GMA 12 UPDATE TO THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PORTION OF THE SPARTA, QUEEN CITY, AND CARRIZO-WILCOX AQUIFERS

Update to Improve Representation of the Transmissive Properties of the Simsboro Aquifer in the Vicinity of the Vista Ridge Well Field

Prepared for Groundwater Management Area 12 Members:
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Dr. Steven Young was the technical lead responsible for developing the approach modified the groundwater model. He supervised the development and application of PEST for model calibration and the analysis of the aquifer pumping test.

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EXECUTIVE SUMMARY

In April 2020, the POSGCD and Groundwater Management Area (GMA) 12 obtained the aquifer pumping test data from Vista Ridge production wells, which are located in Burleson County. POSGCD compared the transmissivity values from these aquifer pumping tests to the transmissivity in the Groundwater Availability Model for the Central Portion of the Sparta/Queen City/ Carrizo-Wilcox aquifers. The comparison showed that the transmissivity values for the Carrizo Aquifer in the GAM closely matched those from the aquifer pumping tests but that the transmissivity values for the Simsboro Aquifer in the GAM do not closely match those from the Vista Ridge project pumping tests. On July 24, 2020, GMA 12 members unanimously voted to have the GMA 12 consultants revise the GAM so that it would more accurately simulate the aquifer test drawdown response measured in nine Vista Ridge Simsboro wells.

The GMA 12 consultants agreed to modify the GAM by adjusting the hydraulic conductivity values of the Simsboro Aquifer in the vicinity of the Vista Ridge well field. The adjustments of the hydraulic conductivity values were determined by using the parameter optimization software called PEST (Doherty, 2018). These adjustments improved the capability of the GAM to simulate the results of the aquifer pumping tests at nine Vista Ridge wells pumping water from the Simsboro Aquifer. The objective function used by PEST included two criteria. One criterion was the match between measured and modeled drawdown. The other criterion was the match between the transmissivity values determined from the measured and simulated drawdown from the aquifer pumping test data using analysis method called the Cooper-Jacob Straight-Line method.

The primary modification of the GAM consisted of changing the hydraulic conductivity of the Simsboro Aquifer by an average ratio of 1.7 within a radial distance of about 18 miles of the Vista Ridge well field. The improved performance of the Modified GAM to reproduce the transmissivity values of the aquifer tests is summarized by the results provided in Tables ES-1 and ES-2 below.

Table ES-1 Average Transmissivity values calculated from the actual and simulated drawdown data from 36-hour aquifer tests conducted at the Nine Vista Ridge Simsboro Production Wells

Number of Wells	Aquifer Test		Transmissivity (ft^2/day)		
	Pumping Rate (gpm)	Duration (hrs)	Aquifer Tests	Modified GAM	Original GAM
9	3,008 to 3,503	36	15,195	15,207	6,599

Table ES-2 Transmissivity values calculated from the actual and simulated 23-day aquifer test conducted at the Vista Ridge Simsboro Production Well # 13

Well	Aquifer Test		Transmissivity (ft^2/day)		
	Pumping Rate (gpm)	Duration (days)	Aquifer Test	Modified GAM	Original GAM
PW-13	3110	23	15,871	15,756	8,453

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ACROYNMS AND ABBREVIATIONS

%	percent
AFY	acre-ft/year
CJSL	Cooper-Jacob Straight-Line method
ft^2/day	square feet per day
The GAM	Groundwater Availability Model for the Central Portion of the Sparta/Queen City/ Carrizo-Wilcox aquifers
GMA	Groundwater Management Area
gpm	gallons per minute
POSGCD	Post Oak Savannah Groundwater Conservation District
PW	Pumping Well
TWDB	Texas Water Development Board

1.0 INTRODUCTION

One of largest groundwater water supply projects in the state is the Vista Ridge Project which delivers water from the Simsboro Aquifer in Burleson County to San Antonio, Texas. The Vista Ridge Project has permits from the Post Oak Savannah Groundwater Conservation District (POSGCD) to pump approximately 35,000 acre-ft/year (AFY) and approximately 15,000 AFY of groundwater from the Simsboro and Carrizo Aquifers, respectively.

In April 2020, the POSGCD and Groundwater Management Area (GMA) 12 obtained the aquifer pumping test data from 18 of the Vista Ridge production wells, 9 of which screened sands in the Carrizo Aquifer and 9 of which screened sands in the Simsboro Aquifer. The data were collected as part of POSGCD's review of an operating permit for Vista Ridge. The aquifer test data included the measured pumping rates and water levels required to calculate transmissivity values. Soon after receipt of the data, POSGCD shared the aquifer test data with other GMA 12 districts. POSGCD and INTERA compared measured drawdowns and the calculated transmissivity values obtained from these aquifer pumping tests to the values obtained by simulating the aquifer tests using the Groundwater Availability Model for the Central Portion of the Sparta/Queen City/ Carrizo-Wilcox aquifers (Young and others, 2018) (henceforth called the GAM). Whereas the GAM provided reasonable matches for the pumping tests in the Carrizo Aquifer, the GAM did not provide reasonable matches for the pumping tests in the Simsboro Aquifer.

On July 24, 2020, GMA 12 members unanimously voted to have the GMA 12 consultants revise the GAM so that it would more accurately simulate the aquifer test drawdown response measured in nine Vista Ridge Simsboro wells.

2.0 VISTA RIDGE AQUIFER PUMPING TEST DATA

Figure 1 shows the locations of the nine Vista Ridge Simsboro wells. In April 2020, Blue Water Systems LP provided POSGCD data from a 36-hour pumping test for each well. In addition, Blue Water Systems LP provided a 23-day aquifer pumping test for well Pumping Well (PW) 13. The data from each of these nine aquifer tests have been added to an updated geodatabase and submitted to the Texas Water Development Board (TWDB) in a separate correspondence.

The transmissivity values from the GAM for the Simsboro Aquifer in the vicinity of the Vista Ridge production field are less than 10,000 square feet per day (ft^2/day). INTERA's analysis of the Vista Ridge aquifer tests yielded transmissivity values that ranged from 11,000 ft^2/day to 20,000 ft^2/day.

3.0 GAM MODIFICATION IMPROVE SIMULATION OF RESULTS FROM AQUIFER PUMPING TESTS

The GAM was modified by adjusting the hydraulic conductivity values of the Simsboro aquifer within a radial distance of about 18 miles from the Vista Ridge well field. The radial distance of 18 miles is based on an estimated radius-of-influence determine from a 23-day aquifer pumping tests at Well PW-13 using the equations developed by Dagroni, (1998) and Bear (1979). The adjustments of the hydraulic conductivity values were determined by the parameter optimization software called PEST (Doherty, 2018). The adjustments were made to improve the capability of the GAM to simulate the results of the aquifer pumping tests. PEST adjusted the hydraulic conductivity values using the pilot points at the locations shown in Figure 2. The objective function used by PEST included two criteria. One criterion was to minimize the difference between measured and modeled drawdown values during the pumping tests. The other criterion was to minimize the difference between the transmissivity values determined from the measured and modeled drawdown from the aquifer pumping test data using the Cooper-Jacob Straight-Line method (CJSL) (Cooper and Jacob, 1949). The modified version of the GAM is referred to as the Modified GAM throughout this report. Figure 3 and Figure 4 shows the Simsboro transmissivity values in the GAM (Young and others, 2018) and the Modified GAM, respectively.

Table 1, Figure 5 and Figure 6 compare the transmissivity values calculated using drawdowns from the actual and simulated aquifer pumping tests. The aquifer tests were simulated by setting the initial conditions equal to the steady-state conditions and then performing the transient pumping simulation using 1-hour time steps. The transmissivity values in Table 1 were calculated using the CJSL method and the slopes of straight lines fitted through the drawdown data from 4 hours to 36 hours. The linear fit was performed using linear regression and the logarithm of time. The process for performing the linear regression was the same as the process used by INTERA to calculate transmissivity values from over 100 aquifer pumping tests in the GAM report (Young and others, 2018). Table 1 provides CJSL-based transmissivity values calculated using a methodology that has definable, objective criteria for fitting a straight-line through the time-drawdown and is applied consistently among the data sets.

Table 1 Transmissivity values calculated from the actual and simulated 36-hour aquifer tests conducted at the nine Vista Ridge Simsboro production wells

Well	Aquifer Test		Transmissivity (ft^2/day)		
	Pumping Rate (gpm)	Duration (hrs)	Aquifer Test	Modified GAM	GAM
PW-9	3110	36	10,928	11,648	5,607
PW-10	3008	36	13,906	15,709	5,979
PW-11	3110	36	17,335	15,709	5,979
PW-12	3110	36	19,785	17,034	7,326
PW-13	3110	36	14,559	16,142	7,036
PW-14	3,008	36	14,664	16,776	7,297
PW-15	3503	36	15,215	13,583	7,175
PW-16	3110	36	10,736	14,552	7,011
PW-17	3110	36	19,629	15,709	5,979
		Average	15,195	15,207	6,599

Table 1 compares the transmissivity values calculated from each well based on the 36-hour pumping tests. Table 1 shows that the average transmissivity value of 15,207 ft^2/day from Modified GAM provides a much better match to the average transmissivity value of 15,195 ft^2/day from the actual aquifer tests than does the average transmissivity value of 6,599 ft^2/day from the GAM. Figure 5 compares the transmissivities calculated at each of the nine wells using the measured water levels and the simulated water levels generated by the GAM (Young and others, 2018). Figure 6 compares the transmissivities calculated at each of the nine wells using the measured water levels and the simulated water levels generated by the Modified GAM. The results in Table 1 and in Figures 5 and 6 show that the Modified GAM provides a significantly better representation of the Simsboro transmissivity values than does the GAM.

Figures 7 through 15 show the measured drawdown values and the simulated drawdown values using the Modified GAM for the 36-hour aquifer tests for the nine wells listed in Table 1. The aquifer pumping tests were simulated using the Connected Linear Network (CLN) package in MODFLOW-USG (Panday and others, 2015) to account for radial flow to a well and to account for well efficiencies less than 100 percent (%). The use of the CLN package does not affect the transmissivity values calculated by the CJSL method but it allows for a more realistic simulation of drawdown, resulting in a better fit to data measured in a pumping well. The average value efficiency used for the nine wells is 91%.

Besides the 36-hour aquifer pumping tests, Blue Water Systems provided POSGCD with a 23-day pumping test conducted in Well PW-13. The water level data collected during the 23-day test indicate that aquifer hydraulic parameters remained consistent and no recognizable boundary to flow was encountered. Table 2 compares the transmissivity calculated using the CJSL method on the measured water levels and the simulated water levels using the Modified GAM and the GAM (Young and others, 2018). The transmissivity from the aquifer pumping test is 15, 871 ft^2/day. The transmissivity from the simulation using the Modified GAM is less than 1% different from the transmissivity calculated from the aquifer pumping test data whereas the transmissivity from the simulation using the GAM is about 45% lower than the transmissivity calculated from the aquifer pumping test data. Figure 16 shows the measured drawdown values and the simulated drawdown values using the Modified GAM for 23-day aquifer test at Well PW-13.

Table 2 Transmissivity values calculated from the actual and simulated 23-day aquifer tests conducted at the Vista Ridge Simsboro Production Well # 13

Well	Aquifer Test		Transmissivity (ft^2/day)		
	Pumping Rate (gpm)	Duration (days)	Aquifer Test	Modified GAM	GAM
PW-13	3110	23	15,871	15,756	8,453

As part of the recalibration of the GAM, several attempts were made to reduce the amount of increase in the Simsboro transmissivity values in the vicinity of line A-A′ shown in Attachment D. These investigations showed that notable reductions in transmissivity values in the vicinity of line A - A′ adversely affected the match between the calculated transmissivity values from the aquifer pumping test and the GAM simulation. Based on these results, we deduced the that the Simsboro transmissivity values in the unmodified GAM and in the vicinity of Line A-A′ and down-dip of Line A-A′ were likely a result of a combination of too great of an trend of decrease in hydraulic conductivity with depth that was built into the GAM (Young and others, 2018) and a possible underestimation of net sand thickness down dip of Line A-A′.

We did not pursue additional studies to adjust Simsboro transmissivity values down in the vicinity and downdip of Line A-A′ for several reasons. One reason is that the additional studies is beyond the scope of GMA 12 directive to modify the GAM by adjusting the hydraulic conductivity values of the Simsboro Aquifer in the vicinity of the Vista Ridge well field. Another reason is that the pursuit of additional studies would likely prevent the completion of the modified GAM for use by GMA 12 for the current planning cycle. In addition, the GMA 12 consultants are unsure if there is sufficient hydrogeological data to properly guide the changes in the Simsboro transmissivity field down dip of Line A-A′ at this time.

4.0 IMPACT OF GAM MODIFICATIONS ON MODEL CALIBRATION STATISTICS

This section describes that process of calibration to historical values of hydraulic heads and documents how the modifications to the GAM impacts the calibration statistics reported by Young and others (2018).

4.1 Calibration Metrics for Hydraulic Head Targets

Conventional calibration metrics associated with simulating hydraulic heads are based on residuals (Anderson and Woessner, 1992). A residual, r, is defined as the difference between an observed and a simulated hydraulic head per Equation 4-1.

$$r = h_o - h_s \qquad \text{(Equation 4-1)}$$

where:

r = residual,
h_o = observed hydraulic head, and
h_s = simulated hydraulic head.

The root mean square error, which is traditionally the basic measure of calibration for hydraulic heads, is defined as the square root of the average square of the residuals and is expressed mathematically by Equation 4-2. Although the root mean square error is useful for describing model error on an average basis, it does not provide insight into spatial trends in the distribution of the residuals. Information about the average error or bias is provided by the mean error and the mean absolute error. The mean error, which is described in Equation 4-3, is the average of the residuals. The absolute mean error, which is described in Equation 4-4, is the average of the absolute value of the mean error.

$$\text{Root Mean Squared Error } = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(h_o - h_s)_i^2} \qquad \text{(Equation 4-2)}$$

$$\text{Mean Error } = \frac{1}{n}\sum_{i=1}^{n}(h_o - h_s)_i \qquad \text{(Equation 4-3)}$$

$$\text{Absolute Mean Error } = \frac{1}{n}\sum_{i=1}^{n}|h_o - h_s|_i \qquad \text{(Equation 4-4)}$$

where:

n = number of observations

A typical calibration criterion for hydraulic heads is that the root mean square error and the mean absolute error are less than or equal to 10% of the observed hydraulic head range in the hydrogeologic unit being simulated. The mean absolute error is useful for describing model error on an average basis but does not provide insight into spatial trends in the distribution of residuals. Examination of the distribution of residuals is necessary to determine if they are randomly distributed over the model grid and not spatially biased. The goodness or acceptability of a set of residuals and their statistics is model- and site-dependent and based on the wide range of possible sources of error and uncertainty in a model simulation.

4.2 Statistics for Hydraulic Head Residuals for Steady-State Conditions

The hydraulic head data set used to check the calibration of the Modified GAM for the 1930 steady state condition is identical to the data set used by Young and others (2018) to calibrate the GAM. Table 3 presents the calibration statistics for steady-state conditions in 1930 for the entire model domain for both the GAM and the Modified GAM. The results in Table 3 show the Modified GAM produces root-mean square errors for the hydrogeologic unit that are within a few tenths of a foot of the calibration statistics produced by the GAM. The calibration statistics were calculated using the routines in Groundwater Vistas (Rumbaugh and Rumbaugh, 2017).

Table 3 Calibration statistics for steady-state conditions for all hydraulic heads in the entire model domain

Hydrogeologic Unit	Count	Mean Error (ft)		Mean Absolute Error (ft)		Root Mean Square Error (ft)		Measured Range (ft)
		GAM	Modified GAM	GAM	Modified GAM	GAM	Modified GAM	
Alluvium	8	11.4	11.4	12.6	12.6	15.3	15.3	21
Sparta	61	-2.5	-2.5	19.9	19.9	25.4	25.4	323
Weches	15	1.5	1.5	13.3	13.3	16.4	16.4	333
Queen City	163	-5.2	-5.2	15.5	15.5	21.0	21.0	310
Reklaw	18	-2.9	-2.9	19.3	19.3	24.9	24.9	218
Carrizo	39	-7.0	-7.0	24.2	24.2	31.5	31.5	285
Calvert Bluff	144	9.1	9.1	20.4	20.4	26.1	26.1	296
Simsboro	17	21.3	21.1	22.7	22.5	29.9	29.8	220
Hooper	57	-5.2	-5.2	13.7	13.7	18.2	18.2	290
All	522	0.3	0.3	18.1	18.1	23.9	23.9	401

4.3 Statistics for Hydraulic Head Residuals for Transient Conditions

The hydraulic head data set used to check the calibration of the Modified GAM over the time period from 1930 to 2010 is identical to the data set used by Young and others (2018) to calibrate the GAM. Table 4 presents the calibration statistics for the transient calibration for the entire model domain for both the GAM and the Modified GAM. The results in Table 5 show the Modified GAM produces root-mean square errors for the hydrogeologic units that are within a few tenths of a foot of the calibration statistics produced by the GAM except for the Simsboro Aquifer. The Modified GAM's root-mean square error of 23.5 ft for the Simsboro Aquifer is approximately 0.4 feet greater than the root-mean square error of 23.1 produced by the GAM for the Simsboro Aquifer. However, the Modified GAM's root-mean square error of 23.5 ft for the Simsboro Aquifer is only about 4% of the range of 609 ft in the entire Simsboro Aquifer. The Modified GAM's root-mean square error of 22.7 ft for all aquifers is approximately 3% of the range of 845 ft in all aquifers. The calibration statistics were calculated using the routines in Groundwater Vistas (Rumbaugh and Rumbaugh, 2017)

Table 4 Calibration statistics for transient conditions based on the equal-by-observed-head weighting scheme for the entire model domain

Hydrogeologic Unit	Count	Mean Error (ft)		Mean Absolute Error (ft)		Root Mean Square Error (ft)		Measured Range (ft)
		GAM	Modified GAM	GAM	Modified GAM	GAM	Modified GAM	
`Alluvium	802	-1.3	-1.4	4.4	4.4	5.7	5.7	81
Sparta	1,167	-3.0	-3.0	13.1	13.1	18.4	18.4	446
Weches	105	-1.9	-1.9	5.9	5.9	7.6	7.6	226
Queen City	1,493	-4.2	-4.2	13.6	13.6	19.9	19.9	414
Reklaw	505	-6.1	-6.1	12.3	12.3	16.3	16.3	423
Carrizo	3,392	-3.1	-3.1	18.0	18.0	29.6	29.7	727
Calvert Bluff	1,759	-2.8	-2.8	12.1	12.0	16.8	16.8	579
Simsboro	1,132	-8.7	-9.8	18.7	19.0	23.1	23.5	609
Hooper	1,023	-11.0	-11.0	17.6	17.6	24.1	24.1	308
All	11,378	-4.5	-4.6	14.7	14.7	22.6	22.7	845

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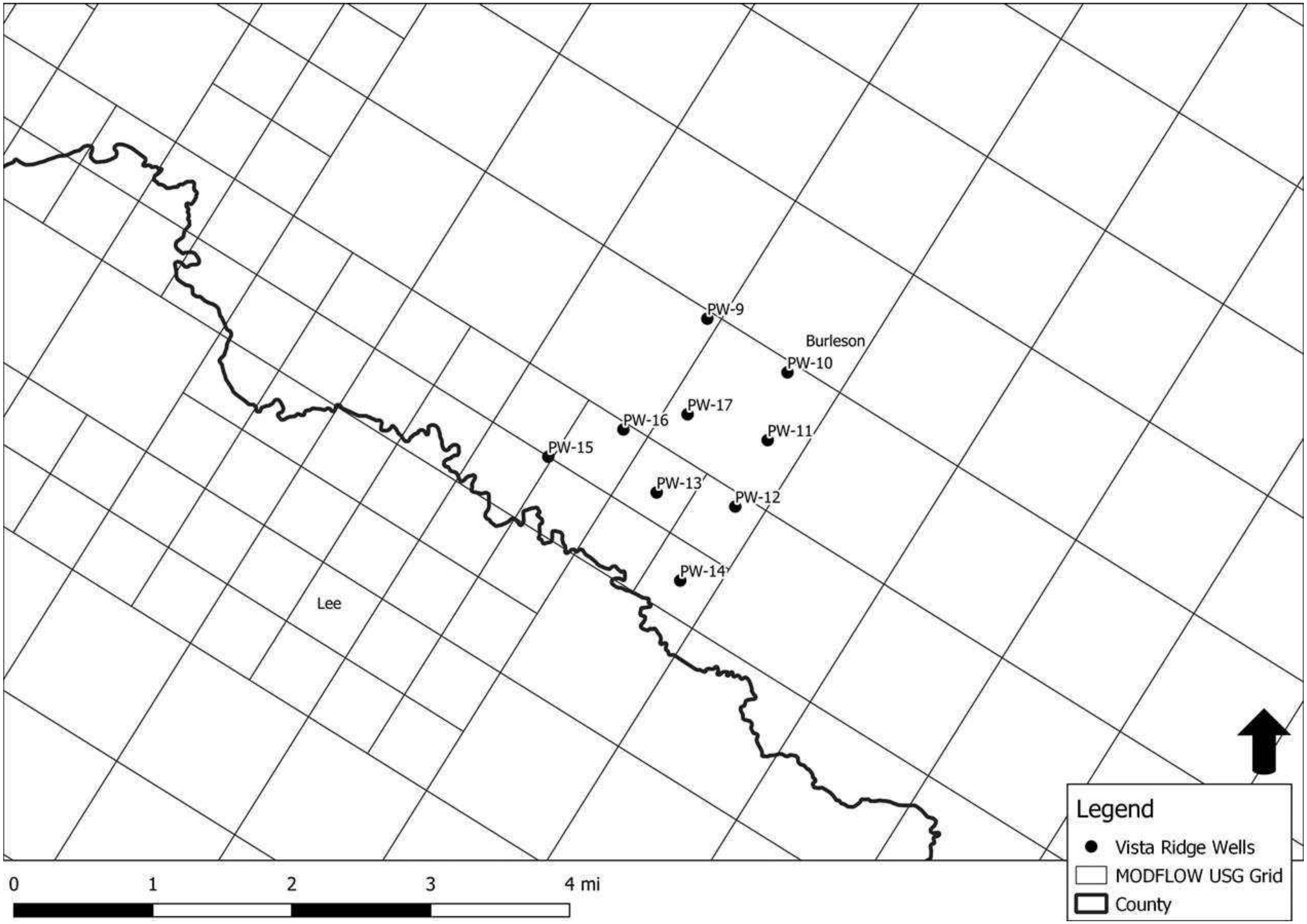

Figure 1 Locations of the nine Vista Ridge Simsboro wells in Burleson County overlaid on the MODFLOW-USG numerical grid used by the Groundwater Availability Model

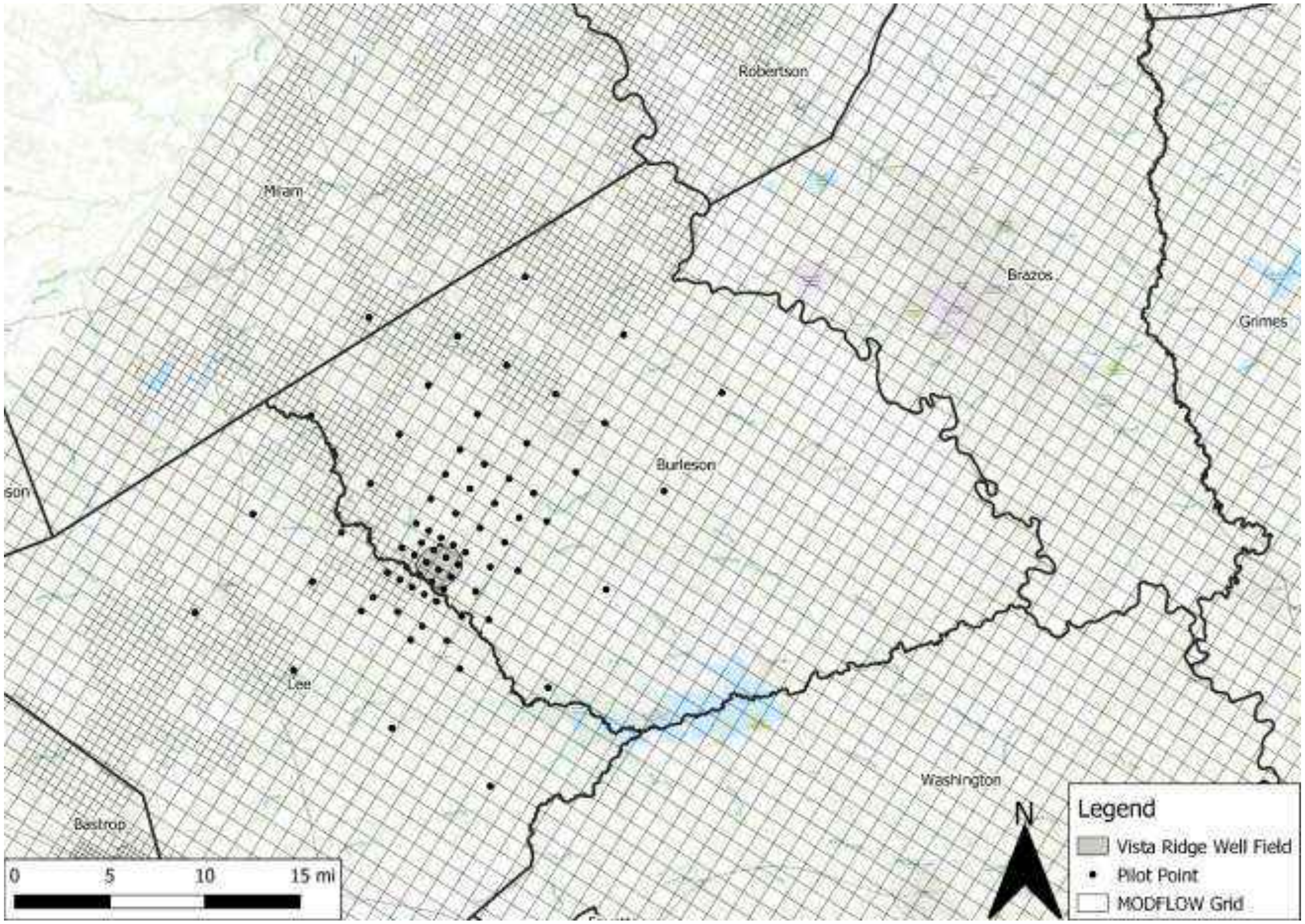

Figure 2 Locations of the pilot points used in PEST to adjust the hydraulic conductivity values during modeling calibration

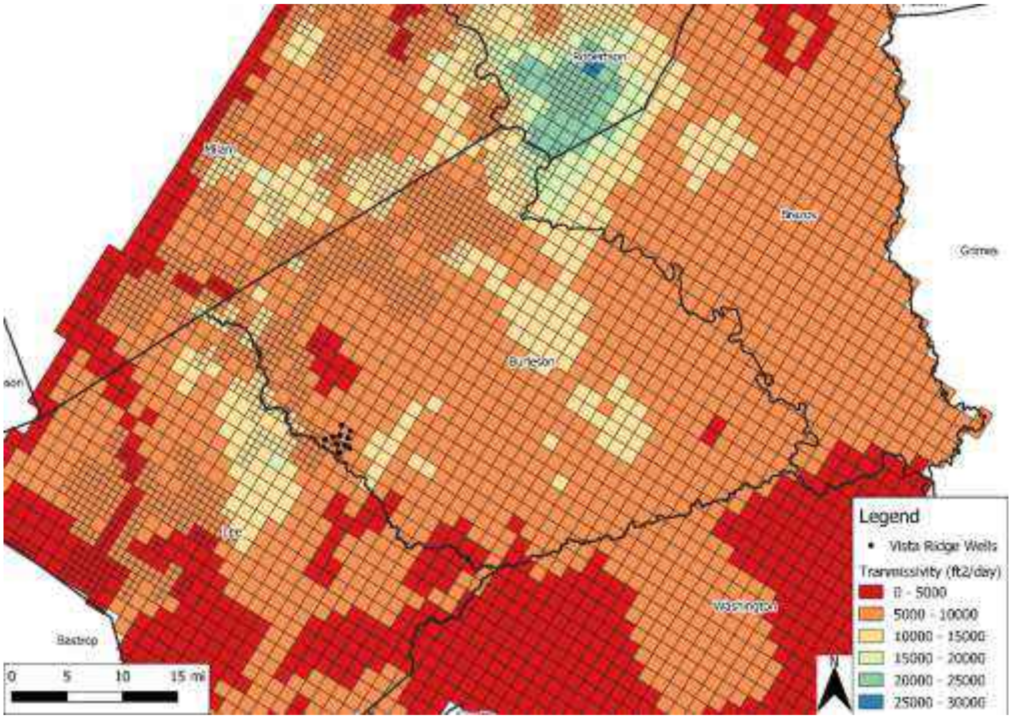

Figure 3 Simsboro Transmissivity Field in the GAM (Young and others, 2018)

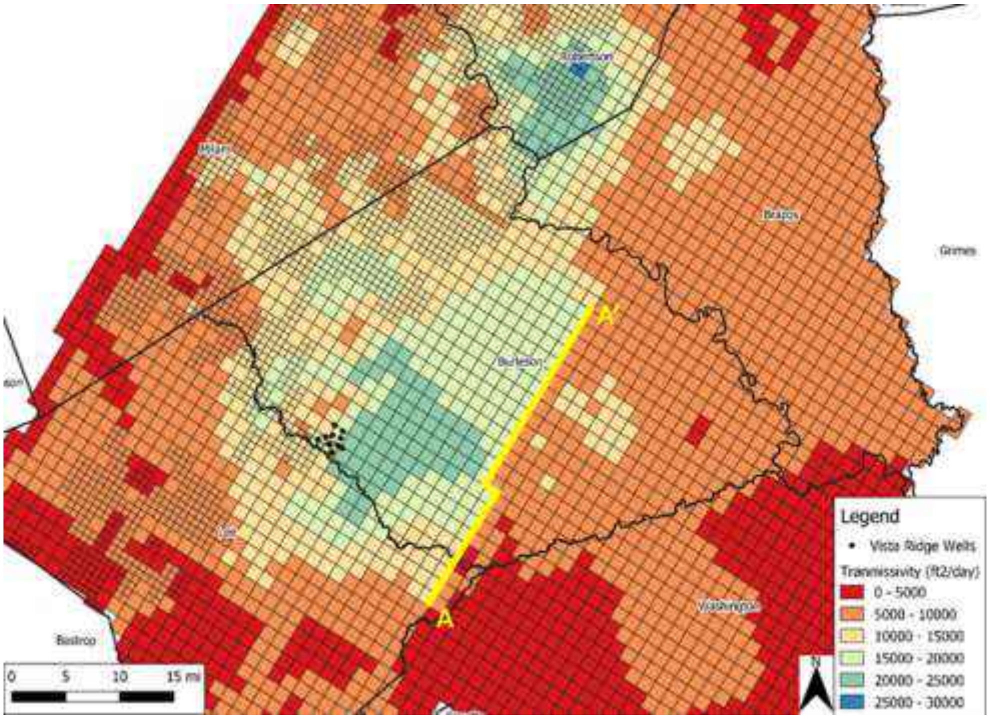

Figure 4 Simsboro Transmissivity Field in the Modified GAM. Line A-A' marks the transition between the modified and unmodified Simsboro transmissivity values down dip of the Vista Ridge well field.

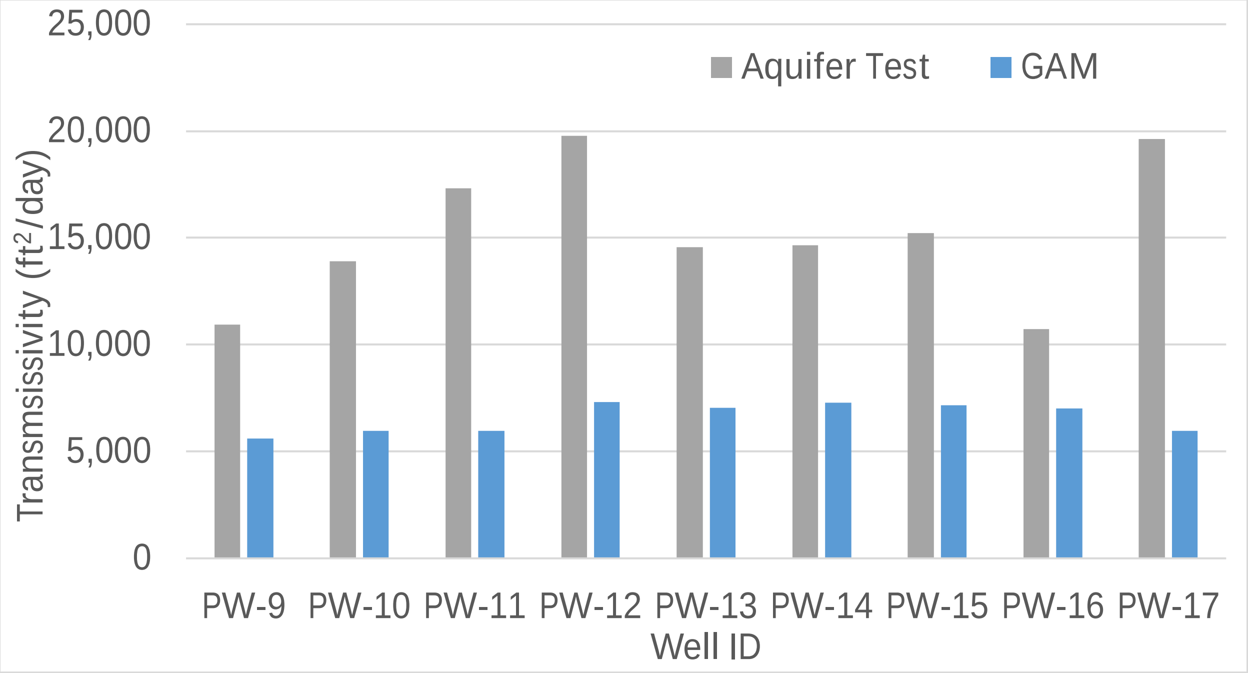

Figure 5 Transmissivity Values calculated using measured and simulated water levels from 36-hour aquifer tests at nine Vista Ridge Production Wells. The simulated water levels were produced using the GAM

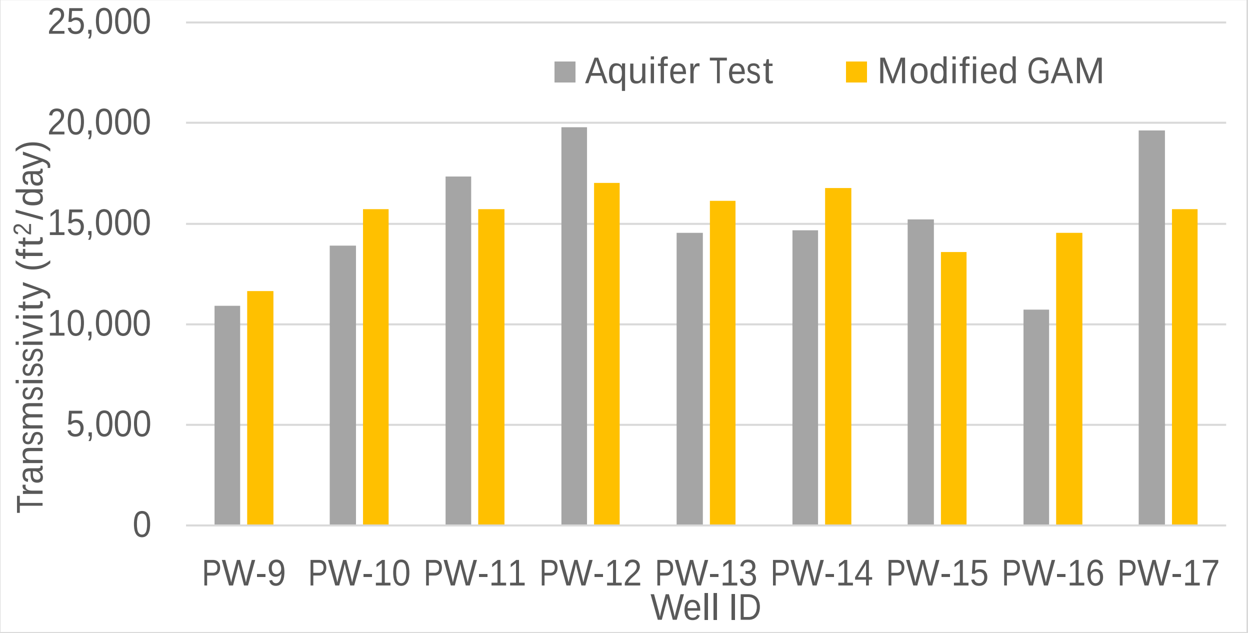

Figure 6 Transmissivity Values calculated using measured and simulated water levels from 36-hour aquifer tests at nine Vista Ridge Production Wells. The simulated water levels were produced using the Modified GAM

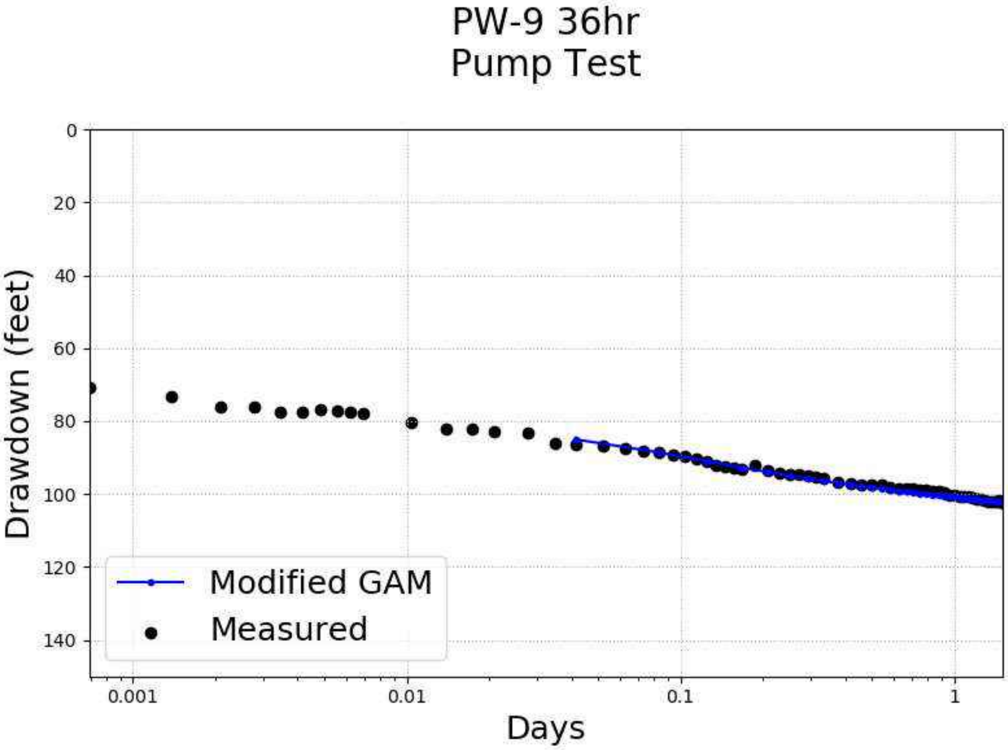

Figure 7 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-9

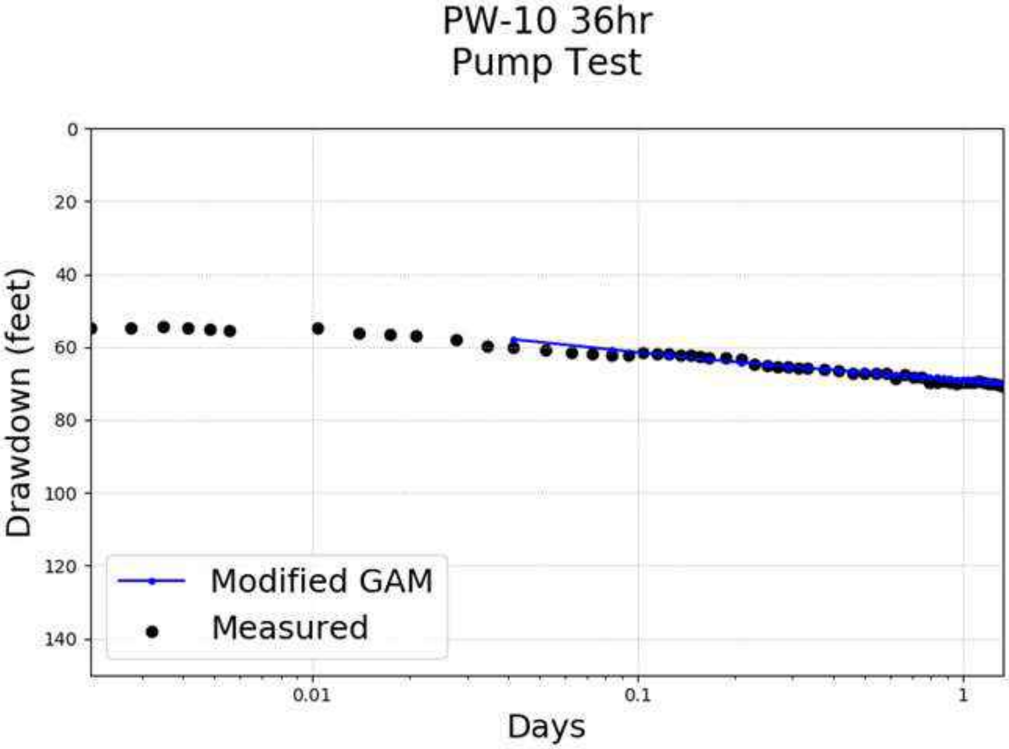

Figure 8 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-10

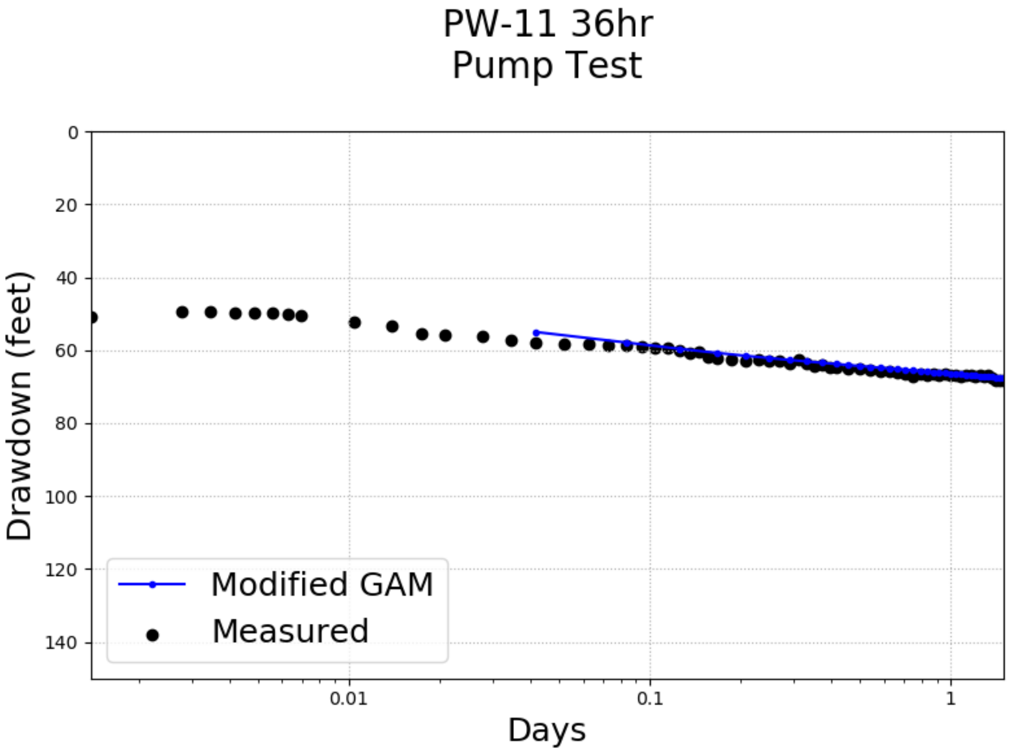

Figure 9 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-11

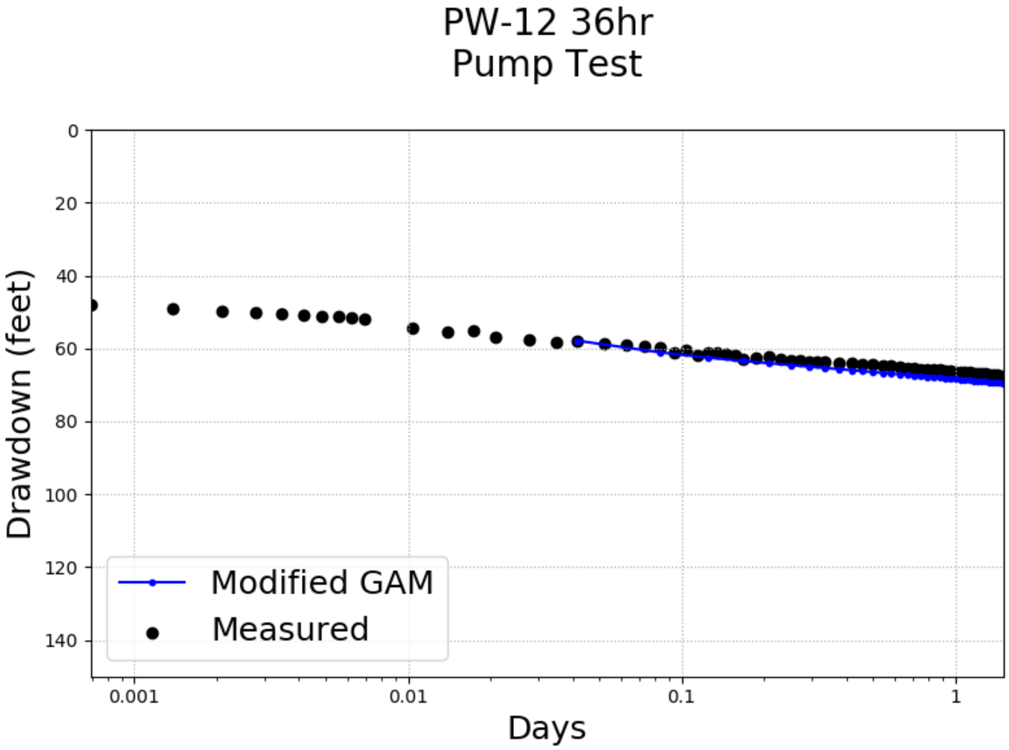

Figure 10 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-12

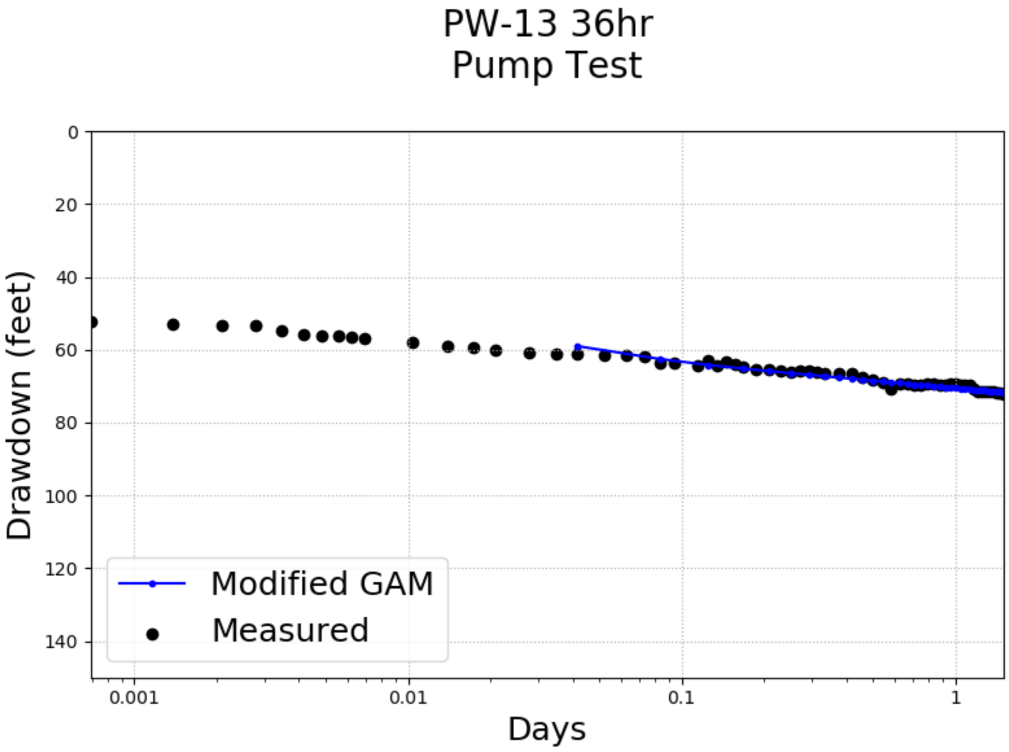

Figure 11 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-13

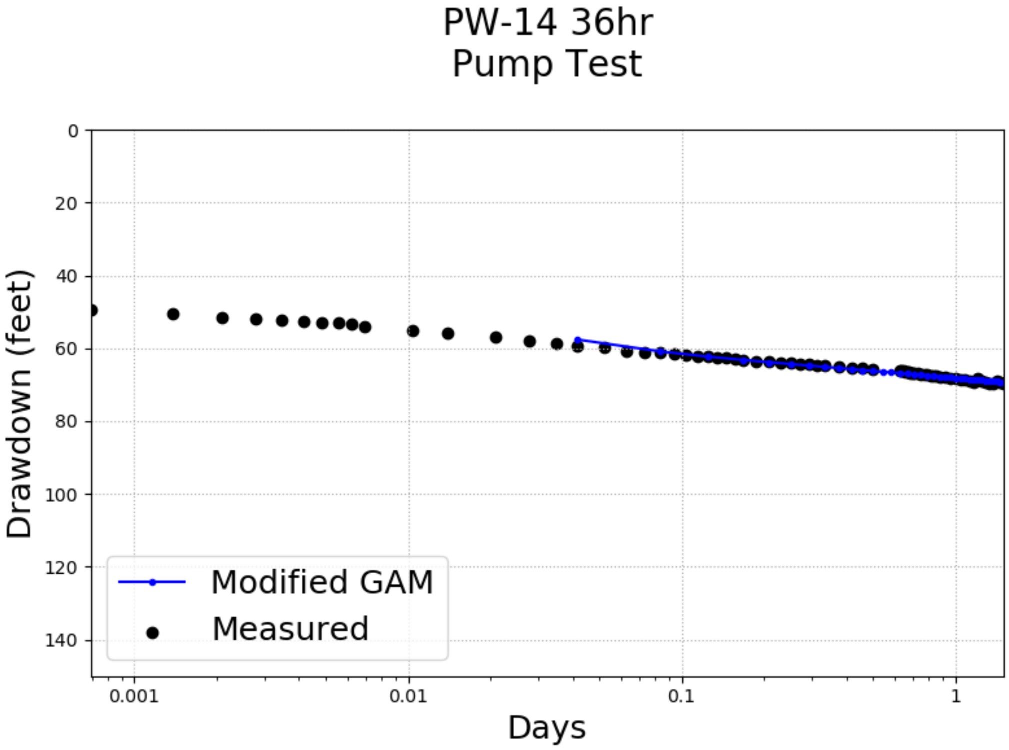

Figure 12 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-14

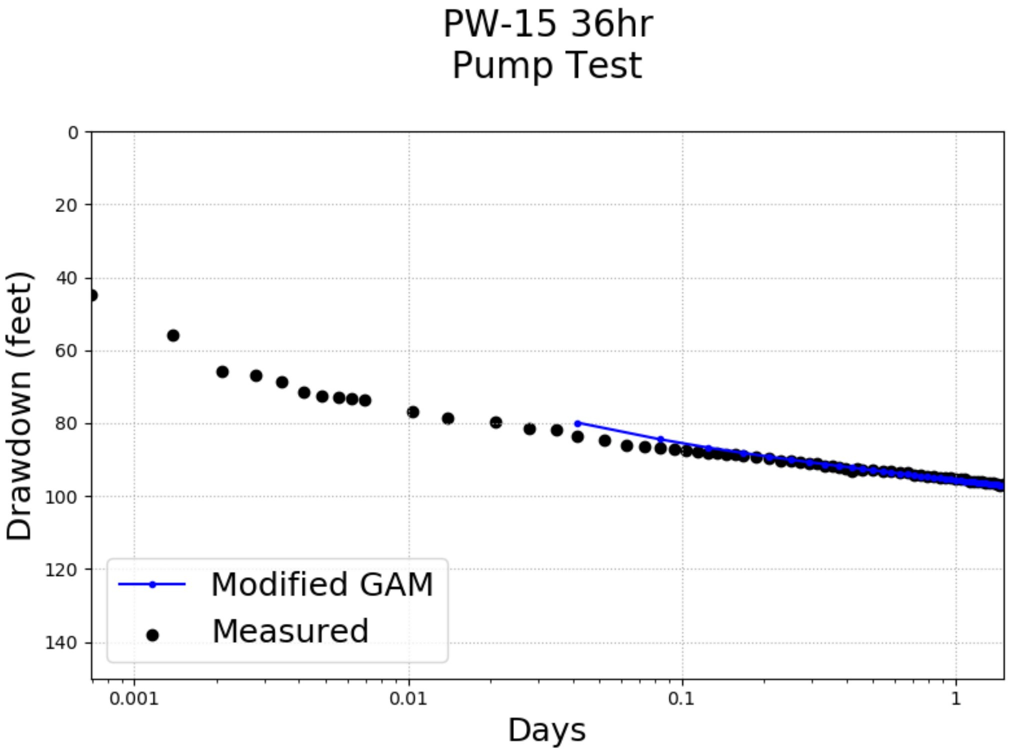

Figure 13 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-15

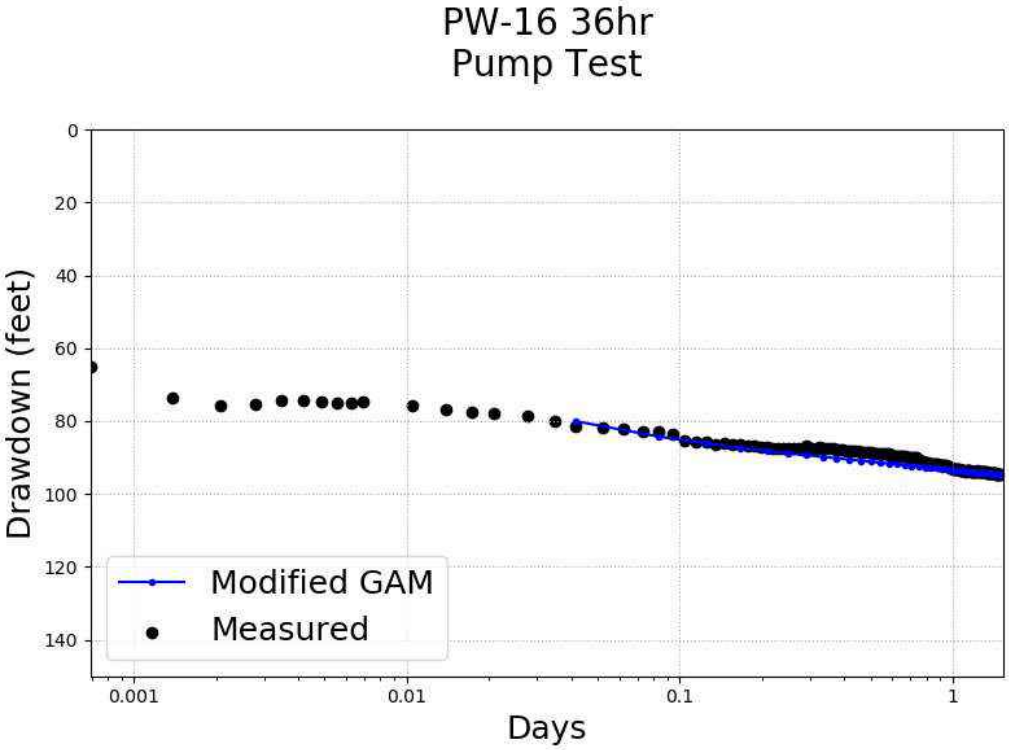

Figure 14 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-16

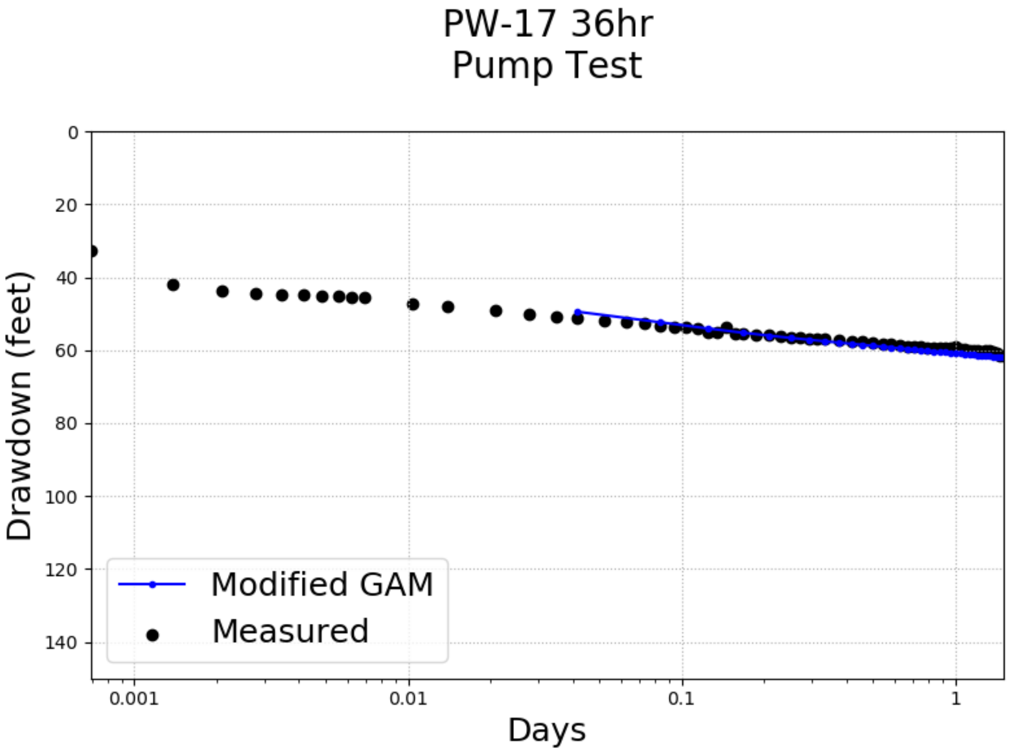

Figure 15 Measured and Simulated water levels for the 36-hour aquifer pumping test performed at Well PW-17

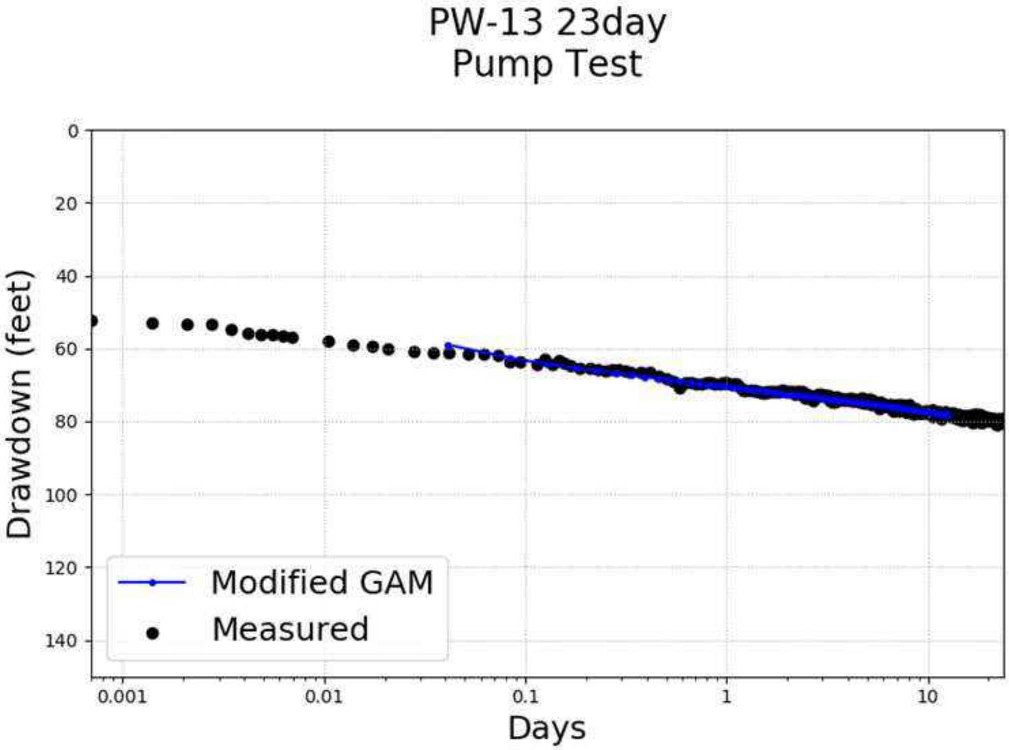

Figure 16 Measured and Simulated water levels for the 23-day aquifer pumping test performed at Well PW-13