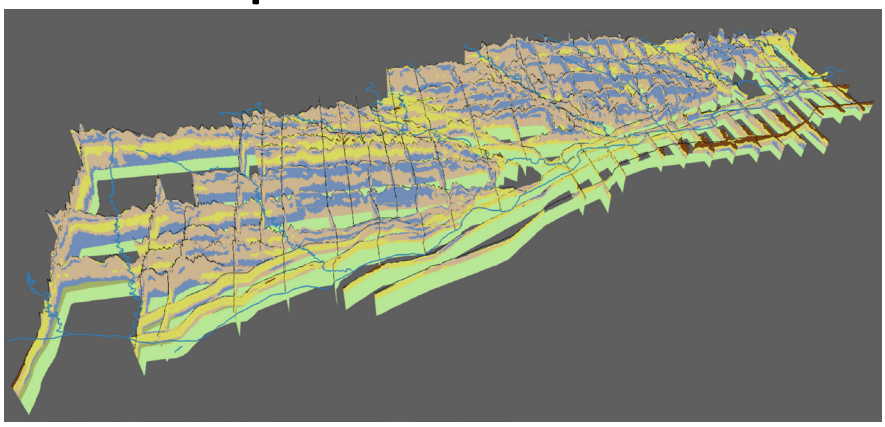
# Airborne Electromagnetic Mapping and Hydrogeologic Framework of Nance County, Nebraska within the Lower Loup Natural Resources District



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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 Nance County, Nebraska within the Lower Loup 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 Lower Loup Natural Resources District (LLNRD) 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 SkyTEM304 HR75 system was flown over the Nance County 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 LLNRD. This work included flight plans, database development, and review of hydrogeologic and geologic work for the area. The LLNRD 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 LLNRD reconnaissance flight lines had a maximum length of approximately 24 miles (39 km) in the east-west direction and about 12 miles (19 km) at their longest in the north-south direction and about 31 miles (50 km) along the Loup River. The flight lines were separated by approximately 0.62 mile (1 km) up to 1.5 miles (2.5 km) in both east-west and north-south directions.

1.4 AGF acquired AEM data over the LLNRD, commencing 19 August 2022 and finishing on 21 August 2022, to support development of the hydrogeological framework. During this time frame, data collected over approximately 531 line-miles (860 line-kilometers) were acquired over the LLNRD AEM survey area. Status reports of the flying were provided to the Contract Representative of LLNRD daily, including the areas flown, production rates, and flight plan for the following day.

1.5 AGF processed and conducted quality assurance and quality control (QA/QC) procedures on all data collected from the acquisition system. AGF delivered preliminary data and inversions on August 22, 2022.

1.6 AGF inverted the AEM data. After final processing, approximately 462-line-miles (749-line kilometers) were retained for inversion amounting to a retention rate of 87.1%. 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 LLNRD 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 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** - Information from boreholes were used to analyze the AEM inversion results. These included CSD information on 17 boreholes containing lithology and stratigraphic information, and ten (10) holes containing geophysical information. NE-DNR wells totaled 1,464 registered well records containing usable lithology information, 647 of those registered well had data to calculate specific capacity.

**2.2 Digitizing Interpreted Geological Contacts** - Characterization and interpretation of the subsurface was performed in cross-section and in derived surface grid formats. Contacts between the geologic units were digitized in 2D including: Quaternary (***Q***), Tertiary Ogallala Group (***To***), Cretaceous Pierre Shale (***Kp***), and Cretaceous Niobrara Formation (***Kn***). The interpretive process benefited from the use of CSD and NE-DNR borehole logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including the Quaternary/Tertiary aquifer material mapping is included in the appendices as well as interpretative surface grids.

**2.3 Resistivity/Lithology Relationship** - Assessment of the sediment character in both the Quaternary/Tertiary Ogallala aquifer system and the consolidated Cretaceous Pierre Shale and Cretaceous Niobrara Formation bedrock was conducted to determine the overall composition of the major categories used to define the aquifer and aquitards in the survey area. An assessment of the resistivity thresholds was used to characterize non-aquifer (<12 ohm-m), marginal (12-25 ohm-m), and aquifer (25-50 ohm-m), including coarse sand-rich intervals (>50 ohm-m). This allowed for the characterization of the ranges of resistivities present in the major geologic units described in this report.

**2.4 Hydrogeological Framework of the LLNRD** - The AEM reveals considerable variability in the Quaternary (***Q***) and Tertiary Ogallala Group (***To***) deposits across the AEM survey area. The subsurface distribution of materials can be generally characterized into two parts: the ***Q*** and the ***To***. The ***Q*** occurs in the Loup River Valley and the dissected plains north of the river. The ***Q*** aquifer, within the AEM survey area, predominantly consists of unconsolidated aquifer and coarse aquifer materials composed of alluvial sediments within the Loup River Valley as well as the Cedar River and Beaver Creek. The ***Q*** materials are directly deposited on the Cretaceous bedrock in the Loup River Valley. The ***Q*** loess covers much of the dissected plains and is composed of marginal and non-aquifer material. ***Q*** materials lie upon Tertiary Ogallala Group (***To***) north of the Loup River Valley. The ***To*** has a heterogeneous mix of aquifer materials. Aquifer and coarse aquifer materials compose the paleo-fluvial sediments. A large area of ***To*** non-aquifer material (clay) occurs at the base of the ***To*** in the western portions of the survey area. The ***To*** also has marginal and non-aquifer material deposits that can act as groundwater flow boundaries creating isolated aquifers and barriers to groundwater flow. The ***Q*** and ***To*** aquifers in the area are generally thin and have limited saturated thickness. There is a large portion of the Nance County AEM survey area that has estimated transmissivities of less than 20,000 gpd/ft. The area of Beaver Creek and around the town of Genoa, Nebraska are all within a region of low transmissivity values. Deeper ***To*** aquifers are some of the best sources of water in the dissected plains. The best source of groundwater is within the thin ***Q*** alluvial sediments along the Loup River Valley. The ***To*** sits upon a small remnant of the

Cretaceous Pierre Shale (***Kp***) in the western portion of the survey area. The ***To*** is deposited on the Cretaceous Niobrara Formation (***Kn***) over the remaining area of the survey. The ***Kn*** bedrock is eroded and has shallow paleochannels eroded into the surface. The ***Kp*** and ***Kn*** are not considered aquifers in this area of Nebraska.

**2.5 Estimation of Aquifer Volume and Water in Storage in the Nance County AEM Survey Area** - The values for the saturated (based on the LLNRD spring 2022 water table) Quaternary (***Q***) aquifer materials have a total volume of **6,001,594** acre-ft. The saturated ***Q*** total volume of water is **1,771,165** acre-ft of groundwater in storage. The extractable total volume of saturated **Q** aquifer materials is **164,747** acre-ft. The values for the saturated (based on the LLNRD spring 2022 water table) Tertiary Ogallala Group (***To***) aquifer materials have a total volume of ***26,708,612*** acre-ft. The saturated ***To*** total volume of water is ***8,848,084*** acre-ft of groundwater in storage. The extractable total volume of saturated ***To*** aquifer materials is ***421,548*** acre-ft. A combination the saturated ***Q*** and ***To*** aquifer materials produce a total volume of **32,710,206** acre-ft. The total groundwater in storage is **10,619,249** acre-ft. The total extractable water is **586,294** acre-ft

**2.6 Groundwater Quality in the Nance County AEM Survey Area -** The AEM provided information on the near surface materials in Nance County. Near surface occurrences of sandy soils and sand deposits (aquifer materials) provide conduits for contaminants to migrate into the groundwater. Using the 3D interpretation of the AEM a near surface occurrence of the aquifer materials map was generated. A depth of ~27 feet was selected to examine the areas of potential impacts. Overlaying the LLNRD water quality data on the aquifer material map of the first 27 feet demonstrates a strong correlation of the near-surface aquifer materials and the elevated nitrates. The thickest of the aquifer materials along the Loup River and southern portions of the Beaver Creek areas display the highest Nitrates from the 2022 sampling. There are some areas of 10 to 20 mg/L in areas of the northeastern area of the survey. These are not related to the surface materials and may be related to deeper elevated nitrates in the sandy portions of the Tertiary Ogallala Group (***To***) in that area.

**2.7 Potential Recharge Zones within the Lower Loup NRD 2022AEM Survey Area** - Using a similar approach in what was utilized in the water quality section the first 27 feet of the AEM model were examined. Those near-surface areas of aquifer materials are dominated by the reaches of the Loup River with sections of the Cedar River and the lower reaches of Beaver Creek. One issue in assessing locations for recharge sites is examining the current land use and ability to deliver water to that location. Utilizing the irrigated acres overlay on the aquifer material within the first 27 feet it is apparent that there are very limited areas of potential recharge with the exception of the shallow materials along the Loup River. There are a few limited areas along the Cedar River and a few of the drainages that drain into Timber Creek. The bottom line is the potential for good recharge sites within the Nance County AEM survey area is limited without the elimination of currently irrigated land.

**2.8 Using AEM Results to Understand the Effect of Groundwater Management and Regulations** - Much of this study was focused on the determination of the groundwater availability within the Nance County AEM survey area. Conflicts and poor well performance were known prior to the work completed in this report. Previous work in the area had indicated that there was limited aquifer resulting from limited saturated thickness and low transmissivity (Summerside et al., 2005). The AEM has provided a much higher resolution of the aquifer configuration. The important findings that can have impacts on the management of the area are related to the estimated transmissivity as was determined in this study. Areas of transmissivity of less than 20,000 gpd/ft were determined. These low transmissivity areas are the first place to start in delineating the control area. The low transmissivity area covers a large portion

of the county, with a substantial area occurring around Beaver Creek and the town of Genoa, Nebraska. The AEM provides a much higher resolution view of the area as compared with the previous mapping, but that is expected and is the goal of this study. These estimates of transmissivity maps can inform the management of the area and provide empirical data on why these decisions were implemented.

## 3. RECOMMENDATIONS

Recommendations provided to the LLNRD 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 LLNRD about their management challenges.

**3.1 Additional AEM Mapping** - The aquifer maps provided in this report represent the detailed hydrogeologic framework developed for the Nance County AEM survey area. The interpretations match well with the CSD and NE-DNR boreholes. No additional high resolution AEM information is needed within Nance County Area to resolve questions of resource management, it is recommended that additional areas of closely spaced lines or "block flights" be collected to develop detailed frameworks in other areas of the District. Other management areas or potential management areas should be mapped in detail to provide information on the hydrogeologic framework which provides detail on recharge, groundwater movement, etc. This could potentially be done in cooperation with the neighboring NRDs to get details on the continuous aquifer system that is shared in the area. For example, the detailed hydrogeologic frameworks presented in this report have provided estimates of groundwater storage capacity. This is done by using existing aquifer characteristic information and calculating groundwater in storage and effective yield. The line spacing for the block flights should be on the order of 0.25 mile (1,320 ft).

**3.2 Siting new test holes and production wells** - The AEM framework maps and profiles provided in this report provide insight on the 3D relationship between current test holes and production groundwater wells. At the time of this report, the currently available lithology data for the LLNRD area was used in building the framework maps and profiles. It is recommended that the results from this report be used to site new test holes and monitoring wells. Often test holes are sited based on previous work that is regional in nature. By utilizing the maps in this report new drilling locations can be sited in optimal locations. The location of any future new water supply wells for communities can also use the results in this report to guide development of new water supply wells. Planners should locate wells in areas of greatest saturated thickness with the least potential for non-point source pollution.

**3.3 Aquifer testing and borehole logging** – Aquifer tests are recommended to improve estimates of aquifer characteristics. A robust aquifer characterization program is highly recommended at the state, regional (NRD's), and smaller municipal levels. Aquifer tests can be designed based on the results of AEM surveys and existing production wells. Additional test holes with detailed, functional, and well calibrated geophysical logging for aquifer characteristics is highly recommended. The few test holes with calibrated geophysical logs in the LLNRD survey area were inadequate. The borehole geophysical logs provided for this investigation demonstrate that additional calibrated and verified geophysical logs are required in the LLNRD. Examples of additional logging would be borehole flow meter logs and geophysical logs including gamma, neutron, electrical, and induction logs. Detailed aquifer characteristics can be accomplished with nuclear magnetic resonance logging (NMR). This is a quick and effective way to characterize porosity and water content, estimates of permeability, mobile/bound water fraction, and pore-size distributions with depth. This is very cost effective when compared to traditional aquifer tests.

**3.4 Groundwater Management: Control Areas, Recharge Areas** - The Nance County hydrogeologic framework in this report provides areas of low transmissivity. It is recommended that these areas be used to define the control areas based on empirical data. The geospatial data products delivered with this report can be directly opened in ESRI's ArcGIS Pro and can be used to provide guidance in the establishment of control areas. The near-surface aquifer materials mapped in this report indicate areas that have increased occurrence of nitrates. This is most probably due to the sandy soils and sands that allow the transport of these contaminates into the groundwater. These maps should be used to develop areas of fertilizer controls. Near surface maps of the aquifer materials also provide insight into areas of recharge. Within the Nance County area there is little to no good recharge areas without the elimination of some irrigated acreages. Any management decisions that would propose recharge would need to be weighed against current land use.

## 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 LLNRD AEM flight lines

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## List of Abbreviations

| | |
|---|---|
| 2D | Two-dimensional |
| 3D | Three-dimensional |
| A*m$^2$ | Ampere meter squared |
| AEM | Airborne Electromagnetic |
| AGF | Aqua Geo Frameworks, LLC |
| AM | Aquifer Material |
| ASR | Aquifer Storage and Recovery |
| b | Saturated thickness |
| 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 |
| IMP | Integrated Management Plan |
| K | Hydraulic Conductivity |
| ***Kn*** | Cretaceous Niobrara Formation |
| ***Kp*** | Cretaceous Pierre Shale |
| Km, km | Kilometers |

| | |
|---|---|
| KMZ, kmz | Keyhole Markup language Zipped file |
| LCI | Laterally-constrained Inversions |
| LLNRD | Lower Loup Natural Resources District |
| 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 |
| NRD | Natural Resources Districts |
| OM | Geosoft Oasis montaj |
| P-MRNRD | Papio-Missouri River Natural Resources District |
| 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.

In recent years landowner conflicts over water availability have arisen in the Lower Loup Natural Resources District (LLNRD) in Nance County, Nebraska. This area reports very low estimates for both saturated thickness and transmissivity of the unconfined portions of the High Plains aquifer. Analysis of the geologic boring logs from existing area wells shows that aquifer-bearing soil materials, like sands and gravels, are limited. As a result, in Fall 2019 the District prohibited new development of certified irrigated acres in an area defined as a “well interference zone”; however, a more scientific-based approach was needed for establishing this new regulatory boundary. Collection of Airborne Electromagnetics (AEM) data covering an approximate 300 square mile (192,000 acres) area in Nance County was intended to assist the development of the new regulatory boundary. The AEM data provided a thorough understanding of the hydrogeology in this critical area with the goal of implementing improved groundwater management for water quality purposes as well as to reduce conflicts and provide sustainable management practices.

This Nance County area is a high priority area targeted for AEM by the LLNRD where ongoing groundwater quantity problems are occurring and potential use conflicts may occur, that traditional methods of investigation have not been able to resolve. The traditional method of collecting hydrogeologic information is accomplished through test hole drilling, where a geologist describes the recovered materials, collects a borehole geophysical log, and interprets the contacts of the hydrogeologic units encountered. Individual test holes provide a single point of information about the area hydrogeology which can be supplemented with existing drillers logs. The geology and the aquifer materials between these points is interpolated utilizing the experience and expertise of trained hydrogeologists. The interpolation of the hydrogeology between points is simply an estimation of the subsurface materials present, but aquifer materials and their properties may change dramatically in as little as a few tens of feet from the individual test hole locations. Individual points of information, like test holes, therefore, provide limited information about the broader aquifer characteristics.

While limited, test holes have been the best available method for assessing aquifer characteristics until the recent improvement of AEM which essentially provides thousands of virtual test holes along the flight path, thereby collecting a nearly seamless cross-section of the aquifer materials. The AEM survey method can remotely cover large areas of the subsurface in a short amount of time and with great detail. This type of seamless cross-section cannot be collected through any other known method in the same amount of time for AEM data acquisition.

Mapping results produced from the AEM data for this project have provided three-dimensional subsurface views of the aquifer materials and estimates of the extents and volumes of the ground water resources available (See Section 5 and *Appendix 2 – 3D Images*). The reconnaissance flight lines conducted for this survey were spaced approximately 2 miles apart, perpendicular to the estimated trend of the aquifer units. Additionally, "tie lines" were spaced approximately 3 miles apart (oriented 90 degrees relative to the reconnaissance flight lines). The trend in the lines were based on the examination of the borehole only derived aquifer model throughout the area. In-fill lines were flown at a spacing of approximately one quarter of a mile to provide detailed information over areas of aquifer zones identified in the reconnaissance flights. Similar approaches to reconnaissance and detailed block flights previously produced successful results in eastern Nebraska within the Papio-Missouri River Natural Resources District (P-MRNRD) (AGF 2021) as well as the Lower Platte South Natural Resources District (LPSNRD) (AGF 2019).

This project mapped a flight block across the Project Area in Nance County, covering approximately 518 miles of AEM survey to develop a three-dimensional view of the aquifer in the vicinities of the City of Fullerton, the City of Genoa, and the Loup River. The project consisted of flight line planning within the block area, collection of AEM data along the flight lines, processing of the raw AEM data, interpretation of the processed data (tied to local geologic interpretations from traditional subsurface mapping), and reporting of the overall results. The AEM survey results have been incorporated into a Geographic Information System (GIS) (ESRI's ArcGIS Pro) for use by LLNRD. The interpretations and GIS will be provided to Nebraska GeoCloud for public use, the CSD, and the NE-DNR at the time of this final report delivery.

CSD geologists will evaluate the AEM survey results with CSD cross-section and ancillary data to make interpretations of the regional geologic setting types encountered and evaluate how well the AEM results match up relative to the cross-sectional data. The resulting map publication and conclusions will provide those interested in the hydrogeology of central Nebraska a comprehensive and improved understanding of the varying hydrogeological settings. That interpretation will follow the approach used for previous Eastern Nebraska Water Resources Assessment (ENWRA) block areas. The NRDs will use groundwater reservoir delineations and associated maps to address groundwater quality problems occurring in this block and to help mitigate potential quantity concerns in the area.

A location map showing the LLNRD is presented in Figure 1-1 and a flight line map is presented in Figure 1-2 and in *Appendix 3 – Deliverables\KMZ\FlightLines*. The 2022 flight area was in Nance County and the towns of Fullerton, Genoa, and Belgrade are within the survey area.

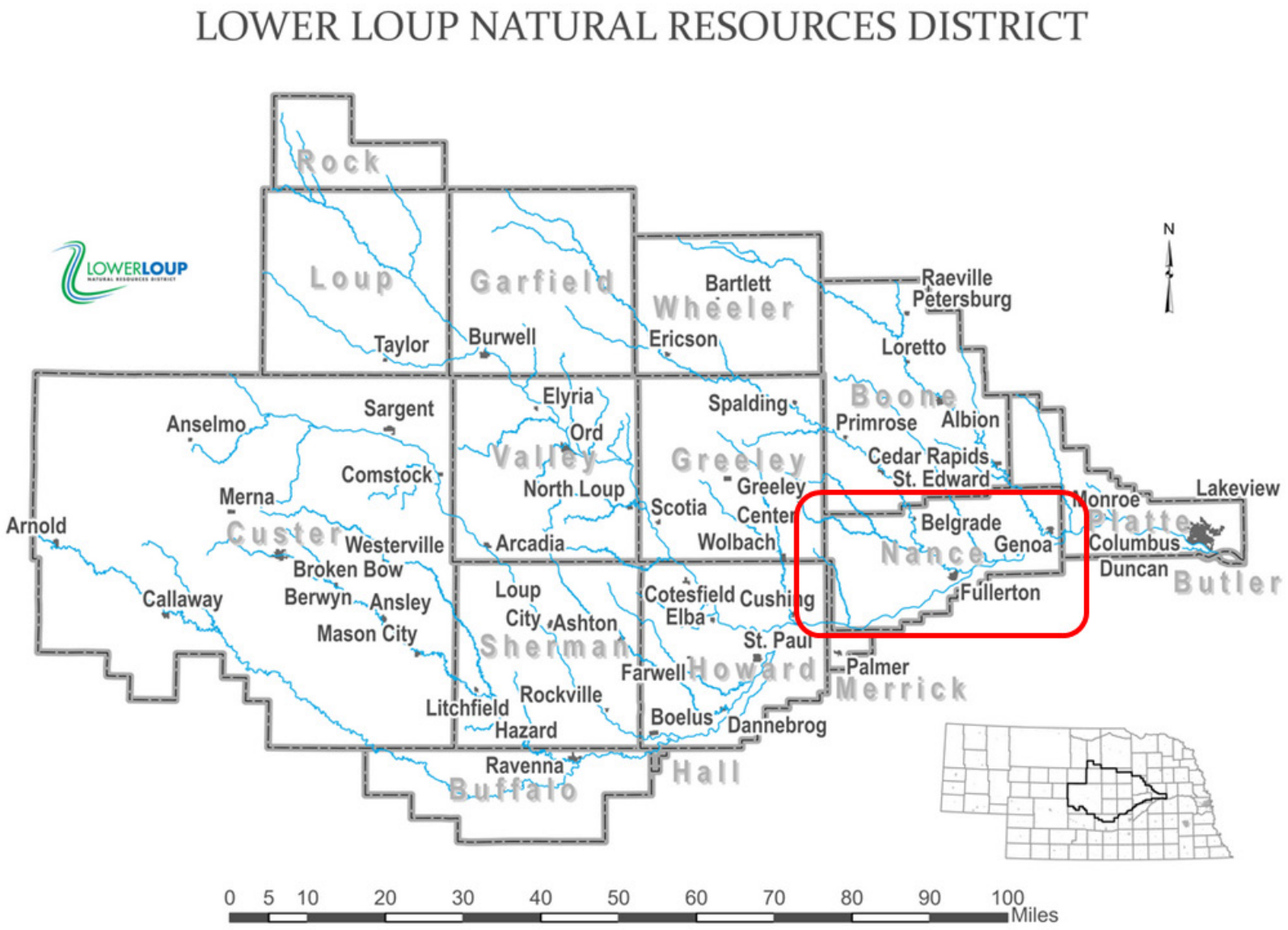



**Figure 1-1. Map of the LLNRD in east central Nebraska (https://www.llnrd.org/). The red box indicates the 2022 AEM survey area around Nance County.**

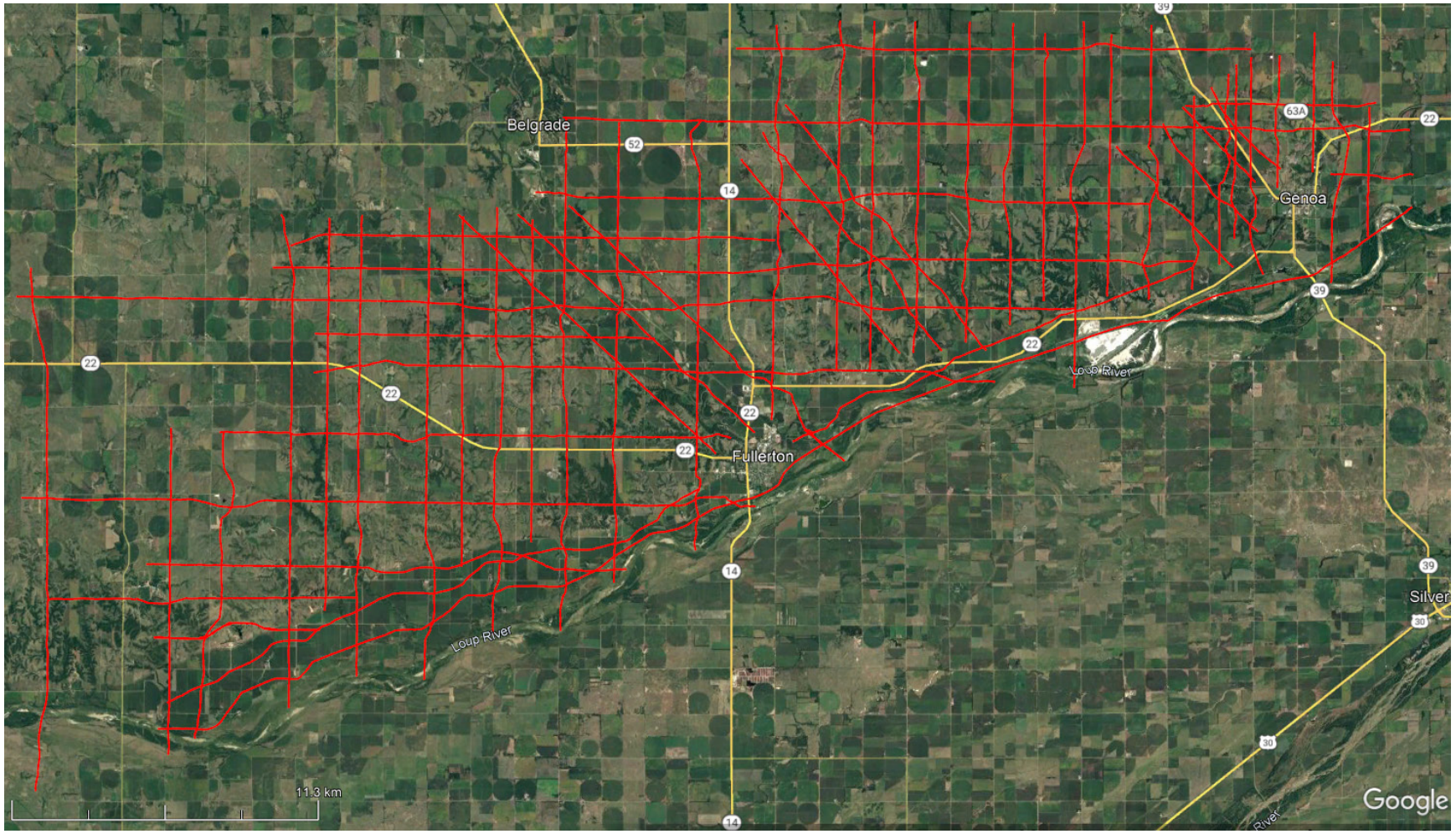



**Figure 1-2. Google Earth image of the LLNRD 2022 AEM survey area including major roads.**

## 1.2 Background

The LLNRD developed a voluntary Integrated Management Plan (IMP) in May, 2016, in conjunction with the Nebraska Department of Natural Resources (NE-DNR) (LLNRD, 2016). Meeting the goals and objectives of the IMP is a District priority. The overall goals of the LLNRD IMP are to better manage hydrologically connected water through a greater understanding of aquifer connectivity between surface water and groundwater, and potential aquifer components that may have an impact on the resource. This project addressed objectives and action items related to these goals by: (1) utilizing the best available data and analysis tools to estimate consumptive water use; (2) assessing the need for additional monitoring; and (3) gathering and analyzing hydrogeologic data.

In addition to developing the voluntary IMP, the LLNRD has adopted a Groundwater Management Plan (GWMP), last revised in 1985 (LLNRD, 1985). Results of this project specifically meet the objectives of the GWMP by addressing specific problems of groundwater quality. Groundwater quality monitoring conducted by LLNRD staff has shown the area around the City of Genoa in Nance County has elevated levels of nitrates.

With the hydrogeologic framework updated through this project, the LLNRD will be better equipped to assess the overall susceptibility of the groundwater resources within the Project Area to impacts from contamination and increasing use and development. The updated hydrogeologic framework will directly inform the delineation of the groundwater resources to be included in the update of the LLNRD GWMP. The AEM data will be used for other studies or products beyond their original intent. For example, CSD may use the AEM data to update bedrock maps, transmissivity and specific yield maps, and maps of secondary aquifers, or a contractor may use the data to site and construct an intentional recharge project.

# 2 Summary of the Hydrogeologic Setting of Nance County

Each year LLNRD produces an annual report characterizing trends in groundwater levels in the groundwater management areas (GWMAs) in the District. Well interference in this area of Nance County has caused local conflicts for water development due to the limited aquifer materials and the lack of understanding of aquifer geometry. For example, in one case, two landowners in the Nance County area reported irrigation well pumping interference during the 2019 and 2020 growing seasons. The wells are located over 2,000 feet apart (Figure 2-1). The east well was constructed in 1975 and the new, west well in 2018, operating for the first time in the summer of 2019. Both wells rely on a sand/sandstone unit for their water source located at the base of the High Plains aquifer, or more specifically, the Tertiary Ogallala Group (***To***) of the High Plains aquifer or Ogallala Aquifer. Based on geologic boring logs, this sand/sandstone unit within the Ogallala Aquifer is estimated at around 20–40 feet of thickness, pinching out completely at an estimated distance of less than a mile to the east. During an LLNRD-monitored pumping experiment a drawdown of 11.3 feet was recorded on the older, east well when the new, west well was set at the default 550 gallons per minute (GPM) pump rate for 25 hours. The older, east well was not set to pump during the experimental period in order to test best-case scenario drawdown. A second recording was done during the same experiment over a 7-hour period, which produced a 4.9-foot drop in water level in the east well. When both wells are pumping at their default rates, 550 GPM for the west well and 440 GPM for the east well, more significant drawdown occurs, as reported by the landowners in both the 2019 and 2020 growing seasons. It should be noted that 2019 and 2020 were considered generally wet seasons with regard to precipitation and groundwater availability in the District, so the pumping effect during a dry season when both wells are pumping for consistently longer periods of time could be much greater than what has been experienced in this area of Nance County.

Groundwater quality monitoring conducted by the LLNRD has shown a portion of Nance County to have elevated levels of nitrates. In an evaluation of nitrate levels using 2020 groundwater sampling data, the geographic area covered by this Project included a high concentration location of more than seven (7) times above the EPA standard for drinking water (MCL) of 10 mg/L, with a concentration of 72.3 mg/L (LLNRD, 2020). This same domestic well also reported consistently high nitrate concentrations in the previous four years, including 65.8 mg/L in 2019, 66.6 mg/L in 2018, 63.3 mg/L in 2017, and 45.4 mg/L in 2016 (LLNRD, 2020). Other wells in the area also reported elevated nitrate concentrations. This includes two sites sampled in 2020 with values of 53 mg/L and 37 mg/L, as well as fifteen other sites that reported concentrations greater than the EPA drinking water standard of 10 mg/L. All of these sites are located within a seven-mile range of the City of Genoa and are located inside the Project Area (see Figure 2-2 – Water Quality Map). As a result of the AEM survey, LLNRD will have a better understanding of the hydrogeology in this area and can make better water quality management decisions. This includes the possibility of defining a new water quality management sub-area using knowledge of the hydrogeologic boundaries defined by AEM data. Establishing a new sub-area sets the stage for allowing the District to bring high nitrate areas under a managed level of control.

Furthermore, Beaver Creek, a stream that flows through the Project Area and is located near the City of Genoa, is on EPA's Clean Water Act Section 303(d) list of impaired waters. This stream segment is

impaired due to elevated levels of *E. coli* bacteria. The data collected as a result of this AEM study will be used to provide an understanding of the potential of groundwater contaminants threatening surface water quality. This is done by direct examination of the aquifer materials and how they are hydrologically connected to the streams.

Finally, given the known levels of contamination of the groundwater in the Project Area, the LLNRD has a dedicated, full-time staff member available to work with the City of Fullerton and City of Genoa to develop a Wellhead Protection Plan (WHPP), as neither community has one in place. The AEM data will provide a better understanding of surface/ground water connectivity around both Fullerton and Genoa, providing the wellhead protection staff with the tools to develop a robust WHPP for those communities.

In summary, with the reported well interference issues, groundwater level declines, elevated nitrate concentrations, *E. coli* stream impairment, and lack of a WHPP in the communities of Fullerton and Genoa in Nance County, this AEM study area is a high priority area in the District for understanding the hydrogeologic framework and groundwater/surface water connectivity.

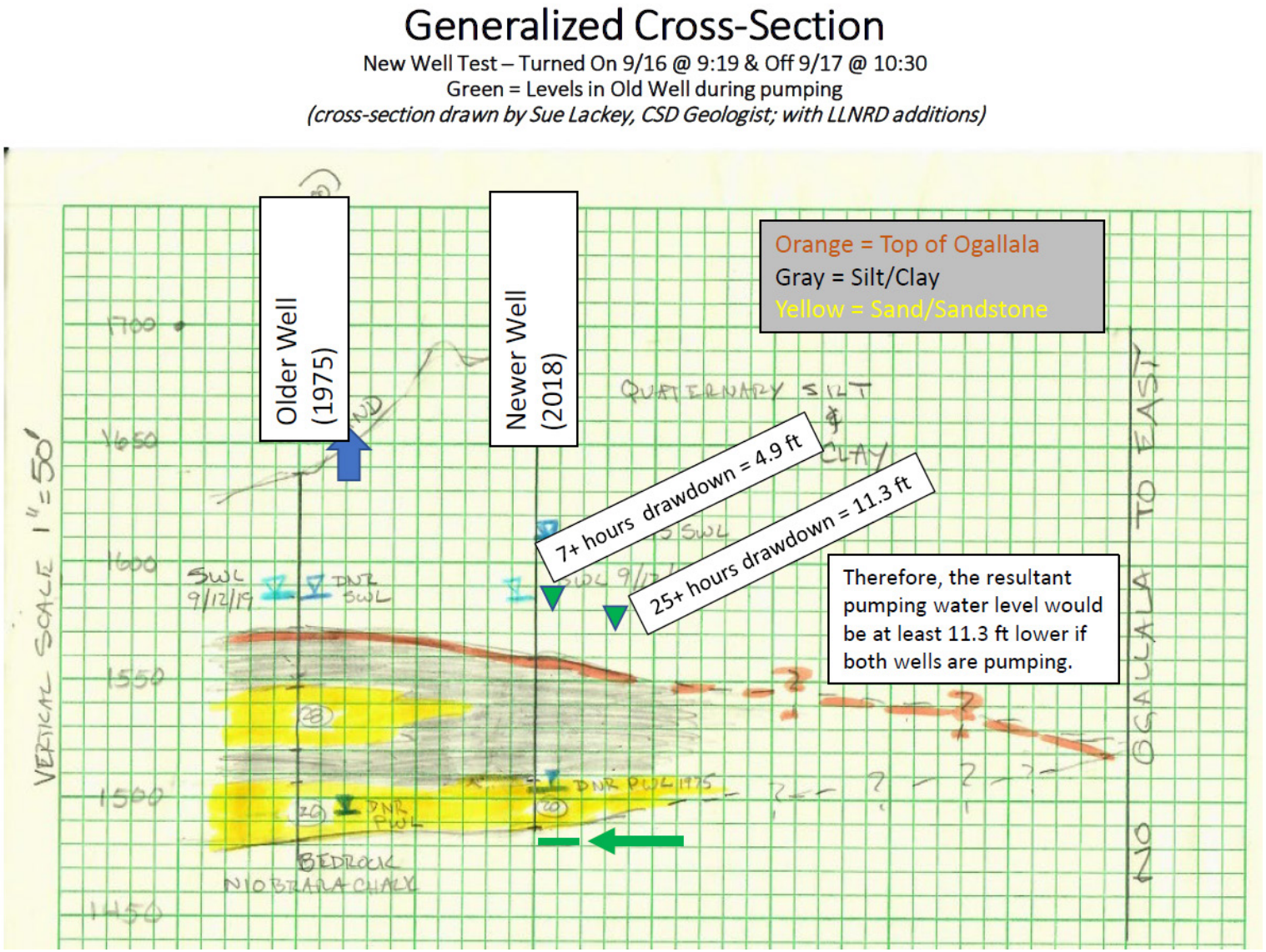



**Figure 2-1. Generalized cross-section of older and newer production wells in the Ogallala Group of the Tertiary geologic period of the High Plains aquifer which appear to be interfering with each other.**

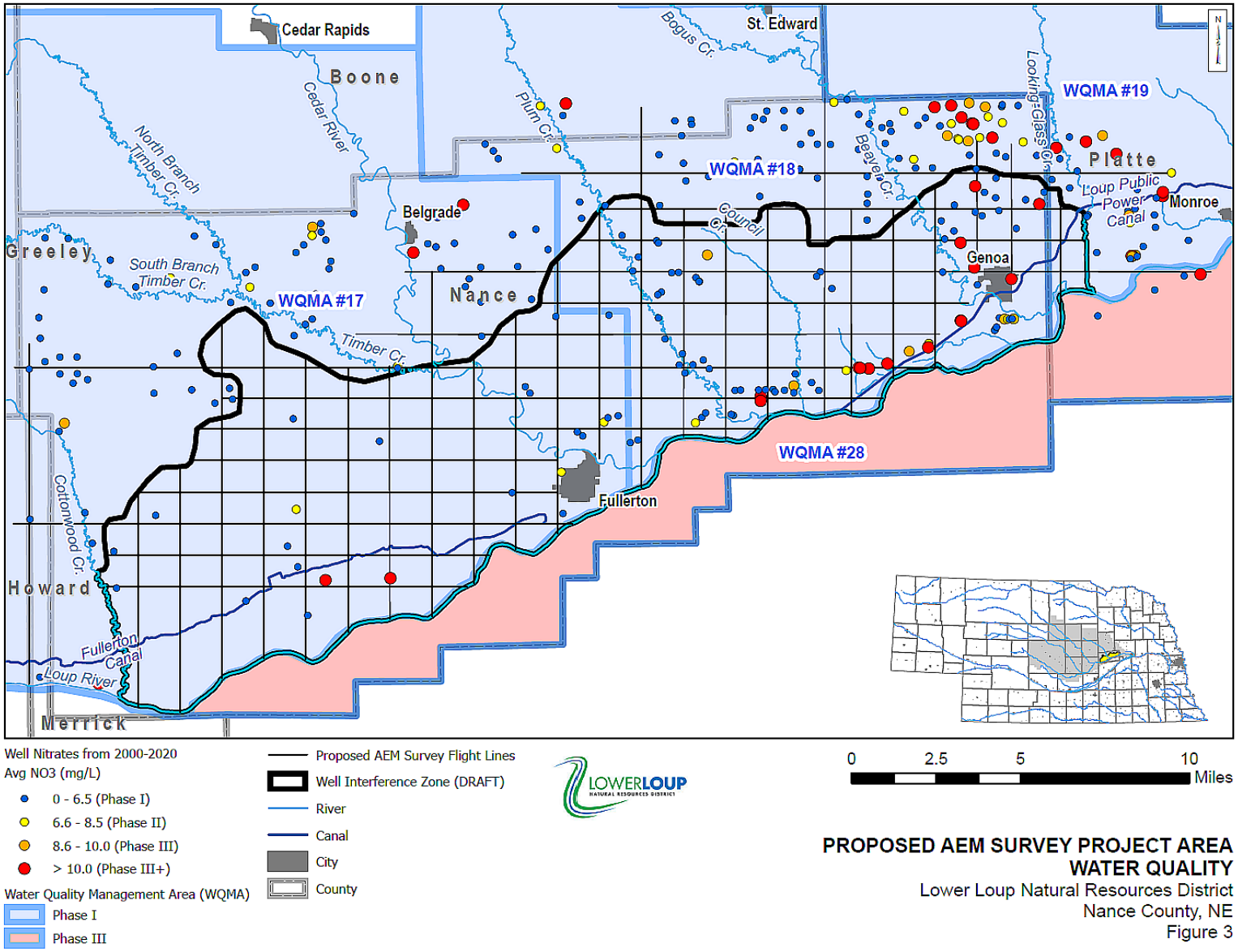



**Figure 2-2. Project area water quality map. Modified from Figure 3 of WSF 2022 proposal.**

# 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, 2022), including 17 wells within and adjacent to the project boundary with information from boreholes (lithology and stratigraphy) drilled between 1930 and 2022 by the CSD and other cooperating agencies; and 2) NE-DNR registered wells database, including 1,464 wells within and adjacent to the project boundary (Nebraska Department of Natural Resources, 2022) (Figure 3-1). The boreholes used in this study can be found as ESRI shapefiles in the *Appendix 3 – Deliverables\Boreholes*.

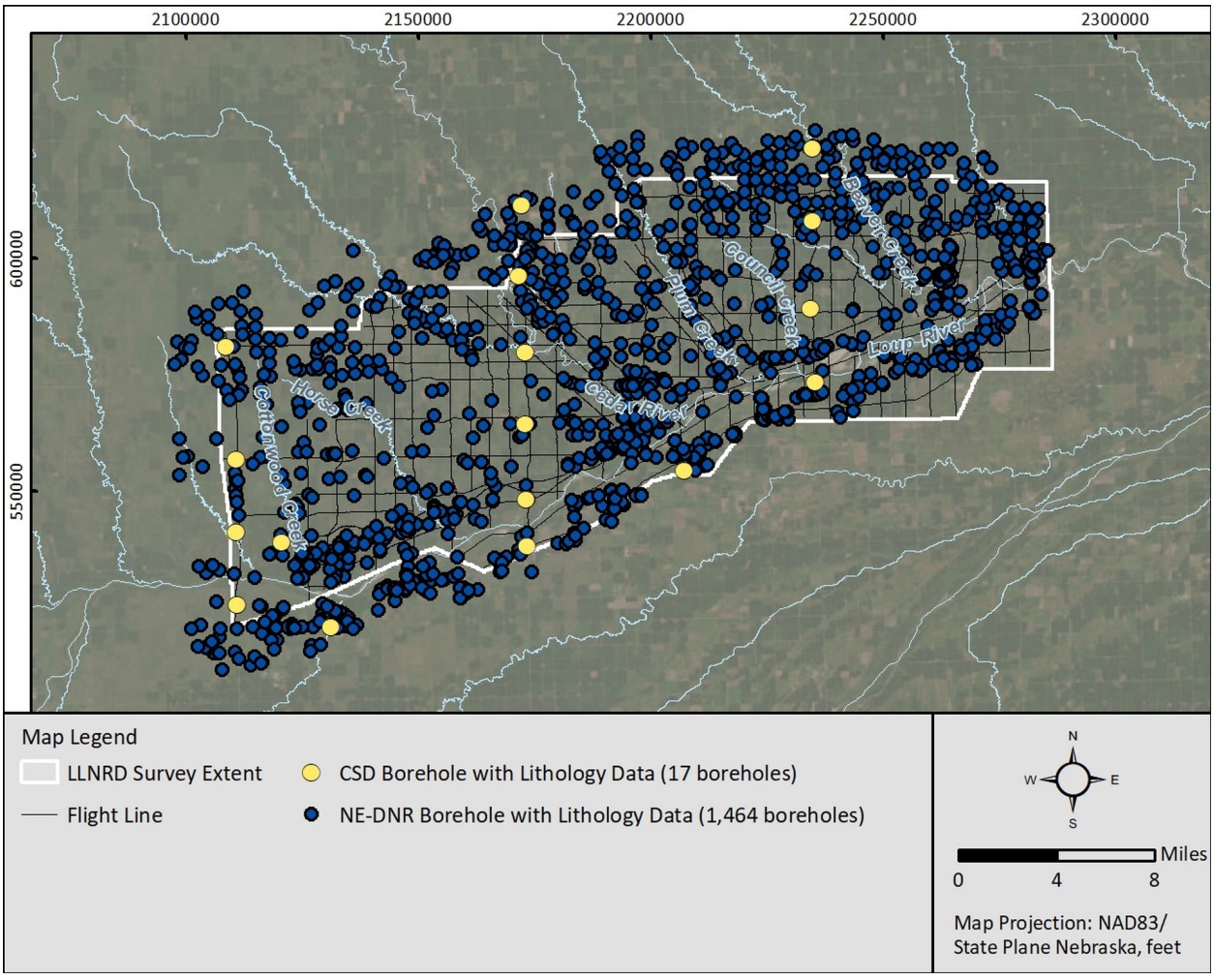



**Figure 3-1. NE-CSD borehole logs (yellow dots) (17 within and adjacent to the project boundary) used for quality control and interpretative purposes. NE-DNR borehole logs (blue dots) (1,464 within and adjacent to the project boundary) used for quality control and interpretative purposes. Map projection is NAD 83, Nebraska State Plane, in 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.

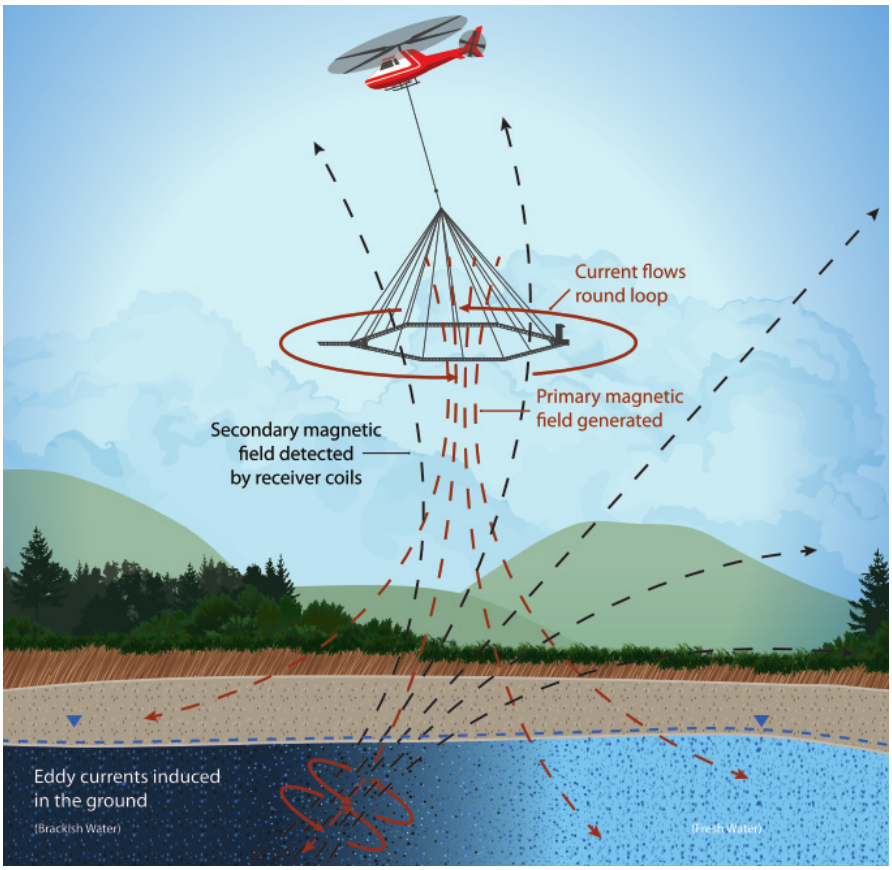



**Figure 4-1: Schematic of an airborne electromagnetic survey, modified from Carney et al. (2015).**

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.

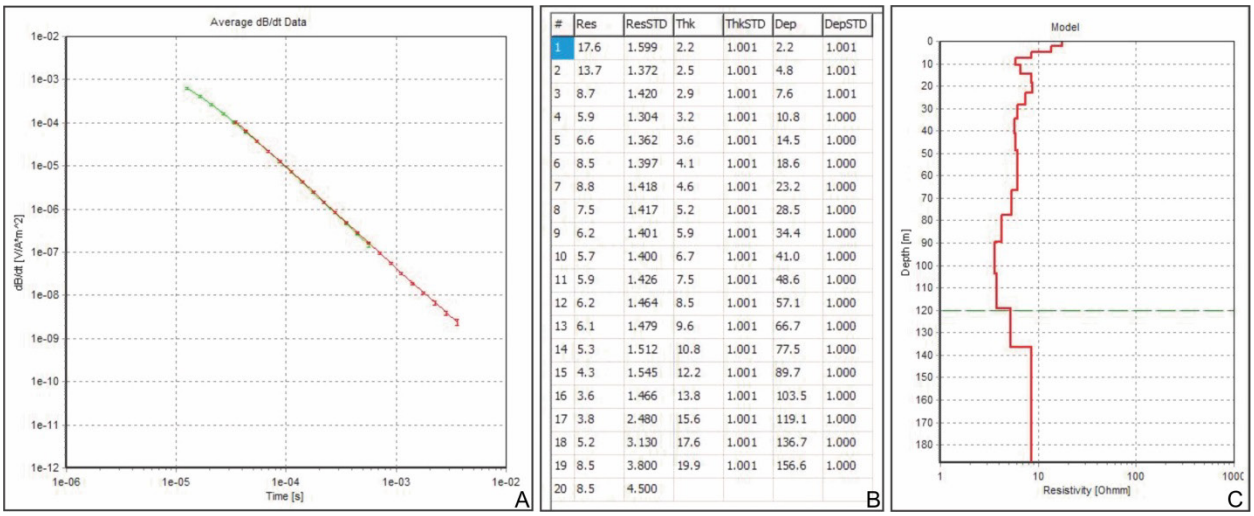



**Figure 4-2: A) Example of a dB/dt sounding curve. B) Corresponding inverted model values. C) Corresponding resistivity earth model.**

## 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 LLNRD, three types of utilities (pipelines, railroads, and power lines) were located. Various public power districts in Central Nebraska provided power line locations in Geographic Information Systems (GIS) ESRI shapefile format. Some areas did not have coverage available for power line locations and were mapped by inspection from Google Earth imagery.

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 LLNRD reconnaissance flight lines had a maximum length of approximately 24 miles (39 km) in the east-west direction and about 12 miles (19 km) at their longest in the north-south direction and about 31 miles (50 km) along the Loup River. The flight lines were

separated by approximately 0.62 mile (1 km) up to 1.5 miles (2.5 km) in both east-west and north-south directions.

## 4.3 AEM Survey Instrumentation

AEM data were acquired using the SkyTEM304 HR75 (304 HR75) airborne electromagnetic system (SkyTem Airborne Surveys Worldwide, 2022). The 304 HR75 is a rigid frame, dual-magnetic moment (Low and High) TEM system. The area of the 304 HR75 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 HR75 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 HR75 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 HR75 is also equipped with a Total Field magnetometer (MAG) and data acquisition systems for both instruments. The SkyTEM304 HR75 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 HR75 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 HR75 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 HR75 in operation.

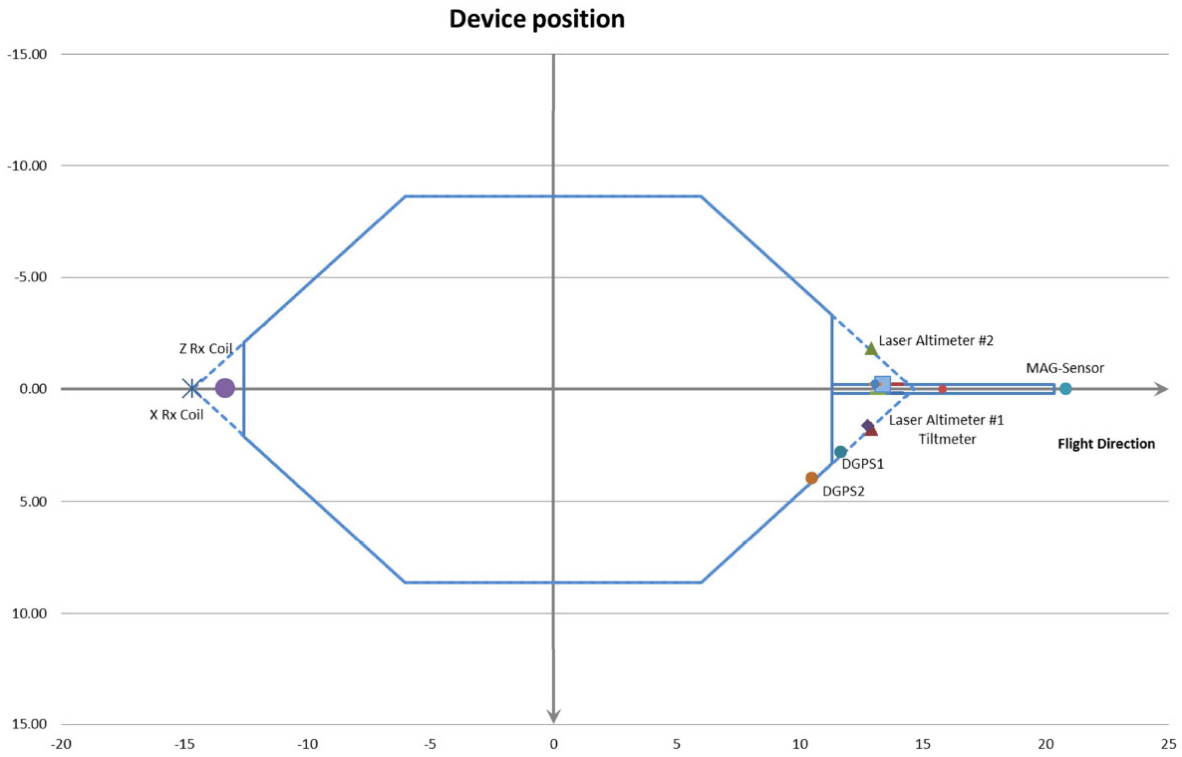



**Figure 4-3: SkyTEM 304HR75 frame, including instrumentation locations and X and Y axes. Distances are in meters. Instrumentation locations listed in Table 4-1.**



**Figure 4-4: Photos of the SkyTEM 304 HR75 system in suspension beneath the helicopter.**

**Table 4-1: Positions of instruments on the SkyTEM 304HR75 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 304HR75 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 HR75 system commenced at the beginning of the 2022 AGF AEM project campaign in Iowa and eastern Nebraska and the system was ferried to the Genoa Regional Airport on August 18, 2022. 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 531.1 line-miles (860.3 line-kilometers) were acquired over the LLNRD AEM survey area between 19 August 2022 and finishing on 21 August 2022. A data acquisition map for the flight lines is presented in Figure 4-5, grouped by acquisition date. For this LLNRD project, the 304 HR75 was flown at an average speed of 45.7 mi/hr (74.0 kilometers/hr) and at an average flight height of 133.1 ft (40.6 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 0.75 degrees and the average roll (tilt angle perpendicular to the direction of travel) was 2.34 degrees. Images of the LLNRD AEM survey ground speeds are presented in Figure 4-6. Flight heights are presented in Figure 4-7. Images of the pitch (X) angle and yaw (Y) angle are presented in Figure 4-8 and Figure 4-9, respectively.

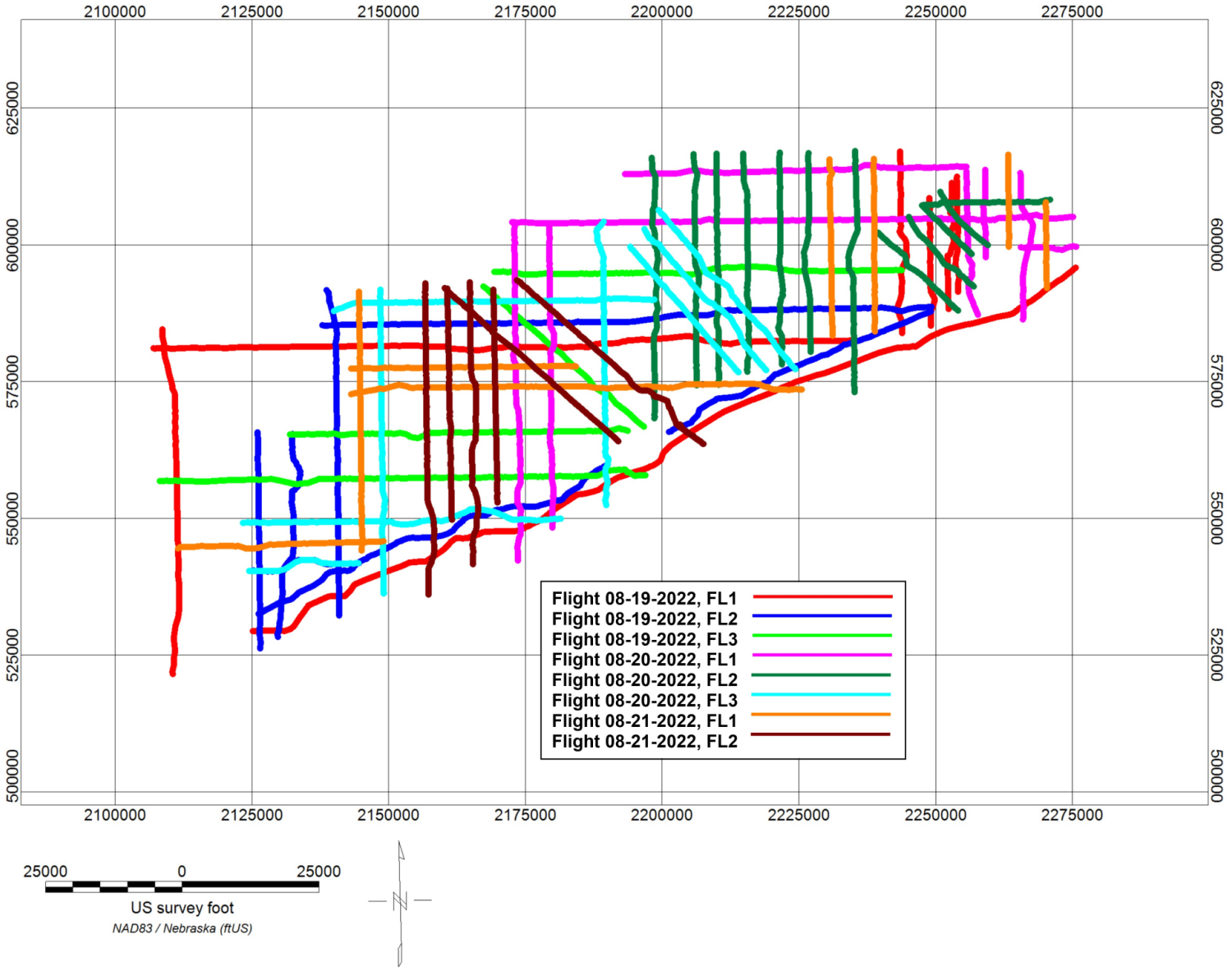



**Figure 4-5. LLNRD 2022 AEM flight lines grouped by acquisition date. Projection is Nebraska State Plane NAD83, feet.**

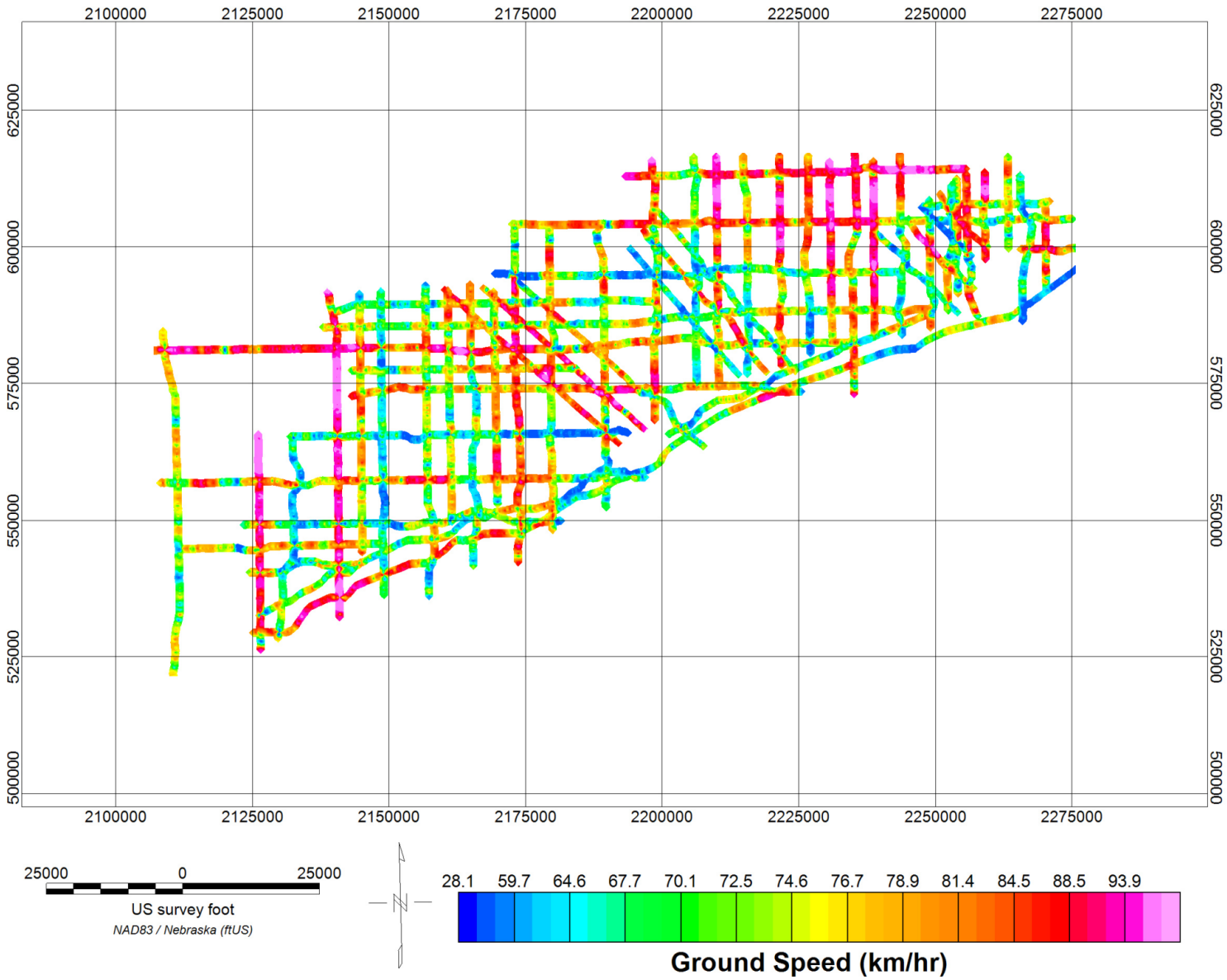



**Figure 4-6. LLNRD 2022 AEM flight lines ground speed. Projection is Nebraska State Plane NAD83, feet.**

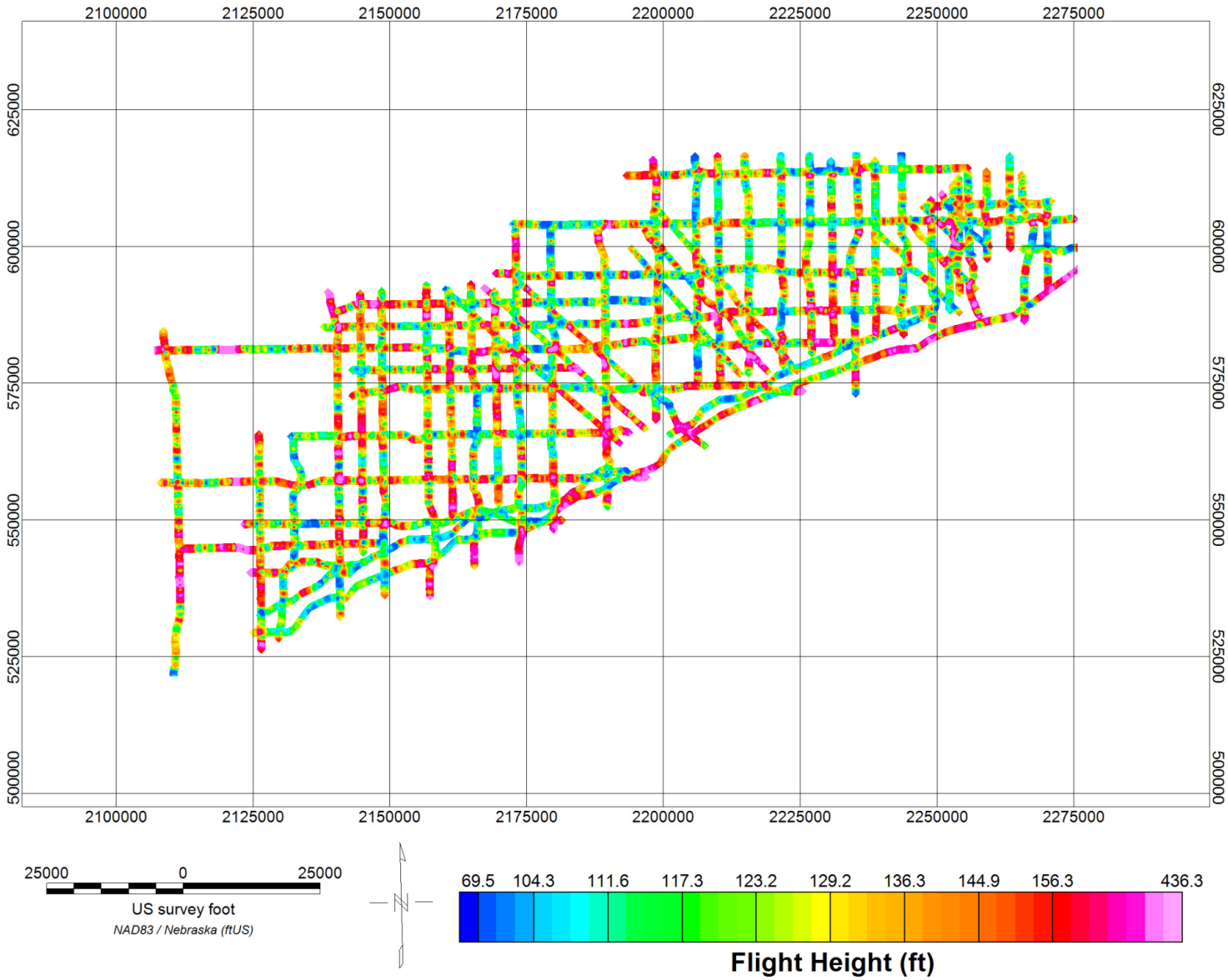



**Figure 4-7. LLNRD 2022 AEM flight lines flight height above the ground surface. Projection is Nebraska State Plane NAD83, feet.**

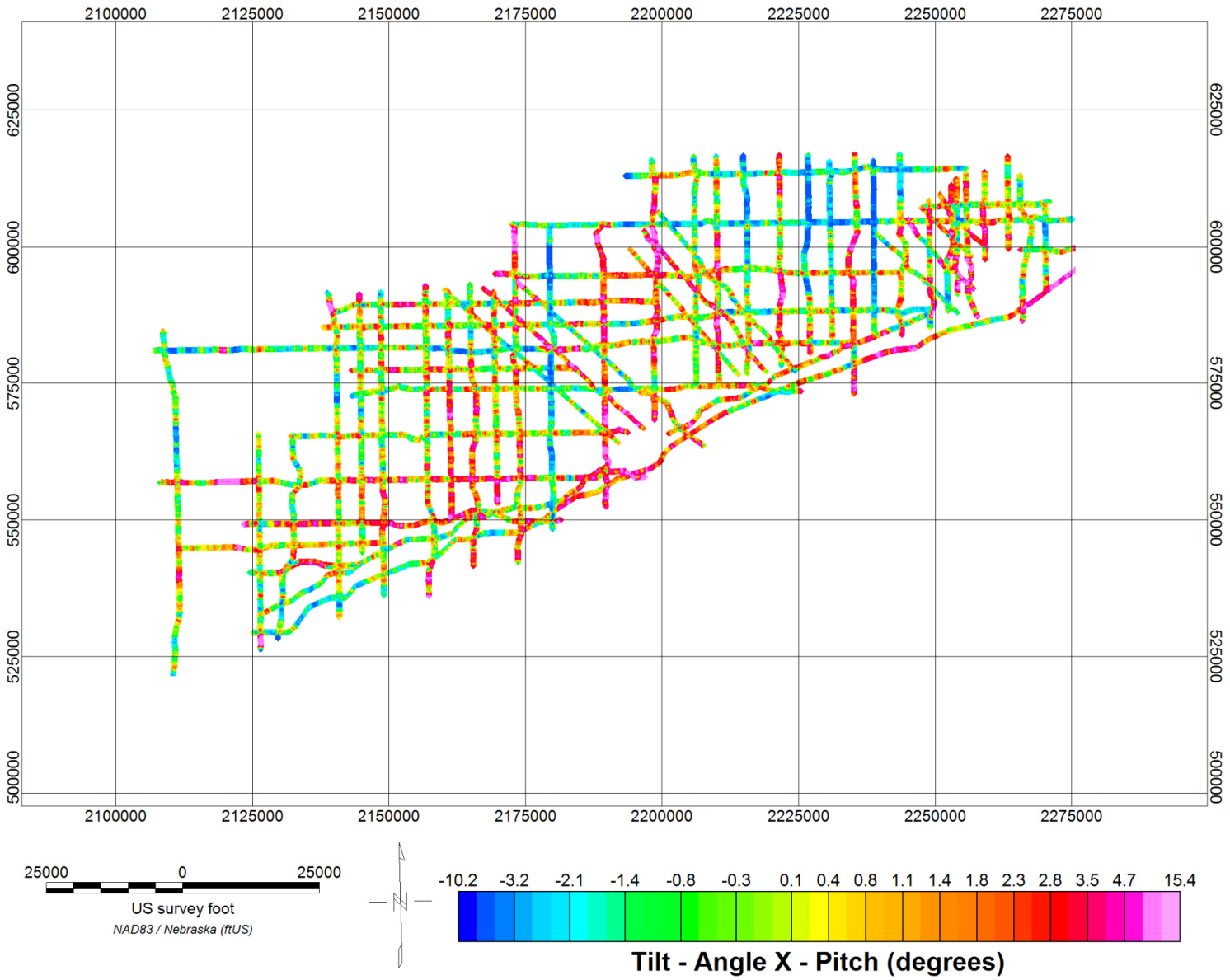



**Figure 4-8. LLNRD 2022 AEM flight lines pitch angle in the +/-X direction of travel. Projection is Nebraska State Plane NAD83, feet.**

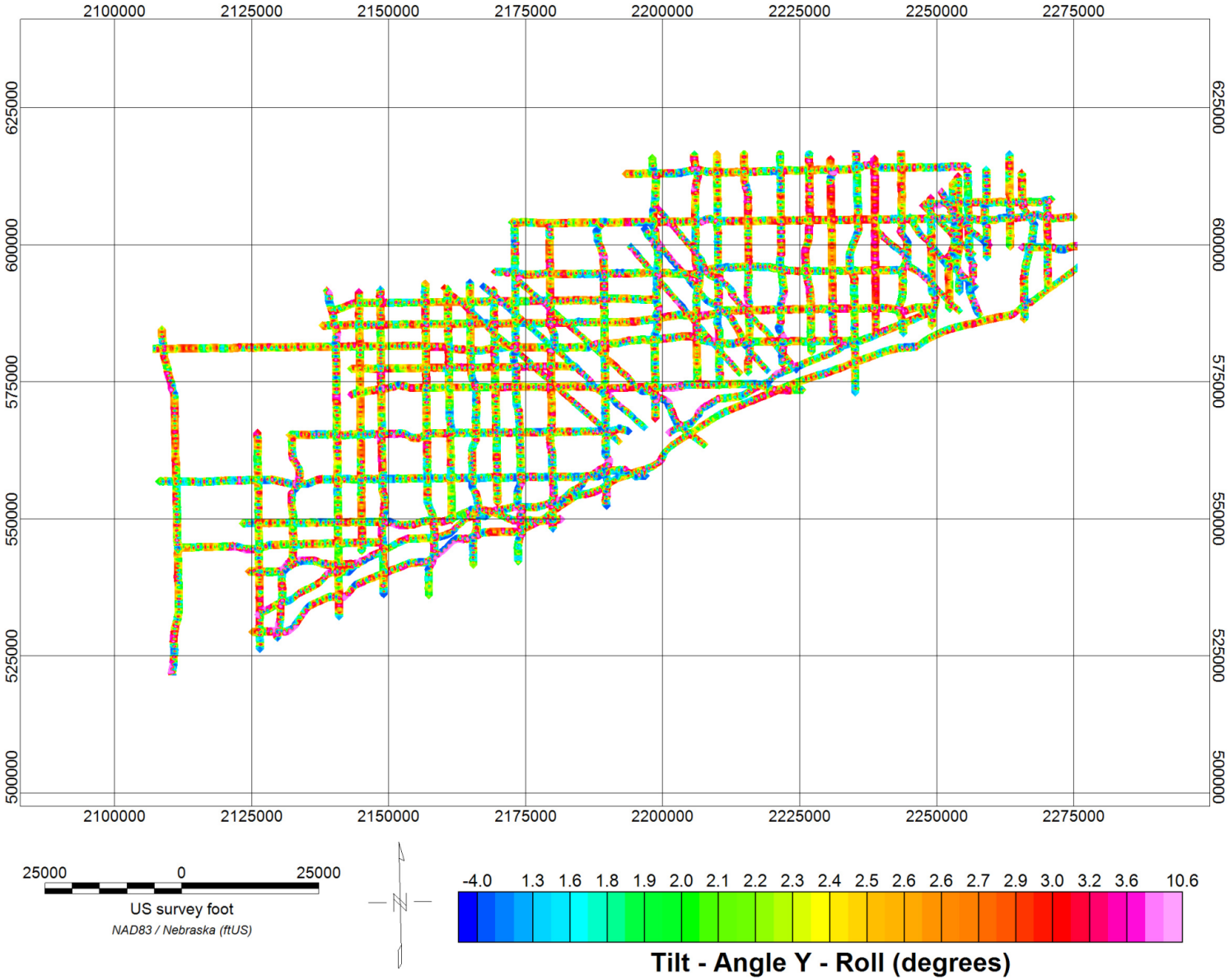



**Figure 4-9. LLNRD 2022 AEM flight lines Y yaw angle perpendicular to the direction of travel. Projection is Nebraska State Plane NAD83, feet.**

### 4.4.1 Primary Field Compensation

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

### 4.4.2 Automatic Processing

The AEM data collected by the 304 HR75 were processed using Aarhus Workbench version 6.7.0.0 (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, 462.5 line-miles (749.3 line-kilometers) were retained for inversion amounting to a retention rate of 87.1%. This high rate is the result of careful flight line planning and design to avoid the infrastructure present in the survey area.

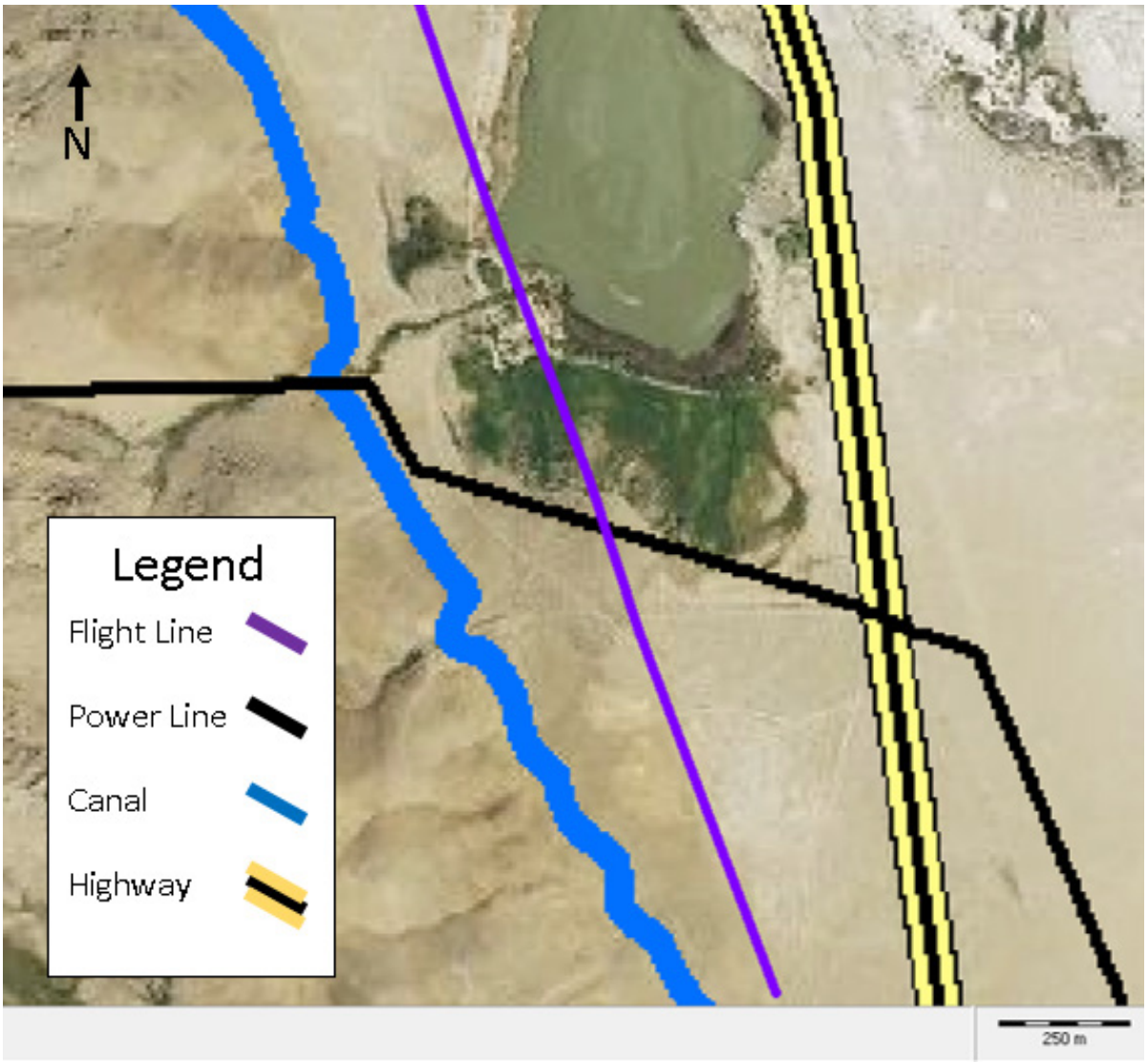



**Figure 4-10: Example locations of electromagnetic coupling with pipelines or power lines.**

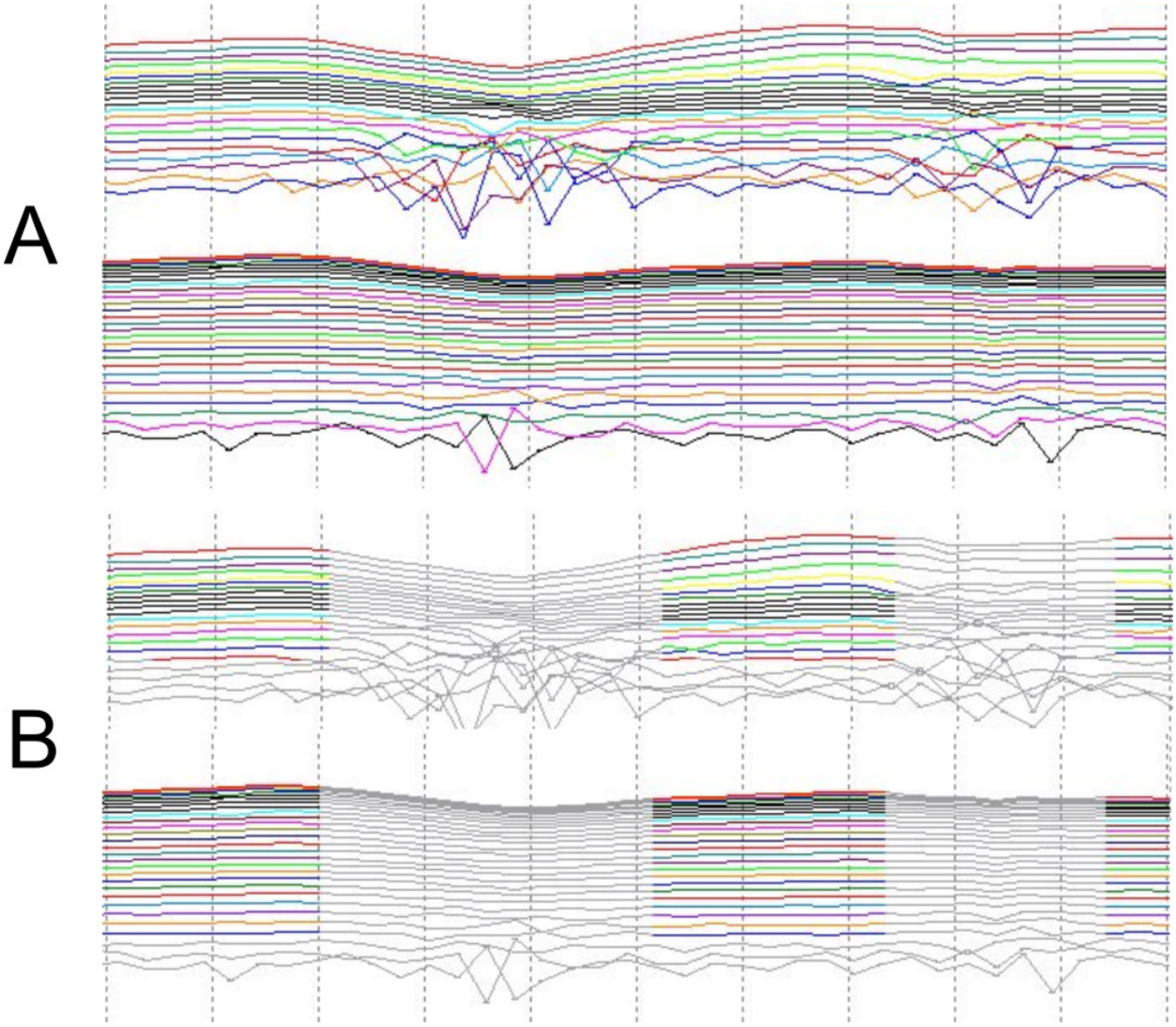



**Figure 4-11: A) Example of AEM data affected by electromagnetic coupling as presented in the Aarhus Workbench editor. The top group of lines is the unedited data with the Low Moment on top and the High Moment on the bottom. The bottom group shows the same data after editing.**

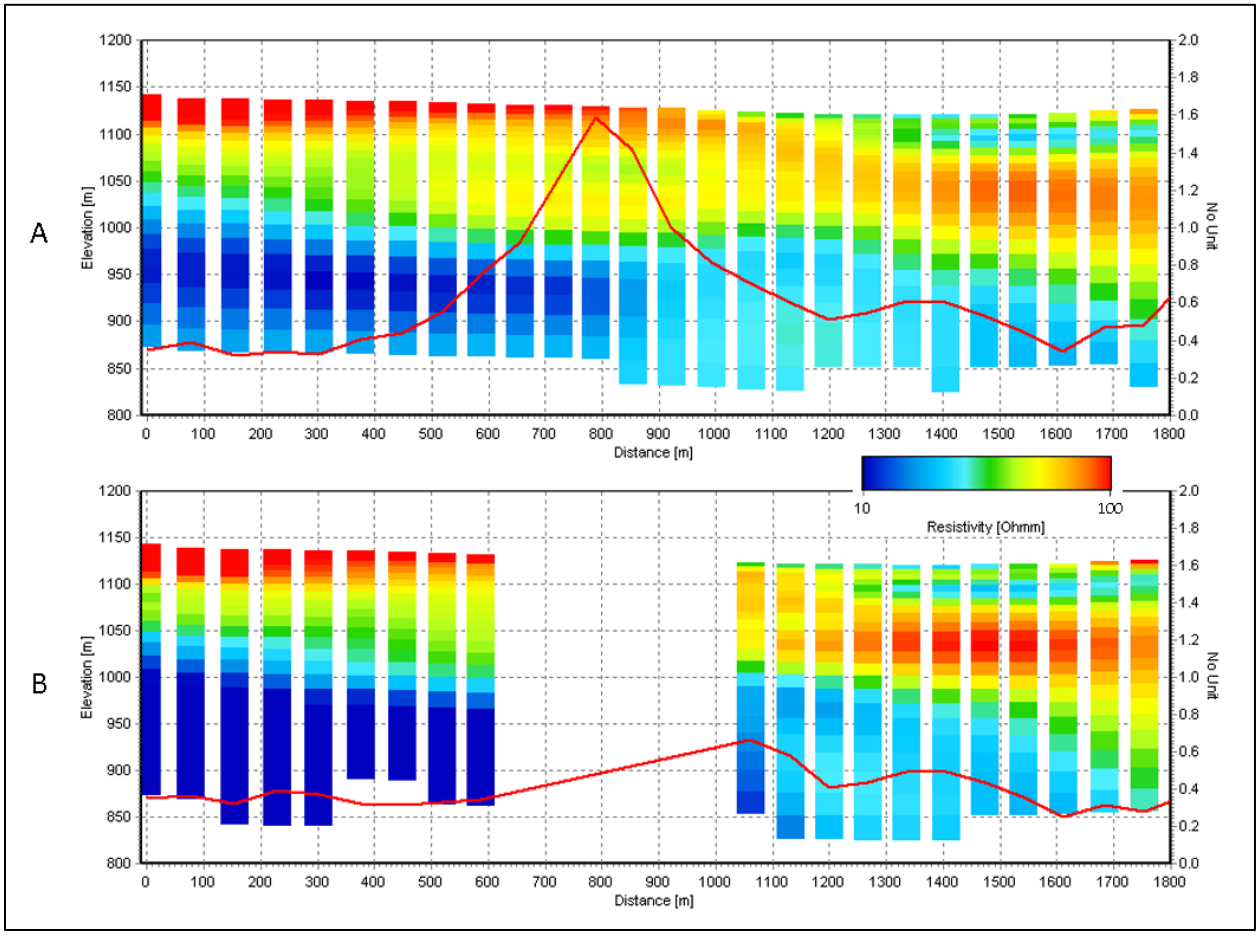



**Figure 4-12: A) Example of Laterally-Constrained inversion results where AEM data affected by coupling with pipelines and power lines were not removed. B) Inversion results where AEM data affected by coupling were removed.**

### *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 LLNRD 2022 AEM survey are presented as a grid in Figure 4-13. The LLNRD 2022 survey As-Flown data and the data retained for inversion are presented in Figure 4-14. The blue lines represent the 87.1% of data retained for inversion and red lines representing data removed due to infrastructure and noise.

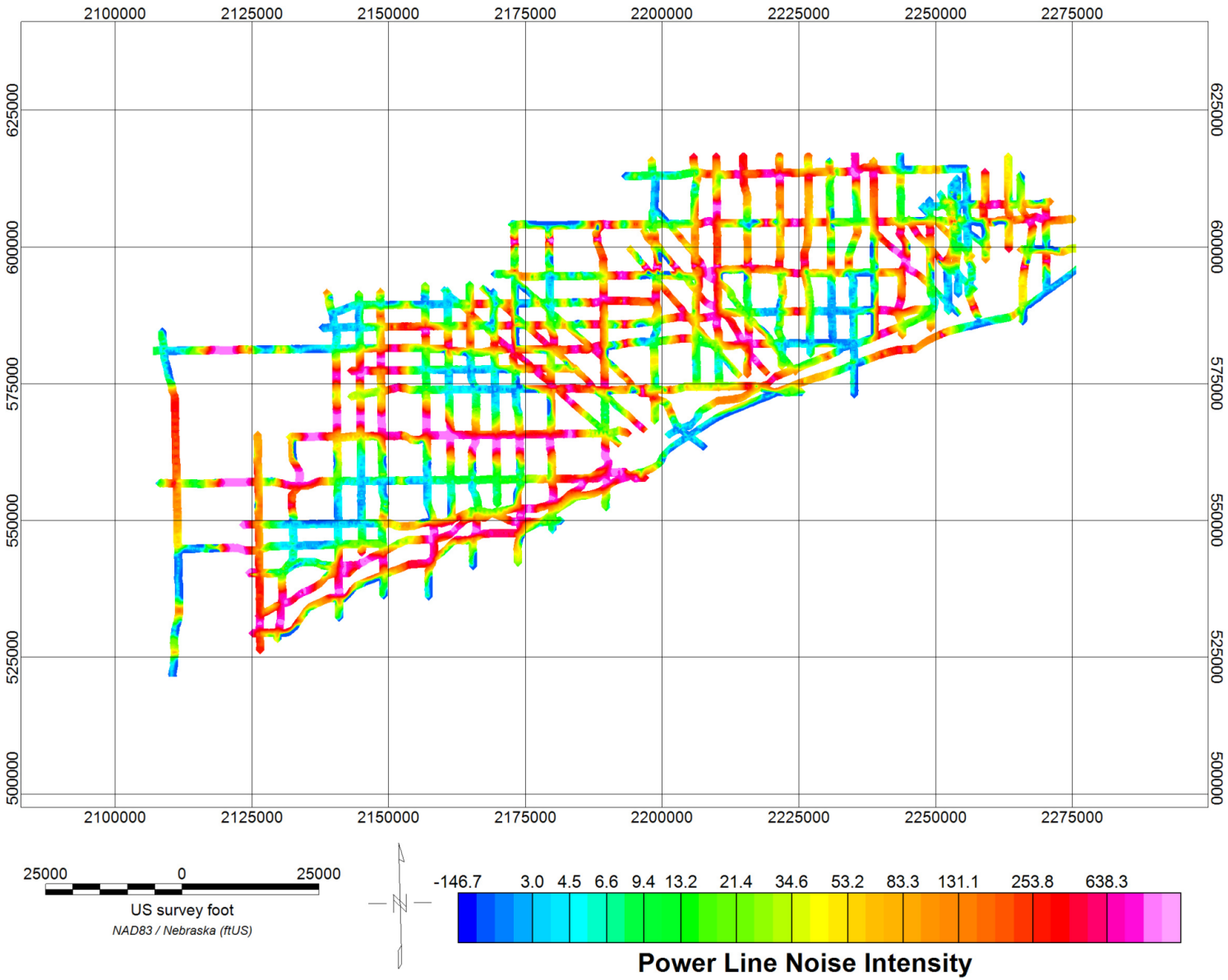



**Figure 4-13: Power Line Noise Intensity (PLNI) map of the LLNRD 2022 project area. Projection is Nebraska State Plane NAD83, feet.**

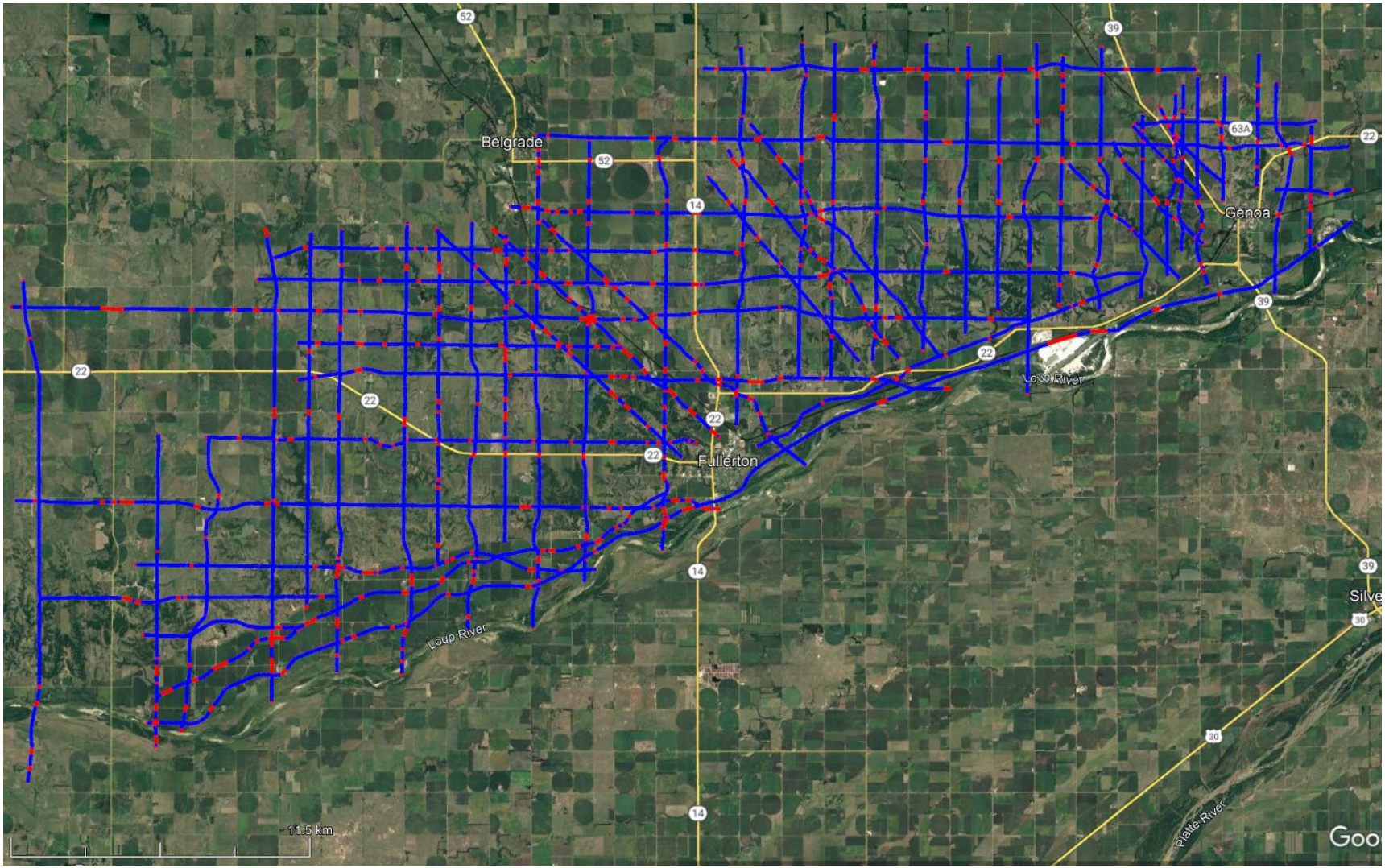



**Figure 4-14. Locations of inverted data (blue lines) along the AEM flight lines (red lines) on the LLNRD 2022 AEM survey area. Where blue lines are not present indicates decoupled (removed) data. Google Earth kmz's of the inverted data locations as well as the "as-flown" flight lines are included in Appendix 3\KMZ.**

### *4.4.5 Magnetic Field Data*

As discussed above, the SkyTEM 304 HR75 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 LLNRD AEM survey area after correcting for diurnal drift and removing the International Geomagnetic Reference Field (IGRF). This data is used in decoupling efforts.

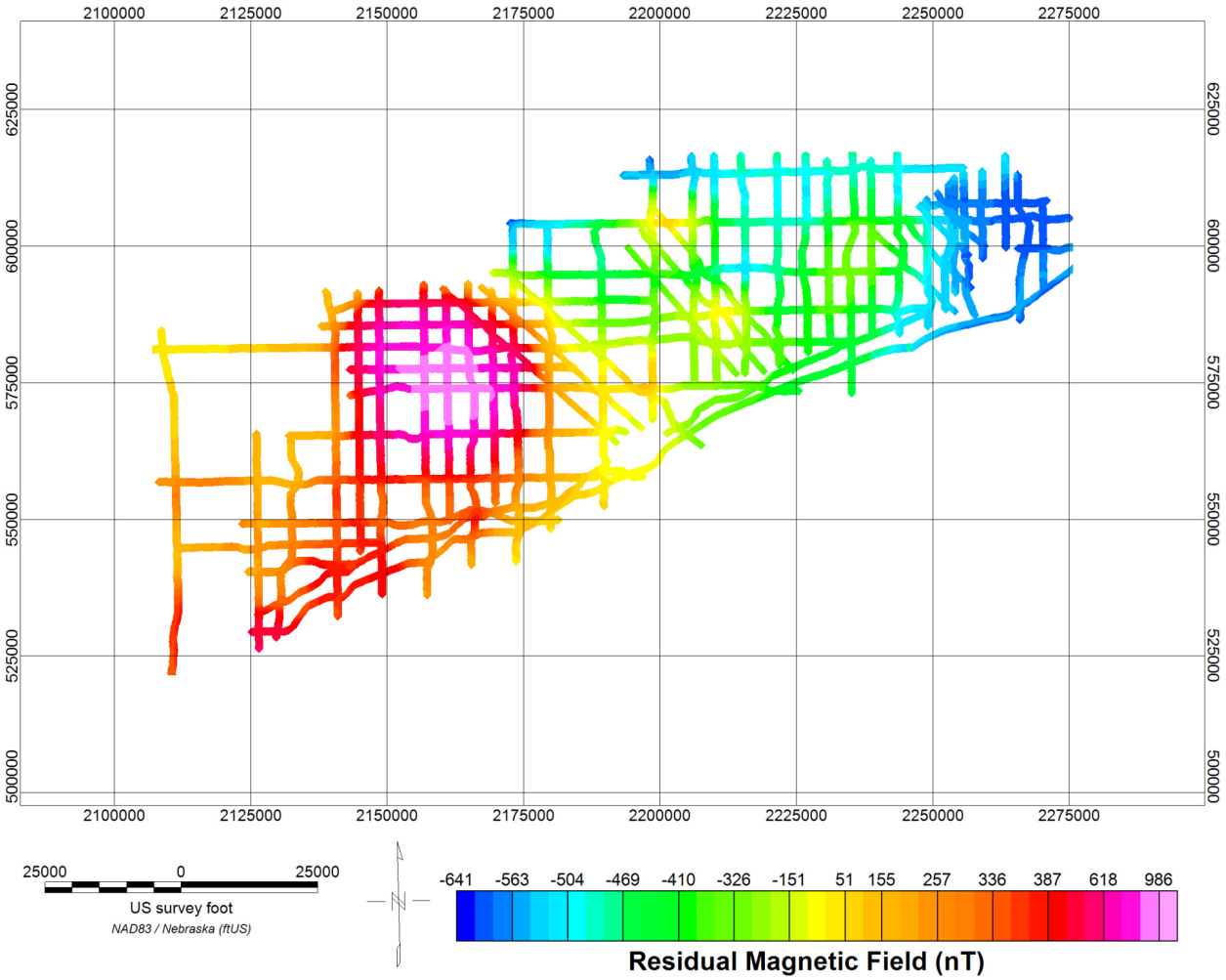



**Figure 4-15. Residual magnetic Total Field intensity data for the LLNRD 2022 AEM survey area corrected for diurnal drift, with the International Geomagnetic Reference Field (IGRF) removed. Projection is Nebraska State Plane NAD83, feet.**

## 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 LLNRD 2022 AEM data were inverted using a 40-layer model structure. The SCI inversions used smooth models, each with a starting resistivity of 40 Ohm-m (equivalent to a 40 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 39$^{th}$ layers were set to 328.1 ft, with thicknesses up to about 10.6 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.

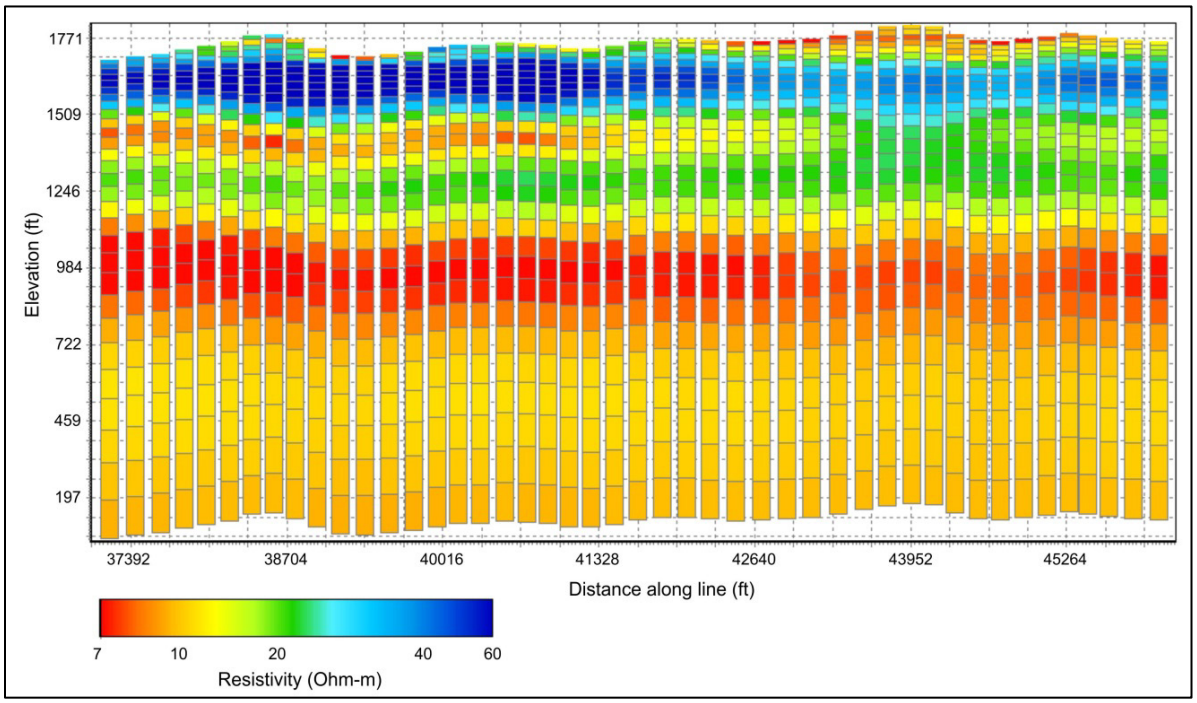



**Figure 4-16. An example of an AEM profile illustrating increasing model layer thicknesses with depth.**

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 | 6.56 | 6.60 | 2.00 | 2.00 | 21 | 156.68 | 8.43 | 47.76 | 2.57 |
| 2 | 13.21 | 6.64 | 4.03 | 2.03 | 22 | 165.22 | 8.54 | 50.36 | 2.60 |
| 3 | 19.94 | 6.73 | 6.08 | 2.05 | 23 | 173.87 | 8.65 | 52.99 | 2.64 |
| 4 | 26.75 | 6.81 | 8.15 | 2.08 | 24 | 182.63 | 8.76 | 55.66 | 2.67 |
| 5 | 33.65 | 6.90 | 10.26 | 2.10 | 25 | 191.50 | 8.87 | 58.37 | 2.70 |
| 6 | 40.64 | 6.99 | 12.39 | 2.13 | 26 | 200.48 | 8.98 | 61.10 | 2.74 |
| 7 | 47.71 | 7.07 | 14.54 | 2.16 | 27 | 209.57 | 9.09 | 63.88 | 2.77 |
| 8 | 54.88 | 7.17 | 16.73 | 2.18 | 28 | 218.78 | 9.21 | 66.68 | 2.81 |
| 9 | 62.13 | 7.25 | 18.94 | 2.21 | 29 | 228.11 | 9.32 | 69.52 | 2.84 |
| 10 | 69.48 | 7.35 | 21.18 | 2.24 | 30 | 237.55 | 9.44 | 72.40 | 2.88 |
| 11 | 76.92 | 7.44 | 23.44 | 2.27 | 31 | 247.12 | 9.56 | 75.32 | 2.92 |
| 12 | 84.45 | 7.53 | 25.74 | 2.30 | 32 | 256.80 | 9.68 | 78.27 | 2.95 |
| 13 | 92.08 | 7.63 | 28.07 | 2.33 | 33 | 266.60 | 9.81 | 81.26 | 2.99 |
| 14 | 99.80 | 7.72 | 30.42 | 2.35 | 34 | 276.53 | 9.93 | 84.28 | 3.03 |
| 15 | 107.63 | 7.82 | 32.80 | 2.38 | 35 | 286.59 | 10.06 | 87.35 | 3.07 |
| 16 | 115.55 | 7.92 | 35.22 | 2.41 | 36 | 296.77 | 10.18 | 90.45 | 3.10 |
| 17 | 123.57 | 8.02 | 37.66 | 2.45 | 37 | 307.08 | 10.31 | 93.59 | 3.14 |
| 18 | 131.69 | 8.12 | 40.14 | 2.48 | 38 | 317.52 | 10.44 | 96.78 | 3.18 |
| 19 | 139.92 | 8.23 | 42.65 | 2.51 | 39 | 328.09 | 10.57 | 100.00 | 3.22 |
| 20 | 148.25 | 8.33 | 45.18 | 2.54 | | | | | |

Figure 4-17 presents a histogram of the LLNRD 2022 SCI inversion data/model residuals and a map of data to model error residuals comparison is presented in Figure 4-18.

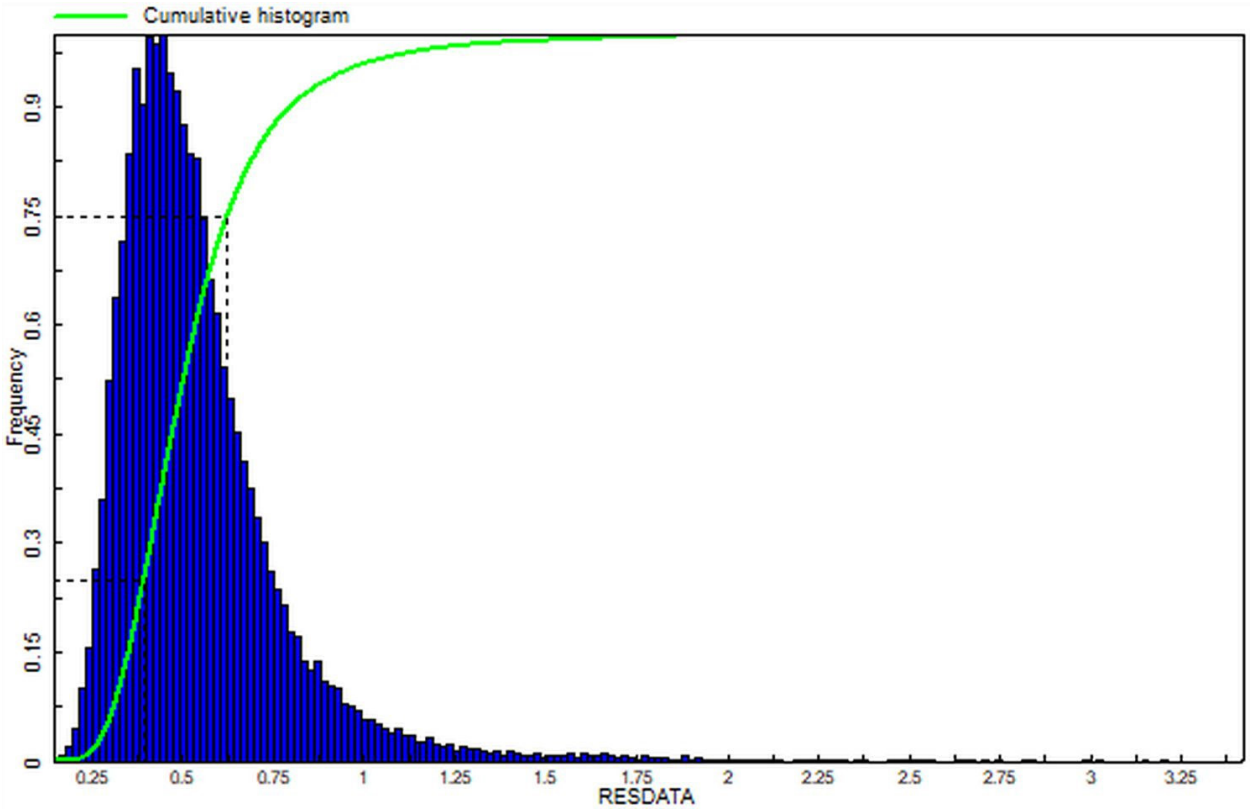



**Figure 4-17. Data/model residual histogram for the LLNRD 2022 SCI inversion results.**

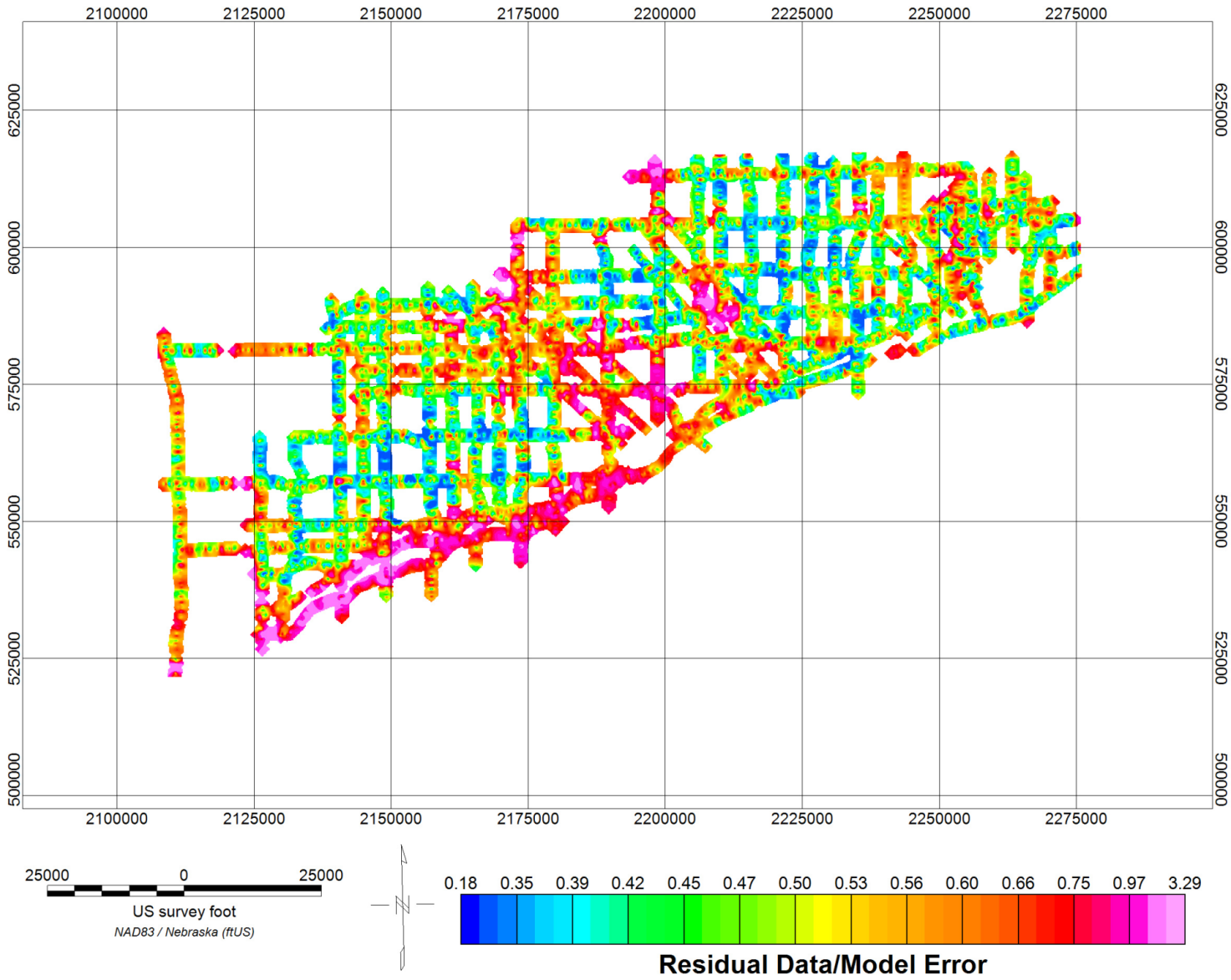



**Figure 4-18. Map of data-inversion model residuals for the LLNRD 2022 SCI inversion results. Projection is Nebraska State Plane NAD83, feet.**

# 5 AEM Results and Interpretation

This section provides the details on the process involved in the interpretation of the LLNRD 2022 AEM Nance County data and inversion results.

## 5.1 Interpretative Process

### *5.1.1 Merging AEM Flight Lines*

After the inversion process, lines from the 2016 LLNRD AEM survey (AGF, 2017) were merged into the area of the Nance County. The resultant combined area allows for improved viewing and interpretation of the Nance County AEM inversions results. Figure 5-1 is a map of the 2022 Nance County AEM survey with the lines that were combined from the 2016 LLNRD AEM survey.

### *5.1.2 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 constructed for the LLNRD survey. The data was downloaded from the National Elevation dataset (NED) located at the National Map Website (U.S. Geological Survey, 2022) at a resolution of 1/3 arc-second or approximately 30 ft. The geographic coordinates are North American Datum of 1983 (NAD 83) and the elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88). The 30 ft grid cell size was resampled to 300 ft to match the cell size used throughout the project and resulting products. Figure 5-2 is a map of the DEM showing a vertical relief of 703 ft with a minimum elevation of 1,479 ft and a maximum elevation of 2,182ft. This DEM was used to reference all elevations within the AEM and borehole datasets.

### *5.1.3 Borehole-Only Surface of the Bedrock*

As a guide in the interpretation of the AEM, a "borehole-only" bedrock surface was prepared using CSD and NE-DNR borehole logs in combination with published geologic maps. For conciseness, the bedrock surface interpolation process is broken down into the following bulleted list:

Data used:

- USGS Map I-2725, "Geologic Maps and Cross Sections Showing Configurations of Bedrock Surfaces, Broken Bow 1 degree by 2 degree Quadrangle, East-Central Nebraska" by Souders (2000)
    - Map extends across the west half of the survey area only.
- USGS Map I-905, "Bedrock Geologic Map Showing Thickness of Overlying Quaternary Deposits, Fremont Quadrangle and Part of Omaha Quadrangle, Nebraska" by Burchett et. al. (1975)
    - Map extends across the east half of the survey area only.

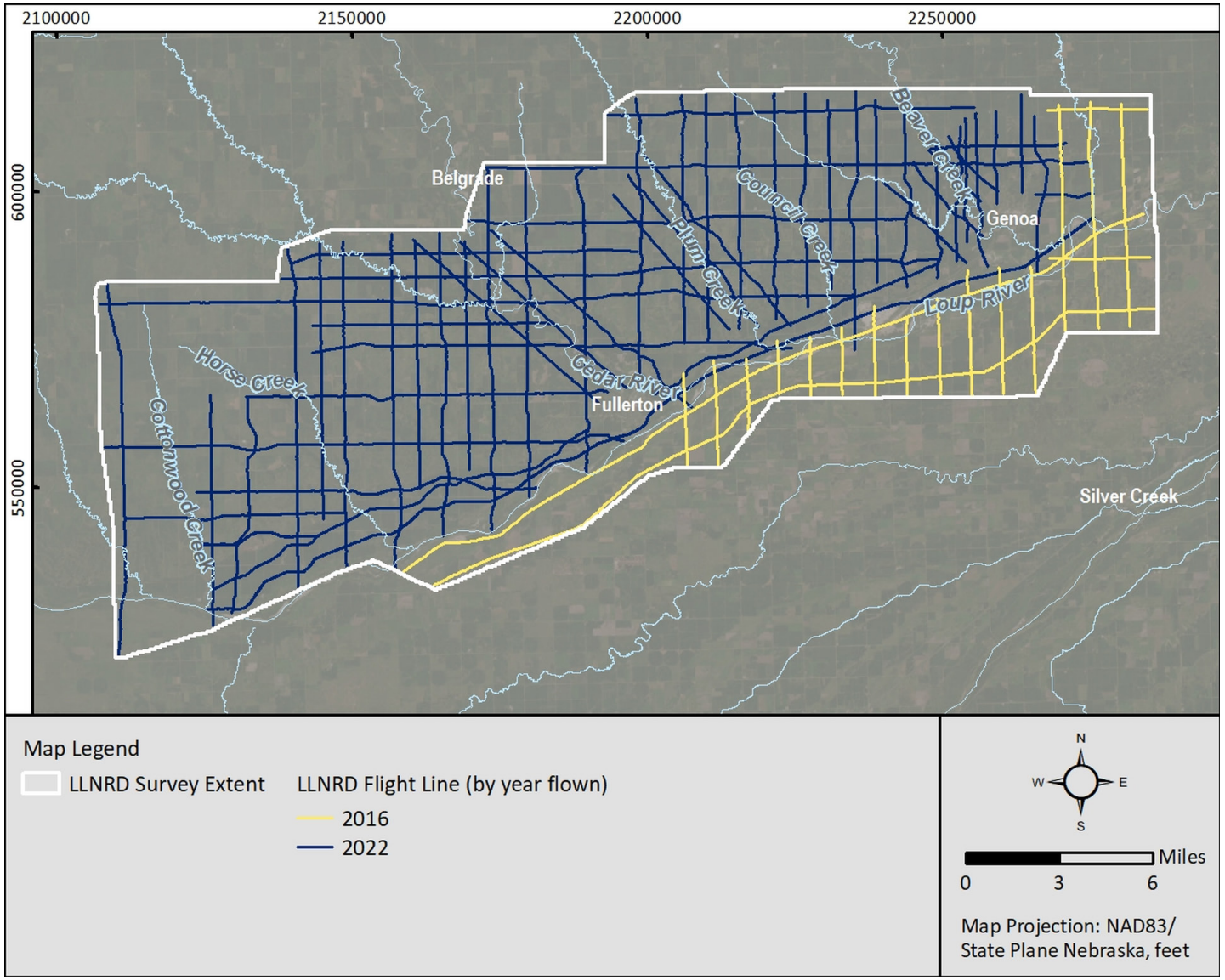



**Figure 5-1. Map of the 2022 Nance County AEM Survey flight lines and the flight lines that were merged in from the 2016 LLNRD AEM survey (AGF, 2017). Map projection is NAD83/State Plane Nebraska, feet.**

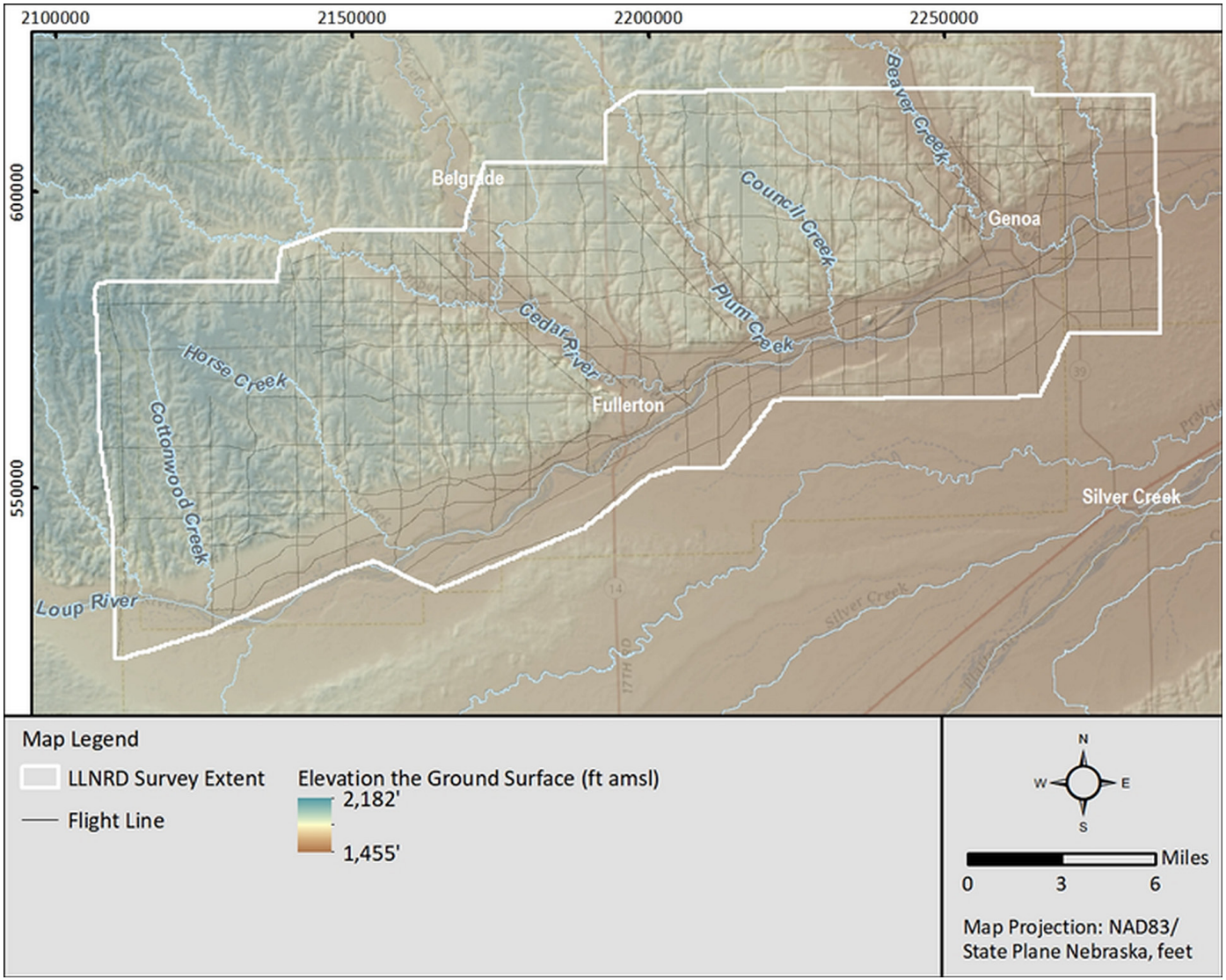



**Figure 5-2. Map of the Digital Elevation Model for the 2022 Nance County AEM Survey Area. Data source is the one-third (1/3) arc -second National Elevation Dataset (U.S. Geological Survey, 2022). The elevation values are referenced to the North American Vertical Datum of 1988 (NAVD 88) (feet).**

- Most up to date DNR and CSD borehole data downloaded from Nebraska GeoCloud

- Published USGS Maps processing:
    - USGS Map I-2725
        - Digitize the contours from the main map that represented the "top elevation of bedrock" (ie. top of ***To***).
        - Digitize the contours from the inset map that represented the base of the ***To***.
        - Convert the two sets of digitized contours to raster datasets.
    - USGS IMAP-905
        - Digitize the contours representing the thickness of the ***Q*** deposits.
        - Convert the contours to a ***Q*** deposits thickness raster dataset.
        - Subtract the ***Q*** deposits thickness dataset from the DEM.
            - The resultant raster dataset is equal to the bottom of ***Q*** deposits, or the top elevation of ***To*** (where it exists).
- DNR borehole processing
    - Extract DNR boreholes within 1.2 miles (2 km) of the planned flight lines
        - 1,674 boreholes are included in the dataset for analysis (dataset referred to as 'working borehole lithology dataset').
    - Extract the elevation values from the raster datasets created from the published geologic maps to the DNR boreholes.
    - Extract project DEM elevation to the DNR boreholes.
    - In a spreadsheet, categorize each borehole's lithology description as either 'Bedrock' or 'Unconsolidated' based on the description type.
        - For example:
            - Sandstone, Shale, Siltstone, Limestone, Chalk = 'Bedrock'
            - Clay, silt, gravel/boulders, etc. = 'Unconsolidated'
    - Review the dataset and flag those boreholes where an 'Unconsolidated' lithologic description was underlying a 'Bedrock' description or where the bedrock value differed greater than 30 ft from the published geologic map values.
    - Revise categorized lithology, as needed, or flag boreholes for removal from the working borehole lithology dataset.
    - Number of DNR boreholes remaining in the working borehole lithology dataset after review and removal = 668.
        - Many of the boreholes were removed from the dataset because no bedrock was indicated in the lithologic log.
- CSD borehole processing
    - Add the CSD borehole stratigraphy table to the working borehole lithology dataset.
    - Number of CSD boreholes included in the working borehole lithology dataset=33.

Borehole bedrock elevation interpolation:

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

    - Final borehole shapefile used for interpolation contained 701 data points and is depicted in Figure 5-3 below.
- Interpolate the borehole point shapefile into a continuous raster dataset using the kriging geostatistical model and export to a 300 ft cell size grid.
- Calculate the residuals of the actual measured top of bedrock elevation to the interpolated top of bedrock elevation.
- Review any borehole where the residual was > 30 ft or < -30 ft. The value of 30 was used because it is a general representation of the degree of error while logging a borehole with mud rotary drilling techniques as it is approximately one drill stem length. Flag those boreholes that appear to be anomalous.
    - Boreholes 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-interpolate 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 bedrock surface was utilized for two processes:

1. The surface assisted with flight line planning. Fill-in flight line extents were selected partly based on the resultant top of bedrock configuration, and
2. The surface acted as a guide in the interpretation of the bedrock within the AEM data profiles described next.

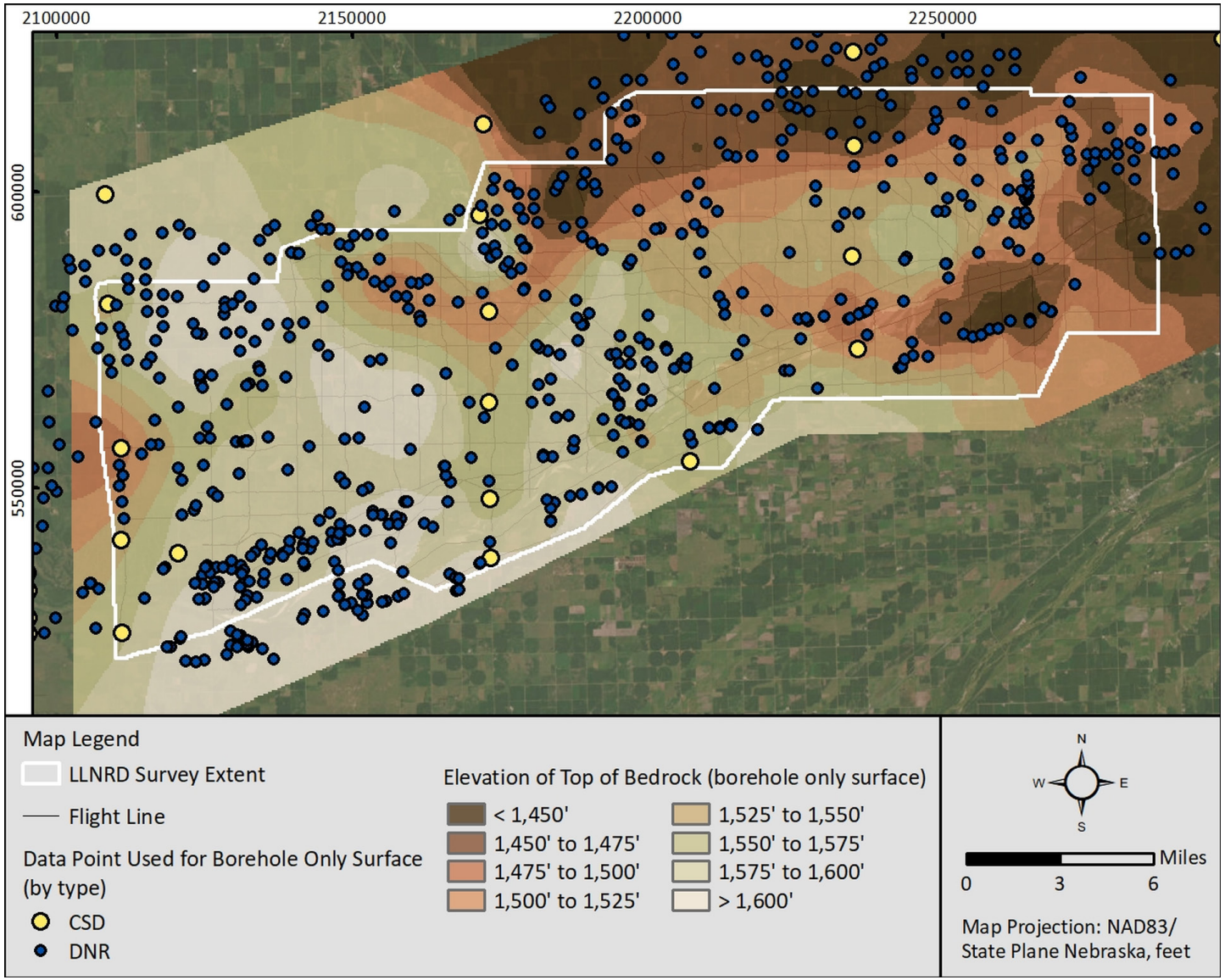



**Figure 5-3. Map of the elevation of the borehole only bedrock surface in the 2022 Nance County AEM Survey Area. Boreholes used in the development of the surface are indicated on the map. Map projection is NAD83/State Plane Nebraska, feet.**

### *5.1.4 Create Interpretative 2D Profiles*

After final combination of the AEM data, characterization of the subsurface was performed in cross-section format using Datamine Discover Profile Analyst (Datamine, 2023). During interpretation, the horizontal and vertical scale of the profiles were adjusted to facilitate viewing. The color scale of the resistivity data was also adjusted to illuminate subtle differences in the resistivity structure within the inverted AEM resistivity data related to the area being interpreted. The first step in the interpretation is digitizing the contacts between the geologic units including: Quaternary (***Q***), Tertiary Ogallala Group (***To***), Cretaceous Pierre Shale (***Kp***), and the Cretaceous Niobrara Formation (***Kn***). The interpretive process benefited from the use of CSD and NE-DNR borehole logs which provided lithologic, stratigraphic, and geophysical information. The interpretations were simultaneously checked against the CSD's Nebraska bedrock geology map (Burchett, 1986), but horizontal extents of geologic units may differ due to the final interpretation of the AEM. The interpretation began with picking the ***Kn/Kp*** and ***Kn/To*** contact, next the ***Kp/To***, and finally the ***To/Q*** contact. The borehole-only surface was mapped on the profiles and was used as a guide for the interpretation. The interpretation of the ***Kn*** included examining the AEM profile section for a high electrical resistivity layer that was also indicated in the borehole logs as the base of aquifer. Many of the CSD as well as the NE-DNR borehole logs stop at the ***Kn*** due to that stratigraphic unit not being considered an aquifer since it is composed predominantly of limestone and shale. Many of the CSD boreholes have stratigraphic calls that assist in the location of the ***Kn***. For the profiles, the clipping distance from the flight line was set independently for the CSD boreholes and the NE-DNR boreholes. Typically, the CSD clipping distance was set to 1,500 ft and the NE-DNR boreholes was set to 1,000 ft. The inversion DOI was also inspected during interpretation of the profiles. ***The Kn/Kp*** contact is typically identified by the low electrically resistivity ***Kp*** overlying the electrically resistive ***Kn***. The ***Kn*** can be challenging to interpret due to the variable nature of the limestone and shale and the often lack of electrical contrast with the variable electrical resistivity of the ***To***. This is the reason the borehole-only surface was used as a reference in the interpretation of the ***Kn/Kp*** and ***Kn/To*** contact.

The interpretation of the ***To/Q*** contact included examination of the CSD and NE-DNR boreholes and comparison with the AEM resistivities. The borehole information is critical in the determination of an estimated top of the ***To***. The following characteristics were used to locate the top of the ***To***: 1) ***To*** indicated on the CSD borehole stratigraphic logs; 2) indication of sandstone, siltstone, or shale in the CSD borehole lithology logs; 3) indication of sandstone, siltstone, shale in the NE-DNR lithology logs; and 4) a generally lower electrical resistivity than the overlying ***Q*** loess deposits. Patterns in the resistivity were also used to match the difference in the ***Q*** and the ***To***. In the areas of coarse ***To*** deposits and Quaternary Alluvial ***Qal*** deposits, the interpretation is more challenging due to lack of resistivity contrast. Resistivity zone patterns were used to match these areas and continuations of the ***To*** from under the low resistivity loess deposits were used to estimate the contact. It should be noted that the top of the ***To*** as interpreted is an estimate. This is due to the challenge of both the lithology interpretation of drill cuttings of the ***To*** and the low electrical resistivity contrast. Throughout this report the ***To*** will be shown as a dashed line and care needs to be exercised in the use of the interpreted top of To surfaces.

Figure 5-4 is an approximately 22-mile-long east-west line, L200801, which crosses Timber Creek, Cedar River, Plum Creek, and Council Creek north of the Loup River. The line is in the middle of the western side of the LLNRD 2022 Nance County survey area. There is a single CSD test hole along the line within 1,500 feet, *27-A-55*, at which the AEM and the CSD test hole both indicate the ***Kn*** at depth. *27-A-55* also indicates the ***To***. A large area of low resistivity material clay is noted above the ***Kn*** on the western side of the profile. Several NE-DNR registered wells are also in the area and indicate sandstone. The high resistivity zone along the Cedar River indicates the sand associated with the alluvial deposits. On the eastern side of the line the loess is also indicated as low electrical resistivity near the surface. Just north of the river, a zone of low resistivity material is indicated by clay in the NE-DNR registered wells. There are slight differences in the elevation of the top ***Kn*** from the borehole only and the interpretation of the AEM. The white areas within the profiles are zones that were cut from the AEM data due to EM-coupling.

Figure 5-5 is an approximately 12.5-mile-long north-south line, L100101, that is west of the Nance County boundary, on the far west of the LLNRD 2022 AEM survey area, and crosses the Loup River on the south end of the line. There are four CSD test holes along the line, from north to south, *42-A-56*, *41-A-56*, *40-A-56*, and *11-A-51*. The AEM and the CSD test holes both indicate that the ***Kn*** and ***Kp*** is present. Along this line the ***Kp*** is only present on the southern end. Several of the NE-DNR registered wells also indicate the top of the ***Kp*** and **Kn** due to their depth extent and the ***Kp*** not being an aquifer. The CSD test holes also indicate the ***To*** and that section is composed of both sandstone and sand with some silt. Several NE-DNR registered wells are also along the flight line and indicate sandstone. There is approximately 130 feet of relief in the ***To*** along this line. The high resistivity zone along the Loup River indicates the sand associated with the alluvial deposits. On the north side of the line the loess is also indicated as low electrical resistivities near the surface.

Figure 5-6 is a 4.5-mile-long north south line, L102001, that is on the east side of the LLNRD 2022 Nance County survey area. While there are no CSD test holes along this flight line, there are three NE-DNR registered wells along this line. The registered wells indicate the presence of the ***Kn*** due to the extent of the drilling with one well indicating shale at the base. The NE-DNR registered wells do indicate a few zones of sandstone related to the ***To*** that is eroded to the south. The flight line crosses Beaver Creek and displays the higher resistivities indicating sand rich materials within the ***Q*** section.

Figure 5-7 is a 32.6-mile east-west line, L300101, located in the southern part of the LLNRD 2022 Nance County survey area slightly to the north of the Loup River. One CSD test hole, 18-A-56, is located along the line. This line is characterized by the high electrical resistivity ***Kn*** and is also indicated by the extent of drilling by the NE-DNR registered test wells. The ***Kn*** variability is displayed in this line as a shale rich zone of the ***Kn*** as indicated by low electrical resistivity. There is an area in the ***Kp*** on the far western end of the line. The To surface is indicated by the sandstones found in the NE-DNR registered wells and is on the west end of the line. The interpreted surface is not solely based on this east-west line but the many north south lines that cut across the area. The ***Q*** section is dominated by the alluvial deposits of the Loup River. However, these deposits are thin on the eastern end of the line.

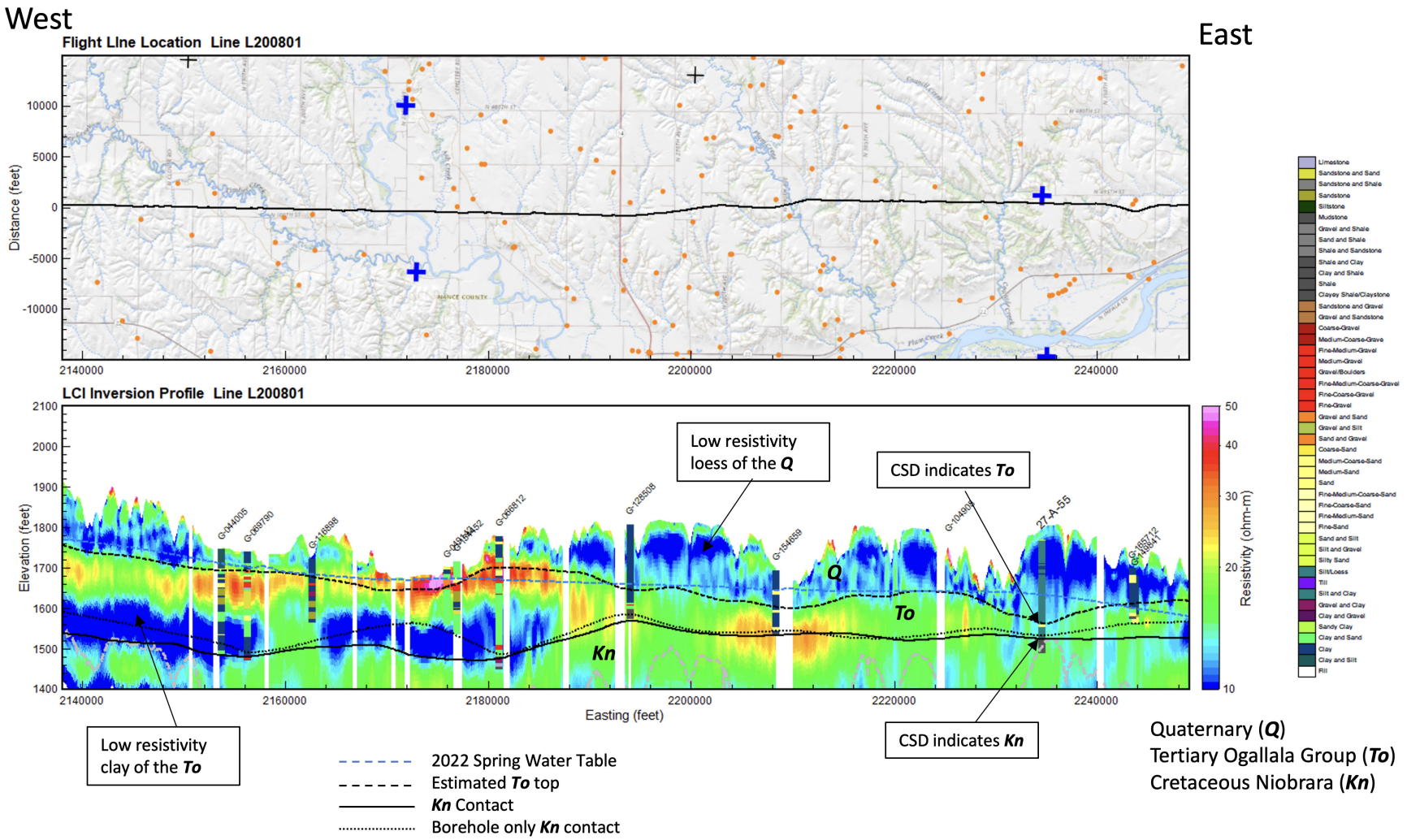



**Figure 5-4. 22-mile-long east-west line L200801. Lithology from CSD test holes within 1,500 feet and Nebraska DNR registered wells within 1,000 feet are projected on the flight line. Gaps in the profile are due to EM decoupling from infrastructure or areas that were not flown due to FFA regulations.**

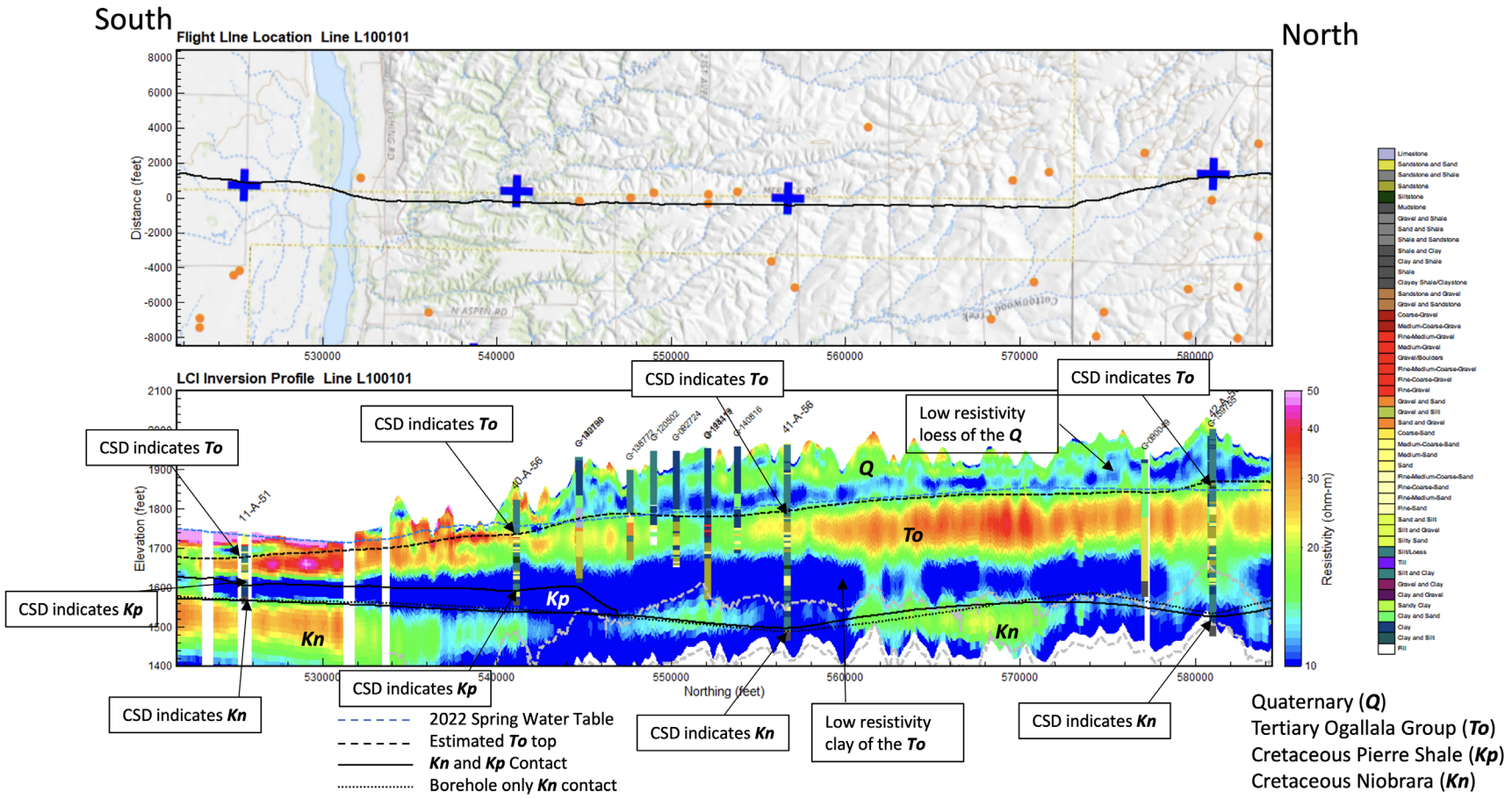



**Figure 5-5. 12.5-mile-long north-south line L100101. Lithology from CSD test holes within 1,500 feet and Nebraska DNR registered wells within 1,000 feet are projected on the flight line. Gaps in the profile are due to EM decoupling from infrastructure or areas that were not flown due to FFA regulations.**

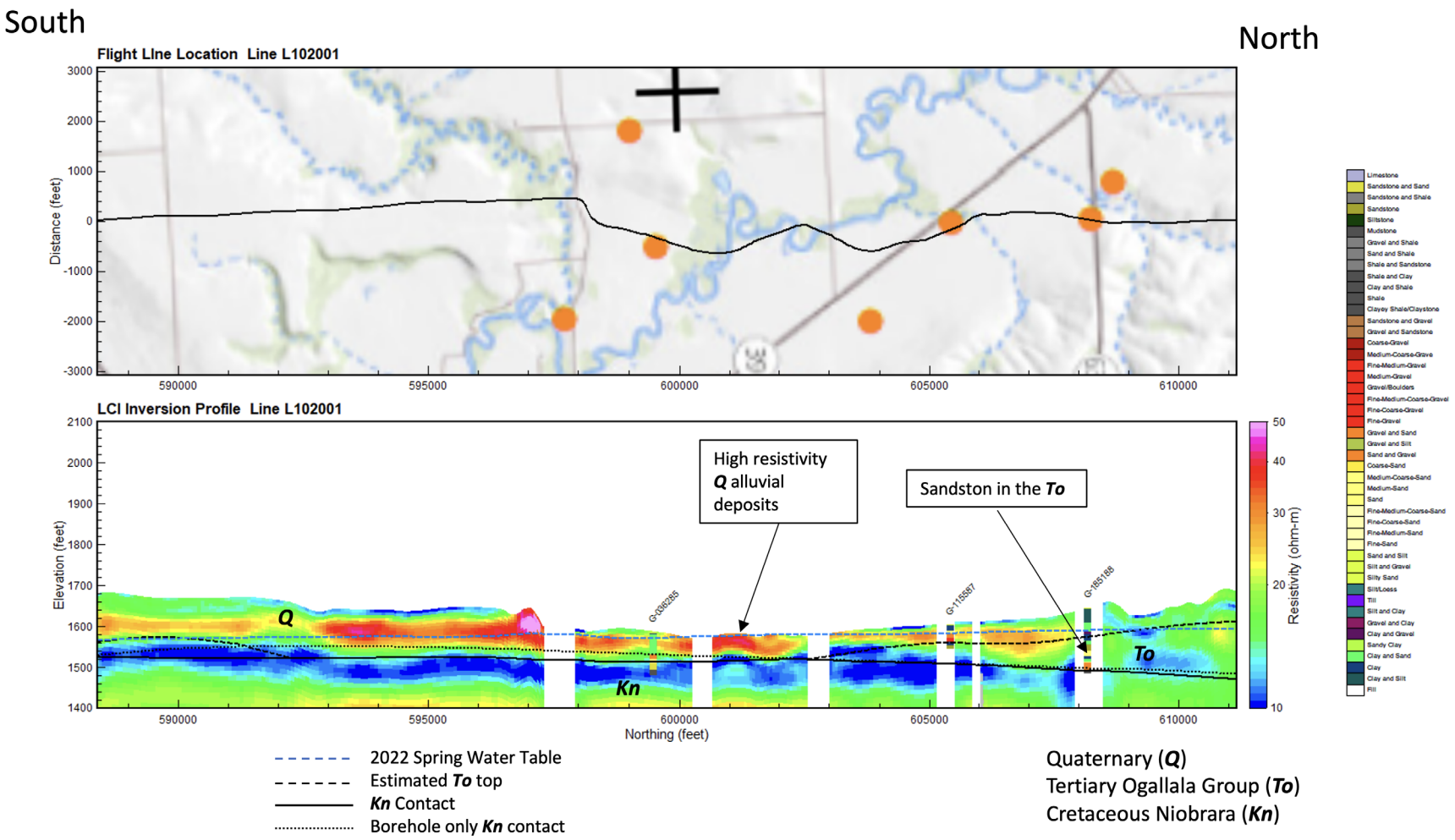



**Figure 5-6. 4.5-mile-long north south line L102001. Lithology from CSD test holes within 1,500 feet and Nebraska DNR registered wells within 1,000 feet are projected on the flight line. Gaps in the profile are due to EM decoupling from infrastructure or areas that were not flown due to FFA regulations.**

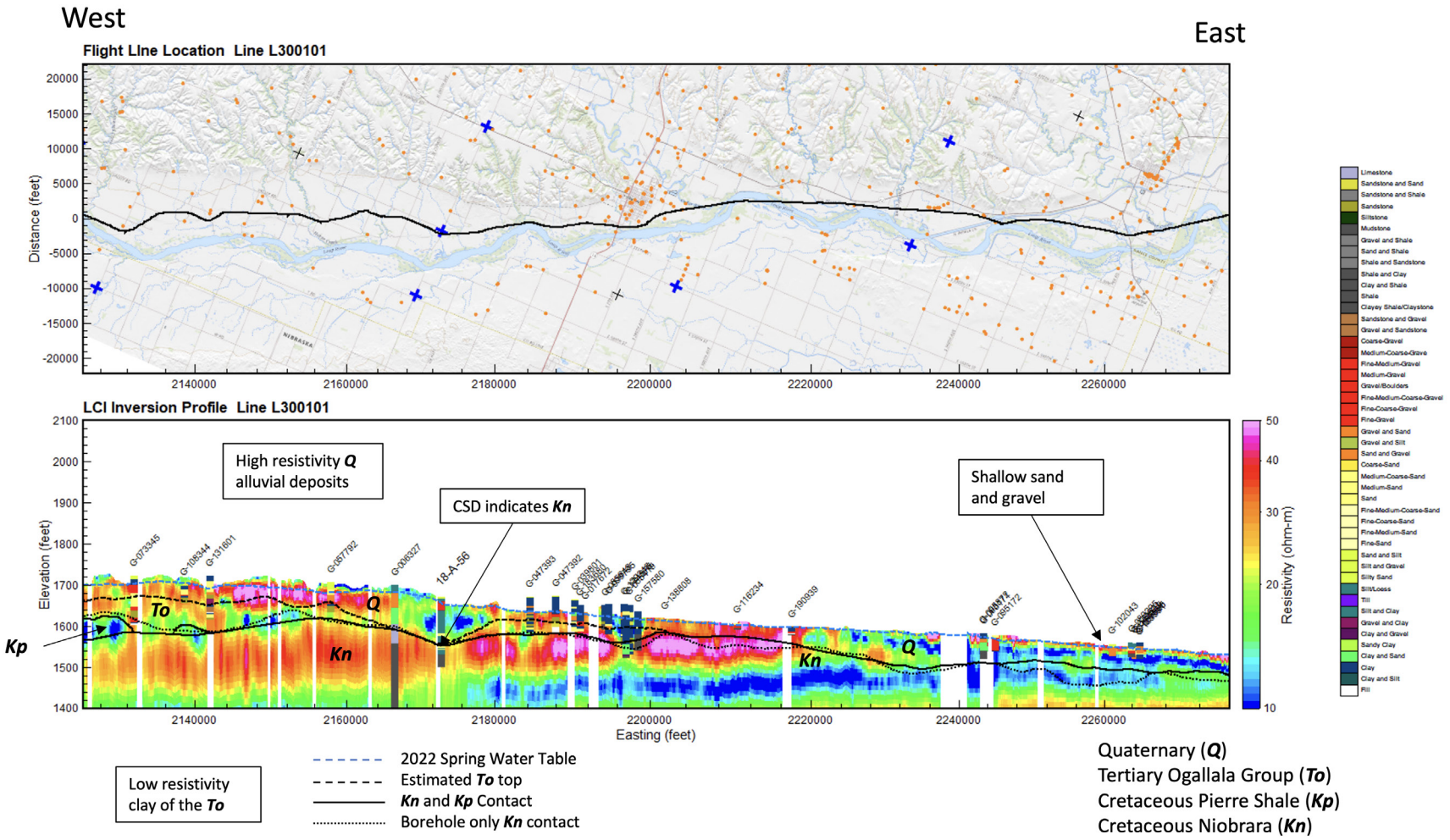



**Figure 5-7. 32.6-mile east-west line L300101. Lithology from CSD test holes within 1,500 feet and Nebraska DNR registered wells within 1,000 feet are projected on the flight line. Gaps in the profile are due to EM decoupling from infrastructure or areas that were not flown due to FFA regulations.**

The above examples illustrate the interpretive process that was used on the profiles provided within this report. Each flight line 2D profile is included in *Appendix 1 – 2D Profiles*.

### *5.1.5 Create Interpretative Surface Grids*

#### *5.1.5.1 Geological Surfaces*

For the LLNRD 2022 AEM survey area, geologic unit top elevation, geologic unit thickness, and geologic unit saturated thickness grids were produced. The terms grid, surface, and raster dataset are used interchangeably, and all refer to a continuous dataset. To create these grids, data such as a ground surface digital elevation model (DEM), water table elevation, CSD boreholes, DNR wells, and AEM interpreted point data of the survey area were imported and processed in a Geographic Information System (GIS) along with ESRI's Spatial and Geostatistical Analyst extensions.

Raster grids representing the elevation of the top of the ***To***, ***Kp***, ***Kn***, and bedrock were produced. To create the grids, AEM data points, CSD boreholes, and some DNR boreholes with top elevation information were compiled for each geologic unit and input into the GIS for processing. In some areas, the CSD boreholes and DNR wells provided data control between flight lines. The number of AEM data points, CSD boreholes, and DNR wells compiled for each geologic unit are shown in Table 5-1 below.

**Table 5-1. The number of data points used to interpolate the elevation of the top of each geologic unit within the LLNRD AEM survey area.**

| Geologic Unit | # of AEM Data Points | # of CSD Boreholes | # of DNR Wells |
|---|---|---|---|
| To | 1605 | 22 | 0 |
| Kn | 1593 | 23 | 249 |
| Kp | 67 | 2 | 0 |

The top elevation point data were interpolated for each geologic unit into a continuous surface using the kriging geostatistical model and exported to 300 ft cell size resolution raster datasets. The surfaces were corrected with the 300 ft resolution ground surface DEM so that each surface was restrained to less than or equal to the DEM elevation. Figure 5-8, Figure 5-9, and Figure 5-10 are maps displaying the top elevation surfaces of ***To, Kp,*** and ***Kn*** within the LLNRD 2022 Nance County survey area, respectively. Using the top elevation grids for the ***Kp*** and ***Kn*** units, a top of bedrock elevation surface was produced by mosaicking, or stitching, the two grids together. Figure 5-11 is a map of the elevation of the top of bedrock surface within the LLNRD 2022 Nance County AEM survey area.

Each top elevation surface was subtracted from the DEM to calculate the depth to (in feet) the top of each surface. Figure 5-12, Figure 5-13, Figure 5-14, and Figure 5-15 are maps displaying the depth to the top of ***To, Kp, Kn,*** and bedrock, respectively.

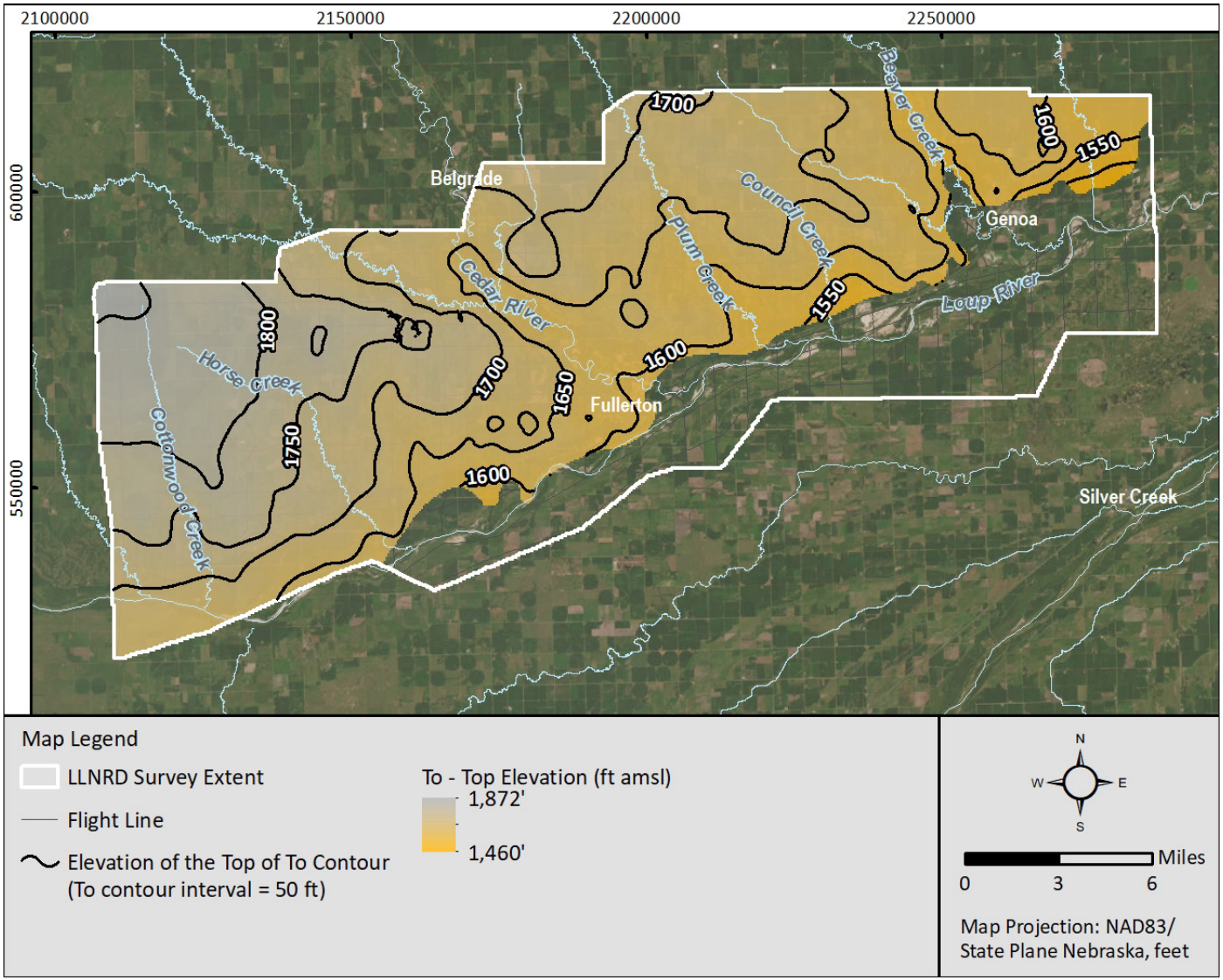



**Figure 5-8. Map of the top of Tertiary Ogallala Group (*To)* elevation within the LLNRD 2022 Nance County AEM survey area. Flight lines are lightly depicted by gray lines and contours are provided for better visualization of the elevation. The projection is NAD83 State Plane Nebraska (feet).**

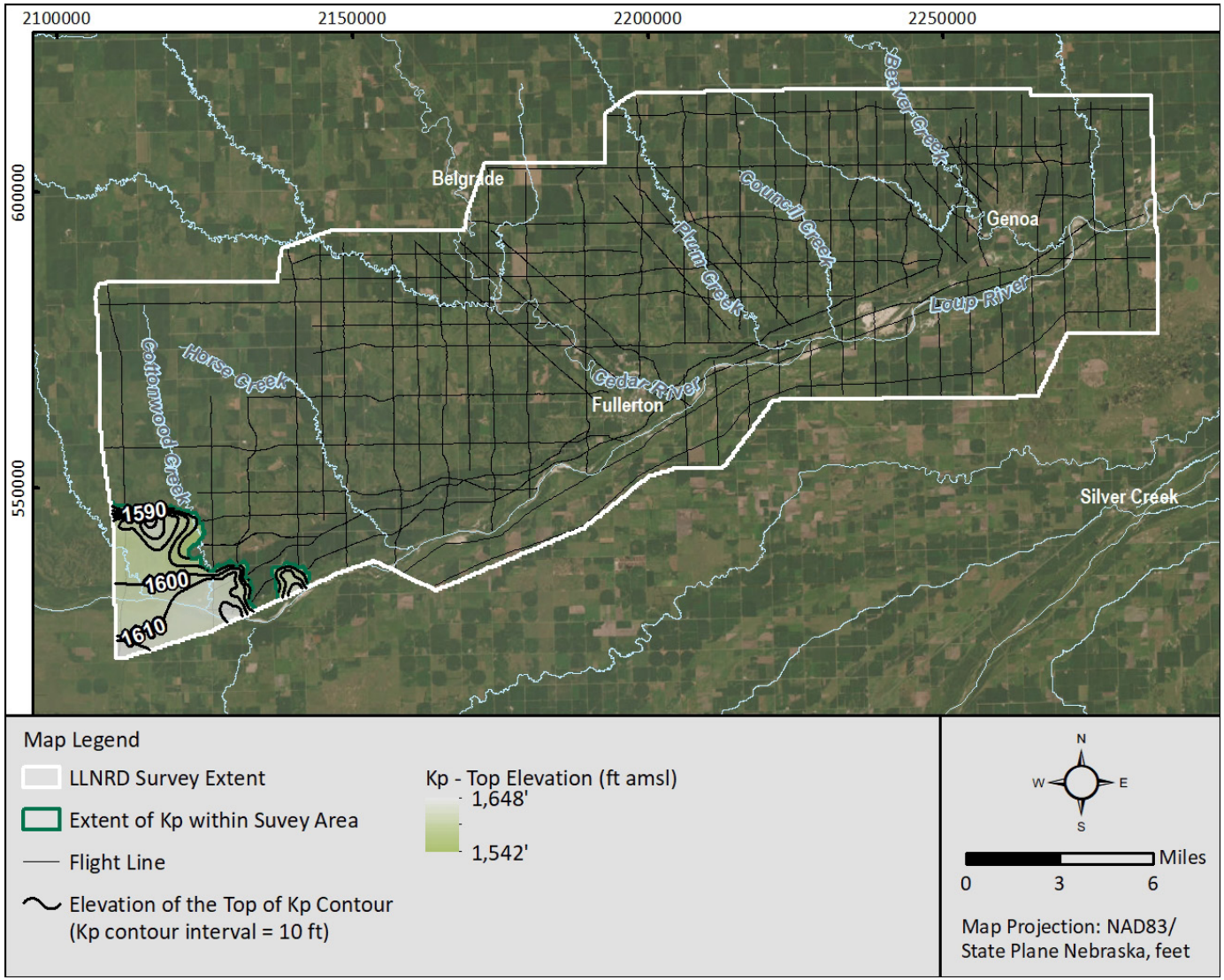



**Figure 5-9. Map of the top of Cretaceous Pierre Shale (*Kp)* elevation within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines and contours are provided for better visualization of the elevation. The *Kp* is only present within the very southwestern corner of the survey area. The projection is NAD83 State Plane Nebraska (feet).**

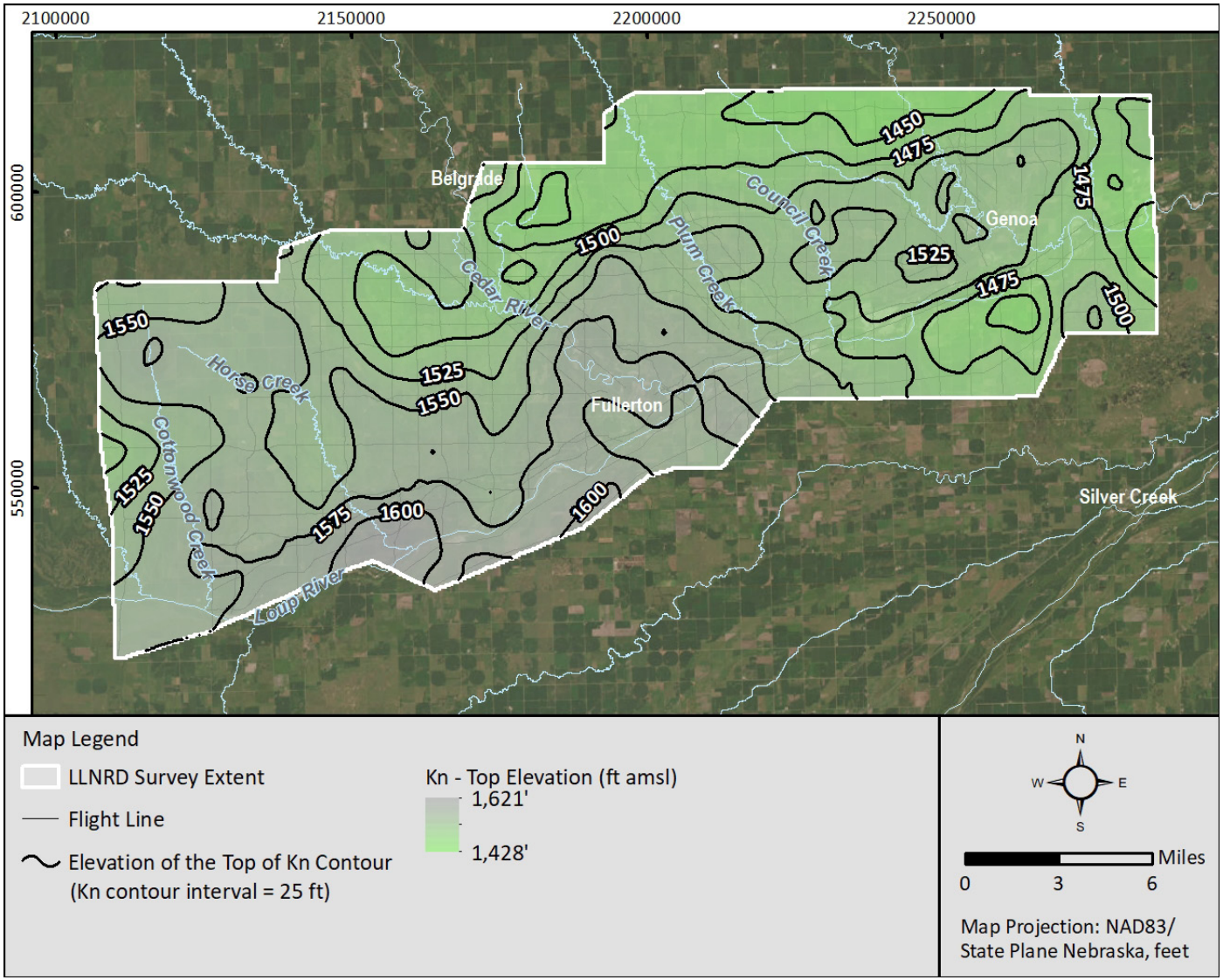



**Figure 5-10. Map of the top of Cretaceous Niobrara Formation (*Kn*) elevation within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines and contours are provided for better visualization of the elevation. The projection is NAD83 State Plane Nebraska (feet).**

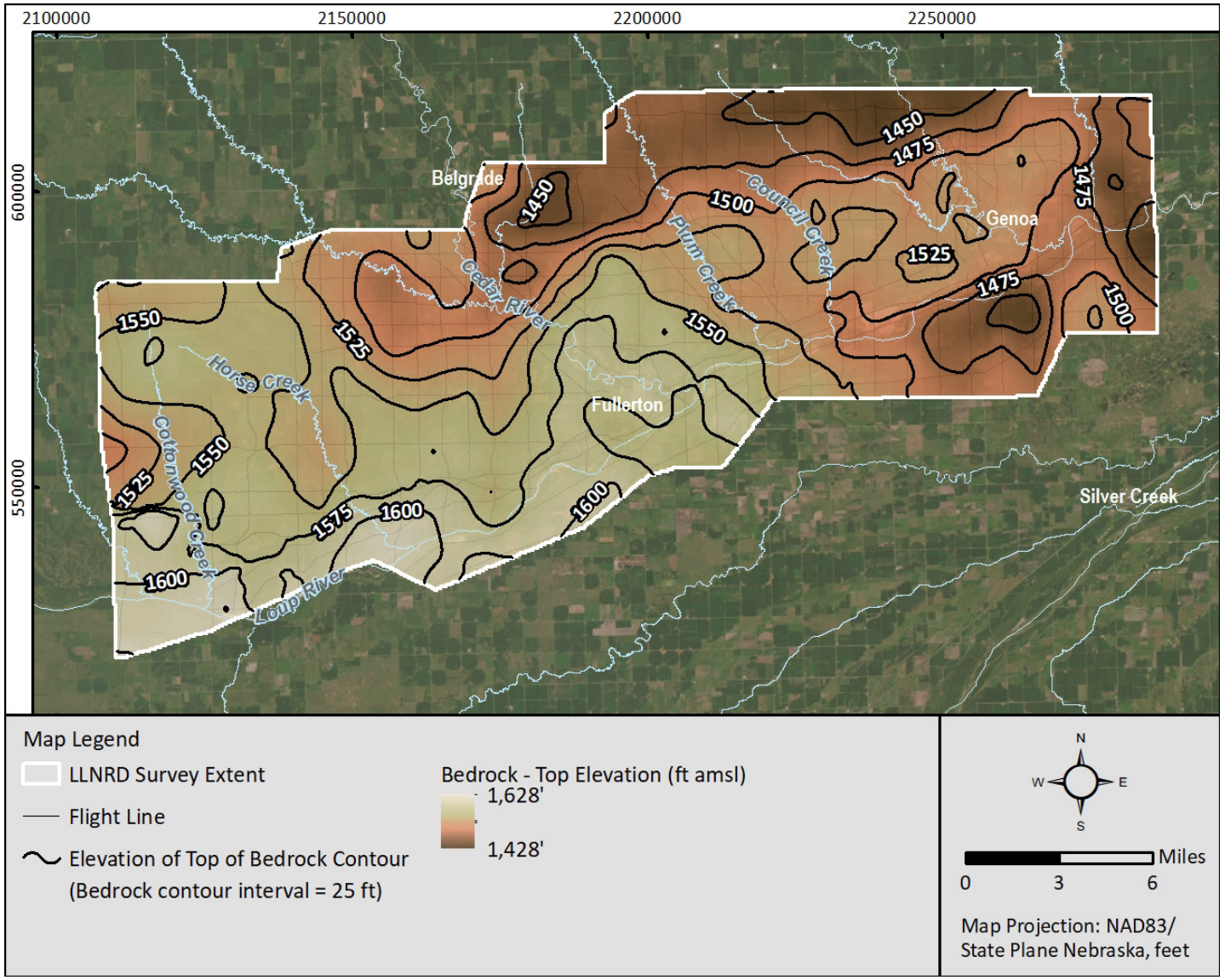



**Figure 5-11. Map of the top of Cretaceous bedrock elevation within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines and contours are provided for better visualization of the elevation. The projection is NAD83 State Plane Nebraska (feet).**

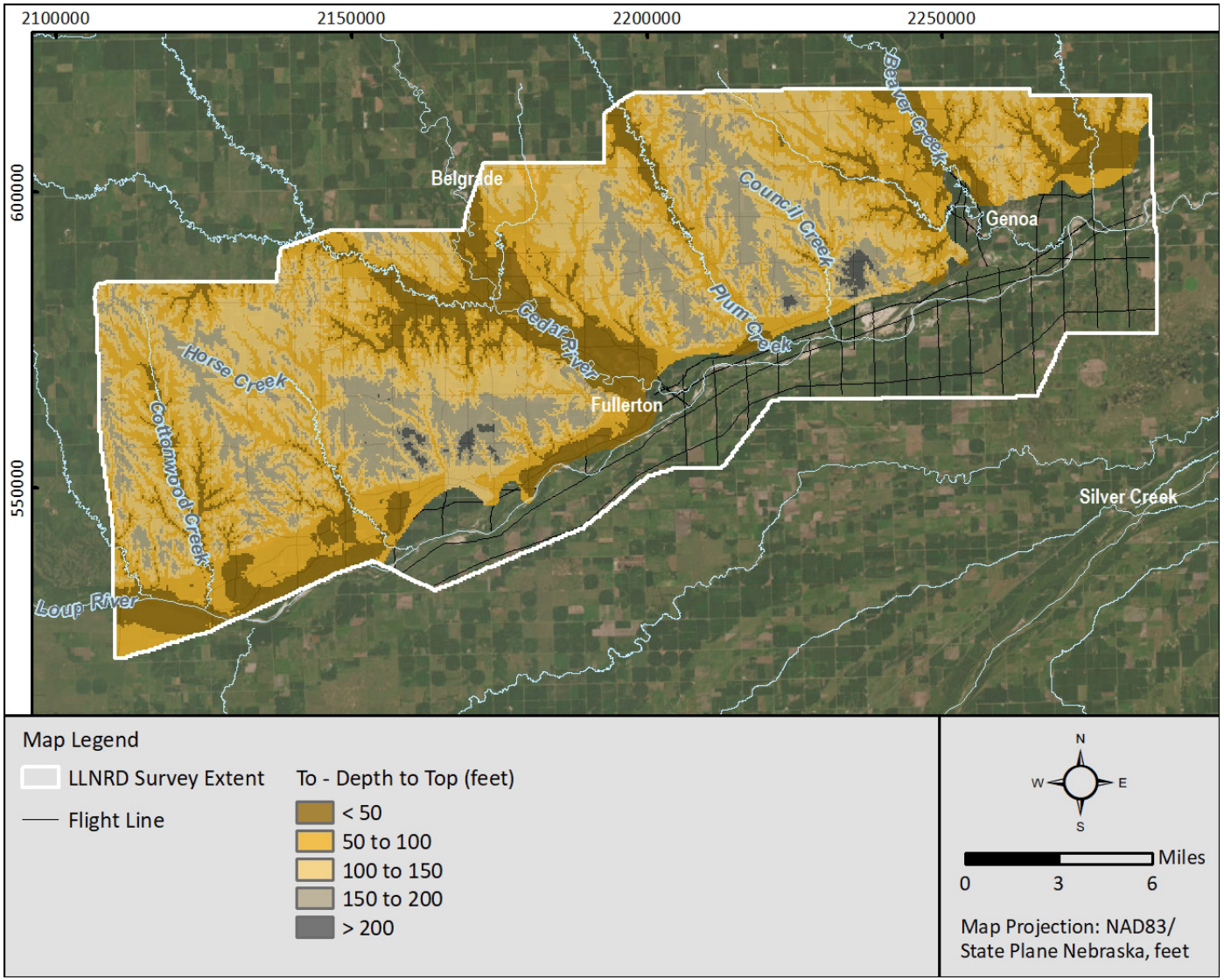



**Figure 5-12. Map of the depth to the top (in feet) of Tertiary Ogallala Group (*To)* within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The *To* does not extend through the entire survey area. The projection is NAD83 State Plane Nebraska (feet).**

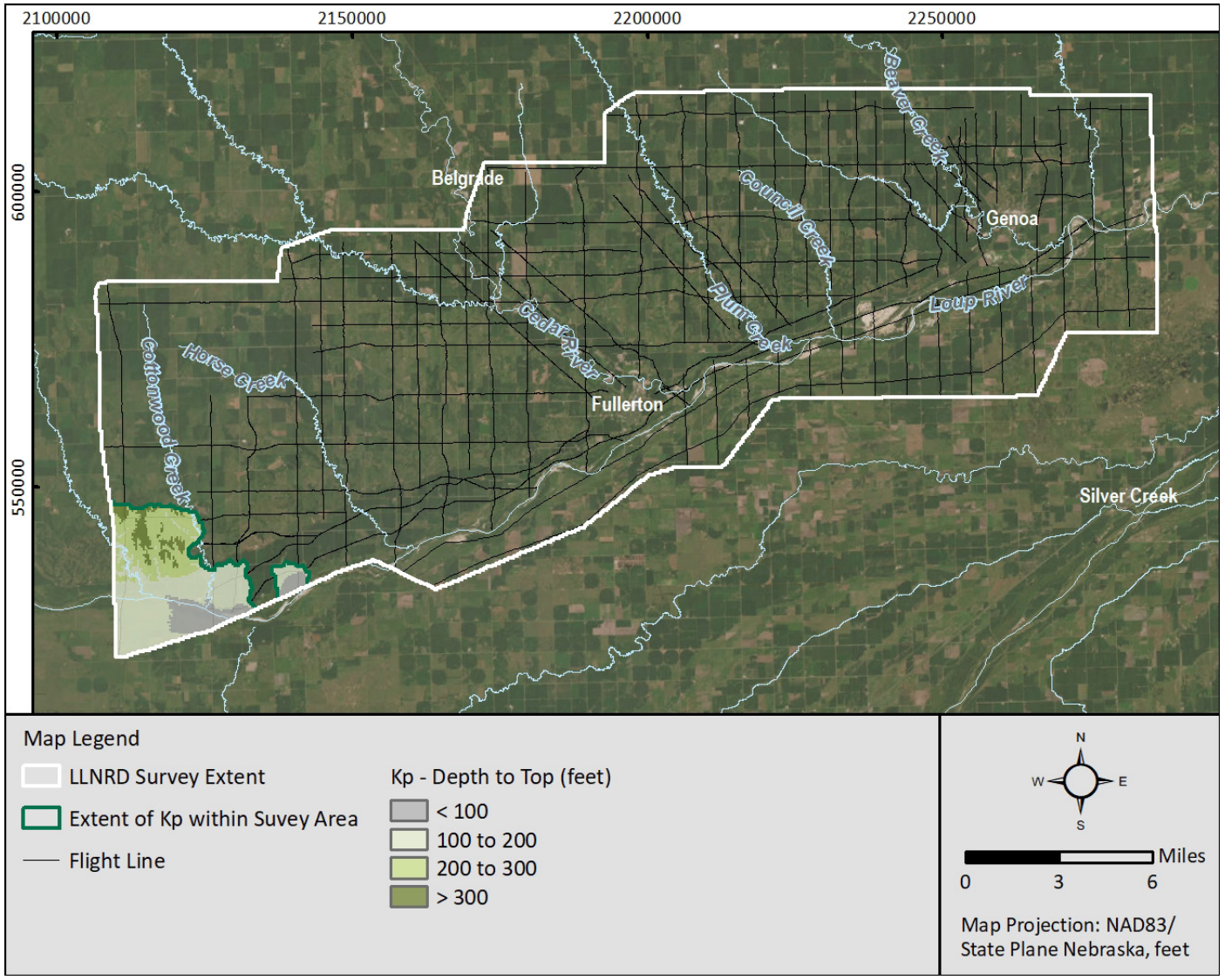



**Figure 5-13. Map of the depth to the top (in feet) of Cretaceous Pierre Shale (*Kp)* within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The *Kp* is only present within the very southwestern corner of the survey area. The projection is NAD83 State Plane Nebraska (feet).**

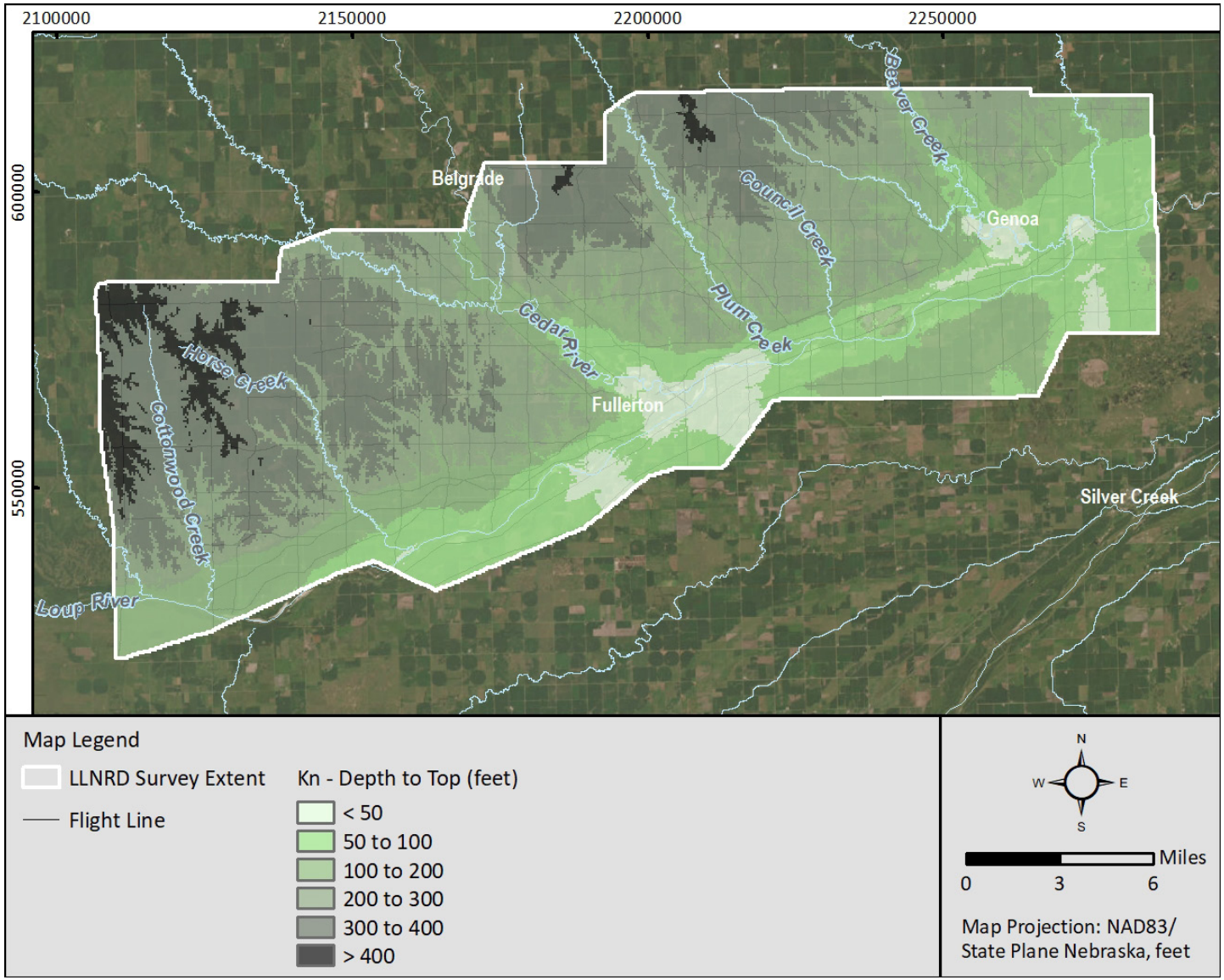



**Figure 5-14. Map of the depth to the top (in feet) of Cretaceous Niobrara Formation (*Kn*) within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

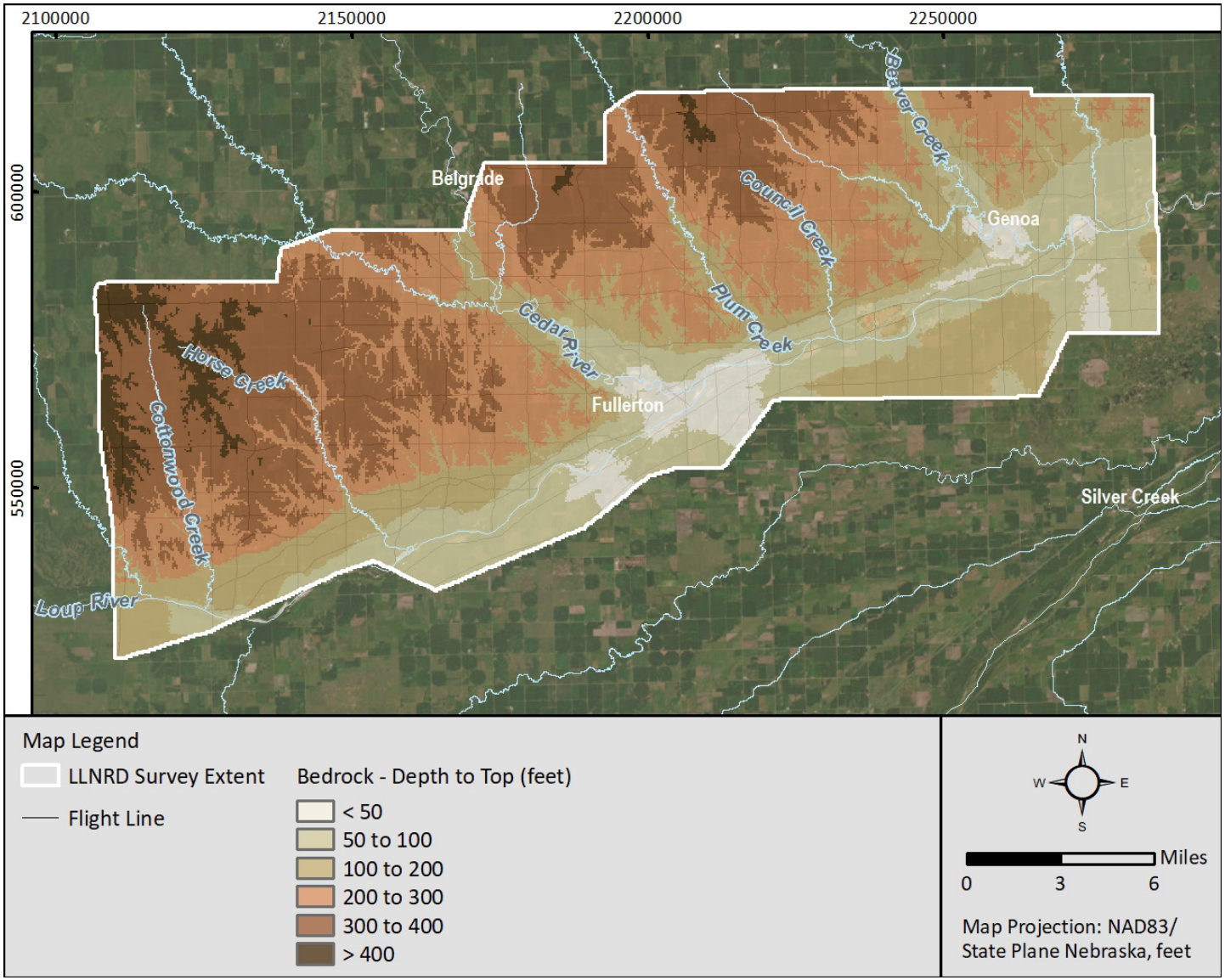



**Figure 5-15. Map of the depth to the top (in feet) of Cretaceous bedrock within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

Total thickness for the ***Q*** and ***To*** were calculated using the top of elevation surfaces and DEM in ESRI's raster calculator. Table 5-2 summarizes the raster calculator input and output for each thickness calculation. The output was set to snap to the 300 ft DEM, then was clipped to each geologic unit extent.

**Table 5-2. The input into ESRI's raster calculator and the resultant output.**

| Raster Calculator Input | Output Result |
|---|---|
| DEM – To/Bedrock | Q Thickness |
| Top of To - Top of Bedrock | To Thickness |

Figure 5-16 and Figure 5-17 are maps displaying the total thickness of ***Q*** and ***To***, respectively.

#### *5.1.5.2 Water Tabel Development*

To assist in the approximation of the saturated materials along the surveyed AEM flight lines, a water table was created from the LLNRD Spring 2022 water levels (Personal Communication, Cam Conrad, 2022), the most recent, water levels recorded within, and adjacent to, the survey extent. The water table was created from 83 water level data points provided by LLNRD and almost 400 control points that were created along the National Hydrography Dataset (NHD) streamlines. Before creating the control points, the NHD streamlines were first revised to better match the aerial imagery as well as the DEM, then points were created along the streamlines approximately every 1 mile and set equal to the DEM elevation. The water table and control points were interpolated into a continuous raster dataset using ESRI's natural neighbor interpolation tool, then the surface was set equal to or less than the DEM elevation. The actual water table data points were compared to the water table surface to ensure that no residual (i.e., actual water table elevation minus interpolation water table elevation) was greater than approximately 3ft. The water table was then clipped to the LLNRD survey area. Figure 5-18 and Figure 5-19 are maps displaying the Spring 2022 water table elevation and the depth to water table, respectively.

The saturated thickness of both ***Q*** and ***To*** were calculated using the top elevation of ***To*** and bedrock as well as the Spring 2022 water table surfaces using ESRI's raster calculator. For the ***Q*** saturated thickness grid, the elevation of the top of bedrock was subtracted from the Spring 2022 water table, then the ***To*** total thickness was subtracted from the result. For the ***To*** saturated thickness grid, the top of ***To*** was mosaicked with the water table in ArcMap using the 'minimum' operator, then the top of bedrock was subtracted from the mosaicked raster dataset. Figure 5-20 and Figure 5-21 are maps displaying the ***Q*** and ***To*** saturated thickness grids within the LLNRD 2022 Nance County AEM survey area, respectively.

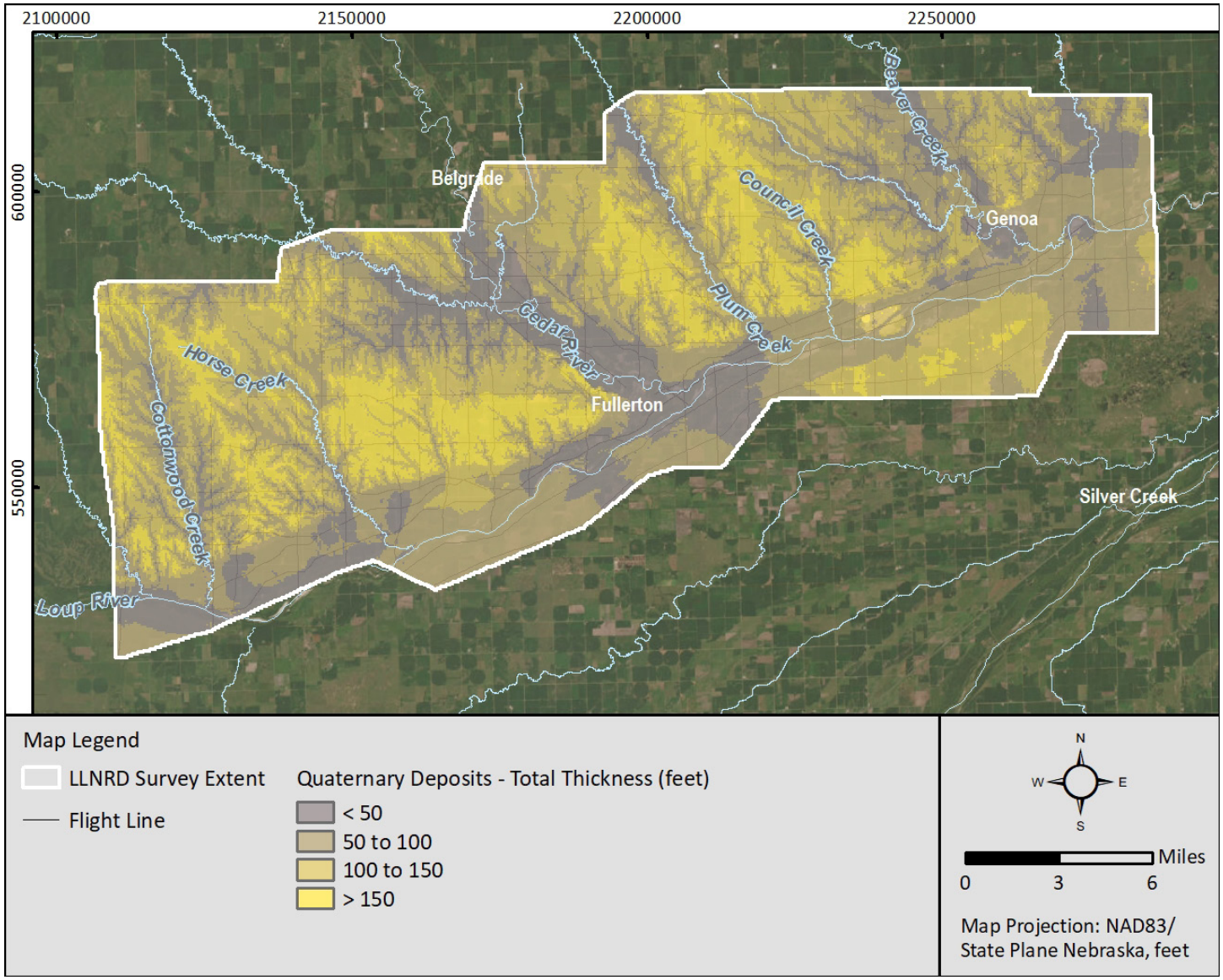



**Figure 5-16. Map of the total thickness of Quaternary (*Q*) deposits (in feet) within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

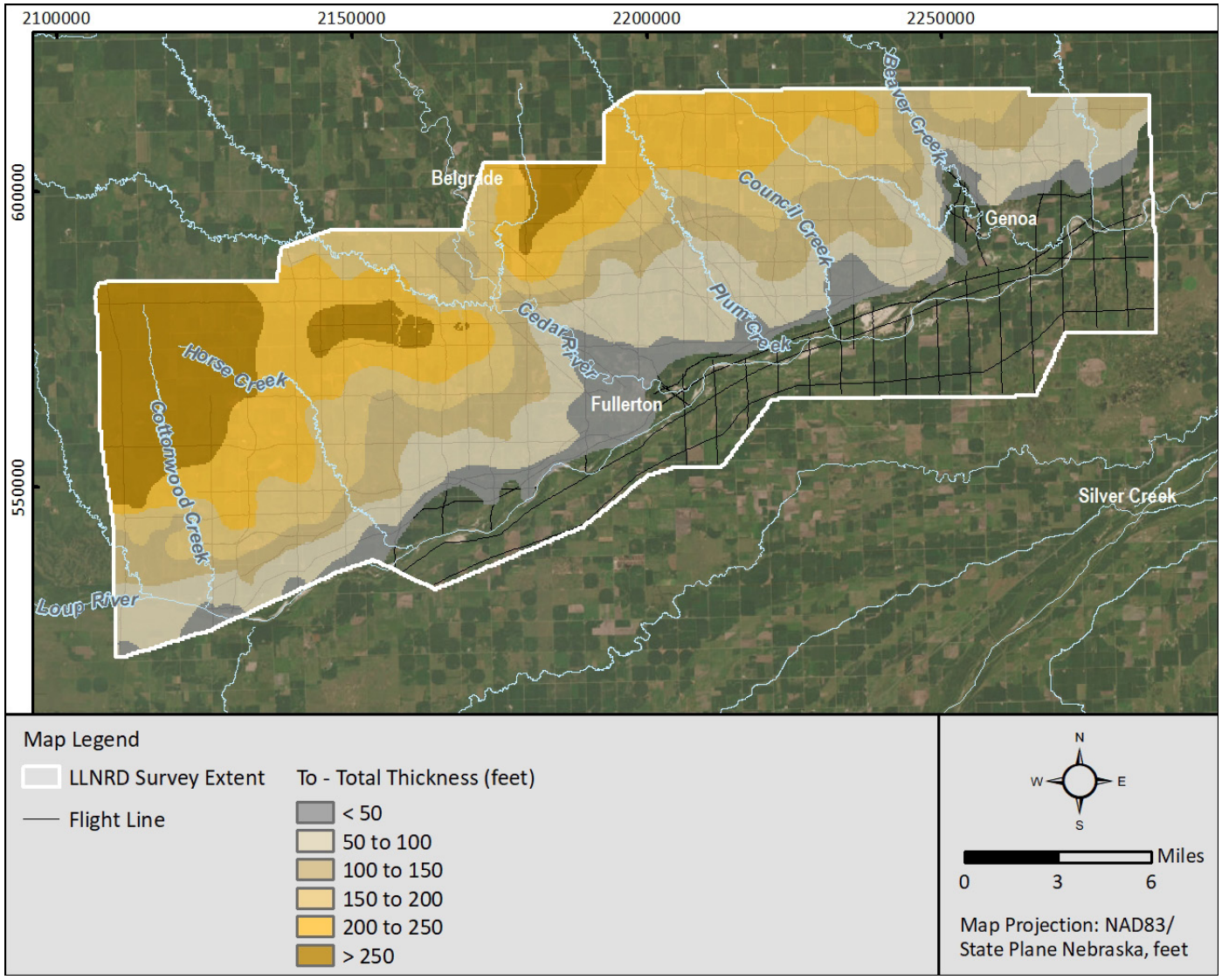



**Figure 5-17. Map of the total thickness of the Tertiary Ogallala Group (*To)* (in feet) within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The *To* does not extend through the entire survey area. The projection is NAD83 State Plane Nebraska (feet).**

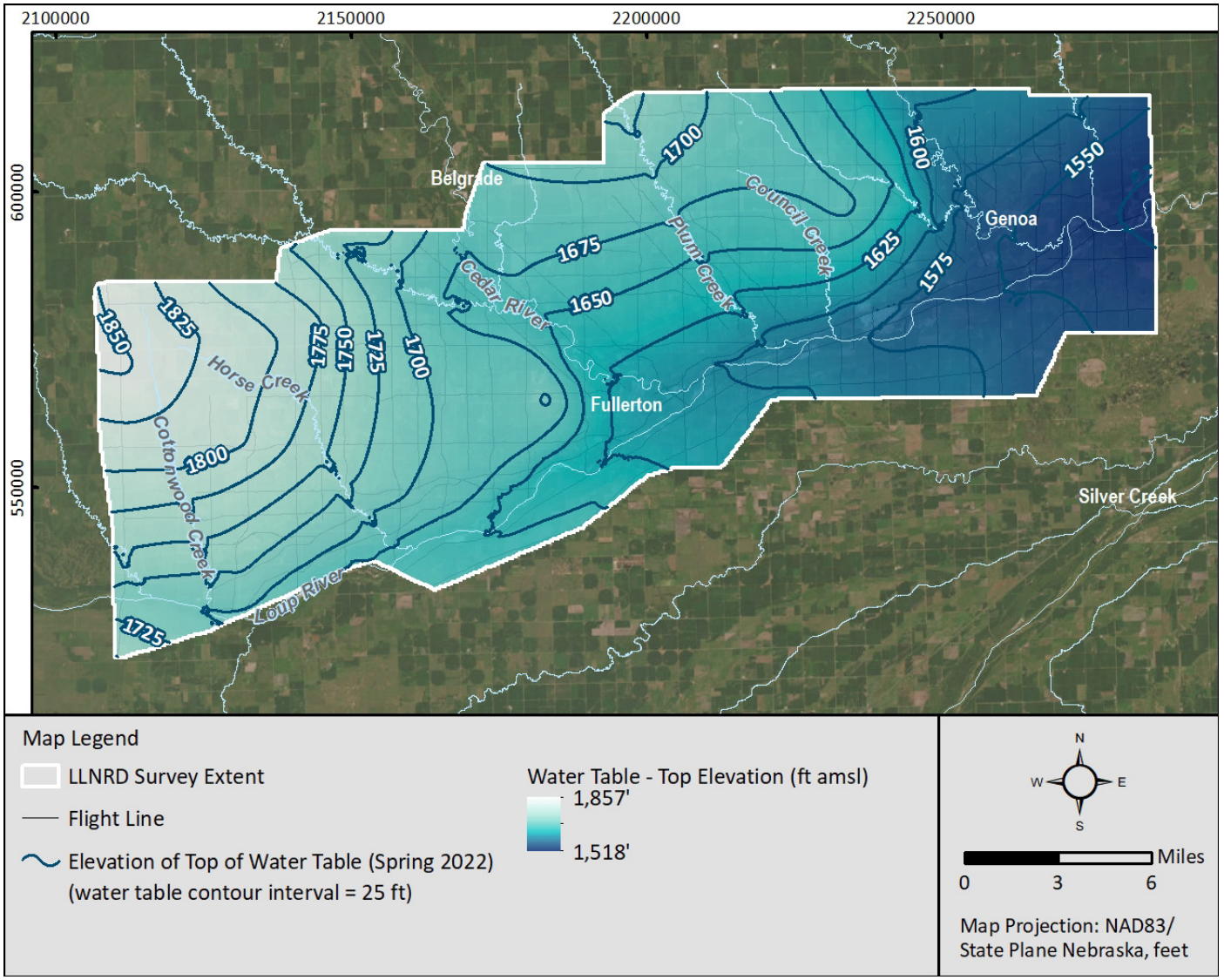



**Figure 5-18. Map of the elevation of the LLNRD Spring 2022 water table within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines and contours are provided for better visualization of the elevation. The projection is NAD83 State Plane Nebraska (feet).**

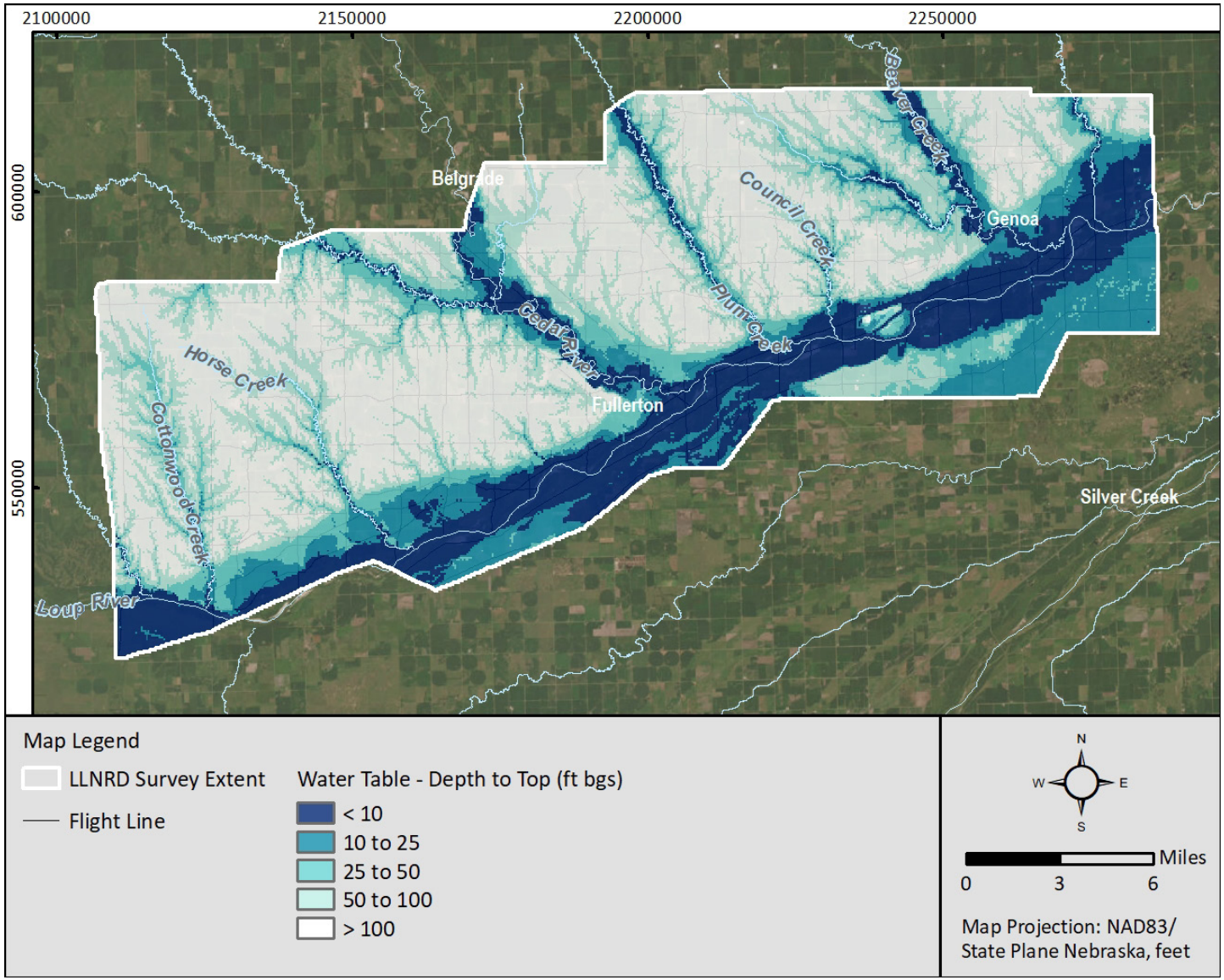



**Figure 5-19. Map of the depth to the LLNRD Spring 2022 water table within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

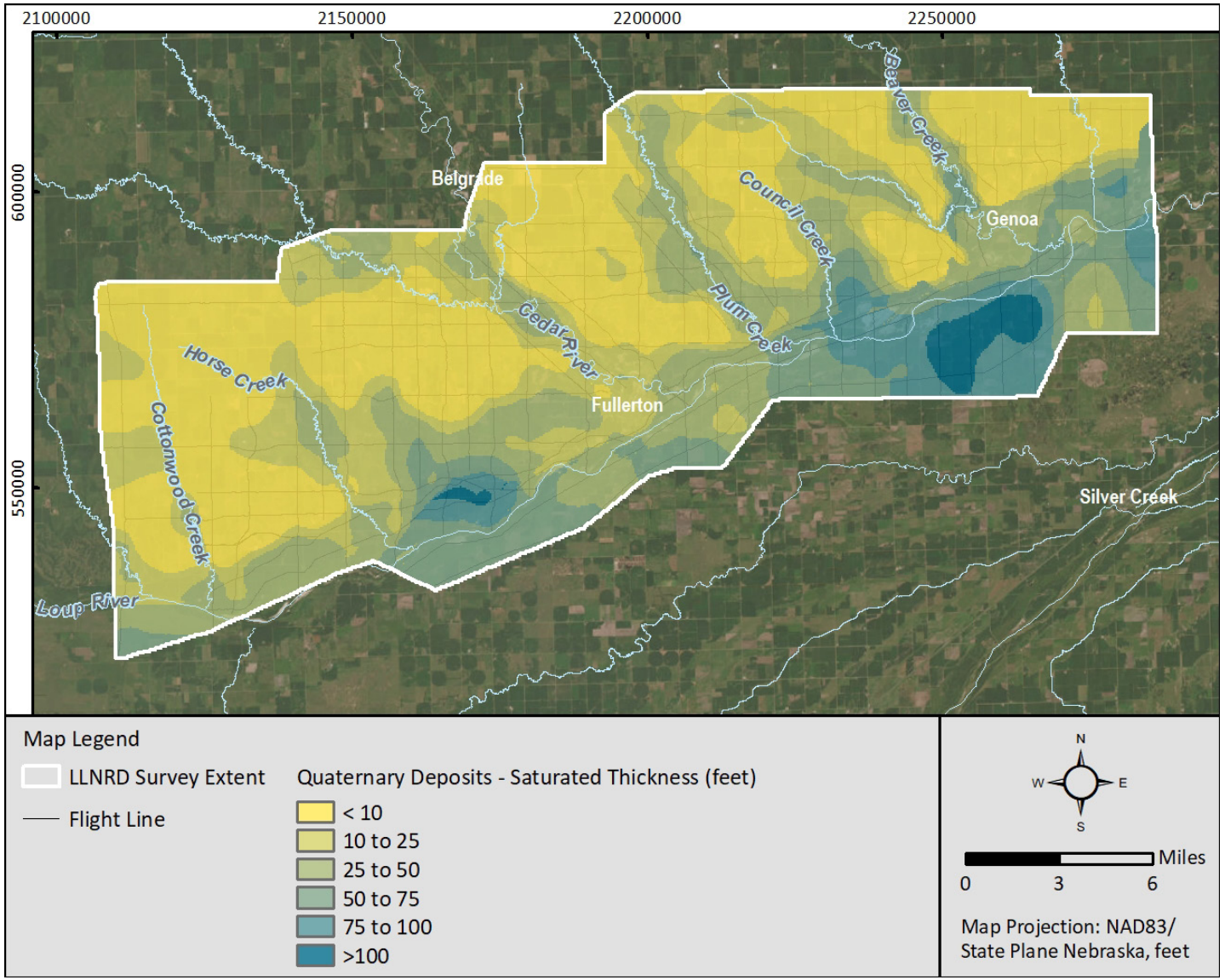



**Figure 5-20. Map of the saturated thickness of Quaternary (*Q*) deposits within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

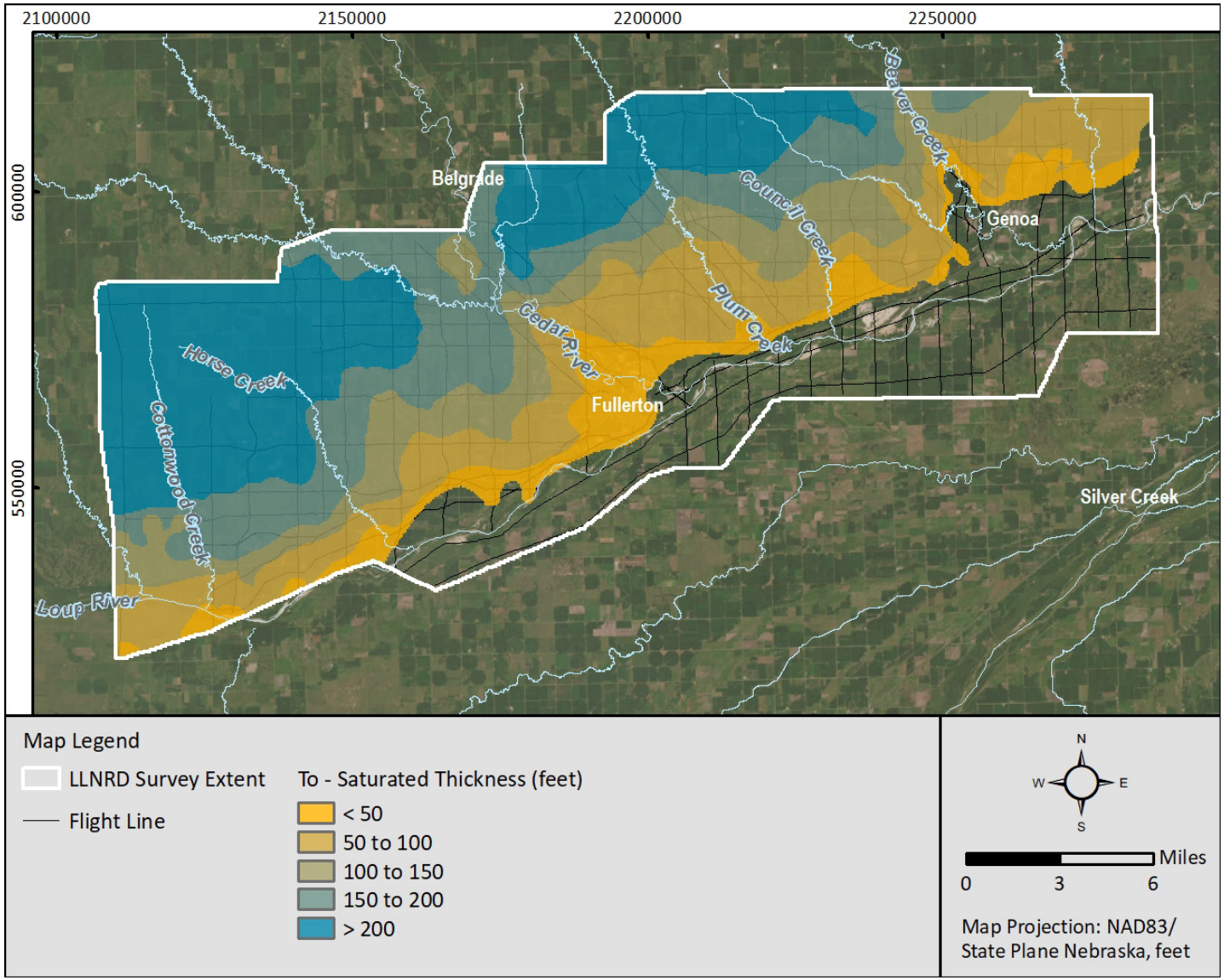



**Figure 5-21. Map of the saturated thickness of Tertiary Ogallala Group (*To)* within the LLNRD 2022 Nance County AEM survey area. Flight lines are depicted by black lines. The projection is NAD83 State Plane Nebraska (feet).**

#### *5.1.5.3 Transmissivity Maps*

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

$$T = K * b \quad (1)$$

where K is the hydraulic conductivity (ft/sec) and b is the saturated aquifer thickness (ft). The K value(s) used to calculate transmissivity within the LLNRD 2022 Nance County AEM survey area were determined based on the "Reed and Piskin" table, which lists lithologic descriptions and estimated hydraulic conductivity values provided in a table developed by E.C. Reed and R. Piskin at the University of Nebraska Conservation and Survey Division School of Natural Resources (Goeke et al., 1992; Cannia et al., 2006). The Reed and Piskin table lists K values based on particle size and degree of sorting. Project K values were selected from the table based on known particle/sorting characteristics of the unconsolidated material within the survey area. Table 5-3 lists the K values that were used to calculated transmissivity for the LLNRD 2022 Nance County AEM survey area:

**Table 5-3. Transmissivity K values used for the LLNRD 2022 Nance County AEM survey area.**

| Material Type | K used for Transmissivity calculation (ft/day) |
|---|---|
| **Marginal** | **18 (Silt, slightly clayey)** |
| **Aquifer and Coarse - Q** | **80 (Medium Sand, moderate sorting)** |
| **Aquifer and Coarse - To** | **51 (Medium Sand with moderate silt content)** |

The transmissivity of each saturated material type (marginal; and aquifer and coarse aquifer) for each aquifer (***Q*** and ***To***) were calculated separately and then added together to determine the overall transmissivity of saturated materials for marginal, aquifer, and coarse aquifer materials. The resultant raster datasets were compared to the values displayed in Summerside et al. (2005). The comparison showed that the calculated values were relatively similar to the values in the published maps, but showed more detail and variation. This is to be expected because the AEM data provided a more expansive data coverage to calculate the transmissivity. Figure 5-22, Figure 5-23, and Figure 5-24 display the range of transmissivity for the ***Q*** marginal, aquifer, and coarse aquifer saturated material; To marginal, aquifer, and coarse aquifer saturated material; and the ***Q/To*** marginal, aquifer, and coarse aquifer saturated material, respectively.

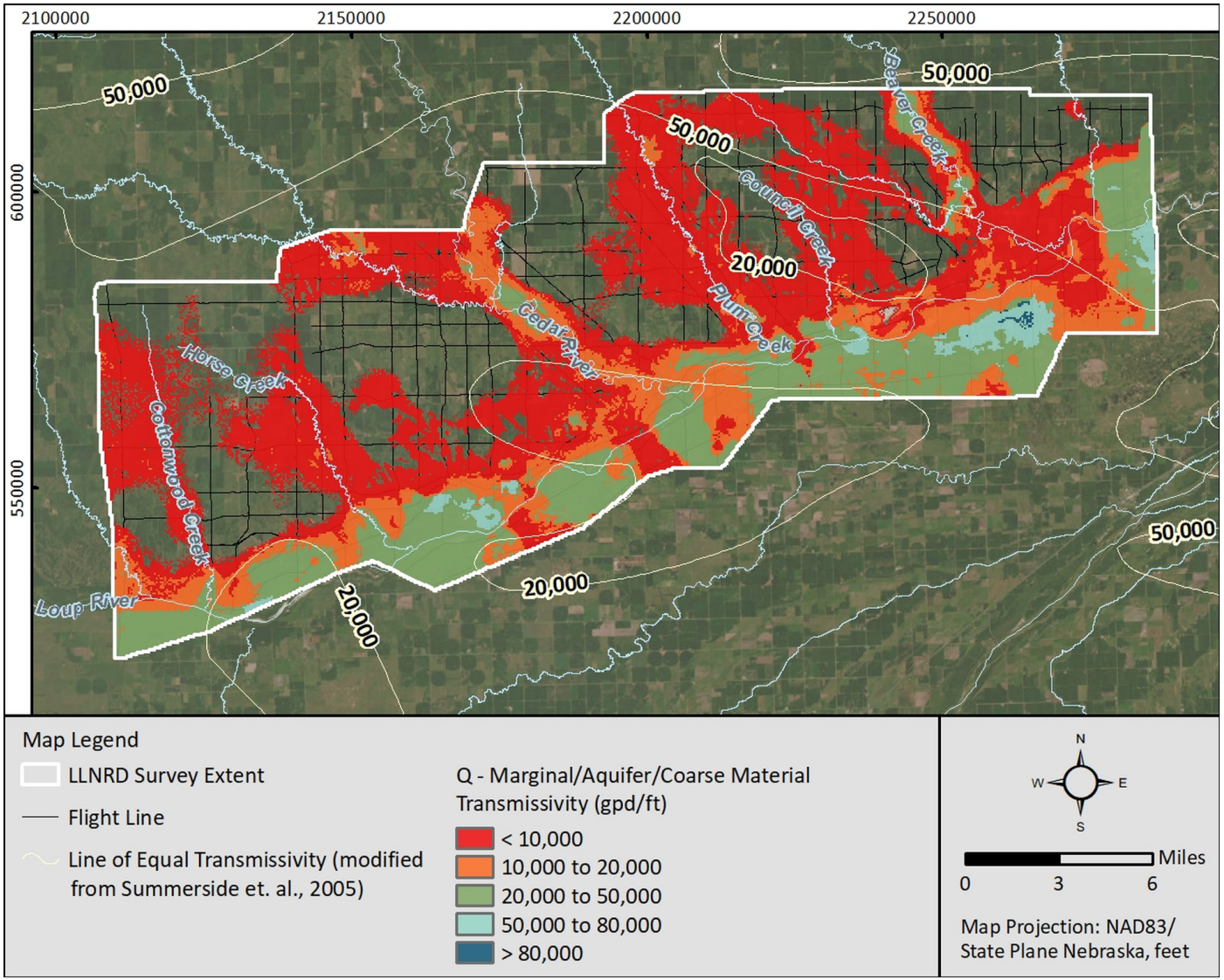



**Figure 5-22. Map of the calculated transmissivity within the Quaternary (*Q*) deposits marginal, aquifer, and coarse aquifer material. Flight lines are depicted as black lines and published transmissivity contours were digitized and added to the map for a visual comparison. The map projection is NAD83 State Plane Nebraska (feet).**

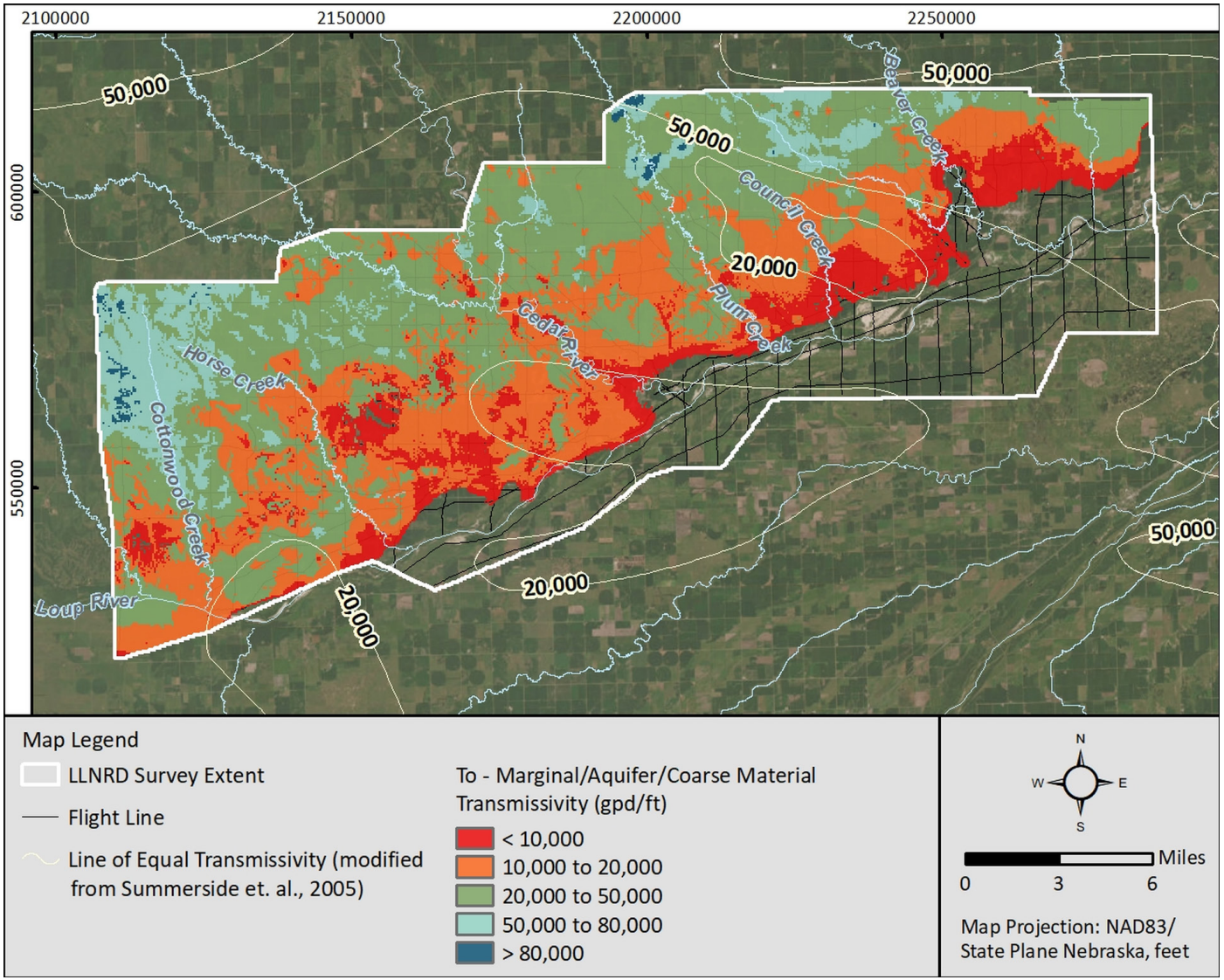



**Figure 5-23. Map of the calculated transmissivity within the Tertiary Ogallala Group (*To)* marginal, aquifer, and coarse aquifer material. Flight lines are depicted as black lines and published transmissivity contours were digitized and added to the map for a visual comparison. The map projection is NAD83 State Plane Nebraska (feet).**

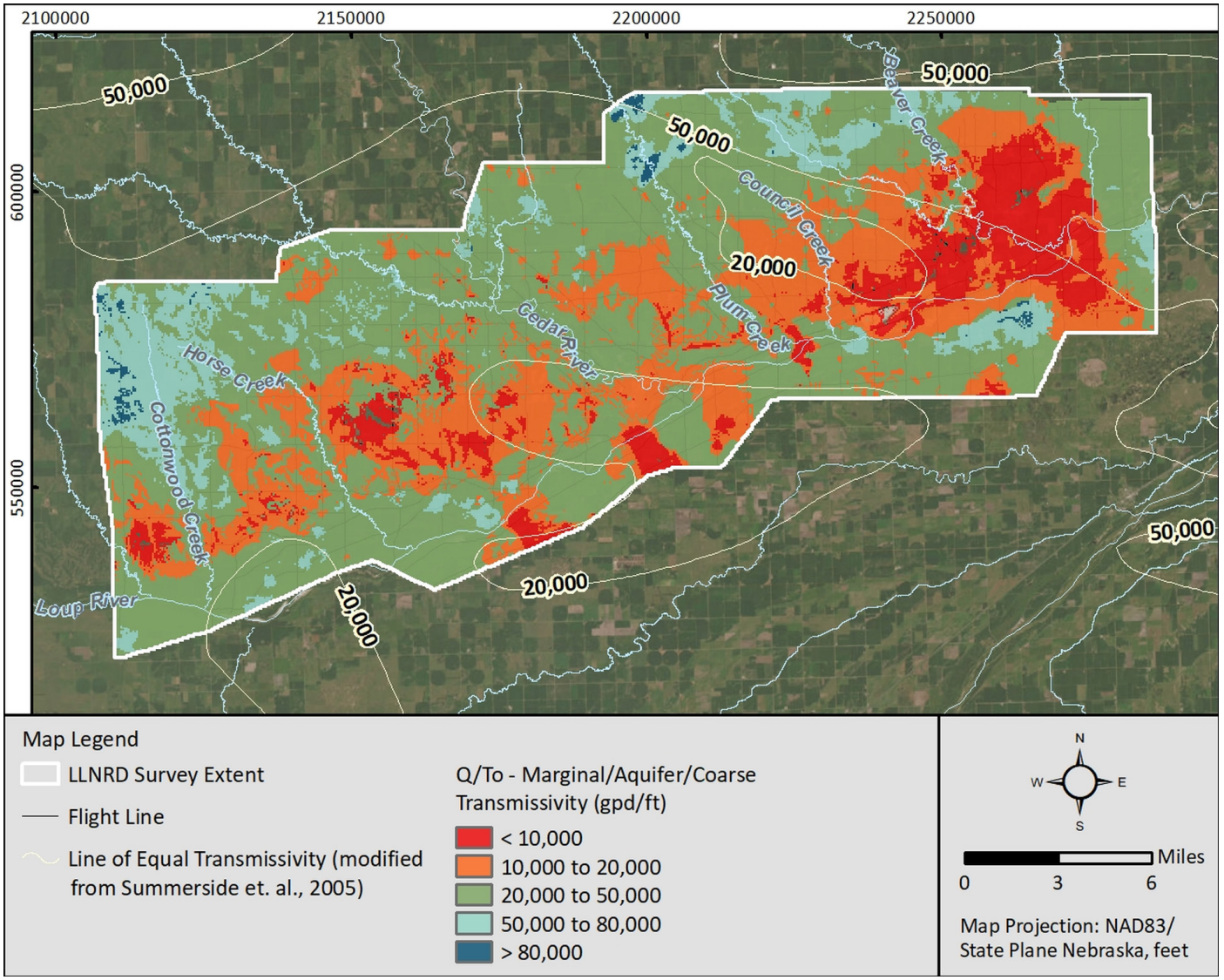



**Figure 5-24. Map of the calculated transmissivity within both the Quaternary (*Q)* deposits and Tertiary Ogallala Group (*To)* marginal, aquifer, and coarse aquifer material. Flight lines are depicted as black lines and published transmissivity contours were digitized and added to the map for a visual comparison. The map projection is NAD83 State Plane Nebraska (feet).**

#### *5.1.5.4 Specific Capacity Maps*

An estimate of specific capacity was made for DNR wells based on the following:

- Screen data were extracted from Nebraska GeoCloud for DNR wells that were located within the survey area.
- Screen top and bottom depths/elevations were compared to the depth to/top elevation of ***To*** and bedrock extracted from the surfaces constructed from the AEM data for each well.
- Based on the comparison, each well was designated with a "completion aquifer" (either ***To***, ***Q***, bedrock, or dually completed).
    - For example, if the top of a well screen was below the bottom of ***Q*** deposits and the bottom of the screen was above the top of bedrock and the well was within the ***To*** extent, then the well was designated as a ***To*** well.
    - Please note that these aquifer designations are estimates based on the depth to the top of the ***To***. As stated above, the top of ***To*** interpretation was estimated due to the lithology interpretation of drill cuttings of the ***To*** and the low electrical resistivity contrast.
- 647 DNR wells within the survey extent contained screen information for analysis.
- After the well was designated with an aquifer, the specific capacity was calculated for each well based on the equation:
    - SC = pumping rate / drawdown (pumping water level-static water level)
- The calculated specific capacity values are only as accurate at the pumping data provided in the DNR dataset (ie. the well logs). The specific capacity values should be considered approximate, but they do give a helpful, general overview of well production rates.
    - Two wells appeared to have anomalously high specific capacity values due to very high pumping rates and were not included on the final maps. These include:
        - G-158746 and G-096010

Figure 5-25, Figure 5-26, and Figure 5-27 display the transmissivity of marginal, aquifer, and coarse aquifer saturated materials along with the specific capacity of wells designated within the ***Q***, ***To***, and ***Q***/***To***, respectively.

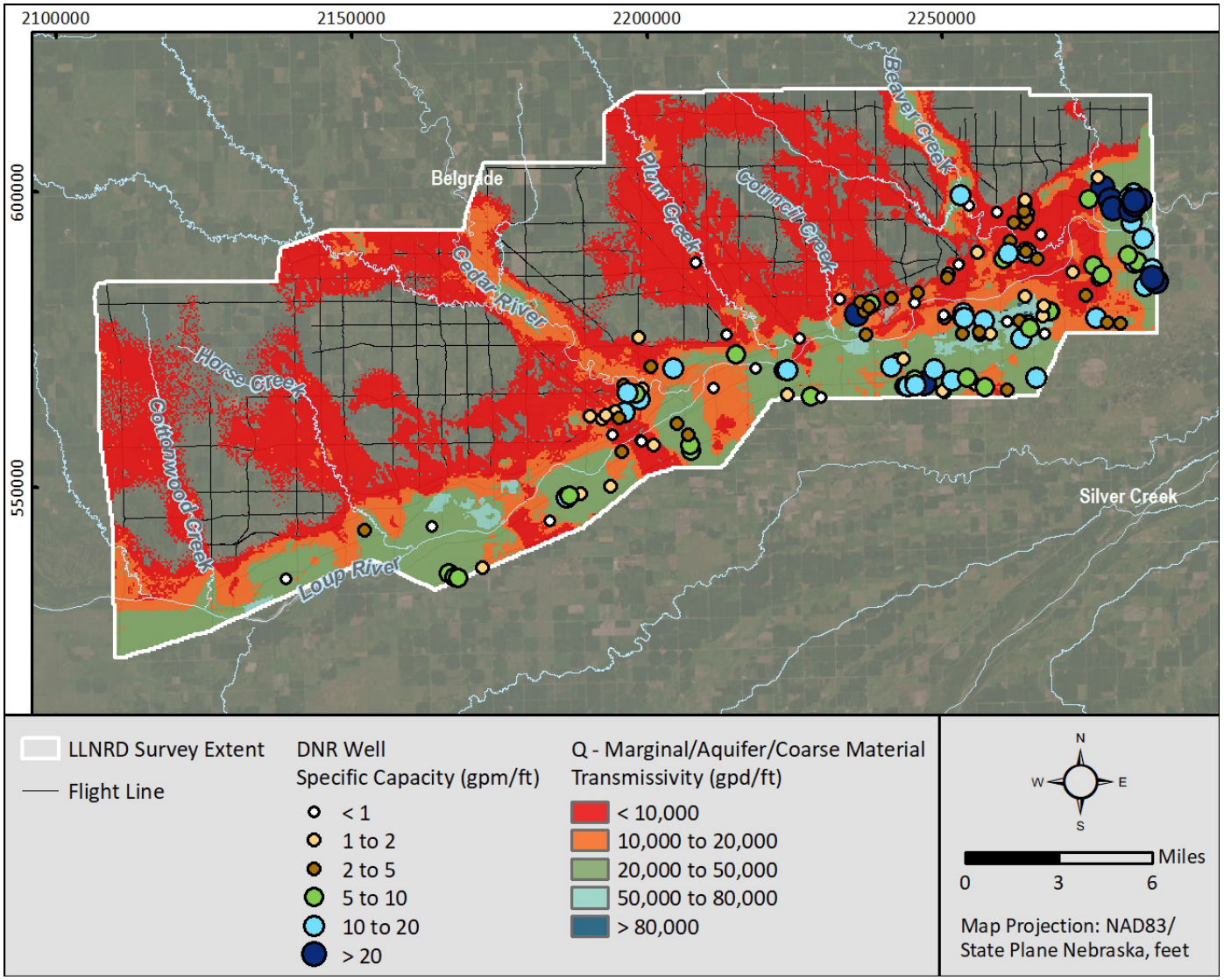



**Figure 5-25. Map of the calculated transmissivity within the Quaternary (*Q)* deposits marginal, aquifer, and coarse aquifer material along with the specific capacity of the DNR wells designated as "*Q*" aquifer wells based on screen interval. Flight lines are depicted as black lines. The map projection is NAD83 State Plane Nebraska (feet).**

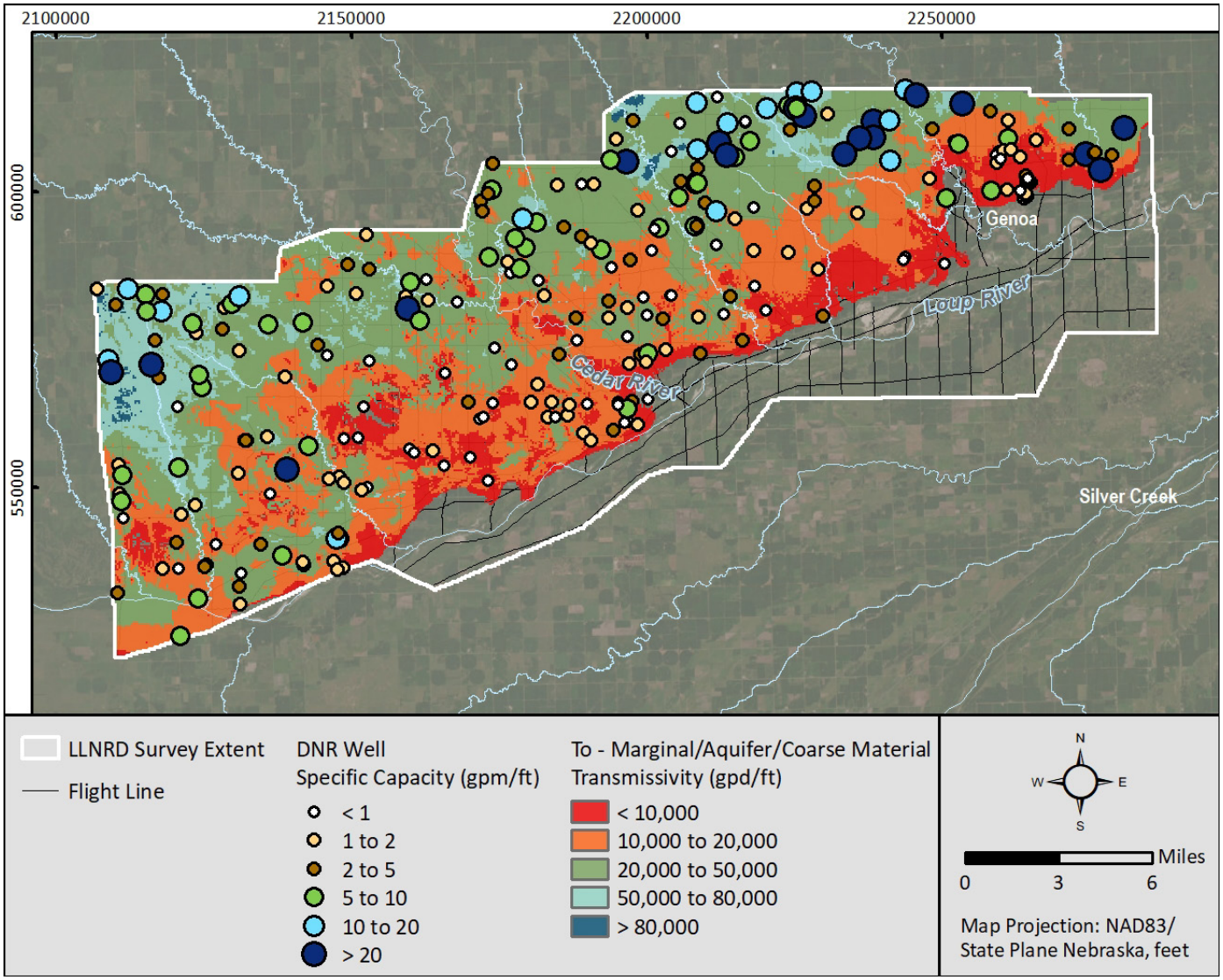



**Figure 5-26. Map of the calculated transmissivity within the Tertiary Ogallala Group (*To)* marginal, aquifer, and coarse aquifer material along with the specific capacity of the DNR wells designated as "*To*" aquifer wells based on screen interval. Flight lines are depicted as black lines. The map projection is NAD83 State Plane Nebraska (feet).**

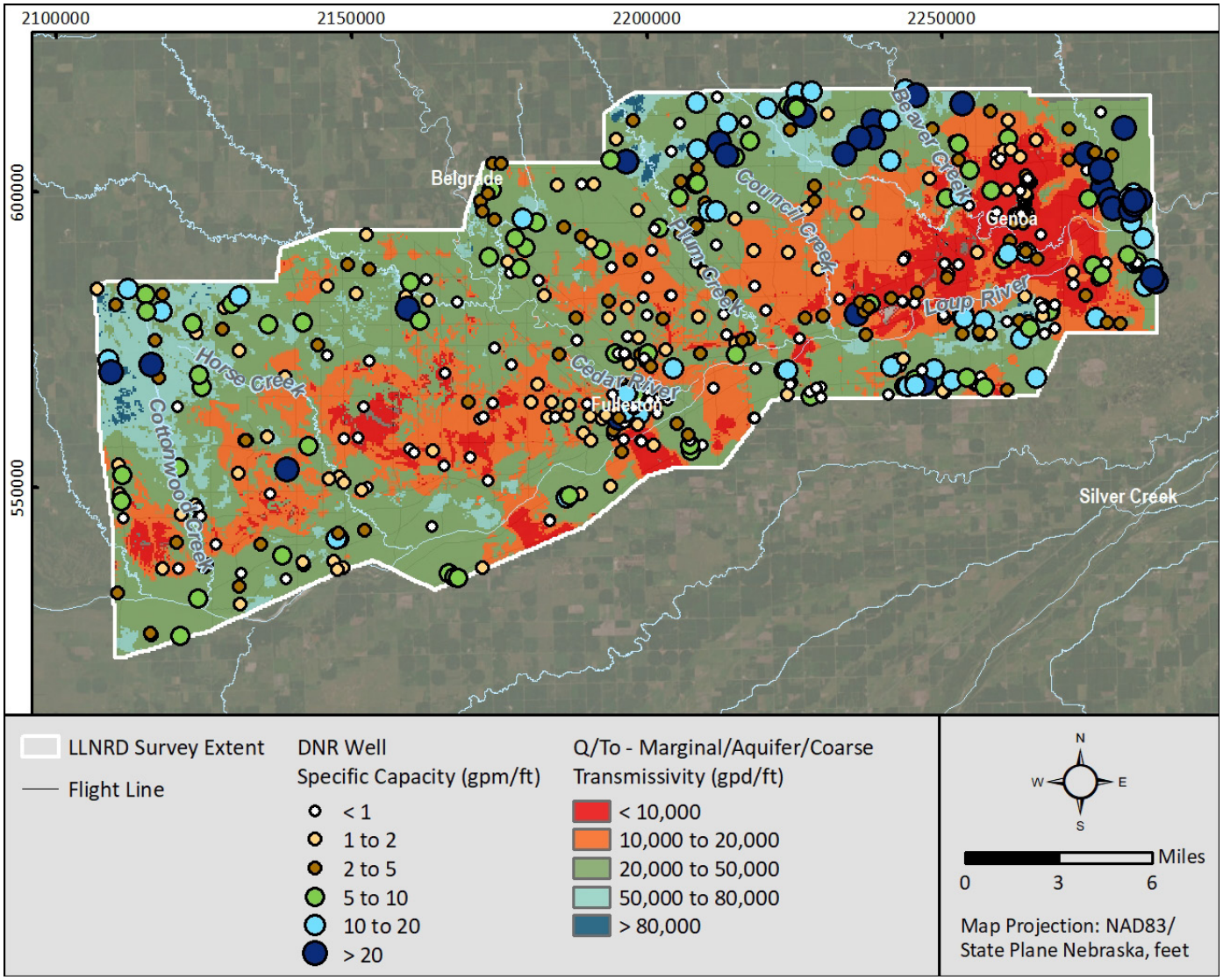



**Figure 5-27. Map of the calculated transmissivity within both the Quaternary (*Q)* deposits and Tertiary Ogallala Group (*To)* marginal, aquifer, and coarse aquifer material along with the specific capacity of the DNR wells designated as "*Q*", "*To*", or both *"Q" and "To"* based on screen interval. Flight lines are depicted as black lines. The map projection is NAD83 State Plane Nebraska (feet).**

#### 5.1.5.5 *Geologic Map Updates*

Based on the addition of AEM data within the LLNRD survey area minor refinements were made to the published geologic map (Burchett, 1986), specifically to the extents of the ***To*** and ***Kp***. There was no published ***Kp*** extent underlying the ***To***; therefore, the ***Kp*** extent was based solely on the interpretation of AEM data. The refinement made to the ***To*** extent is based on the resistivity of the material and "picks" made during the interpretation portion of the project. Figure 5-28 is a map displaying the published geologic map (Burchett, 1986) and the refined extents.

### 5.1.6 *Create 3D Interpretative Voxel Grids*

A voxel grid was completed for the LLNRD Nance County 2022 AEM survey area. The voxel grids were made using a 300 feet grid cell size and the model layer thickness (from Table 4-3). A minimum curvature method was used within Datamine Discover PA (Datamine Discover, 2023). 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 estimated top of the Tertiary Ogallala Group (***To***) and the top of the Cretaceous bedrock using the surface elevation grids discussed above in Section 5.1.5. 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***) and ***To*** materials can also be separated by thresholds developed above for the four lithology classes. Utilizing the voxel grids of the ***Q***, analysis can be made of the thickness of the different materials within the section. Additionally, the ***Q*** and ***To*** voxel can be split into unsaturated and saturated portions utilizing the LLNRD Spring 2022 water table. Figure 5-29 is an exploded diagram of the plot of the stratigraphy of the area including the ***Q, To, Kp,*** and ***Kn*** looking to the north. The voxel grids can be found in *Appendix 3-Deliverables\Voxel*.

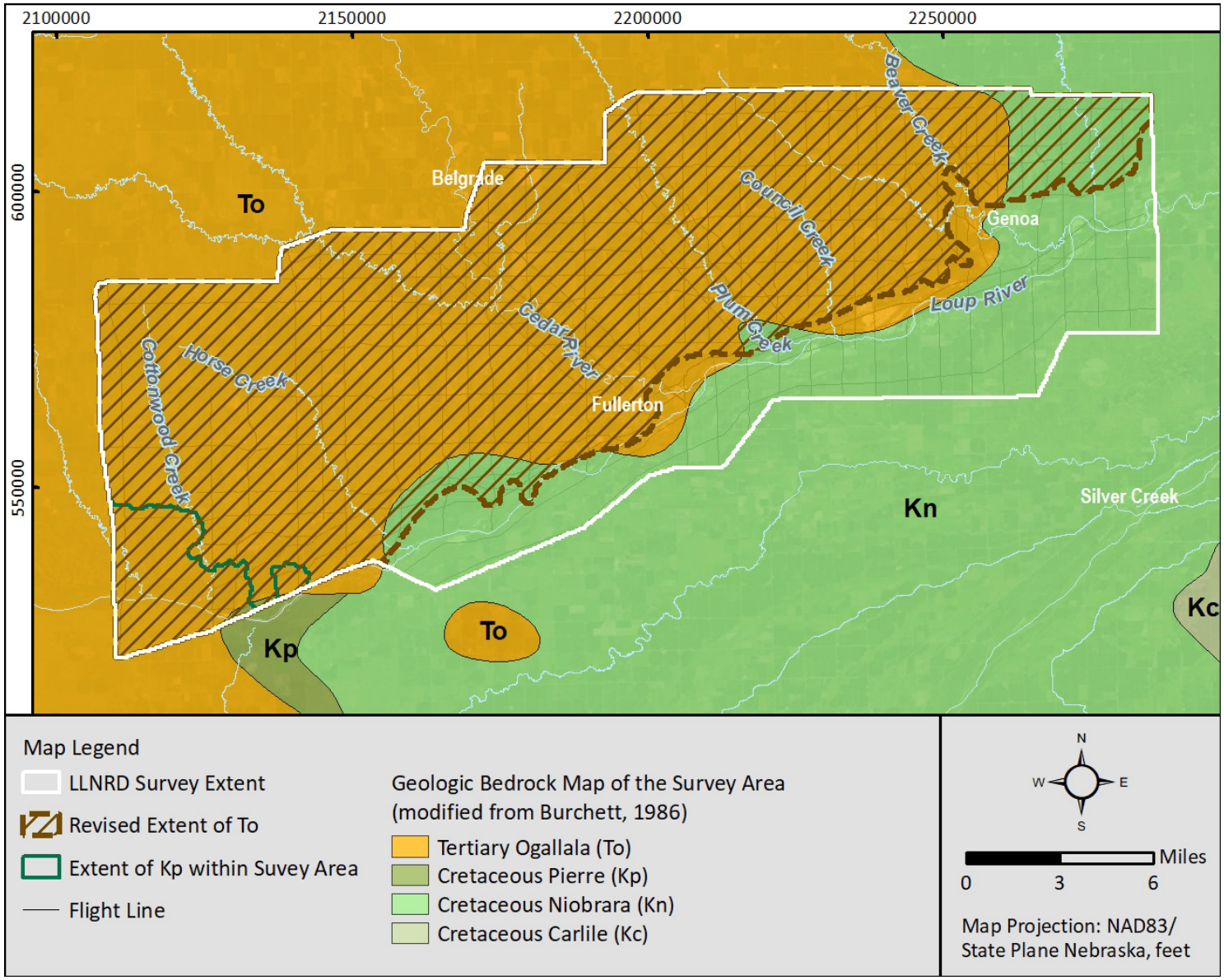



**Figure 5-28. Map displaying the published geologic map (Burchett, 1986) and the refined extents.**

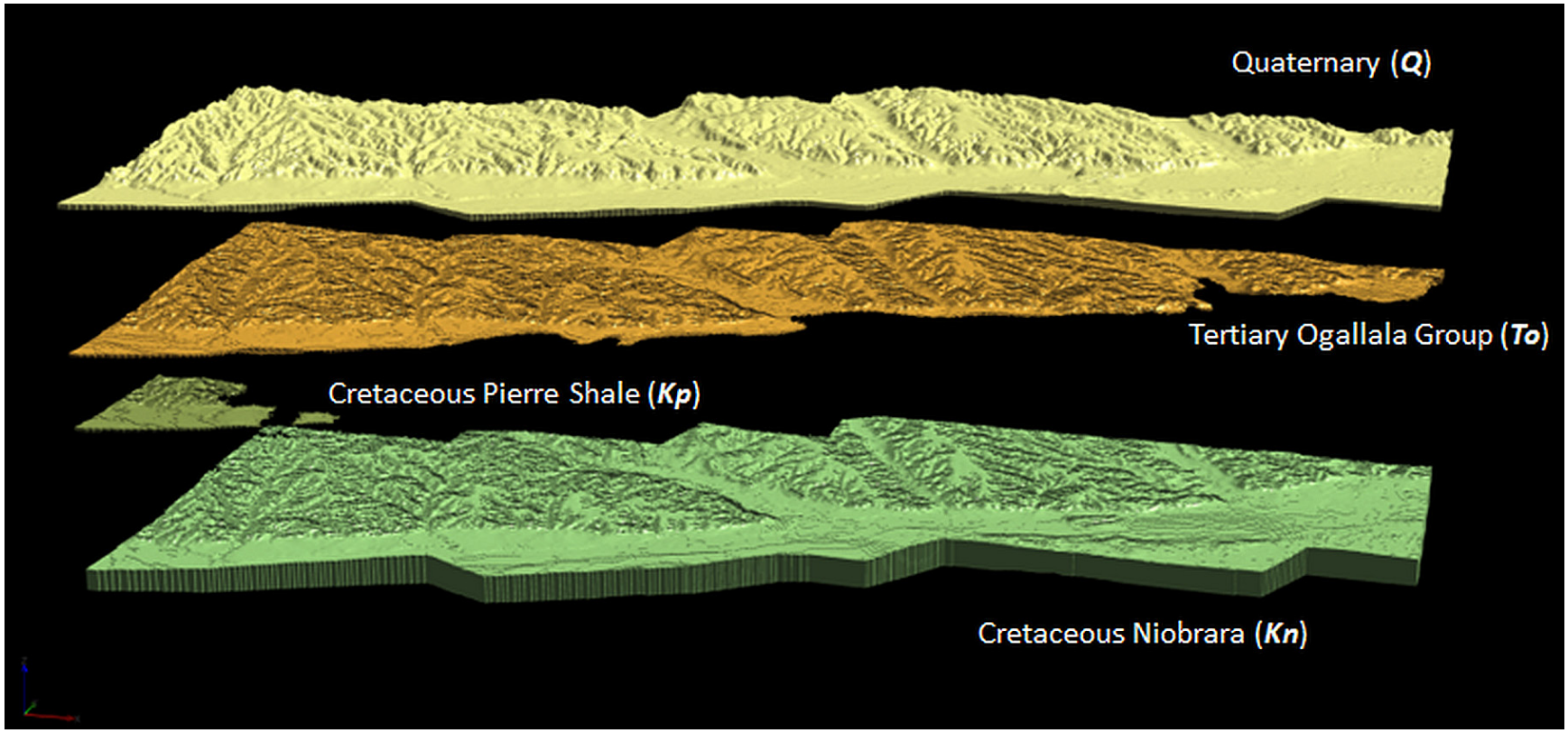



**Figure 5-29. Exploded 3D Voxel model of the stratigraphy of the Nance County AEM area showing the of the Quaternary (*Q*) Tertiary Ogallala Group (*To*), Cretaceous Pierre Shale (*Kp*), and the Cretaceous Niobrara Formation (*Kn*). Not to scale**

## 5.2 Comparison of AEM Inversion Resistivity to Borehole Geophysical Resistivity Logs

Ten geophysical logs existed in the NE-CSD database within the Nance County AEM survey area. These included *26-A-55*, *27-A-55*, 28-A-55, 18-A-56, 19-A-56, 20-A-56, 21-A-56, 40-A-56, 41-A-56, and *42-A-56*. These logs included a Short Normal 16-inch geophysical resistivity log or electric log (E-log) digitized from paper logs. The resistivity logs within the CSD database are of various vintages and conducted by various staff with differing equipment. A critical examination of the absolute values of the resistivity needs to include an awareness of errors in calibration and in the proper operation of the equipment. Many of the early 1940-1980's electric logs were paper logs that were scanned and digitized and then included in the database. There is a long-standing issue with using geophysical logs as ground truth when comparing to AEM acquisition systems and inversions that are well calibrated using modern techniques. Throughout much of the geophysical logging at the time it was acquired, the relative deflections of the resistivity measurements were all that was required or expected from a geophysical log. Operators were seldom trained in the proper operation of a calibrated sonde or in the ability to recognize high contact resistance of a cable head. This has led to many geophysical logs that are uncalibrated within the CSD database. Note that these logs still have scientific merit in their ability to relatively indicate an increase or a decrease in the formation resistivity. The logs used herein are for qualitative comparison to the AEM because detailed calibration and corrections would need to be carried out for the resistivity values in the logs to be directly used as numerical constraints in the inversion of the AEM data (Ley-Cooper and Davis, 2010). In order to compare the E-logs to the AEM data, a 2,000 feet search radius was used around each of the boreholes and any AEM soundings within that distance were averaged and a mean and standard deviation was calculated.

Figure 5-30 is a plot of wells *26-A-55* through *20-A-56* 16-inch Short Normal resistivity logs plotted with the inverted AEM average resistivity and standard deviation within 2,000 feet. There is general agreement to the shape of the resistivity curves with some being more calibrated than others. The one discrepancy is in *18-A-56* were the AEM show a low resistivity zone and the E-log shows a high resistivity zone. This may be related to local variations over the 2,000 feet interval. Figure 5-31 is a plot of 21-A-56 through 42-A-56. As was observed in the other wells the shape of the curves tract but offsets exist between the AEM and the E-logs. These comparisons do show however that the AEM is responding well to the resistivities of the materials within the survey area.

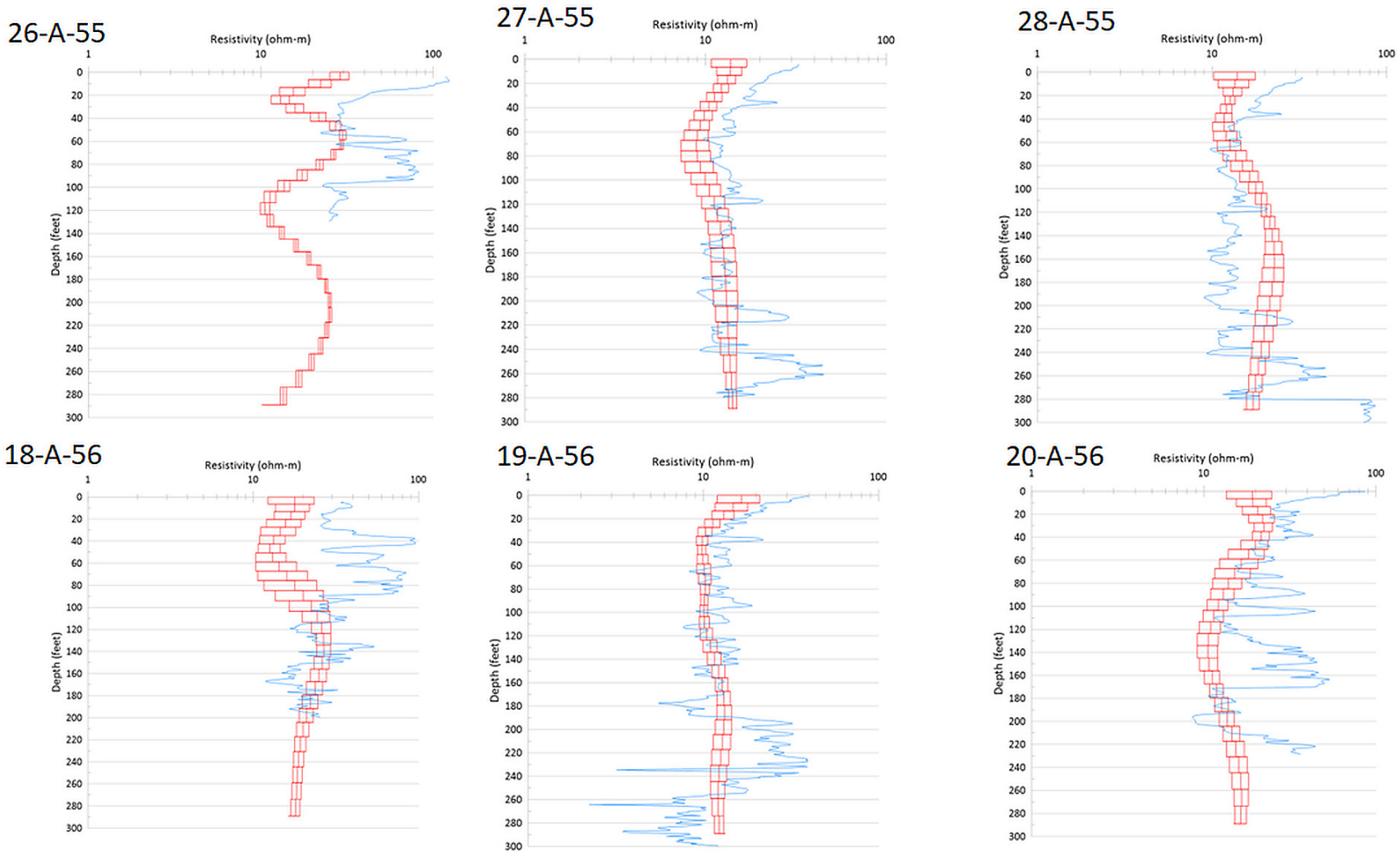



**Figure 5-30. Graph of the *26-A-55 through 20-A-56* 16-inch normal resistivity log values (blue line) and the inverted airborne electromagnetic average resistivity values (red line) within 2,000 feet. Error bars indicated one standard deviation.**

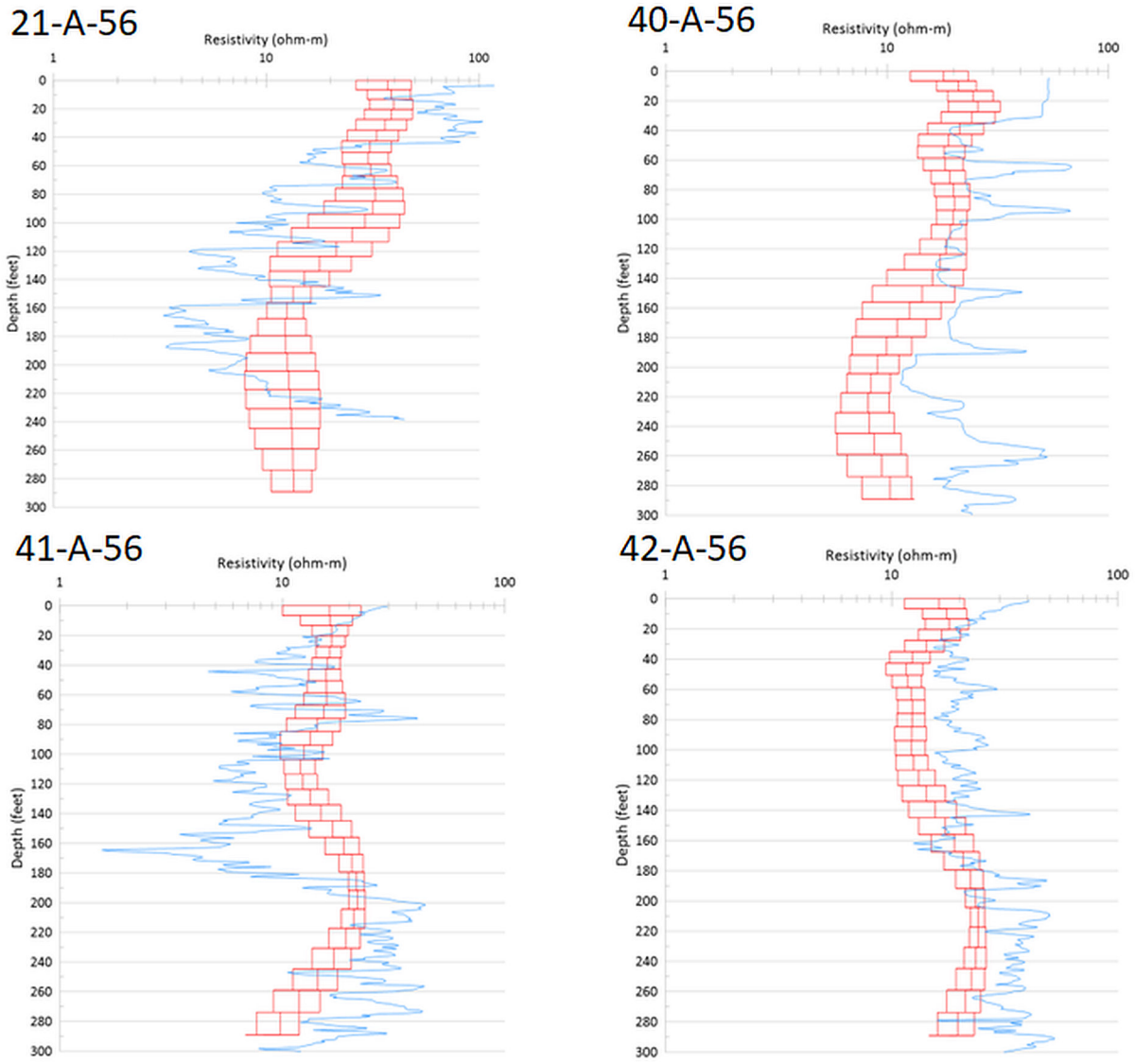



**Figure 5-31. Graph of the *21-A-56 through 42-A-56* 16-inch normal resistivity log values (blue line) and the inverted airborne electromagnetic average resistivity values (red line) within 2,000 feet. Error bars indicated one standard deviation.**

### *5.2.1 Resistivity Relationship in the Quaternary and Ogallala Aquifer System*

A critical aspect of a geophysical survey is assessing the nature of the material detected by the geophysical method applied in the investigation. Regarding the 2022 LLNRD Nance County AEM survey area, assessment of the sediment character in the Quaternary (***Q***) and Tertiary Ogallala (***To***) aquifer system is required to determine the overall composition of the major categories used to define the aquifer and aquitards. This is typically done by utilizing the borehole geophysical logs associated with lithology. In the LLNRD Nance County 2022 AEM survey area there are ten geophysical logs to complete this analysis but they are of the older type that were digitized from paper logs and are not calibrated. Unlike the work that was presented in Carney et al. (2015), uncalibrated logs are inadequate. An assessment of the resistivity thresholds used to characterize non-aquifer, marginal, aquifer, and coarse aquifer materials was conducted using a comparison to the lithologies in the well logs and the AEM resistivity. This allowed for the characterization of the ranges of resistivities present in the ***Q*** and ***To*** units described in this report. It was determined that the Carney et al. (2015) was adequately mapping the aquifer materials. This analysis has been used in the current report for the categorization of the Quaternary and Ogallala aquifer system over the LLNRD survey area. The ***Q*** and ***To*** aquifers were broken down by resistivity for aquifer materials (less than 12 ohm-m – non-aquifer material, 12-20 ohm-m – marginal aquifer material, 20-50 ohm-m for aquifer material, and greater than 50 ohm-m for coarse aquifer material). Figure 5-32 is a plot of the color bar used and the resistivity ranges for the four aquifer material types.

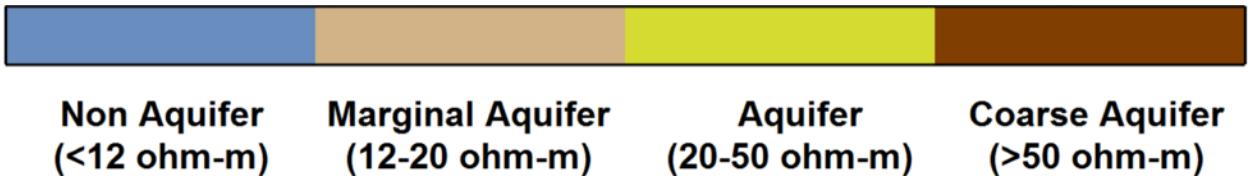



**Figure 5-32. Plot displaying the resistivities by major aquifer material color categories used in the LLNRD Nance County 2022 AEM survey: blue- non-aquifer materials, tan- marginal aquifer materials, yellow- aquifer materials, brown- coarse aquifer materials (Carney et al., 2015)**

## 5.3 Hydrogeological Framework of the LLNRD Nance County 2022 AEM Survey Area

The priority for this survey was to build a detailed hydrogeologic framework to better understand the impact of the low saturated thickness and low transmissivity of the aquifers in Nance County. The end goal is to establish a scientific-based approach to defining new regulatory boundaries.

The AEM reveals variability of the aquifer materials within the ***Q*** and ***To*** deposits, which provide the groundwater supply, and their spatial relationship to each other and the surface water. These spatial relationships can provide insight into groundwater supply in the AEM survey area. The ***Kp*** and ***Kn*** are present beneath the ***To*** throughout much of the AEM survey area. The term bedrock in this report represents the Cretaceous bedrock units of the ***Kp*** and ***Kn***. Along the Loup River, in the southern area of the survey, the ***To*** is eroded away and the ***Q*** sediments are directly deposited on the ***Kn***. Figure 5-33 is the revised geology map of the area based on the interpretation of the AEM. This figure is based on Burchett (1986) with modifications due to the higher resolution AEM data.

For purposes of this report the ***Q*** and ***To*** contain the aquifers for the survey area and share the aquifer materials description. The ***Q*** and ***To*** use the same resistivity color scale to present locations of aquifer materials composed of non-aquifer (blue color in figures), marginal aquifer (tan color in figures), aquifer (yellow color in figures), and coarse aquifer materials (brown color in figures). The ***Q*** materials are composed predominantly of eolian and alluvial deposits. The ***Q*** is a minor aquifer bearing unit in the dissected plains, but is the dominant aquifer in the Loup River valley, Cedar River Valley, and Beaver Creek. Figure 5-34 and Figure 5-35, displayed as 3D fence diagrams, present the overall distribution of ***Q***, ***To***, and Cretaceous materials (as described in Section 2) across the LLNRD 2022 AEM survey area. The ***Q*** aquifer materials can generally be characterized by alluvial materials occupying the drainages. These drainages overlie the ***To*** in the northern parts of the survey area or are directly deposited on the cretaceous bedrock as along the Loup River. Much of the dissected plains portions of Nance County are covered with ***Q*** loess or eolian deposits made up of silt, clay, and fine sand that have limited permeability and storage.

The ***To*** covers the northern portion of the survey area and is overlain by the ***Q***. In much of the area ***Q*** and ***To*** deposits consisting of aquifer and coarse aquifer materials are in hydrologic connection with each other and the Loup River and its tributaries. ***To*** deposits tend to have marginal and non-aquifer materials near its base at the contact with the ***Kp*** and ***Kn.*** The ***Kp*** and ***Kn*** are impermeable shale and limestone, and they are considered aquicludes or boundaries to groundwater flow that is present throughout the survey area. The combined Cretaceous bedrock surface can be considered the bottom of the aquifer.

Figure 5-36 presents an exploded 3D Voxel model of the unsaturated ***Q***, saturated ***Q, To***, and ***Kp*** units. Note that the unsaturated ***Q*** is thickest in the dissected plains areas and thinnest in the river valley. The saturated ***Q*** is the reverse, with the thickest saturated materials in the valley and thin to no saturation in the dissected plains. The ***To*** is thickest in the north under the dissected plains and is thin or absent in the alluvial valleys.

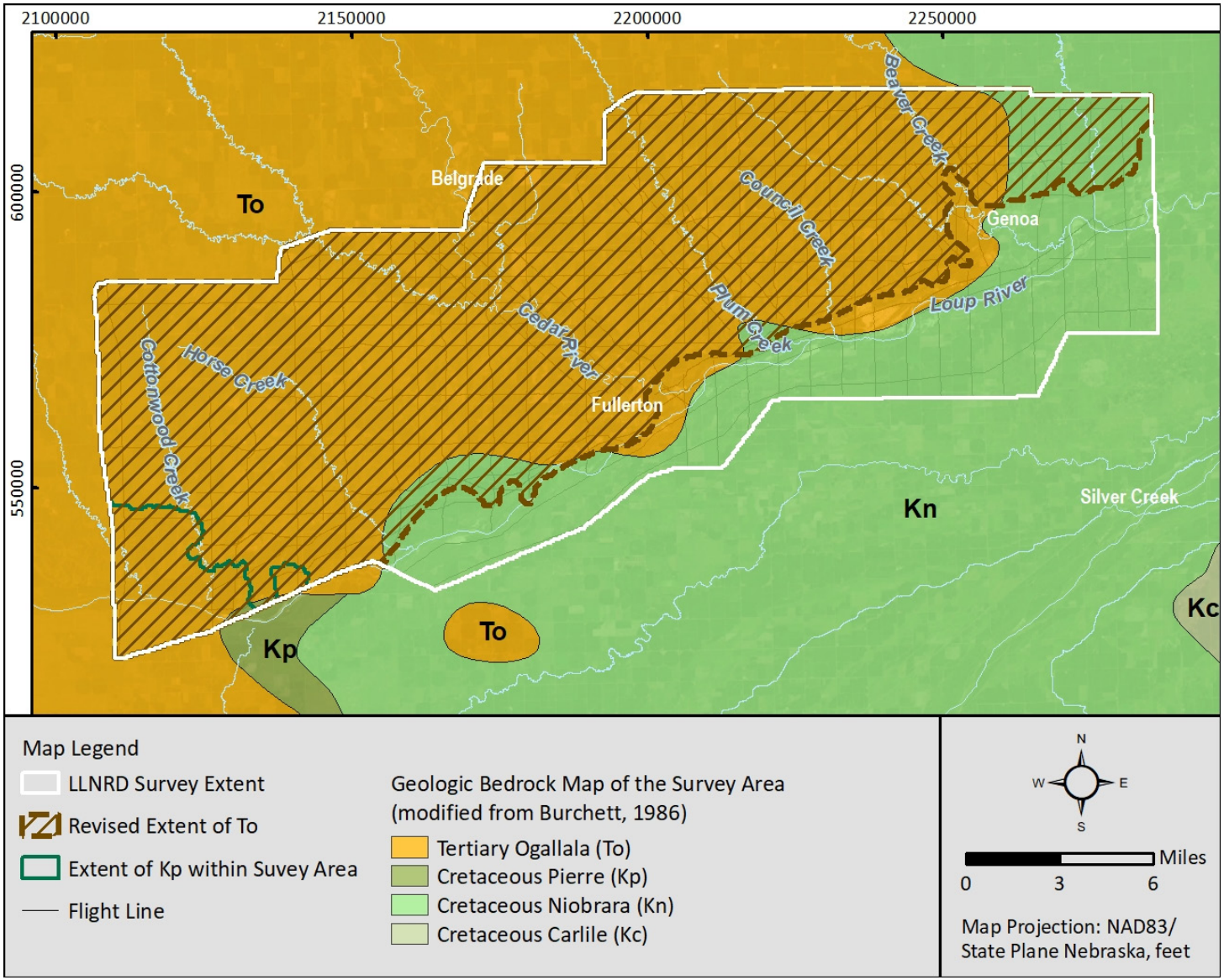



**Figure 5-33. Bedrock map of the survey area modified from Burchett (1986) using the LLNRD Nance County 2022 AEM survey results.**

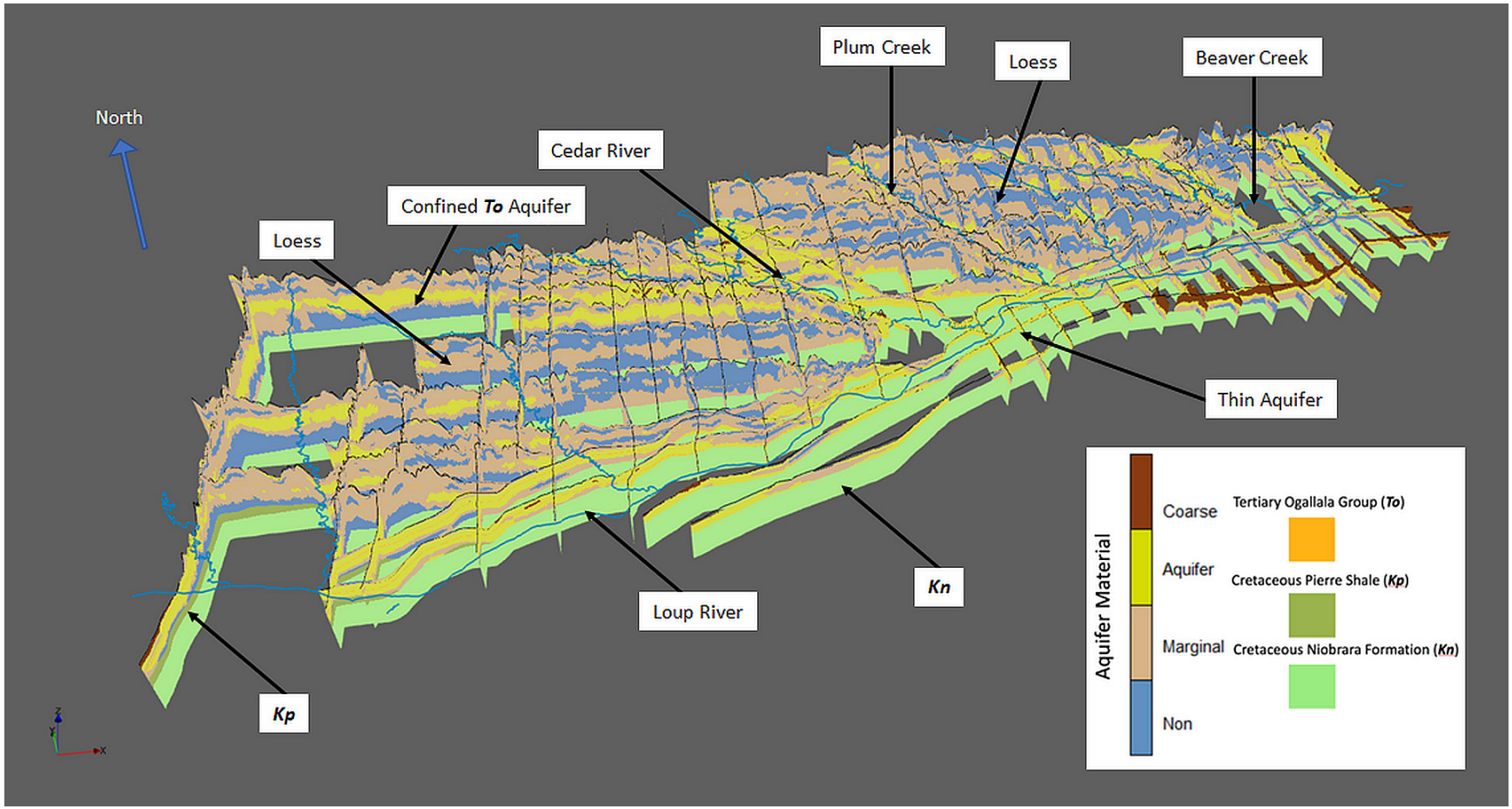



**Figure 5-34. 3D Fence diagram looking to the north of the interpreted distributions of aquifer material within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

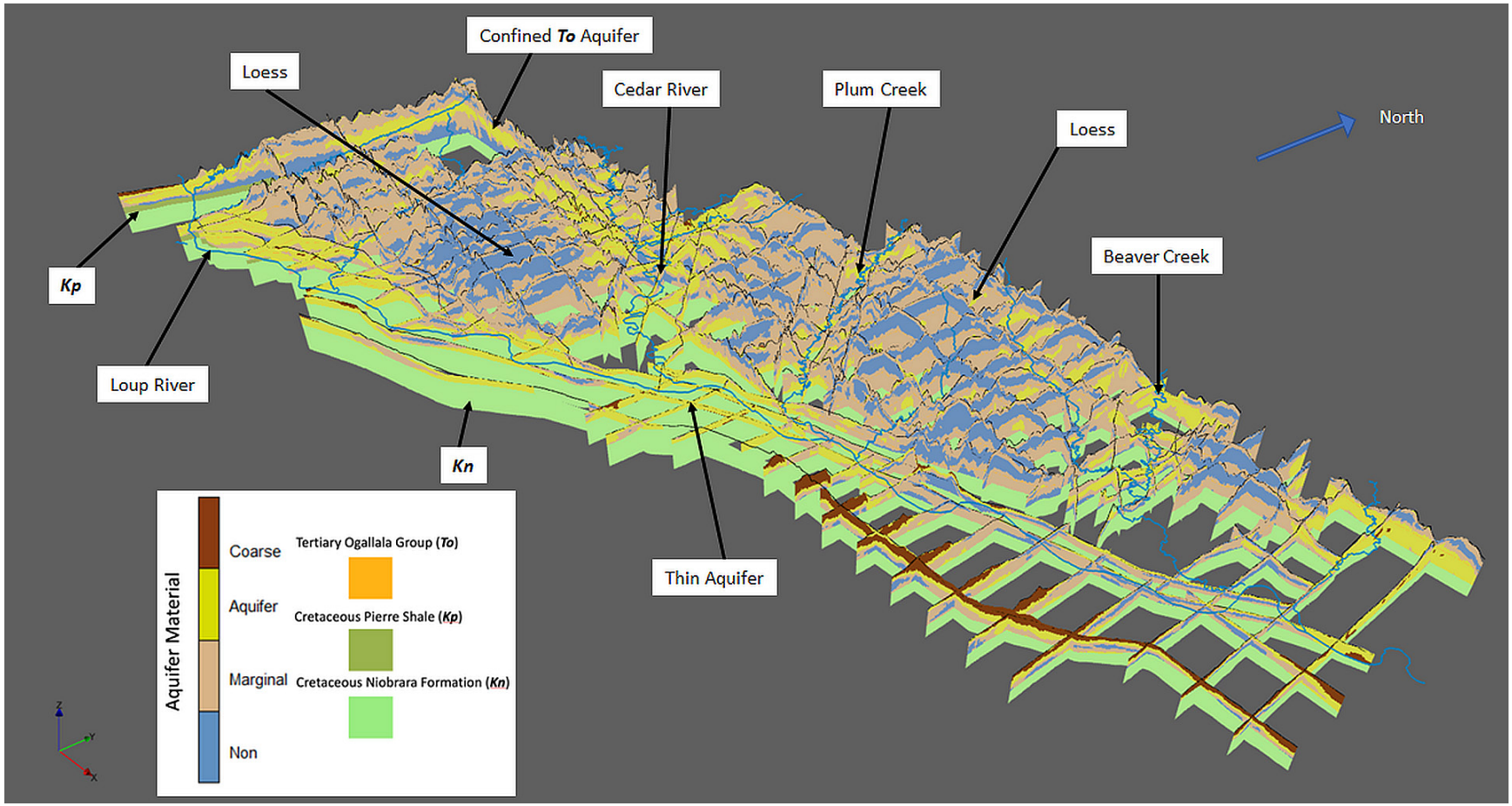



**Figure 5-35. 3D Fence Diagram looking to the northwest of the interpreted distributions of aquifer material within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

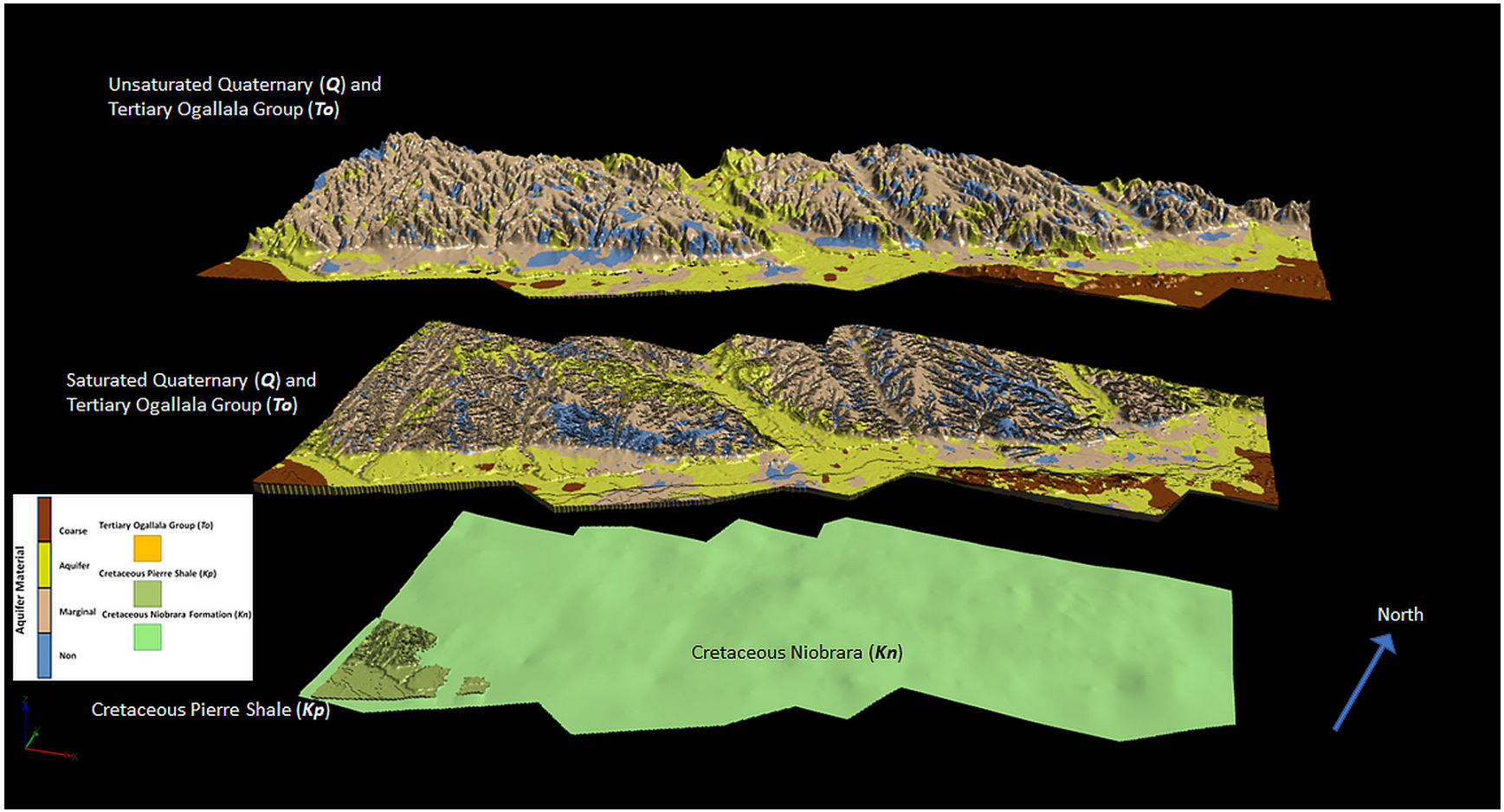



**Figure 5-36. 3D exploded voxel model looking north of the LLNRD 2022 Nance County AEM survey area showing *Q* (Quaternary) and *To* (Tertiary Ogallala Group) unsaturated and saturated, and the Cretaceous Pierre Shale *(Kp*) and Niobrara Formation (*Kn*) bedrock. The figure is not to scale.**

### *5.3.1 The Hydrogeology of the Quaternary*

The Quaternary (***Q***) materials of the LLNRD 2022 Nance County AEM survey area is predominantly composed of two zones: 1) the alluvial sediments dominated by sands and gravels of the valleys, and 2) the loess deposits of eolian silts and clays of the dissected plains.

The first zone is aquifer material in the ***Q*** alluvial sediments (yellow color in figures) and coarse aquifer materials (brown color in figures) that indicate sands and gravels. These deposits are within the stream channels of the area with the largest being the Loup River (Figure 5-37). The Cedar River, Beaver Creek, and, on the far eastern end of the survey area outside Nance county on the western edge of Platte County, the Looking Glass Creek also display alluvial sands and gravel (Figure 5-37). From west to east Cottonwood Creek, Horse Creek, Timber Creek, Plum Creek, Council Creek, and Skeedee Creek do not show much aquifer materials except at the point where they join the Loup River alluvial sediment deposits. While there are also zones of marginal aquifer materials and non-aquifer materials, composed of fine-grained silts and clays within the alluvial deposits of the Loup River, these have been blanked out in Figure 5-37 but are shown in detail below in Figure 5-38 and Figure 5-39.

As noted above, the second ***Q*** zone is the loess deposits of eolian silts and clays of the dissected plains which make up the marginal aquifer and non-aquifer material and are poor aquifers. Figure 5-38 illustrates the dominance of the marginal (tan color in figures) and non-aquifer (blue color in figures) materials in the dissected plains. Looking just at the non-aquifer materials in Figure 5-39 illustrates the areas of clay-rich materials within the ***Q*** section, with most occurring in the dissected plains to the north.

An enhanced understanding of the distribution of ***Q*** aquifer materials can be gained by an examination of the flight line profiles. North-south profile Line L100801 (Figure 5-40) is a good example of the changes in the ***Q*** section across the survey area. On Figure 5-40 the Nance County AEM flight area map inset on the upper right indicates all the flight lines as black lines. The current line displayed in the profiles is indicated in red and boreholes are indicated as blue dots from the CSD database and small olive dots from NE-DNR database. The flight line location map on the upper left indicates the flight line location on a USGS Topography map with the CSD wells indicated by blue crosses and the DNR wells indicated by orange dots. The middle profile is the SCI inversion result which shows the results of the inversion as electrical resistivity. Gaps in the resistivity profile are a result of editing areas of EM-coupling out of the data or of areas that were not over flown due to infrastructure. Located on the profile are lithology indicated on the NE GeoCloud lithology legend from the CSD and NE-DNR databases that are within 1,000 feet of the flight line. When present, the Depth of Investigation (DOI) is indicated by dashed gray lines. The Cretaceous Niobrara (***Kn***) and Cretaceous Pierre Shale (***Kp***) contacts are indicated by solid black lines. The estimated Tertiary Ogallala Group (***To***) contact is indicated by the dashed black line. The Spring 2022 LLNRD water table is indicated by the dashed blue line.

The interpretation profile on the bottom of Figure 5-40 shows the results of the hydrogeological framework interpretation. Located on the profile are NE-DNR database boreholes (gray) within 1,000 feet of the flight line with the screen intervals colored (indicated in the legend) with the specific capacity

in gpm/ft. The Cretaceous Niobrara (***Kn***) and Cretaceous Pierre Shale (***Kp***) are indicated by the colors in the legend. The estimated Tertiary Ogallala Group (***To***) contact is indicated by the dashed orange line. The Spring 2022 LLNRD water table is indicated by the dashed blue line. Estimated aquifer materials are represented by the colors in the legend.

Flight line 100801 in Figure 5-40 crosses the Cedar River, Timber Creek, and ends at the edge of the Loup River. The ***Q*** alluvium can be observed in the steam valleys and the thick loess deposits can be observed to the south of the Cedar River before ending at the edge of the Loup River valley. The specific capacity values for the registered wells that are available along the line also provide insight into the poor yield in the fine-grained sediments. The one anomaly is G-162801 (Figure 5-40) that shows a specific capacity of 5 to 10 gpm/ft that may be related to an extended screen length as well as that the well is located off the flight line (but within 1,000 feet) down in the valley.

The ***Q*** materials are thin in much of the area of the alluvium. Figure 5-41 shows the total thickness of the ***Q*** and Figure 5-42 concentrates on just the thickness of the aquifer and coarse aquifer materials. Most of the aquifer material thickness is 25 to 50 feet.

Using the LLNRD Spring 2022 water table estimates on saturated thickness can be derived from the data. Figure 5-43 is the total saturated thickness of the ***Q*** and Figure 5-44 is the saturated thickness of the aquifer and coarse aquifer material. These figures illustrate the limited aquifer thickness in the ***Q*** alluvial sediments. As indicated above the aquifer material class of marginal can provide some water but at a much lower rate due to the interlayering of clays and silts.

As a comparison, the ***Q*** marginal, aquifer, and coarse aquifer material saturated thickness is indicated in Figure 5-45. Where more thickness is added to the image by including the marginal aquifer material of the ***Q,*** much of the area is still under 50 feet of saturated thickness with only the areas greater than 75 feet saturated thickness occurring along the Loup River.

Using the calculated transmissivity maps and plotting the registered wells with specific capacity data for completions within the ***Q*** an image of the ***Q*** aquifer can be better illuminated (Figure 5-46**)**. Most completions within the ***Q*** are within the Loup River Valley in the higher transmissive materials. The areas of Beaver Creek show a couple wells in the upper reaches but most down on the edge of the Loup River Valley.

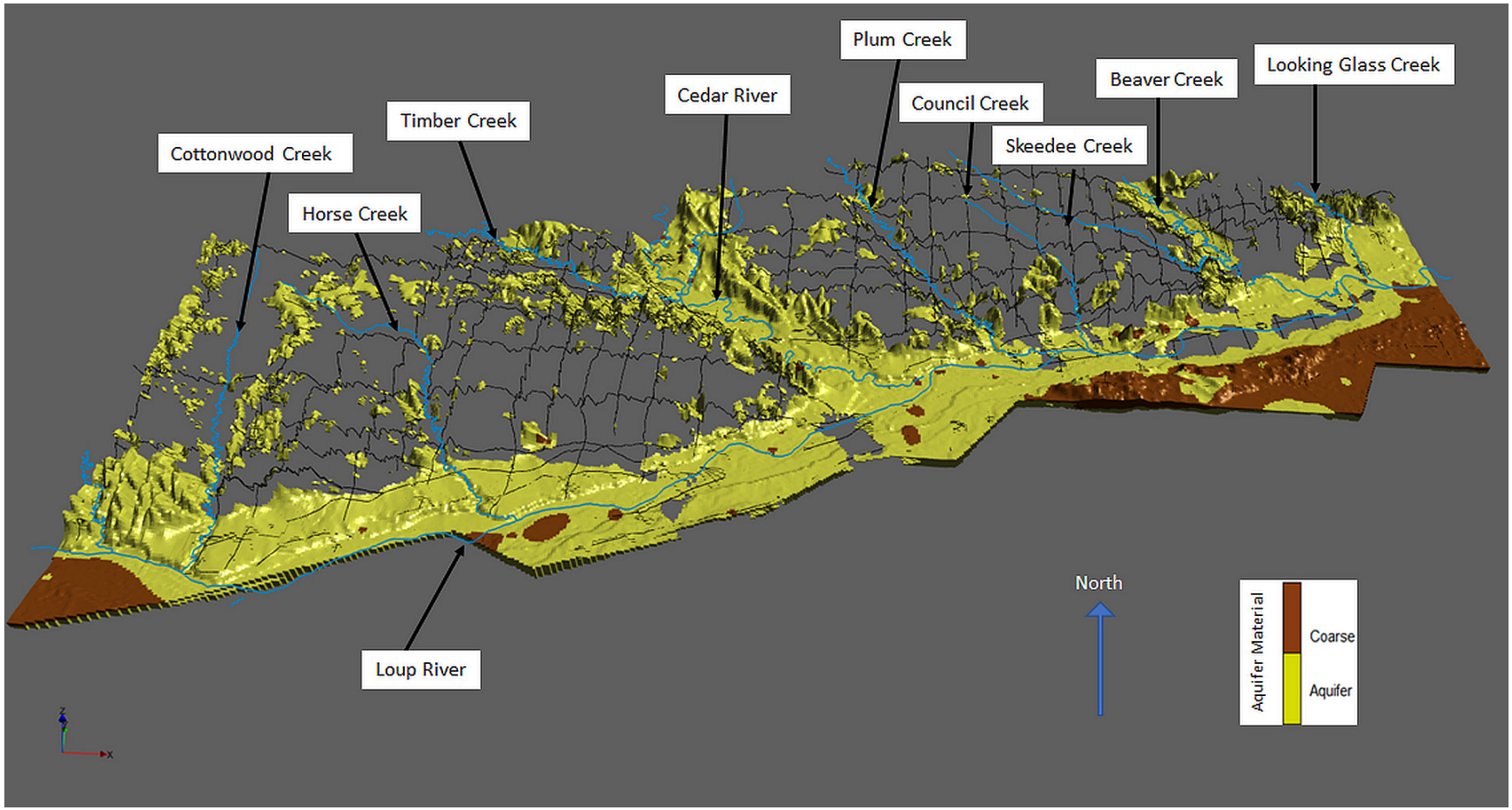



**Figure 5-37. 3D Voxel diagram looking to the north of the interpreted distributions of aquifer and coarse aquifer material of the Quaternary (*Q*) within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

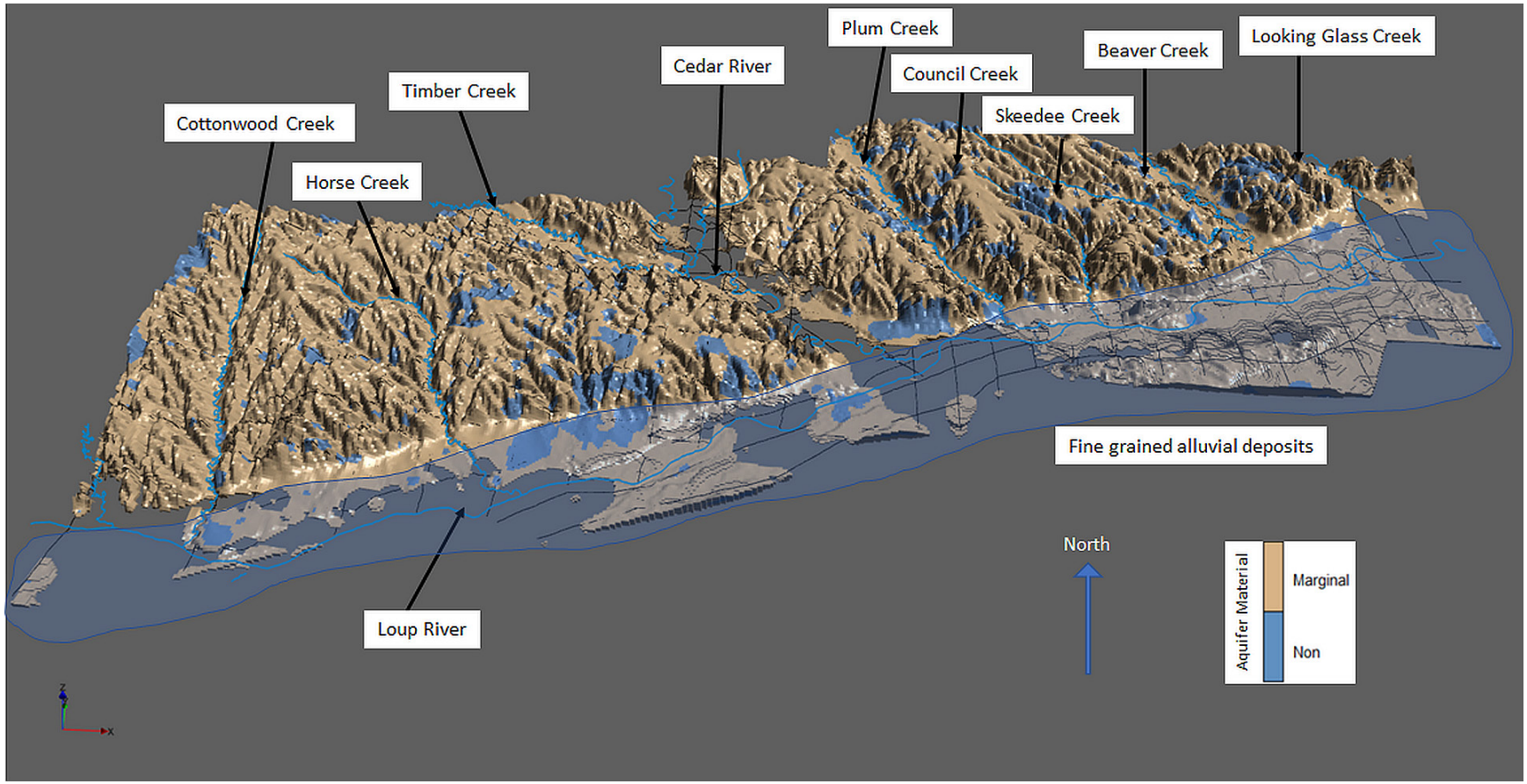



**Figure 5-38. 3D Voxel diagram looking to the north of the interpreted distributions of non- and marginal-aquifer materials of the Quaternary (*Q*) within the LLNRD 2022 Nance County AEM survey area. Note the fine-grained alluvial deposits (blue overlay) along the Loup River. Flight lines are indicated by black lines. V.E.=20x.**

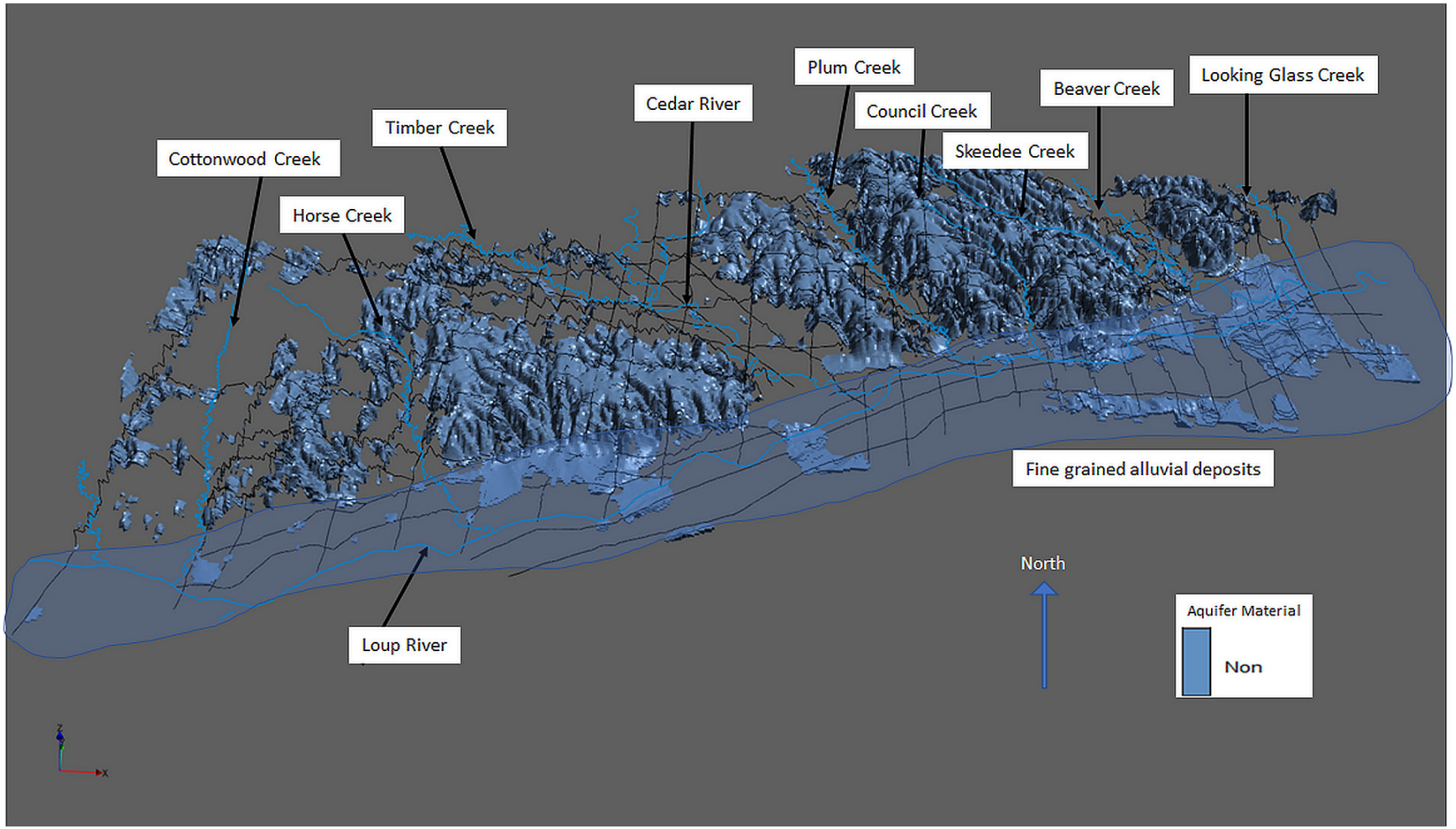



**Figure 5-39. 3D Voxel diagram looking to the north of the interpreted distributions of non-aquifer material of the Quaternary (*Q*) within the LLNRD 2022 Nance County AEM survey area. Again, note the fine-grained alluvial deposits (blue overlay) along the Loup River. Flight lines are indicated by black lines. V.E.=20x.**

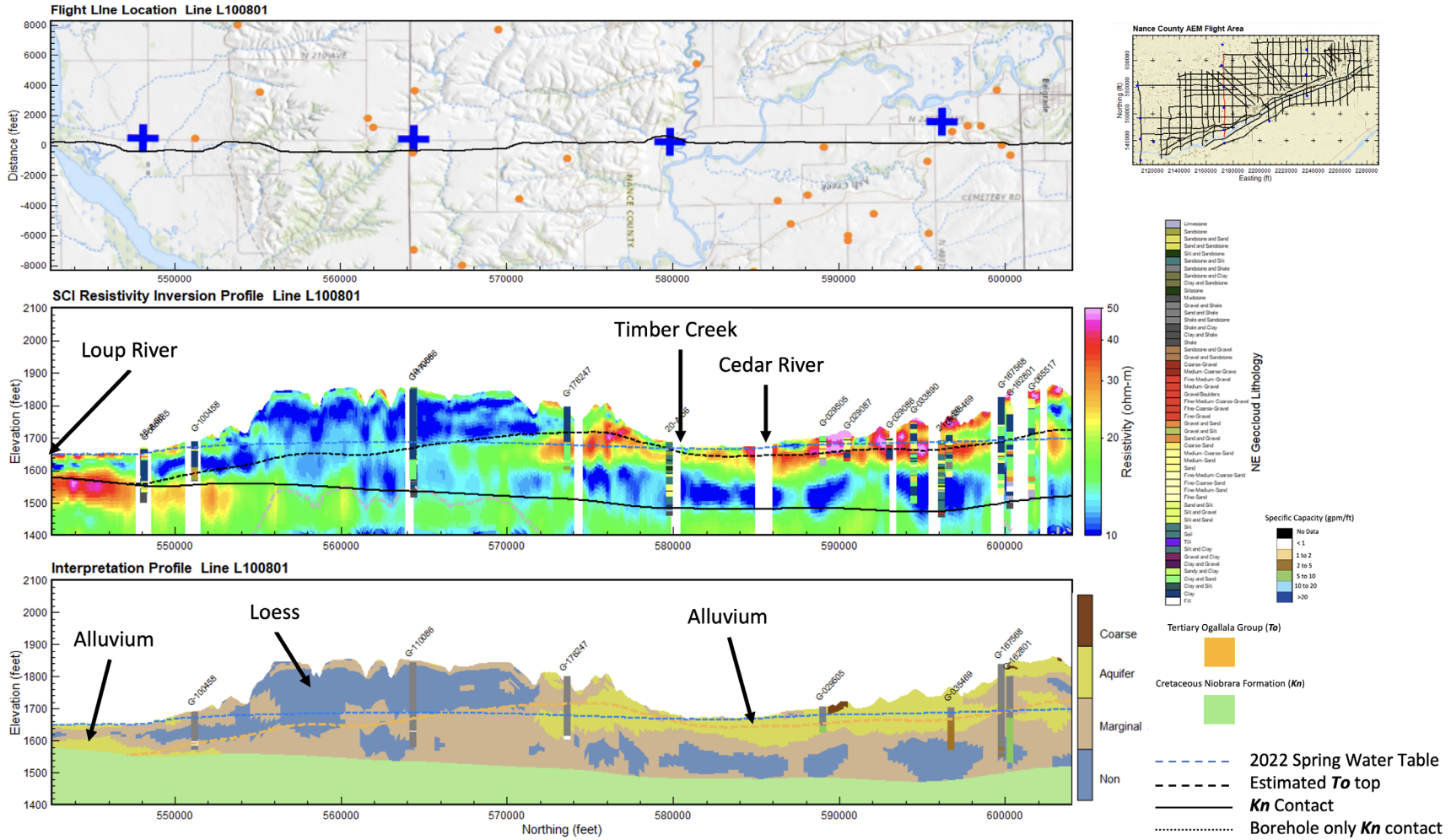



**Figure 5-40. North-south AEM flight line L100801. A location map is on the upper right. On the left the top profile shows the topography along the flight line and CSD wells (blue crosses) and DNR wells (orange dots). The middle profile is the SCI resistivity inversion result showing borehole lithologies and the bottom profile is an interpretative section showing the Cretaceous bedrock (*Kn*) and overlying Tertiary Ogallala (*To*) which are both underlying Quaternary alluvium subdivide into interpreted aquifer materials. Boreholes in the bottom section indicate measured Specific Capacity.**

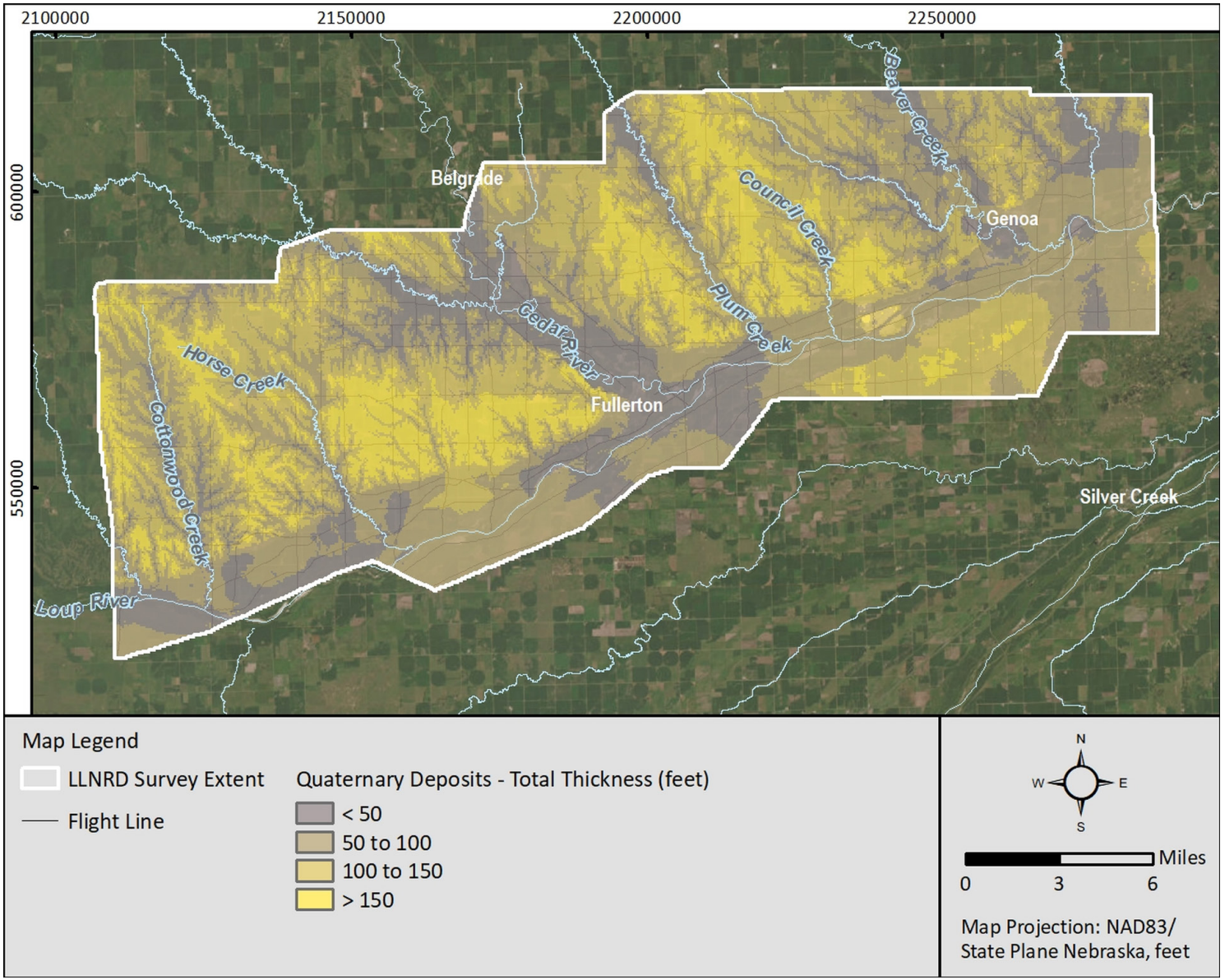



**Figure 5-41. Map of the total Quaternary (*Q*) thickness within the LLNRD 2022 Nance County AEM survey area.**

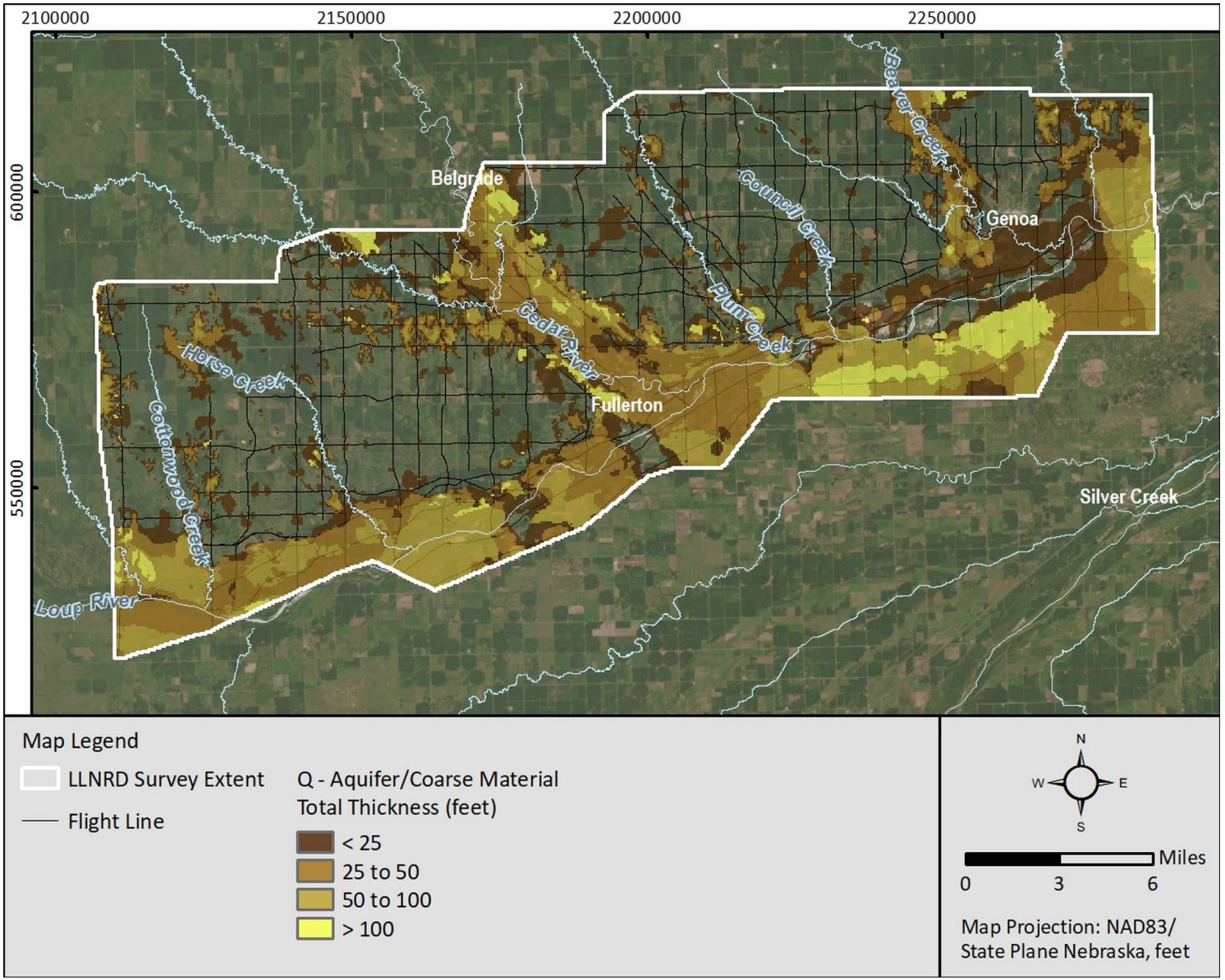



**Figure 5-42. Map of the Quaternary (*Q*) aquifer and coarse aquifer material thickness within the LLNRD 2022 Nance County AEM survey area.**

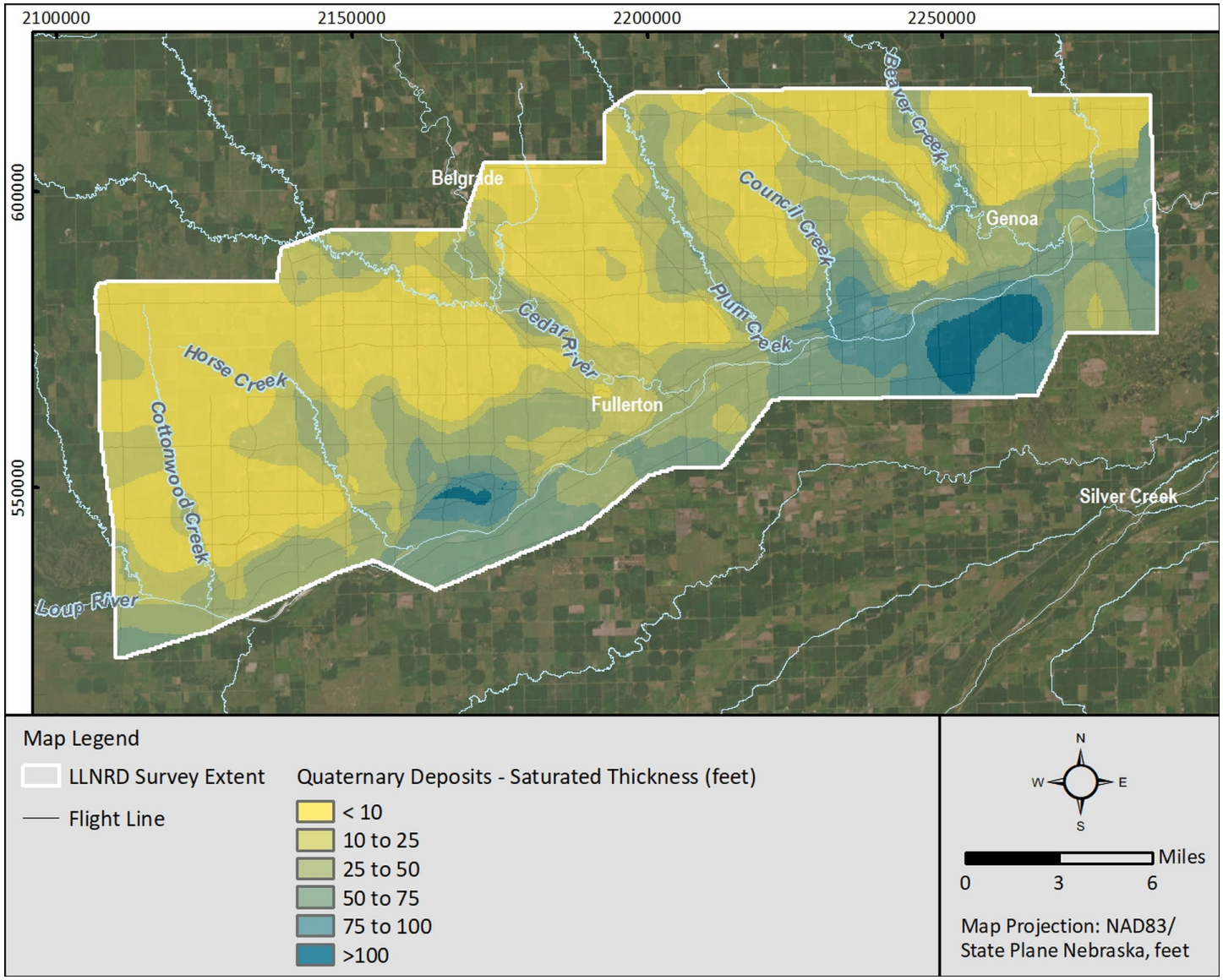



**Figure 5-43. Map of the total saturated Quaternary (*Q*) thickness within the LLNRD 2022 Nance County AEM survey area calculated using the Spring 2022 LLNRD water levels.**

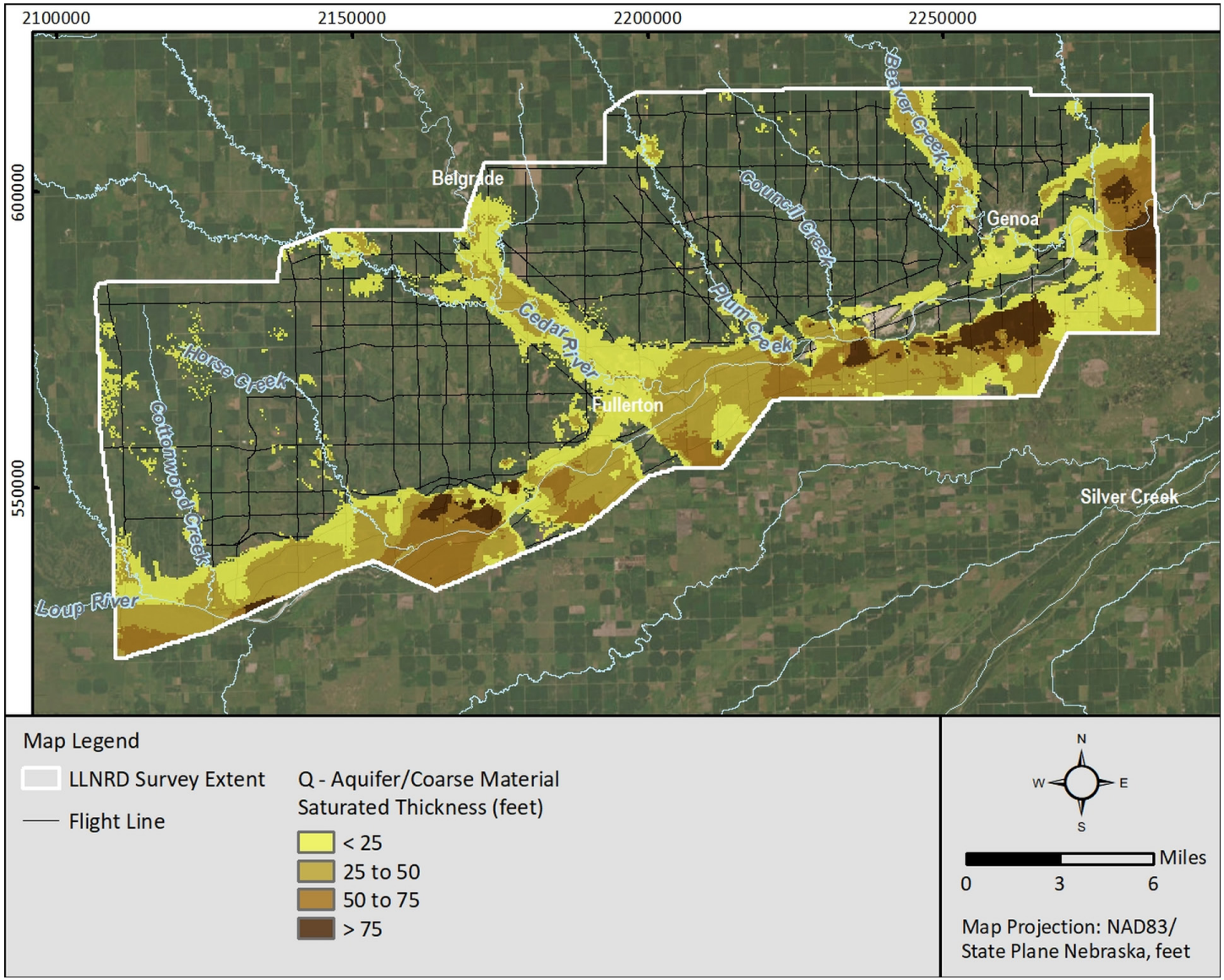



**Figure 5-44. Map of the Quaternary (*Q*) aquifer and coarse aquifer material saturated thickness within the LLNRD 2022 Nance County AEM survey area calculated using the Spring 2022 LLNRD water levels.**

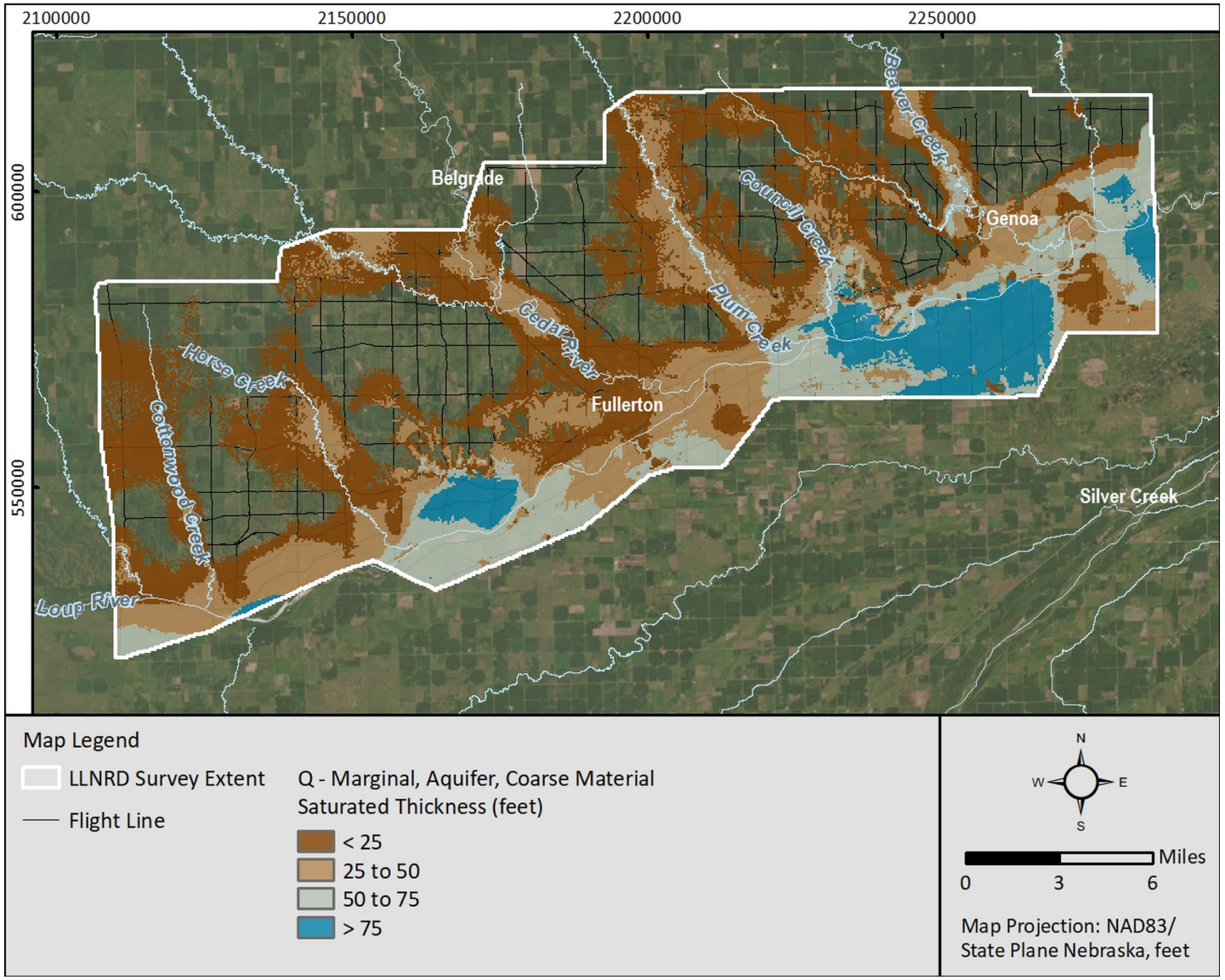



**Figure 5-45. Map of the Quaternary (*Q*) marginal aquifer materials, aquifer materials, and coarse aquifer material thickness within the LLNRD 2022 Nance County AEM survey area calculated using the Spring 2022 LLNRD water levels.**

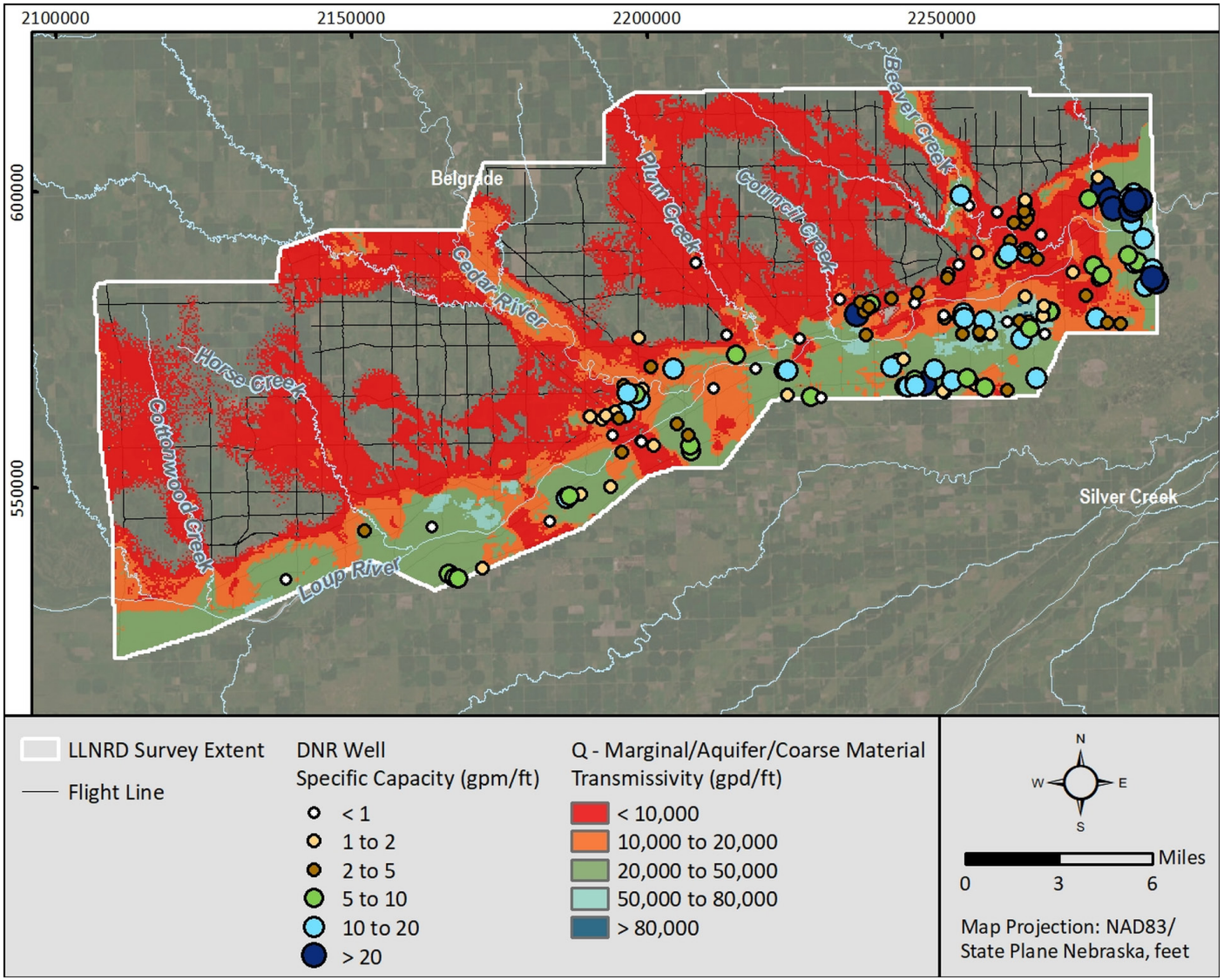



**Figure 5-46. Map of the estimated transmissivity (gpf/feet) of the Quaternary (*Q*) marginal aquifer materials, aquifer materials, and coarse aquifer material transmissivity within LLNRD 2022 Nance County AEM survey area. Specific capacity values from the DNR registered well database for wells screen in the *Q* are shown as indicated by the legend.**

### *5.3.2 Hydrogeology of the Tertiary Ogallala Group*

The Tertiary Ogallala Group (***To***) of the LLNRD Nance County 2022 AEM survey area is predominantly composed of poorly sorted mixtures of clay, silt, sand, and gravel that is unconsolidated and semi consolidated. Aquifer materials (yellow color in figures), composed of alluvial sediments (sands, gravels, and sandstones), are the important hydrogeologic features of the survey area. Thick zones of non-aquifer materials such as clay (blue color in the figures) and marginal aquifer materials (silts, clays, and fine sands and interlayered zones) (tan color in the figures) are layered above and below the aquifer materials. These materials lie on the ***Kp*** in the southwestern section of the survey area only and on the ***Kn*** elsewhere in the survey area, which both serve as the regional aquicludes. A map of the elevation of the top of the Cretaceous bedrock, which can be considered the base of ***To***, is presented in Figure 5-47. The top of the Cretaceous bedrock influenced the depositional environment of the ***To*** due to the control the surface had on the stream gradient at the time of deposition where aquifer materials were deposited; in particular in the paleochannel in the north of the study area and the related bedrock lows. A majority of the ***To*** is saturated throughout the survey area.

Figure 5-48 is a 3D voxel model looking north showing the distribution of ***To*** aquifer and coarse aquifer material. Note that there is very little coarse aquifer material within the ***To***. Also, note the dominance of the aquifer materials along the axis of paleo drainages. Similarly, Figure 5-49 presents a 3D voxel model, looking north, showing the distribution of ***To*** marginal aquifer, aquifer, and coarse aquifer material. Note the widespread distribution of the marginal aquifer materials in the AEM survey area. Figure 5-50 presents a 3D voxel model, looking north, showing the distribution of ***To*** non-aquifer material. There is a large deposit of clay sitting on the top of the ***Kp*** and ***Kn*** in the western portion of the survey area. CSD test holes indicated that it is not shale and contains clay, slit, and some thin layers of sand. The stratigraphy is indicated as ***To***.

Figure 5-51 presents the profile of Line L100101 on the far western edge of the survey area. Well *G-148119* does not match the AEM well. Behind that well is well *G-124411* that does match the AEM (see figure inset). It would look like *G-148119* is not located correctly or is not very well logged due to the poor correlation to the AEM.

The ***To*** varies in thickness from 0 ft in the south to approximately 290 Feet thick in the north (Figure 5-52). The saturated thickness is similar to the total thickness as the majority of the ***To*** is saturated (Figure 5-53). As discussed above, the aquifer materials within the ***To*** indicated paleochannel systems and can be seen in Figure 5-54 which shows the saturated aquifer/coarse aquifer materials. When present, they are from 25 to 100 feet thick. The well completions in the area indicated that much of the marginal aquifer material has also been screened to increase well yield. These materials would include silts, fine sands, and interlayered clays, sands, and gravels. While these materials will not yield as well as the aquifer materials composed of sands and gravels, they will produce some water. Figure 5-55 is a map of the thickness of the marginal and aquifer/coarse materials in the ***To***. Figure 5-56 shows the estimated transmissivity of the marginal, aquifer, and coarse aquifer ***To*** deposits and the Specific Capacity (SC) of the wells which are completed in the ***To***. There is a strong correlation of the thicker aquifer materials to the location of the best wells in the area and the higher transmissive areas.

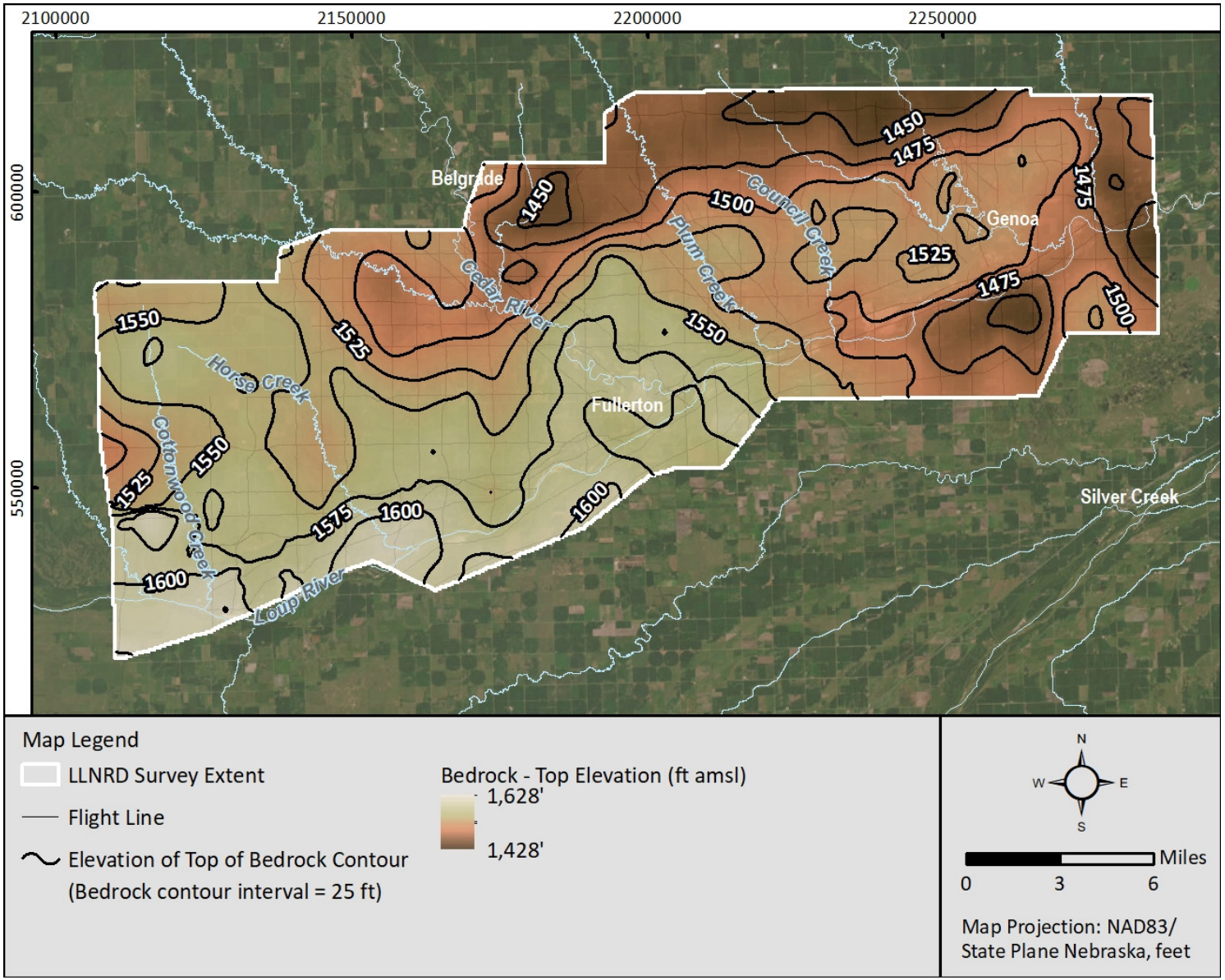



**Figure 5-47. Map of the Cretaceous bedrock surface elevation.**

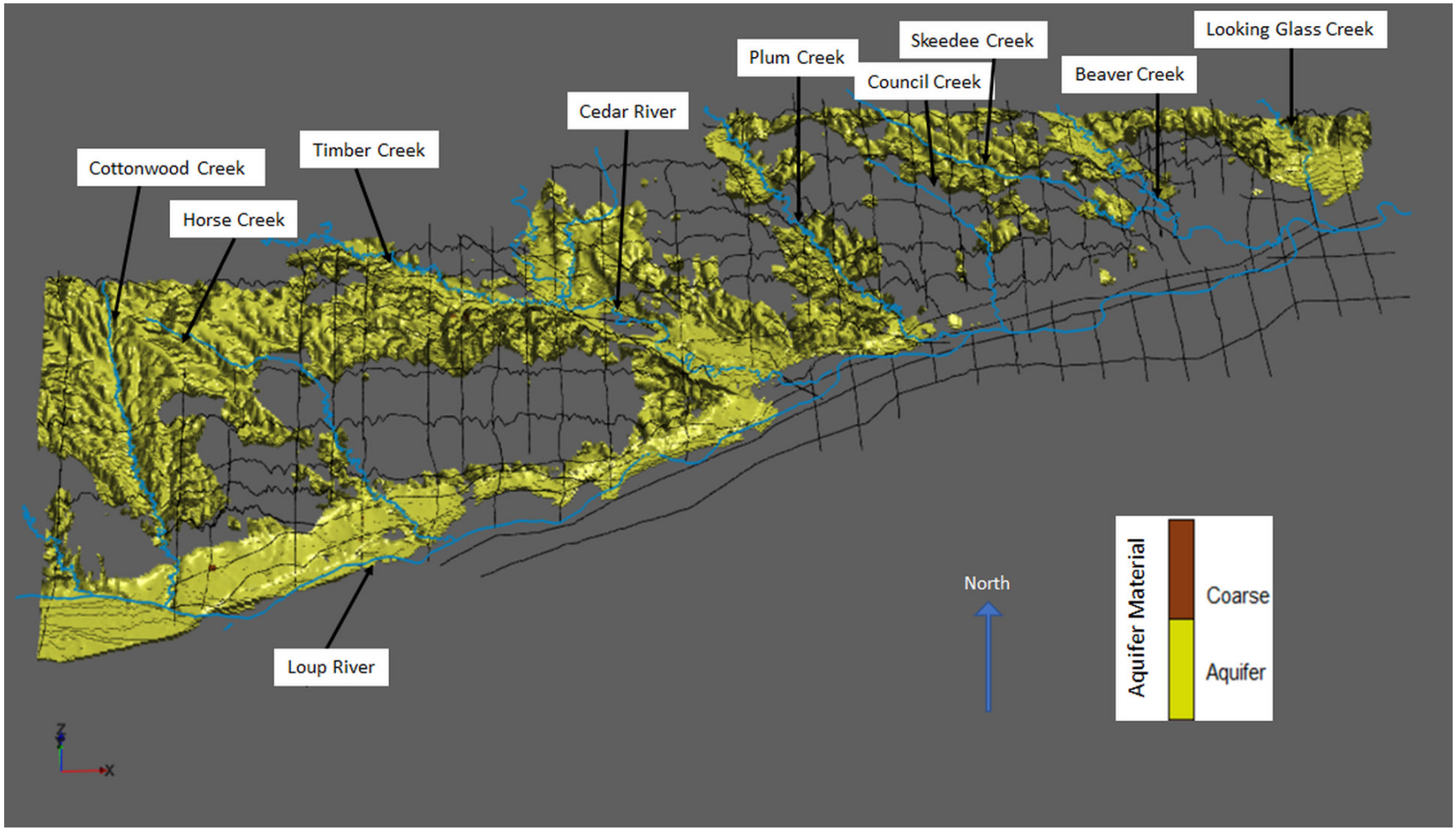



**Figure 5-48. 3D Voxel diagram looking to the north of the interpreted distributions of aquifer and coarse aquifer material of the Tertiary Ogallala Group (*To*) within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

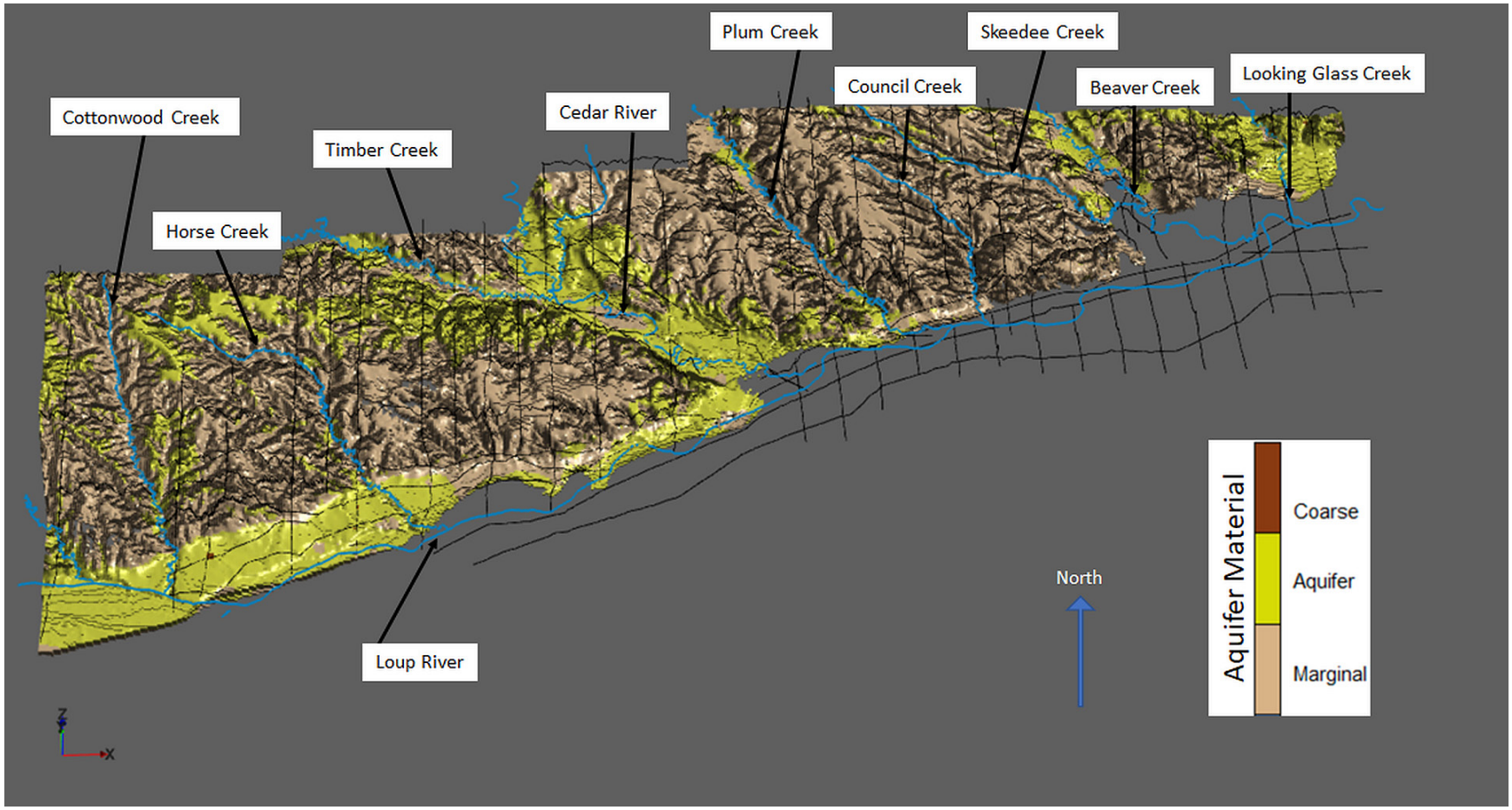



**Figure 5-49. 3D Voxel diagram looking to the north of the interpreted distributions of and marginal aquifer, aquifer, and coarse material of the Tertiary Ogallala Group (*To*) within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

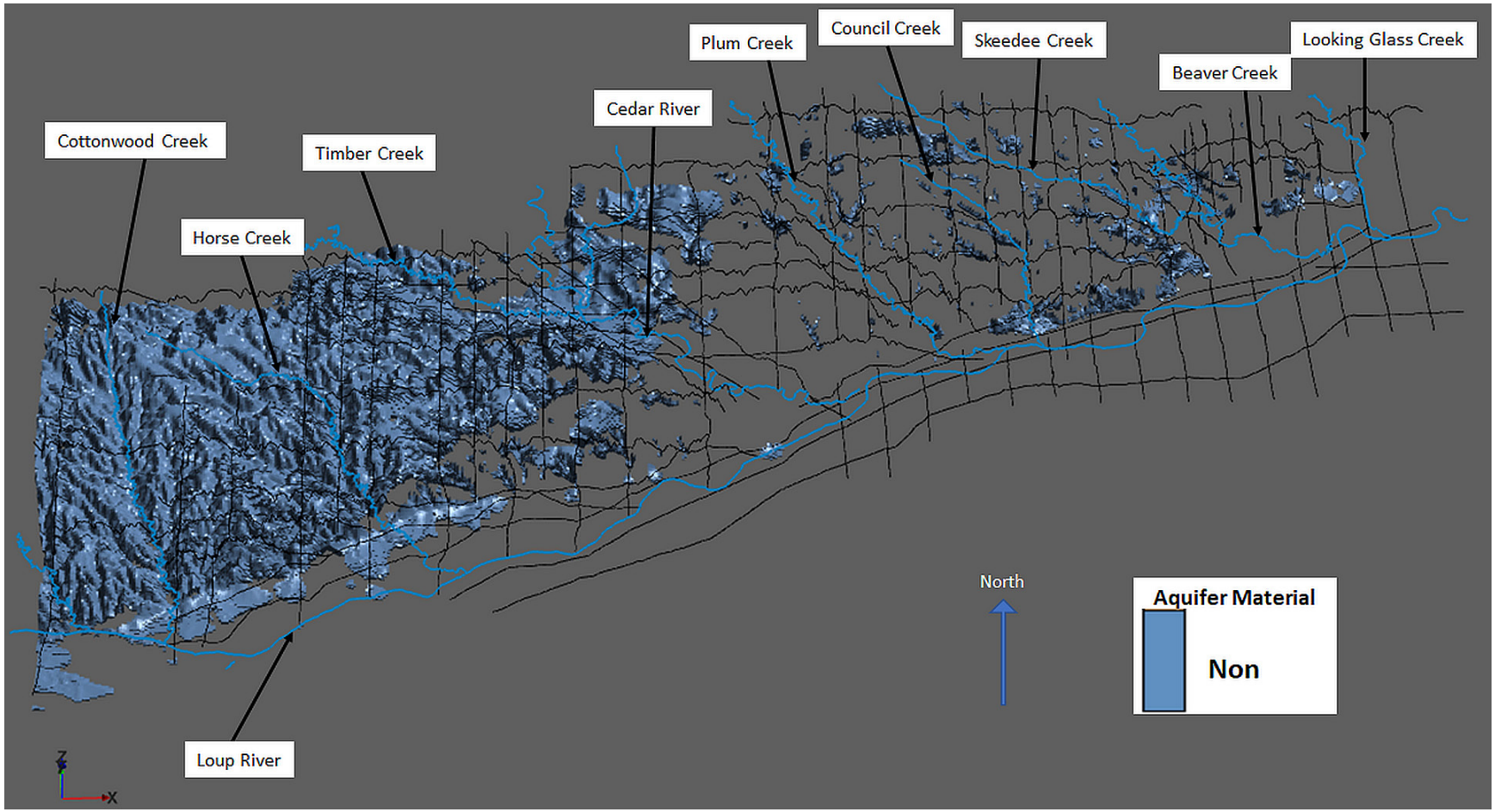



**Figure 5-50. 3D Voxel diagram looking to the north of the interpreted distributions of non-aquifer material of the Tertiary Ogallala Group (*To*) within the LLNRD 2022 Nance County AEM survey area. Flight lines are indicated by black lines. V.E.=20x.**

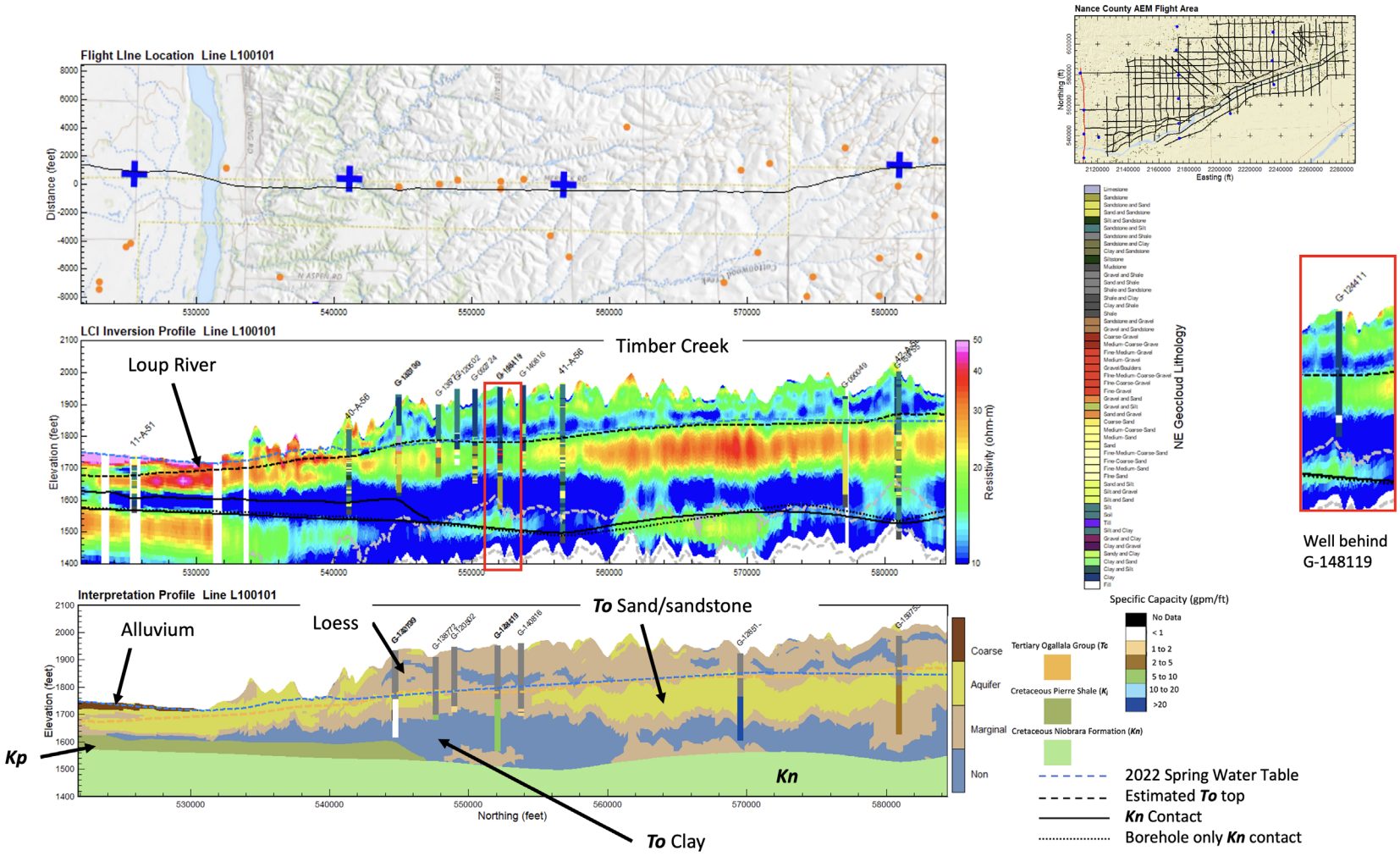



**Figure 5-51. North-south line L100101. A location map is on the upper right. On the left the top profile shows the topography along the flight line and CSD wells (blue crosses) and DNR wells (orange dots). The middle profile is the SCI resistivity inversion result showing borehole lithologies and the bottom profile is an interpretative section showing the Cretaceous bedrock (*Kn*) and overlying Tertiary Ogallala (*To*) which are both underlying Quaternary alluvium subdivide into interpreted aquifer materials. Boreholes in the bottom section indicate measured Specific Capacity. The red box shows the location of the well behind G-148119 and a blow up on the right side of the figure.**

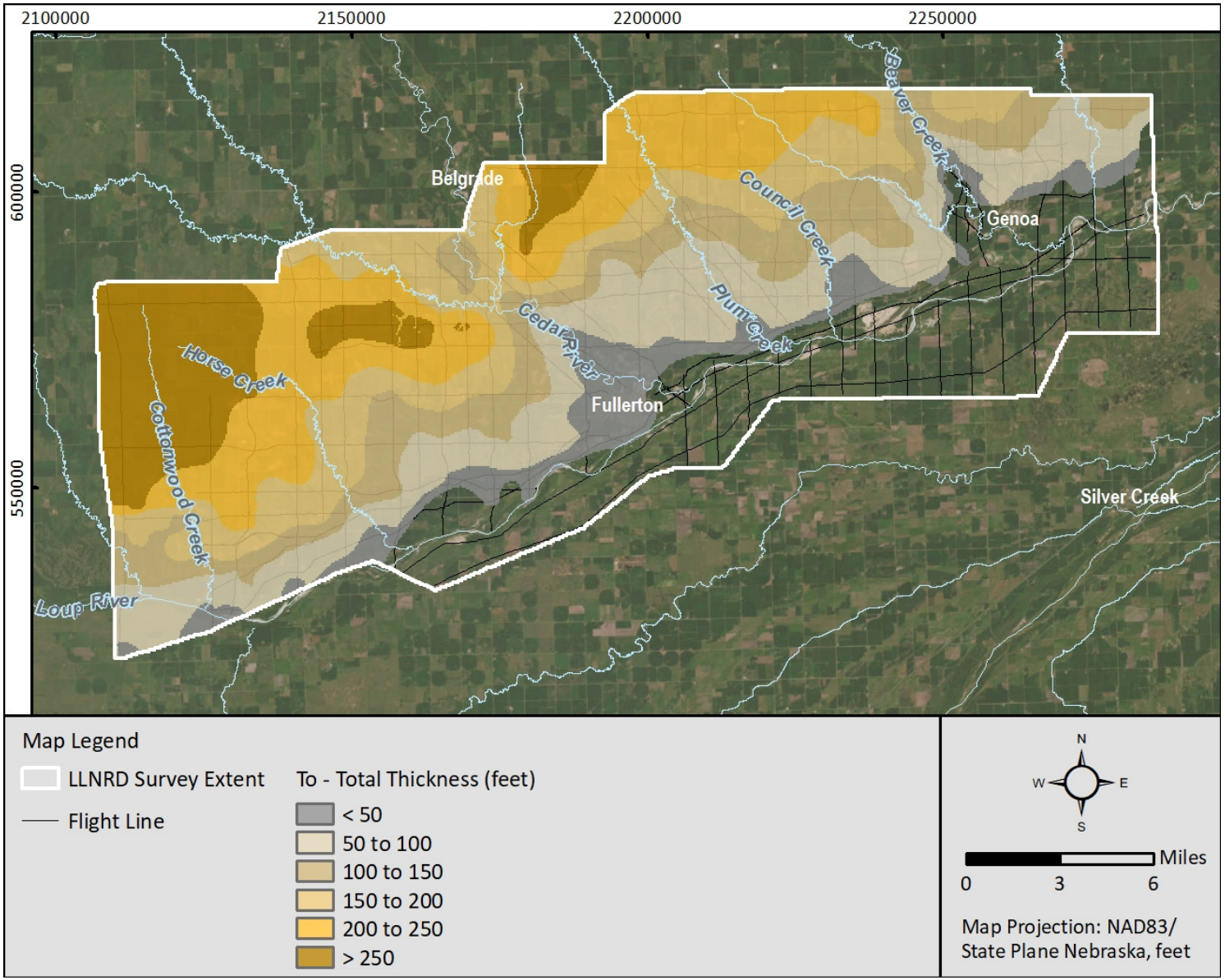



**Figure 5-52. Map of the total Tertiary Ogallala Group (*To*) thickness within the LLNRD 2022 Nance County AEM survey area.**

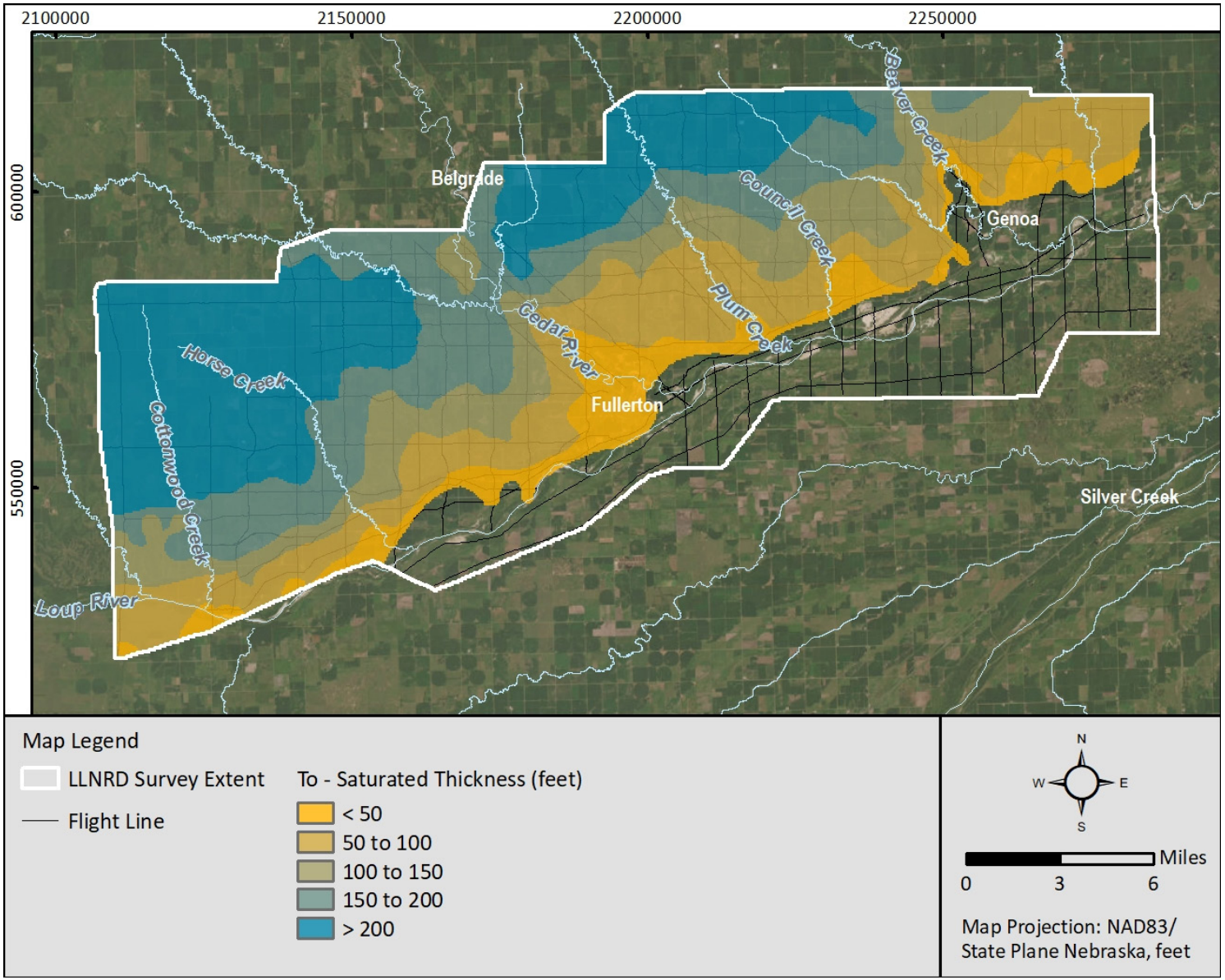



**Figure 5-53. Map of the total Tertiary Ogallala Group (*To*) saturated thickness within the LLNRD 2022 Nance County AEM survey area.**

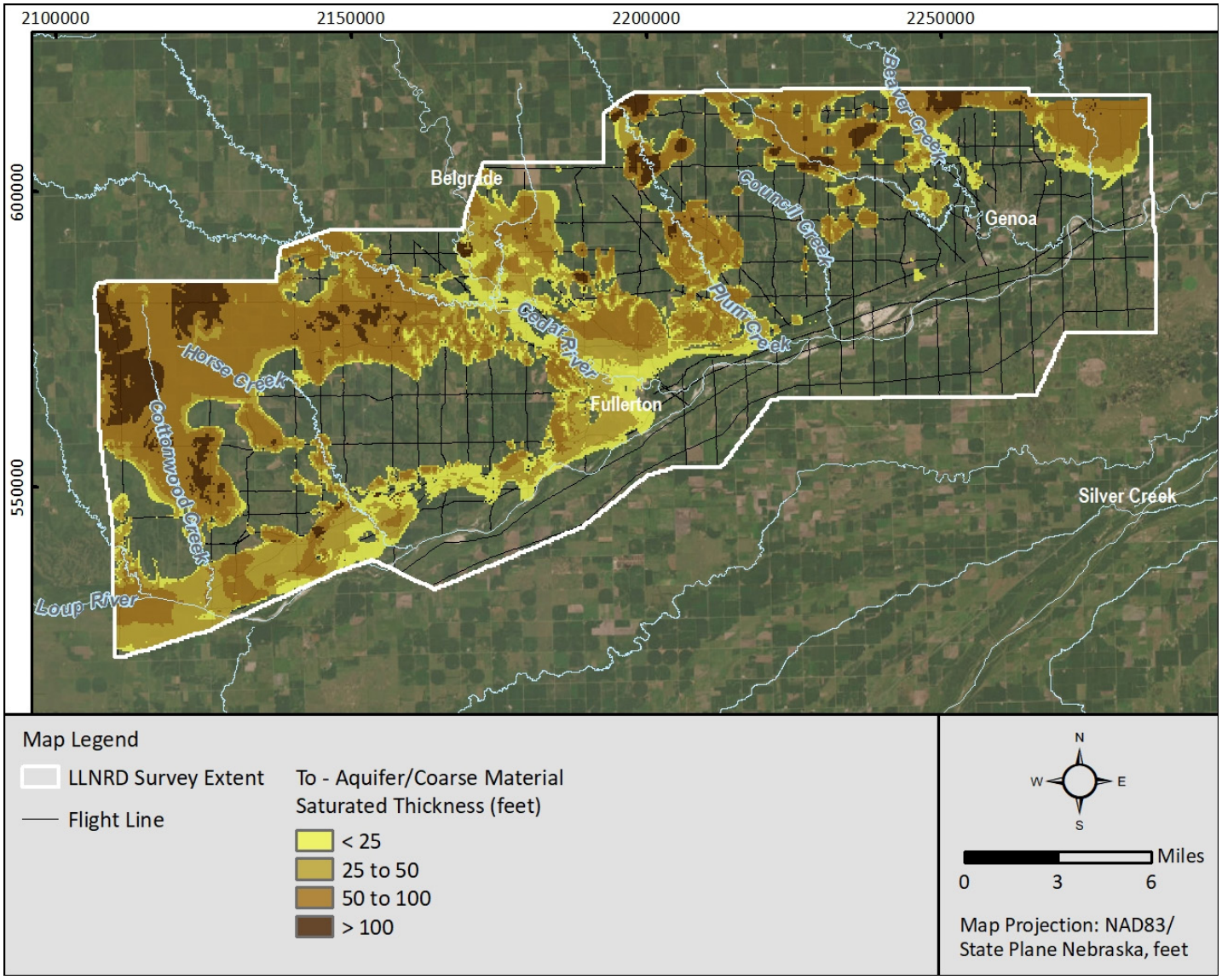



**Figure 5-54. Map of the Tertiary Ogallala Group (*To*) aquifer and coarse aquifer material saturated thickness within the LLNRD 2022 Nance County AEM survey area.**

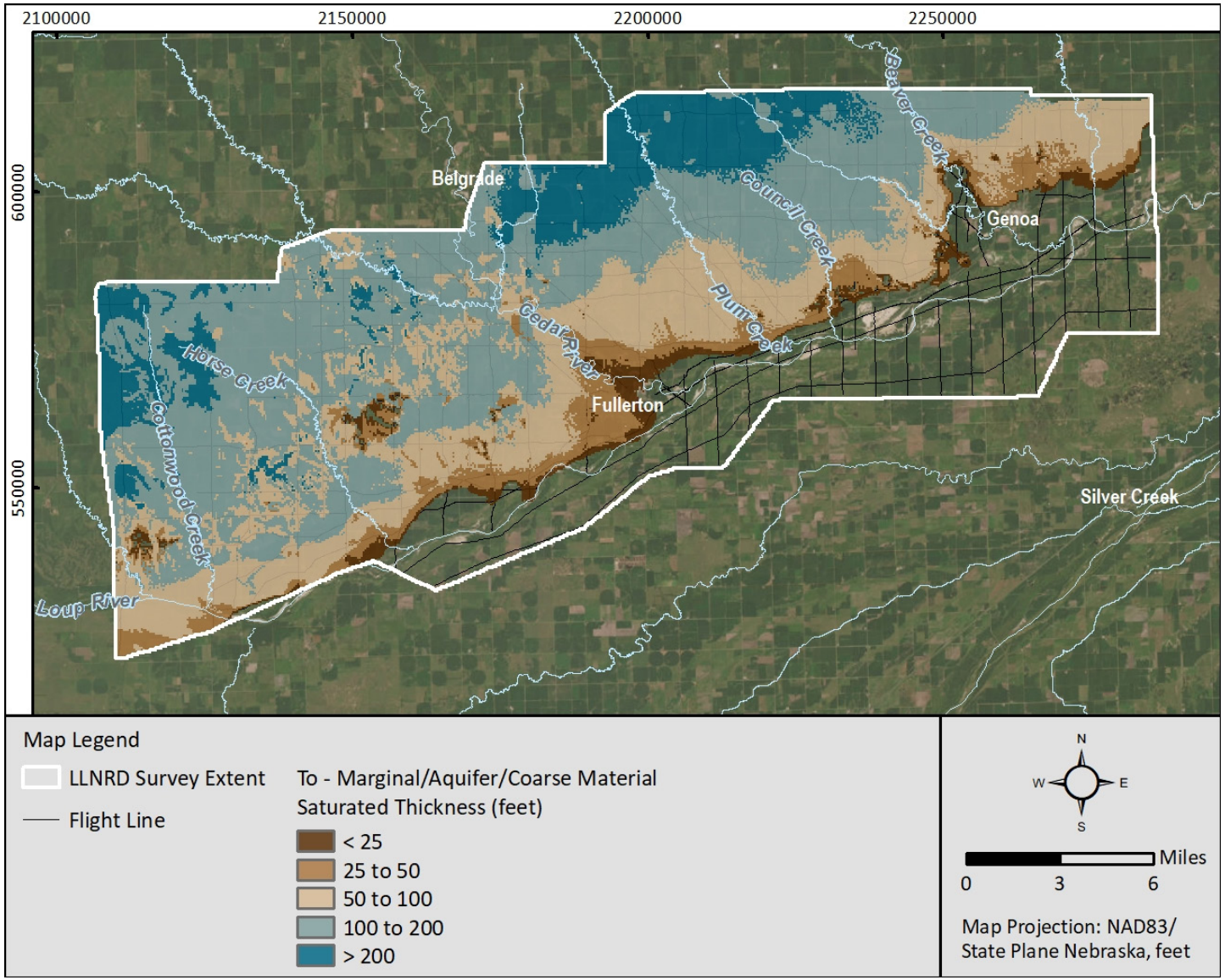



**Figure 5-55. Map of the Tertiary Ogallala Group (*To*) marginal aquifer, aquifer, and coarse aquifer material saturated thickness within the LLNRD 2022 Nance County AEM survey area calculated using the Spring 2022 LLNRD water levels.**

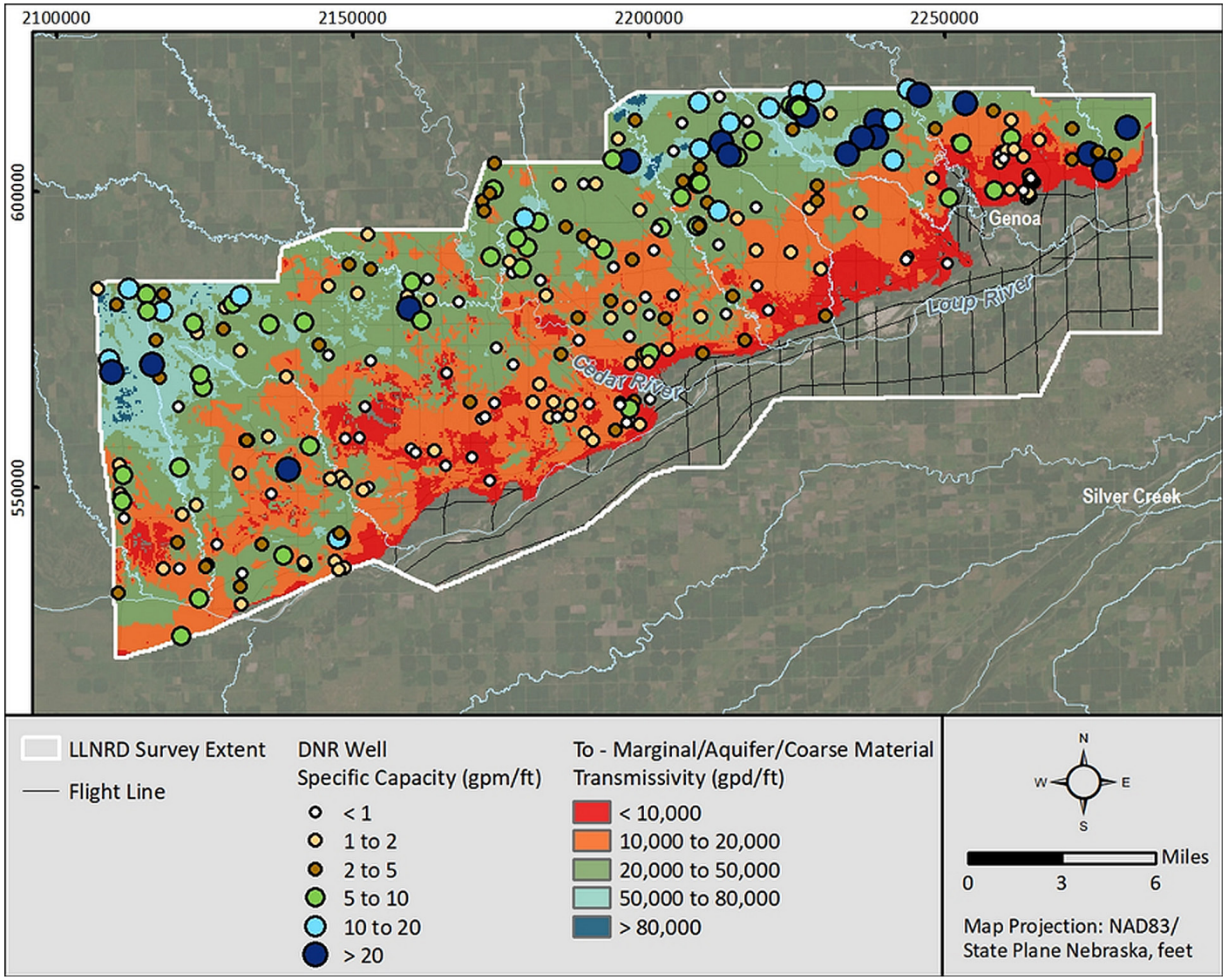



**Figure 5-56. Map of the estimated transmissivity (gpf/feet) of the Tertiary Ogallala (*To*) marginal aquifer, aquifer, and coarse aquifer material transmissivity within the LLNRD 2022 Nance County AEM survey area. Specific capacity values from the DNR registered well database for wells screen in the *To* are shown as indicated by the legend.**

### 5.3.3 The Cretaceous Bedrock Hydrology

The Cretaceous bedrock is made up of the ***Kp*** and ***Kn*** which lies below the ***To.*** These units are considered aquicludes in this area. There is some use of the fractured ***Kn*** within the central area of Nebraska as an aquifer, but that is not common, and the fractures need to be in hydrogeological connection to a water source typically a steam or a good aquifer in the ***Q*** or ***To***.

### 5.3.4 Groundwater in Nance County, Nebraska LLNRD

As discussed above, the groundwater within Nance County, Nebraska is within the alluvial sediments of the Quaternary (***Q***) and the paleo-fluvial sediments of the Tertiary Ogallala Group (***To***). Much of the ***Q*** overlies and is connected to the ***To*** allowing groundwater flow between the units. The groundwater availability is governed by both the ***Q*** and ***To*** in many areas. In general, the ***Q*** is dominant in the Loup River Valley, the lower Cedar River, and the areas of Beaver Creek while the ***To*** is the dominant aquifer in the dissected plains. Many wells show completions in both units. Figure 5-57 shows the DNR specific capacities in the ***Q*** aquifer materials. These wells are completed in the areas of the Loup River alluvium and some areas of Beaver Creek. Figure 5-58 shows the DNR specific capacities in the ***To*** aquifer materials. These wells are all competed in the areas of the sandy fluvial sediments (aquifer material) of the ***To***. The areas that the wells are completed in both the ***Q*** and ***To*** (Figure 5-59) are located in the Cedar River, Plum Creek, and Beaver Creek drainages transition zones of the thin ***Q*** overlying the ***To***.

Inspecting the 3D voxel images of the area can provide more clarification on the location of the completed zones within the wells and their location in relation to the aquifer materials. Figure 5-60 is a view from the east looking to the west of the aquifer and coarse aquifer material of both the ***Q*** and ***To*** with the specific capacity (gpd/ft) displayed over the screened interval in the DNR registered wells. This figure shows the higher specific capacity wells south of the Loup River and some of the wells north of the river within the ***Q*** and ***To*** on the eastern side of the survey area just outside Nance County. Note the area displaying no aquifer material (transparent zones), are mostly marginal aquifer material exists along with the low specific capacity of the wells.

Figure 5-61 is a view from the southwest looking northeast of the western portion of the survey area. The aquifer and coarse aquifer material of both the ***Q*** and ***To*** with the SC (gpd/ft) of the DNR wells are displayed over the screened interval are shown. Figure 5-61 shows the wells in the Loup River as well as the wells in the ***To*** within the dissected plains. Note the area displaying no aquifer material that contains mostly marginal aquifer materials and the low SC of the wells in that region. As indicated above there are many wells completed into zones of the marginal aquifer materials of both the ***Q*** and ***To***. To this end the transmissivity maps of the area are composed of the marginal, aquifer, and coarse aquifer materials.

Figure 5-62 is the transmissivity map of Nance County aquifer (both ***Q*** and ***To***) with the SC values posted from the DNR database. The areas of low transmissivity are indicated in red and orange. It is important to note that the transmissivity is controlled by both the thickness of a unit and its hydraulic conductivity. Thus, a good thin sand will have a similar transmissivity to a thick marginal unit. Some of this impact can

be observed in the areas along the Loup River where we know there are good sand aquifers; they are just thin.

Figure 5-63 is the transmissivity map of Nance County Survey area without the specific capacity values from the DNR registered wells. This map is less cluttered with wells and displays some of the low transmissivity areas around Genoa and Beaver Creek. As an additional check when the groundwater irrigated acres are plotted on the transmissivity maps, another correlation is seen as the low transmissivity areas show very little groundwater irrigated acres.

### *5.3.5 Estimation of Aquifer Volume and Water in Storage for the Lower Loup NRD Nance County AEM Survey Area*

Three-dimensional digital representation of the subsurface resulting from the AEM method provides users the ability to estimate total unsaturated and saturated aquifer volume and the amount of extractable water more accurately. An approximately 360.8 square mile (approximately 230,927 acres) area of AEM data were collected in the LLNRD 2022 AEM survey and integrated with the 2016 AEM survey as shown by the map of as flown flight lines in Figure 5-1.

The criteria for determining the basis for the range of resistivity values used in calculating the volumes of interpreted aquifer material for both ***Q*** and ***To*** are provided in Section 5.2. The resistivity ranges for interpreted non-aquifer, marginal aquifer, aquifer, and coarse aquifer materials are also found in Section 5.2.1. The mapped deposits of the ***Q*** and ***To*** provides information from which the volumes of selected aquifer materials combined with estimated average values for porosity and specific yield are the best estimates for calculation of aquifer volume in acre/ft, groundwater in storage acre/ft and extractable water acre/ft. The area beneath the survey area is included in these calculations and are represented in Figure 5-1 were created in Datamine Discover PA, version 2021, Release Build 17.0.198 (Datamine Discover, 2023).

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

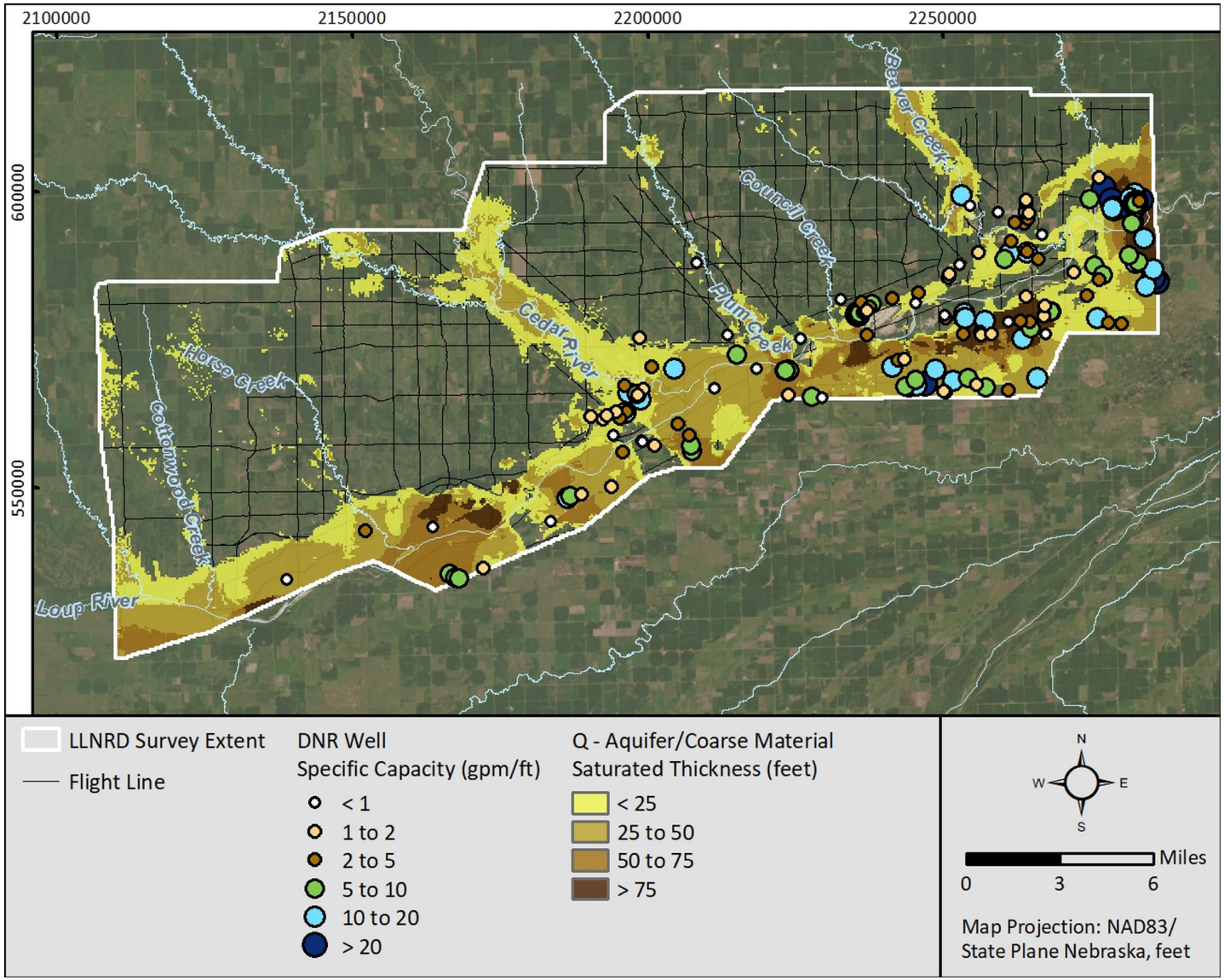



**Figure 5-57. Map of the thickness of the saturated Quaternary (*Q*) aquifer materials and coarse aquifer materials and the specific capacity values from the DNR registered well database for wells completed within the *Q*.**

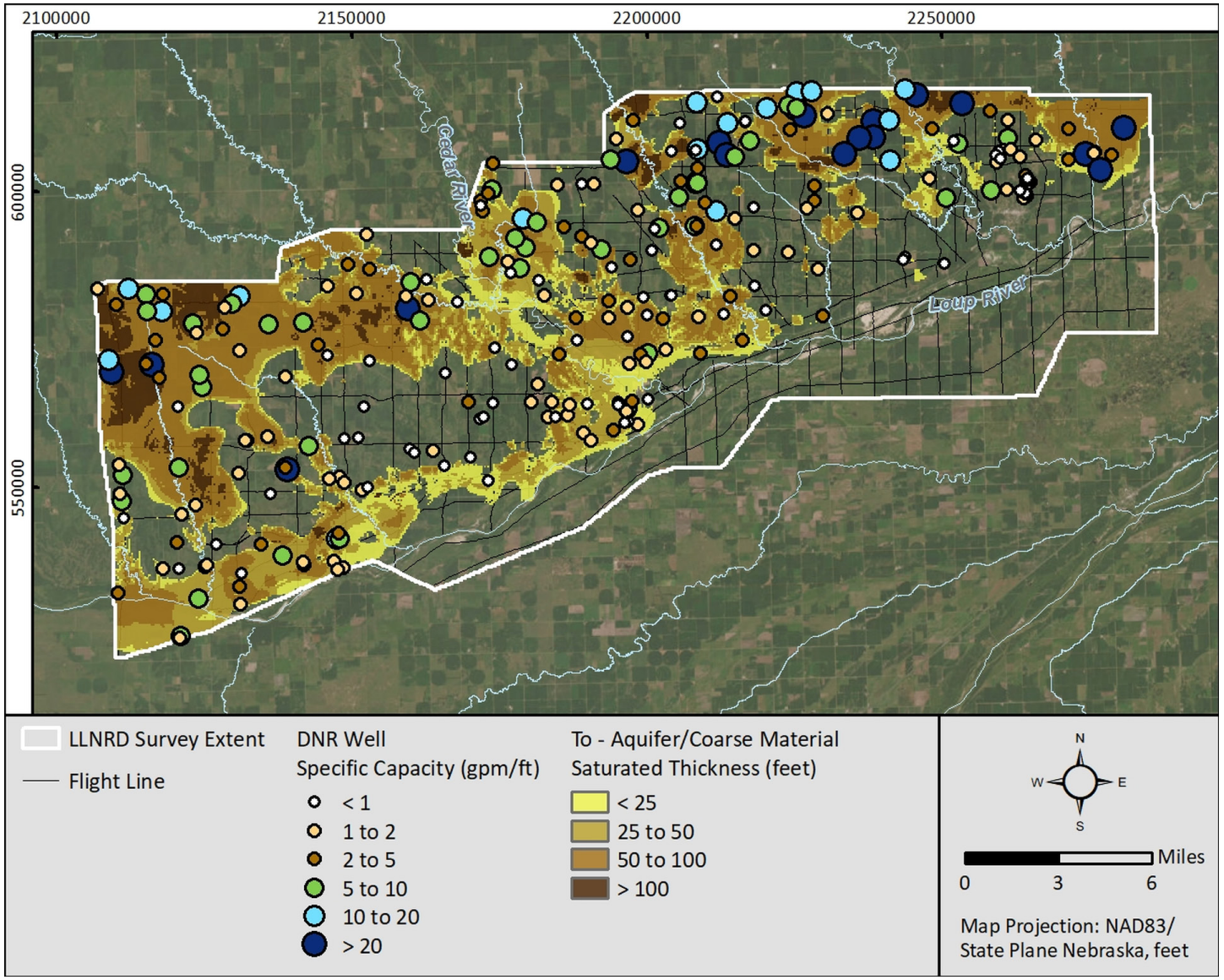



**Figure 5-58. Map of the thickness of the saturated Tertiary Ogallala Group (*To*) aquifer materials and coarse aquifer materials and the specific capacity values from the DNR registered well database for wells completed within the *To*.**

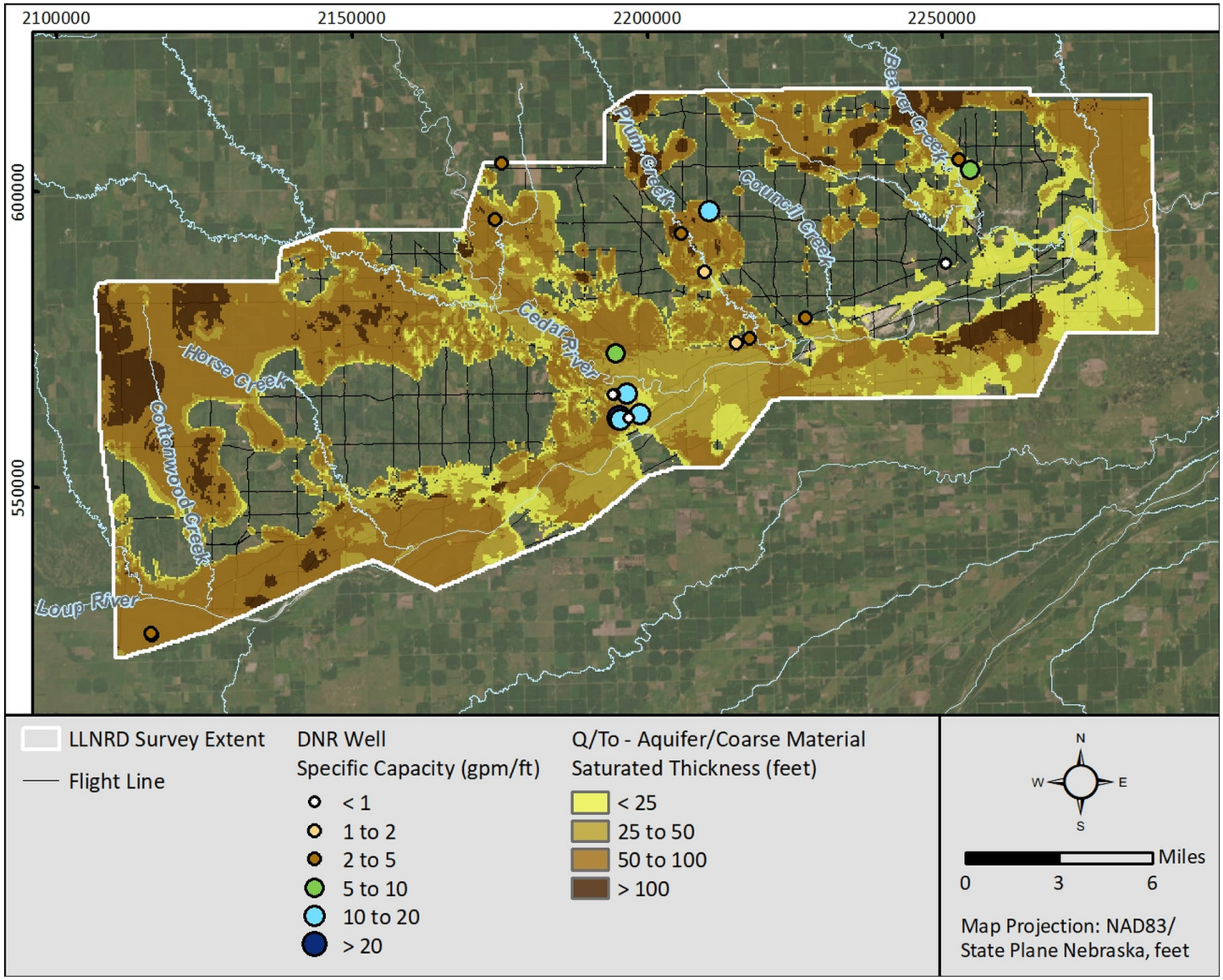



**Figure 5-59. Map of the thickness of the saturated Quaternary (*Q*) and Tertiary Ogallala Group (*To*) aquifer materials and the specific capacity values from the DNR registered well database for wells completed within both the Q and *To*.**

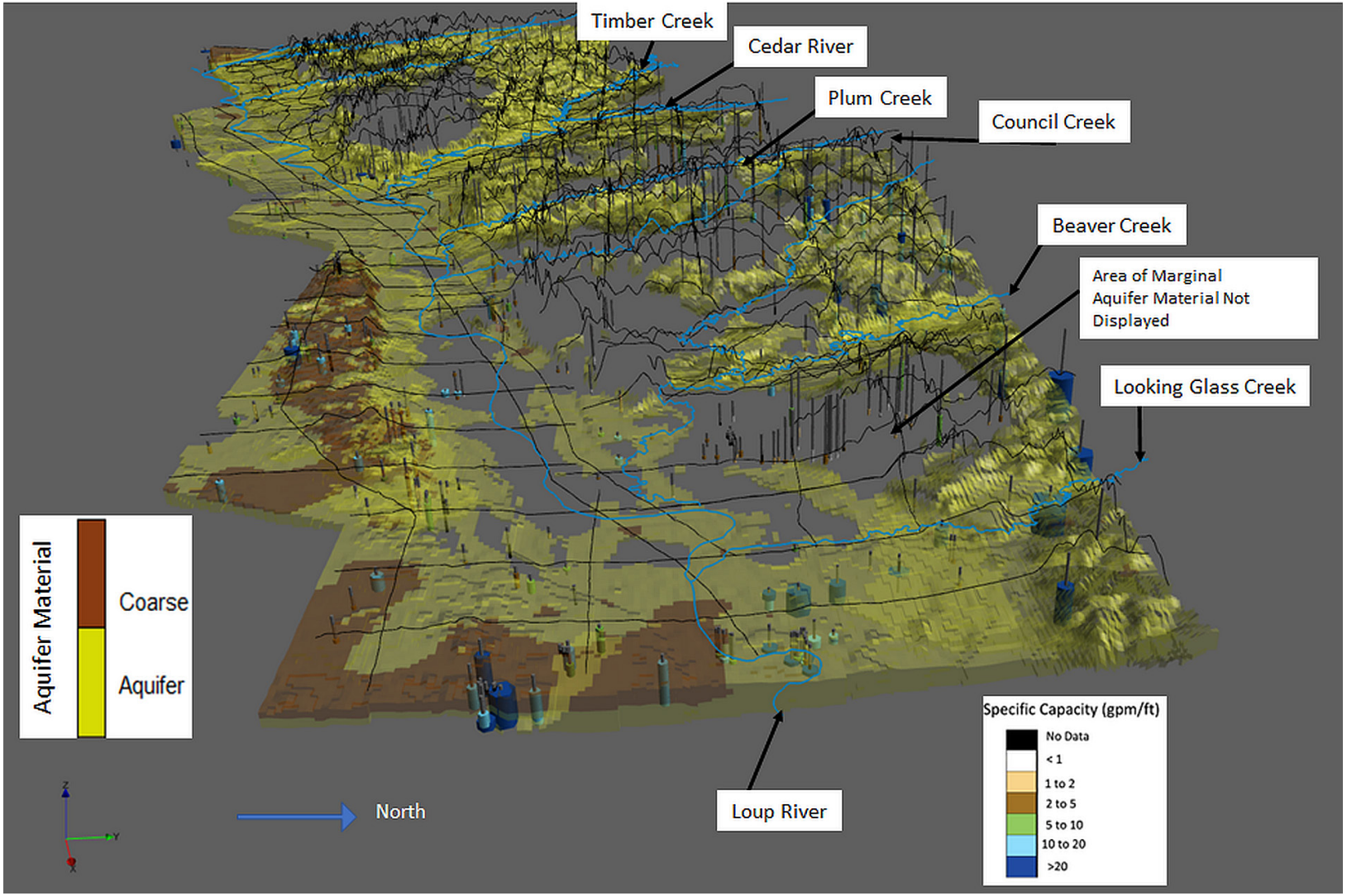



**Figure 5-60. 3D Voxel diagram looking to the west of the eastern portion of the LLNRD 2022 Nance County AEM survey area. The aquifer and coarse aquifer materials of both the saturated Quaternary (*Q*) and the Tertiary Ogallala Group (*To*) are displayed as semi-transparent. Specific capacity values from the DNR registered well database for wells screen are shown as indicated by size and the color indicated in the legend. Flight lines are indicated by black lines. V.E.=20x.**

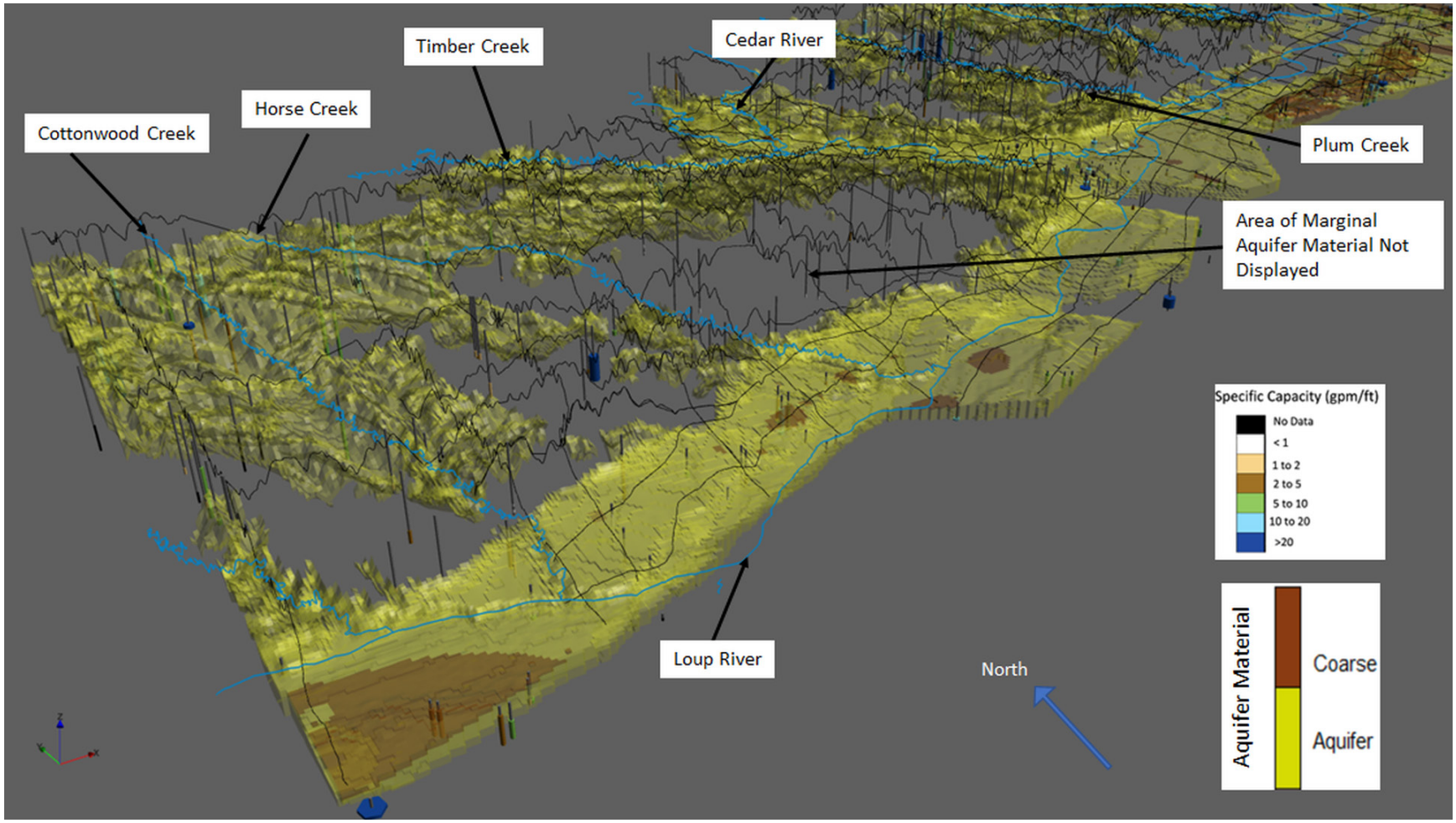



**Figure 5-61. 3D Voxel diagram looking to the northeast of the western portion of the LLNRD 2022 Nance County AEM survey area. The aquifer and coarse aquifer materials of both the saturated Quaternary (*Q*) and the Tertiary Ogallala Group (*To*) are displayed as semi-transparent. Specific capacity values from the DNR registered well database for wells screen are shown as indicated by size and the color indicated in the legend. Flight lines are indicated by black lines. V.E.=20x.**

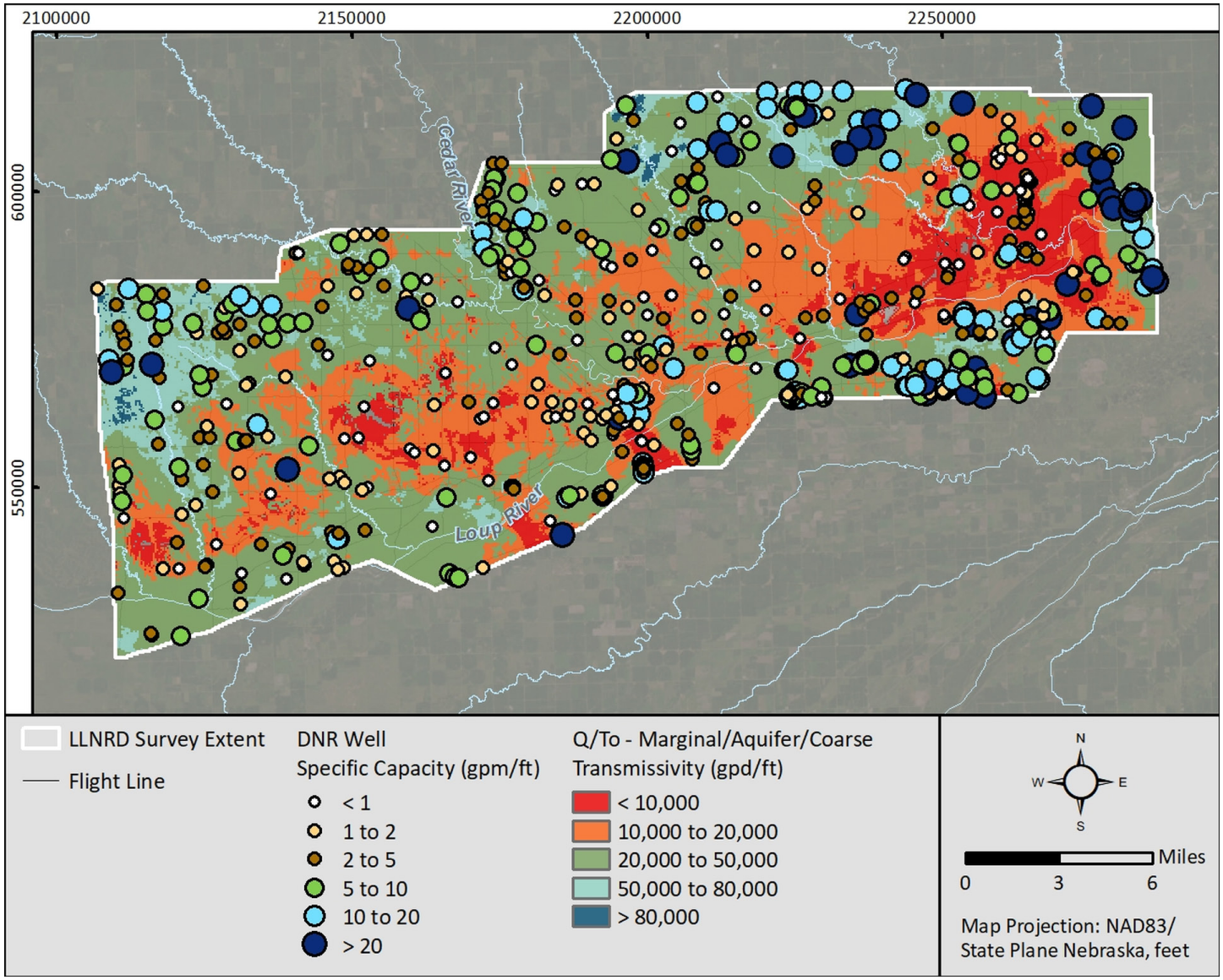



**Figure 5-62. Map of the estimated transmissivity (gpd/feet) of the aquifer materials within LLNRD 2022 Nance County AEM survey area. Specific capacity values from the DNR registered well database for wells screened in *Q*, *To*, or both are shown as indicated by the legend.**

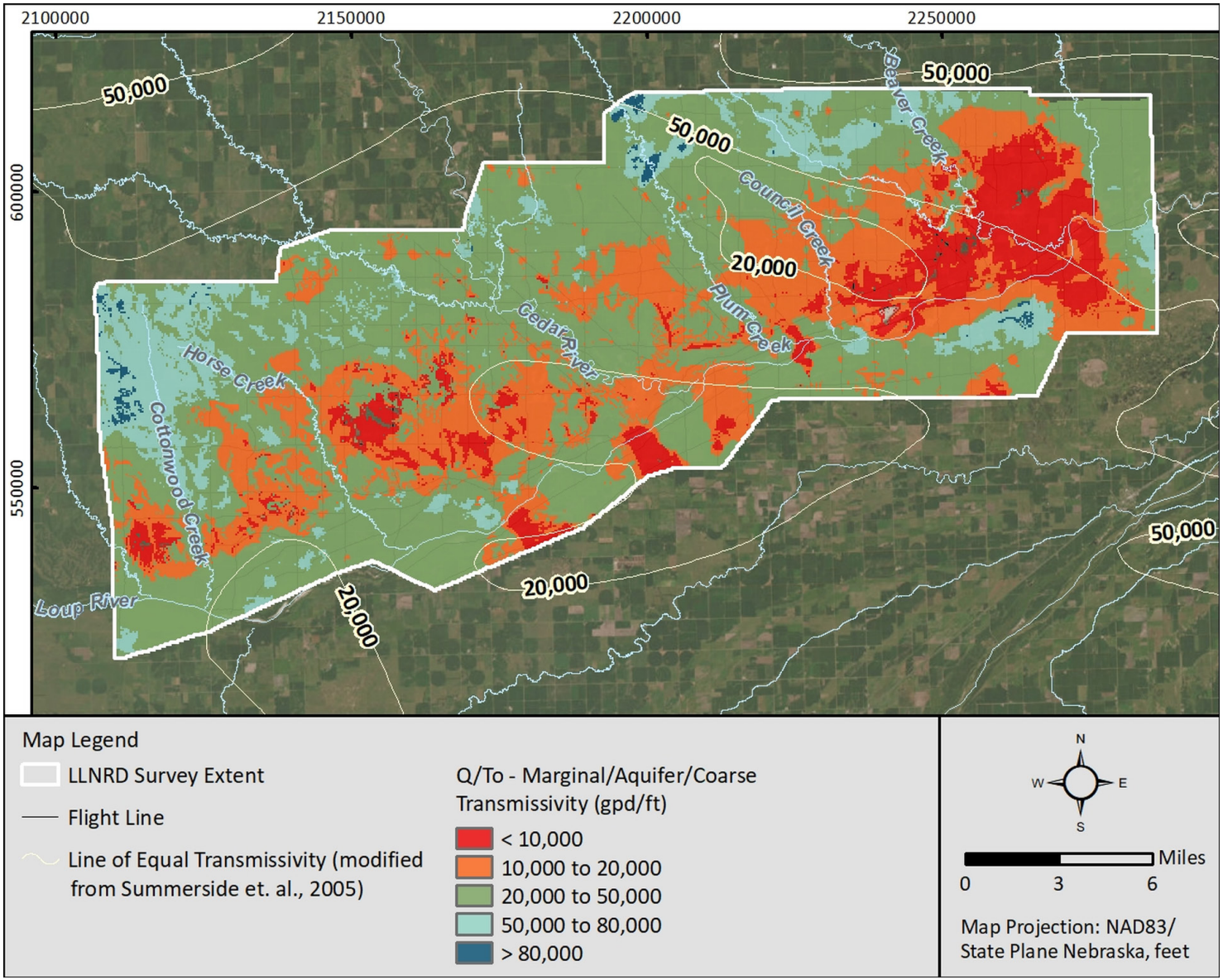



**Figure 5-63. Map of the estimated transmissivity (gpd/feet) of the aquifer materials within LLNRD 2022 Nance County AEM survey area.**

Specific yield values for all ***Q*** and ***To*** aquifer materials were selected by estimating values. Specific yield for non-aquifer materials was chosen at 0.02 (Heath, 1983) and for marginal aquifer materials a value of 0.05 was selected (Heath, 1983). The specific yield for the aquifer material is 0.22 (Heath, 1983). While coarse aquifer materials exist as localized deposits in the survey area, estimates of specific yield for the coarse aquifer material is 0.19 (Heath, 1983). The aquifer and marginal aquifer materials represent the dominant material types by total volume for groundwater storage in the survey area. For specific yield, maps of the area would be improved if new maps were produced using this new AEM survey information plus the addition of aquifer tests or other methods of gaining new data including Nuclear Magnetic Resonance (NMR) surveys to capture aquifer characteristics including: mobile water, total porosity, and hydraulic conductivity.

Table 5-4 and Table 5-5 below show the results of calculations of the amount of groundwater in storage calculated by volume of all ***Q*** materials saturated and unsaturated then multiplied by the estimated porosity. Table 5-6 and Table 5-7 show similar results for the unsaturated and saturated ***To*** materials.

The values in the Table 5-4 for unsaturated ***Q*** all materials have a total volume of **16,065,003** acre-ft. If saturated, the potential total volume of water is **5,579,415** acre-ft of groundwater in storage. The estimate of extractable volume of water is calculated by taking the amount of groundwater in storage times the specific yield. The total volume of extractable water for unsaturated ***Q*** aquifer materials, if fully saturated, would be **291,035** acre-ft. It should be noted that the water yield volume from the non-aquifer and marginal aquifer will drain at a much-reduced rate. These calculations are more academic than useful as will be seen later; there is very little potential for recharge in this area.

The values in the Table 5-5 are for the saturated (based on the LLNRD spring 2022 water table) ***Q,*** all materials, and have a total volume of **6,001,594** acre-ft. The saturated ***Q*** total volume of water is **1,771,165** acre-ft of groundwater in storage. The extractable total volume of saturated ***Q*** aquifer materials is **164,747** acre-ft.

There is only a small portion of the ***To*** that is unsaturated based on the LLNRD 2022 spring water table. The values in the Table 5-6 for unsaturated ***To***, all materials, have a total volume of **878,712** acre-ft. If saturated, the potential total volume of water is **256,973** acre-ft of groundwater in storage. If fully saturated, the potential total volume of extractable water would be **18,661** acre-ft. As indicated for the unsaturated ***Q***, these calculations are more academic than useful as will be seen later; there is very little potential for recharge in this area.

The values in the Table 5-7 are for the saturated (based on the LLNRD spring 2022 water table) ***To*** materials and have a total volume of **26,708,612** acre-ft. The saturated ***To*** total volume of water is **8,848,084** acre-ft of groundwater in storage. The extractable total volume of saturated ***To*** aquifer materials is **421,548** acre-ft.

A useful calculation would be combining the saturated ***Q*** and ***To*** of all materials. Again, this is using the LLNRD spring 2022 water table and the assumed values for the porosity and specific yield as discussed above in tables 5-4, 5-5, 5-6, and 5-7. The total volume of the saturated ***Q*** and ***To*** aquifer materials is

**32,710,206** acre-ft. The total groundwater in storage is **10,619,249** acre-ft. The total extractable water is **586,294** acre-ft.

As stated above, these estimates are based on the water table map as calculated from the LLNRD spring 2022 water levels (Section 5.1.5.2). Also, these volumetric estimates consider only the volume of water assumed in the pore spaces of the aquifer material defined by the resistivity threshold levels and do not account for the possible "confined or semi-confined" water under pressure (head above the aquifer). Note that additional analysis of data for the confined, or semi-confined, areas of the AEM survey area would need to be completed before any designation of these areas can be made. The water table is typically at the top of the ***To*** throughout much of the area. This may indicate that the loess deposits of the ***Q*** are acting more like a semi-confining layer. Aquifer testing may be the only way to ascertain confidently the confining condition of the overlying loess.

An estimate of the area that may be confined can be provided by looking at the unsaturated ***Q*** and ***To*** non-aquifer material and marginal aquifer material thicknesses (Figure 5-64). This volume of water would add to the values reported in Table 5-5, Table 5-6, and Table 5-7. However, too much uncertainty exists in developing an average level of head above the top of the aquifer across the entire project area, as well as defining a representative storativity term for the confined or semi-confined aquifers. Thus, the volumes listed in Table 5-5, Table 5-6, and Table 5-7 are conservative estimates and the amount released from the decline in pressure is not considered.

### *5.3.6 Groundwater Quality in Nance County, Nebraska LLNRD*

As indicated in the introduction, groundwater quality is impacted by nitrates in areas of Nance County, specifically, the LLNRD Water Quality Management Area (WQMA) occupied by the eastern portion of Nance County, WQMA #18. Well head protection plans can also be informed from the information on the potential impact on water quality. The AEM provided information on the near surface materials in Nance County. Near surface occurrences of sandy soils and sand deposits (aquifer materials) provide conduits for contaminants to migrate into the groundwater. Using the 3D interpretation of the AEM a near surface occurrence of the aquifer materials map can be generated. A depth of ~27 (the first four AEM model layers Section 4.5) feet was selected to examine the areas of potential impacts. Using the water quality data collected by the LLNRD (Personal Communication, Tylr Naprstek, February 2023) the data was overlain on the aquifer material map of the first 27 feet (Figure 5-65). Illustrated in Figure 5-65 is the correlation of the thickest area of the aquifer materials along the Loup River and southern portions of the Beaver Creek areas and the elevated Nitrates analysis from 2022. There are some areas of 10 to 20 mg/L in areas of the northeastern area of the survey. These are not related to the surface materials and may be related to deeper elevated nitrates in the sandy portions of the ***To*** in that area.

**Table 5-4. Unsaturated Quaternary (*Q*) aquifer materials underlying the Nance County AEM survey area.**

| Aquifer Material Type | Aquifer Volume (ft3) | Aquifer Volume (acre-ft) | Average Porosity | Groundwater Potential in Storage Volume (acre-ft) | Average Specific Yield | Extractable Potential Water Volume (acre-ft) |
|---|---|---|---|---|---|---|
| Non | 201,647,173,500 | 4,629,182 | 0.4 | 1,851,673 | 0.02 | 37,033 |
| Marginal | 412,071,993,000 | 9,459,871 | 0.35 | 3,310,955 | 0.05 | 165,548 |
| Aquifer | 67,256,703,000 | 1,544,001 | 0.2 | 308,800 | 0.22 | 67,936 |
| Coarse | 18,815,670,000 | 431,948 | 0.25 | 107,987 | 0.19 | 20,518 |
| | **699,791,539,500** | **16,065,003** | | **5,579,415** | | **291,035** |

**Table 5-5. Saturated Quaternary (*Q*) aquifer materials underlying the Nance County AEM survey area.**

| Aquifer Material Type | Aquifer Volume (ft3) | Aquifer Volume (acre-ft) | Average Porosity | Groundwater Potential in Storage Volume (acre-ft) | Average Specific Yield | Extractable Potential Water Volume (acre-ft) |
|---|---|---|---|---|---|---|
| Non | 33,279,768,000 | 763,998 | 0.40 | 305,599 | 0.02 | 6,112 |
| Marginal | 119,004,619,500 | 2,731,970 | 0.35 | 956,190 | 0.05 | 47,809 |
| Aquifer | 101,956,572,000 | 2,340,601 | 0.20 | 468,120 | 0.22 | 102,986 |
| Coarse | 7,188,475,500 | 165,025 | 0.25 | 41,256 | 0.19 | 7,839 |
| | **261,429,435,000** | **6,001,594** | | **1,771,165** | | **164,747** |

**Table 5-6. Unsaturated Tertiary Ogallala Group (*To*) aquifer materials underlying the Nance County AEM survey area.**

| Aquifer Material Type | Aquifer Volume (ft3) | Aquifer Volume (acre-ft) | Average Porosity | Groundwater Potential in Storage Volume (acre-ft) | Average Specific Yield | Extractable Potential Water Volume (acre-ft) |
|---|---|---|---|---|---|---|
| Non | 1,297,890,000 | 29,795 | 0.40 | 11,918 | 0.015 | 179 |
| Marginal | 21,846,690,000 | 501,531 | 0.35 | 175,536 | 0.038 | 6,670 |
| Aquifer | 15,095,893,500 | 346,554 | 0.20 | 69,311 | 0.17 | 11,783 |
| Coarse | 36,238,500 | 832 | 0.25 | 208 | 0.14 | 29 |
| | **38,276,712,000** | **878,712** | | **256,973** | | **18,661** |

**Table 5-7. Saturated Tertiary Ogallala Group (*To*) aquifer materials underlying the Nance County AEM survey area.**

| Aquifer Material Type | Aquifer Volume (ft3) | Aquifer Volume (acre-ft) | Average Porosity | Groundwater Potential in Storage Volume (acre-ft) | Average Specific Yield | Extractable Potential Water Volume (acre-ft) |
|---|---|---|---|---|---|---|
| Non | 293,866,623,000 | 6,746,249 | 0.40 | 2,698,500 | 0.015 | 40,477 |
| Marginal | 626,367,429,000 | 14,379,417 | 0.35 | 5,032,796 | 0.038 | 191,246 |
| Aquifer | 243,019,899,000 | 5,578,969 | 0.20 | 1,115,794 | 0.17 | 189,685 |
| Coarse | 173,200,500 | 3,976 | 0.25 | 994 | 0.14 | 139 |
| | **1,163,427,151,500** | **26,708,612** | | **8,848,084** | | **421,548** |

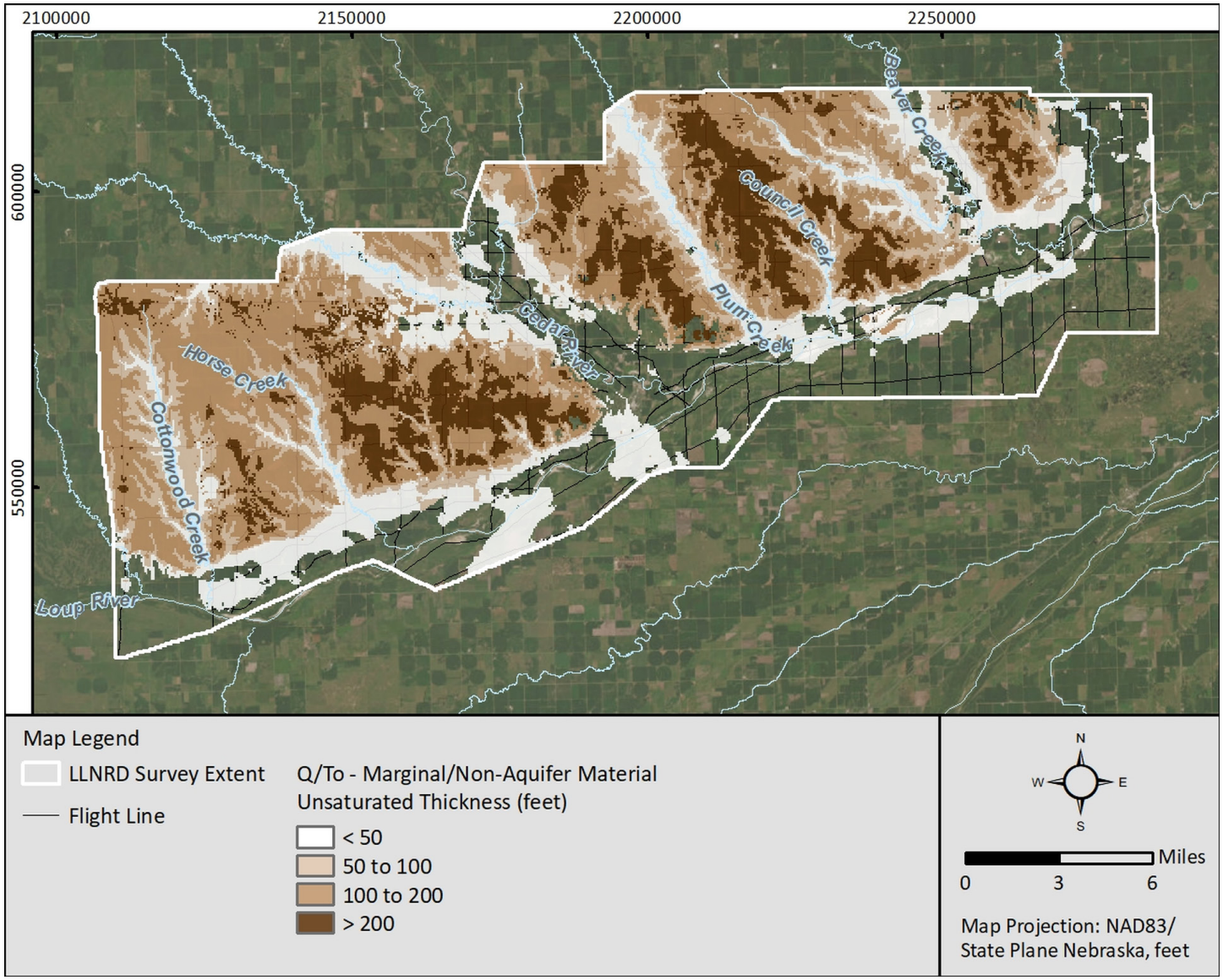



**Figure 5-64. Map of the thickness of the unsaturated Quaternary (*Q*) and Tertiary Ogallala Group (*To*) non- and marginal aquifer materials within the LLNRD 2022 Nance County AEM survey area.**

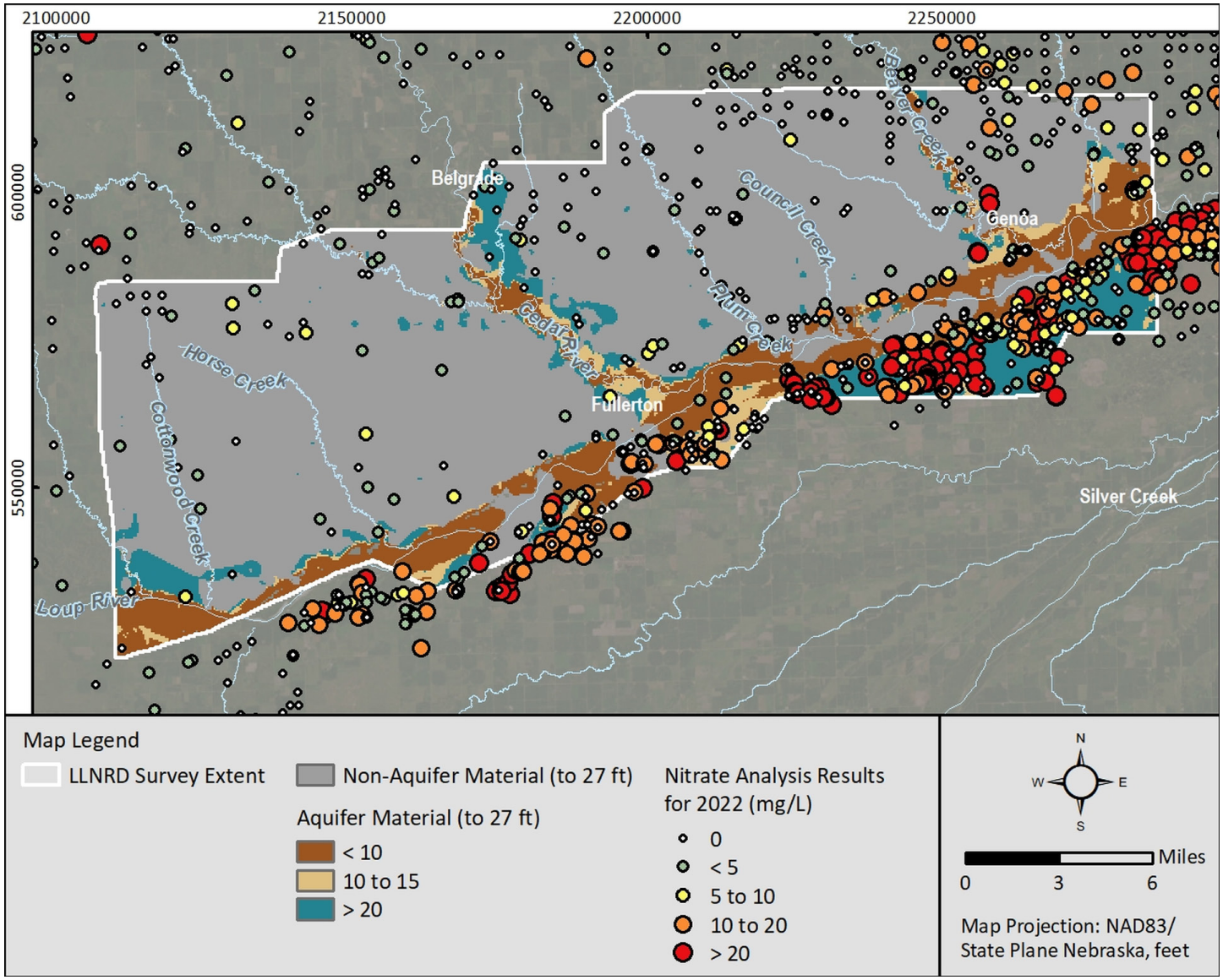



**Figure 5-65. Map of the thickness of the Quaternary (Q) aquifer materials in the first 27 feet within the LLNRD 2022 Nance County AEM survey area. Water quality values from the LLNRD 2022 sampling program (*personal communication, Tylr Naprstek, February 2023*).**

### *5.3.7 Recharge in Nance County, Nebraska LLNRD*

An important question that is required to be assessed in any groundwater availability study is the location of recharge sites. The AEM has the unique ability to map the near-surface aquifer materials as indicated above.

Using a similar approach to what was utilized in the water quality section (Section 5.3.6), the first 27 feet of the AEM model were examined. Figure 5-66 is a plot of the thickness of the aquifer material within the first 27 feet within the Nance County AEM area. Those areas are dominated by the reaches of the Loup River with sections of the Cedar River and the lower reaches of Beaver Creek.

One issue in assessing locations for recharge sites is examining the current land use and ability to deliver water to that location. Utilizing the irrigated acres (Personal Communication, Cam Conrad, 2022) overlay on the aquifer material within the first 27 feet, it is apparent that there are very limited areas of potential recharge with the exception of the shallow materials along the Loup River (Figure 5-67). There are a few limited areas along the Cedar River and a few of the drainages that drain into Timber Creek.

The bottom line is that the potential for good recharge sites within the Nance County AEM survey area is limited without the elimination of currently irrigated land.

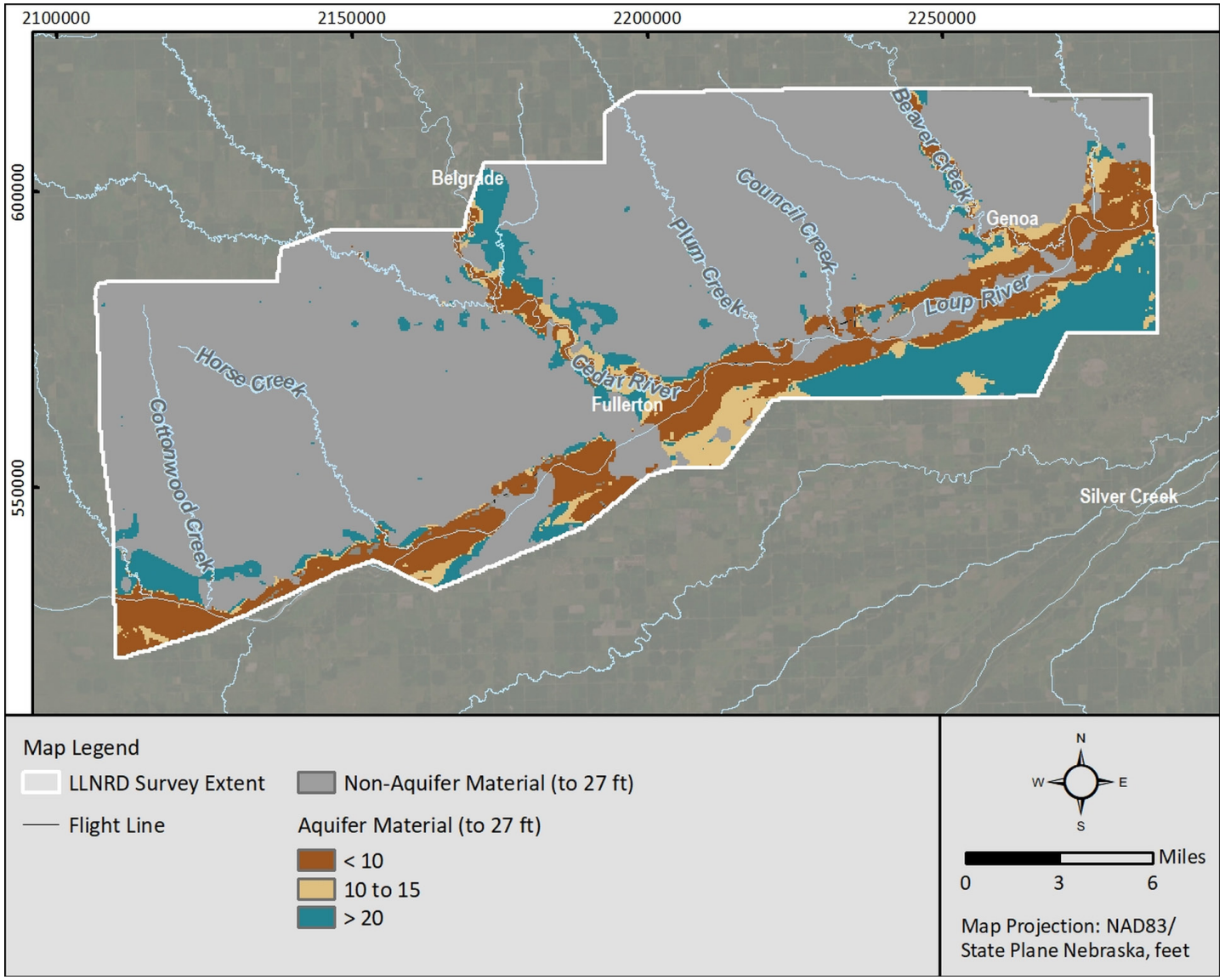



**Figure 5-66. Map of the thickness of the Quaternary (*Q*) aquifer materials in the first 27 feet within the LLNRD 2022 Nance County AEM survey area.**

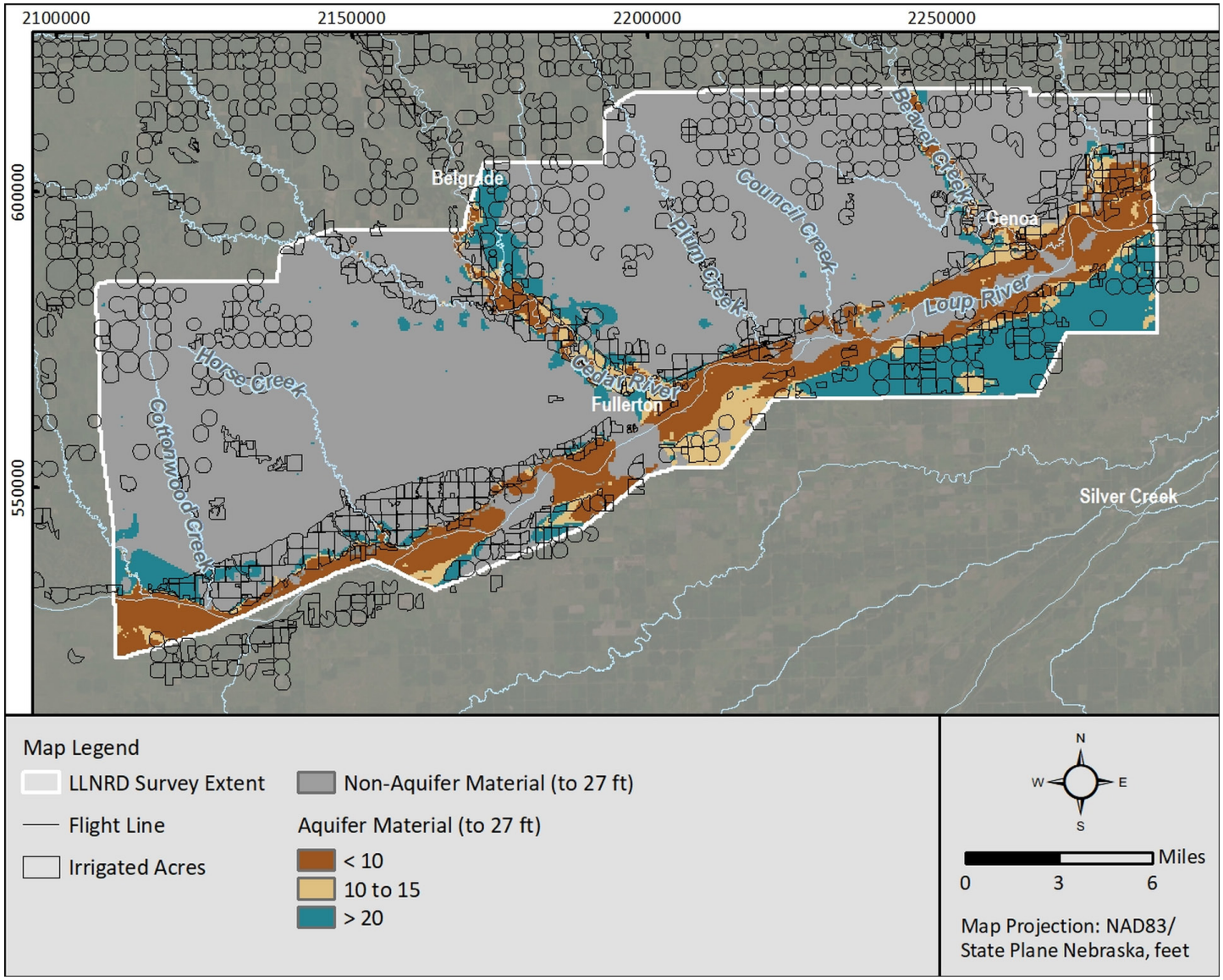



**Figure 5-67. Map of the thickness of the Quaternary (*Q*) aquifer materials in the first 27 feet within the LLNRD 2022 Nance County AEM survey area. Irrigated acres are indicated by the thin black lines (Personal Communication, Cam Conrad, 2022).**

## 5.4 New Understanding of AEM Framework Applied to Water Quantity Management Efforts in Nance County, Nebraska LLNRD

All management plans can be improved as new information is gathered and considered for modifying the management practices. Much of this study was focused on the determination of the groundwater availability within the Nance County AEM survey area. Conflicts and poor well performance were known prior to the work completed in this report. Previous work in the area had indicated that there was limited aquifer material resulting from limited previous saturated thickness and low transmissivity measurements (Summerside et al., 2005). The AEM provides a much higher resolution of the aquifer configuration. The important findings that can have an impact on the management of the area are related to the estimated transmissivities as was determined in this study.

Figure 5-68 is a plot of the transmissivity of less than 20,000 gpd/ft (orange and red areas). These highlighted areas are the first place to start for delineating the control area. This is a large portion of the county with low transmissivity with an especially large area occurring around Beaver Creek and the town of Genoa, Nebraska. These maps are also in general agreement with the maps produced by Summerside et al. (2005). The AEM provides a much higher resolution view of the area as compared with the previous mapping, but that is expected and the goal of this study.

Overlying the groundwater irrigated acres (Personal Communication, Cam Conrad, 2022) on the transmissivity map provides another strong correlation indicating good water availability or not so much (Figure 5-69). There are virtually no groundwater irrigated acres within the low transmissivity zones. These estimates of transmissivity maps can inform the management of the area and provide empirical data on why these decisions were implemented.

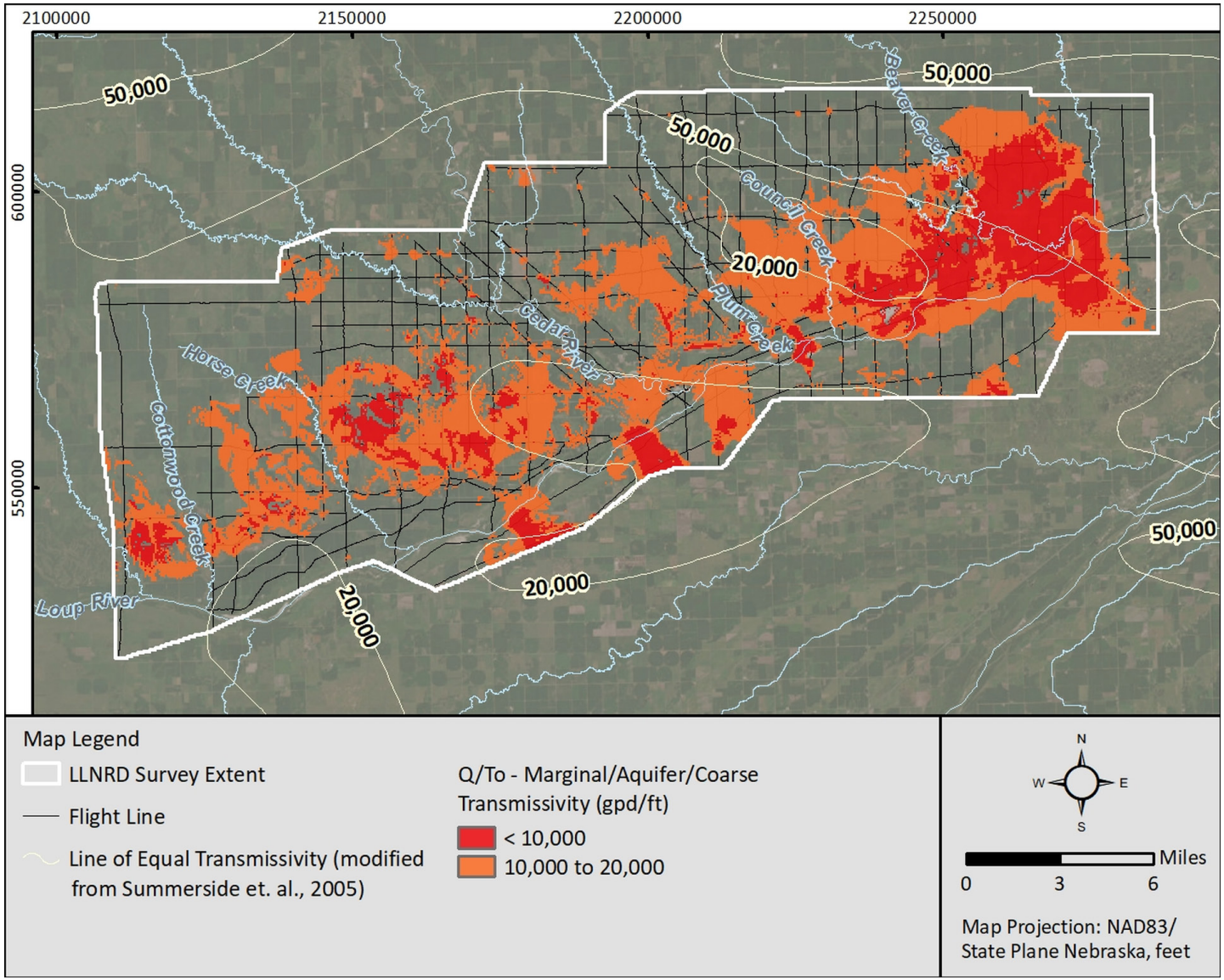



**Figure 5-68. Map of the estimated transmissivity of less than 20,000 (gpd/feet) of the combined Quaternary (*Q*) and Tertiary Ogallala Group (*To*) aquifer within the LLNRD 2022 Nance County AEM survey area. Lines of equal transmissivity modified from (Summerside et al., 2005).**

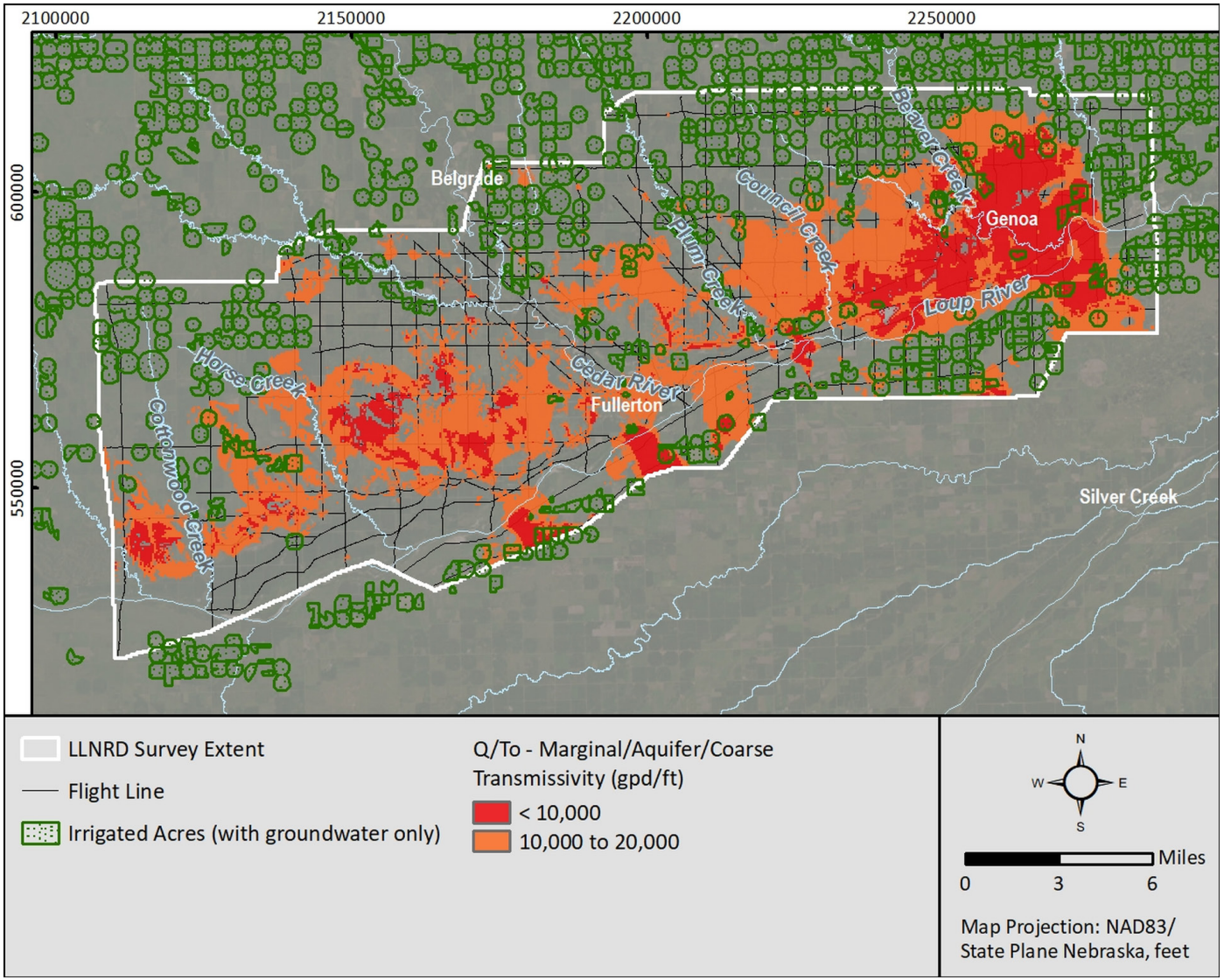



**Figure 5-69. Map of the estimated transmissivity of less than 20,000 (gpd/feet) of the combined Quaternary (*Q*) and Tertiary Ogallala Group (*To*) aquifer within the LLNRD 2022 Nance County AEM survey area and locations of irrigated acres (indicated by shaded areas with thin green lines) (Personal Communication, Cam Conrad, 2022).**

## 5.5 Key AEM Findings

### *5.5.1 Boreholes*

Information from boreholes was used to analyze the AEM inversion results. These included CSD information on 17 boreholes containing lithology and stratigraphic information, and ten (10) holes containing geophysical information. NE-DNR wells totaled 1,464 registered well records containing usable lithology information.

### *5.5.2 Digitizing Interpreted Geological Contacts*

Characterization and interpretation of the subsurface was performed in cross-section and in derived surface grid formats. Contacts between the geologic units were digitized in 2D including: Quaternary (***Q***), Tertiary Ogallala Group (***To***), Cretaceous Pierre Shale (***Kp***), and Cretaceous Niobrara Formation (***Kn***). The interpretive process benefited from the use of CSD and NE-DNR borehole logs. Surface grids of the interpreted geologic formations were then produced. Each flight line profile with interpretation including the Quaternary/Tertiary aquifer material mapping is included in the appendices as well as interpretative surface grids.

### *5.5.3 Resistivity/Lithology Relationship*

Assessment of the sediment character in both the Quaternary/Tertiary Ogallala aquifer system and the consolidated Cretaceous Pierre Shale and Cretaceous Niobrara Formation bedrock was conducted to determine the overall composition of the major categories used to define the aquifer and aquitards in the survey area. A numerically robust assessment of the resistivity thresholds was used to characterize non-aquifer (<12 ohm-m), marginal (12-25 ohm-m), and aquifer (25-50 ohm-m), including coarse sand-rich intervals (>50 ohm-m). This allowed for the characterization of the ranges of resistivities present in the major geologic units described in this report.

### *5.5.4 Hydrogeological Framework of the **Nance County AEM Survey Area***

The AEM reveals considerable variability in the Quaternary (***Q***) and Tertiary Ogallala Group (***To***) deposits across the AEM survey area. The subsurface distribution of materials can be generally characterized into two parts: the ***Q*** and the ***To***. The ***Q*** occurs in the Loup River Valley and the dissected plains north of the river. The ***Q*** aquifer within the AEM survey area predominantly consists of unconsolidated aquifer and coarse aquifer materials composed of alluvial sediments within the Loup River Valley as well as the Cedar River and along Beaver Creek. The ***Q*** loess covers much of the dissected plains and is composed of marginal and non-aquifer material. ***Q*** materials lie upon Tertiary Ogallala Group (***To***) north of the Loup River Valley. The ***To*** has a heterogeneous mix of aquifer materials. Aquifer and coarse aquifer materials compose the paleo-fluvial sediments. A large area of ***To*** non-aquifer material (clay) occurs at the base of the ***To*** in the western portions of the survey area. The ***To*** also has marginal and non-aquifer material deposits that can act as groundwater flow boundaries creating isolated aquifers and barriers to groundwater flow. The ***Q*** and ***To*** aquifers in the area are generally thin and have limited saturated thickness. There is a large portion of the Nance County AEM survey area that has estimated

transmissivities of less than 20,000 gpd/ft. The area of Beaver Creek and around the town of Genoa are all within a region of low transmissivity values. Deeper ***To*** aquifers are some of the best sources of water in the dissected plains. The best source of groundwater is within the thin ***Q*** alluvial sediments along the Loup River Valley. The ***To*** sits upon a small remnant of the Cretaceous Pierre Shale (***Kp***) in the western portion of the survey area. The ***To*** is deposited on the Cretaceous Niobrara Formation (***Kn***) over the remaining area of the survey. The ***Kn*** bedrock is eroded and has shallow paleochannels eroded into the surface. The ***Kp*** and ***Kn*** are not considered aquifers in this area of Nebraska.

### *5.5.5 Estimation of Aquifer Volume and Water in Storage in the Nance County AEM Survey Area*

The values for the saturated (based on the LLNRD spring 2022 water table) Quaternary (***Q***) aquifer materials have a total volume of **6,001,594** acre-ft. The saturated ***Q*** total volume of water is **1,771,165** acre-ft of groundwater in storage. The extractable total volume of saturated **Q** aquifer materials is **164,747** acre-ft.

The values for the saturated (based on the LLNRD spring 2022 water table) Tertiary Ogallala Group (***To***) aquifer materials have a total volume of ***26,708,612*** acre-ft. The saturated ***To*** total volume of water is ***8,848,084*** acre-ft of groundwater in storage. The extractable total volume of saturated ***To*** aquifer materials is ***421,548*** acre-ft.

A combination the saturated ***Q*** and ***To*** aquifer materials produce a total volume of **32,710,206** acre-ft. The total groundwater in storage is **10,619,249** acre-ft. The total extractable water is **586,294** acre-ft.

### *5.5.6 Groundwater Quality in the Nance County AEM Survey Area*

The AEM provided information on the near surface materials in Nance County. Near surface occurrences of sandy soils and sand deposits (aquifer materials) provide conduits for contaminants to migrate into the groundwater. Using the 3D interpretation of the AEM a near surface occurrence of the aquifer materials map was generated. A depth of ~27 feet was selected to examine the areas of potential impacts. Overlaying the LLNRD water quality data on the aquifer material map of the first 27 feet demonstrates a strong correlation of the near-surface aquifer materials and the elevated nitrates. The thickest of the aquifer materials along the Loup River and southern portions of the Beaver Creek areas display the highest Nitrates from the 2022 sampling. There are some areas of 10 to 20 mg/L in areas of the northeastern area of the survey. These are not related to the surface materials and may be related to deeper elevated nitrates in the sandy portions of the Tertiary Ogallala Group (***To***) in that area.

### *5.5.7 Potential Recharge Zones within the Lower Loup NRD 2022 AEM Survey Area*

Using a similar approach in what was utilized in the water quality section the first 27 feet of the AEM model were examined. Those near-surface areas of aquifer materials are dominated by the reaches of the Loup River with sections of the Cedar River and the lower reaches of Beaver Creek. One issue in assessing locations for recharge sites is examining the current land use and ability to deliver water to that location. Utilizing the irrigated acres overlay on the aquifer material within the first 27 feet it is

apparent that there is very limited areas of potential recharge with the exception of the shallow materials along the Loup River. There are a few limited areas along the Cedar River and a few of the drainages that drain into Timber Creek. The bottom line is the potential for good recharge sites within the Nance County AEM survey area is limited without the elimination of currently irrigated land.

### *5.5.8 Using AEM Results to Understand the Effect of Groundwater Management and Regulations*

Much of this study was focused on the determination of the groundwater availability within the Nance County AEM survey area. Conflicts and poor well performance were known prior to the work completed in this report. Previous work in the area had indicated that there was limited aquifer resulting from limited saturated thickness and low transmissivity (Summerside et al., 2005). The AEM has provided a much higher resolution of the aquifer configuration. The important findings that can have impacts on the management of the area are related to the estimated transmissivity as was determined in this study. Areas of transmissivity of less than 20,000 gpd/ft were determined. These low transmissivity areas are the first place to start in delineating the control area. The low transmissivity area covers a large portion of the county, with a substantial area occurring around Beaver Creek and the town of Genoa, Nebraska. The AEM provides a much higher resolution view of the area as compared with the previous mapping, but that is expected and is the goal of this study. These estimates of transmissivity maps can inform the management of the area and provide empirical data on why these decisions were implemented.

## 5.6 Recommendations

Recommendations provided to the LLNRD 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 LLNRD about their management challenges.

### *5.6.1 Additional AEM Mapping*

The aquifer maps provided in this report represent the detailed hydrogeologic framework developed for the Nance County AEM survey area. The interpretations match well with the CSD and NE-DNR boreholes. No additional high resolution AEM information is needed within Nance County Area to resolve questions of resource management, it is recommended that additional areas of closely spaced lines or “block flights” be collected to develop detailed frameworks in other areas of the District.

Other management areas or potential management areas should be mapped in detail to provide information on the hydrogeologic framework which provides detail on recharge, groundwater movement, etc. This could potentially be done in cooperation with the neighboring NRDs to get details on the continuous aquifer system that is shared in the area.

For example, the detailed hydrogeologic frameworks presented in this report have provided estimates of groundwater storage capacity. This is done by using existing aquifer characteristic information and calculating groundwater in storage and effective yield. The line spacing for the block flights should be on the order of 0.25 mile (1,320 ft).

### 5.6.2 Siting new test holes and production wells

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

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

### 5.6.3 Aquifer testing and borehole logging

Aquifer tests are recommended to improve estimates of aquifer characteristics. A robust aquifer characterization program is highly recommended at the state, regional (NRD's), and smaller municipal levels. Aquifer tests can be designed based on the results of AEM surveys and existing production wells.

Additional test holes with detailed, functional, and well calibrated geophysical logging for aquifer characteristics is highly recommended. The few test holes with calibrated geophysical logs in the LLNRD survey area were inadequate. The borehole geophysical logs provided for this investigation demonstrate that additional calibrated and verified geophysical logs are required in the LLNRD.

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

### 5.6.4 Groundwater Management: Control Areas, Recharge areas

The Nance County hydrogeologic framework in this report provides areas of low transmissivity. It is recommended that these areas be used to define the control areas based on empirical data. The geospatial data products delivered with this report can be directly opened in ESRI's ArcGIS Pro and can be used to provide guidance in the establishment on control areas. The near-surface aquifer materials mapped in this report indicate areas that have increased occurrence of nitrates. This is most probably due to the sandy soils and sands that allow the transport of these contaminates into the groundwater. These maps should be used to develop areas of fertilizer controls. Near surface maps of the aquifer materials also provide insight into areas of recharge. Within the Nance County area there is little to no good recharge areas without the elimination of some irrigated acreages. Any management decisions that would propose recharge would need to be weighed against current land use.

# 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, eight (8) flights were required to acquire the LLNRD 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 *LLNRD2022_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 *LLNRD2022_AEM_SCI04_INV_v1.xyz* and the data columns of these databases are described in Table 6-3.

The interpretation results are included in the data file *LLRD2022_InterpSurfaces.xyz* in ASCII format. Table 6-4 describes the data columns of those files.

ESRI ArcGIS raster grids of the surfaces (*.tif and *.flt formats) 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, *LLNRD2022_SCI04_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) and ESRI ArcGIS Pro map package (.mpkx) (Table 6-5)
- 2D profiles, Surfaces, and 3D fence diagrams of the AEM survey inversion results
- Files compatible with the Nebraska GeoCloud (Table 6-7)
- KMZs for LLNRD AEM flight lines (Discussed in Section 6.2).

**Table 6-1. Raw SkyTEM data files**

| Folder | File Name | Description |
|---|---|---|
| Data | ..NavSys.sps, ...PaPc.sps, ...RawData_PFC.skb, ...DPGS.sps | Raw data files included for each flight used in importing to Aarhus Workbench |
| Geo | 20220914_20052_AGF_304_75hz_SKB_PFCwaveform.gex | 304-HR75 System Description |
| | 20220914_20052_AGF_304_75hz_SKB_SR2.gex | |
| | 20220914_20052_AGF_304_75hz_SKB_SR2.sr2 | |
| Mask | 20052_USA_AGF_Nebraska_304_production.lin | Production file listing dates, flights, and assigned line numbers |

**Table 6-2: Channel name, description, and units for LLNRD2022_EM_MAG_AUX.xyz with DEM, magnetic, DGPS, Inclinometer, altitude, and associated data.**

| Parameter | Description | Unit |
|---|---|---|
| Fid | Unique Fiducial Number | |
| Line | Line Number | |
| Flight | Name of Flight | yyyymmdd.ff |
| DateTime | DateTime Format | Decimal days |
| Date | DateTime Format | yyyymmdd |
| Time | Time UTC | hhmmss.sss |
| AngleX | Angle (in flight direction) | Degrees |
| AngleY | Angle (perpendicular to flight direction) | Degrees |
| Height | Filtered Height Measurement | Meters [m] |
| Lon | Longitude, WGS84 | Decimal Degrees |
| Lat | Latitude, WGS84 | Decimal Degrees |
| E_UTM14N_ m | Easting, NAD83 UTM Zone 14N | Meters [m] |
| N_UTM14N m | Northing, NAD83 UTM Zone 14N | Meters [m] |
| DEM | Digital Elevation | Meters [m] |
| Alt | DGPS Altitude above sea level | Meters [m] |
| GDSpeedL | Ground Speed | Kilometers/hour [km/h] |
| Curr_LM | Current, Low Moment | Amps [A] |
| Curr_HM | Current, High Moment | Amps [A] |
| LMZ_G01 | Normalized (PFC-Corrected) Low Moment Z-RxCoil values array | $pV/(m^4*A)$ |
| HMZ_G01 | Normalized (PFC-Corrected) High Moment Z-RxCoil values array | $pV/(m^4*A)$ |

| | | |
|---|---|---|
| **HMX_G01** | **Normalized (PFC-Corrected) High Moment X-RxCoil values array** | **pV/(m$^4$*A)** |
| **PLNI** | **Power Line Noise Intensity monitor** | **V/m$^2$** |
| **Bmag_Raw** | **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 LLNRD2022_AEM_SCI04_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 LLNRD2022_InterpSurfaces.xyz.**

| Parameter | Description | Unit |
|---|---|---|
| **LINE** | **Line Number** | |
| **E_NESP83ft** | **Easting NAD83, Nebraska State Plane** | **Feet [ft]** |
| **N_NESP83ft** | **Northing NAD83, UTM Zone 14N** | **Feet [ft]** |
| **DEM_ft** | **Topography at 100ft sampling (NAVD 1988)** | **Feet [ft]** |
| **East_M** | **Easting UTM Zone 14** | **Meters (m)** |
| **North_M** | **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** |
| **DEP_TOP_FT [0] through DEP_TOP_FT [38]** | **Depth to the top of 39 individual layers** | **Feet [ft]** |
| **DEP_BOT_FT [0] through DEP_BOT_FT [38]** | **Depth to the bottom of 39 individual layers** | **Feet [ft]** |
| **DOI_UPPER_FT** | **More conservative estimate of DOI from Workbench** | **Feet [ft]** |
| **DOI_LOWER_FT** | **Less conservative estimate of DOI from Workbench** | **Feet [ft]** |
| **WT_LLNRD** | **Elevation of the top of the water table from the Nebraska School of Natural Resources Configuration Report, 1995** | **Feet [ft]** |
| **To** | **Estimated elevation of the top of the Tertiary Ogallala Fm.** | **Feet [ft]** |
| **Bedrock** | **Elevation of the top of the bedrock surface** | **Feet [ft]** |
| **Kn** | **Elevation of the top of the Cretaceous Niobrara** | **Feet [ft]** |
| **Kp** | **Elevation of the top of the Cretaceous Pierre Shale** | **Feet [ft]** |

**Table 6-5. Files containing LLNRD 2022 raster datasets (.flt format). All datasets projected to NAD83/State Plane Nebraska, feet and extend throughout the entire LLNRD AEM Survey Area, unless otherwise stated**

| Grid File Name | Description | Grid Cell Size (feet) |
|---|---|---|
| LLNRD_DEM | Digital Elevation Model (ground surface elevation) (NAVD88 feet) of full AEM extent with resolution of 300'. | 300 |
| LLNRD_WT_ElevationTop | Elevation of the top of the Spring 2022 water table elevation (ft asl); created with Spring 2022 data points. | 300 |
| LLNRD_WT_DepthToTop | Depth to the top of the Spring 2022 water table (feet); created with Spring 2022 data points. | 300 |
| LLNRD_To_ElevationTop | Estimated elevation of the top of To (ft asl). | 300 |
| LLNRD_To_DepthToTop | Depth to the top of To (feet). | 300 |
| LLNRD_Kp_ElevationTop | Elevation of the top of Kp (ft asl). Extent is limited to the southwest corner of the AEM survey area. | 300 |
| LLNRD_Kp_DepthToTop | Depth to the top of Kp (feet). Extent is limited to the southwest corner of the AEM survey area. | 300 |
| LLNRD_Kn_ElevationTop | Elevation of the top of Kn (feet). | 300 |
| LLNRD_Kn_DepthToTop | Depth to the top of Kn (feet). | 300 |
| LLNRD_Bedrock_ElevationTop | Elevation of the top of bedrock (feet). | 300 |
| LLNRD_Bedrock_DepthToTop | Depth to the top of bedrock (feet). | 300 |
| LLNRD_Q_ThicknessTotal | Total thickness of Q deposits (feet). | 300 |
| LLNRD_Q_ThicknessSaturated | Saturated thickness of Q deposits (feet). | 300 |
| LLNRD_To_ThicknessTotal | Total thickness of To (feet). | 300 |
| LLNRD_To_ThicknessSaturated | Saturated thickness of To (feet). | 300 |
| LLNRD_QTo_ThicknessTotal | Total thickness of Q deposits and To (feet). | 300 |
| LLNRD_QTo_ThicknessSaturated | Saturated thickness of Q deposits and To (feet). | 300 |
| LLNRD_Q_NonAquifer_TopEle | Elevation of the top of Q deposits; Non-Aquifer material only (feet asl). | 300 |
| LLNRD_Q_Marginal_TopEle | Elevation of the top of Q deposits; Marginal material only (feet asl). | 300 |
| LLNRD_Q_Marginal_Aquifer_Coarse_TopEle | Elevation of the top of Q deposits; Marginal, Aquifer, and Coarse material only (feet asl). | 300 |
| LLNRD_Q_Coarse_TopEle | Elevation of the top of Q deposits; Coarse material only (feet asl). | 300 |
| LLNRD_Q_Aquifer_Coarse_TopEle | Elevation of the top of Q deposits; Aquifer and Coarse material only (feet asl). | 300 |

| | | |
|---|---|---|
| **LLNRD_Q_Aquifer_TopEle** | **Elevation of the top of Q deposits; Aquifer material only (feet asl).** | **300** |
| **LLNRD_To_Marginal_Aquifer_Coarse_TopEle** | **Elevation of the top of To; Marginal, Aquifer, and Coarse material only (feet asl).** | **300** |
| **LLNRD_To_Aquifer_TopEle** | **Elevation of the top of To; Aquifer material only (feet asl).** | **300** |
| **LLNRD_To_Aquifer_Coarse_TopEle** | **Elevation of the top of To; Aquifer and Coarse material only (feet asl).** | **300** |
| **LLNRD_To_NonAquifer_TopEle** | **Elevation of the top of To; Non-Aquifer material only (feet asl).** | **300** |
| **LLNRD_To_Marginal_TopEle** | **Elevation of the top of To; Marginal material only (feet asl).** | **300** |
| **LLNRD_Q_Marginal_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of Q deposits; Marginal, Aquifer, and Coarse material only (feet).** | **300** |
| **LLNRD_Q_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of Q deposits; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_Q_Marginal_SaturatedThickness** | **Saturated thickness of Q deposits; Marginal material only (feet asl).** | **300** |
| **LLNRD_To_Marginal_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of To; Marginal, Aquifer, and Coarse material only (feet)** | **300** |
| **LLNRD_To_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of To; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_To_Marginal_SaturatedThickness** | **Saturated thickness of To; Marginal material only (feet).** | **300** |
| **LLNRD_QTo_Marginal_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of Q deposits and To; Marginal, Aquifer, and Coarse material only (feet).** | **300** |
| **LLNRD_QTo_Aquifer_Coarse_SaturatedThickness** | **Saturated thickness of Q deposits and To; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_QTo_Marginal_SaturatedThickness** | **Saturated thickness of Q deposits and To; Marginal material only (feet).** | **300** |
| **LLNRD_Q_Marginal_Aquifer_Coarse_TotalThickness** | **Total thickness of Q deposits; Marginal, Aquifer, and Coarse material only (feet).** | **300** |
| **LLNRD_Q_Aquifer_Coarse_TotalThickness** | **Total thickness of Q deposits; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_Q_Marginal_TotalThickness** | **Total thickness of Q deposits; Marginal material only (feet).** | **300** |
| **LLNRD_Q_Coarse_TotalThickness** | **Total thickness of Q deposits; Coarse material only (feet).** | **300** |
| **LLNRD_Q_NonAquifer_TotalThickness** | **Total thickness of Q deposits; Non-Aquifer material only (feet).** | **300** |
| **LLNRD_Q_Aquifer_TotalThickness** | **Total thickness of Q deposits; Aquifer material only (feet).** | **300** |
| **LLNRD_To_Marginal_Aquifer_Coarse_TotalThickness** | **Total thickness of To; Marginal, Aquifer, and Coarse material only (feet).** | **300** |

| | | |
|---|---|---|
| **LLNRD_To_Aquifer_Coarse_TotalThickness** | **Total thickness of To; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_To_Marginal_TotalThickness** | **Total thickness of To; Marginal material only (feet).** | **300** |
| **LLNRD_To_NonAquifer_TotalThickness** | **Total thickness of To; Non-Aquifer material only (feet).** | **300** |
| **LLNRD_To_Aquifer_TotalThickness** | **Total thickness of To; Aquifer material only (feet).** | **300** |
| **LLNRD_QTo_Marginal_Aquifer_Coarse_TotalThickness** | **Total thickness of Q deposits and To; Marginal, Aquifer, and Coarse material only (feet).** | **300** |
| **LLNRD_QTo_Aquifer_Coarse_TotalThickness.tif** | **Total thickness of Q deposits and To; Aquifer and Coarse material only (feet).** | **300** |
| **LLNRD_QTo_Marginal_TotalThickness.tif** | **Total thickness of Q deposits and To; Marginal material only (feet).** | **300** |
| **LLNRD_QTo_Marginal_Aquifer_Coarse_Transmissivity** | **Transmissivity (gpd/ft) of Q deposits and To; Marginal, Aquifer, and Coarse material only.** | **300** |
| **LLNRD_Q_Marginal_Aquifer_Coarse_Transmissivity** | **Transmissivity (gpd/ft) of Q deposits; Marginal, Aquifer, and Coarse material only.** | **300** |
| **LLNRD_To_Marginal_Aquifer_Coarse_Transmissivity** | **Transmissivity (gpd/ft) of To; Marginal, Aquifer, and Coarse material only.** | **300** |
| **LLNRD_Recharge_Aquifer_ThicknessTo27ft** | **Total thickness of Aquifer material only down to 27ft. Used to determine possible areas of recharge.** | **300** |
| **LLNRD_Recharge_NonAquifer_TopEle** | **Elevation of Non-Aquifer material where it is present at ground surface. Used to determine where recharge areas may not be possible.** | **300** |

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

| Shapefile File Name | Description |
|---|---|
| Extent_Kp_ForDataClipping | Extent of the Cretaceous Pierre Shale (Kp) with the survey extent. |
| Extent_To_ForDataClipping | Extent of the Ogallala Formation (To) within the survey extent. |
| Extent_Surface_ForDataClipping | Extent used to clip all data to the survey extent. |
| LLNRD_DNR_Wells_withinExtent_SpecificCapacity | NE-DNR wells within survey extent with calculated specific capacity and estimated well designation. |
| LLNRD_Total_flightlines_final_polylines | 2022 and select 2016 flight lines within the survey extent. |

**Table 6-7. Geocloud-import file: LLNRD2022_SCI04_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) |

## 6.2 Description of Included Google Earth KMZ Data and Profiles

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

Unique KMZ files were created for each individual flight line in approximately 10-12-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\LLNRD22_Profiles*" folder. In this folder is a "*GoogleE_Readme.pdf*" file that provides instructions regarding the "*Settings*" changes that need to be made in Google Earth, and how to use the KMZ files in Google Earth including a legend of what attributes are displayed when an AEM sounding location is clicked. This LLNRD22 GoogleE_Readme.pdf file is repeated below as a convenience. An image of the LLNRD22 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 L200901 is presented in Figure 6-3.

### *6.2.1 Included README for the LLNRD 2022 Interpretation KMZ's*

README for:

**LLNRD_Interp_Pt1.kmz**
**LLNRD_Interp_Pt2.kmz**

Data Files - Please copy the folder *LLNRD22_Profiles* to your C:\ drive. Do not rename any of the images within the folder.

Google Earth Instructions:

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

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

STEP 3: Under "*Placemark balloons*", make sure the box is checked to allow access to local files (the profiles).

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

STEP 5: The 2022 LLNRD_Interp_Pt1.kmz and LLNRD_Interp_Pt2.kmz interpretation kmz files within the folder named *LLNRD22_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 Water Table (FT)*** – Elevation of the water table, in feet.

***Elevation To (FT)*** – Estimated elevation of Tertiary Ogallala Fm., in feet.

***Elevation Bedrock (FT)*** – Estimated elevation of the top of the Bedrock, in feet.

***Elevation Kn (FT)*** – Estimated elevation of the Cretaceous Niobrara Fm., in feet.

***Elevation Kp (FT)*** – Estimated elevation of the Cretaceous Pierre Shale, in feet.

***Profile*** – Link to Interpreted AEM profile images.

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

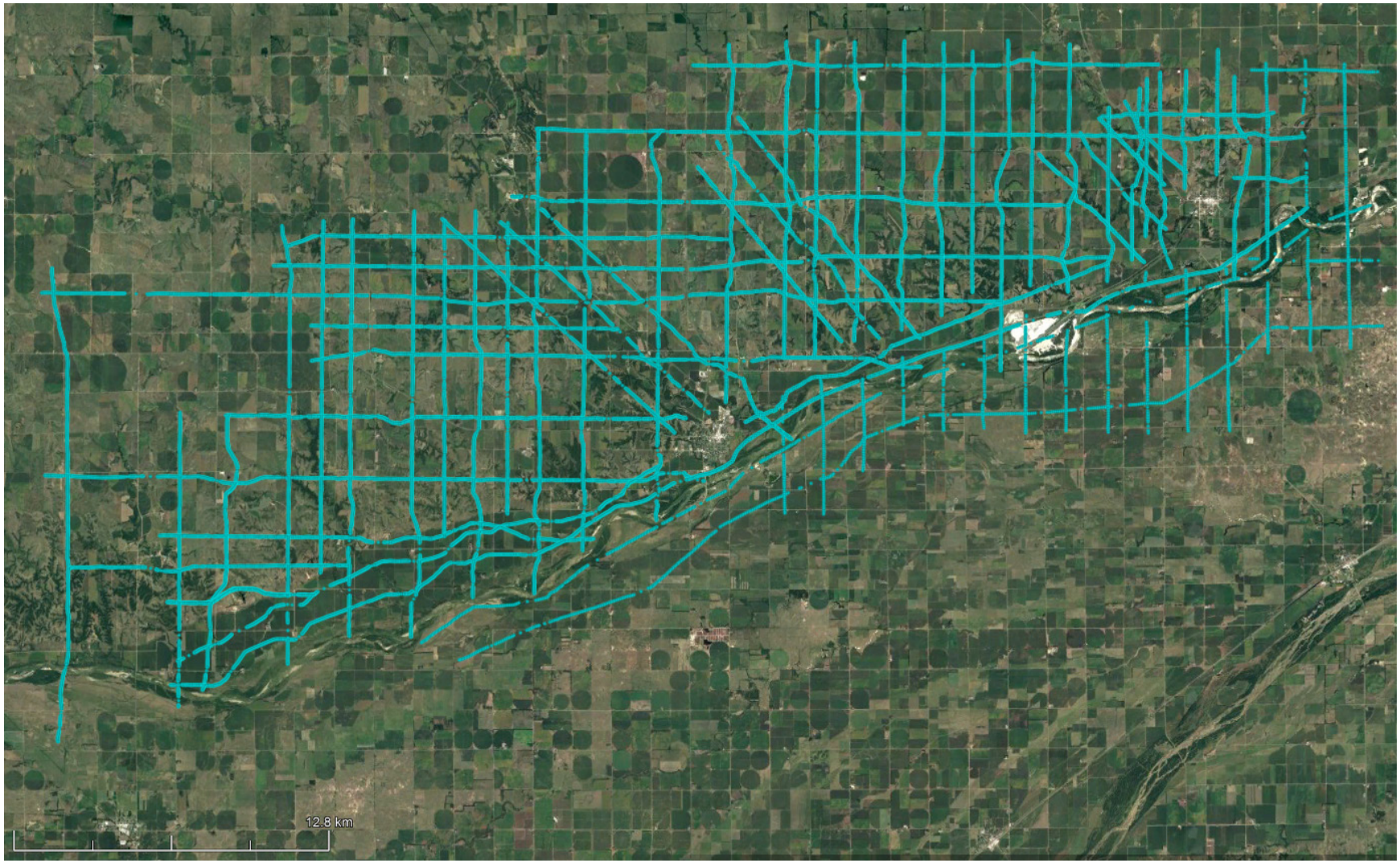



**Figure 6-1. Google Earth KMZ of the LLNRD 2022 AEM survey area showing the AEM Interpretation locations.**

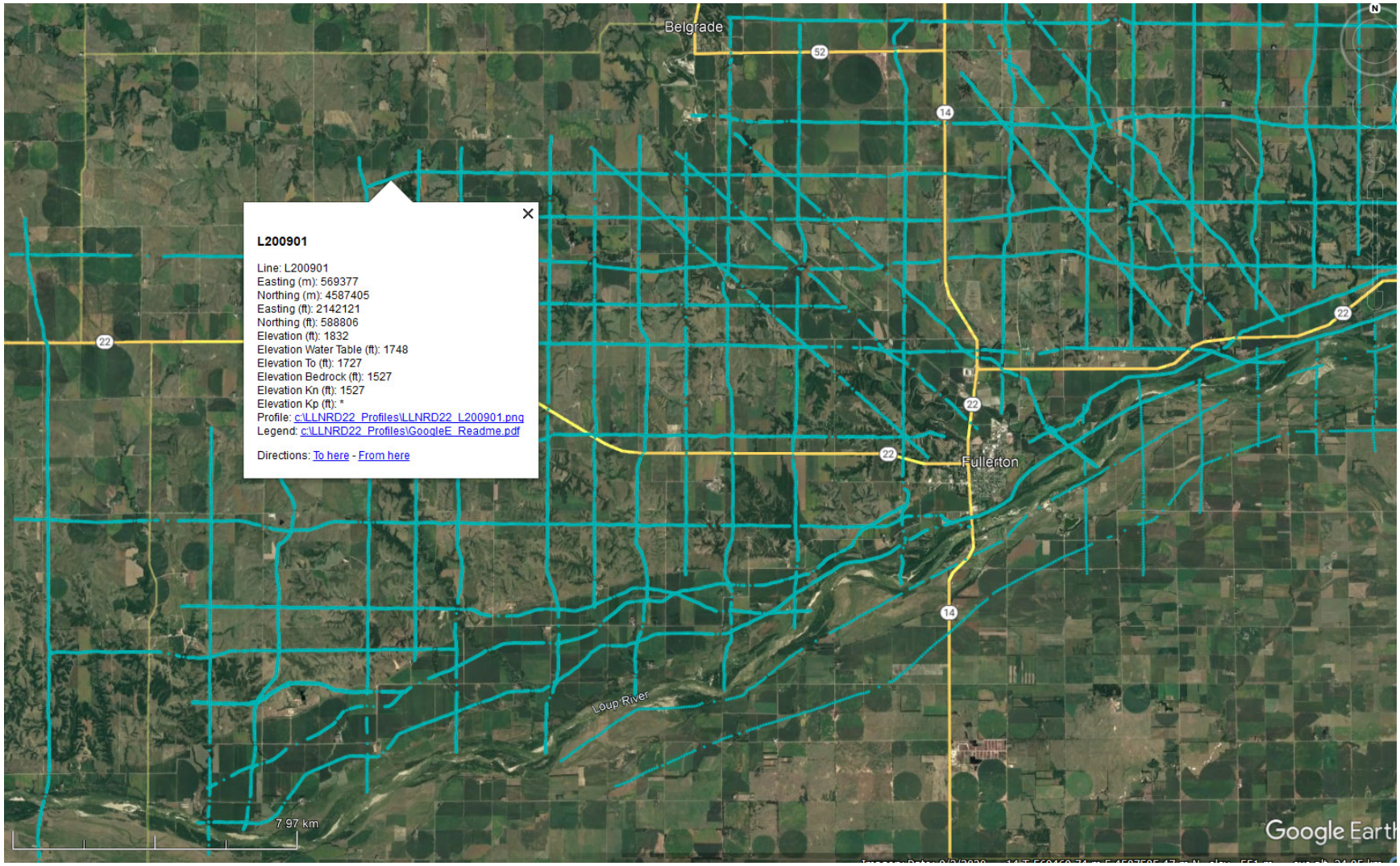
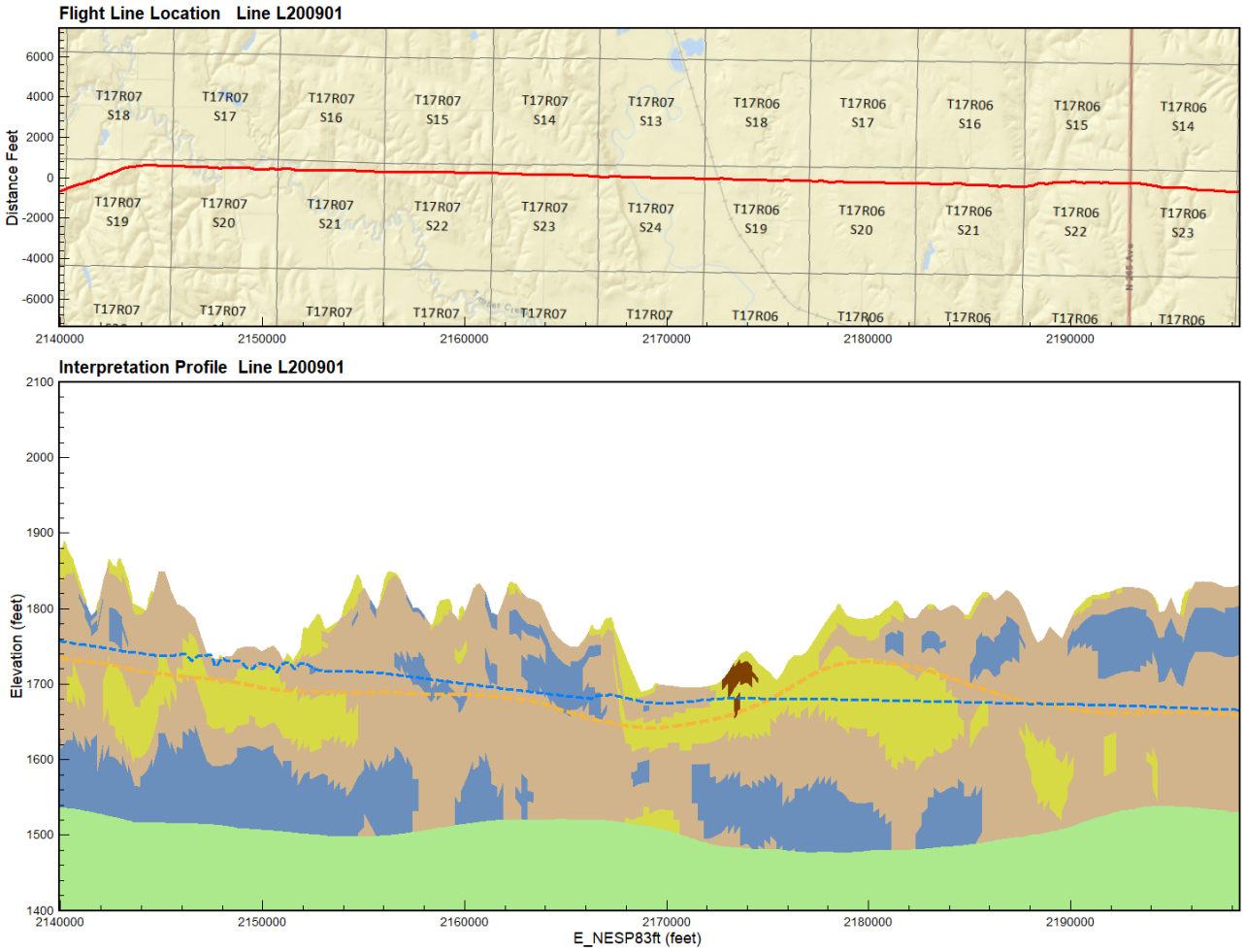



**Figure 6-2. Example of clicking on a location in the LLNRD 2022 AEM survey area. Profile L200901 is presented in Figure 6-3 below.**




Interpreted geological sections from AEM data and flight path location map 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 path is displayed as a red line on the flight path map The Spring 2022 LLNRD water table is indicated by the dashed blue line. The Quaternary (Q) section and the Tertiary Ogallala Group (To) are divided into aquifer material categories as indicated by the legend. The estimated top of the Tertiary Ogallala Group (To) is represented as a dashed orange line. The Cretaceous Pierre Shale (Kp) and the Cretaceous Niobrara Formation (Kn) are indicated by the green colors as referenced in the legend. Additional information regarding the use of this figure and the AEM data may be found in the report titled "Airborne Electromagnetic Mapping and Hydrogeologic Framework of Nance County within Lower Loup Natural Resources District."

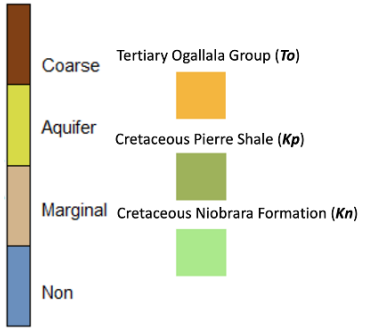



**Figure 6-3. Example of clicking on link to Profile image for line L200901 in the LLNRD 2022 interpretation KMZ.**

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