Cambrian-Ordovician Aquifer Sustainability Study
Linn and Johnson County Groundwater Protected Area
Linn and Johnson County, Iowa

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Water Resources Investigation Report 18

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Executive Summary

Regulatory requirements related to the Cambrian-Ordovician (CO) aquifer were modified by the Iowa Legislator in 2014. As part of the modified regulations, Tier regulations were introduced and two protected water source areas in the CO aquifer were designated, including the Linn and Johnson County Groundwater Protected Area (LJCPA). The Iowa Geological Survey (IGS) was hired by all of the CO water users in the LJCPA and the IDNR to investigate and quantify the sustainability of the CO aquifer in the LJCPA. As part of the investigation, the IGS conducted aquifer pump tests, developed a groundwater flow model for the LJCPA, and simulated future water levels under various usage scenarios.

Aquifer pump tests were conducted to determine local aquifer hydraulic properties of permeability (transmissivity) and storativity within the LJPCA. Nine (9) new aquifer pump tests were conducted in CO wells within the LJCPA. Pump tests included eight conventional pump tests using both production and observation well(s). One (1) recovery test was also conducted using only a production well (Tiffin #4). The nine (9) new aquifer pump tests provided significant additional local information to the nine (9) existing recovery tests for the CO aquifer within the LJCPA that were previously available.

Based on aquifer pump test results, the hydraulic conductivity of the CO aquifer within the LJCPA was found to range from 1 foot/day at both Tiffin #4 and Coralville #1 to 20 feet/day at Marion #5 and #7. Aquifer storativity ranged from 3.6 X 10^{-7} in the Iowa City and University of Iowa (UI) area to 8 X 10^{-5} at North Liberty #7. A zone of low permeability and storage was observed across the southern portion of the LJCPA, and includes the wellfields of Iowa City, Coralville, and Tiffin. The low permeability and storage zone has increased drawdowns, lowered pumping water levels, and reduced water production compared to higher permeability zones, which exist in North Liberty and the Cedar Rapids/Marion area.

Calibration results indicate the LJCPA model was able to adequately simulate the aquifer's response to pumping stress during the pump tests as well as historical static water levels. Historical static water levels from years 2000 to 2017 were provided by the IDNR. The average difference between observed and simulated drawdowns in the pump test observation wells was 0.3 feet and ranged from 0 to 0.8 feet. Model goodness-of-fit was "Acceptable" with no presence of outliers or model bias when simulating yearly static water levels. The model had a correlation coefficient of 0.91 and an NSE of 0.79. The absolute residual mean and RMSE between observed and simulated water levels were 13.9 feet and 16.6 feet, respectively.

Based on the calibrated groundwater flow model, a 30% increase in water use (above 2017 values) by all the users in the LJCPA over a 20 year period (2018-2038) would represent maximum sustainable water use. Not all of the LJCPA water users have the ability to obtain or desire a 30% water use increase, which could allow growing communities or industries to

eventually increase individual water uses above the 30% threshold. Limiting annual water use to no more than 30% above 2017 usage for a 5-year water use permit protects all of the water users within the LJCPA. Observed PWLs can continue to be monitored and compared to simulated results, and can be used to further evaluate future allocations. If PWL trends begin to decline faster than predicted by the model, the Tier 2 and Tier 3 regulatory limits can be implemented to protect the aquifer.

Allocated water usage for the CO aquifer in the LJCPA was also evaluated with the groundwater flow model. Pumping water levels in all of the CO wells in the LJCPA exceed Tier 2 levels with ADM, Iowa City JW-1, Coralville, and Tiffin exceeding Tier 3 levels. Substantial regional well interference in both Johnson and Linn counties was observed when all LJCPA users withdraw at full allocations. It may be necessary to scale back some of the allocated amounts of water from the CO aquifer for several LJCPA water users during the next five year permit cycle to protect against significant well interferences between users.

A most likely water use scenario was developed and evaluated with the groundwater flow model. The likely usage scenario assumed incremental growth for North Liberty reaching 50% after 20 years (based on projections from Fox Engineering); 30% growth for Marion, ADM, and Tiffin; 10% growth for Ingredion and Coralville (after ten years); and no growth for Iowa City and the University of Iowa's Oakdale campus and water plant wells. None of the LJCPA wells had PWLs exceed Tier 2 levels after 20 years in the likely usage scenario. An additional model simulation was conducted assuming an instantaneous usage increase for North Liberty and Tiffin of 50%. Results found Tiffin #4 PWLs dropped below Tier 2 levels, but North Liberty's PWLs remained above Tier 2 after 20 years. Tiffin would be able to remain in compliance with Tier 2 and 3 regulations in this scenario by adding a second CO production well and balancing the pumping rates between the two wells.

Model simulations were also run to evaluate using North Liberty #7 as a fourth production well instead of an ASR well. The main benefit of the four production well scenario was the gain in available drawdown in North Liberty's other wells due to reduced pumping stress and well interference. North Liberty #5, #6, and #8 gained 10, 20, and 15 feet of available drawdown, respectively, in the likely usage scenario.

Groundwater modeling results indicate the CO aquifer can remain a reliable water source for LJCPA users in the coming decades. However, it is important for the users to identify and develop alternative water sources in order to assure a sustainable future water supply. Potential alternative water sources that can be explored in Linn and Johnson Counties include the Silurian aquifer, alluvial aquifers, buried sand and gravel aquifers, surface water, and purchasing water from municipalities with increased water supply capacity. These municipalities include Iowa City in Johnson County and Cedar Rapids in Linn County.

Introduction

The Linn and Johnson County Groundwater Protected Area site (LJCPA) is located in east-central Iowa as shown in Figure 1. Eight water users with nine water use permits are found within the LJCPA that allow withdrawal from the Cambrian-Ordovician (CO) aquifer. Water use permits within the LJCPA include the City of Marion, City of North Liberty, City of Tiffin, City of Coralville, City of Iowa City, Archer Daniels Midland-Cedar Rapids (ADM), Ingredion-Cedar Rapids, the University of Iowa - Oakdale Campus, and the University of Iowa - Water Treatment Plant (UI WTP) as shown in Figure 2. The LJCPA is one of two designated groundwater protected areas for the CO aquifer in Iowa. The other protected area is located in Webster County, and includes the City of Fort Dodge, Certainteed Gypsum, and Georgia Pacific Gypsum.

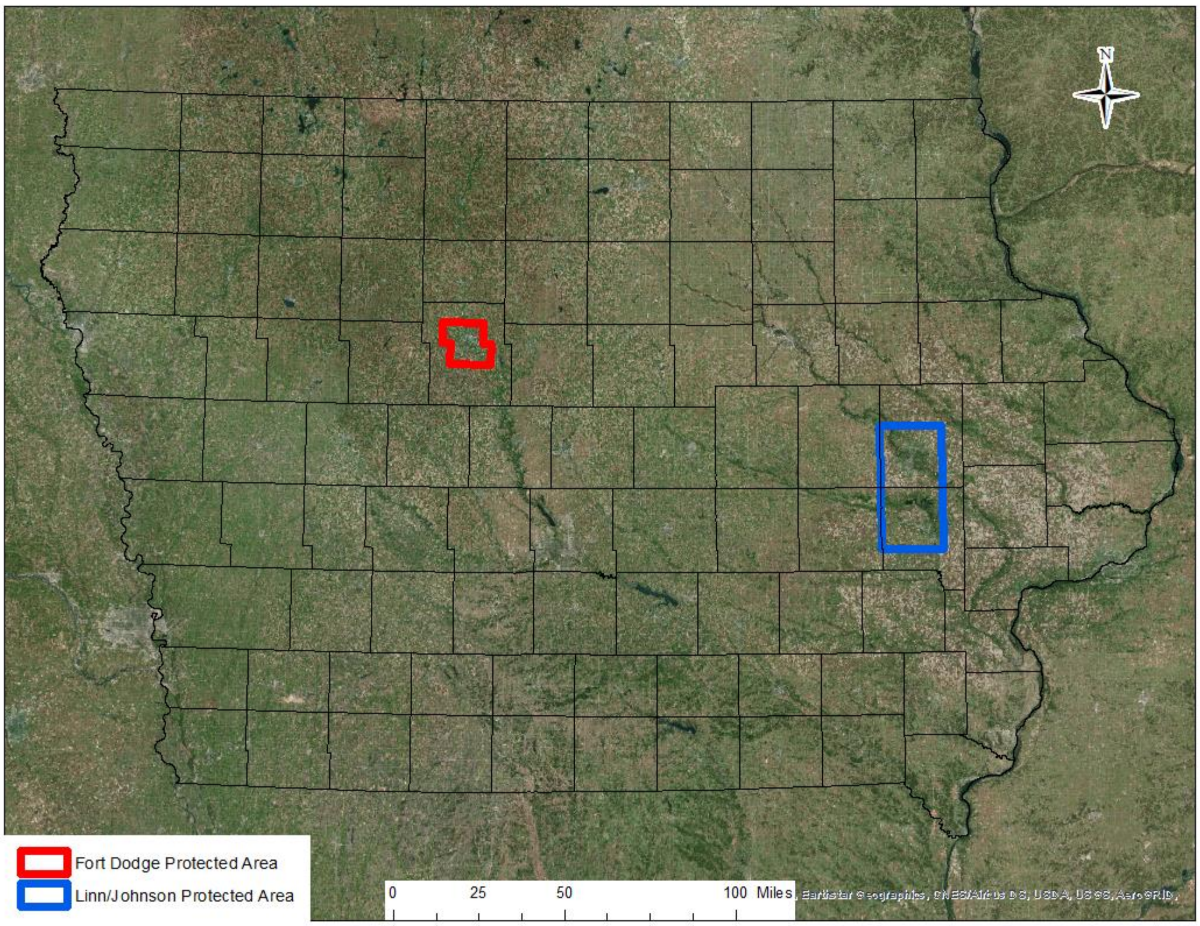


Figure 1: Locations of Iowa's Groundwater Protected Areas for the Cambrian-Ordovician Aquifer

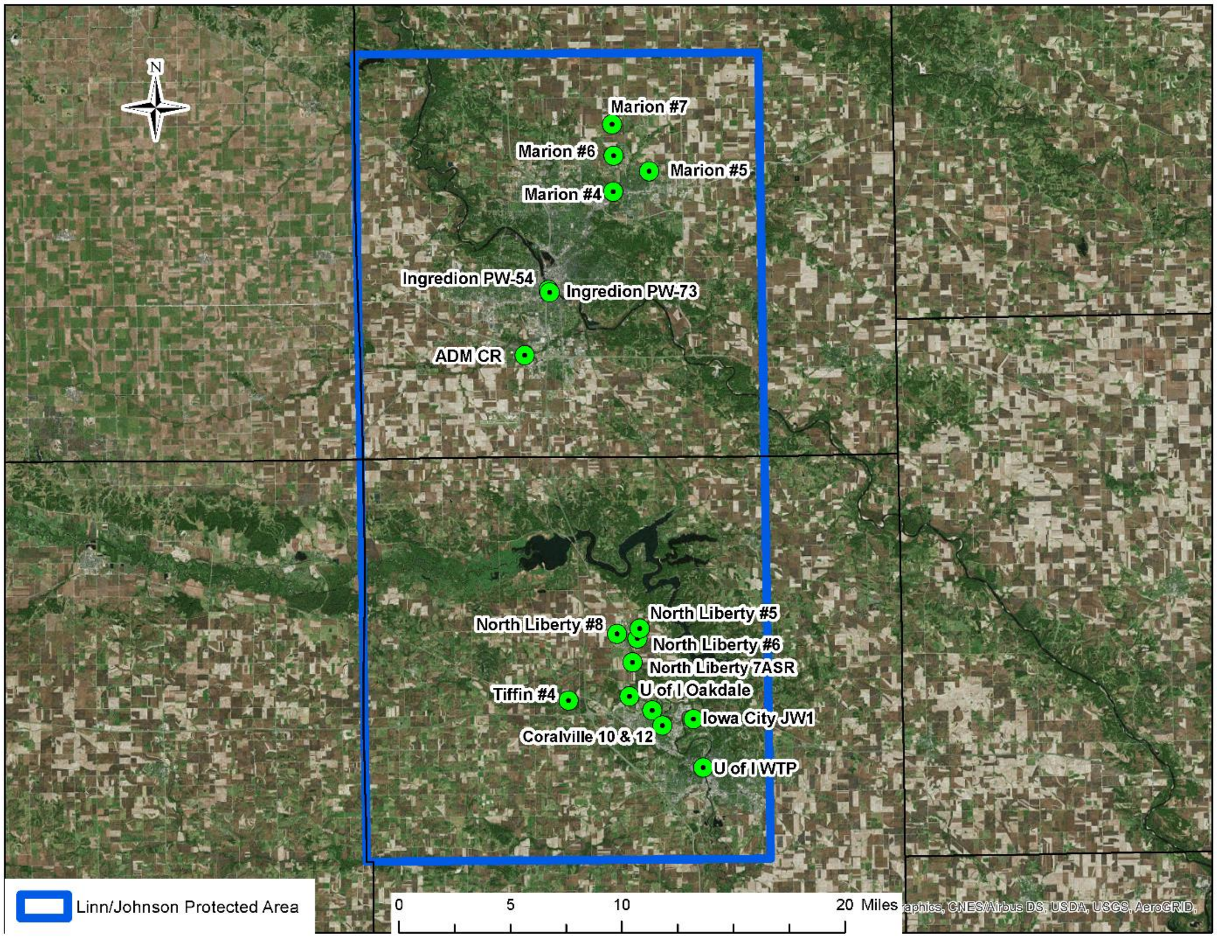


Figure 2: Water users of the Cambrian-Ordovician Aquifer in the Linn and Johnson County Protected Area

Designation of the protected groundwater areas were part of modifications to regulatory requirements for the CO aquifer made in 2014. The Iowa Department of Natural Resources (IDNR) also modified regulatory requirements related to the CO aquifer based on defined Tier 2 and Tier 3 water levels. These thresholds are based on water levels measured in production wells during active pumping (Figure 3). Tier 2 serves as an early warning and is approximately 300 feet lower than the 1978 groundwater elevation. Tier 3 serves as the action level or regulatory limit and is approximately 400 feet lower than the 1978 groundwater elevation. These pumping water level elevations are measured at each production well, and are averaged over any given year.

One major concern in the LJCPA is the long-term, collective well interference created by the combined drawdowns of high capacity public and industrial wells. Declines in groundwater levels often extend radially many miles from each production well. These depressions can interact with each other to accelerate and increase the overall drop in groundwater levels throughout the protected area. Collective well interference makes prediction of long-term pumping water elevations at individual wells virtually impossible based on using observed water levels exclusively. Even proactive water utilities that reduce their overall groundwater withdrawals from the LJPCA may see long-term declines in pumping water levels as a result of well interference or drawdown from another nearby water user.

The Iowa Geological Survey-IIHR Hydroscience and Engineering (IGS) was hired by the eight LJCPA CO aquifer water users and the IDNR to investigate and quantify the sustainability of the CO aquifer in the LJCPA. The investigation involved: conducting aquifer pump tests, developing a groundwater flow model for the LJCPA, and simulating future pumping water levels. Nine (9) aquifer tests were conducted and evaluated to measure aquifer hydraulic parameters governing water flow and production (transmissivity and storativity) within the LJCPA. Current well management information was provided by the water users within the LJCPA. The Iowa Department of Natural Resources provided the historical static water levels, historical pumping water levels, and water usage data. This data was used to calibrate a three-dimensional, local-scale numerical flow model.

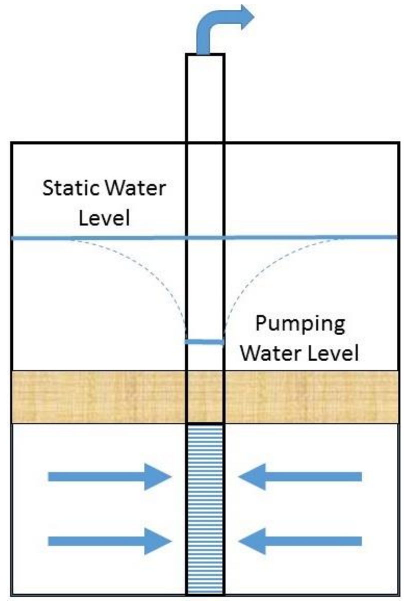


Figure 3: Tier 2 and Tier 3 levels based on pumping water levels

Hydrogeology

A generalized cross-section across Iowa showing the hydrogeologic units is shown in Figure 4. Surficial geology in the LJCPA consists of 20 to 160 feet of glacial drift. Beneath the glacial drift is approximately 900 to 1,000 feet of interbedded limestone and shale units consisting of Devonian-, Silurian-, and Ordovician-aged rocks. The CO aquifer lies beneath Ordovician-aged shales, and consists of three primary hydrostratigraphic units: the Saint Peter Formation (sandstone, 20 to 53 feet thick), Prairie du Chien Group (dolomite/sandstone, 330 to 460 feet thick), and Jordan Sandstone (75 to 180 feet thick). The Prairie du Chien Group is not only the thickest unit within the aquifer, but is also the most productive. Most of the water production in the Prairie du Chien is due to large voids, fractures, and bedding plane features (paleo-karst). The CO aquifer is confined below by the St. Lawrence and Lone Rock formations. The lithology of both of these formations consists of siltstone, dolomite, and sandstone.

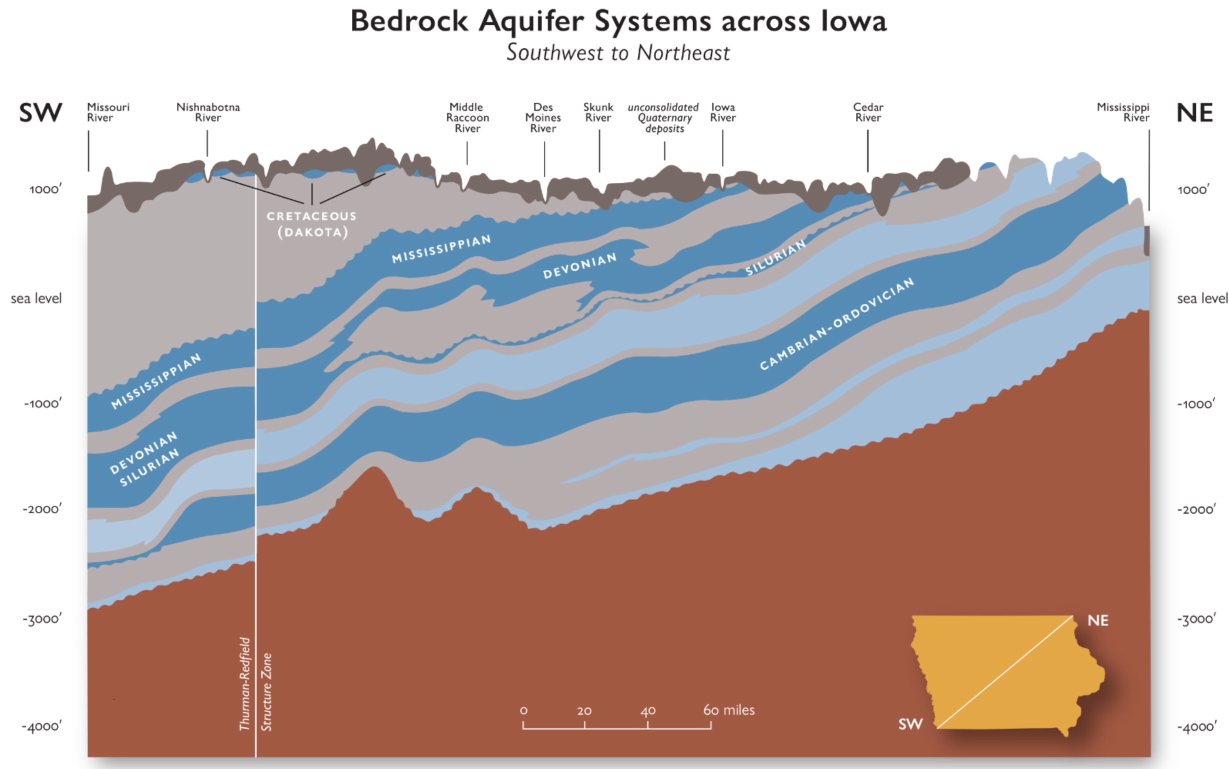


Figure 4: Generalized hydrogeologic cross-section from southwestern to northeastern Iowa with regional aquifers (blue) and confining units (gray)

Regional groundwater flow in the Cambrian-Ordovician aquifer is in a southeasterly direction. However, localized regions of heavy pumping can strongly influence regional groundwater flow directions. Drawdown zones due to pumping within the LJCPA impact flow directions within the region (Figure 5).

Recharge in this report is considered the downward leakage of water into the St. Peter Formation from the overlying Platteville Formation shale units. Recharge into the CO aquifer in the LJCPA is vertically downward through overlying confining beds (Burkart and Buchmiller, 1990). The only known field-measured vertical gradient for the CO aquifer in the state of Iowa occurred in Osceola County, and indicated a downward vertical gradient of 0.03 ft/ft (Munter and others, 1983). The recharge distribution used in the LJCPA mode was obtained from steady-state model development and calibration of the regional CO aquifer model (Gannon and others, 2009), and will be discussed in the calibration section of the report.

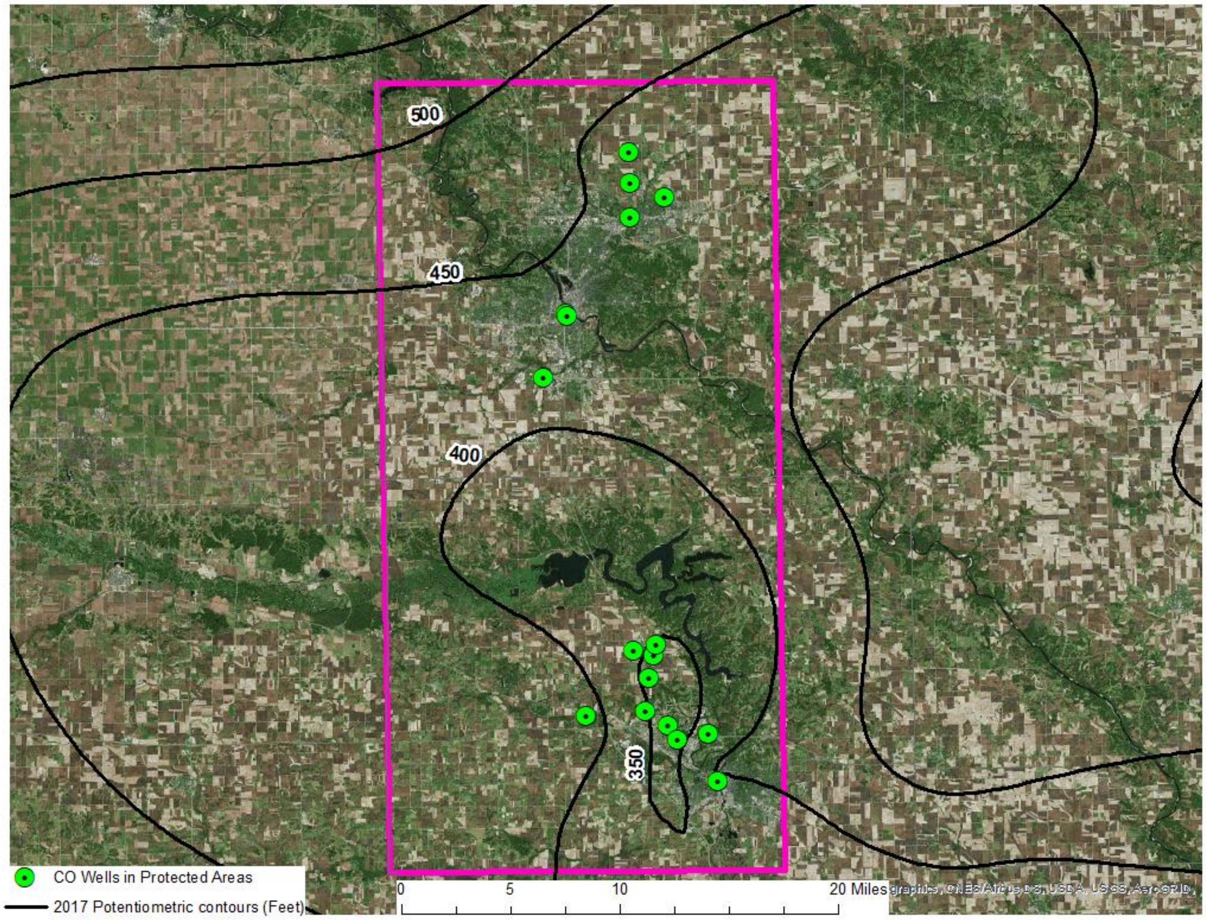


Figure 5: Potentiometric CO aquifer surface contours of the static water level elevation (ft) within the LJCPA in 2017 (Data supplied by the IDNR Water Supply Engineering Section)

Aquifer Test Results

Very little is known about the aquifer properties of the individual formations within the CO aquifer. Most wells drilled into the CO aquifer penetrate all three units (St. Peter, Prairie du Chien, and Jordan), and aquifer pump test results provide an average value of the transmissivity and storativity of the entire aquifer. Aquifer hydraulic properties are used to define and characterize aquifers and include storativity or storage, transmissivity, and hydraulic conductivity. A total of sixteen (16) specific capacity tests have been conducted on production wells located in the LJCPA (Table 1). Specific capacity is measured in a production well after approximately 24 hours of pumping, and is calculated by taking the average discharge in gallons per minute (gpm) divided by the total drawdown in feet. In general, specific capacity shares a direct relationship to aquifer transmissivity (T) with higher specific capacity indicating higher transmissivity. Corresponding transmissivity values estimated from each specific capacity test are also shown in Table 1. The observed specific capacity values were measured in the wells immediately following installation. Observed specific capacity values range from 4.3 gpm/ft (transmissivity: 1,200 ft^2/day) in Iowa City Well JW-1 to 34 gpm/ft (transmissivity: 9,200 ft^2/day) in North Liberty Well #5.

Table 1: Specific Capacity Test Results for Linn and Johnson County

Well Name	W-Number	Discharge (gpm)	Drawdown (ft)	Specific Capacity (gpm/ft)	Transmissivity (ft^2/day)	Aquifer Thickness (ft)	Hydraulic Conductivity (ft/day)
Marion #4	17979	1827	188	9.72	2624	500	5.2
Marion #5	23249	1610	75	21.5	5805	500	11.6
Marion #6	54624	1580	102	15.5	4185	500	8.4
Marion #7	73163	1551	77	20	5400	500	10.8
Ingredion PW-73	17180	1475	44	33.5	9045	520	17.4
Ingredion PW-54	1499	620	60	10.3	2781	520	5.3
ADM	23940	1600	102	15.7	4239	524	8.1
North Liberty #5	35258	1300	38	34	9180	535	17.2
North Liberty #6	55191	1300	79	16.5	4455	528	8.4
North Liberty #7	67309	1882	113	16.6	4482	519	8.6
North Liberty #8	85879	1200	155	7.74	2090	535	3.9
Coralville #10	31377	1200	160	7.5	2025	520	3.9
Coralville #12	61572	1000	202	5	1350	520	2.6
Iowa City JW-1	37000	1000	231	4.33	1169	630	1.9
Iowa City JW-2	13136	1022	185	5.52	1490	620	2.4
UI WTP	14453	1700	202	8.42	2273	620	3.7

Nine (9) new aquifer pump tests were conducted in CO wells within the LJCPA as part of this investigation. The aquifer pump tests included eight conventional pump tests using both production well(s) and observation well(s), and one (1) recovery test using only one production well (Tiffin #4). In addition to the nine new aquifer pump tests, nine (9) existing recovery tests were found for CO aquifer wells in the LJCPA. Both new and existing aquifer pump test results are shown in Table 2 and Appendix A. Based on aquifer test results, the hydraulic conductivity, which is determined by dividing transmissivity by aquifer thickness, ranged from 1 ft/day at both Tiffin #4 and Coralville #1 to 20 ft/day at Marion #5 and #7. A zone of low hydraulic conductivity (permeability) was observed across the southern portion of the LJCPA, including the wellfields at Iowa City, Coralville, and Tiffin. This low hydraulic conductivity zone increases drawdown and lowers pumping water levels compared to the higher permeability zones. Higher hydraulic conductivity (permeability) zones were observed in the North Liberty and the Cedar Rapids/Marion area.

A significant benefit of conducting conventional aquifer pump tests is the ability to calculate aquifer storativity. Storativity is the ability of an aquifer to release a certain volume of water per unit decline in water level. The higher the storativity value the greater volume of water that can be withdrawn per unit decline in water level. Based on the eight conventional pump tests in the LJCPA, the storativity varied by several orders of magnitude ranging from 3.6 X 10^{-7} at the UI WTP to 8 X 10^{-5} at North Liberty #7. The areas of higher storativity corresponded to areas of higher observed hydraulic conductivity and specific capacity values. Areas with higher storativity include North Liberty, Marion, and Ingredion.

Table 2: Pump Test Results for Linn and Johnson County

Well Name	GeoSam Wnumber	Test Type	Transmissivity (ft^2/day)	Aquifer Thickness (ft)	Hydraulic Conductivity (ft/day)	Storativity	Test Date
Ingredion PW-54	1499	Conventional	2,600	520	4.9	3.22 × 10-5	3/14/2018
Marion #5	23249	Conventional	10,200	500	20.4	6.6 x 10-5	3/27/2018
Marion #7	73163	Conventional	9,970	500	20	1.45 x 10-5	3/27/2018
North Liberty #5*	35258	Conventional	8,040	535	15	6 x 10-5	4/24/2017
North Liberty #6	55191	Conventional	5,200	528	9.9	5.9 x 10-5	12/8/2017
North Liberty #7	67309	Conventional	5,600	519	10.8	8.24 x 10-5	12/8/2017
North Liberty #8	85879	Conventional	6,600	535	12.4	5.3 x 10-4	12/22/2017
Tiffin #4	58475	Recovery	610	630	1	NA	10/24/2017
UI WTP	14453	Conventional	2,300	620	3.5	3.6 x 10-7	12/11/2017
ADM	23940	Recovery	2,700	524	5.1	NA	12/17/1976
Coralville #1	17262	Recovery	760	524	1.2	NA	5/27/1965
Coralville #12	61572	Recovery	1,300	648	2.1	NA	12/1/2003
Iowa City JW-1	37000	Recovery	1,300	630	2.1	NA	4/2/1996
Iowa City JW-1	37000	Recovery	1,500	682	2.2	NA	4/15/1996
Iowa City JW-2	13136	Recovery	278	569	0.5	NA	1/18/1963
North Liberty #5	35258	Recovery	3,300	535	6.2	NA	10/15/1994
North Liberty #6	55191	Recovery	2,000	528	5.8	NA	1/7/2002
UI WTP	14453	Recovery	6,300	620	10.2	NA	10/09/1963

* = Pump Test Conducted by Fox Engineering

Groundwater Modeling

Development and Calibration

The statewide groundwater flow model for the Cambrian-Ordovician aquifer (Gannon, et. al., 2009) was re-gridded to create a local scale model of the LJCPA. Grid size was reduced in the study area, especially near the proposed and existing production wells. Grid size ranged from 1 to 25 feet. The model software Visual MODFLOW version 4.6.0.167 was used to simulate the groundwater flow and pumping water elevations. Pumping and injection rates were provided by the LJCPA users, the IDNR, and the United States Environmental Protection Agency.

Model calibration for the regional groundwater flow model of the CO aquifer, which was used to develop the local-scale LJCPA model, is outlined in Gannon et al. (2009). Regional model calibration involved steady-state calibration fitting the pre-development simulated potentiometric map to historic Jordan aquifer static water levels and transient calibration to observed historic levels through time. Aquifer parameters at the regional scale as well as aquifer recharge were optimized in regional model calibration.

Transient model simulations were used to calibrate the local-scale LJCPA model. Aquifer hydraulic parameters of hydraulic conductivity and storativity were optimized. Recharge was not changed in LJCPA calibration because it had been previously-calibrated in the regional flow model, which provides the external boundary conditions for the LJCPA model. Based on calibration of the regional flow model, the recharge or leakage in the LJCPA is 0.001

inches per year (Gannon, et al., 2009). The LJCPA model developed in this investigation was calibrated to specific capacities, pump tests, and historical static water level time series.

For preliminary calibration, the aquifer hydraulic properties were modified to reproduce the specific capacities measured in 14 CO aquifer wells in Linn and Johnson Counties (Table 3). Specific capacity records were taken from driller logs available on the Iowa Geological Survey's GEOSAM database (https://www.iihr.uiowa.edu/igs/geosam/home). Upon preliminary calibration to specific capacity, the average difference in simulated and observed specific capacity was 1.6 gpm/ft and ranged from 0.1 to 4.9 gpm/ft. The preliminary-calibrated model underwent subsequent pump test and static water level time series calibration. Hydraulic conductivity and storativity within the LJCPA area were optimized to: 1) reproduce drawdowns measured in the observation wells during the conventional pump tests conducted in the LJCPA and 2) minimize residuals between observed and simulated yearly static water levels in the LJCPA wells.

Table 3: Observed and Simulated Specific Capacity in LJCPA Wells

Well Name	**GeoSam ID WNumber**	**Specific Capacity (gpm/ft)**	
		Observed	**Simulated**
Marion 4	17979	9.7	9.6
Marion 5	23249	21.5	20.1
Marion 6	54624	15.5	14.4
Marion 7	73163	20.0	19.4
Ingredion 73	17180	33.5	29.5
ADM	23940	15.7	12.3
North Liberty #5	35258	34.0	32.5
North Liberty #6	55191	16.5	14.4
North Liberty #7	67309	16.6	15.7
North Liberty #8	85879	7.7	7.8
Coralville #10	31377	7.5	7.5
Coralville #12	61572	5.0	4.5
Iowa City JW-1	37000	4.3	4.2
UI Water Plant	14453	8.4	3.6

Reproducing drawdowns from pump tests provides a measure of how well a model can characterize an aquifer's response to pumping, which was important for the LJCPA model because the Tier regulations are based on pumping water levels. The ability of the model to simulate the aquifer's response to pumping was done by comparing residuals between simulated and measured drawdowns in the observation wells of the conventional pump tests (Figure 6).

Calibration to time series water level data was important because the model needed to simulate the transient effects of pumping stress in the LJCPA in order to adequately simulate future water levels in the predictive simulations. For time series water level calibration, yearly static water level data from 16 wells within the LJCPA served as calibration targets (Appendix B). Water level data was acquired from the IDNR water level database, the IGS GEOSAM database, the City of Iowa City, and the United States Geological Survey. The model calibration period was 2000 to 2017.

Model goodness-of-fit was evaluated by comparing residuals between simulated and observed yearly static water levels. Evaluating the LJCPA model's performance in calibration was done using MODFLOW's standard calibration statistics in conjunction with the FITEVAL software (http://abe.ufl.edu/carpena/software/FITEVAL.shtml). FITEVAL was developed to provide a standardize framework for evaluating the goodness-of-fit of hydrologic models through a set of performance measures, including: absolute error statistics, dimensionless statistics, and visual comparisons (1:1 lines) (Ritter and Muñoz-Carpena, 2013). Absolute error statistics used in the model goodness-of-fit evaluation were absolute residual mean and root mean square error (RMSE). Dimensionless statistics used were the correlation coefficient (Waterloo Hydrogeologic Inc., 2017) and the Nash–Sutcliffe Efficiency coefficient (NSE) (Ritter and Muñoz-Carpena, 2013). A correlation coefficient of 1 represents a perfect positive correlation between observed and simulated values, whereas a correlation of 0 represents no correlation. The NSE varies from $-\infty$ to 1 with an NSE of 1 indicating the model perfectly predicts observed data and an NSE of 0 indicating the mean of the observed data is a better predictor than the model (Ritter and Muñoz-Carpena, 2013).

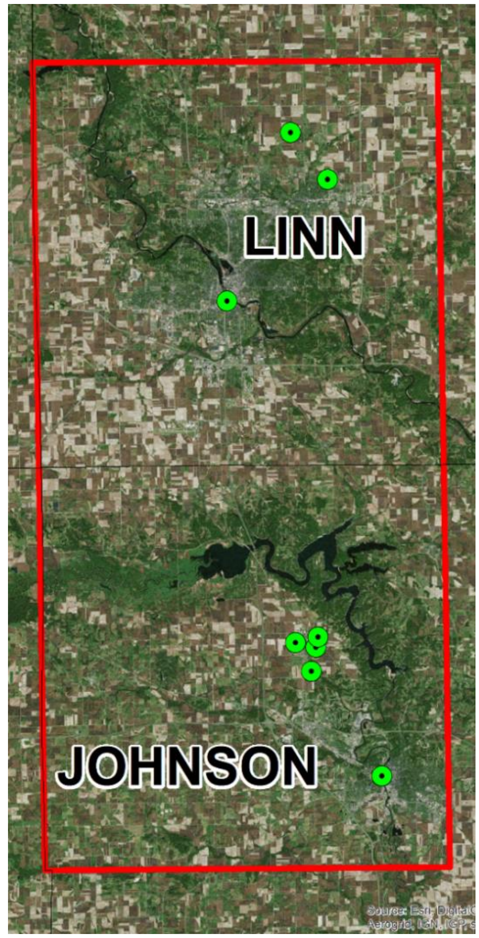


Figure 6: Conventional pump tests used in the pump test calibration

Results found the LJCPA model was able to adequately simulate the aquifer's response to pumping within the LJCPA as well as yearly static water levels. The average difference between observed and simulated drawdowns from the pump test observation wells was 0.26 feet and ranged from 0 to 0.8 feet (Tables 4 and 5). Model goodness-of-fit was "Acceptable" with no presence of outliers or model bias when simulating yearly static water levels (Figure 7). The model had a correlation coefficient of 0.91 and an NSE of 0.79 (Figures 7 and 8). The absolute residual mean and RMSE between observed and simulated water levels were 13.9 feet and 16.6 feet, respectively. A histogram of residuals from the static water level calibration is shown in Figure 9. Time series graphs of simulated and observed static water levels in the LJCPA wells during the calibration period (2000-2017) and historical static water levels can be found in Appendix B.

Calibrated aquifer parameters are shown in Figures 10 through 13. Both hydraulic conductivity and storativity were found to vary by several orders of magnitude within the LJPCA. Hydraulic conductive varied from 0.5 to 25 feet/day (Figures 10, 11, and 12). Storativity varied from 1.2 X 10^{-7} to 1.1 X 10^{-5} (Figures 13). Once calibrated, the LJCPA model was used in the predictive model simulations.

Table 4: Observed and Simulated Drawdowns in Observation Wells from Pump Tests Conducted in the LJCPA

Pumping Well	Observation Well	Drawdown (ft)	
		Observed	Simulated
North Liberty #8*	North Liberty #5*	6.0	5.2
North Liberty #5	North Liberty #6	8.0	7.5
North Liberty #5	North Liberty #7	4.0	3.9
North Liberty #5	North Liberty #8	2.4	2.5
Iowa City JW-1	UI Water Plant	8.0	8.2
Marion #4 and #6	Marion #7	2.0	2.0
Marion #4 and #6	Marion #5	1.0	1.4
Ingredion PW-73	Ingredion PW-54	20.0	20.0

*Pump test conducted by Fox Engineering

Table 5: Aquifer Parameters from the Conventional Pump Tests and the Calibrated Model

Pumping Well	Observation Well	Hydraulic Conductivity (ft/day)		Storativity	
		Observed	Simulated	Observed	Simulated
North Liberty #8*	North Liberty #5*	15.0	20.0	6.1E-05	4.9E-05
North Liberty #5	North Liberty #6	9.9	9.0	5.9E-05	4.8E-05
North Liberty #5	North Liberty #7	10.8	9.0	8.2E-05	4.7E-05
North Liberty #5	North Liberty #8	12.3	8.0	5.4E-04	4.9E-05
Iowa City JW-1	UI Water Plant	3.5	3.0	3.6E-07	1.2E-07
Marion #4 and #6	Marion #7	19.9	20.0	1.1E-05	9.0E-05
Marion #4 and #6	Marion #5	20.4	25.0	6.6E-05	1.1E-04
Ingredion PW-73	Ingredion PW-54	4.9	5.0	3.2E-05	3.2E-05

*Pump test conducted by Fox Engineering

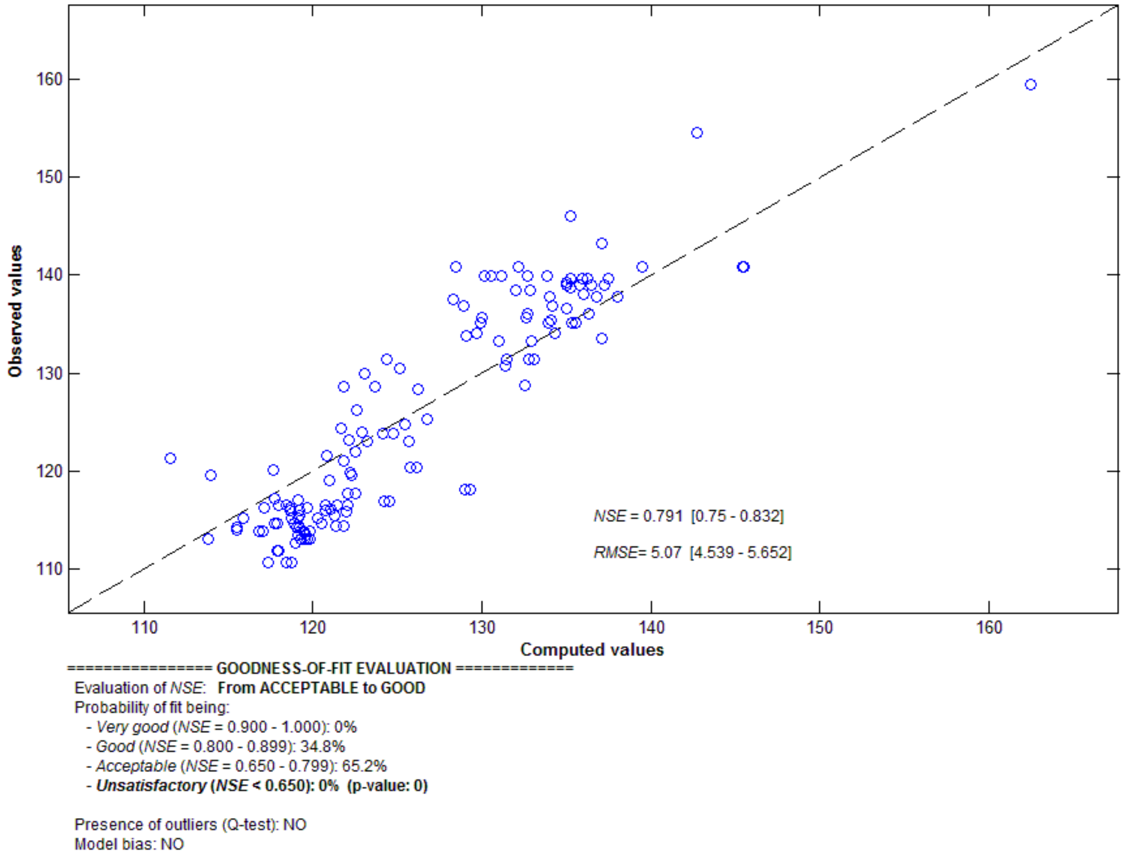


Figure 7: Goodness-of-fit results for the time series water level calibration from FITEVAL

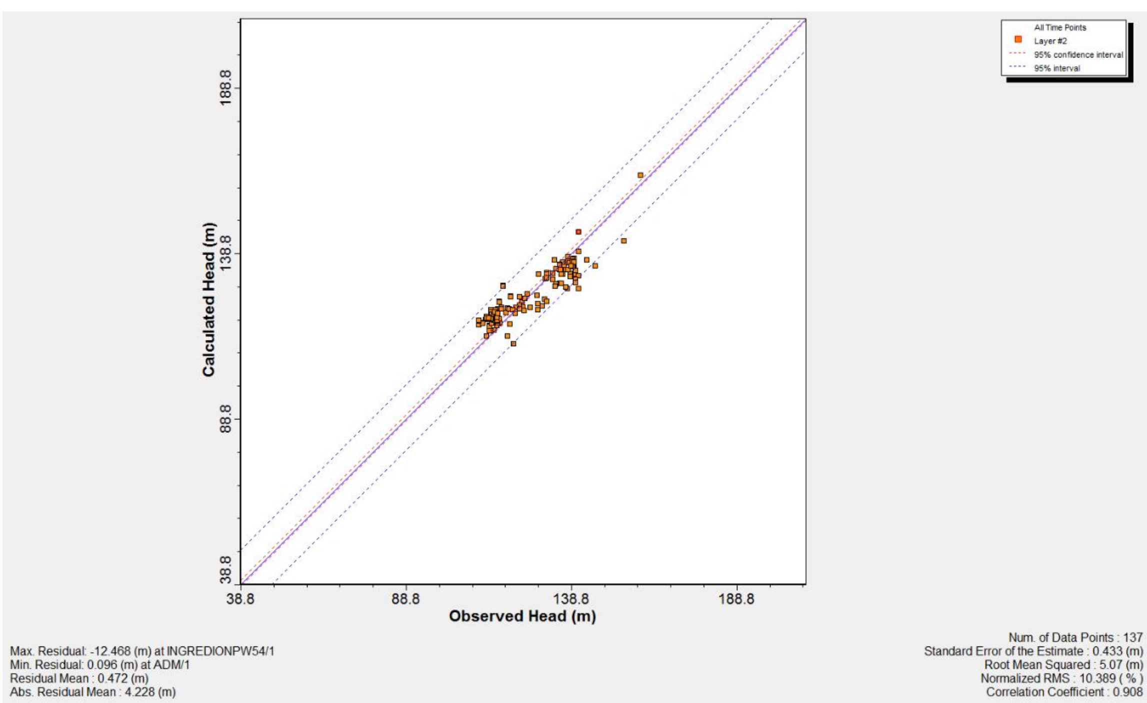


Figure 8: Goodness-of-fit results for the time series water level calibration from MODFLOW

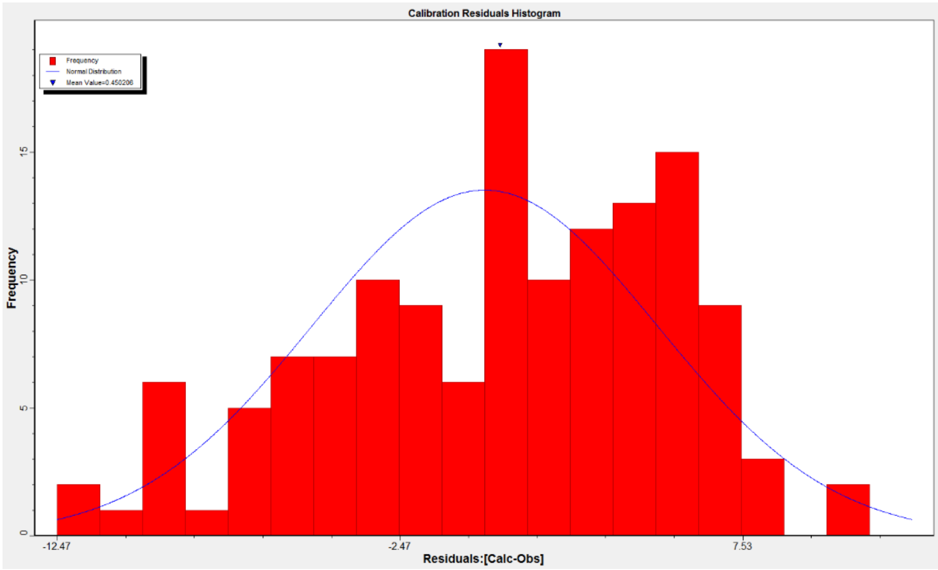


Figure 9: Residuals histogram from the static water level calibration

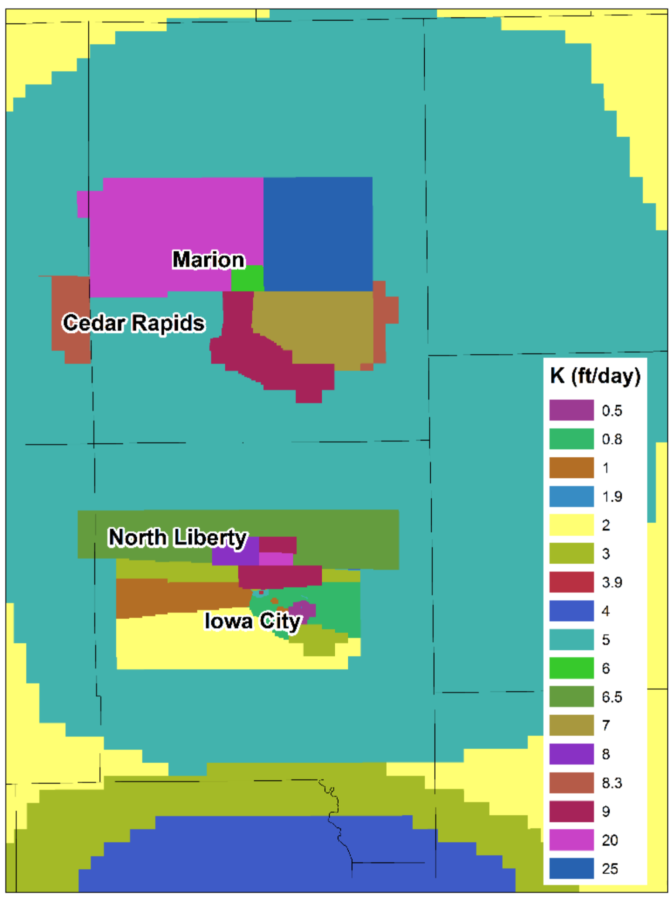


Figure 10: Calibrated hydraulic conductivity (K) distribution for the LJCPA

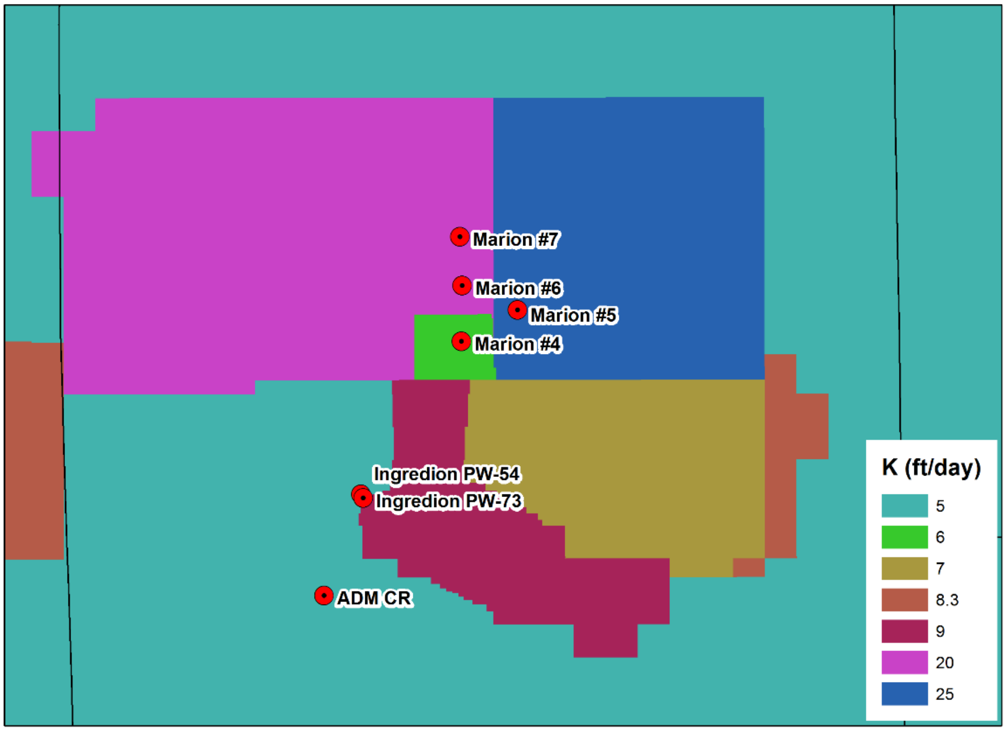


Figure 11: Calibrated hydraulic conductivity (K) distribution for Linn County

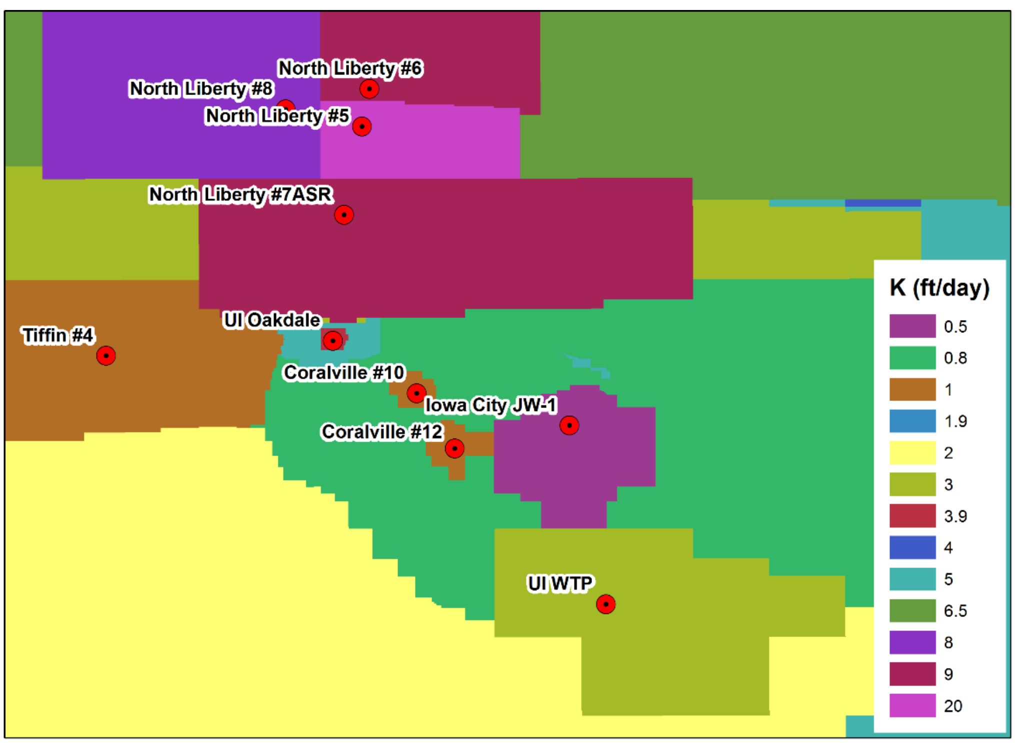


Figure 12: Calibrated hydraulic conductivity (K) distribution for Johnson County

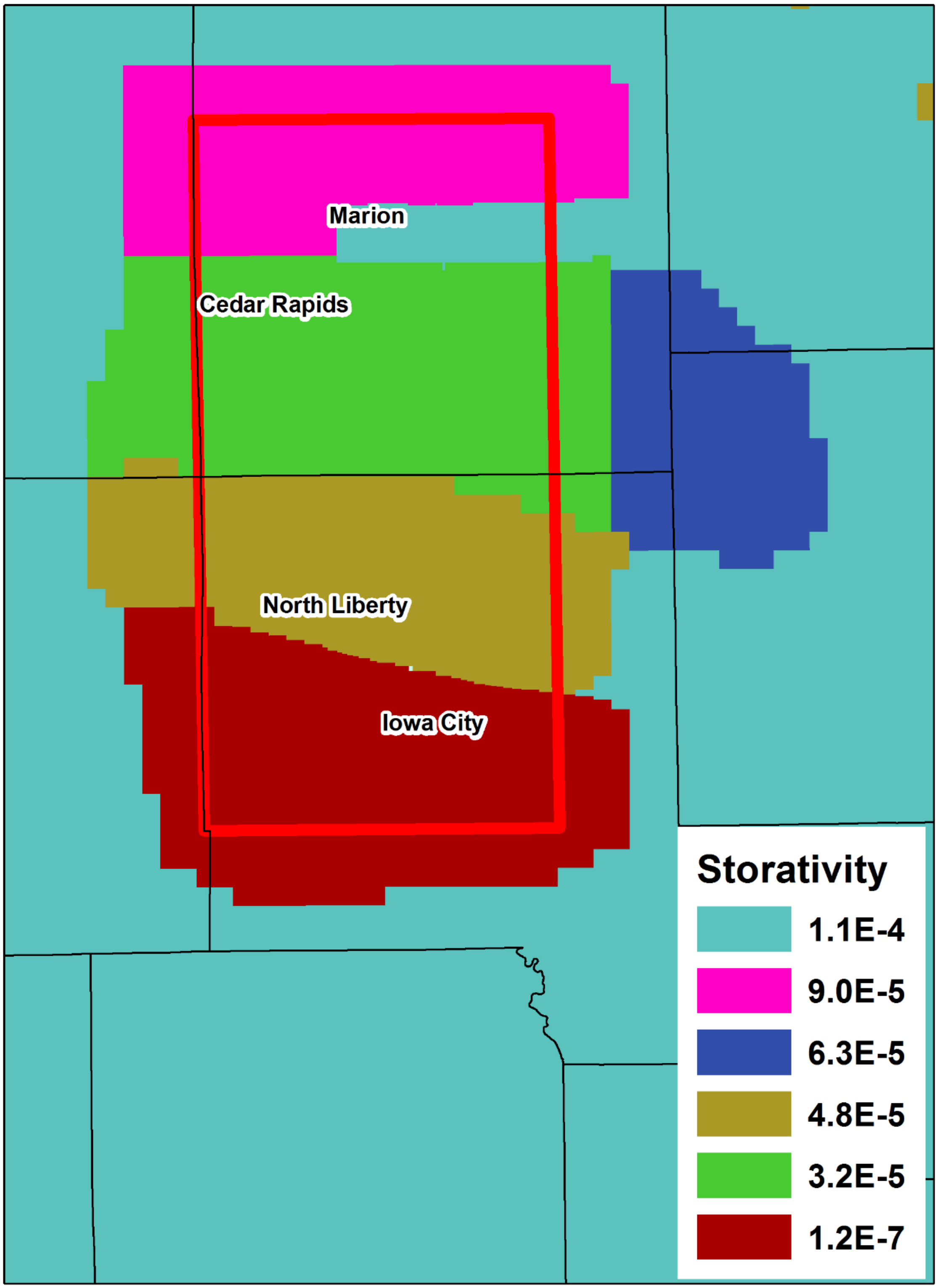


Figure 13: Calibrated storativity (S) distribution for the LJCPA

Regional Modeling

2017 Water Use

The calibrated model was first used to evaluate the sustainability of the CO aquifer within the LJCPA using current (2017) water use data. The intent of simulating current water use was to evaluate the long-term water availability and sustainability of the average daily pumping rates currently utilized within the LJCPA. North Liberty #7 was used as an ASR well throughout each of the simulations with injection and withdrawal rates maintained at 2017 levels. Rather than use the simulated head elevations produced within the model to compare to Tier 2 and Tier 3 elevations, additional simulated drawdowns at 5 year and 20 year periods were added to the observed 2017 pumping water levels provided by the IDNR. The observed 2017 pumping water levels provided a known starting datum, which reduced the uncertainty in predicting the future pumping water levels at each of the CO wells within the LJCPA.

Pumping water levels in Marion #4 and Coralville #12 were both below Tier 2 levels in 2017. In order to evaluate future pumping water levels it was assumed that Marion #4 was rehabilitated back to its original specific capacity. This may or may not be possible, but the PWL was adjusted upward for comparison purposes. The 2017 PWLs in Coralville #10 and #12 were adjusted upward assuming Coralville can install smaller pumps in their wells. Coralville will need to decrease the instantaneous pumping rates to 400–500 gpm or less from their present 820 to 900 gpm in order to get into regulatory compliance. The PWLs in Coralville #10 and #12 were respectively adjusted upward by 43 and 64 feet from the 2017 levels using the wells specific capacities assuming reduced instantaneous pumping rates of 500 gpm. It is suggested Coralville conduct pilot tests in both wells to see if these PWLs are attainable.

The pumping water levels for wells in each wellfield for years 2018 through 2038 during the peak summer usage period are shown in Appendix C. Figure 14 shows the additional drawdowns at year 2038. The pumping water levels in year 2038 increased 5 to 15 feet from 2017 levels. Assuming Marion #4 is rehabilitated to its original specific capacity and smaller pumps are installed in Coralville #10 and #12, there are no production wells in the LJCPA projected that exceed Tier 2 levels. Coralville #12, Marion #4, and North Liberty #7ASR come within 31 feet, 52 feet, and 37 feet, respectively, of the Tier 2 pumping water levels after 20 years (2038) as shown in Figures 15, 16, and 17.

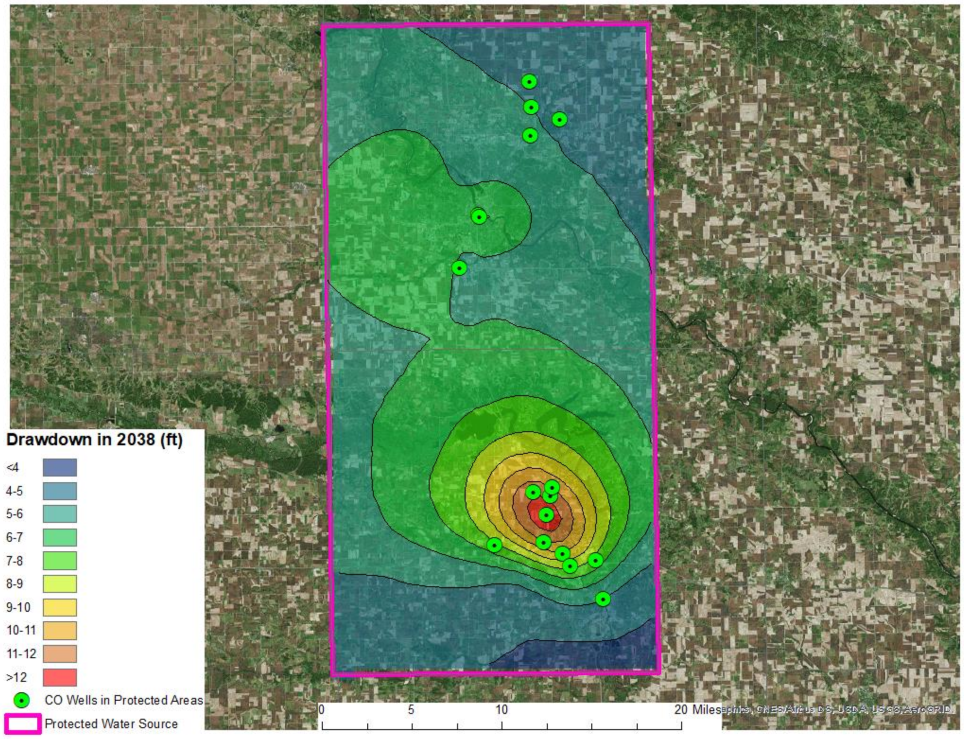


Figure 14: Simulated additional drawdown after 20 years with 2017 water use

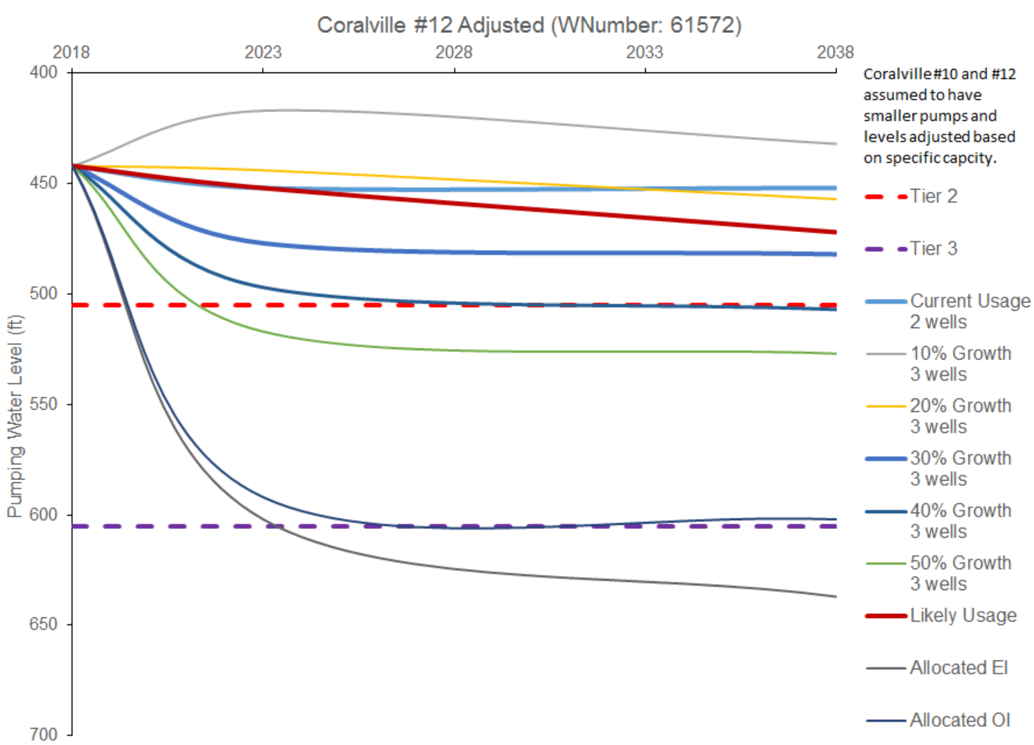


Figure 15: Pumping water levels for Coralville #12 for years 2018 to 2038 (2018 PWL adjusted for smaller pump size)

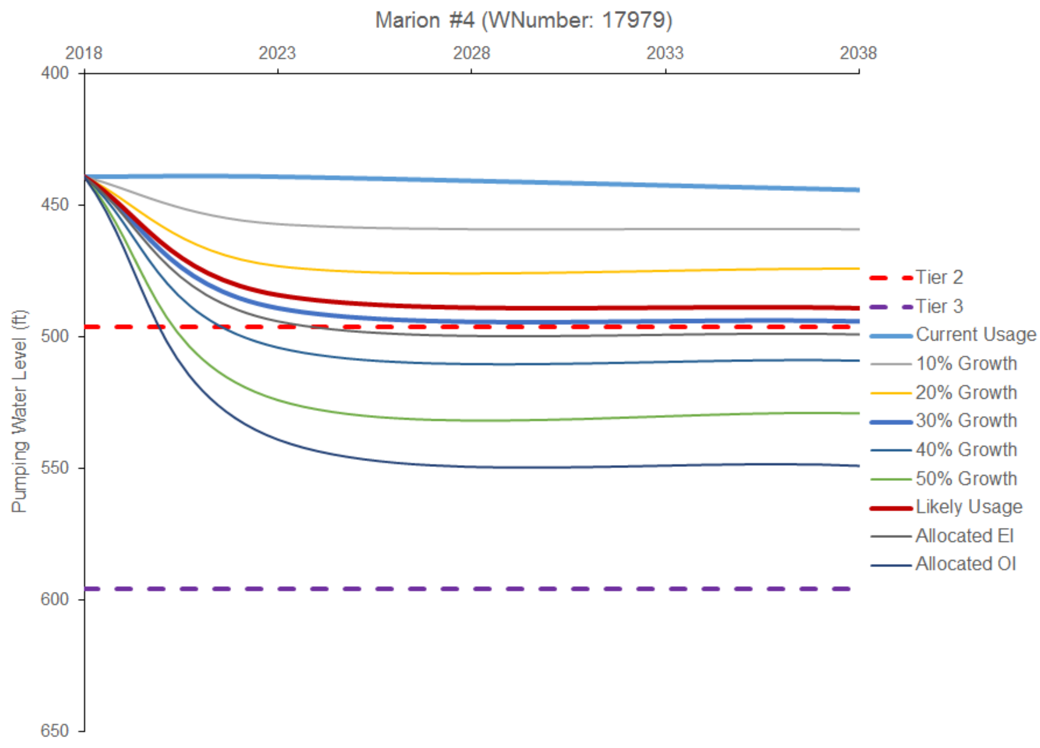


Figure 16: Pumping water levels for Marion #4 for years 2018 to 2038 with water levels adjusted for well rehabilitation back to original specific capacity

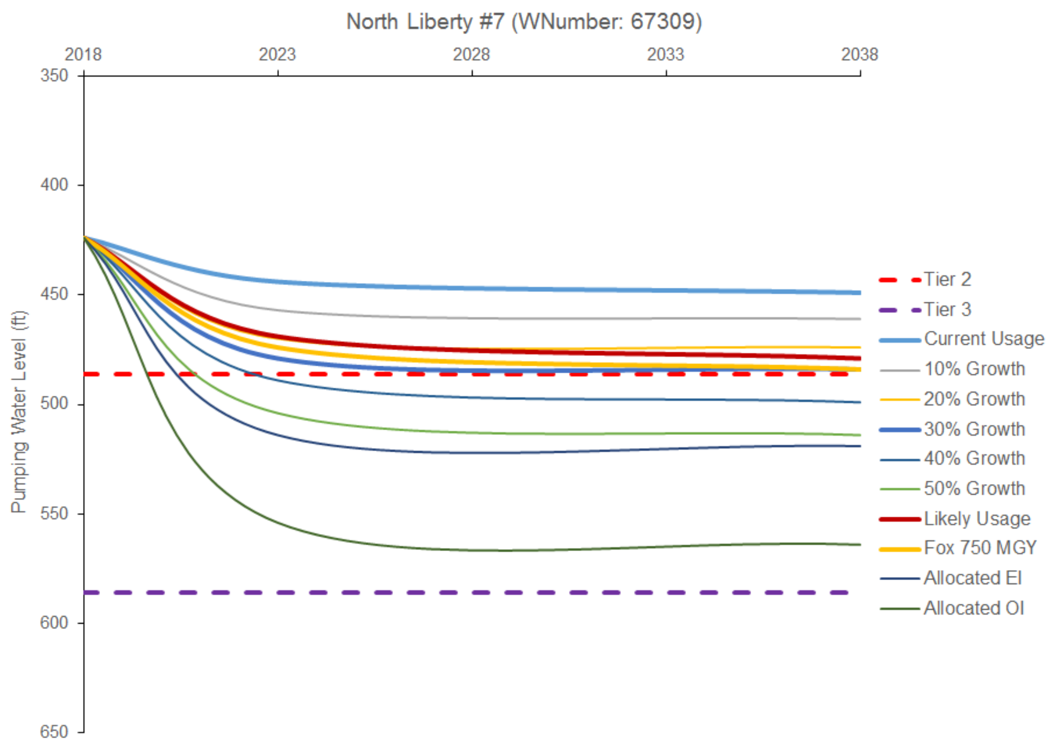


Figure 17: Pumping water levels for North Liberty #7ASR for years 2018 to 2038

Allocated Water Use – Existing Infrastructure

The calibrated model was used to simulate what would happen to pumping water levels in the LJCPA if all of the CO users pumped their allocated amounts. The intent of using allocated water usage in a predictive model simulation was to check if the CO aquifer within the LJCPA is over allocated, and if so, what areas appear to be over allocated. The simulated time period for each model run was 20 years. Several assumptions were made for simulating allocated water use with existing infrastructure. No new production wells or infrastructure were added. Therefore, production for ADM and Ingredion were limited to 2017 water usage. The average daily water use at Iowa City JW-1 and University of Iowa - Water Treatment Plant were both limited to 432,000 gallons per day based on the current pump size found in each well of 300 gallons per minute.

Pumping water levels in the LJCPA wells from the allocated water usage with existing infrastructure model simulation are shown in Appendix C. Most users in Johnson County exceed Tier 2 pumping water levels with Iowa City, Coralville, and Tiffin exceeding Tier 3 levels. The cone of depression in the low permeability zone around Tiffin, Coralville, and Iowa City caused substantial well interference with the North Liberty and University of Iowa wells as shown in Figure 18. The pumping water levels in the University of Iowa wells did not exceed Tier 2 levels; however, the Oakdale well came within 5 feet.

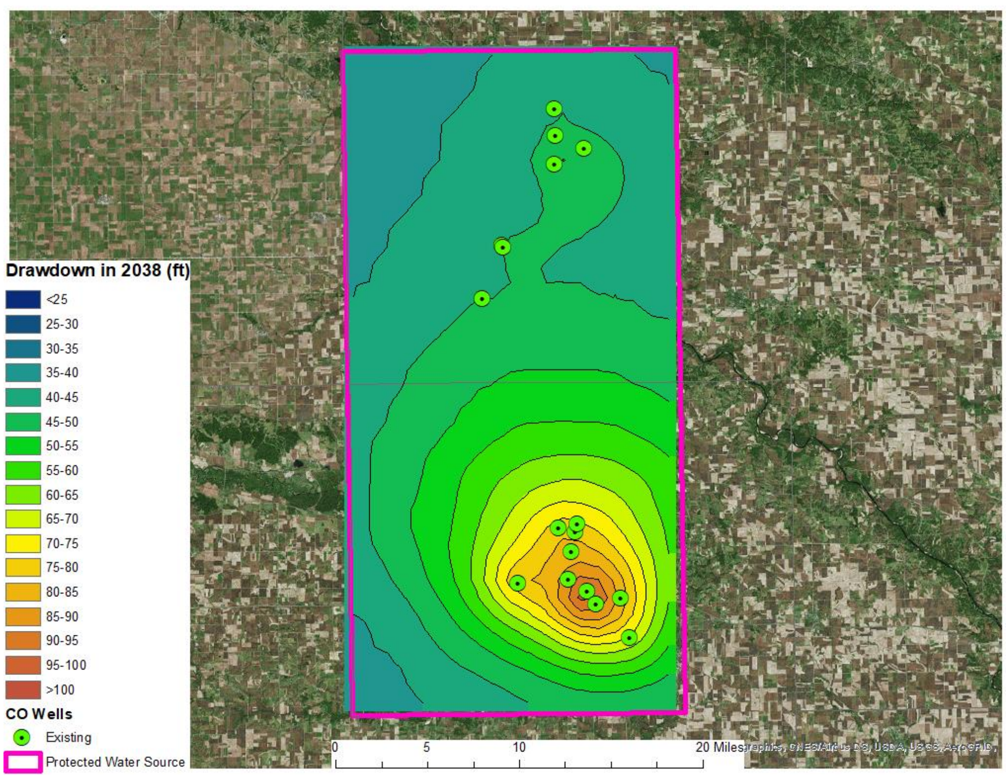


Figure 18: Additional drawdown after 20 years under allocated water use with no new production wells (EI=Existing Infrastructure)

It is very unlikely the CO aquifer in the LJCPA will experience allocated withdrawals from all users. Iowa City JW-1 does not experience significant usage. Coralville does not anticipate significant growth in the CO aquifer, and already exceeds the Tier 2 levels. Coralville will need to implement best management practices in order to get back into compliance under current withdrawals. The allocated model simulation does indicate the City of Tiffin has some limitations regarding future growth in CO water use. Tiffin will need to add an additional CO well(s), reduce instantaneous pumping rates, increase Silurian water usage, and/or identify additional water sources to meet future water needs approaching current allocated usage.

The only water user in Linn County that exceeded Tier 2 pumping water levels in the allocated water use with current infrastructure model simulation was Marion #4. The primary reason that Linn County showed less pumping stress on the CO aquifer was the assumption regarding allocated pumping rates for ADM and Ingredion. Both ADM and Ingredion were assumed to be currently pumping at capacity with 2017 water usage. Therefore, the pumping rates for ADM and Ingredion in the allocated water use with current infrastructure scenario were the same as the 2017 rates. Optimizing infrastructure by adding new wells at both ADM and Ingredion would be needed to simulate each users allocated water usage. The following section of the report describes a scenario where infrastructure at ADM and Ingredion as well as other wellfields in the LJCPA were optimized allowing all users in the LJCPA to withdraw water at allocated rates.

Allocated Water Use – Optimized Infrastructure

The calibrated model was used to simulate what would happen to the pumping water levels in the LJCPA if infrastructure was optimized to allow all users to withdraw allocated amounts. The intent of using the allocated water usage in a predictive model simulation was to check if the CO aquifer was over allocated, and if so, what areas appear to be over allocated. The simulated time period for each model run was 20 years. Additional wells were added for ADM and Ingredion. Three (3) additional production wells were added to ADM's wellfield to increase the daily usage to 6 million gallons per day. Ingredion was assumed to abandon PW-54, add one (1) additional well, and divide the total daily water usage equally between the two active wells (500,000 gpd). Coralville was also assumed to add a third CO well. Usage was then divided equally between the three Coralville CO wells. North Liberty #7 was converted from an ASR well to a production well creating four active production wells. North Liberty water usage was balanced between the four (4) production wells. Additional wells were not assumed to be added to Iowa City's wellfield or at the University of Iowa. Withdrawals at Iowa City JW-1 and the UI WTP were limited to 432,000 gallons per day based on the current pump size in each well of 300 gallons per minute.

All of the CO aquifer wells within the LJCPA exceed Tier 2 levels under the full allocation with optimized infrastructure scenario. Pumping water levels in the ADM wells, Iowa City JW-1, Coralville wells, and Tiffin #4 exceed Tier 3 levels (Appendix C). Model results indicate that if each user in the LJPCA pumped at allocated rates substantial regional well interference in both Johnson and Linn counties would occur (Figure 19). It may be necessary to scale back some of the allocated amounts of water from the CO aquifer at several LJCPA water utilities during the next five year permit cycle to prevent significant well interferences.

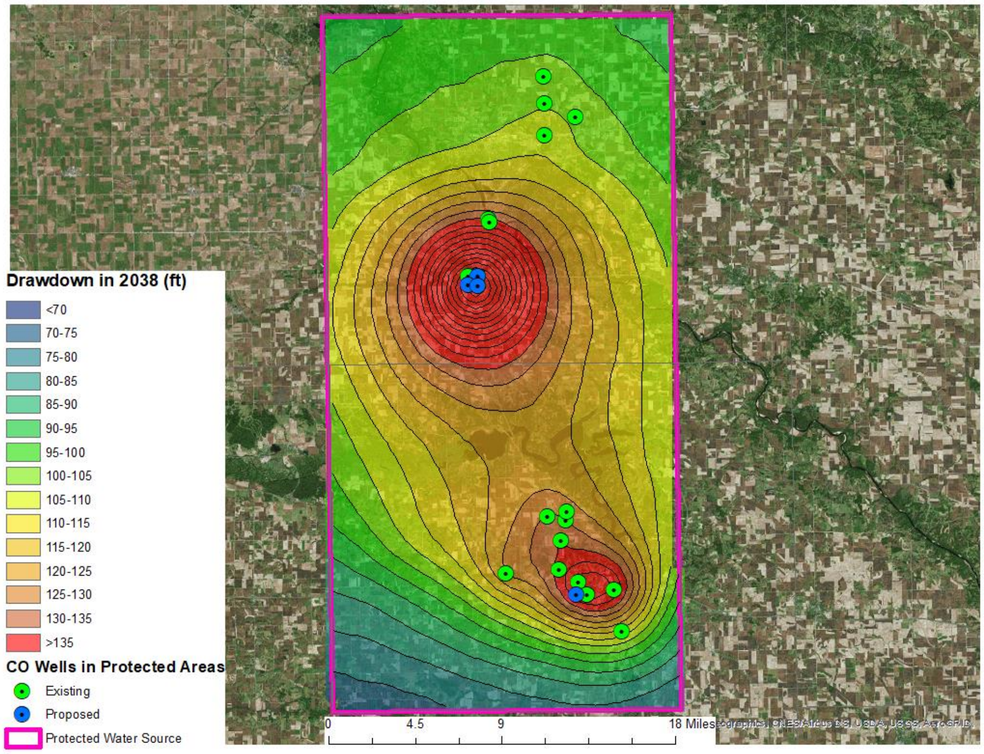


Figure 19: Additional drawdown after 20 years under allocated water use with new production wells (OI=Optimized Infrastructure)

Incremental Water Use Increase – North Liberty #7 as an Aquifer Storage and Recovery Well

The calibrated model was used to simulate an incremental increases in CO water use by all water users in the LJCPA. The intent of conducting incremental increase simulations was to show the limits of the CO aquifer in the LJCPA if every user requested and/or used additional water. The simulated time period for each model run was 20 years. Model simulations were run for 10%, 20%, 30%, 40%, and 50% increases in water use compared to 2017 usage. Usages in the model were increased at the start of each simulation and maintained for 20 years. North Liberty #7 was used as an aquifer storage and recovery well (ASR) throughout each of the simulations with the injection and withdrawal rates kept constant at 2017 levels.

Considering current infrastructure and communications with the LJPCA users, it was assumed at ADM, Coralville, and Ingredion are near maximum capacity at current average daily usages. Increasing daily water production will require an additional production well. In order to simulate projected growth, it was assumed Ingredion PW-54 was replaced with a new well, and new wells were drilled by ADM and Coralville. Actual locations for these proposed wells would be determined by the water users as needed.

Pumping water levels in the LJCPA wells for years 2018 through 2038 during the peak summer usage period are shown in Appendix C. The plots show the PWLs under 10, 20, 30, 40 and 50% growth in water use for a 20-year time period (2018 to 2038). Figure 20 shows the additional drawdown at year 2038 for a 30% increase in water-use

Based on the predictive model simulations and previous assumptions, a 10–20% increase in regional water usage for all users in the LJCPA would not cause any of the PWLs in the production wells to exceed Tier 2 after 20 years. A 30% increase in water use by all LJCPA users caused Marion #4 to exceed the Tier 2 level by 1 foot (Figure 16). A 30% increase could easily be attained by reducing the pumping rates in Marion #4 and Marion #6 and increasing the daily pumping rates in Marion #5 and Marion #7 (Figures 21 and 22). None of the other production wells in the LJCPA have PWLs that exceed Tier 2 levels with a universal 30% growth. North Liberty #7ASR is within 2 feet of the Tier 2 level during the peak summer usage period (withdrawal cycle) after 20 years (year 2038) (Figure 17). Reducing the instantaneous pumping rate during the withdrawal cycle should provide additional available drawdown.

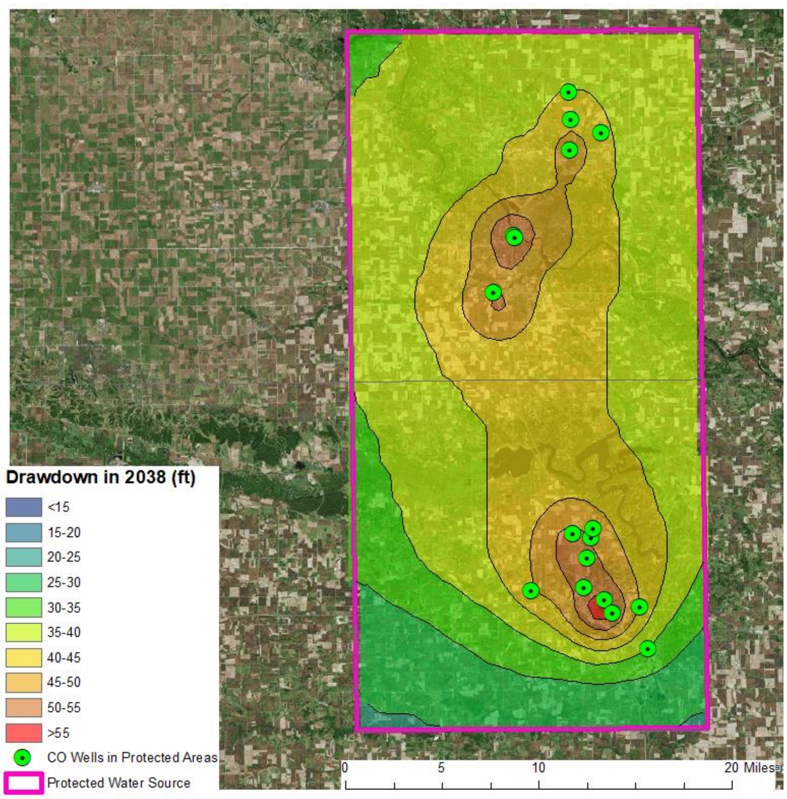


Figure 20: Additional drawdown after 20 years from a uniform water usage increase of 30% within the LJCPA

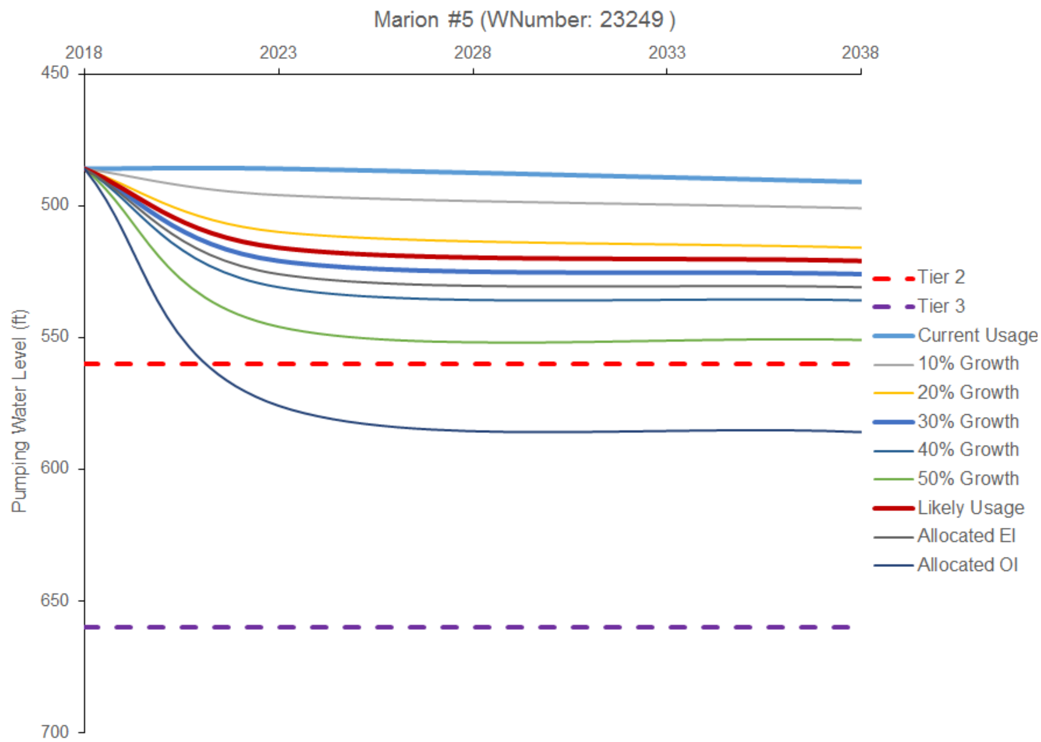


Figure 21: Pumping water levels for Marion #5 for years 2018 to 2038

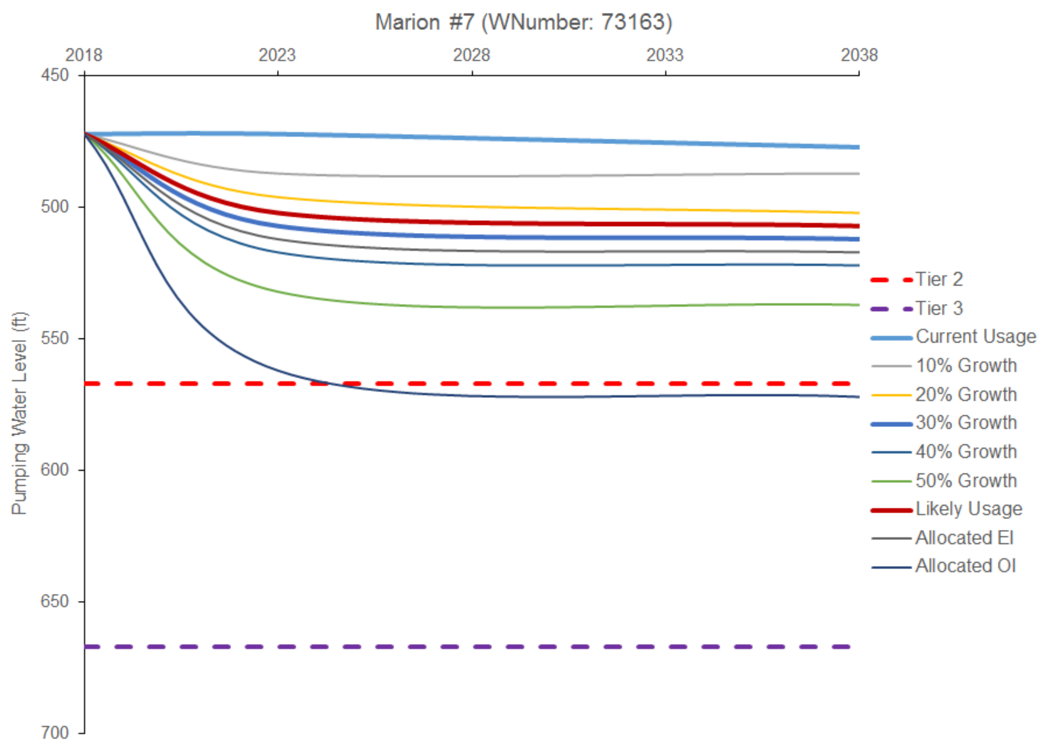


Figure 22: Pumping water levels for Marion #7 for years 2018 to 2038

Further declines in water levels were observed when each user grew by 40–50%. A 40% increase in regional water use caused the pumping water levels in Marion #4 and #6, ADM, North Liberty #7ASR, Coralville #12, and Tiffin #4 to exceed Tier 2 levels (Appendix C). A 50% increase by all users caused all production wells in the LJCPA to exceed Tier 2 levels, except Marion #5 and #7 and the University of Iowa wells.

Results from the percentile growth simulations, indicate a 30% increase in water use (above 2017 values) by all the users in the LJCPA would be the maximum sustainable water use. However, not all of the LJCPA users need or desire a 30% water use increase, which could allow growing communities or industries to eventually increase their CO aquifer water use by more than 30%. Limiting annual water use to no more than 30% above 2017 usage for a 5-year water use permit protects all of the remaining water users within the LJCPA. This also allows observed pumping water levels to be monitored and compared to simulated results. The LJCPA model can then be modified and used to further evaluate future allocations. If PWL trends begin to decline faster than predicted by the model, the Tier 2 and Tier 3 regulatory limits can be implemented to protect the aquifer.

Most Likely Water Use Scenario – North Liberty #7 as an Aquifer Storage and Recovery Well

Results from the regional allocated and incremental increase modeling simulations as well as conversations with the water users in the LJCPA were used to develop a most likely water use scenario. Table 6 provides a likely annual water use at each wellfield, and the reason or justification behind the 20 year usage. New wells are assumed for ADM, Ingredion, and Coralville. Instantaneous pumping rates were assumed to be 500 gpm for each of the three Coralville wells. Table 6 also compares the most likely annual projected usage to the current allocated usage. It should be noted that current allocated usage appears high for ADM, Coralville, Tiffin, and the two University of Iowa permits. North Liberty 20 year water use was based on information provided by Fox Engineering, and included an incremental increase from 500 MGY in 2018 to 750 MGY in 2038. Projected water use in North Liberty was modified by the addition of new Silurian wells, where CO water usage would be reduced by the same amount provided by the new Silurian wells. Because of the incremental increase in CO water usage at North Liberty, an additional 20-year model simulation was run using the 2038 withdrawal amount (750 MGY). This model simulation was run to see whether the 2038 water usage was sustainable long-term. An extra simulation was also run with North Liberty using the 2038 withdrawal amount and Tiffin increasing usage by 50% due to growth.

Table 6: Most Likely Water Use in the Predictive Groundwater Model Simulation

Wellfield	Total Percent Increase	Annual Projected Usage MGY	Current Allocated MGY	Justification
ADM	30%	802	2,181	Based on Regional Modeling
Coralville	0% for 2018-2028 10% 2028-2038	328 and 359	1,650	Per request
Ingredion	10%	386	400	Per request
Iowa City	0%	9	NA	Per request
Marion	30%	1,371	1,400	Based on Regional Modeling
North Liberty	Incremental (50% at year 20)	500 to 750	500	Based on Fox Engineering
Tiffin	30%	63	123.5	Based on Regional Modeling
UI Oakdale	0%	19	63	Per request
UI WTP	0%	37	1,500	Per request

None of the wells had pumping water levels exceed Tier 2 levels in the most likely projected usage scenario (Appendix C). Pumping water levels in Marion #4 and North Liberty #7ASR came within 7 and 12 feet of Tier 2. Both the Marion and North Liberty wellfields would have the capacity to decrease the pumping rates at Marion #4 and North Liberty #7ASR, and make up the difference in other CO wells. Marion #5 and #7 have 39 and 60 feet of available drawdown, respectively (PWLs above Tier 2). North Liberty #7ASR could reduce the injected and withdrawal amounts each year to protect PWLs. Lowering instantaneous pumping rates could also raise PWLs and provide for additional available drawdown.

To evaluate the sustainability of Fox Engineering's projected water usage in year 2038, the North Liberty annual usage was set to 750 MGY for 20 years (rather than the incremental usage). None of the pumping water levels in the LJCPA exceeded Tier 2 levels in the simulation; however, certain wells came close. Pumping water levels in Marion #4 and North Liberty #7ASR came within 2 feet of the Tier 2 levels. North Liberty #5, #6, and #8 came within 19, 13, and 19 feet of the Tier 2 levels as shown in Figures 23, 24, and 25. Pumping rates at Marion #4 and North Liberty #7ASR could be reduced and the cities could make up the difference in their other CO wells. Marion #5 and #7 have 34 and 55 feet of available drawdown before reaching Tier 2. North Liberty #7ASR could reduce the injected and withdrawal amounts each year to protect PWLs. Additional available drawdown may also occur at lower instantaneous pumping rates by raising PWLs.

Adjusting North Liberty's water use to 750 MGY, based on Fox Engineering's projected water usages in 20 years, is a 50% increase over current 2017 usage. In the previous model simulation, the City of Tiffin was limited to a 30% water use increase base on regional modeling. However, the City of Tiffin is also growing. Therefore, an additional model simulation was conducted for a most likely water use scenario with a 50% increase in water use for both North Liberty and Tiffin. When both North Liberty and Tiffin increase water usage by 50% the PWLs at Tiffin drop 3 feet below Tier 2 levels, but North Liberty's PWLs continue to remain above Tier 2 levels. Adding a second CO production well at Tiffin and balancing the pumping rates between the two wells, would allow the PWLs to rebound by approximately 40 feet. This would allow Tiffin to remain in compliance with the Tier 2 and 3 levels.

Most Likely Water Use Scenario – North Liberty #7 as a Production Well

Model simulations were also run to evaluate North Liberty #7 as a fourth production well instead of an ASR well. One interesting aspect of this evaluation is the net gain in water usage simply based on the net loss of water in the ASR process. Based on 2017 injection and withdrawal volumes, 51,700,000 gallons of water were injected and 39,600,000 gallons were withdrawn by North Liberty #7, creating a net loss of 12,100,000 gallons of water. Over a 365 day period, this amounts to 33,000 gallons per day. This volume was ignored in our model simulations, but could play a factor over time in the PWLs.

None of the pumping water levels in the LJPCA wells exceeded Tier 2 levels in the most likely water use scenario with North Liberty utilizing four (4) production wells. Pumping water levels in North Liberty #5, #6, #7, and #8 come within 29, 33, 7, and 34 feet of the Tier 2 levels, respectively. The PWL in North Liberty #7 is slightly better in the four production well simulation versus the three production well and one ASR well simulation (5 additional feet). The main benefit of the four production well scenario is the gain in available drawdown in the other North Liberty wells. North Liberty #5, #6, and #8, gain 10 feet, 20 feet, and 15 feet, respectively. Figures 23, 24, and 25 show the difference in PWLs in North Liberty #5, #6, and #8 when North Liberty #7 is used as a production well versus an ASR well. The gain in available drawdown is primarily the result of spreading out the pumping stress with the 4 production wells compared to 3 wells. Average daily usage and instantaneous pumping rates could be reduced at each North Liberty CO well if North Liberty #7 is used as a production well providing significant benefit in pumping water levels.

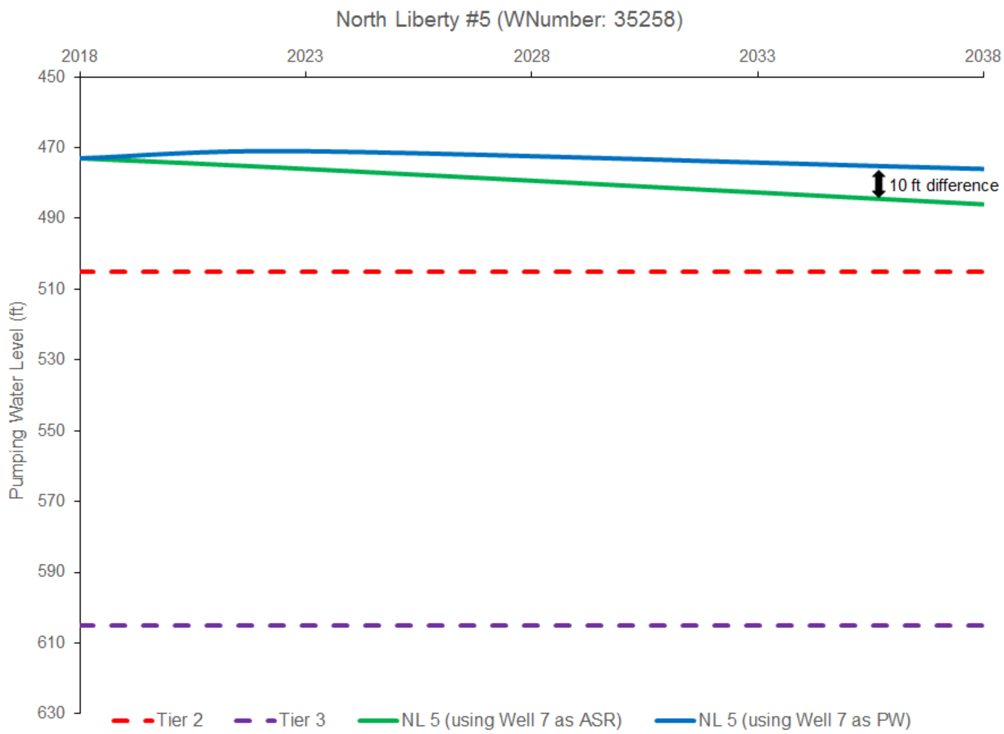


Figure 23: Comparing pumping water levels in North Liberty #5 for years 2018 to 2038 when NL #7 is used as an ASR well and as a production well

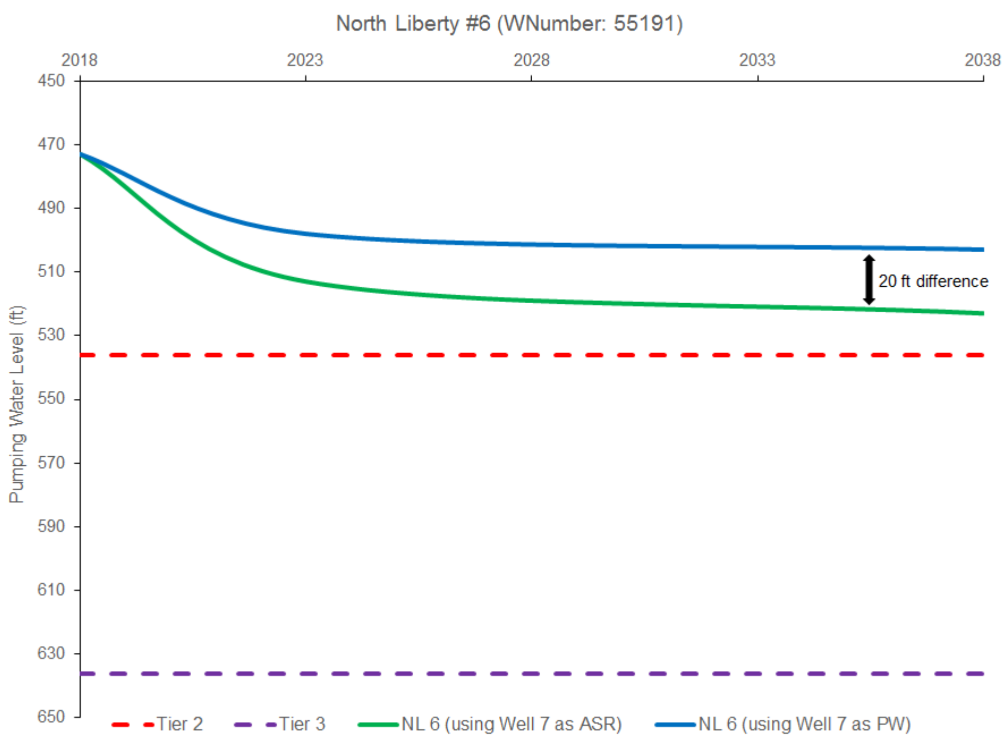


Figure 24: Comparing pumping water levels in North Liberty #6 for years 2018 to 2038 when NL #7 is used as an ASR well and as a production well

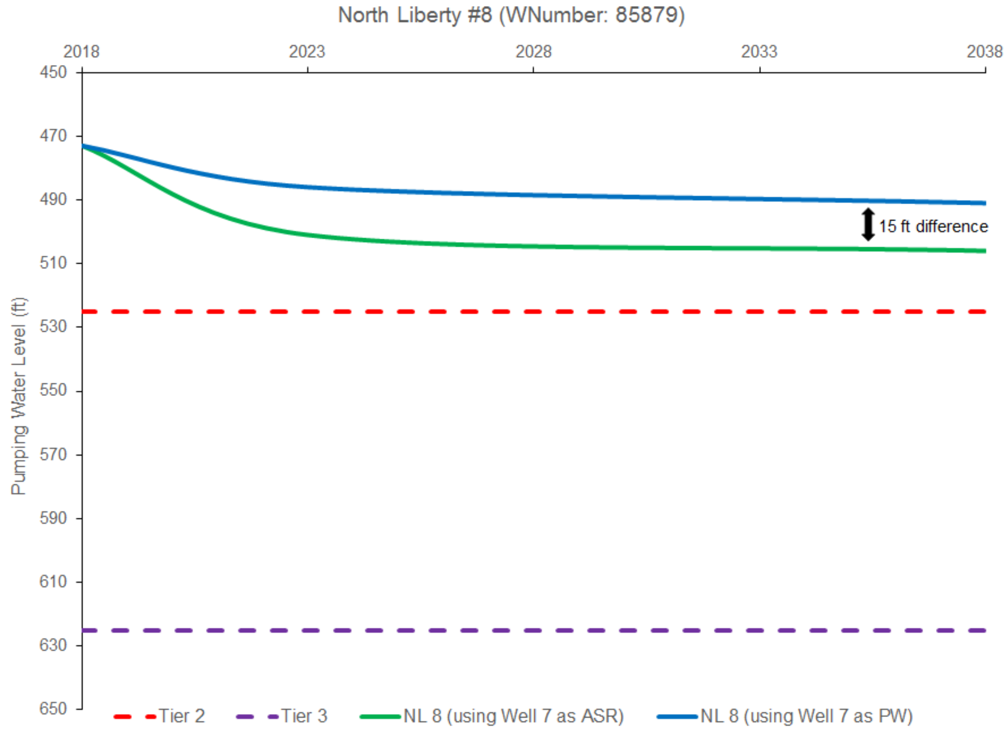


Figure 25: Comparing pumping water levels in North Liberty #8 for years 2018 to 2038 when NL #7 is used as an ASR well and as a production well

Well Interference

Declines in groundwater levels often extend radially many miles from production wells within the LJCPA. Drawdowns from different CO wells can interact and increase the overall decline in pumping water levels throughout the protected area. Therefore, pumping water levels measured in a well are a combination of drawdown from the well itself and drawdowns from nearby wells within the LJCPA. It is important to understand and account for regional, collective well interference caused by long-term pumping within the LJPCA in order to predict long-term pumping water levels. For example, increasing CO aquifer water usage for the City of Marion by 50%, while maintaining all other users at 2017 usage rates, would not cause Marion #6 to reach Tier 2. However, if all users within the LJCPA increased water usage by 50%, model results indicate the additional drawdown from collective well interference would cause Marion #6 to reach Tier 2 pumping water levels (Figure 26).

Additional drawdown after 20 years with all users maintaining 2017 pumping rates is shown in Figure 14. Maintaining current usage within the LJPCA does not appear to cause significant additional water level declines or collective well interference. However, drawdown contours show collective well interference within Johnson County was greater than within Linn

County, which could be expected considering the lower conductivity zone present in the southern portion of the LJCPA.

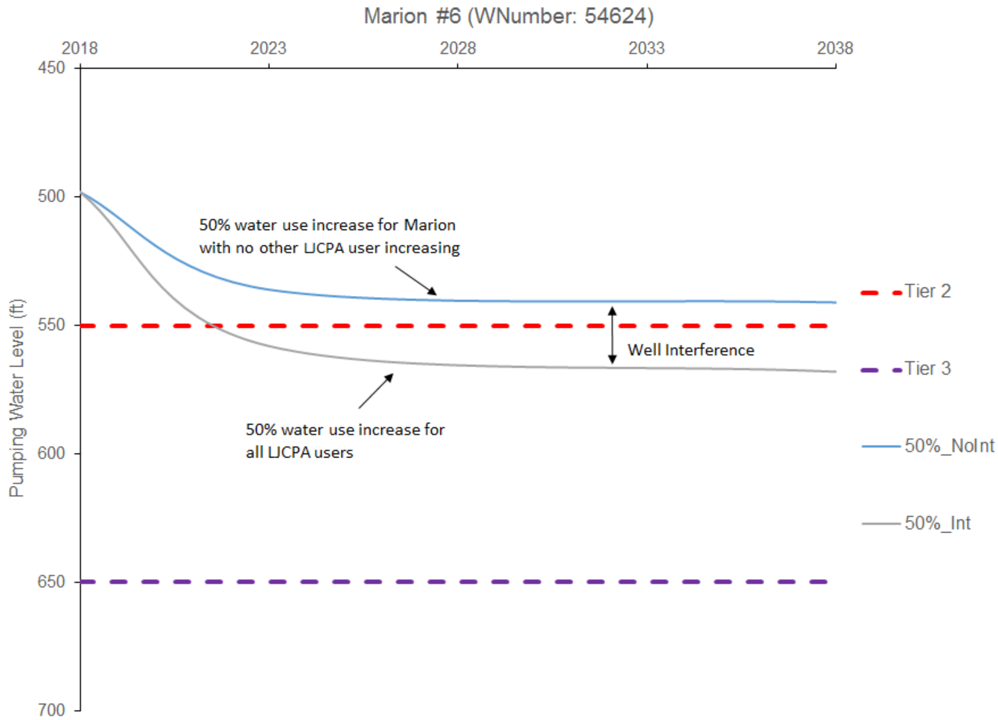


Figure 26: Collective well interference for Marion #6 assuming all users in the LJCPA increase usage by 50%

Well interference after 20 years increased significantly with all users utilizing maximum allocated water usage possible with existing infrastructure (Figure 18). Additional drawdown, caused by the combination of increased pumping and collective well interference, exceed 100 feet in portions of Johnson County under allocated water use. Additional drawdown was significantly less for users in Linn County (ADM, Ingredion, and Marion) in the allocated usage with existing infrastructure simulation. One reason for the lack of drawdown in Linn County compared to Johnson County was the assumption that 2017 water usage for ADM and Ingredion represented the maximum possible withdrawal rates with existing infrastructure. Additional drawdown in Linn County after 20 years increased to over 125 feet within the ADM and Ingredion wellfields when infrastructure was optimized by adding wells so that all users could withdrawal at allocated rates (Figure 19). The drawdown contours after 20 years show significant well interference throughout the entire LJCPA with all users withdrawing at allocated rates.

In order to identify the impact of well interference on specific wellfields, percentage growth model simulations were conducted assuming only a single user was growing at a certain rate (10, 30, and 50%) followed by simulations assuming all users were growing at that rate. The difference in pumping water levels between the simulations represented collective well interference at the universal percentage growth rates. Collective well interference for a selected well at each LJCPA user's wellfield at 10, 30, and 50% growth rates can be found in Appendix C.

Collective well interference was also identified when evaluating sustainable water usage rates within the LJCPA. For the most likely water use scenario, additional drawdown due to well inference for select wells within each user's wellfield are shown in Figures 27 through 37. The figures compare pumping water levels without interference (Likely_NoInt) and with interference (Likely_Int). Additional well interference did not cause any user to enter Tier 2 after 20 years in the most likely usage scenario. The 2017 pumping water level for Coralville #12 was already in Tier 2. The likely growth model simulation assumed Coralville would add a third well to increase production. Even with distributed usage among the three production wells, Coralville #12 was found to fall below Tier 2 when accounting for well interference (Figure 28). If Coralville installed smaller pumps to reduce instantaneous pumping rates and raise PWLs, model results indicate regional well interference in the likely growth scenario would not cause Coralville #12 to enter Tier 2 (Figure 29). Model results also found shifting North Liberty #7 from an ASR to production well would reduce well inference at North Liberty's other CO wells, including North Liberty #6 (Figures 33 and 34). Pumping water levels throughout the LJCPA were shown to be impacted by well interference from the other users (Figures 26 through 37), making it important to account for well interference in projecting future water levels.

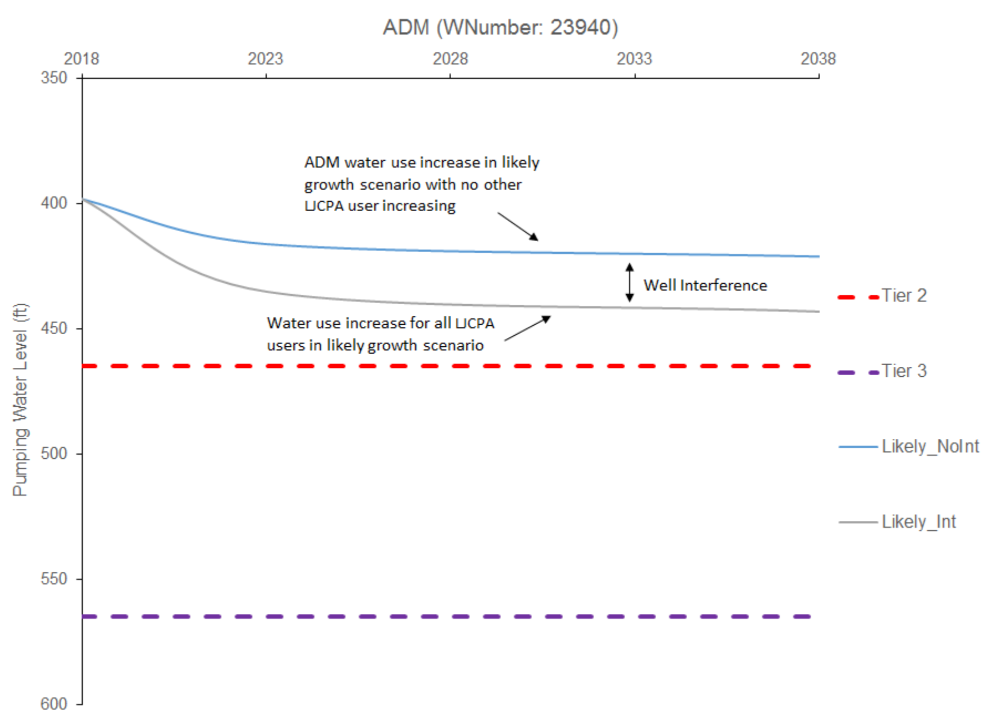


Figure 27: Collective well interference for ADM in the likely growth scenario

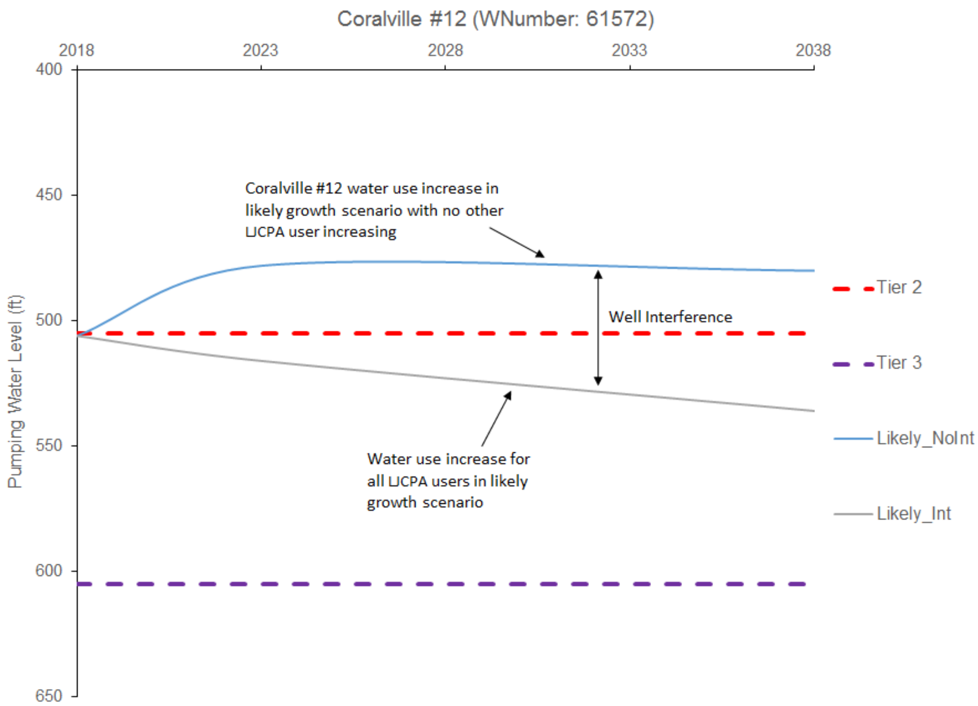


Figure 28: Collective well interference for Coralville #12 in the likely growth scenario

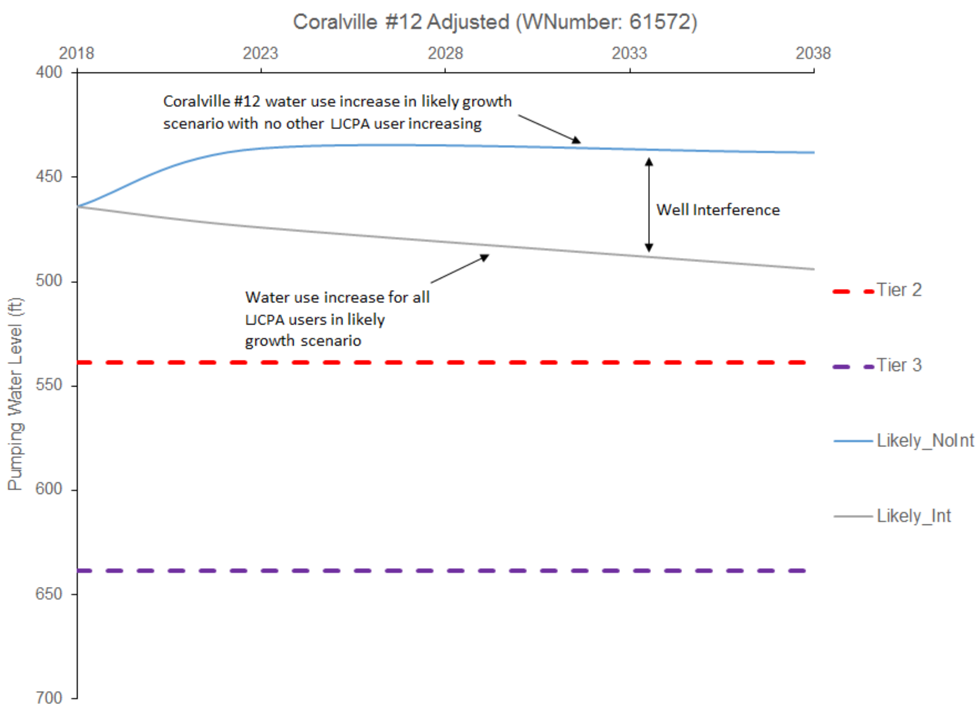


Figure 29: Collective well interference for Coralville #12 with water levels adjusted for smaller pumps in the wells in the likely growth scenario

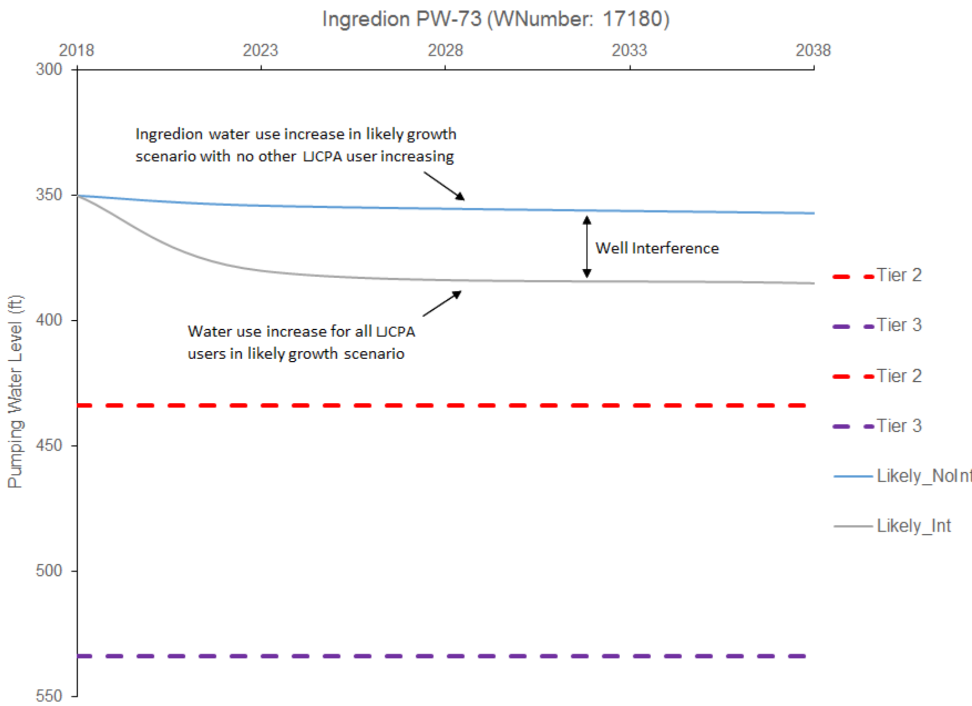


Figure 30: Collective well interference for Ingredion PW-73 in the likely growth scenario

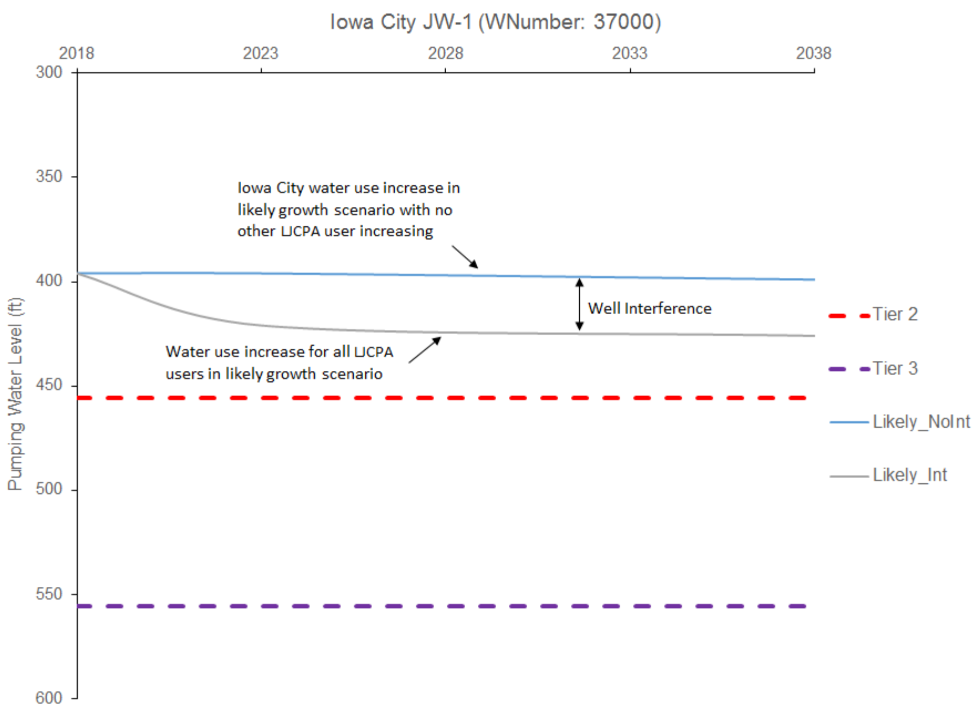


Figure 31: Collective well interference for Iowa City JW-1 in the likely growth scenario

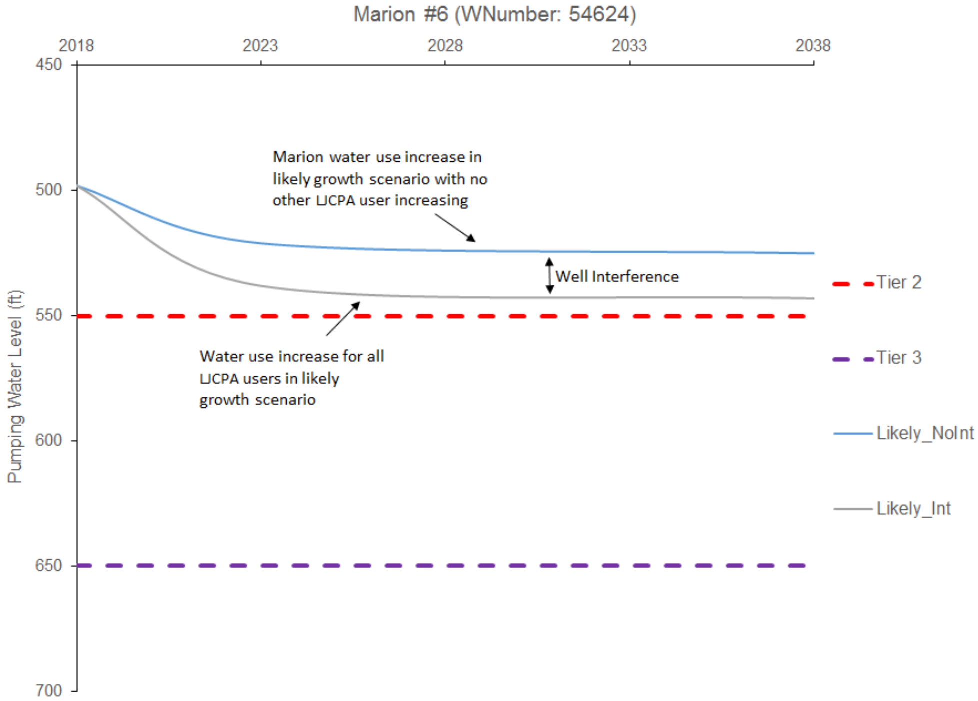


Figure 32: Collective well interference for Marion #6 in the likely growth scenario

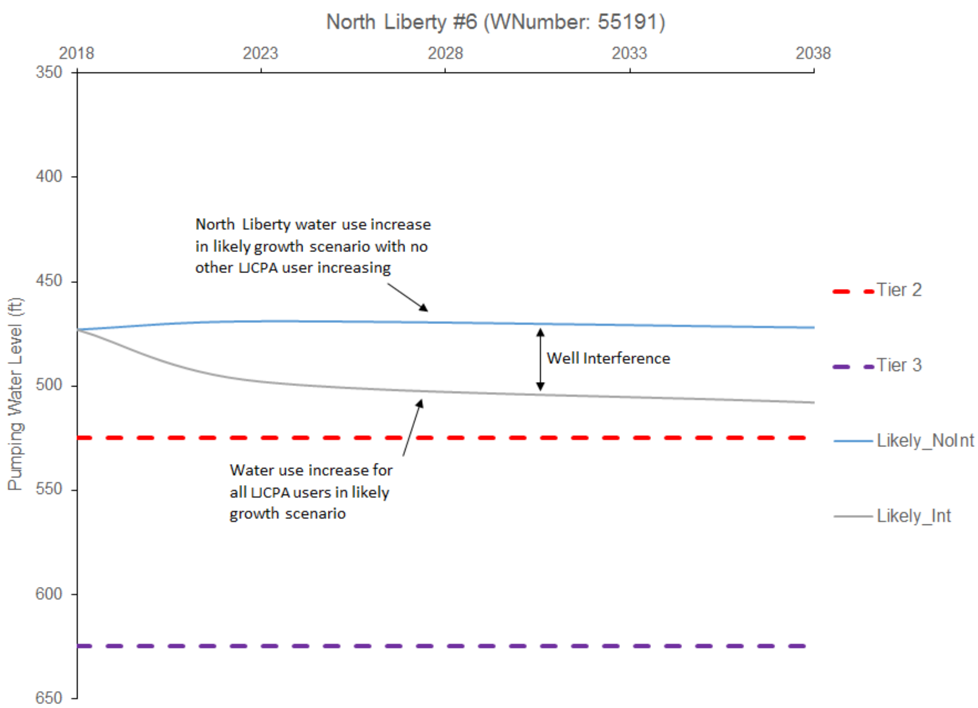


Figure 33: Collective well interference for North Liberty #6 in the likely growth scenario with North Liberty #7 as an ASR well

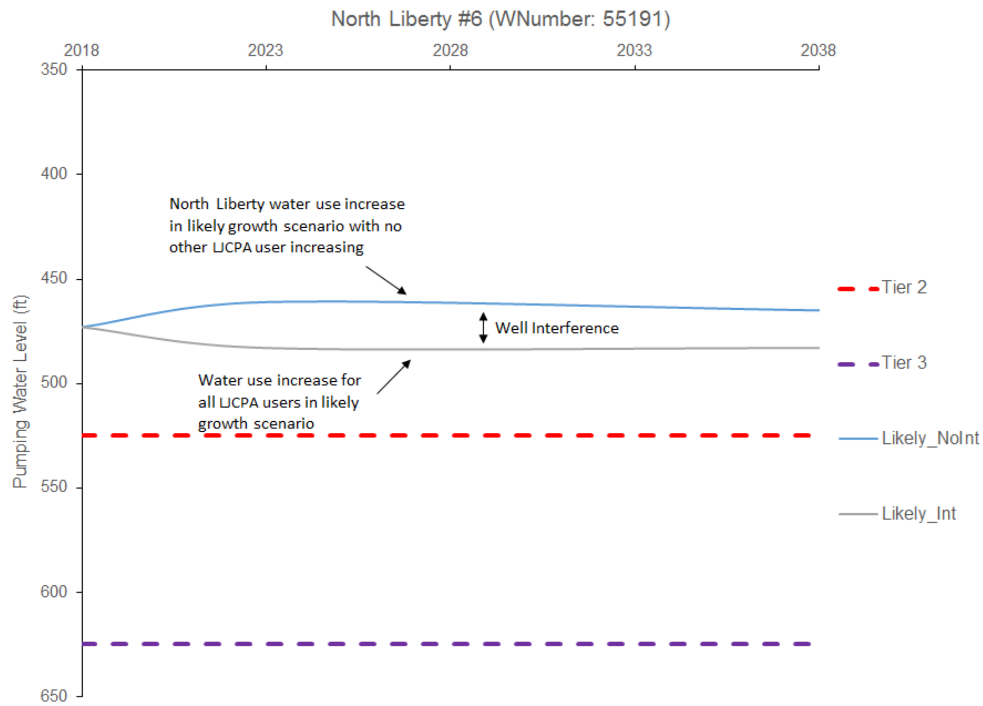


Figure 34: Collective well interference for North Liberty #6 in the likely growth scenario with North Liberty #7 as a production well

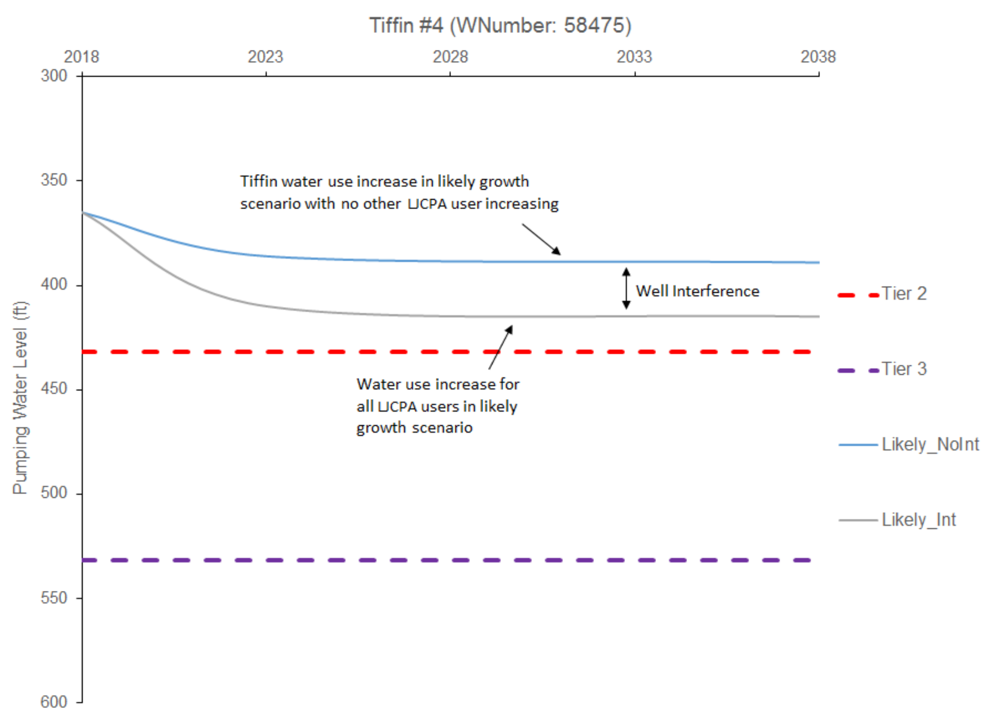


Figure 35: Collective well interference for Tiffin #4 in the likely growth scenario

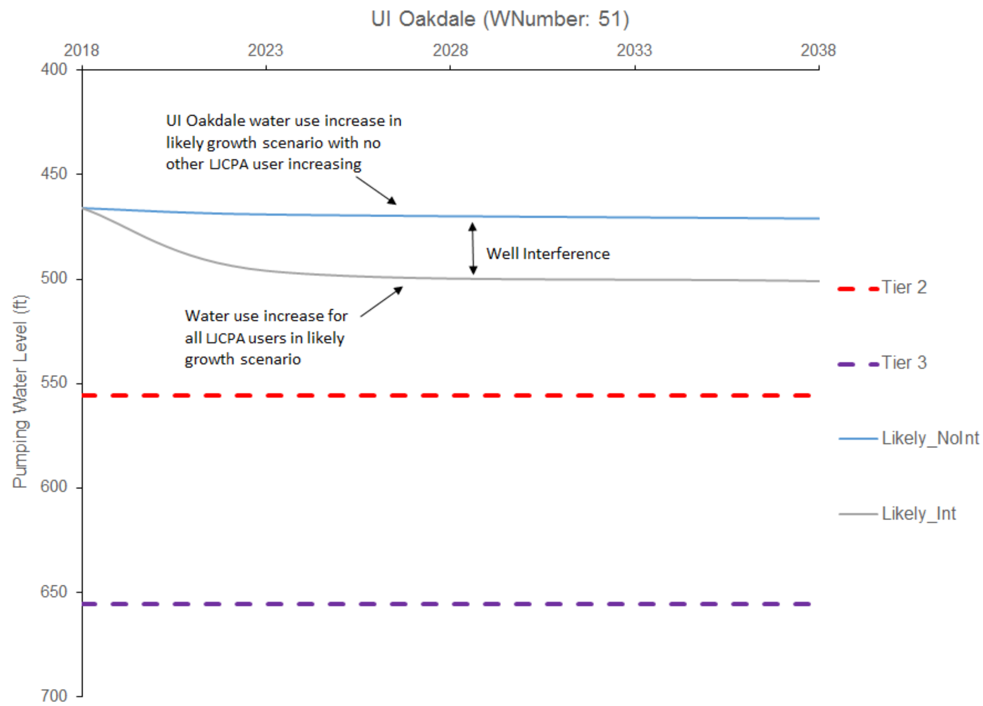


Figure 36: Collective well interference for the UI Oakdale well in the likely growth scenario

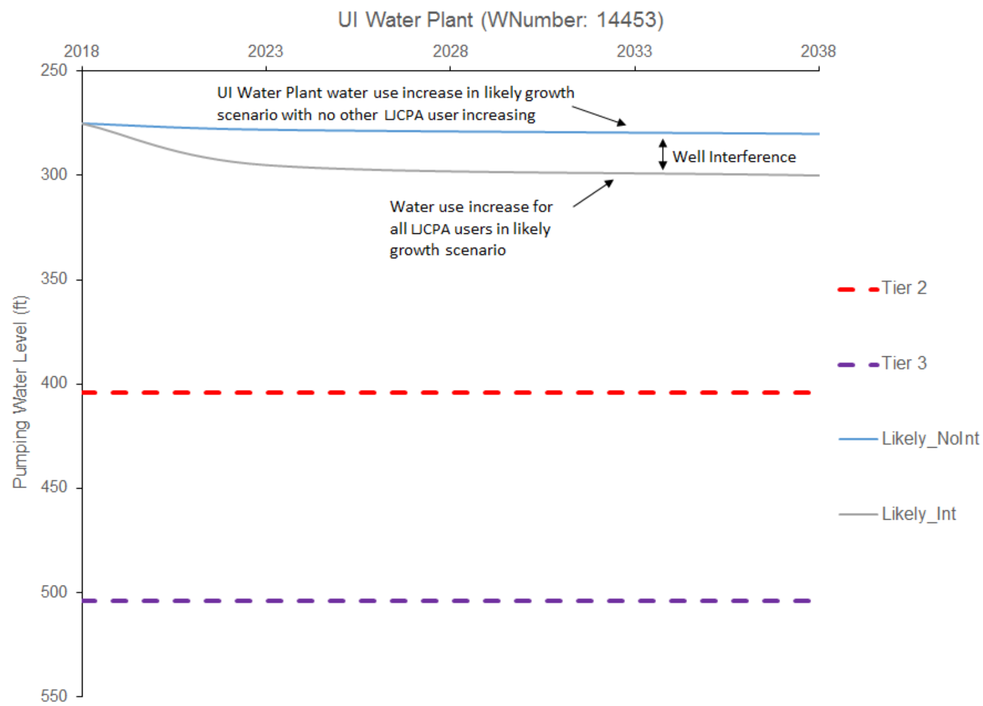


Figure 37: Collective well interference for the UI Water Plant well in the likely growth scenario

Alternative Water Sources

It is important for users in the LJCPA to identify alternative water sources in order to assure a sustainable water supply in the future. Potential alternative water sources that can be explored in Linn and Johnson Counties include the Silurian aquifer, alluvial aquifers, buried sand and gravel aquifers, and surface water. The Silurian bedrock aquifer, which consists primarily of limestone and dolomite, is a major alternative water source. The Silurian aquifer is present throughout the LJCPA. Water production in the Silurian aquifer can be highly variable with production significantly dependent on the presence of large fractures and voids. Isolated buried sand and gravel aquifers can be found in the area. Coralville currently has production wells in a sand and gravel aquifer. The Iowa and Cedar rivers allow for direct surface water intakes as well as alluvial wellfields. Water users also have the option of purchasing water from municipalities with increased water supply capacity. These municipalities include Iowa City in Johnson County and Cedar Rapids in Linn County. Connecting a water line to allow for the possibility of purchasing water can be a feasible option for users within the LJCPA, especially in emergency situations.

Conclusions

The Linn and Johnson County Groundwater Protected Area (LJCPA) was designated by the Iowa legislator in 2014. The Iowa Geological Survey (IGS), which is housed within IIHR Hydroscience and Engineering at the University of Iowa, was hired by all of the CO water users in the LJCPA and the IDNR to investigate and quantify the sustainability of the CO aquifer. The investigation involved: conducting aquifer pump tests, developing a groundwater flow model for the LJCPA, and simulating future water levels. Aquifer pump tests were conducted and evaluated to determine local aquifer hydraulic properties of permeability (transmissivity, hydraulic conductivity) and storativity within the LJPCA. A three-dimensional, local-scale groundwater flow model for the LJCPA was developed and calibrated. The LJCPA model was used to simulate future water levels and evaluate CO aquifer sustainability. Historical static water levels from years 2000 to 2017, historical pumping water levels from years 2014 to 2017, and water usage data from years 2000 to 2017 was provided by the IDNR. The data was used to help calibrate the groundwater flow model. Water users within the LJCPA provided current well management information.

Nine (9) new aquifer pump tests were conducted in CO wells within the LJCPA. Eight conventional pump tests were conducted using both production and observation well(s). One (1) recovery test was also conducted using a production well only (Tiffin #4). The nine (9) new aquifer pump tests provided additional local information in addition to the nine (9) existing recovery tests for the CO aquifer within the LJCPA.

Based on aquifer pump test results, the hydraulic conductivity of the CO aquifer within the LJCPA was found to range from 1 foot/day at both Tiffin #4 and Coralville #1 to 20 feet/day at Marion #5 and #7. Aquifer storativity, determined from the conventional pump tests, ranged from 3.6 X 10^{-7} in the Iowa City area to 8 X 10^{-5} at North Liberty #7. A zone of low permeability was observed across southern Johnson County, and includes the wellfields of Iowa City, Coralville, and Tiffin. The low permeability zone has more drawdown and lower pumping water levels compared to higher permeability zones found in northern Johnson County (North Liberty) and Linn County.

Calibration results indicate the LJCPA model was able to adequately simulate the aquifer's response to pumping stress during pump tests as well as trends in historic static water levels. The average difference between observed and simulated drawdowns from the pump test observation wells was 0.3 feet and ranged from 0 to 0.8 feet. Model goodness-of-fit was "Acceptable" with no presence of outliers or model bias when simulating yearly static water levels. The model had a correlation coefficient of 0.91 and an NSE of 0.79. The absolute residual mean and RMSE between observed and simulated water levels were 13.9 feet and 16.6 feet, respectively.

Based on the calibrated groundwater flow model, a 30% increase in water use (above 2017 values) by all the users in the LJCPA over a 20 year period (2018-2038) would represent maximum sustainable water use. Not all of the LJCPA water users have the ability to obtain or desire a 30% water use increase, which could allow growing communities or industries to eventually increase individual water uses above the 30% threshold. Limiting annual water use to no more than 30% above 2017 usage for a 5-year water use permit protects all of the water users within the LJCPA. Observed PWLs can continue to be monitored and compared to simulated results, and can be used to further evaluate future allocations. If PWL trends begin to decline faster than predicted by the model, the Tier 2 and Tier 3 regulatory limits can be implemented to protect the aquifer.

Using the calibrated groundwater flow model, allocated water usage for the CO aquifer was evaluated in the LJCPA. All of the pumping water levels in CO wells in the LJCPA exceed Tier 2 levels with ADM, Iowa City JW-1, Coralville, and Tiffin exceeding Tier 3 levels. Additional production wells were needed at ADM, Ingredion, and Coralville to allow the water users to withdraw full allocations. Substantial regional well interference in both Johnson and Linn Counties was observed when all LJCPA users withdraw full allocations. Well interference was a significant component of additional drawdown observed in the fully allocated model simulation, indicating the importance of the model's ability to account for well interference when predicting future water levels. It may be necessary to scale back some of the allocated water amounts from the CO aquifer for several LJCPA water users during the next five year permit cycle to protect against significant well interferences between users.

Based on conversations with the water users in the LJCPA along with results from the regional incremental increase modeling simulations, a most likely water use scenario was developed and evaluated with the groundwater flow model. New wells were assumed for ADM, Ingredion, and Coralville. Instantaneous pumping rates were also assumed to be reduced to 500 gpm in each of the three Coralville wells. The North Liberty 20 year water use, which included an incremental increase (500 MGY in 2018 to 750 MGY in 2038), was based on information provided by Fox Engineering. Collective well interference was observed in all LJCPA wells and was accounted for in the model. Based on the model simulations, none of the PWLs in the LJCPA wells exceeded Tier 2 levels in the most likely water use scenario.

An additional model simulation was conducted for a most likely water use scenario where water use for both North Liberty and Tiffin was increased by 50%. Based on results of the model simulation, Tiffin #4 PWLs dropped below Tier 2 levels and North Liberty's PWLs remained above Tier 2. Tiffin would be able to remain in compliance with new Tier 2 and 3 regulations in this scenario by adding a second CO production well and balancing pumping rates between the two wells.

Model simulations were also run to evaluate using North Liberty #7 as a fourth production well instead of an ASR well. North Liberty #7 was found to gain about five (5) feet in additional drawdown when used as a production well. The main benefit of North Liberty using four production wells was the gain in available drawdown projected in North Liberty's other wells. North Liberty #5, #6, and #8 gained 10, 20, and 15 feet of available drawdown, respectively. The gain in available drawdown was primarily the result of spreading out the pumping stress using four (4) production wells versus three (3), as the average daily usage and instantaneous pumping rates could be reduced at each North Liberty CO well. Well interference effects between wells was also found to be reduced in the North Liberty wellfield when using 4 production wells.

Groundwater modeling results indicate the CO aquifer can remain a reliable water source for LJCPA users in the coming decades. However, it is important for users in the LJCPA to identify and develop alternative water sources in order to assure a sustainable future water supply. Potential alternative water sources that can be explored in Linn and Johnson Counties include the Silurian aquifer, alluvial aquifers, buried sand and gravel aquifers, surface water, and purchasing water from municipalities with increased water supply capacity. These municipalities include Iowa City in Johnson County and Cedar Rapids in Linn County.

References

Gannon, J.M., Langel, R.J., Bunker B., & Howes, M. 2009. *Groundwater Availability Mdeling of the Cambrian-Ordovician aquifer in Iowa.* Iowa Geological and Water Survey: Water Resources Investigation Report No. 2A. 160 pages.

Ritter, A., & Muñoz-Carpena, R. 2013. *Performance evaluation of hydrological models: Statistical significance for reducing subjectivity in goodness-of-fit assessments*. Journal of Hydrology 480: 33-45.

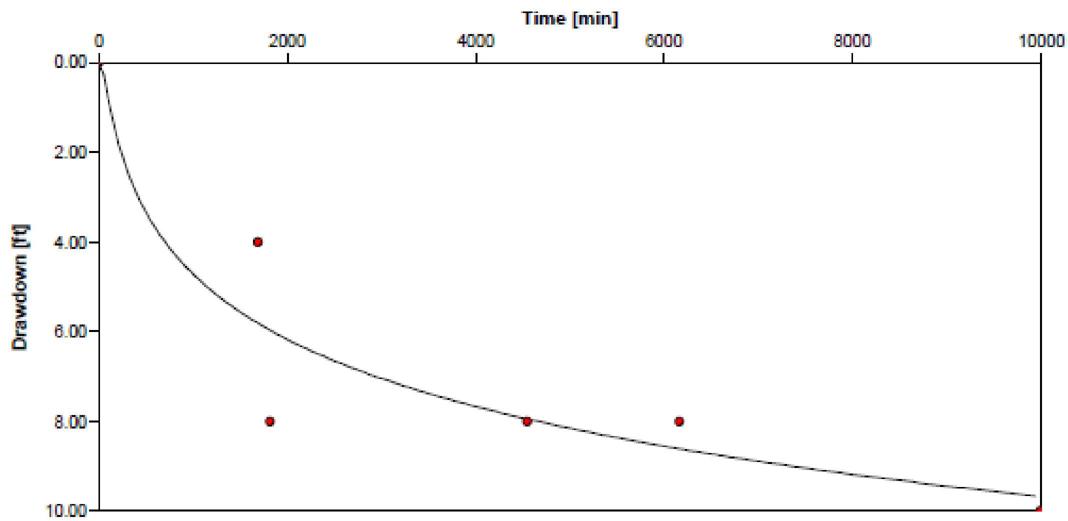
Waterloo Hydrogeological. 2017. Visual MODFLOW Pro, 3D Ground-Water Flow and Contaminant Transport Modeling, Version 4.6.0.168.

Appendix A: Pump Tests

Figure AA-1: Iowa City JW-1/UI Water Plant Pump Test

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: Iowa City JW-1/UI Water Plant LJCPA
	Number:
	Client: Iowa City, UI

Location: Iowa City	Pumping Test: IC JW-1/UI Water Plant	Pumping Well: IC JW-1
Test Conducted by: City of Iowa City, UI		Test Date: 12/11/2017
Analysis Performed by: IGS		Analysis Date: 12/18/2017
Aquifer Thickness: 620.00 ft	Discharge: Rate 317.7 [U.S. gpm]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
UI Water Plant	2.20×10^{3}	3.54×10^{0}	3.61×10^{-7}	34872.0	

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data Page 1 of 1

Project: Iowa City JW-1/UI Water Plant LJCPA

Number:

Client: Iowa City, UI

Location: Iowa City	Pumping Test: IC JW-1/UI Water Plant	Pumping Well: IC JW-1
Test Conducted by: City of Iowa City, UI	Test Date: 12/11/2017	Discharge: Rate 317.7 [U.S. gpm]
Observation Well: UI Water Plant	Static Water Level [ft]: 259.00	Radial Distance to PW [ft]: 34872

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	259.00	0.00
2	1690	263.00	4.00
3	1820	267.00	8.00
4	4550	267.00	8.00
5	6160	267.00	8.00
6	9995	269.00	10.00

IOWA GEOLOGICAL SURVEY

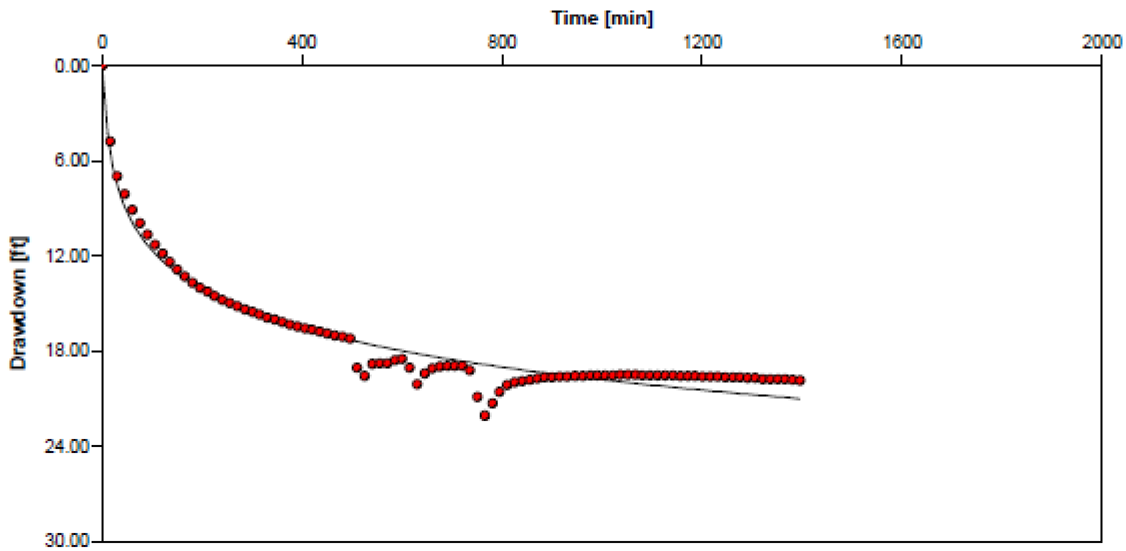
Pumping Test - Discharge Data	Page 1 of 1
Project: Iowa City JW-1/UI Water Plant LJCPA	
Number:	
Client: Iowa City, UI	

Location: Iowa City	Pumping Test: IC JW-1/UI Water Plant	Pumping Well: IC JW-1
Test Conducted by: City of Iowa City, UI	Test Date: 12/11/2017	Discharge: Rate 317.7 [U.S. gpm]
Observation Well: IC JW-1		Radial Distance to PW [ft]: -

	Time [min]	Discharge [U.S. gal/min]
1	0	360.00
2	155	340.00
3	245	338.00
4	380	325.00
5	1375	310.00
6	1525	310.00
7	1825	305.00
8	2964	320.00
9	3265	315.00
10	4490	320.00
11	4705	317.00
12	5735	325.00
13	6130	330.00
14	10015	315.00

Figure AA-2: Ingredion PW-73/PW-54 Pump Test

IOWA GEOLOGICAL SURVEY		Pumping Test Analysis Report
		Project: Ingredion PW-73/PW-54 LJCPA
		Number:
		Client: Ingredion
Location: Linn County	Ingredion PW-73/PW-54	Pumping Well: PW-73
Test Conducted by: Iowa Geological Survey		Test Date: 3/14/2018
Analysis Performed by: Nathan Holt - IGS	Ingredion PW-73 Conventional	Analysis Date: 3/16/2018
Aquifer Thickness: 520.00 ft	Discharge Rate: 599 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
Ingredion PW-54	2.56×10^{3}	4.93×10^{0}	3.22×10^{-5}	700.0	

IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 2
	Project: Ingredion PW-73/PW-54 LJCPA	
	Number:	
	Client: Ingredion	

Location: Linn County	Ingredion PW-73/PW-54	Pumping Well: PW-73
Test Conducted by: Iowa Geological Survey	Test Date: 3/14/2018	Discharge Rate: 599 [U.S. gal/min]
Observation Well: Ingredion PW-54	Static Water Level [ft]: 269.90	Radial Distance to PW [ft]: 700

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	269.90	0.00
2	1	269.916	0.016
3	16	274.716	4.816
4	31	276.894	6.994
5	46	278.027	8.127
6	61	279.006	9.106
7	76	279.841	9.941
8	91	280.59	10.69
9	106	281.232	11.332
10	121	281.795	11.895
11	136	282.291	12.391
12	151	282.767	12.867
13	166	283.20	13.30
14	181	283.622	13.722
15	196	283.921	14.021
16	211	284.195	14.295
17	226	284.47	14.57
18	241	284.697	14.797
19	256	284.919	15.019
20	271	285.111	15.211
21	286	285.297	15.397
22	301	285.478	15.578
23	316	285.637	15.737
24	331	285.803	15.903
25	346	285.955	16.055
26	361	286.094	16.194
27	376	286.243	16.343
28	391	286.36	16.46
29	406	286.491	16.591
30	421	286.592	16.692
31	436	286.705	16.805
32	451	286.823	16.923
33	466	286.928	17.028
34	481	287.031	17.131
35	496	287.157	17.257
36	511	288.981	19.081
37	526	289.506	19.606
38	541	288.739	18.839
39	556	288.703	18.803
40	571	288.702	18.802
41	586	288.485	18.585
42	601	288.403	18.503
43	616	288.99	19.09
44	631	290.003	20.103
45	646	289.358	19.458
46	661	289.031	19.131
47	676	288.908	19.008
48	691	288.871	18.971

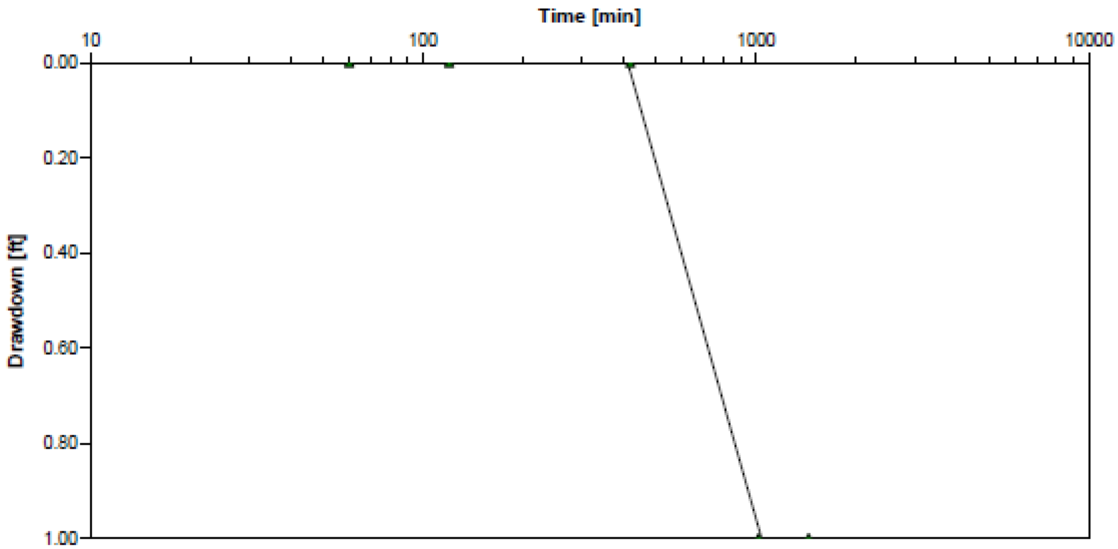
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 2 of 2
	Project: Ingredion PW-73/PW-54 LJCPA	
	Number:	
	Client: Ingredion	

	Time [min]	Water Level [ft]	Drawdown [ft]
49	706	288.879	18.979
50	721	288.85	18.95
51	736	289.144	19.244
52	751	290.825	20.925
53	766	291.979	22.079
54	781	291.217	21.317
55	796	290.48	20.58
56	811	290.053	20.153
57	826	289.89	19.99
58	841	289.806	19.906
59	856	289.725	19.825
60	871	289.663	19.763
61	886	289.596	19.696
62	901	289.573	19.673
63	916	289.527	19.627
64	931	289.521	19.621
65	946	289.515	19.615
66	961	289.487	19.587
67	976	289.475	19.575
68	991	289.445	19.545
69	1006	289.441	19.541
70	1021	289.46	19.56
71	1036	289.436	19.536
72	1051	289.439	19.539
73	1066	289.431	19.531
74	1081	289.448	19.548
75	1096	289.456	19.556
76	1111	289.452	19.552
77	1126	289.453	19.553
78	1141	289.479	19.579
79	1156	289.497	19.597
80	1171	289.492	19.592
81	1186	289.515	19.615
82	1201	289.534	19.634
83	1216	289.527	19.627
84	1231	289.554	19.654
85	1246	289.586	19.686
86	1261	289.599	19.699
87	1276	289.598	19.698
88	1291	289.628	19.728
89	1306	289.635	19.735
90	1321	289.682	19.782
91	1336	289.691	19.791
92	1351	289.719	19.819
93	1366	289.713	19.813
94	1381	289.734	19.834
95	1396	289.766	19.866

Figure AA-3: Marion #4-6/#5 Pump Test

IOWA GEOLOGICAL SURVEY

Pumping Test Analysis Report		
Project: Marion Pump Test		
Number:		
Client:		
Location: Marion, Iowa	Pumping Test: Marion #5 Conventional	Pumping Wells: Marion #4 and #6
Test Conducted by: Andy Smith		Test Date: 3/27/2018
Analysis Performed by: IGS		Analysis Date: 3/29/2018
Aquifer Thickness: 500.00 ft	Rates: 720 gpm (Marion #4) 1544 gpm (Marion #6)	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	
Marion #5	1.02×10^{4}	2.04×10^{1}	6.56×10^{-5}	

IOWA GEOLOGICAL SURVEY	**Pumping Test - Water Level Data** Page 1 of 1
	Project: Marion #4-6/#5 LJCPA
	Number:
	Client:

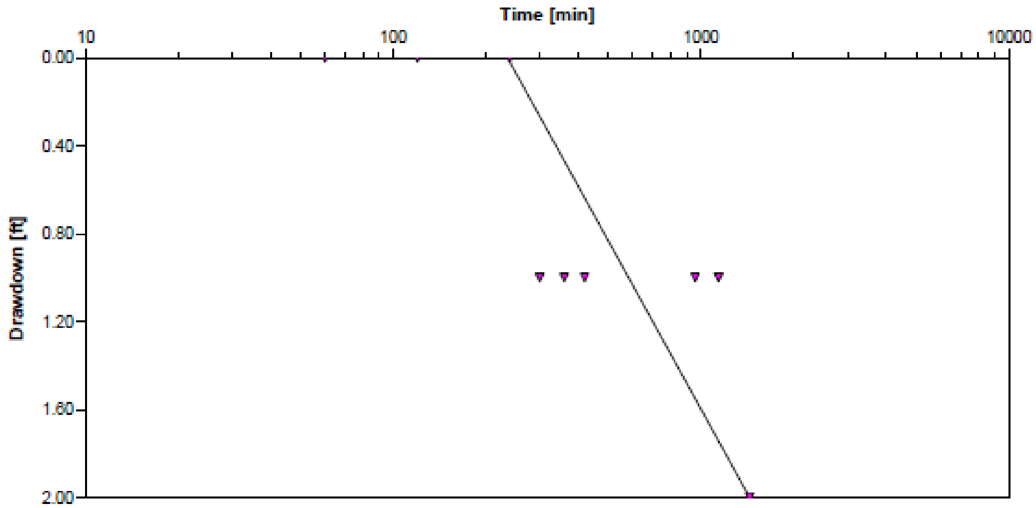
Location: Marion, Iowa	Pumping Test: Marion #4-6/#5	Pumping Wells: Marion #4 and #6
Test Conducted by: Andy Smith	Test Date: 3/27/2018	
Observation Well: Marion #5	Static Water Level [ft]: 398.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	398.00	0.00
2	60	398.00	0.00
3	120	398.00	0.00
4	420	398.00	0.00
5	1020	399.00	1.00
6	1440	399.00	1.00

Figure AA-4: Marion #4-6/#7 Pump Test

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

Location: Marion, Iowa	Pumping Test: Marion #7 Conventional	Pumping Wells: Marion #4 and #6
Test Conducted by: Andy Smith		Test Date: 3/27/2018
Analysis Performed by: IGS		Analysis Date: 3/29/2018
Aquifer Thickness: 500.00 ft	Rates: 720 gpm (Marion #4) 1544 gpm (Marion #6)	



Calculation using COOPER & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	
Marion #7	9.97×10^{3}	1.99×10^{1}	1.45×10^{-5}	

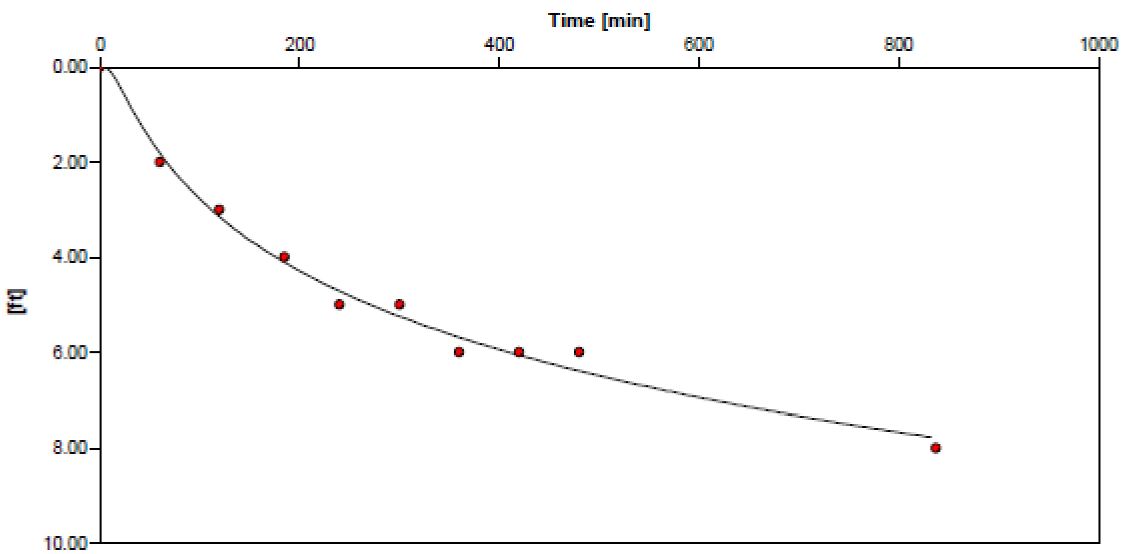
IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 1
	Project: Marion #4-6/#7 LJCPA	
	Number:	
	Client:	

Location: Marion, Iowa	Pumping Test: Marion #4-6/#7	Pumping Wells: Marion #4 and #6
Test Conducted by: Andy Smith	Test Date: 3/27/2018	
Observation Well: Marion #7	Static Water Level [ft]: 423.00	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	423.00	0.00
2	60	423.00	0.00
3	120	423.00	0.00
4	240	423.00	0.00
5	300	424.00	1.00
6	360	424.00	1.00
7	420	424.00	1.00
8	960	424.00	1.00
9	1140	424.00	1.00
10	1440	425.00	2.00

Figure AA-5: North Liberty #5/#6 Pump Test

IOWA GEOLOGICAL SURVEY		**Pumping Test Analysis Report**
		Project: North Liberty #5/#6 LJCPA
		Number:
		Client:
Location: North Liberty, IA	Pumping Test: North Liberty #5/#6	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey		Test Date: 12/8/2017
Analysis Performed by: Nathan Holt	North Liberty LJCPA	Analysis Date: 12/11/2017
Aquifer Thickness: 528.00 ft	Discharge: Rate 885.97 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
NL #6	5.22×10^{3}	9.88×10^{0}	5.89×10^{-5}	2444.0	

Pumping Test Analysis Report	Page 1 of 1
Project: North Liberty #5/#6 LJCPA	
Number:	
Client:	

Location: North Liberty, IA	Pumping Test: North Liberty #5/#6	Pumping Well: NL #5
Test Conducted by: Iowa Geological SurveyTest Date: 12/8/2017		Discharge: Rate 885.97 [U.S. gal
Observation Well: NL #6	Static Water Level [ft]: 441.00	Radial Distance to PW [ft]: 2444

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	441.00	0.00
2	60	443.00	2.00
3	120	444.00	3.00
4	185	445.00	4.00
5	240	446.00	5.00
6	300	446.00	5.00
7	360	447.00	6.00
8	420	447.00	6.00
9	480	447.00	6.00
10	837	449.00	8.00

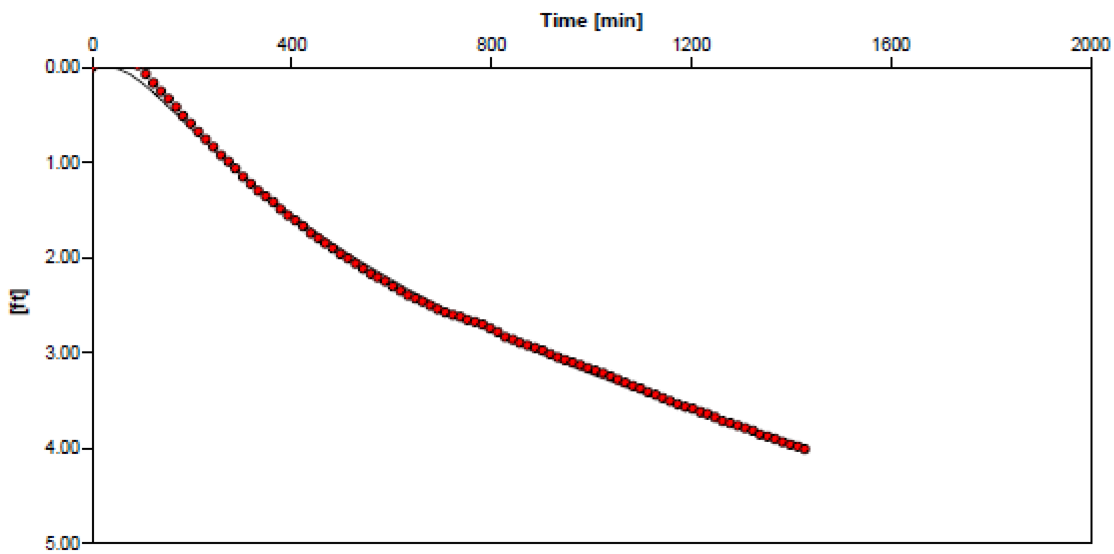
IOWA GEOLOGICAL SURVEY	Pumping Test - Discharge Data	Page 1 of 1
	Project: North Liberty #5/#6 LJCPA	
	Number:	
	Client:	

Location: North Liberty, IA	Pumping Test: North Liberty #5/#6	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey	Test Date: 12/8/2017	Discharge: Rate 885.97 [U.S. gal
Observation Well: NL #5		Radial Distance to PW [ft]: -

	Time [min]	Discharge [U.S. gal/min]
1	0	0.00
2	70	905.00
3	126	899.00
4	190	896.00
5	250	897.00
6	310	889.00
7	375	886.00
8	689	884.00
9	1429	882.00

Figure AA-6: North Liberty #5/#7 Pump Test

Pumping Test Analysis Report		
Project: North Liberty #5/#7 LJCPA		
Number:		
Client:		
Location: North Liberty, IA	Pumping Test: North Liberty #5/#7	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey		Test Date: 12/8/2017
Analysis Performed by: Nathan Holt	North Liberty LJCPA	Analysis Date: 12/11/2017
Aquifer Thickness: 519.00 ft	Discharge: Rate 885.97 [U.S. gal/min]	



Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
NL #7	5.58×10^{3}	1.08×10^{1}	8.24×10^{-5}	5760.0	

IOWA GEOLOGICAL SURVEY

Pumping Test Analysis Report	Page 1 of 2
Project: North Liberty #5/#7 LJCPA	
Number:	
Client:	

Location: North Liberty, IA	Pumping Test: North Liberty #5/#7	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey	Test Date: 12/8/2017	Discharge: Rate 885.97 [U.S. gal
Observation Well: NL #7	Static Water Level [ft]: 388.00	Radial Distance to PW [ft]: 5760

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	388.00	0.00
2	63	387.819	-0.181
3	78	387.899	-0.101
4	93	387.977	-0.023
5	108	388.071	0.071
6	123	388.168	0.168
7	138	388.253	0.253
8	153	388.334	0.334
9	168	388.421	0.421
10	183	388.511	0.511
11	198	388.595	0.595
12	213	388.682	0.682
13	228	388.76	0.76
14	243	388.842	0.842
15	258	388.924	0.924
16	273	388.993	0.993
17	288	389.068	1.068
18	303	389.155	1.155
19	318	389.224	1.224
20	333	389.297	1.297
21	348	389.361	1.361
22	363	389.423	1.423
23	378	389.495	1.495
24	393	389.558	1.558
25	408	389.614	1.614
26	423	389.675	1.675
27	438	389.746	1.746
28	453	389.801	1.801
29	468	389.856	1.856
30	483	389.907	1.907
31	498	389.966	1.966
32	513	390.012	2.012
33	528	390.069	2.069
34	543	390.121	2.121
35	558	390.171	2.171
36	573	390.213	2.213
37	588	390.256	2.256
38	603	390.304	2.304
39	618	390.355	2.355
40	633	390.40	2.40
41	648	390.434	2.434
42	663	390.468	2.468
43	678	390.505	2.505
44	693	390.545	2.545
45	708	390.579	2.579
46	723	390.605	2.605
47	738	390.628	2.628
48	753	390.658	2.658

IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 2 of 2
	Project: North Liberty #5/#7 LJCPA	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
49	768	390.681	2.681
50	783	390.705	2.705
51	798	390.746	2.746
52	813	390.784	2.784
53	828	390.839	2.839
54	843	390.864	2.864
55	858	390.901	2.901
56	873	390.925	2.925
57	888	390.952	2.952
58	903	390.981	2.981
59	918	391.019	3.019
60	933	391.055	3.055
61	948	391.079	3.079
62	963	391.106	3.106
63	978	391.131	3.131
64	993	391.164	3.164
65	1008	391.192	3.192
66	1023	391.222	3.222
67	1038	391.255	3.255
68	1053	391.286	3.286
69	1068	391.318	3.318
70	1083	391.351	3.351
71	1098	391.379	3.379
72	1113	391.417	3.417
73	1128	391.448	3.448
74	1143	391.483	3.483
75	1158	391.513	3.513
76	1173	391.545	3.545
77	1188	391.574	3.574
78	1203	391.593	3.593
79	1218	391.624	3.624
80	1233	391.649	3.649
81	1248	391.683	3.683
82	1263	391.717	3.717
83	1278	391.737	3.737
84	1293	391.766	3.766
85	1308	391.791	3.791
86	1323	391.821	3.821
87	1338	391.858	3.858
88	1353	391.88	3.88
89	1368	391.909	3.909
90	1383	391.938	3.938
91	1398	391.966	3.966
92	1413	391.985	3.985
93	1428	392.016	4.016

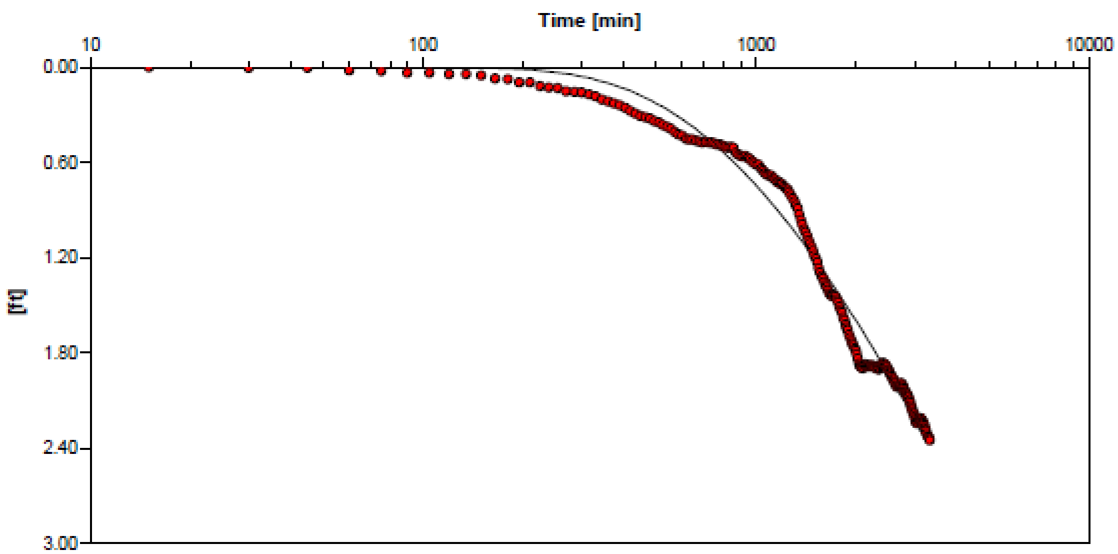
IOWA GEOLOGICAL SURVEY	Pumping Test - Discharge Data	Page 1 of 1
	Project: North Liberty #5/#7 LJCPA	
	Number:	
	Client:	

Location: North Liberty, IA	Pumping Test: North Liberty #5/#7	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey	Test Date: 12/8/2017	Discharge: Rate 885.97 [U.S. gpm]
Observation Well: NL #5		Radial Distance to PW [ft]: -

	Time [min]	Discharge [U.S. gal/min]
1	0	0.00
2	70	905.00
3	126	899.00
4	190	896.00
5	250	897.00
6	310	889.00
7	375	886.00
8	689	884.00
9	1429	882.00

Figure AA-7: North Liberty #5/#8 Pump Test

	Pumping Test Analysis Report	
	Project: North Liberty #5/#8 LJCPA	
	Number:	
	Client:	
Location: North Liberty, IA	Pumping Test: North Liberty #5/#8	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey		Test Date: 12/22/2017
Analysis Performed by: Nathan Holt	North Liberty LJCPA	Analysis Date: 12/27/2017
Aquifer Thickness: 535.00 ft	Discharge: Rate 890 [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]
NL #8	6.60×10^{3}	1.23×10^{1}	5.35×10^{-4}	8.14×10^{-1}	4965.0

IOWA GEOLOGICAL SURVEY

Pumping Test Analysis Report

Project: North Liberty #5/#8 LJCPA

Number:

Client:

Location: North Liberty, IA | Pumping Test: North Liberty #5/#8 | Pumping Well: NL #5

Test Conducted by: Iowa Geological Survey | Test Date: 12/22/2017 | Discharge: Rate 890 [U.S. gpm]

Observation Well: NL #8 | Static Water Level [ft]: 400.81 | Radial Distance to PW [ft]: 4965

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0	400.8068	-0.0032
2	15	400.8108	0.0008
3	30	400.8158	0.0058
4	45	400.8149	0.0049
5	60	400.8304	0.0204
6	75	400.8346	0.0246
7	90	400.8466	0.0366
8	105	400.8462	0.0362
9	120	400.8542	0.0442
10	135	400.853	0.043
11	150	400.8608	0.0508
12	165	400.8801	0.0701
13	180	400.8865	0.0765
14	195	400.9054	0.0954
15	210	400.904	0.094
16	225	400.9289	0.1189
17	240	400.937	0.127
18	255	400.9426	0.1326
19	270	400.9624	0.1524
20	285	400.9679	0.1579
21	300	400.9719	0.1619
22	315	400.9823	0.1723
23	330	400.994	0.184
24	345	401.0142	0.2042
25	360	401.0258	0.2158
26	375	401.0396	0.2296
27	390	401.0503	0.2403
28	405	401.067	0.257
29	420	401.0872	0.2772
30	435	401.1032	0.2932
31	450	401.119	0.309
32	465	401.1264	0.3164
33	480	401.1348	0.3248
34	495	401.1491	0.3391
35	510	401.157	0.347
36	525	401.1743	0.3643
37	540	401.1872	0.3772
38	555	401.1962	0.3862
39	570	401.2195	0.4095
40	585	401.234	0.424
41	600	401.2425	0.4325
42	615	401.2616	0.4516
43	630	401.2668	0.4568
44	645	401.2657	0.4557
45	660	401.274	0.464
46	675	401.2798	0.4698
47	690	401.2854	0.4754
48	705	401.2823	0.4723

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data

Project: North Liberty #5/#8 LJCPA

Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
49	720	401.2858	0.4758
50	735	401.2876	0.4776
51	750	401.2903	0.4803
52	765	401.2975	0.4875
53	780	401.30	0.49
54	795	401.308	0.498
55	810	401.312	0.502
56	825	401.3191	0.5091
57	840	401.3135	0.5035
58	855	401.3196	0.5096
59	870	401.3494	0.5394
60	885	401.364	0.554
61	900	401.369	0.559
62	915	401.3725	0.5625
63	930	401.3684	0.5584
64	945	401.38	0.57
65	960	401.388	0.578
66	975	401.4059	0.5959
67	990	401.4137	0.6037
68	1005	401.4242	0.6142
69	1020	401.4275	0.6175
70	1035	401.4487	0.6387
71	1050	401.4621	0.6521
72	1065	401.4782	0.6682
73	1080	401.4864	0.6764
74	1095	401.4931	0.6831
75	1110	401.4937	0.6837
76	1125	401.5087	0.6987
77	1140	401.5164	0.7064
78	1155	401.5324	0.7224
79	1170	401.5355	0.7255
80	1185	401.5454	0.7354
81	1200	401.5471	0.7371
82	1215	401.5607	0.7507
83	1230	401.5756	0.7656
84	1245	401.5818	0.7718
85	1260	401.5982	0.7882
86	1275	401.6178	0.8078
87	1290	401.6376	0.8276
88	1305	401.6575	0.8475
89	1320	401.6814	0.8714
90	1335	401.7028	0.8928
91	1350	401.7369	0.9269
92	1365	401.7737	0.9637
93	1380	401.8032	0.9932
94	1395	401.8336	1.0236
95	1410	401.8498	1.0398
96	1425	401.8758	1.0658
97	1440	401.9019	1.0919
98	1455	401.9207	1.1107
99	1470	401.9456	1.1356
100	1485	401.9689	1.1589
101	1500	401.998	1.188

Project: North Liberty #5/#8 LJCPA

Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
102	1515	402.0162	1.2062
103	1530	402.0438	1.2338
104	1545	402.0794	1.2694
105	1560	402.1052	1.2952
106	1575	402.1305	1.3205
107	1590	402.1437	1.3337
108	1605	402.1649	1.3549
109	1620	402.185	1.375
110	1635	402.1972	1.3872
111	1650	402.2184	1.4084
112	1665	402.2378	1.4278
113	1680	402.2461	1.4361
114	1695	402.2539	1.4439
115	1710	402.2472	1.4372
116	1725	402.2556	1.4456
117	1740	402.2599	1.4499
118	1755	402.278	1.468
119	1770	402.2946	1.4846
120	1785	402.322	1.512
121	1800	402.3426	1.5326
122	1815	402.3582	1.5482
123	1830	402.3887	1.5787
124	1845	402.4078	1.5978
125	1860	402.4332	1.6232
126	1875	402.4549	1.6449
127	1890	402.4693	1.6593
128	1905	402.4995	1.6895
129	1920	402.518	1.708
130	1935	402.537	1.727
131	1950	402.5544	1.7444
132	1965	402.5663	1.7563
133	1980	402.5862	1.7762
134	1995	402.5983	1.7883
135	2010	402.6229	1.8129
136	2025	402.6507	1.8407
137	2040	402.6822	1.8722
138	2055	402.6935	1.8835
139	2070	402.7024	1.8924
140	2085	402.7054	1.8954
141	2100	402.7086	1.8986
142	2115	402.6935	1.8835
143	2130	402.6878	1.8778
144	2145	402.6973	1.8873
145	2160	402.6999	1.8899
146	2175	402.699	1.889
147	2190	402.6967	1.8867
148	2205	402.6952	1.8852
149	2220	402.6951	1.8851
150	2235	402.6949	1.8849
151	2250	402.70	1.89
152	2265	402.6981	1.8881
153	2280	402.7018	1.8918
154	2295	402.7058	1.8958

Project: North Liberty #5/#8 LJCPA

Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
155	2310	402.7116	1.9016
156	2325	402.7079	1.8979
157	2340	402.718	1.908
158	2355	402.711	1.901
159	2370	402.6994	1.8894
160	2385	402.6858	1.8758
161	2400	402.6781	1.8681
162	2415	402.6803	1.8703
163	2430	402.6809	1.8709
164	2445	402.6856	1.8756
165	2460	402.6946	1.8846
166	2475	402.7032	1.8932
167	2490	402.7174	1.9074
168	2505	402.7229	1.9129
169	2520	402.7336	1.9236
170	2535	402.7445	1.9345
171	2550	402.7589	1.9489
172	2565	402.7628	1.9528
173	2580	402.7784	1.9684
174	2595	402.7827	1.9727
175	2610	402.7989	1.9889
176	2625	402.8062	1.9962
177	2640	402.8208	2.0108
178	2655	402.8266	2.0166
179	2670	402.8254	2.0154
180	2685	402.8248	2.0148
181	2700	402.826	2.016
182	2715	402.8188	2.0088
183	2730	402.8054	1.9954
184	2745	402.8044	1.9944
185	2760	402.816	2.006
186	2775	402.8311	2.0211
187	2790	402.8384	2.0284
188	2805	402.8522	2.0422
189	2820	402.8611	2.0511
190	2835	402.8732	2.0632
191	2850	402.8745	2.0645
192	2865	402.884	2.074
193	2880	402.8933	2.0833
194	2895	402.9104	2.1004
195	2910	402.9248	2.1148
196	2925	402.9458	2.1358
197	2940	402.9572	2.1472
198	2955	402.971	2.161
199	2970	402.9872	2.1772
200	2985	402.9992	2.1892
201	3000	403.0132	2.2032
202	3015	403.0284	2.2184
203	3030	403.0455	2.2355
204	3045	403.0537	2.2437
205	3060	403.0447	2.2347
206	3075	403.0341	2.2241
207	3090	403.0306	2.2206

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data

Project: North Liberty #5/#8 LJCPA

Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
208	3105	403.0285	2.2185
209	3120	403.0273	2.2173
210	3135	403.0306	2.2206
211	3150	403.0284	2.2184
212	3165	403.0426	2.2326
213	3180	403.046	2.236
214	3195	403.0552	2.2452
215	3210	403.0669	2.2569
216	3225	403.0812	2.2712
217	3240	403.0955	2.2855
218	3255	403.1026	2.2926
219	3270	403.1239	2.3139
220	3285	403.1366	2.3266
221	3300	403.1438	2.3338
222	3315	403.1514	2.3414
223	3330	403.1614	2.3514

IOWA GEOLOGICAL SURVEY	Pumping Test - Discharge Data	Page 1 of 1
	Project: North Liberty #5/#8 LJCPA	
	Number:	
	Client:	

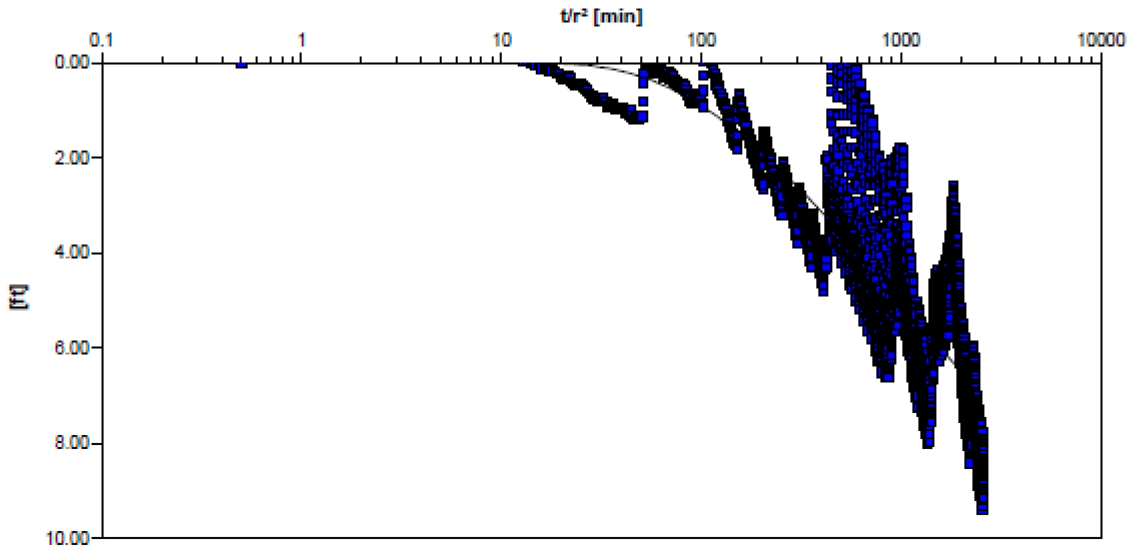
Location: North Liberty, IA	Pumping Test: North Liberty #5/#8	Pumping Well: NL #5
Test Conducted by: Iowa Geological Survey	Test Date: 12/22/2017	Discharge: Rate 890 [U.S. gpm]
Observation Well: NL #5		Radial Distance to PW [ft]: -

	Time [min]	Discharge [U.S. gal/min]
1	0	0.00
2	3330	890.00

Figure AA-8: North Liberty #8/#5 Pump Test

IOWA GEOLOGICAL SURVEY	**Pumping Test Analysis Report** Project: North Liberty #8/#5 LJCPA Number: Client:

Location: North Liberty, IA	Pumping Test: North Liberty #8/#5	Pumping Well: NL #8
Test Conducted by: Fox Engineering		Test Date: 4/24/2017
Analysis Performed by: Mike Gannon, IGS	North Liberty #8	Analysis Date: 2/8/2018
Aquifer Thickness: 535.00 ft	Discharge Rate: 1200 [U.S. gal/min]	



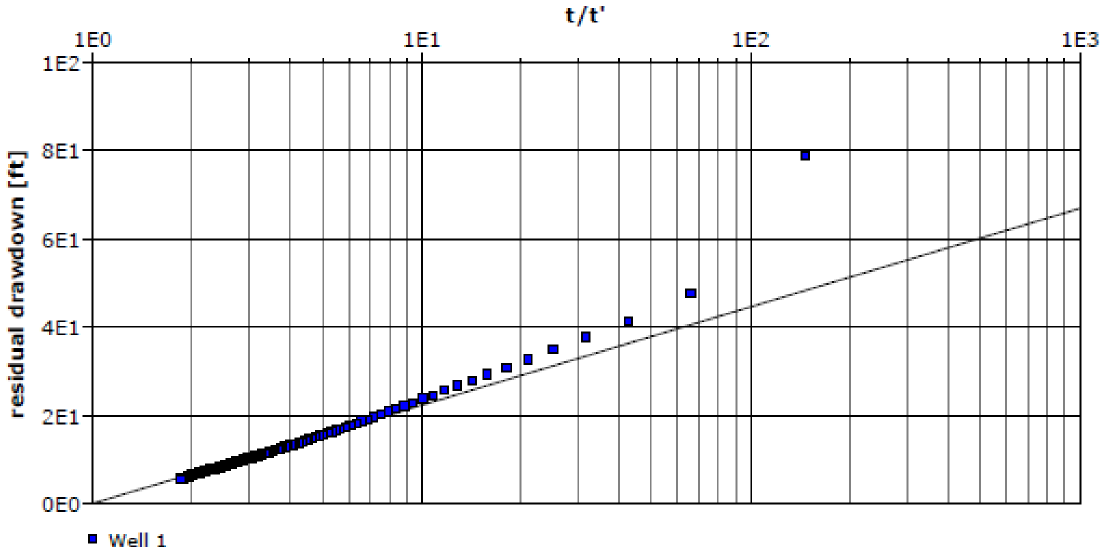
Calculation using Theis

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Storage coefficient	Radial Distance to PW [ft]	
NL #5	8.04×10^{3}	1.50×10^{1}	6.06×10^{-5}	4965.0	

Figure AA-9: Tiffin #4 Pump Test

IOWA GEOLOGICAL SURVEY	Pumping Test Analysis Report
	Project: Tiffin #4 LJCPA
	Number:
	Client:

Location: Tiffin, Iowa	Pumping Test: Tiffin #4 Recovery	Pumping Well: Tiffin #4
Test Conducted by: IGS		Test Date: 10/24/2017
Analysis Performed by: IGS		Analysis Date: 10/25/2017
Aquifer Thickness: 630.00 ft	Discharge: Rate 385 [U.S. gal/min]	



Calculation using THEIS & JACOB

Observation Well	Transmissivity [ft²/d]	Hydraulic Conductivity [ft/d]	Radial Distance to PW [ft]	
Tiffin #4	6.09×10^{2}	9.67×10^{-1}	0.5	

IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 1 of 3
	Project: Tiffin #4 LJCPA	
	Number:	
	Client:	
Location: Tiffin, Iowa	Pumping Test: Tiffin #4 Recovery	Pumping Well: Tiffin #4
Test Conducted by:	Test Date: 10/24/2017	Discharge: Rate 385 [U.S. gal/min]
Observation Well: Tiffin #4	Static Water Level [ft]: 285.90	Radial Distance to PW [ft]: -

	Time [min]	Water Level [ft]	Drawdown [ft]
1	585	364.881	78.981
2	590	333.61	47.71
3	595	327.391	41.491
4	600	323.732	37.832
5	605	320.98	35.08
6	610	318.757	32.857
7	615	316.90	31.00
8	620	315.308	29.408
9	625	313.922	28.022
10	630	312.699	26.799
11	635	311.601	25.701
12	640	310.609	24.709
13	645	309.71	23.81
14	650	308.895	22.995
15	655	308.14	22.24
16	660	307.447	21.547
17	665	306.805	20.905
18	670	306.209	20.309
19	675	305.656	19.756
20	680	305.136	19.236
21	685	304.654	18.754
22	690	304.205	18.305
23	695	303.775	17.875
24	700	303.378	17.478
25	705	302.999	17.099
26	710	302.638	16.738
27	715	302.295	16.395
28	720	301.97	16.07
29	725	301.662	15.762
30	730	301.37	15.47
31	735	301.08	15.18
32	740	300.809	14.909
33	745	300.548	14.648
34	750	300.295	14.395
35	755	300.057	14.157
36	760	299.831	13.931
37	765	299.613	13.713
38	770	299.397	13.497
39	775	299.191	13.291
40	780	298.993	13.093
41	785	298.806	12.906
42	790	298.625	12.725
43	795	298.448	12.548
44	800	298.276	12.376
45	805	298.107	12.207
46	810	297.95	12.05
47	815	297.793	11.893
48	820	297.642	11.742
49	825	297.493	11.593
50	830	297.355	11.455
51	835	297.219	11.319
52	840	297.078	11.178
53	845	296.957	11.057

IOWA GEOLOGICAL SURVEY

Pumping Test - Water Level Data

Project: Tiffin #4 LJCPA

Number:

Client:

	Time [min]	Water Level [ft]	Drawdown [ft]
54	850	296.829	10.929
55	855	296.704	10.804
56	860	296.594	10.694
57	865	296.473	10.573
58	870	296.359	10.459
59	875	296.244	10.344
60	880	296.136	10.236
61	885	296.032	10.132
62	890	295.924	10.024
63	895	295.822	9.922
64	900	295.723	9.823
65	905	295.625	9.725
66	910	295.536	9.636
67	915	295.443	9.543
68	920	295.35	9.45
69	925	295.256	9.356
70	930	295.174	9.274
71	935	295.091	9.191
72	940	295.014	9.114
73	945	294.94	9.04
74	950	294.854	8.954
75	955	294.778	8.878
76	960	294.706	8.806
77	965	294.629	8.729
78	970	294.553	8.653
79	975	294.478	8.578
80	980	294.41	8.51
81	985	294.334	8.434
82	990	294.262	8.362
83	995	294.205	8.305
84	1000	294.136	8.236
85	1005	294.076	8.176
86	1010	294.011	8.111
87	1015	293.946	8.046
88	1020	293.882	7.982
89	1025	293.824	7.924
90	1030	293.762	7.862
91	1035	293.707	7.807
92	1040	293.65	7.75
93	1045	293.592	7.692
94	1050	293.53	7.63
95	1055	293.482	7.582
96	1060	293.423	7.523
97	1065	293.371	7.471
98	1070	293.319	7.419
99	1075	293.27	7.37
100	1080	293.212	7.312
101	1085	293.153	7.253
102	1090	293.107	7.207
103	1095	293.058	7.158
104	1100	293.008	7.108
105	1105	292.956	7.056
106	1110	292.911	7.011
107	1115	292.863	6.963
108	1120	292.819	6.919
109	1125	292.775	6.875
110	1130	292.729	6.829
111	1135	292.682	6.782

IOWA GEOLOGICAL SURVEY	Pumping Test - Water Level Data	Page 3 of 3
	Project: Tiffin #4 LJCPA	
	Number:	
	Client:	

	Time [min]	Water Level [ft]	Drawdown [ft]
112	1140	292.634	6.734
113	1145	292.593	6.693
114	1150	292.544	6.644
115	1155	292.507	6.607
116	1160	292.459	6.559
117	1165	292.422	6.522
118	1170	292.378	6.478
119	1175	292.336	6.436
120	1180	292.289	6.389
121	1185	292.25	6.35
122	1190	292.214	6.314
123	1195	292.174	6.274
124	1200	292.139	6.239
125	1205	292.096	6.196
126	1210	292.056	6.156
127	1215	292.018	6.118
128	1220	291.983	6.083
129	1225	291.943	6.043
130	1230	291.904	6.004
131	1235	291.871	5.971
132	1240	291.828	5.928
133	1245	291.798	5.898
134	1250	291.751	5.851
135	1255	291.716	5.816
136	1260	291.687	5.787

Appendix B: Calibration

Time Series Static Water Level Calibration Graphs

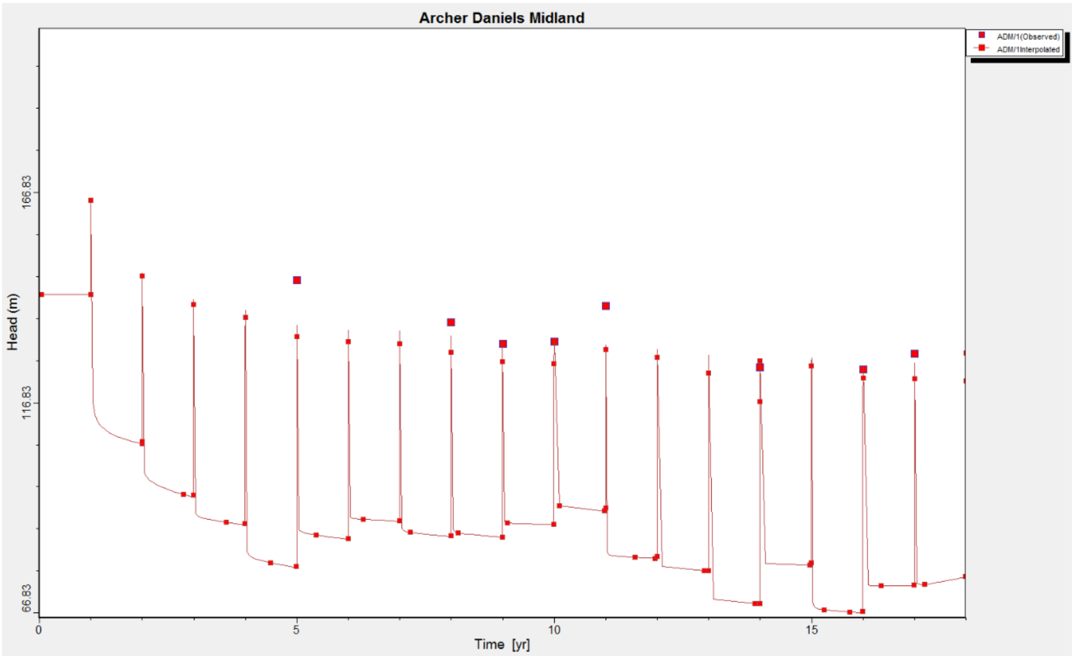


Figure AB-1: Static water level time series for Archer Daniels Midland (WNumber: 23940)

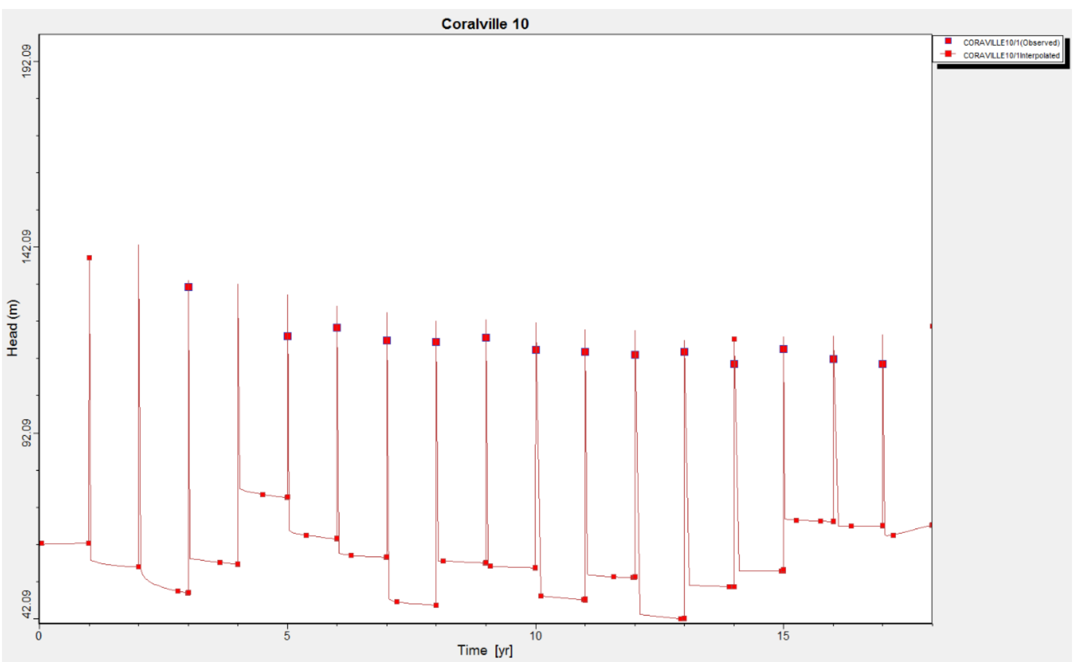


Figure AB-2: Static water level time series for Coralville #10 (WNumber: 31377)

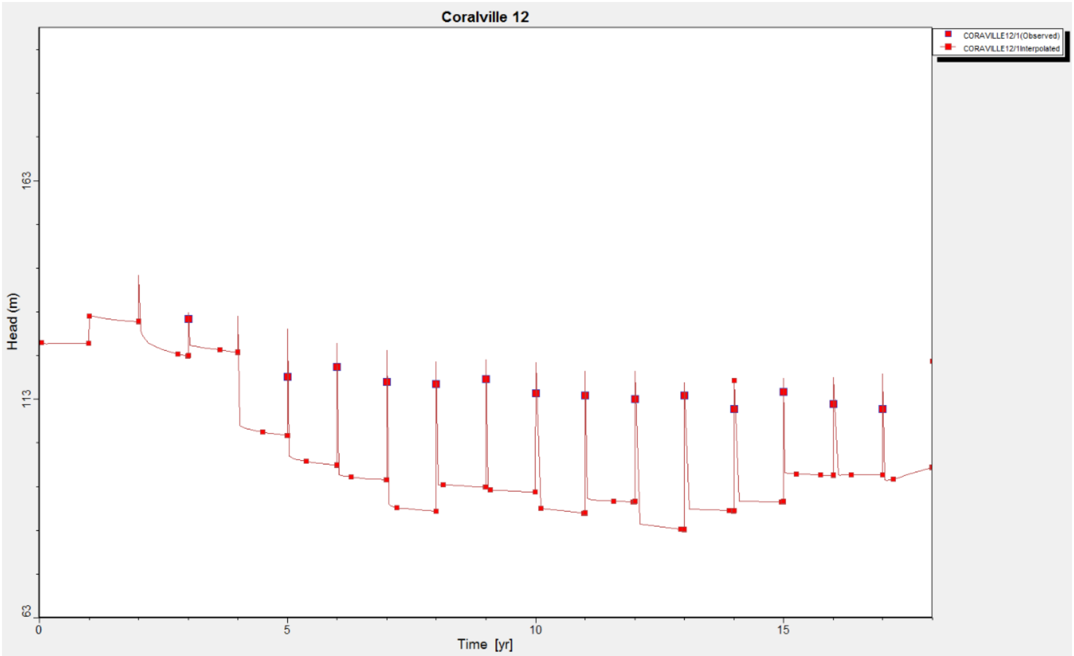


Figure AB-3: Static water level time series for Coralville #12 (WNumber: 61572)

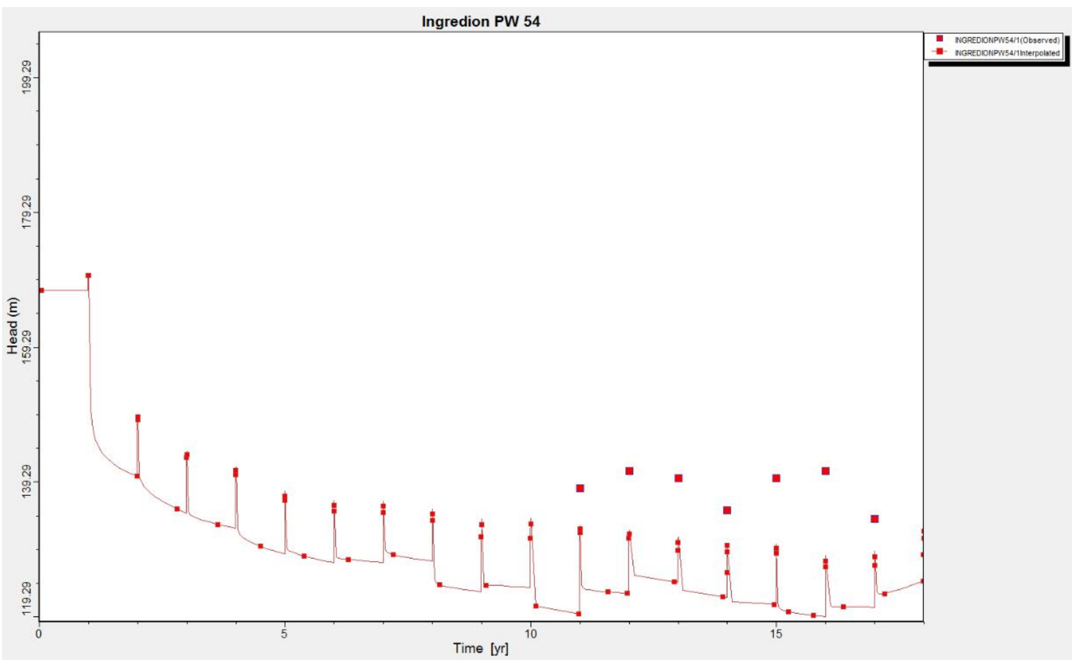


Figure AB-4: Static water level time series for Ingredion PW-54 (WNumber: 1499)

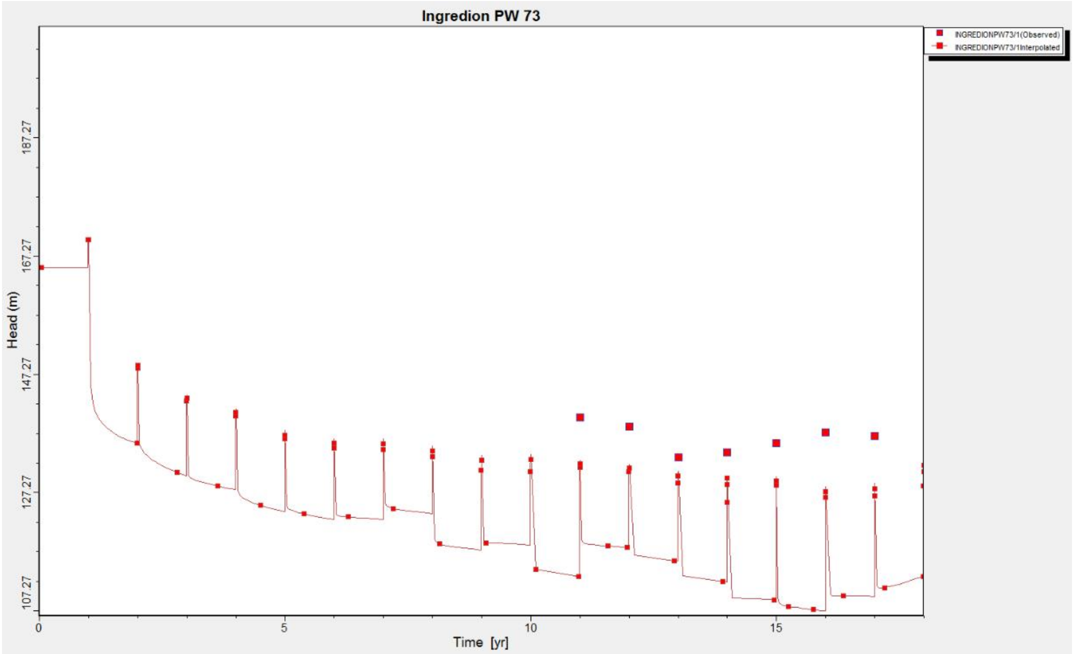


Figure AB-5: Static water level time series for Ingredion PW-73 (WNumber: 17180)

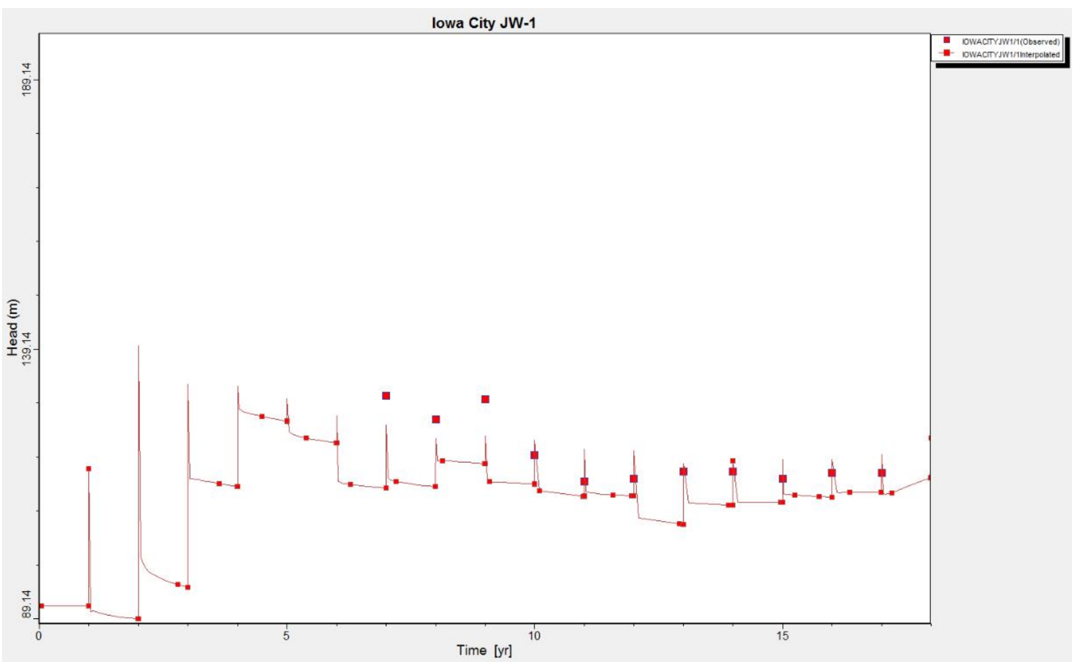


Figure AB-6: Static water level time series for Iowa City JW-1 (WNumber: 37000)

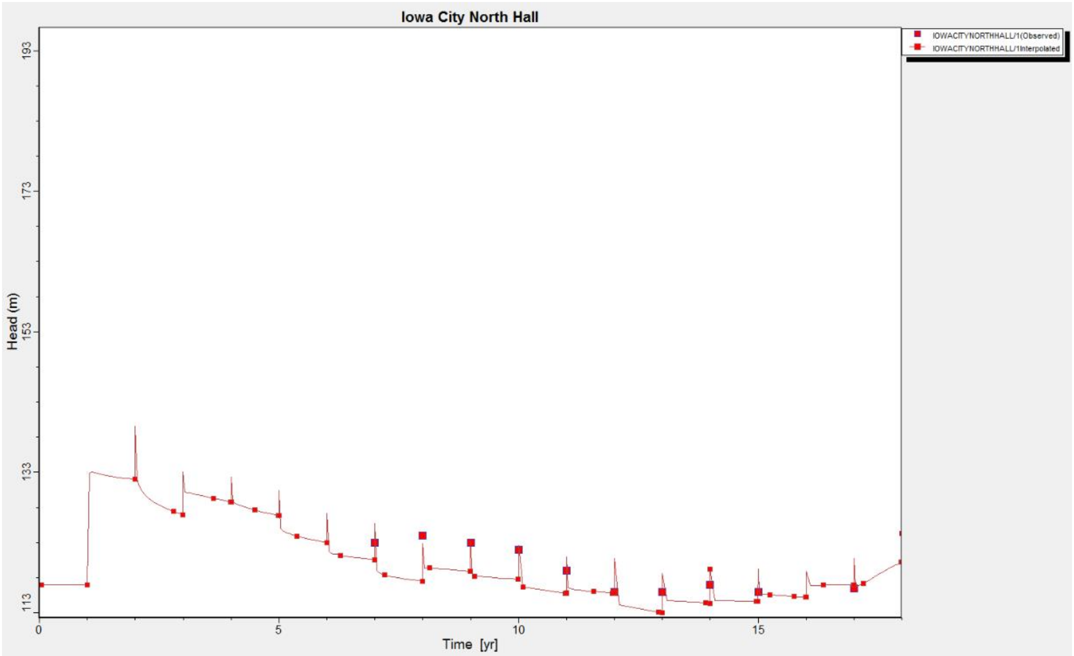


Figure AB-7: Static water level time series for Iowa City North Hall (WNumber: 13136)

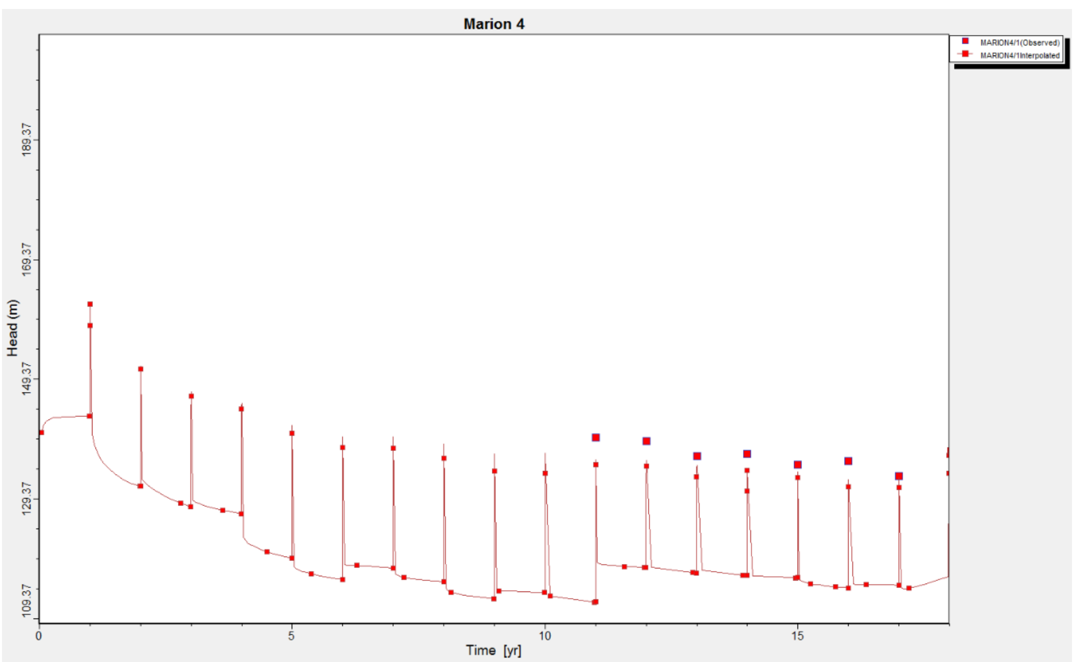


Figure AB-8: Static water level time series for Marion #4 (WNumber: 17979)

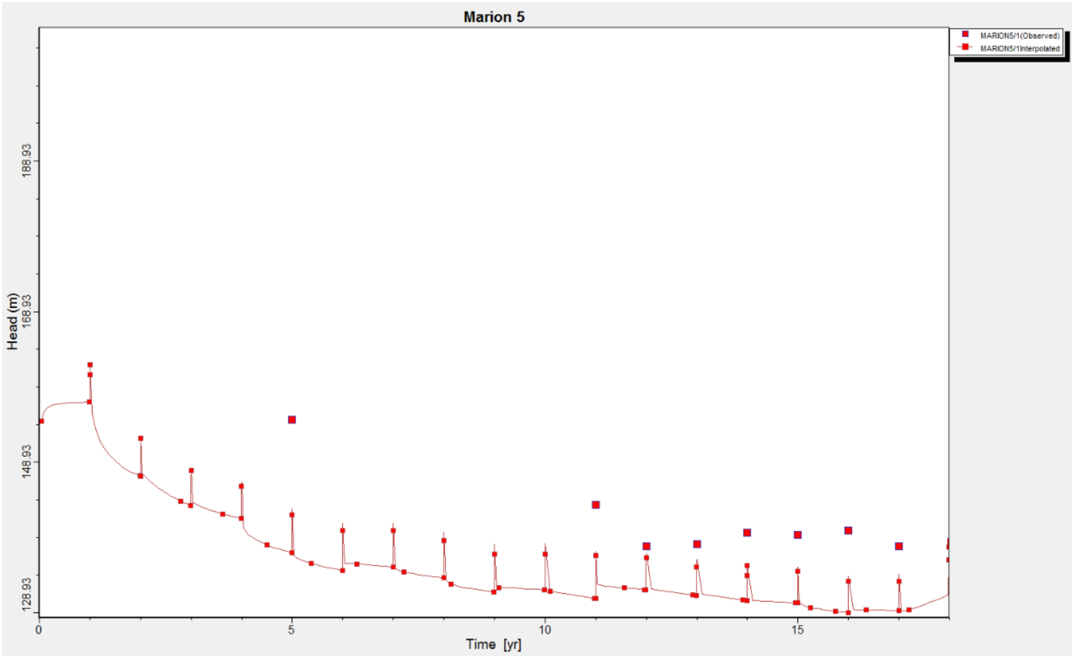


Figure AB-9: Static water level time series for Marion #5 (WNumber: 23249)

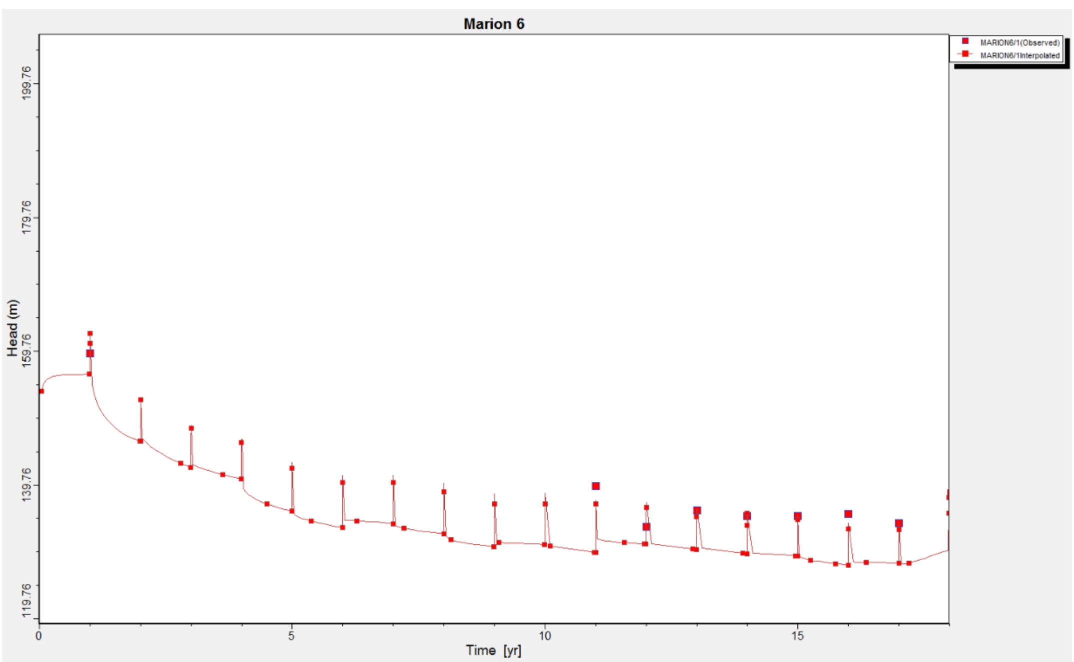


Figure AB-10: Static water level time series for Marion #6 (WNumber: 54624)

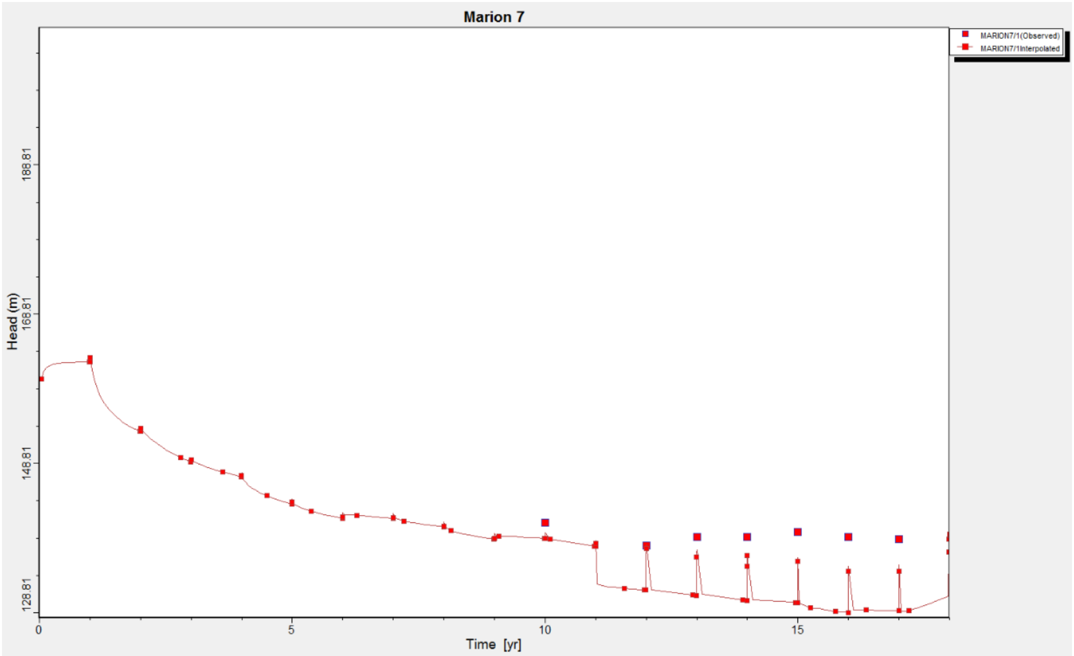


Figure AB-11: Static water level time series for Marion #7 (WNumber: 73163)

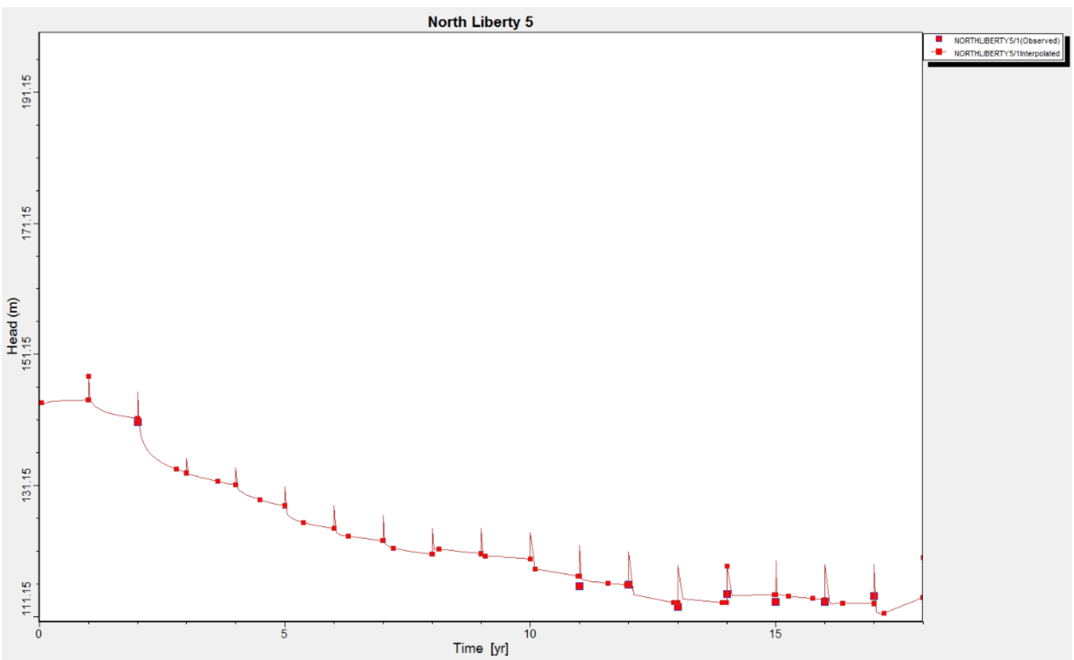


Figure AB-12: Static water level time series for North Liberty #5 (WNumber: 35258)

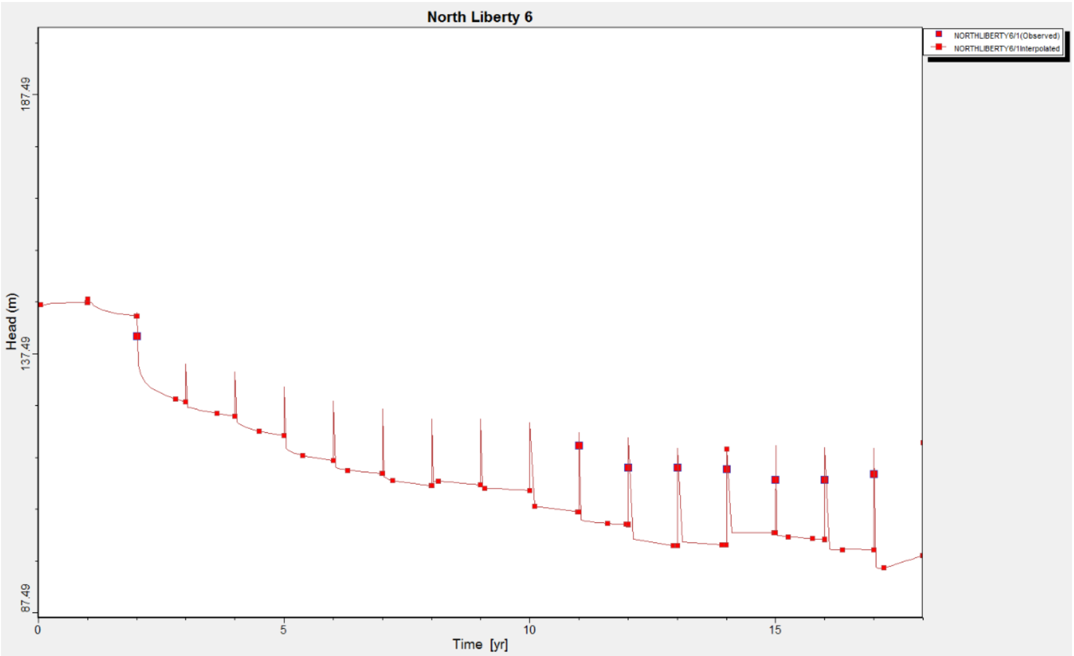


Figure AB-13: Static water level time series for North Liberty #6 (WNumber: 55191)

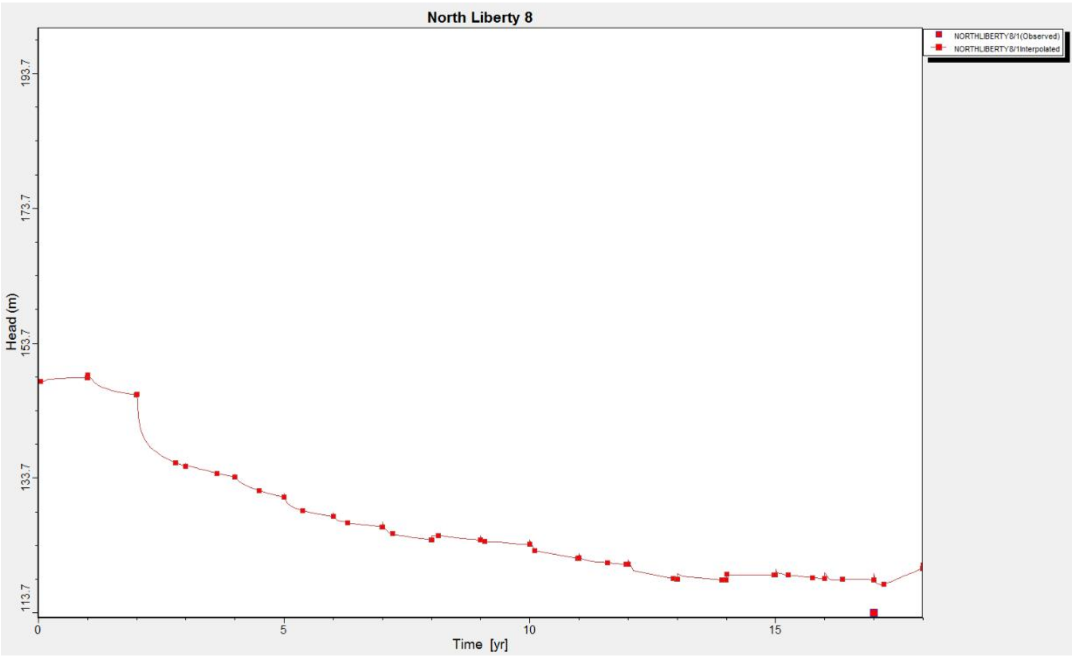


Figure AB-14: Static water level time series for North Liberty #8 (WNumber: 85879)

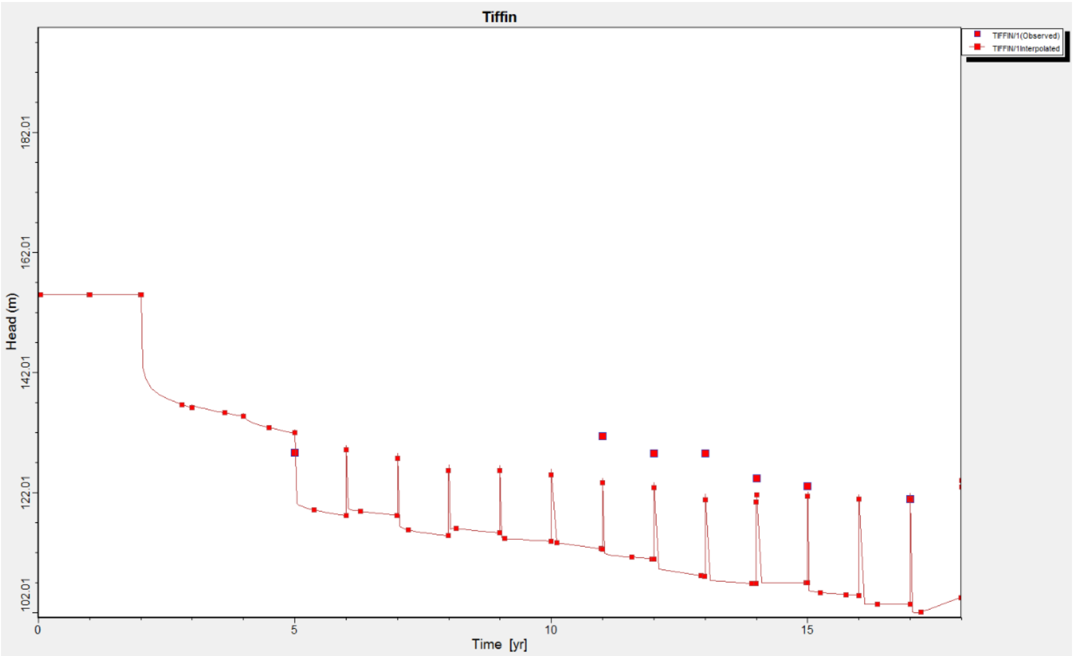


Figure AB-15: Static water level time series for Tiffin #4 (WNumber: 58475)

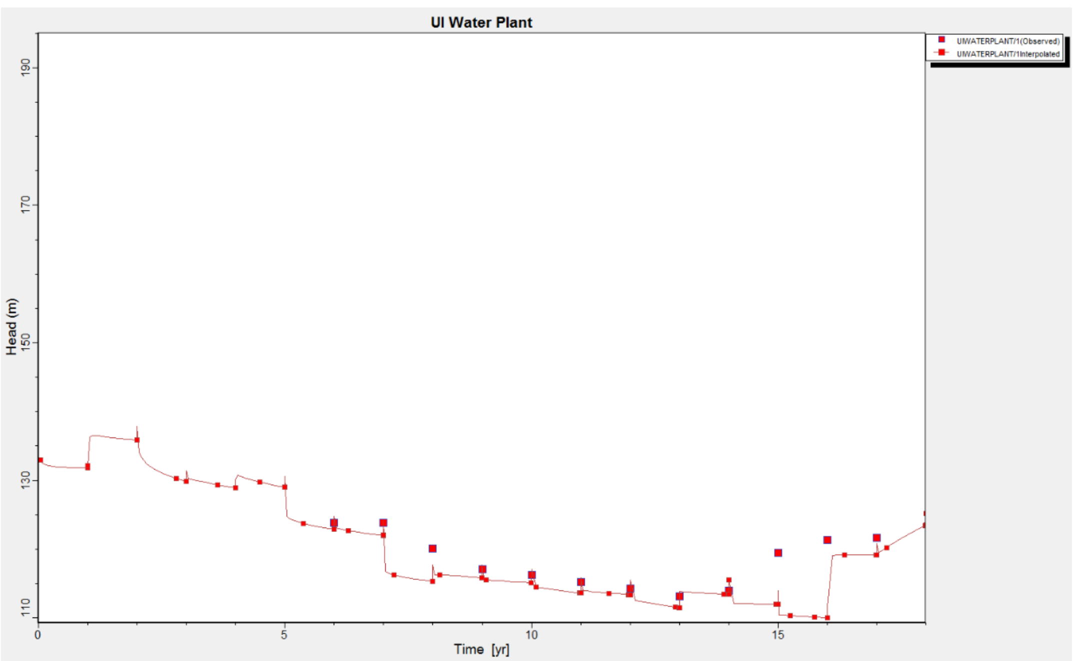


Figure AB-16: Static water level time series for the UI Water Plant (WNumber: 14453)

IOWA GEOLOGICAL SURVEY

Historical Static Water Levels

Table AB-1: Static Water Level Time Series Data from LJCPA Wells used as Model Calibration Targets

Well Name	Year	SWL Elevation (m)	SWL Elevation (ft)
ADM	2005	146.0	479.0
ADM	2008	136.0	446.0
ADM	2009	130.8	429.0
ADM	2010	131.4	431.0
ADM	2011	139.9	459.0
ADM	2014	125.3	411.0
ADM	2016	124.7	409.0
ADM	2017	128.4	421.0
Coralville #10	2003	131.4	431.0
Coralville #10	2005	118.1	387.4
Coralville #10	2006	120.4	394.9
Coralville #10	2007	116.9	383.3
Coralville #10	2008	116.5	382.1
Coralville #10	2009	117.7	386.1
Coralville #10	2010	114.4	375.1
Coralville #10	2011	113.9	373.6
Coralville #10	2012	113.1	371.0
Coralville #10	2013	113.9	373.7
Coralville #10	2014	110.7	363.2
Coralville #10	2015	114.7	376.3
Coralville #10	2016	111.9	367.0
Coralville #10	2017	110.7	363.0
Coralville #12	2003	131.4	431.0
Coralville #12	2005	118.1	387.4
Coralville #12	2006	120.4	394.9
Coralville #12	2007	116.9	383.3
Coralville #12	2008	116.5	382.1
Coralville #12	2009	117.7	386.1
Coralville #12	2010	114.4	375.1
Coralville #12	2011	113.9	373.6
Coralville #12	2012	113.1	371.0
Coralville #12	2013	113.9	373.7
Coralville #12	2014	110.7	363.2
Coralville #12	2015	114.7	376.3

Table AB-1: Static Water Level Time Series Data from LJCPA Wells used as Model Calibration Targets

Coralville #12	2016	111.9	367.0
Coralville #12	2017	110.7	363.0
Ingredion PW54	2011	138.4	454.0
Ingredion PW54	2012	140.9	462.0
Ingredion PW54	2013	139.9	459.0
Ingredion PW54	2014	135.1	443.0
Ingredion PW54	2015	139.9	459.0
Ingredion PW54	2016	140.9	462.0
Ingredion PW54	2017	133.8	439.0
Ingredion PW73	2011	139.9	459.0
Ingredion PW73	2012	138.4	454.0
Ingredion PW73	2013	133.2	437.0
Ingredion PW73	2014	134.1	440.0
Ingredion PW73	2015	135.7	445.0
Ingredion PW73	2016	137.5	451.0
Ingredion PW73	2017	136.9	449.0
Iowa City North Hall	2007	123.0	403.4
Iowa City North Hall	2008	124.0	406.7
Iowa City North Hall	2009	123.0	403.4
Iowa City North Hall	2010	122.0	400.2
Iowa City North Hall	2011	119.0	390.3
Iowa City North Hall	2012	116.0	380.5
Iowa City North Hall	2013	116.0	380.5
Iowa City North Hall	2014	117.0	383.8
Iowa City North Hall	2015	116.0	380.5
Iowa City North Hall	2017	116.5	382.0
Iowa City JW-1	2007	130.5	428.0
Iowa City JW-1	2008	126.2	414.0
Iowa City JW-1	2009	129.9	426.0
Iowa City JW-1	2010	119.5	392.0
Iowa City JW-1	2011	114.6	376.0
Iowa City JW-1	2012	115.2	378.0
Iowa City JW-1	2013	116.5	382.0
Iowa City JW-1	2014	116.5	382.0
Iowa City JW-1	2015	115.2	378.0
Iowa City JW-1	2016	116.2	381.0
Iowa City JW-1	2017	116.2	381.0
Marion #4	2011	139.6	458.0

Table AB-1: Static Water Level Time Series Data from LJCPA Wells used as Model Calibration Targets

Marion #4	2012	139.0	456.0
Marion #4	2013	136.6	448.0
Marion #4	2014	136.9	449.0
Marion #4	2015	135.1	443.0
Marion #4	2016	135.7	445.0
Marion #4	2017	133.2	437.0
Marion #5	2005	154.6	507.1
Marion #5	2011	143.3	470.0
Marion #5	2012	137.8	452.0
Marion #5	2013	138.1	453.0
Marion #5	2014	139.6	458.0
Marion #5	2015	139.3	457.0
Marion #5	2016	139.9	459.0
Marion #5	2017	137.8	452.0
Marion #6	2001	159.5	523.2
Marion #6	2011	139.6	458.0
Marion #6	2012	133.5	438.0
Marion #6	2013	136.0	446.0
Marion #6	2014	135.1	443.0
Marion #6	2015	135.1	443.0
Marion #6	2016	135.4	444.0
Marion #6	2017	134.1	440.0
Marion #7	2010	140.9	462.2
Marion #7	2012	137.8	452.0
Marion #7	2013	139.0	456.0
Marion #7	2014	139.0	456.0
Marion #7	2015	139.6	458.0
Marion #7	2016	139.0	456.0
Marion #7	2017	138.7	455.0
North Liberty #5	2002	140.9	462.2
North Liberty #5	2011	115.8	379.8
North Liberty #5	2012	116.1	380.8
North Liberty #5	2013	112.7	369.8
North Liberty #5	2014	114.6	375.8
North Liberty #5	2015	113.4	371.8
North Liberty #5	2016	113.4	372.0
North Liberty #5	2017	114.3	374.8
North Liberty #6	2002	140.9	462.2

Table AB-1: Static Water Level Time Series Data from LJCPA Wells used as Model Calibration Targets

North Liberty #6	2011	119.8	392.8
North Liberty #6	2012	115.5	378.8
North Liberty #6	2013	115.5	378.8
North Liberty #6	2014	115.2	377.8
North Liberty #6	2015	113.1	370.8
North Liberty #6	2016	113.1	371.0
North Liberty #6	2017	114.3	374.8
North Liberty #8	2017	114.3	374.8
Tiffin	2005	128.7	422.1
Tiffin	2011	131.4	430.9
Tiffin	2012	128.6	421.9
Tiffin	2013	128.6	421.9
Tiffin	2014	124.4	407.9
Tiffin	2015	123.1	403.9
Tiffin	2017	121.0	396.9
UI Water Plant	2006	123.8	406.0
UI Water Plant	2007	123.8	406.0
UI Water Plant	2008	120.1	394.0
UI Water Plant	2009	117.1	384.0
UI Water Plant	2010	116.2	381.0
UI Water Plant	2011	115.2	378.0
UI Water Plant	2012	114.3	375.0
UI Water Plant	2013	113.1	371.0
UI Water Plant	2014	114.0	373.9
UI Water Plant	2015	119.5	392.0
UI Water Plant	2016	121.3	398.0
UI Water Plant	2017	121.6	399.0

*North Liberty #5 and #6 adjusted based on static water levels observed in North Liberty #8. Coralville #10 water levels adjusted based on post-rehab values and used in Coralville #12. Tiffin water levels adjusted based on difference between airline reading and E-line reading taken by IGS during a pump test. Iowa City JW-1 static water levels taken from peaks of bi-weekly data. Iowa City North Hall levels adjusted based on surrounding wells and uncertainties in accuracy of airline datum.

Appendix C: Groundwater Modeling Results

Predicted Water Levels in Various Growth Scenarios

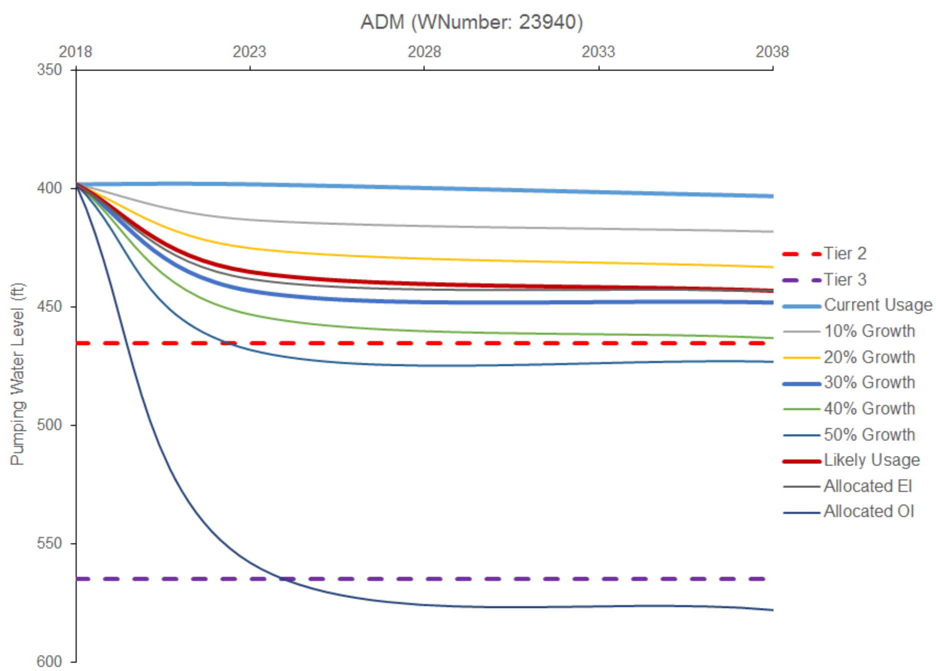


Figure AC-1: Predicted water levels for ADM under different growth scenarios

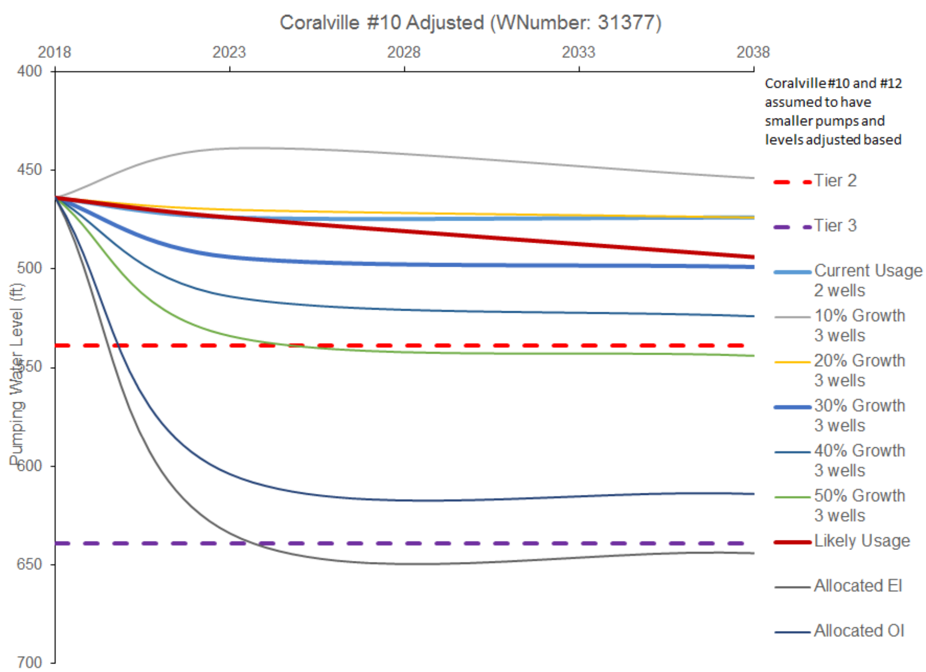


Figure AC-2: Predicted water levels for Coralville #10 under different growth scenarios

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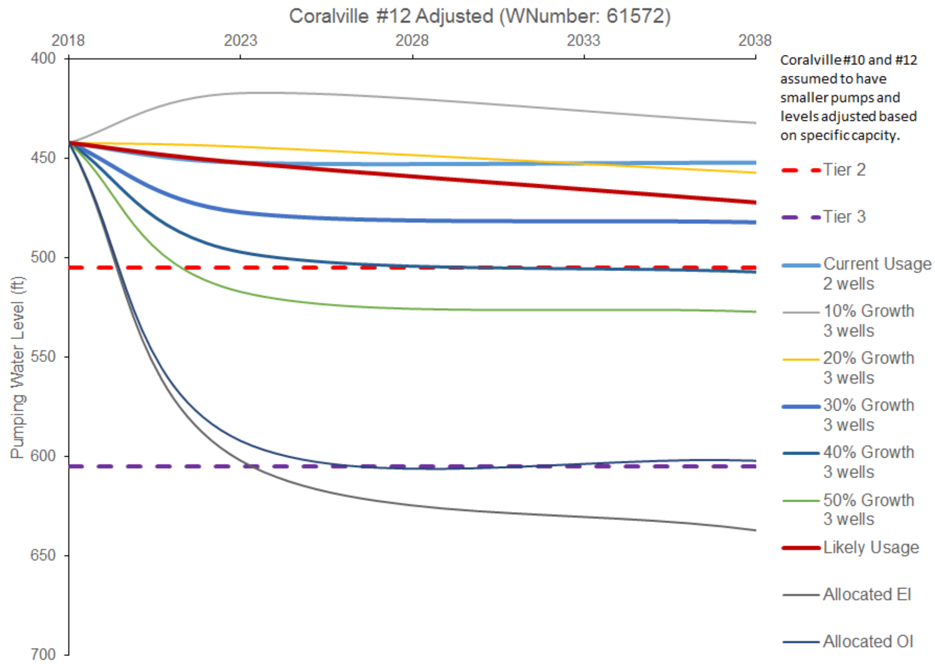

Figure AC-3: Predicted water levels for Coralville #12 under different growth scenarios

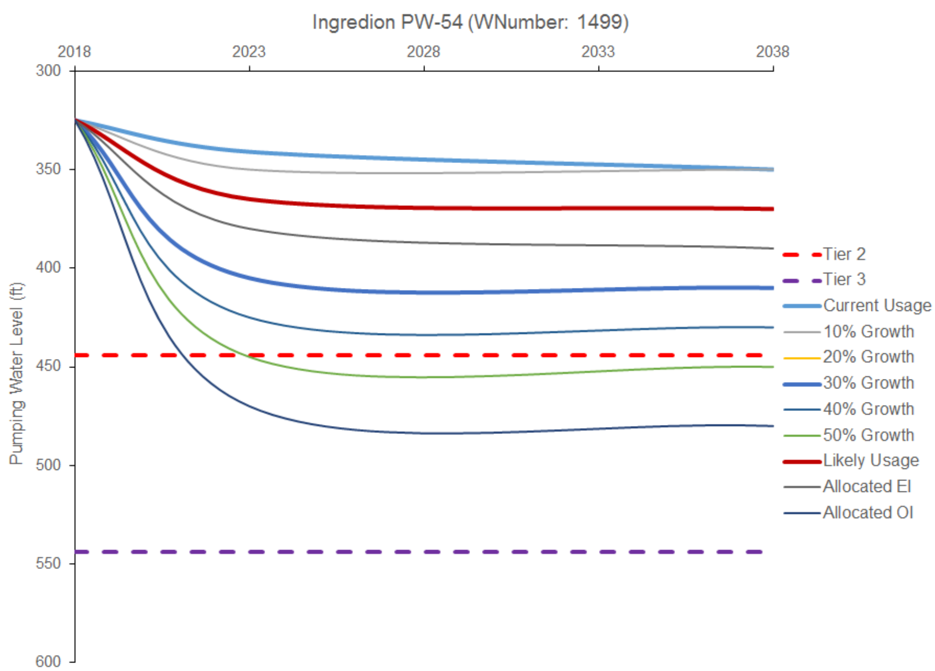

Figure AC-4: Predicted water levels for Ingredion PW-54 under different growth scenarios

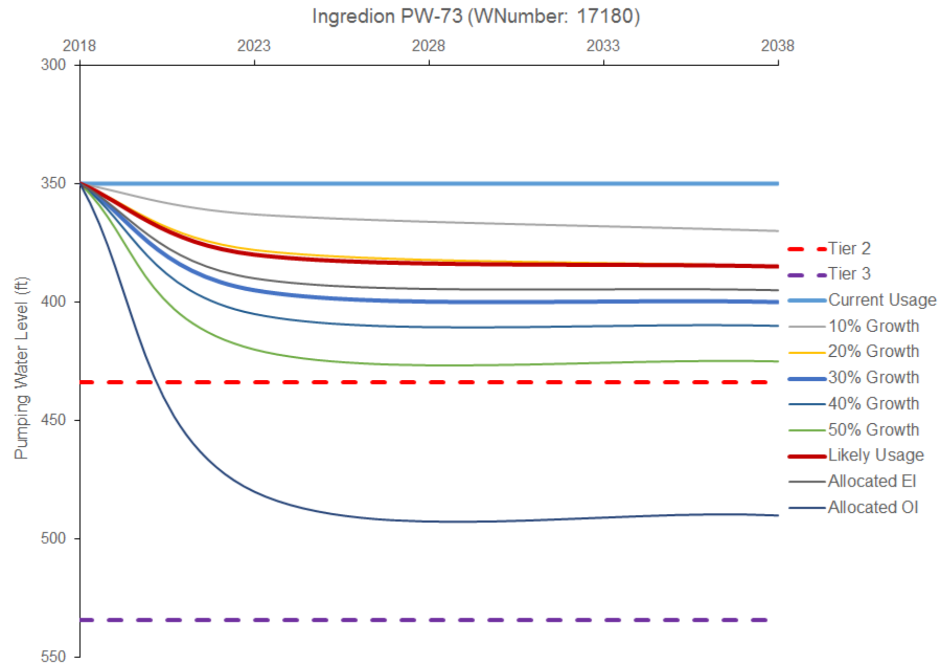

Figure AC-5: Predicted water levels for Ingredion PW-73 under different growth scenarios

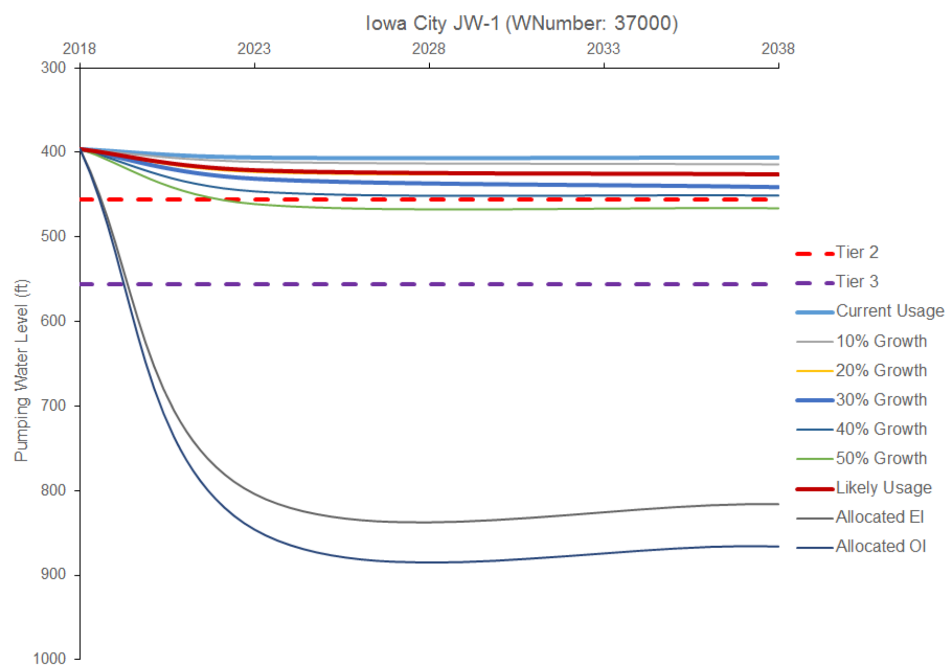

Figure AC-6: Predicted water levels for Iowa City JW-1 under different growth scenarios

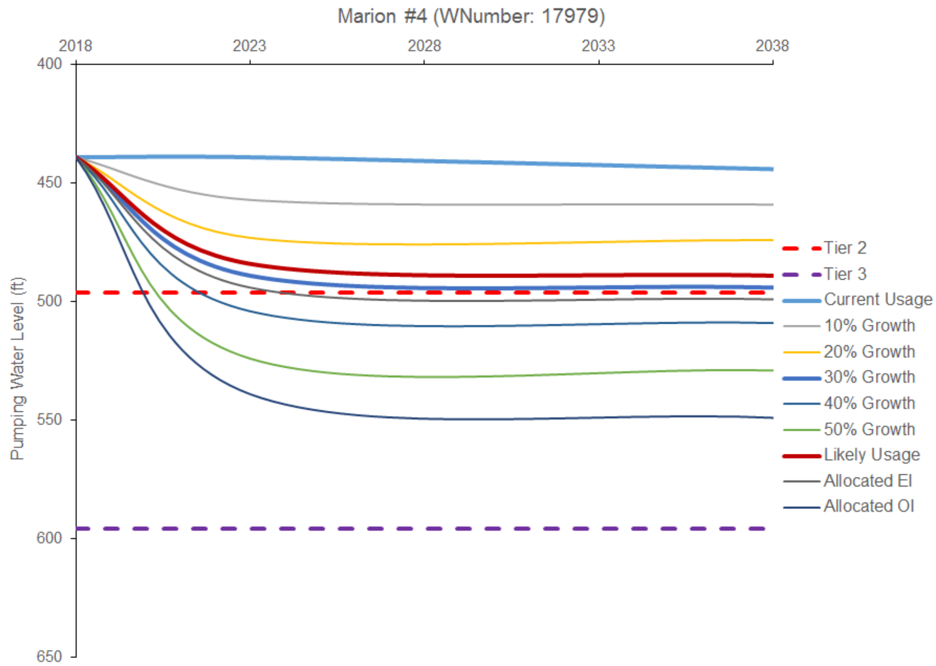

Figure AC-7: Predicted water levels for Marion #4 under different growth scenarios with water levels adjusted assuming well rehabilitation

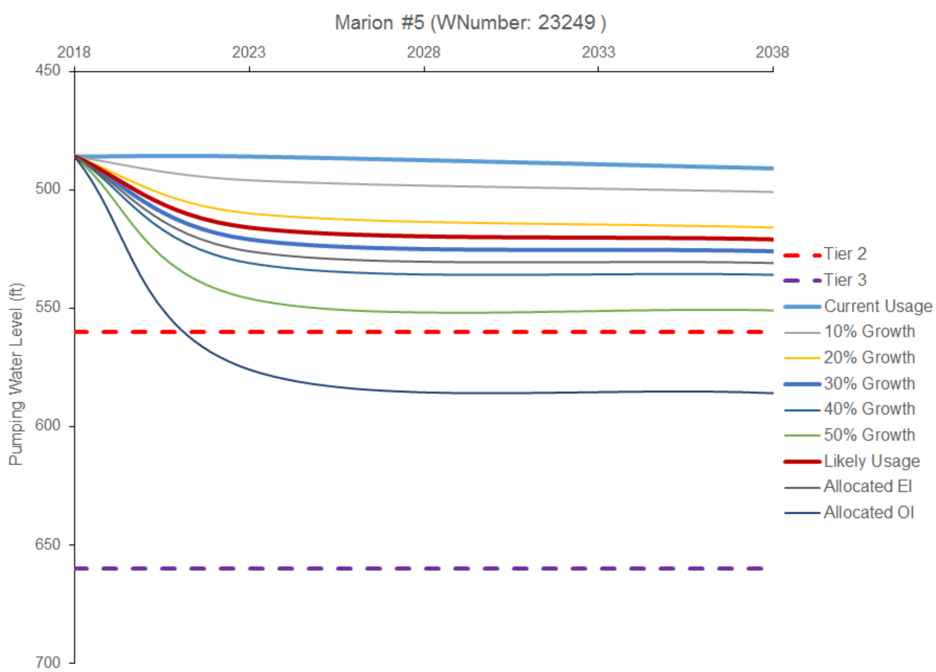

Figure AC-8: Predicted water levels for Marion #5 under different growth scenarios

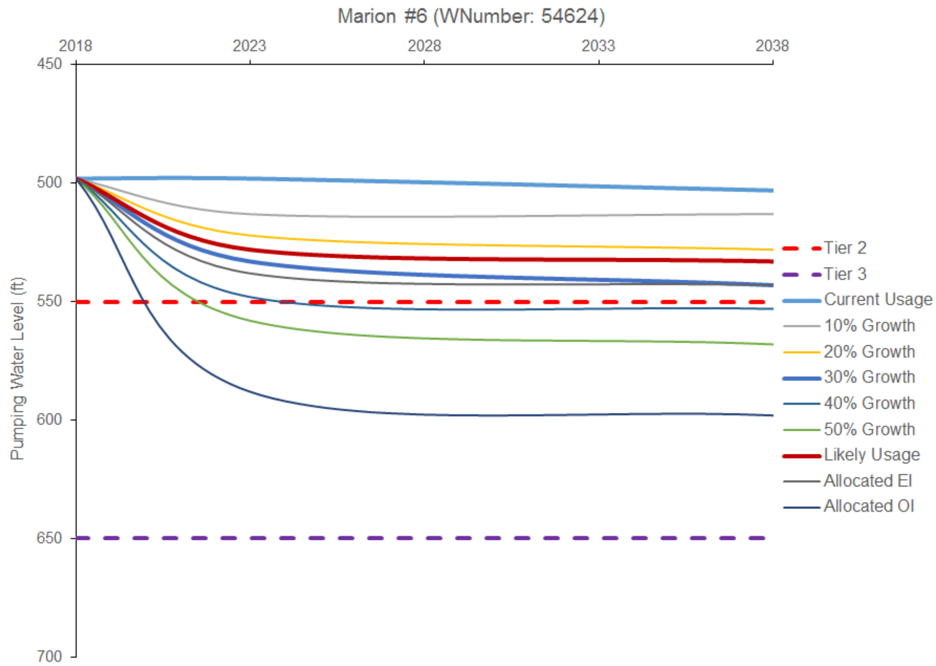

Figure AC-9: Predicted water levels for Marion #6 under different growth scenarios

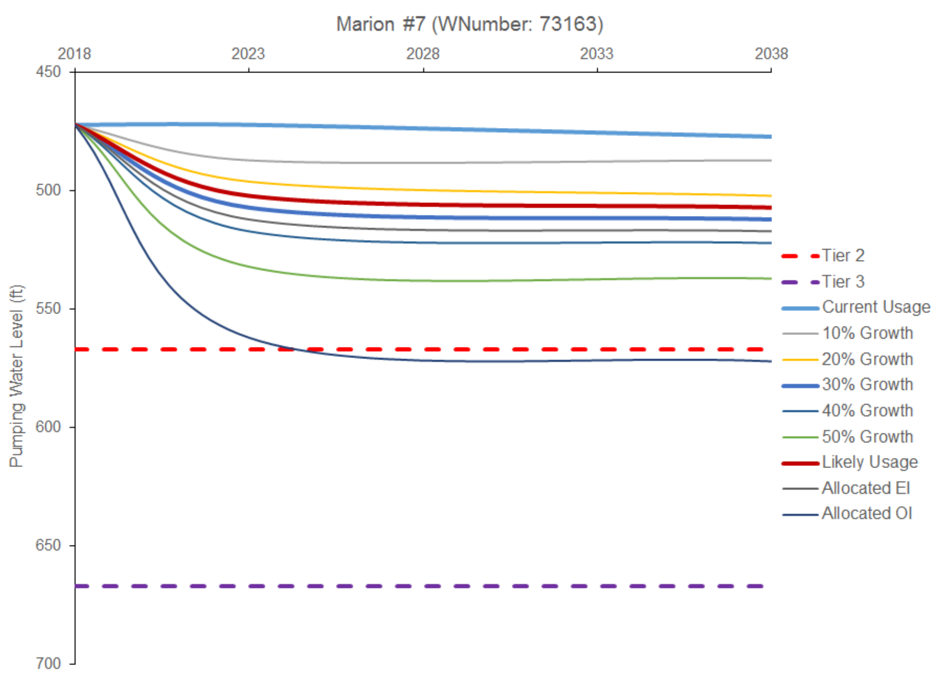

Figure AC-10: Predicted water levels for Marion #7 under different growth scenarios

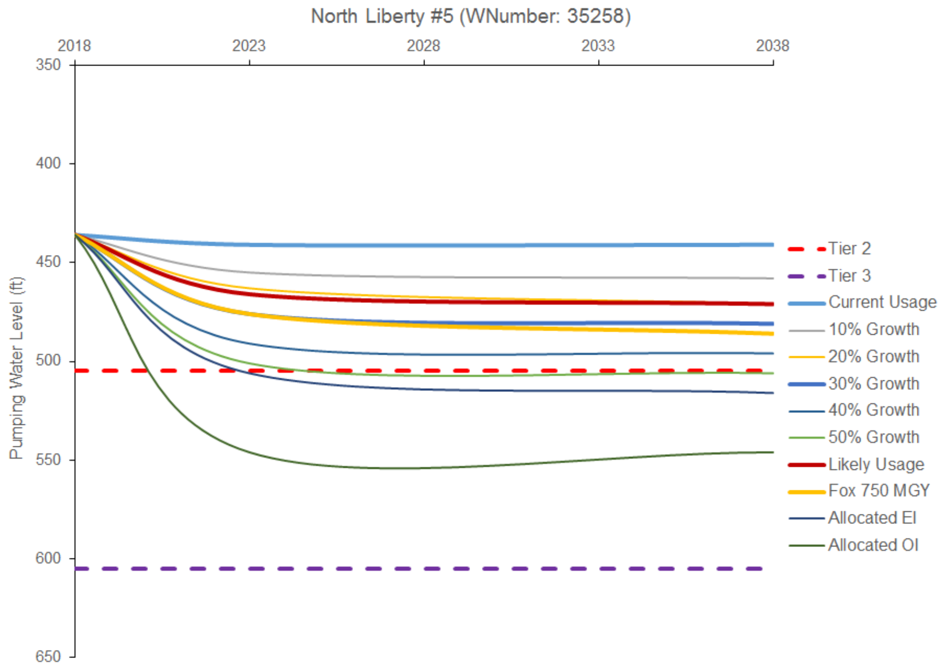

Figure AC-11: Predicted water levels for North Liberty #5 under different growth scenarios

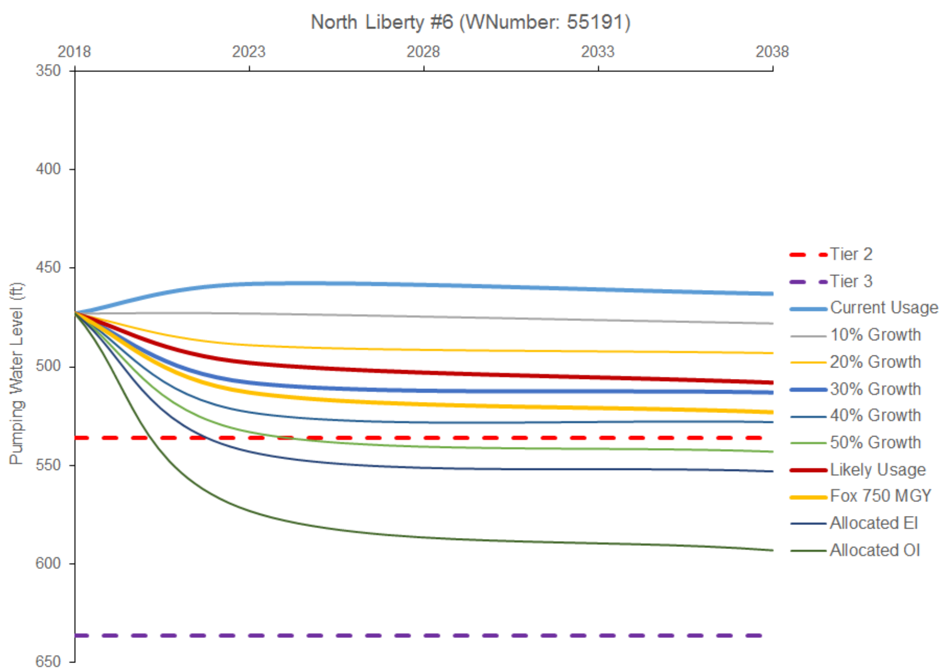

Figure AC-12: Predicted water levels for North Liberty #6 under different growth scenarios

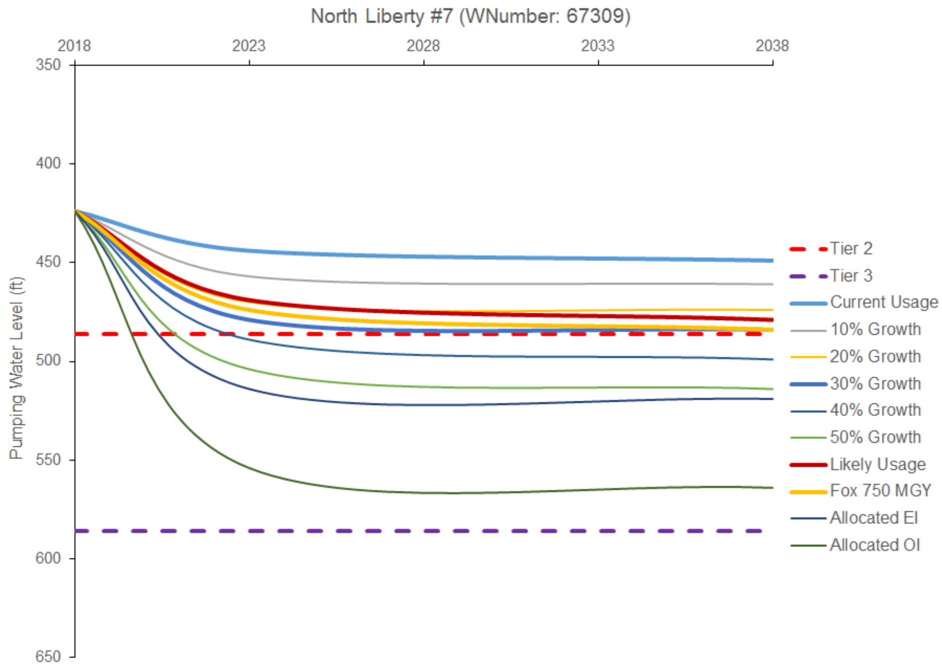

Figure AC-13: Predicted water levels for North Liberty #7 under different growth scenarios

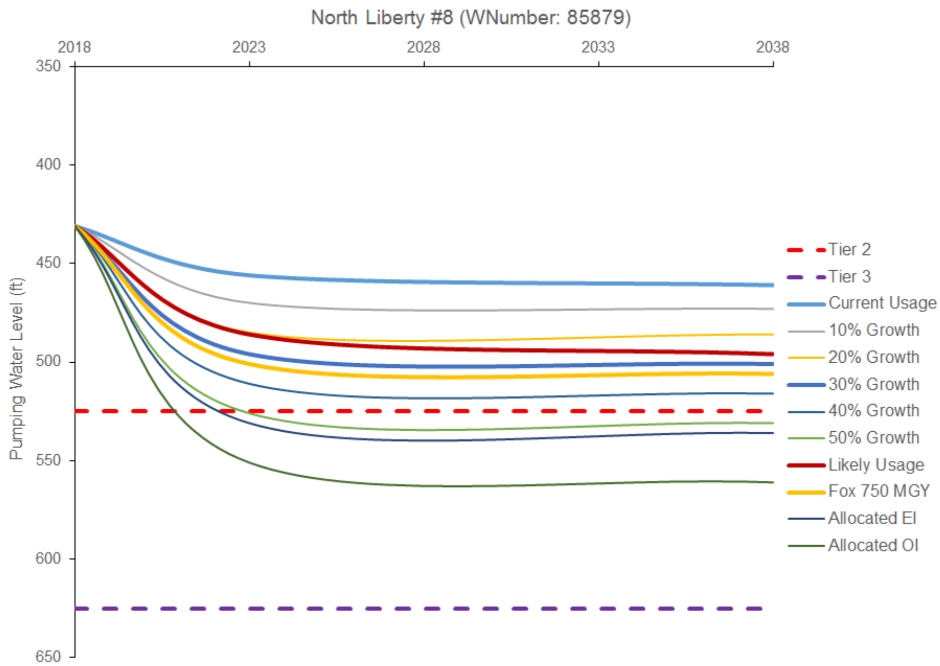

Figure AC-14: Predicted water levels for North Liberty #8 under different growth scenarios

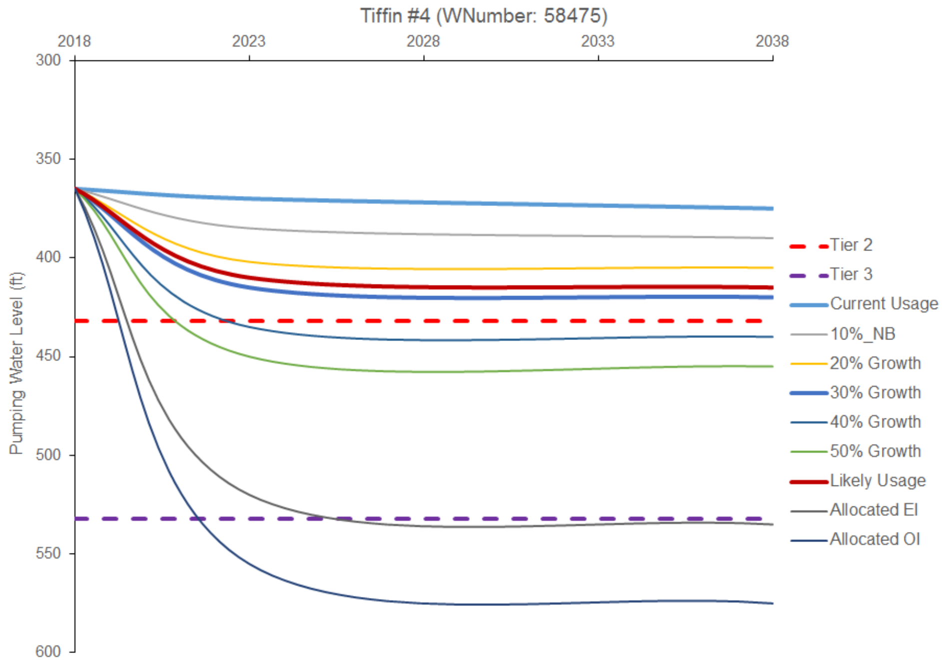

Figure AC-15: Predicted water levels for Tiffin #4 under different growth scenarios

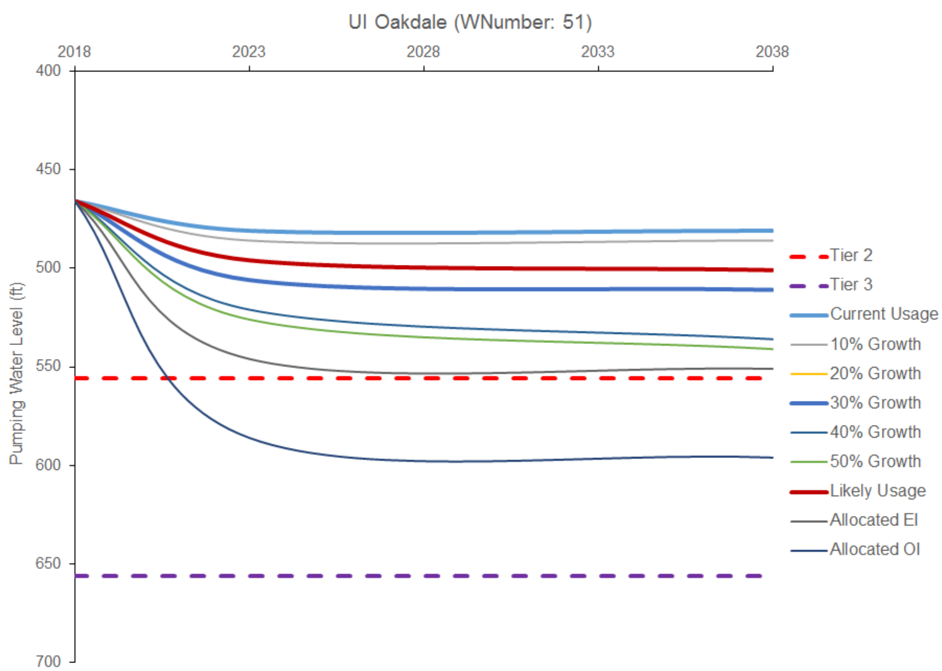

Figure AC-16: Predicted water levels for UI Oakdale under different growth scenarios

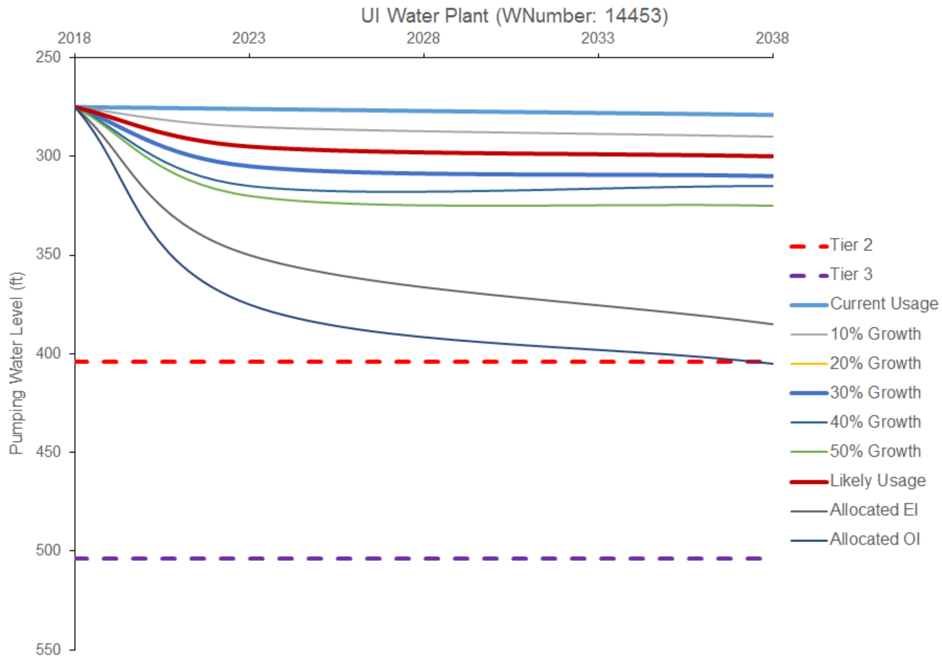

Figure AC-17: Predicted water levels for UI Water Plant under different growth scenarios

Well Interference in Percentage Growth Scenarios

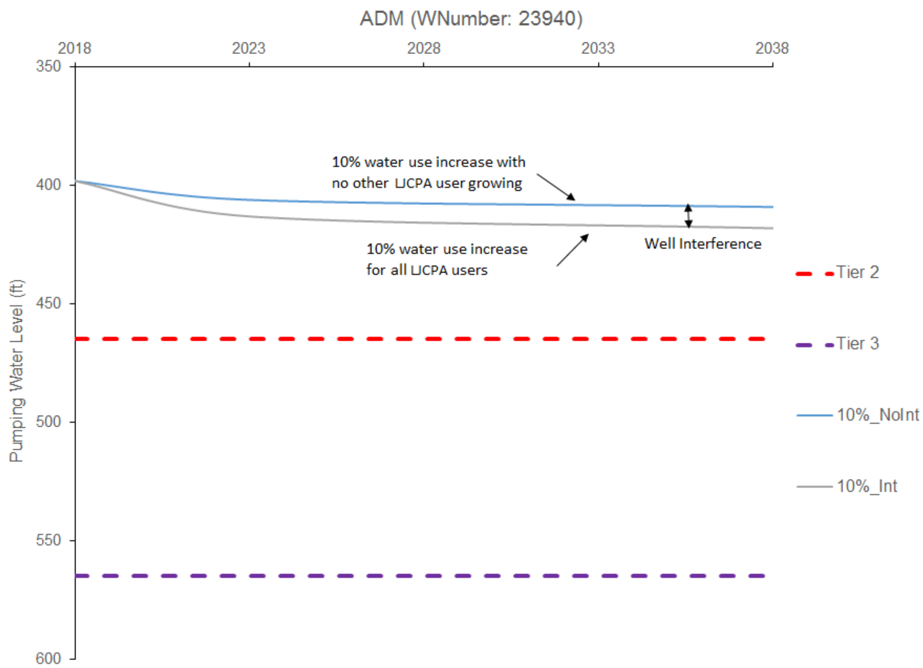

Figure AC-18: Well interference at ADM with 10% growth in the LJPCA

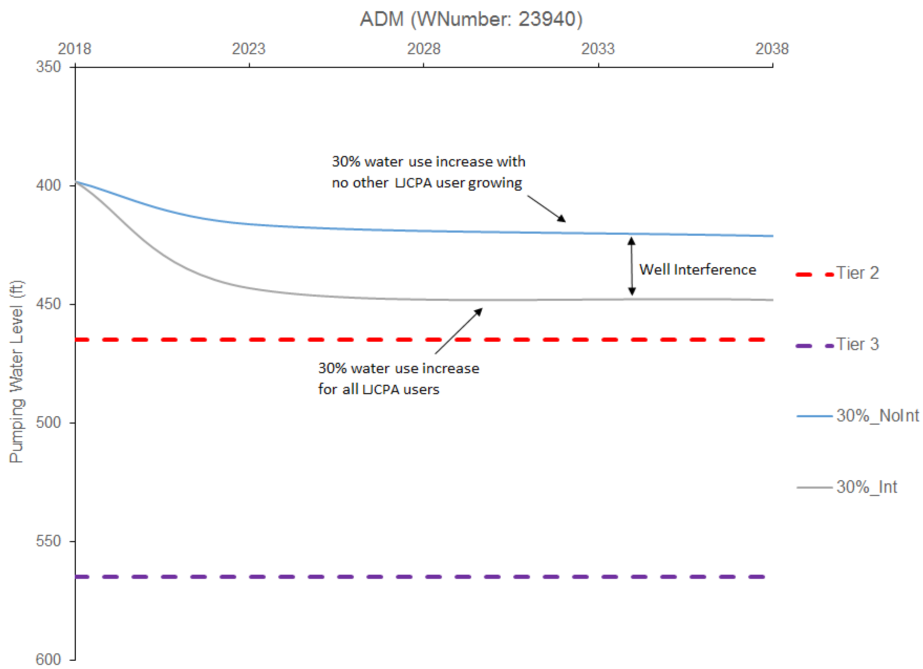

Figure AC-19: Well interference at ADM with 30% growth in the LJPCA

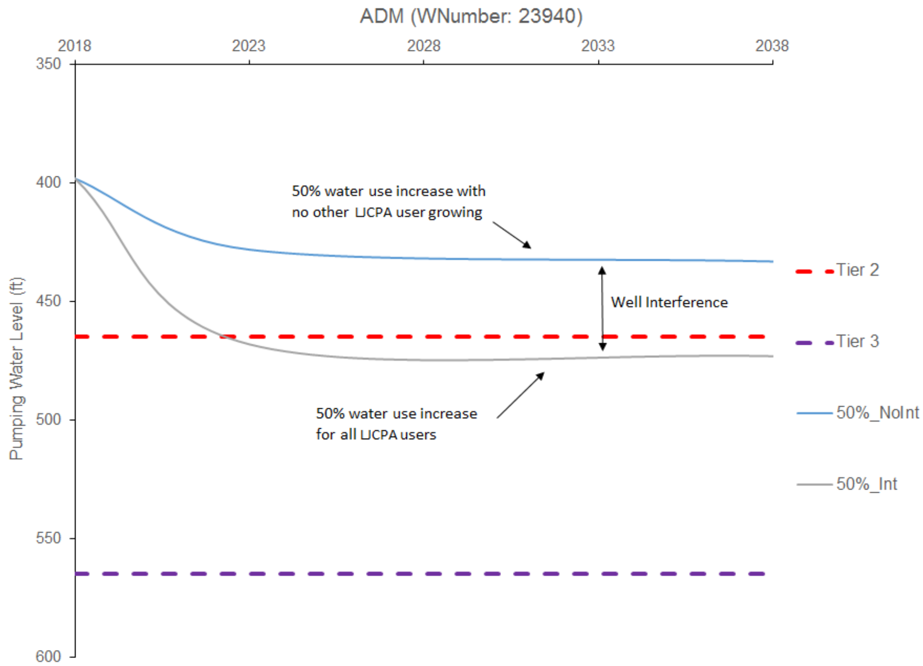

Figure AC-20: Well interference at ADM with 50% growth in the LJPCA

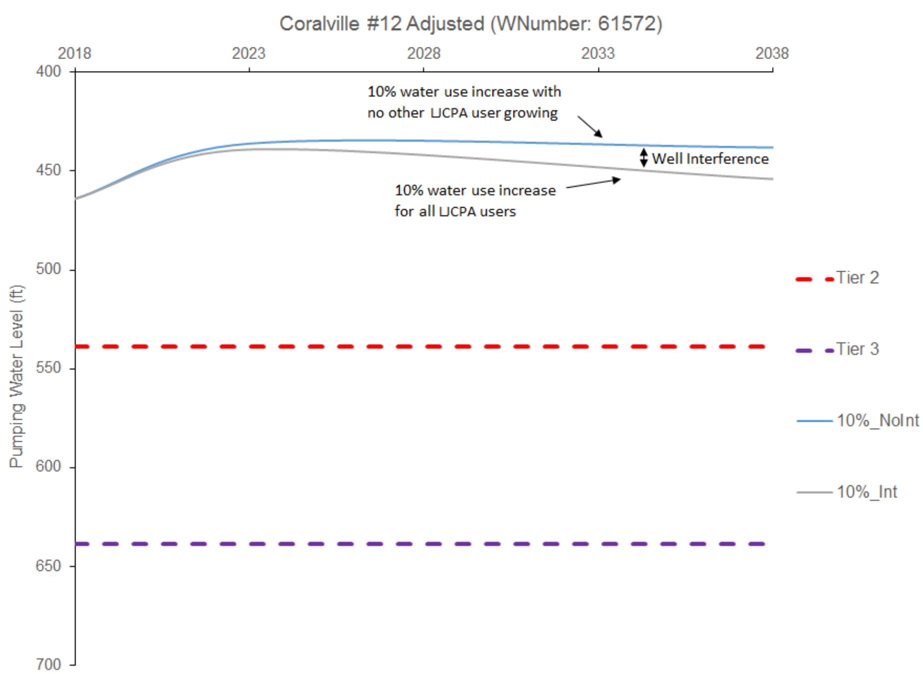

Figure AC-21: Well interference at Coralville #12 with 10% growth in the LJPCA (levels adjusted for smaller pumps in Coralville wells)

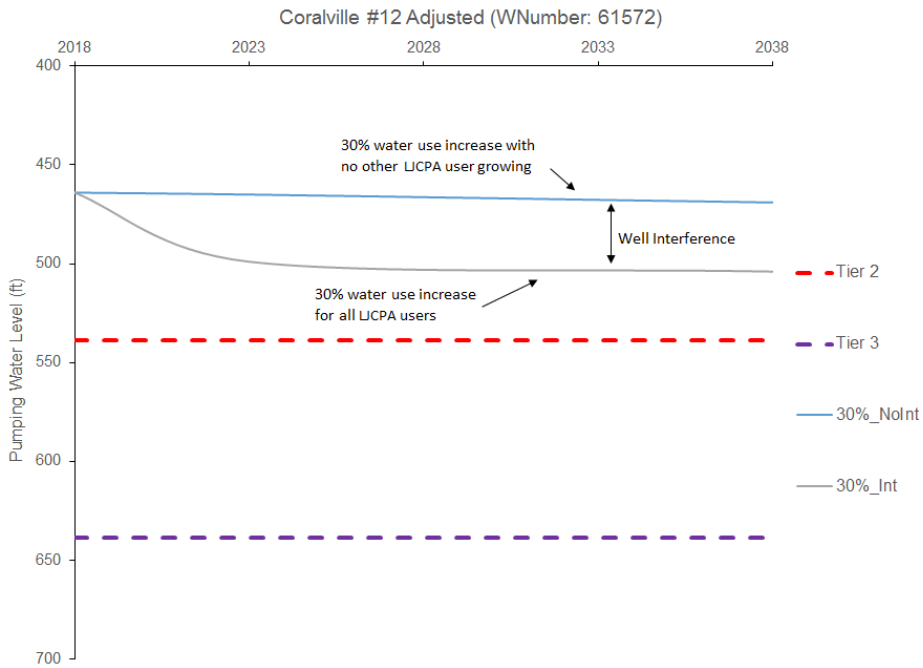

Figure AC-22: Well interference at Coralville #12 with 30% growth in the LJPCA (levels adjusted for smaller pumps in Coralville wells)

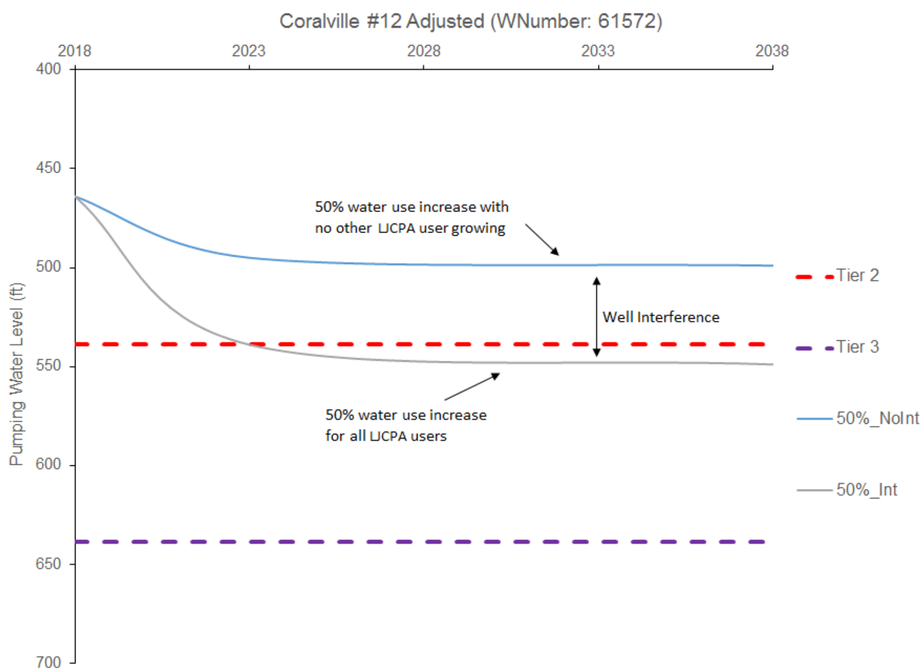

Figure AC-23: Well interference at Coralville #12 with 50% growth in the LJPCA (levels adjusted for smaller pumps in Coralville wells)

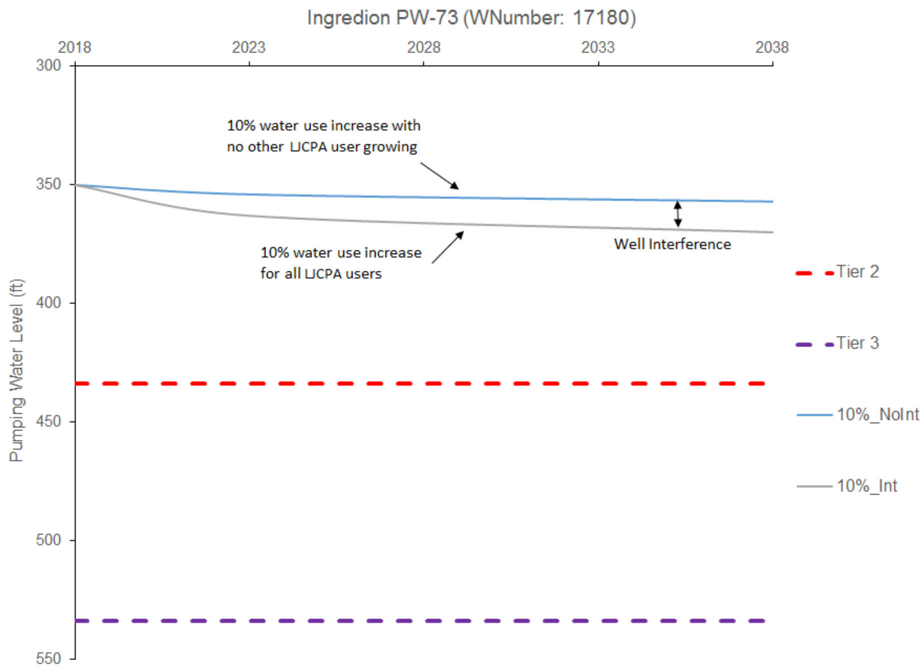

Figure AC-24: Well interference at Ingredion PW-73 with 10% growth in the LJPCA

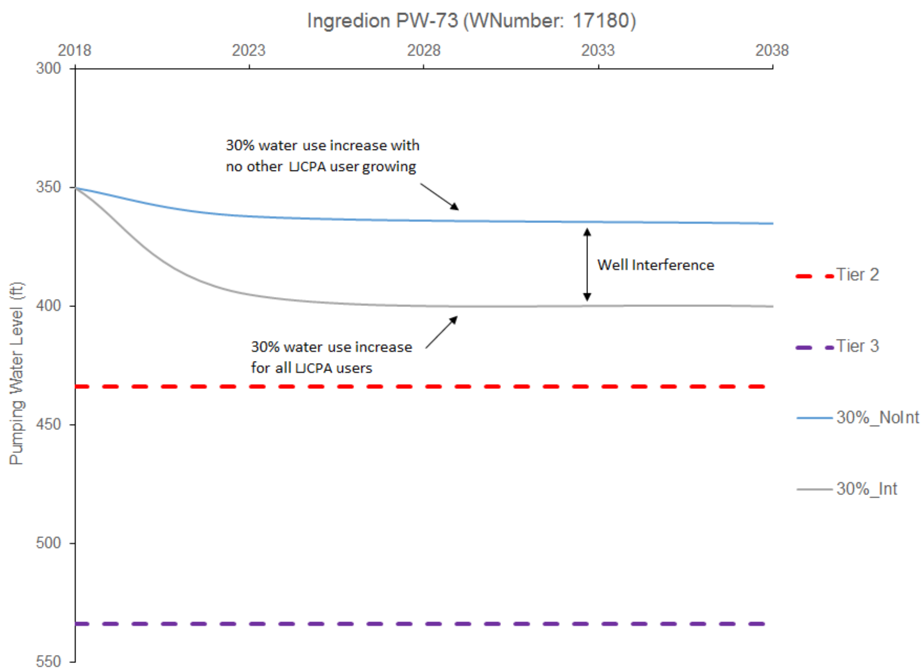

Figure AC-25: Well interference at Ingredion PW-73 with 30% growth in the LJPCA

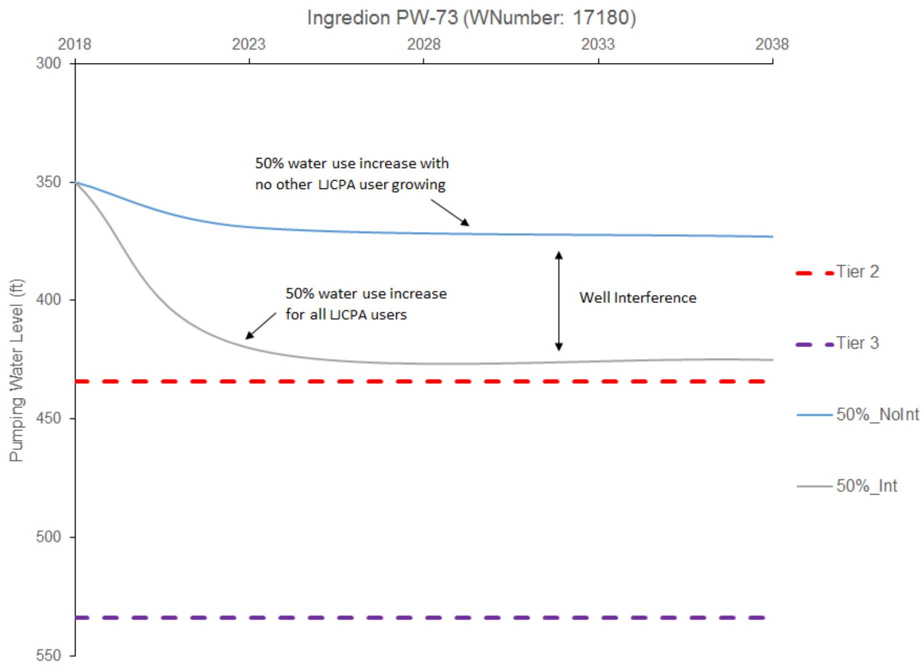

Figure AC-26: Well interference at Ingredion PW-73 with 50% growth in the LJPCA

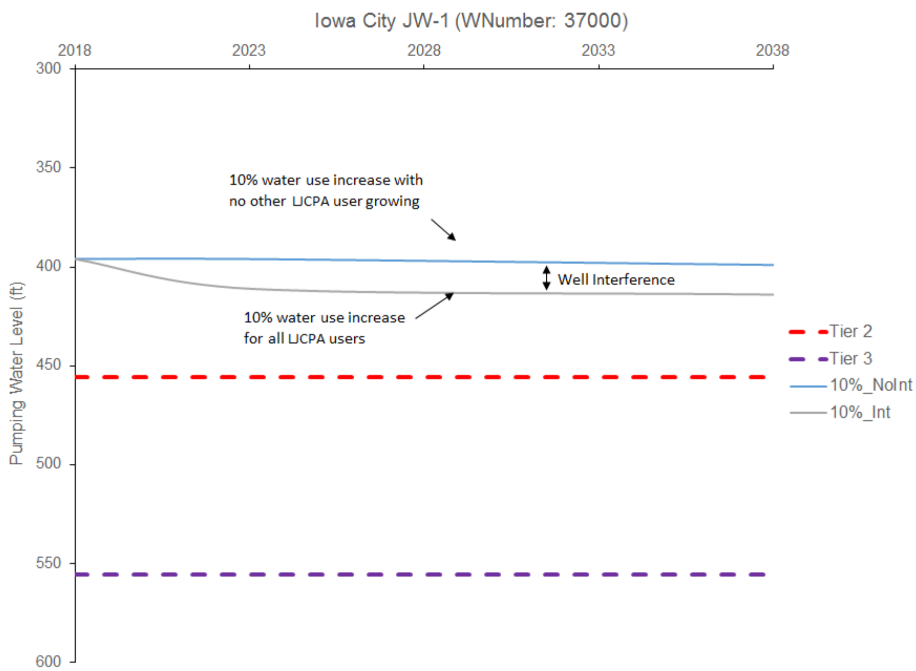

Figure AC-27: Well interference at Iowa City JW-1 with 10% growth in the LJPCA

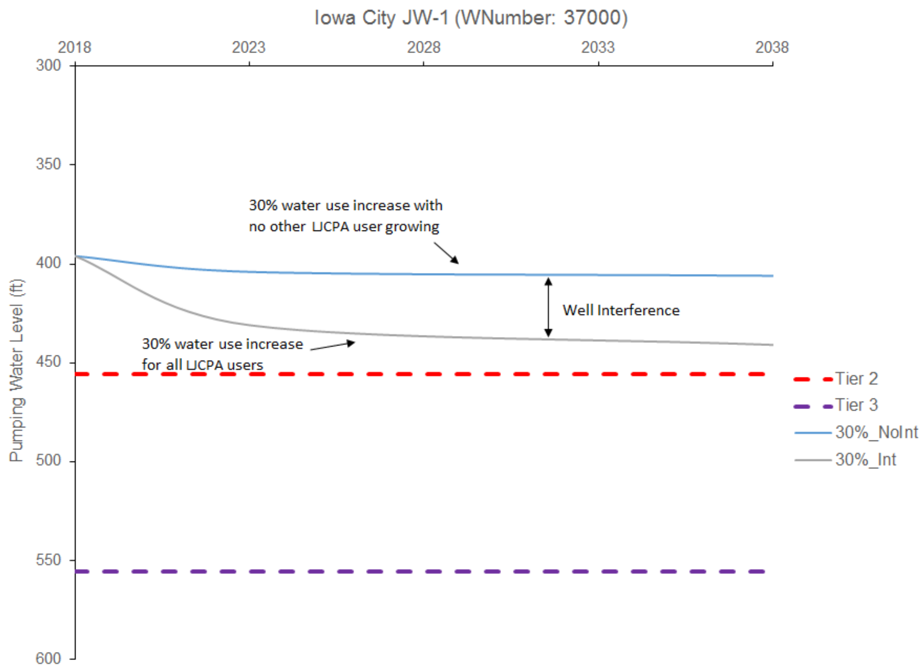

Figure AC-28: Well interference at Iowa City JW-1 with 30% growth in the LJPCA

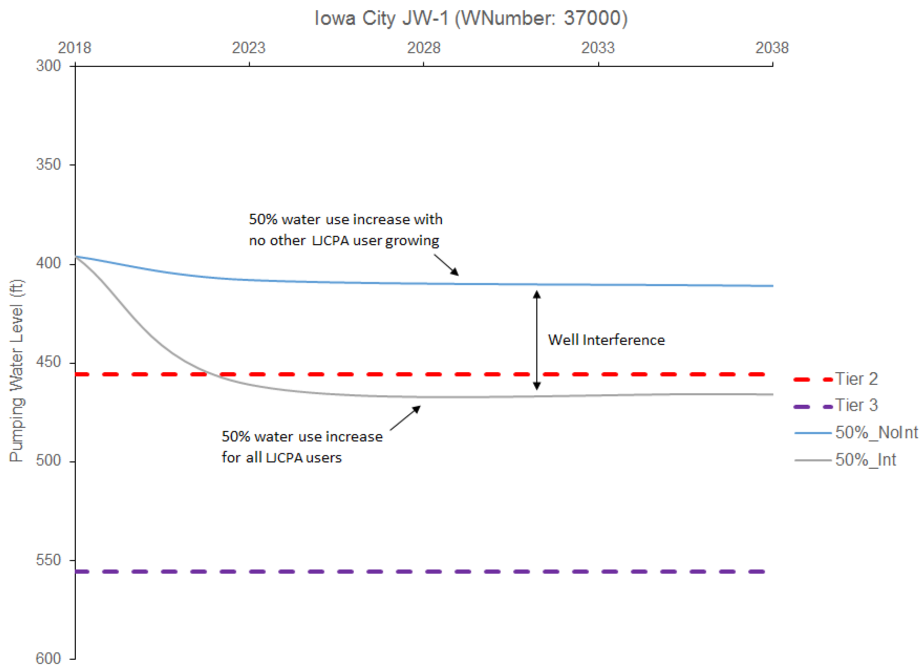

Figure AC-29: Well interference at Iowa City JW-1 with 50% growth in the LJPCA

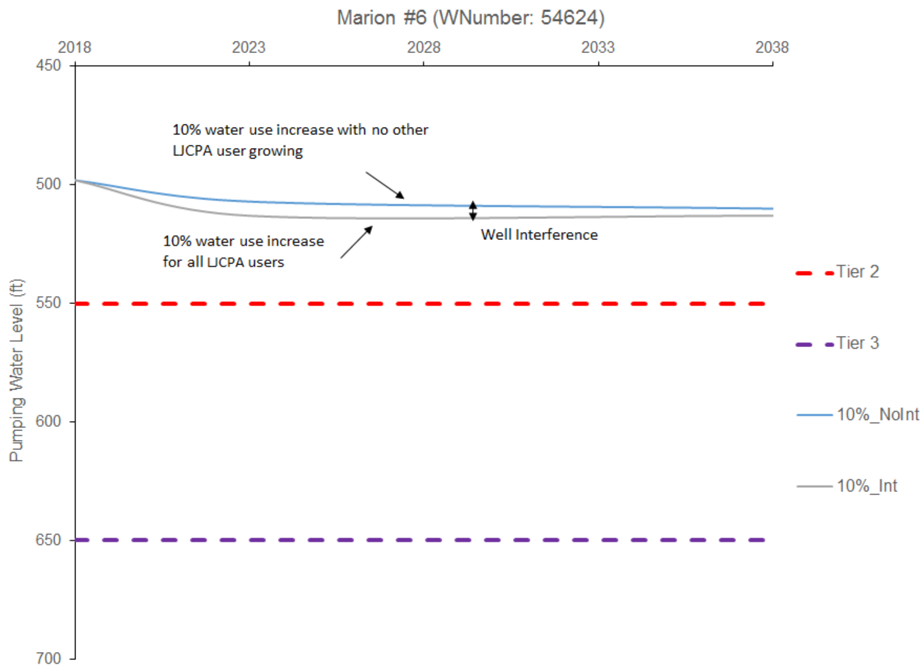

Figure AC-30: Well interference at Marion #6 with 10% growth in the LJPCA

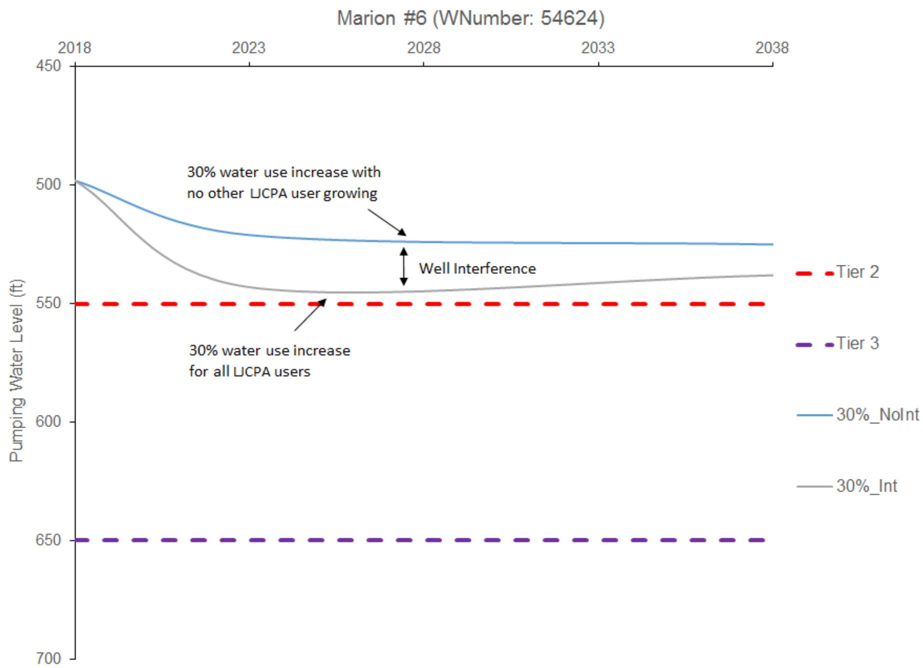

Figure AC-31: Well interference at Marion #6 with 30% growth in the LJPCA

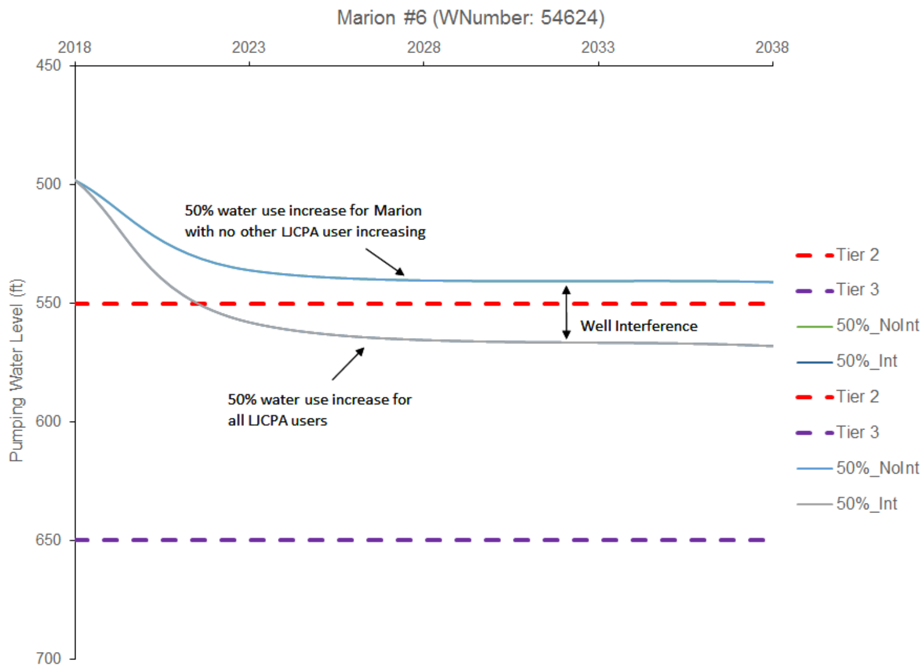

Figure AC-32: Well interference at Marion #6 with 50% growth in the LJPCA

Figure AC-33: Well interference at North Liberty #6 with 10% growth in the LJPCA (North Liberty #7 used as an ASR well)

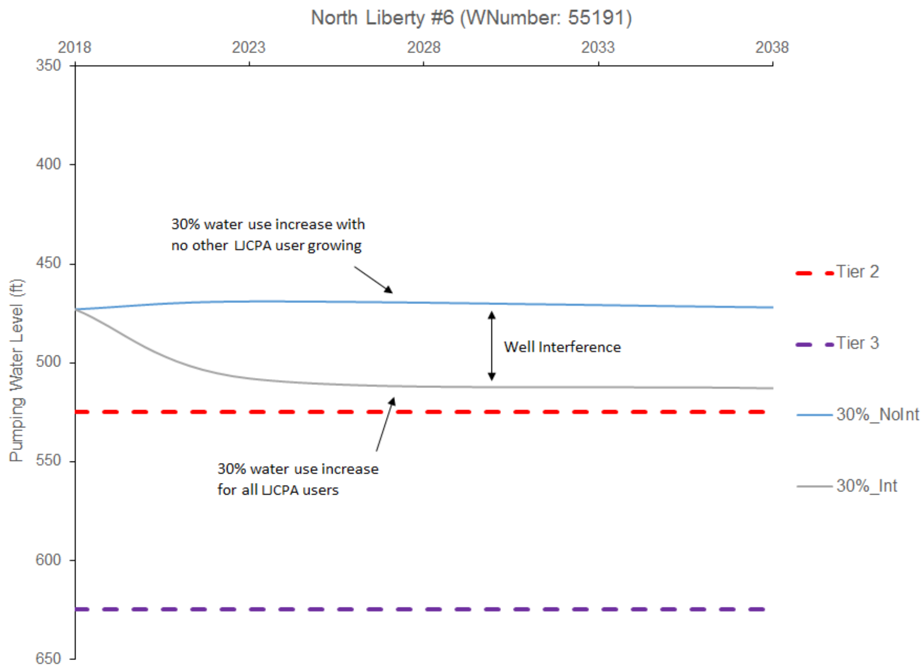

Figure AC-34: Well interference at North Liberty #6 with 30% growth in the LJPCA (North Liberty #7 used as an ASR well)

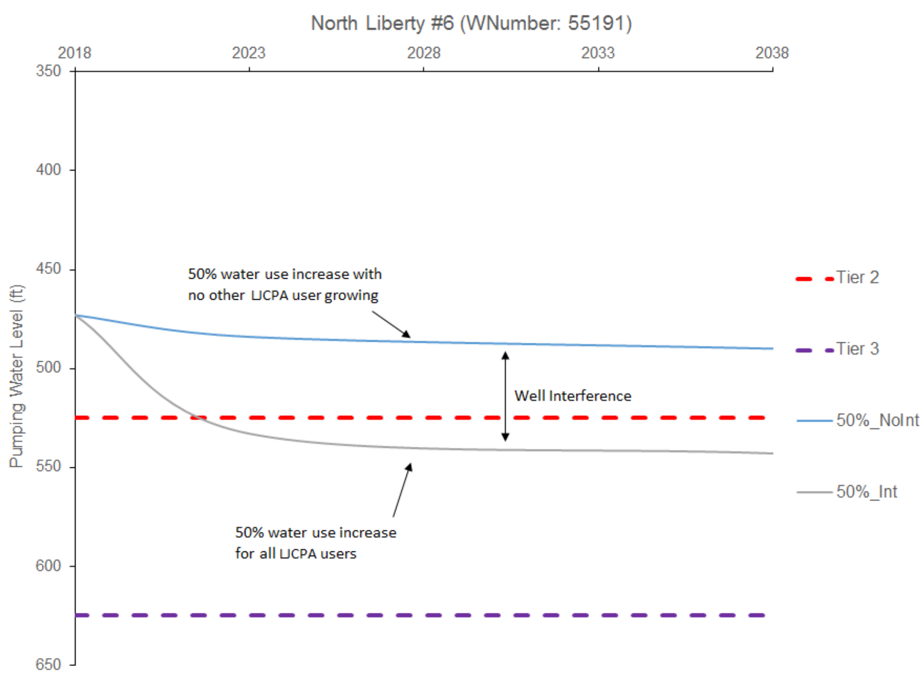

Figure AC-35: Well interference at North Liberty #6 with 50% growth in the LJPCA (North Liberty #7 used as an ASR well)

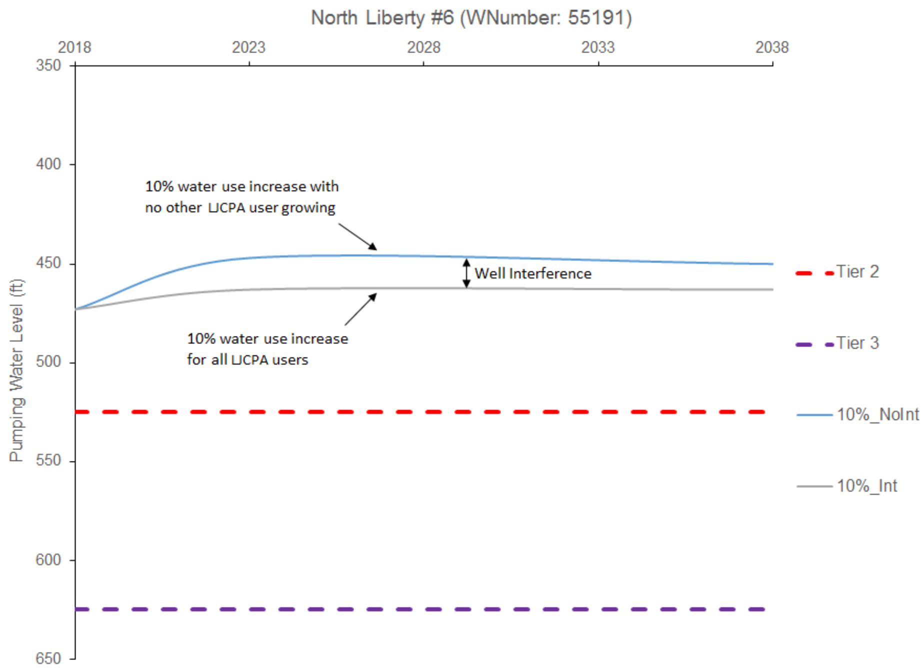

Figure AC-36: Well interference at North Liberty #6 with 10% growth in the LJPCA (North Liberty #7 used as production well)

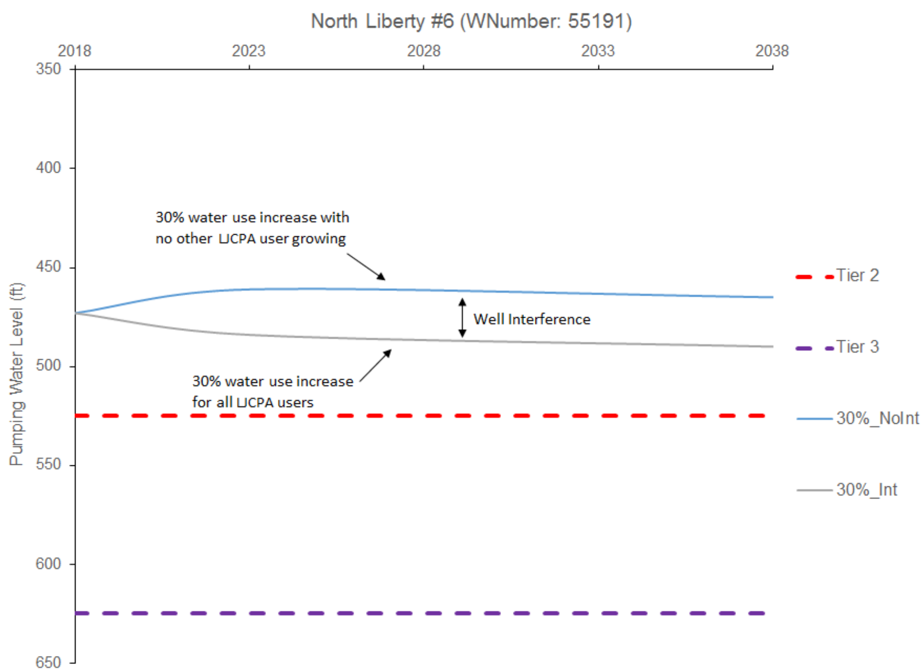

Figure AC-37: Well interference at North Liberty #6 with 30% growth in the LJPCA (North Liberty #7 used as production well)

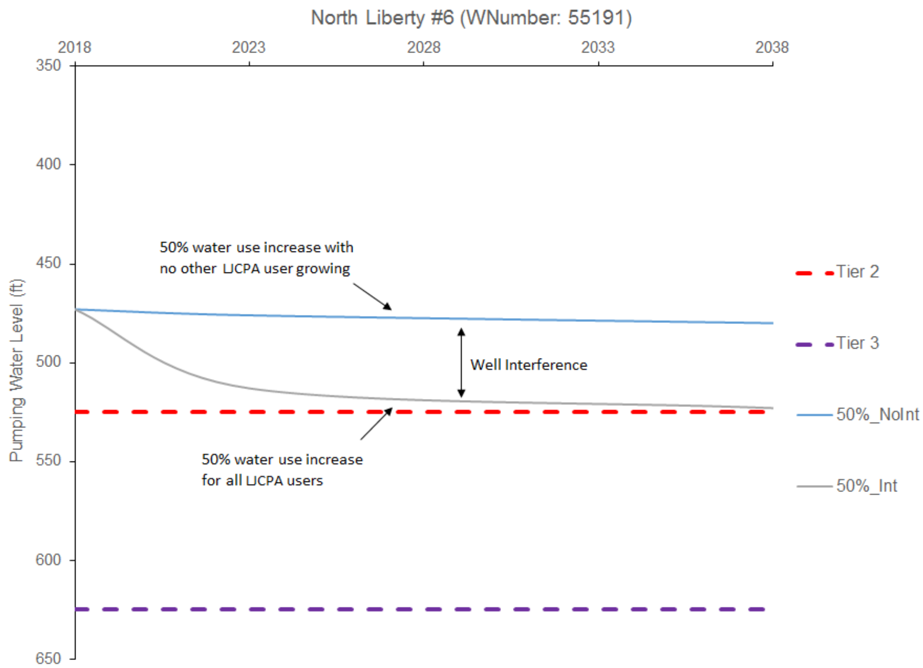

Figure AC-38: Well interference at North Liberty #6 with 50% growth in the LJPCA (North Liberty #7 used as production well)

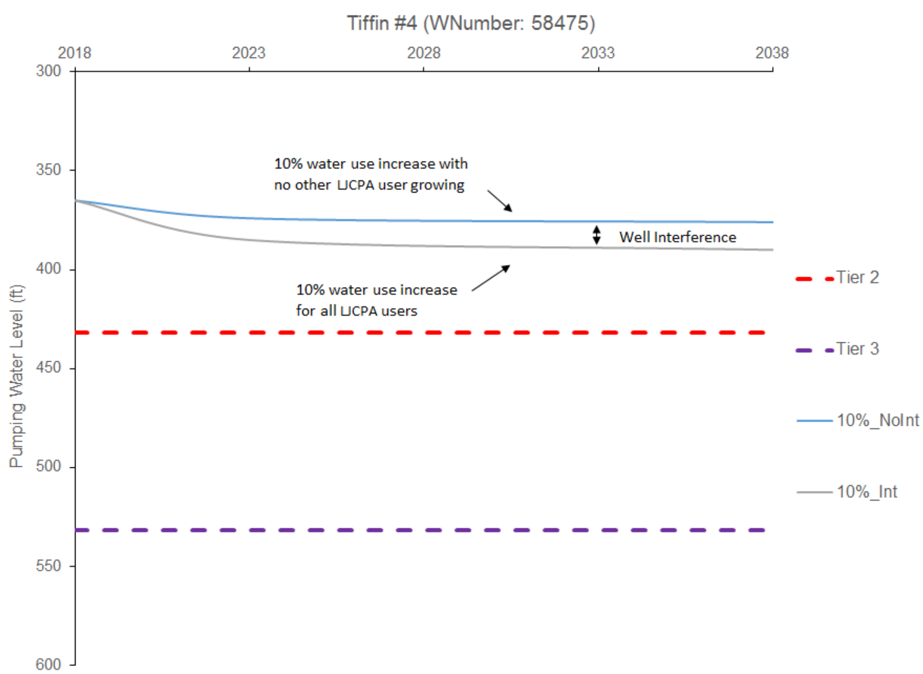

Figure AC-39: Well interference at Tiffin #4 with 10% growth in the LJPCA

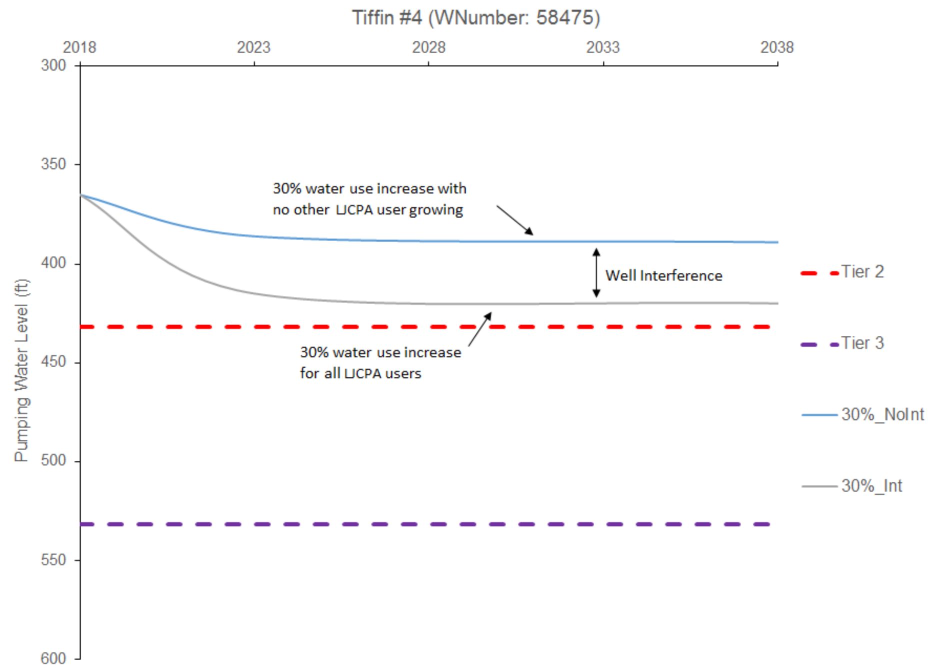

Figure AC-40: Well interference at Tiffin #4 with 30% growth in the LJPCA

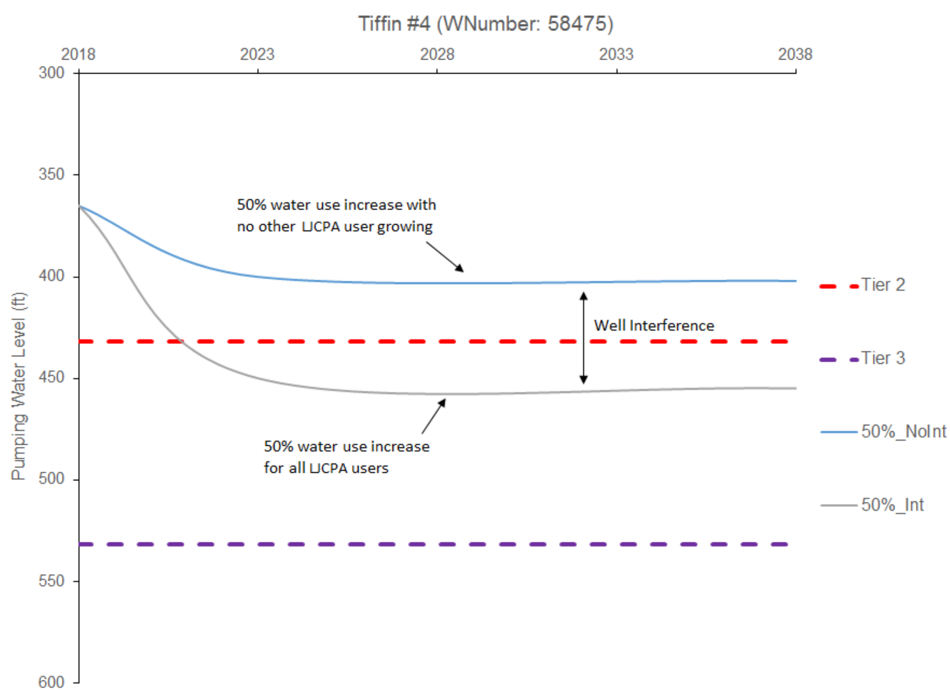

Figure AC-41: Well interference at Tiffin #4 with 50% growth in the LJPCA

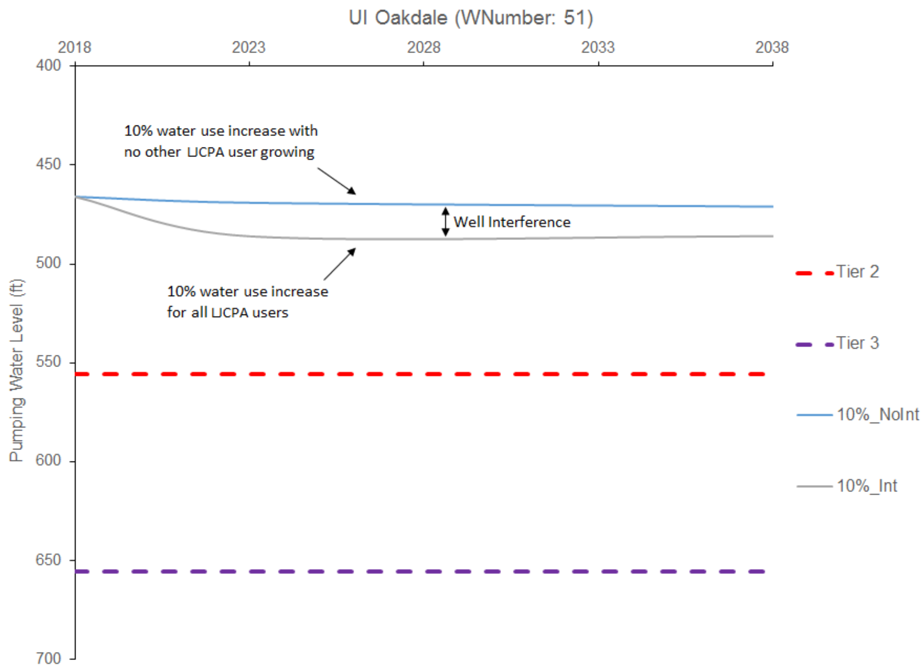

Figure AC-42: Well interference at the UI Oakdale well with 10% growth in the LJPCA

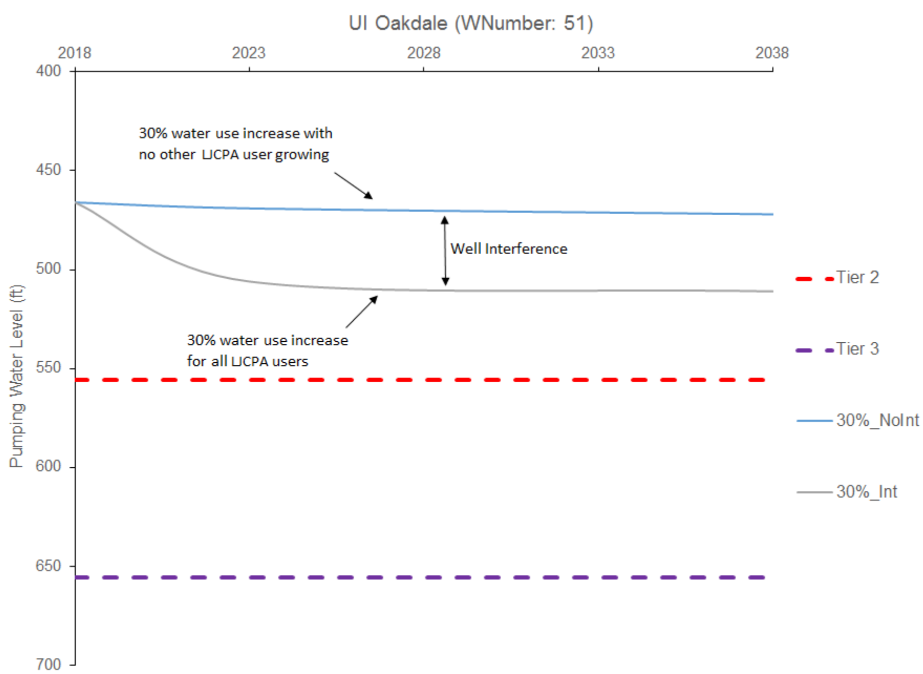

Figure AC-43: Well interference at UI Oakdale well with 30% growth in the LJPCA

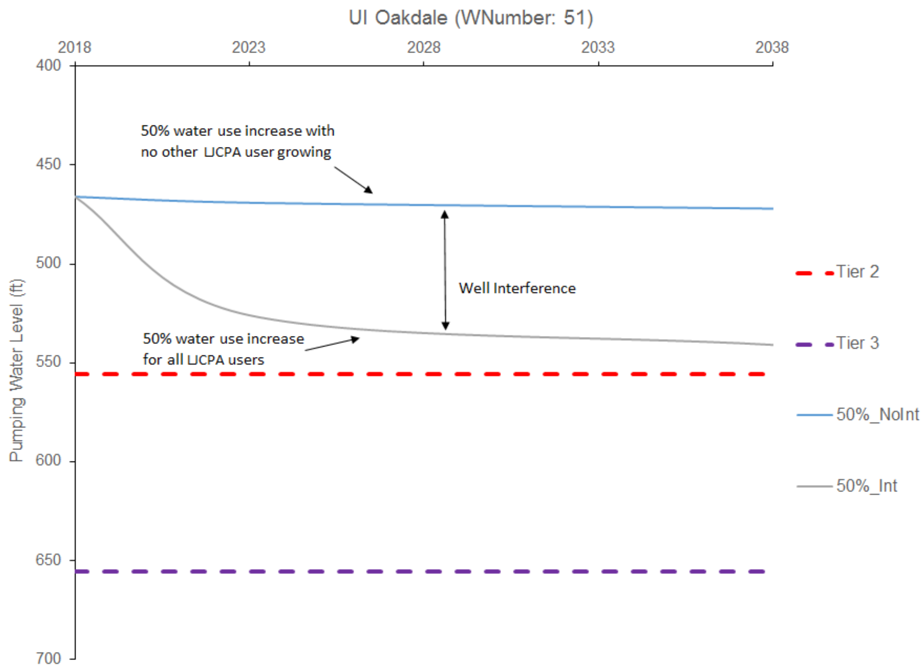

Figure AC-44: Well interference at UI Oakdale well with 50% growth in the LJPCA

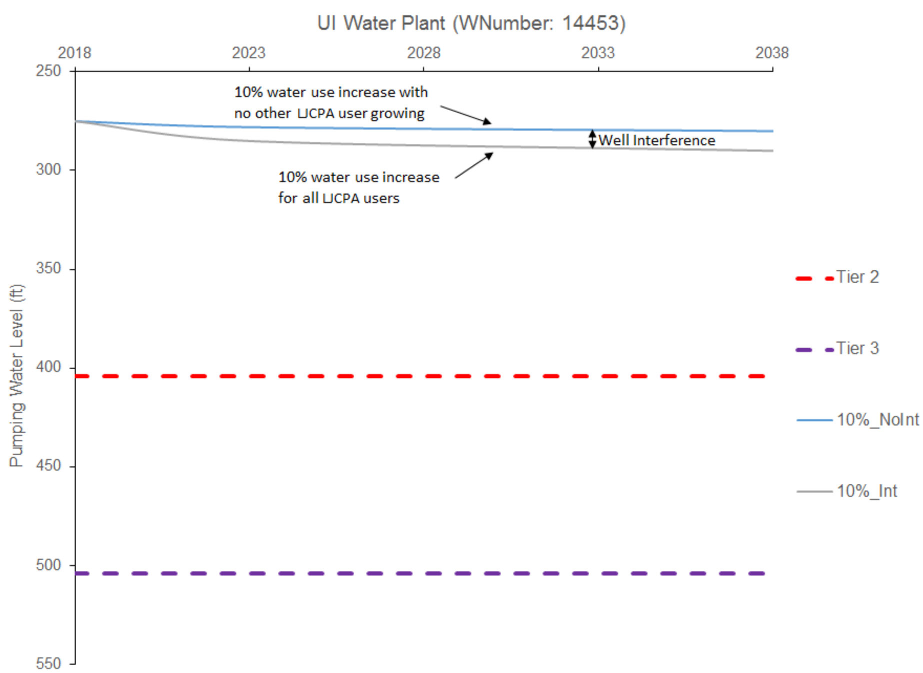

Figure AC-45: Well interference at the UI Water Plant well with 10% growth in the LJPCA

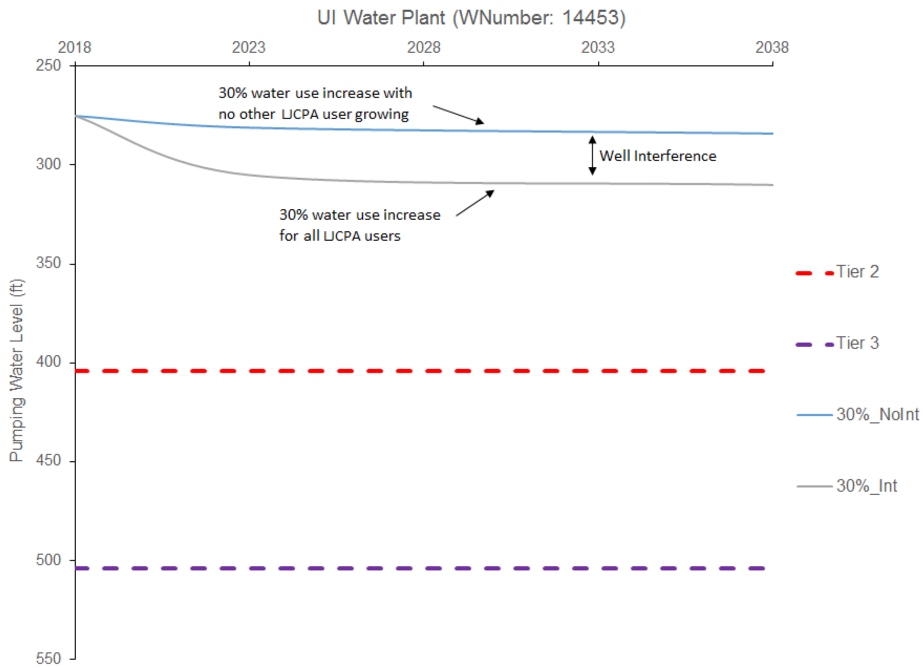

Figure AC-46: Well interference at the UI Water Plant well with 30% growth in the LJPCA

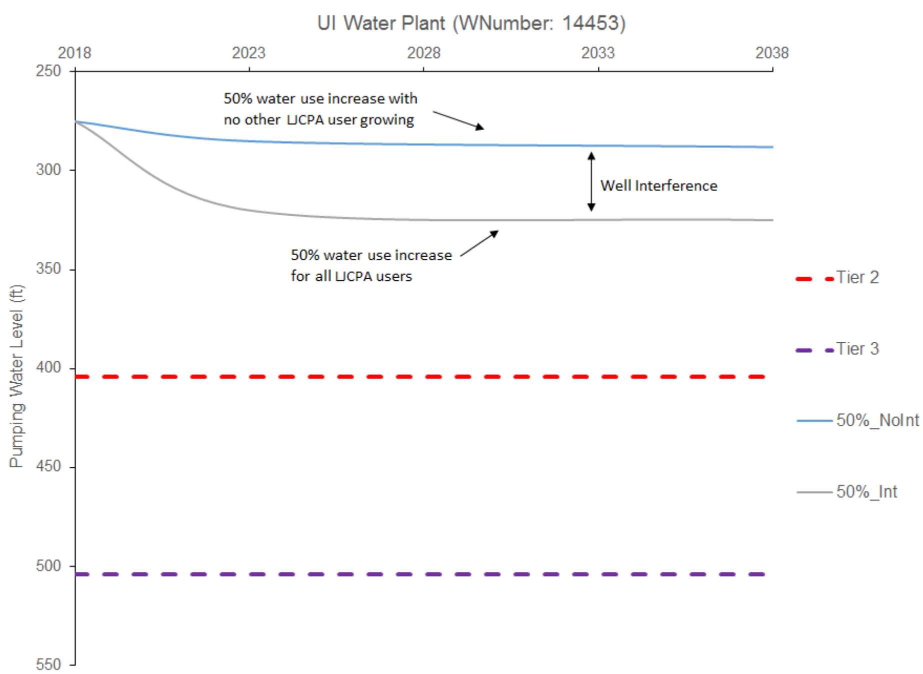

Figure AC-47: Well interference at the UI Water Plant well with 50% growth in the LJPCA