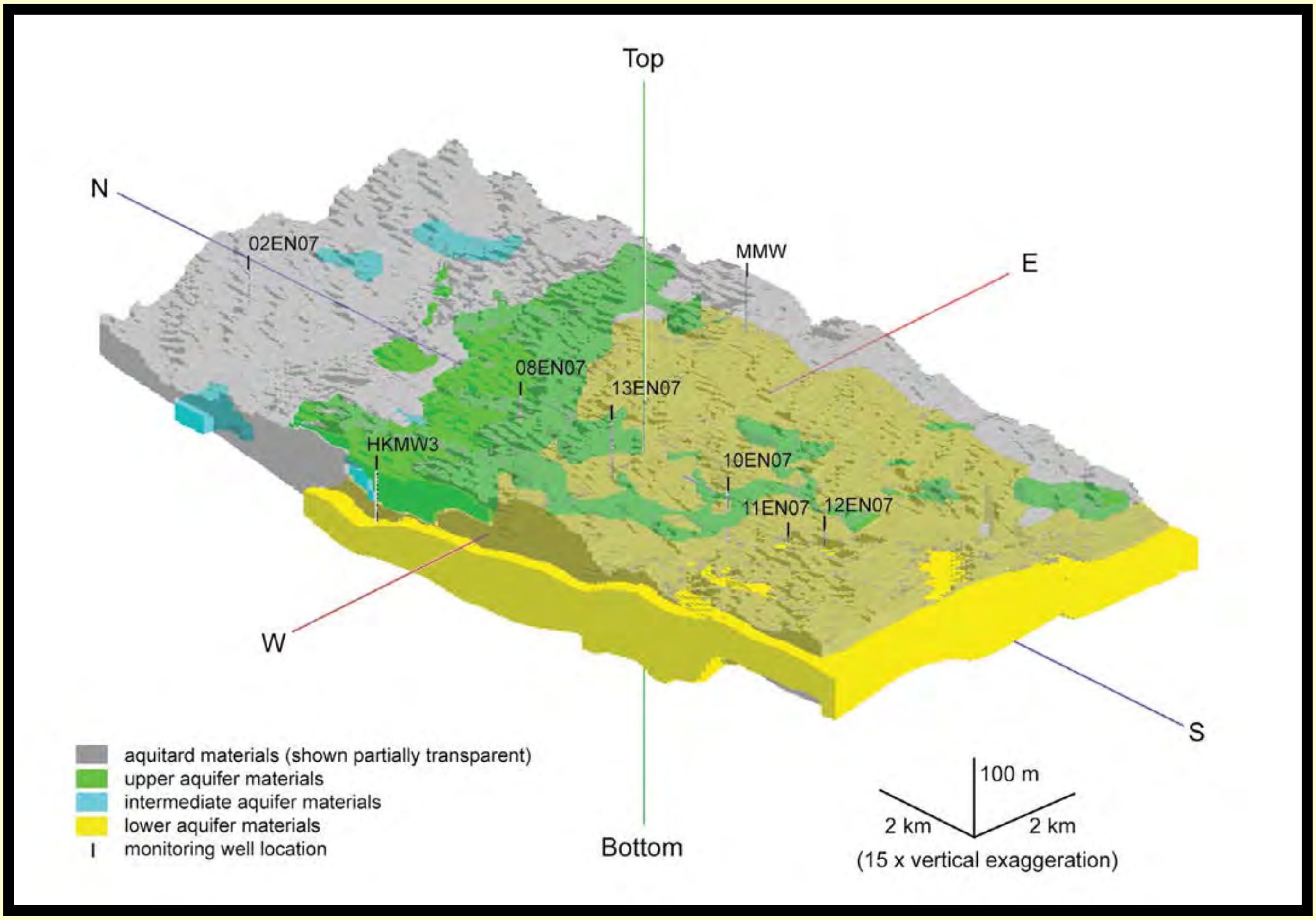
Eastern Nebraska Water Resources Assessment

Three-dimensional hydrostratigraphy of the Firth, Nebraska Area: Results from Helicopter Electromagnetic (HEM) mapping in the Eastern Nebraska Water Resources Assessment (ENWRA)

Jesse T. Korus, R.M. Joeckel and Dana P. Divine

Edited by David R. Larson



Bulletin 3 (New Series)

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

Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
meter (m)	3.281	feet (ft)
kilometer (km)	0.6214	mile (mi)
square kilometer (km2)	247.1	acre
milliliter (mL)	0.0338	ounce (oz)
liter (L)	3.785	gallon
cubic meter (m)	0.0008107	acre-foot

Electrical resistivity is given in ohm-meters (ohm-m) unless otherwise specified.

Electrical frequency is given in hertz (Hz) or kilohertz (kHz) unless otherwise specified.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD88), meters.
Horizontal coordinate information is referenced to the North American Datum of 1983, Universal Transverse Mercator Zone 14 (NAD 83 UTM Zone14N), meters.

Airborne geophysical survey used World Geodetic System of 1984 (WGS84) for global positioning.

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Image on cover: Three-dimensional, hydrostratigraphic block model for the study area (see Fig. 20 and text). View is toward the northeast at approximately 20 degrees above the horizon. Light source is from the east.

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Abstract

Hydrogeologists have long been hindered by the lack of closely spaced subsurface data with high vertical resolution. The complex glacial and preglacial geology of eastern Nebraska is incompletely described because borehole data are too sparse, unequally distributed, and of varying quality. This study employs helicopter electromagnetic (HEM) surveys, from which resistivity-depth sections with ~1 to ~15 m vertical resolution and 3 m horizontal resolution have been produced, in combination with traditional methods, at a pilot study site near Firth, Nebraska. We qualitatively describe the HEM resistivity patterns in the immediate vicinity of test holes and monitoring wells, and conclude that major aquifer/aquitard contacts can be correlated between borehole locations using the 20 ohm-m contour as a guide. We digitize hydrostratigraphic unit contacts on resistivity:depth profiles, interpret elevation maps for each contact, and calculate thicknesses of aquifers and aquitards. The resulting three-dimensional hydrostratigraphic framework reveals information about the groundwater-flow system that was previously unverified or completely unknown. A multi-layer aquifer system with both small- and large-scale discontinuities exists. The lower aquifer, which is largely confined, is shown to be connected to two areas of unconfined conditions that serve as sources of recharge. This framework reveals areas of potential aquifer vulnerability to overdevelopment and contamination. HEM is effective for characterizing hydrogeology in complex glaciated settings such as Firth. At a cost of between approximately $150 and $170 per line kilometer, it is likely justifiable in other investigations where high-resolution hydrogeologic data are required. Our study highlights several limitations of HEM. (1) The depth of investigation of HEM is relatively shallow and may not be sufficient to fully penetrate the primary aquifers of southeastern Nebraska. (2) Thick, fine-grained glacial deposits may further reduce the depth of investigation. (3) Interpretation of the data is non-unique, so it must be accompanied by detailed lithologic, stratigraphic, hydrochemical, and hydraulic head data from multiple test holes and monitoring wells.

1. Introduction

Test-hole drilling and the construction of geological cross sections have been the traditional means of assessing the geological context of groundwater resources in Nebraska. This study integrates traditional drilling methods with advanced geophysical methods to provide improved hydrostratigraphic characterization of the shallow subsurface. The results of helicopter electromagnetic (HEM) surveys are interpreted in the context of pre-existing and newly acquired test-hole data. This interpretation is used to construct a three-dimensional hydrostratigraphic model that exhibits complexity and heterogeneity that would not have been realized using test-hole data alone.

The Firth pilot study area was chosen for investigation for several reasons: 1) The area overlies a major buried valley (paleovalley) aquifer in the glaciated part of Nebraska, an area that is incompletely characterized due to its geologic complexity. 2) The extent, thickness, and interconnectedness of aquifers and aquitards are largely unknown at the local scale. 3) This area exemplifies the convergence of rural and urban interests on the fringes of Nebraska's major metropolitan areas, including population growth and changes in domestic and municipal water-resource use. A major goal of this study was to assess the use of HEM in areas overlain by glacial deposits. A secondary goal was to provide information for understanding the potential impact of large-scale groundwater withdrawals and land-use practices on the quantity and quality of groundwater supplies.

This study is a part of the ongoing Eastern Nebraska Water Resources Assessment (ENWRA) program, a collaborative study among 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).

2. Helicopter Electromagnetic Induction (HEM)

An electromagnetic (EM) survey is a geophysical method that measures the apparent electrical conductivity (or its reciprocal, resistivity) of the subsurface. EM data can be collected from the air or land surface. In airborne applications, the EM transmitter and receiver may be suspended beneath an airplane or a helicopter. EM instruments consist of transmitter and receiver coils. The transmitter coil produces a changing primary magnetic field that induces a current in the ground. This current produces a secondary magnetic field that is measured in the receiver coil. The measured apparent resistivity is a weighted mean of the resistivities of the layers in which the currents were induced. The resistivity depth structure can be obtained through inversion of the apparent resistivity dataset (Siemon, 2009).

EM can be implemented in either the frequency or time domain. In the frequency domain—the method used in this study—exploration depths can range from a few to roughly 100 m depending on the type of instrument and the subsurface conductivity (Paine and Minty, 2005; Robinson et al., 2008). Frequency domain EM instruments towed by helicopters (HEM) are mounted in a cylindrical tube called a "bird" and typically operate at frequencies ranging from 100 kHz to 500 Hz. Exploration depth increases with increasing frequency. Exploration depth also depends on subsurface resistivity, which is controlled by factors such as water content, water chemistry, pore volume and structure, and the electrical properties of the host mineral grains (McNeill, 1980; Paine and Minty, 2005). Higher subsurface conductivity yields lower exploration depths. One serious limitation of HEM is that the signal is distorted by cultural noise sources such as power lines, pipe lines, and buildings. This distortion may extend 100-200 m from the source (Robinson et al., 2008).

Prior to the beginning of this study in 2007, HEM had been employed in few groundwater studies (e.g. Palacky, 1981; Paterson and Bosschart, 1987; Bromley et al., 1994; Paine, 2003; Smith et al., 2003) and even fewer studies of hydrogeology in glaciated settings (e.g. Puranen et al., 1999; Siemon et al., 2004; Best et al., 2006). The study presented herein was motivated in part by the promise that HEM showed in previous studies and the need for additional testing of this method in glaciated settings (Divine et al., 2009).

3. Physical Setting

The Firth pilot study area lies within the dissected till plains of Fenneman (1946), which extends approximately to the glacial limit in eastern Nebraska (Fig. 1). It also lies within Groundwater Region 11 of the Conservation and Survey Division (1998) , which is characterized by: (1) rolling hills on dissected pre-Illinoian till that is mantled by loess, (2) stream valleys filled with Pleistocene and Holocene alluvium, and (3) Pleistocene (and possibly Late Pliocene) buried valleys filled with sand and gravel that are the primary aquifers. Regional water tables in unconsolidated sediments overlying bedrock are between 15 to 61 m below the land surface, depending on topographic position, although shallower, “perched” groundwater exists locally within the succession of loesses and glacial tills (Gosselin et al., 1996). In terms of the total volume of groundwater withdrawn in the region, bedrock aquifers are of secondary importance compared to the aquifers in the overlying unconsolidated sediments (Fig. 2). Only a few domestic wells are completed into bedrock in the study area. Nonetheless, in some parts of the region other than the Firth pilot study area, many irrigation wells and domestic wells tap into bedrock aquifers.

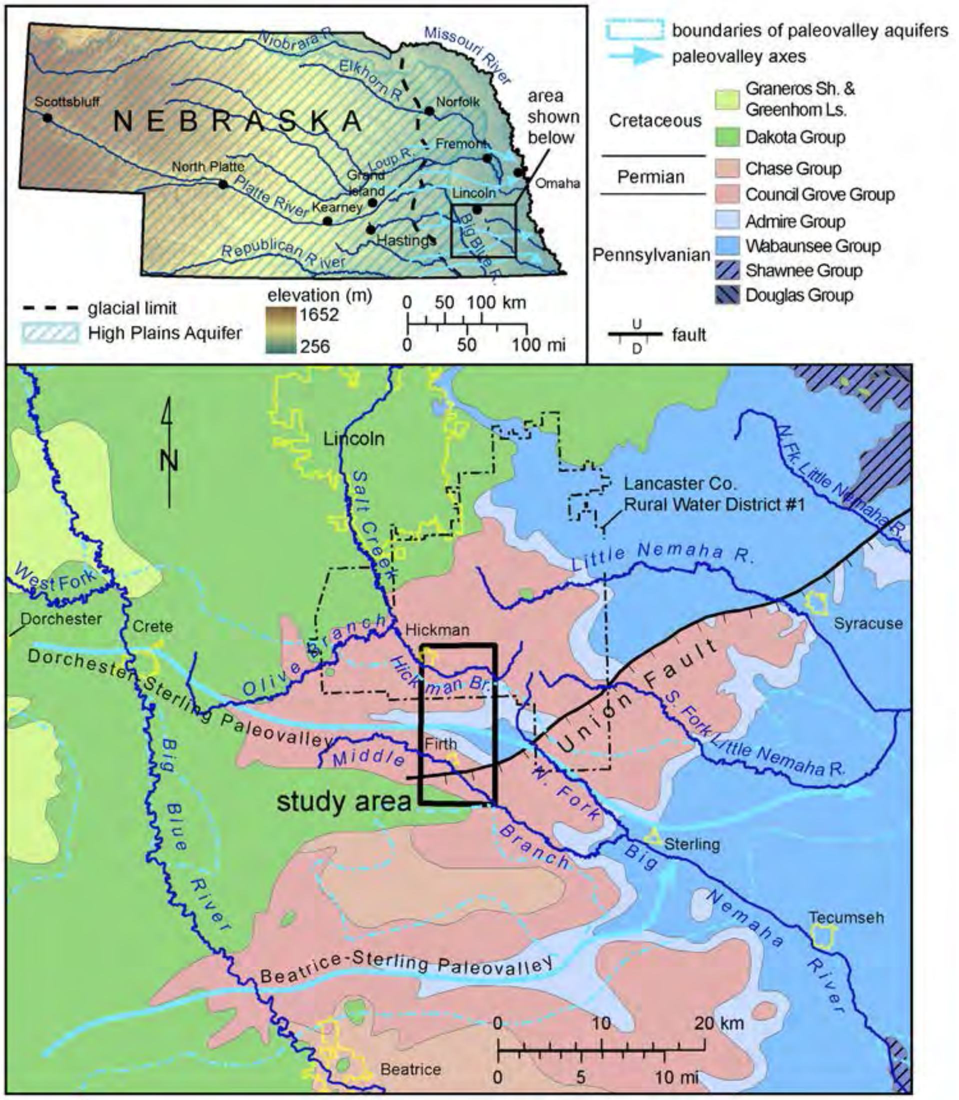


Figure 1. Map of study area. Black box in inset map shows location of lower map. Lower map shows principal geological features in the vicinity of the study site, shown as a black outline around the towns of Firth and Hickman. Bedrock geology from Burchett (1986).

3.1. Stratigraphy of Unconsolidated Materials Overlying Bedrock

The Firth pilot study area is underlain by unconsolidated sediments of varying thicknesses that overlie much older bedrock strata (Fig. 2). The vertical succession of unconsolidated sediments differs between upland areas and the valleys of modern streams.

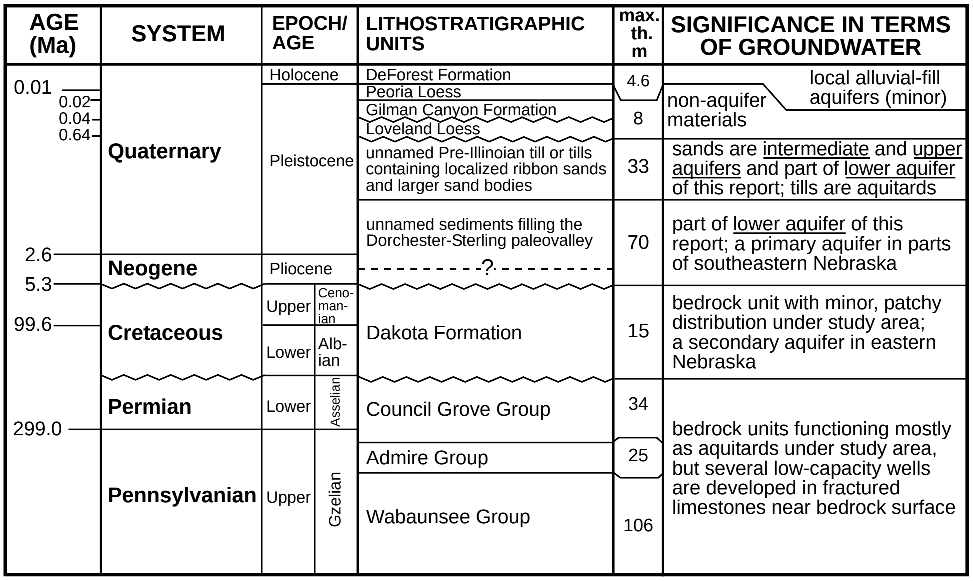
3.1.1. Upland Areas

In upland areas, the overall succession of unconsolidated sediments is, in ascending order:

1. a succession of well-sorted to poorly-sorted sands and silts, with minor gravels, which are mostly limited to the sedimentary fills of paleovalleys (Qpf);

2. one or more glacial tills of pre-Illinoian age (Qt) that extend under almost all of the study area and contain or are underlain by stratified sands and silts (Qss); and

3. Late Pleistocene loess, chiefly the Peoria Loess (Qp) and the underlying and thinner Gilman Canyon Formation (Wisconsinan) (Qgc), which underlie almost all of the study area, and the middle Pleistocene (Illinoian) Loveland Loess (Ql), which is present under the Gilman Canyon Formation, and above glacial till, in some areas. The Sangamon Geosol (Qls) is developed locally at the top of the Loveland Loess.



AGE (Ma)	SYSTEM	EPOCH/ AGE		LITHOSTRATIGRAPHIC UNITS	max. th. m	SIGNIFICANCE IN TERMS OF GROUNDWATER
0.01	**Quaternary**	Holocene		DeForest Formation	4.6	local alluvial-fill aquifers (minor)
0.02		Pleistocene		Peoria Loess		non-aquifer materials
0.04				Gilman Canyon Formation	8	
0.64				Loveland Loess		
				unnamed Pre-Illinoian till or tills containing localized ribbon sands and larger sand bodies	33	sands are intermediate and upper aquifers and part of lower aquifer of this report; tills are aquitards
				unnamed sediments filling the Dorchester-Sterling paleovalley	70	part of lower aquifer of this report; a primary aquifer in parts of southeastern Nebraska
2.6	**Neogene**	Pliocene		- - - - - - - - -?- - - - - - - - -		
5.3	**Cretaceous**	Upper	Cenomanian	Dakota Formation	15	bedrock unit with minor, patchy distribution under study area; a secondary aquifer in eastern Nebraska
99.6		Lower	Albian			
	Permian	Lower	Asselian	Council Grove Group	34	bedrock units functioning mostly as aquitards under study area, but several low-capacity wells are developed in fractured limestones near bedrock surface
299.0	**Pennsylvanian**	Upper	Gzelian	Admire Group	25	
				Wabaunsee Group	106	

Ma = megaannum (million years)

maxiumum thicknesses (max. th.) apply to study area only

﹏﹏﹏﹏﹏ major disconformity

- - - - - - ?- - - - - - age of contact unknown

Figure 2. Stratigraphic chart for bedrock units below the sub-Neogene unconformity and unconsolidated sediments above bedrock in the Firth study area.

Southeastern Nebraska was glaciated prior to the Illinoian Stage of the Pleistocene Epoch, prior to the deposition of the Lava Creek B tephra. There were at least seven glacial advances into the North American Midcontinent between ~ 2,600,000 and ~ 640,000 years ago—the latter age being that of a prominent volcanic ash marker (Boellstorff, 1978a, 1978b; Lanphere et al., 2002, Roy et al., 2004; Balco et al., 2005). Glacial tills at and near the land surface in the uplands of southeastern Nebraska were generally considered to be "Kansan" in age by previous authors (e.g. Reed and Dreeszen, 1965; Burchett and Reed, 1967), making them products of younger pre-Illinoian glaciations. Accordingly, we speculate that glacial tills in the Firth area date to the early or middle Pleistocene Epoch, most likely after the last major reversal of Earth's magnetic field 780,000 years ago (cf. Roy et al., 2004; see also: Mandel and Bettis, 2001), although we have no direct measurements of their ages.

The start of the Pleistocene Epoch was recently revised to ~ 2.6 Ma (Walker and Geissman, 2009; Cohen and Gibbard, 2011). Sediments ranging in age from ~ 1.8 Ma to ~ 2.6 Ma, therefore, were previously included in the Pliocene Epoch of the Neogene System, and the earliest glaciations in southeastern Nebraska were long considered to have been Pliocene events (e.g., Boellstorff, 1978a, 1978b, 1978c; Roy et al., 2004; Walker and Geissman, 2009; Cohen and Gibbard, 2011). Now, however, all advances of the Laurentide ice sheet are fully contained within the time span of the revised Pleistocene Epoch (e.g., Walker and Geissman, 2009; Cohen and Gibbard, 2011).

The most prominent bedrock feature underlying the tills at the study site is a 12 km-wide Pleistocene (and possibly Late Pliocene) paleovalley. This feature, known as the Dorchester-Sterling paleovalley, is readily mappable over a distance of 180 km (Dreezen and Burchett, 1971) and is one of at least five eastward-trending paleovalleys in southeast Nebraska (Fig. 1; Dreezen and Burchett, 1971). Features such as these are common to the glaciated part of North America and have been attributed to: (1) preglacial streams; (2) glacial meltwater streams (e.g., Kehew and Boettger, 1986), including proglacial streams in the front of an advancing ice sheet (Reed and Dreeszen, 1965); (3) subglacial streams; and (4) glacial lake spillways (Kehew and Bottger, 1986). Reed and Dreeszen (1965) interpreted these sub-till sediments as proglacial deposits associated with the advancing ice sheet. Other publications (e.g., Emery, 1966; Keech et al., 1967, Ginsberg, 1983) interpret them as the products of the synglacial blockage of eastward-flowing streams by one or more glacial advances. All of the paleovalleys in southeastern Nebraska follow the overall eastward slope of the landscape away from the Rocky Mountains and intersect the margin of the Laurentide ice sheet at approximately 90° (Dreezen, 1970; Dreezen and Burchett, 1971). Therefore, they predate, rather than coincide with, at least one advance of the Laurentide ice sheet prior to 640 ka. This relationship rules out a glacial spillway origin. Likewise, a subglacial drainage origin is unlikely because such features are generally narrower than those observed in southeast Nebraska (e.g. Barker and Harker, 1984; Ahmad et al., 2009). The paleovalley fills may be preglacial (deposited before ~ 2.6 million years ago), synglacial (deposited at the time of a glacial stage earlier than the one during which the overlying till was deposited), or interglacial (deposited between glacial advances that occurred prior to ~ 640,000 years ago), or some combination thereof.

The age span of the regional loess succession is well-constrained: the Loveland Loess dates to ~ 160,000-120,000 years ago (Forman et al., 1992; Forman and Pierson, 2002), the Gilman Canyon Formation to ~ 45,000-25,000 years ago (Mason et al., 2007), and the Peoria Loess to ~ 25,000-14,000 years ago (Bettis et al., 2003; Mason et al., 2008).

3.1.2. Stream Valleys

The stream valleys in southeastern Nebraska are not mantled by loess or till like the adjacent uplands, although older stream terraces at the margins of these valleys may be mantled by Peoria Loess. Rather, after they were eroded into older unconsolidated sediments or bedrock, they were subsequently filled with alluvium (Qa).

Mandel and Bettis (2001) recognized the near-surface alluvial fill in the modern valley of the South Fork of the Big Nemaha as the geographically widespread Holocene DeForest Formation. The older, but topographically higher, late Wisconsinan silty alluvium underlying Peoria-Loess-mantled stream terraces at the margins of valley floors in the region has been called the Severance Formation (Mandel and Bettis, 2001, 2003). Both the DeForest Formation and the Severance Formation overlie older Pleistocene alluvial deposits, chiefly sands and gravels, and pre-Wisconsinan stream terraces may exist in the Big Nemaha drainage (Mandel and Bettis, 1995; Mandel and Bettis, 2001).

These unconsolidated gravels, sands, and silts constitute a significant source of groundwater in southeastern Nebraska. Silty and clayey unconsolidated materials on valley margins may be eroded upslope and deposited downslope in the form of slopewash (Qsw). These deposits are extensive along valley margins in the Firth area (Joeckel and Dillon, 2007).

3.2. Bedrock Stratigraphy

Bedrock underlying the study site consists primarily of Upper Pennsylvanian and Permian limestones, shales, and mudstones. Burchett (1986) and Burchett et al. (1972) mapped the Upper Pennsylvanian Wabaunsee (Pw) and Admire Groups (Pa) in areas where bedrock was deeply eroded during Late Cenozoic times and as the Upper Pennsylvanian-Lower Permian Council Grove Group (Pcg) in areas where post-Paleozoic erosion reached shallower depths. Both the Admire Group and the Council Grove Group were formerly considered to be entirely within the Permian System, but recent work has moved the Pennsylvanian-Permian boundary upward to the lower part of the Council Grove Group (Sawin et al., 2006).

Upper Pennsylvanian and Permian strata are typically considered to be aquitards in Nebraska (e.g., Pipes, 1987). Nonetheless, the enlarged joints, fractures, and rubbly weathered zones atop limestone beds within these successions have yielded small quantities of water to domestic wells in southeastern Nebraska. Indeed, several domestic wells in the northern one-third of the study area are screened into the very top of the Pennsylvanian-Permian bedrock and produce ~10-20 gallons per minute (gpm) of water. No irrigation wells are known to be completed into these strata in Nebraska. In Kansas, however, where strata of the Admire Group are part of a regional aquitard that includes underlying Pennsylvanian strata, limestones of the Council Grove Group actually yield sufficient water to be considered to be part of the Flint Hills aquifer of Macfarlane (2000), although interbedded shales within the Council Grove Group serve as confining units (Macfarlane, 2000).

Sandstones in the Cretaceous Dakota Formation (Dakota Group of Condra and Reed, 1959) are important secondary aquifers in some parts of southeast Nebraska outside of the Firth pilot study area. These bedrock aquifers supply water to irrigation, domestic, and municipal wells. The logs of registered wells suggest that thin outliers of the Dakota Formation may exist under a small area in the southwestern corner of the study area, although we did not encounter it in any of the test holes drilled as a part of this study. Other workers have described Dakota Formation strata in boreholes or mapped them in the surrounding area.

3.3. Geologic Structure

Bedrock strata have only very shallow regional dips. The Union Fault, the extension of the Thurman-Redfield Fault Zone from Iowa (Condra, 1930; Sims, 1990), is the only known major fault in the study area (Fig. 1). Little is known about this fault except that it represents reactivation of the southern boundary of the Proterozoic Midcontinent Rift System, which itself dates to about 1.0 Ga (Anderson, no date). The actual amount of offset of Upper Paleozoic strata by the Union Fault in the pilot study area is unknown, as are any potential effects that it might have on fluid flow in the shallow to deep subsurface.

4. Groundwater Use: Current and Future

Groundwater withdrawals in the study area primarily serve domestic, irrigation, and public water needs. As of May 2011, there were 346 registered active wells in the study area, although 104 of these wells are either closed loop ground heat exchange wells or monitoring wells (Fig. 3).

There are 181 active registered domestic water wells in the study area, but domestic wells completed prior to September 9, 1993 may be unregistered, making it almost certain that additional unregistered domestic wells are present. After a general increase in new domestic wells between 1994 and 2005, the rate has fallen in recent years (Fig. 4). Domestic well yields are typically between 5 and 50 gpm and serve the household uses of single family dwellings on small acreages. Cumulatively, they represent only a small portion of the total groundwater withdrawals. Moreover, the use of

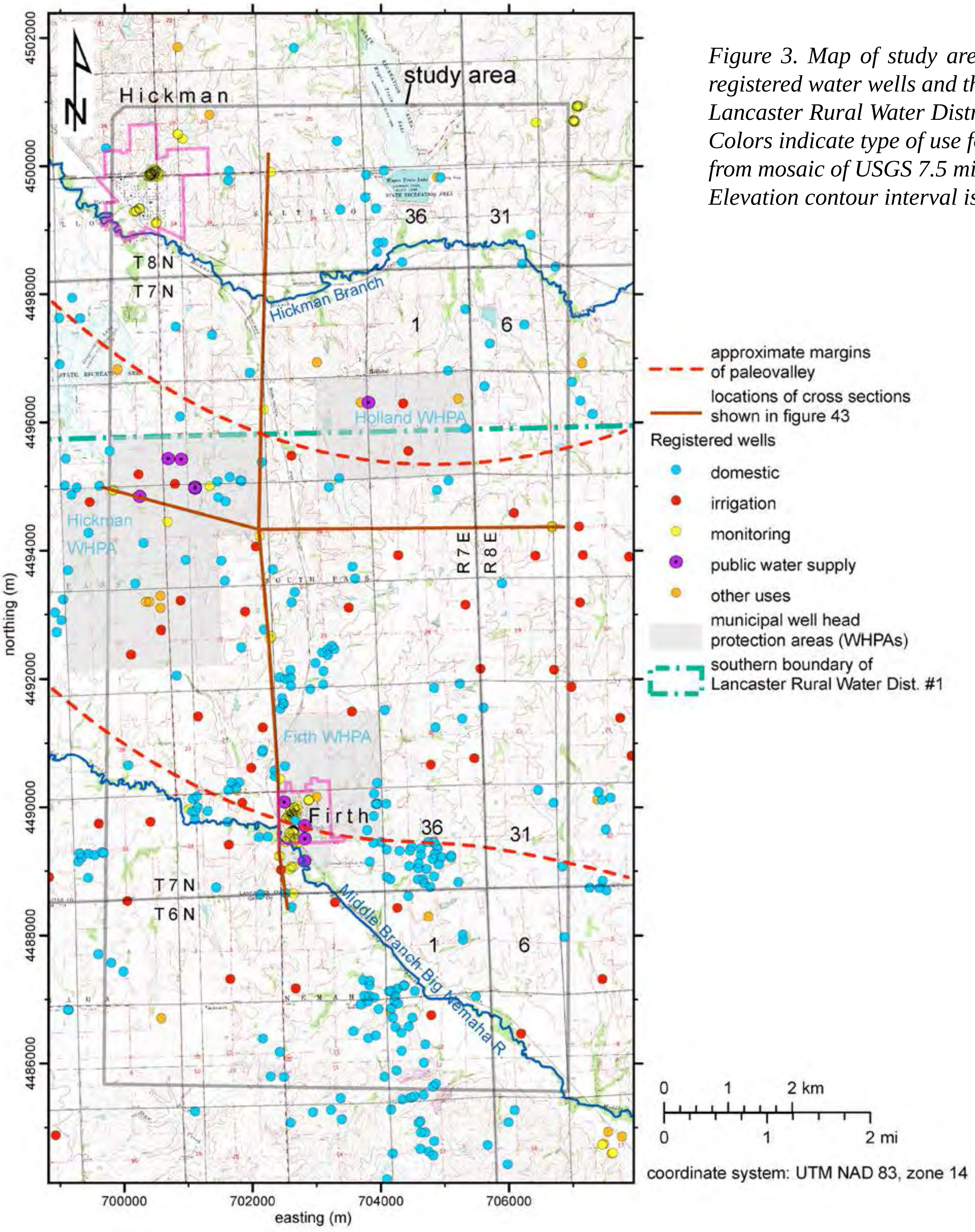


Figure 3. Map of study area showing locations of registered water wells and the southern boundary of Lancaster Rural Water District #1 (see also Fig. 1). Colors indicate type of use for each well. Base map from mosaic of USGS 7.5 minute topographic maps. Elevation contour interval is 10 ft.

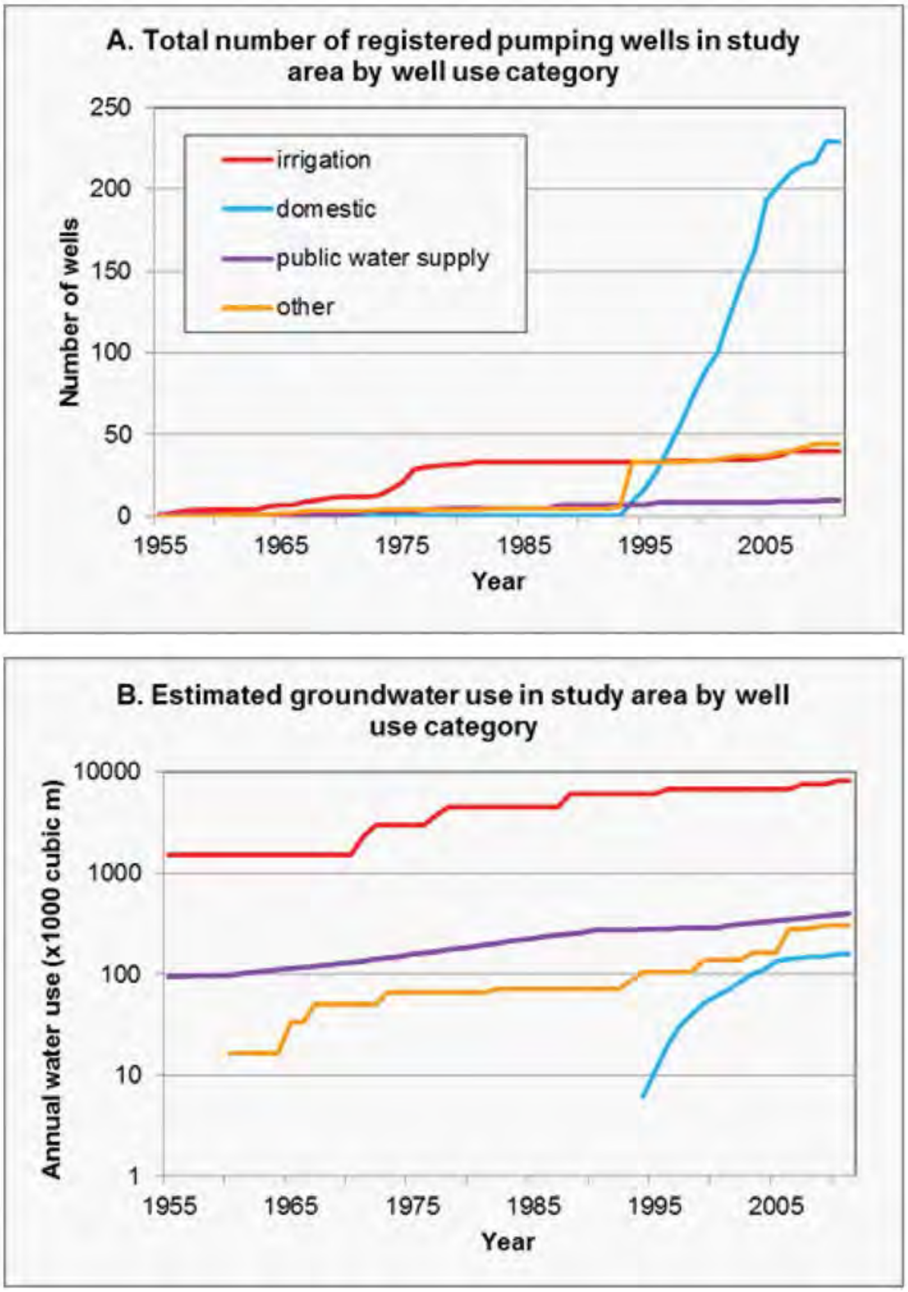


Figure 4. A. Graph showing changes in the number of irrigation, domestic, public water supply, and other registered water wells in the study area since 1955. B. Graph showing the estimated annual water use in cubic meters by well use category. Irrigation estimates assume 37.7 cm/hectare of irrigation per year multiplied by number of hectares irrigated. Public water supply and domestic estimates assume 473 liters per day per person multiplied by estimated municipal population through time. Other well use estimates assume pumping 4 hours per day at pumping rate reported on Nebraska Department of Natural Resources registration form.

domestic wells is not uniform across the study area. Lancaster Rural Water District #1 (LRWD1) supplies domestic water in the northern one-third of the study area, where aquifers are highly localized or absent (Fig. 1). LRWD1 obtains water from the paleovalley aquifer several miles east of the study area and this water is distributed to residences lying generally to the north and east of Hickman.

Most of the 39 active registered irrigation wells in the study area were installed during the 1960's and 1970's, although several were installed during the period 1997-2007 and a few during 1956-1958. Most of these wells are screened in the Dorchester-Sterling paleovalley aquifer and their yields are typically between 600 and 2000 gpm (Fig. 1). Although there are no systematically collected groundwater-use data for the area, estimates show that irrigation withdrawals almost certainly constitute the largest use of water (Fig. 4).

The 15 public water supply wells in the area include municipal wells and wells used for water supply at public areas such as parks and schools. Nine of these wells are municipal wells for the villages of Hickman, Firth, and Holland (Lancaster County Sanitary Improvement District #3). Most of these wells are screened in the paleovalley aquifer, although a few of the Hickman wells are in a shallower glacial aquifer.

The population of the study area is likely to grow in coming decades, thereby increasing demands on domestic and public water supplies (NDED, 2013). No commercial or industrial wells exist in the study area as of May, 2011, but some development of groundwater for these uses may be expected in the future with population growth and the potential expansion of business and industry to Lincoln's suburban fringe. The number of irrigation wells, however, has probably reached its maximum because most irrigable lands in the area are currently irrigated. The actual quantity of groundwater used for irrigation in the future will depend on climatic conditions, practices for irrigated farming, and the types of crops under cultivation.

5. Materials and Methods

5.1. Collection and Compilation of Geophysical and Geologic Data

A helicopter electromagnetic (HEM) and magnetic survey was conducted over the study area in March, 2007. Detailed specifications of this survey are contained in Smith et al. (2008) and are briefly summarized here. The survey consisted of fifty two east-west traverses with ~280 m spacing and two north-south tie lines with ~6 km spacing for a total of 397.9 line km (Fig. 5). Apparent resistivity values were derived from electromagnetic field measurements at six separate frequencies. Apparent resistivities were later transformed into resistivity-depth values using inversion algorithms as described in Smith et al. (2011). The vertical resolution decreases from ~1 to 15 m as depth increases. The horizontal resolution is 3 m. Interference from power lines and other structures was monitored in the 60 Hz signal (Fig. 5). Data from the HEM survey was collected and reported in metric units. Some of the other data was originally collected in U.S. Standard units and then subsequently converted to metric. We have used metric units throughout this report to facilitate direct comparison with the HEM data.

Eleven test holes were drilled in 2007 as a part of this study (Fig. 5). Cores were obtained from seven of these test holes using a split-spoon auger-rig system. Augers were advanced until bedrock was encountered or auger penetration was denied by the resistance of unconsolidated materials. If auger penetration was denied before reaching bedrock, mud rotary drilling was used at the same location to advance the test holes into bedrock.

Downhole geophysical logs (gamma ray, resistivity, and caliper) were recorded for almost the full depth of each mud rotary borehole while drilling mud was still present in the boring. Normal-resistivity logs measure apparent resistivity of the subsurface, and may need to be corrected for bed thickness, borehole diameter, mud-cake thickness, drilling fluid invasion, and other factors to determine true resistivity (Keys, 1990). No such corrections were made in this report, but on the basis of comparisons with other studies involving HEM (Palacky and Stevens, 1990; Best et al., 2006), we surmise that our uncorrected downhole logs yield a range of resistivity values that could be considered typical for unconsolidated sediments. Two resistivity curves were recorded, long-normal (64n) and short-normal (16n). Long-normal curves are generated using electrodes spaced 64-inches apart, short-normal using electrodes spaced 16-inches apart. The apparent resistivity value is recorded at the mid-point between the electrodes. Short-normal probes are considered to investigate only the zone immediately adjacent to the borehole which likely contains drilling fluid, while long-normal probes are capable of investigating a larger subsurface volume potentially including native formation water (Driscoll, 1986). However, long-normal probes are very sensitive to bed thickness, which can make the logs difficult to interpret, especially if the bed thickness is equal to or less than the electrode spacing (Keys, 1990). The 2.5 m-long tool used in this study requires between 2.5 and 3 m of insulation above the cable head. Therefore, resistivity logs begin at 5 m depth, the point at which the uninsulated cable comes into contact with the drilling fluid (Century Geophysical Corporation, 2007).

A gamma log records the total gamma radiation detected in a borehole that is within a certain energy range (Keys, 1990). The most significant naturally occurring, gamma-emitting radioisotopes are potassium-40 and daughter products of the uranium- and thorium-decay series. Potassium is abundant in some feldspar and mica that decompose to clay, while uranium and thorium are concentrated in clay by the processes of adsorption and ion exchange (Keys, 1990). For these reasons, gamma logs exhibit an increase (spike to the right) when clay and shale units are encountered.

Caliper logs continuously record the diameter of the borehole, which is a necessary piece of information in interpreting the normal-resistivity and other geophysical logs (Keys, 1990). Caliper logs also provide information regarding lithology. For example, unconsolidated sand and gravel units may slough and result in a borehole diameter larger than the drilling bit, a clay unit may swell to produce a borehole diameter smaller than the bit, while a consolidated rock unit would be expected to maintain a diameter consistent with the drill bit.

Cores were collected and described in the field or laboratory by geologists. Cuttings collected from mud rotary drilling were described in the field by geologists. Analysis of sand, silt, and clay fractions was conducted on selected core samples using a Malvern laser particle-size analyzer. Samples were prepared with hydrochloric acid to remove carbonates and sodium hexametaphosphate to disaggregate clays prior to particle-size measurement. Gravel percentages were estimated based on gravel weight relative to total sample weight. Because these gravel measurements were done on very small sample sizes, two categories of less than and greater than 20% gravel were used. Test-hole cuttings and cores collected during this project are archived at

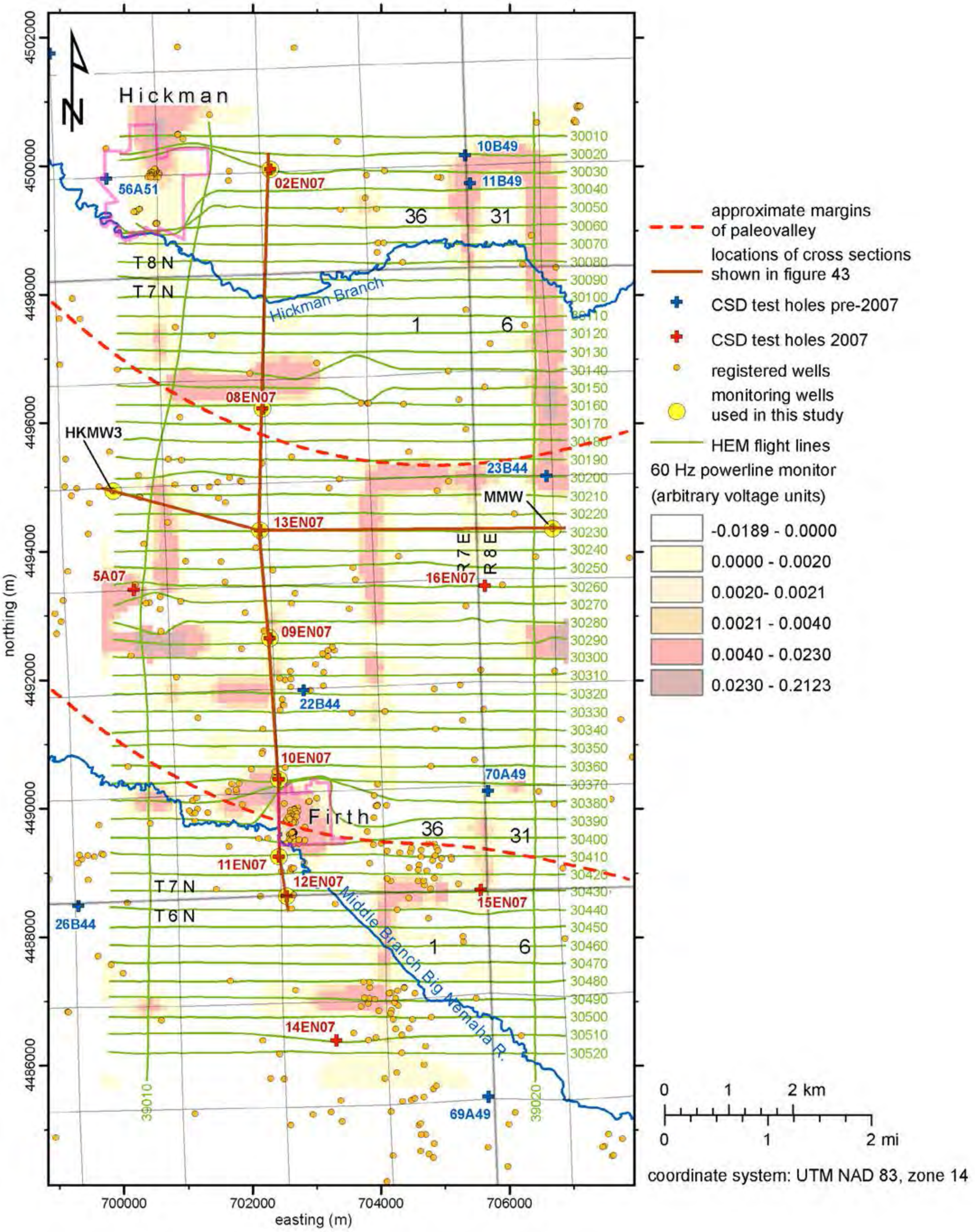


Figure 5. Map of study area showing locations where subsurface data were collected. HEM flight lines are paths taken by helicopter during data acquisition. Some flight paths deviate from east-west orientation because helicopter is not allowed to fly over cultural areas such as towns, schools, and housing developments. High values in powerline monitor show areas of interference. Monitoring well locations are the sites of nests of 2 – 4 wells. Data from existing (blue) and new (red) CSD test holes were used.

CSD. Locations of the logs, depths, and coring type are given in Table 1. Sediment descriptions, geophysical logs, particle size analyses, and stratigraphic units for the CSD test holes collected for this project are given in Figures 6-18. Additional data were compiled from existing CSD test holes (Burchett and Smith, 2003) as well as from drillers' logs contained in the Department of Natural Resources (DNR) registered wells database (NDNR, 2009).

A wide variety of descriptive terms for geological materials appears in the various databases used in this study. In CSD test holes, the range of terms used in the descriptions of cuttings and cores has been standardized (Korus et al., 2011b). In the logs of wells registered with the DNR, however, there is no such standardization and several non-scientific terms have been applied to geologic materials encountered by drilling. This assortment of terminology complicates the effective combination of data from different sources, and therefore we established standardized sets of descriptive terms (keywords) to classify unconsolidated materials and bedrock lithologies encountered in this study. For the CSD test-hole database, sixteen keywords were used (clay; clay and silt; fill; gravel; limestone; limestone and shale; sand; sand and clay; sand and gravel; sand and silt; shale; silt; silt and clay; silt and sand; soil; till). Only eight keywords were used in the DNR database (fill; gravel; limestone; sand; sand and gravel; sandstone; shale; silt, clay or till), but only two of these are not employed in the CSD database. Some of the keywords used in the DNR database differ from those used in the CSD database because individual terms employed by well drillers may refer to multiple lithologies simultaneously. For example, "clay" in a driller's log may actually refer to loess or other silts, glacial till, weathered shale bedrock, or clay in the strict geologic sense. Likewise, even though the term "shale" and "limestone" may have been applied accurately in some cases, comparison with CSD test-hole logs indicates that the term was applied erroneously in other cases to unlithified sediments such as clays, silts, or till, and zones of authigenic carbonate nodules within unconsolidated sediments. Both sets of keywords represent a narrower range of lithologies than the original databases. Such simplifications facilitate the interpretation of geologic data at a scale of resolution that is directly relevant to our study. Therefore, because of all these considerations, a total of 18 keywords were used (Fig. 6) in the combined dataset. The physical characteristics implied by individual keywords allow those keywords to be placed in two groups that correspond to broad ranges of hydraulic conductivity: one generally characteristic of aquifers (e.g. sand, gravel, and similar lithologies) and the other generally characteristic of aquitards (e.g. clay, silt, till, and similar lithologies).

We used queries in Microsoft Access to rapidly assign keywords to lithologic log descriptions in both the CSD and DNR databases. In the DNR registered well database, we searched for the multiple informal terms that have been used to describe any given keyword lithology. For example, we grouped "silt", "clay", "till", "blue clay", "yellow clay", "lean clay", "fat clay", and similar terms under a single corresponding keyword: "silt, clay, or till". These terms were grouped under the same keyword because of the lack of quality control in the DNR database relative to the CSD database. Through comparisons of the logs from DNR-registered wells to CSD test holes in the same small area, for example, it is clear that terms such as "blue clay" refer to intervals that may include loess, till, glaciolacustrine sediments, silts, or some combination thereof. In another example, we grouped terms such as "silty sand" and "gravelly sand" under the keyword "sand" because it is the primary descriptor in both cases. In the CSD database, much less grouping of descriptors was performed because the consistency of operational procedures, the description of cuttings by geologists, and the pre-standardization of terms confers greater quality control.

Table 1. - *New and existing test holes used in this study*

Test hole ID	Year drilled	Cored depth (m)	Rotary depth (m)	Easting (m)	Northing (m)	Elevation (m)	Geophysical logs
02EN07	2007	26.2	26.8	702275.0	4499951.7	406.6	R, G, C
05A07	2007	36.6	115.2	700153.3	4493404.6	428.0	R, G, C
08EN07	2007	21.3	36.3	702151.3	4496224.7	387.0	R, G, C
09EN07	2007	29.0	114.6	702271.1	4492650.0	429.9	R, G, C
10EN07	2007	22.9	96.9	702407.4	4490458.0	416.5	R, G, C
11EN07	2007	15.2	56.4	702410.6	4489251.4	402.4	R, G, C
12EN07	2007	18.3	86.9	702530.8	4488636.5	420.9	R, G, C
13EN07	2007	na	100.0	702117.5	4494331.2	420.2	R, G, C
14EN07	2007	na	42.1	703304.7	4486390.5	426.3	R, G, C
15EN07	2007	na	76.2	705552.8	4488737.2	427.7	R, G, C
16EN07	2007	na	115.2	705620.6	4493468.2	430.7	R, G, C
3A54	1954	na	9.5	698815.5	4501752.2	381.2	none
56A51	1951	na	9.4	699695.7	4499802.6	376.0	none
10B49	1949	na	15.2	705288.1	4500169.8	409.1	none
11B49	1949	na	36.6	705362.7	4499732.8	404.4	none
69A49	1949	na	38.3	705653.6	4485510.9	412.6	none
70A49	1949	na	118.6	705645.0	4490274.5	423.4	none
22B44	1944	na	99.7	702769.0	4491846.4	416.3	none
23B44	1944	na	74.1	706551.9	4495176.8	406.0	none
26B44	1944	na	56.1	699262.4	4488486.5	424.6	none

note: particle size analyses are available for all cored intervals
R: resistivity, G: gamma-ray, C: caliper
Coordinate system: UTM NAD 83 Zone 14

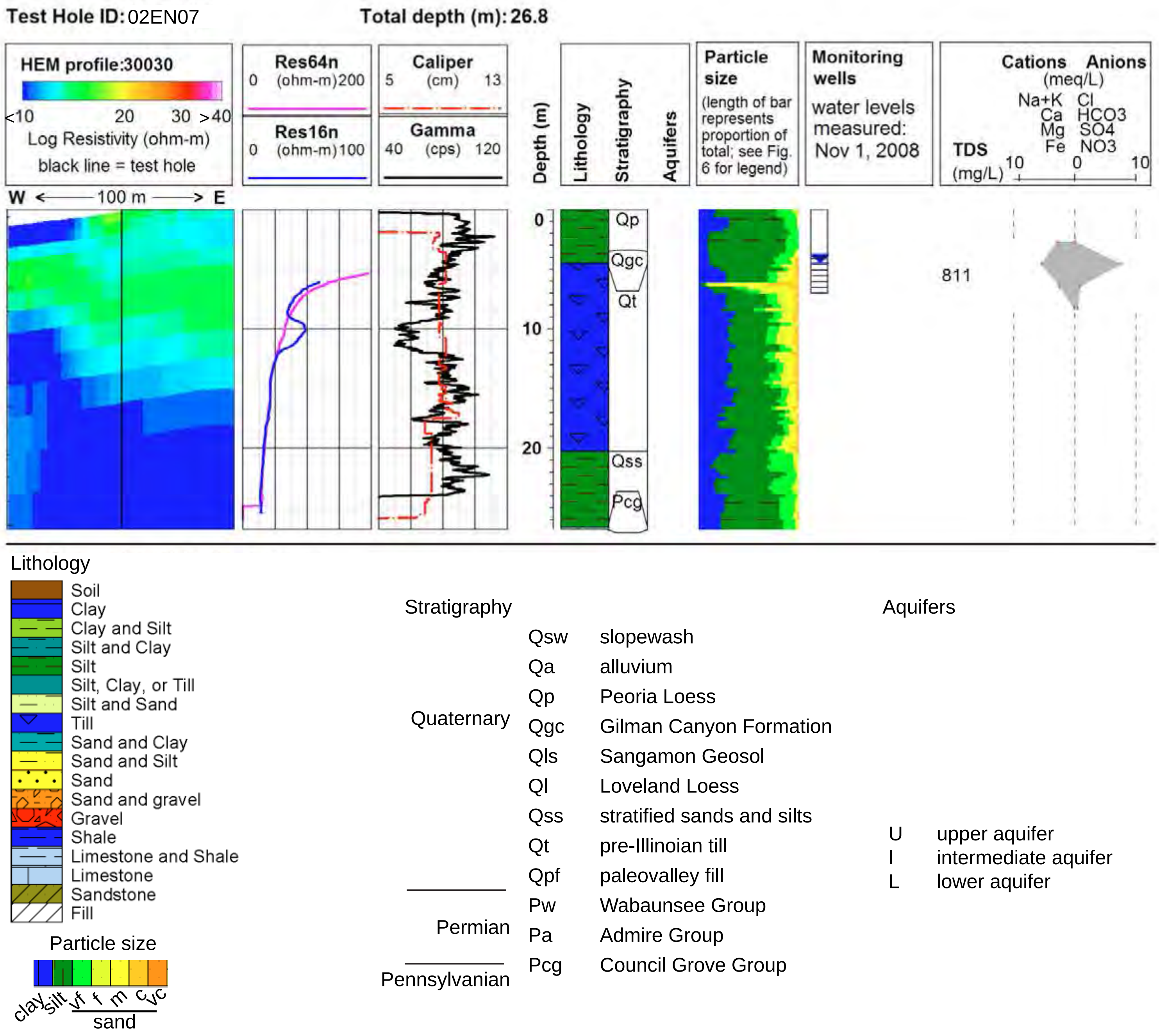


Figure 6. Summary of subsurface data at 02EN07. See Figure 5 for all test hole locations. Legend at bottom is used for figures 6 through 18. Geophysical logs are wrapped such that values greater than maximum (right) continue starting at minimum (left). Vertical line in HEM profile indicates approximate position of borehole.

5.2. Site Selection, Installation, and Instrumentation of Monitoring Wells

Nested monitoring wells were installed so that water-chemistry and water-level data could be collected from multiple hydrostratigraphic units. Thirty monitoring wells were installed at nine different locations (Table 2; Fig. 5). Two wells were drilled prior to this study. The remaining wells were drilled during two separate phases: May – August 2008 and November 2008. The locations and screened intervals of the wells were chosen so that water samples and hydraulic heads from a variety of aquifers could be investigated. Phase I wells were located at seven of the test-hole locations along the north-south transect near the center of the study area (Fig. 5). Phase II wells include three additional wells along the north-south transect and five wells at two additional locations not located at the sites of pre-existing test holes (Fig. 5). Screened intervals for wells on the north-south transect were selected based on geologic and down-hole geophysical logs from the pre-existing test holes. Screened intervals for the remaining two locations were based on the field log generated during drilling. The naming convention for the wells is such that the numbers preceding the hyphen refer to a specific test hole and the numbers after the hyphen denote the

Table 2. - *Well construction data for monitoring wells in this study*

Test hole ID	Well registration number	Well names[a]	Screened interval		Land surface elevation[b] (m)	construction date
			top (m)	base (m)		
02EN07	G-150176	02EN07-23	3.96	7.01	407.91	8/1/2008
08EN07	G-150177	08EN07-15	1.52	4.57	387.28	8/1/2008
	G-150178	08EN07-42	11.28	12.80	387.28	8/1/2008
13EN07	G-150054	13EN07-40	10.67	12.19	421.97	5/5/2008
	G-151459	13EN07-145	42.67	44.20	421.87	11/17/2008
	G-151460	13EN07-190	54.86	56.39	421.60	11/17/2008
	G-151461	13EN07-280	83.82	85.35	421.87	11/18/2008
09EN07	G-150179	09EN07-85	22.86	25.91	430.29	6/4/2008
	G-150180	09EN07-135	39.62	41.15	430.29	6/4/2008
	G-150181	09EN07-218	64.92	66.45	430.29	6/5/2008
	G-150182	09EN07-320	96.01	97.54	430.29	6/9/2008
10EN07	G-150183	10EN07-40	9.14	12.19	414.80	6/10/2008
	G-150184	10EN07-135	39.62	41.15	414.80	6/11/2008
	G-150185	10EN07-235	70.10	71.63	414.80	6/12/2008
	G-150186	10EN07-290	86.87	88.39	414.80	6/13/2008
11EN07	G-150187	11EN07-35	7.62	10.67	401.06	6/16/2008
	G-150188	11EN07-63	17.68	19.20	401.06	6/17/2008
	G-150189	11EN07-105	30.48	32.00	401.06	6/17/2008
	G-150190	11EN07-150	44.20	45.72	401.06	6/17/2008
12EN07	G-150223	12EN07-86	23.17	26.21	415.23	6/19/2008
	G-150222	12EN07-140	41.15	42.67	415.23	6/19/2008
	G-150221	12EN07-190	56.39	57.91	415.23	6/19/2008
	G-150220	12EN07-253	75.29	76.81	415.23	6/18/2008
Hickman monitoring well #3 (HKMW3)	G-151876J	HKMW3-50	12.34	15.39	394.93	12/4/2007
	G-151406	HKMW3-135	39.62	41.15	394.93	11/20/2008
	G-151407	HKMW3-235	68.58	71.63	394.93	11/19/2008
Matthes monitoring well (MMW)	G-151447	MMW-125	36.58	38.10	425.38	11/12/2008
	G-151404	MMW-180	53.34	54.86	425.38	11/13/2008
	G-131363	MMW-260	73.15	79.25	425.38	11/22/2004
	G-151446	MMW-290	86.87	88.39	425.38	11/14/2008

[a] The naming convention for the wells is such that the numbers preceding the hyphen refer to a specific test hole, and the numbers after the hyphen denote the well depth in feet. Standard units were employed exclusively by the drilling crews and the names of wells were already established prior to the writing of this report.

[b] Elevations of monitoring wells may be different than those listed in Table 1 because of small differences in locations of test holes compared to monitoring wells

well depth in feet (Table 2). Although metric units are employed in this study, standard units were employed exclusively by the drilling crews and the names of wells were already established prior to the writing of this report and cannot be changed.

All of the wells were installed using mud rotary techniques. Well casings and screens are flush-threaded 2.5-inch diameter polyvinyl chloride (PVC). Each well within a nested site is installed in a separate borehole according to State of Nebraska regulations. The annular space above the screen and filter pack is filled with bentonite grout. The annulus was back flushed prior to installing the sand pack and grout. EZSeal grout was mixed in a grout mixer and tremmied down the hole. The wells were developed by air lifting until the water was clear. Table 2 summarizes monitoring well construction details.

Dedicated Grundfos submersible pumps are installed in 16 of the 30 wells at the time of this report. The remaining wells are sampled either with a portable Grundfos pump or bailed. An In-Situ LevelTROLL 500 pressure transducer was installed in each of the Phase I wells until May of 2010 when some of these transducers were removed and reinstalled in Phase II wells.

By October 2008, In-Situ Level TROLL 500 gauge pressure transducers were installed in each of the 20 Phase I wells. One of these transducers (11EN07-35) is part of the Conservation and Survey Division (CSD), School of Natural Resources, University of Nebraska real-time monitoring network. Since installation, two of the transducers have malfunctioned. The transducer that failed in well 10EN07-135 was replaced, but the instrument that failed in well 12EN07-290 was not. In April 2010, five of the remaining transducers installed in Phase I wells were removed. These transducers were chosen for removal because their records were the same as other transducers in the same well nest. In May 2010, transducers were installed in nine of the ten Phase II wells (all except MMW-180). All of the transducers are hung from vented cables and therefore automatically correct for barometric pressure changes. Pressure readings are recorded once an hour and converted to depth below the measuring point, which is the top of the PVC well casing. These depths are subtracted from the surveyed elevation of the well casing to determine water elevation in the well.

5.3. Groundwater Chemistry

All monitoring wells were sampled on multiple occasions between September 2008 and November 2010, resulting in a total of 168 samples. Sampling techniques included low flow, bailing, and pumping to dry and returning to collect sample. Low flow was the preferred technique; however, well depth, yield, and accessibility limitations resulted in the variety of sampling techniques. Samples were analyzed for dissolved metals, chloride, sulfate, total alkalinity, hardness, total dissolved solids (TDS), conductance, and nitrate+nitrite as nitrogen. The dissolved metals were field filtered and preserved with nitric acid. Nitrate+nitrite samples were preserved with sulfuric acid. Field parameters were measured using portable water-quality probes and a flow-through cell. The flow-through

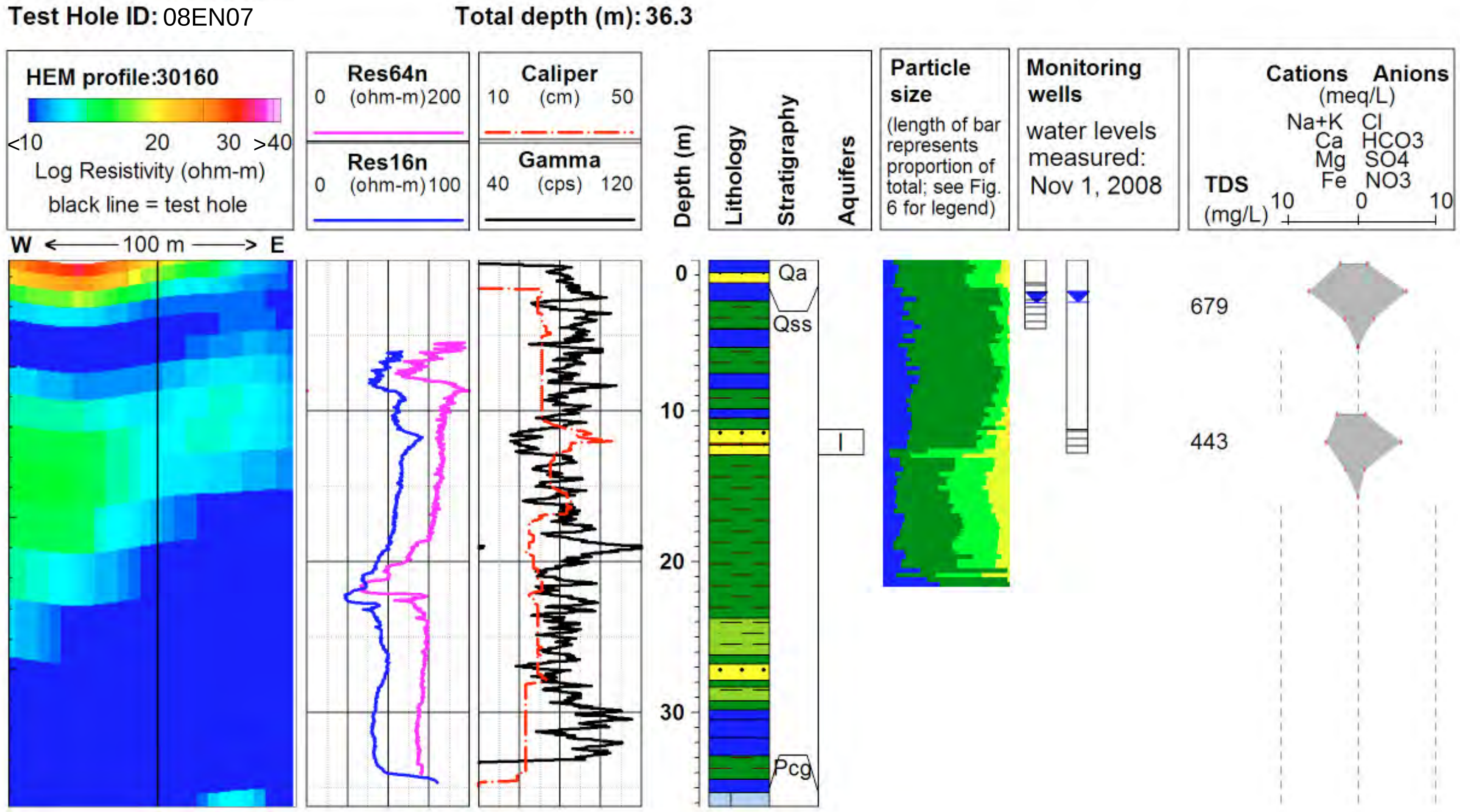


Figure 7. Summary of subsurface data at 08EN07. See Figure 5 for location and Figure 6 for legend. Vertical line in HEM profile indicates approximate position of borehole.

cell was not used at the four wells that were bailed. The water samples were analyzed by Midwest Laboratories, Inc. located in Omaha, NE. Water quality results for each well are summarized using Stiff diagrams on Figures 6 through 18. These diagrams represent the relative proportions of each major cation and anion in milliequivalents per liter (meq/L) in the water samples taken from these wells. Milliequivalents are ionic concentrations converted to units of equivalent weight using the ionic charge and formula weight (Sanders, 1998). Chemically similar waters have similar Stiff diagram shapes.

Quality-control samples consisted of one field blank and one field duplicate per thirty samples. Equipment blanks were also collected during three sampling events. The laboratory reported the results of method blanks, lab duplicates, lab control samples, and matrix spikes for one sampling event (3Q 2009). In this report, analytical results are qualified based on holding time, field blanks, equipment blanks, and field duplicates. Qualification of sample results was performed according to the U.S. Environmental Protection Agency (EPA) Contract Laboratory Program (CLP) Guidelines (USEPA, 1994). Quality assurance and analytical results are tabulated in Appendix A.

Appropriate holding times for samples are specific to analytical methods (USEPA, 1994). There were nine holding time violations in this data set, all for TDS, for which the holding time is seven days. The results were qualified as estimated (denoted by the letter J). The holding time for nitrate or nitrite determined singly using EPA Method 353 is 48 hours, though nitrate+nitrite determined together using the same method may be preserved and held for up to 28 days (O'Dell, 1993). In this study the nitrate+nitrite concentrations are not distinguished from one another. The combined concentrations of nitrate and nitrite are therefore reported as the concentrations of nitrogen.

Equipment blanks consist of deionized water passed through a bailer and tubing used during sampling. Field blanks consist of sample bottles filled with deionized water. Both types of blanks are handled in the same manner as the other samples.

Between two and seven of the analyzed compounds were found in each of the three equipment blanks collected. Three to four of the analyzed compounds were detected in each of the six field blanks collected. According to EPA CLP guidelines, if an analyte is detected in the blank and the concentration detected in the sample is not ten times the detection in the blank, the samples associated with that blank should be re-analyzed.

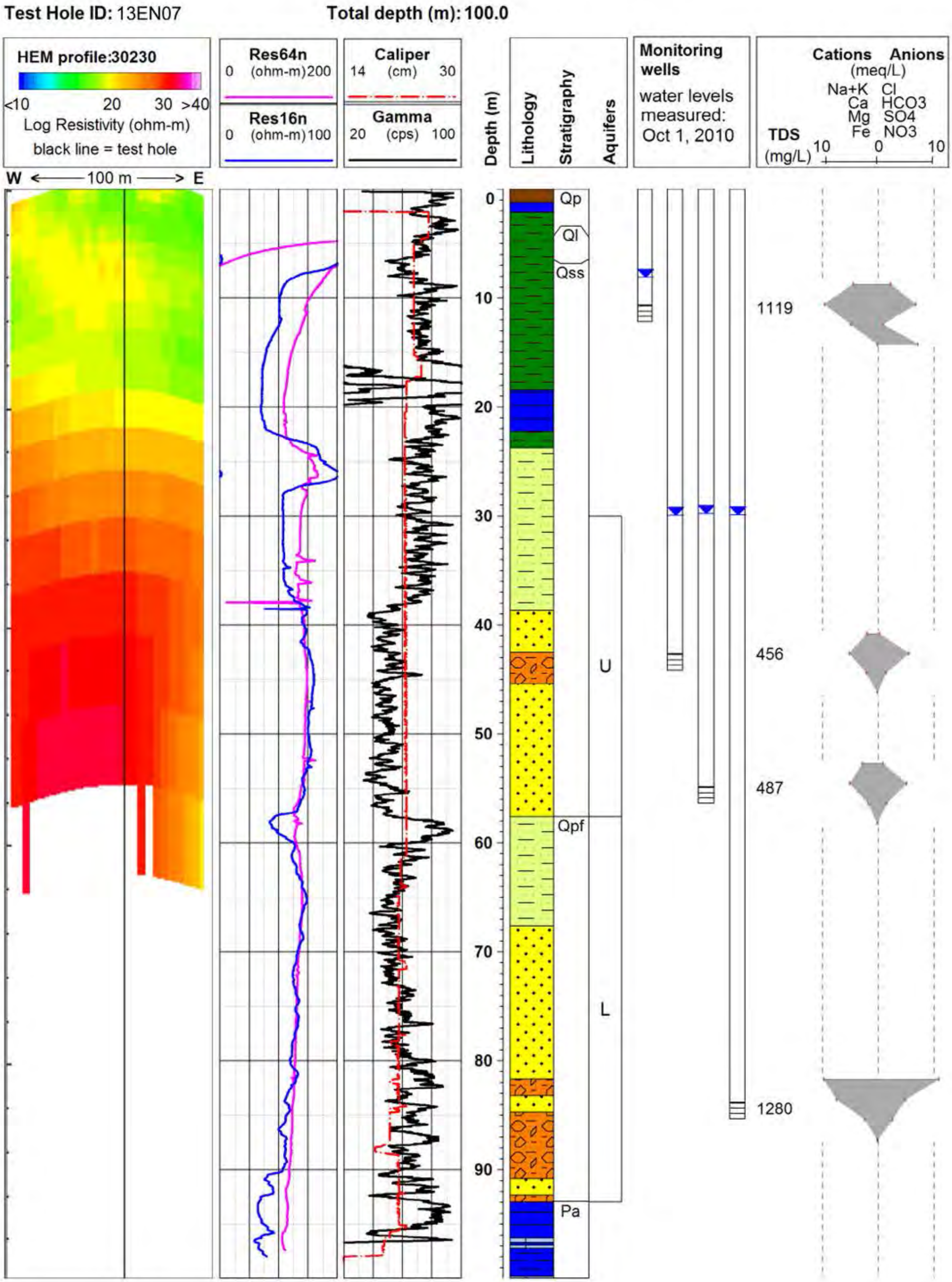


Figure 8. Summary of subsurface data at 13EN07. See Figure 6 for full caption.

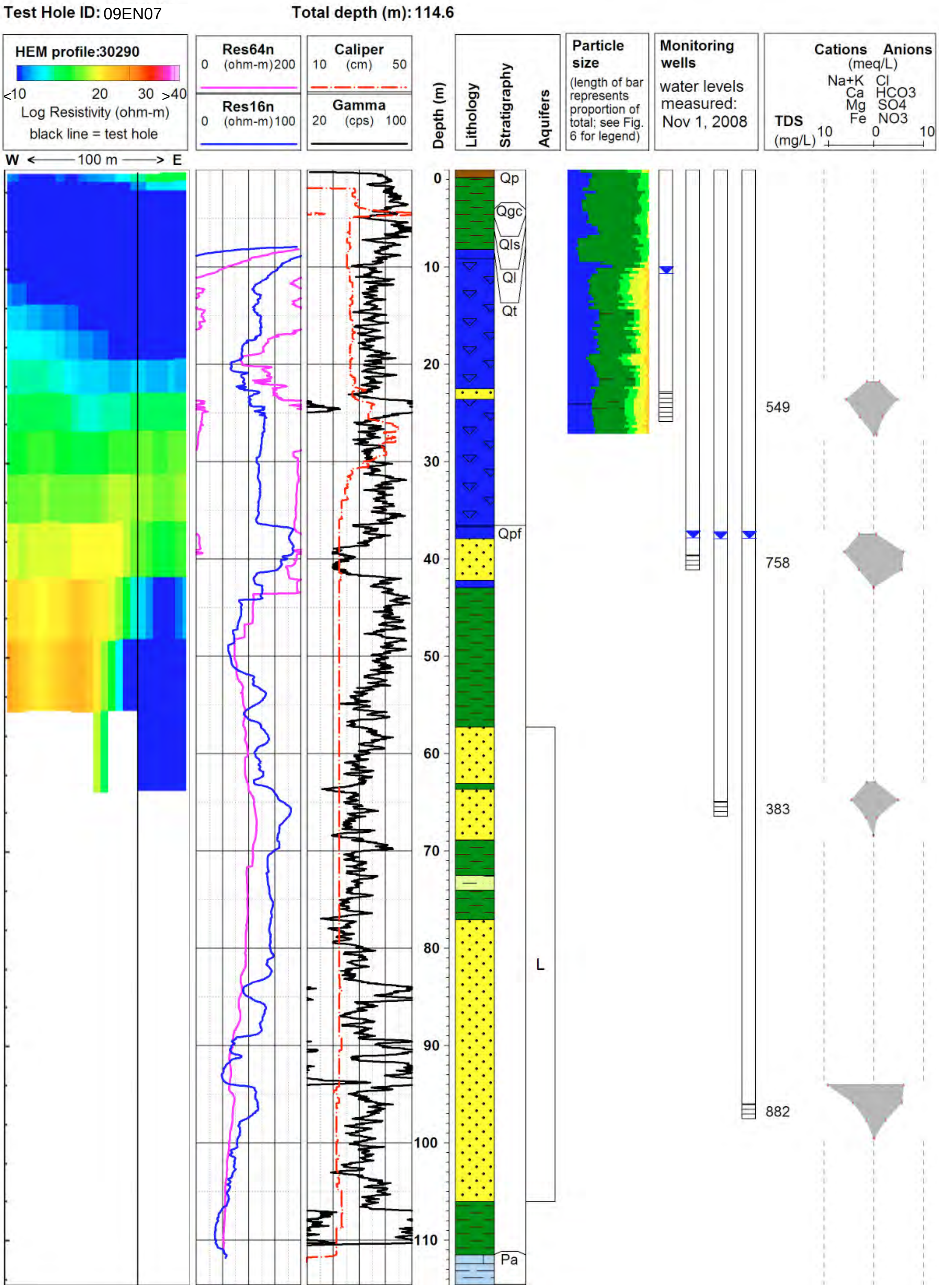


Figure 9. Summary of subsurface data at 09EN07. See Figure 6 for full caption.

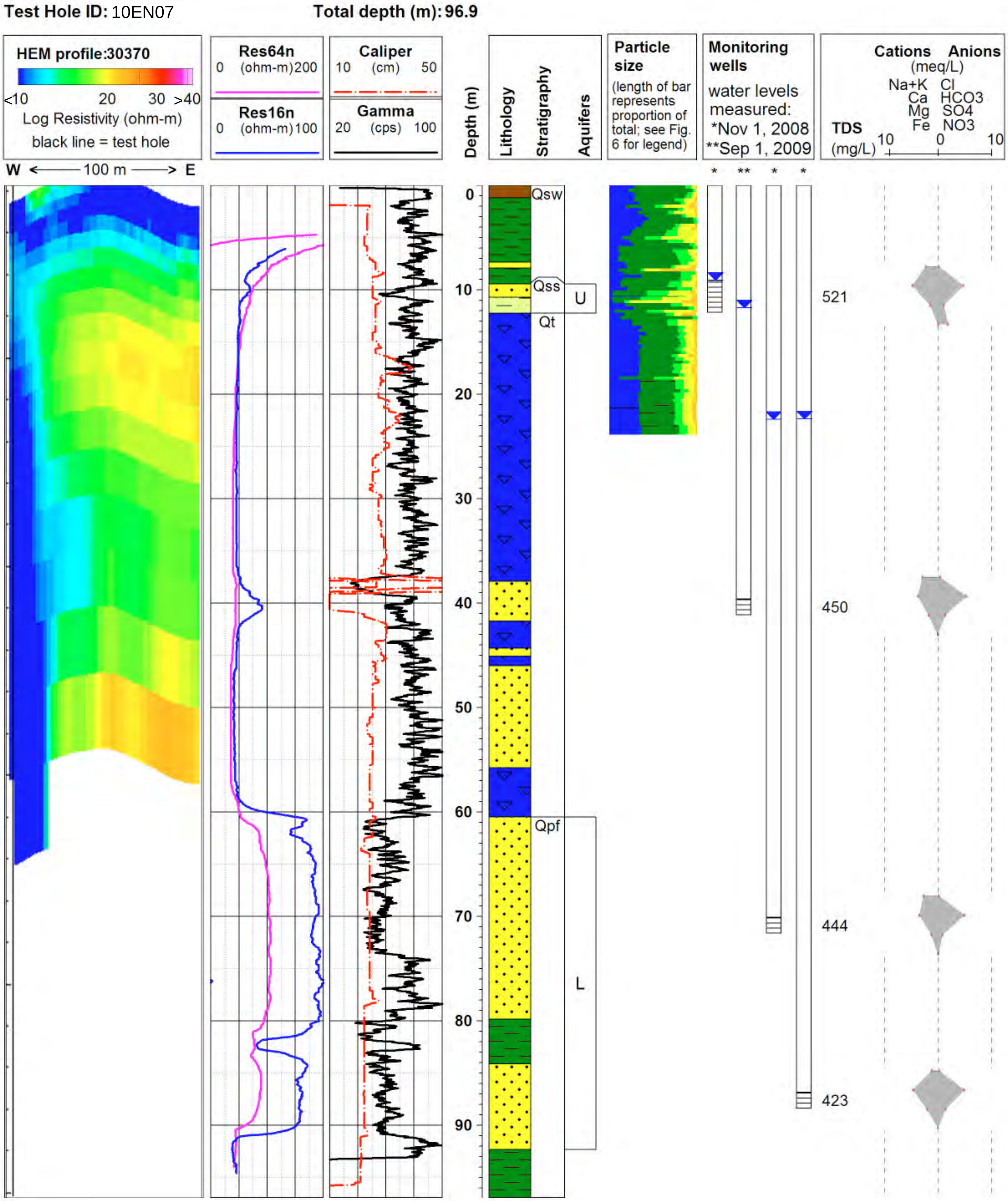


Figure 10. Summary of subsurface data at 10EN07. See Figure 6 for full caption.

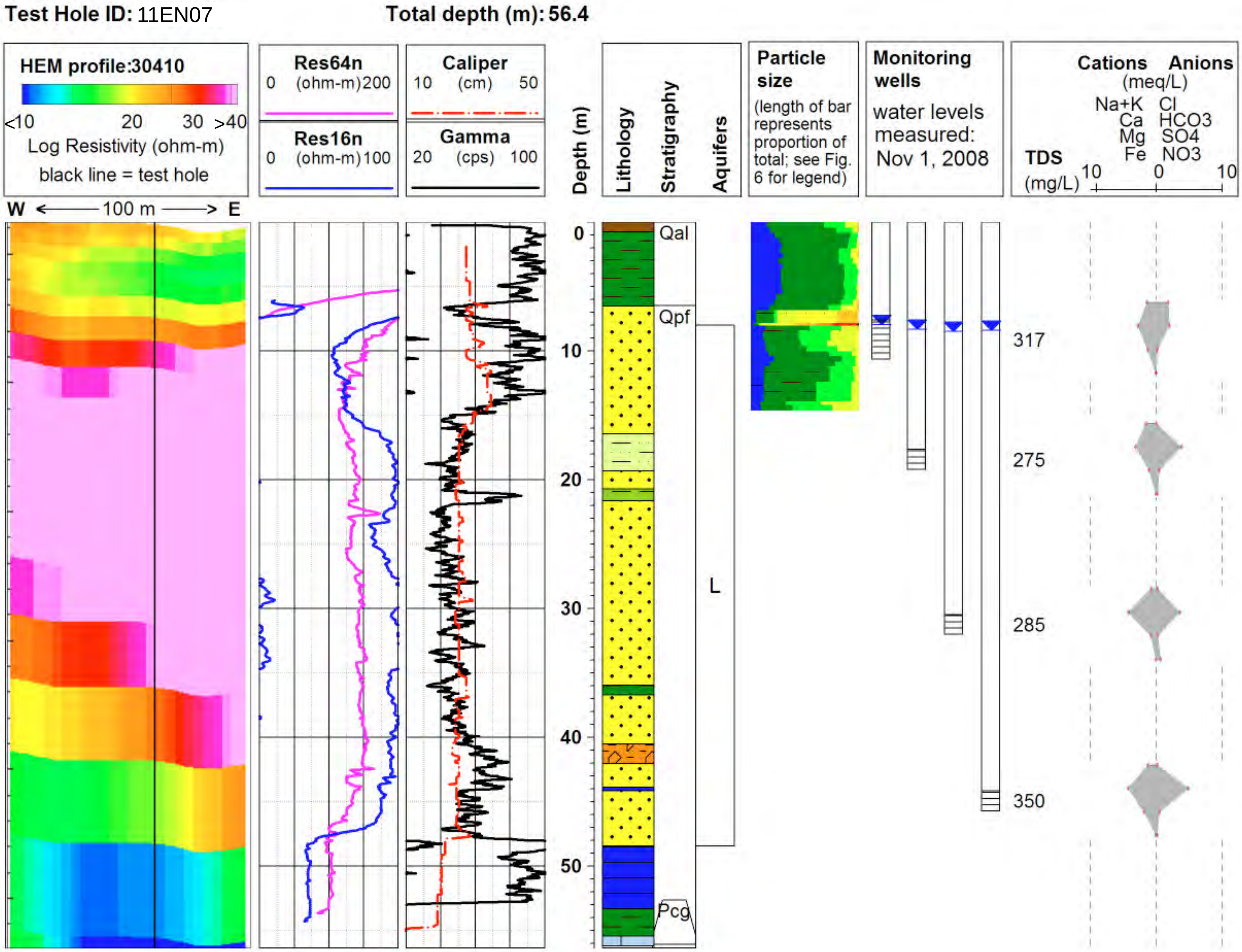


Figure 11. Summary of subsurface data at 11EN07. See Figure 6 for full caption.

If an analyte is detected in a blank and the concentration detected in the sample is not at least five times greater than the concentration detected in the blank, then the sample concentration should be qualified as undetected (denoted by the letter U) (USEPA, 1994). In this study, samples that did not have at least five times the concentration detected in the blank were qualified with a U, and the samples that contained between five and ten times the concentration in the blank were not reanalyzed or rejected, but were qualified as estimated (denoted with a J) (Appendix A). The results were not rejected because these samples are being used for informational purposes only, not for immediate decisions regarding an environmental cleanup. In Appendix A results reported as non-detect by the lab are listed with the detection limit followed by a U.

Duplicate samples consist of two samples collected from the same location in the same manner, at the same time. The results of the sample identified as the standard are compared against those of the sample identified as the duplicate. EPA CLP guidelines suggest that if the concentration of an analyte in the standard and duplicate is greater than five times the detection limit, then the percent difference between the two samples should be less than or equal to 20%. If the concentrations of an analyte are less than five times the detection limit, then the difference should be less than plus/minus the detection limit (USEPA, 1994). In this data, 48 iron samples and 29 manganese samples were qualified as estimated due to failed field duplicates.

5.4. Groundwater Levels

In this study transducer data are recorded as depth to water, which is determined by a reference level set by the user when the transducer is programmed. Inaccuracies in manually measuring the depth to water used as the reference introduce error to the values. Additionally, the accuracy of the subsequently recorded depth-to-water data depends on the transducer hanging at the same point in the well as it was when it was

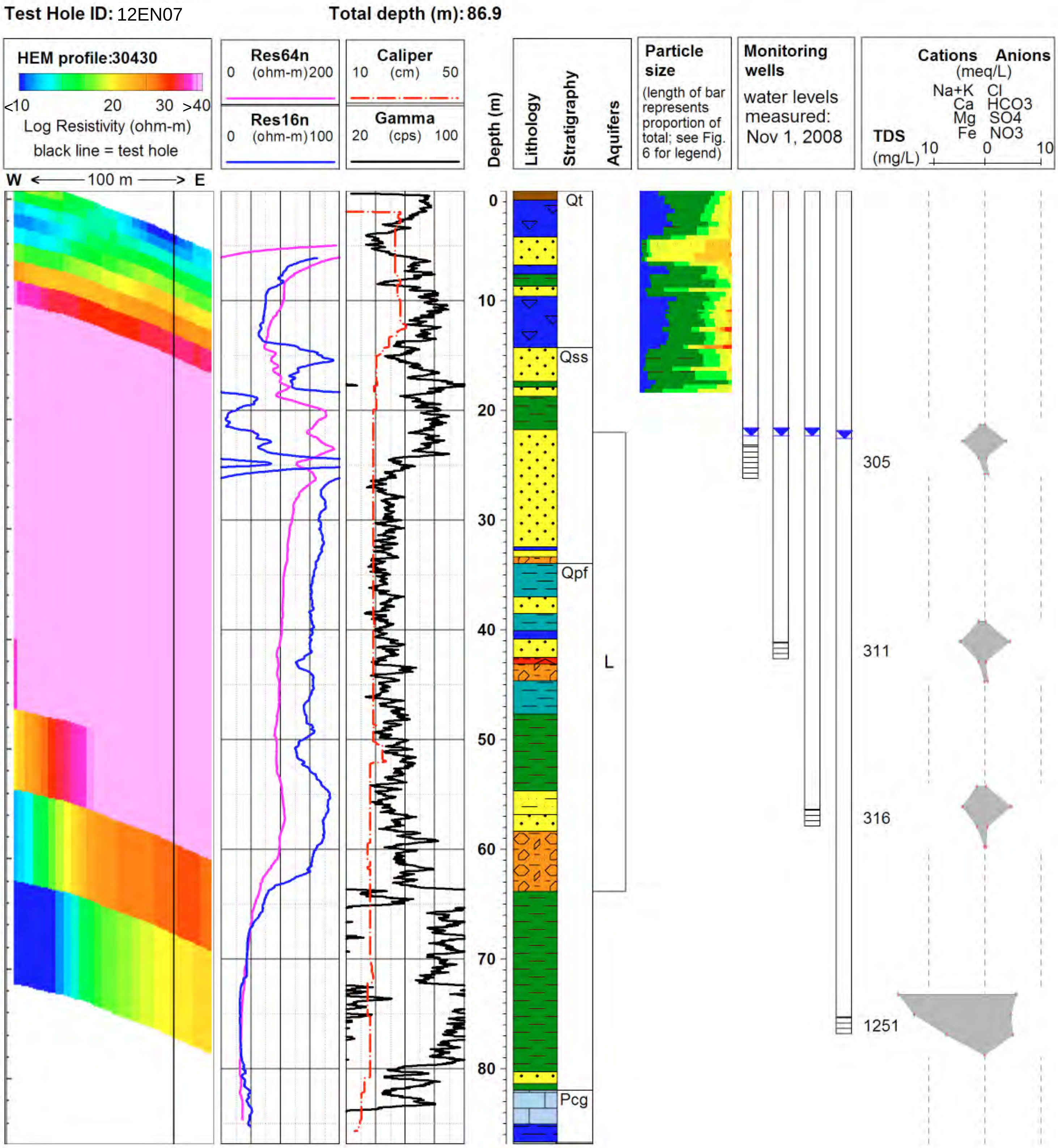


Figure 12. Summary of subsurface data at 12EN07. See Figure 6 for full caption.

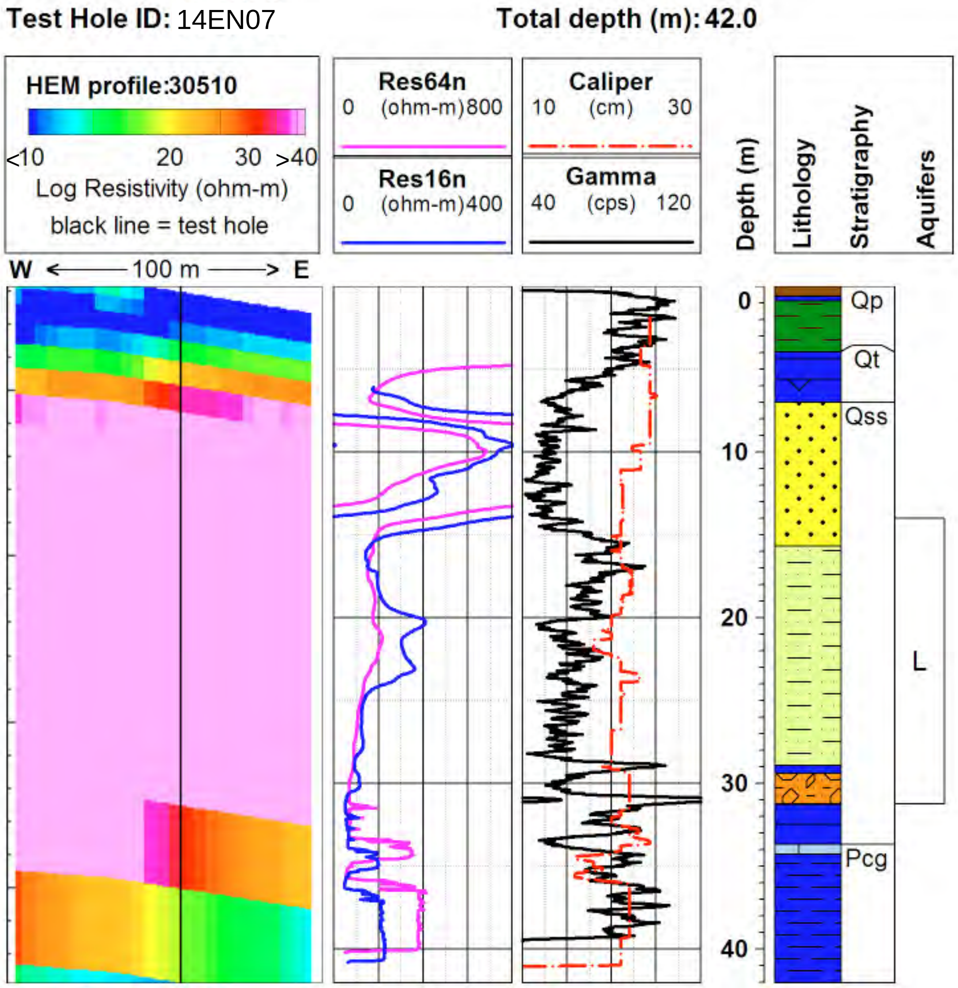


Figure 13. Summary of subsurface data at 14EN07. See Figure 6 for full caption.

programmed. That position is altered slightly when the well is accessed for manual measurements during sampling and transducer downloads. The manual reading taken during transducer download is compared to the water level measured by the transducer, as shown on the In-Situ handheld (Rugged Reader) display, and the difference recorded.

A combined water table/potentiometric surface map (Fig. 19) was prepared for the study area using data from 210 wells. These wells are screened in the Dorchester-Sterling paleovalley aquifer where it is present, but elsewhere they are screened in shallower glacial aquifers or in isolated sand units that are not mappable at the scale of this study. Some of the registered 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 reported for these wells are composites of the hydraulic heads in each saturated unit. The water level measured in any particular well was evaluated in the context of the water levels in surrounding wells. Accordingly, any value that would have suggested an extreme hydraulic anomaly, such as a very localized high or low on the water table/potentiometric surface, was discarded. The elimination of anomalous data does not compromise the overall integrity of the result because the goal of our water table/potentiometric surface map (Fig. 19) was to present average values.

Nine monitoring wells from this study and another nine wells from local and State groundwater-level monitoring networks were measured in 2010, whereas the other wells were measured by drillers during well installations since the mid-1960’s. It is possible to use data from different periods because changes in water levels since predevelopment are less than 5 feet in this area (Korus et al., 2011a). Water levels that were affected by drawdowns during the irrigation season (June through September) and those that were highly anomalous compared to neighboring wells were not used to make the water table/potentiometric surface map. Stream-surface elevations from a topographic map were used to constrain the water-table elevation in valleys.

To draw the contours shown in Figure 19, the locations of the wells and streams were plotted in ESRI ArcGIS (v. 10) and the land surface elevation was extracted from a 10-meter digital elevation model (DEM). The elevation of the water level at each well was then calculated by subtracting the depth to water measurements from the land surface elevation. A raster surface of the water elevation was interpolated with the inverse distance weighting method at 100 m grid spacing. Contours generated from the raster surface were manually smoothed.

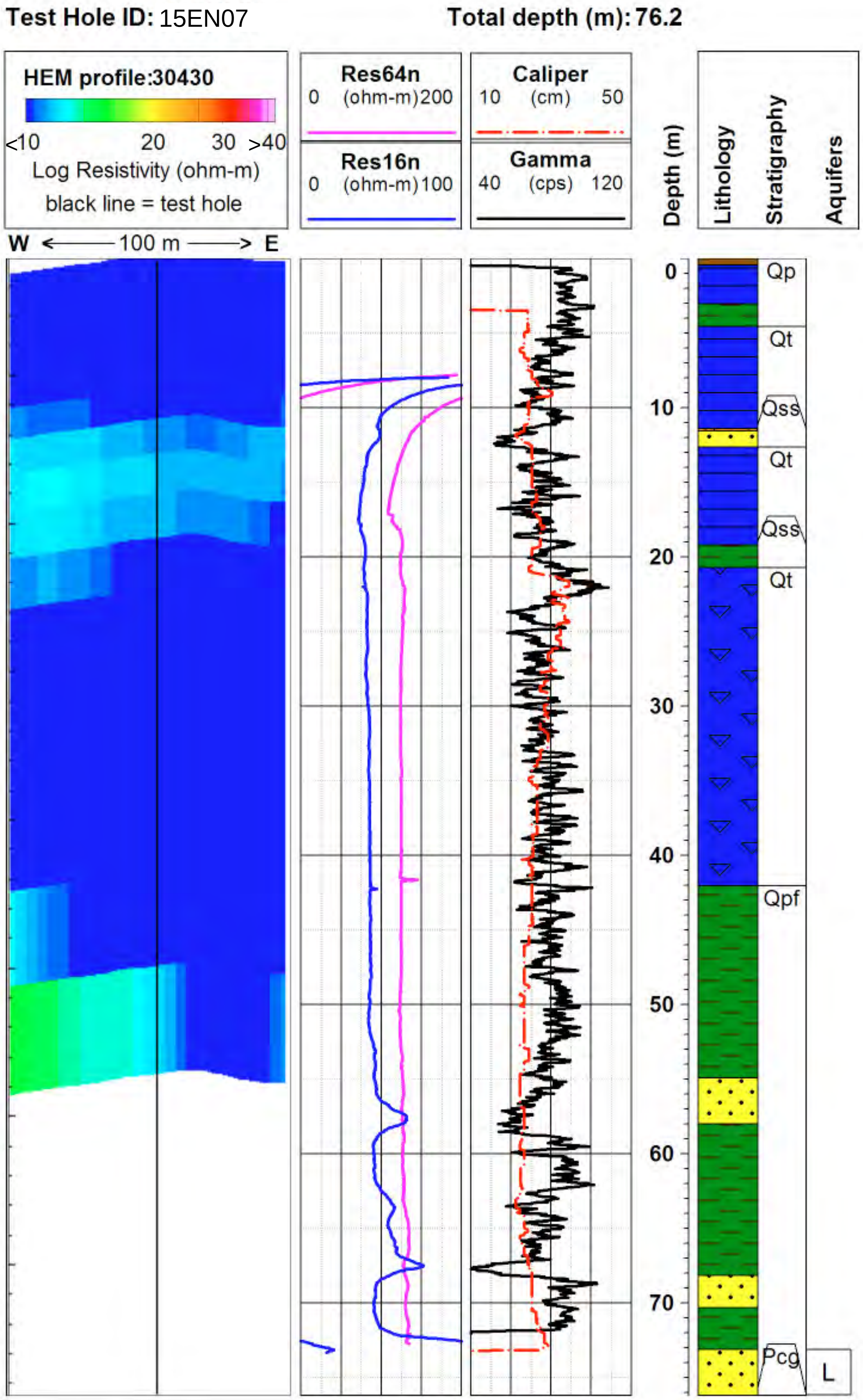


Figure 14. Summary of subsurface data at 15EN07. See Figure 6 for full caption.

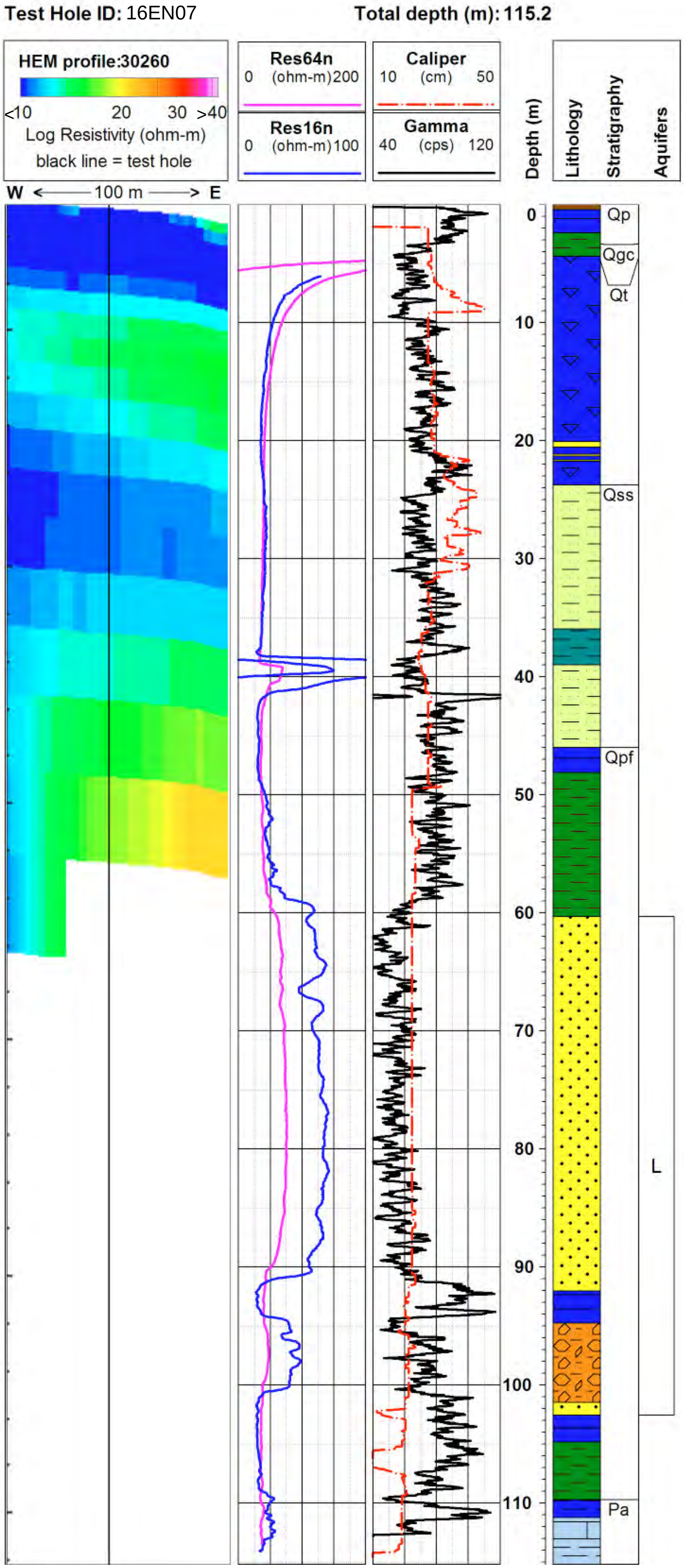


Figure 15. Summary of subsurface data at 16EN07. See Figure 6 for full caption.

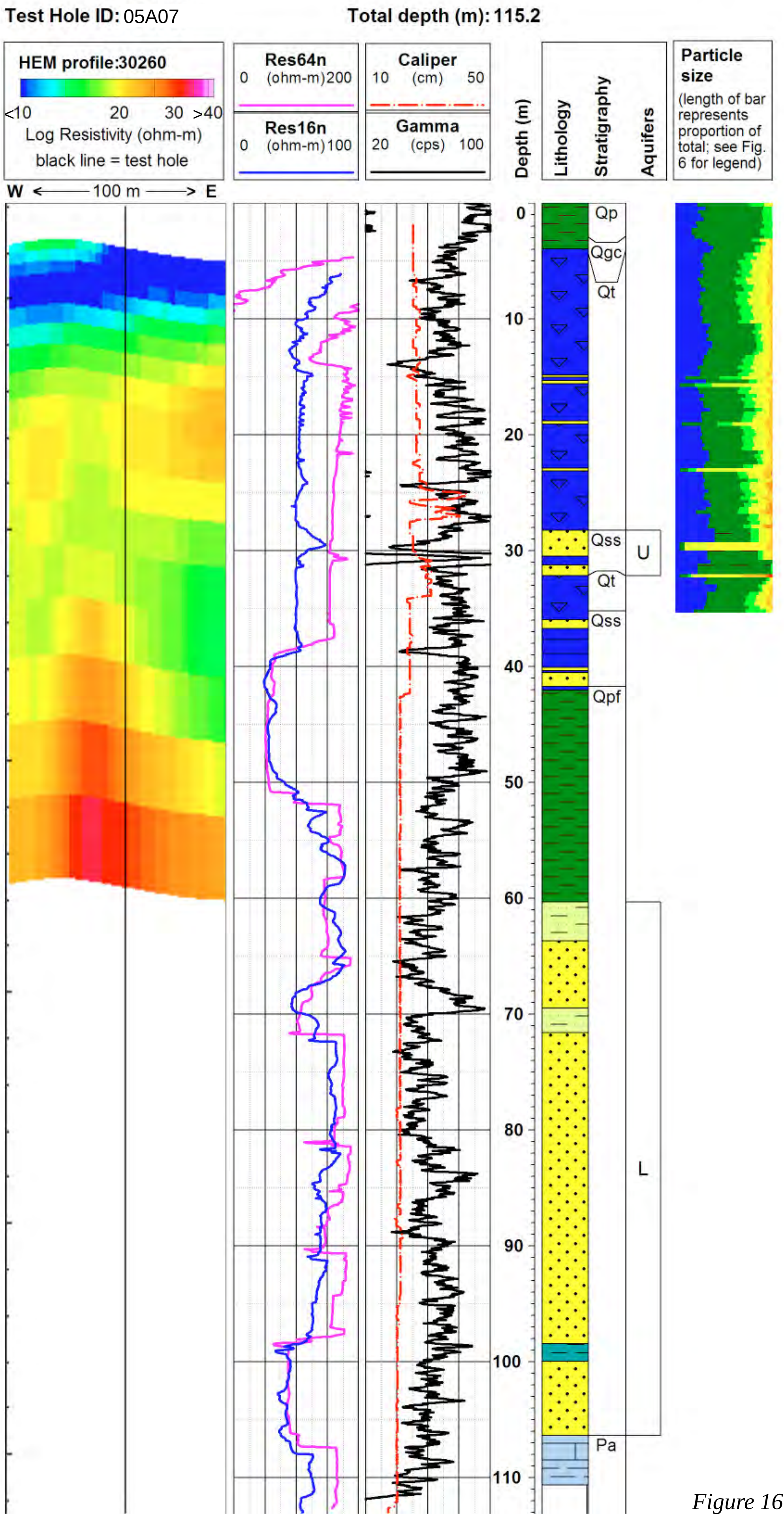


Figure 16. Summary of subsurface data at 05A07. See Figure 6 for full caption.

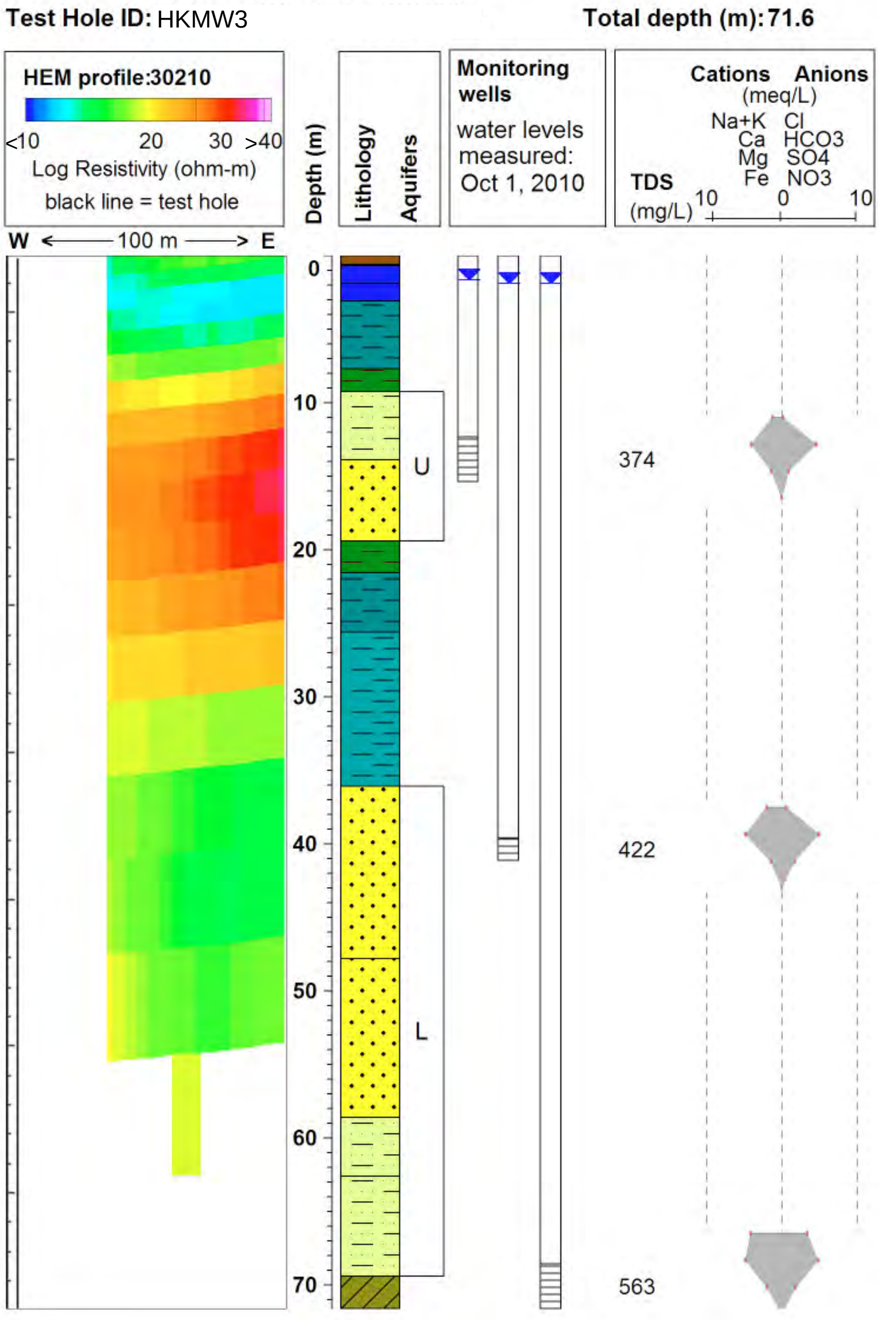


Figure 17. Summary of subsurface data at monitoring well site HKMW3. See Figure 6 for full caption.

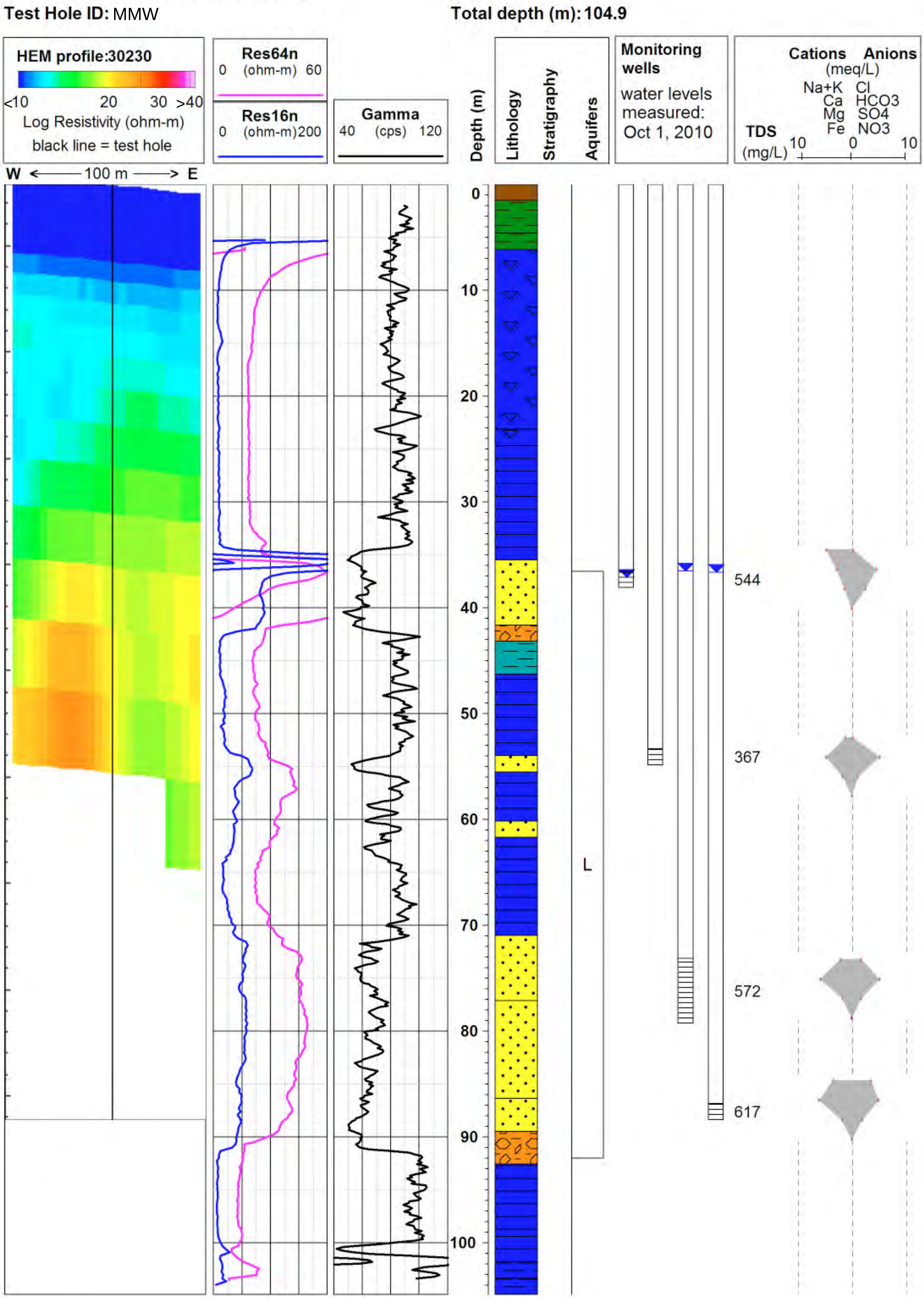


Figure 18. Summary of subsurface data at monitoring well site MMW. See Figure 6 for full caption. No water level data are available for well screened at 54m.

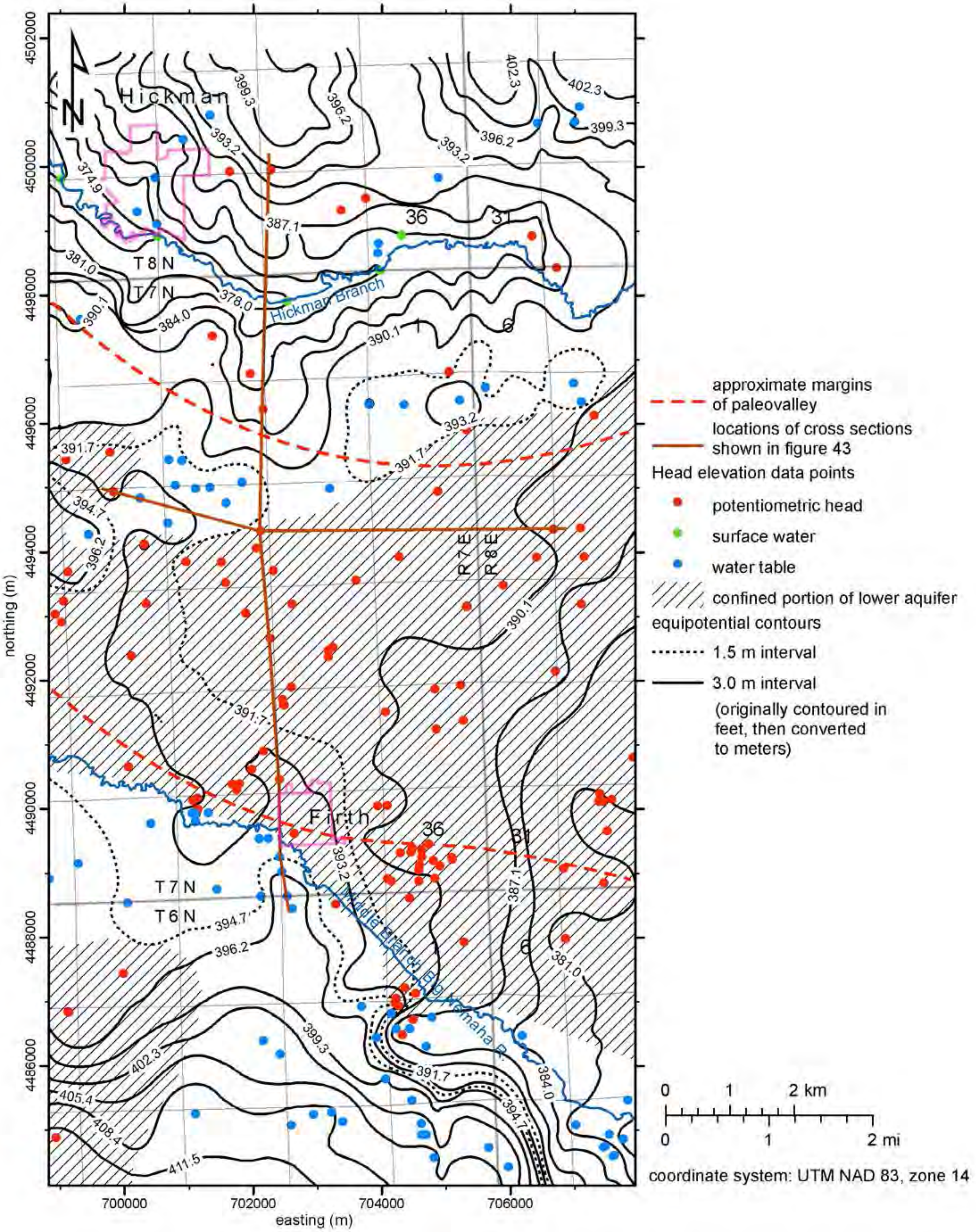


Figure 19. Combined water-table/potentiometric surface map of the study area. Hatching indicates areas of the lower aquifer that are confined and therefore the countours represent a potentiometric surface. The contours in all other areas represent the water-table elevation in the lower aquifer, superimposed lower and upper aquifers, or, in the northern one-third of study area only, the upper aquitard.

6. Results

6.1. HEM Results

HEM resistivity values range from 0 to 4060.1 ohm-m, with a median value of 19.9 ohm-m (Smith et al., 2011). The depth of investigation varies from ~50 to 80 m (Smith et al., 2011). Areas of powerline and other cultural interference were monitored in the 60 Hz frequency and are shown in Figure 5. Other cultural interference such as buildings and pipelines are not monitored by the 60 Hz powerline monitor, but they can be recognized by a distinctive, arc-shaped pattern of anomalously high or low resistivity values in the HEM (Fig. 20). Other results of the HEM survey are outlined in Smith et al. (2008) and Smith et al. (2011).

Subsurface resistivity profiles (Appendix B) were constructed by plotting resistivity-depth values along flight lines using commercially available software (Encom PA, v. 11). HEM resistivities from 10 to 40 ohm-m were mapped to a logarithmic color scale ranging from dark blue to pink. All values 40 ohm-m or greater are shown as pink because they were generally not useful for interpreting hydrostratigraphy (see Section 6). The Encom PA software program was chosen because it enabled us to superimpose borehole logs, geophysical profiles, and other data in an interactive, three-dimensional environment and to make interpretations by digitizing points and polylines directly upon images of the geological and geophysical data.

6.2. Test-Hole Results

Test-hole and monitoring-well data were compared to HEM data along short (100 m), east-west oriented segments of the closest flight lines (Figs. 6-18). Our first test holes were drilled along a north-south transect, perpendicular to the paleovalley axis, at regularly spaced intervals (Fig. 5). These locations were chosen prior to the HEM survey and, therefore, with no knowledge of the resistivity pattern in the subsurface. We drilled a second group of test holes after the initial HEM survey results were made available, but before these data were inverted. The locations of the second group of test holes were chosen on the basis of apparent resistivities (resistivity vs. frequency), but not on the basis of resistivity:depth values. Among the test holes in the second group, 14EN07 was drilled to investigate an area of very high subsurface resistivity values. Test holes 15EN07 and 16EN07 were drilled to investigate two areas of low resistivity. Test hole 5A07 was drilled as part of an unrelated geologic mapping project that overlapped the study area, but the data derived from it were useful for the present study. Data from eight pre-existing CSD test holes in the study area also proved useful.

Test hole 02EN07 (Fig. 6) was drilled to a depth of 27 m at a location directly beneath HEM flight line #30030 (Fig. 5). It is the only borehole for which cores were collected continuously from the land surface to bedrock. This borehole penetrated only a few centimeters of limestone, mapped as Council Grove Group by Burchett et al. (1972). Twenty- two meters of fine-grained glacial sediments directly overlie bedrock, the lowermost part of which consists of clayey silt and the upper part till. The till is succeeded by pedogenically modified silts of the Gilman Canyon Formation, and the uppermost 3.6 m is Peoria Loess and topsoil. HEM resistivity values are less than 20 ohm-m in all parts of the profile. In contrast, long-normal resistivities range from ~50 to 200 ohm-m. Both HEM and borehole resistivity values steadily decrease downward from a depth of 6 m to 27 m. The sand fraction similarly decreases over this same interval. Among the highest HEM resistivities (~14 ohm-m) are those between 5 and 11 m, an interval corresponding to the coarsest, most poorly sorted, and most highly weathered part of the till. This zone of comparatively high resistivity can be traced from east to west for 7 km along the entire length of profile #30030 (Appendix B), and is identifiable in almost all profiles that contain low resistivity materials near the land surface. No marked contrast in resistivity is observed at the water table, which is about 4.5 m below the land surface, near the contact between the Gilman Canyon Formation and the underlying till. The concentration of TDS in groundwater near the water table is 811 mg/L, but the effect of pore-water chemistry on the HEM resistivities cannot be assessed because no other chemical data for groundwater exist below this depth.

Test hole 08EN07 (Fig. 7) was drilled to a depth of 36 m at a location 50 m south of HEM flight line #30160 (Fig. 5). This borehole penetrated 1 m of limestone in the Council Grove Group. Unconsolidated sediments immediately above bedrock consist primarily of laminated silt, clayey silt, sandy silt, and a few beds of silty clay and silty sand. A thin layer of gravel containing clasts of pink metaquartzite was encountered at ~12 m. The borehole diameter increases to >30 cm in this interval, as indicated in the caliper log (Fig. 7). HEM resistivity values are generally less than 20 ohm-m, except for a thin, laterally restricted zone in the upper 2 m where they exceed 20 ohm-m. This zone might correspond to the shallow layer of unsaturated sand between 1 and 2 m. Long-normal resistivities range from ~75 to 200 ohm-m. The interval between 9 m and 20 m corresponds to borehole resistivity values >50 ohm-m and HEM resistivity values of ~12 to 14 ohm-m (near the center of the resistivity:depth profile). The sand fraction over this same interval comprises at least 25%, but commonly 50% or more of the sediments. In HEM profiles to the south of this location, this zone thickens and becomes more highly resistive (~30 ohm-m). Interference from power lines and/or a nearby railroad may have lowered the resistivity values on the eastern side of the HEM profile in Figure 7, resulting in an apparent change in thickness from right to left of this 12-14 ohm-m zone. The thin sand unit from 27-28 m in the lithology log is not mapped in the HEM, probably because it is too thin to be resolved at this depth.

Test hole 13EN07 (Fig. 8) was drilled to a depth of 100 m at a location 10 m north of HEM flight line #30230 (Fig. 5). Cores were not collected at this site, so Quaternary stratigraphic units are recognized only on the basis of cuttings and consequently we place less confidence in our ability to identify them. This borehole penetrated 7 m of interbedded shales and limestones in the Admire Group as mapped by Burchett et al. (1972). An interval of sand-dominated unconsolidated sediments exists immediately above bedrock to a depth of 24 m. Clay and silt are the predominant lithologies above this depth. At least 2 m of Loveland Loess and 4.4 m of Peoria Loess were penetrated. The maximum depth of HEM investigation at this locality is less than 66 m (Fig. 8). HEM resistivity values are > ~15 ohm-m, but below 22 m they are >20 ohm-m. Long-normal resistivities are generally between 100 and 200 ohm-m and increase abruptly at the top of the sand-dominated interval at 22 m. This interval is recognizable in HEM as a broadly lenticular, west-southwest to east-northeast-trending zone of high resistivity between flight lines 30140-30240 (Fig. 20 and Appendix B). A thin zone of HEM resistivity values ~20 ohm-m exists between 5 and 10 m in Figure 8. Borehole resistivity logs are not available over this interval because of the tool configuration (see Section 4.1.), but the gamma readings are slightly lower and cuttings are described as “sandy silts” in this interval. No apparent contrast in HEM resistivity is observed at the water table. TDS in groundwater is comparatively high at shallow depths (12 m) above the upper aquifer. It is, however, much lower (456-487 mg/L) in the upper aquifer, but then increases more than two fold (1280 mg/L) at the bottom of the lower aquifer (Fig. 8). There is no significant difference in lithology between the upper and lower

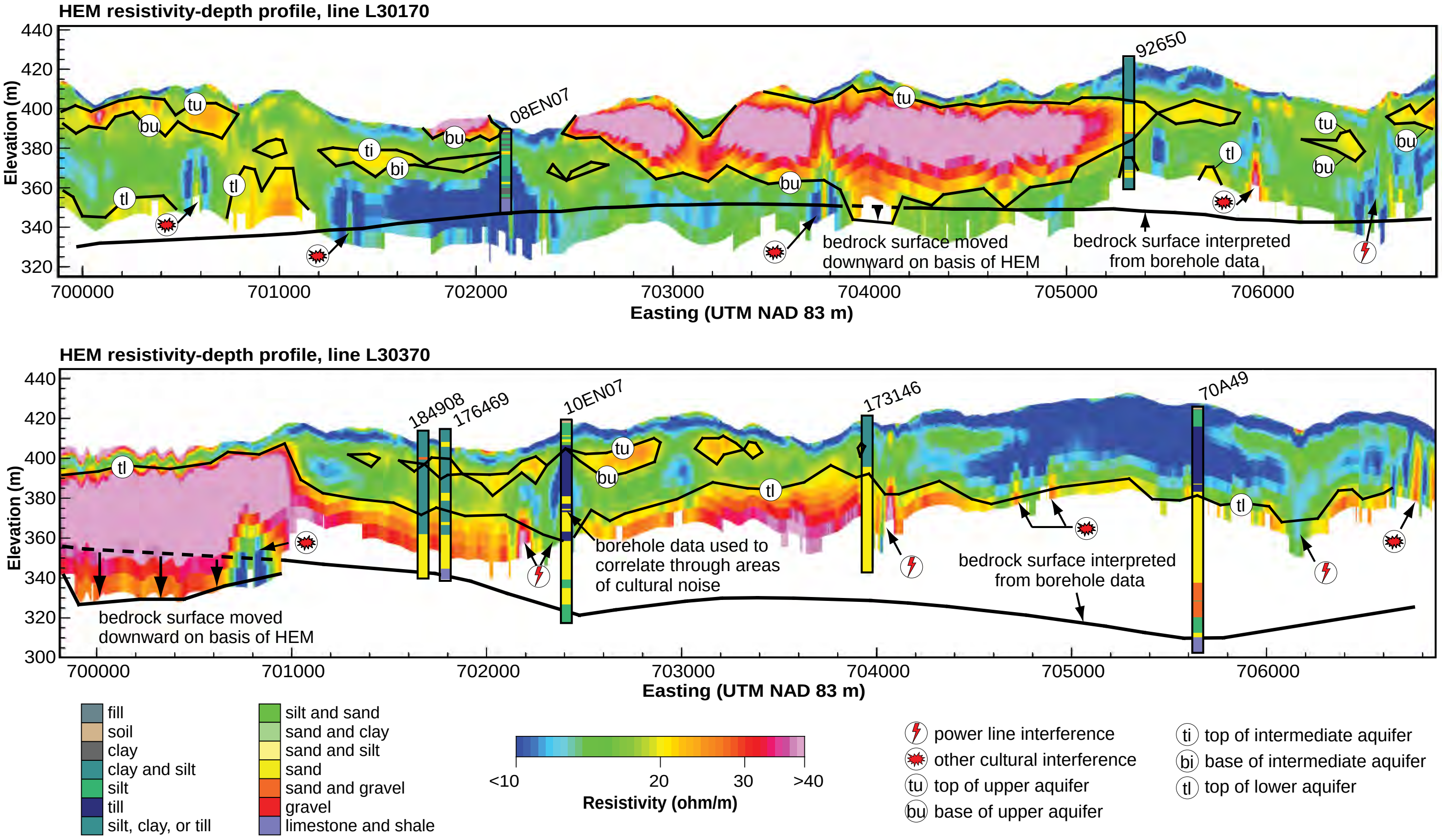


Figure 20. Cross sections through study area showing borehole lithologies superimposed on HEM resistivity-depth profiles. Key interpretive elements are also shown, including: areas of interference in HEM profiles, top and bottom of aquifers, and bedrock surface. The presence or absence of aquifer materials was inferred only from borehole logs in areas where the depth of penetration of HEM was less than the depth of the bedrock surface (i.e. between 70100 and 70600 in line 30370). See Figure 5 for the locations of HEM flight lines 30170 and 30370.

aquifers in 13EN07 (Fig. 8). The lack of a resistivity contrast between these two depth intervals, therefore, indicates that groundwater chemistry does not exert a dominant control on HEM resistivity at this site.

Test hole 09EN07 (Fig. 9) was drilled to a depth of 115 m at a location 75 m north of HEM flight line #30290 (Fig. 5). This borehole penetrated 3 m of limestone and shale bedrock in the Admire Group. The lowermost 54 m of unconsolidated sediments above bedrock consist predominantly of sand with several layers of silt. Till was encountered from 9.1 to 36.6 m. Multiple loess units were encountered in the upper 7.62 m. HEM line #30290 was flown in the vicinity of an east-west trending power line and therefore the resistivity:depth plot displays a significant amount of interference. Nonetheless, the overall pattern of HEM resistivity on the left side of the profile (Fig. 9), in which values gradually increase with depth, is broadly comparable to the increase in grain size with depth. HEM resistivity values range from 10 to ~22 ohm-m, whereas long-normal resistivities are ~50 to 200 ohm-m (abrupt shifts in the borehole resistivity log are probably due to a tool malfunction). Groundwater chemistry does not appear to have an effect on HEM resistivity, as only a slight change in TDS is observed between 37 and 53 m. Low resistivity values between 45 and 70 m on the eastern end of the HEM profile are due to interference.

Test hole 10EN07 (Fig. 10) was drilled to a depth of 97 m at a location 30 m north of HEM flight line #30370 (Fig. 5). This hole was abandoned at a depth of 97 m due to collapse and therefore it did not penetrate bedrock. Unconsolidated pebbly sands and silts are present between 61 and 97 m. Pebbles consist primarily of granite and feldspar. Multiple units of till and sand are present between 38 and 61 m. The thickness of the sand unit between 46 and 56 m, however, may have been overestimated because the overlying sand unit washed out during drilling (as indicated in the caliper log), which may have caused sand to re-circulate through the drilling fluid during the collection of cuttings from underlying units. Furthermore, the borehole resistivity and gamma logs do not indicate sand in this interval. Till is the primary lithology from 12 to 38 m. Interbedded silts and sands exist from the surface to 12 m. HEM resistivity values range from 10 to ~22 ohm-m and long-normal resistivities are ~40 to 110 ohm-m. Low resistivity values in the upper 6 m correspond to surficial sediments dominated by silt. Resistivity values between 6 and ~50 m, however, do not correspond to observed grain size trends or borehole resistivities. The highest HEM resistivities in this interval exist from ~15 to 25 m, which is an interval of till and low borehole resistivity values. These differences are probably due to the fact that, since a power line affected the HEM data at the site of the test hole (see profile 30370 in Fig. 20), the nearest HEM data to which the test hole can be compared lie 40 to 50 m east of its location (Fig. 10). The lithology of this interval may change over this distance. Similarly, the discrepancy between HEM resistivity and borehole data below 38 m may arise partly from the distance between the test hole and the nearest reliable HEM data. Notwithstanding the above discrepancy, the thick sand interval below 60 m, which is clearly defined by the sharp increase in borehole resistivity at that depth, roughly corresponds to the HEM resistivity values >20 ohm-m near the base of the profile. We interpret this sand body as part of the paleovalley fill because of its stratigraphic position below the lowermost till and its granitic/feldspathic composition. Groundwater chemistry is generally uniform with depth, so it does not appear to exert a control on HEM resistivity.

Test hole 11EN07 (Fig. 11) was drilled to a depth of 56 m at a location 27 m south of HEM flight line #30410 (Fig. 5). This borehole penetrated 0.8 m of limestone in the Council Grove Group. Seven meters of silt and clay were encountered above bedrock. A thick succession of pebbly sand with a few thin beds of clay and silt exists from 6.5 m to 48.5 m, and clayey silt is present from the land surface to the top of the sand interval. HEM resistivity values range from ~10 to 80 ohm-m (all values >40 ohm-m are depicted as a single shade of pink). Long-normal resistivities, on the other hand, are between 100 and 200 ohm-m. The contact between silt and sand at 6.5 m, which was observed in both cuttings and core and was confirmed in the borehole geophysical log, appears as a sharp contrast in the HEM resistivity. Below the contact, the HEM resistivity values are > 40 ohm-m and correspond well to the borehole interval logged as sand. Values are <20 ohm-m near the bottom of the borehole where silt and clay are dominant. The apparent thickening of the high resistivity zone from west to east is due to interference. The water table is about 8 m below the land surface, just below the contact between silt and sand. We do not, however, observe any contrast in the resistivity:depth profile that would indicate water saturation exerts a dominant control on the HEM data. Similarly, groundwater chemistry is uniform and appears relatively unimportant in terms of interpreting the HEM resistivity at this location.

Test hole 12EN07 (Fig. 12) was drilled to a depth of 87 m at a location 92 m south of HEM flight line #30430 (Fig. 5). This borehole penetrated 5 m of limestone and shale in the Council Grove Group. Bedrock is overlain by 18 m of predominantly silt, which is overlain by 50 m of interbedded sand, pebbly sand, silt, and clay. The borehole geophysical log is fairly uniform over this interval – resistivity values are high and gamma values are low – suggesting that the interval is sandier than the description of cuttings indicates. Interbedded till and sand exist from the land surface to 14.5 m. Some sand layers are up to 2 m in thickness. Particle-size data show that the till is coarser at this location than at the test-hole locations described above. HEM resistivity values range from ~10 to 100 ohm-m (all values >40 ohm-m are pink). Long-normal resistivities are between ~30 and 190 ohm-m. HEM resistivity values below 20 ohm-m in the upper 10 – 14 m correspond to the till. The base of the till is marked by an increase in both the HEM and borehole resistivities between 12 and 18 m. HEM resistivity values > 40 ohm-m, shown as pink in Figure 12, exist over the entire thickness of the sand-dominated interval. The base of this interval corresponds to slightly lower HEM resistivity values (20 – 30 ohm-m) near the base of the profile. Even though borehole resistivities in the sandy interval (Qss) change markedly at 26 m, which probably marks the position of the water table, the HEM resistivities gives no indication that unsaturated sands are significantly more resistive than saturated sands. At this location as well as the others, the position of the presumed or observed water table does not seem to exert a dominant control on the HEM resistivity values. Groundwater chemistry is uniform within the sand interval, but TDS values are much higher in the silty interval as shown in the deepest well in Figure 12. Higher TDS should yield more conductive materials, and indeed the HEM resistivity values are slightly lower at that depth compared to those immediately above, but this pattern could also be interpreted as a downward decrease in grain size. The apparent dip of layers in the HEM profile appear to be due to relief on the contacts between hydrostratigraphic units, which in many cases, closely follows the modern topography.

Test hole 14EN07 (Fig. 13) was drilled to a depth of 42 m at a location 18 m north of HEM flight line #30510 (Fig. 5). The location was chosen to investigate an area of high resistivity revealed by the initial HEM apparent resistivity maps in Smith et al. (2008). This borehole penetrated 7.7 m of limestone and shale in the Council Grove Group and 2.5 m of clay directly above bedrock. The interval from 7 to 31 m consists of comparatively coarse sediments, whereas the upper 7 m consists of clay, till, and silt. HEM resistivity values range from 10 to 120 ohm-m (all values >40 ohm-m are depicted as a single shade of pink) and are in good agreement with lithologic changes. Long-normal resistivities range from ~70 to 1480 ohm-m. HEM resistivity values > 40 ohm-m correspond to an interval of sand, silt and sand, and sand and gravel from 7 to 31 m. The upper part of this interval crops out locally, and a sand pit has been excavated within several tens of meters from the test-hole location. The borehole resistivity values are extremely high from 7 to 15 m, suggesting that the upper sand body is unsaturated. Actual groundwater level measurements are not available because no monitoring wells were installed at this site, but we interpret unsaturated sands of ~8 m to exist directly above saturated materials at this site. No definitive contrast in HEM resistivity is observed at the presumed water table even though the vertical resolution of HEM at this depth (~2 m; Smith et al., 2011) should be sufficient to provide discrete values for both saturated and unsaturated units. Furthermore, no contrast is observed even if the log resistivity scale is increased to include values up to 100 ohm-m. Pore volume, pore structure, and/or grain mineralogy, therefore, appear to exert stronger controls on HEM resistivity patterns than does the degree of water saturation at this site.

Test hole 15EN07 (Fig. 14) was drilled to a depth of 76 m at a location 30 m north of HEM flight line #30430 (Fig. 5). This location was chosen to investigate an area of low resistivity revealed by the initial HEM apparent resistivity maps in Smith et al. (2008). This borehole penetrated 0.3 m of limestone bedrock mapped as Council Grove Group by Burchett et al. (1972). The lithologies at this site comprise mostly silt, till, and clay, with a few thin layers of sand. Fine-grained deposits at this site are significantly thicker than at the other test-hole sites, and their thickness is verified by the borehole geophysical logs. HEM resistivity values are generally ~10 ohm-m, apparently due to the presence of thick till at this site. Long-normal resistivities are ~100 to 130 ohm-m. A zone of HEM resistivity around 12 ohm-m exists at roughly the same stratigraphic position as the sand described from cuttings from 11.6 to 12.6 m, which also appears as a negative spike in the gamma log. The HEM resistivity values of ~14 ohm-m near the base of the profile generally correspond to the depth at which borehole resistivity values and gamma log values increase slightly. Sediments in the lower half of the test hole are predominantly silt, but the sand fraction was observed to increase slightly in the same intervals as the resistivity spikes and low gamma counts.

Test hole 16EN07 (Fig. 15) was drilled to a depth of 115 m at a location 4 m north of HEM flight line #30260 (Fig. 5). This location was chosen to investigate an area of low resistivity revealed by the initial HEM apparent resistivity maps in Smith et al. (2008). No cores were obtained from this site and no monitoring wells were installed. This borehole penetrated 5 m of limestone and shale bedrock in the Admire Group. Unconsolidated deposits above bedrock comprise, from bottom to top: 7.5 m of clay and silt; 7.5 m of sand and gravel; 3 m of clay; and 32 m of sand. An interval consisting predominantly of silt, with minor amounts of clay and sand, exists between 24 and 60 m. Till is present from 4.5 to 24 m, and the upper 4.5 m is probably Peoria Loess. The effective depth of HEM is generally less than 60 to 65 m at this site and resistivity values are <20 ohm-m, except for a thin zone between 55 and 60 m of values >20 ohm-m on the east side of the profile that apparently corresponds to the upper part of the sand interval. Long-normal resistivities are between ~35 and 75 ohm-m. We interpret the sand body from 60 to 103 m as part of the paleovalley fill based on its depth and its granitic/feldspathic composition. The thin zone of HEM resistivity values ~14 ohm-m from 10 to 20 m corresponds to the middle part of the till, but the sandy zones in the till identified in cuttings are generally near the base or slightly below this interval. This HEM resistivity zone is nonetheless traceable for more than 3 km beyond the site of the test hole, and it is identifiable in almost all profiles that contain low resistivity materials near the land surface (Appendix B). Most of these profiles lie in the northern two-thirds of the study area where loess and till units are thickest. HEM resistivities at this stratigraphic interval increase to >20 ohm-m on the western half of the profile (Fig. 15).

Test hole 05A07 (Fig. 16) was drilled to a depth of 115 m at a location 109 m south of HEM flight line #30260 and 140 m north of flight line #30270 (Fig. 5). Test hole 5A07 was drilled as part of an unrelated geologic mapping project that overlapped the study area. It penetrated 4.2 m of limestone and shale bedrock in the Admire Group. Samples below 111 m were of poor quality and therefore were omitted from Figure 16. Sand is the dominant lithology from the bedrock surface upward to 64 m, and this interval is succeeded by 22 m of silt. It is likely, however, that the sand fraction was underestimated in the description of the cuttings in some intervals. Borehole resistivity and gamma logs are indicative of sand rather than silt from 60.5 – 64 m. Sand is also probably more abundant from 52 to 60.5. Our estimate of the top of the aquifer at 60.5 is, therefore, conservative. The interval from 4 to 42 m consists of till with layers of clay and sand. Loess units recognized in the upper 4 m are the Gilman Canyon and Peoria. HEM resistivity values range from 10 to 35 ohm-m, whereas the long-normal log, which is erratic due to a probable tool malfunction, ranges from ~50 to >200 ohm-m. This test hole was drilled between two different flight lines, and the resistivity:depth profiles along these lines display marked differences. It appears, therefore, that test hole 05A07 is located directly in the middle of a north-south trending change in the electrical properties of the subsurface, rendering comparisons between resistivity:depth profiles and borehole data at this location somewhat tenuous. Nonetheless, we conclude that the high resistivity zone near the base of profile #30260 is probably the top of the lower sand body identified in borehole data, and that the elevation difference between them is due to the either the slope of the sand/silt contact or the misplacement of the contact in the borehole due to under-estimation of the sand fraction in cuttings.

A cluster of three monitoring wells 15, 41, and 72 m deep (Fig. 17) exists 62 m northwest of the western end of HEM flight line #30210, within the Hickman Wellhead Protection Area adjacent to a small creek (HKMW3, Fig. 5). These wells were not drilled at the site of a CSD test hole and geophysical logs were not obtained, so the lithologic log is based on the field descriptions and we have not interpreted stratigraphic units. Aquifer materials (sand and silty sand) were encountered from 9 – 19 m, 36 – 69 m. The upper aquifer coincides with HEM resistivities ~30 ohm-m, although resistivities exceeding 20 ohm-m continue downward to 30 m. HEM resistivity values below 30 m do not exceed 20 ohm-m even though sands are present. Both upper and lower aquifers contain groundwater of similar chemistry. We therefore speculate that the discrepancy between HEM and borehole lithology below 39 m is due to geologic variability over the 69 m of offset between the wells and the profile. The water levels in all three wells are similar to the surface water elevation in the nearby creek. The silt and clay units separating the aquifers are sandy enough that they can be considered leaky aquitards. Irrigation wells in this area are completed into the lower aquifer. Both the upper and lower aquifers, however, show drops in water levels during the summer irrigation season. We take these observations as evidence for leakage across this aquitard (see Section 6.5.).

A cluster of four monitoring wells 38, 55, 79, and 88 m deep (Fig. 18) exists 46 m north of HEM flight line #30230 (Fig. 5). These wells were not drilled at a test-hole site, so the field log is used and stratigraphic units are not assigned. Sands with some gravel were encountered from 35 – 43 m and 71 – 92.5 m. The upper sand corresponds to a contrast in HEM resistivity at ~37 m. HEM resistivity values from the base of the sand downward to the base of the HEM profile generally exceed 20 ohm-m, even though sediments are in this interval mostly fine-grained. The near-vertical band of resistivities <20 ohm-m from 37 – 65 m is due to interference.

Comparison of borehole data to HEM resistivities shows that, in general, thick high resistivity units indicate sand bodies whereas thick low resistivity units indicate fine-grained materials. The vertical resolution of HEM decreases with depth. Resistivity values in the deepest parts of the profile are averaged over larger intervals than those in the shallowest part of the profile, so thin sand bodies are less likely to be resolved at depth. The maximum depth of investigation of HEM in the vicinity of the test holes varies from ~55 m in areas where conductive sediments exist near the land surface (e.g. Fig. 14) to ~75 m in areas dominated by resistive materials (e.g. Fig. 12). Sand bodies that are buried deeper than the depth of investigation may not be recognizable in the HEM profiles. Since HEM resistivity at the study site does not appear to be controlled in any systematic fashion by factors such as degree of water saturation and groundwater chemistry, the contacts between major hydrostratigraphic units can be mapped by correlating contrasts in the HEM resistivities. We cannot directly correlate HEM resistivity values to lithologies. Furthermore, the range of HEM resistivities is lower than the range of long-normal resistivities. Nonetheless, we conclude that, although there are a few exceptions, the 20 ohm-m HEM resistivity value often broadly coincides with major aquifer/aquitard contacts.

6.3. Hydrostratigraphic Interpretation

The hydrostratigraphic interpretation of HEM data is made possible by the existence of spatial contrasts in the inverted electrical resistivity values that may correspond to one or more physical or chemical properties. Through comparison of borehole data to nearby HEM profiles, we established that, at this study site, pore volume/structure and electrical properties of host minerals probably exert a stronger control on HEM resistivities than water content and water chemistry (Figs. 6 – 18 and accompanying discussion). The silts and clays comprising aquitards in the study area are more electrically conductive than sands and gravels due to their smaller pore volumes and more abundant clay minerals. HEM resistivity can be used in a qualitative manner, therefore, to classify aquitard versus aquifer materials, thereby delineating hydrostratigraphic surfaces. Keys to this analysis are 1) determining whether or not a given resistivity value can be used over the entire study area to correlate hydrostratigraphic contacts, and 2) determining how to map hydrostratigraphic contacts below the depth of investigation of HEM. We address these issues below.

6.3.1. Interpretation of HEM Profiles

We placed the inverted resistivity values from Smith et al. (2011) on a survey profile with topography derived from an USGS 10-m digital elevation model (Fig. 20, Appendix B). The 60 Hz signal was plotted above each profile so that anomalous HEM resistivities resulting from power lines and other infrastructure could be recognized by peaks in the signal (it was removed prior to publication). These areas were not used to interpret surfaces. Data on borehole geophysics, lithologies, and particle size from CSD test holes, as well as lithology data from the logs of DNR registered wells, were plotted on resistivity profiles to aid in geologic interpretation of the geophysical data. Geologic materials in the study area are highly variable, so comparisons between borehole data and HEM profiles were based only on those boreholes that lie within about 50 – 100 m of the flight lines (Fig. 20, Appendix B).

Polylines representing interpreted contacts between hydrostratigrapic units were drawn using HEM resistivity contours as a guide. Borehole data, if available for that area, were used to correlate across 1) zones of power line or cultural interference and 2) areas in which the hydrostratigraphic surface was below the maximum depth of investigation of the HEM. The interpreted contacts were numbered from bottom to top to denote stratigraphic position. An adjacent profile was then plotted above the interpreted profile and, if possible, the contacts were correlated to the new profile by matching the locations of resistivity contours in the new profile to those in the previous profile. Contacts were then drawn on the new profile, the next adjacent profile was plotted above it, and the procedure was repeated until all profiles were interpreted.

During the procedure described above, we visually compared our interpreted contacts to lithologic contrasts in boreholes. If the lines of correlation drawn on the basis of resistivity contrasts did not consistently match lithologic contrasts in the borehole data, new correlations were made by tracing a different resistivity contour until better agreement between the two data sets was achieved. Through multiple iterations of this procedure we were able to verify that the 20 ohm-m value is in best agreement with the contrast between sand and silt/clay/till over the majority of the study area. Trial-and-error adjustments were made to the color scale and resistivity range until an acceptable contrast was achieved at roughly 20 ohm-m. These adjustments were important to our analysis because the range of resistivities over which the colors were stretched as well as the stretching method (linear vs. logarithmic) significantly influences the visual identification of key resistivity contours. We found that the 20 ohm-m contour is most readily identified by the contrast between yellow and green. The final iteration was performed using the optimized color scale and resistivity range, and these correlations were used to construct a three-dimensional geologic model (see below). The final interpretations were saved to a database as a series of polylines numbered in stratigraphic order from lowest to highest.

After the final iteration, the vertices of all polylines on the same stratigraphic surface were combined to generate a group of points in three-dimensional space. The minimum curvature contouring algorithm was used to interpolate a surface for that hydrostratigraphic contact. Polygons were constructed to constrain the maximum horizontal extent of the hydrostratigraphic unit and the interpolated surface was deleted ("clipped") beyond the boundaries of the polygon. All of the surfaces generated in this manner were compared to a DEM and were adjusted accordingly so that no surface exceeded the height of the land surface. Similarly, each surface was compared to the next highest stratigraphic surface to check for impossible cross-cutting relationships, and adjustments were made as necessary. The final block model showing the three-dimensional hydrostratigraphic interpretation is shown in Figure 21. The surfaces representing the elevations of the upper and lower bounding surfaces of the hydrostratigraphic units are shown in Figures 22 – 28.

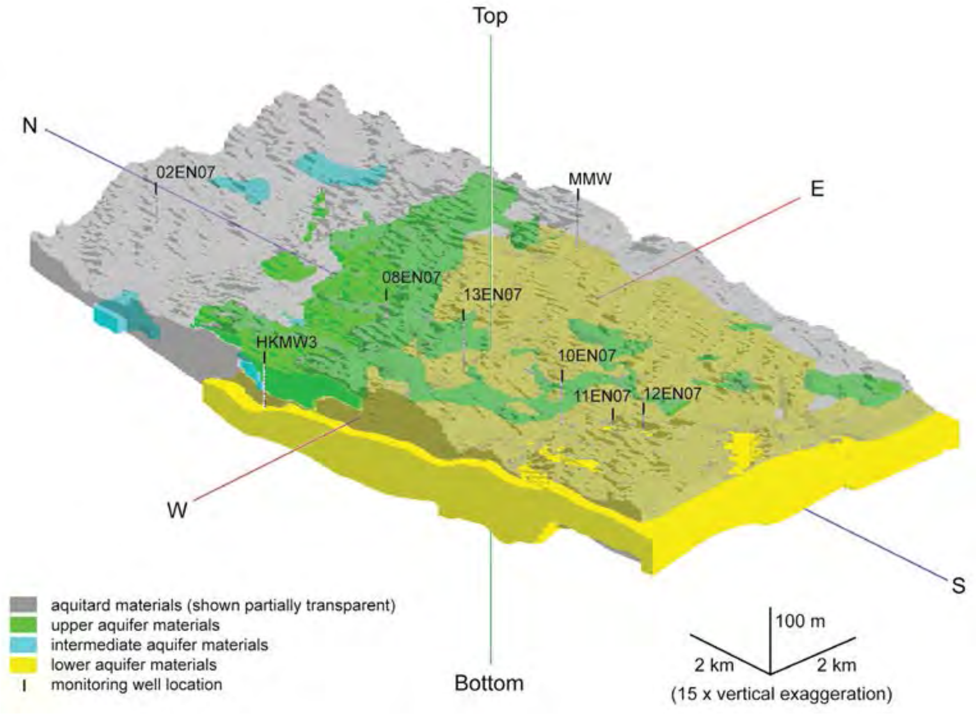


Figure 21. Three-dimensional, hydrostratigraphic block model for the study area made using RockWorks 2006 software by calculating the distances between upper and lower contacts of each hydrostratigraphic unit, as interpreted from HEM and borehole data (see Fig. 20 and text). View is toward the northeast at approximately 20 degrees above the horizon. Light source is from the east.

6.3.2. Interpretation of the Bedrock Surface

The bedrock surface is below the depth of investigation of the HEM in most of the study area. Accordingly, we relied primarily on borehole data within the study area and within 2 km beyond its boundary to interpret the elevation of the bedrock surface. The elevation of the bedrock surface was determined in each borehole that penetrated the full thickness of unconsolidated Late Cenozoic sediments, and these data were used to interpolate a preliminary bedrock surface using the natural neighbor technique in ArcGIS (v. 10). Next, the elevation of the interpolated surface was compared to the depth of boreholes that partially penetrated Cenozoic deposits. Sixty-five of these boreholes were drilled deeper than our modeled bedrock surface, so the maximum elevations of the bedrock at each of these borehole locations can be no higher than the elevation of the depth of the borehole. A new bedrock surface was interpolated using these additional data points. Finally, we refined the modeled bedrock surface to account for areas where bedrock elevations were sparse but the depth of investigation of HEM was sufficient to penetrate a surface interpreted as bedrock. In some of those areas, that interpreted surface differs significantly from the surface generated from borehole data, so the surface generated using borehole data was replaced by the surface generated through the analysis of HEM data. The final composite surface, therefore, includes: (1) areas of greater detail corresponding to areas where the bedrock surface could be interpreted in the resistivity profiles, as well as (2) areas of less detail corresponding to areas where the bedrock surface is based solely on borehole data (Fig. 28).

Figure 28 displays a prominent, west-northwest to east-southeast trending area of comparatively low bedrock elevations near the center of the study area. This feature is part of the larger paleovalley system that extends from near Dorchester to Sterling, Nebraska. As discussed previously, the sedimentary fill of this paleovalley constitutes an important aquifer in southeast Nebraska.

6.4. Three-Dimensional Hydrostratigraphic Model

A three-dimensional geologic block model of the study area was developed using the five hydrostratigraphic units as defined in Section 6.3.1. and shown in Figures 22 – 28. Each cell in the model is 100 m x 100m x 1m, resulting in 74 nodes in the x direction, 155 nodes in the y direction, and 137 nodes in the z direction. The resulting hydrostratigraphic block model (Fig. 21) shows the thicknesses and extents of aquifer and aquitard materials. The water table/potentiometric surface map (Fig. 19) was used to calculate the thicknesses of aquifers. We use

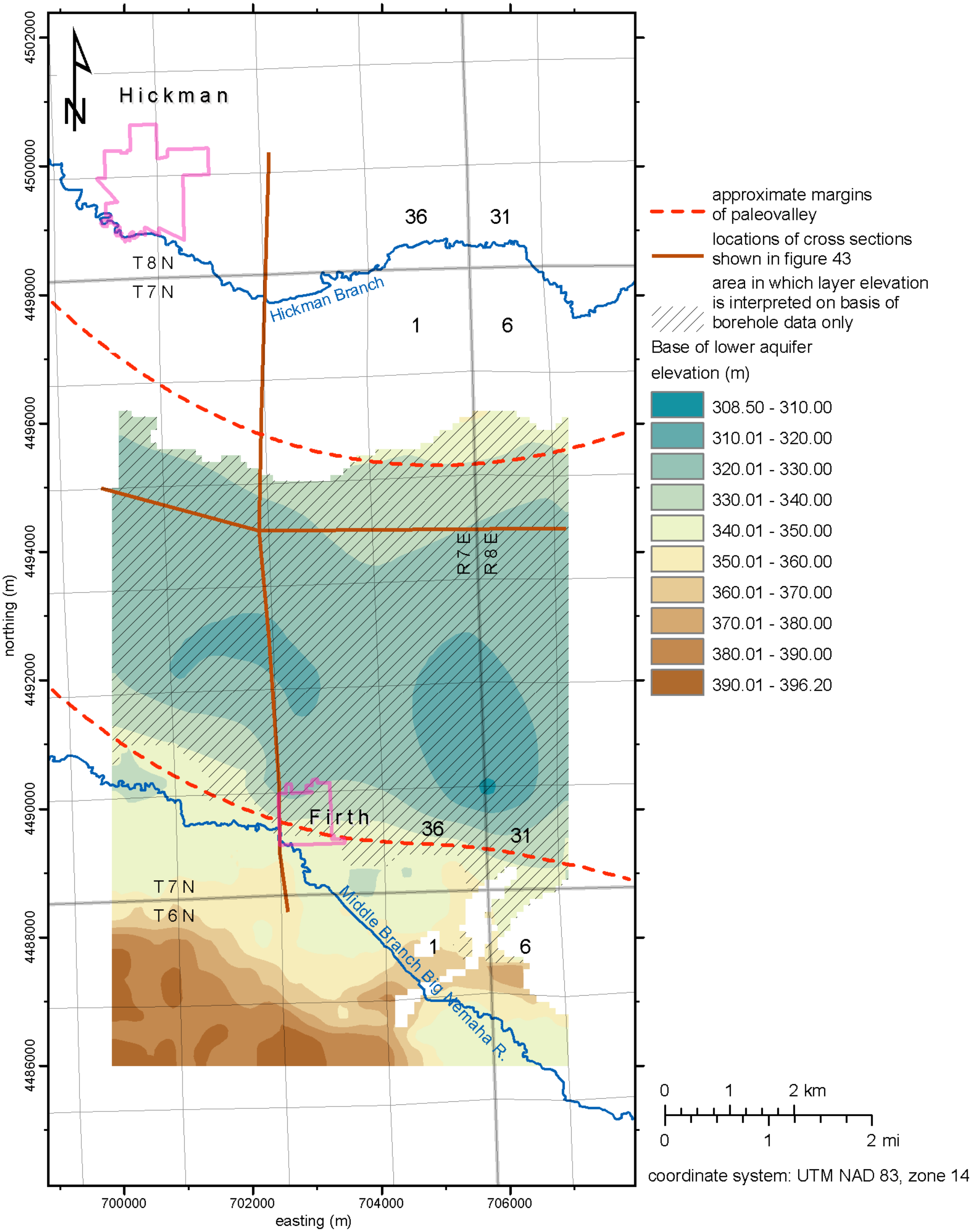


Figure 22. Elevation of the base of the lower aquifer in the study area. Hatched pattern indicates area where the depth of penetration of HEM was less than the depth of the base of the lower aquifer. In these areas, the elevation was interpreted on the basis of borehole logs only.

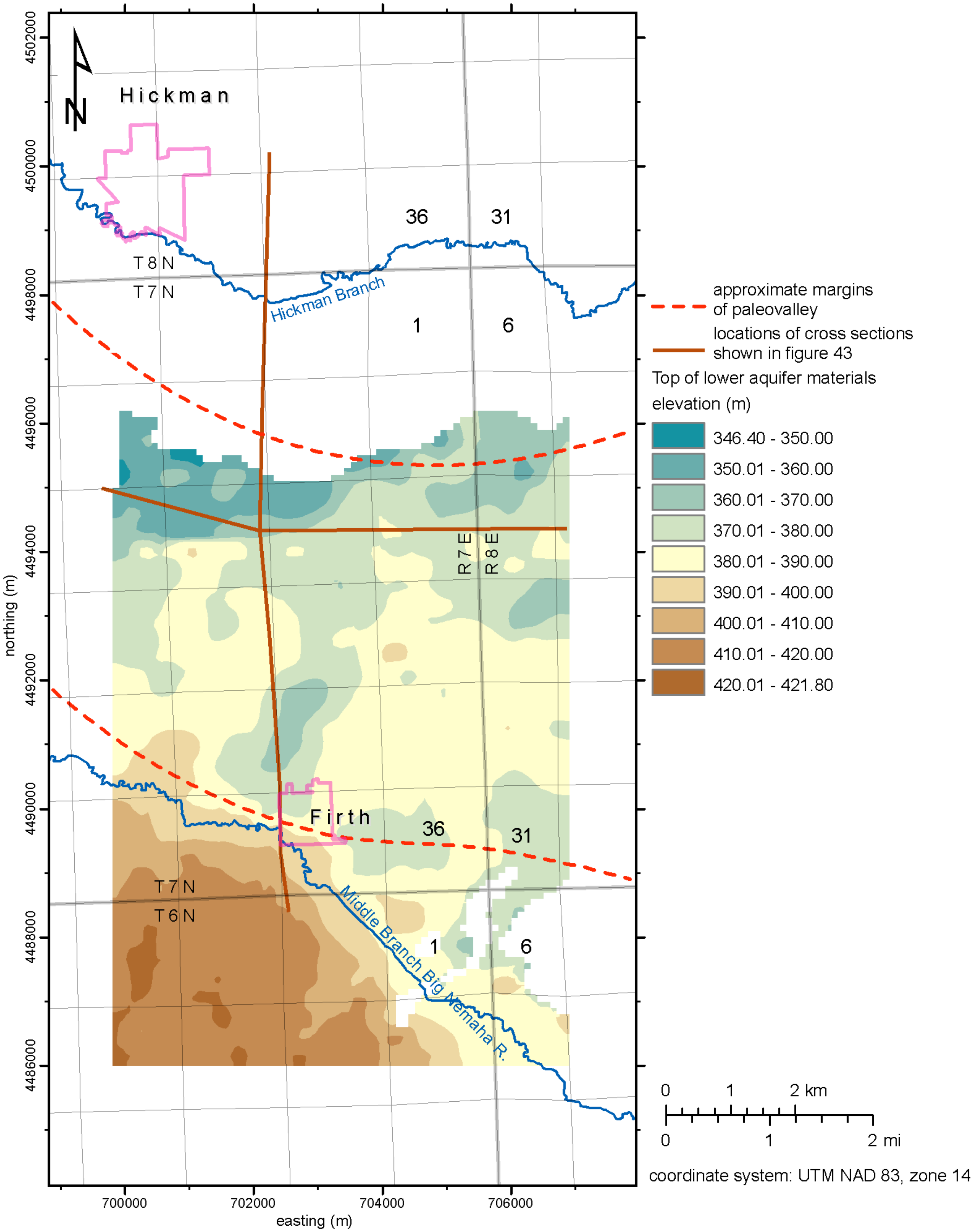


Figure 23. Elevation of the top of the lower aquifer materials in the study area.

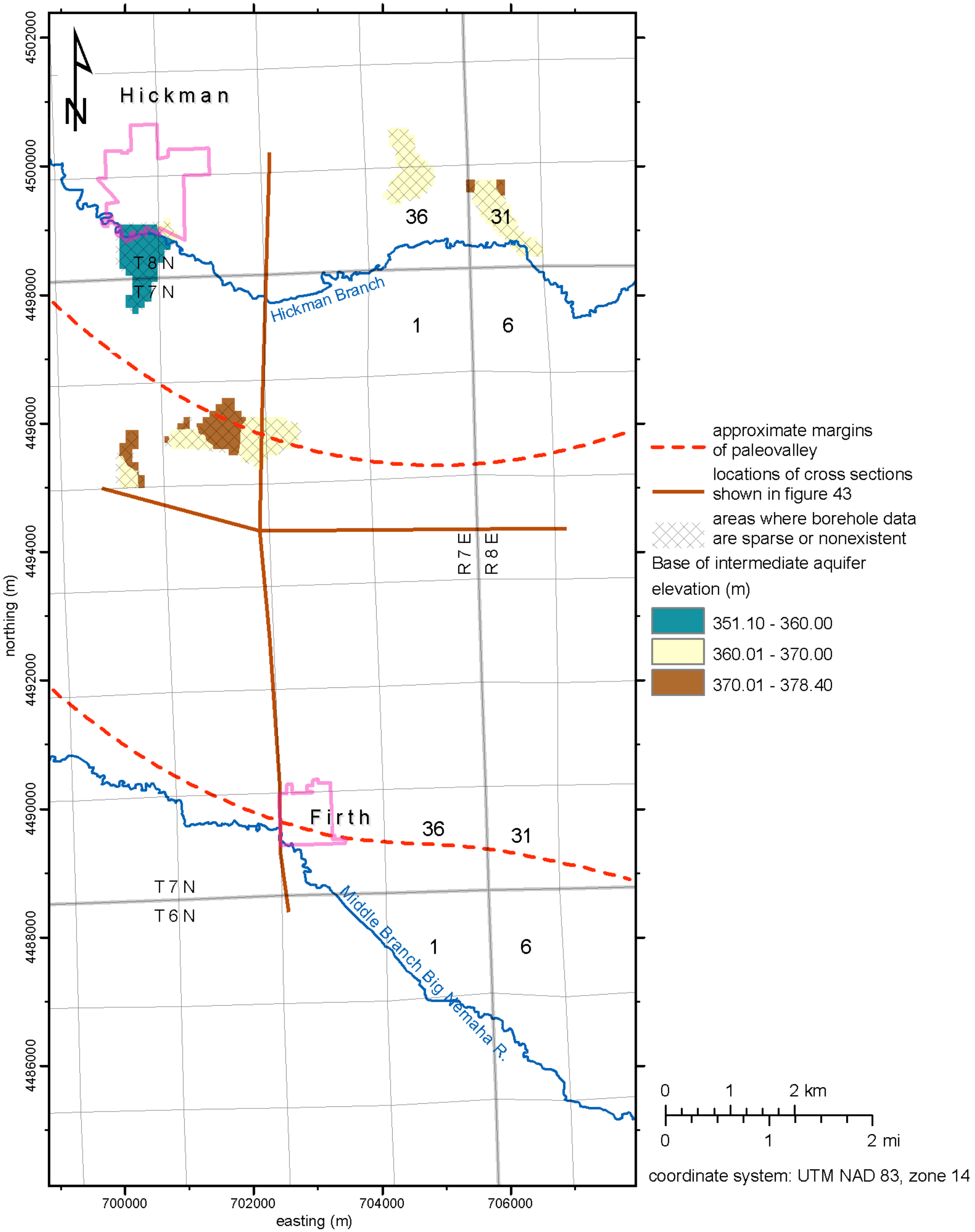


Figure 24. Elevation of the bases of the multiple intermediate aquifers. Borehole data are sparse or nonexistent throughout most of these areas. This surface was interpreted from HEM data alone and thus has not been verified.

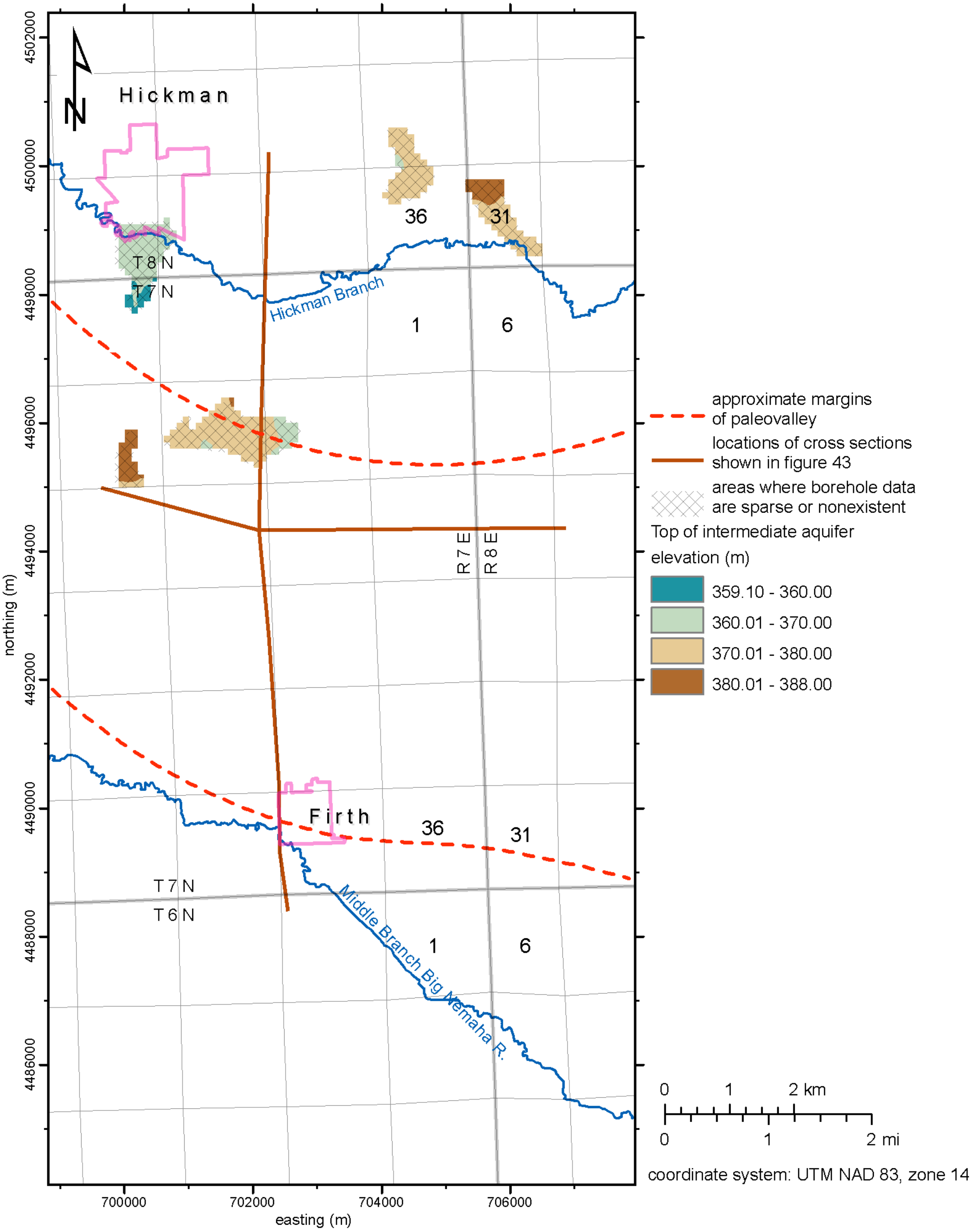


Figure 25. Elevation of the tops of the multiple intermediate aquifers. Borehole data are sparse or nonexistent throughout most of these areas. This surface was interpreted from HEM data alone and thus has not been verified.

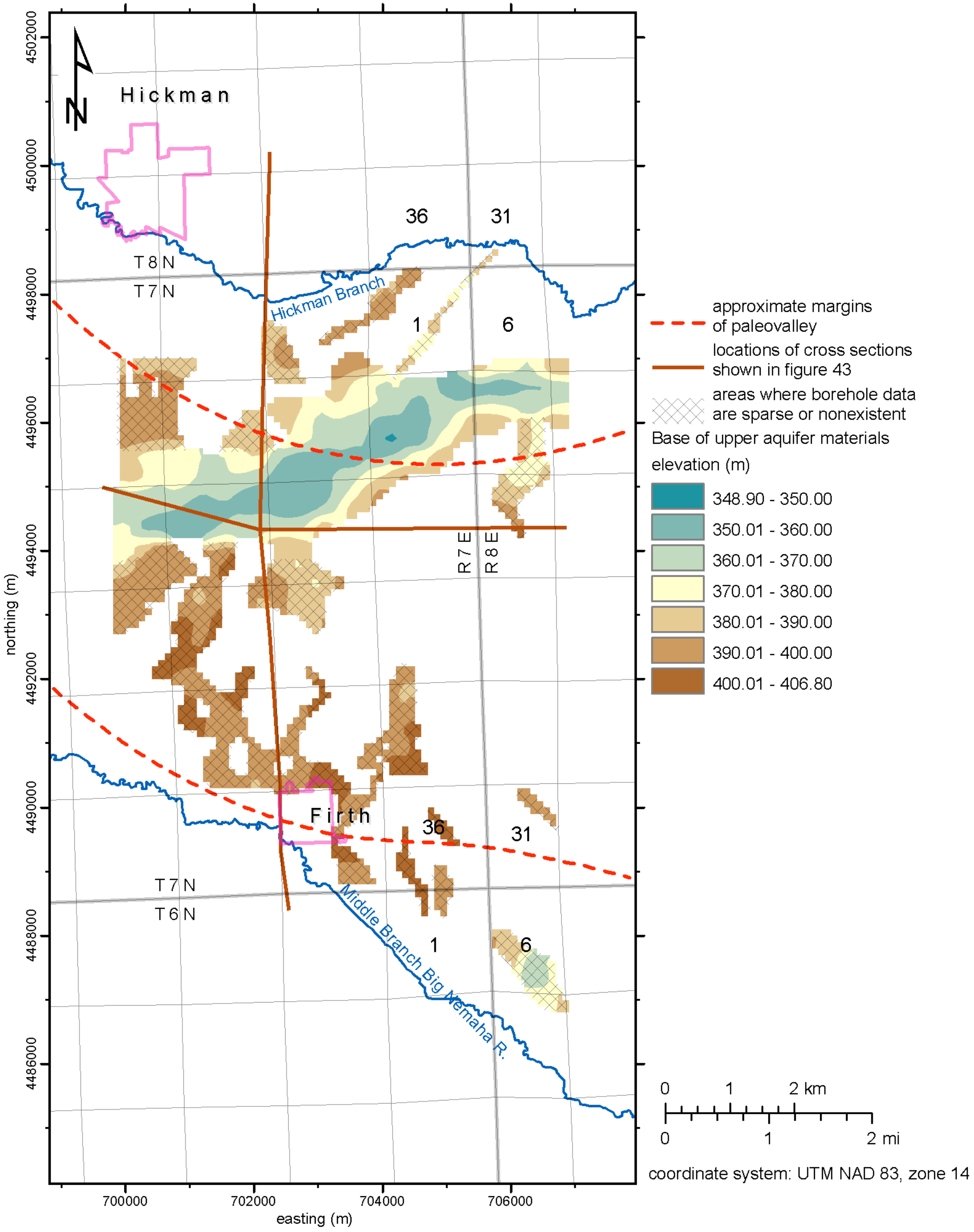


Figure 26. Elevation of the base of the upper aquifer materials. Cross-hatched pattern indicates areas where borehole data are sparse or nonexistent. In these areas, the surface was interpreted from HEM data alone and thus has not been verified.

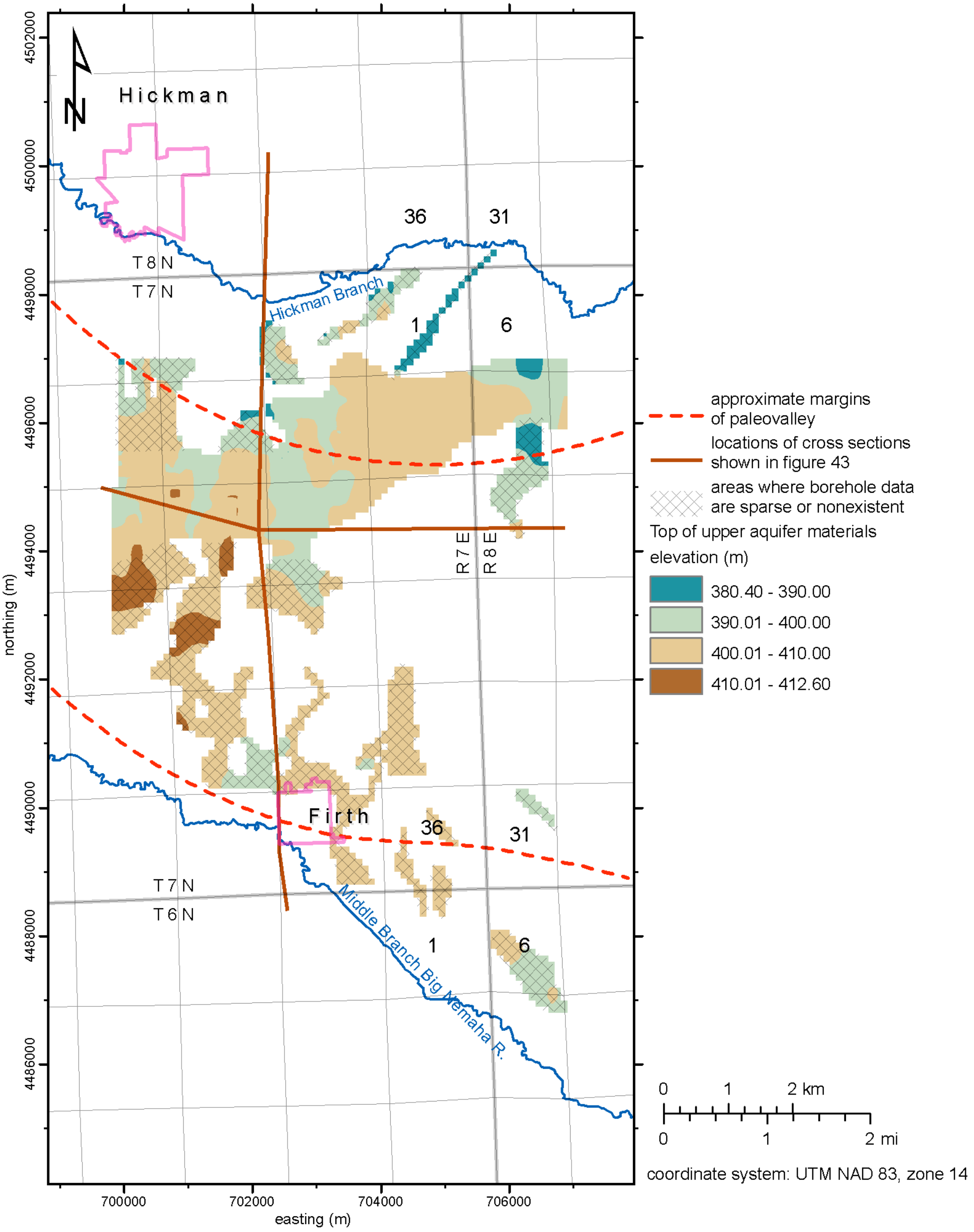


Figure 27. Elevation of the top of the upper aquifer materials. Cross-hatched pattern indicates areas where borehole data are sparse or nonexistent. In these areas, the surface was interpreted from HEM data alone and thus has not been verified.

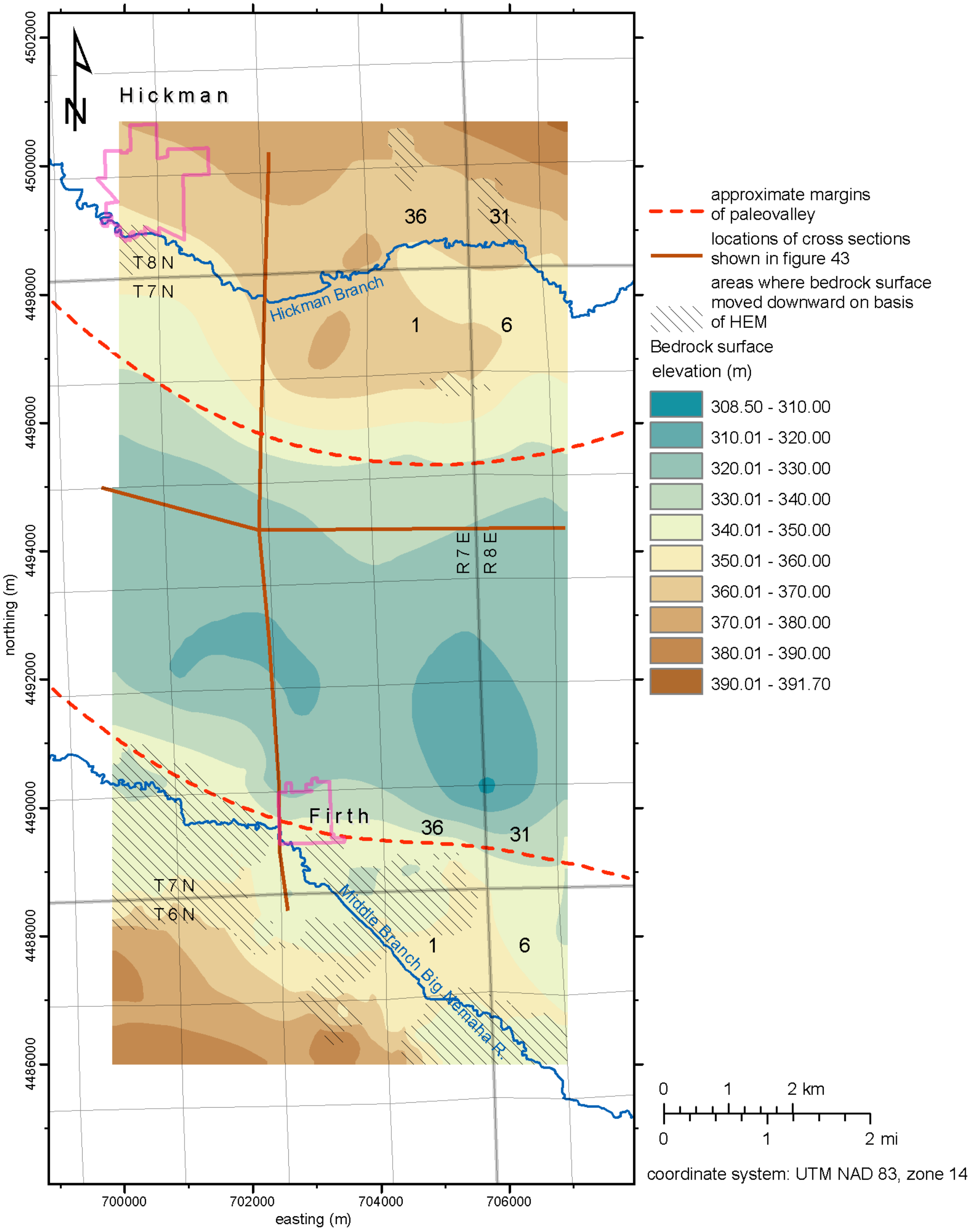


Figure 28. Elevation of the bedrock surface in the study area. Hatched pattern indicates areas where the bedrock surface was moved downward on basis of HEM data that indicated aquifer materials below the surface interpolated from borehole logs only.

groundwater levels and chemistry in forthcoming sections to assess the spatial relationships of the aquifers to one another and surface water.

The five hydrostratigraphic units are: lower, intermediate, and upper aquifers and a lower and upper aquitards. The upper aquitard is considered one hydrostratigraphic unit even though it completely surrounds the intermediate and upper aquifers in most locations.

6.4.1. Lower Aquitard

The lower aquitard (Fig. 29) is identified on the basis of low HEM resistivity values (generally <20 ohm-m) lying above the bedrock surface and below the base of the lower aquifer (Figs. 28 and 22, respectively). It exists only in the southern one third of the study area and attains approximately 27 m in maximum thickness. Boreholes penetrating this unit are sparse and therefore the sediment composition of this unit is mostly unverified.

6.4.2. Upper Aquitard

The upper aquitard (Fig. 30) is identified on the basis of low resistivity values (generally <20 ohm-m) and verified by the occurrence of tills, clays, and silts in test holes and the logs of registered wells. It underlies nearly the entire study area and attains a maximum thickness of approximately 85 m. It is not a single lithostratigraphic unit; rather, it includes all materials, exclusive of the intermediate and upper aquifers, between the top of the lower aquifer and the land surface. The upper aquitard completely surrounds the intermediate and upper aquifers in most locations. The upper aquitard is thin or absent south of the Middle Branch of the Big Nemaha River and over most of the broad, lenticular sand body within the upper aquifer (Fig. 30). It is also absent in a few areas between the lower and upper aquifers (Fig. 31). In these areas, the upper and lower aquifers are in direct contact and therefore operate as a single hydrostratigraphic unit (see Sections 5.4.3. and 5.4.4.). The upper aquitard is at least 10 m thick above most of the intermediate aquifers (Fig. 32) and is variable in thickness above the upper aquifer (Fig. 33)

6.4.3. Lower Aquifer

Lower aquifer materials (Fig. 34) are identified on the basis of high resistivity values (generally > 20 ohm-m) and verified by the occurrence of sands, silty sands, and gravels in test holes and the logs of registered wells. This unit is present in nearly the entire southern two thirds of the study area and it attains nearly 76 m in maximum thickness. It is absent in two areas southeast of Firth. One of these areas, between flight lines 30420 and 30500, was mapped as a narrow, slightly sinuous, northeast to southwest-trending feature in Section 1, T6N, R7E (Fig. 34). In HEM profile # 30430 (Appendix B), this feature appears to have a lenticular cross-section and consists of low-resistivity materials. A few registered wells (e.g. wells 126204 and 119591 in profile #30490) and one of our test holes (15EN07, Fig 14) penetrate the feature, and indicate that it is filled mostly with silt.

The top of the lower aquifer is identifiable in most HEM profiles, but in a few areas it lies below the maximum depth of investigation of HEM. In those areas, correlations were made on the basis of borehole data. The lower aquifer is confined below by either: (a) the bedrock or (b) low-resistivity materials overlying bedrock, which we interpret to be fine-grained sediments of alluvial or lacustrine origins. The base of this aquifer lies below the maximum depth of investigation in the central part of the study area, within the margins of the paleovalley. Borehole logs confirm that most of the deposits below the HEM profiles in this area are sand and gravel. Therefore, we include nearly all deposits lying between the base of the profiles and the bedrock surface in this area as part of the lower aquifer, even though some aquitards of limited thickness and areal extent certainly exist within this interval. Indeed, silt and clay layers were encountered below the depth of HEM, but fully within intervals defined as the lower aquifer, in test holes 09EN07 (Fig. 9), 10EN07 (Fig. 10), 16EN07 (Fig. 15), and 05A07 (Fig. 16).

Since we were not able to identify the water table directly from HEM profiles, we mapped the entire thickness of high-resistivity materials (sands and gravels) at the same stratigraphic level and defined them as lower aquifer materials, regardless of whether they may be saturated or not (Fig. 34). Water-level data and the presence of unsaturated sands in pits and outcrops, however, indicate that parts of this aquifer in the southern one-third of the study area are unconfined. Since the top of the lower aquifer in these areas must be the water table, we used the water-table contour map from Figure 19 to calculate the saturated thickness of the lower aquifer material in the unconfined area (Fig. 35). In the confined portion of the lower aquifer, where it is buried at depths of as much as 60 m, the entire volume of high-resistivity materials identified as the lower aquifer is saturated. The surface representing the top of the lower aquifer in this area is the base of a confining unit consisting of till, alluvial silt and clay, or loess (i.e. the base of the upper aquitard). The hydrostratigraphic model suggests that the lower aquifer is in direct contact with the upper aquifer near its northern limit (Fig. 31 and Appendix B, profile #30230). This condition is confirmed by lithologic and water-level data in test hole 13EN07 (Fig.

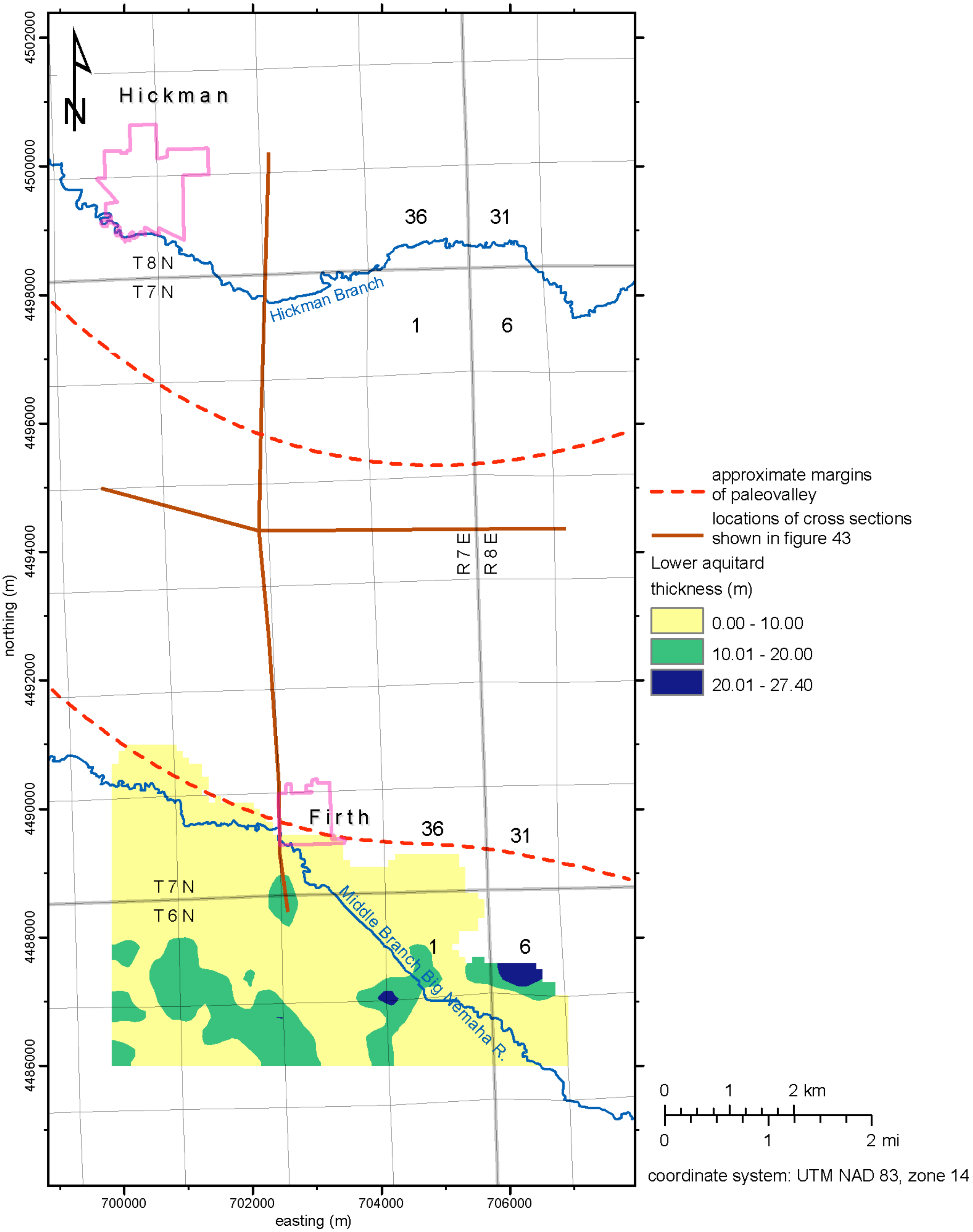


Figure 29. Thickness of the lower aquitard in the study area. This unit is interpreted mostly on the basis of HEM data and is largely unverified.

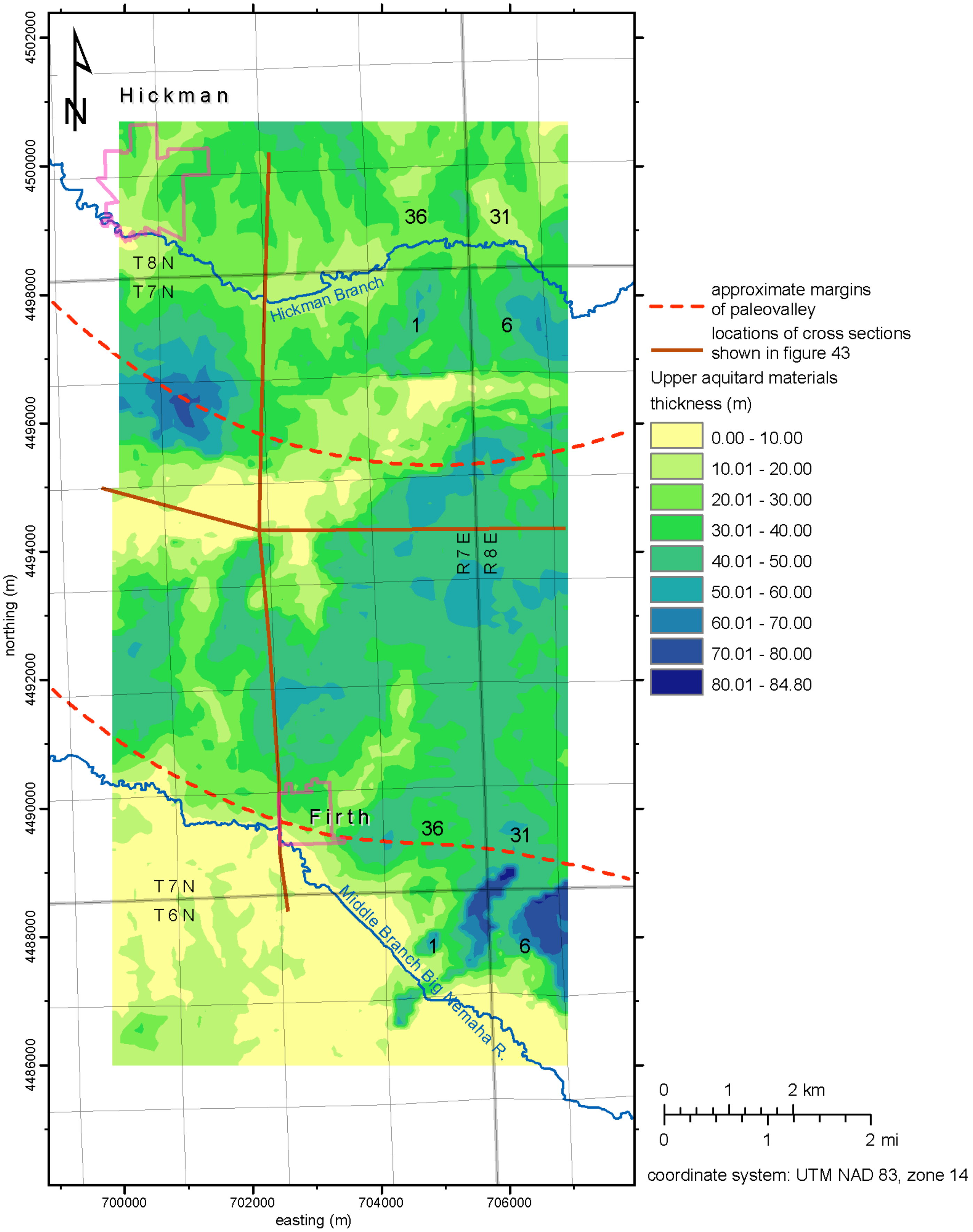


Figure 30. Thickness of the upper aquitard materials including saturated and unsaturated portions. In some areas, aquifers exist within the upper aquitard, so the thickness represents a composite thickness of all layers of the upper aquitard in any given area.

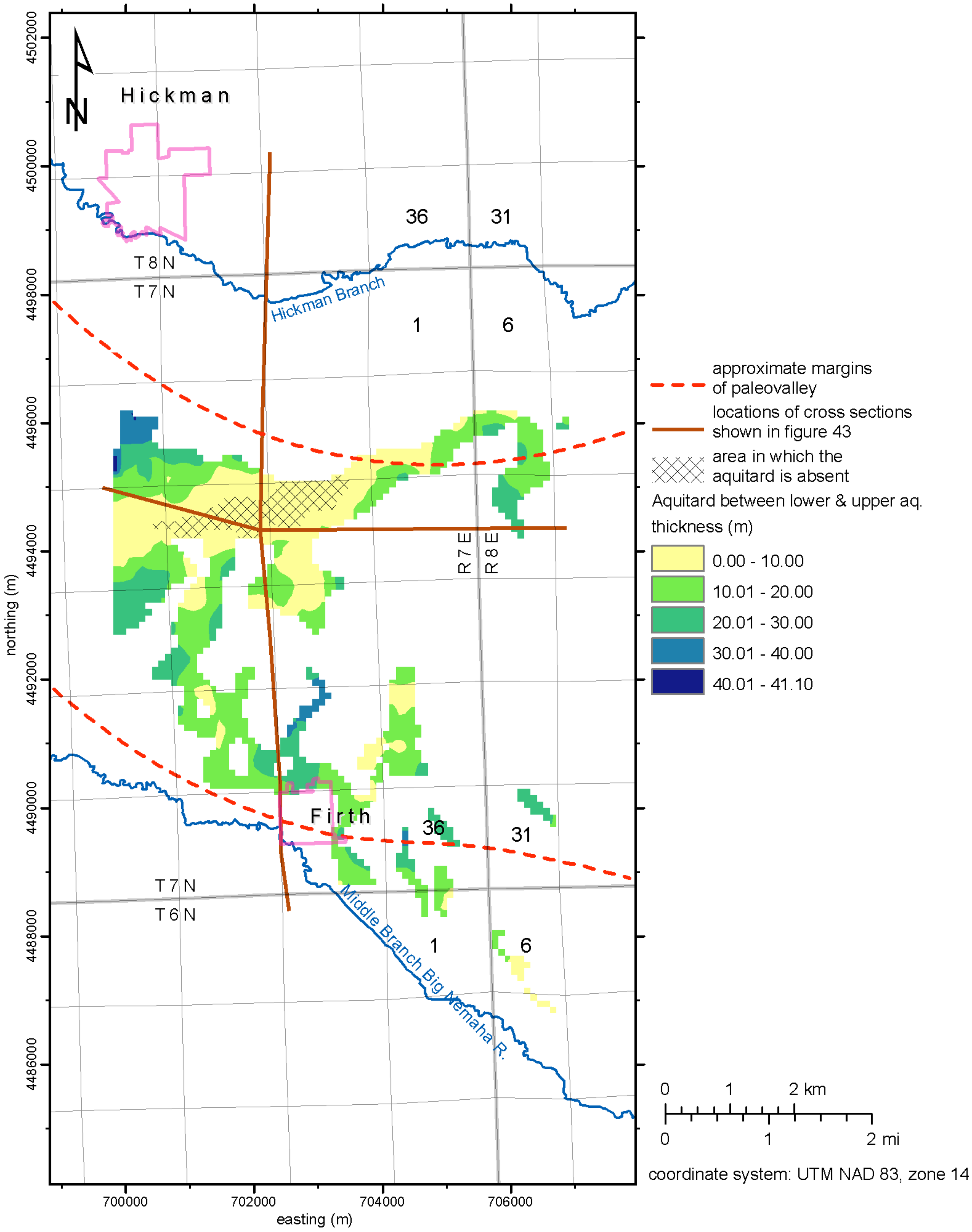


Figure 31. Thickness of the portion of the upper aquitard lying between the lower and upper aquifers. Note that the aquitard is very thin or absent in sections 14 and 15, implying hydrologic connection between the upper and lower aquifers.

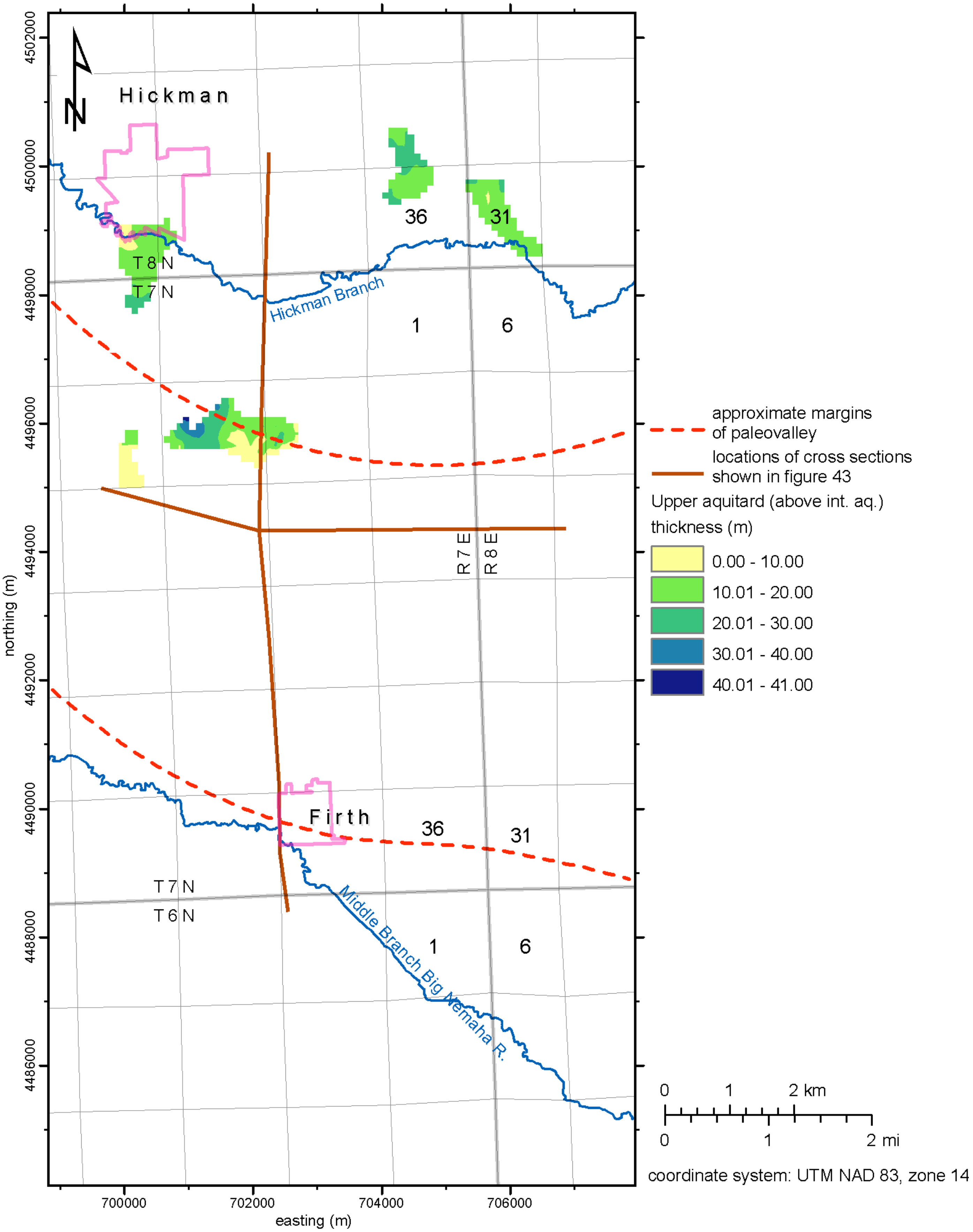


Figure 32. Thickness of the portion of the upper aquitard lying above the intermediate aquifers.

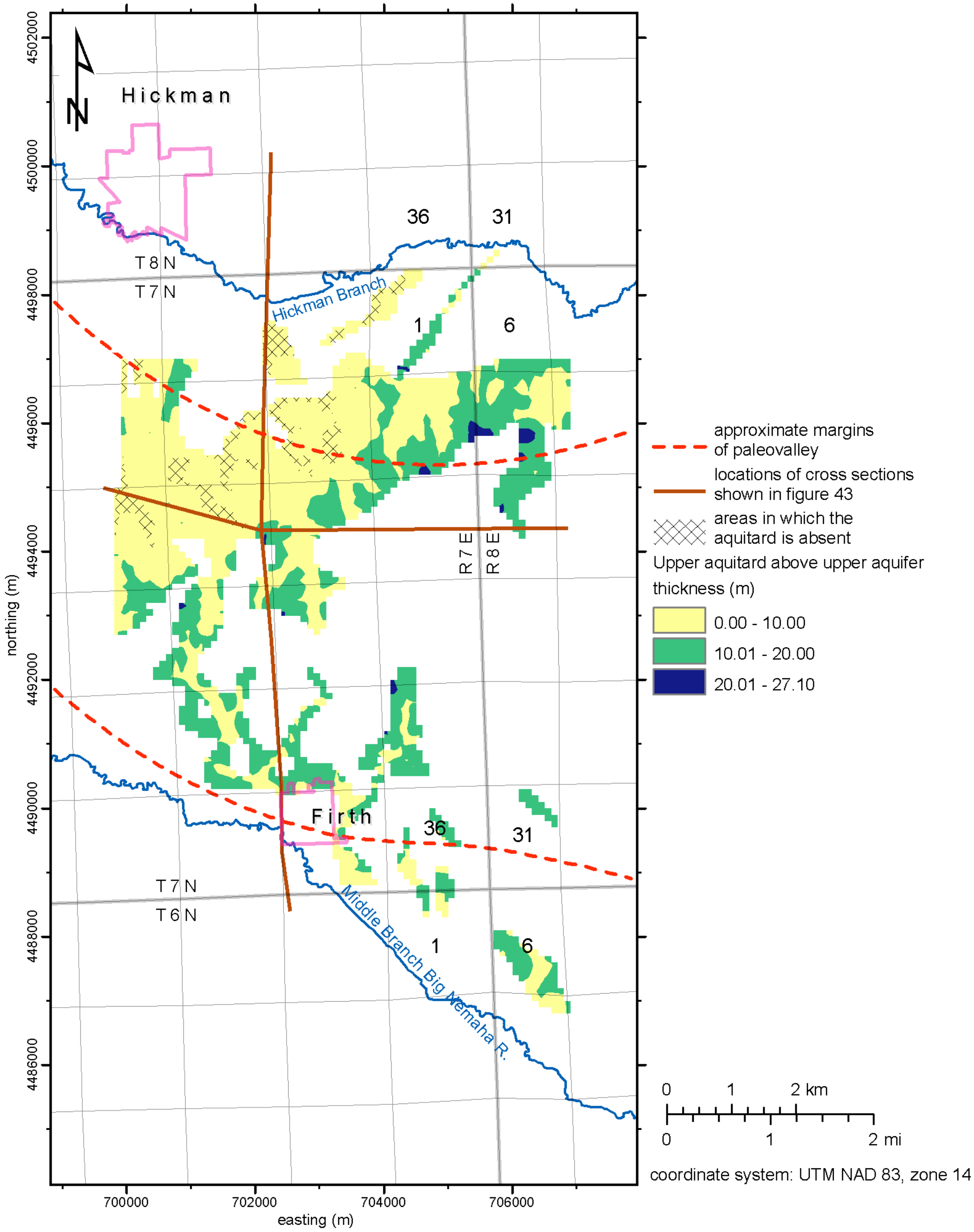


Figure 33. Thickness of the portion of the upper aquitard lying above the upper aquifer.

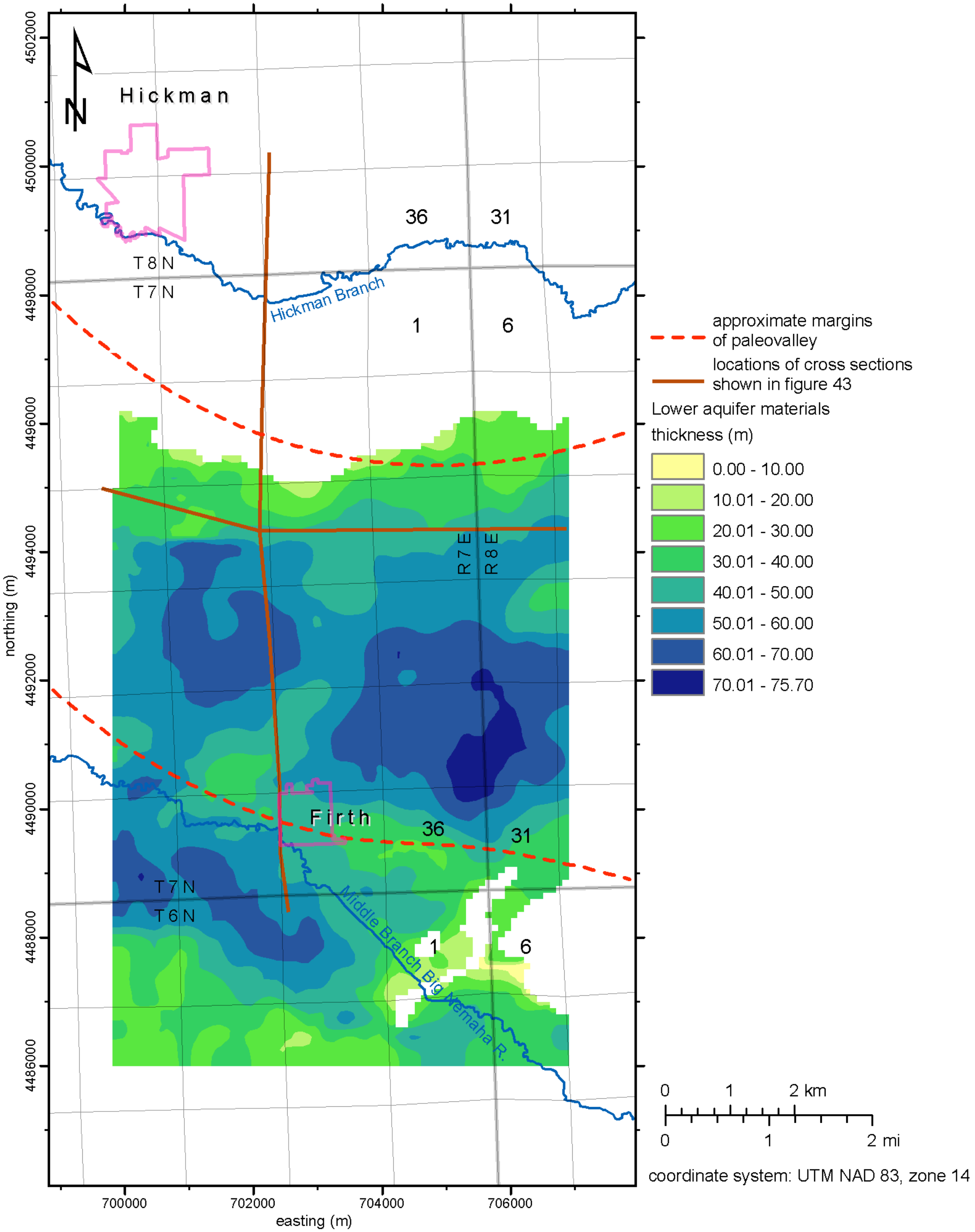


Figure 34. Thickness of the lower aquifer materials including saturated and unsaturated portions.

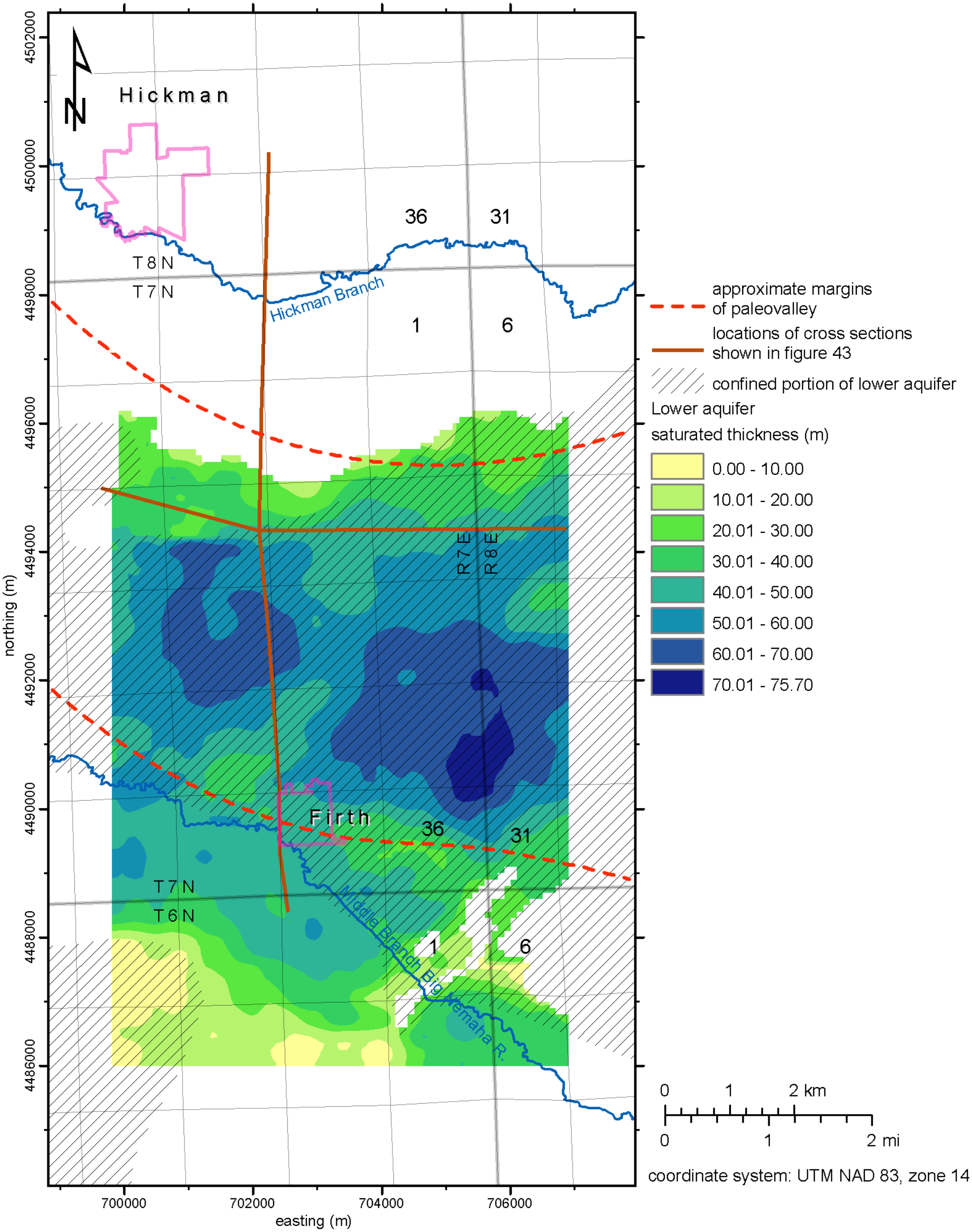


Figure 35. Saturated thickness of the lower aquifer computed by removing all portions of the sand and gravel bodies that lie above the water table in areas where the aquifer is unconfined (see Fig. 19).

8), where the lower and upper aquifers are in contact, forming a single, unconfined aquifer.

We were able to distinguish the upper aquifer from the lower aquifer on the basis of HEM resistivities. Resistivity values in the upper aquifer are generally > 30 ohm-m whereas values in the lower aquifer are generally 20 - 30 ohm-m. We saw no evidence for direct contact between the lower and intermediate aquifers (see Section 5.4.4.) in any of the HEM flight lines.

6.4.4. Intermediate Aquifers

The intermediate aquifers (Fig. 36) are identified on the basis of high resistivity values (generally > 20 ohm-m) in HEM profiles. The key profile in the distinction of these aquifers is the one corresponding to flight line 30170 (Fig. 20), which shows the upper, intermediate, and lower aquifers in superposition and separated from each other by low-resistivity materials. The HEM profile for flight line 30200 also shows three distinct aquifers at different stratigraphic levels. In several places, however, it is difficult to distinguish the intermediate aquifers from the upper aquifer. In these locations, the intermediate aquifers are distinguished from the upper aquifer because it does not exhibit maximum resistivity values as high as those exhibited by the upper aquifer. Cumulatively, the intermediate aquifers occupy a smaller volume than either the upper or lower aquifers. The intermediate aquifers attain a maximum thickness of nearly 21 m. The five mapped bodies composing the intermediate aquifers are irregular to elongate and range in width from 300 to 2000 m. The tops of these sediment bodies lie completely below the depth of the potentiometric surface (Fig. 19) and thus are assumed to be confined aquifers, although we have too few hydraulic head data to confirm this assumption. There are no spatial trends in these aquifers that are as distinct as some of those exhibited by the upper aquifer.

6.4.5. Upper Aquifer

Upper aquifer materials (Fig. 37) are identified on the basis of high resistivity values (generally > 20 ohm-m) and, in large part, they are verified by the occurrence of sands, silty sands, and gravels in test holes and the logs of registered wells. Some upper aquifer materials, however, are interpreted almost entirely from HEM data. The materials that make up the upper aquifer crop out at the land surface along the margins of the valleys of the Middle Branch of the Big Nemaha River and Hickman Branch. In these outcrop areas, the top of this aquifer itself must be the water table. Therefore, we mapped the entire thickness of high-resistivity materials (sands and gravels) at the same stratigraphic level and defined it as upper aquifer material (Fig. 37), and then we calculated the saturated thickness of this unit (Fig. 38) using the water-table/potentiometric surface map (Fig. 19).

The upper aquifer consists of two parts that exist within the same stratigraphic interval: (1) a west-southwest to east-northeast-trending, broadly lenticular sand body with resistivity values generally >30 ohm-m, that tapers at its northern and southern edges (flight lines 30140-30240); and (2) numerous irregular, elongate, slightly to moderately sinuous ribbon-like bodies with resistivity values generally between 20 – 30 ohm-m, appearing between flight lines 30080 and 30490 (e.g. Figs. 20, 21; Appendix B). The large sand body (1) is well-identified by the numerous registered wells that penetrate it; it also appears in HEM profiles as a zone of notably high resistivity. It is interpreted as a large channel fill or a fill of a small valley by virtue of its geometry. The minimum width of this body is no less than 600 m and its maximum width is at least 2200 m. Its maximum thickness is approximately 56 m, including both saturated and unsaturated materials. Its maximum saturated thickness is approximately 44 m (Fig. 38). The upper aquifer is in local contact with the lower aquifer where the intervening aquitard is absent (Figs. 8 and 31). The aquitard overlying the upper aquifer is highly variable in thickness and in some locations is absent altogether (Fig. 33).

The ribbon-like bodies are identified almost entirely on the basis of HEM profiles, and therefore their sediment compositions are mostly unverified. Nonetheless, on the basis of data from a few boreholes and the overall association of high-resistivity signatures with coarser-grained materials, we interpret them as small sand bodies. Some of these small sand bodies appear to have direct connections with the larger sand body, but others are entirely isolated from it and any other high-resistivity units identified in HEM profiles. Ribbon-like features, as we have interpreted them, are generally lenticular in cross-section and range in width from 60 to 1500 m, and in maximum thickness from approximately 15 to 30 m. In the southern one-third of the study area these bodies exhibit a pronounced northwest to southeast trend, but in the northern one-third of the study area, two features show a northeast to southwest trend (Figs. 37 and 38).

In addition to the lower, intermediate, and upper aquifers described above, we also recognized a high-resistivity unit at the land surface (i.e. profiles 30290-30310 and 30380-30390, Appendix B), although this unit is likely to be unsaturated throughout most or all of its thickness.

The total thickness of aquifer materials and the saturated thickness of all aquifers are shown in Figures 39 and 40. These maps can be used

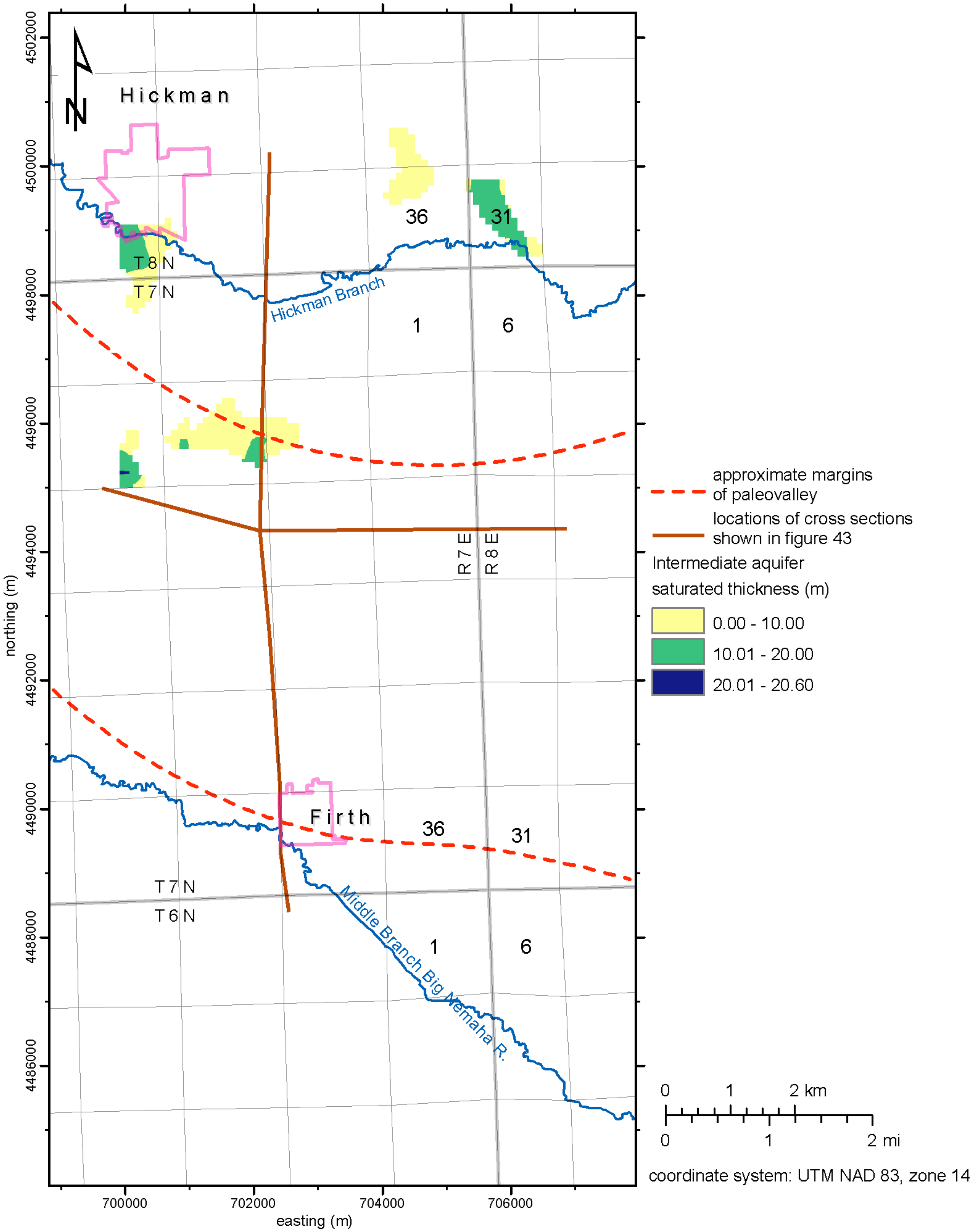


Figure 36. Thicknesses of the multiple intermediate aquifers. Although no water-level data are available for this aquifer, it lies below the interpretive water table (Fig. 19) and is therefore assumed to be fully saturated.

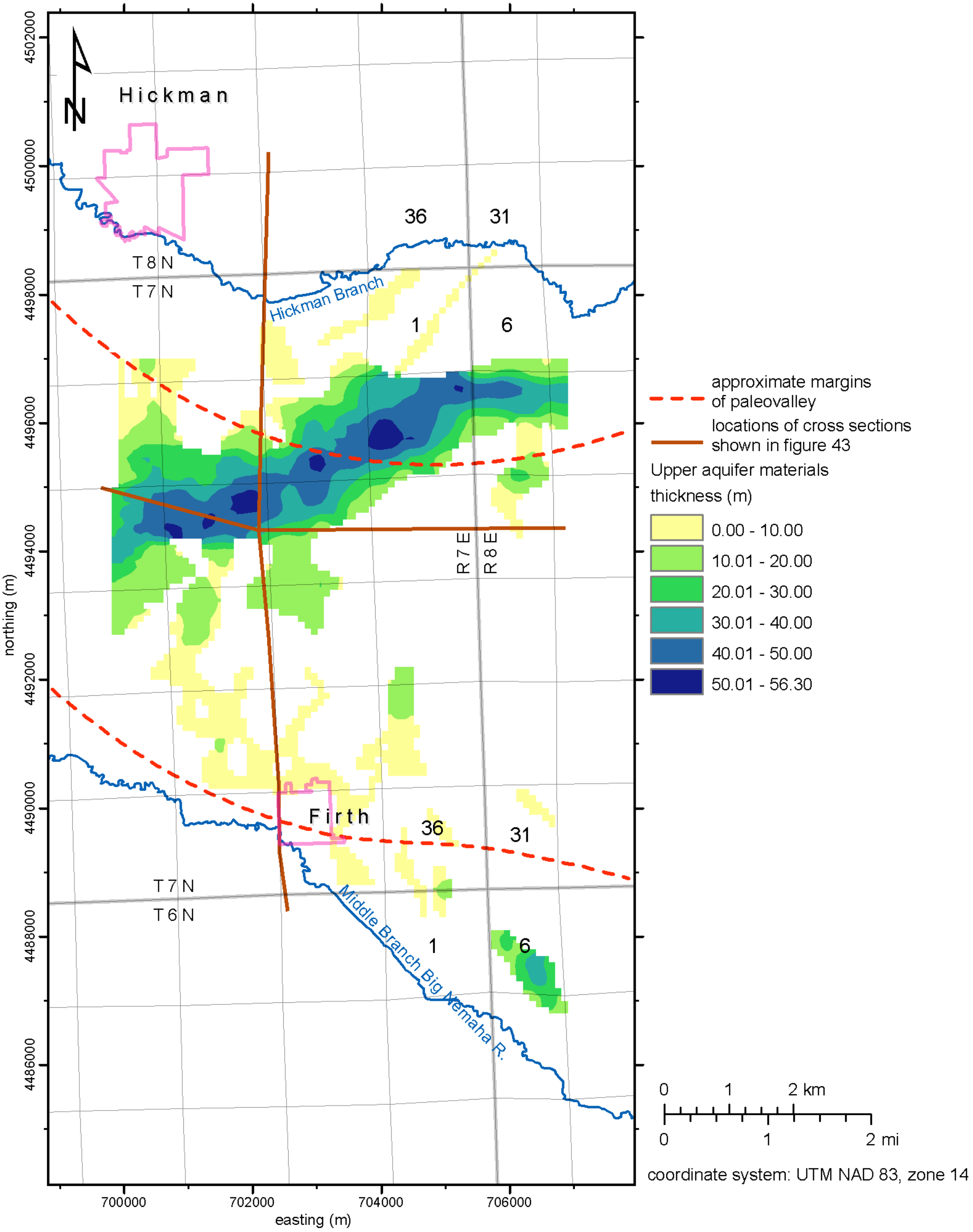


Figure 37. Thickness of the upper aquifer materials including saturated and unsaturated portions.

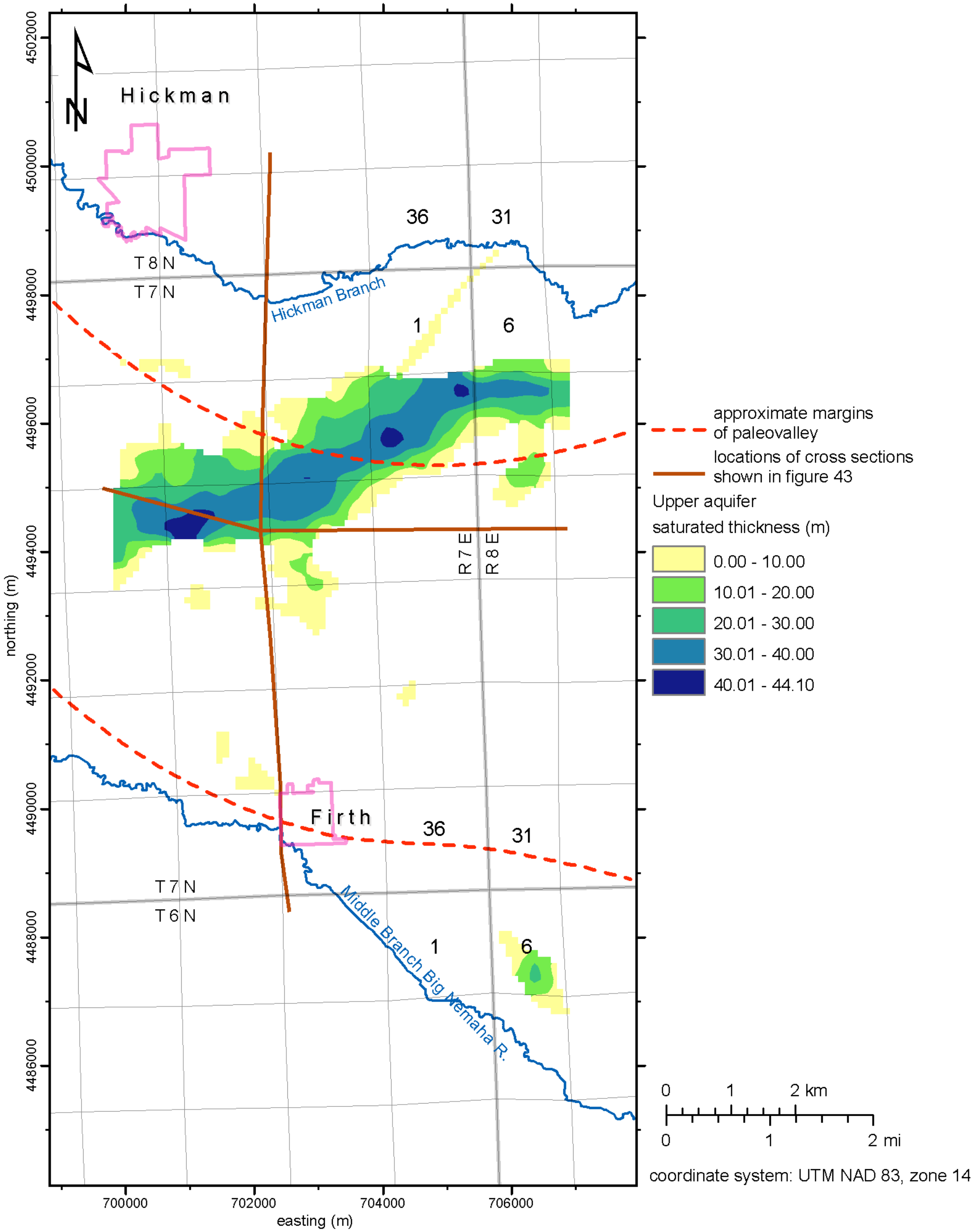


Figure 38. Saturated thickness of the upper aquifer computed by removing all portions of the sand and gravel bodies that lie above the water table or potentiometric surface (Fig. 19). No water-level data are available for the ribbon sands located north and south of the main part of the aquifer. Therefore, the potentiometric surface was used as an approximation of the minimum elevation of the water table in those areas. The actual saturated thickness of the ribbon sands could be greater than shown.

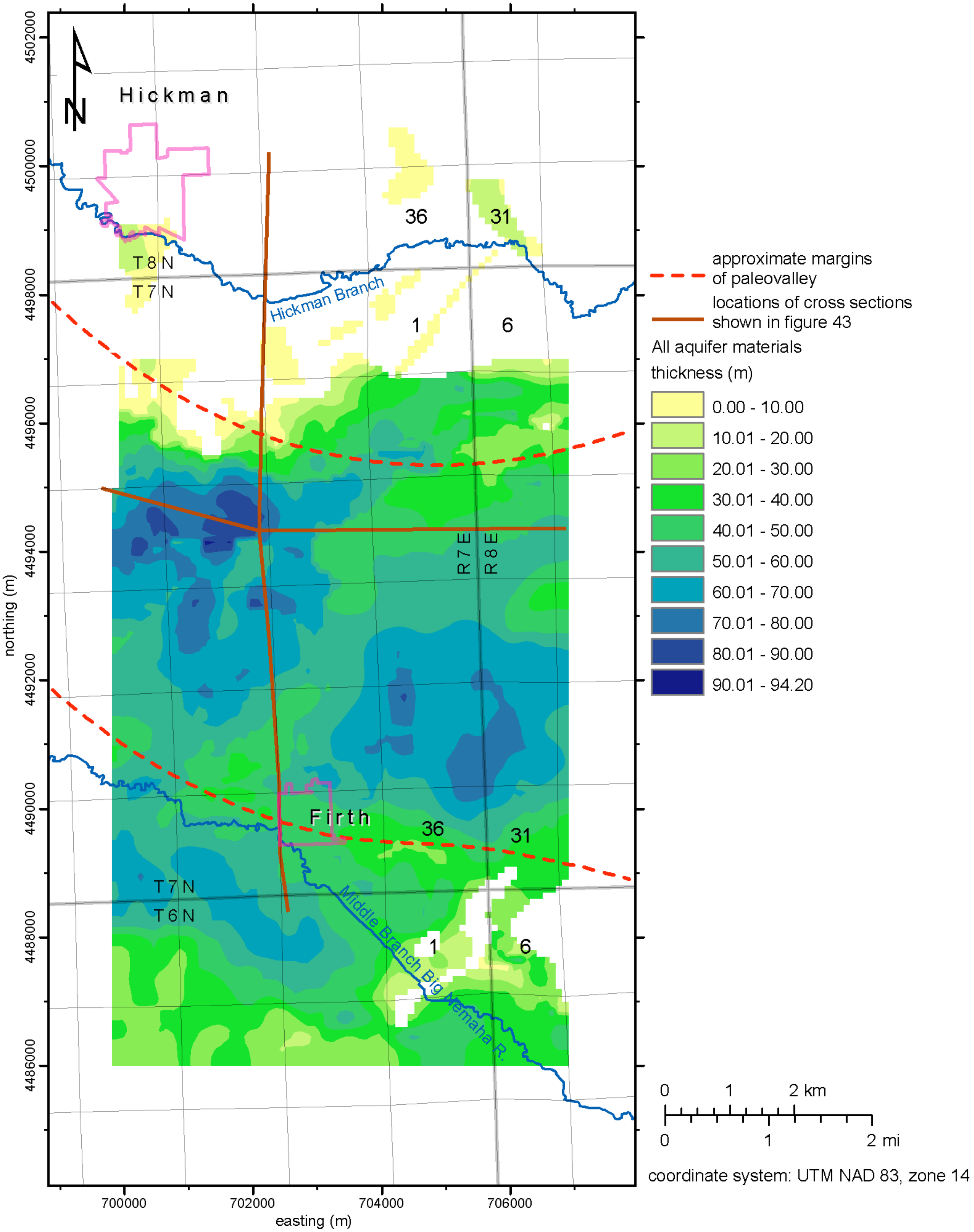


Figure 39. Composite thickness of all aquifer materials including saturated and unsaturated portions.

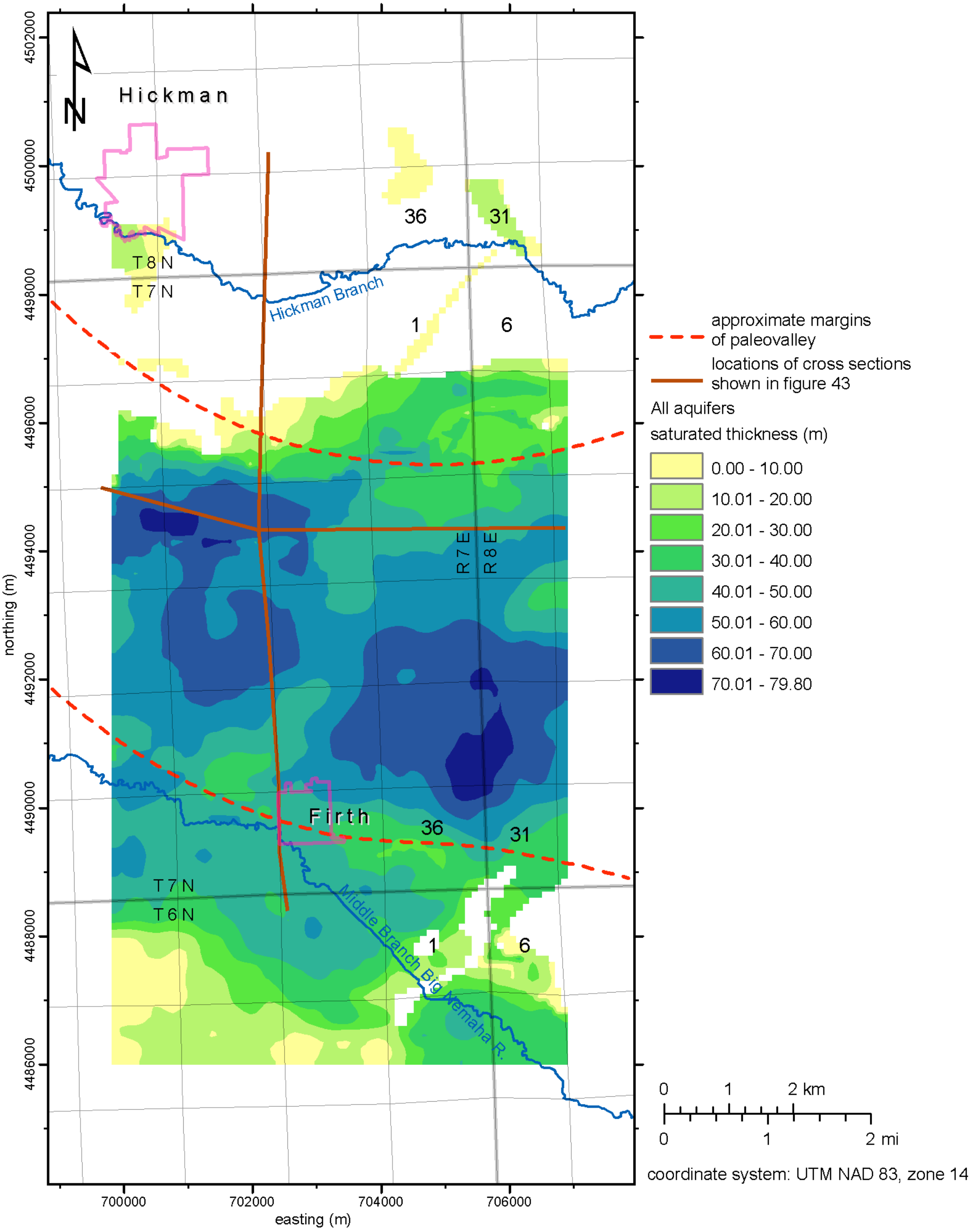


Figure 40. Composite saturated thickness of all aquifers.

to locate groundwater supplies, evaluate the potential for large-scale groundwater development, and assess the potential vulnerability of aquifers to overdevelopment on the basis of aquifer thickness. They should not, however, be used as a stand-alone guide to groundwater availability. Rather, the thickness of individual aquifers and aquitards (Figs. 29 – 38) should be taken into account.

6.5. Groundwater Levels

Groundwater elevations in ENWRA monitoring wells range from a high of approximately 418.8 m above mean sea level in 09EN07-85 to a low of approximately 384.4 m above mean sea level in 08EN07-15 (Fig. 41). Very brief downward spikes in the water levels are the result of purging during water-quality sampling events. 10EN07-135 is very slow to recharge after water-quality sampling, and instead of sharp downward spikes, recharge curves more typical of prolonged pumping occur. Three such curves are evident in the water level record for this well between September 2008 and March 2009. Drawdowns not related to water-quality sampling occur in several of the wells during the summer months and likely represent water level declines due to the pumping of nearby irrigation wells.

Seventeen wells have heads at approximately 393 m above msl and seasonal drawdowns of similar length, but different magnitude (Fig. 41). One well (09EN07-135) has a head of approximately 393 m but does not exhibit seasonal drawdown. The locations of well nests coincide with the test hole locations as shown on Figure 5. The magnitude of the drawdown in a well depends on a wide variety of factors, including but not limited to the proximity of pumping wells and hydraulic boundaries, heterogeneity and thickness of the screened unit, quality of hydraulic connection between the well and the aquifer (well efficiency), and the volume of recharge. The two deep wells at the Matthes Monitoring Well site (MMW-260 and MMW-290; Table 2) have the same seasonal drawdown trend, but a static head at 389 m, which is approximately 3.7-4.6 m lower than the wells along the main north-south transect. This elevation difference is likely due to the location of the MMW well nest about 4.8 km down-gradient from the other wells.

Irrigation wells in the area around well nest HKMW3 are completed into the lower aquifer (Fig. 17, L). Hydrographs of monitoring wells completed in both the upper and lower aquifers show drops in water levels during the summer irrigation season, although the drawdown in the upper aquifer is of lower magnitude that that exhibited by the lower aquifer (Fig. 41). This simultaneous drawdown in two separate aquifers, in addition to the similar chemistries of their waters (Fig. 17), suggests that leakage takes place across the aquitard separating them (see also Section 6.2.).

The wells that do not share the common water level pattern are either screened at a higher elevation, or are located north of the paleovalley (Fig. 5). Seasonal changes in the water levels of these wells varied, but were generally on the order of one to two meters during the three years of data reported. These changes could be significant locally if low-volume wells (such as domestic wells) are installed in the screened units. In the context of the lower aquifer groundwater-flow system, however, the relatively minor changes in the shallower wells is likely insignificant.

Water levels indicate that several test holes were drilled into unconfined aquifers (13EN07, Fig. 8; 11EN07, Fig. 11; 12EN07, Fig. 12). Long-normal resistivity values are higher in the unsaturated sands than they are in the saturated sands. HEM resistivity values, however, tend to increase rather than decrease in a downward direction across the water table (e.g. Fig. 8) or they remain constant across the water table (e.g. Fig. 12). We are unable, therefore, to map the position of the water table using HEM.

6.6. Groundwater Chemistry

The geochemistry of water is affected by many factors including, but not limited to, flow paths through the subsurface, composition of aquifer material, source and age of recharge water, and chemical and biological reactions (Domenico and Schwartz, 1998). Differences in the natural chemistry between water samples from different wells can therefore provide information regarding groundwater flow paths that can augment geologic framework and water-level information. In an effort to better understand the groundwater chemistry of the study area, 168 groundwater samples were collected from the nested wells in the study area between September 2008 and November 2010. Table 3 shows the basic descriptive statistics grouped by analyte. Only results verified by the QA/QC process were included in the statistical analysis and all concentrations below the detection limit were assigned a value equal to one-half the detection limit of the laboratory method used. The average ion balance error for all sampling events ranged from 3.3% to 12.0%. In all but three of the samples, the ion balance error was positive. Normality testing using the Shapiro-Wilk W test (Shapiro and Wilk, 1965; Washington State Department of Ecology, 1992) indicated that the data sets differed significantly from a normal distribution. The natural log (ln)-transformed data were generally closer to normally distributed than were the untransformed data, though only the potassium data set was ln-normally distributed at the 95% confidence level (W= 0.99, p=0.19). Since the ln-transformed data are closer to normally distributed than the untransformed

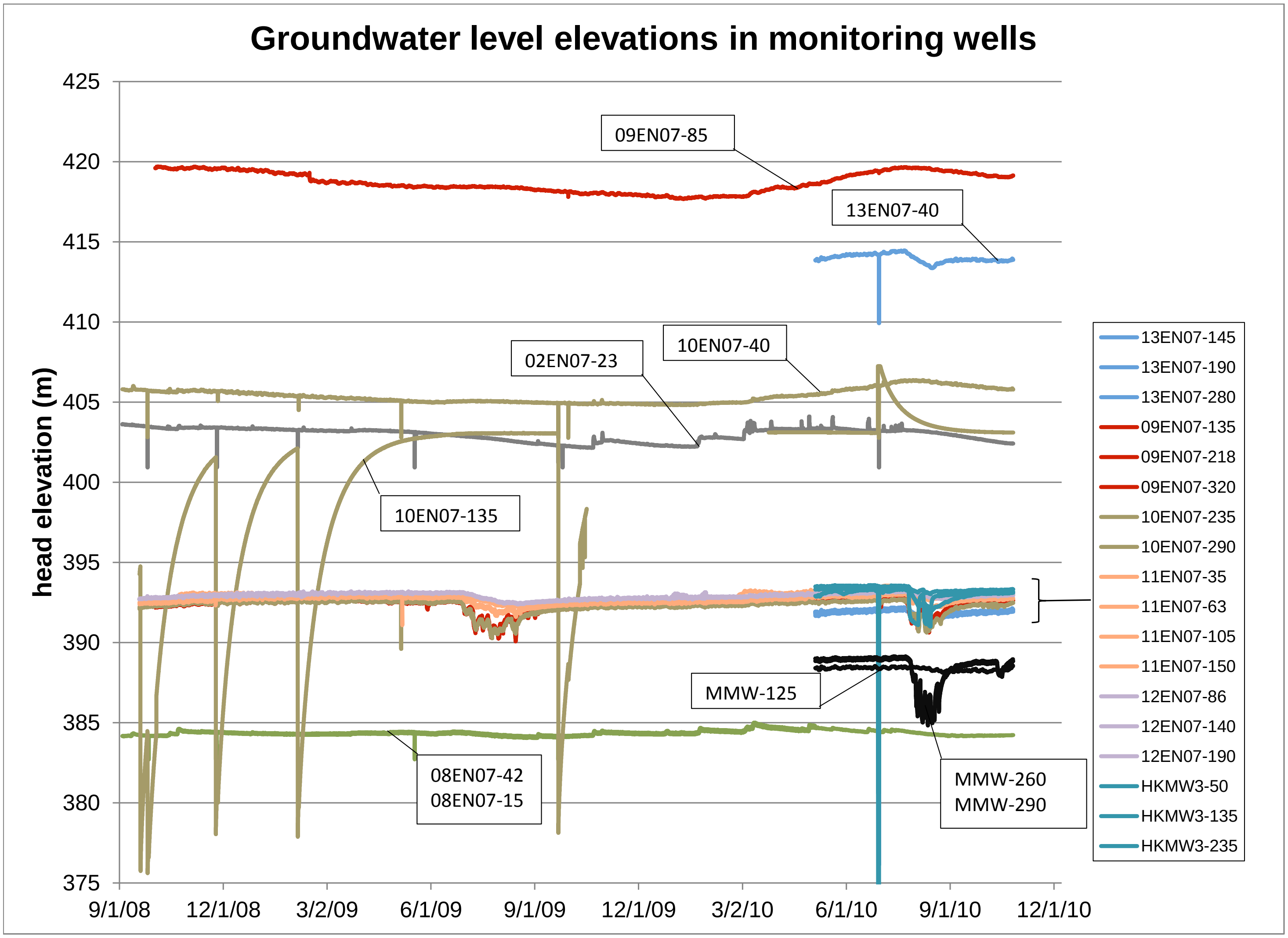


Figure 41. Groundwater-level hydrographs for monitoring wells in this study. Colors correspond to hydrographs from monitoring wells in the same nest. First two numbers in well ID indicate well site, whereas numbers to the right of the dash indicate depth of the well in feet.

data, the basic descriptive statistics in Table 3 use the ln-transformed data.

Table 3. - *Groundwater chemistry descriptive statistics*

Analyte	Number of samples	Geometric mean (mg/L)	ln normal dist?	ln mean (mg/L)	ln variance	ln skewness
Alkalinity	166	309.67	N	5.74	0.15	3.43
Calcium	163	97.40	N	4.58	0.12	1.07
Chloride	166	17.30	N	2.85	2.14	0.19
Iron	89	0.09	N	-2.43	3.94	0.17
Magnesium	157	21.83	N	3.08	0.22	1.01
Manganese	137	0.11	N	-2.24	4.66	-0.39
Nitrate	168	0.67	N	-0.41	4.94	0.74
Potassium	131	4.14	Y	1.42	0.24	0.25
Sodium	157	51.28	N	3.94	0.53	0.79
Sulfate	166	46.72	N	3.84	1.09	-0.70

Piper diagrams were made using RockWorks 2006 software (Fig. 42). Iron, manganese, and nitrate+nitrite as nitrogen were added as additional cations and anions to the default list of ions provided by the software because they are commonly detected in water samples from the monitoring wells. The alkalinity value reported by the laboratory was entered as the bicarbonate concentration, and the carbonate concentration was assumed to be zero. Given the pH of the samples (average pH is 7.3), this assumption is likely valid since the activity of carbonate is negligible at neutral pH levels (Drever,

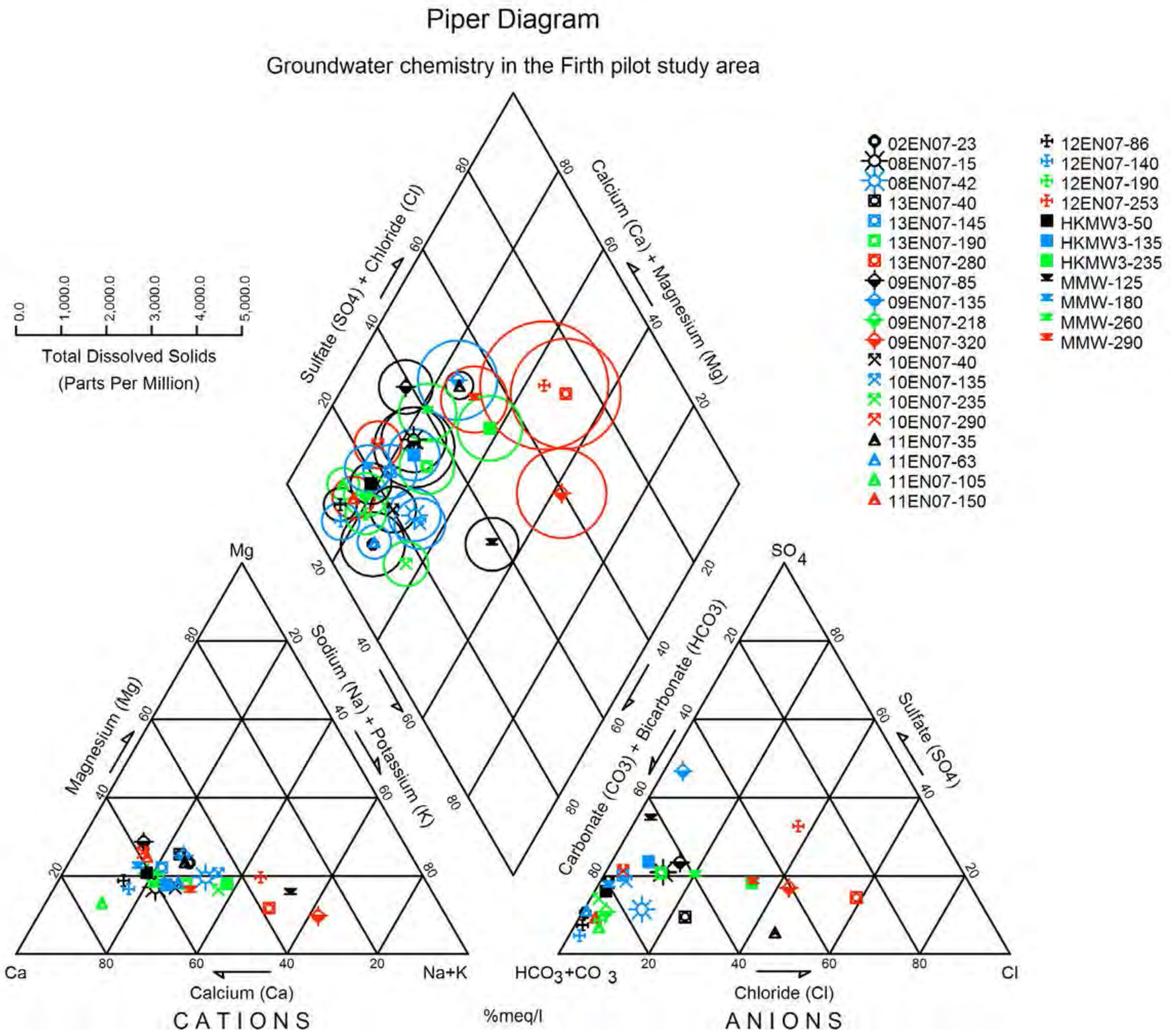


Figure 42. Piper diagram showing hydrochemistry of groundwater from different depths and locations in the study area. First two numbers in well ID indicate well site, whereas remaining numbers to the right indicate depth of the well in feet.

1997). Chloride and calcium are the two analytes having the widest concentration range among wells, followed by alkalinity. In Figure 42, these differences are depicted by the elongated lateral spread of data across the center of the diamond and the upward slant along the sulfate + chloride diagonal.

Spearman's Rank correlation coefficient (Conover, 1986) was used to analyze the data for temporal trends. The Julian date of the sampling event was used as the independent X variable and the mean concentration of samples collected on that date as the dependent Y variable. Iron was the only analyte in which a trend (upward) was significant at the 95% confidence level. However, the iron data set is imbalanced, with 80 of the 89 samples occurring in the first half of the time frame. This imbalance occurred partly because the sampling schedule was changed from quarterly to biannually, and partly because a large number of the data points in the last two sampling events were not used in the statistical analysis due to QA/QC inadequacies.

7. Discussion

7.1. Resistivity Values

A direct comparison of the HEM data of Smith et al. (2011) with borehole data allowed us to differentiate between higher-and lower-resistivity sediments. Accordingly, we determined that HEM resistivity values between 10 and 20 ohm-m correspond to silt, clay, and till and that values >20 ohm-m correspond to sands and gravels. The range of long-normal resistivity values in most of our borehole geophysical logs is ~50 – 200 ohm-m, and the boundary between fine-grained and coarse-grained sediments in the same logs is at ~100 ohm-m. The ranges of HEM resistivities that we assigned to the finer-grained sediments differ from the corresponding ranges attributed to glacial sediments in other airborne- and ground-based EM studies. Palacky and Stevens (1990), for example, found that clays generally had resistivity values of less than 100 ohm and that sand and gravel generally exhibited values greater than 100 ohm-m. Likewise, Best et al. (2006) mapped tills using values between 5 and 15 ohm-m and differentiated sand and gravel using values >70 ohm-m. The discrepancies between our data and these studies suggest that the HEM results from Smith et al. (2011) may be in need of further geophysical analysis.
Our borehole data could be used to rigorously constrain and condition the HEM results. Unfortunately, any revision of the original HEM data is precluded by the multi-phase nature of this study and the operating of multiple different agencies under separate funding agreements and timelines. Future studies should seek to establish more collaborative and flexible partnerships so that different agencies can contribute to an integrated analysis of the entire dataset. Nevertheless, on the basis of multiple direct comparisons (Figs. 6-18; see also Section 5.2) and our systematic correlation of boreholes (Section 5.3), we are confident that the 20 ohm-m contour approximates the contact between major hydrostratigraphic units, even if actual resistivity values exhibited by these units seem to be too low.

Water saturation can exert a strong control on subsurface resistivity values (e.g. Baldridge et al., 2007). In this study, however, we were not able to distinguish between unsaturated and saturated sands in HEM profiles even though long-normal resistivity values clearly change at the position of the water table. This discrepancy is likely the result of the large volumes over which resistivities are averaged in HEM compared to downhole geophysics. Whereas resistivity can be resolved to ~1 m near the land surface and to ~15 m at deeper intervals via HEM (Smith et al., 2011), resistivities are measured every 3 cm in our downhole geophysical logs. Furthermore, other factors such as mineralogy, porosity, or chemistry may exert strong controls on resistivity within the comparatively large volumes represented in HEM, thereby masking any effect that water saturation exerts on the resistivity profile.

7.2. Geological Interpretation

The high resistivity materials comprising the lower aquifer are continuous from north to south for more than nine km (Profile #39010, Appendix B) and from east to west for at least seven km (Profile #30370, Appendix B). We interpret the lower aquifer as a single hydrostratigraphic unit, but the geometries and lithologies of the materials from which it is composed suggest that it actually consists of distinct lower and upper sediment bodies. The lowermost body consists of sands and gravels of the Dorchester-Sterling paleovalley fill, the base of which lies between 310 and 360 m in elevation. Gravels within this body include clasts of granite and potassium feldspar derived from the Rocky Mountains to the west (Stanley and Wayne, 1972). The upper sediment body, in contrast, consists of sands and gravels that do not appear to be genetically related to the paleovalley deposits. The base of the upper body lies between 390 and 400 m in elevation. It is not constrained to the bedrock low in which the underlying paleovalley sediments were deposited. Rather, the upper sediment body overlies a bedrock high south of the paleovalley and its base lies at roughly the same elevation as the top of the paleovalley fill. The upper body contains granules and pebbles of red metaquartzite and dark-colored igneous and metasedimentary rocks, the origin of which is typically considered to be glacial (Stanley and Wayne, 1972). The juxtaposition of these two sediment bodies in the valley of the Middle Branch of the Big Nemaha River, however, provides a hydrologic connection and makes them indistinguishable in HEM profiles (e.g. profiles 30370 – 30420, Appendix B).

The northern edge of the west-southwest to east-northeast-trending, large lenticular body in the upper aquifer materials (Fig. 37) coincides with northern edge of the Dorchester-Sterling paleovalley aquifer. This coincidence, however, does not necessarily imply a genetic relationship between the two depositional units. Moreover, no paleocurrent data exist for sediments comprising the upper aquifer, rendering impossible a differentiation of sediment bodies on the basis of paleoflow. Considering that the ribbon-like bodies trend at approximately 45° to the axis of the Dorchester-Sterling paleovalley, implying flow probably to the southeast, the large lenticular body may instead be an apron of outwash deposited by a stand of the Laurentide ice sheet at the northern margin of the Dorchester-Sterling paleovalley. We speculate that the upper sediment body of the lower aquifer may also be an apron of outwash. Its base is similar in elevation to the base of the largest sediment body in the upper aquifer, HEM profiles and borehole data indicate that the geometries and compositions of these two sediment bodies are at least broadly comparable, and both are lenticular and contain gravel clasts suggestive of a till source.

The geometries of the high-resistivity ribbon-like bodies identified herein as parts of the upper aquifer suggest that they were deposited by much smaller drainages that flowed obliquely to the trend of the antecedent Dorchester-Sterling paleovalley. These ribbon-like bodies definitely underlie Late Pleistocene loess, but their stratigraphic relationships with one or more till units in this area are uncertain. Our rendering of these features implies that their margins pinch out at approximately the same depth below the land surface. This depth corresponds to a narrow zone of slightly higher resistivity (~14 ohm-m) that exists in nearly all of the HEM profiles (Appendix B). Some of these ribbon-like bodies are narrow and deep, but others are broad and shallow. Regardless of their geometries, most of the ribbon-like bodies underlie the trends of extant low-order drainages.

We are not able to confirm that the high-resistivity ribbon-like bodies comprising the intermediate and upper aquifers are indeed sediment bodies given the available dataset, so any conclusions regarding their presence must be considered speculative. Nevertheless, some of these bodies may be the deposits of subglacial drainages that existed near the terminus of the Laurentide ice sheet during one of its retreats. Many authors have described either exposed ("open") or buried tunnel valleys or tunnel channels in association with aquifers in northwestern Europe and the glaciated parts of North America (e.g., Woodland, 1970; Wright, 1973; Barker and Harker, 1984; Piotrowski, 1997, Fisher et al., 2005; Uchupi and Mulligan, 2006; Sandersen et al., 2009; Stewart and Lonergan, 2011). Tunnel valleys are undulating, elongate, partially or completely sediment-filled depressions, as long as a few tens of kilometers, which are eroded by subglacial meltwater underneath a continental ice sheet. Tunnel valleys may be filled with coarse or fine-grained sediments, they are typically narrow and deep, and they may appear as single features or as parts of a larger network of channels. In many cases, they terminate abruptly or cut across older channel-fills or antecedent glacial geomorphic features.

7.3. Aquifer-Aquifer Connections and Groundwater Flow

Our three-dimensional hydrostratigraphic model provides a framework from which to study inter-aquifer connections and groundwater flow paths. We integrated water-level and hydrochemistry data with N-S and E-W cross sections through the model (Fig. 43). Equipotential lines were drawn manually by interpolation using water-level data from 34 different wells at various depths (Table 2; Figs. 6-18). The equipotential contours constructed from these data represent the configuration of the groundwater flow system during intervals of time between 2008 and 2010 when water levels were static. This methodology contrasts with the one employed in the construction of the water table/potentiometric surface map (Fig. 19), which is an average of water levels collected since the 1960s (see Section 5.4.). The differences in the time intervals represented in the cross section (Fig. 43) and the map (Fig. 19) resulted in some localized inconsistencies. Nevertheless, the equipotential lines (Fig. 43) were checked against the interpreted water-table/potentiometric surface map and were found to be consistent overall.

Groundwater flows freely from the unconfined portion of the lower aquifer south of Firth to the confined portion under the uplands to the north. Hydrochemical facies between the unconfined and confined portions of the lower aquifer between monitoring well sites 10EN07, 11EN07, and 12EN07 are similar (Fig. 43). These observations suggest that much of the area south the Middle Branch of the Big Nemaha River is a recharge area for the Dorchester-Sterling paleovalley aquifer further north, a finding that is consistent with our assertion that the two sand bodies of the lower aquifer are hydraulically connected (see Section 6.2.). A subtle groundwater mound, defining a divide between southerly and northerly flowing groundwater, exists along the northern margin of the lower aquifer from section 16, T7N, R7E to section 5, T7N, R8E (Fig. 19). This groundwater mound overlies a portion of the area in which the aquitards separating the upper and lower aquifers is absent (Figs. 31; 43). Because groundwater south of the divide flows south, away from the mound, and since the lower and upper aquifers are connected in this area, the groundwater mound is interpreted as a recharge zone for the deeper, confined portion of the lower aquifer. Further support for freshwater recharge is found in the presence of Ca-Na-HCO3-Cl-SO4 groundwater with relatively low TDS at 44 to 58 m in the upper aquifer at 13EN07 (Figs. 8, 43). The Sterling-Dorechester paleovalley, therefore, is a confined aquifer flanked

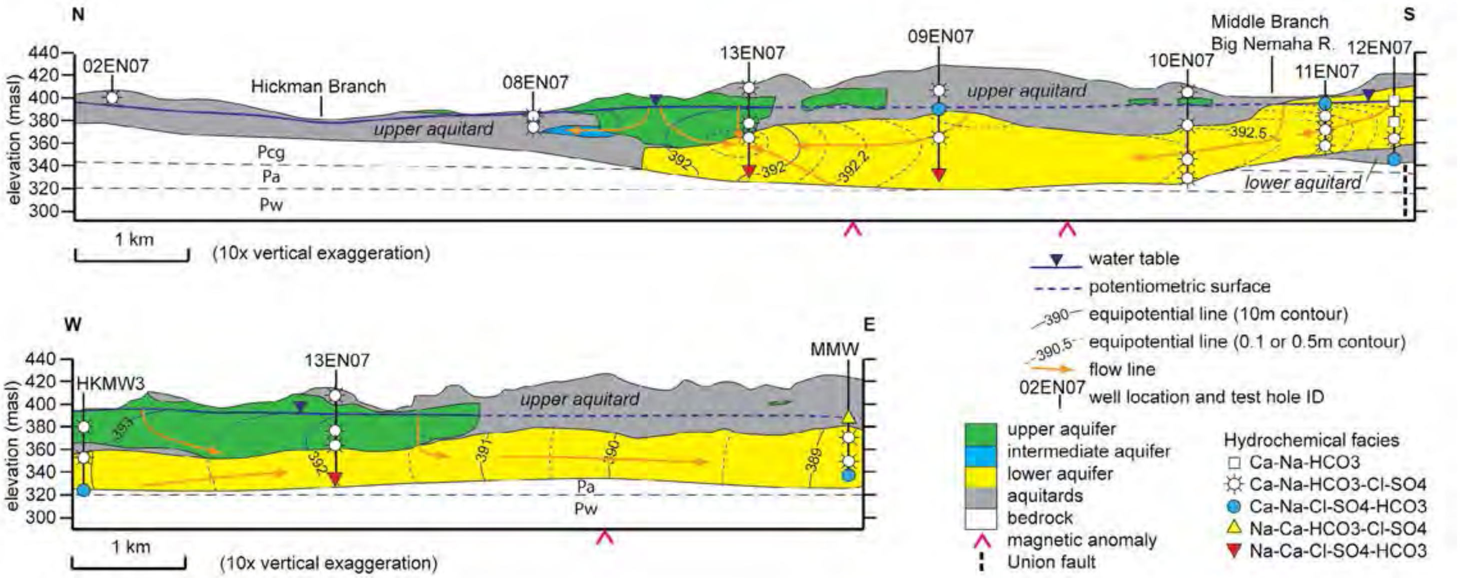


Figure 43. Interpretive N-S and E-W cross sections through study area along transects that intersect monitoring wells (see Fig. 5 for locations). N-S cross section is from monitoring well 02EN07 to 12EN07 in Figure 5, and E-W cross section is from well HKMW3 to MMW in Figure 5. Water levels were measured between 2008 and 2010 during static conditions.

by two recharge areas: A larger area to the south and a smaller area to the north (Fig., 43). Both areas of recharge are related to shallow sand bodies of probable glacial origin that are in contact with the sands and gravels of the paleovalley fill.

In our interpreted groundwater flow system (Fig. 43), the equipotential lines throughout the lower aquifer are rendered as smooth, curved lines because we have generalized the hydrogeologic properties of what we know to be a heterogeneous aquifer. Moreover, the hydraulic data from which we contoured the equipotential lines are limited in quantity. In comparison, the equipotential lines in a fully confined aquifer should be straight, vertical lines, indicating horizontal transmission of water between two aquitards with minimal vertical leakage (Domenico and Schwartz, 1998). If there is actual leakage from the upper and lower aquitards into the lower aquifer, however, equipotential lines would also appear to be curved. The determination of such leakage is beyond the interpretational limits of existing data.

The groundwater flow system depicted in figure 43 also shows groundwater flow lines converging in the vicinity of 13EN07. Flow convergence can result from either localized gravels with high conductivity that provide a pathway for preferential flow or because of pumping. Furthermore, the lithologic log for 13EN07 (Fig. 8) exhibits a comparatively thick zone of gravel within the interval in which flow appears to converge. Evaluating the relative effects of these hypothesized mechanisms in the vicinity of 13EN07 would require a much more detailed investigation.

7.4. Stream-Aquifer Connections

Our analysis of the stream-aquifer connections is qualitative because we do not have any data on hydraulic conductivities of sediments underlying the streams. On the basis of the thicknesses of hydrostratigraphic units beneath the streams, however, we conclude that the degree of hydraulic connection between streams and aquifers is variable across the study site (Fig. 44). There are two perennial stream reaches: Hickman Branch and the Middle Branch of the Big Nemaha River (or simply, Middle Branch). The northern margin of the upper aquifer is separated from Hickman Branch by a portion of the upper aquitard that is at least 20 m thick and 1.5 km wide (Figs. 43). Hickman Branch overlies sand bodies of the intermediate aquifer, but these bodies are separated from the stream by at least 8 m of aquitard and they are completely isolated from the lower and upper aquifers further south. The hydraulic connection between Hickman Branch and the aquifers within the study site, therefore, is weak at best.

The hydraulic connection between Middle Branch and the underlying lower aquifer is much stronger. The water table lies at a lower elevation than the surface of the stream, so the stream is losing over most of this reach. Up-gradient of the fine-grained channel-fill in Section 1, T6N, R7E, however, the water table flattens out and lies at roughly the same elevation of the stream. The channel-fill is a barrier to groundwater flow that is reflected in the lower slope of the water table. The stream appears to be gaining in a small reach in this area. Nonetheless, the downward hydraulic gradient under most of the stream valley suggests that the stream may be a source of recharge to the aquifer, especially in two, highly localized areas where the underlying aquitard is thin or nonexistent (Fig. 44). These areas probably exhibit the strongest degree of hydraulic connection between the aquifer and stream. Elsewhere, the connection is probably somewhat weaker because the ~5-6 m thick aquitard impedes the movement of water between the stream and the aquifer. The weakest connection likely exists over the deeply incised, 40-m thick, fine-grained channel-fill (Fig. 44).

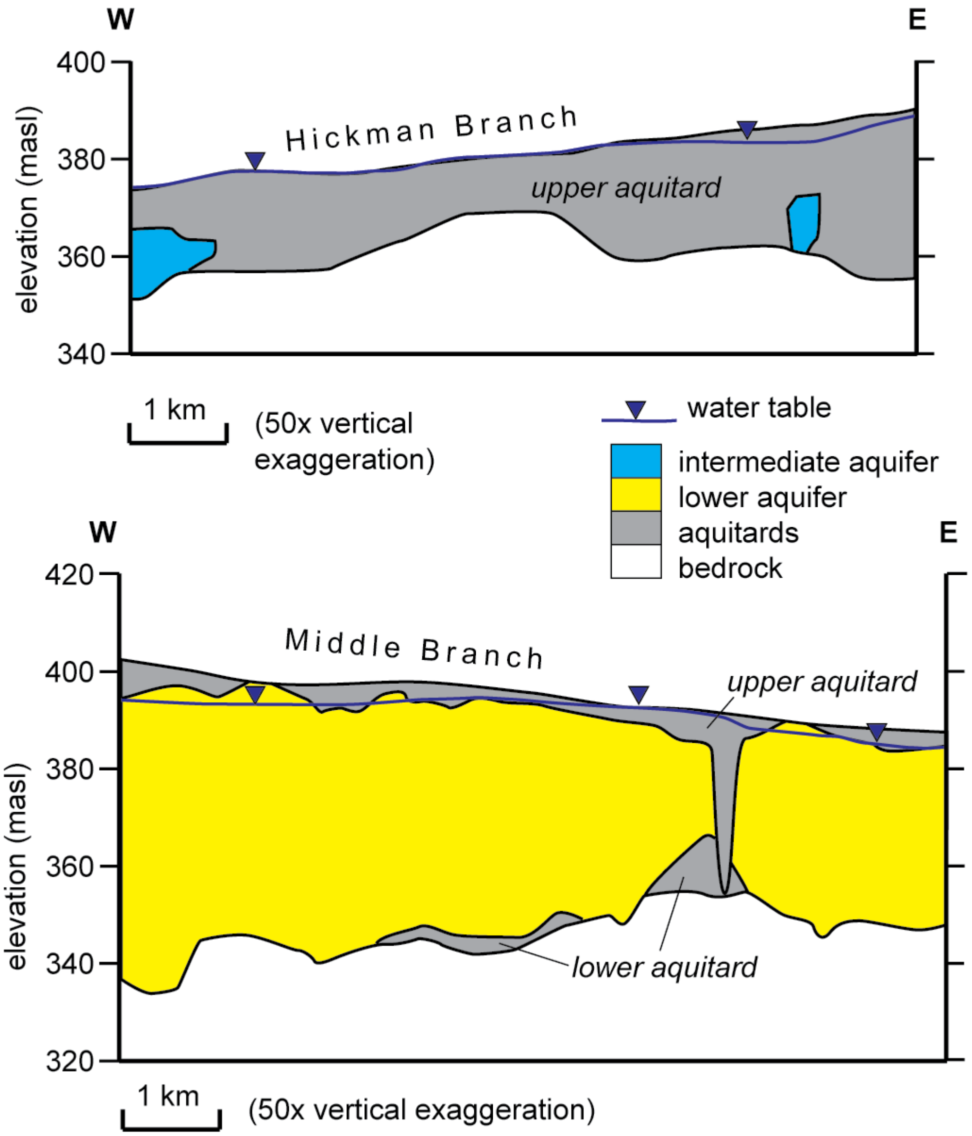


Figure 44. Interpretive cross sections through study area along transects parallel to Hickman Branch and Middle Branch Big Nemaha River showing the elevation of the water table adjacent to the stream (see Fig. 5 for locations). No monitoring wells are located along these transects, so water table/potentiometric surface is interpreted from Figure 19. Note comparatively thick aquitard materials in cross section under Hickman Branch compared to those under Middle Branch, implying greater degree of hydraulic connection between stream and aquifer under Middle Branch. Also note position of water table below stream level indicating losing reaches.

7.5. Implications for Groundwater Quantity

The Firth study area has not experienced large-scale depletion of the aquifer at the time of this study (Korus et al., 2011a). It is nonetheless important to assess the potential effects of future pumping on groundwater levels. To do this, hydrogeologists use groundwater models to effectively and efficiently analyze large, complex hydrogeological datasets. The information required to build a groundwater model includes: 1) a three-dimensional hydrostratigraphic framework, 2) aquifer and aquitard characteristics such as porosity, permeability, and specific yield, 3) information on the locations, rates, and durations of past, present, and future groundwater withdrawals, 4) sources of discharge from and recharge to the aquifer through time, and 5) hydraulic head data from each hydrostratigraphic unit. This study provides a three-dimensional framework for (1) above. It also provides information related to (4) and (5), but hydrological, meteorological, and vadose zone-related data are needed to fully evaluate aspects of discharge and recharge to the groundwater system. The analysis detailed herein does not provide information on (2) or (3).

Notwithstanding these limitations, some generalized inferences regarding future groundwater withdrawals at the Firth site can be made based on the hydrostratigraphic framework itself. The lower aquifer might be expected to be most vulnerable to overpumping in areas where it is thin, laterally restricted, and distal to sources of replenishment. The thinnest portions of the lower aquifer are in the extreme southern part of the study area (Fig. 35). Most of it, however, is at least 30 m in thickness and supports several high-capacity irrigation and public water supply wells (Fig. 3). The northern margin of the lower aquifer is laterally restricted to the north because these deposits pinch out into aquitard materials

(Fig. 35). This zone is termed an aquifer "boundary", and large-scale pumping near this boundary could significantly lower the water table or potentiometric surface.

Although Middle Branch is losing throughout most of its reach, lowering of the water table due to pumping could influence flow in the stream by increasing the difference in hydraulic head between the stream and the water table. Based on the limited information we have about the intermediate aquifers, it would appear that they are laterally restricted, isolated, and not connected to sources of replenishment. These aquifers are probably the most vulnerable to large-scale withdrawals, but no high-capacity wells currently exist in them. The upper aquifer is comparatively less laterally restricted because sand bodies are continuous over long distances. They are, however, laterally restricted due to their widths. The largest sand body in the upper aquifer is relatively thick but is generally <2 km wide. Several high-capacity wells are completed into it but it would likely not support numerous such wells due to its limited lateral extent. The ribbon sands are thin, narrow (<1 km), and surrounded by aquitards. These aquifers would not likely support large-scale withdrawals. They could, however, be targets for domestic water supplies, especially in areas where other aquifers are absent. If our hypothesis that these sediment bodies are related to the modern landscape proves true, then land-surface topography would serve as a guide for exploration of low-yield aquifers in the shallow subsurface.

7.6. Implications for Groundwater Quality

The three-dimensional hydrostratigraphic framework is also useful for identifying pathways through which contaminants could enter the aquifers at the study site. The most vulnerable aquifers are those over which the upper aquitard is thinnest. These areas tend to be underlain by shallow, water-table aquifers and include much of the northwestern part of the upper aquifer and the southernmost part of the lower aquifer (Figs. 30, 33). The part of the lower aquifer comprising the Dorchester-Sterling paleovalley is generally protected from contaminants entering through the vadose zone because it is overlain by a thick sequence of relatively low permeability materials, including loess, till, and fine-grained glacial sediments. There are two areas, however, in which contaminants may enter the lower aquifer. One of these areas is near the valley of the Middle Branch of the Big Nemaha River. Our study suggests that groundwater is recharged to the part of the lower aquifer which exists under water-table conditions, then flows under the valley toward the deeper, confined portion of the lower aquifer (Fig. 43). The other area of potential contamination entry is relatively small and exists where the aquitard separating the upper and lower aquifers is thin or absent (Figs. 31, 43). The upper aquifer in this area contains elevated levels of nitrate-nitrogen which have impacted the drinking water supplies for the City of Hickman and has therefore been designated a Phase II groundwater management area subject to intensified regulation by the Lower Platte South Natural Resources District (LPSNRD, 2010). The areas of heightened vulnerability described here could be used as focal points of management efforts aimed at lowering nitrate levels in the aquifer.

Hydrochemical facies change from predominantly Ca-Na-HCO3-Cl-SO4 types to more chemically evolved Na-Ca-Cl-SO4-HCO3 types at depth (Figs. 42, 43). The most chemically evolved water types occur near the distal portions of groundwater-flow paths directly above the bedrock surface in the deepest parts of the lower aquifer. Seepage from the underlying Paleozoic aquitard may contribute to the elevated levels of sodium and chloride in this groundwater, especially in the vicinity of bedrock structures (Kolm and Peter, 1984; Gosselin et al., 2001). Indeed, the Union Fault passes through the southernmost part of the study area, and other possible faults or fractures are indicated by magnetic anomalies in the HEM data (Fig. 43; Smith et al., 2008). Over large regions, however, slow seepage from the underlying Paleozoic aquitard is possible even in the absence of structurally controlled flow paths (Swenson, 1968; Bredehoeft et al., 1983). This seepage, whether it occurs diffusely or discretely, can be enhanced due to lowering of hydraulic heads in overlying aquifers (e.g. Sophocleous and Ma, 1998). Therefore, high-capacity wells screened near bedrock in the deepest parts of the lower aquifer are most vulnerable to water quality degradation. Indeed, salt-water intrusion has been reported by some groundwater irrigators in nearby areas during periods of peak pumping (Lower Platte South Natural Resources District, personal communication).

8. Conclusions

Our integration of basic hydrogeological data (test-hole logs, water levels, hydrochemistry) with advanced geophysical techniques (HEM) has proven successful for characterizing the hydrostratigraphy in the shallow subsurface at the Firth pilot study site. These methods allow for the three-dimensional interpretation of hydrostratigraphy at a vertical resolution of ~1 to 15 m and a horizontal resolution of 3 m (Smith et al., 2011), which is not possible with traditional techniques alone. We identify aquitards at two stratigraphic levels and aquifers at three stratigraphic levels. The lower aquifer comprises 1) the Late Pliocene (?) – Early Pleistocene (?) Dorchester-Sterling paleovalley aquifer and 2) a younger Pleistocene sand and gravel aquifer of glacial origin. These two sediment bodies are hydrologically connected such that the aquifer in (2) serves as a recharge zone for the aquifer in (1). The upper aquifer is volumetrically smaller than the lower aquifer, but nonetheless is a source of water locally. It also comprises two parts, both of which are related to Pleistocene glacial deposits: (1) a broad, lenticular, west-east trending sand body as much as 56 m thick and (2) numerous irregular, elongate, ribbon-like sand bodies generally <15 m thick. The sand body in (1) is unconfined and the water table within it defines a subtle groundwater mound in the middle part of the study area. This aquifer is in direct contact with – and a source of recharge to – the lower aquifer in a small area surrounding the Hickman municipal well field. The ribbon-like sand bodies are interpreted almost entirely on the basis of HEM and therefore are largely unverified.

Whereas borehole data provide a rigorous basis for identifying hydrostratigraphic units at a single location, HEM provides highly detailed information useful for correlating these units between boreholes. On the basis of the results of this study, we conclude that HEM can be used together with other data to characterize the hydrogeology of areas in the glaciated region of eastern Nebraska with similar geological characteristics to those in the Firth area. This study, however, has revealed several significant limitations which may severely hinder its usefulness in certain geological settings:

1. The depth of investigation of HEM is relatively shallow (~50 to 80 m) and variable. In some areas, the HEM profiles do not extend downward through the full depth of unconsolidated materials overlying bedrock. Many of the paleovalley aquifers in eastern Nebraska, which are of interest to groundwater-resource managers and hydrogeologists, may lie below the depth of investigation of HEM.

2. The presence of highly conductive material near the land surface limits the depth of investigation of HEM by as much as 20 m compared to areas with resistive material near the land surface. Much of the shallow subsurface of eastern Nebraska comprises thick (>15m), fine-grained glacial deposits. HEM may be of limited usefulness in such settings.

3. Multiple physical and chemical conditions may exert a control on HEM resistivities. This non-uniqueness renders the interpretation of HEM ambiguous unless detailed lithologic, stratigraphic, and hydrochemical subsurface data are available at regularly spaced intervals over a study site.

4. HEM was not useful for mapping the position of the water table at the study site. We attribute this limitation to insufficient vertical resolution, the effects of volume averaging, and/or the presence of other physical and chemical conditions that exert a stronger control on resistivity values than water saturation.

Water availability is a significant factor in property valuation and agricultural yields, both of which are important components of local and state tax revenue. Hydrogeological mapping, therefore, has an obvious benefit, but its costs depend on the level of detail required and the methods employed. Traditional methods do not yield the horizontal resolution required to map hydrostratigraphic units in glaciated settings. Drilling test holes at a resolution equivalent to HEM would be extremely costly and practically impossible. These limitations can be overcome by integrating traditional methods with airborne geophysics. The cost of HEM data collection and inversion at the Firth pilot study site was ~$67,600 (~$170 per line kilometer). Although this figure does not include the costs of test-hole and monitoring-well data, which are necessary in order to interpret HEM, the costs of conducting HEM studies are likely justifiable in many circumstances.

The integration of traditional methods with advanced techniques such as HEM has advantages and limitations. We suggest that future studies in eastern Nebraska employ similar integrated methods, but that the range of geological and hydrogeological variability at any given site must be characterized prior to conducting an HEM survey in order to assess its potential usefulness in that area.

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Additional data

Test-hole logs from this study can be obtained from the Conservation and Survey Division, Hardin Hall, 3310 Holdrege Street, University of Nebraska-Lincoln, Lincoln, Nebraska 68583-0961, Phone 402-472-3471, Fax 402-472-2946. Digital copies can be downloaded at http://snr.unl.edu/data/geologysoils/NebraskaTestHole/NebraskaTestHoleIntro.asp

Water levels from wells that are part of the Statewide Monitoring Network can be obtained from the Conservation and Survey Division at the address above, or from http://snr.unl.edu/data/water/NebGW_Levels.asp

Borehole logs and water levels of registered water wells that were used in this study can be obtained from the Nebraska Department of Natural Resources, 301 Centennial Mall South, Lincoln, Nebraska 68509-4676, Phone 402-471-2363, Fax 402-471-2900. Digital copies can be downloaded at http://dnrdata.dnr.ne.gov/wellscs/Menu.aspx

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Appendix A

Well name	Date	Analyte	Result	Unit	Flag
02EN07-23	9/25/08	alk	1,998	mg/L	
02EN07-23	11/26/08	alk	5790	mg/L	
02EN07-23	2/4/09	alk	379	mg/L	
02EN07-23	5/19/09	alk	458	mg/L	
02EN07-23	9/25/09	alk	454	mg/L	
02EN07-23	6/30/10	alk	182	mg/L	
02EN07-23	11/15/10	alk	472	mg/L	
02EN07-23	9/25/08	Ca	435	mg/L	
02EN07-23	11/26/08	Ca	120.2	mg/L	
02EN07-23	2/4/09	Ca	136.03	mg/L	
02EN07-23	5/19/09	Ca	106.37	mg/L	
02EN07-23	9/25/09	Ca	107.8	mg/L	
02EN07-23	6/30/10	Ca	49.85	mg/L	
02EN07-23	11/15/10	Ca	104.71	mg/L	
02EN07-23	9/25/08	cl	5	mg/L	
02EN07-23	11/26/08	cl	5	mg/L	
02EN07-23	2/4/09	cl	41	mg/L	
02EN07-23	5/19/09	cl	1	mg/L	
02EN07-23	9/25/09	cl	1	mg/L	
02EN07-23	6/30/10	cl	2	mg/L	
02EN07-23	11/15/10	cl	2	mg/L	
02EN07-23	9/25/08	cnd	945	uS/cm	
02EN07-23	11/26/08	cnd	965	uS/cm	
02EN07-23	2/4/09	cnd	985	uS/cm	
02EN07-23	5/19/09	cnd	871	uS/cm	
02EN07-23	9/25/09	cnd	983	uS/cm	
02EN07-23	6/30/10	cnd	370	uS/cm	
02EN07-23	11/15/10	cnd	849	uS/cm	
02EN07-23	9/25/08	hrd	1,408	mg/L	
02EN07-23	11/26/08	hrd	433	mg/L	
02EN07-23	2/4/09	hrd	431	mg/L	
02EN07-23	5/19/09	hrd	390	mg/L	
02EN07-23	9/25/09	hrd	403	mg/L	
02EN07-23	11/15/10	hrd	380	mg/L	
02EN07-23	9/25/08	Fe	186	mg/L	J
02EN07-23	11/26/08	Fe	13.12	mg/L	
02EN07-23	2/4/09	Fe	0.55	mg/L	
02EN07-23	5/19/09	Fe	0.03	mg/L	
02EN07-23	9/25/09	Fe	0.03	mg/L	U
02EN07-23	6/30/10	Fe	2.28	mg/L	
02EN07-23	11/15/10	Fe	0.04	mg/L	J
02EN07-23	9/25/08	Mg	78.2	mg/L	
02EN07-23	11/26/08	Mg	32.34	mg/L	
02EN07-23	2/4/09	Mg	22.06	mg/L	
02EN07-23	5/19/09	Mg	30.49	mg/L	
02EN07-23	9/25/09	Mg	32.56	mg/L	
02EN07-23	6/30/10	Mg	11.04	mg/L	
02EN07-23	11/15/10	Mg	28.61	mg/L	
02EN07-23	9/25/08	Mn	3.68	mg/L	
02EN07-23	11/26/08	Mn	0.22	mg/L	
02EN07-23	2/4/09	Mn	0	mg/L	
02EN07-23	5/19/09	Mn	0	mg/L	
02EN07-23	9/25/09	Mn	0	mg/L	
02EN07-23	6/30/10	Mn	0.44	mg/L	
02EN07-23	11/15/10	Mn	0.52	mg/L	J
02EN07-23	9/25/08	nn	6.6	mg/l	
02EN07-23	11/26/08	nn	7	mg/l	
02EN07-23	2/4/09	nn	0	mg/l	
02EN07-23	5/19/09	nn	8.8	mg/l	
02EN07-23	9/25/09	nn	8.8	mg/l	
02EN07-23	6/30/10	nn	0	mg/l	
02EN07-23	11/15/10	nn	2	mg/l	
02EN07-23	9/25/08	K	29.5	mg/L	
02EN07-23	11/26/08	K	8.85	mg/L	
02EN07-23	2/4/09	K	2.53	mg/L	
02EN07-23	5/19/09	K	5.08	mg/L	
02EN07-23	9/25/09	K	5.02	mg/L	
02EN07-23	6/30/10	K	3.01	mg/L	J
02EN07-23	11/15/10	K	4.39	mg/L	
02EN07-23	9/25/08	Na	73.9	mg/L	
02EN07-23	11/26/08	Na	67.88	mg/L	
02EN07-23	2/4/09	Na	51.88	mg/L	
02EN07-23	5/19/09	Na	66.94	mg/L	
02EN07-23	9/25/09	Na	63.03	mg/L	
02EN07-23	6/30/10	Na	30.18	mg/L	
02EN07-23	11/15/10	Na	51.18	mg/L	
02EN07-23	9/25/08	sf	72	mg/L	
02EN07-23	11/26/08	sf	63	mg/L	
02EN07-23	2/4/09	sf	108	mg/L	
02EN07-23	5/19/09	sf	43	mg/L	
02EN07-23	9/25/09	sf	43	mg/L	
02EN07-23	6/30/10	sf	12	mg/L	
02EN07-23	11/15/10	sf	24	mg/L	
02EN07-23	9/25/08	tds	731	mg/L	
02EN07-23	11/26/08	tds	1950	mg/L	
02EN07-23	2/4/09	tds	610	mg/L	
02EN07-23	5/19/09	tds	576	mg/L	
02EN07-23	9/25/09	tds	602	mg/L	J
02EN07-23	6/30/10	tds	432	mg/L	
02EN07-23	11/15/10	tds	564	mg/L	
08EN07-15	9/25/08	alk	403	mg/L	
08EN07-15	11/25/08	alk	406	mg/L	
08EN07-15	2/4/09	alk	1968	mg/L	
08EN07-15	5/18/09	alk	366	mg/L	
08EN07-15	9/25/09	alk	362	mg/L	
08EN07-15	6/30/10	alk	365	mg/L	
08EN07-15	11/15/10	alk	378	mg/L	
08EN07-15	9/25/08	Ca	144	mg/L	
08EN07-15	11/25/08	Ca	146.02	mg/L	
08EN07-15	2/4/09	Ca	113.47	mg/L	
08EN07-15	5/18/09	Ca	126.8	mg/L	
08EN07-15	9/25/09	Ca	127.63	mg/L	
08EN07-15	6/30/10	Ca	126.03	mg/L	
08EN07-15	11/15/10	Ca	119.63	mg/L	
08EN07-15	9/25/08	cl	42	mg/L	
08EN07-15	11/25/08	cl	43	mg/L	
08EN07-15	2/4/09	cl	2	mg/L	
08EN07-15	5/18/09	cl	42	mg/L	
08EN07-15	9/25/09	cl	42	mg/L	
08EN07-15	6/30/10	cl	35	mg/L	
08EN07-15	11/15/10	cl	35	mg/L	
08EN07-15	9/25/08	cnd	1,005	uS/cm	
08EN07-15	11/25/08	cnd	1001	uS/cm	
08EN07-15	2/4/09	cnd	971	uS/cm	
08EN07-15	5/18/09	cnd	877	uS/cm	
08EN07-15	9/25/09	cnd	987	uS/cm	

Well name	Date	Analyte	Result	Unit	Flag
08EN07-15	6/30/10	cnd	852	uS/cm	
08EN07-15	11/15/10	cnd	909	uS/cm	
08EN07-15	9/25/08	hrd	462	mg/L	
08EN07-15	11/25/08	hrd	461	mg/L	
08EN07-15	2/4/09	hrd	419	mg/L	
08EN07-15	5/18/09	hrd	406	mg/L	
08EN07-15	9/25/09	hrd	406	mg/L	
08EN07-15	11/15/10	hrd	387	mg/L	
08EN07-15	9/25/08	Fe	0.06	mg/L	J
08EN07-15	11/25/08	Fe	0.16	mg/L	
08EN07-15	2/4/09	Fe	0.02	mg/L	
08EN07-15	5/18/09	Fe	1.56	mg/L	
08EN07-15	9/25/09	Fe	0.79	mg/L	
08EN07-15	6/30/10	Fe	1.52	mg/L	
08EN07-15	11/15/10	Fe	1.53	mg/L	J
08EN07-15	9/25/08	Mg	25	mg/L	
08EN07-15	11/25/08	Mg	23.52	mg/L	
08EN07-15	2/4/09	Mg	32.99	mg/L	
08EN07-15	5/18/09	Mg	21.63	mg/L	
08EN07-15	9/25/09	Mg	21.31	mg/L	
08EN07-15	6/30/10	Mg	21.17	mg/L	
08EN07-15	11/15/10	Mg	21.22	mg/L	
08EN07-15	9/25/08	Mn	0.48	mg/L	
08EN07-15	11/25/08	Mn	0.31	mg/L	
08EN07-15	2/4/09	Mn	0	mg/L	
08EN07-15	5/18/09	Mn	0.25	mg/L	
08EN07-15	9/25/09	Mn	0.21	mg/L	
08EN07-15	6/30/10	Mn	0.25	mg/L	
08EN07-15	11/15/10	Mn	0.25	mg/L	J
08EN07-15	9/25/08	nn	0	mg/l	
08EN07-15	11/25/08	nn	0	mg/l	
08EN07-15	2/4/09	nn	7	mg/l	
08EN07-15	5/18/09	nn	0	mg/l	
08EN07-15	9/25/09	nn	0	mg/l	
08EN07-15	6/30/10	nn	0	mg/l	
08EN07-15	11/15/10	nn	0	mg/l	
08EN07-15	9/25/08	K	3.68	mg/L	U
08EN07-15	11/25/08	K	2.55	mg/L	
08EN07-15	2/4/09	K	5.64	mg/L	
08EN07-15	5/18/09	K	2.62	mg/L	
08EN07-15	9/25/09	K	2.29	mg/L	
08EN07-15	6/30/10	K	2.18	mg/L	U
08EN07-15	11/15/10	K	2.33	mg/L	
08EN07-15	9/25/08	Na	57.5	mg/L	
08EN07-15	11/25/08	Na	52.14	mg/L	
08EN07-15	2/4/09	Na	68.73	mg/L	
08EN07-15	5/18/09	Na	52.72	mg/L	
08EN07-15	9/25/09	Na	46.93	mg/L	
08EN07-15	6/30/10	Na	46.18	mg/L	
08EN07-15	11/15/10	Na	43.14	mg/L	
08EN07-15	9/25/08	sf	120	mg/L	
08EN07-15	11/25/08	sf	118	mg/L	
08EN07-15	2/4/09	sf	45	mg/L	
08EN07-15	5/18/09	sf	94	mg/L	
08EN07-15	9/25/09	sf	95	mg/L	
08EN07-15	6/30/10	sf	83	mg/L	
08EN07-15	11/15/10	sf	88	mg/L	
08EN07-15	9/25/08	tds	678	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
08EN07-15	11/25/08	tds	645	mg/L	
08EN07-15	2/4/09	tds	1120	mg/L	
08EN07-15	5/18/09	tds	560	mg/L	
08EN07-15	9/25/09	tds	624	mg/L	J
08EN07-15	6/30/10	tds	564	mg/L	
08EN07-15	11/15/10	tds	508	mg/L	
08EN07-42	9/25/08	alk	337	mg/L	
08EN07-42	11/24/08	alk	337	mg/L	
08EN07-42	2/5/09	alk	333	mg/L	
08EN07-42	5/18/09	alk	331	mg/L	
08EN07-42	9/25/09	alk	337	mg/L	
08EN07-42	6/30/10	alk	338	mg/L	
08EN07-42	11/15/10	alk	328	mg/L	
08EN07-42	9/25/08	Ca	83	mg/L	
08EN07-42	11/24/08	Ca	78.97	mg/L	
08EN07-42	2/5/09	Ca	81.99	mg/L	
08EN07-42	5/18/09	Ca	74.95	mg/L	
08EN07-42	9/25/09	Ca	84.99	mg/L	
08EN07-42	6/30/10	Ca	87.33	mg/L	
08EN07-42	11/15/10	Ca	77.65	mg/L	
08EN07-42	9/25/08	cl	33	mg/L	
08EN07-42	11/24/08	cl	33	mg/L	
08EN07-42	2/5/09	cl	33	mg/L	
08EN07-42	5/18/09	cl	33	mg/L	
08EN07-42	9/25/09	cl	34	mg/L	
08EN07-42	6/30/10	cl	35	mg/L	
08EN07-42	11/15/10	cl	35	mg/L	
08EN07-42	9/25/08	cnd	746	uS/cm	
08EN07-42	11/24/08	cnd	743	uS/cm	
08EN07-42	2/5/09	cnd	769	uS/cm	
08EN07-42	5/18/09	cnd	731	uS/cm	
08EN07-42	9/25/09	cnd	812	uS/cm	
08EN07-42	6/30/10	cnd	745	uS/cm	
08EN07-42	11/15/10	cnd	777	uS/cm	
08EN07-42	11/15/10	DO	2.03	mg/L	
08EN07-42	9/25/08	hrd	290	mg/L	
08EN07-42	11/24/08	hrd	277	mg/L	
08EN07-42	2/5/09	hrd	288	mg/L	
08EN07-42	5/18/09	hrd	266	mg/L	
08EN07-42	9/25/09	hrd	300	mg/L	
08EN07-42	11/15/10	hrd	279	mg/L	
08EN07-42	9/25/08	Fe	0.32	mg/L	J
08EN07-42	11/24/08	Fe	0.27	mg/L	
08EN07-42	2/5/09	Fe	0.27	mg/L	
08EN07-42	5/18/09	Fe	0.31	mg/L	
08EN07-42	9/25/09	Fe	0.31	mg/L	
08EN07-42	6/30/10	Fe	0.4	mg/L	
08EN07-42	11/15/10	Fe	0.35	mg/L	J
08EN07-42	9/25/08	Mg	20.2	mg/L	
08EN07-42	11/24/08	Mg	19.4	mg/L	
08EN07-42	2/5/09	Mg	20.11	mg/L	
08EN07-42	5/18/09	Mg	19.23	mg/L	
08EN07-42	9/25/09	Mg	21.41	mg/L	
08EN07-42	6/30/10	Mg	21.66	mg/L	
08EN07-42	11/15/10	Mg	20.46	mg/L	
08EN07-42	9/25/08	Mn	0.39	mg/L	
08EN07-42	11/24/08	Mn	0.37	mg/L	
08EN07-42	2/5/09	Mn	0.38	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
08EN07-42	5/18/09	Mn	0.36	mg/L	
08EN07-42	9/25/09	Mn	0.41	mg/L	
08EN07-42	6/30/10	Mn	0.4	mg/L	
08EN07-42	11/15/10	Mn	0.37	mg/L	J
08EN07-42	9/25/08	nn	0	mg/l	
08EN07-42	11/24/08	nn	0	mg/l	
08EN07-42	2/5/09	nn	0	mg/l	
08EN07-42	5/18/09	nn	0	mg/l	
08EN07-42	9/25/09	nn	0	mg/l	
08EN07-42	6/30/10	nn	0	mg/l	
08EN07-42	11/15/10	nn	0	mg/l	
08EN07-42	9/25/08	K	5.81	mg/L	U
08EN07-42	11/24/08	K	5.97	mg/L	
08EN07-42	2/5/09	K	6.02	mg/L	
08EN07-42	5/18/09	K	5.88	mg/L	
08EN07-42	9/25/09	K	6.35	mg/L	
08EN07-42	6/30/10	K	5.95	mg/L	
08EN07-42	11/15/10	K	5.59	mg/L	
08EN07-42	9/25/08	Na	57.7	mg/L	
08EN07-42	11/24/08	Na	59.24	mg/L	
08EN07-42	2/5/09	Na	57.84	mg/L	
08EN07-42	5/18/09	Na	60.27	mg/L	
08EN07-42	9/25/09	Na	59.94	mg/L	
08EN07-42	6/30/10	Na	60.12	mg/L	
08EN07-42	11/15/10	Na	53.74	mg/L	
08EN07-42	9/25/08	sf	31	mg/L	
08EN07-42	11/24/08	sf	35	mg/L	
08EN07-42	2/5/09	sf	40	mg/L	
08EN07-42	5/18/09	sf	36	mg/L	
08EN07-42	9/25/09	sf	44	mg/L	
08EN07-42	6/30/10	sf	42	mg/L	
08EN07-42	11/15/10	sf	47	mg/L	
08EN07-42	9/25/08	tds	440	mg/L	
08EN07-42	11/24/08	tds	422	mg/L	J
08EN07-42	2/5/09	tds	444	mg/L	J
08EN07-42	5/18/09	tds	458	mg/L	
08EN07-42	9/25/09	tds	478	mg/L	J
08EN07-42	6/30/10	tds	474	mg/L	
08EN07-42	11/15/10	tds	400	mg/L	
13EN07-145	3/17/09	alk	335	mg/L	
13EN07-145	5/19/09	alk	340	mg/L	
13EN07-145	9/25/09	alk	339	mg/L	
13EN07-145	6/30/10	alk	338	mg/L	
13EN07-145	11/15/10	alk	341	mg/L	
13EN07-145	3/17/09	Ca	100.4	mg/L	
13EN07-145	5/19/09	Ca	101.06	mg/L	
13EN07-145	9/25/09	Ca	107.39	mg/L	
13EN07-145	6/30/10	Ca	97.72	mg/L	
13EN07-145	11/15/10	Ca	99.44	mg/L	
13EN07-145	3/17/09	cl	12	mg/L	
13EN07-145	5/19/09	cl	10	mg/L	
13EN07-145	9/25/09	cl	11	mg/L	
13EN07-145	6/30/10	cl	10	mg/L	
13EN07-145	11/15/10	cl	15	mg/L	
13EN07-145	3/17/09	cnd	756	uS/cm	
13EN07-145	5/19/09	cnd	727	uS/cm	
13EN07-145	9/25/09	cnd	791	uS/cm	
13EN07-145	6/30/10	cnd	715	uS/cm	
13EN07-145	11/15/10	cnd	765	uS/cm	
13EN07-145	3/17/09	hrd	343	mg/L	
13EN07-145	5/19/09	hrd	351	mg/L	
13EN07-145	9/25/09	hrd	371	mg/L	
13EN07-145	11/15/10	hrd	345	mg/L	
13EN07-145	3/17/09	Fe	0.08	mg/L	
13EN07-145	5/19/09	Fe	0.07	mg/L	
13EN07-145	9/25/09	Fe	0.04	mg/L	U
13EN07-145	6/30/10	Fe	0.08	mg/L	U
13EN07-145	11/15/10	Fe	0.17	mg/L	J
13EN07-145	3/17/09	Mg	22.65	mg/L	
13EN07-145	5/19/09	Mg	24.09	mg/L	
13EN07-145	9/25/09	Mg	25.09	mg/L	
13EN07-145	6/30/10	Mg	22.85	mg/L	
13EN07-145	11/15/10	Mg	23.79	mg/L	
13EN07-145	3/17/09	Mn	0.21	mg/L	
13EN07-145	5/19/09	Mn	0.21	mg/L	
13EN07-145	9/25/09	Mn	0.09	mg/L	
13EN07-145	6/30/10	Mn	0.74	mg/L	
13EN07-145	11/15/10	Mn	0.46	mg/L	J
13EN07-145	3/17/09	nn	0	mg/l	
13EN07-145	5/19/09	nn	0	mg/l	
13EN07-145	9/25/09	nn	0	mg/l	
13EN07-145	6/30/10	nn	0	mg/l	
13EN07-145	11/15/10	nn	0	mg/l	
13EN07-145	3/17/09	K	5.37	mg/L	
13EN07-145	5/19/09	K	6.26	mg/L	
13EN07-145	9/25/09	K	6.11	mg/L	
13EN07-145	6/30/10	K	5.33	mg/L	
13EN07-145	11/15/10	K	5.47	mg/L	
13EN07-145	3/17/09	Na	40.28	mg/L	
13EN07-145	5/19/09	Na	42.46	mg/L	
13EN07-145	9/25/09	Na	39.48	mg/L	
13EN07-145	6/30/10	Na	39.88	mg/L	
13EN07-145	11/15/10	Na	34.66	mg/L	
13EN07-145	3/17/09	sf	74	mg/L	
13EN07-145	5/19/09	sf	71	mg/L	
13EN07-145	9/25/09	sf	74	mg/L	
13EN07-145	6/30/10	sf	71	mg/L	
13EN07-145	11/15/10	sf	67	mg/L	
13EN07-145	3/17/09	tds	496	mg/L	J
13EN07-145	5/19/09	tds	472	mg/L	
13EN07-145	9/25/09	tds	496	mg/L	
13EN07-145	6/30/10	tds	460	mg/L	
13EN07-145	11/15/10	tds	396	mg/L	
13EN07-190	3/17/09	alk	325	mg/L	
13EN07-190	5/19/09	alk	316	mg/L	
13EN07-190	9/25/09	alk	315	mg/L	
13EN07-190	6/30/10	alk	308	mg/L	
13EN07-190	11/15/10	alk	313	mg/L	
13EN07-190	3/17/09	Ca	107.61	mg/L	
13EN07-190	5/19/09	Ca	98.69	mg/L	
13EN07-190	9/25/09	Ca	101.86	mg/L	
13EN07-190	6/30/10	Ca	94.47	mg/L	
13EN07-190	11/15/10	Ca	91.05	mg/L	
13EN07-190	3/17/09	cl	29	mg/L	
13EN07-190	5/19/09	cl	32	mg/L	
13EN07-190	9/25/09	cl	34	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
13EN07-190	6/30/10	cl	43	mg/L	
13EN07-190	11/15/10	cl	41	mg/L	
13EN07-190	3/17/09	cnd	797	uS/cm	
13EN07-190	5/19/09	cnd	777	uS/cm	
13EN07-190	9/25/09	cnd	841	uS/cm	
13EN07-190	6/30/10	cnd	775	uS/cm	
13EN07-190	11/15/10	cnd	835	uS/cm	
13EN07-190	3/17/09	hrd	355	mg/L	
13EN07-190	5/19/09	hrd	330	mg/L	
13EN07-190	9/25/09	hrd	338	mg/L	
13EN07-190	11/15/10	hrd	307	mg/L	
13EN07-190	3/17/09	Fe	0.09	mg/L	
13EN07-190	5/19/09	Fe	0.21	mg/L	
13EN07-190	9/25/09	Fe	0.17	mg/L	J
13EN07-190	6/30/10	Fe	0.21	mg/L	J
13EN07-190	11/15/10	Fe	0.01	mg/L	J
13EN07-190	3/17/09	Mg	20.8	mg/L	
13EN07-190	5/19/09	Mg	20.09	mg/L	
13EN07-190	9/25/09	Mg	20.41	mg/L	
13EN07-190	6/30/10	Mg	18.49	mg/L	
13EN07-190	11/15/10	Mg	19.34	mg/L	
13EN07-190	3/17/09	Mn	0.27	mg/L	
13EN07-190	5/19/09	Mn	0.18	mg/L	
13EN07-190	9/25/09	Mn	0.15	mg/L	
13EN07-190	6/30/10	Mn	0.2	mg/L	
13EN07-190	11/15/10	Mn	0	mg/L	J
13EN07-190	3/17/09	nn	0	mg/l	
13EN07-190	5/19/09	nn	0	mg/l	
13EN07-190	9/25/09	nn	0	mg/l	
13EN07-190	6/30/10	nn	0	mg/l	
13EN07-190	11/15/10	nn	1.6	mg/l	
13EN07-190	3/17/09	K	4.54	mg/L	
13EN07-190	5/19/09	K	4.98	mg/L	
13EN07-190	9/25/09	K	4.58	mg/L	
13EN07-190	6/30/10	K	4.02	mg/L	J
13EN07-190	11/15/10	K	4.18	mg/L	
13EN07-190	3/17/09	Na	68	mg/L	
13EN07-190	5/19/09	Na	59.3	mg/L	
13EN07-190	9/25/09	Na	52.78	mg/L	
13EN07-190	6/30/10	Na	58.29	mg/L	
13EN07-190	11/15/10	Na	55.06	mg/L	
13EN07-190	3/17/09	sf	82	mg/L	
13EN07-190	5/19/09	sf	80	mg/L	
13EN07-190	9/25/09	sf	77	mg/L	
13EN07-190	6/30/10	sf	72	mg/L	
13EN07-190	11/15/10	sf	71	mg/L	
13EN07-190	3/17/09	tds	518	mg/L	J
13EN07-190	5/19/09	tds	516	mg/L	
13EN07-190	9/25/09	tds	494	mg/L	
13EN07-190	6/30/10	tds	500	mg/L	
13EN07-190	11/15/10	tds	438	mg/L	
13EN07-280	3/17/09	alk	300	mg/L	
13EN07-280	5/19/09	alk	304	mg/L	
13EN07-280	9/25/09	alk	302	mg/L	
13EN07-280	6/30/10	alk	426	mg/L	
13EN07-280	11/15/10	alk	417	mg/L	
13EN07-280	3/17/09	Ca	139.2	mg/L	
13EN07-280	5/19/09	Ca	145.8	mg/L	
13EN07-280	9/25/09	Ca	142.41	mg/L	
13EN07-280	6/30/10	Ca	199.12	mg/L	
13EN07-280	11/15/10	Ca	200.09	mg/L	
13EN07-280	3/17/09	cl	397	mg/L	
13EN07-280	5/19/09	cl	409	mg/L	
13EN07-280	9/25/09	cl	387	mg/L	
13EN07-280	6/30/10	cl	129	mg/L	
13EN07-280	11/15/10	cl	110	mg/L	
13EN07-280	3/17/09	cnd	2015	uS/cm	
13EN07-280	5/19/09	cnd	1955	uS/cm	
13EN07-280	9/25/09	cnd	2053	uS/cm	
13EN07-280	6/30/10	cnd	1997	uS/cm	
13EN07-280	11/15/10	cnd	2003	uS/cm	
13EN07-280	3/17/09	hrd	450	mg/L	
13EN07-280	5/19/09	hrd	477	mg/L	
13EN07-280	9/25/09	hrd	464	mg/L	
13EN07-280	11/15/10	hrd	749	mg/L	
13EN07-280	3/17/09	Fe	0.03	mg/L	
13EN07-280	5/19/09	Fe	0.04	mg/L	
13EN07-280	9/25/09	Fe	0	mg/L	U
13EN07-280	6/30/10	Fe	0	mg/L	U
13EN07-280	11/15/10	Fe	0.02	mg/L	J
13EN07-280	3/17/09	Mg	25.15	mg/L	
13EN07-280	5/19/09	Mg	27.28	mg/L	
13EN07-280	9/25/09	Mg	26.33	mg/L	
13EN07-280	6/30/10	Mg	56.57	mg/L	
13EN07-280	11/15/10	Mg	60.55	mg/L	
13EN07-280	3/17/09	Mn	0.41	mg/L	
13EN07-280	5/19/09	Mn	0.43	mg/L	
13EN07-280	9/25/09	Mn	0.38	mg/L	
13EN07-280	6/30/10	Mn	0.02	mg/L	
13EN07-280	11/15/10	Mn	0	mg/L	J
13EN07-280	3/17/09	nn	0	mg/l	
13EN07-280	5/19/09	nn	0.3	mg/l	
13EN07-280	9/25/09	nn	0.3	mg/l	
13EN07-280	6/30/10	nn	111	mg/l	
13EN07-280	11/15/10	nn	114	mg/l	
13EN07-280	3/17/09	K	4.72	mg/L	
13EN07-280	5/19/09	K	5.83	mg/L	
13EN07-280	9/25/09	K	5.3	mg/L	
13EN07-280	6/30/10	K	3.02	mg/L	J
13EN07-280	11/15/10	K	2.82	mg/L	
13EN07-280	3/17/09	Na	217.06	mg/L	
13EN07-280	5/19/09	Na	263.7	mg/L	
13EN07-280	9/25/09	Na	232.99	mg/L	
13EN07-280	6/30/10	Na	173.87	mg/L	
13EN07-280	11/15/10	Na	113.8	mg/L	
13EN07-280	3/17/09	sf	135	mg/L	
13EN07-280	5/19/09	sf	137	mg/L	
13EN07-280	9/25/09	sf	129	mg/L	
13EN07-280	6/30/10	sf	110	mg/L	
13EN07-280	11/15/10	sf	55	mg/L	
13EN07-280	3/17/09	tds	1202	mg/L	
13EN07-280	5/19/09	tds	1248	mg/L	
13EN07-280	9/25/09	tds	1254	mg/L	
13EN07-280	6/30/10	tds	1450	mg/L	
13EN07-280	11/15/10	tds	1244	mg/L	
13EN07-40	11/26/08	alk	406	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
13EN07-40	9/25/09	nn	100	mg/l	
13EN07-40	6/30/10	nn	67	mg/l	
13EN07-40	11/15/10	nn	50	mg/l	
13EN07-40	11/26/08	K	3.22	mg/L	
13EN07-40	3/17/09	K	3.56	mg/L	
13EN07-40	5/19/09	K	3.74	mg/L	
13EN07-40	5/19/09	K	3.77	mg/L	
13EN07-40	9/25/09	K	3.52	mg/L	
13EN07-40	6/30/10	K	3.18	mg/L	J
13EN07-40	11/15/10	K	4.73	mg/L	
13EN07-40	11/26/08	Na	97.55	mg/L	
13EN07-40	3/17/09	Na	91.84	mg/L	
13EN07-40	5/19/09	Na	104.34	mg/L	
13EN07-40	5/19/09	Na	105.02	mg/L	
13EN07-40	9/25/09	Na	94.73	mg/L	
13EN07-40	6/30/10	Na	100.29	mg/L	
13EN07-40	11/15/10	Na	80.89	mg/L	
13EN07-40	11/26/08	sf	46	mg/L	
13EN07-40	3/17/09	sf	46	mg/L	
13EN07-40	5/19/09	sf	45	mg/L	
13EN07-40	5/19/09	sf	45	mg/L	
13EN07-40	9/25/09	sf	48	mg/L	
13EN07-40	6/30/10	sf	54	mg/L	
13EN07-40	11/15/10	sf	30	mg/L	
13EN07-40	11/26/08	tds	1168	mg/L	
13EN07-40	3/17/09	tds	1286	mg/L	
13EN07-40	5/19/09	tds	1288	mg/L	
13EN07-40	5/19/09	tds	1298	mg/L	
13EN07-40	9/25/09	tds	1278	mg/L	
13EN07-40	6/30/10	tds	892	mg/L	
13EN07-40	11/15/10	tds	620	mg/L	
09EN07-135	9/26/08	alk	350	mg/L	
09EN07-135	11/25/08	alk	376	mg/L	
09EN07-135	2/6/09	alk	395	mg/L	
09EN07-135	9/25/09	alk	422	mg/L	
09EN07-135	6/30/10	alk	318	mg/L	
09EN07-135	11/15/10	alk	311	mg/L	
09EN07-135	9/26/08	Ca	90	mg/L	
09EN07-135	11/25/08	Ca	120.85	mg/L	
09EN07-135	2/6/09	Ca	156.72	mg/L	
09EN07-135	9/25/09	Ca	176.78	mg/L	
09EN07-135	6/30/10	Ca	108.94	mg/L	
09EN07-135	11/15/10	Ca	115.69	mg/L	
09EN07-135	9/26/08	cl	21	mg/L	
09EN07-135	11/25/08	cl	15	mg/L	
09EN07-135	2/6/09	cl	13	mg/L	
09EN07-135	9/25/09	cl	11	mg/L	
09EN07-135	6/30/10	cl	35	mg/L	
09EN07-135	11/15/10	cl	28	mg/L	
09EN07-135	9/26/08	cnd	1,088	uS/cm	
09EN07-135	11/25/08	cnd	1174	uS/cm	
09EN07-135	2/6/09	cnd	1198	uS/cm	
09EN07-135	9/25/09	cnd	1293	uS/cm	
09EN07-135	6/30/10	cnd	859	uS/cm	
09EN07-135	11/15/10	cnd	958	uS/cm	
09EN07-135	9/26/08	hrd	331	mg/L	
09EN07-135	11/25/08	hrd	436	mg/L	
09EN07-135	2/6/09	hrd	571	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
09EN07-135	9/25/09	hrd	650	mg/L	
09EN07-135	11/15/10	hrd	443	mg/L	
09EN07-135	9/26/08	Fe	0.04	mg/L	J
09EN07-135	11/25/08	Fe	1.26	mg/L	
09EN07-135	2/6/09	Fe	0.79	mg/L	
09EN07-135	9/25/09	Fe	0.98	mg/L	
09EN07-135	6/30/10	Fe	0	mg/L	U
09EN07-135	11/15/10	Fe	0.01	mg/L	J
09EN07-135	9/26/08	Mg	25.8	mg/L	
09EN07-135	11/25/08	Mg	32.37	mg/L	
09EN07-135	2/6/09	Mg	42.67	mg/L	
09EN07-135	9/25/09	Mg	50.59	mg/L	
09EN07-135	6/30/10	Mg	34.62	mg/L	
09EN07-135	11/15/10	Mg	37.18	mg/L	
09EN07-135	9/26/08	Mn	0.45	mg/L	
09EN07-135	11/25/08	Mn	1.41	mg/L	
09EN07-135	2/6/09	Mn	1.71	mg/L	
09EN07-135	9/25/09	Mn	2	mg/L	
09EN07-135	6/30/10	Mn	0.33	mg/L	
09EN07-135	11/15/10	Mn	0.23	mg/L	J
09EN07-135	9/26/08	nn	0.2	mg/l	
09EN07-135	11/25/08	nn	0	mg/l	
09EN07-135	2/6/09	nn	0	mg/l	
09EN07-135	9/25/09	nn	0	mg/l	
09EN07-135	6/30/10	nn	2.3	mg/l	
09EN07-135	11/15/10	nn	3.8	mg/l	
09EN07-135	9/26/08	K	9.47	mg/L	J
09EN07-135	11/25/08	K	9.03	mg/L	
09EN07-135	2/6/09	K	10.18	mg/L	
09EN07-135	9/25/09	K	8.99	mg/L	
09EN07-135	6/30/10	K	2.13	mg/L	U
09EN07-135	11/15/10	K	2.89	mg/L	
09EN07-135	9/26/08	Na	153	mg/L	
09EN07-135	11/25/08	Na	102.87	mg/L	
09EN07-135	2/6/09	Na	78.12	mg/L	
09EN07-135	9/25/09	Na	40.9	mg/L	
09EN07-135	6/30/10	Na	43.2	mg/L	
09EN07-135	11/15/10	Na	34.73	mg/L	
09EN07-135	9/26/08	sf	266	mg/L	
09EN07-135	11/25/08	sf	280	mg/L	
09EN07-135	2/6/09	sf	321	mg/L	
09EN07-135	9/25/09	sf	296	mg/L	
09EN07-135	6/30/10	sf	125	mg/L	
09EN07-135	11/15/10	sf	164	mg/L	
09EN07-135	9/26/08	tds	812	mg/L	
09EN07-135	11/25/08	tds	778	mg/L	
09EN07-135	2/6/09	tds	916	mg/L	
09EN07-135	9/25/09	tds	946	mg/L	
09EN07-135	6/30/10	tds	580	mg/L	
09EN07-135	11/15/10	tds	514	mg/L	
09EN07-218	9/26/08	alk	292	mg/L	
09EN07-218	11/25/08	alk	296	mg/L	
09EN07-218	2/6/09	alk	304	mg/L	
09EN07-218	9/25/09	alk	313	mg/L	
09EN07-218	6/30/10	alk	307	mg/L	
09EN07-218	11/15/10	alk	300	mg/L	
09EN07-218	9/26/08	Ca	86	mg/L	
09EN07-218	11/25/08	Ca	79.83	mg/L	

Well name	Date	Analyte	Result	Unit	F
09EN07-218	2/6/09	Ca	89.7	mg/L	
09EN07-218	9/25/09	Ca	89.76	mg/L	
09EN07-218	6/30/10	Ca	91.95	mg/L	
09EN07-218	11/15/10	Ca	90.85	mg/L	
09EN07-218	9/26/08	cl	11	mg/L	
09EN07-218	11/25/08	cl	11	mg/L	
09EN07-218	2/6/09	cl	11	mg/L	
09EN07-218	9/25/09	cl	11	mg/L	
09EN07-218	6/30/10	cl	12	mg/L	
09EN07-218	11/15/10	cl	12	mg/L	
09EN07-218	9/26/08	cnd	623	uS/cm	
09EN07-218	11/25/08	cnd	609	uS/cm	
09EN07-218	2/6/09	cnd	616	uS/cm	
09EN07-218	9/25/09	cnd	671	uS/cm	
09EN07-218	6/30/10	cnd	626	uS/cm	
09EN07-218	11/15/10	cnd	640	uS/cm	
09EN07-218	9/26/08	hrd	287	mg/L	
09EN07-218	11/25/08	hrd	269	mg/L	
09EN07-218	2/6/09	hrd	302	mg/L	
09EN07-218	9/25/09	hrd	301	mg/L	
09EN07-218	11/15/10	hrd	305	mg/L	
09EN07-218	9/26/08	Fe	0.14	mg/L	
09EN07-218	11/25/08	Fe	0.49	mg/L	
09EN07-218	2/6/09	Fe	0.7	mg/L	
09EN07-218	9/25/09	Fe	0.67	mg/L	
09EN07-218	6/30/10	Fe	0.28	mg/L	
09EN07-218	11/15/10	Fe	0.7	mg/L	
09EN07-218	9/26/08	Mg	17.5	mg/L	
09EN07-218	11/25/08	Mg	16.73	mg/L	
09EN07-218	2/6/09	Mg	18.78	mg/L	
09EN07-218	9/25/09	Mg	18.6	mg/L	
09EN07-218	6/30/10	Mg	17.91	mg/L	
09EN07-218	11/15/10	Mg	18.82	mg/L	
09EN07-218	9/26/08	Mn	0.5	mg/L	
09EN07-218	11/25/08	Mn	0.68	mg/L	
09EN07-218	2/6/09	Mn	0.81	mg/L	
09EN07-218	9/25/09	Mn	0.68	mg/L	
09EN07-218	6/30/10	Mn	0.61	mg/L	
09EN07-218	11/15/10	Mn	0.6	mg/L	
09EN07-218	9/26/08	nn	0.2	mg/l	
09EN07-218	11/25/08	nn	0	mg/l	
09EN07-218	2/6/09	nn	0	mg/l	
09EN07-218	9/25/09	nn	0	mg/l	
09EN07-218	6/30/10	nn	0	mg/l	
09EN07-218	11/15/10	nn	0	mg/l	
09EN07-218	9/26/08	K	5.06	mg/L	
09EN07-218	11/25/08	K	4.15	mg/L	
09EN07-218	2/6/09	K	4.38	mg/L	
09EN07-218	9/25/09	K	4.01	mg/L	
09EN07-218	6/30/10	K	3.72	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
13EN07-40	3/17/09	alk	418	mg/L	
13EN07-40	5/19/09	alk	412	mg/L	
13EN07-40	5/19/09	alk	412	mg/L	
13EN07-40	9/25/09	alk	464	mg/L	
13EN07-40	6/30/10	alk	391	mg/L	
13EN07-40	11/15/10	alk	335	mg/L	
13EN07-40	11/26/08	Ca	193.1	mg/L	
13EN07-40	3/17/09	Ca	185.53	mg/L	
13EN07-40	5/19/09	Ca	193.1	mg/L	
13EN07-40	5/19/09	Ca	193.7	mg/L	
13EN07-40	9/25/09	Ca	189.18	mg/L	
13EN07-40	6/30/10	Ca	163.06	mg/L	
13EN07-40	11/15/10	Ca	137.79	mg/L	
13EN07-40	11/26/08	cl	87	mg/L	
13EN07-40	3/17/09	cl	86	mg/L	
13EN07-40	5/19/09	cl	83	mg/L	
13EN07-40	5/19/09	cl	83	mg/L	
13EN07-40	9/25/09	cl	87	mg/L	
13EN07-40	6/30/10	cl	54	mg/L	
13EN07-40	11/15/10	cl	43	mg/L	
13EN07-40	11/26/08	cnd	1764	uS/cm	
13EN07-40	3/17/09	cnd	1789	uS/cm	
13EN07-40	5/19/09	cnd	1664	uS/cm	
13EN07-40	5/19/09	cnd	1677	uS/cm	
13EN07-40	9/25/09	cnd	1859	uS/cm	
13EN07-40	6/30/10	cnd	1265	uS/cm	
13EN07-40	11/15/10	cnd	1124	uS/cm	
13EN07-40	11/26/08	hrd	718	mg/L	
13EN07-40	3/17/09	hrd	689	mg/L	
13EN07-40	5/19/09	hrd	725	mg/L	
13EN07-40	5/19/09	hrd	728	mg/L	
13EN07-40	9/25/09	hrd	710	mg/L	
13EN07-40	11/15/10	hrd	520	mg/L	
13EN07-40	11/26/08	Fe	0	mg/L	
13EN07-40	3/17/09	Fe	0.02	mg/L	
13EN07-40	5/19/09	Fe	0.04	mg/L	
13EN07-40	5/19/09	Fe	0.05	mg/L	
13EN07-40	9/25/09	Fe	0.07	mg/L	U
13EN07-40	6/30/10	Fe	0.02	mg/L	U
13EN07-40	11/15/10	Fe	0.19	mg/L	J
13EN07-40	11/26/08	Mg	57.4	mg/L	
13EN07-40	3/17/09	Mg	54.53	mg/L	
13EN07-40	5/19/09	Mg	59.02	mg/L	
13EN07-40	5/19/09	Mg	59.17	mg/L	
13EN07-40	9/25/09	Mg	57.66	mg/L	
13EN07-40	6/30/10	Mg	48.2	mg/L	
13EN07-40	11/15/10	Mg	42.48	mg/L	
13EN07-40	11/26/08	Mn	0	mg/L	
13EN07-40	3/17/09	Mn	0.52	mg/L	
13EN07-40	5/19/09	Mn	0.2	mg/L	
13EN07-40	5/19/09	Mn	0.23	mg/L	
13EN07-40	9/25/09	Mn	0.01	mg/L	
13EN07-40	6/30/10	Mn	0.03	mg/L	
13EN07-40	11/15/10	Mn	0.07	mg/L	J
13EN07-40	11/26/08	nn	107	mg/l	
13EN07-40	3/17/09	nn	101	mg/l	
13EN07-40	5/19/09	nn	128	mg/l	
13EN07-40	5/19/09	nn	131	mg/l	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
09EN07-218	11/25/08	sf	31	mg/L	
09EN07-218	2/6/09	sf	30	mg/L	
09EN07-218	9/25/09	sf	27	mg/L	
09EN07-218	6/30/10	sf	22	mg/L	
09EN07-218	11/15/10	sf	38	mg/L	
09EN07-218	9/26/08	tds	422	mg/L	
09EN07-218	11/25/08	tds	362	mg/L	
09EN07-218	2/6/09	tds	360	mg/L	J
09EN07-218	9/25/09	tds	418	mg/L	
09EN07-218	6/30/10	tds	416	mg/L	
09EN07-218	11/15/10	tds	298	mg/L	
09EN07-320	9/26/08	alk	346	mg/L	
09EN07-320	11/25/08	alk	345	mg/L	
09EN07-320	2/6/09	alk	347	mg/L	
09EN07-320	9/25/09	alk	352	mg/L	
09EN07-320	6/30/10	alk	357	mg/L	
09EN07-320	11/15/10	alk	286	mg/L	
09EN07-320	9/26/08	Ca	86	mg/L	
09EN07-320	11/25/08	Ca	81.55	mg/L	
09EN07-320	2/6/09	Ca	86.96	mg/L	
09EN07-320	9/25/09	Ca	83.1	mg/L	
09EN07-320	6/30/10	Ca	88.9	mg/L	
09EN07-320	11/15/10	Ca	82.9	mg/L	
09EN07-320	9/26/08	cl	233	mg/L	
09EN07-320	11/25/08	cl	211	mg/L	
09EN07-320	2/6/09	cl	211	mg/L	
09EN07-320	9/25/09	cl	223	mg/L	
09EN07-320	6/30/10	cl	98	mg/L	
09EN07-320	11/15/10	cl	213	mg/L	
09EN07-320	9/26/08	cnd	1,423	uS/cm	
09EN07-320	11/25/08	cnd	1449	uS/cm	
09EN07-320	2/6/09	cnd	1465	uS/cm	
09EN07-320	9/25/09	cnd	1589	uS/cm	
09EN07-320	6/30/10	cnd	1371	uS/cm	
09EN07-320	11/15/10	cnd	1508	uS/cm	
09EN07-320	9/26/08	hrd	290	mg/L	
09EN07-320	11/25/08	hrd	274	mg/L	
09EN07-320	2/6/09	hrd	291	mg/L	
09EN07-320	9/25/09	hrd	279	mg/L	
09EN07-320	11/15/10	hrd	281	mg/L	
09EN07-320	9/26/08	Fe	0.03	mg/L	J
09EN07-320	11/25/08	Fe	0.02	mg/L	
09EN07-320	2/6/09	Fe	0.03	mg/L	
09EN07-320	9/25/09	Fe	0.07	mg/L	U
09EN07-320	6/30/10	Fe	0.04	mg/L	U
09EN07-320	11/15/10	Fe	0.03	mg/L	J
09EN07-320	9/26/08	Mg	18.3	mg/L	
09EN07-320	11/25/08	Mg	16.67	mg/L	
09EN07-320	2/6/09	Mg	17.81	mg/L	
09EN07-320	9/25/09	Mg	17.48	mg/L	
09EN07-320	6/30/10	Mg	17.73	mg/L	
09EN07-320	11/15/10	Mg	17.97	mg/L	
09EN07-320	9/26/08	Mn	0.41	mg/L	
09EN07-320	11/25/08	Mn	0.37	mg/L	
09EN07-320	2/6/09	Mn	0.43	mg/L	
09EN07-320	9/25/09	Mn	0.48	mg/L	
09EN07-320	6/30/10	Mn	0.45	mg/L	
09EN07-320	11/15/10	Mn	0.42	mg/L	J

ame	Date	Analyte	Result	Unit	Flag
7-320	9/26/08	nn	1.9	mg/l	
7-320	11/25/08	nn	1.9	mg/l	
7-320	2/6/09	nn	1.5	mg/l	
7-320	9/25/09	nn	1.2	mg/l	
7-320	6/30/10	nn	1	mg/l	
7-320	11/15/10	nn	2.2	mg/l	
7-320	9/26/08	K	3.78	mg/L	U
7-320	11/25/08	K	3.41	mg/L	
7-320	2/6/09	K	3.67	mg/L	
7-320	9/25/09	K	3.62	mg/L	
7-320	6/30/10	K	3.54	mg/L	J
7-320	11/15/10	K	3.55	mg/L	
7-320	9/26/08	Na	231	mg/L	
7-320	11/25/08	Na	220.08	mg/L	
7-320	2/6/09	Na	208.68	mg/L	
7-320	9/25/09	Na	212.69	mg/L	
7-320	6/30/10	Na	204.07	mg/L	
7-320	11/15/10	Na	201.91	mg/L	
7-320	9/26/08	sf	124	mg/L	
7-320	11/25/08	sf	114	mg/L	
7-320	2/6/09	sf	113	mg/L	
7-320	9/25/09	sf	110	mg/L	
7-320	6/30/10	sf	198	mg/L	
7-320	11/15/10	sf	114	mg/L	
7-320	9/26/08	tds	946	mg/L	
7-320	11/25/08	tds	848	mg/L	
7-320	2/6/09	tds	914	mg/L	
7-320	9/25/09	tds	950	mg/L	
7-320	6/30/10	tds	822	mg/L	
7-320	11/15/10	tds	810	mg/L	
7-85	9/26/08	alk	276	mg/L	
7-85	11/25/08	alk	289	mg/L	
7-85	2/6/09	alk	294	mg/L	
7-85	9/25/09	alk	285	mg/L	
7-85	6/30/10	alk	289	mg/L	
7-85	11/15/10	alk	342	mg/L	
7-85	9/26/08	Ca	110	mg/L	
7-85	11/25/08	Ca	105.76	mg/L	
7-85	2/6/09	Ca	112.15	mg/L	
7-85	9/25/09	Ca	109.11	mg/L	
7-85	6/30/10	Ca	120.93	mg/L	
7-85	11/15/10	Ca	126.91	mg/L	
7-85	9/26/08	cl	41	mg/L	
7-85	11/25/08	cl	42	mg/L	
7-85	2/6/09	cl	43	mg/L	
7-85	9/25/09	cl	46	mg/L	
7-85	6/30/10	cl	36	mg/L	
7-85	11/15/10	cl	33	mg/L	
7-85	9/26/08	cnd	801	uS/cm	
7-85	11/25/08	cnd	825	uS/cm	

Well name	Date	Analyte	Result	Unit	Flag
09EN07-85	11/15/10	hrd	457	mg/L	
09EN07-85	9/26/08	Fe	0.03	mg/L	J
09EN07-85	11/25/08	Fe	0	mg/L	
09EN07-85	2/6/09	Fe	0.04	mg/L	
09EN07-85	9/25/09	Fe	0.02	mg/L	U
09EN07-85	6/30/10	Fe	0.03	mg/L	U
09EN07-85	11/15/10	Fe	0.02	mg/L	J
09EN07-85	9/26/08	Mg	33.1	mg/L	
09EN07-85	11/25/08	Mg	29.96	mg/L	
09EN07-85	2/6/09	Mg	33.37	mg/L	
09EN07-85	9/25/09	Mg	34.14	mg/L	
09EN07-85	6/30/10	Mg	35.02	mg/L	
09EN07-85	11/15/10	Mg	33.95	mg/L	
09EN07-85	9/26/08	Mn	0	mg/L	
09EN07-85	11/25/08	Mn	0	mg/L	
09EN07-85	2/6/09	Mn	0	mg/L	
09EN07-85	9/25/09	Mn	0	mg/L	
09EN07-85	6/30/10	Mn	0	mg/L	
09EN07-85	11/15/10	Mn	0	mg/L	J
09EN07-85	9/26/08	nn	11.4	mg/l	
09EN07-85	11/25/08	nn	8.7	mg/l	
09EN07-85	2/6/09	nn	7.7	mg/l	
09EN07-85	9/25/09	nn	10.5	mg/l	
09EN07-85	6/30/10	nn	8.2	mg/l	
09EN07-85	11/15/10	nn	8.1	mg/l	
09EN07-85	9/26/08	K	3.57	mg/L	U
09EN07-85	11/25/08	K	3.01	mg/L	
09EN07-85	2/6/09	K	3.31	mg/L	
09EN07-85	9/25/09	K	3.25	mg/L	
09EN07-85	6/30/10	K	3.15	mg/L	J
09EN07-85	11/15/10	K	2.88	mg/L	
09EN07-85	9/26/08	Na	32.4	mg/L	J
09EN07-85	11/25/08	Na	30.86	mg/L	
09EN07-85	2/6/09	Na	28.92	mg/L	
09EN07-85	9/25/09	Na	28.94	mg/L	
09EN07-85	6/30/10	Na	32.42	mg/L	
09EN07-85	11/15/10	Na	27.15	mg/L	
09EN07-85	9/26/08	sf	92	mg/L	
09EN07-85	11/25/08	sf	82	mg/L	
09EN07-85	2/6/09	sf	71	mg/L	
09EN07-85	9/25/09	sf	67	mg/L	
09EN07-85	6/30/10	sf	125	mg/L	
09EN07-85	11/15/10	sf	142	mg/L	
09EN07-85	9/26/08	tds	544	mg/L	
09EN07-85	11/25/08	tds	520	mg/L	
09EN07-85	2/6/09	tds	550	mg/L	
09EN07-85	9/25/09	tds	572	mg/L	
09EN07-85	6/30/10	tds	582	mg/L	
09EN07-85	11/15/10	tds	524	mg/L	
10EN07-135	9/19/08	alk	293	mg/L	
10EN07-135	11/26/08	alk	322	mg/L	
10EN07-135	2/5/09	alk	323	mg/L	
10EN07-135	9/25/09	alk	340	mg/L	
10EN07-135	6/30/10	alk	311	mg/L	
10EN07-135	11/15/10	alk	335	mg/L	
10EN07-135	9/19/08	Ca	75	mg/L	
10EN07-135	11/26/08	Ca	70.38	mg/L	
10EN07-135	2/5/09	Ca	72.22	mg/L	
10EN07-135	9/25/09	Ca	74.84	mg/L	
10EN07-135	6/30/10	Ca	77.43	mg/L	
10EN07-135	11/15/10	Ca	76.79	mg/L	
10EN07-135	9/19/08	cl	15	mg/L	
10EN07-135	11/26/08	cl	14	mg/L	
10EN07-135	2/5/09	cl	14	mg/L	
10EN07-135	9/25/09	cl	14	mg/L	
10EN07-135	6/30/10	cl	14	mg/L	
10EN07-135	11/15/10	cl	14	mg/L	
10EN07-135	9/19/08	cnd	690	uS/cm	
10EN07-135	11/26/08	cnd	726	uS/cm	
10EN07-135	2/5/09	cnd	730	uS/cm	
10EN07-135	9/25/09	cnd	774	uS/cm	
10EN07-135	6/30/10	cnd	699	uS/cm	
10EN07-135	11/15/10	cnd	749	uS/cm	
10EN07-135	9/19/08	hrd	275	mg/L	
10EN07-135	11/26/08	hrd	253	mg/L	
10EN07-135	2/5/09	hrd	260	mg/L	
10EN07-135	9/25/09	hrd	273	mg/L	
10EN07-135	11/15/10	hrd	284	mg/L	
10EN07-135	9/19/08	Fe	0.28	mg/L	J
10EN07-135	11/26/08	Fe	0.38	mg/L	
10EN07-135	2/5/09	Fe	0.65	mg/L	
10EN07-135	9/25/09	Fe	0.64	mg/L	
10EN07-135	6/30/10	Fe	0.14	mg/L	U
10EN07-135	11/15/10	Fe	0.46	mg/L	J
10EN07-135	9/19/08	Mg	21.4	mg/L	
10EN07-135	11/26/08	Mg	18.85	mg/L	
10EN07-135	2/5/09	Mg	19.45	mg/L	
10EN07-135	9/25/09	Mg	20.82	mg/L	
10EN07-135	6/30/10	Mg	21.05	mg/L	
10EN07-135	11/15/10	Mg	22.18	mg/L	
10EN07-135	9/19/08	Mn	0.22	mg/L	
10EN07-135	11/26/08	Mn	0.15	mg/L	
10EN07-135	2/5/09	Mn	0.18	mg/L	
10EN07-135	9/25/09	Mn	0.15	mg/L	
10EN07-135	6/30/10	Mn	0.16	mg/L	
10EN07-135	11/15/10	Mn	0.14	mg/L	J
10EN07-135	9/19/08	nn	0.9	mg/l	
10EN07-135	11/26/08	nn	0	mg/l	
10EN07-135	2/5/09	nn	0	mg/l	
10EN07-135	9/25/09	nn	0	mg/l	
10EN07-135	6/30/10	nn	0	mg/l	
10EN07-135	11/15/10	nn	0	mg/l	
10EN07-135	9/19/08	K	6.94	mg/L	J
10EN07-135	11/26/08	K	6.29	mg/L	
10EN07-135	2/5/09	K	6.44	mg/L	
10EN07-135	9/25/09	K	6.58	mg/L	
10EN07-135	6/30/10	K	9.4	mg/L	
10EN07-135	11/15/10	K	6.41	mg/L	
10EN07-135	9/19/08	Na	68.2	mg/L	
10EN07-135	11/26/08	Na	69.28	mg/L	
10EN07-135	2/5/09	Na	64.2	mg/L	
10EN07-135	9/25/09	Na	58.29	mg/L	
10EN07-135	6/30/10	Na	60.15	mg/L	
10EN07-135	11/15/10	Na	51.07	mg/L	
10EN07-135	9/19/08	sf	87	mg/L	
10EN07-135	11/26/08	sf	68	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
10EN07-135	2/5/09	sf	57	mg/L	
10EN07-135	9/25/09	sf	31	mg/L	
10EN07-135	6/30/10	sf	71	mg/L	
10EN07-135	11/15/10	sf	43	mg/L	
10EN07-135	9/19/08	tds	482	mg/L	
10EN07-135	11/26/08	tds	416	mg/L	
10EN07-135	2/5/09	tds	490	mg/L	J
10EN07-135	9/25/09	tds	496	mg/L	
10EN07-135	6/30/10	tds	458	mg/L	
10EN07-135	11/15/10	tds	396	mg/L	
10EN07-235	9/25/08	alk	306	mg/L	
10EN07-235	11/26/08	alk	295	mg/L	
10EN07-235	2/5/09	alk	295	mg/L	
10EN07-235	9/25/09	alk	296	mg/L	
10EN07-235	6/30/10	alk	306	mg/L	
10EN07-235	11/15/10	alk	317	mg/L	
10EN07-235	9/25/08	Ca	47	mg/L	J
10EN07-235	11/26/08	Ca	53.27	mg/L	
10EN07-235	2/5/09	Ca	59.73	mg/L	
10EN07-235	9/25/09	Ca	69.33	mg/L	
10EN07-235	6/30/10	Ca	78.23	mg/L	
10EN07-235	11/15/10	Ca	72.84	mg/L	
10EN07-235	9/25/08	cl	5	mg/L	
10EN07-235	11/26/08	cl	4	mg/L	
10EN07-235	2/5/09	cl	3	mg/L	
10EN07-235	9/25/09	cl	3	mg/L	
10EN07-235	6/30/10	cl	4	mg/L	
10EN07-235	11/15/10	cl	5	mg/L	
10EN07-235	9/25/08	cnd	708	uS/cm	
10EN07-235	11/26/08	cnd	665	uS/cm	
10EN07-235	2/5/09	cnd	653	uS/cm	
10EN07-235	9/25/09	cnd	628	uS/cm	
10EN07-235	6/30/10	cnd	592	uS/cm	
10EN07-235	11/15/10	cnd	624	uS/cm	
10EN07-235	9/25/08	hrd	159	mg/L	J
10EN07-235	11/26/08	hrd	181	mg/L	
10EN07-235	2/5/09	hrd	204	mg/L	
10EN07-235	9/25/09	hrd	234	mg/L	
10EN07-235	11/15/10	hrd	245	mg/L	
10EN07-235	9/25/08	Fe	0.31	mg/L	J
10EN07-235	11/26/08	Fe	0.06	mg/L	
10EN07-235	2/5/09	Fe	0.1	mg/L	
10EN07-235	9/25/09	Fe	0.41	mg/L	
10EN07-235	6/30/10	Fe	0.2	mg/L	J
10EN07-235	11/15/10	Fe	0.15	mg/L	J
10EN07-235	9/25/08	Mg	10.2	mg/L	J
10EN07-235	11/26/08	Mg	11.68	mg/L	
10EN07-235	2/5/09	Mg	13.15	mg/L	
10EN07-235	9/25/09	Mg	14.72	mg/L	
10EN07-235	6/30/10	Mg	15.97	mg/L	
10EN07-235	11/15/10	Mg	15.21	mg/L	
10EN07-235	9/25/08	Mn	0.28	mg/L	
10EN07-235	11/26/08	Mn	0.43	mg/L	
10EN07-235	2/5/09	Mn	0.52	mg/L	
10EN07-235	9/25/09	Mn	0.46	mg/L	
10EN07-235	6/30/10	Mn	0.52	mg/L	
10EN07-235	11/15/10	Mn	0.44	mg/L	J
10EN07-235	9/25/08	nn	1.2	mg/l	

Well name	Date	Analyte	Result	Unit	Flag
10EN07-235	11/26/08	nn	1.5	mg/l	
10EN07-235	2/5/09	nn	1.8	mg/l	
10EN07-235	9/25/09	nn	0.8	mg/l	
10EN07-235	6/30/10	nn	0	mg/l	
10EN07-235	11/15/10	nn	0	mg/l	
10EN07-235	9/25/08	K	3.25	mg/L	U
10EN07-235	11/26/08	K	3.43	mg/L	
10EN07-235	2/5/09	K	3.61	mg/L	
10EN07-235	9/25/09	K	3.02	mg/L	
10EN07-235	6/30/10	K	2.96	mg/L	J
10EN07-235	11/15/10	K	2.8	mg/L	
10EN07-235	9/25/08	Na	100	mg/L	
10EN07-235	11/26/08	Na	87.02	mg/L	
10EN07-235	2/5/09	Na	76.22	mg/L	
10EN07-235	9/25/09	Na	43.77	mg/L	
10EN07-235	6/30/10	Na	41.53	mg/L	
10EN07-235	11/15/10	Na	41.54	mg/L	
10EN07-235	9/25/08	sf	84	mg/L	
10EN07-235	11/26/08	sf	62	mg/L	
10EN07-235	2/5/09	sf	53	mg/L	
10EN07-235	9/25/09	sf	27	mg/L	
10EN07-235	6/30/10	sf	21	mg/L	
10EN07-235	11/15/10	sf	2	mg/L	
10EN07-235	9/25/08	tds	536	mg/L	
10EN07-235	11/26/08	tds	440	mg/L	
10EN07-235	2/5/09	tds	440	mg/L	J
10EN07-235	9/25/09	tds	398	mg/L	
10EN07-235	6/30/10	tds	452	mg/L	
10EN07-235	11/15/10	tds	392	mg/L	
10EN07-290	9/25/08	alk	294	mg/L	
10EN07-290	11/26/08	alk	292	mg/L	
10EN07-290	2/5/09	alk	297	mg/L	
10EN07-290	9/25/09	alk	299	mg/L	
10EN07-290	6/30/10	alk	318	mg/L	
10EN07-290	11/15/10	alk	346	mg/L	
10EN07-290	9/25/08	Ca	91	mg/L	
10EN07-290	11/26/08	Ca	87.32	mg/L	
10EN07-290	2/5/09	Ca	92.92	mg/L	
10EN07-290	9/25/09	Ca	93.36	mg/L	
10EN07-290	6/30/10	Ca	100.8	mg/L	
10EN07-290	11/15/10	Ca	92.73	mg/L	
10EN07-290	9/25/08	cl	8	mg/L	
10EN07-290	11/26/08	cl	8	mg/L	
10EN07-290	2/5/09	cl	8	mg/L	
10EN07-290	9/25/09	cl	9	mg/L	
10EN07-290	6/30/10	cl	9	mg/L	
10EN07-290	11/15/10	cl	10	mg/L	
10EN07-290	9/25/08	cnd	657	uS/cm	
10EN07-290	11/26/08	cnd	671	uS/cm	
10EN07-290	2/5/09	cnd	673	uS/cm	
10EN07-290	9/25/09	cnd	718	uS/cm	
10EN07-290	6/30/10	cnd	717	uS/cm	
10EN07-290	11/15/10	cnd	700	uS/cm	
10EN07-290	9/25/08	hrd	327	mg/L	
10EN07-290	11/26/08	hrd	312	mg/L	
10EN07-290	2/5/09	hrd	336	mg/L	
10EN07-290	9/25/09	hrd	337	mg/L	
10EN07-290	11/15/10	hrd	337	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
10EN07-290	9/25/08	Fe	0.23	mg/L	J
10EN07-290	11/26/08	Fe	0.02	mg/L	
10EN07-290	2/5/09	Fe	0.03	mg/L	
10EN07-290	9/25/09	Fe	0.04	mg/L	U
10EN07-290	6/30/10	Fe	0.05	mg/L	U
10EN07-290	11/15/10	Fe	0.03	mg/L	J
10EN07-290	9/25/08	Mg	23.9	mg/L	
10EN07-290	11/26/08	Mg	23.07	mg/L	
10EN07-290	2/5/09	Mg	25.09	mg/L	
10EN07-290	9/25/09	Mg	25.22	mg/L	
10EN07-290	6/30/10	Mg	24.69	mg/L	
10EN07-290	11/15/10	Mg	25.5	mg/L	
10EN07-290	9/25/08	Mn	0.43	mg/L	
10EN07-290	11/26/08	Mn	0.41	mg/L	
10EN07-290	2/5/09	Mn	0.43	mg/L	
10EN07-290	9/25/09	Mn	0.41	mg/L	
10EN07-290	6/30/10	Mn	0.41	mg/L	
10EN07-290	11/15/10	Mn	0.4	mg/L	J
10EN07-290	9/25/08	nn	0	mg/l	
10EN07-290	11/26/08	nn	0	mg/l	
10EN07-290	2/5/09	nn	0	mg/l	
10EN07-290	9/25/09	nn	0	mg/l	
10EN07-290	6/30/10	nn	0	mg/l	
10EN07-290	11/15/10	nn	0	mg/l	
10EN07-290	9/25/08	K	2.81	mg/L	U
10EN07-290	11/26/08	K	2.81	mg/L	
10EN07-290	2/5/09	K	3.29	mg/L	
10EN07-290	9/25/09	K	3.01	mg/L	
10EN07-290	6/30/10	K	2.8	mg/L	J
10EN07-290	11/15/10	K	2.78	mg/L	
10EN07-290	9/25/08	Na	24.8	mg/L	J
10EN07-290	11/26/08	Na	25.22	mg/L	
10EN07-290	2/5/09	Na	27.89	mg/L	
10EN07-290	9/25/09	Na	25.55	mg/L	
10EN07-290	6/30/10	Na	27.19	mg/L	
10EN07-290	11/15/10	Na	25.29	mg/L	
10EN07-290	9/25/08	sf	67	mg/L	
10EN07-290	11/26/08	sf	67	mg/L	
10EN07-290	2/5/09	sf	68	mg/L	
10EN07-290	9/25/09	sf	68	mg/L	
10EN07-290	6/30/10	sf	29	mg/L	
10EN07-290	11/15/10	sf	2	mg/L	
10EN07-290	9/25/08	tds	404	mg/L	
10EN07-290	11/26/08	tds	408	mg/L	
10EN07-290	2/5/09	tds	438	mg/L	J
10EN07-290	9/25/09	tds	456	mg/L	
10EN07-290	6/30/10	tds	484	mg/L	
10EN07-290	11/15/10	tds	362	mg/L	
10EN07-40	9/25/08	alk	303	mg/L	
10EN07-40	11/26/08	alk	278	mg/L	
10EN07-40	2/6/09	alk	312	mg/L	
10EN07-40	9/25/09	alk	295	mg/L	
10EN07-40	6/30/10	alk	255	mg/L	
10EN07-40	11/15/10	alk	260	mg/L	
10EN07-40	9/25/08	Ca	96	mg/L	
10EN07-40	11/26/08	Ca	91.8	mg/L	
10EN07-40	2/6/09	Ca	114.65	mg/L	
10EN07-40	9/25/09	Ca	100.64	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
10EN07-40	6/30/10	Ca	95.95	mg/L	
10EN07-40	11/15/10	Ca	94.52	mg/L	
10EN07-40	9/25/08	cl	6	mg/L	
10EN07-40	11/26/08	cl	4	mg/L	
10EN07-40	2/6/09	cl	5	mg/L	
10EN07-40	9/25/09	cl	4	mg/L	
10EN07-40	6/30/10	cl	4	mg/L	
10EN07-40	11/15/10	cl	4	mg/L	
10EN07-40	9/25/08	cnd	804	uS/cm	
10EN07-40	11/26/08	cnd	806	uS/cm	
10EN07-40	2/6/09	cnd	820	uS/cm	
10EN07-40	9/25/09	cnd	845	uS/cm	
10EN07-40	6/30/10	cnd	740	uS/cm	
10EN07-40	11/15/10	cnd	773	uS/cm	
10EN07-40	9/25/08	hrd	314	mg/L	
10EN07-40	11/26/08	hrd	294	mg/L	
10EN07-40	2/6/09	hrd	374	mg/L	
10EN07-40	9/25/09	hrd	325	mg/L	
10EN07-40	11/15/10	hrd	309	mg/L	
10EN07-40	9/25/08	Fe	0	mg/L	J
10EN07-40	11/26/08	Fe	0	mg/L	
10EN07-40	2/6/09	Fe	0	mg/L	
10EN07-40	9/25/09	Fe	0	mg/L	U
10EN07-40	6/30/10	Fe	0	mg/L	U
10EN07-40	11/15/10	Fe	0.07	mg/L	J
10EN07-40	9/25/08	Mg	18.1	mg/L	J
10EN07-40	11/26/08	Mg	15.47	mg/L	
10EN07-40	2/6/09	Mg	21.25	mg/L	
10EN07-40	9/25/09	Mg	17.95	mg/L	
10EN07-40	6/30/10	Mg	16.75	mg/L	
10EN07-40	11/15/10	Mg	17.51	mg/L	
10EN07-40	9/25/08	Mn	0	mg/L	
10EN07-40	11/26/08	Mn	0	mg/L	
10EN07-40	2/6/09	Mn	0	mg/L	
10EN07-40	9/25/09	Mn	0	mg/L	
10EN07-40	6/30/10	Mn	0	mg/L	
10EN07-40	11/15/10	Mn	0	mg/L	J
10EN07-40	9/25/08	nn	20	mg/l	
10EN07-40	11/26/08	nn	32.2	mg/l	
10EN07-40	2/6/09	nn	23.4	mg/l	
10EN07-40	9/25/09	nn	24.5	mg/l	
10EN07-40	6/30/10	nn	28.8	mg/l	
10EN07-40	11/15/10	nn	28	mg/l	
10EN07-40	9/25/08	K	2.03	mg/L	U
10EN07-40	11/26/08	K	1.76	mg/L	
10EN07-40	2/6/09	K	2.03	mg/L	
10EN07-40	9/25/09	K	2.01	mg/L	
10EN07-40	6/30/10	K	1.91	mg/L	U
10EN07-40	11/15/10	K	1.88	mg/L	
10EN07-40	9/25/08	Na	67.9	mg/L	
10EN07-40	11/26/08	Na	50.12	mg/L	
10EN07-40	2/6/09	Na	60.26	mg/L	
10EN07-40	9/25/09	Na	49.15	mg/L	
10EN07-40	6/30/10	Na	52.12	mg/L	
10EN07-40	11/15/10	Na	46.64	mg/L	
10EN07-40	9/25/08	sf	72	mg/L	
10EN07-40	11/26/08	sf	51	mg/L	
10EN07-40	2/6/09	sf	73	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
10EN07-40	9/25/09	sf	52	mg/L	
10EN07-40	6/30/10	sf	45	mg/L	
10EN07-40	11/15/10	sf	47	mg/L	
10EN07-40	9/25/08	tds	538	mg/L	
10EN07-40	11/26/08	tds	540	mg/L	
10EN07-40	2/6/09	tds	548	mg/L	
10EN07-40	9/25/09	tds	576	mg/L	
10EN07-40	6/30/10	tds	482	mg/L	
10EN07-40	11/15/10	tds	442	mg/L	
11EN07-105	9/26/08	alk	213	mg/L	
11EN07-105	11/24/08	alk	213	mg/L	
11EN07-105	2/6/09	alk	219	mg/L	
11EN07-105	9/25/09	alk	220	mg/L	
11EN07-105	6/30/10	alk	251	mg/L	
11EN07-105	11/15/10	alk	217	mg/L	
11EN07-105	9/26/08	Ca	82	mg/L	
11EN07-105	11/24/08	Ca	82.84	mg/L	
11EN07-105	2/6/09	Ca	90.03	mg/L	
11EN07-105	9/25/09	Ca	88.08	mg/L	
11EN07-105	6/30/10	Ca	84.6	mg/L	
11EN07-105	11/15/10	Ca	81.75	mg/L	
11EN07-105	9/26/08	cl	7	mg/L	
11EN07-105	11/24/08	cl	7	mg/L	
11EN07-105	2/6/09	cl	7	mg/L	
11EN07-105	9/25/09	cl	9	mg/L	
11EN07-105	6/30/10	cl	10	mg/L	
11EN07-105	11/15/10	cl	11	mg/L	
11EN07-105	9/26/08	cnd	481	uS/cm	
11EN07-105	11/24/08	cnd	505	uS/cm	
11EN07-105	2/6/09	cnd	512	uS/cm	
11EN07-105	9/25/09	cnd	539	uS/cm	
11EN07-105	6/30/10	cnd	509	uS/cm	
11EN07-105	11/15/10	cnd	538	uS/cm	
11EN07-105	9/26/08	hrd	241	mg/L	J
11EN07-105	11/24/08	hrd	242	mg/L	
11EN07-105	2/6/09	hrd	263	mg/L	
11EN07-105	9/25/09	hrd	257	mg/L	
11EN07-105	11/15/10	hrd	242	mg/L	
11EN07-105	9/26/08	Fe	0	mg/L	J
11EN07-105	11/24/08	Fe	0	mg/L	
11EN07-105	2/6/09	Fe	0.18	mg/L	
11EN07-105	9/25/09	Fe	0.04	mg/L	U
11EN07-105	6/30/10	Fe	0.06	mg/L	U
11EN07-105	11/15/10	Fe	0.02	mg/L	J
11EN07-105	9/26/08	Mg	9.01	mg/L	U
11EN07-105	11/24/08	Mg	8.44	mg/L	
11EN07-105	2/6/09	Mg	9.26	mg/L	
11EN07-105	9/25/09	Mg	9.07	mg/L	
11EN07-105	6/30/10	Mg	8.61	mg/L	
11EN07-105	11/15/10	Mg	8.99	mg/L	
11EN07-105	9/26/08	Mn	0	mg/L	
11EN07-105	11/24/08	Mn	0	mg/L	
11EN07-105	2/6/09	Mn	0	mg/L	
11EN07-105	9/25/09	Mn	0.03	mg/L	
11EN07-105	6/30/10	Mn	0.03	mg/L	
11EN07-105	11/15/10	Mn	0	mg/L	J
11EN07-105	9/26/08	nn	9.7	mg/l	
11EN07-105	11/24/08	nn	9.8	mg/l	

Well name	Date	Analyte	Result	Unit	Flag
11EN07-105	2/6/09	nn	9.1	mg/l	
11EN07-105	9/25/09	nn	9.1	mg/l	
11EN07-105	6/30/10	nn	4.7	mg/l	
11EN07-105	11/15/10	nn	10.4	mg/l	
11EN07-105	9/26/08	K	2.24	mg/L	U
11EN07-105	11/24/08	K	2.05	mg/L	
11EN07-105	2/6/09	K	2.23	mg/L	
11EN07-105	9/25/09	K	2.22	mg/L	
11EN07-105	6/30/10	K	1.96	mg/L	U
11EN07-105	11/15/10	K	2.13	mg/L	
11EN07-105	9/26/08	Na	15.5	mg/L	U
11EN07-105	11/24/08	Na	15.14	mg/L	
11EN07-105	2/6/09	Na	15.81	mg/L	
11EN07-105	9/25/09	Na	14.71	mg/L	
11EN07-105	6/30/10	Na	14.76	mg/L	
11EN07-105	11/15/10	Na	14.16	mg/L	
11EN07-105	9/26/08	sf	14	mg/L	
11EN07-105	11/24/08	sf	14	mg/L	
11EN07-105	2/6/09	sf	14	mg/L	
11EN07-105	9/25/09	sf	13	mg/L	
11EN07-105	6/30/10	sf	9	mg/L	
11EN07-105	11/15/10	sf	13	mg/L	
11EN07-105	9/26/08	tds	326	mg/L	J
11EN07-105	11/24/08	tds	274	mg/L	J
11EN07-105	2/6/09	tds	340	mg/L	J
11EN07-105	9/25/09	tds	340	mg/L	
11EN07-105	6/30/10	tds	260	mg/L	
11EN07-105	11/15/10	tds	254	mg/L	
11EN07-150	9/26/08	alk	295	mg/L	
11EN07-150	11/24/08	alk	297	mg/L	
11EN07-150	2/6/09	alk	300	mg/L	
11EN07-150	9/25/09	alk	321	mg/L	
11EN07-150	6/30/10	alk	310	mg/L	
11EN07-150	11/15/10	alk	289	mg/L	
11EN07-150	9/26/08	Ca	82	mg/L	
11EN07-150	11/24/08	Ca	84.91	mg/L	
11EN07-150	2/6/09	Ca	88.33	mg/L	
11EN07-150	9/25/09	Ca	88.51	mg/L	
11EN07-150	6/30/10	Ca	85.67	mg/L	
11EN07-150	11/15/10	Ca	75.78	mg/L	
11EN07-150	9/26/08	cl	7	mg/L	
11EN07-150	11/24/08	cl	8	mg/L	
11EN07-150	2/6/09	cl	7	mg/L	
11EN07-150	9/25/09	cl	7	mg/L	
11EN07-150	6/30/10	cl	8	mg/L	
11EN07-150	11/15/10	cl	6	mg/L	
11EN07-150	9/26/08	cnd	572	uS/cm	
11EN07-150	11/24/08	cnd	630	uS/cm	
11EN07-150	2/6/09	cnd	616	uS/cm	
11EN07-150	9/25/09	cnd	668	uS/cm	
11EN07-150	6/30/10	cnd	600	uS/cm	
11EN07-150	11/15/10	cnd	593	uS/cm	
11EN07-150	9/26/08	hrd	297	mg/L	
11EN07-150	11/24/08	hrd	301	mg/L	
11EN07-150	2/6/09	hrd	314	mg/L	
11EN07-150	9/25/09	hrd	311	mg/L	
11EN07-150	11/15/10	hrd	275	mg/L	
11EN07-150	9/26/08	Fe	0	mg/L	J

Well name	Date	Analyte	Result	Unit	Flag
11EN07-150	11/24/08	Fe	0.01	mg/L	
11EN07-150	2/6/09	Fe	0.05	mg/L	
11EN07-150	9/25/09	Fe	0.07	mg/L	U
11EN07-150	6/30/10	Fe	0.2	mg/L	J
11EN07-150	11/15/10	Fe	0.02	mg/L	J
11EN07-150	9/26/08	Mg	22.3	mg/L	
11EN07-150	11/24/08	Mg	21.54	mg/L	
11EN07-150	2/6/09	Mg	22.97	mg/L	
11EN07-150	9/25/09	Mg	21.93	mg/L	
11EN07-150	6/30/10	Mg	22.37	mg/L	
11EN07-150	11/15/10	Mg	20.62	mg/L	
11EN07-150	9/26/08	Mn	0	mg/L	
11EN07-150	11/24/08	Mn	0	mg/L	
11EN07-150	2/6/09	Mn	0	mg/L	
11EN07-150	9/25/09	Mn	0.13	mg/L	
11EN07-150	6/30/10	Mn	0.04	mg/L	
11EN07-150	11/15/10	Mn	0	mg/L	J
11EN07-150	9/26/08	nn	3.1	mg/l	
11EN07-150	11/24/08	nn	2.2	mg/l	
11EN07-150	2/6/09	nn	2.4	mg/l	
11EN07-150	9/25/09	nn	0	mg/l	
11EN07-150	6/30/10	nn	0.8	mg/l	
11EN07-150	11/15/10	nn	2.8	mg/l	
11EN07-150	9/26/08	K	2.82	mg/L	U
11EN07-150	11/24/08	K	2.5	mg/L	
11EN07-150	2/6/09	K	2.89	mg/L	
11EN07-150	9/25/09	K	2.63	mg/L	
11EN07-150	6/30/10	K	2.5	mg/L	J
11EN07-150	11/15/10	K	2.4	mg/L	
11EN07-150	9/26/08	Na	23.8	mg/L	J
11EN07-150	11/24/08	Na	25.74	mg/L	
11EN07-150	2/6/09	Na	28.35	mg/L	
11EN07-150	9/25/09	Na	35.11	mg/L	
11EN07-150	6/30/10	Na	26.1	mg/L	
11EN07-150	11/15/10	Na	21.55	mg/L	
11EN07-150	9/26/08	sf	26	mg/L	
11EN07-150	11/24/08	sf	35	mg/L	
11EN07-150	2/6/09	sf	29	mg/L	
11EN07-150	9/25/09	sf	12	mg/L	
11EN07-150	6/30/10	sf	25	mg/L	
11EN07-150	11/15/10	sf	19	mg/L	
11EN07-150	9/26/08	tds	374	mg/L	
11EN07-150	11/24/08	tds	336	mg/L	J
11EN07-150	2/6/09	tds	384	mg/L	J
11EN07-150	9/25/09	tds	440	mg/L	
11EN07-150	6/30/10	tds	308	mg/L	
11EN07-150	11/15/10	tds	276	mg/L	
11EN07-35	9/26/08	alk	98	mg/L	
11EN07-35	11/25/08	alk	114	mg/L	
11EN07-35	2/6/09	alk	115	mg/L	
11EN07-35	9/25/09	alk	133	mg/L	
11EN07-35	6/30/10	alk	156	mg/L	
11EN07-35	11/15/10	alk	148	mg/L	
11EN07-35	9/26/08	Ca	38	mg/L	J
11EN07-35	11/25/08	Ca	41.88	mg/L	
11EN07-35	2/6/09	Ca	47.41	mg/L	
11EN07-35	9/25/09	Ca	54.56	mg/L	
11EN07-35	6/30/10	Ca	66.22	mg/L	
11EN07-35	11/15/10	Ca	62.92	mg/L	
11EN07-35	9/26/08	cl	48	mg/L	
11EN07-35	11/25/08	cl	61	mg/L	
11EN07-35	2/6/09	cl	63	mg/L	
11EN07-35	9/25/09	cl	69	mg/L	
11EN07-35	6/30/10	cl	102	mg/L	
11EN07-35	11/15/10	cl	120	mg/L	
11EN07-35	9/26/08	cnd	357	uS/cm	
11EN07-35	11/25/08	cnd	443	uS/cm	
11EN07-35	2/6/09	cnd	438	uS/cm	
11EN07-35	9/25/09	cnd	618	uS/cm	
11EN07-35	6/30/10	cnd	621	uS/cm	
11EN07-35	11/15/10	cnd	690	uS/cm	
11EN07-35	9/26/08	hrd	141	mg/L	J
11EN07-35	11/25/08	hrd	152	mg/L	
11EN07-35	2/6/09	hrd	172	mg/L	
11EN07-35	9/25/09	hrd	199	mg/L	
11EN07-35	11/15/10	hrd	236	mg/L	
11EN07-35	9/26/08	Fe	0.03	mg/L	J
11EN07-35	11/25/08	Fe	0.02	mg/L	
11EN07-35	2/6/09	Fe	0.16	mg/L	
11EN07-35	9/25/09	Fe	0.15	mg/L	J
11EN07-35	6/30/10	Fe	0.03	mg/L	U
11EN07-35	11/15/10	Fe	0.02	mg/L	J
11EN07-35	9/26/08	Mg	11.1	mg/L	J
11EN07-35	11/25/08	Mg	11.47	mg/L	
11EN07-35	2/6/09	Mg	13.32	mg/L	
11EN07-35	9/25/09	Mg	15.36	mg/L	
11EN07-35	6/30/10	Mg	19.83	mg/L	
11EN07-35	11/15/10	Mg	19.06	mg/L	
11EN07-35	9/26/08	Mn	0	mg/L	
11EN07-35	11/25/08	Mn	0	mg/L	
11EN07-35	2/6/09	Mn	0.01	mg/L	
11EN07-35	9/25/09	Mn	0	mg/L	
11EN07-35	6/30/10	Mn	0	mg/L	
11EN07-35	11/15/10	Mn	0	mg/L	J
11EN07-35	9/26/08	nn	1.1	mg/l	
11EN07-35	11/25/08	nn	0.5	mg/l	
11EN07-35	2/6/09	nn	0	mg/l	
11EN07-35	9/25/09	nn	0.6	mg/l	
11EN07-35	6/30/10	nn	0.2	mg/l	
11EN07-35	11/15/10	nn	0.4	mg/l	
11EN07-35	9/26/08	K	5.02	mg/L	U
11EN07-35	11/25/08	K	4.72	mg/L	
11EN07-35	2/6/09	K	5.25	mg/L	
11EN07-35	9/25/09	K	5.81	mg/L	
11EN07-35	6/30/10	K	6.08	mg/L	
11EN07-35	11/15/10	K	5.92	mg/L	
11EN07-35	9/26/08	Na	20.3	mg/L	U
11EN07-35	11/25/08	Na	22.72	mg/L	
11EN07-35	2/6/09	Na	25.23	mg/L	
11EN07-35	9/25/09	Na	38.83	mg/L	
11EN07-35	6/30/10	Na	28.03	mg/L	
11EN07-35	11/15/10	Na	36.03	mg/L	
11EN07-35	9/26/08	sf	10	mg/L	
11EN07-35	11/25/08	sf	11	mg/L	
11EN07-35	2/6/09	sf	11	mg/L	
11EN07-35	9/25/09	sf	11	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
11EN07-35	6/30/10	sf	12	mg/L	
11EN07-35	11/15/10	sf	12	mg/L	
11EN07-35	9/26/08	tds	238	mg/L	J
11EN07-35	11/25/08	tds	228	mg/L	
11EN07-35	2/6/09	tds	310	mg/L	J
11EN07-35	9/25/09	tds	315	mg/L	
11EN07-35	6/30/10	tds	392	mg/L	
11EN07-35	11/15/10	tds	332	mg/L	
11EN07-63	9/26/08	alk	227	mg/L	
11EN07-63	11/24/08	alk	229	mg/L	
11EN07-63	2/6/09	alk	231	mg/L	
11EN07-63	9/25/09	alk	247	mg/L	
11EN07-63	6/30/10	alk	238	mg/L	
11EN07-63	11/15/10	alk	245	mg/L	
11EN07-63	9/26/08	Ca	57	mg/L	J
11EN07-63	11/24/08	Ca	60.24	mg/L	
11EN07-63	2/6/09	Ca	66.55	mg/L	
11EN07-63	9/25/09	Ca	66.1	mg/L	
11EN07-63	6/30/10	Ca	62.12	mg/L	
11EN07-63	11/15/10	Ca	59.44	mg/L	
11EN07-63	9/26/08	cl	2	mg/L	
11EN07-63	11/24/08	cl	2	mg/L	
11EN07-63	2/6/09	cl	1	mg/L	
11EN07-63	9/25/09	cl	0	mg/L	
11EN07-63	6/30/10	cl	1	mg/L	
11EN07-63	11/15/10	cl	1	mg/L	
11EN07-63	9/26/08	cnd	465	uS/cm	
11EN07-63	11/24/08	cnd	484	uS/cm	
11EN07-63	2/6/09	cnd	479	uS/cm	
11EN07-63	9/25/09	cnd	547	uS/cm	
11EN07-63	6/30/10	cnd	482	uS/cm	
11EN07-63	11/15/10	cnd	512	uS/cm	
11EN07-63	9/26/08	hrd	195	mg/L	J
11EN07-63	11/24/08	hrd	201	mg/L	
11EN07-63	2/6/09	hrd	223	mg/L	
11EN07-63	9/25/09	hrd	220	mg/L	
11EN07-63	11/15/10	hrd	199	mg/L	
11EN07-63	9/26/08	Fe	0	mg/L	J
11EN07-63	11/24/08	Fe	0.06	mg/L	
11EN07-63	2/6/09	Fe	0.02	mg/L	
11EN07-63	9/25/09	Fe	0.03	mg/L	U
11EN07-63	6/30/10	Fe	0.06	mg/L	U
11EN07-63	11/15/10	Fe	0.07	mg/L	J
11EN07-63	9/26/08	Mg	12.6	mg/L	J
11EN07-63	11/24/08	Mg	12.19	mg/L	
11EN07-63	2/6/09	Mg	13.63	mg/L	
11EN07-63	9/25/09	Mg	13.44	mg/L	
11EN07-63	6/30/10	Mg	12.61	mg/L	
11EN07-63	11/15/10	Mg	12.53	mg/L	
11EN07-63	9/26/08	Mn	0	mg/L	
11EN07-63	11/24/08	Mn	0	mg/L	
11EN07-63	2/6/09	Mn	0	mg/L	
11EN07-63	9/25/09	Mn	0	mg/L	
11EN07-63	6/30/10	Mn	0	mg/L	
11EN07-63	11/15/10	Mn	0	mg/L	J
11EN07-63	9/26/08	nn	3.7	mg/l	
11EN07-63	11/24/08	nn	4.7	mg/l	
11EN07-63	2/6/09	nn	3.7	mg/l	

Well name	Date	Analyte	Result	Unit	Flag
11EN07-63	9/25/09	nn	3	mg/l	
11EN07-63	6/30/10	nn	2.4	mg/l	
11EN07-63	11/15/10	nn	2.5	mg/l	
11EN07-63	9/26/08	K	1.63	mg/L	U
11EN07-63	11/24/08	K	1.44	mg/L	
11EN07-63	2/6/09	K	1.49	mg/L	
11EN07-63	9/25/09	K	1.71	mg/L	
11EN07-63	6/30/10	K	1.47	mg/L	U
11EN07-63	11/15/10	K	1.39	mg/L	
11EN07-63	9/26/08	Na	38.5	mg/L	J
11EN07-63	11/24/08	Na	33.81	mg/L	
11EN07-63	2/6/09	Na	33.27	mg/L	
11EN07-63	9/25/09	Na	35.13	mg/L	
11EN07-63	6/30/10	Na	34.92	mg/L	
11EN07-63	11/15/10	Na	29.72	mg/L	
11EN07-63	9/26/08	sf	25	mg/L	
11EN07-63	11/24/08	sf	24	mg/L	
11EN07-63	2/6/09	sf	24	mg/L	
11EN07-63	9/25/09	sf	23	mg/L	
11EN07-63	6/30/10	sf	19	mg/L	
11EN07-63	11/15/10	sf	18	mg/L	
11EN07-63	9/26/08	tds	314	mg/L	J
11EN07-63	11/24/08	tds	268	mg/L	J
11EN07-63	2/6/09	tds	320	mg/L	J
11EN07-63	9/25/09	tds	332	mg/L	
11EN07-63	6/30/10	tds	258	mg/L	
11EN07-63	11/15/10	tds	236	mg/L	
12EN07-140	9/25/08	alk	266	mg/L	
12EN07-140	11/24/08	alk	271	mg/L	
12EN07-140	2/5/09	alk	266	mg/L	
12EN07-140	9/25/09	alk	277	mg/L	
12EN07-140	6/30/10	alk	306	mg/L	
12EN07-140	11/15/10	alk	311	mg/L	
12EN07-140	9/25/08	Ca	89	mg/L	
12EN07-140	11/24/08	Ca	85.13	mg/L	
12EN07-140	2/5/09	Ca	88.91	mg/L	
12EN07-140	9/25/09	Ca	86.02	mg/L	
12EN07-140	6/30/10	Ca	87.51	mg/L	
12EN07-140	11/15/10	Ca	83.7	mg/L	
12EN07-140	9/25/08	cl	4	mg/L	
12EN07-140	11/24/08	cl	4	mg/L	
12EN07-140	2/5/09	cl	4	mg/L	
12EN07-140	9/25/09	cl	4	mg/L	
12EN07-140	6/30/10	cl	4	mg/L	
12EN07-140	11/15/10	cl	4	mg/L	
12EN07-140	9/25/08	cnd	567	uS/cm	
12EN07-140	11/24/08	cnd	560	uS/cm	
12EN07-140	2/5/09	cnd	579	uS/cm	
12EN07-140	9/25/09	cnd	589	uS/cm	
12EN07-140	6/30/10	cnd	556	uS/cm	
12EN07-140	11/15/10	cnd	571	uS/cm	
12EN07-140	9/25/08	hrd	275	mg/L	
12EN07-140	11/24/08	hrd	264	mg/L	
12EN07-140	2/5/09	hrd	276	mg/L	
12EN07-140	9/25/09	hrd	270	mg/L	
12EN07-140	11/15/10	hrd	263	mg/L	
12EN07-140	9/25/08	Fe	0.07	mg/L	J
12EN07-140	11/24/08	Fe	0	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
12EN07-140	2/5/09	Fe	0	mg/L	
12EN07-140	9/25/09	Fe	0.6	mg/L	
12EN07-140	6/30/10	Fe	1.62	mg/L	
12EN07-140	11/15/10	Fe	0.79	mg/L	J
12EN07-140	9/25/08	Mg	13.1	mg/L	J
12EN07-140	11/24/08	Mg	12.55	mg/L	
12EN07-140	2/5/09	Mg	13.15	mg/L	
12EN07-140	9/25/09	Mg	13.28	mg/L	
12EN07-140	6/30/10	Mg	13.44	mg/L	
12EN07-140	11/15/10	Mg	12.88	mg/L	
12EN07-140	9/25/08	Mn	0	mg/L	
12EN07-140	11/24/08	Mn	0	mg/L	
12EN07-140	2/5/09	Mn	0	mg/L	
12EN07-140	9/25/09	Mn	0.1	mg/L	
12EN07-140	6/30/10	Mn	0.22	mg/L	
12EN07-140	11/15/10	Mn	0.2	mg/L	J
12EN07-140	9/25/08	nn	8.9	mg/l	
12EN07-140	11/24/08	nn	8.3	mg/l	
12EN07-140	2/5/09	nn	8	mg/l	
12EN07-140	9/25/09	nn	7.4	mg/l	
12EN07-140	6/30/10	nn	0.4	mg/l	
12EN07-140	11/15/10	nn	0	mg/l	
12EN07-140	9/25/08	K	3.38	mg/L	U
12EN07-140	11/24/08	K	3.49	mg/L	
12EN07-140	2/5/09	K	3.67	mg/L	
12EN07-140	9/25/09	K	3.7	mg/L	
12EN07-140	6/30/10	K	3.71	mg/L	J
12EN07-140	11/15/10	K	3.14	mg/L	
12EN07-140	9/25/08	Na	22.1	mg/L	J
12EN07-140	11/24/08	Na	22.67	mg/L	
12EN07-140	2/5/09	Na	22.49	mg/L	
12EN07-140	9/25/09	Na	23.69	mg/L	
12EN07-140	6/30/10	Na	23.13	mg/L	
12EN07-140	11/15/10	Na	20	mg/L	
12EN07-140	9/25/08	sf	11	mg/L	
12EN07-140	11/24/08	sf	11	mg/L	
12EN07-140	2/5/09	sf	11	mg/L	
12EN07-140	9/25/09	sf	11	mg/L	
12EN07-140	6/30/10	sf	2	mg/L	
12EN07-140	11/15/10	sf	2	mg/L	
12EN07-140	9/25/08	tds	352	mg/L	
12EN07-140	11/24/08	tds	328	mg/L	J
12EN07-140	2/5/09	tds	352	mg/L	J
12EN07-140	9/25/09	tds	342	mg/L	
12EN07-140	6/30/10	tds	294	mg/L	
12EN07-140	11/15/10	tds	254	mg/L	
12EN07-190	9/25/08	alk	269	mg/L	
12EN07-190	11/24/08	alk	279	mg/L	
12EN07-190	2/5/09	alk	272	mg/L	
12EN07-190	9/25/09	alk	365	mg/L	
12EN07-190	6/30/10	alk	456	mg/L	
12EN07-190	11/15/10	alk	295	mg/L	
12EN07-190	9/25/08	Ca	77	mg/L	
12EN07-190	11/24/08	Ca	76.56	mg/L	
12EN07-190	2/5/09	Ca	82.11	mg/L	
12EN07-190	9/25/09	Ca	83.5	mg/L	
12EN07-190	6/30/10	Ca	86.91	mg/L	
12EN07-190	11/15/10	Ca	75.65	mg/L	
12EN07-190	9/25/08	cl	8	mg/L	
12EN07-190	11/24/08	cl	8	mg/L	
12EN07-190	2/5/09	cl	9	mg/L	
12EN07-190	9/25/09	cl	11	mg/L	
12EN07-190	6/30/10	cl	10	mg/L	
12EN07-190	11/15/10	cl	14	mg/L	
12EN07-190	9/25/08	cnd	575	uS/cm	
12EN07-190	11/24/08	cnd	587	uS/cm	
12EN07-190	2/5/09	cnd	598	uS/cm	
12EN07-190	9/25/09	cnd	642	uS/cm	
12EN07-190	6/30/10	cnd	654	uS/cm	
12EN07-190	11/15/10	cnd	610	uS/cm	
12EN07-190	9/25/08	hrd	253	mg/L	J
12EN07-190	11/24/08	hrd	252	mg/L	
12EN07-190	2/5/09	hrd	271	mg/L	
12EN07-190	9/25/09	hrd	281	mg/L	
12EN07-190	11/15/10	hrd	259	mg/L	
12EN07-190	9/25/08	Fe	0.08	mg/L	J
12EN07-190	11/24/08	Fe	0	mg/L	
12EN07-190	2/5/09	Fe	0	mg/L	
12EN07-190	9/25/09	Fe	1.77	mg/L	
12EN07-190	6/30/10	Fe	9.75	mg/L	
12EN07-190	11/15/10	Fe	0.73	mg/L	J
12EN07-190	9/25/08	Mg	14.9	mg/L	J
12EN07-190	11/24/08	Mg	14.86	mg/L	
12EN07-190	2/5/09	Mg	16.13	mg/L	
12EN07-190	9/25/09	Mg	17.23	mg/L	
12EN07-190	6/30/10	Mg	16.95	mg/L	
12EN07-190	11/15/10	Mg	16.7	mg/L	
12EN07-190	9/25/08	Mn	0	mg/L	
12EN07-190	11/24/08	Mn	0.01	mg/L	
12EN07-190	2/5/09	Mn	0	mg/L	
12EN07-190	9/25/09	Mn	1.41	mg/L	
12EN07-190	6/30/10	Mn	2.88	mg/L	
12EN07-190	11/15/10	Mn	0.29	mg/L	J
12EN07-190	9/25/08	nn	4.4	mg/l	
12EN07-190	11/24/08	nn	4.2	mg/l	
12EN07-190	2/5/09	nn	4.2	mg/l	
12EN07-190	9/25/09	nn	2.7	mg/l	
12EN07-190	6/30/10	nn	0	mg/l	
12EN07-190	11/15/10	nn	2.9	mg/l	
12EN07-190	9/25/08	K	2.89	mg/L	U
12EN07-190	11/24/08	K	3.04	mg/L	
12EN07-190	2/5/09	K	3.25	mg/L	
12EN07-190	9/25/09	K	3.53	mg/L	
12EN07-190	6/30/10	K	3.14	mg/L	J
12EN07-190	11/15/10	K	3.06	mg/L	
12EN07-190	9/25/08	Na	29.2	mg/L	J
12EN07-190	11/24/08	Na	30.91	mg/L	
12EN07-190	2/5/09	Na	31.27	mg/L	
12EN07-190	9/25/09	Na	34.1	mg/L	
12EN07-190	6/30/10	Na	34.41	mg/L	
12EN07-190	11/15/10	Na	28.71	mg/L	
12EN07-190	9/25/08	sf	22	mg/L	
12EN07-190	11/24/08	sf	21	mg/L	
12EN07-190	2/5/09	sf	23	mg/L	
12EN07-190	9/25/09	sf	23	mg/L	
12EN07-190	6/30/10	sf	1	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
12EN07-190	11/15/10	sf	27	mg/L	
12EN07-190	9/25/08	tds	368	mg/L	
12EN07-190	11/24/08	tds	322	mg/L	J
12EN07-190	2/5/09	tds	352	mg/L	J
12EN07-190	9/25/09	tds	580	mg/L	
12EN07-190	6/30/10	tds	110	mg/L	
12EN07-190	11/15/10	tds	204	mg/L	
12EN07-253	9/25/08	alk	276	mg/L	
12EN07-253	11/25/08	alk	286	mg/L	
12EN07-253	2/6/09	alk	358	mg/L	
12EN07-253	9/25/09	alk	284	mg/L	
12EN07-253	6/30/10	alk	226	mg/L	
12EN07-253	11/15/10	alk	358	mg/L	
12EN07-253	9/25/08	Ca	215	mg/L	
12EN07-253	11/25/08	Ca	112.18	mg/L	
12EN07-253	2/6/09	Ca	143.56	mg/L	
12EN07-253	9/25/09	Ca	295.8	mg/L	
12EN07-253	6/30/10	Ca	298.76	mg/L	
12EN07-253	11/15/10	Ca	287.17	mg/L	
12EN07-253	9/25/08	cl	65	mg/L	
12EN07-253	11/25/08	cl	148	mg/L	
12EN07-253	2/6/09	cl	168	mg/L	
12EN07-253	9/25/09	cl	231	mg/L	
12EN07-253	6/30/10	cl	614	mg/L	
12EN07-253	11/15/10	cl	404	mg/L	
12EN07-253	9/25/08	cnd	851	uS/cm	
12EN07-253	11/25/08	cnd	1272	uS/cm	
12EN07-253	2/6/09	cnd	1343	uS/cm	
12EN07-253	9/25/09	cnd	1820	uS/cm	
12EN07-253	6/30/10	cnd	3240	uS/cm	
12EN07-253	11/15/10	cnd	2457	uS/cm	
12EN07-253	9/25/08	hrd	828	mg/L	
12EN07-253	11/25/08	hrd	404	mg/L	
12EN07-253	2/6/09	hrd	522	mg/L	
12EN07-253	9/25/09	hrd	1146	mg/L	
12EN07-253	11/15/10	hrd	1108	mg/L	
12EN07-253	9/25/08	Fe	0.12	mg/L	J
12EN07-253	11/25/08	Fe	0.02	mg/L	
12EN07-253	2/6/09	Fe	0.06	mg/L	
12EN07-253	9/25/09	Fe	0.04	mg/L	U
12EN07-253	6/30/10	Fe	0.11	mg/L	U
12EN07-253	11/15/10	Fe	0.07	mg/L	J
12EN07-253	9/25/08	Mg	70.9	mg/L	
12EN07-253	11/25/08	Mg	30.29	mg/L	
12EN07-253	2/6/09	Mg	39.52	mg/L	
12EN07-253	9/25/09	Mg	98.78	mg/L	
12EN07-253	6/30/10	Mg	97.48	mg/L	
12EN07-253	11/15/10	Mg	95.06	mg/L	
12EN07-253	9/25/08	Mn	0.91	mg/L	
12EN07-253	11/25/08	Mn	0.3	mg/L	
12EN07-253	2/6/09	Mn	0.4	mg/L	
12EN07-253	9/25/09	Mn	1.41	mg/L	
12EN07-253	6/30/10	Mn	1.46	mg/L	
12EN07-253	11/15/10	Mn	1.36	mg/L	J
12EN07-253	9/25/08	nn	0	mg/l	
12EN07-253	11/25/08	nn	0	mg/l	
12EN07-253	2/6/09	nn	0	mg/l	
12EN07-253	9/25/09	nn	0	mg/l	

Well name	Date	Analyte	Result	Unit	Flag
12EN07-253	6/30/10	nn	0	mg/l	
12EN07-253	11/15/10	nn	0	mg/l	
12EN07-253	9/25/08	K	8.34	mg/L	J
12EN07-253	11/25/08	K	4.15	mg/L	
12EN07-253	2/6/09	K	4.85	mg/L	
12EN07-253	9/25/09	K	10.16	mg/L	
12EN07-253	6/30/10	K	9.63	mg/L	
12EN07-253	11/15/10	K	8.76	mg/L	
12EN07-253	9/25/08	Na	305	mg/L	
12EN07-253	11/25/08	Na	126.3	mg/L	
12EN07-253	2/6/09	Na	150.13	mg/L	
12EN07-253	9/25/09	Na	482.63	mg/L	
12EN07-253	6/30/10	Na	446.24	mg/L	
12EN07-253	11/15/10	Na	393.21	mg/L	
12EN07-253	9/25/08	sf	116	mg/L	
12EN07-253	11/25/08	sf	172	mg/L	
12EN07-253	2/6/09	sf	126	mg/L	
12EN07-253	9/25/09	sf	309	mg/L	
12EN07-253	6/30/10	sf	830	mg/L	
12EN07-253	11/15/10	sf	784	mg/L	
12EN07-253	9/25/08	tds	564	mg/L	
12EN07-253	11/25/08	tds	826	mg/L	
12EN07-253	2/6/09	tds	900	mg/L	
12EN07-253	9/25/09	tds	1272	mg/L	
12EN07-253	6/30/10	tds	2344	mg/L	
12EN07-253	11/15/10	tds	1598	mg/L	
12EN07-86	9/25/08	alk	235	mg/L	
12EN07-86	11/24/08	alk	232	mg/L	
12EN07-86	2/5/09	alk	240	mg/L	
12EN07-86	9/25/09	alk	228	mg/L	
12EN07-86	9/25/08	Ca	77	mg/L	
12EN07-86	11/24/08	Ca	77.72	mg/L	
12EN07-86	2/5/09	Ca	81.48	mg/L	
12EN07-86	9/25/09	Ca	83.89	mg/L	
12EN07-86	9/25/08	cl	3	mg/L	
12EN07-86	11/24/08	cl	3	mg/L	
12EN07-86	2/5/09	cl	2	mg/L	
12EN07-86	9/25/09	cl	2	mg/L	
12EN07-86	9/25/08	cnd	518	uS/cm	
12EN07-86	11/24/08	cnd	509	uS/cm	
12EN07-86	2/5/09	cnd	525	uS/cm	
12EN07-86	9/25/09	cnd	539	uS/cm	
12EN07-86	9/25/08	hrd	247	mg/L	J
12EN07-86	11/24/08	hrd	250	mg/L	
12EN07-86	2/5/09	hrd	261	mg/L	
12EN07-86	9/25/09	hrd	266	mg/L	
12EN07-86	9/25/08	Fe	0.08	mg/L	J
12EN07-86	11/24/08	Fe	0	mg/L	
12EN07-86	2/5/09	Fe	0.02	mg/L	
12EN07-86	9/25/09	Fe	0.01	mg/L	U
12EN07-86	9/25/08	Mg	13.4	mg/L	J
12EN07-86	11/24/08	Mg	13.48	mg/L	
12EN07-86	2/5/09	Mg	14.05	mg/L	
12EN07-86	9/25/09	Mg	13.58	mg/L	
12EN07-86	9/25/08	Mn	0	mg/L	
12EN07-86	11/24/08	Mn	0	mg/L	
12EN07-86	2/5/09	Mn	0	mg/L	
12EN07-86	9/25/09	Mn	0	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
12EN07-86	9/25/08	nn	10.3	mg/l	
12EN07-86	11/24/08	nn	9.1	mg/l	
12EN07-86	2/5/09	nn	8.9	mg/l	
12EN07-86	9/25/09	nn	8.9	mg/l	
12EN07-86	9/25/08	K	1.44	mg/L	U
12EN07-86	11/24/08	K	1.62	mg/L	
12EN07-86	2/5/09	K	1.78	mg/L	
12EN07-86	9/25/09	K	1.88	mg/L	
12EN07-86	9/25/08	Na	18.3	mg/L	U
12EN07-86	11/24/08	Na	18.23	mg/L	
12EN07-86	2/5/09	Na	19.04	mg/L	
12EN07-86	9/25/09	Na	19.72	mg/L	
12EN07-86	9/25/08	sf	16	mg/L	
12EN07-86	11/24/08	sf	15	mg/L	
12EN07-86	2/5/09	sf	14	mg/L	
12EN07-86	9/25/09	sf	15	mg/L	
12EN07-86	9/25/08	tds	332	mg/L	J
12EN07-86	11/24/08	tds	272	mg/L	
12EN07-86	2/5/09	tds	334	mg/L	J
12EN07-86	9/25/09	tds	338	mg/L	
HKMW3-135	3/16/09	alk	302	mg/L	
HKMW3-135	5/18/09	alk	274	mg/L	
HKMW3-135	9/25/09	alk	301	mg/L	
HKMW3-135	11/15/10	alk	301	mg/L	
HKMW3-135	3/16/09	Ca	97.02	mg/L	
HKMW3-135	5/18/09	Ca	78.23	mg/L	
HKMW3-135	9/25/09	Ca	97.3	mg/L	
HKMW3-135	11/15/10	Ca	96.67	mg/L	
HKMW3-135	3/16/09	cl	23	mg/L	
HKMW3-135	5/18/09	cl	5	mg/L	
HKMW3-135	9/25/09	cl	23	mg/L	
HKMW3-135	11/15/10	cl	19	mg/L	
HKMW3-135	3/16/09	cnd	808	uS/cm	
HKMW3-135	5/18/09	cnd	571	uS/cm	
HKMW3-135	9/25/09	cnd	799	uS/cm	
HKMW3-135	11/15/10	cnd	732	uS/cm	
HKMW3-135	3/16/09	hrd	316	mg/L	
HKMW3-135	5/18/09	hrd	263	mg/L	
HKMW3-135	9/25/09	hrd	318	mg/L	
HKMW3-135	11/15/10	hrd	320	mg/L	
HKMW3-135	3/16/09	Fe	0.04	mg/L	
HKMW3-135	5/18/09	Fe	0.19	mg/L	
HKMW3-135	9/25/09	Fe	0.14	mg/L	J
HKMW3-135	11/15/10	Fe	0.63	mg/L	J
HKMW3-135	3/16/09	Mg	17.75	mg/L	
HKMW3-135	5/18/09	Mg	16.55	mg/L	
HKMW3-135	9/25/09	Mg	18.19	mg/L	
HKMW3-135	11/15/10	Mg	18.95	mg/L	
HKMW3-135	3/16/09	Mn	0.17	mg/L	
HKMW3-135	5/18/09	Mn	4.87	mg/L	
HKMW3-135	9/25/09	Mn	0.32	mg/L	
HKMW3-135	11/15/10	Mn	0.54	mg/L	J
HKMW3-135	3/16/09	nn	0	mg/l	
HKMW3-135	5/18/09	nn	0.2	mg/l	
HKMW3-135	9/25/09	nn	0	mg/l	
HKMW3-135	6/30/10	nn	0	mg/l	
HKMW3-135	11/15/10	nn	0	mg/l	
HKMW3-135	3/16/09	K	2.79	mg/L	
HKMW3-135	5/18/09	K	7.79	mg/L	
HKMW3-135	9/25/09	K	3.49	mg/L	
HKMW3-135	11/15/10	K	3.54	mg/L	
HKMW3-135	3/16/09	Na	74.86	mg/L	
HKMW3-135	5/18/09	Na	28.61	mg/L	
HKMW3-135	9/25/09	Na	50.18	mg/L	
HKMW3-135	11/15/10	Na	39.27	mg/L	
HKMW3-135	3/16/09	sf	105	mg/L	
HKMW3-135	5/18/09	sf	44	mg/L	
HKMW3-135	9/25/09	sf	89	mg/L	
HKMW3-135	11/15/10	sf	75	mg/L	
HKMW3-135	3/16/09	tds	518	mg/L	J
HKMW3-135	5/18/09	tds	380	mg/L	
HKMW3-135	9/25/09	tds	518	mg/L	
HKMW3-135	11/15/10	tds	368	mg/L	
HKMW3-235	3/16/09	alk	292	mg/L	
HKMW3-235	5/18/09	alk	290	mg/L	
HKMW3-235	9/25/09	alk	307	mg/L	
HKMW3-235	11/15/10	alk	291	mg/L	
HKMW3-235	3/16/09	Ca	96.42	mg/L	
HKMW3-235	5/18/09	Ca	95.54	mg/L	
HKMW3-235	9/25/09	Ca	98.76	mg/L	
HKMW3-235	11/15/10	Ca	97.2	mg/L	
HKMW3-235	3/16/09	cl	118	mg/L	
HKMW3-235	5/18/09	cl	121	mg/L	
HKMW3-235	9/25/09	cl	22	mg/L	
HKMW3-235	11/15/10	cl	120	mg/L	
HKMW3-235	3/16/09	cnd	1044	uS/cm	
HKMW3-235	5/18/09	cnd	1011	uS/cm	
HKMW3-235	9/25/09	cnd	735	uS/cm	
HKMW3-235	11/15/10	cnd	1065	uS/cm	
HKMW3-235	3/16/09	hrd	336	mg/L	
HKMW3-235	5/18/09	hrd	339	mg/L	
HKMW3-235	9/25/09	hrd	326	mg/L	
HKMW3-235	11/15/10	hrd	348	mg/L	
HKMW3-235	3/16/09	Fe	0.12	mg/L	
HKMW3-235	5/18/09	Fe	0.35	mg/L	
HKMW3-235	9/25/09	Fe	0.25	mg/L	
HKMW3-235	11/15/10	Fe	0.15	mg/L	J
HKMW3-235	3/16/09	Mg	23.48	mg/L	
HKMW3-235	5/18/09	Mg	24.03	mg/L	
HKMW3-235	9/25/09	Mg	19.19	mg/L	
HKMW3-235	11/15/10	Mg	25.67	mg/L	
HKMW3-235	3/16/09	Mn	0.96	mg/L	
HKMW3-235	5/18/09	Mn	0.9	mg/L	
HKMW3-235	9/25/09	Mn	0.62	mg/L	
HKMW3-235	11/15/10	Mn	0.87	mg/L	J
HKMW3-235	3/16/09	nn	0	mg/l	
HKMW3-235	5/18/09	nn	0	mg/l	
HKMW3-235	9/25/09	nn	0	mg/l	
HKMW3-235	6/30/10	nn	0.3	mg/l	
HKMW3-235	11/15/10	nn	0	mg/l	
HKMW3-235	3/16/09	K	5.76	mg/L	
HKMW3-235	5/18/09	K	6.21	mg/L	
HKMW3-235	9/25/09	K	3.85	mg/L	
HKMW3-235	11/15/10	K	5.71	mg/L	
HKMW3-235	3/16/09	Na	94.97	mg/L	
HKMW3-235	5/18/09	Na	96.67	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
HKMW3-235	9/25/09	Na	34.33	mg/L	
HKMW3-235	11/15/10	Na	87.78	mg/L	
HKMW3-235	3/16/09	sf	88	mg/L	
HKMW3-235	5/18/09	sf	88	mg/L	
HKMW3-235	9/25/09	sf	56	mg/L	
HKMW3-235	11/15/10	sf	86	mg/L	
HKMW3-235	3/16/09	tds	618	mg/L	
HKMW3-235	5/18/09	tds	632	mg/L	
HKMW3-235	9/25/09	tds	458	mg/L	
HKMW3-235	11/15/10	tds	544	mg/L	
HKMW3-50	3/16/09	alk	271	mg/L	
HKMW3-50	5/18/09	alk	299	mg/L	
HKMW3-50	9/25/09	alk	273	mg/L	
HKMW3-50	6/30/10	alk	277	mg/L	
HKMW3-50	11/15/10	alk	280	mg/L	
HKMW3-50	3/16/09	Ca	81	mg/L	
HKMW3-50	5/18/09	Ca	94.51	mg/L	
HKMW3-50	9/25/09	Ca	79.52	mg/L	
HKMW3-50	6/30/10	Ca	83.06	mg/L	
HKMW3-50	11/15/10	Ca	77.89	mg/L	
HKMW3-50	3/16/09	cl	5	mg/L	
HKMW3-50	5/18/09	cl	25	mg/L	
HKMW3-50	9/25/09	cl	5	mg/L	
HKMW3-50	6/30/10	cl	5	mg/L	
HKMW3-50	11/15/10	cl	4	mg/L	
HKMW3-50	3/16/09	cnd	592	uS/cm	
HKMW3-50	5/18/09	cnd	766	uS/cm	
HKMW3-50	9/25/09	cnd	614	uS/cm	
HKMW3-50	6/30/10	cnd	569	uS/cm	
HKMW3-50	11/15/10	cnd	620	uS/cm	
HKMW3-50	3/16/09	hrd	270	mg/L	
HKMW3-50	5/18/09	hrd	311	mg/L	
HKMW3-50	9/25/09	hrd	266	mg/L	
HKMW3-50	11/15/10	hrd	264	mg/L	
HKMW3-50	3/16/09	Fe	0.23	mg/L	
HKMW3-50	5/18/09	Fe	0.02	mg/L	
HKMW3-50	9/25/09	Fe	0.26	mg/L	
HKMW3-50	6/30/10	Fe	0.39	mg/L	
HKMW3-50	11/15/10	Fe	0.44	mg/L	J
HKMW3-50	3/16/09	Mg	16.4	mg/L	
HKMW3-50	5/18/09	Mg	17.85	mg/L	
HKMW3-50	9/25/09	Mg	16.34	mg/L	
HKMW3-50	6/30/10	Mg	16.92	mg/L	
HKMW3-50	11/15/10	Mg	16.8	mg/L	
HKMW3-50	3/16/09	Mn	5.38	mg/L	
HKMW3-50	5/18/09	Mn	0.12	mg/L	
HKMW3-50	9/25/09	Mn	4.39	mg/L	
HKMW3-50	6/30/10	Mn	4.35	mg/L	
HKMW3-50	11/15/10	Mn	4.27	mg/L	J
HKMW3-50	3/16/09	nn	0	mg/l	
HKMW3-50	5/18/09	nn	0.3	mg/l	
HKMW3-50	9/25/09	nn	0	mg/l	
HKMW3-50	6/30/10	nn	0	mg/l	
HKMW3-50	11/15/10	nn	0	mg/l	
HKMW3-50	3/16/09	K	7.29	mg/L	
HKMW3-50	5/18/09	K	3.47	mg/L	
HKMW3-50	9/25/09	K	7.04	mg/L	
HKMW3-50	6/30/10	K	5.61	mg/L	
HKMW3-50	11/15/10	K	5.49	mg/L	
HKMW3-50	3/16/09	Na	25.9	mg/L	
HKMW3-50	5/18/09	Na	69.4	mg/L	
HKMW3-50	9/25/09	Na	25.04	mg/L	
HKMW3-50	6/30/10	Na	22.84	mg/L	
HKMW3-50	11/15/10	Na	21.09	mg/L	
HKMW3-50	3/16/09	sf	45	mg/L	
HKMW3-50	5/18/09	sf	101	mg/L	
HKMW3-50	9/25/09	sf	43	mg/L	
HKMW3-50	6/30/10	sf	42	mg/L	
HKMW3-50	11/15/10	sf	39	mg/L	
HKMW3-50	3/16/09	tds	354	mg/L	J
HKMW3-50	5/18/09	tds	506	mg/L	
HKMW3-50	9/25/09	tds	352	mg/L	
HKMW3-50	6/30/10	tds	356	mg/L	
HKMW3-50	11/15/10	tds	282	mg/L	
MMW-125	3/17/09	alk	241	mg/L	
MMW-125	5/19/09	alk	271	mg/L	
MMW-125	9/25/09	alk	301	mg/L	
MMW-125	11/15/10	alk	279	mg/L	
MMW-125	3/17/09	Ca	45.38	mg/L	
MMW-125	5/19/09	Ca	47.57	mg/L	
MMW-125	9/25/09	Ca	65.08	mg/L	
MMW-125	11/15/10	Ca	86.16	mg/L	
MMW-125	3/17/09	cl	14	mg/L	
MMW-125	5/19/09	cl	9	mg/L	
MMW-125	9/25/09	cl	8	mg/L	
MMW-125	11/15/10	cl	6	mg/L	
MMW-125	3/17/09	cnd	730	uS/cm	
MMW-125	5/19/09	cnd	702	uS/cm	
MMW-125	9/25/09	cnd	748	uS/cm	
MMW-125	11/15/10	cnd	1041	uS/cm	
MMW-125	3/17/09	hrd	165	mg/L	
MMW-125	5/19/09	hrd	179	mg/L	
MMW-125	9/25/09	hrd	240	mg/L	
MMW-125	11/15/10	hrd	326	mg/L	
MMW-125	3/17/09	Fe	0.17	mg/L	
MMW-125	5/19/09	Fe	0.03	mg/L	
MMW-125	9/25/09	Fe	0.69	mg/L	
MMW-125	11/15/10	Fe	0.04	mg/L	J
MMW-125	3/17/09	Mg	12.93	mg/L	
MMW-125	5/19/09	Mg	14.3	mg/L	
MMW-125	9/25/09	Mg	18.78	mg/L	
MMW-125	11/15/10	Mg	27.01	mg/L	
MMW-125	3/17/09	Mn	0.64	mg/L	
MMW-125	5/19/09	Mn	0.54	mg/L	
MMW-125	9/25/09	Mn	0.51	mg/L	
MMW-125	11/15/10	Mn	0.36	mg/L	J
MMW-125	3/17/09	nn	0.2	mg/l	
MMW-125	5/19/09	nn	0	mg/l	
MMW-125	9/25/09	nn	0	mg/l	
MMW-125	11/15/10	nn	0	mg/l	
MMW-125	3/17/09	K	6.15	mg/L	
MMW-125	5/19/09	K	6.75	mg/L	
MMW-125	9/25/09	K	7.19	mg/L	
MMW-125	11/15/10	K	5.84	mg/L	
MMW-125	3/17/09	Na	106.67	mg/L	
MMW-125	5/19/09	Na	102.47	mg/L	

Well name	Date	Analyte	Result	Unit	Flag
MMW-125	9/25/09	Na	67.03	mg/L	
MMW-125	11/15/10	Na	106.62	mg/L	
MMW-125	3/17/09	sf	132	mg/L	
MMW-125	5/19/09	sf	106	mg/L	
MMW-125	9/25/09	sf	92	mg/L	
MMW-125	11/15/10	sf	290	mg/L	
MMW-125	3/17/09	tds	548	mg/L	
MMW-125	5/19/09	tds	496	mg/L	
MMW-125	9/25/09	tds	492	mg/L	
MMW-125	11/15/10	tds	640	mg/L	
MMW-180	3/16/09	alk	316	mg/L	
MMW-180	5/19/09	alk	310	mg/L	
MMW-180	9/25/09	alk	315	mg/L	
MMW-180	11/15/10	alk	275	mg/L	
MMW-180	3/16/09	Ca	97.01	mg/L	
MMW-180	5/19/09	Ca	91.31	mg/L	
MMW-180	9/25/09	Ca	100.17	mg/L	
MMW-180	11/15/10	Ca	82.95	mg/L	
MMW-180	3/16/09	cl	6	mg/L	
MMW-180	5/19/09	cl	6	mg/L	
MMW-180	9/25/09	cl	6	mg/L	
MMW-180	11/15/10	cl	7	mg/L	
MMW-180	3/16/09	cnd	680	uS/cm	
MMW-180	5/19/09	cnd	649	uS/cm	
MMW-180	9/25/09	cnd	703	uS/cm	
MMW-180	11/15/10	cnd	571	uS/cm	
MMW-180	3/16/09	hrd	326	mg/L	
MMW-180	5/19/09	hrd	312	mg/L	
MMW-180	9/25/09	hrd	335	mg/L	
MMW-180	11/15/10	hrd	276	mg/L	
MMW-180	3/16/09	Fe	0.04	mg/L	
MMW-180	5/19/09	Fe	0.04	mg/L	
MMW-180	9/25/09	Fe	0.09	mg/L	U
MMW-180	11/15/10	Fe	0.02	mg/L	J
MMW-180	3/16/09	Mg	20.26	mg/L	
MMW-180	5/19/09	Mg	20.48	mg/L	
MMW-180	9/25/09	Mg	20.72	mg/L	
MMW-180	11/15/10	Mg	16.78	mg/L	
MMW-180	3/16/09	Mn	0.33	mg/L	
MMW-180	5/19/09	Mn	0.14	mg/L	
MMW-180	9/25/09	Mn	0.27	mg/L	
MMW-180	11/15/10	Mn	0.01	mg/L	J
MMW-180	3/16/09	nn	0	mg/l	
MMW-180	5/19/09	nn	0.2	mg/l	
MMW-180	9/25/09	nn	0	mg/l	
MMW-180	11/15/10	nn	0	mg/l	
MMW-180	3/16/09	K	7.07	mg/L	
MMW-180	5/19/09	K	6.82	mg/L	
MMW-180	9/25/09	K	5.26	mg/L	
MMW-180	11/15/10	K	4.26	mg/L	
MMW-180	3/16/09	Na	27.64	mg/L	
MMW-180	5/19/09	Na	28.48	mg/L	
MMW-180	9/25/09	Na	20.93	mg/L	
MMW-180	11/15/10	Na	18.01	mg/L	
MMW-180	3/16/09	sf	60	mg/L	
MMW-180	5/19/09	sf	57	mg/L	
MMW-180	9/25/09	sf	49	mg/L	
MMW-180	11/15/10	sf	31	mg/L	
MMW-180	3/16/09	tds	422	mg/L	J
MMW-180	5/19/09	tds	430	mg/L	
MMW-180	9/25/09	tds	404	mg/L	
MMW-180	11/15/10	tds	266	mg/L	
MMW-260	3/16/09	alk	340	mg/L	
MMW-260	5/19/09	alk	310	mg/L	
MMW-260	9/25/09	alk	305	mg/L	
MMW-260	11/15/10	alk	297	mg/L	
MMW-260	3/16/09	Ca	121.93	mg/L	
MMW-260	5/19/09	Ca	114.83	mg/L	
MMW-260	9/25/09	Ca	118.38	mg/L	
MMW-260	11/15/10	Ca	112.25	mg/L	
MMW-260	3/16/09	cl	60	mg/L	
MMW-260	5/19/09	cl	61	mg/L	
MMW-260	9/25/09	cl	61	mg/L	
MMW-260	11/15/10	cl	121	mg/L	
MMW-260	3/16/09	cnd	861	uS/cm	
MMW-260	5/19/09	cnd	839	uS/cm	
MMW-260	9/25/09	cnd	915	uS/cm	
MMW-260	11/15/10	cnd	1063	uS/cm	
MMW-260	3/16/09	hrd	388	mg/L	
MMW-260	5/19/09	hrd	368	mg/L	
MMW-260	9/25/09	hrd	378	mg/L	
MMW-260	11/15/10	hrd	362	mg/L	
MMW-260	3/16/09	Fe	0.75	mg/L	
MMW-260	5/19/09	Fe	0.7	mg/L	
MMW-260	9/25/09	Fe	0.68	mg/L	
MMW-260	11/15/10	Fe	0.53	mg/L	J
MMW-260	3/16/09	Mg	20.2	mg/L	
MMW-260	5/19/09	Mg	19.6	mg/L	
MMW-260	9/25/09	Mg	20.09	mg/L	
MMW-260	11/15/10	Mg	20.08	mg/L	
MMW-260	3/16/09	Mn	0.59	mg/L	
MMW-260	5/19/09	Mn	0.52	mg/L	
MMW-260	9/25/09	Mn	0.5	mg/L	
MMW-260	11/15/10	Mn	0.48	mg/L	J
MMW-260	3/16/09	nn	0	mg/l	
MMW-260	5/19/09	nn	0	mg/l	
MMW-260	9/25/09	nn	0	mg/l	
MMW-260	11/15/10	nn	0	mg/l	
MMW-260	3/16/09	K	4.45	mg/L	
MMW-260	5/19/09	K	4.74	mg/L	
MMW-260	9/25/09	K	4.45	mg/L	
MMW-260	11/15/10	K	4.19	mg/L	
MMW-260	3/16/09	Na	47.34	mg/L	
MMW-260	5/19/09	Na	49.09	mg/L	
MMW-260	9/25/09	Na	44.23	mg/L	
MMW-260	11/15/10	Na	42.35	mg/L	
MMW-260	3/16/09	sf	80	mg/L	
MMW-260	5/19/09	sf	81	mg/L	
MMW-260	9/25/09	sf	80	mg/L	
MMW-260	11/15/10	sf	88	mg/L	
MMW-260	3/16/09	tds	580	mg/L	
MMW-260	5/19/09	tds	564	mg/L	
MMW-260	9/25/09	tds	580	mg/L	
MMW-260	11/15/10	tds	562	mg/L	
MMW-290	3/16/09	alk	304	mg/L	
MMW-290	5/19/09	alk	294	mg/L	
MMW-290	9/25/09	alk	292	mg/L	
MMW-290	11/15/10	alk	308	mg/L	
MMW-290	3/16/09	Ca	124.4	mg/L	
MMW-290	5/19/09	Ca	115.71	mg/L	
MMW-290	9/25/09	Ca	120.06	mg/L	
MMW-290	11/15/10	Ca	121.04	mg/L	

Appendix A - *continued*

Well name	Date	Analyte	Result	Unit	Flag
MMW-290	3/16/09	cl	124	mg/L	
MMW-290	5/19/09	cl	125	mg/L	
MMW-290	9/25/09	cl	123	mg/L	
MMW-290	11/15/10	cl	62	mg/L	
MMW-290	3/16/09	cnd	1093	uS/cm	
MMW-290	5/19/09	cnd	1038	uS/cm	
MMW-290	9/25/09	cnd	1126	uS/cm	
MMW-290	11/15/10	cnd	869	uS/cm	
MMW-290	3/16/09	hrd	400	mg/L	
MMW-290	5/19/09	hrd	377	mg/L	
MMW-290	9/25/09	hrd	389	mg/L	
MMW-290	11/15/10	hrd	395	mg/L	
MMW-290	3/16/09	Fe	0.04	mg/L	
MMW-290	5/19/09	Fe	0.02	mg/L	
MMW-290	9/25/09	Fe	0.04	mg/L	U
MMW-290	11/15/10	Fe	0.67	mg/L	J
MMW-290	3/16/09	Mg	21.87	mg/L	
MMW-290	5/19/09	Mg	21.19	mg/L	
MMW-290	9/25/09	Mg	21.58	mg/L	
MMW-290	11/15/10	Mg	22.48	mg/L	
MMW-290	3/16/09	Mn	0.44	mg/L	
MMW-290	5/19/09	Mn	0.42	mg/L	
MMW-290	9/25/09	Mn	0.15	mg/L	
MMW-290	11/15/10	Mn	0.53	mg/L	J
MMW-290	3/16/09	nn	0	mg/l	
MMW-290	5/19/09	nn	0	mg/l	
MMW-290	9/25/09	nn	0	mg/l	
MMW-290	11/15/10	nn	0	mg/l	
MMW-290	3/16/09	K	4.46	mg/L	
MMW-290	5/19/09	K	4.77	mg/L	
MMW-290	9/25/09	K	7.51	mg/L	
MMW-290	11/15/10	K	4.3	mg/L	
MMW-290	3/16/09	Na	83.92	mg/L	
MMW-290	5/19/09	Na	82.09	mg/L	
MMW-290	9/25/09	Na	70.83	mg/L	
MMW-290	11/15/10	Na	67.37	mg/L	
MMW-290	3/16/09	sf	92	mg/L	
MMW-290	5/19/09	sf	91	mg/L	
MMW-290	9/25/09	sf	88	mg/L	
MMW-290	11/15/10	sf	80	mg/L	
MMW-290	3/16/09	tds	652	mg/L	
MMW-290	5/19/09	tds	666	mg/L	
MMW-290	9/25/09	tds	684	mg/L	
MMW-290	11/15/10	tds	466	mg/L	

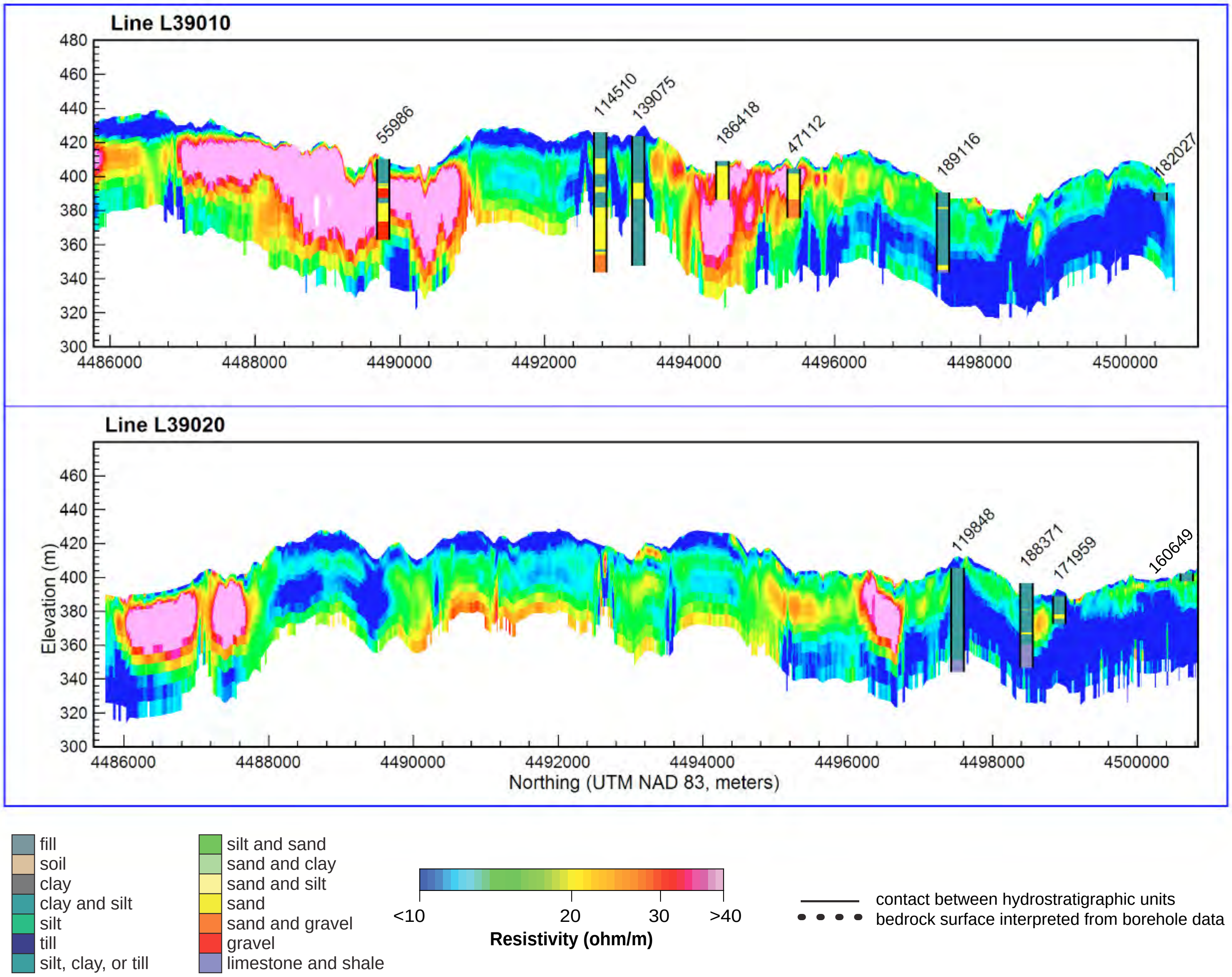
Abbreviations: alk: alkalinity, Ca: calcium, Cl: chloride, cnd: conductance, hrd: harness, Fe: iron, Mg: magnesium, Mn: manganese, nn: nitrate-nitrogen, K: potassium, Na: sodium, sf: sulfate, tds: total dissolved solids

non-detects were replaced with zero

red indicates values that were not used in calculations

Flags: U: concentration in sample <5x concentration detected in blank, J: concentration in sample 5 - 10 times concentration detected in blank

Appendix B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420
400
380
360
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320
300
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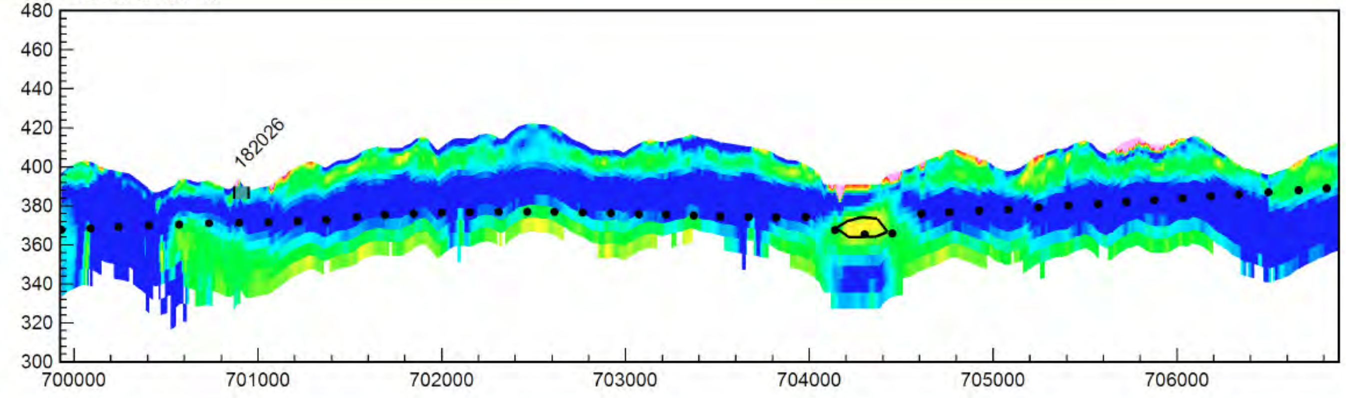
47112
189116
182027
4486000
4488000
4490000
4492000
4494000
4496000
4498000
4500000
Line L39020
Elevation (m)
460
440
420
400
380
360
340
320
300
119848
188371
171959
160649
4486000
4488000
4490000
4492000
4494000
4496000
4498000
4500000
Northing (UTM NAD 83, meters)
fill
soil
clay
clay and silt
silt
till
silt, clay, or till
silt and sand
sand and clay
sand and silt
sand
sand and gravel
gravel
limestone and shale
<10
20
30
>40
Resistivity (ohm/m)
contact between hydrostratigraphic units
bedrock surface interpreted from borehole data

Line L30010



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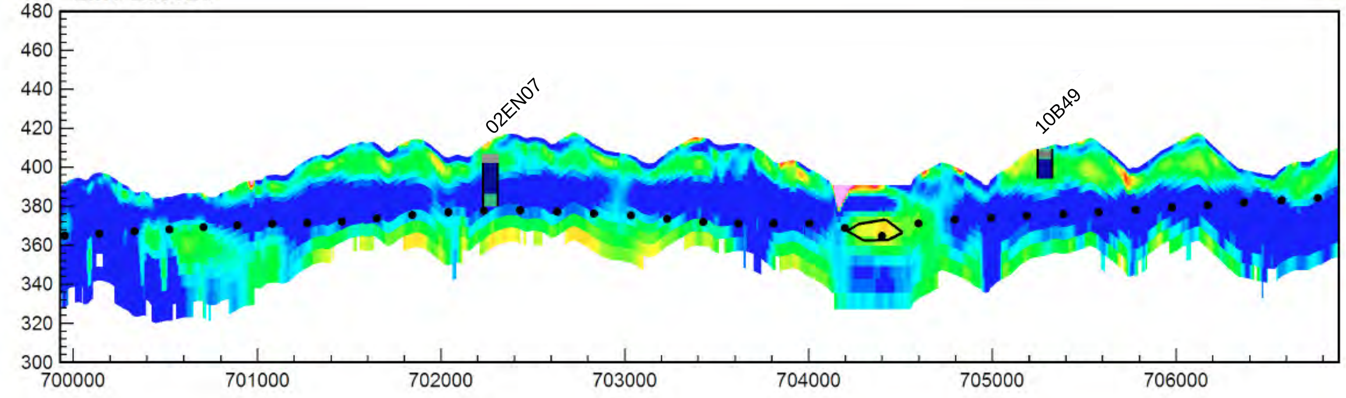

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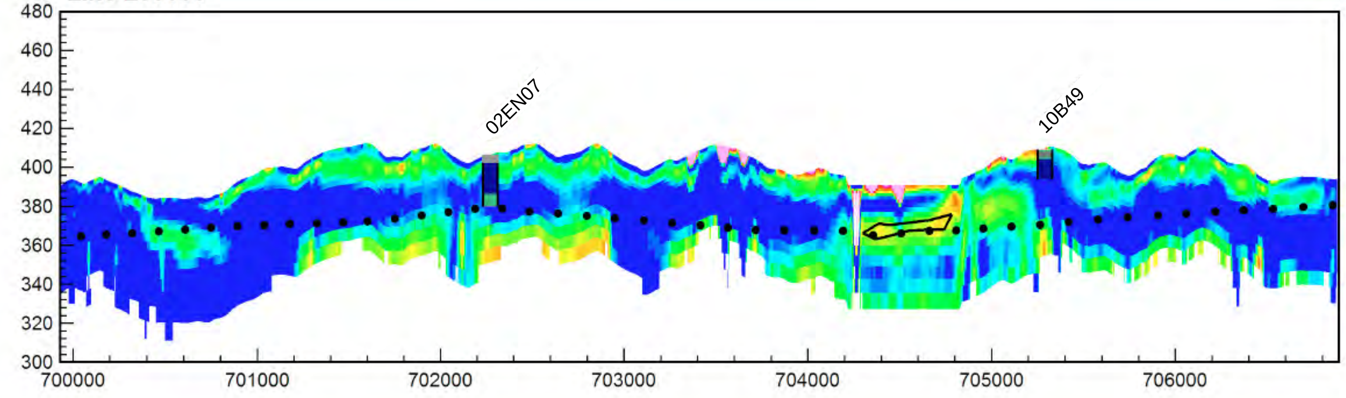

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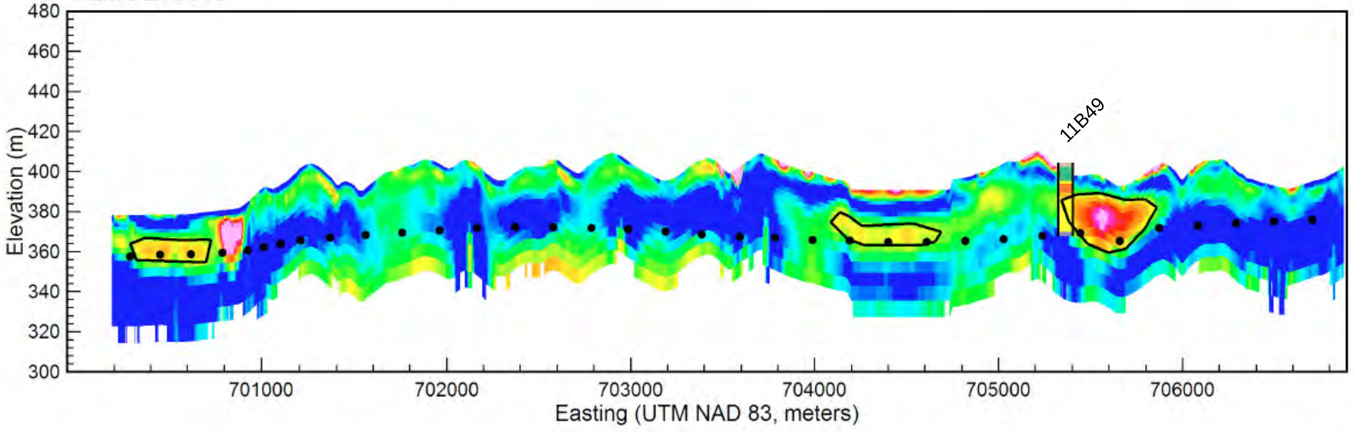

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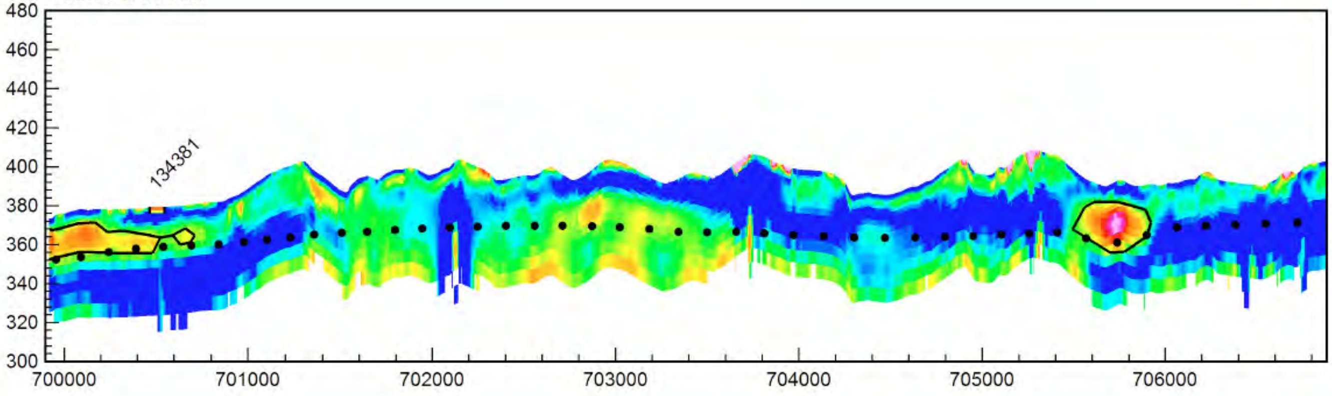

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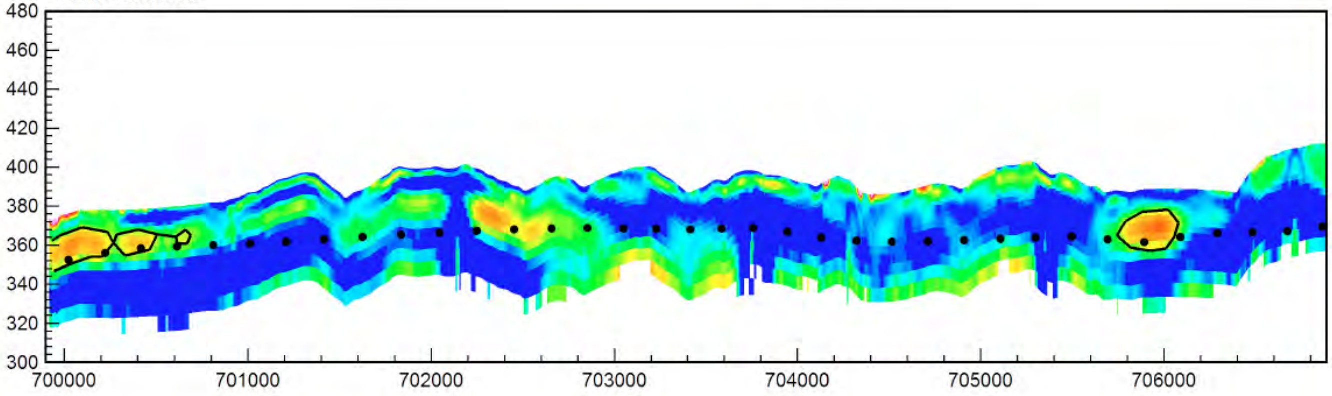

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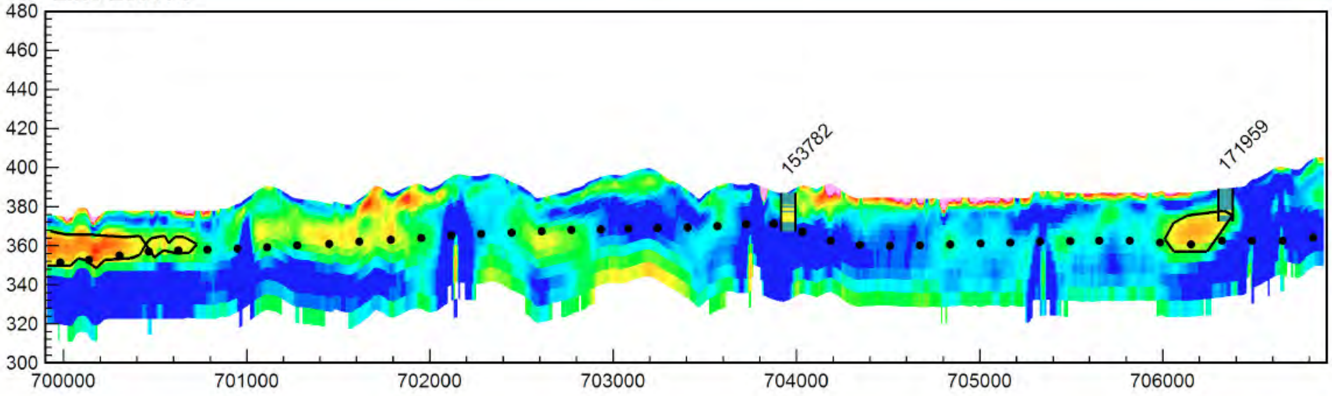

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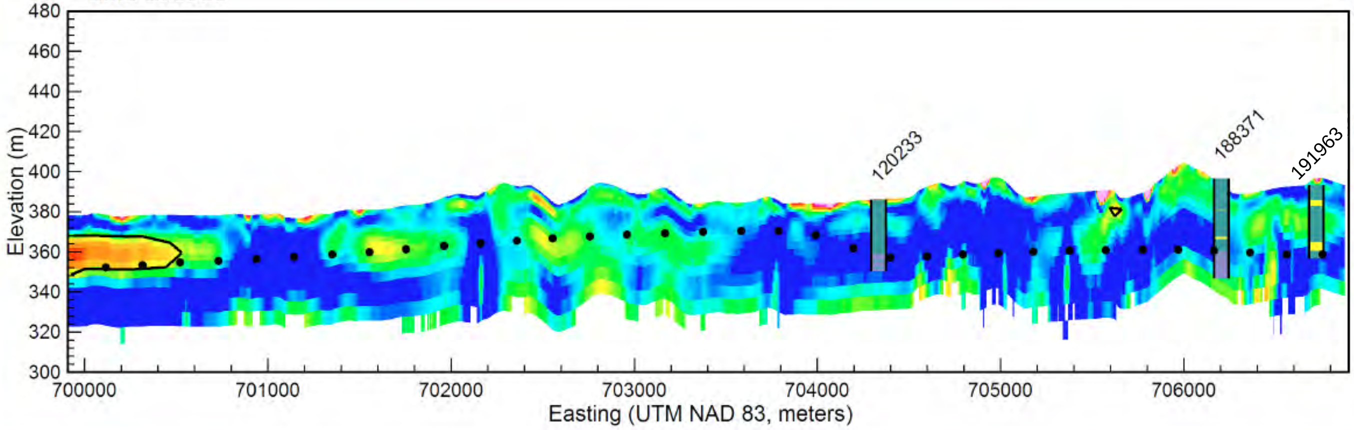
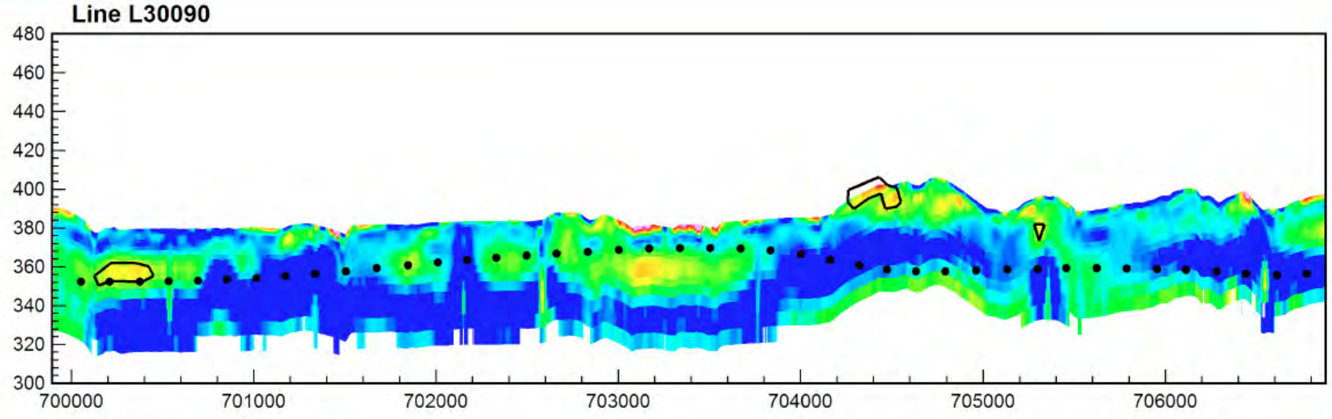


Appendix B - *continued*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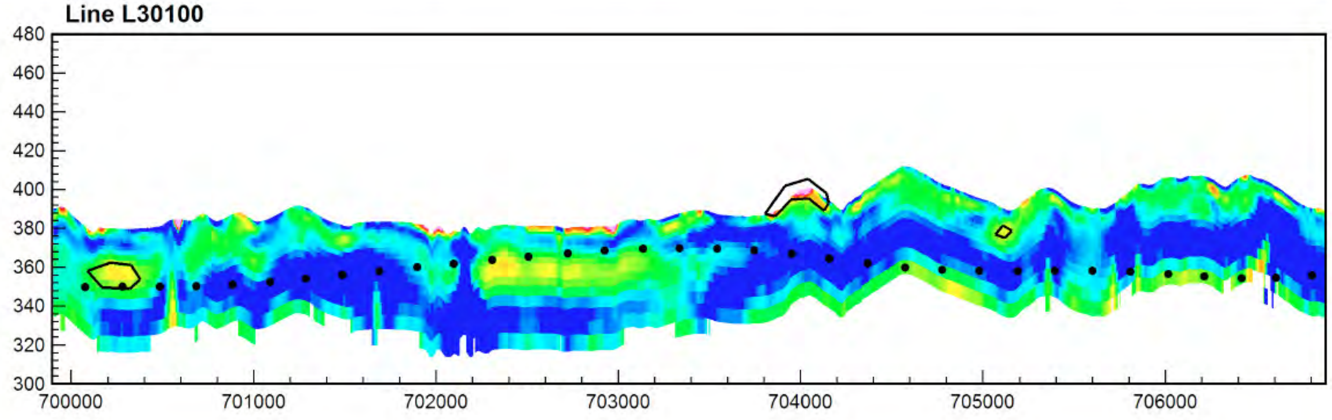
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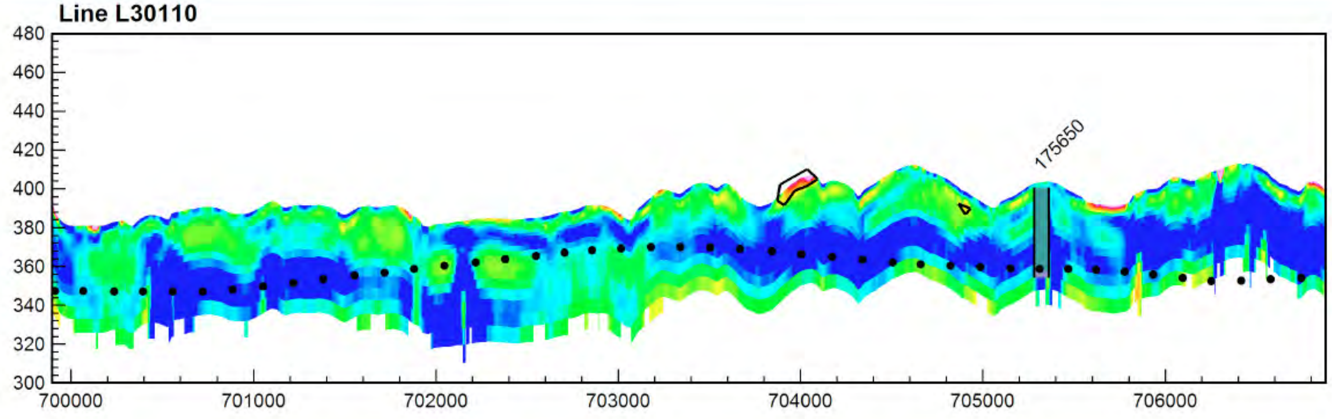
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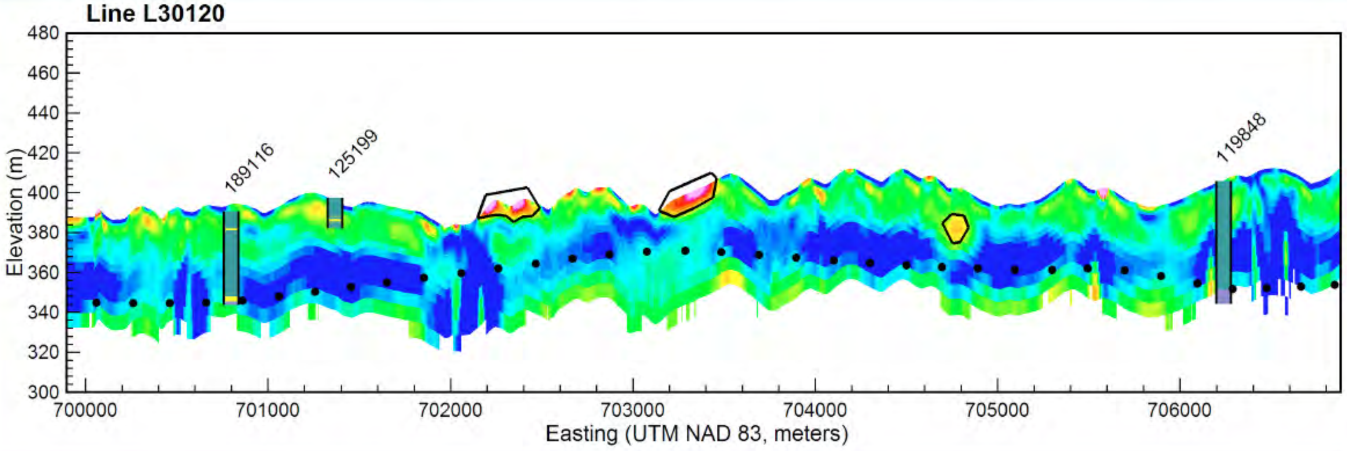
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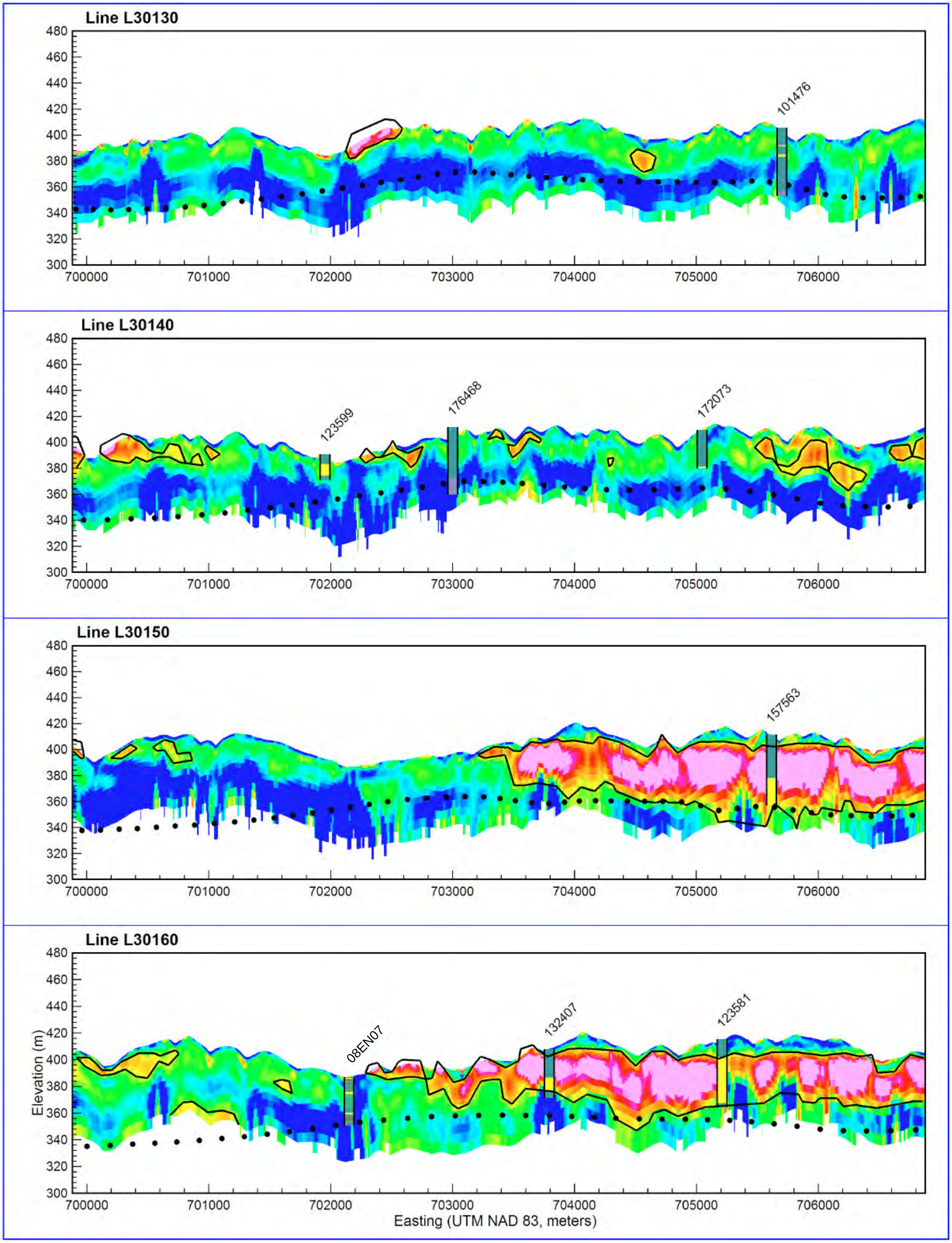
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Line L30140
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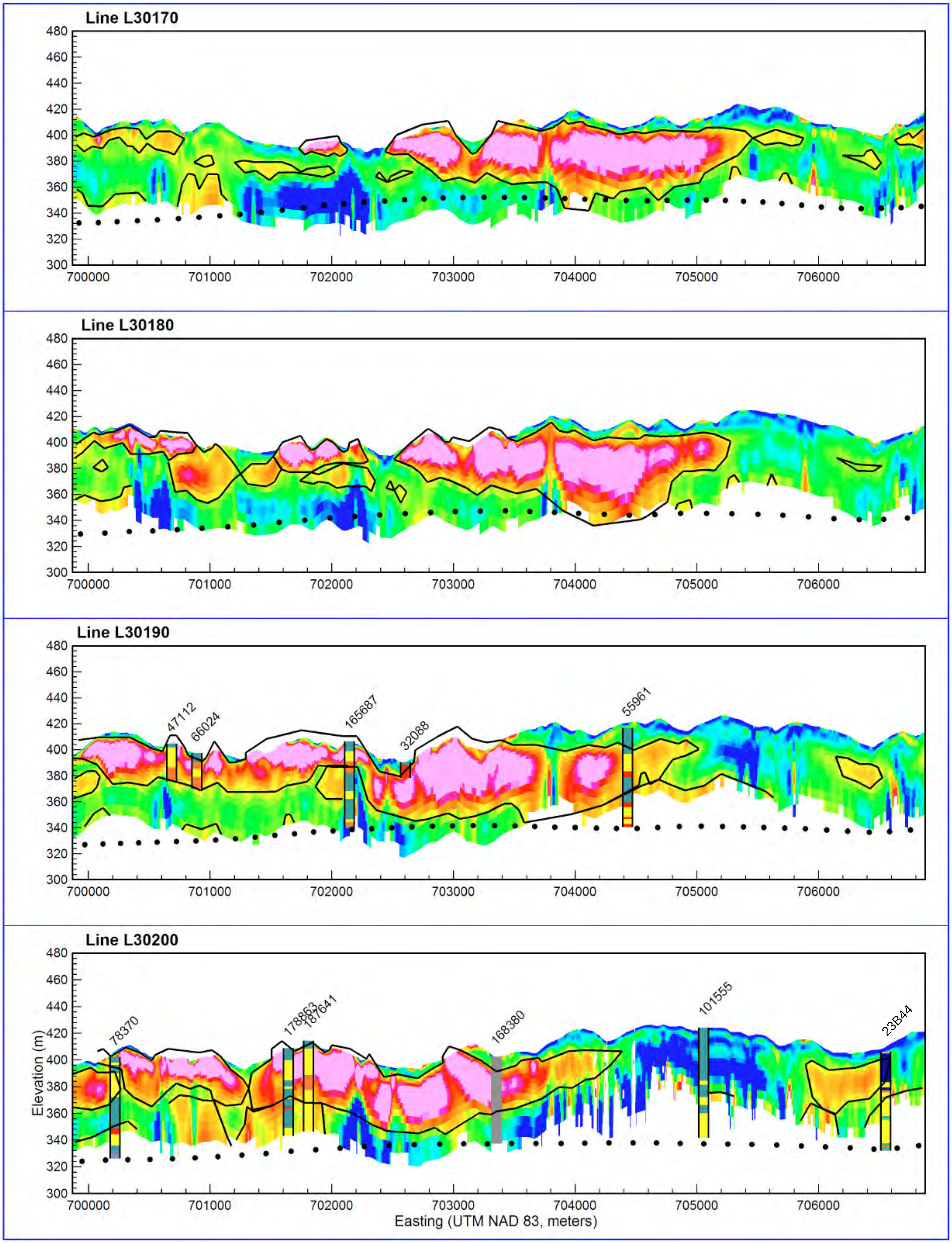
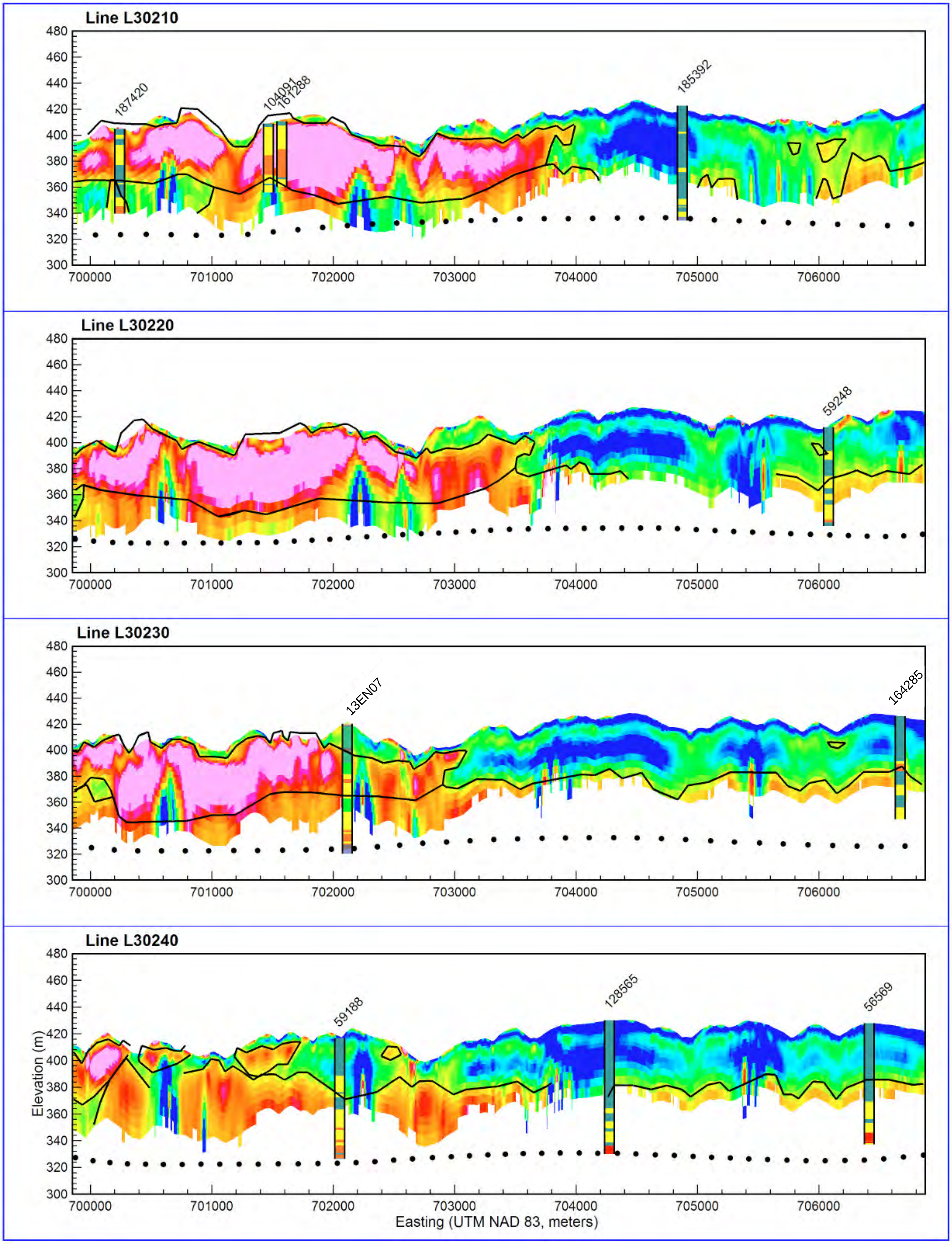
Line L30150
157563
Line L30160
08EN07
132407
123581
480
460
440
420
400
380
360
340
320
300
Elevation (m)
700000
701000
702000
703000
704000
705000
706000
Easting (UTM NAD 83, meters)

Appendix B - *continued*

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Line L30220
59248
Line L30230
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Line L30240
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56569
480
460
440
420
400
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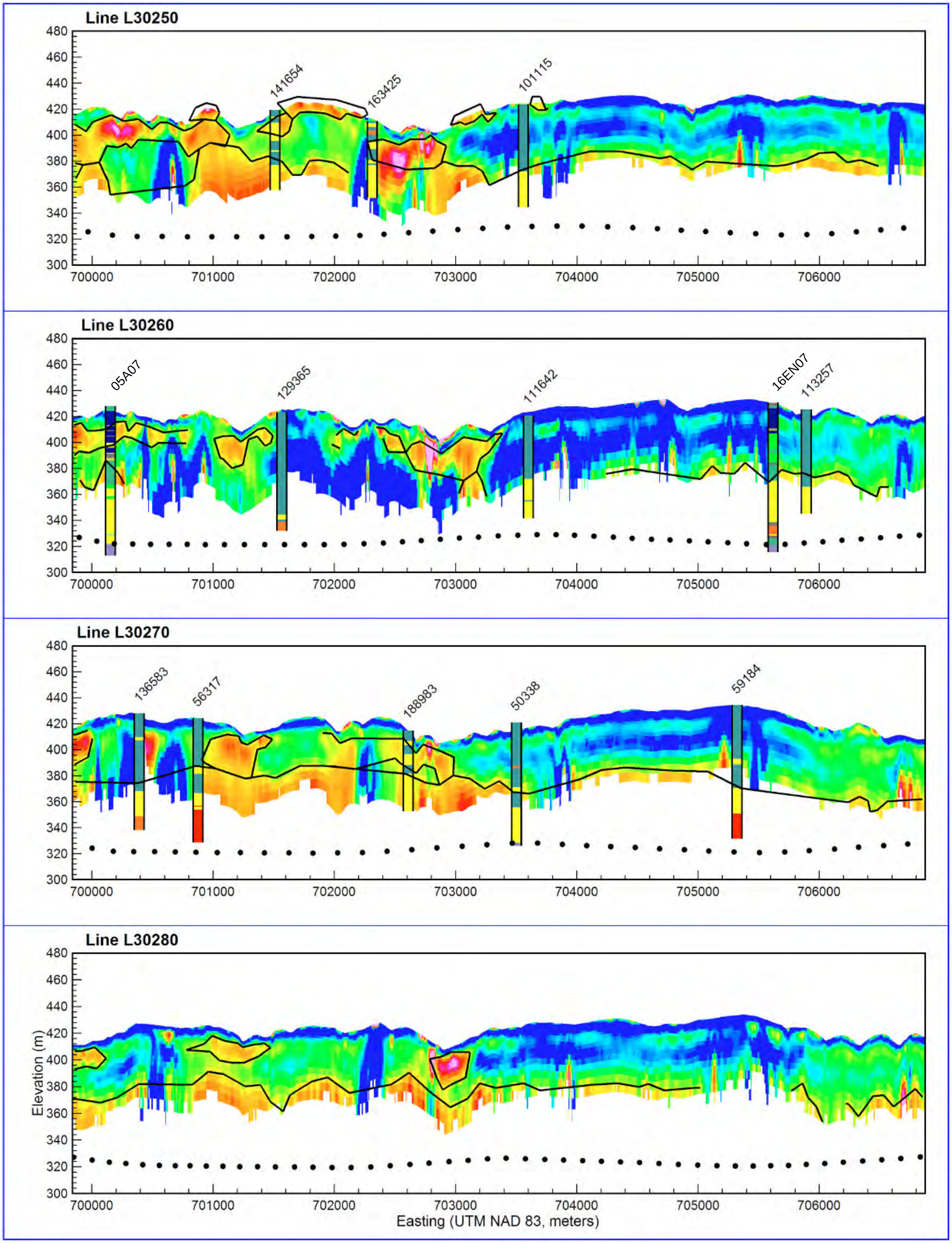
706000
Elevation (m)
Easting (UTM NAD 83, meters)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Line L30260
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Line L30270
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188983
50338
59184
Line L30280
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460
440
420
400
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340
320
300
Elevation (m)
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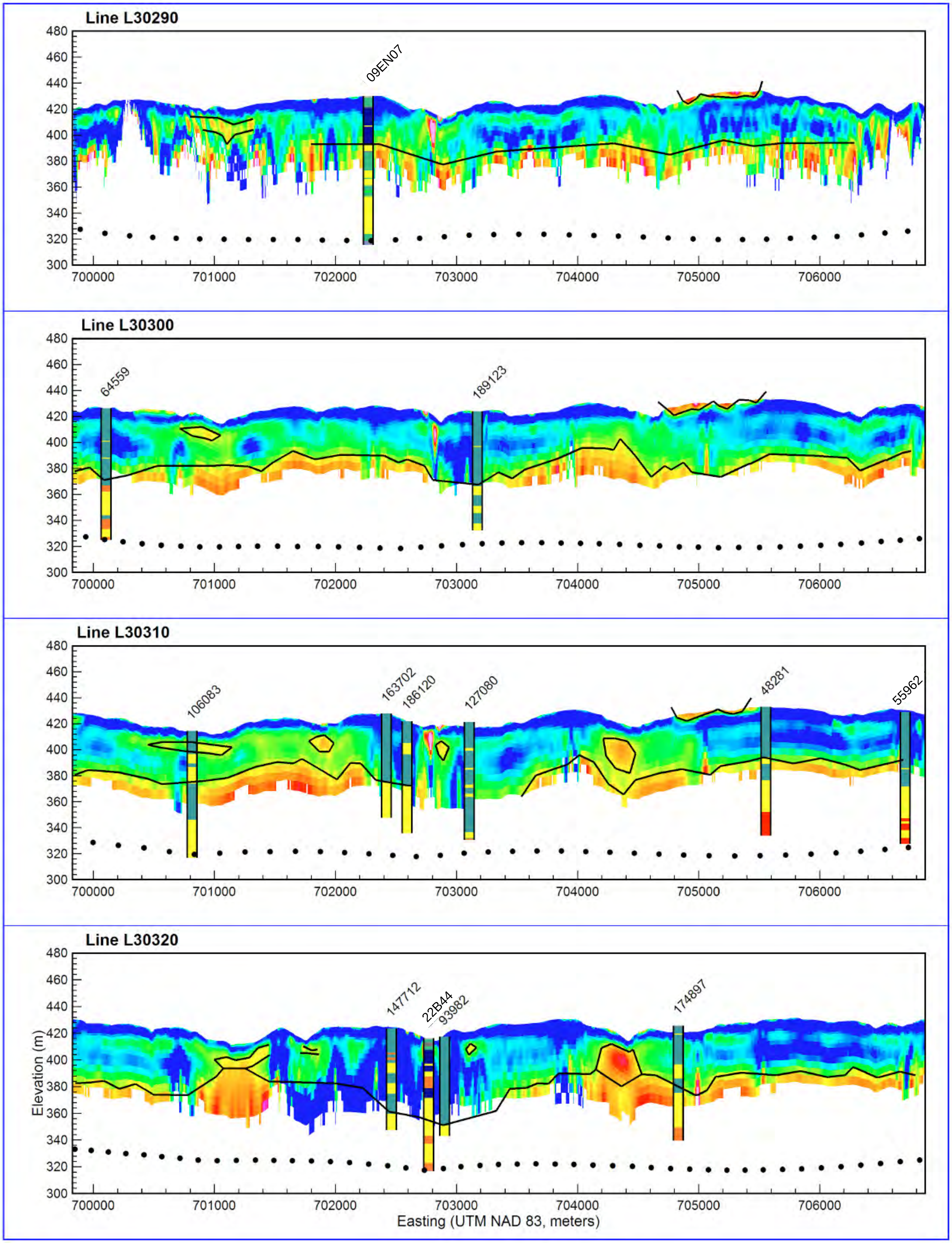
702000
703000
704000
705000
706000
Easting (UTM NAD 83, meters)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Line L30300
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Line L30310
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Line L30320
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22B44
93982
174897
480
460
440
420
400
380
360
340
320
300
700000
701000
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704000
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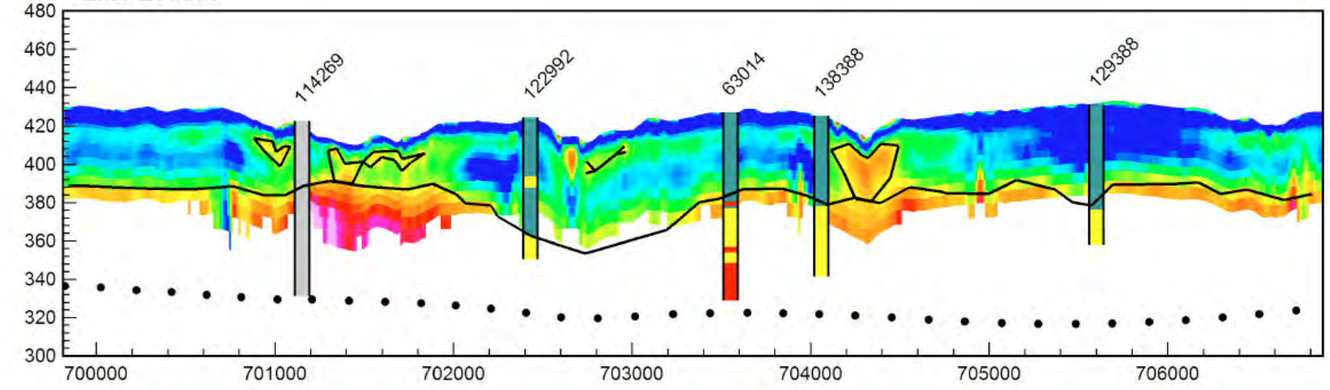
706000
Elevation (m)
Easting (UTM NAD 83, meters)

Line L30330



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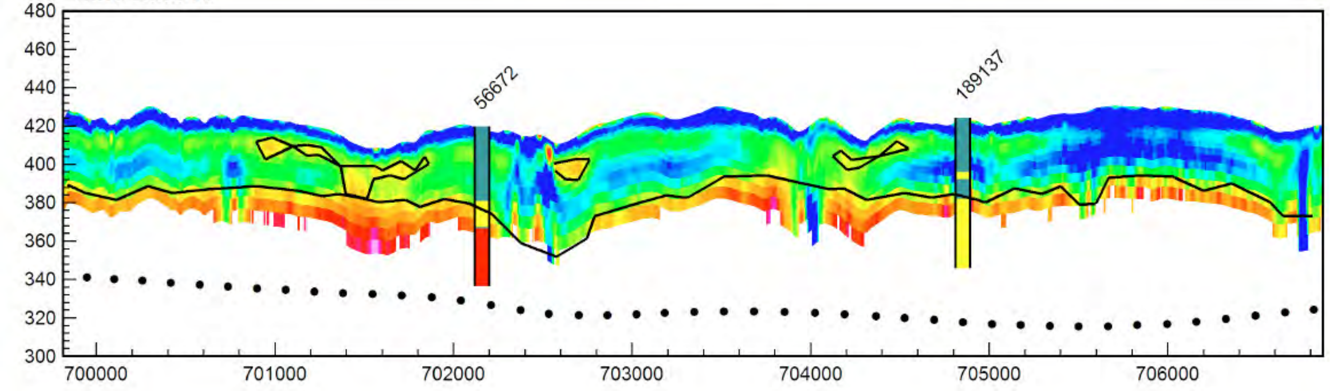

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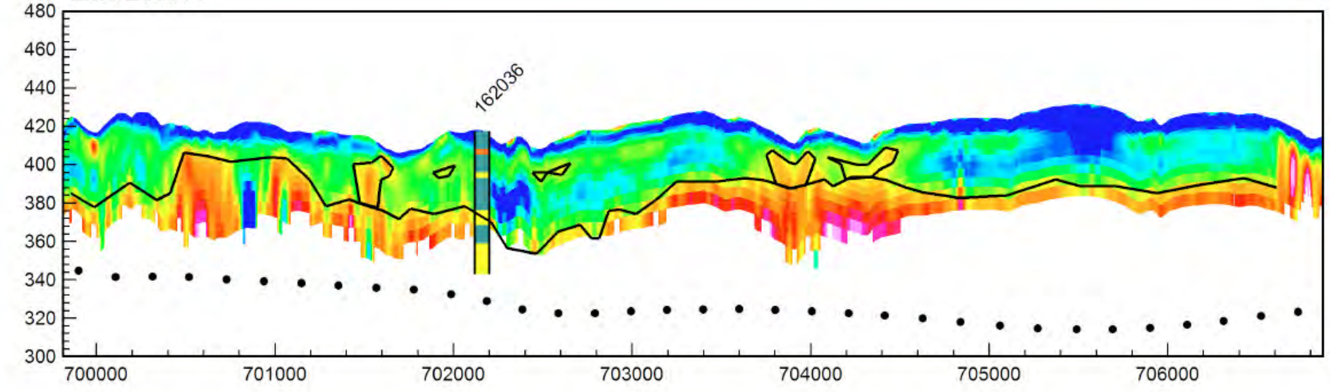

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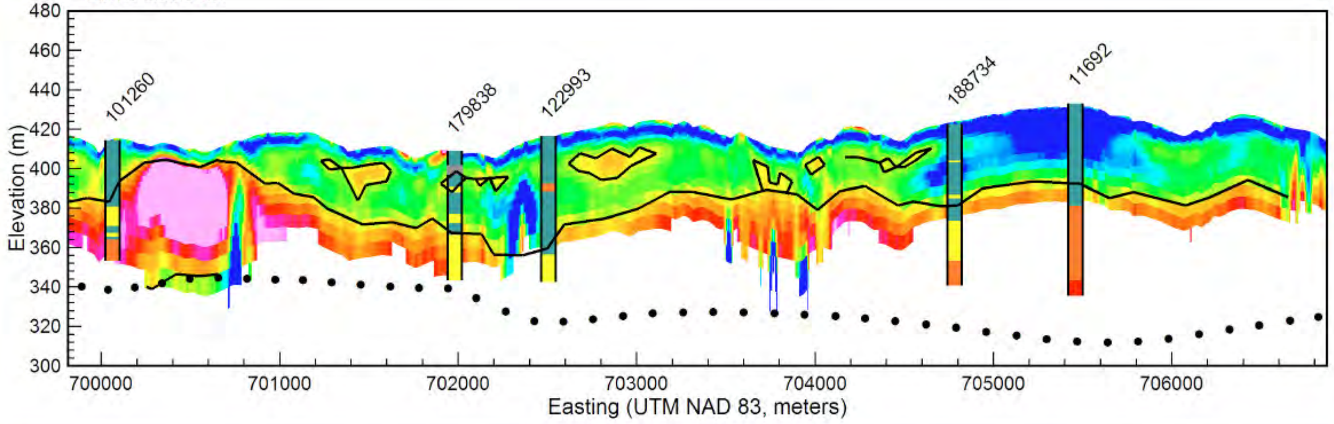

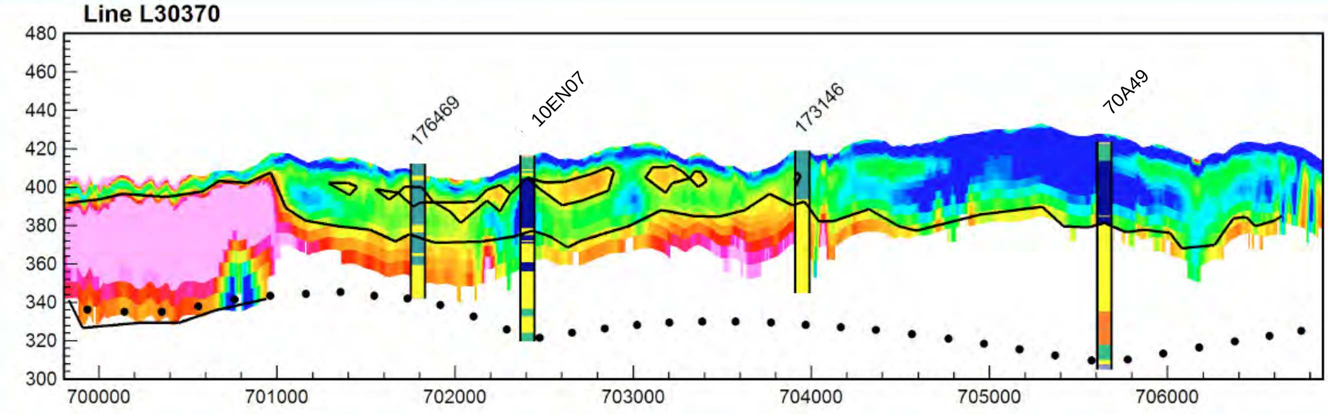
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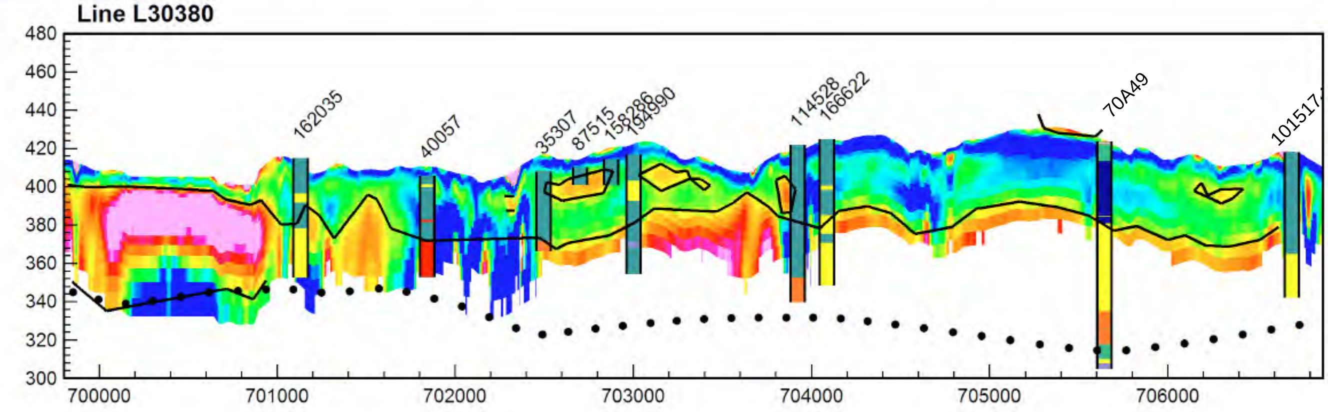
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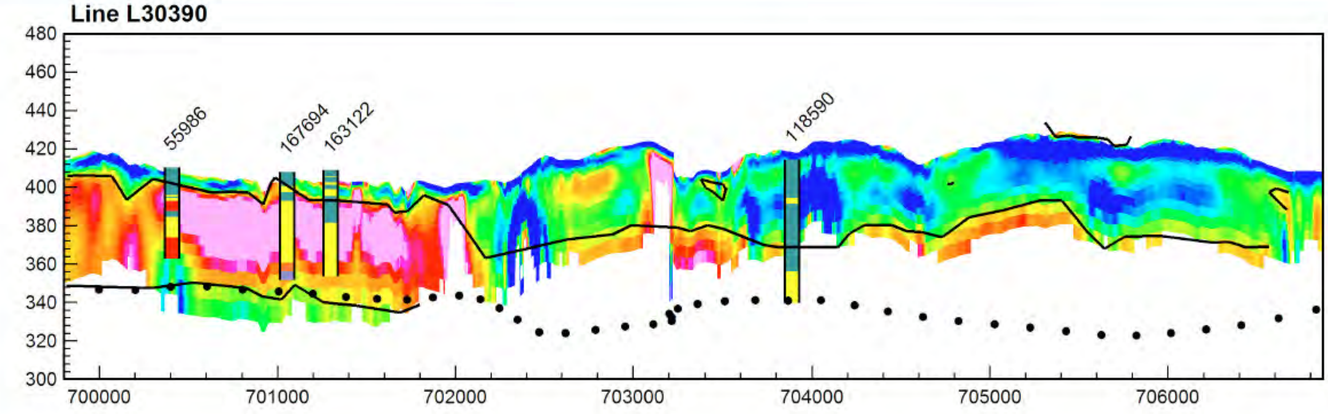
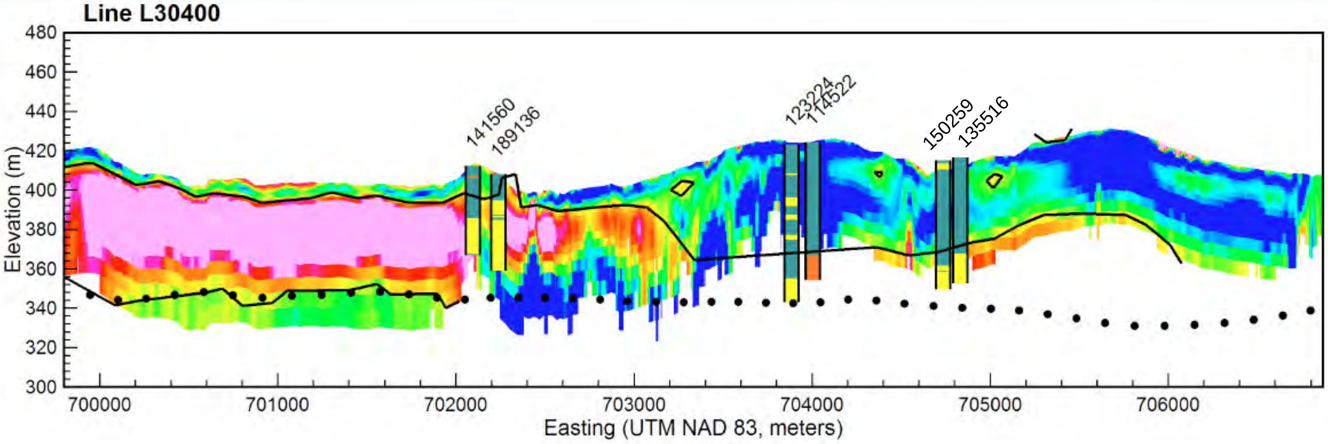
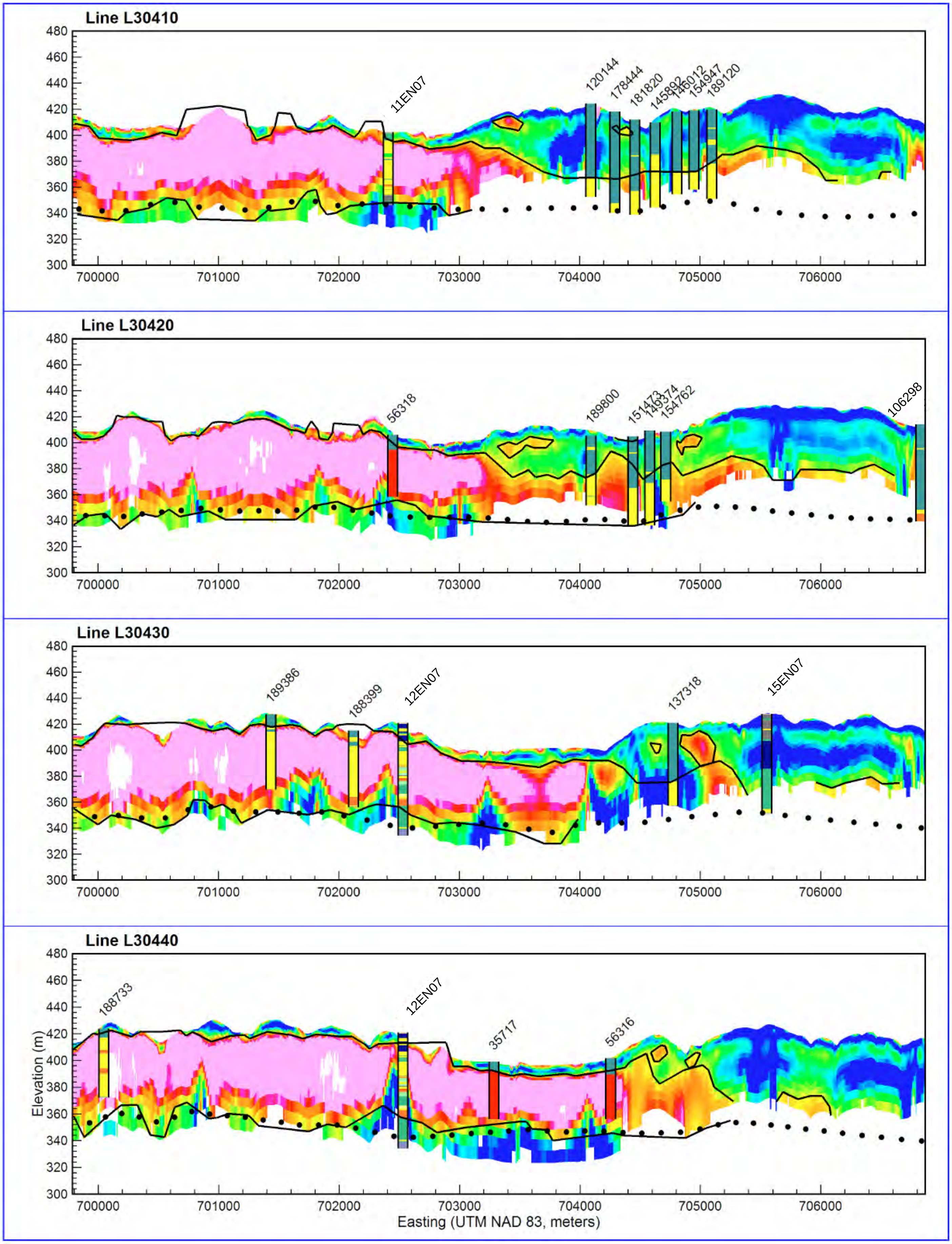
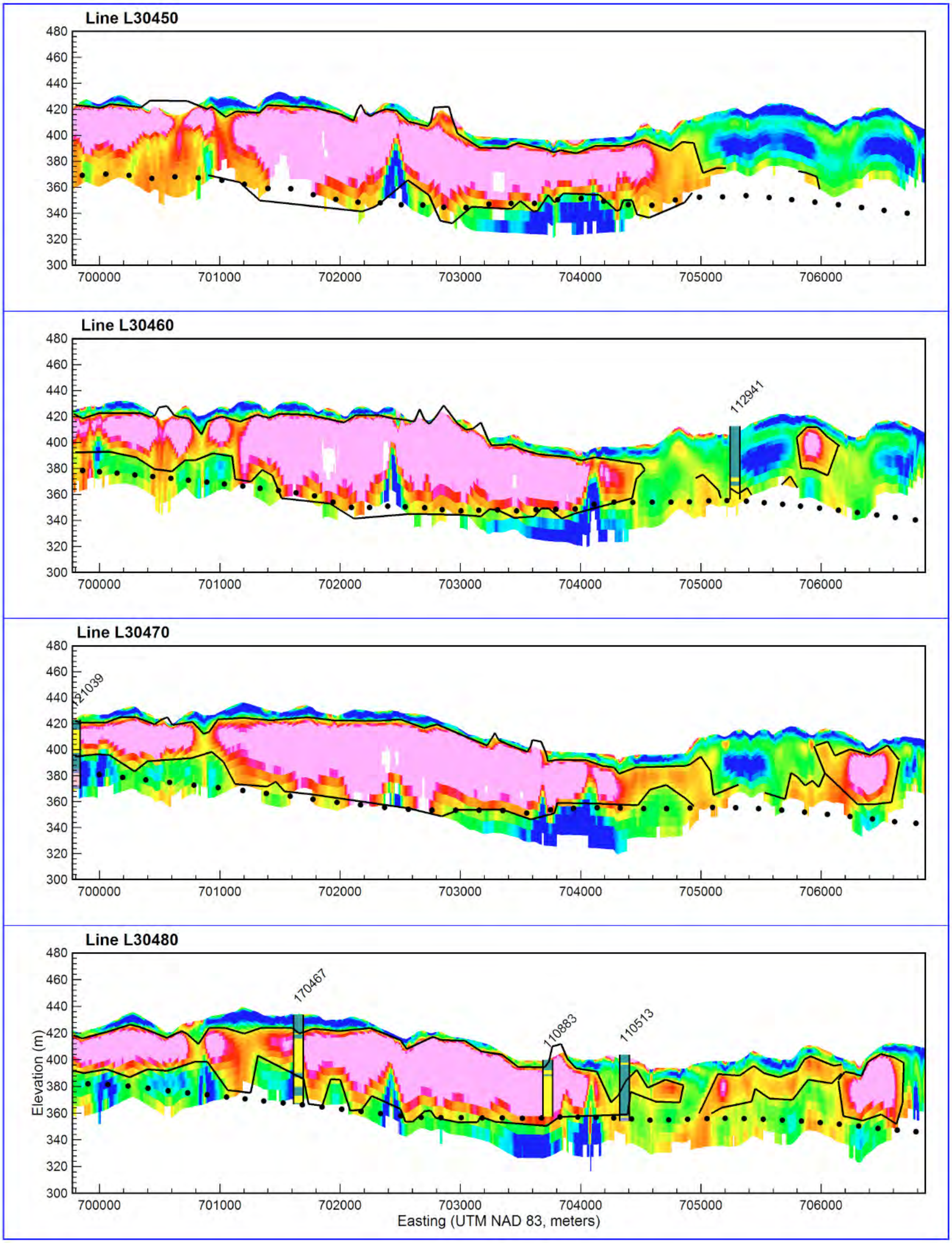
166622
70A49
101517
700000
701000
702000
703000
704000
705000
706000


Line L30390
480
460
440
420
400
380
360
340
320
300
55986
167694
163122
118590
700000
701000
702000
703000
704000
705000
706000

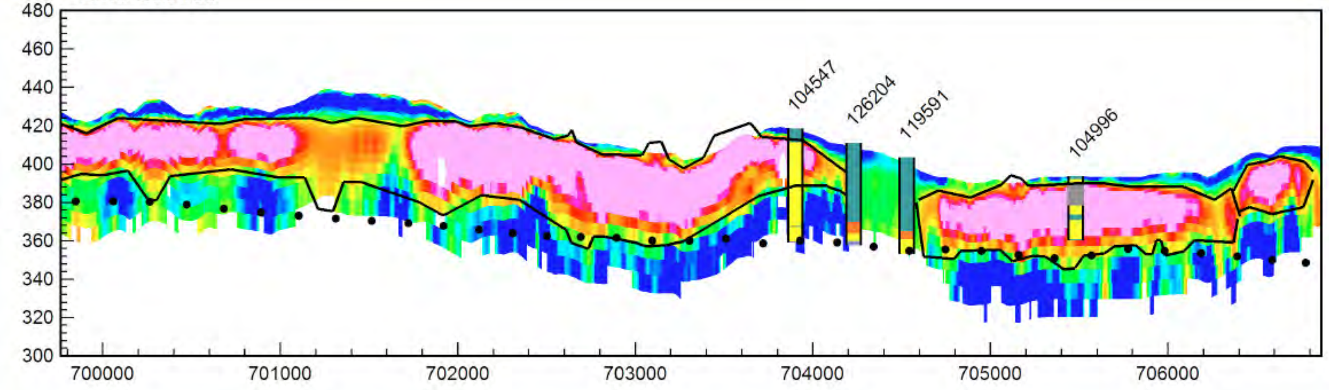

Line L30400
480
460
440
420
400
380
360
340
320
300
Elevation (m)
141560
189136
123224
114522
150259
135516
700000
701000
702000
703000
704000
705000
706000
Easting (UTM NAD 83, meters)

Appendix B - *continued*

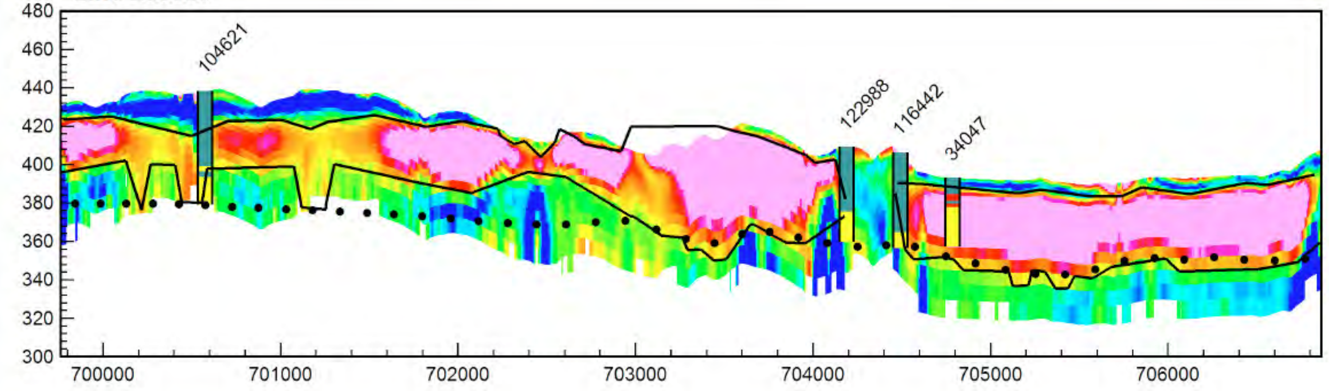



Line L30450
Line L30460
112941
Line L30470
21039
Line L30480
170467
110883
110513
480
460
440
420
400
380
360
340
320
300
Elevation (m)
700000
701000
702000
703000
704000
705000
706000
Easting (UTM NAD 83, meters)

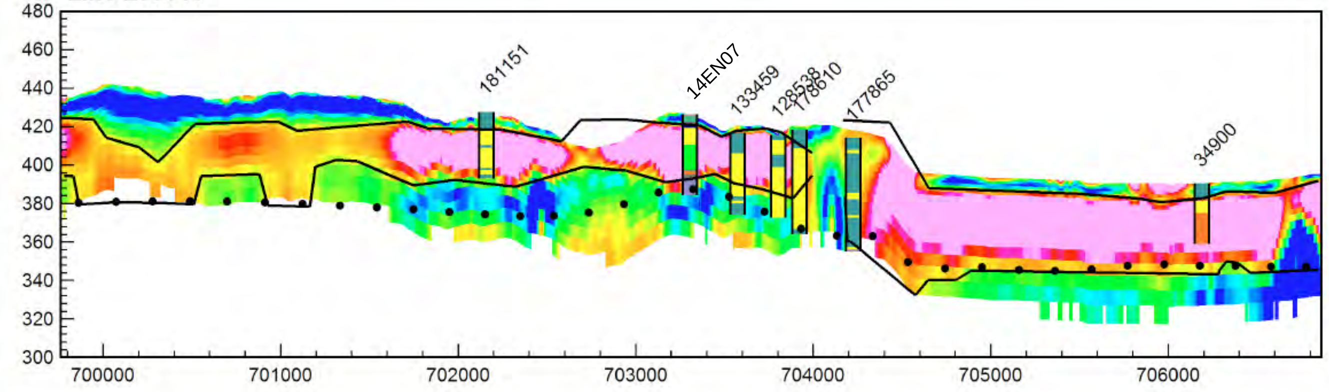
Line L30490



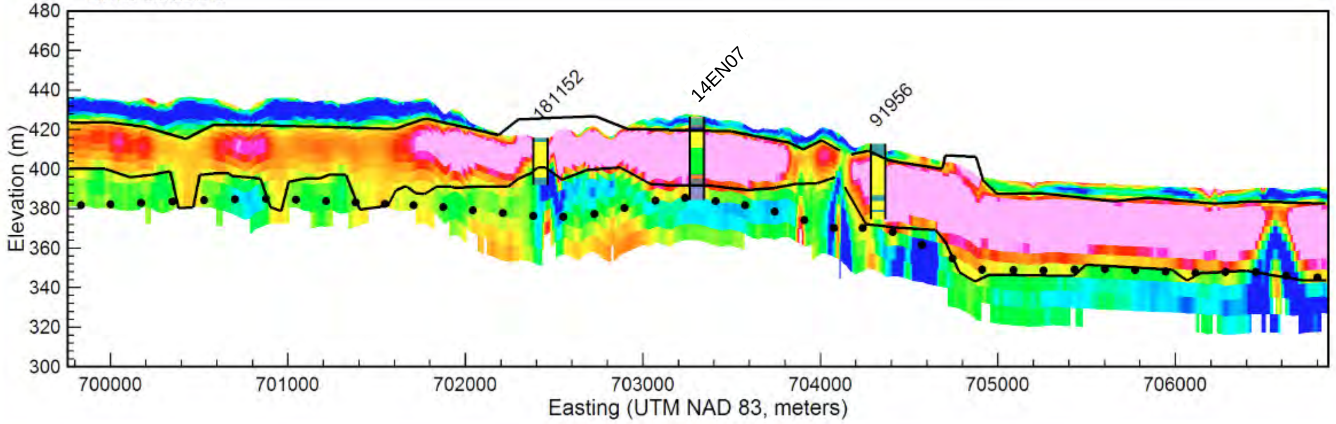
Line L30500



Line L30510



Line L30520



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