Jefferson Groundwater Investigation
Greene County, Iowa

Iowa Geological and Water Survey
Technical Information Series 56

Iowa Department of Natural Resources
Chuck Gipp, Director

December 2013

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Jefferson Groundwater Investigation
Greene County, Iowa

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of individuals assisting in the production of this report. Paul Richardson, City of Jefferson, provided background information and support during the project. Robert Rowden, Iowa Geological and Water Survey, and Brent Beste, Iowa Rural Water Association, assisted with field geophysical data acquisition. Much of the previous understanding of the buried sand and gravel aquifer near Jefferson is based on bedrock surface data completed by Raymond Anderson, as well as previous Iowa Geological and Water Survey geologists. Deborah Quade contributed to the Quaternary geology background information. Well locations used in the report were updated by Iowa Geological and Water Survey students Matt Bopes, Carolyn Koebel, and Kelli Naughton. Tim Healy, Greene County, provided several drilling records to assist the study. Technical and editorial reviews were conducted by Keith Schilling and Lynette Seigley of the Iowa Geological and Water Survey. The report layout was completed by Mindy Kralicek, Iowa Department of Natural Resources.

INTRODUCTION

The Iowa Source Water Protection (SWP) program, funded by the United States Environmental Protection Agency, provides an established method for a community water supply to take action in protecting their source of drinking water before water quality or quantity issues arise (Iowa Department of Natural Resources, 2012). Communities that take preventive measures through this voluntary program can have health and financial benefits for their citizens by ensuring that naturally safe, minimally treated drinking water is readily available.

To become successful in SWP a community must: 1) know the source of its drinking water, 2) have an accurate inventory of potential contaminant sources and pathways to the source water area, and 3) proactively address potential drinking water issues of concern. The Iowa SWP program strives to protect all public drinking water from contamination. The program also provides focused assistance to many Iowa communities.

To aid communities in SWP efforts, the Iowa Department of Natural Resources (DNR) Iowa Geological and Water Survey (IGWS) utilizes computer models and established methods to characterize the source water areas for all active community water supplies in the state. Groundwater SWP areas in Iowa are commonly characterized by aquifer with, in decreasing order of use, Silurian-Devonian, alluvial, Cambrian-Ordovician, buried sand and gravel, Dakota, and Mississippian aquifers supplying water to Iowa citizens (Table 1). The SWP program annually updates assessments on all public water supplies that have drilled a new well, significantly changed pumping, or discontinued an active well. Additionally, the SWP program annually updates geospatial inventories of known contaminants, wells, land use, and nitrate-nitrogen (N) trends to help willing communities rank and address their unique source water concerns.

Table 1. Community source water areas in 2012.

Source Aquifer	# of Communities
Silurian-Devonian	302
Alluvial	170
Cambrian-Ordovician	151
Buried Sand and Gravel	115
Miscellaneous	76
Dakota	70
Mississippian	61
Total	**945**

Fourth in use among groundwater community supplies, “Buried Sand and Gravel” (formerly referred to as “Pleistocene” by the Iowa SWP program) source aquifers account for approximately 12 percent of community source water areas in Iowa and provide roughly 230,000 Iowans in communities with a source of drinking water (Groundwater Capture Zones - DNR Geological Information Systems Library). Despite its extensive use as a source of drinking water, SWP delineations for buried sand and gravel systems have historically been of limited use as an accurate estimate of a community’s source of drinking water. Due to limitations of data, methodology, and models, many buried sand and gravel systems have imprecise 2,500 ft. setback distances or concentric “time-of-travel” circle delineations. Conversely, the five other major aquifers typically have established aquifer dimensions which give greater confidence in the capture zone and reduce the area needed for a community to implement source water protection practices.

BACKGROUND

The City of Jefferson, Iowa, obtains its water from six active wells in a buried sand and gravel aquifer. The wells vary in depth from 150 to 180 ft. below the ground surface. Many buried sand and gravel aquifers, like the aquifer that Jefferson uses, are remnants of historic river deposits covered by glacial till or interbedded sand and gravel within till layers. The Iowa DNR IGWS initiated a geologic, geophysical, and hydrogeologic investigation to gather and summarize aquifer characteristics for the buried sand and gravel aquifer near Jefferson.

This report details the scientific work completed by Iowa DNR IGWS and delineates the source water capture zones for the City of Jefferson. These areas were created to assist with best management practices to protect the quality of groundwater and reduce the potential for surface contamination that could impact groundwater supplies.

The objective of this investigation is to refine source water capture zones, a computer-modeled source water area, typically using 2-, 5- and 10-yr. time-of-travel periods, for the City of Jefferson. A source water assessment, completed in 2012 for the City of Jefferson, contained fixed radius circle capture zones due to a lack of aquifer information. Unlike regional bedrock aquifers that have had published studies summarizing aquifer characteristics, published studies on sand and gravel aquifers are limited. Lessons learned after completion of the Jefferson investigation will be used to direct work on other buried sand and gravel aquifers, which account for approximately 11 percent of active public wells in Iowa (Public Wells – DNR GIS Library). The investigation will inventory prior published and unpublished reports, all available geologic and hydrologic data, as well as prompt the collection of new geologic and geophysical data to refine capture zones. Alongside refined capture zones, a detailed well inventory within the capture zones can be determined.

Jefferson was chosen for this study for several reasons. The city expressed interest in completing a SWP plan, requiring refined capture zones and aquifer characteristics. The study area contained a relatively high concentration of geologic data from well records when compared to other buried sand and gravel aquifer sites. Additionally, involvement from city and county leaders allowed for a collaborative effort. The investigation was focused near Jefferson wells 7 and 8 to provide more aquifer information in that area. Investigation results are intended to provide aquifer information to guide Jefferson's Source Water Plan and its implementation.

SCOPE OF WORK

This groundwater investigation will:

a) Collect, assess, and improve available geospatial information in the area, including information from the Iowa DNR Private Well Tracking System and GEOSAM databases, as well as add to existing information through paper records existing in Greene County office records.
b) Use lithologic and stratigraphic data collected from above sources to interpret local bedrock elevation with the extent and thickness of buried sand and gravel in the area immediately surrounding Jefferson.
c) Use electrical resistivity (ER) geophysical imaging to interpret buried sand and gravel extent and thickness in the region near Jefferson wells 7 and 8.
d) Estimate the local dimension of the buried sand and gravel aquifer using information from b) and c).
e) Estimate groundwater direction and properties of the buried sand and gravel aquifer using local observation well water levels and a pump test.
f) Use information from d) and e) to more accurately model the capture zone for the City of Jefferson's SWP planning and implementation efforts.

Results from the Jefferson investigation will be compiled to improve SWP program methods

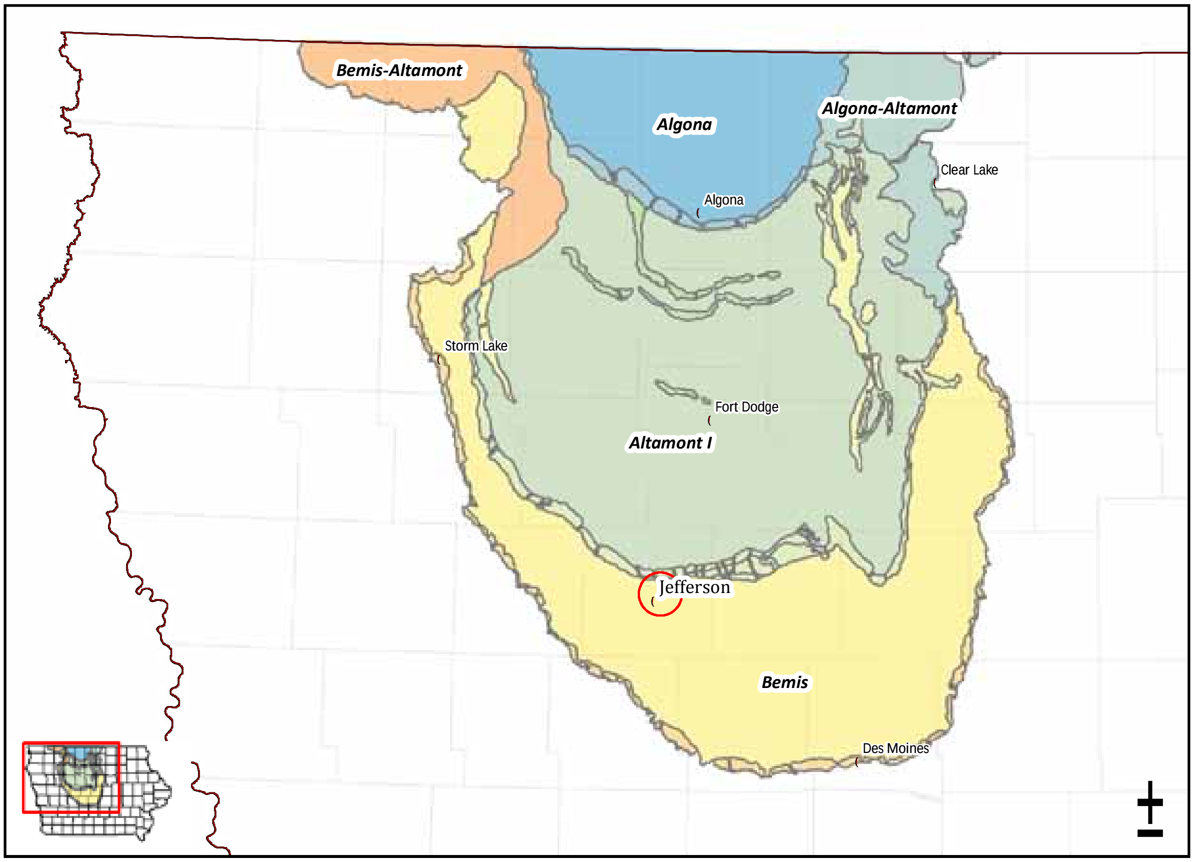

Figure 1. Des Moines Lobe landform region and associated glacial advances and moraines. A red circle around Jefferson represents the four mile study area.

and modeling for all communities that choose to enter the SWP program and currently use buried sand and gravel aquifers as a water source.

GEOLOGIC HISTORY AND SETTING

The Jefferson study area is located on the Des Moines Lobe (DML), the most recently glaciated area of the state. The DML is the product of a Late Wisconsin lobate extension of the Laurentide Ice Sheet that flowed down a regional topographic low into Iowa approximately 15,000 years ago. The study area is bounded by the Bemis Moraine, the terminal moraine of the DML dated approximately 14,500 to 14,000 years ago, and the slightly younger Altamont Moraine Complex dated approximately 13,500 years ago.

Jefferson lies on the Bemis till plain. The Bemis Moraine is approximately fifteen miles southwest of Jefferson and the slightly younger Altamont I Moraine is approximately four miles to the north (Figure 1). The DML landform is bounded by pre-Wisconsin topographic highs on the east (Mississippian bedrock) and west (pre-Wisconsin glacial deposits comprising the Prairie Coteau).

In the study area, bedrock consists of Pennsylvanian-age sedimentary rocks belonging to the Lower and Upper Cherokee Groups (Figure 2) that consist of interbedded shale, coal, and limestone. Cretaceous rocks belonging to the Windrow Formation occasionally overlie Pennsylvanian rocks, and can be found beneath surficial material approximately three miles

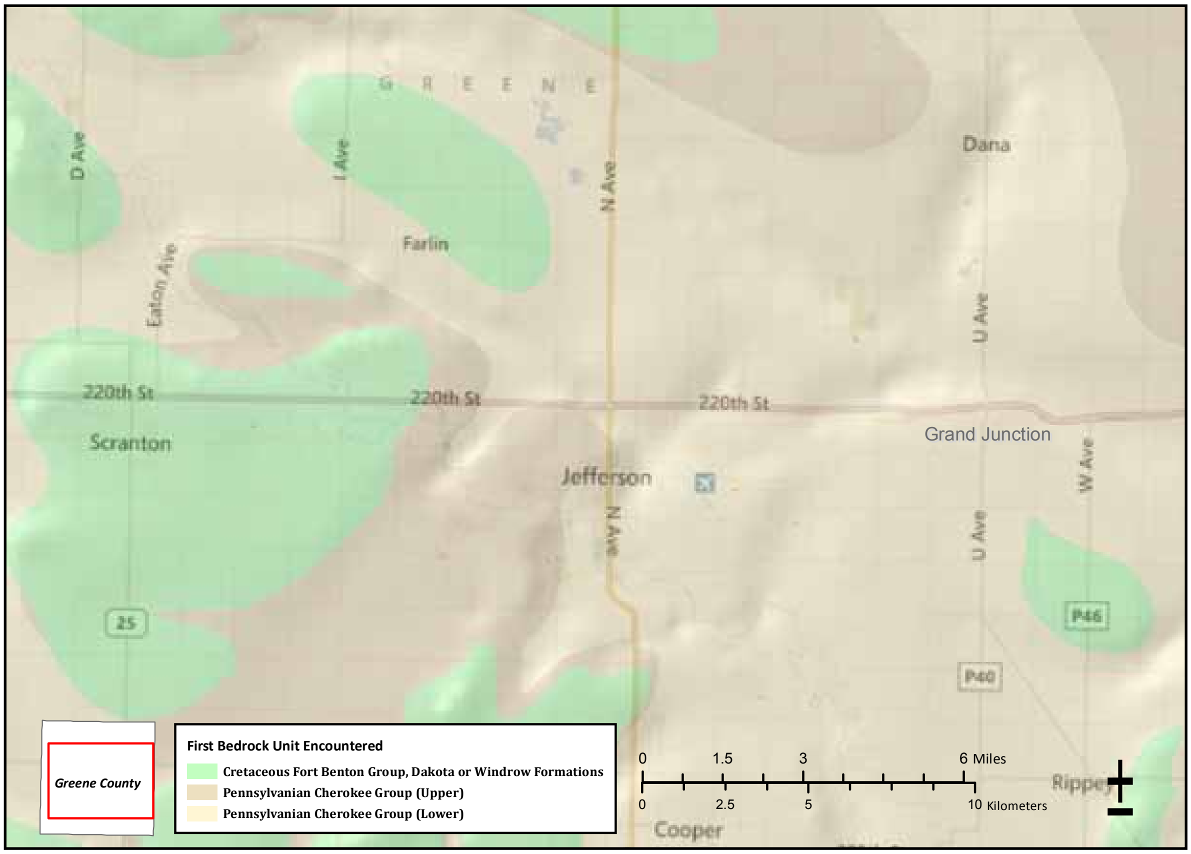

Figure 2. Map showing first bedrock units encountered underlying surficial geologic material near Jefferson.

west and south of town. Exposed bedrock is uncommon in the Jefferson area.

Surficial deposits that overlie bedrock consist of Pre-Illinoian and Wisconsin-age glacial and glaciofluvial sediments that range from less than 150 ft. to greater than 170 ft. in thickness. In the study area, the Late Wisconsin-age glacial and glaciofluvial sediment package can vary in thicknesses, and is underlain by the much older and undifferentiated Pre-Illinoian-age glacial, fluvial or colluvial sediments.

BURIED SAND AND GRAVEL AQUIFERS

Many buried sand and gravel aquifers, like the aquifer that is used by the City of Jefferson, are remnant deposits from historic rivers that were covered by glacial till or consist of interbedded sand and gravel within till layers. Physical aquifer information such as thickness, extents, and variability of coarse deposits is often limited in sand and gravel aquifers. Unlike alluvial aquifers where well-defined valleys can delineate aquifer extents, many buried sand and gravel aquifers do not have a valley or depression visible from the land surface and can be laterally discontinuous. Much of what is known of these systems is obtained from the drilling of water wells. Similar to alluvial aquifers, buried sand and gravel aquifers can have widely variable water production and quality characteristics. Depositional variability can be associated with the historic river's previous course or other depositional characteristics associated with glacial outwash.

Prior publications mention buried sand and gravel aquifers but efforts to map boundaries, determine water quality characteristics, or the like have not been completed in Iowa. Iowa's Groundwater Basics, (Prior, et al., 2003) discusses two types of buried sand and gravel aquifers: buried valley aquifers and glacial drift aquifers. A figure within the publication shows a statewide map of potential buried valley aquifers that is a good reference on a statewide scale. The figure loses application potential on a local scale such as the Jefferson study area. Ground-Water Data for Alluvial Buried Channel, Basal Pleistocene and Dakota Aquifer in West-Central Iowa (Hunt and Runkle, 1985) summarized a comprehensive study on water quality, production, and lithology for an eight county area that includes Greene County. The study contained several well logs but did not map buried sand and gravel aquifer boundaries.

GEOLOGIC SITE ASSESSMENT

A study radius of four miles around city wells 7 and 8 was chosen to focus the investigation. Geologic information was gathered from the IGWS GEOSAM database, the DNR Private Well Tracking System database, and from several well logs provided by Greene County. Appendix A lists well information gathered from GEOSAM for use in this assessment. Locations of utilized well points were updated based on well records and county assessor parcel data, and LiDAR elevations were derived. Data from the geophysical investigation were factored into the geologic site assessment.

Well records were analyzed to determine the extent of the buried sand and gravel aquifer within the four mile study area. Figure 3 shows the distribution of data points utilized in the study along with sand and gravel thickness and bedrock surface interpretations. All data in Figure 3 contain at least a lithologic formation log from the drilling process; several contain rock chip samples and a detailed lithologic and stratigraphic log. A buried sand and gravel isopach map was generated based on all available data and is shown in Figure 4. The isopach map shows where major aquifer boundaries may be located and how aquifer thickness appears to vary within the Jefferson area. It appears the thickest sand and gravel in the aquifer may trend in a north-south direction though Jefferson and may trend east to the north of town. Thinner sands and gravels may be connected immediately west and northwest of town but were either not thick enough or there were insufficient data to incorporate these into the aquifer isopach. This figure does not show where absolute boundaries are but provides an interpretation based on geologic data at the time of this publication. For example, Figure 3 shows an area immediately east of town that contained very few data points. Additional geologic data obtained in areas lacking sufficient data will help update and refine aquifer extent and thickness interpretations.

GEOPHYSCIAL INVESTIGATION

Field Data Collection

A geophysical investigation was conducted to gather additional information related to aquifer characteristics near city wells 7 and 8. An Advanced Geosciences Inc. SuperSting R8, 8-channel 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 ft. apart, driven approximately one ft. into the ground, and connected via electrode cables and a switch box to a central ER meter.

Two surveys were completed April 16, 2013 (Figure 5). One transect was completed in an east-west orientation and one in a north-

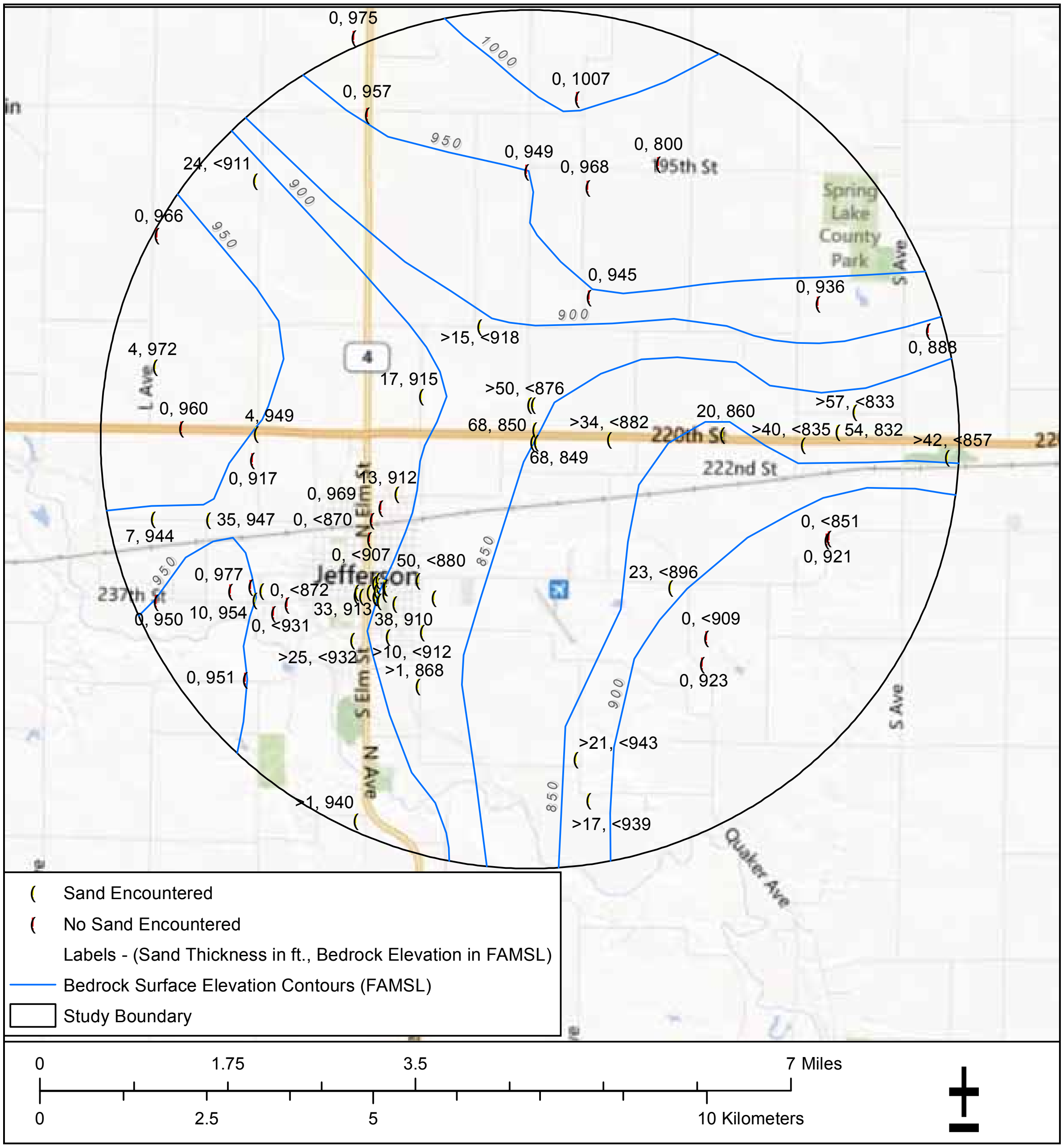

Figure 3. Location of geologic data points used. Labels indicate sand and gravel thickness in feet and bedrock surface elevation in feet above mean sea level.

south orientation; a total of 7,603 individual resistivity measurements were collected. Transect locations were chosen based on their proximity to wells 7 and 8 so that geophysical interpretations could be made in conjunction with existing geologic data. Transects were oriented in a perpendicular arrangement to determine how geologic materials vary in either direction.

Field data were obtained using dipole-dipole configurations; chosen to maximize data

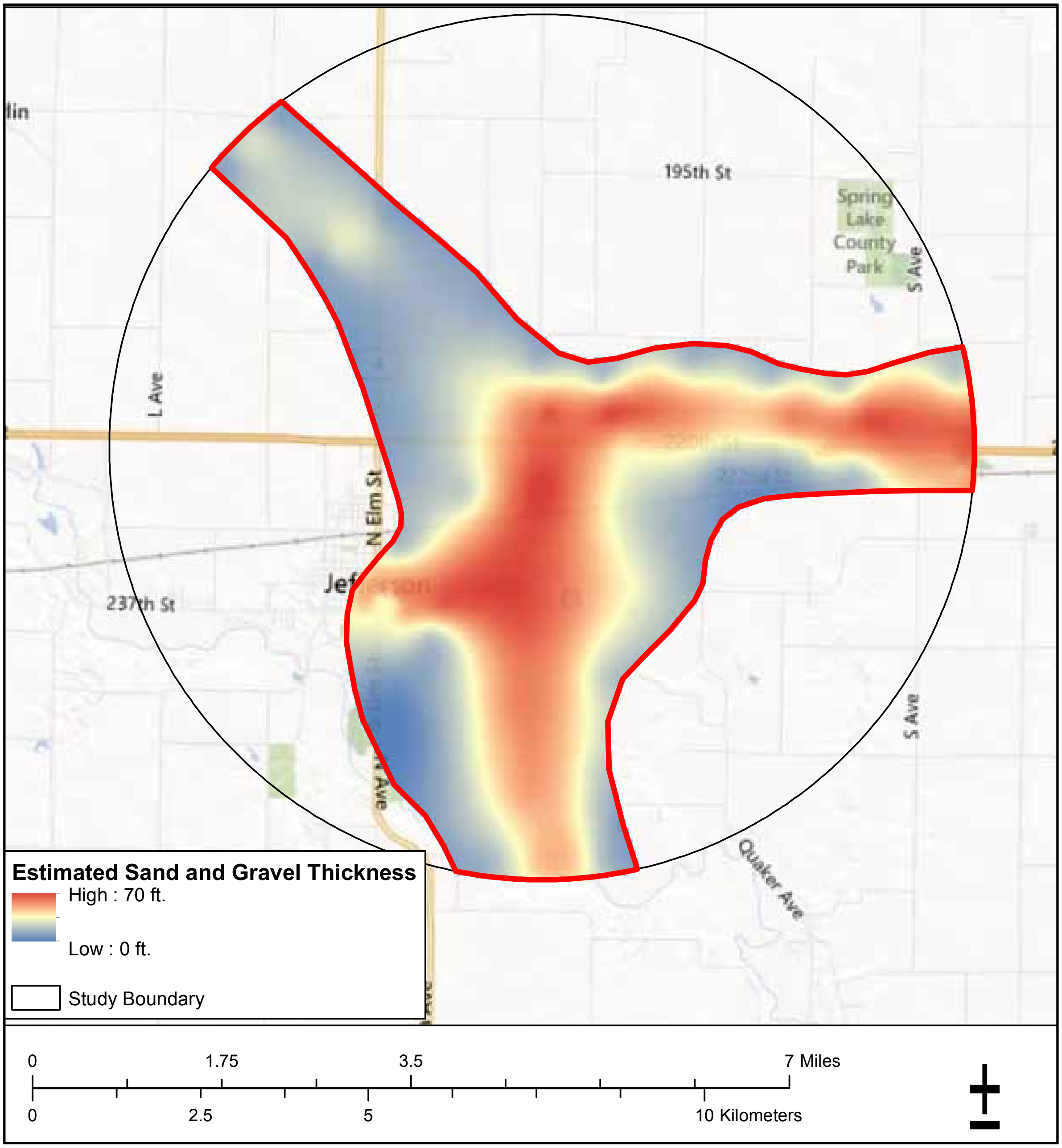

Figure 4. Interpreted aquifer boundary and sand and gravel thickness map.

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 that case, a third or fourth measurement was 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" fashion, resulting in a single data set along an entire transect.

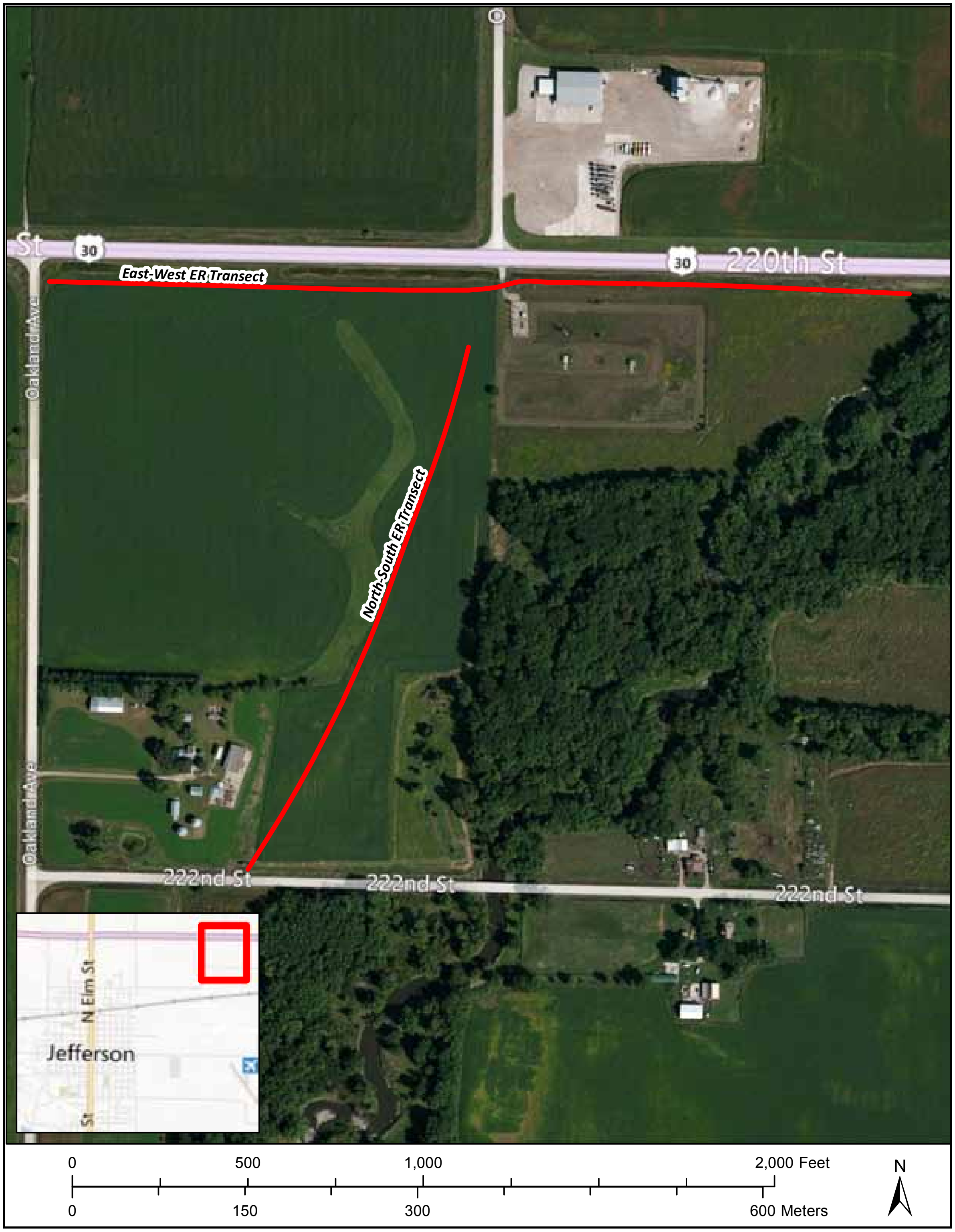

Figure 5. Map showing ER transect locations.

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 fine 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 square (rms) values were below 5 percent, and L2 norm ratio values were close to 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

Electrical resistivity tomography uses direct current as a means of modeling the subsurface. Generally, coarse grained material is more resistive to electrical charge than fine grained material. Drilling log records and rock chip samples from city wells 7 and 8 were analyzed and used in the interpretation of the geophysical data.

Figure 5 shows the two geophysical transect locations near wells 7 and 8. The final geophysical models for the east-west transect and north-south transect are shown in figures 6 and 7, respectively. Models were corrected for land surface elevation using LiDAR elevation data. Approximate locations for wells 7 and 8 are indicated on the East-West Model with solid lines marking the known contacts of geologic units associated with the buried sand and gravel aquifer. The known contacts correlate well to the geophysical model results. Variability in the upper aquifer surface is evident in the profiles. Dashed lines show interpreted contacts between key lithologic units.

The geophysical models suggest that a consistently thick sequence of glacial till (>100 ft. thick) is protecting the aquifer in the study area. Aquifers overlain by thicker confining layers are less susceptible to surface-sourced contamination than aquifers overlain by thin confining layers. Areas of higher resistivity may suggest a higher concentration of coarse grained gravels. The variability of resistivity values in the two models is indicative of modern river systems or glacial outwash as sediment deposition is largely dependent on the river's course through time. Geophysical data collected at the north-south model suggests that coarse-grained alluvium is present just below the land surface, likely representing deposits associated with nearby Hardin Creek. A thick unit of glacial till separates this alluvium from the buried sand and gravel, making hydraulic connection between the two unlikely. Model resolution and data quality diminish exponentially with depth so it is difficult to determine where the buried sand and gravel aquifer may be in contact with the bedrock surface. The Pennsylvanian bedrock contact was interpreted based on the occurrence of shale in Jefferson Well 7, at 175 ft. below the ground surface, which is consistent with geologic logs from nearby wells.

HYDROGEOLOGIC ANALYSES AND GROUNDWATER MODELING

Hydrogeologic data were obtained from two separate aquifer pump tests using city wells 7 and 8 and three nearby observation wells. A pressure transducer was placed in each of the three observation wells, and water level data was collected every 15 minutes over the course of approximately 13 days.

Based on aquifer pump test results, the transmissivity of the buried sand and gravel

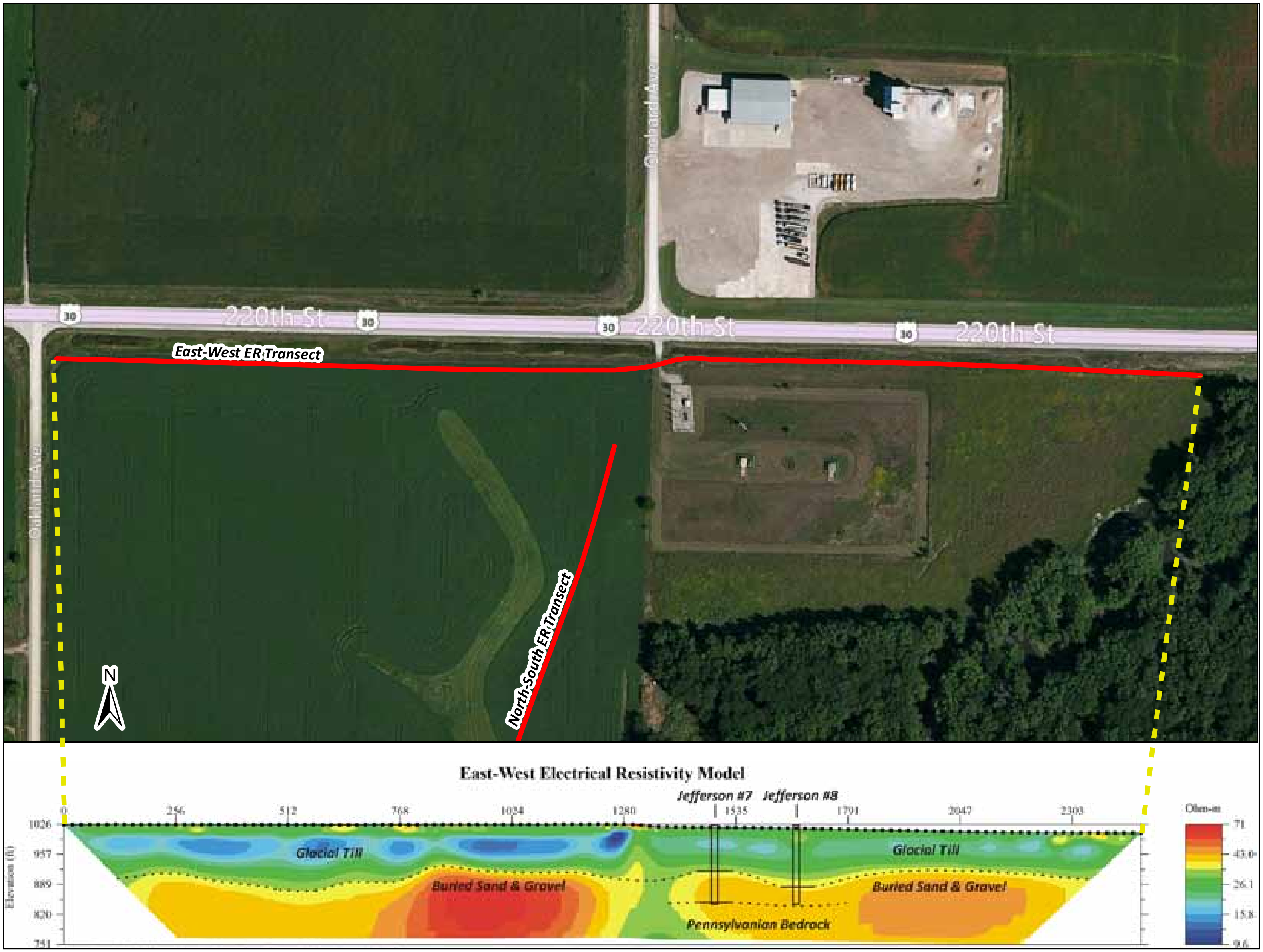

Figure 6. ER model results for the east-west transect. Dashed lines indicate interpreted geologic contacts. Jefferson wells 7 and 8 are drawn to show their approximate location. Known geologic contacts from well records are shown by a solid line.

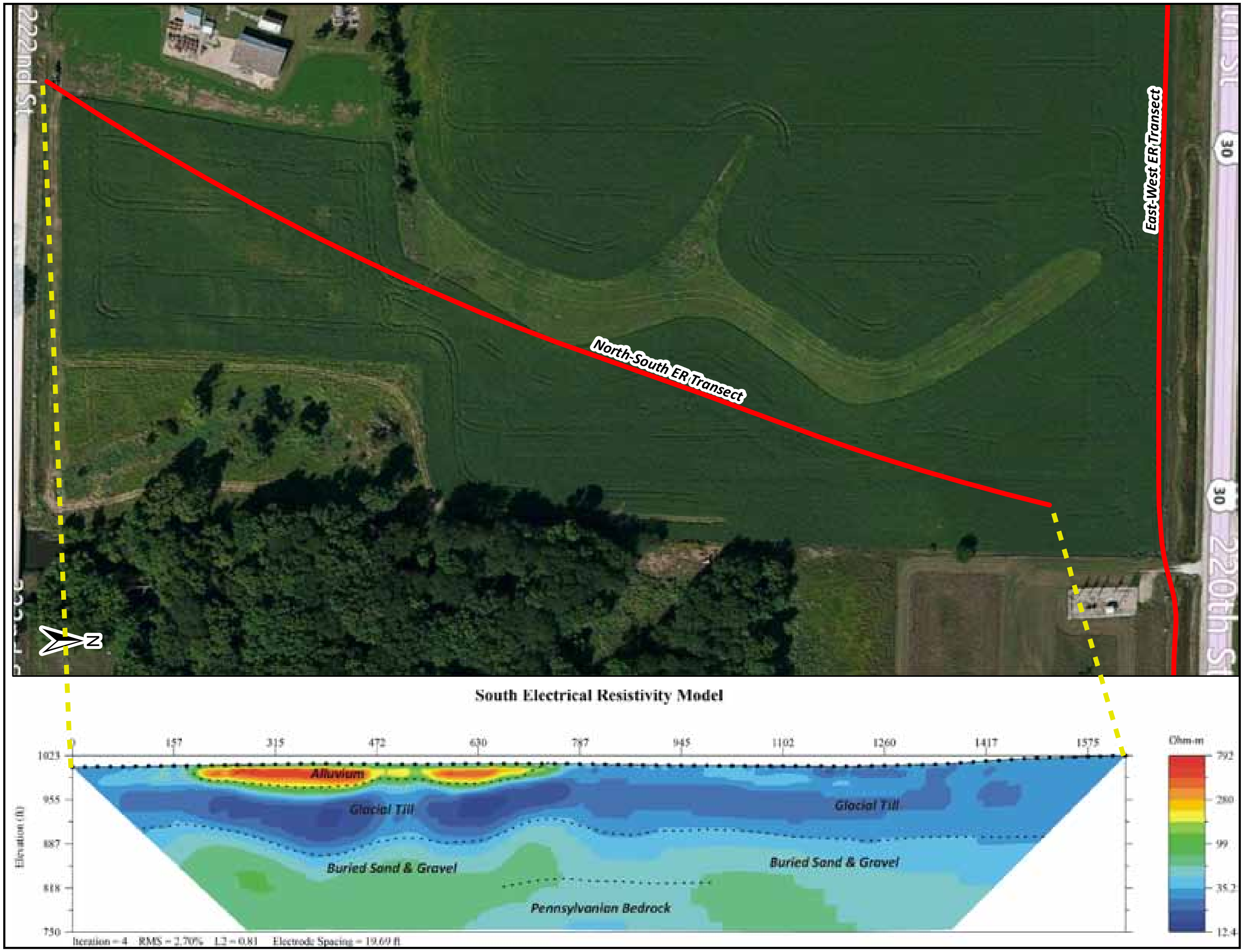

Figure 7. ER model results for the north-south transect. Dashed lines indicate interpreted geologic contacts. Note highly resistive alluvium in upper left of model.

aquifer was found to range from 9,130 ft.^{2}/day near observation well 2 (Well 8) to 14,700 ft.^{2}/day near observation well 3 (Well 8). The arithmetic mean transmissivity value is 12,000 ft.^{2}/day. Results and data from the two separate pump tests are shown in Appendix B.

Hydraulic conductivity can be calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity was found to range from 183 to 293 ft./day, with an arithmetic mean of 240 ft./day.

The model Visual MODFLOW version 2011.1 was used to simulate the groundwater flow in the buried sand and gravel aquifer in the proposed study area. A three-layered model was used for the simulation. The borehole logs were obtained from the GEOSAM database, and the elevation data was obtained from LiDAR (two-foot contour interval).

The model boundary conditions and inputs include the following:

- Layer 1 is assumed to be primarily silty clay. The horizontal hydraulic conductivity was assigned a value of 0.03 ft./day. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 2 is the buried sand and gravel aquifer. The horizontal hydraulic conductivity values were assigned based on the pump test results. These were modified slightly in the transient model to fit the model results to observed values. The vertical hydraulic conductivity values were assigned values 1/10 of the horizontal hydraulic conductivity values.
- Layer 3 is assumed to be primarily shale. The horizontal hydraulic conductivity was assigned a value of 0.03 ft./day. The vertical hydralic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- The lateral limits of the sand and gravel were considered no-flow boundaries. This was represented by deactivating the grids outside the buried sand and gravel aquifer boundary.
- General head boundaries were used to represent flow through conditions within the buried sand and gravel.
- The pumping stress caused city wells 4, 6, 7, 8, 9, and 10 were simulated in the transient model. Annual usage was obtained from the City of Jefferson for year 2012.
- Storativity values ranged from 0.00019 to 0.00035, and were based on the pump test results.
- The total number of rows and columns were 300 by 300.

The model was initially run to simulate non-pumping conditions. The non-pumping or steady-state model was calibrated using static water levels measured in the three observation wells and the six city production wells.

The pumping or transient model calibration was performed using pump test results from City of Jefferson wells 7 and 8. Hydraulic conductivity and storativity values were adjusted until the simulated water levels matched the observed values from the three observation wells.

A source water assessment, completed in 2012 for the City of Jefferson, contained fixed radius circle capture zones due to a lack of aquifer information. Through the use of information obtained from this investigation and the particle tracking module in Visual MODFLOW, groundwater movement or travel time was simulated for the public wells. The particle tracking results can be used to evaluate the source water capture zones. Revised 2-, 5-, and 10-yr. capture zones were evaluated for the in-town well field (wells 4, 6, 9, and 10) and the out-of-town well field (wells 7 and 8), and shown in Figure 8. The original capture zones are also shown in Figure 8 to provide context to the revisions. The revised capture zones significantly focus the footprint to reflect new gradient, boundary, and other aquifer information. SWP can use these capture zones to prioritize

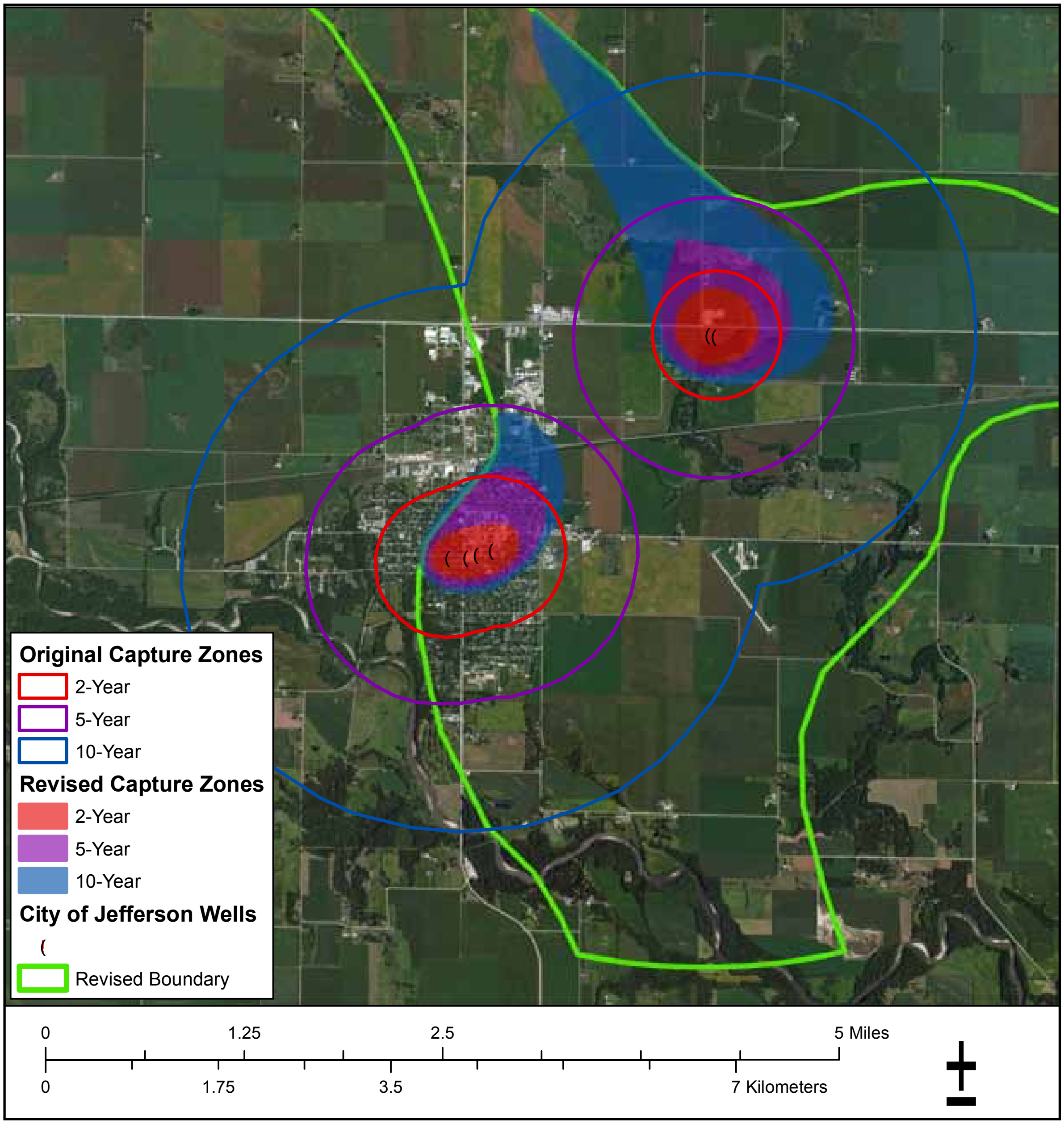

Figure 8. Original and revised 2-, 5-, and 10-yr. capture zones for the City of Jefferson active wells. The revised capture zones contain a significantly smaller and targeted footprint when compared to the original.

potential point and non-point sources of contamination and implement best management practices. These best management practices have the potential to improve and protect an aquifer's long-term water quality. The entire source water capture zone was considered to have low susceptibility to contamination from the surface based on an interpretation of more than 100 ft. of a cumulative confining layer such as till, clay, and shale between the source water aquifer and land surface. While the thick confining layer near Jefferson limits the possibility of surface contamination, it also limits recharge to the aquifer. While the potential for surface water and contamination to enter the aquifer through the confining layer is low, the potential exists for surface contamination to reach the aquifer through improperly constructed or abandoned wells.

CONCLUSIONS

The Iowa DNR initiated a geologic, geophysical, and hydrogeologic investigation to gather and summarize aquifer characteristics for the buried sand and gravel aquifer near Jefferson. The City of Jefferson expressed interest in completing a SWP plan which required the investigation to refine capture zones and gather additional aquifer information. The investigation was focused near Jefferson wells 7 and 8 to provide more aquifer information in that area.

The buried sand and gravel aquifer is most likely Wisconsinan in age associated with the advance of the Des Moines Lobe ice sheet. Geophysical surveys were completed to gather information on the variability and characteristics of the aquifer in the surveyed area. Geophysical models suggest a continuous, thick confining layer of glacial till overlies the buried sand and gravel aquifer in the surveyed area. Water, potential contaminants, and elements move very slowly through glacial till, offering good protection from surface contaminants. Areas of higher resistivity may suggest a higher concentration of coarse grained sands and gravels. The variability of resistivity values in the two models is indicative of modern river systems or glacial outwash as sediment deposition is largely dependent on the river's course through time.

A geologic site assessment was completed, including data from wells within four miles of Jefferson wells 7 and 8. Well data were used to create a geologic interpretation of the aquifer boundaries and thicknesses of the sand and gravel. It appears the thickest sand and gravel in the aquifer may trend in a north-south direction though Jefferson before trending east-north of town.

A hydrogeologic assessment was completed for the aquifer. Pressure transducers were installed and pumping data were collected from city-owned and other nearby wells. Results from these tests show hydraulic connection between three different observation wells and city production wells. Aquifer parameters were gathered and used to create refined 2-, 5-, and 10-yr. source water capture zones. Capture zones are intended to assist in the identification of point and non-point aquifer contamination sources.

FURTHER STUDIES AND LESSONS LEARNED

Geologic knowledge was gained from varying sources in this groundwater investigation. Lessons learned from this study can assist further investigations in this or other buried sand and gravel aquifer settings. Reviewing the relevance and limitations of each source will assist future buried sand and gravel aquifer investigations.

The quality, quantity, and geographic distribution of driller's logs are directly related to the success of accurately delineating buried sand and gravel aquifer dimensions. Striplogs produced by geologists may not serve as vital a role in delineating buried sand and gravel aquifers as they do in bedrock aquifers. Bedrock aquifer studies rely on striplogs for stratigraphic information while buried sand and gravel aquifer studies can benefit from either driller's logs or striplogs.

ER tomography proved valuable in finding contacts between the aquifer and confining units of contrasting resistivity. It was less successful in differentiating between the aquifer and underlying bedrock at depth. In future studies, ER might be best suited to locating lateral boundaries of buried sand and gravel aquifers. Future studies incorporating geophysical surveying techniques should also incorporate forward modeling. Forward modeling is a method used in ER surveys to create an initial model based on interpretations. Forward modeling before field data collection can provide insight into whether the equipment and inversion software is able to define aquifer boundaries as needed.

As a direct result of this investigation, Jefferson's source water capture zones decreased by approximately 90 percent. A significant reduction in capture zones allows municipalities a better opportunity to implement SWP practices. While it may be unusual for other investigations to decrease capture zones as significantly as Jefferson, future studies may benefit from a similar reduction.

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APPENDIX A

WELLS USED

W-Number	Name of Owner	Total Depth	Website Link (additional site information available online)
1034	Mcdonald	142	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=1034
4866	Jefferson, City Of	355	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=4866
4867	Jefferson, City Of	155	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=4867
4914	Jefferson, City Of	2,307	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=4914
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24921	Jefferson, City Of	90	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=24921
24922	Jefferson, City Of	170	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=24922
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33417	Hall, Donald	109	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=33417
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40473	Jefferson, City Of	163	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=40473
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49142	Hensley & Hudson	431	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49142
49143	Sorenson, Bill	453	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49143
49165	Reuter, Cecil	440	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49165
49169	Shriver, Meredith	460	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=49169
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50137	Minnihan, Kent	320	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=50137
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64448	Martino, Nicola	120	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=64448
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67739	Tri County Lumber	180	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=67739
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75917	Hamilton, Mark	150	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=75917
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75924	Dunlop, Don	198	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=75924
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75961	Rueter, Cecil	200	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=75961
75965	Schilling, Brett	151	http://www.igsb.uiowa.edu/webapps/geosam/Scripts/geocard.asp?wnumber=75965

APPENDIX B

PUMP TESTS

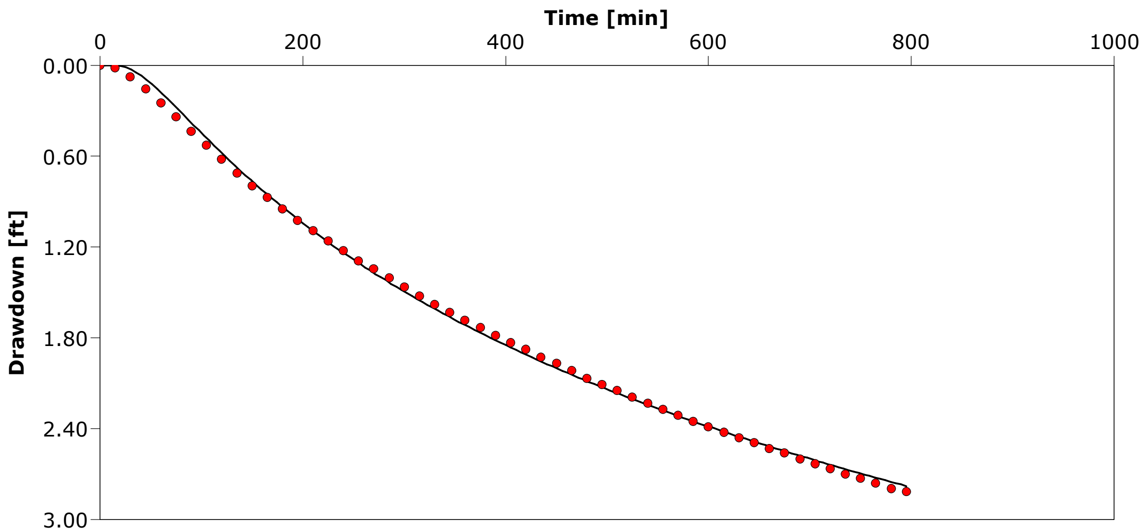
Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test - Water Level Data** Page 1 of 1 Project: Jefferson Pump Tests Number: Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR	Test Date: 12/4/2012	Discharge Rate: 1155 [U.S. gal/min]
Observation Well: ob1	Static Water Level [ft]: 37.22	Radial Distance to PW [ft]: 3782

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	37.22	0.00
2	15	37.237	0.017
3	30	37.295	0.075
4	45	37.375	0.155
5	60	37.469	0.249
6	75	37.561	0.341
7	90	37.656	0.436
8	105	37.747	0.527
9	120	37.841	0.621
10	135	37.93	0.71
11	150	38.014	0.794
12	165	38.09	0.87
13	180	38.168	0.948
14	195	38.244	1.024
15	210	38.312	1.092
16	225	38.381	1.161
17	240	38.444	1.224
18	255	38.512	1.292
19	270	38.565	1.345
20	285	38.626	1.406
21	300	38.685	1.465
22	315	38.743	1.523
23	330	38.799	1.579
24	345	38.85	1.63
25	360	38.903	1.683
26	375	38.953	1.733
27	390	39.003	1.783
28	405	39.051	1.831
29	420	39.097	1.877
30	435	39.147	1.927
31	450	39.19	1.97
32	465	39.237	2.017
33	480	39.286	2.066
34	495	39.326	2.106
35	510	39.369	2.149
36	525	39.412	2.192
37	540	39.453	2.233
38	555	39.492	2.272
39	570	39.532	2.312
40	585	39.57	2.35
41	600	39.608	2.388
42	615	39.645	2.425
43	630	39.681	2.461
44	645	39.713	2.493
45	660	39.751	2.531
46	675	39.782	2.562
47	690	39.821	2.601
48	705	39.852	2.632
49	720	39.883	2.663
50	735	39.921	2.701
51	750	39.947	2.727
52	765	39.98	2.76
53	780	40.014	2.794
54	795	40.035	2.815

	Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
		Project: Jefferson Pump Tests
		Number:
		Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR		Test Date: 12/4/2012
Analysis Performed by:	New analysis 1	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1155 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ob1	1.12×10^{4}	2.24×10^{2}	1.86×10^{-4}	3782.0	

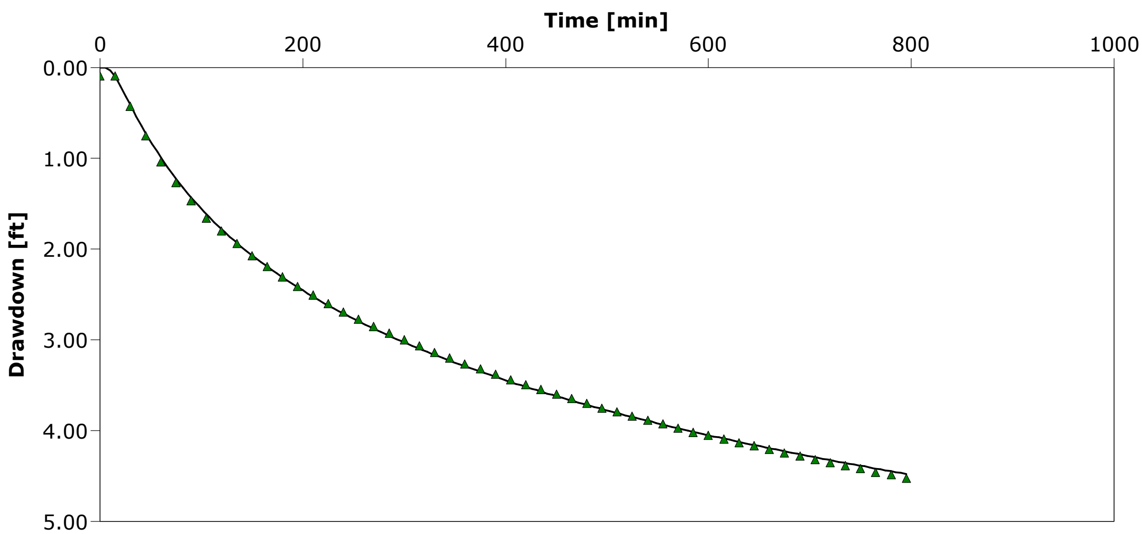
Contact Info Address Company Name City, State/Province	Pumping Test - Water Level Data	Page 1 of 1
	Project: Jefferson Pump Tests	
	Number:	
	Client:	

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR	Test Date: 12/4/2012	Discharge Rate: 1155 [U.S. gal/min]
Observation Well: ob2	Static Water Level [ft]: 33.67	Radial Distance to PW [ft]: 1823

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	33.762	0.092
2	15	33.763	0.093
3	30	34.098	0.428
4	45	34.425	0.755
5	60	34.711	1.041
6	75	34.937	1.267
7	90	35.137	1.467
8	105	35.328	1.658
9	120	35.47	1.80
10	135	35.613	1.943
11	150	35.744	2.074
12	165	35.864	2.194
13	180	35.977	2.307
14	195	36.081	2.411
15	210	36.18	2.51
16	225	36.271	2.601
17	240	36.362	2.692
18	255	36.445	2.775
19	270	36.522	2.852
20	285	36.595	2.925
21	300	36.673	3.003
22	315	36.74	3.07
23	330	36.813	3.143
24	345	36.871	3.201
25	360	36.938	3.268
26	375	36.991	3.321
27	390	37.052	3.382
28	405	37.107	3.437
29	420	37.166	3.496
30	435	37.22	3.55
31	450	37.268	3.598
32	465	37.32	3.65
33	480	37.368	3.698
34	495	37.425	3.755
35	510	37.464	3.794
36	525	37.512	3.842
37	540	37.554	3.884
38	555	37.599	3.929
39	570	37.642	3.972
40	585	37.687	4.017
41	600	37.722	4.052
42	615	37.762	4.092
43	630	37.801	4.131
44	645	37.839	4.169
45	660	37.876	4.206
46	675	37.918	4.248
47	690	37.949	4.279
48	705	37.988	4.318
49	720	38.02	4.35
50	735	38.055	4.385
51	750	38.088	4.418
52	765	38.129	4.459
53	780	38.158	4.488
54	795	38.195	4.525

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Jefferson Pump Tests
	Number:
	Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR		Test Date: 12/4/2012
Analysis Performed by:	New analysis 2	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1155 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ob2	1.12×10^{4}	2.25×10^{2}	2.52×10^{-4}	1823.0	

Contact Info Address Company Name City, State/Province	**Pumping Test - Water Level Data** Page 1 of 2
	Project: Jefferson Pump Tests
	Number:
	Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR	Test Date: 12/4/2012	Discharge Rate: 1155 [U.S. gal/min]
Observation Well: 0b3	Static Water Level [ft]: 35.88	Radial Distance to PW [ft]: 5925

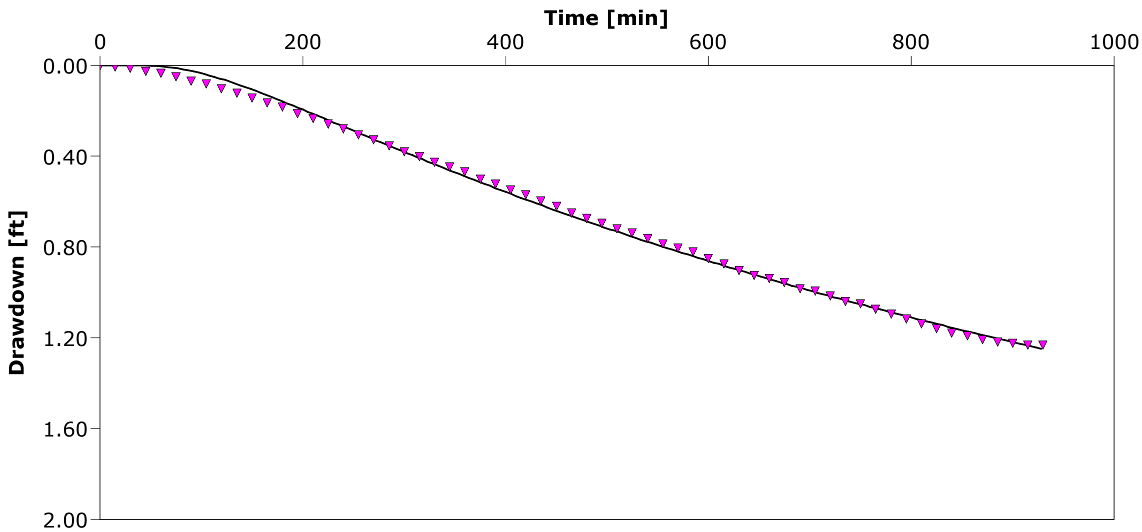
	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	35.884	0.004
2	15	35.888	0.008
3	30	35.893	0.013
4	45	35.906	0.026
5	60	35.914	0.034
6	75	35.93	0.05
7	90	35.949	0.069
8	105	35.962	0.082
9	120	35.985	0.105
10	135	36.002	0.122
11	150	36.025	0.145
12	165	36.046	0.166
13	180	36.065	0.185
14	195	36.094	0.214
15	210	36.114	0.234
16	225	36.138	0.258
17	240	36.161	0.281
18	255	36.188	0.308
19	270	36.209	0.329
20	285	36.235	0.355
21	300	36.261	0.381
22	315	36.282	0.402
23	330	36.306	0.426
24	345	36.329	0.449
25	360	36.35	0.47
26	375	36.381	0.501
27	390	36.403	0.523
28	405	36.429	0.549
29	420	36.452	0.572
30	435	36.477	0.597
31	450	36.502	0.622
32	465	36.531	0.651
33	480	36.554	0.674
34	495	36.575	0.695
35	510	36.60	0.72
36	525	36.62	0.74
37	540	36.644	0.764
38	555	36.667	0.787
39	570	36.686	0.806
40	585	36.702	0.822
41	600	36.73	0.85
42	615	36.756	0.876
43	630	36.784	0.904
44	645	36.805	0.925
45	660	36.818	0.938
46	675	36.838	0.958
47	690	36.865	0.985
48	705	36.875	0.995
49	720	36.897	1.017
50	735	36.92	1.04
51	750	36.932	1.052
52	765	36.954	1.074
53	780	36.976	1.096
54	795	36.998	1.118
55	810	37.019	1.139
56	825	37.04	1.16
57	840	37.058	1.178

Contact Info Address Company Name City, State/Province	Pumping Test - Water Level Data	Page 2 of 2
	Project: Jefferson Pump Tests	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
58	855	37.073	1.193
59	870	37.088	1.208
60	885	37.10	1.22
61	900	37.104	1.224
62	915	37.111	1.231
63	930	37.113	1.233

	Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
		Project: Jefferson Pump Tests
		Number:
		Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 7	Pumping Well: Well 7
Test Conducted by: IDNR		Test Date: 12/4/2012
Analysis Performed by:	New analysis 3	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1155 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
0b3	1.45×10^{4}	2.89×10^{2}	2.74×10^{-4}	5925.0	

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test - Water Level Data** Page 1 of 2 Project: Jefferson Pump Tests Number: Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR	Test Date: 12/5/2012	Discharge Rate: 1170 [U.S. gal/min]
Observation Well: ob1	Static Water Level [ft]: 37.57	Radial Distance to PW [ft]: 3587

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	37.57	0.00
2	15	37.614	0.044
3	30	37.694	0.124
4	45	37.79	0.22
5	60	37.894	0.324
6	75	37.998	0.428
7	90	38.103	0.533
8	105	38.195	0.625
9	120	38.29	0.72
10	135	38.378	0.808
11	150	38.466	0.896
12	165	38.546	0.976
13	180	38.624	1.054
14	195	38.703	1.133
15	210	38.775	1.205
16	225	38.847	1.277
17	240	38.916	1.346
18	255	38.981	1.411
19	270	39.048	1.478
20	285	39.107	1.537
21	300	39.167	1.597
22	315	39.225	1.655
23	330	39.282	1.712
24	345	39.339	1.769
25	360	39.393	1.823
26	375	39.443	1.873
27	390	39.492	1.922
28	405	39.545	1.975
29	420	39.595	2.025
30	435	39.643	2.073
31	450	39.689	2.119
32	465	39.737	2.167
33	480	39.781	2.211
34	495	39.827	2.257
35	510	39.872	2.302
36	525	39.913	2.343
37	540	39.958	2.388
38	555	39.997	2.427
39	570	40.038	2.468
40	585	40.081	2.511
41	600	40.119	2.549
42	615	40.152	2.582
43	630	40.194	2.624
44	645	40.23	2.66
45	660	40.266	2.696
46	675	40.303	2.733
47	690	40.337	2.767
48	705	40.373	2.803
49	720	40.408	2.838
50	735	40.436	2.866
51	750	40.473	2.903
52	765	40.495	2.925
53	780	40.534	2.964
54	795	40.566	2.996
55	810	40.599	3.029
56	825	40.629	3.059
57	840	40.657	3.087

Contact Info
Address
Company Name
City, State/Province

Pumping Test - Water Level Data

Project: Jefferson Pump Tests

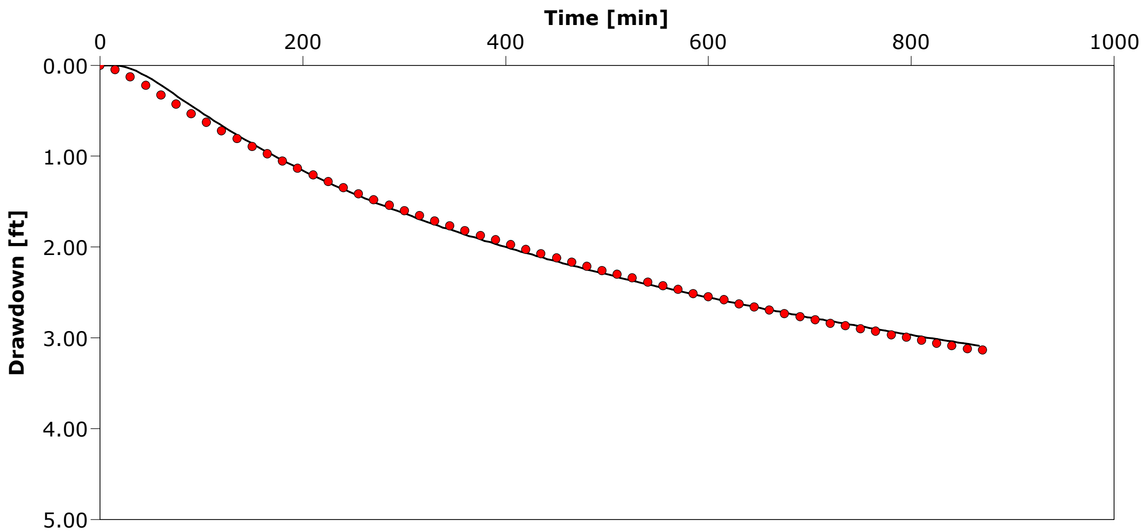
Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
58	855	40.693	3.123
59	870	40.704	3.134

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Jefferson Pump Tests
	Number:
	Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR		Test Date: 12/5/2012
Analysis Performed by:	New analysis 3	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1170 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ob1	1.12×10^{4}	2.23×10^{2}	1.87×10^{-4}	3587.0	

Contact Info Address Company Name City, State/Province	**Pumping Test - Water Level Data** Page 1 of 2 Project: Jefferson Pump Tests Number: Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR	Test Date: 12/5/2012	Discharge Rate: 1170 [U.S. gal/min]
Observation Well: ob2	Static Water Level [ft]: 34.09	Radial Distance to PW [ft]: 1870

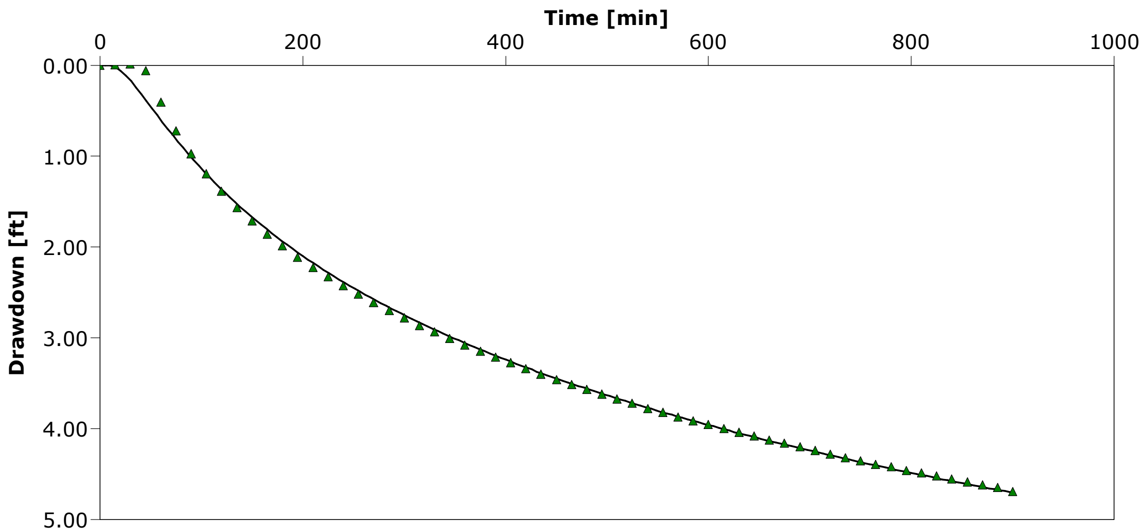
	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	34.092	0.002
2	15	34.082	-0.008
3	30	34.078	-0.012
4	45	34.149	0.059
5	60	34.496	0.406
6	75	34.813	0.723
7	90	35.064	0.974
8	105	35.284	1.194
9	120	35.478	1.388
10	135	35.655	1.565
11	150	35.802	1.712
12	165	35.948	1.858
13	180	36.078	1.988
14	195	36.206	2.116
15	210	36.314	2.224
16	225	36.417	2.327
17	240	36.517	2.427
18	255	36.612	2.522
19	270	36.703	2.613
20	285	36.789	2.699
21	300	36.872	2.782
22	315	36.956	2.866
23	330	37.026	2.936
24	345	37.10	3.01
25	360	37.167	3.077
26	375	37.238	3.148
27	390	37.302	3.212
28	405	37.364	3.274
29	420	37.427	3.337
30	435	37.488	3.398
31	450	37.551	3.461
32	465	37.604	3.514
33	480	37.656	3.566
34	495	37.709	3.619
35	510	37.764	3.674
36	525	37.813	3.723
37	540	37.867	3.777
38	555	37.912	3.822
39	570	37.962	3.872
40	585	38.003	3.913
41	600	38.044	3.954
42	615	38.092	4.002
43	630	38.131	4.041
44	645	38.173	4.083
45	660	38.216	4.126
46	675	38.251	4.161
47	690	38.292	4.202
48	705	38.331	4.241
49	720	38.369	4.279
50	735	38.409	4.319
51	750	38.441	4.351
52	765	38.481	4.391
53	780	38.513	4.423
54	795	38.548	4.458
55	810	38.58	4.49
56	825	38.609	4.519
57	840	38.646	4.556

Contact Info Address Company Name City, State/Province	Pumping Test - Water Level Data	Page 2 of 2
	Project: Jefferson Pump Tests	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
58	855	38.674	4.584
59	870	38.709	4.619
60	885	38.739	4.649
61	900	38.786	4.696

	Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
		Project: Jefferson Pump Tests
		Number:
		Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR		Test Date: 12/5/2012
Analysis Performed by:	New analysis 2	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1170 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ob2	9.13×10^3	1.83×10^2	3.51×10^{-4}	1870.0	

	Contact Info Address Company Name City, State/Province	Pumping Test - Water Level Data	Page 1 of 2
		Project: Jefferson Pump Tests	
		Number:	
		Client:	

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR	Test Date: 12/5/2012	Discharge Rate: 1170 [U.S. gal/min]
Observation Well: 0b3	Static Water Level [ft]: 35.88	Radial Distance to PW [ft]: 6126

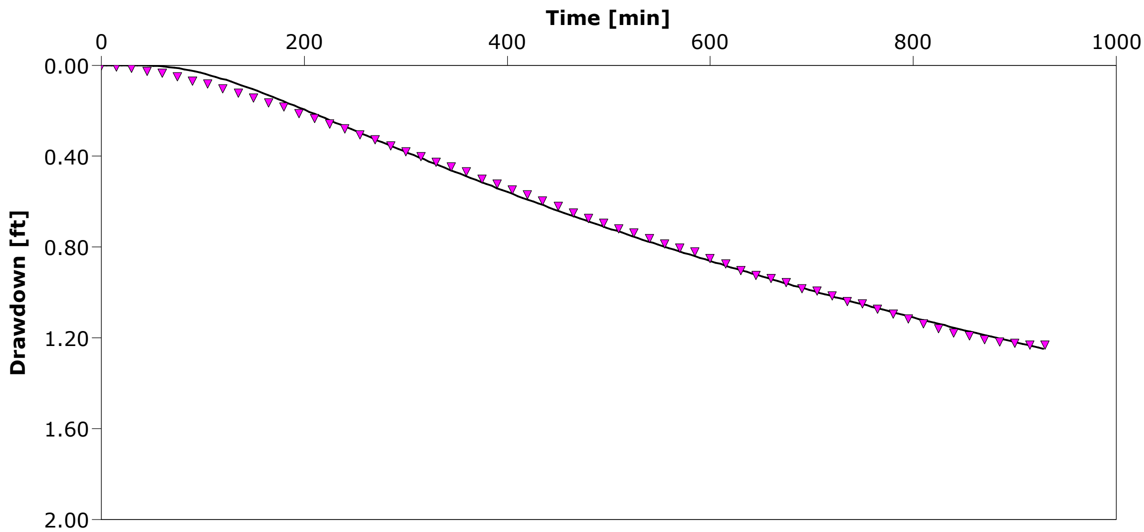
	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	35.884	0.004
2	15	35.888	0.008
3	30	35.893	0.013
4	45	35.906	0.026
5	60	35.914	0.034
6	75	35.93	0.05
7	90	35.949	0.069
8	105	35.962	0.082
9	120	35.985	0.105
10	135	36.002	0.122
11	150	36.025	0.145
12	165	36.046	0.166
13	180	36.065	0.185
14	195	36.094	0.214
15	210	36.114	0.234
16	225	36.138	0.258
17	240	36.161	0.281
18	255	36.188	0.308
19	270	36.209	0.329
20	285	36.235	0.355
21	300	36.261	0.381
22	315	36.282	0.402
23	330	36.306	0.426
24	345	36.329	0.449
25	360	36.35	0.47
26	375	36.381	0.501
27	390	36.403	0.523
28	405	36.429	0.549
29	420	36.452	0.572
30	435	36.477	0.597
31	450	36.502	0.622
32	465	36.531	0.651
33	480	36.554	0.674
34	495	36.575	0.695
35	510	36.60	0.72
36	525	36.62	0.74
37	540	36.644	0.764
38	555	36.667	0.787
39	570	36.686	0.806
40	585	36.702	0.822
41	600	36.73	0.85
42	615	36.756	0.876
43	630	36.784	0.904
44	645	36.805	0.925
45	660	36.818	0.938
46	675	36.838	0.958
47	690	36.865	0.985
48	705	36.875	0.995
49	720	36.897	1.017
50	735	36.92	1.04
51	750	36.932	1.052
52	765	36.954	1.074
53	780	36.976	1.096
54	795	36.998	1.118
55	810	37.019	1.139
56	825	37.04	1.16
57	840	37.058	1.178

Contact Info Address Company Name City, State/Province	Pumping Test - Water Level Data	Page 2 of 2
	Project: Jefferson Pump Tests	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
58	855	37.073	1.193
59	870	37.088	1.208
60	885	37.10	1.22
61	900	37.104	1.224
62	915	37.111	1.231
63	930	37.113	1.233

	Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
		Project: Jefferson Pump Tests
		Number:
		Client:

Location: Jefferson, Iowa	Pumping Test: Pump Test Well 8	Pumping Well: Well 8
Test Conducted by: IDNR		Test Date: 12/5/2012
Analysis Performed by:	New analysis 1	Analysis Date: 12/12/2012
Aquifer Thickness: 50.00 ft	Discharge Rate: 1170 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
0b3	1.47×10^{4}	2.93×10^{2}	2.59×10^{-4}	6126.0	

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