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

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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.

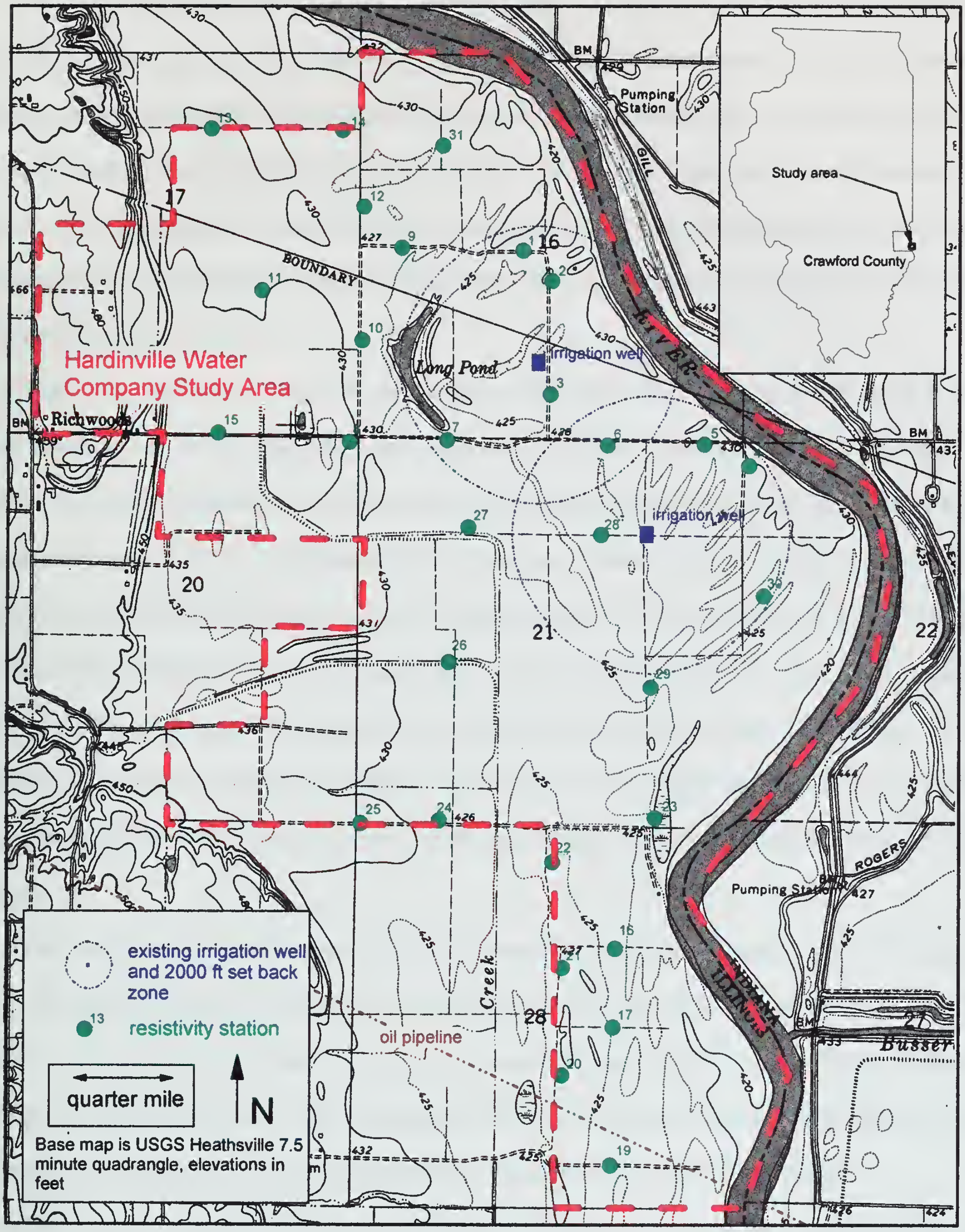


Figure 1. Location of study area and resistivity station.

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

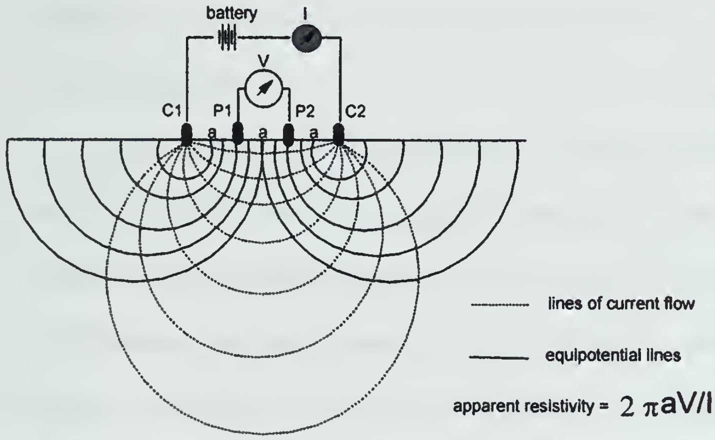


Figure 2. Schematic drawing of Wenner electrode configuration.

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).

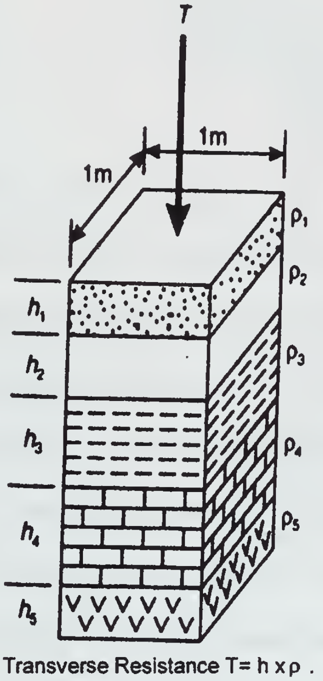


Figure 3. Schematic drawing of resistivity layers and parameters used to calculate transverse resistance.

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.

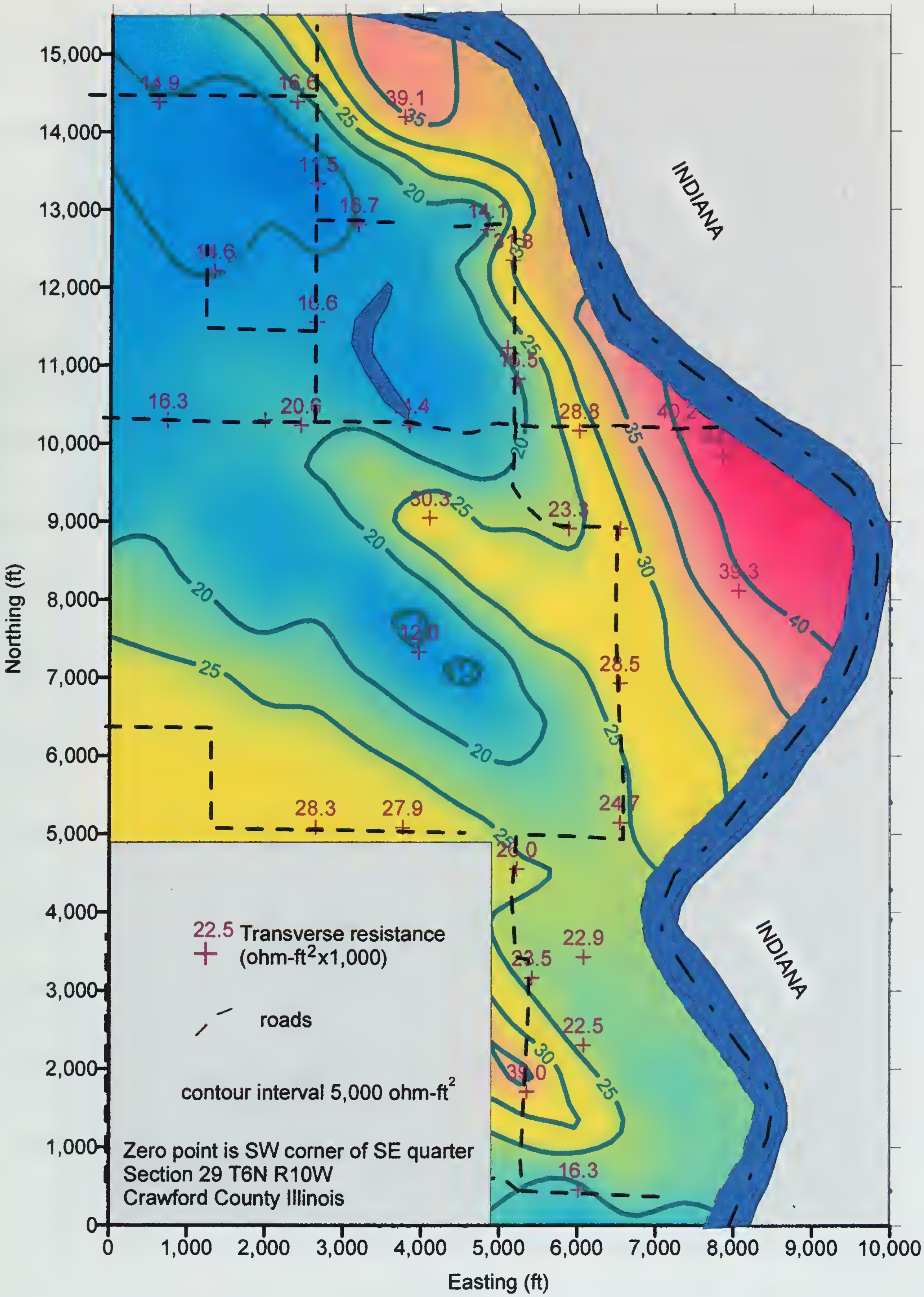
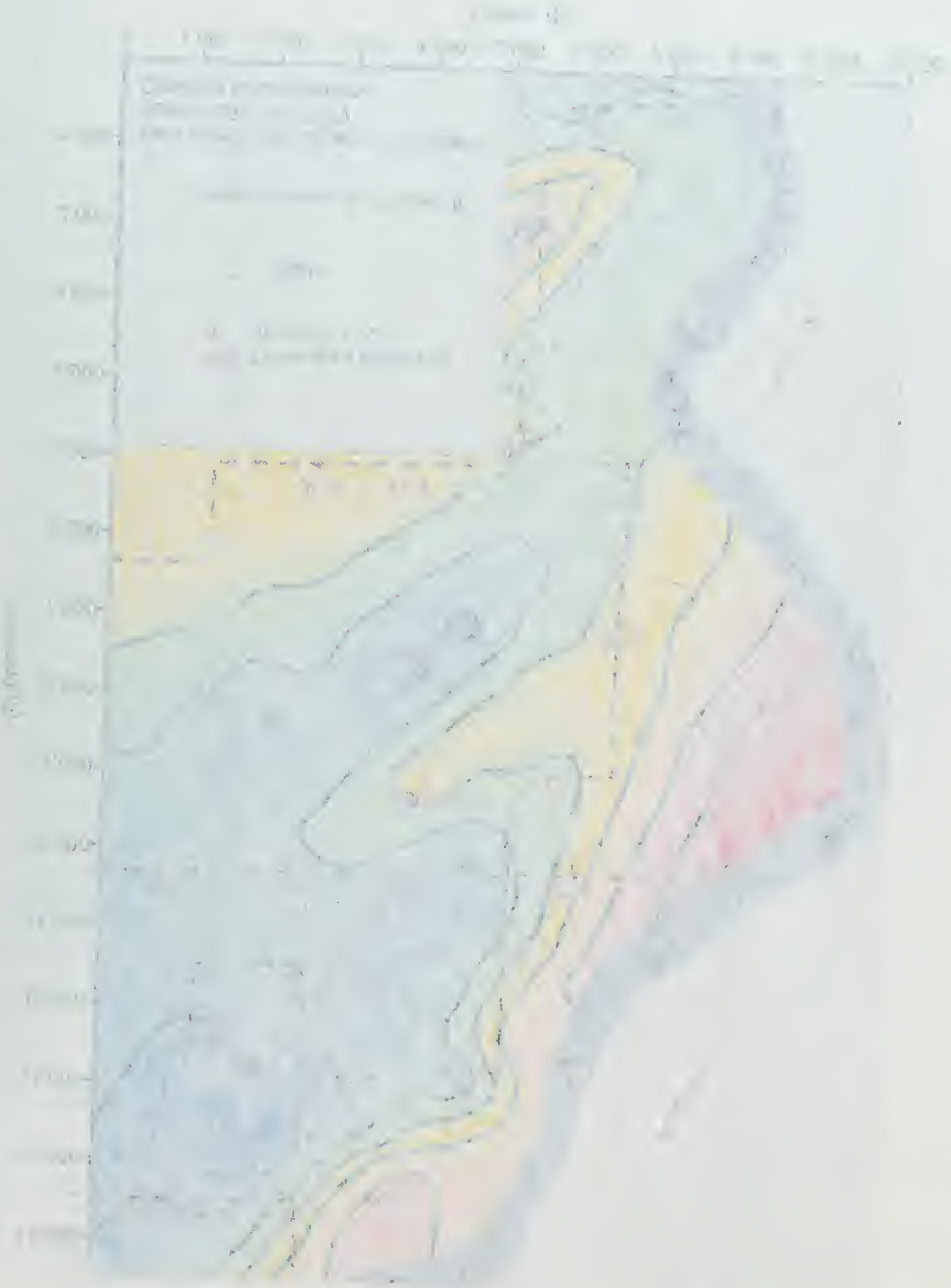


Figure 4. Transverse resistance of the primary layer.

Figure 4. [illegible]



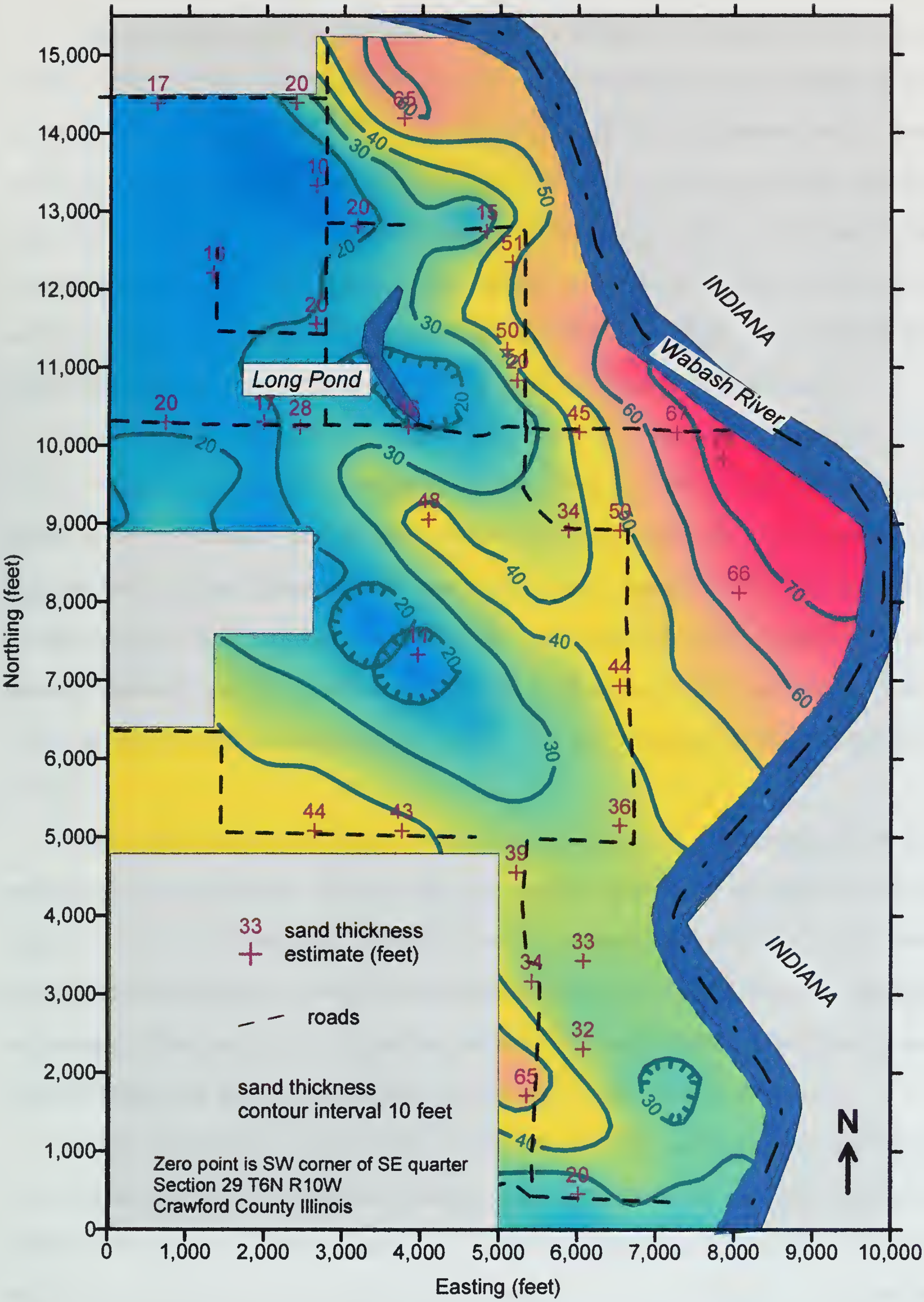
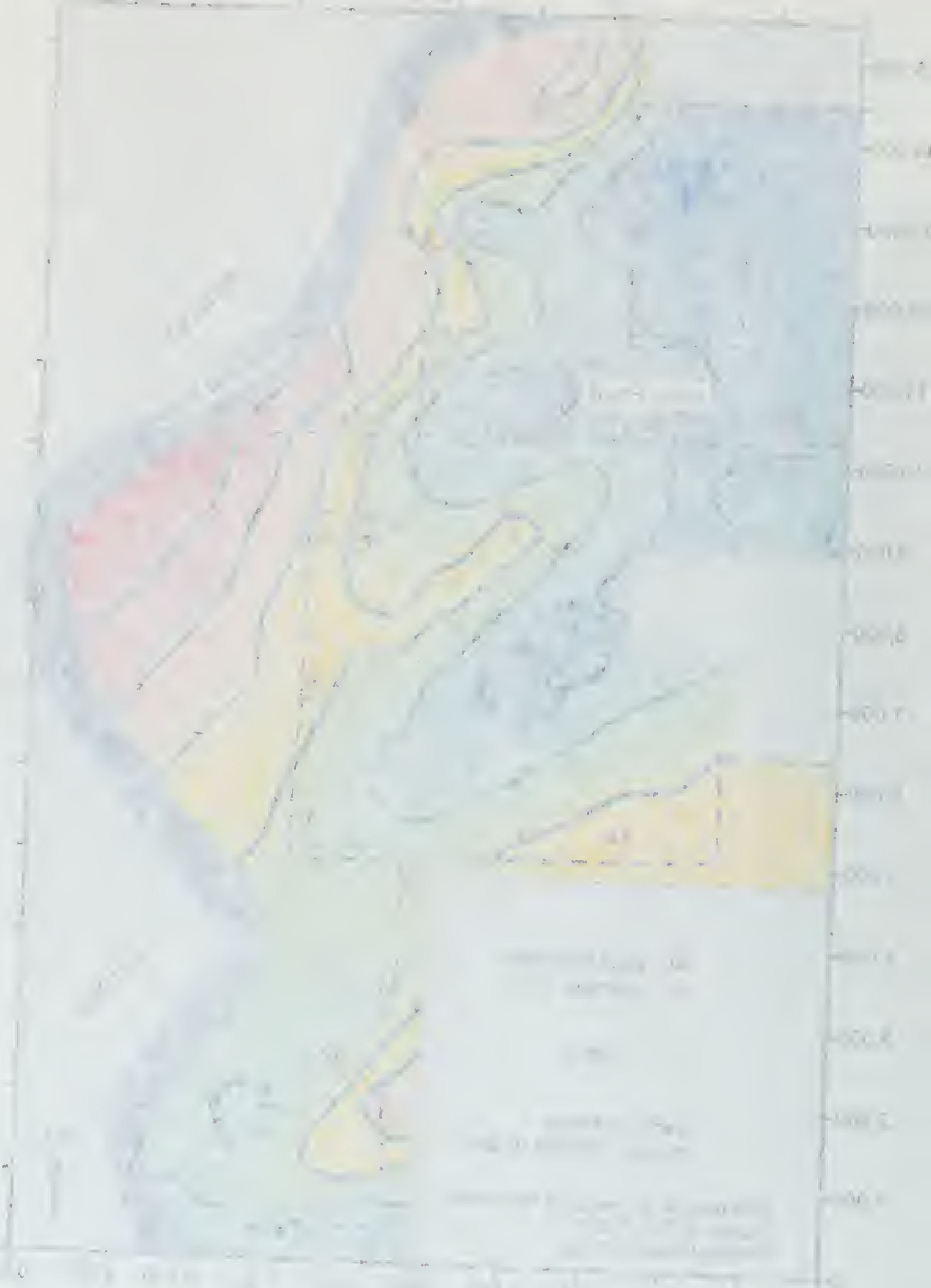


Figure 5. Estimated aquifer thickness.



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.

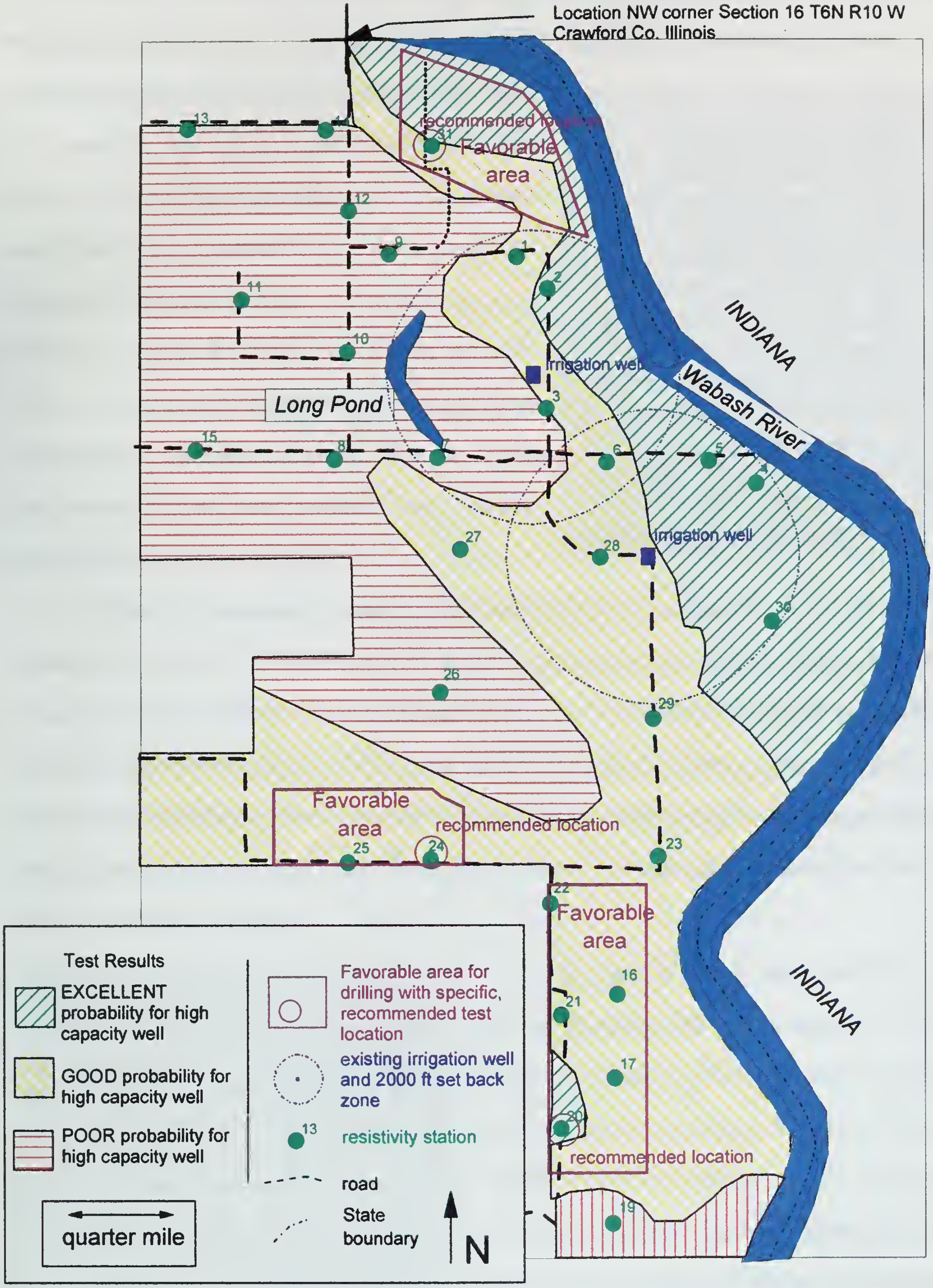


Figure 6. Relative probability for successfully installing a large capacity well, based on thickness of aquifer materials, showing areas recommnded for test drilling.

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