Aquifer Characterization and Drought Assessment Rock River Alluvial Aquifer

Iowa Geological and Water Survey
Water Resources Investigation Report 9

Iowa Department of Natural Resources
Chuck Gipp, Director
February 2014

Printed in-house on recycled paper.

Aquifer Characterization and Drought Assessment Rock River Alluvial Aquifer

Iowa Geological and Water Survey
Water Resources Investigation Report 9

Prepared by

Jason A. Vogelgesang

J. Michael Gannon

Deborah J. Quade

February 2014

Iowa Department of Natural Resources
Chuck Gipp, Director

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This investigation evaluated groundwater resources of the alluvial aquifer located adjacent to the Rock River. Recent drought conditions prompted this study and can have a dramatic affect on groundwater resources. The primary objective of this study was to evaluate the aquifer to aid in future water supply development. Existing geologic information combined with geophysical surveys and drilling were compiled to better understand the extent and thicknesses of coarse grained alluvium. Several hydrogeologic parameters were gathered to estimate well potential in the aquifer. The study can be referenced when considering future development or well field expansion.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of individuals assisting in the production of this report. Robert Rowden of the Iowa Geological and Water Survey (IGWS) completed a portion of the Rock River alluvial aquifer delineation, completed data collection and analysis, and assisted with geophysical and drilling field efforts. Huaibao Liu of the IGWS completed a portion of the Rock River alluvial aquifer delineation and completed data collection and analysis. Stephanie Tassier-Surine provided geophysical transect and drilling location contributions. Well locations used in the report were updated by Carolyn Koebel of the IGWS. The report layout and final editing were completed by Mindy Kralicek with the Iowa Department of Natural Resources.

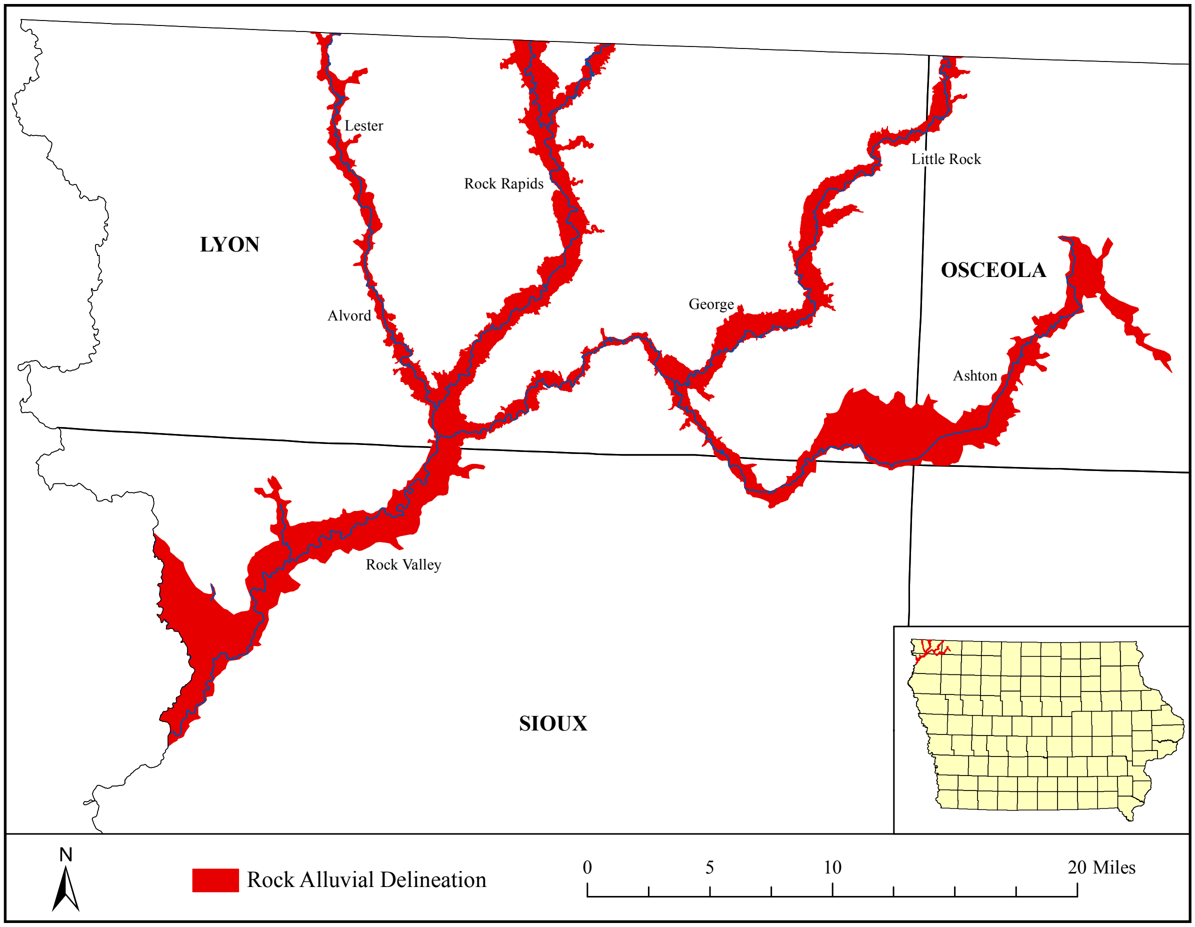


Figure 1. Extent of the Rock River alluvial aquifer study area.

INTRODUCTION AND HYDROLOGIC SETTING

The objective of this report is to evaluate groundwater resources of the alluvial aquifer located adjacent to the Rock River. Recent drought conditions prompted this study and can have a dramatic effect on groundwater resources. The evaluation summarizes geologic, hydrologic, and geophysical information and can be referenced when considering future development or well field expansion. In addition to the main branch of the Rock River, the study area also includes Mud Creek, Kanaranzi Creek, the Little Rock River, and Otter Creek (Figure 1). The Rock River and its tributaries are found in Lyon, O'Brien, Osceola, and Sioux counties. For the purposes of this summary report, the alluvial aquifer will be referred to as the Rock River aquifer.

CLIMATE

The climate of northwest Iowa is classified as sub-humid. Based on data compiled by Iowa State University (Mesonet, Iowa State University, 2013), the average annual precipitation in the four county study area ranges from 26 inches per year in Rock Rapids (Lyon County) to 28 inches per year in Sheldon (O'Brien County).

The study area has historically experienced moderate to severe droughts. Table 1 shows the minimum annual precipitation amounts

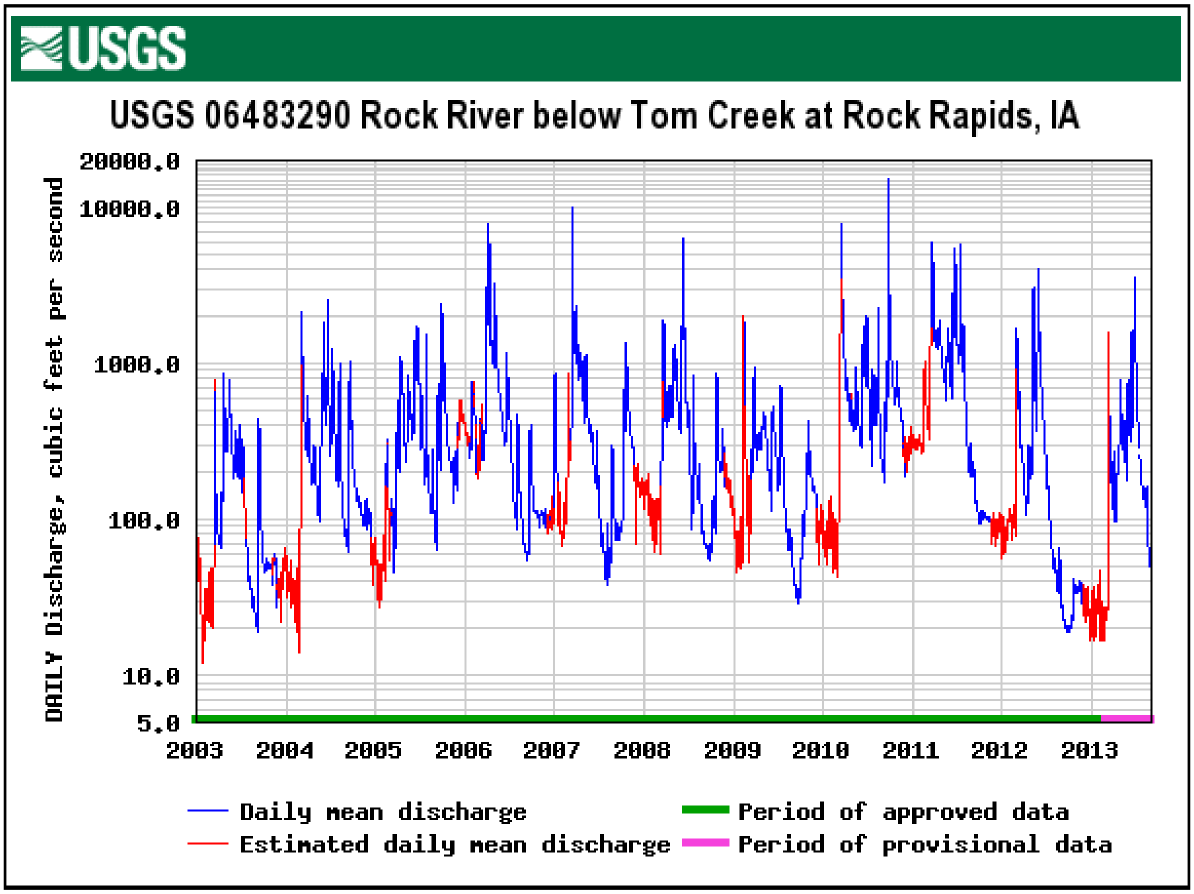


Figure 2. Daily average streamflow at USGS Rock Rapids gage (2003 to 2013).

for a select number of cities in the study area (Mesonet, Iowa State University, 2013). These minimum annual precipitation amounts range from 10.31 inches in Rock Rapids in 1974 to 15.41 inches in Sheldon in 1958.

SURFACE WATER

Two gaging stations operated by the United States Geological Survey (USGS) show streamflow trends over time in the study area. Average daily discharge over the last ten years in the Rock River near Rock Valley and Rock Rapids are shown in Figures 2 and 3. The lowest average daily discharge observed at the Rock Valley gage was 26 cubic feet per second (cfs) on January 26, 2003, as well as January 13, 2013. The lowest average daily discharge observed at the Rock Rapids gage was 12 cfs on January 26, 2003.

The Iowa Administrative Code (IAC) [567] Chapter 52.4 has rules that protect consumptive water users during moderate to severe droughts for rivers with watersheds greater than or equal to 50 square miles, which includes the Rock River watershed. These rules involve the concept of protective low-flow in streams and rivers. The protective low-flow value is defined as the discharge in cubic feet per

Table 1. Minimum annual precipitation for select communities along or near the Rock River.

Location	Minimum Inches (Year)
Rock Rapids	10.31 (1974)
Sibley	14.38 (1976)
Hawarden	13.85 (1976)
Sheldon	15.41 (1958)

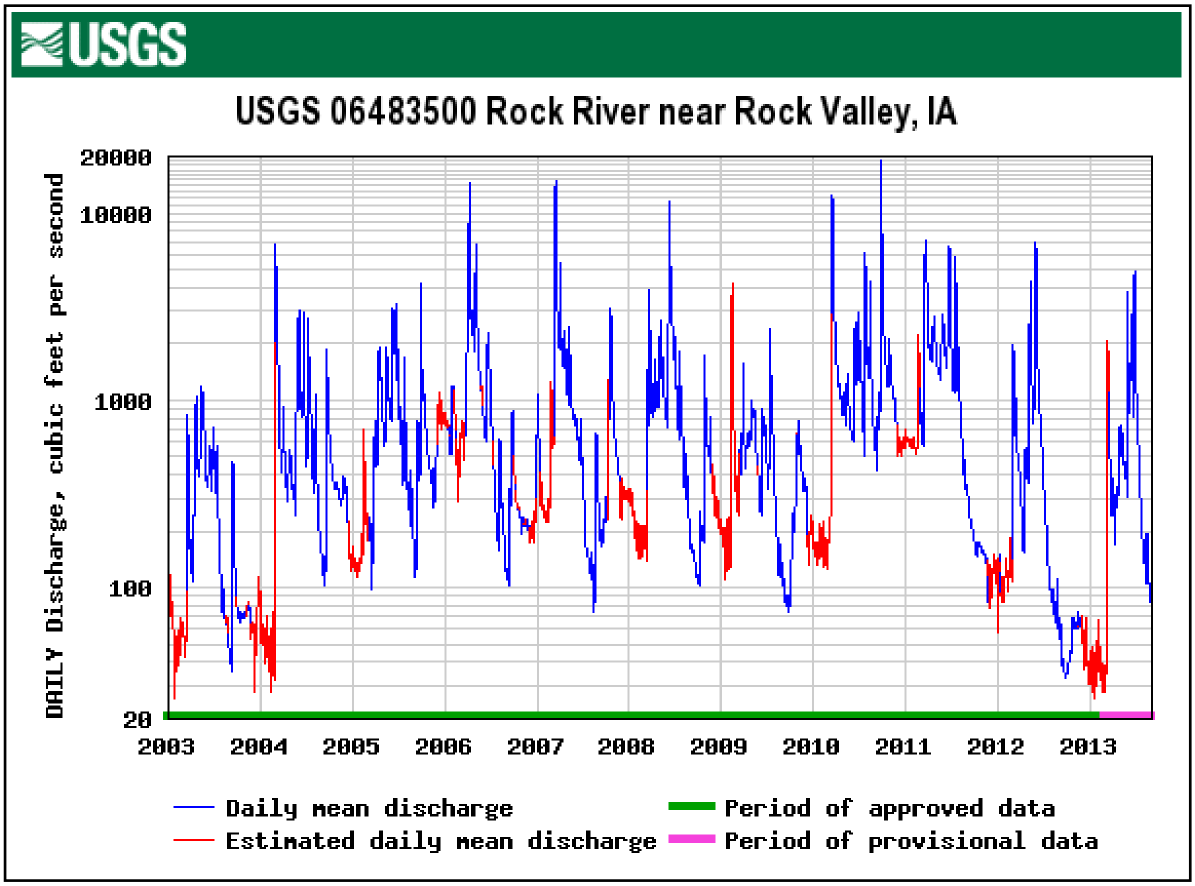


Figure 3. Daily average streamflow at USGS Rock Valley gage (2003 to 2013).

second that is equal to or exceeds this discharge 84 percent of the time over a certain period of time (generally 10 years or more). When streamflow measurements drop below the protective low-flow value, withdrawals from irrigation wells and surface water intakes within 0.125 miles from the river must cease pumping. The protective low-flow value for the Rock Valley gage is reported as 26 cfs (IAC [567] 52.8). No low-flow value is assigned for the Rock Rapids gage. The streamflow at the Rock Valley gage has fallen to 26 cfs twice in the past ten years, January 26, 2003, and January 13, 2013; but has not fallen below the protective low-flow threshold.

The 7Q10 value is defined as the lowest average flow for seven consecutive days that is expected to occur once over a 10-year period. When stream flow measurements drop below the 7Q10 value, withdrawals from irrigation wells within 0.25 mile from the river and irrigation intakes must cease pumping. The 0.125 mile low-flow zone and the 0.25 mile 7Q10 zone for the Rock River and its major tributaries were delineated using ESRI ArcGIS software. According to IGWS well files, a total of 18 wells were found within the protected low-flow zone and 19 wells were found in the 7Q10 zone. The wells found in each of these zones are listed in Table 2.

GEOLOGY

Geologic Setting

The study area (Figure 1) lies near the border of the Northwest Iowa Plains and the

Table 2. Wells found in the 1/8 mile and 1/4 mile buffers for protected low flow and 7Q10 streamflow values.

Water Use Permit Owner	Wells	Buffer Distance from River	Flow Restriction
Albert Van Zanten	2	1/4-mile	7Q10
Alvin Bleyenberg	1	1/4-mile	7Q10
Betty R Foreman	1	1/4-mile	7Q10
David Hansen & Dan Murphy	1	1/4-mile	7Q10
Debra Vant Hul	1	1/4-mile	7Q10
Gerald Van Grootheest	1	1/4-mile	7Q10
Gregory J & Shirley A Koenen	3	1/4-mile	7Q10
Huyser Farms	1	1/4-mile	7Q10
Jay Grevengoed	1	1/4-mile	7Q10
Jerome L Henningfeld	1	1/4-mile	7Q10
John C Kooima	1	1/4-mile	7Q10
Kirk Hulstein	1	1/4-mile	7Q10
Marion J Rus	1	1/4-mile	7Q10
Paul L Kats	1	1/4-mile	7Q10
Randy Kats - Home	2	1/4-mile	7Q10
Riverbottom Farms Inc	1	1/4-mile	7Q10
Rock Valley Golf Club	1	1/4-mile	7Q10
V&b Farms Inc.	2	1/4-mile	7Q10
Vant Hul Farm	1	1/4-mile	7Q10
Albert Groeneweg	1	1/8-mile	Low Flow & 7Q10
George Van Den Top	4	1/8-mile	Low Flow & 7Q10
Gerald Van Grootheest	1	1/8-mile	Low Flow & 7Q10
Gregory J & Shirley A Koenen	1	1/8-mile	Low Flow & 7Q10
Jay Grevengoed	1	1/8-mile	Low Flow & 7Q10
John Van Veldhuizen	2	1/8-mile	Low Flow & 7Q10
Kirk Hulstein	1	1/8-mile	Low Flow & 7Q10
Marion J Rus	1	1/8-mile	Low Flow & 7Q10
Phillip G Kooima	1	1/8-mile	Low Flow & 7Q10
Riverbottom Farms Inc	1	1/8-mile	Low Flow & 7Q10
Ron Van Veldhuizen	3	1/8-mile	Low Flow & 7Q10
Sioux County Conservation	1	1/8-mile	Low Flow & 7Q10
Steve Abma	1	1/8-mile	Low Flow & 7Q10
Tim R & Clarine Kooima	1	1/8-mile	Low Flow & 7Q10
V&b Farms Inc.	2	1/8-mile	Low Flow & 7Q10
Vande Vegte Farm	1	1/8-mile	Low Flow & 7Q10
Vant Hul Farm	1	1/8-mile	Low Flow & 7Q10
Wayne Davelaar	1	1/8-mile	Low Flow & 7Q10

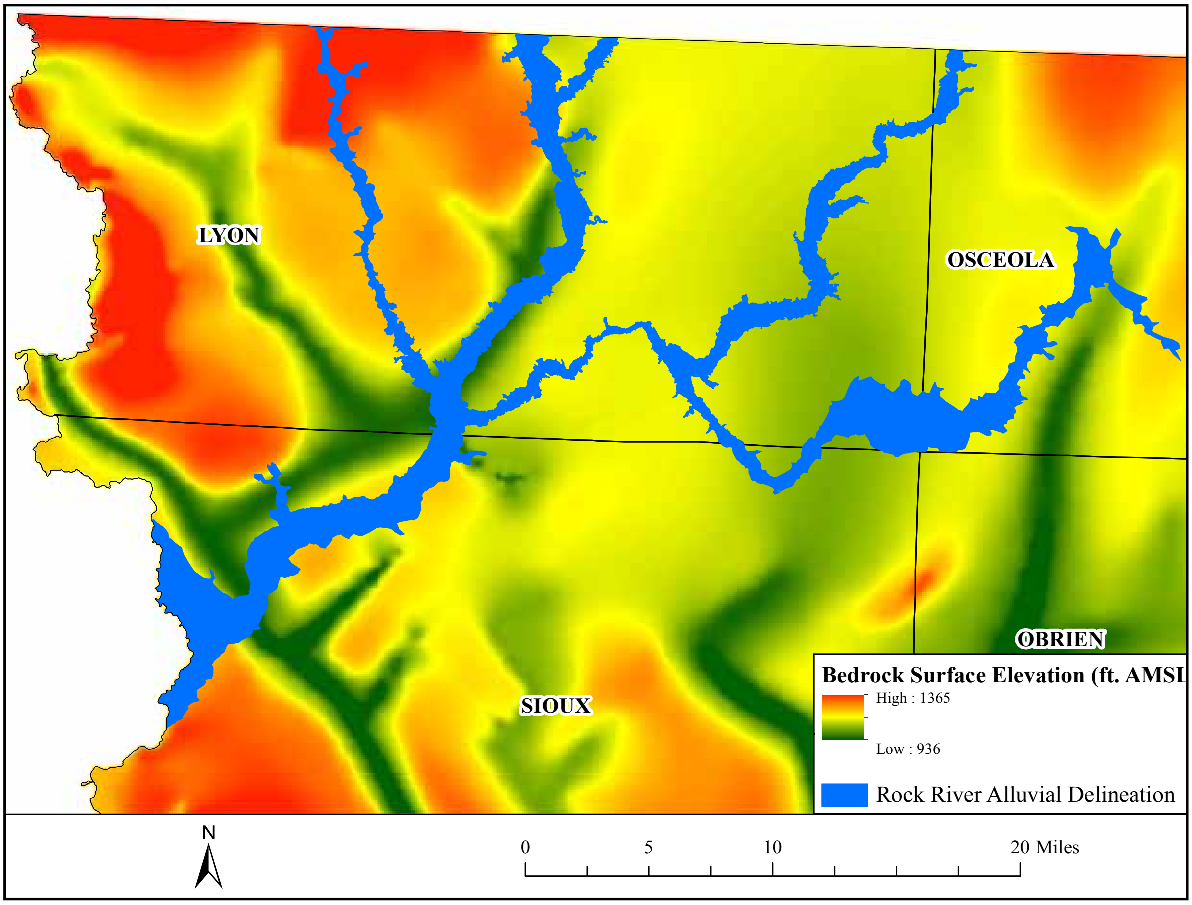


Figure 4. Bedrock surface elevation map showing bedrock highs (reds) and lows (greens).

Des Moines Lobe Landform Region. The bedrock surface consists of Cretaceous-age sedimentary rocks belonging to the Fort Benton Group. The primary lithologies are shales and mudstones to very fine to medium grained sandstones (Witzke, et al., 1997). Exposed bedrock is limited in the area. Figure 4 shows the bedrock surface elevation of the Rock River area. Bedrock channels exist in the study area and can also be seen in Figure 4. The bedrock surface is overlain by a thick mantle (approximately 300 feet) of Pre-Illinoian and Wisconsin-age glacial tills and alluvium.

The area has a complex geologic history punctuated by at least seven periods of glaciation between 2.2 million and 500,000 years ago during the pre-Illinoian Episode. More recent glacial activity most likely occurred between 38,000 and 24,000 years ago during the Wisconsin Episode and is often referred to as the Tazewell Advance and/or the Sheldon Creek Formation (Prior, 1991). The full extent of the Sheldon Creek Formation in the study area is still poorly understood. The level rolling topography is reminiscent of the Iowan Erosion Surface landscape in northeastern Iowa. All of northern Iowa was subjected to an intense period of cold from 21,000 to 16,500 years ago during the Wisconsin full glacial (Bettis, 1989). During that time, the landscape was dominated by permafrost and intense freeze and thaw activity coupled with stream action, slope wash, and wind deflation which likely resulted in the intensive erosion that formed

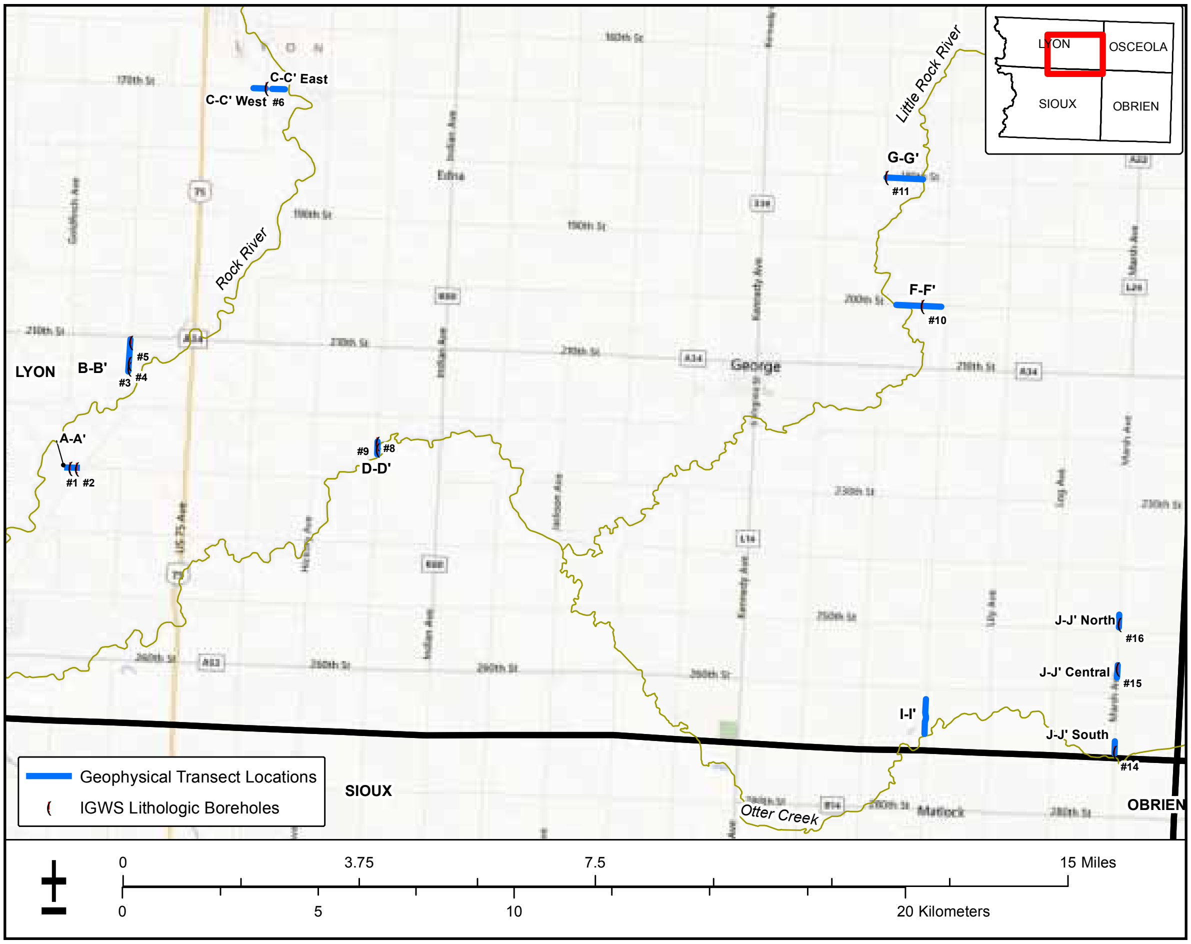


Figure 5. Locations of geophysical surveys and lithologic boreholes.

the muted low-relief landscape present today.

The nearby Des Moines Lobe Landform Region is the most recently glaciated area in the state and is the source area for the valleys of the Rock River and Little Rock River, as well as Otter Creek. The headwaters of all three streams start on the Bemis Moraine, the terminal moraine of the Des Moines Lobe (DML). The earliest advance of the DML age is dated at approximately 14,500 years ago and is the approximate age for all gravels encountered overlying the Sheldon Creek Formation. All three streams carried sediment-laden glacial meltwater (outwash) as they served as a drainage conduit for the DML glacier. All outwash deposits observed in the study area are identified as the Noah Creek Formation.

The Rock River outwash deposits range in thickness from 37 to 53 feet and vary in texture from loamy sand, matrix-supported pebble gravel, to pea gravel based on six borings that were collected along the Rock River (Figure 5). No loess mantled terraces were encountered in these borings. The Little Rock River outwash deposits range in thickness from 26 feet to 47 feet and vary in texture from medium pebbly sand to coarse gravel. Overall, the deposits along the Little Rock are not as coarse-grained as encountered in the Rock River borings. The Otter Creek deposits range in thickness from 16 feet to 20 feet and vary in texture from a loamy pebbly sand to a loamy coarse gravel.

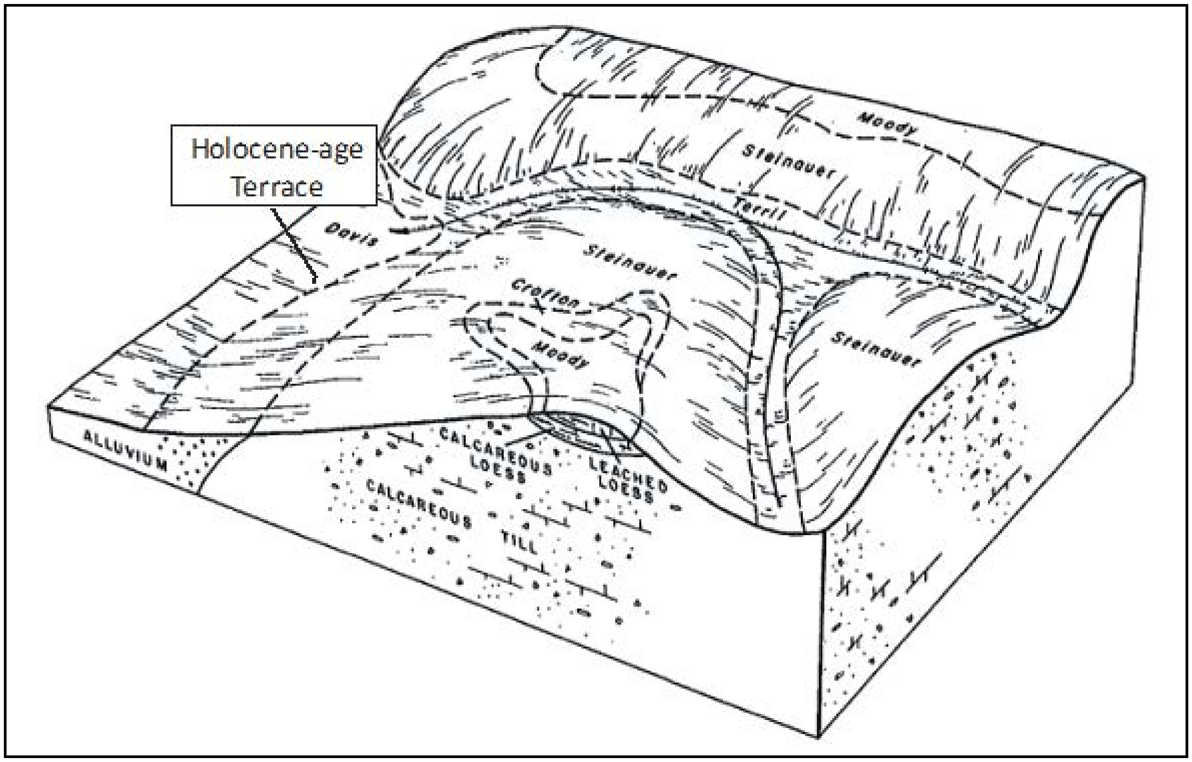


Figure 6. Block diagram representation of soil-geomorphic relationship of Holocene-age terraces to the adjacent uplands in northwest Iowa (modified from Soil Survey of O'Brien County, 1981).

The Otter Creek deposits appear to reflect several till advances and may represent the two advances of the Sheldon Creek Formation. More stratigraphic studies are warranted in this area to better determine the age of the underlying tills and the intervening gravel deposits. (See Appendix B for additional borehole information.)

Valley Geomorphic Setting

Hudson Episode Terraces

Hudson Episode terraces are adjacent to the modern day floodplain of the Rock, Little Rock, and Otter Creek valleys. The age of these terraces are 10,000 years or younger. Surface soils are silt loam or silty clay loam in texture and were most likely formed in reworked loess that had been deposited in the valleys. In the study area, these terraces are often mapped as the Davis, Spillco, Calco, or Colo soil series (Figure 6). Borings in these units consisted of as much as 13 feet of silt loam, silty clay loam, and heavy silty clay loam sediments overlying older Wisconsin-age sand and gravels.

Late Wisconsin-age Terraces

Late Wisconsin-age terraces are located at a slightly higher elevation above the modern day floodplain of the Rock, Little Rock, and Otter Creek valleys. The age of these terraces is approximately 14,500 years old and related to the terminal advance of the Des Moines Lobe. Surface soils are mapped as Dempster or Estherville and can vary from loam to sandy loam in texture. These soils are developed in the underlying Late Wisconsin-age sand and gravels (Figure 7).

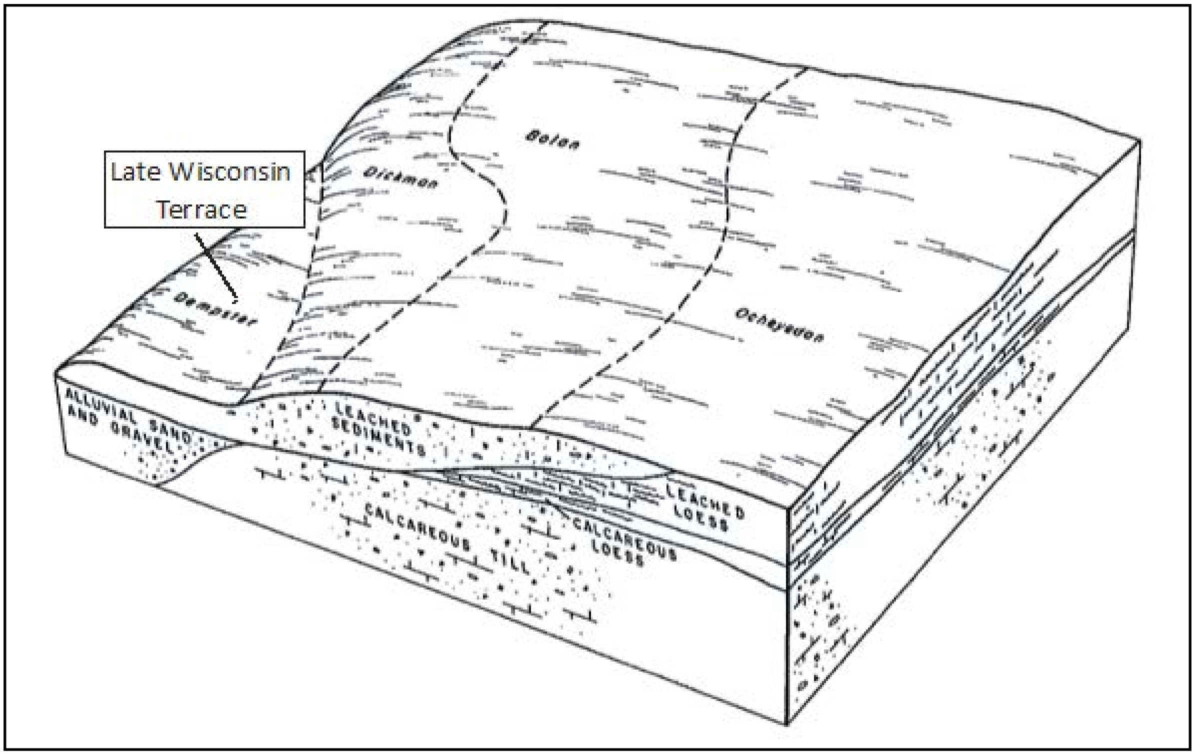


Figure 7. Block diagram representation of soil-geomorphic relationship of Late Wisconsin-age terraces to the adjacent uplands in northwest Iowa (modified from Soil Survey of Lyon County, 1978).

Loess-Mantled Wisconsin-age Terraces

Loess-mantled Wisconsin-age terraces were identified at a higher elevation above the modern day floodplain in the Little Rock and Otter Creek valleys. These terraces are mantled with a non-effervescent loess cap (5 to 6 feet) and are related to the drainage of an earlier Wisconsin glacial advance (Sheldon Creek Formation). Surface soils are mapped as Galva stratified substratum and often are mapped as a bench phase (Figure 8). The soil texture is a silty clay loam to silt loam, which developed in the underlying Wisconsin-age loamy pebbly sand unit. This unit is referred to as “unnamed loamy sediments” and is correlative to loamy sediments observed on the Iowan Erosion Surface in eastern Iowa. Underlying this unit is a non-effervescent silty to sandy clay loam unit which may correlate with the Farmdale Paleosol/Pisgah Formation or a post Farmdalian period of stability on the landscape roughly 16,500 years ago. In places, this unit overlies the Sheldon Creek Formation glacial till and can also overlie outwash related to the Sheldon Creek Formation. The study area has a fairly complex recent history (38,000 years to the present) and a more thorough geologic investigation is warranted to address stratigraphic details in the study area.

Regional Stratigraphic Units

The stratigraphic framework of northwest Iowa consists of materials from the pre-Illinoian, Wisconsin, and Hudson episodes (Figure 9). The underlying surficial units found in the study area include pre-Illinoian till, Wisconsin-age till, Wisconsin-age outwash, and Wisconsin-age loess. Pre-Illinoian materials

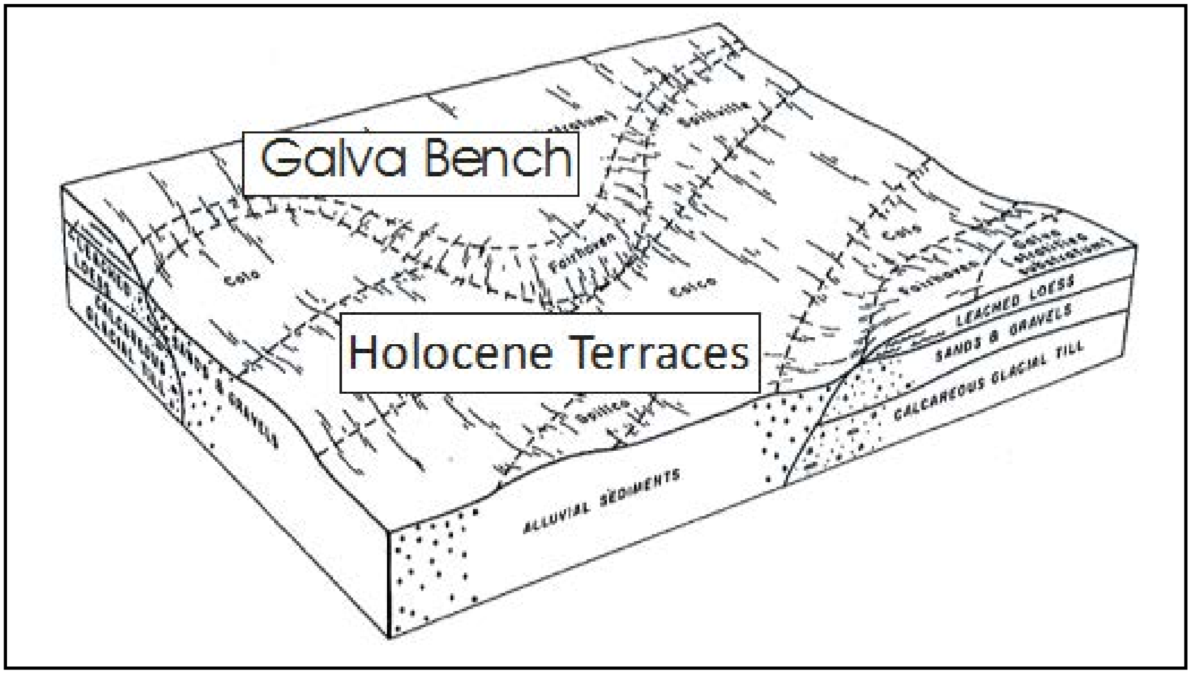


Figure 8. Block diagram representation of soil-geomorphic relationships of Wisconsin-age loess mantled terraces (Galva Bench) to the adjacent uplands in northwest Iowa (modified from Soil Survey of O'Brien County, 1981).

are composed of glacial tills of the A, B, and C tills as well as the intervening paleosols and unnamed sand and gravel units (Bettis, 1990). Overlying the pre-Illinoian materials is the Sheldon Creek Formation which is composed of at least two glacial tills and intervening sand and gravel bodies. The Sheldon Creek is an undifferentiated unit at this time.

The studied stream valleys are filled with the Wisconsin Episode outwash deposits of the Noah Creek Formation. These outwash deposits overlie Wisconsin and pre-Wisconsin-age glacial till. The sedimentology and stratigraphy of these deposits indicate they were deposited in aggrading braided streams that carried glacial meltwater from ice-marginal sources. Bedload varied from massive to crudely planar-bedded gravels, to coarse-grained pebbly sand low-amplitude channel fills.

Northwest Iowa is mantled by Wisconsin Episode loess deposits of the Peoria Formation. These materials may overlie glacial till, Wisconsin-age alluvium, or unnamed erosion surface sediments. The Peoria Formation includes wind-blown materials and two facies are recognized: a silt facies (loess) and a sand facies (eolian sand). Materials are well-sorted, may be interbedded and range in texture from silt to medium sand. The Peoria Formation is time-transgressive, with deposition occurring between approximately 23,000 and 11,000 Radio Carbon Years Before Present (RCYBP) (Bettis, 1989). Loess deposition was most rapid from about 21,000 to 16,000 years ago during the period of intense cold associated with the Iowan Surface.

The Pisgah Formation originated as eolian silt and was altered by a combination of colluvial hillslope processes, and pedogenic and periglacial processes. The Pisgah ranges in texture from silt loam (loess) to loamy sand and includes loess, colluvium, slope deposits and mixing zone materials. The Pisgah Formation was previously referred to as the "basal

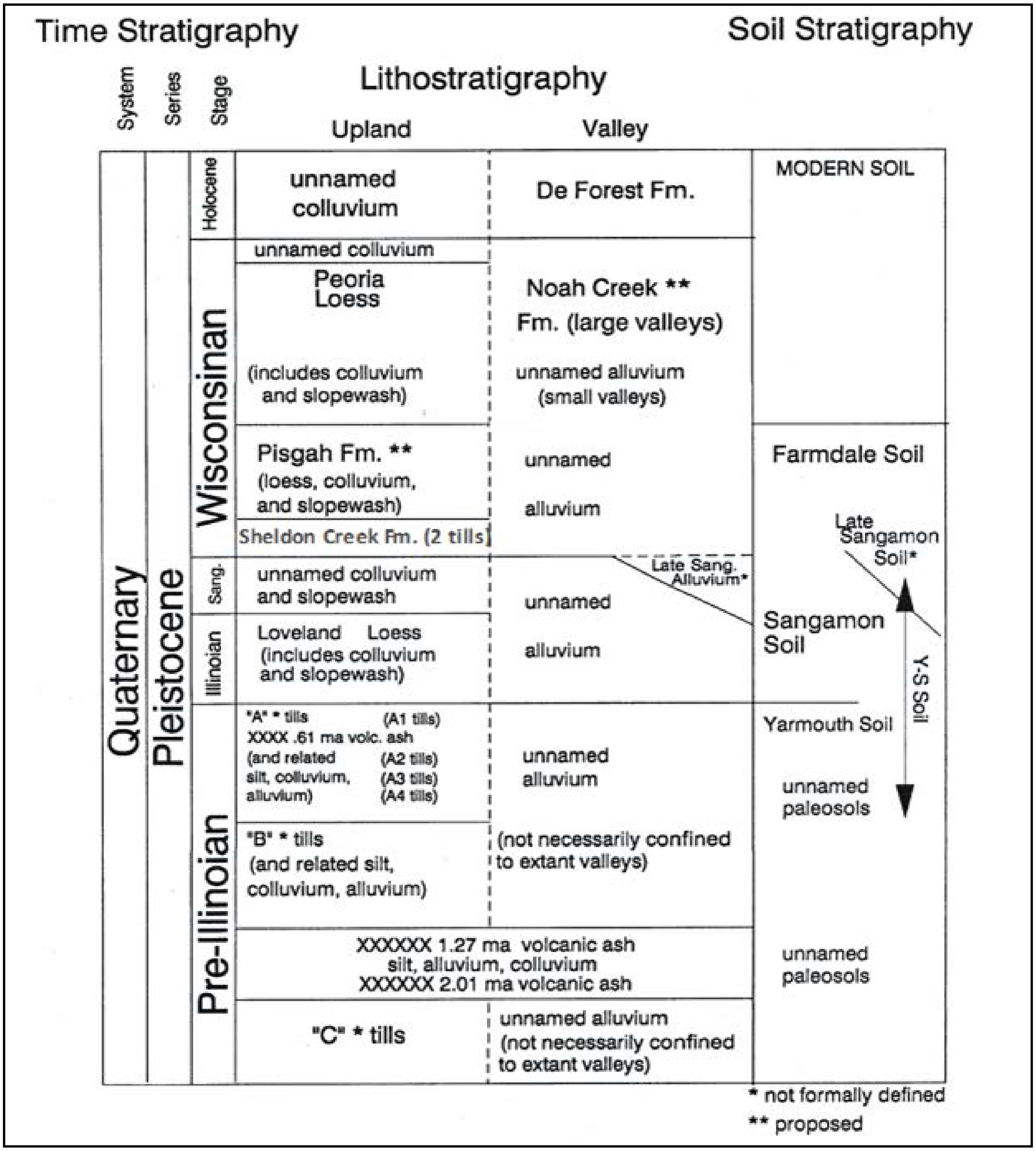


Figure 9. Generalized Pleistocene stratigraphic framework for western Iowa (modified to include northwest Iowa, from Bettis, 1990).

Wisconsin loess," or the "basal Wisconsin sediment," and is the stratigraphic equivalent of the Roxanna Silt of Illinois and the Gilman Canyon Formation of Nebraska, although the lithologic properties vary (Bettis, 1990). Pedogenic alteration at its base has resulted in its incorporation with the underlying Sangamon Geosol. The Pisgah Formation is typically much

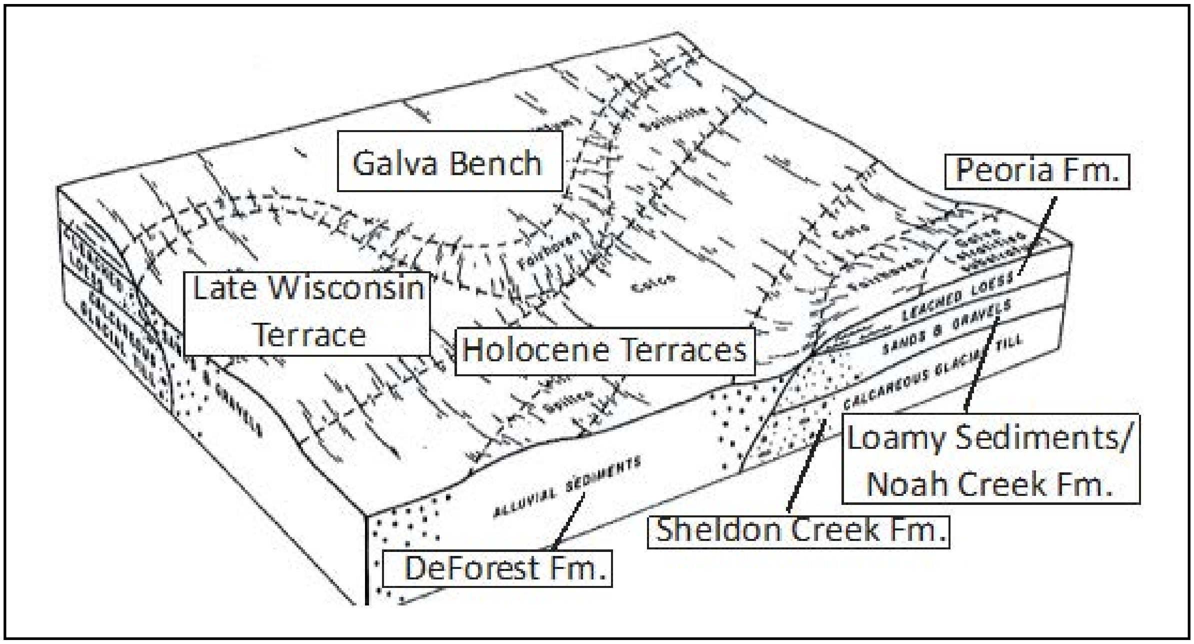


Figure 10. Block diagram representation of soil-geomorphic and underlying stratigraphic relationships of Holocene and Wisconsin- age terraces to the adjacent uplands in Northwest Iowa (modified from Soil Survey of O'Brien County, 1981).

thinner than the Peoria Formation and has the Farmdale Geosol developed in its surface. The Pisgah Formation was deposited between approximately 30,000 and 24,000 RCYBP (Bettis, 1989). However, more recent studies have identified Farmdalian-like geosols that may be as young as 16,500 RCYBP.

The Farmdale Geosol is an interstadial soil that represents a brief period of landscape stability during the Wisconsin glacial. It is expressed as a thin, dark grayish brown buried soil, and commonly contains charcoal. Periglacial activity has often altered the contact resulting in a discontinuous or mixed horizon. The Farmdale is widespread throughout the Midwest and is commonly identified in Illinois and Indiana (Hall and Anderson, 2000). Dates for the Farmdale Geosol range from 28,000 to 16,500 RCYBP (Bettis, 1989). Figure 10 offers a more complete understanding of the soil-geomorphic and stratigraphic relationships among terraces of Wisconsin and Holocene age and the surrounding uplands.

AQUIFER THICKNESS

A sand and gravel thickness map (Figure 11) was completed for the Rock River alluvial aquifer to provide a general understanding of where groundwater resources are located and how those resources vary across the aquifer. The aquifer consists of sand and gravel deposited by the modern river system and is highly variable in both thickness and grain size. Determining variability can be helpful in finding regions with the most groundwater potential.

Existing data from 150 drilling logs, lithologic logs (strip-logs), bridge boring files, and geophysical surveys were compiled and analyzed to estimate sand and gravel thicknesses shown in Figure 11. The locations of all existing information were confirmed before use. The sand and gravel is overlain by fine-grained sediments that consist of clay, silt, and silty-sand. These finer grained sediments range in thickness from 0 to 25 feet with an average thickness of 6 feet.

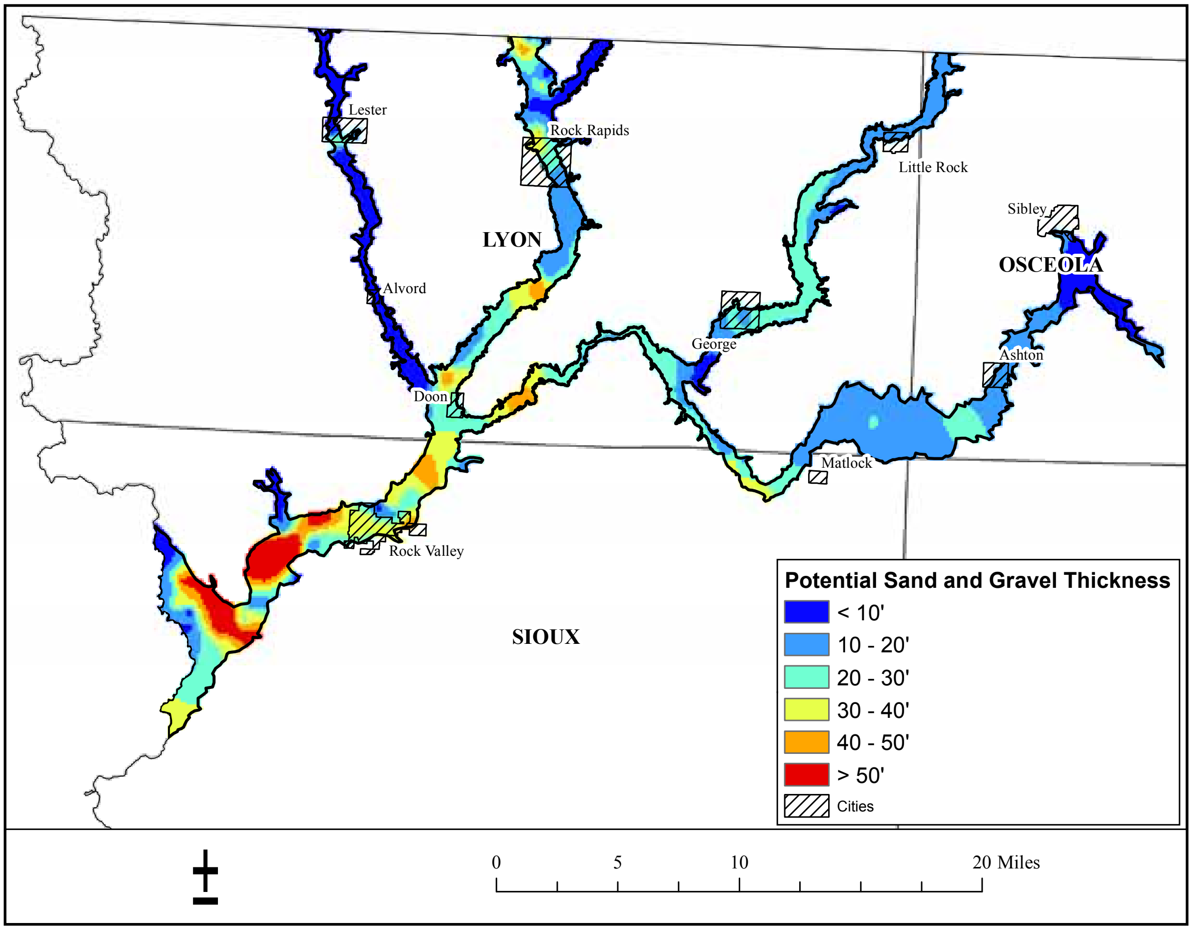


Figure 11. Potential sand and gravel thickness in the Rock River alluvial aquifer.

HYDROGEOLOGY

Assuming groundwater table conditions are a reflection of the ground surface, regional groundwater flow is toward the Rock River and its tributaries in a general southerly and westerly direction. The Rock River is a gaining stream during most of the year. Exceptions to this occur during high river stage when temporary bank storage may cause a transient reversal in flow direction, and near high capacity wells where pumping stress may reverse the groundwater flow direction and create induced recharge from the river into the aquifer. Groundwater recharge sources are precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall.

In northwest Iowa much of the groundwater recharge occurs in the early spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of precipitation events and when they occur seasonally.

Water Storage and Availability

Based on a surface area of the Rock River aquifer of approximately 3.1 billion square feet, an average saturated aquifer thickness of 25 feet, and a specific yield of 0.15, approximately 87 billion gallons of groundwater is stored in the Rock River aquifer. Not all of this storage is available for use, and the drawdown is not uniform across the entire aquifer. If we assume that most wells in the Rock River aquifer have average screen lengths of 10 feet (15 feet of saturated sand and gravel is available for drawdown), the total volume of groundwater available from storage would be approximately 52 billion gallons.

A groundwater study conducted by the Iowa DNR in 2006 calibrated an average annual groundwater recharge of 6 inches within the alluvium along the Rock River in Sioux County (Gannon, 2006). At the average recharge rate of 6 inches per year in the Rock River alluvium, approximately 12 billion gallons per year (bgy) of water would recharge the aquifer. If we classify a severe drought as half the annual precipitation (Gannon, 2006) and we assume this corresponds to an estimated recharge of 3 inches per year (half the normal recharge), approximately 6 bgy of precipitation recharge enters the aquifer during a severe drought. Much of this recharge is removed from the aquifer through river baseflow and evapotranspiration. The actual rate of groundwater discharged into the Rock River and the induced recharge (created by pumping stress) from the Rock River would need to be quantified using hydrographs, analytical methods, or numerical modeling methods.

Total current water usage for the study area, not including private wells, is estimated at 3.4 bgy (Iowa DNR GIS Library). The volume of induced recharge provided by the Rock River is unknown but would significantly add to the total recharge. Local pumping stress can also affect groundwater availability. The application of a calibrated groundwater flow model may help evaluate the local water balance concerns.

Wells

Forty-nine active public wells were located within the model area and include four community systems (DNR GIS Library). The locations of the public wells within the aquifer are shown in Figure 12. In addition to the public wells, there are approximately 46 water-use wells that are used for ethanol production, irrigation, and livestock. Annual water-use was obtained from the Iowa DNR water-use database and is listed in Table 3. If more than one well is used, the reported value reflects a combined total for all wells.

Pump Test Results

Hydraulic properties are used to define and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Nine aquifer pump test results were found in the Rock River alluvial aquifer and their results are shown in Table 4. Pump tests were completed near the cities of Doon, George, Rock Rapids, and Rock Valley.

In addition to the aquifer pump tests, a total of 22 specific capacity tests were made available by various consultants, well drillers, and communities. The locations of these tests are shown in Figure 13. Table 4 lists the pump test results for each test, the method of analysis, transmissivity values, aquifer thickness, and hydraulic conductivity values. Original data and graphs of three pump tests are found in Appendix A. The remaining six pump tests were analyzed by IGWS staff and entered in databases, but the graphs and raw data could not be located. The hydrogeologic parameters from these tests are included in Table 4.

Hydraulic conductivity values indicate the rate at which water can move through a permeable medium. Hydraulic conductivity was estimated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity in the Rock River alluvial aquifer was found to range from 35.8 to 810 feet/, with an arithmetic mean of 249 feet/day.

Transmissivity values indicate the rate at which water is transmitted through the aquifer when considering factors such as the hydraulic

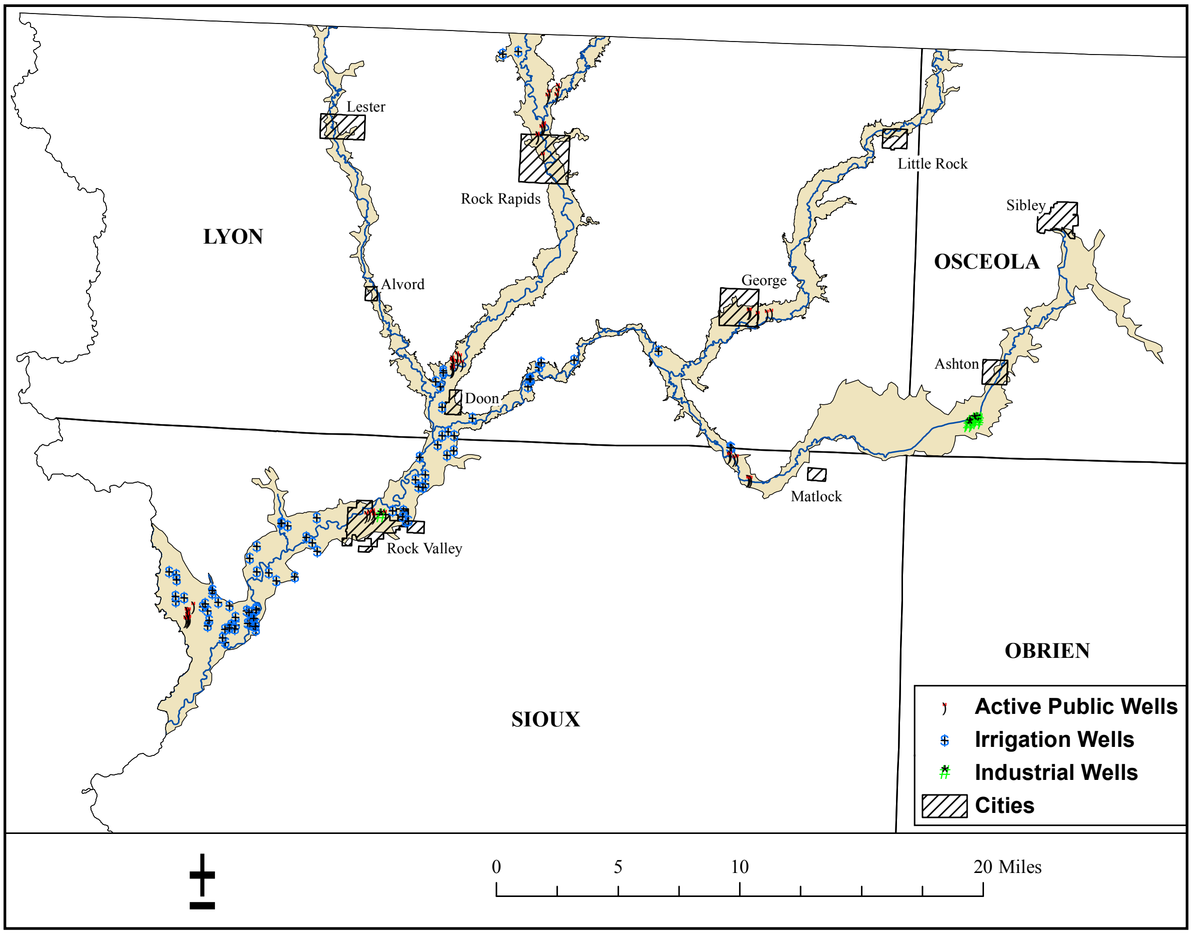


Figure 12. Location of active production wells in the Rock River alluvial aquifer.

gradient and aquifer thickness. Based on aquifer test results, the transmissivity of the Rock River aquifer was found to range from 1,110 feet^2/day at the City of Rock Valley well #3 to 21,700 feet^2/day at Rock Valley Rural Water District well #2. Based on available data, the arithmetic mean transmissivity value was estimated to be 6,550 feet^2/day. The regional transmissivity distribution is shown in Figure 14, and was based on multiplying the average hydraulic conductivity value of 249 feet/day by the aquifer thickness (Figure 11).

Estimated Well Yield

The potential well yield was estimated by converting the transmissivity value (Table 4) to specific capacity, and multiplying this by one-half of the saturated sand and gravel thickness (average value of the available head in the Rock River aquifer). The potential well yield distribution is shown on Figure 15. Potential well yields greater than 800 gallons per minute (gpm) are found near the cities of Doon, Rock Rapids, and Rock Valley.

GEOPHYSICAL INVESTIGATIONS

Field Data Collection

A geophysical investigation was conducted to gather additional information related to aquifer characteristics at select sites in the study area. An Advanced Geosciences Inc. (AGI)

Table 3. Permitted and reported water use for public, industrial, and irrigation wells in the Rock River alluvial aquifer.

Owner	Permit Usage (mgy)	2012 Actual Usage (mgy)
Albert Groeneweg	53.1	0.0
Albert Van Zanten	46.9	3.4
Alvin Bleyenberg	44.0	23.9
David Hansen	97.8	46.7
Debra Vant Hul	128.7	50.1
Elmer Van Den Top	46.3	29.4
George Van Den Top	35.8	0.0
George, City of	60.0	42.6
Gerald Van Grootheest	32.6	19.5
Gregory J & Shirley A Koenen	79.3	46.1
Hoogendoorn Farms Ltd	316.1	326.1
Huyser Farms	73.3	1.5
James Jespersen Farm	32.6	0.0
Jay Grevengoed	88.0	74.5
Jbh Groeneweg Site 1	56.0	0.0
Jerome L Henningfeld	49.9	32.7
John C Kooima	78.9	73.3
John Van Veldhuizen	94.5	0.0
Kirk Hulstein	78.2	24.8
Larry Van Veldhuizen	35.8	40.6
Laurence Vant Hul	48.9	13.0*
Lyon-Sioux Rural Water System	955.0	629.7
Marion J Rus	52.1	26.2
Mark Vant Hul	26.1	24.5
Marvin Vonk	37.5	36.1
Otter Creek Ethanol, Llc Dba Poet Biorefining - Ashton	345.0	123.8
Otter Valley Country Club	13.0	1.4
Phillip G Kooima	26.1	22.2
Pork Xtra Llc	156.4	65.4
Randy Kats - Home	97.8	28.2
Ranschau Brothers	44.0	46.0*
Riverbottom Farms Inc	24.4	34.6
Rock Rapids, City of	560.0	259.6
Rock Valley Comm School-W1448	6.5	1.8
Rock Valley Rural Water District	1,940.0	810.3
Roger Miller	74.9	35.0
Rural Water System No 1 (hudson Well)	593.0	0.0
Rural Water System No 1 (winterfeld)	19.6	0.0
Sioux County Conservation	65.2	0.0
Steve Abma	52.1	72.0
Tim R & Clarine Kooima	84.7	37.8
V Murlyn Wennblom	53.8	59.9
Van Veldhuizen Ron	29.3	14.9
Vande Vegte Farm	25.1	16.2
Vande Vegte Farm, Inc	26.1	0.0
Vant Hul Farm	34.2	0.0
Vink Farm	13.0	6.8
Wayne Davelaar	42.4	0.0
Wesley Kats Farm	52.1	31.5
Westra Farms Inc	52.1	0.0
Totals	6,837	3,158
**2011 value used*		

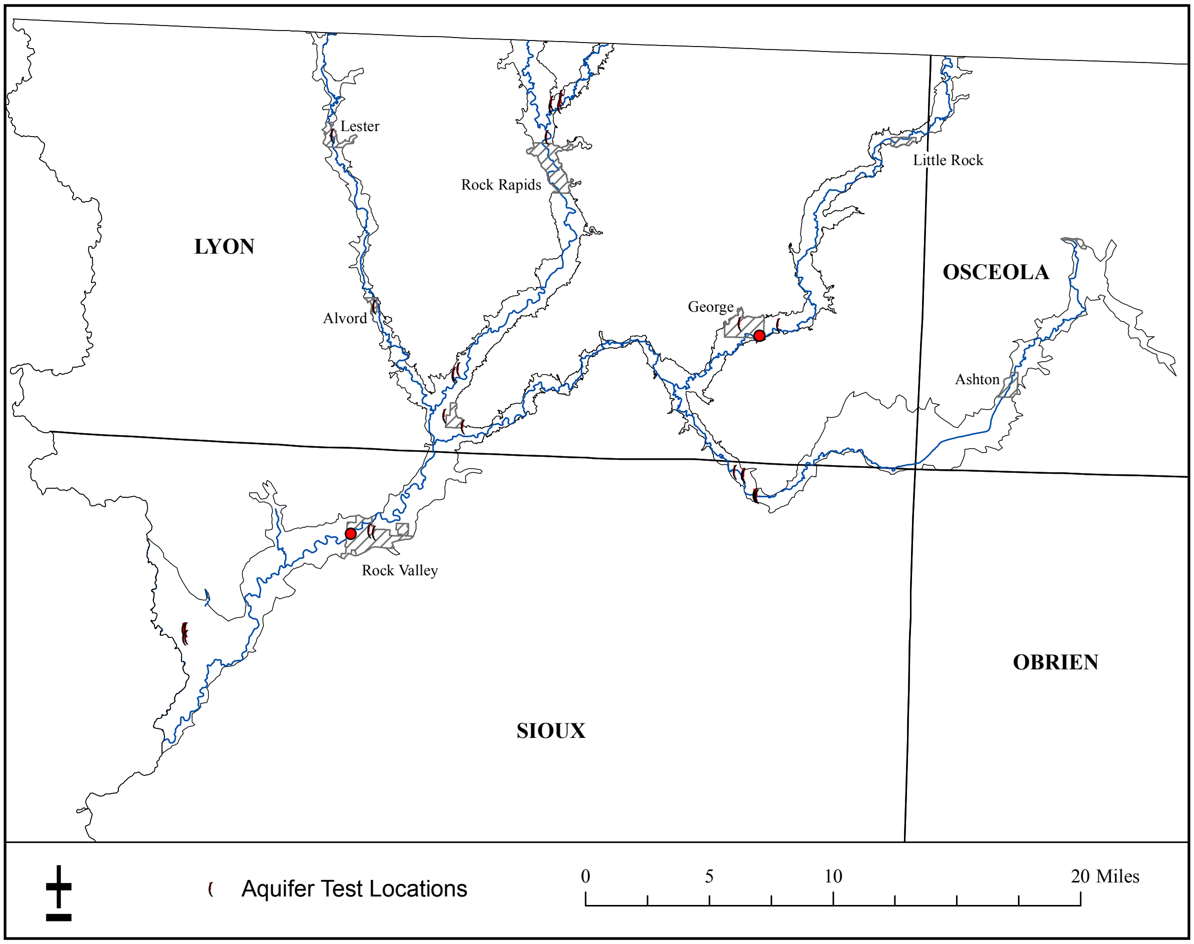


Figure 13. Locations of aquifer tests in the Rock River alluvial aquifer.

SuperSting R8, 8-channel electrical resistivity (ER) meter was used to collect all geophysical measurements. Field measurements were obtained by introducing a direct current into the ground through current electrodes and measuring resulting voltages through multiple potential electrodes. An array of 56 stainless steel electrode stakes were spaced approximately 20 feet apart, driven approximately one foot into the ground, and connected via electrode cables and a switch box to a central ER meter.

Eleven surveys were completed in October, 2012. Transect locations (Figure 5) were prioritized based on areas with insufficient well data, relatively higher aquifer usage, and were located such that a drill rig could gain access to ground truth results. A total of 15,511 individual resistivity measurements were collected.

Field data were obtained using dipole-dipole configurations; chosen to maximize data collection by utilizing all channels to acquire data. Measure time was set at 3.6 seconds and measurements were stacked (averaged) twice, unless the standard deviation of all channels was less than 2 percent. In this case, a third and possibly fourth measurement were taken and included in the average. To quantify error, overlapping data were collected in areas already covered by normal measurement. Reciprocal data were collected to further quantify error. Data were collected in "roll-along"

Table 4. Aquifer pump test results for wells open in the Rock River alluvial aquifer (methods based on Freeze and Cherry, 1979).

Well Number	Well Name	Well Depth (ft.)	Saturated Thickness (ft.)	Date	Method	Transmissivity (ft.^{2}/day)	Hydraulic Conductivity (ft/day)
35299	Alvord, City Of #2	38	21	Unknown	Specific Capacity	1320.00	62.86
36966	Boyden, City Of #1 (3)	36	10	Unknown	Specific Capacity	4000.00	400.00
36965	Boyden, City Of #2 (4)	29	19	Unknown	Specific Capacity	3210.00	168.95
39370	Doon, City Of #3	35	24	Unknown	Specific Capacity	4166.00	173.58
30242	Doon, City Of #4 (6)	60	25	Unknown	Specific Capacity	7150.00	286.00
39918	George, City Of #2	30	24	6/1/1973	Pump Test	2688.00	112.00
40606	Lester, City Of #2	31	24	Unknown	Specific Capacity	1920.00	80.00
37770	Lyon-Sioux RWS - Boyden #2 (4)	41	31	Unknown	Specific Capacity	9000.00	290.32
64318	Lyon-Sioux RWS - Otter Creek #1 (7)	38	31	Unknown	Specific Capacity	7140.00	230.30
64316	Lyon-Sioux RWS - Otter Creek #2 (5)	43	36	Unknown	Specific Capacity	5260.00	146.10
64317	Lyon-Sioux RWS - Otter Creek #3 (6)	40	33	Unknown	Specific Capacity	4166.70	126.20
56787	Lyon-Sioux RWS Doon Subsystem #D-10	34	23	11/18/2002	Specific Capacity	12000.00	510.64
56789	Lyon-Sioux RWS Doon Subsystem #D-8	33	23	11/15/2002	Specific Capacity	2660.00	115.65
56788	Lyon-Sioux RWS Doon Subsystem #D-9	31	21	11/18/2002	Specific Capacity	6000.00	292.68
40663	Lyon-Sioux RWS George Subsystem #5	35	17	Unknown	Specific Capacity	4000.00	235.29
57084	Rock Rapids, City Of #12	30	14	9/2/2009	Specific Capacity	1344.00	96.15
53714	Rock Rapids, City Of #14	21	16	Unknown	Pump Test	4050.00	253.13
53715	Rock Rapids, City Of #15	24	18	Unknown	Pump Test	2950.00	163.89
53716	Rock Rapids, City Of #16	22	19	Unknown	Pump Test	2650.00	139.47
53717	Rock Rapids, City Of #17	26	20	Unknown	Pump Test	3775.00	188.75
53718	Rock Rapids, City Of #18	34	19	Unknown	Pump Test	4430.00	233.16
29270	Rock Valley RWD #1	58	24	Unknown	Specific Capacity	19440.00	810.00
29271	Rock Valley RWD #2	38	36	Unknown	Specific Capacity	21700.00	602.78
41699	Rock Valley RWD #3	Unknown	45	Unknown	Specific Capacity	10000.00	223.71
50856	Rock Valley RWD #4	40	28	Unknown	Specific Capacity	9178.00	324.31
44624	Rock Valley RWD #5	50	38	Unknown	Specific Capacity	20000.00	526.32
41696	Rock Valley, City Of #3	49	31	9/23/2004	Specific Capacity	1111.00	35.84
41694	Rock Valley, City Of #6	78	57	Unknown	Specific Capacity	8040.00	141.05

fashion, resulting in a single data set along an entire transect.

Data Inversion

Data were processed using AGI EarthImager 2D version 2.4.0 software. A smooth model inversion method was used. The inversion mesh was 3 x 3 meters for the near-surface region in each transect and coarsened with depth. Resistivity values below 1 Ohm-m or above 10,000 Ohm-m were removed as these values are typically representative of erroneous data. Inversion was stopped after four iterations as root-mean-squared (RMS) values were below 9 percent, and L2 norm ratio values were less than 1.

Models provide an interpretation of how the subsurface responds to electrical influence. Model results can be indicative of a number of variables including, but not limited to, mineralogy, water saturation, compaction and available pore space, dissolved ions in pore fluid, as well as other geologic, biologic, and chemical factors. Interpretation of these data must be in the context of additional site information.

Data Synthesis

Geophysical surveys were completed in the Rock River alluvium as a means of assessing aquifer characteristics such as extent, thicknesses, and predominant grain size. ER models show how the subsurface responds to electrical charge. These models are beneficial in that they provide a relative view of subsurface variability along transects. Sand, gravel, and other coarse material tend to resist electrical

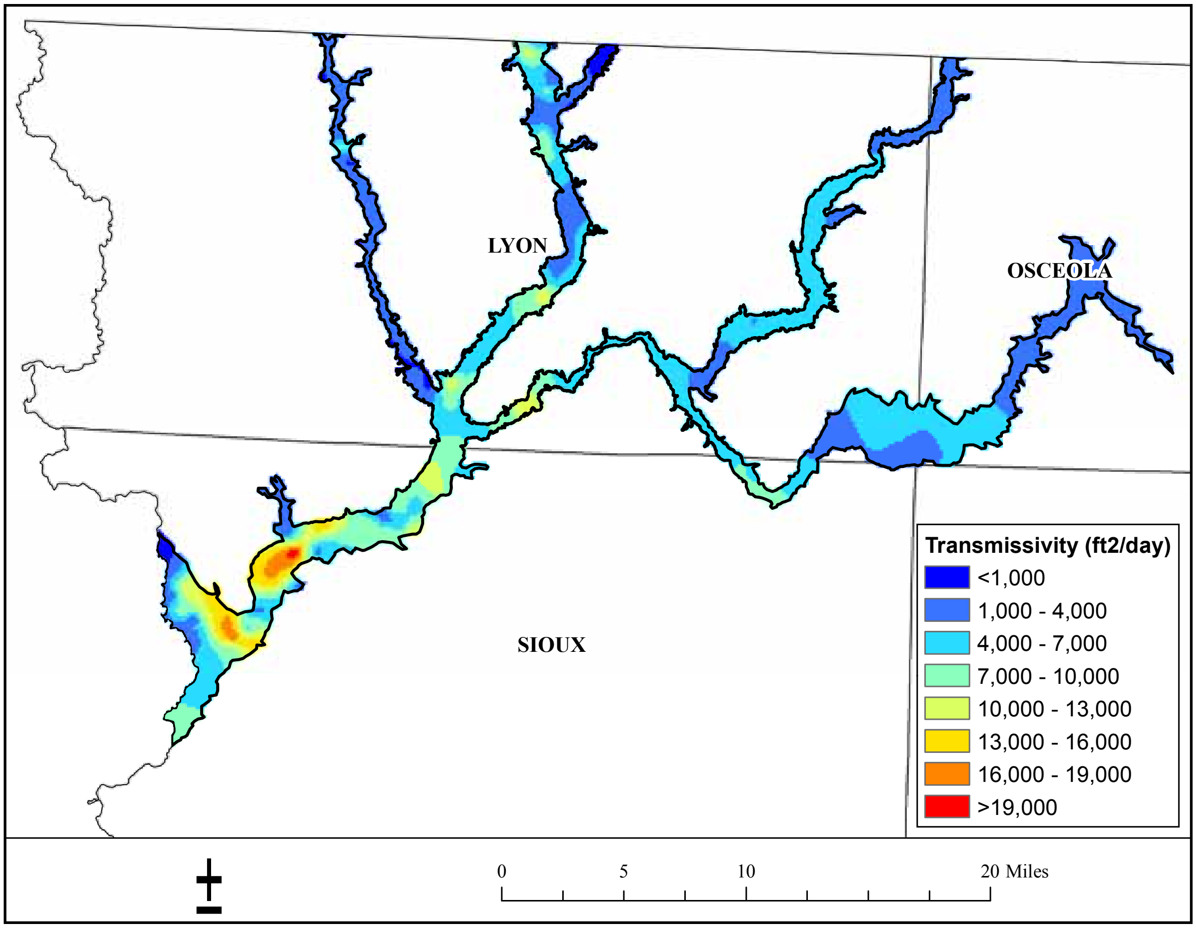


Figure 14. Transmissivity distribution within the Rock River aquifer based on data found in Table 4.

charge and are generally represented by higher resistivity values. Clay, silt, and other fine grained material tend to conduct electricity and are generally represented by lower resistivity values. Models were interpreted in context of boreholes drilled for detailed geologic information and geophysical correlation. Figure 5 shows borehole locations alongside geophysical transect locations. Sand and gravel depths encountered in a borehole were associated with a range of resistivity values in the ER model to determine subsurface extent and thickness associated with that material. The geophysical surveys and drilling were completed in areas with little or no existing information to supplement existing data. Geophysical models shown in Appendix C can be used as a resource for future aquifer development.

Local scale groundwater availability modeling assessments can provide site specific information that regional studies cannot. A groundwater availability modeling investigation was recently completed for the Hudson aquifer, in Sioux County, Iowa (Gannon and Vogelgesang, 2014). The assessment incorporated groundwater and geophysical modeling efforts to evaluate current and proposed groundwater withdrawals. The study was completed in the Rock River aquifer study area and can be referenced for more detailed aquifer information in that region.

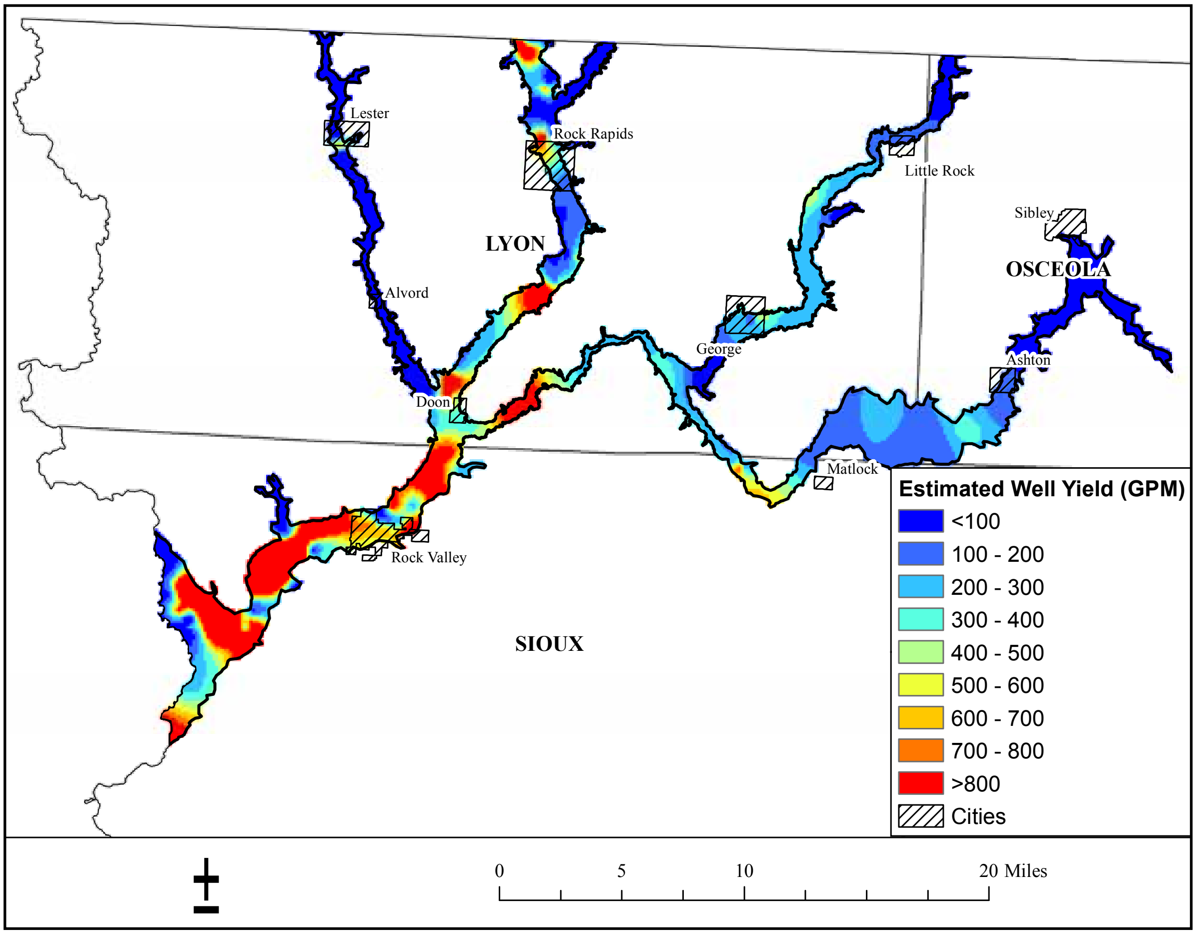


Figure 15. Potential well yield in gallons per minute.

CONCLUSIONS

The Iowa DNR initiated a geologic, geophysical, and hydrogeologic investigation to gather and summarize aquifer information on the Rock River alluvial aquifer. The purpose of this study was to provide a resource for future development or well field expansion. Special attention was given to drought conditions as prolonged dry periods can affect groundwater resources.

The study area lies near the border of the Northwest Iowa Plains and the Des Moines Lobe Landform Regions. The Cretaceous-age sedimentary rocks are overlain by a thick mantle of pre-Illinoian and Wisconsin-age glacial tills and alluvium. The area has a complex geologic history with several periods of glaciation. Outwash deposits encountered through drilling ranged in thickness from 16 to 53 feet.

Approximately 87 billion gallons of groundwater is stored in the Rock River aquifer. A groundwater study conducted by the Iowa DNR in 2006 calibrated an average annual groundwater recharge of 6 inches within the alluvium along the Rock River in Sioux County (Gannon, 2006). At the average recharge rate of 6 inches per year in the Rock River alluvium, approximately 12 bgy of water would recharge the aquifer. Approximately 6 bgy of precipitation recharge enters the aquifer during a severe drought. Total current water usage for the study area, not including private wells, is estimated at 3.4 bgy (Iowa DNR GIS Library).

Forty-nine active public wells were located within the model area and include four community systems (DNR GIS Library). In addition to the public wells, there are approximately 46 water-use wells that are used for ethanol production, irrigation, and livestock.

Hydraulic properties were obtained from nine aquifer pump tests. In addition to the aquifer pump tests, a total of 22 specific capacity tests were made available by various consultants, well drillers, and communities. Hydraulic conductivity in the Rock River alluvial aquifer was found to range from 35.8 to 810 feet/day, with an arithmetic mean of 249 feet/day. The transmissivity of the Rock River aquifer was found to range from 1,110 feet^2/day at the City of Rock Valley well #3 to 21,700 feet^2/day at Rock Valley Rural Water District well #2. Based on available data, the arithmetic mean transmissivity value was estimated to be 6,550 feet^2/day. The potential well yield distribution was calculated for the Rock River alluvial aquifer. Potential well yields greater than 800 gallons per minute (gpm) are found near the cities of Doon, Rock Rapids, and Rock Valley.

Eleven ER geophysical surveys were completed in areas with insufficient well data and relatively higher aquifer usage. ER models provide a means of assessing aquifer characteristics such as extent, thicknesses, and predominant grain size. These models are beneficial in that they provide a relative view of subsurface variability along transects. Thirteen boreholes were drilled near transects to correlate the geophysical models. Sand and gravel depths encountered in a borehole were associated with a range of resistivity values in the ER model to determine subsurface extent and thickness associated with that material.

REFERENCES

Bettis, E.A., III, 1989, Geologic Reconnaissance of the Coralville Lake Area, Geological Society of Iowa Guidebook 51, p. 93-100.

Bettis, E.A., III, 1990, Holocene Alluvial Stratigraphy and Selected Aspects of the Quaternary History of Western Iowa, Iowa Geological Survey Bureau Guidebook 9, p. 1-16.

Burger, H.R., Sheehan, A.F., and Jones, C.H., 2006, Introduction to Applied Geophysics: Exploring the Shallow Subsurface, W.W. Norton & Company, Inc. New York, NY, 554 p.

Dankert, W.N., Hanson, L.T., and Reckner, R.L., 1981, Soil Survey of O'Brien County, Iowa: Des Moines, United States Department of Agriculture – Soil Conservation Service, 125 p.

Dankert, W.N., Hanson, L.T., 1978, Soil Survey of Lyon County, Iowa: Des Moines, United States Department of Agriculture – Soil Conservation Service, 101 p.

Fetter, C.W., 2001, Applied Hydrogeology, Prentice-Hall, Inc. Upper Saddle River, NJ, 598 p.

Freeze, R.A, and Cherry, J.A., 1979, Groundwater, Prentice-Hall, Inc. Englewood Cliffs, NJ, 604 p.

Gannon, J.M., 2006, Hydrogeologic summary report, Hudson wellfield, Garfield Township, Sioux County, Iowa, Iowa Department of Natural Resources – Iowa Geological and Water Survey, unpublished.

Gannon, J.M., 2012, Aquifer Characterization and Drought Assessment, Floyd River Alluvial Aquifer, Iowa Department of Natural Resources-Iowa Geological and Water Survey, Water Resources Investigation 6, 29 p.

Gannon, J.M., and Vogelgesang, J.A., 2014, Groundwater Availability Modeling for the Hudson Aquifer, Sioux County, Iowa, Iowa Department of Natural Resources – Iowa Geological and Water Survey, Open File Report 13-2, 23 p.

Hall, R.D., and Anderson, A.K., 2000, Comparative Soil Development of Quaternary Paleosols of the Central United States, Palaeogeography, Palaeoclimatology, Palaeoecology, vol.158, no.1-2, p. 109-145.

Iowa Administrative Code (IAC) 567 Chapter 52.4

Iowa State University, Mesonet, 2013, available at: http://mesonet.agron.iastate.edu/climodat, accessed September 2013.

Prior, J.C., 1991, Landforms of Iowa, Iowa City, University of Iowa Press, 154 p.

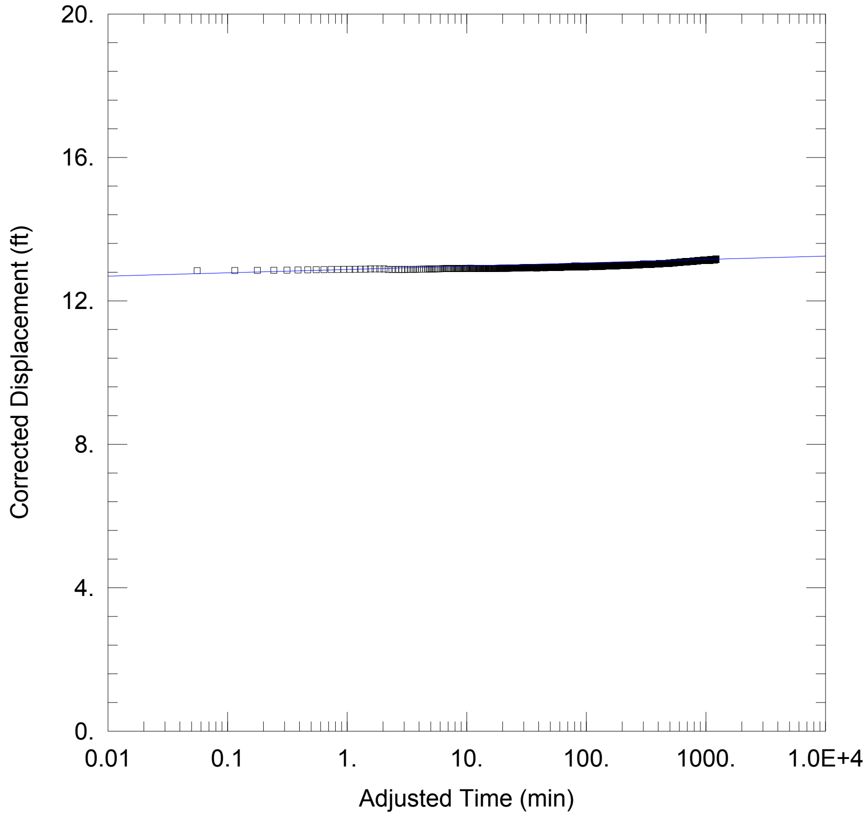
Thompson, C.A., 1987, Water Resources of the Rock River Alluvial Aquifer, Iowa Department of Natural Resources - Iowa Geological Survey, Open File Report 87-1, 109 p.

Witzke, B.J., Ludvigson, G.A., Anderson, R.R., Bunker, B.J., Slaughter, M.K., Giglierano, J.P., Whitsett, T.M., and Bounk, M.J., 1997, Bedrock Geology of Northwest Iowa, Digital Geologic Map of Iowa, Phase 1, Iowa Department of Natural Resources – Iowa Geological and Water Survey, Open File Map 97-1

APPENDIX A

PUMP TESTS

City of Rock Valley, Well #5



WELL TEST ANALYSIS

Data Set: C:\Projects\WaterPlan\2013\Rock\PumpTests\RockValley5Obs.aqt
Date: 11/26/13 Time: 11:34:49

PROJECT INFORMATION

Client: City of Rock Valley
Location: Rock Valley, Iowa
Test Well: Rock Valley Well #5
Test Date: 07/29/99 - 07/30/99

AQUIFER DATA

Saturated Thickness: 33. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Rock Valley #5	0	0

Observation Wells

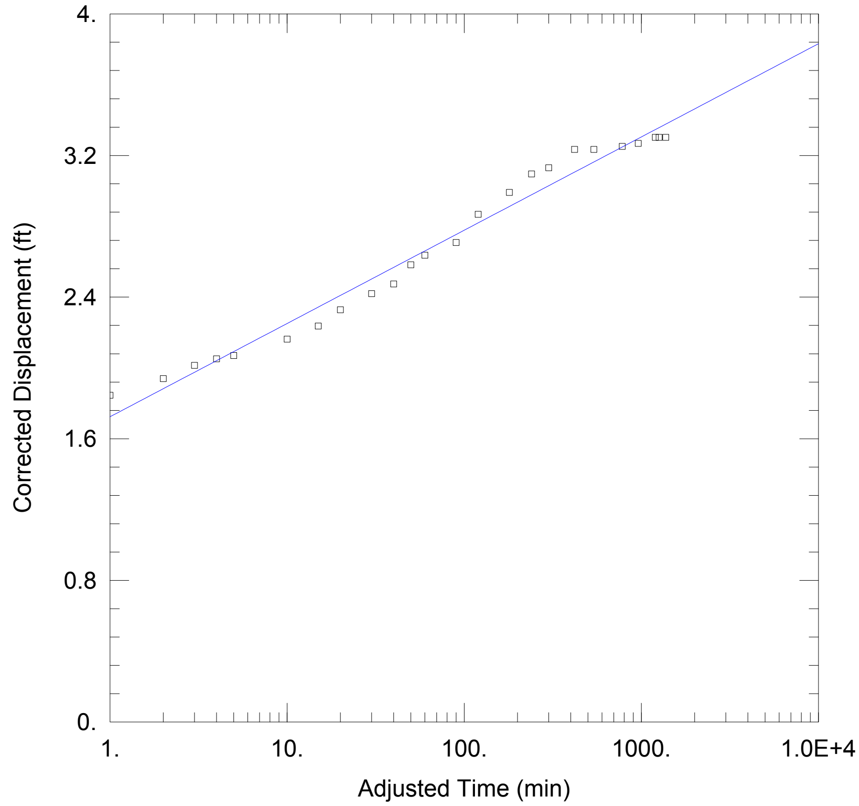
Well Name	X (ft)	Y (ft)
□ Observation Well	0	150

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 1.513E+5 ft^2/day S = 8.058E-141

City of George, Well #4



WELL TEST ANALYSIS

Data Set: C:\Projects\WaterPlan\2013\Rock\PumpTests\George4Obs.aqt
Date: 12/11/13 Time: 14:54:59

PROJECT INFORMATION

Company: Lacey & Sons
Client: City of George
Location: George, Iowa
Test Well: George #4
Test Date: 10/21/81 - 10/22/81

AQUIFER DATA

Saturated Thickness: 20.4 ft Anisotropy Ratio (Kz/Kr): 1.04E-5

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
George #4	0	0

Observation Wells

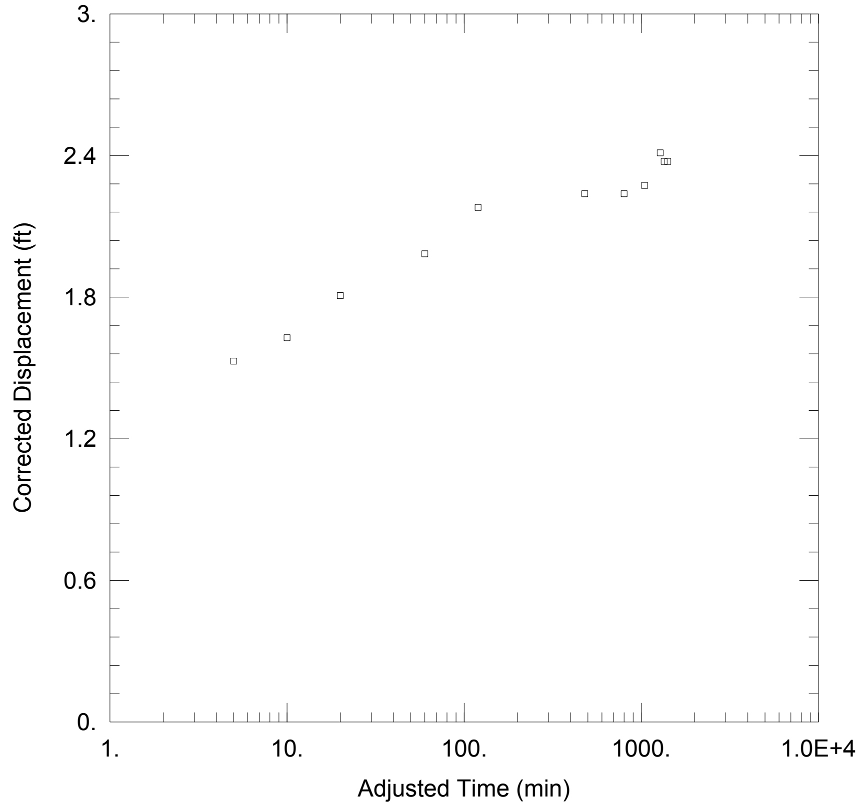
Well Name	X (ft)	Y (ft)
□ Observation Well #1	0	-20

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 1.339E+4 ft^2/day S = 2.792E-5

City of Doon, Well #6



WELL TEST ANALYSIS

Data Set: C:\Projects\WaterPlan\2013\Rock\PumpTests\Doon6Obs.aqt
Date: 12/11/13 Time: 14:50:30

PROJECT INFORMATION

Company: Alton Well Drilling
Client: City of Doon
Location: Doon, Iowa
Test Well: Doon #6
Test Date: 03/30/88 - 03/31/88

AQUIFER DATA

Saturated Thickness: 36.04 ft Anisotropy Ratio (Kz/Kr): 0.09621

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Doon #6	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ Observation Well	0	90

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 3.17E+4 ft^2/day S = 1.705E-61

APPENDIX B

WELLS USED

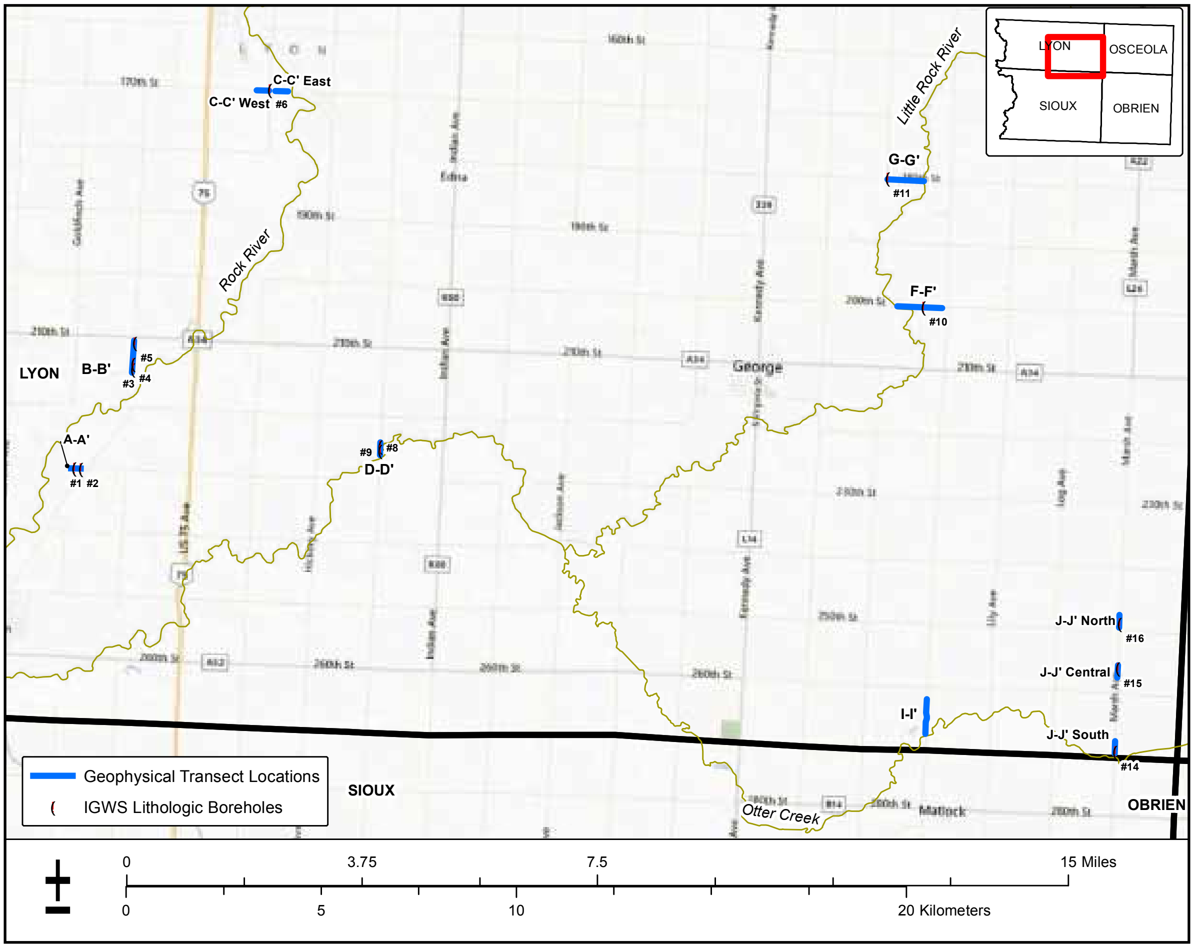
W-Number	Name of Owner	Total Depth	Website Link (additional site information available online)
3786	Bollinger, Marion	19	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=3786
23266	George, City Of	50	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=23266
24568	Gravengoed, Jay	320	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=24568
24584	Boyden, City Of	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=24584
25301	Rock Rapids, City Of	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=25301
25511	Vanveldhuizen, Jasper	300	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=25511
25900	IGS-USGS	481	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=25900
26095	Suter, Dave	272	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26095
26099	Rock Valley, City Of	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26099
26100	Rock Valley, City Of	122	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26100
26383	Versteeg, Nick	245	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26383
26424	Rock Rapids, City Of	230	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26424
26627	George, City Of	34	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=26627
27697	Kooiker, Robert	45	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27697
27729	Iowa Geological Survey	29	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27729
27730	Iowa Geological Survey	21	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27730
27731	Iowa Geological Survey	15	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27731
27732	Iowa Geological Survey	48	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27732
27733	Iowa Geological Survey	41	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27733
27734	Iowa Geological Survey	32	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27734
27735	Iowa Geological Survey	41	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27735
27736	Iowa Geological Survey	96	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27736
27737	Iowa Geological Survey	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=27737
28007	Spies, Les	95	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=28007
28026	Berg, Douglas	223	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=28026
28450	Sibley, City Of	772	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=28450
28849	Postma, Ken	32	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=28849
29271	Rock Valley Rwd	38	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=29271
29278	Van Groothees, Gerald	50	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=29278
30242	Doon, City Of	60	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=30242
36965	Boyden, City Of	29	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=36965
36966	Boyden, City Of	36	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=36966
37597	Kooima, Gerrit	85	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=37597
37671	Wennblom, Murlynn	39	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=37671
39484	Sieperda Anthony -- Estate	48	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=39484
39488	Vanvelduizen, John C.	306	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=39488
41682	Rock Rapids, City Of	0	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=41682
41685	Rock Rapids, City Of	0	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=41685
41694	Rock Valley, City Of	0	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=41694
41696	Rock Valley, City Of	52	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=41696
42034	Valley Machine Co.	100	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=42034
42752	Groeneweg Farms	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=42752
44624	Rock Valley Rwd	50	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=44624
45515	Abma, Edwin J.	57	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45515
45522	Hoogendoorn Farms, Ltd.	51	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45522
45523	Hoogendoorn Farms, Ltd.	35	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45523
45524	Hoogendoorn Farms, Ltd.	44	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45524
45526	Kats, Kenneth	48	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45526
45762	Murphy, Dr. Daniel	68	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45762
45763	Murphy, Dr. Daniel	62	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45763
45782	Hooyer, Phil	49	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45782
45826	Smith, Judson	57	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45826
45859	Van Veldhuizen, Ronald	38	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45859
45860	Van Veldhuizen, Ronald	13	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45860
45861	Van Veldhuizen, Ronald	28	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45861
45890	Henningfeld, Jerome L	65	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45890
45968	George, City Of	32	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=45968
46176	Murphy, Daniel J.	62	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46176
46177	Murphy, Daniel J.	68	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46177
46178	Van Den Top, Elmer	127	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46178
46203	Pine Grove Pork	41	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46203
46394	Van Zanten, Albert	80	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46394
46403	Rus, Marion	95	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46403

W-Number	Name of Owner	Total Depth	Website Link (additional site information available online)
46404	Rus, Marion	48	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=46404
47008	Van Beek, Wilma	47	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=47008
47153	Boon, Frank	15	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=47153
48245	Hoekstra, Eldon	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=48245
48692	Sleepy Hollow Sow Unit	31	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=48692
49476	Groeneweg, Loren	100	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49476
49516	Niemeyer, Harold	46	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49516
50058	Doon, City Of	57	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=50058
51439	South Dakota Geo. Survey	30	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51439
51440	South Dakota Geo. Survey	16	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51440
51441	South Dakota Geo. Survey	10	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51441
51449	South Dakota Geo. Survey	16	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51449
51450	South Dakota Geo. Survey	15	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51450
51451	South Dakota Geo. Survey	30	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51451
51452	South Dakota Geo. Survey	30	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51452
51454	South Dakota Geo. Survey	35	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51454
51455	South Dakota Geo. Survey	48	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51455
51456	South Dakota Geo. Survey	60	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51456
51457	South Dakota Geo. Survey	70	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51457
51458	South Dakota Geo. Survey	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51458
51750	Rock Valley Mw-1	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51750
51751	Rock Valley Mw-2	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51751
51752	Rock Valley Mw-3	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51752
51753	Rock Valley Mw-3d	50	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51753
51754	Rock Valley Mw-4	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51754
51756	Rock Valley Mw-8	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51756
51757	Rock Valley Mw-8d	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51757
51758	Rock Valley Mw-9	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51758
51759	Rock Valley Mw-10	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51759
51760	Rock Valley Mw-12	25	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=51760
52043	Techen, Eldon	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=52043
52553	Heokstra, Eldon	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=52553
52710	Frontier Communications	18	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=52710
56787	Lyon Sioux Rural Water	336	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=56787
56788	Lyon Sioux Rural Water	30	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=56788
56789	Lyon Sioux Rural Water	33	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=56789
56790	Rock Valley Rural Water	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=56790
61472	Rural Water System #1	55	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61472
61473	Rural Water System #1	80	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61473
61474	Rual Water System #1	95	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61474
61475	Rural Water System #1	65	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61475
61476	Rural Water System #1	60	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61476
61477	Rural Water System #1	55	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=61477
64316	Lyon Sioux Rw	43	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64316
64317	Lyon Sioux Rw	39	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64317
64318	Lyon Sioux	38	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64318
64401	Rock Valley Rwd	36	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64401
64402	Rock Valley Rwd	50	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64402
65577	Rock Valley Rural Water	34	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=65577
65578	Rock Valley Rural Water	40	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=65578
76567	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76567
76568	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76568
76569	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76569
76570	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76570
76571	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76571
76572	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76572
76573	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76573
76574	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76574
76575	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76575
76576	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76576
76577	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76577
76578	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76578
76910	Iowa Geological Survey	Unknown	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=76910

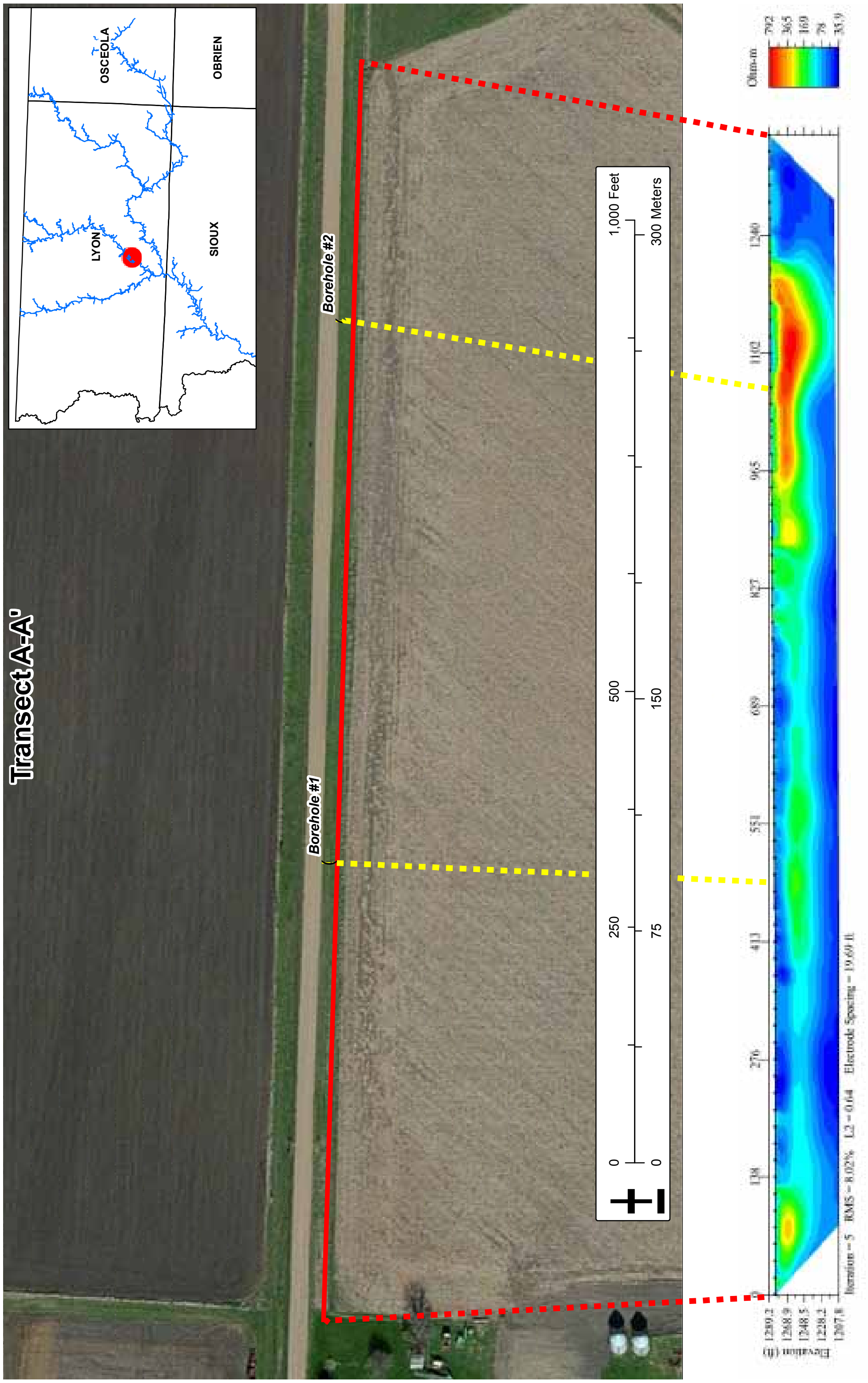
W-Number	Name of Owner	Total Depth	Website Link (additional site information available online)
N/A	IGS RR1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR2 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR2 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR2 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR2 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR3 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR3 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR3 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS RR3 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS Doon1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS Doon1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS Doon1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	IGS Doon1 Seismic Profile	N/A	ftp://ftp.igsb.uiowa.edu/igspubs/pdf/OFR-1987-1.pdf
N/A	Bridge Boring	45	N/A
N/A	Bridge Boring	55	N/A
N/A	Bridge Boring	55	N/A
N/A	Bridge Boring	48	N/A
N/A	Bridge Boring	68	N/A
N/A	Bridge Boring	78	N/A
N/A	Bridge Boring	45	N/A
N/A	Bridge Boring	40	N/A
N/A	Bridge Boring	60	N/A
N/A	Bridge Boring	64	N/A
N/A	Bridge Boring	38	N/A

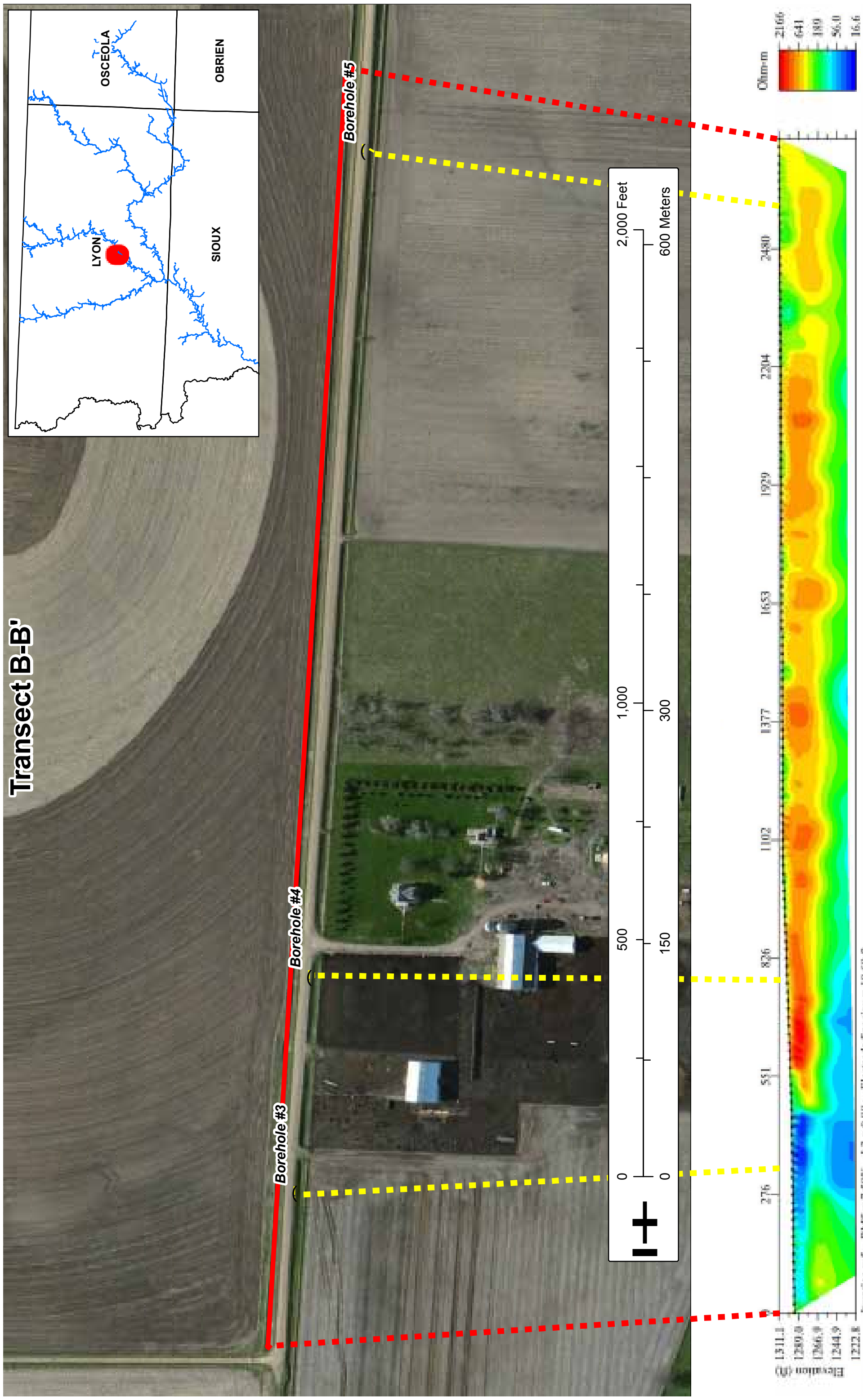
APPENDIX C

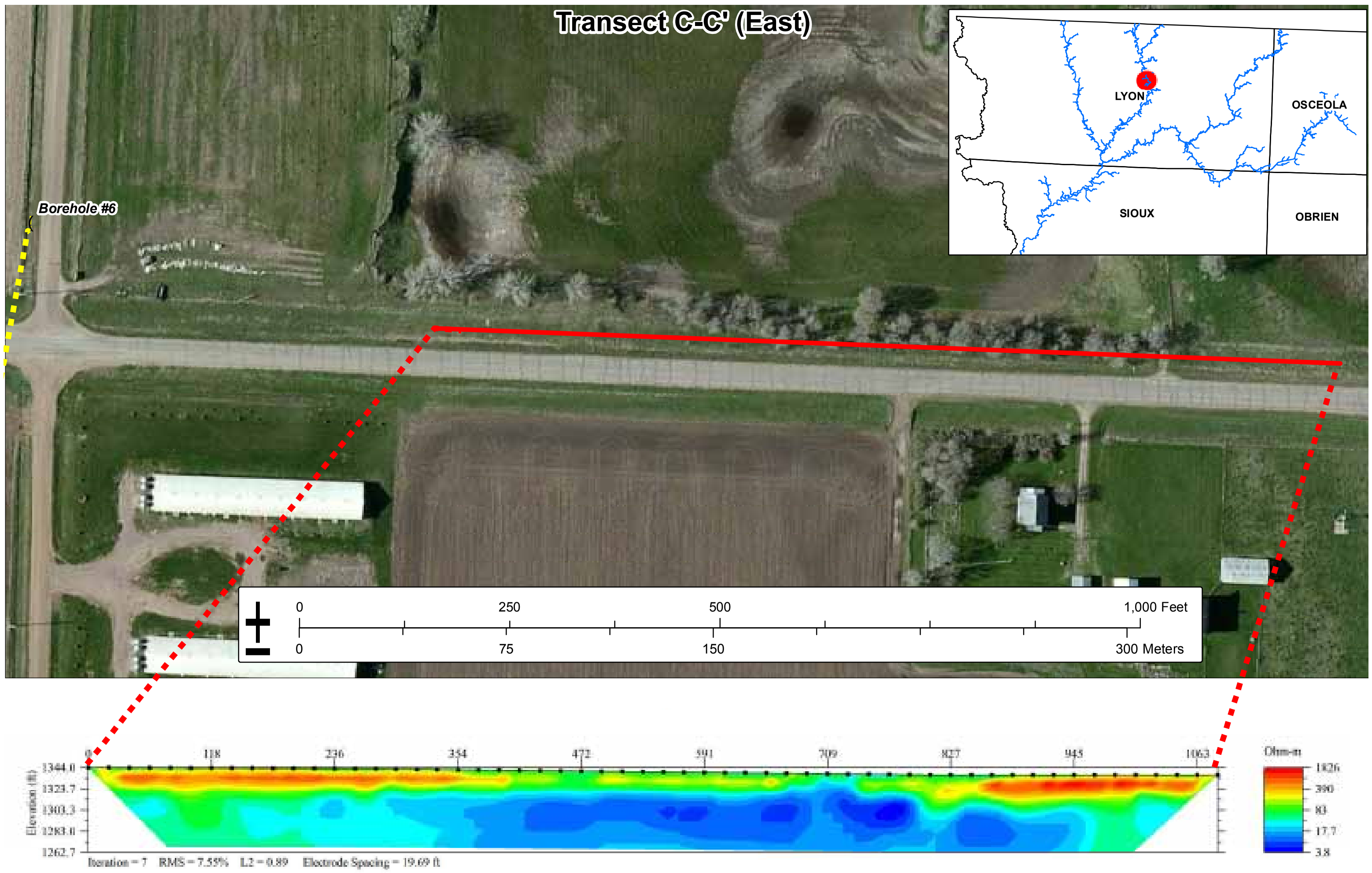
GEOPHYSICAL MODELS

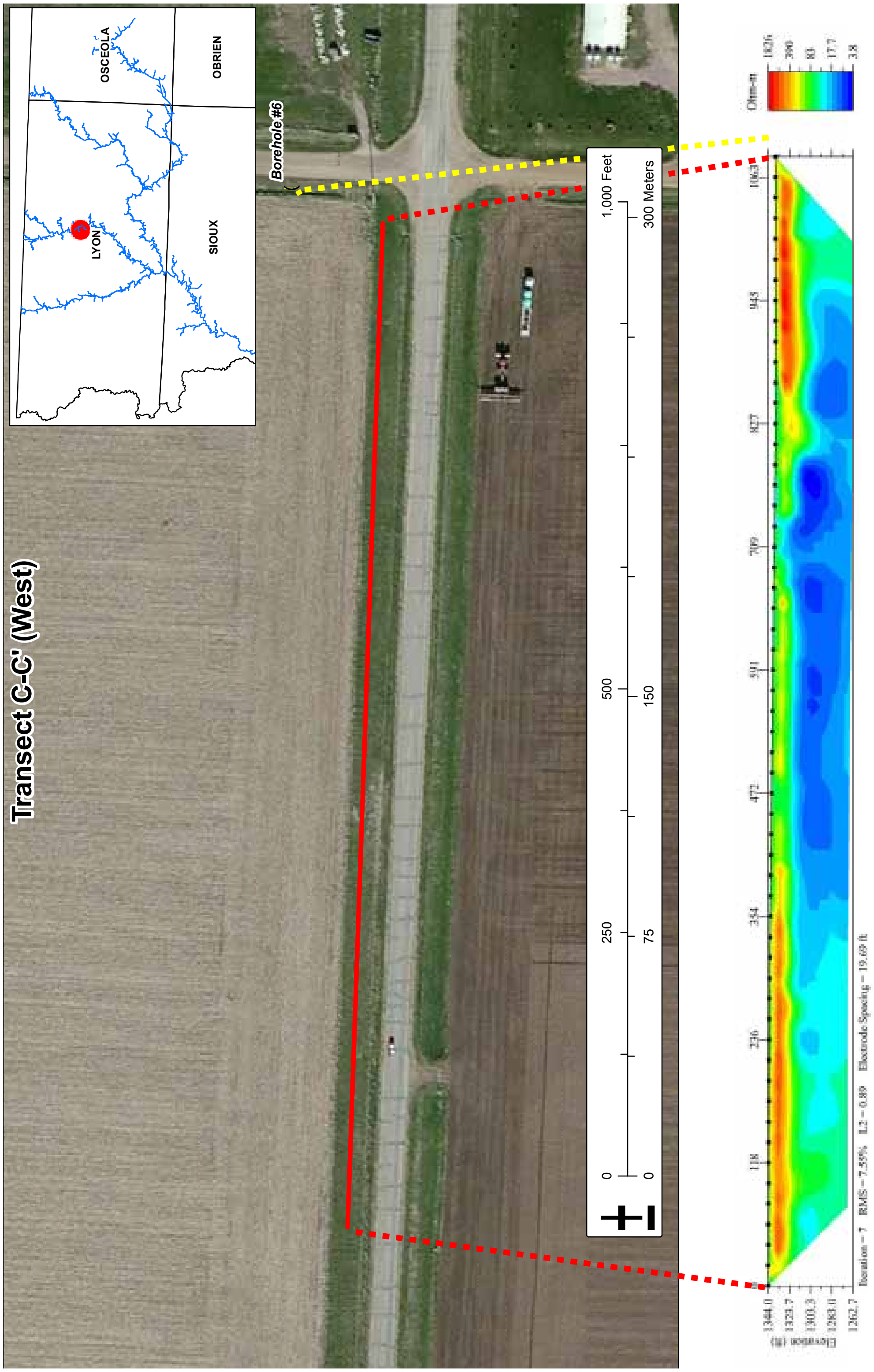


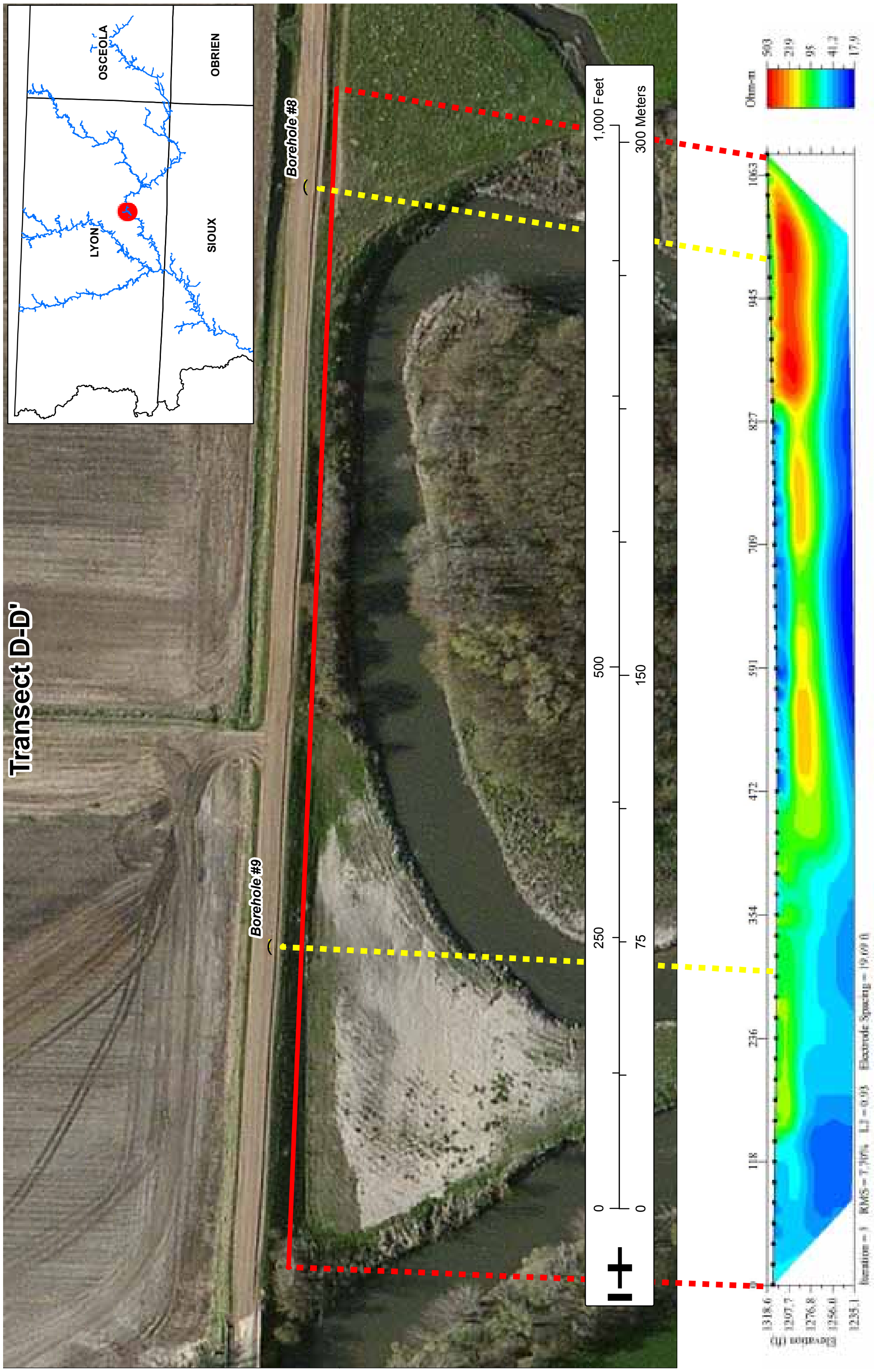
Rock River alluvial aquifer geophysical models


Transect A-A'
OSCEOLA
OBRIEN
LYON
SIOUX
Borehole #1
Borehole #2
0
250
500
1,000 Feet
0
75
150
300 Meters
Ohm-m
792
365
169
78
35.9
Elevation (ft)
0
138
276
413
551
689
827
965
1102
1240
Iteration = 5 RMS = 8.02% L2 = 0.64 Electrode Spacing = 19.69 ft

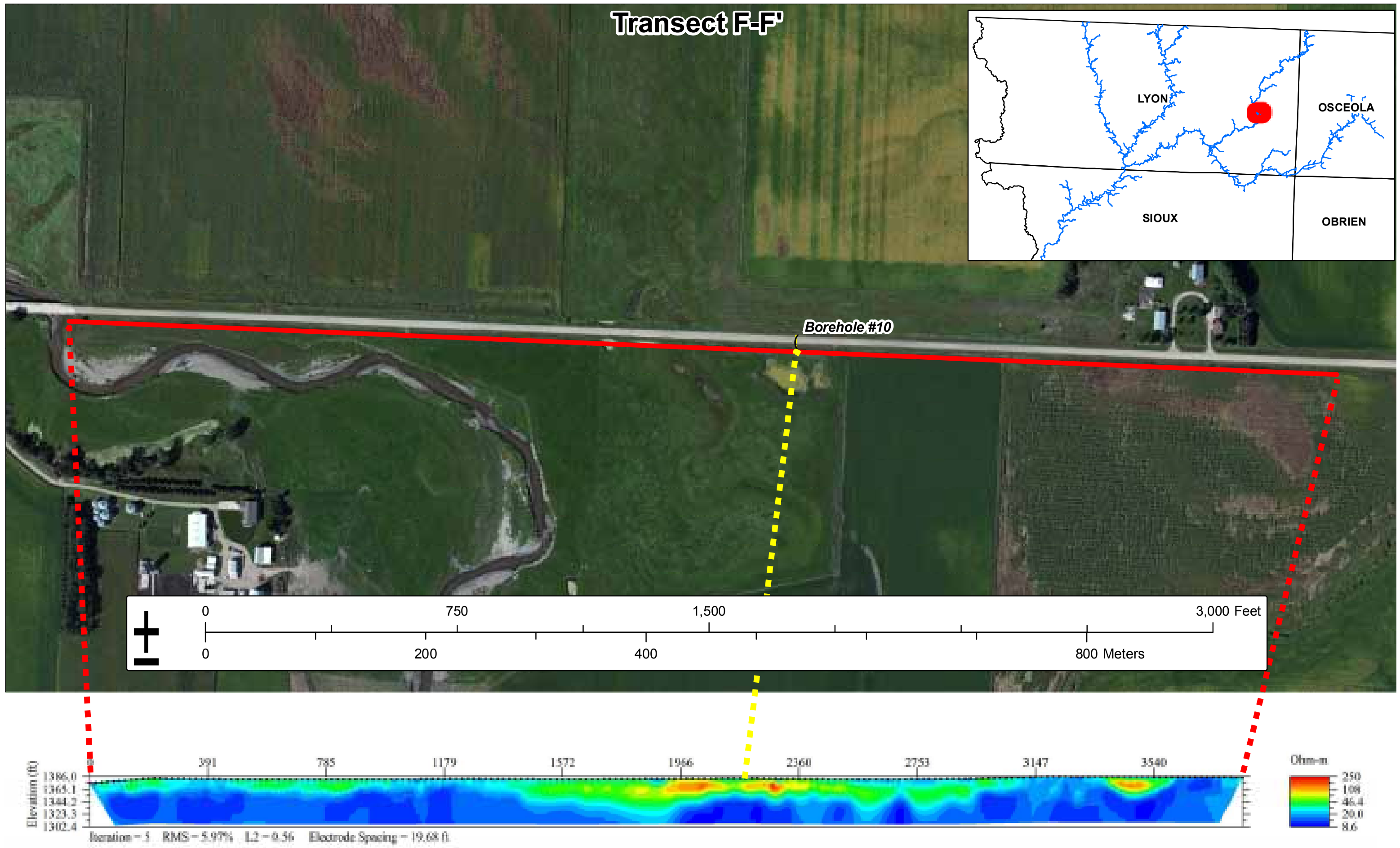

Transect B-B'
OSCEOLA
OBRIEN
LYON
SIOUX
Borehole #5
Borehole #4
Borehole #3
0
500
1,000
2,000 Feet
0
150
300
600 Meters
Ohm-m
2166
641
189
56.0
16.6
0
276
551
826
1102
1377
1653
1929
2204
2480
Elevation (ft)
1311.1
1289.0
1266.9
1244.9
1222.8
Iteration = 5 RMS = 7.50% L2 = 0.88 Electrode Spacing = 19.69 ft

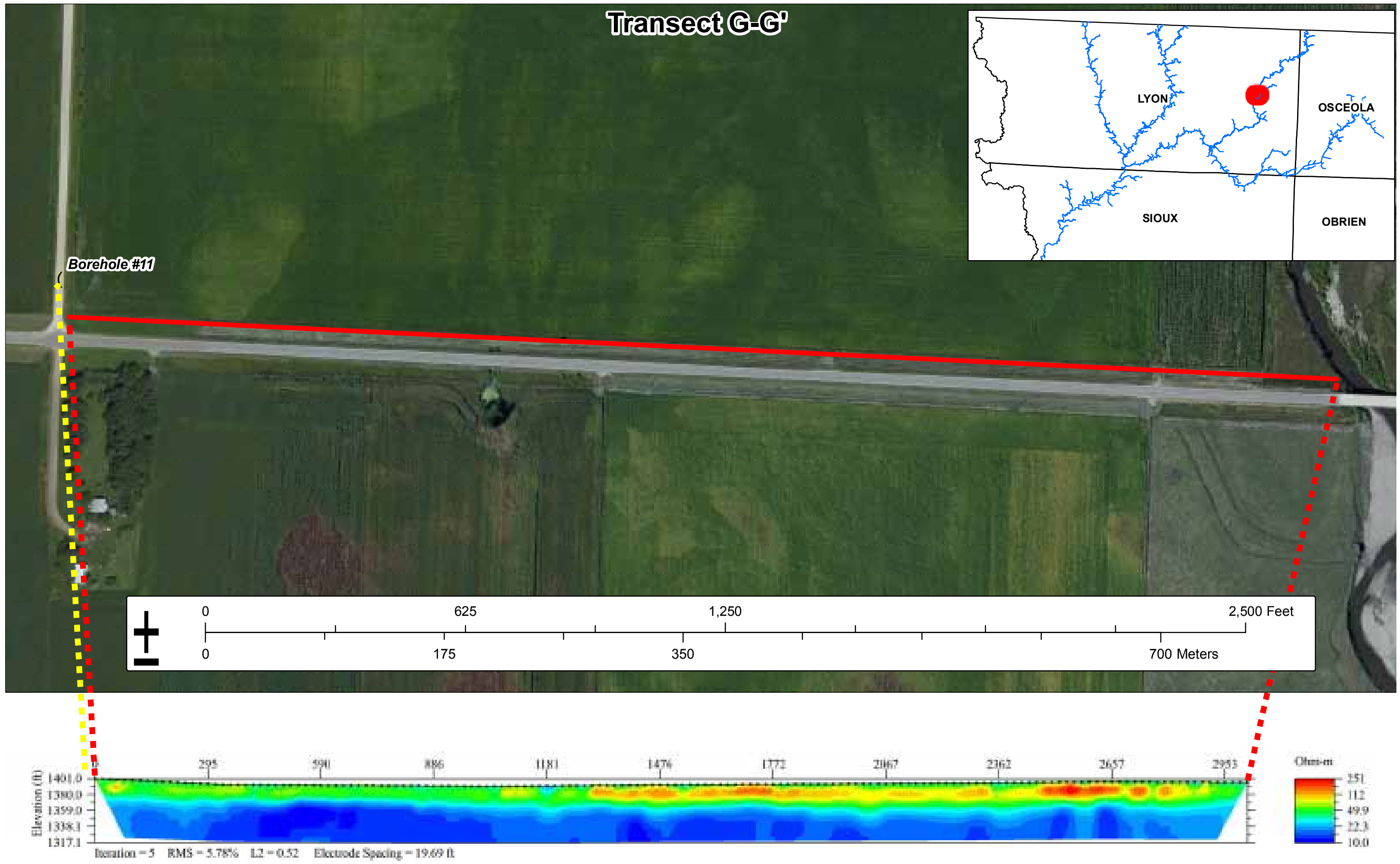

Transect C-C' (East)
LYON
OSCEOLA
SIOUX
OBRIEN
Borehole #6
0
250
500
1,000 Feet
0
75
150
300 Meters
Elevation (ft)
1344.0
1323.7
1303.3
1283.0
1262.7
0
118
236
354
472
591
709
827
945
1063
Ohm-m
1826
390
83
17.7
3.8
Iteration = 7 RMS = 7.55% L2 = 0.89 Electrode Spacing = 19.69 ft


Transect C-C' (West)
OSCEOLA
OBRIEN
LYON
SIOUX
Borehole #6
1,000 Feet
500
250
0
300 Meters
150
75
0
Ohm-m
1826
390
83
17.7
3.8
Elevation (ft)
1344.0
1323.7
1303.3
1283.0
1262.7
Iteration = 7 RMS = 7.55% L2 = 0.89 Electrode Spacing = 19.69 ft

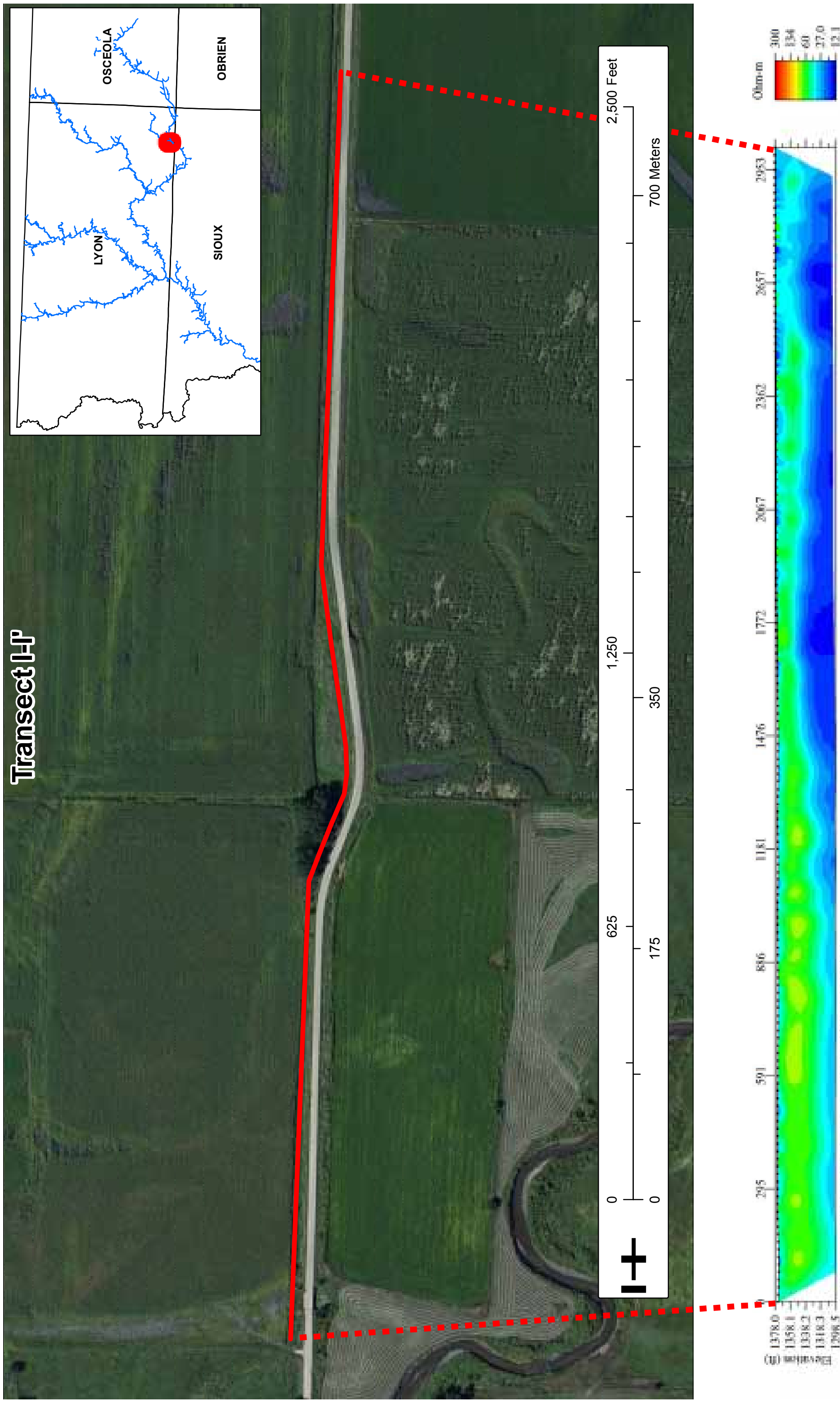


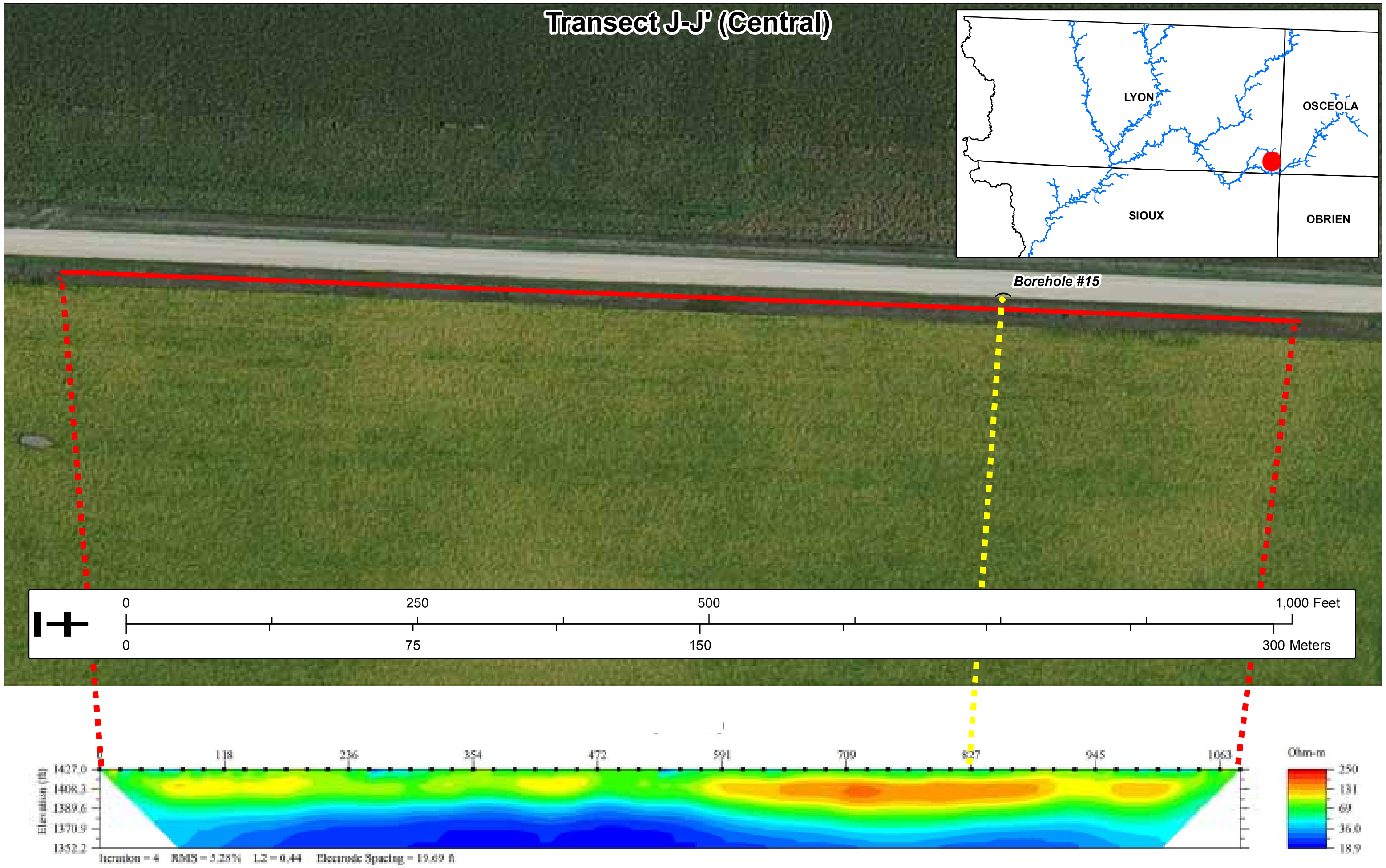
Transect D-D'
Borehole #8
Borehole #9
OSCEOLA
OBRIEN
LYON
SIOUX
0
250
500
1,000 Feet
0
75
150
300 Meters
Ohm-m
Elevation (ft)


Transect F-F'
LYON
OSCEOLA
SIOUX
OBRIEN
Borehole #10
0
750
1,500
3,000 Feet
0
200
400
800 Meters
Elevation (ft)
1386.0
1365.1
1344.2
1323.3
1302.4
391
785
1179
1572
1966
2360
2753
3147
3540
Iteration = 5 RMS = 5.97% L2 = 0.56 Electrode Spacing = 19.68 ft
Ohm-m
250
108
46.4
20.0
8.6

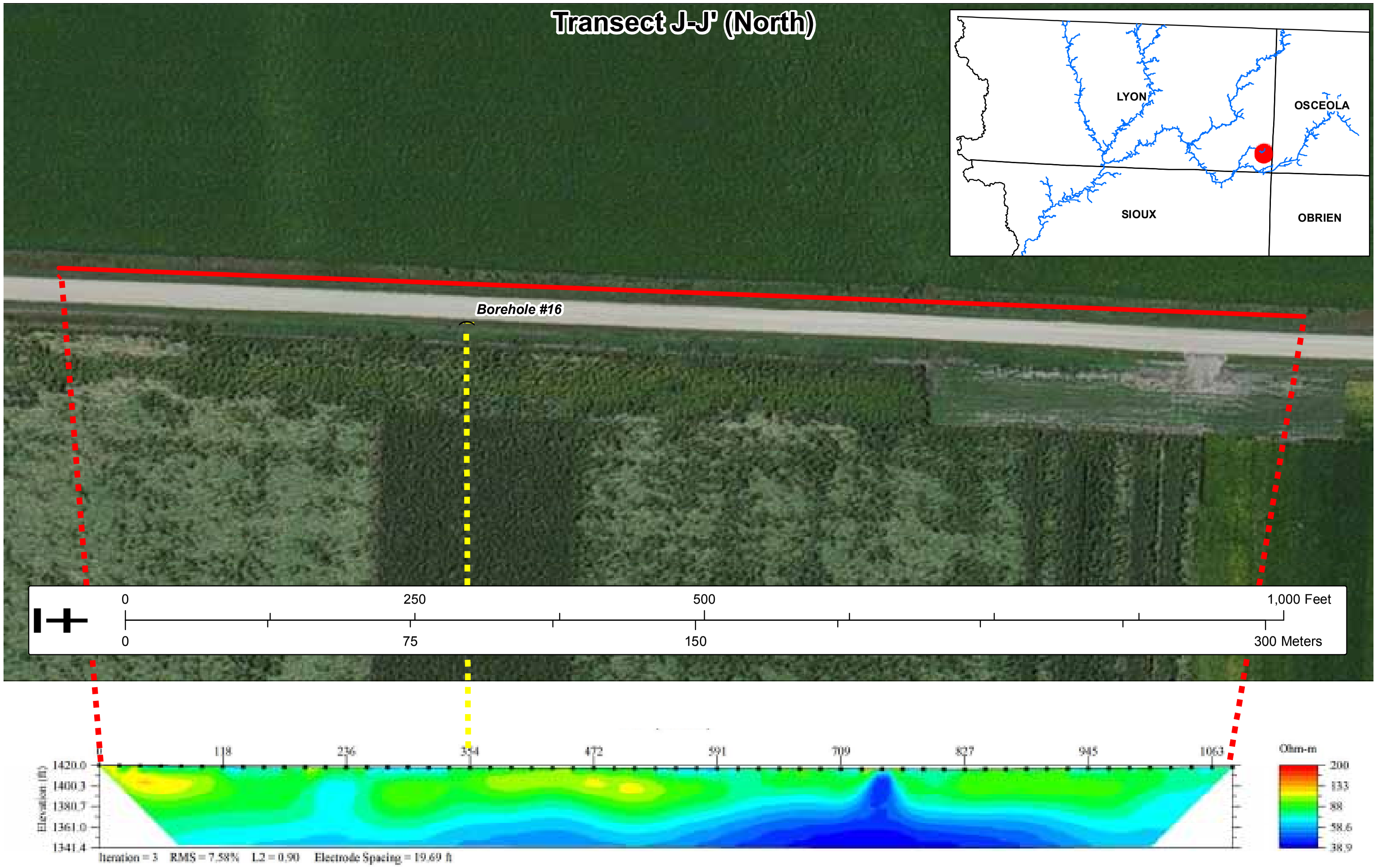


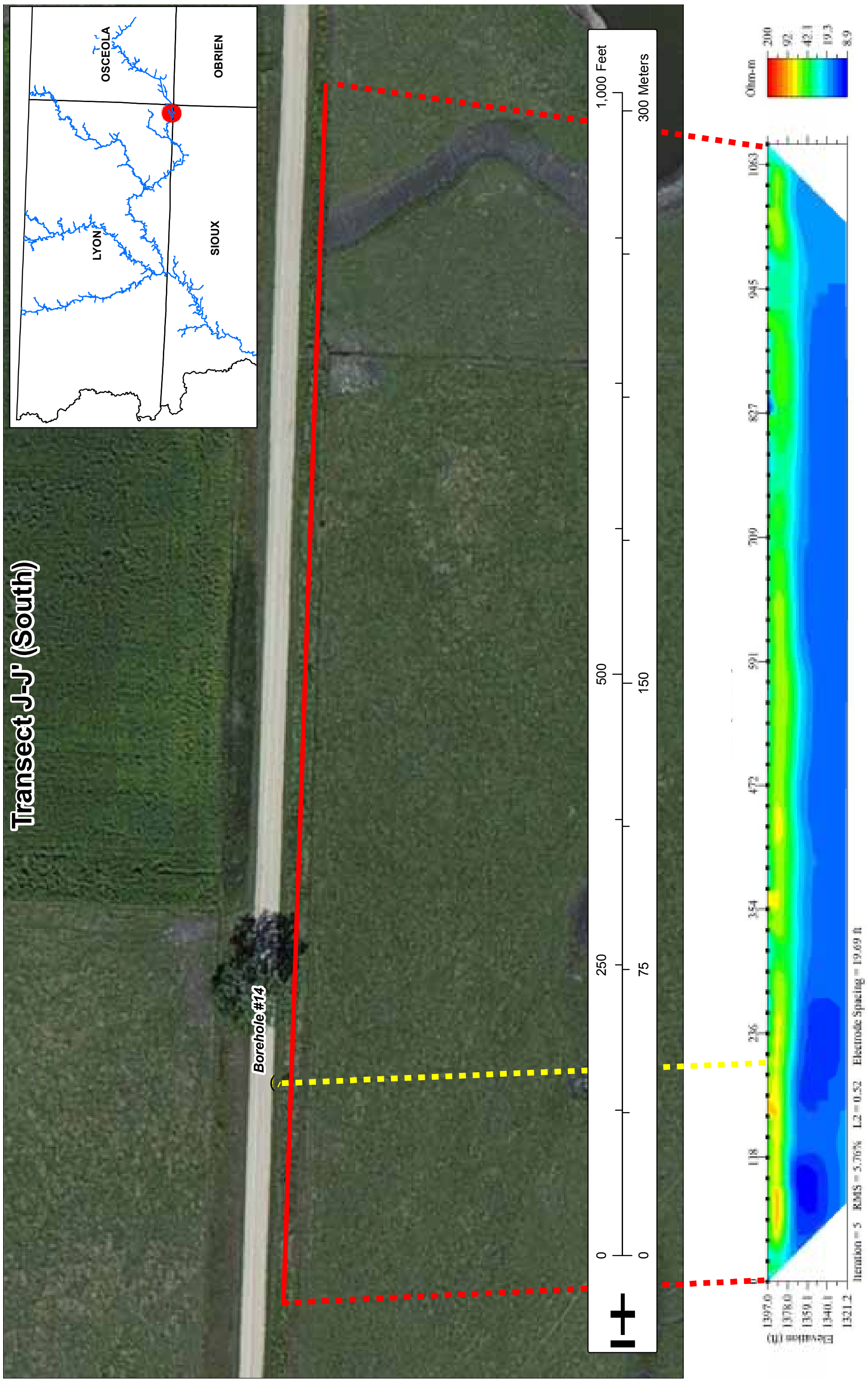
Transect G-G'
LYON
OSCEOLA
SIOUX
OBRIEN
Borehole #11
0
625
1,250
2,500 Feet
0
175
350
700 Meters
Elevation (ft)
1401.0
1380.0
1359.0
1338.1
1317.1
0
295
590
886
1181
1476
1772
2067
2362
2657
2953
Ohm-m
251
112
49.9
22.3
10.0
Iteration = 5 RMS = 5.78% L2 = 0.52 Electrode Spacing = 19.69 ft


Transect I-I'
OSCEOLA
OBRIEN
LYON
SIOUX
0
625
1,250
2,500 Feet
0
175
350
700 Meters
Ohm-m
300
134
60
27.0
12.1
Elevation (ft)
1378.0
1358.1
1338.2
1318.3
1298.5
0
295
591
886
1181
1476
1772
2067
2362
2657
2953
Iteration = 4 RMS = 5.88% L2 = 0.54 Electrode Spacing = 19.69 ft



Transect J-J' (Central)
LYON
OSCEOLA
SIOUX
OBRIEN
Borehole #15
0
250
500
1,000 Feet
0
75
150
300 Meters
Elevation (ft)
1427.0
1408.3
1389.6
1370.9
1352.2
0
118
236
354
472
591
709
827
945
1063
Iteration = 4 RMS = 5.28% L2 = 0.44 Electrode Spacing = 19.69 ft
Ohm-m
250
131
69
36.0
18.9


Transect J-J' (North)
LYON
OSCEOLA
SIOUX
OBRIEN
Borehole #16
0
250
500
1,000 Feet
0
75
150
300 Meters
Elevation (ft)
1420.0
1400.3
1380.7
1361.0
1341.4
118
236
354
472
591
709
827
945
1063
Iteration = 3 RMS = 7.58% L2 = 0.90 Electrode Spacing = 19.69 ft
Ohm-m
200
133
88
58.6
38.9



Transect J-J' (South)
OSCEOLA
OBRIEN
LYON
SIOUX
Borehole #14
0
250
500
1,000 Feet
0
75
150
300 Meters
Ohm-m
200
92
42.1
19.3
8.9
Elevation (ft)
1397.0
1378.0
1359.1
1340.1
1321.2
118
236
354
472
591
709
827
945
1063
Iteration = 5 RMS = 5.76% L2 = 0.52 Electrode Spacing = 19.69 ft

Iowa Department of Natural Resources
Geological and Water Survey
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
(319) 335-1575
www.igsb.uiowa.edu