Aquifer Characterization and Drought Assessment Ocheyedan River Alluvial Aquifer

Iowa Geological Survey
Water Resources Investigation Report 10

IOWA GEOLOGICAL SURVEY

Aquifer Characterization and Drought Assessment Ocheyedan River Alluvial Aquifer

Prepared by

J. Michael Gannon
and
Jason A. Vogelgesang

Iowa Geological Survey
Water Resources Investigation Report 10

IOWA GEOLOGICAL SURVEY

TABLE OF CONTENTS

EXECUTIVE SUMMARY. v

ACKNOWLEDGMENTS. vi

INTRODUCTION AND HYDROLOGIC SETTING. 1

Climate. 1

Surface Water. 2

GEOLOGY. 4

Aquifer Thickness. 5

HYDROGEOLOGY. 6

Water Storage and Availability. 8

Wells. 9

Pump Test Results. 10

Estimated Well Yield. 12

CONCLUSIONS. 13

REFERENCES. 16

APPENDIX A. 17

LIST OF FIGURES

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

Figure 2. Daily average streamflow at USGS streamgage 06605000 on the Ocheyedan River near Spencer (2004 to 2014) 2

Figure 3. Daily average streamflow at USGS Streamgage 06604440 on the Little Sioux River near Spencer (2004 to 2014) 3

Figure 4. Daily average streamflow at USGS Streamgage 06605850 on the Little Sioux River at Linn Grove (2004 to 2014) 4

Figure 5. Bedrock elevation map indicating bedrock valleys 5

Figure 6. Isopach (thickness) map of the Ocheyedan River aquifer and its tributaries 6

Figure 7. Distribution of groundwater level data in study area 7

Figure 8. Observed groundwater elevation contours for Osceola County Rural Water District and surrounding area 9

Figure 9. Observed groundwater elevation contours for Iowa Lakes Regional Water and surrounding area 10

Figure 10. Locations of known public wells and water-use permit wells in the Ocheyedan River aquifer 11

Figure 11. Aquifer test locations in the Ocheyedan River aquifer and hydraulic conductivity distribution based on data found in Appendix A 13

Figure 12. Transmissivity distribution within the Ocheyedan River aquifer based on data found in Appendix A 14

Figure 13. Potential well yield in gallons per minute (gpm) based on the transmissivity distribution, Figure 6, and one-half the available drawdown 15

LIST OF TABLES

Table 1. Minimum annual precipitation for select communities in Osceola, O'Brien, Clay, and Dickenson counties 2

Table 2. Groundwater elevation data for the fall of 2013 and the spring of 2014 8

Table 3. Surface elevation data for May 27, 2014 8

Table 4. Permitted water use and actual water use for public, industrial, and irrigation wells in the Ocheyedan River aquifer . . . 12

EXECUTIVE SUMMARY

The Iowa Geological Survey completed a hydrogeologic evaluation of the water resources in the Ocheyedan River aquifer in Osceola, O'Brien, Clay and Dickinson counties in Iowa. The work was funded under the Water Plan Program of the Iowa Department of Natural Resources. The primary objective of this study was to evaluate the aquifer for future water supply development. Future work will include a calibrated groundwater flow model of the Osceola County Rural Water District (OCRWD) northern wellfield, which will be used to predict future well interference, available drawdown, optimal maximum pumping rates, and quantifying induced (river) recharge.

Based on the groundwater elevation data, surface water flows toward OCRWD and Iowa Lakes Regional Water (ILRW) wellfields. Without this induced recharge, high capacity production wells and irrigation wells would not be able to sustain their pumping rates during prolonged droughts.

Groundwater recharge sources are precipitation, induced recharge from surface water, and seepage from glacial drift and terraces along the valley wall. A groundwater study conducted in 2011 calibrated an average annual groundwater recharge of approximately 8 inches within the alluvium near the ILRW wellfield in Clay County (Gannon, 2011). At an average groundwater recharge rate of 8 inches per year, approximately 13 billion gallons per year (bgy) of precipitation 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 4 inches per year (half the average recharge), approximately 6.5 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 available for use would need to be quantified using hydrographs, analytical methods, and numerical modeling.

Total current water usage for the study area, not including private wells, is estimated at 3.1 billion gallons per year (8.6 million gallons per day), with a peak usage of 16.33 million gallons per day. Well interference likely occurs between the irrigation wells and the OCRWD and ILRW wells during peak summer-time usage. The application of a calibrated groundwater flow model will help evaluate the magnitude and significance of this well interference.

The distribution of potential well yield was estimated by converting the transmissivity value to specific capacity, and multiplying this by one-half the saturated sand and gravel thickness. Potential well yields greater than 400 gallons per minute (gpm) are found near Spencer, ILRW, and OCRWD. There appears to be areas between the City of Everly and south of OCRWD, and near the upper Little Sioux River that have potential well yields less than 100 gpm.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of the individuals who assisted in the production of this report. Matthew Streeter reviewed driller's logs and assisted with the Quaternary interpretation. Editorial review was provided by Jessica Bristow. The report layout was done by Jessica Bristow.

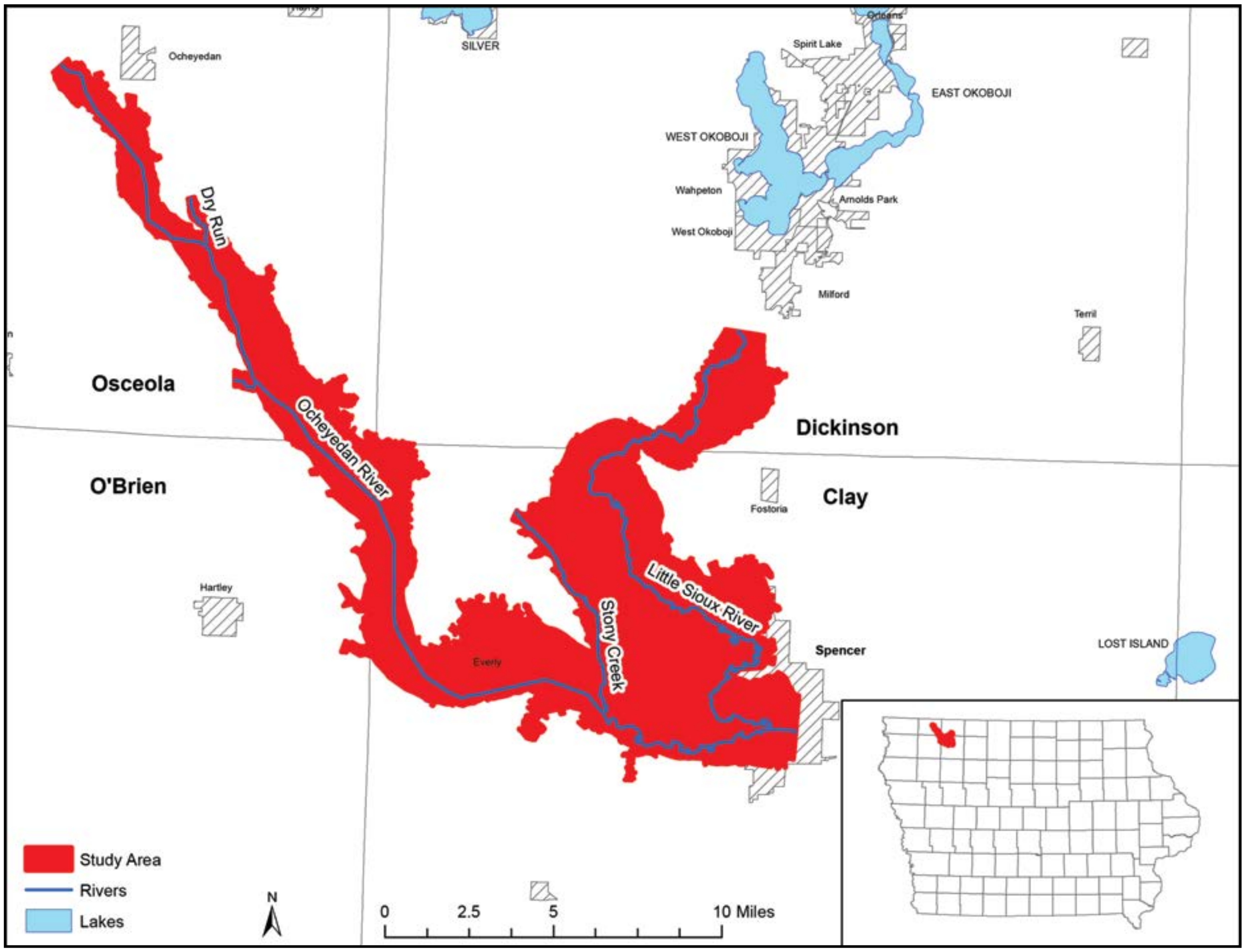


Figure 1. Extent of the Ocheyedan River aquifer study area.

INTRODUCTION AND HYDROLOGIC SETTING

The objective of this report is to evaluate groundwater resources of the alluvial aquifer located adjacent to the Ocheyedan River (Figure 1). The evaluation summarizes geologic and hydrologic information and can be referenced when considering future development or well field expansion. In addition to the main branch of the Ocheyedan River, the study area also includes Dry Run Creek, Stony Creek, and a portion of the Upper Little Sioux River. The Ocheyedan River and its tributaries are found in Clay, Dickinson, O'Brien, and Osceola counties. For the purposes of this summary report the alluvial aquifer will be referred to as the Ocheyedan River aquifer.

Climate

The climate of northwest Iowa is classified as sub-humid. Based on data compiled by Iowa State University

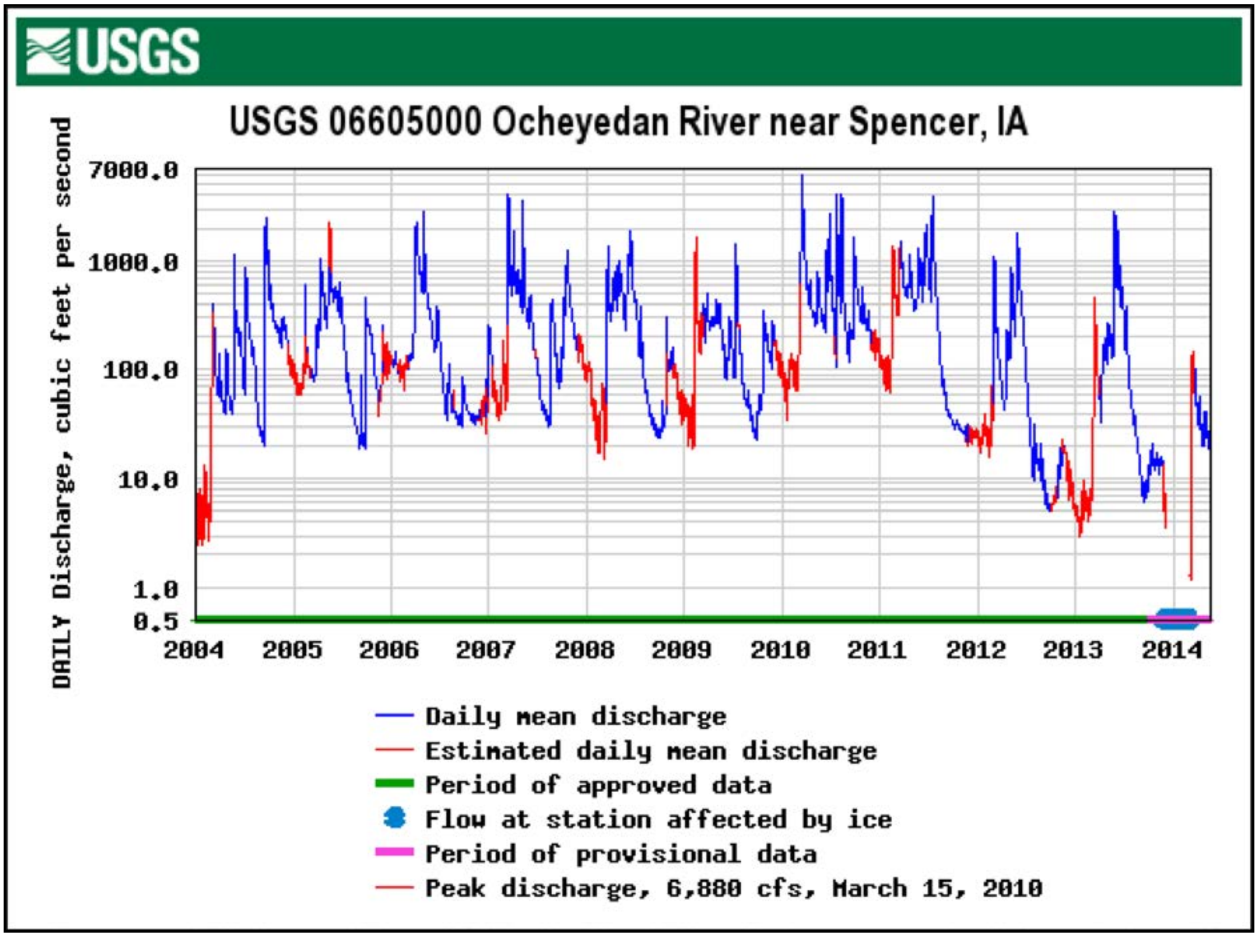


Figure 2. Daily average streamflow at USGS streamgage 06605000 on the Ocheyedan River near Spencer (2004 to 2014).

(Mesonet, Iowa State University, 2014), the average annual precipitation in the four county study area ranges from 27 inches per year near Sutherland to 29 inches per year in Primghar.

The study area has historically experienced moderate to severe droughts. Table 1 shows the minimum annual precipitation amounts for a select number of cities in the study area (Mesonet, Iowa State University, 2014). These minimum annual precipitation amounts range from 12.70 inches in Milford in 1958 to 15.41 inches in Sheldon in 1958.

Surface Water

Two gaging stations operated by the United States Geological Survey (USGS) show streamflow trends over time in the

Table 1. Minimum annual precipitation for select communities in Osceola, O'Brien, Clay, and Dickenson counties.

Location	Minimum Inches (Year)
Milford	12.70 (1958)
Primghar	14.96 (1958)
Sheldon	15.41 (1958)
Sibley	14.38 (1976)
Spencer	14.41 (1958)
Sutherland	14.80 (1976)

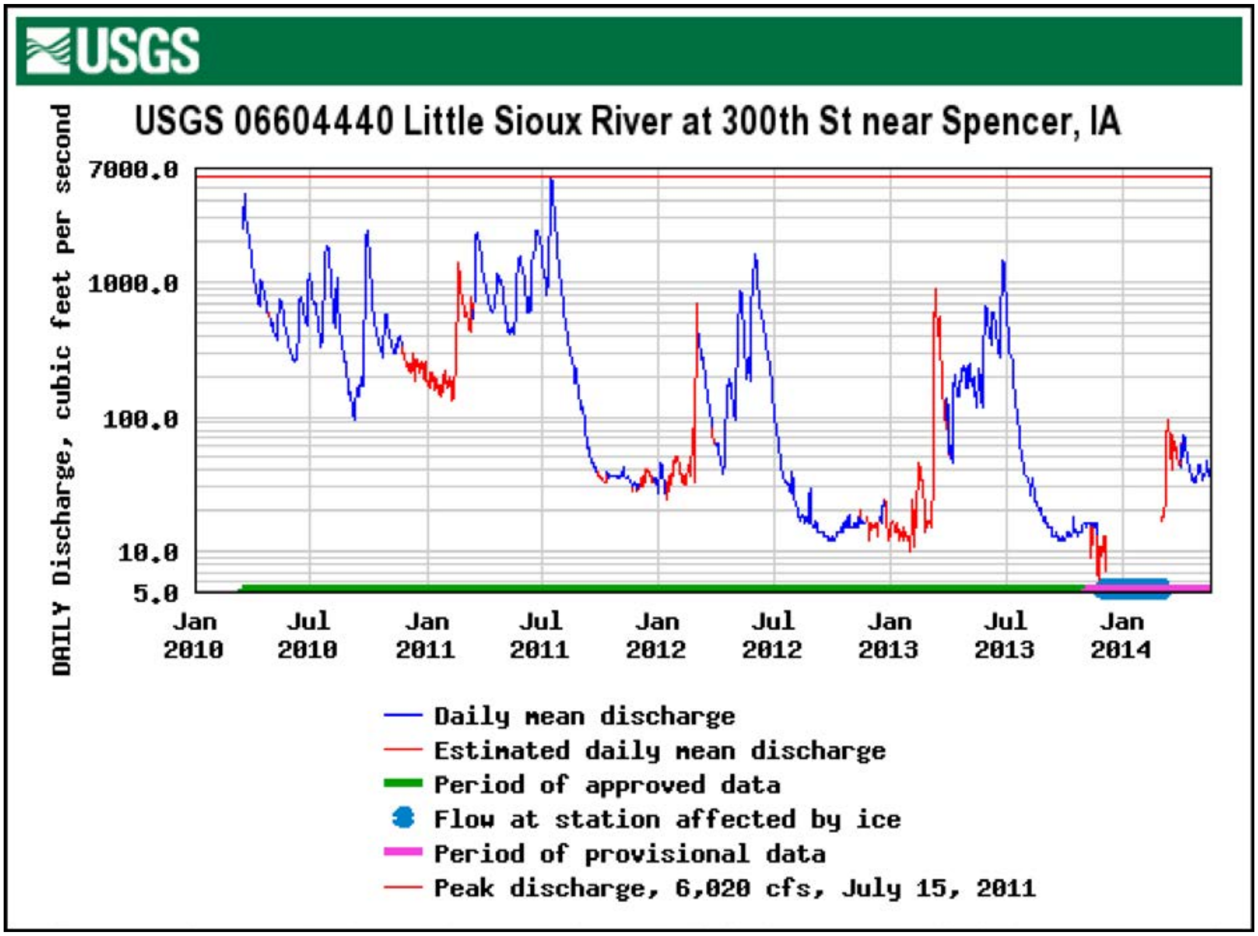


Figure 3. Daily average streamflow at USGS Streamgage 06604440 on the Little Sioux River near Spencer (2004 to 2014).

study area. Average daily discharge over the last ten years in the Ocheyedan and Little Sioux rivers near Spencer are shown in Figures 2 and 3. The lowest average daily discharge observed at the Ocheyedan River gage was 5 cubic feet per second (cfs) on September 23 – 24, 2012. The lowest average daily discharge observed at the Little Sioux River gage was 12 cfs, which was observed for several days in late September and early October, 2012 and 2013.

The Iowa Administrative Code (IAC) [567] Chapter 52.8 has rules that protect consumptive water users during moderate to severe droughts for rivers with watersheds greater than or equal to 50 square miles. The Ocheyedan River watershed is approximately 434 square miles, but is not included in Chapter 52.8(3). The protective low flow value at the Linn Grove gage on the Little Sioux River is used for the Ocheyedan River, Stony Creek and the Upper Little Sioux River. 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 to or exceeds this discharge 84 percent of the time over a certain period of time (generally

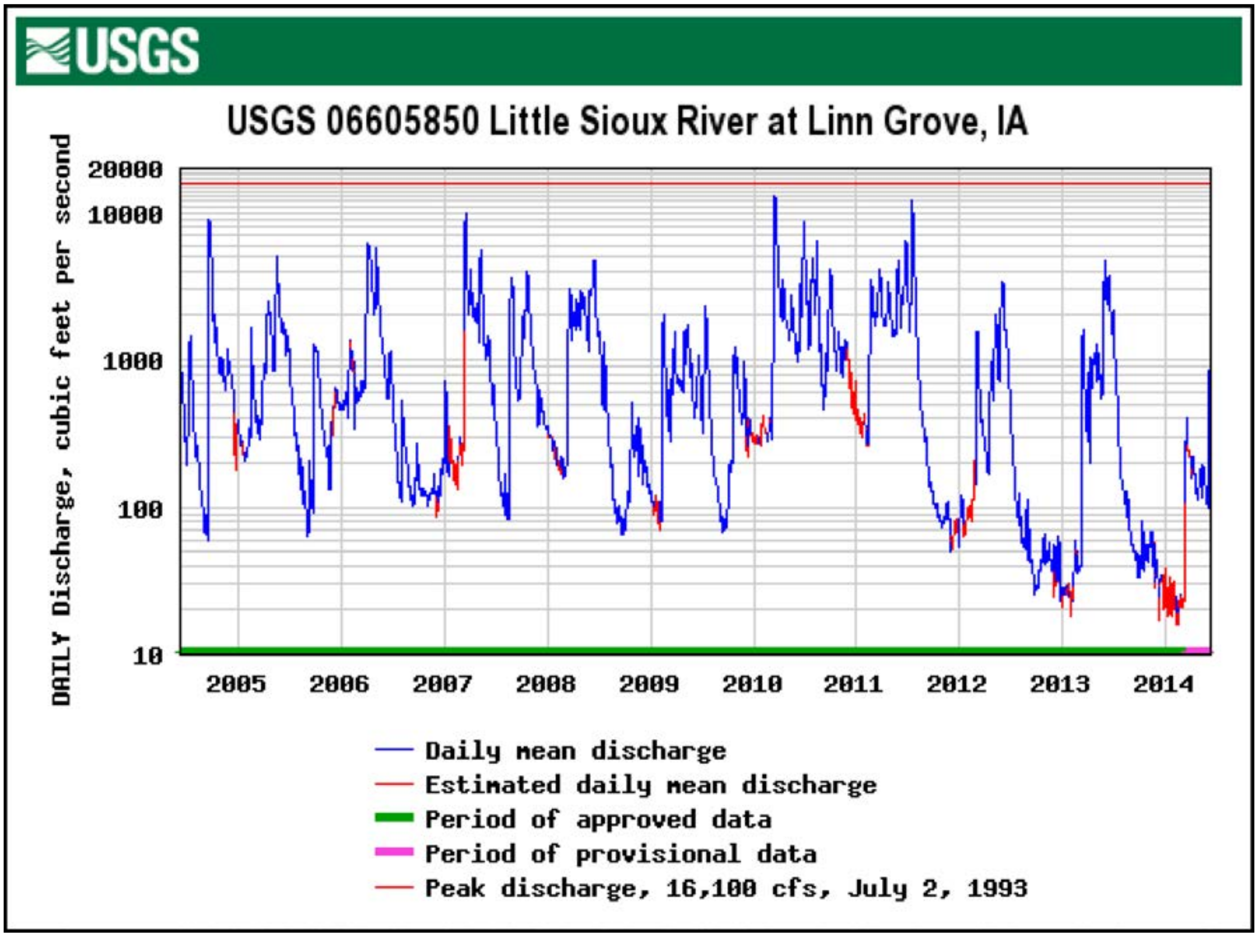


Figure 4. Daily average streamflow at USGS Streamgage 06605850 on the Little Sioux River at Linn Grove (2004 to 2014).

10 years or more). When streamflow measurements drop below the protective low-flow value, withdrawals from irrigation wells and surface water intakes within 0.125 miles from the river must cease pumping. The protective low-flow value for the Linn Grove gage is reported as 42 cfs (IAC [567] 52.8). The streamflow at the Linn Grove gage has fallen to 42 cfs or lower from September through March of 2012 and 2013, and September through March of 2013 and 2014 (Figure 4). These are the only two periods of below protective flow from 2004 to 2014 at the Linn Grove gage.

GEOLOGY

The study area (Figure 1) lies within the Northwest Iowa Plains landform region, except the far northwest portion which lies within the Des Moines Lobe landform region. There are no known bedrock exposures in the study area (IDNR – Bedrock Exposure Database). The bedrock surface lies beneath an average of 260 feet of glacial tills and alluvium (IDNR – Bedrock Depth Database). The bedrock surface primarily consists of Cretaceous-age sedimentary rocks belonging to the Dakota Formation. The primary lithologies

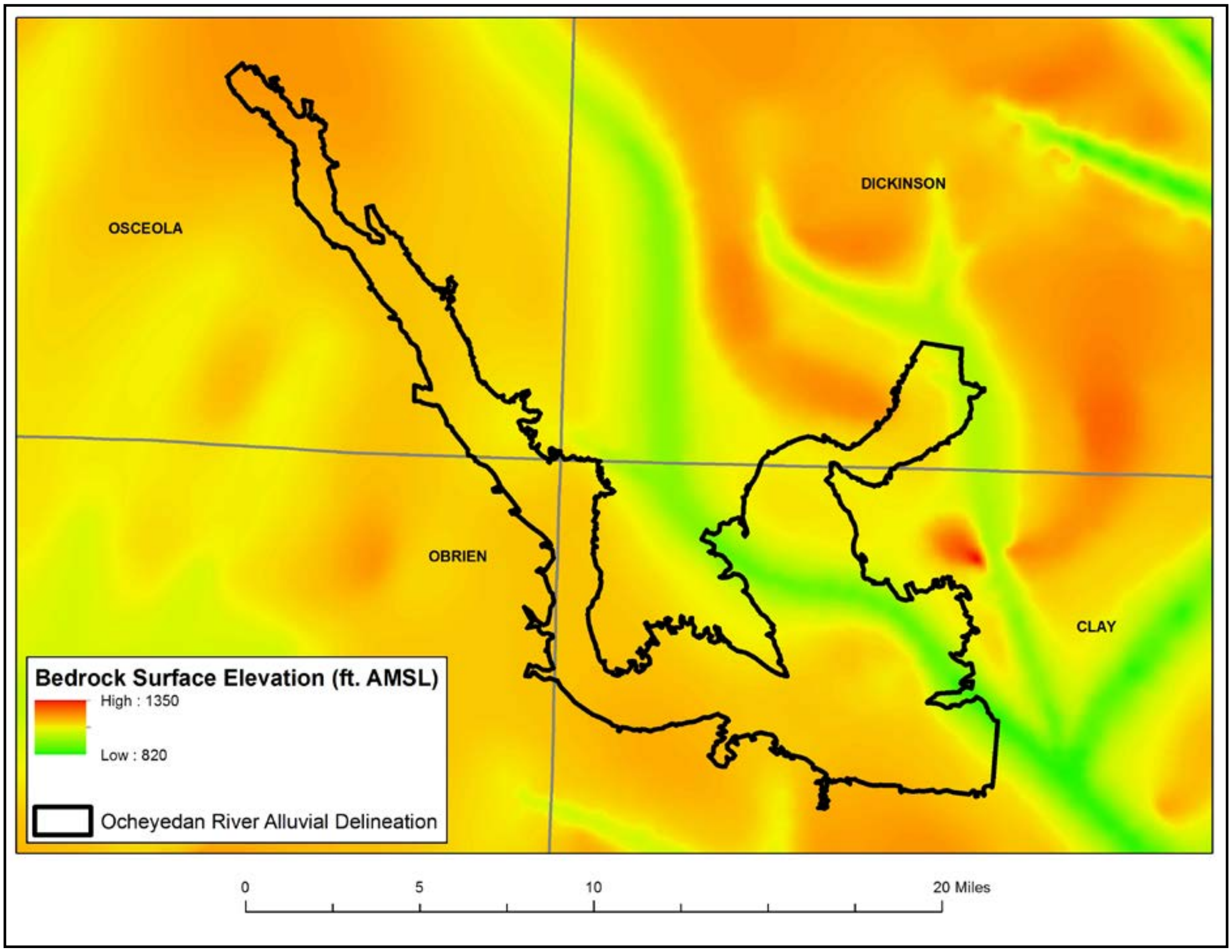


Figure 5. Bedrock elevation map indicating bedrock valleys (shown in green).

are shales and mudstones to very fine to medium grained sandstones (Witzke, *et al.*, 1997). Figure 5 shows the bedrock surface elevation of the Ocheyedan River area. Bedrock channels appear to exist in the study area and can also be seen in Figure 5.

Aquifer Thickness

Glacial melt-water from the Wisconsinan-age deposited various thicknesses of sand and gravel along the modern day Ocheyedan River valley and its tributaries. The thickness of alluvial deposits along the Ocheyedan River ranges from <10 to over 40 feet, but averages approximately 20 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 252 striplogs and driller's logs, the distribution of sand and gravel thickness was estimated and is shown on Figure 6. The locations of all existing information were confirmed before

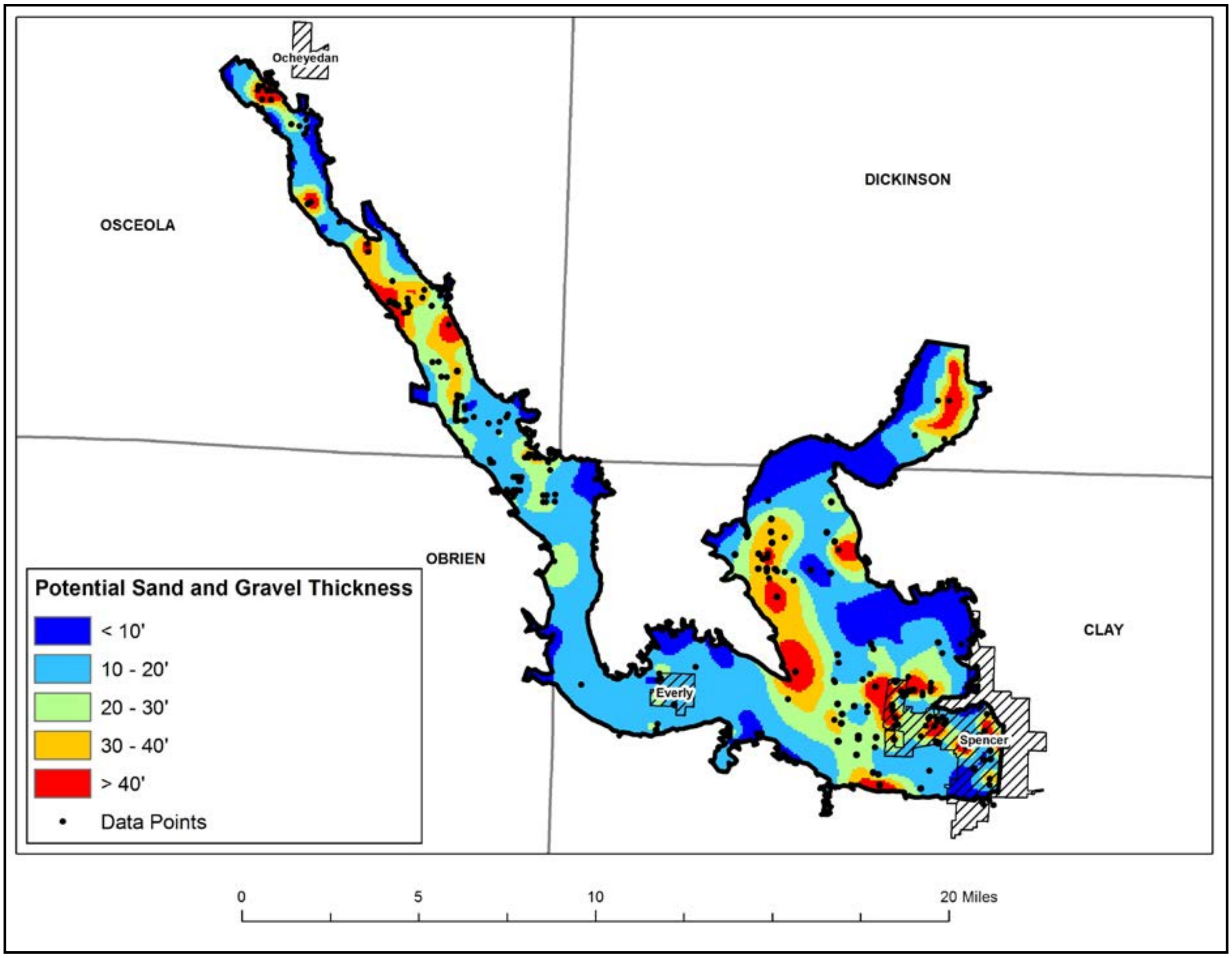


Figure 6. Isopach (thickness) map of the Ocheyedan River aquifer and its tributaries.

use. Based on Figure 6, over 40 feet of sand and gravel occurs near Spencer, to the east of Stony Creek, and near the Osceola County Rural Water District (OCRWD) wellfield. The sand and gravel is overlain by fine-grained sediments consisting of clay, silt, and silty-sand.

HYDROGEOLOGY

Assuming groundwater table conditions are a reflection of the ground surface, regional groundwater flow is toward the Ocheyedan River and its tributaries in a general southerly and easterly direction. Water level data from thirty-eight wells were used to evaluate the groundwater surface (Table 2). The water level data was obtained from the Iowa Department of Natural Resources Water Use database, and from the various water utilities, and represent drought conditions during the fall of 2013 and the spring of 2014. The available water level data is not evenly distributed, but is clustered near OCRWD, and the Iowa Lakes Regional Water (ILRW) wellfield as shown in Figure 7. Due to the lack of groundwater level

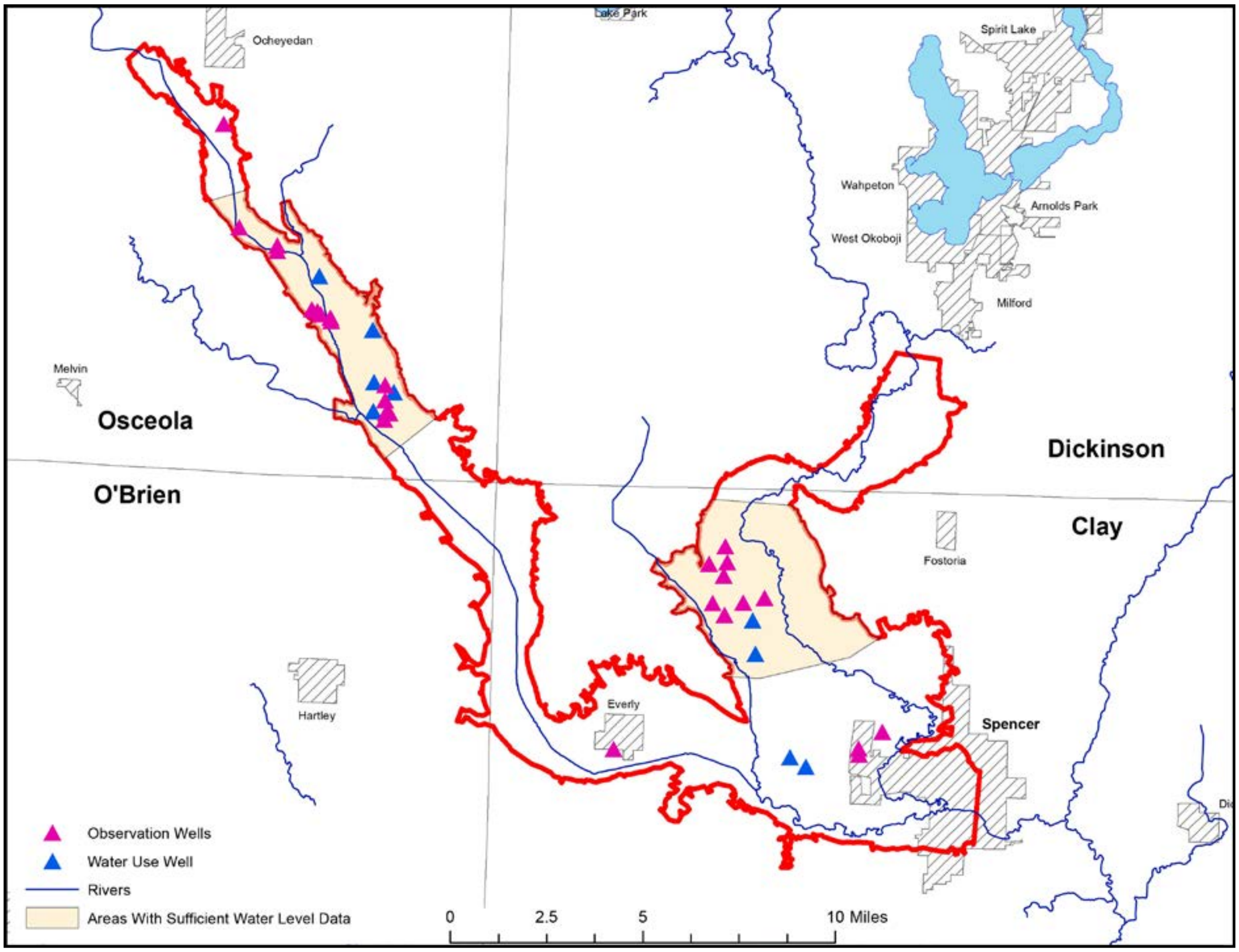


Figure 7. Distribution of groundwater level data in study area.

data, groundwater elevation maps could only be generated for the OCRWD and ILRW wellfields. Using the groundwater elevation data in Table 2, and the surface water elevations in Table 3, groundwater elevation maps were contoured as shown on Figures 8 and 9. Relatively large zones of depression occur in the groundwater surface near OCRWD and ILRW wellfields as a result of the high pumping rates.

Based on the groundwater contour elevations, surface water from both the Ocheyedan River and Stony Creek flow toward OCRWD and ILRW wellfields. Without this induced recharge, high capacity production wells and irrigation wells would not be able to sustain their pumping rates during prolonged droughts.

Groundwater recharge sources include 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 on annual precipitation data. In 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 the precipitation events, and when they occur seasonally. Based on previous

Table 2. Groundwater elevation data for the fall of 2013 and the spring of 2014.

Monitoring Point	Ground Elevation (ft)	SWL* (feet)	Groundwater Elevation (ft)
ILRW Ob Well 1	1358.8	10.5	1,348.3
ILRW Ob Well 2	1364.3	11.0	1,353.3
ILRW Ob Well 3	1362.7	7.5	1,355.2
ILRW Ob Well 4	1362.7	11.8	1,350.9
ILRW Ob Well 5	1362.7	7.3	1,355.4
ILRW Ob Well 6	1362.7	14.0	1,348.7
ILRW Ob Well 7	1367	11.2	1,355.8
ILRW Ob Well 8	1371	13.0	1,358.0
Ocheyedan Well 3	1472	12.0	1,460.0
OCRW H-1	1440	14.1	1,425.9
OCRW H-2	1438	17.4	1,420.6
OCRW R-1	1410	13.0	1,397.0
OCRW R-2	1408	13.2	1,394.8
OCRW C-1	1420	15.5	1,404.5
OCRW C-2	1420	16.5	1,403.5
OCRW D-1	1450	14.8	1,435.2
OCRW D-2	1424	16.8	1,407.2
OCRW D-3	1422	11.4	1,410.6
OCRW D-4	1428	11.5	1,416.5
OCRW S-1	1404	18.0	1,386.0
OCRW S-2	1404	17.4	1,386.6
OCRW S-3	1404	14.3	1,389.7
Spencer Well 2	1334	13.0	1,321.0
Spencer Well 3	1335	14.6	1,320.4
Spencer Well 4	1335	11.9	1,323.1
Spencer Well 9	1331	23.4	1,307.6
Everly Well 3	1352	12.0	1,340.0
CF Industries	1336	9.7	1,326.3
Carrie Jones	1434	38.0	1,396.0
Corn Belt Power	1336	6.3	1,329.7
Delmar Brockshus	1356	15.0	1,341.0
Jeff Monster	1430	13.0	1,417.0
Karmen Schoelerman	1406	4.0	1,402.0
Larry Ten Lkey	1412	9.5	1,402.5
Maria Jean Rindsig	1359	10.3	1,348.7
Ron Petersen	1418	6.5	1,411.5
Rossman Farms	1408	4.0	1,404.0
Spencer Golf and CC	1323	28.0	1,295.0
SWL= Static Water Level in the fall of 2013 or spring of 2014			

studies (Gannon, 2006 and Gannon, 2011), the annual rate of precipitation recharge during 2013 was estimated to be 4 inches/ year, and 0 inches during June 1 through August 31.

Water Storage and Availability

Based on a surface area of the Ocheyedan aquifer of approximately 2.6 billion square

Table 3. Surface elevation data for May 27, 2014.

Location	Bridge Elevation (ft)	Depth to River (ft)	Stage Elevation (ft
G-1 *	1456	16	1440
G-2 *	1456	19	1437
G-3 *	1449	20	1429
G-4 *	1435	16	1419
G-5 *	1432	18	1414
G-6 *	1422	21	1401
G-7 *	1416	17	1399
G-8 *	1410	18	1392
G-9 *	1404	15	1389
G-10 *	1414	16	1398
LS-1 **	NA	NA	1321
LS-2 **	NA	NA	1323
LS-3 **	NA	NA	1325
LS-4 **	NA	NA	1327
USGS gage***	NA	NA	1323.41
LS-5 **	NA	NA	1320
LS-6 **	NA	NA	1318
SC-1 **	NA	NA	1354
SC-2 **	NA	NA	1352
SC-3 **	NA	NA	1350
SC-4 **	NA	NA	1348
SC-5 **	NA	NA	1346
SC-6 **	NA	NA	1344
SC-7 **	NA	NA	1342
SC-8 **	NA	NA	1340
SC-9 **	NA	NA	1338
* = depth to river measurements taken on May 27, 2014			
** = Based on LiDar and USGS gage correction			
NA = Not Applicable			
***= USGS Gage 6604440 Little Sioux River Near Spencer on May 27, 2014			

feet (Figure 1), an average saturated aquifer thickness of 20 feet, and a specific yield of 0.15, approximately 58 billion gallons of groundwater is stored in the Ocheyedan River aquifer. Not all of this storage is available for use, and the drawdown is not uniform across the aquifer.

A groundwater study conducted in 2011 calibrated an average annual groundwater recharge of 8 inches within the alluvium near the ILRW wellfield in Clay County (Gannon, 2011). At an average groundwater recharge rate of 8 inches per year approximately 13 billion gallons per year (bgy) of water would recharge the aquifer. If we classify a severe drought as half the annual precipitation (Gannon,

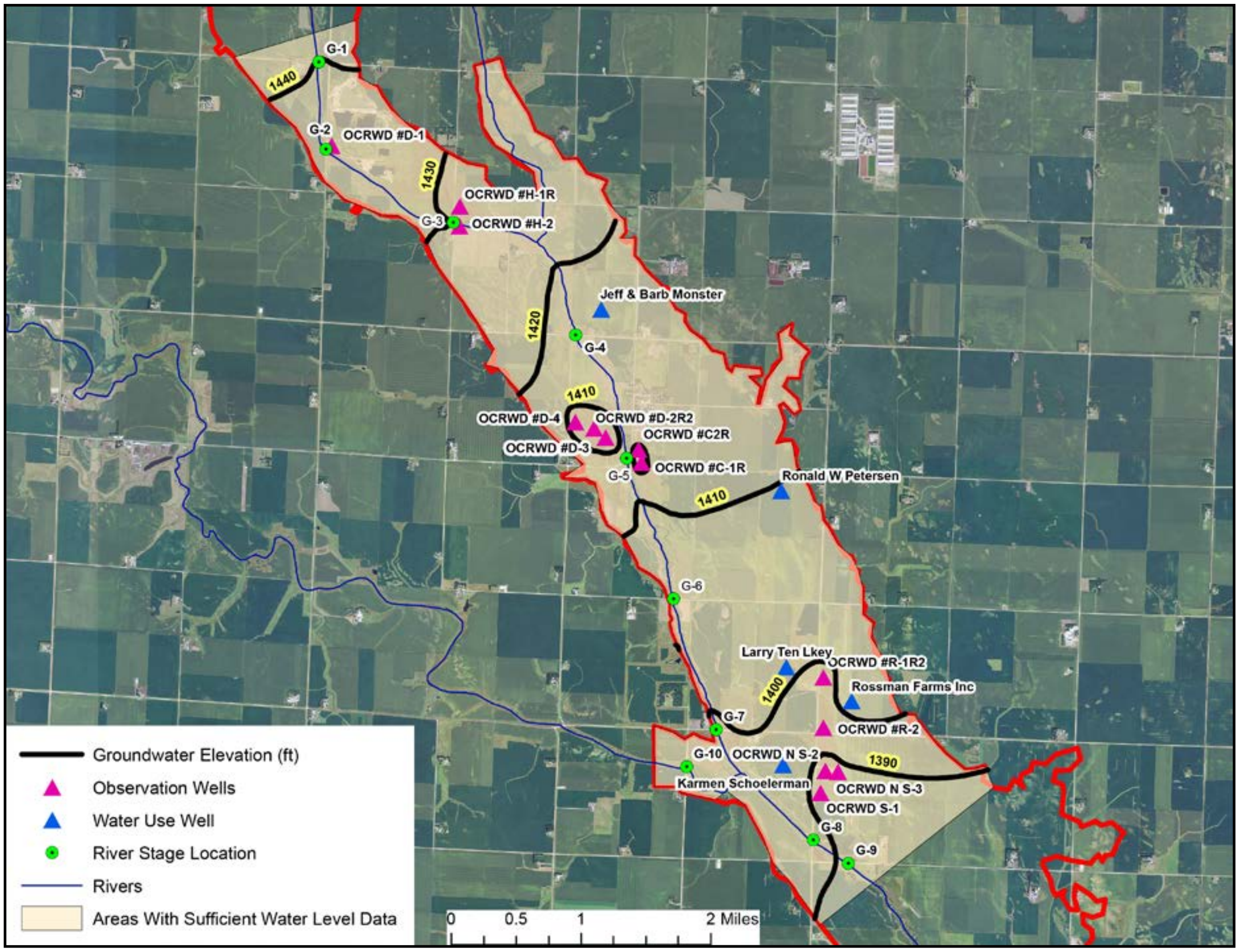


Figure 8. Observed groundwater elevation contours for Osceola County Rural Water District and surrounding area.

2006) and we assume this corresponds to an estimated recharge of 4 inches per year (half the normal recharge), approximately 6.5 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 available during a drought would need to be quantified using hydrographs, analytical methods and numerical modeling.

The volume of induced recharge provided by the Ocheyedan River and Stony Creek is unknown, but would significantly add to the total recharge. Local pumping stress can also affect groundwater availability. The application of a calibrated groundwater flow model could be used to evaluate local water balance concerns.

Wells

Twenty-nine active public wells were located within the model area and include five systems or communities (IDNR Water-Use database). The locations of the public wells within the aquifer are shown in

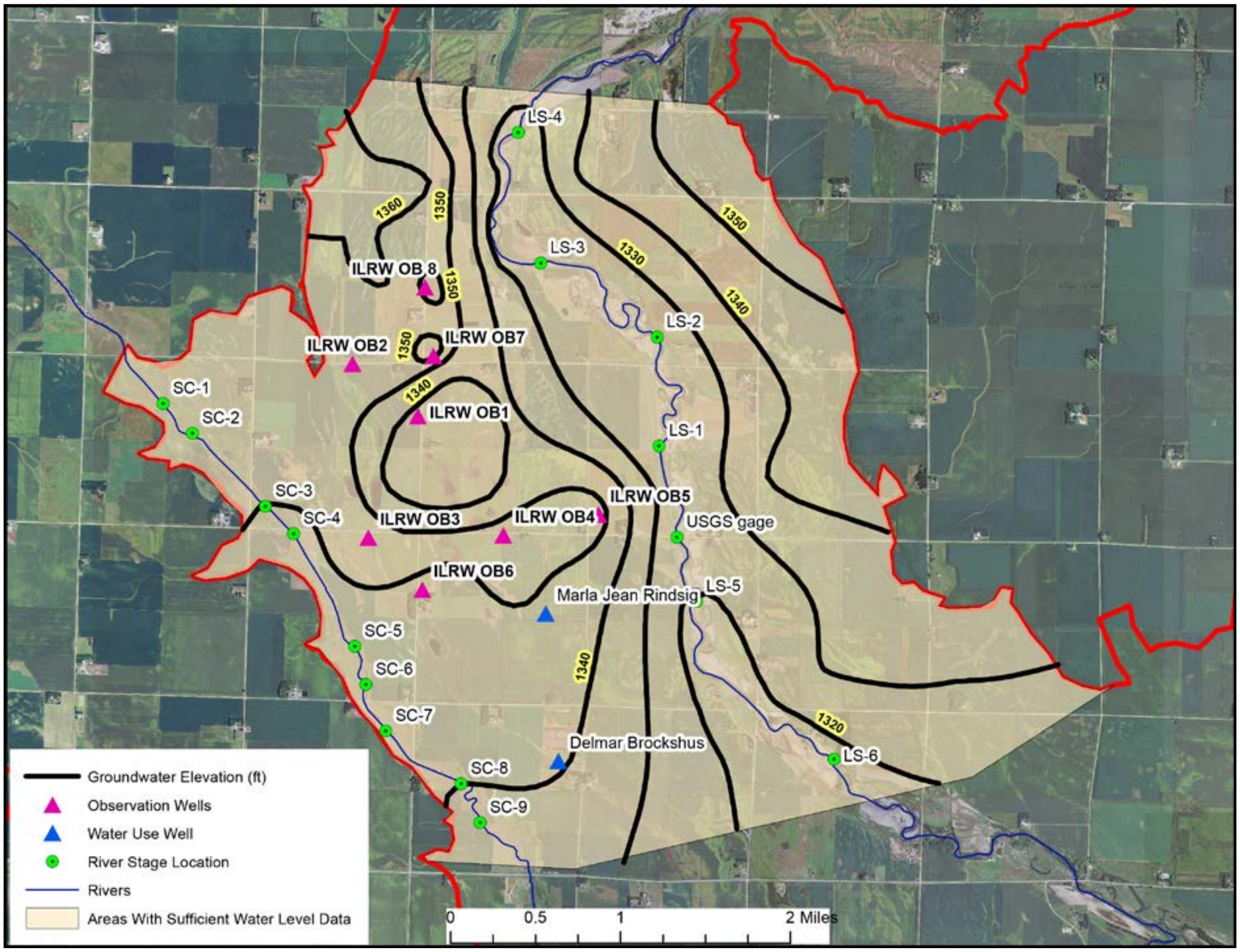


Figure 9. Observed groundwater elevation contours for Iowa Lakes Regional Water and surrounding area.

Figure 10. In addition to the public wells, there are approximately forty-six water-use wells that are used primarily for irrigation, livestock, and industry. Annual water-use was obtained from the Iowa DNR Water-Use database and is listed in Table 4. If more than one well is used, the reported value reflects a combined total for all wells. Total water usage for the study area, not including private wells, is estimated at 3.1 billion gallons per year (8.6 million gallons per day), with a peak usage of 16.33 million gallons per day (Table 4). Well interference likely occurs between the irrigation wells and the public wells. The application of a calibrated groundwater flow model may be helpful in evaluating the magnitude and significance of this well interference.

Pump Test Results

Hydraulic properties are used to define and characterize aquifers and include specific yield or storage, transmissivity, and hydraulic conductivity. The most reliable aquifer properties are those obtained from controlled aquifer tests with known

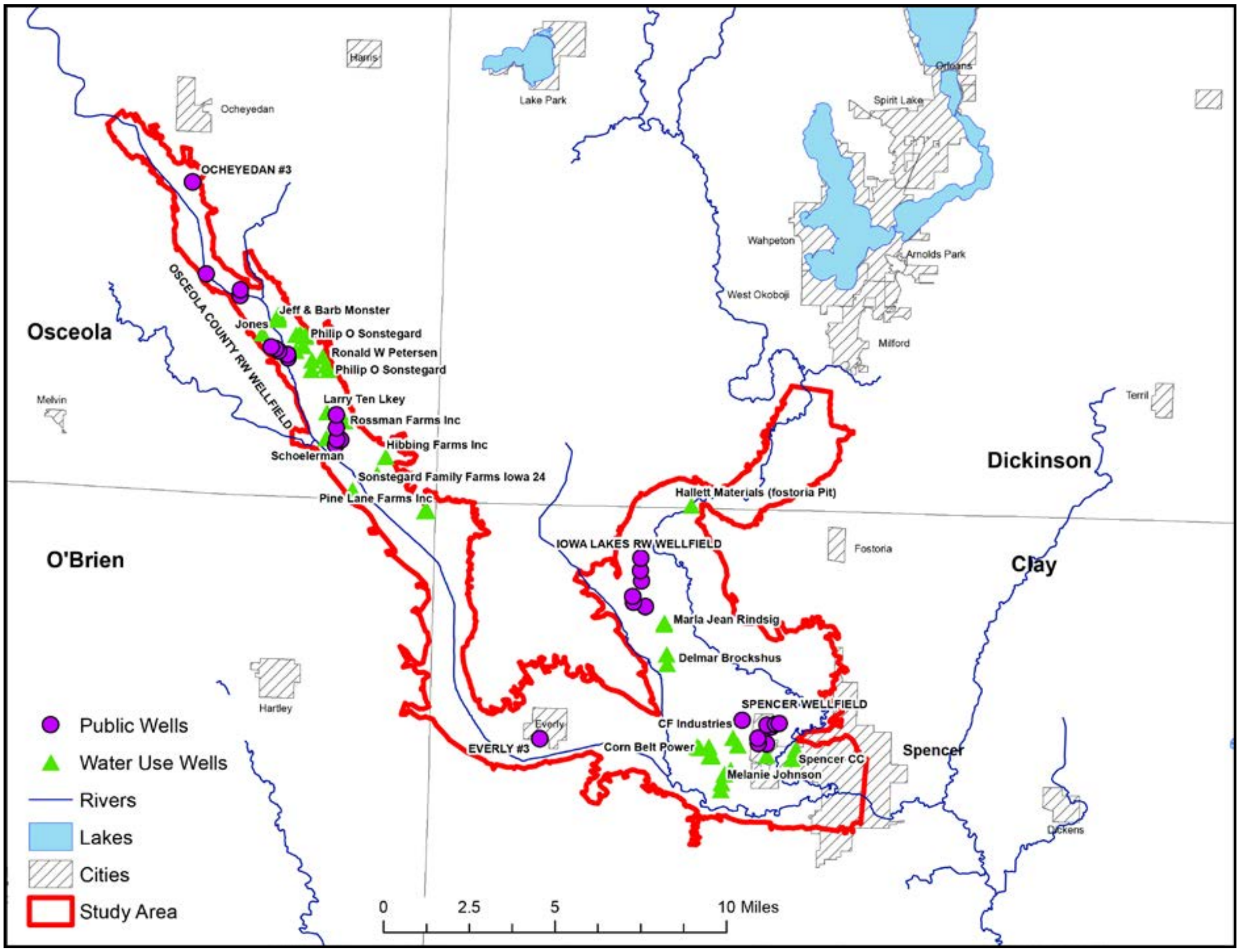


Figure 10. Locations of known public wells and water-use permit wells in the Ocheyedan River aquifer.

pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Six aquifer pump test results were found in the study area and their results are shown in Appendix A. All six pump tests were completed at ILRW wellfield northwest of Spencer.

In addition to the aquifer pump tests, a total of 66 specific capacity tests were made available by various consultants, well drillers, and communities. The locations of these tests are shown in Figure 11. Appendix A lists the pump test results for each test, the method of analysis, transmissivity values, and hydraulic conductivity values. Original data and graphs of the pump tests are also found in Appendix A.

Hydraulic conductivity values indicate the rate at which water can move through a permeable medium. Hydraulic conductivity was estimated by dividing the transmissivity by the overall aquifer thickness. Hydraulic conductivity in the study area was found to range from 14 to 1,300 feet/day, with an arithmetic mean of 355 feet/day. The regional hydraulic conductivity distribution is shown in Figure 11.

Table 4. Permitted water use and actual water use for public, industrial, and irrigation wells in the Ocheyedan River aquifer.

Permit Held	Number of Wells	Average Q (GPD)	Peak Q (GPD)	Maximum Historical Q (MGY) (year)	Allocated Q (MGY)
Iowa Lakes RW	6	1,088,219	1,267,613	397.2 (2013)	550
Ocheyedan	1	66,301	NA	24.2 (1993)	25
Osceola County RW	13	3,394,521	3,780,935	1,239 (2013)	1,700
Spencer	8	1,800,000	2,032,600	657 (2013)	1,500
Everly	1	79,726	NA	29.1 (1997)	45
Alliance Concrete	1	20,548	NA	7.5 (2000)	32.9
CF Industries	2	45,205	50,580	16.5 (2009)	42.4
Carrie Jones *	1	508,889	NA	45.8 (2013)	52.1
Corn Belt Power	5	322,192	NA	117.6 (2005)	1,200
Delmar Brockshus **	2	130,000	NA	15.6 (2003)	58.7
Hallet (Fostoria)	1	192,778	NA	34.7 (2013)	50
James Reppert	1	0	0	0	52
Jeff Monster *	3	361,111	NA	32.5 (2012)	45.6
Sonstegard Farms *	13	1,504,444	1,811,000	135.4 (2013)	251.6
Karmen Schoelerman *	1	395,556	NA	35.6 (2007)	45.6
Larry Ten Lkey *	2	666,667	967,000	60 (2012)	182.5
Maria Jean Rindsig *	2	434,444	946,000	39.1 (2013)	48.9
Melanie Johnson *	4	1,685,556	NA	151.7 (2002)	222.8
Nutriom Iowa	1	0	0	0	7.5
Ron Petersen *	2	588,889	1,051,000	53 (2013)	48.9
Rossman Farms *	1	205,556	448,400	18.5 (2012)	44.3
Rutter Farms *	2	0	0	0	39.1
Spencer Golf and CC**	2	123,333	223,000	22.2 (2012)	58.7
* = Based on a 90 day Irrigation Season					
**=Based on 120 day Irrigation Season					
Q = Discharge (gallons per day)					

Transmissivity values indicate the rate at which water is transmitted through the aquifer when considering factors such as the hydraulic gradient and aquifer thickness. Based on aquifer test results, the transmissivity of the aquifer was found to range from 330 feet^2/day west of Everly to 36,600 feet^2/day at Spencer Well #8. Based on available data, the arithmetic mean transmissivity value was estimated to be 10,000 feet^2/day. The regional transmissivity distribution is shown in Figure 12.

Estimated Well Yield

The potential well yield was estimated by converting the transmissivity value to specific capacity, and multiplying this by one-half the saturated sand and gravel thickness (Figure 6). The potential well yield distribution is shown on Figure 13. Potential well yields greater than 400 gallons per minute (gpm) are found near Spencer, ILRW, and OCRWD. There appears to be areas between the City of Everly and south of OCRWD, and near the

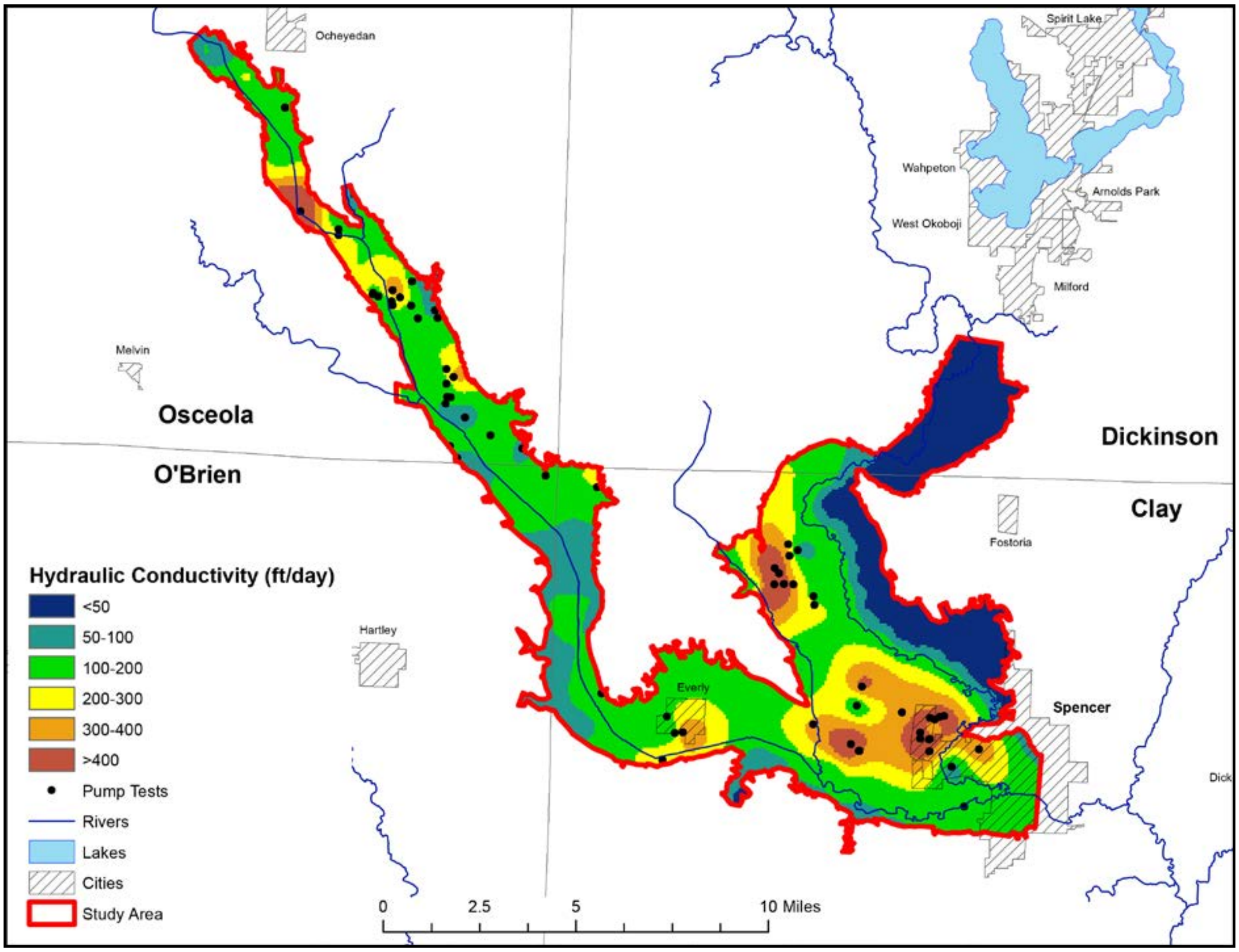


Figure 11. Aquifer test locations in the Ocheyedan River aquifer and hydraulic conductivity distribution based on data found in Appendix A.

upper Little Sioux River that have potential well yields less than 100 gpm.

CONCLUSIONS

The Iowa Geological Survey initiated a geologic and hydrologic investigation of the Ocheyedan River alluvial aquifer. The purpose of this study was to provide a resource for future development or well field expansion. Special attention was given to drought conditions as prolonged dry periods can affect groundwater resources.

The study area lies near the border of the Northwest Iowa Plains and the Des Moines Lobe Landform Regions. The Cretaceous-age sedimentary rocks are overlain by a thick mantle of glacial tills and alluvium. The area has a complex geologic history with several periods of glaciation.

A groundwater study conducted in 2011 calibrated an average annual groundwater recharge of 8 inches within the alluvium near the ILRW wellfield in Clay County (Gannon, 2011). At an average groundwater recharge rate of 8 inches per year

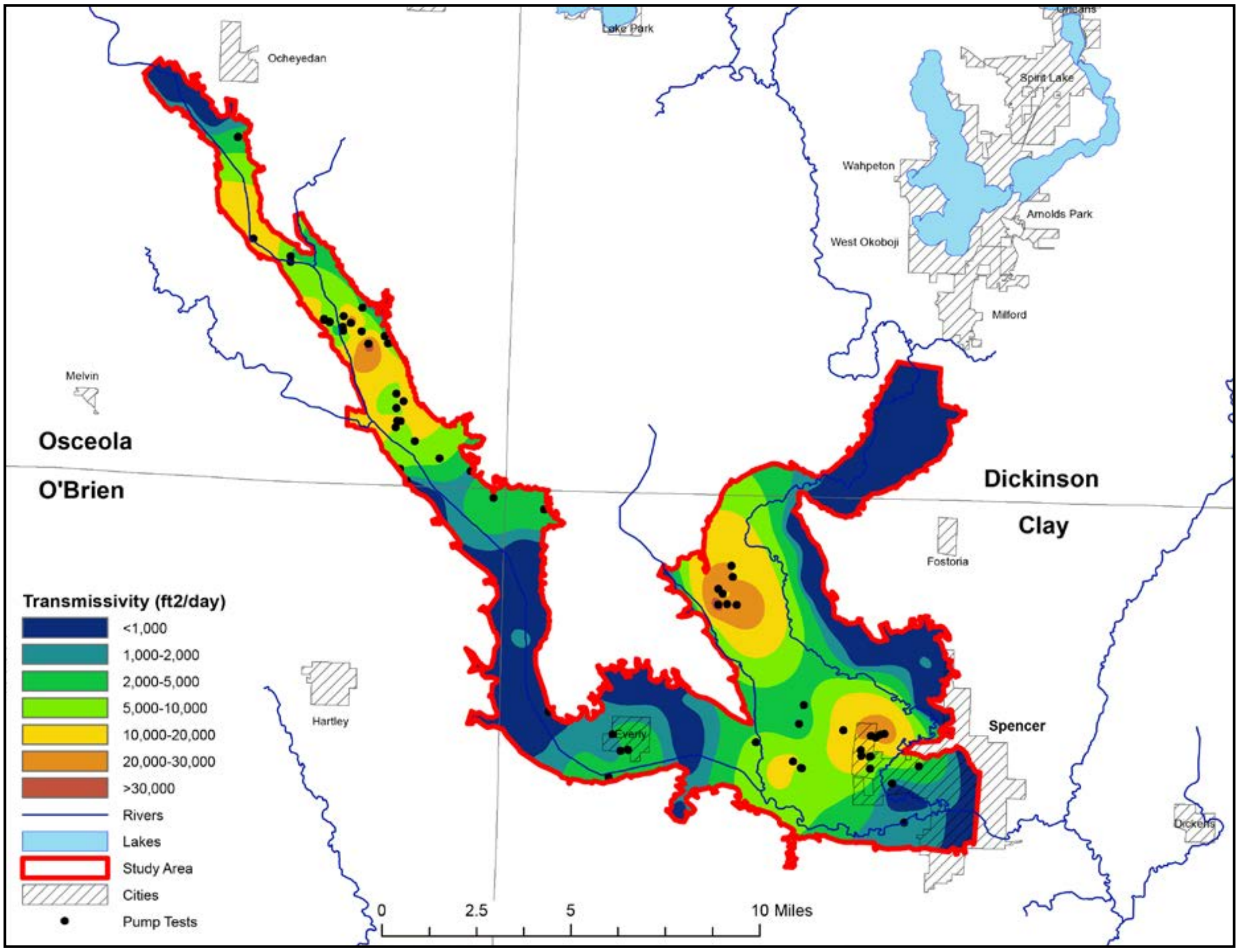


Figure 12. Transmissivity distribution within the Ocheyedan River aquifer based on data found in Appendix A.

approximately 13 billion gallons per year (bgy) of water would recharge the aquifer. Approximately 6.5 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 discharge and recharge would need to be quantified using hydrographs, analytical methods, and numerical modeling. Total current water usage for the study area, not including private wells, is estimated at 3.1 bgy (Iowa DNR Water-Use Database).

Twenty-nine active public wells were located within the model area and include five systems or communities (Iowa DNR Water-Use Database). In addition to the public wells, there are approximately 46 water-use wells that are used for irrigation, livestock, and industry.

Hydraulic properties were obtained from six aquifer pump tests. In addition to the aquifer pump tests, a total of 66 specific capacity tests were made available by various consultants, well drillers, and communities. Hydraulic conductivity in the Ocheyedan River alluvial aquifer

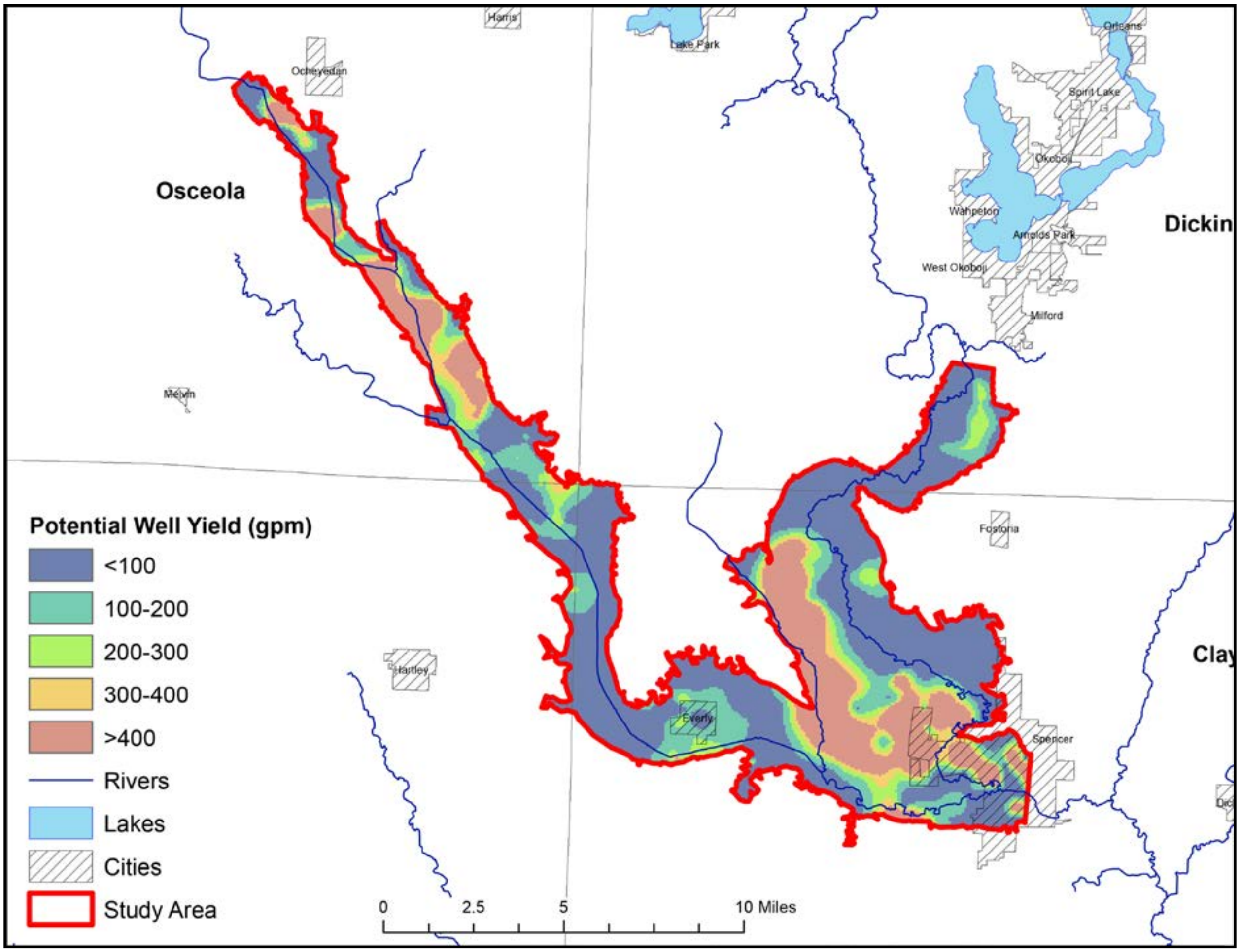


Figure 13. Potential well yield in gallons per minute (gpm) based on the transmissivity distribution, Figure 6, and one-half the available drawdown.

was found to range from 14 to 1,300 feet/day, with an arithmetic mean of 355 feet/day. The transmissivity of the Ocheyedan River aquifer was found to range from 330 feet^2/day west of the City of Everly to 36,600 feet^2/day at Iowa Lakes Rural Water District. Based on available data, the arithmetic mean transmissivity value was estimated to be 10,000 feet^2/day.

Potential well yield distribution was estimated using the transmissivity distribution and one-half the sand and gravel thickness. Potential well yields greater than 400 gallons per minute (gpm) are found near Spencer, ILRW, and OCRWD. There appears to be areas between the City of Everly and OCRWD, and along most of the upper Little Sioux River, which have potential well yields less than 100 gpm.

REFERENCES

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

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

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

Gannon, J.M., 2011, *Hydrogeologic Summary Report, Iowa Lakes Regional Water District-Stony Creek*, Iowa Department of Natural Resources – Iowa Geological and Water Survey.

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

Iowa Administrative Code (IAC) 567 Chapter 52.8

Iowa Department of Natural Resources Water-Use Database, available at: http://programs.iowadnr.gov/wateruse, accessed June 2014.

Iowa State University, *Mesonet*, 2014, available at: http://mesonet.agron.iastate.edu/climodat, accessed May 2014.

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

Vogelgesang, J.A., Gannon, J.M., and Quade, D.J., 2014, *Aquifer Characterization and Drought Assessment, Rock River Alluvial Aquifer*, Iowa Department of Natural Resources-Iowa Geological and Water Survey, Water Resources Investigation Report 9, 43 p.

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

APPENDIX A

Pump test data and results

Well Name	SWL (ft)	PWL (ft)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Transmissivity (ft2/day)	Hydraulic Conductivity (ft/day)	METHOD
SPENCER #1	19	25	211	35	7,040	435	SPC Method
SPENCER #2	15	21	363	61	18,000	706	SPC Method
EVERLY #3	12	24	100	8	1,660	128	SPC Method
SPENCER #3	19	25	439	76	15,746	1,016	SPC Method
EVERLY #4	7	11	82	21	4,100	410	SPC Method
SPENCER #7	8	16	503	63	12,580	247	SPC Method
SPENCER #10	13	19	704	124	24,700	463	SPC Method
SPENCER #8	10	15	517	103	36,668	601	SPC Method
EVERLY #1	12	27	150	10	2,000	182	SPC Method
SPENCER #9	11	20	602	67	25,874	470	SPC Method
SPENCER #11	11	24	900	69	13,846	355	SPC Method
ILRW #10	9	21	597	50	9,950	332	SPC Method
ILRW #4 (Ob Well 1)	7	NA	450	NA	22,900	990	Neuman
ILRW #4 (Ob Well 2)	7	NA	450	NA	29,900	1,300	Neuman
ILRW #2 (Ob Well 1)	9	19	800	80	30,400	980	Jacob
ILRW #2 (Ob Well 2)	9	19	800	80	35,100	1,130	Jacob
ILRW #3 (Ob Well1)	5	NA	435	NA	25,800	990	Jacob
ILRW #3 (Ob Well2)	5	NA	435	NA	25,200	970	Jacob
ILRW #6	12	20	550	69	13,750	458	SPC Method
ILRW #9	9	20	550	50	10,000	303	SPC Method
ILRW #8	9	26	850	50	10,000	303	SPC Method
OCRWD S-1	3	28	400	16	3,200	94	SPC Method
OCRWD S-3	4	20	400	25	5,000	156	SPC Method
OCRWD S-2	4	20	400	25	5,000	139	SPC Method
OCRWD R-2	17	32	225	16	3,000	143	SPC Method
OCRWD R-1R2	5	19	500	36	7,143	193	SPC Method
OCRWD R-1R	16	24	225	30	6,000	250	SPC Method
OCRWD C-1	16	30	450	31	6,250	208	SPC Method
OCRWD C-2	18	32	400	30	5,714	197	SPC Method
OCRWD C2R	4	22	600	33	6,666	133	SPC Method
OCRWD D-2	15	31	450	28	5,625	137	SPC Method
OCRWD D-2R1	4	22	600	33	6,667	133	SPC Method
OCRWD D-3	11	18	500	71	14,286	223	SPC Method
OCRWD D-4	10	23	480	37	7,385	172	SPC Method
OCRWD H-2	17	20	150	45	7,330	282	SPC Method
OCRWD H-1R	4	19	550	37	7,333	171	SPC Method
OCRWD H-1	18	36	270	15	3,000	83	SPC Method

Well Name	SWL (ft)	PWL (ft)	Pumping Rate (gpm)	Specific Capacity (gpm/ft)	Transmissivity (ft2/day)	Hydraulic Conductivity (ft/day)	METHOD
OCRWD D-1	17	22	450	98	19,600	632	SPC Method
OCHEYEDAN #3	13	18	80	16	3,200	178	SPC Method
OCKEYEDAN #1	12	18	80	13	2,660	121	SPC Method
W11083	11	12	20	20	4,000	200	SPC Method
W15325	17	25	50	6	1,250	74	SPC Method
W25486	9	19	800	80	16,000	516	SPC Method
W36946	17	21	150	38	7,500	441	SPC Method
W37074	8	35	1100	41	8,148	232	SPC Method
W37710	8	11	159	59	11,800	590	SPC Method
W42033	6	22	400	24	4,850	156	SPC Method
W42084	9	15	800	133	26,700	890	SPC Method
W42092	5	25	600	30	6,000	200	SPC Method
W42094	6	28	500	23	4,545	190	SPC Method
W42554	19	25	211	35	7,000	414	SPC Method
W42708	9	16	1200	171	34,300	1,070	SPC Method
W42709	5	15	600	60	12,000	343	SPC Method
W42756	6	28	450	20	4,090	102	SPC Method
W42757	11	29	300	17	3,330	74	SPC Method
W44749	8	11	20	7	1,300	83	SPC Method
W45222	4	16	20	2	330	14	SPC Method
W45919	6	10	40	9	1,780	71	SPC Method
W6534	10	13	60	20	4,000	421	SPC Method
W47043	7	14	300	43	8,571	429	SPC Method
W47044	10	19	295	33	6,550	386	SPC Method
W47049	14	19	145	29	5,800	322	SPC Method
W48367	10	20	200	19	3,810	120	SPC Method
W48370	6	8	20	10	2,000	118	SPC Method
W50333	17	34	400	24	4,700	392	SPC Method
W55206	14	17	24	8	1,600	178	SPC Method
W55261	5	11	20	3	670	48	SPC Method
W55283	22	23	23	15	3,070	236	SPC Method
W56049	13	14	26	26	5,200	200	SPC Method
W65327	5	11	400	67	13,300	417	SPC Method
W67722	10	14	20	5	1,000	67	SPC Method
W67724	7	26	700	37	7,370	167	SPC Method

IOWA GEOLOGICAL SURVEY

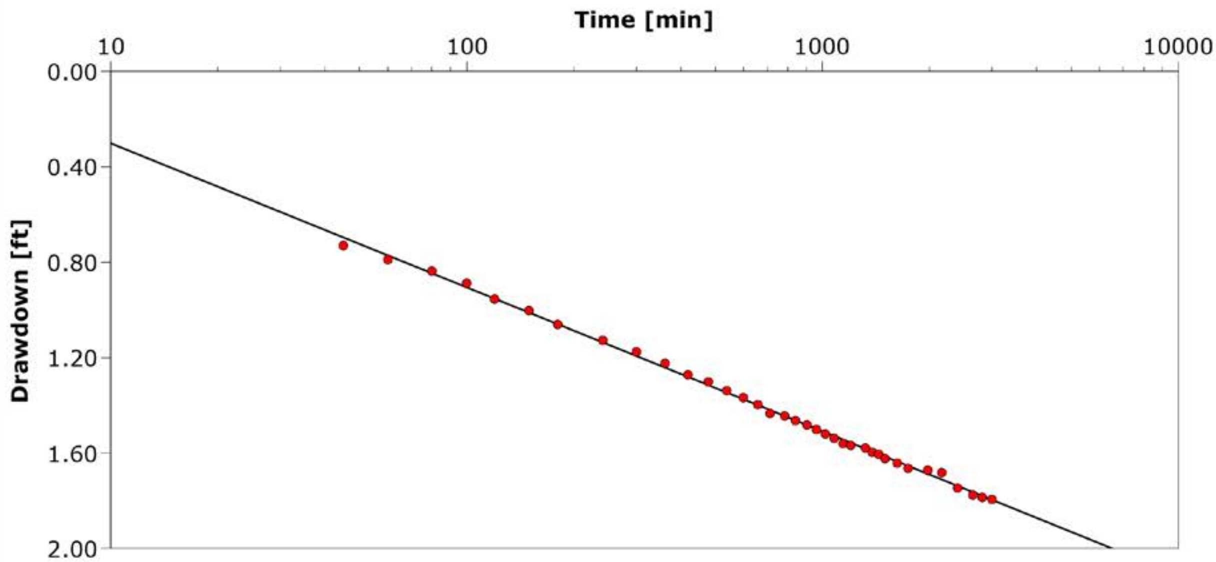
Pumping Test - Water Level Data	Page 1 of 1
Project: ILRW	
Number:	
Client:	

Location: North of Spencer, Iowa	Pumping Test: ILRW Well 2	Pumping Well: Well 2
Test Conducted by:	Test Date: 9/30/1980	Discharge Rate: 520 [U.S. gal/min]
Observation Well: OB 1	Static Water Level [ft]: 7.23	Radial Distance to PW [ft]: 48.5

	Time [min]	Water Level [ft]	Drawdown [ft]
1	45	7.97	0.74
2	60	8.03	0.80
3	80	8.08	0.85
4	100	8.13	0.90
5	120	8.20	0.97
6	150	8.25	1.02
7	180	8.31	1.08
8	242	8.38	1.15
9	300	8.43	1.20
10	361	8.48	1.25
11	419	8.53	1.30
12	479	8.56	1.33
13	538	8.60	1.37
14	600	8.63	1.40
15	659	8.66	1.43
16	712	8.70	1.47
17	784	8.71	1.48
18	840	8.73	1.50
19	903	8.75	1.52
20	962	8.77	1.54
21	1021	8.79	1.56
22	1082	8.81	1.58
23	1142	8.83	1.60
24	1201	8.84	1.61
25	1320	8.85	1.62
26	1380	8.87	1.64
27	1439	8.88	1.65
28	1500	8.90	1.67
29	1621	8.92	1.69
30	1739	8.94	1.71
31	1980	8.95	1.72
32	2160	8.96	1.73
33	2403	9.03	1.80
34	2644	9.06	1.83
35	2820	9.07	1.84
36	3000	9.08	1.85

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: ILRW
	Number:
	Client:

Location: North of Spencer, Iowa	Pumping Test: ILRW Well 2	Pumping Well: Well 2
Test Conducted by:		Test Date: 9/30/1980
Analysis Performed by:	New analysis 2	Analysis Date: 6/5/2014
Aquifer Thickness: 31.00 ft	Discharge Rate: 520 [U.S. gal/min]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 1	3.04×10^{4}	9.80×10^{2}	6.36×10^{-2}	48.5	

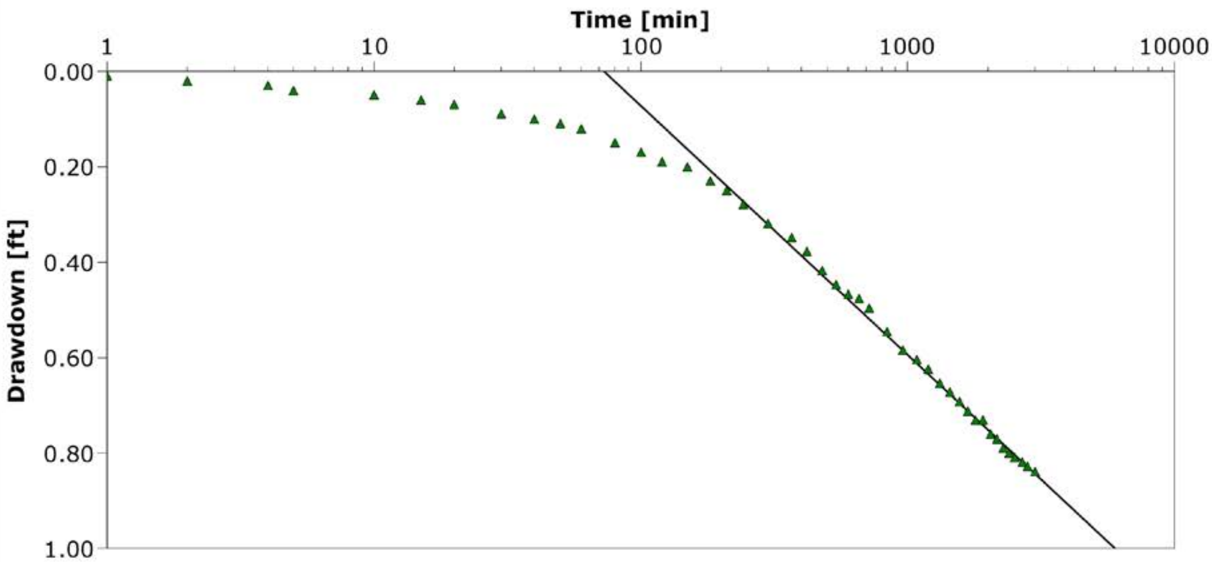
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 1
	Project: ILRW	
	Number:	
	Client:	

Location: North of Spencer, Iowa	Pumping Test: ILRW Well 2	Pumping Well: Well 2
Test Conducted by:	Test Date: 9/30/1980	Discharge Rate: 520 [U.S. gal/min]
Observation Well: OB 2	Static Water Level [ft]: 6.71	Radial Distance to PW [ft]: 221.5

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	6.71	0.00
2	1	6.72	0.01
3	2	6.73	0.02
4	4	6.74	0.03
5	5	6.75	0.04
6	10	6.76	0.05
7	15	6.77	0.06
8	20	6.78	0.07
9	30	6.80	0.09
10	40	6.81	0.10
11	50	6.82	0.11
12	60	6.83	0.12
13	80	6.86	0.15
14	100	6.88	0.17
15	120	6.90	0.19
16	150	6.91	0.20
17	182	6.94	0.23
18	210	6.96	0.25
19	243	6.99	0.28
20	300	7.03	0.32
21	367	7.06	0.35
22	420	7.09	0.38
23	478	7.13	0.42
24	540	7.16	0.45
25	598	7.18	0.47
26	659	7.19	0.48
27	720	7.21	0.50
28	840	7.26	0.55
29	963	7.30	0.59
30	1084	7.32	0.61
31	1198	7.34	0.63
32	1322	7.37	0.66
33	1441	7.39	0.68
34	1562	7.41	0.70
35	1679	7.43	0.72
36	1800	7.45	0.74
37	1920	7.45	0.74
38	2044	7.48	0.77
39	2163	7.49	0.78
40	2282	7.51	0.80
41	2400	7.52	0.81
42	2520	7.53	0.82
43	2700	7.54	0.83
44	2823	7.55	0.84
45	3000	7.56	0.85

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: ILRW
	Number:
	Client:

Location: North of Spencer, Iowa	Pumping Test: ILRW Well 2	Pumping Well: Well 2
Test Conducted by:		Test Date: 9/30/1980
Analysis Performed by:	New analysis 3	Analysis Date: 6/5/2014
Aquifer Thickness: 31.00 ft	Discharge Rate: 520 [U.S. gal/min]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB 2	3.51×10^4	1.13×10^3	8.14×10^{-2}	221.5	

IOWA GEOLOGICAL SURVEY

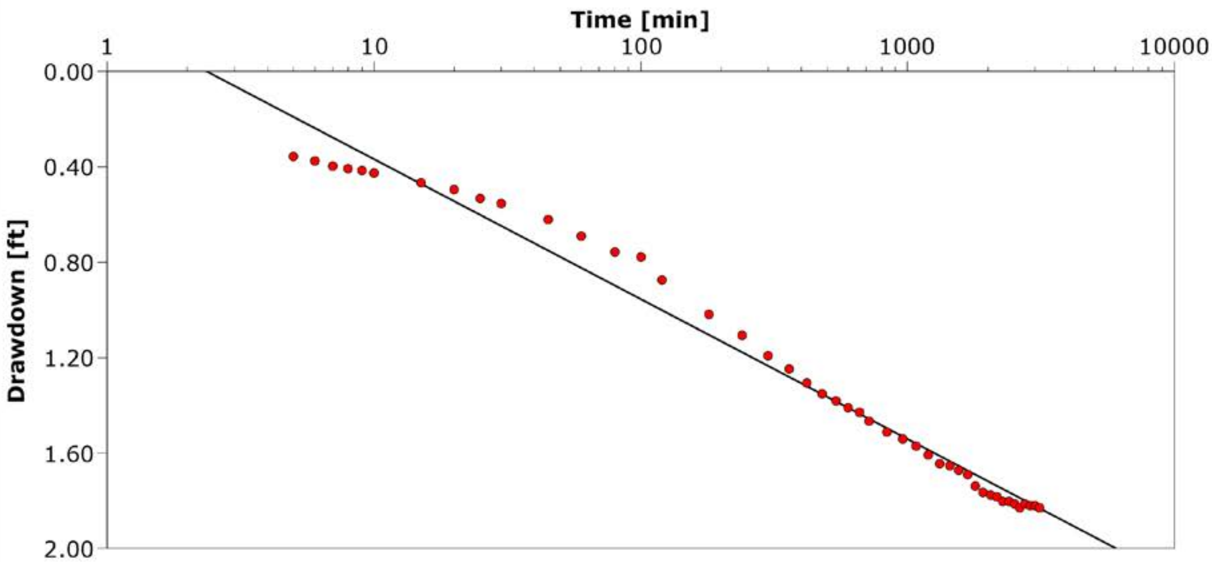
Pumping Test - Water Level Data	Page 1 of 1
Project: ILRW Pump Test	
Number:	
Client:	

Location: North of Spencer, Iowa	Pumping Test: Well 3 pump Test	Pumping Well: Well 3
Test Conducted by:	Test Date: 11/6/1980	Discharge Rate: 430 [U.S. gal/min]
Observation Well: OB1	Static Water Level [ft]: 6.01	Radial Distance to PW [ft]: 56

	Time [min]	Water Level [ft]	Drawdown [ft]
1	5	6.37	0.36
2	6	6.39	0.38
3	7	6.41	0.40
4	8	6.42	0.41
5	9	6.43	0.42
6	10	6.44	0.43
7	15	6.48	0.47
8	20	6.51	0.50
9	25	6.55	0.54
10	30	6.57	0.56
11	45	6.64	0.63
12	60	6.71	0.70
13	80	6.78	0.77
14	100	6.80	0.79
15	120	6.90	0.89
16	180	7.05	1.04
17	240	7.14	1.13
18	300	7.23	1.22
19	360	7.29	1.28
20	420	7.35	1.34
21	480	7.40	1.39
22	540	7.43	1.42
23	600	7.46	1.45
24	660	7.48	1.47
25	720	7.52	1.51
26	840	7.57	1.56
27	960	7.60	1.59
28	1080	7.63	1.62
29	1200	7.67	1.66
30	1320	7.71	1.70
31	1440	7.72	1.71
32	1560	7.74	1.73
33	1680	7.76	1.75
34	1800	7.81	1.80
35	1920	7.84	1.83
36	2050	7.85	1.84
37	2160	7.86	1.85
38	2280	7.88	1.87
39	2400	7.88	1.87
40	2520	7.89	1.88
41	2640	7.91	1.90
42	2760	7.89	1.88
43	2880	7.90	1.89
44	3000	7.90	1.89
45	3120	7.91	1.90

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report**
	Project: ILRW Pump Test
	Number:
	Client:

Location: North of Spencer, Iowa	Pumping Test: Well 3 pump Test	Pumping Well: Well 3
Test Conducted by:		Test Date: 11/6/1980
Analysis Performed by:	New analysis 2	Analysis Date: 6/5/2014
Aquifer Thickness: 26.00 ft	Discharge Rate: 430 [U.S. gal/min]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB1	2.58×10^4	9.93×10^2	3.04×10^{-2}	56.0	

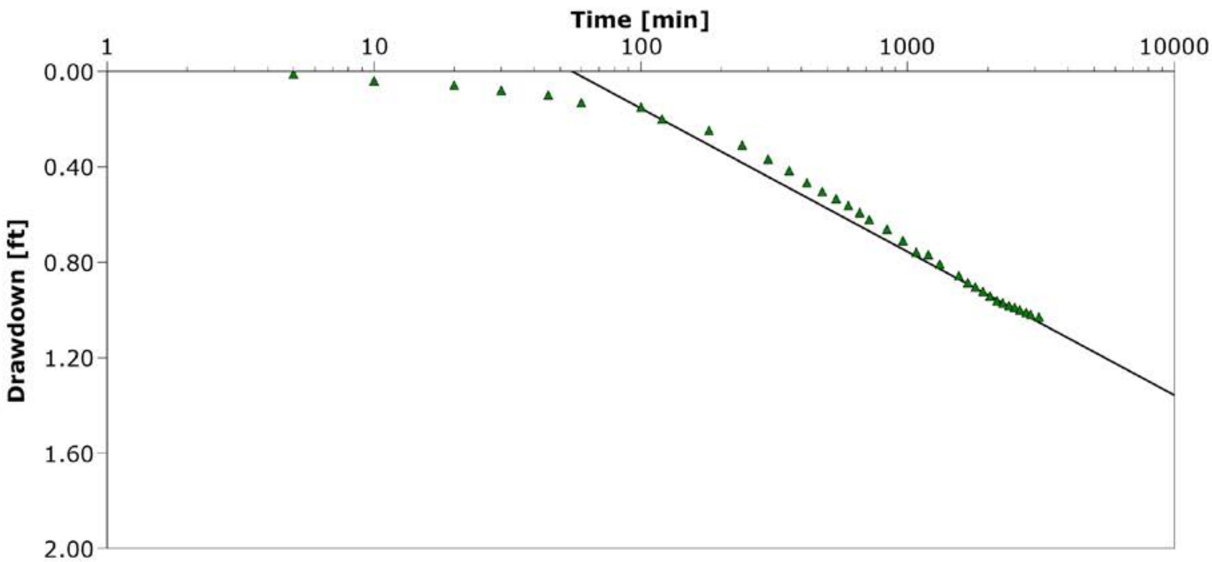
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 1
	Project: ILRW Pump Test	
	Number:	
	Client:	

Location: North of Spencer, Iowa	Pumping Test: Well 3 pump Test	Pumping Well: Well 3
Test Conducted by:	Test Date: 11/6/1980	Discharge Rate: 430 [U.S. gal/min]
Observation Well: OB2	Static Water Level [ft]: 6.70	Radial Distance to PW [ft]: 189.3

	Time [min]	Water Level [ft]	Drawdown [ft]
1	5	6.37	0.36
2	6	6.39	0.38
3	7	6.41	0.40
4	8	6.42	0.41
5	9	6.43	0.42
6	10	6.44	0.43
7	15	6.48	0.47
8	20	6.51	0.50
9	25	6.55	0.54
10	30	6.57	0.56
11	45	6.64	0.63
12	60	6.71	0.70
13	80	6.78	0.77
14	100	6.80	0.79
15	120	6.90	0.89
16	180	7.05	1.04
17	240	7.14	1.13
18	300	7.23	1.22
19	360	7.29	1.28
20	420	7.35	1.34
21	480	7.40	1.39
22	540	7.43	1.42
23	600	7.46	1.45
24	660	7.48	1.47
25	720	7.52	1.51
26	840	7.57	1.56
27	960	7.60	1.59
28	1080	7.63	1.62
29	1200	7.67	1.66
30	1320	7.71	1.70
31	1440	7.72	1.71
32	1560	7.74	1.73
33	1680	7.76	1.75
34	1800	7.81	1.80
35	1920	7.84	1.83
36	2050	7.85	1.84
37	2160	7.86	1.85
38	2280	7.88	1.87
39	2400	7.88	1.87
40	2520	7.89	1.88
41	2640	7.91	1.90
42	2760	7.89	1.88
43	2880	7.90	1.89
44	3000	7.90	1.89
45	3120	7.91	1.90

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: ILRW Pump Test
	Number:
	Client:

Location: North of Spencer, Iowa	Pumping Test: Well 3 pump Test	Pumping Well: Well 3
Test Conducted by:		Test Date: 11/6/1980
Analysis Performed by:	New analysis 1	Analysis Date: 6/5/2014
Aquifer Thickness: 26.00 ft	Discharge Rate: 430 [U.S. gal/min]	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
OB2	2.52×10^4	9.69×10^2	6.08×10^{-2}	189.3	

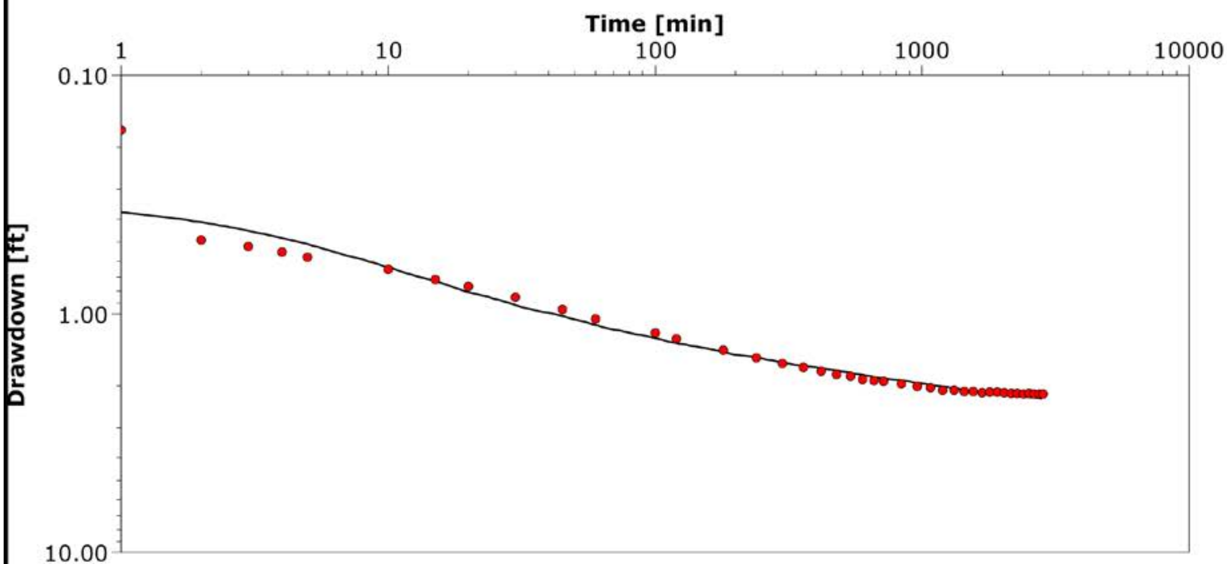
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 1
	Project: ILRW Well 4 Pump Test	
	Number:	
	Client:	

Location: ILRW North of Spencer, Iowa	Pumping Test: Well 4	Pumping Well: Well 4
Test Conducted by:	Test Date: 9/22/1980	Discharge Rate: 450 [U.S. gal/min]
Observation Well: OB1	Static Water Level [ft]: 6.09	Radial Distance to PW [ft]: 50

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	6.09	0.00
2	1	6.26	0.17
3	2	6.58	0.49
4	3	6.61	0.52
5	4	6.64	0.55
6	5	6.67	0.58
7	10	6.74	0.65
8	15	6.81	0.72
9	20	6.86	0.77
10	30	6.94	0.85
11	45	7.05	0.96
12	60	7.14	1.05
13	100	7.29	1.20
14	120	7.36	1.27
15	180	7.51	1.42
16	240	7.62	1.53
17	300	7.70	1.61
18	360	7.77	1.68
19	420	7.83	1.74
20	480	7.88	1.79
21	540	7.92	1.83
22	600	7.97	1.88
23	660	8.00	1.91
24	720	8.01	1.92
25	840	8.06	1.97
26	960	8.10	2.01
27	1080	8.13	2.04
28	1200	8.18	2.09
29	1320	8.18	2.09
30	1440	8.20	2.11
31	1560	8.21	2.12
32	1680	8.23	2.14
33	1800	8.22	2.13
34	1920	8.22	2.13
35	2040	8.23	2.14
36	2160	8.24	2.15
37	2280	8.25	2.16
38	2400	8.26	2.17
39	2520	8.25	2.16
40	2640	8.26	2.17
41	2760	8.26	2.17
42	2850	8.26	2.17

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: ILRW Well 4 Pump Test
	Number:
	Client:

Location: ILRW North of Spencer, Iowa	Pumping Test: Well 4	Pumping Well: Well 4
Test Conducted by:		Test Date: 9/22/1980
Analysis Performed by:	New analysis 2	Analysis Date: 6/5/2014
Aquifer Thickness: 23.00 ft	Discharge Rate: 450 [U.S. gal/min]	



Calculation using 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	2.29×10^{4}	9.96×10^{2}	2.09×10^{-2}	4.11×10^{-2}	2.31×10^{4}	50.0

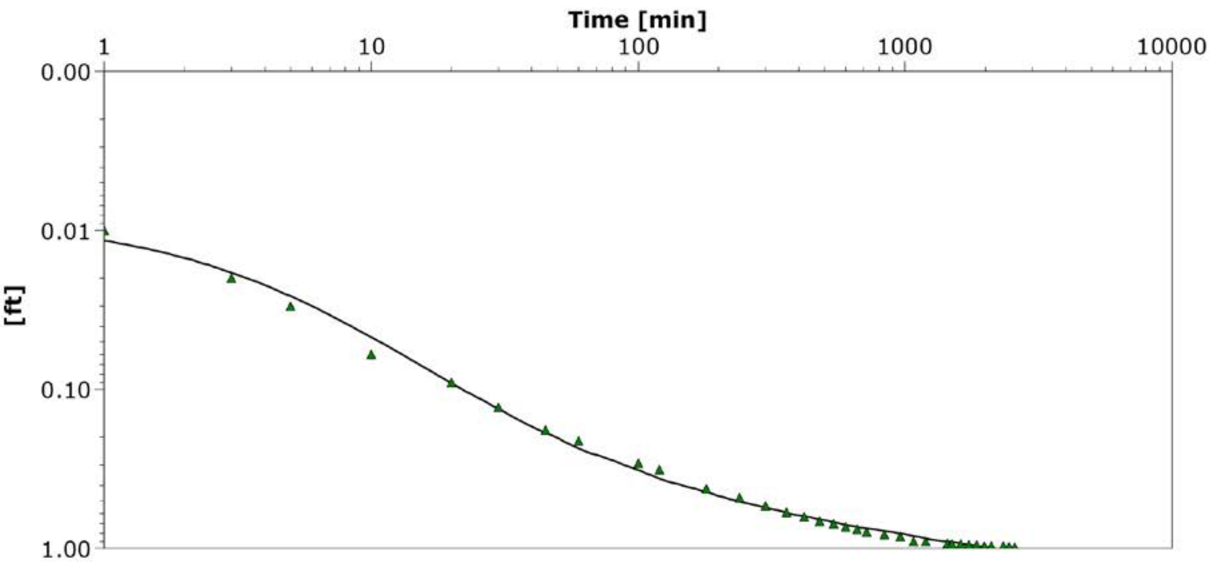
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 1
	Project: ILRW Well 4 Pump Test	
	Number:	
	Client:	

Location: ILRW North of Spencer, Iowa	Pumping Test: Well 4	Pumping Well: Well 4
Test Conducted by:	Test Date: 9/22/1980	Discharge Rate: 450 [U.S. gal/min]
Observation Well: OB2	Static Water Level [ft]: 6.88	Radial Distance to PW [ft]: 200

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	6.88	0.00
2	1	6.89	0.01
3	3	6.90	0.02
4	5	6.91	0.03
5	10	6.94	0.06
6	20	6.97	0.09
7	30	7.01	0.13
8	45	7.06	0.18
9	60	7.09	0.21
10	100	7.17	0.29
11	120	7.20	0.32
12	180	7.30	0.42
13	240	7.36	0.48
14	300	7.42	0.54
15	360	7.47	0.59
16	420	7.51	0.63
17	480	7.55	0.67
18	540	7.58	0.70
19	600	7.61	0.73
20	660	7.64	0.76
21	720	7.67	0.79
22	840	7.70	0.82
23	960	7.72	0.84
24	1080	7.78	0.90
25	1200	7.78	0.90
26	1440	7.81	0.93
27	1500	7.82	0.94
28	1620	7.82	0.94
29	1740	7.83	0.95
30	1860	7.83	0.95
31	1980	7.84	0.96
32	2100	7.84	0.96
33	2340	7.84	0.96
34	2460	7.85	0.97
35	2580	7.86	0.98

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report** Project: ILRW Well 4 Pump Test Number: Client:

Location: ILRW North of Spencer, Iowa	Pumping Test: Well 4	Pumping Well: Well 4
Test Conducted by:		Test Date: 9/22/1980
Analysis Performed by:	New analysis 1	Analysis Date: 6/5/2014
Aquifer Thickness: 23.00 ft	Discharge Rate: 450 [U.S. gal/min]	



Calculation using 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]
OB2	2.99×10^4	1.30×10^3	3.27×10^{-2}	6.17×10^{-2}	4.49×10^4	200.0

Iowa Geological Survey
The University of Iowa
300 Trowbridge Hall
Iowa City, Iowa 52242-1585
(319) 335-1575
www.iowageologicalsurvey.org