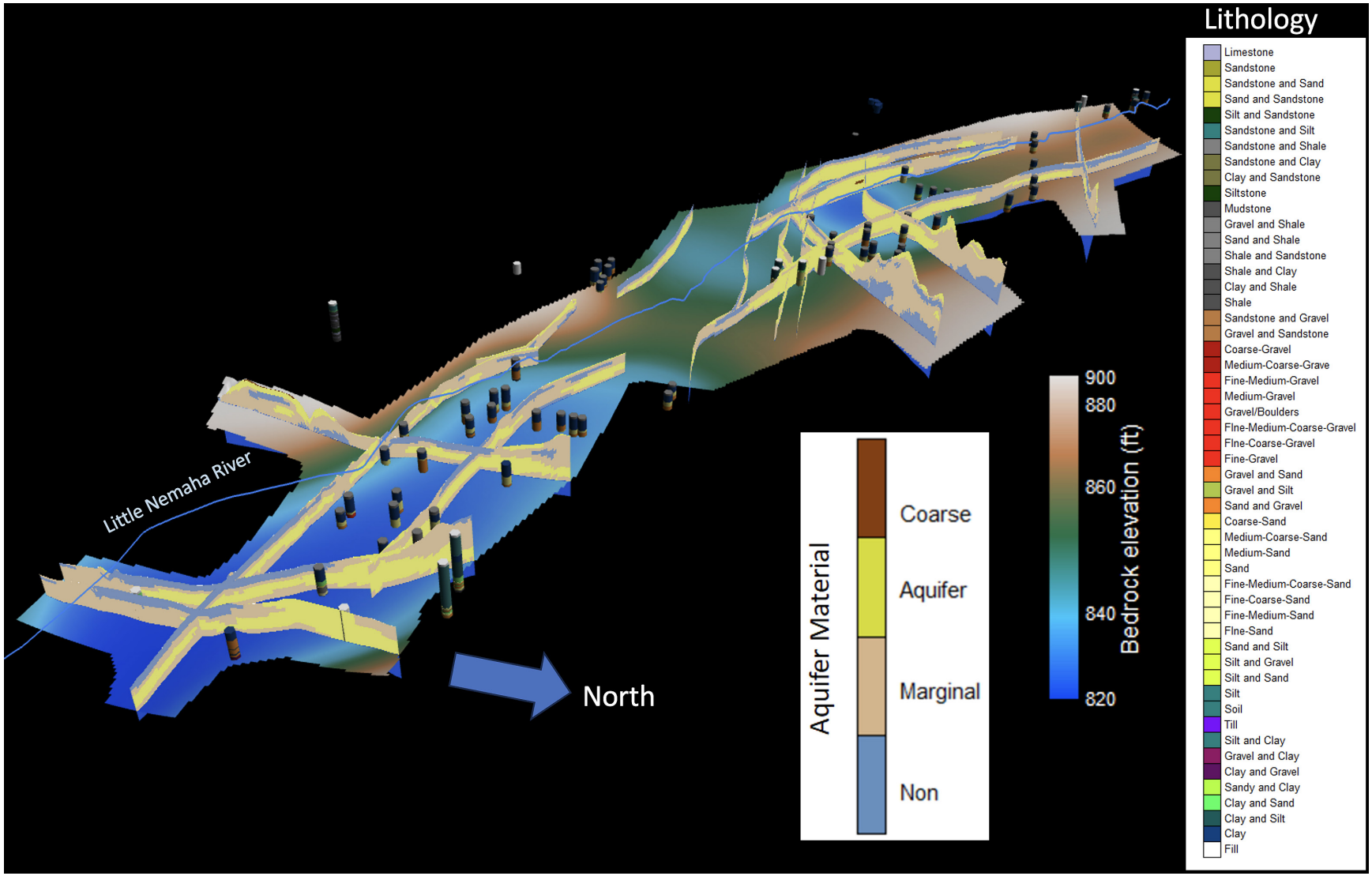


Figure 5-41. 3D fence diagram looking to the west of the 2023 Auburn flight lines with CSD and NE-DNR lithology and stratigraphy borehole logs with the bedrock elevation surface. Vertical exaggeration 15x.

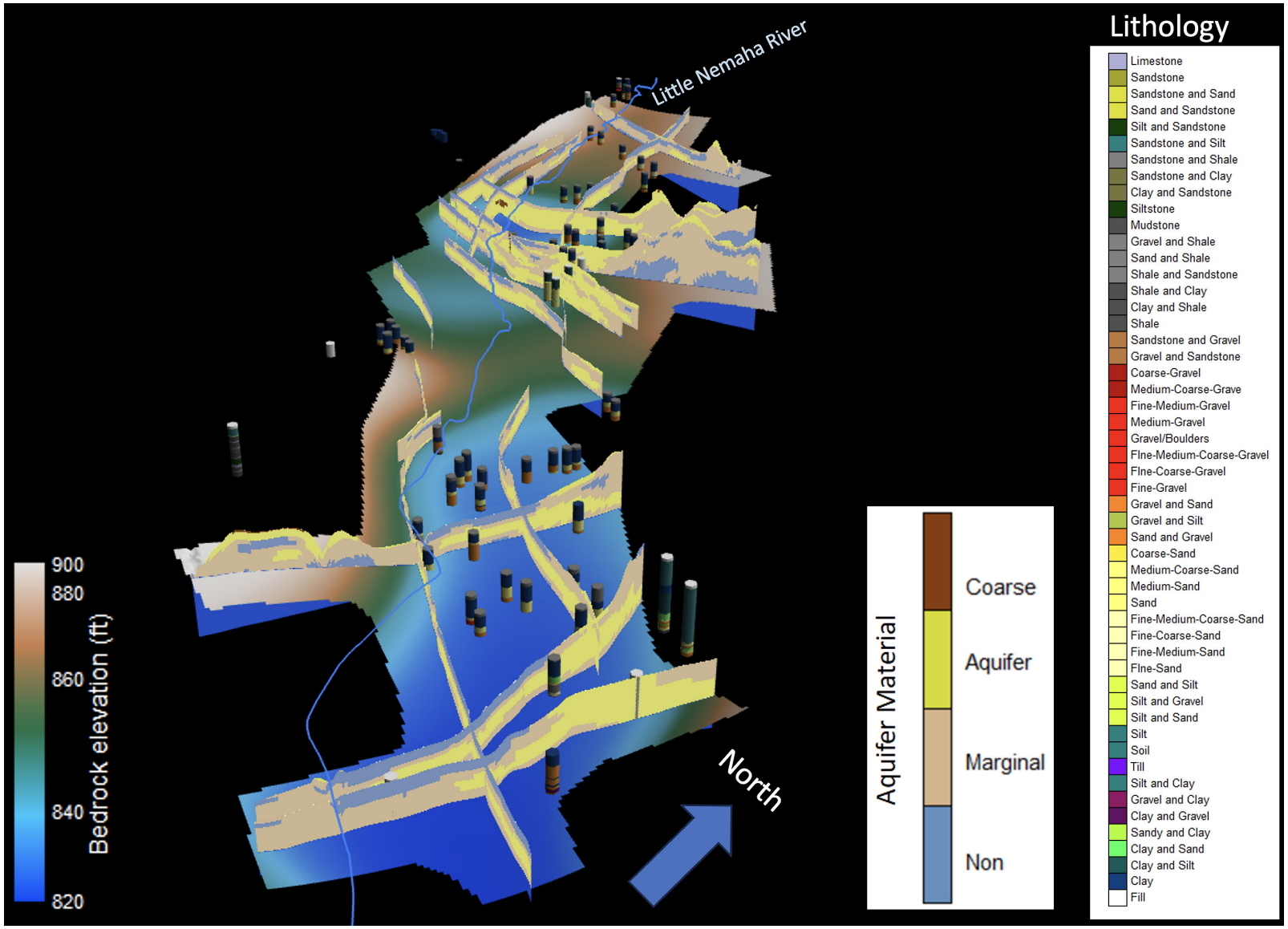


Figure 5-42. 3D fence diagram looking to the west-northwest of the 2023 Auburn flight lines with CSD and NE-DNR lithology and stratigraphy borehole logs with the bedrock elevation surface. Vertical exaggeration 15x.

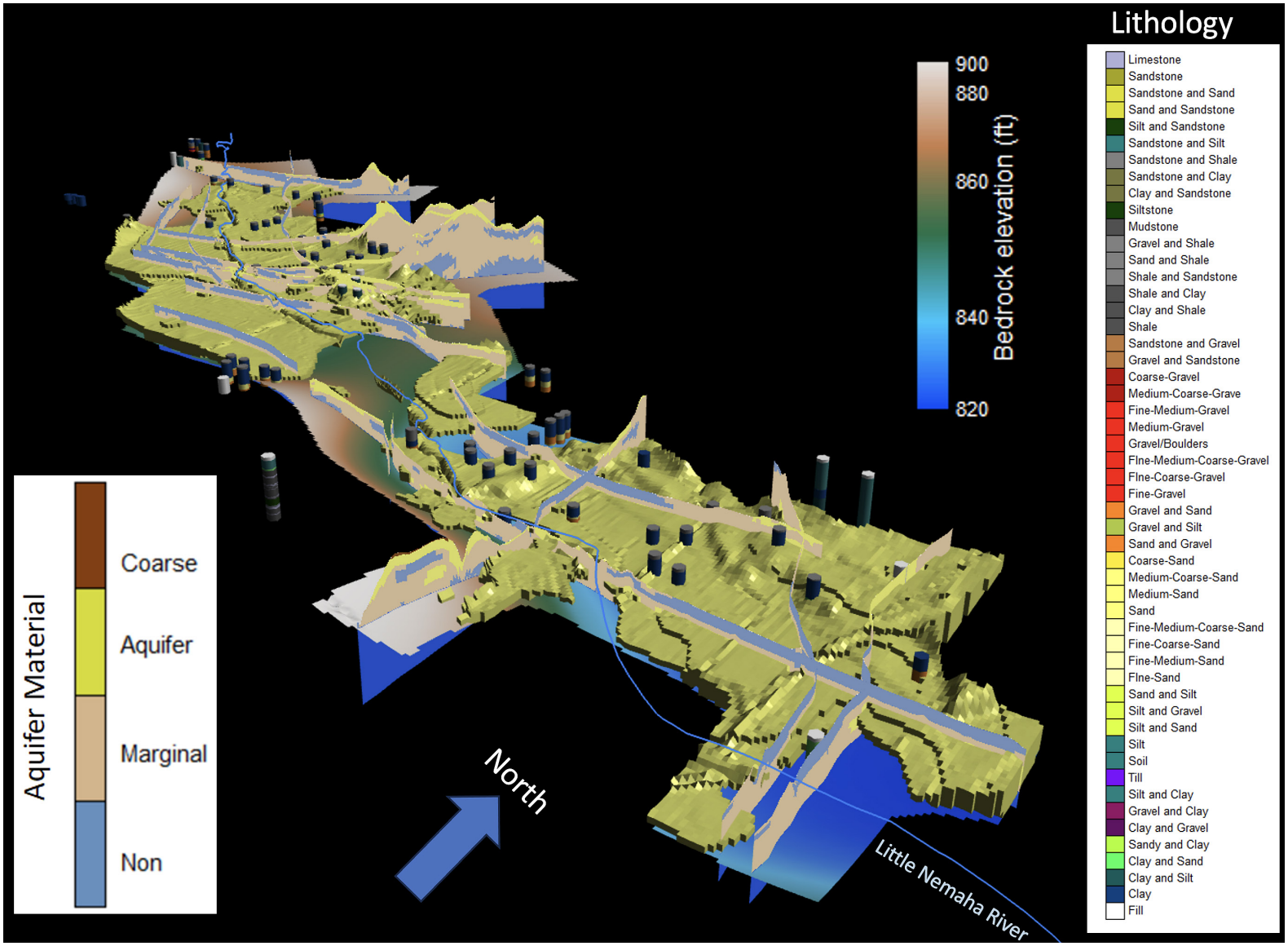


Figure 5-43. 3D fence diagram with 3D voxel of the Quaternary (*Q*) Aquifer Materials looking to the northwest of the 2023 Auburn flight lines with CSD and NE-DNR lithology and stratigraphy borehole logs with the bedrock elevation surface. Vertical exaggeration 15x.

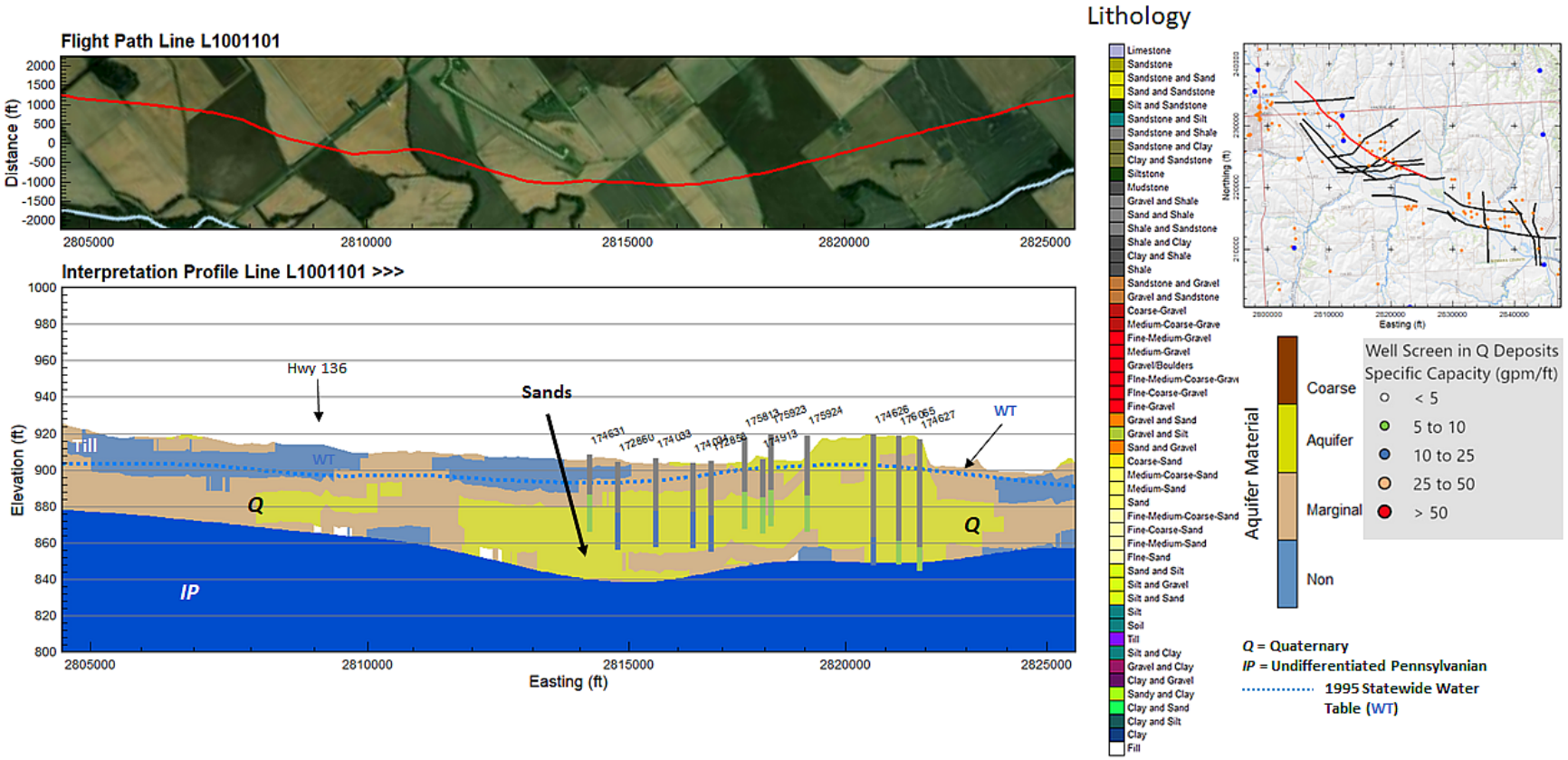


Figure 5-44. Profile of east-west line L1001101 AEM interpretation. CSD and NE-DNR test holes within 1000 feet are projected on the profile indicating stratigraphy and Specific Capacity (where available). Stratigraphy, Quaternary aquifer materials and Specific Capacity are indicated by the legends.

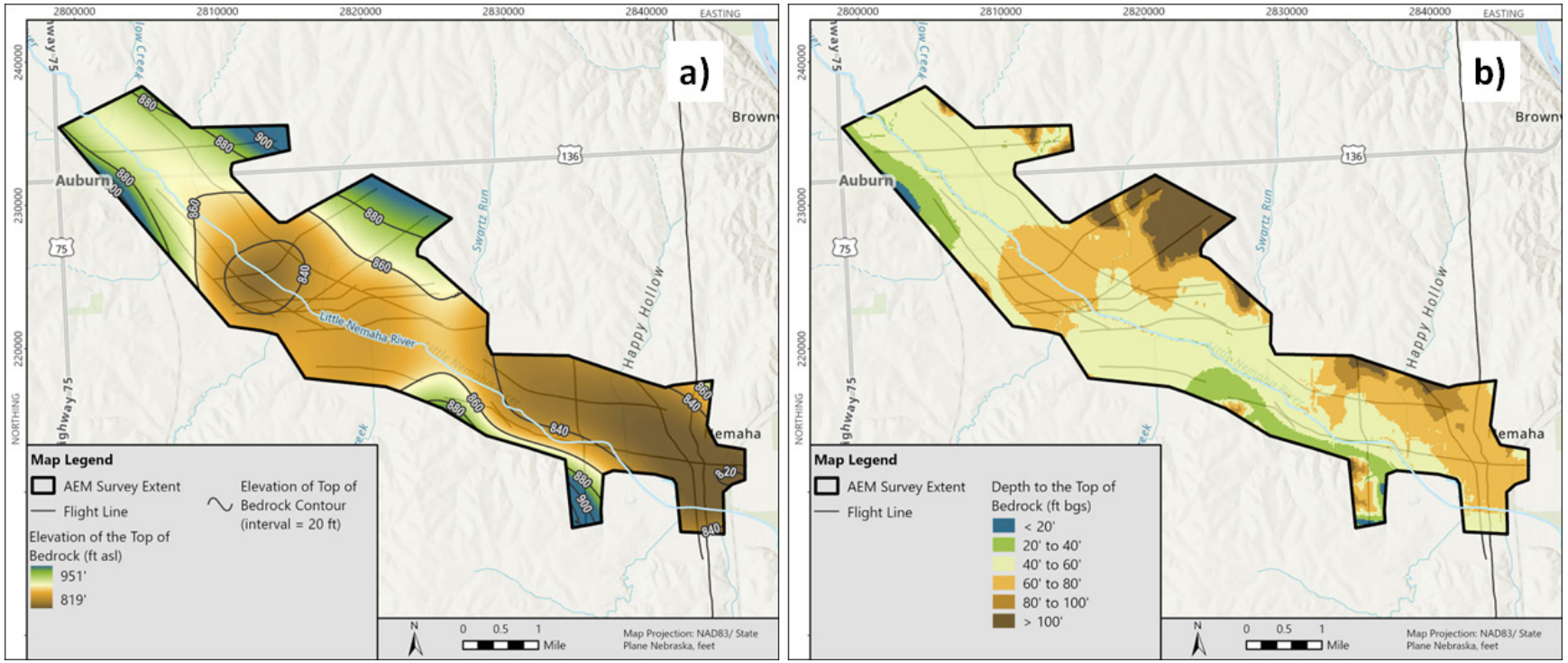


Figure 5-45. a) Map of the bedrock elevation for the 2023 Auburn AEM flight area. b) Map of the depth to bedrock from the 2023 Auburn AEM flight area. The projection is NAD83 State Plane Nebraska (feet).

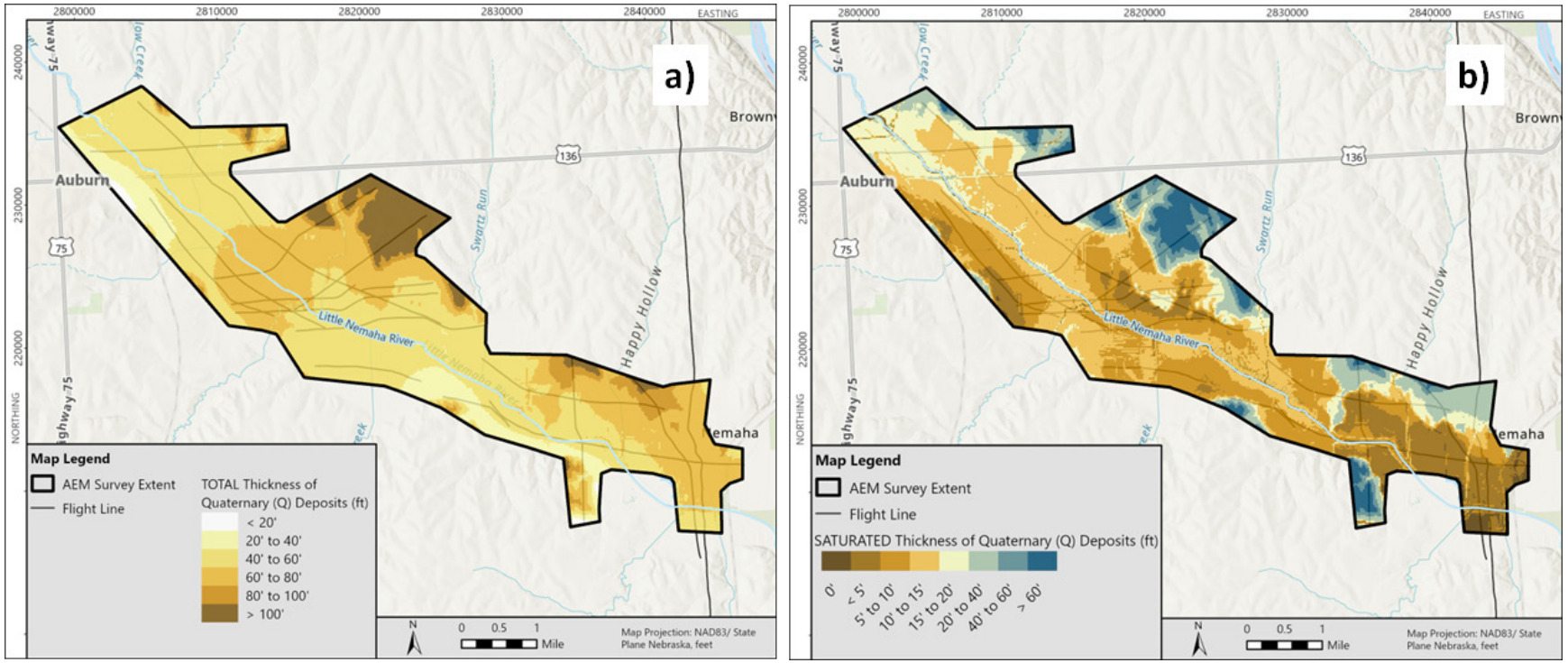


Figure 5-46. a) Map of the Total thickness of the Quaternary (*Q*) deposits in the Auburn AEM survey area; b) Map of the Saturated thickness of the Quaternary (*Q*) deposits in the Auburn AEM survey area. The projection is NAD83 State Plane Nebraska (feet).

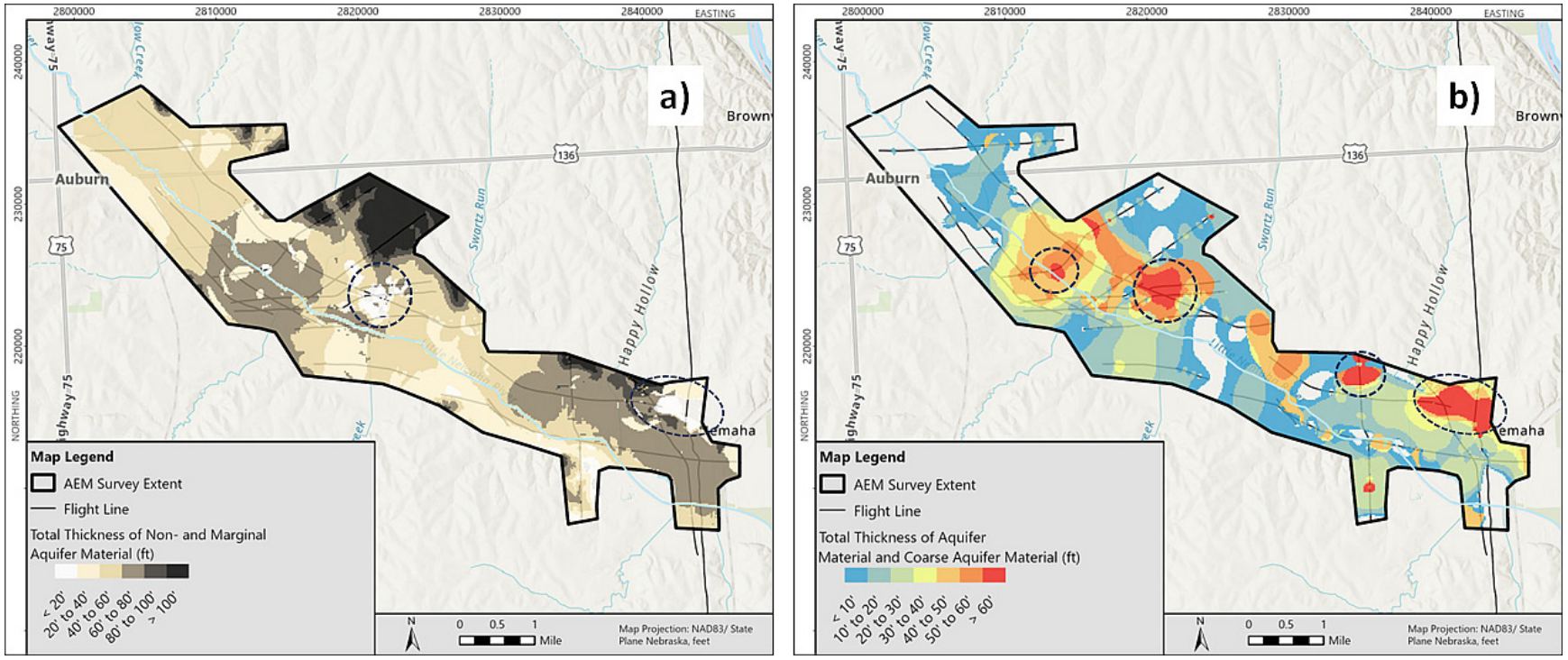


Figure 5-47. a) Map of the Total thickness of Non-Aquifer Material and Marginal Aquifer Material within the Auburn AEM survey area. Dotted circles indicate areas of lesser thickness; b) Map of the Total thickness of Aquifer Material and Coarse Aquifer Material within the Auburn AEM survey area. Dotted circles indicate areas of greater thickness. The projection is NAD83 State Plane Nebraska (feet).

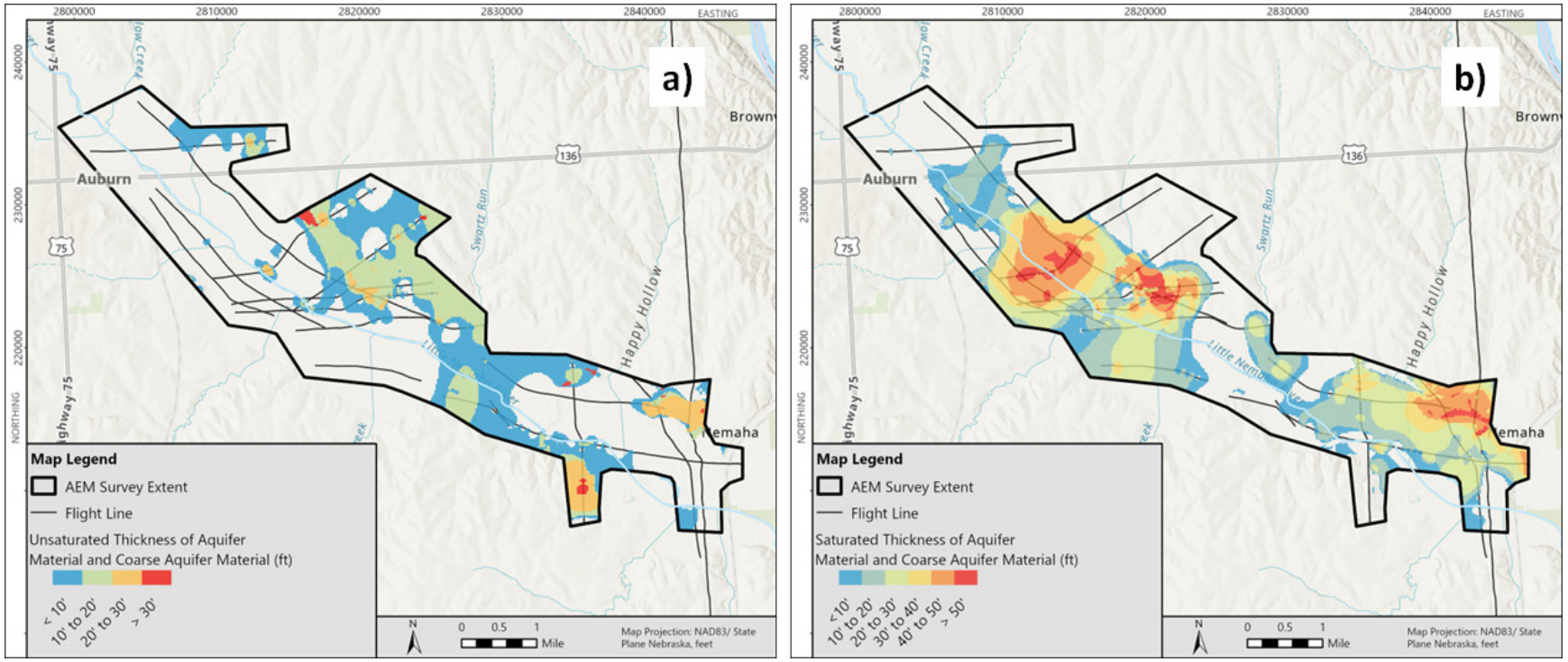


Figure 5-48. a) Map of the Unsaturated thickness of Aquifer Material and Coarse Aquifer material within the Auburn AEM survey area. b) Map of the Saturated thickness of Aquifer Material and Coarse Aquifer Material within the Auburn AEM survey area. The projection is NAD83 State Plane Nebraska (feet).

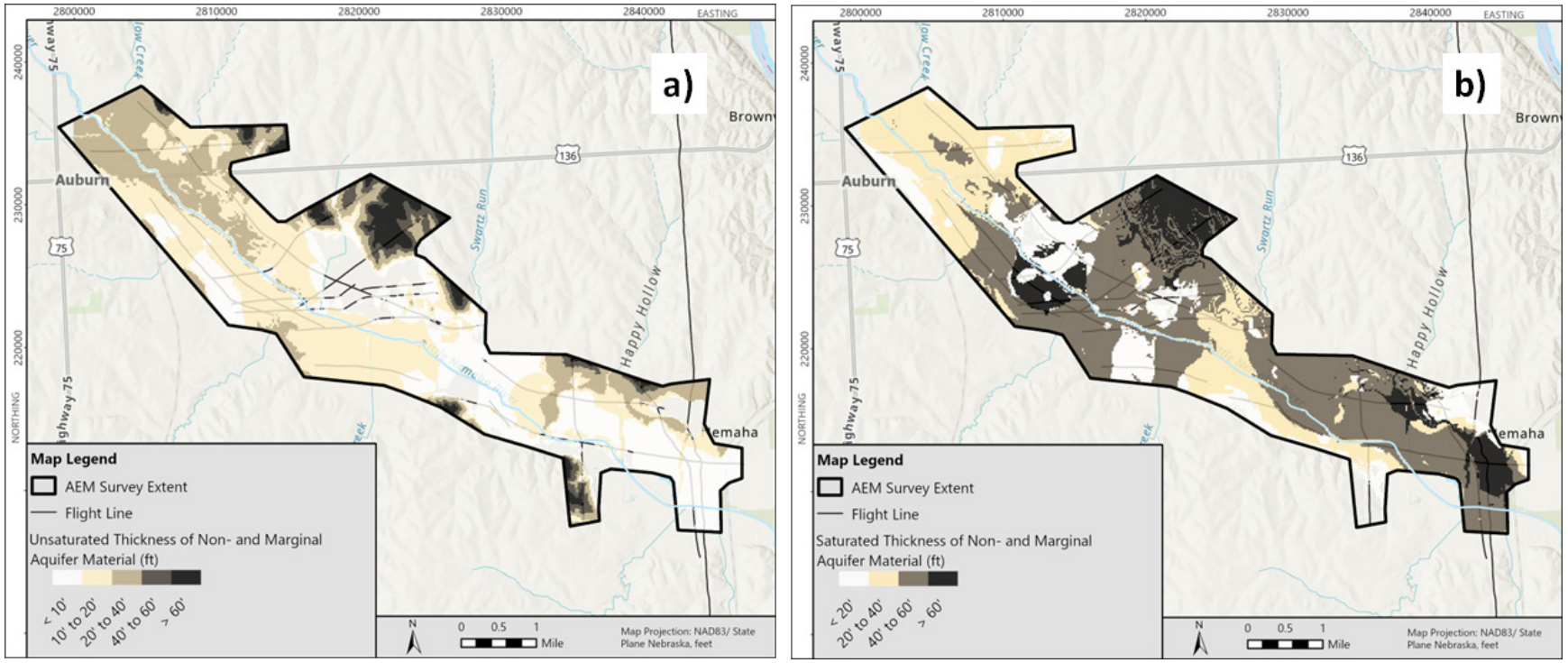


Figure 5-49. a) Map of the Unsaturated thickness of Non-Aquifer and Marginal Material within the Auburn AEM survey area. b) Map of the Saturated thickness of Non-Aquifer and Marginal Material within the Auburn AEM survey area. The projection is NAD83 State Plane Nebraska (feet).

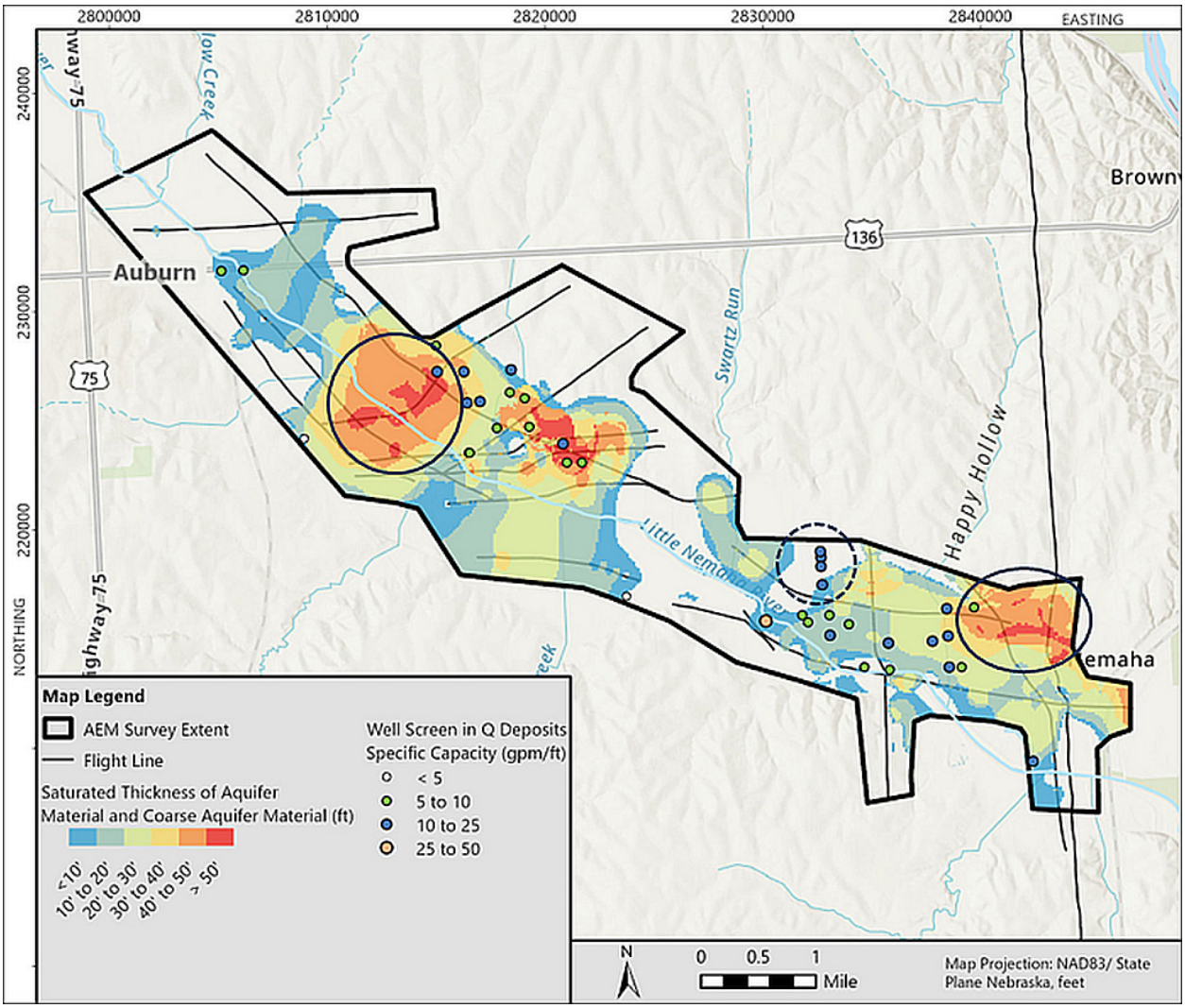


Figure 5-50. Map of the Saturated thickness of Aquifer Material and Coarse Aquifer material within the Auburn AEM survey area with the Specific Capacity values calculated from the NE-DNR registered wells indicated. Dashed circle surrounds area with no saturated Aquifer and Coarse Aquifer Material. Solid circles surround areas of potential future production wells. The projection is NAD83 State Plane Nebraska (feet).

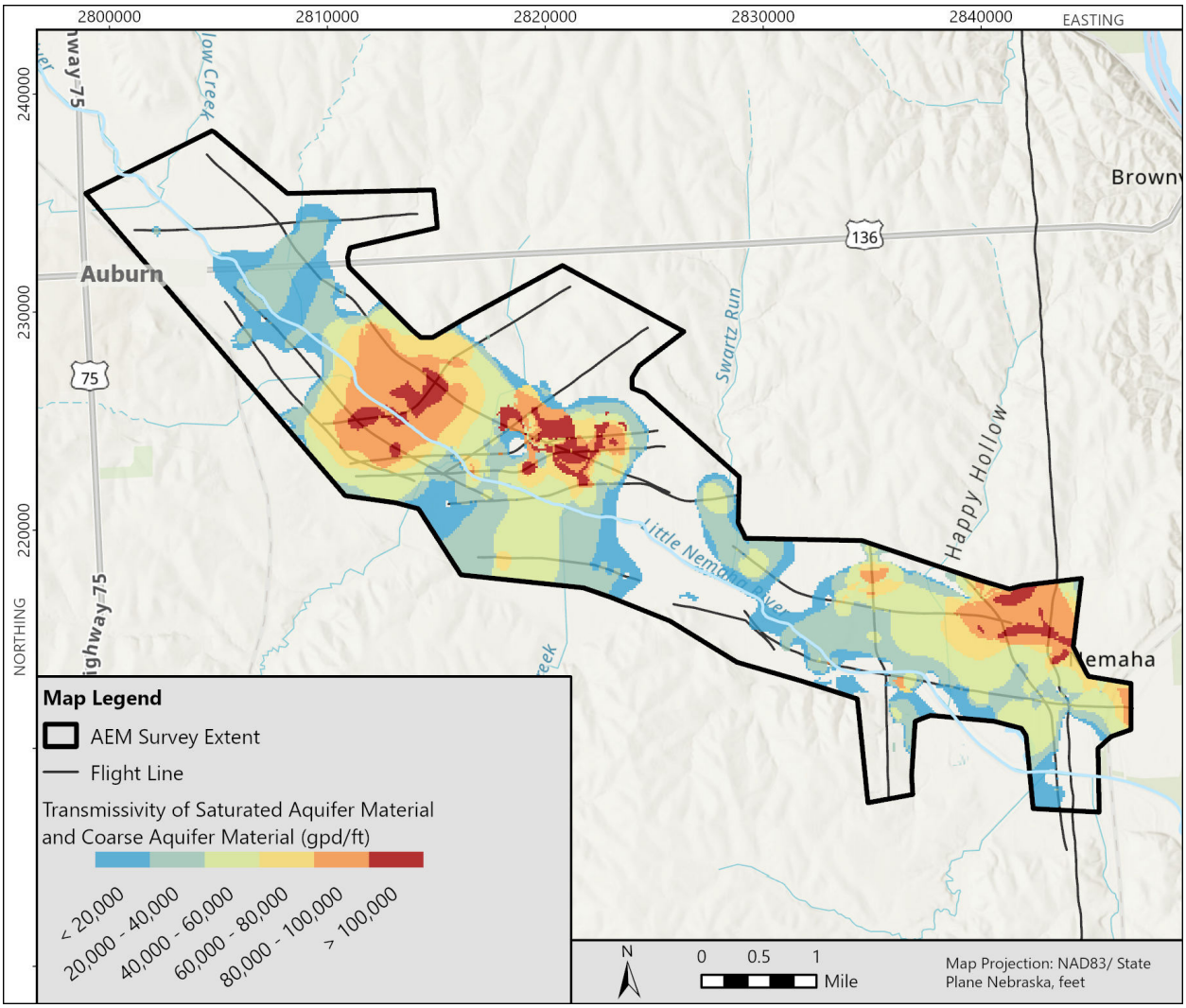


Figure 5-51. Map of the estimated Transmissivity in the Auburn area within the Auburn AEM survey area for Saturated Aquifer Material and Coarse Aquifer Material. The projection is NAD83 State Plane Nebraska (feet).

5.4 Recharge Areas in the Combined NNRD 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 40-layer model was developed for the layer inversions and interpretations for the NNRD. From these interpretations a near-surface map was constructed that includes the interval from 0 ft to 6.56 ft (0 m to 2.0 m) or the first layer of the AEM inversion. Recalling the discussion around Table 4-3, that 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 shows all aquifer materials including Non-Aquifer Material, Marginal Aquifer Material, Aquifer Material, and Coarse Aquifer Material and indicate the areas at the land surface that can potentially transmit water to the groundwater aquifers in the area. The coarse aquifer material can transmit the largest volume of water and the non-aquifer material being the least able to transmit water.

The results of the interpretation of the aquifer materials of the combined NNRD AEM survey area are explained in detail in Section 5.3. The interpreted aquifer material types for the first model layer for the combined NNRD AEM survey area are presented in Figure 5-52 and for the Auburn AEM survey area in Figure 5-53. Areas of coarse aquifer material (brown colored material) will have the highest potential to transmit the largest amount of water to the groundwater system with the aquifer material (yellow colored material) potentially transmitting slightly less water downward as both units are permeable and transmissive. The marginal aquifer material (tan colored material) has a very low potential to transmit water downward and the non-aquifer material (blue colored material) will transmit minimal to no water to the groundwater aquifer.

Because the slope of the land surface plays a large role in the amount of residence time that water will spend in an area, the longer the length of time spent at a location, the greater the amount of infiltration potential. The greatest possibility for recharge in the NNRD AEM survey area is the alluvial valley floor and the creek beds that have aquifer and coarse aquifer materials near the land surface. In the Rolling Hills, the best possible location for recharge would be where there is a combination of aquifer and coarse aquifer materials at the land surface on the uplands with little relief in elevation.

A Google Earth KMZ file of the NNRD recharge materials and locations are included in Appendix 3 - Deliverables\KMZ\Recharge.

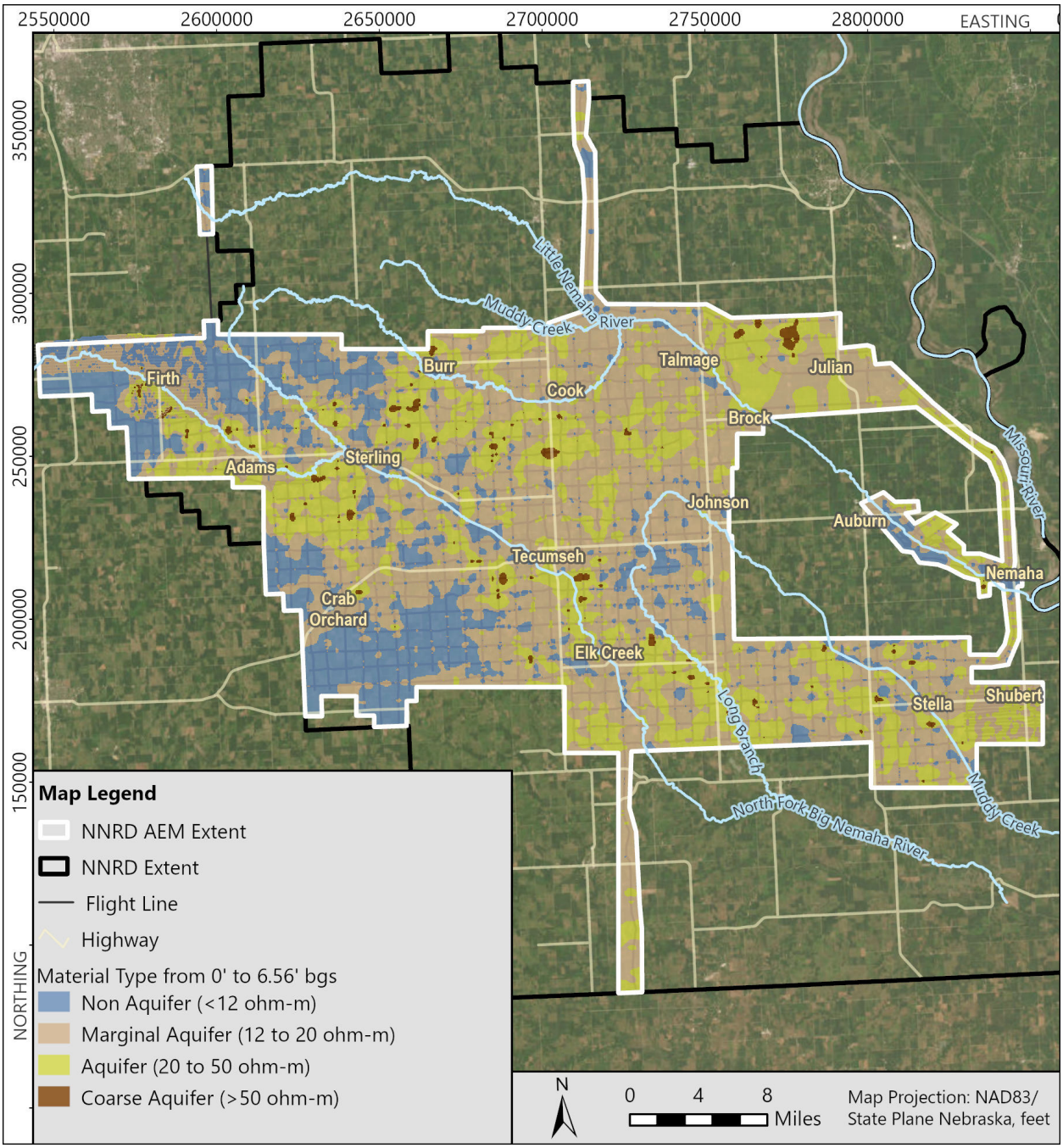


Figure 5-52. Google Earth image of potential recharge for the range 0-6.56 ft (AEM inversion model layer 1) within the combined NNRD AEM flight area.

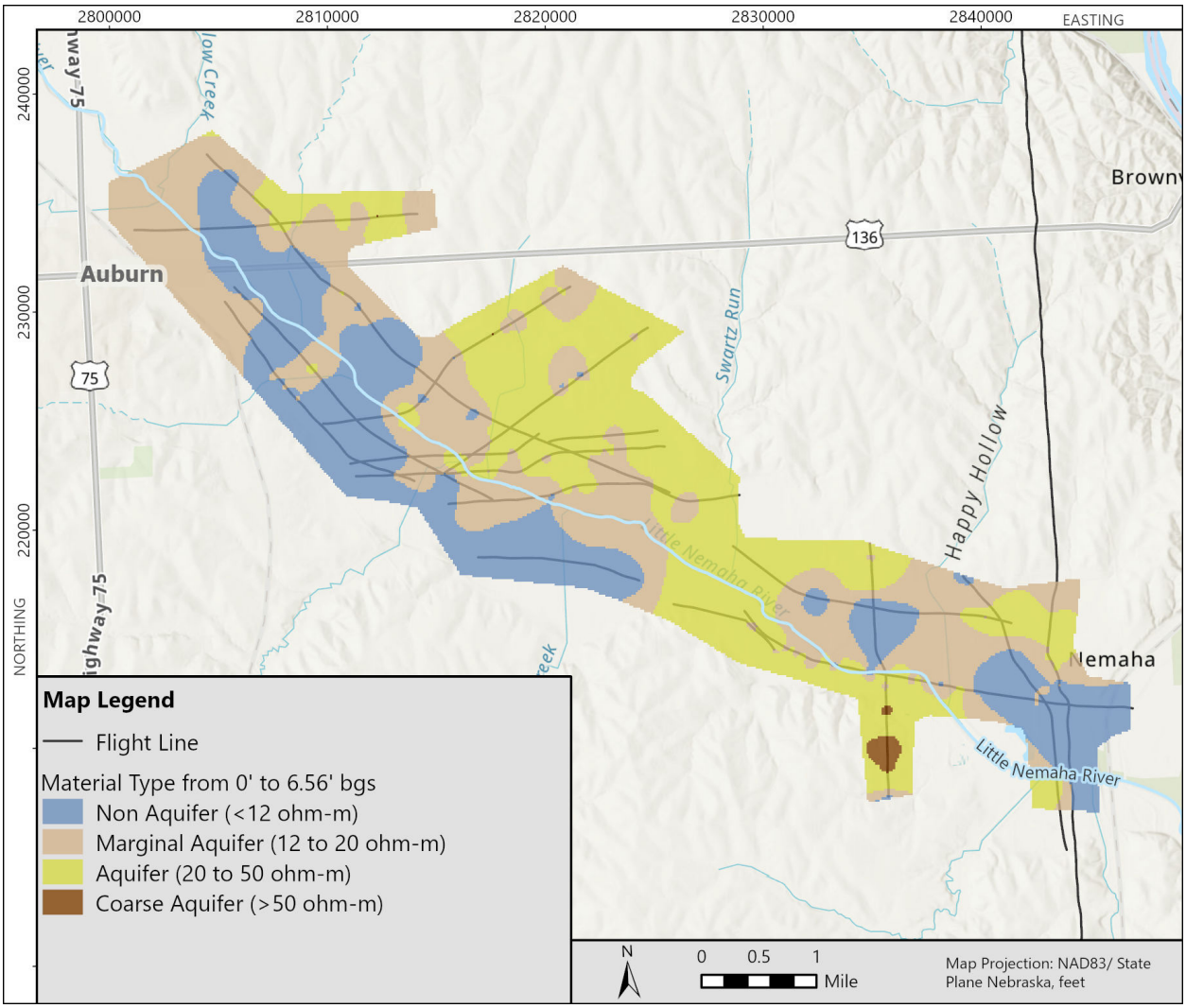


Figure 5-53. Map of potential recharge for the range 0-6.56 ft (AEM inversion model layer 1) within the Auburn AEM flight area.

5.5 Bedrock Structure

The AEM illuminates much of the bedrock units under the overlying Quaternary Aquifer Materials. As noted above, the bedrock in this area is composed of limestones and shales and has virtually no aquifers. The area is, however, rich in structural complexity. As was noted in Carney et al. 2015b, many of the deeper structures are revealed by the AEM. The AEM data within the NNRD can be utilized by others to further refine and revise the bedrock mapping in the area. For example, Figure 5-54 is a 3D voxel solid model of the undivided ***IP*** with the bedrock elevation indicated by the colored surface. Layering and faults can be seen as the changes in resistivity, especially in the center of the survey area. While outside the scope of this study, we hope that this dataset will provide a wealth of geological data for future investigation.

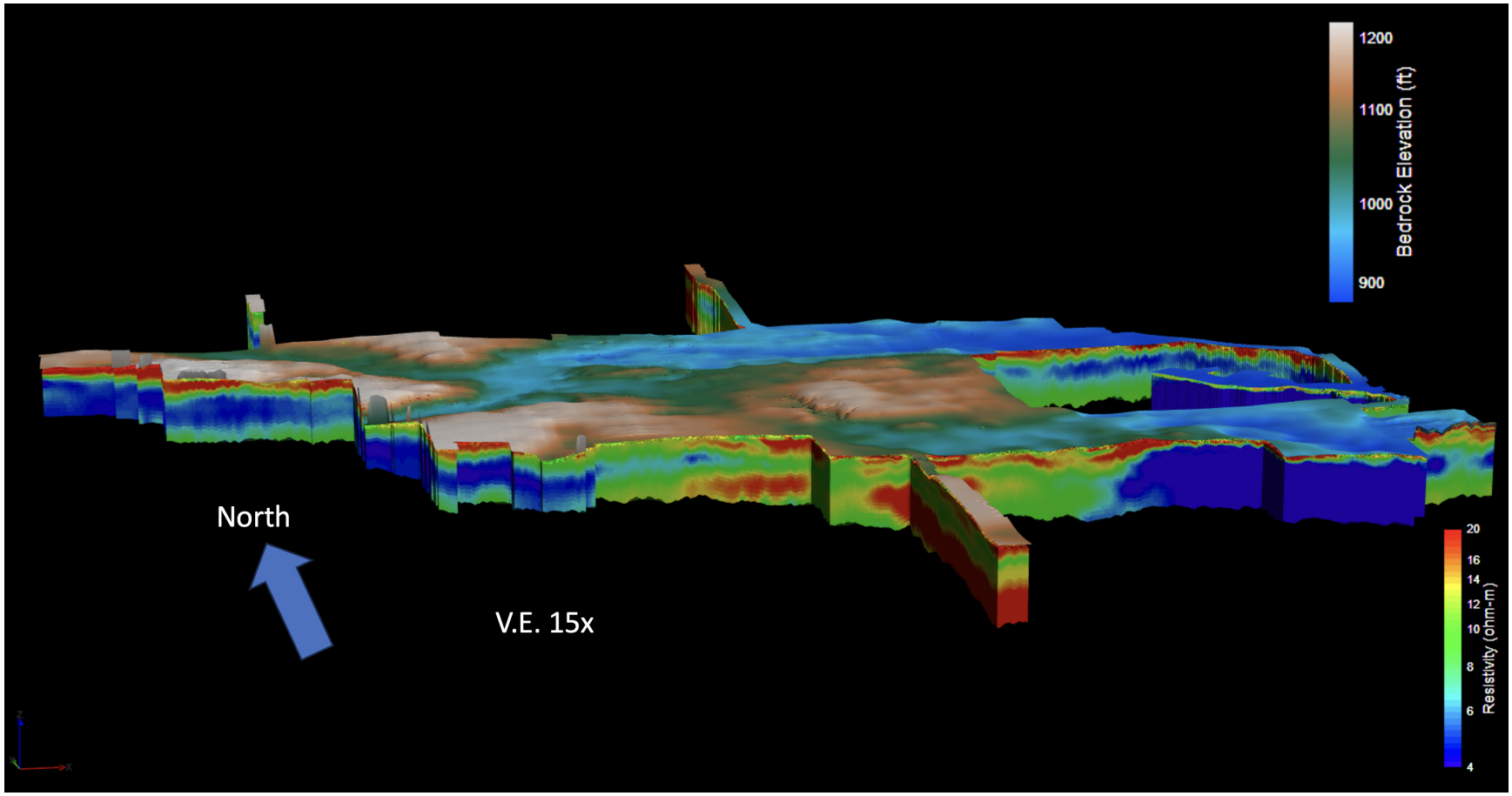


Figure 5-54. 3D diagram with bedrock elevation as a shaded surface and the 3D voxel of the resistivity of the undifferentiated Pennsylvanian (*IP*) and other bedrock units. Vertical exaggeration 15x.

5.6 Key AEM Findings

5.6.1 Boreholes

The interpretive process benefited from the use of Conservation and Survey Division (CSD) and Nebraska Department of Natural Resources (NE-DNR) borehole logs. Information from boreholes was used to analyze the AEM inversion results and were important for all areas in the NNRD, especially for interpreting the top of the undifferentiated Pennsylvanian and Paleozoic (***IP***). The ***IP*** was a challenging unit to interpret due to the highly variable resistivity. This unit when compared to the Quaternary (***Q***) often had limited or no contrast in the electrical resistivity between the different geologic units. The bedrock surface that was developed for this project from CSD and surrounding NE-DNR boreholes was used as a guide for the interpretation of the ***IP*** in areas of low electrical resistivity contrast and no local boreholes.

The dependence on just boreholes for geologic interpretation has its limitations because sometimes the boreholes are incorrect, improperly located, have improper stratigraphic/lithology picks, and/or have other errors. These errors in the boreholes are more often encountered in the NE-DNR registered wells. Very rarely inconsistencies are also encountered in the oldest of the CSD wells. The errors in the CSD wells, though limited, may be due to poor positioning prior to the evolution of GPS and modern survey methods. As in all surveys of this nature, the use of boreholes with AEM needs to be approached in a thoughtful, professional manner.

*5.6.2 **Merging AEM data***

The historic AEM data that was acquired in the NNRD from 2007 until 2020 was merged with the 2023 data. Before the 2015 and 2018 data could be combined with the 2020 and 2023 data to create 3D voxels, the inverted earth model structures for 2015 and 2018 had to be converted into the 40-layer 2020 and 2023 inverted model layer structure with a first layer depth of -2 m (-6.6 ft) and 39th layer depth of -325 m (-1066.3 ft). The 2015 inversion models had 30 layers with a first layer depth of -5 m (-16.4 ft) and a 29th layer depth of -500.2 m (-1,641.1 ft). The 2018 inversion models had 40 layers with a first layer depth of -1 m (-3.3 ft) and a 39th layer depth of -349.9 m (-1,147.7 ft). The total combined AEM data within NNRD is 1,910.5 line-miles (3,074.7 line-km). These data were not reinverted, but the inversions were combined with the inversions of the 2023 data. Lower Platte South Natural Resources District (LPSNRD) had the Firth and Sprague Block AEM data reinverted in 2022 as part of their hydrogeological framework (AGF, 2022). Those new inversions were utilized for the portions of those blocks that lie within the NNRD. These combined data sets provided a comprehensive set of cross-sections and voxel models across the areas of the most important aquifers within the District. The well calibrated SkyTEM 304 data and stable inversions provide combined sections that displayed no breaks in the images. The exceptions were the 2007 and 2009 RESOLVE frequency domain data that has an inherently shallower imaging ability and the 2015 SkyTEM 508 that has a much deeper imaging ability and Depth of Investigation (DOI).

5.6.3 Digitizing Interpreted Geological Contacts

Characterization and interpretation of the subsurface was performed in cross-section and derived 2D and 3D surface grid formats. Contacts between the geologic units were digitized in 2D profiles including: ***Q***, ***Kd***, and ***IP***. The interpretive process benefited from the use of CSD and NE-DNR borehole logs. Surface grids of the interpreted geologic units were then produced. Each flight line profile with interpretations is included in the appendices as well as the Quaternary aquifer material mapping as interpretative surface grids.

5.6.4 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 determined and used to characterize non-aquifer (<12 ohm-m), marginal (12-20 ohm-m), aquifer (20-50 ohm-m), and coarse sand-rich intervals (>50 ohm-m) (Carney et al., 2015a). This allowed for the characterization of the major geologic units described in this report using their ranges of resistivities. The ***Kd*** was not subdivided in this study due to the thin nature of the eroded remnant in the northwest part of the survey area and the limited flight line coverage.

5.6.5 Hydrogeological Framework of the NNRD

The NNRD AEM survey area reveals variability in the Quaternary (***Q***) deposits across the NNRD AEM survey area. The ***Q*** deposits make up the aquifer materials overlying the undifferentiated ***IP*** bedrock units. The aquifer material and coarse aquifer material exist in paleochannels up to approximately 200 feet thick. These are separated by ***Q*** deposits that consist of marginal to non-aquifer materials including glacial till and loess. The paleochannel systems are also apparent in the AEM-interpreted saturated aquifer and coarse aquifer thickness maps. The AEM-derived hydrogeological interpretation correlates very well with the recorded borehole Specific Capacity data across the field area. Adjustments and refinements of the paleochannel configuration have been made based on the AEM data and the use of the Specific Capacity values. Note that some of the isolated deposits of aquifer and coarse aquifer materials outside the main paleochannels also show a good match with the NE-DNR Specific Capacity values. Using the saturated thickness of the aquifer and coarse aquifer material and an estimate of the hydraulic conductivity, an estimate of the transmissivity was developed. These values compare well with the Leggette, Brashears, & Graham (LBG) values derived from using the Specific Capacity (AGF, 2021; AGF, 2019; and LBG, 2017). The coarsest and thickest areas of the saturated paleochannels have the highest transmissivity values. It is important to note that the transmissivity values were derived by only using the saturated thickness of the aquifer and coarse aquifer materials. This provides an additional view of the possible transmissive properties of the materials within the NNRD AEM survey area.

5.6.6 Potential Recharge Zones within the NNRD AEM Survey Area

Locations where the AEM inversion results show either aquifer or coarse aquifer material at the land surface can be considered as locations of higher likelihood for recharge due to the 2D and 3D spatial nature of the aquifer material distribution. The opposite is also true where AEM data analysis shows non-aquifer material or marginal aquifer material at the surface. Those areas will likely not be optimal recharge locations. The highest rate of recharge can be expected in the central areas in the paleochannel region due to the presence of unsaturated aquifer and coarse aquifer materials from the surface down to the water table. This determination is based on reconnaissance-type flight lines. It should be noted that in some of these areas the results shown in the recharge maps are based more on interpolation between data points and less actual AEM data.

Note that areas with aquifer and coarse aquifer materials at the surface can also become conduits for infiltration of nitrates into the groundwater system. A potential solution for any nonpoint source water quality contamination is adding 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 an accurate representation of the aquifer materials in the first ~6 feet from the land surface downward.

5.6.7 Auburn

Selected AEM profiles were acquired around the town of Auburn to assist in their water resources assessment. The results show a lenticular deposit of sands within the Little Blue River alluvial valley. Many DNR registered wells are within the area that are already utilizing the resources. A few new areas were identified where additional wells maybe placed, but the resource is limited with many wells already completed within the aquifer materials as detected by the AEM survey

5.7 Recommendations

Recommendations provided to the NNRD 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 NNRD about their management challenges.

5.7.1 Additional AEM Mapping or Ground Based Geophysics

The hydrogeologic maps provided in this report represent the hydrogeologic framework developed for the NNRD at reconnaissance level with approximately 1-mile spacing between flight lines for much of the AEM survey area. The bulk of the aquifer areas of the NNRD have been covered. Additional AEM data would need to be targeted as infill to determine fine details of specific areas including well head protection areas or well fields. If ground access is achievable and the areas are only a section or two (640-1280 acres) in size, ground-based Time Domain Electromagnetics using a towed system maybe a feasible and economic solution. A system that is based on the SkyTEM electronics that is on the market is the TEM Company's tTEM system (TEM Company, 2024).

5.7.2 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 29 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 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.

5.7.3 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 NNRD 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 results of this report can also be used to guide development of new water supply wells for local communities. Planners should locate wells in areas of greatest saturated thickness with the least potential for non-point source pollution. An example of a good well location would be one located above a confined aquifer with a large volume of coarse aquifer and aquifer material surrounding it 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 NNRD.

5.7.4 Aquifer testing and borehole logging

Aquifer tests are recommended to improve estimates of aquifer characteristics. There were limited previous reports available on aquifer properties outside of 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. 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.

5.7.5 Recharge Zones

The NNRD hydrogeologic framework in this report provides areas of recharge from the near surface. Reconnaissance-level AEM investigations provide limited detailed information between the lines for understanding recharge throughout the survey area. For detailed recharge sites additional infill AEM can be flown or ground-based tTEM surveys can be conducted. This should be done in areas identified by the NNRD that are of priority importance for management purposes. It is further recommended that future work integrate new soils and land use maps with the results of this study to provide details on soil permeability, slope, and water retention. This will provide a more complete understanding of the transport of water from the land surface to the groundwater aquifer. A potential solution to water quality, quantity, and stream depletion is adding additional fresh surface water as recharge to select areas of rangeland or other areas. Additional work can be done to identify where the best locations are for these types of management efforts. This information can and has been used in Nebraska to improve Well Head Protection Areas by refining groundwater travel time estimates and the boundary areas.

5.7.6 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 NNRD exist and what additional information would be required for final selections of MAR sites. Additional AEM mapping in new block flight locations and along the streams in the NNRD is valuable for locating potential MAR locations. A detailed plan for locating and developing MAR sites would be beneficial to the NNRD for storage and release of water for stream flow and other uses. The unsaturated aquifer and coarse aquifer material maps provide information on areas that warrant further investigation.

5.7.7 Updating previous groundwater reports and Groundwater Management Plans

The information provided in this report should be used to update the groundwater information and management of the Nemaha Natural Resources District. Integrating data presented in this report with the historical work as well as the inclusion of future AEM mapping enhancements, a greater understanding of the District can be achieved. The addition of estimates of groundwater in storage, recharge areas, hydrologic connection to streams, and consideration of managed aquifer recharge sites will greatly improve the District's overall groundwater management plans.

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, four (4) flights were required to acquire the 2023 NNRD AEM data (Figure 4-5). Grouped by flight date, there are four (4) data files 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 *NNRD2023_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 *NNRD2023_AEM_SCI02_INV_v1.xyz* and the data columns of these databases are described in Table 6-3.

The interpretation results are included in three data files: *Auburn_NNRD2023_Interp.xyz*, *Firth_Sprague_NNRD2023_Interp2.xyz*, and *NNRD23_Combined_InterpSurfaces.xyz* in ASCII format. Table 6-4 describes the data columns of those files. There are three files because the Auburn AEM data are mostly separate from the main NNRD 2023 AEM flight area and the 2007 Firth and 2009 Sprague FEM survey areas have different depth arrays (only down to -328 ft) than those for the Auburn and combined NNRD 2015, 2018, 2020, and 2023 AEM survey areas (down to -1,066 ft).

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 6-5 and stored in Appendix 3 - Deliverables\ESRI. Included shapefiles are listed in Table 6-6.

In addition, a data file, *NNRD2023_SCI02_InvResults_GeoCloud_v1.xyz*, with the Nebraska Geocloud format is included in Appendix 3_Deliverables\GeoCloud. The format is listed in Table 6-7.

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 column format (Table 6-3)
- Interpretations as ASCII *.xyz (Table 6-4)
- ESRI GIS files – raster grids (*.flt) (Table 6-5), Shapefiles (Table 6-6), and ESRI ArcGIS Pro map package (.mpkx)
- Voxel export files for Auburn area and combined NNRD AEM survey data
- 2D profiles, Surfaces, and 3D fence diagrams of the AEM survey inversion results
- Files compatible with the Nebraska GeoCloud (Table 6-7)
- KMZs for NNRD AEM flight lines, interpretative profiles, recharge zones (Discussed in Section 6.2).

Table 6-1. Raw SkyTEM data files

Folder	File Name	Description
Data	..NavSys.sps, ...PaPc.sps, ...RawData_PFC.skb, ...PPP.sps	Raw data files included for each flight used in importing to Aarhus Workbench
Geo	20230615_20065_USA_AGF_NE_304M_SKB.gex	304HM System Description
	20065_USA_AGF_CO_304M_SR2.gex	
	20065_USA_AGF_CO_304M_SR2.sr2	
Mask	20065_AGF_Survey_NNRD.lin	Production file listing dates, flights, and assigned line numbers

Table 6-2: Channel name, description, and units for NNRD2023_EM_MAG_AUX.xyz with DEM, magnetic, DGPS, Inclinometer, altitude, and associated data.

Parameter	Description	Unit
Line	Line Number	
E_UTM14Nm	Easting, NAD83 UTM Zone 14N	Meters [m]
N_UTM14Nm	Northing, NAD83 UTM Zone 14N	Meters [m]
DEM_m	Digital Elevation	Meters [m]
E_NESPCS83ft	Easting, NAD83 Nebraska State Plane	Feet [ft]
N_NESPCS83ft	Northing, NAD83 Nebraska State Plane	Feet [ft]
DEM_ft	Digital Elevation	Feet [ft]
Fid	Unique Fiducial 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_m	System Height Measurement Above Ground	Meters [m]
Height_ft	System Height Measurement Above Ground	Feet [ft]
Lon	Longitude, WGS84	Decimal Degrees
Lat	Latitude, WGS84	Decimal Degrees
Alt	DGPS Altitude above sea level (elevation)	Meters [m]
GDSpeedL	Ground Speed	Kilometers/hour [km/h]
LMcurrent	Current, Low Moment	Amps [A]
HMcurrent	Current, High Moment	Amps [A]
LM_Z_dBdt_G01	Normalized (PFC-Corrected) Low Moment Z-RxCoil values array	$pV/(m^4*A)$

LM_X_dBdt_G01	**Normalized (PFC-Corrected) Low Moment X-RxCoil values array**	**pV/(m^4*A)**
HM_Z_dBdt_G01	**Normalized (PFC-Corrected) High Moment Z-RxCoil values array**	**pV/(m^4*A)**
HM_X_dBdt_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	**Raw Base Station Mag Data filtered**	**nanoTesla [nT]**
Diurnal	**Diurnal Mag Data**	**nanoTesla [nT]**
MAG_Raw	**Raw Mag Data**	**nanoTesla [nT]**
MAG_COR	**Corrected Magnetic Data**	**nanoTesla [nT]**
RMF	**Residual Magnetic Field**	**nanoTesla [nT]**
TMI	**Total Magnetic Intensity**	**nanoTesla [nT]**

Table 6-3. Channel name, description, and units for NNRD2023_AEM_SCI02_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 Auburn_NNRD2023_Interp.xyz, Firth_Sprague_NNRD2023_Interp2.xyz, and NNRD23_Combined_InterpSurfaces.xyz.

Parameter	Description	Unit
LINE	**Line Number**	
E_NESP83ft	**Easting NAD83, Nebraska State Plane**	**Feet [ft]**
N_NESP83ft	**Northing NAD83, Nebraska State Plane**	**Feet [ft]**
DEM_ft	**Topography at 100ft sampling (NAVD 1988)**	**Feet [ft]**
E_UTM14Nm	**Easting UTM Zone 14**	**Meters (m)**
N_UTM14Nm	**Northing UTM Zone 14**	**Meters (m)**
DEM_m	**Topography at 100ft sampling (NAVD 1988)**	**Meters (m)**
RESDATA	**Inversion model residuals of each individual sounding**	
RESTOTAL	**Inversion model average of all residuals**	
RHO[0] through RHO[38]	**Array of Inverted model resistivities of each layer**	**Ohm-m**
DepTop23ft[0] through DepTop23ft[38]	**Depth to the top of 39 individual layers**	**Feet [ft]**
DepBot23ft[0] through DepBot23ft[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]**
Watertable1995	**Elevation of the top of the water table from the Nebraska School of Natural Resources Configuration Report, 1995**	**Feet [ft]**
Bedrock	**Estimated elevation of the bedrock surface**	**Feet [ft]**
Kd	**Elevation of the top of the Cretaceous Dakota Group**	**Feet [ft]**
IP	**Elevation of the top of Undifferentiated Pennsylvanian units**	**Feet [ft]**

Table 6-5. Files containing NNRD 2023 raster datasets (.flt format). All datasets projected to NAD83/State Plane Nebraska, feet .

Area	Name	Resolution	About
AUBURN	Auburn_AquiferCoarse_Material_Saturated_Thickness	100	Saturated thickness (ft) of aquifer material and coarse aquifer material within the Auburn area.
AUBURN	Auburn_AquiferCoarse_Material_Total_Thickness	100	Total thickness (ft) of aquifer material and coarse aquifer material within the Auburn area.
AUBURN	Auburn_AquiferCoarse_Material_Unsaturated_Thickness	100	Unsaturated thickness (ft) of aquifer material and coarse aquifer material within the Auburn area.
AUBURN	Auburn_NonMarginal_Material_Saturated_Thickness	100	Saturated thickness (ft) of non- and marginal material within the Auburn area.
AUBURN	Auburn_NonMarginal_Material_Total_Thickness	100	Total thickness (ft) of non- and marginal material within the Auburn area.
AUBURN	Auburn_NonMarginal_Material_Unsaturated_Thickness	100	Unsaturated thickness (ft) of non- and marginal material within the Auburn area.
AUBURN	NNRD_Auburn_Bedrock_DepthTo	100	Depth to the top of bedrock (ft bgs) within the Auburn area.
AUBURN	NNRD_Auburn_Bedrock_Elevation	100	Elevation of the top of bedrock (ft asl) within the Auburn area.
AUBURN	NNRD_Auburn_GroundSurface_Elevation	100	Ground surface elevation (ft asl) within the Auburn area.
AUBURN	NNRD_Auburn_Q_Saturated_Thickness	100	Saturated thickness (ft) of Q deposits within the Auburn area.
AUBURN	NNRD_Auburn_Q_Total_Thickness	100	Total thickness (ft) of Q deposits within the Auburn area.
AUBURN	NNRD_Auburn_Transmissivity_gpdpft	100	Transmissivity (gallons per day per foot) of saturated aquifer and coarse aquifer material within the Auburn area.
AUBURN	NNRD_Auburn_WaterTable_1995_Elevation	100	Water table elevation (ft asl) within the Auburn area.
AUBURN	Auburn_NearSurfaceMaterial	100	Material type (based on ohm-m) of the top 6.56' (from surface to 6.56' bgs).
Firth/Sprague	FirthSprague_Aquifer_Material_Total_Thickness	100	Total thickness (ft) of aquifer material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_AquiferCoarse_Material_Saturated_Thickness	100	Saturated thickness (ft) of aquifer material and coarse aquifer material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_AquiferCoarse_Material_Total_Thickness	100	Total thickness(ft) of aquifer material and coarse aquifer material within the Firth/Sprague area.

Firth/Sprague	FirthSprague_AquiferCoarse_Material_Unsaturated_Thickness	100	Unsaturated thickness (ft) of aquifer material and coarse aquifer material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_Coarse_Material_Total_Thickness	100	Total thickness (ft) of coarse aquifer material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_Marginal_Material_Total_Thickness	100	Total thickness (ft) of marginal material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_Non_Material_Total_Thickness	100	Total thickness (ft) of non-aquifer material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_NonMarginal_Material_Saturated_Thickness	100	Saturated thickness (ft) of non- and marginal material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_NonMarginal_Material_Total_Thickness	100	Total thickness of non- and marginal material within the Firth/Sprague area.
Firth/Sprague	FirthSprague_NonMarginal_Material_Unsaturated_Thickness	100	Unsaturated thickness of non- and marginal material within the Firth/Sprague area.
NNRD	NNRD_Aquifer_Material_Total_Thickness	300	Total thickness (ft) of aquifer material within the NNRD AEM survey area.
NNRD	NNRD_AquiferCoarse_Material_Saturated_Thickness	300	Saturated thickness (ft) of aquifer material and coarse aquifer material within the NNRD AEM survey area.
NNRD	NNRD_AquiferCoarse_Material_Total_Thickness	300	Total thickness (ft) of aquifer material and coarse aquifer material within the NNRD AEM survey area.
NNRD	NNRD_AquiferCoarse_Material_Unsaturated_Thickness	300	Unsaturated thickness (ft) of aquifer material and coarse aquifer material within the NNRD AEM survey area.
NNRD	NNRD_Bedrock_DepthTo	300	Depth to the top of bedrock (ft bgs) within the NNRD AEM survey area.
NNRD	NNRD_Bedrock_Elevation	300	Elevation of the top of bedrock (ft asl) within the NNRD AEM survey area.
NNRD	NNRD_Coarse_Material_Total_Thickness	300	Total thickness (ft) of coarse aquifer material within the NNRD AEM survey area.
NNRD	NNRD_GroundSurface_Elevation	300	Ground surface elevation (ft asl) within the NNRD AEM survey area.
NNRD	NNRD_IP_Elevation	300	Elevation of the top of Undifferentiated Pennsylvanian and Paleozoic units (IP) within the NNRD AEM survey area (ft asl).
NNRD	NNRD_Kd_Elevation	300	Elevation of the top of Cretaceous Dakota Group (Kd) within the NNRD AEM suvey area (ft asl).

NNRD	NNRD_Marginal_Material_Total_Thickness	300	Total thickness (ft) of marginal material within the NNRD AEM survey area.
NNRD	NNRD_NearSurfaceMaterial	100	Material type (based on ohm-m) of the top 6.56' (from surface to 6.56' bgs). Original resolution of entire area except for the Firth/Sprague area was 300ft, then sampled down to 100 ft to match the Firth/Sprague resolution.
NNRD	NNRD_Non_Material_Total_Thickness	300	Total thickness (ft) of non-aquifer material within the NNRD AEM survey area.
NNRD	NNRD_NonMarginal_Material_Saturated_Thickness	300	Saturated thickness (ft) of non- and marginal material within the NNRD AEM survey area.
NNRD	NNRD_NonMarginal_Material_Total_Thickness	300	Total thickness (ft) of non- and marginal material within the NNRD AEM survey area.
NNRD	NNRD_NonMarginal_Material_Unsaturated_Thickness	300	Unsaturated thickness (ft) of non- and marginal material within the NNRD AEM survey area.
NNRD	NNRD_Q_Saturated_Thickness	300	Saturated thickness (feet) of Q deposits within the NNRD AEM suvey area.
NNRD	NNRD_Q_Total_Thickness	300	Total thickness (feet) of Q deposits within the NNRD AEM suvey area.
NNRD	NNRD_Transmissivity_gpdpft	300	Transmissivity (gallons per day per foot) of saturated aquifer and coarse aquifer material within the NNRD AEM survey area.
NNRD	NNRD_WaterTable_1995_DepthTo	300	Depth to the top of CSD 1995 water table (ft bgs) within the NNRD AEM survey area.
NNRD	NNRD_WaterTable_1995_Elevation	300	Elevation of the top of CSD 1995 water table (ft asl) within the NNRD AEM survey area.

Table 6-6. Relevant features and extents as ESRI Shapefiles. NAD83/State Plane Nebraska, feet.

Name	About
Boreholes_for_AEMInterp_CSD_NNRD	Conservation Survey Division (CSD) boreholes within the NNRD boundary.
Boreholes_for_AEMInterp_DNR_NNRD	Nebraska Department of Natural Resources (DNR) within the NNRD boundary with lithology data that
Contours_Auburn_TopElevation_Bedrock_20ft	Contours for the top of bedrock elevation within the Auburn area (interval = 20 ft).
Contours_Auburn_TopElevation_WaterTable1995_20ft	Contours for the top of the 1995 CSD water table elevation within the Auburn area (interval = 20 ft).
Contours_GroundSurfaceElevation_100ft	Contours for the ground surface elevation within the NNRD AEM survey area (100 ft).
Contours_TopElevation_Bedrock_50ft	Contours for the top of bedrock elevation within the NNRD AEM survey area (interval = 50 ft).
Contours_TopElevation_IP_50ft	Contours for the top of Undifferentiated Pennsylvanian and Paleozoic units (IP) elevation
Contours_TopElevation_Kd_25ft	Contours for the top of Cretaceous Dakota Group (Kd) within the NNRD AEM survey area (interval =
Contours_TopElevation_WaterTable1995_100ft	Contours for the top of the 1995 CSD water table elevation within the NNRD AEM surve area (interval
DNR_Wells_SC_Data	Nebraska Department of Natural Resources (DNR) within the NNRD boundary with specific capacity
Extent_AEM_Projects	Extent of AEM survey projects within the NNRD boundayr.
Extent_Auburn	Extent of the Auburn AEM survey.
Extent_Kd	Extent of the Cretaceous Dakota Group (Kd) within the NNRD AEM survey area.
Extent_Nemaha_NRD	Extent of the Nemaha Natural Resources District.
Extent_NNRD_AEM	Extent of the NNRD AEM survey area (where flight lines were flown).
FlightLines_NNRD	All flight lines, with IDs, within the NNRD AEM survey area.
FlightLines_Vintage	All flight lines, by year flown, within the NNRD AEM survey area.
NNRD_Major_StreamsRivers	Major streams and rivers within the NNRD AEM survey area extracted from the USGS National
PaleochannelExtent_KorusEtAl_2013	Approximate extent of paleochannels within and adjacent to the NNRD AEM survey area digitized

Table 6-7. Geocloud-import file: NNRD2023_SCI02_InvResults_GeoCloud_v1.xyz. (*_geocloud.xyz)

LINE	**Original Line Number**
X_SP_FT	**Easting Nebraska State Plane (feet) NAD83**
Y_SP_FT	**Northing Nebraska State Plane (feet) NAD83**
ELEV_FT	**Elevation above sea level (feet) from USGS Data Elevation Model**
X_SP_M	**Easting Nebraska State Plane (meters) NAD83**
Y_SP_M	**Northing Nebraska State Plane (meters) NAD83**
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_0 to 38	**Resistivity of layers 1 to 39 (Ohm-m)**
RHO_STD_0 to 38	**Standard deviation of resistivity of layers 1 to 39**
DEP_TOP_FT_0 to 38	**Depth to top of layer 1 to 39 (negative feet)**
DEP_BOT_FT_0 to 38	**Depth to bottom of layer 1 to 39 (negative feet)**
DEP_TOP_M_0 to 38	**Depth to top of layer 1 to 39 (negative meters)**
DEP_BOT_M_0 to 38	**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 6-8. Columns in NNRD 2023 AEM 3D Voxel files Auburn_Q_VoxelXYZData.xyz and NNRD23_Q_VoxelXYZData.xyz.

E_NESPCS83ft	**Easting, NAD83 Nebraska State Plane, in feet**
N_NESPCS83ft	**Northing, NAD83 Nebraska State Plane, in feet**
Depth_ft	**Northing Nebraska State Plane (feet) NAD83**
Voxel_15to23_300ft (NNRD23) **Voxel_Auburn_100ft (Auburn)**	**Interpolated NNRD 2023 3D voxel model resistivity**

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*". In addition, KMZ files of the Recharge grids (all NNRD and only Auburn) have also been produced and are included in "*Appendix_3_Deliverables\KMZ\Recharge*".

Unique KMZ files were created for each individual flight line in approximately 10-12-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 water table. These KMZ files are located within the "*Appendix_3_Deliverables\KMZ\Interpretation*" 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 GoogleE_Readme.pdf file is repeated below as a convenience. An image of the Auburn_Interp_KMZ layout is presented in Figure 6-1 and an example of clicking on points is presented in Figure 6-2. A 2D profile of line L1000501 is presented in Figure 6-3. An image of the FirthSprague_Interp_KMZ layout is presented in Figure 6-4 and an example of clicking on points is presented in Figure 6-5. A 2D profile of line L30280 is presented in Figure 6-6. An image of the NNRD23_Combined_Interp_Pt1.kmz and NNRD23_Combined_Interp_Pt2.kmz layout is presented in Figure 6-7 and an example of clicking on points is presented in Figure 6-8. A 2D profile of line L301301c is presented in Figure 6-9.

6.2.1 Included README for the Combined NNRD 2023 Interpretation KMZ's

README for:

Auburn_Interp_KMZ.kmz

FirthSprague_Interp_KMZ.kmz

NNRD23_Combined_Interp_Pt1.kmz, NNRD23_Combined_Interp_Pt2.kmz

Data Files - Please copy the folders Auburn_Profiles, FrthSprg_Profiles, and NNRD23_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 "*KML Content Security*", 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 *Auburn_Interp_KMZ.kmz, FirthSprague_Interp_KMZ.kmz, NNRD23_Combined_Interp_Pt1.kmz, NNRD23_Combined_Interp_Pt2.kmz* interpretation files within the folders named *Auburn_Profiles, FrthSprg_Profiles, and NNRD23_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) ground surface elevation in feet.

Elevation WaterTable1995 (ft) – Elevation of the 1995 water table, in feet.

Elevation Cretaceous Dakota Gp (ft) – Estimated elevation of Cretaceous Dakota Group Fm., ***Kd***, in feet.

Elevation Undifferentiated Pennsylvanian (ft) – Estimated elevation of the undifferentiated Pennsylvanian (***IP***) geological formations, in feet.

Profile – Link to Interpreted AEM profile images.

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

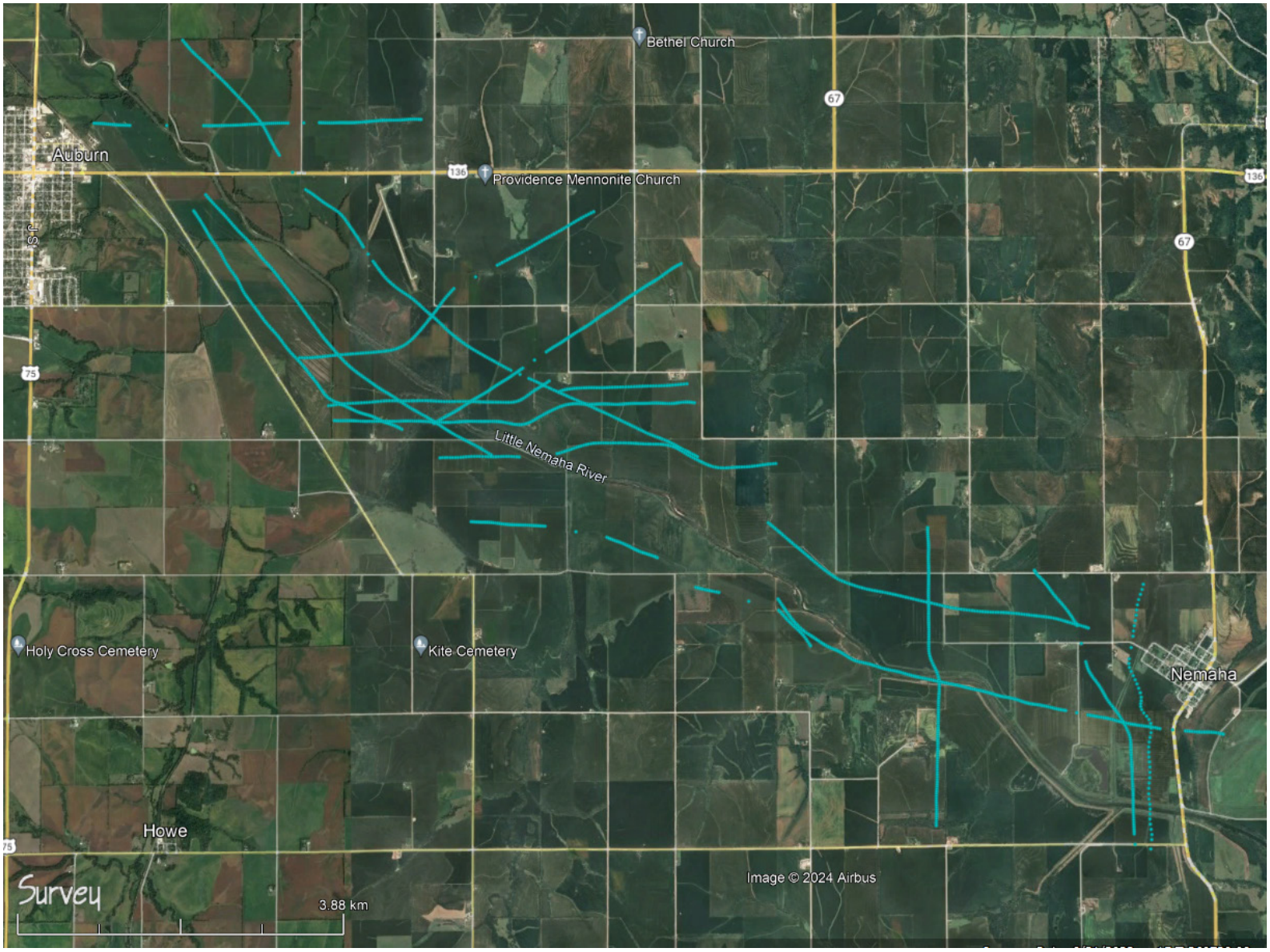


Figure 6-1. Google Earth KMZ of the Auburn AEM survey area showing the AEM Interpretation locations.

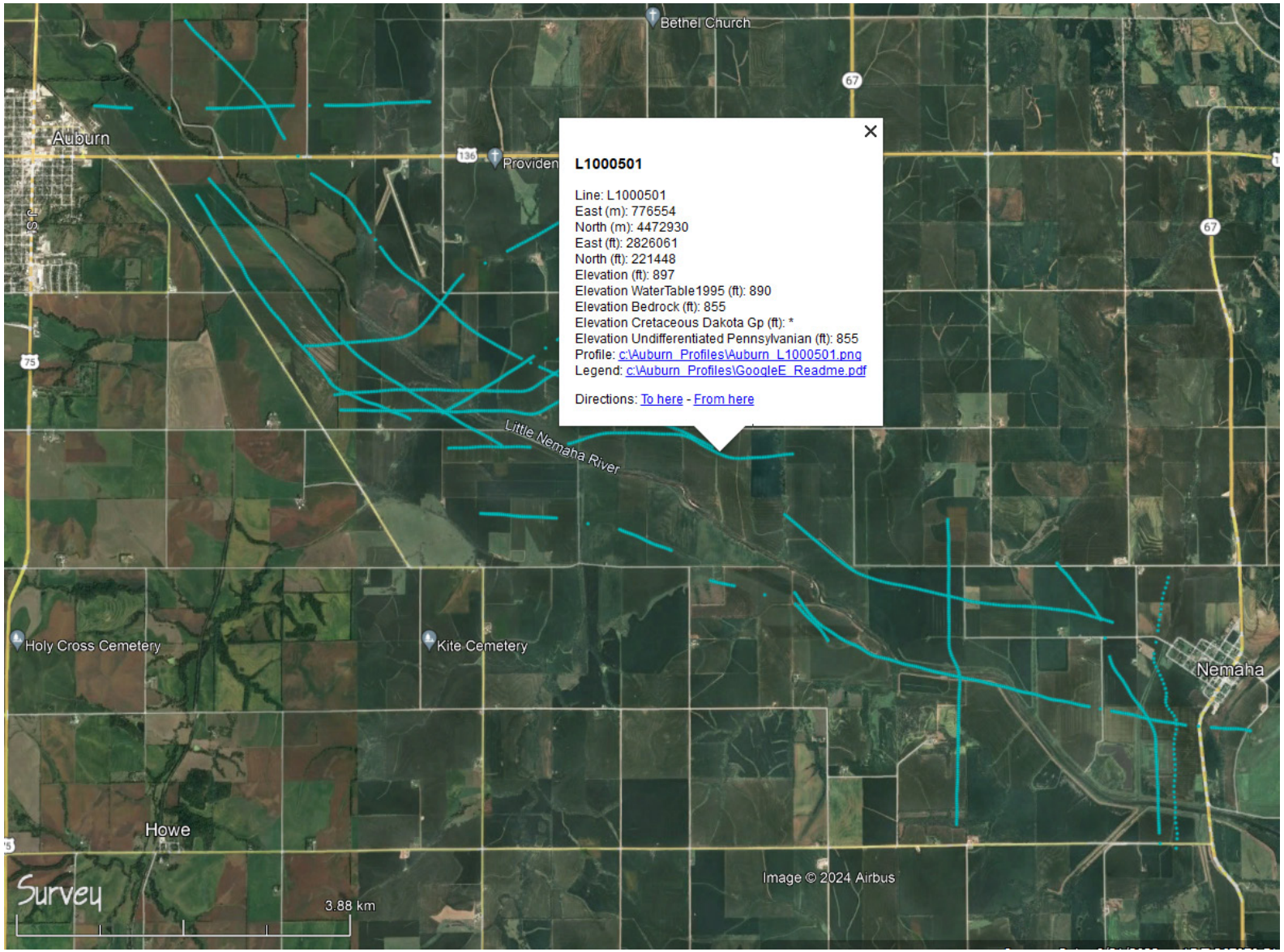
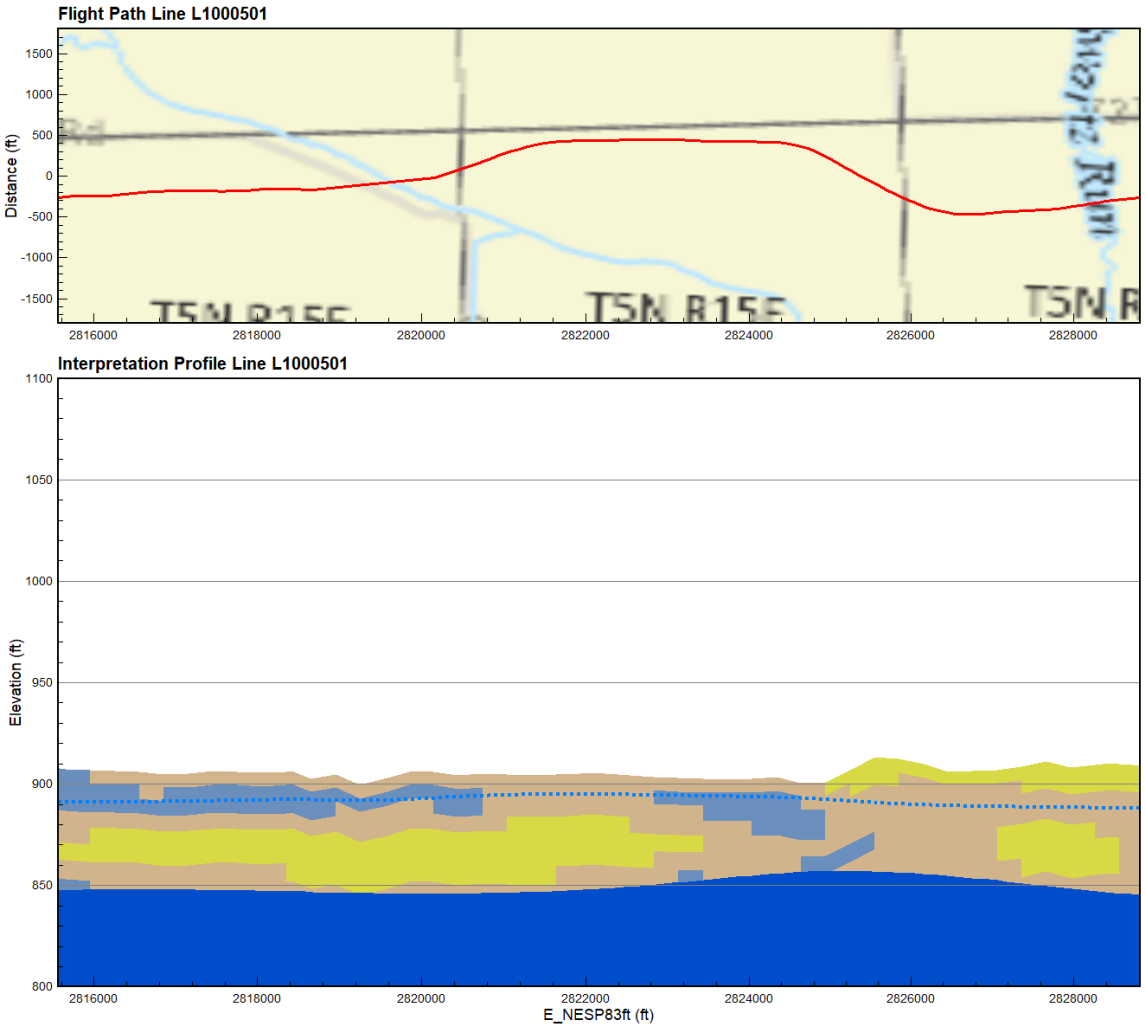


Figure 6-2. Example of clicking on a location in the Auburn AEM survey area. Profile L1000501 is presented in Figure 3 below.



Interpreted geological sections from Airborne Electromagnetic (AEM) data collected over portions of the Nemaha Natural Resources District (NNRD) provided in conjunction with the Google Earth kmz file. The projected downline distance is equal for the flight path (top image) and the AEM data interpretation (bottom image). The Flight Location Map indicates the flight path on a Public Land Survey System Map. The Interpretation Profile shows the results of the interpretation of the inversion as electrical resistivity and the existing geological information. Colors are indicated by the legends. The 1995 Statewide Nebraska Conservation and Survey Division (CSD) water table is indicated by the dashed blue line. The project projection and vertical datum are NAD83 Nebraska State Plane (feet) and NAVD88 (feet). Additional information regarding the use of this figure and the AEM data may be found in the report titled "Airborne Electromagnetic Mapping and Hydrogeological Framework of portions of the Nemaha Natural Resources District." Prepared for the NNRD by Aqua Geo Frameworks, LLC

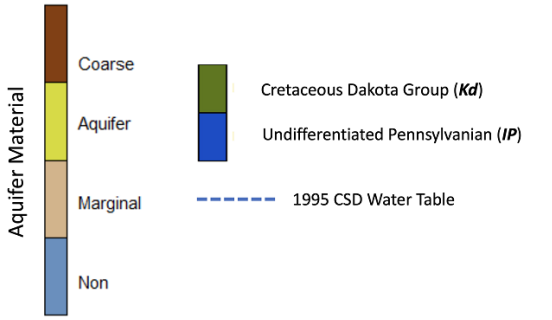


Figure 6-3. Example of clicking on link to Profile image for line L1000501.

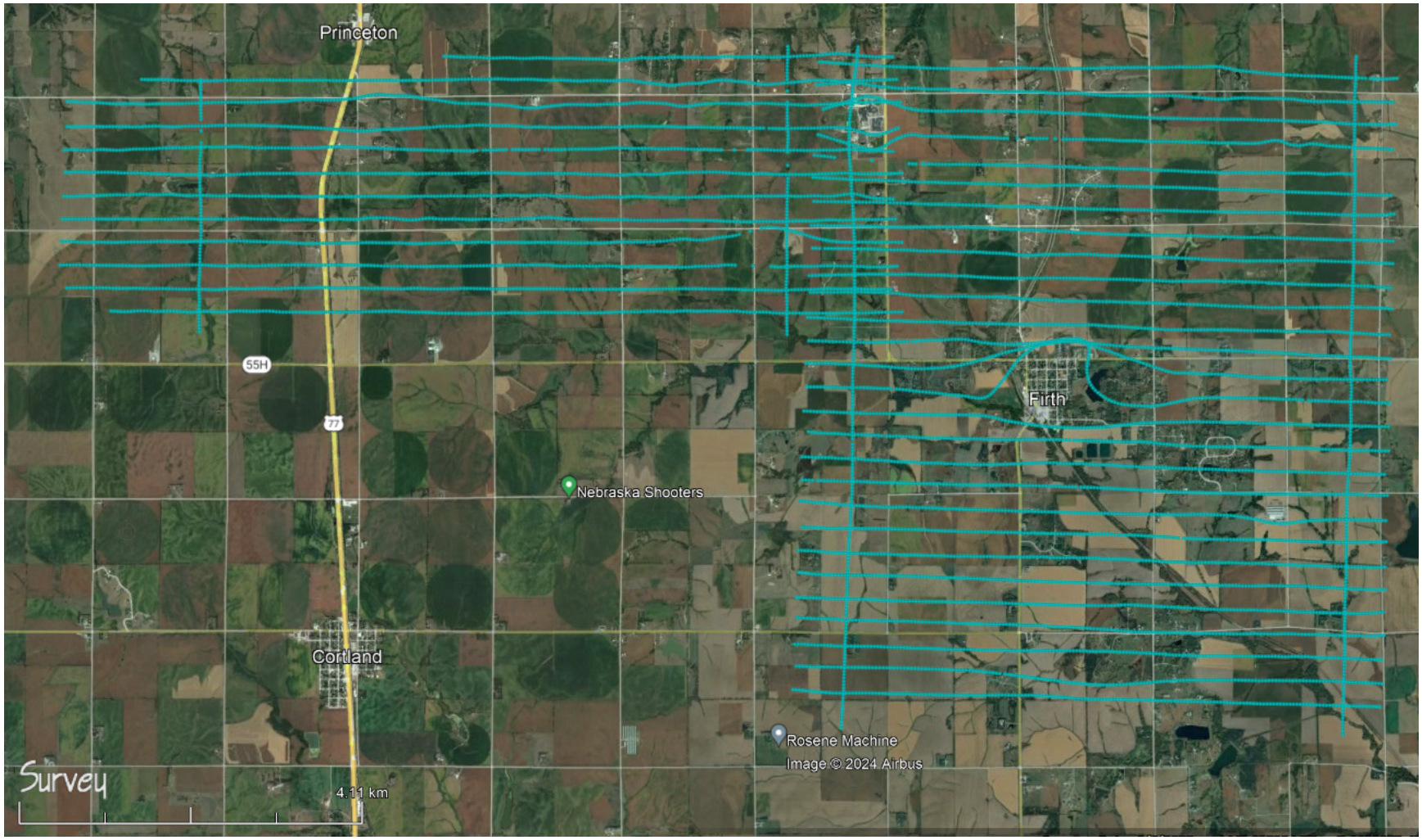


Figure 6-4. Google Earth KMZ of the Firth-Sprague AEM survey area showing the AEM Interpretation locations.

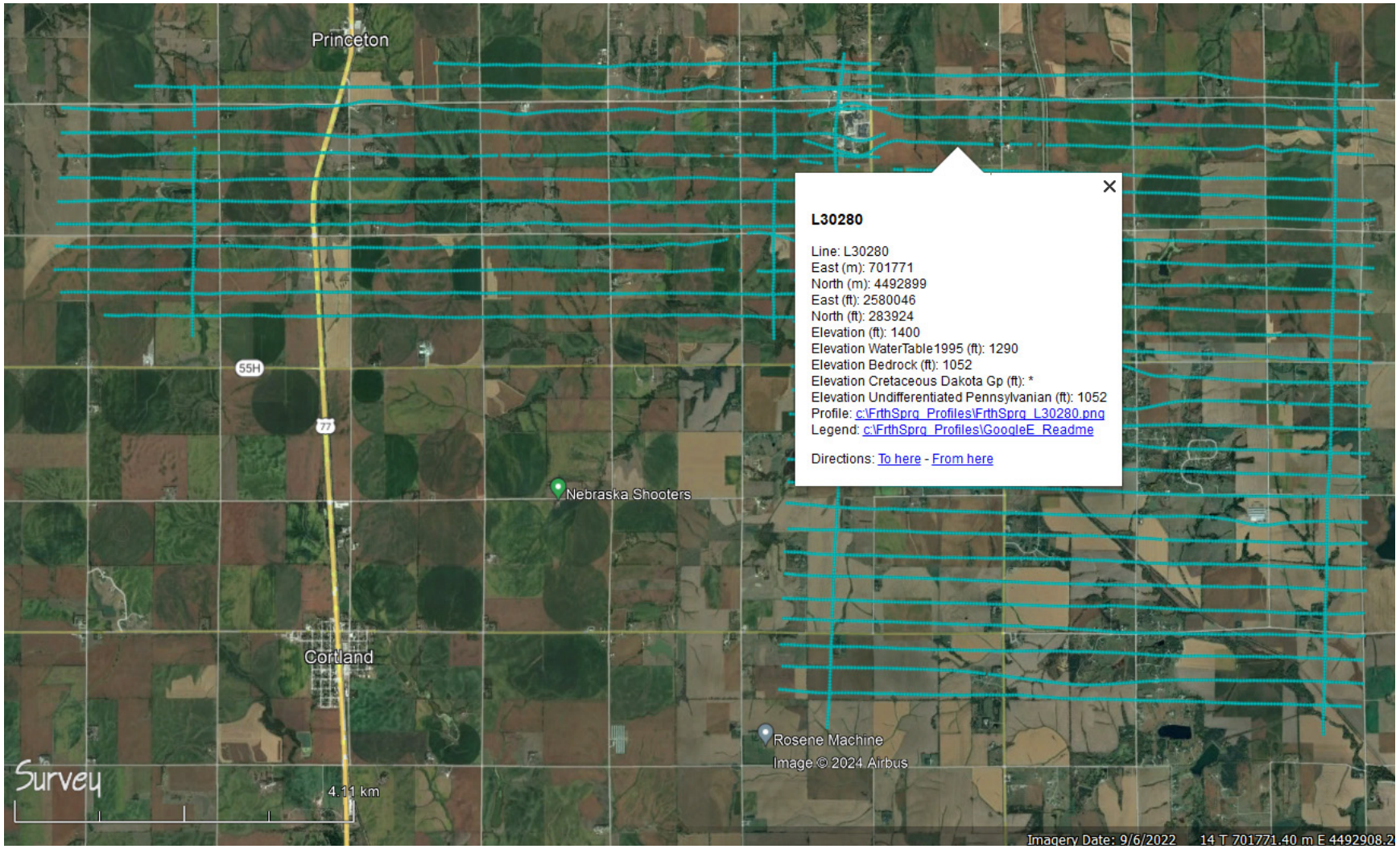
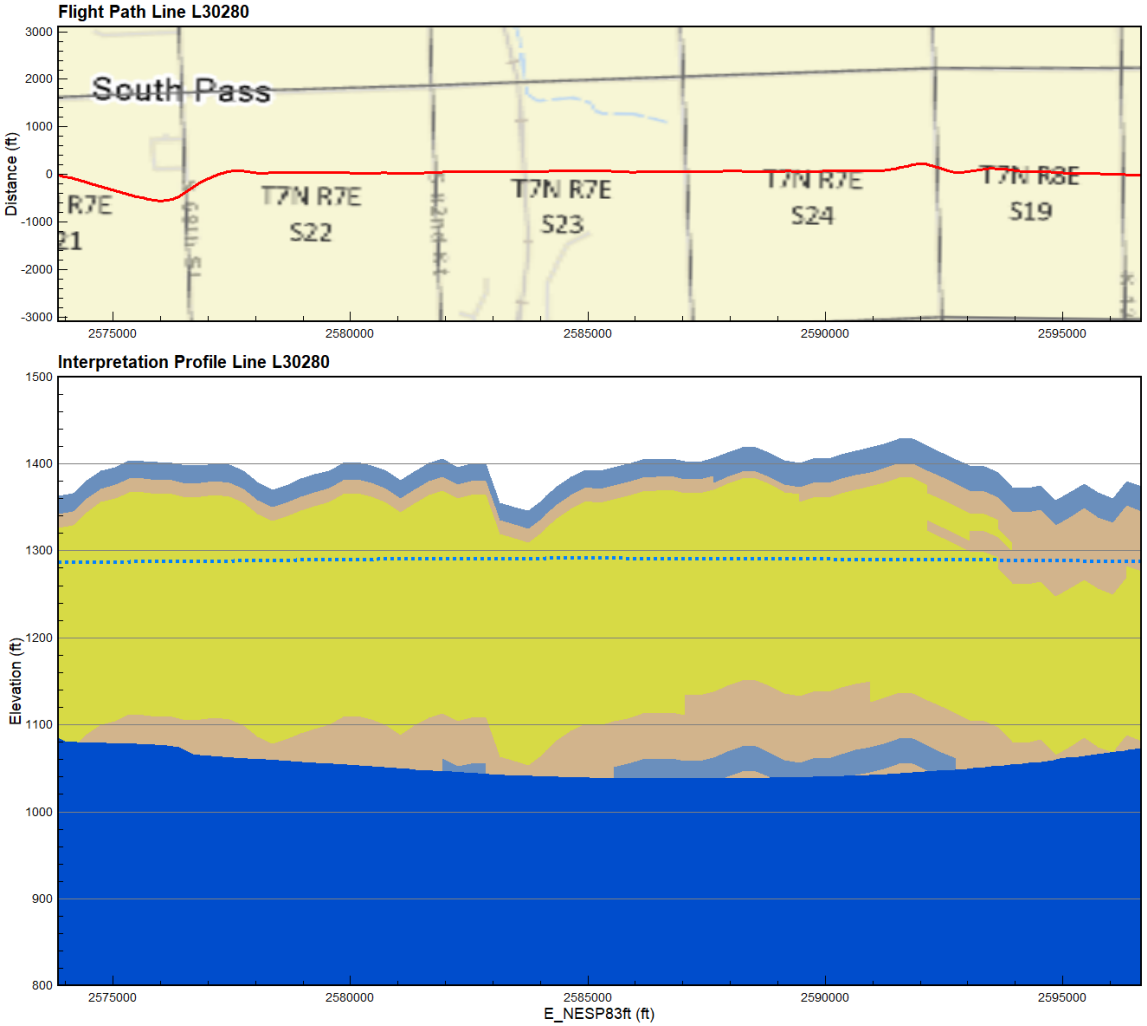


Figure 6-5. Example of clicking on a location in the Firth-Sprague AEM survey area. Profile L30280 is presented in Figure 6 below.



Interpreted geological sections from Airborne Electromagnetic (AEM) data collected over portions of the Nemaha Natural Resources District (NNRD) provided in conjunction with the Google Earth kmz file. The projected downline distance is equal for the flight path (top image) and the AEM data interpretation (bottom image). The Flight Location Map indicates the flight path on a Public Land Survey System Map. The Interpretation Profile shows the results of the interpretation of the inversion as electrical resistivity and the existing geological information. Colors are indicated by the legends. The 1995 Statewide Nebraska Conservation and Survey Division (CSD) water table is indicated by the dashed blue line. The project projection and vertical datum are NAD83 Nebraska State Plane (feet) and NAVD88 (feet). Additional information regarding the use of this figure and the AEM data may be found in the report titled "Airborne Electromagnetic Mapping and Hydrogeological Framework of portions of the Nemaha Natural Resources District." Prepared for the NNRD by Aqua Geo Frameworks, LLC

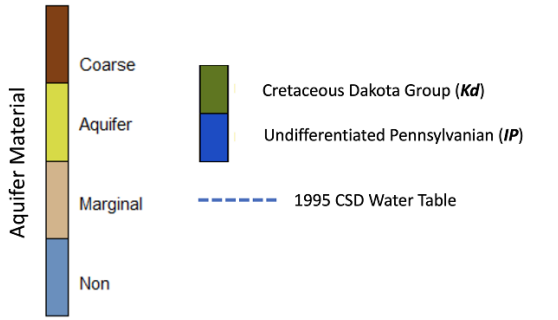


Figure 6-6. Example of clicking on link to Profile image for line L30280.

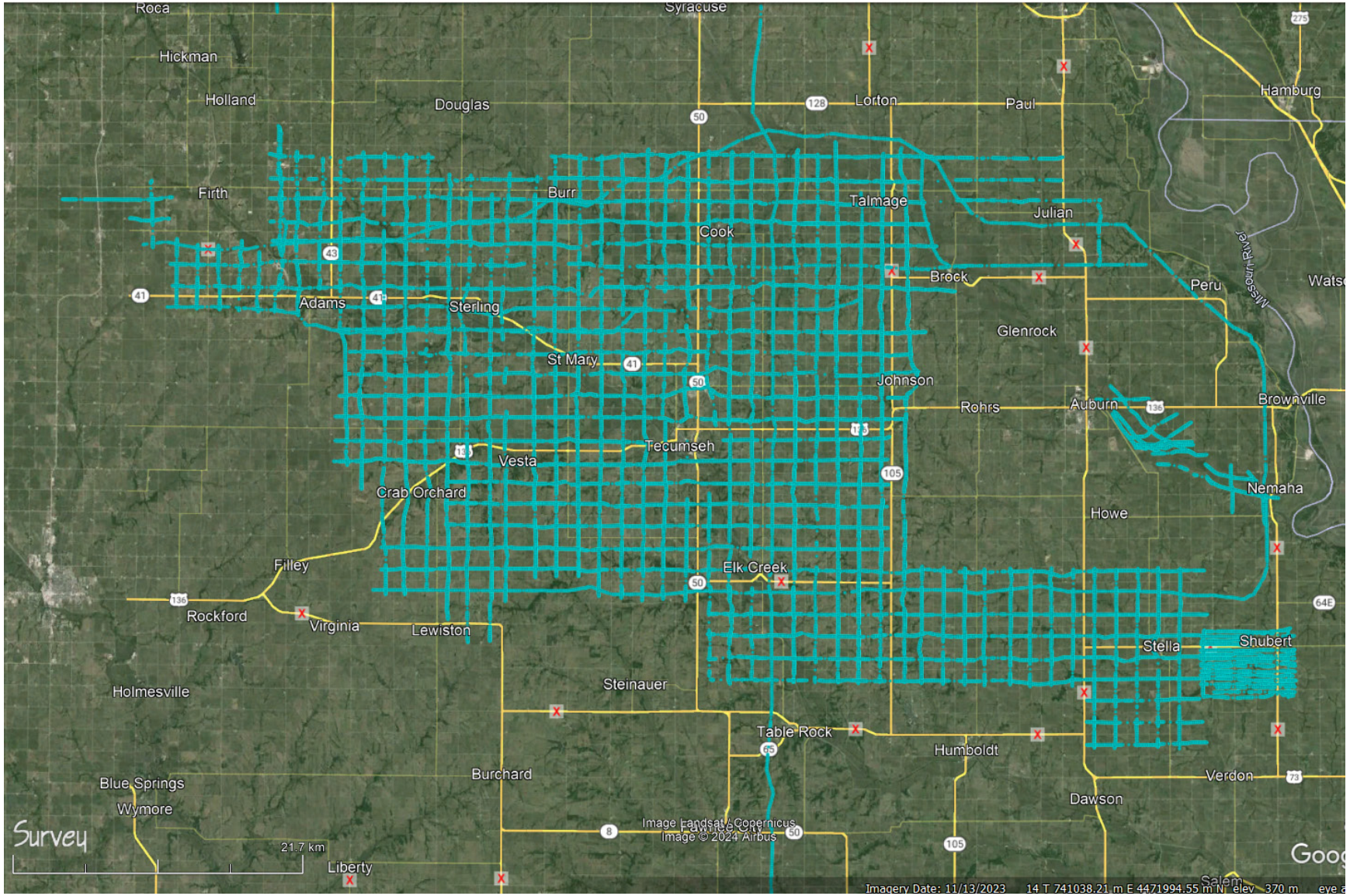


Figure 6-7. Google Earth KMZ of the combined NNRD AEM survey area showing the AEM Interpretation locations.

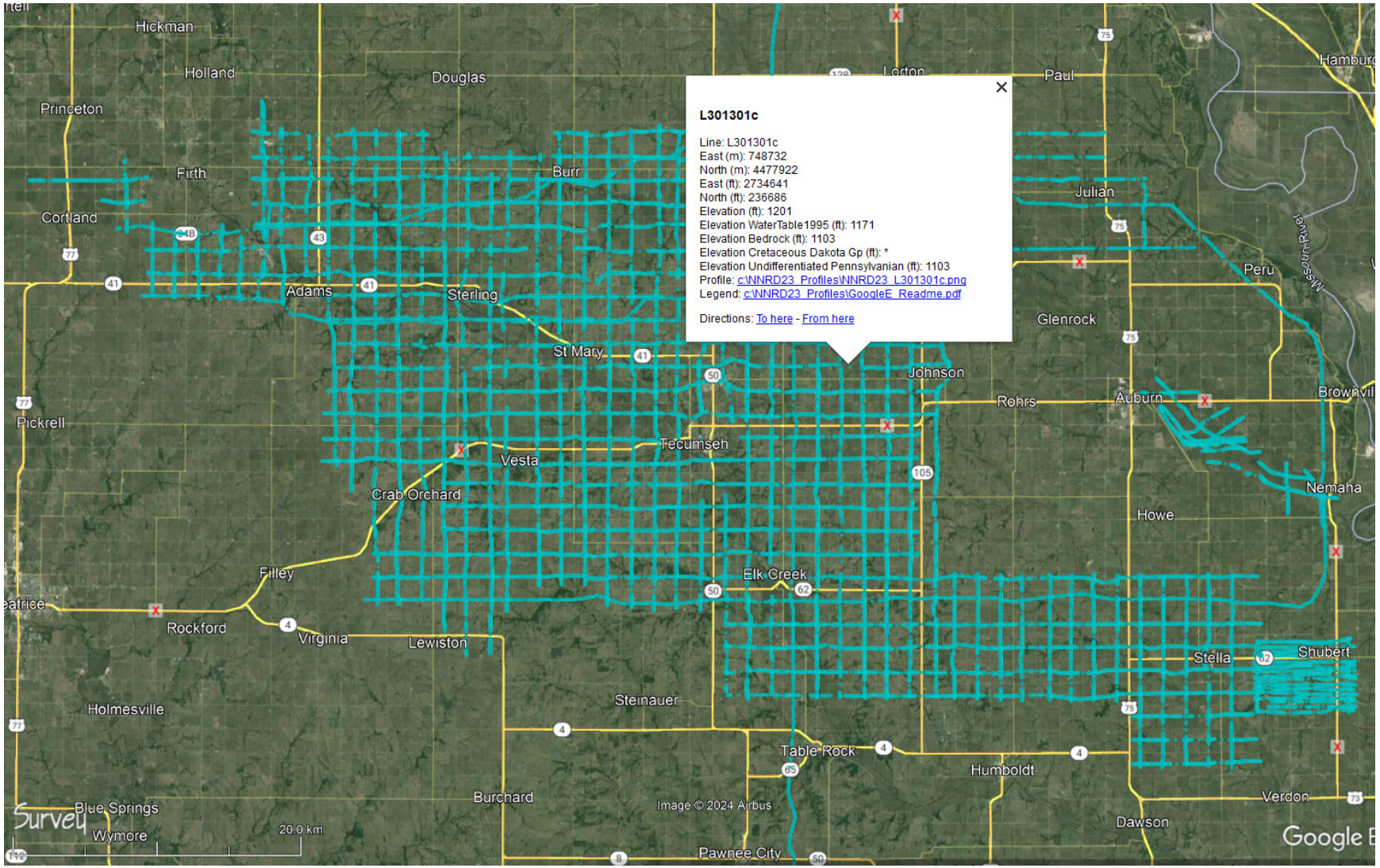
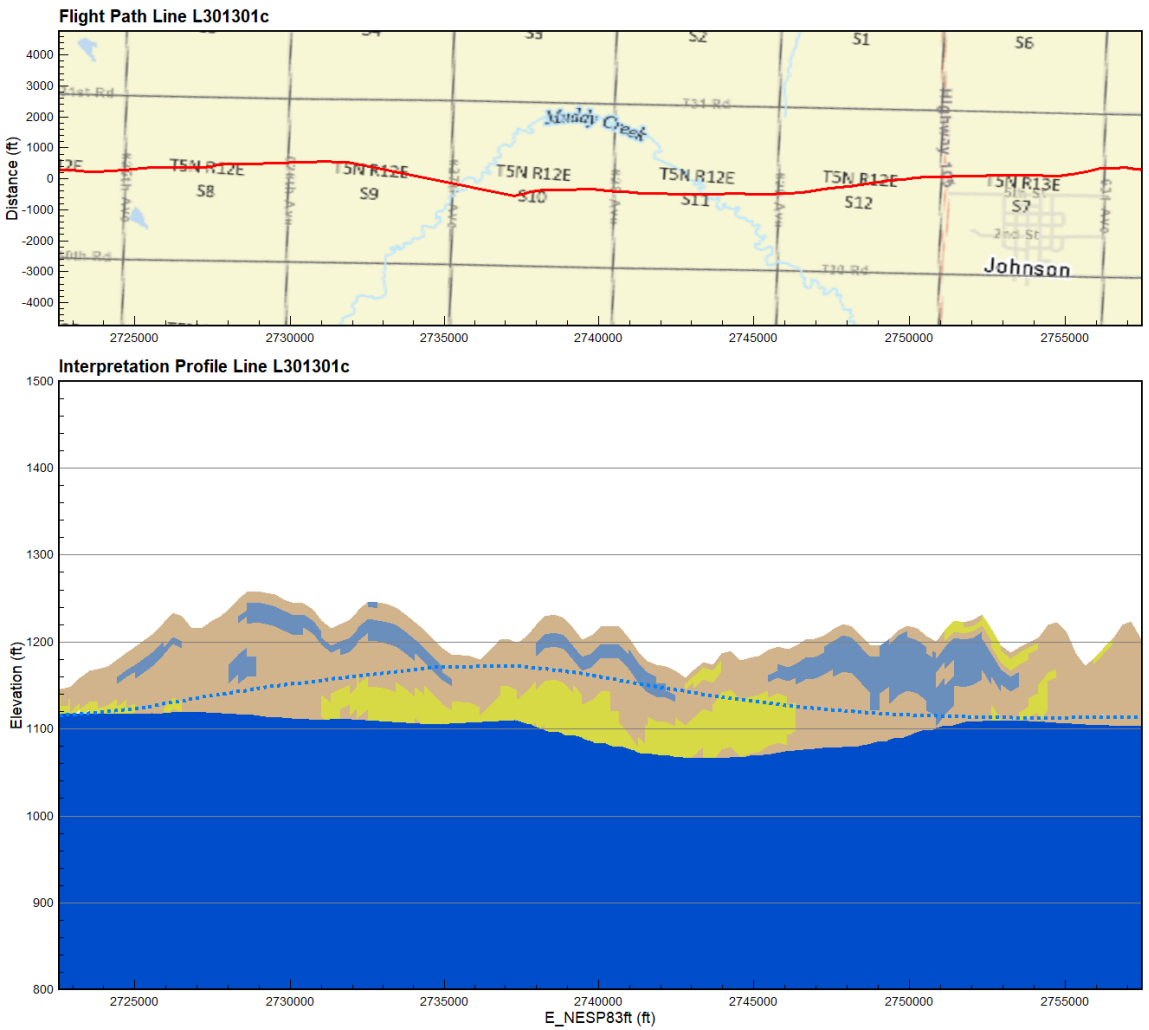


Figure 6-8. Example of clicking on a location in the combined NNRD AEM survey area. Profile L301301c is presented in Figure 9 below.



Interpreted geological sections from Airborne Electromagnetic (AEM) data collected over portions of the Nemaha Natural Resources District (NNRD) provided in conjunction with the Google Earth kmz file. The projected downline distance is equal for the flight path (top image) and the AEM data interpretation (bottom image). The Flight Location Map indicates the flight path on a Public Land Survey System Map. The Interpretation Profile shows the results of the interpretation of the inversion as electrical resistivity and the existing geological information. Colors are indicated by the legends. The 1995 Statewide Nebraska Conservation and Survey Division (CSD) water table is indicated by the dashed blue line. The project projection and vertical datum are NAD83 Nebraska State Plane (feet) and NAVD88 (feet). Additional information regarding the use of this figure and the AEM data may be found in the report titled "Airborne Electromagnetic Mapping and Hydrogeological Framework of portions of the Nemaha Natural Resources District." Prepared for the NNRD by Aqua Geo Frameworks, LLC

Figure 6-9. Example of clicking on link to Profile image for line L301301c.

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