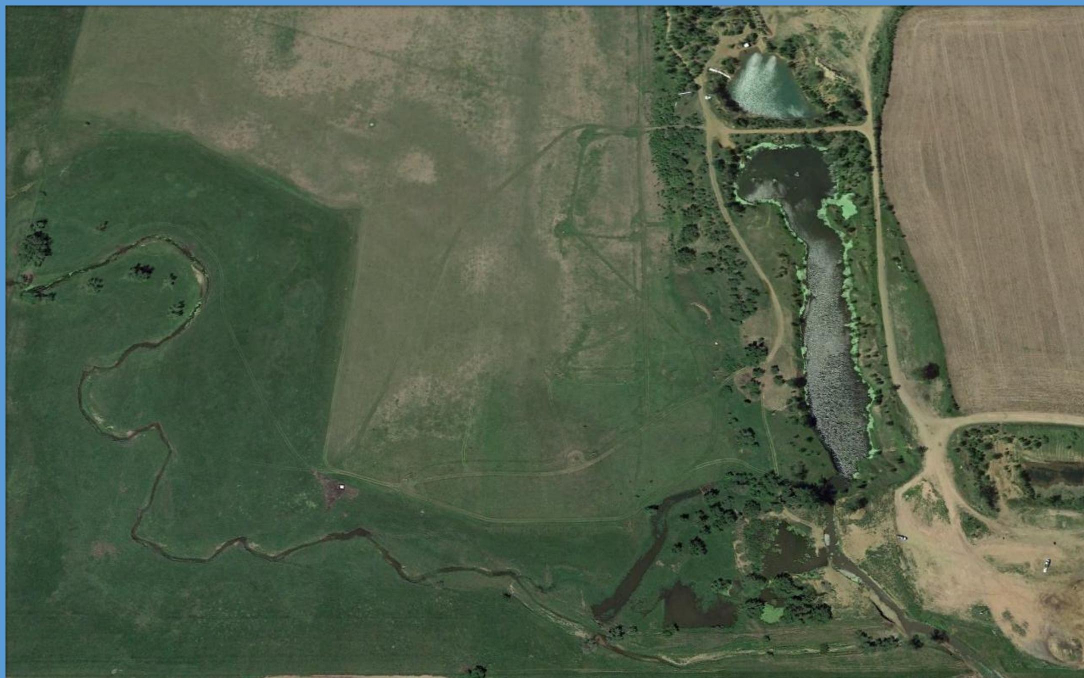

Investigation of a Recharge Basin to Improve Drought Resiliency and Aquifer Sustainability

Rock Valley Rural Water

Water Resources Investigation Report 15

The University of Iowa

IOWA GEOLOGICAL SURVEY

IIHR Hydroscience & Engineering

Investigation of a Recharge Basin to Improve Drought Resiliency and Aquifer Sustainability
Rock Valley Rural Water

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EXECUTIVE SUMMARY

The Iowa Geological Survey completed a hydrogeologic investigation of the alluvial aquifer near the Rock Valley Rural Water District wellfield, located in Sioux County, Iowa. The main purpose of the investigation was to evaluate the newly constructed recharge basin as a drought resiliency strategy, and evaluate the potential water quality impacts related to the basin. Monthly water level measurements and groundwater quality samples were collected at the site for approximately 12 months. In addition, a three-dimensional groundwater flow model was developed to evaluate the groundwater quantity benefits.

Based on data from the on-site production and observation wells, the thickness of alluvial deposits beneath the Rock Valley Rural Water District wellfield varies from 37 to 58 feet, and averages approximately 45 feet. The deposits are not uniform or homogeneous but include clay, silt, sand, gravel, cobbles, and boulders. The alluvial aquifer consists of glacial outwash deposits that may have been associated with the ancestral Big Sioux River.

Based on the observed monthly water levels, the recharge basin creates a groundwater mound of approximately 8 to 10 feet. The general groundwater flow direction and hydraulic gradient stays relatively constant throughout the 12 month period due to the stability of the water level elevation in the recharge basin throughout the year. The groundwater table elevations also remain relatively constant. The one exception is in the month of February, when the water levels are approximately 2 feet higher than normal. The rise in water levels during the month of February may be related to the relatively low water use during the winter months and the newly constructed beaver dam first observed during the month of February. There are also fluctuations in groundwater elevations and flow directions based on which production wells are actively pumping and which wells are idle.

Pump tests were conducted in RVRWD Production Wells 2, 7, and 9. Observation wells OB 3, OB4, and OB5 were used to measure drawdowns. Transmissivity values range from 13,900 ft^2/day near OB3 to 40,400 ft^2/day near OB4. Hydraulic conductivity values were found to range from 348 to 1,010 feet/day, with an arithmetic mean of 730 feet/day. Storativity values or specific yield range from 0.014 near OB3 to 0.1 near OB4. In addition to the aquifer parameter estimation, the observed drawdown data was also used to help calibrate the groundwater flow model.

Based on the calibrated groundwater flow model, the recharge basin would provide additional groundwater storage to the RVRWD production wells for approximately 19 months. During the summer of the second year of severe drought the groundwater elevations reached the approximate pump elevations in five of the RVRWD production wells and the model produced dry cells.

Nitrate as nitrogen concentrations in the shallow groundwater directly downgradient of the recharge basin were consistently lower than in the basin. Based on water quality results, nitrate reduction in the recharge basin ranged from 41% in November 2016 to 98% in January 2016, with an average reduction for the 12 month period of 64%.

The nitrate/chloride ratio in the water sampled from the recharge basin is much higher than the groundwater sampled from downgradient observation well OB5. The biological reduction within the recharge basin sediments is decreasing the nitrate concentrations, but the chloride concentrations remain relatively unchanged. Based on the nitrate/chloride ratios, the primary nitrate reduction process observed in the recharge basin is attributed to biological reduction.

The nitrate as nitrogen concentrations in both the RVRWD production wells and the on-site observation wells fluctuate seasonally, with the highest concentrations generally occurring during the winter and early spring months. Biological reduction in the recharge basin and the low nitrate precipitation recharge related to the uptake by prairie grass, slowly reduces the nitrate concentrations in the shallow groundwater throughout the growing season and into the fall.

The management of the recharge basin is dependent on the proper use of the inlet control valve located on Unnamed Creek. This requires the balance between reducing drought impacts by increasing groundwater storage (leaving the valve open) and minimizing the nitrate concentrations in the recharge basin and shallow groundwater during flood events (closing the valve).

INTRODUCTION

The Iowa Geological Survey completed a hydrogeologic investigation of the alluvial aquifer near the Rock Valley Rural Water District (RVRWD) wellfield which is located in Sioux County, Iowa (Figure 1). The current users include RVRWD and approximately twenty-one irrigation wells. The main purpose of the investigation was to evaluate the newly constructed recharge basin as a drought resiliency strategy. The objective of using a recharge basin near a high capacity wellfield is to increase the surface water storage within the aquifer. During moderate to severe droughts, little if any precipitation recharge enters an alluvial aquifer. To maintain well capacity and water production, alluvial aquifers must rely on nearby streams, rivers, and other surface water as sources of recharge. Recharge basins provide additional groundwater storage during periods of normal or above normal precipitation. This additional storage is then available to maintain water production during dry periods and droughts.

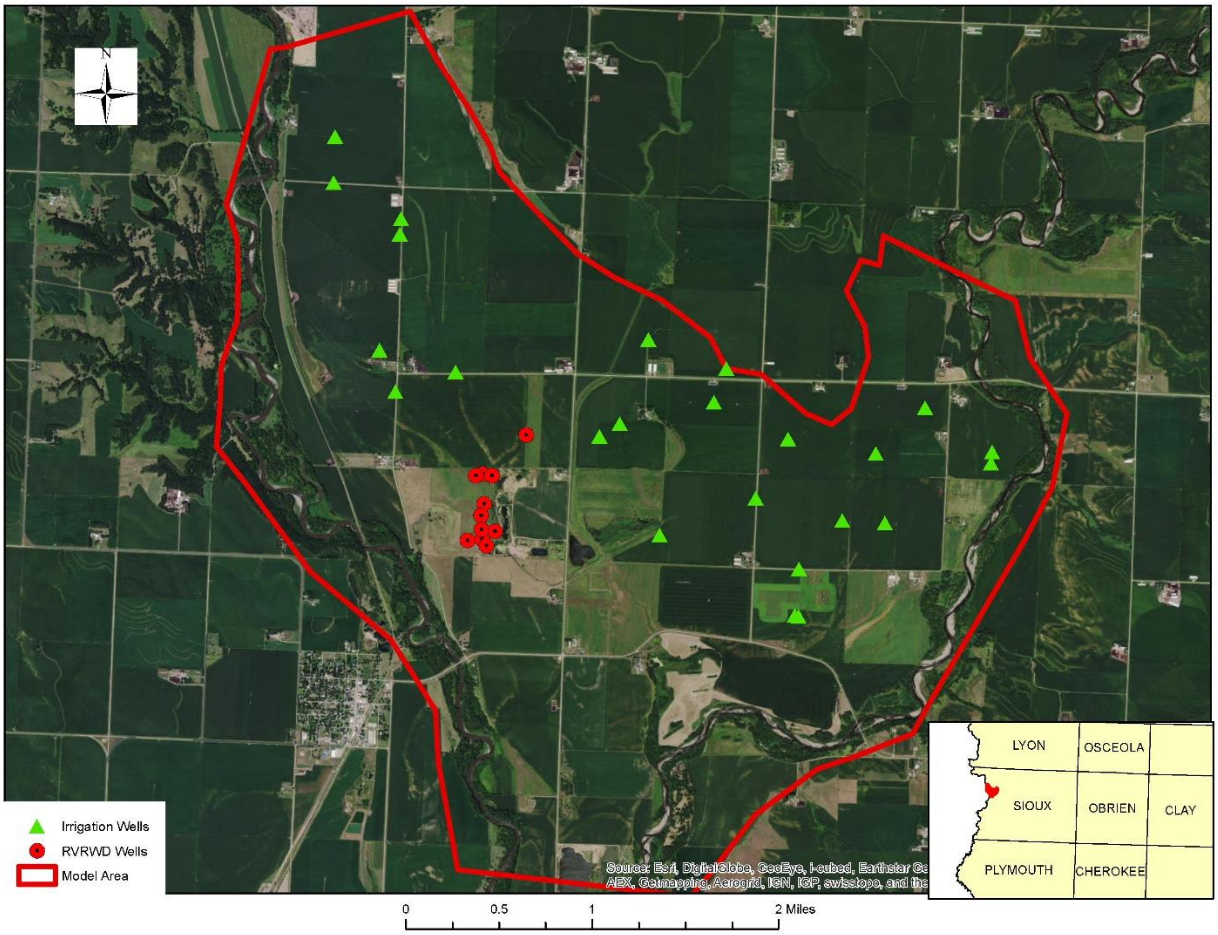

Figure 1. Rock Valley Rural Water District location and model extent.

Monthly water level measurements and water quality samples were collected at the site for approximately one year. In addition, a three-dimensional groundwater flow model was developed to evaluate the groundwater quantity benefits, and to see what, if any, impacts the recharge basin may have on groundwater quality. Previous investigations have been conducted by Quad States Services, Inc. (QSSI) (Groundwater Modeling Report-Rock Valley Rural Water Wellfield, December 2005), Leggette

Bradshears & Graham, Inc. (LBG) (Potential Well-Field Interference, Rock Valley Rural Water District, August 15, 2005), and the Iowa Geological Survey in 2006 and 2014 (Gannon and Vogelgesang, 2014). In addition to the monthly water level readings collected during 2015 and 2016, the current investigation also uses water level data and pumping rates that were collected during the 2012 and 2013 drought.

Site Background Information

Iowa experienced a severe statewide drought starting in the fall of 2011 with dry conditions continuing throughout most of 2012 and 2013. Discharge in many rivers reached historic lows during the widespread drought. Annual rainfall was more than 5 to 10 inches below normal in some areas. The lowest average daily discharge in the Rock River at Rock Rapids (USGS #06483290) was recorded in 2013 at 26 cubic feet per second (cfs). Like rainfall, river discharge has been low during other drought years, including 1958, 1976, and 2003. However, unlike previous droughts, the security risk associated with the 2012-13 drought increased significantly due to sociological and economic changes in water distribution and use. The rapid expansion of rural water systems and the concentration of livestock in animal feeding operations (AFOs) combined to place additional strain on the limited water resources. Unlike the past, when most farms and small rural communities relied on their own wells, regional rural water systems now supply most of the water to individual farms, livestock producers, AFOs, and rural communities.

Northwest Iowa, especially Sioux County, was hit particularly hard by the extended drought. Although Sioux County has a relatively low population of 34,937 residents (U.S. Census Bureau, 2015), 1.2 million hogs and 395,000 cattle were marketed in 2015 (USDA, Census of Agriculture, 2015). In addition, Sioux County is the state's leader in dairy production and second in egg production. The increase in water consumption by both urban and rural users in 2012 and 2013 put an enormous strain on water utilities, especially rural water districts. The largest public water system in Sioux County is RVRWD (Figure 1), which is located approximately 10 miles southwest of the City of Rock Valley. Over 75 percent of the water sold by RVRWD in 2012 was used by livestock. Overall, RVRWD sold an average of 2.2 million gallons per day (mgd) of water in 2012, with a peak day usage of 3.8 mgd. In addition to RVRWD, approximately twenty-one nearby irrigation wells pumped an average of 13.7 mgd of water during the summer of 2012.

To alleviate the stress on the aquifer, and to maintain a continuous water supply to its customers, RVRWD implemented an emergency water plan on May 30, 2013. The emergency water plan involved pumping water from the Big Sioux River using a temporary water use permit obtained from the Iowa Department of Natural Resources. Water was pumped from the river to a nearby sand and gravel pit (Figure 2) at approximately 3,000 gallons per minute. Both static and pumping water levels in the RVRWD production wells began to rise, and water production increased to pre-drought levels. The emergency water plan provided a short term solution to the water quantity needs at RVRWD, but the overall water quality impact on the shallow alluvial aquifer remained unknown.

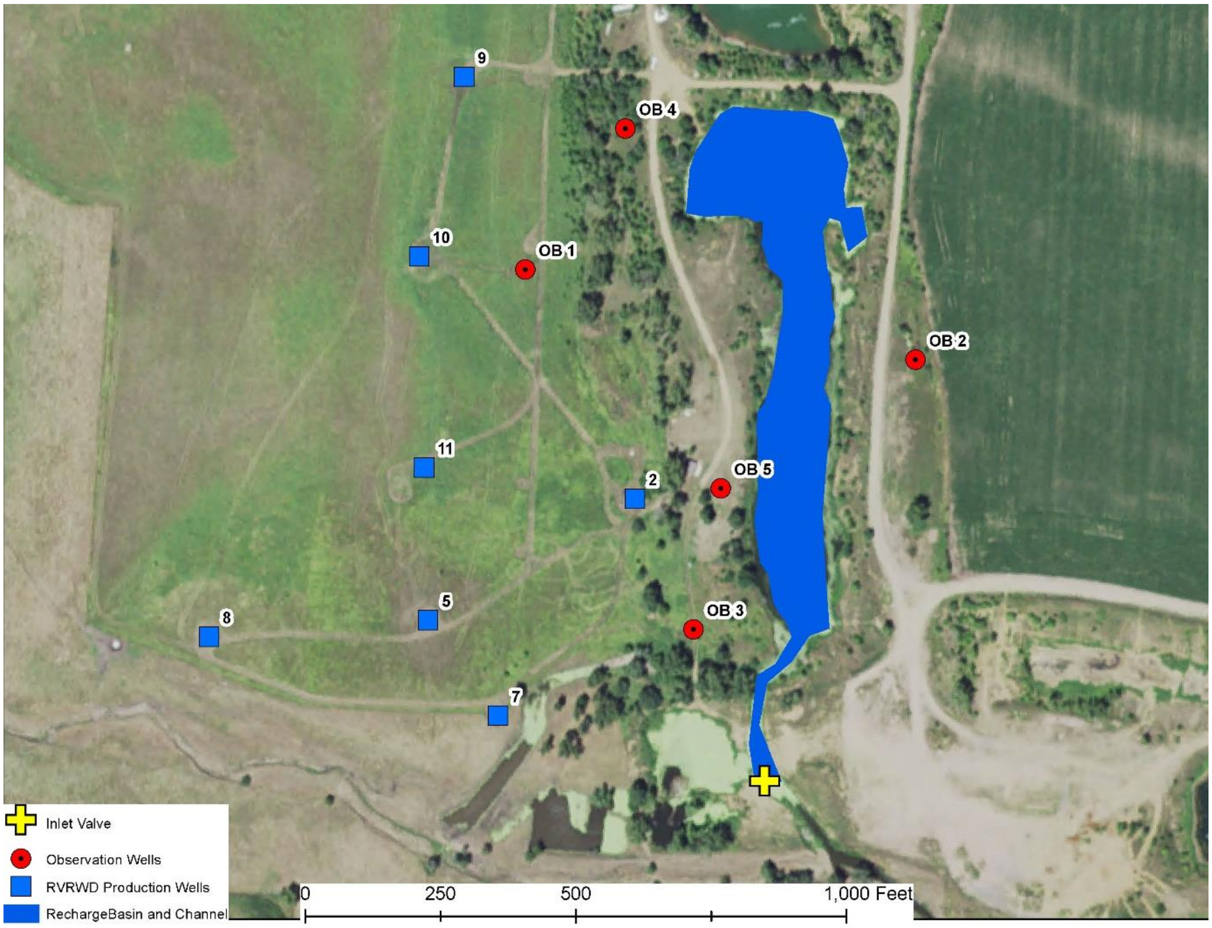

Figure 2. Sand and gravel quarry location used as a recharge basin. Unnamed Creek was re-routed into the quarry.

An engineered recharge basin was designed by DGR Engineering, Inc., and constructed in the former sand and gravel pit near RVRWD during the fall of 2013. Permits were acquired by the IDNR and the U.S. Corps of Engineers. As part of this design, a small Unnamed Creek (17 square mile drainage area) was diverted into the recharge basin. On June 17, 2014, surface water from the Unnamed Creek began to fill the basin. Over the next 3 months, groundwater elevations rose approximately 11 to 15 feet in the RVRWD wellfield. This additional recharge allowed RVRWD to maintain water production from its 11 shallow wells. However, important questions still remain regarding the duration of this benefit during an extended drought and the potential impacts of this induced recharge on water quality.

Field Activities and Data Collection

On November 4, 2015, four additional observation wells (OB2, OB3, OB4, and OB5)were installed as shown on Figure 3. The wells consisted of 2-inch diameter schedule 40 PVC, and were screened from 30 to 40 feet using 0.010 slot screen. Driller's logs and well construction diagrams are shown in Appendix A. A steel protective casing was also used for each well to complete the installation. The top of the PVC casing elevation for each new observation well, one existing observation well (OB1), and one piezometer (PZ-1-installed near SW-3) were surveyed using a David White transit and survey rod. The top of Production Well 10 was used as the datum elevation.

Monthly water levels were measured starting in November of 2015 using an In-Situ electronic water level probe. The monthly water levels and groundwater elevations are shown in Appendix B. Water samples were also collected monthly from each observation well and piezometer location using a peristaltic pump. In addition, water samples were collected in the Unnamed Creek upstream and downstream of Solberg pond, in the recharge basin, and in RVRWD Production Wells 2, 7, 9, and 10 (Figure 3). Samples were analyzed for nitrate as nitrogen and total chloride. All of the sampling locations are shown in Figure 3.

In addition to the collection of water quality samples, a calibrated local-scale groundwater model was developed to evaluate the duration of the water storage benefits. The groundwater flow model revised a regional model developed by the Iowa Geological Survey in 2014 (Gannon and Vogelgesang, 2014).

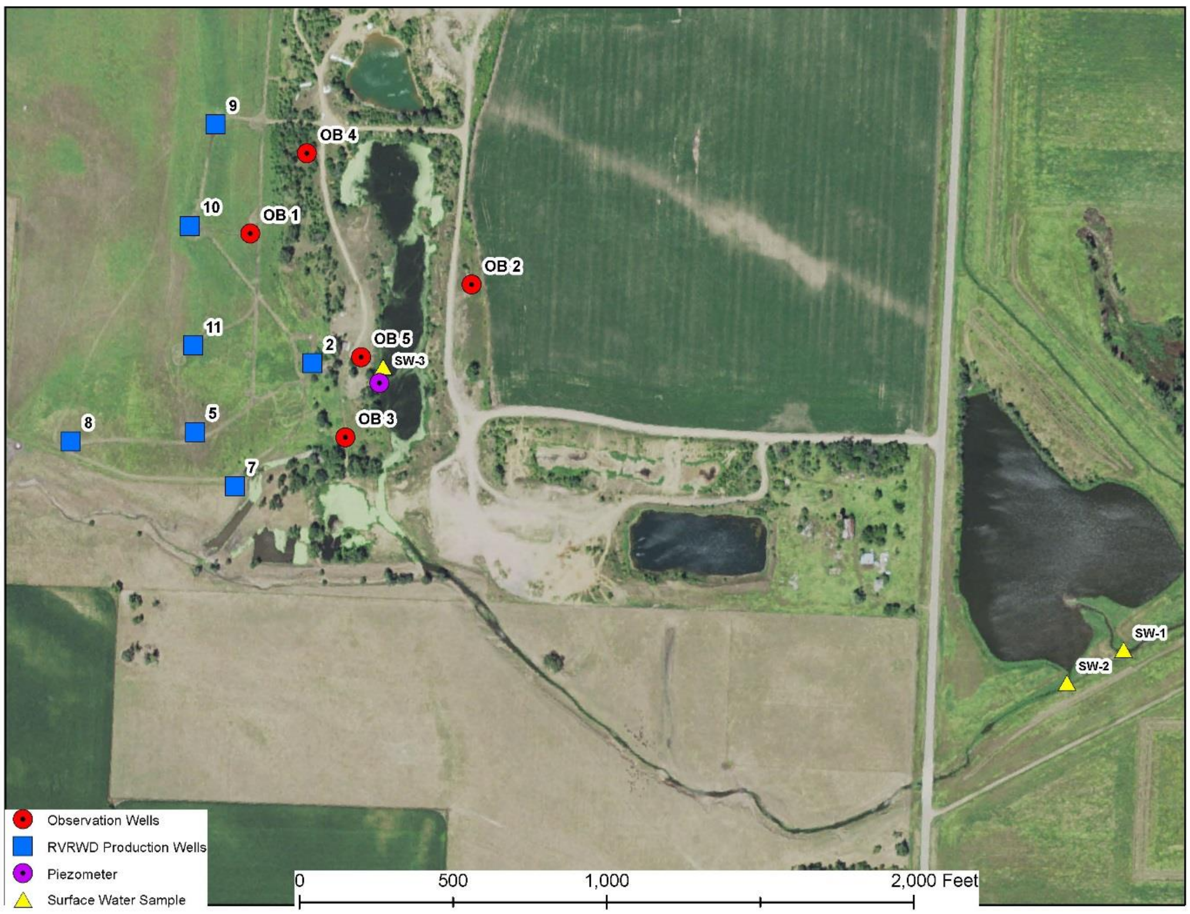

Figure 3. Rock Valley Rural Water District wellfield showing the location of existing observation well OB1, four new observation wells OB2, OB3, OB4, and OB5, and surface water sample locations SW1, SW2, and SW3.

GEOLOGY

Based on data from the on-site production wells and observation wells (Appendix A), the thickness of alluvial deposits beneath the RVRWD wellfield varies from 37 to 58 feet, and averages approximately 45 feet. The deposits are not uniform or homogeneous but include clay, silt, sand, gravel, cobbles and boulders. The alluvial aquifer consists of glacial outwash deposits that may have been associated with the ancestral Big Sioux River. The upper 2 to 5 feet of the aquifer consists of fine grained sand or silty sand topsoil. Beneath the topsoil is fine to very coarse sand, gravel, cobbles and boulders. The base of the aquifer is underlain by either glacial till, alluvial clay, or Cretaceous shale throughout the study area.

HYDROGEOLOGY

Groundwater flow in the vicinity of the RVRWD wellfield is strongly influenced by the newly constructed recharge basin. Monthly water level data from the five on-site observation wells and one piezometer were used to generate groundwater elevation contour maps. Figures 4 through 7 show the observed groundwater table elevations for November 2015, February 2016, April 2016, and July 2016. The monthly data can be found in Appendix B. Based on the observed monthly water levels, the recharge basin creates a groundwater mound of approximately 8 to 10 feet. The general groundwater flow direction and hydraulic gradient stays relatively constant throughout the 12-month period due to the stability in the water level elevation in the recharge basin. The groundwater table elevations also remain relatively constant. The one exception is in the month of February, when the water levels were approximately 2 feet higher than normal. The rise in water levels during the month of February may be related to the relatively low water use during the winter months and the newly constructed beaver dam first observed during the month of February. Groundwater elevations and flow directions also fluctuated when production wells were actively pumping and when the wells were idle. Our measured evaluations did not factor in the active versus inactive pumping cycles.

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 on annual precipitation data. In Iowa much of the precipitation 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. The annual rate of precipitation recharge during 2012 was calibrated to be approximately 4 inches/year, and 0 inches per year during the span of June 1 through August 31 (Gannon and Vogelgesang, 2014).

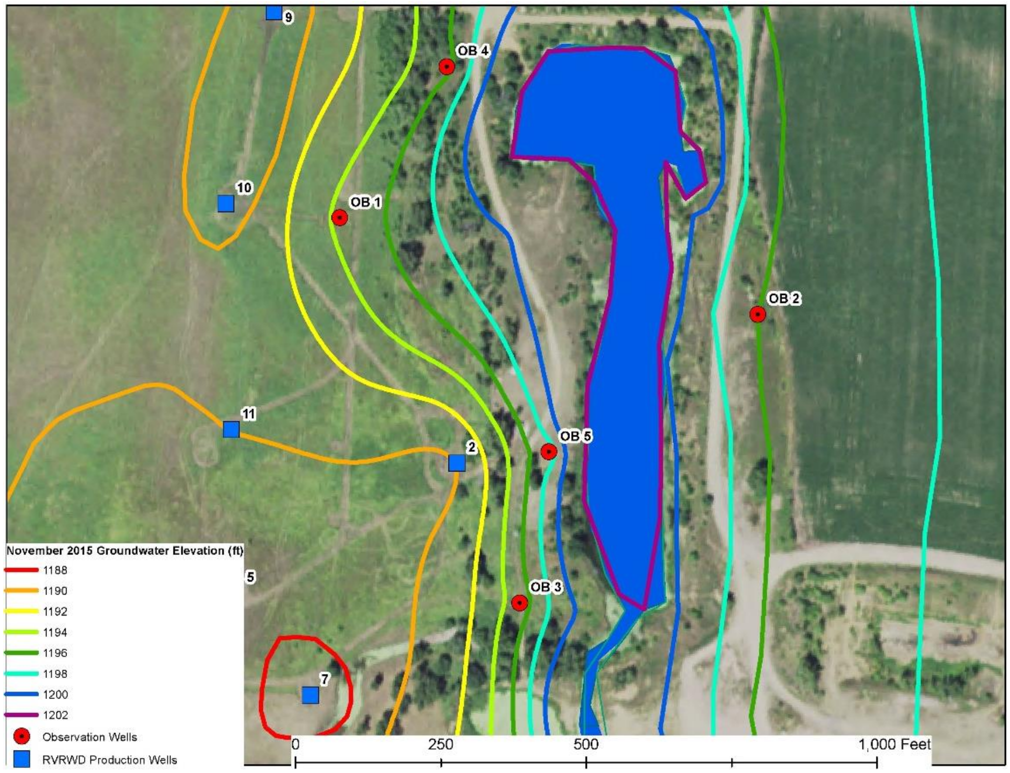

Figure 4. Observed groundwater elevation contour map for November 2015.

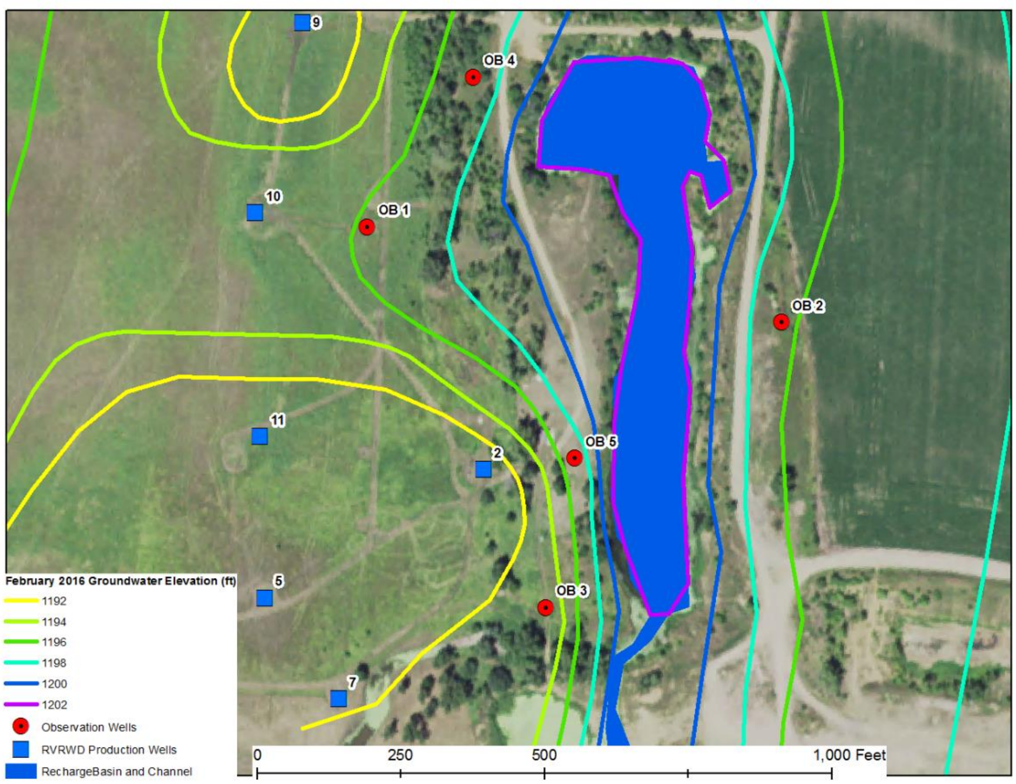

Figure 5. Observed groundwater elevation contour map for February 2016.

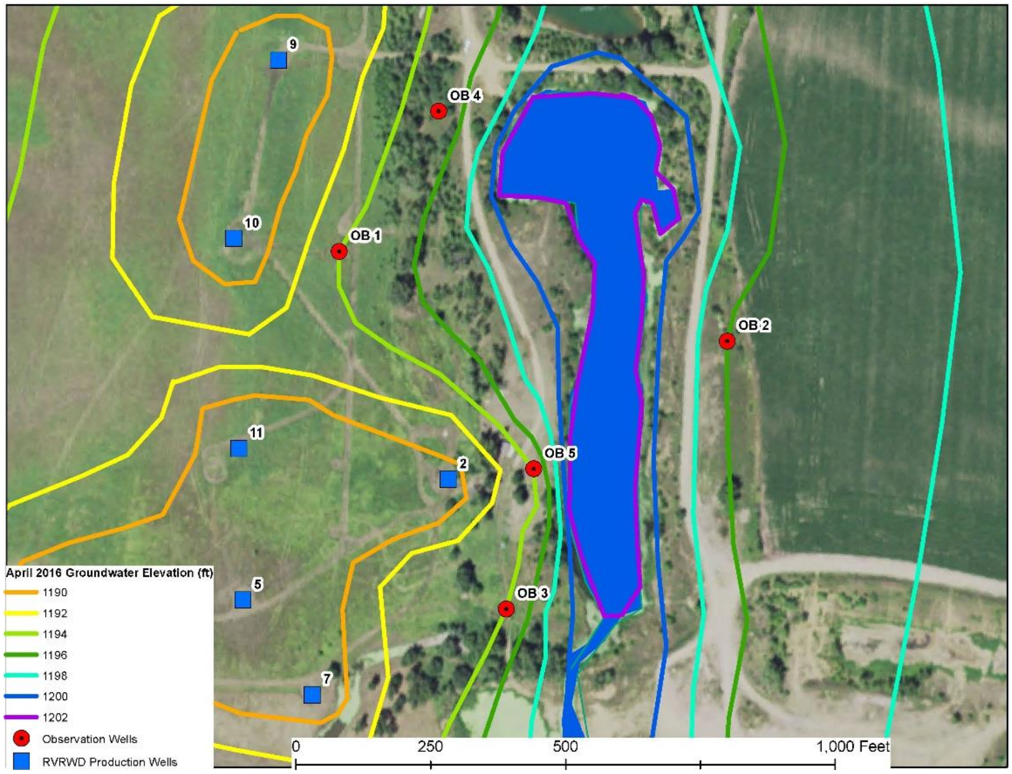

Figure 6. Observed groundwater elevation contour map for April 2016.

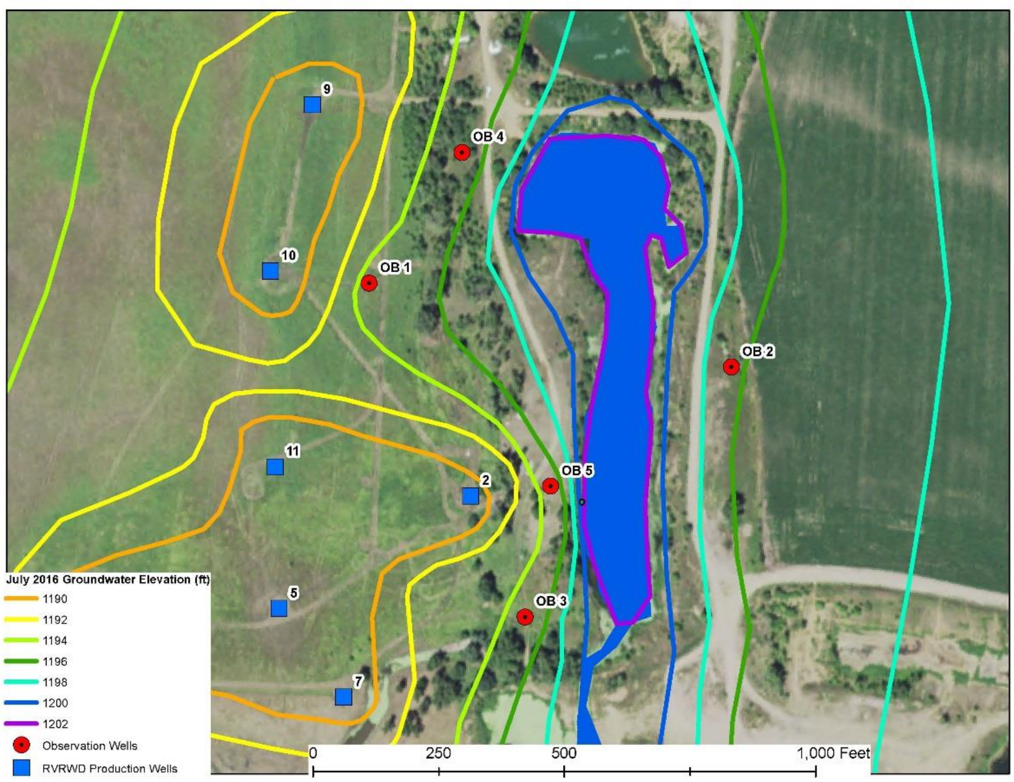

Figure 7. Observed groundwater elevation contour map for July 2016.

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 pump tests with known pumping rates, pumping duration, accurate well locations, and accurate water level measurements. Pump tests were conducted in RVRWD Production Wells 2, 7, and 9. Observation wells OB3, OB4, and OB5 were used to measure drawdowns. Table 1 shows the pump test results, which indicate transmissivity values range from 13,900 ft^2/day near OB3 to 40,400 ft^2/day near OB4. Storativity values or specific yield range from 0.014 near OB3 to 0.1 near OB4. In addition to the aquifer parameter estimation, the observed drawdown data was also used to help calibrate the groundwater flow model. This will be discussed later in the report. The pump test graphs and raw data are shown in Appendix C.

Table 1. Aquifer pump test and model calibration results at the Rock Valley Rural Water District wellfield.

Observation Well	Calculated Transmissivity (ft2/day)	Calculated Hydraulic Conductivity (ft./day)	Calculated Storativity	Observed Drawdown Feet	Simulated Drawdown Feet	Model Hydraulic Conductivity K (ft/day
Observation Well 3	13,900	348	0.014	0.45	0.44	400
Observation Well 4	40,400	1010	0.1	0.28	0.4	1000
Observation Well 5	33,300	833	0.06	0.697	0.67	750

Hydraulic conductivity can be calculated by dividing transmissivity by the overall aquifer thickness. Hydraulic conductivity values were found to range from 348 to 1,010 feet/day, with an arithmetic mean of 730 feet/day. The graphs and raw data tables from the pump tests can be found in Appendix C.

Irrigation Wells

Most of the land use in the vicinity of RVRWD is in row crop agriculture. A large percentage of the corn acreage is irrigated due to the sandy soils in the valley. Approximately twenty-one (21) irrigation wells were identified in the valley as shown in Figure 1. Annual irrigation rates available for the known irrigation wells (Mike Anderson, IDNR-Water Supply Engineering Section) are given in Table 2.

Table 2. Annual and peak water usage for irrigation wells based on Iowa Department of Natural Resources water-use database.

Permit Held	Number of Wells	Average Q (GPD)	Peak Q (GPD)	Maximum Historical Q (GPD)	Allocated Q (gpd)
RVRWD	11	2,220,000	3,800,000	Not Applicable	Not Applicable
Harley Kats (Estate)	1	Not Applicable	Not Applicable	526,000*	869,000*
Jay Grevengoed 1	3	Not Applicable	Not Applicable	1,005,000*	435,000*
Jay Grevengoed 2	1	Not Applicable	Not Applicable	428,000*	435,000*
Marvin Vonk	1	Not Applicable	Not Applicable	602,000*	625,000*
Ranschau Brothers	1	Not Applicable	Not Applicable	977,000*	733,000*
Murlyn Wennblom	2	Not Applicable	Not Applicable	1,000,000*	896,000*
Hoogendoorn Farms 1	5	Not Applicable	Not Applicable	4,619,000*	4,290,000*
Hoogendoorn Farms 2	1	Not Applicable	Not Applicable	1,109,000*	978,000*
Roger Miller	1	Not Applicable	Not Applicable	908,000*	1,249,000*
Arnold Zomermaand	1	Not Applicable	Not Applicable	1,076,000*	815,000*
Westra Farms	2	Not Applicable	Not Applicable	358,000*	868,000*
Loren Groeneweg	2	Not Applicable	Not Applicable	1,090,000*	2,607,000*
* = Based on a 60 day Irrigation Season (Maximum and allocated usage)					
Q = Discharge (gallons per day)					
(yellow)	= Irrigation discharge used in the model				

GROUNDWATER MODELING

The model software Visual MODFLOW Classic Version v.4.6.0.167 (June 2016) was used to simulate the groundwater flow in the alluvial aquifer under severe drought conditions. The original model was developed in 2014 (Gannon and Vogelgesang, 2014), and was recalibrated in the vicinity of the RVRWD wellfield using the new on-site test borings and pump test data. A two-layered model was used for the simulation. Borehole logs were obtained from the IGS GEOSAM database and from on-site test borings, and elevation data were obtained from LiDAR (2-foot contour intervals). The model boundary conditions and inputs include the following:

- Layer 1 includes the thin topsoil as well as the sand and gravel aquifer. The horizontal hydraulic conductivity was calibrated within the model. The vertical hydraulic conductivity value was assigned a value 1/10 the horizontal hydraulic conductivity.
- Layer 2 is primarily silty clay (glacial till or shale). The horizontal hydraulic conductivity was assigned a value of 0.03 feet/day. The vertical hydraulic conductivity value was assigned a value 1/10 the horizontal hydraulic conductivity.
- The uplands were considered no-flow boundaries. This was represented by de-activating the grids outside the alluvial aquifer boundary. The alluvial aquifer boundary was estimated using Natural Resource Conservation Service (NRCS) soils data and LiDAR elevation data.
- The Rock River and Big Sioux River were represented as river boundaries. The surface water elevations were estimated using LiDAR data. Surface water elevations were subtracted by five feet to represent drought conditions. Unnamed Creek was assumed to be dry for the severe drought simulations. The vertical conductivity of the Rock and Big Sioux Rivers was estimated at 1/10 the average horizontal conductivity of the alluvial aquifer. The model represented baseflow (summer-time) conditions and the stage was kept the same throughout the simulated time period.

- General-head boundaries were used for the numerous sand and gravel pits in the area, including Solberg Pond and the RVRWD recharge basin. These general head values were obtained from LiDAR elevation data (RVRWD recharge basin used surveyed elevations). For the drought simulations, a water level drop of five feet was assumed to occur during the summer months in Solberg Pond as well as in nearby sand and gravel pits near RVRWD.
- General-head boundaries were used to represent the benches or terraces to the north of the alluvial aquifer. Groundwater elevations were estimated from the closest well or observation point.
- RVRWD wells and the 21 irrigation wells were included in the model simulation. Usage was obtained from the IDNR Water Use Database, IDNR Water Supply Section, and RVRWD (Table 2).
- Specific yield value was 0.06 and specific storage value was 0.001 in both model layers.
- Average annual recharge was calibrated for drought conditions (4 inches per year). The summer 90-day period during drought simulations was assigned 0 inches of recharge.
- The model domain consisted of 369 rows by 349 columns. The grid size varied from 3 feet to 128 feet.

Calibration Results

The model developed in 2014 (Gannon and Vogelgesang, 2014) was recalibrated using the pump test data collected from September 27 through September 28, 2016. Total observed drawdowns in the observation wells ranged from 0.28 feet in observation well OB4 to 0.697 feet in observation well OB5. Hydraulic conductivity values were adjusted to match the simulated drawdowns to the observed values. Figures 8, 9, and 10 show the simulated drawdown values from the aquifer pump tests. The simulated versus observed drawdowns are presented in Table 1.

Calibrated hydraulic conductivity throughout the aquifer ranged from 348 feet/day to 1,000 feet/day. Based on model calibration, the area near observation well OB4 had the highest hydraulic conductivity of 1,000 feet/day. Hydraulic conductivity values in this range are indicative of coarse sand, gravel and cobbles.

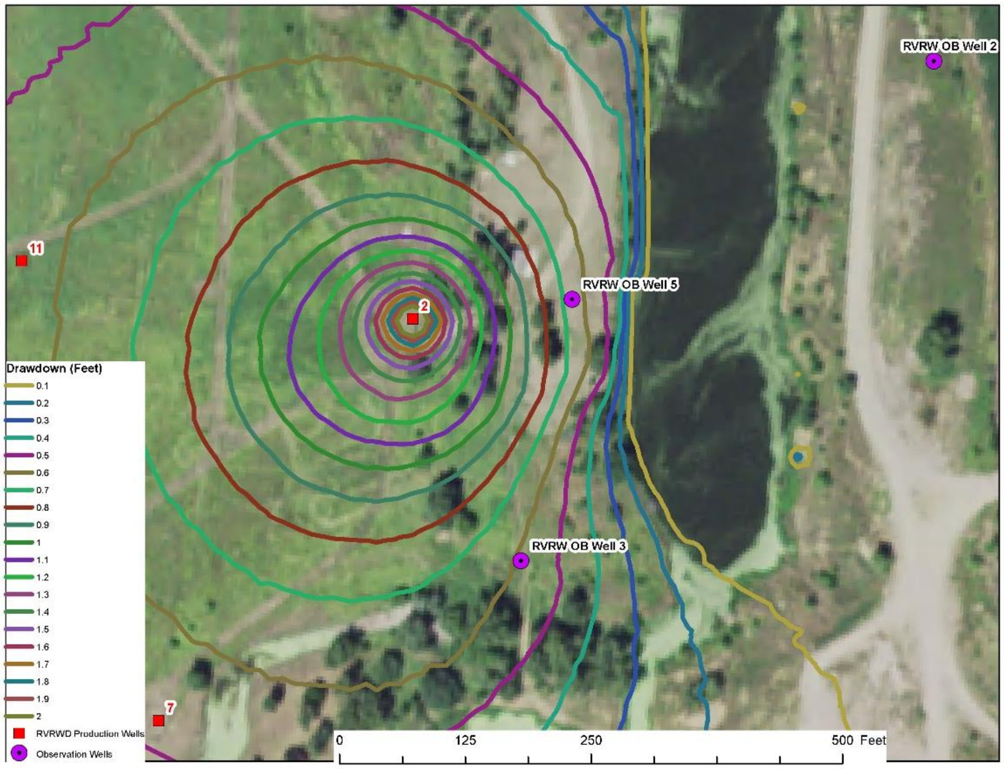

Figure 8. Simulated drawdown contours for aquifer pump test Well 2-Observation Well OB5.

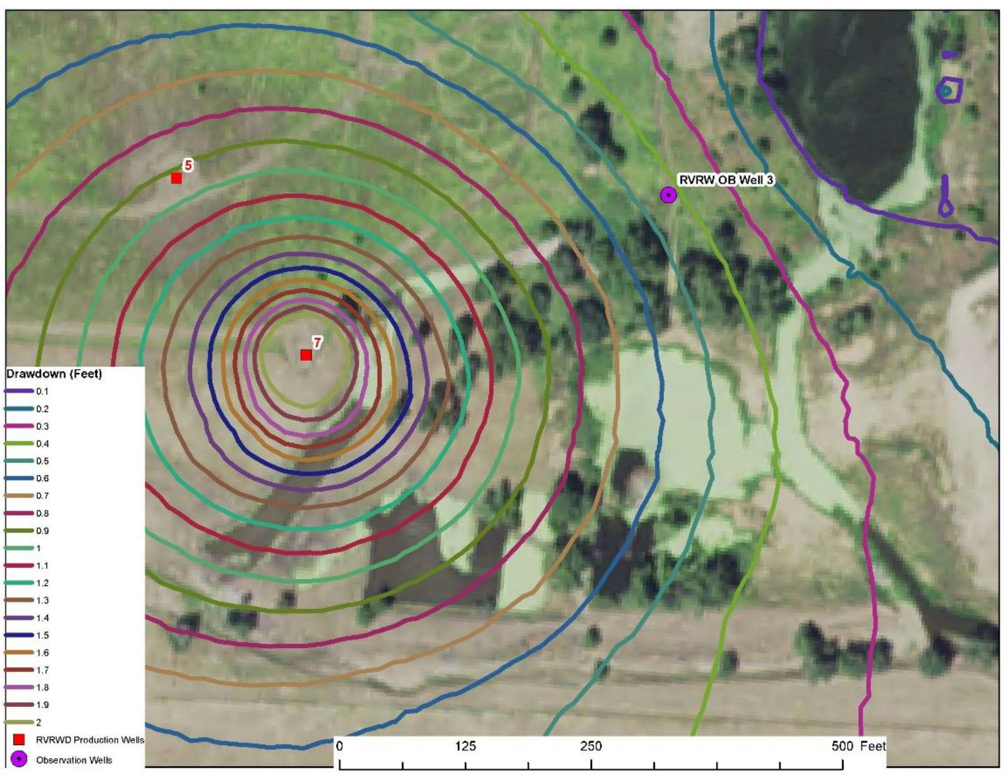

Figure 9. Simulated drawdown contours for aquifer pump test Well 7-Observation well OB3.

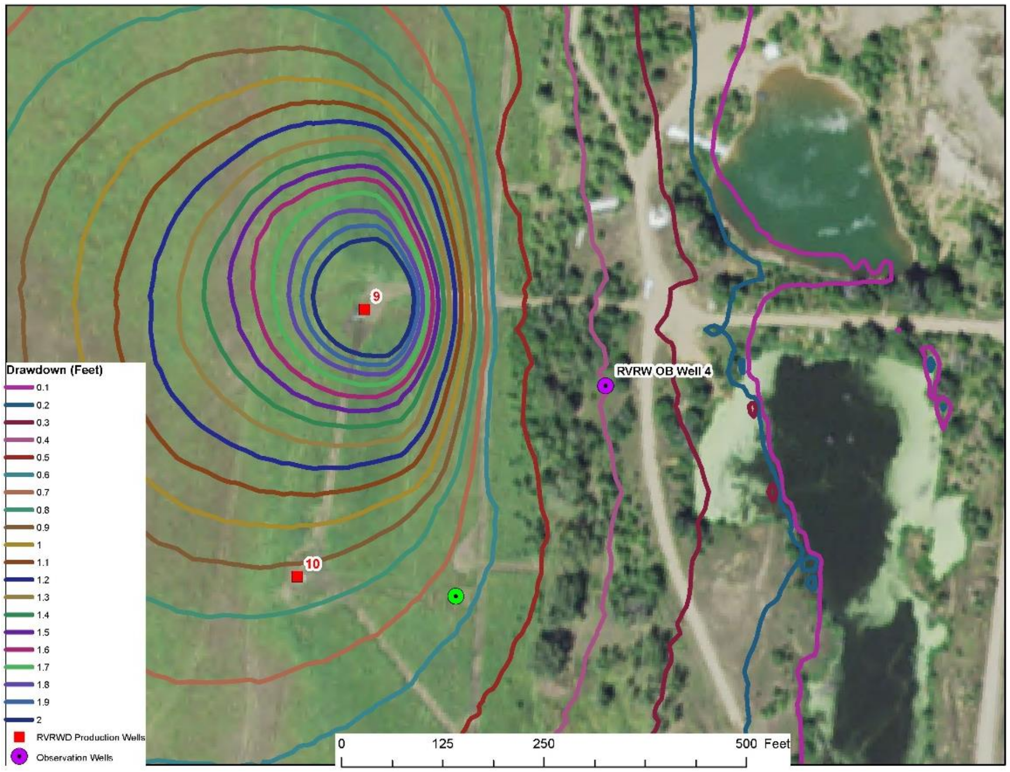

Figure 10. Simulated drawdown contours for aquifer pump test Well 9-Observation well OB4.

Drought Duration Model Simulations

The calibrated groundwater flow model was used to simulate the benefits of the newly constructed recharge basin during a severe two-year drought representative of the 2012 to 2013 drought. The model assumed that inflow from Unnamed Creek would cease to enter the recharge basin at the start of the severe drought. The river boundary used to represent Unnamed Creek was removed. Both Solberg pond and the recharge basin were represented by general head boundaries. The elevation of Solberg pond was assumed to be five feet lower at the start of the severe drought than normal levels. The model simulation was design such that surface water and groundwater storage related to the recharge basin would be slowly depleted by the RVRWD production wells. Evapotranspiration from the recharge basin was assumed to be negligible.

Table 3 shows the simulated impact of a severe drought starting January 1 and continuing for the next 24 months. The recharge basin provides additional groundwater storage to the RVRWD production wells for approximately 19 months. During the summer of the second year of severe drought, the groundwater elevations reached the approximate pump elevations in five of the RVRWD production wells, and the model produced dry cells. Figures 11, 12, and 13 show the simulated groundwater elevations at the start of the severe drought, after 9 months of severe drought, and after 16 months of severe drought. The simulated pumping water elevations recover slightly during the winter and spring of the second year of severe drought (Figure 13). The majority of the precipitation recharge occurs during the fall and spring, and the pumping rates of the RVRWD wells decrease during this non-peak water use period. In addition, the irrigation wells are shut off during the fall, winter, and spring months, which allows the groundwater elevations to recover slightly. As the summer peak water use period begins, both the RVRWD wells increase their daily pumping, and the irrigation wells begin to run. Surface water in the recharge basin and the associated groundwater storage has been completely depleted. The additional pumping stress from the RVRWD production wells and the irrigation wells creates additional simulated drawdown, and many of the RVRWD wells need to shut down to allow the groundwater levels to recover.

Table 3. Simulated impact of a severe 2-year drought starting January 1st.

Production Well	Pump Elevation (ft)	PWL Elevation January 1 Start of Drought	PWL Elevation Sept. 1st Year 9 months of Drought	PWL Elevation April 2nd Year 16 months of Drought	PWL Elevation July 2nd Year 19 months of Drought
1	1175	1198	1186	1192	1180
2	1170	1194	1176	1182	dry cell
3	1170.8	1198	1184	1190	1180
4	1177.6	1198	1186	1192	1180
5	1165	1194	1172	1182	dry cell
6	1185.5	1200	1192	1188	dry cell
7	1171.3	1194	1174	1182	dry cell
8	1166.2	1194	1176	1184	1170
9	NA	1196	1180	1186	1174
10	1170	1194	1180	1186	1174
11	NA	1194	1174	1182	dry cell

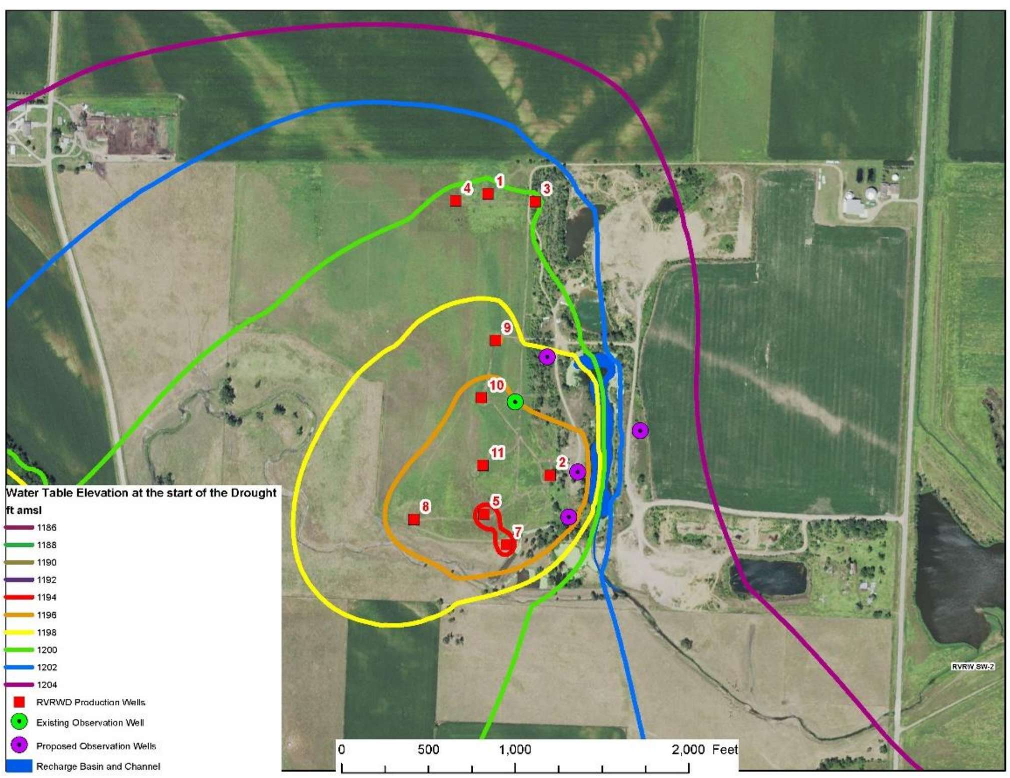

Figure 11. Simulated groundwater elevation contours at the start of a 2-year severe drought.

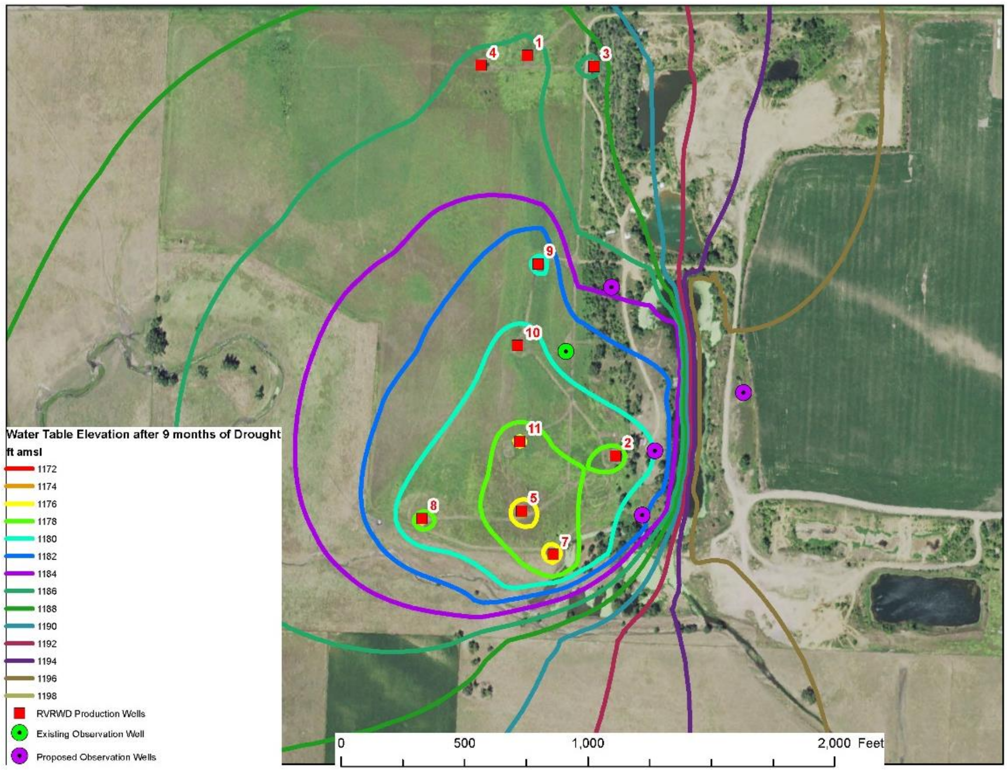

Figure 12. Simulated groundwater elevation contours after 9 months of a 2-year severe drought.

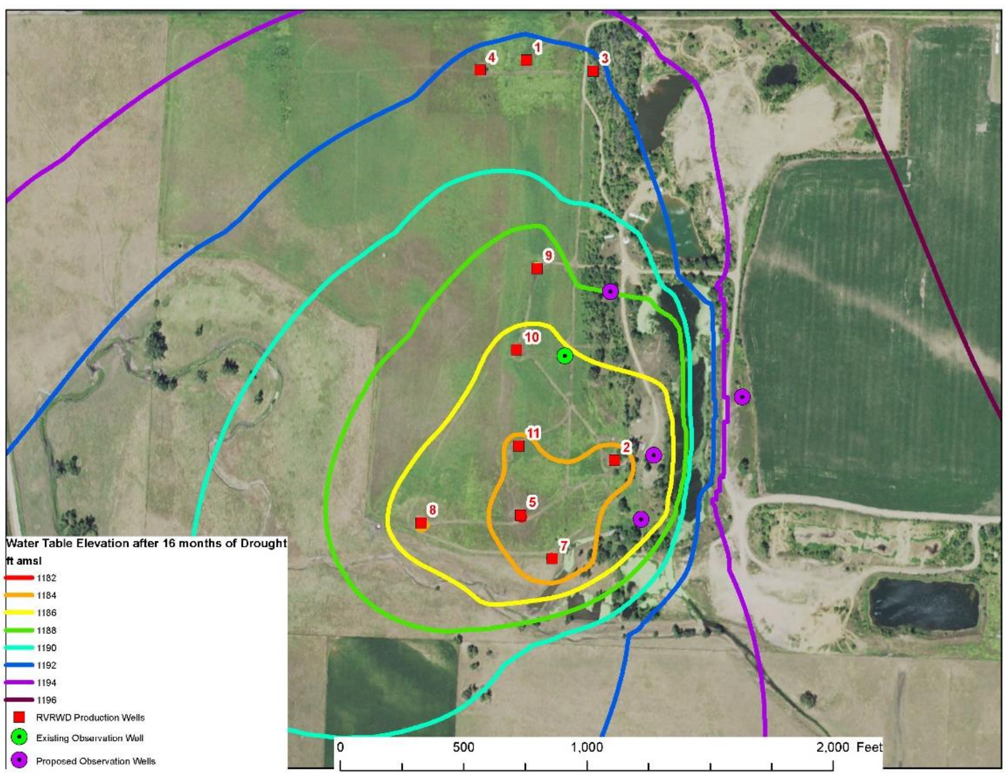

Figure 13. Simulated groundwater elevation contours after 16 months of a 2-year severe drought.

WATER QUALITY EVALUATION

Water samples were collected monthly from the five on-site observation wells, the RVRWD production wells 7, 9, 10, and 11, the Unnamed Creek both upstream and downstream of Solberg Pond, and the recharge basin. Samples were analyzed for nitrate as nitrogen and total chloride. Figures 14, 15, and 16 show the nitrate as nitrogen concentrations throughout the 12 month period for the surface water samples, the observation wells, and the production well samples. The wells and surface water sampling locations are shown in Figure 3.

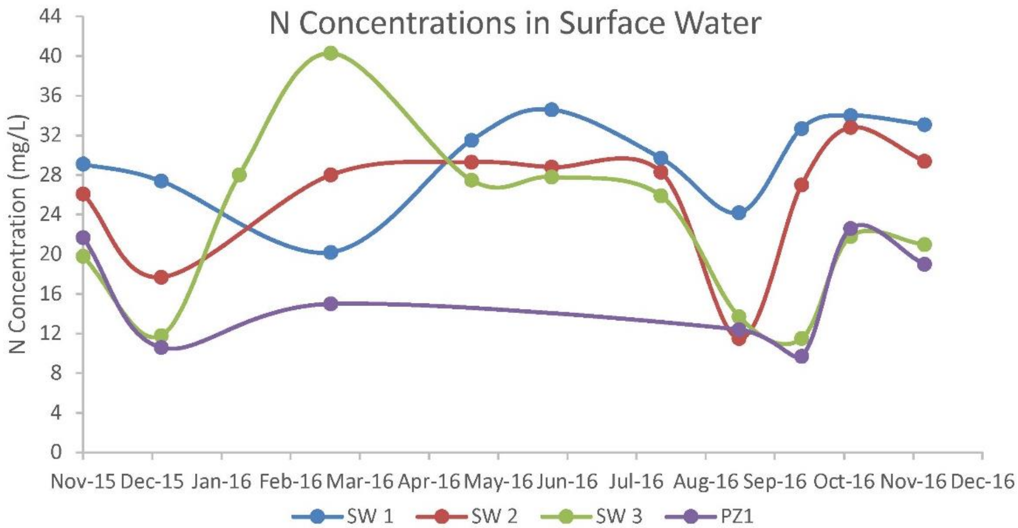

Figure 14. Monthly nitrate as nitrogen concentrations measured in the surface water sample locations for November 2015 through November 2016.

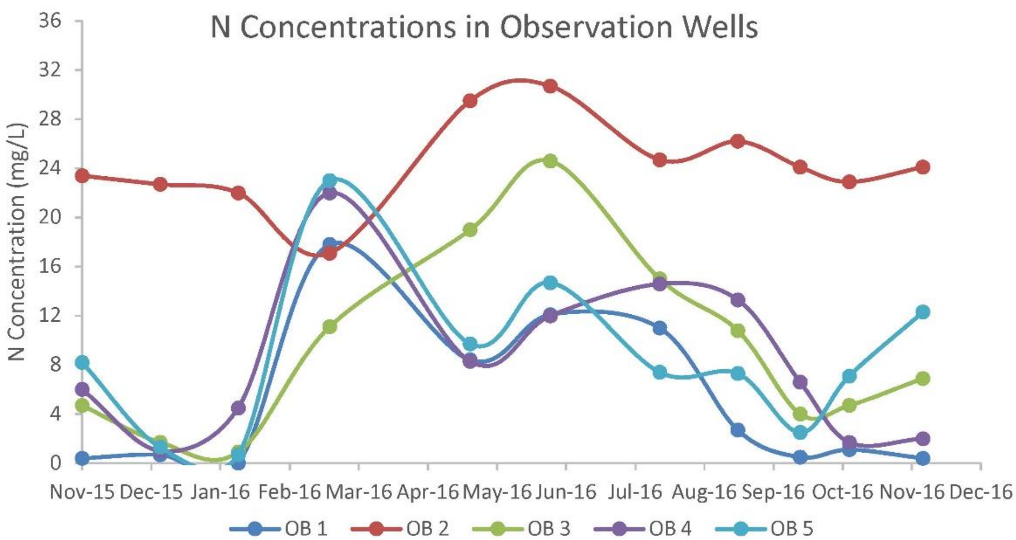

Figure 15. Monthly nitrate as nitrogen concentrations measured in the surface water sample locations for November 2015 through November 2016.

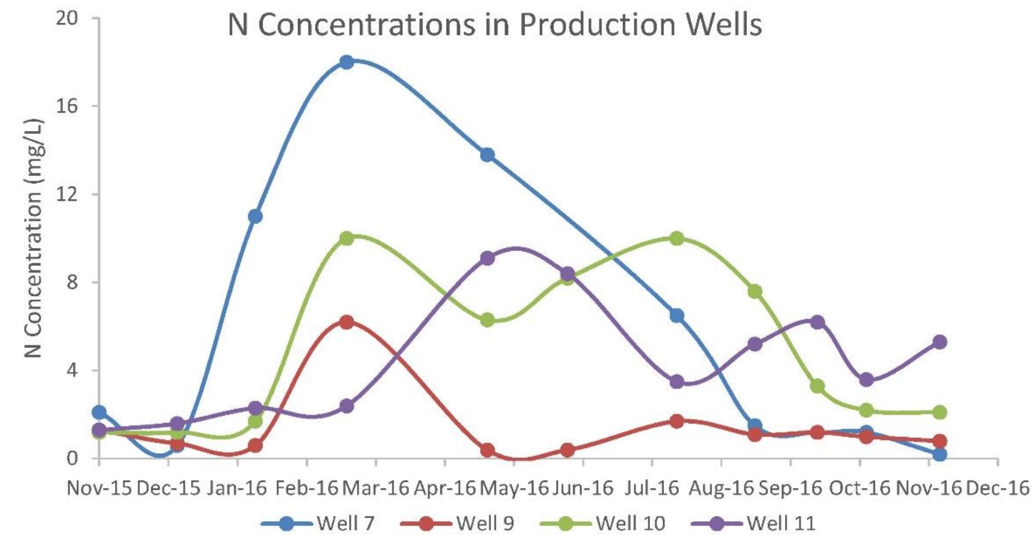

Figure 16. Monthly nitrate as nitrogen concentrations measured in the RVRWD production wells for November 2015 through November 2016.

Surface Water Quality

Based on Figure 14, nitrate concentrations in Unnamed Creek tends to be higher upstream (SW1) of Solberg pond than downstream (SW2), except for water samples collected in January and February 2016. The water samples collected during January and February may have been influenced by the abnormally high precipitation and flooding that occurred during the months of November and December. The slug of nutrient-rich water entering the Pond may have caused higher concentrations coming out of Solberg Pond than entering the Pond during the months of January and February. If January and February are excluded, reduction of nitrate appears to be occurring in Solberg Pond.

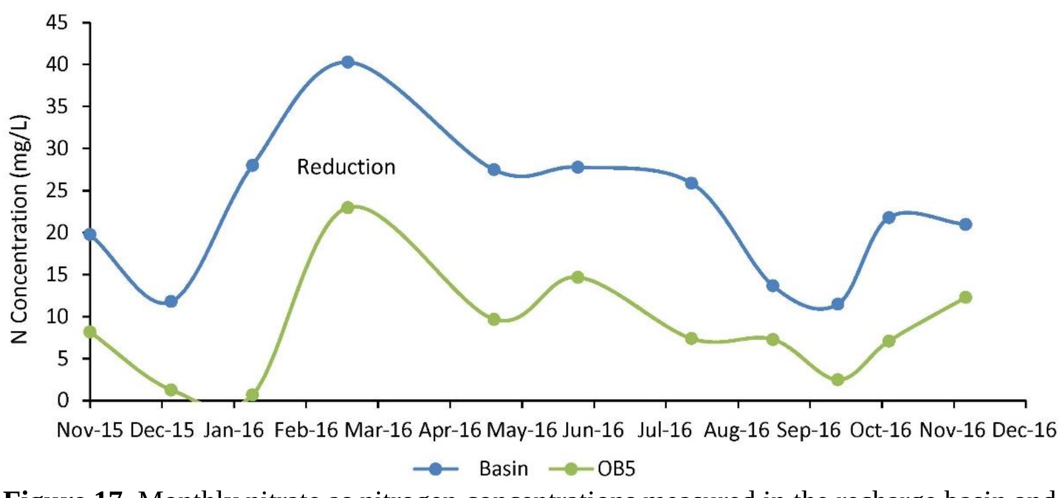

Figure 17. Monthly nitrate as nitrogen concentrations measured in the recharge basin and in the shallow groundwater downgradient of the basin.

The monthly nitrate as nitrogen concentrations in the recharge basin and in water samples collected in downgradient observation well OB5 is shown in Figure 17. Observation well 5 is the closest downgradient well to the recharge basin. Nitrate concentrations in the shallow groundwater directly downgradient of the recharge basin is consistently lower than the basin. The percentage of nitrate reduction per month in the recharge basin is shown in Table 4. Based on the water quality results, nitrate reduction ranged from 41% in November 2016 to 98% in January 2016. Average reduction for the 12 month period was 64%. A discussion of the process or processes involved with the nitrogen reduction will be discussion later in the report.

Table 4. Percentage of nitrate reduction as water flows from the recharge basin into the shallow groundwater downgradient of the basin.

Sampling Date	Nov. 2015	Dec. 2016	Jan. 2016	Feb. 2016	April 2016	May 2016	July 2016	Aug. 2016	Sept 2016	Oct. 2016	Nov. 2016
Nitrate as N in Basin (ppm)	19.8	11.8	28	40.3	27.5	27.8	25.9	13.7	11.5	21.8	21
Nitrate as N in OB5 (ppm)	8.2	1.3	0.7	23	9.7	14.7	7.4	7.3	2.5	7.1	12.3
Percent Reduction	59%	89%	98%	43%	65%	47%	71%	47%	78%	67%	41%

Groundwater Quality

Based on Figures 15 and 16, the nitrate as nitrogen concentrations in both the on-site observation wells and the RVRWD production wells fluctuate seasonally, with the highest concentrations generally occurring during the winter and early spring months. The seasonal fluctuation in nitrate concentrations in the shallow groundwater is strongly influenced by the nitrate concentration within the recharge basin. The flooding that occurred during the late fall and early winter of 2015 resulted in nitrate as nitrogen concentrations of over 40 ppm within the recharge basin.

Figures 18, 19, 20, and 21 show the nitrate as nitrogen concentrations for the months of November 2015, February 2016, April 2016, and July 2016 surrounding the RVRWD wellfield. The impact of the late fall 2015 flooding is apparent in Figure 19 where nitrate concentrations of over 40 ppm were observed in the recharge basin during the month of February. The induced recharge from the basin was observed to migrate quickly downgradient toward the observation wells and eventually to the production wells. The pumping stress created by the RVRWD production wells further increased the hydraulic gradient, which enhanced the migration of the nitrate plume to the west.

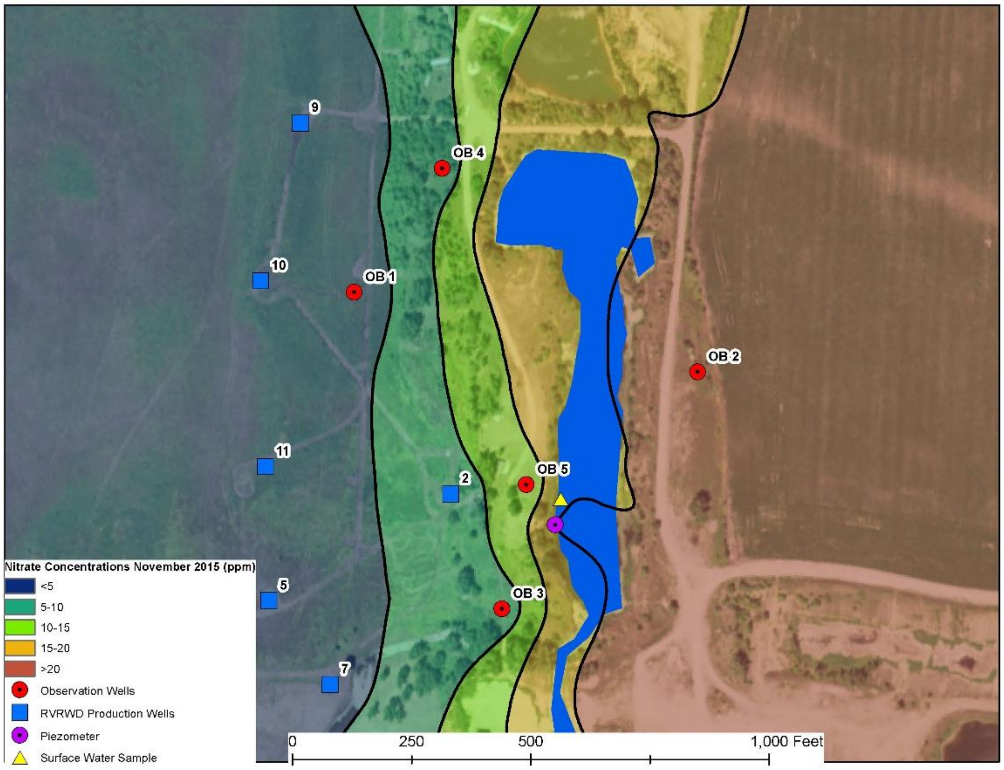

Figure 18. Nitrate as nitrogen concentrations near the RVRW wellfield in November 2015.

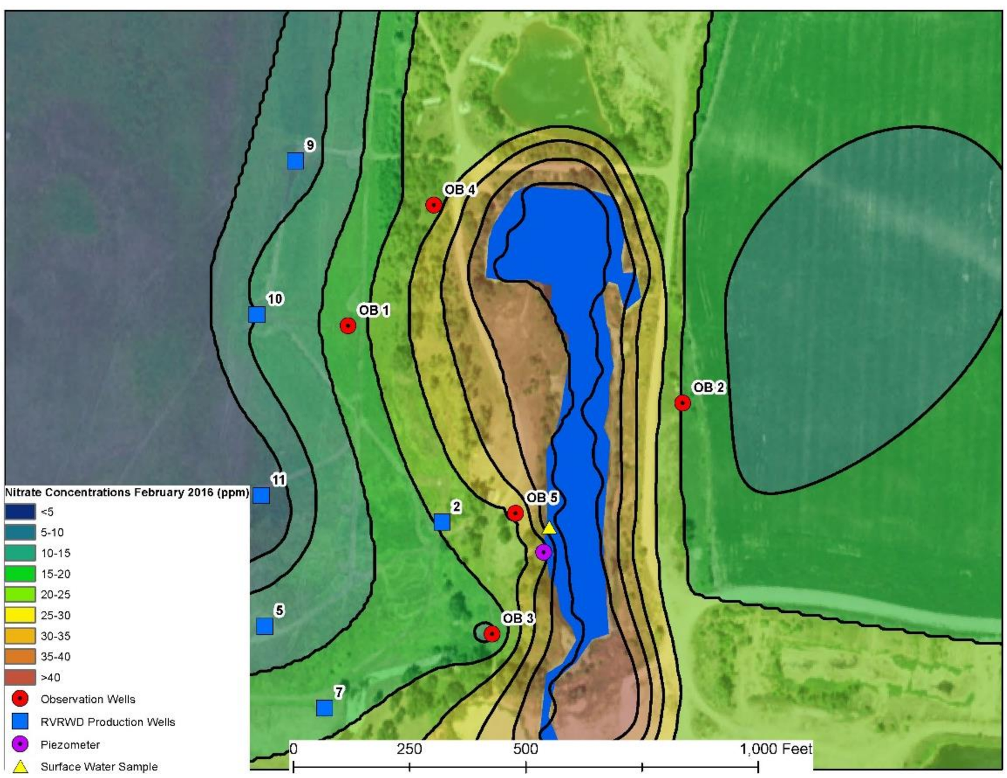

Figure 19. Nitrate as nitrogen concentrations near the RVRW wellfield in February 2016.

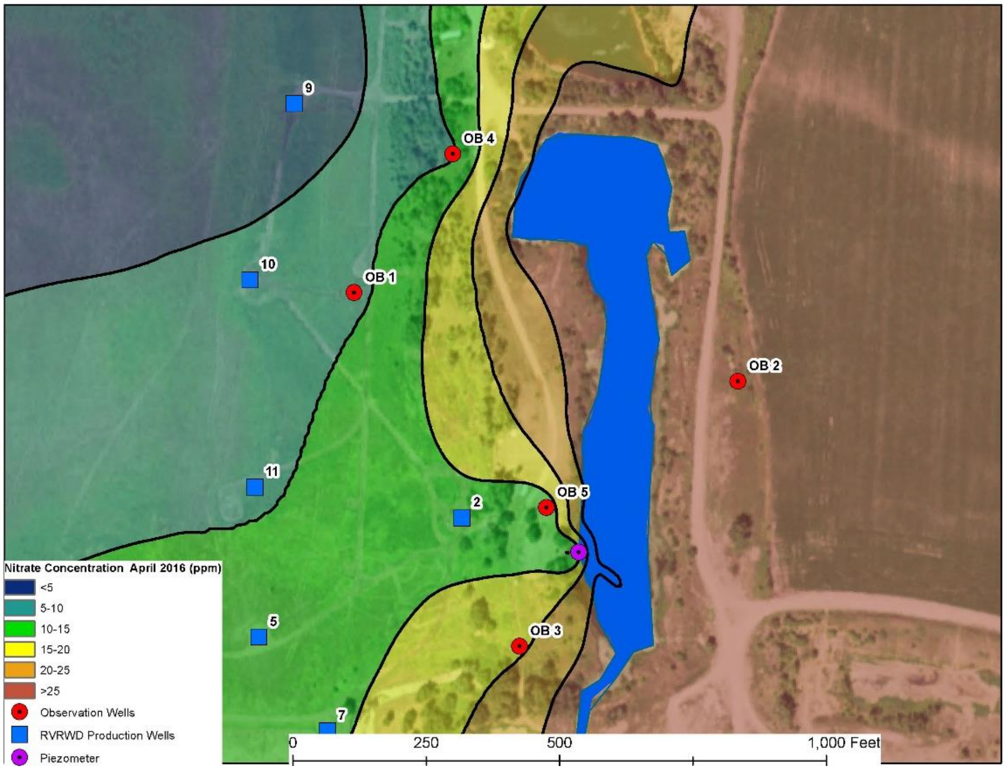

Figure 20. Nitrate as nitrogen concentrations near the RVRW wellfield in April 2016.

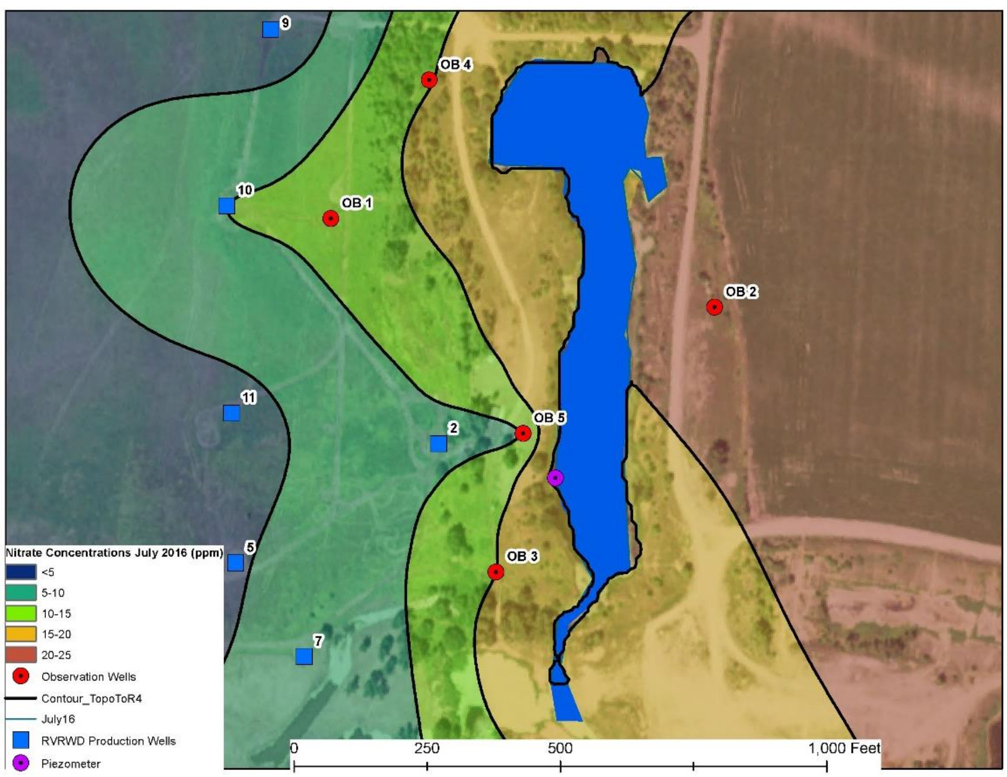

Figure 21. Nitrate as nitrogen concentrations near the RVRW wellfield in July 2016.

The precipitation recharge within the RVRWD wellfield is assumed to be very low in nitrates due to the establishment of prairie grass within the wellhead. During the winter months, the frost in the subsurface inhibits or completely stops the vertical recharge of low-nitrate water. In other words, the mixing of the precipitation recharge, which is low in nitrates, with the basin recharge, which is high in nitrates, would not occur. This would logically increase the nitrate concentrations in the shallow groundwater downgradient of the recharge basin during the winter months.

Based on the observed data as shown in Figures 18, 20 and 21, the nitrate as nitrogen concentrations within the shallow groundwater tend to decrease during the spring, summer, and fall months. This downward trend in nitrate concentrations is related to several factors. One factor has been discussed previously, and involves the increase in low-nitrate precipitation recharge, which mixes with the induced recharge from the basin. A second factor that may explain the downward trends in nitrate concentrations during the spring, summer and fall months may be related to the biological uptake by riparian zones along the basin shoreline and aquatic plants during the growing season.

The declining nitrate concentrations related to precipitation recharge would obviously not occur or be greatly diminished during an extended drought. During an extended drought, recharge to the production wells would primarily occur through the recharge basin. The lack of low-nitrate precipitation recharge could have negative impacts on the groundwater quality during an extended drought. It is likely nitrate concentrations within the recharge basin would be lower due to the lack of high nitrate runoff from the Unnamed Creek watershed, and biological reduction may further reduce the overall nitrate concentrations, but the lack of low-nitrate precipitation recharge could elevate the nitrate concentrations within the RVRWD production wells. Proper management of the recharge basin via the inlet control valve on Unnamed Creek could play an important role in reducing the nitrate impacts during a drought. Reducing high nitrate inflow from Unnamed Creek during flood events would likely reduce the overall nitrate concentration within the recharge basin. Regulating the inflow of Unnamed Creek between drought benefits and nitrate concerns is essential and will be discussed later in the report.

Observation well OB2 is located upgradient of the recharge basin and downgradient of a corn field. Groundwater samples collected from OB2 are generally greater than 20 ppm nitrate as nitrogen, with the highest concentrations occurring during the late spring and early summer (Figure 15). The consistently high nitrate concentrations in well OB2 would be representative of corn acreage in Iowa. The higher spring and summer nitrate concentrations would represent the impacts of commercial fertilizer that is normally applied in late fall or early spring. The fall applied fertilizer is confined to the vadose or unsaturated zone during the winter due to the frost in the subsurface. Frost disappears during the spring, which results in a slug of nitrate-rich recharge into the shallow groundwater. Uptake of nitrate by the emerging corn plants slowly lowers the nitrate concentrations throughout the growing season (Figure 15).

Chloride Results

Surface water and groundwater samples were analyzed for chloride. Chloride samples from February through June were not collected because the laboratory equipment used for the chloride analyses was down for repairs. High chloride concentrations in rural Iowa are normally associated with either animal waste or winter road salt. RVRWD wellfield is situated in a largely rural location approximately 4.5 miles south of State Highway 18; therefore, chloride impacts from road salt are assumed to be minimal.

Livestock production in Sioux County is an important agricultural business. Sioux County leads all counties in Iowa in hog production, cattle on feed, and dairy production (USDA, 2015). It is assumed that elevated chloride concentrations in Unnamed Creek (Figure 22) are associated with livestock waste, and recharge from the basin introduces additional chloride into the groundwater within the RVRWD wellfield.

Changes in the nitrate/chloride ratio can also be used to help evaluate the process behind the reduction in nitrates. If nitrate reduction is occurring as a result of biological reduction within the basin sediments, the nitrate/chloride ratio should decrease. Figures 22 and 23 show the monthly chloride concentrations and the nitrate-chloride ratios upstream and downstream of Solberg pond. The chloride concentrations are approximately the same upstream and downstream of Solberg Pond, but the nitrate-chloride ratios decrease slightly between the upstream and downstream samples. This would indicate some biological reduction may be occurring within Solberg pond. However, the reduction of nitrates in Solberg Pond appears to accelerate from July through October, which suggests that most of the nitrate reduction in Solberg Pond may be the result of uptake by the riparian zone and aquatic plants.

Based on Figure 24, the nitrate/chloride ratio in the water from the recharge basin is much higher than the groundwater sampled from downgradient observation well OB5. The biological reduction within the basin sediments appears to be reduce the nitrate concentrations, but the chloride concentrations remain relatively unchanged as shown in Figure 25. Based on the nitrate/chloride ratios, the primary nitrate reduction process shown in Figure 17 and quantified in Table 4 is attributed to biological reduction.

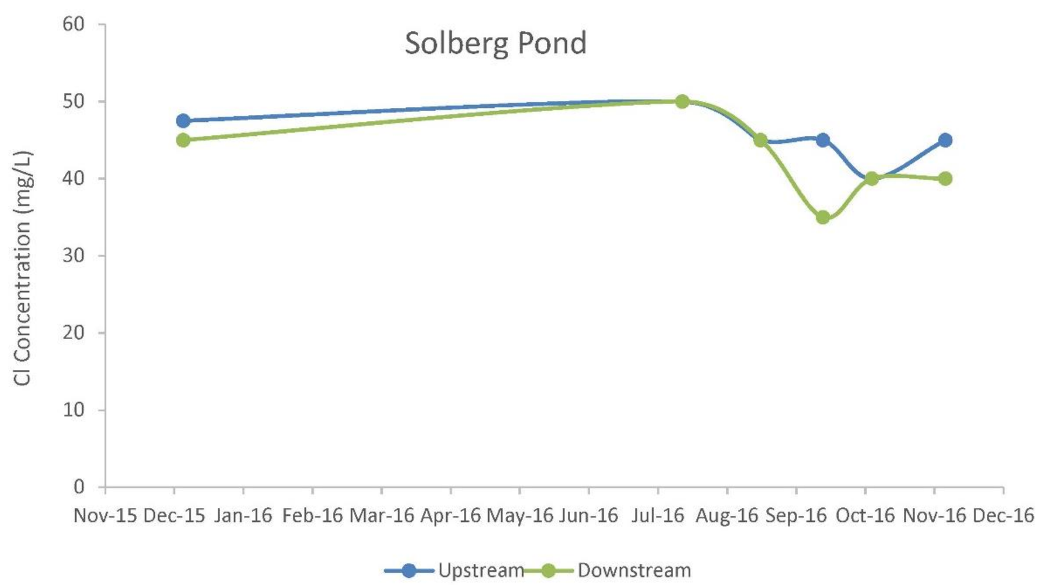

Figure 22. Monthly total chloride concentrations in Unnamed Creek upgradient and downgradient of Solberg Pond.

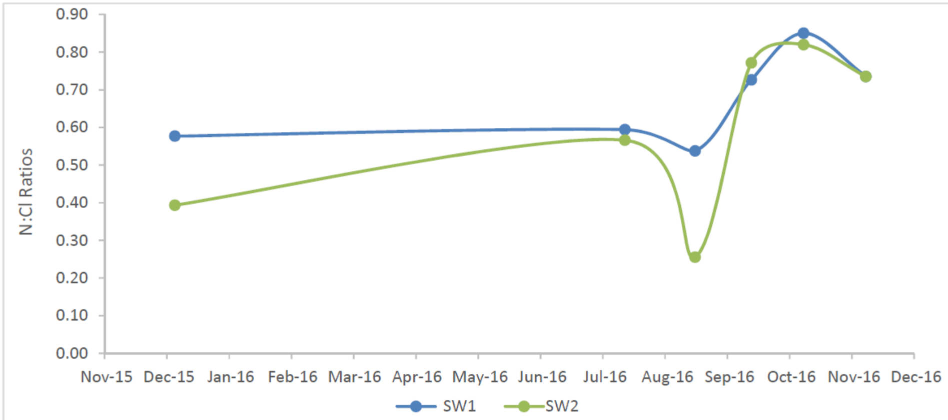

Figure 23. Nitrate-Chloride ratios in samples collected in Unnamed Creek upgradient and downgradient of Solberg Pond.

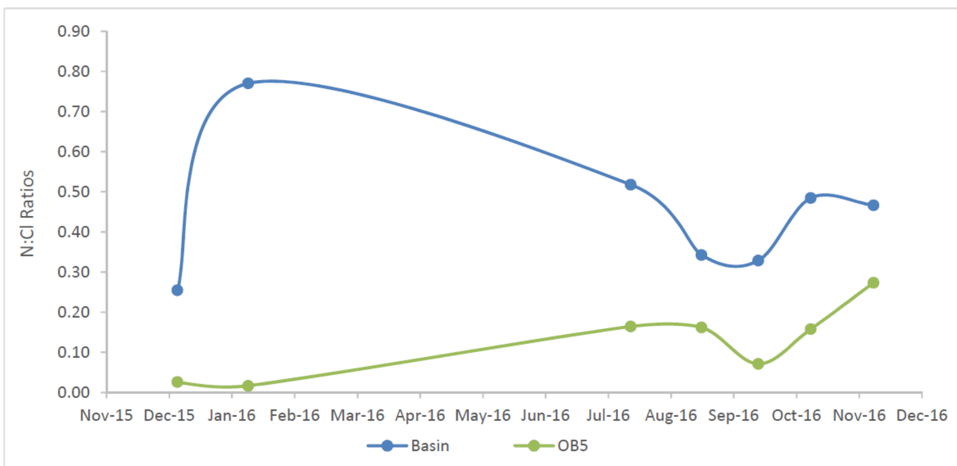

Figure 24. Nitrate-Chloride ratios in samples collected in the recharge basin and in downgradient observation well OB5.

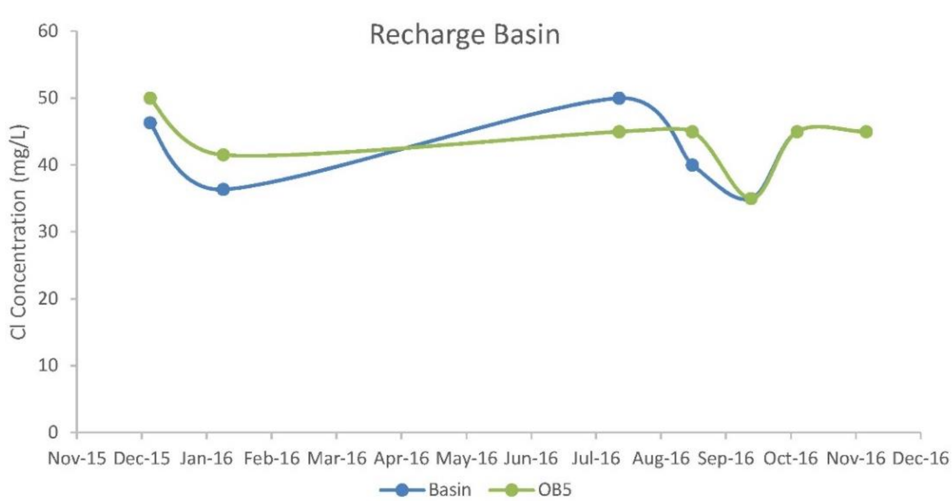

Figure 25. Total chloride concentrations in samples collected in the recharge basin and in downgradient observation well OB5.

Control Structure and Long Term Management of the Recharge Basin

Figure 2 shows the approximate location of the control inlet valve that regulates inflow from Unnamed Creek into the recharge basin. Proper management of the water quality within the recharge basin is dependent on the proper use of the control valve. This requires balance between reducing drought impacts on water quantity by increasing groundwater storage, while minimizing the nitrate concentrations in the recharge basin and shallow groundwater. Water samples could be collected periodically from Unnamed Creek to help evaluate whether the inlet valve should be open or shut. The valve should be shut during periods of flooding and excessive runoff. The valve should be open during the spring to maximize groundwater storage prior to the summer peak-usage season. Depending on the monitoring results in Unnamed Creek, the valve should be left open under normal baseflow conditions and during dry or drought conditions. Biological reduction should reduce nitrate concentrations approximately 60% or more in the basin recharge, which helps to minimize the potential impacts due to nitrates. During severe multi-year droughts when Unnamed Creek stops flowing for extensive periods of time, it may be necessary to pump water from the Big Sioux River as an emergency contingency plan. This will require a temporary water use permit prior to pumping.

CONCLUSIONS

The Iowa Geological Survey completed a hydrogeologic investigation for the alluvial aquifer near the Rock Valley Rural Water District wellfield, located in Sioux County, Iowa. The main purpose of the investigation was to evaluate the newly constructed recharge basin as a drought resiliency strategy, and evaluate the potential water quality impacts related to the basin. Monthly water level measurements and groundwater quality samples were collected at the site for approximately 12 months. In addition, a three-dimensional groundwater flow model was developed to evaluate the groundwater quantity benefits.

Based on data from the on-site production wells and observation wells, the thickness of alluvial deposits beneath the Rock Valley Rural Water District wellfield varies from 37 to 58 feet, and averages approximately 45 feet. The deposits are not uniform or homogeneous but include clay, silt, sand, gravel, cobbles and boulders. The alluvial aquifer consists of glacial outwash deposits that may have been associated with the ancestral Big Sioux River.

Based on the observed monthly water levels, the recharge basin creates a groundwater mound of approximately 8 to 10 feet. The general groundwater flow direction and hydraulic gradient stays relatively constant throughout the 12 month period due to the stability in the water level elevation in the recharge basin throughout the year. The groundwater table elevations also remain relatively constant. The one exception is in the month of February, when the water levels were approximately 2 feet higher than normal. The rise in water levels during the month of February may be related to the relatively low water use during the winter months and the newly constructed beaver dam first observed during the month of February. There are also fluctuations in groundwater elevations and flow directions based on which production wells are actively pumping and which wells are idle.

Pump tests were conducted in RVRWD production wells 2, 7, and 9. Observation wells OB3, OB4, and OB5 were used to measure drawdowns. Transmissivity values ranged from 13,900 ft^2/day near OB3 to 40,400 ft^2/day near OB4. Hydraulic conductivity values were found to range from 348 to 1,010 feet/day, with an arithmetic mean of 730 feet/day. Storativity values or specific yield range from 0.014 near OB3 to 0.1 near OB4. In addition to the aquifer parameter estimation, the observed drawdown data was also used to help calibrate the groundwater flow model.

Based on the calibrated groundwater flow model, the recharge basin would provide additional groundwater storage to the RVRWD production wells for approximately 19 months. During the summer of the second year of severe drought the groundwater elevations reach the approximate pump elevations in five of the RVRWD production wells, and the model produces dry cells.

Nitrate as nitrogen concentrations in the shallow groundwater directly downgradient of the recharge basin were consistently lower than the basin. Based on water quality results, nitrate reduction in the recharge basin ranged from 41% in November 2016 to 98% in January 2016, with an average reduction for the 12 month period of 64%.

The nitrate/chloride ratio in the water sampled from the recharge basin was much higher than the groundwater sampled from downgradient observation well OB5. The biological reduction within the recharge basin sediments appears to be decreasing the nitrate concentrations, but the chloride concentrations remain relatively unchanged. Based on the nitrate/chloride ratios, the primary nitrate reduction process observed in the recharge basin can be attributed to biological reduction.

The nitrate as nitrogen concentrations in both the RVRWD production wells and the on-site observation wells fluctuate seasonally, with the highest concentrations generally occurring during the winter and early spring months. Biological reduction in the recharge basin and the low-nitrate precipitation recharge related to the uptake by prairie grass slowly reduces the nitrate concentrations in the shallow groundwater throughout the growing season and into the fall.

The management of the recharge basin is dependent on the proper use of the inlet control valve located on Unnamed Creek. Proper management requires a balance between reducing drought impacts by increasing groundwater storage (leaving the valve open) and minimizing nitrate concentrations in the recharge basin and shallow groundwater during flood events (closing the valve).

REFERENCES

Gannon, J. M., and Vogelgesang, J. A., 2014, Iowa Geological and Water Survey, OFR-13-2, 32 p.

Groundwater modeling report-Rock Valley Rural Water Wellfield, December 2005, Quad States Services, Inc.

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Appendix A

Driller's Logs and Well Construction Diagrams for the New Observation Wells

MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name RURWD	**Permit No.**
Well or Piezometer No. #1	
Dates Started Nov. 4, 2015	**Date Completed** Nov. 4, 2015

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 1st St.
Distance & direction from boundary to well	Nevada, IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid** —
Top of well casing	**Bore Hole diameter** 7½'
Benchmark elevation	**Soil sampling method** —
Benchmark description	**Depth of boring** 40'

C. MONITORING WELL INSTALLATION	
Casing material PVC	**Placement method** Pour in
Length of casing 32½'	**Volume** 400 lbs
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter —	**Material**
Casing joint type Flush Joint	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material PVC	**Surface seal design:** Cement
Screen opening size .010	**Material of protective casing:** Steel
Screen length 10'	**Material of grout between protective casing and well casing:** Bentonite & Cement
Depth of Well 40'	**Protective cap:** 4x4
Filter Pack:	**Material** Steel
Material Silicia	**Vented?:** ☐ Y ☒ N **Locking?:** ☒ Y ☐ N
Grain Size .010	**Well cap:**
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 25'	**Vented?:** ☐ Y ☒ N
Material Bentonite	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

06/2011 cmz DNR Form 542-1277

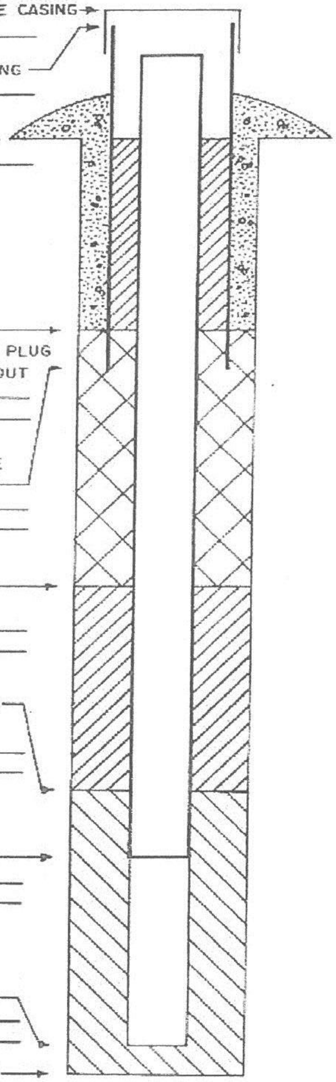
ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

TOP OF PROTECTIVE CASING
ELEVATION ________

TOP OF WELL CASING
ELEVATION ________

GROUND SURFACE
ELEVATION ________



0 - 2' Sandy Topsoil
2' - 40' - Med Sand

TOP OF BACKFILL
BASE OF CONCRETE PLUG AND BENTONITE GROUT
ELEVATION ________
DEPTH 24

BASE OF PROTECTIVE CASING
ELEVATION ________
DEPTH 30

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ________
DEPTH 25

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ________
DEPTH 25

TOP OF SCREEN
ELEVATION ________
DEPTH 30

BOTTOM OF SCREEN
ELEVATION ________
DEPTH 40

BASE OF FILTER PACK
ELEVATION ________
DEPTH 41

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
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MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name RURWD	**Permit No.**
Well or Piezometer No. #2	
Dates Started Nov. 4. 2015	**Date Completed** Nov. 4. 2015

A. SURVEYED LOCATIONS AND ELEVATIONS	B. SOIL BORING INFORMATION
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 18th St.
Distance & direction from boundary to well	Nevada. IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid** –
Top of well casing	**Bore Hole diameter** 7½"
Benchmark elevation	**Soil sampling method** –
Benchmark description	**Depth of boring** 40'

C. MONITORING WELL INSTALLATION	
Casing material Pvc	**Placement method** Pour in
Length of casing 32½'	**Volume** 400 lbs
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter –	**Material**
Casing joint type Flush Joint	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material Pvc	**Surface seal design:** Cement
Screen opening size .010	**Material of protective casing:**
Screen length 10'	**Material of grout between protective casing and well casing:** Bentonite & Cement
Depth of Well 40'	**Protective cap:** Steel
Filter Pack:	**Material**
Material Silicia	**Vented?:** ☐ Y ☒ N **Locking?:** ☒ Y ☐ N
Grain Size .010	**Well cap:**
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 25'	**Vented?:** ☐ Y ☒ N
Material Bentonite	

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

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Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

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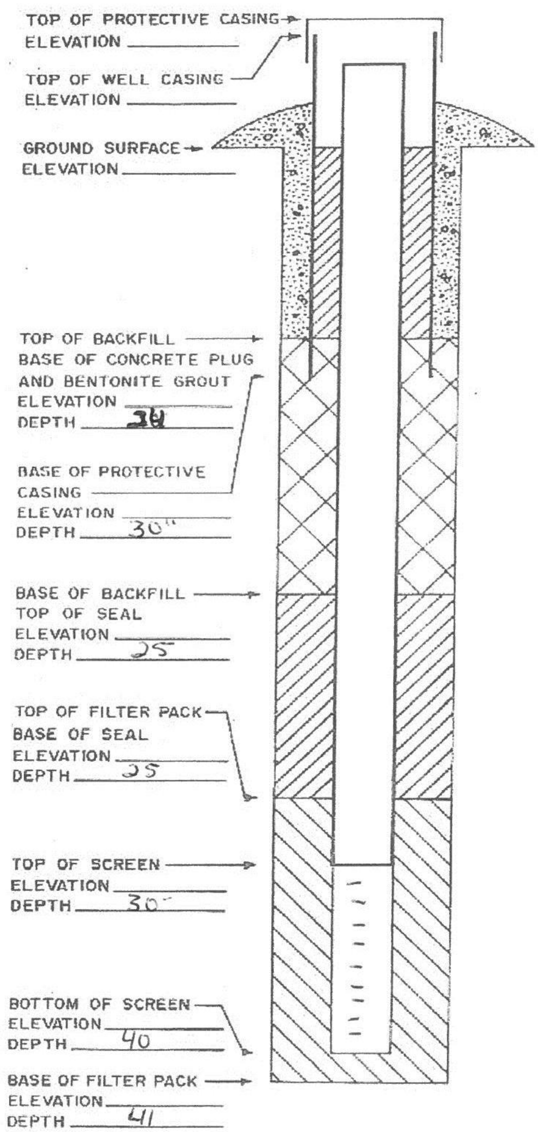
ELEVATIONS: ± 0.01 FT. MSL

DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG (SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).



0 - 3 Sandy Topsoil
3 - 41 med. Sand

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MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name	RURWD	**Permit No.**	
Well or Piezometer No.	#3		
Dates Started	Nov. 5, 2015	**Date Completed**	Nov. 5, 2015

A. SURVEYED LOCATIONS AND ELEVATIONS		B. SOIL BORING INFORMATION	
Locations (± 0.5 ft.):		**Name & address of construction company**	
Specify corner of site		Rewerts Well Co	
Distance & direction along boundary		742 W. 18th St	
Distance & direction from boundary to well		Nevada, IA 50201	
Elevations (± 0.01 ft. MSL):		**Name of driller**	Justin Rewerts
Ground Surface		**Drilling method**	HSA
Top of protective casing		**Drilling fluid**	–
Top of well casing		**Bore Hole diameter**	7½"
Benchmark elevation		**Soil sampling method**	–
Benchmark description		**Depth of boring**	40'

C. MONITORING WELL INSTALLATION			
Casing material	PVC	**Placement method**	Pour in
Length of casing	32½'	**Volume**	400 lbs
Outside casing diameter	2"	**Backfill (if different from seal):**	
Inside casing diameter	–	**Material**	
Casing joint type	Flush Joint	**Placement method**	
Casing/screen joint type	" "	**Volume**	
Screen material	PVC	**Surface seal design:**	
Screen opening size	.010	**Material of protective casing:**	
Screen length	10'	**Material of grout between protective casing and well casing:**	Bentonite & Cement
Depth of Well	40	**Protective cap:**	Steel
Filter Pack:		**Material**	
Material	Silicia	**Vented?:** ☐ Y ☐ N	**Locking?:** ☒ Y ☐ N
Grain Size	.010	**Well cap:**	
Volume		**Material**	
Seal (minimum 3 ft. length above filter pack):	25'	**Vented?:** ☐ Y ☒ N	
Material	Bentonite		

D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)			
Water level		**Stabilization time**	
Well development method			
Average depth of frostline			

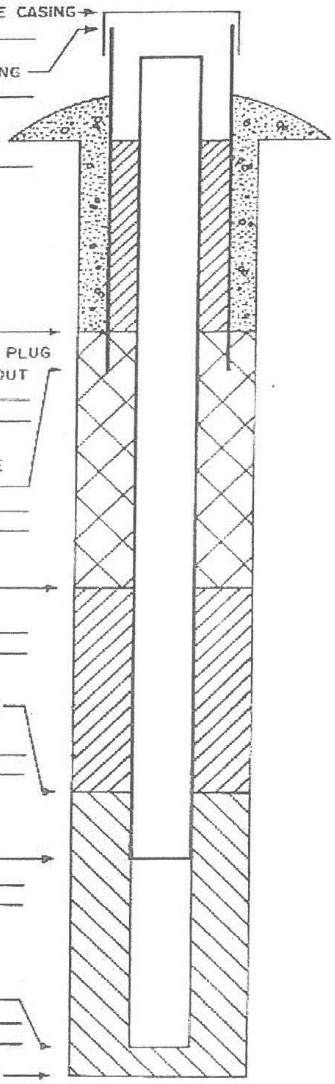
Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

06/2011 cmz DNR Form 542-1277

ELEVATIONS: ± 0.01 FT. MSL
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).



TOP OF PROTECTIVE CASING
ELEVATION ____________

TOP OF WELL CASING
ELEVATION ____________

GROUND SURFACE
ELEVATION ____________

TOP OF BACKFILL
BASE OF CONCRETE PLUG AND BENTONITE GROUT
ELEVATION ____________
DEPTH 24'

BASE OF PROTECTIVE CASING
ELEVATION ____________
DEPTH 30"

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ____________
DEPTH 25

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ____________
DEPTH 25

TOP OF SCREEN
ELEVATION ____________
DEPTH 30

BOTTOM OF SCREEN
ELEVATION ____________
DEPTH 40

BASE OF FILTER PACK
ELEVATION ____________
DEPTH 41

0 - 2 Sandy Top Soil
2 - 20 med. Sand
20 - 30 Large Cobbles
30 - 40 Cobbles & med Sand

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
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MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name RVRWD	**Permit No.**
Well or Piezometer No. #4	
Dates Started Nov. 5. 2015	**Date Completed** Nov. 5. 2015
A. SURVEYED LOCATIONS AND ELEVATIONS	**B. SOIL BORING INFORMATION**
Locations (± 0.5 ft.):	**Name & address of construction company**
Specify corner of site	Rewerts Well Co
Distance & direction along boundary	742 W. 18th St.
Distance & direction from boundary to well	Nevada, IA
Elevations (± 0.01 ft. MSL):	**Name of driller** Justin Rewerts
Ground Surface	**Drilling method** HSA
Top of protective casing	**Drilling fluid** –
Top of well casing	**Bore Hole diameter** 7½
Benchmark elevation	**Soil sampling method** –
Benchmark description	**Depth of boring** 40'
C. MONITORING WELL INSTALLATION	
Casing material Pvc	**Placement method** Pour in
Length of casing 32½	**Volume** 400 lbs
Outside casing diameter 2"	**Backfill (if different from seal):**
Inside casing diameter	**Material**
Casing joint type Flush Thread	**Placement method**
Casing/screen joint type " "	**Volume**
Screen material Pvc	**Surface seal design:**
Screen opening size .010	**Material of protective casing:**
Screen length 10'	**Material of grout between protective casing and well casing:** Bentonite & Concrete
Depth of Well 40'	**Protective cap:**
Filter Pack:	**Material**
Material Silicia	**Vented?:** ☐ Y ☐ N **Locking?:** ☒ Y ☐ N
Grain Size .010	**Well cap:** Steel
Volume	**Material**
Seal (minimum 3 ft. length above filter pack): 25'	**Vented?:** ☐ Y ☐ N
Material Bentonite	
D. GROUNDWATER MEASUREMENT (± 0.01 foot below top of inner well casing)	
Water level	**Stabilization time**
Well development method	
Average depth of frostline	

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

Please mail completed form to: Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

06/2011 cmz DNR Form 542-1277

ELEVATIONS: ± 0.01 FT. MSL

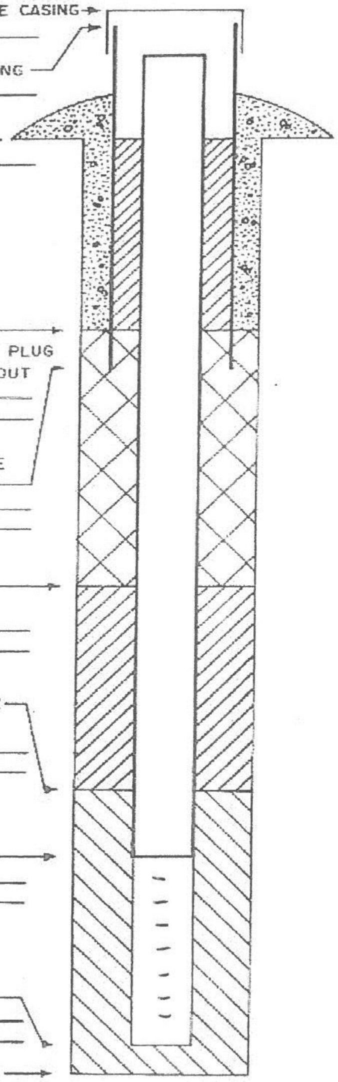
DEPTHS: ± 0.1 FT. FROM
GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL).

TOP OF PROTECTIVE CASING
ELEVATION ____________

TOP OF WELL CASING
ELEVATION ____________

GROUND SURFACE
ELEVATION ____________



TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION ____________
DEPTH 24"

BASE OF PROTECTIVE
CASING
ELEVATION ____________
DEPTH 30"

BASE OF BACKFILL
TOP OF SEAL
ELEVATION ____________
DEPTH 25

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION ____________
DEPTH 25

TOP OF SCREEN
ELEVATION ____________
DEPTH 30

BOTTOM OF SCREEN
ELEVATION ____________
DEPTH 40

BASE OF FILTER PACK
ELEVATION ____________
DEPTH 41

0 - 2" Black Top soil
2 - 15' Brown Clay
15 - 30 med. Sand
30 - 40 Cobbles & med Sand

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Questions? Call or Email: Nina Koger Environmental Engineer Sr., 515-725-8309, nina.koger@dnr.iowa.gov

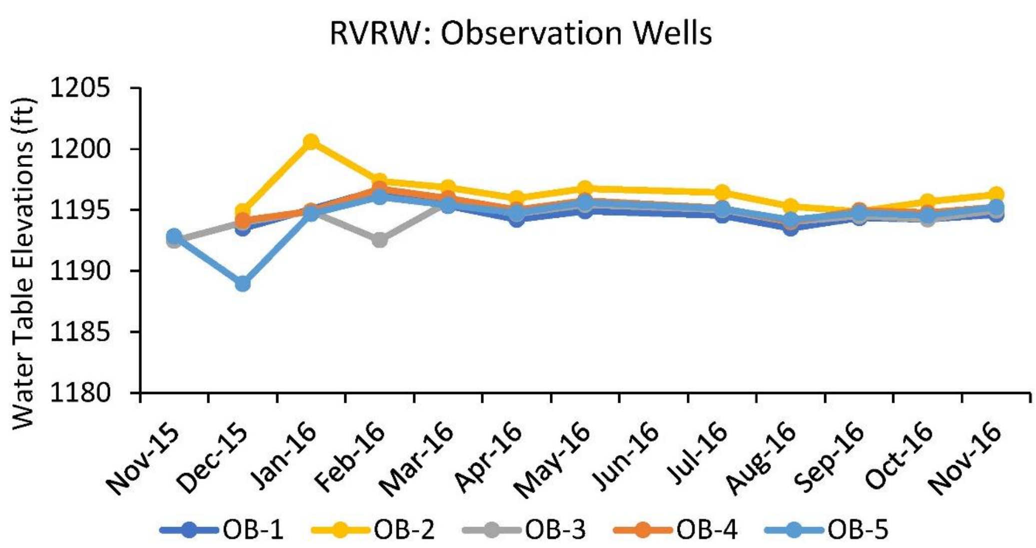
06/2011 cmz DNR Form 542-1277

Appendix B

Monthly Water Level Measurements in the On-site Observation Wells

Static Water Level* (ft)													
Well Name	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
OB-1		14.36		11.2	12.49	13.62	12.94		13.31	14.35	13.49	13.6	13.22
OB-2		29.37	23.68	26.9	27.43	28.3	27.51		27.85	28.97	29.39	28.58	28
OB-3	22.2	20.7	19.8	22.12	19.05	19.98	19.24		19.66	20.65	20.15	20.42	19.72
OB-4		24.45	23.68	21.86	22.62	23.55	22.83		23.42	24.53	23.63	23.82	23.34
OB-5	21.45	25.35	19.6	18.23	18.9	19.52	18.67		19.21	20.12	19.53	19.76	19.06
PZ-1	6.59	7.2		7.47		7.72				5.8	5.52	5.65	5.79
SW-1		3.2											
SW-2													
SW-3					3.45						5.15	4.96	5.1
*Depth from top of metal casing													
**SW: Surface water to top of metal casing													
Dry													
Frozen													
PZ not sealed in sediment													
New PZ installed													

Static Water Elevations* (ft)													
Well Name	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16
OB-1		1193.5		1196.66	1195.37	1194.24	1194.92		1194.55	1193.51	1194.37	1194.26	1194.64
OB-2		1194.9	1200.59	1197.37	1196.84	1195.97	1196.76		1196.42	1195.3	1194.88	1195.69	1196.27
OB-3	1192.48	1193.98	1194.88	1192.56	1195.63	1194.7	1195.44		1195.02	1194.03	1194.53	1194.26	1194.96
OB-4		1194.14	1194.91	1196.73	1195.97	1195.04	1195.76		1195.17	1194.06	1194.96	1194.77	1195.25
OB-5	1192.86	1188.96	1194.71	1196.08	1195.41	1194.79	1195.64		1195.1	1194.19	1194.78	1194.55	1195.25
PZ-1	1202.18	1201.57		1201.3		1201.05				1202.97	1203.25	1203.12	1202.98
SW-1													
SW-2													
SW-3					1205.32						1203.62	1203.81	1203.67
*Based on 2016 Survey													



Appendix C

Aquifer Pump Tests

IOWA GEOLOGICAL SURVEY	**Pumping Test - Water Level Data** Page 1 of 2
	Project: Rock Valley Rural Water Well 2
	Number:
	Client:

Location:	Pumping Test: Well 2	Pumping Well: Well 2
Test Conducted by:	Test Date: 9/27/2016	Discharge Rate: 425 [U.S. gal/min]
Observation Well: Observation Well 5	Static Water Level [ft]: 20.67	Radial Distance to PW [ft]: 165

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	20.669	0.00
2	15	20.671	0.002
3	30	20.767	0.098
4	45	20.825	0.156
5	60	20.872	0.203
6	75	20.903	0.234
7	90	20.93	0.261
8	105	20.954	0.285
9	120	20.978	0.309
10	135	20.994	0.325
11	150	21.015	0.346
12	165	21.029	0.36
13	180	21.041	0.372
14	195	21.056	0.387
15	210	21.07	0.401
16	225	21.081	0.412
17	240	21.091	0.422
18	255	21.104	0.435
19	270	21.114	0.445
20	285	21.123	0.454
21	300	21.132	0.463
22	315	21.142	0.473
23	330	21.151	0.482
24	345	21.157	0.488
25	360	21.167	0.498
26	375	21.175	0.506
27	390	21.181	0.512
28	405	21.188	0.519
29	420	21.196	0.527
30	435	21.203	0.534
31	450	21.209	0.54
32	465	21.216	0.547
33	480	21.223	0.554
34	495	21.231	0.562
35	510	21.235	0.566
36	525	21.237	0.568
37	540	21.243	0.574
38	555	21.249	0.58
39	570	21.254	0.585
40	585	21.26	0.591
41	600	21.265	0.596
42	615	21.27	0.601
43	630	21.276	0.607
44	645	21.278	0.609
45	660	21.285	0.616
46	675	21.288	0.619
47	690	21.294	0.625
48	705	21.295	0.626
49	720	21.302	0.633
50	735	21.305	0.636
51	750	21.307	0.638
52	765	21.313	0.644
53	780	21.315	0.646

Pumping Test - Water Level Data

Project: Rock Valley Rural Water Well 2

Number:

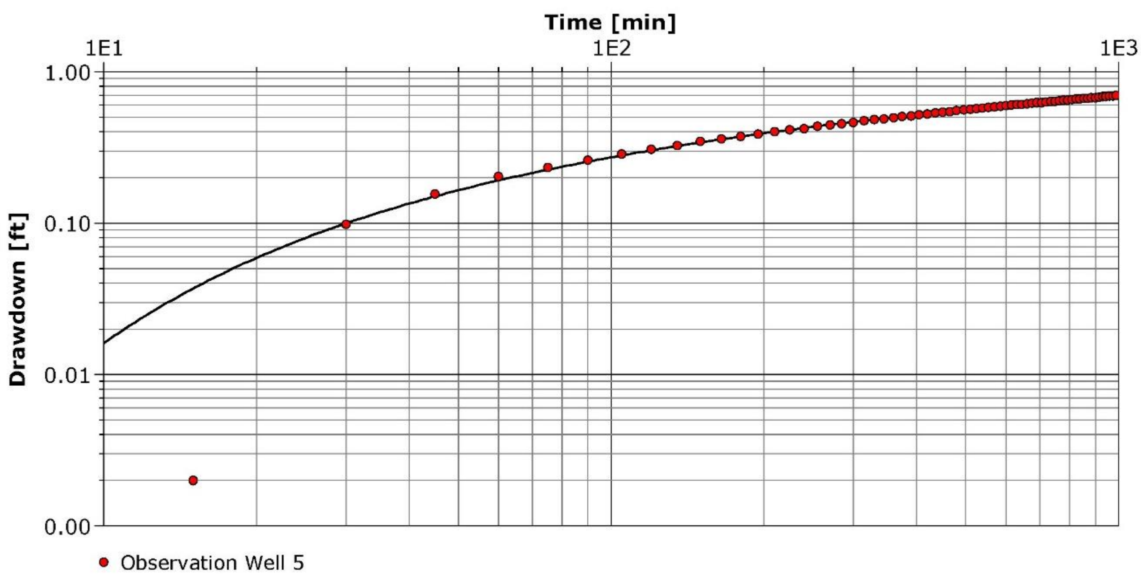
Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
54	795	21.32	0.651
55	810	21.322	0.653
56	825	21.328	0.659
57	840	21.332	0.663
58	855	21.334	0.665
59	870	21.336	0.667
60	885	21.339	0.67
61	900	21.345	0.676
62	915	21.35	0.681
63	930	21.355	0.686
64	945	21.355	0.686
65	960	21.359	0.69
66	975	21.361	0.692
67	990	21.366	0.697

Pumping Test Analysis Report	
Project: Rock Valley Rural Water Well 2	
Number:	
Client:	

IOWA GEOLOGICAL SURVEY

Location:	Pumping Test: Well 2	Pumping Well: Well 2
Test Conducted by:		Test Date: 9/27/2016
Analysis Performed by:	New analysis 1	Analysis Date: 9/27/2016
Aquifer Thickness: 40.00 ft	Discharge Rate: 425 [U.S. gal/min]	



Calculation using Theis

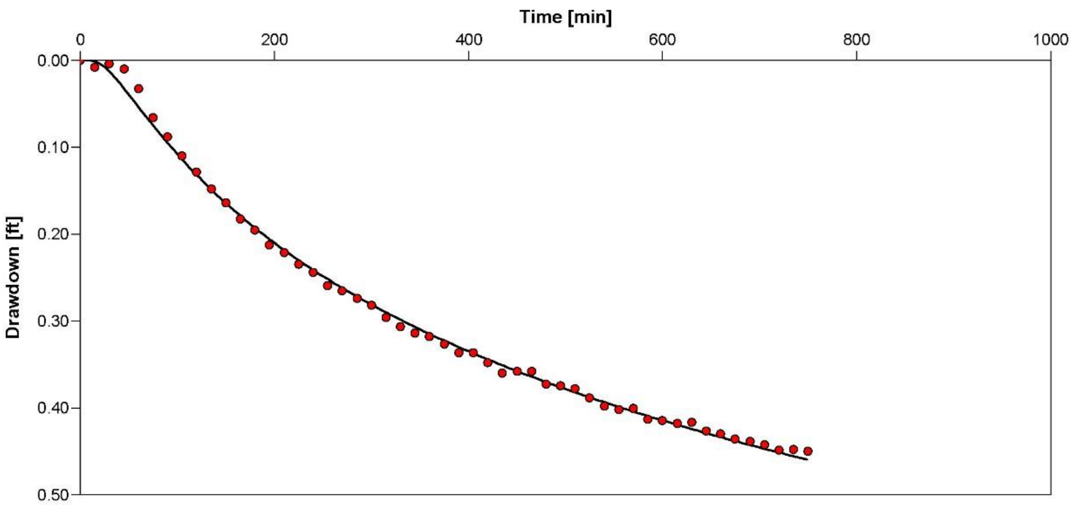
Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Observation Well 5	3.33×10^4	8.33×10^2	5.55×10^{-2}	165.0	

IOWA GEOLOGICAL SURVEY	**Pumping Test - Water Level Data**	Page 1 of 1
	Project: Rock Valley Rural Water Well 7	
	Number:	
	Client:	

Location:	Pumping Test: Well 7	Pumping Well: Well 7
Test Conducted by:	Test Date: 9/27/2016	Discharge Rate: 200 [U.S. gal/min]
Observation Well: Observation Well 3	Static Water Level [ft]: 20.65	Radial Distance to PW [ft]: 400

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	20.649	0.00
2	15	20.657	0.008
3	30	20.653	0.004
4	45	20.659	0.01
5	60	20.682	0.033
6	75	20.715	0.066
7	90	20.737	0.088
8	105	20.759	0.11
9	120	20.778	0.129
10	135	20.797	0.148
11	150	20.813	0.164
12	165	20.832	0.183
13	180	20.844	0.195
14	195	20.862	0.213
15	210	20.87	0.221
16	225	20.884	0.235
17	240	20.893	0.244
18	255	20.908	0.259
19	270	20.914	0.265
20	285	20.923	0.274
21	300	20.931	0.282
22	315	20.945	0.296
23	330	20.956	0.307
24	345	20.963	0.314
25	360	20.967	0.318
26	375	20.976	0.327
27	390	20.986	0.337
28	405	20.986	0.337
29	420	20.997	0.348
30	435	21.009	0.36
31	450	21.007	0.358
32	465	21.007	0.358
33	480	21.022	0.373
34	495	21.024	0.375
35	510	21.027	0.378
36	525	21.038	0.389
37	540	21.047	0.398
38	555	21.051	0.402
39	570	21.05	0.401
40	585	21.062	0.413
41	600	21.064	0.415
42	615	21.067	0.418
43	630	21.066	0.417
44	645	21.076	0.427
45	660	21.079	0.43
46	675	21.085	0.436
47	690	21.088	0.439
48	705	21.092	0.443
49	720	21.098	0.449
50	735	21.097	0.448
51	750	21.099	0.45

Pumping Test Analysis Report		
Project: Rock Valley Rural Water Well 7		
Number:		
Client:		
Location:	Pumping Test: Well 7	Pumping Well: Well 7
Test Conducted by:		Test Date: 9/27/2016
Analysis Performed by:	New analysis 1	Analysis Date: 9/27/2016
Aquifer Thickness: 40.00 ft	Discharge Rate: 200 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Observation Well 3	1.39×10^{4}	3.48×10^{2}	1.36×10^{-2}	400.0	

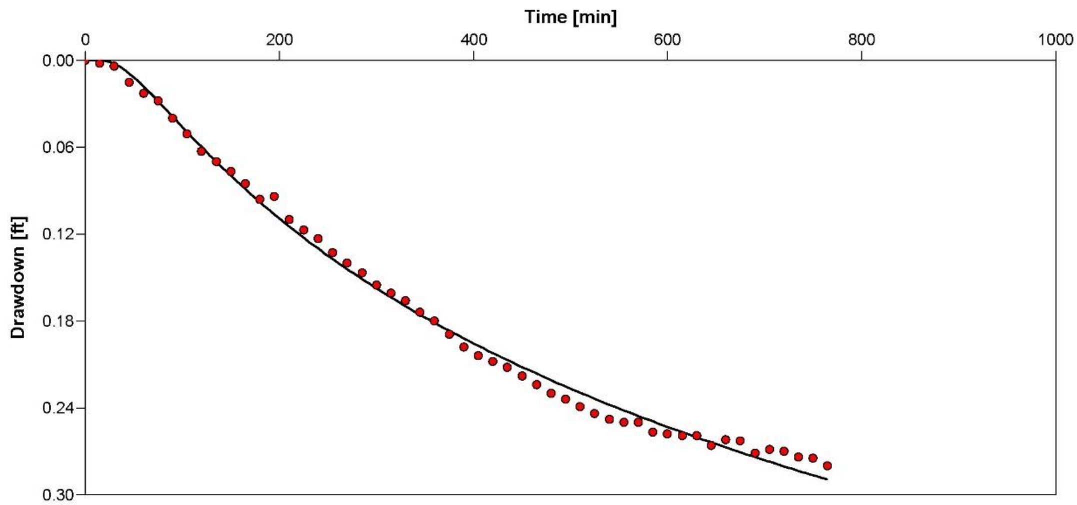
IOWA GEOLOGICAL SURVEY	**Pumping Test - Water Level Data** Page 1 of 1
	Project: Rock Valley Rural Water
	Number:
	Client:

Location:	Pumping Test: Pumping Test Well 9	Pumping Well: Well 9
Test Conducted by:	Test Date: 9/28/2016	Discharge Rate: 450 [U.S. gal/min]
Observation Well: Observation Well 4	Static Water Level [ft]: 24.33	Radial Distance to PW [ft]: 312

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	24.329	0.00
2	15	24.331	0.002
3	30	24.333	0.004
4	45	24.344	0.015
5	60	24.352	0.023
6	75	24.357	0.028
7	90	24.369	0.04
8	105	24.38	0.051
9	120	24.392	0.063
10	135	24.399	0.07
11	150	24.406	0.077
12	165	24.414	0.085
13	180	24.425	0.096
14	195	24.423	0.094
15	210	24.439	0.11
16	225	24.446	0.117
17	240	24.452	0.123
18	255	24.462	0.133
19	270	24.469	0.14
20	285	24.476	0.147
21	300	24.484	0.155
22	315	24.49	0.161
23	330	24.495	0.166
24	345	24.503	0.174
25	360	24.509	0.18
26	375	24.518	0.189
27	390	24.527	0.198
28	405	24.533	0.204
29	420	24.537	0.208
30	435	24.541	0.212
31	450	24.547	0.218
32	465	24.553	0.224
33	480	24.559	0.23
34	495	24.563	0.234
35	510	24.568	0.239
36	525	24.573	0.244
37	540	24.577	0.248
38	555	24.579	0.25
39	570	24.579	0.25
40	585	24.586	0.257
41	600	24.587	0.258
42	615	24.588	0.259
43	630	24.588	0.259
44	645	24.595	0.266
45	660	24.591	0.262
46	675	24.592	0.263
47	690	24.60	0.271
48	705	24.598	0.269
49	720	24.599	0.27
50	735	24.603	0.274
51	750	24.604	0.275
52	765	24.609	0.28

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: Rock Valley Rural Water
	Number:
	Client:

Location:	Pumping Test: Pumping Test Well 9	Pumping Well: Well 9
Test Conducted by:		Test Date: 9/28/2016
Analysis Performed by:	New analysis 1	Analysis Date: 9/28/2016
Aquifer Thickness: 40.00 ft	Discharge Rate: 450 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Observation Well 4	4.04×10^{4}	1.01×10^{3}	1.01×10^{-1}	312.0	