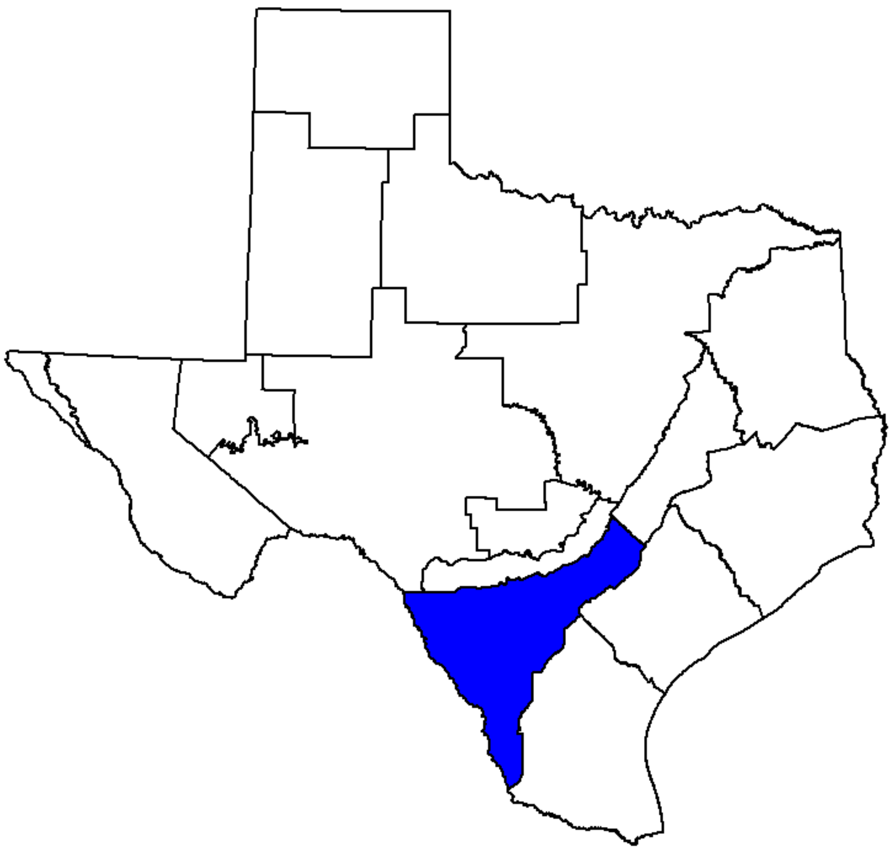
GMA 13 Model (2025 Version)

Documentation of GMA 13 Model (2025 Version): Update to Groundwater Availability Model for the Southern Portion of the Carrizo-Wilcox, Queen City, and Sparta Aquifers



Prepared for:
Groundwater Management Area 13

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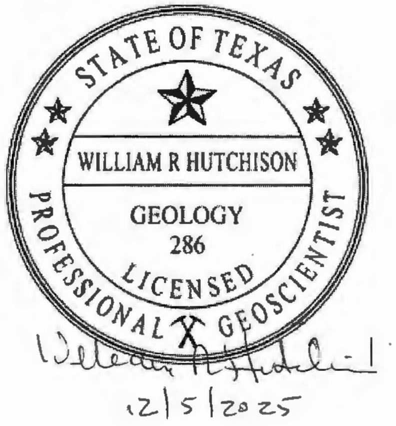


1.0 Introduction

1.1 New GAM Approved in 2023

The Groundwater Availability Model (GAM) that has been used by the groundwater conservation districts (GCDs) in Groundwater Management Area 13 (GMA 13) since the initiation of joint planning is documented in Kelley and others (2004). This GAM covered the southern portion of the Carrizo-Wilcox, Queen City, and Sparta Aquifers. For the last two rounds of joint planning (2016 and 2021), the calibration period of this "old GAM" was extended as documented in Hutchison (2017).

TWDB contracted to have the "old GAM" updated. The "new GAM" was submitted to TWDB in January 2023 and was documented in Panday and others (2023). On May 10, 2023, Dr. Daryn Hardwick, Manager of Groundwater Availability Modeling for TWDB, sent an email to stakeholders with a link to the updated model files and report, including the public comments and responses. Please note that the conceptual model report (Schorr and others, 2021) and the numerical model report (Panday and others, 2023) listed the aquifers in different order. This report follows the convention of listing the major aquifer first (Carrizo-Wilcox).

As part of model development, alternative predictive simulations were run for the predictive period (2018 to 2080) using the "new GAM". The results of these simulations demonstrated that, under the range of conditions tested, groundwater levels equilibrate, and pumping rates remain constant. This is in contrast with the "old GAM" that had persistently declining groundwater elevations and reductions in pumping rates due to dry cell problems associated with the older MODFLOW code that was used in the "old GAM".

Based on the preliminary predictive simulations that were completed as part of development of the "new GAM", the "outcrop problem" associated with the "old GAM" had been addressed. The "old GAM" was not a suitable tool to evaluate potential DFCs in the outcrop area due to persistently falling groundwater levels, even in scenarios with reduced pumping. The "new GAM" responded consistently to increases in pumping and decreases in pumping:

- When pumping is increased, drawdown increases.
- When pumping is decreased, drawdown decreases and/or groundwater recovery is "observed".

The preliminary predictive simulations, therefore, demonstrated that the "new GAM" is a suitable tool to assist in developing GMA 13's "primary DFCs" (outcrop areas) and GMA 13's "secondary DFCs" whether these are defined as only the downdip area or the total area. Furthermore, the work documented in the Technical Memoranda associated with the development of the "new GAM" demonstrated that it can be used to calculate DFCs on a GMA 13-wide basis, or on a county-aquifer basis, or a GCD-aquifer basis.

The "new GAM" consists of nine layers of cells discretized using an "oct-tree" grid, with smaller cells sizes associated with surface water features. Table 1 summarizes the names of each layer. The surficial layer of the model domain is presented in Figure 1.

Table 1. Model Layer Numbers and Stratigraphic Units

Layer Number	Hydrostratigraphic Unit
1	Quaternary Alluvium
2	Overlying or Younger Units
3	Sparta Aquifer
4	Weches Aquitard
5	Queen City Aquifer
6	Reklaw Aquitard
7	Carrizo and Upper Wilcox Aquifers
8	Middle Wilcox Aquifer
9	Lower Wilcox Aquifer

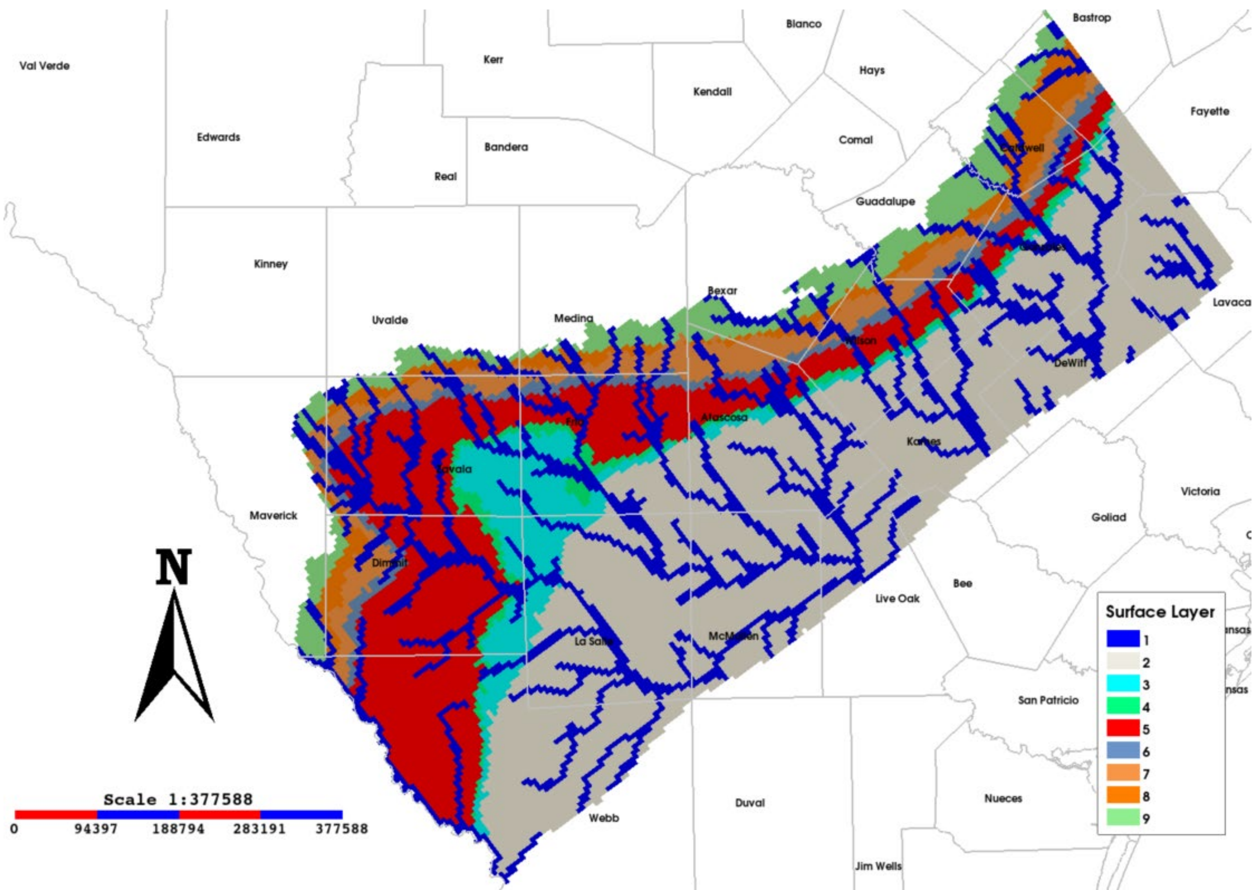


Figure 1. Surficial Layer of Model Domain

1.2 Public Comments Regarding the New GAM

During the public comment period for the new GAM, three issues were raised:

- Transmissivity estimates in some areas.
- Storativity/Specific yield estimates in some areas.
- Calibration period pumping estimates in some areas.

Formal responses to the comments were included in Panday and others (2023). The Texas Water Development Board accepted the model and released it as the new official GAM for the southern portion of the Carrizo-Wilcox Aquifer in April 2023. In a May 17, 2023 letter from Jeff Walker, Executive Administrator of TWDB to the General Manager of the Wintergarden Groundwater Conservation District, TWDB acknowledged that the high hydraulic conductivity and transmissivity values in La Salle County and other areas are recognized as model limitations.

1.3 GMA 13 Action Regarding the New GAM

GMA 13 adopted a resolution on September 15, 2023 to update the "new GAM". This update would address the public comments and follow the TWDB guidance document (dated May 2023) related to obtaining approval for a model recalibration performed by a consultant.

This technical memorandum documents the updates and changes made to the "new GAM". For clarity and to avoid confusion with the terminology:

- The "old GAM" refers to the GAM (Kelley and others, 2004, as updated by Hutchison (2017)
- The "new GAM" refers to the updated GAM documented by Panday and others (2023)
- The "GMA 13 Model (2024 Version)" refers to the update of the new GAM documented in Hutchison (2024).
- The "GMA 13 Model (2025 Version)" refers to the update of the GMA 13 Model (2024 Version documented in this report.

1.4 GMA 13 Model (2024 Version) Updated Elements

1.4.1 Webb County Issues

Independent of the public comments, Dr. Jordan Furnans of LRE Water provided summary results of two drilling logs and aquifer tests in an email dated June 1, 2023. LRE subsequently provided a technical memorandum dated January 30, 2024 that provided additional information related to the results of aquifer tests in the Sparta Aquifer and the Carrizo Aquifer. These data are discussed below and have been incorporated into the GMA 13 Model.

1.4.2 Wintergarden GCD Pumping Estimates

In February 2024, Wintergarden GCD provided groundwater pumping data from oil and gas operators and three reports from Southwest Research Institute (SWRi). The oil and gas pumping data covered the years 2010 to 2022. The SWRi information included groundwater pumping estimates from a local scale groundwater model for Carrizo Aquifer in five counties, the Queen City Aquifer in two counties, and the Sparta Aquifer for two counties through 1999. These data are discussed below and have been incorporated into the GMA 13 model.

1.4.3 SAWS Data

On June 16, 2024, Steven Siebert of the San Antonio Water System (SAWS) provided updated pumping data for the Regional Carrizo Project in Gonzales County, the Local Carrizo Project in Bexar County, and the Brackish Desalination Project in Bexar County.

It appears that the pumping in Gonzales County had already been incorporated into the "new GAM". The pumping in Bexar County provided by SAWS was incorporated into the initial estimates of pumping in the GMA 13 Model as developed in a later section.

1.5 Release of the GMA 13 Model (2024 Version)

A draft of the GMA 13 Model (2024 Version) report and model files were provided to the groundwater conservation districts of GMA 13 on August 16, 2024. The draft was updated four times from August 16, 2024 to September 11, 2024 in response to comments received.

GMA 13 approved the GMA 13 Model (2024 Version) at their meeting of September 20, 2024, and it was submitted to TWDB on September 23, 2024 for their review. In an email to GMA 13 on December 6, 2024, TWDB sought clarification of the location of the model files. GMA 13 responded on the same day.

On December 18, 2024, TWDB notified GMA 13 that the "recalibrated GAM had passed our initial review" and released the New GAM report and files for a 60-day public review.

1.6 Comments on GMA 13 Model (2024 Version)

TWDB received five letters with "public" comments:

- RW Harden & Associates (dated February 18, 2025)
- Gonzales County UWCD (dated February 19, 2025
- Evergreen UWCD (dated February 20, 2025
- San Antonio Water System (dated February 20, 2025)
- Ted Boriack (dated February 20, 2025)

Two of the five comment letters were sent from groundwater conservation district (GCD) members of GMA 13. Many of the issues raised by the GCD members extended beyond the original scope of the GAM update approved by GMA 13 on September 15, 2023. In response to the comments of the GCDs and the other three letters, additional updates were completed. This updated version is referred to as GMA 13 Model (2025 version). As noted below, specific responses to the five comment letters are included in Appendix G.

In summary, this report documents updates to the 2024 version based on the comments to the following:

- Pumping locations
- Transmissivity values in some areas
- Ratio of vertical to horizontal hydraulic conductivity values in some areas

Comments related to layering are not within the scope of the update. Comments related to specific yield were addressed specifically in Hutchison (2024) and are repeated in Section 5.2 of this report. Comments related to PEST limits were based on a misunderstanding of the documented use of the specific factors in the 2024 version. Comments related to rising groundwater levels were evaluated and found to be unfounded.

1.7 Uploaded Files

All files associated with the 2024 version of the GMA 13 Model had been previously uploaded to a Google Drive folder that can be accessed with the following link:

https://drive.google.com/drive/folders/1TrsRJuroTMfU8VJq3kQhDmHZLMa_yMpn?usp=sharing

Files associated with preliminary analyses presented in previous GMA 13 meetings are also archived at this location.

To avoid confusion, the 2025 version of the GMA 13 Model were uploaded to a different Google Drive folder that can be accessed at this location:

https://drive.google.com/drive/folders/1ysgVFUL2Ri4gYb65aDdva0zoZkwavWwc?usp=sharing

2.0 Model Simulation Period

The "new GAM" simulation was discretized into 39 stress periods. The first stress period was specified as steady-state and labeled "pre-development". The pumping was zero and recharge was set to average. The second stress period was also specified as steady-state and labeled as the year 1980. The recharge was slightly less than average and pumping was specified. There is no explanation in Panday and others (2023) for including two steady-state stress periods.

Both versions of the GMA 13 Model eliminated the first (pre-development) stress period. The first stress period in the GMA 13 Model is specified as steady state, has average recharge, and has non-zero pumping. The objective of this stress period is to provide stable initial heads for the transient stress periods (stress periods 2 to 38) that represent 1981 to 2017.

MODFLOW packages that involve specifying time-dependent boundary conditions were reviewed and updated as part of this change in time discretization. The "new GAM" input for RIV, GHB, and EVT were constant in all stress periods. The RIV and EVT files were updated to remove redundant specification of input for stress periods 2 to 38. The RCH input file for the "new GAM" specified the steady-state recharge rate for each cell and a multiplier that varied with each stress period (Panday and others, 2023). These multipliers were updated to reflect that GMA 13 Model's first stress period has a recharge multiplier of 1.0. All other annual recharge multipliers (stress periods 2 to 38) remained the same in the initial run of the GMA 13 Model.

Table 2 presents the updated time discretization and includes the annual multiplier for recharge.

Table 2. Stress Period Summary for GMA 13 Model

Stress Period Number	Number of Time Steps	Stress Period Length (days)	Year	Stress Period Type	Stress Period Recharge Multiplier
1	1	365	1980	Steady-State	1
2	1	365	1981	Transient	1.20989
3	1	365	1982	Transient	0.81749
4	1	365	1983	Transient	0.83798
5	1	365	1984	Transient	0.70988
6	1	365	1985	Transient	1.14073
7	1	365	1986	Transient	1.07720
8	1	365	1987	Transient	1.09008
9	1	365	1988	Transient	0.50285
10	1	365	1989	Transient	0.66994
11	1	365	1990	Transient	0.99623
12	1	365	1991	Transient	1.18867
13	1	365	1992	Transient	1.33770
14	1	365	1993	Transient	0.85791
15	1	365	1994	Transient	1.08213
16	1	365	1995	Transient	0.83718
17	1	365	1996	Transient	0.59276
18	1	365	1997	Transient	1.16594
19	1	365	1998	Transient	1.16846
20	1	365	1999	Transient	0.66986
21	1	365	2000	Transient	1.01355
22	1	365	2001	Transient	0.91178
23	1	365	2002	Transient	1.55017
24	1	365	2003	Transient	1.13060
25	1	365	2004	Transient	1.48048
26	1	365	2005	Transient	0.74975
27	1	365	2006	Transient	0.67044
28	1	365	2007	Transient	1.60549
29	1	365	2008	Transient	0.63511
30	1	365	2009	Transient	0.91541
31	1	365	2010	Transient	1.14038
32	1	365	2011	Transient	0.52732
33	1	365	2012	Transient	0.90734
34	1	365	2013	Transient	0.99553
35	1	365	2014	Transient	0.88412
36	1	365	2015	Transient	1.46113
37	1	365	2016	Transient	1.38951
38	1	365	2017	Transient	1.13780

3.0 Annual Calibration Targets

The annual targets developed for calibration of the GMA 13 Model were the same in the 2024 version and the 2025 version.

3.1 Annual Targets from New GAM

The Groundwater Vistas file for the "new GAM" that was delivered to TWDB is named *GMA13_Historical_Period_Calibration.gwv* (dated 5/1/2022). The targets used in calibration of the model were contained in this Groundwater Vistas file and were exported and saved as *target2.csv* (dated 7/22/2024). The calibration targets consisted of 23,815 groundwater elevations (or heads) for individual wells at times listed in the file. The simulation times were converted to decimal years for further processing.

A Fortran program (*anntarg.exe*) was written to read the full set of targets and the model grid file (*GMA13shortgrid.csv*). Groundwater elevations measured in the last quarter of a year or the first quarter of the subsequent year were saved and considered "annual" end-of-year targets for further use. The final output file (*anntarg.dat)* includes the following for each of the 14,023 annual targets from 1981 to 2017:

- Model cell number (labeled as "node")
- Model layer
- Outcrop status of cell (1=outcrop, 2= downdip)
- County code
- Stress period
- Year
- Measured groundwater elevation (labeled as "GWE")
- Weight (used in Vistas file for the "new GAM")
- Decimal date

3.2 Removal of Duplicate Targets

Analysis of the resulting target file using the Fortran program *checktarg.exe* found that targets are located in 1,092 model cells (*targlist.dat*). The output file *targcount.dat* lists the cell, stress period, and number of targets for each cell-stress period pair. Of the 7,000 cell-stress period pairs, 718 have more than one target (161 have more than 20 targets, and one has 46 targets). This means that during calibration, as many as 46 targets are used in a single cell in a single stress period.

As part of calibration, spatial and temporal interpolation can be applied to multiple targets (i.e. more than one well in a cell, or more than one groundwater elevation measurement in a stress period). This common technique is applied in Groundwater Vistas. However, if the variation in actual groundwater elevations within a single cell-stress period pair is large, the interpolation scheme may result in calibration difficulties.

Actual groundwater elevation differences within these 718 cell-stress period pairs were analyzed further with the Fortran program *ActGWEDuplicates.exe*. This program:

- Reads the list of cells with targets (*targlist.dat*)
- Reads the annual target file from the "new GAM" described above (*anntarg.dat*)
- Find the minimum and maximum actual groundwater elevation for each cell-stress period pair
- Calculates the average actual groundwater elevation for each cell-stress period pair
- Writes *actgweminmax.dat* which includes the minimum, maximum, and average actual groundwater elevation for each of the 7,000 cell-stress period pairs. Also included are the difference between the minimum and maximum actual groundwater elevation.

The difference between the minimum and maximum actual groundwater elevation for the 719 cell-stress period pairs with more than one target ranges from 0 to about 143 feet. Figure 2 presents the distribution of the differences. It can be seen that about 40 percent of the duplicates have a difference of 5 feet or less.

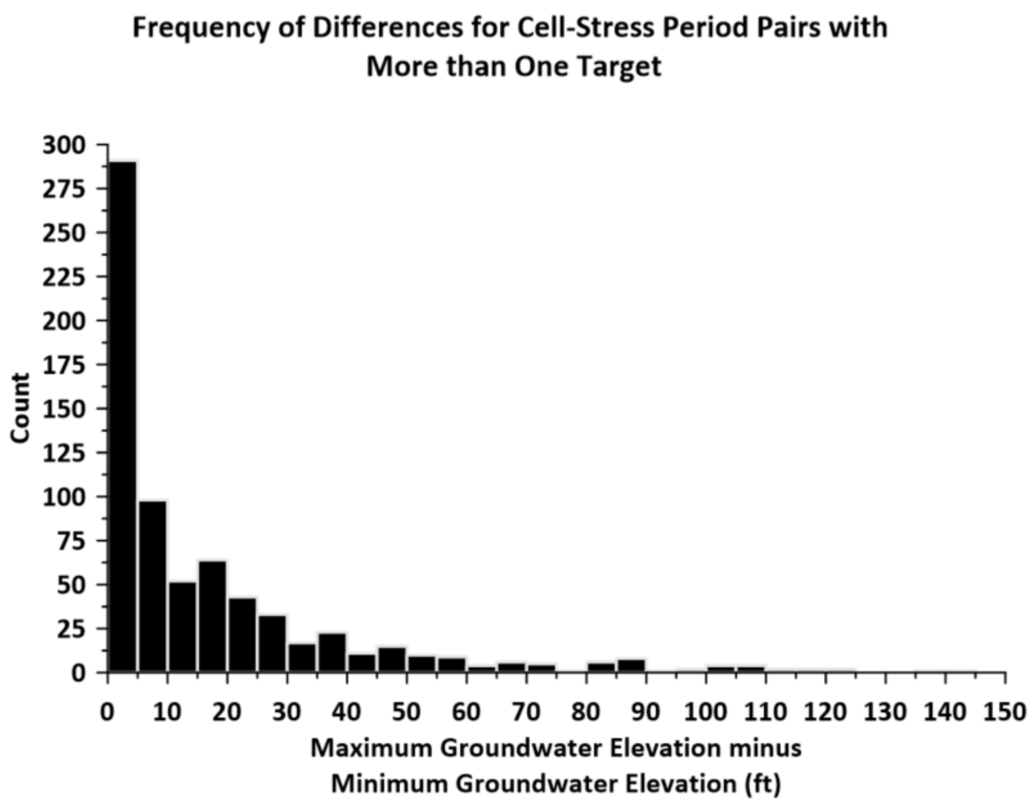


Figure 2. Frequency Distribution of Differences in Target Duplicates

3.3 GMA 13 Model Targets

The file named *actgweminmax.dat* described above was saved as *GMA13Targets.xlsx* and *GMA13Targets.csv* for calibration of the GMA 13 Model.

Figure 3 presents the number of targets by year. Figure 4 presents the number of targets by model layer. Figure 5 presents the number of targets in outcrop cells and downdip cells.

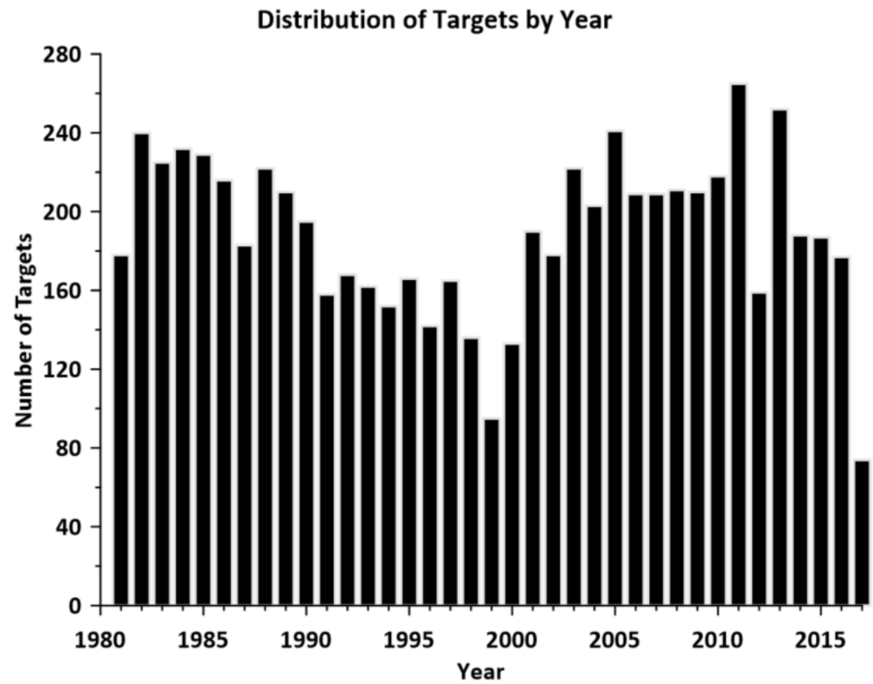


Figure 3. Target Distribution by Year

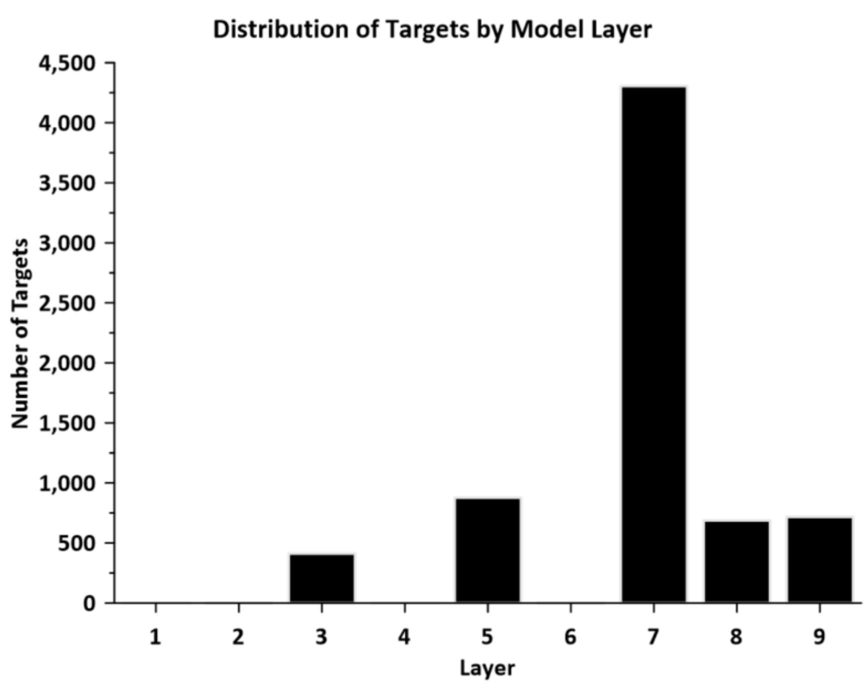


Figure 4. Target Distribution by Model Layer

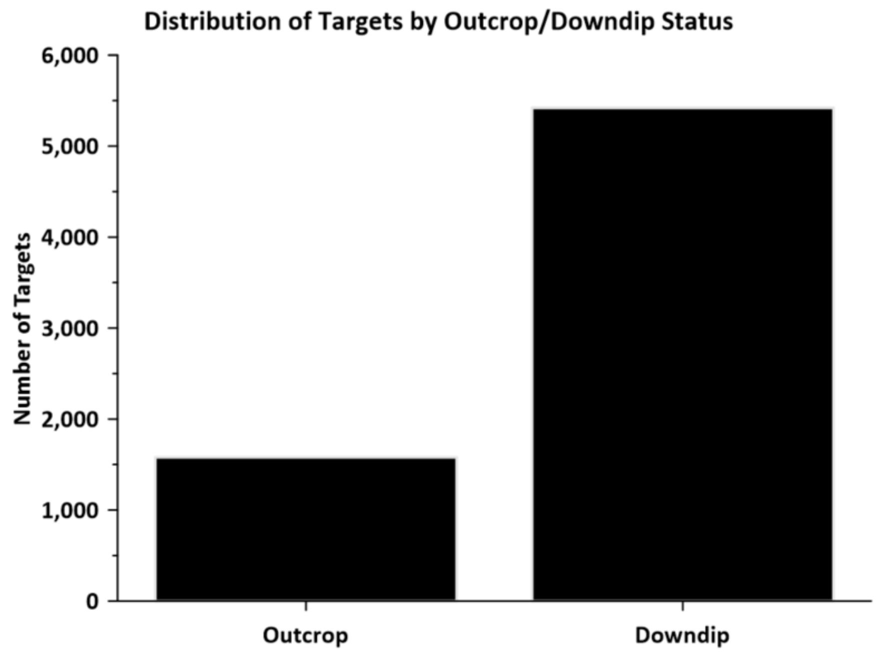


Figure 5. Target Distribution by Cell Type (Outcrop and Downdip)

4.0 Calibration of New GAM Using GMA 13 Model Targets

A baseline set of calibration statistics for the "new GAM" using the annual targets described above were developed. These statistics were used as the foundation for assessing the calibration of the GMA 13 Model as described later in this report.

4.1 Post Processor for New GAM

The Fortran program *gethedNG.exe* was written to read the binary hds file of the "new GAM" (*GMA13_Historical_Period_Calibration.hds*) and write several files that compare the actual heads in *GMA13Targets.csv* with the simulated heads from the new GAM model.

The program:

- Reads the model output file (*GMA13_Historical_Period_Calibration.hds*) and shifts the output by one stress period to reflect the change in stress period specification of the GMA 13 Model targets.
- Reads the actual groundwater elevation data for 7,000 targets (*GMA13Targets.csv*). Included in the target file are the cell number, layer of the cell, status of the cell (outcrop or downdip), stress period of the target, year of the target, and actual groundwater elevation.
- Various statistics are calculated after each record is read
- Once all the records are read, the mean of the residuals (calculated as actual minus simulated) and the mean of the absolute value of the residuals are calculated for:
    - Groundwater occurrence status (outcrop (1), downdip (2), overall (3))
    - Model layer (layers 1 to 9, 10 = overall)
- Calculates standard deviation of the residuals
- Calculates scaled statistics
- Writes summary statistics for outcrop, downdip, and overall for each layer and for the entire model domain
- Writes output files that lists the comparison of each record:
    - Overall model domain (a*ctsimcal.dat)*
    - All targets in outcrop cells (*actsimcalOC.dat*)
    - All targets in layer *x* for targets in outcrop cells (*x*=layers 3, 5, 7, 8, and 9: *actsimLxOC.dat*)
    - All targets in layer *x* for targets in downdip cells (*x* = layers 3, 5, 7, 8, and 9: *actsimLxDD.dat*
- Writes the heads for stress period 1 (*sp1hds.dat*) for use as the initial conditions in subsequent runs of the model.

4.2 New GAM Calibration Results

These files were imported and saved in a single Excel spreadsheet named *ActSimCalibAll.xlsx*. The Excel spreadsheet named *ActSimCalibLayerOCDD.xlsx* has individual tabs for each aquifer layer (3, 5, 7, 8, and 9) for outcrop (OC) and downdip (DD) areas. The summary calibration statistics for the "new GAM" using these targets as follows:

- Table 3 presents all targets
- Table 4 presents outcrop targets
- Table 5 presents downdip targets

the summary calibration statistics of each of the layer-outcrop/downdip groups, as well as the overall summary calibration statistics of the "new GAM" using the annual targets.

Table 3. "New GAM" Summary Calibrations Statistics – All Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	411	878	4,306	688	717	7,000
Range in Observations	296.22	475.19	869.38	826.82	507.47	895.06
Minimum Residual	-232.49	-258.37	-373.01	-317.28	-199.12	-373.01
Maximum Residual	115.05	192.88	256.44	153.29	98.84	256.44
Residual Mean	-8.33	-8.56	7.96	15.09	0.79	4.90
Sum of Squared Residuals	5.98E+05	2.35E+06	8.74E+06	1.35E+06	5.70E+05	1.36E+07
Absolute Residual Mean	25.33	33.12	30.12	31.76	20.26	29.37
Residual Standard Deviation	37.22	51.07	44.33	41.68	28.18	43.82
Root Mean Square Error	38.15	51.78	45.04	44.33	28.19	44.09
Scaled Residual Standard Deviation	0.1257	0.1075	0.0510	0.0504	0.0555	0.0490
Scaled Absolute Residual Mean	0.0855	0.0697	0.0346	0.0384	0.0399	0.0328
Scaled Root Mean Square Error	0.1288	0.1090	0.0518	0.0536	0.0555	0.0493
Scaled Residual Mean	-0.0281	-0.0180	0.0092	0.0182	0.0016	0.0055

Table 4. "New GAM" Summary Calibrations Statistics – Outcrop Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	90	407	638	159	285	1,579
Range in Observations	258.40	391.70	409.11	486.04	407.50	509.39
Minimum Residual	-75.83	-120.05	-75.81	-96.61	-109.79	-120.05
Maximum Residual	78.67	192.88	91.93	90.29	83.93	192.88
Residual Mean	-11.19	8.10	-6.04	19.04	4.57	1.75
Sum of Squared Residuals	1.43E+05	5.62E+05	4.14E+05	2.66E+05	1.05E+05	1.49E+06
Absolute Residual Mean	32.93	26.73	18.52	32.46	13.73	22.00
Residual Standard Deviation	38.19	36.28	24.75	36.18	18.63	30.66
Root Mean Square Error	39.80	37.17	25.47	40.88	19.18	30.71
Scaled Residual Standard Deviation	0.1478	0.0926	0.0605	0.0744	0.0457	0.0602
Scaled Absolute Residual Mean	0.1274	0.0682	0.0453	0.0668	0.0337	0.0432
Scaled Root Mean Square Error	0.1540	0.0949	0.0623	0.0841	0.0471	0.0603
Scaled Residual Mean	-0.0433	0.0207	-0.0148	0.0392	0.0112	0.0034

Table 5. "New GAM" Summary Calibrations Statistics – Downdip Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	321	471	3,668	529	432	5,421
Range in Observations	258.76	446.62	810.77	776.99	474.76	845.23
Minimum Residual	-232.49	-258.37	-373.01	-317.28	-199.12	-373.01
Maximum Residual	115.05	147.02	256.44	153.29	98.84	256.44
Residual Mean	-7.53	-22.96	10.40	13.90	-1.71	5.81
Sum of Squared Residuals	4.56E+05	1.79E+06	8.32E+06	1.09E+06	4.65E+05	1.21E+07
Absolute Residual Mean	23.20	38.64	32.14	31.55	24.56	31.51
Residual Standard Deviation	36.91	57.25	46.48	43.12	32.76	46.93
Root Mean Square Error	37.67	61.68	47.63	45.31	32.80	47.28
Scaled Residual Standard Deviation	0.1426	0.1282	0.0573	0.0555	0.0690	0.0555
Scaled Absolute Residual Mean	0.0897	0.0865	0.0396	0.0406	0.0517	0.0373
Scaled Root Mean Square Error	0.1456	0.1381	0.0587	0.0583	0.0691	0.0559
Scaled Residual Mean	-0.0291	-0.0514	0.0128	0.0179	-0.0036	0.0069

One to one plots of measured groundwater elevations versus simulated groundwater elevations for all targets are presented in Figure 6 (all targets) and Figure 7 (outcrop area targets). The red diagonal line represents a perfect match.

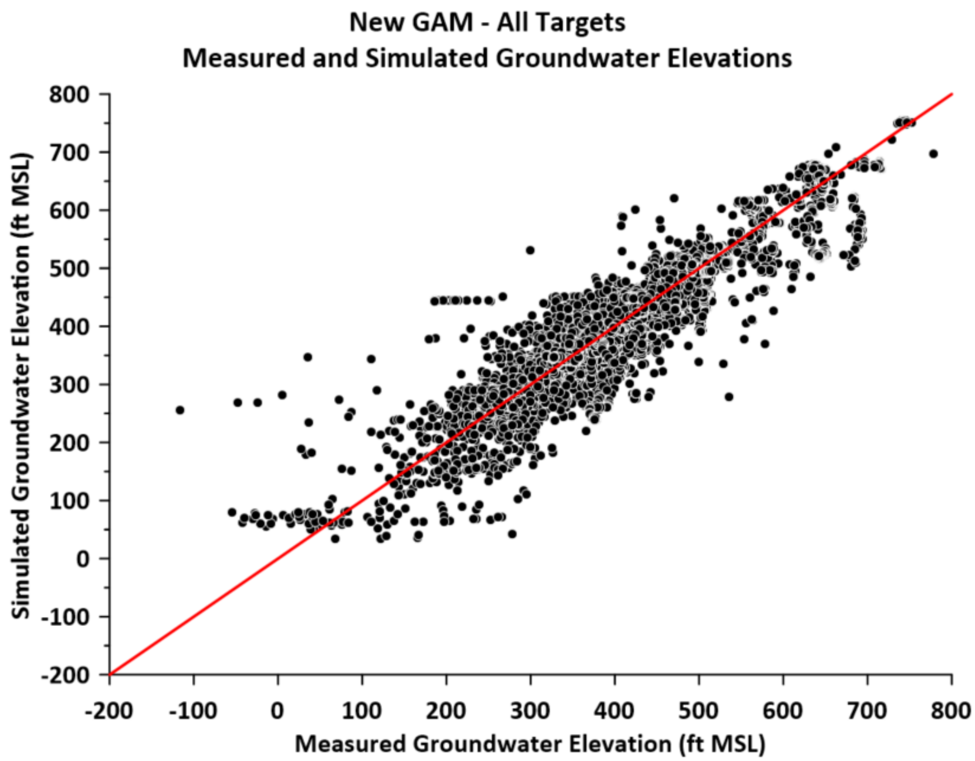


Figure 6. New GAM: Measured vs. Simulated Groundwater Elevations – All Targets

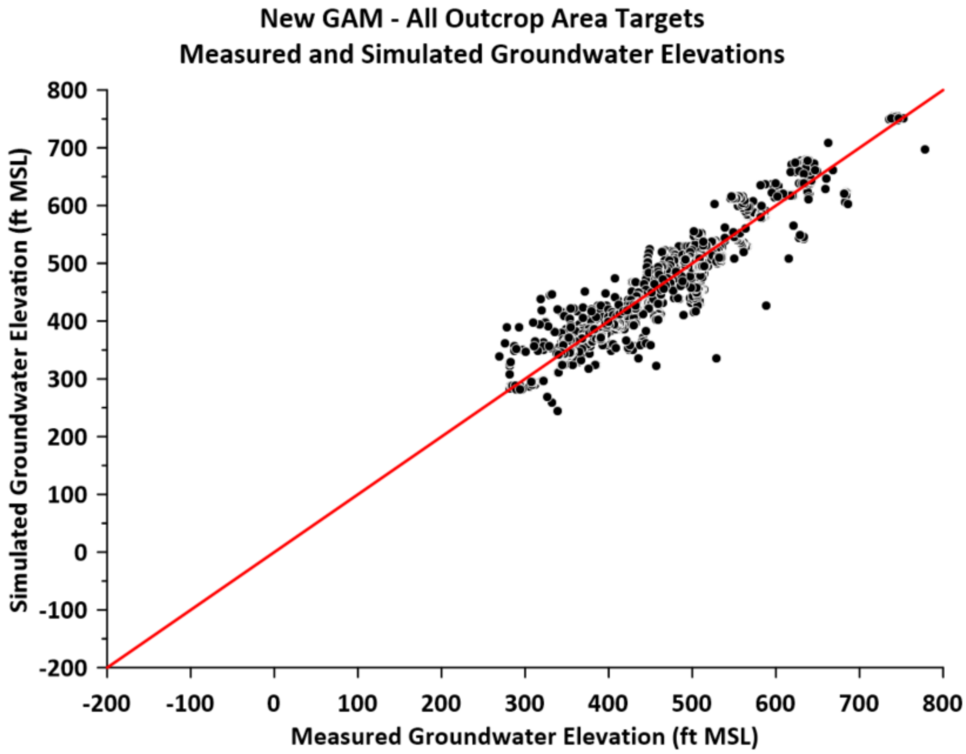


Figure 7. New GAM: Measured vs. Simulated Groundwater Elevations - Outcrop Targets

5.0 New GAM Parameters

The model input files from the "new GAM" were processed using the Fortran program *GAMParam.exe*. Output includes selected data for each cell in the model grid. Output files include a master file *GAMPram.dat* and files for each model layer (*ParamL**x**.dat,* where ***x*** equals the model layer number). The master file was imported into an Excel spreadsheet named *GAMParam.xlsx*. the tab named *All Layers* contains the parameters for the entire model.

5.1 Hydraulic Conductivity and Transmissivity

The tab named *KT MinAvgMax* in the Excel file named *GAMParam.xlsx* contains the minimum, average, and maximum values for hydraulic conductivity and transmissivity. The *KT MinAvgMax* sheet is presented below as Table 6. Frequency plots for the parameters in Table 4 are presented in Appendix A.

Table 6. Minimum, Average, and Maximum Values for Relevant New GAM Parameters

Minimum

Layer	Aquifer Name	Cell Thickness (ft)	Kx (ft/day)	Kz/Kx Ratio	Kz (ft/day)	Transmissivty (gpd/ft)
3	Sparta	6	1.00E-01	3.92E-03	1.73E-03	8
5	Queen City	6	1.15E-01	2.00E-01	5.43E-02	16
7	Carrizo-Upper Wilcox	6	9.83E-02	8.15E-06	1.93E-06	22
8	Middle Wilcox	6	9.51E-02	1.54E-04	2.28E-05	14
9	Lower Wilcox	6	8.92E-02	8.02E-03	2.44E-03	18

Average

Layer	Aquifer Name	Cell Thickness (ft)	Kx (ft/day)	Kz/Kx Ratio	Kz (ft/day)	Transmissivty (gpd/ft)
3	Sparta	202	1.02	0.06	0.04	1,655
5	Queen City	738	106.66	0.83	91.00	670,408
7	Carrizo-Upper Wilcox	745	41.91	0.09	6.82	350,022
8	Middle Wilcox	467	6.48	0.13	0.10	10,794
9	Lower Wilcox	708	11.36	0.17	1.29	19,805

Maximum

Layer	Aquifer Name	Cell Thickness (ft)	Kx (ft/day)	Kz/Kx Ratio	Kz (ft/day)	Transmissivty (gpd/ft)
3	Sparta	635	4.56	0.57	0.16	16,360
5	Queen City	1,946	1,139	1.02	1,014	9,386,962
7	Carrizo-Upper Wilcox	1,680	1,064	1.12	699	10,171,605
8	Middle Wilcox	2,090	606	1.30	1.51	1,144,614
9	Lower Wilcox	3,210	570	0.99	86.53	3,298,857

It should be noted that the public comments focused on high transmissivity values in the Carrizo-Wilcox Aquifer. However, this review also identified issues with high transmissivity values in the Queen City Aquifer. The Sparta, Middle Wilcox, and Lower Wilcox also exhibit issues to a lesser extent. As a comparison standard, reasonable maximum transmissivity values for the alluvium and each aquifer are provided below (and form the basis for the GMA 13 Model):

- Alluvium = 1,000 gpd/ft
- Sparta Aquifer = 4,000 gpd/ft
- Queen City Aquifer = 10,000 gpd/ft
- Carrizo-Upper Wilcox Aquifer = 100,000 gpd/ft
- Middle Wilcox Aquifer = 25,000 gpd/ft
- Lower Wilcox Aquifer = 50,000 gpd/ft

This review also identified an issue with the Kz/Kx ratio (the ratio between vertical and horizontal hydraulic conductivity) that was not part of the public comments. In the input file for the "new GAM" for aquifer parameters (*GMA13_Historical_Period_Calibration.npf*), the ratio of vertical hydraulic conductivity to horizontal hydraulic conductivity is specified using the keyword *K33OVERK*. These ratios are read in a file named *GMA13_Historical_Period_Calibration._kz*. This means that Kz (vertical hydraulic conductivity) is calculated as the horizontal hydraulic conductivity (Kx) times the Kz/Kx ratio (i.e. the input file parameter labeled Kz). Values less than 1 means that the vertical hydraulic conductivity is less than the horizontal hydraulic conductivity. As a general standard, a value of 0.10 or less would likely be considered appropriate.

The naming convention of the input file (i.e. using Kz in the name) is potentially confusing since the input data are ratios and not the actual Kz values. The convention of expressing the ratio this way is new and unique to MODFLOW 6 (as compared to earlier versions of MODFLOW). For example, in MODFLOW-2005 and MODFLOW-USG, the vertical hydraulic conductivity is specified as either Kz or the ratio of Kx to Kz (horizontal to vertical). Thus, ratios in older versions of MODFLOW, as a general standard, should be 10 or greater.

Average Kz/Kx ratio (the ratio between vertical and horizontal hydraulic conductivity) in Table 6 do not meet the general standard discussed above. The maximum values include some values that exceed a value of 1.0, which means that the vertical hydraulic conductivity is greater than the horizontal hydraulic conductivity, which is not reasonable.

Details on adjustments to the "new GAM" parameters for the initial values for the GMA 13 Model are discussed below in Section 9.

5.2 Storativity and Specific Yield

Among the public comments received, it was asserted that the specific yield values in the "new GAM" were "unreasonable". Specifically, it was asserted that the use of 0.005 as a specific yield value would underestimate the storage of water in the unconfined portion of the model domain by a factor of about 40 and lead to overpredictions of water-table drawdown.

The assertion of the use of 0.005 for all unconfined areas is not true. The model input files include an input file for specific yield named *GMA13_Historical_Period_Calibration._sy*. Data for specific yield are included in the GAM parameter file discussed above. Estimates for specific yield for the alluvium (layer 1 of the "new GAM") is specified as 0.1 for all cells. Layer 2 is the lumped unit called "Overlying Formations" and is not formally part of the simulation. In the unconfined area of layers 3 to 9, the specific yield value is specified as 0.005.

A specific yield of 0.1 is appropriate for relatively thin cells and representative of clean sand. As drilling and electric logs show, interlayered clays are common in the Sparta, Queen City, and Carrizo-Wilcox Aquifers. A specific yield of 0.005 is appropriate for relatively thick cells where interbedded clays are more likely. These thicker cells are more likely to be characterized as semi-confined even though the cell classified as "unconfined" in a MODFLOW context.

While this discussion works on a conceptual or qualitative level, an open question is how the specification of specific yield will affect storage calculations and model calibration (as raised in the public comment).

5.2.1 Impact of Specific Yield on Storage Calculations

TWDB has historically used GAMs to calculate Total Estimated Recoverable Storage (TERS). The GAMs provide a convenient means to make the calculation, but there is considerable uncertainty with the results due to a variety of concerns mostly revolving around the uncertainty of some of the GAM parameters. When the "old GAM" was developed in 2004, it is doubtful that the developers considered the possibility of using the model to calculate total aquifer storage. Many of the GAM parameters crucial to the TERS calculations are, in fact, place holder values for which there is no underlying supporting data. These "place holder" values have no effect on model results or calibration. Thus, there is no basis to assert that a change to these parameters is "unreasonable".

Because the public comment focused on the impact of storage, it is reasonable to infer that the underlying concern is on how the specific yield specification will impact the calculation of TERS ("Consequently, the volume of water assigned to the GAM aquifer layers is approximately $1/40^{th}$ of the volume that is described by documented, appropriate values of specific yield").

The assertion in the public comment was tested quantitatively. For the alluvium and outcrop area of the aquifer units (layers 3, 5, 7, 8, and 9), Table 7 summarizes an analysis of storage volume of the "new GAM" and three alternative specifications of specific yield. The calculations associated with Table 4 are contained in the Excel spreadsheet named *Sy and Storage Alternatives.xlsx.*

Table 7. Specific Yield and Storage Volume Alternatives – Outcrop Area

Layer Number	Cell Count	Area (million acres)	Average Saturated Thickness in 2017 (ft)	Storage in 2017 (million AF)			
				"New GAM"	Sy Scen 100	Sy Scen 200	Sy Scen 300
1	213,508	2.16	2	0.48	0.44	0.48	0.48
3	4,548	0.70	129	0.39	1.92	5.74	7.45
5	17,362	2.11	526	5.67	6.55	9.35	14.26
7	4,581	0.62	161	0.43	1.34	3.31	5.20
8	3,735	0.46	156	0.32	1.04	2.59	4.02
9	6,644	0.77	220	0.75	1.95	4.61	7.52
Total	250,378	6.81	N/A	8.05	13.23	26.08	38.93

Please note that the table summarizes the cell count, area (in millions of acres), and average saturated thickness of the unconfined portion of each layer listed. The volume of water in each cell (unconfined cells only) is calculated as:

Storage Volume (million acre-feet) = Area (million acres) * Saturated Thickness (ft) * Specific Yield

The storage volume in 2017 in Table 7 is the sum of all cells in the specified layer. Four alternative storage volumes are presented based on four alternatives of specific yield:

- The calibrated "New GAM" (Sy = 0.1 in layer 1 and Sy = 0.005 in layers 3 to 9)
- Sy Scenario 100 (Sy = 0.1 for cells with saturated thickness less than 100 ft, Sy = 0.005 for cells with saturated thickness greater than 100 ft)
- Sy Scenario 200 (Sy = 0.1 for cells with saturated thickness less than 200 ft, Sy = 0.005 for cells with saturated thickness greater than 200 ft)
- Sy Scenario 300 (Sy = 0.1 for cells with saturated thickness less than 300 ft, Sy = 0.005 for cells with saturated thickness greater than 300 ft)

In the alluvium, when a specific yield of 0.005 is applied to cells with saturated thickness greater than 100 feet, the storage is less than the calibrated model because the calibrated model specific yield is 0.1. When the threshold saturated thickness is increased to 200 or 300 ft, there is no change to the calculated storage volume because there are only a few cells in the alluvium with a saturated thickness of greater than 100 feet.

However, in the aquifer units (layers 3, 5, 7, 8 and 9) the calculated storage in the outcrop area increases when the application of a specific yield of 0.1 is applied to thicker cells. The calibrated model specific yield is 0.005, so the application of 0.1 results in increased calculated storage volumes. The total storage volume for the alluvium and all aquifer layers for the "new GAM" is about 8 million acre-feet. Under the most extreme alternative (specific yield of 0.1 for cells with saturated thickness greater than 300 feet), the calculated storage volume is about 39 million acre-feet. This represents an increase by a factor of about 5 (not 40 as asserted in the public comment).

The scenario "Sy Scen 100" (saturated thickness threshold of 100 ft) may be most reasonable from the perspective of the alluvial layer, in which saturated thickness is almost always less than 100 feet. Reasonableness in this context means applying this 100 ft threshold would be most consistent across all layers.

5.2.2 Impacts on Model Calibration

The impact of the choice of specific yield threshold was also examined quantitatively in the context of model calibration. Four alternative specific yield scenarios were simulated:

- The calibrated "New GAM" (Sy = 0.1 in layer 1 and Sy = 0.005 in layers 3 to 9)
- Sy Scenario 100 (Sy = 0.1 for cells with saturated thickness less than 100 ft, Sy = 0.005 for cells with saturated thickness greater than 100 ft)
- Sy Scenario 200 (Sy = 0.1 for cells with saturated thickness less than 200 ft, Sy = 0.005 for cells with saturated thickness greater than 200 ft)
- Sy Scenario 300 (Sy = 0.1 for cells with saturated thickness less than 300 ft, Sy = 0.005 for cells with saturated thickness greater than 300 ft)

Table 8 summarizes the calibration statistics of the simulation results.

Table 8. Calibration Statistics: Alternative Specific Yield Simulations

Statistic	"New GAM"	Sy Scen 100	Sy Scen 200	Sy Scen 300
Thickness Threshold	N/A	100 ft	200 ft	300 ft
Number of Observations	2,394	2,394	2,394	2,394
Range in Observations	541.59	541.59	541.59	541.59
Minimum Residual	-185.36	-185.35	-185.32	-182.70
Maximum Residual	207.96	207.60	203.57	196.63
Residual Mean	-0.95	-0.95	-1.12	-1.52
Sum of Squared Residuals	1,793,770	1,787,352	1,756,272	1,724,904
Absolute Residual Mean	18.80	18.77	18.57	18.43
Residual Standard Deviation	27.36	27.31	27.07	26.80
Root Mean Square Error	27.37	27.32	27.09	26.84
Scaled Residual Standard Deviation	0.0505	0.0504	0.0500	0.0495
Scaled Absolute Residual Mean	0.0347	0.0347	0.0343	0.0340
Scaled Root Mean Square Error	0.0505	0.0505	0.0500	0.0496
Scaled Residual Mean	-0.0017	-0.0018	-0.0021	-0.0028

The alternative specification of specific yield has no significant effect on calibration statistics. The lack of change in calibration statistics makes it difficult to find the "correct" threshold of saturated thickness that would be appropriate to define higher and lower specific yield values.

From a practical standpoint, any modification in specific yield to address the comment would have a greater effect on cells with head targets than in cells without targets. The outcrop area cells with targets were evaluated to gain some perspective on the variation in saturated thickness. The Excel spreadsheet *TargListParam.xlsx* contains the data used in this analysis. These data were developed using the Fortran program *TargParam.exe*. A summary of the frequency of saturated thickness in the outcrop cells with targets is shown in Figure 8.

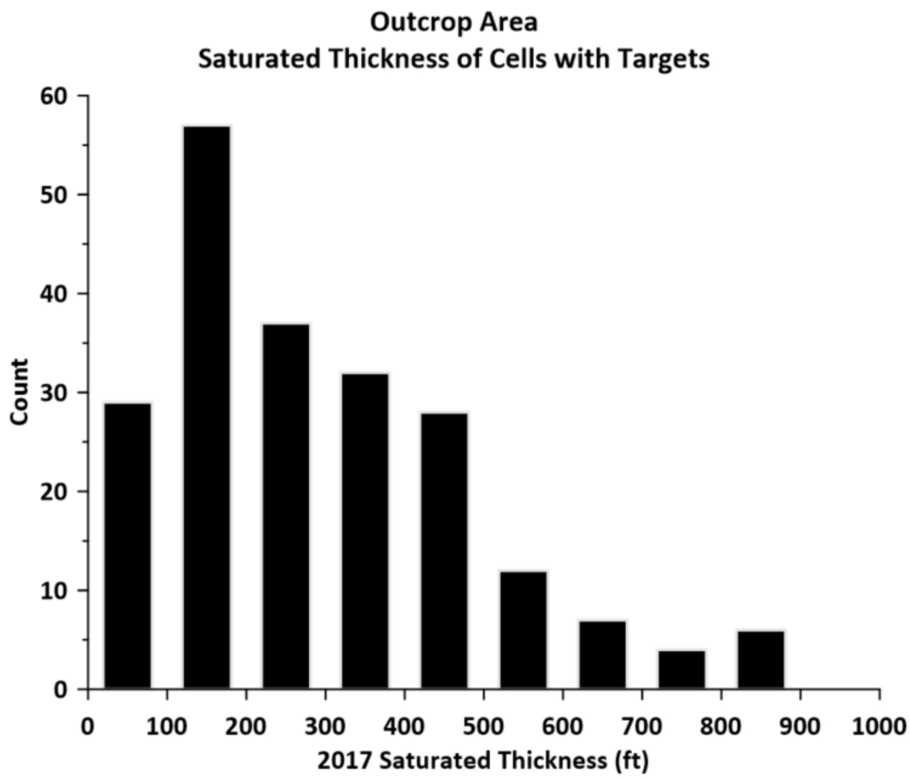


Figure 8. Outcrop Area: Saturated Thickness of Cells with Targets

Please note that of the 216 outcrop cells with targets, only about 15 percent have saturated thicknesses less than 100 feet. It would be expected that the cells with more than 100 feet of saturated thickness have a higher probability of clay interbeds than those cells with less than 100 feet of saturated thickness.

Based on this analysis, the GMA 13 Model includes a specific yield modifications as follows:

- Specific yield is 0.1 for cells with saturated thickness less than 100 feet
- Specific yield is 0.005 for cells with saturated thickness greater than 100 feet

These modifications were made in response to the public comment and will provide a more consistent conceptualization of specific yield. However, the modifications will have minimal impact on improving model calibration.

6.0 Webb County Aquifer Test Data from LRE

These data were used in the development of the 2024 version of the GMA 13 Model. No changes were made when the 2024 version was updated to the 2025 version. This section of the report is simply repeated from Hutchison (2024).

6.1 Summary of Aquifer Test Results

As noted above, LRE provided a technical memorandum dated January 30, 2024 that provided information related to the results of aquifer tests in the Sparta Aquifer and the Carrizo Aquifer in Webb County. The x-and y-coordinates of the wells were used in the Fortan program *getcellnum.exe* to find the model cell containing each well. The cell thickness and horizontal hydraulic conductivity for these cells were then used to calculate the transmissivity of the cell. The relevant data are summarized in Table 9.

Table 9. Summary of LRE Aquifer Tests

Well Name	From LRE Tech Memo (1/30/2024)		From "New" GAM (Panday and others, 2023)					Revised Initial Estimate of Horizontal Hydraulic Conductivity based on LRE Aquifer Tests for GMA 13 Model (ft/day)
	Aquifer	Aquifer Transmissivity (gpd/ft)	GAM Cell Number	Layer	Cell Thickness (ft)	Horizontal Hydraulic Conductivity (ft/day)	GAM Transmissivity (gpd/ft)	
Huisache	Sparta	400	265202	3	287	3.60	7,798	0.19
Catalinas	Sparta	550	265200	3	305	3.90	8,956	0.24
MK HC	Sparta	1,000	265201	3	295	3.80	8,395	0.45
Malvinas	Sparta	1,500	263204	3	142	2.50	2,670	1.41
Pilas HC	Sparta	900	263507	3	157	2.60	3,036	0.77
Antennas	Sparta	1,600	264545	3	238	3.30	5,864	0.90
PI-SP-01	Sparta	1,200	263507	3	157	2.60	3,036	1.02
Malvinas	Sparta	2,200	263204	3	142	2.50	2,670	2.07
EOG Gonzales WSW #1	Carrizo	1,150	338738	7	1211	57.00	512,700	0.13
MK-CZ-01	Carrizo	858	339569	7	1378	0.14	1,456	0.08
PI-CZ-01	Carrizo	1,550	338933	7	1334	0.11	1,098	0.16

In the center portion of Table 6, the relevant aquifer parameters from the "new GAM" are presented. It can be seen that the "new GAM" estimates of transmissivity are higher than those calculated from the aquifer tests. The right column of Table 9 represent the recalculated horizontal hydraulic conductivity based on the transmissivity from the aquifer tests that were used as new initial conditions in the GMA 13 Model as discussed below.

These data are consistent with the public comments noted above regarding "new GAM" transmissivity values. Correcting these high transmissivities is one of the key objectives of this effort, and these data are useful to the development of the GMA 13 Model.

6.2 Use of Aquifer Test Results

The LRE Technical Memorandum contained minimal information on the methods used to estimate transmissivity from the aquifer test data. The only specific citations were the Cooper-Jacob method and the Theis recovery method. For some of the estimates, no method was cited.

It appears that the effects of leakage from overlying formations and the effects of partial penetration were not incorporated into the analysis. While these effects are generally small and can be ignored, it does highlight that the resulting estimates should be used as guides rather than as absolute values. Thus, as described below, the hydraulic conductivity estimates from the "new GAM" were adjusted to match the results of the aquifer test analyses. These represent the initial estimates for the GAM 13 Model and were adjusted as part of calibration.

As part of the analysis to incorporate the aquifer test results into the GMA 13 Model the following analyses were completed in the Fortran program *getcellnum.exe:*

- The distances between the tested wells was calculated (*LRE Sparta Dist.dat* and *LRE Carrizo Dist.dat*).
- Listed all cells within a specified distance from each test well (initially set at 3 miles). There were a number of duplicate cells in this list because there were instances where a cell was within 3 miles of more than one tested well (*lrecells.dat*)
- Reduced the full list of "nearby cells" to a list where the cells are listed only once with the closest tested well identified for purposes of assigning initial hydraulic conductivity values (*lrecellslist.dat*)

7.0 Evergreen UWCD Pumping Test Results

Incorporation of the pumping test results provided by Evergreen UWCD represented an update to the 2024 version and are now part of the GMA 13 Model (2025 Version).

In their comment letter of February 20, 2025, Evergreen UWCD provided the results of 49 aquifer tests that provided estimates of transmissivity, and latitude and longitude coordinates of the tests. These coordinates were converted to the GAM coordinate system, and the wells were located on the model grid. Figure 9 presents the locations and estimated transmissivity of the 49 provided tests.

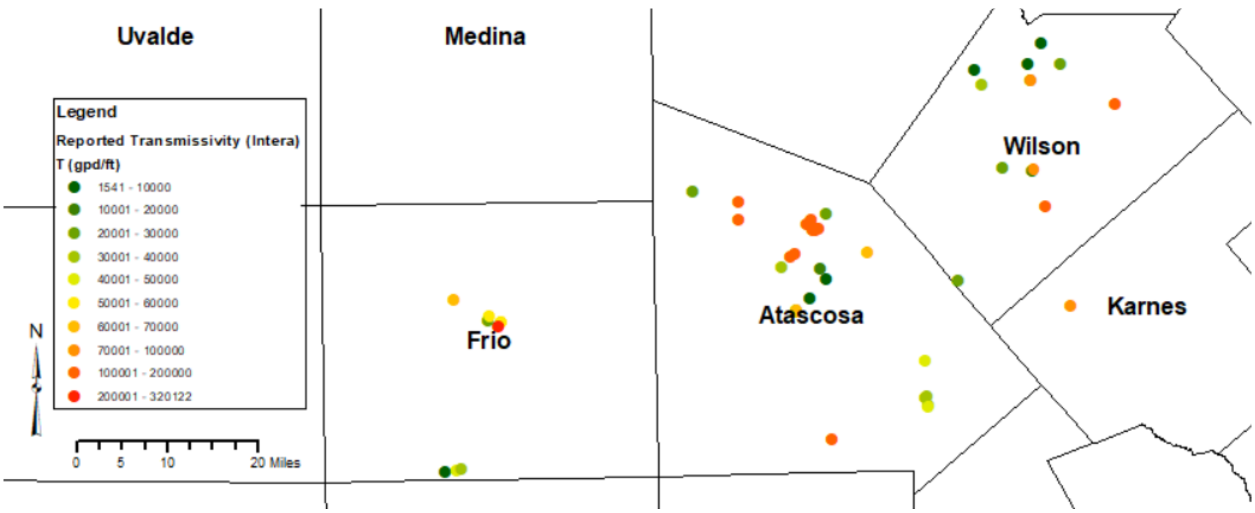


Figure 9. Location of Pumping Tests and Estimated Transmissivities

Please note that many of the test locations are clustered. The test results were evaluated and plotted in Figure 10, which cross plots the estimated transmissivity of a single test with the average of all transmissivity results of these test results within two miles.

Please note that the highest estimated transmissivity value is somewhat of an outlier (i.e. a linear trend between single test transmissivity and average transmissivity can be seen in all other values). Thus, the upper transmissivity limit used in calibration was increased to 200,000 gpd/ft. The analysis of the data, however, shows that tripling the upper limit (as suggested in the comment letter) is not supported by the submitted data.

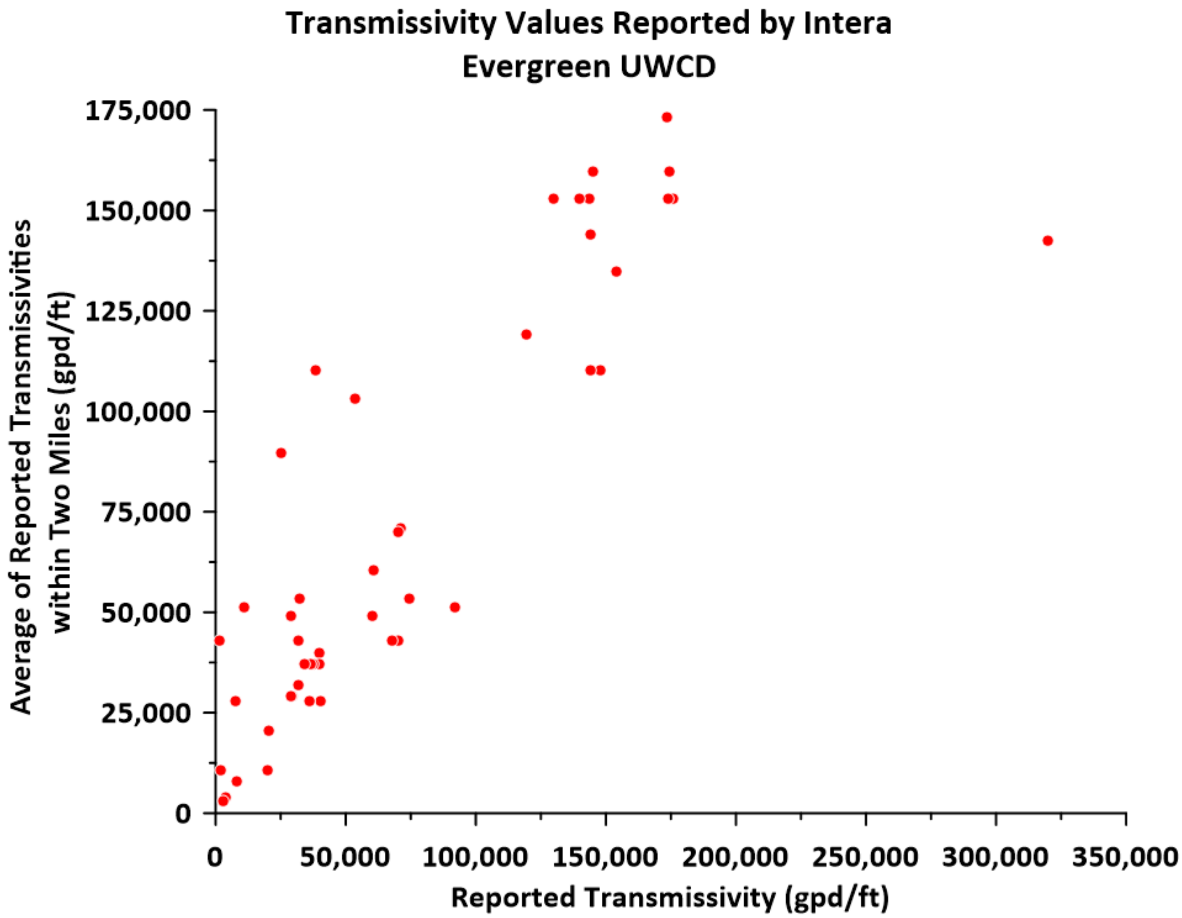


Figure 10. Pumping Test Transmissivity vs. Average Transmissivity from all Tests Within Two Miles

8.0 Wintergarden GCD Pumping Estimates

As noted above, Wintergarden GCD provided pumping data and model files with pumping estimates for the Carrizo Aquifer in five counties, the Queen City Aquifer in two counties, and the Sparta Aquifer in two counties. These data were incorporated into the 2024 version and are also included in the 2025 version of the GMA 13 Model.

The Carrizo Aquifer data were supplemented with pumping estimates from TWDB. These estimates were compared to the pumping specifications in the "new GAM". The time periods of the data and estimates from the various sources are summarized below:

- Wintergarden GCD oil and gas data = 2010 to 2022
- SWRi model estimates = 1930 to 1999
- "New GAM" pumping estimates = 1980 to 2017
    - "Old GAM" pumping estimates = 1975 to 2011 (Webb County only)
- TWDB Estimates
    - Irrigation water use = 1985 to 2021
    - Groundwater pumping estimates = 2000 to 2021

The following sections present the pumping comparisons for each county and the adjustment approach of "new GAM" pumping estimates for the GMA 13 Model. Please note that the comparison hydrographs are limited to the calibration period of the "new GAM" (1980 to 2017) even though some of the data sources have earlier starting dates and later end dates than the calibration period.

For each of the counties, the black line represents the pumping estimates in the Carrizo Aquifer for the "new GAM". This is the baseline that needs to be adjusted for the GMA 13 Model. The other colored lines represent estimates from the other sources. Thus, the discussion is focused on how the baseline needs to be adjusted in response to the other data sources.

The qualitative discussion in the next five subsections represent the general adjustments to the "new GAM" pumping for the five counties in the Carrizo Aquifer for the GMA 13 Model. Details of the quantitative adjustments for the initial values for the GMA 13 Model are discussed in a later section. Also, adjustments during model calibration are discussed later in the section covering model calibration.

The final two subsections cover the provided estimates for the Queen City Aquifer and the Sparta Aquifer.

8.1 Dimmit County – Carrizo Aquifer

Figure 11 presents the hydrograph comparison of Carrizo Aquifer pumping in Dimmit County.

The SWRi estimates (blue line) suggest that pumping needs to be increased from 1980 to 1999. From 2001 to 2012, minor changes are expected. The Wintergarden oil and gas data (red line) suggest that a large increase is needed from 2013 to 2017.

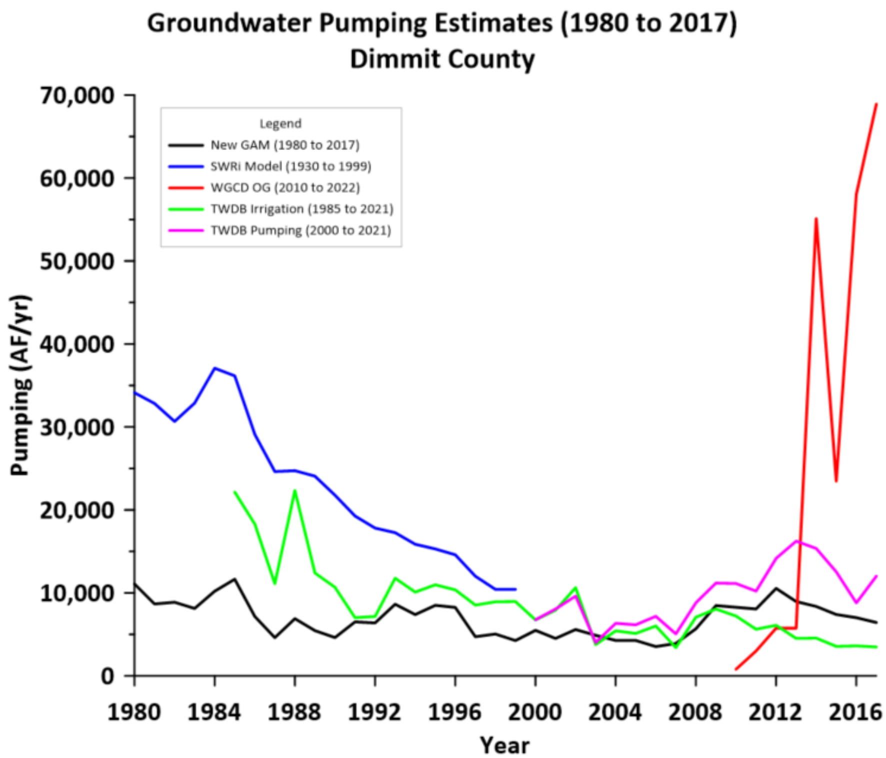


Figure 11. Groundwater Pumping Estimates (Carrizo) - Dimmit County

8.2 Frio County – Carrizo Aquifer

Figure 12 presents the hydrograph comparison of Carrizo Aquifer pumping in Frio County.

TWDB and SWRi estimates suggest that the pumping needs to be increased from 1980 to 1992. The "new GAM" pumping after about 2005 appears to be associated with high transmissivity values discussed earlier. The pumping will be decreased to amounts more consistent with the TWDB data.

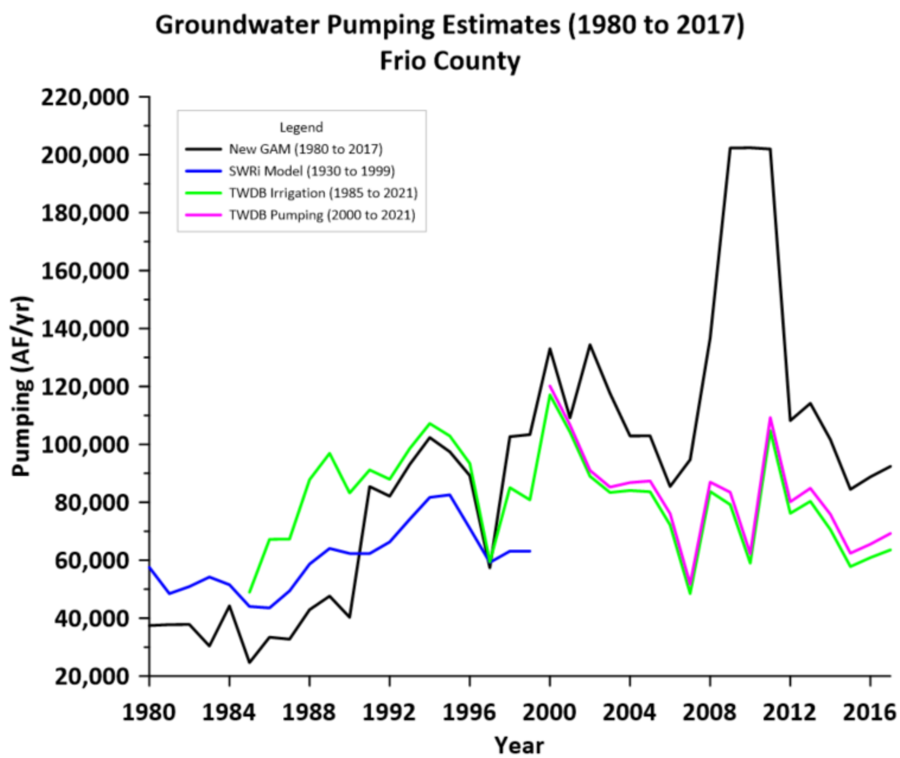


Figure 12. Groundwater Pumping Estimates (Carrizo) - Frio County

8.3 LaSalle County – Carrizo Aquifer

Figure 13 presents the hydrograph comparison of Carrizo Aquifer pumping in LaSalle County.

The comparison shows that LaSalle County has relatively low pumping compared to the other four counties in this analysis. There is also a fairly wide variation in the various estimates.

From 1980 to 2000, the TWDB estimates suggest that pumping needs to be increased. From 2001 to 2012, the TWDB estimates suggest that pumping needs to be reduced. Finally, from 2013 to 2017, the TWDB estimates suggest that pumping needs to be increased.

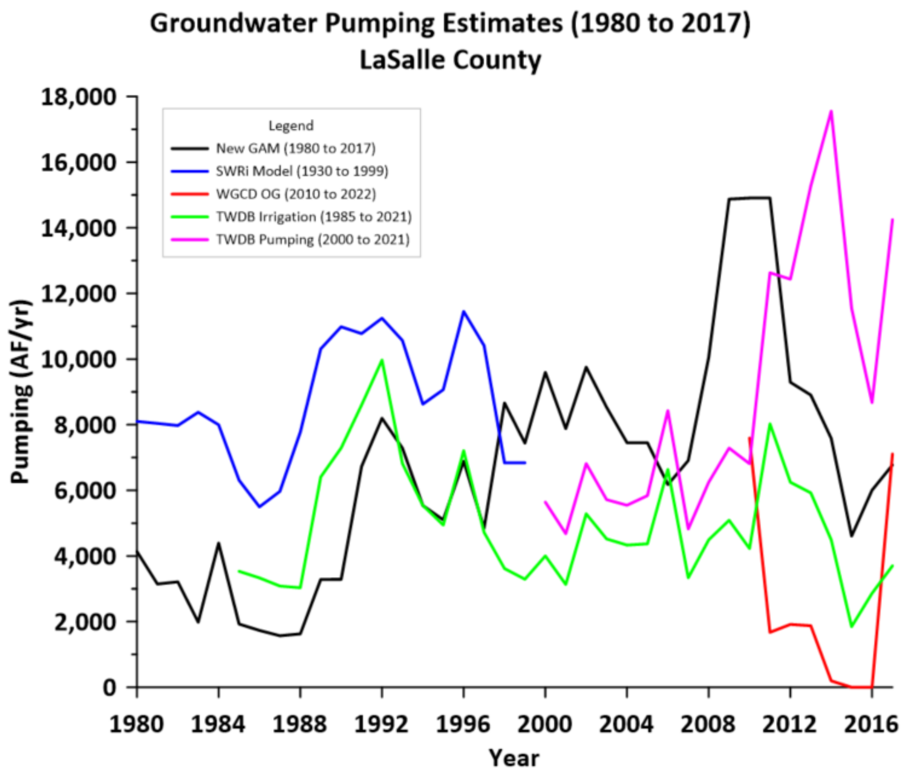


Figure 13. Groundwater Pumping Estimates (Carrizo) - LaSalle County

8.4 Webb County – Carrizo Aquifer

Figure 14 presents the hydrograph comparison of Carrizo Aquifer pumping in Webb County. For Webb County, the "old GAM" estimates of pumping are also included for context given public comments about the current Webb County MAG (modeled available groundwater).

Webb County has no representation on GMA 13 because there is no GCD in Webb County. When DFCs were adopted in 2010 and 2016, there was no participation or input from any entity in Webb County. From 1980 to about 2010, historic estimates of pumping are consistent. This consistency suggests that the current MAG is not "arbitrary" and is based on historic estimates of pumping.

Legacy Water did provide comments to GMA 13 after the proposed DFC was adopted in 2021 but provided no context regarding county-wide pumping estimates. GMA 13 committed to evaluating Legacy Water's proposed project as part of the current round of joint planning (proposed DFC deadline of May 1, 2026). This work of improving the "new GAM" and developing the GMA 13 Model is part of that effort to incorporate appropriate estimates of historic pumping in the calibrated GMA 13 Model.

Based on this comparison, SWRi model estimates suggest that an increase in pumping is warranted from 1980 to 1992. A large increase in pumping is warranted based on the TWDB estimates from 2010 to 2017. For context, Legacy Water's planned deliveries in 2060 are projected to be about 33,000 AF/yr, which would represent a large increase over historic pumping.

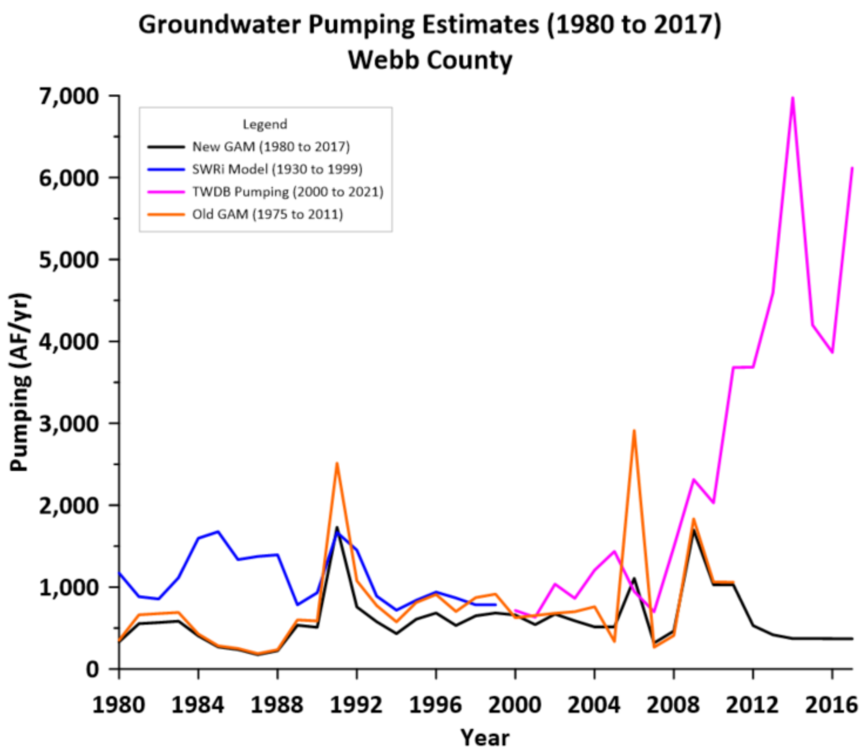


Figure 14. Groundwater Pumping Estimates (Carrizo) - Webb County

8.5 Zavala County – Carrizo Aquifer

Figure 15 presents the hydrograph comparison of Carrizo Aquifer pumping in Zavala County.

From 1980 to 2000, pumping should be increased based on the SWRi model estimates and the TWDB estimates. The TWDB data suggest that a decrease in pumping is warranted from 2008 to 2017. Similar to LaSalle County, the high pumping during this period in the "new GAM" appears to be associated with the high transmissivity discussed earlier.

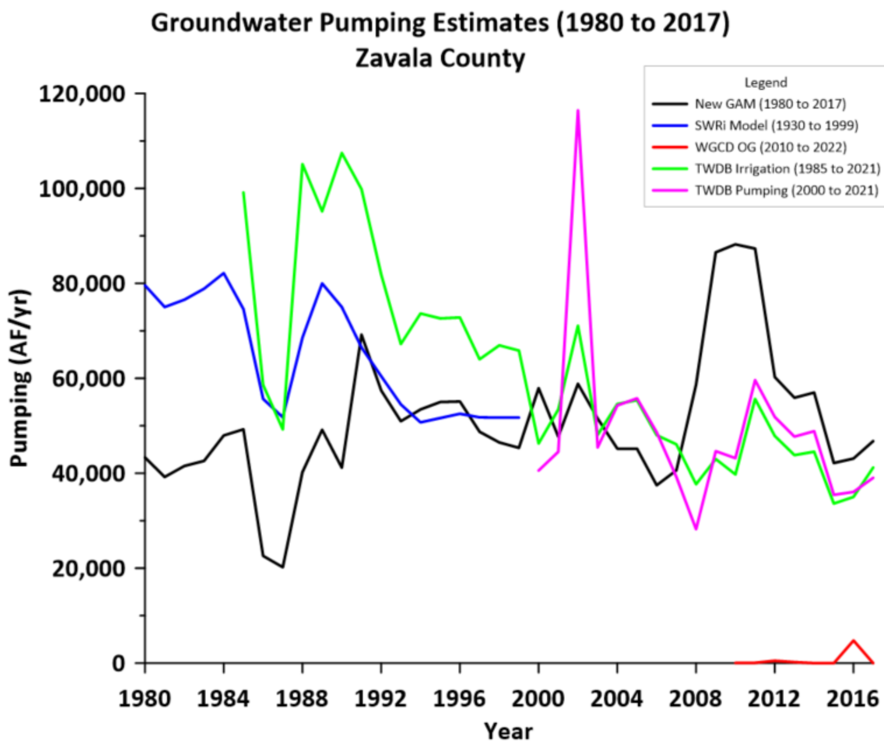


Figure 15. Groundwater Pumping Estimates (Carrizo) - Zavala County

8.6 Queen City Aquifer

Figure 16 presents the hydrograph comparison of Queen City pumping in Frio County. Figure 17 presents the hydrograph comparison of Queen City pumping in LaSalle County. Please note pumping in both counties are small and adjustments to the "new GAM" pumping estimates will be minor in terms of total acre-feet of pumping.

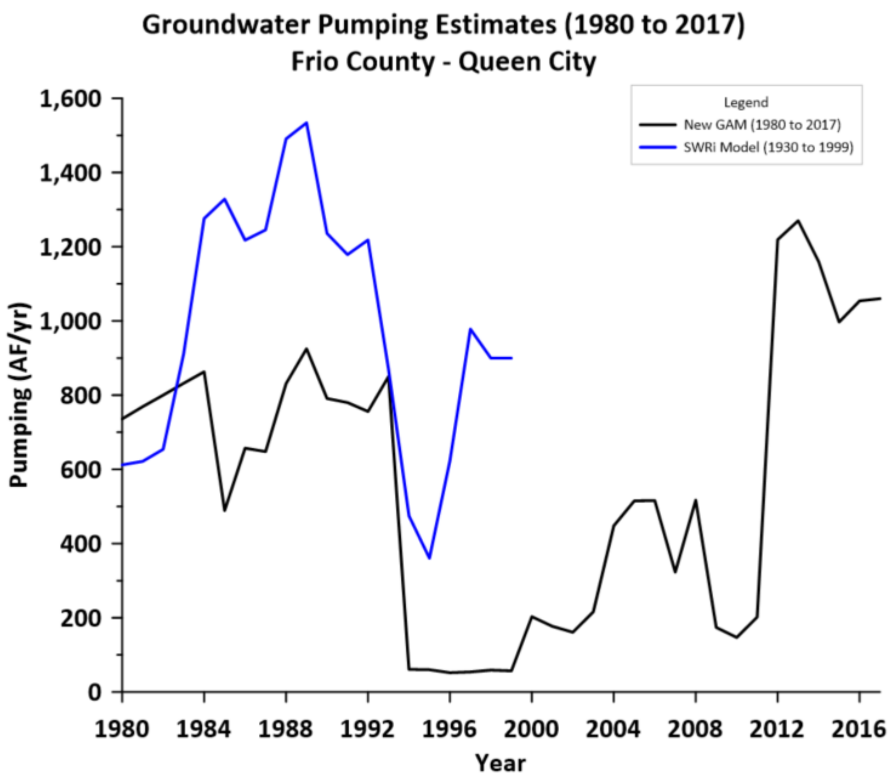


Figure 16. Groundwater Pumping Estimates (Queen City) - Frio County

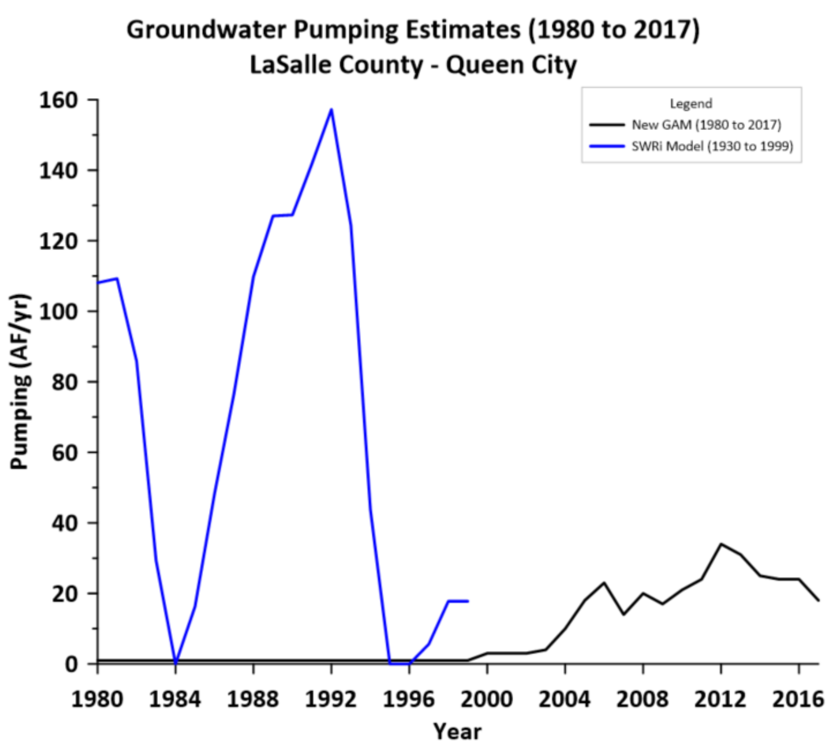


Figure 17. Groundwater Pumping Estimates (Queen City) - LaSalle County

8.7 Sparta Aquifer

Figure 18 presents the hydrograph comparison of Sparta pumping in Frio County. Figure 19 presents the hydrograph comparison of Sparta pumping in LaSalle County. Similar to the comparison of Queen City pumping, pumping from the Sparta is small, and adjustments to the "new GAM" pumping estimates will be minor in terms of total acre-feet of pumping.

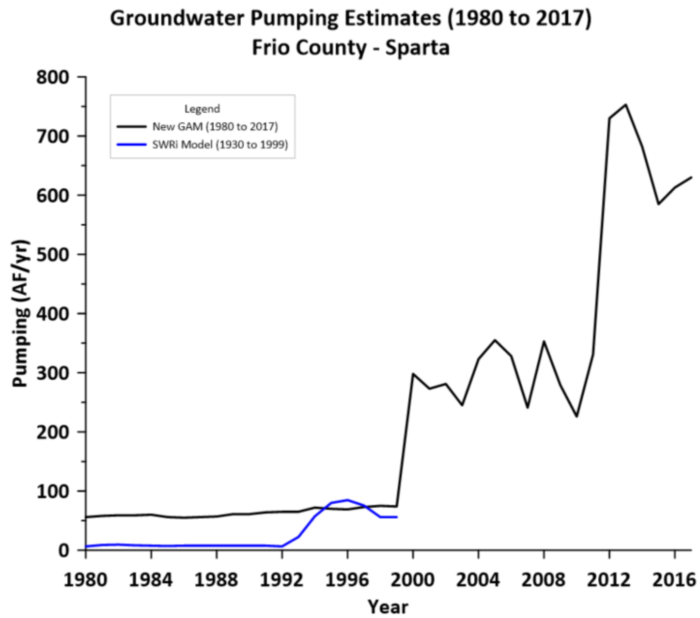


Figure 18. Groundwater Pumping Estimates (Sparta) - Frio County

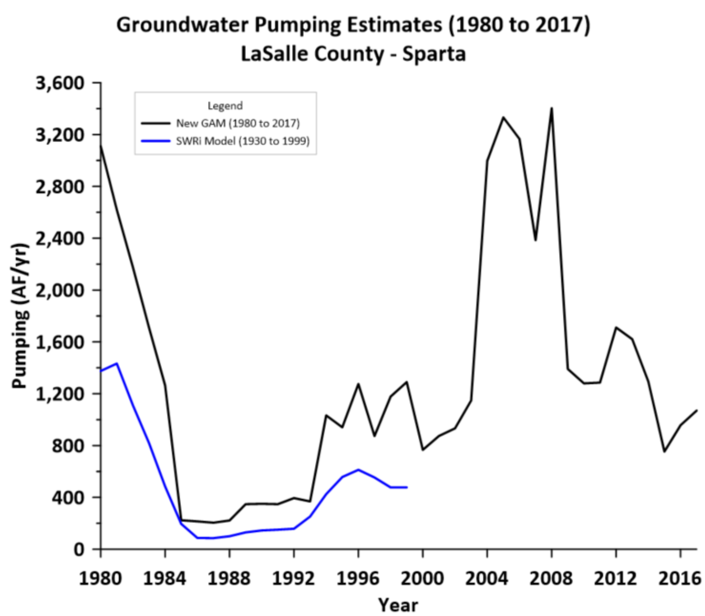


Figure 19. Groundwater Pumping Estimates (Sparta) - LaSalle County

9.0 Initial Adjustments to Aquifer Parameters (2024 Version)

Aquifer parameters from the "new GAM" were adjusted as detailed below as initial estimates for the GMA 13 Model. The objective of these initial adjustments was to address issues discussed in detail earlier:

- High transmissivity values in the "new GAM"
- Unreasonable ratios between vertical and horizontal hydraulic conductivity in the "new GAM"
- Applying a more conceptually consistent approach to specifying specific yield

A final objective was to align the transmissivity values in Webb County in the GMA 13 Model to those estimated from the aquifer tests completed by LRE as discussed earlier.

9.1 Aquifer Parameter Pre-Processor

The Fortran program *MakeAqParam.exe* was written to accomplish the initial adjustments. The program:

- Reads a file (*CountyZone*.csv) that lists the counties in the model domain and assigns a zone number to each county. This file was developed to facilitate parameter adjustments during model calibration.
- Reads two files (*KxAdjFac.csv* and *KzxAdjFac.csv*) that specify adjustment factors organized by zone and model layer for horizontal hydraulic conductivity (*Kx* or *hcx*) and the ratio of vertical to horizontal hydraulic conductivity (*Kzx* or *hczx*). These files will be used during automated calibration using PEST.
- Reads the parameter file (*GAMParam.dat*)
- Updates all horizontal hydraulic conductivity values with the adjustment factors.
- Reads the LRE hydraulic conductivity estimates from the aquifer tests (*LREK.csv*)
- Reads the list of cells that are within a specified distance to the aquifer test wells (*lrecellslist.dat*). Initially, the specified distance is three miles. Applies the LRE-estimated horizontal hydraulic conductivity values to these cells. By completing this step after the global adjustments, other parts of Webb County are adjusted during calibration independent of the cells near the aquifer tests in Webb County.
- Reads the file of various limits and constraints (*Constraints.csv*). Table 10 presents the data in *Constraints.csv*.
- Fills the specific yield and specific storage arrays with values based on the data in *Constrains.csv*.
- Applies the constraints by making final adjustments to horizontal hydraulic conductivity and the ratio of vertical to horizontal hydraulic conductivity. This final step ensures that as adjustment factors in *KAdjFac.csv* are updated, the adjusted values are within limits set in *Constraints.csv*.
- Writes MODFLOW input files and parameter summary files.
- Writes *LRECompare.dat* that compares the aquifer test results (in terms of hydraulic conductivity) to the input values for the GMA 13 Model. Please note that two of the aquifer

tests are from the same well and yield slightly different values. These are noted in the comparison file since only one value is chosen rather than averaging the results. Table 11 presents the data in *LRECompare.dat.*

Table 10. Aquifer Parameter Constraints and Input Data

Layer	Maximum Transmissivity (gpd/ft)	Maximum Vertical to Horizontal Hydrailic Conductivty Ratio	Specific Yield		Storativity (dimensionless)
			Saturated Thickness < 100	Saturated Thickness > 100	
1	1,000	0.1	0.1	0.005	1.00E-04
2	1,000	0.1	0.1	0.005	1.00E-04
3	4,000	0.1	0.1	0.005	1.00E-04
4	1,000	0.1	0.1	0.005	1.00E-04
5	10,000	0.1	0.1	0.005	1.00E-04
6	1,000	0.1	0.1	0.005	1.00E-04
7	100,000	0.1	0.1	0.005	1.00E-04
8	25,000	0.1	0.1	0.005	1.00E-04
9	50,000	0.1	0.1	0.005	1.00E-04

Table 11. Comparison of Hydraulic Conductivity:
LRE Aquifer Test Estimates and Initial Values of GMA 13 Model

Well Name	Aquifer Designation	Cell	Layer	LRE Estimated Kx (ft/day)	Initial Value of Kx for GMA 13 Model (ft/day)	Estimated Kx/Model Kx
Huisache	Sparta	265202	3	0.1863	0.1863	1.0000
Catalinas	Sparta	265200	3	0.2411	0.2411	1.0000
MKHC	Sparta	265201	3	0.4532	0.4532	1.0000
Malvinas	Sparta	263204	3	1.4122	1.4122	1.0000
Pilas HC	Sparta	263507	3	0.7664	0.7664	1.0000
Antennas	Sparta	264545	3	0.8988	0.8988	1.0000
PI-SP-01	Sparta	263507	3	1.0218	0.7664	1.3333
Malvinas	Sparta	263204	3	2.0713	1.4122	1.4667
EOG Gonzales WSW #1	Carrizo	338738	7	0.1270	0.1270	1.0000
MK-CZ-01	Carrizo	339569	7	0.0832	0.0832	1.0000
PI-CZ-01	Carrizo	338933	7	0.1553	0.1553	1.0000

Notes: (yellow) Two Tests in Same Cell
(green) Two Tests in Same Cell

For the initial run of the GMA 13 Model, all layer adjustment factors were set to 1.0, and only the transmissivity and maximum vertical to horizontal hydraulic conductivity ratios were used to adjust aquifer parameters.

10.0 Initial Adjustments to Groundwater Pumping (2024 Version)

Groundwater pumping from the "new GAM" were adjusted as detailed below as initial estimates for the GMA 13 Model. Additional adjustments were made during the calibration of the GMA 13 Model. The objective of these initial adjustments was to update the groundwater pumping with the data and estimates previously discussed for the five counties covered in the Wintergarden GCD data.

10.1 New GAM Pumping

Groundwater pumping estimates in the "new GAM" were extracted from the model's cell-by-cell flow file (*GMA13_Historical_Period_Calibration.cbb*) using the Fortran program *CalibPump.exe*.

The program:

- Reads a list of counties (*colist.dat*)
- Reads the model grid file (*GMA13shortgrid.csv*)
- Reads the cbb file, and converts the pumping into AF/yr
- Sums the pumping by county and layer, and counts cells with pumping
- Writes output files for each county with annual pumping by layer
- Writes summary files:
    - A file that lists the well count and pumping for each year by county-layer unit (*countsum.dat*)
    - A file that lists the number of stress periods of pumping in each county-layer unit (*countsumallsp.dat*)

The files are located in the Google Drive folder named *NewGAMPump.*

The pumping files are named *PumpXX*, where *XX* is the county name. The first two columns are codes to identify the county followed by the county name. The fourth column is the year. The next nine columns are the pumping for the county in each layer. The last column is the total Carrizo-Wilcox Aquifer pumping for the county (i.e. the sum of layers 7, 8, and 9). The pumping files for each county provided the baseline data for adjustments for the GMA 13 Model.

The well count files are named *WcountXX*, where *XX* is the county name. The first two columns are codes to identify the county followed by the county name. The fourth column is the year. The next nine columns are the well counts for the county in each layer.

10.2 Initial Pumping Estimates for GMA 13 Model (2024 Version)

The earlier discussion of the groundwater pumping data and estimates from Wintergarden GCD provided the basis to develop initial estimates of pumping in the Carrizo Aquifer for the GMA 13 Model for five counties, the Queen City Aquifer for two counties, and the Sparta Aquifer for two counties. Adjustments on these nine county-aquifer units were the primary focus of this model update.

Other adjustments included the Carrizo Wilcox pumping in Bexar County based on updated data from SAWS discussed earlier, and other adjustments that were based on a review of the pumping in other county-aquifer units in the context of the transmissivity adjustments discussed above. Table 12 presents a summary of the county-layer units and the basis for the adjustments for the initial values of the GMA 13 Model.

Table 12. Summary of the Basis for Adjustments to "New GAM" Pumping

County Code	County Name	Sparta	Queen City	Carrizo-Upper Wilcox	Middle Wilcox	Lower Wilcox
7	Atascosa	x	x	x	x	x
15	Bexar			x	x	x
28	Caldwell		x	x	x	x
64	Dimmit			x	x	x
82	Frio	x	x	x	x	x
89	Gonzales	x	x	x	x	
94	Guadalupe			x	x	x
128	Karnes			x		
139	LaSalle	x	x	x		
159	Maverick			x	x	x
162	McMullen			x		
163	Medina			x	x	x
232	Uvalde			o	x	x
240	Webb	x		x	o	o
247	Wilson	x	x	x	x	x
254	Zavala	z	z	x	x	x

Legend	Description	Count
x	**Adjustments Based on WGCD Data and Estimates**	9
x	**Adjustments Based on SAWS Data**	1
x	**Limited Adjustments Based on Transmissivity Corrections**	40
o	**No Adjustment - Minimal Pumping**	3
z	**Sparta and Queen City in Zavala County - see report text**	2
	Aquifer Unit Not Present or No Pumping	25

Counties not listed above were considered boundary areas of GMA 13 and no pumping adjustments were made.

The details of the adjustments based on the WGCD data and estimates, the SAWS data, and the minor adjustments made based on the correction of aquifer parameters are discussed more fully below.

10.2.1 Initial Estimates Based on Wintergarden GCD Data and TWDB Estimates

Adjustments to nine county-layer units were made based on the Wintergarden GCD data and TWDB estimates presented earlier. The files that contain these adjustments are listed below

- Sparta Aquifer (Layer 3):
  - Frio County (*Sp Frio.xlsx*)
  - LaSalle County (*Sp LaSalle.xlsx*)
- Queen City Aquifer (Layer 5):
  - Frio County (*QC Frio.xlsx*)
  - LaSalle County (*QC Lasalle.xlsx*)
- Carrizo Aquifer (Layer 7)
  - Dimmit County (*CZ Dimmit.xlsx*)
  - Frio County (*CZ Frio.xlsx*)
  - LaSalle County (*CZ LaSalle.xlsx*)
  - Webb County (*CZ Webb.xlsx*)
  - Zavala County (*CZ Zavala.xlsx*)

Each file contains the annual pumping estimates from each source as described earlier, the pumping from the "new GAM", the initial pumping estimate for the GMA 13 Model, and the multiplication factor to convert the "new GAM" pumping into the initial estimate of GMA 13 Model pumping. The spreadsheets are color coded to show which estimates were applied in each year or groups of years.

10.2.2 Initial Estimates Based on SAWS Data

The SAWS data described earlier is in the file named *SAWS Data.xlsx*. It contains pumping from three SAWS projects:

- Regional Carrizo (Gonzales County)
- Local Carrizo (Bexar County)
- Brackish Desal (Bexar County)

As noted earlier, the data from Gonzales County appear to be included in the "new GAM" pumping estimates.

Adjustment is Layer 7 (Carrizo Aquifer) in Bexar County are contained in the file *CZ Bexar.xlsx*. The annual pumping data from SAWS and the pumping from the "new GAM" are included. The initial pumping estimate for the GMA 13 Model, and the multiplication factor to convert the "new GAM" pumping into the initial estimate of GMA 13 Model pumping are also included. The spreadsheet is color coded to show which estimates were applied in each year or groups of years.

10.2.3 Initial Estimates in Other County-Layer Units

Pumping in all other county-layer units were adjusted for the initial run of the GMA 13 Model as documented in the following spreadsheets:

- *Atascosa.xlsx* (Layer 3, 5, 7, 8, and 9)
- *Bexar.xlsx* (Layers 8 and 9)
- *Caldwell.xlsx* (Layers 5, 7, 8, and 9)
- *Dimmit.xlsx* (Layers 8 and 9)
- *Frio.xlsx* (Layers 8 and 9)
- *Gonzales.xlsx* (Layers 3, 5, 7, and 8)
- *Guadalupe.xlsx* (Layers 7, 8, and 9)
- *Karnes.xlsx* (Layer 7)
- *Maverick.xlsx* (Layers 7, 8, and 9)
- *McMullen.xlsx* (Layer 7)
- *Medina.xlsx* (Layers 7, 8, and 9)
- *Uvalde.xlsx* (Layers 8 and 9)
- *Webb.xlsx* (Layer 3)
- *Wilson.xlsx* (Layers 3, 5, 7, 8, and 9)
- *Zavala.xlsx* (Layers 8 and 9)

Each spreadsheet has a tab for the relevant model layer. Tabs with no data means that the layer does not exist in that county, there is no pumping in that county-layer unit, or the data are contained in a different spreadsheet based on Wintergarden GCD data and estimates or SAWS data as described above.

All spreadsheets are color coded to show which estimates were applied in each year or group of years. Lack of color means that an estimate was applied without specific reference to an underlying set of data.

All county-layer units had some adjustment except Gonzales County in Carrizo-Upper Wilcox or Middle Wilcox layers for the initial GMA 13 Model pumping estimates. Ms. Laura Martin-Preston, General Manager of Gonzales County UWCD confirmed via email on June 17, 2024 that the "new GAM" pumping estimates in Gonzales County appeared to be correct.

10.3 Groundwater Pumping Pre-Processor for Initial Run of GMA 13 Model

The Fortran program *InitialPump.exe* was written to adjust pumping in the "new GAM" based on the factors described above on a county-layer basis. These adjustments yielded the pumping for the initial run of the GMA 13 Model. The program:

- Reads a list of county codes and output file names (*CoListCode.dat*)
- Reads a modified version of the model grid file (*GMA13shortgrid.csv*)
- Reads the adjustment factors (by layer) for each county:
    - *Sparta.csv*

  - *QueenCity.csv*
  - *Carrio-UpperWilcox.csv*
  - *MiddleWilcox.csv*
  - *LowerWilcox.csv*
- Read the "new GAM" pumping from the cell-by-cell flow file (*GMA13_Historical_Period_Calibration.cbb*)
- Calculate pumping based on the "new GAM" and adjustment factors
- Sum the pumping by county-layer units
- Write the initial pumping by county-layer units (output files are organized by county, with pumping in each layer in separate columns)
- Write the MODFLOW WEL file

11.0 Initial Run of GMA 13 Model (2024 Version)

The initial run of the GMA 13 Model (2024 Version) was completed with the adjustments to aquifer parameters and pumping that were described above. In addition, the GMA 13 Model has only 38 stress periods with the first stress period specified as steady state to provide a stable set of initial conditions for the transient stress periods (2 to 38) that represent 1981 to 2017.

The executable code is the same one that was used in the "new GAM":

mf6_IoBuff_Flush_AFRW.exe

This version of MODFLOW (version 6.2.2) was modified for the "new GAM" to flush the output buffer when running (to speed up model runs) and modified the output of the automatic flow reduction to create spreadsheet output. For convenience, this executable was renamed *mf6GMA13.exe*.

11.1 Model Files

Model files for the GMA 13 Model are specified in *mfsim.nam* and *GMA13-1SS.nam*. Table 13 presents these files and how they were either modified from the equivalent "new GAM" files or remained unchanged.

Table 13. GMA 13 Model Files (nam)

mfsim.nam Files

File Name	Description	Changes from "New GAM"
GMA13-1SS.tdis	Time Discretization	Changed Number of Stress Periods
GMA13-1SS.nam	Name File (see below)	Updated File Names
GMA13 -1SS.ims	Solver Parameters	No Changes

GMA13-1SS.nam Files

File Name	Description	Changes from "New GAM"
GMA13-1SS.lst	Standard Output	N/A
GMA13-1SS.dis	Grid Specifications	No Changes
GMA13-1SS.ic6	Initial Conditions	No Changes
GMA13-1SS.oc6	Output Control	Updated File Names and Stress Periods
GMA13-1SS.npf	Aquifer Parameters	Changes as Described
GMA13-1SS.sto	Storage Parameters	Changes as Described
GMA13-1SS.hfb	Horizontal Flow Barrier (Faults)	No Changes
GMA13-1SS.riv	River Package	Revised as a Single Stress Period
GMA13-1SS.ghb	General Head Boundary Package	No Changes
GMA13-1SS.wel	Groundwater Pumping	Changes as Described
GMA13-1SS.rch	Recharge	Updated to Reflect Stress Period Changes
GMA13-1SS.evt	Evapotranspiration	Revised as a Single Stress Period

In addition, files are specified in various files listed above (ic6, npf, oc, sto, and wel) are summarized in Table 14.

Table 14. GMA 13 Model Files (ic6, npf, oc, sto, wel)

GMA13-1SS.ic6 Files

File Name	Description	Changes from "New GAM"
sp1hds.dat	Initial Heads	No Changes

GMA13-1SS.npf Files

File Name	Description	Changes from "New GAM"
GMA13Kx.dat	Horizontal Hydaulic Conductivity	Changes as Described
GMA13Kzx.dat	Ratio of Vertical Hydraulic Conductivity to Horizontal Hydraulic Conductivity	Changes as Described

GMA13-1SS.oc Files

File Name	Description	Changes from "New GAM"
GMA13-1SS.cbb	Cell-by-Cell Output	N/A
GMA13-1SS.hds	Simulated Heads Output	N/A

GMA13-1SS.sto Files

GMA13Ss.dat	Specific Storage	Changes as Described
GMA13Sy.dat	Specific Yield	Changes as Described

GMA13-1SS.wel Files

File Name	Description	Changes from "New GAM"
GMA13WELreduce.csv	Pumping Reduction Output	N/A

11.2 Post-Processor for Groundwater Elevations

The Fortran program *gethedGMA13.exe* was written to process the GMA 13 Model simulated groundwater output file (*GMA13-1SS.hds*) and compare the results with actual groundwater elevation data (*GMA13Targets.csv*). The actual groundwater elevation data file is discussed above.

The program:

- Reads the model output file (*GMA13-1SS.hds*)
- Reads the actual groundwater elevation data for 14,023 targets (*GMA13Targets.csv*). Included in the target file are the cell number, layer of the cell, status of the cell (outcrop or downdip), county code of the cell, stress period of the target, year of the target, actual groundwater elevation, weight of the target used in the "new GAM", and the date of the measurement in decimal years.
- Various statistics are calculated after each record is read
- Once all the records are read, the mean of the residuals (calculated as actual minus simulated) and the mean of the absolute value of the residuals are calculated for:
    - Groundwater occurrence status (outcrop (1), downdip (2), overall (3))

    - Model layer (layers 1 to 9, 10 = overall)
- Calculates standard deviation of the residuals
- Calculates scaled statistics
- Writes summary statistics for outcrop, downdip, and overall, for each layer and for the entire model domain
- Writes output files that lists the comparison of each record:
    - Overall model domain (a*ctsimcal.dat)*
    - All targets in outcrop cells (*actsimcalOC.dat*)
    - All targets in layer *x* for targets in outcrop cells (*x*=layers 3, 5, 7, 8, and 9: *actsimLxOC.dat*)
    - All targets in layer *x* for targets in downdip cells (*x* = layers 3, 5, 7, 8, and 9: *actsimLxDD.dat*
- Writes the heads for stress period 1 (*sp1hds.dat*) for use as the initial conditions in subsequent runs of the model.

The overall model domain results were imported into an Excel file (*ActSimAll IR.xlsx*) and the 13 statistics calculated by the post processor were calculated as a means to verify the accuracy of the post processor results. Table 15 presents the comparison.

Table 15. Summary Statistics from Initial Run for Overall Model Domain

Statistic	Excel	Post-Processor
Number of Observations	7,000	7,000
Range in Observations	895.06	895.06
Minimum Residual	-352.63	-352.63
Maximum Residual	772.77	772.77
Residual Mean	71.81	71.81
Sum of Squared Residuals	1.59E+08	1.59E+08
Absolute Residual Mean	84.18	84.18
Residual Standard Deviation	132.28	132.27
Root Mean Square Error	150.50	150.50
Scaled Residual Standard Deviation	0.1478	0.1478
Scaled Absolute Residual Mean	0.0940	0.0940
Scaled Root Mean Square Error	0.1681	0.1681
Scaled Residual Mean	0.0802	0.0802

11.3 Results of Initial Run of GMA 13 Model (2024 Version)

The results for the initial run are summarized in:

- Table 16: Summary statistics from initial run for all targets
- Table 17: Summary statistics from initial run for targets in outcrop cells
- Table 18: Summary statistics from initial run for targets in downdip cells
- Figure 20: Comparison of actual and simulated groundwater elevations for all targets

- Figure 21: Comparison of actual and simulated groundwater elevations for targets in outcrop cells
- Appendix B: Comparison of actual and simulated groundwater elevations for targets as follows:
    - Sparta Aquifer (Layer 3), outcrop
    - Sparta Aquifer (Layer 3), downdip
    - Queen City Aquifer (Layer 5), outcrop
    - Queen City Aquifer (Layer 5), downdip
    - Carrizo-Upper Wilcox Aquifers (Layer 7), outcrop
    - Carrizo-Upper Wilcox Aquifers (Layer 7), downdip
    - Middle Wilcox (Layer 8), outcrop
    - Middle Wilcox (Layer 8), downdip
    - Lower Wilcox (Layer 9), outcrop
    - Lower Wilcox (Layer 9), downdip

Table 16. Summary Statistics from Initial Run for All Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	411	878	4,306	688	717	7,000
Range in Observations	296.22	475.19	869.38	826.82	507.47	895.06
Minimum Residual	-232.65	-173.86	-352.63	-300.32	-205.04	-352.63
Maximum Residual	115.17	320.19	772.77	636.03	180.07	772.77
Residual Mean	-8.42	10.55	103.45	75.51	-0.70	71.81
Sum of Squared Residuals	5.89E+05	2.76E+06	1.42E+08	1.31E+07	6.04E+05	1.59E+08
Absolute Residual Mean	25.21	34.82	110.42	84.97	20.03	84.18
Residual Standard Deviation	36.92	55.02	148.90	115.26	29.01	132.27
Root Mean Square Error	37.87	56.02	181.31	137.79	29.01	150.50
Scaled Residual Standard Deviation	0.1246	0.1158	0.1713	0.1394	0.0572	0.1478
Scaled Absolute Residual Mean	0.0851	0.0733	0.1270	0.1028	0.0395	0.0940
Scaled Root Mean Square Error	0.1278	0.1179	0.2085	0.1666	0.0572	0.1681
Scaled Residual Mean	-0.0284	0.0222	0.1190	0.0913	-0.0014	0.0802

Table 17. Summary Statistics from Initial Run for Targets in Outcrop Cells

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	90	407	638	159	285	1,579
Range in Observations	258.40	391.70	409.11	486.04	407.50	509.39
Minimum Residual	-72.59	-126.74	-55.51	-100.54	-110.34	-126.74
Maximum Residual	78.92	320.19	184.07	225.62	91.70	320.19
Residual Mean	-11.53	29.24	26.97	24.08	2.97	20.74
Sum of Squared Residuals	1.31E+05	1.74E+06	2.17E+06	5.02E+05	9.60E+04	4.64E+06
Absolute Residual Mean	32.08	38.21	36.11	36.11	13.34	32.31
Residual Standard Deviation	36.37	58.51	51.63	50.75	18.11	50.06
Root Mean Square Error	38.16	65.41	58.25	56.17	18.36	54.18
Scaled Residual Standard Deviation	0.1408	0.1494	0.1262	0.1044	0.0445	0.0983
Scaled Absolute Residual Mean	0.1242	0.0976	0.0883	0.0743	0.0327	0.0634
Scaled Root Mean Square Error	0.1477	0.1670	0.1424	0.1156	0.0450	0.1064
Scaled Residual Mean	-0.0446	0.0746	0.0659	0.0495	0.0073	0.0407

Table 18. Summary Statistics from Initial Run for Targets in Downdip Cells

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	321	471	3,668	529	432	5,421
Range in Observations	258.76	446.62	810.77	776.99	474.76	845.23
Minimum Residual	-232.65	-173.86	-352.63	-300.32	-205.04	-352.63
Maximum Residual	115.17	184.85	772.77	636.03	180.07	772.77
Residual Mean	-7.54	-5.59	116.75	90.96	-3.12	86.69
Sum of Squared Residuals	4.58E+05	1.01E+06	1.39E+08	1.26E+07	5.08E+05	1.54E+08
Absolute Residual Mean	23.28	31.88	123.35	99.66	24.45	99.28
Residual Standard Deviation	37.03	46.06	156.11	124.37	34.14	144.50
Root Mean Square Error	37.79	46.40	194.94	154.09	34.28	168.51
Scaled Residual Standard Deviation	0.1431	0.1031	0.1925	0.1601	0.0719	0.1710
Scaled Absolute Residual Mean	0.0900	0.0714	0.1521	0.1283	0.0515	0.1175
Scaled Root Mean Square Error	0.1460	0.1039	0.2404	0.1983	0.0722	0.1994
Scaled Residual Mean	-0.0292	-0.0125	0.1440	0.1171	-0.0066	0.1026

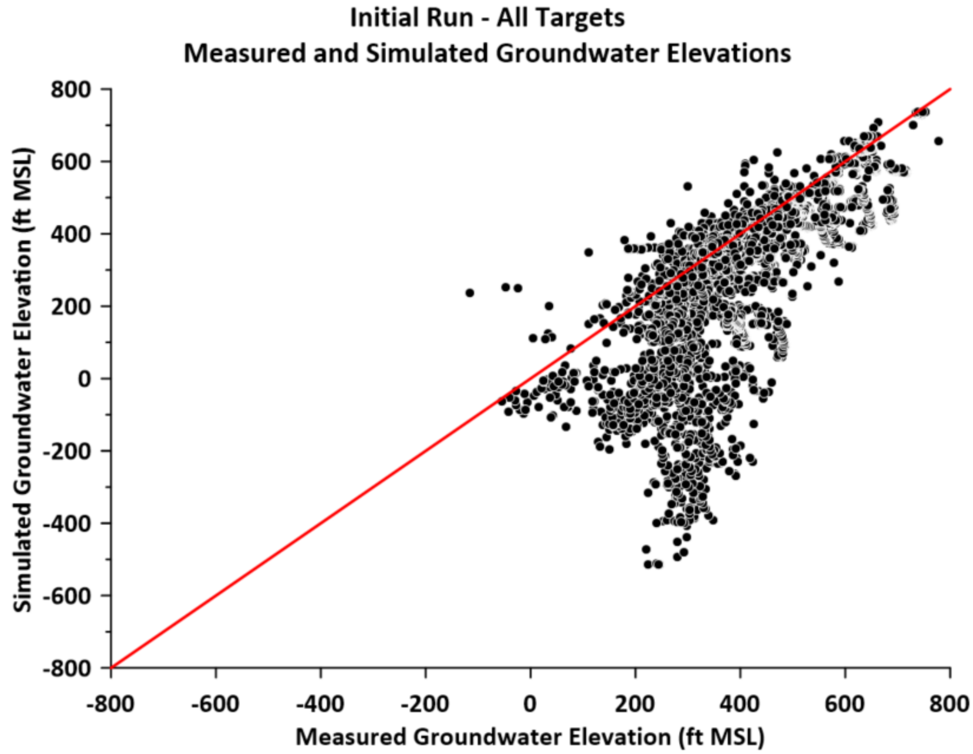


Figure 20. Actual vs. Simulated Groundwater Elevations for All Targets (Initial Run)

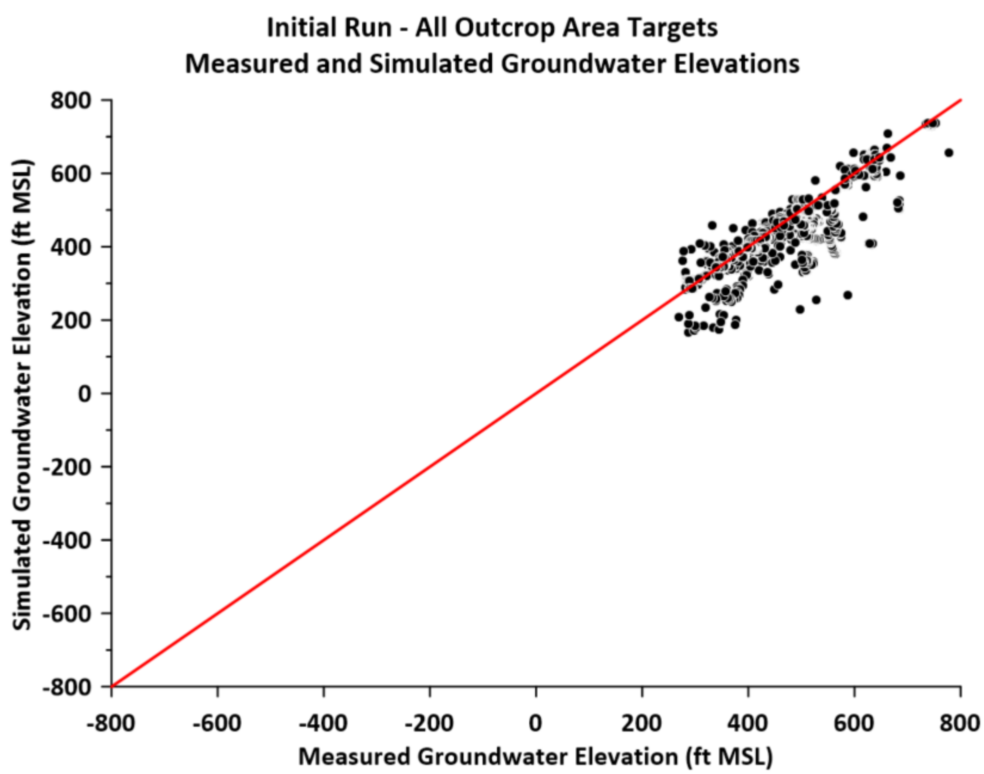


Figure 21. Actual vs. Simulated Groundwater Elevations for Targets in Outcrop Cells (Initial Run)

12.0 Calibration of GMA 13 Model (2024 Version)

The discussion of the results of the initial run of the GMA 13 Model (2024 Version) relied on a comparison of actual and simulated groundwater elevations, and the statistical analysis of the residuals. A residual is calculated for each target as the actual groundwater elevation minus the simulated groundwater elevation. Thus, positive residuals mean that the simulated groundwater elevations are lower than the actual groundwater elevations, and negative residuals mean that the simulated groundwater elevations are higher than the actual groundwater elevations.

The process of adjusting model input parameters to obtain a better match between actual and simulated groundwater elevations is termed calibration. The calibration process focused on two main generalities:

- Positive residuals can be improved with higher hydraulic conductivity values (i.e. higher transmissivity) and/or lower pumping
- Negative residuals can be improved with lower hydraulic conductivity values (i.e. lower transmissivity) and/or higher pumping

An inspection of the one-to-one plot of the actual groundwater elevations and the simulation groundwater elevations from the initial run presented earlier depicts several simulated groundwater elevations a few hundred feet below the actual groundwater elevations. Most of these occur in layer 7 (Carrizo-Upper Wilcox Aquifer). An inspection of the output file shows that many of these are in cells with relatively low transmissivity. Therefore, the initial parameter adjustment was to raise the hydraulic conductivity in the area of those cells, but within the transmissivity limits discussed earlier. Pumping adjustments in cells near target cells for both positive and negative residuals are also warranted since most of the initial pumping specified was based on estimates rather than hard data.

Calibration of the GMA 13 Model was completed in two steps: 1) an initial set of parameter adjustments based on an evaluation of the results of the initial run, and 2) four automated parameter adjustment using PEST.

Adjustments to horizontal hydraulic conductivity, the ratio of vertical to horizontal hydraulic conductivity, and pumping were made using the Fortran program *CalAdj.exe*. This program:

- Reads the Kx and Kzx files from the initial run of the model discussed above.
- Reads the pumping file from the initial run of the of the model discussed above.
- Reads the x- and y-coordinates, layer, and saturated thickness for each cell.
- Reads the comparison of actual and simulated groundwater elevations from the initial run of the model discussed above.
- Calculates the average residual for each target cell and writes a summary in *avgresid.dat*.
- Reads the layer-specific constraints for transmissivity and vertical to horizontal hydraulic conductivity in *Constraints.csv*.
- Reads adjustment factors in *CalAdjFac.dat*.
- Apply adjustments to the initial run parameters for all cells

  - For the initial set of parameter adjustments and the first two automated PEST runs, pumping adjustments were made to cells in the same layer within five miles of the target cell. For the third and fourth automated PEST runs, the pumping adjustments were made to cells in the same layer within two miles of the target cell.
  - Adjustments to horizontal hydraulic conductivity (Kx) and the ratio of vertical to horizontal hydraulic conductivity (Kzx) were made to cells in the same layer within five miles of the target cell.
- Evaluate if the adjusted parameters are within the overall constraints (in *Constraints.csv*). Reset the parameters if necessary.
- Check the adjusted parameters with LRE aquifer test data and write the results in *LRECheck.dat*).
- Write the Kx and Kzx files for a new run.
- Write the pumping file for a new run.

All files associated with the initial run and the four automated PEST runs are included in the Google Drive folder.

The fourth automated PEST run yielded results that were deemed adequate for purposes of this update. The calibration run was named *Cal04*. Details of the results of the calibration results of the GMA 13 Model (2024 Version) are documented in Hutchison (2024)

13.0 Calibration of GMA 13 Model (2025 Version)

The GMA 13 Model (2025 Version) was updated from the GMA 13 Model (2024 version with:

- The WEL file included metered pumping data from Gonzales County UWCD, Guadalupe County UWCD, and Plum Creek Conservation District. Also, pumping was adjusted in McMullen County to be consistent with data provided after the 2024 version was released. Please note that one data point provided by Gonzales County UWCD was deleted (over 15,000 AF of pumping in 2013 from a single well completed in the Sparta Aquifer).
- The pumping test data provided by Evergreen UWCD were incorporated by using the two-mile average transmissivity for each test as described above. These updated parameters were applied to all cells within five mile of each test location.

Calibration consisted of adjusting aquifer parameters and pumping using two pre-processors: *AqParamAdj.exe* and *AdjAnnPump.exe.*

The program *AqParamAdj.exe*:

- Reads baseline values for Kx, Kzx, Ss, and Sy (from the 2024 version of the model)
- Reads county codes, coordinates, layer, saturated thickness, and outcrop/downdip status of each cell
- Reads a file with adjustment factors (*AqParamFac.dat*)
- Applies the adjustment factors
- Reads constraints (*Constraints.csv*)
- Applies the constraints to layers 3 to 9
- Reads the Intera pumping test average transmissivities and replaces the values in the Kx array
- Reads the LRE hydraulic conductivity values for Webb County and replaces the values in the Kx array.
- Writes updated parameters for model input and as summary files.

Constraints used for this calibration effort are summarized in Table 19.

Table 19. Aquifer Parameter Constraints

Layer	Maximum Transmissivity (gpd/ft)	Maximum Kzx Ratio	Minimum Kzx Ratio	Max Stortativity (dimensionless)
1	2,000	0.1	0.0001	0.001
2	2,000	0.1	0.0001	0.001
3	8,000	0.1	0.0001	0.001
4	2,000	0.1	0.0001	0.001
5	25,000	0.1	0.0001	0.001
6	2,000	0.1	0.0001	0.001
7	200,000	0.1	0.0001	0.001
8	40,000	0.1	0.0001	0.001
9	50,000	0.1	0.0001	0.001

The program *AdjAnnPump.exe*:

- Reads the model grid file
- Reads the dynamic pumping file that contains the annual cell-by-cell pumping that can be adjusted. The metered pumping for Caldwell, Gonzales, and Guadalupe Counties have been removed from this file.
- Reads the annual adjustment factors by county
- Applies the annual adjustments to the dynamic pumping locations
- Updates the pumping array with metered data in Caldwell, Gonzales, and Guadalupe Counties.
- Counts wells in each stress period
- Reads the text lines from the WEL input file
- Writes an updated WEL file (*GMA13-2025.wel*)
- Sums pumping by county and layer
- Write summary file of summed pumping by county

14.0 Calibration Results of GMA 13 Model (2025 Version)

The eleventh automated PEST run yielded results that were deemed adequate for purposes of this update. The discussion below covers the results of this run which was named *Cal11*.

14.1 Groundwater Elevations

The Fortran program *gethedGMA13.exe* was modified slightly from the version documented in Hutchison (2024). The program:

- Reads the hds file (*GMA13-2025.hds*)
- Reads the county codes, coordinates, layer, and saturated thickness for each cell (*countycodesxy.dat)*
- Reads the aquifer parameters (*GMA13Kx.dat, GMA13Kzx.dat, GMA13Ss.dat, GMA13Sy.dat*)
- Reads the target file (*GMA13Targets.csv*) and calculates summary statistics
- Calculates various statistics of the calibration
- Reads the pumping file (*GMA13-2025.wel*) and sums pumping within five miles of each target
- Reads a list of target cells
- Writes output files for all targets (*actsimcal.dat*)
- Calculates minimum, average, and maximum residuals for each target cell
- Writes the first stress period head array for subsequent model runs.
- Writes minimum, average, and maximum residuals for each target cell

The file *acsimcal.dat* was imported into an Excel file named *ActSimCal11.xlsx*. The tab named *all* contains all targets. Other tabs are as follows:

- OC = all outcrop targets
- DD = all downdip targets
- SpartaOC = all outcrop targets in the Sparta Aquifer
- SpartaDD = all downdip targets in the Sparta Aquifer
- QCOC = all outcrop targets in the Queen City Aquifer
- QCDD = all downdip targets in the Queen City Aquifer
- CWOC = all outcrop targets in the Carrizo-Wilcox Aquifer
- CWDD = all downdip targets in the Carrizo-Wilcox Aquifer

The results are summarized as follows:

- Table 20: Summary statistics from final calibration run for all targets
- Table 21: Summary statistics from final calibration run for targets in outcrop cells
- Table 22: Summary statistics from final calibration run for targets in downdip cells
- Figure 22: Comparison of actual and simulated groundwater elevations for all targets

- Figure 23: Comparison of actual and simulated groundwater elevations for targets in outcrop cells
- Figure 24: Comparison of actual and simulation groundwater elevation for targets in downdip cells

Table 20. Summary Statistics from Calibrated GMA 13 Model for All Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	411	878	4,306	688	717	7,000
Range in Observations	296.22	475.19	869.38	826.82	507.47	895.06
Minimum Residual	-230.03	-216.01	-347.33	-275.34	-116.63	-347.33
Maximum Residual	117.74	215.60	240.62	138.08	113.73	240.62
Residual Mean	-5.86	-3.57	-1.07	4.72	3.61	-0.62
Sum of Squared Residuals	5.44E+05	1.78E+06	5.74E+06	1.62E+06	4.90E+05	1.02E+07
Absolute Residual Mean	23.22	29.33	25.10	34.73	18.52	25.79
Residual Standard Deviation	35.92	44.90	36.49	48.35	25.90	38.12
Root Mean Square Error	36.39	45.04	36.50	48.58	26.15	38.13
Scaled Residual Standard Deviation	0.1212	0.0945	0.0420	0.0585	0.0510	0.0426
Scaled Absolute Residual Mean	0.0784	0.0617	0.0289	0.0420	0.0365	0.0288
Scaled Root Mean Square Error	0.1228	0.0948	0.0420	0.0588	0.0515	0.0426
Scaled Residual Mean	-0.0198	-0.0075	-0.0012	0.0057	0.0071	-0.0007

Table 21. Summary Statistics from Calibrated GMA 13 Model for Outcrop Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	90	407	638	159	285	1,579
Range in Observations	258.40	391.70	409.11	486.04	407.50	509.39
Minimum Residual	-86.25	-146.01	-79.68	-95.89	-106.77	-146.01
Maximum Residual	66.00	215.60	75.19	73.24	103.06	215.60
Residual Mean	1.85	6.36	-8.64	19.73	5.36	1.21
Sum of Squared Residuals	8.96E+04	6.40E+05	4.45E+05	2.03E+05	9.38E+04	1.47E+06
Absolute Residual Mean	23.05	26.29	20.94	29.57	12.18	21.73
Residual Standard Deviation	31.50	39.14	24.97	29.79	17.33	30.51
Root Mean Square Error	31.55	39.65	26.42	35.74	18.14	30.53
Scaled Residual Standard Deviation	0.1219	0.0999	0.0610	0.0613	0.0425	0.0599
Scaled Absolute Residual Mean	0.0892	0.0671	0.0512	0.0608	0.0299	0.0427
Scaled Root Mean Square Error	0.1221	0.1012	0.0646	0.0735	0.0445	0.0599
Scaled Residual Mean	0.0071	0.0162	-0.0211	0.0406	0.0131	0.0024

Table 22. Summary Statistics from Calibrated GMA 13 Model for Downdip Targets

Statsitic	Sparta (Layer 3)	Queen City (Layer 5)	Carrizo-Upper Wilcox (Layer 7)	Middle Wilcox (Layer 8)	Lower Wilcox (Layer 9)	All
Number of Observations	321	471	3,668	529	432	5,421
Range in Observations	258.76	446.62	810.77	776.99	474.76	845.23
Minimum Residual	-230.03	-216.01	-347.33	-275.34	-116.63	-347.33
Maximum Residual	117.74	103.67	240.62	138.08	113.73	240.62
Residual Mean	-8.02	-12.16	0.25	0.20	2.45	-1.15
Sum of Squared Residuals	4.55E+05	1.14E+06	5.29E+06	1.42E+06	3.96E+05	8.71E+06
Absolute Residual Mean	23.27	31.96	25.82	36.28	22.70	26.97
Residual Standard Deviation	36.77	47.69	37.99	51.82	30.19	40.06
Root Mean Square Error	37.64	49.22	37.99	51.82	30.29	40.07
Scaled Residual Standard Deviation	0.1421	0.1068	0.0469	0.0667	0.0636	0.0474
Scaled Absolute Residual Mean	0.0899	0.0716	0.0318	0.0467	0.0478	0.0319
Scaled Root Mean Square Error	0.1454	0.1102	0.0469	0.0667	0.0638	0.0474
Scaled Residual Mean	-0.0310	-0.0272	0.0003	0.0003	0.0052	-0.0014

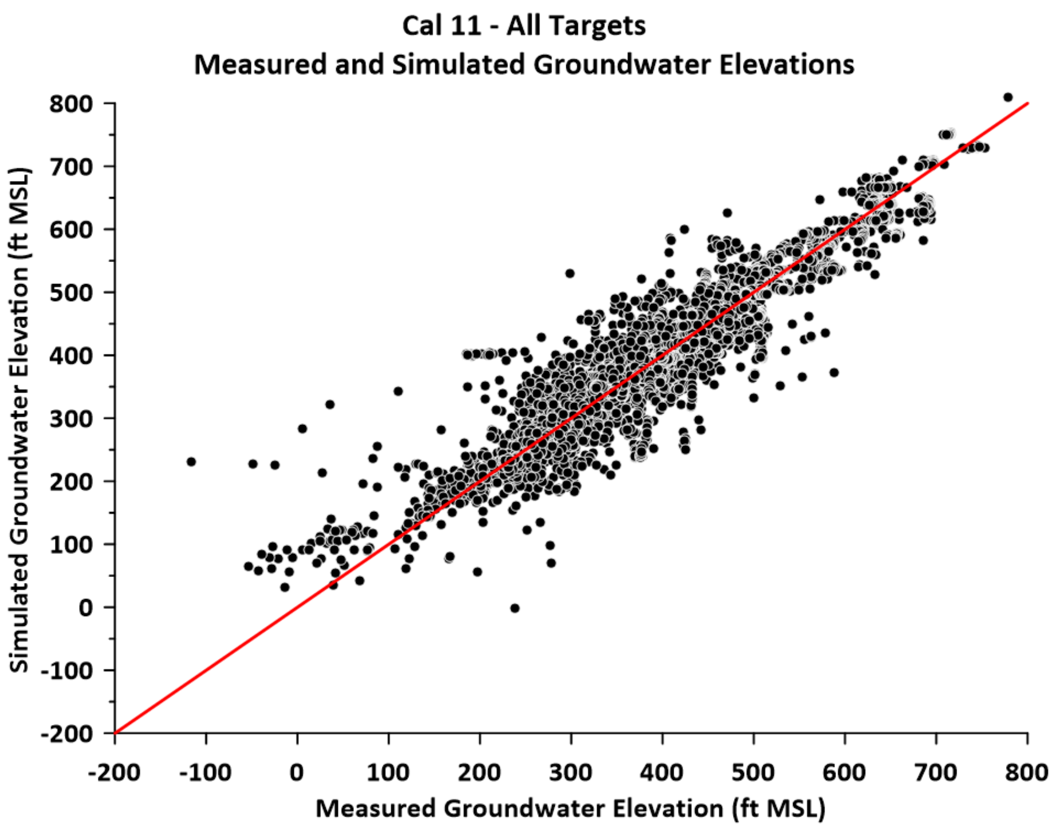


Figure 22. Actual vs. Simulated Groundwater Elevations for All Targets (Calibrated Model)

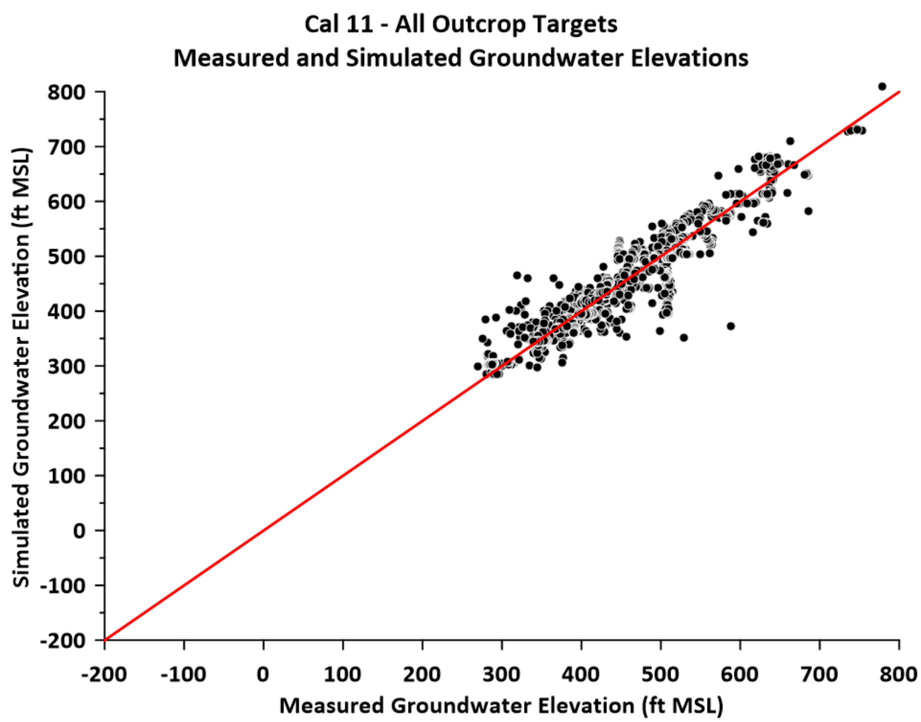


Figure 23. Actual vs. Simulated Groundwater Elevations for Outcrop Targets (Calibrated Model)

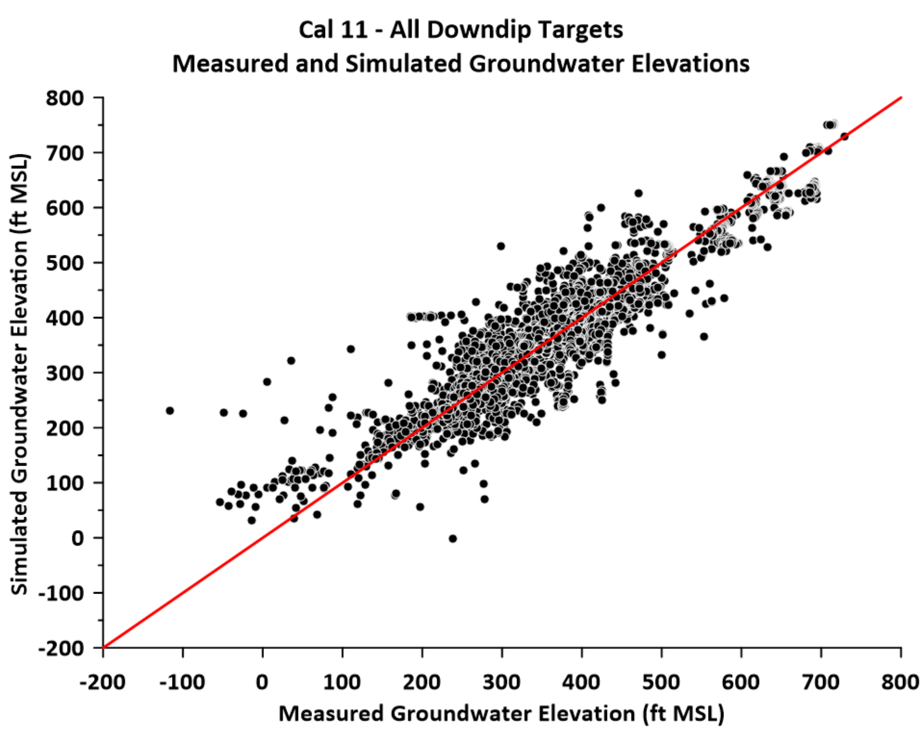


Figure 24. Actual vs. Simulated Groundwater Elevations for Downdip Targets (Calibrated Model)

In addition, Appendix C presents the comparison of actual and simulated groundwater elevations for targets as follows:

- Sparta Aquifer (Layer 3), outcrop
- Sparta Aquifer (Layer 3), downdip
- Queen City Aquifer (Layer 5), outcrop
- Queen City Aquifer (Layer 5), downdip
- Carrizo-Wilcox Aquifer (Layers 7 to 9), outcrop
- Carrizo-Wilcox Aquifer (Layers 7 to 9), downdip

14.2 Scaled Absolute Residual Mean Comparison

TWDB has established standards for calibration for Groundwater Availability Models. When the "new GAM" (Panday and others, 2023) was developed, one of the key standards was "mean absolute error between measured hydraulic head and simulated hydraulic head should be less than 10 percent of the maximum hydraulic head drop across the model area and better" for each layer. This statistic is the "Scaled Absolute Residual Mean" previously presented in the summaries of the calibration, and the TWDB standard is met if the value is less than 0.10.

Summary comparisons of this statistic by model layer (and overall) from Panday (2023) and others, Hutchison (2024), and this update are presented as follows:

- Table 23: All targets
- Table 24: Outcrop targets
- Table 25: Downdip targets

Please note that the Panday and others (2023) comparison uses the same annual targets used in Hutchison (2024) and this update, and not the full set of targets used in Panday and others (2023) as documented earlier in this report. In all tables, results that are greater than 0.10 (the TWDB standard) are highlighted in yellow. Please note that in this update, the standard is met for all layers in outcrop cells, downdip cells, and all cells.

Table 23. Summary of Scaled Absolute Residual Mean - All Targets

Layer	Targets	Panday (2023)	Hutchison (2024)	Hutchison (2025)
Sparta (Layer 3)	411	0.0851	0.0809	0.0784
Queen City (Layer 5)	878	0.0733	0.0591	0.0617
Carrizo-Upper Wilcox (Layer 7)	4,306	0.1270	0.0370	0.0289
Middle Wilcox (Layer 8)	688	0.1028	0.0447	0.0420
Lower Wilcox (Layer 9)	717	0.0395	0.0363	0.0365
All	7,000	0.0940	0.0338	0.0288

Table 24. Summary of Scaled Absolute Residual Mean - Outcrop Targets

Layer	Targets	Panday (2023)	Hutchison (2024)	Hutchison (2025)
Sparta (Layer 3)	90	0.1242	0.1037	0.0892
Queen City (Layer 5)	407	0.0976	0.0592	0.0671
Carrizo-Upper Wilcox (Layer 7)	638	0.0883	0.0427	0.0512
Middle Wilcox (Layer 8)	159	0.0743	0.0652	0.0608
Lower Wilcox (Layer 9)	285	0.0327	0.0307	0.0299
All	1,579	0.0634	0.0393	0.0427

Table 25. Summary of Scaled Absolute Residual Mean – Downdip Targets

Layer	Targets	Panday (2023)	Hutchison (2024)	Hutchison (2025)
Sparta (Layer 3)	321	0.0900	0.0896	0.0899
Queen City (Layer 5)	471	0.0714	0.0723	0.0716
Carrizo-Upper Wilcox (Layer 7)	3,668	0.1521	0.0428	0.0318
Middle Wilcox (Layer 8)	529	0.1283	0.0496	0.0467
Lower Wilcox (Layer 9)	432	0.0515	0.0470	0.0478
All	5,421	0.1175	0.0393	0.0319

14.3 Average Drawdown Hydrographs

Appendix D presents hydrograph comparisons of average drawdown by county. The post-processor *countyavghed.exe* was written to develop the data for these hydrographs:

- County names, county codes, and county file names are read in *CoListCode.dat*
- The target calibration file (*actsimcal.dat*) discussed above is read and actual heads and simulated heads are summed by layer and county.
- Average groundwater elevations are calculated
- Drawdowns (using 1982 as a base year) are calculated
- An overall results file (*allcountyavg.dat*) and results for each county are written. Average groundwater elevations and drawdown are written

These hydrographs demonstrate that the updated model is a suitable tool to estimate average drawdowns by county and aquifer for "predictive" scenarios.

14.4 Pumping

Calibrated model groundwater pumping estimates for GMA 13 by aquifer are presented in:

- Figure 25 (Sparta)
- Figure 26 (Queen City)
- Figure 27 (Carrizo-Wilcox)

Please note that in each graph, the outcrop and downdip pumping are presented in the form of stacked bars. Data for these graphs was saved in the Excel file named *PumpSummary.xlsx*.

Calibrated model groundwater pumping estimates for GMA 13 by county and model layer from the calibrated GMA 13 Model were developed using the Fortran program *CalPump.exe*. Appendix E presents the pumping by county for the Minor Aquifers (Sparta and Queen City). Appendix F presents the pumping by county for the Major Aquifer (Carrizo-Wilcox Aquifer). Please note that pumping for the Carrizo-Wilcox is shown for each model layer:

- Layer 7 = Carrizo-Upper Wilcox
- Layer 8 = Middle Wilcox
- Layer 9 = Lower Wilcox

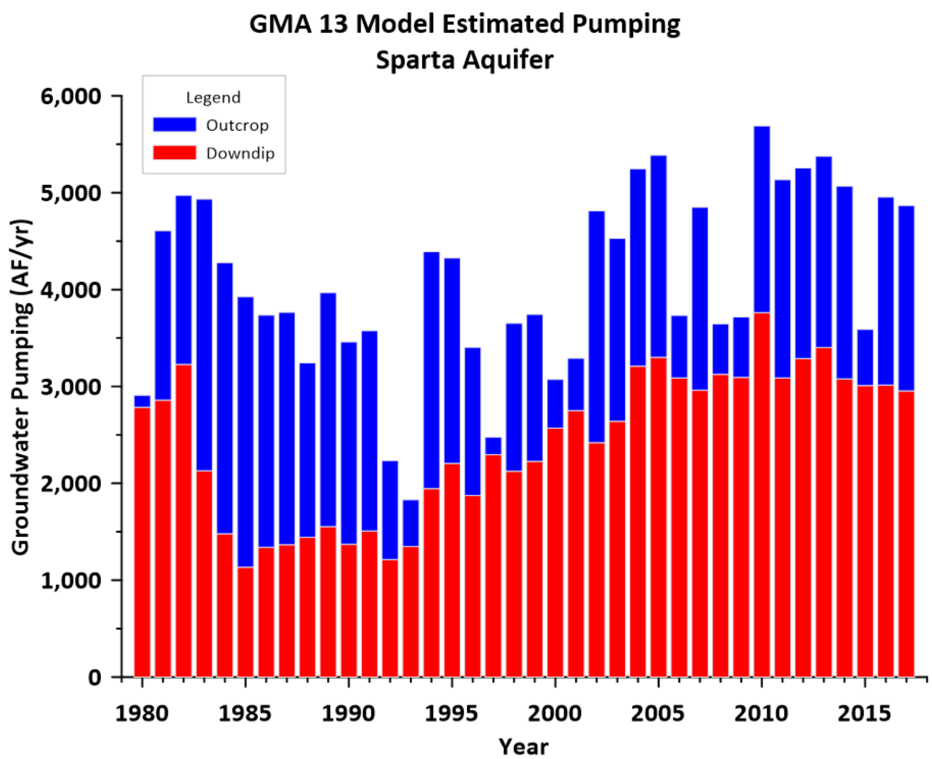


Figure 25. Groundwater Pumping in GMA 13 - Sparta Aquifer

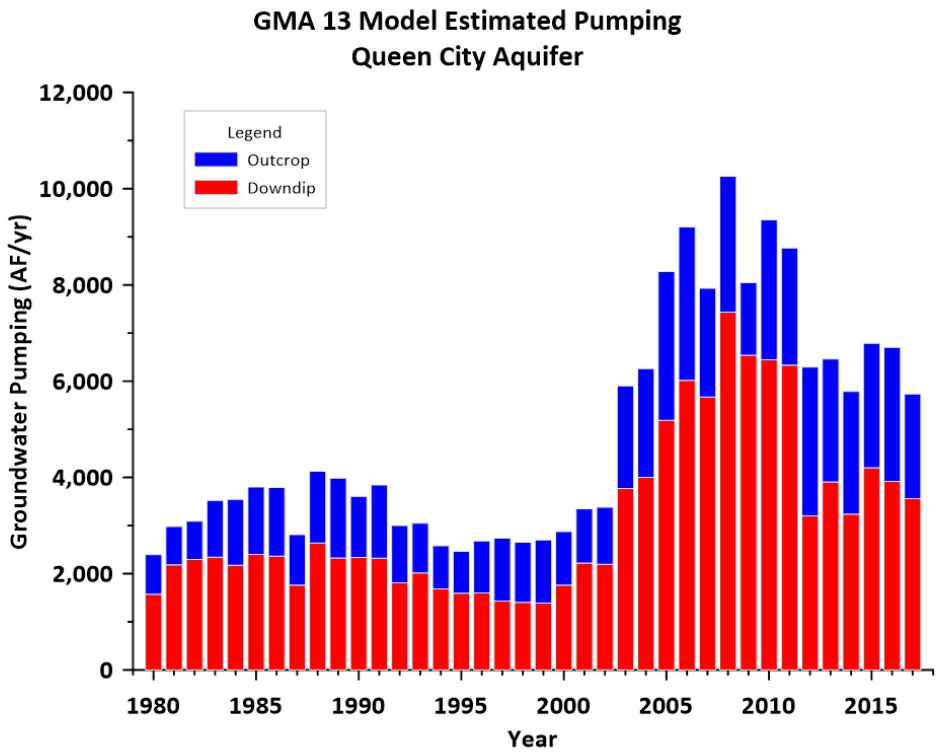
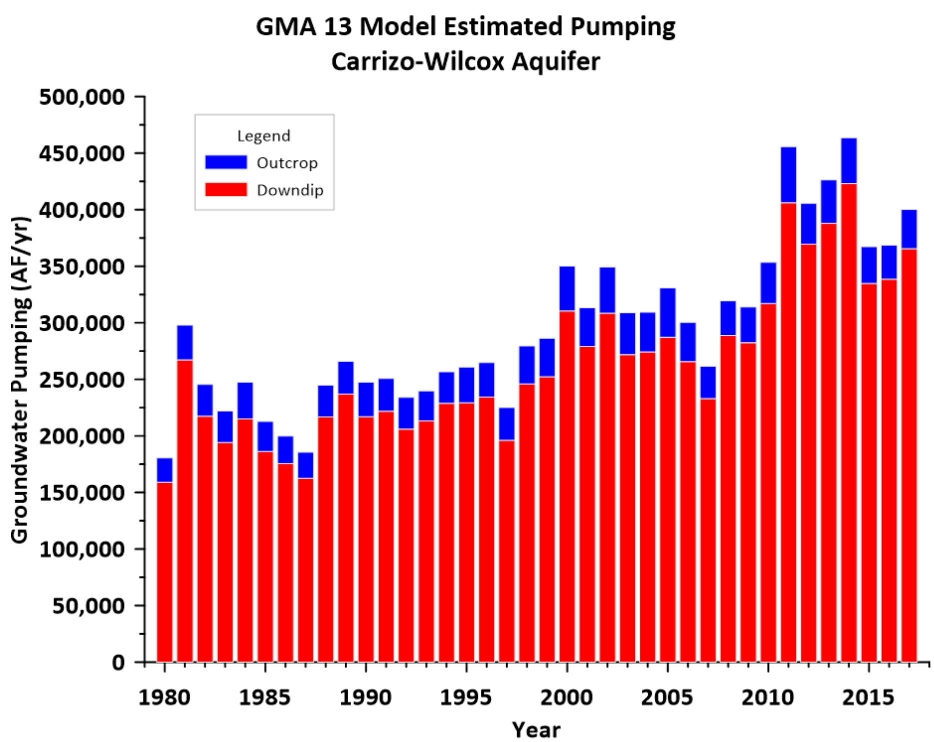


Figure 26. Groundwater Pumping in GMA 13 – Queen City Aquifer



igure 27. Groundwater Pumping in GMA 13 – Carrizo-Wilcox Aquifer

14.5 Model Parameters

The Excel file *ModelParam.xlsx* contains the cell-by-cell values of:

- Cell number
- Layer number
- Outcrop/downdip status (outcrop =1, downdip=2)
- County code
- Basin code
- GCD code
- GMA code
- Cell center x-coordinate (GAM coordinates)
- Cell center y-coordinate (GAM coordinates)
- Cell center latitude
- Cell center longitude
- Cell area (square feet)
- Cell area (acres)
- Top elevation of cell (ft MSL)
- Bottom elevation of cell (ft MSL)
- Cell thickness (ft)
- Horizontal hydraulic conductivity (Kx) (ft/day)
- Ratio of Kz to Kx
- Vertical hydraulic conductivity (Kz) (ft/day)
- Transmissivity (gpd/ft)
- Specific storage (1/ft)
- Storativity (dimensionless)
- Specific yield (dimensionless)

A summary of minima, average, and maxima of these parameters is presented in Table 26.

Table 26. GMA 13 Model Parameter Summary

Minimum

Layer	Cell Thickness (ft)	Kx (ft/day)	Kz/Kz Ratio	Kz (ft/day)	Transmissivity (gpd/ft)	Specific Storage (1/ft)	Storativity (dimensionless)	Specific Yield (dimensionless)
3	6	2.10E-02	1.70E-03	2.47E-04	1	1.42E-07	8.91E-06	4.95E-03
5	6	9.80E-02	2.25E-03	9.64E-04	1	4.30E-08	4.60E-05	3.43E-03
7	6	8.32E-02	1.00E-04	1.19E-05	2	5.52E-08	3.08E-05	2.02E-03
8	6	3.67E-02	1.00E-04	1.29E-05	1	4.78E-08	3.81E-05	3.43E-03
9	6	7.24E-02	2.27E-03	6.72E-04	8	3.12E-08	1.32E-06	3.43E-03

Average

Layer	Cell Thickness (ft)	Kx (ft/day)	Kz/Kz Ratio	Kz (ft/day)	Transmissivity (gpd/ft)	Specific Storage (1/ft)	Storativity (dimensionless)	Specific Yield (dimensionless)
3	202	9.44E-01	4.37E-02	3.65E-02	1,449	1.39E-06	1.37E-04	1.70E-02
5	738	5.77E+00	8.84E-02	4.75E-01	10,330	1.72E-06	1.99E-04	1.33E-02
7	745	9.57E+00	3.13E-02	4.25E-01	48,270	2.98E-06	3.46E-04	1.55E-02
8	467	5.29E+00	4.13E-02	9.78E-02	6,945	2.15E-06	2.33E-04	1.38E-02
9	708	8.33E+00	7.01E-02	4.40E-01	10,441	9.67E-07	1.70E-04	1.42E-02

Maximum

Layer	Cell Thickness (ft)	Kx (ft/day)	Kz/Kz Ratio	Kz (ft/day)	Transmissivity (gpd/ft)	Specific Storage (1/ft)	Storativity (dimensionless)	Specific Yield (dimensionless)
3	635	6.56E+00	1.00E-01	3.77E-01	8,000	1.01E-04	1.60E-02	0.1
5	1946	1.39E+03	1.00E-01	9.64E+01	25,000	1.04E-04	3.01E-02	0.1
7	1680	2.16E+02	1.00E-01	1.67E+01	200,001	1.04E-04	2.72E-02	0.1
8	2090	2.50E+02	1.00E-01	4.12E+00	40,000	1.04E-04	1.49E-02	0.1
9	3210	5.64E+02	1.00E-01	2.56E+01	50,000	1.00E-04	1.29E-02	0.1

Because transmissivity values were one of the key issues raised in the public comments, maps of transmissivity values were developed and presented below for the aquifer layer:

- Figure 28 – Sparta Aquifer (Layer 3)
- Figure 29 – Queen City Aquifer (Layer 5)
- Figure 30 – Carrizo-Upper Wilcox Aquifer (Layer 7)
- Figure 31 – Middle Wilcox (Layer 8)
- Figure 32 – Lower Wilcox (Layer 9)

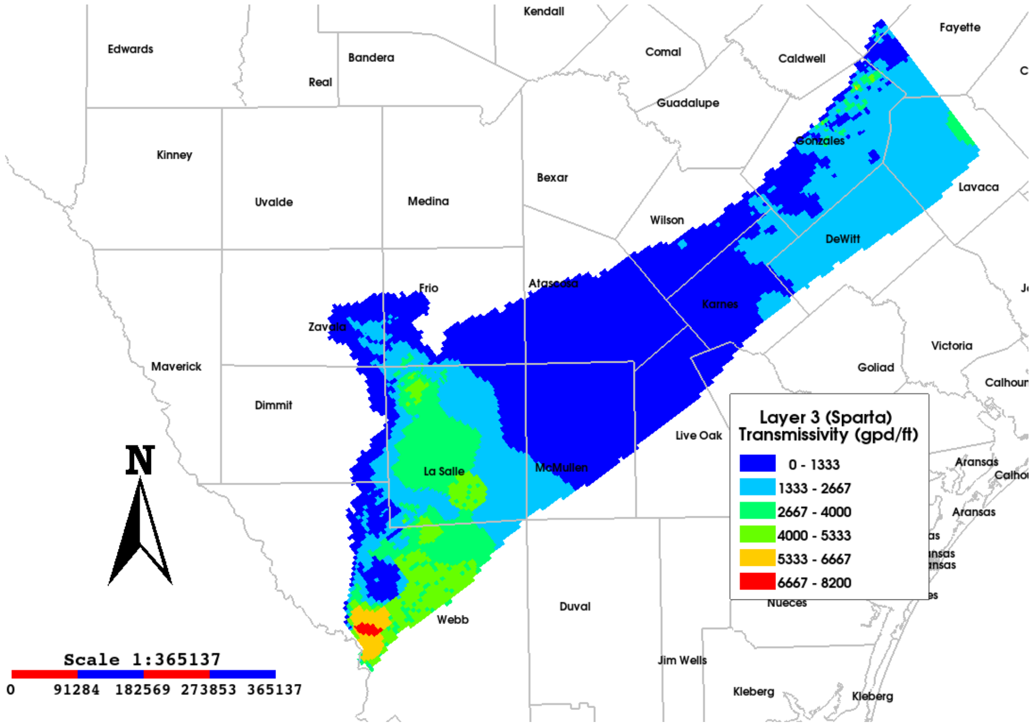


Figure 28. GMA 13 Model Transmissivity - Sparta Aquifer (Layer 3)

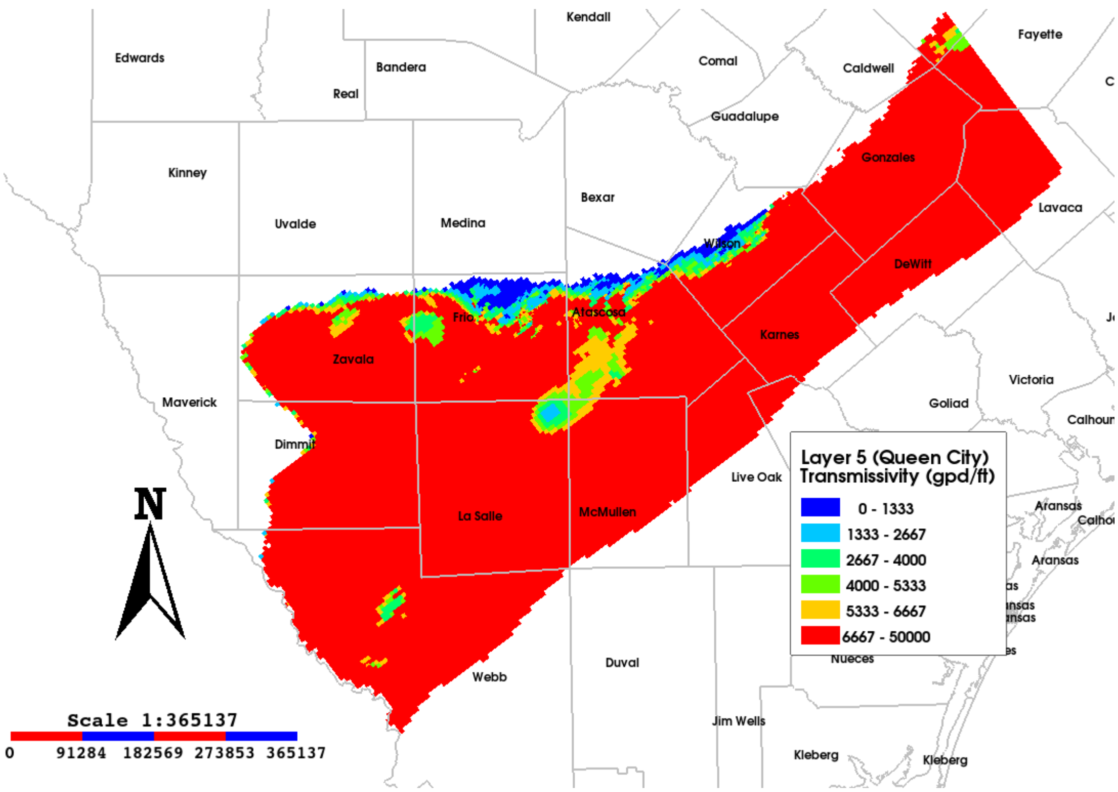


Figure 29. GMA 13 Model Transmissivity – Queen City Aquifer (Layer 5)

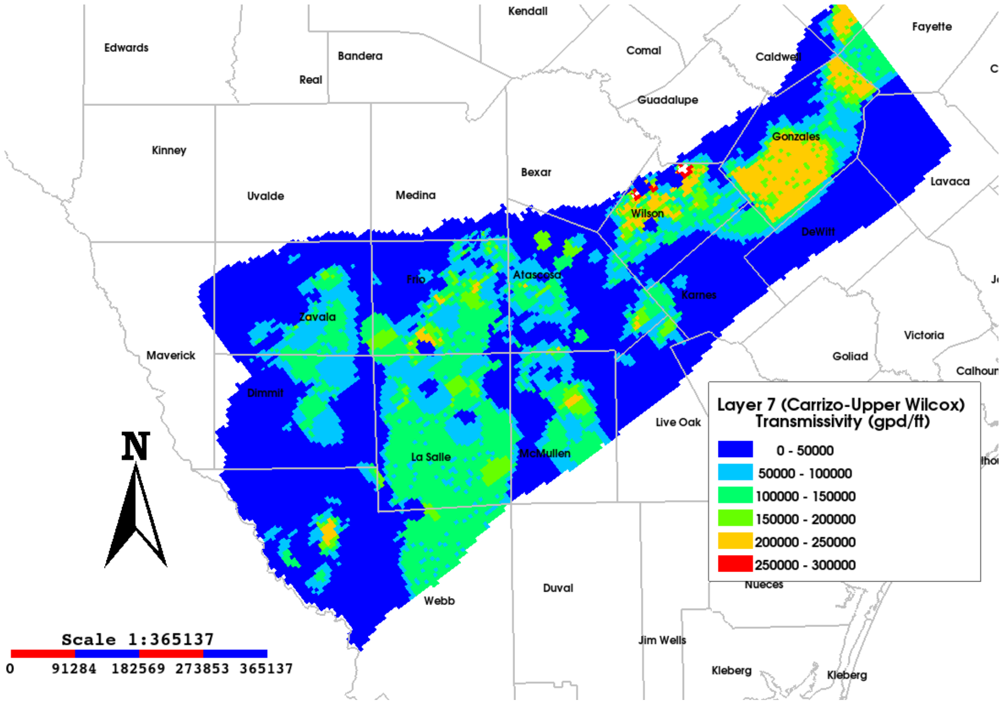


Figure 30. GMA 13 Model Transmissivity – Carrizo-Upper Wilcox Aquifer (Layer 7)

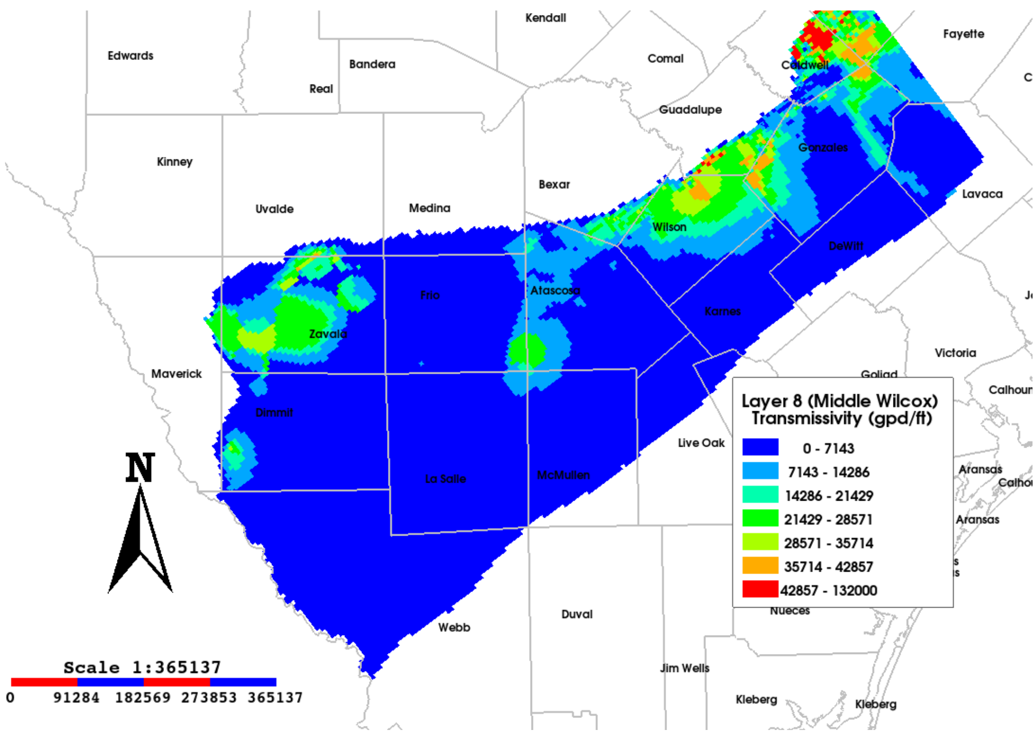


Figure 31. GMA 13 Model Transmissivity – Middle Wilcox (Layer 8)

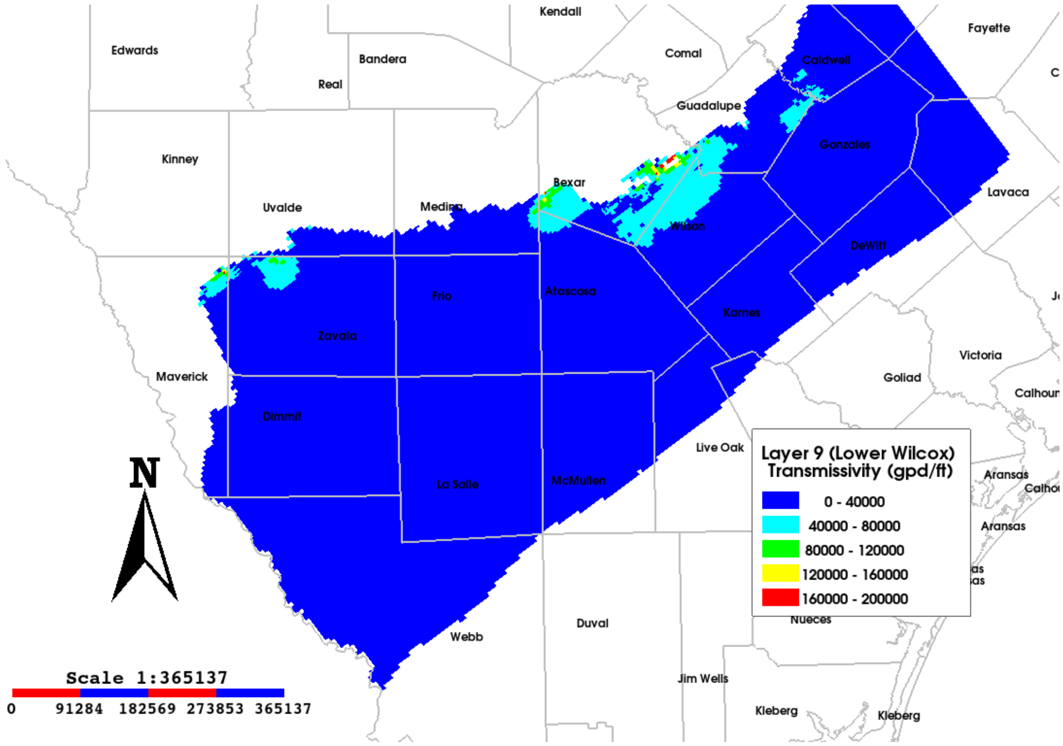


Figure 32. GMA 13 Model Transmissivity – Lower Wilcox Aquifer (Layer 9)

14.6 Groundwater Budgets

Groundwater budgets for the GMA 13 portion of the model by aquifer were developed using ZONEBUDGET 6, developed by the USGS.

Zones were defined using the Fortran program *Zones.exe*. The program reads a list of cell attributes (layer, outcrop/downdip status, and GMA). For purposes of this application, outcrop cells have an index of 1, and downdip cells have an index of 2.

For cells in GMA 13, the first two digits of the zone number is 13, the third digit is the outcrop/downdip status (1 or 2), and the fourth digit is the layer number. The zone number outside of GMA 13 is the GMA number times 100 (i.e. GMA 15 cells are all in Zone 1500, regardless of outcrop/downdip status and regardless of model layer).

A total of six GMA 13 groundwater budgets were developed and saved in the file *GMA Aquifer Zone Budget.xlsx*. Summaries for the three aquifers (Sparta, Queen City, and Carrizo-Wilcox) for outcrop and downdip portions are presented below as follows:

- Table 27 – Sparta Aquifer
- Table 28 – Queen City Aquifer
- Table 29 – Carrizo-Wilcox Aquifer

Table 27. GMA 13 Groundwater Budgets - Sparta Aquifer

Groundwater Budget from GMA 13 Model
GMA 13 Portion of Sparta Outcrop
(Zone 1313)
Average Flows 1981 to 2017 (AF/yr)

Inflow	AF/yr
General Head Boundary (GHB)	4,410
Recharge (RCH)	20,277
Total Inflow	**24,687**

Outflow	
Pumping (WEL)	1,712
Evapotranspiration (EVT)	7,158
GMA 12 (Zone 1200)	3
Alluvium (Zone 1311)	5,189
Queen City Outcrop (Zone 1315)	319
Sparta Downdip (Zone 1323)	2,068
Weches Downdip (Zone 1324)	7,581
Mexico (Zone 9900)	1,792
Total Outflow	**25,821**

Inflow-Outflow	-1,134
Model Estimated Storage Change	-1,134
Model Error	0

Groundwater Budget from GMA 13 Model
GMA 13 Portion of Sparta Downdip
(Zone 1323)
Average Flows 1981 to 2017 (AF/yr)

Inflow	AF/yr
GMA 12 (Zone 1200)	104
Net Overlying Units (Zones 1312 and 1322)	11,622
Sparta Outcrop (Zone 1313)	2,068
GMA 15 (Zone 1500)	1,075
GMA 16 (Zone 1600)	413
Total Inflow	**15,281**

Outflow	
Pumping (WEL)	2,416
General Head Boundaries (GHB)	5,254
Weches Downdip (Zone 1324)	7,680
Mexico (Zone 9900)	49
Total Outflow	**15,400**

Inflow-Outflow	-119
Model Estimated Storage Change	-119
Model Error	0

GMA 13 Model (2025 Version)

Table 28. GMA 13 Groundwater Budgets - Queen City Aquifer

Groundwater Budget from GMA 13 Model GMA 13 Portion of Queen City Outcrop (Zone 1315)

Average Flows 1981 to 2017 (AF/yr)

Inflow

	AF/yr
Recharge (RCH)	49,760
GMA 12 (Zone 1200)	169
Alluvium (Zone 1311)	19,728
Sparta Outcrop (Zone 1311)	319
Total Inflow	**69,976**

Outflow

Pumping (WEL)	1,747
Evapotranspiration (EVT)	984
Queen City Downdip (Zone 1325)	8,714
Reklaw Downdip (Zone 1326)	60,719
Mexico (Zone 9900)	5,857
Total Outflow	**78,021**

Inflow-Outflow	-8,046
Model Estimated Storage Change	-8,046
Model Error	0

Groundwater Budget from GMA 13 Model GMA 13 Portion of Queen City Downdip (Zone 1325)

Average Flows 1981 to 2017 (AF/yr)

Inflow

	AF/yr
General Head Boundaries (GHB)	1,089
GMA 12 (Zone 1200)	275
Weches (Zones 1314 and 1324)	20,792
Queen City Outcrop (Zone 1315)	8,714
GMA 15 (Zone 1500)	769
GMA 16 (Zone 1600)	326
Total Inflow	**31,966**

Outflow

Pumping (WEL)	3,181
Reklaw Downdip (Zone 1326)	29,775
Mexico (Zone 9900)	3
Total Outflow	**32,958**

Inflow-Outflow	-992
Model Estimated Storage Change	-992
Model Error	0

Table 29. GMA 13 Groundwater Budgets - Carrizo-Wilcox Aquifer

Groundwater Budget from GMA 13 Model GMA 13 Portion of Carrizo-Wilcox Outcrop (Zone 1317)

Average Flows 1981 to 2017 (AF/yr)

Inflow

	AF/yr
Recharge (RCH)	85,747
GMA 10 (Zone 1000)	2,769
Alluvium (Zone 1311)	87,699
Total Inflow	**176,214**

Outflow

Pumping (WEL)	32,560
Evapotranspiration (EVT)	2,147
GMA 12 (Zone 1200)	1,160
Carrizo-Wilcox Downdip (Zone 1327)	148,627
Mexico (Zone 9900)	1,517
Total Outflow	**186,011**

Inflow-Outflow	-9,797
Model Estimated Storage Change	-9,797
Model Error	0

Groundwater Budget from GMA 13 Model GMA 13 Portion of Carrizo-Wilcox Downdip (Zone 1327)

Average Flows 1981 to 2017 (AF/yr)

Inflow

	AF/yr
General Head Boundaries (GHB)	1,389
GMA 10 (Zone 1000)	220
GMA 12 (Zone 1200)	2,209
Reklaw (Zones 1316 and 1326)	100,436
Carrizo-Wilcox Outcrop (Zone 1317)	148,627
GMA 16 (Zone 1600)	1,089
Total Inflow	**253,970**

Outflow

Pumping (WEL)	266,495
GMA 15 (Zone 1500)	607
Mexico (Zone 9900)	377
Total Outflow	**267,479**

Inflow-Outflow	-13,509
Model Estimated Storage Change	-13,509
Model Error	0

15.0 References

Hutchison, W.R., 2017. Extension of GAM Calibration Period for Carrizo-Wilcox, Queen City, and Sparta Aquifers. GMA Technical Memorandum 17-01. August 25, 2017, 81p.

Hutchison, W.R., 2024. Documentation of GMA 13 Model: Update to Groundwater Availability Model for the Southern Portion of the Carrizo-Wilcox, Queen City, and Sparta Aquifers. GMA 13 Technical Memorandum 1 – Final, September 23, 2024, 124p.

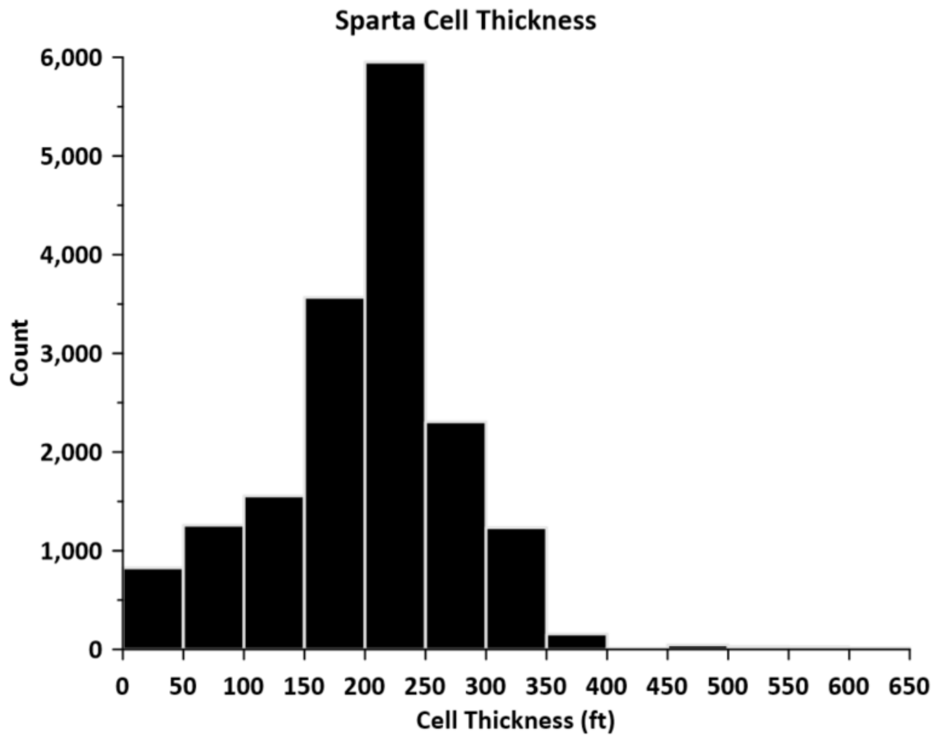
Kelley, V. A., Deeds, N. E., Fryar, D. G., and Nicot, J. P., 2004, Groundwater availability models for the Queen City and Sparta aquifers: contract report to the Texas Water Development Board, 867 p.

Panday, S., Wycoff, R., Martell, G., Schorr, S., Zivic, M., Hutchison, W.R., and Rumbaugh, J., 2023. Final Numerical Model Report: Update to the Groundwater Availability Model for the Southern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers. Texas Water Development Board Contract 1948312321. January 2023, 1972p.

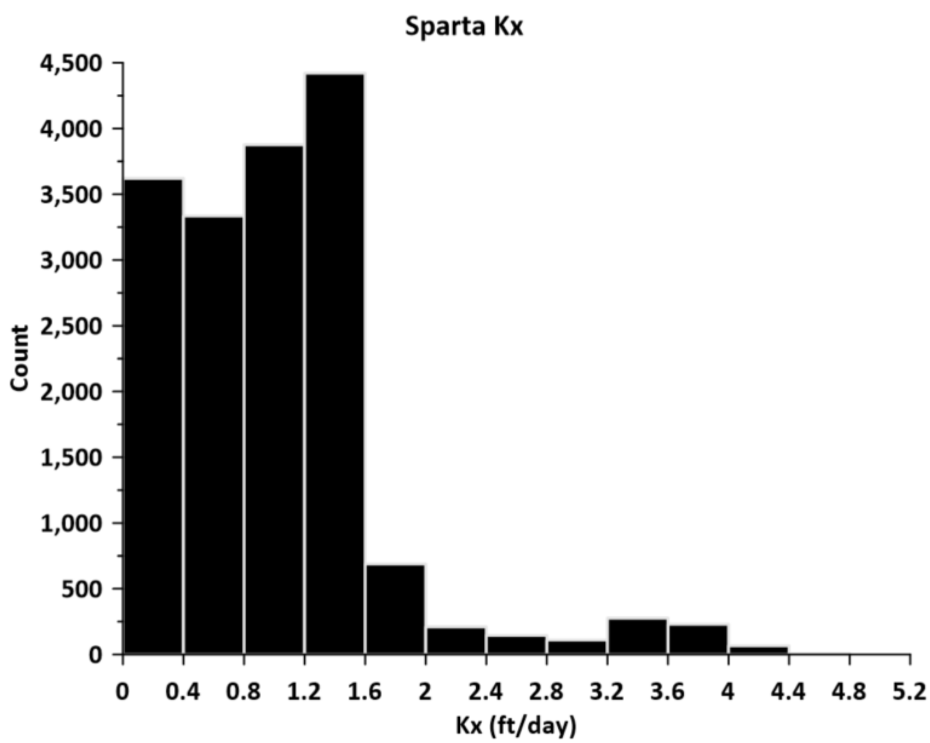
Schorr, S., Zivic, M., Panday, S., Hutchison, W.R., and Rumbaugh, J., 2021. Conceptual Model Report: Update to the Groundwater Availability Model for Southern Portion of the Carrizo-Wilcox, Queen City, and Sparta Aquifer. Texas Water Development Board Contract 1948312321. January 2021, 213p.

Appendix A

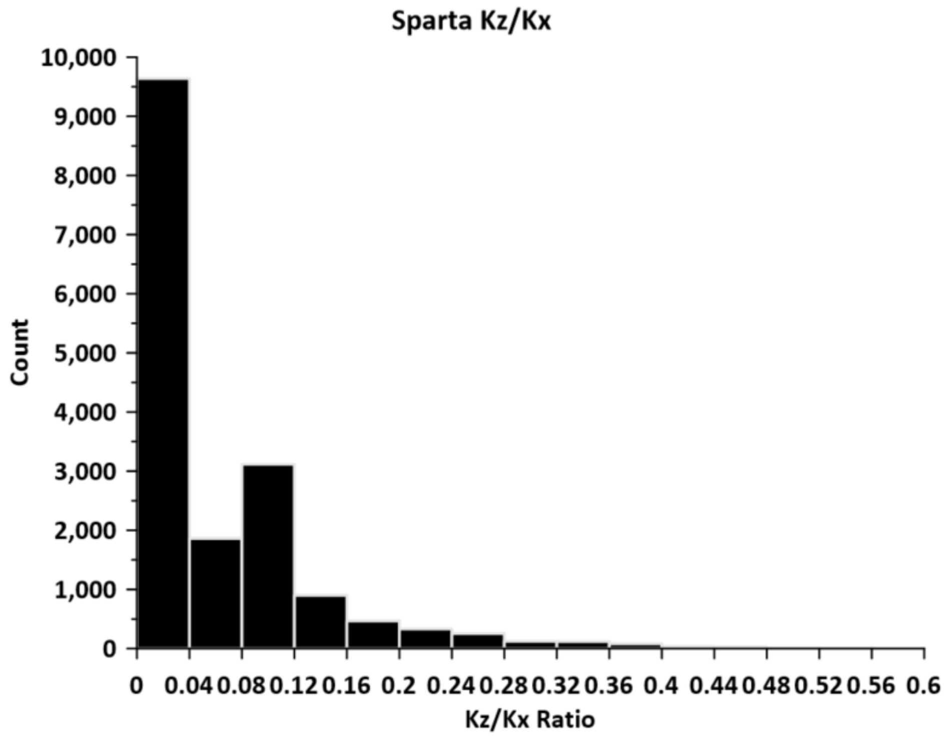
Frequency Plots of Cell Thickness, Kx, Kz/Kx Ratio, Kz, and Transmissivity for “New GAM”

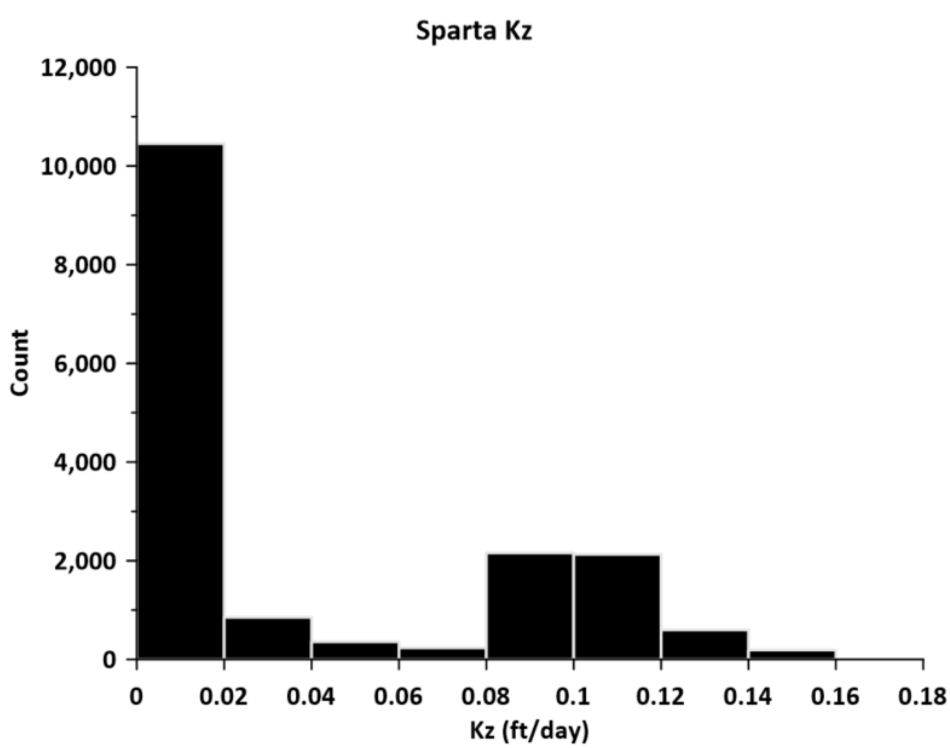


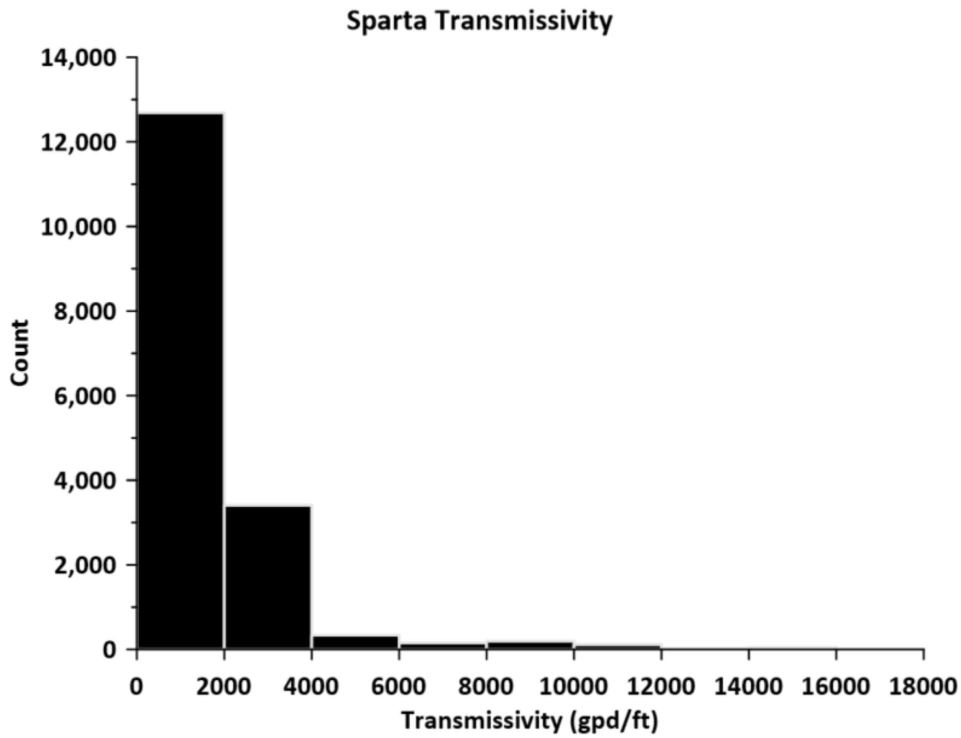
Sparta Cell Thickness
6,000
5,000
4,000
3,000
2,000
1,000
0
Count
0 50 100 150 200 250 300 350 400 450 500 550 600 650
Cell Thickness (ft)

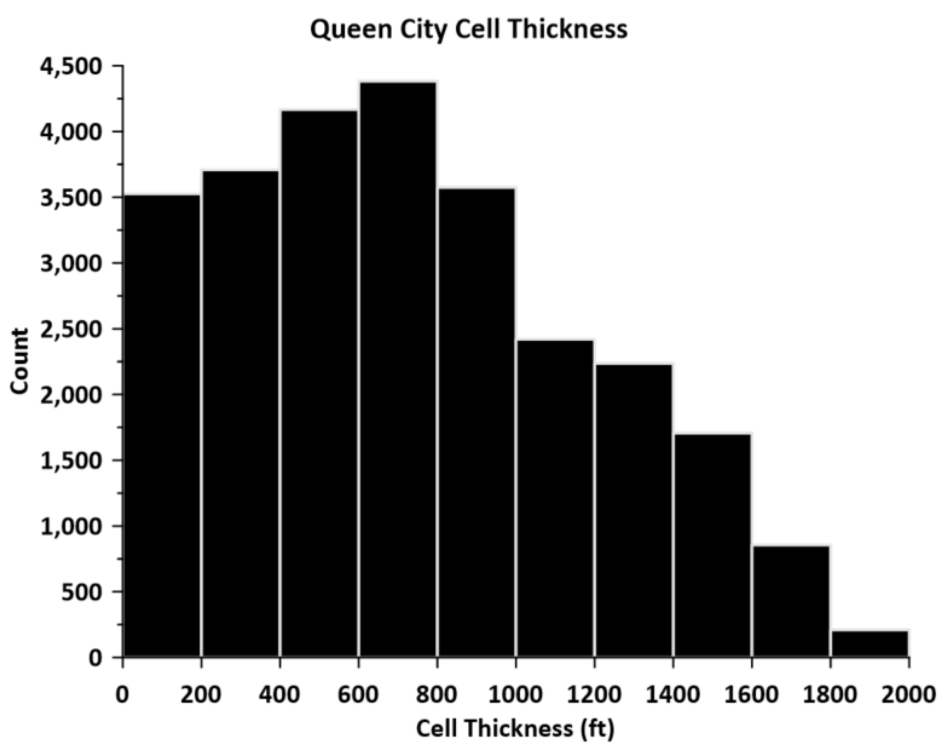


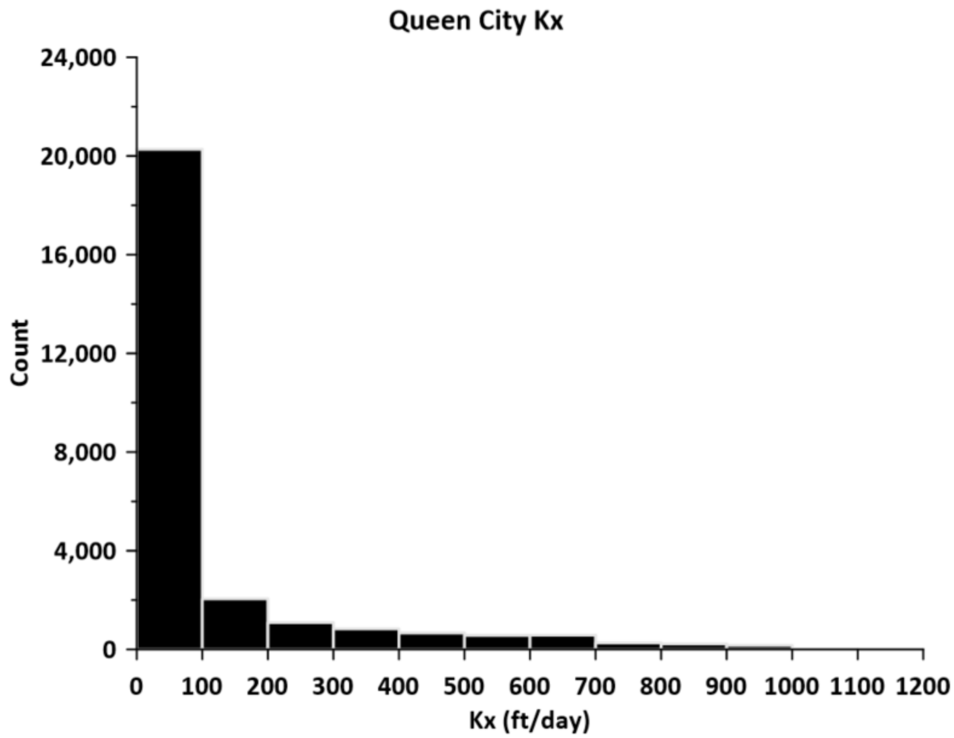
Sparta Kx
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Count
0 0.4 0.8 1.2 1.6 2 2.4 2.8 3.2 3.6 4 4.4 4.8 5.2
Kx (ft/day)

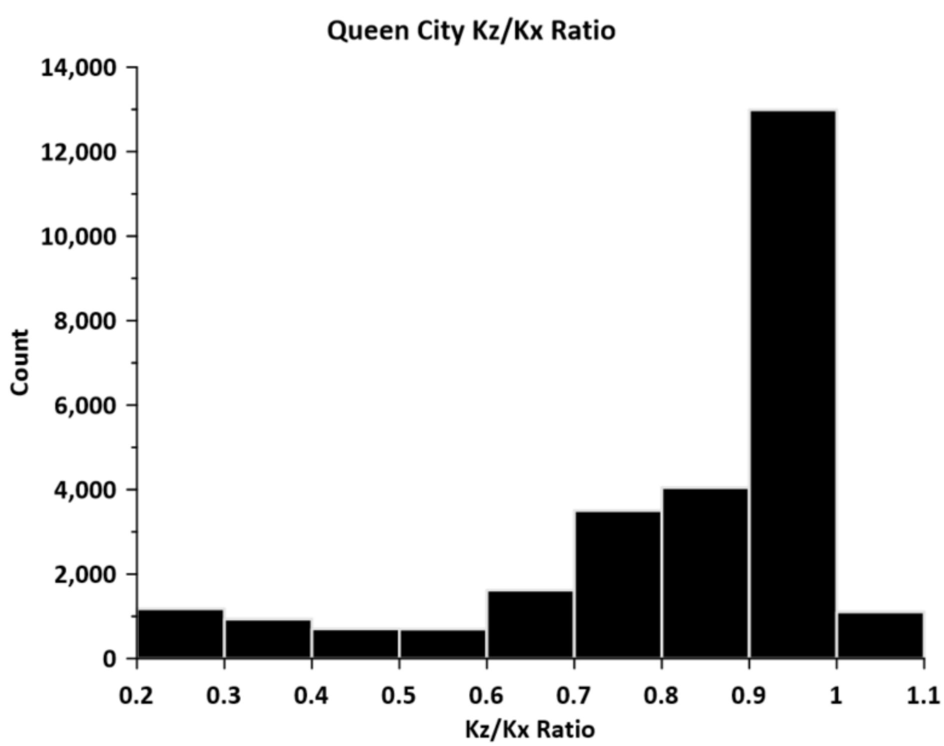

Sparta Kz/Kx
Count
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0 0.04 0.08 0.12 0.16 0.2 0.24 0.28 0.32 0.36 0.4 0.44 0.48 0.52 0.56 0.6
Kz/Kx Ratio

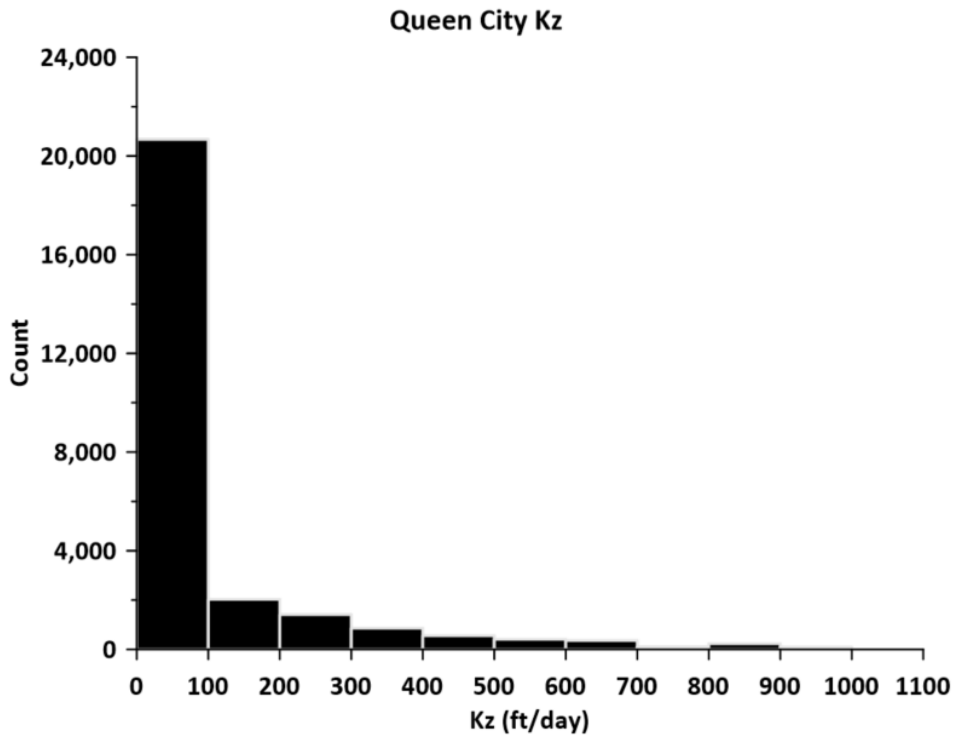

Sparta Kz
Count
12,000
10,000
8,000
6,000
4,000
2,000
0
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18
Kz (ft/day)

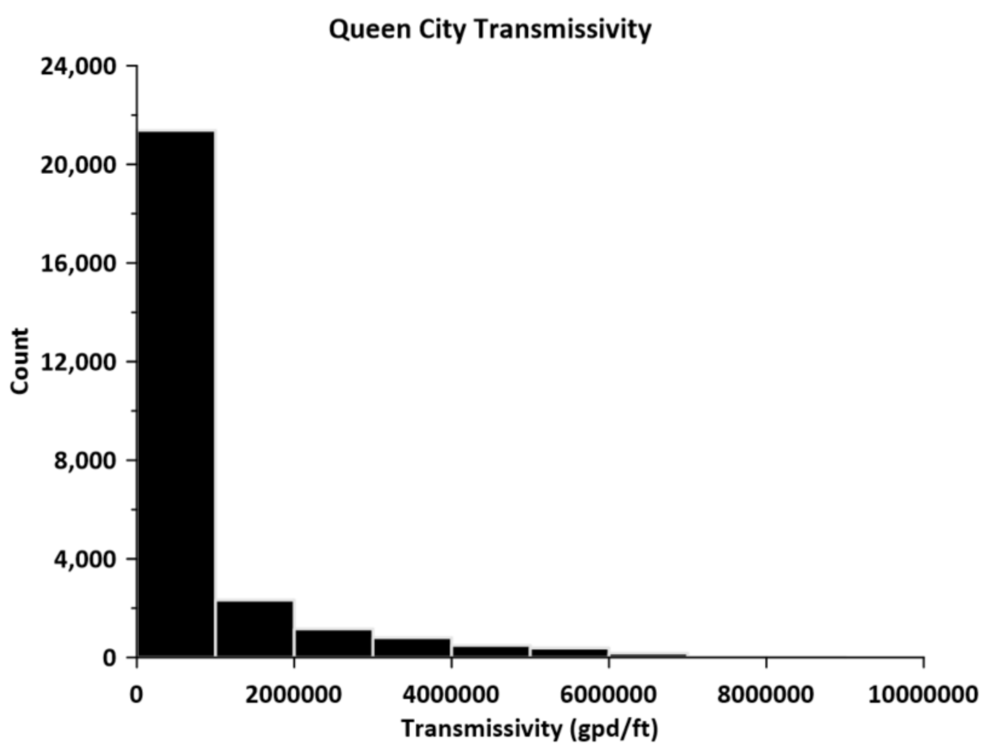

Sparta Transmissivity
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Transmissivity (gpd/ft)

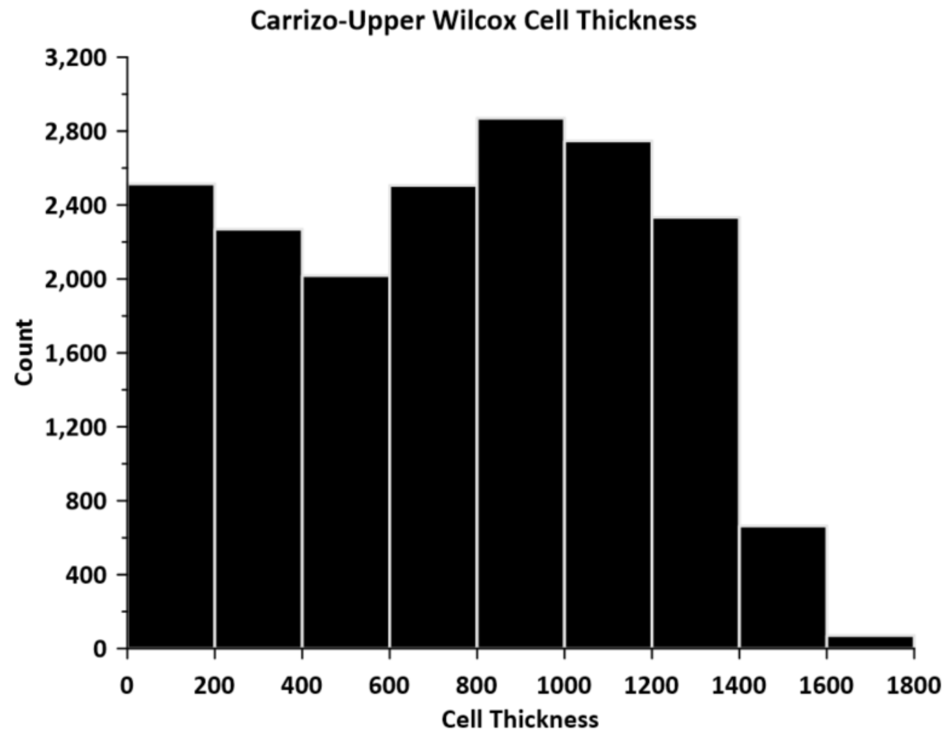

Queen City Cell Thickness
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Count
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Cell Thickness (ft)

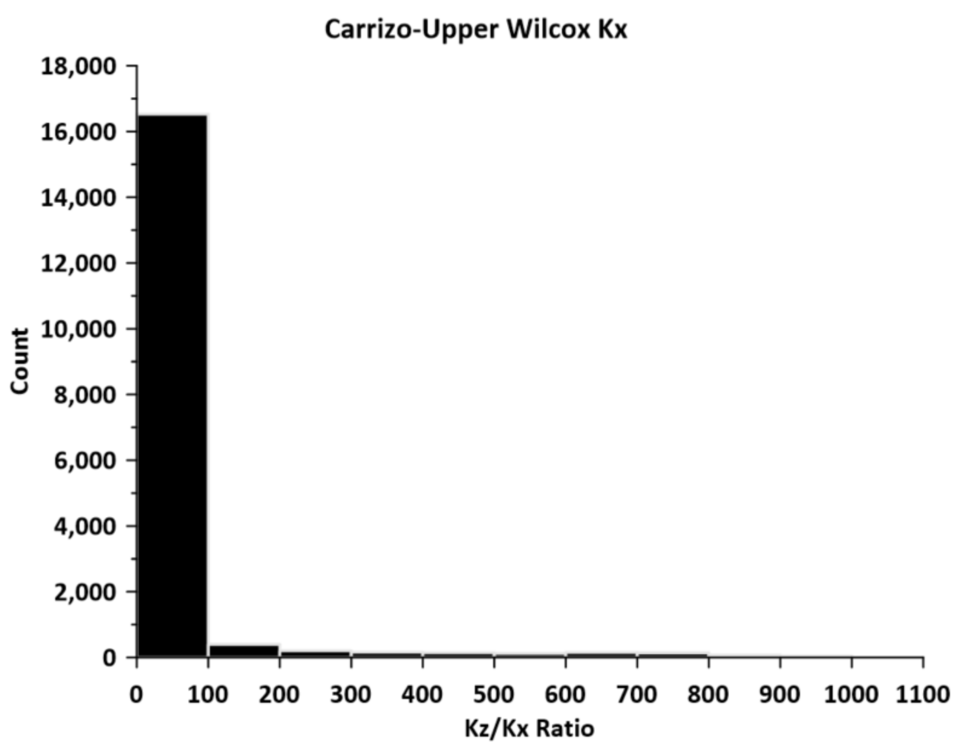

Queen City Kx
Count
24,000
20,000
16,000
12,000
8,000
4,000
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
Kx (ft/day)

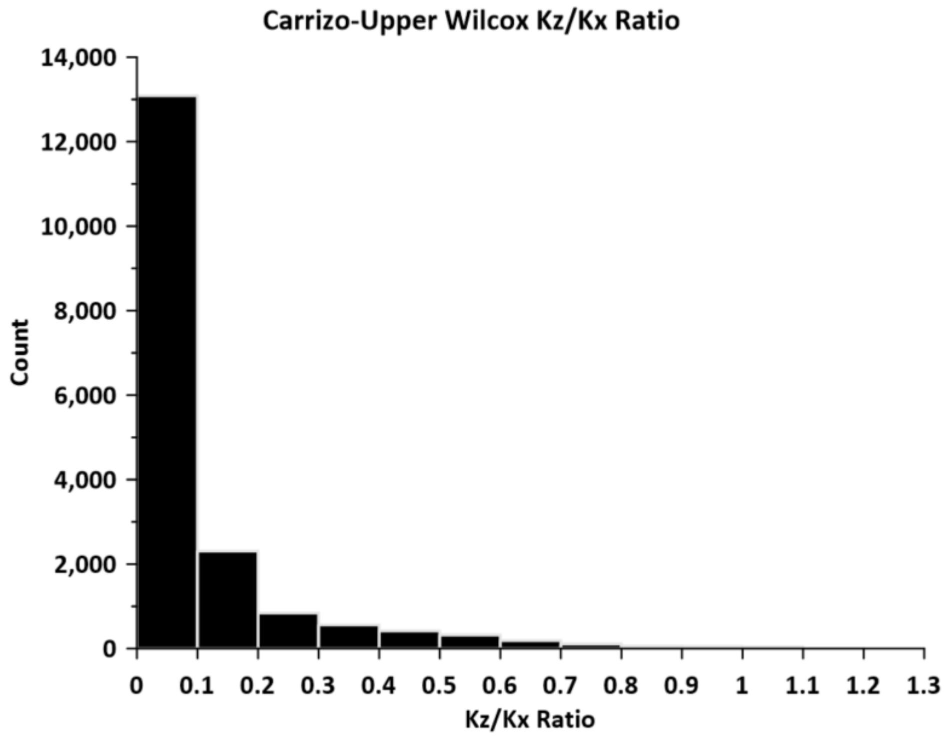

Queen City Kz/Kx Ratio
Count
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1
Kz/Kx Ratio

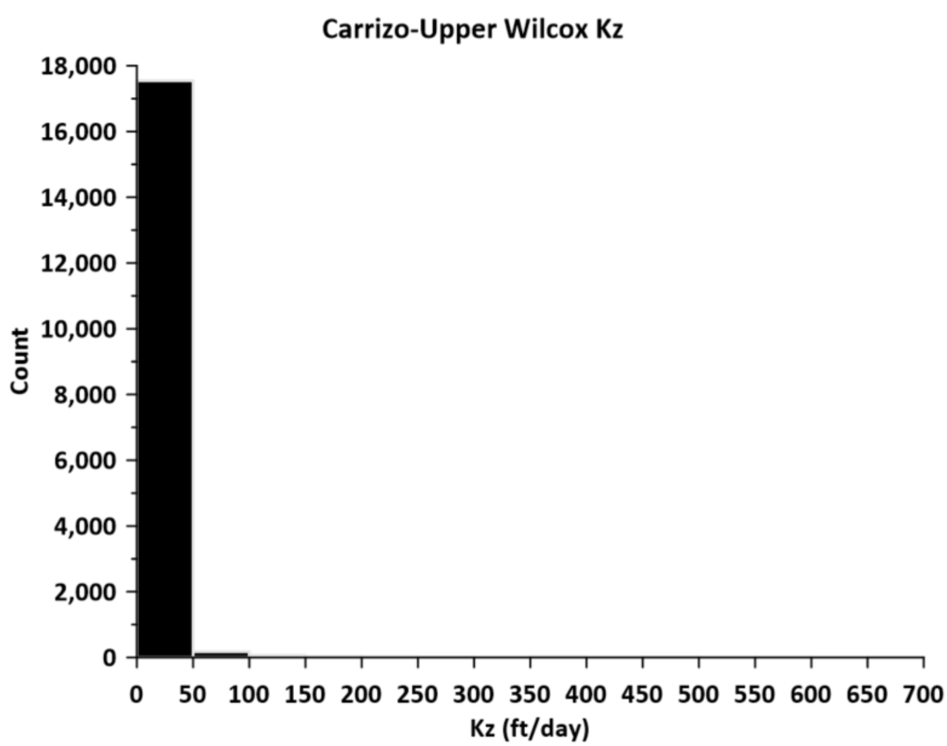

Queen City Kz
24,000
20,000
16,000
12,000
8,000
4,000
0
Count
0
100
200
300
400
500
600
700
800
900
1000
1100
Kz (ft/day)

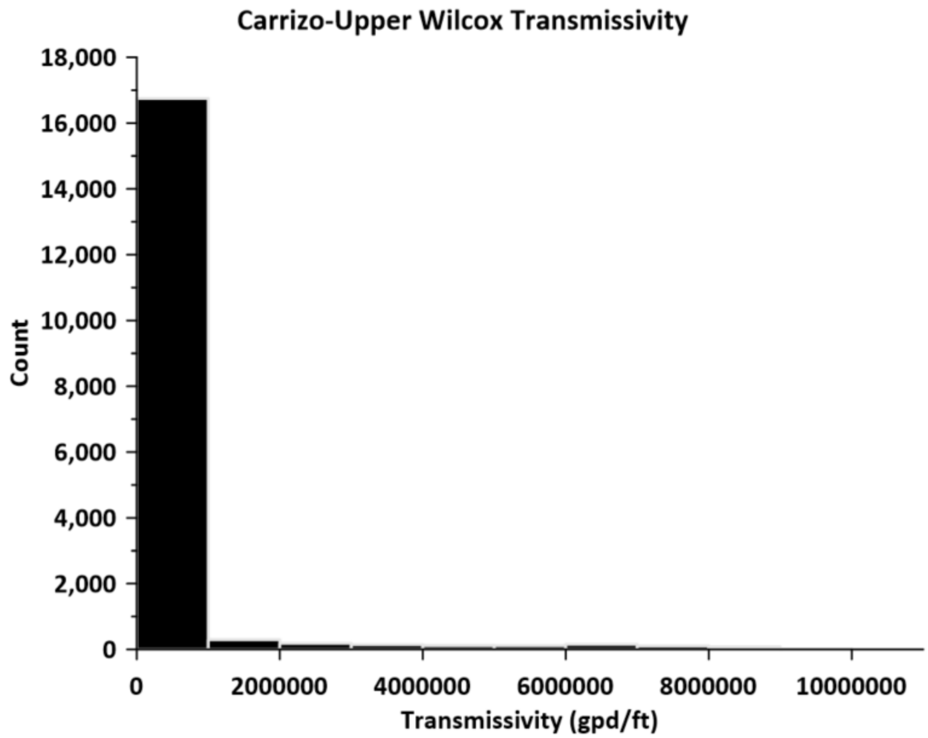

Queen City Transmissivity
24,000
20,000
16,000
12,000
8,000
4,000
0
Count
0
2000000
4000000
6000000
8000000
10000000
Transmissivity (gpd/ft)

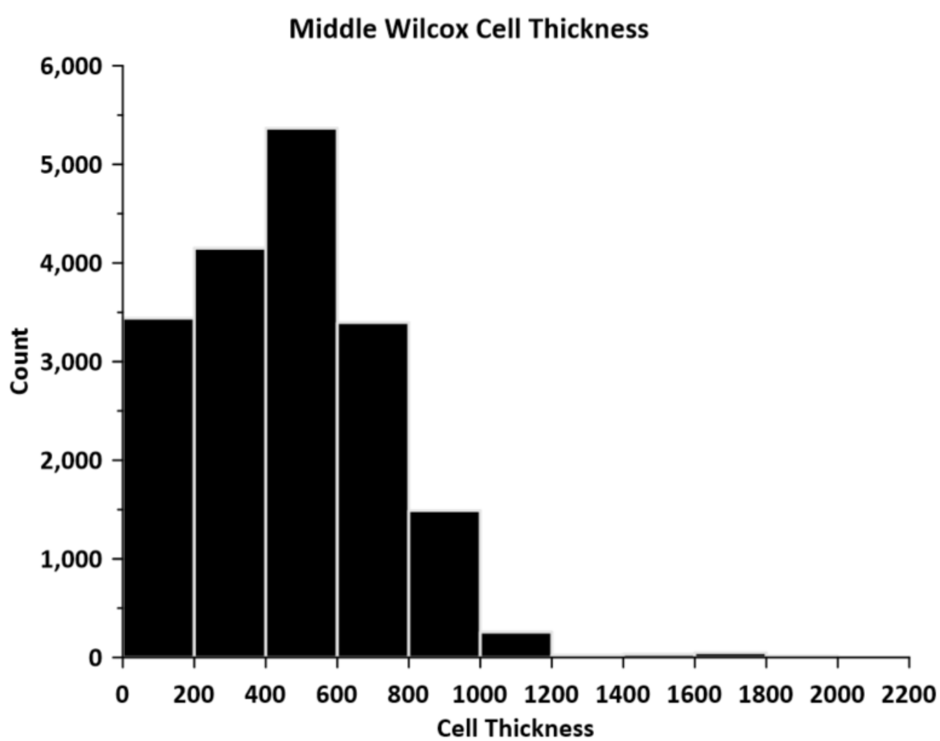

Carrizo-Upper Wilcox Cell Thickness
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
Count
0
200
400
600
800
1000
1200
1400
1600
1800
Cell Thickness

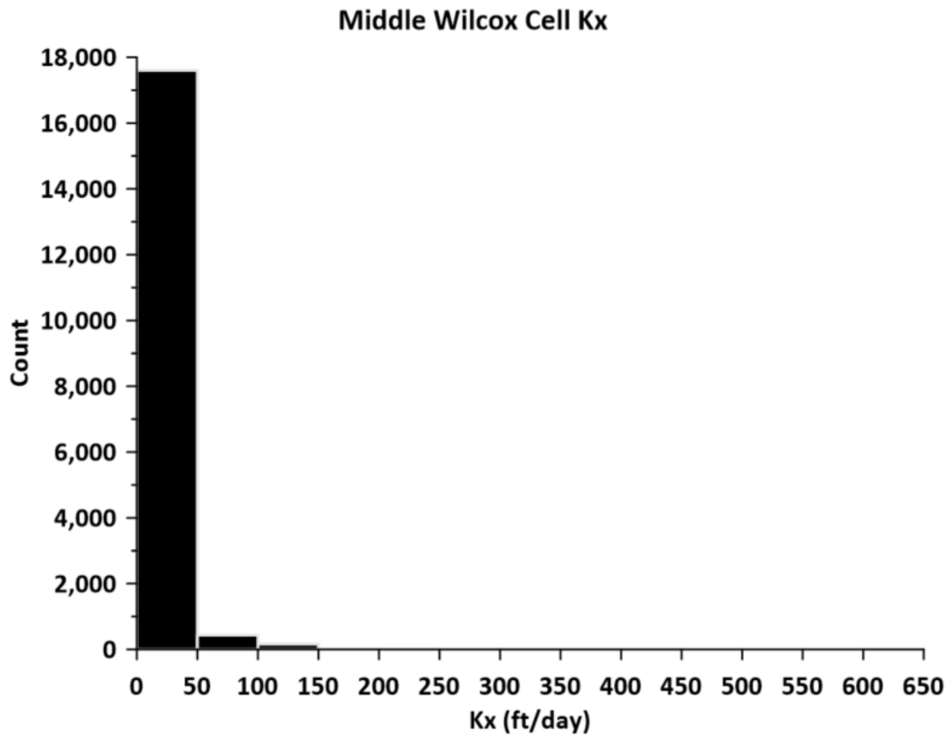

Carrizo-Upper Wilcox Kx
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
100
200
300
400
500
600
700
800
900
1000
1100
Kz/Kx Ratio

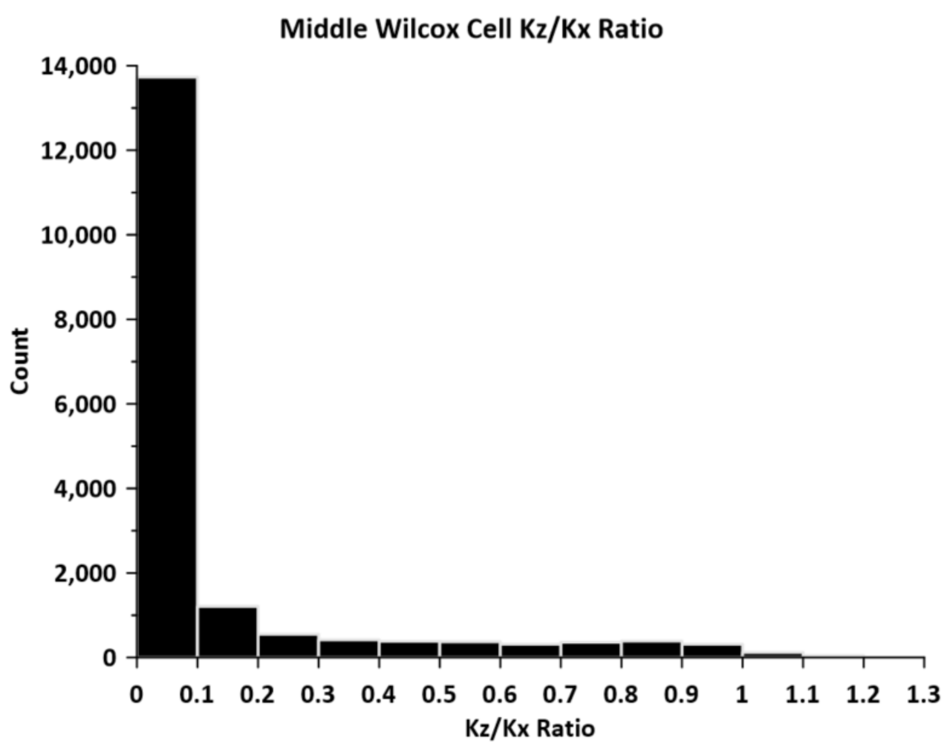

Carrizo-Upper Wilcox Kz/Kx Ratio
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
Kz/Kx Ratio

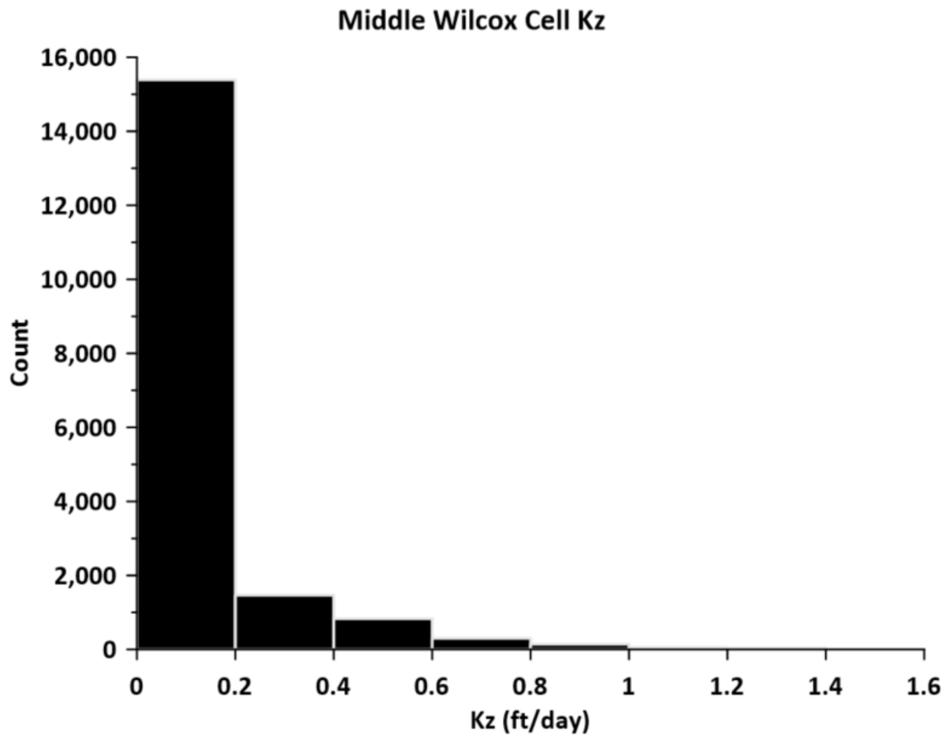

Carrizo-Upper Wilcox Kz
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Kz (ft/day)

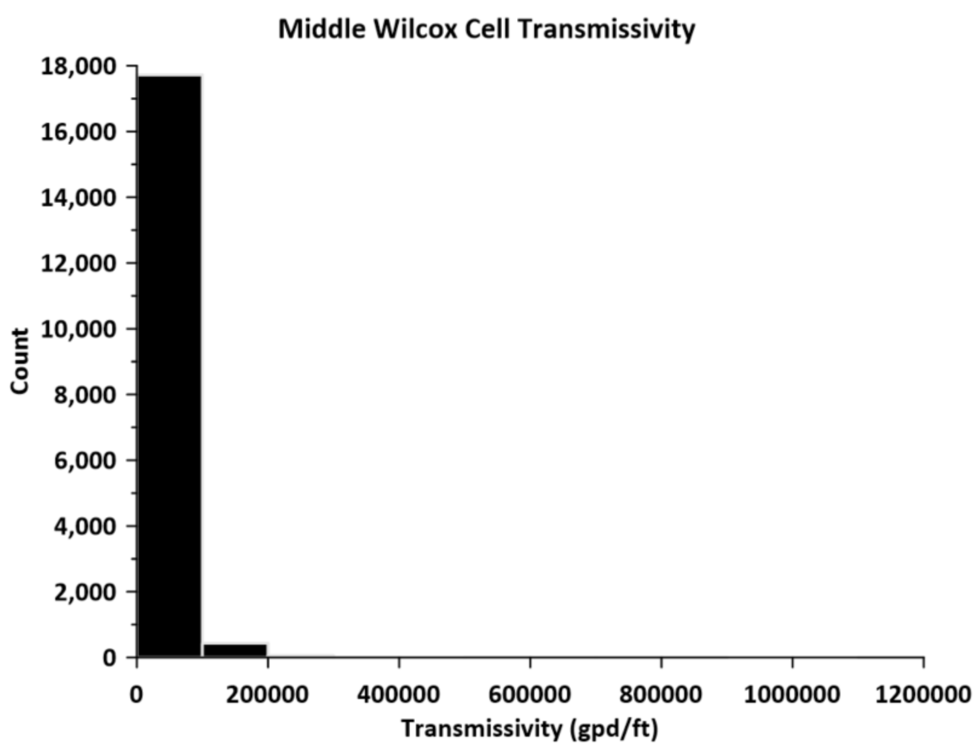

Carrizo-Upper Wilcox Transmissivity
Count
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
2000000
4000000
6000000
8000000
10000000
Transmissivity (gpd/ft)

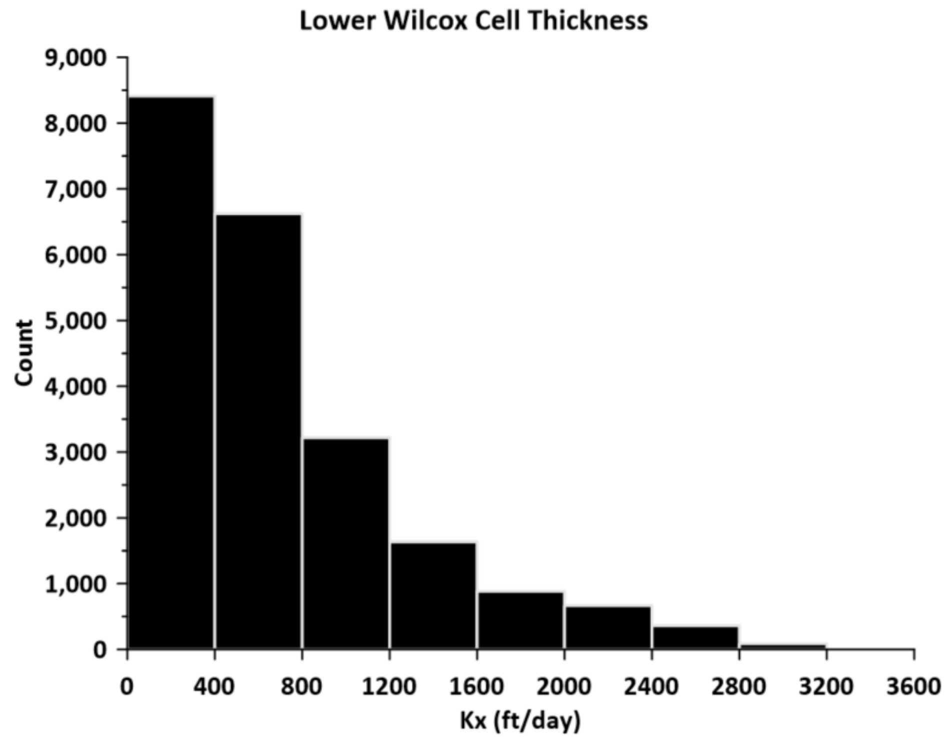

Middle Wilcox Cell Thickness
Count
6,000
5,000
4,000
3,000
2,000
1,000
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Cell Thickness

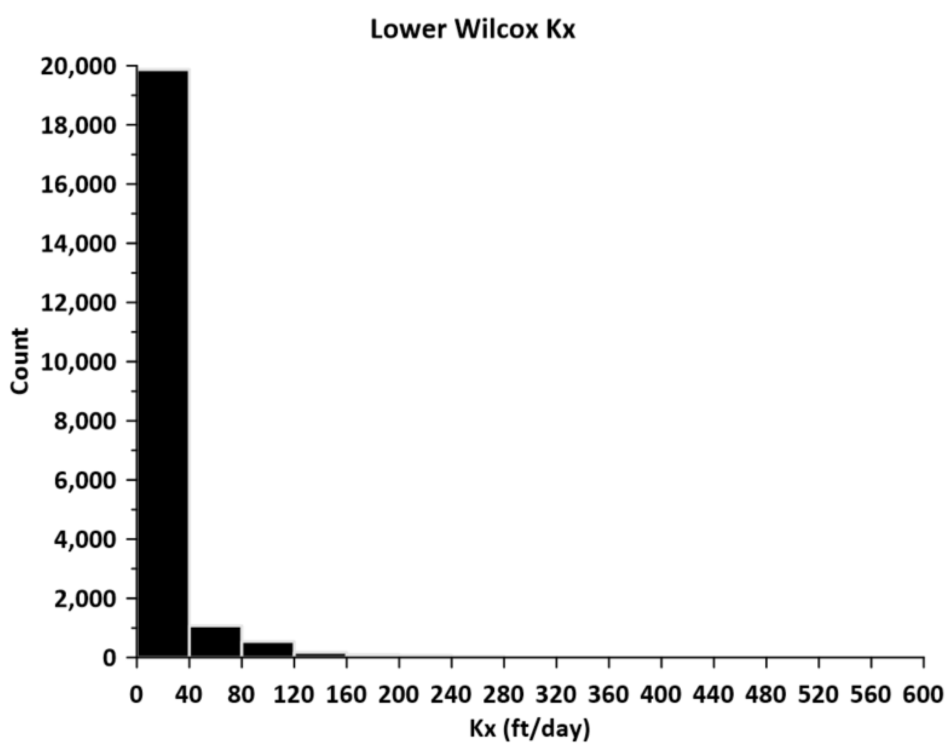

Middle Wilcox Cell Kx
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Kx (ft/day)

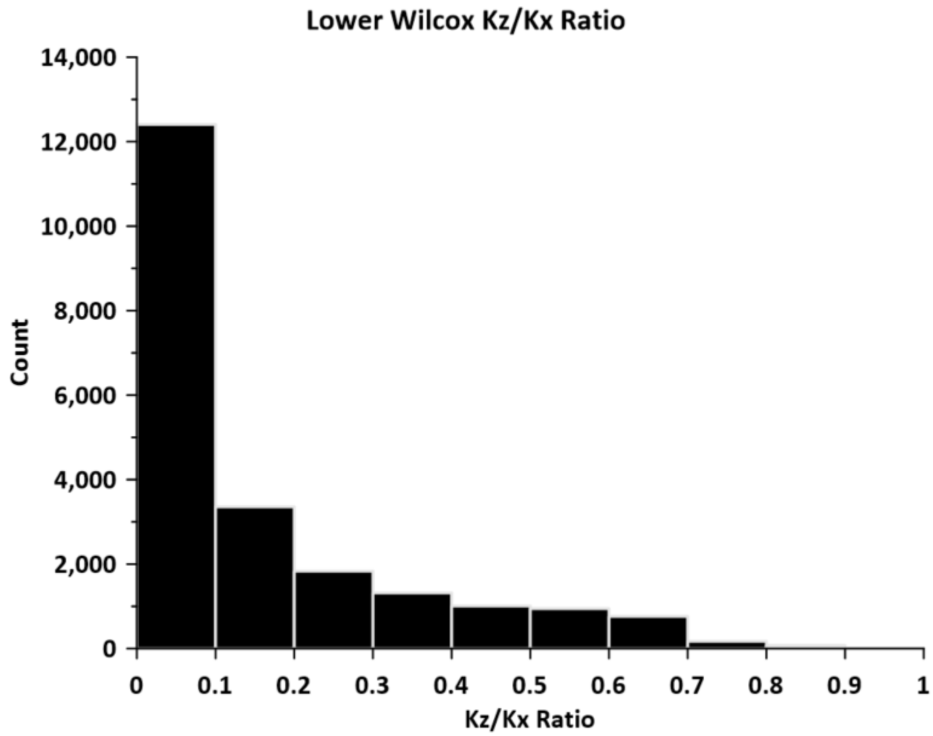

Middle Wilcox Cell Kz/Kx Ratio
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
Kz/Kx Ratio

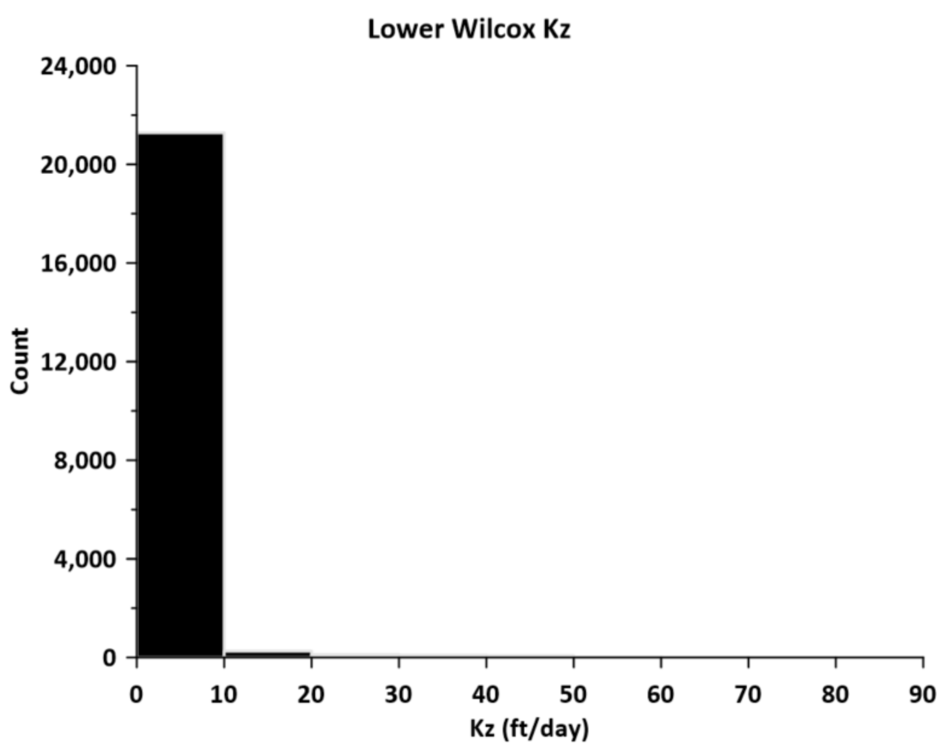

Middle Wilcox Cell Kz
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Kz (ft/day)

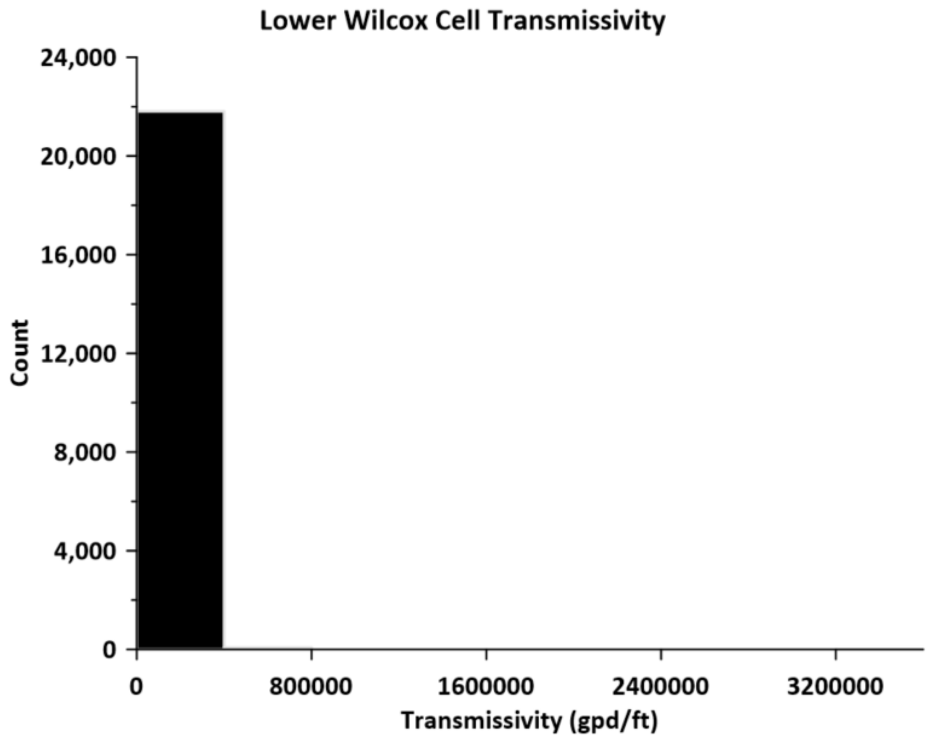

Middle Wilcox Cell Transmissivity
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
200000
400000
600000
800000
1000000
1200000
Transmissivity (gpd/ft)


Lower Wilcox Cell Thickness
Count
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
Kx (ft/day)


Lower Wilcox Kx
Count
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
Kx (ft/day)


Lower Wilcox Kz/Kx Ratio
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Count
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Kz/Kx Ratio

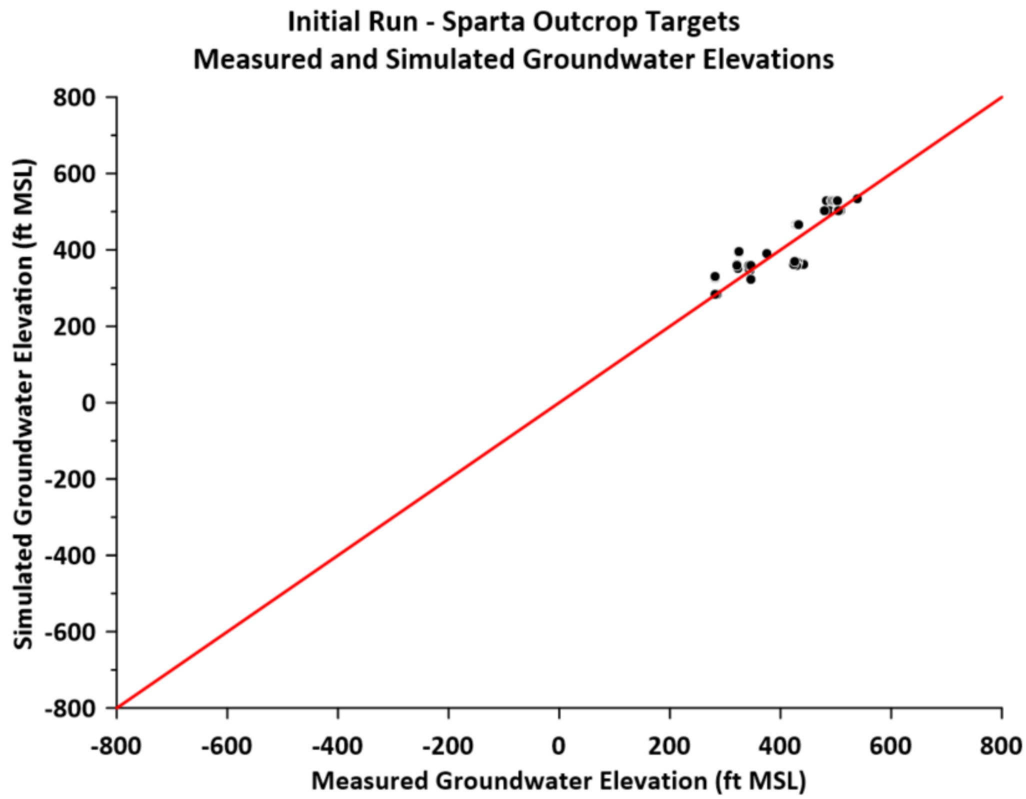

Lower Wilcox Kz
24,000
20,000
16,000
12,000
8,000
4,000
0
Count
0
10
20
30
40
50
60
70
80
90
Kz (ft/day)

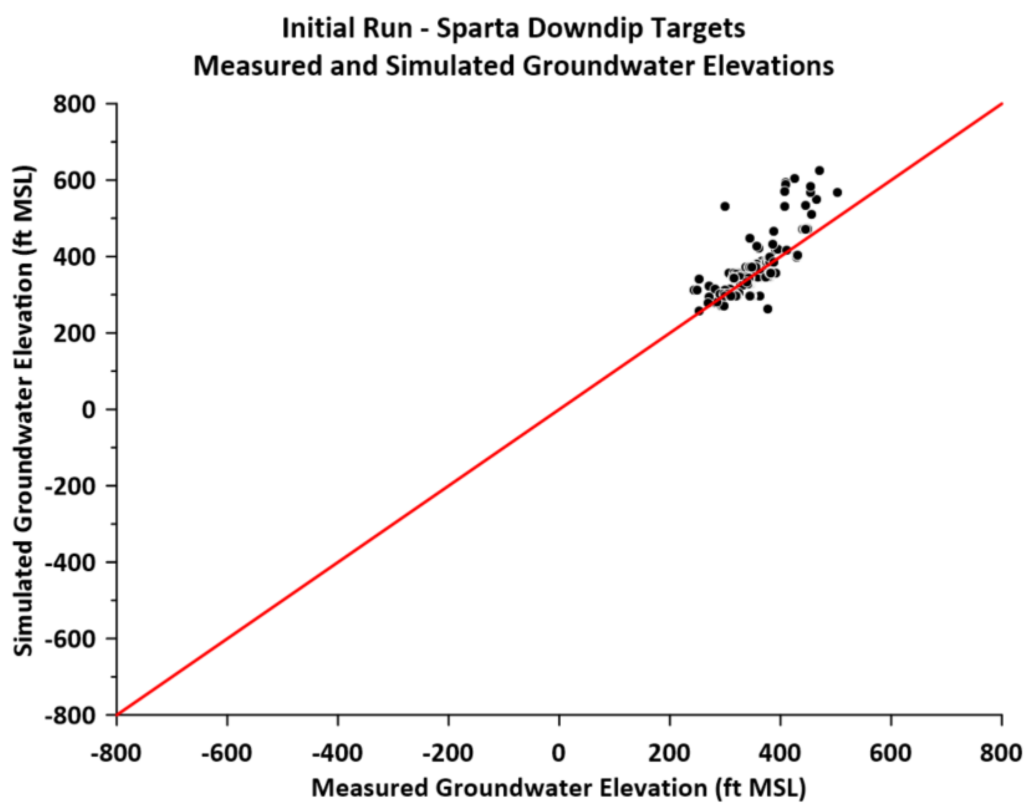

Lower Wilcox Cell Transmissivity
24,000
20,000
16,000
12,000
8,000
4,000
0
Count
0
800000
1600000
2400000
3200000
Transmissivity (gpd/ft)

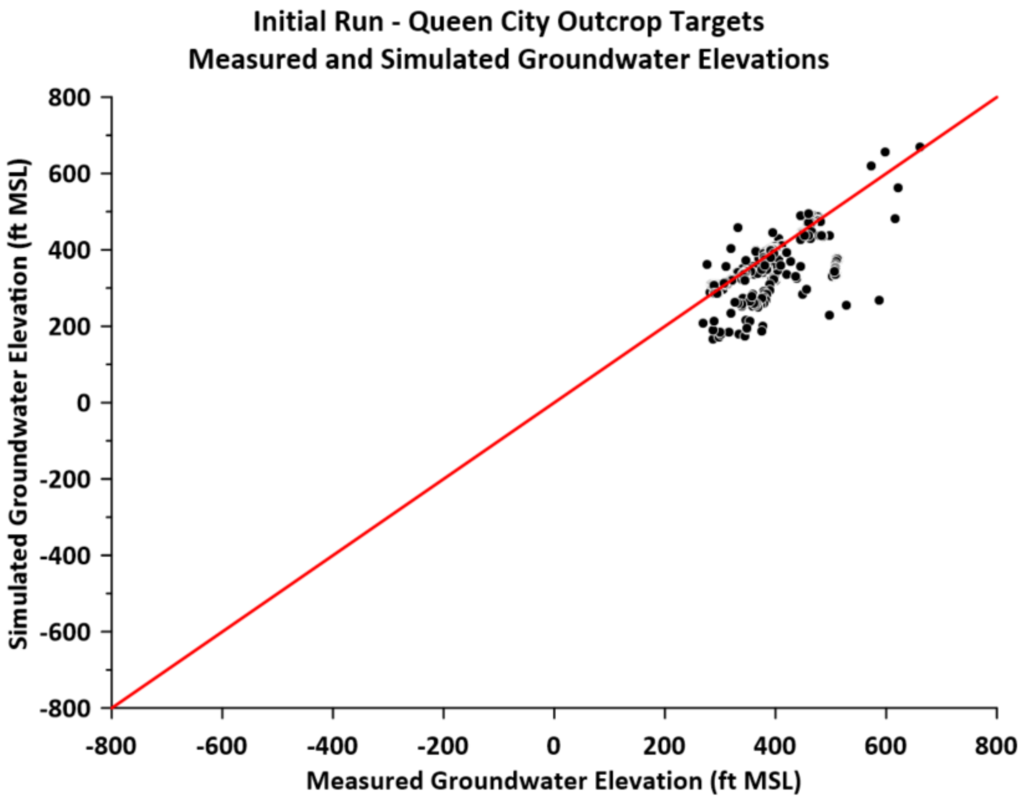
Appendix B

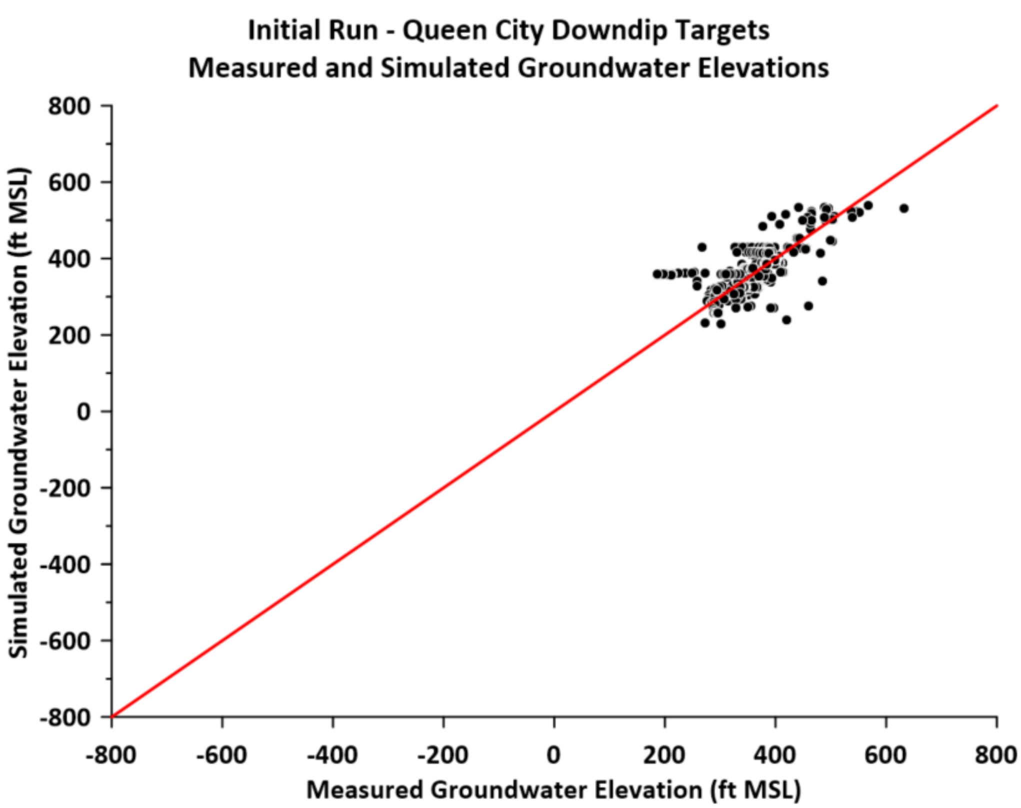
Actual vs. Simulated Groundwater Elevations

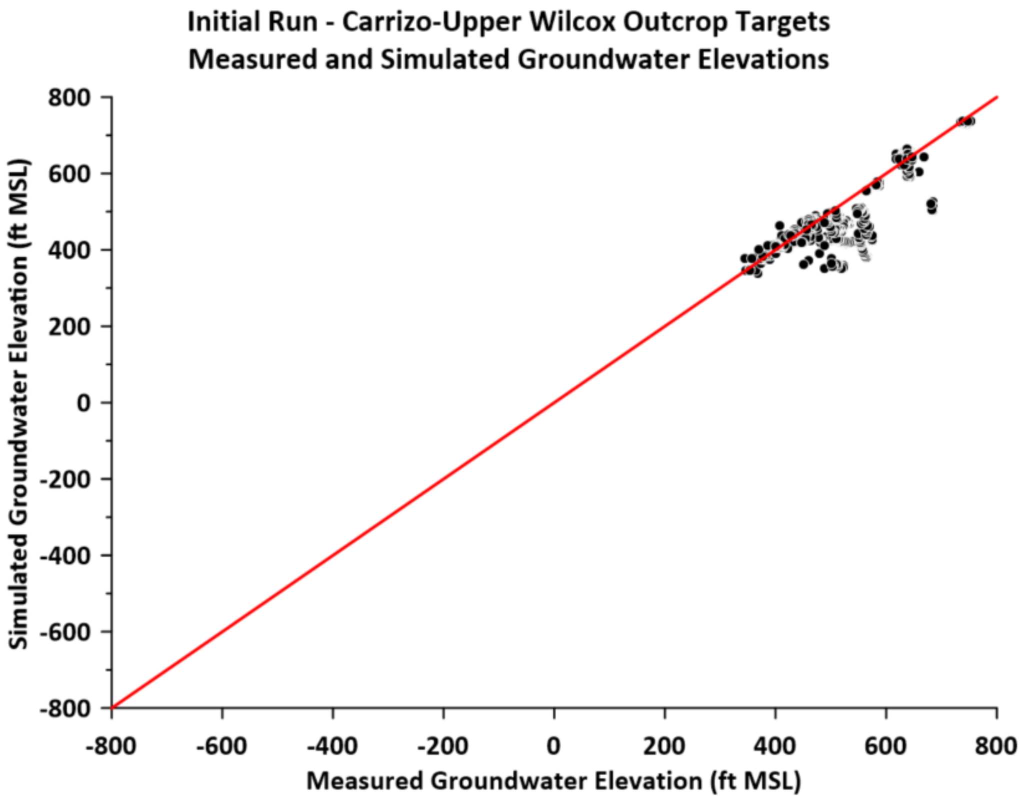
Initial Run of GMA 13 Model

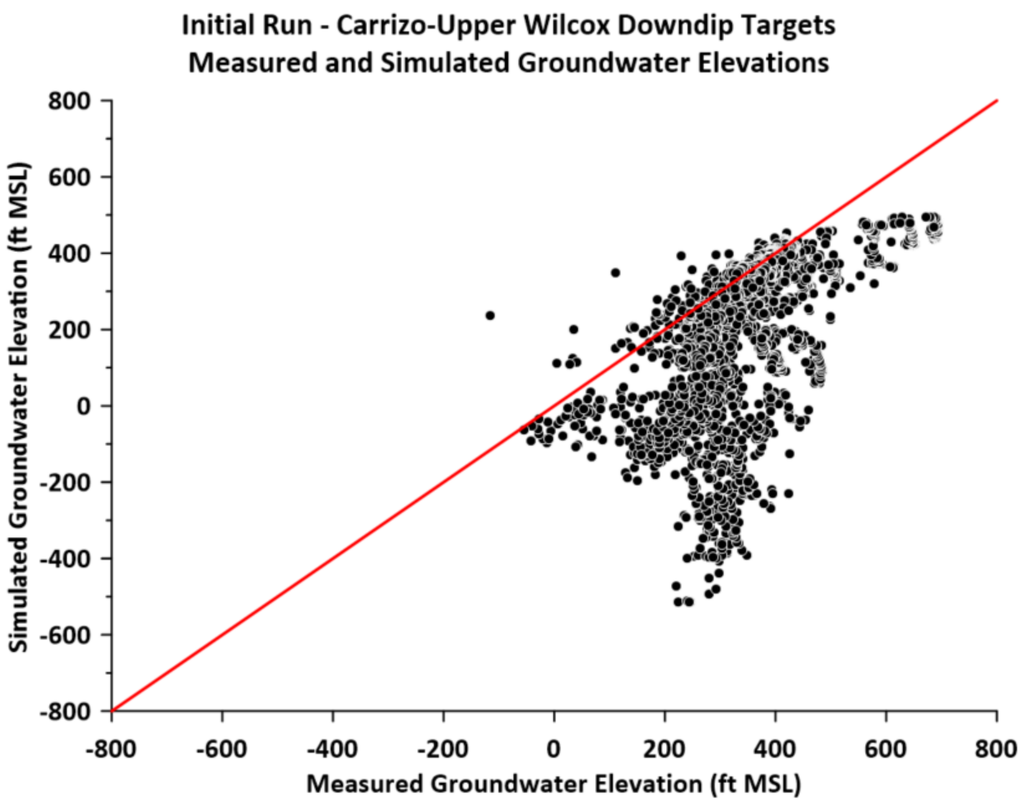

Initial Run - Sparta Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

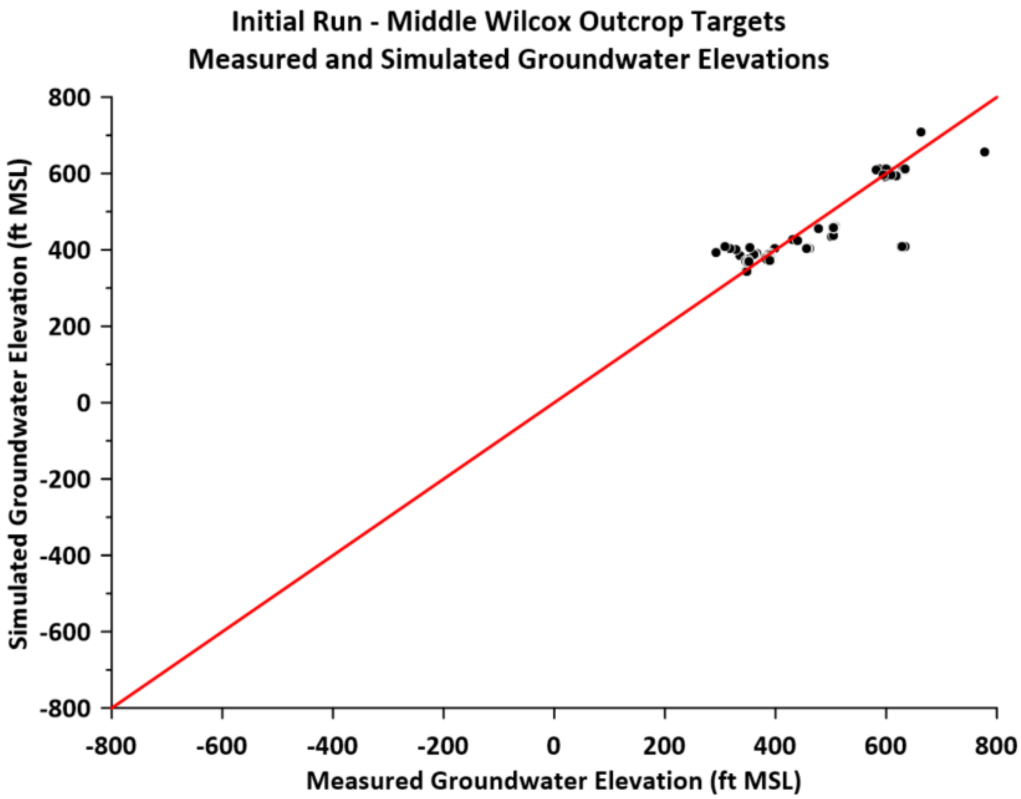

Initial Run - Sparta Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

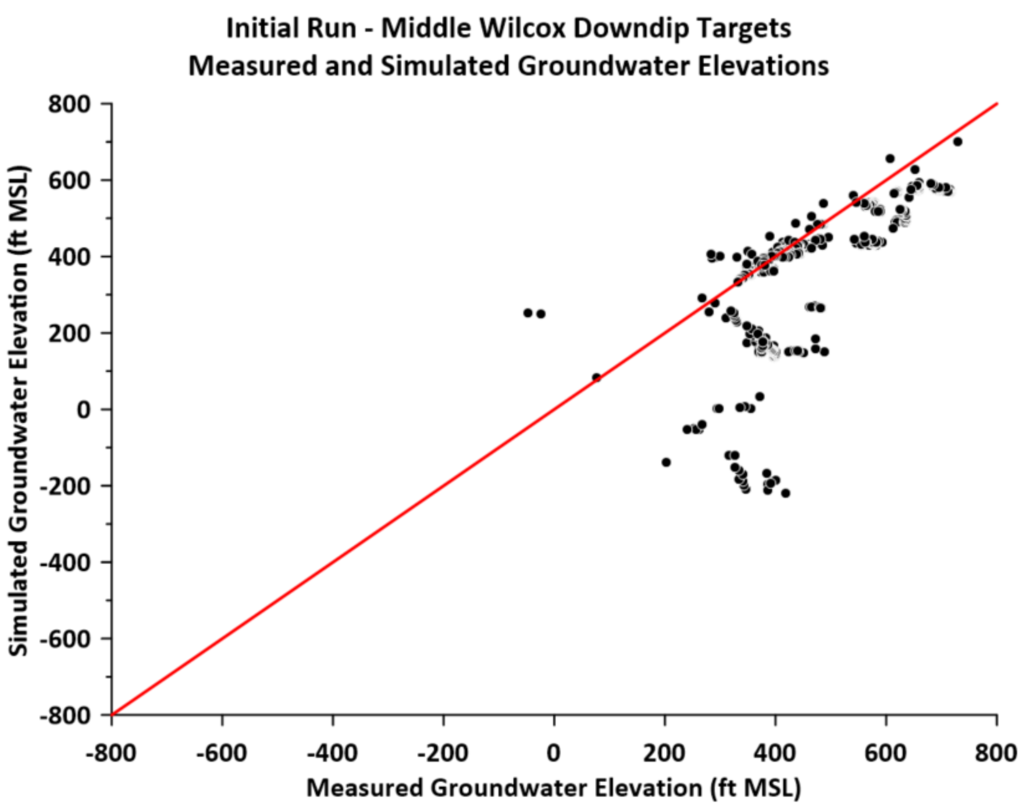

Initial Run - Queen City Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

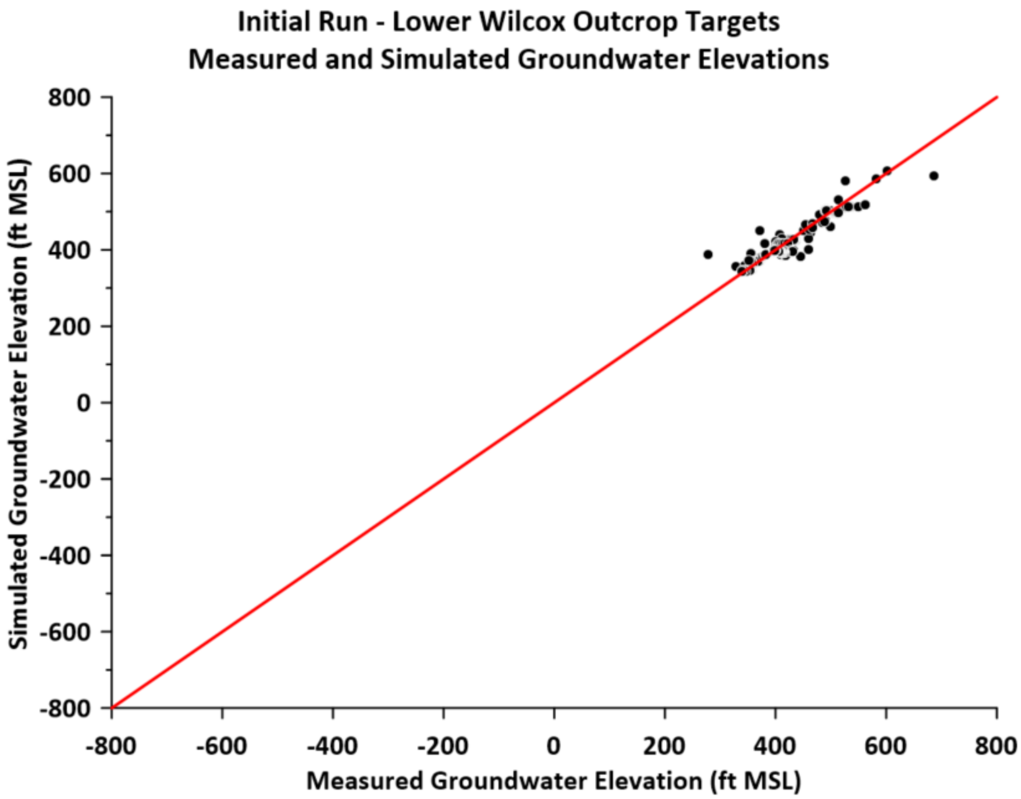

Initial Run - Queen City Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

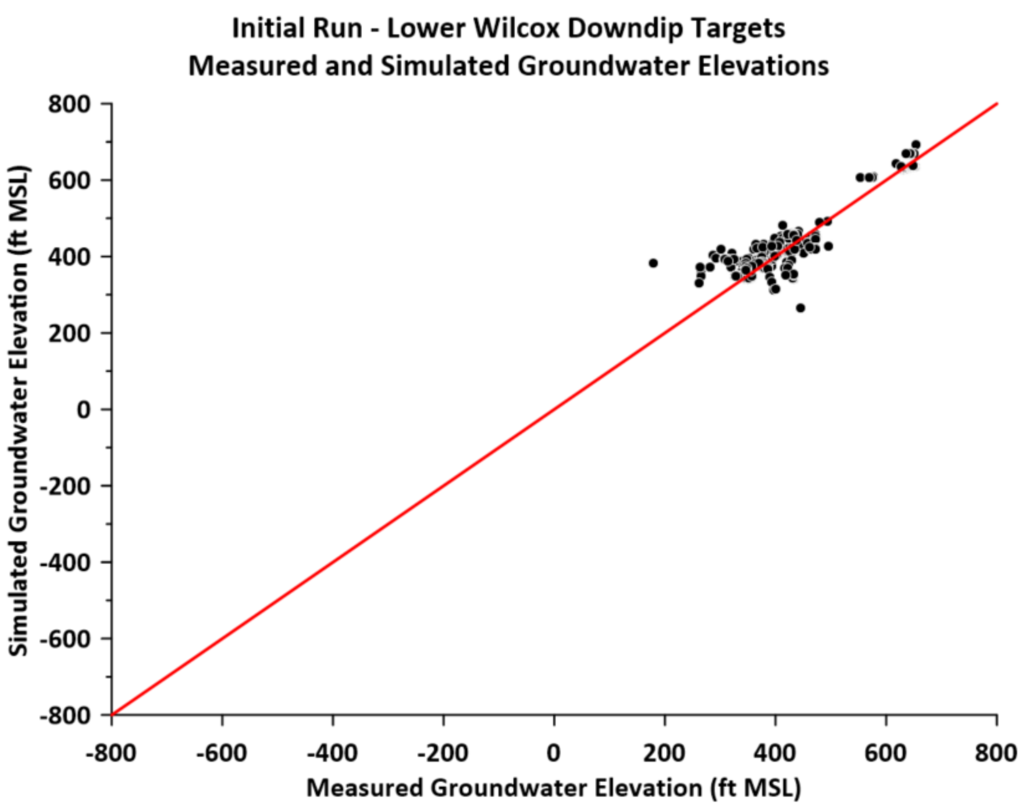

Initial Run - Carrizo-Upper Wilcox Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800


Initial Run - Carrizo-Upper Wilcox Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800


Initial Run - Middle Wilcox Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800
Measured Groundwater Elevation (ft MSL)


Initial Run - Middle Wilcox Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800
-800
-600
-400
-200
0
200
400
600
800
Measured Groundwater Elevation (ft MSL)


Initial Run - Lower Wilcox Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

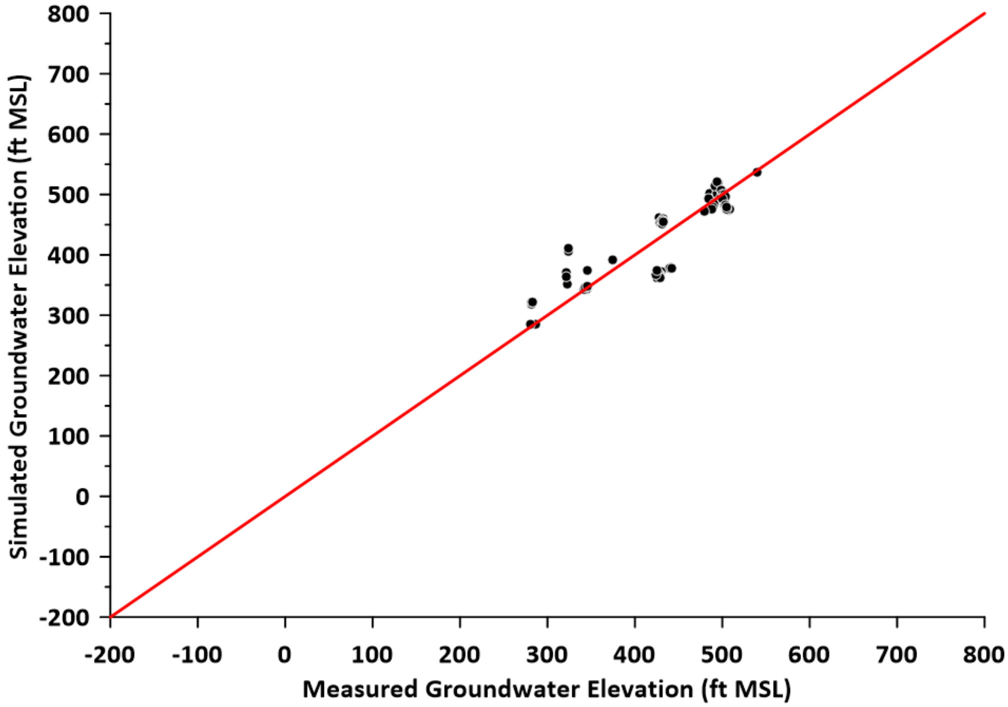

Initial Run - Lower Wilcox Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
600
400
200
0
-200
-400
-600
-800

Appendix C

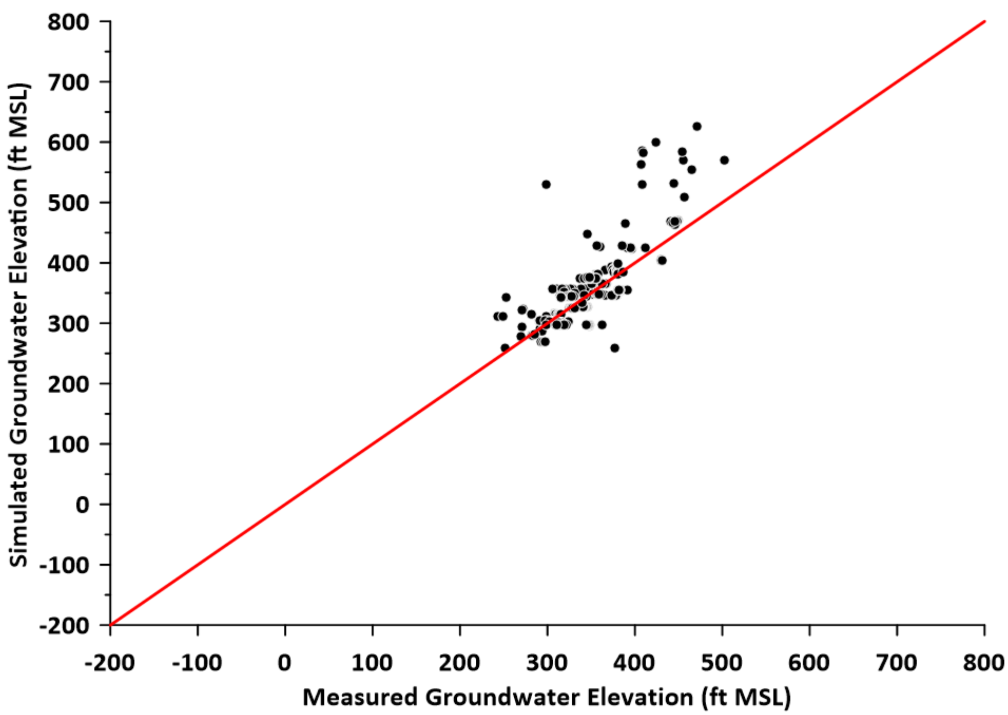
Actual vs. Simulated Groundwater Elevations

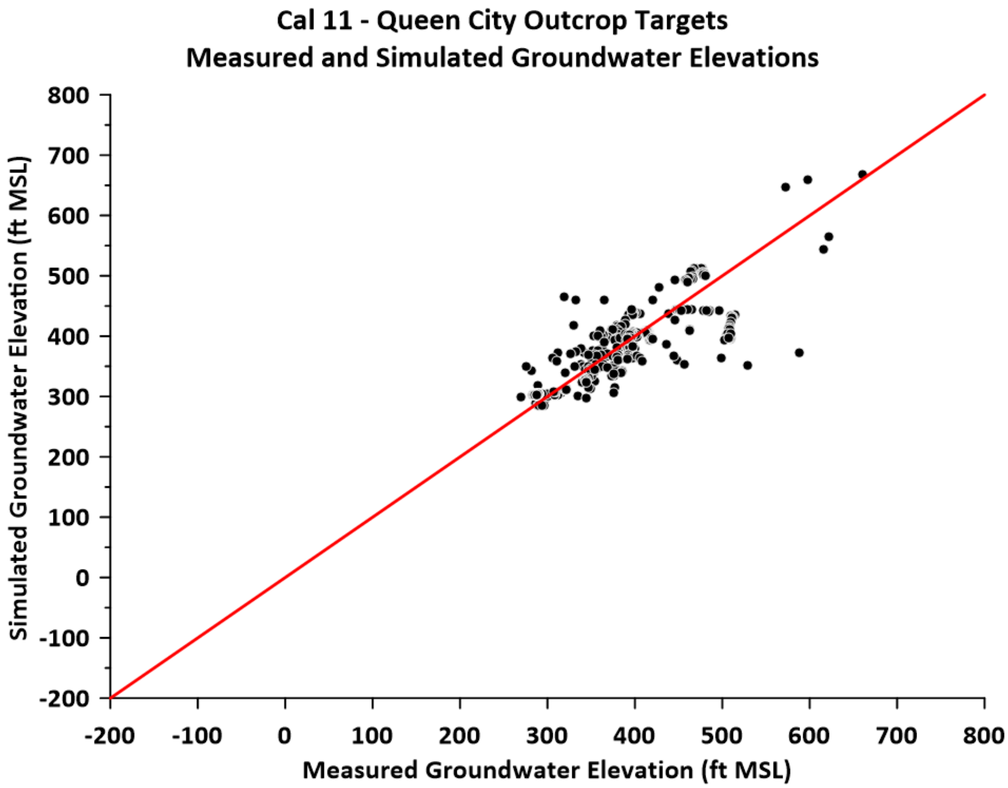
Calibrated GMA 13 Model (2025 Version)

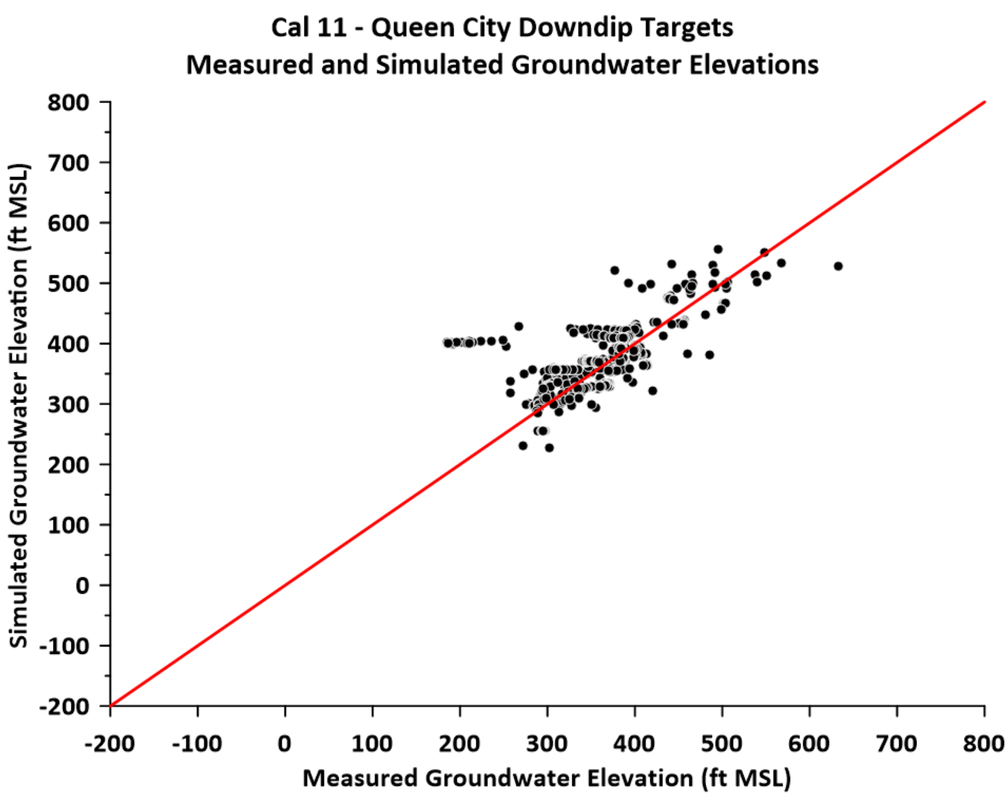
Cal 11 - Sparta Outcrop Targets
Measured and Simulated Groundwater Elevations

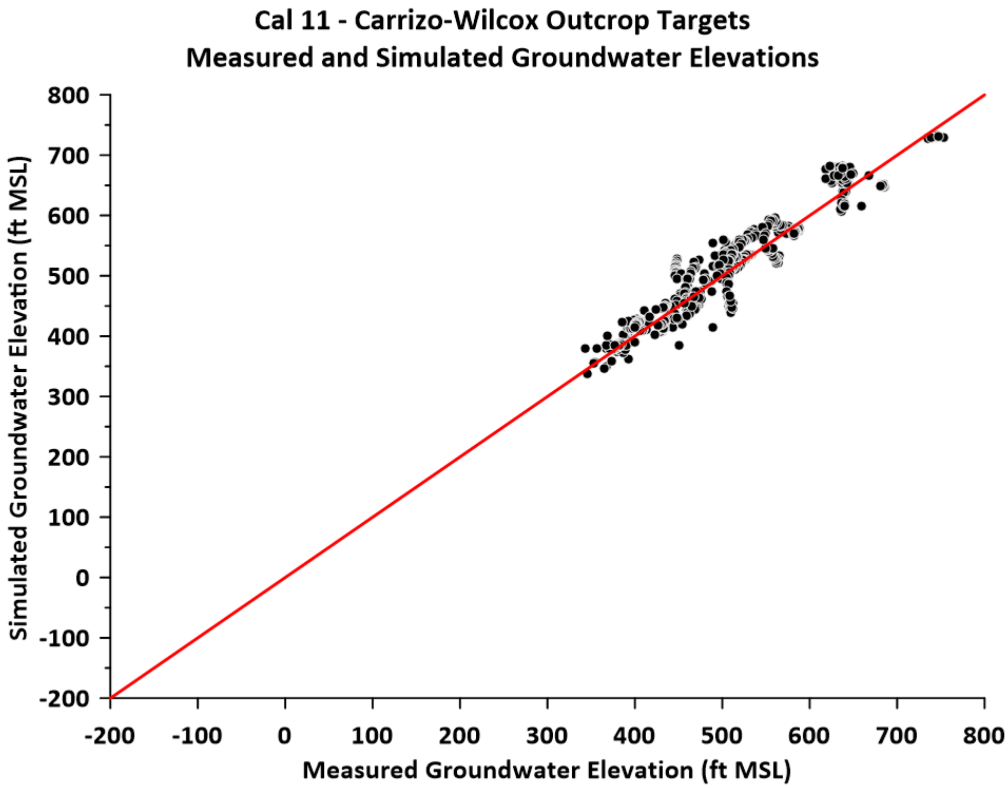


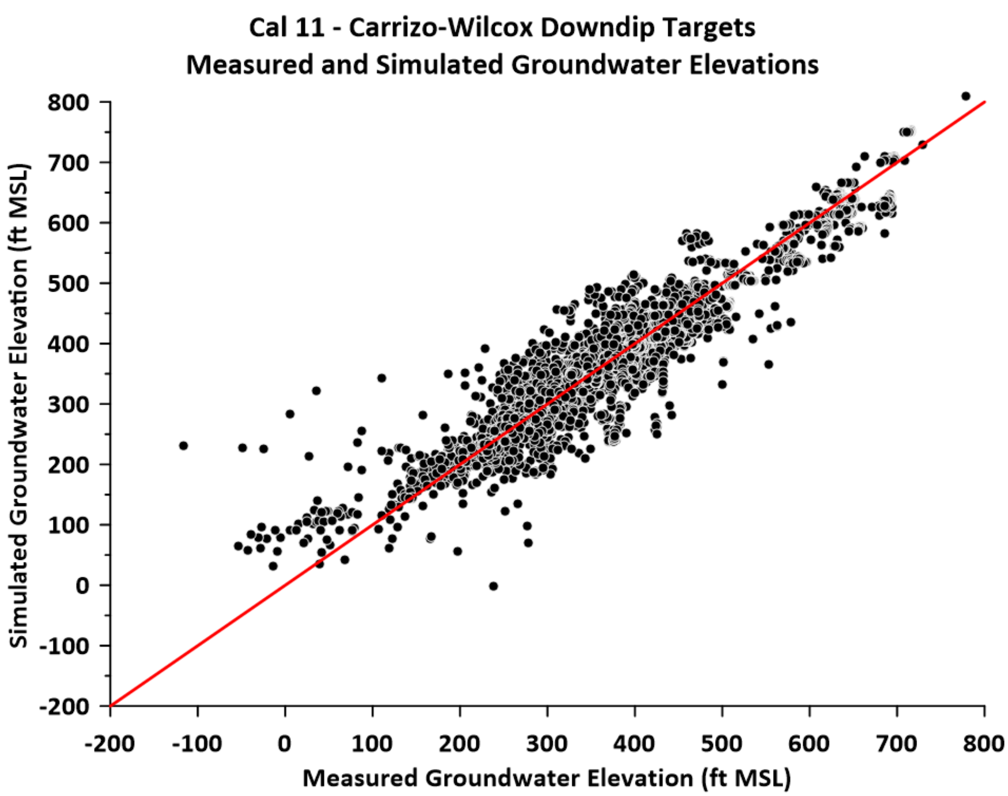
Cal 11 - Sparta Downdip Targets
Measured and Simulated Groundwater Elevations




Cal 11 - Queen City Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
700
600
500
400
300
200
100
0
-100
-200
-200
-100
0
100
200
300
400
500
600
700
800


Cal 11 - Queen City Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
700
600
500
400
300
200
100
0
-100
-200
-200
-100
0
100
200
300
400
500
600
700
800

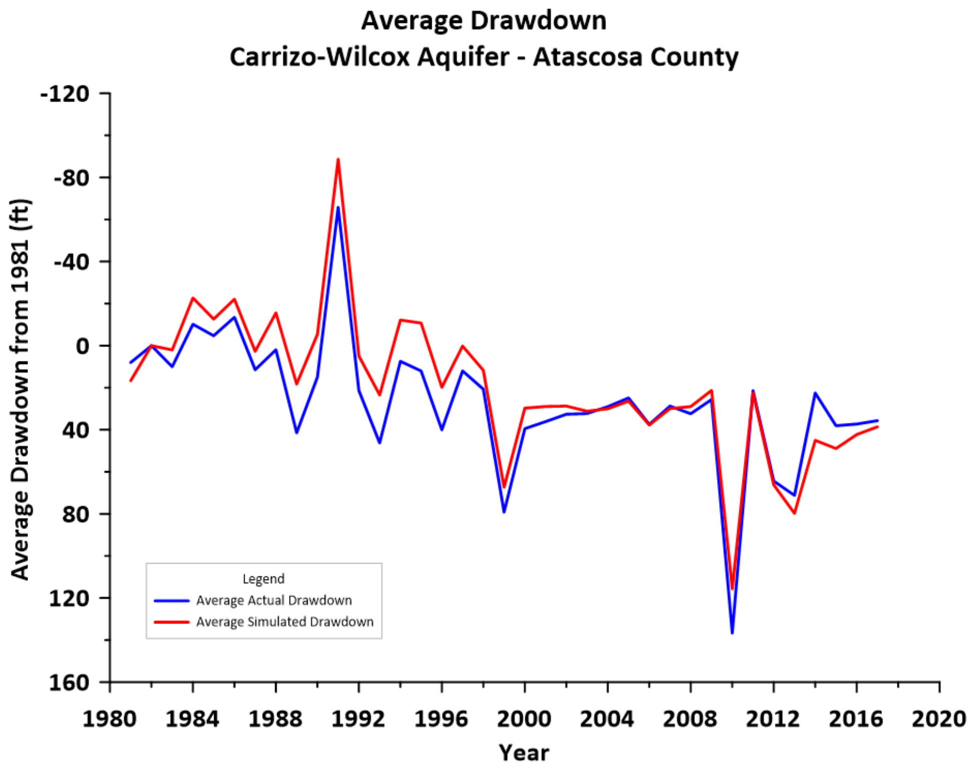

Cal 11 - Carrizo-Wilcox Outcrop Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
700
600
500
400
300
200
100
0
-100
-200
-200
-100
0
100
200
300
400
500
600
700
800

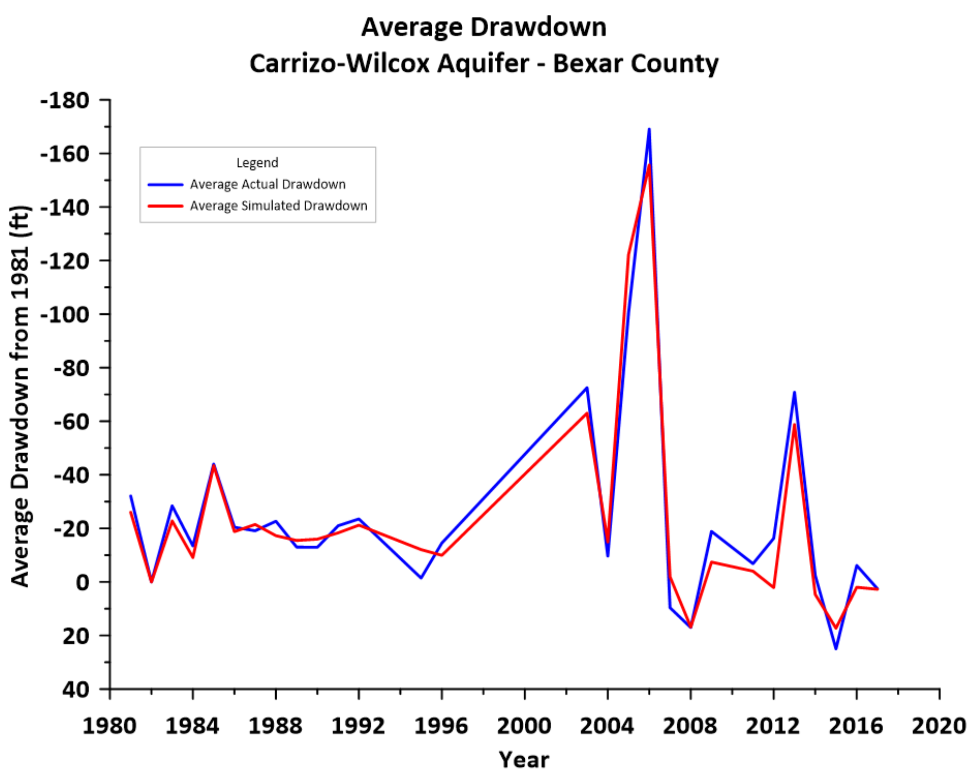

Cal 11 - Carrizo-Wilcox Downdip Targets
Measured and Simulated Groundwater Elevations
Simulated Groundwater Elevation (ft MSL)
Measured Groundwater Elevation (ft MSL)
800
700
600
500
400
300
200
100
0
-100
-200
-200
-100
0
100
200
300
400
500
600
700
800

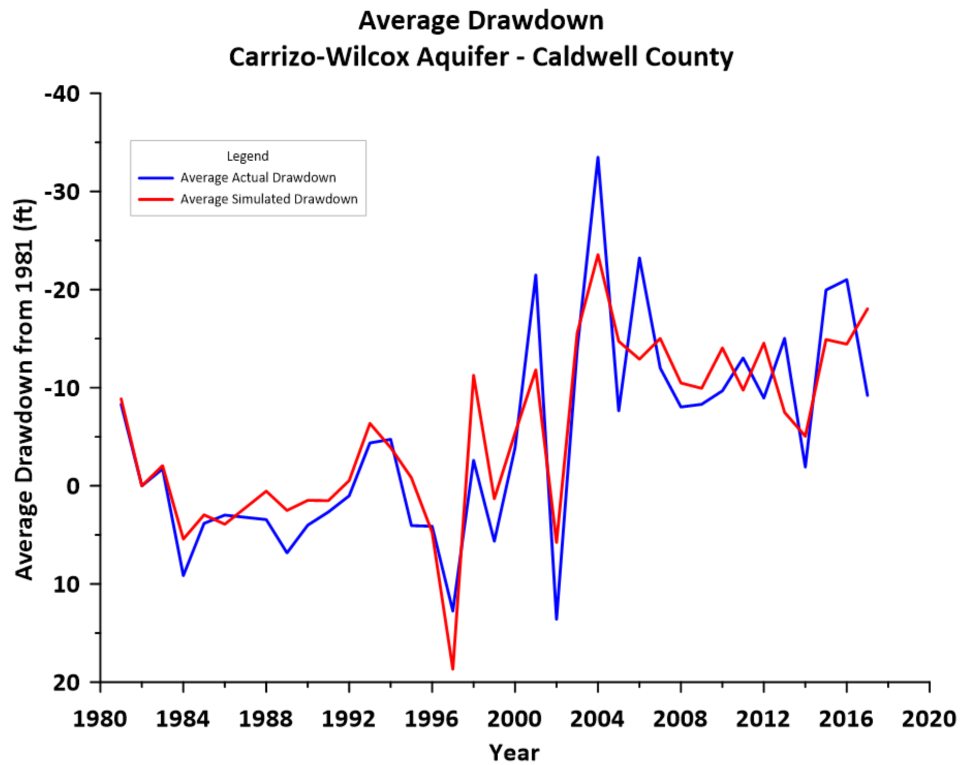
Appendix D

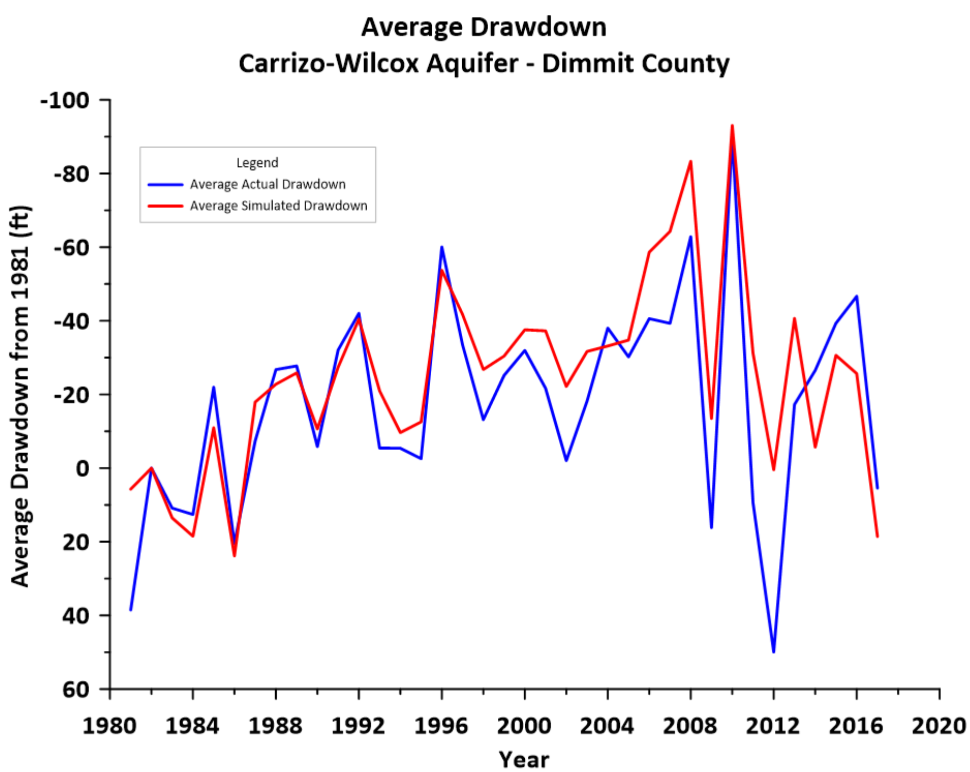
Hydrographs of Average Drawdown by County

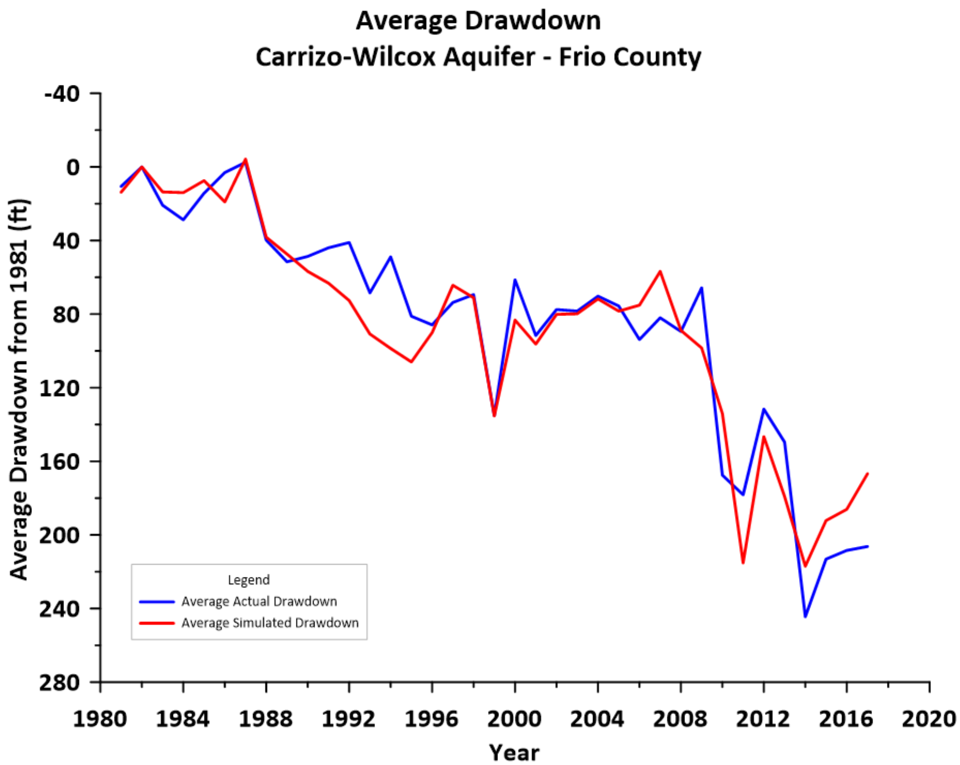
Calibrated GMA 13 Model (2025 Version)

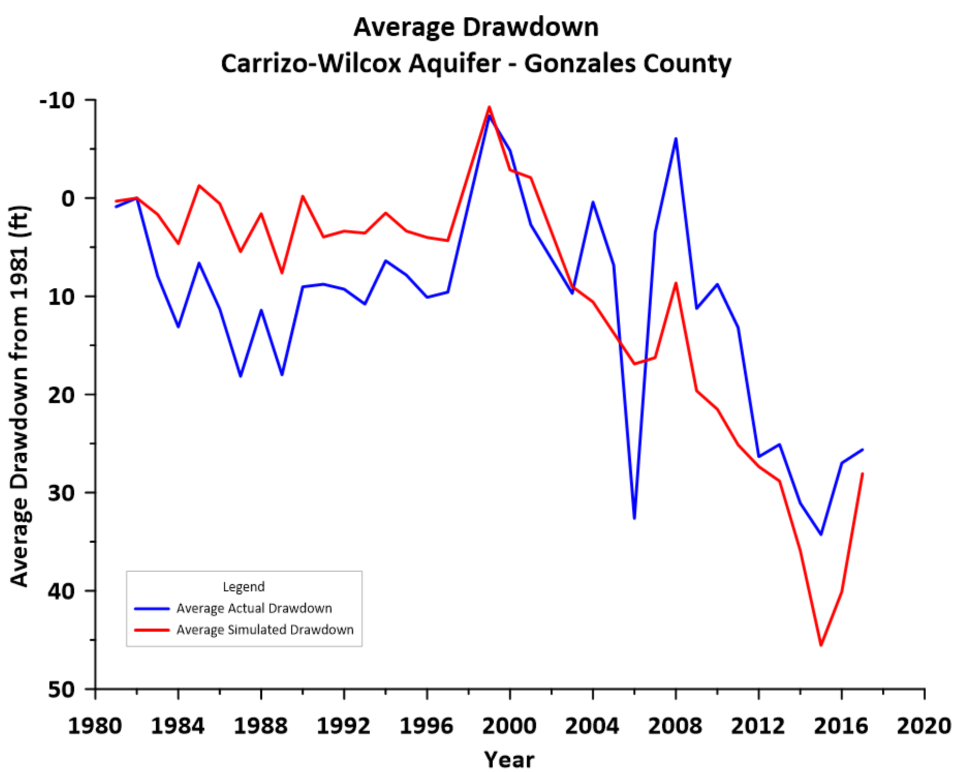

Average Drawdown
Carrizo-Wilcox Aquifer - Atascosa County
Average Drawdown from 1981 (ft)
-120
-80
-40
0
40
80
120
160
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown

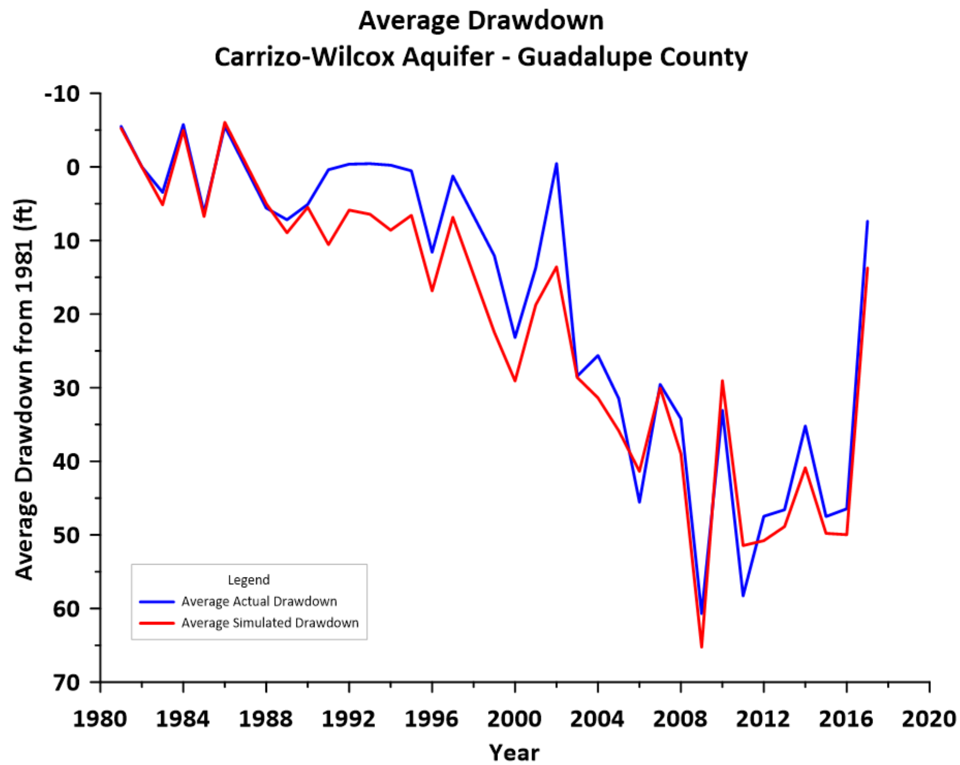

Average Drawdown
Carrizo-Wilcox Aquifer - Bexar County
Average Drawdown from 1981 (ft)
-180
-160
-140
-120
-100
-80
-60
-40
-20
0
20
40
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown


Average Drawdown
Carrizo-Wilcox Aquifer - Caldwell County
Legend
Average Actual Drawdown
Average Simulated Drawdown
Average Drawdown from 1981 (ft)
-40
-30
-20
-10
0
10
20
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year

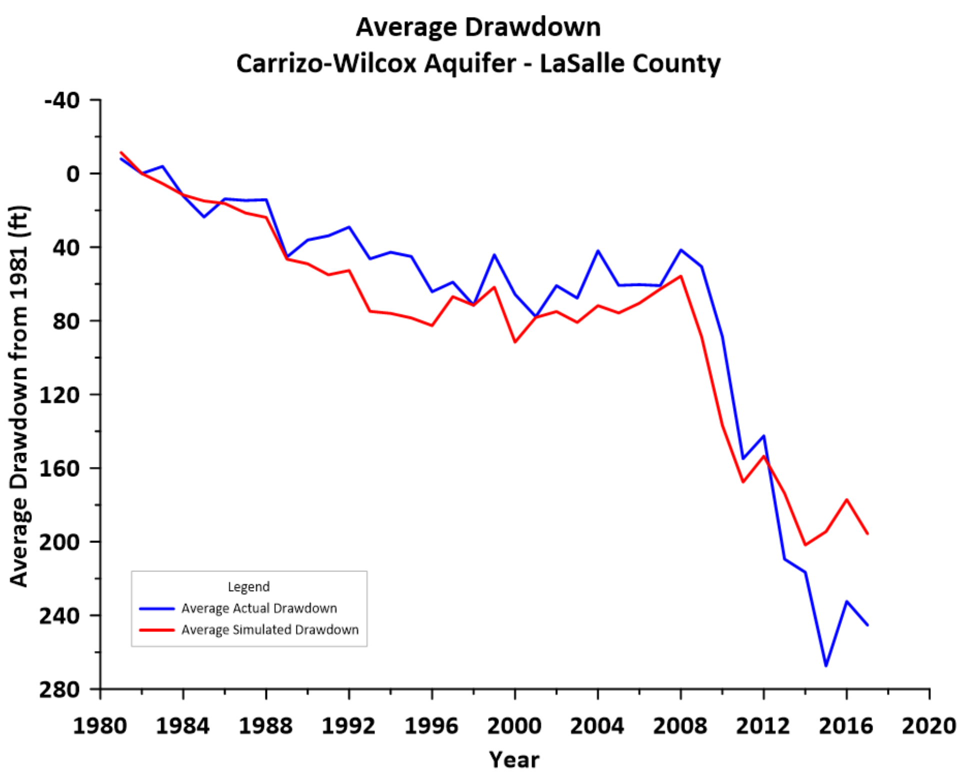

Average Drawdown
Carrizo-Wilcox Aquifer - Dimmit County
Legend
Average Actual Drawdown
Average Simulated Drawdown
Average Drawdown from 1981 (ft)
-100
-80
-60
-40
-20
0
20
40
60
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year


Average Drawdown
Carrizo-Wilcox Aquifer - Frio County
Average Drawdown from 1981 (ft)
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown
-40
0
40
80
120
160
200
240
280
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020

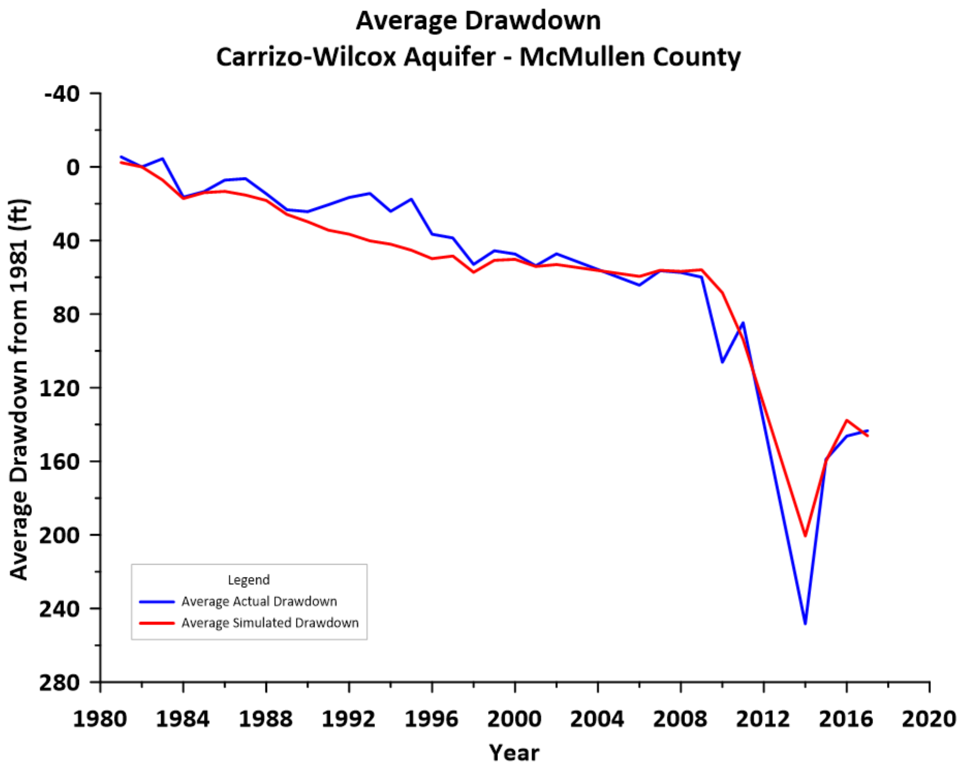

Average Drawdown
Carrizo-Wilcox Aquifer - Gonzales County
Average Drawdown from 1981 (ft)
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown
-10
0
10
20
30
40
50
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020

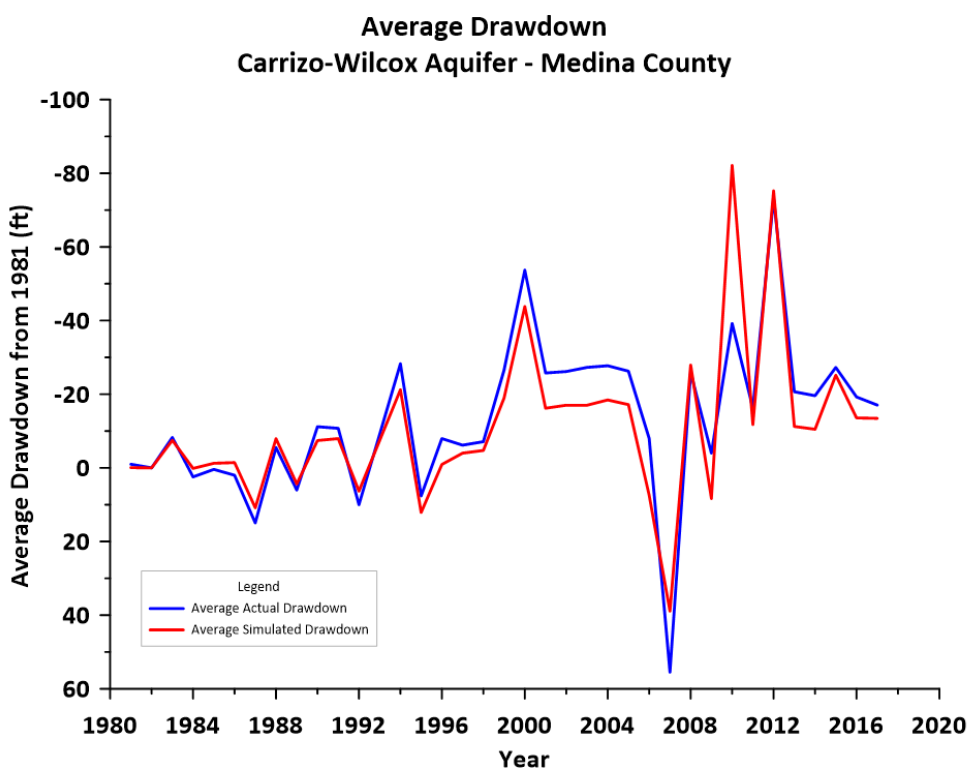


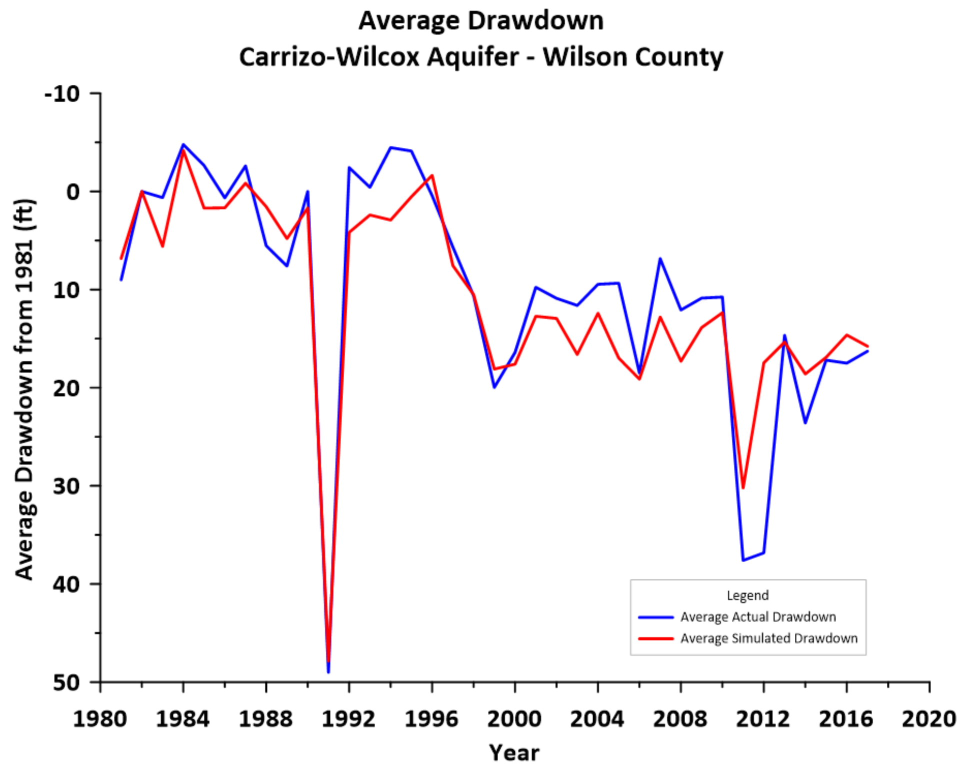
Average Drawdown
Carrizo-Wilcox Aquifer - Guadalupe County
Average Drawdown from 1981 (ft)
-10
0
10
20
30
40
50
60
70
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown

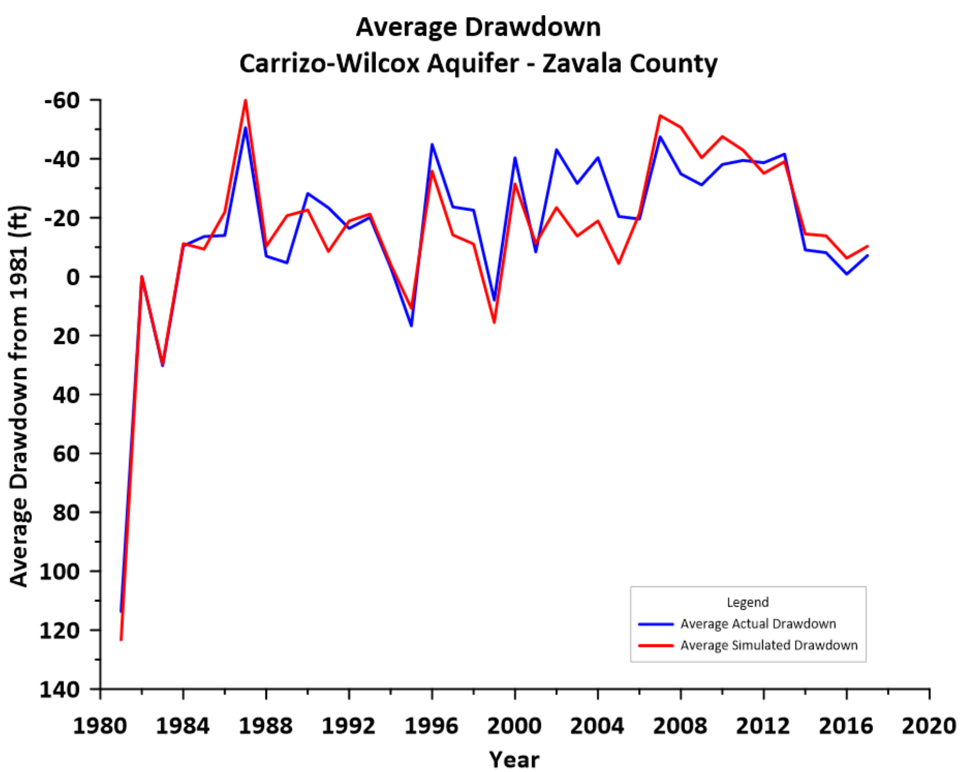


Average Drawdown
Carrizo-Wilcox Aquifer - LaSalle County
Average Drawdown from 1981 (ft)
-40
0
40
80
120
160
200
240
280
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown


Average Drawdown
Carrizo-Wilcox Aquifer - McMullen County
Average Drawdown from 1981 (ft)
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown
-40
0
40
80
120
160
200
240
280
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020


Average Drawdown
Carrizo-Wilcox Aquifer - Medina County
Average Drawdown from 1981 (ft)
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown
-100
-80
-60
-40
-20
0
20
40
60
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020

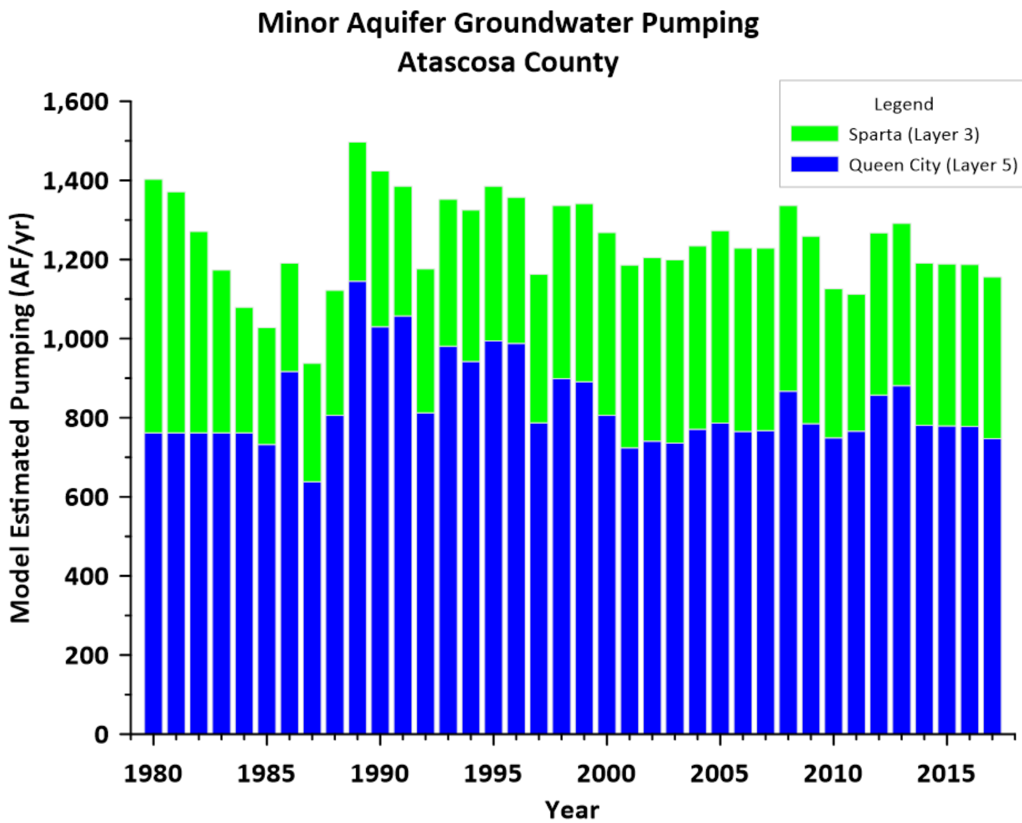

Average Drawdown
Carrizo-Wilcox Aquifer - Wilson County
Average Drawdown from 1981 (ft)
-10
0
10
20
30
40
50
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown


Average Drawdown
Carrizo-Wilcox Aquifer - Zavala County
Average Drawdown from 1981 (ft)
-60
-40
-20
0
20
40
60
80
100
120
140
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
2020
Year
Legend
Average Actual Drawdown
Average Simulated Drawdown

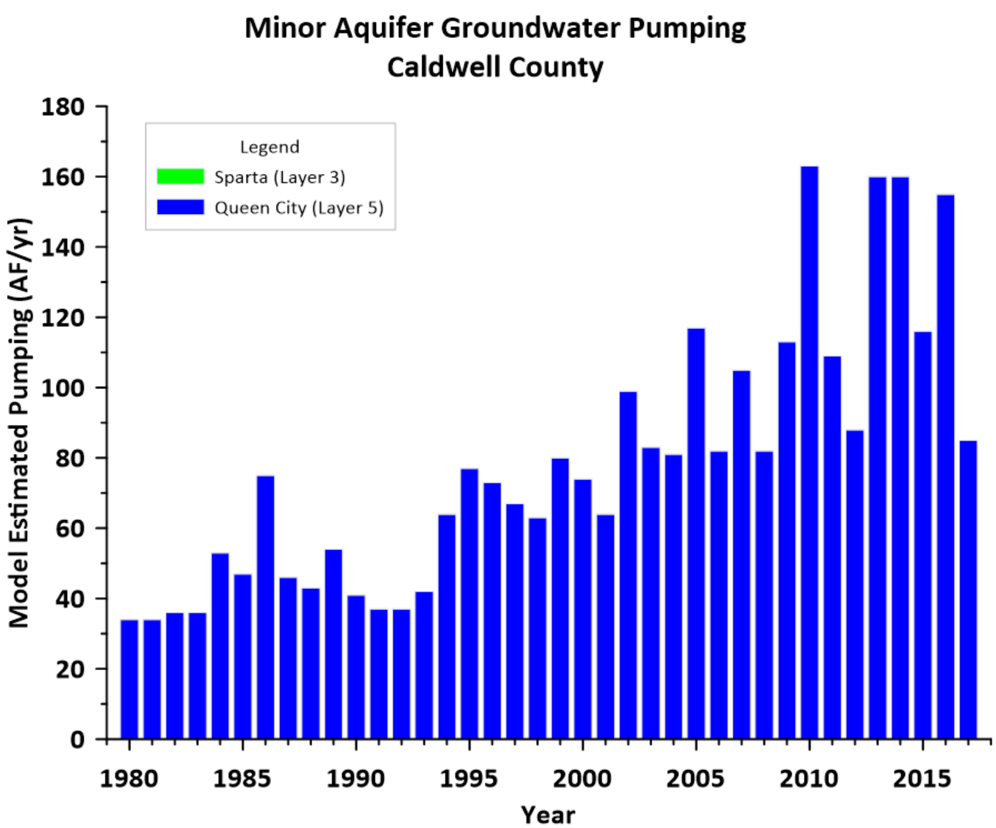
Appendix E

Minor Aquifer Pumping by County

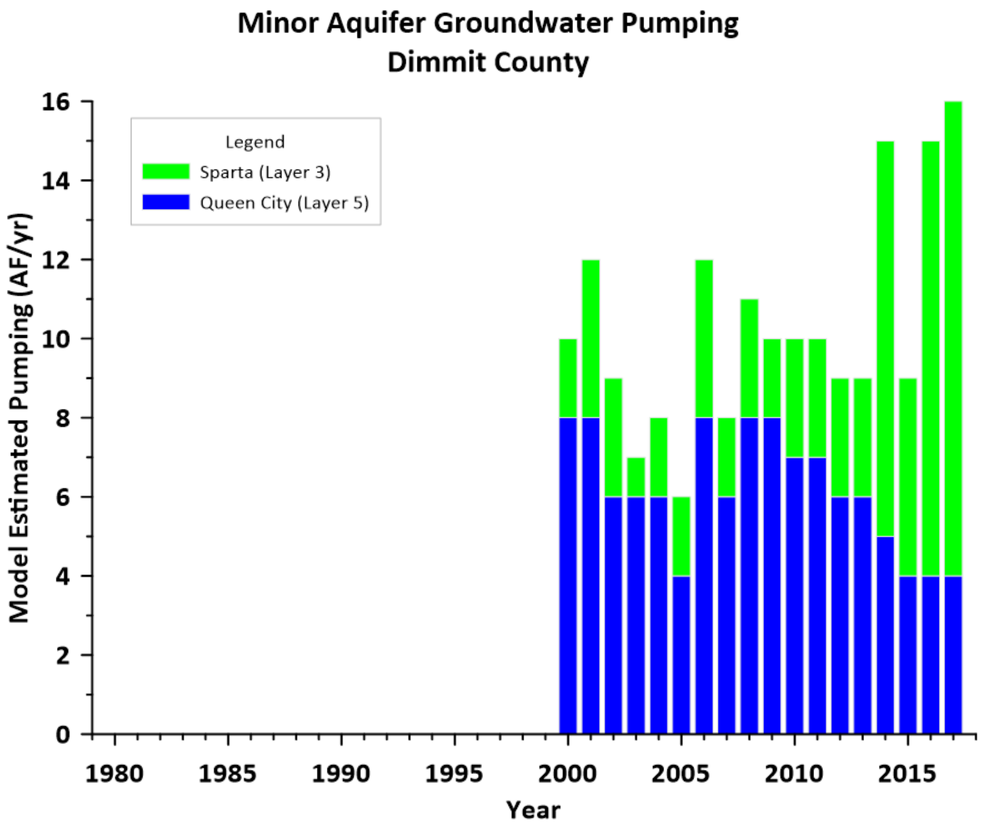
Calibrated GMA 13 Model (2025 Version)

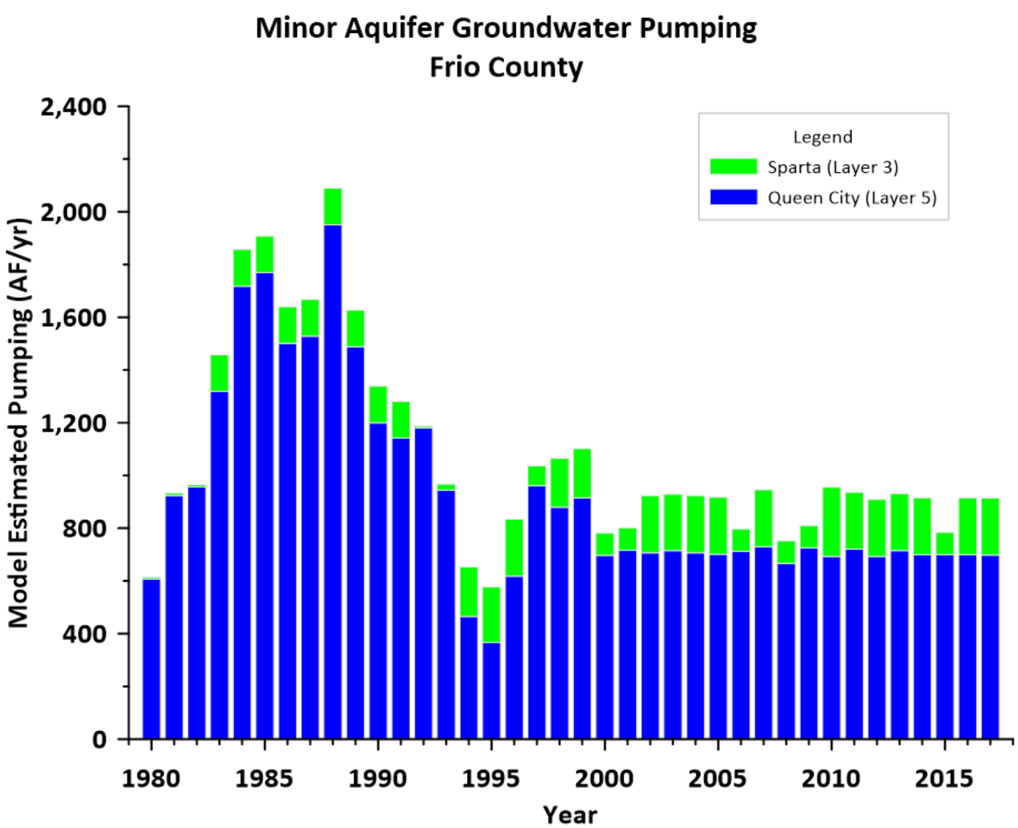


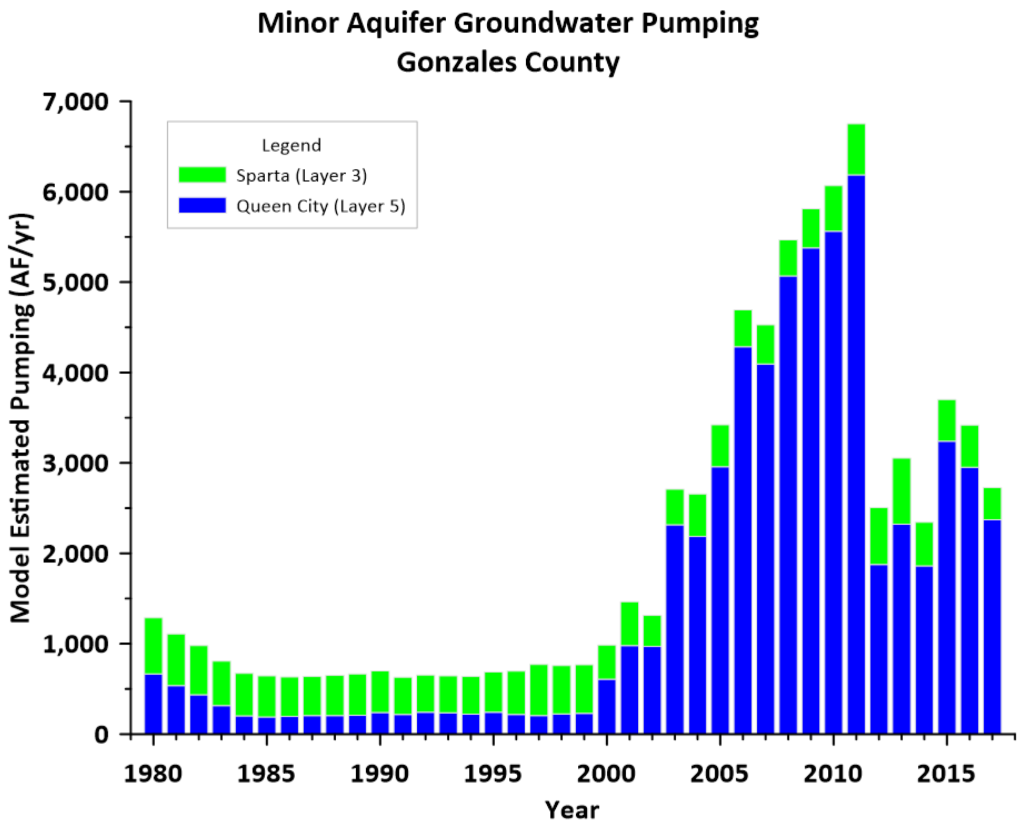
Minor Aquifer Groundwater Pumping
Atascosa County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
1,600
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

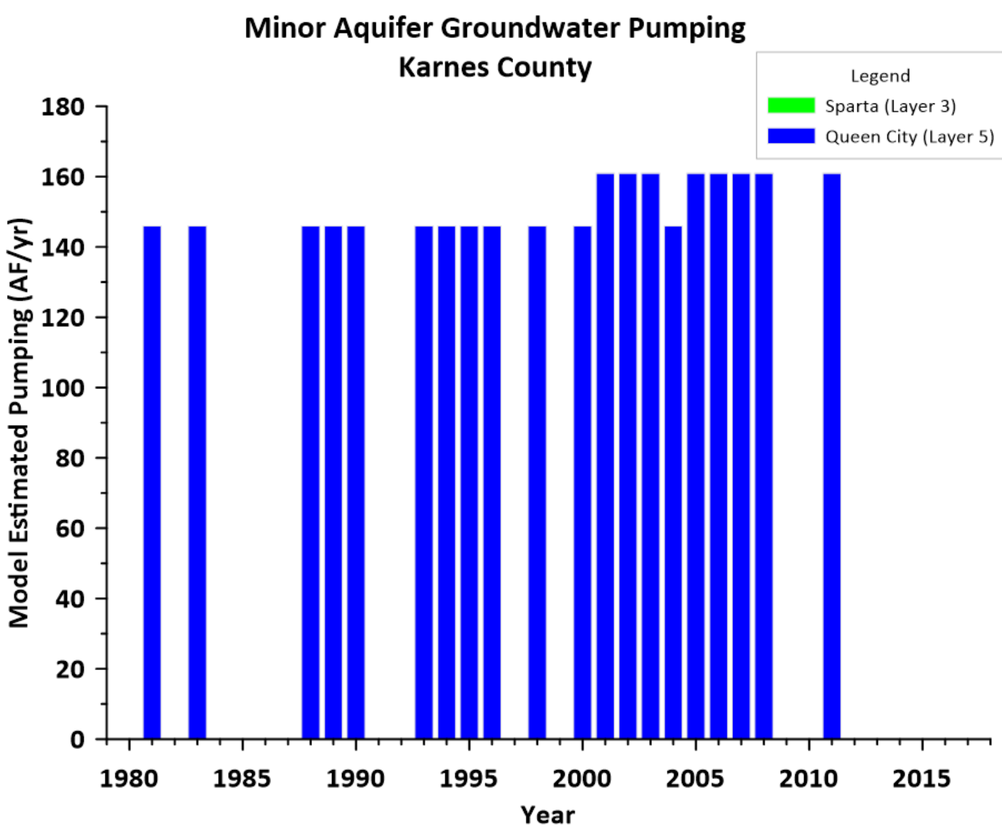


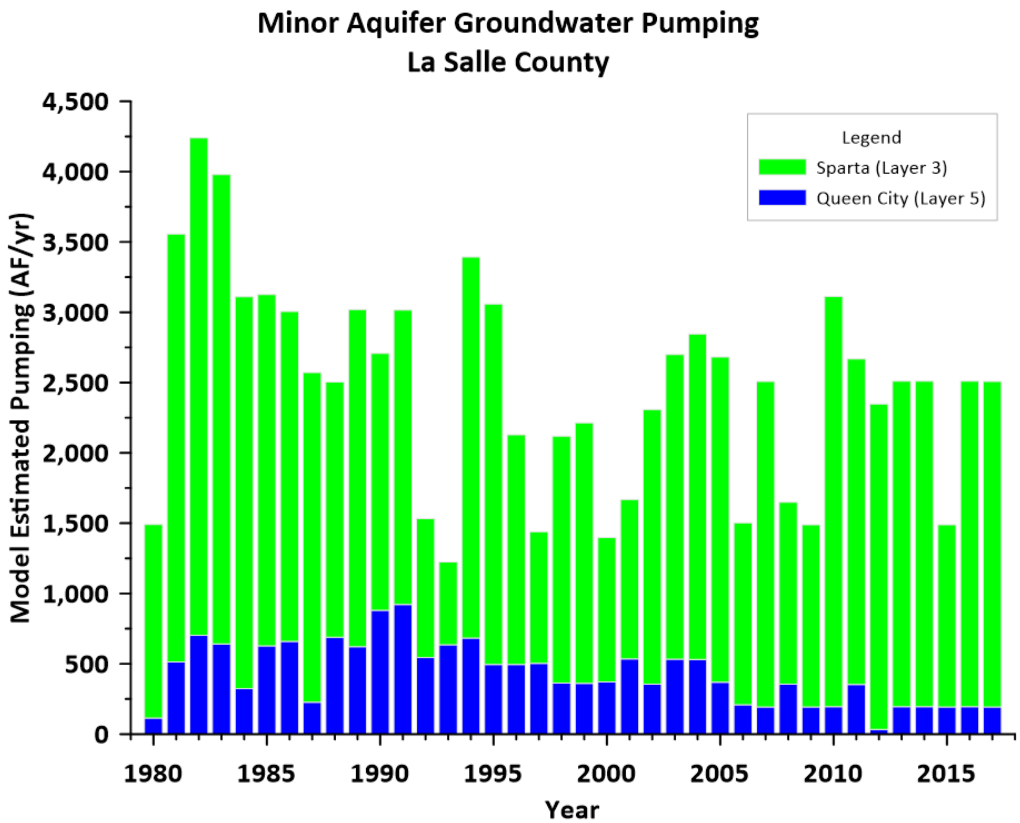
Minor Aquifer Groundwater Pumping
Caldwell County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
180
160
140
120
100
80
60
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

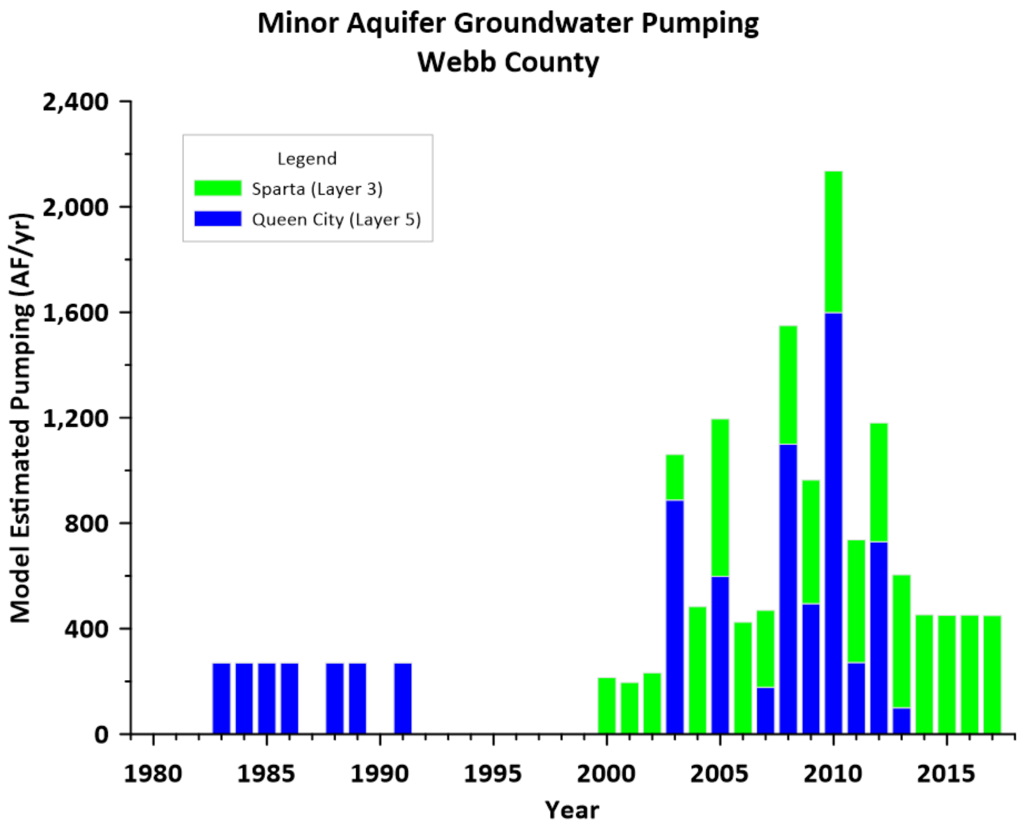

Minor Aquifer Groundwater Pumping
Dimmit County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
Year
0
2
4
6
8
10
12
14
16
1980
1985
1990
1995
2000
2005
2010
2015

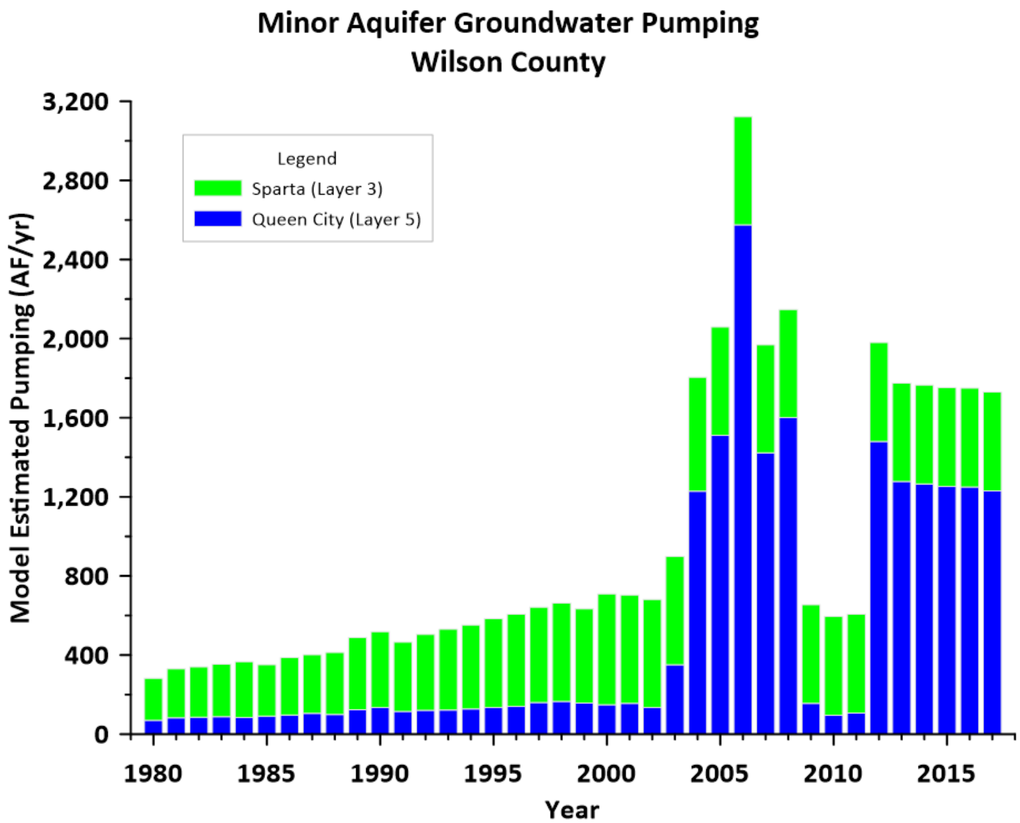

Minor Aquifer Groundwater Pumping
Frio County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
Year
0
400
800
1,200
1,600
2,000
2,400
1980
1985
1990
1995
2000
2005
2010
2015


Minor Aquifer Groundwater Pumping
Gonzales County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Minor Aquifer Groundwater Pumping
Karnes County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
180
160
140
120
100
80
60
40
20
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Minor Aquifer Groundwater Pumping
La Salle County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

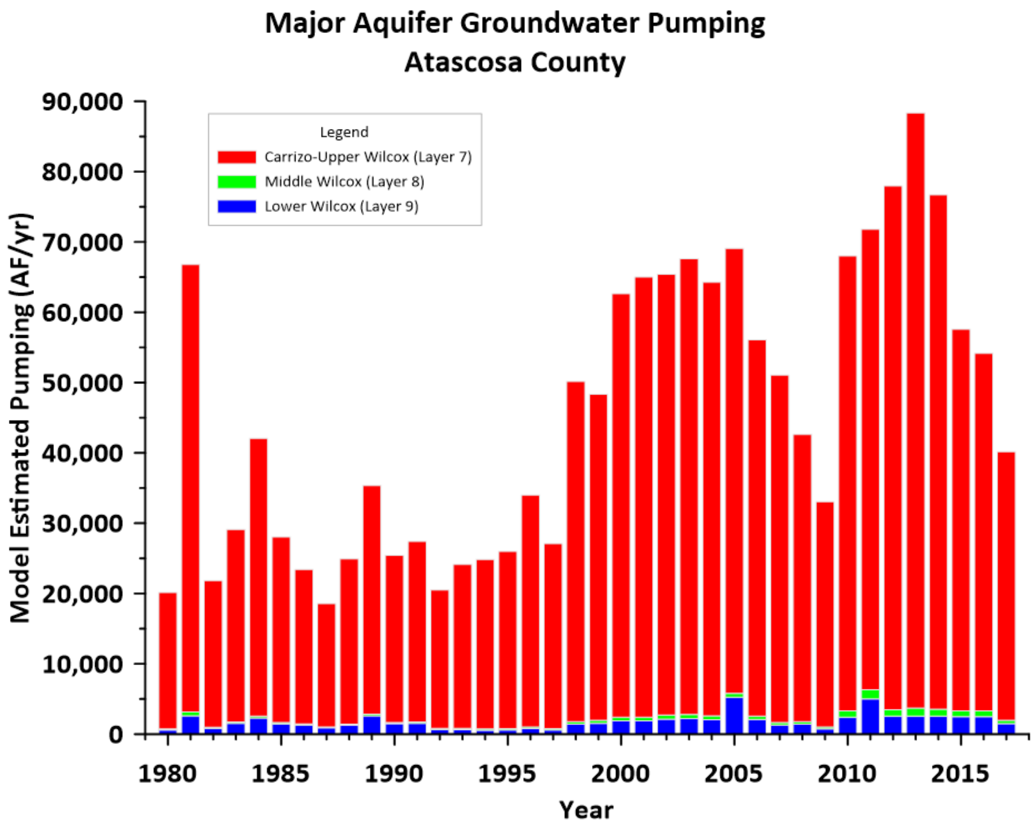

Minor Aquifer Groundwater Pumping
Webb County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
2,400
2,000
1,600
1,200
800
400
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

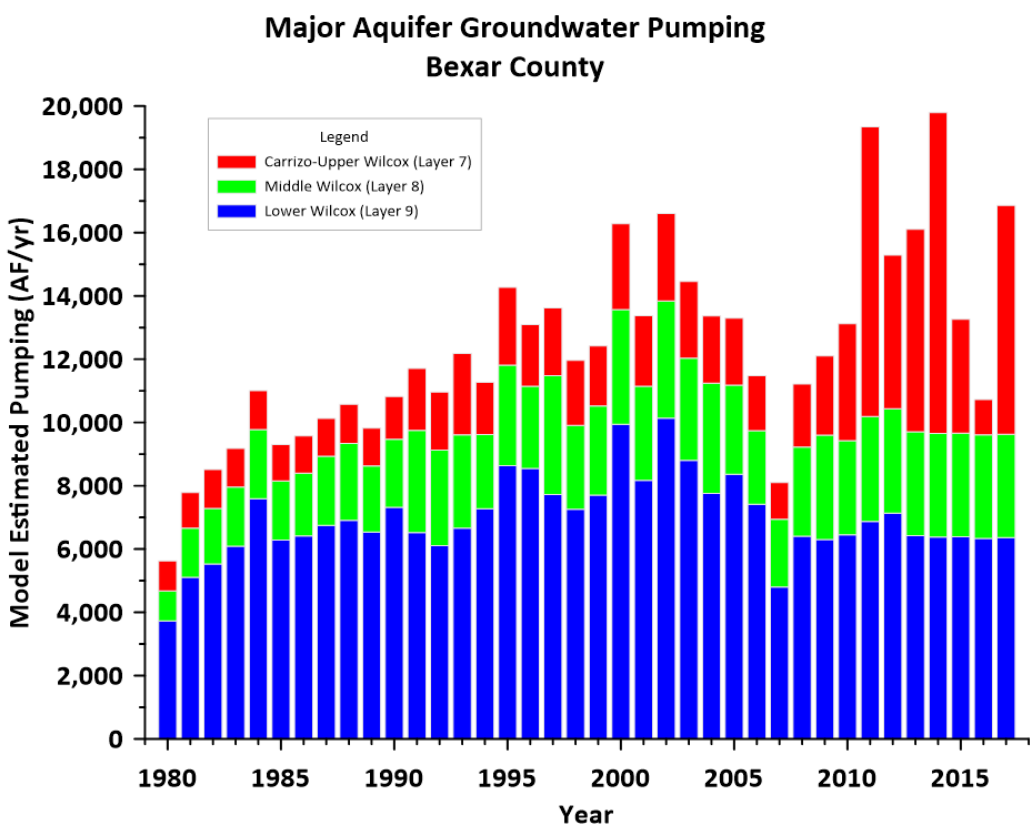

Minor Aquifer Groundwater Pumping
Wilson County
Legend
Sparta (Layer 3)
Queen City (Layer 5)
Model Estimated Pumping (AF/yr)
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

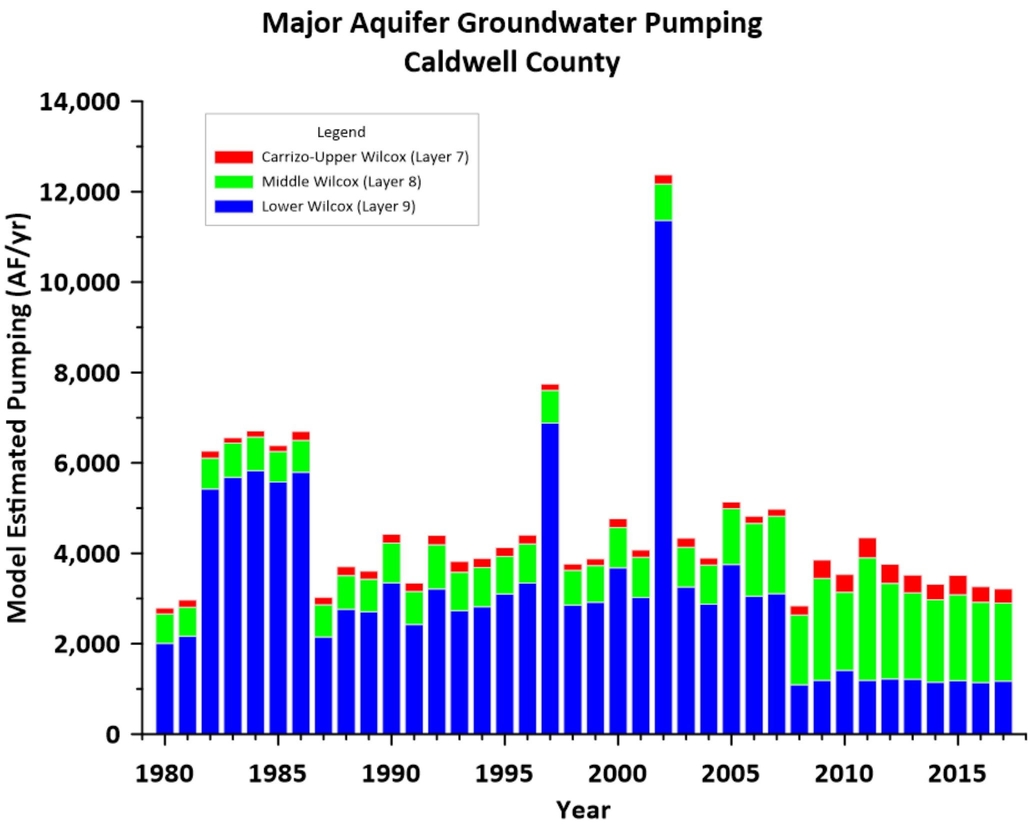
Appendix F

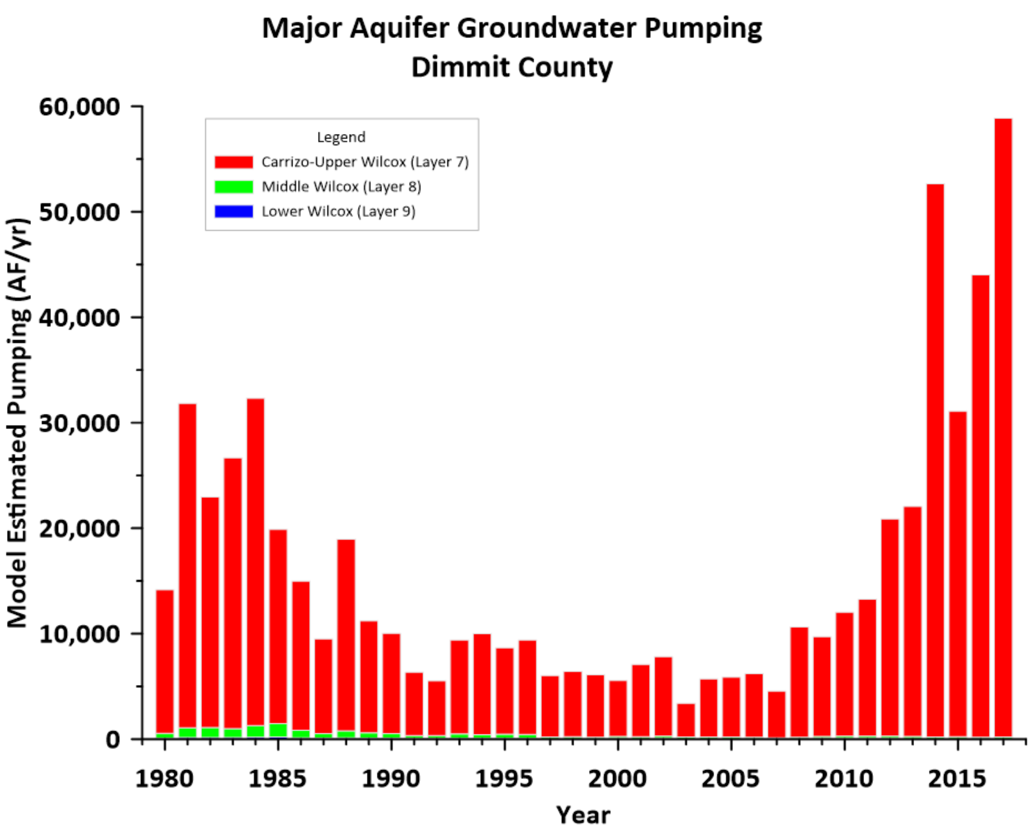
Major Aquifer Pumping by County

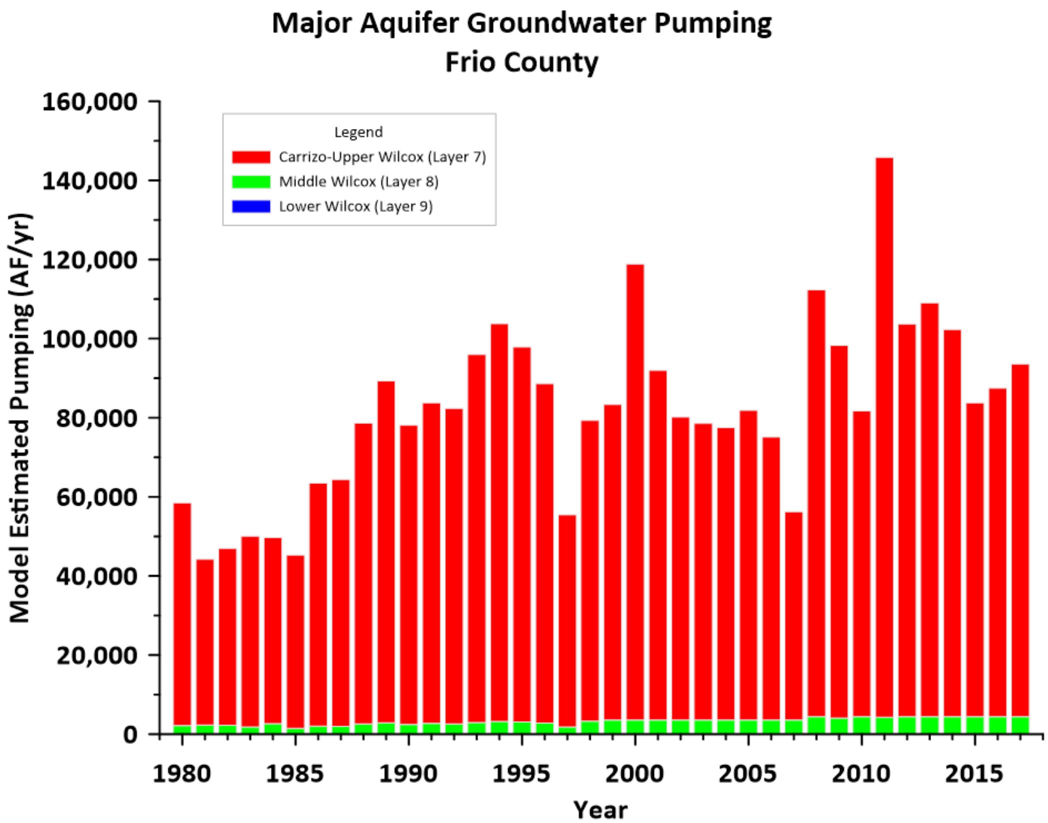
Calibrated GMA 13 Model (2025 Version)

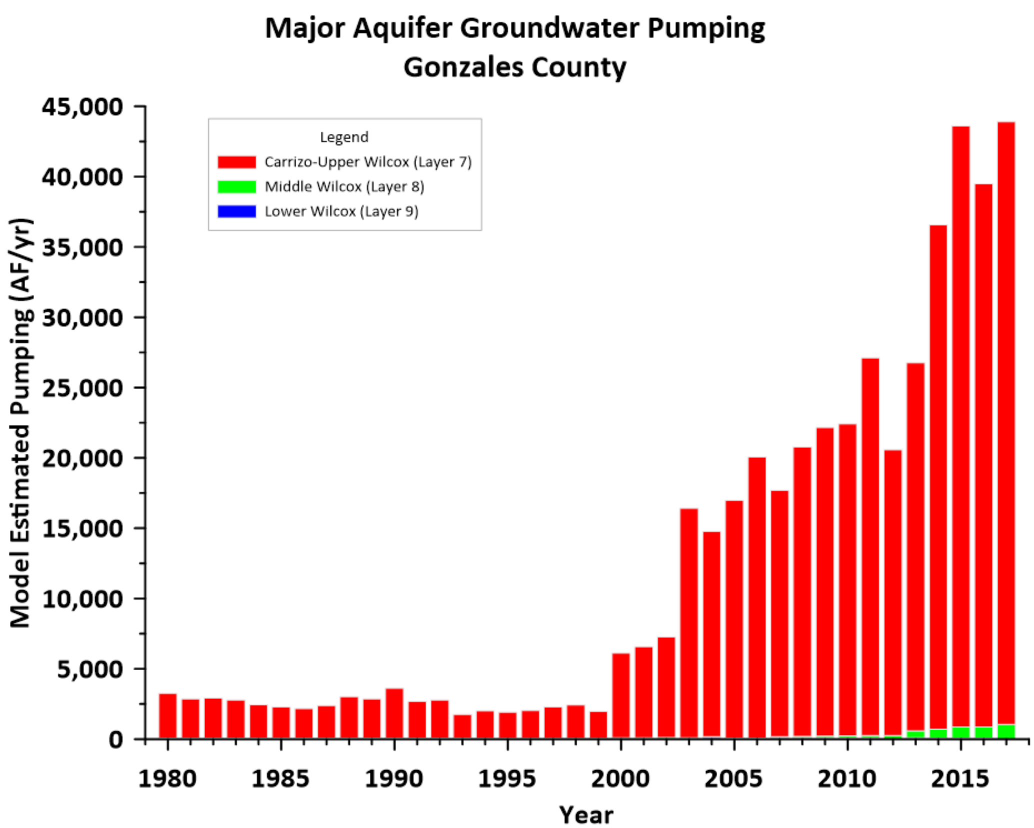

Major Aquifer Groundwater Pumping
Atascosa County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

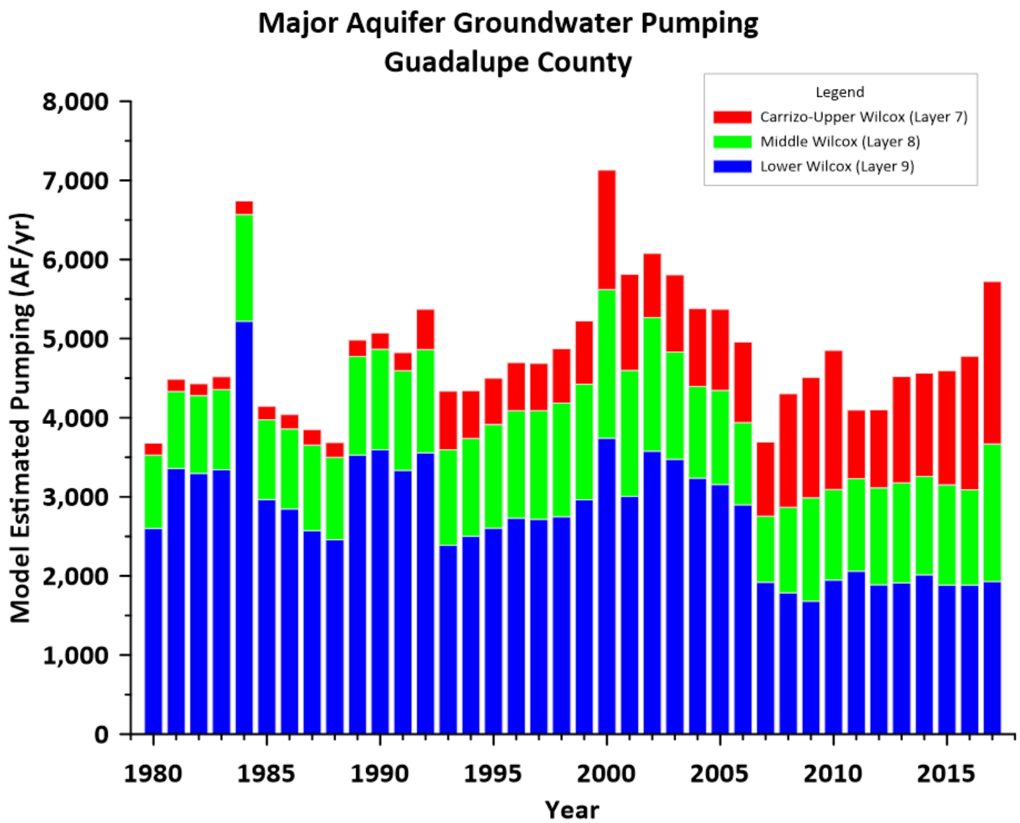

Major Aquifer Groundwater Pumping
Bexar County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

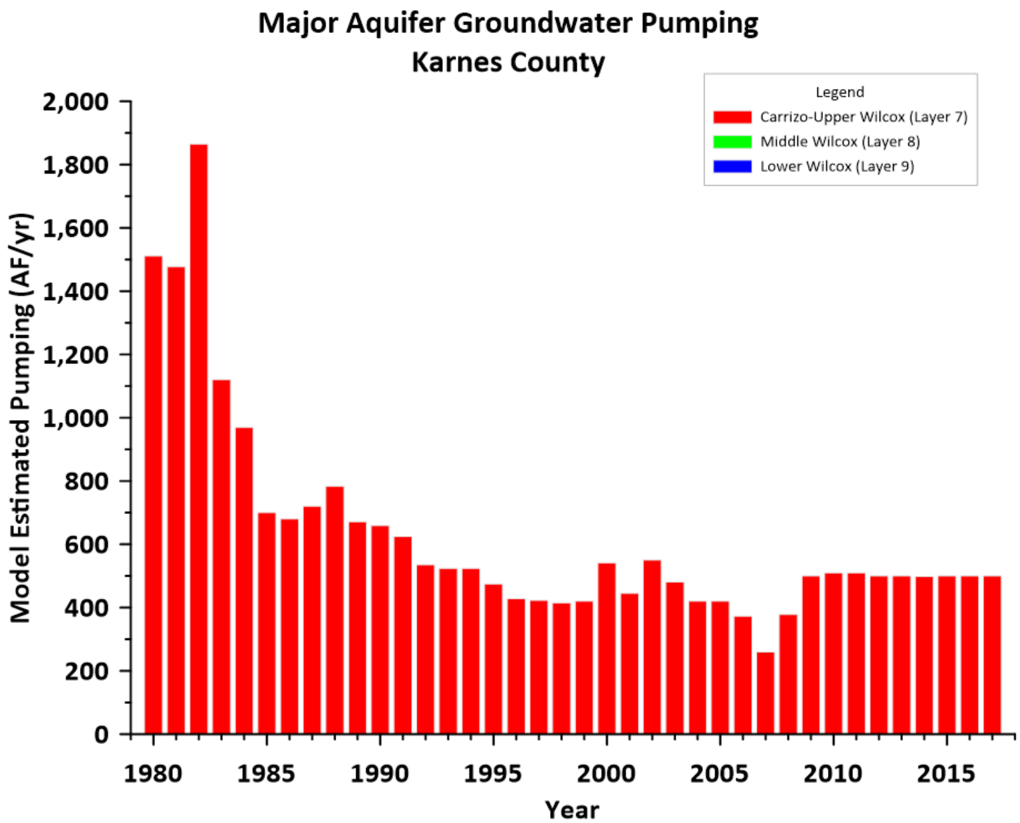

Major Aquifer Groundwater Pumping
Caldwell County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
1980
1985
1990
1995
2000
2005
2010
2015
Year

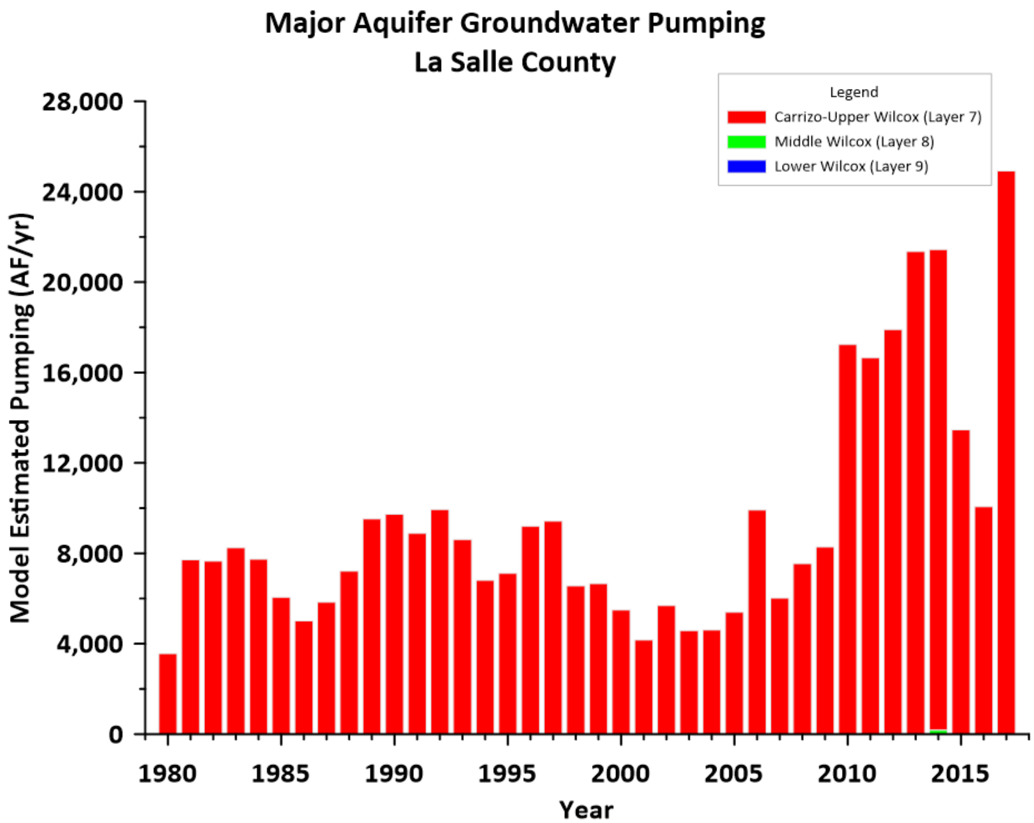

Major Aquifer Groundwater Pumping
Dimmit County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
0
10,000
20,000
30,000
40,000
50,000
60,000
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Frio County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

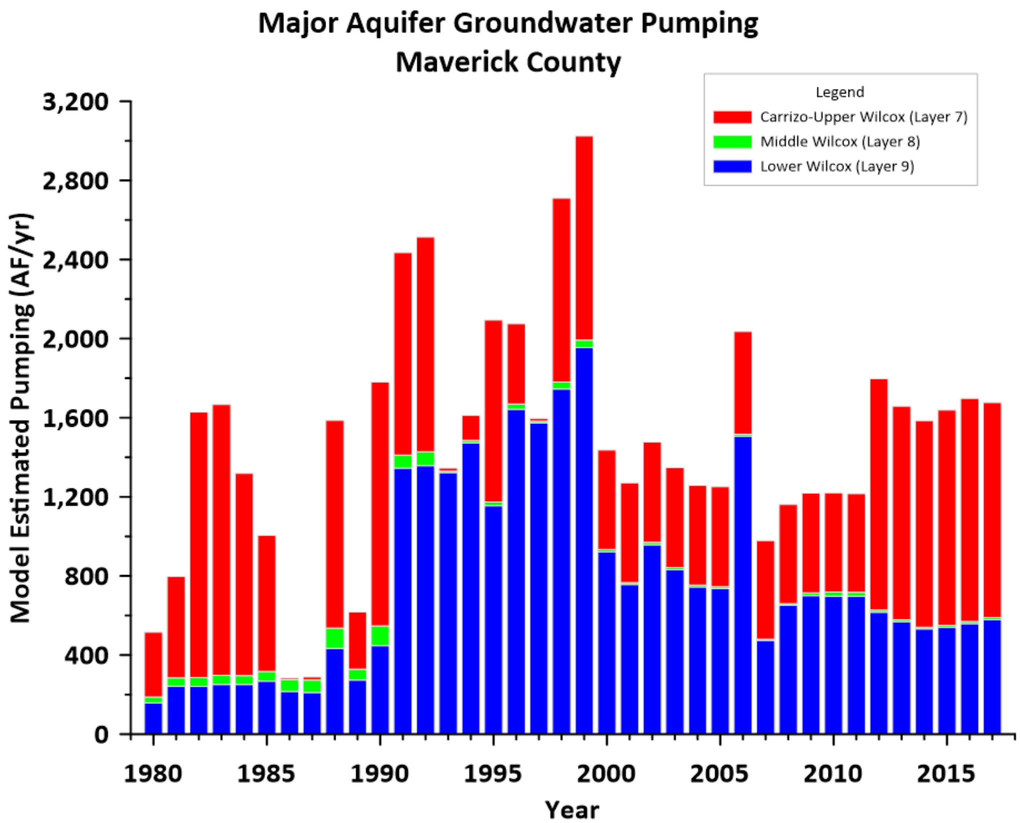

Major Aquifer Groundwater Pumping
Gonzales County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Guadalupe County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

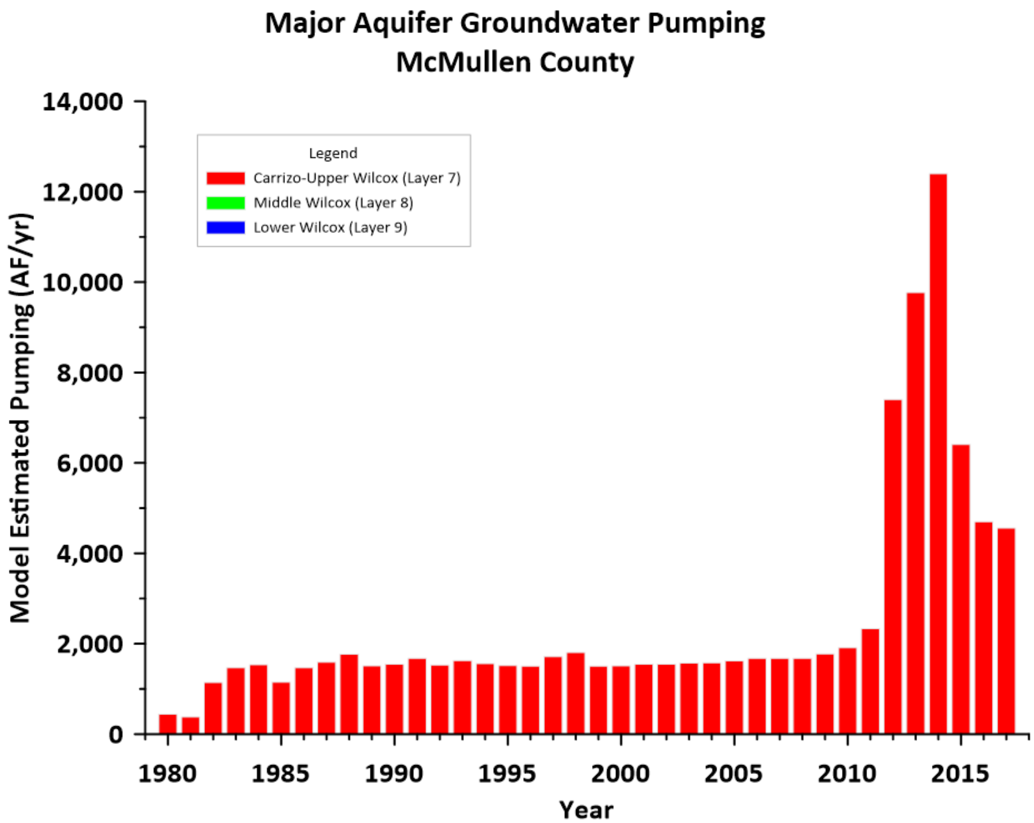

Major Aquifer Groundwater Pumping
Karnes County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

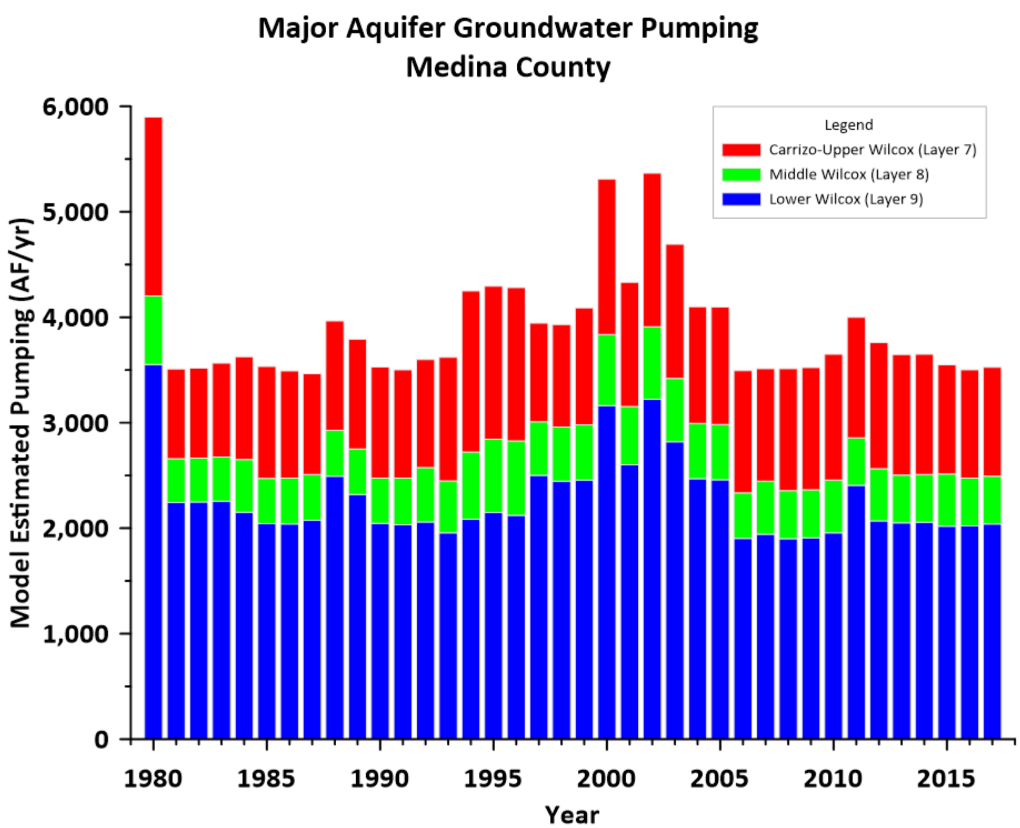


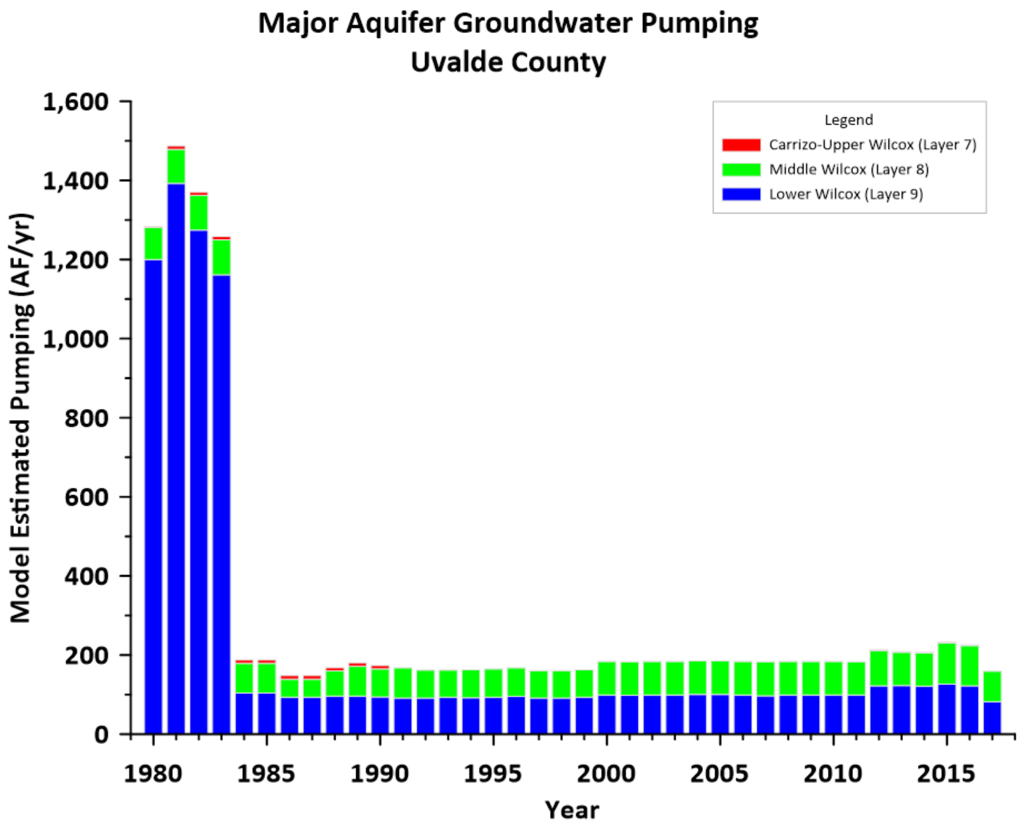
Major Aquifer Groundwater Pumping
La Salle County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
28,000
24,000
20,000
16,000
12,000
8,000
4,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

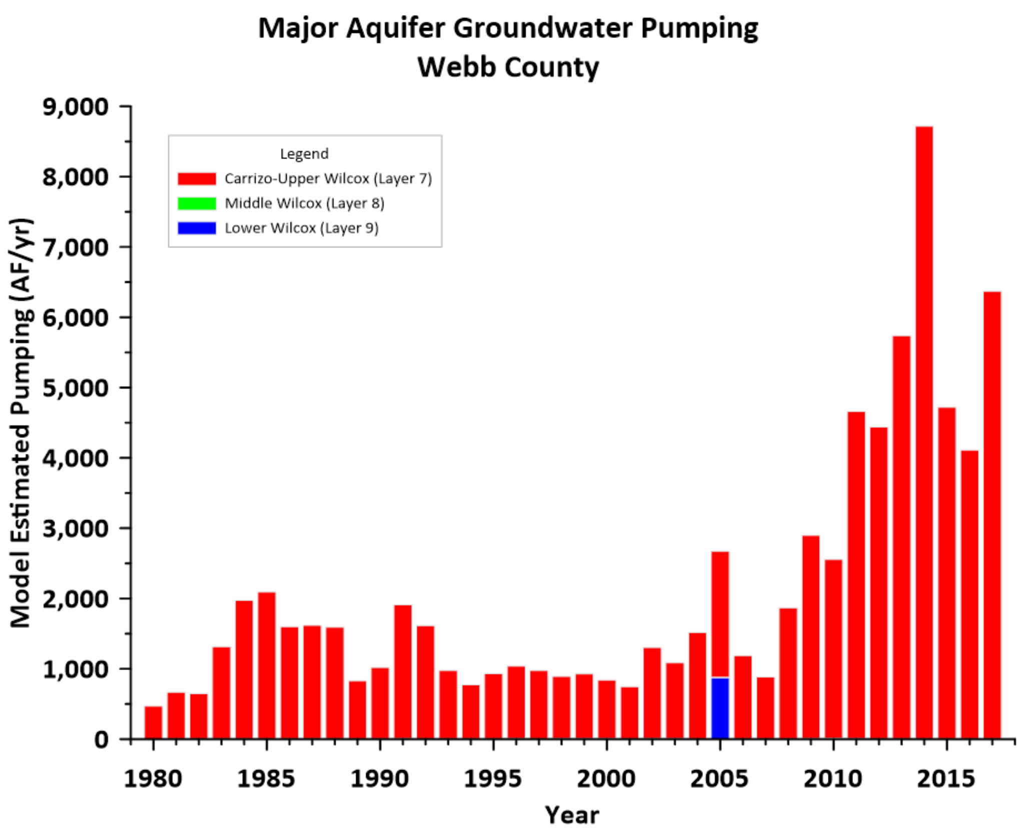


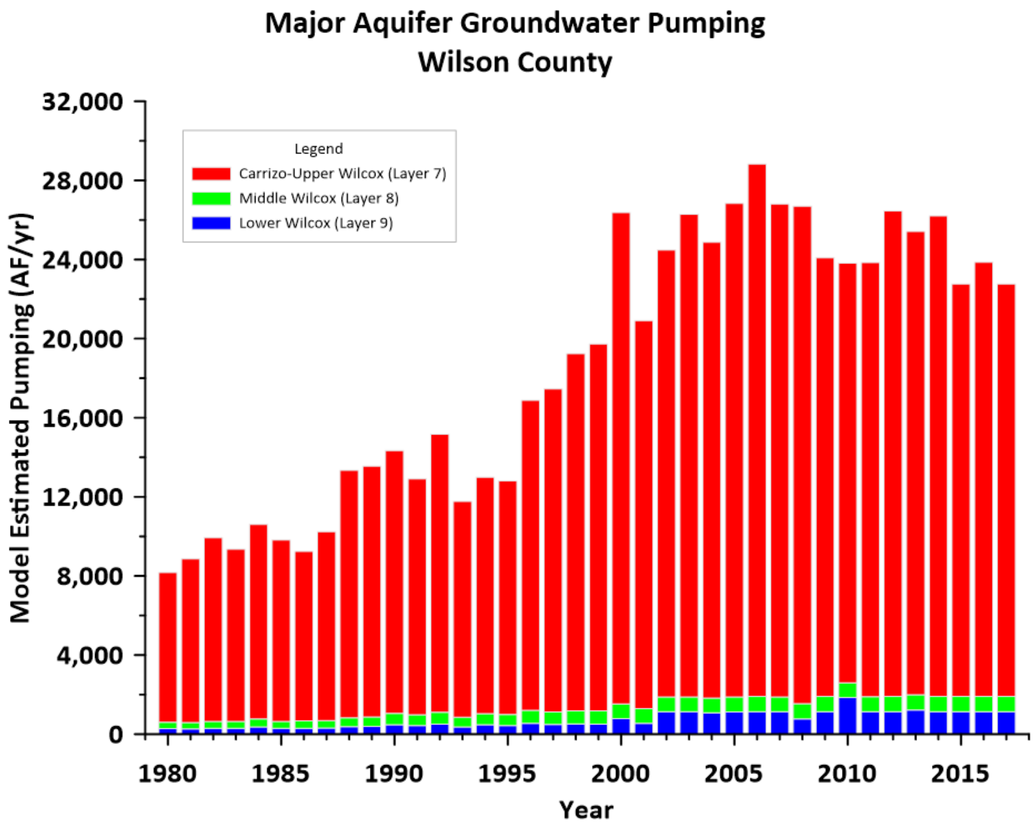
Major Aquifer Groundwater Pumping
Maverick County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

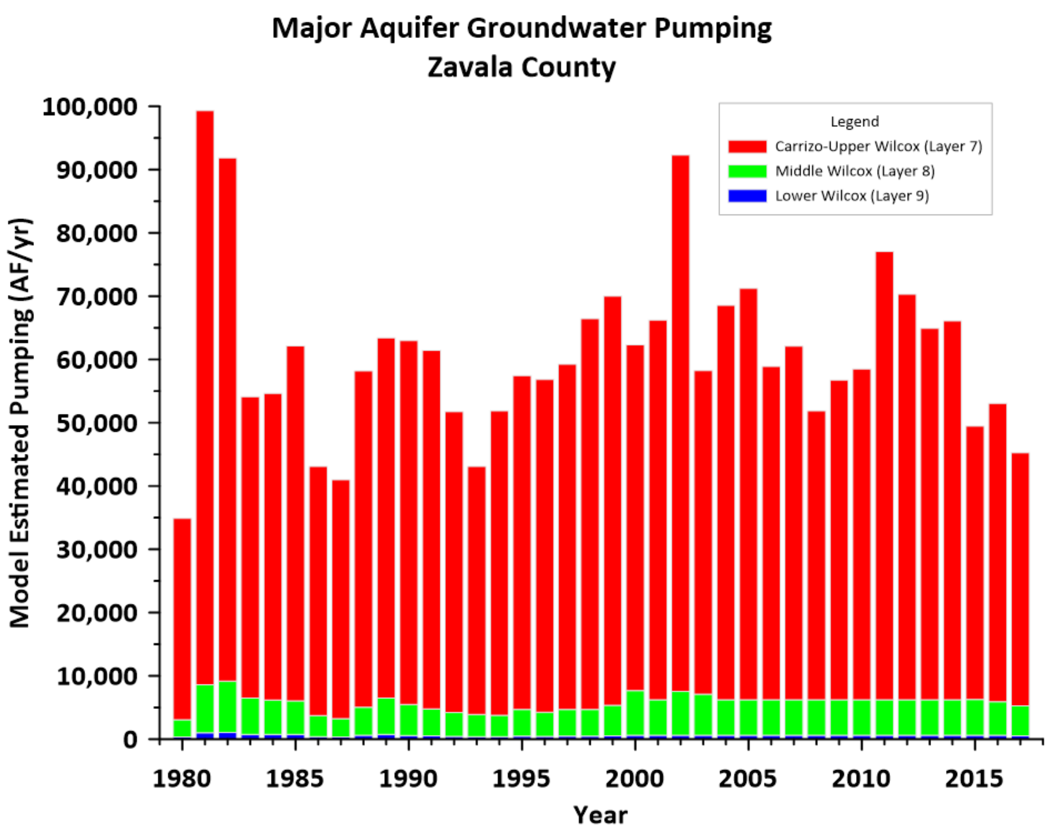

Major Aquifer Groundwater Pumping
McMullen County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Medina County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Uvalde County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
1,600
1,400
1,200
1,000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Webb County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Wilson County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
32,000
28,000
24,000
20,000
16,000
12,000
8,000
4,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year


Major Aquifer Groundwater Pumping
Zavala County
Legend
Carrizo-Upper Wilcox (Layer 7)
Middle Wilcox (Layer 8)
Lower Wilcox (Layer 9)
Model Estimated Pumping (AF/yr)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1985
1990
1995
2000
2005
2010
2015
Year

Appendix G

Response to February 2025 Comments Letters on GMA 13 Model (2024 Version

Introduction

This version of the model represents the second update of Panday and others (2023). Public comments on Panday and others (2023) included:

- Issues with calibration period pumping estimates in some areas
- Transmissivity estimates in some areas
- Storativity and specific yield estimates in some areas.

Comment responses were included in Panday and others (2023), and TWDB released the updated GAM without modification of the model files in May 2023.

GMA 13 contracted to update Panday and others (2023). The scope of work was originally focused on the three issues listed above. However, the scope was expanded to include the inclusion of data from Webb County and from Wintergarden GCD, which were documented in Hutchison (2024).

The updated version of the GAM (GMA 13 Model), documented in Hutchison (2024) was approved by GMA 13 for submittal to TWDB in September 2024. TWDB released the GMA 13 Model for public review on December 18, 2024.

During the 60-day public comment period, five letters were received in February 2025 from:

- Ted Boriack
- Gonzales County UWCD
- Evergreen UWCD
- RW Harden & Associates
- San Antonio Water System (SAWS)

Comment Letter Topics

The main topics of each of the comment letters are presented below.

Ted Boriack

1. Irresponsible Permitting Amid GAM Revision
2. Failure to Address Localized Impacts of Concentrated Well Fields
3. No Modeling of Subsidence Risk
4. No Assessment of Water Quality Degradation
5. Inadequate Mitigation Planning and Funding
6. The Unaddressed "Taking" of Groundwater from Uncompensated Landowners
7. Permitting Beyond the MAG and Stranded Infrastructure Risks
8. No Socioeconomic Impact Analysis
9. Bureaucratic Failures and Lack of Transparency

Items 1, 2, and 5 to 9 are outside the scope of a model update, and do not warrant a response. Items 3 and 4 are relevant to model updates and the responses are presented below.

Hutchison (2024) represented an update of Panday and others (2023). Panday and others (2023) did not include subsidence and did not include solute transport. Updating the model to include these features was beyond the scope of work.

Gonzales County UWCD

1. Low specific yields
2. Pumping locations
3. 2021 MAG in 2020 is lower than 2017 MAG in 2020
    a. Seeking "transparency" in how calculations are "determined"
4. Transmissivity values are too low

Item 3 is outside the scope of a model update and does not warrant a response. Items 1, 3, and 4 are relevant to model updates. Because the topics overlap with other letters, the responses are presented below by topic.

Evergreen UWCD

1. Combining Carrizo and Upper Wilcox into a single layer
2. Transmissivity values are inconsistent with aquifer test results
3. Specific yield values are too low

Attached to the Evergreen UWCD letter was a report by Intera. The Intera letter provided more detail on the layering issue and provided data from 49 pumping tests in support of the transmissivity comment.

The Intera report, however, does not include any discussion of the specific yield comment. The Evergreen UWCD letter also incorrectly stated that the specific yield values in Hutchison (2024) have "the potential to significantly underestimate groundwater availability".

Because these three topics overlap with other letters, the responses are presented below by topic.

RW Harden & Associates

1. Unreasonably low specific yield values
2. Widespread simulated groundwater level rise
3. Improper modeled pumpage assignment
4. Inaccurate transmissivity

Because these topics overlap with other letters, the responses are presented below by topic.

San Antonio Water System (SAWS)

1. Specific yield values
2. Historic pumping locations
3. PEST limits
4. Transmissivity values
5. Ratio of horizontal to vertical hydraulic conductivity

Because these topics overlap with other letters, the responses are presented below by topic.

Summary of Comment Topics

As noted above, four of the letters include considerable duplication in the issues raised. For purposes of response, the following seven topics are covered in this response.

1. Layering (Combining Carrizo and Upper Wilcox)
2. Specific yield
3. PEST limits
4. Pumping locations
5. Transmissivity values
6. Ratio of vertical to horizontal hydraulic conductivity values
7. Rising groundwater levels

Responses to Comments

Model Layering

Schorr and others (2021) documented the conceptual model of Panday (2023) and documented the choice to combine the Carrizo and Upper Wilcox into a single layer. This topic was covered at two GMA 13 meetings (November 8, 2019 and June 26, 2020). No objections were raised at those meetings. In addition, TWDB hosted a GAM Update Stakeholder meeting on March 4, 2021. The model layering was covered, and no comments were received. No comments were received during the public comment period for Panday and others (2023). These concerns were raised in the February 2025 letters.

In summary, the layering decision in Schorr and others (2021) and Panday and others (2023) was made to be consistent with BRACS work (part of TWDB). On a regional scale, this is appropriate. Local scale models may need more detailed layering and including these additional layers would not be inconsistent with the regional GAM.

Specific Yield Values

This was a subject of comments to Panday and others (2023). Reponses to those comments are included in Panday and others (2023). Moreover, the subject was covered extensively in Hutchison (2024).

In summary, there is a fundamental disagreement on this topic. The use of "textbook" values in thick unconfined cells is not reasonable.

PEST Limits

The comment expressed concern over "excessive flexibility" in pumping rates during adjustment, and that this could impact predictive capability.

It appears that there was a misunderstanding regarding the use of the factors that were referenced in the comment. The large increases were limited to a two-mile area around a calibration target in order to increase pumping in the immediate area of a monitoring well with a high simulated groundwater elevation.

As will be discussed in the next section, the issue has largely been addressed with the incorporation of metered pumping data from three districts. Despite numerous requests in 2018 and 2019, the metered pumping data were not provided when Schorr and others (2021) and Panday and others (2023) were being developed. To the extent that actual pumping locations were not known, the use of these high factors was an attempt to increase pumping at specific locations to better match targets.

The comment regarding the predictive capability of the updated model has been addressed in the updated report by including comparison hydrographs of average drawdown by county for all targets.

Pumping Locations

As a result of the February 2025 comments, three groundwater conservation districts (Gonzales County UWCD, Guadalupe County UWCD, and Plum Creek Conservation District) provided spreadsheets with metered pumping data. The update is documented in the updated report.

This update also provided an opportunity to update the McMullen County data that had been provided after the GMA 13 Model (Hutchison, 2024) had been submitted.

Including these data made a significant difference improving the confidence of the model as evidenced by the comparison hydrographs of average drawdowns (actual and simulated) for each county that are included in the report.

Transmissivity

As documented in Hutchison (2024), Panday and others (2023) had inappropriately high transmissivity values in large areas of the model. Indeed, one of the primary objectives of the update in 2024 was to correct these values.

In February 2025, several comments noted that transmissivity values in the 2024 update were too low and inconsistent with pumping test results. RW Harden & Associates provided some summary maps with "average" transmissivity comparisons between test results and the 2024 update. Evergreen UWCD included a report from Intera that contained the results of 49 tests (including well coordinates).

As noted in the report, this update incorporated the Intera transmissivity estimates from previous tests into the model. Also, based on these test results, the maximum transmissivity constraints were increased during calibration of this update.

Ratio of Vertical to Horizontal Hydraulic Conductivity

As discussed in Hutchison (2024), Panday and others (2023) had some unrealistic vertical to horizontal conductivity ratios. In some areas, vertical conductivity was higher than horizontal conductivity. This issue had not been raised in the initial public review of Panday and others (2024), and it was discussed at the GMA 13 meeting on September 15, 2023.

The comment from SAWS identified areas where a minimum constraint was needed. This minimum constraint was added as documented in the report.

Rising Groundwater Levels

One of the comments of RW Harden & Associates incorrectly asserted that measured data did not support areas of rising groundwater levels.

Hutchison (2024) documented the decreased pumping in Dimmit and Zavala counties during the early portion of the model calibration period. One set of the pumping estimates were provided by SWRi on behalf of Wintergarden GCD based on their work for the district. The other set of estimates were downloaded from TWDB.

In addition, measured groundwater elevation from the TWDB groundwater database document groundwater level rises.