Aquifer Characterization and Drought Assessment Floyd River Alluvial Aquifer

Iowa Geological and Water Survey
Water Resources Investigation Report 6

Iowa Department of Natural Resources
Chuck Gipp, Director
September 2012

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Prepared by

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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, which would 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 understand the shallow groundwater resources in the Floyd River alluvial aquifer (Floyd River aquifer) in northwest Iowa. The primary objective of this study was to evaluate the aquifer for future water supply development. A groundwater flow model of the Floyd River aquifer was created for the City of Sheldon using Visual MODFLOW 2011.1. The model can be used to predict future well interference, drawdown, and maximum sustainable pumping rates.

Based on available pumping records, an average of 2.21 billion gallons of water are pumped from the Floyd River aquifer each year. Additional water production is available from the aquifer, but limitations exist during extremely dry years. Maximum estimated well yields exceed 200 gpm near Hospers, Le Mars, Merrill, Sioux Center, and Sioux City. The average well yield is slightly less than 100 gpm.

The groundwater flow model for the Floyd River aquifer near Sheldon was used to simulate a severe drought. Water level data during the summer of 2012 were used to help calibrate the model. Based on the mass balance calculations in the model, the percentage of water production supplied by the Floyd River (induced recharge) increased from 54 percent during normal rainfall conditions to 68 percent during a severe drought. The increase in induced recharge allows the City of Sheldon public wells to maintain water production during prolonged dry periods. Limitations in water production exist when streamflow along the Floyd River drops below 1.58 cubic feet per second.

INTRODUCTION

The purpose of this report is to evaluate the groundwater resources in the alluvial aquifer located adjacent to the Floyd River (Figure 1) in northwest Iowa as it relates to drought conditions. In addition to the main branch of the Floyd River, the study area also includes the West Fork of the Floyd River, Deep Creek, and Mink Creek (Figure 1). The Floyd River and its tributaries are found in O'Brien, Plymouth, Sioux, and Woodbury counties. For the purposes of this summary report the alluvial aquifer will be referred to as the Floyd River aquifer. The evaluation was completed by the Iowa Geological and Water Survey, Iowa Department of Natural Resources (IDNR).

CLIMATE

The climate of northwest Iowa is classified as sub-humid. Based on data compiled by Iowa State University (Mesonet, Iowa State University, 2012), the average annual precipitation in O'Brien, Plymouth, Sioux, and Woodbury counties ranges from 25 inches per year in Sioux City (Woodbury County) to 28 inches per year in Sanborn (O'Brien County). Approximately 16 to 18 inches of precipitation occurs during the months of April through October (Wahl, Meyer, and Karsten, 1982).

Northwest Iowa has historically experienced moderate to severe droughts. Table 1 shows the minimum annual precipitation amounts for a select number of cities in northwest Iowa

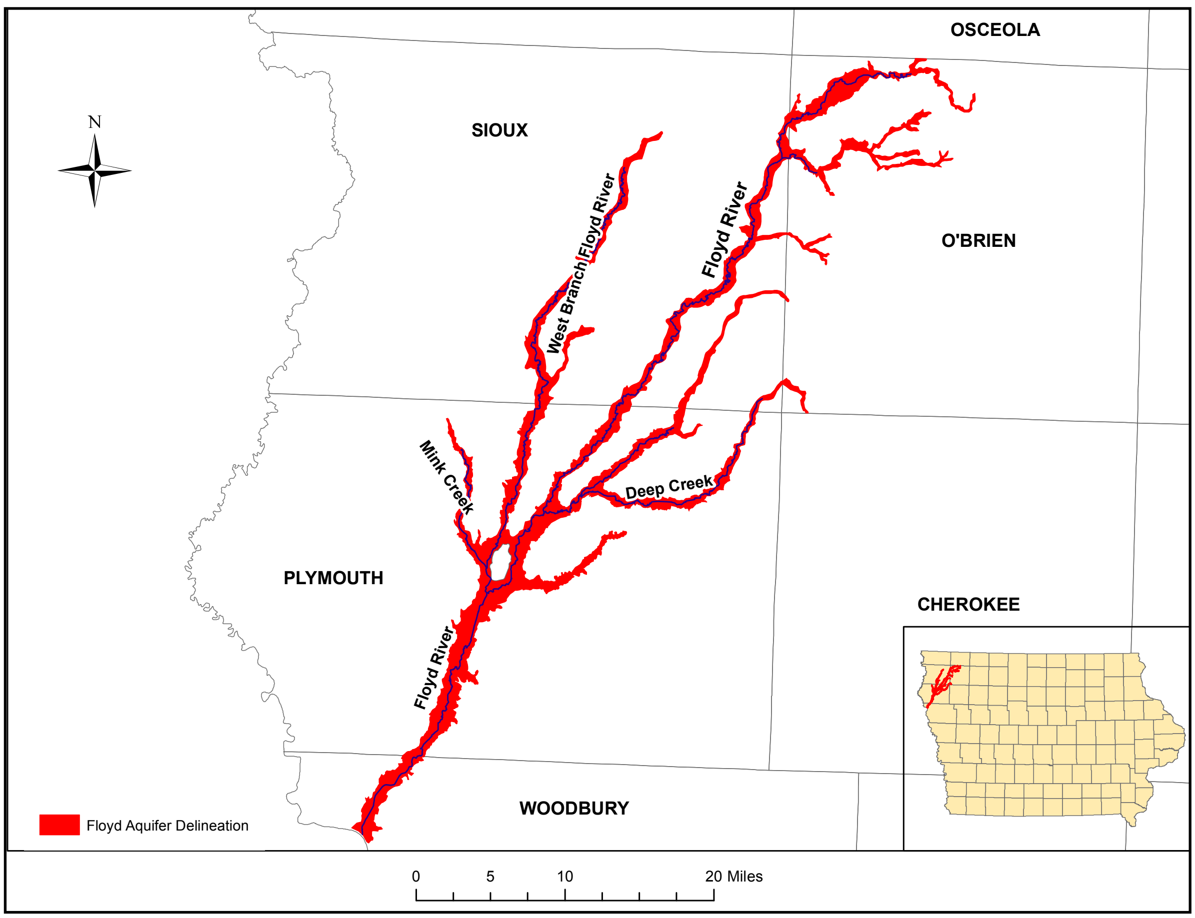

Figure 1. Extent of the Floyd River aquifer study area.

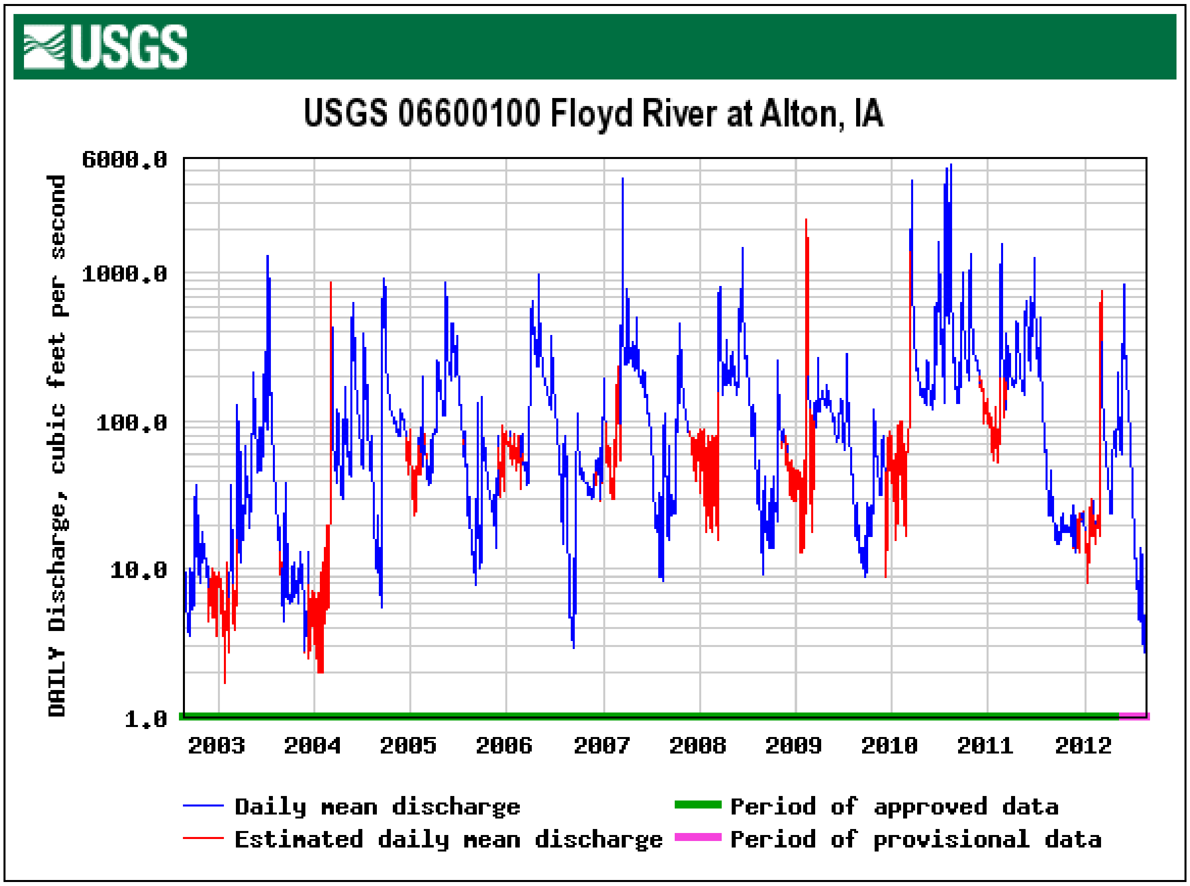

Figure 2. Daily average streamflow at USGS stream gage at Alton (2002 to 2012).

(Mesonet, Iowa State University, 2012). These minimum annual precipitation amounts range from 12.99 inches in Le Mars in 1976 to 15.41 inches in Sheldon in 1958.

SURFACE WATER

Figures 2 and 3 show the average daily streamflow in the Floyd River based on the United States Geological Survey (USGS) gaging stations near Alton and James, Iowa, over the last 10 years. The lowest average daily flow at Alton over the last 10 years was 1.7 cubic feet per second (cfs) on January 26, 2003, and the lowest recorded average daily flow was 0 cfs from August 22 through August 25, 1958. The lowest average daily flow at James over the last 10 years was 29 cubic feet per second (cfs) on March 5, 2003, and the lowest recorded average daily flow at James was 0.9 cfs in February 1959.

The Iowa Administrative Code (IAC) 567 Chapter 52.4 has rules that protect consumptive water users during moderate to severe droughts for rivers with watersheds greater than

Table 1. Minimum annual precipitation for select communities along the Floyd River.

Location	Minimum Inches (Year)
Le Mars	12.99 (1976)
Sheldon	15.41 (1958)
Sioux City	14.33 (1976)
Spencer	14.41 (1958)
Storm Lake	13.90 (1976)

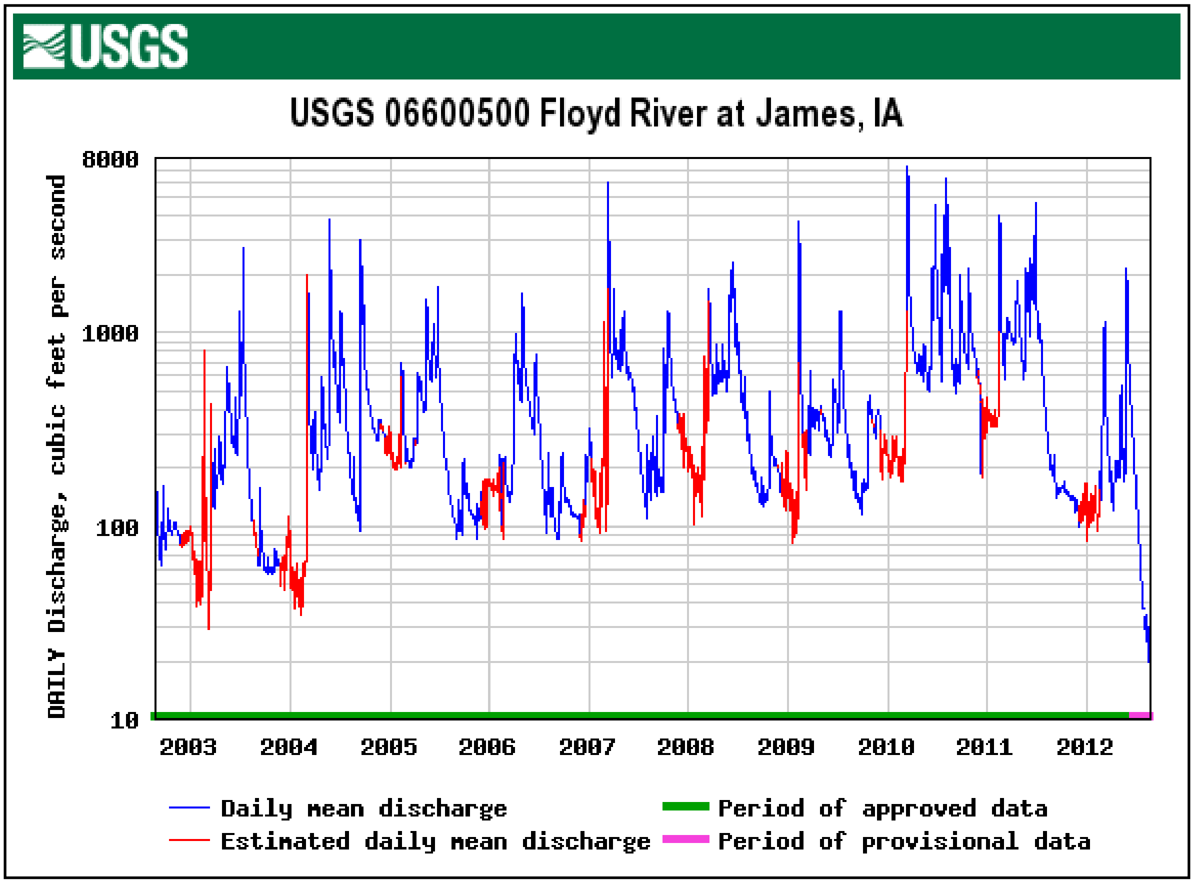

Figure 3. Daily average streamflow at USGS stream gage at James (2002 to 2012).

or equal to 50 square miles (this includes the Floyd River watershed). These rules involve the concept of protective low-flow in streams and rivers. The protective low-flow value is defined as the discharge in cubic feet per second that is equal or exceeds this discharge 84 percent of the time over a certain period of time (generally 10 years or more). When streamflow measurements drop below the protective low-flow value, withdrawals from irrigation wells and surface water intakes within 0.125 miles from the river must cease pumping. Table 2 shows the protected low-flow discharge measurements for the Alton gage and the James gage based on streamflow data from 1982 to 2012 (Eash, 2012). The total number of times the low-flow value has been reached over the last 10 years is also listed. Table 2 also lists the protective low-flow value for the gage at James as listed in IAC 567 Chapter 52.8(3). Table 3 lists the number of times the low-flow value has been reached in any given water year. Note the higher frequency of low streamflow conditions from 2002 through 2006, and the lack of low streamflow conditions from 2007 to 2010. The increase in the low streamflow conditions from 2002 to 2006 can be attributed to lower average rainfall at Sheldon of 28.64 inches per year (Mesonet, Iowa State University, 2012). The average rainfall at Sheldon from 2007 to 2010 was 31.1 inches per year (Mesonet, Iowa State University, 2012).

The 7Q10 value is defined as the lowest average flow for seven consecutive days that is expected to occur once over a 10-year period.

Table 2. Protected low flow and 7Q10 in cubic feet per second (cfs) and the number of times these flows were reached between 2002 and 2012.

Gage Location	Ch 52.8(3) Low Flow(cfs)	USGS low Flow$_1$ (CFS)	Days below Low Flow 2002-2012	USGS 7Q10$_1$ (CFS)	Days below 7Q10 2002-2012
Alton	NA	8.23	299*	0.69	0*
James	22.0	52.30	55*	8.27	0*
$_1$ (Eash, 2012)					
*based on Eash (2012) up to 8/20/2012					
NA - Not Available					

Table 3. The number of days streamflow discharge was below USGS low flow measurements at the USGS Alton and James gages.

	# of days below USGS low flow$_1$	**# of days below USGS low flow$_1$**
Water Year	**Alton Gage (8.23 cfs)**	**James Gage (52.3 cfs)**
2002	78	0
2003	152	24
2004	46	31
2005	3	0
2006	19	0
2007	0	0
2008	0	0
2009	0	0
2010	0	0
2011	0	0
2012*	30	30
* data from January 1 to August 20, 2012		
$_1$ (Eash, 2012)		

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

Well Owner	Buffer Distance from River	Flow Restriction
Gary Schindel	1/4-mile	7Q10
Craig Anderson	1/4-mile	7Q10
Plymouth Energy	1/4-mile	7Q10
Le Mars Golf W-4060	1/4-mile	7Q10
Le Mars Golf W-4061	1/8-mile	Low Flow & 7Q10
Sheldon Golf	1/8-mile	Low Flow & 7Q10

When streamflow measurements drop below the 7Q10 value, withdrawals from irrigation wells within 0.25 miles from the river and irrigation intakes must cease pumping. The 7Q10 discharge measurements for the Alton and James gaging stations based on streamflow data from 1982 to 2012 are 0.69 and 8.27 cfs (Eash, 2012). Streamflow values at both the Alton and James gaging stations were never below the 7Q10 discharge throughout the period from January 1, 2002, through August 20, 2012. The last time the streamflow value at Alton dropped at or below 0.69 cfs was December 22, 1989.

The 0.125 mile low-flow zone and the 0.25 mile 7Q10 zone for the Floyd River and its major tributaries were delineated using ARCMAP. A total of six wells are found within the protected low-flow zone and two wells are found in the 7Q10 zone. The wells found in each of these zones are listed in Table 4.

GEOLOGY

Most of the Floyd River watershed is developed in glacial till classified as Pre-Illinoian age

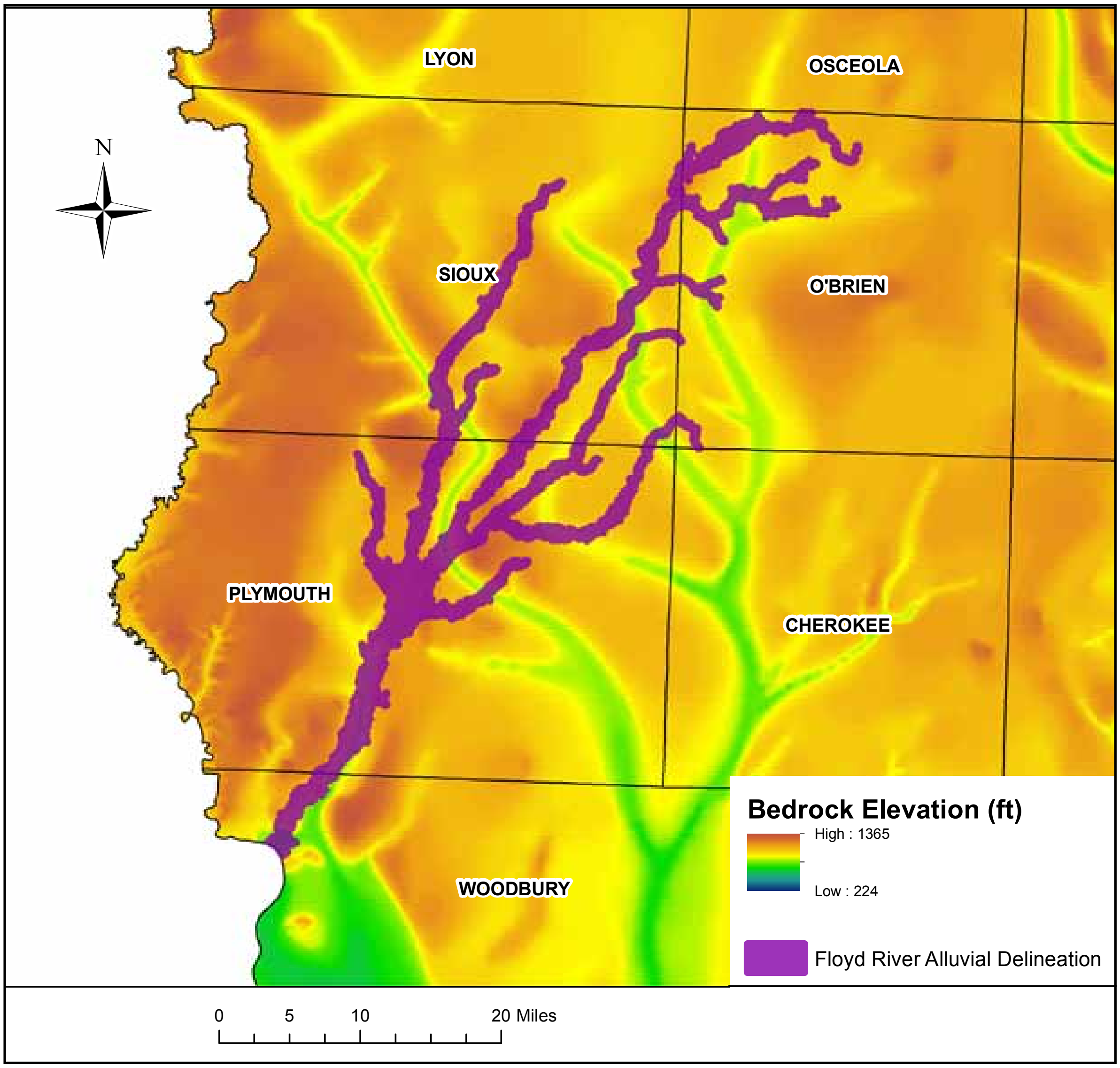

Figure 4. Bedrock elevation map indicating bedrock valleys (shown in green).

(Wahl, Meyers, Karsten, 1982; Hallberg, 1980). Wisconsin-age Sheldon Creek Formation is found in the head-waters of the Floyd River watershed in O'Brien and far northeastern Sioux counties (Quade and Seigley, 2006) The complex glacial deposits range in thickness from zero to more than 400 feet. At least two buried channels have been identified beneath the Floyd River (Figure 4). These buried valleys were eroded into the bedrock or glacial tills between transgressions of glacial ice (Wahl, Meyers, Karsten, 1982). These buried valleys are sometimes filled with sand and gravel and used as local aquifers, but are often filled with poorly sorted clay, silt, sand, gravel, and boulder deposits (Ruhe, 1969). Wisconsin age loess covers most of the watershed except the alluvial valleys.

Glacial meltwater from the Wisconsinan age deposited various thicknesses of sand and gravel

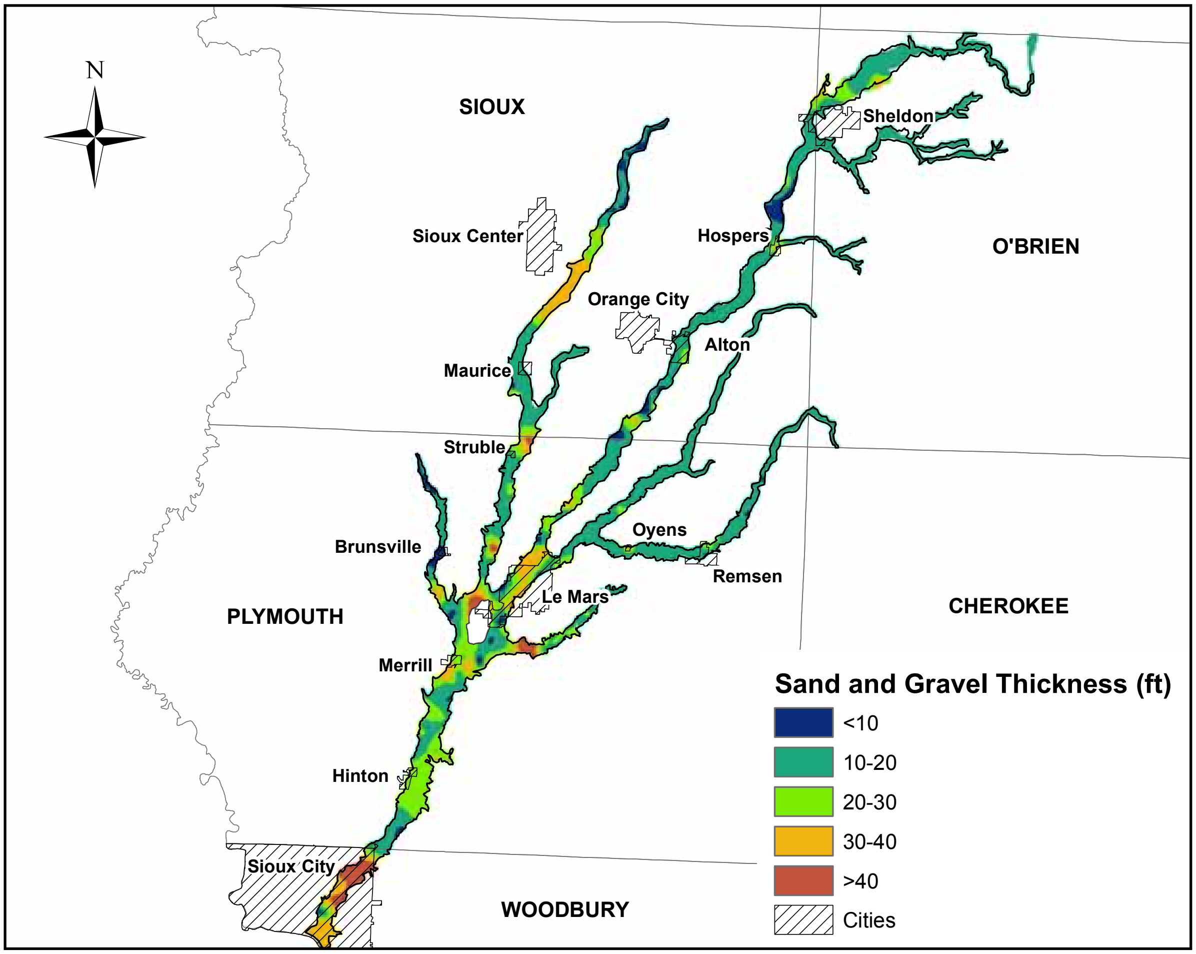

Figure 5. Isopach (thickness) map of the Floyd River aquifer and its tributaries.

along the modern day Floyd River valley and its tributaries. The thickness of alluvial deposits along the Floyd River ranges from under 10 to over 60 feet, but averages approximately 30 feet. The alluvial deposits are not uniform or homogeneous, but include silt, clay, sand, gravel, 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.

Based on existing data from 244 striplogs and driller's logs found in the IDNR GEOSAM database, the distribution of sand and gravel thickness was estimated and is shown on Figure 5. The sand and gravel is overlain by fine-grained sediments consisting of clay, silt, and silty-sand. These finer grained sediments range in thickness from 2 to 20 feet with an average thickness of 10 feet.

Beneath the Quaternary (unconsolidated sediments) deposits is Cretaceous bedrock. The lithology of the bedrock varies from shale to sandstone. The depth of the bedrock surface also varies from less than 50 feet to over 300 feet.

HYDROGEOLOGY

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

It is difficult to measure the groundwater recharge based solely on annual precipitation data. In northwest Iowa much of the groundwater recharge occurs in the early spring and fall. The actual amount of groundwater recharge depends on the intensity and distribution of precipitation events, and when they occur seasonally. Based on previous modeling conducted by the Iowa Geological and Water Survey in Garfield Township in Sioux County, Iowa, three inches of annual groundwater recharge would represent a severe drought (Gannon, 2006). This will be discussed in greater detail in the groundwater modeling section of this report.

Water Storage and Availability

Based on a surface area of the Floyd River aquifer of approximately 3.6 billion square feet, an average saturated aquifer thickness of 15 feet, and a specific yield of 0.15, approximately 60.1 billion gallons of groundwater is stored in the Floyd River aquifer. Obviously, not all of this storage is available for use, and the drawdown is not uniform across the entire aquifer. If we assume that most wells in the Floyd River aquifer have minimum screen lengths of 10 feet (5 feet of saturated sand and gravel is available for drawdown), the total volume of groundwater available from storage would be approximately 20 billion gallons.

A groundwater study conducted by the IDNR in 2006 calibrated an average annual groundwater recharge of six inches within the alluvium along the Rock River in Sioux County (Gannon, 2006). If we assume an average recharge of six inches per year in the Floyd River alluvium, approximately 13.4 billion gallons per year (bgy) of water would recharge the aquifer. If we classify a severe drought as half the annual precipitation (Gannon, 2006), and we assume this corresponds to an estimated recharge of three inches per year (half the normal recharge), approximately 6.7 bgy of precipitation recharge enters the aquifer during a severe drought. Much of this recharge is removed from the aquifer through river baseflow and evapotranspiration. The actual rate of groundwater discharged into the Floyd River and the induced recharge (created by pumping stress) from the Floyd River would need to be quantified using hydrographs, analytical methods, or numerical modeling methods.

Total current water usage for the study area, not including private wells, is 2.21 bgy. The volume of induced recharge provided by the Floyd River is unknown, but would significantly add to the total recharge. The other important consideration is the impact caused by local pumping stress, which is much different than the aquifer average. The application of a calibrated groundwater flow model may help evaluate the local water balance concerns.

Wells

Forty-five active public wells were found within the model area and include seven systems or communities (IDNR GIS Library). The locations of the public wells within the aquifer are shown in Figure 6. Total permitted annual water use and actual water use per system is shown in Table 5.

In addition to the public wells, there are approximately 12 water-use wells that are used for ethanol production, irrigation, and livestock. Annual water-use was obtained from the IDNR water-use database and is listed in

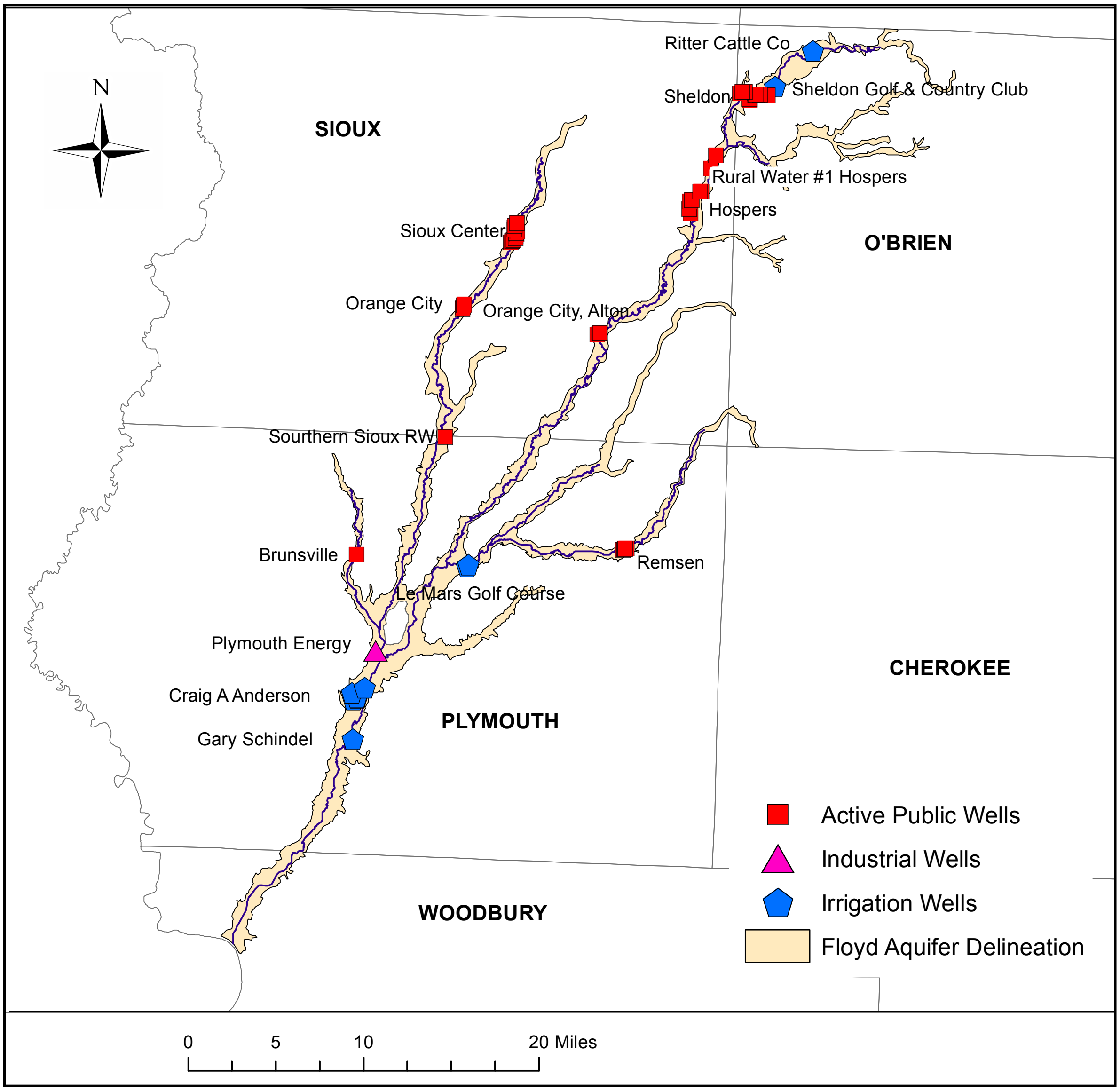

Figure 6. Location of active production wells in the Floyd River aquifer.

Table 5. The actual pumping rate per well is unknown, and the withdrawal per well would be the average based on the total usage divided by the number of known wells.

Aquifer Test Results

Hydraulic properties are used to define and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Ten aquifer pump test results were found in the Floyd River alluvial aquifer and are listed in Table 6. Six pump tests were conducted on wells in the Sioux Center wellfield, three pump tests were conducted in the Sheldon wellfield, and one pump test was

Table 5. Permitted water use and actual water use for public, industrial, and irrigation wells in the Floyd River aquifer.

Owner	Permit Usage (mgy)	Actual Usage (mgy) 2010
Brunsville 1 alluvial well)	7.0	4.3
Remsen (5 alluvial wells)	98.0	78.3
Southern Sioux County RWS (1 alluvial well)	1095.0	562.1
Orange City (7 alluvial wells)	462.0	49.1
Sioux Center (12 alluvial wells)	475.0	375.8
Rural Water System #1 Hospers$_2$ (8 alluvial wells)	1310.0	0.0
Sheldon (11 alluvial wells)	440.0	377.2
Gary Schindel (1 well)	60.2	0.0
Craig Anderson (6 wells)	136.0	0.0
Le Mars City Golf Course (2 wells)	149.9	29.5
Sheldon City Golf Course (1 well)	27.7	6.5
Ritter Cattle (1 well)	15.0	0.0
Plymouth Energy (1 well)	284.0	169
footnotes		
$_2$ *Began operation in 2012*		

Table 6. Aquifer pump test results for wells open in the Floyd River aquifer (Methods based on Freeze and Cherry, 1979).

Wnumber	Well Name	Well Depth (ft)	Thickness (ft)	Date	Method	Transmissivity (ft2/day)	Hydraulic Conductivity (ft/day)	Storativity
41646	Remsen #2	37.00	21	Not Available	Specific Capacity	4660.00	221.90	Not Available
41642	Remsen #1	34.00	16	Not Available	Specific Capacity	2140.00	133.75	Not Available
42551	S. Sioux RWS # S-2	69.00	29	Not Available	Specific Capacity	2330.00	80.34	Not Available
42552	S. Sioux RWS #S-1	70.00	37	Not Available	Specific Capacity	13480.00	364.32	Not Available
41180	Orange City #7	30.00	13	Not Available	Specific Capacity	2200.00	169.20	Not Available
41178	Orange City #8	30.00	13	Not Available	Specific Capacity	1600.00	123.00	Not Available
41179	Orange City #9	30.00	13	Not Available	Specific Capacity	6600.00	507.00	Not Available
41182	Orange City #1	41.00	19	Not Available	Specific Capacity	3100.00	159.79	Not Available
30246	Orange City #5	41.00	33	4/18/1989	Specific Capacity	3170.00	95.48	Not Available
30247	Orange City #4	40.00	33	4/20/1989	Specific Capacity	5000.00	151.52	Not Available
41184	Orange City #3	69.00	36	Not Available	Specific Capacity	5000.00	138.89	Not Available
41183	Orange City #2	69.00	37	Not Available	Specific Capacity	7400.00	200.00	Not Available
40230	Hospers #3	47.00	23	Not Available	Specific Capacity	1870.00	81.30	Not Available
42484	Sioux Center #11	49.00	25	4/12/1990	Pump Test	9072.00	367.29	Not Available
42483	Sioux Center #10	42.00	24	11/16/1989	Pump Test	6480.00	270.00	Not Available
42482	Sioux Center #9	39.00	27	11/9/1989	Pump Test	7344.00	270.00	Not Available
42485	Sioux Center #12	42.00	26	5/7/1992	Pump Test	5760.00	220.69	Not Available
42486	Sioux Center #13	44.00	26	5/6/1992	Pump Test	4032.00	158.12	Not Available
35427	Sioux Center #3R	30.00	15	5/6/1992	Pump Test	1965.00	131.00	Not Available
40237	Hospers RWS#1	32.50	20	6/26/1973	Pump Test	2941.00	147.05	0.02
34994	Sheldon #14	21.00	14	1/11/2002	Specific Capacity	3640.00	260.00	Not Available
34993	Sheldon #13	28.00	18	1/11/2002	Specific Capacity	4500.00	250.00	Not Available
42407	Sheldon #10	39.00	30	11/25/1963	Specific Capacity	5200.00	173.33	Not Available
42409	Sheldon #12	35.00	27	6/20/1979	Specific Capacity	2380.00	88.15	Not Available
42408	Sheldon #11	32.00	22	7/20/1979	Specific Capacity	2250.00	102.27	Not Available
67649	Sheldon #5	29.00	21	5/12/2009	Pump Test	6130.00	292.00	Not Available
42401	Sheldon Well 3-1	20.00	21	6/8/2012	Pump Test	4210.00	175.00	0.08
42401	Sheldon Well 3-2	20.00	21	6/8/2012	Pump Test	2490.00	119.00	0.1

conducted at Rural Water #1 near Hospers.

In addition to the aquifer pump tests, a total of 18 specific capacity tests were made available by various consultants, well drillers, and communities. The distribution of these tests is shown in Figure 7. Table 6 lists the pump test results for each test, the method of analyses, transmissivity values, aquifer thickness, hydraulic conductivity values, and storativity values (aquifer pump test results only). Original

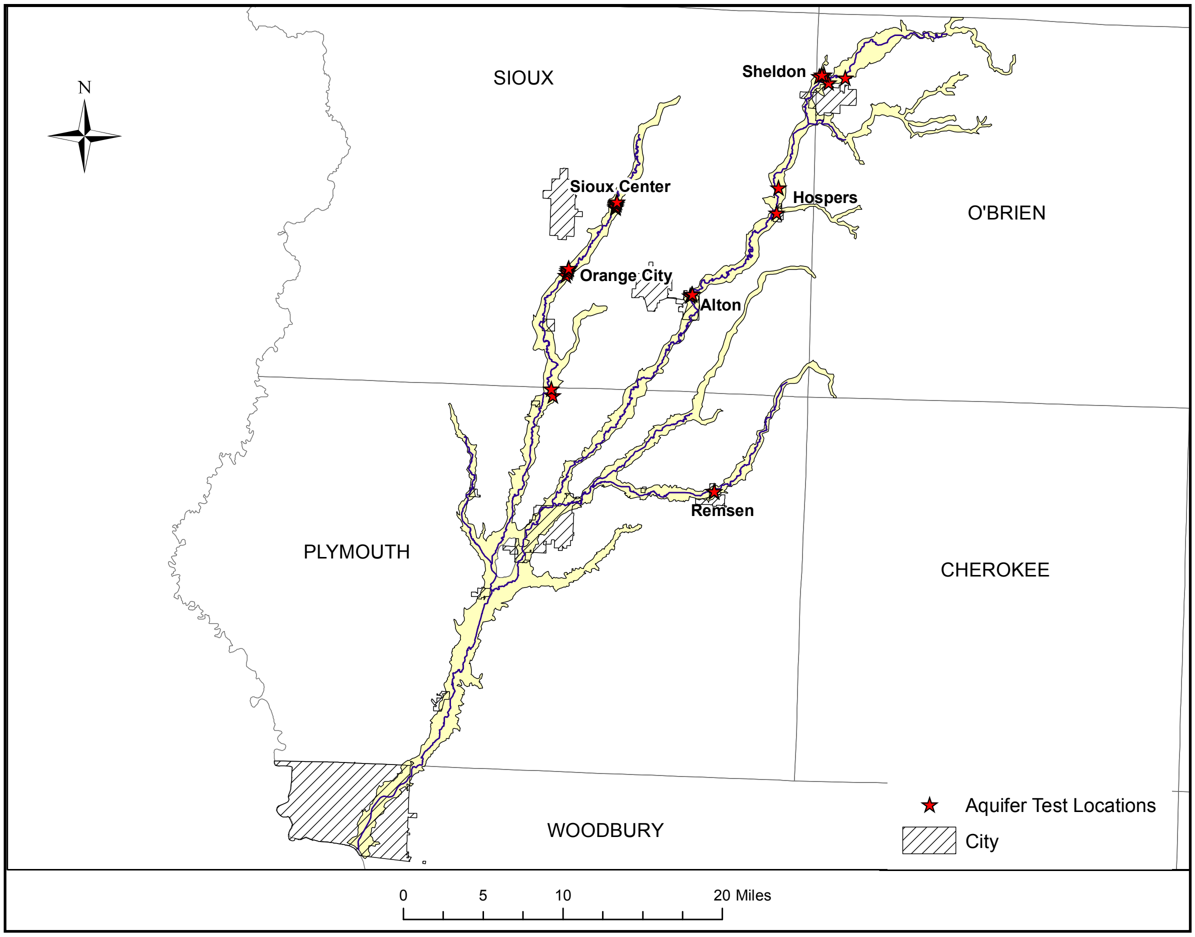

Figure 7. Aquifer test locations in the Floyd River aquifer.

data and graphs of four pump tests are found in Appendix A. The remaining six pump tests were analyzed by IGWS staff, but the graphs and raw data could not be found.

Hydraulic conductivity can be calculated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity was found to range from 80 to 507 feet/day, with an arithmetic mean of 195 feet/day.

Based on aquifer test results, the transmissivity of the Floyd River aquifer was found to range from 1,600 feet^2/day at Orange City Well 8 to 13,480 feet^2/day at Southern Sioux Rural Water System Well S-1. The arithmetic mean transmissivity value is 4,500 feet^2/day. The regional transmissivity distribution is shown on Figure 8, and is based on multiplying the average hydraulic conductivity value of 195 feet/day by the aquifer thickness (Figure 5).

Estimated Well Yield

The potential well yield was estimated by converting the transmissivity value to specific capacity (Table 6), and multiplying this by one-half of the saturated sand and gravel thickness (average value of the available head in the Floyd River aquifer). The potential well yield distribution is shown on Figure 9. Potential well yields greater than 200 gallons per minute (gpm) are found near Sioux Center, Le Mars, south of Hospers, Merrill, and Sioux City.

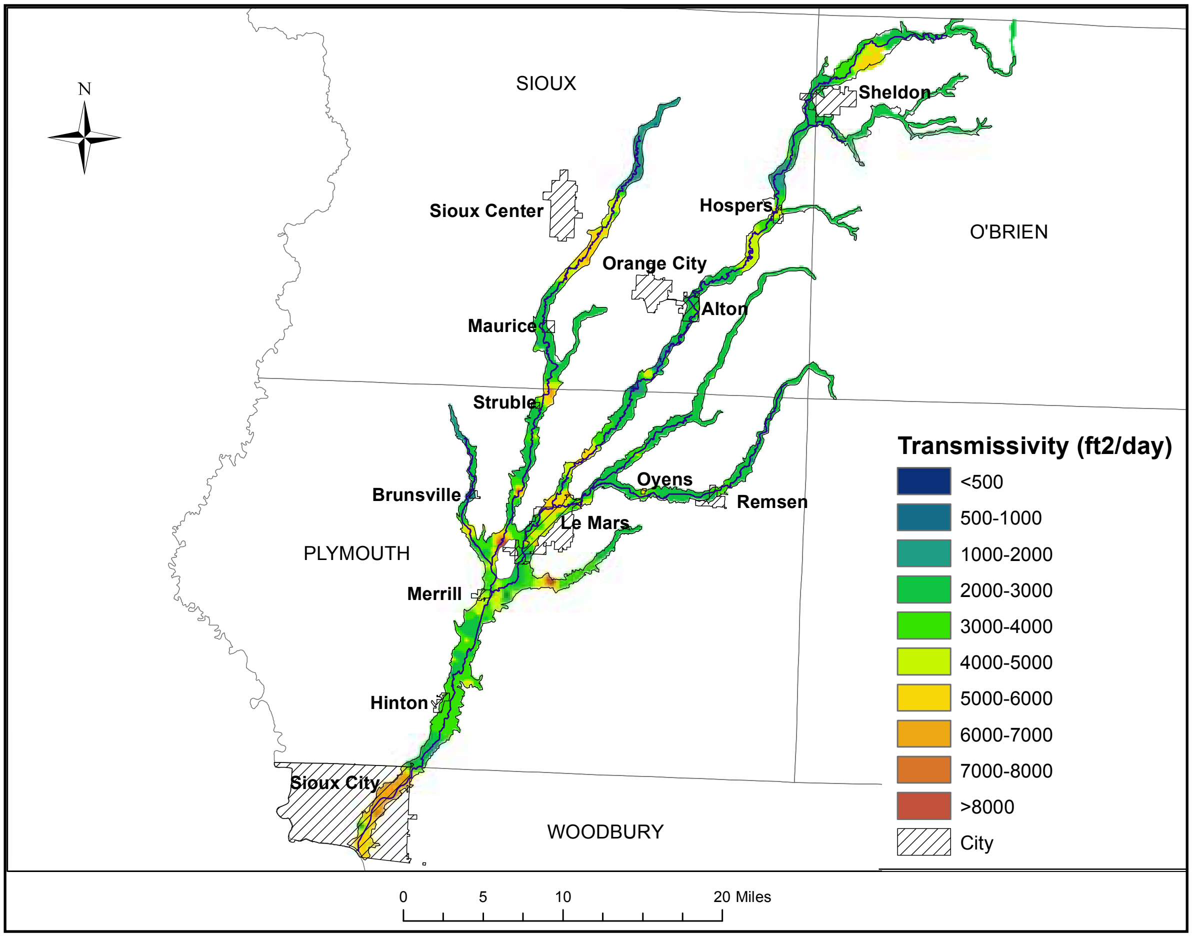

Figure 8. Transmissivity distribution within the Floyd River aquifer based on data found in Table 6.

GROUNDWATER MODELING

With the permission of the City of Sheldon, the model Visual MODFLOW version 2011.1 was used to simulate the groundwater flow in the alluvial aquifer (Figure 10). The model was created to evaluate the water availability during a severe drought. A three-layered model was used for the simulation. The borehole logs were obtained from the IGWS 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 9 feet and is primarily silty clay and silt. The horizontal hydraulic conductivity was assigned a value of 0.1 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 of the horizontal hydraulic conductivity.
- Layer 2 is the sand and gravel aquifer. The horizontal hydraulic conductivity was assigned a value of 150 feet per day based on two pump tests conducted on Sheldon Well 3. 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 0.01 feet/day. The vertical hydraulic conductivity value was assigned a

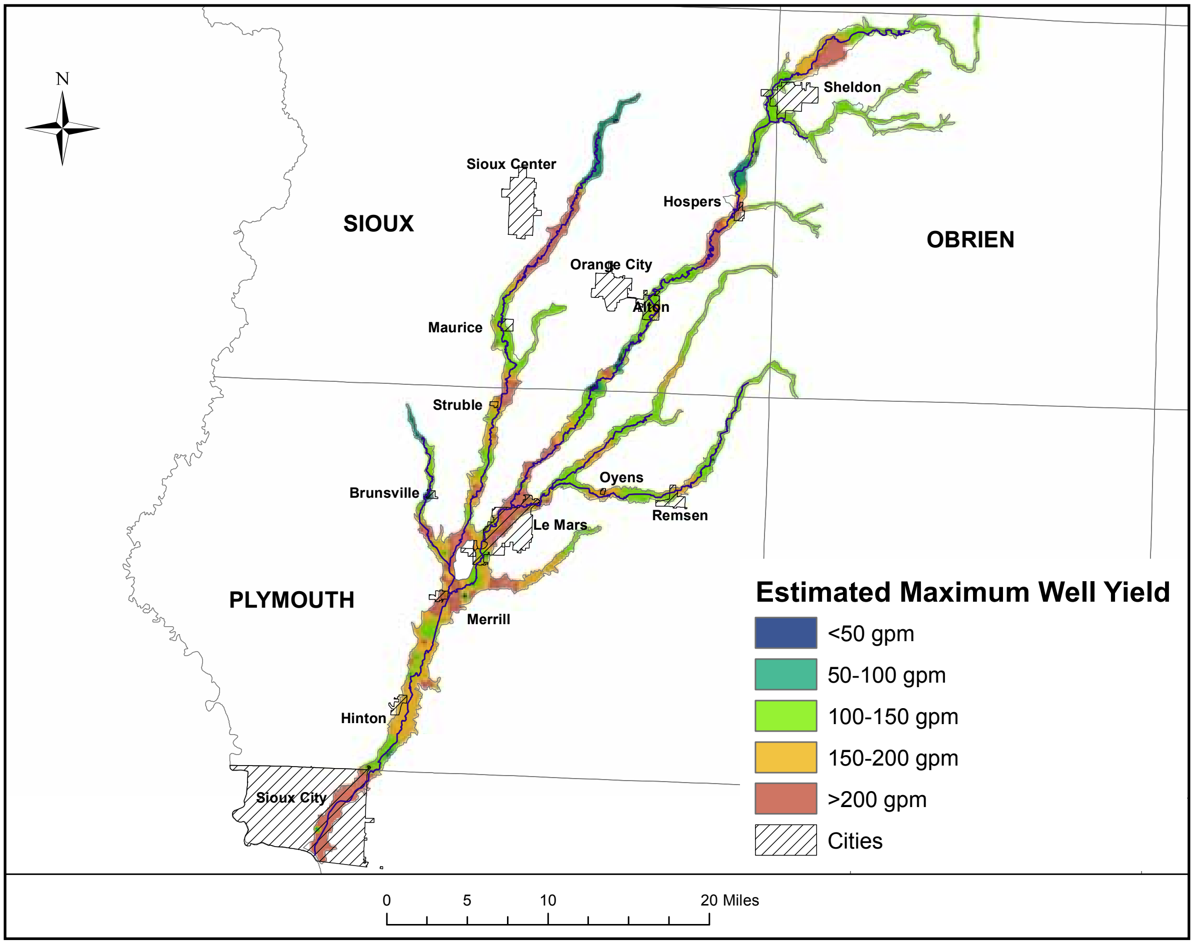

Figure 9. Potential well yield in gallons per minute (gpm) based on Figure 8 and available drawdown.

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 boundary was estimated using NRCS soils data and LiDAR elevation data.
- The Floyd River was represented as a river boundary. The surface water elevations were estimated using LiDAR data. A water level depth of 1 foot was assumed. The vertical conductivity of the streambed was originally estimated at 1/10 the average horizontal conductivity of the alluvial aquifer (15 ft/day). The vertical conductivity value of the streambed was later adjusted based on the results of an induced recharge field test. This will be discussed in the calibration section of the report. The model represented baseflow (summertime) conditions, and the stage was kept the same throughout the simulated time period.
- General head boundaries were used in the numerous sand and gravel pits in the area. These general head values were obtained from LiDAR elevation data.
- City of Sheldon wells were included in the model simulation. Annual usage was obtained from the IDNR water use database for year 2011, and the daily pumping

Table 7. Observed versus simulated head elevations for steady-state non-pumping conditions.

Well Owner	Observed Head Elev. (ft)	Simulated Head Elev. (ft)
Ritter Cattle	1431.064	1430.3752
Sheldon Golf Course	1394	1395.7384
Sheldon Well 13	1387.44	1386.4232
Sheldon Well 8	1383.668	1385.308
Sheldon Well 6	1382.52	1383.8976
Sheldon Well 14	1380.88	1382.028
Sheldon Well 12	1376.452	1374.32
Sheldon Well 10	1371.04	1373.828

rate per well was held constant at 94,000 gpd.

- Sheldon Golf Course and Ritter Cattle Company also have water use permits. The pumping rates were obtained from the IDNR water use database. The pumping rate for the Ritter Cattle well was held constant at 17,000 gpd, and the Sheldon Golf course well was pumped at 52,000 gpd during the growing season.
- An average specific yield value of 0.1 was used based on the pump test results from Sheldon Well 3.
- Average annual recharge was calibrated to be seven inches/year. Drought conditions were simulated using a recharge value of three inches, respectively.
- The total number of rows and columns were 246 by 303. The grid size varied from 3 feet to 164 feet.

Calibration Results

The model was initially run for a 10-year time period to simulate non-pumping conditions. The model was calibrated using static groundwater elevations found in GEOSAM and provided by the City of Sheldon. Table 7 compares simulated values to observed water levels, and Figure 10 shows the simulated water table map. The residual mean error was +0.6 feet (2.85%) for the eight observation wells.

Local scale calibration was performed using pump test results from Sheldon Well 3. Hydraulic conductivity and specific yield values were adjusted to match the simulated water levels to the observed values. The simulated versus observed drawdowns for observation wells 3-1 and 3-2 were 0.6 versus 0.64 feet, and 1 versus 1.05 feet.

Transient Simulations

Following the calibration of the model, several simulations were conducted using various pumping rates for the City of Sheldon wells, Sheldon Golf Course well, and the Ritter Cattle Company well. The pumping rates for the golf course well and the Ritter Cattle Company well were based on the maximum annual usage as found in the IDNR water use database. The following inputs were used in the model:

Simulation 1 Normal Precipitation

- Recharge seven inches per year (normal recharge)
- Sheldon wellfield usage based on 94,000 gpd per well
- Sheldon Golf Course usage – 54,000 gpd for 120 days
- Ritter Cattle Company usage – 17,000 gpd

Simulation 2
Severe Drought Conditions

- Recharge three inches per year
- Sheldon wellfield usage based on 141,000 gpd per well (50% increase)
- Sheldon Golf Course usage - 108,000 gpd for 120 days (100% increase)
- Ritter Cattle Company usage – 34,000 gpd (100% increase)

Figure 10. Simulated Water Table Elevation under steady-state (non-pumping) conditions for the Sheldon local scale model.

Results

Simulation 1 Normal Precipitation

The first simulation was conducted using an average rainfall of 28 inches per year and an average recharge of 7 inches per year. The maximum total simulated summer drawdown near Sheldon city wells under normal precipitation ranged from 4 to 5 feet (Figure 11).

Based on mass balance output from Visual MODFLOW, the percentage of water production supplied by the Floyd River (induced recharge) was estimated to be 54 percent. The other 46 percent of the water production was supplied by precipitation recharge.

Simulation 2
Severe Drought Conditions

The second simulation was conducted using an average rainfall of 15 inches per year and an average recharge of 3 inches per year. The maximum total simulated summer drawdown near the Sheldon city wells ranged from 9 to 10 feet (Figure 12). This is an increase of 5 feet of drawdown from normal (non-drought) conditions.

Based on mass balance output from Visual MODFLOW, the percentage of water production supplied by the Floyd River (induced recharge) increased to 60.3 percent. Approximately 31.9 percent of the

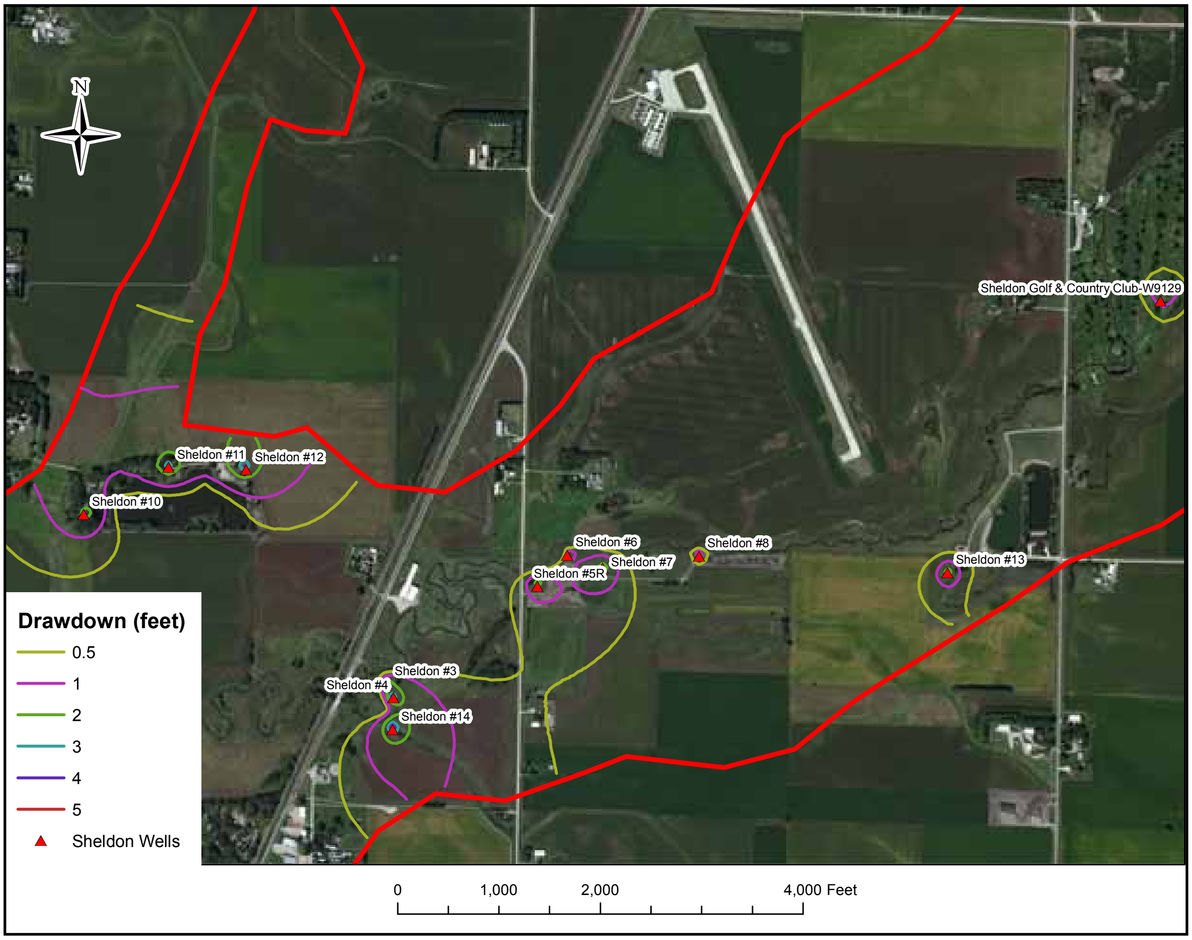

Figure 11. Simulated drawdown in feet under normal precipitation conditions for the Sheldon local scale model.

water production is supplied by precipitation recharge, and 7.8 percent is supplied by the induced recharge of several sand and gravel pits. The increase in induced recharge prevents much higher drawdowns in the City of Sheldon wells. Without recharge from the Floyd River and nearby sand and gravel pits, a severe drought would significantly reduce water production in the area wells.

Induced recharge from the Floyd River could be limited during a severe drought. If streamflow would happen to drop below the value of induced recharge (critical flow value), the city wells would not be able to maintain necessary pumping rates. The critical flow value based on the percentage of induced recharge is 1.58 cfs. Based on historical streamflow values from the USGS Alton stream gage, below critical streamflow values occurred in 1958, 1989, and 2012. There may have been additional critical streamflows that occurred in the upper reaches of the Floyd River (in addition to 1958, 1989, and 2012), but there are no historical streamflow values from the Floyd River at Sheldon. The City of Sheldon does have the option of supplementing their water supply with a well open in the Dakota aquifer (Well 9), which has a pumping capacity of approximately 600 gpm. Well 9 has been in use through most of the summer of 2012.

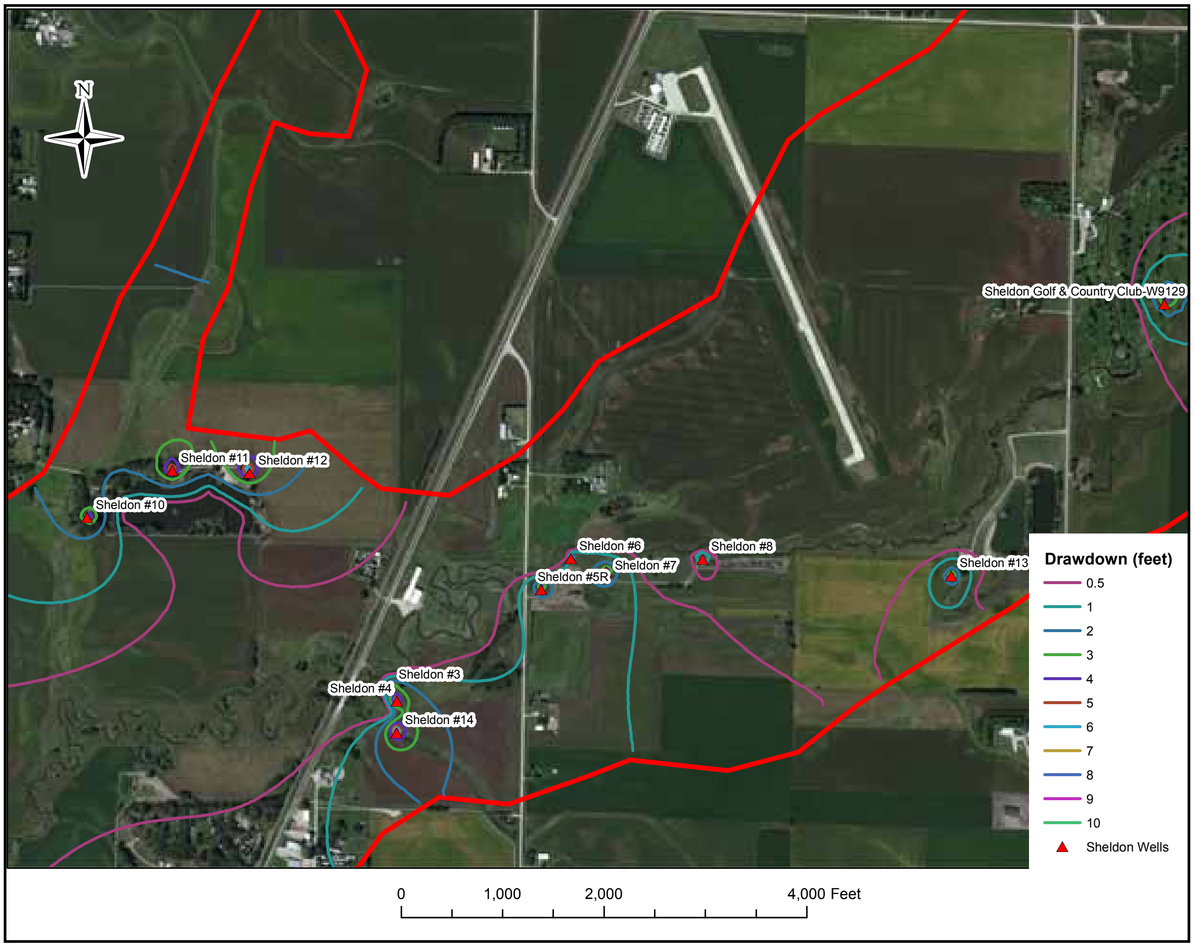

Figure 12. Simulated drawdown in feet under severe drought conditions for the Sheldon local scale model.

CONCLUSIONS

Based on the geologic and hydrogeologic data available in this study area, the following conclusions can be made:

- Based on public and water use wells screened in the Floyd River alluvial aquifer, approximately 2.21 billion gallons of water is withdrawn from the aquifer each year.
- Water users include five cities, two rural water systems, one ethanol plant, two golf courses, one livestock facility, and two irrigation permits.
- Two additional aquifer pump tests were conducted in the aquifer using City of Sheldon Well 3 and two observation wells. These pump tests were used to calculate local aquifer parameters, calibrate the Sheldon groundwater flow model, and to estimate the percentage of induced recharge from the Floyd River.
- Transmissivity values in the Floyd River aquifer estimated from pump tests and specific capacity tests ranged from approximately 1,600 ft^2/day to 13,480 ft^2/day.
- A groundwater flow model was constructed for the Floyd River aquifer near the City of Sheldon to evaluate the groundwater availability during a severe drought.

- Induced recharge near the City of Sheldon ranges from 54 percent during normal precipitation years to 68 percent during severe drought years.
- The critical streamflow value in the Floyd River necessary to provide induced recharge to the City of Sheldon alluvial wells was calculated to be 1.58 cfs. If streamflow in the Floyd River drops near or below the critical flow value, the city will need to supplement its water supply with their Dakota well (Well 9).

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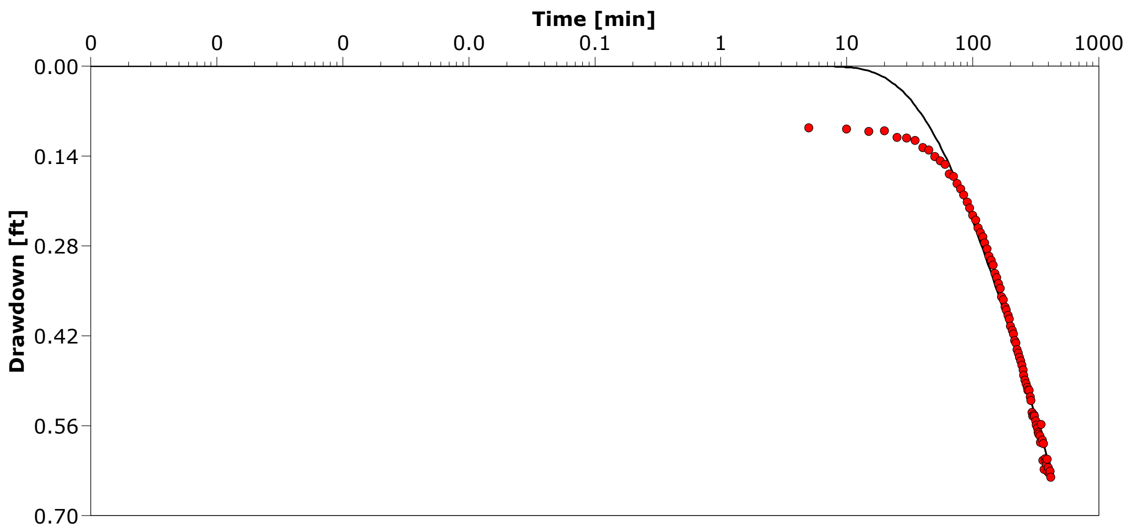
APPENDIX A

AQUIFER PUMP TESTS, DATA AND GRAPHS

1. City of Sheldon Well 3 observation well OB 3-1

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test Analysis Report
	Project: Sheldon Well3
	Number:
	Client:

Location: Sheldon, Iowa	Pumping Test: Sheldon Well 3	Pumping Well: Well 3
Test Conducted by: Mike Gannon		Test Date: 6/8/2012
Analysis Performed by:	New analysis 2	Analysis Date: 6/11/2012
Aquifer Thickness: 21.00 ft	Discharge Rate: 80 [U.S. gal/min]	



Calculation after Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 3-1	3.69×10^{3}	1.75×10^{2}	7.61×10^{-2}	72.0	

1. City of Sheldon Well 3 observation well OB 3-1

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test - Water Level Data	Page 1 of 2
	Project: Sheldon Well3	
	Number:	
	Client:	

Location: Sheldon, Iowa	Pumping Test: Sheldon Well 3	Pumping Well: Well 3
Test Conducted by: Mike Gannon	Test Date: 6/8/2012	Discharge Rate: 80 [U.S. gal/min]
Observation Well: OB 3-1	Static Water Level [ft]: 6.10	Radial Distance to PW [ft]: 72

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	6.197	0.097
2	5	6.196	0.096
3	10	6.198	0.098
4	15	6.202	0.102
5	20	6.201	0.101
6	25	6.211	0.111
7	30	6.212	0.112
8	35	6.216	0.116
9	40	6.227	0.127
10	45	6.231	0.131
11	50	6.241	0.141
12	55	6.247	0.147
13	60	6.253	0.153
14	65	6.268	0.168
15	70	6.272	0.172
16	75	6.283	0.183
17	80	6.291	0.191
18	85	6.301	0.201
19	90	6.312	0.212
20	95	6.321	0.221
21	100	6.332	0.232
22	105	6.34	0.24
23	110	6.352	0.252
24	115	6.359	0.259
25	120	6.366	0.266
26	125	6.375	0.275
27	130	6.385	0.285
28	135	6.396	0.296
29	140	6.402	0.302
30	145	6.41	0.31
31	150	6.423	0.323
32	155	6.429	0.329
33	160	6.439	0.339
34	165	6.446	0.346
35	170	6.459	0.359
36	175	6.464	0.364
37	180	6.475	0.375
38	185	6.48	0.38
39	190	6.488	0.388
40	195	6.494	0.394
41	200	6.505	0.405
42	205	6.512	0.412
43	210	6.517	0.417
44	215	6.527	0.427
45	220	6.531	0.431
46	225	6.541	0.441
47	230	6.547	0.447
48	235	6.554	0.454
49	240	6.559	0.459
50	245	6.566	0.466
51	250	6.573	0.473

1. City of Sheldon Well 3 observation well OB 3-1

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

Pumping Test - Water Level Data Page 2 of 2

Project: Sheldon Well3

Number:

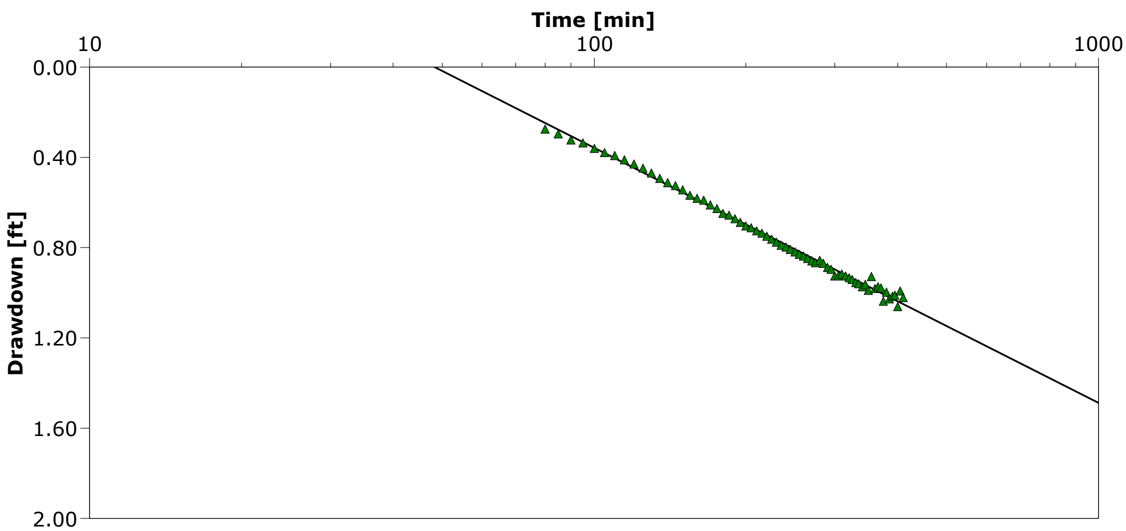
Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
52	255	6.347	0.847
53	260	6.356	0.856
54	265	6.366	0.866
55	270	6.377	0.877
56	275	6.385	0.885
57	280	6.373	0.873
58	285	6.387	0.887
59	290	6.407	0.907
60	295	6.417	0.917
61	300	6.447	0.947
62	305	6.446	0.946
63	310	6.438	0.938
64	315	6.448	0.948
65	320	6.454	0.954
66	325	6.463	0.963
67	330	6.477	0.977
68	335	6.483	0.983
69	340	6.496	0.996
70	345	6.486	0.986
71	350	6.514	1.014
72	355	6.45	0.95
73	360	6.506	1.006
74	365	6.498	0.998
75	370	6.503	1.003
76	375	6.565	1.065
77	380	6.523	1.023
78	385	6.554	1.054
79	390	6.542	1.042
80	395	6.536	1.036
81	400	6.59	1.09
82	405	6.518	1.018
83	410	6.548	1.048

2. City of Sheldon Well 3 observation well OB 3-2

Iowa Department of Natural Resources **Iowa Geological and Water Survey** **Iowa City, Iowa**		**Pumping Test Analysis Report**
		Project: Sheldon Well3
		Number:
		Client:

Location: Sheldon, Iowa	Pumping Test: Sheldon Well 3	Pumping Well: Well 3
Test Conducted by: Mike Gannon		Test Date: 6/8/2012
Analysis Performed by:	New analysis 4	Analysis Date: 6/11/2012
Aquifer Thickness: 21.00 ft	Discharge Rate: 80 [U.S. gal/min]	



Calculation after Cooper & Jacob

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 3-2	2.49×10^{3}	1.19×10^{2}	1.07×10^{-1}	42.0	

2. City of Sheldon Well 3 observation well OB 3-2

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test - Water Level Data	Page 1 of 2
	Project: Sheldon Well3	
	Number:	
	Client:	

Location: Sheldon, Iowa	Pumping Test: Sheldon Well 3	Pumping Well: Well 3
Test Conducted by: Mike Gannon	Test Date: 6/8/2012	Discharge Rate: 80 [U.S. gal/min]
Observation Well: OB 3-2	Static Water Level [ft]: 5.50	Radial Distance to PW [ft]: 42

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	5.563	0.063
2	5	5.561	0.061
3	10	5.56	0.06
4	15	5.561	0.061
5	20	5.573	0.073
6	25	5.578	0.078
7	30	5.593	0.093
8	35	5.604	0.104
9	40	5.62	0.12
10	45	5.639	0.139
11	50	5.659	0.159
12	55	5.68	0.18
13	60	5.694	0.194
14	65	5.721	0.221
15	70	5.732	0.232
16	75	5.763	0.263
17	80	5.776	0.276
18	85	5.797	0.297
19	90	5.824	0.324
20	95	5.839	0.339
21	100	5.862	0.362
22	105	5.881	0.381
23	110	5.896	0.396
24	115	5.915	0.415
25	120	5.933	0.433
26	125	5.954	0.454
27	130	5.975	0.475
28	135	5.999	0.499
29	140	6.019	0.519
30	145	6.033	0.533
31	150	6.051	0.551
32	155	6.075	0.575
33	160	6.09	0.59
34	165	6.097	0.597
35	170	6.119	0.619
36	175	6.136	0.636
37	180	6.159	0.659
38	185	6.167	0.667
39	190	6.182	0.682
40	195	6.199	0.699
41	200	6.216	0.716
42	205	6.225	0.725
43	210	6.239	0.739
44	215	6.25	0.75
45	220	6.264	0.764
46	225	6.278	0.778
47	230	6.292	0.792
48	235	6.304	0.804
49	240	6.312	0.812
50	245	6.325	0.825
51	250	6.335	0.835

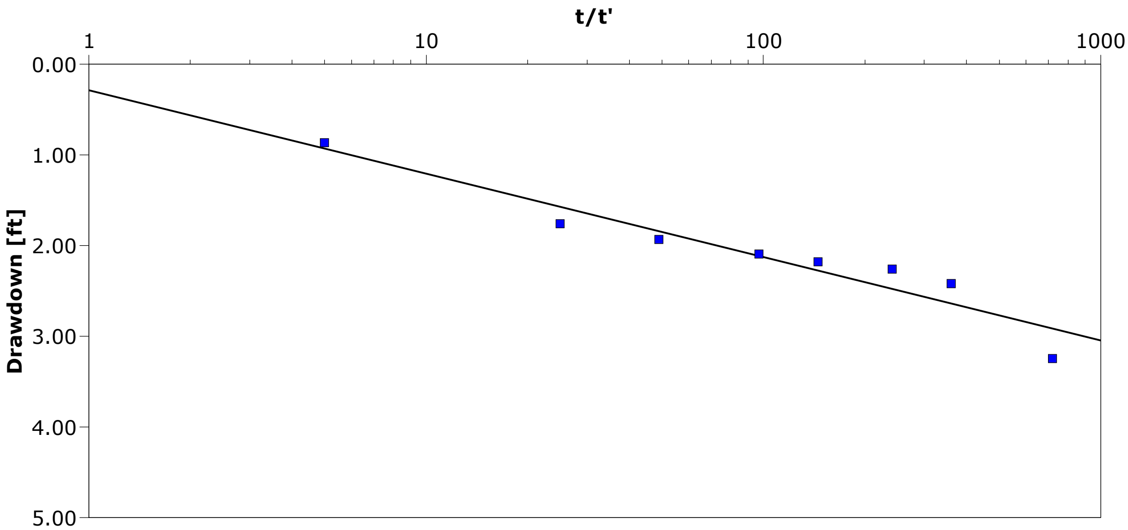
2. City of Sheldon Well 3 observation well OB 3-2

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	Pumping Test - Water Level Data	Page 2 of 2
	Project: Sheldon Well3	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
52	255	6.582	0.482
53	260	6.589	0.489
54	265	6.595	0.495
55	270	6.60	0.50
56	275	6.605	0.505
57	280	6.605	0.505
58	285	6.615	0.515
59	290	6.621	0.521
60	295	6.639	0.539
61	300	6.645	0.545
62	305	6.643	0.543
63	310	6.645	0.545
64	315	6.653	0.553
65	320	6.659	0.559
66	325	6.664	0.564
67	330	6.67	0.57
68	335	6.673	0.573
69	340	6.676	0.576
70	345	6.686	0.586
71	350	6.658	0.558
72	355	6.682	0.582
73	360	6.714	0.614
74	365	6.688	0.588
75	370	6.728	0.628
76	375	6.711	0.611
77	380	6.715	0.615
78	385	6.721	0.621
79	390	6.712	0.612
80	395	6.732	0.632
81	400	6.725	0.625
82	405	6.735	0.635
83	410	6.731	0.631
84	415	6.74	0.64

3. City of Sheldon Well 5 recovery test

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test Analysis Report**	
	Project: Sheldon Well 5 Recovery Test	
	Number: W-67649	
	Client:	
Location: Sheldon, Iowa	Pumping Test: Sheldon Well 5 Recovery	Pumping Well: Well 1
Test Conducted by:		Test Date: 5/12/2009
Analysis Performed by:	New analysis 4	Analysis Date: 1/10/2012
Aquifer Thickness: 13.00 ft	Discharge: variable, average rate 99.2 [U.S. gal/min]	



Calculation after Theis & Jacob

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	3.80×10^3	2.92×10^2	0.5	

3. City of Sheldon Well 5 recovery test

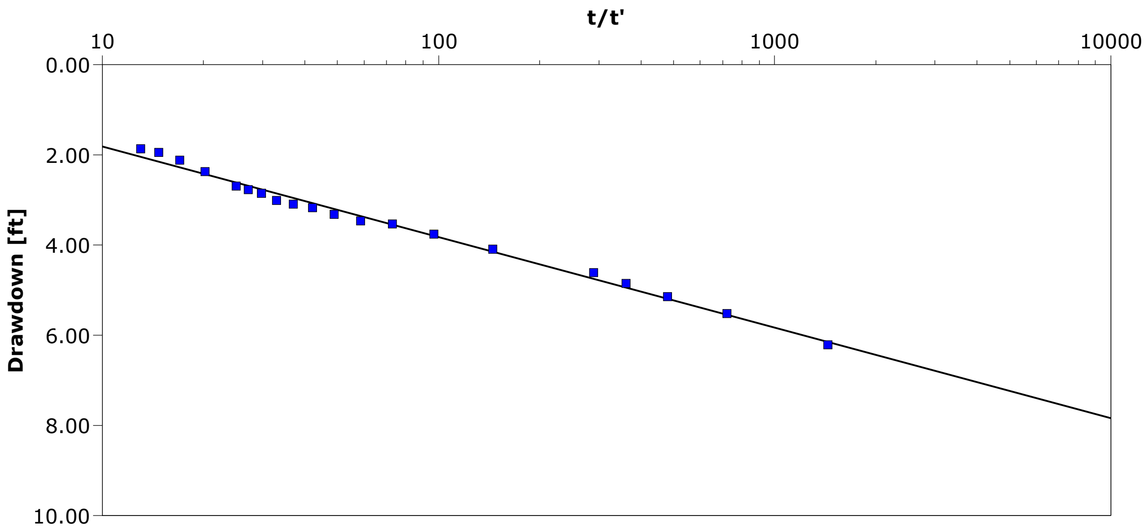
Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data** Page 1 of 1 Project: Sheldon Well 5 Recovery Test Number: W-67649 Client:

Location: Sheldon, Iowa	Pumping Test: Sheldon Well 5 Recovery	Pumping Well: Well 1
Test Conducted by:	Test Date: 5/12/2009	Discharge: variable, average rate 99.2 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 11.80	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1442	15.60	3.80
2	1444	14.50	2.70
3	1446	14.30	2.50
4	1450	14.20	2.40
5	1455	14.10	2.30
6	1470	13.90	2.10
7	1500	13.70	1.90
8	1800	12.70	0.90

4. City of Sioux Center Well 3R Recovery Test

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa		Pumping Test Analysis Report Project: Sioux Center Well 3R Recovery Test Number: W-35427 Client:
Location: Sioux Center, Iowa	Pumping Test: Sioux Center Well 3R Recovery Test	Pumping Well: Well 1
Test Conducted by:		Test Date: 4/8/1994
Analysis Performed by:	New analysis 2	Analysis Date: 1/10/2012
Aquifer Thickness: 15.00 ft	Discharge: variable, average rate 112.21 [U.S. gal/min]	



Calculation after Theis & Jacob

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Well 1	1.97×10^3	1.31×10^2	1.0	

4. City of Sioux Center Well 3R Recovery Test

Iowa Department of Natural Resources Iowa Geological and Water Survey Iowa City, Iowa	**Pumping Test - Water Level Data**	Page 1 of 1
	Project: Sioux Center Well 3R Recovery Test	
	Number: W-35427	
	Client:	

Location: Sioux Center, Iowa	Pumping Test: Sioux Center Well 3R Recovery Test	Pumping Well: Well 1
Test Conducted by:	Test Date: 4/8/1994	Discharge: variable, average rate 112.21 [U.S. gal/min]
Observation Well: Well 1	Static Water Level [ft]: 8.50	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	1441	17.30	8.80
2	1442	15.80	7.30
3	1443	15.10	6.60
4	1444	14.60	6.10
5	1445	14.20	5.70
6	1450	13.40	4.90
7	1455	12.90	4.40
8	1460	12.60	4.10
9	1465	12.50	4.00
10	1470	12.30	3.80
11	1475	12.10	3.60
12	1480	12.00	3.50
13	1485	11.90	3.40
14	1490	11.70	3.20
15	1495	11.60	3.10
16	1500	11.50	3.00
17	1515	11.10	2.60
18	1530	10.80	2.30
19	1545	10.60	2.10
20	1560	10.50	2.00

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