Groundwater Availability Modeling Of the Mississippian Aquifer North-Central Iowa

Iowa Geological and Water Survey
Water Resources Investigation Report 8

Iowa Department of Natural Resources
Chuck Gipp, Director

June 2013

Cover: Artesian flowing well in Benson Flowing Well Park west of Clarion, Iowa. Groundwater flows naturally to the ground surface due to pressure within the Mississippian aquifer.

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Prepared by

J. Michael Gannon
Robert M. McKay, Geologist

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The authors would like to acknowledge the contributions of the many individuals who assisted in the production of this report. First, much of our understanding of the Mississippian aquifer in Iowa is built on the work of previous Iowa Geological Survey geologists Paul Horick and Bill Bunker. Various companies supplied pump test and recovery test data including Layne Christiansen and Shawver Well Company. Editorial reviews were provided by Lynette Seigley, Mindy Kralicek, and Ryan Clark. The report layout was done by Mindy Kralicek.

EXECUTIVE SUMMARY

Increased demand for groundwater by agriculture, industries, and municipalities has raised concerns for the long-term sustainability of the resource. In 2007, the Iowa legislature began funding a comprehensive Water Resources Management program to be implemented by the Iowa Department of Natural Resources. A key aspect of the program is to evaluate and quantify the groundwater resources across the state using computer simulation models. These models help answer questions such as: How much water can be pumped from an aquifer over 10, 20, or 100 years? or Will my well go dry?

This report documents an intensive one-year investigation of the hydrogeology of the Mississippian aquifer in north-central Iowa, and the construction of a groundwater flow model that can be used as a planning tool for future water resource development. The hydrologic characteristics of the geologic layers included in the modeling of the Mississippian aquifer were also investigated.

A total of 19 aquifer pump tests and recovery tests and 140 specific capacity tests were used to calculate the aquifer parameters. The hydraulic properties of the Mississippian aquifer were shown to vary considerably in both the lateral and vertical direction. The hydraulic conductivity of the aquifer ranges from 0.14 to 1,510 feet per day, with an arithmetic mean of 123 feet per day. Transmissivity values range from 17 to 93,000 $ft.^2$/day. The storage coefficient of the Mississippian aquifer ranges from 10^{-4} to 10^{-1}.

Recharge to most of the Mississippian aquifer is through confining beds that include glacial till and various shale units. Due to the highly variable thickness and coverage of these confining units, the rate of recharge ranges from 10^{-3} inches per year over the southwestern half of the study area to 1.5 inches per year over north-central portions of the study area, and along the major river valleys, where the confining beds are thin or absent.

With this information, a numerical groundwater flow model of the Mississippian aquifer was developed using three hydrogeologic layers. The model was created using Visual MODFLOW version 11.1. Hydrologic processes examined in the model include net recharge, hydraulic conductivity, specific storage, general head boundaries, constant head boundaries, well discharge, river boundaries, and well interference.

The modeling approach involved the following components:

1. Calibrating a pre-development steady-state model using water level data from historic records.
2. Calibrating a transient model using water-use data from 2003 to 2012. Simulated water levels were compared to observed water level measurements.

The calibrated model provided good correlation for transient conditions. A root mean square error of 16.8 feet was calculated. This is a relatively small error for an aquifer that covers most of north-central Iowa. Simulated water level changes are most sensitive to changes in hydraulic conductivity.

Based on the groundwater flow modeling results, an additional 1 billion gallons per year (bgy) of groundwater could be withdrawn from the Mississippian aquifer using precipitation recharge alone. A much higher withdrawal rate is possible based on the relatively large volume of groundwater (10.6 bgy) that is discharged into the major river systems. Not all of this water could be withdrawn without potentially impacting the baseflow conditions of these rivers. A conservative estimate of 50 percent of the river recharge might be available for new or amended water use permits. This would be an additional 6.3 bgy of additional groundwater availability (5.3 bgy from converted river recharge and 1 bgy from available precipitation recharge).

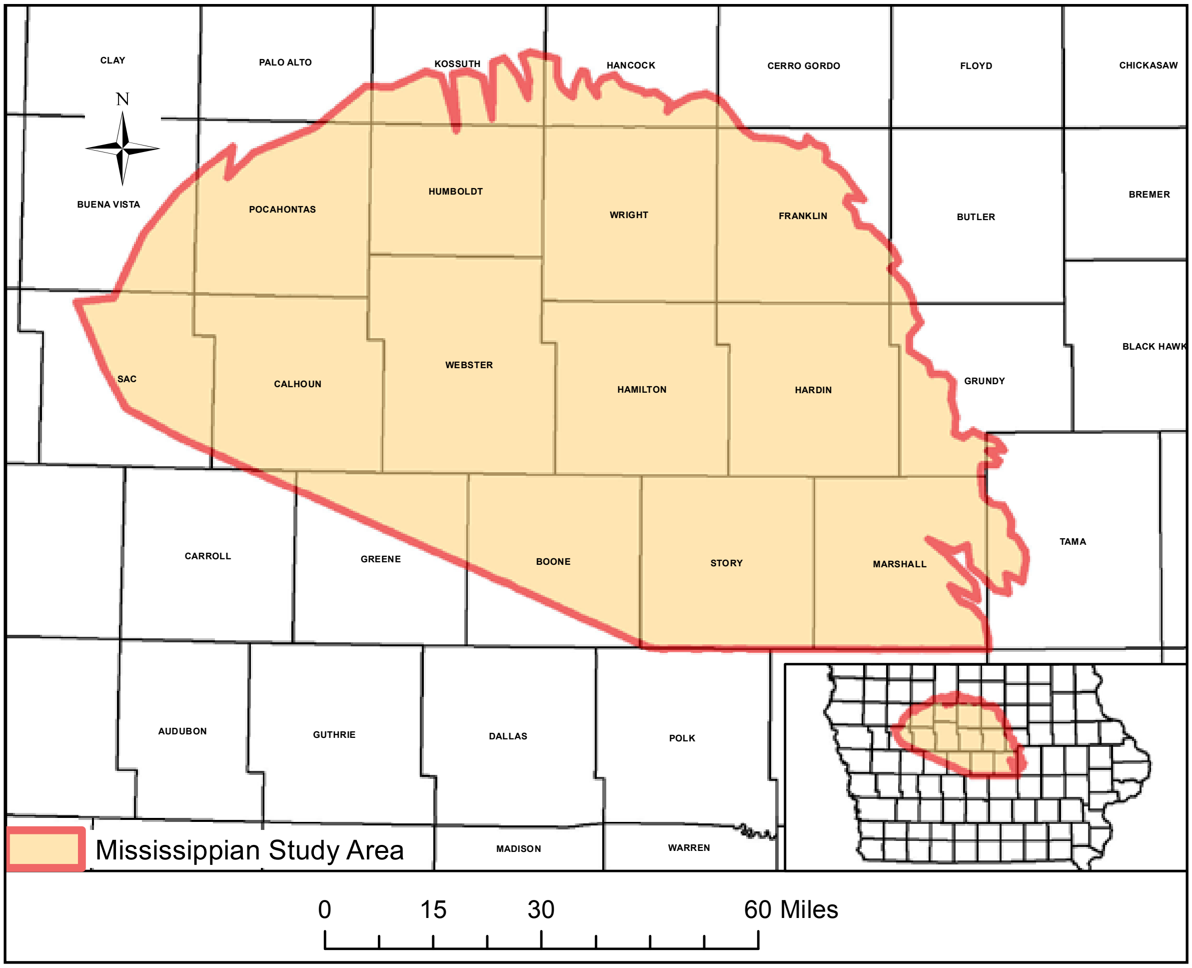

Figure 1. Mississippian aquifer study area in Iowa.

INTRODUCTION

The Mississippian aquifer is one of the most dependable sources of groundwater in north-central Iowa. Wells drilled into the Mississippian aquifer supply large volumes of water to livestock, industries, and municipalities. Based on the aquifer's relatively shallow depth, and its relatively good water quality, it is also widely used by both rural subdivisions and private well owners. An earlier study of the Mississippian aquifer was conducted by Horick and Steinhilber (1973). In this earlier study, the authors prepared a potentiometric map of the aquifer, evaluated the geology, and prepared an aquifer-wide water balance.

The purpose of this study was to provide an updated, comprehensive, and quantitative assessment of groundwater availability in the Mississippian aquifer in north-central Iowa. The study area for the Mississippian aquifer includes all or part of ten counties as shown in Figure 1. The assessment included the development of a three-dimensional groundwater flow model to guide future development and utilization of the aquifer. The study included the following tasks:

- Collecting, compiling, and analyzing available geologic and hydrologic data;
- Collecting, compiling, and estimating the location and amounts of groundwater withdrawals within the study area;

- Constructing and calibrating a groundwater flow model;
- Simulating future water-use scenarios and the overall groundwater availability within the aquifer;
- Documenting the data used in the model simulations.

GEOLOGY

Mississippian rocks of the study area consist primarily of a thick sequence of interbedded limestone and dolostone strata that attain a maximum thickness of 470 feet. Subordinate amounts of shale, siltstone and sandstone are concentrated at the base and within the upper parts of the overall rock sequence. Exposures of Mississippian aquifer strata at the land surface are not common and are confined to small areas along major rivers and drainages where rock quarries are typically developed. Mississippian strata are at the bedrock surface across the northeastern half of the study area, but are dominantly covered by varying thicknesses of Quaternary age glacial till and alluvial unconsolidated sediments. Across the remainder of the study area Mississippian strata are buried by a combination of Quaternary, Cretaceous and Pennsylvanian age strata of varying thickness. Mississippian strata are not mapped within the Manson Impact structure in the western portion of the study area, although small intact blocks of Mississippian rocks do occur along the northeast margin within the structure. Mississippian strata are displaced by faults within the Fort Dodge graben in Webster County (Hale, 1955), and along the northeast extension of the Thurman-Redfield Structural Zone western Story County (Witzke et al., 2010).

Mississippian Aquifer Stratigraphy

The stratigraphic succession has been divided into a series of Groups and Formations that are based on the recognition of distinctive lithofacies and stacked cycles of transgressive and regressive depositional lithologies as discussed by Woodson and Bunker (1989), and Witzke and Bunker (1996 and 2005), and illustrated in Figure 2. The basal portion of each cycle was deposited during a transgression or flooding and deepening of the Mississippian shelf seaway. The middle and upper portions of each depositional cycle would have been deposited during a gradual progradation of the shoreline seaward and filling of the accommodation space within the shelf water column. In general, shallow water lithologies dominate to the northwest and deeper water lithologies dominate to the southeast, thereby defining a shelf that gradually sloped and deepened from the northwest to the southeast across the study area.

Basal Mississippian strata of the Prospect Hill siltstone and Chapin limestone overlie Devonian shale across the study area; they are generally less than 20 feet thick and are not considered to be water producing. Overlying the basal Prospect Hill and Chapin are the cherty limestones and dolostones of the Maynes Creek Formation, 110 to 140 feet thick, which comprise the lower fourth of the Mississippian sequence. Maynes Creek strata can be highly productive where sufficiently fractured and/or karsted, especially where overlain by alluvial sand and gravel.

The Gilmore City and Burlington formations overlie the Maynes Creek and share a lateral facies relationship; combined they occupy the middle third of the aquifer. Skeletal, oolitic and mud-dominated limestone and lesser dolostone of the Gilmore City Formation is thickest in the northwest and gradually thins to the southeast and is replaced laterally by cherty, glauconitic, and skeletal dolostones of the Burlington Formation. Maximum thickness of the Gilmore City is 140 feet in the Fort Dodge area, and maximum thickness of the Burlington, of approximately 90 feet, occurs in southern Marshall County. The Burlington Formation is included in the lower portion

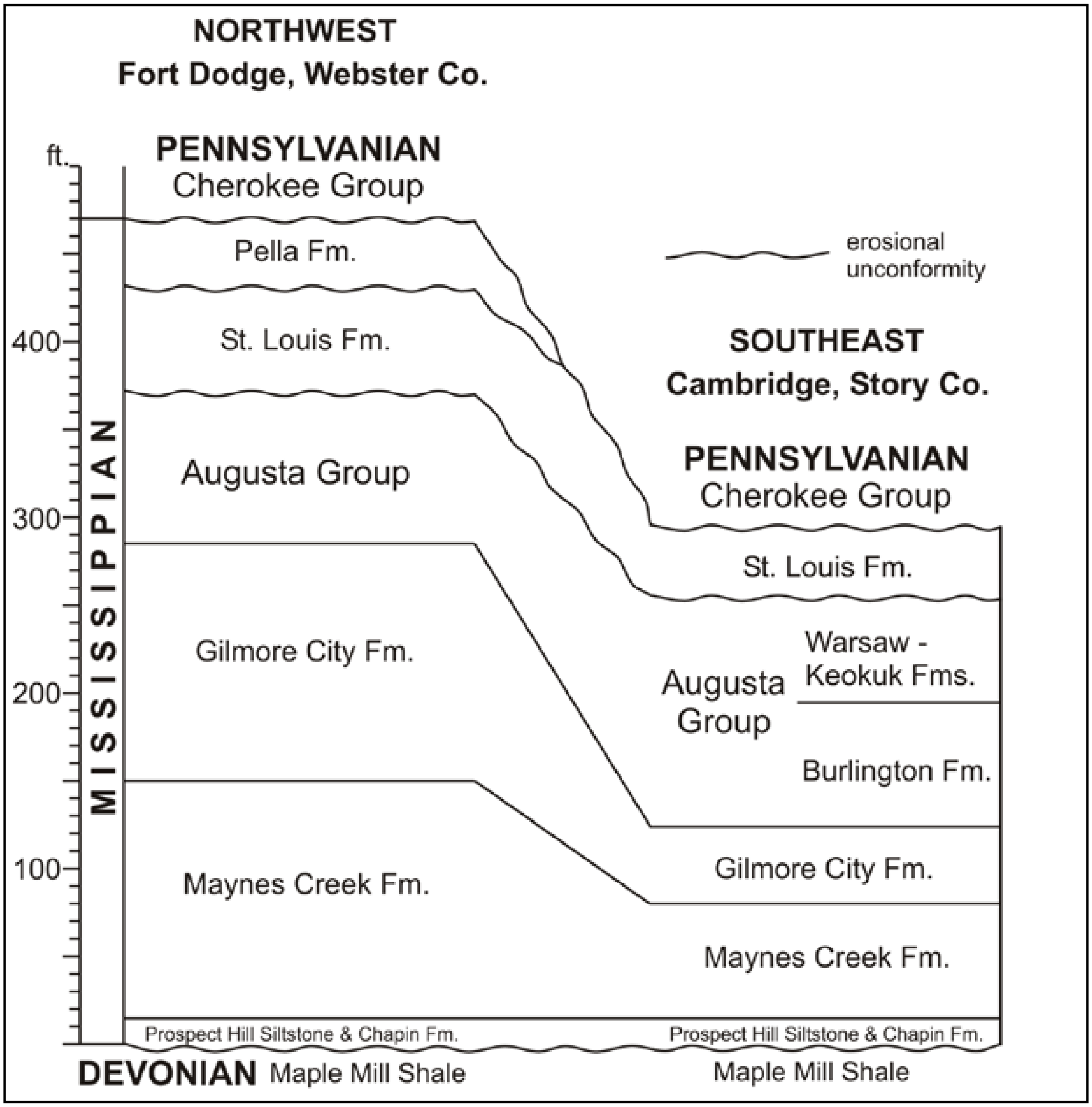

Figure 2. Stratigraphic chart of the Mississippian aquifer rock sequence showing formations and groups, and their thickness variations between the northwest and southeast portions of the study area. Bounding Pennsylvanian and Devonian units serve as upper and lower aquifer confining strata.

of the Augusta Group for mapping purposes. Water production from the generally dense limestones and dolostones of the Gilmore City and Burlington formations varies tremendously based upon fracture density, the presence or absence of karst, and vertical proximity to saturated alluvial sand and gravel. Above the Burlington Formation is the remainder and upper portion of the Augusta Group, variably cherty dolomite and lesser shale which are lateral equivalents of the Keokuk and Warsaw formations of southeast Iowa. Maximum thickness of the Augusta Group is 90 feet in the northwest part of the study area at Fort Dodge and 140 feet to the southeast at State Center in Marshall County. Generally, the shaley nature of the upper Augusta Group precludes it from being considered a productive aquifer.

Overlying the Augusta Group and comprising the upper fourth of the Mississippian aquifer is the St. Louis and overlying Pella formations. The St. Louis Formation is composed of sandstone, dolostone and limestone and has a maximum thickness of 60 feet at Fort Dodge. The Pella Formation is comprised of calcareous shale and lesser limestone and attains a maximum thickness of 50 feet in Webster County. Of the two, only the St. Louis is capable of serving as an aquifer.

Confining Units of the Mississippian Aquifer

Devonian shale of the Maple Mill and Sheffield formations underlie the Mississippian aquifer and form a lower confining unit. Total confining shale thickness varies across the study area from 20 feet in the northwest to 100 feet in the southeast. These shale formations effectively separate the carbonates (limestones and dolostones) of the Mississippian aquifer from those of the underlying Devonian carbonate aquifer.

The upper portion of the Augusta Group, above the Burlington Formation, serves as a confining unit within the Mississippian aquifer due to its shaley characteristics. Likewise, where present, the shales of the Pella Formation serve as an uppermost confining unit; however, Pella shales are often eroded or missing and the more common and widespread upper confining unit is shale and mudstone of the overlying Pennsylvanian lower Cherokee Group. The Pennsylvanian lower Cherokee Group rests unconformably on Mississippian strata across the entire southwest half of the study area, and as outliers across the northeast half. Unconformable erosional relief along the Mississippian/Pennsylvanian contact exceeds 150 feet regionally. Basal lower Cherokee Group strata typically are composed of shale and mudstone, but occasionally may be sandstone in hydraulic connection with underlying Mississippian carbonates.

In the far northwest portion of the study area, Cretaceous Dakota Formation overlies Mississippian strata. Dakota Formation strata may vary from sandstone to mudstone and therefore may or may not serve as an upper confining unit.

In the northeastern half of the study area, where Mississippian strata are present at the bedrock surface and overlain by Quaternary unconsolidated material, glacial till serves as an upper confining unit across a significant area.

HYDROGEOLOGY

Hydrostratigraphic Units

Three distinct hydrostratigraphic layers were identified for groundwater flow modeling of the Mississippian aquifer. Each of the layers consists of various geologic formations that include both confining units and local and regional aquifers. The geologic complexity was simplified in order to focus the modeling efforts on the hydrology. The stratigraphic, formational, and hydrostratigraphic units are presented in Figure 2.

Hydrostratigraphic Layer 1

The upper most hydrostratigraphic layer (Layer 1) includes the following systems, groups, or formations lumped together as a single unit: Quaternary System (glacial till and alluvial sediments), Pennsylvanian System (southwestern area only), Cretaceous System (northwest region only). Layer 1 varies in thickness from less than 25 feet in along the major rivers and the edge of the outcrop region to over 500 feet in parts of Boone, Calhoun, Greene, Sac, and Story counties. For the pur-

Table 1. Aquifer pump test results for wells open in the Mississippian aquifer.

WNumber	Name	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Thickness (ft)	Storage	Method
3375	Bode	8070	67.30	120	NA	Recovery
13238	Conrad	533	5.30	101	NA	Recovery
8847	Eagle Grove	4980	17.50	285	0.0007	Theis
34052	Eldora 93-2	3440	26.70	129	NA	Recovery
566	Havelock	85	0.94	90	NA	Recovery
2162	Hubbard	473	1.93	245	NA	Recovery
27238	Jolley Well 1	67	0.20	335	NA	Recovery
55996	Marshalltown #15	93300	1510.00	62	NA	Recovery
8215	Moorland	17	0.04	425	NA	Recovery
6622	Randall #1	118	0.50	236	NA	Recovery
2075	Roland #1	1770	9.70	182	NA	Recovery
2973	Rolfe #2	6030	92.70	65	NA	Recovery
3374	Rutland #1	9780	28.80	340	NA	Recovery
54830	Rutland Marsh	2480	7.10	349	NA	Recovery
54648	Somers #2	8330	83.30	100	NA	Recovery
5188	Steamboat Rock	3870	59.30	65	NA	Recovery
26357	Whitten #2	559	5.30	105	NA	Recovery
63949	Belmond Global	56000	412.00	136	0.0090	Theis
3269	Ackley	659	8.90	74	0.0001	Theis

poses of this report, Layer 1 behaves as a regional confining layer over most of the study area. Exceptions to this occur along parts of the Iowa, Des Moines, and Skunk rivers, where alluvial deposits may be in direct contact with the aquifer. Layer 1 is the source of net recharge for the Mississippian aquifer. No attempt was made to model groundwater flow within the various aquifers and confining beds in Layer 1. The primary purpose of this layer was to provide a long-term source of recharge or leakage for the Mississippian aquifer, and to create confining conditions within most of Layer 2.

The shale units of the Pennsylvannian System and various glacial tills create a relatively low permeability layer over most of the of the study area. The lateral extent and thickness of these units creates a regional confined or leaky confined aquifer system. The horizontal and vertical hydraulic conductivity of Layer 1 was estimated based on the lithology and soil type found in boring logs and driller's logs.

Hydrostratigraphic Layer 2 (Mississippian aquifer)

The Mississppian aquifer in north-central Iowa includes the Meramecian, Osagean, and Kinderhookian Series. The Kinderhookian Series is the most productive of the three, escially the Gilmore City and Hampton formations. Wells located in Belmond, Eagle Grove, and Story City can produce between 500 and 882 gallons per minute (gpm), and wells located in Marshalltown can produce between 1,000 and 4,000 gpm. Much of this production is coming from fractures, voids, and karst features within the limestone and dolostone.

The most reliable hydraulic properties are those obtained from controlled aquifer pump tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Nineteen aquifer pump tests conducted in wells open in the Mississippian aquifer were found in our study area. In addition to the aquifer pump tests, a total of 140 specific capacity tests were obtained. The distribution of these tests is shown in Figure 3. Table 1 lists the pump/recovery results for each test, the method of analyses, transmissivity values, aquifer thickness, hydraulic conductivity values, storativity values (aquifer pump test results only), and who collected the data. Appendix A contains the raw data and graphs for the pump/recovery tests, and Appendix B contains the results for the specific capacity tests.

Based on aquifer test results, the transmis-

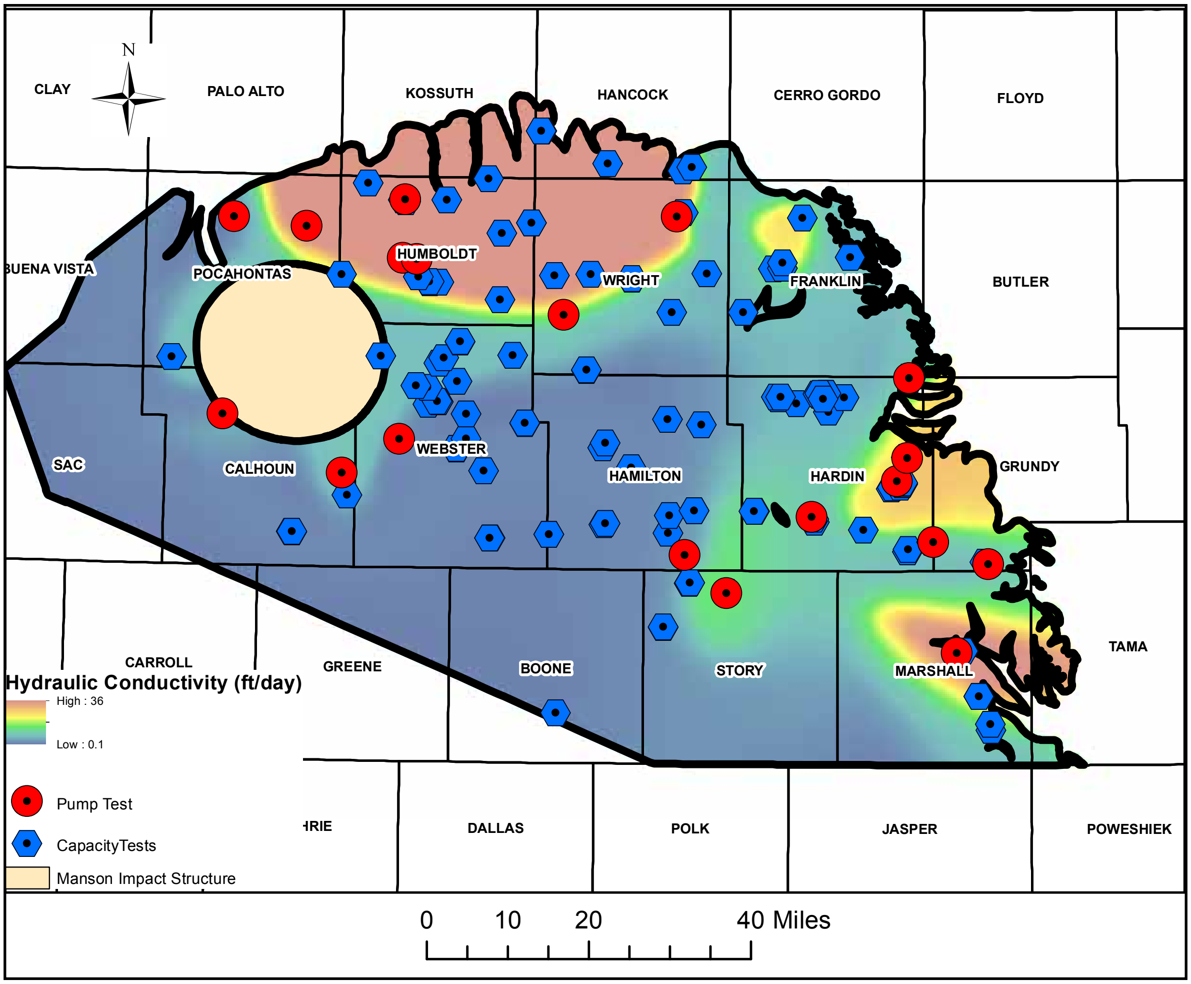

Figure 3. Location of aquifer tests conducted in the Mississippian aquifer and hydraulic conductivity distribution.

sivity of the Mississippian aquifer was found to range from 17 ft.^{2}/day in City of Moorland Well 1, to 93,300 ft.^{2}/day in City of Marshalltown Well 15. The arithmetic mean transmissivity value is 10,500 ft.^{2}/day. Much of the variability in the transmissivity is related to the secondary permeability (fractures, voids and karst features) found within the limestone and dolomite units. Local transmissivity may be much higher or lower than those listed in Table 1. This is largely due to the fractures and voids found especially in the Gilmore City and Hampton formations. These fractures and voids have limited lateral extent, and may not be representative of the regional permeability distribution.

Hydraulic conductivity is considered an intrinsic parameter, which means that it is independent of the thickness of the formation. It is calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity is also the input variable used in the groundwater model. Hydraulic conductivity was found to range from 0.04 to 1,510 feet/day, with an arithmetic mean of 123 feet/day. If the Belmond Global test well and Marshalltown Well 15 pump tests are excluded from the average, the arithmetic mean hydraulic conductivity value is 45 feet/day. The standard deviation of the hydraulic conductivity was 339. The regional horizontal hydraulic conductivity distribution in the Mississippian aquifer is shown on Figure 3 and is based on data found in Table 1 and Appendices A and B.

Another important aquifer parameter mesured during an aquifer test is the dimensionless storage coefficient. The storage coefficient or storativity is equal to the volume of water released from a vertical column of the aquifer per unit surface area of the aquifer and unit decline in water level (Freeze and Cherry, 1979). Based on aquifer pump test data, the storage coefficient of the Mississippian aquifer ranges from 10^{-4} in the City of Ackley inactive well 1, to 9×10^{-3} in the Belmond Global test well.

Hydrostratigraphic Layer 3

The stratigraphic unit below the Mississippian aquifer is the Devonian System, and comprises Layer 3. The Devonian System is dominated by shale, siltstone and limestone, and forms a regional confining and semi-confining unit.

GROUNDWATER RECHARGE AND DISCHARGE IN THE MISSISSIPPIAN AQUIFER

Recharge to the Mississippian aquifer in the study area is from precipitation where the bedrock is at or near the surface, leakage to the aquifer from the major river systems (loosing stretches of the Iowa, Skunk and Des Moines River systems), leakage from overlying shale and glacial deposits, and groundwater inflow from outside the study area. The primary sources of discharge include the pumping of production wells, discharge into the major river systems (gaining stretches of the Iowa, Skunk and Des Moines River systems), and groundwater outflow from the study area.

Efforts have been made to quantify the water balance of the Mississippian aquifer. Horick and Steinhilber (1973) used the estimated groundwater recharge as an indicator of groundwater availability. Using a uniform recharge value of 0.03 inches per year, they estimated the groundwater availability to be 360 million gallons per day. They ignored the contributions from areas overlain with thin glacial tills and alluvial sand and gravel.

Based on data provided by the Iowa DNR water-use database for wells pumping over 25,000 gallons per day (gpd), the withdrawal of groundwater from the Mississippian aquifer is estimated to be 15.6 million gallons per day (mgd). If private wells are included in the daily water usage, the total withdrawal increases to 16.6 mgd.

The daily rate of water lost or gained by various stretches of the major river systems in our study area would require many streamflow measurements. The loosing and gaining stretches, along with the associated flow rates, would vary depending on weather conditions, the river stage, the groundwater elevations, and pumping rates of the Mississippian wells. An estimate of groundwater discharge/recharge to the major rivers will be discussed in the modeling section of the report.

GROUNDWATER FLOW

Groundwater elevation contours or potentiometric surface in the Mississippian aquifer were estimated using water level measurements collected from wells open in the Mississippian aquifer (Appendix C). The potentiometric surface was contoured using data collected from 2000 to 2010, and is shown in Figure 4. Regional groundwater flow is generally from northwest to southeast, with the major rivers strongly influencing local flow conditions. Groundwater contours have been slightly influenced by the major pumping centers in Franklin, Hamilton, Hardin, Humboldt, Webster, and Wright counties.

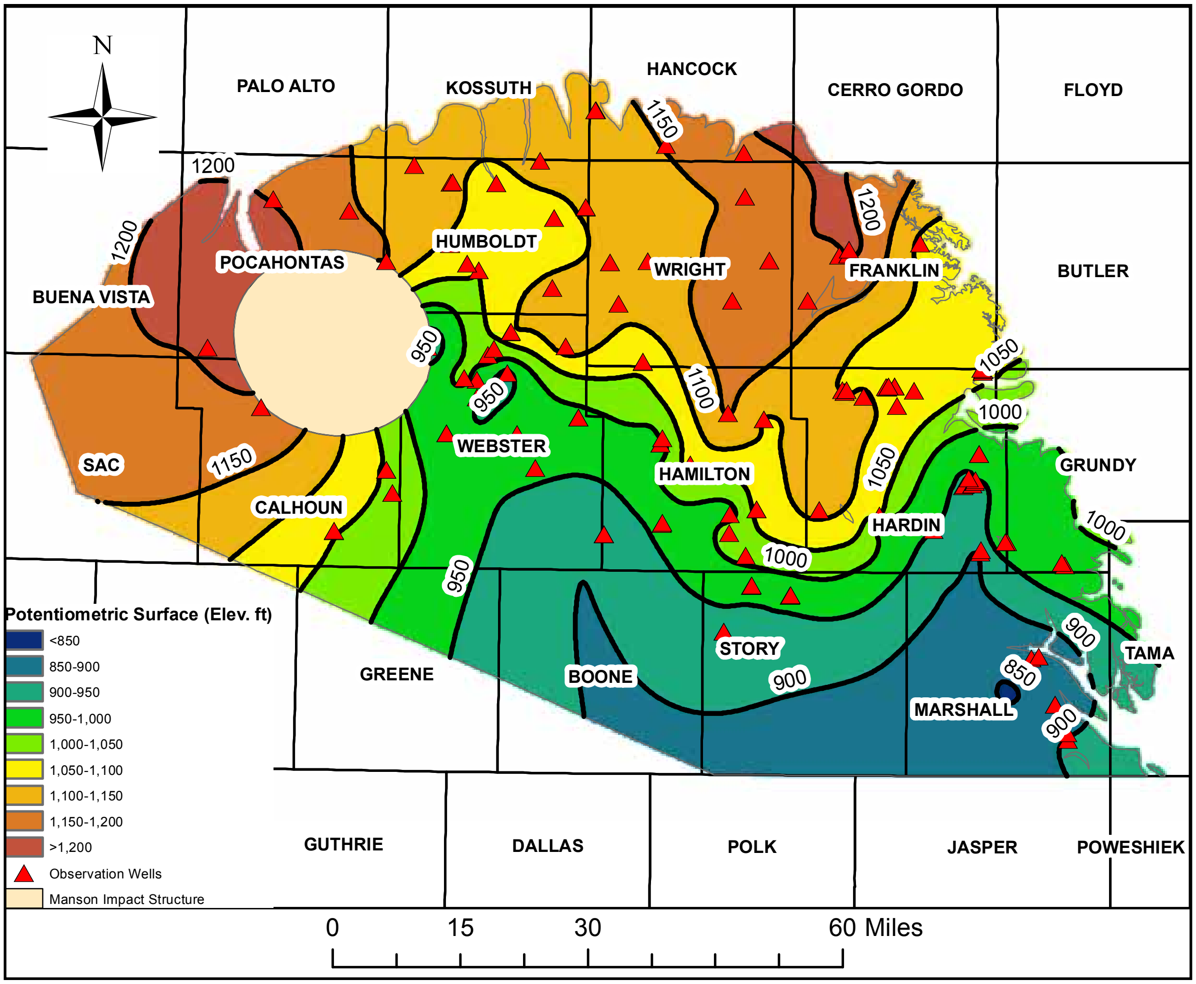

Figure 4. Observed potentiometric elevations in the Mississippian aquifer 2000 to 2010.

CONCEPTUAL GROUNDWATER MODEL

A conceptual model represents our best understanding of the three-dimensional geology and hydrogeology. A conceptual model does not necessarily use formations or stratigraphic units, but relies primarily on variations in lithology and hydraulic parameters to represent groundwater flow conditions. The following items represent the basic elements of the conceptual model of the Mississippian aquifer:

- The Mississippian aquifer was modeled using three layers based on the hydrostatic units discussed earlier in this report.
- The regional confining beds and localized aquifers above the Mississippian aquifer comprise Layer 1.
- The Mississippian aquifer is represented by Layer 2 and is confined or unconfined above by various shale, glacial deposits, and alluvium. Flow-through boundaries are assumed to be along the southwest edge of the study areas.
- The base of the model (Layer 3) represents the Devonian System. Layer 3 is considered a confining or semi-confining unit.
- Recharge varies based on lithology, soil type, and thickness of layer 1.

- For simplicity, baseflow river conditions are used in the model, and are based on LiDAR elevations.
- To evaluate steady-state conditions, the static water levels (non-pumping conditions) were used.
- Drawdown in static water levels since predevelopment has been caused by pumping and to a lesser extent fluctuations in precipitation.

Model Design

A numerical model of the Mississippian aquifer in north-central Iowa was developed to evaluate groundwater availability and sustainability using historic, current, and future usage scenarios.

Code and Software

Groundwater flow in the Mississippian aquifer was simulated using Visual MODFLOW Version 2011.1 (Schlumberger Water Services/Waterloo Hydrogeologic, Inc. 2011). The preconditioned conjugate-gradient method was used to solve the linear and non-linear flow conditions (Hill, 1990). MODFLOW is a widely used finite difference groundwater modeling program originally developed by the United States Geological Survey.

Model Parameters

The following model parameters were included in Visual MODFLOW:

- The model consisted of three layers as described in the conceptual model.
- The top surface for each of the three layers was entered using 583 by 411 meter grids. The grid dimensions were modified near major pumping centers, and range from 6 to 20 meters. The top of Layer 1 was the ground-surface elevation (LiDAR). The top surfaces for Layers 2 and 3 were derived from geologic grid surfaces.
- Layer 1 represents glacial deposits, alluvium, limestone, and shale. Because the type of lithology, soil type and thickness determine the vertical movement of groundwater to the Mississippian aquifer, the aquifer parameters assigned to this layer varied. The hydraulic conductivity distribution for Layer 1 is shown in Figure 5. The vertical hydraulic conductivity was assigned a value of one-tenth of the horizontal value.
- Horizontal hydraulic conductivity values in the Mississippian aquifer were obtained from aquifer pump tests and are shown in Figure 3. The vertical hydraulic conductivity was assigned a value that was one-tenth of the horizontal value.
- Visual MODFLOW uses the parameter specific storage (Ss), which is defined by the flowing equations:

  Ss = S/B
  Where:
  S = Storativity
  B = aquifer thickness

  The specific storage distribution was calculated by taking the average storativity value of 5×10^{-3} from Table 1, and dividing this by the thickness of the Mississippian aquifer.
- A horizontal hydraulic conductivity value of 10^{-3} ft./day was assigned to Layer 3 to represent the confining nature of this boundary. A vertical hydraulic gradient of 10^{-4} ft./day was also assigned.

Model Boundary Conditions

The model perimeter for the Mississippian aquifer was assigned using a combination of physical and hydraulic boundaries. Boundary conditions include the following:

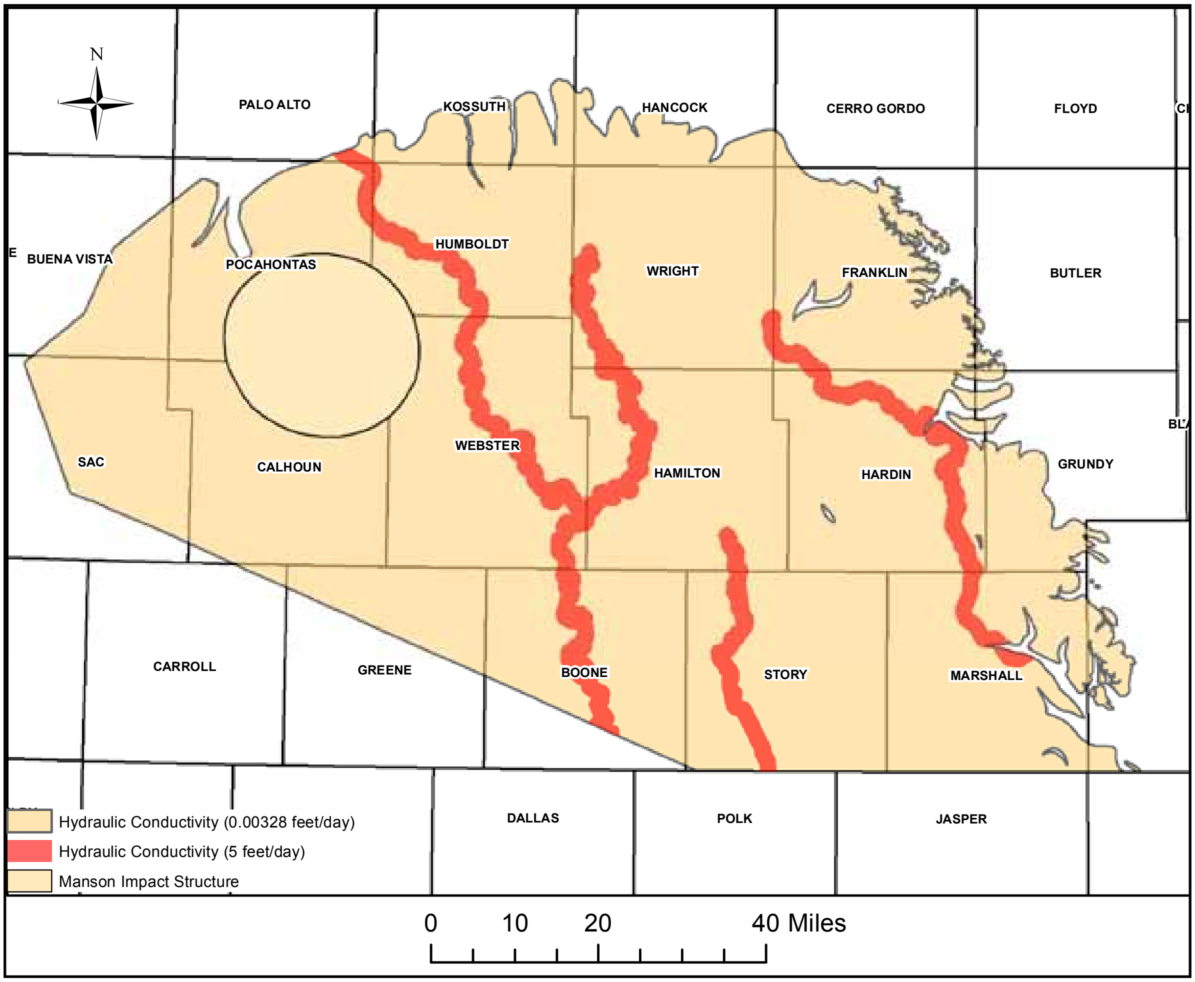

Figure 5. Hydraulic conductivity distribution within hydrostratigraphic layer 1.

- Flow-through boundaries were designated along the outer boundary of the study area. These were represented by general head boundaries in the model. The general head values were based on the pre-development potentiometric surface derived from available well data. General-head boundaries were used in the model to represent fluctuations in ground water elevations over time.
- The recharge or discharge of water from the Iowa, Skunk and Des Moines rivers were designated using river boundaries. The values used for river boundaries were based on the LiDAR elevation data along the major rivers.
- Net recharge values were used to simulate the recharge that passes through the base of the Layer 1. Higher recharge values were given in areas with less than 25 feet of glacial drift overlying the Mississippian bedrock, and alluvial valleys that may be in direct hydraulic connection with the Mississippian aquifer. The net recharge values used are based on model calibration methods and are shown in Figure 6.

Steady-State Conditions

Steady-state or pre-development conditions represent the non-pumping or static water level

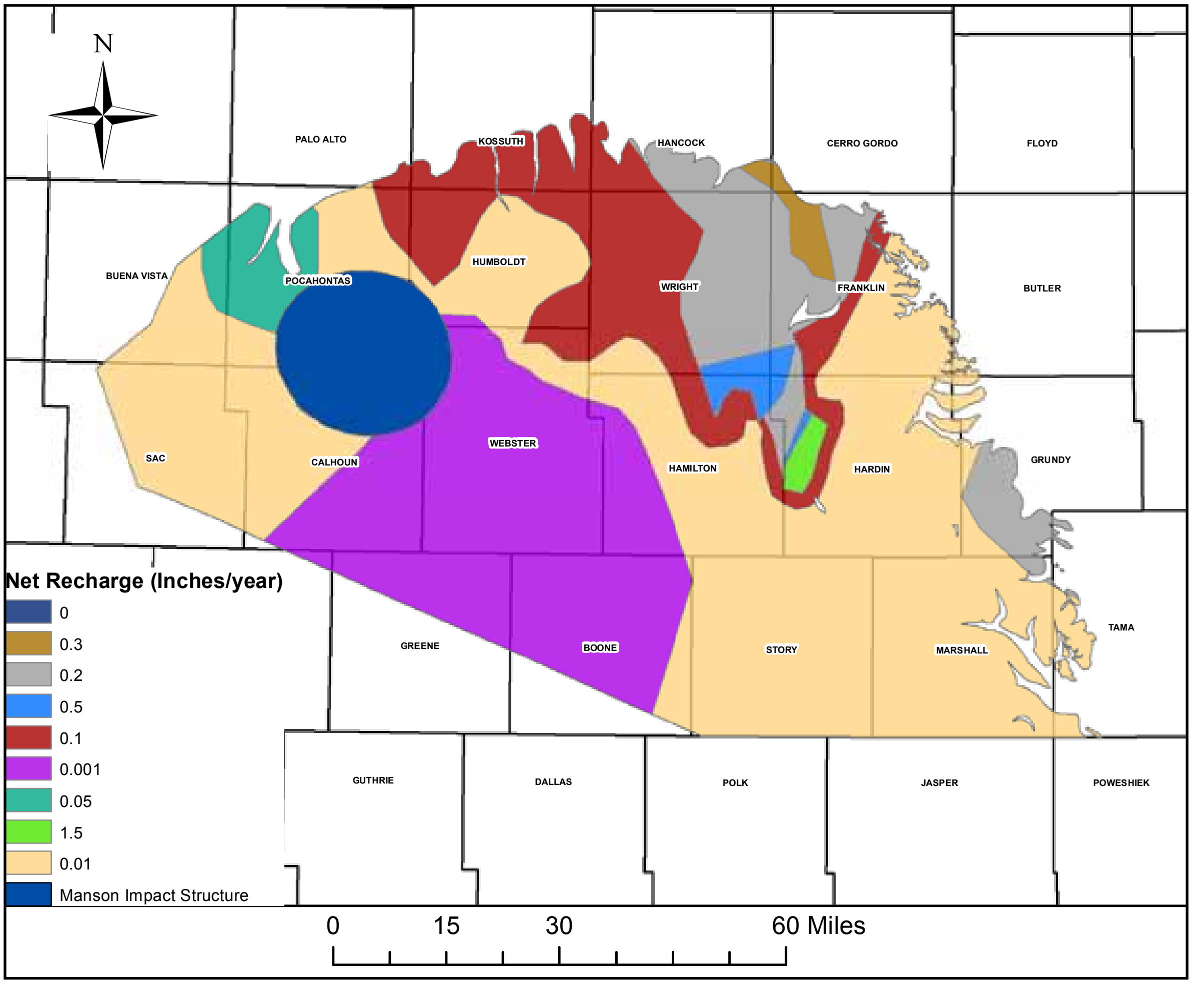

Figure 6. Distribution of net recharge (leakage) in the Mississippian aquifer.

conditions. One hundred and twenty-five historic water levels were found in the GEOSAM database, and are assumed to represent static or non-pumping water level conditions (Appendix C). Each of these water levels was converted to elevation. If more than one water level was recorded, the oldest measured value was used.

Steady-State Calibration

Steady-state model calibration involved adjusting hydraulic properties and recharge rates to reduce model calibration error. There were no pumping wells activated during the calibration period in order to represent pre-development conditions. The higher recharge values occur along the Iowa, Skunk, and Des Moines rivers and where Mississippian bedrock is within 25 feet of the land surface. The lower recharge values occur over areas where thicker glacial tills and Pennsylvanian confining beds occur.

A total of 90 out of 125 observation wells (Appendix C) were used in the calibration. The elimination of 35 observation wells was due to duplicate wells in a single location, and wells that appeared to be influenced by pumping stress. In order to evaluate model results, the root mean square error (RMSE) of the residuals between observed and simulated water levels were used based on the following equation:

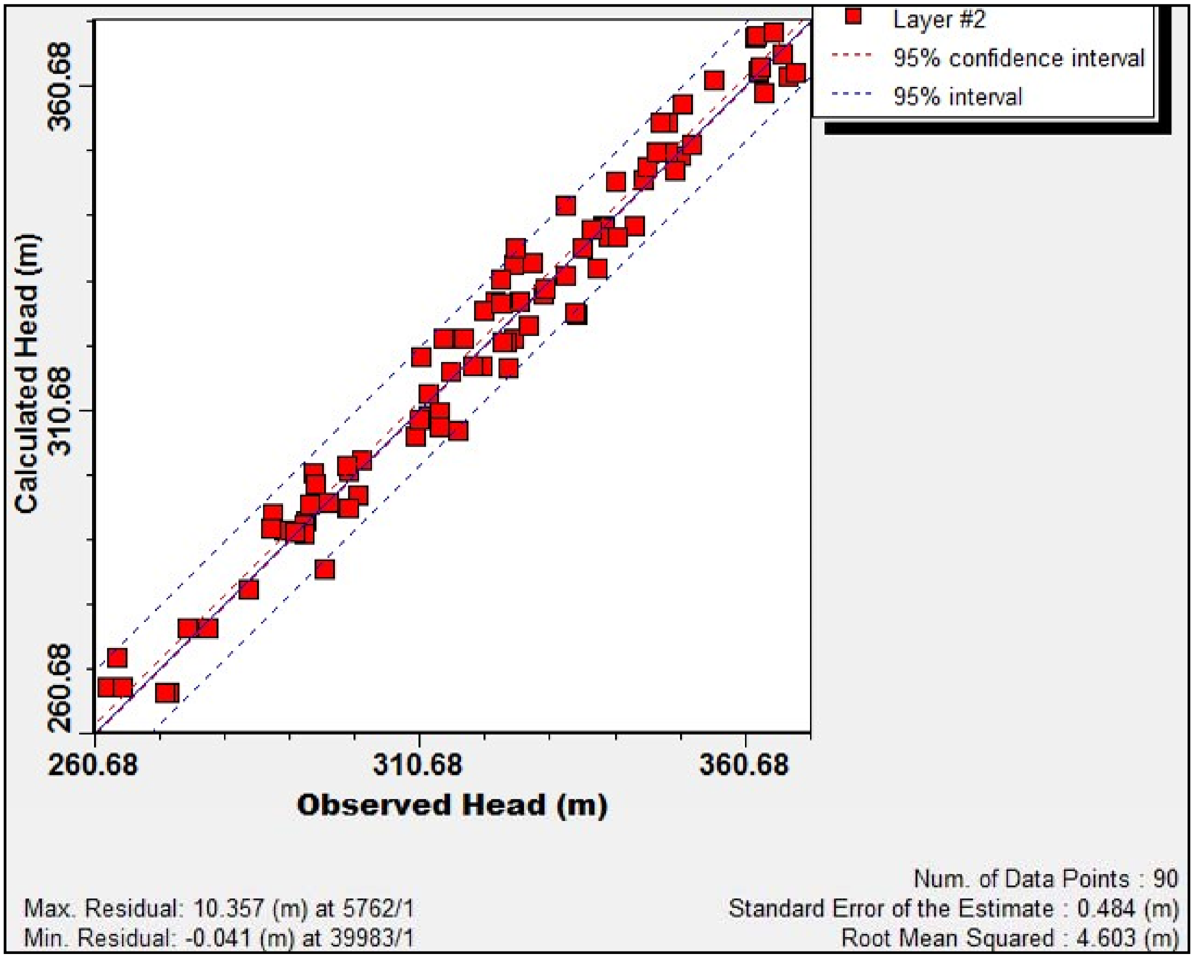

Figure 7. Steady-state calibration results and distribution of simulated verus observed groundwater elevations.

$$RMSE = \sqrt[N]{\sum (M - S)^2 / N}$$

Where:

N = number of observations
M = the measured head value in meters
S = the simulated head value in meters

The smaller the RMSE value, the closer the overall match is between the simulated and observed heads. The calibration method consisted of adjusting model input parameters within hydrologically justifiable limits to minimize the RMSE values. The primary parameters that were adjusted were net recharge and hydraulic conductivity.

Figure 7 shows the observed pressure head levels versus simulated values for the final steady-state calibration. The lowest value for the RMSE during the steady-state calibration was 15.1 feet. This error was considered to be relatively small compared to the size of the Mississippian aquifer modeled. For comparison, the RMSE for the Ogallala aquifer in North Texas was 36 feet for steady-state conditions (Anderson and Woessner, 1992), 17.2 feet for the Silurian aquifer in east-central Iowa (Gannon et. al., 2011), and 14.8 feet for the Lower Dakota aquifer in northwest Iowa (Gannon et. al., 2008).

Table 2. Sensitivity analyses for steady state model.

Calibration Parameter	Percent Change	RMSE (meters)	RMSE (feet)	Change From Calibrated (feet)
Recharge	0%	4.60	15.10	0.00
	10%	5.15	16.91	1.81
	-10%	5.03	16.50	1.40
	25%	5.70	18.68	3.58
	-25%	5.40	17.71	2.61
	50%	7.17	23.52	8.42
	-50%	6.71	22.01	6.91
Hydraulic Conductivity	0%	4.60	15.10	0.00
	10%	5.02	16.48	1.38
	-10%	5.18	17.00	1.90
	25%	5.25	17.20	2.10
	-25%	5.81	19.06	3.96
	50%	5.75	18.86	3.76
	-50%	10.98	36.02	20.92

The correlation coefficient between observed and simulated pressure head values was 0.986. The range of errors was 34 feet in well W-5762 to 0.13 feet in well W-39983, with an absolute error of 12.3 feet. Of the 90 measured water levels used for calibration, 49 were lower than simulated values, and 41 were higher than simulated values.

Steady-State Sensitivity Analysis

A sensitivity analysis was conducted to observe the relative impact on the RMSE by adjusting one parameter and holding the other parameters constant. The approach used in the Mississippian aquifer was to vary one parameter by a certain percentage from the calibrated values and evaluate the RMSE. Table 2 presents the changes in RMSE for recharge and hydraulic conductivity based on this approach. The steady-state model appears to be more sensitive to changes in hydraulic conductivity than recharge when small percentages of change are used, and more sensitive to recharge at larger percentages of change.

Transient Model

The pumping data from year 2003 through 2012 included public wells, industrial wells, and other permitted users with daily usage greater than 25,000 gallons. This data was obtained from Iowa DNR water-use permits, calling communities, and using the Iowa DNR Source Water data. If a permit had multiple active wells, and specific usage per well was unknown, the pumping rate was equally assigned to each active well. The spatial distribution of the water use permits are shown in Figure 8. The production data can be found in Appendix D.

Model Calibration

A total of 90 static water levels were obtained from USGS data, monthly operating reports, and the Iowa DNR GEOSAM database. Figure 9 shows the observed versus the simulated head values for water year 2012. The correlation coefficient is approximately 0.985, and the RMSE is 5.13 meters (16.8 feet).

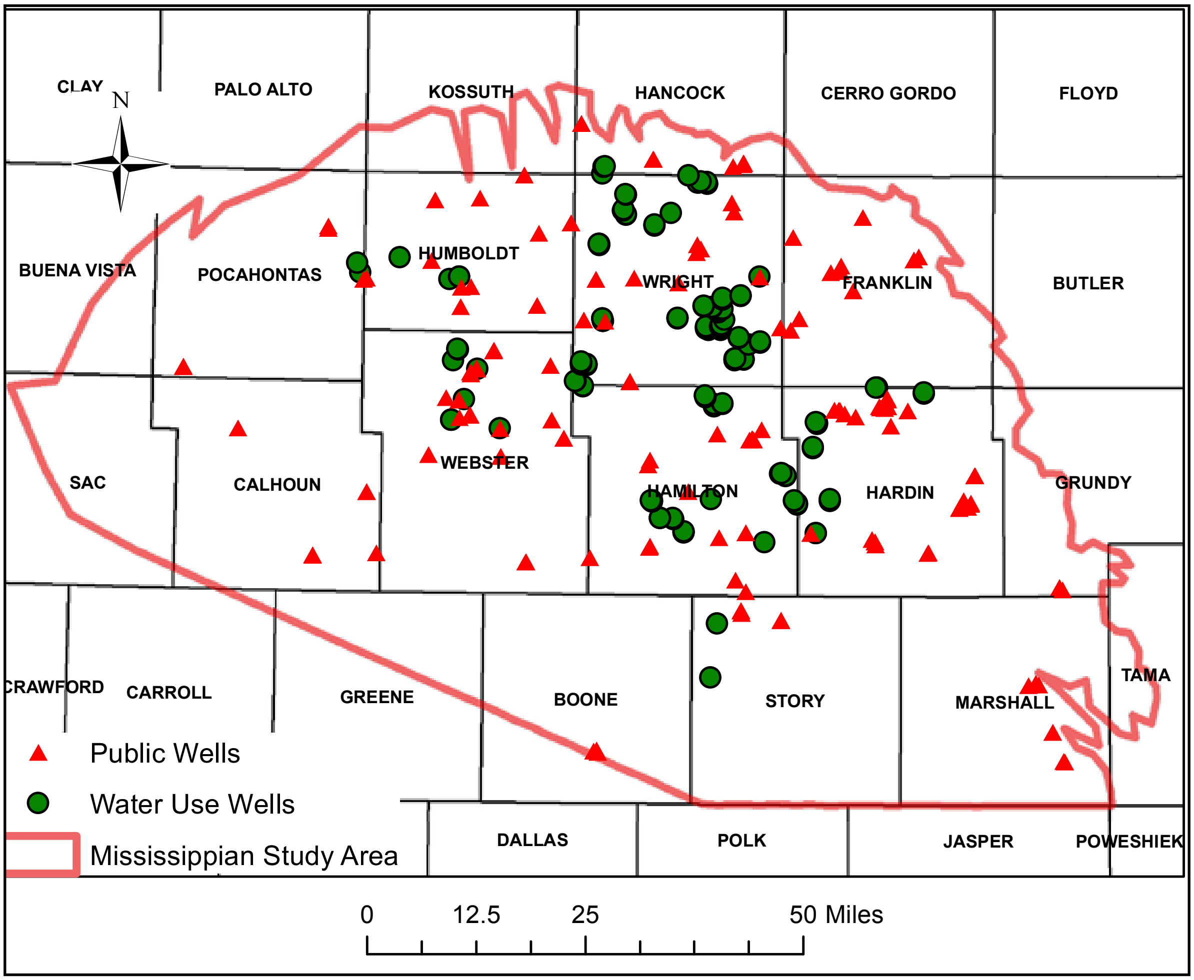

Figure 8. Production wells used for transient simulation.

Local scale calibration was performed using pump test results from production wells and associated observation well data. (Table 1, Appendix A). The locations of the pump tests are shown on Figure 3. Calibration was achieved by adjusting the hydraulic conductivity and comparing observed groundwater elevations with simulated values. The simulated versus observed groundwater elevations are shown in Table 3. The difference in the observed drawdown to the model simulated drawdown ranged from 0.1 feet in Ackley well 3 (inactive), to 0.4 feet in the Belmond Global Ethanol test well. These differences in drawdown between observed and simulated represent 1.7 and 12 percent errors, respectively.

A model simulated potentiometric map for water year 2012 is shown in Figure 10. The simulated potentiometric map correlates well with the observed data (Figure 4).

Decline in Water Levels (Drawdown) Over Time

To help evaluate the sustainability of the Mississippian aquifer the declines in water levels or drawdown was calculated. Figure 11 shows the decline in water levels from the non-pumping potentiometric map to 2012 levels. Groundwater withdrawals have resulted in drawdowns that range from 35 to 40 feet near

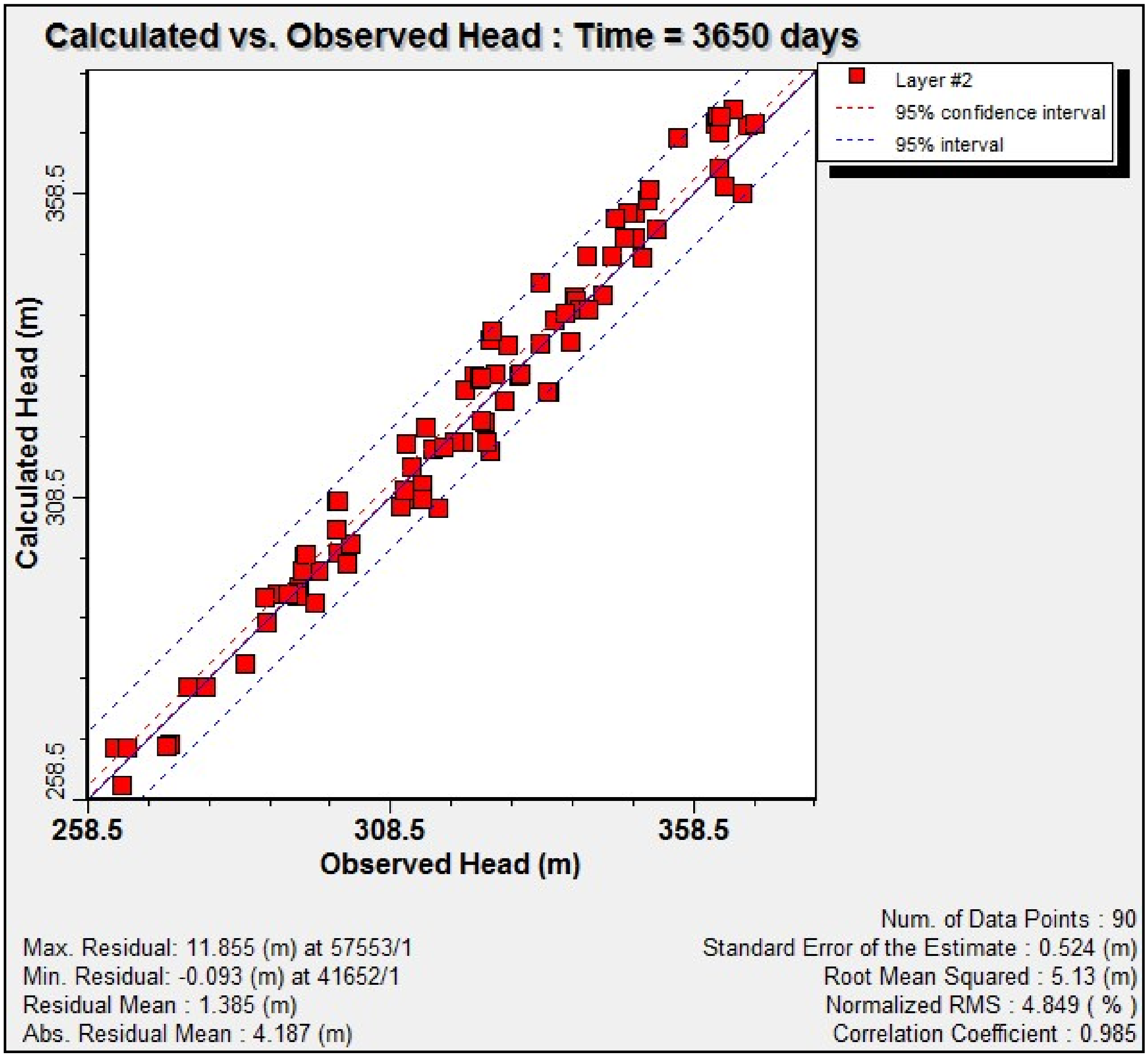

Figure 9. Transient calibration results of simulated verus observed groundwater elevations.

the City of Marshalltown. Iowa Falls, Clarion, Eagle Grove, and southeast Wright County have regional drawdowns in the 20 to 25 foot range. The drawdowns in southeast Wright County are the result of a large number of livestock permits. Based on the model results, the drawdowns have stabilized, and would not increase unless corresponding pumping rates increase or severe drought conditions occur.

Table 3. Observed drawdowns versus simulated drawdowns for aquifer pump tests.

Well Name	W-Number	UTM X	UTM Y	Observed Drawdown (ft)	Simulated Drawdown (ft)
Ackley #3	1576	495960	4711452	6.0	6.1
Eagle Grove #4	8855	426317	4724030	4.0	4.2
Global Ethanol	8284	448355	4743401	3.3	3.7

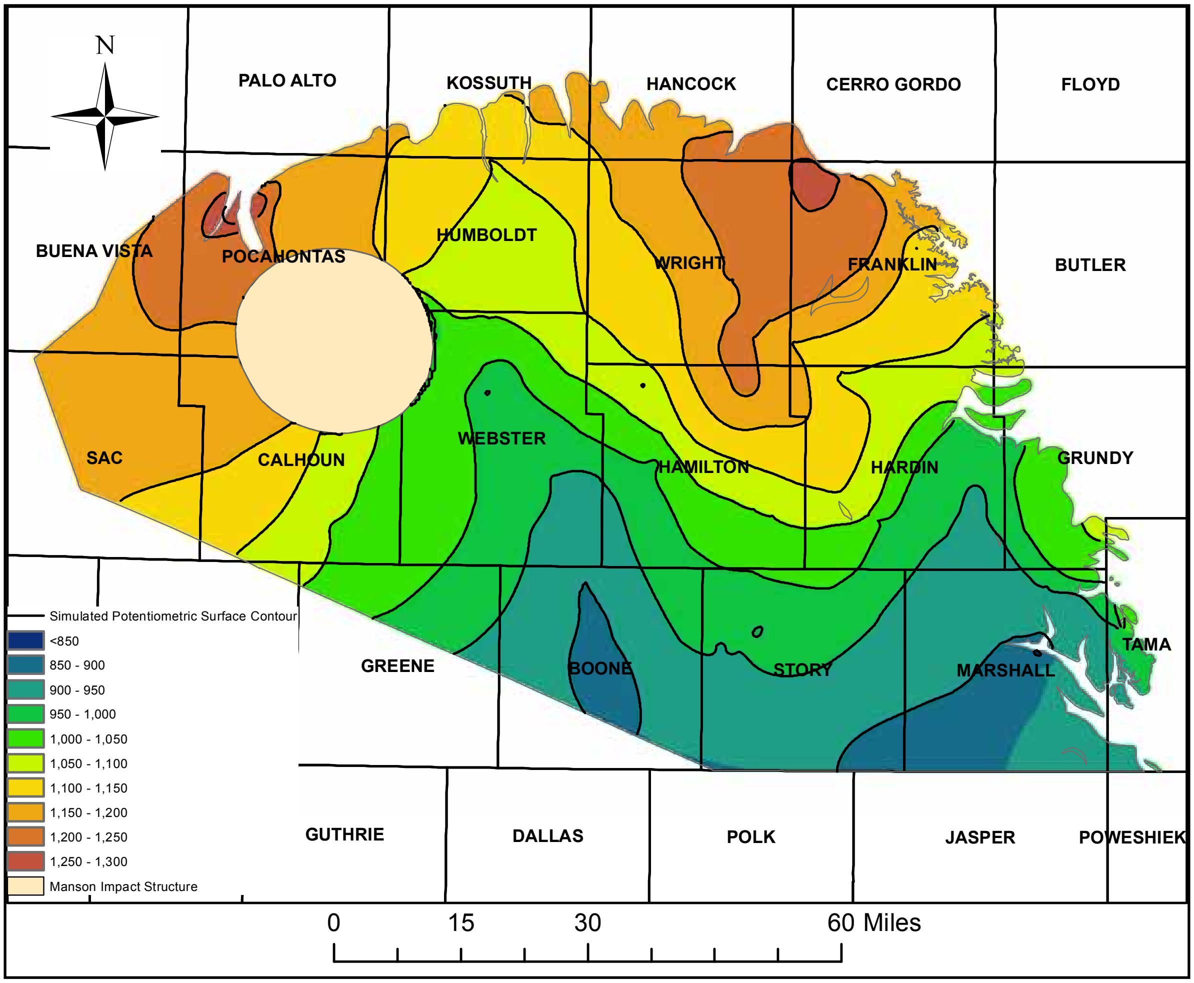

Figure 10. Simulated (modeled) potentiometric surface.

Transient Mass Balance Results

Approximately +6.7 billion gallons per year (bgy) were recharged into the aquifer from precipitation, +1.7 bgy flowed into the study area, -4.08 bgy flowed out of the study area, -5.7 bgy were removed by pumping (excluding private well usage), +9.7 bgy were derived from storage, +1.7 bgy flowed into the aquifer from river recharge, and -10.6 bgy was discharged into the major rivers from the Mississippian aquifer. A mass balance error of approximately 3 percent was calculated by Visual MODFLOW.

Based on the groundwater flow modeling results, an additional 1 bgy of groundwater could be withdrawn from the Mississippian aquifer using precipitation recharge alone. A much higher withdrawal rate is possible based on the relatively large volume of groundwater (10.6 bgy) that is discharged into the major river systems. Not all of this water could be withdrawn without potentially impacting the baseflow conditions of these rivers. A conservative estimate of 50 percent of the river recharge might be available for new or amended water use permits. This would be an additional 6.3 bgy of additional groundwater availability (5.3 bgy from converted river recharge and 1 bgy from available precipitation recharge).

PREDICTIONS FOR FUTURE WATER USAGE

One of the most powerful uses of a calibrated regional groundwater flow model is using the model to predict future impacts to an aquifer based on various pumping scenarios. The uncertainty in projected pumping rates may be the most important factor in determining the accuracy of the flow model (Konikow, 1986). Calibration error that is related to allocating pumping from too many or too few wells is compounded if the projection of total future pumping does not prove accurate (Dutton, Reedy, Mace, 2001).

Even more important than the actual pumping rate is predicting the approximate locations of future wells and permits. Locations for future wells are more likely within the current major producing zones, since industry and population growth generally occur in these areas.

Two different future water usage scenarios were simulated using the calibrated transient model. The first model run assumes a 25 percent increase in water usage over a 10-year period, and a second model run assumes a 50 percent increase in water usage over a 10-year period. Each of these simulations and the assumptions used are described in the following sections.

Using the 2012 groundwater elevation contours as the initial groundwater surface, a simulation was run using the production wells found in our groundwater flow model and increasing the withdrawal rate in each well by 25 percent. The total daily withdrawal of groundwater by production wells increased from 15.6 mgd to 19.5 mgd. Figure 12 represents the additional simulated drawdown based on the proposed pumping scenario (25 percent increase in pumping rates). Based on the groundwater model, an additional 5 to 9 feet of additional drawdown would occur near the City of Marshalltown and the City of Iowa Falls, and approximately 1 to 4 feet of additional drawdown would occur near major pumping centers in Wright, Webster, Hardin, and Calhoun counties. Based on these relatively small additional drawdowns, the Mississippian aquifer is able to handle the 25 percent increase in pumping rates.

Using the 2012 groundwater elevation contours as the initial groundwater surface, a second future use simulation was run using the production wells found in our groundwater flow model and increasing the withdrawal rate in each well by 50 percent. The total daily withdrawal of groundwater by production wells increased from 15.6 mgd to 23.4 mgd. Figure 13 represents the simulated additional drawdown based on the proposed pumping scenario (50 percent increase in pumping rates). Based on the groundwater model, an additional 12 to 16 feet of drawdown would occur near the City of Marshalltown, the City of Iowa Falls, and the City of Fonda and approximately 5 to 9 feet of additional drawdown would occur near major pumping centers in Wright, Webster, Hardin, and Calhoun counties. In addition to the increase in drawdown, the drawdown area in Wright County expands into the adjacent counties. Based on these relatively small additional drawdowns, the Mississippian aquifer is also able to handle the 50 percent increase in pumping rates.

LIMITATIONS OF THE MODEL

As with all models, limitations exist regarding the evaluation of potential future use scenarios. Models are tools to assist with water use planning and water allocations. The following are known limitations:

- When the number of wells and locations were known, but the percentage of water use was unknown, pumping rates were equally divided among the active wells. Improvements in monthly water use reporting would be extremely useful for transient model simulation.
- Head values near flow-through boundaries may not accurately represent

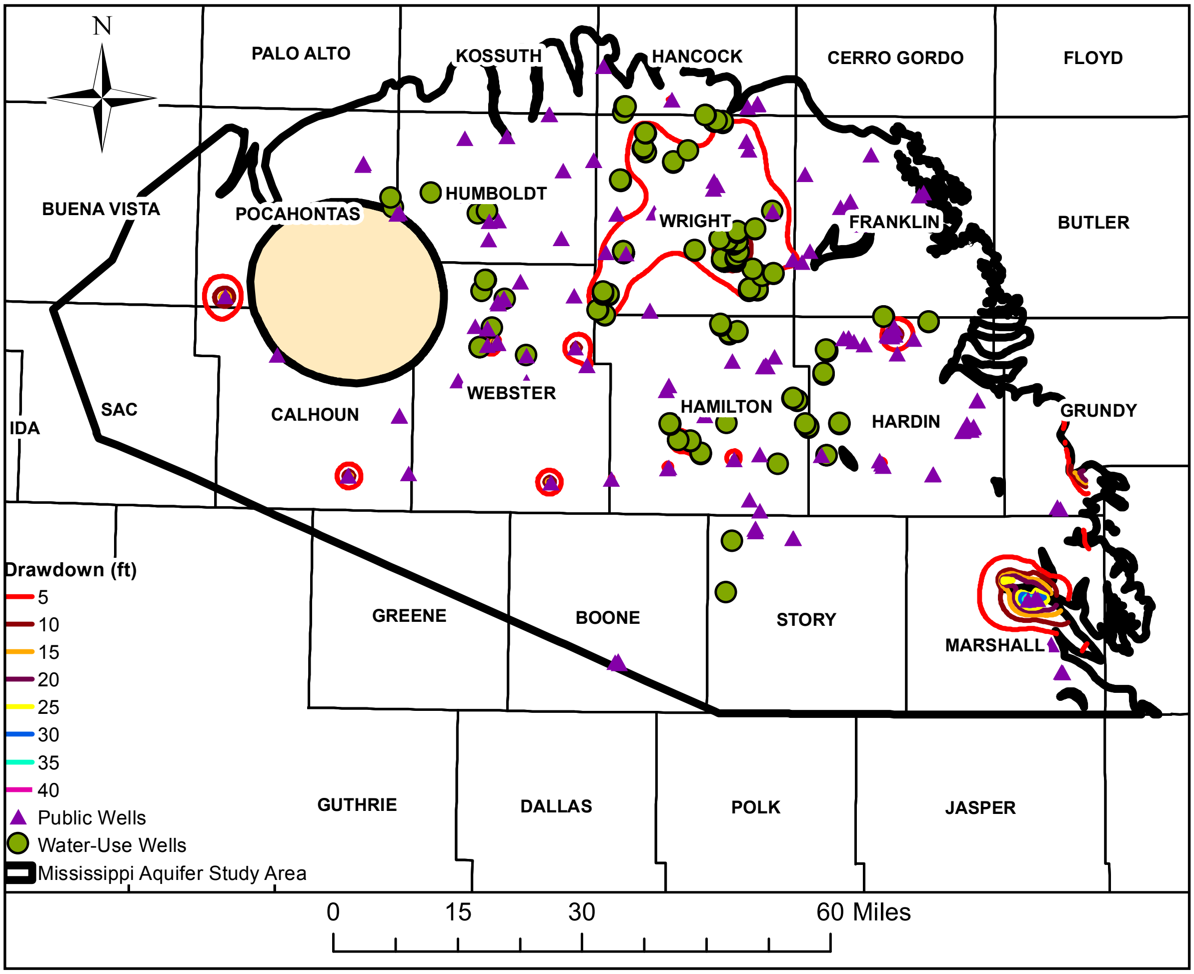

Figure 11. Simulated additional drawdown in feet from steady-state non-pumping conditions to pumping conditions.

observed values. This error increases at higher pumping rates and the closer the wells are to the actual flow-through boundary. General-head boundaries were used to minimize this error.

- The fluctuations in river elevations were not entered into the model. Baseflow conditions were assumed to exist based on the LiDAR elevations used in the model. The changes in river elevations would impact the hydrologic interaction between the rivers and the Mississippian aquifer. Many of these changes are very transitory and would impact wells closest to major rivers. Most of the Mississippian aquifer is overlain by either glacial till, Pennsylvanian shale, or both, which minimizes the hydrologic interaction.
- Average pumping rates were used in the model. No attempt was made to enter monthly or daily changes in pumping rates.

FUTURE DATA NEEDS

Additional data would improve our understanding of the hydrogeology and future water availability, and provide more accurate input parameters for our model. Future improvements in aquifer parameters, water level data, storage coefficients, and water use information would

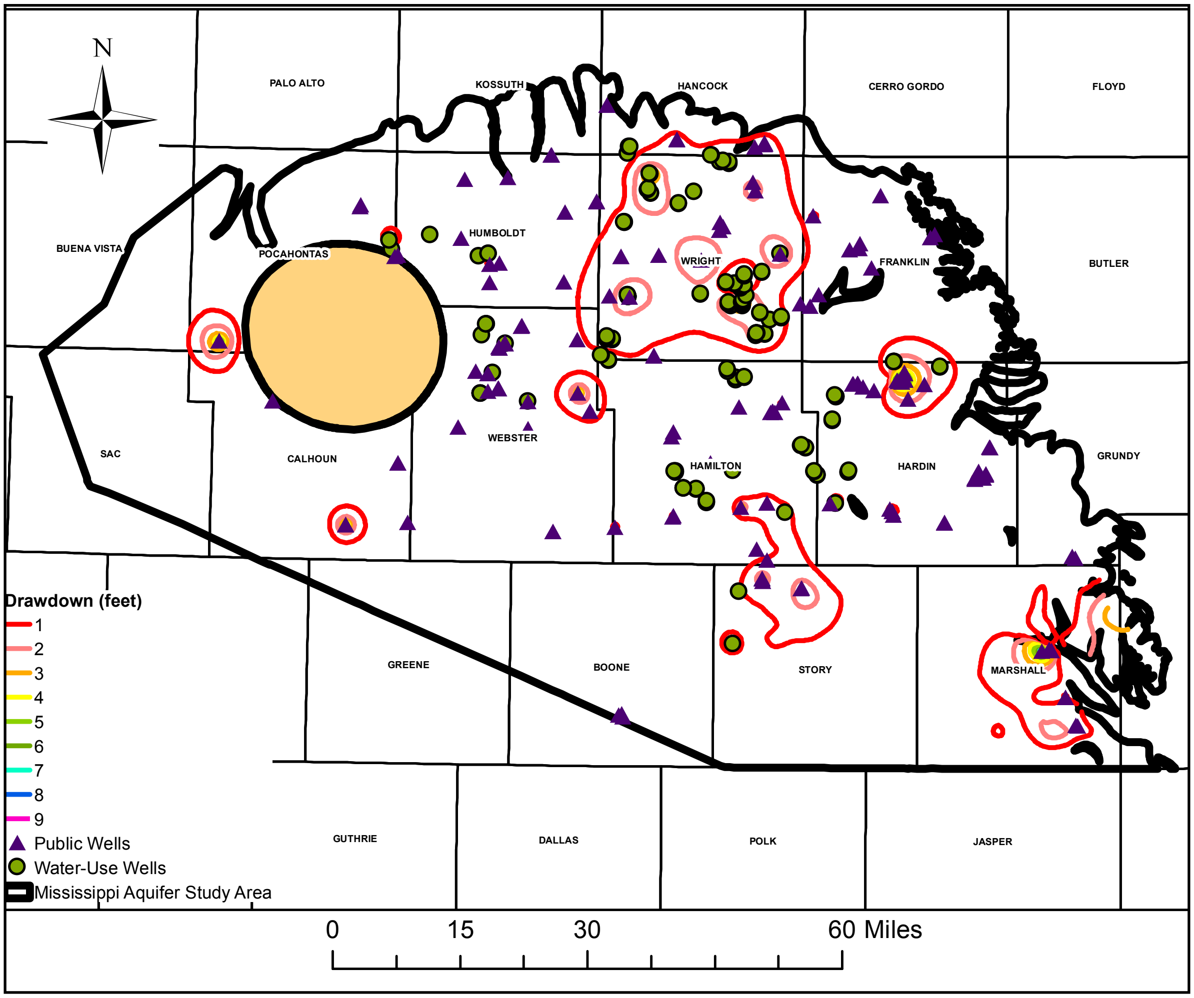

Figure 12. Simulated additional drawdown in feet from current pumping conditions assuming a 25 percent increase in the pumping rates.

provide more confidence in future predictions. The following is a short list of recommendations:

- Additional 24-hour pump tests could be conducted in the high usage areas to more accurately calculate storage coefficients and transmissivity values.
- Starting a water level network is important for the future evaluation of the Mississippian aquifer model as a predictive tool.
- Time series water level readings could be collected in one or more observation wells or inactive production wells to monitor potential well interference and additional drawdown.
- Water quality data could be collected.

CONCLUSIONS

Increased demand for groundwater by agriculture, industries, and municipalities has raised concerns for the long-term sustainability of the resource. In 2007, the Iowa legislature began funding a comprehensive Water Resources Management program to be implemented by the Iowa Department of Natural Resources. A key aspect of the program is to evaluate and quantify the groundwater resources across the state using computer simulation models. These models help answer questions such as: How much water can be pumped from an aquifer over 10, 20, or 100 years? or Will my well go dry?

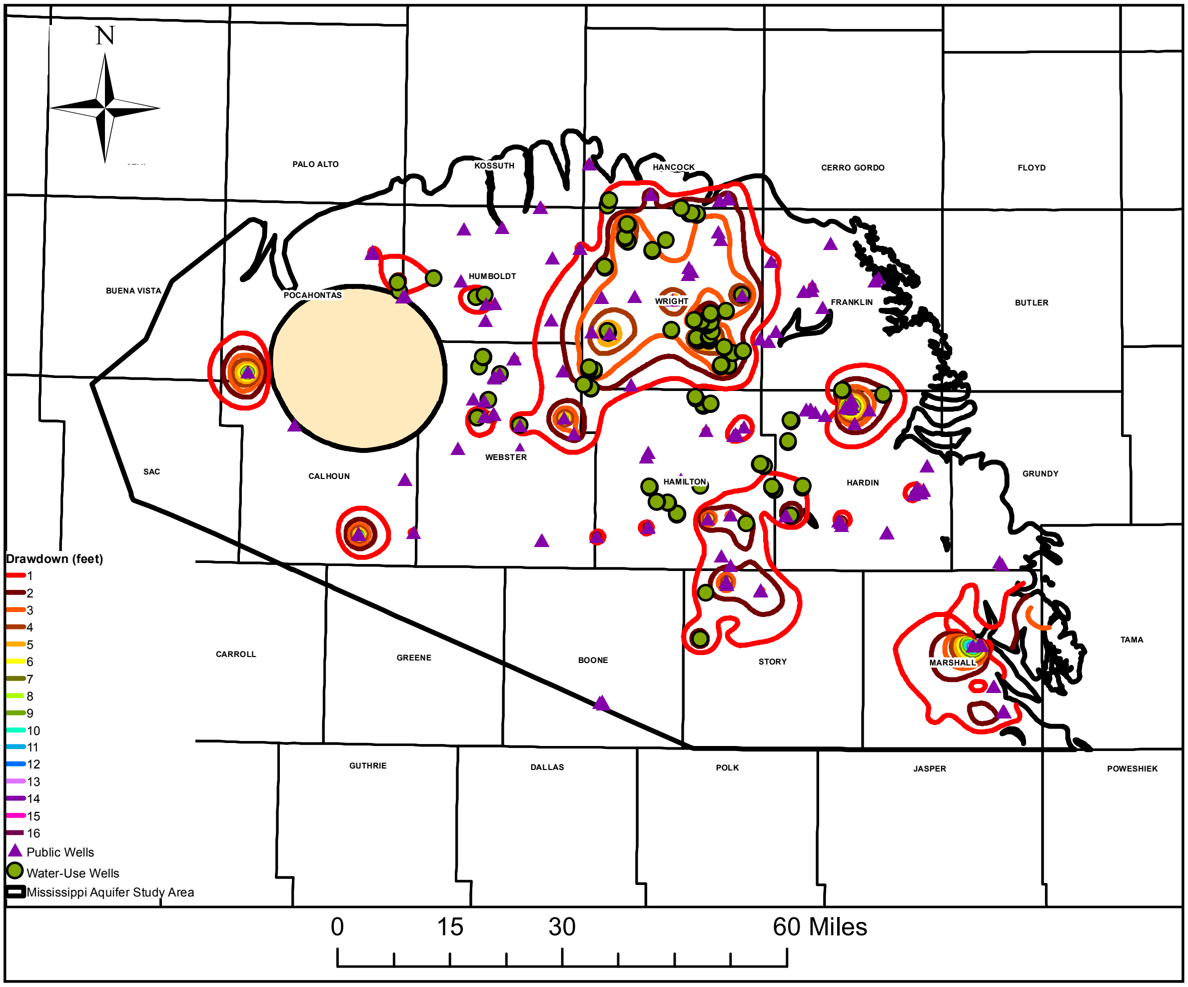

Figure 13. Simulated additional drawdown in feet from current pumping conditions assuming a 25 percent increase in the pumping rates.

This report documents an intensive one-year investigation of the hydrogeology of the Mississippian aquifer in north-central Iowa, and the construction of a groundwater flow model that can be used as a planning tool for future water resource development. The hydrologic characteristics of the geologic layers included in the modeling of the Mississippian aquifer were also investigated.

A total of 19 aquifer pump tests and recovery tests and 140 specific capacity tests were used to calculate the aquifer parameters. The hydraulic properties of the Mississippian aquifer were shown to vary considerably in both the lateral and vertical direction. The hydraulic conductivity of the aquifer ranges from 0.14 to 1,510 feet per day, with an arithmetic mean of 123 feet per day. Transmissivity values range from 17 to 93,000 $ft.^2$/day. The storage coefficient of the Mississippian aquifer ranges from 10^{-4} to 10^{-1}.

Recharge to most of the Mississippian aquifer is through confining beds that include glacial till and various shale units. Due to the highly variable thickness and coverage of these confining units, the rate of recharge ranges from 10^{-3} inches per year over the southwestern half of the study area to 1.5 inches per year over north-central portions of the study area, and along the major river valleys, where the confining beds are thin or absent.

With this information, a numerical groundwater flow model of the Mississippian aquifer was developed using three hydrogeologic layers. The model was created using Visual MODFLOW version 11.1. Hydrologic processes examined in the model include net recharge, hydraulic conductivity, specific storage, general head boundaries, constant head boundaries, well discharge, river boundaries, and well interference.

The modeling approach involved the following components:

1. Calibrating a pre-development steady-state model using water level data from historic records.
2. Calibrating a transient model using water-use data from 2003 to 2012. Simulated water levels were compared to observed water level measurements.

The calibrated model provided good correlation for transient conditions. A root mean square error of 16.8 feet was calculated. This is a relatively small error for an aquifer that covers most of north-central Iowa. Simulated water level changes are most sensitive to changes in hydraulic conductivity.

Based on the groundwater flow modeling results, an additional 1 billion gallons per year (bgy) of groundwater could be withdrawn from the Mississippian aquifer using precipitation recharge alone. A much higher withdrawal rate is possible based on the relatively large volume of groundwater (10.6 bgy) that is discharged into the major river systems. Not all of this water could be withdrawn without potentially impacting the baseflow conditions of these rivers. A conservative estimate of 50 percent of the river recharge might be available for new or amended water use permits. This would be an additional 6.3 bgy of additional groundwater availability (5.3 bgy from converted river recharge and 1 bgy from available precipitation recharge).

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APPENDIX A

AQUIFER TEST DATA

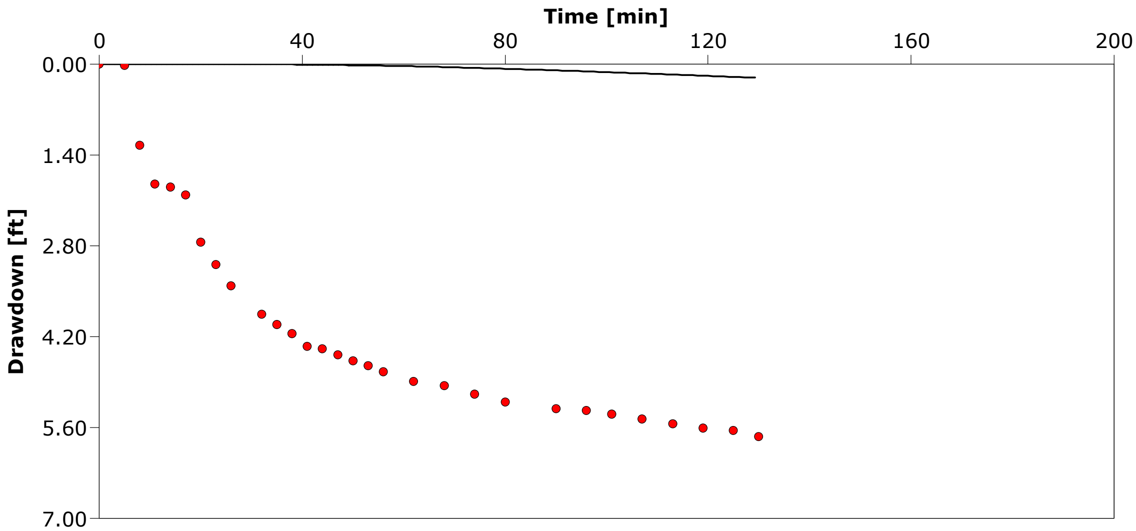
Contact Info Address Company Name City, State/Province	**Pumping Test - Water Level Data** Page 1 of 1
	Project: Ackley Well 4
	Number:
	Client:

Location: Ackley, Iowa	Pumping Test: Pump Test	Pumping Well: Well 4
Test Conducted by:	Test Date: 6/18/1948	Discharge Rate: 80 [U.S. gal/min]
Observation Well: Marshall Canning	Static Water Level [ft]: 34.90	Radial Distance to PW [ft]: 2000

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	34.90	0.00
2	5	34.92	0.02
3	8	36.15	1.25
4	11	36.75	1.85
5	14	36.79	1.89
6	17	36.92	2.02
7	20	37.64	2.74
8	23	37.99	3.09
9	26	38.32	3.42
10	32	38.75	3.85
11	35	38.91	4.01
12	38	39.05	4.15
13	41	39.25	4.35
14	44	39.29	4.39
15	47	39.38	4.48
16	50	39.47	4.57
17	53	39.55	4.65
18	56	39.64	4.74
19	62	39.79	4.89
20	68	39.86	4.96
21	74	39.99	5.09
22	80	40.11	5.21
23	90	40.21	5.31
24	96	40.24	5.34
25	101	40.29	5.39
26	107	40.37	5.47
27	113	40.44	5.54
28	119	40.51	5.61
29	125	40.55	5.65
30	130	40.64	5.74

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Project: Ackley Well 4 Number: Client:

Location: Ackley, Iowa	Pumping Test: Pump Test	Pumping Well: Well 4
Test Conducted by:		Test Date: 6/18/1948
Analysis Performed by:	New analysis 1	Analysis Date: 1/4/2012
Aquifer Thickness: 74.00 ft	Discharge Rate: 80 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Marshall Canning	9.30×10^{2}	1.26×10^{1}	1.00×10^{-4}	2000.0	

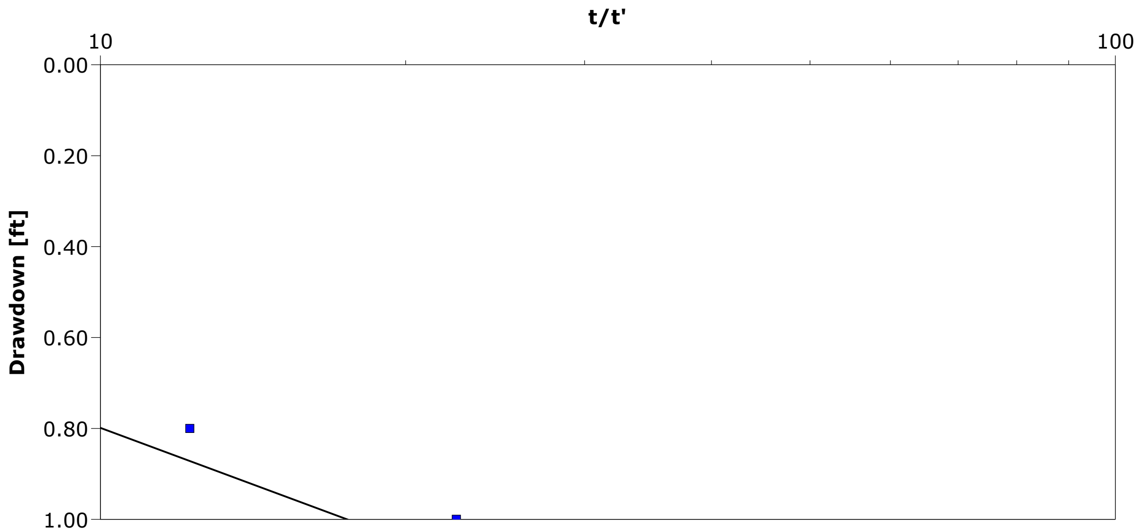
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1
	Project: Bode City Well 2 Recovery Test
	Number:
	Client:

Location: Bode, Iowa	Pumping Test: Bode Recovery Test	Pumping Well: Well 2
Test Conducted by:	Test Date: 8/11/1948	Discharge: variable, average rate 190 [U.S. gal/mir
Observation Well: Well 2		Radial Distance to PW [ft]: -

	Time [min]	Discharge [U.S. gal/min]
1	450	190.00
2	490	0.00

Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report Project: Bode City Well 2 Recovery Test Number: Client:

Location: Bode, Iowa	Pumping Test: Bode Recovery Test	Pumping Well: Well 2
Test Conducted by:		Test Date: 8/11/1948
Analysis Performed by:	New analysis 5	Analysis Date: 1/4/2012
Aquifer Thickness: 120.00 ft	Discharge: variable, average rate 190 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]
Well 2	8.07×10^{3}	6.73×10^{1}	0.33

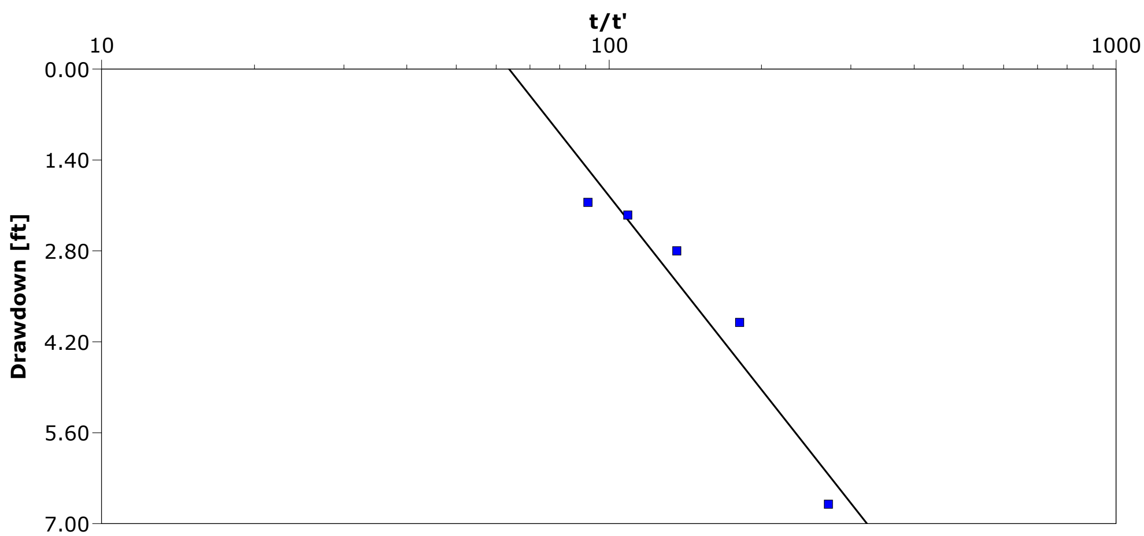
Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Page 1 of 1 Project: Conrad Recovery Test Number: Client:

Location: Conrad, Iowa	Pumping Test: Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 3/19/1962	Discharge: variable, average rate 150 [U.S. gal/mir
Observation Well: Well 1	Static Water Level [ft]: 10.80	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	542	17.50	6.70
2	543	14.70	3.90
3	544	13.60	2.80
4	545	13.05	2.25
5	546	12.85	2.05

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Conrad Recovery Test
	Number:
	Client:

Location: Conrad, Iowa	Pumping Test: Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 3/19/1962
Analysis Performed by:	New analysis 3	Analysis Date: 1/5/2012
Aquifer Thickness: 100.00 ft	Discharge: variable, average rate 150 [U.S. gal/min]	



Calculation using THEIS & JACOB

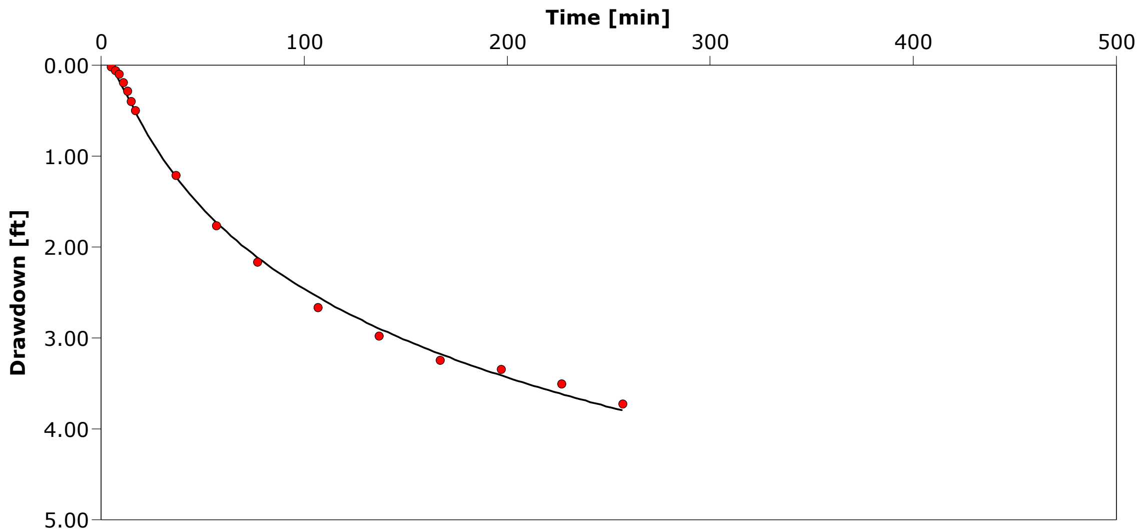
Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	5.33×10^2	5.33×10^0	0.41	

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

Location: Eagle Grove, Iowa	Pumping Test: Pumping Test 1	Pumping Well: Well 1
Test Conducted by:	Test Date: 8/6/1962	Discharge Rate: 500 [U.S. gal/min]
Observation Well: Theater Well	Static Water Level [ft]: 7.00	Radial Distance to PW [ft]: 500

	Time [min]	Water Level [ft]	Drawdown [ft]
1	5	7.02	0.02
2	7	7.06	0.06
3	9	7.10	0.10
4	11	7.19	0.19
5	13	7.29	0.29
6	15	7.40	0.40
7	17	7.50	0.50
8	37	8.21	1.21
9	57	8.77	1.77
10	77	9.17	2.17
11	107	9.67	2.67
12	137	9.98	2.98
13	167	10.25	3.25
14	197	10.35	3.35
15	227	10.51	3.51
16	257	10.73	3.73

Contact Info **Address** **Company Name** **City, State/Province**		**Pumping Test Analysis Report**
		Project: Eagel Grove
		Number:
		Client:
Location: Eagle Grove, Iowa	Pumping Test: Pumping Test 1	Pumping Well: Well 1
Test Conducted by:		Test Date: 8/6/1962
Analysis Performed by:	New analysis 4	Analysis Date: 1/5/2012
Aquifer Thickness: 285.00 ft	Discharge Rate: 500 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Theater Well	4.98×10^{3}	1.75×10^{1}	7.11×10^{-4}	500.0	
Well 1	9.30×10^{2}	3.26×10^{0}	1.00×10^{-4}	0.67	
Average	2.95×10^{3}	1.04×10^{1}	4.05×10^{-4}		

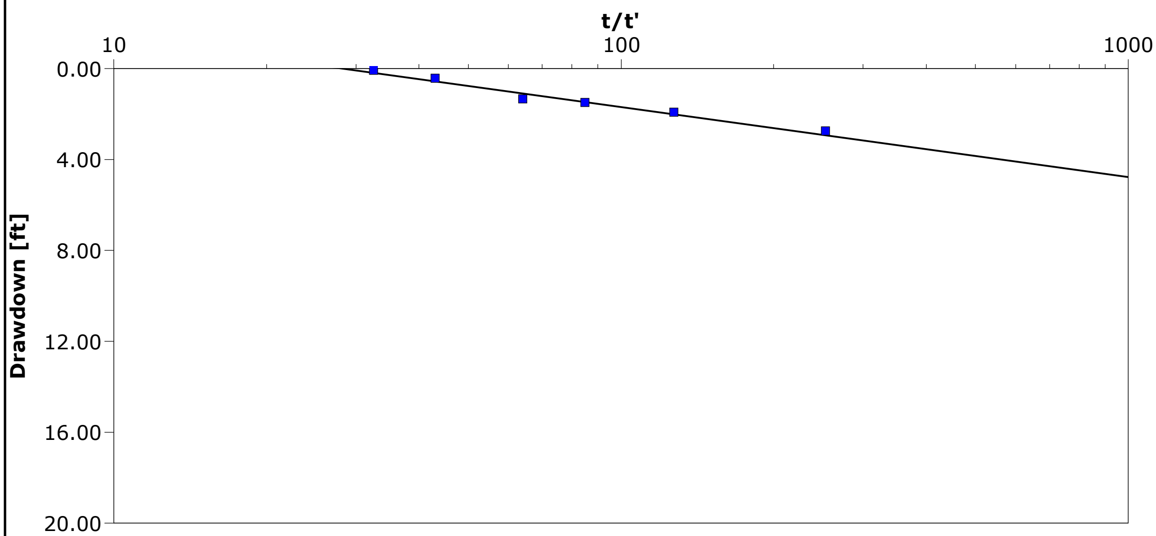
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1 Project: Eldora Well CW93-2 Number: Client:

Location: Eldora, Iowa	Pumping Test: CW93-2	Pumping Well: CW93-2
Test Conducted by: Layne Western	Test Date: 2/4/1993	Discharge: variable, average rate 300 [U.S. gal/mir
Observation Well: CW93-2	Static Water Level [ft]: 114.50	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1260	133.67	19.17
2	1265	117.25	2.75
3	1270	116.42	1.92
4	1275	116.00	1.50
5	1280	115.83	1.33
6	1290	114.92	0.42
7	1300	114.58	0.08

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Eldora Well CW93-2 Number: Client:

Location: Eldora, Iowa	Pumping Test: CW93-2	Pumping Well: CW93-2
Test Conducted by: Layne Western		Test Date: 2/4/1993
Analysis Performed by:	New analysis 2	Analysis Date: 12/21/2011
Aquifer Thickness: 129.00 ft	Discharge: variable, average rate 300 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
CW93-2	3.44×10^3	2.67×10^1	0.2	

Contact Info
Address
Company Name
City, State/Province

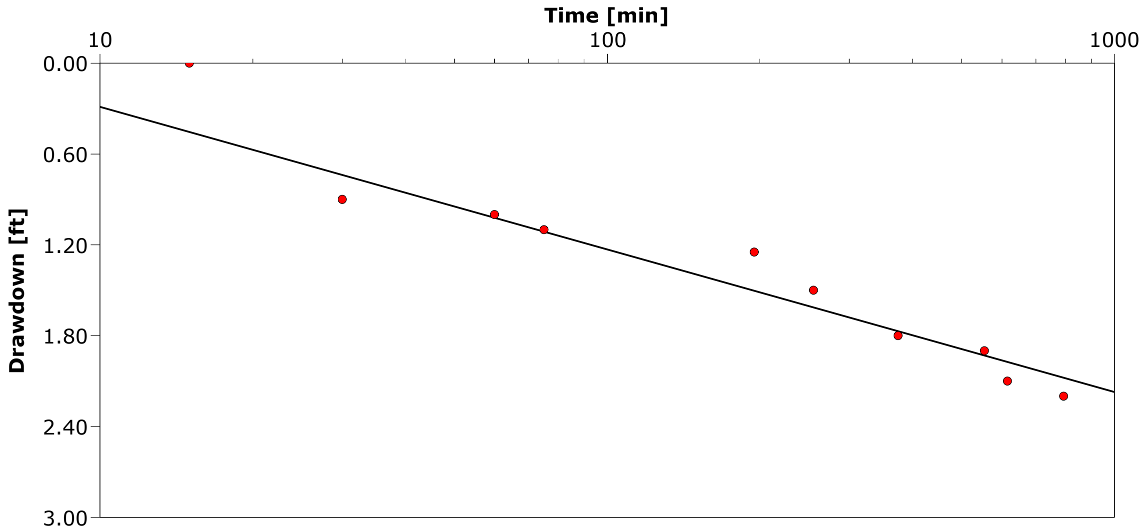
Pumping Test Analysis Report	Page 1 of 1
Project: Global Renewable Resources	
Number:	
Client:	

Location: Belmond, Iowa	Pumping Test: Global Pump Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 8/13/2007	Discharge Rate: 1500 [U.S. gal/min]
Observation Well: ow1	Static Water Level [ft]: 28.00	Radial Distance to PW [ft]: 220

	Time [min]	Water Level [ft]	Drawdown [ft]
1	15	28.00	0.00
2	30	28.90	0.90
3	60	29.00	1.00
4	75	29.10	1.10
5	195	29.25	1.25
6	255	29.50	1.50
7	375	29.80	1.80
8	555	29.90	1.90
9	615	30.10	2.10
10	795	30.20	2.20

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Global Renewable Resources Number: Client:

Location: Belmond, Iowa	Pumping Test: Global Pump Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 8/13/2007
Analysis Performed by:	New analysis 2	Analysis Date: 1/9/2012
Aquifer Thickness: 136.00 ft	Discharge Rate: 1500 [U.S. gal/min]	

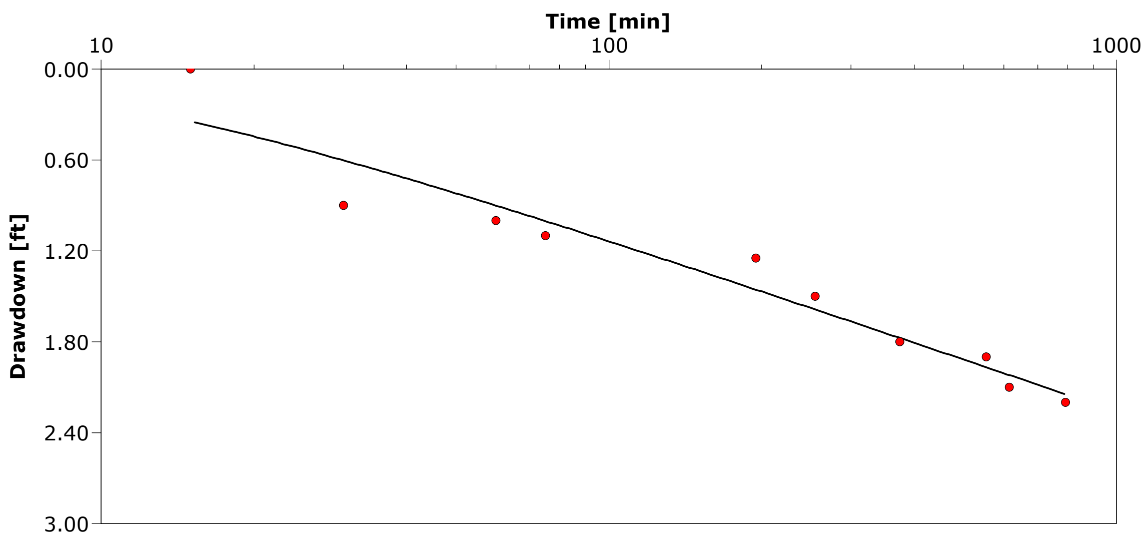


Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ow1	5.60×10^{4}	4.12×10^{2}	8.96×10^{-3}	220.0	

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Project: Global Renewable Resources Number: Client:

Location: Belmond, Iowa	Pumping Test: Global Pump Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 8/13/2007
Analysis Performed by:	New analysis 3	Analysis Date: 1/9/2012
Aquifer Thickness: 136.00 ft	Discharge Rate: 1500 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
ow1	4.60×10^{4}	3.38×10^{2}	1.62×10^{-2}	220.0	

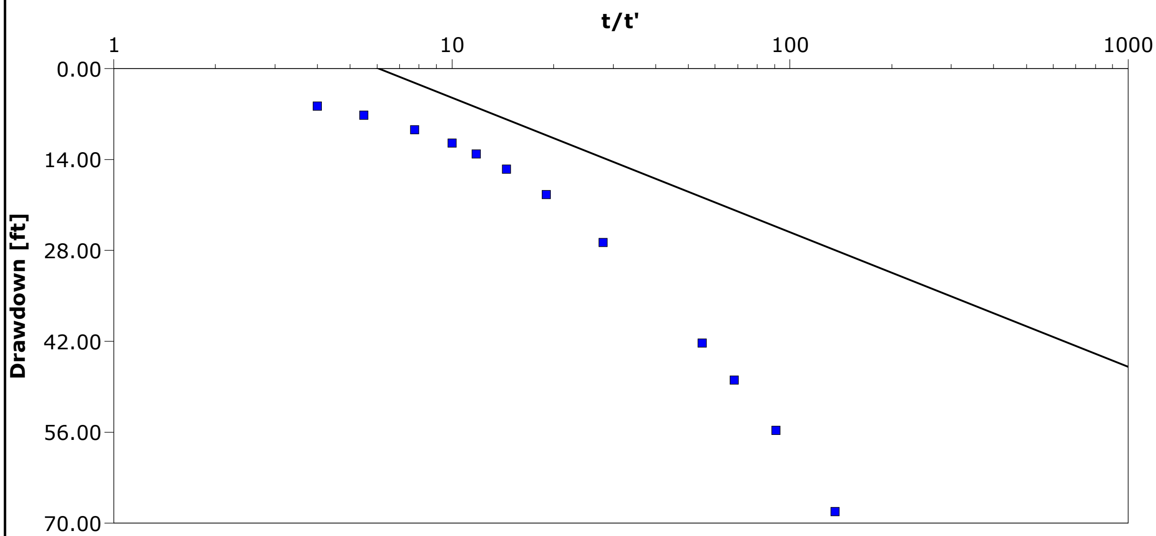
Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report — Page 1 of 1
	Project: Havelock Recovey Test
	Number:
	Client:

Location: Havelock, Iowa	Pumping Test: Havelock Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 7/30/1937	Discharge: variable, average rate 50 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 28.75	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	272	97.00	68.25
2	273	84.50	55.75
3	274	76.75	48.00
4	275	71.00	42.25
5	280	55.50	26.75
6	285	48.20	19.45
7	290	44.25	15.50
8	295	41.90	13.15
9	300	40.25	11.50
10	310	38.20	9.45
11	330	35.90	7.15
12	360	34.50	5.75

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Havelock Recovey Test
	Number:
	Client:

Location: Havelock, Iowa	Pumping Test: Havelock Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 7/30/1937
Analysis Performed by:	New analysis 2	Analysis Date: 1/5/2012
Aquifer Thickness: 90.00 ft	Discharge: variable, average rate 50 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	8.49×10^{1}	9.44×10^{-1}	0.25	

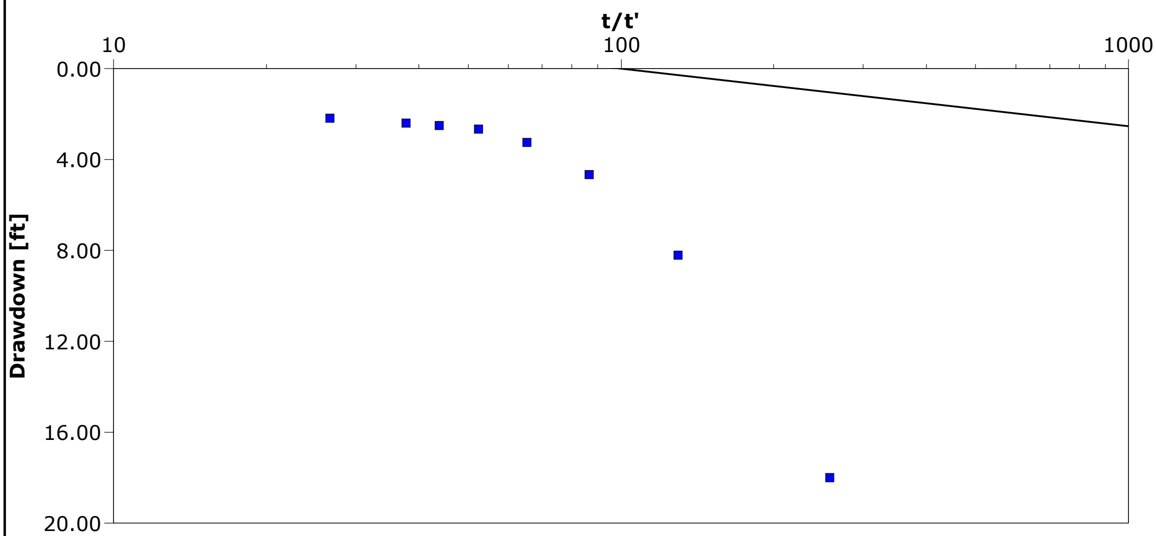
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1
	Project: Hubbard Recovery Test
	Number:
	Client:

Location: Hubbard, Iowa	Pumping Test: Hubbard Recovery Test Well	Pumping Well: Well 2
Test Conducted by:	Test Date: 11/14/1945	Discharge: variable, average rate 34 [U.S. gal/min]
Observation Well: Well 2	Static Water Level [ft]: 28.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	258	46.00	18.00
2	259	36.20	8.20
3	260	32.67	4.67
4	261	31.25	3.25
5	262	30.67	2.67
6	263	30.50	2.50
7	264	30.40	2.40
8	267	30.20	2.20

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Project: Hubbard Recovery Test Number: Client:

Location: Hubbard, Iowa	Pumping Test: Hubbard Recovery Test Well 2	Pumping Well: Well 2
Test Conducted by:		Test Date: 11/14/1945
Analysis Performed by:	New analysis 2	Analysis Date: 1/5/2012
Aquifer Thickness: 245.00 ft	Discharge: variable, average rate 34 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 2	4.73×10^2	1.93×10^0	0.41	

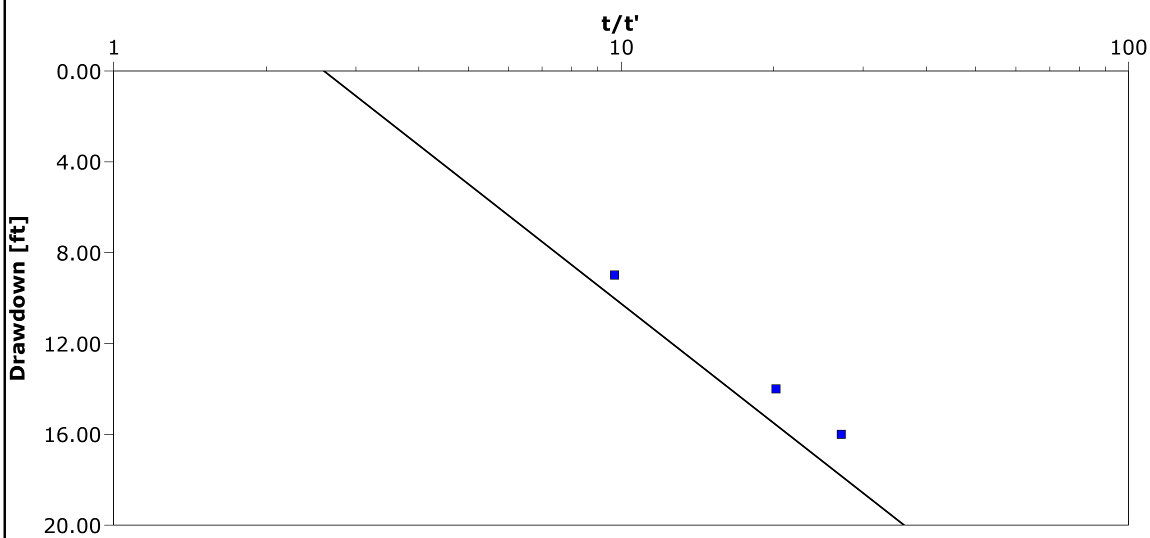
Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Page 1 of 1 Project: Jolly Recovery Test Number: Client:

Location: Jolly, Iowa	Pumping Test: Jolly Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 11/17/1983	Discharge: variable, average rate 33 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 36.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1495	52.00	16.00
2	1515	50.00	14.00
3	1605	45.00	9.00

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Jolly Recovery Test
	Number:
	Client:

Location: Jolly, Iowa	Pumping Test: Jolly Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 11/17/1983
Analysis Performed by:	New analysis 4	Analysis Date: 1/6/2012
Aquifer Thickness: 331.00 ft	Discharge: variable, average rate 33 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]
Well 1	6.65×10^{1}	2.01×10^{-1}	0.28

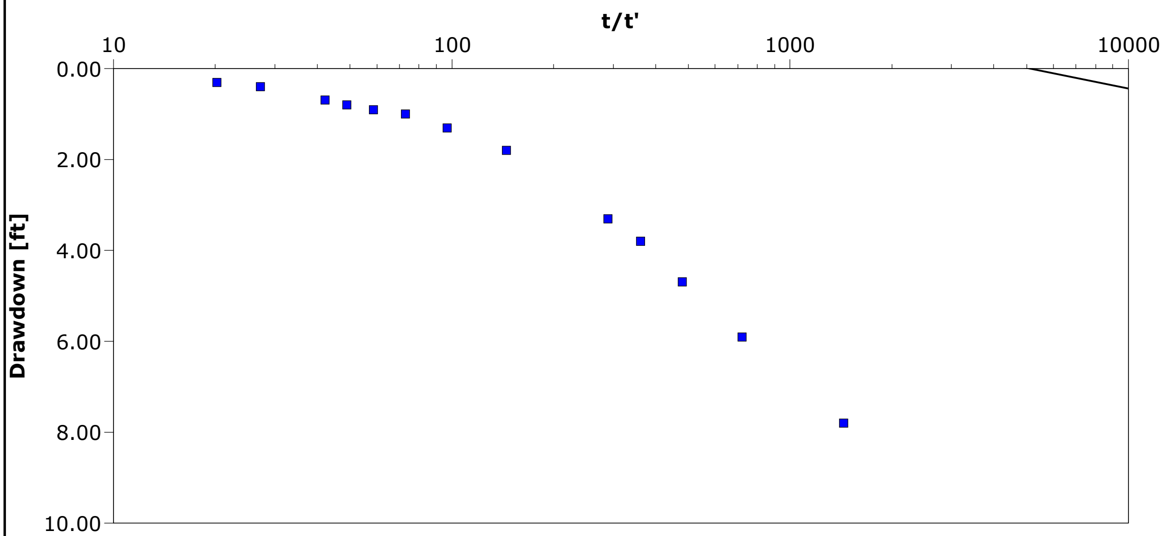
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1
	Project: Marshalltown Well 15 Recovery Test
	Number:
	Client:

Location: Marshalltown, Iowa	Pumping Test: Marshalltown Well 15 Recove	Pumping Well: Well 1
Test Conducted by:	Test Date: 3/5/2002	Discharge: variable, average rate 4000 [U.S. gal/m
Observation Well: Well 1	Static Water Level [ft]: 10.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1441	17.80	7.80
2	1442	15.90	5.90
3	1443	14.70	4.70
4	1444	13.80	3.80
5	1445	13.30	3.30
6	1450	11.80	1.80
7	1455	11.30	1.30
8	1460	11.00	1.00
9	1465	10.90	0.90
10	1470	10.80	0.80
11	1475	10.70	0.70
12	1495	10.40	0.40
13	1515	10.30	0.30

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Marshalltown Well 15 Recovery Test Number: Client:

Location: Marshalltown, Iowa	Pumping Test: Marshalltown Well 15 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 3/5/2002
Analysis Performed by:	New analysis 2	Analysis Date: 1/6/2012
Aquifer Thickness: 62.00 ft	Discharge: variable, average rate 4000 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	9.33×10^4	1.51×10^3	1.0	

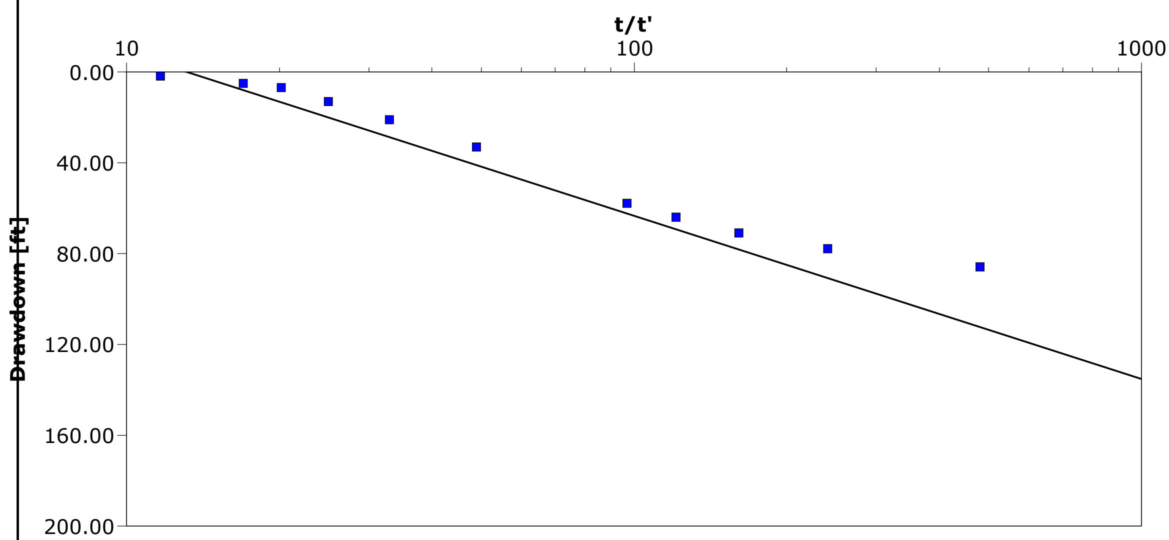
Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report**	Page 1 of 1
	Project: Moorland Recovery Test	
	Number:	
	Client:	

Location: Moorland, Ioowa	Pumping Test: Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 4/1/1957	Discharge: variable, average rate 35 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 180.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	480	320.00	140.00
2	481	266.00	86.00
3	482	258.00	78.00
4	483	251.00	71.00
5	484	244.00	64.00
6	485	238.00	58.00
7	490	213.00	33.00
8	495	201.00	21.00
9	500	193.00	13.00
10	505	187.00	7.00
11	510	185.00	5.00
12	525	182.00	2.00

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Moorland Recovery Test Number: Client:

Location: Moorland, Ioowa	Pumping Test: Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 4/1/1957
Analysis Performed by:	New analysis 3	Analysis Date: 1/5/2012
Aquifer Thickness: 447.00 ft	Discharge: variable, average rate 35 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]
Well 1	1.72×10^{1}	3.84×10^{-2}	0.33

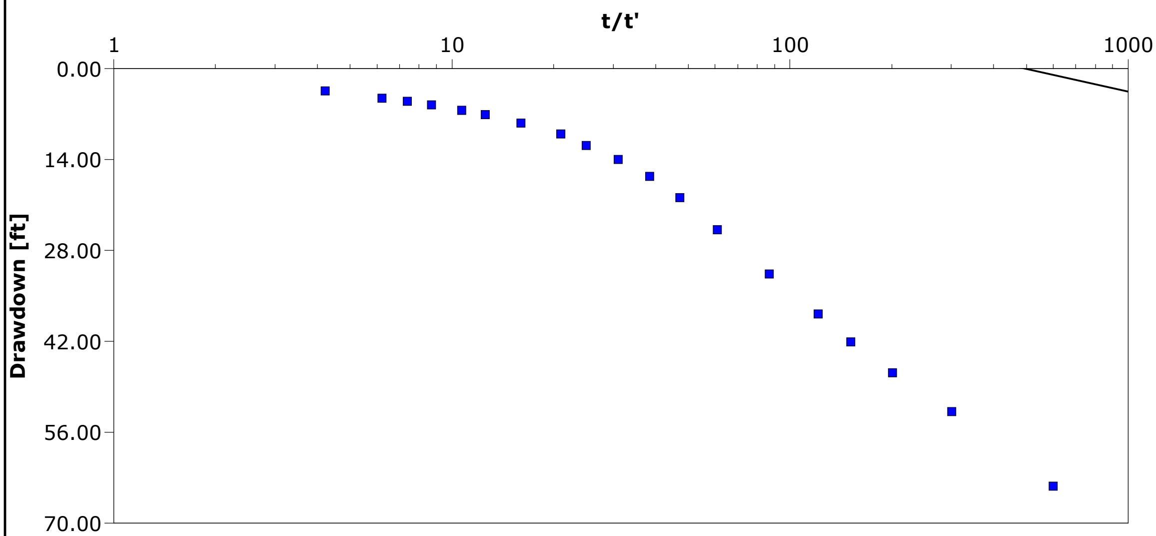
Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report	Page 1 of 1
	Project: Randall Recovery Test	
	Number:	
	Client:	

Location: Randall, Iowa	Pumping Test: Randall Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 6/16/1954	Discharge: variable, average rate 40 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 13.16	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	601	77.50	64.34
2	602	66.00	52.84
3	603	60.00	46.84
4	604	55.25	42.09
5	605	51.00	37.84
6	607	44.80	31.64
7	610	38.00	24.84
8	613	33.00	19.84
9	616	29.80	16.64
10	620	27.20	14.04
11	625	25.00	11.84
12	630	23.20	10.04
13	640	21.60	8.44
14	652	20.30	7.14
15	662	19.63	6.47
16	678	18.79	5.63
17	694	18.23	5.07
18	715	17.71	4.55
19	786	16.61	3.45

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Randall Recovery Test Number: Client:

Location: Randall, Iowa	Pumping Test: Randall Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 6/16/1954
Analysis Performed by:	New analysis 4	Analysis Date: 1/13/2012
Aquifer Thickness: 258.00 ft	Discharge: variable, average rate 40 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	1.22×10^{2}	4.71×10^{-1}	0.25	

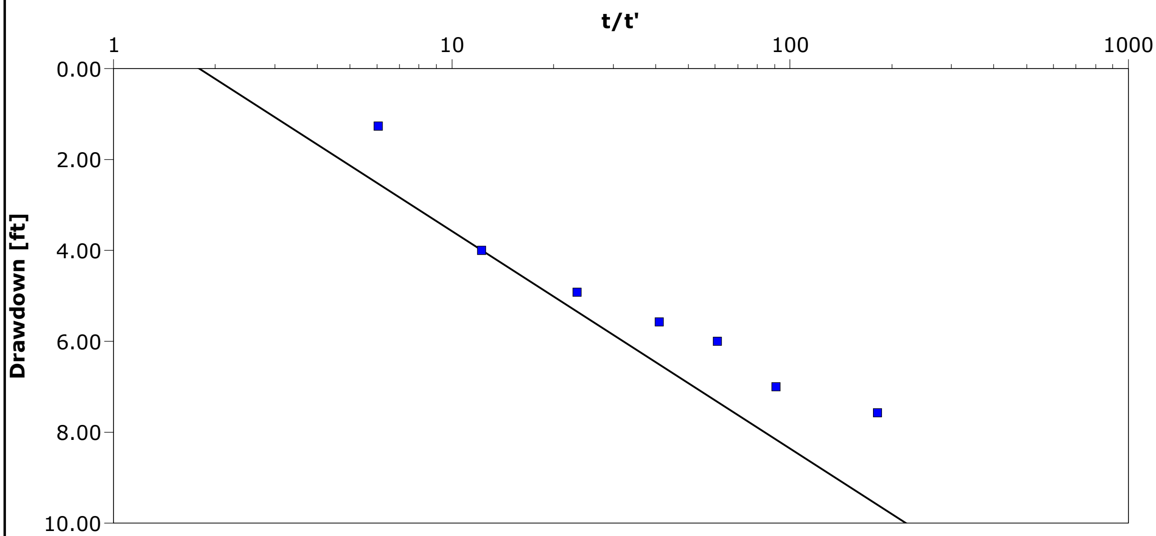
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1 Project: Roland Recovery Test Well 1 Number: Client:

Location: Roland, Iowa	Pumping Test: Roland Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 6/13/1945	Discharge: variable, average rate 240 [U.S. gal/mir
Observation Well: Well 1	Static Water Level [ft]: 28.33	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	362	35.90	7.57
2	364	35.33	7.00
3	366	34.33	6.00
4	369	33.90	5.57
5	376	33.25	4.92
6	392	32.33	4.00
7	431	29.60	1.27

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Roland Recovery Test Well 1 Number: Client:

Location: Roland, Iowa	Pumping Test: Roland Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 6/13/1945
Analysis Performed by:	New analysis 2	Analysis Date: 1/5/2012
Aquifer Thickness: 182.00 ft	Discharge: variable, average rate 240 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	1.77×10^{3}	9.70×10^{0}	0.33	

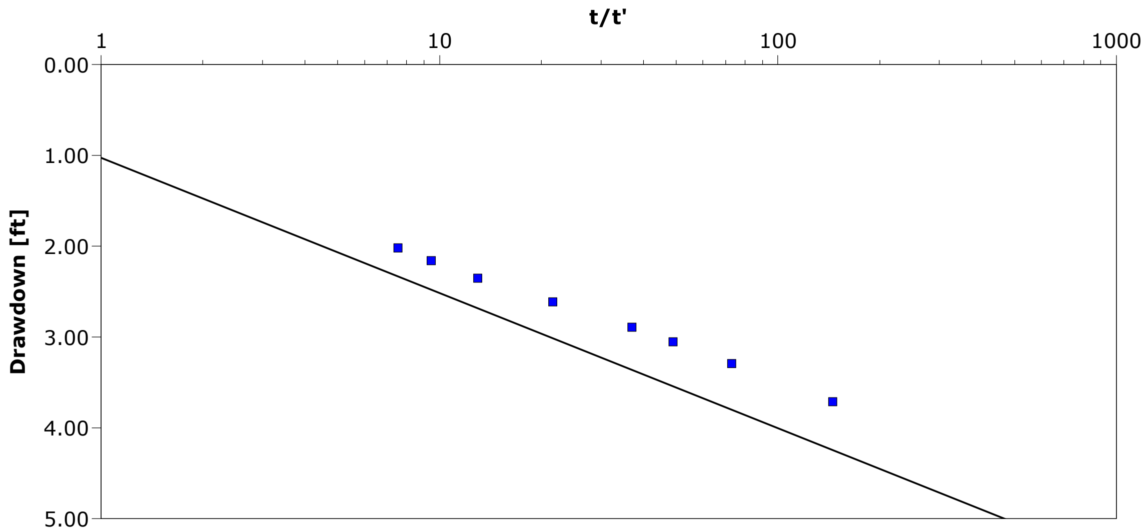
Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report**	Page 1 of 1
	Project: Rolfe #2 Recovery Test	
	Number:	
	Client:	

Location:	Pumping Test: Rolfe Well 2 Recovery Test	Pumping Well: Well 2
Test Conducted by:	Test Date: 9/2/1947	Discharge: variable, average rate 255 [U.S. gal/mir
Observation Well: Well 2	Static Water Level [ft]: 20.31	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	145	24.02	3.71
2	146	23.60	3.29
3	147	23.36	3.05
4	148	23.20	2.89
5	151	22.92	2.61
6	156	22.66	2.35
7	161	22.47	2.16
8	166	22.33	2.02

Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report Project: Rolfe #2 Recovery Test Number: Client:

Location:	Pumping Test: Rolfe Well 2 Recovery Test	Pumping Well: Well 2
Test Conducted by:		Test Date: 9/2/1947
Analysis Performed by:	New analysis 2	Analysis Date: 1/5/2012
Aquifer Thickness: 65.00 ft	Discharge: variable, average rate 255 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 2	6.03×10^3	9.28×10^1	0.41	

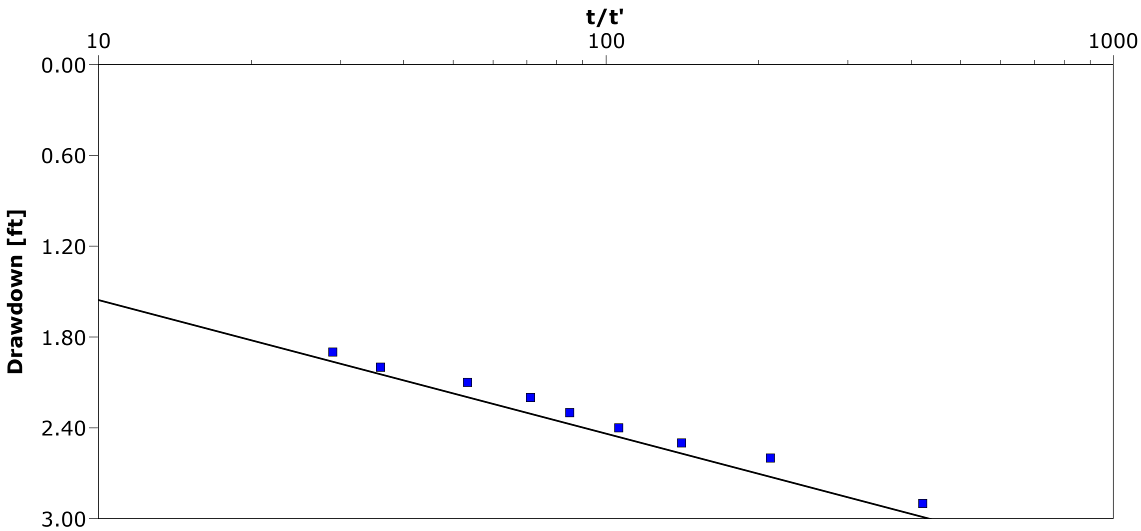
Contact Info Address Company Name City, State/Province	**Pumping Test - Water Level Data** Page 1 of 1
	Project: Rutland Well 1 Recovery Test
	Number:
	Client:

Location: Rutland, Iowa	Pumping Test: Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 8/12/1948	Discharge: variable, average rate 245 [U.S. gal/mir
Observation Well: Well 1	Static Water Level [ft]: 33.10	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	421	36.00	2.90
2	422	35.70	2.60
3	423	35.60	2.50
4	424	35.50	2.40
5	425	35.40	2.30
6	426	35.30	2.20
7	428	35.20	2.10
8	432	35.10	2.00
9	435	35.00	1.90

Contact Info **Address** **Company Name** **City, State/Province**		**Pumping Test Analysis Report** Project: Rutland Well 1 Recovery Test Number: Client:

Location: Rutland, Iowa	Pumping Test: Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 8/12/1948
Analysis Performed by:	New analysis 3	Analysis Date: 1/5/2012
Aquifer Thickness: 340.00 ft	Discharge: variable, average rate 245 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	9.78×10^3	2.88×10^1	0.41	

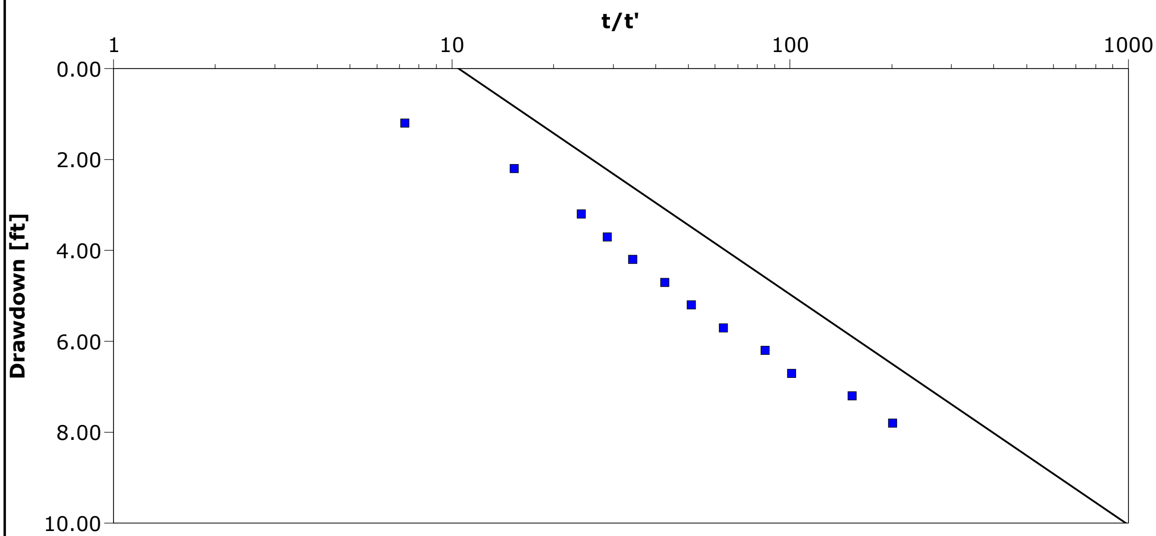
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1
	Project: Rutland Marsh
	Number:
	Client:

Location: Rutland, Iowa	Pumping Test: Packer Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 1/15/2002	Discharge: variable, average rate 20 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 43.80	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	50.25	51.60	7.80
2	50.33	51.00	7.20
3	50.5	50.50	6.70
4	50.6	50.00	6.20
5	50.8	49.50	5.70
6	51	49.00	5.20
7	51.2	48.50	4.70
8	51.5	48.00	4.20
9	51.8	47.50	3.70
10	52.16	47.00	3.20
11	53.5	46.00	2.20
12	58	45.00	1.20

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Rutland Marsh Number: Client:

Location: Rutland, Iowa	Pumping Test: Packer Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 1/15/2002
Analysis Performed by:	New analysis 3	Analysis Date: 1/6/2012
Aquifer Thickness: 20.00 ft	Discharge: variable, average rate 20 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	1.39×10^{2}	6.95×10^{0}	0.17	

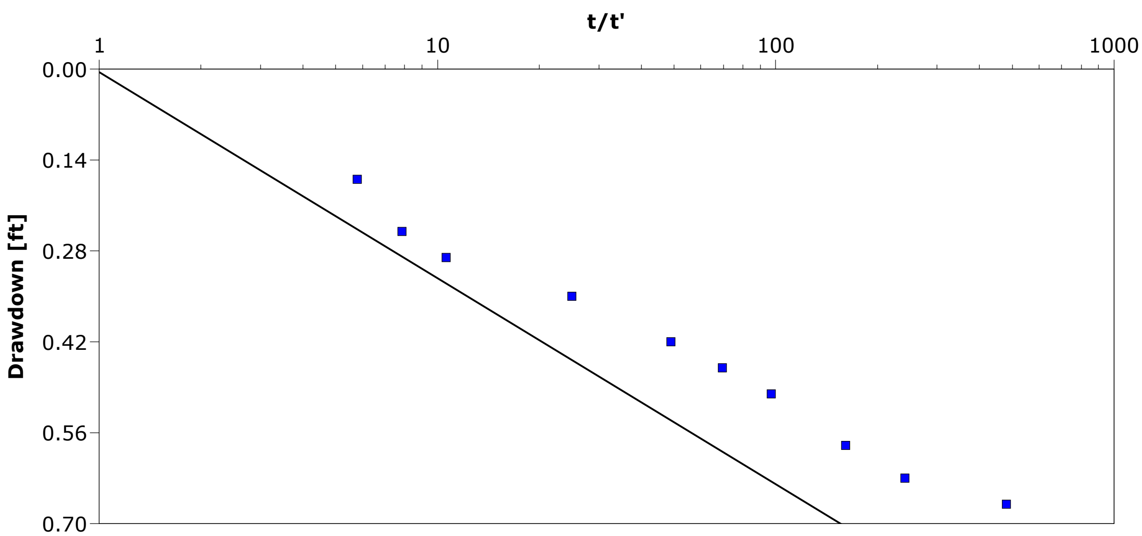
Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report	Page 1 of 1
	Project: Somers Well 2 Recovery Test	
	Number:	
	Client:	

Location: Somers, Iowa	Pumping Test: Somers Well 2 Recovery Tes	Pumping Well: Well 2
Test Conducted by:	Test Date: 9/7/2001	Discharge: variable, average rate 75 [U.S. gal/min]
Observation Well: Well 2	Static Water Level [ft]: 106.50	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	481	107.17	0.67
2	482	107.13	0.63
3	483	107.08	0.58
4	485	107.00	0.50
5	487	106.96	0.46
6	490	106.92	0.42
7	500	106.85	0.35
8	530	106.79	0.29
9	550	106.75	0.25
10	580	106.67	0.17

Contact Info **Address** **Company Name** **City, State/Province**	**Pumping Test Analysis Report** Project: Somers Well 2 Recovery Test Number: Client:

Location: Somers, Iowa	Pumping Test: Somers Well 2 Recovery Test	Pumping Well: Well 2
Test Conducted by:		Test Date: 9/7/2001
Analysis Performed by:	New analysis 2	Analysis Date: 1/6/2012
Aquifer Thickness: 100.00 ft	Discharge: variable, average rate 75 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 2	8.33×10^{3}	8.33×10^{1}	0.2	

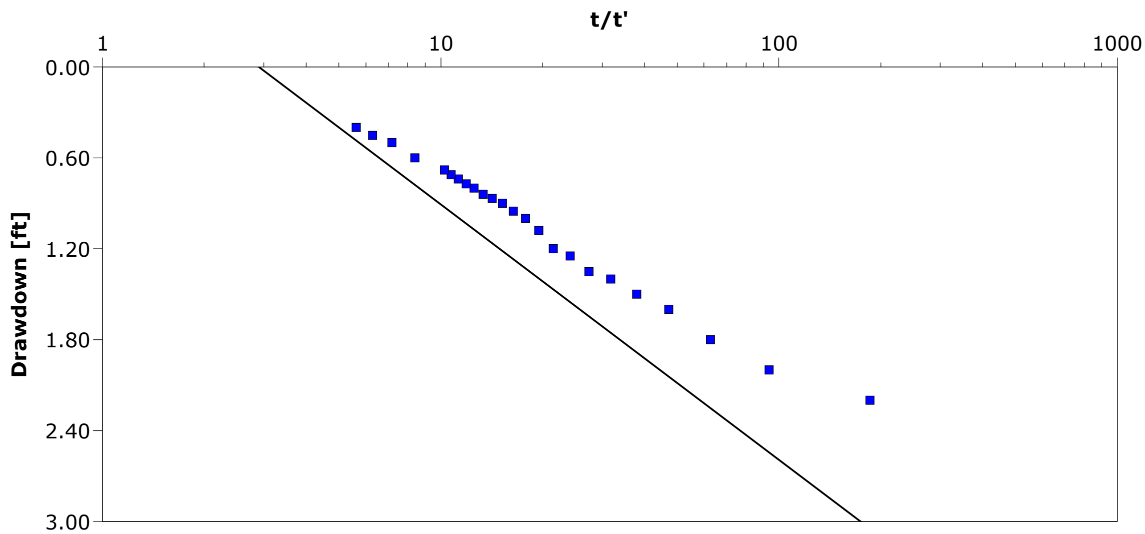
Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report** Page 1 of 1 Project: Steamboat Rock Recovery Test Number: Client:

Location: Steamboat Rock, Iowa	Pumping Test: Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 9/26/1951	Discharge: variable, average rate 185 [U.S. gal/mir
Observation Well: Well 1	Static Water Level [ft]: 56.50	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	186	58.70	2.20
2	187	58.50	2.00
3	188	58.30	1.80
4	189	58.10	1.60
5	190	58.00	1.50
6	191	57.90	1.40
7	192	57.85	1.35
8	193	57.75	1.25
9	194	57.70	1.20
10	195	57.58	1.08
11	196	57.50	1.00
12	197	57.45	0.95
13	198	57.40	0.90
14	199	57.37	0.87
15	200	57.34	0.84
16	201	57.30	0.80
17	202	57.27	0.77
18	203	57.24	0.74
19	204	57.21	0.71
20	205	57.18	0.68
21	210	57.10	0.60
22	215	57.00	0.50
23	220	56.95	0.45
24	225	56.90	0.40

Contact Info Address Company Name City, State/Province	**Pumping Test Analysis Report**
	Project: Steamboat Rock Recovery Test
	Number:
	Client:

Location: Steamboat Rock, Iowa	Pumping Test: Well 1 Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 9/26/1951
Analysis Performed by:	New analysis 3	Analysis Date: 1/5/2012
Aquifer Thickness: 65.00 ft	Discharge: variable, average rate 185 [U.S. gal/min]	



Calculation using THEIS & JACOB

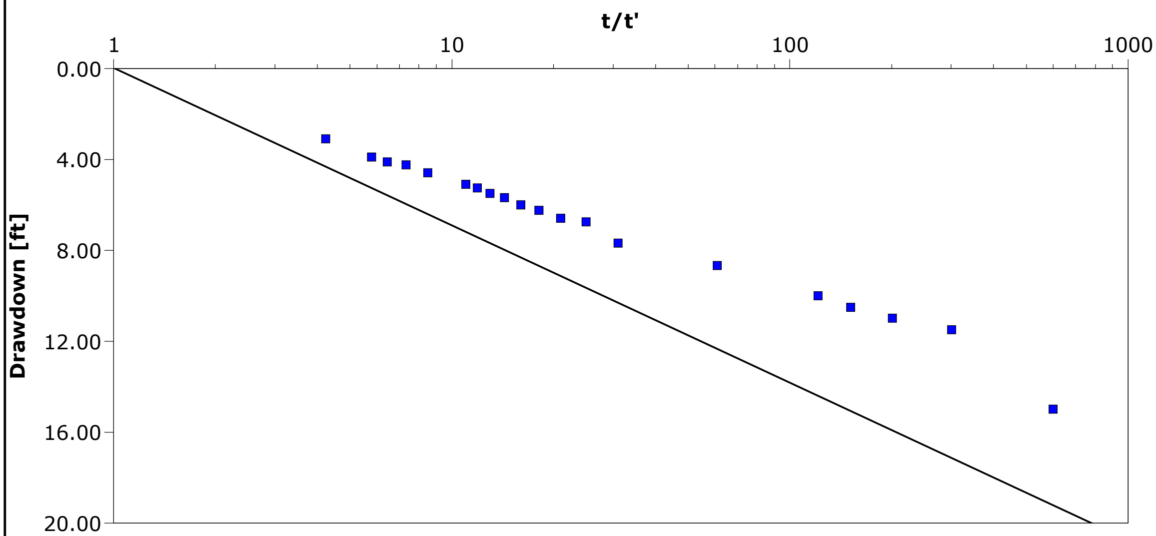
Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	3.87×10^3	5.95×10^1	0.33	

Contact Info Address Company Name City, State/Province	Pumping Test Analysis Report	Page 1 of 1
	Project: Whitten Recovery Test	
	Number:	
	Client:	

Location: Whitten, Iowa	Pumping Test: Well 2	Pumping Well: Well 2
Test Conducted by:	Test Date: 7/13/1978	Discharge: variable, average rate 110 [U.S. gal/mir
Observation Well: Well 2	Static Water Level [ft]: 60.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	601	75.00	15.00
2	602	71.50	11.50
3	603	71.00	11.00
4	604	70.50	10.50
5	605	70.00	10.00
6	610	68.67	8.67
7	620	67.67	7.67
8	625	66.75	6.75
9	630	66.60	6.60
10	635	66.25	6.25
11	640	66.00	6.00
12	645	65.67	5.67
13	650	65.50	5.50
14	655	65.25	5.25
15	660	65.10	5.10
16	680	64.60	4.60
17	695	64.25	4.25
18	710	64.10	4.10
19	725	63.90	3.90
20	785	63.10	3.10

Contact Info **Address** **Company Name** **City, State/Province**		**Pumping Test Analysis Report** Project: Whitten Recovery Test Number: Client:
Location: Whitten, Iowa	Pumping Test: Well 2	Pumping Well: Well 2
Test Conducted by:		Test Date: 7/13/1978
Analysis Performed by:	New analysis 2	Analysis Date: 12/21/2011
Aquifer Thickness: 105.00 ft	Discharge: variable, average rate 110 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 2	5.59×10^{2}	5.33×10^{0}	0.33	

APPENDIX B

SPECIFIC CAPACITY DATA

Well Number	Well Name	UTM X	UTM Y	SWL (ft)	PWL (ft)	Pumping Rate (gpm)	SPC (gpm/ft)	T (ft^2/day)	K (ft/day)
26208	GREEN CASTLE REC AREA #1	511379	4641414	98	120	25	1.14	308	3
7405	FERGUSON #1	511174	4642690	60	125	50	0.77	208	2
38029	CAMP MITIGWA-#FRANKEL WELL 1	424780	4644948	0	0	55	0.23	63	1
41370	TIMBER VALLEY MHP #1	508912	4648127	38	40	50	25.00	6750	338
41371	TIMBER VALLEY MHP #2	508901	4648144	38	40	50	25.00	6750	169
55996	MARSHALLTOWN #15	504437	4656827	10	18	2000	243.90	48780	1524
27630	MARSHALLTOWN #11	505804	4657226	18	40	2000	90.90	25543	281
18113	GILBERT #2 (W18113)	446228	4661922	75	117	110	2.60	690	26
39922	GILBERT #2 (W39922)	446245	4661936	30	31	100	100.00	2700	129
41704	ROLAND #2 (W41704)	458742	4668763	95	140	130	2.88	778	1
2075	ROLAND #4 (W2075)	458743	4668764	55	70	200	13.33	3600	23
52392	ROLAND #3 (W52392)	458831	4668846	50	90	200	5.00	1350	12
26786	STORY CITY #3	451382	4670617	10	203	603	3.12	844	14
2158	STORY CITY #2	451448	4670705	20	7	647	24.40	6592	51
13238	CONRAD #3	510729	4674463	11	34	160	6.95	1900	20
19097	CONRAD #4	510150	4674898	19	45	220	8.46	2300	24
6622	RANDALL #1	450351	4676269	13	143	52	0.40	100	0.4
20260	UNION #2 (W20260)	494778	4676948	30	86	200	3.60	1000	7
2419	UNION #1	494882	4677385	23	28	300	60.00	16200	120
26357	WHITTEN #2	499803	4678803	68	139	120	1.70	470	5
43137	WHITTEN #OLD	499487	4678805	55	73	40	2.20	600	6
32171	DAYTON #2	411783	4679604	62	165	175	1.70	459	2
5548	DAYTON #3	411713	4679616	91	139	230	4.79	1293	3
67444	DAYTON #4	411722	4679624	142	221	227	2.87	776	1
10811	STRATFORD #3	423533	4680365	156	270	75	0.66	180	1
32358	STRATFORD #2	423495	4680365	205	232	200	7.40	2000	10
35820	STRATFORD #4	423455	4680377	247	468	155	0.70	200	3
38927	LITTLE WALL LAKE AREA #1	447217	4680629	23	31	20	2.50	675	9
10722	LOHRVILLE #3	372382	4680884	88	120	300	9.40	2540	36
25434	LOHRVILLE #4	372362	4680919	107	323	225	1.04	280	1
67474	LOHRVILLE #5	372376	4680985	112	137	300	12.00	3237	23
2364	NEW PROVIDENCE #1	485919	4681173	175	200	50	2.00	540	3
23253	STANHOPE #5	434473	4682290	153	270	70	0.60	160	0.4
15874	STANHOPE #4	434610	4682545	140	225	40	0.47	127	0.3
15024	HUBBARD RECREATION CLUB #1	476270	4682742	150	246	75	0.78	210	2
66734	HUBBARD #5	476093	4683330	78	260	200	1.10	297	2
2162	HUBBARD #2	475656	4683910	28	68	97	2.40	650	3
40481	JEWELL #3	447380	4684156	50	95	225	5.00	1350	27
30982	RADCLIFFE #4	464300	4684893	84	154	299	4.30	1150	5
8549	RADCLIFFE #3	464254	4684917	59	90	215	7.00	1890	7
3492	ELLSWORTH #3	452353	4685023	22	30	191	23.90	6500	27
6237	ELLSWORTH #4	452354	4685026	24	33	211	23.40	6330	26
39329	PRIARIE VALLEY HIGH SCHOOL #1	383403	4688131	120	351	30	0.13	34	0.1
39672	ELDORA #4	491531	4689433	110	115	230	46.00	12420	108
14548	ELDORA #5	491767	4689670	140	180	275	6.90	1860	14
58740	ROCK N ROW ADVENTURES #1	493324	4689758	15	37	15	0.68	184	3
47078	PINE LAKE CHRISTIAN CENTER #1	493665	4690253	70	80	10	1.00	270	3
47081	PINE LAKE CHRISTIAN CENTER #4	493776	4690304	45	55	30	3.00	810	9
47082	PINE LAKE CHRISTIAN CENTER #5	493807	4690538	50	89	30	0.77	208	4
34052	ELDORA #OW	492542	4690967	115	154	400	10.30	2770	34
54648	SOMERS #2	382297	4692573	106	109	75	25.00	6700	122
21059	SOMERS #1	382336	4692600	102	111	50	5.60	1500	16
45842	DOLLIVER STATE PARK #2	410486	4692931	20	58	18	0.23	60	1
40484	KAMRAR #1	439869	4693611	47	68	50	2.40	640	11
5188	STEAMBOAT ROCK #1	494581	4695491	57	64	125	17.90	4800	83
42593	STEAMBOAT ROCK #2	494554	4695579	57	84	250	9.30	2500	44
7383	OTHO #1	405160	4697359	160	180	50	2.50	675	2
25023	OTHO #3	405157	4697418	118	199	275	3.40	918	3
12698	OTHO #2	405109	4697428	110	125	100	6.60	1782	5
38928	BRIGGS WOODS GOLF COURSE #1	434229	4697549	80	120	25	0.63	170	3
19658	BRIGGS WOODS PARK #1	434607	4698479	60	120	25	0.42	110	1
17317	COATS SUBDIV WATER SUPPLY #1	407030	4699345	130	165	14	0.40	108	1
8215	MOORLAND #1	393719	4699411	180	320	35	0.25	68	0.1
62830	MOORLAND #3	393729	4699413	204	272	143	2.10	568	4
47013	NORSEMAN INN BEST WESTERN #1	453769	4702156	90	160	30	0.43	120	2
1931	DUNCOMBE #2	418701	4702383	49	96	37	0.79	210	0.3
23221	DUNCOMBE #3	418715	4702426	85	185	100	1.00	270	1
39389	DUNCOMBE #4	418717	4702427	158	266	108	1.00	270	1
14992	BLAIRSBURG #2	447018	4703216	71	167	115	1.20	325	1
8174	CELOTEX CORPORATION #1	407004	4704238	185	349	270	1.65	445	2
27238	JOLLEY #1	358620	4704397	36	311	33	0.12	32	0
26356	SOUTHPARK #1	479022	4704677	47	51	152	43.00	11725	55
33349	FORT DODGE ASPHALT #1	399428	4706241	157	200	20	0.46	120	20
37001	CALKINS NATURE CENTER #1	472610	4706359	30	88	25	0.43	116	1
216	FORT DODGE #9	401463	4706677	41	44	1810	21.62	5837	18
352	FORT DODGE #14	401318	4706823	20	0	2900	85.30	23031	94
17997	ALDEN #2	469052	4707234	51	90	250	6.40	1730	6
43213	MEADOW HILLS GOLF COURSE #2	482165	4707527	-2	140	75	0.53	143	1
35279	ALDEN #3	468625	4707601	55	74	49	2.60	702	10

Well Number	Well Name	UTM X	UTM Y	SWL (ft)	PWL (ft)	Pumping Rate (gpm)	SPC (gpm/ft)	T (ft^2/day)	K (ft/day)
59295	IOWA LIMESTONE CO #3	469476	4707666	20	60	30	0.75	150	1
40450	IOWA FALLS #ELK RUN 3	477919	4707922	41	105	300	4.70	1300	8
8350	IOWA FALLS #ELK RUN 1	477182	4708066	9	126	350	3.00	820	5
63841	IOWA FALLS #ELK RUN 4	476957	4708263	26	111	410	4.82	965	5
40398	IOWA FALLS #PINE STREET 2	478496	4708334	35	115	750	9.40	2500	16
32361	IOWA FALLS #PINE STREET 1	478493	4708338	35	115	750	9.40	2500	18
40399	IOWA FALLS #PINE STREET 3	478490	4708341	35	115	750	9.40	2500	16
9059	IOWA FALLS #ELK RUN 2	477358	4708349	12	137	200	1.60	430	3
73520	BECKER WATER AND ROAD #2	399397	4709552	125	175	10	0.20	54	0
63045	RABINER TREATMENT CENTER #2	397048	4709969	87	236	90	0.60	163	0
48524	FORT DODGE ICE & COLD #1	405252	4710810	180	342	55	0.34	93	0
6097	ACKLEY #5	495184	4711086	27	116	75	0.84	227	3
32362	ACKLEY #6	495348	4711448	35	55	525	26.25	7088	68
1576	ACKLEY #3	495317	4711472	33	120	123	1.41	381	6
3269	ACKLEY #1	495007	4711615	36	69	55	1.67	451	6
54304	WOOLSTOCK #2	430921	4712919	51	79	220	8.00	2200	31
5762	WOOLSTOCK #1	430920	4713016	41	49	210	26.30	7087	177
54800	LAKEWOOD ADDITION #3	401578	4714363	97	297	50	0.25	68	1
54463	KENNEDY PARK #2	402624	4715443	84	239	45	0.29	78	1
995	FONDA #2	348476	4715726	26	45	1180	62.00	16770	122
31926	CLARE #2	390095	4715839	288	471	110	0.60	150	3
43008	VINCENT #3	416299	4715946	20	40	100	5.00	1400	56
23299	BADGER #3	405775	4718567	80	140	60	1.00	270	1
3303	BADGER #2	405849	4718667	55	149	30	0.32	90	0
8847	EAGLE GROVE #4	426317	4724027	5	96	680	7.50	2025	7
57553	IOWA DEPARTMENT OF TRANS. #1	462097	4724508	3	60	75	1.32	355	3
56929	DECOSTER FARMS FEED MILL #1	447854	4724510	40	110	30	0.43	116	12
42646	THOR #2	413770	4726990	36	127	85	0.93	252	1
40356	HUMBOLDT #3	399786	4730333	50	75	1300	52.00	10400	35
3222	DAKOTA CITY #2	401607	4730505	50	80	112	3.70	999	2
40354	HUMBOLDT #2 (NORTH SPRING)	399738	4730551	50	75	1300	52.00	10400	35
40355	HUMBOLDT #1 (SOUTH SPRING)	399736	4730553	50	75	1300	52.00	10400	35
10665	CLARION #3	439922	4731127	28	34	820	136.70	37000	333
38089	CLARION #1	439921	4731197	34	39	600	120.00	32400	324
30322	HUMBOLDT COUNTY CLUB #2	397557	4731602	18	35	15	0.88	238	30
39983	GOLDFIELD #2	424618	4731773	18	50	125	3.90	1050	8
34627	HOLMES #1	431751	4731995	16	36	20	1.00	270	2
9420	GILMORE CITY #3	382339	4732073	72	78	626	104.00	28200	194
2929	ROWAN #1	454847	4732204	24	70	110	2.40	648	5
64730	DUDLEY'S CORNER #2	468016	4733064	36	80	30	0.68	184	3
38846	CAL GRADE AND HIGH SCHOOL #1	469818	4733282	43	45	60	30.00	8100	99
54194	LATIMER #3	469906	4734267	38	80	350	8.30	2250	54
3374	RUTLAND #1	394367	4735288	33	39	236	39.30	10600	303
32722	GOLD KEY MOTEL #2	483343	4735346	30	141	30	0.27	70	1
34687	HARDY #2	414089	4740254	70	78	60	7.50	2000	71
2973	ROLFE #2	375320	4741617	20	33	255	19.30	5200	42
4815	RENWICK #2	420030	4742222	39	45	460	76.67	20700	450
41652	RENWICK #1	420033	4742227	44	45	460	460.00	124200	2700
60425	ZION REFORMED CHURCH #1	473875	4743271	28	100	15	0.21	56	1
566	HAVELOCK # OLD 2	360839	4743824	28	195	70	0.42	114	1
9241	BELMOND #2	450171	4744271	30	57	250	9.26	2500	18
45937	BODE #3	395010	4746448	38	121	150	1.80	486	1
40624	LIVERMORE #2	403142	4746819	62	78	125	8.00	2160	15
36513	BODE #1 (W36513)	394518	4746836	30	45	60	4.00	1080	9
3375	BODE #2	394899	4746982	40	94	190	3.50	945	6
7548	OTTOSEN #2	387557	4750208	40	140	35	0.35	95	0
40649	LU VERNE #1	411451	4751078	13	22	150	16.70	4500	56
39984	GOODELL #2	449992	4752582	53	57	160	40.00	10800	208
40486	KANAWHA #2	435206	4754005	33	38	500	100.00	27000	338
4864	CORWITH #1 (W4864)	421996	4760539	33	63	200	6.70	1800	51
6225	CORWITH #2	421950	4760544	38	68	200	6.70	1800	51

APPENDIX C

STATIC WATER LEVEL DATA

W Number	Well Name	UTM X	UTM Y	SWL (ft)
26208	GREEN CASTLE RECREATION AREA #1	511379	4641414	905
7405	FERGUSON #1	511174	4642690	891
41370	TIMBER VALLEY MHP #1	508912	4648127	862
41371	TIMBER VALLEY MHP #2	508901	4648144	869
55996	MARSHALLTOWN #15	504437	4656827	866
27630	MARSHALLTOWN #11	505804	4657226	854
18113	GILBERT #2 (W18113)	446228	4661922	916
39922	GILBERT #2 (W39922)	446245	4661936	962
41704	ROLAND #2 (W41704)	458742	4668763	939
2075	ROLAND #4 (W2075)	458743	4668764	979
52392	ROLAND #3 (W52392)	458831	4668846	982
26786	STORY CITY #3	451382	4670617	976
2158	STORY CITY #2	451448	4670705	952
13238	CONRAD #3	510729	4674463	982
19097	CONRAD #4	510150	4674898	983
6622	RANDALL #1	450351	4676269	1019
20260	UNION #2 (W20260)	494778	4676948	902
2419	UNION #1	494882	4677385	912
26357	WHITTEN #2	499803	4678803	971
43137	WHITTEN #OLD	499487	4678805	983
10811	STRATFORD #3	423533	4680365	956
32358	STRATFORD #2	423495	4680365	906
35820	STRATFORD #4	423455	4680377	863
38927	LITTLE WALL LAKE AREA #1	447217	4680629	1023
10722	LOHRVILLE #3	372382	4680884	1066
67474	LOHRVILLE #5	372376	4680985	1041
2364	NEW PROVIDENCE #1	485919	4681173	951
23253	STANHOPE #5	434473	4682290	965
15874	STANHOPE #4	434610	4682545	983
15024	HUBBARD RECREATION CLUB #1	476270	4682742	965
66734	HUBBARD #5	476093	4683330	1044
2162	HUBBARD #2	475656	4683910	1067
40481	JEWELL #3	447380	4684156	987
30982	RADCLIFFE #4	464300	4684893	1098
8549	RADCLIFFE #3	464254	4684917	1122
3492	ELLSWORTH #3	452353	4685023	1063
6237	ELLSWORTH #4	452354	4685026	1061
39329	PRIARIE VALLEY HIGH SCHOOL #1	383403	4688131	1035
39672	ELDORA #4	491531	4689433	944
14548	ELDORA #5	491767	4689670	941
58740	ROCK N ROW ADVENTURES #1	493324	4689758	936
47078	PINE LAKE CHRISTIAN CENTER #1	493665	4690253	939
47081	PINE LAKE CHRISTIAN CENTER #4	493776	4690304	961
47082	PINE LAKE CHRISTIAN CENTER #5	493807	4690538	956
34052	ELDORA #OW	492542	4690967	941
54648	SOMERS #2	382297	4692573	1046

W Number	Well Name	UTM X	UTM Y	SWL (ft)
21059	SOMERS #1	382336	4692600	1051
45842	DOLLIVER STATE PARK #2	410486	4692931	961
40484	KAMRAR #1	439869	4693611	1074
5188	STEAMBOAT ROCK #1	494581	4695491	964
42593	STEAMBOAT ROCK #2	494554	4695579	973
7383	OTHO #1	405160	4697359	966
38928	BRIGGS WOODS GOLF COURSE #1	434229	4697549	974
19658	BRIGGS WOODS PARK #1	434607	4698479	1015
17317	COATS SUBDIVISION WATER SUPPLY #1	407030	4699345	988
8215	MOORLAND #1	393719	4699411	976
62830	MOORLAND #3	393729	4699413	951
47013	NORSEMAN INN BEST WESTERN #1	453769	4702156	1100
23221	DUNCOMBE #3	418715	4702426	1023
39389	DUNCOMBE #4	418717	4702427	950
14992	BLAIRSBURG #2	447018	4703216	1151
27238	JOLLEY #1	358620	4704397	1193
26356	SOUTHPARK #1	479022	4704677	1081
33349	FORT DODGE ASPHALT #1	399428	4706241	954
37001	CALKINS NATURE CENTER #1	472610	4706359	1109
216	FORT DODGE #9	401463	4706677	945
17997	ALDEN #2	469052	4707234	1106
43213	MEADOW HILLS GOLF COURSE #2	482165	4707527	1082
35279	ALDEN #3	468625	4707601	1100
59295	IOWA LIMESTONE CO #3	469476	4707666	1092
8350	IOWA FALLS #ELK RUN 1	477182	4708066	1060
63841	IOWA FALLS #ELK RUN 4	476957	4708263	1054
40398	IOWA FALLS #PINE STREET 2	478496	4708334	1052
32361	IOWA FALLS #PINE STREET 1	478493	4708338	1052
40399	IOWA FALLS #PINE STREET 3	478490	4708341	1053
9059	IOWA FALLS #ELK RUN 2	477358	4708349	1059
73520	BECKER WATER AND ROAD #2	399397	4709552	968
63045	RABINER TREATMENT CENTER #2	397048	4709969	1017
48524	FORT DODGE ICE & COLD #1	405252	4710810	942
6097	ACKLEY #5	495184	4711086	1060
32362	ACKLEY #6	495348	4711448	1061
1576	ACKLEY #3	495317	4711472	1058
3269	ACKLEY #1	495007	4711615	1057
54304	WOOLSTOCK #2	430921	4712919	1059
5762	WOOLSTOCK #1	430920	4713016	1067
54800	LAKEWOOD ADDITION #3	401578	4714363	1029
54463	KENNEDY PARK #2	402624	4715443	1029
995	FONDA #2	348476	4715726	1202
31926	CLARE #2	390095	4715839	926
43008	VINCENT #3	416299	4715946	1119
23299	BADGER #3	405775	4718567	1071
3303	BADGER #2	405849	4718667	1100

W Number	Well Name	UTM X	UTM Y	SWL (ft)
8847	EAGLE GROVE #4	426317	4724027	1106
57553	IOWA DEPARTMENT OF TRANS. #1	462097	4724508	1167
56929	DECOSTER FARMS FEED MILL #1	447854	4724510	1190
42646	THOR #2	413770	4726990	1114
40356	HUMBOLDT #3	399786	4730333	1052
10665	CLARION #3	439922	4731127	1144
38089	CLARION #1	439921	4731197	1140
30322	HUMBOLDT COUNTY CLUB #2	397557	4731602	1069
39983	GOLDFIELD #2	424618	4731773	1112
34627	HOLMES #1	431751	4731995	1132
9420	GILMORE CITY #3	382339	4732073	1148
2929	ROWAN #1	454847	4732204	1188
64730	DUDLEY'S CORNER #2	468016	4733064	1191
38846	CAL GRADE AND HIGH SCHOOL #1	469818	4733282	1205
54194	LATIMER #3	469906	4734267	1209
3374	RUTLAND #1	394367	4735288	1093
32722	GOLD KEY MOTEL #2	483343	4735346	1093
34687	HARDY #2	414089	4740254	1066
2973	ROLFE #2	375320	4741617	1156
4815	RENWICK #2	420030	4742222	1119
41652	RENWICK #1	420033	4742227	1114
60425	ZION REFORMED CHURCH #1	473875	4743271	1190
566	HAVELOCK # OLD 2	360839	4743824	1198
9241	BELMOND #2	450171	4744271	1156
40624	LIVERMORE #2	403142	4746819	1076
36513	BODE #1 (W36513)	394518	4746836	1127
3375	BODE #2	394899	4746982	1111
7548	OTTOSEN #2	387557	4750208	1118
40649	LU VERNE #1	411451	4751078	1144
39984	GOODELL #2	449992	4752582	1189
40486	KANAWHA #2	435206	4754005	1152
4864	CORWITH #1 (W4864)	421996	4760539	1144
6225	CORWITH #2	421950	4760544	1138

APPENDIX D

WATER USE DATA

WNUMBER	Well Name	UTM X	UTM Y	Pumping Rate (gpd)
7405	FERGUSON #1	511174	4642690	-6000
25669	FERGUSON #2	510903	4642805	-3000
38028	CAMP MITIGWAA	425017	4644469	-5800
38027	CAMP MITIGWA-B*	424244	4644723	-5800
38029	CAMP MITIGWA-C	424780	4644948	-5800
41370	TIMBER VALLEY1	508912	4648127	-12000
41371	TIMBER VALLEY2	508901	4648144	-12000
26625	MARSHALLTOWN6	506328	4657204	-481000
55996	MARSHALLTOWN15	504437	4656827	-2385000
40768	MARSHALLTOWN14	506320	4656932	-34000
27630	MARSHALLTOWN11	505804	4657226	-818000
2075	ROLAND #4 (W20*	458743	4668764	-58750
52392	ROLAND #3	458831	4668846	-58750
61257	STORY CITY #4	451544	4670079	-111333
26786	STORY CITY #3	451382	4670617	-111333
2158	STORY CITY #2	451448	4670705	-111333
70494	RIVERSIDE LUTH	452337	4674138	-2750
13238	CONRAD #3	510729	4674463	-70000
19097	CONRAD #4	510150	4674898	-70000
6622	RANDALL #1	450351	4676269	-12000
32171	DAYTON #2	411783	4679604	-46000
67444	DAYTON #4	411722	4679624	-46000
32358	STRATFORD #2	423495	4680365	-34800
10722	LOHRVILLE #3	372382	4680884	-37375
67474	LOHRVILLE #5	372376	4680985	-59625
2364	NEW PROVIDENCE*	485919	4681173	-13000
40995	NEW PROVIDENCE2	485963	4681298	-13000
10435	FARNHAMVILLE #1	384155	4681316	-21666
23253	STANHOPE #5	434473	4682290	-19010
15874	STANHOPE #4	434610	4682545	-19010
15024	HUBBARD RECR	476270	4682742	-1000
66733	HUBBARD #4	476093	4683330	-45000
66734	HUBBARD #5	476093	4683330	-45000
29425	HUBBARD #3	475598	4683814	-45000
40481	JEWELL #3	447380	4684156	-115000
30982	RADCLIFFE #4	464300	4684893	-23500
8549	RADCLIFFE #3	464254	4684917	-23500
3492	ELLSWORTH #3	452353	4685023	-39500
6237	ELLSWORTH #4	452354	4685026	-39500
39671	ELDORA #3	491735	4689529	-100333
14548	ELDORA #5	491767	4689670	-100333
58740	ROCK N ROW	493324	4689758	-300
47081	PINE LAKE 4	493776	4690304	-200
47082	PINE LAKE 5	493807	4690538	-200
37946	ELDORA #6	492488	4690947	-100333
54648	SOMERS #2	382297	4692573	-4875

WNUMBER	Well Name	UTM X	UTM Y	Pumping Rate (gpd)
21059	SOMERS #1	382336	4692600	-4875
56297	COMMUNITY Chch	441654	4692632	-30
5188	STEAMBOAT Rck1	494581	4695491	-12000
42593	STEAMBOAT Rck2	494554	4695579	-12000
38928	BRIGGS WOODS	434229	4697549	-200
19658	BRIGGS WOODS	434607	4698479	-200
56268	WOODLAND AC2	407045	4699105	-3500
56267	WOODLAND AC1	407032	4699109	-3500
62830	MOORLAND #3	393729	4699413	-15000
31923	I-35 TRUCK	453024	4702148	-11000
47013	NORSEMAN INN1	453769	4702156	-1000
38932	BOONDOCKS TRUC	453486	4702321	-3500
38933	BOONDOCKS TRK	453409	4702410	-3500
23221	DUNCOMBE #3	418715	4702426	-20000
39389	DUNCOMBE #4	418717	4702427	-20000
14992	BLAIRSBURG #2	447018	4703216	-16500
18640	WILLIAMS #3	455220	4704028	-34000
8174	CELOTEX #1	407004	4704238	-100000
27238	JOLLEY #1	358620	4704397	-5000
26356	SOUTHPARK #1	479022	4704677	-900
70495	KOCH NITROGEN3	416522	4705845	-175000
33349	FORT DODGE ASP	399428	4706241	-50
37001	CALKINS NATURE	472610	4706359	-500
216	FORT DODGE #9	401463	4706677	-616666
32213	FORT DODGE #12	401418	4706753	-616666
352	FORT DODGE #14	401318	4706823	-616666
56307	MARTIN M1	470583	4706993	-500
43213	MEADOW HILLSGC	482165	4707527	-500
56305	IOWA LS1	469654	4707583	-500
35279	ALDEN #3	468625	4707601	-37500
56117	ALDEN #4	468632	4707631	-37500
59295	IOWA LS3	469476	4707666	-500
40450	IOWA FALLS ER 3	477919	4707922	-100680
8350	IOWA FALLS 1	477182	4708066	-100680
63841	IOWA FALLS #4	476957	4708263	-159410
40398	IOWA FALLS 2	478496	4708334	-251700
32361	IOWA FALLS 1	478493	4708338	-125850
40399	IOWA FALLS 3	478490	4708341	-100680
73521	BECKER WATER 1	399364	4709509	-750
73520	BECKER WATER 2	399397	4709552	-750
38941	Moose #2	478487	4709564	-700
38935	SCENIC CITY MO*	478397	4709804	-1500
63045	RABINER	397048	4709969	-3000
54304	WOOLSTOCK #2	430921	4712919	-8500
5762	WOOLSTOCK #1	430920	4713016	-8500
54800	LAKEWOOD ADD3	401578	4714363	-13000

WNUMBER	Well Name	UTM X	UTM Y	Pumping Rate (gpd)
45849	LAKEWOOD #2	401476	4714664	-13000
45850	LAKESIDE #1	402737	4715190	-4000
54463	KENNEDY PARK #2	402624	4715443	-3000
54054	FONDA #4	348482	4715718	-337120
24583	FONDA #3	348492	4715749	-37252
43008	VINCENT #3	416299	4715946	-12500
23299	BADGER #3	405775	4718567	-32500
3303	BADGER #2	405849	4718667	-32500
56901	DOWS GC	460551	4722398	-20000
3121	DOWS #4	458676	4722848	-35000
8847	EAGLE GROVE #4	426317	4724027	-207325
56930	EAGLE GROVE CC	422445	4724316	-900
57553	IDNR#1	462097	4724508	-200
39311	CHANTLAND Co	399711	4726789	-2300
42646	THOR #2	413770	4726990	-30000
70451	ST JOHNS LUTH	472144	4729625	-200
40356	HUMBOLDT #3	399786	4730333	-468360
3222	DAKOTA CITY #2	401607	4730505	-73200
10665	CLARION #3	439922	4731127	-332000
39983	GOLDFIELD #2	424618	4731773	-32000
39982	GOLDFIELD #1	424614	4731773	-32000
39961	GILMORE CITY #2	381807	4731836	-33500
34627	HOLMES #1	431751	4731995	-2400
9420	GILMORE CITY #3	382339	4732073	-33500
2929	ROWAN #1	454847	4732204	-22000
64730	DUDLEY'S Cnr1	468016	4733064	-1000
38846	CAL GRADE HS	469818	4733282	-3000
54194	LATIMER #3	469906	4734267	-54000
3374	RUTLAND #1	394367	4735288	-22100
32722	GOLD KEY MOTEL	483343	4735346	-600
56278	DORRELL #1	484168	4735983	-1500
56289	SECOND PLEAS#1	443276	4736693	-400
56283	WILSON SD 9	443985	4737395	-2700
73178	LAKE CORNELIA	443385	4738194	-200
34657	ALEXANDER #1	461069	4739470	-18500
34687	HARDY #2	414089	4740254	-2400
41710	ROLFE #1	375240	4741221	-35290
2973	ROLFE #2	375320	4741617	-35290
4815	RENWICK #2	420030	4742222	-14000
41652	RENWICK #1	420033	4742227	-14000
60425	ZION Church	473875	4743271	-500
9241	BELMOND #2	450171	4744271	-314000
56902	CATTLEMEN'S	449684	4745900	-250
45937	BODE #3	395010	4746448	-30000
28522	LIVERMORE #4	403265	4746805	-38000
40649	LU VERNE #1	411451	4751078	-16500

WNUMBER	Well Name	UTM X	UTM Y	Pumping Rate (gpd)
40650	LU VERNE #2	411491	4751096	-16500
39984	GOODELL #2	449992	4752582	-12000
38568	SPARBOE Corp2	451846	4752971	-20050
50575	SPARBO Co3	451919	4753133	-20050
36004	SPARBOE Corp	451827	4753305	-20050
40485	KANAWHA #1	435239	4753951	-32500
40486	KANAWHA #2	435206	4754005	-32500
4864	CORWITH #1 (W4*	421996	4760539	-27500
6225	CORWITH #2	421950	4760544	-27500

Well Name	UTM X	UTM Y	Permited Water Use (mgy)	Pumping Rate (gpd)
Ames GC	445856	4658244	34	-93699
Anderson	447000	4668192	7	-17808
Heglund	455826	4683188	52	-141096
Friendly Fair	465319	4684871	3	-8932
Central Iowa Renewable (4 wells)	465319	4684871	262	-575000
Iowa Select13	440901	4685031	18	-16545
Iowa Select 13	440913	4685146	18	-16545
Iowa Selct13	440899	4685282	18	-16545
Decoster 12	438948	4687524	10	-14000
Decoster 12	438923	4687639	10	-14000
Iowa S FO15 1	436570	4687734	26	-23744
Iowa S FO15 2	436546	4687745	26	-23744
Iowa S FO15 3	436539	4687750	26	-23744
Prestage P2081	461827	4690195	13	-18000
Prestage P2082	461861	4690343	13	-18000
Iowa S 14-1	435053	4690739	18	-10000
Iowa S 12 1	467813	4690811	18	-10000
Prestage 207 1	461256	4690833	13	-4500
Iowa S 14 -2	435040	4690971	18	-10000
Iowa S 14 3	434836	4690983	18	-10000
Prestage 207 2	461259	4690993	13	-4500
Iowa S 10 1	445893	4691127	18	-50000
Iowa S 12 -2	467848	4691147	18	-10000
PrestageP205 1	459638	4695386	13	-4500
PrestageP205 2	459639	4695485	13	-4500
PrestageP206 1	458726	4695835	13	-4500
PrestageP206 2	458856	4695938	13	-4500
PrestageP201 1	464759	4700525	13	-4500
PrestageP201 2	464775	4700806	13	-4500
Certainteed	407003	4704238	75	-57200
Boomsmas Ald1	465466	4705022	30	-15000
Boomsmas Adl2	465489	4705216	30	-15000
Boomsmas Adl3	465282	4705353	30	-15000
Deerwood 1	397984	4705784	10	-10000
Deerwood 2	397984	4705784	10	-10000
Deerwood 3	397984	4705784	10	-10000
DecosterSow31	446474	4708308	12	-14000
DecosterSow32	446440	4708691	12	-14000
DecostSow10 1	448095	4708789	9	-13000
DecostSow10 2	448095	4708844	9	13000
Willow Ridge	400326	4709642	20	-53425
DecosterSow1 1	444891	4709934	12	-16000
DecosterSow1 2	444781	4710295	12	-16000
Iowa S Sow11 1	485177	4710688	18	-25000
Iowa S Sow11 2	485186	4710837	18	-25000
Ham & Eggs 1	476538	4711711	11	-10000
Ham & Eggs 2	476464	4711734	11	-10000
Ham & Eggs 3	476370	4711737	11	-10000
Glessner 9 1	422350	4712015	11	-15000
Glessner 9 2	422342	4712121	11	-15000
Iowa Q 10 -1	420952	4713014	11	-15000

Well Name	UTM X	UTM Y	Permited Water Use (mgy)	Pumping Rate (gpd)
Iowa Q 10-2	420835	4713020	11	-15000
Lakeside GC	402806	4715193	24	-66849
Daybreak Fd 1	423025	4715923	30	-28000
Sparboe 1	421994	4716015	178	-40000
Daybreak Fd 2	423025	4716017	30	-28000
Daybreak Fd 3	423016	4716097	30	-28000
Sparboe 2	421990	4716162	178	-40000
Sparboe 3	421999	4716315	178	-40000
Sparboe 4	421998	4716473	178	-40000
Sparboe 5	421999	4716624	178	-40000
Environ 1	450267	4716749	35	-17000
Deer Creek	398307	4716757	22	-61370
Decoster 2-1	451934	4716880	9	-13000
Decoster 2-2	451946	4717057	9	-13000
Environ 2	450444	4717143	35	-17000
Environ 3	450324	4717145	35	-17000
Environ 4	450410	4717159	35	-17000
Sparboe Hum1	399229	4718830	30	-23000
Sparboe Hum2	399221	4718859	30	-23000
Sparboe Hum3	399088	4718884	30	-23000
Iowa S25-1	452915	4719724	11	-14000
Iowa S25-2	452856	4719725	11	-14000
Decoster 17-1	455033	4720056	9	-13000
Decoster 17-2	455042	4720219	9	-13000
Decoster 6-1	451060	4720940	9	-13000
Decoster 6-2	451067	4721026	9	-13000
Prestage204-1	445506	4722392	24	-22000
South 1	447738	4722393	32	-22000
Prestage204-2	445581	4722464	24	-22000
Prestage204-3	445559	4722468	24	-22000
West 1	445040	4722635	25	-17000
South 2	447466	4722704	32	-22000
West 2	445049	4722758	25	-17000
West 3	445049	4722938	25	-17000
West 4	445044	4723024	25	-17000
South 3	447645	4723045	32	-22000
South 4	447773	4723130	32	-22000
Decoster Conc	447788	4723442	15	-41096
Ag ProcessEG1	426043	4724123	225	-110000
Ag ProcessEG2	426043	4724123	225	-110000
Central Iowa 2	426043	4724123	262	-140000
East 1	448341	4724343	28	-76712
Ag ProcessEG3	425900	4724471	289	-110000
Central Iowa3	425900	4724471	262	-140000
Decoster 8-1	439710	4724563	9	-13000
Decoster 8-2	439709	4724671	9	-13000
North 1	447311	4725693	37	-25000
North 2	447323	4725892	37	-25000
Decoster 14-1	448086	4726235	9	-13000
North 3	446924	4726280	37	-25000
North 4	447321	4726284	37	-25000

Well Name	UTM X	UTM Y	Permited Water Use (mgy)	Pumping Rate (gpd)
Decoster 14-2	448089	4726302	9	-13000
Decoster 15-1	446176	4726498	9	-13000
Decoster 15-2	446174	4726602	9	-13000
Decoster 13-1	444581	4726760	9	-13000
Decoster 13-2	444585	4726861	9	-13000
Decoster 5-1	448036	4728015	9	-8000
Decoster 5-2	448031	4728179	9	-8000
Decoster 5-3	448079	4728298	9	-8000
Decoster 16-1	451444	4728654	9	-13000
Decoster 16-2	451448	4728797	9	-13000
Humboldt CC2	397691	4731745	19	-51781
Central Iowa3	454847	4732204	262	-140000
Corn Belt1	399471	4732230	10	-15000
Central Iowa4	399471	4732230	262	-140000
Martin MarG	381177	4733022	77	-50000
Martin MarM	380708	4734832	400	-500000
I Hemerson	388499	4735843	18	-49315
Iowa S 18-1	425353	4738086	24	-10000
Iowa S 18-2	425370	4738268	24	-10000
Iowa S 18-3	425255	4738270	24	-10000
Iowa SKJ20-1	435557	4741684	26	-9000
Iowa SKJ20-2	435552	4741848	26	-9000
Decoster 9-1	430274	4743661	9	-13000
Decoster 9-2	430276	4743758	9	-13000
Prestage 202-1	438489	4743968	11	-30411
Decoster 11-1	429723	4744411	9	-13000
Decoster 11-2	429803	4744616	9	-13000
Iowa S 14-1	430236	4747358	22	-8000
Iowa S 14-2	430203	4747363	22	-8000
Iowa S 14-3	430085	4747448	22	-8000
Prestage 219-1	445198	4749365	26	-12000
Prestage 220-1	443636	4749616	26	-12000
Prestage 220-2	443473	4749649	26	-12000
Prestage 219-2	445191	4749685	26	-12000
Prestage 220-3	444002	4749854	26	-12000
Prestage 221-1	441831	4750920	26	-12000
Prestage 221-2	441727	4750921	26	-12000
Iowa S 13-1	425929	4751330	22	-8600
Iowa S 13-2	426144	4752549	22	-8600
Iowa S 13-3	426337	4752590	22	-8600

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