Results of geophysical studies in the Farmer City-Mansfield area, Piatt and DeWitt Counties, Illinois

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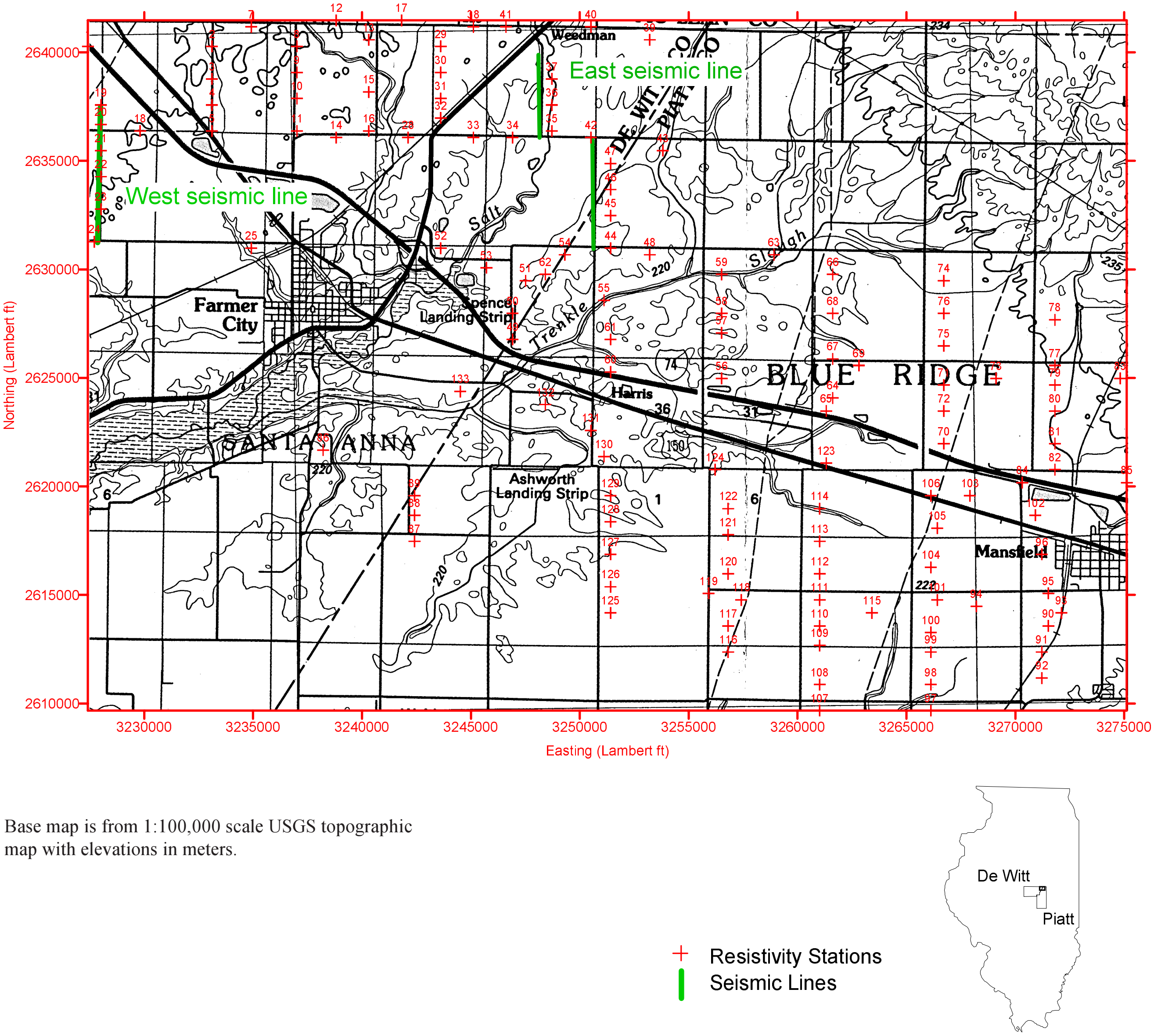
Introduction and Hydrogeologic Background

Farmer City (population 2,114) and Mansfield (pop. 929) are located in a rural area of central Illinois (figure 1). The 60 square mile study area includes parts of Townships 20 and 21 North and Ranges 5 and 6 East in Piatt and DeWitt Counties. Wisconsin Episode moraines rise to over 750 feet in elevation in both the northwest and northeast corners of the area. The central and southern parts of the area are relatively flat lowlands (elevations between 700 and 725 feet) with small southwest draining streams. The most significant stream is Salt Creek which flows past the east edge of Farmer City. South of Farmer City, Salt Fork widens into the man-made Lake Clinton.

The principle groundwater resources in the area are sand and gravel deposits within the Glasford Formation and the upper parts of the Banner Formation and are similar to other areas of central Illinois not underlain by a major bedrock valley (Kempton et al., 1982). Glasford sand and gravel deposits are widespread, but discontinuous. Upper Banner sand and gravel may be present in a small, east-west trending bedrock valley north of Farmer City. Potential for groundwater use increases where these deposits overlie one another. Although detailed lithologic studies are often able to differentiate the major sand and gravel deposits of the Glasford and Banner Formations, for this more generalized study they will be considered as one unit, called here the "middle sands". Many of these deposits include gravel as well as sand. One measure of the overall groundwater resource potential of the middle sands is the total thickness of the sand deposits. Total thickness is helpful in determining the potential of a site for moderate or large groundwater resources or the suitability of the site for landfills or other sensitive



Base map is from 1:100,000 scale USGS topographic map with elevations in meters.

Figure 1. Location of study area in central Illinois showing seismic lines and resistivity stations.

installations. However, this measure is only a first estimate of available resources, because it doesn't indicate the continuity or texture of the sand deposits.

A database of well and boring records compiled from data available at the ISGS for a related groundwater study included 175 records in the study area (figure 2). Because of the sparseness of the data set, maps in this report were created using a relatively coarse grid size and averaging interpolation scheme that smoothed local variations. Consequently some of the contours do not precisely match local maxima or minima values in the underlying data sets.. Of the 175 available records, 143 encountered

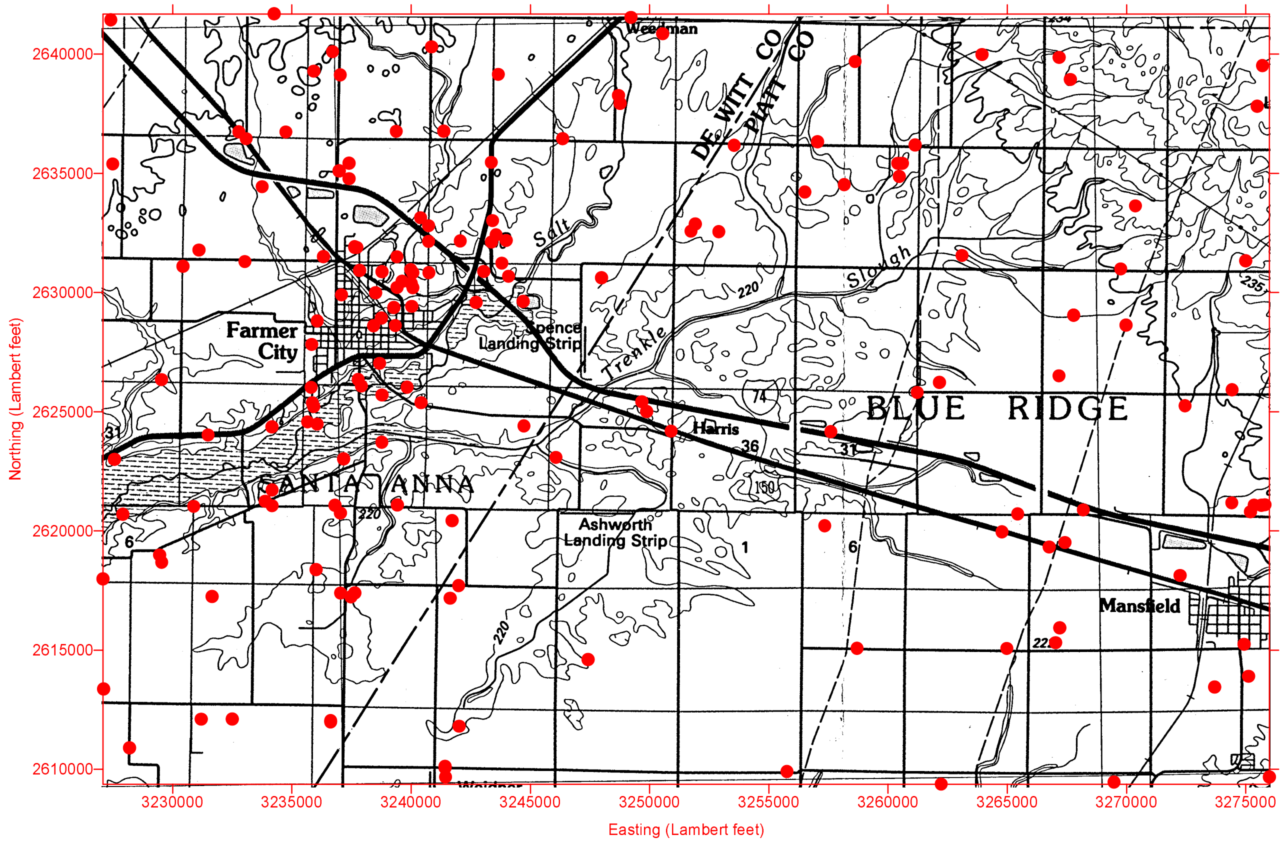


Figure 2. Location of wells in study area.

some part of the middle sand deposits and 66 penetrated horizons known to be below the middle sands. Thickness of the middle sands (figure 3) was computed from the subset of the lithologic data base that penetrated these deposits. Those borings that did not fully penetrate the middle sands were used to put a minimum limit on the thickness of the sands (Jones et al., 1986).Water wells and other borings have generally been concentrated in and near the towns, leaving very sparse data coverage away from these towns. Even using the partially penetrating borings, the data are very sparse and the resulting map (figure 3) has considerable uncertainty within the rural parts of the study area. To increase the density of data within the study area, an electrical earth resistivity survey was conducted. Although resistivity data are not as precise as boring data, resistivity data can provide much wider coverage with less expense.

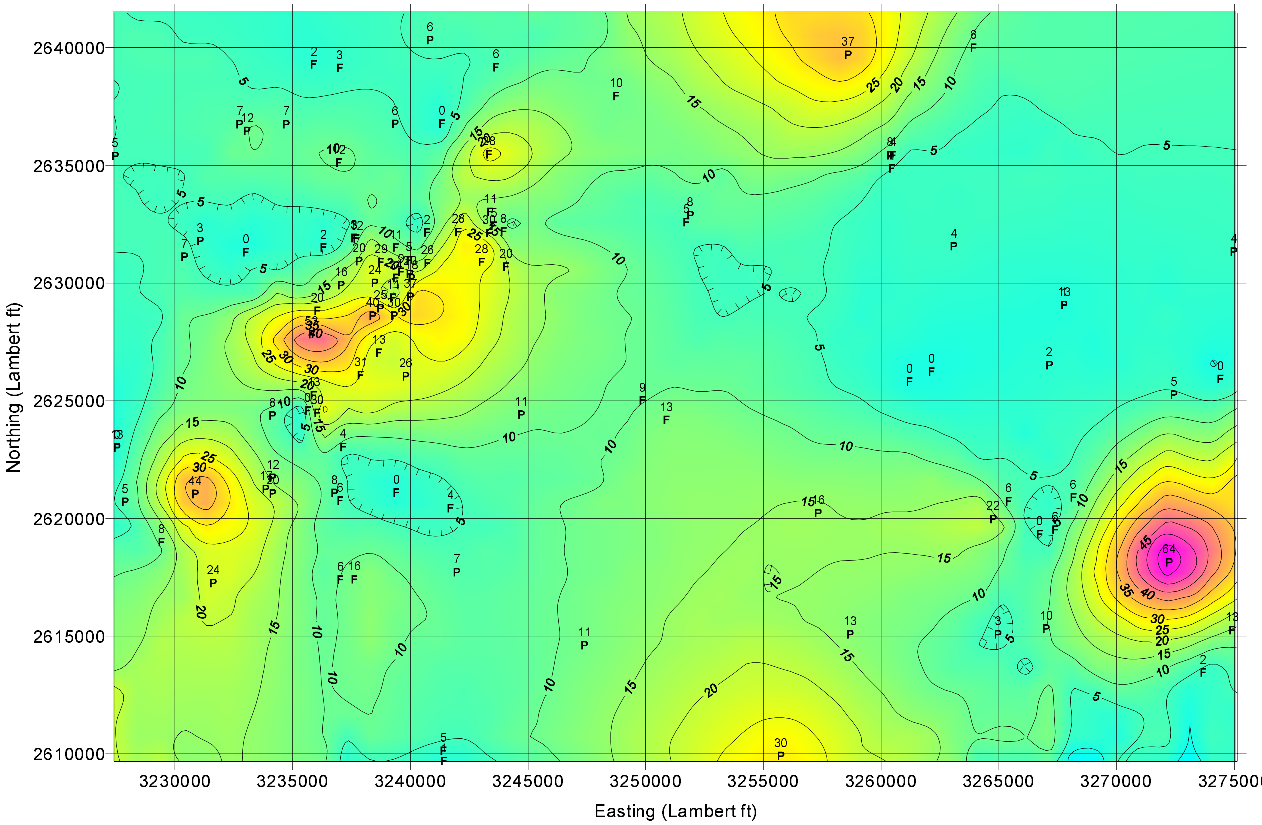


Figure 3. Middle sand thickness. Each data point symbol shows thickness (feet) and whether the boring fully (F) or partially (P) penetrated the entire Glasford and Upper Banner units.

Resistivity Survey

Electrical earth resistivity is sensitive to the proportion of sand and clay in earth materials (Buhle and Brueckmann, 1964). Sand deposits have larger resistivity values than clay or shale. This generalization is only a first order approximation, other factors also affect the earth resistivity. Two of these other factors are the fluid content and the presence of other lithologies especially limestone and sandstone. For example, unsaturated materials generally have much larger resistivity than water-saturated deposits. Salinity or other chemical variations in the fluid can be important, but in this study we assumed that the aquifers are filled with fresh water. Both limestone and sandstone have large resistivity values similar to, or greater than, sand. Also, cultural interferences from metal and electrical sources artificially reduce the apparent resistivity.

For each resistivity measurement (figure 4), a known electrical current was passed into the ground through two outside electrodes (C1 and C2) and the resulting electrical potential measured with two inside electrodes (P1 and P2). All four electrodes are kept in a line with equal spacings (a) between them. This system, known as a Wenner-type array, can be used to obtain a one-dimensional profile of the apparent earth resistivity by increasing the spacing between the electrodes (Reynolds, 1997). Mathematical inversion of the apparent resistivity profile results in a set of resistivity layers at the site (Zohdy, 1974; Zohdy and Bisdorf, 1975). Each layer is characterized by a thickness and resistivity value (figure 5). In general, the inversion process results in a non-unique solution of layer parameters. That is, the values of the layer parameters (resistivity and thickness) are not uniquely determined, but are only one set of many equivalent solutions. A more unique property, the transverse resistance, is obtained by calculating the product of the thickness and resistivity for each layer (Maillet, 1947).

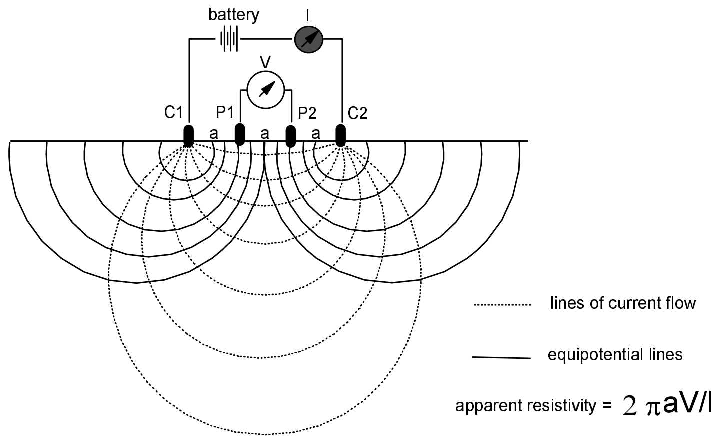


Figure 4. Schematic drawing of Wenner electrode configuration.

During the summer of 1996, 133 resistivity stations were occupied at about ¼ mile intervals along many rural roads in the area (figure 1). At each station, resistivity was measured using a Wenner electrode array with inter-electrode spacings varying from 5 to 320 feet. Apparent resistivity profiles were inverted to resistivity layers. The transverse resistance was calculated for each layer.

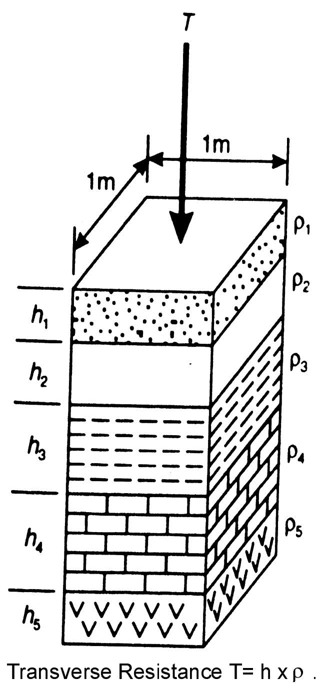


Figure 5. Schematic drawing of resistivity layers and transverse resistance, after Reynolds (1996).

Seismic Refraction Survey

Two seismic refraction lines were recorded north of Farmer City during the summer of 1996 to provide more detailed data on the small bedrock valley in the area. Seismic refraction surveys have been successful in locating buried bedrock valleys in northern and central Illinois (Heigold, 1990; Larson, 1994; Larson and Poole, 1989). Seismic refraction tests record the seismic energy from a small, buried explosion. The energy radiates in all directions through the ground. Some of this energy travels down to the bedrock surface where it is refracted back up to the ground surface (figure 6). The returned energy is recorded by a series of sensors (geophones) laid in a line near the explosion. The recorded information is used to calculate the depth to the bedrock surface beneath the charge and sensors.

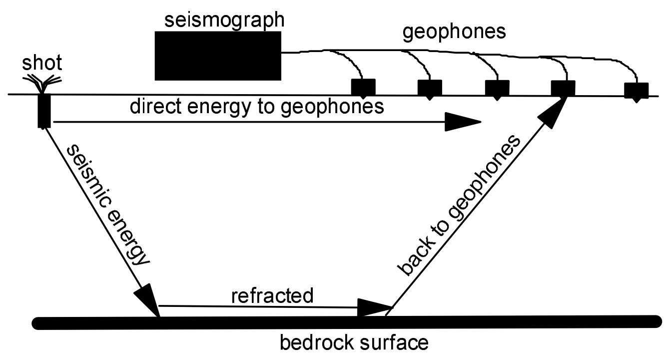


Figure 6. Schematic drawing of the seismic refraction method.

For this study, the seismic refraction sensor configuration consisted of a line of 24 14-Hz geophones placed at 50-foot intervals for a total of 1,150 feet. Explosions at the center and at both ends of the geophone line were created by detonating 1/3 to 1 pound of Kinepak explosive buried in 5-foot deep boreholes. Longer profiles were created by aligning consecutive geophone lines end-to-end along the profile. Generally, adjacent lines were situated such that the end geophones on adjoining lines were placed at the same spot. Data were recorded in digital format for later processing.

Two sets, or lines, of seismic data were acquired (figure 1). The Farmer City West Line was approximately 1.25 miles long and was run along a north-south township road through the center of sections 18 and 19, T. 21 N., R. 5 E. The Farmer City East Line was broken into two parts. The north part was approximately 0.75 miles long and was run along a township road through the center of section 14 T. 21 N., R. 5 E. The south part was about 1 mile long and was offset from the north part by about ½ mile. It was run along a township road dividing Sections 23 and 24 of T. 21 N., R. 5 E.

Refraction data were interpreted using the modified delay time and ray tracing method (Scott et al. 1972;). A computer program (SIPT2, by Rimrock Geophysics, 1992) was used to calculate the elevation of the bedrock beneath each geophone, compensating for variations in ground surface elevation and changes in the thickness of the near surface, low-velocity zone. Geologic data in the form of logs from water wells were available near the north and south parts of the East Line. These data were used to constrain the geophysical interpretation. No control wells were available near the West Line. Seismic velocities were manipulated in the calculations until the calculated bedrock surface elevations gave a close match to the well data. A range of velocities was tried, the set most closely matching the well data was used.

Two refracting surfaces were imaged in this study, the water table and the top of bedrock. The seismic technique measures bulk characteristics of earth materials and usually interprets interfaces at slightly deeper positions than other methods, such as drilling. For instance, for the top of bedrock, the seismic refraction method includes highly fractured or weathered rock as part of the overburden and the depth reported by the seismic method is to "fresh" or unfractured rock. Also, the seismic method will over-estimate the depth to the bedrock when a layer of sand is sandwiched between the bedrock and a thick layer of clay. The seismic waves are not refracted by the sand which has a lower seismic velocity then either the clay or bedrock, hence the method reports an apparent depth which is calculated based only on the higher velocity clay layer. No attempt was made to compensate for these possible errors.

Results

Bedrock elevations calculated from the refraction survey are listed in Table 1. The seismic data do not confirm the presence of one distinct bedrock valley in the area. A valley may be present, but if so the relief is too gentle to be detected with the seismic refraction method. More likely, the bedrock topography is slightly undulating, with shallow depressions and rises.

Table 1. Farmer City Area Refraction Survey Results
(Survey located in T 21 N R 5 E DeWitt and Piatt Counties)

Line name	Section	Feet from East Line	Feet from North Line	Average Bedrock Elevation (avg. of 12 geophones)
Farmer City East	14	2640	1650	533 feet
			2250	519
			2850	566
			3450	531
			4050	514
			4650	556
	23	0	600	564
			1200	568
			1800	569
			2400	563
			3000	546
			3600	529
			4200	527
			4800	528
Farmer City West	18	2640	4600	563
			5200	515
	19	2640	500	517
			1100	537
			1700	527
			2300	545
			2900	532
			3500	532
			4100	551
			4700	550

Resistivity stations, boring logs, and the seismic data were combined to create cross sections in the northern part of the study area. These cross sections are generalized in figure 7 to depict the general resistivity structure of the study area. The resistivity field generally has four distinct layers. From the ground surface these layers are: (1) a surface layer usually less than 10 feet thick with variable resistivity, (2) a shallow (about 10 to 60 feet deep) layer with relatively small resistivity values (about 100 to 250

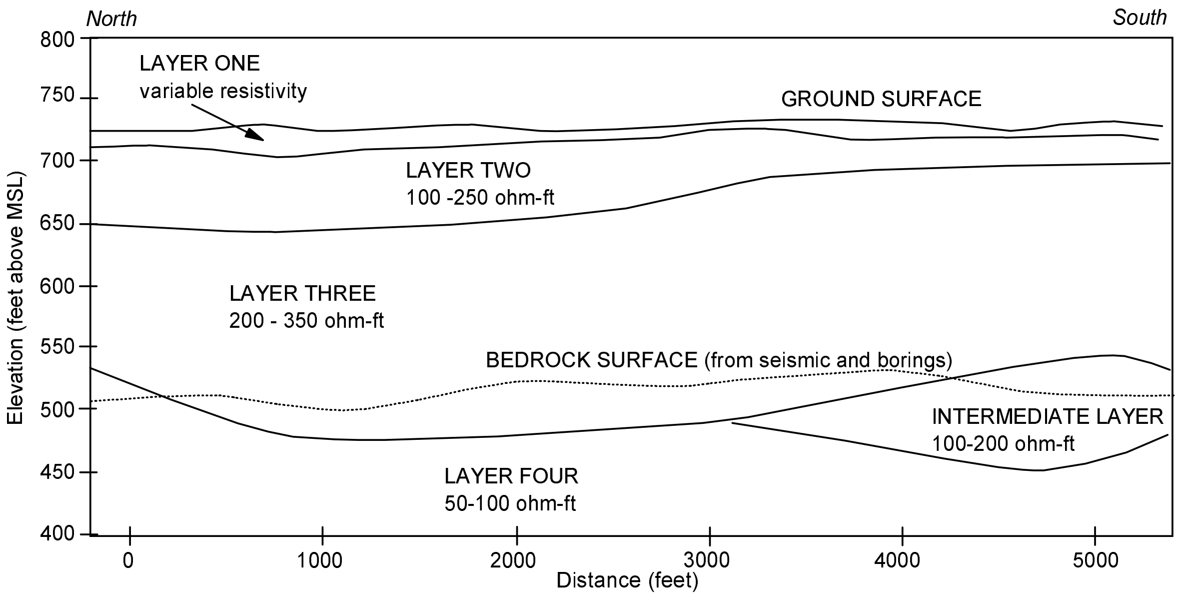


Figure 7. Generalized cross section north of Farmer City which integrates resistivity layers with seismic refraction results and boring records.

ohm-ft), (3) a deeper (about 50 to 200 feet deep) layer with relatively large resistivity values (about 200 to 350 ohm-ft), and (4) a very deep (greater than 200 feet deep) layer with relatively small resistivity values (about 50 to 100 ohm-ft). Many stations have a fifth layer between layers 3 and 4 with intermediate resistivity values (about 100 to 200 ohm-ft).

The geologic data suggest that the boundary between layers 2 and 3 approximates the boundary between the Wedron and Mason Groups (above) and the Glasford Formation (below). Also, the base of layer 3 approximates the bedrock surface based on well logs and seismic data. There is insufficient geologic information to confidently interpret the significance of the intermediate layer that sometimes occurs beneath layer 3 and above layer 4. This layer may represent finer-grained material (silt or clay) within the glacial deposits, or it may be an artifact of the resistivity inversion process. Because of the averaging effects of the resistivity measurement and the non-uniqueness problem of the resistivity inversion, correspondences between stratigraphic units and resistivity layers are only approximate. Using a conservative approach to the data, only layer 3 resistivity values were used in calculating transverse resistance values for each station. Adding resistivity values from the intermediate layer would increase the transverse resistance without justification.

Similar patterns in the resistivity data are present throughout the rest of the study area. One important exception is within the bottoms of Salt Creek. In this small area, the shallow resistivity values (layers 1 and 2) are much larger (greater than 200 ohm-ft) than elsewhere suggesting the presence of coarse-grained alluvium or outwash within this valley.

The primary focus of this study was on resistivity layer 3 which approximates the combination of the Glasford Formation and upper parts of the Banner Formation. Instead of considering the resistivity values and layer thicknesses separately, the transverse resistance of layer 3 was calculated and mapped (figure 8). This map has a visual appearance similar to the map of middle sand thickness computed from the lithologic data (figure 3). To the extent that transverse resistance is a measure of sand thickness, it is reasonable to expect that these two maps have many similarities. Upon examination, many of the

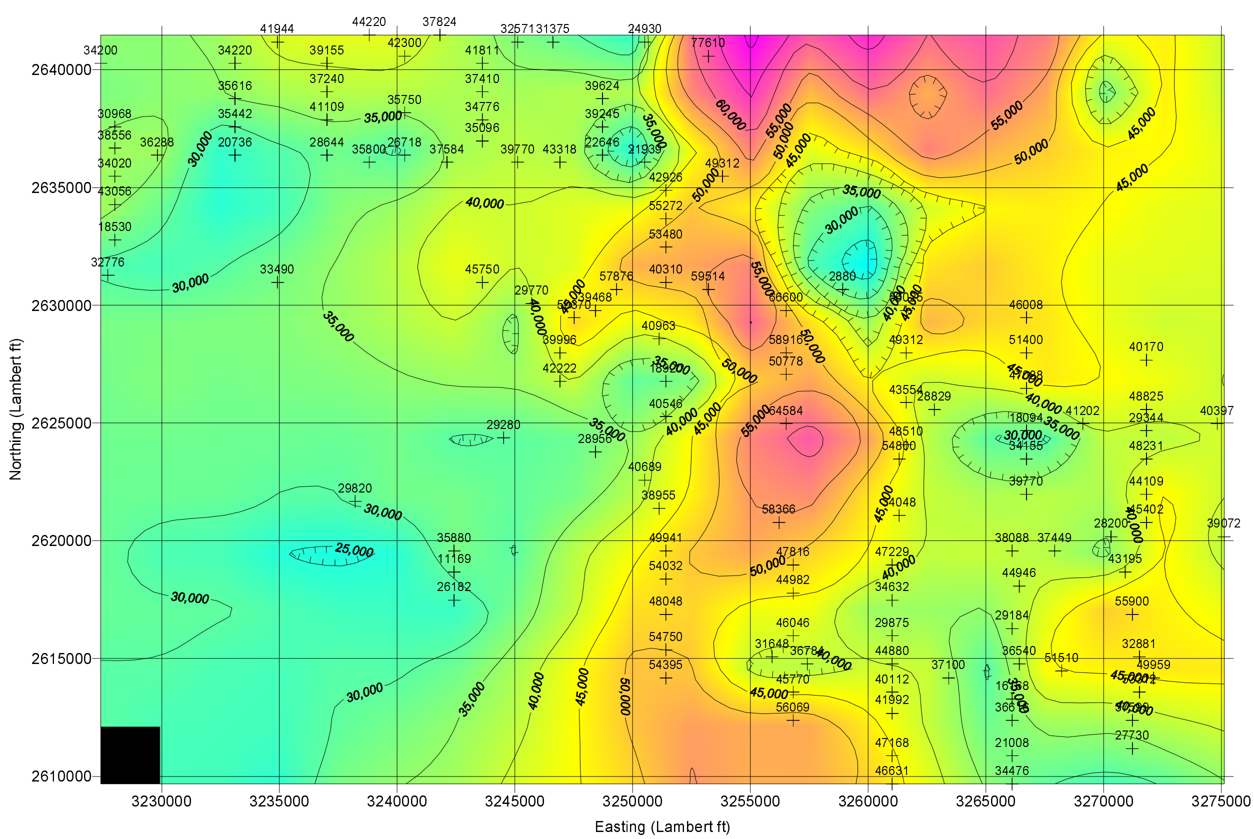


Figure 8. Transverse resistance (ohm-ft^2) of resistivity layer 3.

discrepancies between the two maps can be attributed to the differences in data distribution: the resistivity data are concentrated in the rural areas, the lithologic data are concentrated in and near Farmer City. The transverse resistance data were scaled so that values were in the same range as the actual sand thickness data. The resulting map (figure 9) of sand pseudo-thickness shows many similarities to the map of actual sand thickness. Finally, the actual sand thickness data were used to further scale the pseudo-thickness data and the two data sets were merged (Jones et al., 1986) and plotted together (figure 10). This process honors individual values in the actual sand thickness data set by calculating a local correction to the pseudo-thickness data. The map of the merged data preserves most of the characteristics of the map based solely on the well logs, but has the benefit of the greater data density of the resistivity survey in the rural areas. By filling in the gap in the center of the area, between Farmer City and Mansfield, the final map suggests that the sand deposits are relatively widespread and that a high probability exists of encountering 10 to 15 feet of sand throughout the area. Because of the way the lithologic data were combined, it is not possible to determine whether the sand is present in one thick deposit or two or three thinner deposits.

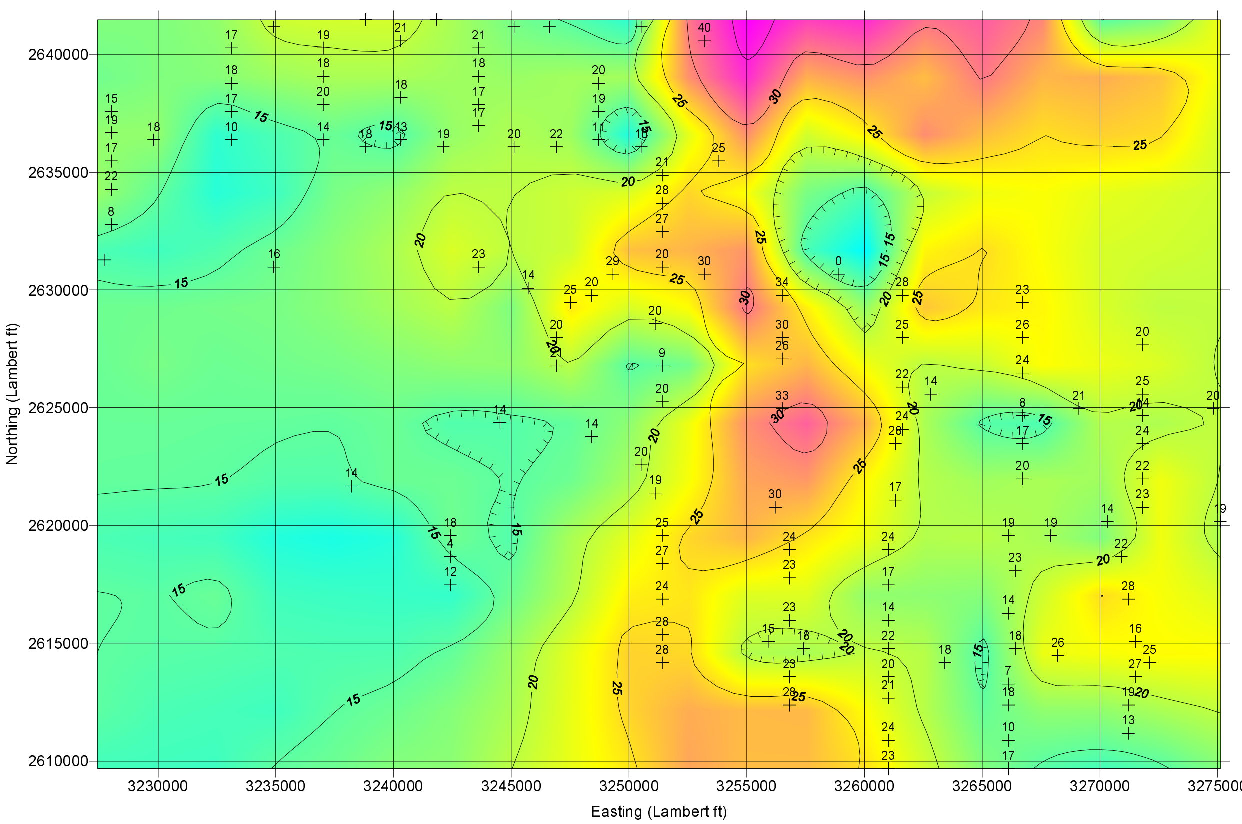


Figure 9. Scaled pseudo-thickness (feet) of resistivity layer 3.

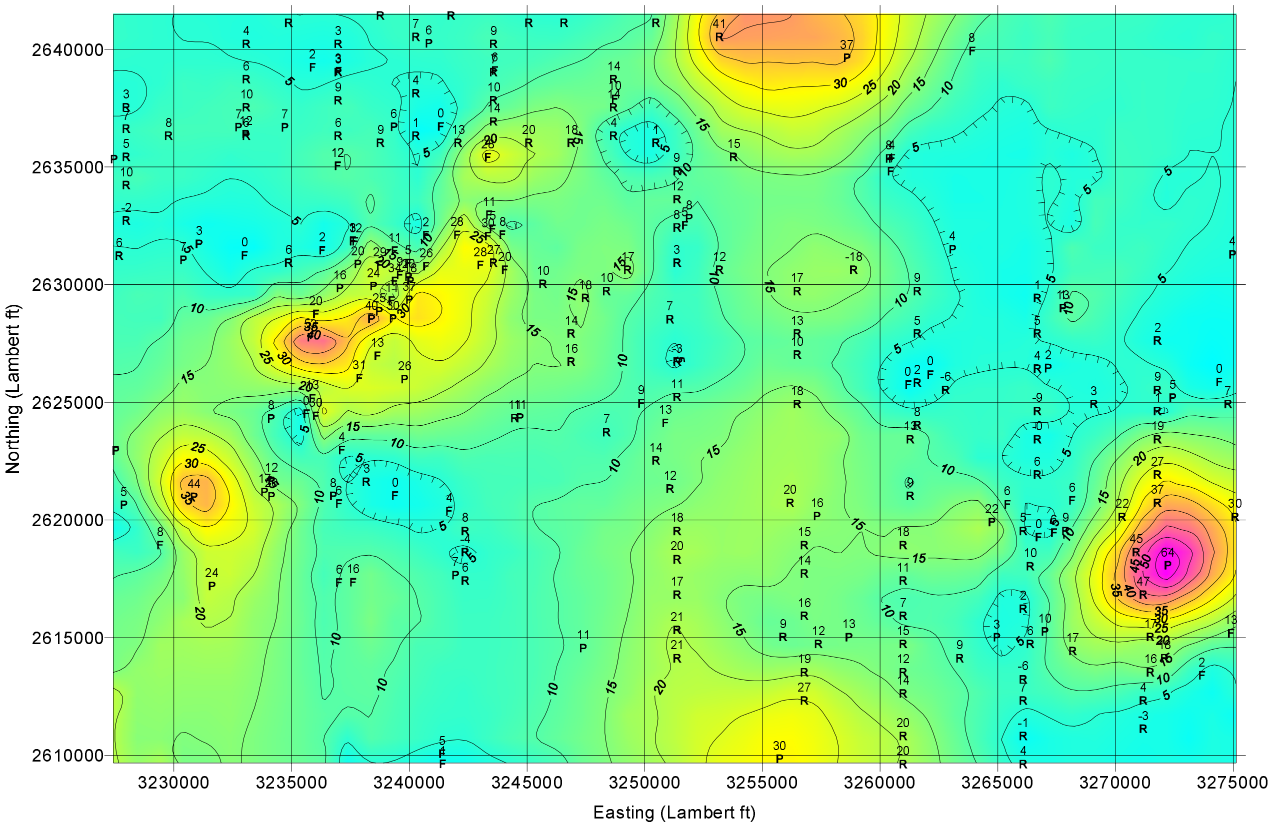


Figure 10. Predicted middle sand thickness (feet) based on boring data (points shown with either F or P, see figure 3) merged with scaled pseudo-thickness data (points shown with R).

Conclusions

Resistivity and seismic refraction surveys were used to supplement borehole data in a study of the groundwater resource potential of the Farmer City-Mansfield area. The seismic refraction survey, conducted in an area of very limited borehole control, suggests that a distinct bedrock valley is probably not present north of Farmer City. Therefore, the prospect of widespread sand and gravel within bedrock depressions there is very limited.

The borehole data alone suggest only minimal water resources in the rural areas. The resistivity data, which provide more dense coverage of these rural areas, when merged with the borehole data, fill out the picture and suggest that 10 to 15 feet of sand might be present beneath most of the area. Because of the way the data were combined, it is not possible to determine whether the sand is present in one thick deposit or two or three thinner deposits.

Acknowledgments

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