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Geology and Aquifer Sensitivity of Quaternary Glacial Deposits Overlying a Portion of the Mahomet Buried Bedrock Valley Aquifer System

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Abstract: To characterize the distribution of Holocene and Late Quaternary deposits and to assess the contamination potential of the Mahomet Aquifer, surficial geologic and aquifer sensitivity maps of the Gibson City East 7.5-Minute Quadrangle were created. Geologic data, extent, and thickness of the geologic materials were coupled with LiDAR topographic data and analyzed using ESRI's ArcGIS 10.6.1. Aquifer sensitivity to contamination was calculated based on the depth to the first aquifer unit, aquifer thickness, and the lithology of the aquifer materials. The surficial geologic mapping identified five lithostratigraphic units: the Cahokia Formation, the Equality Formation, the Henry Formation, and the Yorkville and Batestown Members of the Lemont Formation. The southeast to northwest trending Illiana Morainic System is the most prominent feature in the study area and delineates the maximum extent of the glaciers during the Livingston Phase of glaciation. Postglacial deposits of the Cahokia Formation, alluvium, interfinger, and overlie with glacial outwash of the Henry Formation along channels and drainage ways downslope of the moraine. The areas of least sensitivity are located over the Illiana Morainic System, whereas the greatest potential to contamination occurs where the thickest deposits of the Henry Formation and Cahokia Formation lie at or just below the land surface.

Keywords: surficial geology; aquifer sensitivity; Wisconsin Glacial Episode; Illinoian Glacial Episode; Mahomet Aquifer; Glacial Deposits

1. Introduction

The Mahomet Aquifer System, which is found within the Mahomet Bedrock Valley and includes both the Mahomet Aquifer and the overlying aquifer and non-aquifer units, is the principal groundwater resource in east-central Illinois, USA. The Mahomet Aquifer provides an estimated 20,000 cubic meters (53 million gallons) per day of drinking water to approximately 120 public water supplies and thousands of rural wells, together serving over 500,000 people [1]. In 2015, the U.S. Environmental Protection Agency designated the Mahomet Aquifer System a sole-source aquifer [1]. Because of the aquifer system's significance to the communities it serves, the Illinois State Geological Survey (ISGS) designated the eastern Mahomet Bedrock Valley a priority geologic mapping area (Figure 1). Detailed geologic maps can provide a more precise characterization of the materials comprising the Mahomet Aquifer System, so that more informed land use decisions can be made to better protect this invaluable resource.

In east-central Illinois, sources of groundwater contamination can be non-point sources, such as fertilizer and pesticide applied on agricultural lands, chloride dissolution from road salting, and from point sources, specifically leaking underground storage tanks and pipelines, and leachate from landfills and dumps [2]. Aquifer sensitivity maps can be created to help in the assessment of contamination potential. Aquifer sensitivity refers to the relative ease with which a contaminant can move from the land surface into the subsurface [3]. The maps are based on information from surficial geologic maps, borehole geologic logs, and surface and downhole geophysical surveys.

Aquifer sensitivity maps have been used by land-use planners and government agencies for identifying areas of high risk and making decisions for future development [4]. In Illinois since the mid-1980s, these maps were compiled at state, regional, and county scales to assist in landfill siting, prioritizing areas for groundwater monitoring, selecting candidate areas for development of low-level radioactive waste disposal facilities, and studying the potential effects of agricultural chemicals on shallow groundwater quality [5–9]. This effort includes mapping for aquifer sensitivity in parts of 11 counties (e.g., [10–16]).

The first comprehensive methodology for aquifer sensitivity was DRASTIC, which was proposed by the US EPA by Aller et al. [17]. DRASTIC was designed to be a straightforward, nationally used tool for groundwater pollution hazard assessment. DRASTIC parameters include depth to aquifer, net recharge, soil material, aquifer material, topography, vadose impacts, and conductivity. The importance of each parameter on pollution potential are balanced by rating weight multipliers, and the weighted sum of each factor provides the final variability index. For example, ratings vary from 1–10, and reflect the significance of classes within a factor. For example, silty soils are assigned and lower rating than sandy soil, and steeper slopes have a lower rating than gentler slopes [18–20]. Modified versions of DRASTIC have been used in the glaciated regions of the Great Lakes area, with topography and recharge being eliminated because of overall gentle slopes and consistencies of recharge [21–27]. DRASTIC and related techniques have since been applied globally in a variety of geology and hydrogeologic settings (e.g., [28–34]).

Because most water wells in east-central Illinois are constructed in unconsolidated glacial deposits, geologic maps outlining their distribution are necessary. These maps are made from a combination of data from field observations, soil surveys, borehole logs, or remotely-sensed data (e.g., light detection and ranging (LiDAR) data and satellite and aerial imagery). These data are typically compiled in GIS software for analysis, interpretation, and creation of the map. Surficial geologic maps form a basis upon which other derivative maps can be made for specific purposes, such as groundwater management, exploration for mineral resources, or mitigation of natural hazards. Thus, the goal of this research is to assess the vulnerability of a portion of the Mahomet Aquifer, an aquifer sensitivity map was created in conjunction with the development of the surficial geologic map of the area. This work provides a better understanding of the distribution of Quaternary and Holocene (postglacial) deposits within the Gibson City East 7.5-Minute Quadrangle.

2. Materials and Methods

2.1. Study Area

The Gibson City East 7.5-Minute Quadrangle occurs in southern Ford and northern Champaign counties in Illinois (Figure 1). The map area primarily includes rural agricultural land, but does contain part of Gibson City, a small town with a population of less than 4000 residents. The mapping completed for this study drew upon the previous work in adjacent areas [35–38].

Surficial deposits within the Gibson City East Quadrangle are a product of glacial and postglacial processes that occurred during the Hudson and Wisconsin Episodes. The Hudson Episode represents modern and older postglacial deposits dating back to approximately 14,700 years before present (BP) [39,40]. The Cahokia Formation, which includes deposits of poorly sorted sand, silt, clay, and gravel found on floodplains and in river channels are the only sediments in the Quadrangle dating to the Hudson Episode. The thickness of the Cahokia Formation varies but was found to be up to ~4.5 m (15 ft) thick in the adjacent Rantoul Quadrangle [35]. The Peoria Silt of the Hudson Episode is believed to blanket much of the area within the Quadrangle with up to 1 m of wind-blown clayey silt, but it is not typically included on surficial geologic maps in adjacent areas as it is less than 1.5 m (5 ft) thick.

The glacial sediments of the Wisconsin Episode present in the Gibson City East Quadrangle were deposited by the Decatur Sublobe that comprised the Lake Michigan Lobe of the Laurentide Ice Sheet [41]. The advance of the Decatur Sublobe into east–central Illinois occurred during the Michigan Subepisode approximately 24,000–14,700 years BP [40]. The Michigan Subepisode represents the last major glaciation during the latter part of the Wisconsin Episode. Eight phases of ice margin advance and retreat of the Lake Michigan Lobe occurred during this time period. Of these phases, only glacial tills of the Putnam and Livingston Phases that occurred between ~24,200–22,200 years BP and ~22,200–21,100 years BP, respectively [40] are found within the Quadrangle.

Diamicton forming the Illiana Morainic System, the most prominent landform in the Quadrangle, was deposited during the Livingston Phase. This diamicton (interpreted as till) is assigned to the Yorkville Member of the Lemont Formation [42]. The Yorkville is characterized by its dark grey color, and silty clay to silty clay loam texture. It is ~3–9 m (10–30 ft) thick in the adjacent Rantoul Quadrangle [37]. Southwest of the Illiana Morainic System, deposits of the Equality Formation, the Batavia Member of the Henry Formation, and the Batestown Member of the Lemont Formation occur at the land surface. The Equality Formation consists of brown to gray to reddish-brown silt and clay that is bedded to laminated that was deposited in a proglacial lacustrine environment. The deposits are ~1.5–6 m (5–20 ft) thick in the Rantoul Quadrangle [35] but have been found to be up to approximately 20 m (65 ft) thick in east-central Illinois [43]. These sediments were deposited late into the Putnam Phase as the glaciers receded northward. These glacial lakes could have persisted into the Livingston Phase, and even into postglacial time. The Batavia Member of the Henry Formation includes deposits of sand and gravel (glacial outwash) that contains some beds of silt [42]. The outwash was deposited along the ice margin as the Illiana Morainic System was being formed to the east and north and interpreted to be associated with the later part of the Livingston Phase. Outwash ranges considerably in thickness, from upwards of 65 m (213 ft) in major valleys to less than one meter (4 ft) in fans along moraine fronts, but is only up to ~7.6 m (25 ft) thick in the Rantoul Quadrangle [37]. The oldest surficial deposits in the Gibson City East Quadrangle, diamicton classified to the Batestown Member, was deposited during the latter part of the Putnam Phase [44] when the Laurentide Ice Sheet retreated north of Champaign County and readvanced to the Champaign Moraine. This till is distinguished from the Yorkville Member by its slightly coarser texture (silt loam to loam) [42]. The Batestown Member was found to be between ~7.6 to ~22.8 m (25–75 ft) thick in the Rantoul Quadrangle [35].

In the subsurface, the Tiskilwa Formation underlies the Batestown Member (Figure 2). The Tiskilwa Formation till was deposited during the Shelby Phase ~24,000–22,000 years BP [39,40]. The diamicton is defined as reddish grey to grey clay loam to loam.

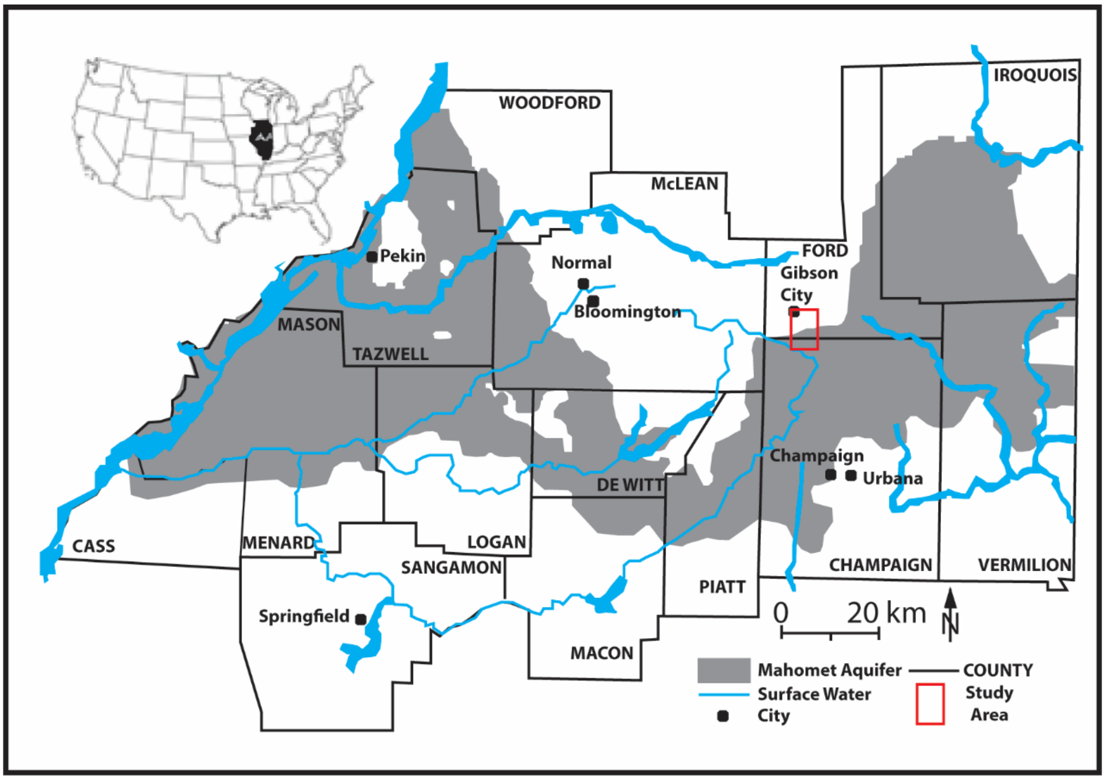

Figure 1. Map of the Mahomet Aquifer (gray area) in east-central Illinois, USA. Mapping area is highlighted by red box. Figure modified from [45].

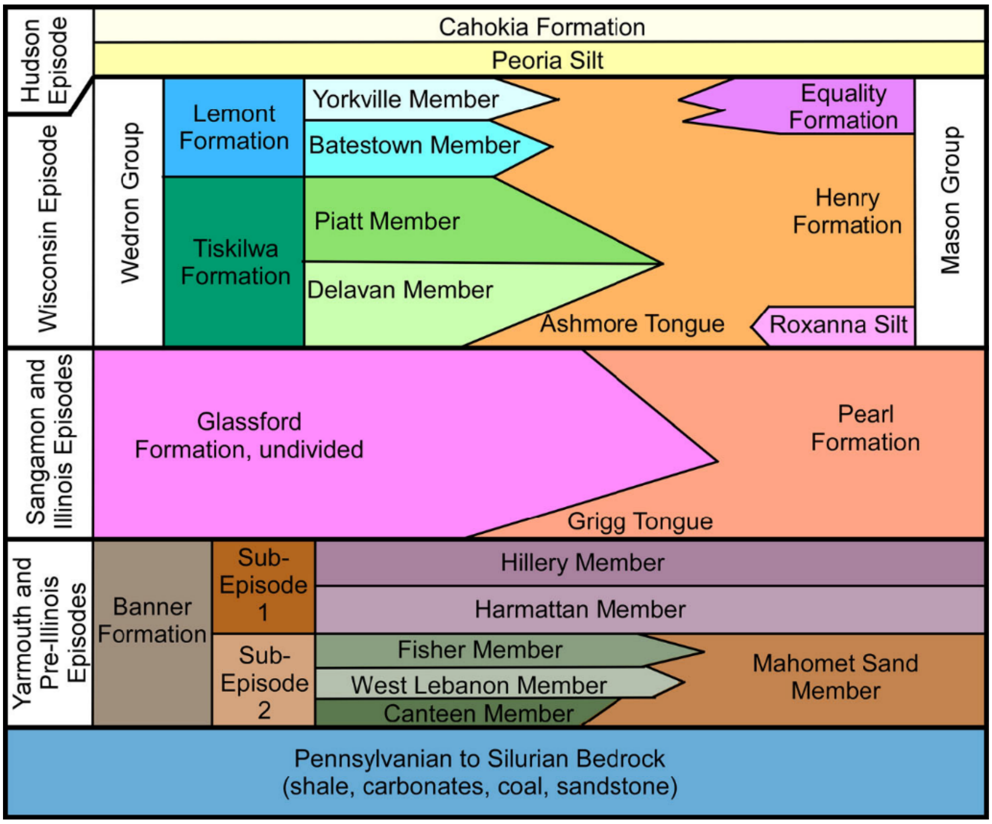

Figure 2. Generalized lithostratigraphy of Quaternary-age sediments in east-central Illinois. All units that rest unconformably above the bedrock strata are Quaternary in age. Modified from [39].

Underlying the Wisconsin Episode are diamicton (tills) of the Vandalia Member (Glasford Formation) and outwash deposits of the Pearl Formation, deposited during the Illinois Episode [46]. Interstratified layers of sand and gravel within the upper part of the Vandalia Member form aquifers, but they have a limited areal extent. Pre-Illinois Episode deposits of the Banner Formation compose the lower part of the glacial sedimentary succession (Figure 2). The Banner Formation includes the uppermost Tilton Member, followed by diamicton (tills) of the Hillery and Harmattan Members, and glacial outwash of the Mahomet Sand Member. The Mahomet Aquifer is composed of sands and gravels classified to the Mahomet Sand Member. Silurian to Devonian bedrock, primarily limestone and dolomite, underlie the Quaternary-age deposits. The thickness of preglacial, glacial, and postglacial deposits overlying the bedrock ranges from 60 to 90 m (200 to 300 ft) within the Gibson City East Quadrangle, with thicker deposits over the Mahomet Bedrock Valley [47].

2.2. Surficial Geologic Methods

A surficial geologic map was developed for the Gibson City East 7.5-Minute Quadrangle to better visualize the distribution of glacial and postglacial deposits at the land surface and in the shallow subsurface in the study area. Mapping was completed at the 1:24,000 scale.

The first step in developing the surficial geologic map was to assemble a parent material map of the soils by compiling United States Department of Agriculture (USDA)—Natural Resource Conservation Service (NRCS) soil data for Ford and Champaign counties [48,49], which were available as a shapefile. The shapefile was imported into ESRI's ArcMap ™ software (Version 10.6.1), and the vector data were clipped to the boundary of the quadrangle. The polygons were then coded by parent material. When delineating the parent materials, only deposits at least 1.5 m (5 ft) thick were included. When deposits did not meet this specification, the underlying unit was used.

Geologic and geophysical logs recorded during the drilling of water wells, highway and bridge borings, oil and gas exploration borings, and coal structure test borings were obtained from the Illinois State Geological Survey (ISGS) to further verify the material thicknesses and extent of the parent materials. Within the Quadrangle, 206 boreholes exist with information (of varying quality) about the subsurface geology. Geologic logs from nine highway projects in Ford County and 10 projects in Champaign County were also examined. As part of the mapping process, the water well boreholes were located more accurately using tax parcel data or verified in the field. Water well locations had to be verified as the locations are displayed by default at the center of the $\frac{1}{4}$-$\frac{1}{4}$-$\frac{1}{4}$-section on the ISGS ILWATER website.

After verifying the thickness and extent of the various parent materials, they were then classified to lithostratigraphic units using the frameworks developed by Willman et al. [42,50]. In some instances, the parent material could not be directly translated to a lithostratigraphic unit based solely on its lithologic description. An example of this is the Ashkum silty clay loam (MUSYM = 232A), which was found in both the southwestern corner of the Quadrangle south of the moraine as well as in the moraine complex. Based on the lithologic description of the parent material, the Yorkville Member would be the most direct translation for the Ashkum silty clay loam, however, Johnson et al. [51] classified the Batestown Member as the till south of the Illiana Morainic System and the Yorkville Member as the younger, coarser grained till immediately to the northeast and overlying the Batestown Member. Therefore, it does not make sense to classify every polygon containing the Ashkum loam as the Yorkville Member. In these instances, LiDAR data were useful for mapping the geomorphic landforms, which assisted in differentiating lithostratigraphic units.

LiDAR elevation data were obtained from the ISGS as a raster dataset in the form of a digital terrain model (DTM) and derivative hillshaded georectified image. The LiDAR data have an average of 0.68 m or better horizontal resolution and vertical accuracy of 15.0 cm. The LiDAR model was used to identify the boundaries of floodplains, fans, moraines, glacial lake basins, and partially buried esker-tunnel valley ridges. The Illiana Morainic System, which could be identified using the LiDAR, served as a distinguishing feature between the two till units within the Quadrangle. To assist with defining the extent of fan deposits, two-foot contours were generated from the DTM. Having contours at this topographic scale was useful for the discernment of subtle differences in elevation. Small depressions or bowl like features were interpreted as kettles (cf. [52]), while narrow linear ridges that were partially buried could be eskers, kames, or crevasse fills (cf. [53,54]).

The last step in developing the map included field verification of the geologic (map) units. This step proved difficult as there were no large outcrops or natural exposures within the Quadrangle. During the time of field verification, several fields were being excavated for the placement of tile drains. The trenching allowed for visual identification of the surficial material at three different locations.

Following the fieldwork, polygons were created and digitized in ArcMap to represent the various lithostratigraphic units. The polygons were then saved as individual layer files in ArcMap, and then imported into a topographic style template, provided by the USGS (https://viewer.nationalmap.gov/tools/topotemplate/).

2.3. Aquifer Sensitivity Methods

Aquifer sensitivity within Gibson City East Quadrangle was determined from the surficial geology map and borehole database following the methodology described by Berg [2]. Aquifer sensitivity is based on the depth to the shallowest aquifer unit and the relative thickness of the aquifer unit. Studies in the glaciated upper US Midwest by Klaseus et al. [55] in Minnesota and Libra et al. [56] in Iowa highlighted the importance of depth to aquifer unit and reported a very low occurrence of contamination of agrichemicals in groundwater below ~35 m (115 ft) depth. Aquifer thickness is also assessed in this classification system. Thicker aquifer units are generally considered to contain more valuable groundwater resources than thinner aquifers, and thus are deemed more sensitive. Section 620.210 of the Illinois Amendments to Groundwater Quality Standards (35 Ill. Admin. Code § 620) was used by Berg [2] to specifically define what constitutes an aquifer in the classification system. The code states that a potable groundwater resource can be found in a porous coarse-grained sand and gravel aquifer greater than 1.5 m (5 ft) thick. For our analysis, ranges in hydraulic conductivity were drawn from Berg [2] for the various geologic materials (Table 1).

Table 1. Hydraulic conductivity of typical geologic materials in east-central Illinois [2]. Aquifer materials are shaded in green and aquitard materials are shaded in red.

Geologic Material	Hydraulic Conductivity (m/s)	Comment
Coarse sand and gravel, well sorted	1×10^{-1}	May be highly permeable; good aquifer material
Fine sand and silty sand	1×10^{-3} to 1×10^{-1}	Good aquifer material
Silty to clayey glacial sediments	1×10^{-7} to 1×10^{-3}	Includes till and lacustrine sediment; commonly contain gravel/sand lenses; generally non-aquifer material
Silt and fine sand	1×10^{-4} to 1×10^{-2}	Loess; non-aquifer material; surficial unit

The first step in completing the aquifer sensitivity analysis involved further analyzing borehole geologic logs to determine the depth to the uppermost aquifer at each location, the thickness of that aquifer unit, and properties of the aquifer materials. When analyzing the logs, the first sand and gravel unit encountered from the land surface that was at least 1.5 m (5 ft) thick used in the analysis.

The data were compiled in a spreadsheet and analyzed. A logical formula using "IF" statements was computed to assign an aquifer sensitivity classification value to each borehole. An additional formula was then written to convert the alphanumeric aquifer sensitivity classifications into numeric classifications (i.e., A1 = 1, A2 = 2, etc.) in order that an interpolation analysis could performed later using ArcGIS software. The spreadsheet data file was then joined to the attribute table of well location information in ArcMap allowing the sensitivity classifications to be visualized spatially in the study area.

To evaluate sensitivity ratings between the limited number of boreholes, we applied an inverse distance weighted (IDW) interpolation IDW was chosen over other interpolation methods because the IDW algorithm assumes that the variable being mapped decreases in influence with distance from its sampled location [57]. Therefore, the measured values closest to the prediction location have more influence on the predicted value than those farther away. Our assumption was that the geology at a given location is more likely to be consistent with the nearest borehole than material further away. It is understood that the interpolation did not consider other parameters such as the geomorphology and subsurface heterogeneities mapped in adjacent areas when making interpolations between boreholes. Therefore, the IDW results serve as an initial analysis which helps to begin to define sensitivity boundaries. Results of the IDW analysis were overlain over the surficial geologic map to assist in refining the boundaries of the sensitivity classes. The IDW was referenced when sensitivities varied within the same geologic unit. The IDW results were utilized for defining the boundary between the E1 and D3 regions within the moraine complex, as well as determining the extent of some of the small sand and gravel lenses found throughout the quadrangle. In several areas on the map, the IDW produced 'bull's-eye' shapes around lone boreholes where the aquifer sensitivity varied from the surrounding classifications (e.g. Section 35, T23N, R8E). These regions may represent heterogeneities in the aquifer units or could be a result of problematic data. The surficial geology was referenced in these regions to try and more accurately define the extent of the areas represented by the singular data points. If no surface features were present, these 'bull's-eye' regions were left off the final renderings of the aquifer sensitivity map and the data point was incorporated with the surrounding sensitivity class.

3. Results

3.1. Surficial Geology

The interpreted parent materials map revealed five materials within the Gibson City Quadrangle: sand, silt, clay, and gravel; silt and clay; sand and gravel; diamicton; and a mix of diamicton and silt and clay. These deposits were translated into five lithostratigraphic units represented on the surficial geologic map (Figure 3). The units, from youngest to oldest, are as follows: the Cahokia Formation, Equality Formation, the Batavia Member of the Henry Formation, and the Yorkville and Batestown Members of the Lemont Formation. The following section provides a detailed description of the how the units were assigned based upon the lithology and the geomorphic features within the Gibson City East Quadrangle.

Within the quadrangle, the Cahokia Formation is as much as 4.5 m (15 ft) thick and was identified in the floodplains and channels of the Sangamon River, Drummer Creek, Dickerson Slough, Blackford Slough, as well as several other small, unnamed streams. The LiDAR hillshade aided in the identification these channels and floodplains (Figure 4). The Cahokia Formation was also found in fan-shaped deposits that emanate from the valleys of the moraine, where the topography flattens out to south of the Illiana Morainic System. In these areas, the alluvium onlaps with glacial outwash. Only five boreholes penetrated the fan deposits. Therefore, defining the extent of the alluvial deposits was guided by the configuration of 0.61 m (2-foot) contours derived from the LiDAR DEM. Drilling into these deposits generally encountered thin deposits of fine-grained sediment (silt and clay) in the valleys of the moraine with thicker, coarser deposits (sand and gravel mixed with clay) in the fans.

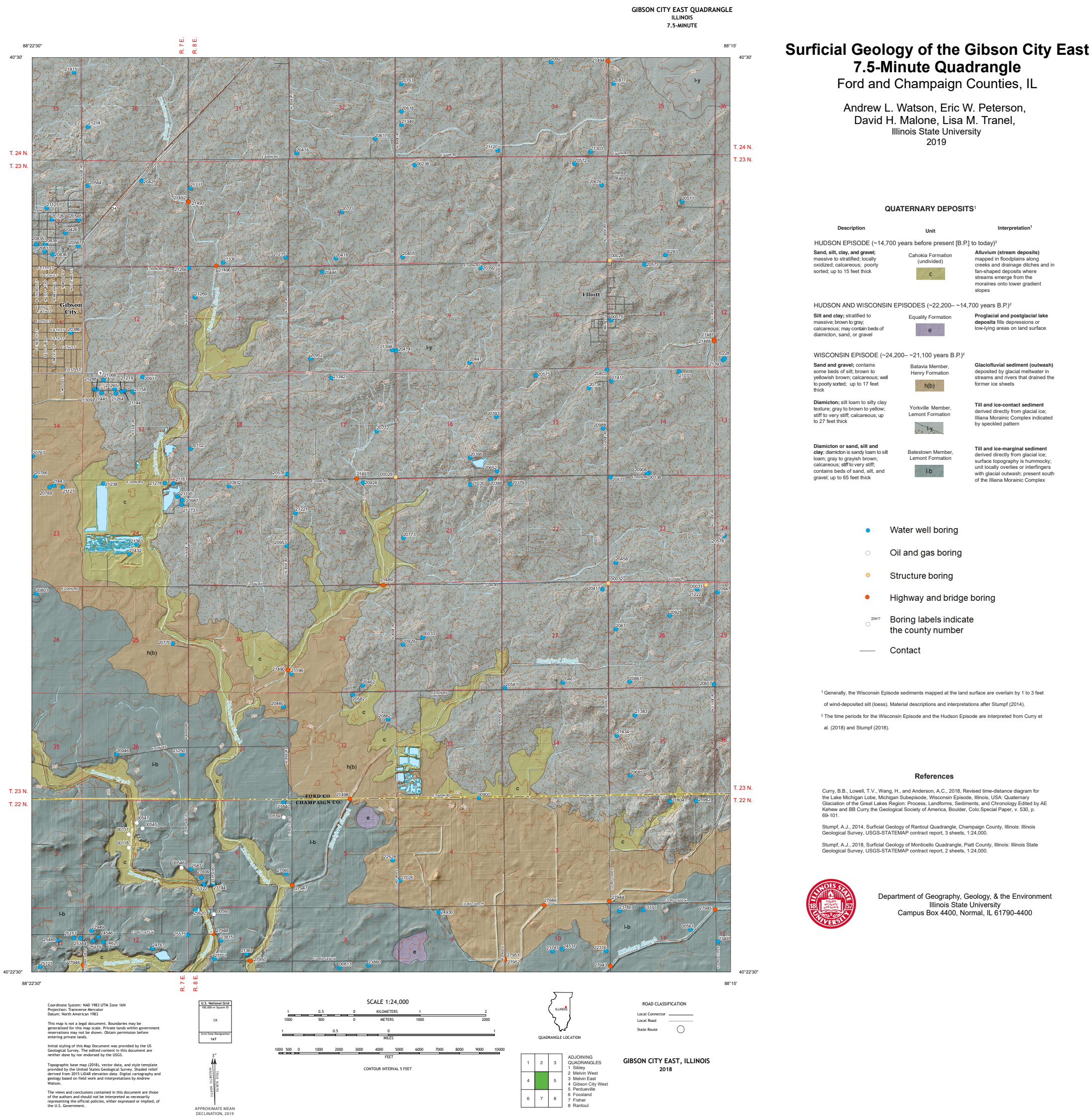

Figure 3. Surficial geologic map of the Gibson City East Quadrangle. A higher resolution pdf has been provided as a supplementary file.

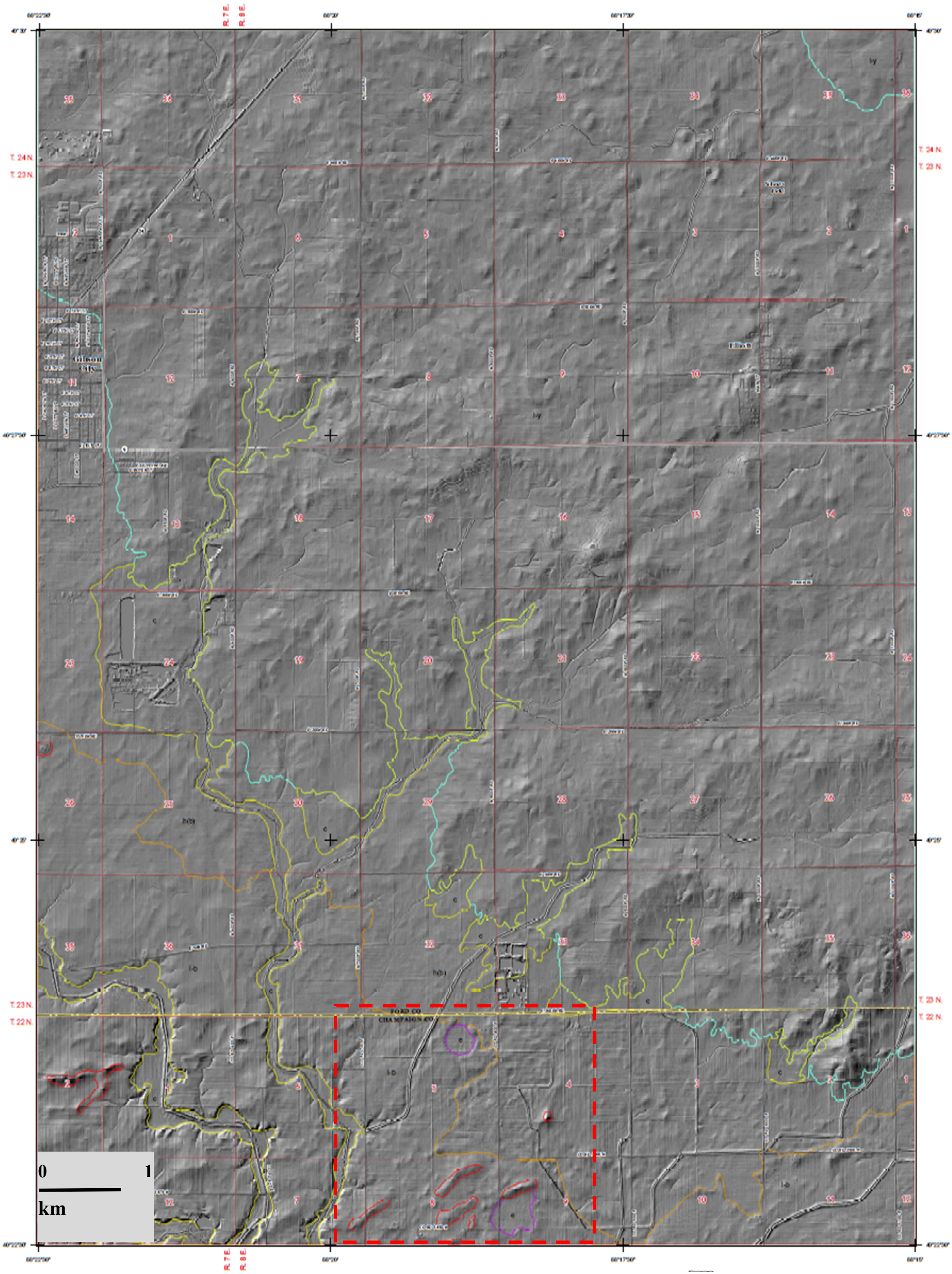

Figure 4. LiDAR hillshaded DEM depicting the following geomorphologic features within the Gibson City East Quadrangle: morainic system outlined in blue (and yellow where the boundary is shared with alluvium), flood plains/river channels outlined in yellow, outwash plain outlined in brown, glacial lake plains outlined in purple, and esker/kame-type features in red. Red numbers indicate the section lines. Dashed red line outlines the area illustrated in Figure 5.

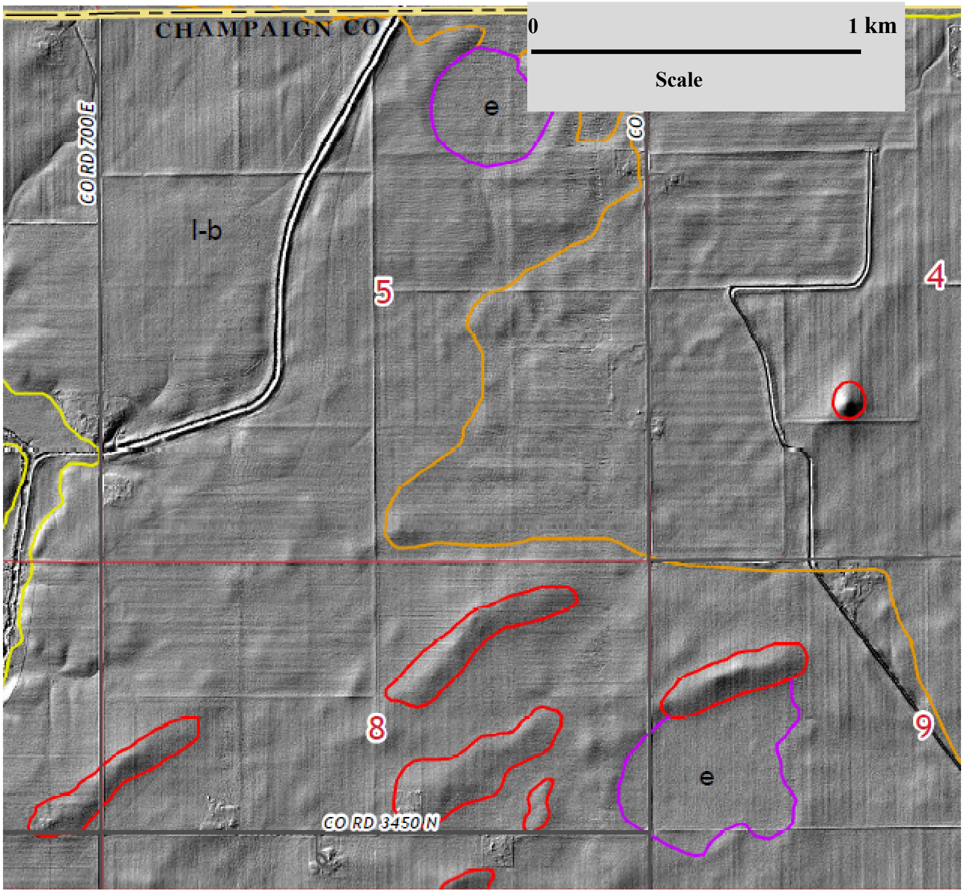

Figure 5. LiDAR hillshaded DEM outlined in Figure 4 resembling the following geomorphologic features within the Gibson City East Quadrangle: glacial lake plains outlined in purple, outwash plain outlined in brown, and esker-type ridges/kame-like features outlined in red. The red numbers indicate the section number.

The Equality Formation is interpreted to be in two locations in the south-central region of the quadrangle. The two areas identified as lacustrine within the quadrangle occur in bowl shaped depressions seen in the LiDAR (Figure 5). The larger area soil data classified the parent material as outwash, which could suggest the effects of permafrost [58]. However, well data were unavailable at either of these locations to confirm the units and given presence of similar features in neighboring quadrangles, the areas were classified as the Equality Formation.

The informally named Batavia Member of the Henry Formation represents outwash plains on the down ice edge of moraines. In the area, the Batavia Member is as much as 5.2 m (17 ft) thick within the quadrangle and was deposited along the front of the Illiana Morainic System, converging into the valleys. The Batavia Member deposit trends from southeast to northwest, forming a natural division between the two till units found within the quadrangle. Borehole logs in Section 14 (T23N, R7E) and Sections 4 and 5 (T22N, R8E) generally showed coarser deposits of sand and gravel, while the deposits in the remaining portions of the Batavia Member showed finer deposits of silty sand and sand.

The informally named Wasco member of the Henry Formation comprises sand and gravel found in eskers and kames. Wasco Member deposits were not identified on the surficial geologic map as no borings are available to confirm their sedimentology; however, deposits bearing slight resemblance to these features are present in the south and southeastern region of the quadrangle (Figure 5).

Two Members of the Lemont Formation were identified in the Gibson City East Quadrangle, the Yorkville and Batestown. The Yorkville Member is as much as 8.2 m (27 ft) thick and is the dominant surficial unit in the quadrangle, with the extent indicated by the Illiana Morainic System. The Yorkville Member polygon in the northeast corner of the map which does not contain the speckled pattern represents ground moraine deposits as opposed to the deposits found within the moraine system.

The final unit found in the quadrangle, the Batestown Member, is as much as 19.8 m (65 ft) thick in the quadrangle and was located in the southwest and southeast corners of the study area, south of the Illiana Morainic System. Where present, the surface topography is hummocky. The Batestown comprises ground moraine deposits, signifying the retreat of glacial ice.

3.2. Aquifer Sensitivity

The aquifer sensitivity analysis identified nine sensitivity classes for potential contamination in the Gibson City East Quadrangle ranging from highest sensitivity (A3) to lowest sensitivity (E1) (Figure 6 and Table 2).

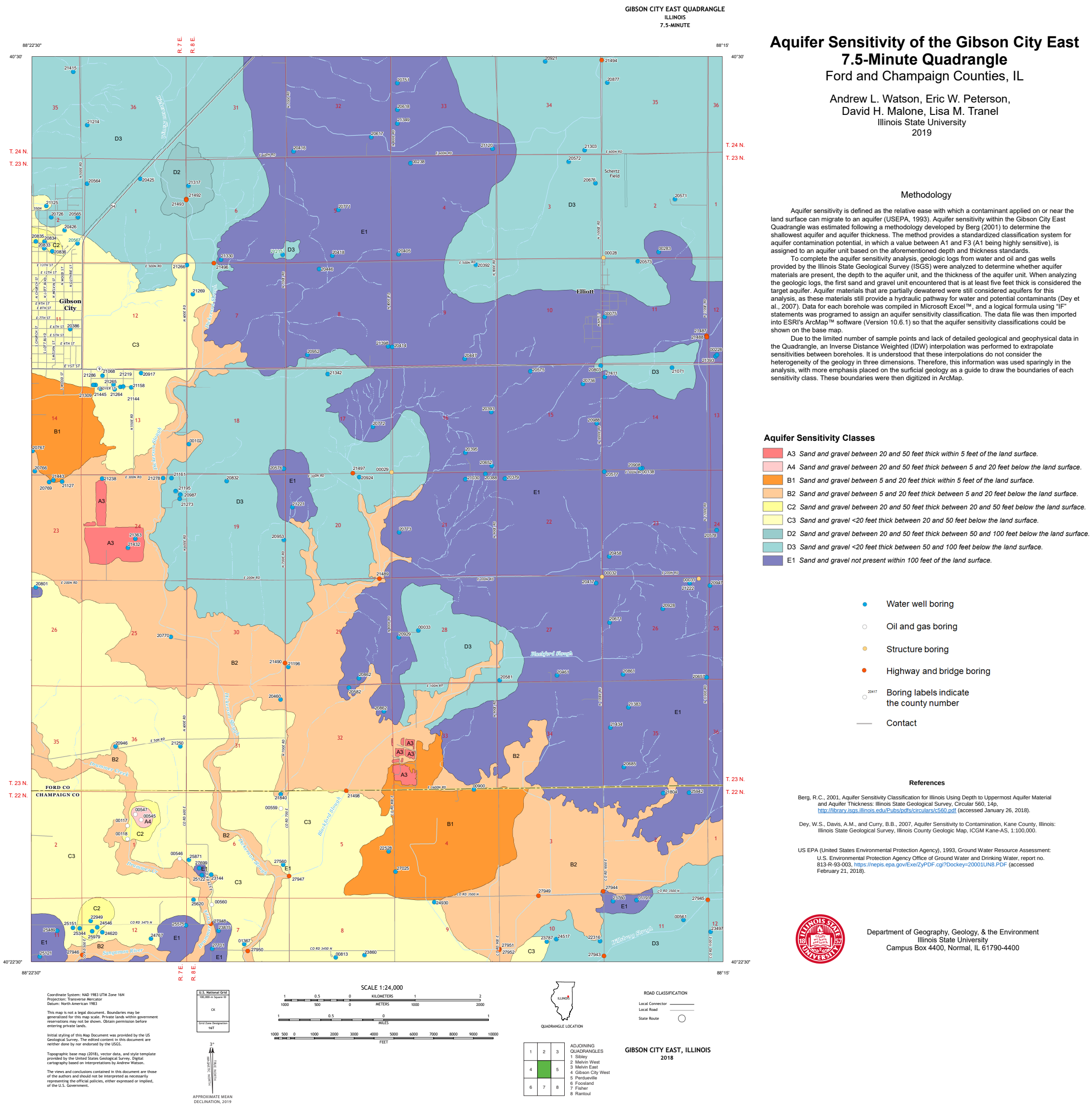

Figure 6. Aquifer sensitivity map of the Gibson City East Quadrangle. A higher resolution pdf has been provided as a supplementary file.

Table 2. Classification system for aquifer sensitivity (From [2]). Five primary map categories are differentiated (**A**–**E**). Materials designated by A represent high aquifer sensitivity, B represent moderately high aquifer sensitivity, C represent moderate aquifer sensitivity, D represent moderately low aquifer sensitivity, and E represent low aquifer sensitivity. Please see Berg [2] for more detail. The categories are further subdivided into more detailed units based upon the described conditions. The color background for the Sensitivity Class is consistent with the designation used in Figure 6.

Sensitivity Class	Description
A3	Sand and gravel or high-permeability bedrock 6 to 15.3 m (20–50 ft) thick within 1.5 m (5 ft) of the land surface.
A4	Sand and gravel or high-permeability bedrock 6 to 15.3 m (20–50 ft) thick between 1.5 and 6 m (5 and 20 ft) below the land surface.
B1	Sand and gravel or high-permeability bedrock between 1.5 and 6 m (5 and 20 ft) thick within 1.5 m (5 ft) of the land surface.
B2	Sand and gravel or high-permeability bedrock between 1.5 and 6 m (5 and 20 ft) thick between 1.5 and 6 m (5 and 20 ft) below the land surface.
C2	Sand and gravel or high-permeability bedrock between 6 to 15.3 m (20–50 ft) thick between 6 to 15.3 m (20–50 ft) below the land surface.
C3	Sand and gravel or high-permeability bedrock $<$ 6 m (20 ft) thick between 6 to 15.3 m (20–50 ft) below the land surface.
D2	Sand and gravel or high-permeability bedrock between 6 to 15.3 m (20–50 ft) thick between 15.3 and 30.5 m (50 and 100 ft) below the land surface.
D3	Sand and gravel or high-permeability bedrock $<$ 6 m (20 ft) thick between 15.3 and 30.5 m (50 and 100 ft) below the land surface.
E1	Sand and gravel or high-permeability bedrock not present within 30.5 m (100 ft) of the land surface.

The lowest values for aquifer sensitivity, E1, align in the area of the Yorkville Member, on the apex of moraines within the Illiana Morainic System. This area represents the thickest succession of glacial deposits within the Gibson City East Quadrangle, where aquifer material is not present within 30.5 m (100 ft) of the land surface. Smaller areas mapped as E1 are scattered throughout the southern portion of the quadrangle. These areas represent the absence of aquifer material in the boreholes indicating regions where small, local aquifers pinch out.

The D2-3 sensitivity classes are also found primarily within the boundaries of the Illiana Morainic System; however, these values tend to be located directly north or south of the apex of the moraine. The D sensitivity class represents aquifer material that is found between 15.3 m (50 ft) and 30.5 m (100 ft) of the land surface. The location of these classes shows the gradual thinning of confining sediments as we move away from the apex of the moraine.

Intermediate values for aquifer sensitivity, C2-3, were found primarily in the northwest lobe of the Illiana Morainic System and to the southwest where the Batestown Member is present. Aquifer sensitivity classes in the C range represent aquifer material that is present between 6.1 m (20 ft) and 15.3 m (50 ft) below the land surface. It is possible there is less till overlying the aquifers in the northwest lobe of the moraine as later meltwater may have eroded some of the overlying sediment. Within the southwest region, there are limited wells and they are randomly spaced, which may skew the IDW results in the area. The random distribution of the wells and wide variance in sensitivity classifications made interpretations in this region difficult. The C3 classification was designated the default value in southwest region of the map where a lack of data was present. This classification was the most common class assigned to wells in this area, and a general assumption was made that the subsurface geology in this region is consistent. It should be expected that an intermediate sensitivity value, e.g. the C class, would belong in the area south of the moraine terminus, where there is less till. In general, this study tended to error on the side of assigning higher sensitivity values. Small areas of the C2 were also found in the southwest corner of the map. The C2 class represents areas where the aquifers are thicker (6–15 m).

The B1 and B2 sensitivity classes were primarily assigned to the Batavia Member of the Henry Formation and to the Cahokia Formation. The B1 classification, which contains aquifers within 1.5 to 6 m of the land surface, was assigned to the regions of the Henry Formation that contained coarser sand and gravel deposits (Section 14, T23N, R7E and Sections 4 and 5 of T22N, R8E). The B2 classification, which contains slightly deeper aquifer material between 1.5 and 6 m below the land surface, was assigned to the remaining portions of the Batavia Member where the surficial outwash deposits are finer grained containing silty sand and sand. The B2 classification was also assigned to the deposits of the Cahokia Formation, because the boreholes within the Cahokia contains finer grained surficial deposits in the top 1.5 m of the borehole log, with coarser sand and gravel deposits present between 1.5 m and 6 m below the land surface.

The highest values for aquifer sensitivity, A3 and A4, were found south of the Illiana Morainic System. Only four borehole logs depicted aquifer units that could be interpreted to the A classifications, representing small lenses of thicker aquifer material found between 1.5 m and 6 m below the land surface. Two of the four boreholes classified as A were petroleum wells (Section 1, T22N, R7E). The surficial data provided with these logs may be suspect as the sensitivity classifications were outliers in the area and petroleum loggers tend to speed through unconsolidated materials, lumping units together and providing limited descriptions of the materials. Investigation into these areas including a geophysical investigation would help to verify and more accurately define the boundaries of these highly sensitive areas. Two former gravel pits that are now ponds (Section 24, T23N, R7E and Section 33, T23N, R8E) were assigned to the A3 classification because they may have exposed deep aquifers to the surface. Additional investigations into the connectivity of these units would also be beneficial.

The northern half of the Gibson City East Quadrangle where the surficial deposits are comprised of the Yorkville Member is assigned a low aquifer sensitivity to contamination. Areas with surficial deposits of the Henry and Cahokia Formations exhibit higher sensitivities. A large portion of the higher sensitivity surficial aquifers overly the Mahomet Aquifer in the southern portion of the Quadrangle. Fortunately, there are no known recharge areas for the Mahomet Aquifer within the Gibson City East Quadrangle. To confirm this assumption, an additional examination of the lithology of the wells that draw form the Mahomet Aquifer was conducted. The stratigraphy showed no such stacked sequences of the sediments that would allow communication with the Mahomet Aquifer. This conclusion is confirmed by Hackley et al. [59], who sampled a well in the study area and found the groundwater had low $^{14}C_{DIC}$ activity (28.1 pMC), indicating there was a minimal potential for recharge.

4. Discussion

4.1. Surficial Geology

The youngest of the Wisconsin Episode deposits is the Equality Formation. The Equality Formation represents two areas in the quadrangle where glacial lakes were once present. There are two possible interpretations of how these lakes formed. The first is that these lakes are kettle lakes that formed when ice blocks broke off from the retreating ice during the end of Putnam Phase of the Michigan Subepisode. The second interpretation is that these lakes are a result of younger meltwater from the Livingston Phase of the Michigan Subepisode filling in depressions in the topography created by the erosion of the Batestown Member. The closed depressions in this setting imply the features are kettle lakes. Boreholes could help to verify that these are in fact lake deposits and not just depressions in the land surface, as the presence of varves would confirm the lacustrine nature of these features. While either interpretation for how these lake deposits formed might show varves in a boring, slumping around the lake might confirm that these are kettles because as the ice block melted the surrounding sediment may lose some of its stability, allowing for slumping to occur.

The Batavia Member of the Henry Formation contains outwash deposits representing the retreat of the Livingston Phase ice. The coarser sand and gravel outwash deposits found in Section 14 (T23N, R7E) and Sections 4 and 5 (T22N, R8E) represent areas where the glacial meltwater was flowing faster, allowing it to carry these larger sediments. These areas may indicate where the primary channels of a braided stream system existed coming from the moraine. The remaining areas of the Batavia Member contain finer grained deposits, likely representing regions where meltwater was flowing more slowly.

The Yorkville Member, which comprises the Illiana Morainic System, represents the maximum extent of the advancement of the Livingston ice and is the result of a period in which accumulation was roughly equal to ablation allowing the ice to remain stagnant for an extended period of time and permitting the continuous deposition of unsorted sediment at the glacial margin. Additionally, the northwest to southeast trend of the moraine complex indicates the ice was flowing from the northeast.

The Batestown Member is a result of an advance of the Decatur Sublobe during the Putnam Phase, which extended further south beyond the confines of the quadrangle. The lack of a moraine in the southern portion of the quadrangle signifies a constant retreat of the ice. The hummocky features that trend from northeast to southwest in the south-central portion of the quadrangle help to determine the direction of flow of meltwater, if there was any. These features were described as possibly being Wasco Member eskers and kames in the results section; however, since the sedimentology of these deposits could not be confirmed, the features are interpreted to be the result of meltwater eroding the till of the Batestown Member.

4.2. Aquifer Sensitivity

The aquifer sensitivity map of the Gibson City East Quadrangle helped to establish a base work for the hydrogeology and contamination potential of the study area. This analysis may provide insight into the subsurface hydrogeology and flow patterns.

The E and D classifications represent areas where thick sequences of silty to clayey diamicton at the land surface prevent rapid infiltration. These classifications which are present primarily in the moraine complex, represent an area where aquifer material is not present within 15.2 m of the land surface. The thickest sequence of Yorkville Member diamicton was only observed to be 8.3 m (27 ft) thick. This indicates that as the Livingston ice advanced it likely eroded away any older outwash deposits left by the retreating Putnam Phase, which could have comprised local aquifers. While infiltration and aquifer sensitivity are low in the area of the moraine, increased surface runoff may occur due to the steeper slopes from the moraine complex, especially in the winter months when fields are fallow. Surface runoff on the south side of the moraine may make its way to the Cahokia and Henry Formations at the base of the moraine, meaning some surface water on the moraine could end up recharging the upper most aquifer units connected to the Henry and Cahokia. Additionally, drain tiles within the diamicton are designed to route infiltrating water to the valley channels within the moraine, moving water from areas of low sensitivity to areas with high sensitivity.

The A and B classifications represent areas where higher rates of infiltration are expected due to the coarser-grained sediments classified to the Henry and Cahokia Formations. The Henry and Cahokia Formations likely characterize areas where the majority of recharge for the uppermost aquifer units occurs. Landowners or developers should exercise caution above these areas as contamination can more easily infiltrate these shallow aquifers. Additionally, if these lands are to be further developed, more refined studies including geophysical investigations should be completed to more accurately refine the extent of the sensitive aquifer materials.

The methodology utilized for this analysis is useful for determining the sensitivity of the uppermost aquifer units; however, it is limited because it does not define the sensitivities of deeper aquifer units (more than 30 m below ground surface) such as the Mahomet Aquifer. Several studies have indicated there may be localized connections between aquifer units which may allow for communication between the surface and the Mahomet Aquifer [45,46,59]. The uppermost aquifer units within the Gibson City East Quadrangle have highest sensitivities where they underly the Henry and Cahokia Formations. Thick sequences of till classified to the Tiskilwa and Glasford Formations may separate these aquifers from the Mahomet Aquifer and prevent direct recharge [60]. Generally, in east-central Illinois, layers of coarse-grained sediments are either thin or not common in the diamicton units directly overlying the Mahomet Sand Member. Furthermore, the thick diamictons classified to the Tiskilwa and Glasford Formations prevent rapid infiltration from the land surface to the Mahomet Aquifer. These areas have a relatively low potential to transmit surface water to the Mahomet Aquifer. While DRASTIC may provide more detailed results, the method requires data that may not be readily available, e.g., net recharge, hydraulic conductivity values, and impact of the vadose zone. DRASTIC would necessitate additional 3-D geologic mapping in the study area, particularly where the Mahomet Aquifer is present. While these data would help to further revise the aquifer sensitivity analyses, they would be costly. The Berg method [2] provides an adequate evaluation of the vulnerability of the shallowest aquifer with fewer data requirements.

5. Conclusions

This study was completed to provide a better understanding of the distribution of the surficial glacial and postglacial deposits within the Gibson City East Quadrangle, and to determine the sensitivity to contamination of the various shallow aquifers. With this information, water resource managers and planners could make more informed decisions on land use in an area that partially overlies the Mahomet Bedrock Valley.

The surficial geologic mapping identified five lithostratigraphic units that represent the glacial and postglacial events that occurred over the past ~24,000 years or so. The Illiana Morainic System, which trends from northwest to southeast, is the prominent landform in the study area, which delineates the farthest extent of Yorkville ice into the study area. The use of LiDAR elevation topographic grids and hillshaded images allowed me to more accurately delineate boundaries of the geologic units that were reported in the county soil reports and borehole geologic logs.

The aquifer sensitivity analysis was conducted based upon information derived from the surficial geologic map. The nine classes applied represent geologic materials having high to low sensitivity A3 to E1, respectively. In general, much of the study area has a low aquifer contamination potential, especially in the eastern region overlying the Illiana Morainic System. The thick sequences of silty to clayey till extending from the land surface too deep within the subsurface inhibits the direct infiltration into the underlying aquifer. Higher rates of infiltration are expected where sand and gravel of the Henry and Cahokia Formations are present at or just below the land surface.

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