Eastern Nebraska Water Resources Assessment

Three-dimensional Hydrostratigraphy of the Swedeburg, Nebraska Area: Results from Helicopter Electromagnetic (HEM) Mapping for the Eastern Nebraska Water Resources Assessment (ENWRA)

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Bulletin 5 (New Series)

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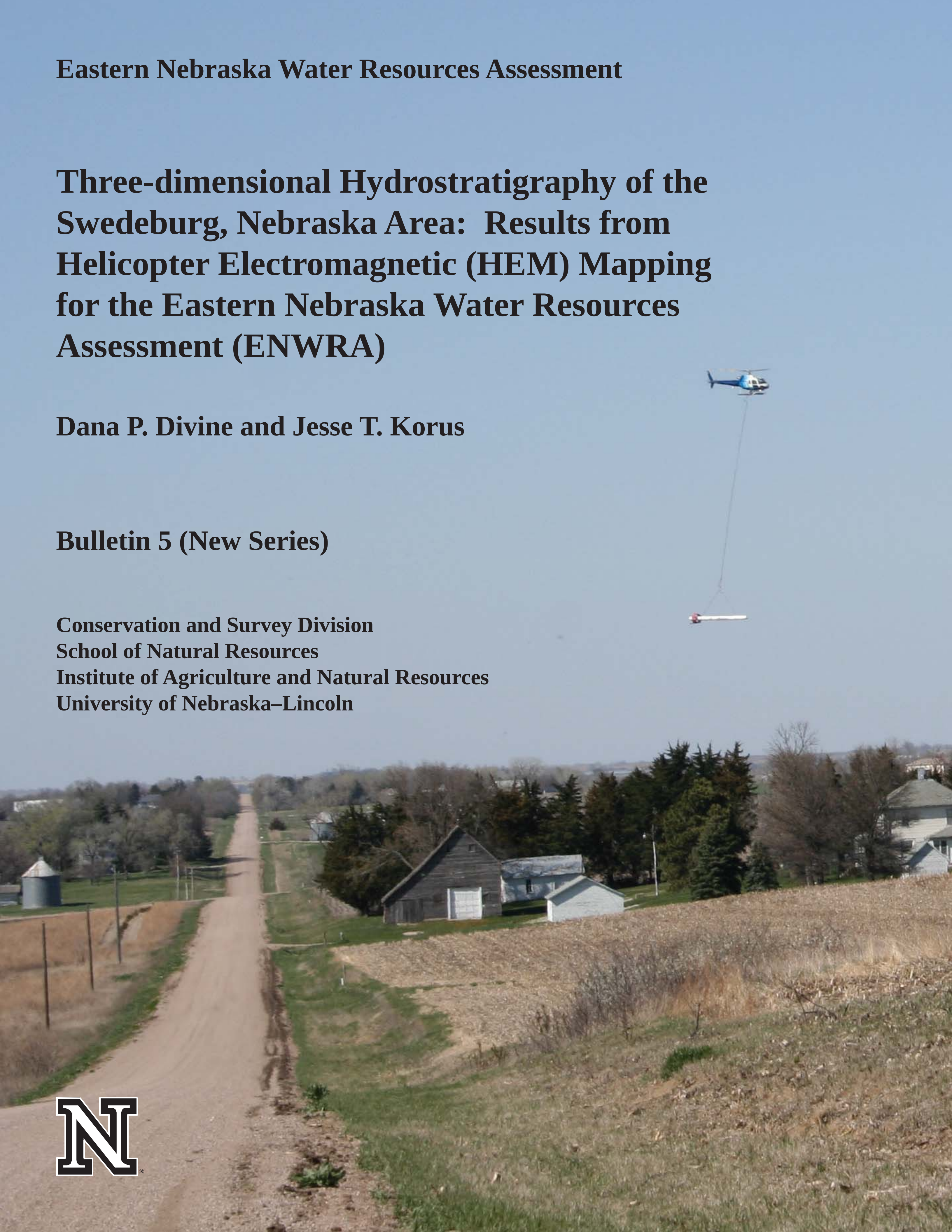

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Cover photo: Helicopter and geophysical equipment fly over farm buildings in the Swedeburg study area. Photograph by Gregory V. Steele, USGS.

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INTRODUCTION

Groundwater resources under much of eastern Nebraska are contained within or beneath Quaternary glacial deposits. The heterogeneity and complexity of these deposits have hindered efforts to characterize them in detail. Test-hole drilling alone is not effective for mapping these units over large regions, but in certain settings, borehole data can be integrated with geophysical methods to map hydrostratigraphic units at high resolution and in three-dimensions. This study integrates test hole drilling and Helicopter Electromagnetic (HEM) surveys to characterize the hydrostratigraphy of an area around Swedeburg in eastern Nebraska.

Helicopter Electromagnetic (HEM) surveys were flown in 2007 at three pilot study sites in eastern Nebraska as part of the ongoing Eastern Nebraska Water Resources Assessment (ENWRA), a collaborative study between six of Nebraska's Natural Resources Districts, the Conservation and Survey Division (CSD) of the School of Natural Resources at the University of Nebraska-Lincoln, the Nebraska Department of Natural Resources (DNR), and the United States Geological Survey (USGS). The rationale and history behind ENWRA are outlined in Divine et al. (2009). The purpose of the pilot studies was to assess the effectiveness of HEM at mapping the complex geology of Quaternary alluvial and glacial deposits. The pilot studies were conducted at three sites that together encompass the wide range of hydrogeologic settings in eastern Nebraska. The results of the pilot studies prompted resource managers to survey a 73 square-kilometer (28 square-mile) area around Swedeburg in Saunders County (Fig. 1). The results of the Swedeburg study are presented herein.

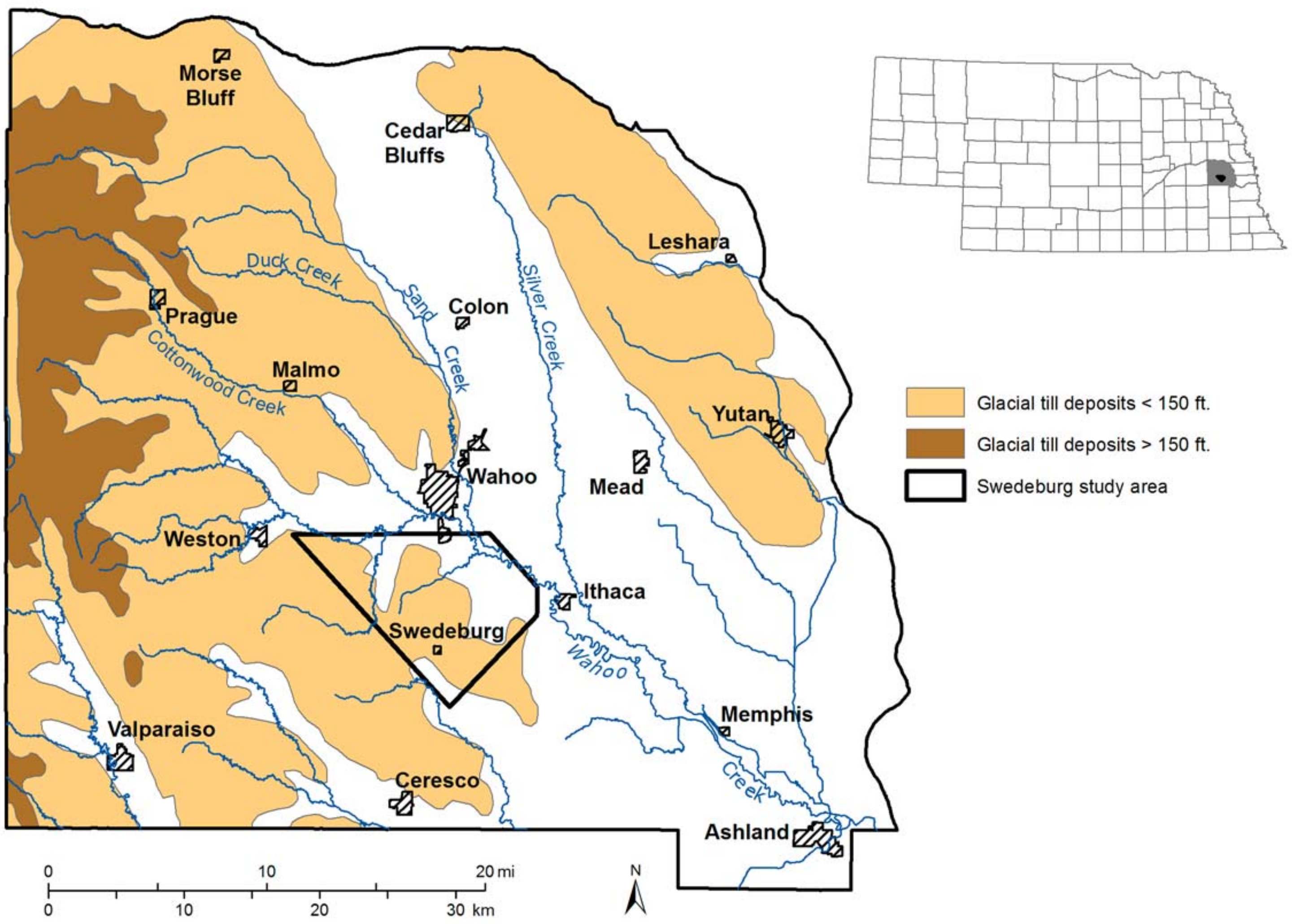


Figure 1. Location of the Swedeburg survey area in Saunders County, Nebraska. Glacial till mantles the uplands on the west side of the survey area. White areas consist of loess and/or alluvium over bedrock.

GEOLOGIC SETTING

The study area lies within the Dissected Till Plains, a physiographic area that includes eastern Nebraska and parts of Iowa, Kansas, Minnesota, Missouri, and South Dakota (USGS, 2003). Aquifers in this part of eastern Nebraska occur primarily within unconsolidated Quaternary deposits, though Lower Cretaceous Dakota Formation bedrock serves as an important secondary aquifer in the survey area.

Upland areas are underlain by a succession of unconsolidated sediments consisting of late Pleistocene loess (chiefly the Peoria Loess) underlain by one or more glacial tills of pre-Illinoisan age (Fig. 1). These glacial tills contain or are underlain by stratified sands and silts which serve as localized primary aquifers in the study area.

Bedrock beneath the unconsolidated Quaternary deposits in the Swedeburg area consists of the Cretaceous Dakota Formation and Pennsylvanian limestones and shales (Fig. 2). The Dakota Formation consists of mudstones and sandstones, the latter being secondary aquifers where Quaternary sands and gravels are thin or absent. Pennsylvanian bedrock units comprise a major regional aquitard.

AGE	SYSTEM			STRATIGRAPHIC UNIT	max. th. ft (m)	SIGNIFICANCE IN TERMS OF GROUNDWATER
0.01	Quaternary	Holocene		DeForest Formation	45 (14)	local alluvial-fill aquifers (minor)
0.02		Pleistocene		Peoria Loess		non-aquifer materials
0.04				Gilman Canyon Formation		
0.64				Loveland Loess		
				Pre-Illinoian tills with localized ribbon sands and larger sand bodies	238 (73)	sands are upper resistive unit and lower resistive unit where it appears above bedrock in this report; tills are aquitards
2.6	Neogene	Pliocene		?		
5.3	Cretaceous	Upper	Ceno-man-ian	Dakota Formation	>249 (76)	bedrock unit with widespread distribution under study area; a secondary aquifer in eastern Nebraska
99.6		Lower	Alb-ian			
>299.0	Pennsylvanian			undifferentiated		bedrock units functioning as aquitards under study area

major disconformity NB: maxiumum thicknesses (max. th.) are for Swedeburg study area only

Figure 2. Stratigraphy and groundwater characteristics for the study area. Thicknesses are calculated from Conservation and Survey Division test holes.

GROUNDWATER ISSUES

Both groundwater quantity and quality management issues exist in the Swedeburg area. The Quaternary sand and gravel deposits are typically limited in extent and overdevelopment may result if groundwater withdrawals exceed the aquifer yield. Estimating the aquifer yield, however, requires detailed information regarding an aquifer's extent, thickness, hydraulic conductivity, and recharge rate. These details have not been fully resolved in the study area. Furthermore, stream-aquifer connections, which can affect aquifer yield and integrated management of surface and groundwater, are currently not accurately understood at the local scale.

Groundwater quality issues involve agricultural contaminants and elevated total dissolved solids (TDS). TDS is typically higher in the Dakota Formation than in Quaternary aquifers, but the opposite situation exists in some areas. Given this complexity, it is difficult for resource managers to accurately address these issues. Details regarding aquifer thickness, extent, interconnectedness, and degree of confinement will allow managers to address both quality and quantity issues at a local level.

MATERIALS AND METHODS

A helicopter electromagnetic (HEM) survey was conducted over the study area in April and May, 2009. Detailed specifications of this survey are contained in Smith et al. (2011) and are briefly summarized here. The survey consisted of 30 southeast-northwest traverses with approximately 280 meter spacing, and four southwest-northeast tie lines with variable spacing, for a total of 307 line kilometers (190 miles) (Fig. 3). Apparent resistivity values were derived from electromagnetic field measurements at five separate frequencies. Apparent resistivities were later transformed into resistivity-depth values using inversion algorithms as described in Smith et al. (2011). Interference from power lines and other structures was monitored in the 60 hertz signal. Details regarding the methods used to interpret the combined test hole data and inverted HEM profiles are provided in Korus et al. (2013).

Eight test holes were drilled in 2010 and 2011 as a part of this study (Fig. 3). Cores were obtained from these test holes using a split spoon auger rig system. Augers were advanced until penetration was denied by the resistance of unconsolidated materials and mud rotary drilling was used at the same location to advance the test holes into bedrock. Downhole geophysical logs (gamma ray and resistivity) were recorded for the full depth of each borehole. Cores and cuttings were described in the field or laboratory by geologists and are archived at CSD. Additional geologic data used in this report was compiled from driller's logs contained in the Department of Natural Resources (DNR) registered wells database (NDNR, 2012) (Fig. 4) and unpublished test hole logs archived at CSD (Fig.3).

Photo by Gregory V. Steele, USGS.

Helicopter used to fly the HEM survey shown behind the cylindrical tube containing electromagnetic hardware.

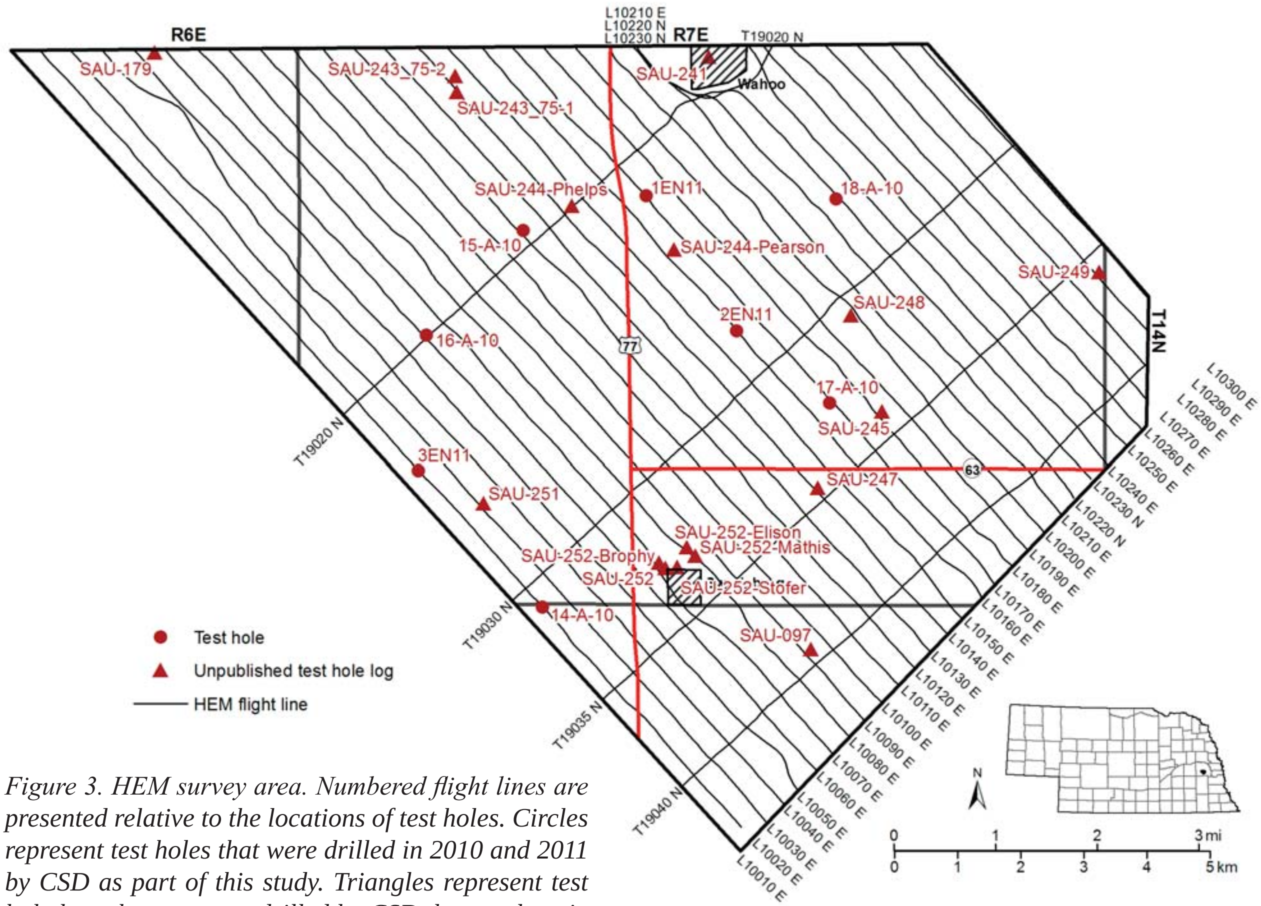


Figure 3. HEM survey area. Numbered flight lines are presented relative to the locations of test holes. Circles represent test holes that were drilled in 2010 and 2011 by CSD as part of this study. Triangles represent test hole logs that were not drilled by CSD, but are kept in archived files at CSD.

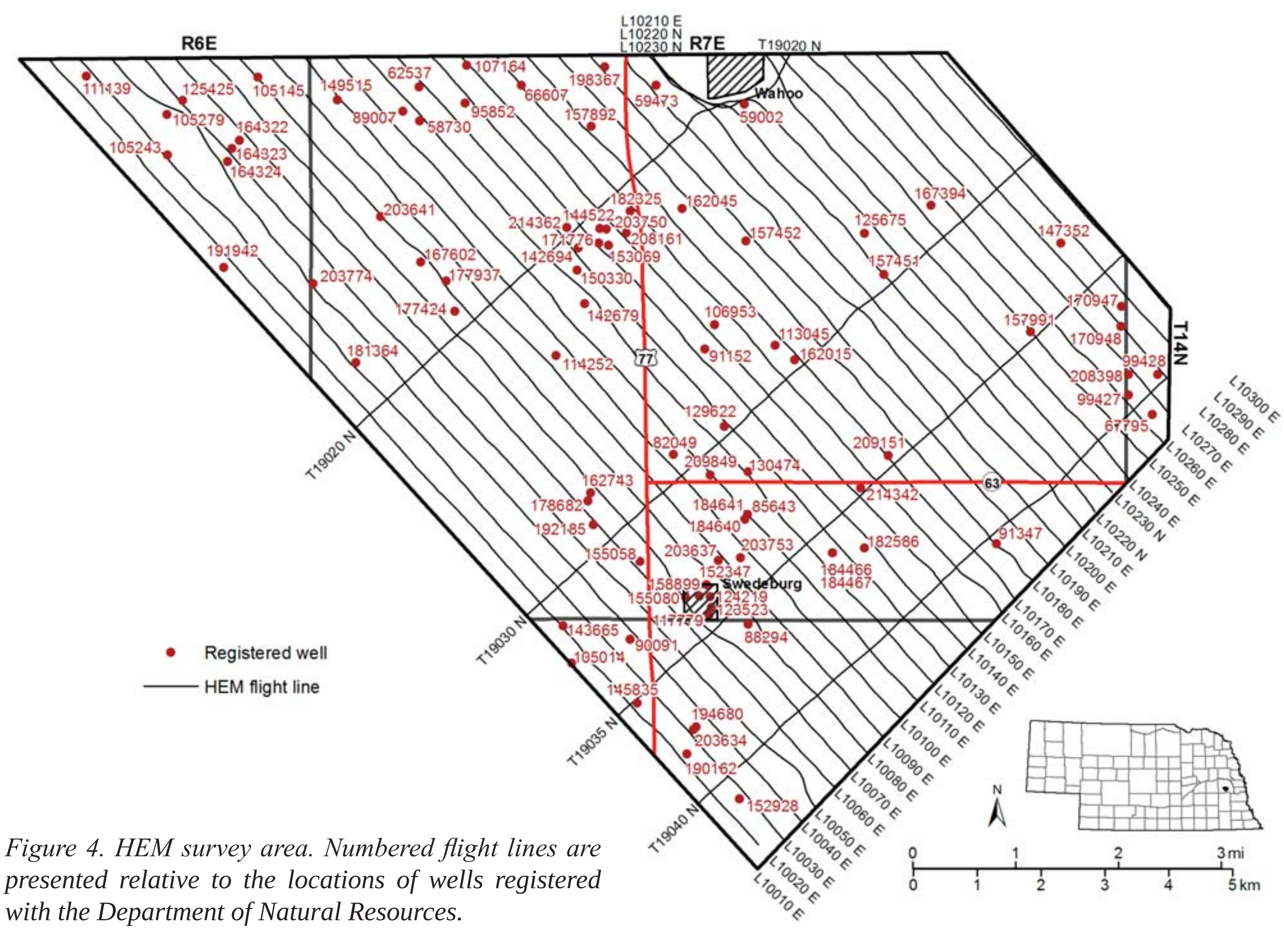


Figure 4. HEM survey area. Numbered flight lines are presented relative to the locations of wells registered with the Department of Natural Resources.

Test Holes and HEM profiles

Subsurface resistivity profiles were constructed by plotting resistivity-depth values from Smith et al. (2011) along flight lines using Encom PA, a commercially available software program (Fig. 5). The datum for each sounding point along the profile is the topographic surface derived from an USGS 10-m digital elevation model. Resistivities from 10 to 40 ohm-meters were mapped to a linear color scale ranging from dark blue to pink. Borehole logs within 100 to 300 meters (approximately 330 to 980 feet) of the flight line were superimposed on the resistivity-depth profile. Resistive lithologies such as sand and gravel are represented on the boreholes with orange and red, while conductive lithologies such as silt and clay are represented with green and blue. Anomalous HEM resistivities resulting from power lines and other infrastructure were recognized by high 60 Hz signals.

The top and bottom of a prominent resistive unit is defined with solid black lines and referred to in this report as the upper resistive unit. The upper resistive unit typically

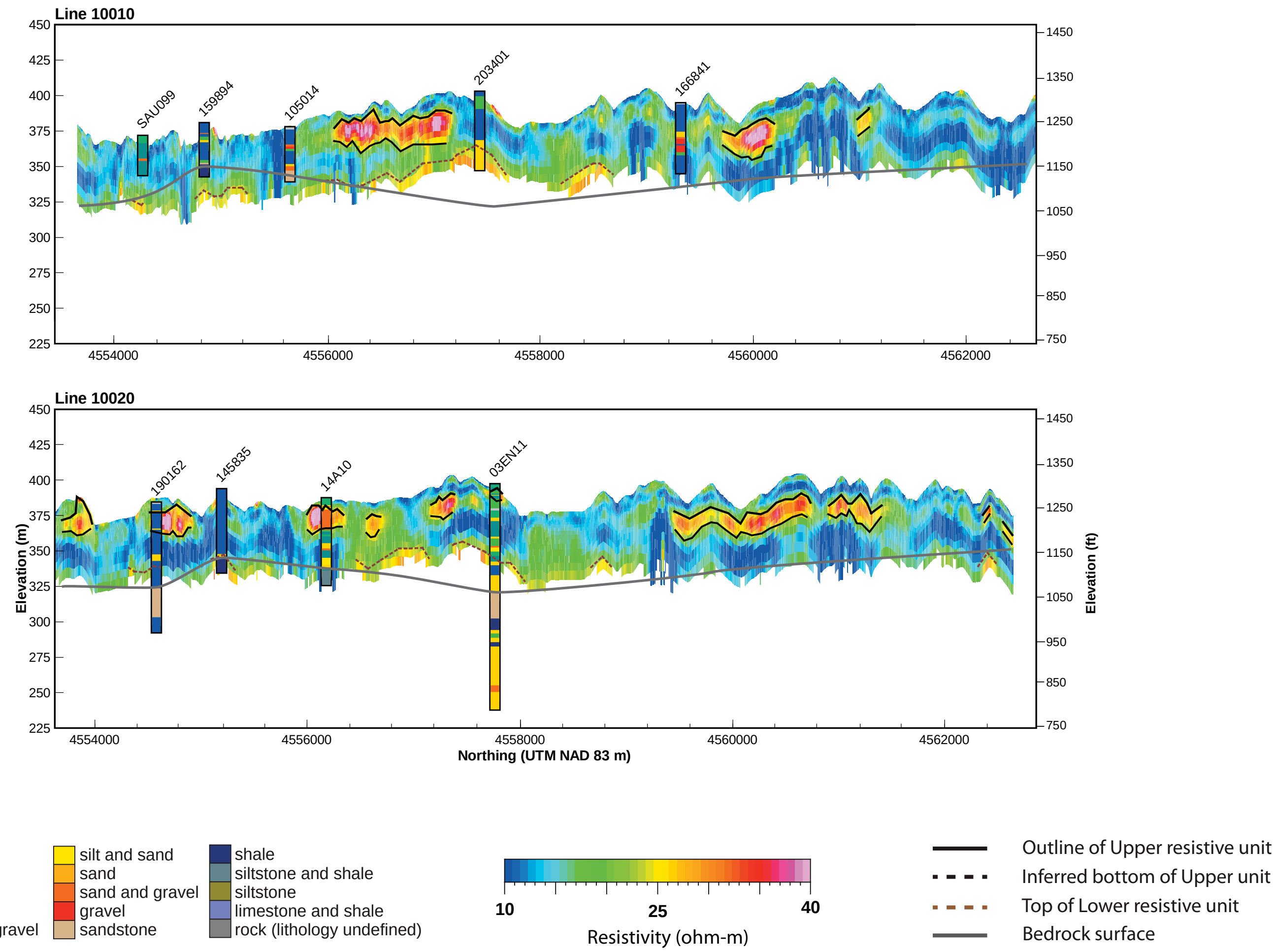
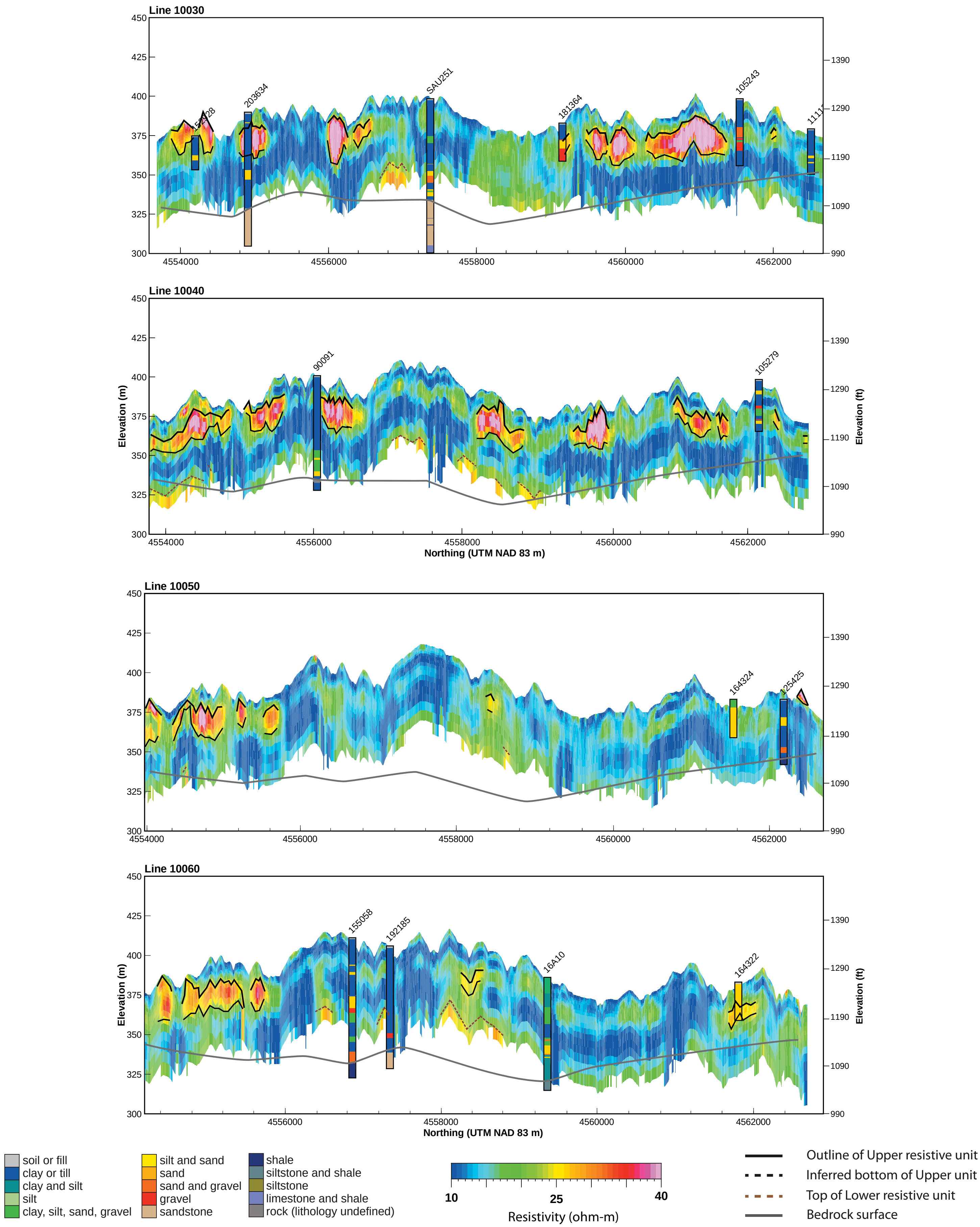


Figure 5. Inverted HEM resistivity profiles. Inverted HEM data from all of the flight lines are shown in profile. Lithologic logs of test holes are superimposed on the HEM profiles. Hydrostratigraphy was intentionally omitted from the last four profiles, which represent the tie lines.



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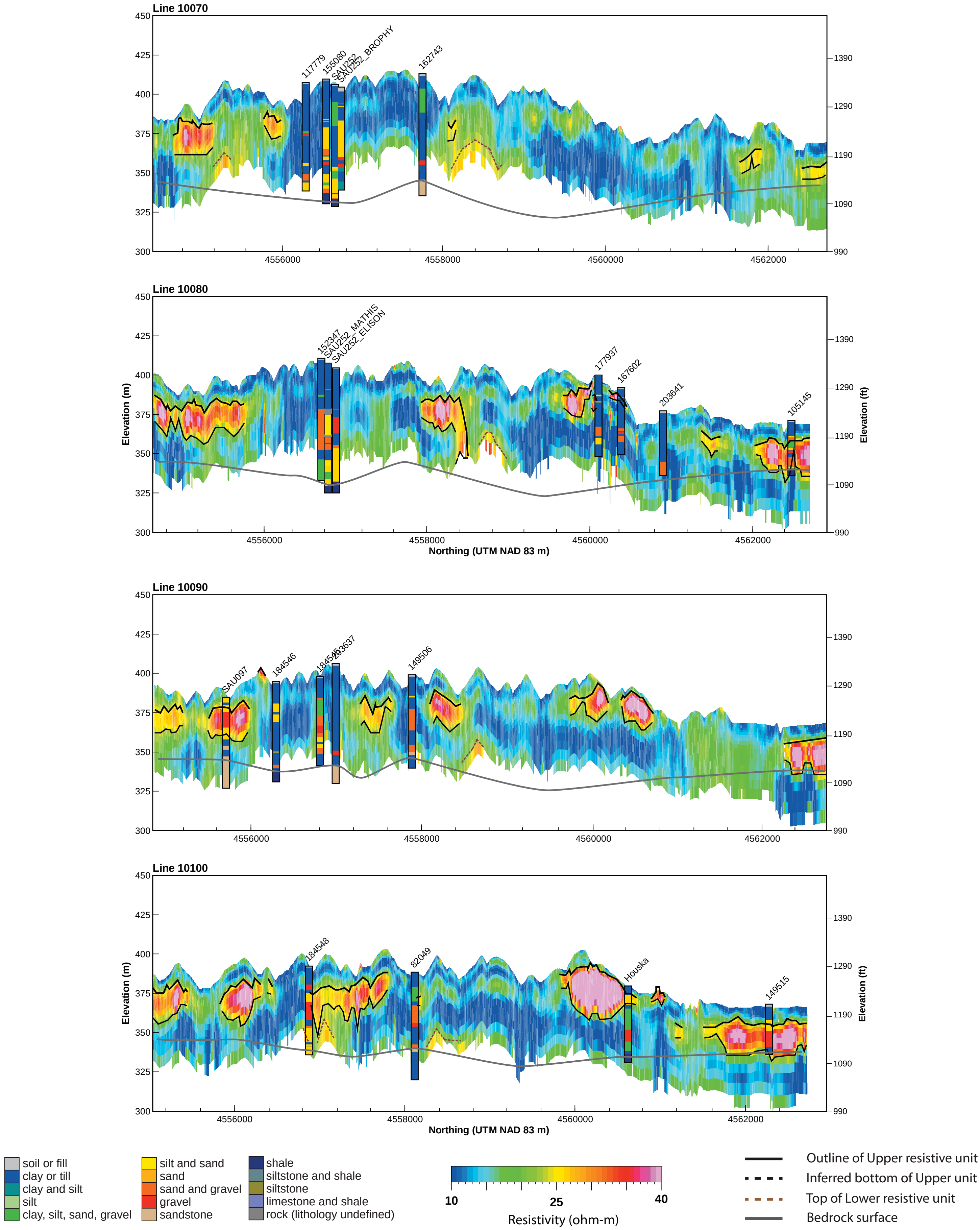

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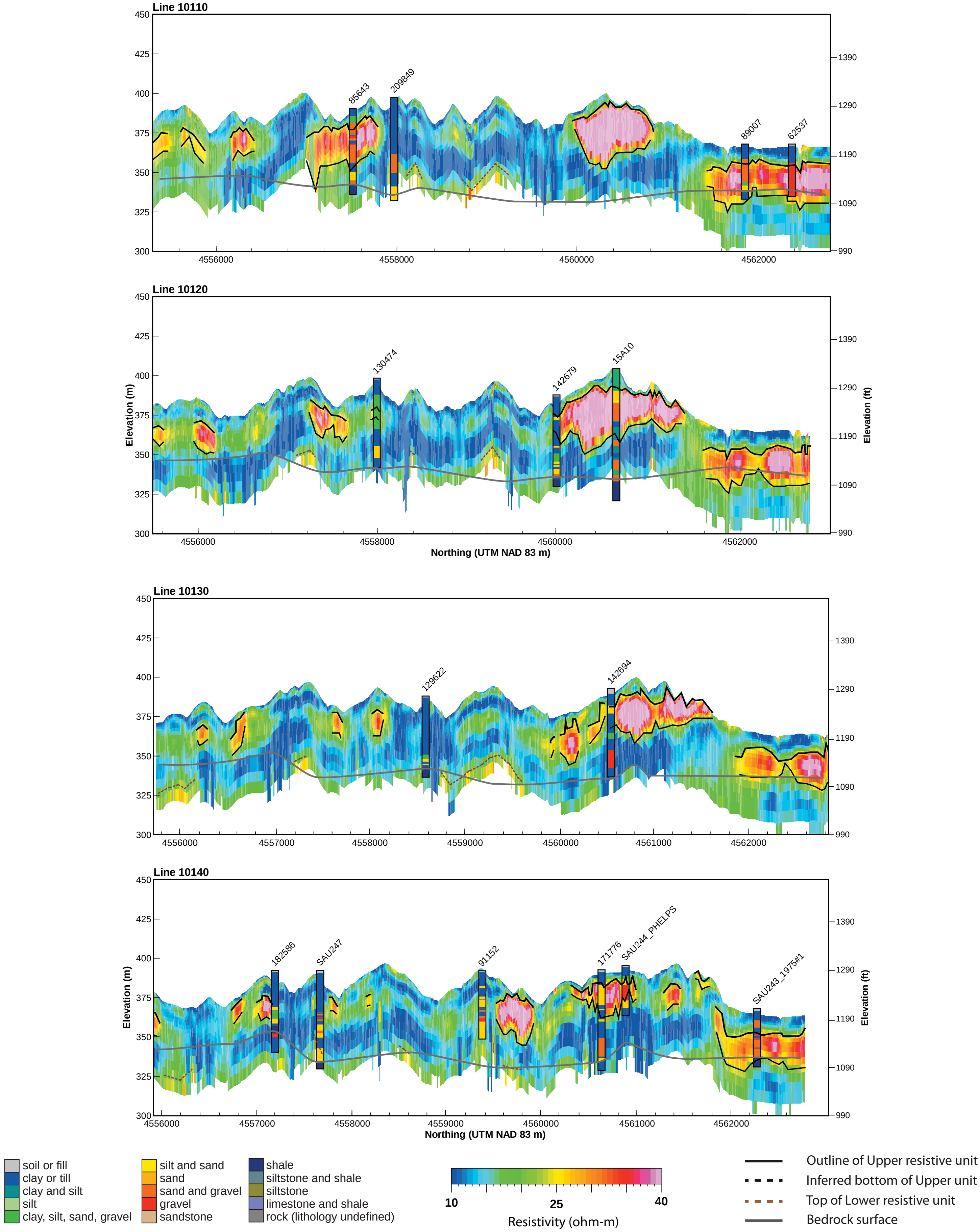

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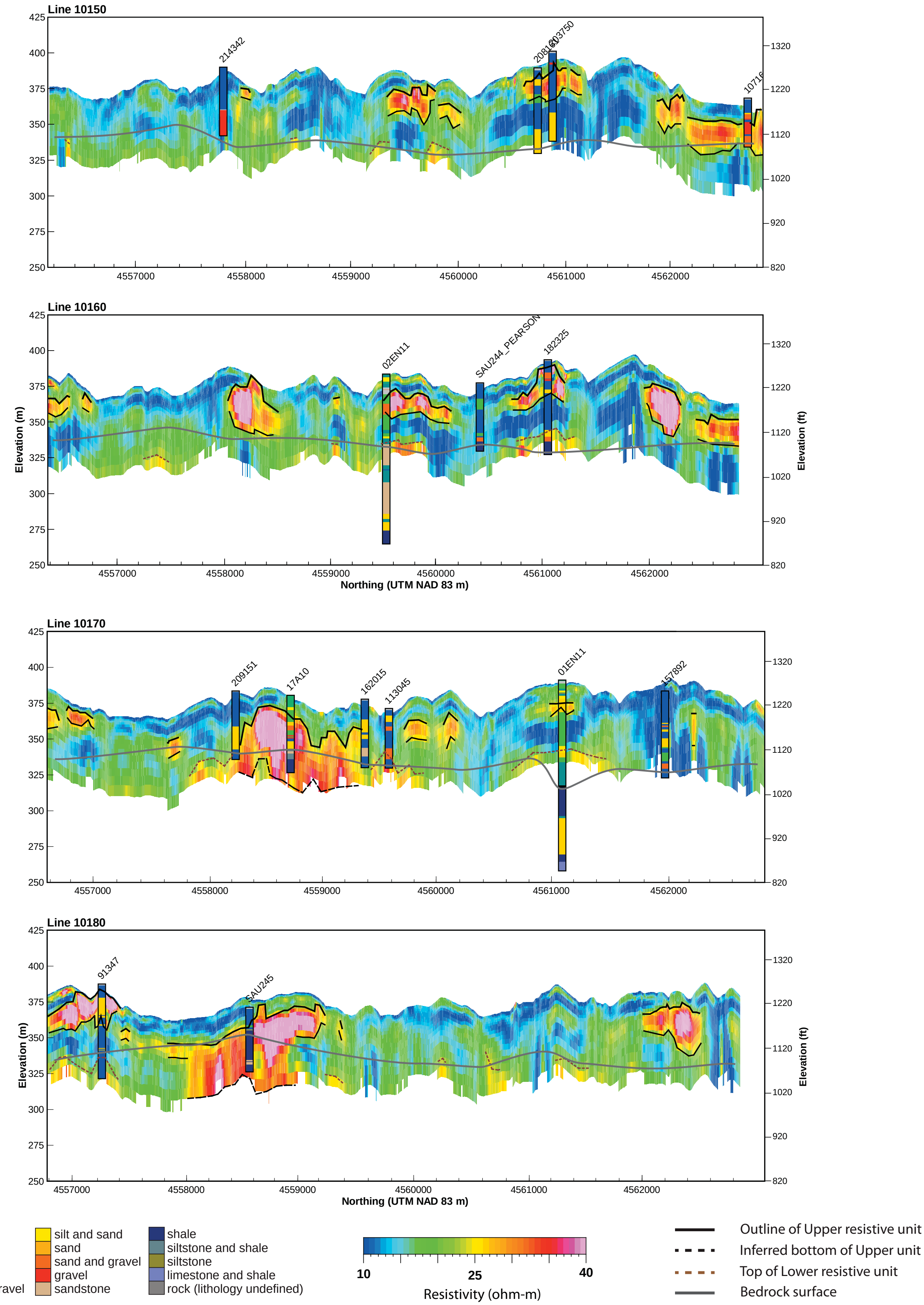

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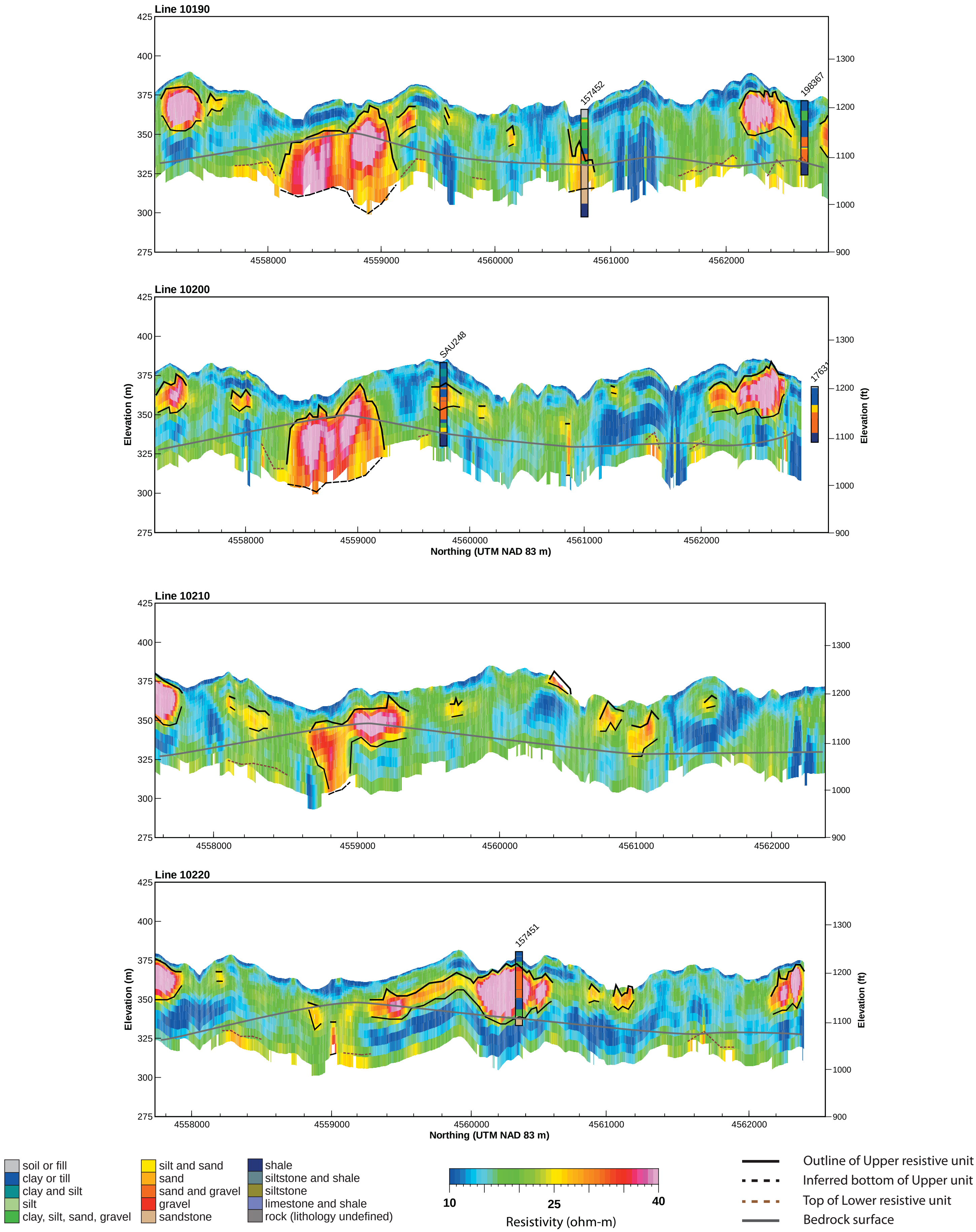

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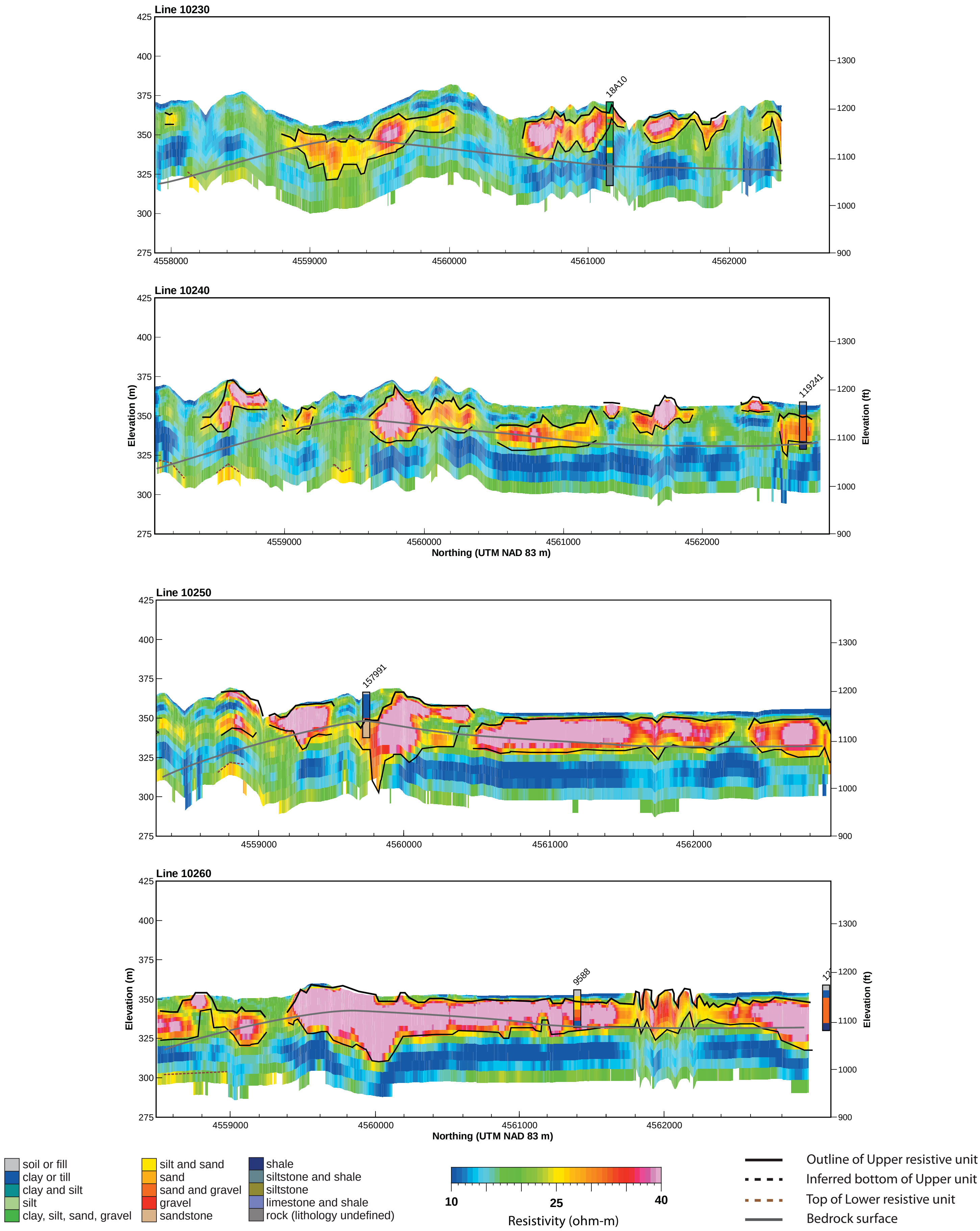

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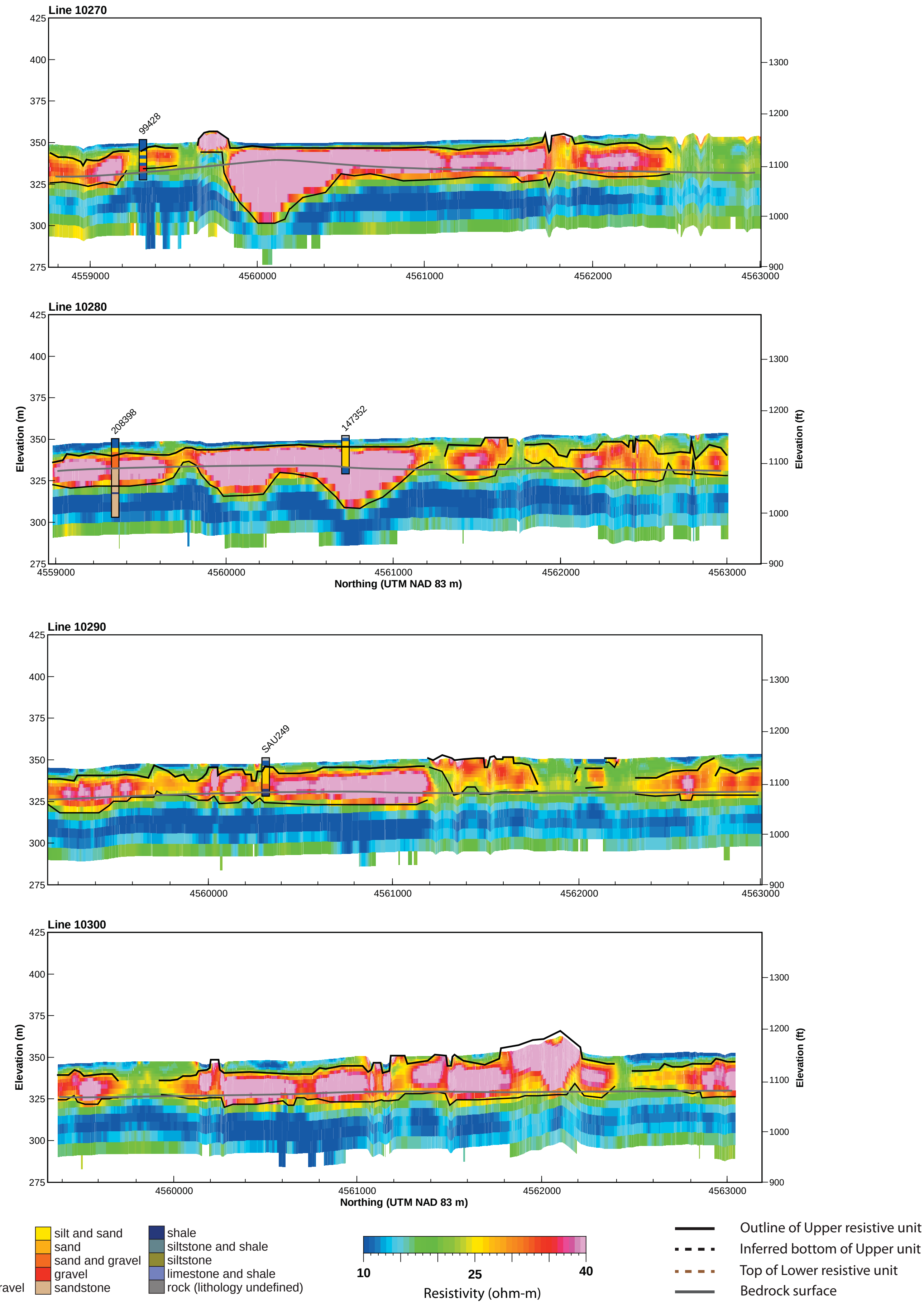

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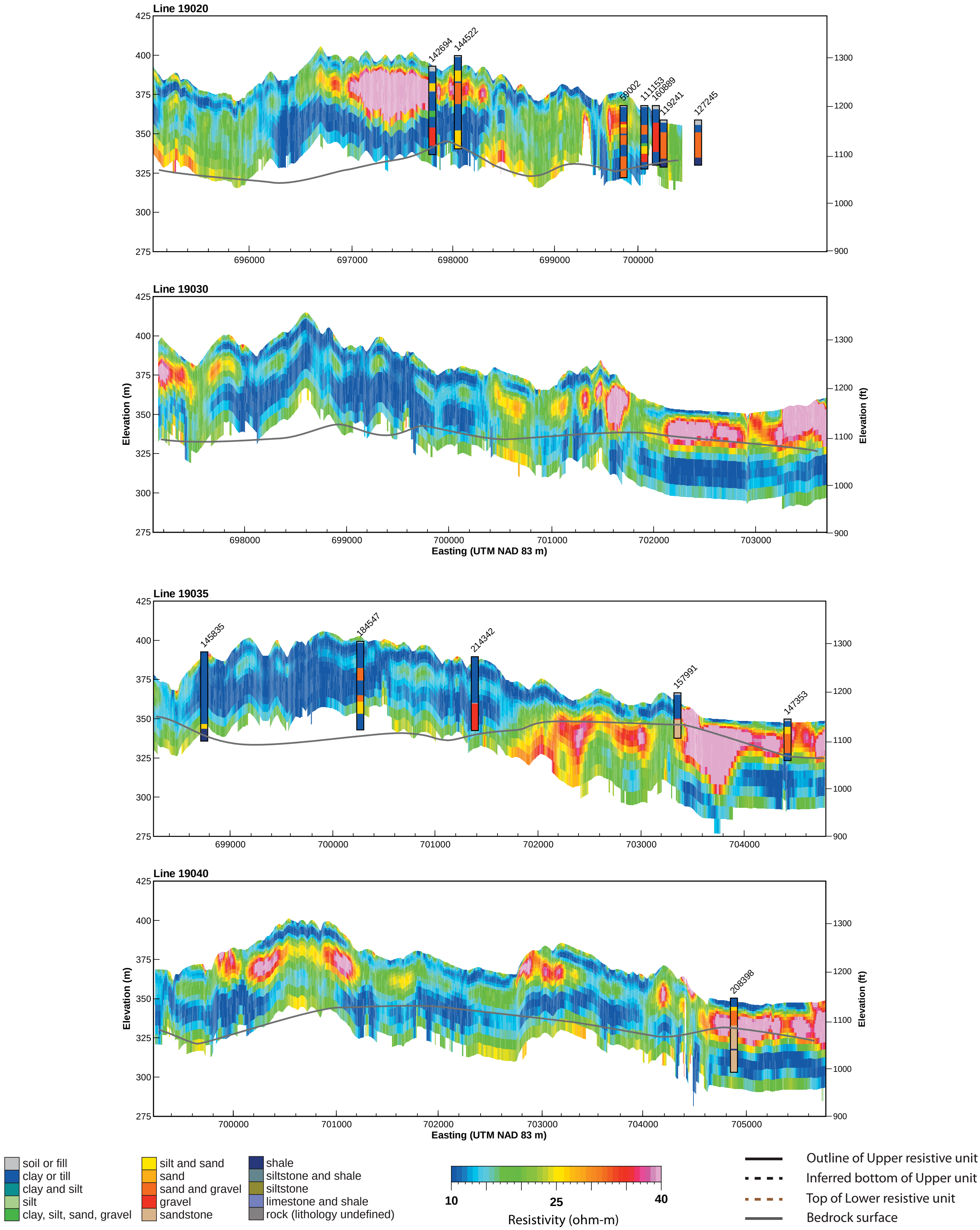

Figure 5 (continued). Inverted HEM resistivity profiles. Inverted HEM data from all of the flight lines are shown in profile. Lithologic logs of test holes are superimposed on the HEM profiles. Hydrostratigraphy was intentionally omitted from the last four profiles, which represent the tie lines.

consists of material having resistivity greater than 25 ohm-meters and appears on the HEM profiles as orange, red, and pink. The last four profiles in Figure 5 (profiles 19020 through 19040) are from SW-NE tie lines that run perpendicular to the other profiles (Fig. 3). Since there were only four tie lines, these profiles were not used to map the upper resistive unit because doing so could result in irregular contours around the SW-NE data.

In addition to the upper resistive unit, a somewhat less resistive (approximately 25 ohm-meters) unit exists at the very bottom of many of the profiles. The top of this unit was traced in a light brown dashed line. The base of this unit was not mapped by the HEM and no apparent pattern of its distribution emerged, so its full thickness and extent could not be determined.

Photo by Bruce D. Smith, USGS

Personnel discuss strategy before the HEM flight.

Depths less than 25 meters

Comparison of CSD test hole data to HEM resistivities show a generally good correlation between lithology and resistivity at depths less than 25 meters (80 feet) as thick sand units logged in test holes correspond to high resistivity units in HEM profiles. Examples of this correspondence can be seen in the following test holes shown on Figure 5: 14-A-10 on profile 10020; 15-A-10 on profile 10120; 02-EN-11 on profile 10160; and 01-EN-11 on profile 10170. Also as expected, thick units of predominantly silt, clay, or till at shallow depths in CSD test holes correspond to low resistivity units in HEM. Examples of this association can be seen in the following test holes shown on Figure 5: 03-EN-11 on profile 10020; and 16-A-10 on profile 10060.

The match between driller's logs and HEM resistivities at depths less than 25 meters (80 feet) is less consistent. Some driller's logs indicate sand over intervals of high HEM resistivity, as would be expected. Examples on Figure 5 include: 85643 on profile 10110; and 91347 on profile 10180. Other driller's logs do not indicate sand in intervals of high HEM resistivity (see for example 203634 on profile 10030). Furthermore, some driller's logs indicate thick sands within intervals of low resistivity (see for example 91152 on profile 10140).

The comparatively good match between lithology and resistivity in CSD test holes at shallow depths could be due to the fact that the test holes were intentionally drilled at locations directly underlying the HEM flight paths (Fig. 3). In addition, CSD test holes undergo much more rigorous quality control standards than do typical test holes for water wells. The lack of correspondence between lithology and resistivity in some driller's logs may be due to one or more factors, including: 1) the lack of quality control on the retrieval of cuttings, 2) inaccurate sample description, 3) inaccurate or incorrect location information, and 4) the difference in location between the borehole and the HEM flight line (Fig. 4).

We conclude, on the basis of CSD test holes and at depths generally less than 25 meters (80 feet), that high resistivity units indicate materials composing aquifers (where saturated) whereas thick low resistivity units indicate materials composing aquitards.

Depths greater than 25 meters

At depths greater than 25 meters (80 feet), the correspondence between lithology and HEM resistivity is poor for both CSD test holes and driller's logs. Around Swedeburg (T14N, R7E, Section 33), for example, numerous well logs clearly indicate thick sand units at depths from 25 to 75 meters (80 to 240 feet), but HEM profiles are clearly conductive in this area (Fig. 5, profiles 10070 and 10080). Similarly, in T14N, R7E section 26 and the eastern portion of section 27, lithologic logs from 209151, 17-A-10, and SAU-245, indicate clay, claystone, siltstone, and shale with interbedded layers of sandstone within a resistive unit (Fig. 5, profiles 10170 and 10180). Figure 5 shows many other examples of the poor match between lithology and resistivity at depths greater than 25 meters (80 feet).

Although high resistivity units exist at depths below 25 meters, these units may or may not be aquifer materials.

Groundwater Levels

A combined water table/potentiometric surface map (Fig. 6) was prepared for the study area using data from 154 wells located within two miles of the survey area. Data from nine of these wells were collected in the spring of 2009 when the HEM flights occurred. The other measurements were taken by drillers during well installations from 1991 to 2011. Water levels measured during the irrigation season (June through September) were discarded. One stream surface elevation from a topographic map was used to constrain the water table elevation in Wahoo Creek valley.

Numerous water-bearing units, each of which may have a different hydraulic head value, occur in the survey area. Many of the wells from which water levels were obtained contain a gravel pack that extends from the surface seal to the bottom of the well. This type of construction results in a connection between any water bearing units though which the well was drilled. The water levels in such wells are a composite of the hydraulic heads in each saturated unit. Saturated thickness estimates, which are based on the water level data, are therefore limited by the quality of the data.

The water table/potentiometric surface contours on Figure 6 indicate that groundwater generally flows southwest to northeast, though a groundwater high appears to exist immediately north of Swedeburg. Locally, groundwater flows away from this high. A relatively steep groundwater gradient (approximately 0.009) appears to exist between the ground water high and Wahoo Creek valley.

Hydrostratigraphy

The hydrostratigraphic interpretation of the Swedeburg area is depth-restricted due to the limitations of HEM resolution at depths greater than 25 meters (80 feet), as discussed above. Even though the inverted HEM profiles of the Swedeburg area show approximately the top 60 meters (approximately 200 feet) of the subsurface, direct correlation between HEM resistivity and lithology is not accurate for this entire thickness. Furthermore, there are some areas on the seven western-most flight lines where the top of bedrock is below the depth of the inverted HEM profiles. The bedrock surface, therefore, is interpreted entirely from borehole data.

Bedrock

The bedrock surface depicted by a dark gray line on the HEM profiles (Fig. 5) was defined entirely by borehole data. HEM data was not used to define the bedrock surface for a variety

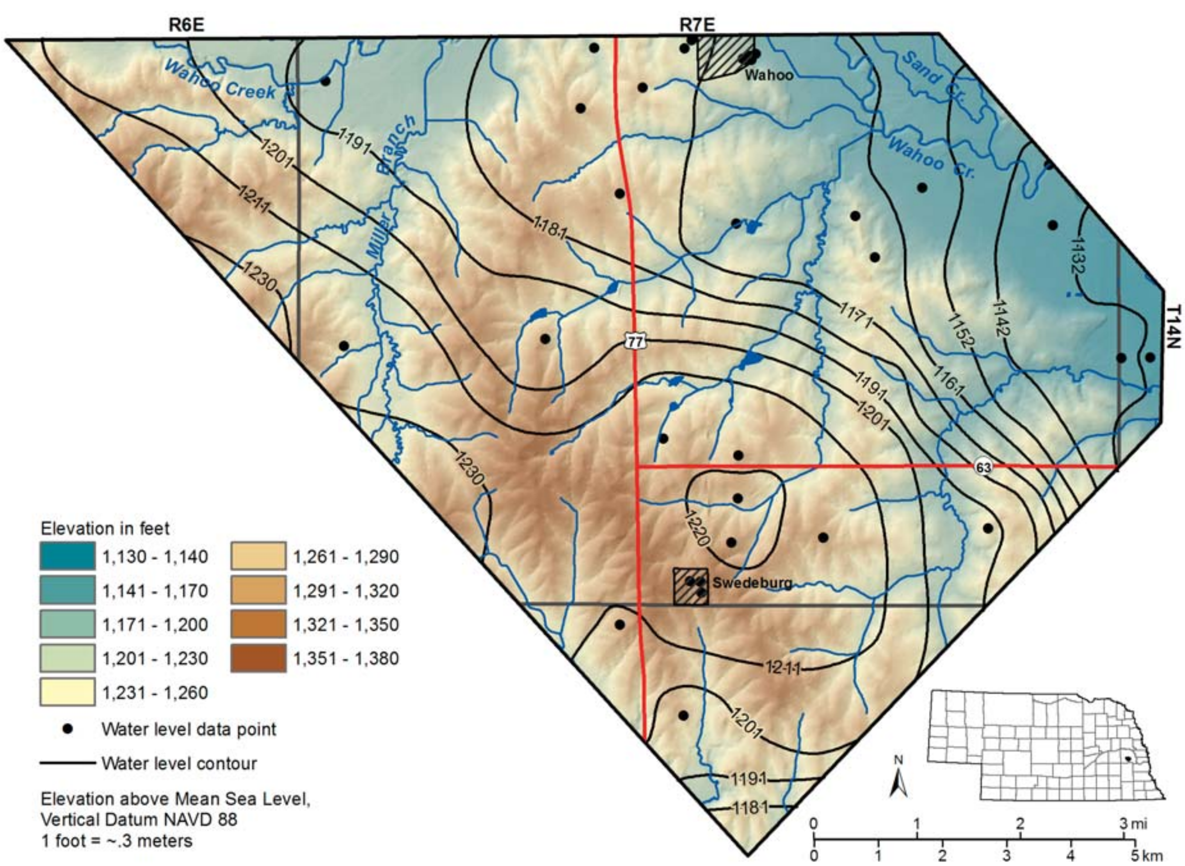

Figure 6. Generalized water table/potentiometric surface. These contours are based primarily on depth to water measurements made by drillers once for each well sometime between 1991 and 2011. Wells are represented as black dots. Screen intervals and gravel packs in these wells may cross multiple lithologic units. Contour intervals were converted from meters to feet resulting in odd numbered intervals.

of reasons, the foremost being that the lithology of the uppermost bedrock unit in the study area (Lower Cretaceous Dakota Formation) varies greatly and may be either mudrock or sandstone in the study area (Burchett and Summerside, 1998). Where saturated by fresh water, mudrock is electrically conductive and sandstone is electrically resistive, so the same bedrock surface could appear as a range of colors on the HEM profiles. Secondly, the natural water quality in the Dakota Formation varies. Total Dissolved Solids in the Dakota Formation of southeastern Nebraska can vary between 380 and 12,500 parts per million (ppm) (Gosselin et al., 2003). Saline water has been reported in some wells in the survey area. Since dissolved solids conduct electricity, non-uniform groundwater chemistry in the Dakota Formation can also result in a range of colors on the HEM profiles even when lithology is consistent.

Figure 7 shows the estimated bedrock surface for the survey area. The elevation varies from a low of approximately 311 meters (1020 feet) to a high of approximately 353 meters (1158 feet) and has approximately 42 meters (138 feet) of relief. There are no definite patterns in the bedrock surface, though bedrock highs occur in T14N, R7E, sections 26 and 34/35.

Upper resistive unit

The upper resistive unit is identified on the basis of high resistivity values (generally greater than 25 ohm-meters) and is identifiable in all of the HEM profiles. It consists of a series of linear ribbons and isolated lenses with no preferred orientation. There is no readily apparent pattern to the distribution of these units. The top elevation ranges from a low of 337 meters (1106 feet) to a high of 392 meters (1286 feet) and has approximately 55 meters (180 feet) of relief (Fig. 8). The top of the upper resistive material is generally highest in T14N, R7E section 20 between Miller Branch Creek and the tributary to Wahoo Creek and lowest in T14N,R7E section 26 and on the east side of the study area in the Wahoo Creek valley.

The bottom of the upper resistive unit is identifiable in most of the HEM profiles, though it was estimated in five profiles because the bottom of the unit appeared to extend beyond the depth of the HEM (Fig. 9, Section 26). At this location, the resistive unit extends well below the bedrock surface even though nearby test holes indicate predominantly mudrock at this depth (Fig. 5, profiles 10170 and 10180). The bottom elevation ranges from a low of approximately 306.5 meters (1006 feet) to a high of 384.5 meters (1261 feet) for a total

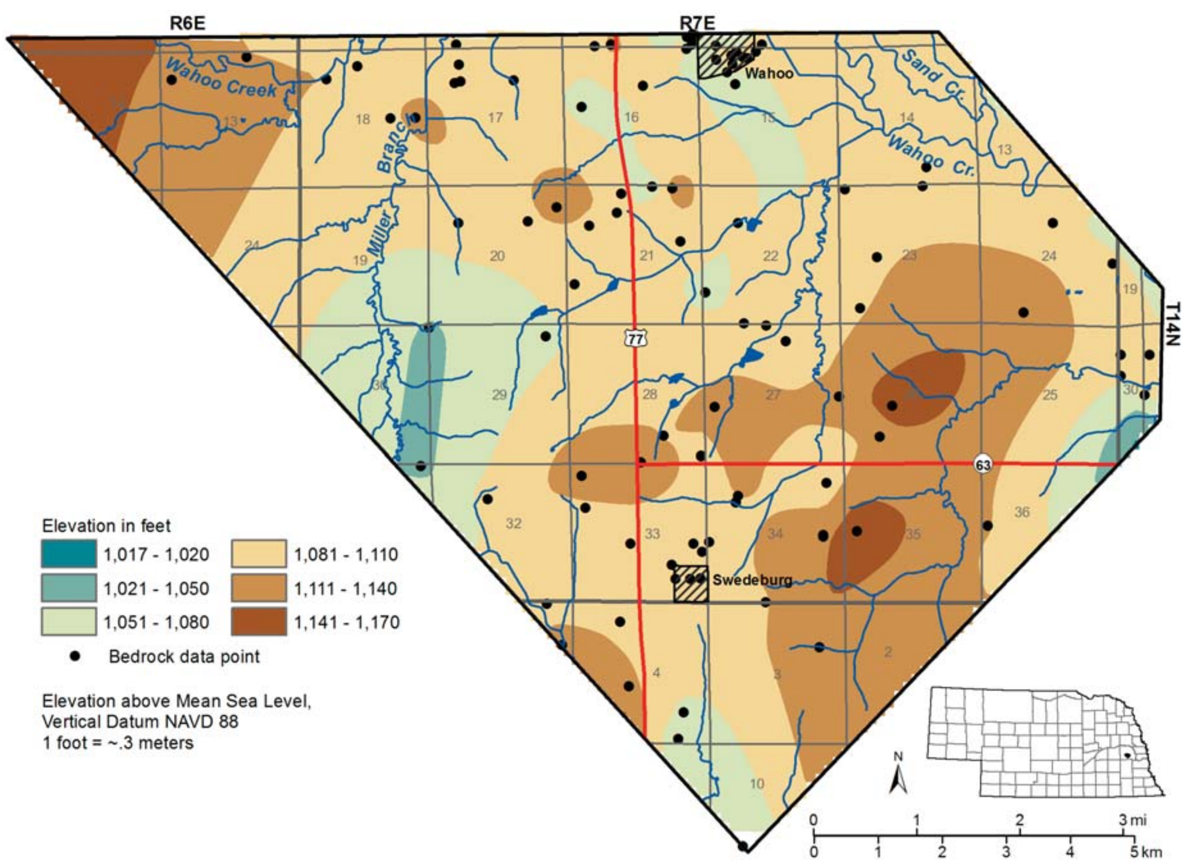

Figure 7. Elevation of the bedrock surface. This surface is interpolated based on lithologic data from test holes and registered wells represented as black dots. Relatively low bedrock elevation is shown in blue and relatively high bedrock elevation in brown.

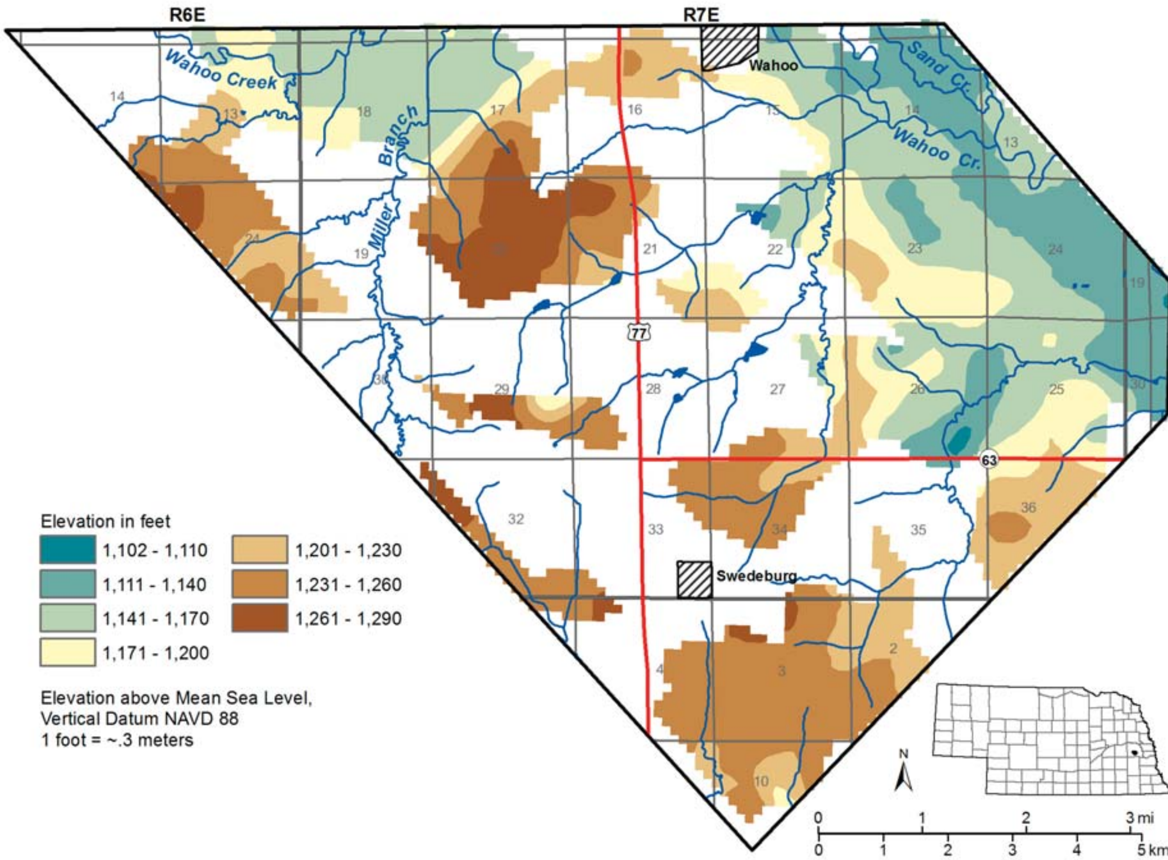

Figure 8. Elevation of the top of the upper resistive unit. Relatively low elevations are shown in blue, relatively high elevations shown in brown. The aquifer material is absent in portions of the survey area shown in white.

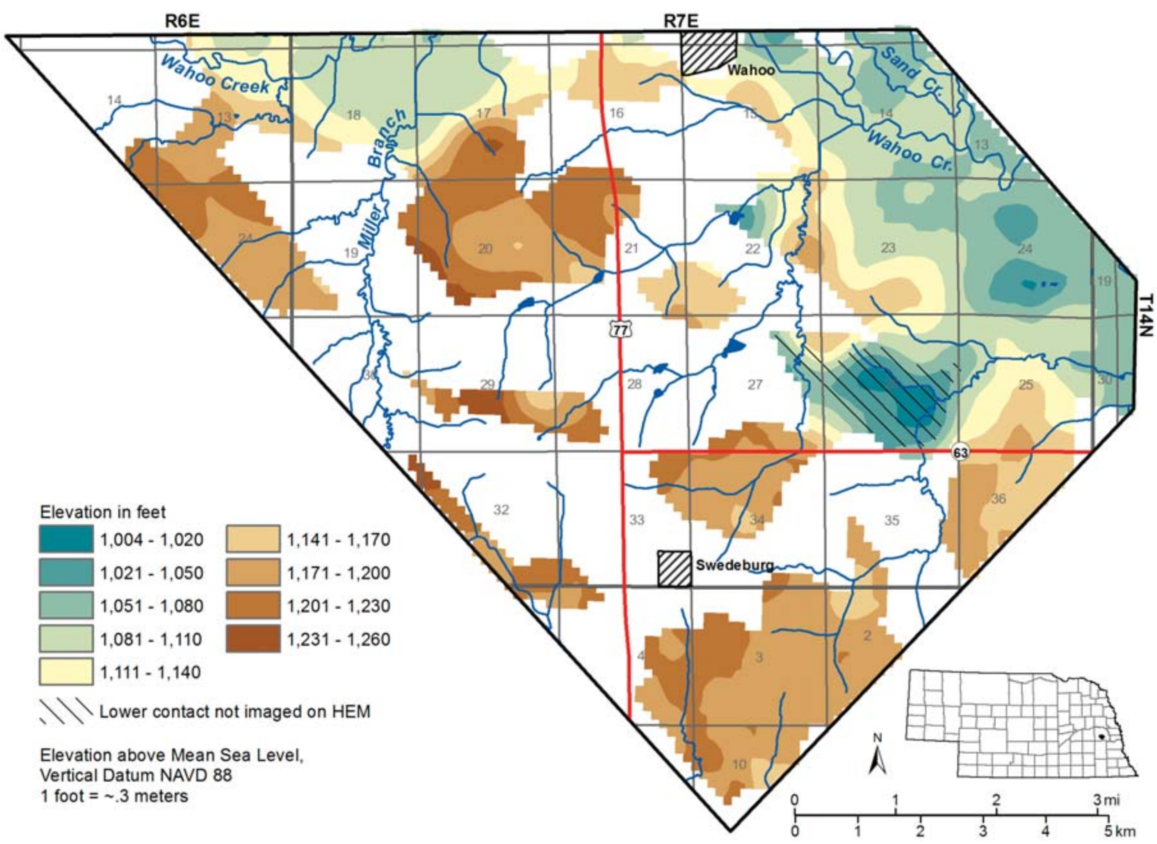

Figure 9. Elevation of the bottom of the upper resistive unit. Relatively low elevations are shown in blue, relatively high elevations shown in brown. The aquifer material is absent in portions of the survey area shown in white.

relief of approximately 78 meters (256 feet). The bottom of the upper resistive material generally follows the same pattern as the upper surface in that a high occurs between Miller Branch Creek and the tributary to Wahoo Creek and the low points occur in T14N,R7E section 26 and in the east side of the study area in the Wahoo Creek valley.

The thickest part of the upper resistive material occurs in the eastern portion of the study area where the bottom of the unit is inferred (mostly in T14N, R7E, S26), although there are a few comparably thick spots T14N, 7E, section 24 and T14N, 7E, section 20 (Fig. 10). Much of the thickness in section 24 is below the estimated bedrock surface and the lithology is unknown because no test holes penetrate the entire thickness in this area. In section 20, however, the entire thickness of the resistive unit is above bedrock.

The thickness of the upper resistive material varies from zero to 53 meters (0 to 175 feet). Saturated thickness also varies between zero and 53 meters because the thickest portion of the unit in T14N, R7E section 26 is completely saturated. We infer on the basis of lithologic logs in this area that the aquifer in section 26 may be overestimated or of low hydraulic conductivity. The pattern of saturated thickness (Fig. 11) does not match the pattern of overall thickness because much of the upper resistive unit is unsaturated. Perhaps most notable is the thick resistive body in T14N, R7E, section 20 (Fig. 10), which does not appear in Figure 11 because most of the unit has 3 meters (10 feet) or less saturated thickness.

In all the profiles northeastward from profile 10170, borehole logs and the interpolated bedrock surface indicate that the upper resistive unit is partially comprised of Dakota Formation. West of profile 10170, however, the upper resistive unit consists almost entirely of unconsolidated Quaternary material. This stratigraphic overlap in the upper resistive unit occurs at least partially because the glacial deposits in the Wahoo Creek valley are thin and the bedrock surface is shallow enough to be imaged by HEM. It is therefore important to note that the upper resistive unit as it appears on Figs. 8 through 11 is an amalgam of unconsolidated Quaternary glacial deposits and consolidated Dakota Formation bedrock.

Resolution of Deep Aquifers with HEM

Swedeburg

The HEM survey did not image two relatively deeply buried sand units used as aquifers in the study area. One of these units is under the town of Swedeburg. Flight lines 10070 and 10080 bound Swedeburg on the west and east side, respectively. The three boreholes on the left (south) side of each of these profiles were drilled in the Swedeburg area (Fig. 5). The wells are generally screened in the interval between 200 and 235 feet below ground surface, which is beyond the bottom boundary of the HEM profiles. The lithologic descriptions on the well logs vary widely between adjacent boreholes, and the geometry of the unit is not clear. The conflicting lithologic descriptions suggest that either the geology is complex or the lithology was not accurately described. Additionally, the vertical resolution of HEM decreases from 1 meter (3 feet) to 15 meters (50 feet) as depth increases (Smith et al., 2011) and it is likely that some of the lithologic units are thinner than the vertical resolution of the HEM at this site. Elevated salinity, which can make a sand unit appear blue on the HEM, likely does not occur at this location given that total soluble salts were measured at 461 parts per million (ppm) in SAU252 in 1988.

The hydrostratigraphy changes considerably a short distance north and east of Swedeburg. Saturated portions of the upper resistive unit occur in T14N, R7E, section 34 (Fig. 11). The HEM profiles are helpful in visualizing the heterogeneity of the upper resistive unit in this area. On profile 10090 (Fig.5), registered domestic well 203637 installed in the residential development east of Swedeburg confirms the absence of the upper resistive unit at that location. One profile east (10100), however, the upper resistive unit is present, and two profiles east (10110) the unit is approximately 80 feet thick in registered irrigation well 85643. The total depth of this irrigation well extends below the upper resistive unit, and it is possible that some of the yield comes from a deeper sand unit (screen and gravel pack information is unavailable).

Township 14, Range 7E, Section 21

The other deep aquifer not imaged by HEM is in T14N, R7E, sections 20 and 21. The wells drawing water from this aquifer are primarily associated with a small residential development in the northwest quarter of section 21. These wells appear on profiles 10100 through 10150 between northing coordinates 4560000 and 4561000 meters (Fig. 5). Borehole logs indicate that lithology is more consistent than the Swedeburg area, with the top of the deep aquifer unit occurring on average about 43 meters (140 feet) below ground surface, immediately above the Dakota bedrock surface. The average thickness of the unit is approximately 11 meters (37 feet). The probable reason for this unit not being imaged on the HEM profiles is lack of resolution at depth.

Resolution of Saline Aquifers with HEM

High total dissolved solids concentrations in the Dakota Formation can increase the conductivity of sand and

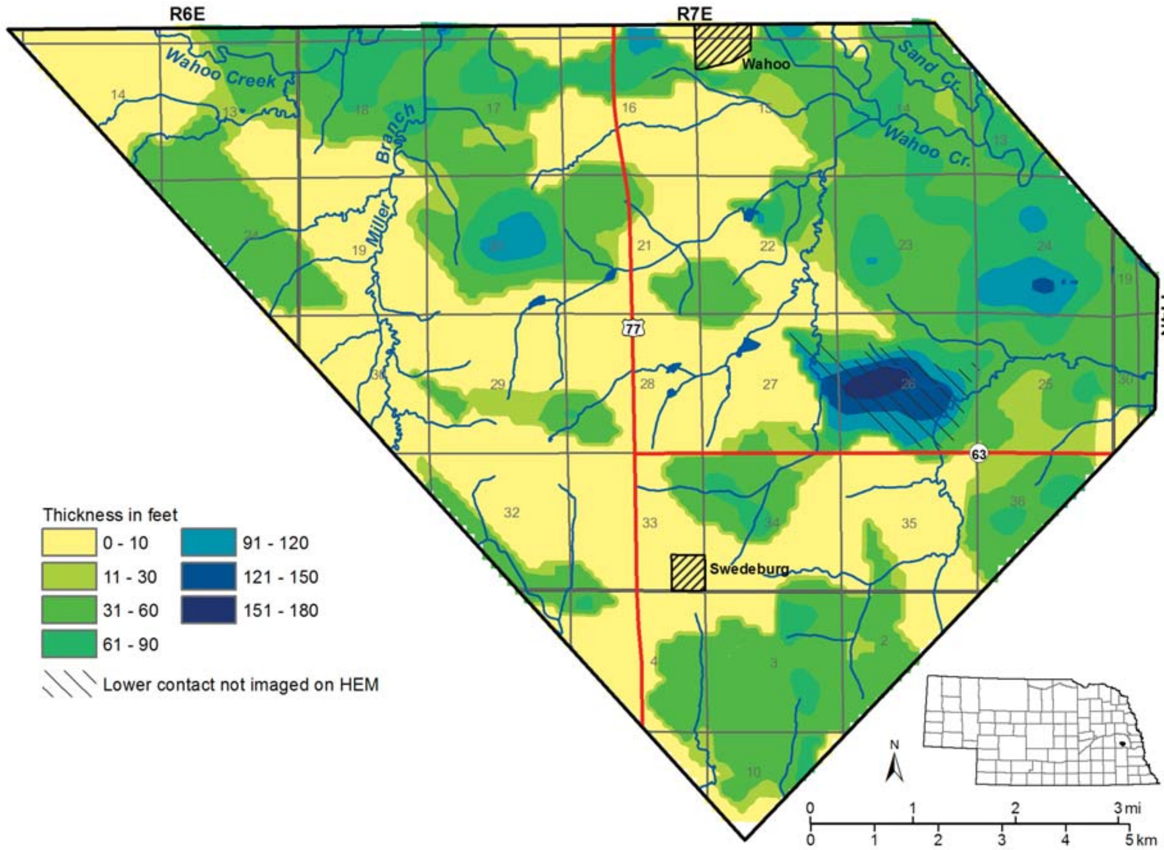

Figure 10. Thickness of the upper resistive unit. This map depicts the difference in elevation between the top and bottom surfaces of the lower aquifer material. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.

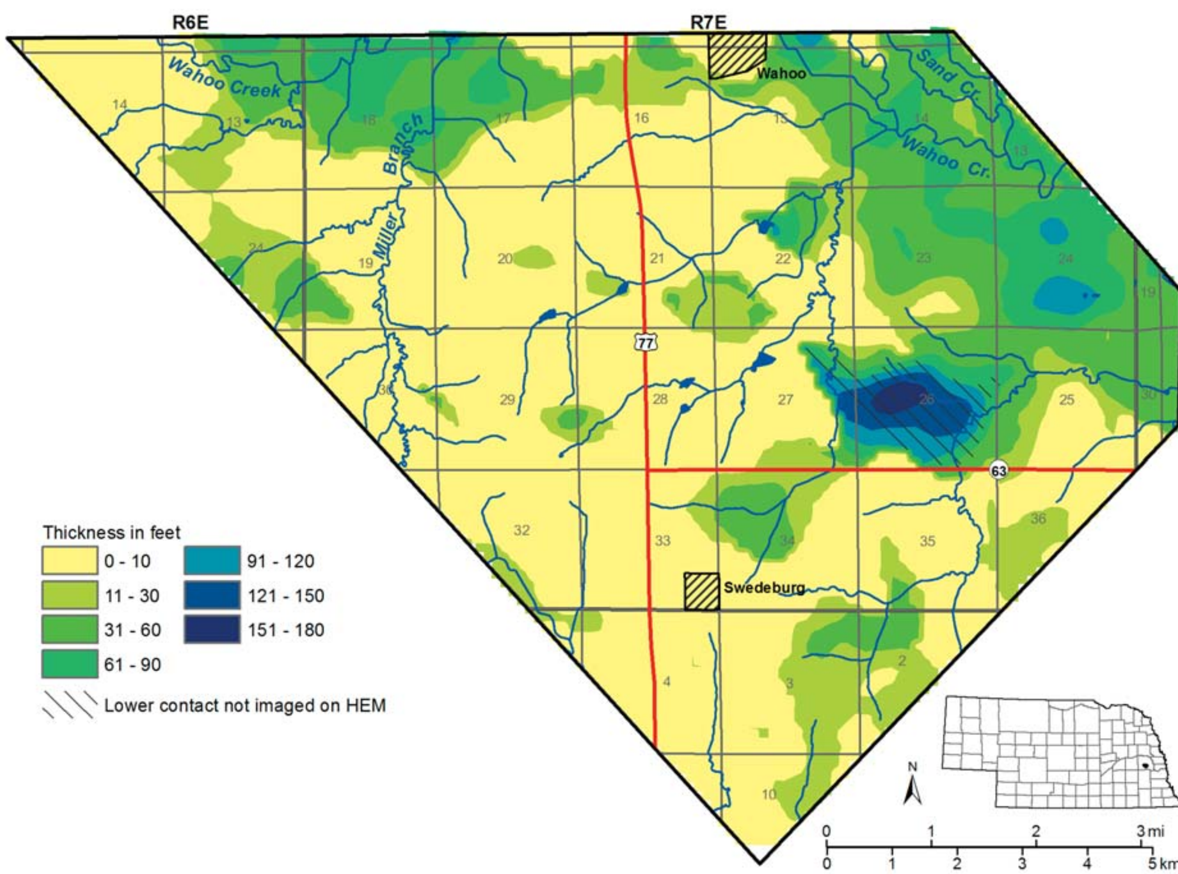

Figure 11. Saturated thickness of upper resistive unit. This map incorporates the water table/potentiometric surface map with the thickness of the upper resistive unit map to illustrate the saturated thickness of the upper resistive unit. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.

gravel units and make them appear blue on the HEM profile when it would normally appear red or pink if it was unsaturated or saturated with fresh water. Elevated salinity does appear on some of the HEM profiles in the survey area. The most notable locations being on profile 10090 about one mile southeast of Swedeburg and on the eastern six profiles of the survey area (Fig. 5). Identifying salinity on the HEM profiles is only possible if a borehole or well exists in a saline area and a water quality sample was collected. The two areas noted above were identified based only on a few boreholes.

The saline area on profile 10090 was identified using borehole SAU097 (an unpublished log in CSD archives). The lithology of this borehole is sandstone from 37.2 to 53.3 meters below ground surface (122 to 175 feet). The HEM profile is blue, indicating relatively high conductivity, which could be interpreted as a saline aquifer. This interpretation is supported by a note on the borehole log that reads: salty 1,650-1,750 ppm.

Photo by Bruce D. Smith, USGS

The electromagnetic hardware is encased in a cylindrical tube also called a "bird".

The interpretation of saline groundwater in the eastern portion of the survey area is based partly on registered well 208398 (Fig. 5, profile 10280). The lithology for this well log indicates sandstone, though the HEM profile shows a laterally extensive conductive layer corresponding to the sandstone interval. Water chemistry data does not exist for well 208398, but chemistry was collected in a test well (1986-4) installed one mile away in T14N, R8E, section 21 for the town of Ithaca. The down hole geophysical log for this test well indicates that the resistivity drops significantly at approximately 122 feet below ground surface, about 20 feet below the top of the Dakota Formation. Five water quality samples collected from this well all had Total Dissolved Solids concentrations greater than 2,200 ppm (Appendix A).

Given that much of the vertical extent of the Dakota Formation is below the depth imaged on the HEM profiles, it is likely that some areas of existing salinity are not identified. For example, the downhole geophysical log for SAU251 (profile 10030) suggest a fresh/salt interface transition around 70 to 73 meters below ground surface (230 to 240 feet), but HEM inversion reaches to only about 60 meters below ground surface.

Areas of Potential Recharge/Vulnerability

Groundwater recharge and vulnerability to contamination are controlled by many factors, such as precipitation, depth to the water table, and the hydraulic conductivity of materials above the water table. Determining these characteristics was beyond the scope of this study, but the thickness of saturated and unsaturated fine-grained materials (silt, clay, till) that exist above the upper resistive unit can be used as a first approximation of groundwater vulnerability. Figure 12 depicts areas where fine-grained units are thin or absent above the upper resistive unit. This map was made by subtracting the top of the upper resistive unit from the land surface elevation to give the thickness of fine grained deposits above the uppermost coarse-grained unit. Locations having five meters (approximately 16 feet) or less of fine-grained units above the upper resistive unit are colored yellow.

Figure 12 suggests that Wahoo Creek valley on the east side of the survey area has the largest area where groundwater is readily recharged and contamination can occur quickly. The other areas of high vulnerability are smaller and spaced widely throughout the study area, some areas associated with hill slopes and others with drainages. Unlike the Wahoo Creek valley on the east side of the study area, the Wahoo Creek/Miller Branch valley in the north part of the study area is not indicated as having high recharge/vulnerability.

Hydrologically Connected Surface Water and Groundwater

Hydrostratigraphic profiles were made under each of the creeks in the study area to investigate the potential degree of connection. The grids used to construct the profiles were relatively coarse (100 meter square cells), so the profiles must be regarded as estimates only. The profiles for Miller Branch Creek and Wahoo Creek on the north side of the study area did not show any significant connection to the upper resistive unit. The profile under Sand Creek and the Tributary to Wahoo Creek indicated connection to the

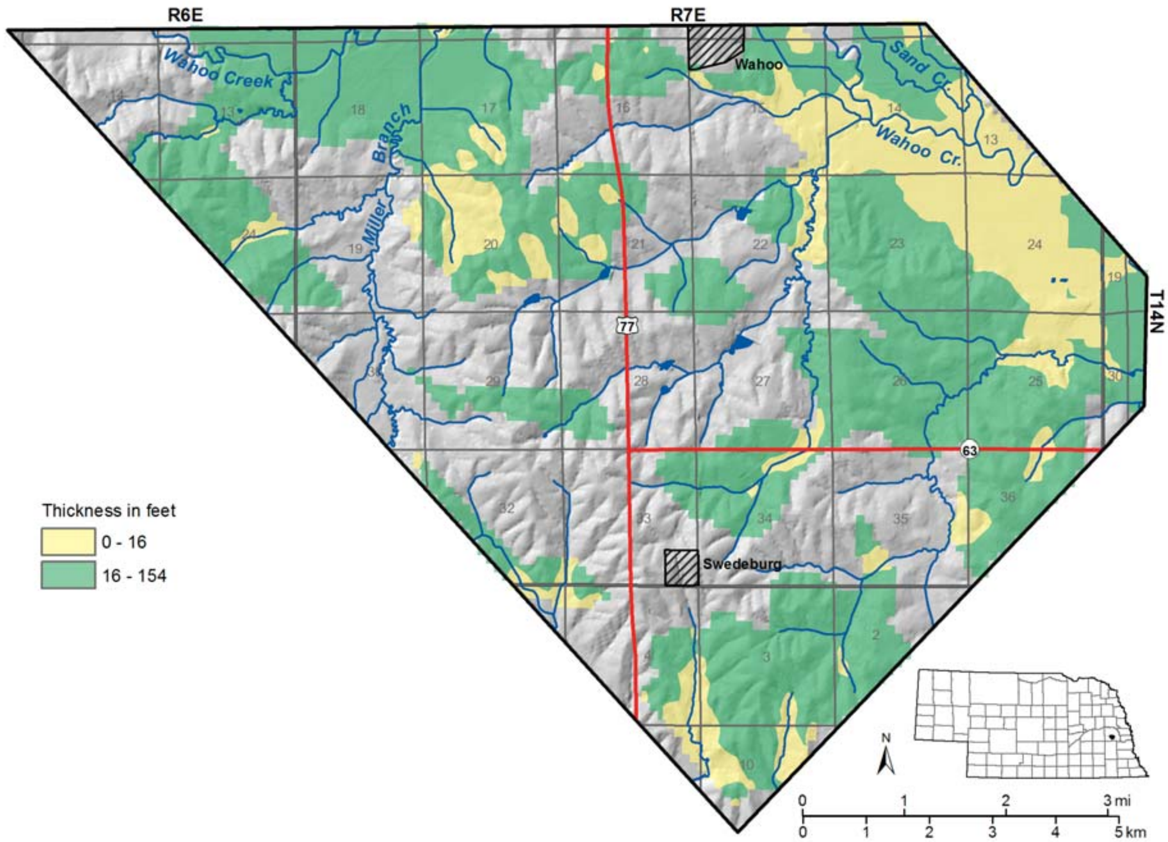

Figure 12. Potential recharge areas vulnerable to contamination. This map shows the locations where the fine-grained material above the upper resistive unit is five meters thick or less. Topographic relief is appears in the background as shades of gray.

upper resistive unit only occurs at their confluences with Wahoo Creek in the east portion of the study area. These profiles are not included in this report due to the limited information that they provide. The profile under Wahoo Creek (Fig. 13) indicates that there is connection between portions of the creek and the upper resistive unit on the east side of the study area, primarily at the confluences of an unnamed tributary and Sand Creek.

The profile under Wahoo Creek (Fig. 13) starts at the northeast edge of the survey area, includes confluences with a tributary and Sand Creek, and ends on the east side of the study area. Approximately four kilometers (about 2.5 miles) of Wahoo Creek is included in this portion of the flight area. There are only two wells serving as control points for the water table/potentiometric surface in this portion of the Wahoo Creek valley, which is not enough to provide an accurate estimate of the hydraulic head in the upper resistive unit under the creek.

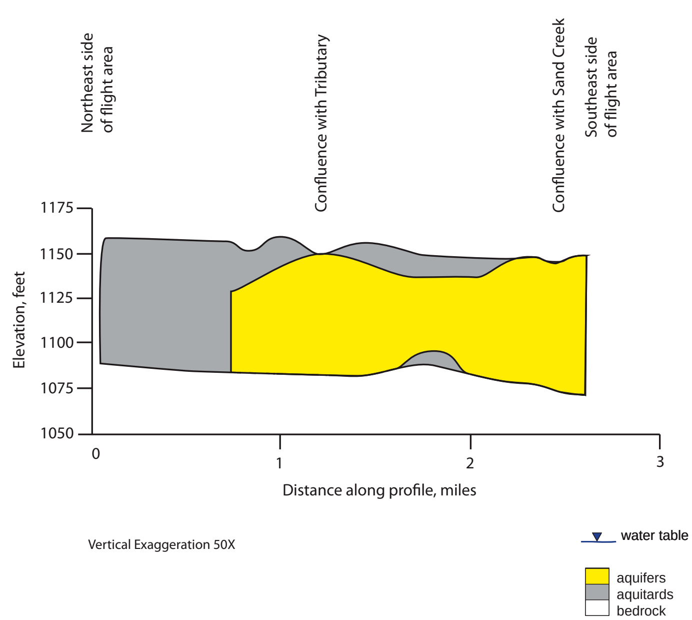

Figure 13. Hydrostratigraphic profile under Wahoo Creek. This figure depicts the upper resistive unit in relation to fine-grained material and the ground surface under Wahoo Creek on the east side of the survey area.

DISCUSSION

Implications for Resource Managers

Resource managers seek to preserve the quantity and quality of groundwater. Identifying areas where groundwater and surface water are hydrologically connected is part of this task. In Nebraska, hydrologically connected areas are important because they are (or likely will be) managed to comply with Integrated Management Plans, whereas groundwater not in hydrologic connection with surface water can be managed according to the NRD Groundwater Management Plans (Divine et al., 2009). Given these goals, this study has two important implications for resources managers.

First, average saturated thickness in the upper resistive unit varies from zero to 53 meters (0 to 175 feet) as shown in Fig 11. This unit is most vulnerable to contamination in the Wahoo Creek valley on the eastern side of the study area (Fig. 12). The Wahoo Creek valley on the north side of the study area does not appear to be as vulnerable. Wahoo Creek is likely hydrologically connected to groundwater in the eastern portion of the study area (Fig. 13), though none of the other creeks in the study area appear to have significant hydrologic connection to the upper resistive unit.

Second, hydrostratigraphy in the survey area is highly variable. If monitoring wells are to be screened in the same water-bearing unit as production wells, the monitoring wells may have to be very near to the production wells.

Potential Future Work

The focus of this report is the three-dimensional geologic framework, namely the extent and thickness, of hydrostratigraphic units. Estimating the aquifer yield to prevent overdevelopment would also require estimates of hydraulic conductivity and recharge rates. Information gained from aquifer tests (e.g. Coranco Great Plains, Inc., 2007) apply only to small portions of the subsurface, given the limited extent and thickness of aquifers in the study area. Caution would need to be used if the hydraulic data were to be applied to other portions of the survey area. The recharge rates can be estimated using a variety of techniques (e.g. Scanlon et al., 2002). One such technique is isotopic ratio sampling (e.g. Gates et al., 2008), which was conducted in the Lower Platte North Natural Resources District in 2011.

The HEM analysis raises some questions regarding the hydrostratigraphic framework in T14N, R7E, section 26. More drilling could be conducted here to investigate the nature of the subsurface. Also, the HEM profiles suggest a laterally continuous area of elevated total dissolved solids in the Dakota Formation in the Wahoo Creek valley on the east side of the study area, but limited data was available for verification. Nested wells could be installed at both of these locations if more data is desired.

CONCLUSIONS

The primary goal of this study was to better understand the hydrostratigraphic framework in the vicinity of Swedeburg, Nebraska. The HEM profiles of the Swedeburg area show approximately the top 60 meters (approximately 200 feet) of the subsurface. Except in the southwestern-most part of the study area, this 60 meters is sufficient to image the entire thickness of Quaternary deposits and the top of bedrock. The use of resistivity values to map hydrostratigraphic units, however, appears to be limited to approximately the upper 25 meters of the subsurface. Below this depth, lithology and resistivity do not appear to have a consistent relationship. The inability to use HEM to map units at this depth may be attributed to the effects of groundwater salinity on HEM, the limited resolution of the HEM data at depth, and the highly variable nature of lithology in the Quaternary deposits and in bedrock.

An upper resistive unit was defined based on comparison between CSD test holes and HEM data. The upper resistive unit consists of both unconsolidated Quaternary deposits and consolidated Dakota bedrock. The upper resistive unit appears to consist of aquifer materials in most locations, but in some locations it may consist of materials that have poor aquifer properties such as mudrock. The saturated thickness of the upper resistive unit is generally greatest on the north and west sides of the study area. Isolated areas of relatively thick saturation occur in T14N, R7E, section 26 and 34. The saturated thickness shown for section 34 occurs in unconsolidated Quaternary deposits. Much of the saturated thickness in section 26, however, occurs in mudrock and has low transmissivity.

The resolution of HEM at depth was insufficient to map the aquifers occurring near the town of Swedeburg and in

T14N, R7E, sections 20 and 21. Elevated total dissolved solids (TDS) concentrations in shallow portions of the Dakota Formation were apparent on the HEM profiles, though high TDS groundwater that occurs deeper than 60 meters (200 feet) was not imaged. Scattered areas of potentially high groundwater recharge rates and vulnerability to contamination exist around the survey area, with the most continuous area occurring in the eastern Wahoo Creek valley. Hydrostratigraphic profiles under the creeks indicate that portions of the Wahoo Creek valley in the east part of the survey area is likely in hydrologic connection with the upper resistive unit. None of the other creeks in the survey area appear to have significant hydrologic connection with groundwater.

ACKNOWLEDGEMENTS

Funding for this work was provided by Lower Platte North Natural Resources District and the Nebraska Environmental Trust.

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JOHNSON-ERICKSON-O'BRIEN & ASSOCIATES
WAHOO • NEBRASKA CITY • HASTINGS • SCHUYLER

142 WEST 11TH STREET
P.O. BOX 207
WAHOO, NEBRASKA 68066
402-443-4661

BURTON A. JOHNSON
E. GERALD ERICKSON
TERRENCE A. O'BRIEN
ERIC J. ERICKSON
RON D. BOTTORFF
JERRY G. HAIN
JAMES A. PESCHEL
CHARLES E. SWANSON

January 17, 1987

Mr. Frank Smith
University of Nebraska
Conservation and Survey Division
113 Nebraska Hall
Lincoln, NE 68508

Dear Mr. Smith:

As we have discussed, we are working with the Village of Ithaca on a project involving a new municipal water system. Enclosed please find a copy of the data which has been developed so far from the drilling and testing.

You will note that there has been six test holes drilled since the program started. You will also note that test holes #2 and #2A were not cased and test pumped.

It can be seen that while the water quality sample results from test wells 1986-1, 1986-2 and 1986-3 all show a level of manganese above the recommeded limit, the other water quality parameters were not beyond acceptable limits. There is concern that the manganese will cause a nuisance condition. We have discussed the use of poly-phosphates to sequester the manganese and this would be an alternative if better quality water is not located.

You will note that test hole #5 (Well #1986-4) was drilled deeper than holes 1 thru 4. This hole was screened at three separate levels in an attempt to determine the variance in the water quality. The water sample results show that while the lower levels do not contain as much manganese, there is very high sulfates, chlorides and total dissolved solids.

It is important to note that the sample from the upper screened area (92' to 102') also had high TDS, CL and SO_4. This is somewhat puzzling since the domestic wells in the immediate area do not indicate salts or sulfates. I have included a copy of data provided to us by the Village listing results for samples taken from existing domestic wells for your information. It is speculated that the sample may be from the same formation but in the lower portion which results in the higher TDS, etc.

Mr. Frank Smith
January 17, 1987
Page Two

The purpose of this letter is to provide you with the attached information for your reference prior to our meeting, January 21, 1987.

If you have any questions concerning the attached, please feel free to advise.

Very truly yours,

JOHNSON-ERICKSON-O'BRIEN
& ASSOCIATES, INC.

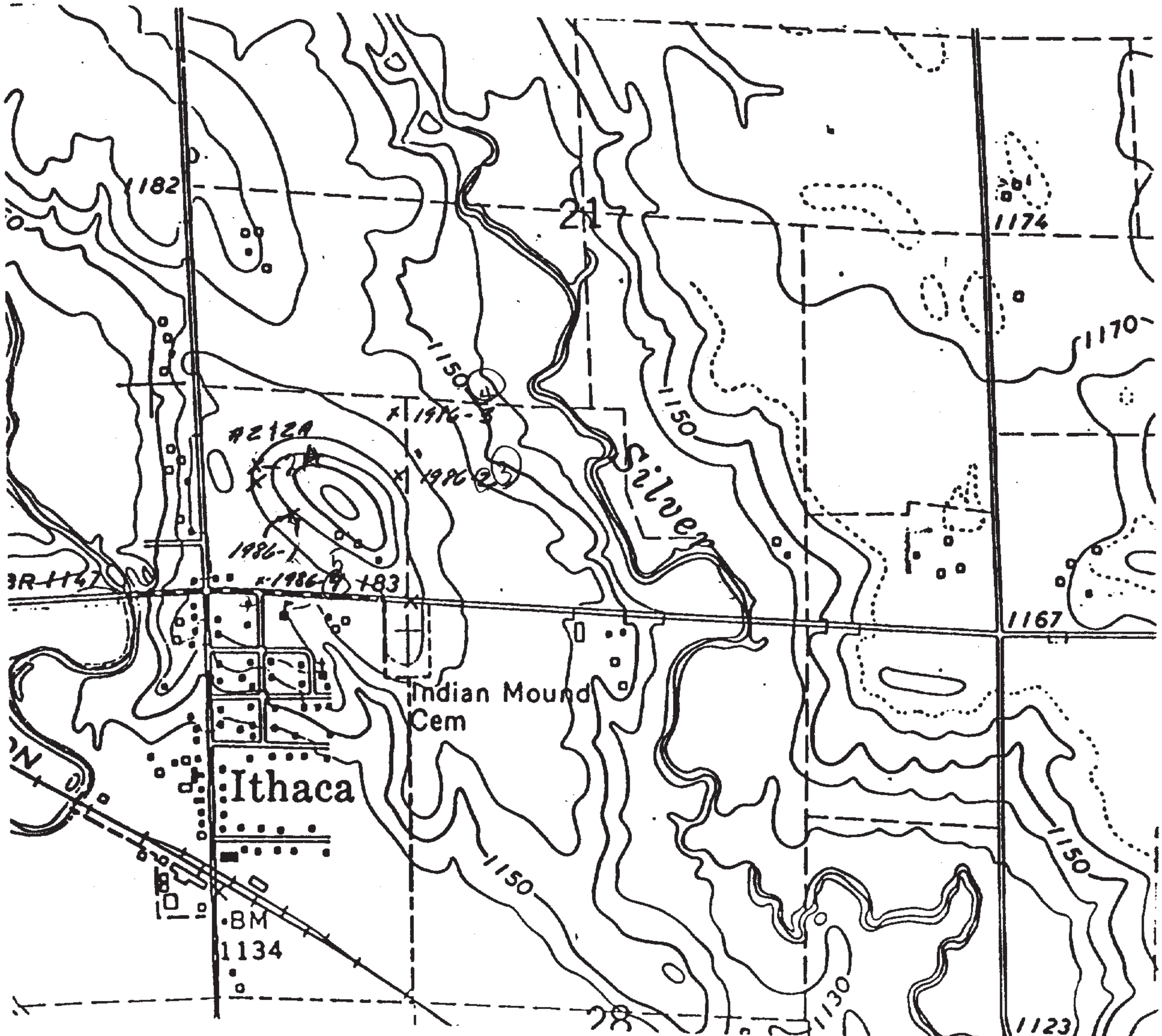
Ron Bottorff

RB:wj

pc:Craig Savage/Bill Lee,
NE Dept of Health, w/enc
Harlow Inman, FmHA, w/enc
Craig Quick, Chairman, w/enc

enc

MI-22-33



Test well locations

O Test Hole

1/16/87

Grosch Drilling and Exploration

DIVISION OF

Grosch Irrigation Co., Inc.

Well Drilling and Complete Installations

Silver Creek, Nebraska 68663 .... Telephone 308/773-2261
X Albion, Nebraska 68620 .... Telephone 402/395-6437
O'Neill, Nebraska 68763 .... Telephone 402/336-1805
Fremont, Nebraska 68025 .... Telephone 402/727-4850
Mason City, Illinois 62664 .... Telephone 217/482-5479
Dublin, Georgia 31021 .... Telephone 912/275-0013

WELL DRILLING
PUMPS · MOTORS
ENGINES

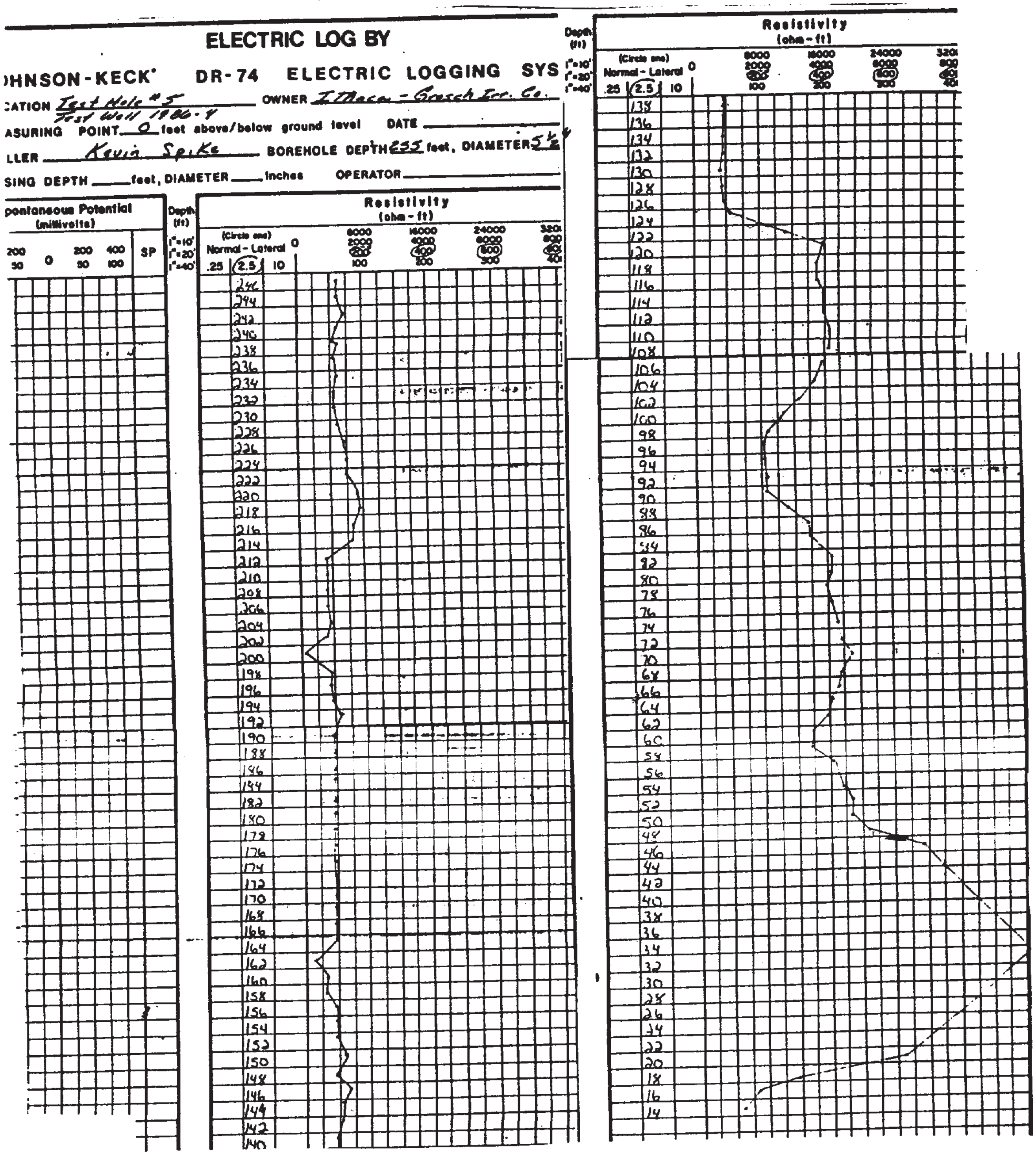
Test hole # 5
Test Well # 1986-4

0-16	Top soil & clay
16-45	Fine med sand
45-101	Med coarse sand & fine gravel
101-124	Dakota sandstone (dark color)
124-148	Shale
148-149	Pyrite
149-155	Shale
155-161½	Dakota sandstone
161½-162	Pyrite
162-249	Dakota sandstone
249-251	Shale
251-255	Dakota sandstone

Gravel pack 242-195
H.P. Bentonite 195-190
Gravel pack 190-135
H.P. Bentonite 135-130
Gravel pack 130-75
H.P. Bentonite 75-70
Bentonite slurry 70-0

242-222	screen	20'
222-182	plain	40'
182-162	screen	20'
162-102	plain	60'
102-92	screen	10'
92-0	plain	[illegible]

[illegible] plain
70' screen
[illegible]

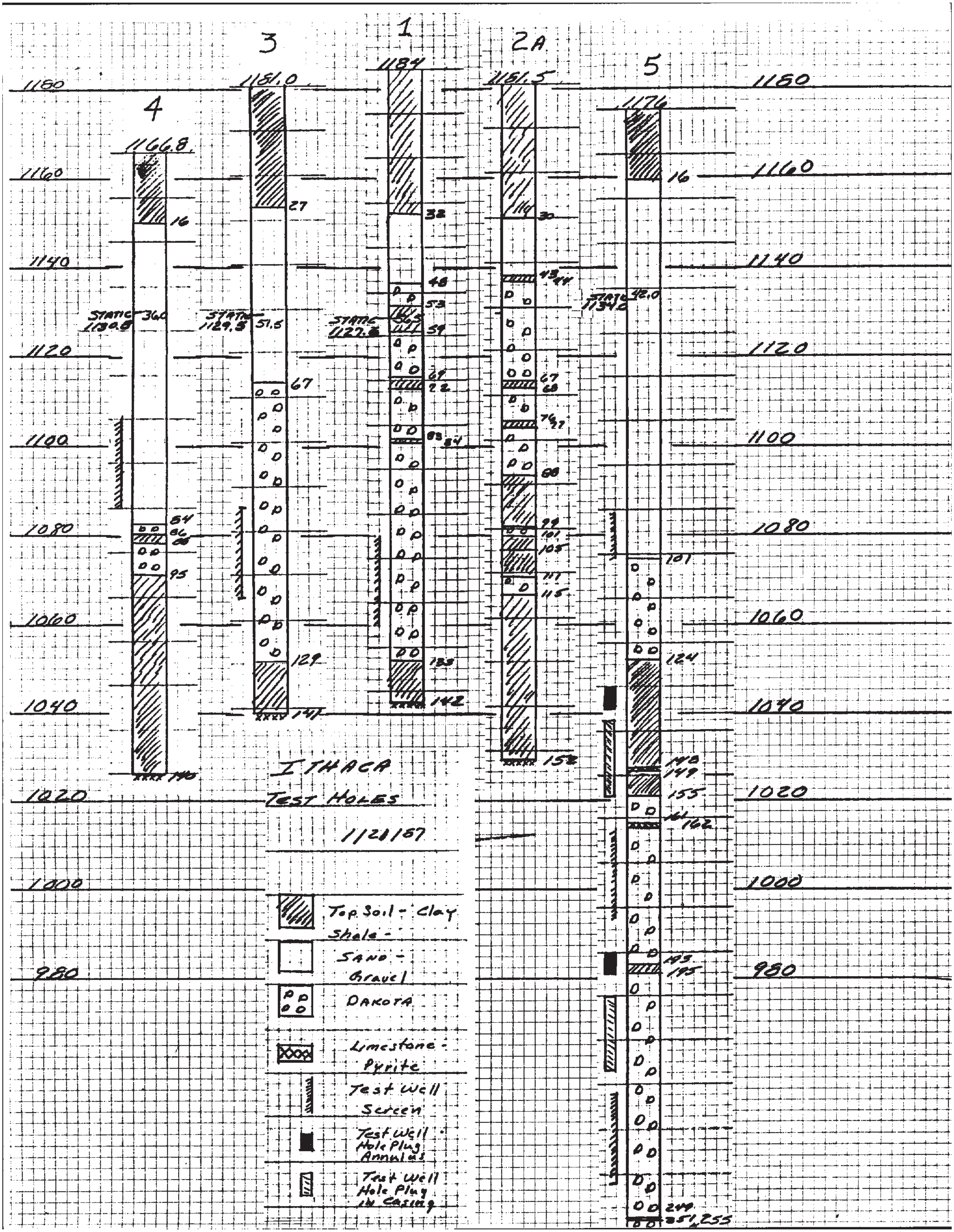


ELECTRIC LOG BY
JHNSON-KECK DR-74 ELECTRIC LOGGING SYS
CATION Test Hole #5 Test Well 1986-4
OWNER Ithaca - Gresch Irr. Co.
ASURING POINT 0 feet above/below ground level
DATE
LLER Kevin Spike
BOREHOLE DEPTH 255 feet, DIAMETER 5 1/4
SING DEPTH feet, DIAMETER inches
OPERATOR
Spontaneous Potential (millivolts)
SP
Depth (ft)
Resistivity (ohm-ft)
(Circle one) Normal - Lateral
.25 2.5 10

Results recv'd by phone from Harris Labs

Ithaca Test Well # 1986-4

	182'-162' 1/12/87	102'-92' 1-14-87	Results Recv'd 12/19/87 222-242'	182'-162'	92-102'
Ca	209.8	109.8			
Fe	.86	0.06			
Hard	697.7	639.5			
pH	7.4	7.3			
Mn	0.08	0.44	.13	.11	.13
NO_3	0.14	<0.05	.55	.65	.35
Na	640	627	700	700	550
SO_4	1100	1020	1000	1000	1000
Fl	1.44	1.44			
Cl	706	667	700	700	600
T. Alk	189	186			
TDS	2522	2304	2400	2430	2240
	↑ >60 Hrs+ Pumping	↑ 40 Hr+ Pumping	Test pumping 2 Hr +/- for Original Testing		



ITHACA
Test Holes
1/28/87
Top Soil - Clay
Shale -
Sand -
Gravel
Dakota
Limestone -
Pyrite
Test Well
Screen
Test Well
Hole Plug
Annulus
Test Well
Hole Plug
in Casing
4
3
1
2A
5
1166.8
1181.0
1184
1181.5
1176
STATIC 1130.8
STATIC 1129.5
STATIC 1127.8
STATIC 1134.0
1180
1160
1140
1120
1100
1080
1060
1040
1020
1000
980

Harris Laboratories, Inc.

624 PEACH STREET, P.O. BOX 80837 • LINCOLN, NEBRASKA 68501 • TELEPHONE 402/476-2811

RECEIVED
JAN 20 1987
JOHNSON-ERICKSON-O'BRIEN & ASSOCIATES

Report of Analysis

For	Grosh Irrigation Co. P. O. Box 337 Silver Creek, NE 68663	Date	December 19, 1986
		Laboratory No.	46044
Sample of	Water	Received	December 17, 1986
Sample Marked	As Below		

	Well #4 102-92	Well #4 102-162	Well #4 242-222
Calcium	206.7 mg/l	209.7 mg/l	209.2 mg/l
Chloride	700 mg/l	700 mg/l	600 mg/l
Flouride	1.64 mg/l	1.67 mg/l	1.71 mg/l
Iron	.13 mg/l	.21 mg/l	.20 mg/l
Total Alkalinity (as $CaCO_3$)	190 mg/l	184 mg/l	186 mg/l
Total Hardness (as $CaCO_3$)	694.8 mg/l	704.3 mg/l	700.6 mg/l
Total Dissolved Solids	2400 mg/l	2430 mg/l	2240 mg/l
pH	7.3	7.3	7.3
Manganese	.13 mg/l	.11 mg/l	.13 mg/l
Nitrate-Nitrogen	.55 mg/l	.65 mg/l	.35 mg/l
Sodium	713 mg/l	677 mg/l	553 mg/l
Sulfate	1000 mg/l	1000 mg/l	1000 mg/l

NITRATE WARNING FOR WATER

It is recommended that water containing nitrate-nitrogen in excess of 10 parts per million never be used to prepare infant formula. It is also recommended that the family physician be consulted in cases where a drinking water supply greatly exceeds this figure. The use of water containing 10-50 parts per million nitrate-nitrogen may cause certain health problems in swine. Do not use water containing more than 50 parts per million nitrate-nitrogen for swine.

Method of Analysis:

Standard Methods for the Examination fo water and Wastes 16th Edition, APHA, 1985

Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, 1979

SAMPLES ARE DISCARDED IN 15 DAYS FROM DATE OF REPORT UNLESS WE ARE REQUESTED, IN WRITING, TO RETAIN THEM FOR A LONGER PERIOD. PERISHABLE SAMPLES ARE USUALLY DISCARDED IMMEDIATELY UNLESS CLIENT HAS REQUESTED SPECIAL HANDLING (FREEZING, ETC.) IN ADVANCE.

HL 68

Respectfully submitted,
HARRIS LABORATORIES, Inc.

By John E Howe

Funding for this project was provided by the Nebraska Environmental Trust and the Lower Platte North Natural Resources District.

Conservation and Survey Division
School of Natural Resources
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln