Aquifer Characterization through GPR and Borehole Analysis
Eau Claire Municipal Well Field, Wisconsin

Mark M Green[1], Patrick A Keicher[1], Harry M Jol[1], Sean M Morrison[1]

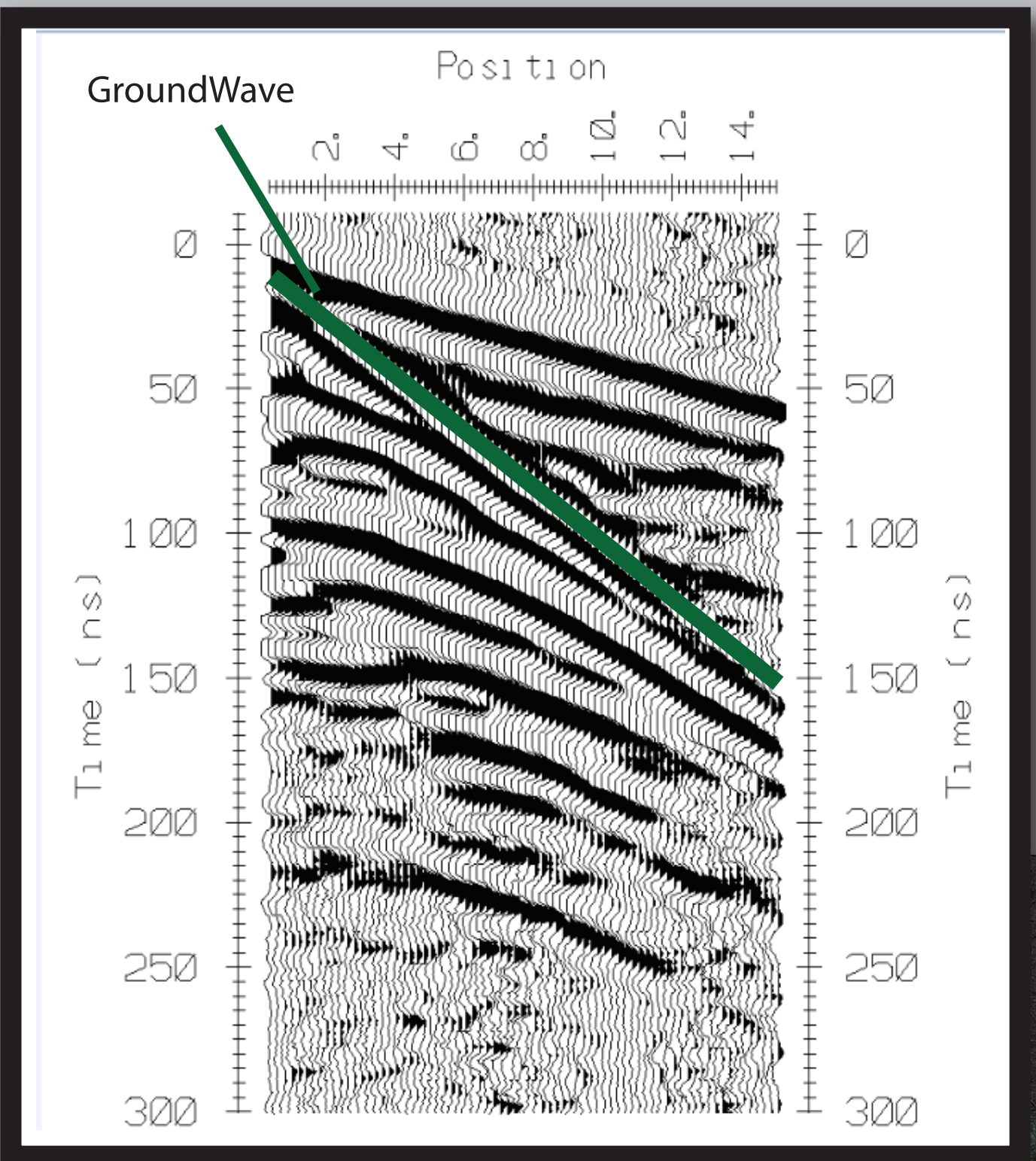
[1]University of Wisconsin, Eau Claire
105 Garfield Ave, Eau Claire, WI, 54703

Abstract

Traditionally, aquifer characterization is conducted by extrapolating stratigraphy between boreholes and producing a fence diagram. However, the point-source nature of boreholes can produce inaccurate models so a better methodology is needed. Ground penetrating radar (GPR) is a geophysical method using electromagnetic signals and provides a non-invasive way to image the subsurface. Our project's goal is to improve characterization of the aquifer supplying the Eau Claire municipal well field by correlating borehole data with GPR profiles to produce stratigraphic models at a higher degree of accuracy than traditional methods. Using a pulseEKKO 100 system, GPR data was collected across a 150 m and two 50 m transects to a depth of 12 m using a frequency of 100 MHz with a 0.5 m step size and 1 m antennae separation. The results show two facies representing a migrating sidebar and an expanding floodplain. Borehole data was collected to a depth of 30 m revealing grain size ranging between medium sand to gravel. Combining these data will ultimately lead to more accurate models than those produced using only point-source data. This method is effective in many geologic settings and can provide hydrogeologists with an accurate, cost-effective way to characterize aquifers without relying on costly point-source data.

Methods

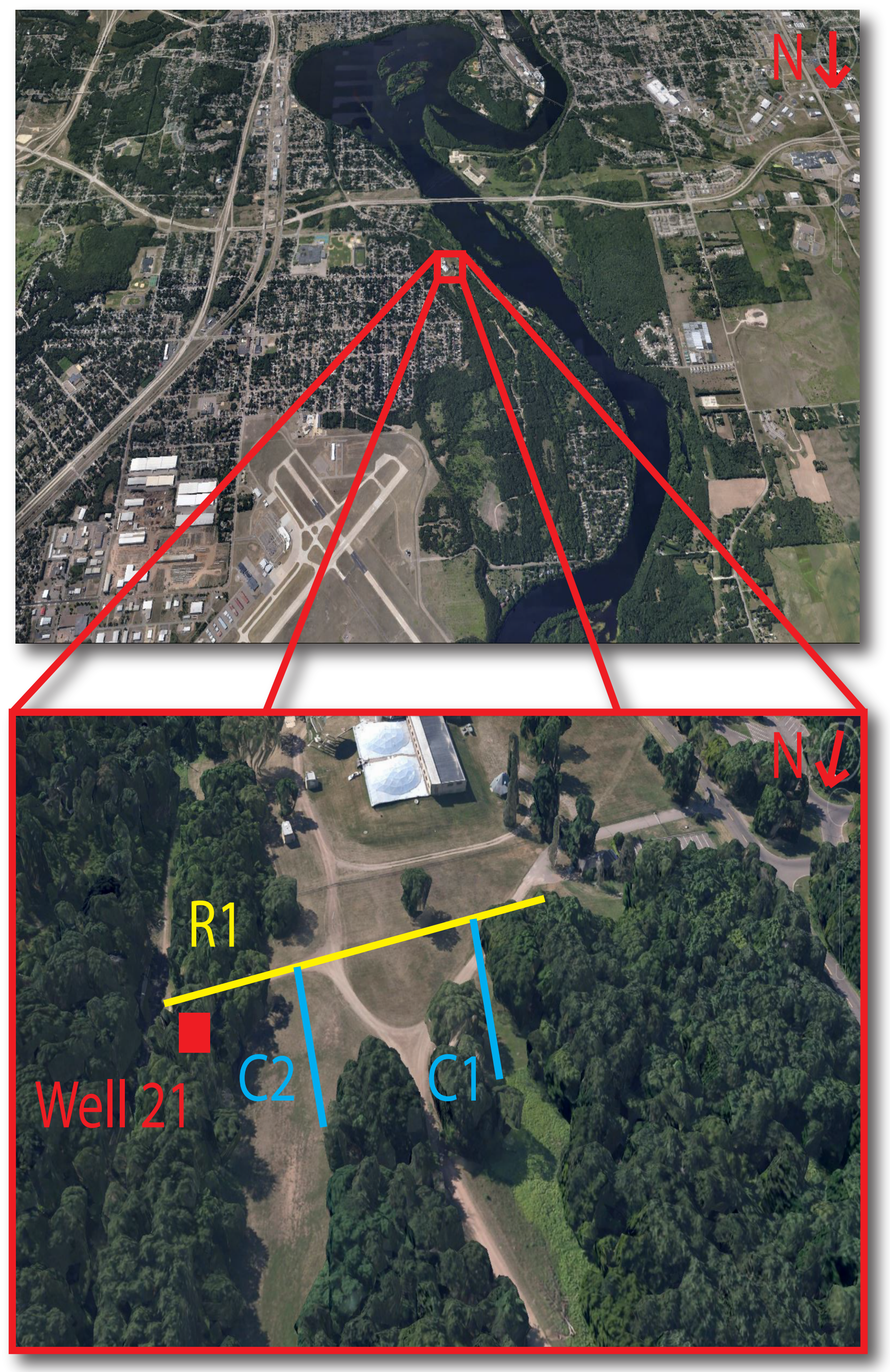
Our data collection methodology was three-fold: 1) to collect and analyze data from secondary sources addressing the hydrogeologic aspects of the Eau Claire municipal well field (ECMWF), 2) to collect primary source GPR data on site, and 3) to process the data and assess their viability in characterizing groundwater flow. 1) Initially we contacted the drilling companies responsible for installing the high-capacity wells supplying the ECMWF to acquire drill logs from the borings. Upon analysis the geologic data for Well log 21 was determined to be the best available and so we chose its location as our target area. We were also given a tour of the ECMWF and information about the aquifer (e.g. water table depth, water quality, water removal rates); (Greene, 2014). 2) To begin on site data collection, we measured a 150 m transect (R1) and two 50 m transects (C1 and C2) perpendicular to R1 and recorded GPS coordinates at the transects' endpoints. Using a Topcon laser level and surveying rods we recorded elevation differences every two meters to calibrate our subsurface reflections with the area relief (Jol and Bristow, 2003). Using a pulseEKKO 100 GPR system we first recorded a common midpoint (CMP) centered at the 75 m mark of the R1 transect to determine the subsurface velocity; this technique is necessary to convert our electromagnetic wave travel time measurements to depth. Following the CMP survey data was collected across the R1, C1, and C2 transects using a frequency of 100 MHz with a 0.5 m step size and 1 m antennae separation (Jol and Bristow, 2003). We also collected data along the C2 transect at 50 MHz with a 1 m step size and 2 m antennae separation and at 200 MHz with a 0.10 m step size and 0.5 m antennae separation to determine the most effective resolution for imaging reflections in the study area (Jol and Bristow, 2003).

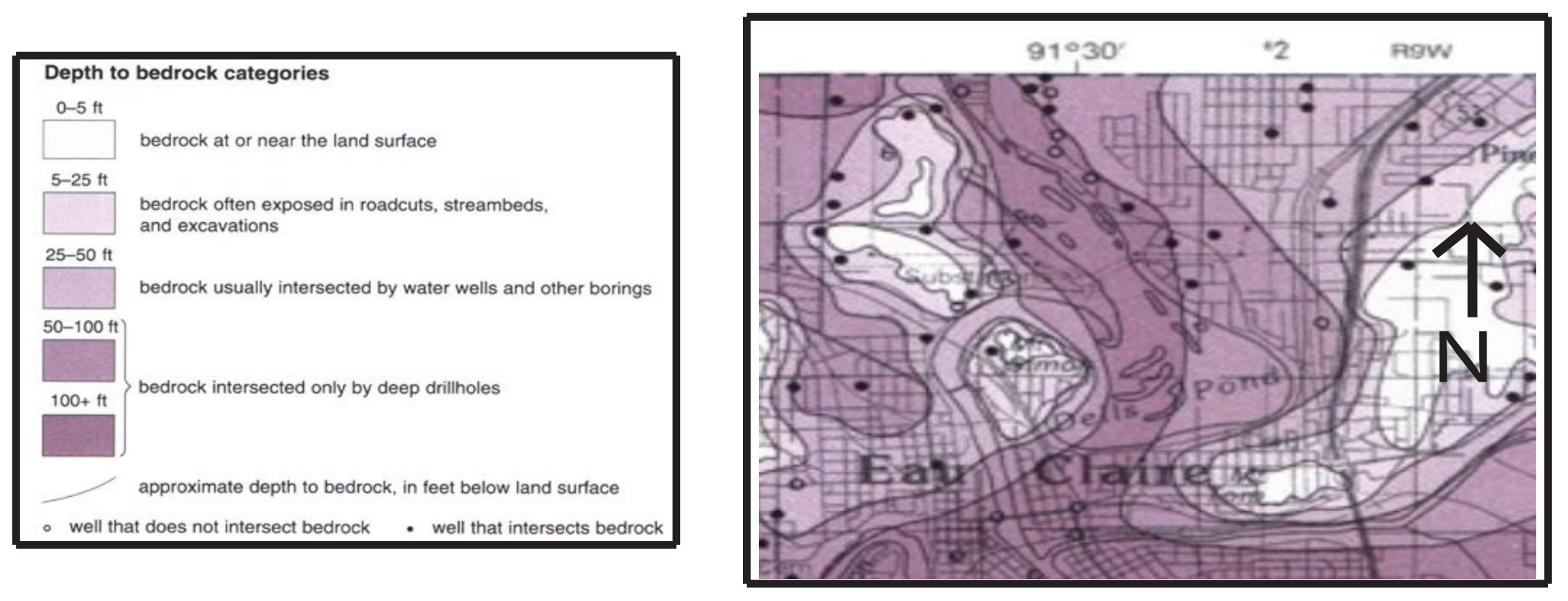


Analysis

Based upon State records of well bore logs the subsurface at the ECMWF has been characterized by the Wisconsin Geological Survey (WGS). These logs provide stratigraphic data which has been geospatially compiled by the WGS to map depth to bedrock within Eau Claire County (Johnson, 1993). This map shows that the ECMWF straddles a deep (> 30 meters) bedrock valley between the Chippewa Rivers lowest terraces in northern Eau Claire (Johnson, 1993). This bedrock valley contains glacial outwash sediments overlain by braided stream deposits that form a heterogeneous unconfined aquifer more than 30 meters deep from which up to 61 million liters of high quality water is pumped daily (Johnson, 1993; Greene, 2014). The heterogeneity of the valley sediments in the locale of the ECMWF can be categorized into three stratigraphic facies based upon their depositional environment. GPR images and the Well 21 drill log confirm an upper facies containing alluvial sediments from depths of 0 to 5 m that are deposited by aggradation of the Chippewa River floodplain and result in a relatively permeable and well sorted deposit above the middle facies (Roberts and Brevard, 1997). Our GPR investigation revealed a middle facies containing braided stream structures formed by the Chippewa River between depths of 3 to 12 meters (See results table) (Roberts and Brevard, 1997; Bridge and Lunt, 2006). The lowest facies consist of well graded sands and gravels deposited during the end of the Wisconsin glaciation which reach thicknesses of up to 20 meters above the bedrock within the ECMWF (Johnson, 1993).

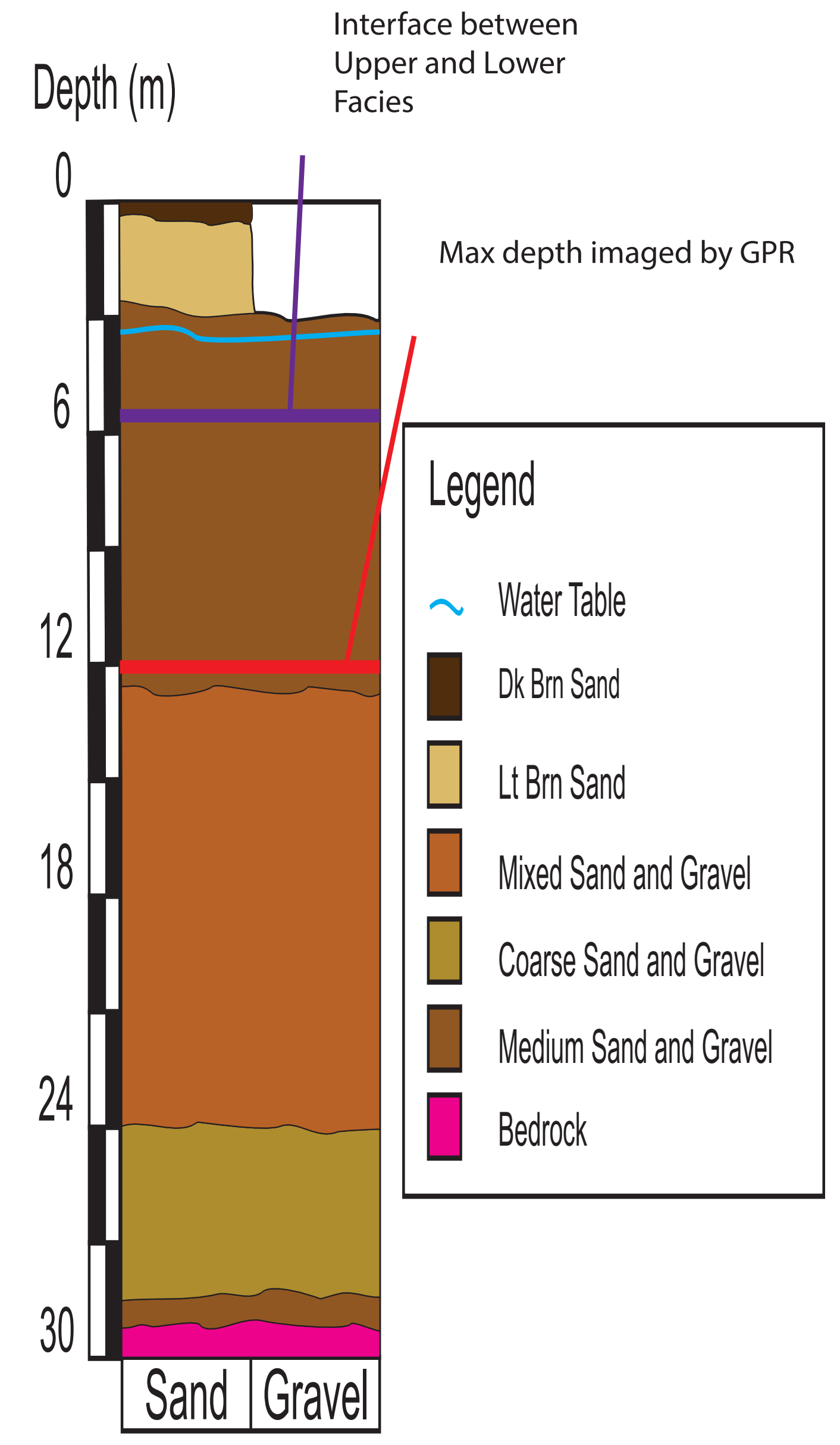
Study Area



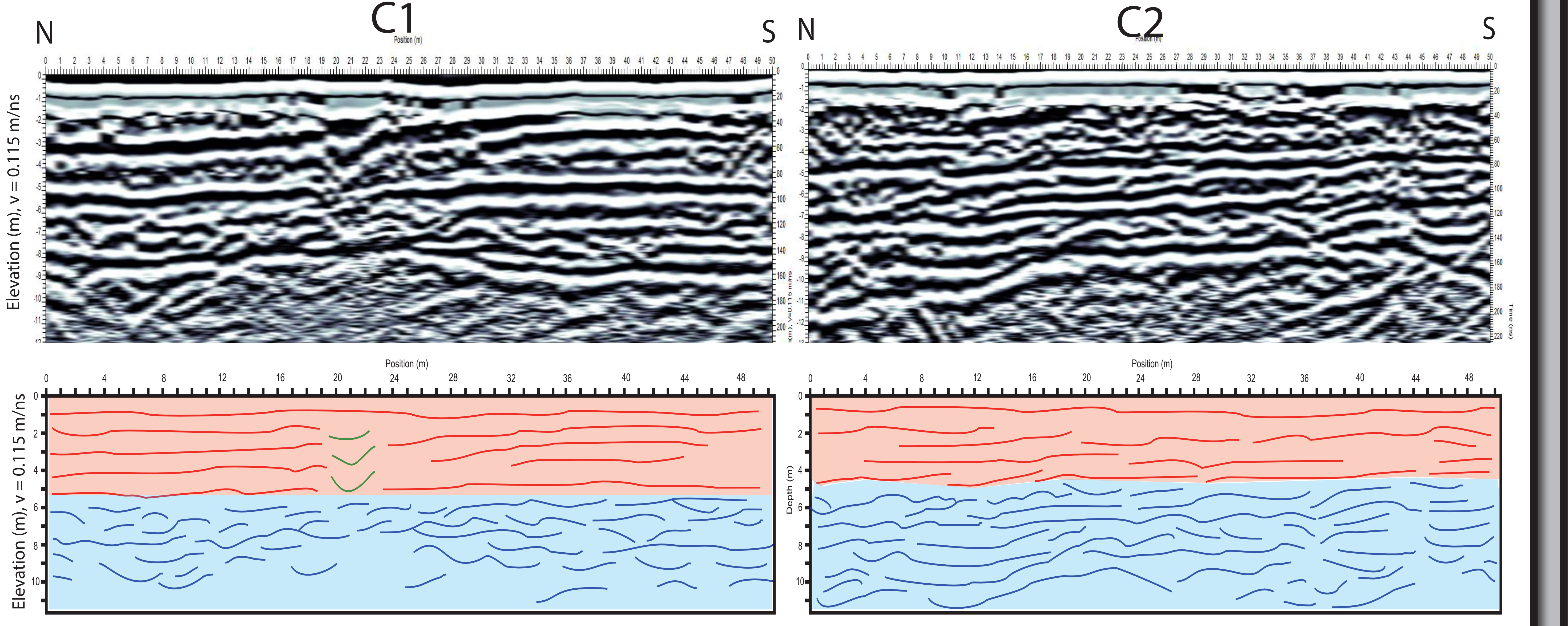


Radar Facies	Radar Stratigraphy Description		Interpretation	
	C1	C2	C1	C2
Upper	Upper radar facies between 0 - 6 m depth which has a relatively uniform thickness and contains continuous to semi-continuous horizontal parallel to sub-parallel reflections with lengths of tens of meters. These reflections have a 0.5 - 1 meter vertical seperation.		The modern terrace and floodplain deposits. This facies contains well sorted coarse grained sands and fine gravels as seen in the Well 21 drill log. The continuity and thickness of the facies suggests deposition subsequent to periodic erosion (Roberts, and Bravard 1997).	
Middle	This facies is characterized by distinct hummocky reflections. Reflections in the southern portion of the transect dip to the south whereas reflections in the northern portion dip to the north. A large trough and fill structure can be observed near the southernmost portion of the transect. Throughout the transect hummocky reflections are bounded on top and bottom by continuous horizontal reflections.	The upper facies grades into a lower facies characterized by reflections exhibiting sub-parallel to crosscut geometry. The reflections are often semi-continuous except where crosscut. These reflections dip gently to the south throughout the transect but are cut by lenticular reflections slightly dipping south.	Observed patterns are likely associated with braided channel patterns. Hummocky and trough structures result from the migration of a bar in a channel (Bridge and Lunt, 2006). As the bar migrates in the channel, water flows over it and forms a trough on the down gradient side which is subsequently filled by sediment to form hummocky fill structures as the bar progrades. The lenticular structures are suggestive of gravel lenses deposited during this period while the smaller trough and fill structures may represent small seasonal channels which cut across the floodplain during flooding (Roberts and Brevard, 1997) .	
Lower	Reflections beneath the middle radar facies are not imaged due to signal attenuation.		Well graded glacial outwash sediments contain fine grained sediments that cause radar signals to attenuate beneath depths of about 12 m (Johnson, 1993). This interpretation is supported by a facies change identified in the Well 21 drill log.	

Well 21 Core Log



Results



Summary

Subsequent to on site data collection Sensors and Software, Inc.'s EKKOproject and Lineview software was used to compile elevation, CMP, and transect data to produce the images seen in the results section. The data collected along R1 contained a significant amount of noise (likely emanating from FM radio waves or power lines) as well as many underground obstructions (e.g. pipes) which interferes with our image clarity and hinders interpretation (Jol and Bristow, 2003). Through the western portion of the R1 transect noise decreases and the quality of the image increases. The C1 and C2 transects produced images which can be interpreted and are believed to be representative of the western portion of R1. Prominent reflections from C1 and C2 were geometrically characterized and formatted with Coreldraw to assist in interpreting sedimentary facies (Jol and Bristow 2003). C1 and C2 both illustrate a subtle change of sedimentary facies within the mixed sand and gravel not observed in the Well 21 bore log (Jol and Bristow, 2003). Two distinct facies are interpreted; aggrading floodplain deposits, shown as red traces, and braided stream deposits, shown as blue traces (Roberts and Bravard, 1997; Bridge and Lunt, 2006). The green traces in C1 are anomalous and represent an underground obstruction (e.g. pipe) (Jol and Bristow, 2003). A lower facies identified in the Well 21 drill log as a well graded glacial outwash exists below the depth of about twelve meters but could not be imaged with GPR due to signal attenuation caused by fine grained sediments (e.g. silts, clay) (Johnson, 1993). The reflections which are interpreted as braided stream deposits and categorized as a middle facies is of interest during a hydrogeologic characterization of the aquifer because it contains adjacent well sorted sedimentary units of varying hydrogeologic properties; the type and spatial extent of these units control how water moves within the upper portions of the aquifer (Slater and Comas, 2009; Bridge and Lunt, 2006).

Acknowledgments

This was a project for an independent study through the University of Wisconsin: Department of Geography and Anthropology. We would like to extend our thanks to Dr. Harry Jol of the UWEC, for providing equipment and serving as our mentor through this project, and to Sean Morrison for his help and guidance as a field assistant. We would also like to thank Linda Richards of Mark J Traut Wells, Inc., for providing data for the drill core logs at well 21, and the people at Sensors and Software, Inc., for providing exceptional GPR processing software and advice. We would like to extend a special thanks to Tim Greene of the Eau Claire municipal well field for accommodating us and for his continued support for the UWEC Department of Geology.

References

Bridge, J., and Lunt, I., 2006, Depositional Models of Braided Rivers: International Association of Sedimentologists, Special Publication 36. (Bridge and Lunt, 2006)
Johnson, D. M., 1993, Depth to Bedrock Map of Eau Claire, Wisconsin: http://wisconsingeologicalsurvey.org/pdfs/M122_web.pdf (4-2014) (Johnson, D. 1993)
Jol, H., and Bristow, C., 2003, GPR in sediments: advice on data collection, basic procession and interpretation, a good practice guide: Geological Society of London, Special Publication 211, pg. 9-27. (Jol and Bristow, 2003)
Greene, T. 2014, Eau Claire Department of Public Works, Water Division, Water Plant Supervisor: Personal Communication
Roberts, M., Bravard, J., and Jol, H., 1997, Radar signatures and structures of an avulsed channel: Rhone River, Aoste, France: Journal of Quaternary Science 12, pg. 35-42. (Roberts and Bravard, 1997)
Slater, L., and Comas, X., 2009, Ground Penetrating Radar: Theory and Applications, Oxford, UK: Elsevier Science, Chapter 7. The Contribution of Ground Penetrating Radar on Water Resource Research, pg. 203-239. (Slater and Comas, 2009)