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TECHNICAL MEMORANDUM

To: Barton Springs/Edwards Aquifer Conservation District

From: Wade Oliver, P.G., INTERA
James Pinkard, INTERA

Date: April 16, 2018

RE: Recalibration and Predictive Simulations of the Analytic Element Tool to Evaluate the Trinity Aquifer in Hays County, Texas

INTRODUCTION:

This Technical Memorandum documents an evaluation of the Trinity Aquifer in Hays County, Texas performed by INTERA, Inc. for Barton Springs/Edwards Aquifer Conservation District (“BSEACD” or the “District”). Electro Purification, LLC (EP) is seeking a production permit from the District to produce up to 2.5 million gallons of groundwater annually from the Cow Creek layer of the Trinity Aquifer in central Hays County.

As part of the process of developing desired future conditions for the Trinity Aquifer, INTERA developed an analytic element groundwater model for the aquifer in this area in 2016 for Groundwater Management Area 10. For this earlier model we used the groundwater modeling code TTIM. TTIM is useful for evaluating impacts at the well-scale, though it does contain simplifications from the level of detail that is included in a typical MODFLOW-based groundwater availability model.

Since the development of the TTIM analytic element model in 2016, a series of aquifer tests were performed by EP with monitoring of many nearby wells. These provide valuable additional information on the hydrogeology of the aquifer. Since the Texas Water Development Board has not yet developed a groundwater availability model for the Trinity Aquifer that extends through this area, the modeling evaluation documented here builds on and is considered a recalibration of the TTIM model previously developed using the information derived from the additional aquifer tests. We have also run a series of predictive simulations using the recalibrated model to evaluate potential drawdown impacts in the individual units of the Trinity Aquifer, and on selected wells in the area, due to proposed pumping from the EP well field.

This memorandum documents the conceptual model of the Trinity Aquifer in central Hays County, the recalibration of the TTIM analytic element model, and the predictive simulations. The layout of the EP well field is shown in Figure 1 below.

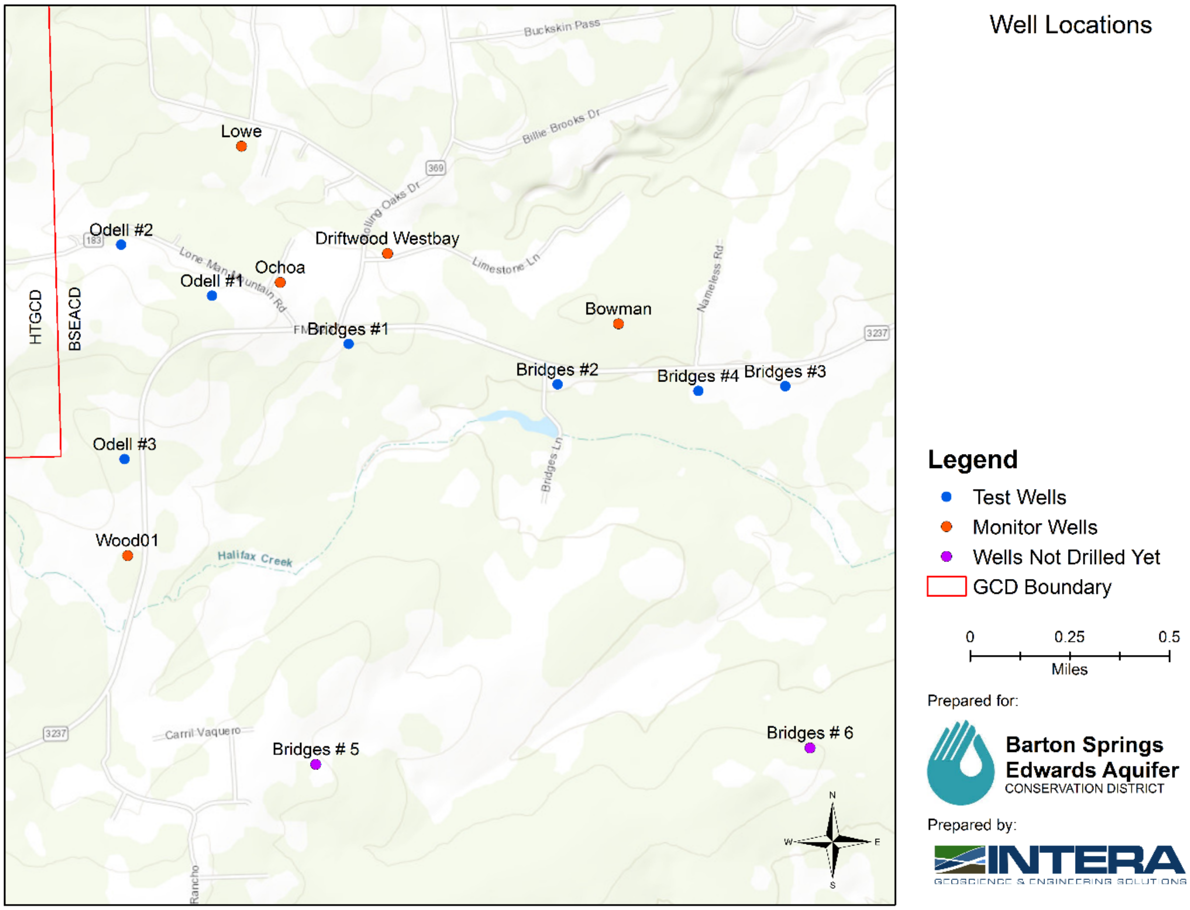

Figure 1. Electro Purification Well Field Layout

APPROACH:

Groundwater model development typically includes defining the conceptual model of groundwater flow prior to designing and calibrating the model for use in predictive simulations. The conceptual model of flow describes the current understanding of aquifer hydrogeology given available information and the purpose of the project. For this evaluation, we sought to better understand the hydraulic properties such as hydraulic conductivity and storativity and the degree of hydraulic connection between the various units within the Trinity Aquifer. The numerical model is the representation of this conceptual model of the aquifer in computer code. All models, by definition, are simplifications of reality. When developed and applied appropriately, however, they can be very useful in increasing the level of understanding about how the aquifer works, defining those characteristics of the aquifer that most determine how it responds to pumping and assisting decision-makers responsible for groundwater management.

CONCEPTUAL MODEL:

The conceptual model of the Trinity Aquifer in central Hays County has been described in several reports recently including the earlier modeling study (Oliver and others, 2016), the hydrogeologic report prepared for EP (WRGS, 2017), and by the District in Technical Memo 2018-0213 (Hunt and Smith, 2018). Briefly, the Trinity Aquifer in the vicinity of the EP well field underlies the Edwards formation. The Trinity Aquifer includes the upper and lower Glen Rose units, the Hensel, the Cow Creek, and the Sligo and Hosston formations of the Lower Trinity. The Hammett Shale is a confining unit that separates the Middle Trinity from the Lower Trinity. These units are shown in the stratigraphic chart in Figure 2.

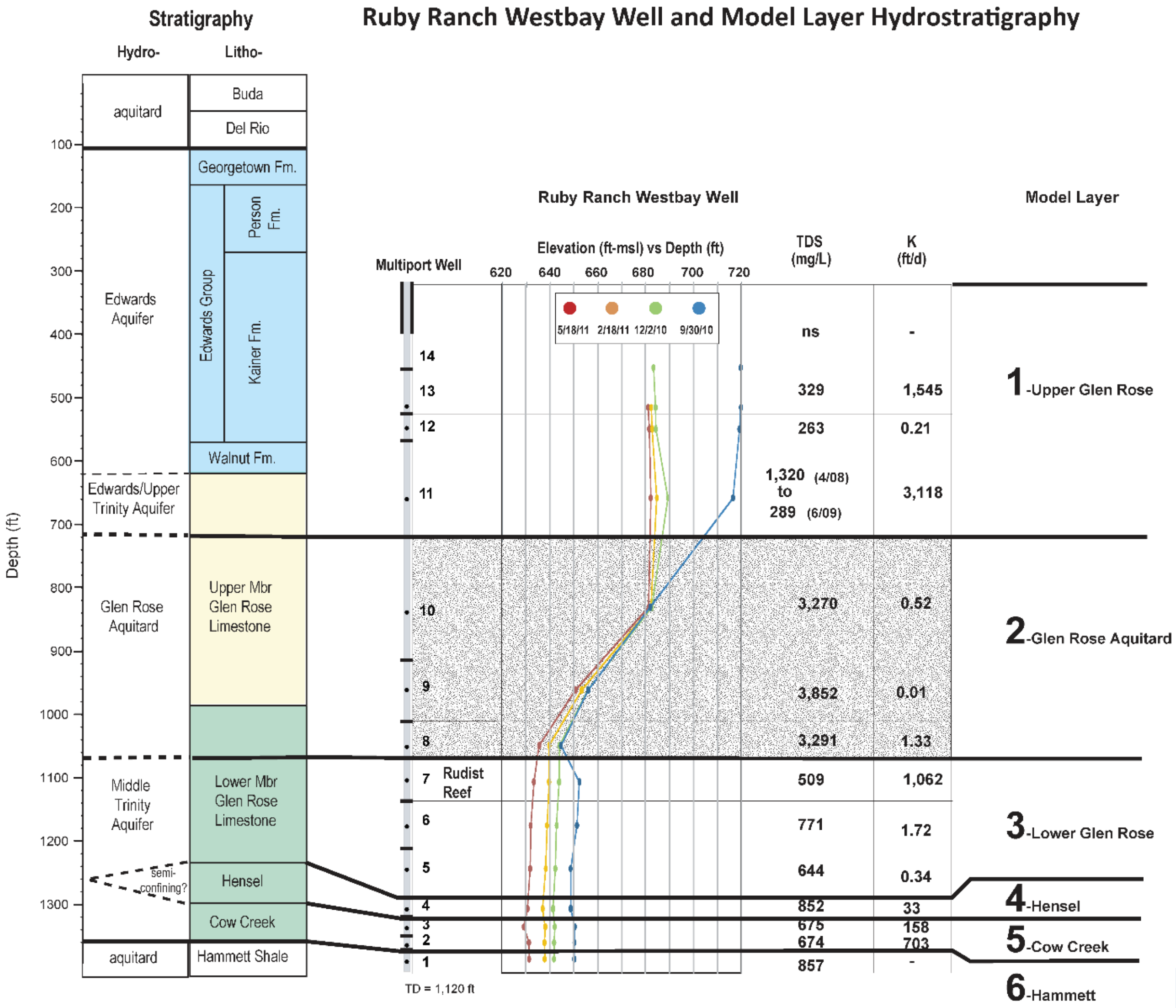

Figure 2. Stratigraphic chart, Ruby Ranch Westbay well, and model layer hydrostratigraphy

The geologic units of the Trinity Aquifer outcrop to the northwest of the EP well field and dip toward the southeast. The Balcones Fault Zone runs through Hays County and is oriented along strike from southwest to northeast. Hunt and Smith (2018) indicate several faults running through the EP well field including the Wimberley, East, and Rolling Oaks faults. These faults were most recently mapped by Collins (2002) and have the potential to impact and possibly restrict the movement of groundwater from recharge areas to the northwest.

One of the key hydrogeologic characteristics of the Trinity Aquifer that influences the impact of pumping from the Cow Creek in the EP well field is the vertical hydraulic conductivity of the Hensel. The Hensel is relatively thin unit that is generally low permeability and may limit flow between the Cow Creek and the shallower Lower Glen Rose. WRGS (2015) and WRGS (2017) refer to this unit as the Bexar Shale. One of the key findings in Oliver and others (2016) was that the vertical hydraulic conductivity of the Hensel is not well constrained and that modeled drawdowns in shallower units such as the Lower Glen Rose due to pumping in the EP well field are very sensitive to this parameter. A key focus of this analysis is to better constrain the Hensel vertical hydraulic conductivity in addition to other hydraulic properties.

The hydraulic properties derived from the analysis in Oliver and others (2016) are shown in Table 1 below.

Table 1. Hydraulic properties derived from the analysis in Oliver and others (2016)

Unit	Thickness (ft)	Horizontal K (ft/d)	Transmissivity (ft^2/d)	Vertical Anisotropy	Specific Storage
Edwards	65	1.00E+01		5.00E-01	7.94E-07
Upper Glen Rose	470	1.74E-03		1.68E-02	1.50E-05
Lower Glen Rose	195	2.33E-01	45.5	4.91E-01	3.29E-07
Hensel	45	1.00E-04	0.0	1.00E-02	1.52E-04
Cow Creek	75	6.06E+00	454.3	6.58E-02	1.00E-07
Hammett	50	5.00E-07		1.00E-02	1.00E-04

WRGS (2017) is the hydrogeologic evaluation prepared for EP in support of the production permit application for the well field. It also documents the most recent series of aquifer tests conducted in late 2016 during which the Bridges 1, Bridges 2 and Odell 2 wells were each tested for 5 days. We reviewed WRGS (2017), the District's review and request for clarifications on the report (BSEACD, 2017), and the letter addendum to the report provided by WRGS on behalf of EP (Khorzad, 2017).

In general, we agree with the technical observations by the District in BSEACD (2017) regarding the hydrogeologic evaluation. We did not assess the observations relating to the District's rules and guidelines. WRGS (2017) documents a series of sophisticated aquifer tests that appear to have collected very valuable data for the District. One issue identified by the District that we also identified in our review is that the analysis by WRGS uses an inconsistent conceptual model regarding the connection of the Cow Creek to the outcrop area. On the one hand, the report suggests that pumping of the EP well field will not influence formations near the surface or area springs because it is “isolated” by the overlying Hensel and faults. On the other hand, the report suggests that one key shortcoming of analytical evaluations of the aquifer (such as the TTIM evaluation documented here and the Theis approach used in the hydrogeologic evaluation) is that it does not include recharge to the aquifer, which occurs at the surface. If the aquifer is isolated from the surface, then recharge is not a relevant factor. If it is not isolated from the surface, then recharge is relevant, but so are the impacts of the pumping on shallow wells and discharges at the surface such as springs and seeps.

Another issue we identified is that the WRGS (2017) report does not quantify impacts to wells in formations above the Cow Creek such as the Lower Glen Rose. As described in Oliver and others (2016), even if one assumes the vertical hydraulic conductivity (Kv) of the Hensel is very restrictive, the drawdowns in the Cow Creek are of such a magnitude that they can still create significant drawdowns in the shallower units even with a Kv as low as 10^{-4} or 10^{-5} feet per day. There are also some responses in the shallow units during the test that WRGS dismisses as erroneous that may point to a connection between the units (for example, the delayed drawdown in Odell 1). These responses are discussed in additional detail in BSEACD Technical Memo 2017-1010.

NUMERICAL MODEL:

Model Code:

The code chosen for this analysis is the transient analytic element groundwater modeling code known as TTIM (Bakker, 2015). TTIM was selected because it contains many characteristics that are key to this analysis including the ability to calibrate to pumping tests and evaluate drawdowns at a local scale for aquifers overlying and underlying the pumping unit (Cow Creek). A TTIM analytic element model can be developed much more cost effectively than a MODFLOW groundwater availability model. However, there are characteristics of the aquifer that are not simulated as part of the TTIM analysis. For instance, a MODFLOW groundwater availability model has aquifer properties that can vary spatially. A TTIM model assumes uniform aquifer properties horizontally within a particular unit. Similarly, a MODFLOW model can incorporate spatially varying aquifer structure and thickness. A TTIM model assumes uniform aquifer thickness. MODFLOW groundwater models have user-defined cell sizes. For the Texas Water Development Board’s groundwater availability models, this is typically 1 mile by 1 mile. By contrast, a TTIM model is not limited by a user-defined cell size. Instead, the water level change (drawdown) is calculated at user-defined locations. That is, it can calculate drawdown at individual wells.

Given these differences in the assumptions and limitations of each of the modeling codes, MODFLOW is typically better suited for large, regional-scale groundwater resource evaluations. With its ability to evaluate impacts at individual well sites, TTIM is typically better suited for more local scale evaluations such as the EP well field.

Model Calibration:

As with the model calibration described in Oliver and others (2016), the calibration of the analytic element model described here focused on matching – to the extent possible – the results of the aquifer tests. We used the parameter estimation code PEST (Watermark, 2004) to aid in the matching of drawdowns in the pumping tests during model calibration. When using PEST, each of the model parameters were adjusted within a reasonable range guided by the conceptual model to better match observed water level declines.

For the calibration, we did not perform a single calibration setup that spanned all three aquifer tests. This would have been inappropriate because we do not have information on all the aquifer stresses (for example, pumping rates and times for all wells in the area) during the interim period between tests. Instead, we performed three separate calibrations to determine the hydraulic properties that best match the results of each test. Figure 3 shows the relationship between the measured and modeled water levels in wells calibrated to the Bridges 2 aquifer test. Figure 4 shows the relationship between the measured and modeled water levels in wells calibrated to the Bridges 1 aquifer test. Figure 5 shows the relationship between the measured and modeled water levels in wells calibrated to the Odell 2 aquifer test.

The aquifer parameters resulting from this approach for each test are shown in the right three columns of Table 2. These parameters are most reliable for the Cow Creek unit as that is where the majority of the monitoring wells were screened. The calibrated horizontal hydraulic conductivity of the Cow Creek among the three separate calibrations ranged from 2.7 to 13.9 feet per day. This is consistent with the range of hydraulic conductivities reported in WRGS (2017).

The calibrated vertical hydraulic conductivity of the Hensel, the parameter that most determines how much drawdowns in the Cow Creek impact shallower units like the Lower Glen Rose, ranged from 0.006 to 0.05 feet per day. This is significantly higher than the 1×10^{-6} value used in Oliver and others (2016) and is primarily driven by the drawdown observed in the Lower Glen Rose during each of the aquifer tests. For example, during the Bridges 2 aquifer test, the shallow portion of the Bridges 2 well, sealed off by a packer and denoted as “upbridge_well2” in Figure 3, shows approximately 8 feet of drawdown. Similar responses are also seen in the shallow portions of the Bridges 1 and Odell 2 wells sealed off from the producing interval by a packer. Though there are not abundant data points on which to base this conclusion, the results that are available suggest that the Hensel acts as a leaky confining layer, not a layer that hydrologically isolates the Cow Creek from shallower units like the Lower Glen Rose.

The final hydraulic parameters for the model are also shown in Table 2, along with a comparison to the values used in Oliver and others (2016). We selected the final values using 1) the calibrated values from the three aquifer tests, and 2) professional judgement given the conceptual model of the aquifer and the purpose of the modeling simulation. For example, the calibrated parameters are generally three significant digits and among the tests can vary over orders of magnitude. The final values are generally 1 to 2 significant digits.

Given the purpose of the modeling as an evaluation of the expected impacts of pumping the Cow Creek, the final value we selected for the vertical hydraulic conductivity of the Hensel was 10^{-5} feet per day. While this is an order of magnitude higher than the value used during the modeling in Oliver and others (2016), it is 2 to 3 orders of magnitude more restrictive than the vertical hydraulic conductivity indicated through the results of the aquifer test. This approach was taken so that the quantitative modeled impacts to the shallower units presented later in this report can be considered conservative. As shown in Oliver and others (2016), which included a sensitivity analysis of results to the vertical hydraulic conductivity of the Hensel, drawdowns in the Lower Glen Rose will be greater at higher hydraulic conductivities such as those estimated in the individual aquifer tests. The horizontal hydraulic conductivity of the Cow Creek, 4 feet per day, is consistent with the values estimated in the individual aquifer tests, in WRGS (2017), and in Hunt and Smith (2018).

Figures 6, 7 and 8 show the relationship between measured and modeled drawdowns for the Bridges 2, Bridges 1, and Odell 2 aquifer tests, respectively, using the final hydraulic parameters shown in Table 2.

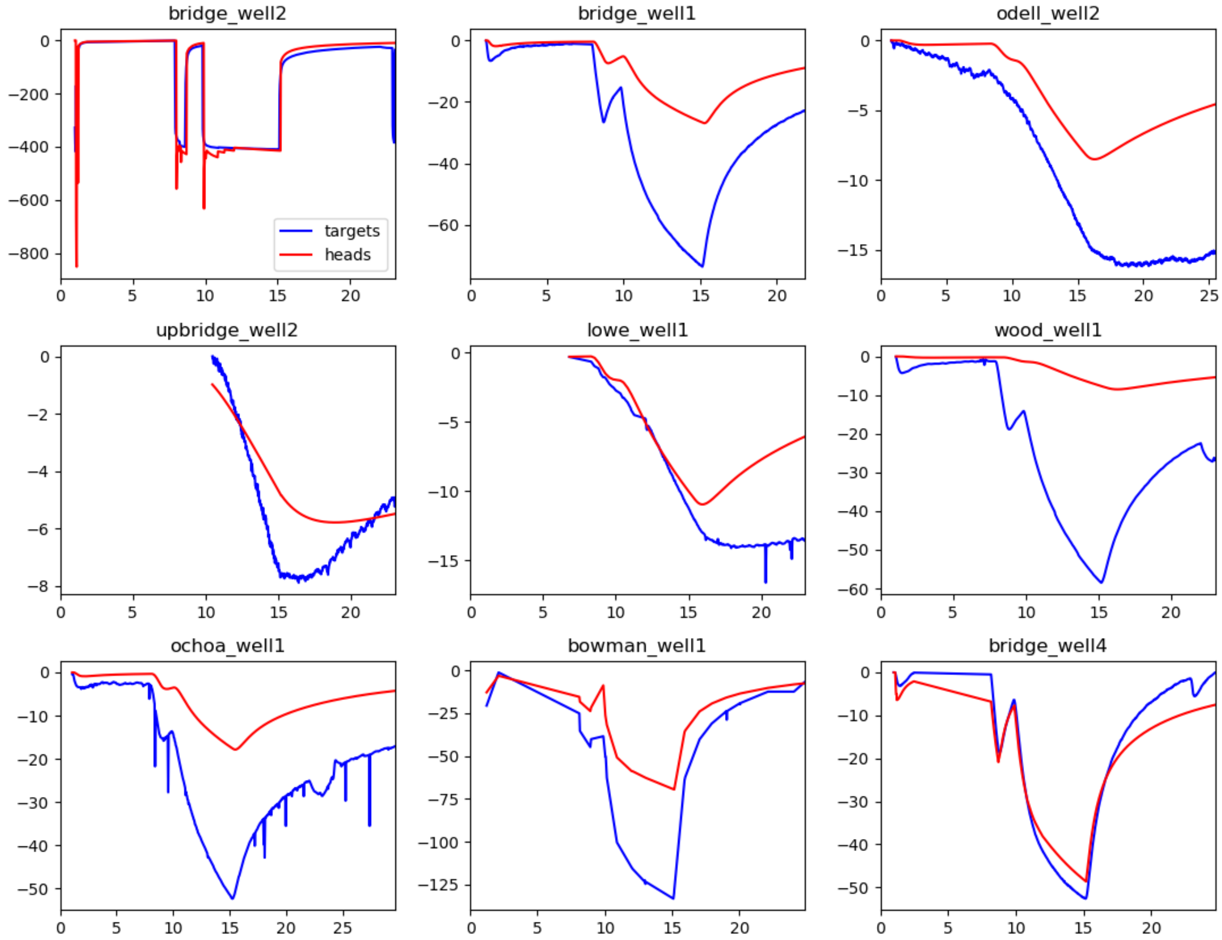

Figure 3. Measured (blue) versus modeled (red) drawdown in feet in wells calibrated to the Bridges 2 aquifer test.

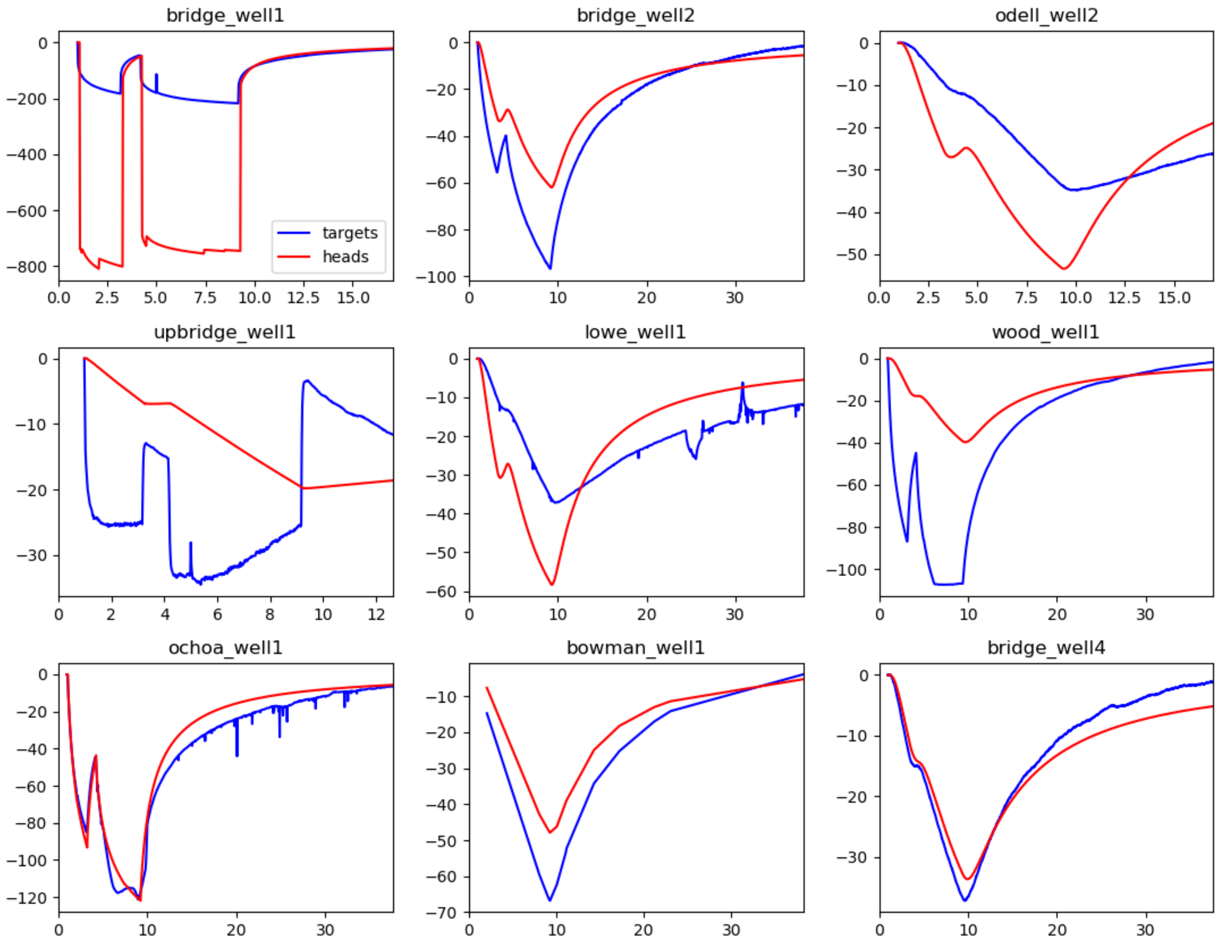

Figure 4. Measured (blue) versus modeled (red) drawdown in feet in wells calibrated to the Bridges 1 aquifer test.

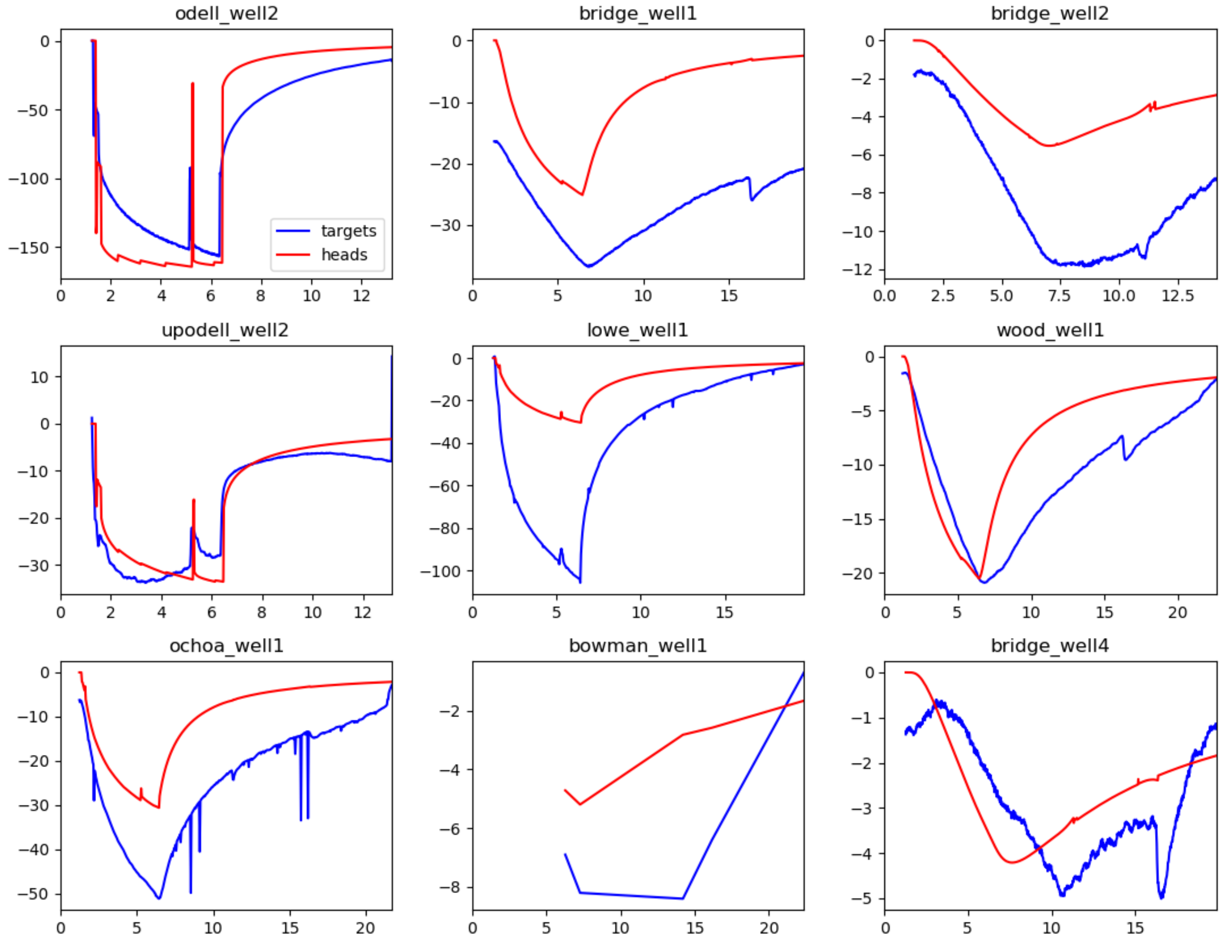

Figure 5. Measured (blue) versus modeled (red) drawdown in feet in wells calibrated to the Odell 2 aquifer test.

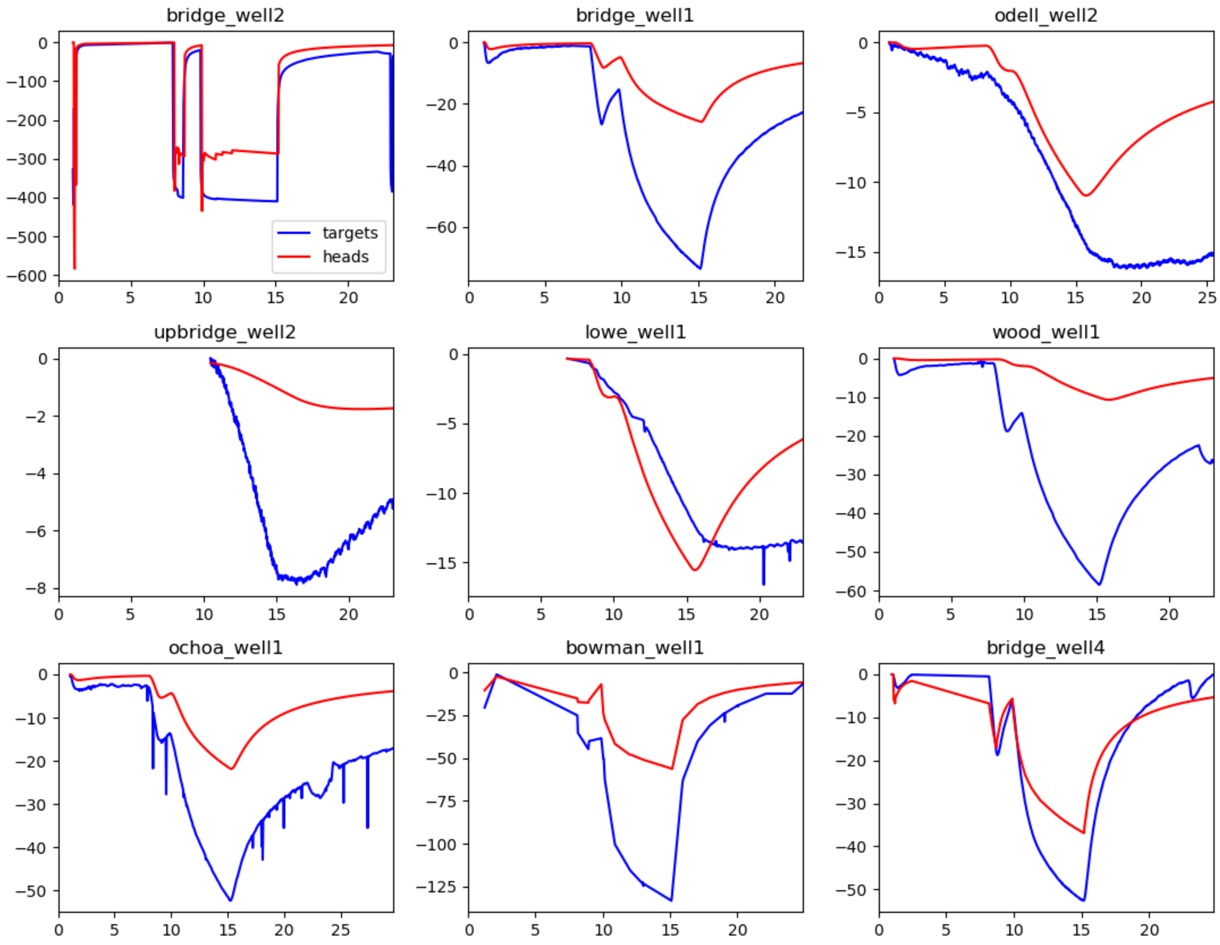

Figure 6. Measured (blue) versus modeled (red) drawdown in feet in wells with final calibration parameters during the Bridges 2 aquifer test.

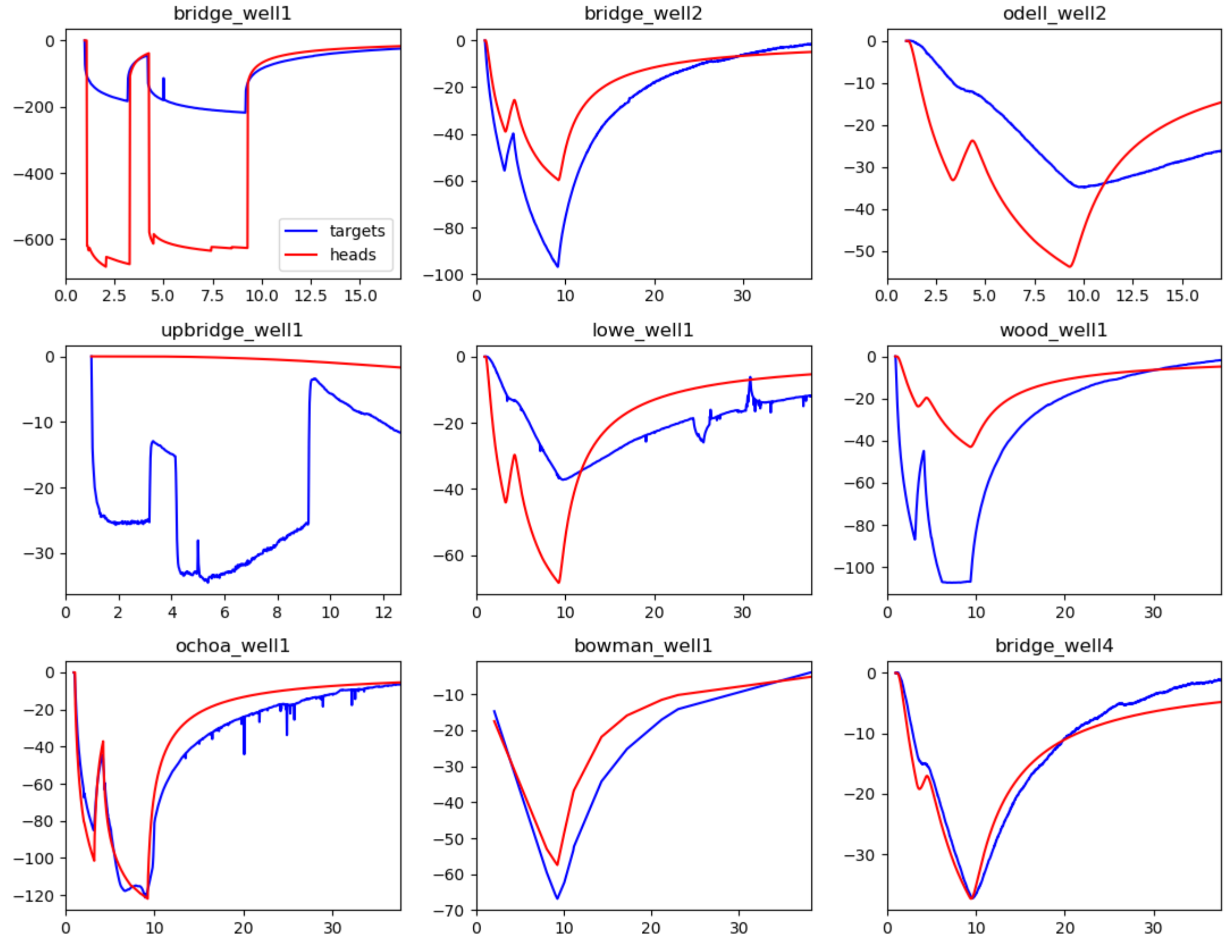

Figure 7. Measured (blue) versus modeled (red) drawdown in feet in wells with final calibration parameters during the Bridges 1 aquifer test.

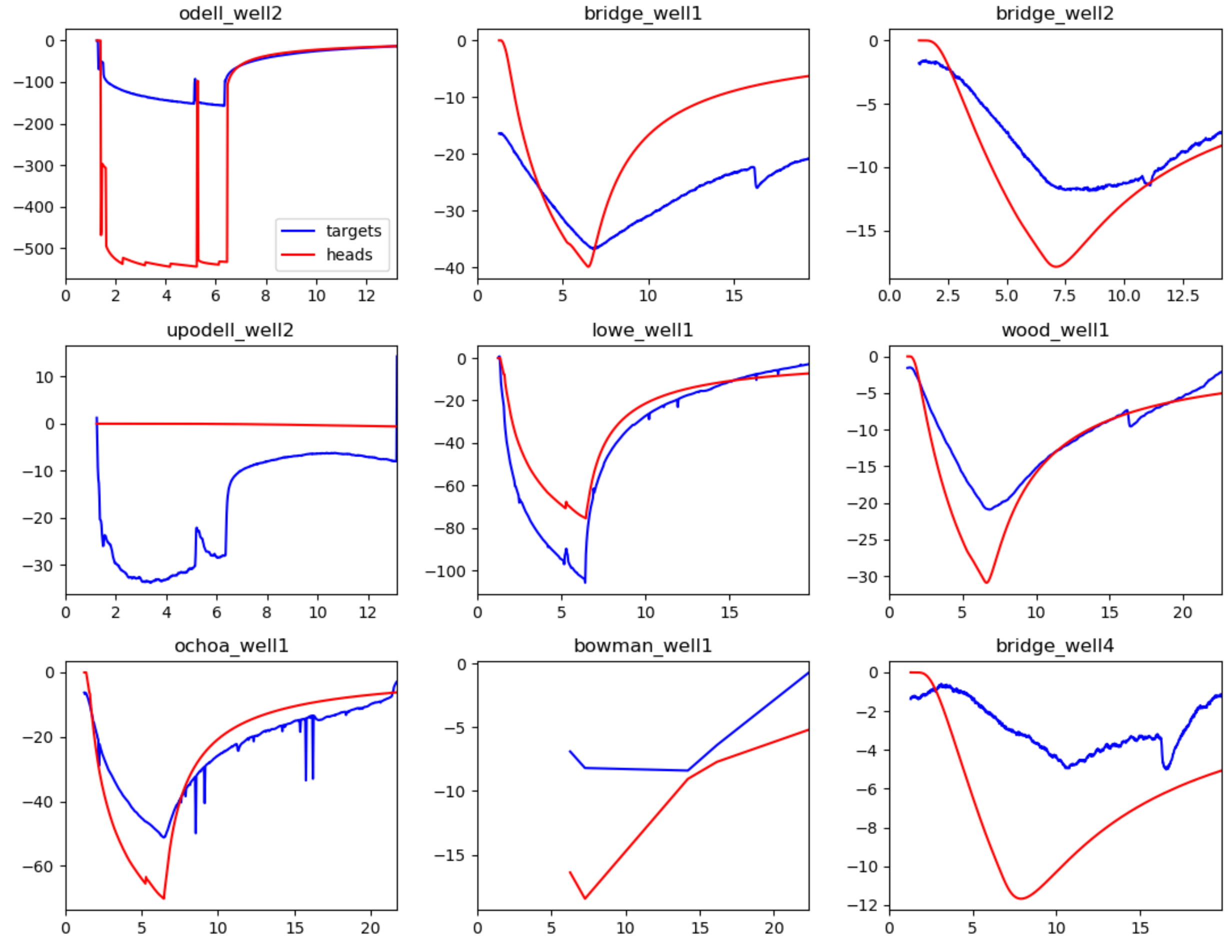

Figure 8. Measured (blue) versus modeled (red) drawdown in feet in wells with final calibration parameters during the Odell 2 aquifer test.

Table 2. Comparison of hydraulic properties for each unit in the analytical model. Final values are shown along with a comparison to the study for GMA 10 (Oliver and others, 2016), and the parameters from calibrating to the individual aquifer tests.

Unit	Parameter	Final Value	Anisotropy	GMA10 Study	GMA 10 Anisotropy	Bridges1	Bridges2	Odell2
Upper Glen Rose	Kh (ft/d)	**1.00E-03**		1.74E-03		1.58E-04	1.09E-03	1.58E-04
Upper Glen Rose	Kv (ft/d)	**1.00E-05**	**1.00E-02**	2.92E-05	1.68E-02	1.00E-02	1.00E-02	1.00E-05
Upper Glen Rose	Ss (1/ft)	**1.50E-05**		1.50E-05		5.00E-07	5.00E-07	5.00E-07
Lower Glen Rose	Kh (ft/d)	**2.50E-01**		2.33E-01		2.00E-03	2.00E-02	2.00E-02
Lower Glen Rose	Kv (ft/d)	**1.00E-01**	**4.00E-01**	1.14E-01	4.91E-01	2.80E-04	4.27E-04	1.00E-04
Lower Glen Rose	Ss (1/ft)	**1.00E-06**		3.29E-07		1.00E-06	1.21E-06	1.00E-06
Hensel	Kh (ft/d)	**1.00E-04**		1.00E-04		3.05E-05	1.00E-04	3.63E-02
Hensel	Kv (ft/d)	**1.00E-05**	**1.00E-01**	1.00E-06	1.00E-02	1.00E-02	5.87E-03	5.00E-02
Hensel	Ss (1/ft)	**1.00E-06**		1.52E-04		1.00E-06	1.00E-06	1.00E-06
Cow Creek	Kh (ft/d)	**4.00E+00**		6.06E+00		3.23E+00	2.67E+00	1.39E+01
Cow Creek	Kv (ft/d)	**4.00E-01**	**1.00E-01**	3.99E-01	6.58E-02	3.62E-01	7.76E-04	2.03E-01
Cow Creek	Ss (1/ft)	**8.00E-07**		1.00E-07		8.00E-07	8.00E-07	8.00E-07
Hammett	Kh (ft/d)	**1.00E-07**		5.00E-07		1.41E-07	1.41E-07	1.41E-07
Hammett	Kv (ft/d)	**1.00E-09**	**1.00E-02**	5.00E-09	1.00E-02	1.00E-09	1.00E-09	1.00E-09
Hammett	Ss (1/ft)	**1.00E-06**		1.00E-04		2.72E-06	2.72E-06	2.72E-06

PREDICTIVE SIMULATIONS:

Following the calibration of the model to each of the aquifer tests and finalizing representative hydraulic properties for each of the aquifer units, we used the model to evaluate the potential long-term impacts of pumping in the well field under a range of scenarios chosen in coordination with the District. The results of these scenarios are described below. Cross-sections of drawdown in the Cow Creek and Lower Glen Rose aquifers for each of the scenarios are shown in the Appendix.

Scenario Parameters:

Each of the scenarios described below uses the same hydraulic properties and reflects drawdowns that occur over a period of 7 years. The differences between the scenarios relate to the magnitude of pumping – ranging from 0.5 to 2.5 million gallons per day – and the locations of the pumping wells.

The Bridges 1 well was chosen to represent drawdowns in the EP well field because of its location at the center of the field. Driftwood Westbay well modeled drawdowns are also shown. This well is located approximately one-quarter mile north of the well field and is equipped to monitor water levels in discrete zones of the aquifer. During production from the well field, data from this well could be used to monitor the impacts of pumping on neighboring properties and evaluate how closely measured impacts match predicted impacts.

Scenario 1: Pumping of 2.5 Million Gallons Per Day (MGD)

Scenario 1 represents a 7-year predictive simulation with pumping in the seven wells which have already been drilled (Figure 1). Note that this includes Odell 1 even though it was recently recompleted to the Lower Glen Rose and is no longer screened in the Cow Creek. This was done to address comments by the District on WRGS (2017) in which pumping as assigned to wells that had not yet been drilled (Bridges 5 and Bridges 6).

Table 3 shows the pumping rates for each well, which was guided by the assumptions used in WRGS (2017) and Khorzad (2018). Bridges 1 had the highest rate at 645 gallons per minute. Bridges 3 had the lowest rate at 48 gallons per minute.

Table 4 shows the drawdown for Scenario 1 for each unit of the Upper and Middle Trinity at the Bridges 1 well and the nearby Driftwood Westbay well. The Cow Creek exhibited the highest drawdown - over 1,000 feet. Since Bridges 1 is a pumping well, this is considered a pumping-level drawdown. In the nearby Driftwood Westbay well, the drawdown is much less, about 550 feet, but still significant.

Drawdowns in the Lower Glen Rose are also much less than the Cow Creek, but still significant despite the low vertical hydraulic conductivity used for the Hensel in the model. In both the Bridges 1 and Driftwood Westbay wells the drawdown in the Lower Glen Rose is about 175 feet after 7 years. There is little to no drawdown in the overlying Upper Glen Rose unit during this period.

Scenarios 2, 3, and 4: Pumping Reduced from Maximum

Scenarios 2, 3 and 4 represent pumping from the same wells as in Scenario 1, but with the rate of pumping reduced by 30 percent, 50 percent and 80 percent, respectively. The purpose of these runs is to show the drawdown impact that could occur if the well field does not produce at the full 2.5 million gallons per day capacity discussed in WRGS (2017). For the field as a whole, Scenarios 2, 3 and 4 contain 1.75, 1.25 and 0.5 million gallons of pumping per day (Table 3)

As one would expect, reducing the pumping results in less drawdown than Scenario 1 (Table 4). For example, in Scenario 4 the production of 0.5 million gallons per day (347 gallons per minute) from the field results in a drawdown of about 210 feet at Bridges 1 and 110 feet at the Driftwood Westbay well. Drawdown impacts in the Lower Glen Rose are reduced as well relative to Scenario 1.

Figures 9 and 10 show the drawdown in the Cow Creek for Scenario 3 at the EP well field and in southeast Hays County, respectively. While the greatest drawdown is at the well field, the model indicates that drawdowns of more than 40 feet will occur in the Cow Creek across most of the county. It is important to note that at the county scale, some of the assumptions inherent with the analytic element modeling approach are not as valid as at the well field scale. For example, we would expect drawdowns to preferentially propagate along the strike of the aquifer from the southwest to the northeast as opposed to down dip given the faulting in the area, consistent with the drawdown observations during the aquifer testing (Hunt and Smith, 2018).

Figures 11 and 12 show the drawdown in the Lower Glen Rose for Scenario 3 at the EP well field and in southeast Hays County, respectively. The magnitude of drawdown in the Lower Glen Rose is less than that of the Cow Creek shown in Figures 9 and 10, though significant drawdowns are expected in the unit across a large area of Hays County as well for this scenario.

Scenarios 5: Pumping 2.5 Million Gallons Per Day (MGD) from 5 Wells

WRGS (2017) describes the intention of EP to equip the well field to produce from only five wells. Three of these wells have already been drilled (Odell 2, Bridges 1, and Bridges 2) and two have not yet been drilled (Bridges 5 and Bridges 6). According to WRGS (2017), these latter two wells will be located along the southern boundary of the Bridges property and will each be equipped to produce at 325 gallons per minute. For Scenario 5 we used the pumping rates for each of these five wells specified in WRGS (2017). Note that the actual production capacity of these two wells is not known because they have not yet been drilled.

Table 4 shows the drawdown for this scenario at the Bridges 1 and Driftwood Westbay wells. In general, Scenario 5 shows less drawdown in these wells than Scenario 1, primarily because the pumping rate in Bridges 1 is less in Scenario 5 and a significantly amount of pumping has shifted to the southern end of the property away from the Driftwood Westbay well. On the well field scale, it is likely that the Scenario 5 arrangement results in less well interference than the arrangement in Scenario 1. At the regional scale and in shallower units it is unlikely that there will be significant differences in impacts between Scenario 1 and Scenario 5 since the total pumping rate is the same.

Table 3. Pumping rates for each predictive model run scenario by well

Well Name	Already Drilled?	Pumping Rate by Scenario (gallons per minute)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Odell 1	Yes	95	67	48	19	
Odell 2	Yes	560	392	280	112	550
Odell 3	Yes	175	123	88	35	
Bridges 1	Yes	645	452	323	129	436
Bridges 2	Yes	148	104	74	30	100
Bridges 3	Yes	48	34	24	10	
Bridges 4	Yes	66	46	33	13	
Bridges 5	No					325
Bridges 6	No					325
Total Pumping (gallons per minute)		**1,737**	**1,216**	**869**	**347**	**1,736**
Total Pumping (million gallons per day)		**2.50**	**1.75**	**1.25**	**0.50**	**2.50**

Table 4. Predictive simulation drawdowns (in feet) for scenarios 1 through 5

Run Length		**7 Years**				
Field Pumping Rate (MGD)		**2.5**	**1.75**	**1.25**	**0.5**	**2.5**
Number of Wells		**7**	**7**	**7**	**7**	**5**
Unit	**Site**	**Scen1**	**Scen2**	**Scen3**	**Scen4**	**Scen5**
Upper Glen Rose	Bridges 1	-2	-1	-1	0	-2
Lower Glen Rose	Bridges 1	-176	-123	-88	-35	-172
Hensel	Bridges 1	-452	-316	-226	-90	-392
Cow Creek	Bridges 1	-1063	-744	-531	-213	-838
Trinity	Bridges 1	-980	-686	-490	-196	-776
Upper Glen Rose	Driftwood Westbay	-2	-1	-1	0	-2
Lower Glen Rose	Driftwood Westbay	-175	-123	-88	-35	-171
Hensel	Driftwood Westbay	-361	-253	-180	-72	-327
Cow Creek	Driftwood Westbay	-548	-384	-274	-110	-485
Trinity	Driftwood Westbay	-514	-360	-257	-103	-456

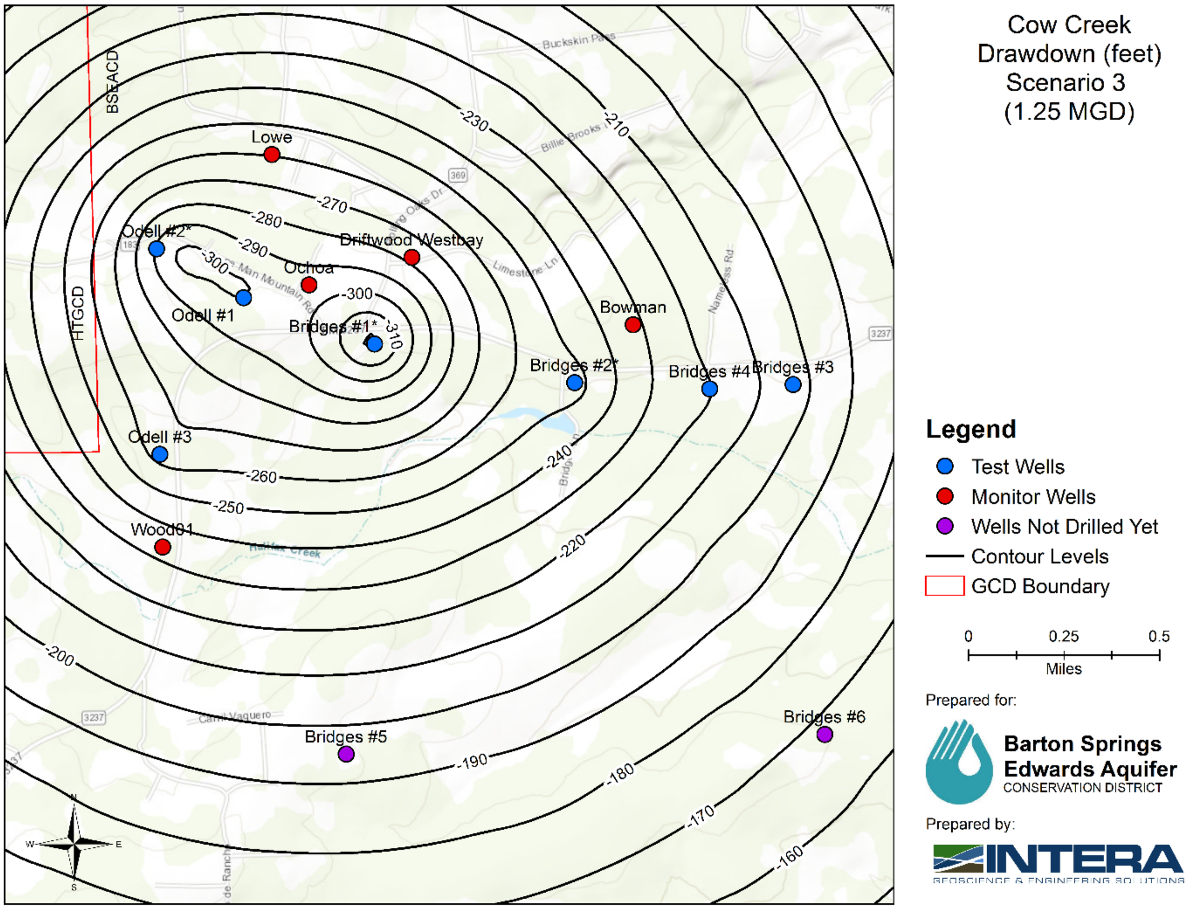

Figure 9. Estimated drawdown after 7 years in the Cow Creek near the EP well field for Scenario 3 (1.25 million gallons per day)

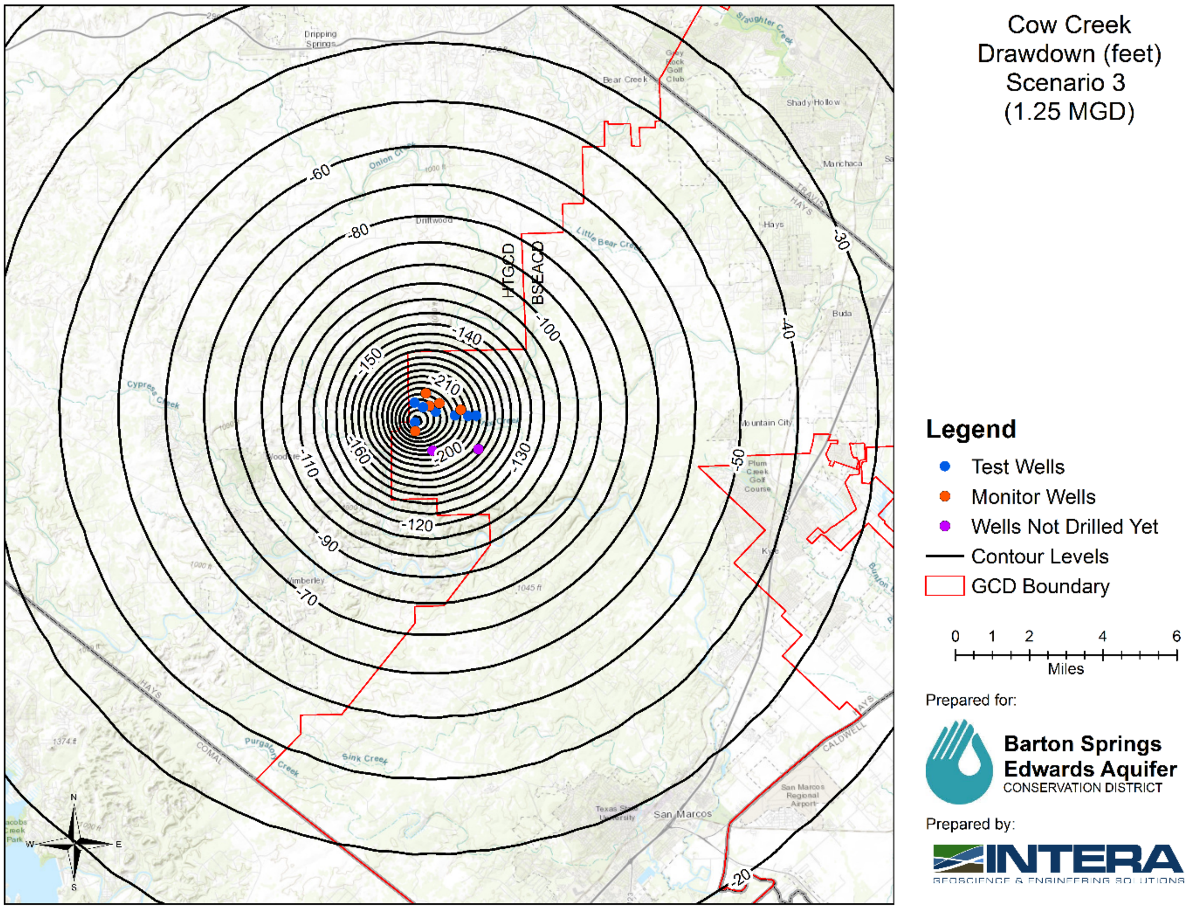

Figure 10. Estimated drawdown after 7 years in the Cow Creek in southeast Hays County for Scenario 3 (1.25 million gallons per day)

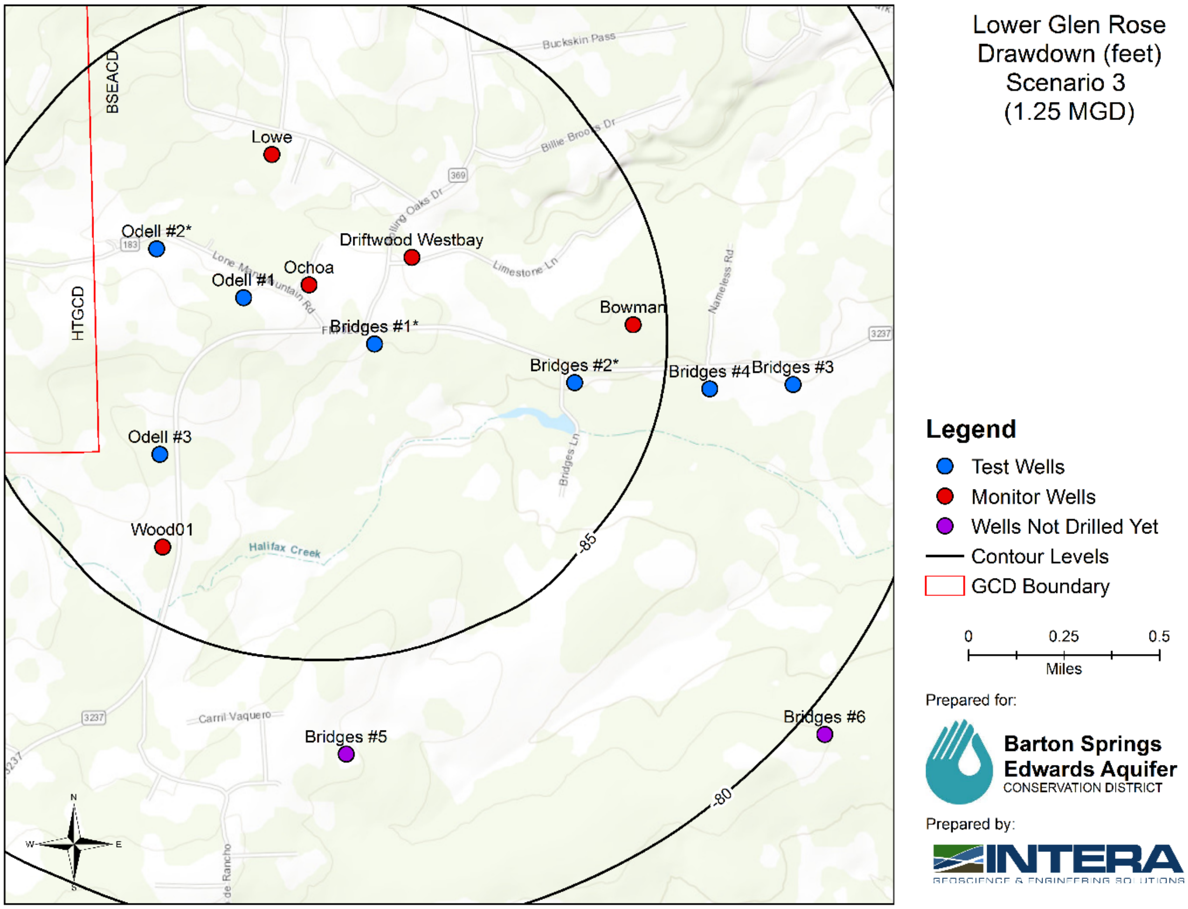

Figure 11. Estimated drawdown after 7 years in the Lower Glen Rose near the EP well field for Scenario 3 (1.25 million gallons per day)

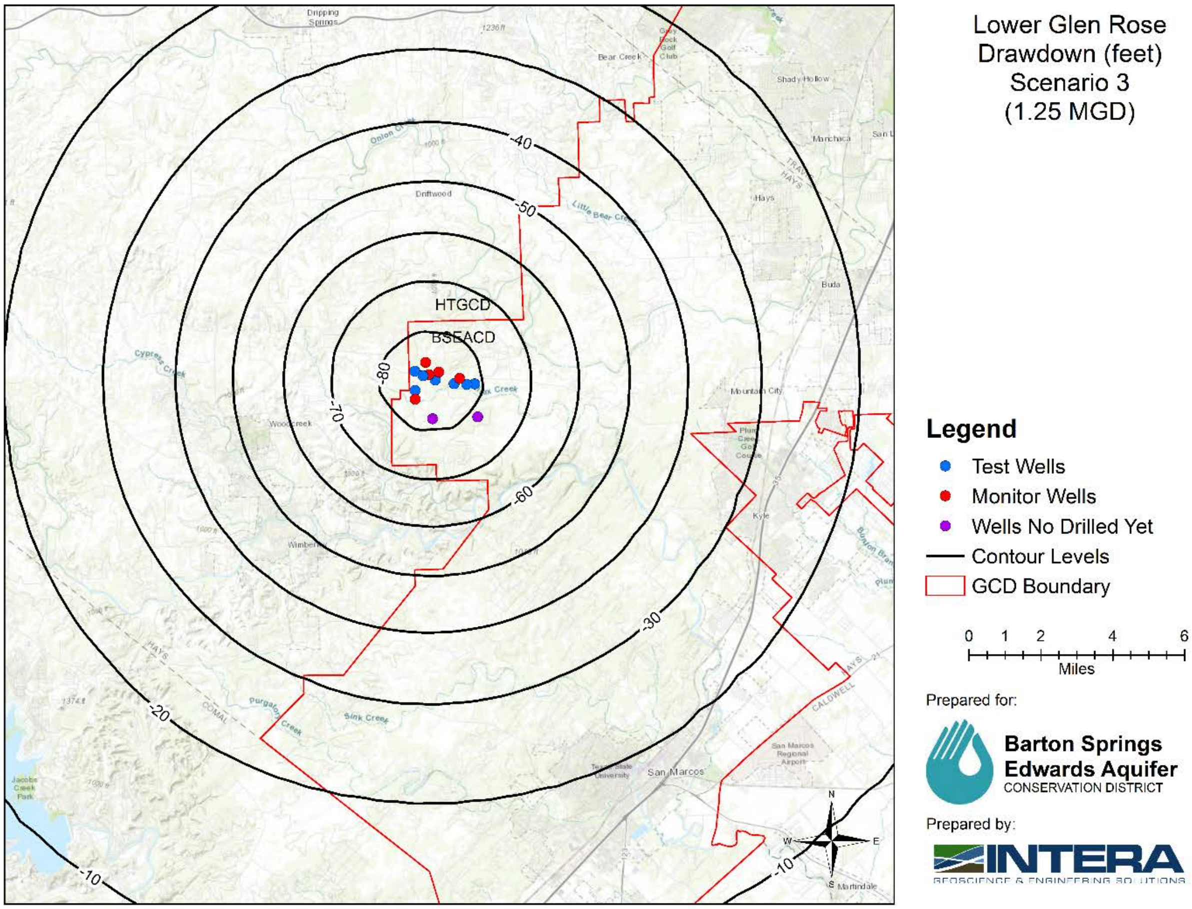

Figure 12. Estimated drawdown after 7 years in the Lower Glen Rose in southeast Hays County for Scenario 3 (1.25 million gallons per day)

CONCLUSIONS AND LIMITATIONS

There are several conclusions that can be drawn about the impacts of pumping from the EP well field given the results presented above and the previous studies relating to the proposed well field. First, production of 2.5 million gallons per day will result in substantial drawdowns in the EP well field. Drawdowns of 100 feet or more in the Cow Creek are likely to extend miles from the well field.

As described in Oliver and others (2016), the long-term drawdown of the Cow Creek will be significantly influenced by the degree of connection between the Cow Creek and the Lower Glen Rose through the less permeable Hensel unit. If the Hensel provides more hydrologic separation between the Cow Creek and the Lower Glen Rose than was simulated, then drawdowns will be greater in the Cow Creek and less in the Lower Glen Rose than what is shown in Table 4. If the Hensel allows for more hydrologic communication between the units than was simulated, then the drawdowns will be less in the Cow Creek and greater in the Lower Glen Rose than what is shown in Table 4. As described above, for the modeling presented here we used a vertical hydraulic conductivity for the Hensel that is conservative and generally restricts flow. Though characterized as ambiguous in the report, the aquifer tests documented in WRGS (2017) indicate that there may be significant hydrologic communication between the Hensel and the Lower Glen Rose.

All modeling studies inherently have simplifications and limitations to their applicability. This analysis is no different. As described above, the modeling code selected for this analysis (TTIM) is best suited to local/well field-scale analyses than for drawdowns over large areas or in highly heterogeneous systems.

TTIM does not directly account for recharge from precipitation to the aquifer, though because it assumes an infinite aquifer extent, it allows for lateral flow – and increases in lateral flow – that would be observed in a system connected to an up-dip recharge area. While the analysis presented here has limitations, it is our opinion that it is the best tool available at this time to evaluate impacts to the Trinity Aquifer from the proposed well field.

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GEOSCIENTIST SEAL:

This report documents the work of the following Licensed Texas Geoscientist:
Wade A. Oliver, P.G.

Mr. Oliver managed the project, was responsible for technical oversight and assisted with documentation.

WAO 4/16/18
WADE A. OLIVER
GEOLOGY
11112

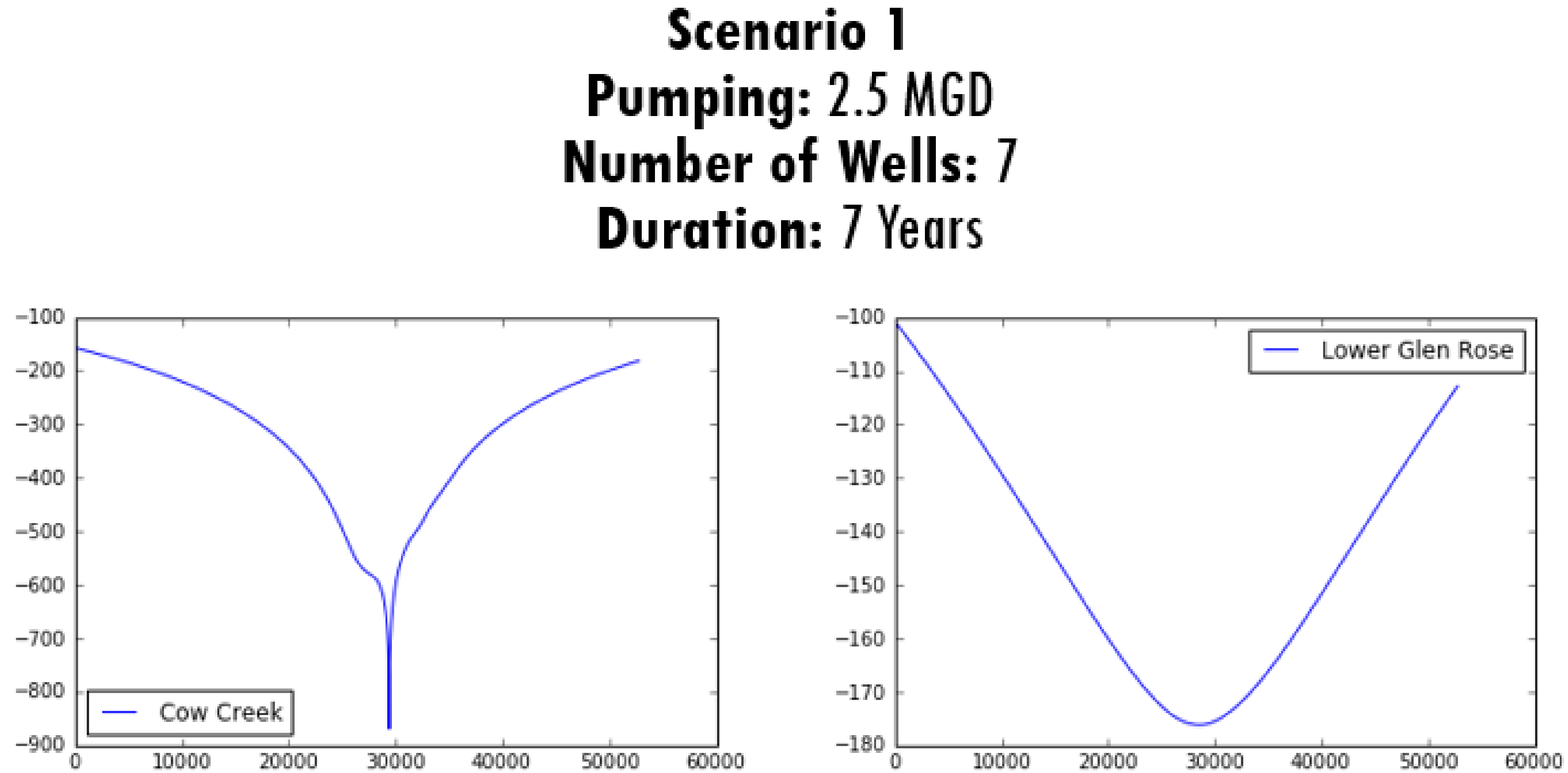
April 16, 2018

Signature

Date

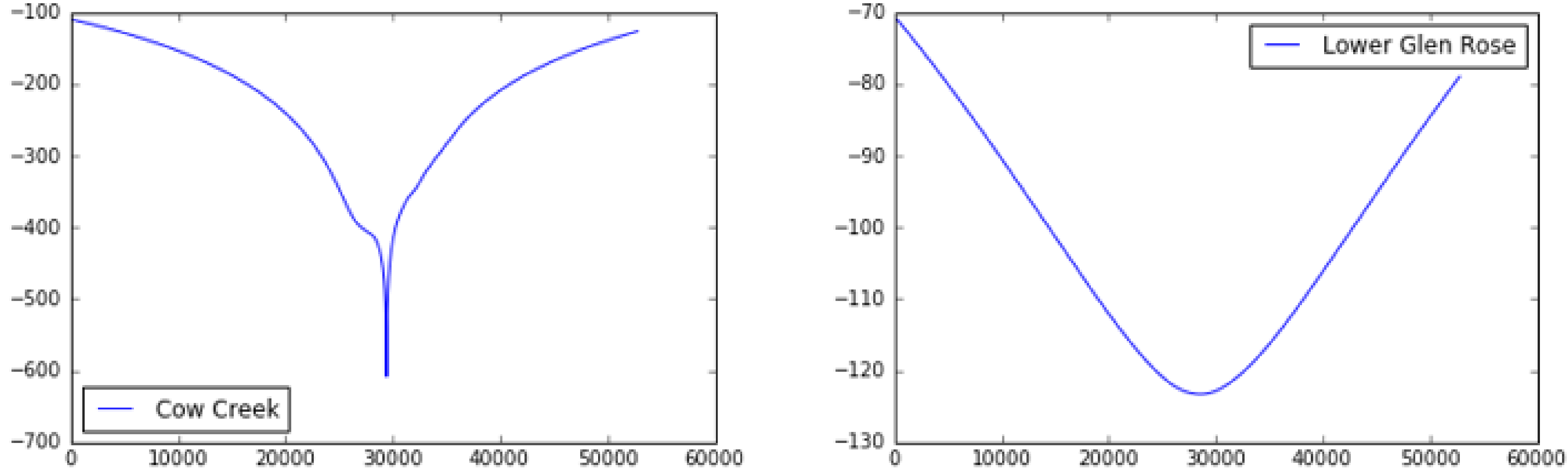
APPENDIX

Drawdown Profiles for Predictive Pumping Scenarios 1 through 5



Scenario 1
Pumping: 2.5 MGD
Number of Wells: 7
Duration: 7 Years

Figure A-1. Drawdown profiles for Scenario 1 across a 10-mile cross-section through the Bridges 1 in the EP well field.



Scenario 2
Pumping: 1.75 MGD (30% reduction)
Number of Wells: 7
Duration: 7 Years

Figure A-2. Drawdown profiles for Scenario 2 across a 10-mile cross-section through the Bridges 1 in the EP well field.

Scenario 3

Pumping: 1.25 MGD (50% reduction)

Number of Wells: 7

Duration: 7 Years

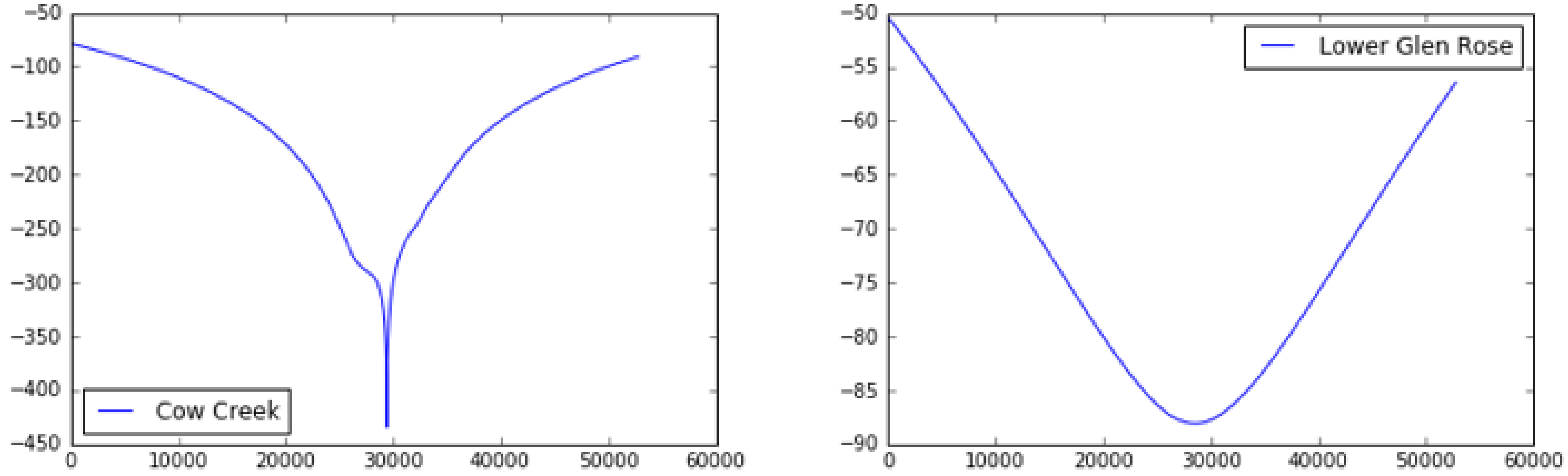


Figure A-3. Drawdown profiles for Scenario 3 across a 10-mile cross-section through the Bridges 1 in the EP well field.

Scenario 4
Pumping: 0.5 MGD (80% reduction)
Number of Wells: 7
Duration: 7 Years

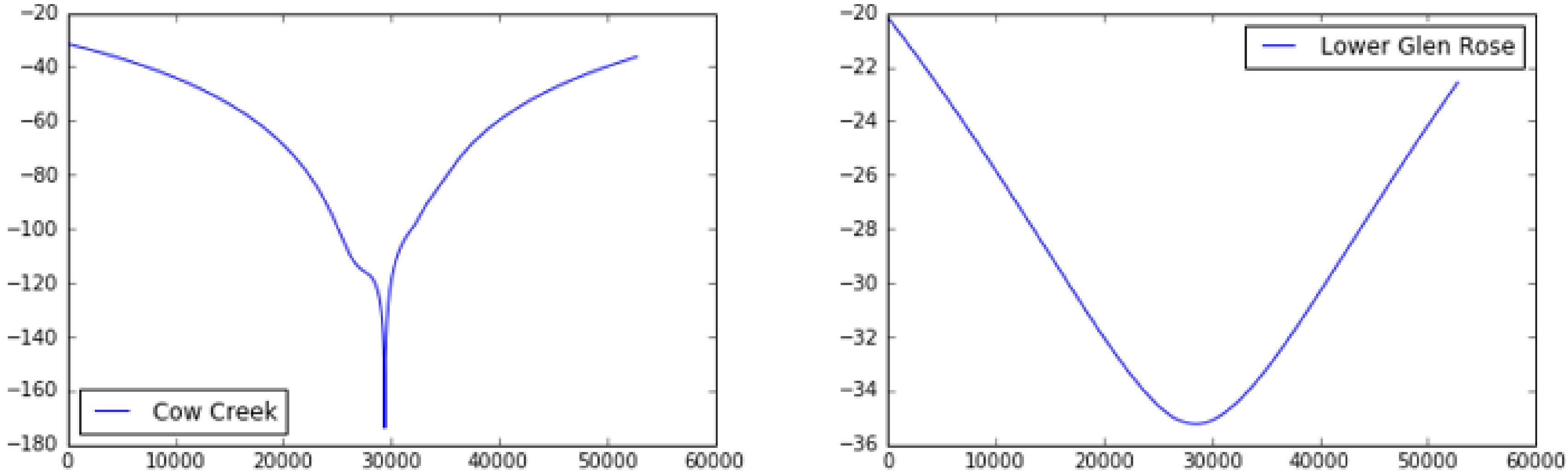


Figure A-4. Drawdown profiles for Scenario 4 across a 10-mile cross-section through the Bridges 1 in the EP well field.

Scenario 5

Pumping: 2.5 MGD

Number of Wells: 5

Duration: 7 Years

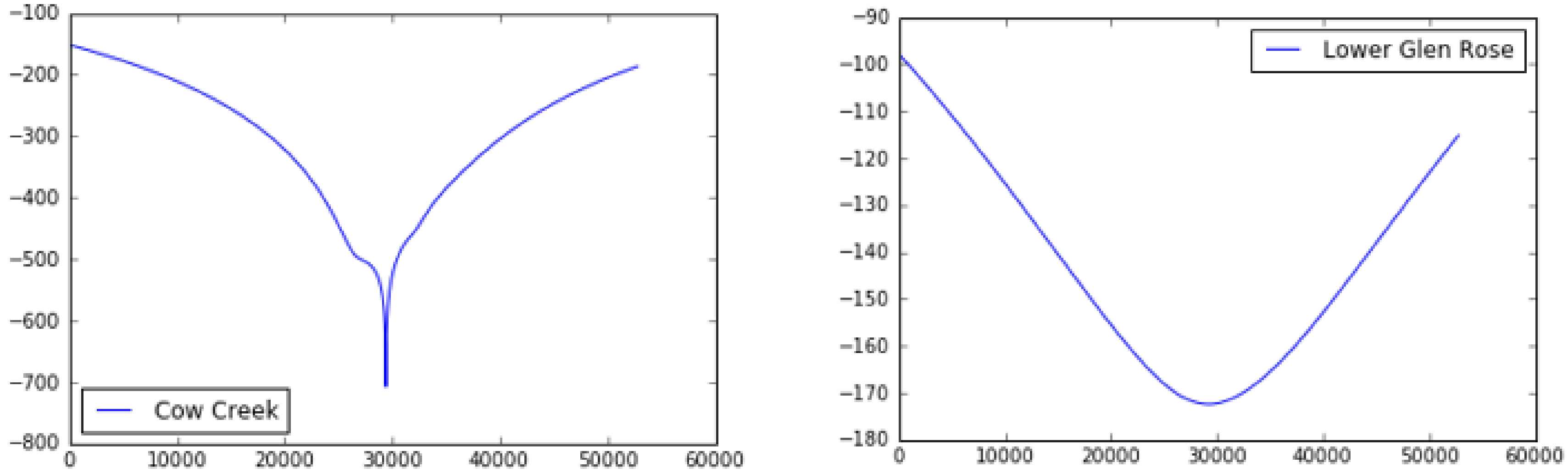


Figure A-5. Drawdown profiles for Scenario 5 across a 10-mile cross-section through the Bridges 1 in the EP well field.