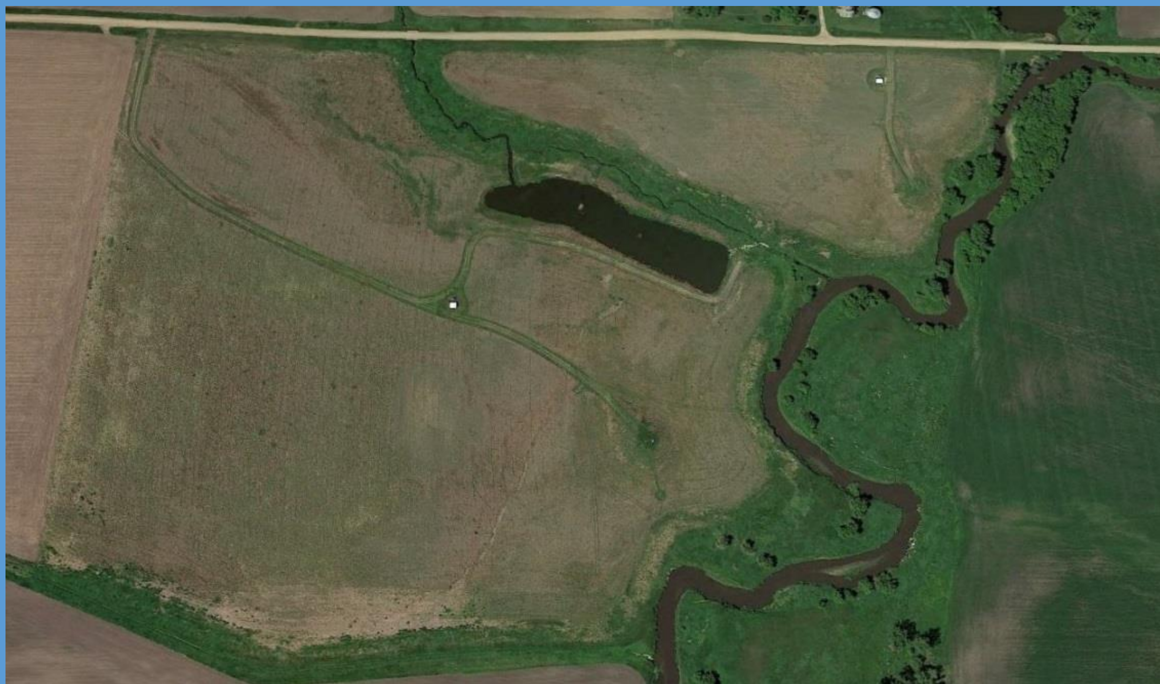

Investigation of a Floodplain Pond to Improve Alluvial Aquifer Sustainability: A Quantity and Quality Report

Water Resources Investigation Report 16

The University of Iowa

IOWA GEOLOGICAL SURVEY

IIHR Hydroscience & Engineering

Investigation of a Floodplain Pond to Improve Alluvial Aquifer Sustainability: A Quantity and Quality Report

Prepared by

Nathan L. Holt
J. Michael Gannon
and
Jason A. Vogelgesang

Iowa Geological Survey
Water Resources Investigation Report 16

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EXECUTIVE SUMMARY

The Iowa Geological Survey completed a hydrogeologic investigation on a segment of the Floyd River alluvial aquifer which contains the Rural Water Systems #1 wellfield. The wellfield is located near the town of Hospers in Sioux County, Iowa. The purpose of the investigation was to evaluate how a floodplain pond within the wellfield impacts groundwater recharge, drought resiliency, and water quality. The floodplain pond in the context of groundwater availability serves as a tool for storing surface water and providing recharge to the aquifer. Therefore, in this report the floodplain pond will be termed a “recharge basin.” As part of this project, the Iowa Geological Survey conducted a geophysical investigation, installed observation wells, collected monthly water level and quality samples for 12 months, and executed three-dimensional groundwater flow modeling of the alluvial aquifer wellfield using Visual MODFLOW.

Evaluation of driller’s logs and the geophysical investigation within the wellfield indicates the sand and gravel alluvial aquifer ranges from 8–20 feet. The most conductive and productive aquifer material appears to be in close proximity to the Floyd River. The aquifer material becomes less conductive moving away from the river. Monthly water levels as well as nitrate and chloride concentrations were collected from multiple observation wells, piezometers, and surface water locations. Observed water levels indicate the recharge basin does provide recharge to the aquifer with most of the recharge moving toward the south and production well PL1-4. Water levels in the basin remained relatively constant throughout of the monitoring period (November 2015 – November 2016). The only exception was August 2016 when the water level in the basin dropped by over two feet. Water levels in the aquifer, which were measured by the observation wells, were also lowest in August 2016.

Surface water recharge to the aquifer was shown to impact water quality. Production well PL1-4 had nitrate levels in excess of 10 mg/L in four of the 12 months sampled, while nitrate levels in PL1-8 did not exceed 10 mg/L in any month. Nitrate dynamics in the production wells correlated closely with nitrate dynamics observed in the surface water. During April 2016, the month of highest observed nitrate levels in the surface water, nitrate concentrations in production wells PL1-4 and PL1-8 were measured at 16.30 mg/L and 9.43 mg/L, respectively. The maximum contaminant level for nitrate in drinking water is 10 mg/L.

Nitrate levels in the observation wells north of the recharge basin, OB-1 and OB-2, were consistently less than levels in the observation well south of the basin, OB-3. Nitrate levels in the observation wells indicate that the recharge basin has better connection with and provides more recharge to the aquifer south of the basin. “Short-circuiting” also appears to be occurring in the basin, where a portion of the surface water that enters the basin quickly makes its way into the aquifer through the upper portion of the basin without adequate time for optimum nitrate removal. A major nitrate removal process in the basin appears to be biological reduction as nitrate removal efficiency was greatest in the warmer months.

A local-scale groundwater flow model was developed using Visual MODFLOW. The model was calibrated and validated to observed monthly water levels collected during the study. The model was used to quantify and compare induced recharge to the production wells from the recharge basin and from the Floyd River; evaluate the impact of the recharge basin on drought resiliency; and assess two new drought resiliency strategies at the wellfield. The new drought strategies evaluated by the model were construction of new recharge basins and implementation of a low-head dam/rock riffle in the Floyd River.

Model results found the recharge basin provided 9% of the water production to wells PL1-4 and PL1-8 during the study period (November 2015 – November 2016), while induced recharge from the Floyd River was found to provide 52% of the water production. Similar to what was observed in the measured water and nitrate levels, model results indicate the recharge basin provides more water to PL1-8 than PL1-4.

During the drought simulation, rainfall in the model was reduced and the Floyd River stage was modified to

represent 2012 drought levels. Based on model results, the recharge basin was found to provide protection against drought. When the basin was maintained at the water level measured in November 2015 (1341.5 feet), the pumping water levels at PL1-4 or PL1-8 did not reach the pump elevations after 500 days in the drought simulation, indicating the pumps would not go dry. When the basin water level was not maintained, water levels reached the pump elevation at production well PL1-4 after 4 days. While the recharge basin was found to provide some resiliency against drought, model simulations suggest the Floyd River is a greater factor in terms of maintaining water levels in the aquifer and at the production wells.

Model results also indicate additional resiliency strategies—new recharge basins or a low-head dam/rock riffle—would improve drought protection and increase recharge to the aquifer. Under drought conditions, 500-day model simulations found maintaining the new recharge basins at elevations from 1341.5–1345 feet increased recharge from the basins and Floyd River to the aquifer by 9–28% compared to simulations without the new basins. Aquifer recharge was observed to increase with higher water level elevations in the new basins. Therefore, constructing new basins with higher water elevations and creating storage volume by building berms around the basin's border, could create more productive basins than creating volume by digging down under the sand and gravel package into the clay layer below the aquifer.

Construction of a low-head dam or rock riffle to increase or maintain stage along the Floyd River was also shown to be a potentially beneficial drought resiliency strategy. After 500 days in the drought scenario, the model found a low-head dam/rock riffle set at elevations from 1334–1337 feet increased recharge to the aquifer by 5–45% compared to simulations without the strategy where the river stage was allowed to fall. Model results found the low-head dam/rock riffle had a greater impact on water levels at the production wells than the new recharge basins due to the proximity of the production wells to the Floyd River. The new recharge basins were located to the north and west of the current recharge basin and had a greater impact on the aquifer water levels in the portion of the aquifer further away from the river.

INTRODUCTION

Shallow alluvial aquifer systems in northwest Iowa are susceptible to drought and groundwater contamination from nonpoint sources. Many rural water systems use these alluvial aquifers. Rural Water System #1 (RWS#1) utilizes the shallow alluvial aquifer within the floodplain of the Floyd River in Sioux County, Iowa. Currently, the system has seven active alluvial wells 22–40 feet deep that are spread out along 3–4 miles of the Floyd River floodplain. Nearly 1,300 customers with an average monthly usage of 72,000 gallons are supplied water by RWS#1. The majority of water usage is directed toward agricultural purposes, including livestock.

Figure 1. Rural Water System #1 wellfield containing a floodplain pond.

Like many rural water systems utilizing shallow alluvial aquifers, RWS#1 is looking for new ways to improve water sustainability by increasing groundwater storage, while not sacrificing water quality. In 2012, a floodplain pond (≈1.3 acres) was excavated between two of RWS#1's wells along the Floyd River (Figure 1). A small creek draining an upstream watershed along with direct rainfall provides inflow into the pond. The pond discharges to the Floyd River, evaporates into the atmosphere, and seeps into the alluvial aquifer.

The objective of this study was to evaluate water quantity and quality impacts of the floodplain pond on the surrounding alluvial aquifer. The effectiveness of the pond to capture, store, and provide water to the aquifer was assessed. Groundwater recharge from the pond to the aquifer was quantified. The nitrate removal efficiency of the pond was also quantified. The evaluation involved a combination of a geophysical investigation, monthly collection of water levels as well as nitrate and chloride concentrations, and the development of a calibrated, local-scale groundwater flow model. The pond-aquifer system was evaluated for the monitoring period November 2015 to November 2016 as well as under drought conditions.

From an aquifer perspective, the floodplain pond evaluated in this study acts as a recharge source to the alluvial aquifer. Therefore, throughout this report the pond will be referred to as a "recharge basin."

CLIMATE

The climate of northwest Iowa is classified as sub-humid. Long-term (65-year) average annual rainfall for the town of Sibley, located 25 miles from the study area, is around 28 inches (Mesonet, Iowa State University, 2017). The region typically receives the majority of rainfall from the spring through the early fall (April–September). Severe droughts can impact the area. Rainfall from the five driest years on record range from 14.38–19.38 inches.

GEOLOGY

Deposits in the alluvial aquifer consists of sand and gravels. The alluvial aquifer is overlain by fine-grained sediments of clay, silt, and silty-sand. Underlying the sand and gravel aquifer is clay. Based on data from 17 driller's logs available from RWS#1 and the Iowa Geological Survey's (IGS) GEOSAM database in conjunction with a geophysical investigation, thickness of the sand and gravel aquifer in the area around the production wells ranges from 8–20 feet (Figure 2). Aquifer extent in the wellfield area is shown in Figure 2 and was developed from existing driller's logs in conjunction with the area's soil data provided by the USDA's NRCS Web Soil Survey (USDA, 2016).

GEOPHYSICAL INVESTIGATION

A)

B)

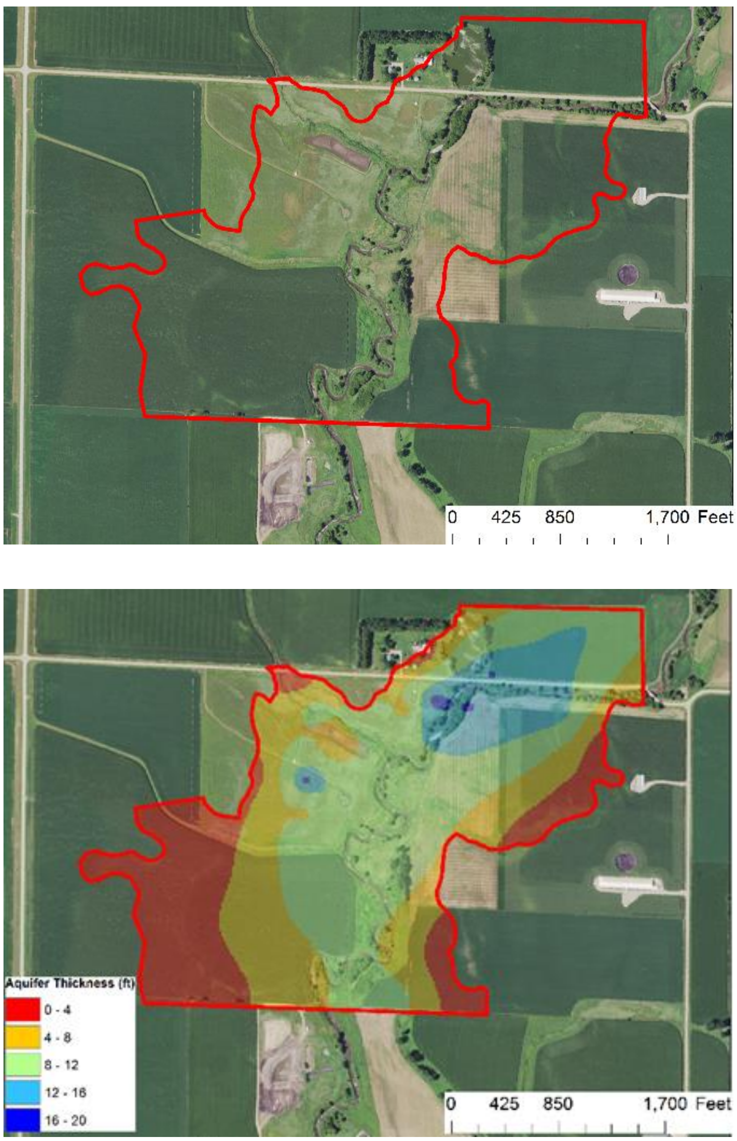

Figure 2. A) Extent and B) thickness of the sand and gravel aquifer at the RWS#1 wellfield evaluated in this study.

A geophysical investigation was conducted to help evaluate changes in lithology within the wellfield, assist in the assessment of aquifer thickness, gather additional information about aquifer properties, aid in the identification of potential locations for observation wells, and help with development of the local-scale groundwater flow model. Geophysical measurements were collected using an Advanced Geosciences Inc. (AGI) SuperSting R8, channel electrical resistivity (ER) meter.

Four total geophysical transects were completed (Figure 3). Lines 1 and 2 followed the hillslope perpendicular to the Floyd River. Lines 3 and 4 ran from the recharge basin toward the production wells. Field measurements were obtained by introducing a direct current into the ground through current electrodes and measuring resulting voltages through potential electrodes. An array of up to 56 electrodes were spaced approximately 20 feet apart, driven approximately one foot into the ground, and connected via electrode cables and a switch box to a central ER meter. A dipole-dipole collection configuration was utilized to maximize data collection. Measure time was set at 3.6 seconds and measurements were stacked (averaged) twice, unless the standard deviation of all channels was less than 2%. In that case, a third measurement was taken and included in the average. To quantify error, overlapping data were collected in areas already covered by normal measurement.

Data were processed using AGI EarthImager 2D version 2.4.0 software. A smooth model inversion method was used. The inversion mesh was fine for the near-surface region in each transect and coarsened with depth. Resistivity values below one Ohm-m or above 10,000 Ohm-m were removed as these values are typically representative of erroneous data. Inversion was stopped once root-mean-squared (RMS) values were at or below 3% and L2 norm ratio values were less than one.

Generally, coarse-grained sediments are more resistive to electrical charge than fine-grained sediments. In alluvial aquifers where coarse-grained material usually facilitates quicker groundwater flow, electrical resistivity measurements provide a way to identify more productive (coarser) aquifer material. All lines showed resistivity values below 100 Ohm-m, indicating the sand and gravel package comprising the aquifer is not overly coarse and the aquifer consists mainly of fine to medium-sized sand. Line 1, which ran south of and parallel to the recharge basin, suggests there is a large portion of resistive sand and gravel beneath the hillslope; however, areas that lack subsurface moisture can also appear resistive and the sediments in this region are likely dry. Another area of higher resistivity in Line 1 was observed at the southern end of the basin (Appendix A1). This resistive area is also observed in Line 3, which runs from the southern point of the basin to production well PL1-8 (Appendix A3). Lines 2 and 4 found only moderate aquifer material to the north of the basin (Appendix A2 and A4). The best sand and gravel packages in terms of aquifer productivity appear to parallel the river and extend outward along the south-eastern border of the recharge basin. Outside of the near-river-area, the saturated sediment package in the aquifer has moderately-productive material.

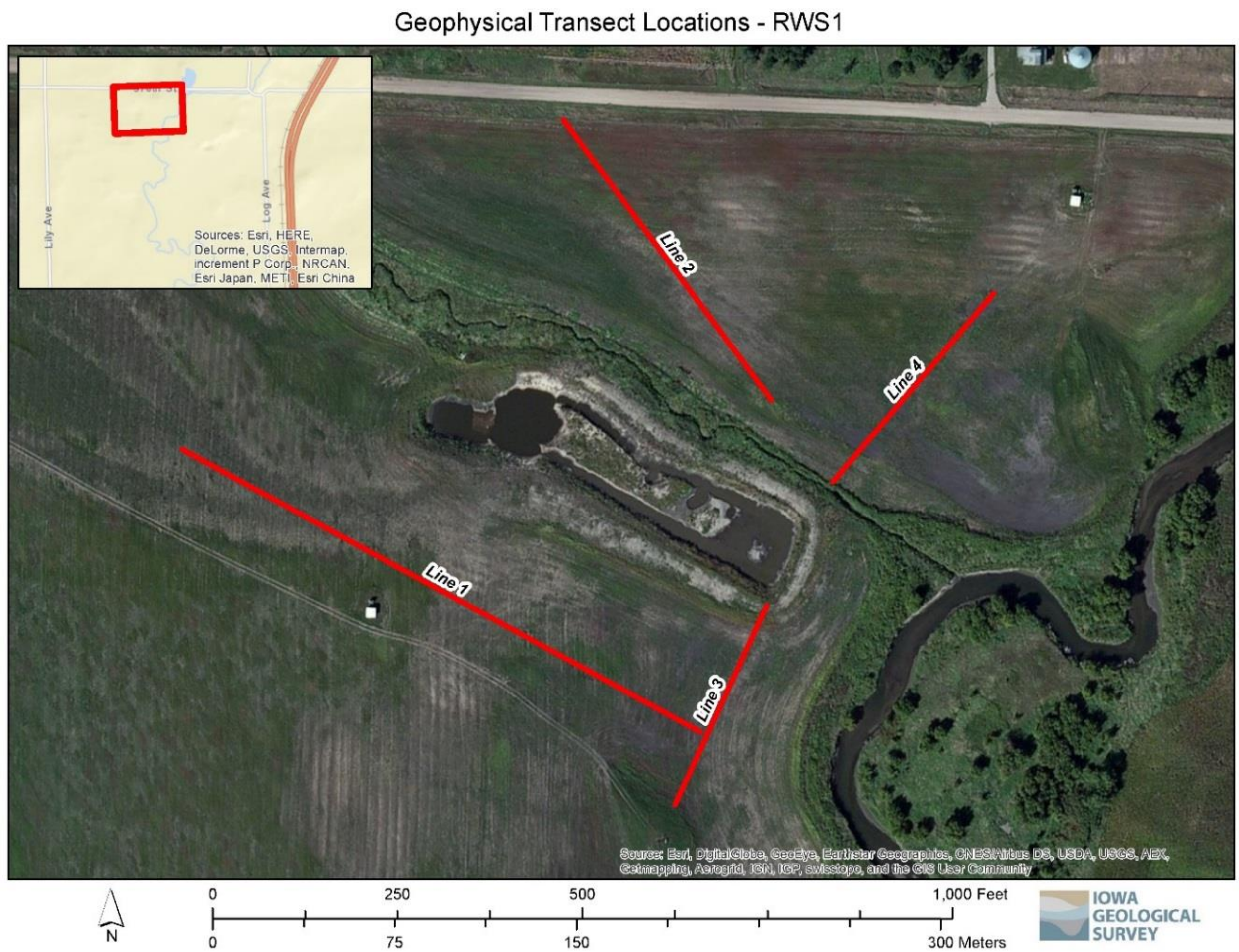

Figure 3. Geophysical transects evaluated at RWS#1.

WATER MONITORING

Water levels were collected on a monthly basis using an In-Situ electronic water level probe from three groundwater observation wells (OB1, OB2, and OB3), one piezometer in the recharge basin (PZ-1), one piezometer downgradient of the recharge basin (PZ-2), and one surface water location in the recharge basin (SW-3). The observation wells and piezometers were installed as part of this study. The groundwater observation wells were installed at three locations in the alluvial aquifer: north of the basin approximately 260 feet from PL1-4 (OB1), along the upper tributary that runs through the wellfield and partially supplies water to the basin (OB2), and immediately downgradient of the middle portion of the recharge basin (OB3). The piezometers (PZ-1 and PZ-2) were installed at the southern end of the recharge basin.

Water quality samples were collected from the water level monitoring locations as well as from three other surface water locations outside of the recharge basin (SW-1, SW-2, and SW-4) and from the two production wells in the wellfield (PL1-4 and PL1-8). Surface water samples were collected from the tributary (SW-1), Floyd River (SW-2), recharge basin (SW-3), and basin outlet (SW-4). Water samples from the observation wells and piezometers were collected using a peristaltic pump. Water quality samples were analyzed for nitrate as nitrogen (NO_x-N) and total chloride (Cl). Monthly water levels and quality results are given in Appendix B. Water monitoring locations are shown in Figure 4.

Figure 4. Water monitoring at RWS#1 consisting of four surface water locations (SW-1, SW-2, SW-3, SW-4), three groundwater observation wells (OB1, OB2, OB3), and two piezometers in the recharge basin sediments (PZ-1, PZ-2).

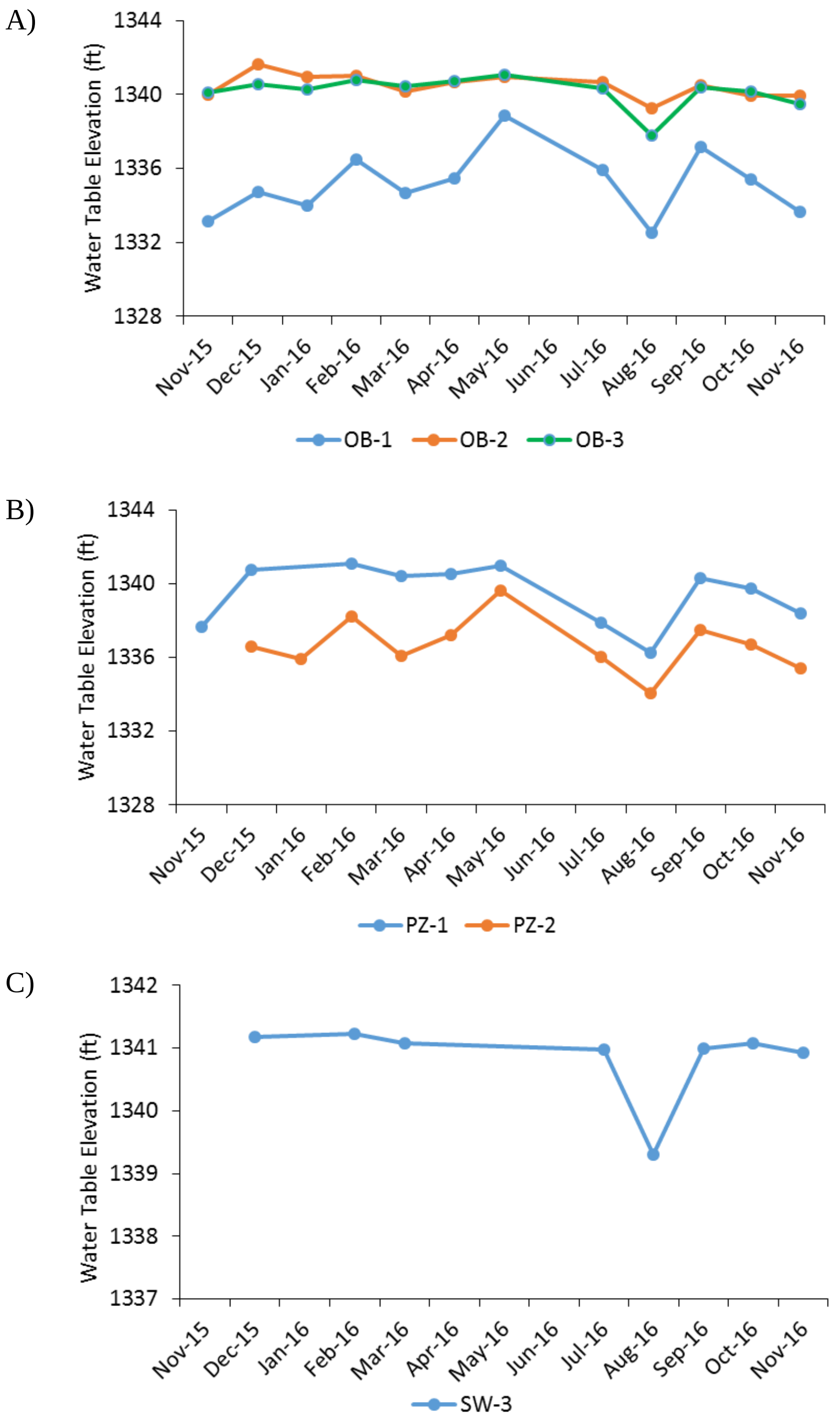

Figure 5. Monthly water level elevations in the A) observation wells, B) piezometers, and C) recharge basin.

Monthly waters levels in the aquifer throughout the monitoring period are shown in Figure 5. Water levels in OB1 had greater observed fluctuations than in OB2 and OB3. Lack of fluctuation in OB2 and OB3 suggests the basin is providing some recharge to the aquifer. The basin does not appear to provide much recharge to the aquifer in the area of OB1, which is upgradient of the basin. The correlation of fluctuations in piezometers (PZ-1 and PZ-2) with the basin (SW-3) water levels shows a strong hydraulic connection between surface water in the basin and the basin sediments. Figure 5A also indicates a seasonal variation in water levels within the aquifer. During the summer months (May through August 2016), when evapotranspiration rates and demand were greatest, water levels on-average decreased. Aquifer recharge from abnormally high rainfall during the fall 2015 months likely caused the increase in water levels observed during those months. In the winter months, when evapotranspiration was minimal and demand decreased, aquifer water levels were steady.

Water table contour maps of the alluvial aquifer wellfield are given in Figures 6, 7, and 8. The contours were developed from groundwater flow model results of water levels in the aquifer when the pumps were off (Figure 6) and when the pumps were on (Figures 7 and 8). The groundwater flow model was calibrated using monthly observed water levels and is described later in the report (Groundwater Modeling). Figure 6 represents water levels during November 2015 when pumps were off. Figure 7 represents pumping levels during a month of observed low water levels (August 2016). Figure 8 represents pumping levels during a month of observed high water levels (September 2016). Water levels in the alluvial aquifer without pumping (Figure 6) shows the Floyd River drains the aquifer went pumps are off (Figure 6). However, pumping water levels indicate the Floyd River supplies water to the production wells when pumping with PL1-4 drawing more from the Floyd River than PL1-8 (Figures 7 and 8). Water levels also indicate the basin recharges the aquifer during periods of high and low water levels.

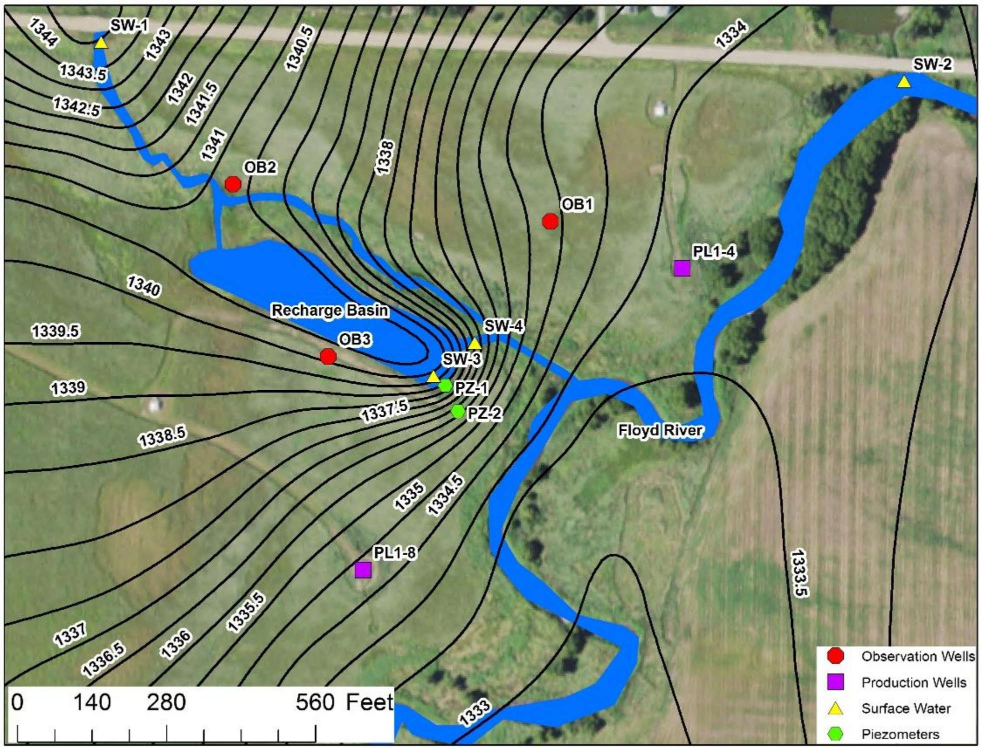

Figure 6. Water level elevations (feet) in the RWS#1 wellfield during November 2015 without pumping.

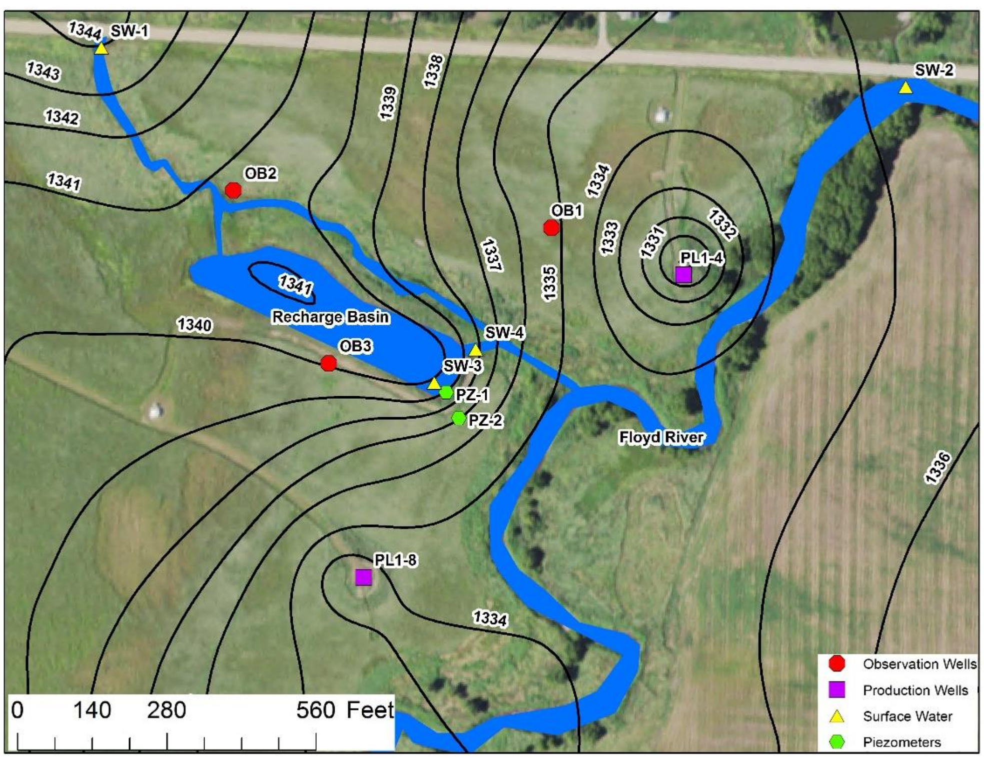

Figure 7. Water level elevations (feet) in the RWS#1 wellfield during a month of observed lower water levels (August 2016).

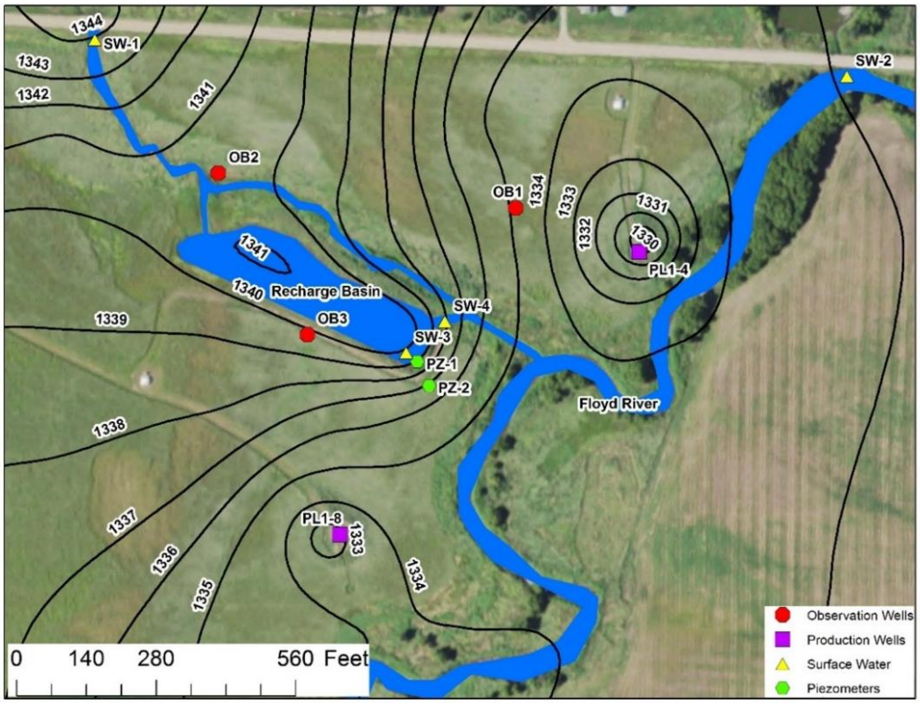

Figure 8. Water level elevations in the RWS#1 wellfield during a month of observed higher water levels (September 2016).

Monthly nitrate as nitrogen (NO_x-N) concentrations in the aquifer throughout the monitoring period are given in Figure 9. The Environmental Protection Agency (EPA) has set a maximum contaminant level for nitrate as nitrogen in drinking water at 10 mg/L. Production well PL1-4 had nitrate levels in excess of 10 mg/L in four of the 12 months sampled, while nitrate levels in PL1-8 did not exceed 10 mg/L in any month. Nitrate levels appeared to fluctuate seasonally. Nitrate levels steadily rose throughout the winter months in the surface sampling locations due to the lack of nitrogen uptake by corn and soybean in the surrounding watersheds as well as the prairie grass which covers the aquifer's wellfield. The recharge basin's ability to reduced nitrates also decreased during winter months as biological nitrogen fixing slowed (Figure 9B). During the spring and summer, nitrate concentrations steadily decreased in all surface water bodies and the recharge basin as biological activity in the surface water and uptake throughout the watershed increased.

Visual comparison of nitrate levels in the production and observation wells with surface water levels indicate changes in nitrate levels in the aquifer tend to correlate with changes in nitrate levels in the surface water, which suggests the aquifer receives a significant amount of recharge from surface water (Figure 9). Nitrate concentrations in PL1-4 where consistently higher and had greater fluctuation than PL1-8, suggesting PL1-4 relies more heavily on surface water recharge from the Floyd River than does PL-8. Considering proximity to the Floyd River, the nitrate concentration data supports the water level data suggesting PL1-4 draws more recharge into the aquifer from the Floyd River than does PL1-8. This connection does allow PL1-4 to have greater production than PL1-8 (100 vs. 45 gpm); however, PL1-4 is more vulnerable to water quality issues.

Observation well 3 had greater fluctuation and consistently higher nitrate concentrations than OB1 and OB2 with concentrations consistently above 10 mg/L. Based on the location of OB3 (Figure 1), results show significant connection between the upper portion of the recharge basin and the surrounding aquifer. Such a connection allows for "short-circuiting", where surface water that enters the basin quickly exits by entering the sand and gravel aquifer instead of spending time in the basin and traveling through a fine grain sediment package where nitrogen reduction can occur through physical, chemical, and biological processes. The connection of the upper portion of the basin to the sand and gravel aquifer was made during basin construction when the basin was excavated down into and through the sand and gravel package in the upper portion of the basin. Concentrations observed in PZ-1 and PZ-2 show the southern portion of the basin has fine grain sediments that successfully reduce nitrate concentrations as water enters the aquifer. Increasing the amount of fine grain sediments in the upper portion of the basin and along the boundary where the basin is connected with the surrounding aquifer would improve nitrogen treatment efficiency. Deposition of fine grain sediments will occur over time and increased nitrogen reductions can be expected. Re-designing the upper portion of the basin to prevent "short-circuiting" and establishment of aquatic plants which uptake nitrogen (e.g. Cattails) would also help reduce the levels of nitrates entering the aquifer.

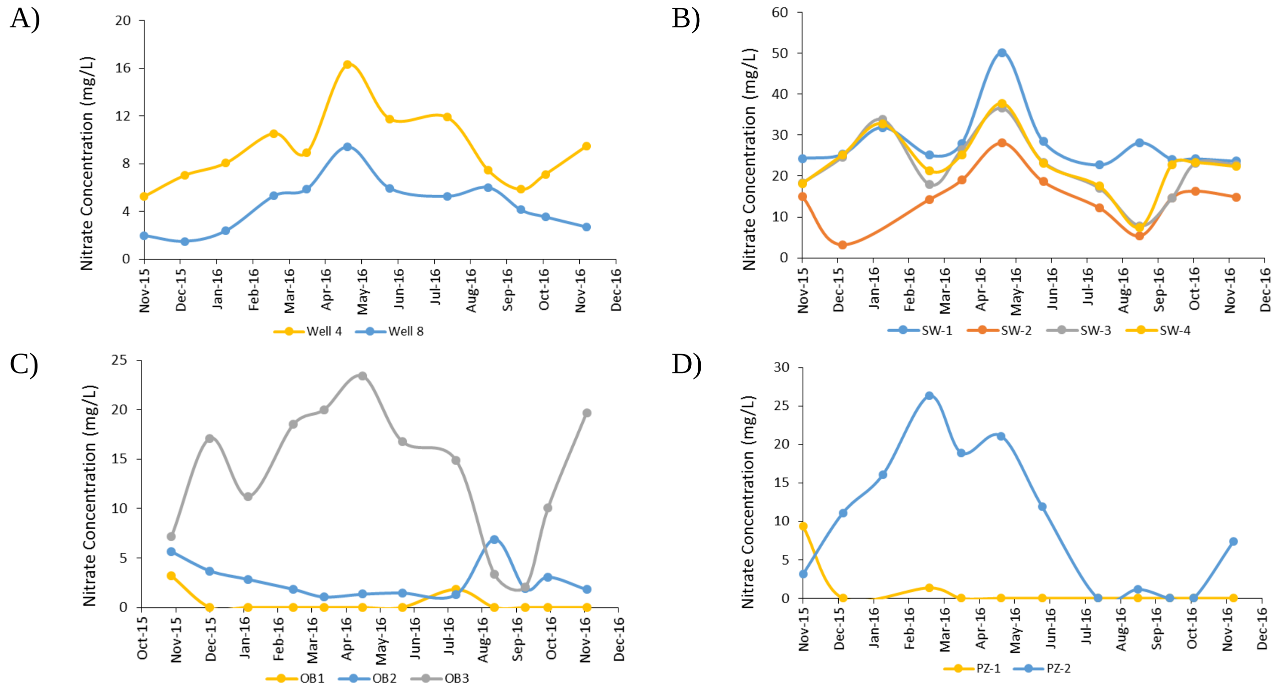

Figure 9. Monthly nitrate levels in the A) production wells (PL1-4, PL1-8), B) surface water (SW-1: tributary, SW-2: Floyd River, SW-3: recharge basin, SW-4: recharge basin discharge), C) observation wells (OB1, OB2, OB3) and D) piezometers (PZ-1, PZ-2).

Nitrate removal efficiency of the recharge basin for both surface water and recharge entering the aquifer is given in Table 1. Removal rates in Table 1 are based on the average of monthly nitrate concentrations collected during the study. The basin reduced surface water nitrate concentrations by 18%. Nitrate treatment efficiency of the surface water could be improved by increasing residency time of water in the basin through development of cells or barriers, which would provide more time for settlement, biological reduction, and dissolution. In terms of removing nitrates entering the aquifer, the lower portion of the basin was more efficient than the upper portion of the basin (45% vs. 30% nitrate removal efficiency).

Table 1. Nitrate removal efficiency of the recharge basin.

Removal	Inflow*	Outflow	Average Concentration (mg/L)**	Removal Rate (mg/L)**	Removal Efficiency (%)**
Surface Water	Tributary (SW-1)	Basin Discharge (SW-4)	23.1	4.9	18%
Upper Portion of Basin to Aquifer	Recharge Basin (SW-3)	Aquifer near Upper Portion of Basin (OB-3)	13.7	8.5	30%
Lower Portion of Basin to Aquifer		Aquifer Downgradient of Lower Portion of Basin (PZ-2)	9.8	12.5	45%

*Average inflow from the tributary (SW-1) and in the recharge basin (SW-3) measured during the study were 28.0 and 22.2 mg/L, respectively.

**Based on average of reduction measured on a monthly basis.

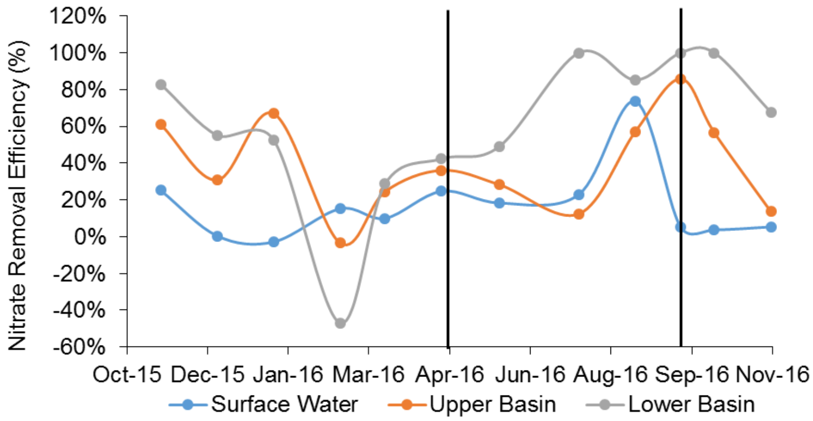

Figure 10. Monthly nitrate removal efficiency of the recharge basin.

Nitrogen removal efficiency appeared to change seasonally with best removal in the spring through summer period (Figure 10). During the spring and summer, warmer temperatures allowed for biological reduction to take place in the basin. September 2016 was also a warmer month; however, that month experienced significant rainfall and the drop in nitrate removal efficiency in the surface water and upper portion of the basin can be attributed to the lack of residency time of water in the basin before discharging into the aquifer or downstream to the Floyd River. Nitrate levels in the lower portion of the basin did not respond to the September 2016 rainfall, whereas nitrate levels in the upper portion of the basin did. Differences observed in nitrate removal efficiency between the upper and lower portion of the basin in September 2016 highlight the potential benefits of building up fine grain sediments in the basin and providing residency time for water in the basin. Based on nitrate removal efficiency results, increasing residency time in the basin by creating smaller cells, increasing the amount of fine grain sediments between the basin and aquifer (which will occur over time), and establishment of aquatic plants will improve nitrate treatment efficiency of the basin. Increasing biological reduction could be very beneficial as it would occur during the warmer months of spring, summer, and fall when water usage is greatest.

Surface water and groundwater samples were also analyzed for chlorides. Chloride in northwest Iowa's surface water and groundwater is associated with animal waste and winter road salt. Given RWS#1's rural location within Sioux County, the impact of road salt on chloride concentrations can be assumed to be minimal. Sioux County leads all counties in Iowa in cattle on feed as well as hog and dairy production (USDA, 2015). The majority of chloride introduced into the environment in the area is likely from livestock waste. Chloride in surface water and groundwater is relatively conservative (non-reactive), meaning the element is mobile and does not undergo significant biological reduction in the environment. While nitrate is also mobile, it does undergo biological reduction. The ratio of nitrate to chloride (N:Cl) provides an indicator of whether nitrate is being reduced through biological activity or by dissolution. If nitrates are being reduced through biological processes, then the N:Cl ratio should decrease. If nitrates are being reduced through dissolution and not biological reduction or no reduction is taking place, the N:Cl ratio should not decrease. In other words, nitrates will be impacted by biological reduction and chlorides will not; however, but both nitrates and chlorides will be impacted similarly by dissolution.

Monthly N:Cl ratios in the production wells, observation wells, piezometers, and surface water are shown in Figure 11. Seasonal biological reduction was observed in the production wells and in the surface water (Figures 11A and 11B). An observed decreasing trend in nitrate/chloride ratios during the warmer months (April-September) suggests biological reduction. Uptake from prairie grass in the wellfield and the biological processes occurring throughout the watershed were contributing causes to the biological reduction observed in the production wells and surface water. Nitrate/chloride ratios at observation well 3 (OB3) as well as the piezometers (PZ-1 and PZ-2) were also shown to decrease during the warmer months (Figure 11C). The decreasing trend in OB3, PZ-1, and PZ-2 represents biological reduction from the basin sediments. During the cooler months, nitrate/chloride ratios in OB3, PZ-1, and PZ-2 appear to increase suggesting the lack of biological reduction from the recharge basin sediments (Figure 11C). Ratios in observation wells 2 and 3 (OB2 and OB3) were not observed to be as high or fluctuate as much as OB3. The N:Cl ratios from OB2 and OB3 suggest that the wellfield area north of the basin that is not in the near-vicinity of the Floyd River has less connection with the basin and the river, which supports results of the geophysical investigation.

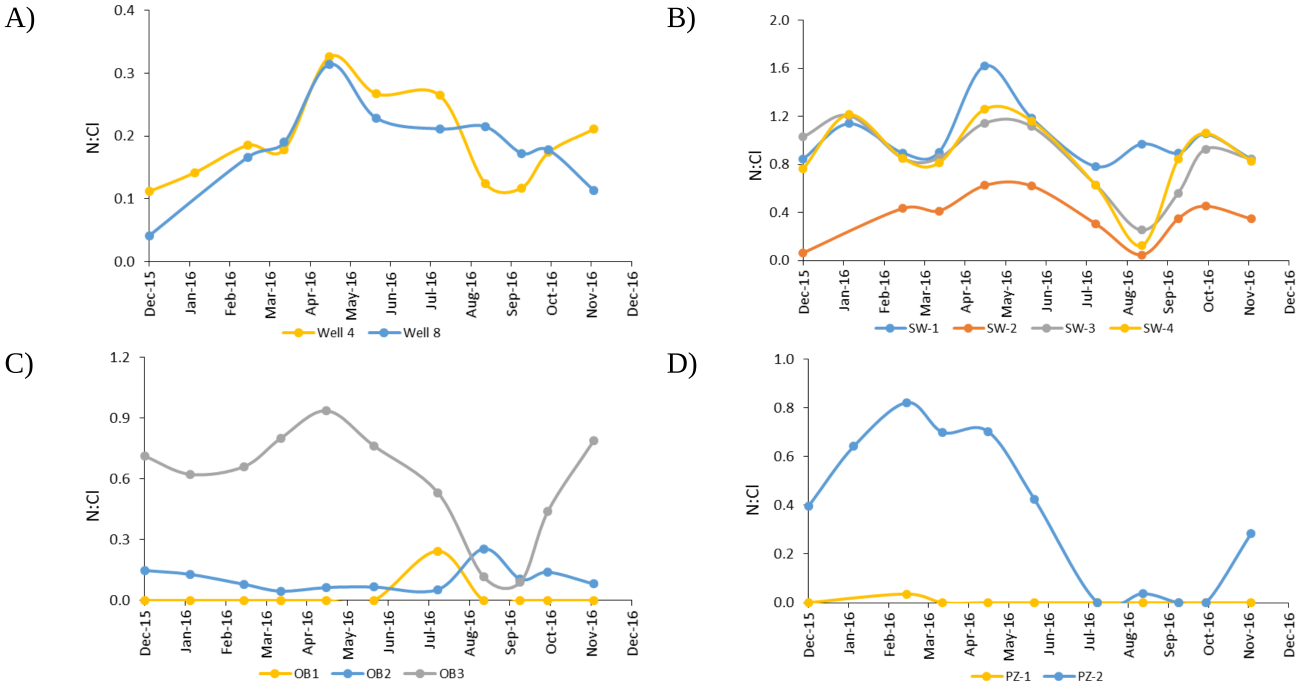

Figure 11. Monthly nitrate to chloride ratios in the A) production wells (PL1-4, PL1-8), B) surface water (SW-1: tributary, SW-2: Floyd River, SW-3: recharge basin, SW-4: recharge basin discharge), C) observation wells (OB1, OB2, OB3) and D) piezometers (PZ-1, PZ-2).

GROUNDWATER MODELING

Groundwater flow in the alluvial aquifer system was simulated using the modeling software Visual MODFLOW Classic Version v.4.6.0.167 (June 2016). A local-scale, three-layer model was developed for the simulations. Depth, thickness, and extent of model layers were determined from borehole logs provided by RWS#1 and taken from the IGS GeoSam database, a web soil survey of the study area taken from United States Department of Agriculture's Natural Resource Conservation Service (UDSA NRCS, https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx), and results from the geophysical investigation. Model layer information, boundary conditions, and inputs are described below:

- Layer 1 represented the top soil and overlying fine grained alluvial silt and clay consisting of silty clay loam. Layer 1 was assigned horizontal and vertical hydraulic conductivities of 0.1 and 0.001 feet/day, respectively. Surface elevation of layer was developed from LiDAR (2-ft contours).
- Layer 2 represented the alluvial sand and gravel aquifer system. Aquifer thickness ranged from 8–20 feet in the area around the production wells (Figure 1B). Horizontal conductivity ranged from 75–175 feet/day. Horizontal conductivity and its variation within the aquifer was determined from pump tests conducted using production wells PL1-4 and PL1-8, the geophysical investigation, and model calibration. Variation of horizontal conductivity in the aquifer within the model is shown in Appendix C. Vertical conductivity was assumed to be 1/10th of horizontal conductivity.
- Layer 3 represented a low-permeability layer below the aquifer primarily consisting of clay. A uniform thickness of 26.25 feet was assumed. Horizontal conductivity for Layer 3 was 0.001 feet/day with vertical conductivity assumed to be 1/10th of horizontal conductivity.
- Extent of the alluvial aquifer surrounding the Floyd River in the local-scale groundwater model, shown in Figure 1A, was determined from the USDA NRCS web soil survey (Appendix D). Model cells outside of

the alluvial aquifer area were designated as inactive cells (no-flow) in all three model layers.

- The Floyd River was represented as a river boundary. River stage in the wellfield area was determined using river stage from United States Geological Survey (USGS) river gauge station in Alton, Iowa (USGS station: 06600100). Stage elevations were interpolated using LiDAR elevations of river stages at Alton and in the wellfield area. The Floyd River was assigned a horizontal hydraulic conductivity of 1 foot/day, a width of 26.25 feet (determined from ArcGIS), and a riverbed thickness of 1.64 feet.
- The tributary which runs through the wellfield was assigned as a river boundary condition.
- The recharge basin was represented as a general head boundary. Surface water elevations of the basin were measured on a monthly basis throughout the study. Hydraulic conductivity of the basin sediments was assumed to be 15 feet/day and uniform throughout the basin.
- A general head boundary was used to represent the pond located north of the wellfield.
- Production wells located in the wellfield, PL1-4 and PL1-8, were assumed to pump at constant rates of 100 gpm (PL1-4) and 45 gpm (PL1-8) during pumping simulations.
- The aquifer was assigned an average specific yield of 0.00393 based on pump test results (Appendix E).
- Recharge to the aquifer was derived from rainfall data taken from the Iowa State University Mesonet weather station located in Sibley, IA, approximately 25 miles from the wellfield (site: IA7664). It was assumed 27% of rainfall that fell on the surface enters the alluvial aquifer system. Aquifer recharge from rainfall ranged from 0.12–2.46 inches/month during the months of data collection (Nov. 2015–Nov. 2016). Recharge during drought simulations was assumed to be 0.25 inches/month or 3 inches/year.
- The model grid was comprised of 350 rows and 477 columns with grid cell sizes ranging from 2–13 feet.

Calibration and Validation Results

A steady-state model of the wellfield area was initially developed for calibration. The model employed a daily time step and a simulation length of 365 days. Measured water levels from November 2015 in the observation wells OB1, OB2, and OB3 as well as piezometer PZ-2 served as calibration targets. Production wells PL1-4 and PL1-8 were assumed to be pumping during model calibration in order to accurately represent the wellfield when the November 2015 water levels were collected. Production wells PL1-4 and PL1-8 both employee pump motors with variable frequency drive and it was assumed the pumps ran continuously at rates of 100 and 45 gpm, respectively. Observed and simulated heads during calibration are given in Table 2. Model performance in calibration was evaluated using the FITEVAL software which provides visual comparison (1:1 line), performance statistics (Nash-Sutcliffe Coefficient of Efficient or NSE and Root Mean Square Error or RMSE), outlier presence, bias identification, and qualitative model performance based on NSE results ("Very Good" to "Unsatisfactory") (A. Ritter and R. Muñoz-Carpena, 2013. http://abe.ufl.edu/carpena/software/FITEVAL.shtml). As shown in Figure 12, the model performed "Very Good" in calibration with an NSE of 0.971 and a RMSE of 0.460 feet. An NSE above 0.65 is considered "Acceptable." Figure 13 shows the simulated water table map at the end of the steady-state simulation.

Table 2. Observed and simulated water levels during calibration of steady state model.

Well*	Observed Head Elevation (ft)	Simulated Head Elevation (ft)
OB1	1333.14	1333.57
OB2	1340.03	1340.61
OB3	1340.09	1339.74
PZ-2	1336.58	1337.03

*OB1: Observation Well 1, OB2: Observation Well 2, OB3: Observation Well 3, PZ-2: Piezometer 2.

A transient model with a daily time step was developed from the calibrated, steady-state model. For validation, the model was setup to simulate the collection period of this study (November 2015 through November 2016). Monthly water levels collected throughout the study served as validation targets for the model. Performance of the model was "Acceptable" in validation with an NSE of 0.798 and an RMSE of 1.169 feet, Appendix F. Upon removal of an identified outlier, May 2016 at OB1 (observed: 1339.17 feet vs. simulated: 1334.91 feet), the model performance in validation improved to “Good” with an NSE of 0.853 and RMSE of 1.005 feet. Water table maps from the transient model during months of low (August 2016) and high (September 2016) waters levels are shown in Figures 7 and 8, respectively. The validated transient model was then used to perform the simulations described below.

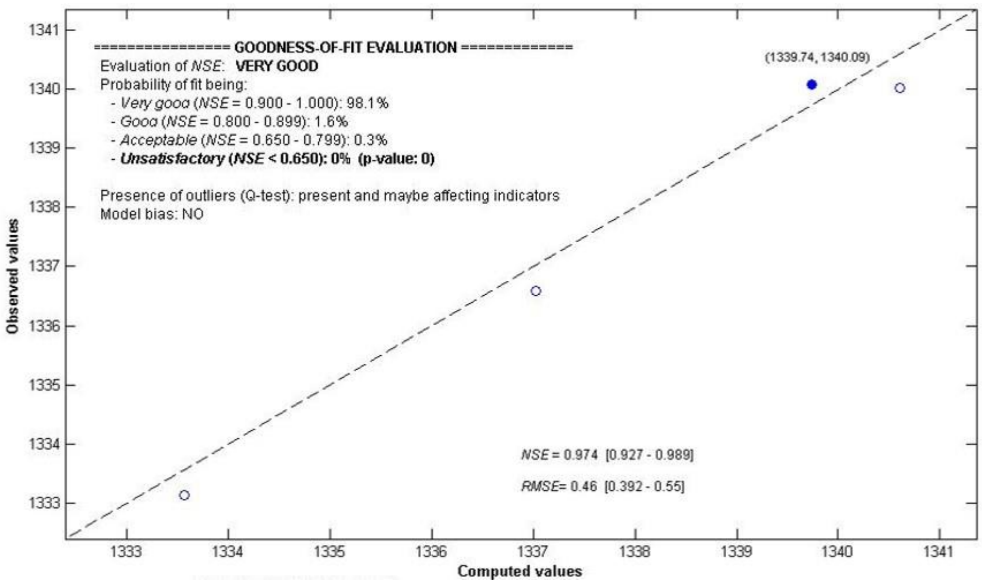

Figure 12. Calibration results for the steady-state Visual MODFLOW simulation.

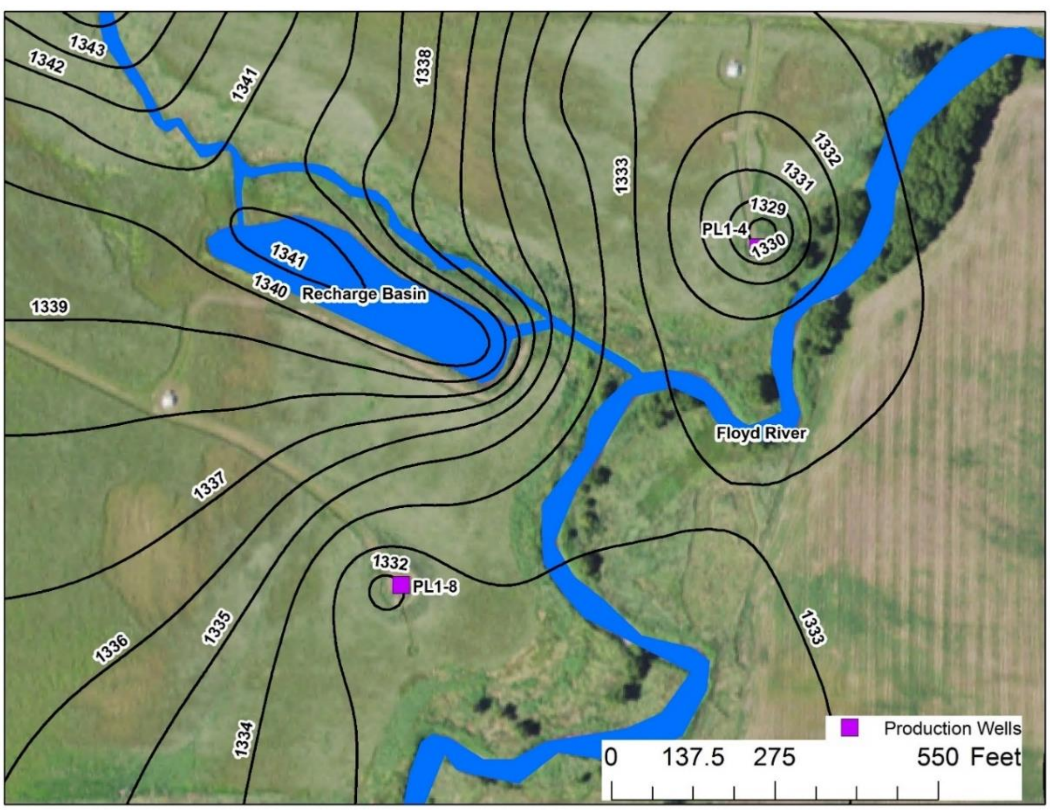

Figure 13. Water levels in November 2015 from the steady-state model calibration.

Simulation 1: Induced Recharge from the Basin and River to Aquifer

Induced recharge to the aquifer from the recharge basin and from the Floyd River was simulated using the transient model. The simulation was conducted for the period of data collection (November 2015–November 2016). Production wells PL1-4 and PL1-8 were turned off for the first model run. During the second run, production wells were turned on with PL1-4 and PL1-8 continuously pumping at 100 and 45 gpm, respectively. Induced recharge to the aquifer with and without pumping was calculated using mass balances tracked by Visual MODFLOW's Zone Budget. Induced recharge from the basin to the aquifer during pumping represented 9% of the water extracted from PL1-4 and PL1-8 during the study period. Induced recharge from the Floyd River to the aquifer during pumping accounted for 52% of the water extracted from PL1-4 and PL1-8. Precipitation recharge accounted for the remaining of water production. Induced recharge from the Floyd River during the model simulation agreed with results from a previous study of the Floyd River's alluvial aquifer. The study found the Floyd River contributed 54% of the water production to the aquifer through induced recharge during years with normal precipitation (Gannon, 2008). Overall, the river was found to provide over five times the amount induced recharge to the wellfield than the recharge basin.

Simulation 2: Impact of the Recharge Basin during a Drought

Considering the amount of induced recharge provided by the Floyd River for water production, the RWS#1 wellfield can be vulnerable to a drought when recharge provided by the Floyd River is reduced. The impact of the recharge basin on the aquifer during drought conditions was simulated. To simulate drought conditions the tributary running through the wellfield was removed, the reach of the Floyd River within the wellfield area was set at stages representing 2012 drought levels, and the elevation of the private pond to the north of the basin was adjusted based on the Floyd River stage. Recharge to the aquifer was also reduced to 3 inches/year as was done in the Gannon (2008) study to represent recharge during drought conditions in the Floyd River alluvial aquifer. Two model runs were conducted. The first model run maintained the recharge basin at a constant level of 1341.5 feet throughout the simulation, which represented a normal level observed during this study's monitoring period. In the second model run, the recharge basin was allowed to drain. The purpose was to determine the how much protection the basin could provide during a drought.

With the basin maintained at a constant level, drawdown did not reach the pump elevations of either PL1-4 or PL1-8 after 500 days. Water levels at PL1-4 did come within 1 foot of the pump but stabilized before reaching the pump. Without the basin, water levels at PL1-4 reached the pump after 5 days and did not reach PL1-8 after 500 days. While water levels at PL1-8 were still observed to be above the pump without the basin, levels did come within 1.2 feet of the pump elevation. Removal of the basin caused drawdown to increase by 0.8 feet at PL1-4 and 3.0 feet at PL1-8. The basin appeared to provide more recharge to production well PL1-8 than PL1-4, while PL1-4 appeared to be more closely tied to the Floyd River. Considering production well PL1-8 is downstream of the basin and PL1-4 is closer to the river, model observations seem viable. Results indicate the recharge basin does provide some protection against drought. However, the wellfield can still be vulnerable to drought due to its dependence on the Floyd River for induced recharge. Possible further drought protection measures for the wellfield could include implementation of a structure (rock riffle/low-head dam) along the Floyd River to raise the stage or creation of new recharge basins within the wellfield. Future drought strategies were assessed in Simulation 3.

Simulation 3: Impact of Future Drought Resiliency Strategies

Two future strategies to improve wellfield performance and drought resiliency were evaluated using the groundwater model: 1) new recharge basins and 2) low-head dam or rock riffle. Both strategies were evaluated separately. The first drought strategy assessed was the impact of two proposed new recharge basins. Locations of the new basins are shown in Figure 14. The basins would increase surface water storage and recharge into aquifer within the wellfield area. The second drought strategy evaluated, implementation of a low-head dam or rock riffle in the Floyd River, was done to evaluate how increasing stage in the Floyd River would increase recharge into the aquifer. The location of the proposed low-head dam or rock riffle is given in Figure 15. Both drought strategies were evaluated using the drought simulation describe in Simulation 2. The model was run for 500 days, aquifer recharge from rainfall was set at the drought level of 3 inches/day, pumping in PL-4 and PL-8 was assumed continuous, and the current recharge basin was maintained at the same level as was done during Simulation 2 (1341.5 feet). Model results for each strategy were compared with results from the drought simulation without the new drought strategies.

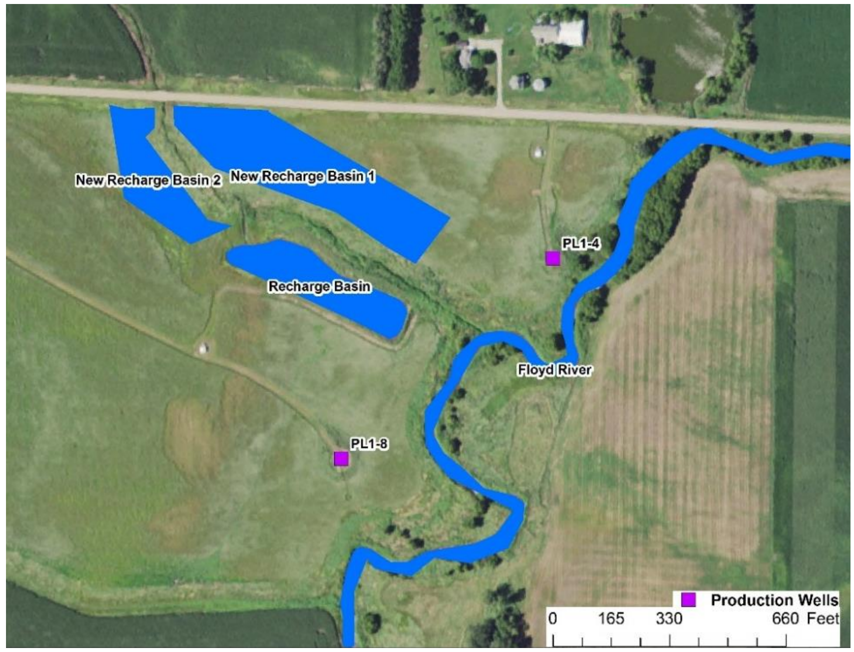

Figure 14. Location of two proposed new recharge basins.

In the simulation with the new basins, the model was run multiple times with new basins maintained at different elevations (1341.5–1345 feet). The Floyd River was maintained at the same 2012 drought levels as was done during Simulation 2. In the low-head dam/rock riffle simulation, the new recharge basins were removed. During the low-head dam/rock riffle simulation, model runs were conducted with the low-head dam/rock riffle at multiple elevations (1334–1337 feet). Floyd River stage was adjusted based on the elevation of the low-head dam/rock riffle. The lowest elevation of the structure (1334 feet) was selected based on the average level of the Floyd River during this study's monitoring period (November 2015 – November 2016).

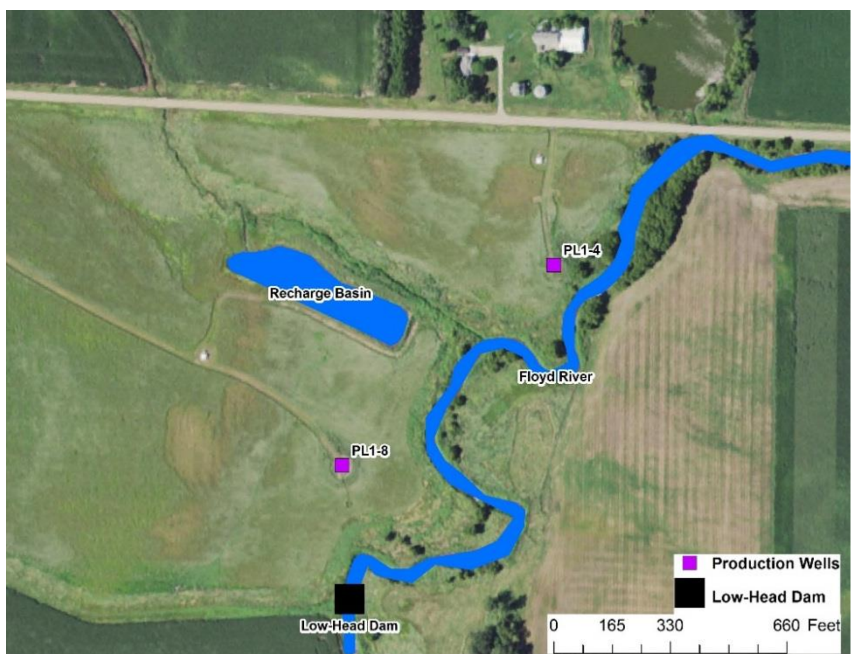

Figure 15. Location of a potential low-head dam or rock riffle.

Recharge to the aquifer from the basins and river was increased by 9–28% during the drought simulation with the new recharge basins compared to without the recharge basins (Table 3, Figure 16). Water levels in production wells PL1-4 and PL1-8 after 500 days of continuous pumping were found to be 1–2 feet higher with the new recharge basins (Figures 17–19). It was observed that maintaining the new recharge basins at higher water levels increased recharge to the aquifer. Results suggest designing the basins to maximize water level elevation. A suggestion would be minimizing depth of digging and creating volume by using excavated material to form berms around the basins above ground level. Model results also suggest that digging the basins down into the clay layer below the aquifer's sand layer would not increase aquifer recharge because the volume of water in the lower clay layer would not be accessed by the aquifer. Instead, creating storage volume by building the basins shallower and upward could be a more productive strategy.

Table 3. Results of model simulations evaluating impacts of new recharge basins or a low-head dam/rock riffle on the alluvial aquifer during a drought

Scenario	Design Elevation of New Strategy (feet)	Basin Recharge to Aquifer (mgd)	Floyd River Recharge to Aquifer (mgd)	Net Combined Recharge (mgd)*	Increase in Aquifer Recharge (%)
No New Strategy	N/A	0.19	0.14	0.33	N/A
New Recharge Basins	1341.5	0.23	0.13	0.36	9%
	1343	0.26	0.13	0.38	16%
	1345	0.30	0.12	0.42	28%
Low-Head Dam/Rock Riffle on Floyd River	1334	0.14	0.21	0.35	5%
	1335	0.13	0.26	0.39	18%
	1337	0.10	0.38	0.48	45%

*Combined recharge rate from river and basin(s).

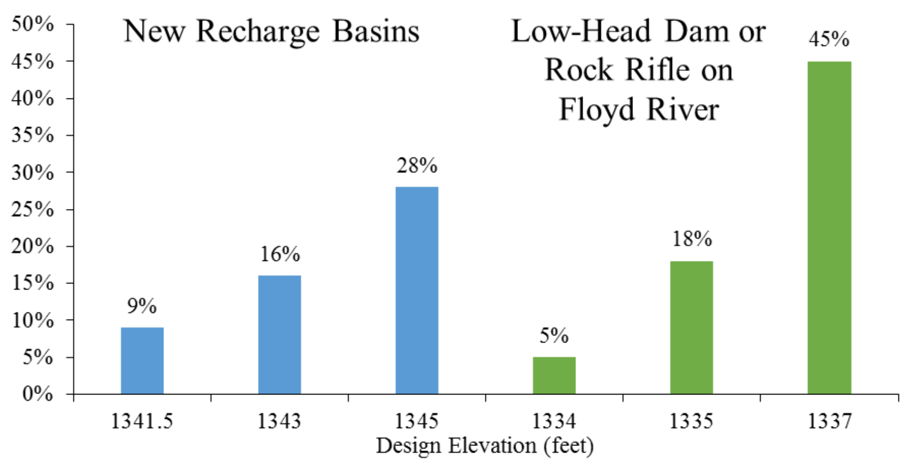

Figure 16. Increase in aquifer recharge from new drought strategies during the drought simulation conducted with Visual MODFLOW.

Model results found the drought strategy of implementing a low-head dam or rock riffle along the Floyd River increased induced recharge to the aquifer during the drought simulation by 5–45% (Table 3). Water levels at wells PL1-4 and PL1-8 during pumping were also raised by 2–5 feet depending of stage of the low-head dam/rock riffle (Figures 20–22). While both drought strategies (new basins or low-head dam/rock riffle) would increase recharge to the aquifer, the low-head dam/rock riffle was shown to have a greater impact on water levels in the production wells PL1-4 and PL1-8 due to the proximity and connectivity of the wells to the Floyd River, especially during pumping.

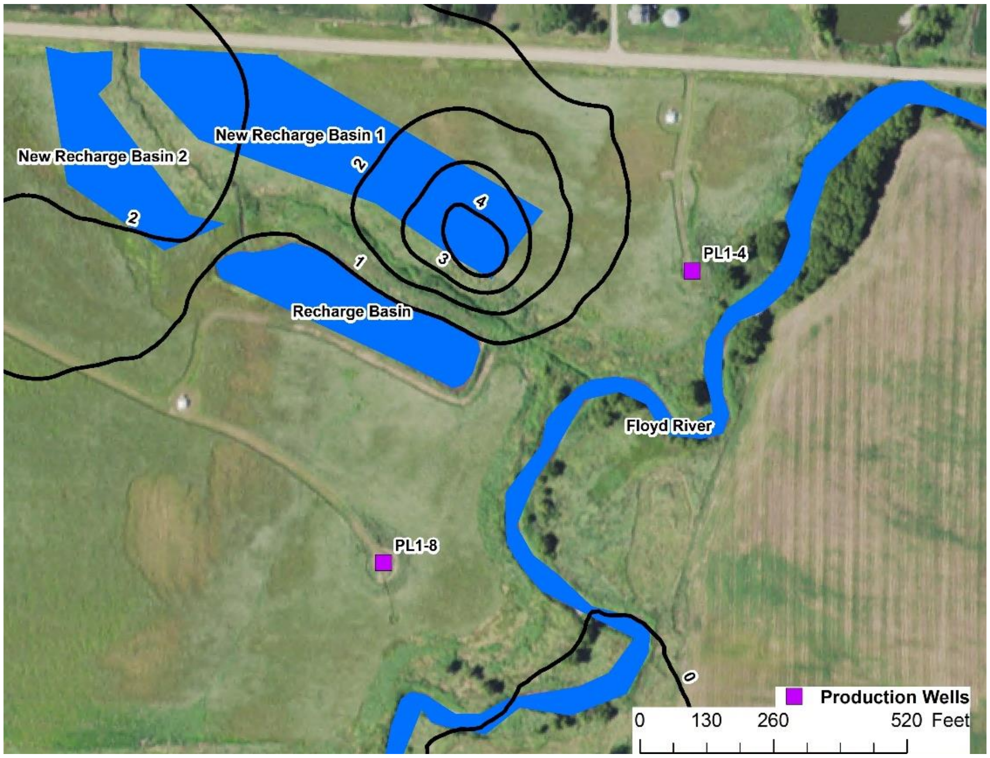

Figure 17. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with new recharge basins maintained at 1341.5 feet.

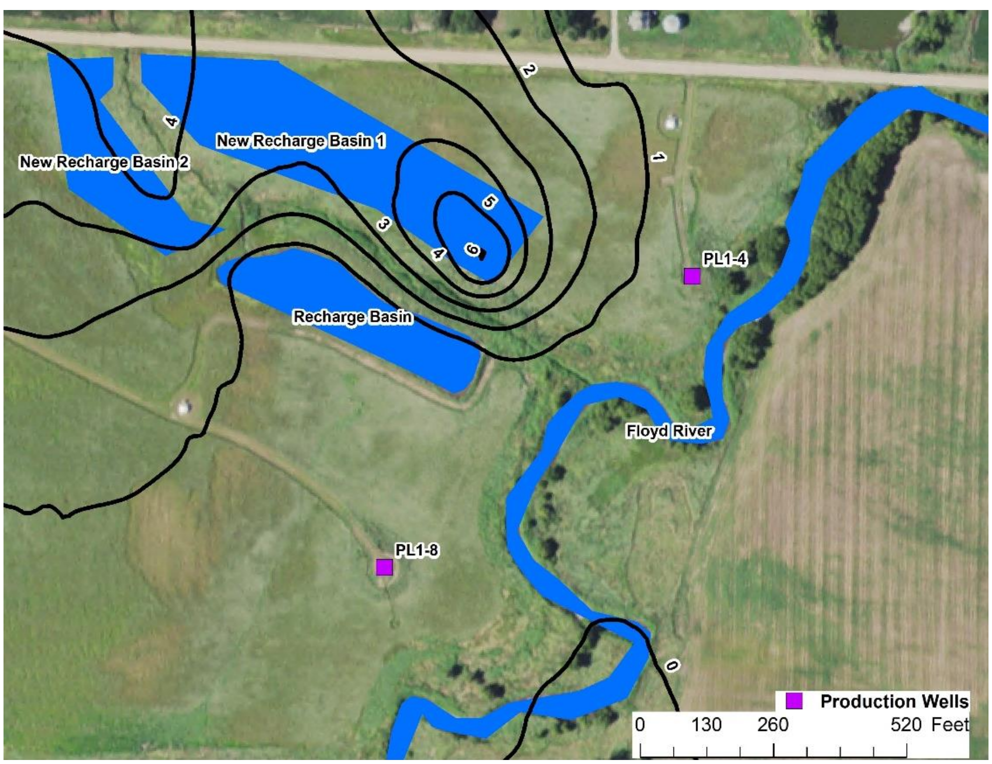

Figure 18. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with new recharge basins maintained at 1343 feet.

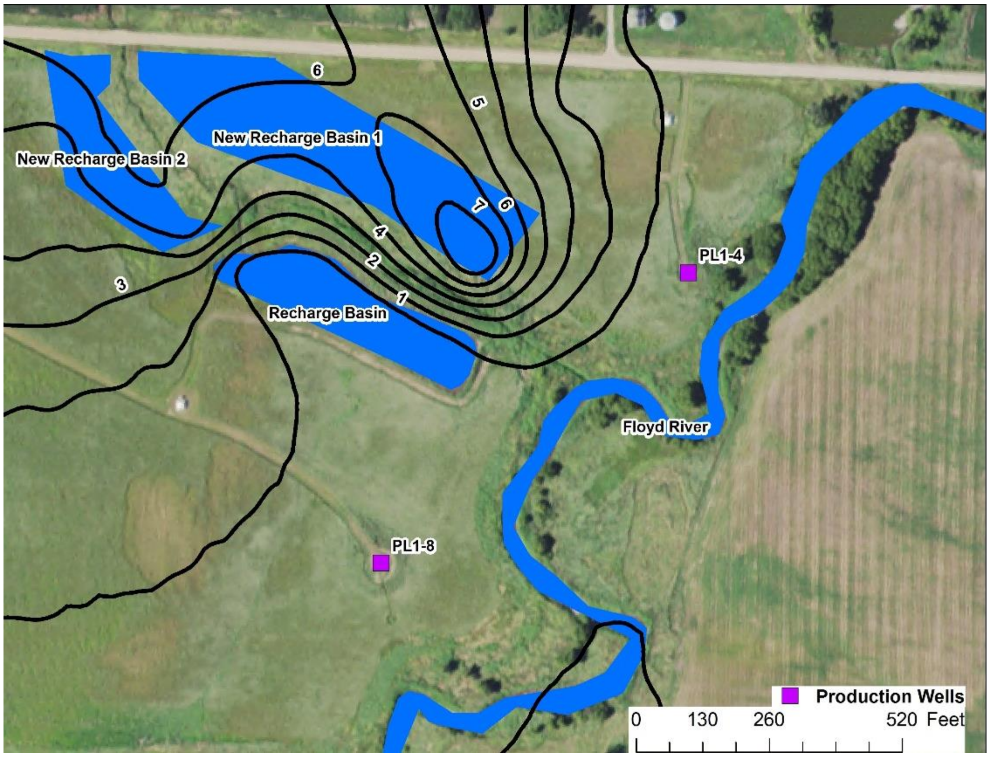

Figure 19. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with new recharge basins maintained at 1345 feet.

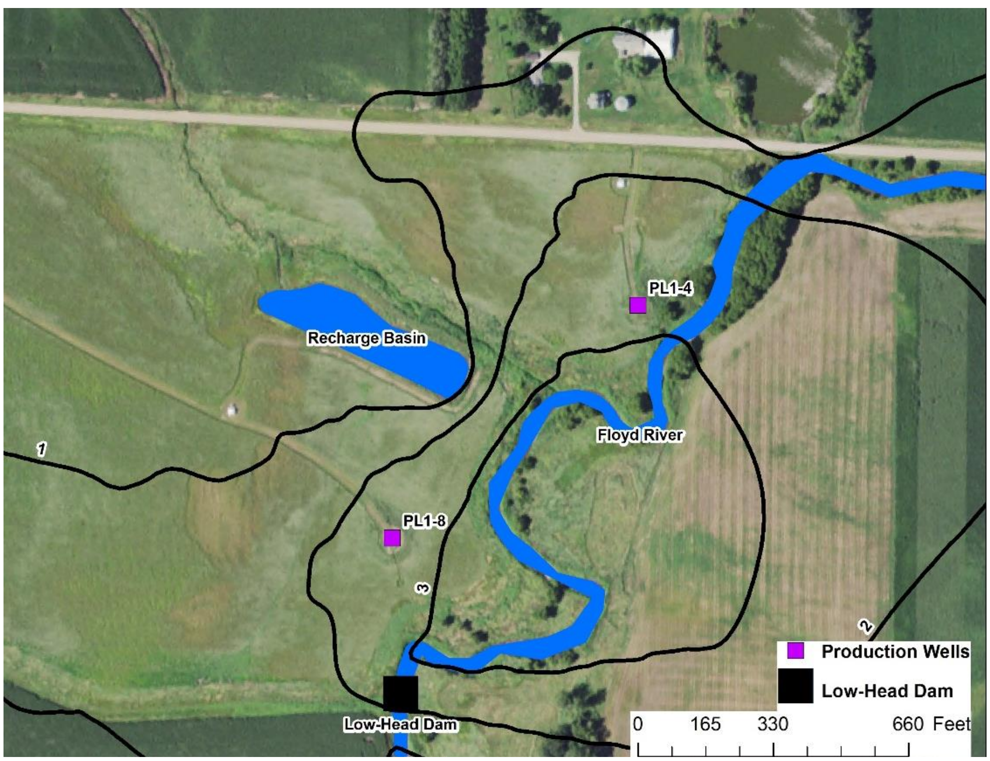

Figure 20. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with a low-head dam or rock riffle set at 1334 feet.

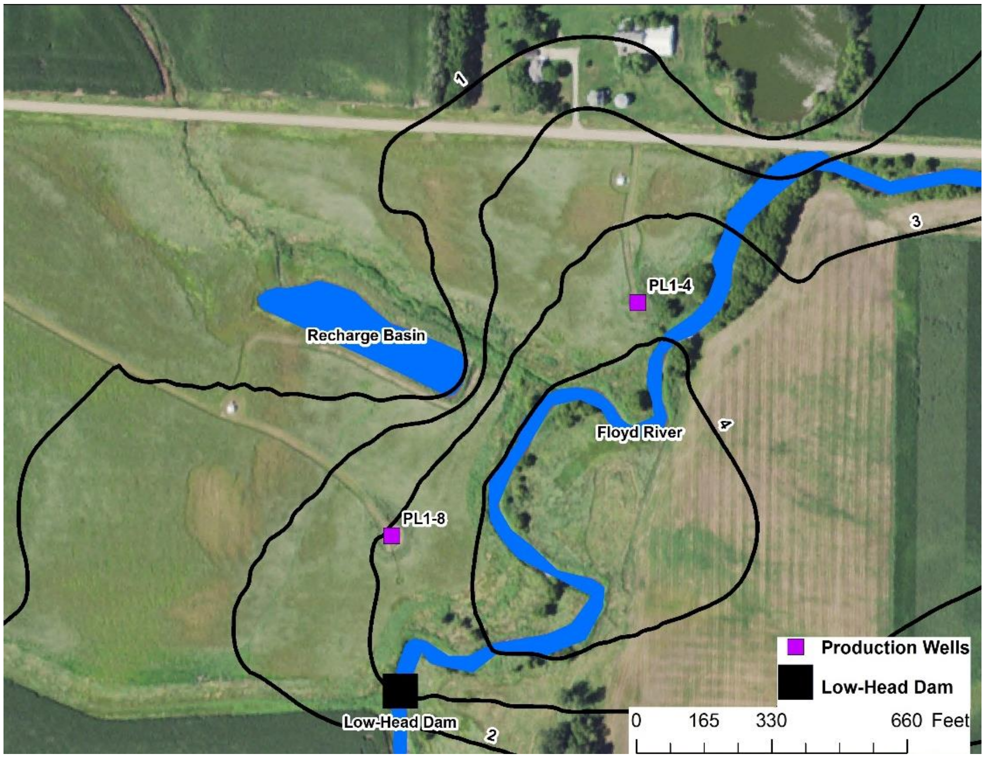

Figure 21. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with a low-head dam or rock riffle set at 1335 feet.

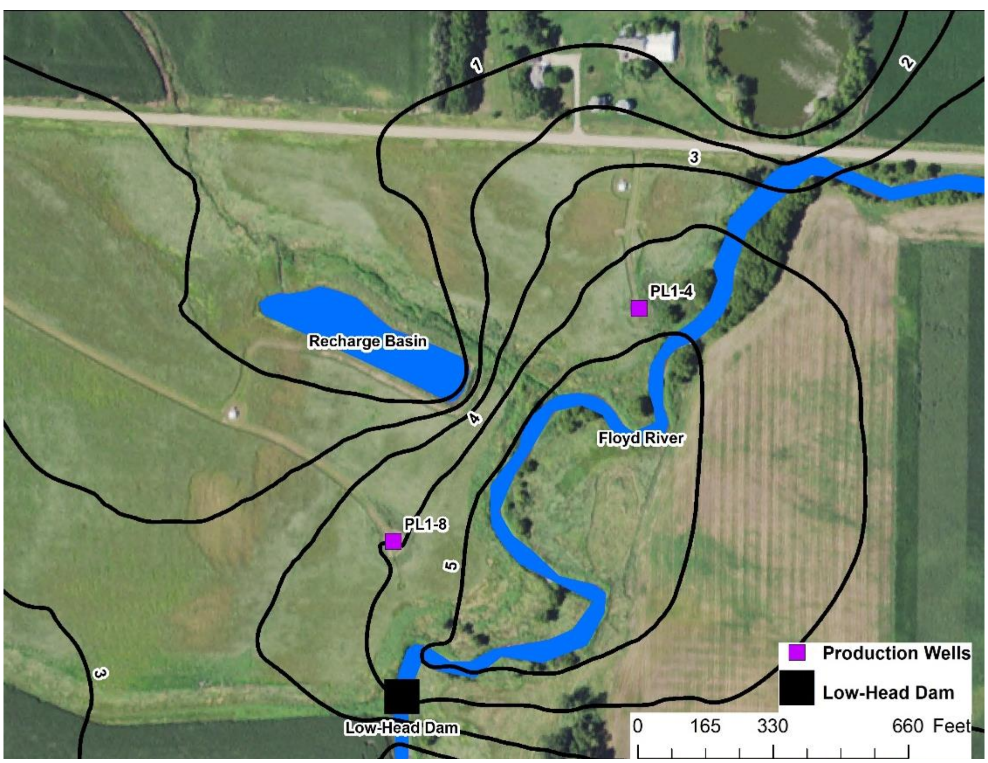

Figure 22. Increase in aquifer water levels (feet) after the end of the 500 day drought simulation with a low-head dam or rock riffle set at 1337 feet.

CONCLUSIONS

The Iowa Geological Survey completed a hydrogeologic investigation of an alluvial aquifer at a Rural Water Systems #1 wellfield located in Sioux County, Iowa. The purpose of the investigation was to evaluate water quantity and quality impacts of a floodplain pond on the alluvial aquifer utilized by the wellfield. The evaluation involved conducting a geophysical investigation, implementing observation wells, collecting monthly water quantity and quality measurements for 12 months, and executing three-dimensional groundwater flow model simulations of the alluvial aquifer wellfield using Visual MODFLOW.

Based on driller's logs and the geophysical investigation, the thickness of the sand and gravel aquifer in the area around the production wells ranges from 8–20 feet. The geophysical investigation found the most conductive and productive aquifer material lies in close proximity to the Floyd River. In general, the saturated aquifer materials become less conductive as distance from the Floyd River increases. The wellfield area to the south of the recharge basin appears to be more conductive than the area to the north of the recharge basin.

Observed water and nitrate levels suggest the alluvial aquifer wellfield has good hydraulic connection with the Floyd River, and the river appears to supply a significant amount of induced recharge to the production wells during pumping. Changes in nitrate concentrations measured in the Floyd River correlated closely with changes in nitrate concentrations in production wells PL1-4 and PL1-8, especially PL1-4. Nitrate dynamics in the production wells also correlated closely with nitrate concentrations observed in the other surface water sampling locations. During the month of highest nitrate concentration levels in the surface water bodies (April 2016), the concentrations in production wells PL1-4 and PL1-8 were measured at 16.30 mg/L and 9.43 mg/L, respectively. The maximum contaminant level for nitrate in drinking water is 10 mg/L.

Water levels in OB1 suggest the recharge basin does not have great connectivity with the northern portion of the aquifer and production well PL1-4. Most of the recharge provided by the basin moves toward the south. However, nitrate levels in OB3 indicate "short-circuiting" may be occurring, where nitrate-rich surface water that enters the basin via the tributary makes its way into the aquifer through the upper portion of the basin without adequate time for nitrate removal processes. Nitrate concentrations in observation well 3, located along the southern border of the upper portion of the recharge basin, were consistently higher than concentrations in observation wells 1 and 2.

A local-scale groundwater flow model was developed, calibrated, and validated to observed monthly water levels collected during the study. The model was used to quantify induced recharge from the recharge basin and the Floyd River to the production wells; evaluate the impact of the recharge basin on water sustainability during a drought; and assess new drought resiliency strategies at the wellfield, including construction of new recharge basins and implementation of a low-head dam/rock riffle structure in the Floyd River. Model results found the recharge basin provided 9% of the water production to wells PL1-4 and PL1-8 during our study period (November 2015 to November 2016). Induced recharge from the Floyd River was found to provide 52% of the water production. Similar to what was observed in the measured water and nitrate levels, model results indicate the recharge basin provides more water to PL1-8 than PL1-4. It should be noted that not all recharge that enters the aquifer from the basin reaches the production wells.

Drought model simulations found the recharge basin provides some protection against drought. During the drought simulation, rainfall recharge to the aquifer was reduced and the Floyd River stage water set to represent 2012 drought levels. When the basin was maintained at the water level measured in November 2015 (1341.5 feet), the pumping water levels at PL1-4 or PL1-8 did not reach the pump elevations after 500 days indicating the pumps would not go dry. When the basin water level was not maintained, water levels reached the pump elevation at production well PL1-4 after 4 days. Water levels were not observed to reach the pump elevation of production well PL1-8 after 500 days. Simulation results show the recharge basin does provide some water storage; however, the Floyd River still plays a larger role in maintaining water levels at the pumps.

Two potential new basins were evaluated using the drought model: (1) constructing new recharge basins in the wellfield and (2) implementing a rock riffle/low-head dam structure in the Floyd River. Model results indicate both drought strategies—new recharge basins or a low-head dam/rock riffle—would improve drought resiliency and could be very beneficial if more production wells are going to be added to the wellfield. Model simulations found constructing new basins would improve drought resiliency of the alluvial aquifer. Under drought conditions, maintaining the new recharge basins at elevations from 1341.5–1345 feet increased recharge from the basins and Floyd River to the aquifer by 9–28% compared to simulations without the new basins after 500 days. Aquifer recharge was observed to increase with higher water levels in the new basins. Therefore, constructing new basins higher and creating volume by building berms around the basin's border would create more productive basins than creating volume by digging down through the sand and gravel package into the clay layer below the aquifer.

Implementing a low-head dam or rock riffle structure to raise and maintain stage in the Floyd River was also shown to be a potentially beneficial drought resiliency strategy using the model. After 500 days in the drought simulation, a low-head dam or rock riffle set at elevations from 1334–1337 feet increased recharge to the aquifer by 5–45% compared to simulations without the structure. Implementation of a low-head dam/rock riffle on the Floyd River was shown to have a greater impact on water levels at production wells PL1-4 and PL1-8 than construction of new recharge basins due to the proximity of the production wells to the Floyd River. Because the new recharge basins were located to the north and west of the current basin, the new basins were shown to have a greater impact on water levels further from the river.

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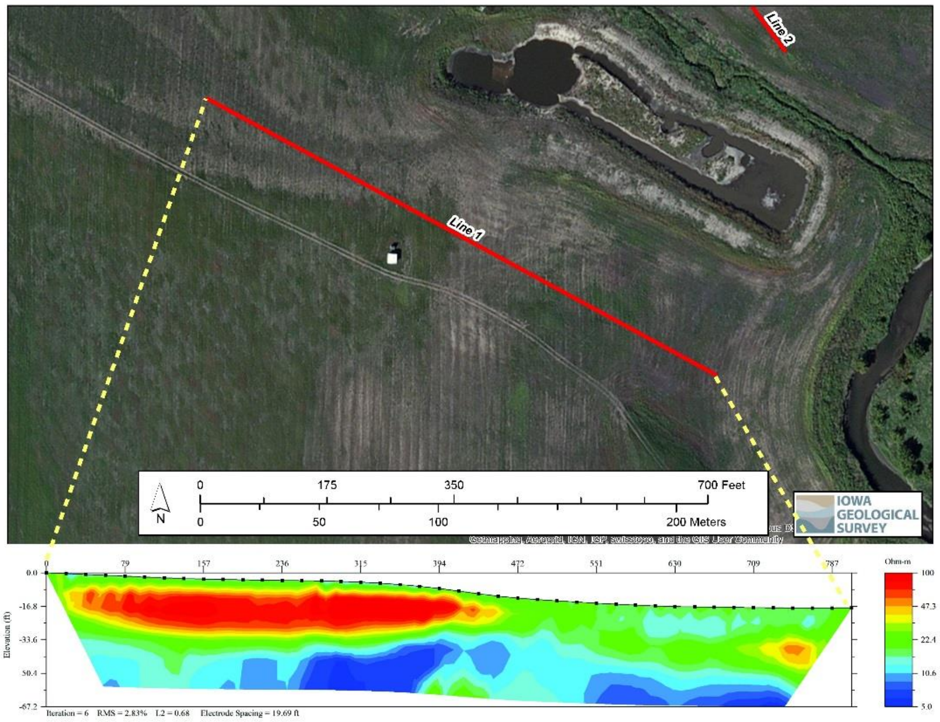
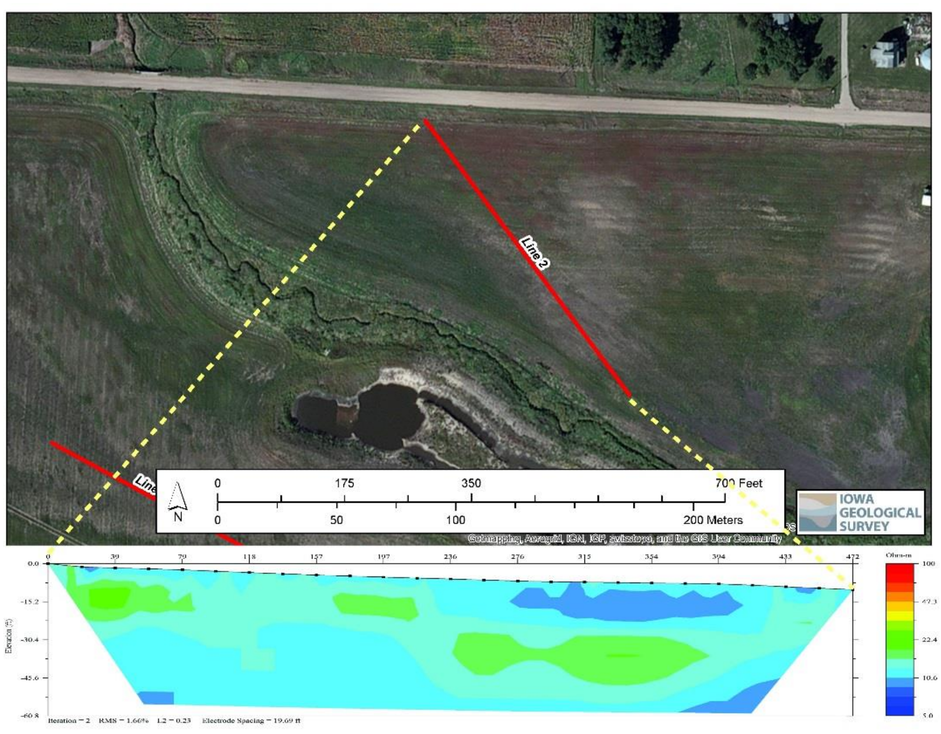
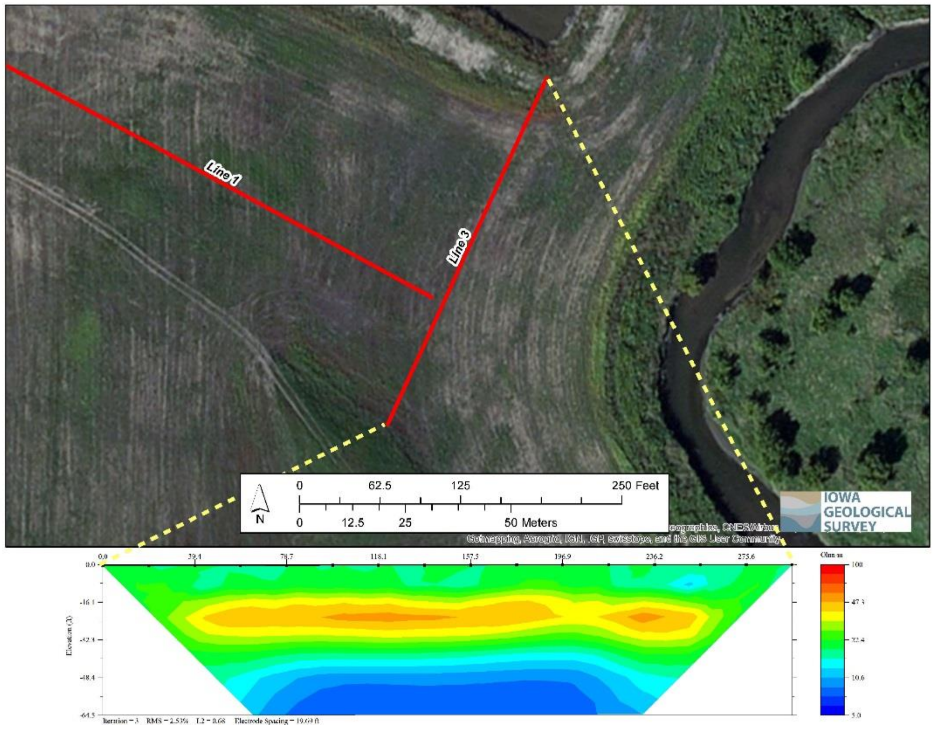
APPENDIX A: Geophysical Investigation Results



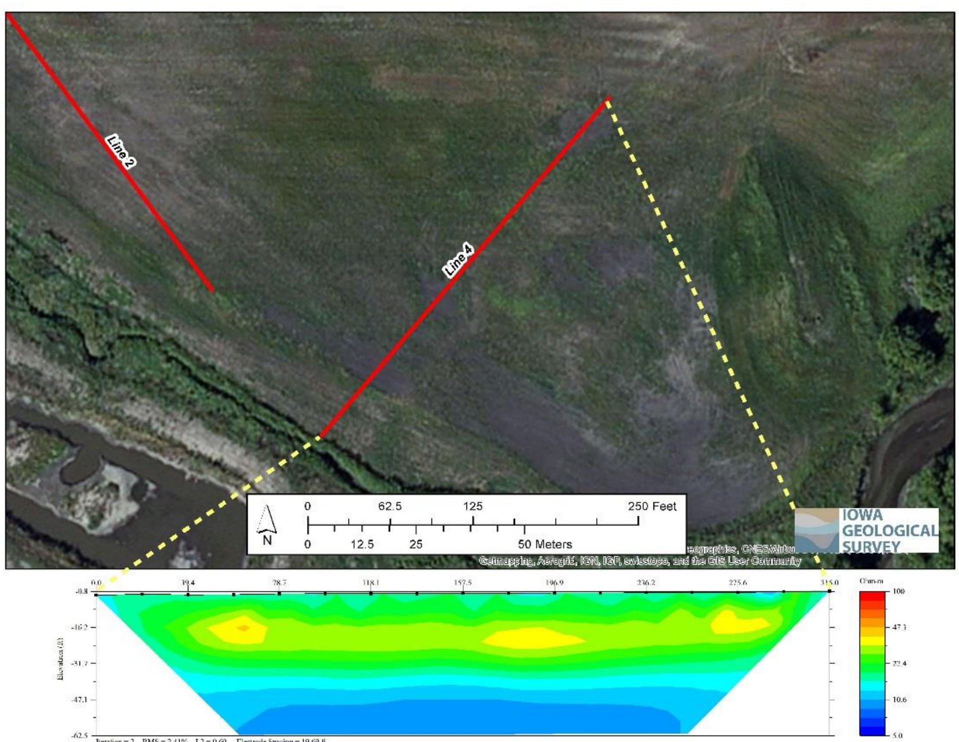
1) Electrical resistivity transect along Line 1 running south of the recharge basin.



2) Electrical resistivity transect along Line 2 running north of the recharge basin.



3) Electrical resistivity transect along Line 3 running south of the recharge basin.



4) Electrical resistivity transect along Line 4 running north of the recharge basin.

APPENDIX B: Monthly Water Levels and Nitrate and Chloride Concentrations

Water level elevations (ft) measured during the study.

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
PZ-1	1337.64	1340.77		1341.11	1340.41	1340.51	1340.96		1337.87	1336.24	1340.31	1339.76	1338.37
PZ-2		1336.58	1335.9	1338.21	1336.09	1337.18	1339.6		1336	1334.04	1337.48	1336.7	1335.43
OB-1	1333.14	1334.75	1334	1336.45	1334.64	1335.46	1338.85		1335.92	1332.51	1337.16	1335.4	1333.66
OB-2	1340.01	1341.61	1340.94	1341.02	1340.16	1340.68	1340.92		1340.66	1339.27	1340.5	1339.91	1339.94
OB-3	1340.09	1340.55	1340.25	1340.79	1340.44	1340.74	1341.08		1340.31	1337.8	1340.4	1340.17	1339.45
SW-1													
SW-2													
SW-3		1341.18		1341.23	1341.07				1340.98	1339.3	1340.99	1341.07	1340.93

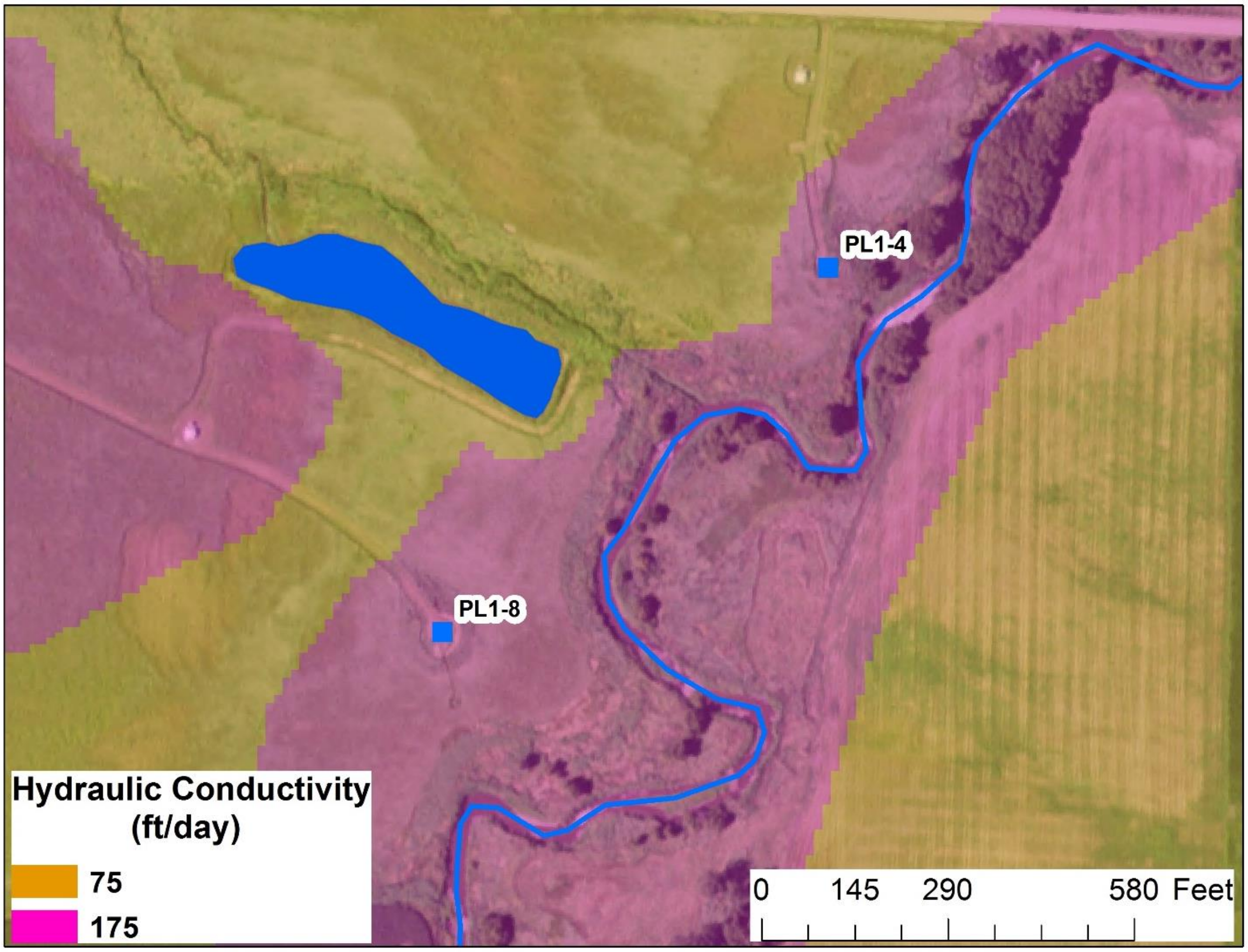
Nitrate concentrations measured during the study.

Well	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
SW-1	24.30	25.30	31.90	25.10	28.00	50.20	28.40		22.70	28.15	24.1	24.2	23.6
SW-3	18.30	24.70	33.80	17.90	26.50	36.60	23.40		17.00	7.84	14.6	23.2	22.8
SW-4	18.20	25.20	32.80	21.30	25.20	37.80	23.20		17.50	7.46	22.8	23.3	22.35
SW-2	15.00	3.20		14.30	19.00	28.10	18.60		12.20	5.35	14.6	16.3	14.9
OB2	5.65	3.70	2.83	1.83	1.06	1.34	1.46		1.29	6.89	1.89	3.07	1.8
OB3	7.15	17.10	11.20	18.50	20.00	23.40	16.80		14.90	3.37	2.08	10.10	19.7
OB1	3.20	<1	<1	<1	<1	<1	<1		1.83	<1	<1	<1	<1
Well 4	5.26	7.04	8.07	10.55	8.93	16.30	11.75		11.90	7.46	5.85	7.13	9.49
Well 8	2.00	1.51	2.40	5.32	5.88	9.43	5.94		5.28	6.02	4.14	3.55	2.71
PZ-1	9.33	<1		1.36	<1	<1	<1		<1	<1	<1	<1	<1
PZ-2	3.15	11.10	16.05	26.30	18.90	21.10	11.90		<1	1.16	<1	<1	7.37
	3.15	11.10	16.05	26.30	18.90	21.10	11.90		0.00	1.16	0	0	7.37

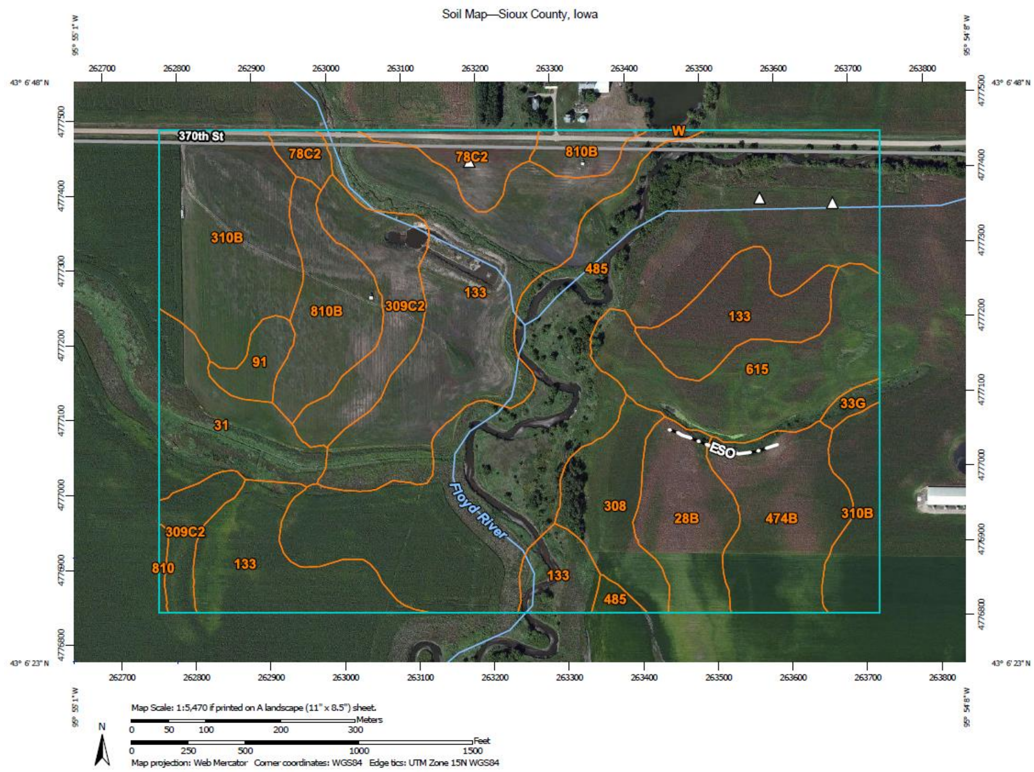
Chloride concentrations measured during the study.

Well	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
SW-1		30	28	28	31	31	24		29	29	27	23	28
SW-3		24	28	21	31	32	21		27	31	26	25	27
SW-4		33	27	25	31	30	20		28	60	27	22	27
SW-2		50		33	46	45	30		40	113	42	36	43
OB2		25	22	23	23	21	22		24	27	18	22	22
OB3		24	18	28	25	25	22		28	29	23	23	25
OB1		4	5.2	5.5	2.5	3.5	3.5		7.5	5.5	4.5	3.5	3.5
Well 4		63	57	57	50	50	44		45	60	50	41	45
Well 8		36.5		32	31	30	26		25	28	24	20	24
PZ-1		50		38	28	41	36		33	35	23	27	28
PZ-2		28	25	32	27	30	28		28	31	25	23	26

APPENDIX C: Horizontal Hydraulic Conductivity of the Alluvial Aquifer in the Groundwater Flow Model



APPENDIX D: Web Soil Survey



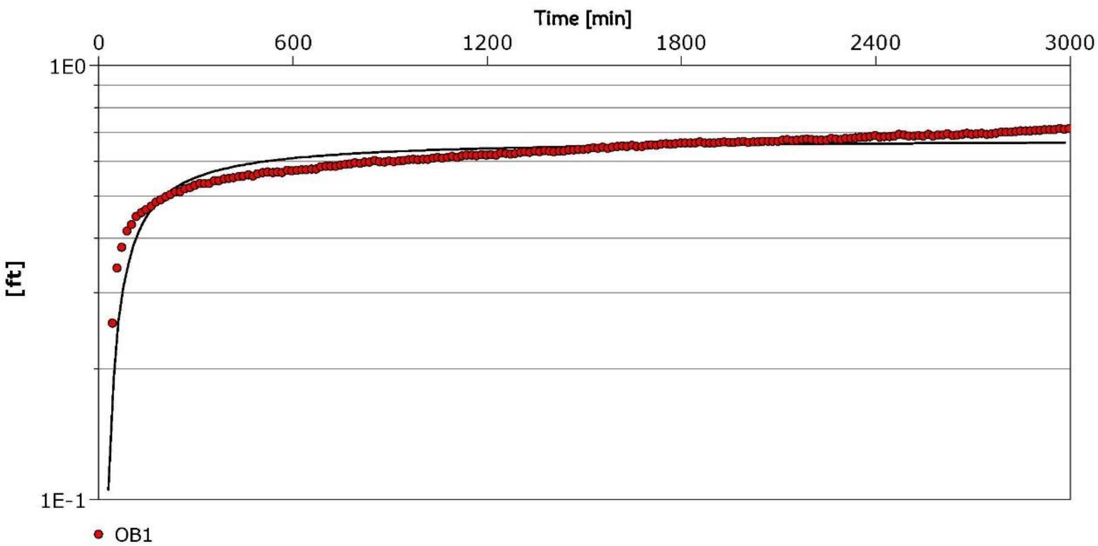
Sioux County, Iowa (IA167)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
28B	Dickman sandy loam, 2 to 5 percent slopes	6.3	4.1%
31	Afton silty clay loam, 0 to 2 percent slopes, occasionally flooded	7.1	4.6%
33G	Steinauer clay loam, 18 to 40 percent slopes	0.6	0.4%
78C2	Sac silty clay loam, 5 to 9 percent slopes, moderately eroded	4.1	2.6%
91	Primghar silty clay loam, 0 to 2 percent slopes	1.7	1.1%
133	Colo silty clay loam, deep loess, 0 to 2 percent slopes, occasionally flooded	35.9	23.2%
308	Wadena loam, 32 to 40 inches to sand and gravel, 0 to 2 percent	5.6	3.6%
309C2	Allendorf silty clay loam, 5 to 9 percent slopes, moderately eroded	8.7	5.6%
310B	Galva silty clay loam, 2 to 5 percent slopes	16.1	10.4%
474B	Bolan loam, 2 to 5 percent slopes	8.7	5.6%
485	Spillville loam, 0 to 2 percent slopes	41.2	26.6%
615	Colo-Spillville complex, channeled, 0 to 2 percent slopes	10.5	6.8%
810	Galva silty clay loam, terrace, 0 to 2 percent slopes	0.3	0.2%
810B	Galva silty clay loam, terrace, 2 to 5 percent slopes	7.9	5.1%
W	Water	0.0	0.0%
Totals for Area of Interest		**154.6**	**100.0%**

APPENDIX E: Aquifer Pump Tests

1. Production well PL1-4 and Observation Well 1

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: Rural Water System #1 Conventional (72615)
	Number:
	Client:

Location:	Pumping Test: Conventional (72615)	Pumping Well: PL-4, Well 3
Test Conducted by: Iowa Geological Survey		Test Date: 10/21/2016
Analysis Performed by:	New analysis 2	Analysis Date: 11/11/2016
Aquifer Thickness: 12.00 ft		



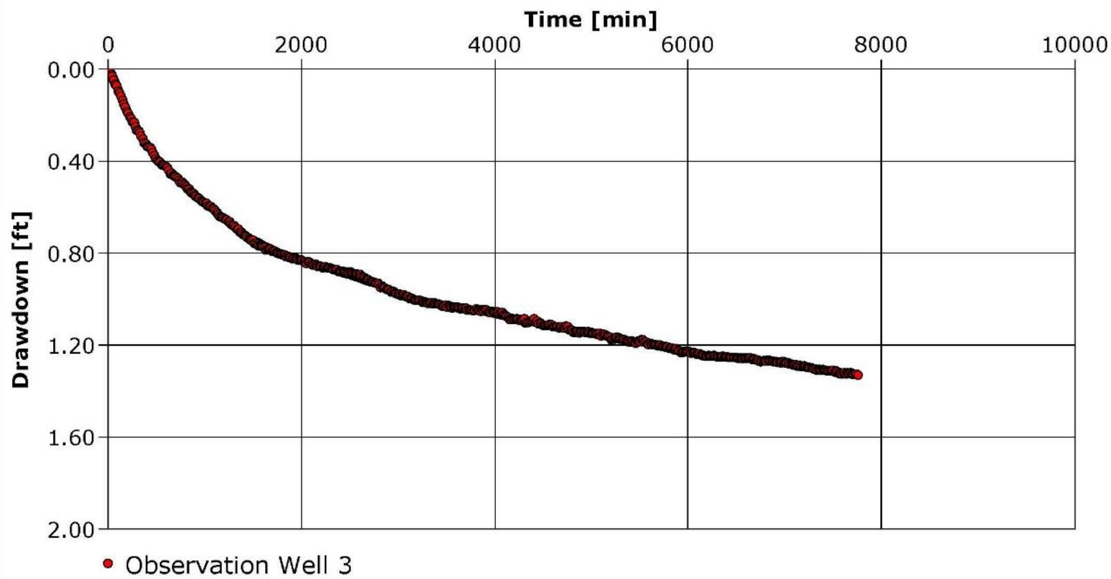
Calculation using Neuman

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Specific Yield	Ratio K(v)/K(h)	Ratio Sy/S
OB1	2.19×10^{3}	1.83×10^{2}	3.89×10^{-3}	1.00×10^{0}	9.71×10^{5}

2. Production Well PL1-8 and Observation Well 3

IOWA GEOLOGICAL SURVEY

Pumping Test Analysis Report		
Project: RWS#1 PL-8 Conventional (73310)		
Number:		
Client:		
Location:	Pumping Test: Conventional (73310)	Pumping Well: PL-8
Test Conducted by: Iowa Geological Survey		Test Date: 9/9/2016
Analysis Performed by: Nathan Holt	Theis	Analysis Date: 9/27/2016
Aquifer Thickness: 14.00 ft	Discharge Rate: 45 [U.S. gal/min]	

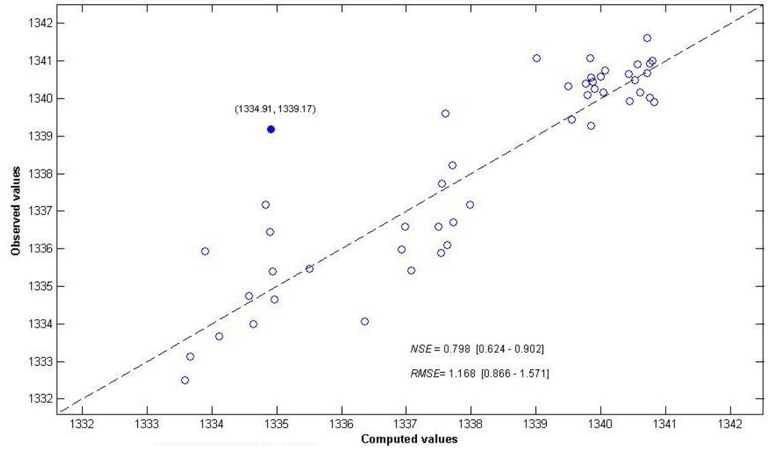


Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Ratio K(v)/K(h)	Radial Distance to PW [ft]
Observation Well 3	1.86×10^{3}	1.33×10^{2}	3.93×10^{-3}	2.99×10^{-1}	410.0

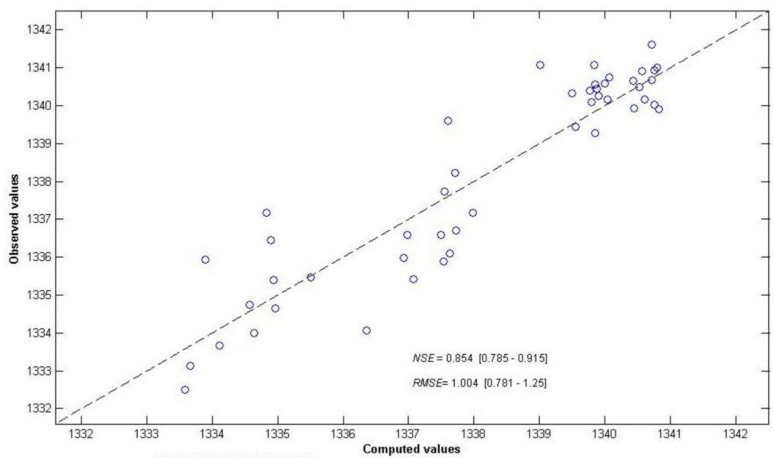
APPENDIX F: Model Validation Results

A) Validation Results with Outlier.



Evaluation of NSE:	**From Unsatisfactory to Very Good**
Probability of fit being	
-Very Good (NSE = 0.900-1.000)	5.6%
- Good (NSE = 0.800-0.899)	44.7%
- Acceptable (NSE = 0.650-0.799)	47.6%
- Unsatisfactory (NSE < 0.650)	2.1%
Presence of Outliers (Q-test):	Present and maybe affecting indicators
Model Bias:	NO

B) Validation Results without Outlier.



Evaluation of NSE:	**From Acceptable to Very Good**
Probability of fit being:	
-Very Good (NSE = 0.900-1.000)	8.7%
- Good (NSE = 0.800-0.899)	85.3%
- Acceptable (NSE = 0.650-0.799)	6.0%
- Unsatisfactory (NSE < 0.650)	0.0%
Presence of Outliers (Q-test):	NO
Model Bias:	NO