An Electrical Earth Resistivity Survey in The Wabash River Bottoms Eastern Crawford County, Illinois

Timothy H. Larson and Steven L. Sargent

Groundwater Geology Section

Illinois State Geological Survey

Open File Series 2000 - 5

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INTRODUCTION

An electrical earth resistivity survey was conducted as part of a groundwater resource investigation in the Wabash River bottoms of eastern Crawford County south of Palestine (parts of Sections 16, 17, 20-22, and 28, T. 6N, R. 10 W., figure 1). This site is a potential location for a 1,000 gallon per minute (gpm) well field to supply water to the Hardinville Water Company. Because the area has limited geological data from well logs or other sources, the resistivity survey was used to help determine the most favorable locations to drill the proposed high capacity well.

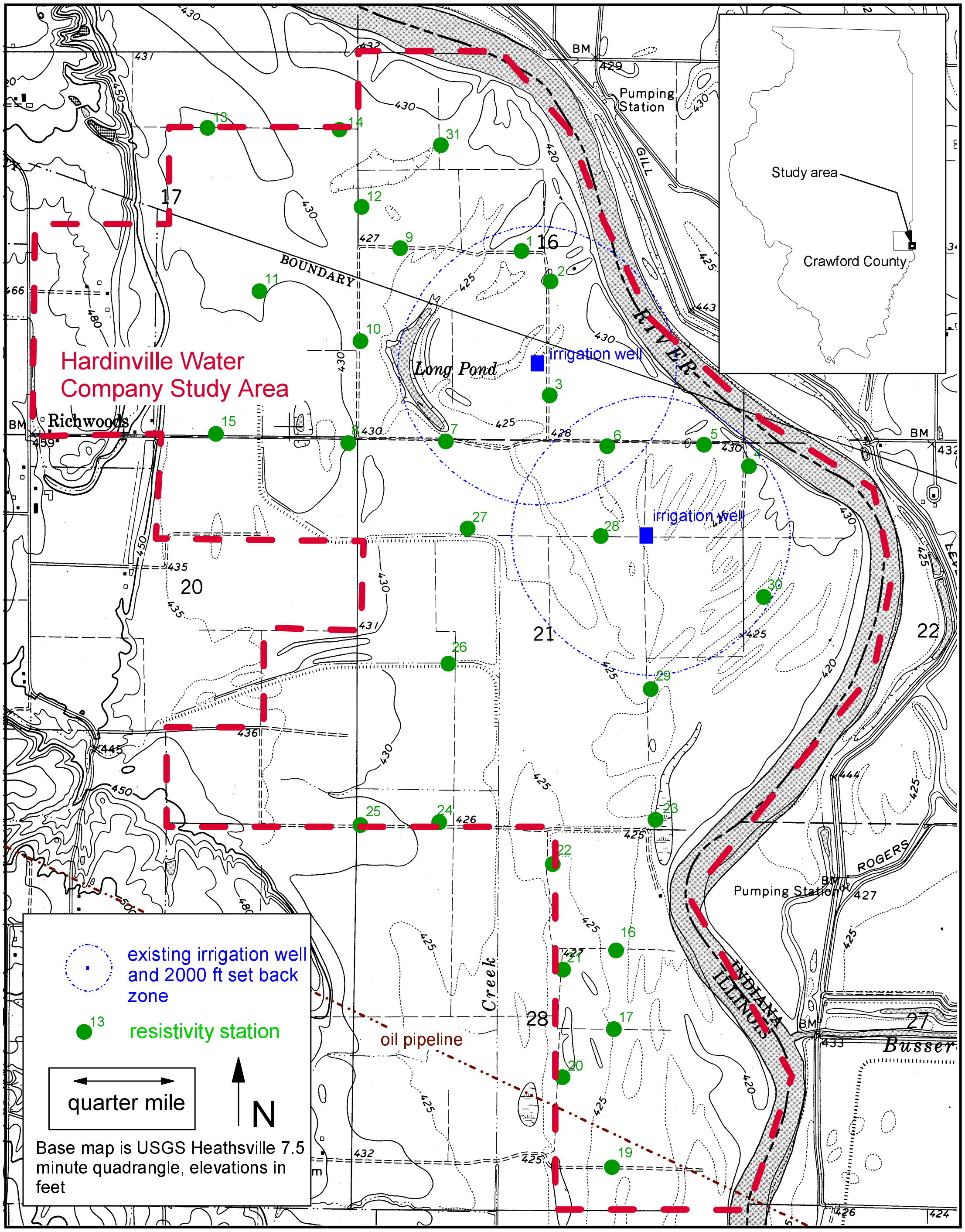

Figure 1. Location of study area and resistivity station.

GEOLOGICAL AND HYDROLOGICAL FRAMEWORK

The study site is located in eastern Crawford County in the flood plains of the Wabash River. The surface elevation ranges from about 480 to 500 feet above sea level on the bedrock bluffs at the west side of the area, to 420 feet at the Wabash River. Bedrock of Pennsylvanian age is exposed in some locations in the bluffs at the west side of the area. Although primarily shale, some coal, limestone and sandstone beds have been encountered in wells in or near the study area. To the east, the bedrock surface has been eroded so that it is now between 50 and 100 feet below the ground surface at the edge of the Wabash River (Piskin and Bergstrom, 1975).

Valley-fill deposits consist of sand and gravel of the Wisconsin Episode, Henry Formation (Hansel and Johnson, 1996), possibly intertongued with silt and clay of the Equality Formation (Hansel and Johnson, 1996), beneath recent alluvium of the Cahokia Formation (Willman and Frye 1970 and Hansel and Johnson, 1996). The Wabash River served as an outlet for large volumes of sediment during the retreat of the Wisconsin glaciers. Coarse-grained outwash that filled the main valley blocked many of the tributaries (Horberg, 1950) forming many slack water lakes. High-standing terrace remnants are still present in the study area, but are generally confined to the extreme western edge of the valley (Awalt, 1996). Subsequent downcutting has stripped out some of the younger surficial outwash deposits and replaced them with about 10 feet of fine- to coarse-grained alluvium assigned to the post-glacial Cahokia Formation.

Two large-capacity irrigation wells have been completed in the eastern part of the area on the meander belt of the modern river flood plain (figure 1). Both wells encountered 40 feet of Henry Formation sand and gravel beneath 9 feet of Cahokia Formation silt or clay. Much of the Cahokia Formation sediment may have been reworked from the underlying Henry (and possibly Equality) Formation. The records from these wells indicate that bedrock was not encountered.

Only one other well record was available at the ISGS for this study area. Located in the southwest quarter of Section 17 this well encountered 17 feet of soil and sand above 2 feet of coal and 7 feet of shale. Although the shallow sand may be alluvium of the Cahokia Formation, it is more likely part of the Wisconsin episode terrace system (Awalt, 1996). Similarly, a small gravel pit near the center of Section 28 is probably associated with outwash terrace deposits (Awalt, 1996).

The groundwater geology of the study area is very similar to that described by Pryor (1956) for White County which is 60 miles downstream. Bedrock units, in particular the shallow sandstones, supply small to moderate quantities of groundwater for domestic use, but these shallow wells are often inadequate during dry conditions. Water obtained from deeper aquifers is commonly too highly mineralized for general use. Sand and gravel aquifers are thin and discontinuous in the uplands of the area, but are thick and continuous within the Wabash River valley. A significant difference between White County and this study area in Crawford County is the relative position of the modern and ancient Wabash River Valleys. In White County, the modern valley generally overlies the ancient valley and most of the valley is within Illinois. In Crawford County, most of the ancient channel lies in Indiana, east of the modern channel (Horberg, 1950). However, there are a few places in Crawford County (such as at Palestine and Hutsonville) where the Wabash River flood plain is at least a mile wide and can support large capacity well fields. The study area is one of these areas having a wide flood plain, and it therefore has the potential for supporting successful large-capacity wells.

METHODS

Electrical earth resistivity is sensitive to the proportion of sand and clay in earth materials (Buhle and Brueckmann, 1964). Sand-rich deposits have larger resistivity values than clay or shale. This generalization is only an approximation; other factors also affect the earth resistivity values. 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 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

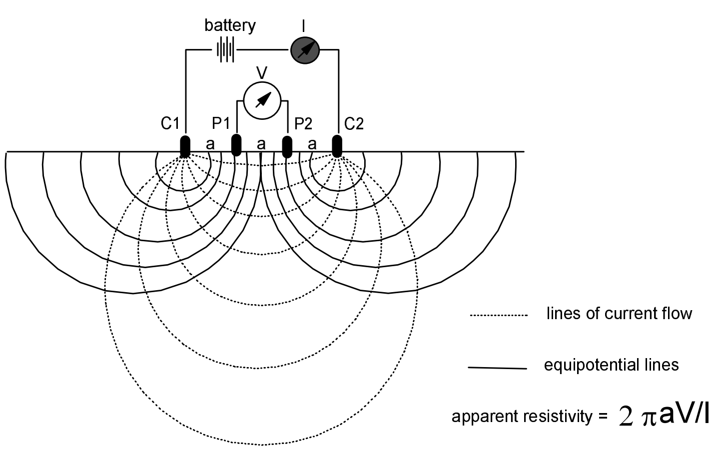

Figure 2. Schematic drawing of Wenner electrode configuration.

have large resistivity values similar to, or greater than, unlithified sand. Also, interferences from metal and electrical sources installed by humans artificially reduce the apparent resistivity.

For each resistivity measurement (figure 2), a known electrical current is 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 spacing (**a**) between them. This system, known as a Wenner-type array, can be used to obtain a one-dimensional profile of the variation in apparent earth resistivity with increasing depth 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 3). 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 solution, the transverse resistance, is obtained by calculating the product of the thickness and resistivity for each layer (Maillet, 1947).

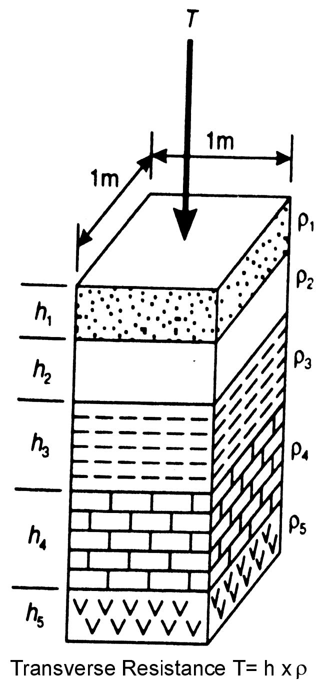

Figure 3. Schematic drawing of resistivity layers and parameters used to calculate transverse resistance.

The flow of water through porous media has many similarities, both theoretical and physical, with the flow of electricity through the same porous media (Freeze and Cherry, 1979).

One of the many analogs between the two systems is aquifer transmissivity and transverse resistance. In other studies, the geophysically derived parameter, transverse resistance, has been used with varying degrees of success to estimate the hydraulic parameter, aquifer transmissivity, (Kupfersberger and Bloschl, 1995). In this study, the transverse resistance will be used to estimate the aquifer (sand and gravel) thickness, which is comparable to estimating the transmissivity of the aquifer while assuming a constant hydraulic conductivity. This estimate approximates the relative yield of the aquifer (Larson et al., 2000).

Thirty resistivity stations were distributed throughout the area at ¼ to ½ mile intervals where accessible (figure 1). Resistivity tests used the Wenner electrode configuration with a maximum spacing of 180 feet between adjacent electrodes. This spacing was chosen to provide sufficient electrical penetration to investigate the entire thickness of the drift, which was estimated to be between 50 and 100 feet thick. Apparent resistivity profiles were inverted to resistivity layers (Appendix I). The transverse resistance was calculated for each layer.

RESULTS

Aquifer material in Illinois is characterized as resistivity layers with resistivity values of 200 ohm-ft or greater (Heigold et al., 1985). At least one, and in some cases, two resistivity layers at every station met this criterion, suggesting that aquifer material is present throughout the study area. However, most of the stations with two layers having large resistivity values were located in the western part of the study area. The deeper of these two layers may be influenced by shallow sandstone and may not reflect sand and gravel. In a conservative, though possibly subjective process, only one of the large resistivity layers at each station was chosen for further analysis (see Appendix II for details). The transverse resistance of this primary layer is shown in figure 4. Using the three water well records as constraints, the transverse resistance was scaled to approximate aquifer thickness (Appendix II, figure 5). Data were interpolated using SURFER (Golden Software, 1995) to a 650 foot square grid using a kriging algorithm with a 3 to 1 northwest anisotropy, and an octant search radius of 4500 feet. These gridding parameters were chosen to produce a relatively fine grid while taking into account both the sampling anisotropy created by use of the road network and the natural anisotropy of the field site.

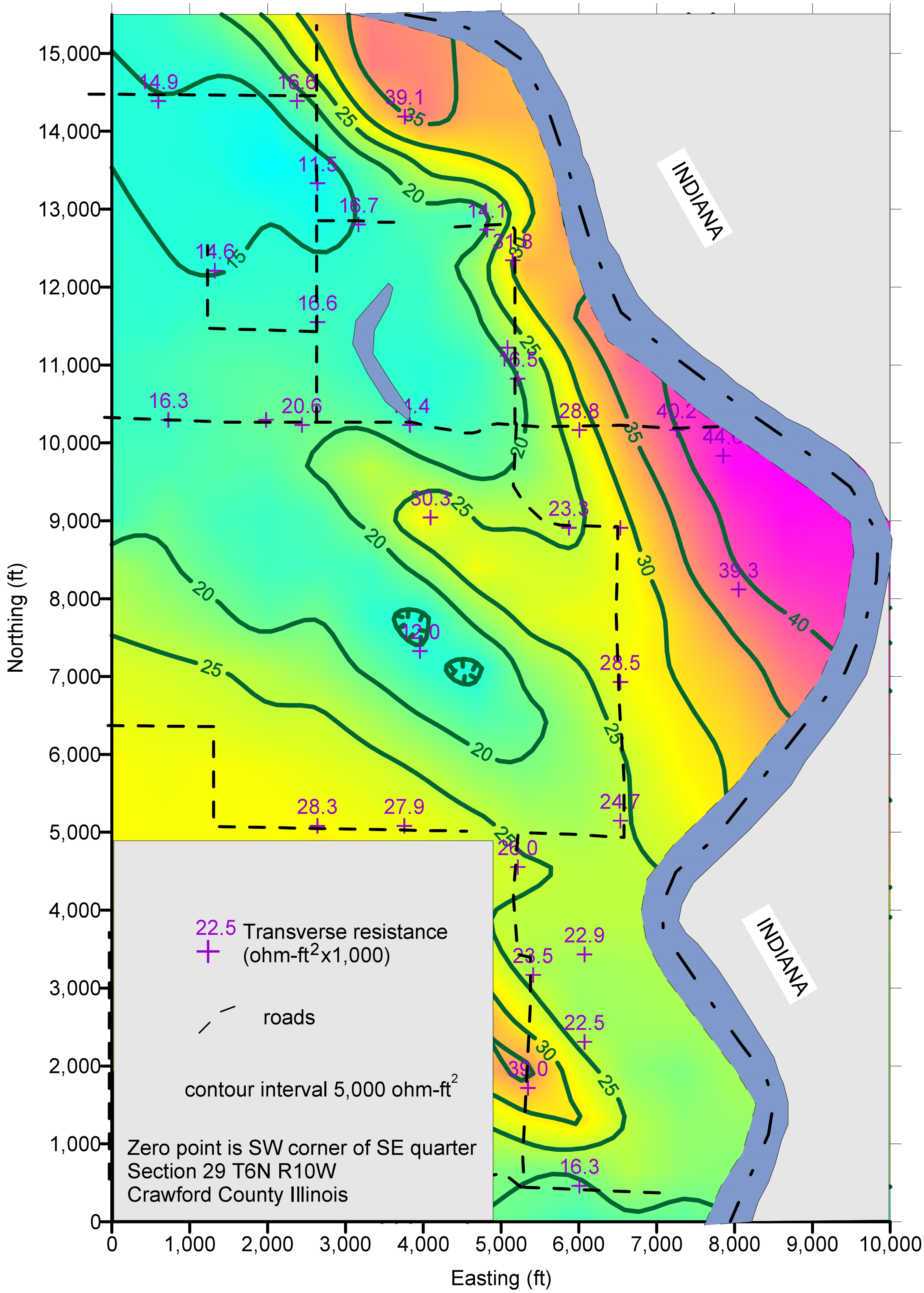

Figure 4. Transverse resistance of the primary layer.

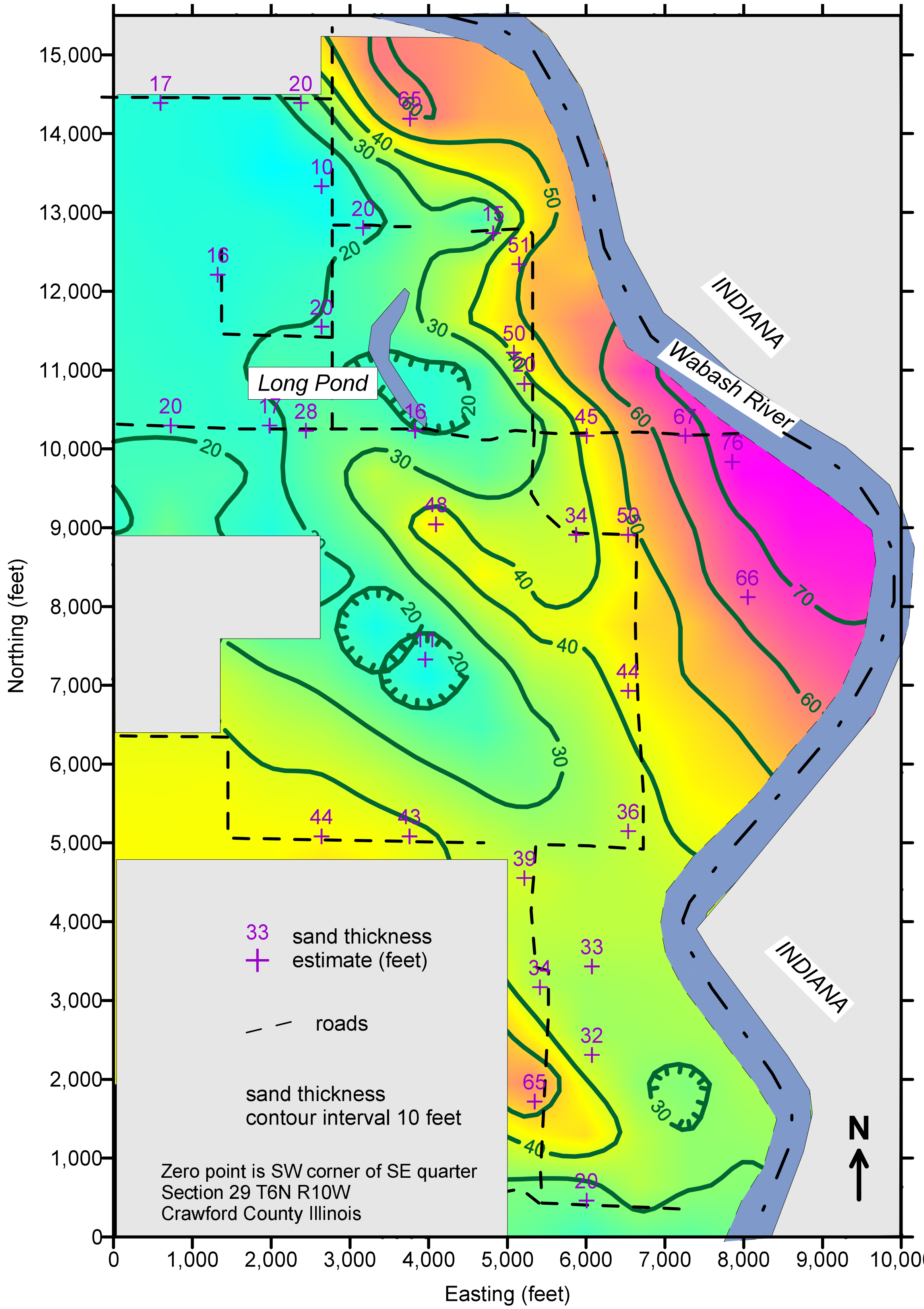

Figure 5. Estimated aquifer thickness.

Based on this map of estimated sand thickness, the study area can be divided into zones with EXCELLENT, GOOD, or POOR probabilities for completing high capacity (1,000 gpm) wells (figure 6). The largest area with EXCELLENT probabilities for completing high capacity wells is in the eastern part of the study area, very near the Wabash River. Resistivity readings in this area were consistently higher than in other areas. Sand and gravel deposits up to 70 feet thick may be expected in this area. A small area that rates as EXCELLENT is in the southern part of the study area. Shallow gravel deposits sufficient to support a small gravel pit are located in this area. The shallow gravel is probably of alluvial origin, but deeper alluvial or glacial sands and possibly gravel may also be present.

Sand and gravel deposits 30 to 50 feet thick are likely to be present beneath the area shown as GOOD in figure 6. The two irrigation wells located within this area encountered 40 feet of sand and gravel. Resistivity values in the rest of the area shown as GOOD were similar to the values near the two irrigation wells, suggesting that subsurface conditions can be expected to be similar throughout most of the area shown as GOOD. However, no records of wells or borings from the southern part of the study area are available to confirm this expectation. In the northern part of the study area, the area shown as GOOD markes the transition zone between the EXCELLENT area near the river and the POOR area to the west.

Resistivity values were much lower in the northwestern and southern-most parts of the study area, shown as POOR in figure 6. Although some sand and gravel may be present in these areas, it is likely to be less than 15 feet thick. This sand is probably underlain either by clay or shale bedrock. The boundary between the areas with POOR probability and GOOD probability for completing high capacity wells should not be considered a sharp divide, but rather a smooth transition between the two areas. More geologic information from drill holes would be needed to refine these boundaries.

A large oil pipeline crosses the extreme southern part of the study area. This structure influenced one, and possibly two, of the resistivity readings in the area. Data from the resistivity station that was definitely affected by the pipeline were not included in this analysis, however the data from the other station (shown as station 19) were included. This station was located sufficiently far from the pipeline to suggest that the low values may have natural causes.

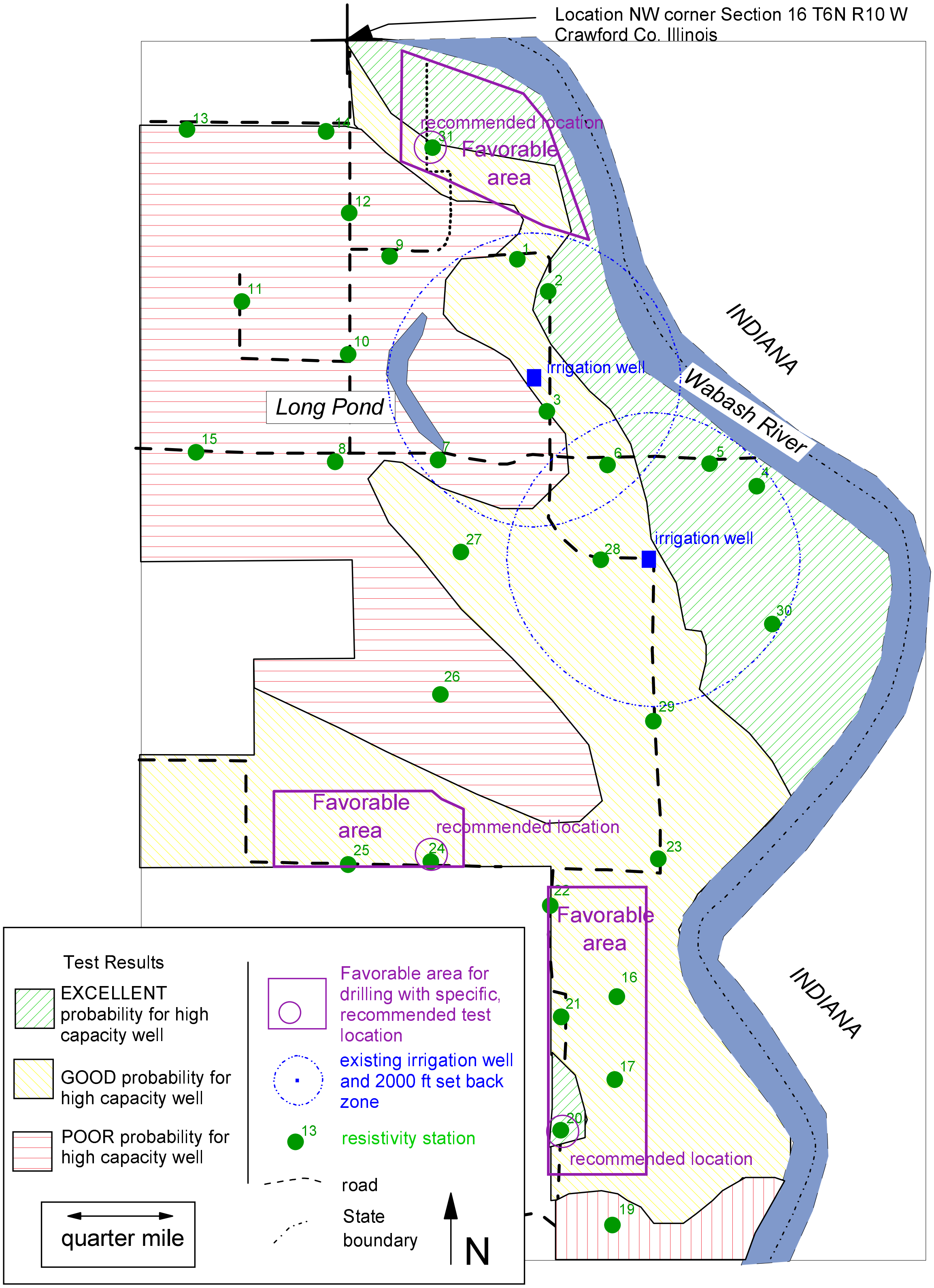

Figure 6. Relative probability for successfully installing a large capacity well, based on thickness of aquifer materials, showing areas recommnded for test drilling.

RECOMMENDATIONS

Three areas are shown in figure 6 as FAVORABLE for further testing. These areas lie completely within the study area, have GOOD to EXCELLENT probabilities for completing high capacity wells, are at least 2000 feet from existing high capacity wells, are accessible by existing roads, and have one dimension exceeding a half mile. Each of these areas could, theoretically, support two or more production wells spaced a half mile apart. A recommended test location is shown for each area (figure 6). This location is at the resistivity station having the greatest estimated sand thickness in the favorable area. The field location of these recommended stations may be more clearly identified on figure 1.

> WELL FIELD INTERFERENCE
>
> Because of the potential for interference from the existing irrigation wells, it would be advisable to attempt to locate new high-capacity wells far from the existing wells. The exact separation that would be required can only be determined following a test of the aquifer materials, but a separation of 1000 feet is the minimum wellhead protection setback in any location within Illinois (Illinois EPA) and in river bottoms a separation of 2000 feet or ½ mile is common. For instance, the Hutsonville municipal wells, located in similar deposits about 15 miles upstream from this site, are separated ½ mile from each other.

The largest and southern-most area, defined by resistivity stations 16, 17, 20, 21, and 22 includes a small area rated as EXCELLENT based on very high resistivity readings at station 20 and the known presence of a gravel deposit. However, this gravel may be very shallow and depending on the water table conditions, may not be saturated. If not, it will not add significant thickness to the aquifer in the area. Otherwise, the resistivity values are very similar to those near the irrigation wells, suggesting that similar materials may be present in this area. However, no records of drill holes are available from this area to confirm the aquifer conditions.

> WATER WELLS ON FLOOD PLAINS
>
> Because of the health risks associated with frequent flooding, special regulations apply to the construction of water wells within the 100-year flood plain of any river in Illinois. Although locating the precise boundaries of this area is beyond the scope of this report, much of the study area almost certainly lies within the 100-year flood plain of the Wabash River. The Illinois State Water Survey and the Illinois EPA can provide more information on how to safely construct water wells in this environment.

The other favorable area located in the southern half of the study area is very similar to the first. They might have been considered as one area, except that they are physically separated by No Business Creek. Resistivity values at stations 24 and 25 are greater than at nearby stations 22 and 23, suggesting the presence of thick sand and gravel deposits in this favorable area. However, the area is not rated EXCELLENT because there are no drill holes available to confirm the presence of sand and gravel. The large resistivity values could also be caused by a spur of shallow sandstone or limestone that extends from the bluffs to the west. Also the resistivity values from station 26, at the north end of this farm field are much smaller than those at surrounding stations. Although this reading may represent a small, isolated area of fine-grained material, it may also be a southern extension of the large northwest area rated as POOR. There is not enough information to confidently determine the southern extent of this POOR area.

Another favorable area is located in the extreme northeast part of the study area. Technically, this area is the most favorable of the three because it is most likely to be underlain by the thickest sand and gravel deposits. However, this area is also very near existing irrigation wells that may cause hydraulic interference, and it is the most remote of the favorable areas.

A fourth area, defined by stations 23, 29 and 30 was contemplated, but ultimately not recommended. The probability of encountering thick sand and gravel deposits in this area ranges from GOOD to EXCELLENT, but the area is near existing irrigation wells and most of the area is presently wooded and not easily accessible.

SUMMARY

Sand and gravel deposits, 30 to 50 feet thick are probably present beneath most of this study area. Deposits may thicken to 70 feet or more near the Wabash River. Three areas that are favorable for further testing have been defined. Testing should commence in any one of these three areas with a test hole at or near the indicated resistivity station. If adequate sand and gravel deposits are encountered in this test hole then one or two other test holes should be drilled in the same area to confirm the extent of the deposit. If adequate sand and gravel deposits are not encountered, then testing should proceed to one of the other favorable areas. The test holes should be drilled to bedrock, samples collected for grain-size analysis, and geophysical logs run in each. If appropriate, a full-scale production test should be conducted at one of these sites.

The geology of the northwestern part of the study area is different from the rest of the area. Only thin sand and gravel deposits are likely in this part of the study area and test drilling is not recommended there.

ACKNOWLEDGMENTS

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Appendix I Results of numerical inversion of resistivity data

Resistivity data are tabulated for each station in the following manner:

Line 1: Station identifier with prefix "hard" followed by the two-digit station number.

Line 2: Header

Column 1: AB/2:	a-spacing (ft)
Column 2: OBS:	observed apparent resistivity (ohm-ft)
Column 3: REDUCED THICKNESS:	calculated layer thickness (ft)
Column 4: REDUCED DEPTH:	running sum of layer thicknesses (ft)
Column 5: REDUCED RESISTIVITY:	calculated layer resistivity (ohm-ft)

Lines 3-15: Data

The program requires that the deepest layer extend to infinity. This requirement is met by assigning the maximum value possible to the last layer thickness.
For more information, see Zohdy and Bisdorf, 1975.

hard01

AB/2	OBS
5.000	142.314
10.000	142.000
20.000	173.542
30.000	202.256
40.000	231.975
60.000	272.565
80.000	278.973
100.000	268.920
120.000	260.878
140.000	251.579
160.000	243.285
180.000	236.373
200.000	236.248

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.76793	3.76793	150.31470
7.05897	10.82690	121.39120
13.76142	24.58832	228.52670
32.75473	57.34305	472.10970
107.93970	165.28280	171.72050
99999810.00000	99999980.00000	301.94580

hard02

AB/2	OBS
5.000	104.301
10.000	145.770
20.000	205.523
30.000	245.421
40.000	240.520
60.000	267.475
80.000	277.968
100.000	291.226
120.000	293.299
140.000	277.088
160.000	266.407
180.000	254.469

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.57950	4.57950	83.25996
2.79703	7.37652	227.73620
13.16241	20.53893	314.93960
20.14260	40.68153	280.27450
93.42349	134.10500	333.84890
99999820.00000	99999950.00000	139.45360

hard03

AB/2	OBS
5.000	99.903
10.000	163.363
20.000	246.929
30.000	291.037
40.000	316.924
60.000	327.794
80.000	300.839
100.000	273.947
120.000	252.584
140.000	244.542
160.000	223.179
180.000	210.927

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.15603	3.15603	64.72976
1.65778	4.81381	147.08590
37.91399	42.72780	468.43050
82.38205	125.10980	187.44810
99999840.00000	99999970.00000	147.63620

hard04

AB/2	OBS
5.000	198.549
10.000	149.540
20.000	180.579
30.000	206.968
40.000	225.818
60.000	254.469
80.000	275.706
100.000	287.142
120.000	297.069

140.000	294.242
160.000	294.556
180.000	290.660

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.28565	3.28565	255.33270
1.61974	4.90539	152.30600
6.19948	11.10487	86.42448
134.67480	145.77960	329.60860
99999840.00000	99999980.00000	219.38550

hard05

AB/2	OBS
5.000	220.854
10.000	129.434
20.000	145.519
30.000	182.652
40.000	202.067
60.000	238.258
80.000	262.386
100.000	272.376
120.000	283.497
140.000	281.487
160.000	281.989
180.000	274.261

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.22284	3.22284	335.72430
1.58298	4.80582	158.03330
5.21449	10.02031	53.04994
118.24180	128.26210	336.28470
99999840.00000	99999970.00000	176.28750

hard06

AB/2	OBS
5.000	78.540
10.000	90.823
20.000	145.644
30.000	193.679
40.000	221.545
60.000	237.127
80.000	248.563
100.000	256.668
120.000	261.255
140.000	267.412
160.000	276.963
180.000	284.440

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
2.45457	2.45457	86.41461
7.41187	9.86644	64.93507
10.54500	20.41145	621.33110
116.41470	136.82620	248.50170
99999820.00000	99999960.00000	434.38700

hard07

AB/2	OBS
5.000	89.221
10.000	106.626
20.000	161.541
30.000	202.633
40.000	227.954
60.000	253.150
80.000	251.076
100.000	237.819
120.000	217.901
140.000	208.916
160.000	198.549
180.000	183.218

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.65485	4.65485	90.61955
5.38601	10.04086	82.60400
33.29523	43.33609	436.74800
89.88898	133.22510	174.57920
99999790.00000	99999930.00000	88.08936

hard08

AB/2	OBS
5.000	264.208
10.000	333.637
20.000	423.487
30.000	450.504
40.000	441.582
60.000	401.873
80.000	363.671
100.000	325.155
120.000	306.494
140.000	285.445
160.000	262.386
180.000	251.076

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.79483	4.79483	234.45470
41.17371	45.96854	516.26150
84.35263	130.32120	234.86960
99999850.00000	99999980.00000	199.48660

hard09

AB/2	OBS
5.000	64.717
10.000	82.153
20.000	128.742
30.000	163.520
40.000	187.742
60.000	222.048
80.000	232.478
100.000	218.969
120.000	203.575
140.000	190.004
160.000	181.257
180.000	170.212

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
2.64333	2.64333	63.28650
2.33655	4.97989	51.50614
5.15061	10.13049	81.27669
46.46877	56.59926	362.92690
74.49332	131.09260	147.45520
99999800.00000	99999930.00000	86.92308

hard10

AB/2	OBS
5.000	91.735
10.000	145.142
20.000	221.168
30.000	256.354
40.000	275.958
60.000	283.497
80.000	269.926
100.000	248.186
120.000	229.211
140.000	203.198
160.000	184.977
180.000	171.908

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.35036	3.35036	67.48989
1.72969	5.08005	113.55950
42.97799	48.05804	386.92950
84.83880	132.89680	163.58220
99999800.00000	99999940.00000	94.24081

hard11

AB/2	OBS
5.000	71.314
10.000	103.484
20.000	151.927
30.000	180.202
40.000	197.543
60.000	209.984
80.000	205.083
100.000	196.664
120.000	186.234
140.000	179.448
160.000	172.913
180.000	165.122

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
5.30752	5.30752	61.05959
58.12372	63.43125	252.21000
76.42007	139.85130	147.29220
99999830.00000	99999970.00000	109.79040

hard12

AB/2	OBS
5.000	50.077
10.000	65.219

20.000	103.421
30.000	138.733
40.000	162.609
60.000	188.119
80.000	195.030
100.000	189.752
120.000	179.448
140.000	165.373
160.000	157.834
180.000	148.158

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
2.87036	2.87036	47.68829
2.10499	4.97536	37.60497
4.91001	9.88537	59.54344
26.75912	36.64449	426.28970
87.98816	124.63270	142.63420
99999800.00000	99999930.00000	73.59093

hard 13

AB/2	OBS
5.000	79.168
10.000	95.002
20.000	140.492
30.000	172.285
40.000	192.265
60.000	202.821
80.000	196.035
100.000	177.186
120.000	159.844
140.000	147.781
160.000	135.717
180.000	123.276

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
9.12709	9.12709	76.06504
49.50890	58.63599	297.79460
72.51022	131.14620	97.46462
99999780.00000	99999900.00000	57.92695

hard14

AB/2	OBS
5.000	67.858
10.000	71.000
20.000	97.641
30.000	129.308
40.000	153.058
60.000	182.464
80.000	195.533
100.000	198.549
120.000	196.035
140.000	188.244
160.000	181.961
180.000	169.985

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.54082	3.54082	68.21127
6.75612	10.29694	57.52685
10.33122	20.62816	177.24610

53.65296	74.28112	307.34640
64.12056	138.40170	152.64230
99999780.00000	99999920.00000	76.89369

hard14

AB/2	OBS
5.000	67.858
10.000	71.000
20.000	97.641
30.000	129.308
40.000	153.058
60.000	182.464
80.000	195.533
100.000	198.549
120.000	196.035
140.000	188.244
160.000	181.961
180.000	169.985

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.54082	3.54082	68.21127
6.75612	10.29694	57.52685
10.33122	20.62816	177.24610
53.65296	74.28112	307.34640
64.12056	138.40170	152.64230
99999780.00000	99999920.00000	76.89369

hard 16

AB/2	OBS
5.000	76.341
10.000	114.103
20.000	183.595
30.000	230.342
40.000	264.396
60.000	301.970
80.000	311.143
100.000	289.027
120.000	251.830
140.000	231.347
160.000	213.126
180.000	196.789

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.67588	3.67588	55.99842
4.61304	8.28892	145.30910
48.86865	57.15756	467.42340
72.49925	129.65680	165.57450
99999780.00000	99999900.00000	89.81998

hard 17

AB/2	OBS
5.000	316.044
10.000	417.204
20.000	508.938
30.000	484.434
40.000	472.747
60.000	419.968

80.000	354.874
100.000	309.133
120.000	276.711
140.000	259.496
160.000	248.311
180.000	234.111

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
2.67143	2.67143	238.58180
42.24446	44.91590	534.69930
87.41556	132.33150	220.40170
99999840.00000	99999980.00000	180.77170

hard 18

AB/2	OBS
5.000	109.013
10.000	123.150
20.000	150.294
30.000	178.694
40.000	197.041
60.000	202.067
80.000	207.094
100.000	219.283
120.000	224.687
140.000	239.264
160.000	246.301
180.000	243.159

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
7.56158	7.56158	103.48520
99999990.00000	100000000.00000	230.87990

hard 19

AB/2	OBS
5.000	73.199
10.000	112.909
20.000	168.012
30.000	201.690
40.000	226.446
60.000	251.453
80.000	270.428
100.000	282.743
120.000	286.513
140.000	288.524
160.000	280.481
180.000	264.648

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.41256	3.41256	52.84774
2.49504	5.90760	87.22686
51.05086	56.95846	320.29750
53.41949	110.37790	419.33440
35.23751	145.61550	230.16650
99999750.00000	99999900.00000	108.10350

hard 20

AB/2	OBS
5.000	613.867
10.000	772.832
20.000	697.434
30.000	620.150
40.000	555.434
60.000	453.143
80.000	380.007
100.000	351.230
120.000	329.490
140.000	307.876
160.000	288.524
180.000	266.910

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.13485	3.13485	466.33190
11.31010	14.44494	1072.06100
106.78180	121.22670	364.73350
99999800.00000	99999920.00000	147.44220

hard 21

AB/2	OBS
5.000	89.850
10.000	126.292
20.000	186.988
30.000	217.147
40.000	234.740
60.000	249.945
80.000	255.851
100.000	254.469
120.000	244.290
140.000	235.745
160.000	224.184
180.000	208.099

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
5.21928	5.21928	74.54649
79.55136	84.77065	297.06220
62.18330	146.95390	194.61620
99999780.00000	99999930.00000	100.15030

hard 22

AB/2	OBS
5.000	51.585
10.000	71.754
20.000	116.490
30.000	147.969
40.000	170.400
60.000	197.543
80.000	213.628
100.000	221.796
120.000	223.933
140.000	224.310
160.000	219.158
180.000	211.492

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.87535	4.87535	43.48301
4.44515	9.32050	93.26787
92.45288	101.77340	282.74800
99999870.00000	99999980.00000	137.44940

hard 23

AB/2	OBS
5.000	92.363
10.000	118.689
20.000	181.584
30.000	222.990
40.000	243.285
60.000	274.073
80.000	281.989
100.000	275.832
120.000	263.894
140.000	256.857
160.000	245.296
180.000	228.457

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
5.07474	5.07474	82.13284
4.31434	9.38908	137.01590
69.33190	78.72099	358.27830
64.63535	143.35630	198.86930
99999790.00000	99999940.00000	111.80110

hard 24

AB/2	OBS
5.000	127.549
10.000	133.204
20.000	180.704
30.000	214.508
40.000	237.756
60.000	262.386
80.000	264.899
100.000	251.956
120.000	242.028
140.000	228.708
160.000	224.184
180.000	211.492

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
10.10633	10.10633	127.11560
91.65569	101.76200	303.41200
99999860.00000	99999960.00000	121.33670

hard 25

AB/2	OBS
5.000	109.013
10.000	100.594
20.000	119.381
30.000	143.634
40.000	164.619
60.000	204.329

80.000	219.158
100.000	227.451
120.000	227.703
140.000	220.791
160.000	216.142
180.000	203.575

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.36509	4.36509	117.24480
6.25402	10.61910	76.95514
12.25495	22.87406	157.48850
91.64449	114.51860	307.50420
99999820.00000	99999930.00000	97.07697

hard 26

AB/2	OBS
5.000	117.810
10.000	130.690
20.000	178.694
30.000	204.141
40.000	216.644
60.000	222.048
80.000	222.173
100.000	215.513
120.000	210.361
140.000	205.837
160.000	200.157
180.000	197.920

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
8.55667	8.55667	114.44590
45.66653	54.22320	260.54120
99999940.00000	100000000.00000	184.61080

hard 27

AB/2	OBS
5.000	59.156
10.000	71.188
20.000	110.835
30.000	145.707
40.000	174.673
60.000	217.147
80.000	243.285
100.000	258.867
120.000	262.386
140.000	272.690
160.000	272.439
180.000	265.779

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
9.78829	9.78829	56.92612
8.45844	18.24674	253.77710
77.64113	95.88786	388.60780
99999870.00000	99999970.00000	178.03520

hard 28

AB/2	OBS
5.000	60.915
10.000	78.477

20.000	118.124
30.000	149.665
40.000	185.731
60.000	243.913
80.000	264.396
100.000	259.496
120.000	242.782
140.000	227.828
160.000	212.120
180.000	208.099

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.85444	4.85444	53.05605
5.21426	10.06870	83.50748
7.46640	17.53510	251.25900
61.52967	79.06477	374.67770
99999880.00000	99999960.00000	139.07870

hard 28

AB/2	OBS
5.000	60.915
10.000	78.477
20.000	118.124
30.000	149.665
40.000	185.731
60.000	243.913
80.000	264.396
100.000	259.496
120.000	242.782
140.000	227.828
160.000	212.120
180.000	208.099

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.85444	4.85444	53.05605
5.21426	10.06870	83.50748
7.46640	17.53510	251.25900
61.52967	79.06477	374.67770
99999880.00000	99999960.00000	139.07870

hard 30

AB/2	OBS
5.000	76.655
10.000	100.908
20.000	153.435
30.000	200.182
40.000	236.499
60.000	289.529
80.000	315.667
100.000	328.611
120.000	331.752
140.000	335.145
160.000	335.773
180.000	325.720

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
4.93129	4.93129	67.75944
5.96540	10.89669	110.28100
87.48372	98.38041	451.78160
99999870.00000	99999970.00000	215.60620

hard 31

AB/2	OBS
5.000	145.456
10.000	240.646
20.000	363.168
30.000	393.956
40.000	385.034
60.000	351.356
80.000	339.795
100.000	319.186
120.000	317.427
140.000	303.478
160.000	280.481
180.000	272.565

REDUCED THICKNESS	REDUCED DEPTH	REDUCED RESISITIVITY
3.30093	3.30093	90.54473
1.18720	4.48812	230.63250
11.41874	15.90686	812.86530
133.73870	149.64560	292.48950
99999830.00000	99999980.00000	209.63950

Appendix II: Transverse resistance data set

The following table was used to construct maps of estimated thickness (pseudothickness) of sand in the study area. The columns of data are:

1. Station: these are the station numbers used in the field. Station 17 was situated over a buried pipeline and not used. Irrig1, Irrig2, and house1 refer to records of water wells. The actual sand thickness from these wells is used in the pseudothickness columns.

2.and 3. Easting and Northing: These are locations in feet from the SW corner of SE quarter Section 29 T6N R10W Crawford County Illinois.

4. T-1: Transverse resistance of aquifer layer 1. Where the transverse resistance is the product of the layer thickness (ft) and layer resistivity (ohm-ft). Aquifer layer 1 was selected from the output of the inversion model and is the upper-most layer having a thickness greater than 5 feet and resistivity greater than 180 ohm-ft. Transverse resistance is reported in units of (ft*ft*ohm/100).

5. T layer2: Transverse resistance of aquifer layer2. Transverse resistance is as defined above. Aquifer layer two is the second layer (if present) having a thickness greater than 5 feet and resistivity greater than 180 ohm-ft. In cases where the second layer is also the base layer of the model, the thickness is taken to be 180 less the depth to top of that layer.

6. Sum T1 + T2: A simple summation of columns 4 and 5.

7. Pseudothickness using T_{sum}: This column is a scaling of the preceding column to approximate the thickness (in feet) of the sand reported in Irrig1, Irrig2, and House1. The scaling formula is 80*(T1+T2)/Max(T1+T2). The offset value of 80 is arbitrarily assigned to produce a reasonable fit.

8. T "primary" layer: Transverse resistance of the "primary" aquifer layer. This column uses values from T-1 unless T-2 is significantly greater. Some subjectivity was used to choose these values.

9. Pseudothickness using $T_{primary}$: This column is similar to column 7, but is a scaling of Transverse resistance of the "primary" aquifer layer. The scaling formula is $(70*T_{prim}/35) - 13$. This formula is somewhat arbitrary and is designed to make the gridded data match as closely as possible to Irrig1, Irrig2 and House1.

station	easting (ft)	northing (ft)	T1 (transverse resistance layer 1)	T layer 2	sum T1 + T2	pseudo-thickness Tsum	T "primary" layer	pseudo-thickness $T_{primary}$
1	4818	12738	14.1	18.7	32.8	46.0	14.1	15.2
2	5148	12342	5.6	31.8	37.4	52.5	31.8	50.6
3	5214	10824	16.5	15.2	31.7	44.5	16.5	20
4	7854	9834	44.5		44.5	62.5	44.6	76.2
5	7260	10164	40.2		40.2	56.4	40.2	67.4
6	6006	10164	6.2	28.8	35	49.1	28.8	44.6
7	3828	10230	14.4	15.8	30.2	42.4	14.4	15.8
8	2442	10230	20.6	18.6	39.2	55.0	20.6	28.2
9	3168	12804	16.7		16.7	23.4	16.7	20.4
10	2640	11550	16.6		16.6	23.3	16.6	20.2
11	1320	12210	14.6		14.6	20.5	14.6	16.2
12	2640	13332	11.5		11.5	16.1	11.5	10
13	594	14388	14.9		14.9	20.9	14.9	16.8
14	2376	14388	16.6		16.6	23.3	16.6	20.2
15	726	10296	16.3	22	38.3	53.8	16.3	19.6
16	6072	3432	22.9		22.9	32.1	22.9	32.8
18	6072	2310	22.5	19.2	41.7	58.5	22.5	32
19	6006	462	16.3	22.2	38.5	54.0	16.3	19.6

20	5346	1716	11.8	39	50.8	71.3	39	65
21	5412	3168	23.5	12	35.5	49.8	23.5	34
22	5214	4554	26		26	36.5	26	39
23	6534	5148	24.7	12.9	37.6	52.8	24.7	36.4
24	3756	5082	27.9		27.9	39.2	27.9	42.8
25	2640	5082	28.3		28.3	39.7	28.3	43.6
26	3956	7326	12	23.3	35.3	49.5	12	11
27	4092	9042	30.3		30.3	42.5	30.3	47.6
28	5874	8910	23.3		23.3	32.7	23.3	33.6
29	6534	6930	28.5		28.5	40.0	28.5	44
30	8052	8118	39.3	17.7	57	80.0	39.3	65.6
31	3762	14190	8	39.1	47.1	66.1	39.1	65.2
irrig1	5082	11220				50.0		50
irrig2	6534	8910				50.0		50
house1	1980	10296				17.0		17
min	594	462			11.5	16.1	11.5	10
max	8052	14388			57	80.0	44.6	76.2

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