# IMPACT OF AIRBORNE ELECTROMAGNETIC (AEM) SURVEYS IN GROUNDWATER MANAGEMENT IN THE LOWER PLATTE SOUTH NATURAL RESOURCES DISTRICT, NEBRASKA, USA

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## SUMMARY

The Lower Platte South Natural Resources District has collected several thousand line kilometres of Airborne Electromagnetic (AEM) data during five surveys beginning in 2007 and continuing through 2016 to develop a hydrogeologic framework for priority groundwater management areas. Frequency domain systems were originally used in 2007 and 2008. A shift to time domain electromagnetics was required to increase the depth of investigation in areas of conductive glacial till beginning in 2013. The AEM surveys were collected as reconnaissance and block flight lines. Careful calibration and diligent inversions were required to maximize resolution of the AEM data. The AEM-improved hydrogeologic framework was the basis for changes to the management area boundaries and the type of management controls for many of the areas. The revised Dwight-Valparaiso-Brainard management area has experienced improvements in ground water levels and recent regulation changes have allowed an increase in groundwater pumping in the eastern region. Based on the AEM, a new recharge area was identified, and management controls were implemented to reduce non-point source pollution over the recharge area. The AEM-derived hydrogeological framework information has been used for the following: to vary management techniques based on the degree of aquifer confinement and in-season water declines; to determine the amount of groundwater in storage; to locate potential recharge areas; to guide the installation of monitoring wells; to locate and install surface water gages to understand groundwater-surface water relationships; to locate areas for vadose zone characterization; and, finally, to assist local public water suppliers with the management of limited aquifers.

**Key words:** airborne, electromagnetic, groundwater, recharge, management.

## INTRODUCTION

The use of AEM survey data to develop new hydrogeologic frameworks related to groundwater management by Nebraska's Natural Resources Districts (NRDs) has been a cornerstone of proactive work in the groundwater field since 2006. The Lower Platte South NRD (LPSNRD) has been a leader in supporting AEM surveys on its own and as part of the Eastern Nebraska Water Resources Assessment group (ENWRA). As one of 23 NRDs in Nebraska they are responsible for management of the groundwater quality, quantity and groundwater-surface water interaction. The LPSNRD has active groundwater management areas in the district with the Dwight-Valparaiso-Brainard Special Management Area (DVB SMA) using AEM survey data (Carney *et al.*, 2014) to modify the previous management rules and regulations related to groundwater quantity and quality. The location of the DVB SMA is on the northwestern edge of the LPSNRD (Figure 1).

The geologic setting of the DVB SMA is made up of a complex mix of Quaternary glacial till, glacial outwash, alluvium filled paleo-channels and Cretaceous bedrock. Most of the groundwater in the area is produced from the glacial outwash and the alluvial paleo-channels. These groundwater sources have sufficient capacity to provide irrigation for agriculture, municipal supply, and domestic wells (Carney *et al.*, 2014). The nature of the hydrogeology of the area is such that sustainable supply concerns prompted the LPSNRD to initially restrict groundwater development in the DVB SMA based on water level changes and complaints from the public on groundwater use interference and declining well performance.

The confined aquifer units in the DVB SMA, while not showing signs of long-term water level declines, respond rapidly to irrigation well pumping in the summer months. In cases of dry weather and high irrigation demand, ground water levels can decrease on the order of 30 m in a matter of several days, leading to decreased well yield especially in older, shallower wells. As a result, the District has imposed regulations consisting of the following directives: a prohibition on new irrigated land development, an allocation of groundwater irrigation application of 76 cm over 3 years with a maximum of 30 cm in any one year, irrigators must complete a management certification class, the LPSNRD has established cost share for improved irrigation management, deeper wells for domestic uses are required to avoid seasonal draw-down effects, and a requirement that all new wells be approved by the LPSNRD Board of Directors.

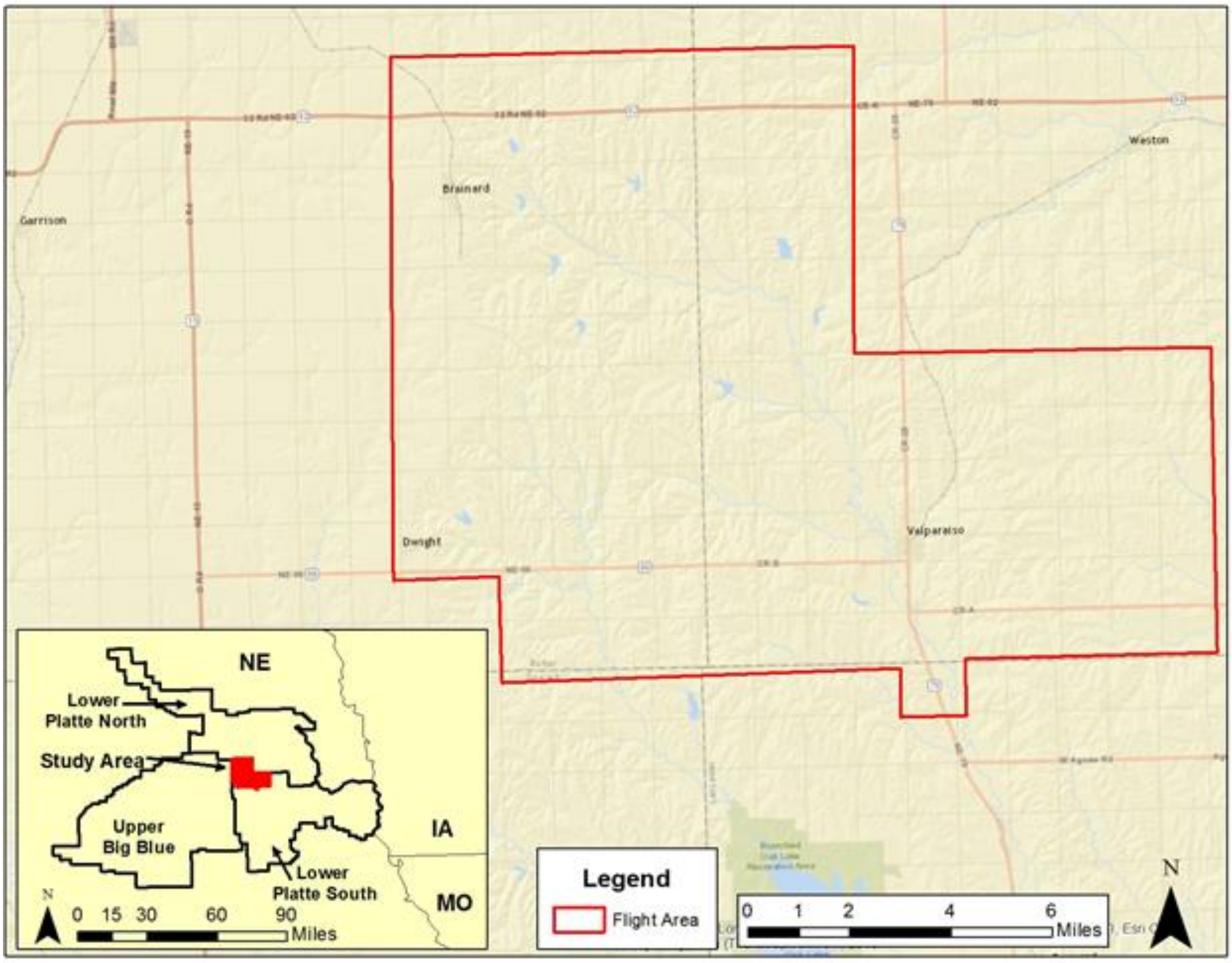


**Figure 1: Location of the study area within the Lower Platte South Natural Resources District of eastern Nebraska, USA.**

The AEM survey was used to alter the management rules of the DVB SMA management area by removing the allocation requirement in the easternmost management area in 2017 (Figure 2). This area was proven to be a recharge area with an unconfined aquifer so the LPSNRD board relied on the AEM survey results to make the decision. The AEM data has been instrumental in this management in three primary ways: First, detailed information on the extent and occurrence of confining units, aquifer materials, and potential recharge areas has guided the District's installation of new monitoring wells, allowing those wells to be sited to maximize the value of ground water data collected. Second, this data has yielded important insight into the geometry, volume, and degree of confinement of the various aquifer units in the area. This information was used to justify removing the allocation requirement in the eastern part of the SMA, as it was possible to demonstrate that the aquifer units there were essentially unconfined, and thus extensive in-season water declines are not a concern. Finally, the AEM data have played an important role in raising public knowledge of the ground water issues facing the DVB SMA. Detailed, easy-to-understand maps, cross-sections, as well as publicly accessible electronic versions (e.g. KMZ files for use with Google Earth) have increased the public's confidence in the NRD's knowledge of the ground water resources, and have to some extent eased concerns about the regulatory actions taken in that area.

Future AEM surveys are planned to improve the sub surface information the LPSNRD relies on to make groundwater management decisions in other areas of the district. This is vital in the LPSNRD as the complex glacial geology means that many aquifers are of limited extent and highly discontinuous. These limitations mean that ground water quantity as well as quality concerns (e.g. from nitrate-nitrogen contamination, a common issue in an agricultural state like Nebraska) are magnified.

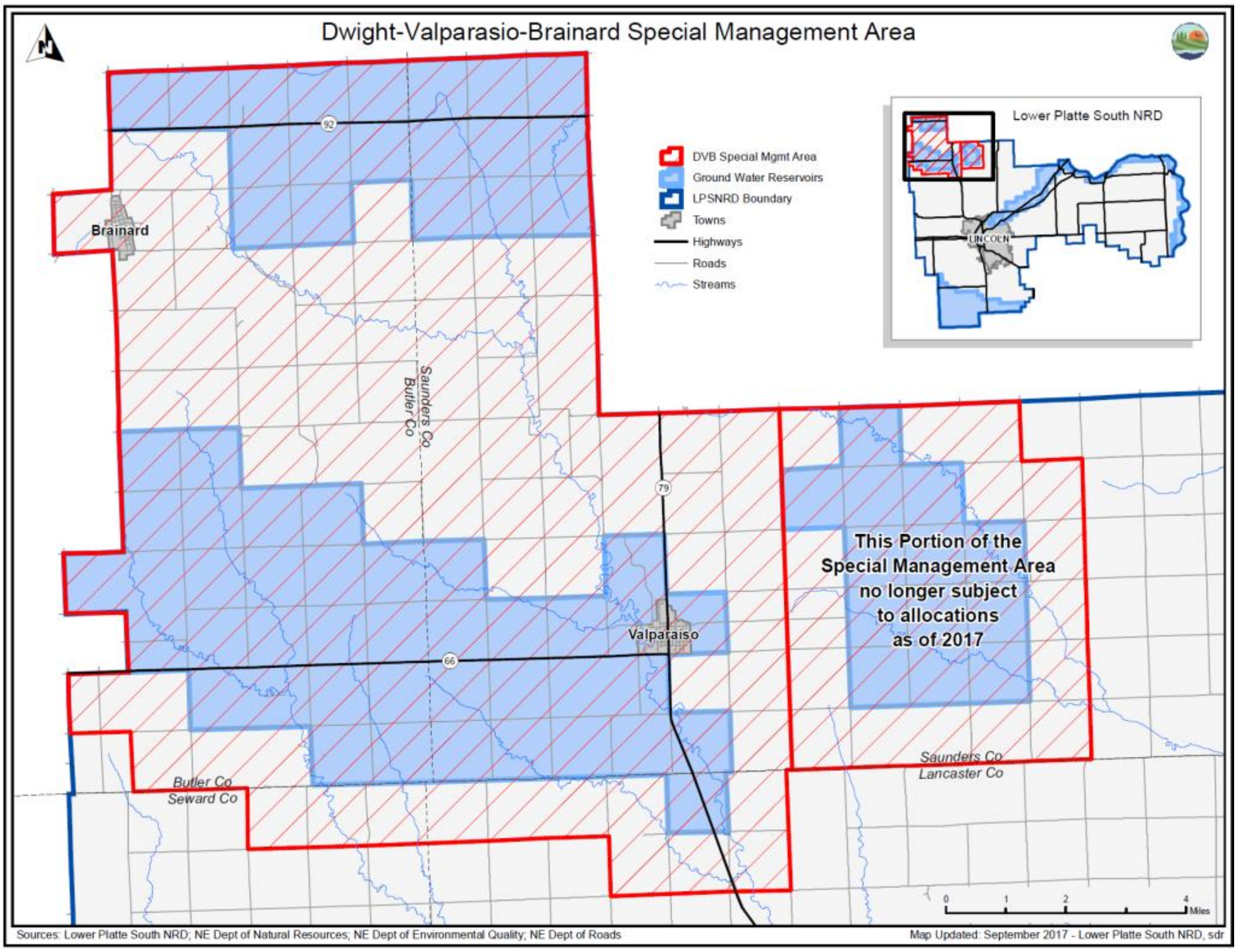


**Figure 2: Identification of the ground water reservoirs within the Dwight-Valparaiso-Brainard Special Management Area (DVB SMA) and the area to the east that has been removed from the SMA.**

## METHODS AND RESULTS

The AEM measurements in the project area were completed with the SkyTEM 304 system. The SkyTEM system is a rigid frame, dual-moment transient electromagnetic (TEM) system developed over the past ten years (Sørensen and Auken, 2004). In contrast to other TEM systems, the SkyTEM system has the receiver coil positioned slightly behind and above the transmitter wire in a "null" position, where the intensity of the primary field is minimized. The SkyTEM system was initially designed for groundwater mapping, and to this end employs two transmitter moments with different currents and different numbers of transmitter wire turns. The low current, or low moment (LM) mode, with a moment of 3,140 (number of turns × current × amp × area ($m^2$) - also known as NIA), is used to record early-time data which constrain the near-surface information, while the high current, or high moment (HM) mode, with a moment of 145,000 NIA, improves the signal-to-noise ratio at late time gates and greater depths. The SkyTEM 304, has a transmitter area of 314 m2, and is intermediate between the SkyTEM 101 system, used for very near-surface applications, and the SkyTEM 508, designed for deeper investigations. The SkyTEM 304 system records data at time gates ranging from 1.6 µs to 11 ms. The gates analysed in the LPSNRD survey fall between 9.6 µs and 7.0 ms, with the latest recorded gates being too noisy for use, and the gates before 5 µs contaminated by residual primary field that was not removed at the time of this survey in 2013. The SkyTEM system is calibrated to a ground test site in Lyngby, Denmark where the system was developed (Foged *et al.*, 2013). Approximately 1,331 km were flown within the three project area blocks (Figure 3). Flight operations began on 13 August and continued through 22 August 2013. The AEM survey was flown with a line separation of approximately 300 metres in a north-south direction and approximately 1500 metre spacing in the east-west direction.

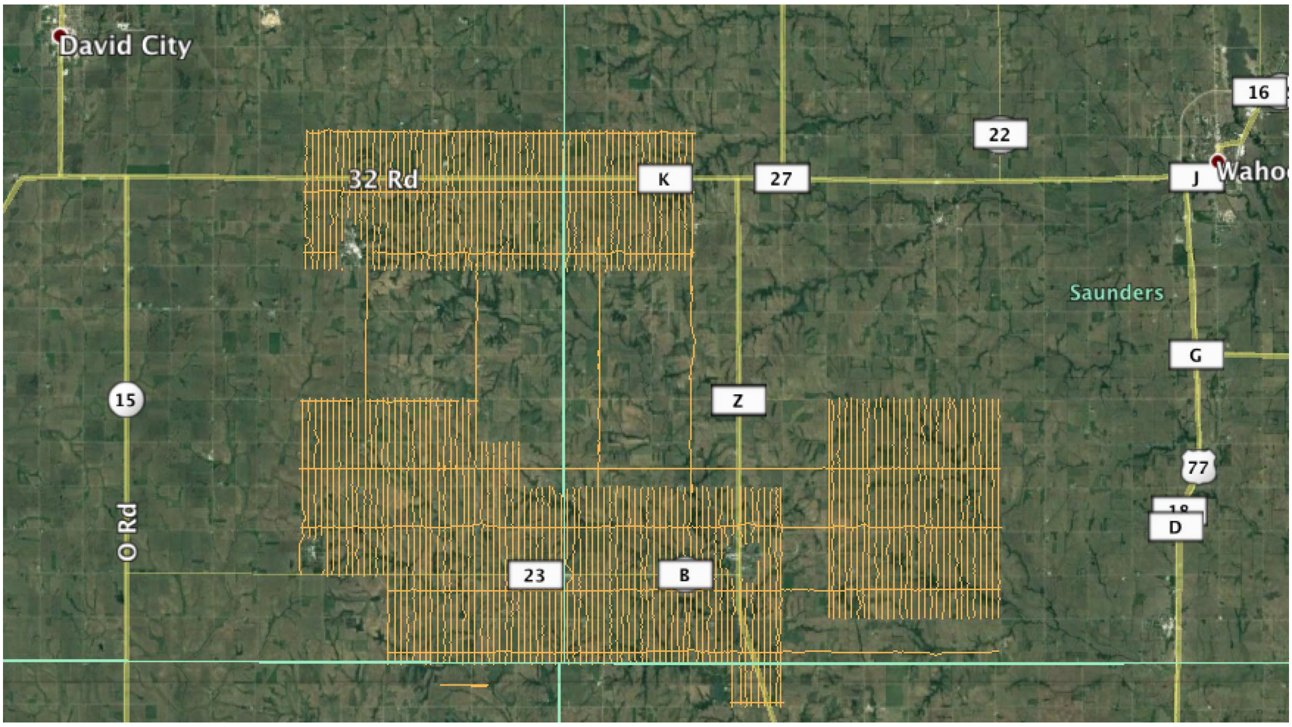


**Figure 3: Google Earth Map with the location of the 2013 flight lines within the Lower Platte Natural Resources District.**

The software program Aarhus Geophysics Workbench version 4.1.1.768 (Aarhus Geophysics, 2013) was used for the processing and inversion of the AEM data. The data were first subjected to automatic processing algorithms provided within the Workbench program. GPS locations were filtered using a stepwise, second-order polynomial filter of 9 seconds with a step length of 0.5 seconds. Filters were also applied to both tilt metre readings - a median filter of 3 seconds and an average filter of 2 seconds. The TEM data are then corrected for tilt deviations from level. The sensor altitude data are corrected using a series of two polynomial filters. The length of both eighth-order polynomial filters were set to 30 seconds with shift lengths of 6 seconds. The lower and upper thresholds were 1 and 30 metres, respectively. The TEM data were subjected to several different filters including slope, sign, and trapezoidal filters. The Cap Sign Filters cull data when the value changes sign and began at 1.5 × 10-5 seconds for the Low Moment and 1 × 10-4 seconds for the High Moment. The noise level for the Cap Sign Filter was set to 5 × 10-7 ms*v/m2 with a slope of -0.5 for the Low Moment and 2 × 10-7 ms*v/m2 with a slope of -05 for the High Moment. The cap slope filter removed four time gates before the change in sign for both moments. The cap slope filter uses the same time periods, noise levels, and noise slopes as the Cap Sign Filter and removes sounding data if the second order derivative of the dB/dt curve is outside of the specified minimum and maximum slopes. The minimum slope was -0.5 and the maximum slope was 0.5 for both moments. The Average Sign Filter works on the averaged data, removing data when a change in sign occurs. The Average Slope Filters were not used on this data set. Trapezoidal filters were used to average the TEM sounding data. The times used to define the trapezoidal filters for the Low Moment were 1 × 10-5, 1 × 10-4, and 1 × 10-3 with widths of 2, 5 and 10 seconds. The times used to define the trapezoid for the High Moment were 1 × 10-4, 1 × 10-3, and 1 × 10-2 with widths of 5, 10, and 20 seconds. The spike factor and minimum number of gates were both set to 25 percent for both soundings. After processing, which included elimination of some data due to signal interference, the remaining AEM data coverage for the three blocks was approximately 928 kilometres, which was about 70 percent of the total data collected in the project area. After the implementation of the automatic filtering, the TEM data were manually examined using a sliding 2-minute time window. The data were examined for possible coupling with surface and buried metal as well as for late time-gate noise levels. Data affected by these were removed. In addition, the results of the automatic filtering processes were monitored. In some instances, TEM data that were removed by the automatic filters were re-included. The magnetic Total Field data as well as the 60 Hz power line data were also used to remove coupling. The TEM data were then inverted using a laterally-constrained inversion (LCI) algorithm. A starting model consisting of 30 layers each with a starting resistivity of 12 ohm-m was used. This model went to a depth of over 300 metres with the thickness of the layers increasing with depth. The vertical resistivity standard deviation was set to 2, while the lateral resistivity standard deviation was set to 1.6. Following the LCI, profile and depth slices were created to examine the results of the inversion. When remaining electromagnetic couplings were identified in the sections, the data were again manually edited and additional LCIs were performed.

After the results of the second LCI were determined to be free of couplings, a spatially-constrained inversion (SCI) was performed. Each of the infill grids and the reconnaissance grid were processed using an SCI analysis. A starting model consisting of 30 layers with an initial resistivity of 12 ohm-m was used. This model again went to a depth of beyond 300 metres with the thickness of the layers increasing with depth. The vertical resistivity standard deviation was set to 2, while the lateral resistivity standard deviation was set to 1.6. The SCI created sections in which the inversions are spatially constrained (Viezzoli *et al.*, 2008). The approximate section size selected was 100 soundings, with a minimum of 50 soundings. Once again, the inversion results via 2D profiles and depth slices were examined. If any remaining electromagnetic coupling was detected, it was removed and the inversions run again.

Results of the inversion show two distinct areas within the survey area. An area to the west that shows subsurface resistors that indicated coarse materials within the Quaternary section and an area to the east that indicates that the resistive materials within the Quaternary section are at the surface (Figure 4). The resistive materials at the surface is a recharge area that is connected to an unconfined aquifer system directly below. This aquifer system is continuous as it dips to the west and becomes a confined groundwater system when it is covered by glacial till. These important facts allowed for the change in groundwater management boundaries in 2017.

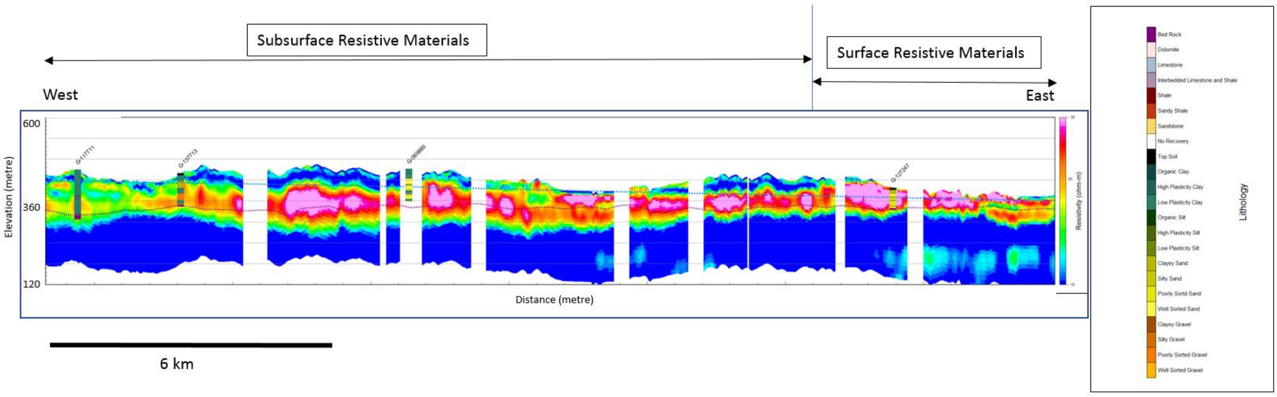


**Figure 4: West to east profile showing the two distinct areas of the study area including the area to the west that has subsurface resistive materials and the area to the east that has surface resistive materials. Boreholes are indicated by coloured vertical bars.**

Examining the area in 3D provides a view of the interconnected nature of the subsurface materials within the study area. The areas to the west are dominated by paleochannel deposits that are deposited along paths versus the glacial outwash deposits that dominate the eastern side of the study area (orange voxel of coarse aquifer material (>20 ohm-m) in Figure 5). The narrow paleochannel that is seen in the southern block of the DVB SMA tends from west to east where it joins with the outwash deposits in the east. This continuous deposition of aquifer and coarse aquifer materials gives the DVB SMA a defined recharge area which is linked to an unconfined aquifer which in turn is linked to a confined aquifer. The AEM block to the north is composed of outwash material. All of the 3D maps were used for determining the amount of groundwater in storage. These mapped boundaries and volumes are critical information for the LPSNRD groundwater management plan (LPSNRD, 1995).

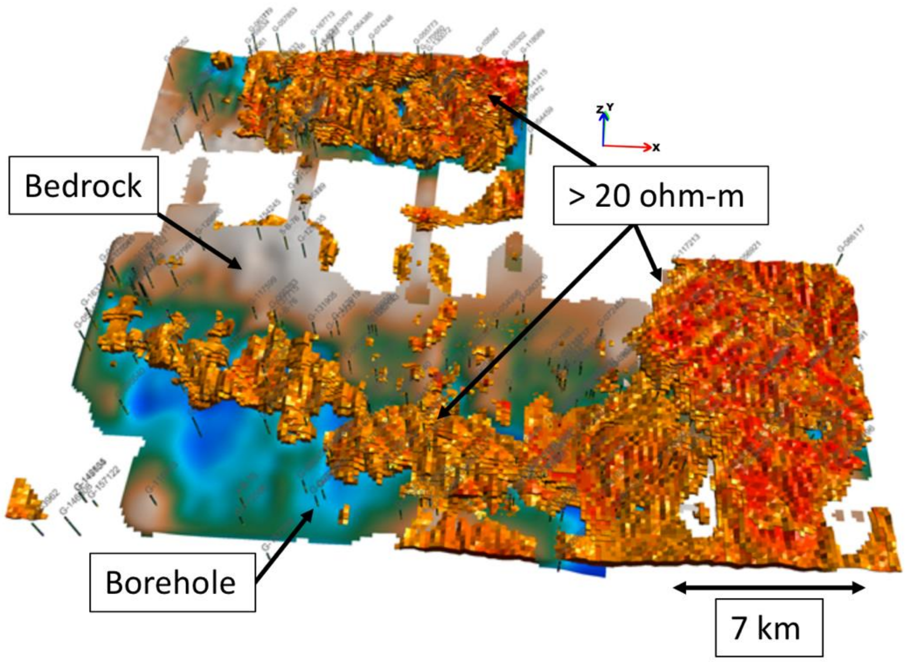


**Figure 5: 3D image of the interpreted bedrock surface (shaded surface) and the interrupted coarse aquifer material > 20 ohm-m (orange voxel grid) within the study area looking down toward the north. Boreholes are indicated as 3D tubes. Vertical exaggeration is 5X.**

The results of the AEM survey provided information on the geometry of the aquifers within the study area. As previously described, these management efforts are necessary to deal with rapid in-season water level declines of up to 30 m during the summer irrigation season in more highly confined aquifer units, which has resulted in conflicts between well owners. The regulations LPSNRD has adopted regarding irrigation water pumping allocations and restrictions on new irrigated acres has been fundamentally supported by the availability of detailed AEM data which has increased understanding of the extent and occurrence of confining units, aquifer materials, and recharge areas. That data has guided installation of new monitoring wells, allowed for appropriate adjustment of regulations due to variability in the degree of confinement of aquifer units, and has helped members of the public to a greater understanding of the complex geology of the area. This knowledge has helped promote acceptance of management and regulatory actions adopted by LPSNRD in the DVB SMA. Detailed, easy-to-understand maps, cross-sections, as well as publicly accessible electronic versions (e.g. KMZ files for use with Google Earth) have increased the public's confidence in the NRD's knowledge of the ground water resources and have, to some extent, eased concerns about the regulatory actions taken in that area.

## CONCLUSIONS

Going forward, the LPSNRD plans to utilize its existing AEM data as well as that currently planned for future collection in several different ways. As already mentioned, the more detailed knowledge of subsurface geology provided by AEM makes siting of monitoring wells more efficient and reliable and will allow for more detailed estimates of aquifer volumes. This is vital in the LPSNRD as the complex glacial geology means that many aquifers are of limited extent and highly discontinuous. These limitations mean that ground water quantity as well as quality concerns (e.g. from nitrate-nitrogen contamination, a common issue in an agricultural state like Nebraska) are magnified. The District will utilize the AEM data to provide more reliable input to public water suppliers as well as individual well owners as to the availability and quality of ground water throughout its jurisdiction. In the event regulatory action is necessary, the AEM data will bolster the case for regulations involving ground water quantity or quality. In addition, current Nebraska law allows the State of Nebraska to work with individual Natural Resources Districts to evaluate the connection between surface and ground water, and to develop Integrated Management Plans (IMPs) to manage the connected resource. Thus, the LPSNRD will continue to utilize the AEM data to analyse and refine its understanding of the connection between its surface and ground water and then work with the State as well as other NRDs to manage its water resources.

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## REFERENCES

Carney, C. P., Pierce, K.S., Abraham, J.D., Steele, G.V., Genco, A.G., and Cannia, J.C., 2014, Hydrogeologic Assessment and Framework Development of the Aquifers beneath the Brainard-Valparaiso Area of the Lower Platte South Natural Resources District in Eastern Nebraska, Prepared for the Lower Platte South Natural Resources District by Exploration Resources International Geophysics LLC, Vicksburg, MS. http://www.lpsnrd.org/Programs/gwaem.htm (accessed on August 30, 2017).

Foged, N., Auken, E., Christiansen, A. V. and Sørensen, K., I., 2013, Test site calibration and validation of airborne and ground based TEM systems. Geophysics, 78, 95–106.

Lower Platte South Natural Resources District (LPSNRD), 1995. Ground water management plan - Lower Platte South NRD. (To obtain a copy of the entire Ground Water Management Plan, contact the NRD)

Sørensen, K., and Auken, E., 2004, SkyTEM - A new high-resolution helicopter transient electromagnetic system, Exploration Geophysics 35, 191–199.

Viezzoli, A., Christiansen, A.V., Auken, E., and Sørensen, K., 2008, Quasi-3D modeling of airborne TEM data by spatially constrained inversion, Geophysics, 73, 105-113.