Groundwater Availability Modeling Des Moines River Aquifer Palo Alto and Emmet Counties, Iowa

Iowa Geological and Water Survey
Water Resources Investigation Report No. 4

Iowa Department of Natural Resources
Roger L. Lande, Director

COVER

Central pivot irrigation sprinkler.
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May 2011

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EXECUTIVE SUMMARY

Increased demands for groundwater by agriculture, industries, and municipalities have raised concerns about the future availability of groundwater in Iowa. 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?"

A hydrogeologic study was initiated to more fully understand the shallow groundwater resources in the West Fork of the Des Moines River alluvial aquifer (Des Moines River aquifer). The primary objective of this study was to evaluate the potential impact of the new Iowa Lakes Regional Water wellfield near Osgood (Osgood wellfield, Palo Alto County) on the nearby irrigation wells. A computer simulation model of the Des Moines River aquifer was created using Visual MODFLOW version 2010.1. The model predicts future well interference, drawdown, and maximum sustainable pumping rates.

The groundwater flow model for the proposed Osgood wellfield involved six new public wells with an annual permitted water use of 539 million gallons per year (mgy). The Osgood wellfield is divided into a north wellfield (proposed Well 6) and south wellfield (proposed wells 1 through 5). A total of 14 irrigation water use permits (24 known irrigation wells) and two existing public water use permits (City of Emmetsburg and City of Graettinger) are located in the model area with permitted water use totaling 1.15 billion gallons per year. Worst-case historical drought conditions based on the 1958 drought were simulated, and the impact of the new Osgood wellfield on the nearby irrigation wells was evaluated. Maximum additional drawdowns in the nearby irrigation wells caused by the pumping of the Osgood wellfield ranged from 4.2 feet to 5.8 feet in the south wellfield, and 0.4 to 0.7 feet in the north wellfield.

Based on the mass balance calculations in Visual MODFLOW, the percentage of water production supplied by the Des Moines River and Jack Creek (induced recharge) increased from 10.9 percent during normal rainfall conditions to 58.4 percent during a severe drought. The increase in induced recharge prevents much higher drawdowns in both the irrigation wells and the Osgood wellfield wells. Without the recharge from the Des Moines River and Jack Creek, a severe drought would significantly reduce the water production in the area wells.

Based on the model results, adequate water resources are available to meet the current and future water withdrawals in the Des Moines River aquifer. Adjustments in pumping cycles and rotating active and inactive wells may be necessary during a severe drought. The irrigation wells may need to pump during the night when water demand is lower for the Osgood wellfield, or Iowa Lakes Regional Water may want to pump additional water from the north wellfield (Well 6) to reduce the pumping stress on the south wellfield (wells 1 through 5). Cooperation would be necessary for both Iowa Lakes Regional Water and the irrigators. This proactive approach can be a useful planning tool during a severe drought. The model can also be used to evaluate the maximum sustainable withdrawal from the area, and to potentially limit new water use permits and prevent over-allocation of the groundwater resources.

INTRODUCTION

This report evaluates the groundwater resources in the alluvial aquifer located along the West Fork of the Des Moines River, Palo Alto County, Iowa, from just north of Graettinger to south of Emmetsburg (Figure 1). For the purposes of this summary report, the alluvial aquifer will be referred to as the Des Moines River aquifer. Current water users include the City of Graettinger, City of Emmetsburg, Hillcrest Golf and County Club in Graettinger, and approximately 24 irrigation wells.

The primary objective of this study was to evaluate the potential impact of the proposed Iowa Lakes Regional Water (ILRW) wellfield (figures 1 and 2) near Osgood (Osgood wellfield, Palo Alto County) on the nearby irrigation wells. Iowa Lakes Regional Water has proposed adding six production wells in two general wellfield areas in the Des Moines River aquifer. Proposed ILRW wells 1 through 5 will be installed in the south wellfield, and proposed ILRW Well 6 will be installed in the north wellfield.

CLIMATE

The climate of northwest Iowa is classified as sub-humid. The average annual precipitation in Palo Alto and Emmet counties ranges from 30 to 32 inches per year (IDALS, 2010). Approximately 18 to 20 inches of precipitation occur from April through October.

Northwest Iowa has historically experi-

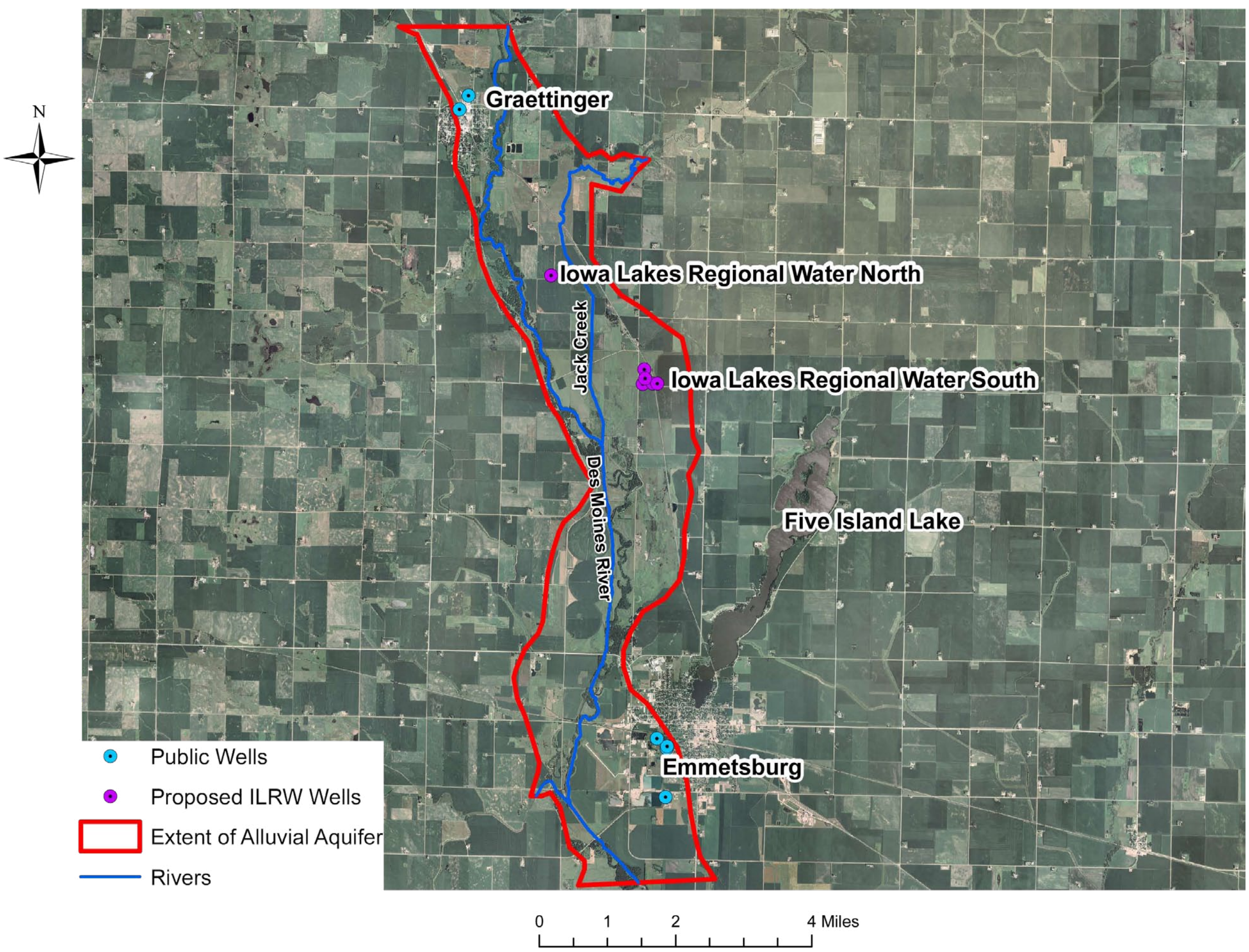

Figure 1. Extent of Des Moines River aquifer study area in Palo Alto and Emmet counties.

enced moderate to severe droughts. Table 1 shows the minimum annual precipitation amounts for a select number of cities in northwest Iowa (IDALS, 2010). These minimum annual precipitation amounts range from 13.90 inches in Storm Lake (Buena Vista County) to 15.41 inches in Sheldon (O'Brien County). The minimum annual precipitation for Emmetsburg was 15.20 inches in 1958, which is approximately 50 percent of the normal precipitation.

SURFACE WATER

Drainage in the study area is toward the West Fork of the Des Moines River (Figure

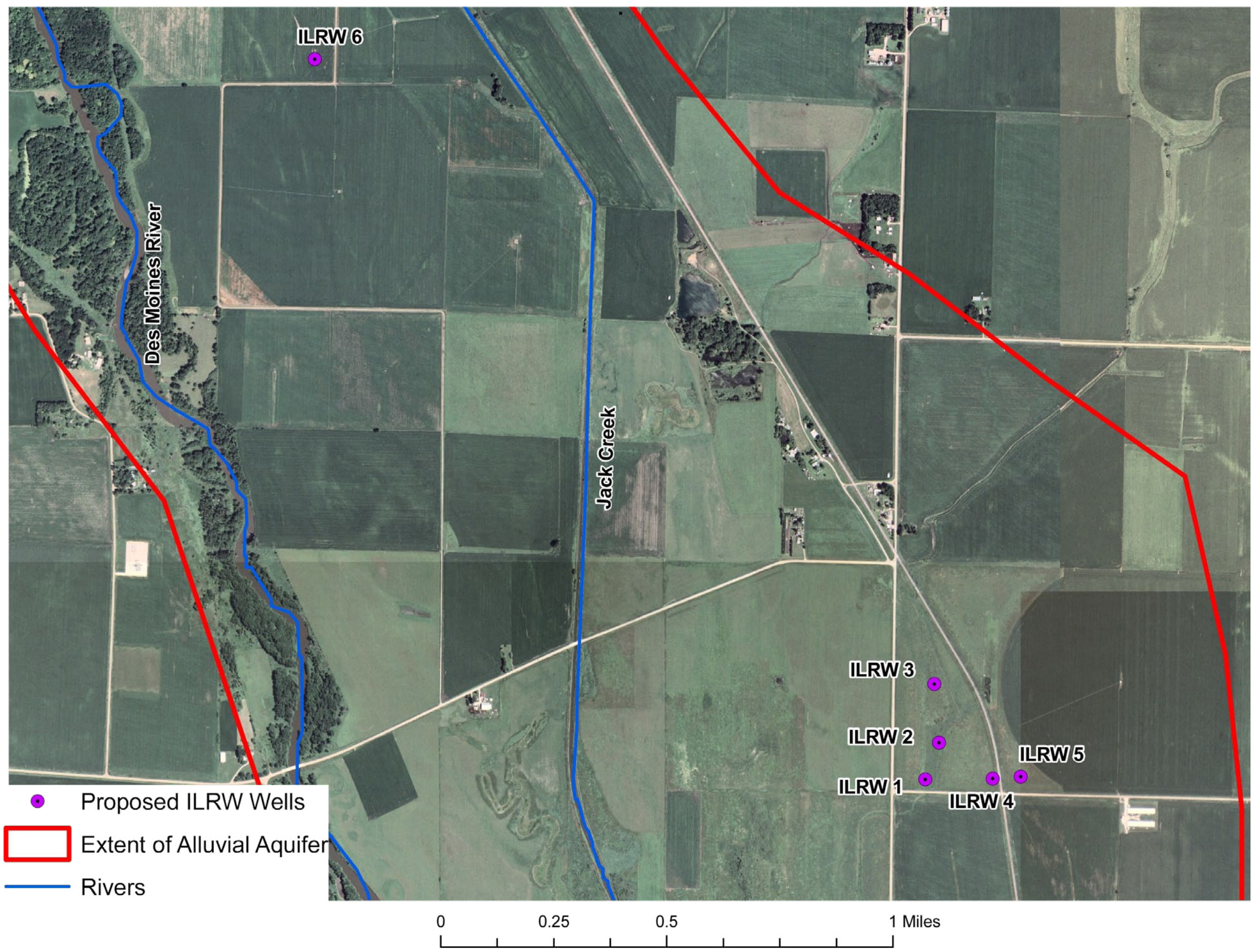

Figure 2. Iowa Lakes Regional Water (ILRW) Osgood Wellfield in Palo Alto and Emmet counties.

Table 1. Historical minimum and maximum monthly precipitation (inches) in select locations in northwest Iowa (IDALS, 2010).

Location	County	Minimum Inches (year)	Maximum Inches (year)
Emmetsburg	Palo Alto	15.20 (1958)	45.15 (1993)
Estherville	Emmet	15.10 (1897)	45.04 (1993)
Spencer	Clay	14.41 (1958)	42.51 (1951)
Sheldon	O'Brien	15.41 (1958)	46.02 (1951)
Storm Lake	Buena Vista	13.90 (1976)	45.94 (1951)

1). Jack Creek is a major tributary that flows between the ILRW north and south wellfields, and discharges into the Des Moines River southwest of the south wellfield. Jack Creek may be a major source of recharge to the alluvial aquifer when its stage is high or during periods of high water use.

Figure 3 shows the average daily streamflow in the West Fork of the Des Moines River at the United States Geological Survey (USGS) gaging station near Humboldt, Iowa. The Humboldt gaging station is the closest gaging station that records streamflow data and is approximately 35 miles downstream of Emmetsburg. The lowest average daily flow was 13 cubic feet per second (cfs) from January 12 through February 2, 1977. In general, the lowest average daily streamflows occur during the winter months. The lowest non-winter average daily flow was 30 cfs on May 17, 2000. This was followed by an average daily flow of 1,110 cfs three days later.

A USGS gaging station exists south of Emmetsburg, but only has stage data from 2009 and 2010. Because of the lack of streamflow and historic data, the hydrologic information from this gage has little value to this study.

GEOLOGY

The thickness of alluvial deposits along the West Fork of the Des Moines River varies from 6 to over 50 feet, but averages approximately 20 feet (Thompson, 1984). The alluvial deposits are not uniform or homogeneous, but vary from coarse sand and gravel to cobbles and boulders. The yields that can be expected in wells screened in these sediments depend on the thickness of alluvium, the grain size or texture, and interconnectedness of the various sand and gravel units.

The Des Moines River aquifer consists of sand and gravel deposited by the modern river system and is highly variable in both thickness and grain size. Cobble and boulder zones are found near Graettinger and in isolated areas throughout the aquifer. Tremendous well yields are produced in these cobble zones (Thompson, 1984). The sand and gravel thickness of the Des Moines River

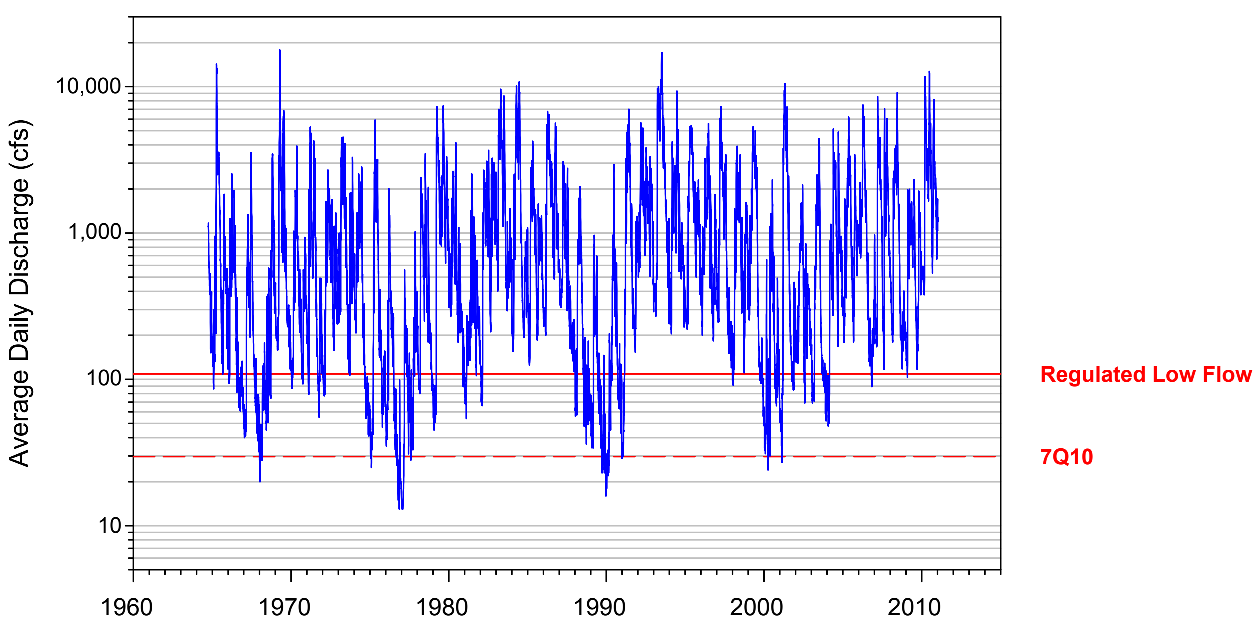

Figure 3. Average daily streamflow at USGS gaging station at Humboldt (1965 through 2010) in Humboldt County.

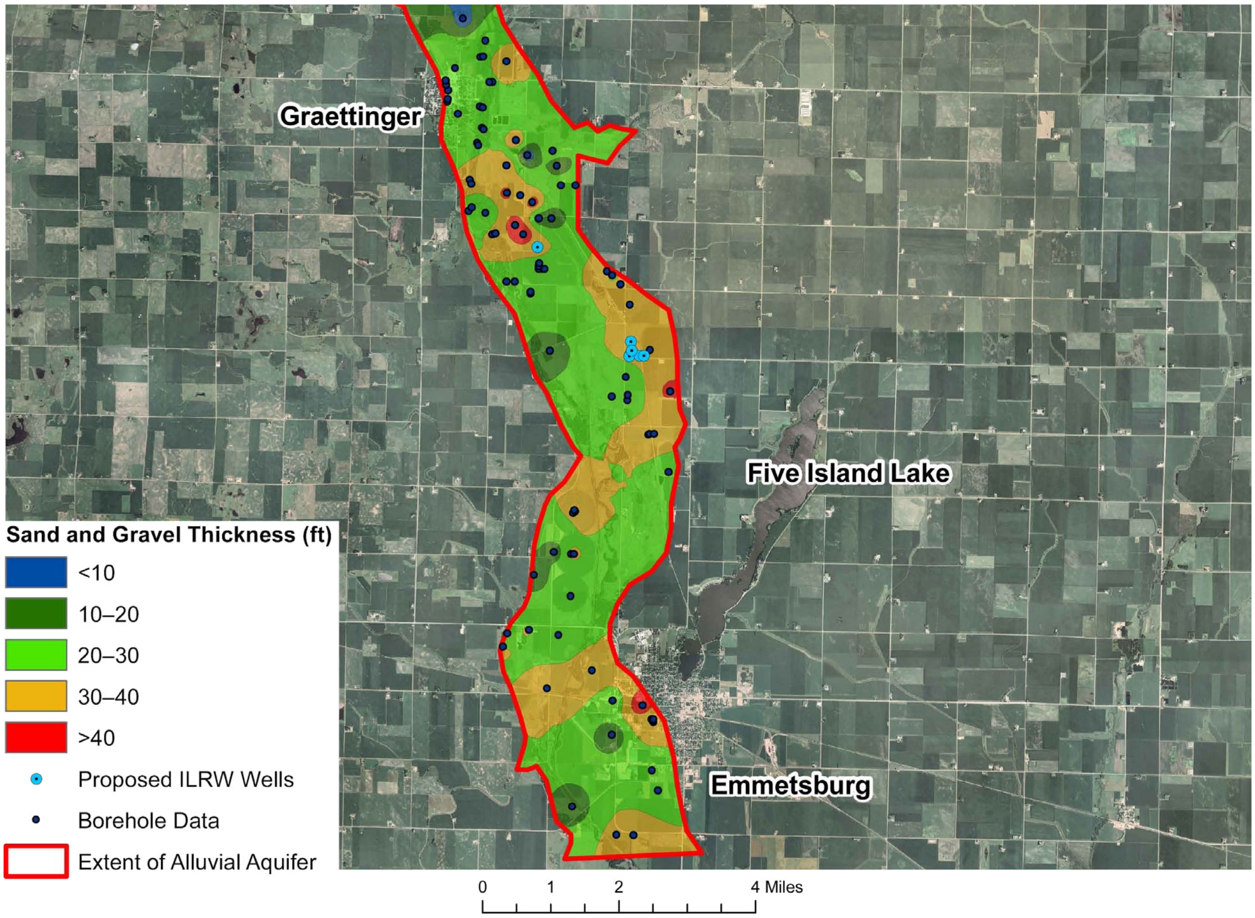

Figure 4. Isopach (thickness) map of the West Des Moines River aquifer and its tributaries.

aquifer (Figure 4) is based on existing data from 82 striplogs and drillers' logs. The sand and gravel is overlain by fine-grained sediments consisting of silt and silty sand that range in thickness from 2 to 6 feet. The Des Moines River aquifer is underlain by glacial till throughout the study area.

HYDROGEOLOGY

Regional groundwater flow is directed toward the Des Moines River and Jack Creek in a general southerly direction. The hydraulic gradient is similar to the land surface topography in most locations. During most of the year the Des Moines River is a gaining stream. Exceptions to this occur during high river stage when temporary bank storage may cause a transient reversal in flow direction, and near high capacity wells where pumping stress may reverse the groundwater flow direction, which creates induced recharge from the river into the aquifer. Groundwater recharge sources are precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall.

Groundwater levels from many of the irrigation wells are found in the IDNR water use database. Table 2 displays the average groundwater elevation from 2001 to 2009 measured in 10 irrigation wells. An average groundwater elevation was used because of the uncertainty as to when these water level measurements were taken.

Measuring the groundwater recharge

based on annual precipitation data is difficult. In northwest Iowa, much of the groundwater recharge occurs in the spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of the precipitation events and when they occur seasonally. Based on previous modeling conducted by the Iowa Geological and Water Survey in Garfield Township in Sioux County, Iowa, 4 inches of annual groundwater recharge would represent a severe drought (Gannon, 2006). This was approximately one-half the calibrated normal recharge (8.5 inches).

Based on a surface area of approximately 22.9 square miles, an average saturated aquifer thickness of 20 feet, and an effective porosity of 25%, approximately 23.9 billion gallons of groundwater is stored in the Des Moines River aquifer. Based on an average recharge of 8.5 inches per year, approximately 3.4 billion gallons of water recharges the aquifer directly as precipitation. Based on a severe drought recharge of 4 inches per year, approximately 1.6 billion gallons of water recharges the aquifer. The actual amount of induced recharge from the Des Moines River and Jack Creek was calculated using Visual MODFLOW version 2010.1 (Schlumberger Water Services, 2010) and will be discussed later in the report. Total current permitted water use for the study area not including the ILRW permit is 1.19 billion gallons per year (bgy), which is less than the drought recharge of 1.6 bgy. Adding the ILRW permit brings the total to 1.7 bgy, which exceeds the recharge amount. The volume of recharge provided by the Des Moines River and Jack Creek is unknown, but would significantly add to the recharge total in the aquifer. The other important water balance consideration is the impact caused by local pumping stress, which is much different than the aquifer average water balance. The application of a calibrated groundwater flow model will help evaluate the local water balance concerns and will be discussed later in the groundwater modeling section of this report.

Public Wells

Two public water supplies are found within the model area. They include the City of Graettinger, which has two active alluvial wells (wells 4 and 7), and the City of Emmetsburg, which has 4 active alluvial wells (wells 1, 4, 5, and 7). Emmetsburg also has two wells screened in the Dakota sandstone aquifer (wells 6 and 8). The location of the public wells within the aquifer is shown in Figure 1. Total permitted annual water use is shown in Table 3.

Figures 1 and 2 show the location of the proposed north and south ILRW wellfields. Based on the information found in several on-site drillers' logs, these wells may vary in depth from 38 to 40 feet. The stratigraphy consists of several feet of topsoil overlying sand and gravel. The logs also indicate several cobble or boulder zones, which are probably the zones of highest production.

Irrigation Wells

A large percentage of the land use in the study area is in row crop agriculture. Much of the corn acreage is irrigated due to the sandy soil in the valley. Twenty-four (24) known irrigation wells were identified in the model area (Figure 5). Annual irrigation rates were obtained from the IDNR water use database from 2000 through 2009 and are listed in Table 4. The actual pumping rate per well is unknown, and the withdrawal per well is the average based on the total usage divided by the number of known irrigation wells.

Aquifer Test Results

Hydraulic properties are used to define

Table 2. Average static water levels for irrigation wells located in study area and corresponding model simulated results.

Irrigation Well Owner	Total Well Depth (ft)	UTM X Coord.	UTM Y Coord.	Observed Head Elev. (ft)	Range in Observed Head (ft)	Simulated Head Elev. (ft)
William W. Frevert	45	361356	4775069	1,195.89	1,193.89 to 1,196.89	1,196.61
Hajas Farm 2	41	360648	4777090	1,201.96	1,201.96	1,200.87
Soper Farms (south)	40	362892	4780806	1,210.39	1,209.39 to 1,211.39	1,207.89
Herke Farms	50	362171	4782399	1,211.04	1,211.04	1,209.14
Dale Opheim	45	362778	4783008	1,211.21	1,211.21	1,209.89
Soper Farms (north)	40	359998	4784747	1,210.62	1,209.62 to 1,211.62	1,212.03
Doug Herke	55	359596	4785524	1,211.83	1,211.83 to 1,212.83	1,213.60
Richard Herke	58	360195	4785356	1,215.34	1,214.84 to 1,218.34	1,213.57
John and Dale Hoffman	60	359198	4786562	1,216.65	1,214.65 to 1,218.65	1,215.54
Hillcrest Golf and Country Club	33	358005	4787953	1,229.21	1,229.21	1,228.85

Table 3. Total annual water use permitted in study area.

Water Use Permit	Permited Water Use (mgy)[1]
William W. Frevert	54.4
Richard Nelson	106.9
Soper Farms (south)	32.6
Herke Farms	104.3
Dale Opheim (south)	68.4
Don Peterson (may be outside model area)	50.5
Soper Farms (north)	52.1
Richard Herke	34.2
Doug Herke	65.2
Douglas Herke	13
John and Dale Hoffman	208.5
Hillcrest Golf and Country Club	21.2
Dale Opheim (north)	22.8
Alice Torreson Trust	19.6
City of Graettinger	50
City of Emmetsburg	250 (1/2 of total from alluvial aquifer)
Iowa Lakes Regional Water	539
Total	1,693
[1] mgy = million gallons per year	

and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Three existing and two new aquifer pump tests were conducted in the Des Moines River aquifer. The existing data were obtained from DeWild Grant Reckert and Associates from both the proposed north (Well P-2B) and south (Well P-13A) ILRW wellfields, and from a pump test conducted by the Iowa Geological Survey near Osgood (Thompson, 1984). The new aquifer tests were conducted by the IDNR in October of 2010 at Graettinger Well 7 and Emmetsburg Well 7 (Figure 6).

In addition to the aquifer pump tests, a total of 19 specific capacity tests were made available by various consultants, well drillers, and communities. The distribution of these tests is shown in Figure 6. Tables 5 and 6 list the pump test results and the specific capacity

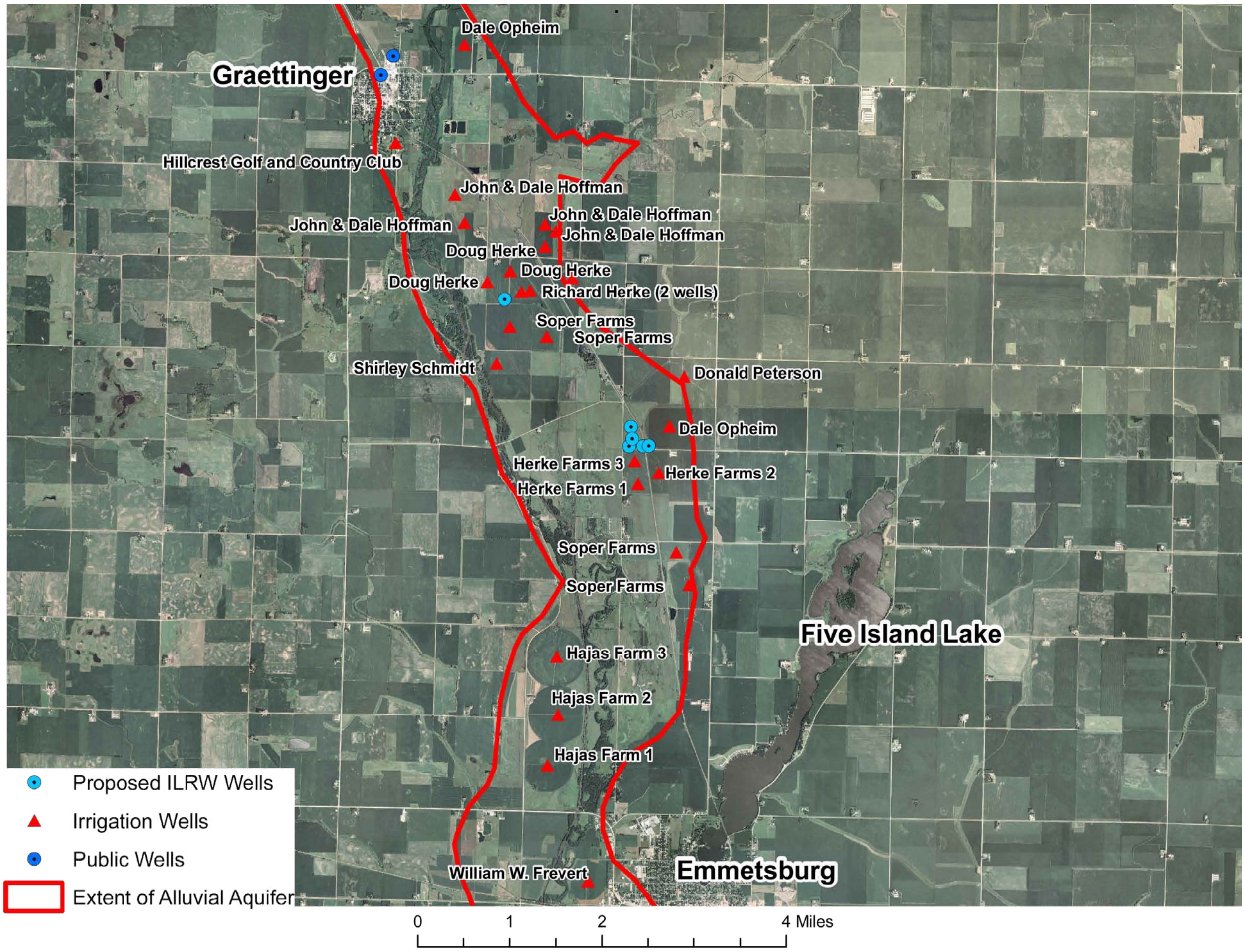

Figure 5. Locations of irrigation wells in study area.

Table 4. Annual water use by permit from 2000 through 2009.

Water Use Permit	2000 Water Use (mgy)[1]	2001 Water Use (mgy)[1]	2002 Water Use (mgy)[1]	2003 Water Use (mgy)[1]	2004 Water Use (mgy)[1]	2005 Water Use (mgy)[1]	2006 Water Use (mgy)[1]	2007 Water Use (mgy)[1]	2008 Water Use (mgy)[1]	2009 Water Use (mgy)[1]
William W. Frevert	9.3	15.9	18.5	19.3	9.9	7.5	11.9	11.7	7.9	9.7
Hajas Farm[2]	0.0	8.3	31.9	41.0	20.0	33.3	NA	NA	NA	NA
Richard Nelson	48.9	54.1	63.0	63.0	38.1	43.4	59.8	38.0	48.9	48.9
Soper Farms (south)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	1.0
Herke Farms	15.1	12.8	28.9	29.8	11.9	12.8	12.6	11.9	8.2	7.0
Dale Opheim (south)	10.4	9.3	8.2	9.1	9.9	7.5	1.0	5.0	5.5	4.0
Don Peterson	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soper Farms (north)	7.8	3.1	7.1	3.0	2.6	2.0	7.3	7.3	6.9	6.7
Richard Herke	27.6	5.2	12.5	22.0	9.7	10.3	11.3	14.4	13.5	16.5
Doug Herke	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	5.8
Douglas Herke	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	2.9	1.3
John and Dale Hoffman	24.8	29.7	0.0	0.0	23.1	29.0	42.7	29.2	31.0	27.9
Hillcrest Golf and Country Club	15.4	0.0	13.5	14.0	9.6	23.1	12.6	17.5	17.4	7.6
Dale Opheim (north)	6.9	2.1	2.4	3.3	6.0	7.2	20.6	5.0	5.5	1.8
Alice Torreson Trust	52.5	7.4	10.5	10.5	14.9	8.3	9.4	11.7	13.1	14.5
City of Graettinger	30.0	31.1	28.8	28.1	29.8	30.2	34.1	37.4	31.9	26.9
City of Emmetsburg[3]	125.0	123.0	118.0	118.0	118.2	112.0	119.0	107.0	108.0	107.0
Total	374	302	343	361	304	327	342	298	305	287
[1] mgy=million gallons per year										
[2] Hajas Farm Permit is no longer active										
[3] Approximately 1/2 of Emmetsburg usage is from the alluvial aquifer										

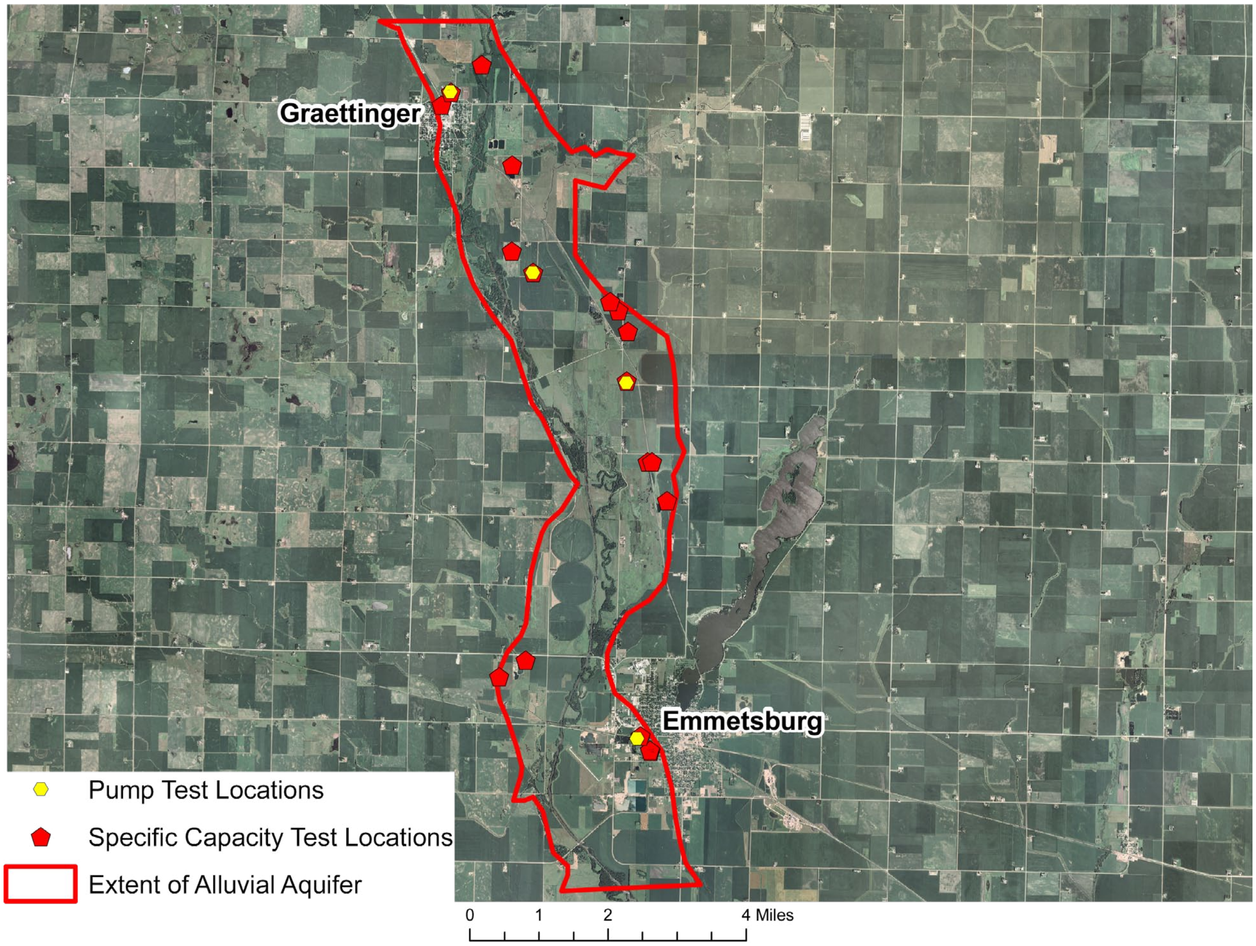

Figure 6. Distribution of specific capacity and pump tests in study area.

Table 5. Aquifer pump test results for wells open in the Des Moines River aquifer (methods based on Freeze and Cherry, 1979).

Location	Aquifer Thickness (ft)	Transmissivity (ft²/day)	Hydraulic Conductivity (ft/day)	Storage Coefficient	Method
Graettinger Well 7	17	10,010	593	0.017	Neuman
Emmetsburg Well 7 (north)	50	49,500	990	0.5	Neuman
Emmetsburg Well 7 (west)	50	54,600	1090	0.5	Neuman
ILRW P-2B (OW47)$_a$	29	36,600	1260	0.5	Neuman
ILRW P-13A (OW32W)$_a$	27	15,100	561	0.5	Neuman
ILRW P-13A (OW200S)$_a$	27	18,800	698	0.2	Boulton
WD6$_b$	27	40,100 to 73,500	1,490 to 2,720	0.0005 to 0.2	Theis

$_a$Data provided by Layne Christensen
$_b$Results obtained from Thompson (1984)

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. Original data and graphs of the test results are shown in Appendix A.

Based on aquifer test results, the transmissivity of the Des Moines River aquifer was found to range from 10,100 feet^2/day at Graettinger Well 7 to 54,600 feet^2/day at Emmetsburg Well 7 (west observation well). The arithmetic mean transmissivity value is 30,770 feet^2/day. The relatively high transmissivity values are the result of cobble and boulder zones found near the base of the alluvial aquifer. These zones were encountered at all four pump test locations.

Hydraulic conductivity can be calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity was found to range from 593 to 1,260 feet/day, with an arithmetic mean of 865 feet/day. The regional horizontal hydraulic conductivity distribution, which is based on data found in tables 5 and 6, is shown in Figure 7.

GROUNDWATER MODELING

Visual MODFLOW version 2010.1 was used to simulate the groundwater flow in the alluvial aquifer in the study area. A three-layered model was used for the simulation. The bottom of the sand and gravel unit at each irrigation well was assumed to be the bottom of each well. The borehole logs were obtained from the GEOSAM database, and the elevation data was obtained from LiDAR (2-foot contour interval). The model boundary conditions and inputs include the following:

- Layer 1 varies in thickness from 1 foot to 5 feet and is primarily silty sand. The horizontal hydraulic conductivity was assigned a value of 10 feet/day. The vertical hydraulic conductivity value was assigned

Table 6. Specific capacity test results for wells open in the West Des Moines aquifer based on IDNR Source Water Database.

W-Number	UTM X	UTM Y	Well Owner	Discharge (gpm)[1]	Drawdown (ft)	Specific Capacity	Transmissivity (ft^2/day)	Aquifer Thickness (ft)	Hydraulic Conductivity (ft/day)
33749	362624	4774076	City of Emmetsburg	1,007	49	21	4,200	30	142
39710	362608	4774096	City of Emmetsburg	600	10	60	12,000	39	308
62018	362392	4774431	City of Emmetsburg	600	8	78	15,600	56	279
62024	362392	4774431	City of Emmetsburg	600	27	22	4,400	36	123
53270	359100	4775815	Ray Hoffert	25	18	1	280	33	9
53264	359713	4776201	Darrin Adams	40	21	2	400	33	12
53269	363004	4779921	Richard Nelson	20	12	2	333	23	15
42710	362559	4780814	Soper Farms	300	2	150	30,000	33	915
42711	362660	4780816	Soper Farms	300	2	150	30,000	33	915
63041	362066	4782707	Iowa Lakes Rural Water	880	9	98	19,600	33	594
44078	362095	4783861	Donald E Peterson	950	10	95	19,000	30	644
45098	361872	4784341	Dale Wilcoxin	15	1	15	3,000	36	83
47167	361679	4784552	Steve & Jill Aldous	25	4	6	1,250	23	54
63042	359887	4785233	Iowa Lakes Rural Water	629	6	101	20,200	39	505
42038	359392	4785733	Richard Herke	1,000	30	34	680	46	147
44191	359404	4787736	John Studer	550	4	138	27,500	33	833
39988	357750	4789137	City of Graettinger	288	4	82	16,500	30	557
60838	357973	4789433	City of Graettinger	250	4	623	12,500	23	543
10759	358694	4790080	Clarence Wickert	9	6	2	300	26	11
[1] gpm=gallons per minute									

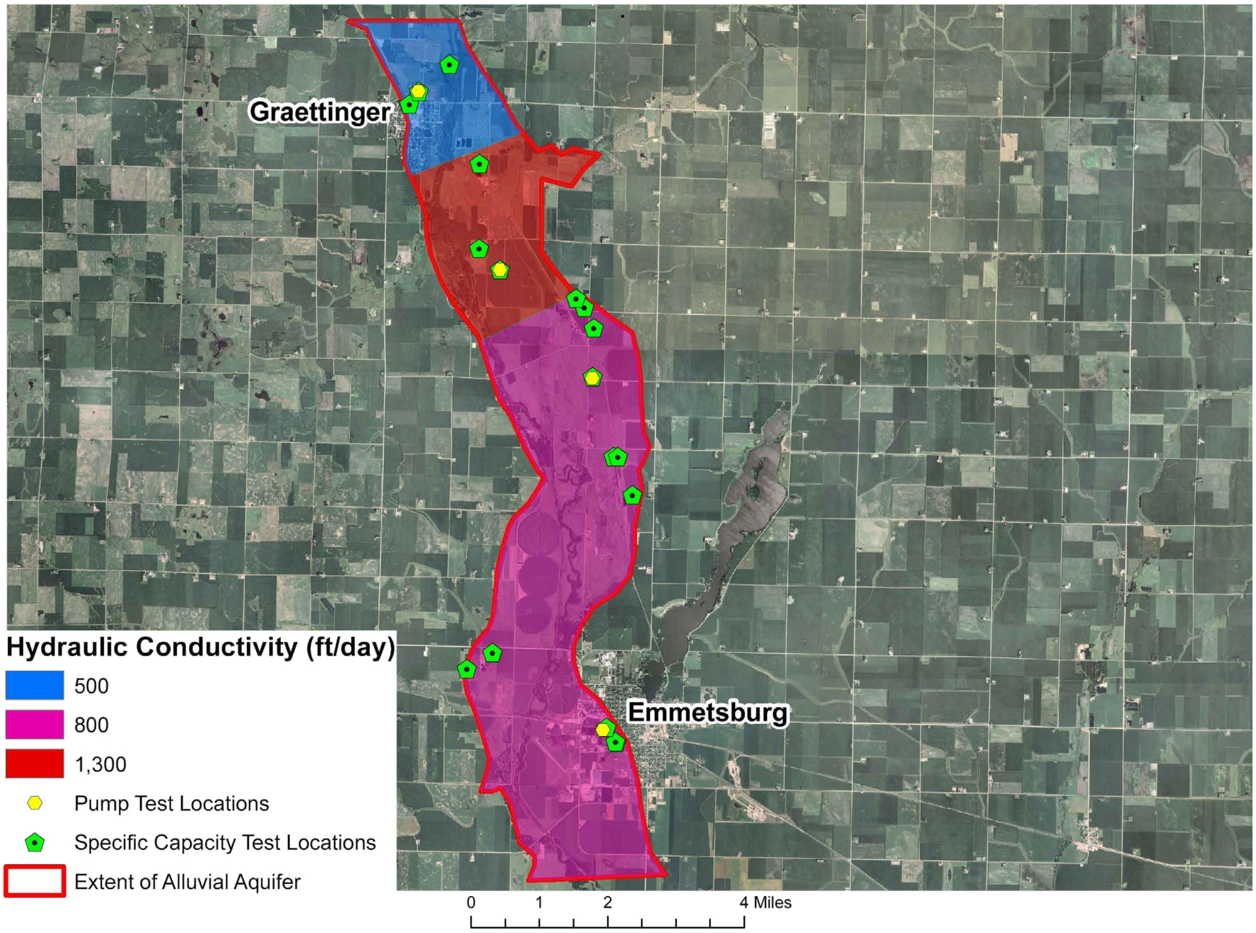

Figure 7. Horizontal hydraulic conductivity distribution within active model area based on data found in tables 5 and 6.

a value 1/10 of the horizontal hydraulic conductivity.

- Layer 2 is the sand and gravel of the Des Moines River aquifer. The horizontal hydraulic conductivity was calibrated within the model and is shown in Figure 7. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 3 is primarily silty clay (glacial till). The horizontal hydraulic conductivity was assigned a value of 0.03 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- The uplands to the west and east were considered no-flow boundaries. This was represented by de-activating the grids outside the alluvial aquifer boundary. This was estimated using NRCS soils data and LiDAR elevation data.
- The West Fork of the Des Moines River and Jack Creek were represented as river boundaries. The surface water elevations were estimated using LiDAR data. A water level depth of 3 feet was used. The vertical conductivity of the streambed was estimated at 1/10 the average horizontal conductivity of the alluvial aquifer (87 ft/day). The model represented baseflow (summer) conditions, and the stage was kept the same throughout the simulated time period.
- A general head boundary was used to the

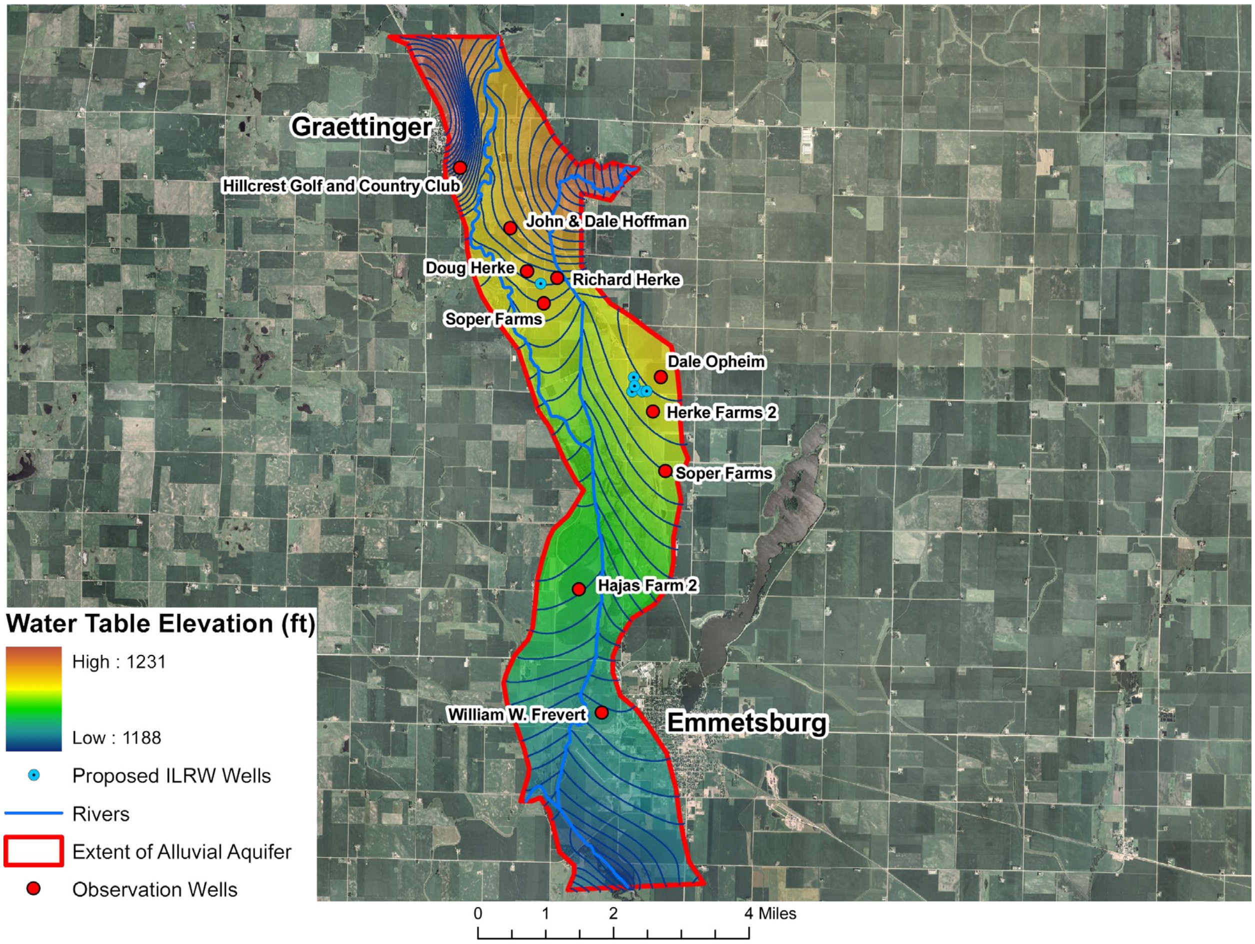

Figure 8. Simulated water table elevation map for non-pumping conditions.

north of Graettinger and to the south of Emmetsburg to represent flow-through conditions. These general head values were estimated from nearby observation well data.

- The City of Graettinger and City of Emmetsburg's wells were included. Annual usage was obtained from the IDNR water use database for years 2000 through 2009 (Table 4).
- A total of 24 irrigation wells were used in the model. The pumping rates were obtained from the IDNR water use database and are shown in Table 4.
- An average specific yield value of 0.4 was used.
- Average annual recharge was calibrated to be 8.5 inches per year. Drought conditions were simulated using recharge values of 6 and 4 inches, respectively.
- The total number of rows and columns were 500 by 360. The grid size varied from 5 feet to 100 feet.

Calibration Results

The model was initially run to simulate non-pumping conditions. The model was calibrated using the irrigation well groundwater elevations as reported to the IDNR in the water use database. Table 2 compares simulated values to observed water levels. Figure 8 shows the simulated water table map. The overall error was +0.61 feet for the ten obser-

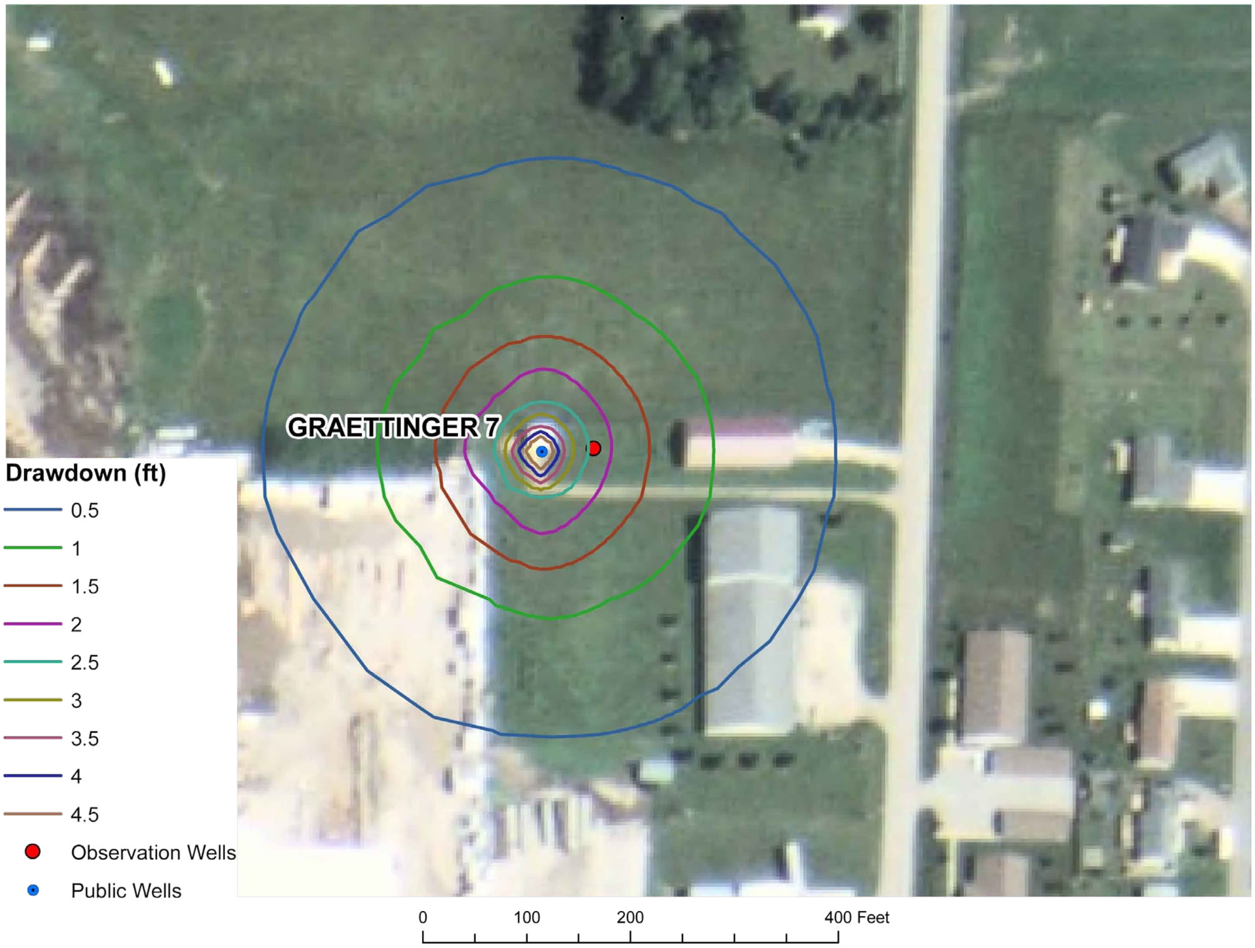

Figure 9. Graettinger Well 7 pump test simulation results.

vation wells.

Local scale calibration was performed using pump test results from Graettinger Well 7, Emmetsburg Well 7, ILRW north wellfield (Test Well P-2B), and ILRW south wellfield (Test Well P-13A). Hydraulic conductivity and specific yield values were adjusted to match the simulated water levels to the observed values. Figures 9, 10, 11, and 12 show the simulated drawdown values. The simulated versus observed groundwater elevations are shown in Table 7.

MODFLOW Simulations

Following the calibration of the model, several simulations were conducted using the proposed ILRW wells, City of Graettinger wells, City of Emmetsburg wells, and the 24 irrigation wells. The pumping rates for the irrigation wells were the maximum historical seasonal withdrawals listed in Table 4. Figure 5 shows the approximate locations of each well. The following simulations were conducted:

<u>Simulation 1</u> Normal Precipitation

- Recharge: 8.5 inches per year (normal recharge)
- Emmetsburg wellfield usage based on Table 4
- Graettinger wellfield usage based on Table 4
- Proposed ILRW wellfield – summer

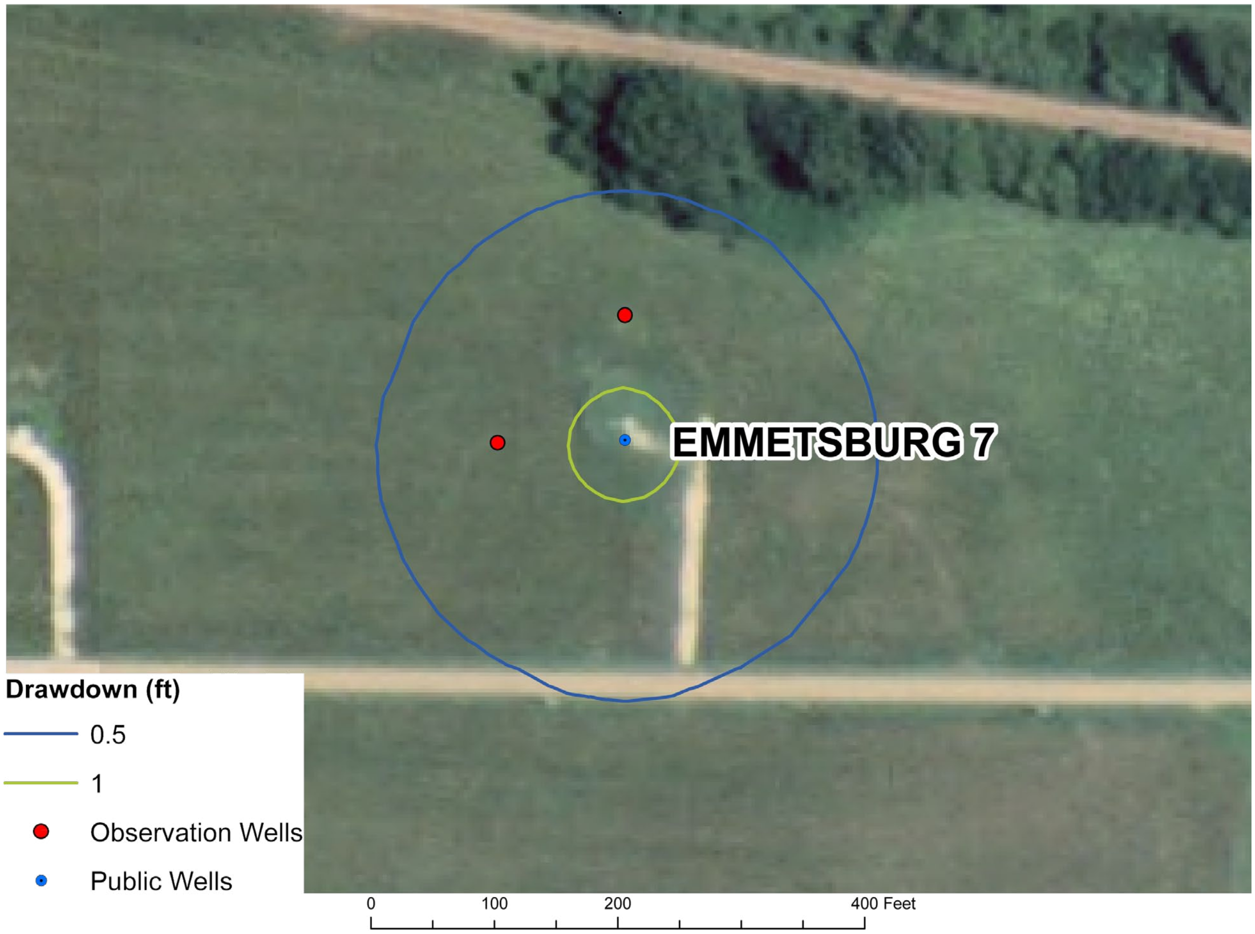

Figure 10. Emmetsburg Well 7 pump test simulation results.

usage 2,100 gpm
- 60-day transient irrigation season, maximum pumping rates based on Table 4

Simulation 2 Moderate Drought Conditions
- Recharge: 6 inches per year
- Emmetsburg wellfield usage based on Table 4
- Graettinger wellfield usage based on Table 4
- Proposed ILRW wellfield – summer usage 2,100 gpm
- 60-day transient irrigation season, maximum pumping rates based on Table 4

Simulation 3 Severe Drought Conditions
- Recharge: 4 inches per year
- Emmetsburg wellfield usage based on Table 4
- Graettinger wellfield usage based on Table 4
- Proposed ILRW wellfield – summer usage 2,100 gpm
- 60-day transient irrigation season, maximum pumping rates based on Table 4

RESULTS

Simulation 1 Normal Precipitation

The first simulation was conducted using an average rainfall of 30 to 32 inches per year and a calibrated average recharge of 8.5 inches per year. The maximum total simulated summer drawdown near the proposed ILRW north and south wellfields ranged from 8 to

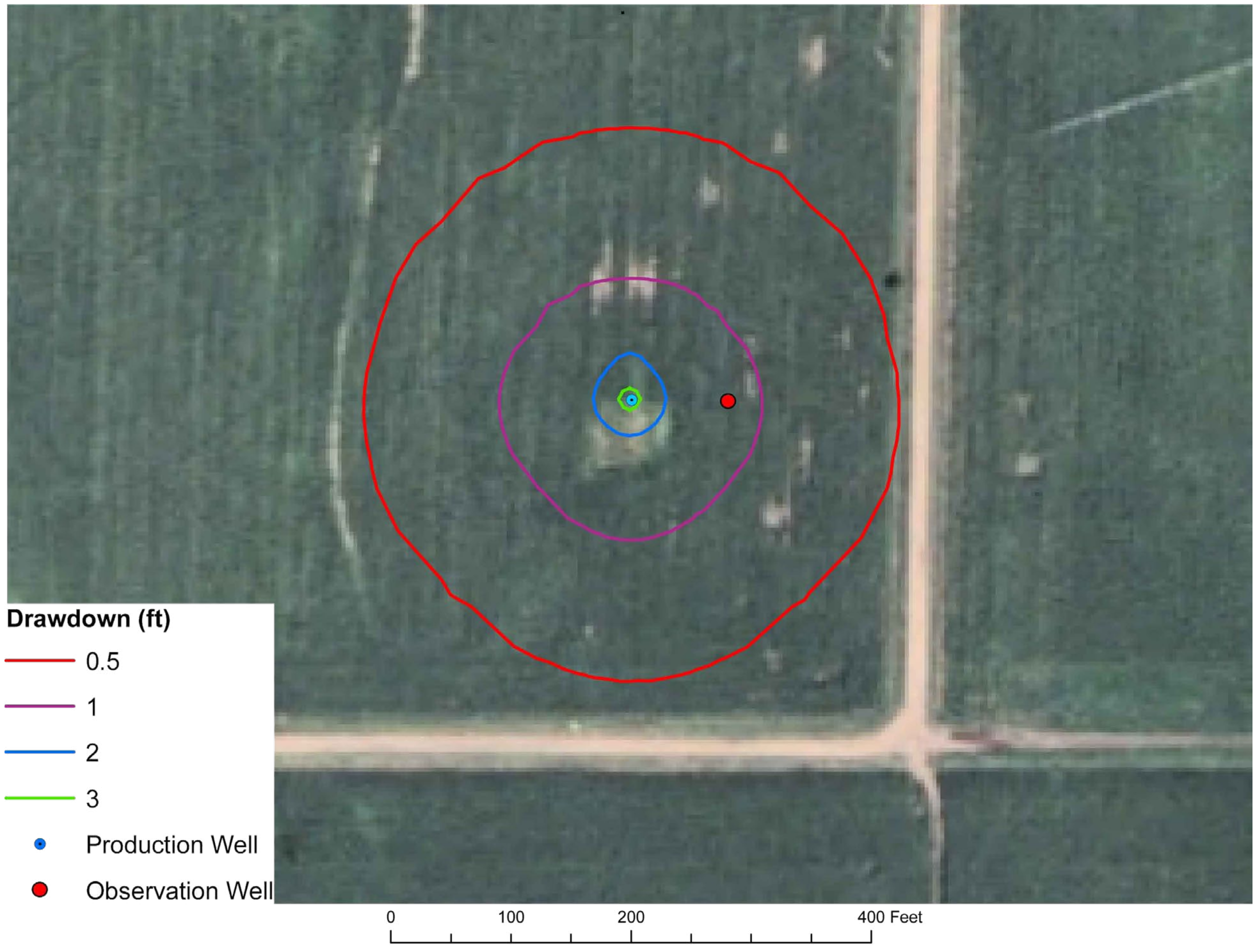

Figure 11. ILRW Test Well P-2B pump test simulation results.

10 feet, and the additional drawdown caused by the pumping of the proposed ILRW north and south wellfields is shown in figures 13 and 14.

Table 8 shows the simulated additional drawdown at each irrigation well caused by the ILRW wells. The additional drawdown caused by the pumping of the proposed south ILRW wells ranges from 2.7 feet in Herke Farm's Well 1, to 4.1 feet in the Dale Orpheim well and Herke Farms Well 3. This additional drawdown may slightly reduce the daily pumping time for the irrigation wells and the total daily production, but both the irrigators and ILRW should meet their water needs.

The additional drawdown caused by the pumping of the proposed north ILRW Well 6 ranges from 0.2 feet in the Soper Farms well, to 0.6 feet in the Doug Herke well. This additional drawdown would not significantly alter the daily pumping of the irrigation wells or the total daily production.

Based on the mass balance calculations from Visual MODFLOW, the percentage of water production supplied by the Des Moines River and Jack Creek (induced recharge) was 10.1 percent. The remaining 89.9 percent of the water production is supplied by precipitation recharge.

<u>Simulation 2</u> Moderate Drought Conditions

The second simulation was conducted using an average rainfall of 20 to 22 inches per

Figure 12. ILRW Test Well P-13A pump test simulation results.

Table 7. Observed drawdown versus model simulated drawdown for aquifer pump tests.

Pump Test Location	Observed Drawdown (ft)	Simulated Drawdown (ft)	Difference (ft)	Difference (percentage)
ILRW P-2B (OW47)	1.40	1.30	0.10	7%
ILRW P-13A (OW32)	4.10	4.30	-0.20	-5%
ILRW P-13A (OW200S)	1.40	1.10	0.30	21%
Graettinger Well 7	2.40	2.35	0.05	2%
Emmetsburg Well 7 (north)	0.70	0.76	-0.06	-9%
Emmetsburg Well 7 (west)	0.79	0.77	0.02	3%

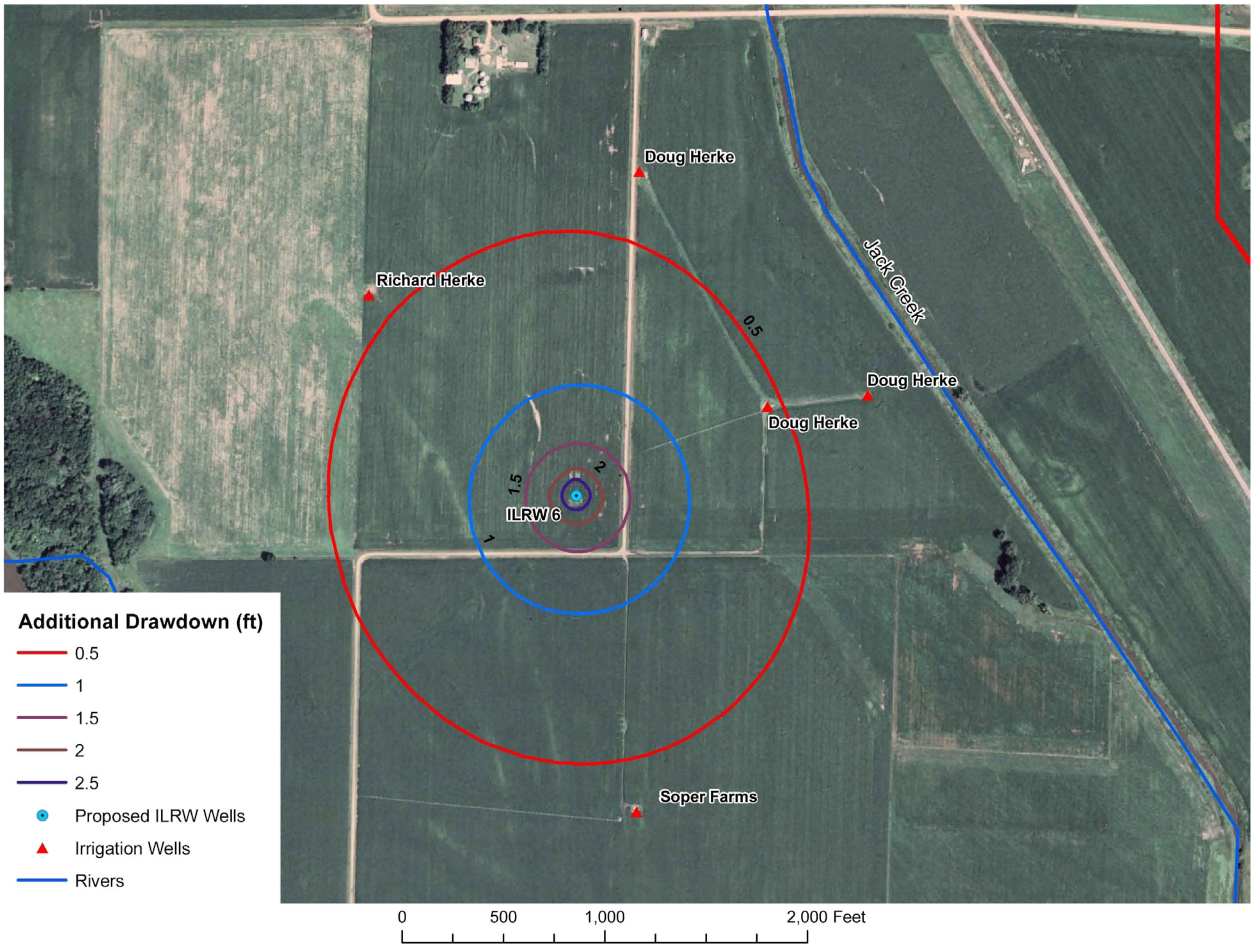

Figure 13. Simulated drawdown map for ILRW north wellfield (Well 6) for normal rainfall conditions (8.5 inches of recharge).

year and an average recharge of 6 inches per year. The maximum total simulated summer drawdown near the proposed ILRW north and south wellfields ranged from 9 to 11 feet, and the additional drawdown caused by the pumping of the proposed ILRW north and south wellfields is shown in figures 15 and 16.

Table 8 shows the simulated additional drawdown at each irrigation well caused by the ILRW wells. The additional drawdown caused by the pumping of the proposed south ILRW wells ranges from 3.6 feet in Herke Farms Well 1, to 5.1 feet in the Dale Orpheim well. This additional drawdown may further reduce the daily pumping time for the irrigation wells and the total daily production, but both the irrigators and ILRW should meet most of their water needs.

The additional drawdown caused by the pumping of the proposed north ILRW Well 6 ranges from 0.4 feet in the Soper Farms well, to 0.7 feet in the Doug Herke well. This additional drawdown would not significantly alter the daily pumping of the irrigation wells or the total daily production.

Based on the mass balance calculations from Visual MODFLOW, the percentage of water production supplied by the Des Moines River and Jack Creek (induced recharge) was approximately 32 percent. The remaining 68 percent of the water production is supplied

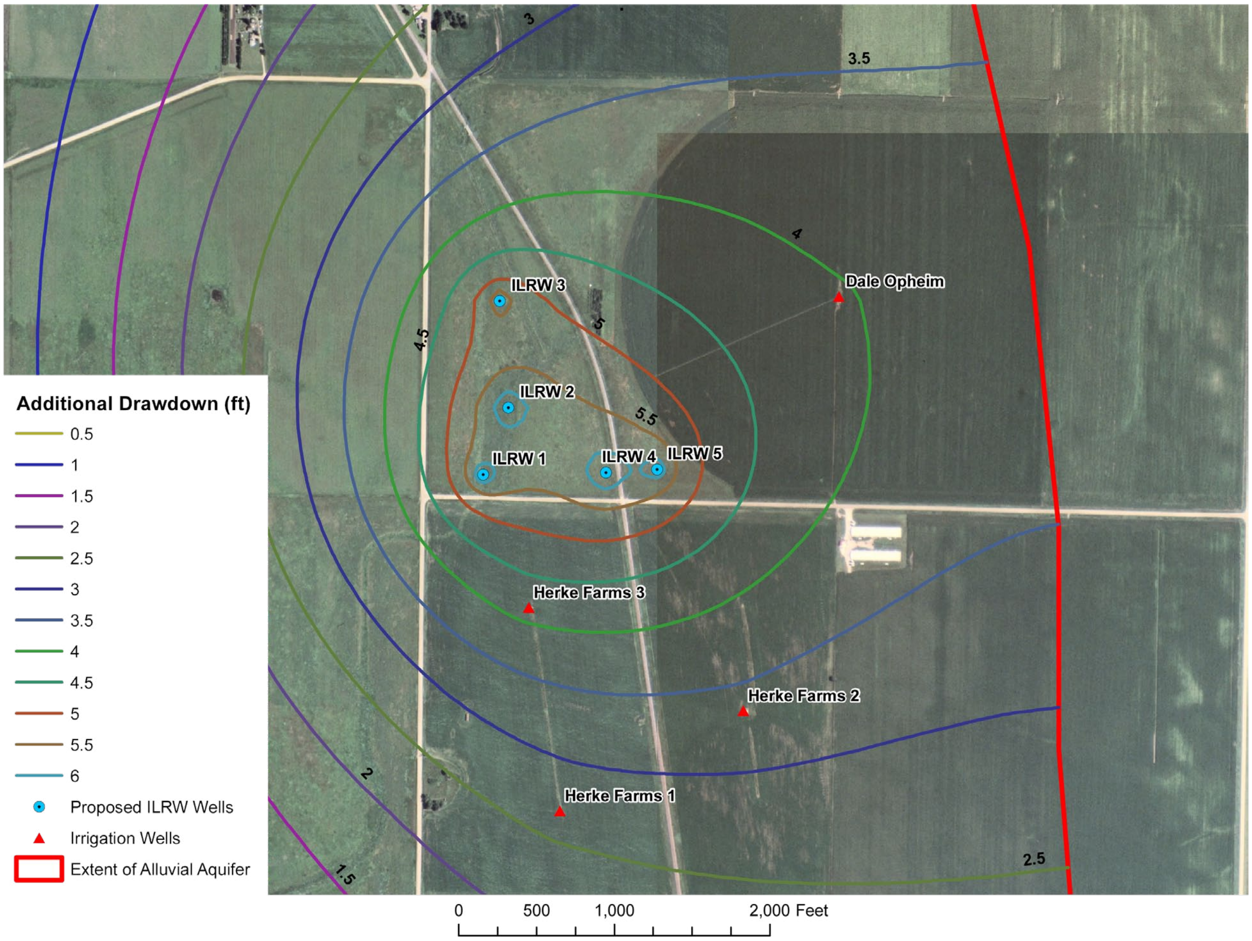

Figure 14. Simulated drawdown map for ILRW south wellfield (wells 1 through 5) for normal rainfall conditions (8.5 inches of recharge).

Table 8. Simulated drawdown for various drought scenarios near ILRW wellfields.

South Wellfield			
	Normal Rainfall	6 Inches of Recharge	4 Inches of Recharge
Well Owner	Drawdown (ft)	Drawdown (ft)	Drawdown (ft)
Dale Opheim	4.1	5.1	5.8
Herke Farms Well 3	4.1	5	5.6
Herke Farms Well 2	3.3	4.3	5
Herke Farms Well 1	2.7	3.6	4.2
North Wellfield			
	Normal Rainfall	6 Inches of Recharge	4 Inches of Recharge
Well Owner	Drawdown (ft)	Drawdown (ft)	Drawdown (ft)
Doug Herke 3	0.2 to 0.6	0.4 to 0.7	0.4 to 0.7
Soper Farms	0.2	0.4	0.7

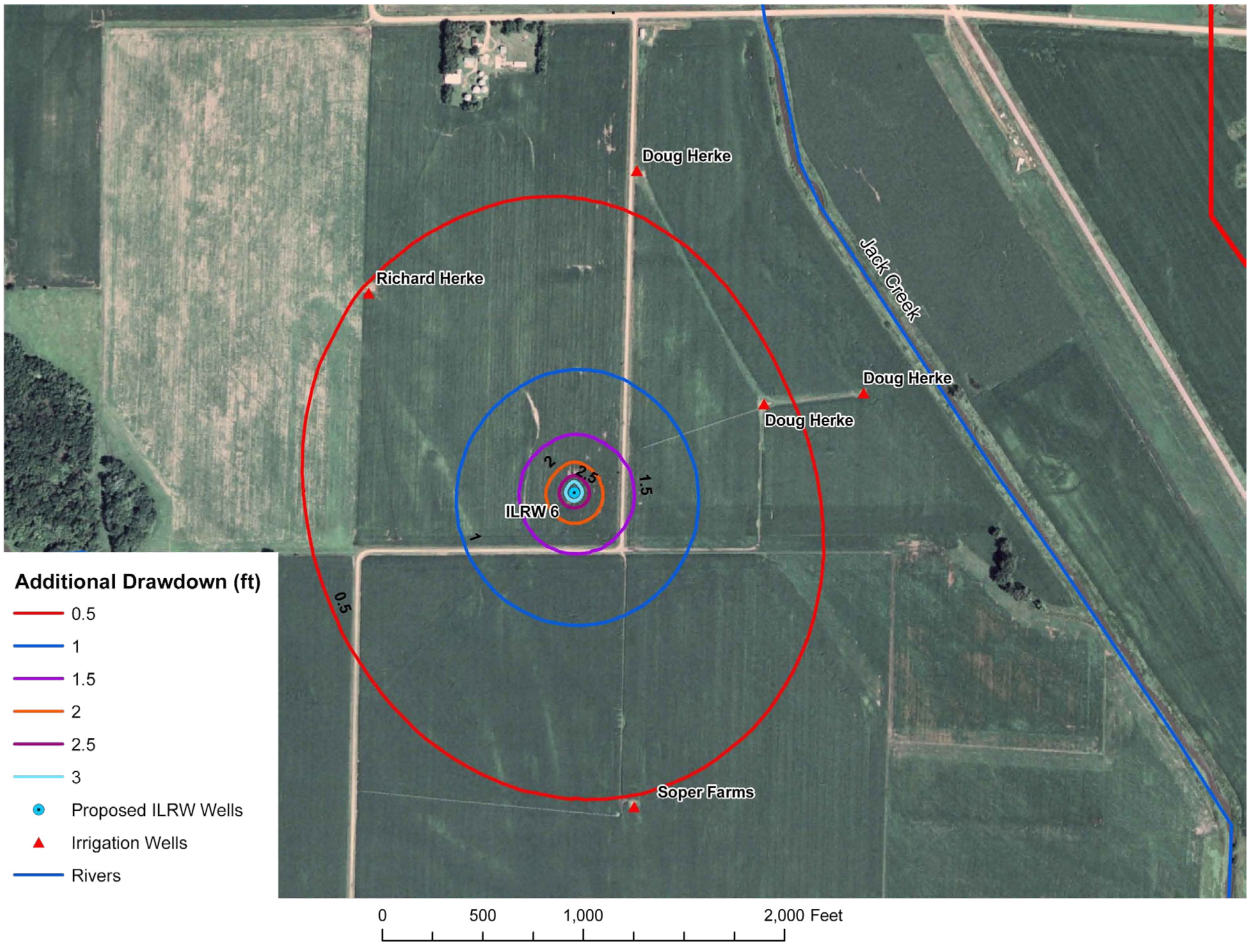

Figure 15. Simulated drawdown map for ILRW north wellfield (Well 6) for a moderate drought (6 inches of recharge).

by precipitation recharge. The increase in induced recharge prevents much higher drawdowns in both the irrigation wells and the ILRW wells. Without the recharge from the Des Moines River and Jack Creek, a moderate drought would significantly reduce the water production in the area wells.

Simulation 3 Severe Drought Conditions

The third simulation was conducted using an average rainfall of 15 to 16 inches per year and an average recharge of 4 inches per year. The maximum total simulated summer drawdown near the proposed ILRW north and south wellfields ranged from 10 to12 feet, and the additional drawdown caused by the pumping of the proposed ILRW north and south wellfields is shown on figures 17 and 18.

Table 8 shows the simulated additional drawdown at each irrigation well caused by the ILRW wells. The additional drawdown caused by the pumping of the proposed south ILRW wells ranges from 4.2 feet in Herke Farms Well 1, to 5.8 feet in the Dale Orpheim well. This additional drawdown may reduce the daily pumping time for the irrigation wells and the total daily production. Management of both the irrigation wells and the ILRW wells may be necessary so that both water users can meet their water needs. The irrigation wells may need to pump during the

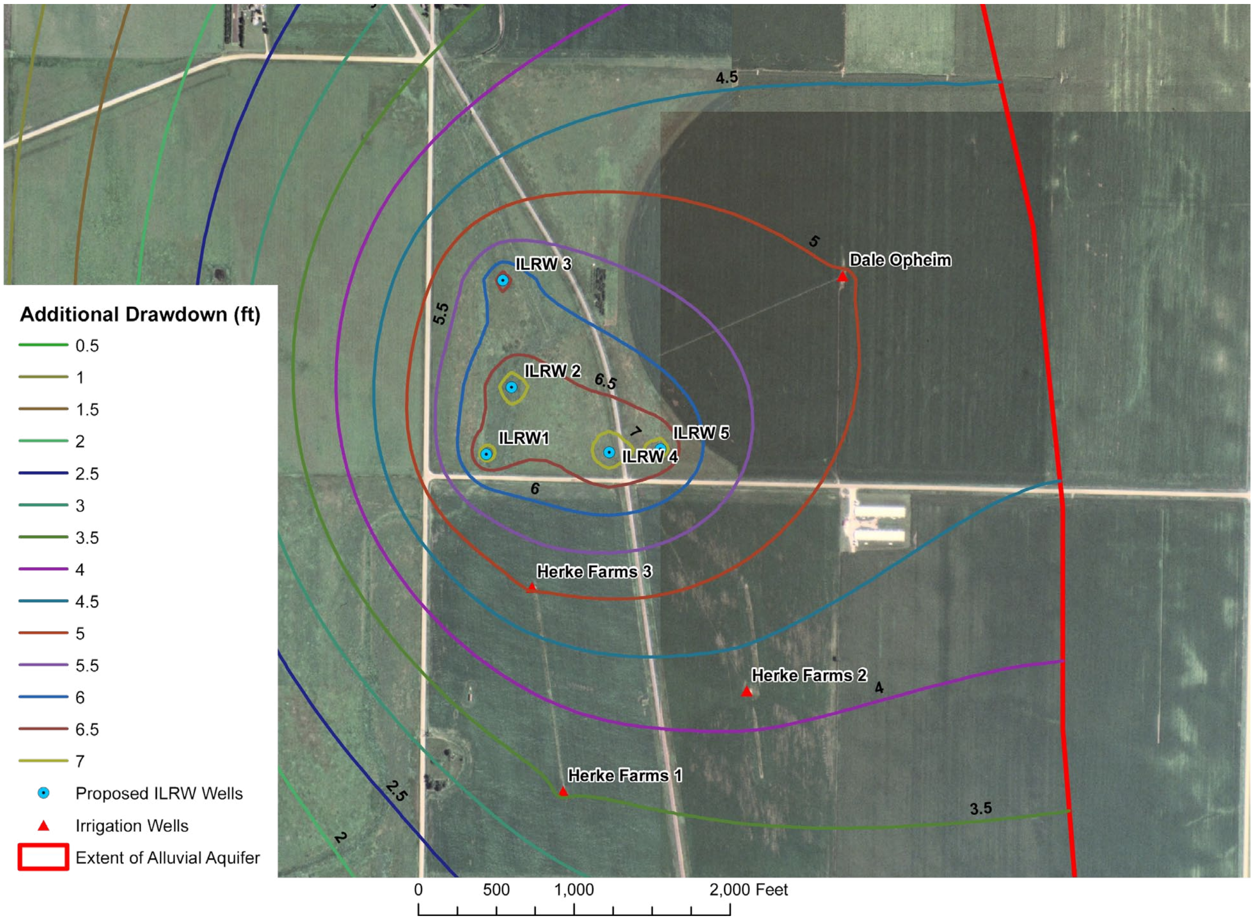

Figure 16. Simulated drawdown map for ILRW south wellfield (wells 1 through 5) for a moderate drought (6 inches of recharge).

night when water demand is lower for ILRW, or ILRW may want to pump additional water from Well 6 to reduce the pumping stress on the south wellfield. Cooperation would be necessary for both ILRW and the irrigators.

The additional drawdown caused by the pumping of the proposed north ILRW Well 6 ranges from 0.4 feet in the Soper Farms well, to 0.7 feet in the Doug Herke well, which is approximately the same as the moderate drought. This additional drawdown would not significantly alter the daily pumping of the irrigation wells or the total daily production.

Based on the mass balance calculations from Visual MODFLOW, the percentage of water production supplied by the Des Moines River and Jack Creek (induced recharge) increased to 58.4 percent. The remaining 41.6 percent of the water production is supplied by precipitation recharge. The increase in induced recharge prevents much higher drawdowns in both the irrigation wells and the ILRW wells. Without the recharge from the Des Moines River and Jack Creek, a severe drought would significantly reduce the water production in the area wells.

CONCLUSIONS

Based on the geologic and hydrogeologic data available in this study area, the follow-

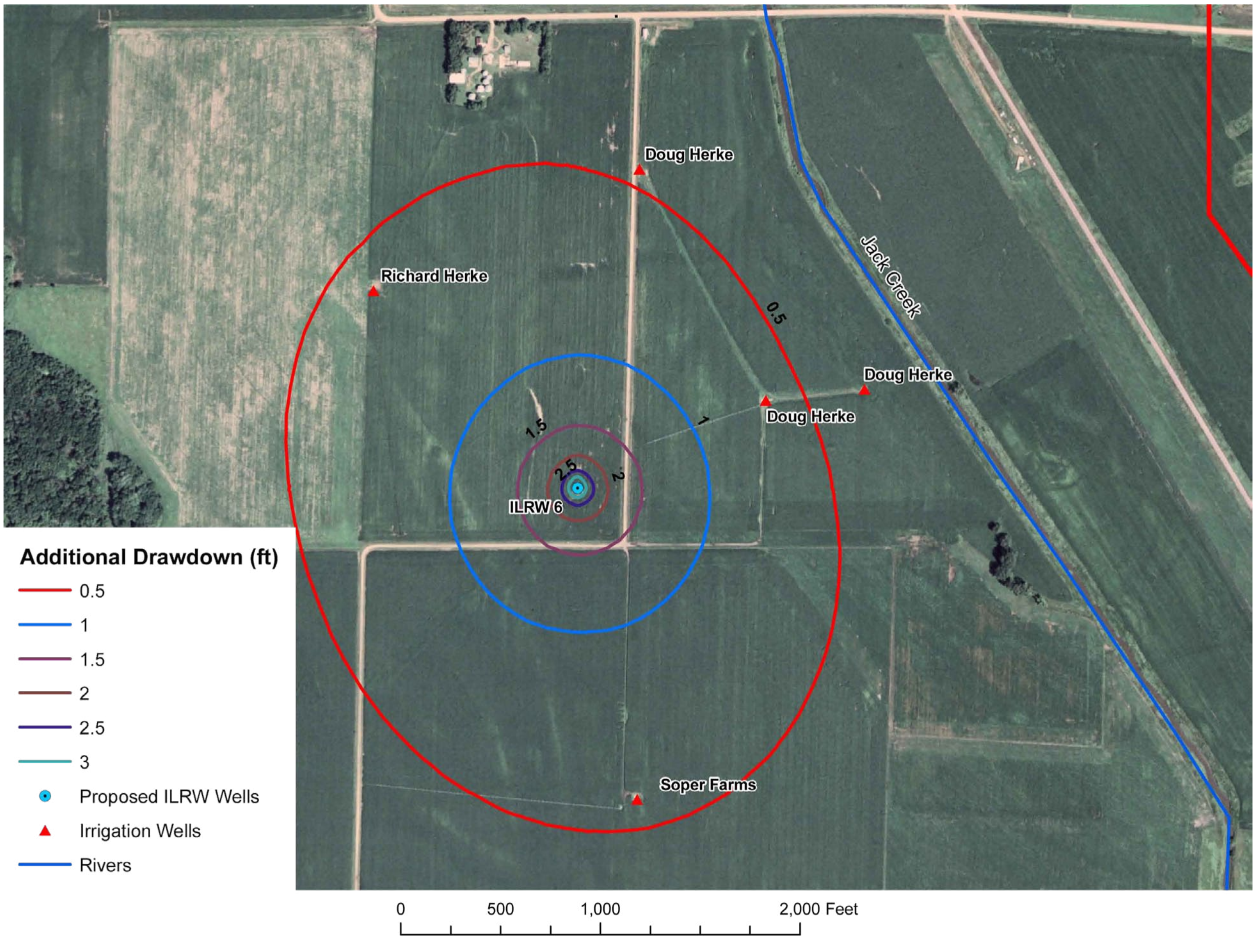

Figure 17. Simulated drawdown map for ILRW north wellfield (Well 6) for a severe drought (4 inches of recharge).

ing conclusions can be made:

- The sand and gravel alluvium located along the West Fork of the Des Moines River varies from 6 to 50 feet in thickness, with an average thickness of 20 feet.
- Transmissivity values range from 10,000 ft^2/day in Graettinger to approximately 54,000 ft^2/day in Emmetsburg.
- Based on several drought simulations using the groundwater flow model Visual MODFLOW, a severe drought would cause maximum drawdowns near ILRW of 10 to 12 feet, and additional drawdowns of 4.2 to 5.8 feet in the closest irrigation wells near the ILRW south wellfield.

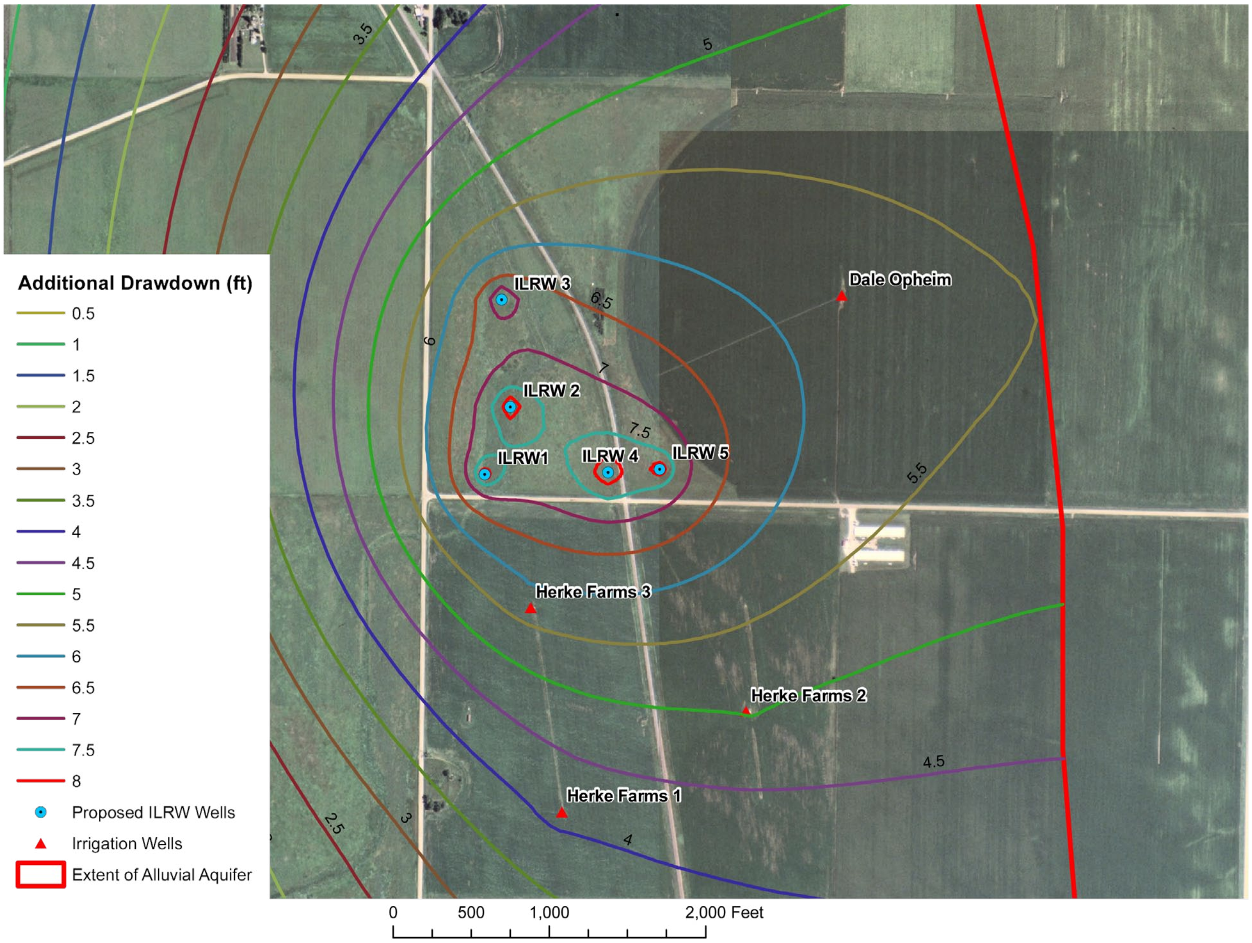

Figure 18. Simulated drawdown map for ILRW south wellfield (wells 1 through 5) for a severe drought (4 inches of recharge).

- Based on the model results, proper management and cooperation between the local irrigators and ILRW would be necessary during a severe drought to assure uninterrupted water supply. This may require nighttime irrigation by the farmers, or different pumping rotations of production wells by ILRW.
- The increase in induced recharge during a severe drought prevents much higher drawdowns in both the irrigation wells and the ILRW wells. Without the recharge from the Des Moines River and Jack Creek, a severe drought would significantly reduce the water production in the area wells.

ACKNOWLEDGEMENTS

The author 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 Des Moines River aquifer in Iowa is built on the work of previous and current Iowa Geological and Water Survey and United States Geological Survey geologists. Layne Christiansen, Inc. supplied pump test and recovery test data. Paul Kroenke (City of Graettinger) and Jeff Morey (City of Emmetsburg) assisted in aquifer pump tests in their communities. Lynette Seigley, Chad Fields, Paul VanDorpe, Deanna Thomann, and Richard Langel provided technical and editorial reviews.

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APPENDIX A.

AQUIFER PUMP TEST DATA

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data**	Page 1 of 3
	Project: Graettinger Pump Test	
	Number:	
	Client:	

Location: Graettinger, Iowa	Pumping Test: Pumping Test Well 7	Pumping Well: Well 7
Test Conducted by: Mike Gannon	Test Date: 10/19/2010	Discharge Rate: 256 [U.S. gal/min]
Observation Well: OB1	Static Water Level [ft]: 16.33	Radial Distance to PW [ft]: 50

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	16.336	0.006
2	10	17.523	1.193
3	20	17.751	1.421
4	30	17.808	1.478
5	40	17.853	1.523
6	50	17.902	1.572
7	60	17.915	1.585
8	70	17.954	1.624
9	80	17.977	1.647
10	90	18.00	1.67
11	100	18.005	1.675
12	110	18.031	1.701
13	120	18.057	1.727
14	130	18.063	1.733
15	140	18.073	1.743
16	150	18.09	1.76
17	160	18.102	1.772
18	170	18.112	1.782
19	180	18.129	1.799
20	190	18.138	1.808
21	200	18.165	1.835
22	210	18.168	1.838
23	220	18.174	1.844
24	230	18.189	1.859
25	240	18.201	1.871
26	250	18.208	1.878
27	260	18.213	1.883
28	270	18.23	1.90
29	280	18.234	1.904
30	290	18.246	1.916
31	300	18.254	1.924
32	310	18.266	1.936
33	320	18.274	1.944
34	330	18.281	1.951
35	340	18.292	1.962
36	350	18.304	1.974
37	360	18.308	1.978
38	370	18.31	1.98
39	380	18.324	1.994
40	390	18.321	1.991
41	400	18.335	2.005
42	410	18.346	2.016
43	420	18.343	2.013
44	430	18.359	2.029
45	440	18.361	2.031
46	450	18.375	2.045
47	460	18.376	2.046
48	470	18.382	2.052
49	480	18.387	2.057
50	490	18.40	2.07
51	500	18.407	2.077

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data**	Page 2 of 3
	Project: Graettinger Pump Test	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
52	510	18.41	2.08
53	520	18.413	2.083
54	530	18.429	2.099
55	540	18.429	2.099
56	550	18.428	2.098
57	560	18.435	2.105
58	570	18.444	2.114
59	580	18.453	2.123
60	590	18.449	2.119
61	600	18.463	2.133
62	610	18.46	2.13
63	620	18.467	2.137
64	630	18.459	2.129
65	640	18.468	2.138
66	650	18.473	2.143
67	660	18.474	2.144
68	670	18.471	2.141
69	680	18.476	2.146
70	690	18.479	2.149
71	700	18.482	2.152
72	710	18.49	2.16
73	720	18.485	2.155
74	730	18.493	2.163
75	740	18.497	2.167
76	750	18.501	2.171
77	760	18.507	2.177
78	770	18.508	2.178
79	780	18.514	2.184
80	790	18.52	2.19
81	800	18.519	2.189
82	810	18.527	2.197
83	820	18.528	2.198
84	830	18.532	2.202
85	840	18.534	2.204
86	850	18.544	2.214
87	860	18.546	2.216
88	870	18.548	2.218
89	880	18.555	2.225
90	890	18.557	2.227
91	900	18.564	2.234
92	910	18.565	2.235
93	920	18.566	2.236
94	930	18.576	2.246
95	940	18.577	2.247
96	950	18.582	2.252
97	960	18.581	2.251
98	970	18.587	2.257
99	980	18.59	2.26
100	990	18.591	2.261
101	1000	18.603	2.273
102	1010	18.608	2.278
103	1020	18.603	2.273
104	1030	18.607	2.277
105	1040	18.613	2.283
106	1050	18.619	2.289
107	1060	18.623	2.293

Iowa Department of Natural Resources
Iowa Geological and Water Survey
Iowa City, Iowa

Pumping Test - Water Level Data

Project: Graettinger Pump Test

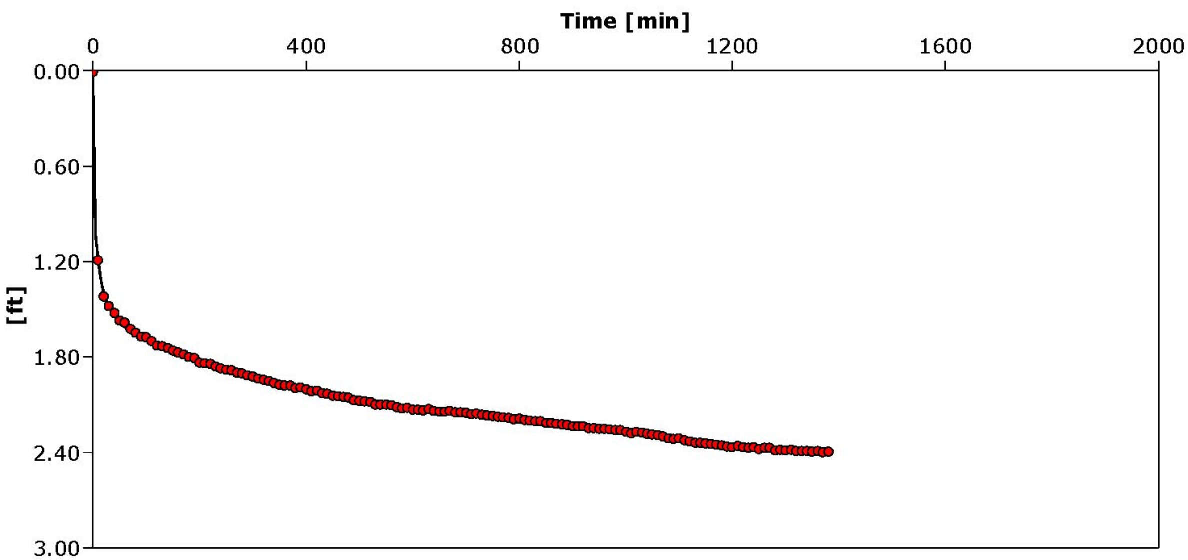
Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
108	1070	18.63	2.30
109	1080	18.64	2.31
110	1090	18.646	2.316
111	1100	18.643	2.313
112	1110	18.653	2.323
113	1120	18.66	2.33
114	1130	18.67	2.34
115	1140	18.67	2.34
116	1150	18.675	2.345
117	1160	18.679	2.349
118	1170	18.681	2.351
119	1180	18.686	2.356
120	1190	18.693	2.363
121	1200	18.696	2.366
122	1210	18.688	2.358
123	1220	18.697	2.367
124	1230	18.70	2.37
125	1240	18.699	2.369
126	1250	18.71	2.38
127	1260	18.702	2.372
128	1270	18.701	2.371
129	1280	18.716	2.386
130	1290	18.715	2.385
131	1300	18.716	2.386
132	1310	18.714	2.384
133	1320	18.722	2.392
134	1330	18.721	2.391
135	1340	18.72	2.39
136	1350	18.725	2.395
137	1360	18.721	2.391
138	1370	18.731	2.401
139	1380	18.724	2.394

	Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test Analysis Report**
		Project: Graettinger Pump Test
		Number:
		Client:

Location: Graettinger, Iowa	Pumping Test: Pumping Test Well 7	Pumping Well: Well 7
Test Conducted by: Mike Gannon		Test Date: 10/19/2010
Analysis Performed by:	New analysis 1	Analysis Date: 10/21/2010
Aquifer Thickness: 17.00 ft	Discharge Rate: 256 [U.S. gal/min]	



Calculation after Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OB1	1.01×10^{4}	5.93×10^{2}	1.70×10^{-2}	5.93×10^{-4}	1.00×10^{1}	50.0

	Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test - Water Level Data	Page 1 of 2
		Project: Emmetsburg Pump Test	
		Number:	
		Client:	

Location: Emmetsburg, Iowa	Pumping Test: Well 7	Pumping Well: well 7
Test Conducted by:	Test Date: 10/20/2010	Discharge Rate: 672 [U.S. gal/min]
Observation Well: West well	Static Water Level [ft]: 9.08	Radial Distance to PW [ft]: 100

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	9.087	0.007
2	10	9.246	0.166
3	20	9.337	0.257
4	30	9.39	0.31
5	40	9.435	0.355
6	50	9.463	0.383
7	60	9.497	0.417
8	70	9.524	0.444
9	80	9.549	0.469
10	90	9.571	0.491
11	100	9.589	0.509
12	110	9.603	0.523
13	120	9.62	0.54
14	130	9.638	0.558
15	140	9.649	0.569
16	150	9.663	0.583
17	160	9.676	0.596
18	170	9.69	0.61
19	180	9.701	0.621
20	190	9.711	0.631
21	200	9.723	0.643
22	210	9.732	0.652
23	220	9.744	0.664
24	230	9.745	0.665
25	240	9.75	0.67
26	250	9.758	0.678
27	260	9.764	0.684
28	270	9.778	0.698
29	280	9.784	0.704
30	290	9.782	0.702
31	300	9.794	0.714
32	310	9.798	0.718
33	320	9.797	0.717
34	330	9.799	0.719
35	340	9.806	0.726
36	350	9.808	0.728
37	360	9.819	0.739
38	370	9.819	0.739
39	380	9.816	0.736
40	390	9.83	0.75
41	400	9.83	0.75
42	410	9.826	0.746
43	420	9.844	0.764
44	430	9.839	0.759
45	440	9.843	0.763
46	450	9.842	0.762
47	460	9.847	0.767
48	470	9.851	0.771
49	480	9.849	0.769
50	490	9.853	0.773
51	500	9.856	0.776

Iowa Department of Natural Resources
Iowa Geological and Water Survey
Iowa City, Iowa

Pumping Test - Water Level Data

Project: Emmetsburg Pump Test

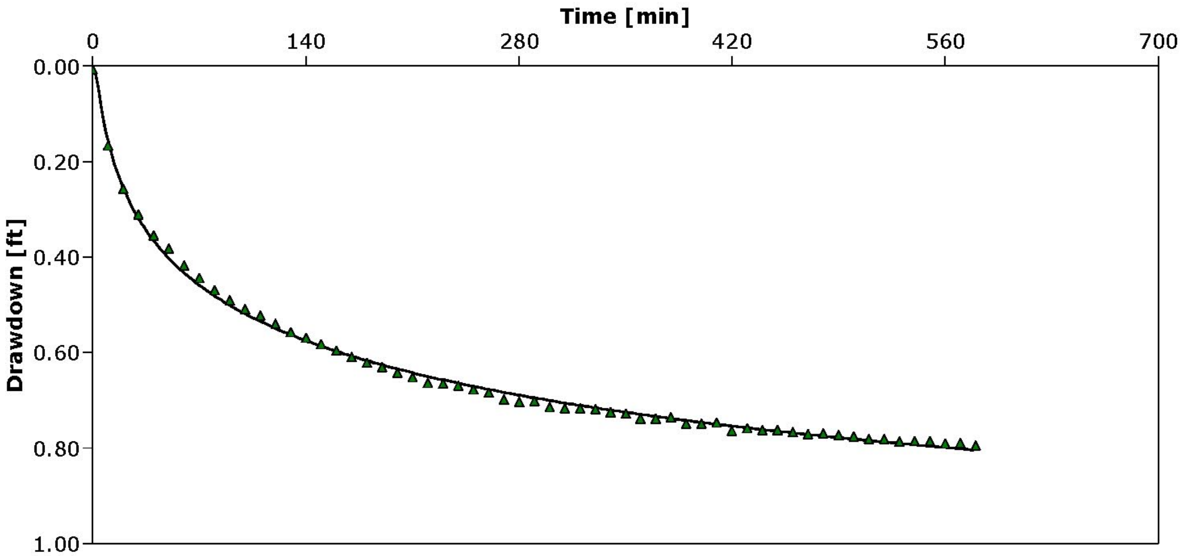
Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
52	510	9.861	0.781
53	520	9.861	0.781
54	530	9.867	0.787
55	540	9.865	0.785
56	550	9.866	0.786
57	560	9.871	0.791
58	570	9.87	0.79
59	580	9.874	0.794

	Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test Analysis Report Project: Emmetsburg Pump Test Number: Client:

Location: Emmetsburg, Iowa	Pumping Test: Well 7	Pumping Well: well 7
Test Conducted by:		Test Date: 10/20/2010
Analysis Performed by:	New analysis 1	Analysis Date: 10/25/2010
Aquifer Thickness: 50.00 ft	Discharge Rate: 672 [U.S. gal/min]	



Calculation after Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
West well	5.46×10^{4}	1.09×10^{3}	5.00×10^{-1}	1.70×10^{-4}	1.00×10^{1}	100.0

Iowa Department of Natural Resources
Iowa Geological and Water Survey
Iowa City, Iowa

Pumping Test - Water Level Data

Project: Emmetsburg Pump Test

Number:

Client:

Location: Emmetsburg, Iowa	Pumping Test: Well 7	Pumping Well: well 7
Test Conducted by:	Test Date: 10/20/2010	Discharge Rate: 672 [U.S. gal/min]
Observation Well: north well	Static Water Level [ft]: 9.28	Radial Distance to PW [ft]: 100

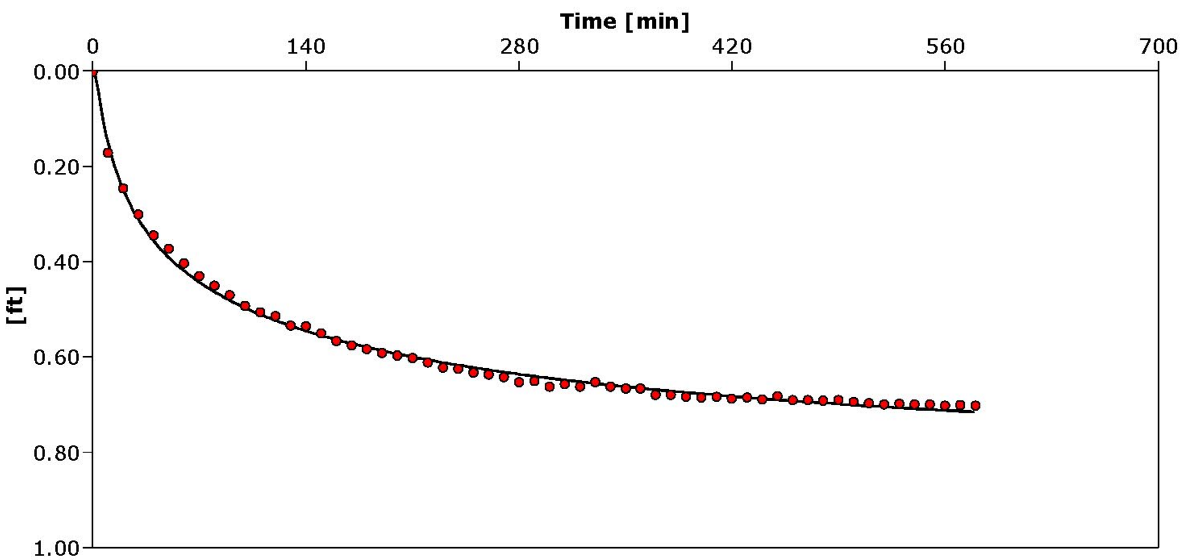
	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	9.283	0.003
2	10	9.452	0.172
3	20	9.526	0.246
4	30	9.581	0.301
5	40	9.625	0.345
6	50	9.653	0.373
7	60	9.684	0.404
8	70	9.71	0.43
9	80	9.731	0.451
10	90	9.75	0.47
11	100	9.773	0.493
12	110	9.787	0.507
13	120	9.795	0.515
14	130	9.815	0.535
15	140	9.816	0.536
16	150	9.831	0.551
17	160	9.847	0.567
18	170	9.856	0.576
19	180	9.864	0.584
20	190	9.872	0.592
21	200	9.877	0.597
22	210	9.883	0.603
23	220	9.892	0.612
24	230	9.903	0.623
25	240	9.905	0.625
26	250	9.913	0.633
27	260	9.918	0.638
28	270	9.922	0.642
29	280	9.933	0.653
30	290	9.931	0.651
31	300	9.943	0.663
32	310	9.937	0.657
33	320	9.943	0.663
34	330	9.934	0.654
35	340	9.942	0.662
36	350	9.947	0.667
37	360	9.946	0.666
38	370	9.96	0.68
39	380	9.96	0.68
40	390	9.964	0.684
41	400	9.965	0.685
42	410	9.964	0.684
43	420	9.968	0.688
44	430	9.966	0.686
45	440	9.969	0.689
46	450	9.963	0.683
47	460	9.97	0.69
48	470	9.97	0.69
49	480	9.972	0.692
50	490	9.971	0.691
51	500	9.975	0.695

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data**	Page 2 of 2
	Project: Emmetsburg Pump Test	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
52	510	9.977	0.697
53	520	9.98	0.70
54	530	9.979	0.699
55	540	9.98	0.70
56	550	9.98	0.70
57	560	9.983	0.703
58	570	9.981	0.701
59	580	9.983	0.703

	Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test Analysis Report
		Project: Emmetsburg Pump Test
		Number:
		Client:

Location: Emmetsburg, Iowa	Pumping Test: Well 7	Pumping Well: well 7
Test Conducted by:		Test Date: 10/20/2010
Analysis Performed by:	New analysis 1	Analysis Date: 10/25/2010
Aquifer Thickness: 50.00 ft	Discharge Rate: 672 [U.S. gal/min]	



Calculation after Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
north well	4.95×10^4	9.90×10^2	5.00×10^{-1}	2.28×10^{-3}	1.00×10^1	100.0

Iowa Department of Natural Resources
Iowa Geological and Water Survey
Iowa City, Iowa

Pumping Test - Water Level Data Page 1 of 1

Project: Osgood Well Field

Number:

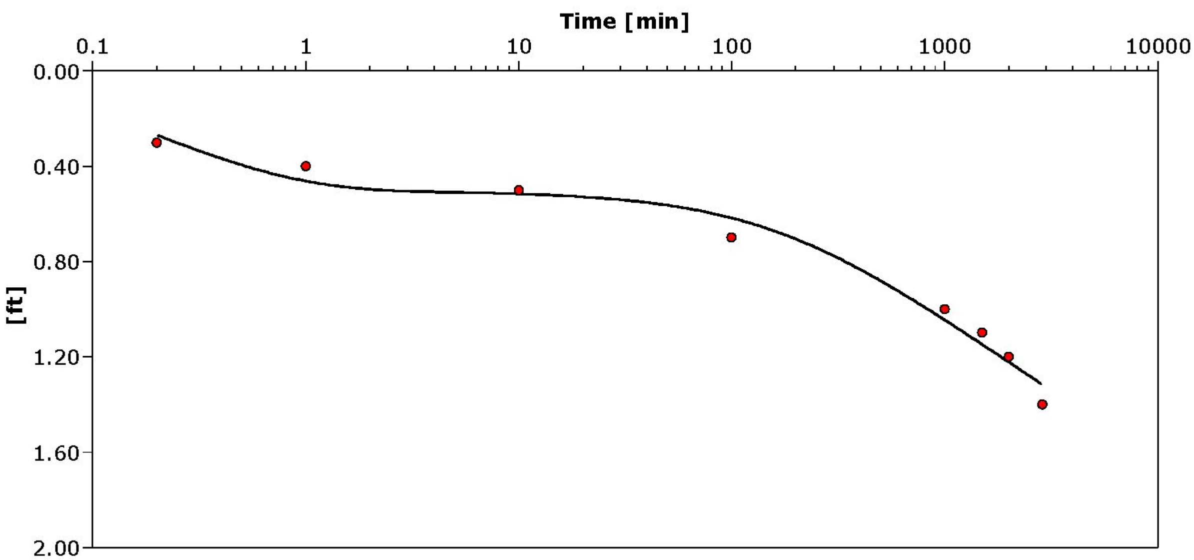
Client: Iowa Lakes Regional Water

Location:	Pumping Test: P-2B	Pumping Well: P-2B
Test Conducted by: Layne Western	Test Date: 8/12/2005	Discharge Rate: 629 [U.S. gal/min]
Observation Well: OW	Static Water Level [ft]: 10.00	Radial Distance to PW [ft]: 47

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0.2	10.30	0.30
2	1	10.40	0.40
3	10	10.50	0.50
4	100	10.70	0.70
5	1000	11.05	1.05
6	2000	11.15	1.15
7	2880	11.40	1.40

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test Analysis Report** Project: Osgood Well Field Number: Client: Iowa Lakes Regional Water	

Location:	Pumping Test: P-2B	Pumping Well: P-2B
Test Conducted by: Layne Western		Test Date: 8/12/2005
Analysis Performed by: IGWS	OW47	Analysis Date: 7/22/2010
Aquifer Thickness: 29.00 ft	Discharge Rate: 629 [U.S. gal/min]	



Calculation after Neuman

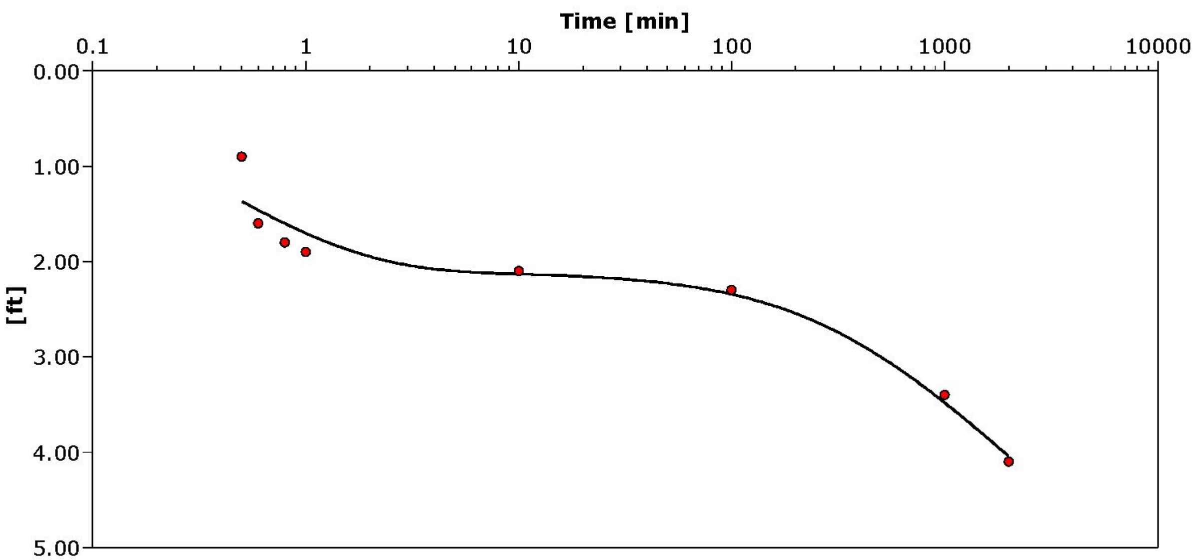
Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OW	3.66×10^{4}	1.26×10^{3}	5.00×10^{-1}	2.34×10^{-2}	2.98×10^{2}	47.0

Iowa Department of Natural Resources **Iowa Geological and Water Survey** **Iowa City, Iowa**	**Pumping Test - Water Level Data**	Page 1 of 1
	Project: Osgood Well Field	
	Number:	
	Client:	

Location: Emmetsburg	Pumping Test: P-13A	Pumping Well: P-13A
Test Conducted by:	Test Date: 5/13/2005	Discharge Rate: 880 [U.S. gal/min]
Observation Well: OW32W	Static Water Level [ft]: 11.00	Radial Distance to PW [ft]: 32

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0.5	11.90	0.90
2	0.6	12.60	1.60
3	0.8	12.80	1.80
4	1	12.90	1.90
5	10	13.10	2.10
6	100	13.30	2.30
7	1000	14.40	3.40
8	2000	15.10	4.10

Iowa Department of Natural Resources **Iowa Geological and Water Survey** **Iowa City, Iowa**		**Pumping Test Analysis Report**
		Project: Osgood Well Field
		Number:
		Client:
Location: Emmetsburg	Pumping Test: P-13A	Pumping Well: P-13A
Test Conducted by:		Test Date: 5/13/2005
Analysis Performed by: IGWS	OW32W	Analysis Date: 7/22/2010
Aquifer Thickness: 27.00 ft	Discharge Rate: 880 [U.S. gal/min]	



Calculation after Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S	Radial Distance to PW [ft]
OW32W	1.51×10^{4}	5.61×10^{2}	5.00×10^{-1}	2.48×10^{-2}	2.74×10^{2}	32.0

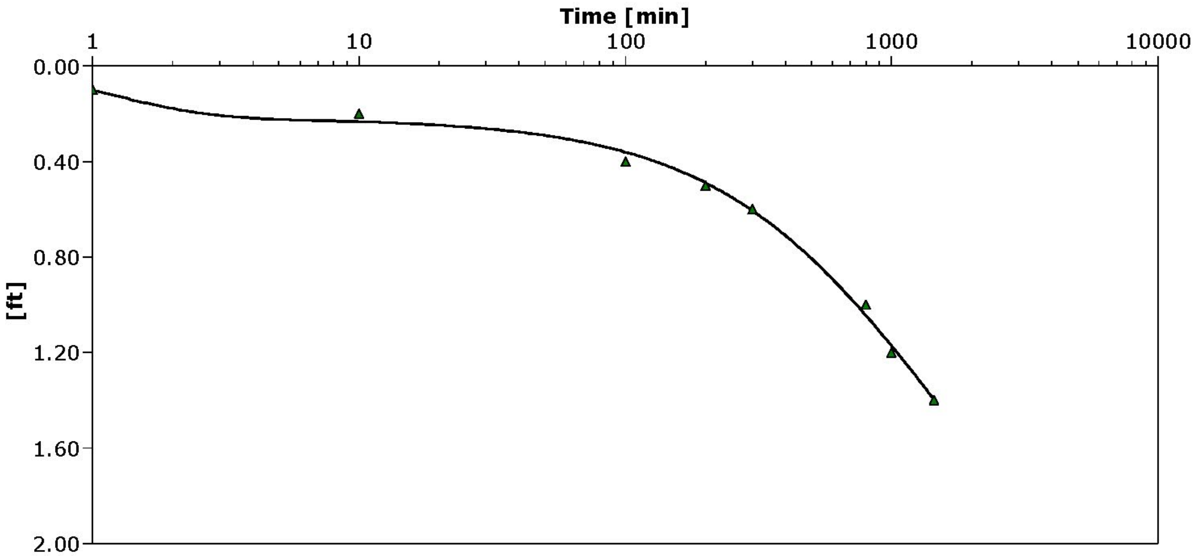
Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data** Page 1 of 1 Project: Osgood Well Field Number: Client:

Location: Emmetsburg	Pumping Test: P-13A	Pumping Well: P-13A
Test Conducted by:	Test Date: 5/13/2005	Discharge Rate: 880 [U.S. gal/min]
Observation Well: OW200S	Static Water Level [ft]: 11.00	Radial Distance to PW [ft]: 200

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1	11.10	0.10
2	10	11.20	0.20
3	100	11.40	0.40
4	200	11.50	0.50
5	300	11.60	0.60
6	800	12.00	1.00
7	1000	12.20	1.20
8	1440	12.40	1.40

Iowa Department of Natural Resources **Iowa Geological and Water Survey** **Iowa City, Iowa**		**Pumping Test Analysis Report**
		Project: Osgood Well Field
		Number:
		Client:

Location: Emmetsburg	Pumping Test: P-13A	Pumping Well: P-13A
Test Conducted by:		Test Date: 5/13/2005
Analysis Performed by: IGWS	OW200S	Analysis Date: 7/22/2010
Aquifer Thickness: 27.00 ft	Discharge Rate: 880 [U.S. gal/min]	



Calculation after Boulton

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Drainage factor	Ratio Sy/S	Radial Distance to PW [ft]
OW200S	1.88×10^{4}	6.98×10^{2}	1.64×10^{-1}	2.35×10^{-2}	1.31×10^{2}	200.0

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