

February 27th, 2026

Champaign County Executive and Champaign County Board
Scott M. Bennett Administrative Center
102 E. Main Street
Urbana, IL 61801

Dear Mr. Summers, Ms. Locke and Board Members,

Please accept this draft version of the final report as the Illinois State Geological Survey (ISGS) deliverable for fulfillment of contract AJ586: Geophysical Mapping of the Mahomet Aquifer using Airborne Electromagnetic Method with Champaign County Board.

Upon review and acceptance of this report, please provide a letter to the ISGS confirming your approval. If you require any further clarification of the details in the report or would like information added/removed please contact us. We are willing to meet with you to provide further explanation about the contents in the report, the organization of the information presented, and more information on geology and geophysics.

Your letter of approval will be forwarded to the Contract and Grants Office at the University of Illinois at Urbana-Champaign in order that the contract can be closed.

Best regards,

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Geophysical Mapping of the Mahomet Aquifer using Airborne Electromagnetic Method

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Submitted under contract to:

Champaign County Executive and Champaign County Board
Steve Summers, County Executive and Jennifer Locke, County Board Chair
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EXECUTIVE SUMMARY

An important mission of the Prairie Research Institute (PRI) is to bridge the worlds of applied geosciences and policy. PRI provides decision makers with science-based knowledge of natural resources. Groundwater science, in particular, is aimed at explaining aquifer systems by implementing objective, standardized scientific tools and methods. Unfortunately, the policy of managing groundwater resources often depends on subjective interests. Thus, integrating new scientific methods and clear communication strategies is key to keeping stakeholders and the public informed. Implementing scientifically informed policy associated with the Mahomet aquifer will have positive impacts on the quality of life, water security, sustainability, and risk. Furthermore, successful science-based policy can greatly advance the progression of fundamental science.

This report summarizes the results of a three-year project commissioned by Champaign County directing the Illinois State Geological Survey (ISGS) to study, in high resolution, the framework and geometry of the Mahomet aquifer within the jurisdiction of Champaign County. This project uses high density helicopter-borne time-domain electromagnetic measurements (HTEM) to provide reliable data with which Champaign County can formulate effective and sustainable strategies to protect groundwater resources and the economy of the county. The main objectives of this project are to: 1) improve delineation of the Mahomet aquifer boundary in Champaign County; 2) better define, in high resolution, the extent of aquifer and non-aquifer units; and 3) develop a 3-D geologic model of Champaign County and create an updated geological framework. County-scale maps illustrating results from the project show the distribution of geologic aquifer and non-aquifer materials, later defined as aquifer units and confining units. Understanding the geometry and the general make-up of these aquifer and confining units will facilitate decision making regarding the protection and sustainable management of this critical groundwater resource in the county.

For this project we used traditional geophysical methods including ground-based electrical resistivity tomography (ERT), seismic reflection, horizontal-vertical spectral ratio (HVSr), and borehole information to complement an advanced airborne geophysical method, HTEM. These traditional ground-based geophysical methods were specifically used in areas where HTEM data could not be collected (e.g., in cities and other populated areas); and in other instances, they were used to confirm the HTEM results (in this case, the use of borehole information). This report describes the methods used by the ISGS to collect newly acquired geophysical data, and the processes used to analyze and interpret these data. The geological and geophysical data acquired were the basis for developing geologic models. A summary that describes how the data were used to construct a 3-D geologic model of the project area is provided. Hydrogeological implications of the modeling are also described.

Approximately 3,145 km (1,954 miles) of HTEM data were collected within Champaign County, extending from the Ford County/Champaign County border in the north, between County Road

500 and County Road 400, north of the Village of Pesotum in the south. We also acquired a total of 4.3 miles of 2-D ERT data, and total of 15.66 kms (9.72 miles) of 2-D seismic reflections data on several roadways in Champaign County. Distribution of the ERT and seismic profiles depended on HTEM data coverage and the need to complement HTEM data. Additionally, a total of 180 HVSR points were collected inside Champaign County between the summers of 2023 and 2025, and two new boreholes were drilled in the unincorporated areas of Flatville and Sydney, Illinois.

Findings from this report provide a more refined bedrock topography, which is the basis for the Mahomet Bedrock Valley that houses the Mahomet aquifer. This newly mapped bedrock valley indicates that the general pattern of this topographic map is more variable than that seen on traditionally made maps. Maps illustrating the newly defined Mahomet aquifer boundary, geological materials inside the aquifer boundary, and the thickness of Mahomet aquifer, are all described in this report. Perhaps more importantly are the maps illustrating distribution of all the aquifer in Champaign County and the interconnectivity of these aquifers with the Mahomet aquifer, answering important questions pertaining to groundwater quality, quantity, availability, and recharge. The delivered data includes processed HTEM data and presentations, interpreted results, and model presentations. All figures created during data processing and interpretation will be included in the digital data delivery.

1. INTRODUCTION

1.1 Mahomet Bedrock Valley (MBV)

The most prominent, but hidden, geological feature in Champaign County is the Mahomet Bedrock Valley (MBV); a preglacial bedrock valley infilled and deeply buried by glacial deposits. This ancient preglacial landscape feature formed hundreds of millions of years ago and is part of a drainage system incised into the ancient bedrock surface that crosses Illinois and eastern North America. These bedrock valleys are largely filled and buried by up to hundreds of feet of glacial deposits of the most recent, Pleistocene glaciations. In particular, the MBV was once part of an extensive mid-continental preglacial drainage system known as the Teays-Mahomet Bedrock Valley System (Melhorn and Kempton 1991), which, during the Late Tertiary and Early Pleistocene, drained the Appalachian Mountains westward to the Gulf of Mexico (Horberg 1945).

The MBV underlies portions of 14 counties in east-central Illinois, from near the modern Illinois River, east to the Illinois/Indiana State line. The MBV does not appear to be aligned with any known bedrock structural feature, fracture pattern, or change in lithology. Rather, along its 125-mile course in Illinois, the MBV was incised across prominent regional structural features and lithologic boundaries. For example, in Champaign County, the MBV transects the LaSalle Anticlinorium, which is a belt of domed and folded rocks that extends northwestward from the Village of Pesotum through northwest Champaign County (Nelson, in press; Kolata 2005). The LaSalle Anticlinorium extends farther northward into north-central Illinois. While the bedrock entrenchment in Champaign County is relatively shallow, the deepest channel in the MBV is 200–300 feet lower than the surrounding landscape and has historically been mapped in the subsurface between the 300- and 500-foot above sea level (asl) contours (Kempton et al. 1991). The deepest channel has been known, informally, to well drillers since the 1930s. Horberg (1945, 1950) first mapped the MBV (Figure 1) and built the framework for mapping other bedrock valleys in Illinois. In east-central Illinois, the MBV generally ranges from 5 miles wide in central Piatt County to almost 20 miles wide in eastern Champaign and Ford Counties. A few broad benches (bedrock terraces) have been identified along the MBV (Kempton et al. 1991). They are especially well developed in northeastern Champaign County and northern Vermilion County between elevations 400 and 450 feet asl, and between 450 and 500 feet asl in southwestern Iroquois County. These terraces indicate periods when bedrock erosion rates increased, which left former topographic benches abandoned at higher elevations.

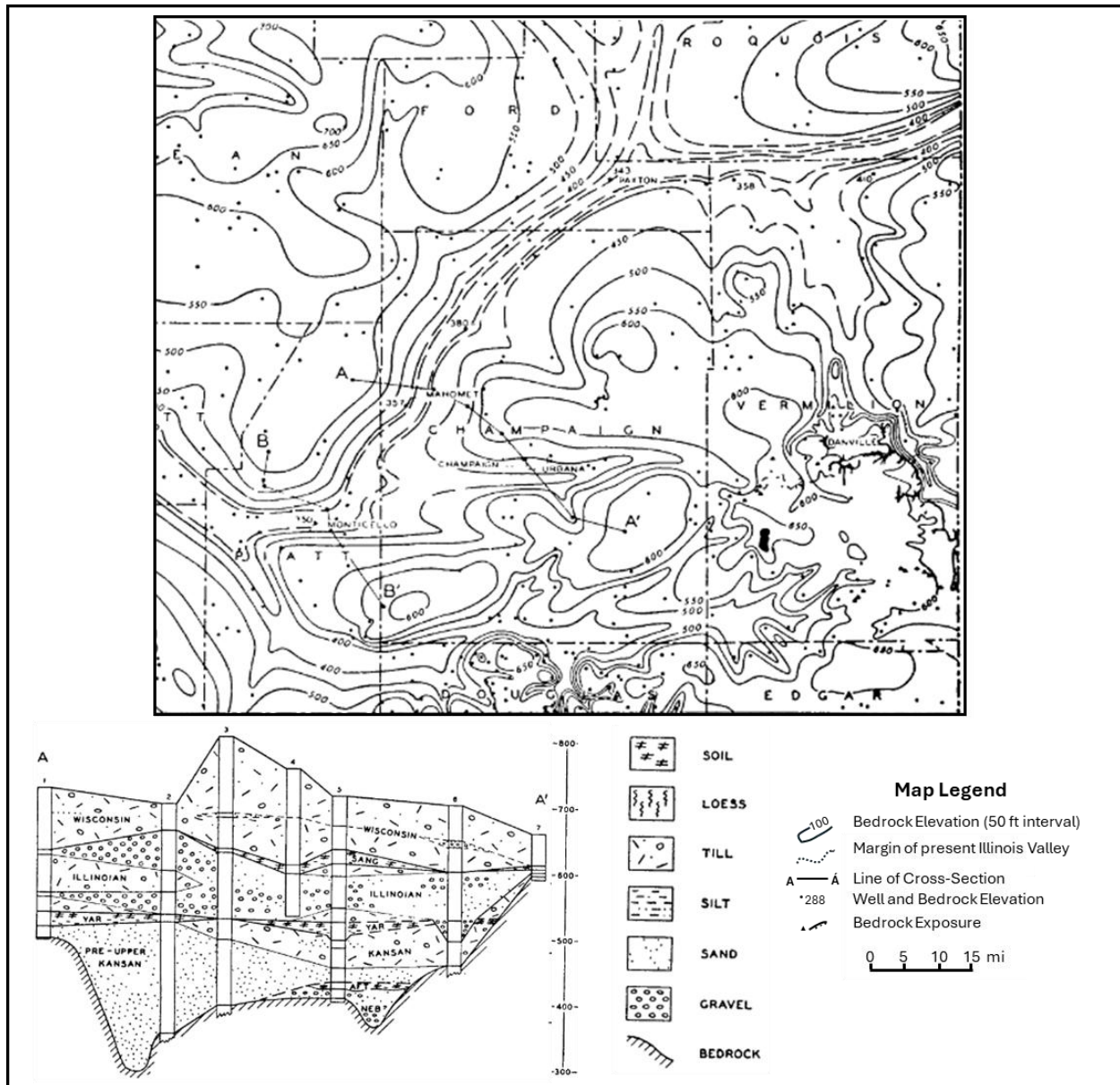


Figure 1. Bedrock topography and geologic cross section of glacial deposits in east-central Illinois. The course of the Mahomet Bedrock Valley (MBV) shows prominently on the bedrock surface in cross section the sediments deposited during the Wisconsin, Illinoian, and pre-Illinoian glaciations. Figure modified from Horberg, 1945.

Several glaciations have impacted Illinois over the past 1 million years. The glaciations are named the Wisconsin Episode (60,000–14,700 years ago), the Illinoian Episode (200,000–130,000 years ago) and the pre-Illinoian Episode ~1,200,000–420,000 years ago). The glacial sediments that infill the MBV are generally associated with Illinoian and pre-Illinoian Episode glaciations (Stumpf and Atkinson, 2015). The sediments from these glacial events differ in lithology, thickness, and extent, which has been used to help categorize them into different, mappable, geologic (lithostratigraphic) units (Kempton et al. 1991; Stumpf and Dey 2012). For example, deposits of pebbly, medium to coarse sand and gravel often found along the lowest part of the

MBV, deposited during earliest (pre-Illinois Episode) glaciation, have historically been associated with the Mahomet aquifer, which is the primary groundwater resource for 15 counties in the east-central Illinois. Although the geological heterogeneity in the MBV has been described in numerous geologic and hydrogeologic reports (for example, Kempton et al. 1991; Langenheim and Nelson 1992; Visocky and Schicht 1969; Herzog et al. 1995, 2003; Berg and Abert 1994; McLean et al. 1997; Soller et al. 1999; Wilson et al. 1998; Roadcap et al. 2011; Stumpf and Dey 2012 and Stumpf and Atkinson, 2015; Brown et al. 2018). Our understanding of its origins and subsequent burial is continually evolving as new data are obtained and analyzed.

1.2 Problem

Given the need to improve our understanding of the available groundwater resources in Champaign County and the flow of groundwater within the Mahomet aquifer and other aquifers in the area, Champaign County contracted Illinois State Geological Survey (ISGS) to complete a high-resolution geophysical study of the Mahomet aquifer within the jurisdiction of Champaign County. The long-term sustainability of available groundwater resources is a growing problem in many regions of the United States due to excessive groundwater withdrawals (Konikow 2015). Increased withdrawals are generally a function of population growth, increased frequency of droughts, industrial growth, and increased agricultural demand (e.g., Alley et al., 1999). In 2015, groundwater extraction from 66 principal aquifers (as defined by the U.S. Geological Survey) in the United States totaled 79,200 Mgal/d (Lovelace et al. 2020). Of the water withdrawn from these principal aquifers, 81% (63,900 Mgal/d) was from unconsolidated and semi-consolidated sand and gravel aquifer systems. Thus, glacial sand and gravel aquifers found in buried bedrock valleys are an important subset of the unconsolidated aquifers (Figure 1). In east-central Illinois, the Mahomet aquifer supplies approximately 220 Mgal/d of water to communities, agriculture, industry, and rural wells in a region having a total population of ~1 million people (Ammons et al. 2018). Improving our understanding of the 3-dimensional (3-D) geometry of the sediments filling the MBV, the distribution and complexity of the Mahomet aquifer, and the connections to adjacent watersheds and geologic formations is one of the best ways to improve long-term planning of our groundwater resources.

Results from this project are used to create integrated predictive models that can be used to improve the accuracy of groundwater models for improved resource management and protection. Collectively, this work will provide support for sustainable water-supply planning strategies that protect public health and help grow local economies when impacted by increased water demand due to population growth (Figure 2), changing climate conditions, and other large demand stresses (e.g., industrial expansion and data centers). Water security is critical for maintaining community sustainability, public health, and economic security. This project implemented rapid data collection techniques and state-of-the-art science-based data analysis methodologies to better resolve the boundaries and internal complexities of aquifers. The results of this project also provide a critical basis for water managers and stakeholders to ensure the security of the water supply for such instances ranging from localized over-use to contamination.

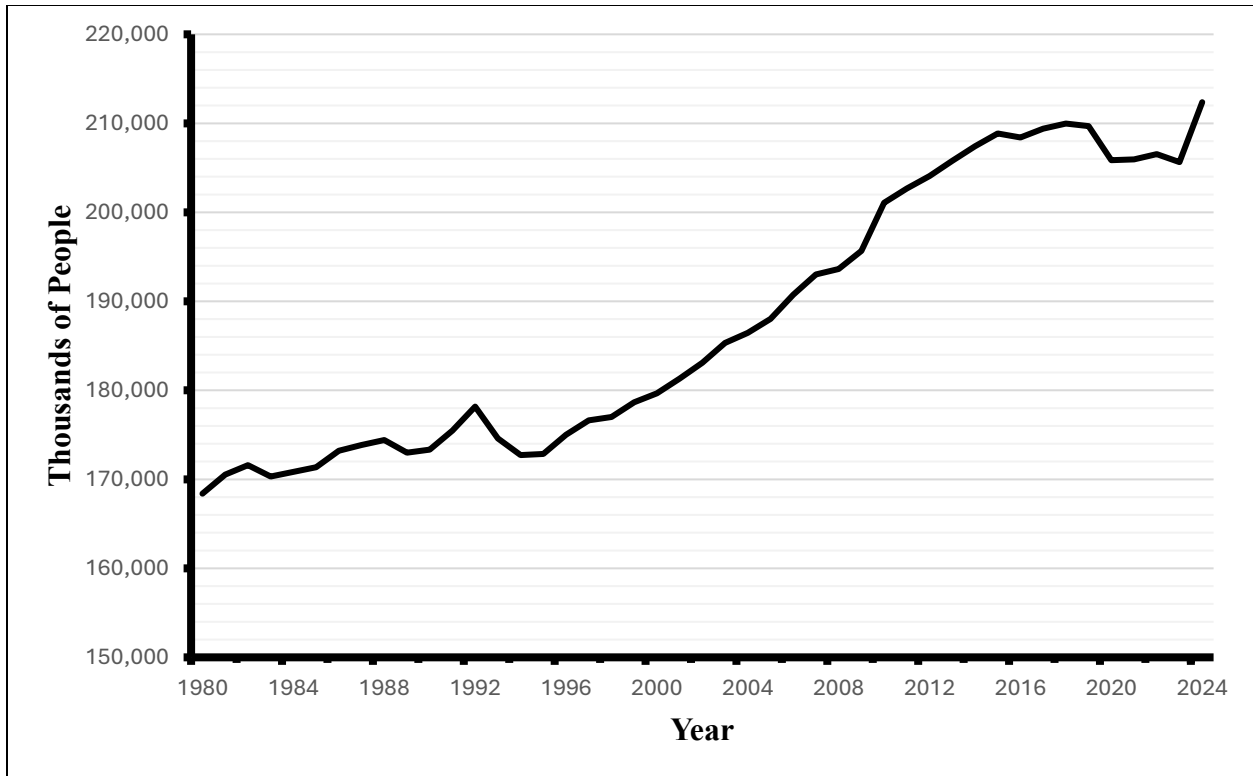


Figure 2. Population in the Champaign-Urbana metropolitan area from 1980–2024. Data are from the U.S. Census Bureau (U.S. Census Bureau 2025).

For years, ISGS scientists and colleagues have focused their time and resources on improving our understanding of the Mahomet aquifer. These studies have included the collection and analysis of high-quality ground-collected data. These data typically include lithological descriptions from drilling logs (Kempton et al. 1991; Stumpf and Dey 2012), borehole geophysical logs (Ismail et al. 2013; Stumpf and Ismail 2013), and electrical and seismic geophysical profiles (Foster and Buhle 1951; Buhle and Brueckmann 1964; Larson et al. 1997; Pugin et al. 2003, 2004). The most recent studies, Soller et al. (1999), Pugin et al. (2003, 2004), Stumpf and Dey (2012), and Stumpf et al. (in review) improved our understanding of the heterogeneity in the geology of the MBV and resolved isolated bodies of sand and gravel that were deposited during the different glacial episodes. However, there are still large portions of the MBV, including many areas where the Mahomet aquifer is present, that have not been studied in detail. Even though decades of research have provided important insights into the geology of the MBV, the data resolution is not uniform (i.e., data points are clustered or far apart). In particular, maps of the local complexities of the MBV are still incomplete. To address these issues, this project used an advanced airborne data collection technology that exponentially increased the data resolution across the MBV area, which drastically improved the resolution of subsurface geologic maps.

2. OBJECTIVES

The sustainable availability of an adequate and high-quality groundwater supply is essential for public health, environmental protection, and economic development. With a growing population (Figure 2) and changing climate, groundwater resources and their supply planning are becoming increasingly complex. This led the Champaign County Board to fund a three-year program for high-resolution mapping of the Mahomet aquifer within Champaign County. Our current understanding of the distribution and characteristics of the Mahomet aquifer in Champaign County is based largely on information collected from drilling and some ground-based geophysics, for example electrical resistivity and seismic data, reported by Stumpf and Dey, (2012), Ismail et al. (2013) and Stumpf and Ismail (2013). This approach has been used in geologic mapping for decades but is limited by low resolution and a sparse dataset. While information obtained from drilling is the most accurate, significant distance between boreholes adds a degree of uncertainty to the interpolation upon which the resulting maps and models are based.

This project focused on the use of state-of-the-art airborne geophysical mapping technology to greatly improve data resolution and subsurface information associated with the Mahomet aquifer. Thus, these data were used to greatly improve the resulting geological mapping, geological models and, especially, the hydrogeological framework of the Mahomet aquifer. The major objectives of this project were to:

I. **Improve delineation of the Mahomet aquifer boundary**

There are currently two published boundaries: (1) Mahomet Aquifer System, defined by the U.S. Environmental Protection Agency (USEPA) in its 2015 sole-source designation (USEPA, 2015); and (2) Mahomet aquifer defined by the Illinois State Water Survey (ISWS) (Roadcap et al. 2011), currently used to constrain regional groundwater flow models within the MBV, and coincides with the top of the MBV and Mahomet aquifer. This boundary historically has been delineated by the 500-foot elevation contour line. However, a few studies of the Mahomet aquifer for Champaign County and other parts of east-central Illinois (Kempton et al. 1991; Stumpf and Dey 2012) have interpreted the Mahomet aquifer to extend above the 500-foot elevation contour. Most recently, a third Mahomet aquifer boundary was interpreted in Champaign County through use of traditional and ground-based 3-D mapping methods. While this is an informal boundary (i.e. not for public use) that has not been published or undergone administrative review by the ISGS, it includes additional modifications to the USEPA 2015 and Roadcap et al. (2011) boundaries. The high-resolution geophysical data acquired for this project will be used to better delineate the boundary of the Mahomet aquifer.

II. **Better define extent of aquifer and non-aquifer units**

Understanding the detailed character of the geologic materials found over the MBV is key to understanding the storage capacity and possible groundwater flow patterns. Studies done in east-central Illinois by both the ISGS and ISWS on the Mahomet aquifer

have repeatedly demonstrated the presence of layers of non-aquifer materials within the deposits considered to compose the upper and Lower Glasford Aquifers and the Mahomet aquifer. For example, the complex nature of the glacial deposits overlying the bedrock surface is well documented by Stumpf and Dey (2012) and Stumpf and Atkinson (2015). Furthermore, Stohr et al. (2015) demonstrated the complexity of aquifer materials within the glacial sequence of the Illinois Episode that are analogous to the pre-Illinois Episode glacial deposits that infill the MBV (Figure 3). These results are used to improve our understanding of the distribution and proportions of non-aquifer and aquifer units within the Mahomet aquifer.

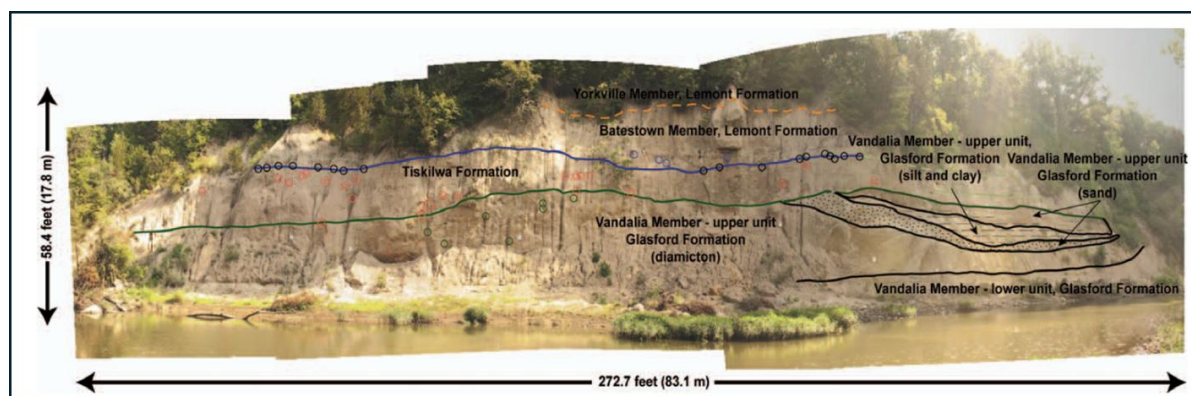


Figure 3. Glacial deposits outcropping along the Middle Fork Vermilion River, Illinois (from Stohr et al. 2015). Buried channels filled with sand and gravel within non-aquifer deposits were assigned to the upper part of the Glasford Formation.

III. Develop a 3-D geological model of the Champaign County and create an updated geological framework

A detailed geologic model of east-central Illinois, including the area underlain by the Mahomet aquifer was developed by Stumpf and Dey (2012). The geological framework accompanying the model incorporated data and interpretations compiled from geological and geophysical studies completed in Champaign County and surrounding areas between 2007 and 2012. This geological framework incorporates aspects of previous lithostratigraphic classifications from Hansel and Johnson (1996), Kempton et al. (1991), Willman and Frye (1970), and Willman et al. (1975). The geologic model developed by Stumpf and Dey (2012) is the most recent depiction of the Mahomet aquifer and used the most updated datasets available at that time.

The data collected for this project will help update the geological framework of Stumpf and Dey (2012) by filling in the large gaps in data between boreholes and ground-based geophysical surveys and increasing the resolution of the geological framework and the estimated proportions (scenarios) of non-aquifer and aquifer units, respectively. These results include a new map of the bedrock topography in Champaign County. Lastly, in collaboration with ISWS, the results from this project (i.e., various iterations of the geologic model) will be used in updating the regional groundwater flow model that guides the water-supply planning effort in Champaign County.

3. PROJECT AREA

3.1 Previous Work

During the last half century or so, our understanding of the subsurface geology in east-central Illinois has evolved with the collection of borehole and geophysics data (both ground-based and downhole) as part of formal scientific studies and resource exploratory work. These findings are the basis of regional geologic classifications for glacial Pleistocene deposits (e.g., Kempton et al. 1991) and Paleozoic sedimentary bedrock (Langenheim and Nelson 1992). In addition, they are used to delineate and characterize water and mineral resources that are the backbone of the region's social and economic prosperity.

Since the mid-twentieth century, significant research has been undertaken to determine the formation, extent, and characteristics of the MBV and the associated Mahomet aquifer (e.g., Visocky and Schicht 1969; Herzog et al. 1995, 2003). These periodic re-evaluations were undertaken to study drought events and applications for increasing groundwater withdrawals from the Mahomet aquifer.

By the 1970s and 1980s, GIS technologies were introduced for 2-D and 3-D geologic model development and visualization (Berg and Abert 1994; McLean et al. 1997). These studies provided an extensive information base for future cooperative mapping projects (e.g., Soller et al., 1999). Furthermore, in 1993, cooperative studies were undertaken to determine hydrogeological characterization of the glacial deposits (Herzog et al. 1995), and development of a computer-based mathematical model of groundwater flow (Wilson et al. 1998). The ISWS later constructed a larger, regional numerical groundwater flow model of the entire Mahomet aquifer (Roadcap et al. 2011). Subsequently, Stumpf and Dey (2012) and Stumpf and Atkinson (2015) made significant advances in characterizing the MBV and its valley fill by integrating newly acquired data with historical records. A revised geological framework was developed for east-central Illinois.

3.2 Geology

The Mahomet aquifer area was glaciated multiple times during the Pleistocene Epoch over the last ~1.2 million years. The glacial sequence, formed from the three glacial episodes, is 200–400 feet thick and completely conceals the deeply dissected bedrock surface, which is a major unconformity directly beneath the glacial deposits (Kempton et al. 1991) (Figure 1). The glacial episodes were preceded by the Pliocene–Early Pleistocene preglacial period, interspersed with warmer interglacial periods (Yarmouth and Sangamon Episodes), and followed by a postglacial period known as the Hudson Episode or Holocene Epoch (Curry et al. 2011). During the nonglacial times, drainage continually adjusted to meet new river base levels, alluvium and lacustrine sediments accumulated in valleys and low-lying areas, and pedological processes formed well-developed soils in thick deposits on the land surface. Surficial sediments were reworked by the actions of wind and water on the land surface.

Land surface topography in Champaign County (Figure 4) is also defined by the action of wind and water and ice. The advances and retreats of multiple ice margins formed till and clay ridges (moraines) and lowland river valleys, some of them filled with sand and gravel, till and silt. These features bear no direct relation to the MBV and bedrock topography in general, and they cross MBV at various angles without change in trend or elevation. The main uplands we see in Champaign County, are the Gifford, Rantoul and Champaign Moraines (Figure 4), predominantly made up of till and clays. The lowlands include portions of two major river valleys in Champaign County. The Sangamon River Valley, in the northwest part of the county, and the Middle Fork River Valley, in the northeast-most part of the county.

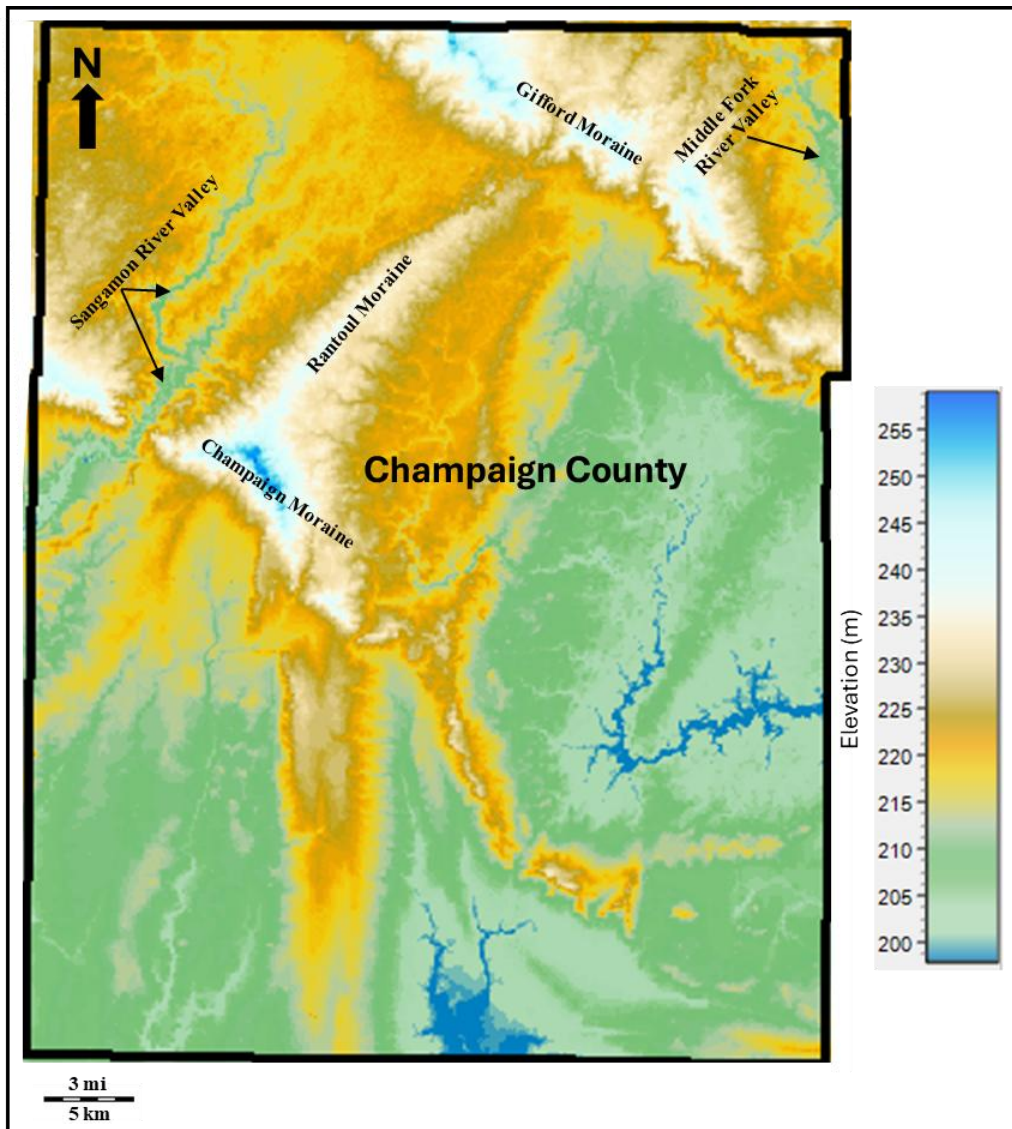


Figure 4. Digital Elevation Model (DEM) of Champaign County.

3.3 Geological Framework

The geological framework of Champaign County was developed considering geological framework models for east-central Illinois by Stumpf et.al., (in review), Stumpf and Dey (2012), Hansel and Johnson (1996), Willman et al. (1975), and Willman and Fyre (1970). The geological framework for Champaign County includes sedimentary bedrock units, Silurian to Pennsylvanian in age, which are mostly dolomites, shales, and siltstones, Pleistocene-age glacial deposits, and Holocene postglacial deposits. In general, glacial deposits in Champaign County are made up of diamicton (till), silt, clay (lake sediment), and sand and gravel (outwash). These deposits are differentiated based on their physical characteristics (e.g., color, lithology, and mineralogy), stratigraphic position, and age (Kempton et al. 1991; Soller et al. 1999; Stumpf and Dey 2012). In postglacial times, loess (windblown silt and sand) was deposited across the land surface, and alluvium (silt, sand, and gravel) was deposited in river valleys and low-lying areas on uplands (Grimley et al. 2016).

The geological framework includes six geologic units (A to F in vertical profile) from the land surface into the Silurian-age bedrock. **Unit A** represents the postglacial deposits and uppermost glacial deposits of the Wisconsin Episode glaciation, including glacial tills of the Yorkville and Batestown Members (Lemont Formation) and the Tiskilwa Formation, and lake sediment and outwash of the Equality Formation and Henry Formation, respectively. The unit also includes outwash assigned to the Pearl Formation deposited during the Illinois Episode glaciation. **Unit B** comprises dolomite-rich sandy glacial till with layers of sand and gravel, and silt and clay deposited during the Illinois Episode glaciation that were assigned by Stumpf and Atkinson (2015) to the upper and middle units of the Vandalia Member (Glasford Formation).

Unit C includes silty glacial till (lower unit) of the Vandalia Member (Glasford Formation), local deposits of silt and clay of the Bellflower tongue (Teneriffe Silt), and deposits of well-sorted sand and gravel, assigned to the Grigg member (Pearl Formation), that are widespread across the MBV and on the adjacent uplands. **Unit D** comprises the clayey tills of the Tilton, Hillery, Harmattan and West Lebanon Members (Banner Formation) deposited during the pre-Illinois Episode glaciation. They overlie or are interstratified with thick deposits of well-sorted pebbly sand and gravel assigned to the Fisher and Rantoul members and Mahomet Sand Member (Banner Formation) in the MBV, and layers of silt, clay, and sand (lacustrine deposits) assigned to the Pesotum, Belgium and Blackford Members (Banner Formation) in the tributary valleys.

Unit E is assigned to the gray, massive to vuggy, finely crystalline dolomite, Silurian or Devonian in age, that subcrop on the Mahomet Dome or Rantoul Anticline (Nelson, in press), structural features of the LaSalle Anticlinorium. **Unit F** is distinguished in the HTEM data, and comprises shales, siltstones, limestones, and claystones of Pennsylvanian to Devonian in age that subcrop along the flanks of the LaSalle Anticlinorium and in the southern and eastern parts of the Champaign County (Nelson, in press). This unit also includes the discontinuous preglacial deposits assigned to the Canteen and Dewitt members and weathered bedrock (residuum) of the Oak Formation. These lowermost Pleistocene-age units are included in Unit F because of similar resistivity values, and it is difficult to identify the contact between the lowermost clayey glacial

till of the Banner Formation and soft and friable weathered surface of the Pennsylvanian-age shales.

3.4 Hydrostratigraphic Framework

The hydrogeology of Champaign County is complex due to the horizontally and vertically heterogeneity between deposits of coarse-grained sand and gravel (aquifer units), and fine-grained, overconsolidated glacial till or deposits of glaciolacustrine silt and clay (non-aquifer, confining units) (Roadcap et al. 2011). Accordingly, aquifers in contemporaneous geologic units can be limited in one area and productive in other areas. Also, aquifers in some places can overlap one another and can be hydraulically connected with each other.

A hydrostratigraphic framework was developed to organize complex and often discontinuous glacial sediments into units with similar hydraulic properties (aquifers and confining units) for use by the ISWS to update the regional groundwater flow model for northeastern Illinois. Grouping hydraulic parameters may be justified for developing regional groundwater-flow models as this may not appreciably sacrifice simulation accuracy (Arihood et al. 2019).

In developing a framework to support the groundwater-flow simulations in the unconsolidated glacial deposits and sedimentary bedrock, ten aquifer and confining units were designated to comprise the six geologic units defined in Section 3.3. The uppermost, **Shallow confining unit**, includes the glacial tills and intervening fine- and coarse-grained sediments and postglacial sediments assigned to Unit A. The **Shallow aquifer** includes the deposits of coarse-grained sand and gravel of the Mason Group (Abrams et al. 2023), including the Ashmore Tongue (Henry Formation), the first coarse-grained sand and gravel deposited during the Wisconsin Episode glaciation, and outwash assigned to the Pearl Formation. The **Upper Middle confining unit** comprises Unit B and lowermost glacial till and fine-grained sediments of Unit A. The **Upper Middle aquifer** includes the intervening layers of coarse sand and gravel of the glacial till assigned to Unit B and well-sorted sand and gravel (Pearl Formation) assigned to Unit C. This aquifer unit would be partly analogous to the upper Glasford Aquifer of Wilson et al. (1998).

The **Lower Middle confining unit** comprises the glacial till of the Glasford Formation and uppermost glacial tills of the Banner Formation and their associated fine-grained sediments of Units C and D, respectively. The **Lower Middle aquifer** is primarily the well-sorted sand and gravel of the Griggs tongue (Pearl Formation) assigned to Unit C and may also include the well-sorted pebbly sand and gravel of the Mahomet aquifer (Unit D). This aquifer is likely analogous to the Lower Glasford Aquifer of Wilson et al. (1998). The **Mahomet confining unit** includes the glacial tills of the Banner Formation and their associated fine-grained sediments (Unit D), and in places silty glacial till (lower unit) of the Vandalia Member and deposits of silt and clay of the Bellflower tongue (Unit C). The **Mahomet aquifer** is primarily the well-sorted pebbly sand and gravel of the Mahomet aquifer (Unit D). In places where the finer-grained sediments of the Mahomet confining unit are absent, Unit D may include the well-sorted sand and gravel of the

Pearl Formation (Unit C). This unit is most likely analogous to the Mahomet aquifer of Herzog et al. (1995).

The **Carbonate confining unit** includes Pleistocene-age preglacial deposits, and shales, siltstones, limestones and claystones of Pennsylvanian- to Devonian-age assigned to Unit F. The **Carbonate aquifer** includes the ridge-forming Silurian and Devonian dolomite of Unit E.

4. METHODS

This project focused on the collection of high-resolution helicopter-based geophysical data and the use of advanced modeling methods to create improved models of aquifer material distribution throughout most of Champaign County. This involved the collection, processing, and interpretation of approximately 3,145 km (1,954 miles) of helicopter time-domain electromagnetics (HTEM) data within the Champaign County boundaries. The HTEM data-collection boundaries are the Ford County/Champaign County border in the north, and between County Road 500 and County Road 400, north of the Village of Pesotum (Figure 5, green line) in the south. Along the 79 flight lines, more than 57,600 soundings were collected. Each sounding contains 40 resistivity values, resulting in more than 2.3 million individual resistivity values across the project area.

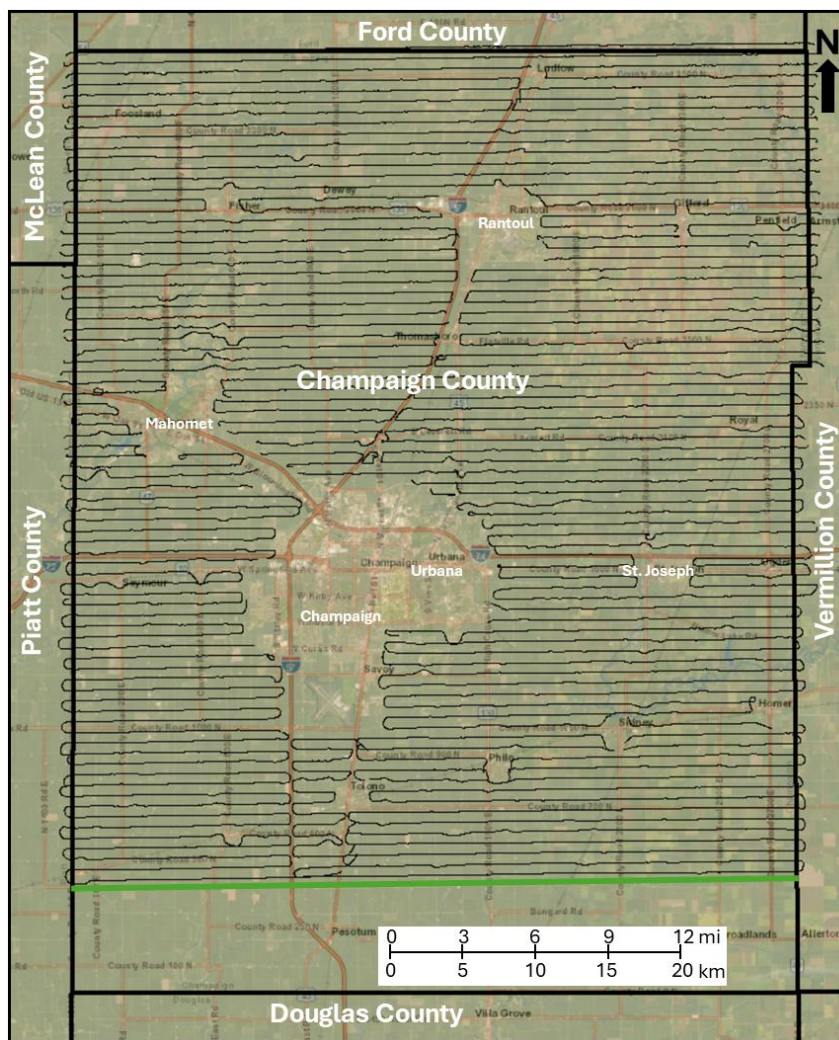


Figure 5. HTEM flight lines in Champaign County. Data were collected along 79 flight lines spaced at ~2,132 feet (650 m), from the Ford-Champaign County border to between County Road 500 and County Road 400, north of Pesotum. The green line shows HTEM data extent in southern Champaign County.

In addition to the HTEM data, funding was provided for the collection of other high-quality data : 1) ground-based geophysics data (i.e., seismic reflection profiles; 2) horizontal-vertical spectral ratio (HVSR) observation points; 3) electrical resistivity tomography (ERT) profiles); 4) drilling-based core sample descriptions; and 5) geophysical borehole data (Figure 6). Together, these data were used to develop the new, high-resolution 3-D model of aquifer and confining unit distribution (see Section 3.4 Hydrostratigraphic framework).

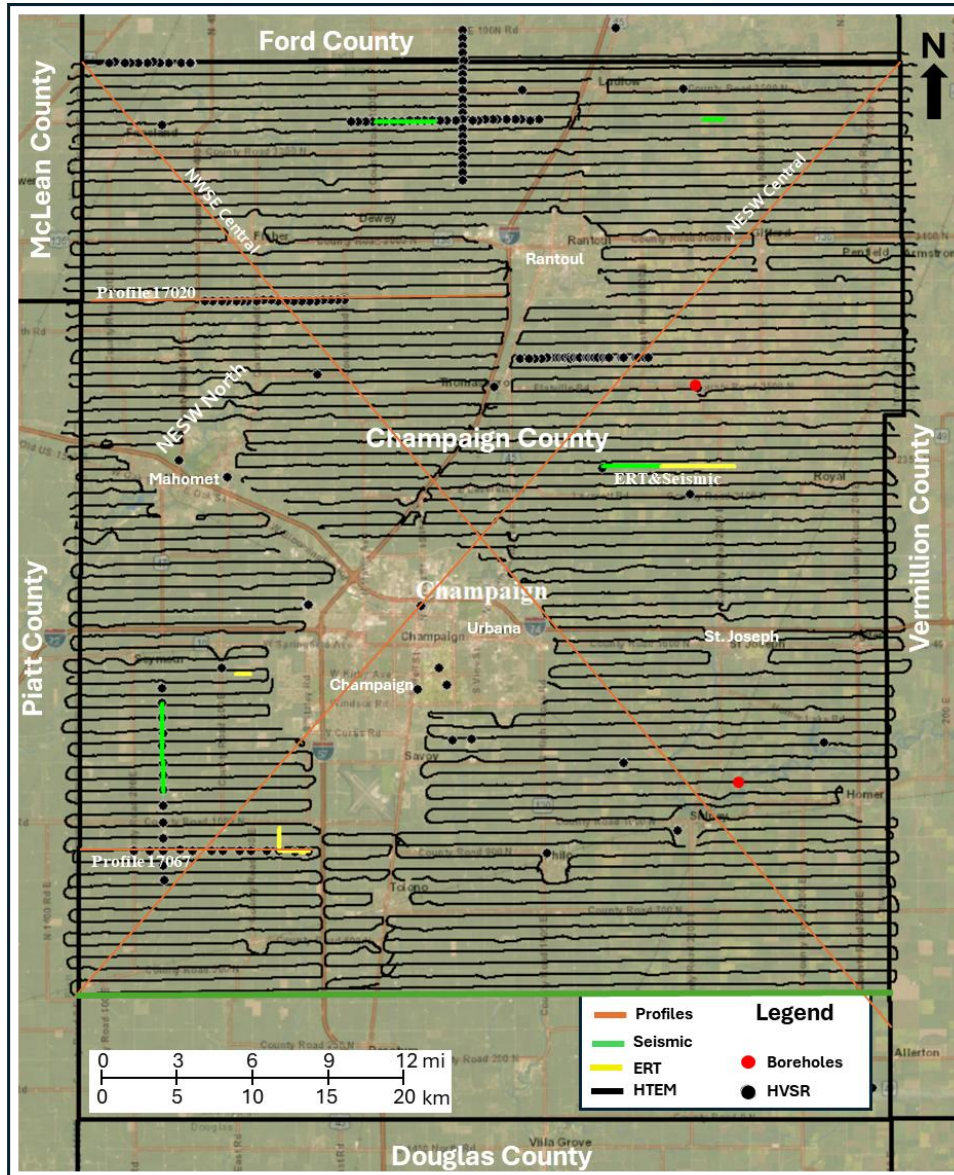


Figure 6. Additional ground-based geophysical data collection in Champaign County between 2023 and 2024. A total of 4.32 mi of ERT data (yellow lines) were collected along some HTEM lines. Seismic data (green lines, 9.72 miles) were co-located with both ERT, HTEM and HVSR (black dots) data. The orange lines present selected 2-D profiles of various data discussed below. The green line shows HTEM data extent in southern Champaign County.

All of the newly acquired and existing ground-based geophysical data and borehole information were used to improve the processing and interpretation of the HTEM data, and to provide information on the geometry of the Mahomet aquifer in the areas not accessible by the HTEM method (e.g., urban areas including the cities of Champaign and Urbana and the villages of Mahomet, Rantoul, etc.).

4.1 Field-Data Compilation and Collection

4.1.1 Helicopter Time-Domain Electromagnetics (HTEM)

The airborne geophysical characterization in Champaign County involved the collection of HTEM data, which over the full 3,000+ km of flight line, produced millions of individual resistivity observations throughout the shallow subsurface. For this project, we contracted with SkyTEM Canada Inc., an international leader in the collection of high-resolution HTEM data. SkyTEM's acquisition system includes a dual-moment configuration that uses two concurrent EM pulses to image the subsurface at two different depth intervals (Sørensen and Auken 2004). The dual-moment HTEM system is designed to target both shallow and deeper subsurface deposits at a higher resolution than traditional HTEM systems. The use of dual-moment data for this project allows us to identify and interpret deposits throughout the upper 200–400 feet (60–120 m) below ground surface.

The HTEM (and ERT) methods measure variations in electrical resistivity in the subsurface. The measured resistivity (with units in ohm meters) is a bulk physical property of subsurface geologic materials that describe the resistance of an electrical current through the material (Figure 7). Electrical resistivity correlates well with several physical and chemical properties of these geological materials, including particle size, texture, bulk density, and ionic content (salinity) of pore water. Thus, two-dimensional (2-D) electrical resistivity measurements can be correlated with subsurface geologic material(s) (Figure 7). Different physical characteristics of specific rock types and variations in fluid saturation, porosity, clay mineral quantity (i.e., fraction) within a rock type all affect resistivity and are often investigated with the use or application of these geophysical methods.

The SkyTEM airborne HTEM system was mounted on a frame suspended about 40 m below the helicopter and was flown at a height of 36 m above land surface (Figure 8) or land-based objects (e.g., powerlines, trees). The helicopter was flown at an average of 60 miles/h (96.7 km/h), depending on the wind conditions during data collection. Observations were collected every ~33–98 feet (~10–30 m) along the flight transect. This spacing of data was selected because it is sufficient to characterize high-resolution horizontal variations in sediment types throughout the project area. The raw HTEM data received from SkyTEM were processed and inverted using Aarhus Workbench software. Data processing, inversion, and interpretation were completed by ISGS scientists.

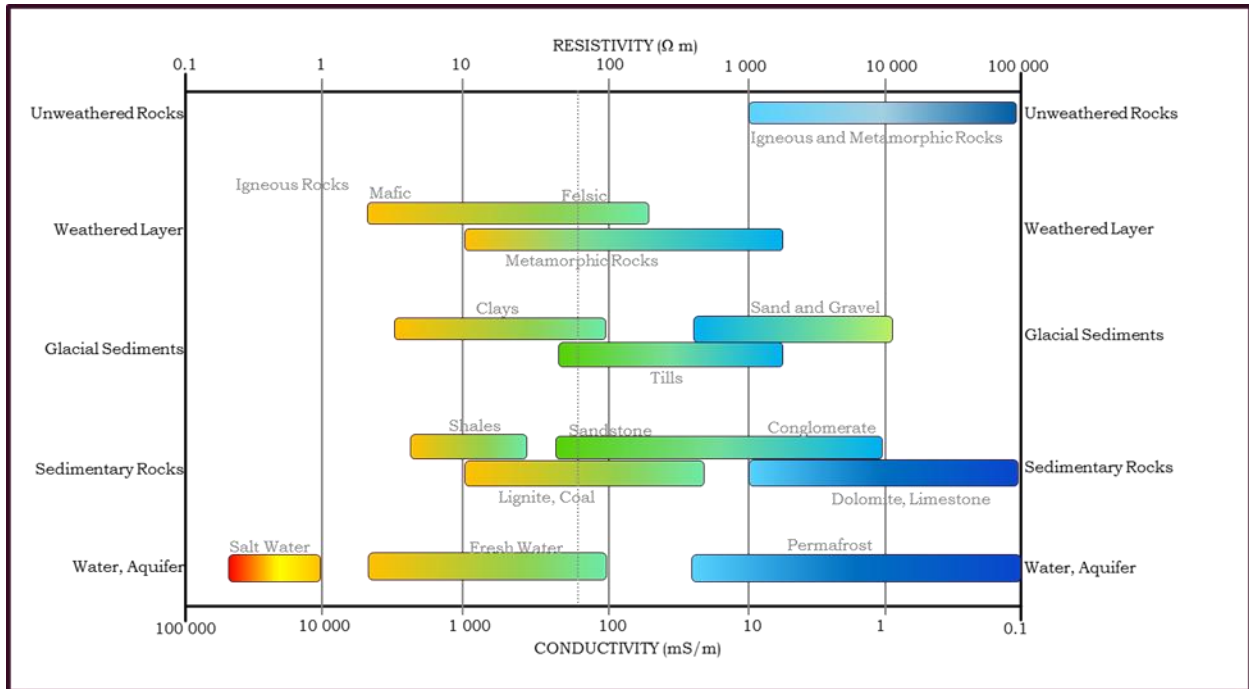


Figure 7. Resistivity range for various geologic materials (figure modified from Palacky 1987)

4.1.2 Electrical Resistivity Tomography (ERT)

As opposed to the helicopter-borne measurements in HTEM, resistivity measurements in ERT profiles are made by transmitting a direct current into the ground through a pair of electrodes (i.e., metal spikes) and measuring the resulting voltage using another pair of electrodes (Figure 8). The measured current and voltage are then converted into resistivity using a sequence of equations that consider the configuration of the electrodes on the ground. The resistivity distributions from ERT profiles, like HTEM resistivity distributions, are used to infer the characteristics of the geologic materials in the shallow subsurface.

For long 2-D profiles, a desired number of electrodes connected to a multi-core cable are laid out on the ground (Figure 8) and multiple measurements are carried out simultaneously and in rapid succession at different locations and depths along the profile to make a complete image of the subsurface. This is accomplished by switching electrodes which are taking measurements forward along a profile, and by increasing the separation between active electrodes to increase the depth of investigation. The depth of investigation of an ERT survey is the function of the spacing between electrodes. The aim of an overall process is to measure the resistivity of a dense network of points that can be used to create a (2-D) cross section of subsurface resistivity. ERT interpretations, supported by borehole data or alternate geophysical data, can accurately represent the geometry of the lithology and hydrology of the subsurface.

We acquired a total of 4.3 miles of ERT data on several roadways in Champaign County in the summer of 2023 (Figure 6 and Table 1). These profiles were collected to provide a secondary data source to the data acquired using the HTEM method. The goal was to use the ERT data to help validate the HTEM data. For all profiles collected in Champaign County, a dipole-dipole

ERT configuration was used. Profiles of continuous resistivity measurements were obtained every 5 meters, estimating resistivity values to depths of approximately 300 feet (100 m).

Table 1. ERT Survey Summary, Champaign County

Profile	Length (km)	Length (miles)
1500N	0.8	0.50
2200N	3.995	2.48
900N	1.565	0.97
700E	1.400	0.87
Total	6.960	4.32

4.1.3 Seismic Reflection Surveys

Seismic reflection methods have been used for mapping bedrock and overlying sediments for decades. Seismic reflection surveys measure the propagation of velocity and amplitude of seismic waves in the subsurface. There are two groups of seismic waves: 1) body waves which can travel through the subsurface and 2) surface waves that travel across the land surface. Body waves include compressional (P) and shear (S) waves. P-waves are the fastest type of seismic wave, and their movement is parallel to the direction of wave propagation. P-wave velocity depends on both the texture of the unconsolidated sediments or bedrock and the infills of pore space. Shear waves are slower than P-waves and travel perpendicular to the direction of wave propagation. S-wave velocity depends only on the properties of sediment or bedrock.

The strength of seismic reflection waves depends on the acoustic impedance contrast, which is fairly significant between the bedrock and the overlying sediments. The seismic reflection method also can differentiate between sediment having high clay and sand contents if the deposits they comprise attain a sufficient thickness, typically greater than 20 feet (6 m) thick. In addition, seismic reflection data can be collected more quickly than other geophysical methods, especially along easily accessible roads and trails. For example, data can be collected along one mile of road in one day using the Landstreamer seismic reflection acquisition system manufactured by the ISGS.

Seismic reflection surveys were conducted in the summer of 2024 by students and ISGS employees. A total of 15.66 kms (9.72 miles) of P-wave seismic reflection data were acquired (Table 2) as follows; Line 1 on County Road 300 E between County Road 1400 N and County Road 1100 N; Line 2 on County Road 2200 N between County Road 1800 E and County Road 2200 E; Line 3 on County Road 3400 N between County Road 1000 E and County Road 1200 E; and Line 4 on County Road 3400 N between County Road 2100 E and County Road 2200 E. The main objectives of these P-wave surveys were: 1) to map the bedrock topography in the project

area and compare these results with what was obtained from the HTEM and other geophysical data; and 2) characterize the sediments overlying the bedrock.

Table 2. Seismic Survey Summary, Champaign County

Line Number	Length (km)	Length (miles)
Line 1 – County Road 300 E	4.85	3.01
Line 2 – County Road 2200 N	6.44	4.00
Line 3 – County Road 3400 N	3.29	2.04
Line 4 – County Road 3400 N	1.08	0.67
Total	15.66	9.72

4.1.4 Horizontal-Vertical Spectral Ratio (HVSr)

The HVSr method is a 1-D seismic technique that makes use of naturally occurring ground vibrations (i.e., seismic noise) to delineate depth to different geological materials, especially depth to bedrock. These ground vibrations are produced by a combination of wind waves, long-period ocean waves, and locally, industry and vehicle traffic noise. Highly sensitive, 3-channel seismometers are used to record background vibrations in an area over a period of about 20 minutes (Figure 8). In order to capture the three-dimensional character of the vibrations, recordings are made in three directions: up/down, north/south, and east/west. Except for the occasional passing of a vehicle, the signals appear to be just random vibrations, white noise. By using advanced signal processing techniques, we can glean useful hydrogeologic information.

To extract the signal from the noise, the seismic recordings are first converted to spectra and then the amplitudes of the three components are compared, frequency-by-frequency. Over most of the spectrum the signal is noise; the amplitudes of the horizontal and vertical components are the same. But at a specific frequency there is resonance; the amplitude of the horizontal component becomes greater than the vertical component. This resonant peak is a proxy for depth to a change in the subsurface geological material. Due to their differing physical properties, the most abrupt changes in seismic character in Illinois are often at the interface between bedrock and the overlying unconsolidated material, enabling the finding of depth to bedrock and, with some awareness of the regional geology, a basic understanding of lithology.

A total of 180 HVSr points were collected in Champaign County between the summers of 2023 and 2025. These data were collected to equally cover the HTEM, ERT, and seismic study areas, including areas not covered by other geophysical data.

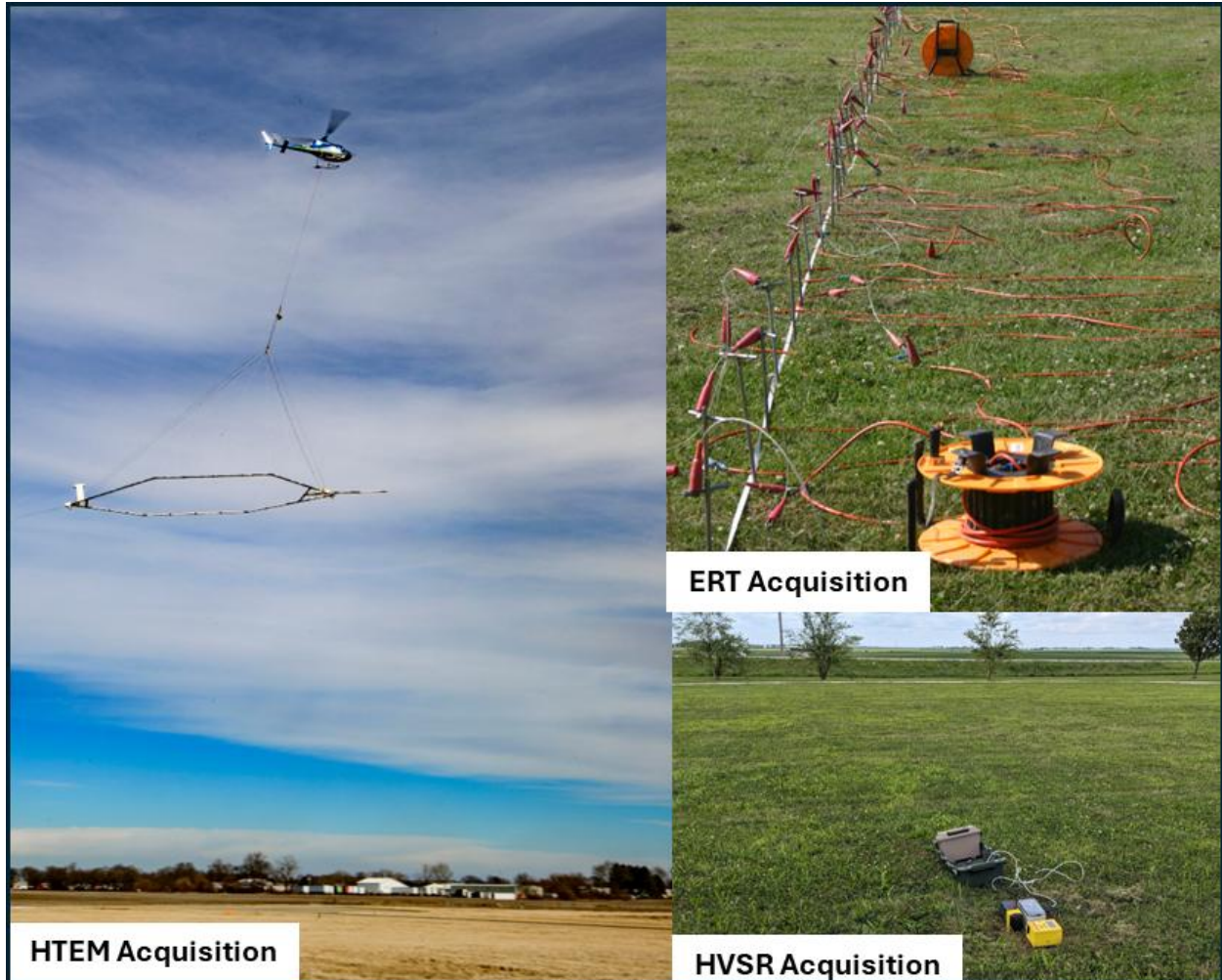


Figure 8. Instrumentation used in acquiring new HTEM, ERT and HVSR data in Champaign County.

4.1.5 Drilling

Boreholes have been used for decades as the most valuable source of information during geological mapping. Analysis and interpretation of the information obtained from boreholes can reveal mappable relationships between geologic units in the subsurface. While the most accurate source of information, boreholes are limited in their value because they only observe a discrete volume of the subsurface, effectively providing a vertical (1-D) description of geological information at the borehole location. Depending on the size of the project area, several boreholes, drilled at strategic locations, can be used for geological mapping and/or ground-truthing of other data types. For this project, two boreholes were drilled near the unincorporated area of Flatville and Town of Sydney, Illinois (Figure 6), to ground-truth the HTEM and other geophysical data. The Flatville borehole was selected to ground-truth HTEM data located within the Mahomet Bedrock Valley, while the Sydney location was selected to ground-truth data outside the bedrock valley. Boreholes extending from the land surface to bedrock (77.72 m in Flatville and 60.35 m in Sydney) were drilled to collect geological cores and/or samples (Figure 9) of glacial and nonglacial sediment and bedrock. The cores and samples were used to examine

the physical characteristics of the drilled geological material. Table 3 and Table 4 present geological information from drilled cores and/or samples from Flatville and Sydney, respectively.

Together with core sample collection, downhole geophysical measurements were acquired to support the geological description of core samples and also to support other surface geophysical methods. One of the most common and reliable downhole geophysical logging methods used, particularly within unconsolidated sediments, is natural gamma. Natural gamma logging is a passive method that detects variations in energy emitted from naturally occurring radioactive isotopes (radioisotopes) present within the earth surrounding the borehole. Most natural earth radiation is generated from isotopes of Potassium-40 (^{40}K), and the natural decay series of Uranium-238 (^{238}U) and Thorium-232 (^{232}Th) (Keys 1990; Telford et al. 1990; Kearey and Brooks 1991; Rider 1996). Measurements are collected using a thallium activated sodium-iodide scintillation gamma ray detector located in the bottom half of a probe, which when struck by a gamma ray emits a pulse of light. The light emissions are amplified by a photon multiplier and outputted as a current pulse that is transmitted through a cable to the receiver. The pulses are counted and displayed as counts per second (CPS).

In Illinois, these radioisotopes are more abundant in clay-rich sediments and bedrock (shale and claystone), and less concentrated in well-sorted sand and gravel or carbonate rich materials. In glacial sediments, variability in gamma response is related principally to the matrix clay content and locally to the presence of concentrations of granitic, gneissic, and shale rocks, which are a source of K, U, and Th (Pehme 1984). Consequently, a low natural gamma response generally indicates zones of porous and permeable sand and gravel in unconsolidated sediments, and crystalline limestone and dolomite bedrock.

Table 3. Geologic log from a borehole drilled in Flatville, Illinois (*Drilling began July 17th, 2023, on the site located at Latitude: 40.23928°; Longitude: -88.061668°*)

Depth Top (m)	Depth Bottom (m)	Depth Top (ft)	Depth Bottom (ft)	Description
0	3.05	0	10.00	Silt and clay (with sand lenses)
3.05	9.14	10.00	29.99	Diamicton (silt clay loam)
9.14	18.29	29.99	60.00	Sand and diamicton (interbedded)
18.29	33.53	60.00	110.00	Sand (fine sand)
33.53	42.67	110.00	139.99	Diamicton (silt clay loam)
42.67	76.20	139.99	250.00	Sand and Gravel (coarse)
76.20	77.72	250.00	254.99	Dolomite/Limestone

Table 4. Geologic log from a borehole drilled in Sydney, Illinois (*Drilling began on October 16th, 2023, on the site located at Latitude: 40.045279°; Longitude: -88.038239°*)

Depth Top (m)	Depth Bottom (m)	Depth Top (ft)	Depth Bottom (ft)	Description
0	1.52	0	4.99	Silt and sand
1.52	13.72	4.99	45.01	Till
13.72	15.24	45.01	50.00	Paleosol
15.24	16.76	50.00	54.99	Sand
16.76	18.29	54.99	60.00	Gravel
18.29	21.34	60.00	70.01	Sand
21.34	33.53	70.01	110.01	Till
33.59	51.82	110.01	170.01	Silt and sand
51.82	56.39	170.01	185.01	Shale (weathered bedrock)
56.39	60.35	185.01	197.99	Sandstone/siltstone

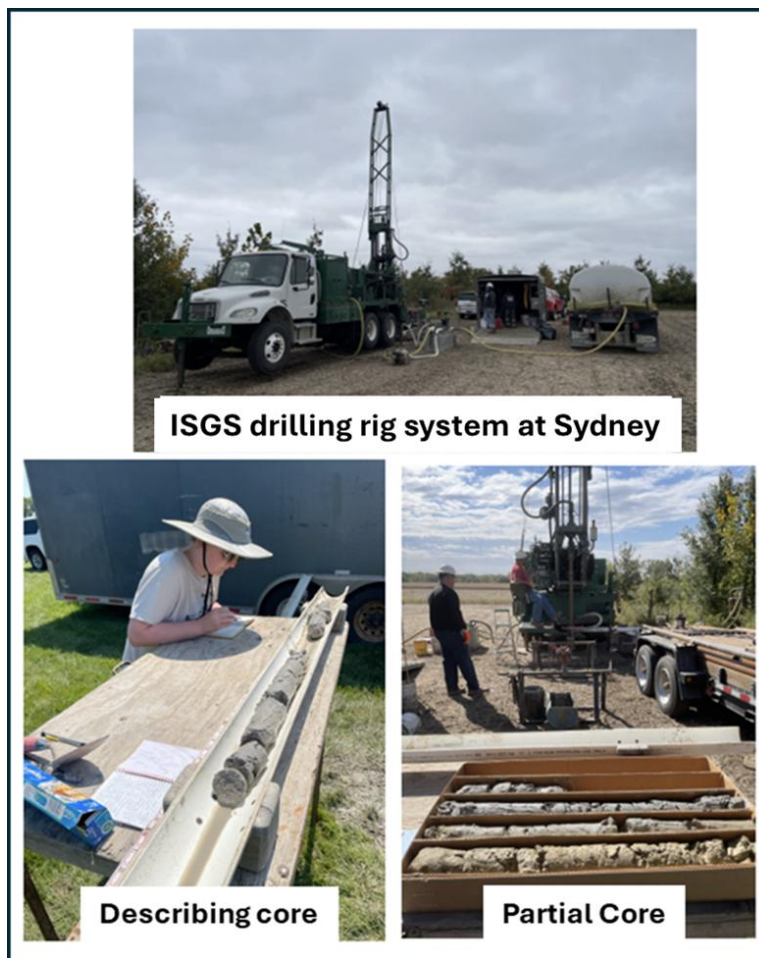


Figure 9. Photos of drilling and core/sample analysis in Sydney, Illinois. Core samples were collected for analysis from surface to a depth of 77.72 m in Flatville and 60.35 m in Sydney.

4.2 Geological Modeling

4.2.1 HTEM Data Interpretation Process

The process for HTEM data interpretation was based on a new method developed specifically for this project, the Material-Type Characterization (MTC) method (Keefer et al., in preparation). This MTC method involves the combination of multiple sources of geologic knowledge with the observed resistivity values to obtain high-resolution interpretations of material-type distributions throughout the project area. The MTC goal is twofold, to enable a high-resolution interpretation of the HTEM data that captures what is known about the geology, and to enable the creation of multiple, geologically plausible interpretations that are anchored in the data and knowledge, and that express variations captured in conceptual models of material type distribution.

The MTC process starts with the interpolation of the more than 2,300,000 inverted HTEM resistivity values (Figure 10) into a single 3-D cube of resistivity values (Figure 11). The HTEM data distribution is so dense that 3-D interpolation can be configured to create a high-resolution 3-D grid of resistivity values that is anchored to the observations. The cell size chosen for the 3-D models in this project is 100 m × 100 m × 2 m (100 m cell size in the horizontal or N–S and E–W directions, and 2 m cell size in the vertical direction). The full 3-D grid used for this project is 468 cells wide (E–W direction), 522 cells long (N–S direction), and 130 cells high (vertical direction).

Once the resistivity data is interpolated to a 3-D grid, the distribution of resistivity values within the grid is analyzed. The grid is sliced horizontally, from bottom to the top, and the occurrence and changes in resistivity values are noted and summarized. This resistivity summary is further analyzed considering our current knowledge of glacial deposits across Illinois, based on decades of research at the Illinois State Geological Survey (Hansel and Johnson 1996; Grimley and Phillips 2011; Stumpf et. al., in review). This analysis and comparison to the regional geologic history allows for the identification and mapping of electro-stratigraphic units within the 3-D resistivity cube (Figure 11). These units can be based primarily on changes in resistivity patterns but also on an awareness of regional changes in material properties, reflecting patterns in the resistivity values that are compatible with sediment patterns expected within the project area.

In the current project area, six electro-stratigraphic units were identified, Units A–F. Because these units are based on patterns in HTEM data, they do not correlate perfectly with the formal lithostratigraphic units in Illinois (Stumpf et. al., in review; Hansel and Johnson, 1996). Generally, Unit A is defined by relatively low resistivity values; most values are between 30 and 55 Ohm-m. Deposits in Unit A are of the Wisconsin Episode (Wedron and Mason Groups) and primarily contain fine to loamy textured diamictons, and poorly to moderately sorted sands. Unit B is defined by moderate resistivity values; most resistivity values are between 45 and 75 Ohm-m. Deposits in Unit B are primarily of the late Illinois Episode (Pearl and Glasford Formations), with some Wisconsin (Tiskilwa Formation and Ashmore Tongue) and early Illinoian sediments (Glasford and Pearl Formations) expected locally. Sediments in Unit B primarily contain a mixture of moderately to poorly sorted sands, with less frequent occurrences of loamy diamicton. Unit C is defined by relatively low resistivity values; most values are between 30 and 60 Ohm-

m. Deposits in Unit C are generally of the late pre-Illinois Episode (Banner Formation), with some early Illinois Episode (early Glasford and Pearl Formations) expected locally. Sediments in Unit C primarily contain mixtures of loamy diamictons with all levels of sorted sands. Unit D is defined by relatively high resistivity values; most values are between 55 and 125 Ohm-m. Deposits in Unit D are primarily of the early to middle pre-Illinois Episode (Banner Formation) with some late Banner expected locally. Unit E is defined by low resistivity values; most values are between 5 and 40 Ohm-m. Deposits in Unit E are primarily shales and sandstones of the Mississippian and Pennsylvanian Period, with some pre-Illinois Episode (early Banner Formation) fine-grained deposits expected at the top surface; these fine-grained Banner sediments are expected primarily in the southeastern quarter of the project area. Unit F is defined primarily by high to very high resistivity values; most values are between 50 and 250 Ohm-m, with some areas of lower and much higher resistivity locally. Deposits in Unit F are primarily carbonates of the Silurian and Devonian Period, with potentially some Mississippian and Pennsylvanian shales, and some pre-Illinois (early Banner sediments) expected locally.

Once these stratigraphic units are defined, their distribution, with knowledge of sediment and rock types in these zones, are used to model the resistivity-to-material type relationship. This relationship defines the different material types that could be associated with any observed resistivity value. As noted above (Figure 7), there are several different geologic material types that correspond to most resistivity values. As also noted above (Section 4), the electrical resistivity of earth materials is dependent on several properties: 1) porosity; 2) particle size distribution; and 3) specific conductance of the fluid in the pore spaces. Following research from Denmark (Foged et al. 2014), we determined that for our project, the fraction of the geologic material that is composed of clay minerals (i.e., clay mineral fraction) could be used as the primary predictor of material types for each resistivity measurement. To improve the reliability of each material type-resistivity pairing, we relied on the thousands of particle size analyses that have been conducted at the ISGS over the years and that have been used to identify and characterize the formal geologic units throughout the state (Hansel and Johnson 1996; Grimley and Phillips 2011; Stumpf et.al., in review).

For this project, the primary goal was the delineation of deposits classified according to hydrostratigraphic units (e.g., aquifers and confining units). This classification only required the identification of general hydrologic material types. The hydrologic material type classifications for this project include a sandy aquifer, carbonate aquifer, clayey confining unit, leaky clayey confining unit, and shale confining unit. However, the detail in historical geologic knowledge allowed us to identify lithologic material types, which are defined using more general sedimentologic terms. There are several lithologic material types that can be grouped into hydrologic material types, providing more insight on the high-resolution distribution of these more detailed characteristics. While not directly relevant to the County Board and their use of this information, these lithologic material types are expected to be particularly relevant to groundwater modelers or hydrologists interested in gaining the more detailed insights provided by the HTEM data. The lithologic material classification for this project contains 20 units: clay, clayey sediments, silt and clay sediments, silty sediments, silt, fine diamicton, loamy diamicton,

coarse diamicton, very poorly sorted sands, poorly sorted sands, moderately sorted sands, well sorted sands, very well sorted sands, extremely well sorted sands, partially cemented sands, cemented sands, shale, weathered shale, carbonate, and weathered carbonate. The resulting relationship between resistivity, lithologic material type, and hydrologic material type is presented in Table 5.

Table 5. Resistivity – Material Type Relationships

Resistivity Range (ohm m)	Lithologic Material Type	Hydrologic Material Type
1 - 15	Shale	Shale Confining Unit
15 - 20	Clay; Shale; Weathered Shale	Clayey Confining Unit; Shale Confining Unit
20 - 35	Clay; Clayey Sediments; Silt and Clay Sediments; Fine Diamicton; Loamy Diamicton; Weathered Shale	Clayey Confining Unit; Shale Confining Unit
35 - 45	Silt and Clay Sediments; Fine Diamicton; Loamy Diamicton; Very Poorly Sorted Sands; Weathered Shale	Clayey Confining Unit; Leaky Clayey Confining Unit; Shale Confining Unit
45 - 55	Silty Sediments; Loamy Diamicton; Poorly Sorted Sands; Coarse Diamicton; Weathered Shale	Clayey Confining Unit; Leaky Clayey Confining Unit; Shale Confining Unit
55 - 120	Silty Sediments; Silt; Loamy Diamicton; Coarse Diamicton; Moderately Sorted Sands; Well Sorted Sands; Weathered Carbonate	Clayey Confining Unit; Leaky Clayey Confining Unit; Sandy Aquifer; Carbonate Aquifer
120 - 600	Silt; Very Well Sorted Sands; Extremely Well Sorted Sands; Partially Cemented Sands; Cemented Sands; Weathered Carbonate; Carbonate	Clayey Confining Unit; Sandy Aquifer; Carbonate Aquifer
>600	Cemented Sands; Carbonate	Carbonate Aquifer

Table 5 clearly shows the ambiguity in interpreting material type from almost any resistivity value. For example, a resistivity value of 100 Ohm-m could be due to the occurrence of 7 different lithologic material types or 4 different hydrologic material types. The MTC method includes a process for reducing and managing the ambiguities in these relationships, which results in an improvement in the utility of material-type interpretations from the HTEM data.

Traditional geologic modeling and mapping efforts reflect a geologist's most likely, or preferred interpretation of material type distributions. Largely because the sparse datasets used in traditional mapping led to an extremely high level of uncertainty, it is both difficult to characterize this uncertainty, and difficult to generate alternative interpretations that honor the data. The availability of uncertainty characterizations, particularly in the form of alternative interpretations, can be helpful to groundwater modelers, hydrologists, and decision makers because it allows them to consider alternative geological framework models and test the impact

of differences to their targeted outcomes. This type of capability can be valuable for improving risk assessments for difficult water resources or planning decisions. The MTC method provides the ability to generate multiple interpretations of the material type distributions. The large HTEM dataset provides grounding for these alternate interpretations, dramatically improving their reliability, to a degree that is not available with traditional modeling and mapping of datasets.

The main tool we used for managing the ambiguities within the resistivity-to-material type relationship is a geologic conceptual model, specifically conceptual models of lithologic material type occurrence within each of the stratigraphic units. Each conceptual model is based on the historical regional knowledge of material distribution within that depth range, and of a generalization of patterns of aquifer occurrence observed within borehole-based data.

For this project, we identified three conceptual models for each of the 6 electro-stratigraphic units. The first conceptual model, and the one we use exclusively within this report, is the Preferred conceptual model. It defines what the geologists interpreted as the most likely, or preferred, proportion of the 20 lithologic material types for each electro-stratigraphic unit. This conceptual model was based on a review of the resistivity distributions in each unit, the various existing publications on the geology in the region, the extensive records of particle size distribution across Champaign County, the availability of geophysical borehole logs of various kind (i.e., natural gamma logs, electrical resistivity logs), available core sample descriptive logs, and available water well drillers logs.

As an example of how these conceptual models were used, the Preferred conceptual model for Unit A suggested that for resistivity values of 55–75 Ohm-m, deposits are interpreted as poorly sorted sand 12% of the time, loamy diamicton 70% of the time, and coarse diamicton 16% of the time. The same resistivity range in Unit B would be interpreted as moderately sorted sand 60% of the time and loamy diamicton the remaining 40% of the time. In Unit D this range of resistivity values would be interpreted as well sorted sand 30% of the time, loamy diamicton 30% of the time, and moderately sorted sand 40% of the time. This approach of constraining material type occurrence for each resistivity category was carried out for each of the 6 electro-stratigraphic units for each conceptual model.

In choosing how to model alternative material type distributions, it is helpful to consider the needs of specific stakeholders. Experts in groundwater resource protection and management are a prominent stakeholder group for the geological model of the project area. To create alternative interpretations that support the needs of this group, we recognized that groundwater protection and management decisions are most affected by the quantity and distribution of sand aquifers. We determined that it would be helpful for this stakeholder group if we created two additional conceptual models to explore alternative interpretations in the amount and distribution of sand—one could explore significantly higher likelihood of sand occurrence and one could explore significantly lower likelihood of sand. These conceptual models, called HiFreqSand and LoFreqSand respectively, were created to contain geologically plausible changes to the proportions of the 20 material types within each electro-stratigraphic unit. The resulting 3-D

interpretations from these alternate conceptual models are not presented in this report to avoid complicating discussions with general, non-technical audiences about the distribution and character of aquifers. The creation of different interpretations, based on different conceptual models, is designed to be of particular use to technical stakeholders who understand and regularly work with uncertainty in geologic material distributions.

The ability to model high-resolution variations in large numbers of material types is fundamental to providing high-fidelity geologic models that better support groundwater management and protection needs in high-use and high-vulnerability situations. However, the main goal of this project was the interpretation of the 3-D distribution of hydrostratigraphic units. In developing the process for converting hydrologic material type to hydrostratigraphic units, we determined that a simplified hydrologic material type classification made the process easier to implement. This simplified classification has only three categories: aquifer, leaky confining unit, and confining unit. The 3-D model of hydrostratigraphic units applies to this 3-category hydrologic material type interpretation with the distribution of the 6 electro-stratigraphic units to delineate the distribution of ten hydrostratigraphic units (Table 6). This 3-D model of hydrostratigraphic unit distributions is the final product and end goal of this project.

Table 6. Hydrostratigraphic units, their constituent hydrologic material types, and corresponding stratigraphic units.

Hydrostratigraphic Unit Name	Constituent Hydrologic Material Type	Corresponding Electro-Stratigraphic Units
Shallow confining unit	Confining Unit, Leaky Confining Unit	Unit A
Shallow aquifer	Aquifer	Unit A
Upper middle confining unit	Confining Unit, Leaky Confining Unit	Unit B, Unit C
Upper middle aquifer	Aquifer	Unit B, Unit C
Lower middle confining unit	Confining Unit, Leaky Confining Unit	Unit B, Unit C, Unit D
Lower middle aquifer	Aquifer	Unit B, Unit C, Unit D
Mahomet confining unit	Confining Unit, Leaky Confining Unit	Unit C, Unit D
Mahomet aquifer	Aquifer	Unit D
Carbonate confining unit	Confining Unit, Leaky Confining Unit	Unit D, Unit E
Carbonate aquifer	Aquifer, Leaky Confining Unit	Unit D, Unit F

To ensure the 3-D grids of interpreted hydrologic material type and hydrostratigraphic unit distributions were accurate, we conducted several evaluation and validation efforts. These involved graphical display and subsequent analysis of the interpretations to ensure the proportions of aquifers and confining units, and the spatial distribution of these units met with our expectations based on Stumpf's (in review) material type patterns, and general patterns of hydrologic material type from borehole-based observations. Specifically, we created and

evaluated a set of vertical cross sections (profiles) and elevation-based map views (horizontal slices) through the 3-D grid. The hydrologic material type distributions were analyzed first. Whenever the distribution did not fit either Stumpf's predicted patterns or the borehole-based observational data, the conceptual models were adjusted until the interpreted distribution met, and validated, these expectations. This same type of graphically based evaluation was conducted with the hydrostratigraphic unit distributions; discrepancies between expectations and interpretations were addressed by either changing the criteria for defining the different hydrostratigraphic units, or by adjusting the computer program that we used to make the assignments. This process was repeated until the distribution of hydrostratigraphic units, as observed in profiles and horizontal slices, was consistent with our definitions of these units.

4.3 Limitations, Uncertainty and Data Resolution

As we have noted, traditional geologic mapping and modeling studies use much smaller datasets than are available with HTEM surveys. In a county with the size of Champaign, traditional mapping projects would collect a few dozen core sample sets, producing detailed descriptive logs of variations in material type. Interpretations of geologic unit distributions, the character or architecture of those units, and the resolution of the interpretations of these distributions are influenced heavily by the sparsity of the underlying data. In these studies, geologic units are often generalized, ignoring internal variations in material type and properties, to reliably identify the units in the sparse data and to produce unit boundaries that are sufficiently reliable for the data distribution while still addressing stakeholder needs. While there have been incremental improvements in data quality over the past 70+ years, these innovations have not resulted in large increases in the number of observations collected for most mapping or modeling efforts. This absence in dramatic change in data quantity has resulted in the development of stable and standard approaches to data analysis, interpretation, and model creation. The uncertainties of these interpretations are large and rarely quantified, as the sparsity and irregularity of data make the uncertainties difficult to estimate. The application of maps and models, made from these standard methods to a range of problems and decision-making situations, has demonstrated that the reliability of these models is typically sufficient for their purpose. University research into the value of high-resolution, high-reliability geologic models, however, suggests that improved resolution and reliability in model results would provide significant value to a range of stakeholder applications.

Innovations in helicopter-based TEM data collection, processing, and interpretation were developed in the early 2000s, and provided a significant increase in data quantity to geologic modeling studies focused on the upper 1000 feet (305 m) from land surface. This jump in data quantity resulted in a sea-change of capabilities for subsurface geologic modeling, particularly dramatic improvements in the spatial resolution and accuracy of material type interpretations. This Champaign County project has collected 57,600 1-D resistivity soundings (similar in geometry to core sample sets), which have provided more than 2.3 million individual resistivity values. The value of these datasets has resulted in regional HTEM datasets being collected across the globe. Discussions with researchers and HTEM contractors suggest these data are being used

primarily to help characterize aquifer systems under increasing stresses of demand with population growth and climate-induced changes in recharge. The transformative increase in data, with HTEM surveys, allows for equally significant changes in how the subsurface is described and understood. The MTC interpretation method, developed for this project, is one example of how these data are providing transformative capabilities for understanding the subsurface.

5. RESULTS AND INTERPRETATIONS

5.1 Geophysical Results

All 2-D resistivity inversion results from the HTEM survey resulted in a similar six-layer structure divided into unconsolidated quaternary deposit layers and bedrock layers. So, for the sake of brevity, we primarily focus on just a few figures (and profiles) for illustration (although integrated results from the inversion of all lines are presented later). Figure 10 illustrates 2-D resistivity results from all of the profiles (flight lines) from the HTEM survey, while Figure 11 illustrates the interpolated 3-D cube of the resistivity results from Figure 10. The results in both figures are presented in the form of resistivity in Ohm m. All images show in high resolution six-layers consistent with high resistivity layers (red and pink) indicative of coarse-grained material (sand and gravel) and/or carbonates (dolomite and limestone). The low resistivity layers (blue and green) are indicative of fine-grained material, such as clay and shale.

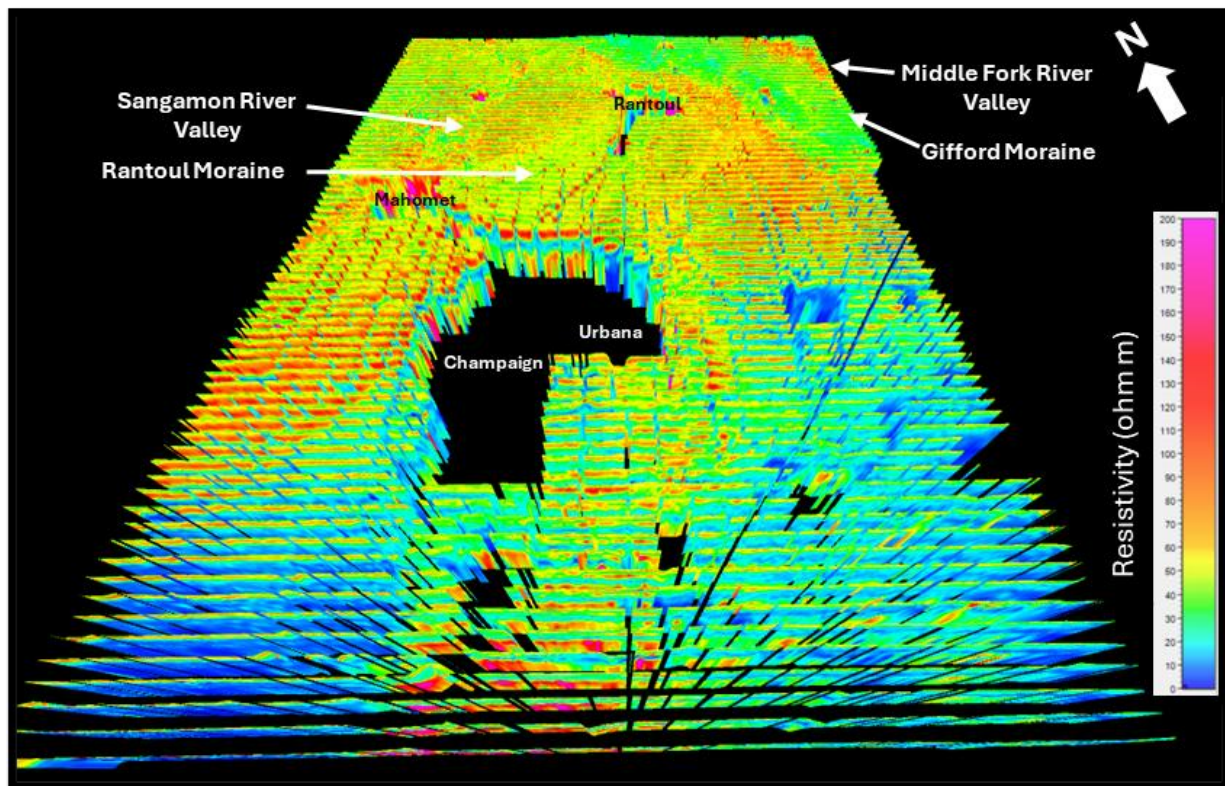


Figure 10. Perspective view of the resistivity results along the HTEM survey lines in Champaign County. The variations in resistivity values shown can be correlated to the different geologic materials found in the subsurface. High resistivity values (red and pink colors) represent coarse-grained materials (e.g., sand and gravel) and/or carbonate bedrock (e.g., limestone and dolomite), whereas the lowest resistivity values (bluish colors), denote the presence of fine-grained materials (e.g., glacial clays and shale bedrock).

While the north side of Champaign County shows dominant high resistivity layers for both shallow and deeper sediments (Figures 10 and 11), the southern side is dominated by low resistivity sediments, especially in the deeper layers, with some medium resistivity layers in the

shallow sediments (Figure 10). Such contrast is expected, given the expected contrast in distribution of the bedrock materials, and sand and gravel materials. The northern side of Champaign County is known to be dominated by very resistive dolomitic bedrock (Figure 11) overlaid by resistive sand and gravel of the Mahomet aquifer and other shallow aquifers. Due to similarity in resistivity between sand and gravel, and dolomite, it is difficult to visually pick a contact between these two layers in Figure 11. In contrast, the southern side of the county is dominated by low resistivity shale bedrock (Figure 10) and the dolomitic Pesotum Anticline, in the center of the county.

Another prominent feature that we are able to map at high resolution with the contrast in resistivity distribution, is the low to medium resistivity Gifford Moraine in the northeast corner of the county (Figure 4, Figures 10 and 11). The Gifford Moraine is associated with glacial deposits, primarily made up of clay materials. South of the town of Rantoul (Figures 10 and 11) we see the low resistivity Rantoul Moraine, made up of clay material (Figure 4 and Figures 11). On the topmost corner of Champaign County, northeast of the Gifford Moraine, we see a resistive feature trending southeast; this feature is interpreted to be the Middle Fork River filled with sandy materials. It is worth noting that the feature we see in the middle of Figure 11 (resistive bedrock) and the shallow conductive (less resistive) layer on the western side of Figures 11 and in Figure 10 are major features that are continuous for most of the county.

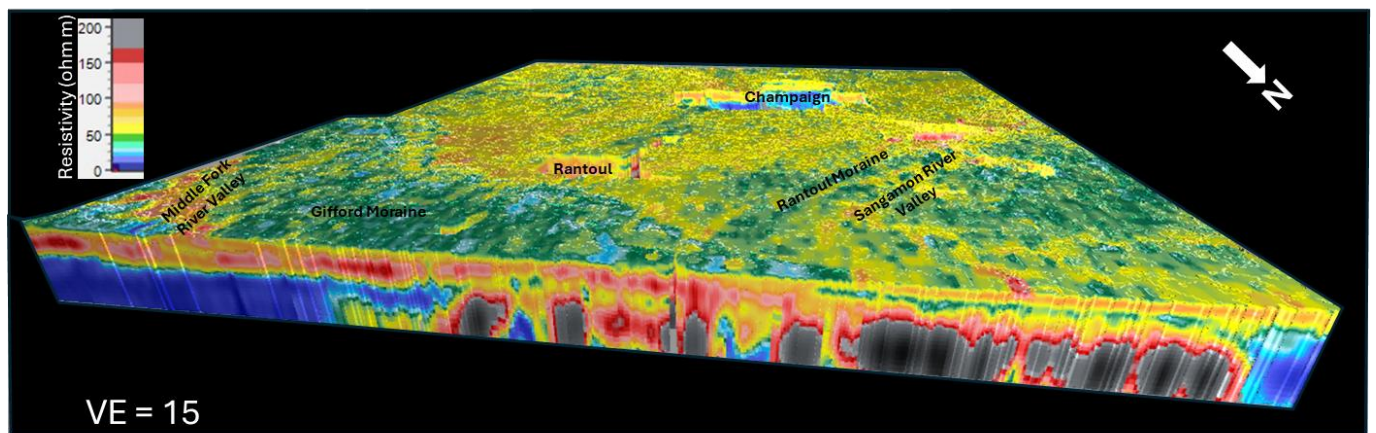


Figure 11. Perspective view towards the south of the 3-D model of the interpolated HTEM resistivity values created from data along the survey lines shown in Figure 10. The highest resistivity values (red and gray colors) represent coarse-grained materials (e.g., sand and gravel) and/or carbonate bedrock (e.g., limestone and dolomite), whereas the lowest resistivity values (bluish colors) denote fine-grained materials (e.g., glacial clays and shale).

Considerable variation in distribution of resistivity of mappable features, is captured when moving through different elevations. The major feature of interest in this project is the sand and gravel material, i.e., aquifer materials. Figure 12 shows the distribution of resistivity at 170 m (560 feet) elevation. The estimated distribution of sand and gravel material (high resistivity) is predominant in the middle of the project area, trending northeast–southwest, with higher resistivity observed in the middle of the project area and northeast corner of the county. The

higher resistivity sections in this area can be interpreted as areas dominated by coarser grained materials, which are thick aquifer materials. There is a considerable decrease in resistivity (i.e., change in distribution of geological materials) as you move northwest and southeast of the project area. This low resistivity layer (blue) is interpreted as a shale bedrock layer surrounding the resistive unconsolidated aquifer materials. Overlying the shale bedrock layer on northwest and southwest of the project area are channel like features of high resistivity. The channel like features enclosed in the dashed black circles in Figure 12 are interpreted as possible sand-filled buried channels connected to the MBV. The possible buried channels are mapped in high resolution on high bedrock elevation in areas outside the MBV, suggesting a possible feeding into the MBV.

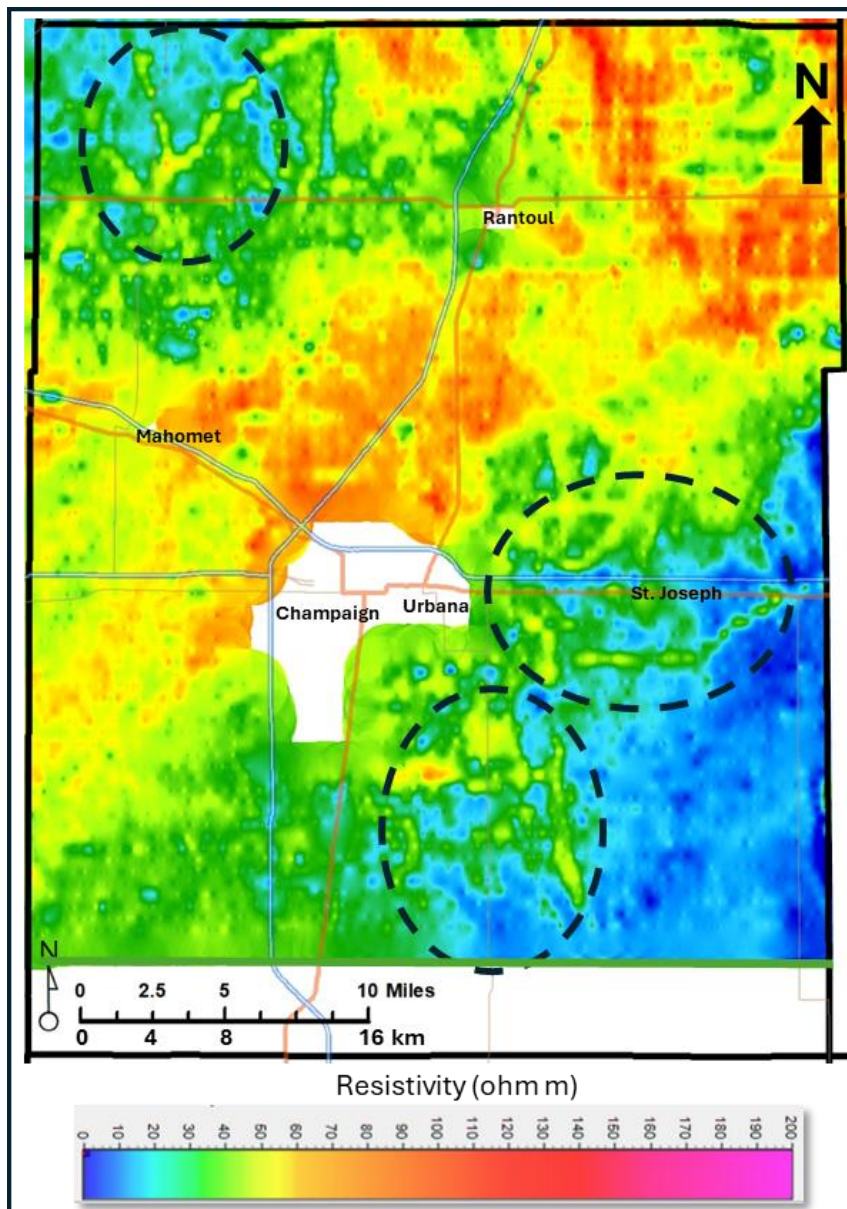


Figure 12: Horizontal slice through the 3-D HTEM resistivity model at 170 m (560 feet) elevation. The dashed black circles delineate possible areas with buried channels connected to the MBV. The highest resistivity

values (red and dark orange colors) represent coarse-grained materials (e.g., sand and gravel) and/or carbonate bedrock (e.g., limestone and dolomite), whereas the lowest resistivity values (bluish colors) represent fine-grained materials (e.g., glacial clays and shale). The green line shows HTEM data extent in southern Champaign County.

The 2-D inversion results of two long profiles across the project area, NWSE Central and NESW Central (Figure 6) presented in Figure 13 show the six geological layers varying in resistivity values with depth. As expected, the deeper bedrock Units E and F show the high resistivity values corresponding to the dolomite bedrock layer and low resistivity values corresponding to the shale bedrock layer, respectively. A sharp contrast in resistivity is observed between the shale bedrock (Unit F) and the overlying high resistivity Unit D (e.g., at 25,000–40,000 m on NWSE Central and 0–60,000 m NESW Central). This contact is mapped in high resolution due to the high contrast in resistivity values, and its elevation can be interpreted as the bedrock topography (top of bedrock) and bottom of the MBV. Conversely, the contact between Units D (sand and gravel) and E (dolomite) is very difficult to define due to both having high resistivity values, for example at 10,000–25,000 m on Figure 12 NWSE Central. Here we use general knowledge of the project area, and borehole information to define the contact (bedrock topography) between dolomite, and sand and gravel. Note, data gaps along the profiles (Figure 13) are areas with removed bad data (along powerlines) and/or areas without data (e.g., Fisher, Champaign, Urbana, and Gifford).

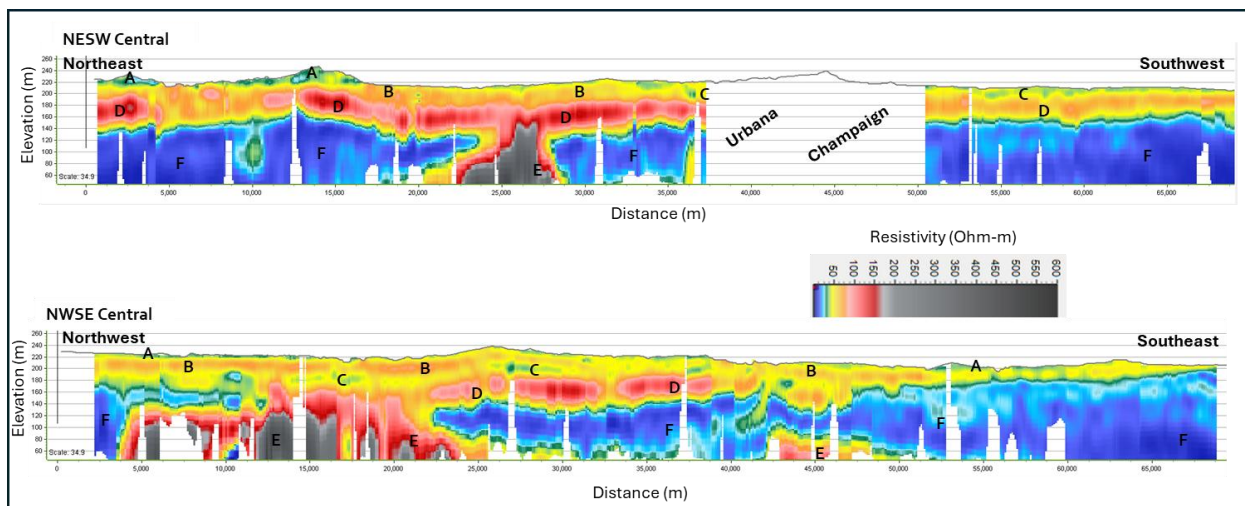


Figure 13. Cross sections showing resistivity values in 2-D with the interpreted geological units labeled. The geological units are correlated with the variations in resistivity values. See text for detailed description of Units A through F. The location of cross section transects NESW Central and NWSE Central are shown in Figure 6. The data gaps along the profiles (white areas) are areas where data was removed (returned data was impacted by powerlines) and/or areas where data could not be collected.

The top three unconsolidated Units A–C are easily identified due to a contrast in resistivity values between those three geological units (Figure 13). Unit C has low resistivity characteristics of the silty glacial till present in this area. Worth noting is that Unit C is not continuous and is missing in some locations (e.g., from 30,000–65,000 m along profile NWSE Central). Unit B,

shows high resistivity values, corresponding to coarse-grained sandy material also known to contain some dolomite. Lastly, the thin, low resistivity, uppermost layer observed everywhere in the project area is Unit A, characterized by clayey till.

Figure 14 illustrates the P-wave seismic reflection data from Line 2 acquired along County Road 2200 N with superimposed collocated ERT results from profile 2200N. A survey of seismic Line 2 was able to image four seismic units in the area. These seismic units are identified within the unconsolidated and consolidated sediments. Units A and B–D are identified within the unconsolidated sediments and include deposits of the thin clayey till (Unit A) and a single reflector for Units B–D which comprise silty till (Unit C), and sand and gravel of both Units B and D. These sediments contain fairly weak reflectors, and as a result were grouped into the same seismic unit. Multiple bedrock units were delineated within the consolidated area, including folded strata associated with the LaSalle Anticlinorium (i.e., Dolomite assigned to Unit E). The strong seismic reflector between Units B–D and E is identified as the top of the bedrock unit associated with the shale layer of Unit F.

Strong correlation between the seismic results and the ERT results add confidence to our interpretation of geological layers in this area. Due to the nature of the ERT survey, we are unable to resolve variations between Units B, C and D, hence we grouped them together as a thick resistive layer, corresponding to seismic Units B–D. Coincidentally, we are able to resolve the variation in resistivity between Units A and F, hence able to map the uppermost Unit A and the top of shale bedrock (Unit F), both correlating well with the seismic reflection results. ERT is limited in the depth of investigation compared to HTEM or seismic surveys, as a result we are not able to image the deeper dolomite bedrock in this profile.

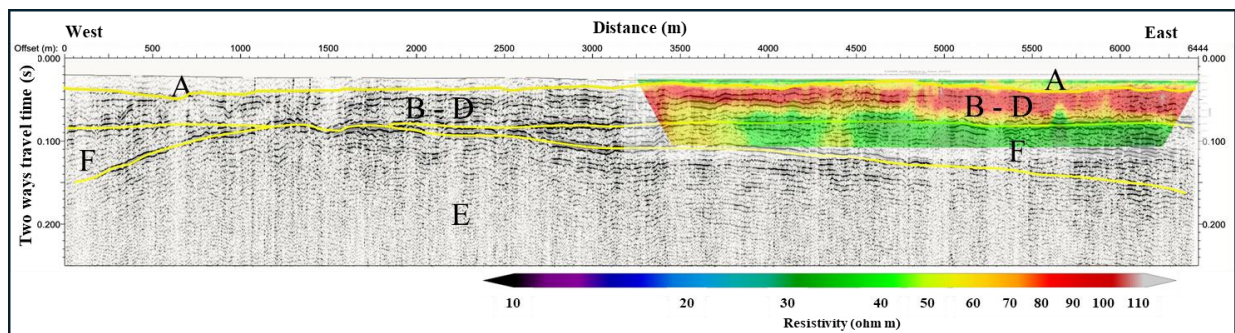


Figure 14. Cross section showing P-wave seismic reflection data in 2-D with superimposed ERT results acquired along County Road 2200 N, southwest of Rantoul (see Figure 6 for location of the profiles). Both sets of geophysical data can be correlated to the geological Units A–F, especially the top of bedrock or Unit F.

The inferred elevation of the bedrock surface (dashed black line) delineated by HVSr points (yellow circles) in Figure 15, is consistent with the tops of bedrock Units F and E in Profile 17020 and the top of Unit F in Profile 17067 inferred from the HTEM data. Variations in resistivity between Units D, and F and E, mark the contact between unconsolidated sand and gravels assigned to Unit D and the top of consolidated bedrock sediments assigned to Unit F and E. These data, from both HTEM and HVSr are generally consistent with the known

interpretation of the elevation of bedrock surface from previous data (i.e., known borehole information) and the new borehole information from Tables 2 and 3, and Figure 6. Please note, Profile 17067 below, as shown in Figure 6, is located on the south side of Champaign County, where the deeper subsurface is predominantly shale (Figure 10). The consistency of bedrock elevation between the two geophysical datasets and the borehole data, increase confidence in our interpretation (and delineation of geological layers) of the geophysical datasets.

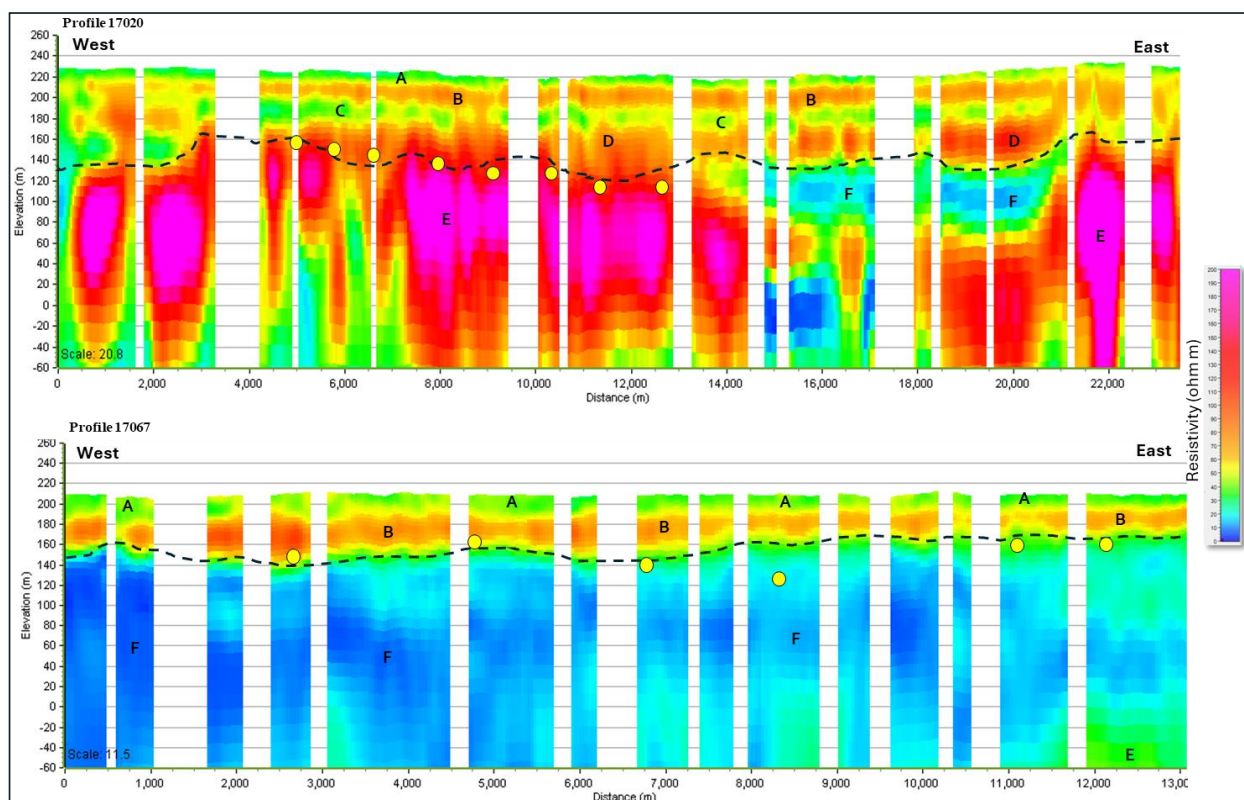


Figure 15. Cross sections showing the contact between unconsolidated glacial sediments (Units A–D) and the bedrock Units E and F. The dashed black line delineates the top of the bedrock. The interpolated top of bedrock is confirmed from both the resistivity and HVSR results (yellow circles). The data gaps along the profiles (white areas) are areas where data was removed (returned data was impacted by powerlines) and/or areas where data could not be collected.

5.2 Drill Logs

The geological information taken from the drilling logs (Figure 16) assisted in confirming and better resolving our interpretations of the geophysical data described above. More specifically, the information from the two stratigraphic test holes helped confirm the results we are seeing from the profiles within MBV (e.g., Profile 17020, Figures 15 and 16a) and those outside MBV (e.g., Profile 17067, Figures 15 and 16b). Note, due to averaging in geophysical data during processing (e.g., inversion), HTEM and ERT are both unable to resolve thin layers, especially geological layers of similar resistivity values. For example, in the unincorporated area of Flatville and the neighboring areas, HTEM is unable to resolve the thin sandy units at 10–16 m deep (Figure 16a) between the silty till layers. These units above 20 m deep in Figure 16a are all

averaged and imaged as a till layer in Figures 13 and 15. The same averaging is observed in Figure 16b for the sandy units at 16–22 m deep.

Analysis of natural gamma radiation data from the unincorporated area of Flatville (Figure 16a) and Sydney (Figure 16b) confirms a correlation between geologic materials and radioisotope abundance. Generally, higher natural gamma radiation was measured in silt and fine sand, and the lowest in sand and gravel (Figure 16a, b). The well sorted coarse-grained sand and gravel have much lower gamma radiation. Overall, the bedrock measured a much higher gamma radiation as compared to the unconsolidated sediments (Figure 16b). The bedrock in the boreholes analyzed include shale, sandstone, and siltstone.

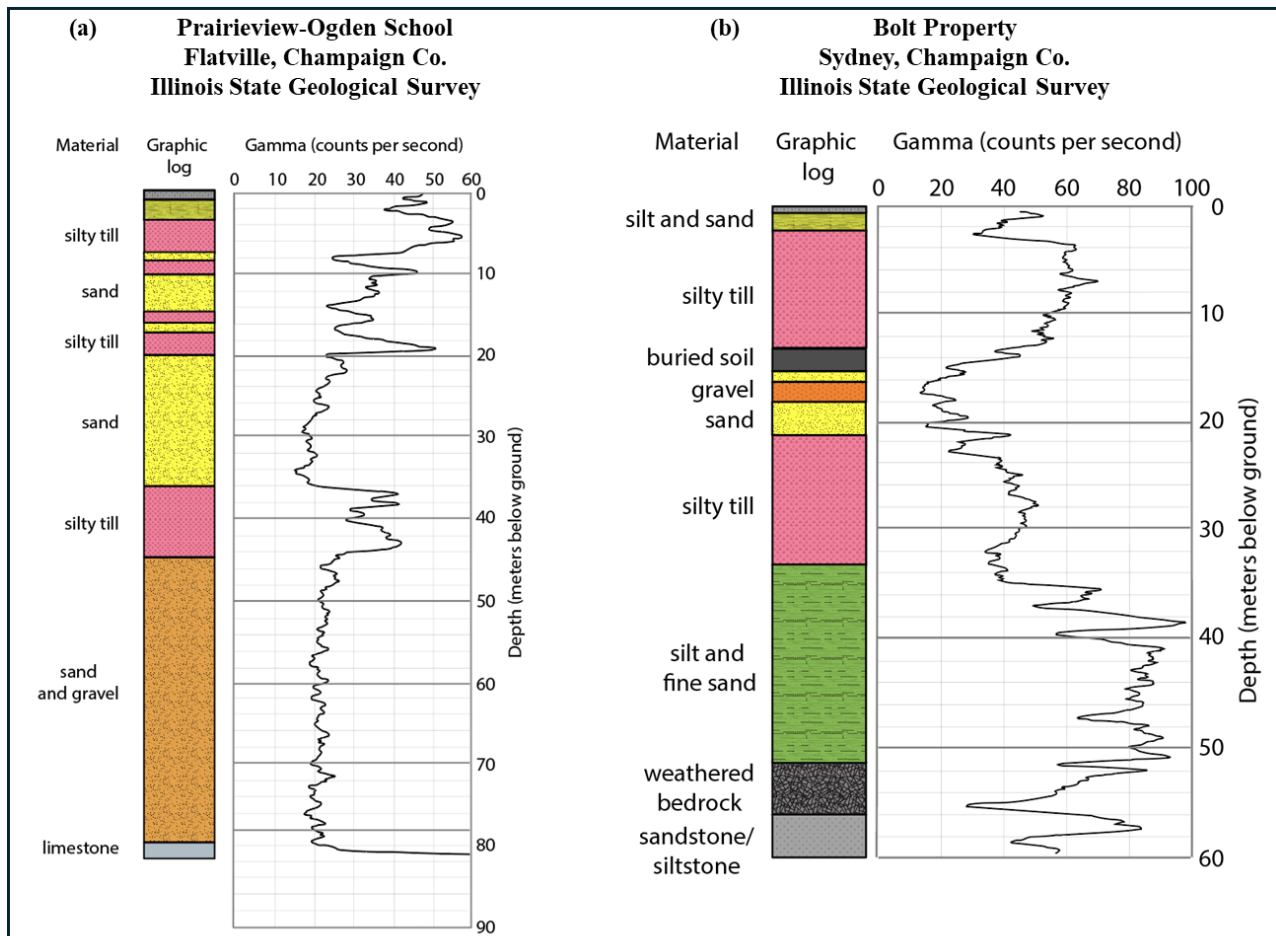


Figure 16. Downhole geological and geophysical data collected from the stratigraphic test holes drilled in (a) incorporated area of Flatville, IL and (b) Sydney, IL. The natural gamma radiation log data (black line on the depth graphs) were used to supplement the physical cores samples collected. A complete description of the geology is provided in tables 2 and 3.

5.3 Geological Modeling Results

5.3.1 Bedrock topography

The high-resolution results of the HTEM dataset and the interpolated 3-D grid allowed for the creation of a bedrock topography map that is grounded in many observations (Figure 17). The accuracy of the bedrock topography map varies somewhat across the project area. Locations with sand and gravel directly on top of shale bedrock are some of the most accurate contacts (e.g., much of the central portion of the project area), because the resistivity contrast between the two types of deposits are large and the contact is easy to identify in the data. Locations where there is fine-grained sediment on top of the shale bedrock (e.g., southeastern quadrant of project area) are expected to be less accurate, as the resistivity differences between the fine-grained sediments and shale bedrock are not large, and the inversions have a difficult time distinguishing these subtle variations. Locations where there is sand and gravel overlying carbonate bedrock are expected to be in the middle of this accuracy range, because the resistivity difference between the two materials is more variable, ranging from slight to significant.

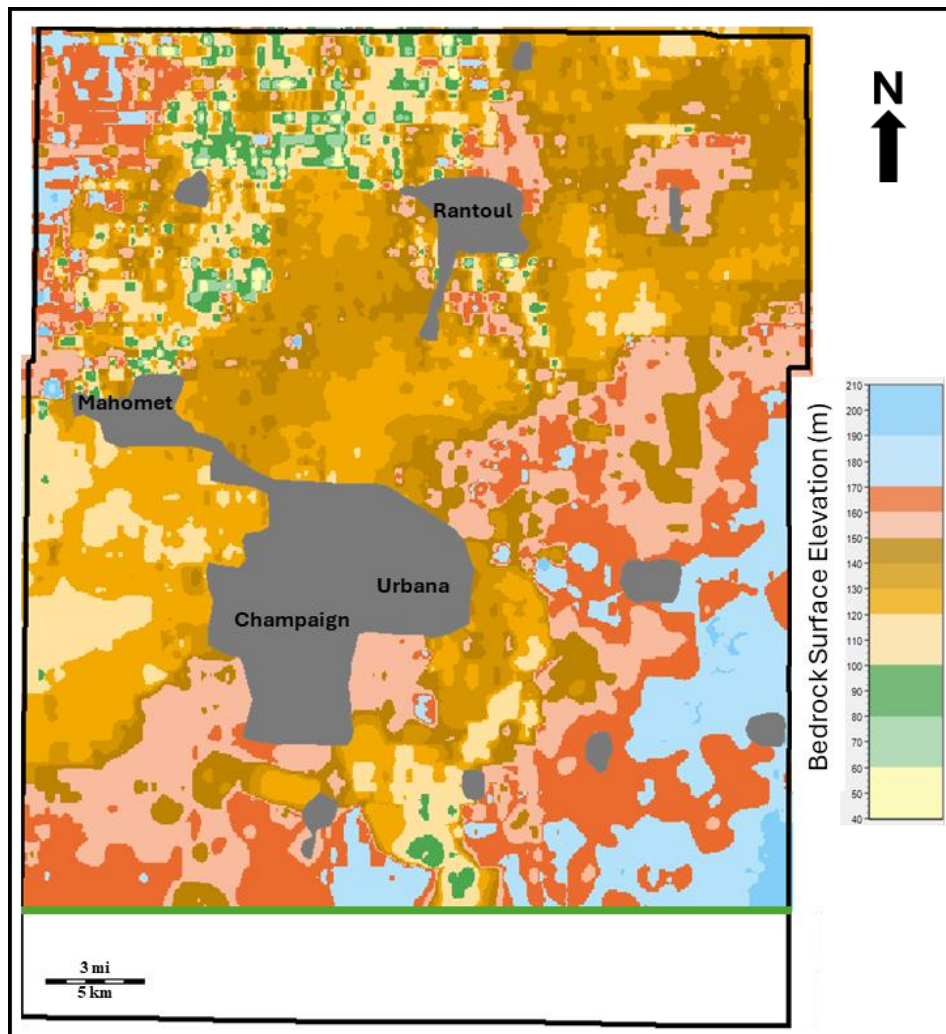


Figure 17. Revised bedrock topography of the project area based on the interpolated HTEM resistivity data. The green line shows HTEM data extent in southern Champaign County.

The general pattern of this bedrock topography map is more detailed than maps traditionally made using borehole geologic logs and surface geophysical data, for example Nelson (in press) map (Figure 18). This is due to the large amount of data that is used in the HTEM map, as opposed to the sparse borehole datasets available in traditional maps. The new map clearly shows the Mahomet Bedrock Valley trending SW–NE through the center of the project area. The elevations for most of the valley are in the 100–150 m elevation range. In contrast to Nelson’s map, however, this HTEM-based map has a more complicated thalweg (lowest points in the valley) shape. In Nelson’s (in press) map, the thalweg is clear, located in the northwestern portion of the county and in the 100–120 m elevation range, west of Rantoul. On the new map, the thalweg is in the same general location, but the shape is less well defined, and the elevations are notably both shallower and deeper than in Nelson’s map, with elevations in the 50–145 m range, and with a more bullseye pattern to the surface in this area. Analysis of this surface suggests that the rocks at the bedrock surface in this area are carbonates, which are known to be karstic in other areas of Illinois. The patterns in the bedrock surface in this area are consistent with karstic surfaces made up of irregular surface patterns due to the presence of sinkholes, caves, and steeply walled channels. Karstic bedrock occurs in carbonate rocks (e.g., limestone) and is formed by the dissolution of portions of the rock, typically along joint or fracture surfaces. This dissolution forms caves connected by sinkholes. A second area where carbonate bedrock is at the bedrock surface is under and southeast of Rantoul. This area also has irregular, bullseye-rich patterns on the topographic surface.

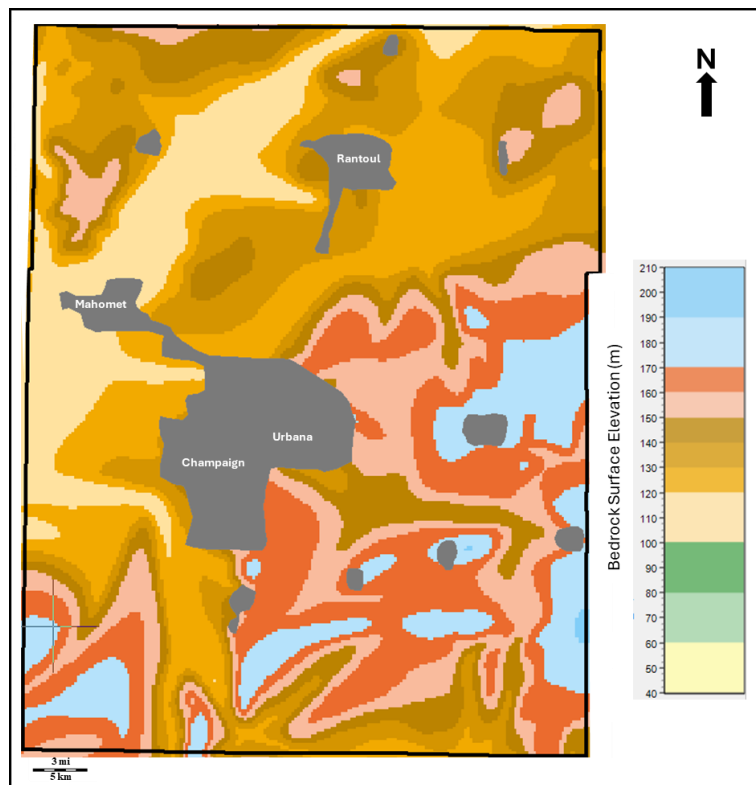


Figure 18. Topography of the bedrock surface (from Nelson in press). Drawing of this map was exclusively based on borehole geologic and geophysics logs and the results from surface geophysical surveys.

Another important characteristic of this new, HTEM-based bedrock topographic map is the near-horizontal, gently sloping nature in the southeastern portion of the MBV. In this area, there are near-horizontal benches, or terraces, in the 150–160 m and 160–174 m intervals. Nelson’s map showed more prominent uplands in this portion of the project area.

The new map also provides more definition of the channel located east and southeast of the City of Urbana and Village of Savoy. While the presence of this channel is clear in the data, its exact position and shape is unclear because there are fine-grained sediments on top of the shale in this location, and the bedrock surface is difficult to reliably identify. It is possible that this feature is actually two channels, in positions close to those identified by Nelson (in press) (Figure 18). Targeted core samples are needed to resolve the exact distribution of these features.

6. DISCUSSION

6.1 Mahomet Aquifer Delineation

One of the primary goals of this project, was to develop a new extent or boundary for the Mahomet aquifer. Figure 19 shows the new Mahomet aquifer boundary and the 2011 boundary (Roadcap et al. 2011) on the new bedrock surface elevation map. This new Mahomet aquifer boundary is based on a combination of the new bedrock surface elevation map, the distribution of materials using the 20-category material type classification, and the Preferred conceptual model of lithologic material type distribution.

The distribution of sandy sediments, as defined by the 20-category material type classification, was analyzed to identify the potential maximum extent of potential aquifer deposits at various elevations throughout the project area. This analysis included Moderately Sorted Sands, Well Sorted Sands, Very Well Sorted Sands, and Extremely Well Sorted Sands as composing potential aquifer deposits. The results of this analysis showed that most of the Mahomet aquifer was located at or below 525 feet (160 m) elevation. Based on previous analyses of the sedimentary framework throughout the Mahomet Bedrock Valley, and a recognition that shallower aquifers occur in contact with and above the Mahomet aquifer, we identified 570 feet (174 m) as the maximum elevation of the top of the Mahomet aquifer. The new boundary of the Mahomet aquifer (Figure 19) is the result of this analysis. It is important to note that while the boundary suggests a maximum lateral extent to the deposits of the Mahomet aquifer, the distribution of the aquifer materials within this boundary are variable, or non-uniform (Figure 20). A more complete discussion of the distribution of sediments within the Mahomet aquifer boundary is presented in Sections 6.2 and 6.3.

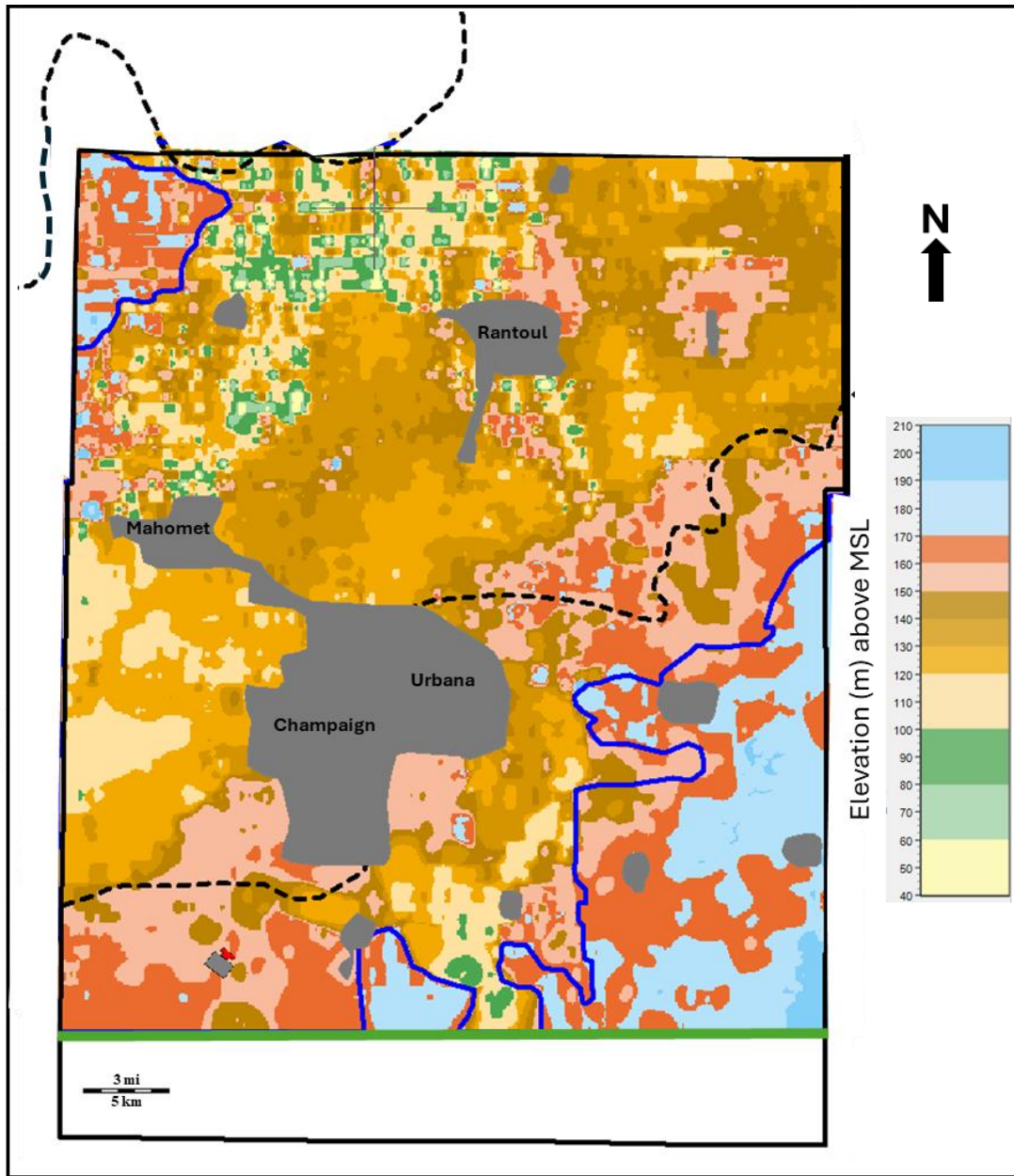


Figure 19. Revised boundary of the Mahomet aquifer boundary (blue line) on the bedrock topography map developed from the interpreted from HTEM data. The new boundary is compared to the boundary developed by Roadcap et al. (2011) shown as the dashed black line. The green line shows HTEM data extent in southern Champaign County.

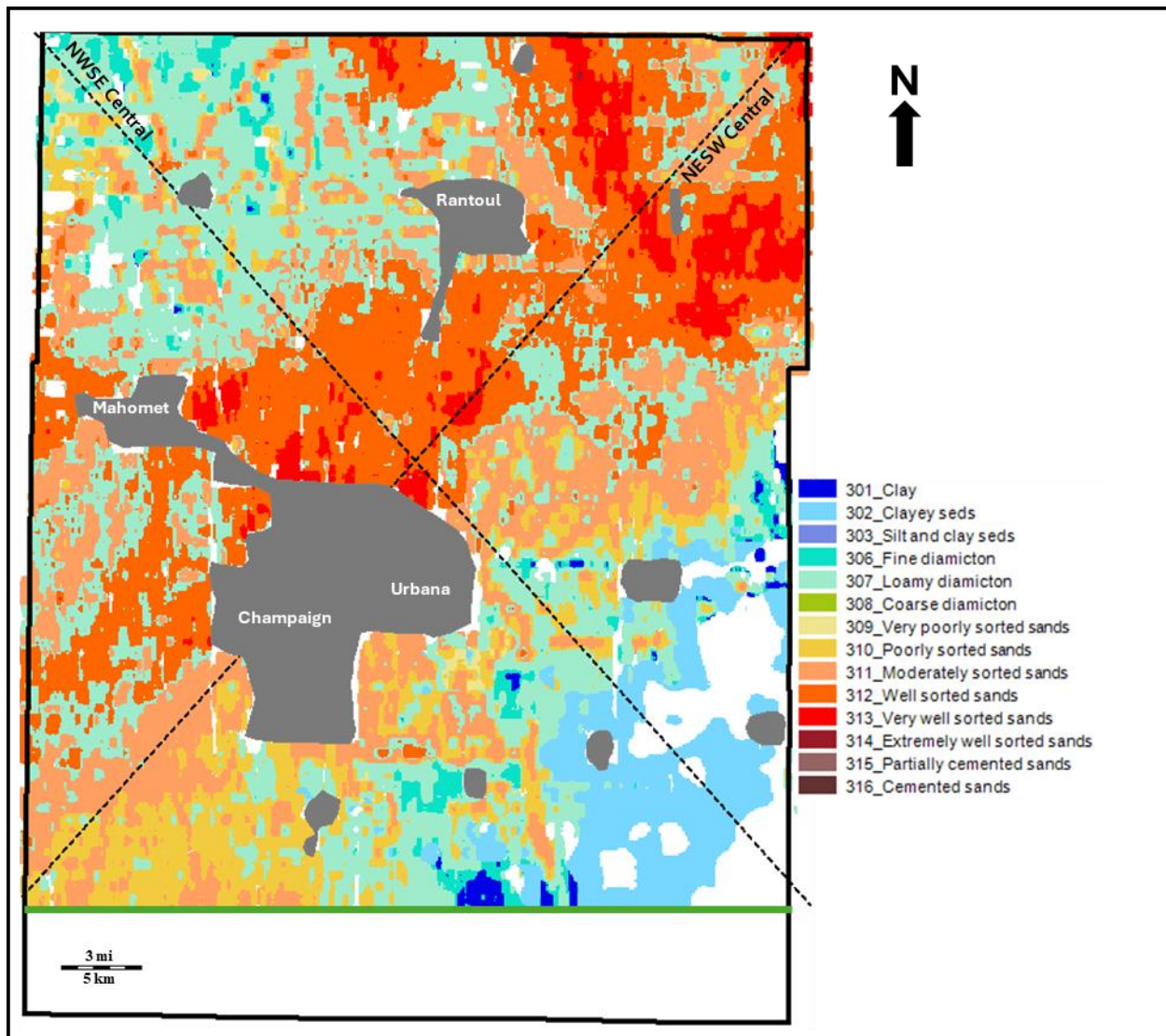


Figure 20. Geologic material types interpreted from HTEM data shown within the MBV at 174 m. The green line shows HTEM data extent in southern Champaign County. The dashed lines mark the locations of the 2-D cross sections (Figure 13).

6.2 Mahomet Aquifer Characterization

The new material-type characterization (MTC) method for interpreting the HTEM data (see Section 4.1) offers a new view into the internal makeup of the Mahomet aquifer. In the past, with limited borehole locations and ground-based geophysical data, the aquifer has generally been conceptualized as nearly homogenous throughout its distribution (Roadcap et al. 2011). The MTC method, which is based on the HTEM data, have revealed patterns and variations in the Mahomet aquifer than have never been seen before (Figure 20).

Along with aquifer thickness variations, the MTC method estimates material type changes within the aquifer (Figure 21). The distribution of these material types in the subsurface has never been

resolved at this resolution before and has important implications on preferred groundwater flow paths and geologic history. Based on the HTEM data and the MTC method, much of the aquifer materials in the southern branch of the Mahomet aquifer are characterized as well-sorted to very well sorted sand (Figure 21). Those materials also likely include gravel and sand/gravel intervals that were unresolvable in the HTEM data. In the northern branch of the aquifer in Champaign County, the materials in the lowermost portions of the bedrock valley are largely characterized as well-sorted sands, but they also include newly resolved patchy intervals of loamy diamicton (silty-rich materials). In the uppermost portions of the northern branch of the aquifer, the materials, where present, are characterized mostly as loamy diamicton.

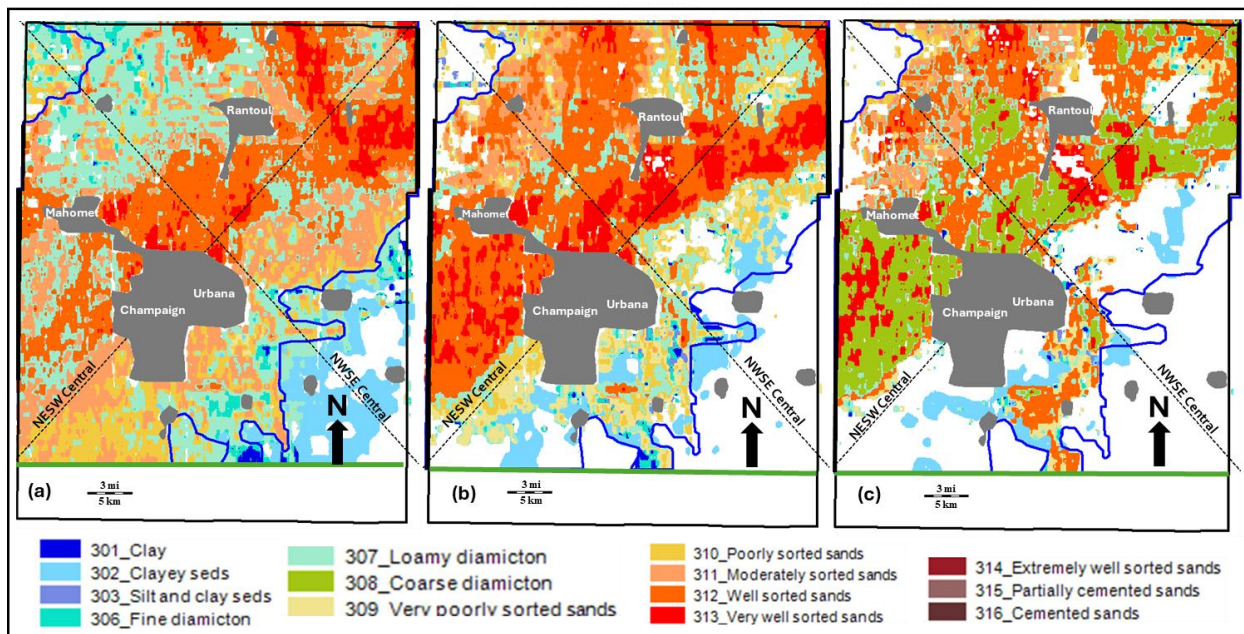


Figure 21. Distribution of geologic material types within the MBV at elevations of (a) 174 m, (b) 160 m, and (c) 150 m. The green line shows HTEM data extent in southern Champaign County. The blue line delineates the new boundary of the Mahomet aquifer interpreted from HTEM data. The green line shows HTEM data extent in southern Champaign County. The dashed lines mark the locations of the cross sections (Figure 13).

The southern and northern branches of the Mahomet aquifer in Champaign County are generally separated by materials characterized as loamy diamicton that trend southwest to northeast from Mahomet to Gifford. At elevations of 560 feet and above, those loamy diamicton materials are generally covered by shallow, thinner, well-sorted sands of the Mahomet aquifer (20–50 feet thick) southeast of the town of Rantoul. At Gifford, the Mahomet aquifer is generally absent (deeper elevations) or thin (higher elevations) and consistently characterized as largely loamy diamicton materials where present.

The identification of these new patterns of material-type changes has important implications on local variability of groundwater supply and local potential for aquifer recharge throughout Champaign County. Without high-density data, patterns of geologic changes must be implied, but this project has allowed us to estimate the internal structure and variability of material types

based on actual, measured data. Furthermore, the scale of resolvable variability from HTEM data and the MTC method is on the order of tens to hundreds of feet, as opposed to hundreds to thousands of feet with traditional mapping methods.

6.3 Water Resources in and around Mahomet Bedrock Valley

6.3.1 Hydrostratigraphy

The material-type characterization methods predicted changes and patterns of materials within the extent of the Mahomet aquifer (Figures 20 and 21), but the MTC method was also applied to the complete geologic framework of Champaign County. That framework includes both aquifer and non-aquifer materials, both inside and outside of the Mahomet Bedrock Valley (see Section 3.4).

The material types are a valuable indicator of geologic-material variability. However, those material-types can be further categorized into hydro-type units that are most relevant to the aquifer system. The eleven material types (Figure 21), which were based on texture, were re-categorized into hydrostratigraphic units, which are based on implied hydrologic characteristics and stratigraphy. The hydrostratigraphic characterization is more reflective of aquifer characteristics and relationships in the geologic framework.

The MTC results included ten hydrostratigraphic units (1-10) and one sub-unit of the Mahomet aquifer (11) (Figure 22). Aquifer units were defined as the Carbonate aquifer, Mahomet aquifer, Lower Middle aquifer, Upper Middle aquifer, and Shallow aquifer (units 1, 3, 5, 7, and 9, respectively in Figure 22). The confining units (non-aquifer units) were defined as the Carbonate confining unit, Mahomet confining unit, Lower Middle confining unit, Upper Middle confining unit and the Shallow confining unit (units 2, 4, 6, 8, and 10, respectively in Figure 22). The Local confining deposit (unit 11) was defined as non-aquifer materials within the Mahomet aquifer.

The Carbonate aquifer is the lowermost aquifer that was characterized, and it is a carbonate bedrock unit that is overlain by the Carbonate confining unit, which is composed largely of fine-grained shale and siltstone. The Carbonate aquifer is exposed at the bedrock surface in north-central Champaign County (Figure 23) from the northern county line, through the area of Rantoul, to the area of the town of Sellers. In these areas, the Carbonate aquifer is likely hydraulically connected to the Mahomet aquifer and/or shallower aquifers.

The aquifers that overlie the Carbonate aquifer and Carbonate confining unit are generalized into four sand-and-gravel aquifer units that fill the Mahomet Bedrock Valley and partially extend outside the valley. In the lowermost elevations of the MBV, the Mahomet aquifer is the predominant aquifer unit (unit 3 in Figure 22d–h) at elevations between 425 and 550 feet. The Local Confining deposit (unit 11) is predicted consistently throughout the Mahomet aquifer, in particular near elevations of 500 and 550 feet (Figures 22d, f and 23). The Local Confining unit has not been mapped or defined previously, and its presence and distribution provide more insights into the local variability of the aquifer in Champaign County. The Lower Middle aquifer

is present most predominantly throughout the south branch of the MBV and is generally separated from the underlying Mahomet aquifer by the Mahomet Confining unit (unit 4 in Figure 23) at elevations between 575 and 590 feet? (unit 5 in Figure 22b, c). The Upper Middle aquifer is less extensive and present largely in the northeast portions of the south branch of the MBV and within the north branch of the MBV (unit 7 in Figure 22a, b). The Shallow aquifer is predicted in small, local patches throughout the county, but most predominantly in an area east of Gifford. The modeled thicknesses and distributions of the sand-and-gravel aquifers are shown in Figure 24.

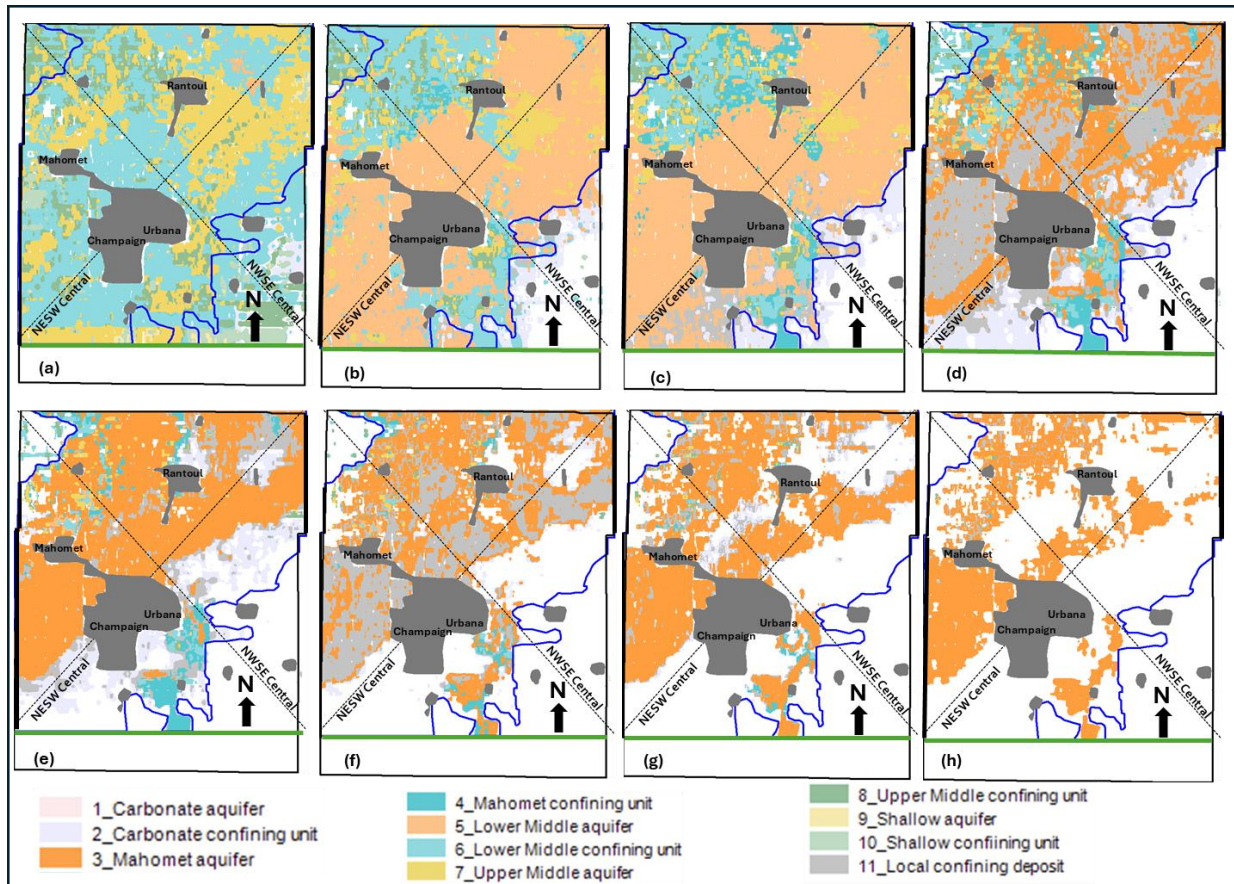


Figure 22. Maps showing the distribution of non-bedrock aquifer units and non-aquifer units in Champaign County at elevations of (a) 623 feet (190 m), (b) 590 feet (180 m), (c) 577 feet (176 m), (d) 551 feet (168 m), (e) 525 feet (160 m) (f) 492 feet (150 m), (g) 459 feet (140 m), and (h) 426 feet (130 m). The distributions are inferred from the interpreted from HTEM data. The green line shows HTEM data extent in southern Champaign County. The blue line is the new boundary of the Mahomet aquifer. The dashed lines mark the locations of the cross sections (Figure 23) through the hydrostratigraphic model. White areas delineate where the bedrock is present at the specified elevation (i.e., subcrops).

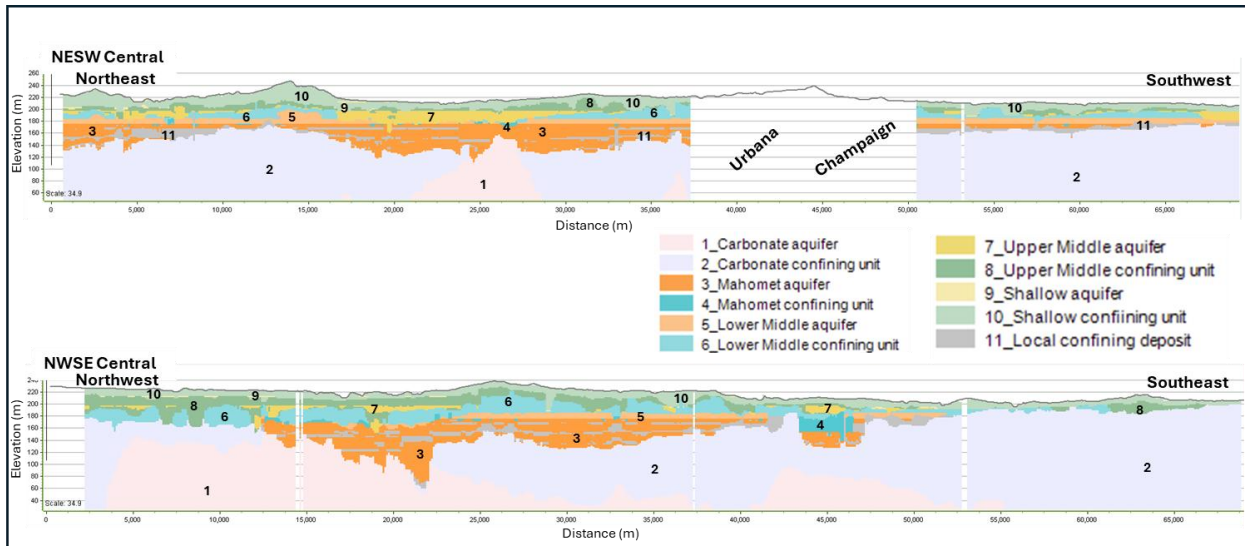


Figure 23. Cross sections displaying hydrostratigraphic units in 2-D in Champaign County. The units were defined from the MTC methodology (described in the text). The data gaps along the profiles (white areas) are areas where data was removed (returned data was impacted by powerlines) and/or areas where data could not be collected.

The thickness of the Mahomet aquifer changes depending on location within the MBV (Figure 24). Within the county, some of the thickest parts of the aquifer (160–200 feet thick) are present in an area about 9 miles east of the City of Champaign and near the towns of Bondville and Seymour (Figure 24a). This southern part of the aquifer extends to the northeast through the unincorporated areas of Leverett and Flatville, and Penfield where the aquifer is thinner (100–130 feet thick). Another branch of the MBV extends from the Bondville-Seymour area northward through Mahomet, Dewey and west of Ludlow (Figure 24). This branch traces the regional trend of the MBV that extends from the Illinois River near Havana across Illinois into north-central Indiana. In Champaign County, this part of the Mahomet aquifer (northern part) varies more locally in thickness between 100 and 200 feet thick (Figure 24).

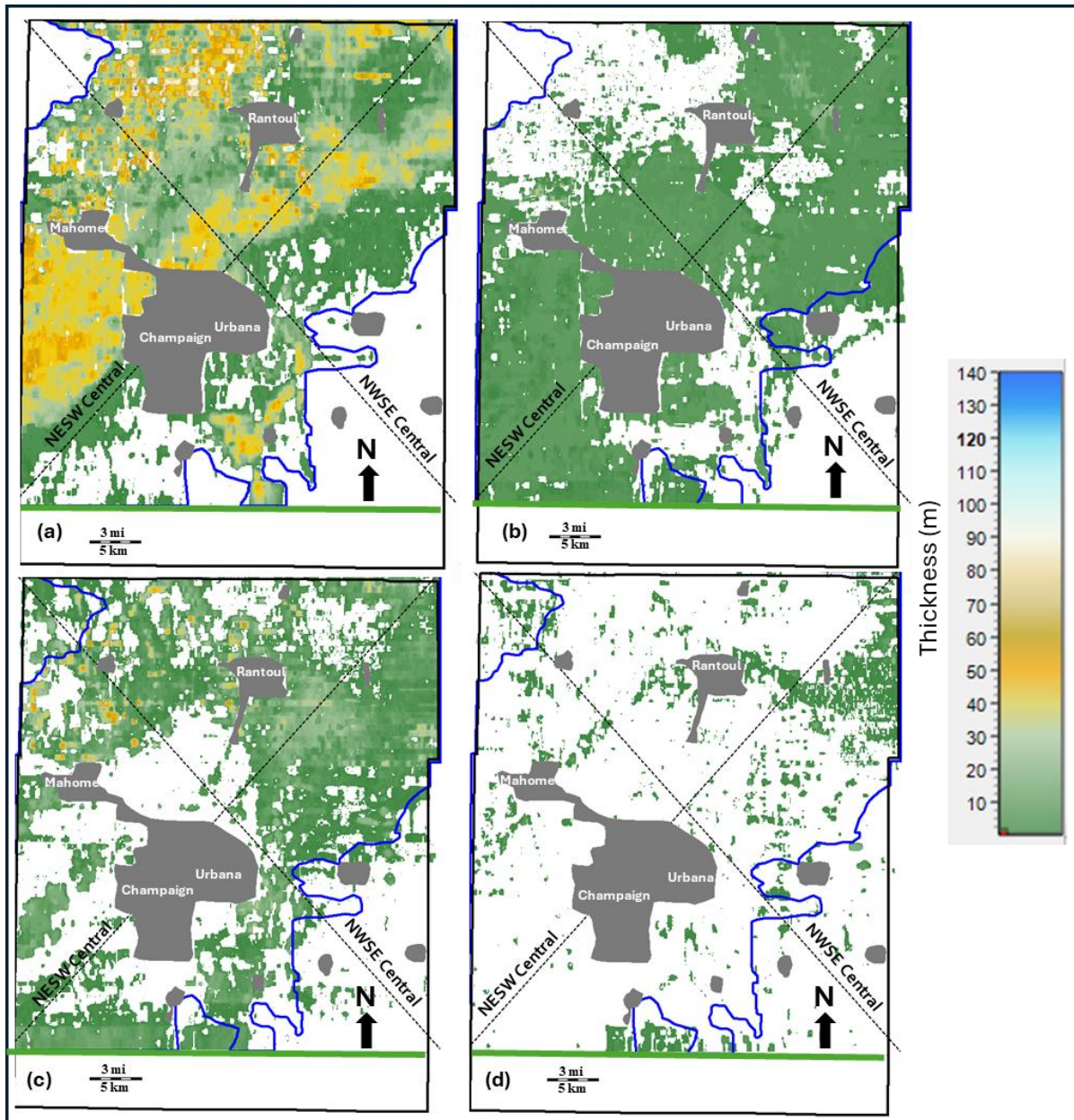


Figure 24. Thickness of the (a) Mahomet aquifer (b) Lower Middle aquifer (c) Upper Middle aquifer (d) Shallow aquifer in Champaign County. The green line shows HTEM data extent in southern Champaign County. The blue line is the new boundary of the Mahomet aquifer interpreted from HTEM data. The green line shows HTEM data extent in southern Champaign County. The dashed lines mark the locations of the cross sections (Figure 23) through the hydrostratigraphic model.

6.3.2 Buried channels

One of the goals of this project was to delineate, within the capabilities of the HTEM data, the distribution of ‘buried channels’ that are associated with the Mahomet aquifer. To avoid confusion as to what these channels are, how they are defined, and what they represent, we address these issues here. In the context of this project and report, we define buried channels to be channel-like features, within the HTEM material-type interpretations, which are located

within and adjacent to the boundary of the Mahomet aquifer. Several of these buried channel features are observable in Figure 25. These deposits are usually composed of sandy material types (i.e., Moderately Sorted Sands to Extremely Well Sorted Sands). However, some buried channels can be composed of finer grained material types (i.e., Clay to Poorly Sorted Sands). In general, buried channels are only identifiable when they are situated within material types of contrasting resistivity (i.e., when the resistivity contrast of the channel fills with the surrounding glacial deposits makes them more distinguishable) (Figure 12). The buried channels that are most relevant to understanding the aquifers in the project area are the sandy-type channels. When we analyzed the resistivity distributions, we did identify some smaller buried channel features that were within similar material types—both sandy and fine-grained—but these were very difficult to delineate and trace.

All the channels that we observed are interpreted as representing deposits left behind from channelized flow systems (i.e., rivers) that have eroded, or scoured, the surrounding material and left behind deposits in the channel. This is a normal sedimentary process in river systems, including those under, on top of, behind, and in front of glaciers, as was the case in the processes that produced these features.

The occurrence of buried channel deposits in the project area, therefore, is not surprising, nor unusual. Their significance is primarily that, by their channelized nature, they allow focused flow of water through the surrounding volume of sediments. This results in a level of complexity in groundwater flow that is difficult to anticipate or interpret from typical hydrologic datasets, and so is only readily identifiable through the identification of these types of channelized geologic deposits. The identification of these channel features does allow for improved interpretations of groundwater flow in future analyses.

Sandy buried channel deposits were most clearly identifiable in two main areas of the project area (Figure 25). In the northwestern part of the project area, west of Rantoul, the buried channels in the northwest are largely features that suggest they were part of Unit B and represent an erosive event later in the Illinois Episode, which scoured down into the sands in the Mahomet aquifer and the overlying diamicton deposits. These deposits, when sandy enough, are portions of the Upper Middle aquifer, and can locally scour down into the Lower Middle aquifer and the Mahomet aquifer. In the east-central portion of the project area, east of Urbana and Savoy, the buried channel features appear to be older than those in the northwest and are largely scoured into the pre-existing fine-grained sediments that are on top of the shale bedrock in this region. These channel deposits, when present below 571 feet (174 m) elevation, would be considered part of the Mahomet aquifer. When the deposits are present above 571 feet (174 m) elevation, they are assigned to the Lower Middle aquifer and can serve as an additional source of water in the local areas where they are present.

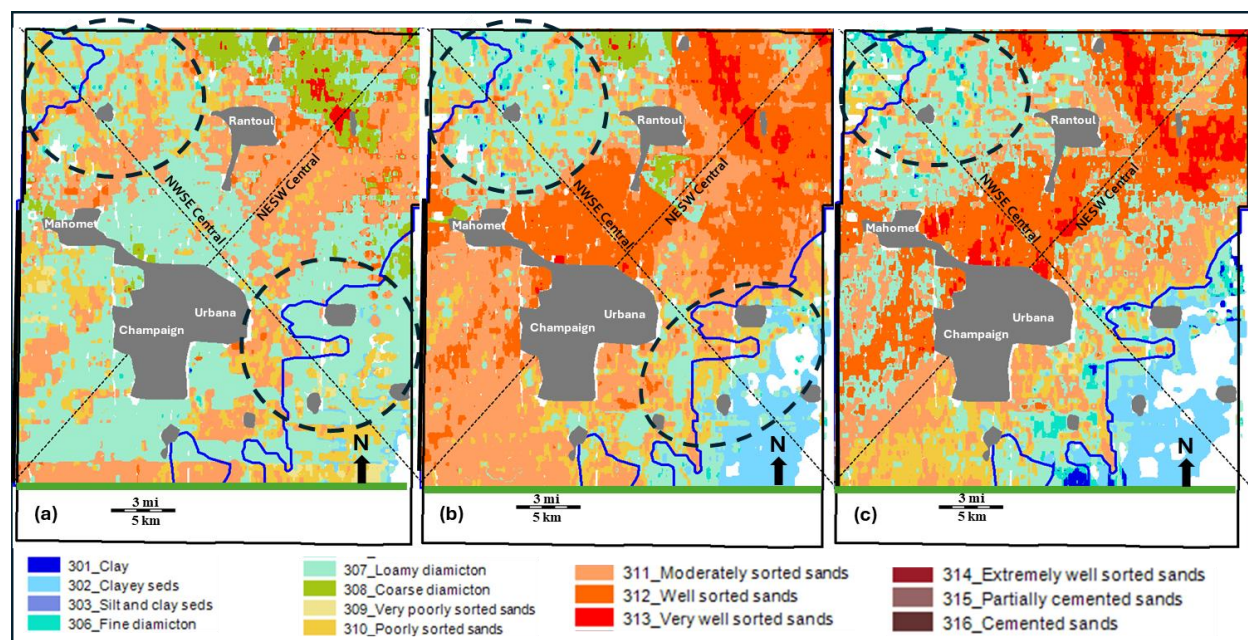


Figure 25. Buried channels identified in Champaign County at elevations of (a) 623 feet (190 m), (b) 590 feet (180 m), and (c) 571 feet (174 m). White areas delineate where the bedrock is present at the specified elevation (i.e., subcrops). The green line shows HTEM data extent on their southern side of Champaign County. The blue lines delineate the new boundary of the Mahomet aquifer. The green line shows HTEM data extent in southern Champaign County. The dashed black lines mark the locations of the 2-D cross sections (Figure 23) through the hydrostratigraphic model.

6.4 Evaluating Aquifer Connectivity and Aquifer Recharge

The complex history of the glaciers and meltwater rivers has resulted in a complex distribution of materials. The HTEM data and MTC interpretation method have provided a way to map their distribution and identify the interconnections between the different aquifers at a very high resolution—the thickness of 3-D grid cells in the vertical direction is 6 feet (2 m) and the horizontal grid cell size is 328 feet (100 m) on each side (Figure 11). Figure 26 shows the distribution of the Mahomet aquifer and the connections with overlying aquifers. As is clear from this map, more than half of the Mahomet aquifer is in direct contact with at least one overlying aquifer. The most common interconnection is with the Mahomet aquifer and the Lower Middle aquifer. Next is an interconnection is with the Mahomet aquifer and both the Lower and Middle aquifers. While not spatially significant, there is a surprising amount of connectivity between the Mahomet and all three of the overlying aquifers. This co-occurrence is mostly in the northeastern part of the county (Figure 26).

Recharge of groundwater is a concept that is very difficult to measure and is most frequently estimated using groundwater flow models. Another method that has been used for approximate relative differences in recharge to an aquifer, particularly over larger areas, is to examine variations in the cumulative thickness of confining unit deposits overlying the aquifer (Keefer and Berg 1990). This approach was used in a map predicting relative differences in aquifer contamination potential (Berg et al. 1984), which was later used as a strategy for designing

landfill compliance limitations (Hensel et al. 1991). The overriding assumption in this approach is that most recharge to a shallow aquifer is from directly above. In this situation, the thicker the overlying confining unit deposits, the longer it takes for groundwater to recharge the underlying aquifer. This approach is not meant to be a replacement for direct field observation of groundwater head gradients, or for calibrated groundwater flow models. It is recommended for use as a first-approximation tool for guiding land-use decisions in lieu of these other sources of information. Figure 27 shows the cumulative thickness of confining unit deposits overlying the Mahomet aquifer. This map identifies areas where the relative thicknesses of confining unit deposits are particularly thin (i.e., west of unincorporated area of Flatville), moderately thick (e.g., north and northwest of Champaign, north of Mahomet, west of Rantoul), or very thick (i.e., north of Rantoul).

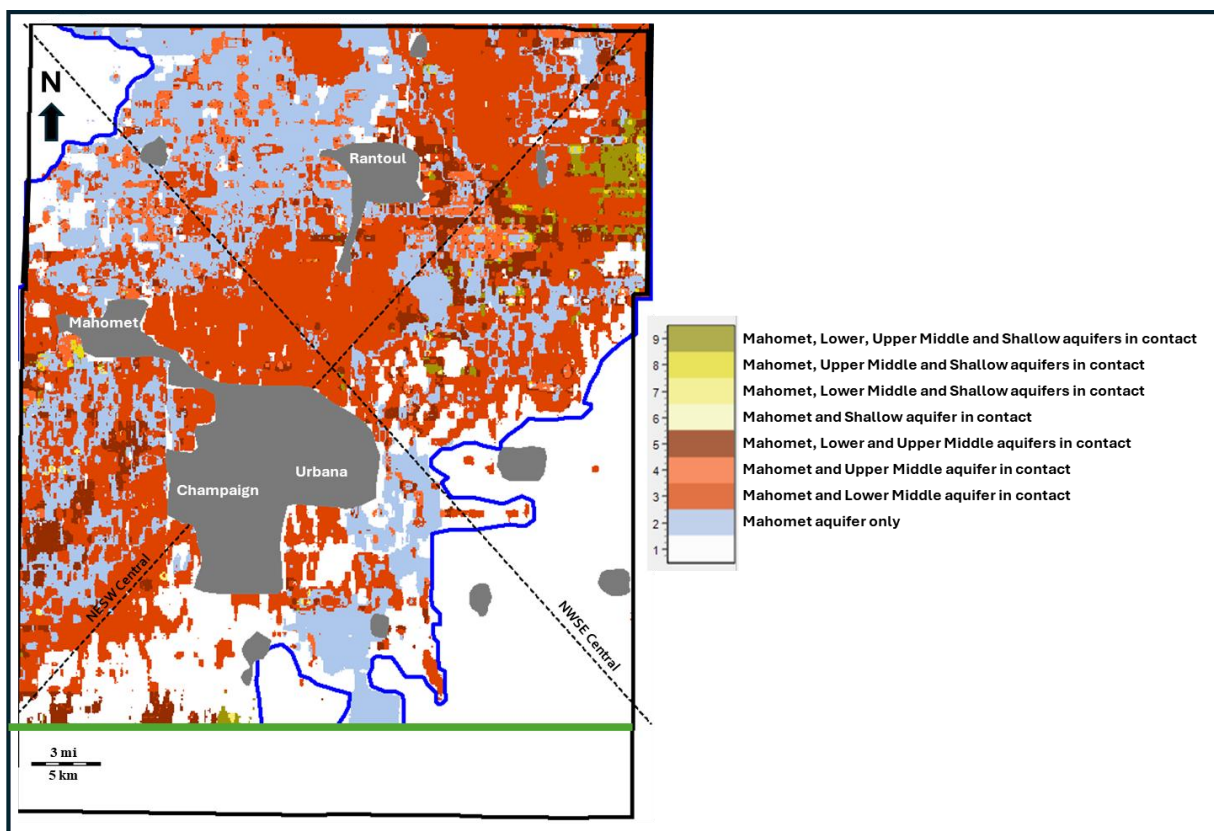


Figure 26. Areas of connectivity between the Mahomet aquifer and the shallower, overlying aquifer units. White areas delineate where the Mahomet aquifer is not present. The green line shows HTEM data extent on their southern side of Champaign County. The blue line is the boundary of the Mahomet aquifer interpreted from HTEM data. The black dashed lines mark the locations of the cross sections (Figure 23) through the hydrostratigraphic model.

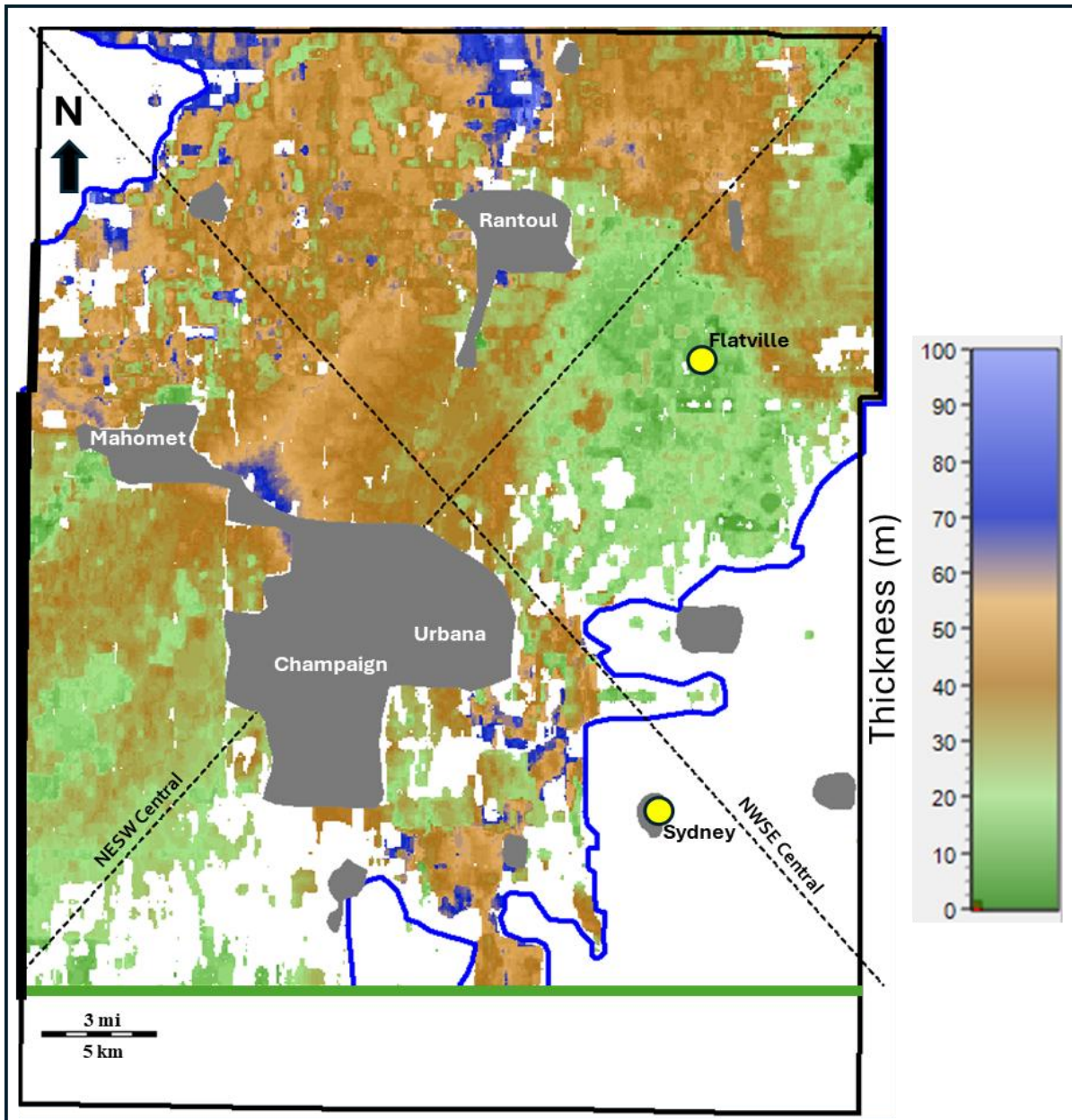


Figure 27. Total thickness of confining (clayey materials) above the Mahomet aquifer. White areas delineated where the Mahomet aquifer is not present. The green line shows HTEM data extent on their southern side of Champaign County. The blue line is the boundary of the Mahomet aquifer interpreted from HTEM data. The dashed lines mark the locations of the cross sections (Figure 23) through the hydrostratigraphic model.

The Flatville and Sydney boreholes support this MTC estimate of the thickness of confining units (Figure 16). The Flatville test hole (Figure 16a) indicated thin non-aquifer materials (less than 30 feet thick) overlying thick sequences of sand, and sand and gravel (collectively up to 200 feet thick). The Sydney test hole indicated mostly non-aquifer materials (fine-grained diamicton and silt) throughout the entire thickness of sediments (180 feet, Figure 16b).

7. DATABASE MANAGEMENT

Processed data collected as part of this project, and the resulting maps will be made available to the public through an accessible archive, Illinois Geospatial Data Clearinghouse <https://clearinghouse.isgs.illinois.edu>, the HTEM project website <https://htem.isgs.illinois.edu/> or the Champaign County GIS Consortium <https://www.ccgisc.org/DataAndServices.aspx>. ISGS will follow internal standard operating procedures for data/metadata format and quality control procedures to ensure accuracy of the data. Datasets posted on the website generally include additional information on using the dataset and background project information. All of the maps and data will be made available in a geospatial format and archived in a map projection/grid coordinate system as specified by the Champaign County. Data will be posted to the website within one year from the end of the project. Publications and maps will be posted as they are developed and accepted for publication. The raw data will be made available upon request by contacting the ISGS project manager Kisa Mwakanyamale Gilkie kemwaks@illinois.edu.

8. FUTURE WORK

A major priority for future work by ISGS researchers is to complete the HTEM-based characterization and map the extent of the MBV beyond Champaign County. Federally appropriated funds from ??? are currently being used for HTEM characterization of the MBV north and east of Champaign County. This leaves the mapping the rest of the MBV west of Champaign County. The importance of this characterization can be understood by comparing the updated aquifer boundaries, delineated by this project, to the USEPA Mahomet Aquifer System Sole Source Aquifer (SSA) boundary (USEPA 2015), which was delineated using the existing geological and hydrogeological data that was of lower resolution than this newly acquired HTEM data. The boundary developed by the USEPA significantly underestimates the extent of the Mahomet aquifer delineated in this project, particularly in eastern Champaign County. In addition, although not currently calculated, the unparalleled amount of information in the HTEM data suggests that potential changes to estimates of saturated thickness of the Mahomet aquifer will be significantly different from those calculated in 2015. To highlight the differences between the USEPA's 2015 characterizations and that available from HTEM data, if we consider only the sand and gravel materials of the Mahomet aquifer (i.e., aquifer sediments at or below approximately 174 m [570 feet]) (Figure 28a), the aquifer is very narrow in the eastern portion of the MBV, and USEPA did not include a significant portion of the aquifer extent in the southeastern and eastern part of Champaign County. Additional areas within the new boundary demonstrating presence of other shallow aquifers within the Mahomet Aquifer System are illustrated in Figure 28b. We anticipate the new sediment distribution in the northern and western portions of the Mahomet Aquifer System, could further exacerbate the impacts of old boundaries and saturated thickness calculations.

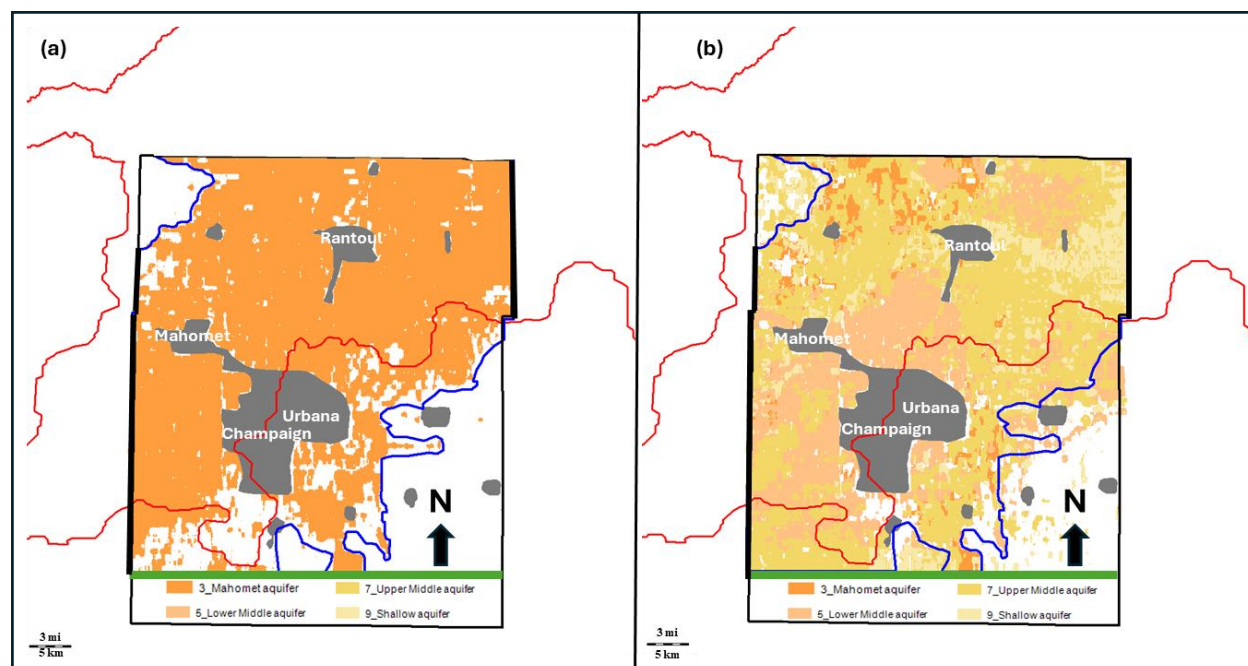


Figure 28. Comparison between Mahomet Aquifer System distribution within the Sole Source Project Review Area from USEPA and the new Mahomet aquifer boundary delineated from this project. (a) Comparison with Mahomet aquifer only. (b) Comparison with all other aquifers. Red is boundary from USEPA and blue is the new Mahomet aquifer boundary from HTEM.

The ISGS project researchers will continue to work with groundwater flow modelers at the ISWS to integrate the results from this project (i.e., 3-D models of geologic material types) with groundwater flow modeling efforts. Insights on interconnections of the different aquifers within the Mahomet Aquifer System, and on the variability of aquifer materials within the different aquifers, have the potential to improve predictions of groundwater flow, to reduce the uncertainty of sustainable water management decisions, and to use this improved information for associated decisions surrounding public and environmental health and economic development throughout Champaign County.

The PRI will continue to seek funds to collect additional HTEM data and other geological and geophysical data in southern Champaign County (south of County Road 500 N). The southern boundary of the Mahomet aquifer is currently mapped as following the southern boundary of the study area. This suggests the Mahomet aquifer, and Mahomet Aquifer System may extend further south of the current project boundary. Characterization of this portion of the County will be beneficial to further characterize tributary valleys to the MBV and to interpret the distribution of aquifers and confining units. The current study has suggested that additional information is needed to improve our understanding of the topography of the bedrock surface, the distribution of tributary valleys, and the nature of overlying Mahomet Aquifer System deposits. ISGS researchers will continue to advance this new MTC interpretation method for HTEM data, particularly in three major directions. The first direction for method advancement involves the direct incorporation of borehole geologic descriptions into the interpretations. As noted

throughout this report, the current interpretations are grounded in the HTEM data. Borehole, seismic, and electrical resistivity tomography (ERT) data were used to further shape the conceptual models that we used in the MTC method; helping assign geologically plausible material types to the observed resistivity value distributions. Our first priority in method advancement would be to directly integrate the high-quality geologic descriptions into direct interpretations with the resistivity data. This and other advancements in the MTC interpretation method will inevitably result in changes to the interpreted material distributions and to the various aquifer and confining unit boundaries. Our second priority for method advancement is to define a workflow for generating, documenting, and publishing updated interpretations. The third priority in MTC method advancement is to develop a workflow, in collaboration with the groundwater flow modelers, for identification of joint geologically and hydrologically plausible material type distributions based on insights from groundwater modeling using HTEM-based material type interpretations. ISGS and ISWS researchers have already begun discussions in this direction, and future work will continue these discussions, leading to the formal development of this critical workflow.

9. CONCLUSIONS

The use of airborne geophysical mapping technology, HTEM, to map the Mahomet aquifer in Champaign County has revealed many important aspects of its geometry, not resolvable previously. The results of this project have produced the first-ever high-resolution distribution of all the aquifers and confining units in east-central Illinois, anchored to the newly acquired high-resolution HTEM data. The analysis of all the acquired data and the use of the MTC method have been essential to the identification of the aquifer and non-aquifer materials which are later categorized as aquifer units and confining units. The observations from dense HTEM data and MTC analysis have revealed material type changes within the aquifer, and the distributions of these materials have important implications for mapping preferential pathways of groundwater flow paths.

Although the Mahomet aquifer is the principal groundwater resource in Champaign County, other shallow glacial sand and gravel aquifers are also present and comprise, locally, important sources of groundwater, particularly where the Mahomet aquifer is not present. Identification of channelized Upper Middle aquifer deposits, Lower Middle aquifer and Shallow aquifer, above and intersecting with the Mahomet aquifer in several areas of Champaign County, has increased the need to better define what we call “Mahomet aquifer” in the region. These other shallow aquifers are likely hydrologically connected and locally provide a significant source of groundwater for domestic and agricultural wells. In these areas where the aquifer materials are thicker, they may provide sufficient water for commercial operations, small municipalities, or supplement the water supply of a larger municipality. These additional water resources may contribute further to the sustainable management of groundwater resources in Champaign County.

In Champaign County, the Mahomet aquifer has no surface expression as it is buried by a thick clayey till. Identification of shallow channelized sand features (filling buried channels) in the northwest and southeast parts of the project area, that locally intersect or overlie the Mahomet aquifer, could offer potential local recharge zones and additional water resources. While not present across the entire project area, these sand and gravel deposits form a continuous feature within the MBV that may be up to 30 m (~100 ft) thick.

Groundwater does not readily move through fine-grained geologic materials such as glacial tills and silt and clays, and shale bedrock because the pore spaces are small and poorly connected. The complex nature of glacial geological material and distribution of such materials in the subsurface are major factors affecting the availability, quantity, and quality of groundwater. The imaged presence of fine-grained material (i.e. non-aquifer materials) within the Mahomet aquifer makes it very challenging to predict how much water there is and how fast the water is traveling, and which direction it moves. Our high-resolution identification of a significant number of fine-grained discontinuous layers (baffles) throughout the Mahomet aquifer, will help resolve these challenges and answer all critical questions pertaining to groundwater availability, quantity, and

quality. Combining this information during groundwater flow modeling, will help refine groundwater flow pattern within Mahomet aquifer.

It is important to remember that, filling the gaps where data are limited, and determining the 3-D distribution of geologic materials that either yield water or act as barriers to groundwater flow will help us understand the available resource in east-central Illinois. Understanding the geologic framework is essential to comprehend where groundwater occurs and how it behaves in the subsurface. Future integration of the Champaign County Mahomet aquifer mapping results, with the results from the ongoing northeast Mahomet aquifer (Vermillion, Iroquois, Ford, and Livingstone) mapping project interpretations, and evolution of the HTEM data interpretation method (MTC) will result in new versions of material distribution. This new and improved information of the geologic framework and hydrostratigraphy, will greatly improve accuracy of all current groundwater decision making and future groundwater predictions. Future collaboration with groundwater flow modelers will result in updated versions of material distribution, due to the constraints provided by groundwater flow calculations, which will be further improvements to our understanding of the Mahomet aquifer system in east-central Illinois.

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