Draft Technical Memorandum 4

Calculation of Drawdown from Existing Modeled Available Groundwater Using Updated Groundwater Availability Model

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October 3, 2022

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A – Modeled Available Groundwater for the Sparta, Queen City, and Carrizo-Wilcox Aquifers by County
B – Comparison of County-Aquifer Pumping Estimates: 2020 and 2080, MAG Report (Wade, 2022), Spreadsheet Calculations, WEL File Pre-Processor
C – Grid Cell Count and Acreage by County and Aquifer
D – Output Pumping Comparisons (MAG, Scen2020, and Scen2080) with Current MAG

1.0 Executive Summary

This technical memorandum summarizes the calculation of average drawdown from existing modeled available groundwater (MAG) using the updated groundwater availability model. The existing MAG for GMA 13 was developed using a "project-centric" approach rather than an approach that emphasized aquifer availability. Consequently, pumping in some counties increase during the simulation period (2011 to 2080). Also, some pumping decreased during the simulation period. These pumping decreases may have been specified in response to a limitation of the old GAM (i.e. persistently declining groundwater elevations even with pumping reductions).

The simulations with the new GAM consisted of two pumping endmembers: one where input pumping was specified at the 2020 MAG amounts (Scen2020), and one where input pumping was specified at the 2080 MAG amounts (Scen2080). Both simulations were run for the period 2018 to 2080.

The results generally show:

- The new GAM provides consistent results in that pumping increases (as compared to 2017 pumping) result in drawdown and pumping decreases (as compared to 2017 pumping) result in groundwater elevation recoveries.
- The new GAM drawdowns are generally less than the old GAM.
- At some of the pumping locations, input pumping cannot be sustained due to declining groundwater elevations. However, once the pumping rates are initially reduced over a period of a few years, pumping for the last several decades of the simulation is sustainable.
- Specified pumping decreases (compared to 2017 pumping) in several counties result in groundwater elevation recoveries that may need to be evaluated by districts in GMA 13, depending on their management objectives.
- The simulation results demonstrate vertical connection in some areas (i.e. cross formational flow and drawdown impacts).
- The simulations results demonstrate the potential for drawdown impacts across county lines/district boundaries.

2.0 Background

One of the uses of the updated Groundwater Availability Model for the Southern Portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers documented in the main report will be to support the Joint Planning Process that leads to the adoption of desired future conditions by the groundwater conservation districts in Groundwater Management Area 13 and the calculation of the modeled available groundwater by TWDB. As part of the work associated with developing the updated Groundwater Availability Model, five technical memoranda appear in the Appendix of the report:

- Technical Memorandum 1: Pumping Comparisons
- Technical Memorandum 2: Pumping Sensitivity
- Technical Memorandum 3: Recharge Sensitivity
- Technical Memorandum 4: Calculation of Drawdown from Existing Modeled Available Groundwater Using Updated Groundwater Availability Model
- Technical Memorandum 5: Calculation of Future Pumping from Existing Desired Future Conditions Using Updated Groundwater Availability Model

This technical memorandum summarizes the calculation of average drawdown from existing modeled available groundwater using the updated groundwater availability model.

3.0 Parameters and Assumptions

3.1 Modeled Available Groundwater

Wade (2022) reported the modeled available groundwater associated with the desired future conditions adopted by the groundwater conservation districts in Groundwater Management Area 13. Modeled Available Groundwater values for the Sparta, Queen City, and Carrizo-Wilcox aquifers by county and decade are presented in Appendix A (also saved in the Excel file named *GMA13MAGsbyCounty_2021.xlsx*). The modeled available groundwater values for all of Groundwater Management Area 13 (as reported in Wade, 2022) are graphically summarized as follows:

- Figure 1: Sparta Aquifer
- Figure 2: Queen City Aquifer
- Figure 3: Carrizo-Wilcox Aquifer

Please note that for the Sparta and Queen City aquifers, there is an initial decline from 2020 to 2030, then a smaller, but discernable decline from 2030 to 2080. In the Carrizo-Wilcox Aquifer, there is a drop in modeled available groundwater from 2020 to 2030, then an increase from 2030 to 2070, and finally a small drop from 2070 to 2080. The existing MAG for GMA 13 was developed using a "project-centric" approach rather than an approach that emphasized aquifer availability.

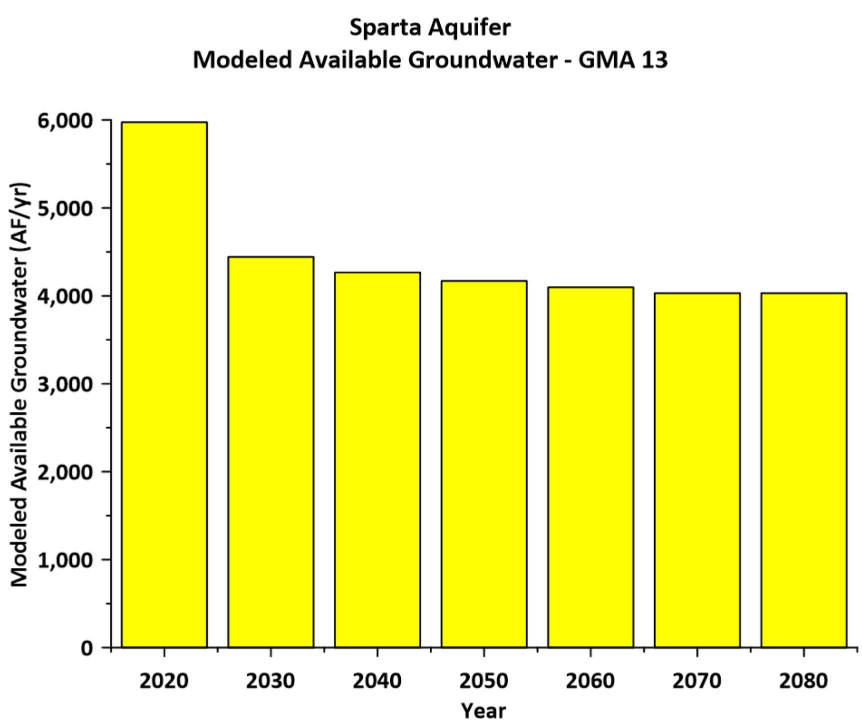


Figure 1. Sparta Aquifer Modeled Available Groundwater

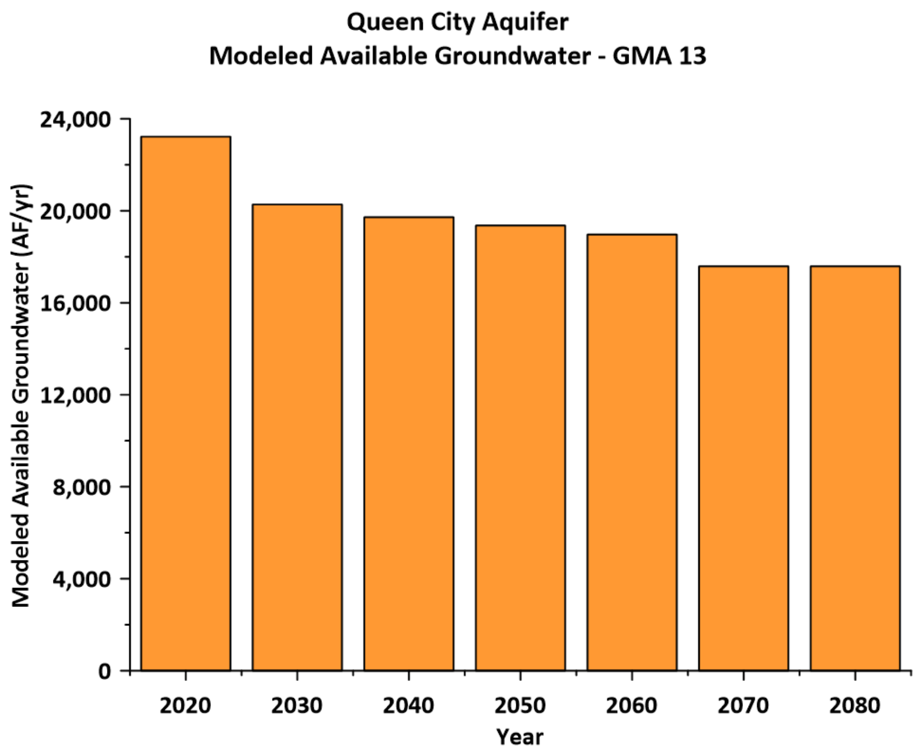


Figure 2. Queen City Aquifer Modeled Available Groundwater

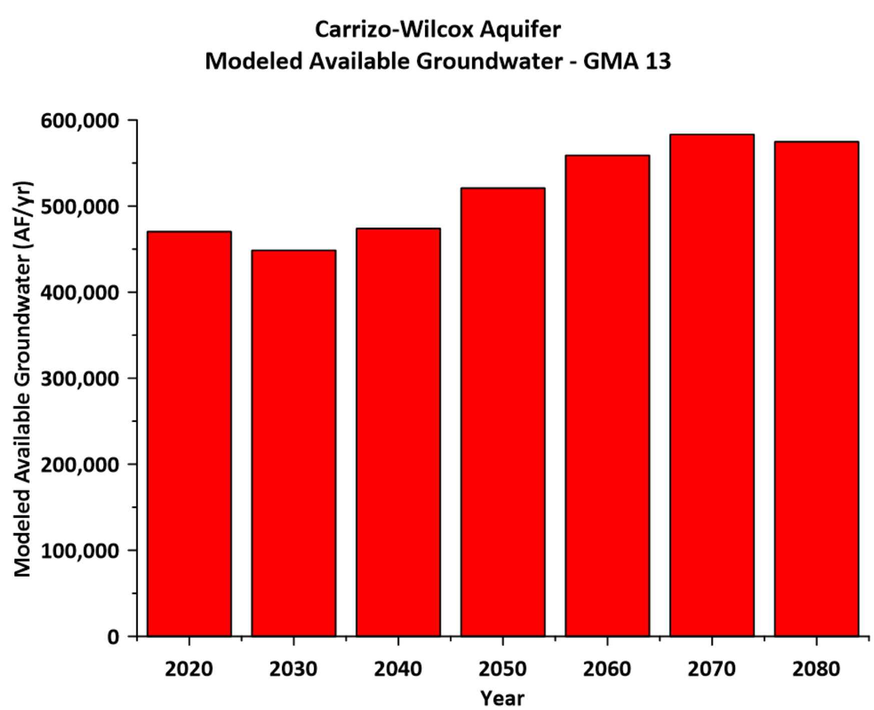


Figure 3. Carrizo-Wilcox Aquifer Modeled Available Groundwater

3.2 Analysis of WEL Cell Pumping Changes in MAG Run

The objective of the analyses contained in this Technical Memorandum is to calculate the average drawdowns using the existing modeled available groundwater values with the new Groundwater Availability Model. The model files used by Wade (2022) for the modeled available groundwater calculations were used to characterize various changes made in the assumptions of pumping after 2018.

Total model pumping from the files used by Wade (2022) is summarized in Figure 4. Please note that there is a significant increase in pumping in 2019. Thus, for the purposes of this analysis, the pumping in 2018 represents "historic" pumping and pumping from 2019 to 2080 represents "future" pumping. Analyses were completed that compared 2018 pumping with 2020 pumping and compared 2018 pumping with 2080 pumping to better develop a procedure to simulate "future" pumping with the new Groundwater Availability Model.

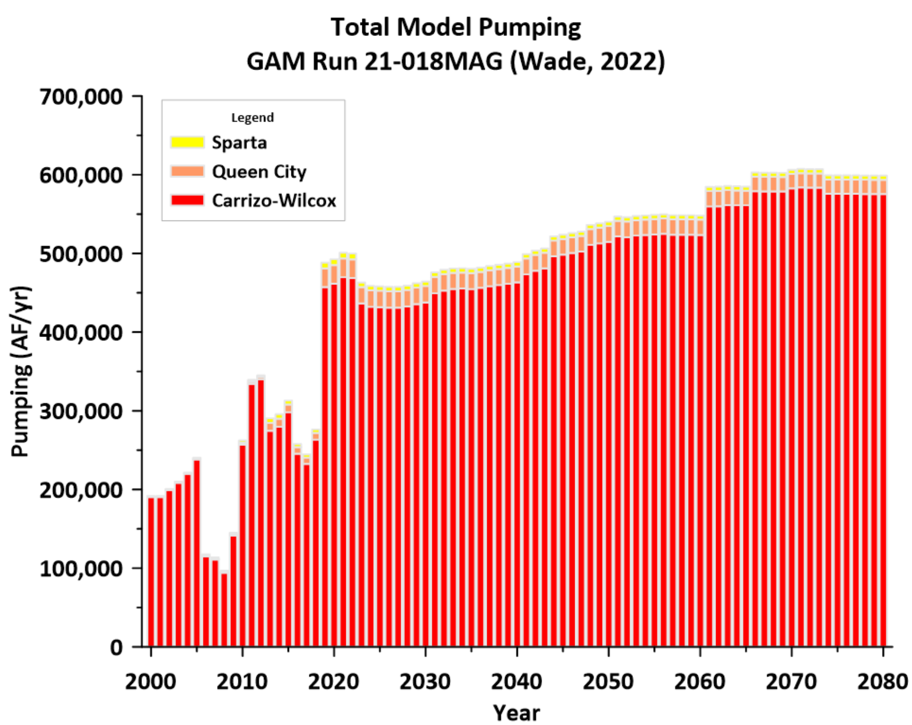


Figure 4. Total Model Pumping: 2000 to 2080

3.2.1 Pumping in 2018, 2020, and 2080

For the purposes of this analysis, the pumping output from the model run (i.e. derived from the *cbb* file) was extracted for the years 2018 (the last year before general increases above the historic pumping were observed), 2020 (the first year of the modeled available groundwater report), and 2080 (the final year of the modeled available groundwater report). The FORTRAN program named *PumpList.exe* was written to extract the individual years cell-by-cell pumping. The output file was named *pumpcompare201820202080.dat*, and included the layer, row, column, and county of each cell with pumping in 2018, 2020, and 2080.

The FORTRAN program named *PumpCellNewGrid.exe* was written to add the x- and y-coordinates of each of the cells. The output file was named *PumpList.dat*.

Finally, the FORTRAN program named *PumpNewGrid.exe* was written to assign the model cell number from the new Groundwater Availability Model. This was accomplished by finding the new GAM cell that was closest to the center of the old GAM cell and assigning the appropriate layer in the new GAM. Output was named *pumplistnewgrid.dat*.

3.2.2 Characterizing 2020 and 2080 Pumping in Comparison to 2018 Pumping

The output file *pumplistnewgrid.dat* from the final step above was imported to an Excel file named *MAG Analysis.xlsx* in the tab named *All*. Through various sorting routines, the other tabs in *MAG Analysis.xlsx* contain the following sets of WEL cells:

- *New Locations* (cells with no pumping 2018 that have pumping specified in either 2020 or 2080)
- *Old Locations All* (cells with pumping in 2018 and pumping in either 2020 or 2080)
- *Old Loc 2020 zero* (cells with pumping in 2018, but no pumping in 2020)
- *Old Loc 2020 Reduc* (cells with pumping in 2020 that is lower than 2018 pumping)
- *Old Loc 2020 Same* (cells with pumping in 2020 that is the same as 2018 pumping)
- *Old Loc 2020 Inc* (cells with pumping in 2020 that is higher than 2018 pumping)
- *Old Loc 2080 zero* (cells with pumping in 2018, but no pumping in 2080)
- *Old Loc 2080 Reduc* (cells with pumping in 2080 that is lower than 2018 pumping)
- *Old Loc 2080 Same* (cells with pumping in 2080 that is the same as 2018 pumping)
- *Old Loc 2080 Inc* (cells with pumping in 2080 that is higher than 2018 pumping)

The following bar charts summarize the data associated with the 2020 and 2080 pumping as compared with 2018 pumping:

- Summary of New Locations, Zero Pumping, Pumping Reductions, Same Pumping, Pumping Increases:
  - Figure 5 (2020)
  - Figure 6 (2080)
- Summary of Distribution of Pumping Reductions
  - Figure 7 (2020 compared to 2018)
  - Figure 8 (2080 compared to 2018)
- Summary of Distribution of Pumping Increases
  - Figure 9 (2020 compared to 2018)
  - Figure 10 (2080 compared to 2018)

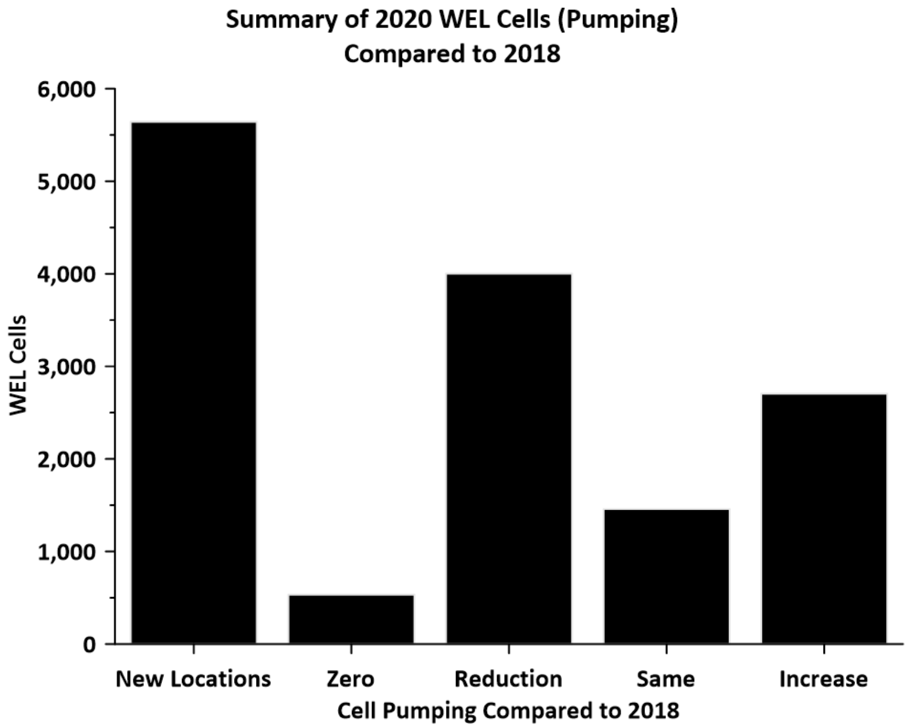


Figure 5. Characterization of WEL Cells in 2020 Compared to 2018

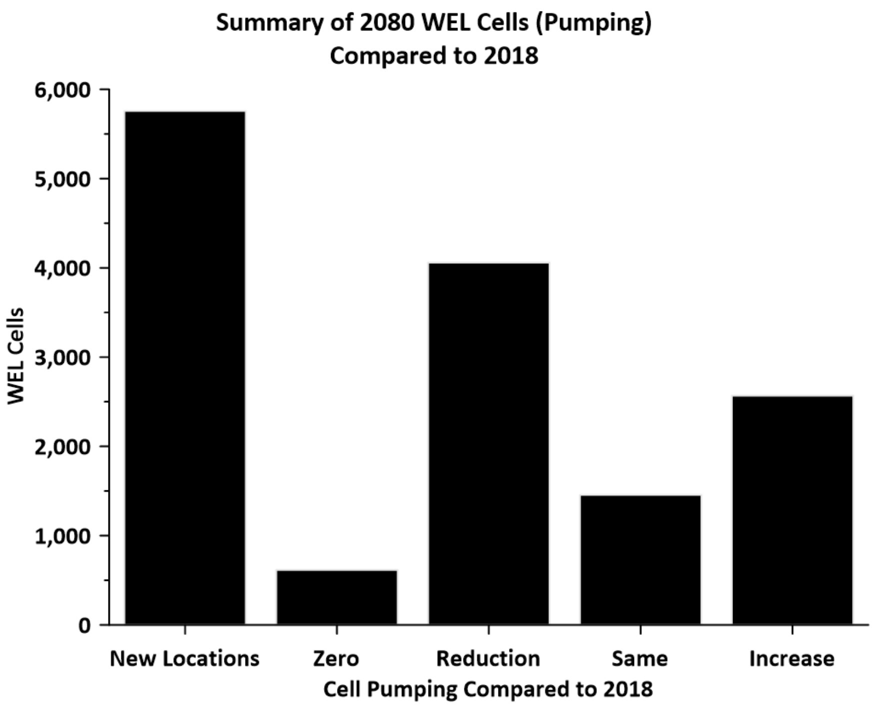


Figure 6. Characterization of WEL Cells in 2080 Compared to 2018

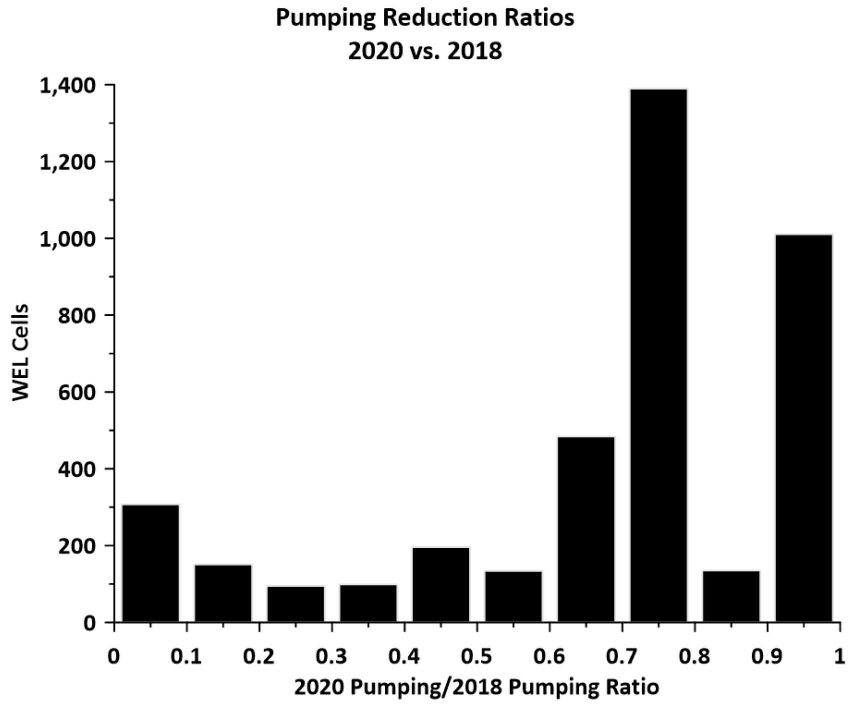


Figure 7. Pumping Reduction Ratios: 2020 vs. 2018

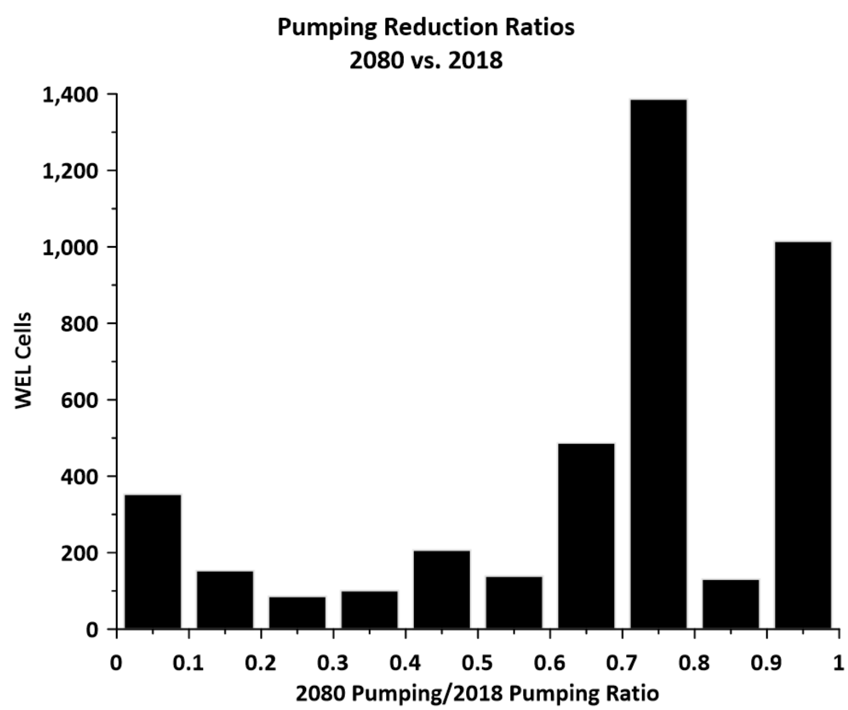


Figure 8. Pumping Reduction Ratios: 2080 vs. 2018

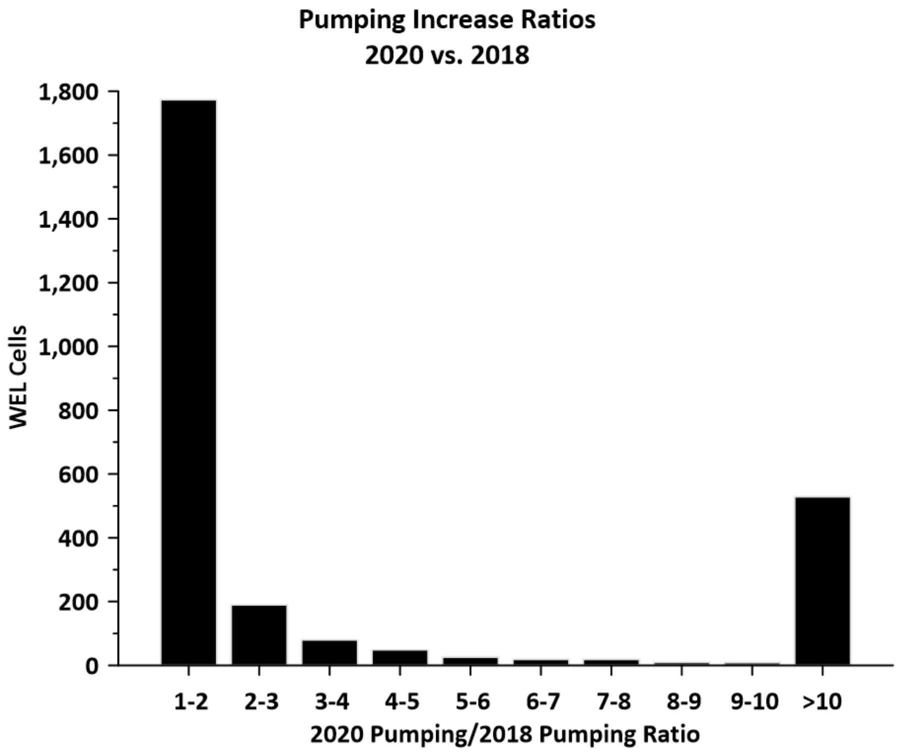


Figure 9. Pumping Increase Ratios: 2020 vs. 2018

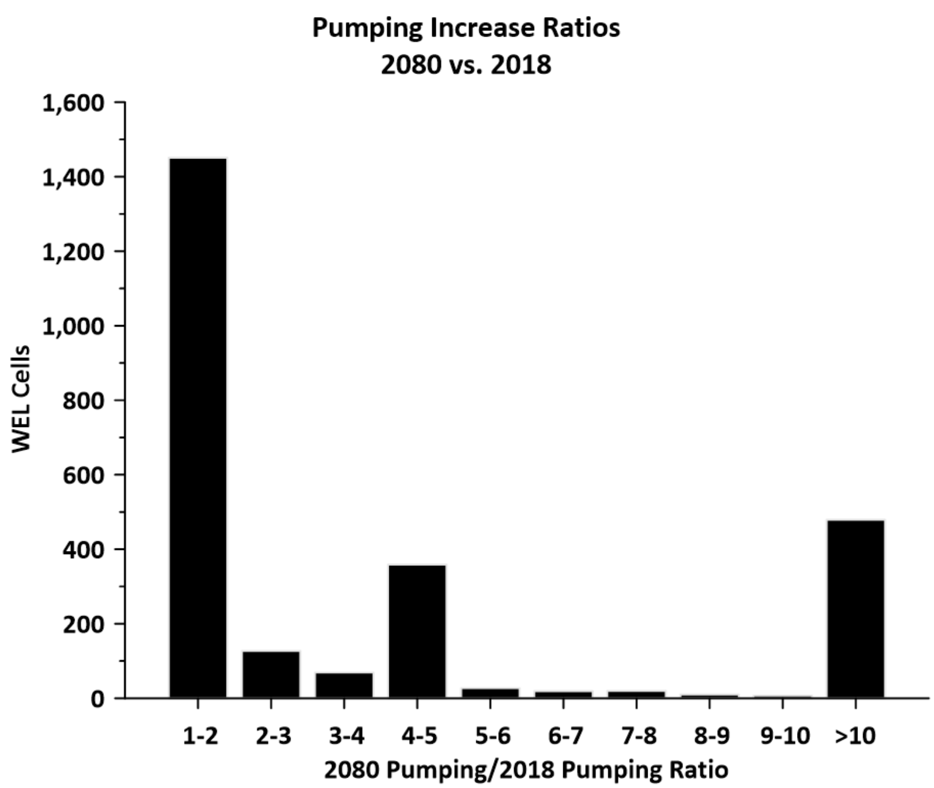


Figure 10. Pumping Increase Ratios: 2080 vs. 2018

3.3 New GAM 2017 Pumping

The new Groundwater Availability Model is calibrated through 2017, so the pumping in 2017 is the logical starting point to apply increases (or decreases) for future scenarios at existing pumping locations.

The output file named *2017pumpout.dat* from the analysis presented in Technical Memorandum 2 was used as input to a FORTRAN program named *Pump2017.exe* to summarize pumping on a county-model layer basis. Output from this program is named *Pump2017sum.dat*.

3.4 Applying Pumping from MAG Run to New GAM

As documented above, the old location pumping in 2020 and 2080 in the MAG run (using the existing GAM) has a significant number of cells that are increased, decreased, unchanged, and set to zero as compared to 2018. Coupled with the change in grid, strict adherence to every cell-by-cell change in the pumping file of the "future" portion of the MAG simulation, many of which are undocumented, presents difficulties.

3.4.1 Old Locations

For purposes of this analysis, it was assumed that the 2017 pumping in the new GAM could be adjusted on a county-model layer basis to match pumping at the old locations on a county-model layer basis in the existing GAM used to complete the MAG simulation. To fully test the concept, the procedure was applied to MAG pumping in 2020 and 2080.

As documented above, the spreadsheet named *MAG Analysis.xlsx* included a tab named *Old Locations All* that included MAG simulation pumping in 2020 and 2080 for 8,698 cells. This tab was extracted and saved as *MAGoldloc.csv*, which was the input to a FORTRAN program named *OldLocations.exe*. The two output files from this program are named *pump2020old.dat* and *pump2080old.dat*.

County-model layer pumping for 2017 from the new GAM, and the county-model layer 2020 and 2080 pumping from the MAG run using the existing GAM were imported as individual tabs in the Excel file *Fac2020and2080.xlsx*. Factors were calculated and are presented in the *pump2020old* and *pump2080old* tabs to the right of the pumping data. These represent the multiplication factors to adjust (on a county-model layer basis) the 2017 pumping of the new GAM to match "old location" pumping in the MAG run.

Please note that the pumping is calculated for all counties, even those outside of GMA 13. Also, since the old GAM did not include any pumping from Mexico and the new GAM did include some assumed pumping from Mexico, the Mexican pumping from the new GAM is included.

3.4.2 New Locations

As documented above, the spreadsheet named *MAG Analysis.xlsx* included a tab named *New Locations* that included MAG simulation pumping in 2020 and 2080 for 5,766 cells at locations where pumping was zero in 2018. This tab was extracted and saved as *MAGnewloc.csv*, which was the input to a FORTRAN program named *NewLocations.exe*. The two output files from this program are named *pump2020new.dat* and *pump2080new.dat*.

The new location pumping output files were added to the Excel file *Fac2020and2080.xlsx* described above in the old locations section as tabs named *pump2020new* and *pump2080new*.

3.4.3 Combined Old Location and New Location Pumping

The tabs named *PumpScen2020* and *PumpScen2080* represent the county-model layer and county-aquifer pumping totals for the scenarios based on 2020 MAG pumping and 2080 MAG pumping using the new GAM.

To the right of the county-model layer pumping calculations are county-aquifer pumping sums. Layer 3 is the Sparta Aquifer, Layer 4 is the Queen City Aquifer, and the Carrizo-Wilcox Aquifer pumping is the sum of pumping in Layers 7, 8, and 9.

The tab named *Compare with MAG Report* uses the county-aquifer values in the *PumpScen2020* and *PumpScen2080* tabs and the MAG report values described earlier and presented in Appendix A. This tab is presented as Table 1.

Minor differences between the MAG values and the results of this analysis can be seen in Table 1, but overall, the calculations using the old and new location approach described above reasonably represents the MAG report pumping of Wade (2022).

Table 1. Comparison of County-Aquifer Calculated Pumping with MAG Report

County	Aquifer	2020 Pumping (AF/yr)		2080 Pumping (AF/yr)	
		MAG Report	This Analysis	MAG Report	This Analysis
Atascosa	Sparta	1,218	1,219	932	935
Frio	Sparta	897	931	534	556
Gonzales	Sparta	3,524	3,552	2,451	2,488
La Salle	Sparta	0	986	0	986
McMullen	Sparta	0	0	0	0
Wilson	Sparta	335	462	114	156
Atascosa	Queen City	4,070	4,072	4,285	4,299
Caldwell	Queen City	4,842	5,113	3,977	4,261
Frio	Queen City	6,702	6,755	3,927	3,971
Gonzales	Queen City	4,973	5,063	4,500	4,604
Guadalupe	Queen City	0	0	0	0
LaSalle	Queen City	1	12	1	12
McMullen	Queen City	3	0	3	0
Wilson	Queen City	2,631	2,778	892	944
Atascosa	Carrizo-Wilcox	51,924	51,780	59,982	59,982
Bexar	Carrizo-Wilcox	69,727	69,537	67,849	67,849
Caldwell	Carrizo-Wilcox	18,180	18,169	49,594	49,633
Dimmit	Carrizo-Wilcox	3,895	4,125	3,885	4,125
Frio	Carrizo-Wilcox	114,827	114,009	79,131	78,784
Gonzales	Carrizo-Wilcox	60,431	57,069	96,161	96,562
Guadalupe	Carrizo-Wilcox	55,637	50,352	41,659	40,519
Karnes	Carrizo-Wilcox	693	708	1,043	1,061
La Salle	Carrizo-Wilcox	6,554	6,536	6,536	6,536
Maverick	Carrizo-Wilcox	547	545	276	276
McMullen	Carrizo-Wilcox	7,789	7,768	4,854	4,854
Medina	Carrizo-Wilcox	2,635	2,658	2,628	2,647
Uvalde	Carrizo-Wilcox	0	0	0	0
Webb	Carrizo-Wilcox	912	909	910	909
Wilson	Carrizo-Wilcox	38,229	38,119	125,670	126,361
Zavala	Carrizo-Wilcox	38,303	38,440	34,540	34,634

3.5 Scenario Pumping

The FORTRAN program *scenpump.exe* was written to create two WEL files: one based on the 2020 MAG values, and one based on the 2080 MAG values. The program:

- Reads the list of county codes and names
- Reads the pumping factors (by county-model layer) for old locations from *pumpfac2020.csv* and *pumpfac2080.csv*
- Reads the old location cells and pumping, calculates 2020 and 2080 pumping based on the county-model layer factors and increments the appropriate pumping arrays
- Readds the new location cells and pumping for 2020 and 2080, and increments the appropriate pumping arrays
- Converts pumping in AF/yr to ft^3/day (for model input)

- Fills the county-model layer summary arrays with pumping (in AF/yr)
- Writes county-model layer summary files
- Writes the lists for 2020 and 2080 pumping scenarios (cell and pumping in ft^3/day)

The actual WEL files were then created by hand by adding the appropriate headers (*scen2020.wel* and *scen2080.wel*).

The summary files with scenario pumping (2020 and 2080) by county-model layer were imported into *FAC2020and2080.xlsx* Excel file under the tabs named *WEL input 2020* and *WEL input 2080*. An additional comparison tab (*Compare with MAG and WEL*) was also created to compare the WEL input values with the MAG Report values and spreadsheet calculation values (previously presented as Table 1). The full comparison table is presented in Appendix B.

3.6 Other Model Files

The directory on the share site named *BaseFiles* contains all model files for the simulations other than the simulated pumping files described earlier

3.6.1 Files Unchanged from Calibrated Model

Table 2 presents the model files that were unchanged from the calibration run of the model.

Table 2. Model Files Unchanged from Calibrated Model

File Name	File Date	Description
GMA13_Historical_Period_Calibration._kx	5/10/2022	Horizontal hydraulic conductivity
GMA13_Historical_Period_Calibration._kz	5/10/2022	Vertical hydraulic conductivity
GMA13_Historical_Period_Calibration._ss	5/10/2022	Specific storage
GMA13_Historical_Period_Calibration._sy	5/10/2022	Specific yield
GMA13_Historical_Period_Calibration.dis	5/10/2022	Discretization
GMA13_Historical_Period_Calibration.hfb	5/10/2022	Horizontal fflow barrier
GMA13_Historical_Period_Calibration.ims	5/10/2022	Solver
GMA13_Historical_Period_Calibration.npf	5/10/2022	Node property flow

3.6.2 Files Modified from the Calibrated Model

Table 3 presents the model files that were modified from the calibration run of the model in order to run the predictive simulations. The pumping files were discussed earlier.

Table 3. Model Files Modified from the Calibrated Model

File Name	File Date	Description
calsp39hds.dat	5/27/2022	Starting heads
mfsim.nam	5/27/2022	Simulation name file
pred.evt	5/25/2022	Evapotranspiration
pred.ghb	5/25/2022	General head boundary
pred.ic6	5/27/2022	Initial condition file
pred.oc6	5/26/2022	Output control
pred.riv	5/25/2022	River
pred.sto	5/25/2022	Storage
pred.tdis	5/25/2022	Time discretization
predbase.nam	5/26/2022	GWF Model name file

The modifications were generally associated with using the final stress period from the calibrated model and holding all parameters constant for the sensitivity simulation, which was run from 2018 to 2080 (63 stress periods). Modifications also included updating the file names for the simulations.

Please note that no recharge file is listed above. It was not part of the general group of modified files and not included in this directory. The recharge file for both scenarios was the average annual recharge as defined in the steady state version of the calibration model (*scen3.rch*) as documented in Technical Memorandum 3.

3.7 Average Drawdown Calculation

3.7.1 Grid Counts and Acreage

Model output includes groundwater elevation results for each model cell. Drawdown can be calculated by subtracting the groundwater elevation in a specific cell over two different time periods. Average drawdown can be calculated by averaging the drawdown results in multiple cells. Typical average drawdown calculations involve county-aquifer units or GMA-aquifer units.

The old GAM had a regular grid where all cells were 640 acres, or one square mile. Averaging drawdowns with the old GAM was a relatively simple calculation of summing all drawdown results over a defined area and dividing the sum by the number of cells.

The new GAM has a variable grid that is refined near streams, and the cell sizes range from 10 acres to 640 acres. Thus, averaging drawdown must be weighted by the cell size. Appendix C contains summary tables of cell counts, areas, and average cell size for each county-aquifer unit for outcrop, downdip and total areas. Appendix C also presents bar graphs of the average cell size for each county-aquifer unit. Data for these tables and graphs was developed using a FORTRAN code that read the grid file of the new GAM. All data associated with the tables and graphs in Appendix C are contained in the directory named *GridFile* on the share site.

3.7.2 Average Drawdown Calculations

Average drawdown calculations were performed using a FORTRAN post-processor named *PredDD.exe*. The post-processor reads the simulation output file and the files with acreage totals for each unit (county-aquifer and GMA13-aquifer). Drawdowns for each cell are calculated based on a starting point of 2017 (the last stress period of the calibration period). The cell drawdown values are then multiplied by the cell acreage (drawdown-acreage product). The sum of all drawdown-acreage products for a particular unit (county-aquifer or GMA13-aquifer) are then divided by the total acreage of that unit to obtain and average drawdown.

4.0 Methods and Results

As noted above, two predictive simulations were completed to test the capabilities of the new GAM in the context of evaluating alternative desired future conditions:

- Scen2020 used the 2020 MAG values as the input for all stress periods
- Scen2080 used the 2080 MAG values as the input for all stress periods

Model input and output files for these simulations are contained in the directories named *Pump2020Scen* and *Pump2080Scen*.

4.1 Simulation Pumping

The development of the input data sets for pumping were previously described. Output from the simulations included actual pumping after reductions were applied on a cell-by-cell basis for each stress period to reflect declining groundwater levels that are not consistent with maintaining the "requested" level of pumping.

Table 4 presents a summary by GMA 13 county of the calibrated maximum pumping from 1980 to 2017, the year in which the maximum pumping occurred, the calibrated model pumping in 2017 (to provide context for how it changed in the predictive simulations), the simulated output pumping for 2020 (for both Scen2020 and Scen2080), and the simulated output pumping for 2080 (for both Scen2020 and Scen2080).

Table 4. Summary of Output Pumping

County	1980 to 2017 Maximum Pumping (AF/yr)	Year of Maximum Pumping	Calibrated Model Pumping (2017)	Simulated 2020 Pumping (AF/yr)		Simulated 2080 Pumping (AF/yr)	
				Scen2020	Scen2080	Scen2020	Scen2080
Atascosa	103,705	2010	38,745	54,632	62,592	54,593	62,563
Bexar	24,971	2010	2,424	44,134	41,722	42,843	40,291
Caldwell	6,835	2010	4,303	19,874	52,479	19,612	51,872
Dimmit	11,650	2012	6,439	4,121	4,121	4,123	4,124
Frio	202,782	2010	94,084	116,658	80,328	116,861	80,561
Gonzales	39,627	2015	36,111	65,670	103,635	65,669	103,633
Guadalupe	10,374	2010	3,271	29,325	28,556	27,590	25,830
Karnes	1,865	1982	1,332	691	1,043	691	1,043
LaSalle	16,281	2009	7,861	7,534	7,534	7,534	7,534
Maverick	3,346	1992	45	531	268	531	269
McMullen	1,804	1998	289	7,767	4,853	7,767	4,853
Medina	15,080	1984	1,835	2,611	2,611	2,607	2,611
Uvalde	4,047	1980	7	0	0	0	0
Webb	2,408	2009	425	954	954	954	954
Wilson	32,674	2010	23,956	39,228	118,057	39,213	118,043
Zavala	93,305	2011	50,607	38,427	34,631	38,439	34,634
GMA 13	-	-	271,734	432,157	543,384	570,754	570,754

Figure 11 presents the total pumping in GMA 13 (Sparta, Queen City, and Carrizo-Wilcox aquifers) for the calibrated model, the two predictive scenarios (Scen2020 and Scen2080), and, for comparison, the calibrated model period. Please note that while the intent was to set pumping at either 2020 levels of the MAG (Scen2020) or 2080 levels of the MAG (Scen2080), the model reduces the "requested" pumping to a level that is consistent with groundwater elevations that can sustain that amount of pumping. Appendix D presents similar hydrographs of individual counties in GMA 13.

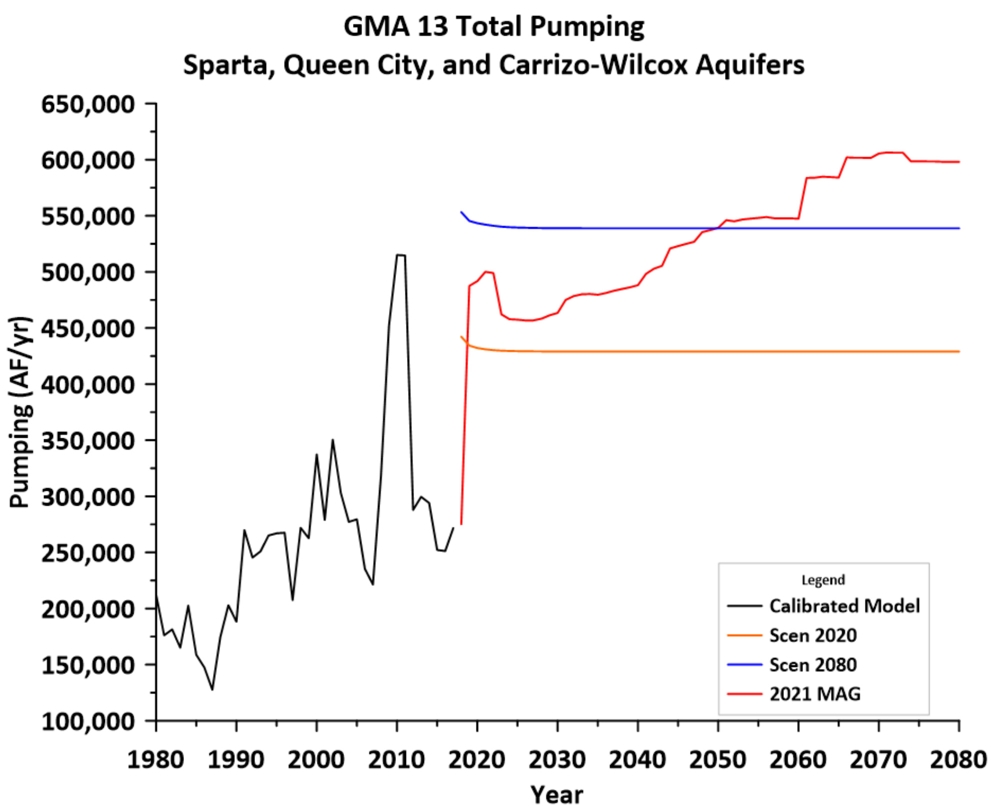


Figure 11. GMA 13 Total Pumping Comparison

The MAG simulation with the old GAM is characterized by a sharp increase in 2019, 2020, and 2021 (as compared with 2018 pumping) followed by a rapid decline after 2021 for the next 5 to 6 years.

Note after a few years for Scen2020 and Scen2080 pumping, the reductions are relatively small in the first few years of the simulations, and pumping is essentially sustainable for most of the simulations. However, more detailed examination of the results are needed to specifically identify the areas where pumping reductions were imposed.

The actual reductions are saved in output files named *Scen2020_wel_reduce.csv* and *Scen2080-wel_reduce.csv*. These files were subsequently processed to sum the total reductions for each stress period and saved as Excel files (*Scen2020_wel_reduce.xlsx* and *Scen2080_welreduce.xlsx*). These annual reductions from the input pumping (i.e. the WEL file) are presented in Figure 12.

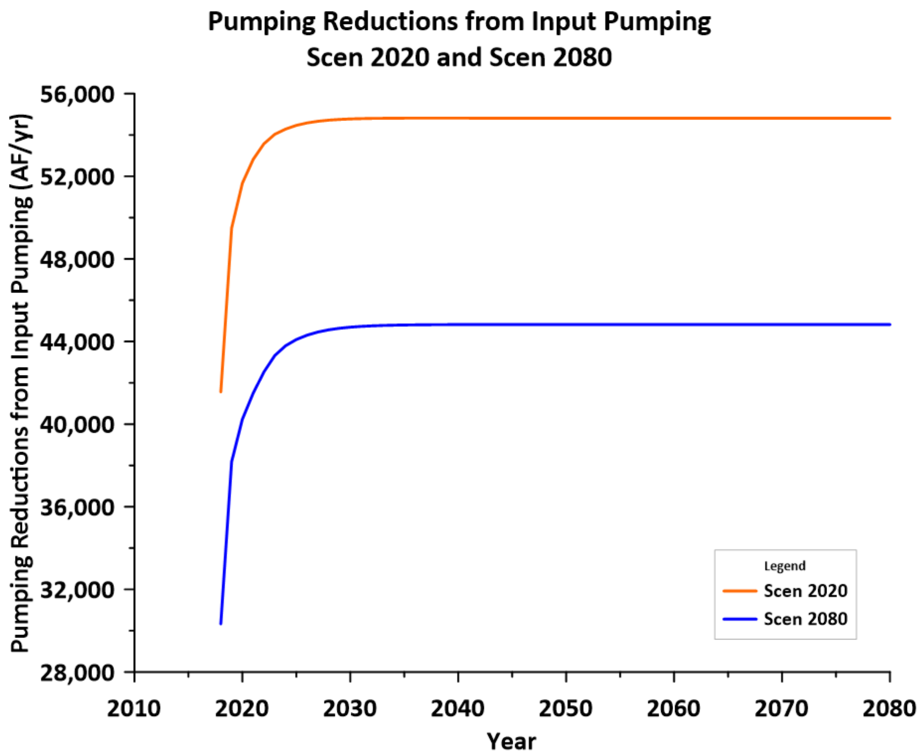


Figure 12. Pumping Reductions for Scen2020 and Scen2080

4.2 Average Drawdown

4.2.1 Desired Future Condition Average Drawdown

GMA 13 adopted a "secondary" DFC for the Sparta, Queen City, and Carrizo-Wilcox aquifers in GMA 13: average drawdown of 49 feet (+/- 5 feet) for all of GMA 13. The drawdown is calculated from the end of 2012 conditions through the year 2080. Furnans and Keester (2022, pp. 14-15) reported that the desired future condition is consistent with simulation "GMA13_2019_001" summarized during a meeting of Groundwater Management Area 13 members on March 19, 2021.

Documentation from Furnans (2022) inconsistently reported the starting date for drawdown calculations as 2000 and 2012, and only reported drawdowns through 2070. Furnans and Keester (2022) reported the drawdown calculations as 2012, and only reported drawdowns through 2070. Wade (2022) subsequently clarified that the intent was to use 2011 as the starting point for drawdown calculations but did not report the drawdown values for 2080 as part of her MAG report.

In order to have a consistent set of drawdown calculations through 2080 that used 2011 as a starting point to compare with the drawdown calculations of the predictive simulations, the FORTRAN program *getdd.exe* was written to calculate average drawdowns for county-model layer and county-aquifer units through 2080 using the output from Furnans (2022) and Furnans and Keester

(2022) designated as "GMA13_2019_001". A summary of 2011 to 2080 average drawdown is presented in Table 5, which provides some additional information (i.e. average drawdowns for each county-aquifer unit) that can be useful to evaluate the predictive drawdowns from the new GAM with similar pumping assumptions.

Table 5. Summary of Average Drawdown in feet (2011 to 2080) for DFC Simulations

County	Sparta	Queen City	Carrizo-Wilcox	Overall Aquifer	Overall*
Atascosa	15.28	24.11	131.87	104.63	94.93
Bexar	-	0.00	109.04	109.04	107.92
Caldwell	-	91.79	52.82	53.59	51.55
Dimmit	-	-	-4.63	-4.63	-4.60
Frio	5.37	-1.97	56.00	46.89	43.51
Gonzales	21.29	26.57	169.56	144.34	127.35
Guadalupe	0.00	**	143.92	143.72	139.24
Karnes	0.00	0.00	202.53	202.53	185.58
LaSalle	2.40	17.90	16.24	16.11	17.43
Maverick	-	-	-12.36	-12.36	-12.16
McMullen	26.24	39.64	46.11	45.34	48.00
Medina	-	-	30.75	30.75	30.68
Uvalde	-	-	15.79	15.79	15.79
Webb	-	-	-4.28	-4.28	-4.90
Wilson	11.58	19.89	241.79	204.79	178.64
Zavala	-	-	13.45	13.45	10.23
GMA13	14.38	19.41	62.29	58.54	53.57

* Overall includes Weches and Reklaw aquitards

** Queen City in Guadalupe County is only one cell in new GAM, calculations ignored

The overall average drawdown estimate that includes the two aquitard units is consistent with the documentation provided in Wade (2022). Please note that the overall average drawdown for GMA 13 from this calculation is about 54 feet, which is consistent with the "secondary" DFC of 49 feet (+/- 5 feet) as adopted by GMA 13.

4.2.2 Predictive Scenario Average Drawdown

Average drawdown from 2017 to 2080 for the county-aquifer units in GMA 13 are presented below as:

- Table 6 and Figure 13: Scen2020 (input pumping set equal to 2020 MAG pumping, as described above)
- Table 7 and Figure 14: Scen2080 (input pumping set equal to 2080 MAG pumping, as described above)

Please note that these summaries include breakdowns for the outcrop area, downdip area, and overall area of each GMA 13 county.

Table 6. Average Drawdowns (2017 to 2080) for: Scen2020

County	Outcrop Area Drawdown (ft)			Downdip Area Drawdown (ft)			Overall Drawdown (ft)		
	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox
Atascosa	23.63	16.39	11.69	1.96	13.93	30.80	3.36	14.37	30.10
Bexar	-	-	20.58	-	-	43.99	-	-	28.00
Caldwell	-	10.23	19.53	-	-	24.06	-	10.23	21.93
Dimmit	0.96	0.29	-6.10	-	0.11	-30.25	0.96	0.26	-28.56
Frio	3.94	13.17	-1.02	1.41	3.93	20.29	2.78	8.10	20.15
Gonzales	6.04	4.04	31.96	0.44	3.73	37.83	0.79	3.78	37.79
Guadalupe	-	-	51.61	-	-	63.03	-	-	56.45
Karnes	-	-	-	0.39	1.96	28.18	0.39	1.96	28.18
LaSalle	0.98	-	-	-0.01	0.39	45.80	0.13	0.39	45.80
Maverick	-	-	-3.40	-	-	-19.45	-	-	-7.26
McMullen	-	-	-	0.05	0.96	84.73	0.05	0.96	84.73
Medina	-	-	2.82	-	-	7.03	-	-	4.69
Uvalde	-	-	-4.82	-	-	-9.18	-	-	-6.21
Webb	1.10	0.92	5.07	0.06	0.14	46.87	0.18	0.47	46.65
Wilson	8.35	14.20	6.59	1.19	4.63	26.58	2.06	8.39	25.37
Zavala	-14.84	-1.16	-14.12	-	-0.89	-66.46	-14.84	-1.09	-62.98
GMA13	0.13	4.17	11.82	0.51	3.15	22.29	0.45	3.49	21.56

Table 7. Average Drawdowns (2017 to 2080) for: Scen2080

County	Outcrop Area Drawdown (ft)			Downdip Area Drawdown (ft)			Overall Drawdown (ft)		
	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox
Atascosa	24.87	10.58	11.05	1.89	11.45	24.08	3.38	11.29	23.60
Bexar	-	-	21.48	-	-	48.74	-	-	30.13
Caldwell	-	12.95	30.50	-	-	106.99	-	12.95	71.04
Dimmit	0.96	0.20	-12.13	-	-0.10	-76.68	0.96	0.15	-72.17
Frio	2.47	-17.71	-28.82	-0.35	-1.24	-57.16	1.18	-8.67	-56.97
Gonzales	5.88	8.38	51.97	0.38	7.44	96.83	0.73	7.58	96.55
Guadalupe	-	-	82.50	-	-	148.93	-	-	110.63
Karnes	-	-	-	0.67	3.65	50.27	0.67	3.65	50.27
LaSalle	0.97	-	-	-0.01	0.08	-59.66	0.12	0.08	-59.66
Maverick	-	-	-5.89	-	-	-32.66	-	-	-12.32
McMullen	-	-	-	0.03	0.51	15.30	0.03	0.51	15.30
Medina	-	-	-1.99	-	-	-3.52	-	-	-2.67
Uvalde	-	-	-8.33	-	-	-15.39	-	-	-10.59
Webb	1.09	0.65	1.95	0.06	0.06	-15.00	0.17	0.31	-14.91
Wilson	15.11	22.94	21.81	2.29	9.47	98.18	3.85	14.75	93.53
Zavala	-14.91	-1.23	-23.92	-	-1.68	-111.14	-14.91	-1.34	-105.34
GMA13	0.09	0.35	15.80	0.50	3.03	-12.91	0.43	2.15	-10.88

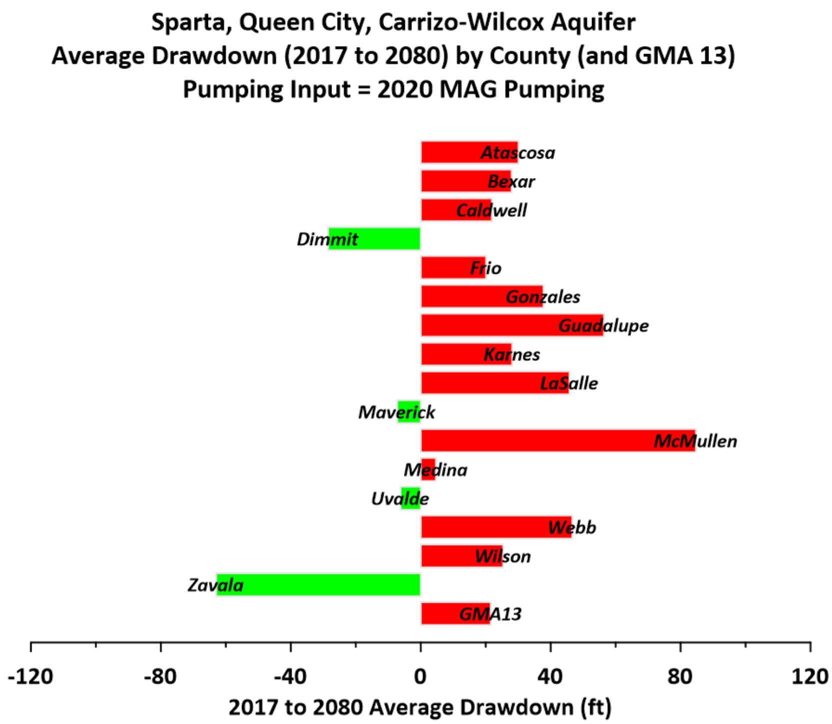


Figure 13. Average Drawdowns (2017 to 2080) for Scen2020

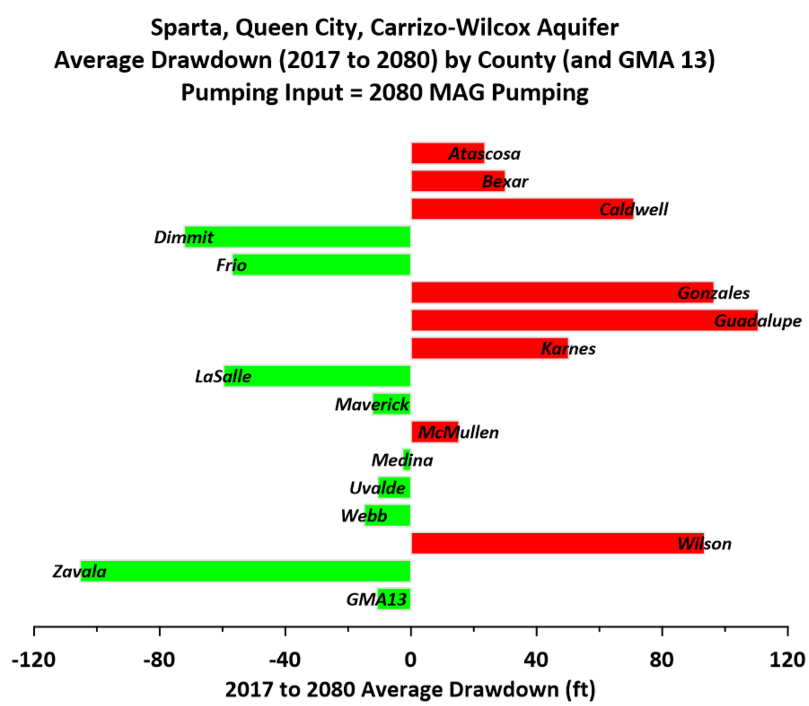


Figure 14. Average Drawdowns (2017 to 2080) for Scen2080

Please note that the average drawdown in each county is impacted by whether the overall pumping during the scenario is generally higher than 2017 pumping or less than 2017 pumping. To provide some context for these relationships, Table 8 and Figure 15 are presented.

Table 8. Summary of Pumping Differences and Average Drawdown

County	County Code on Figure	Calibrated Model Pumping (2017)	Simulated 2080 Pumping (AF/yr)		Pumping Differences (AF/yr)		2017 to 2080 Simulated Drawdown (ft)	
			Scen2020	Scen2080	Scen2020 - 2017	Scen2080 - 2017	Scen2020	Scen2080
Atascosa	AT	38,745	54,593	62,563	15,848	23,818	30.10	23.60
Bexar	BE	2,424	42,843	40,291	40,419	37,867	28.00	30.13
Caldwell	CA	4,303	19,612	51,872	15,309	47,569	21.93	71.04
Dimmit	DI	6,439	4,123	4,124	-2,316	-2,315	-28.56	-72.17
Frio	FR	94,084	116,861	80,561	22,777	-13,523	20.15	-56.97
Gonzales	GO	36,111	65,669	103,633	29,558	67,522	37.79	96.55
Guadalupe	GU	3,271	27,590	25,830	24,319	22,559	56.45	110.63
Karnes	KA	1,332	691	1,043	-641	-289	28.18	50.27
LaSalle	LA	7,861	7,534	7,534	-327	-327	45.80	-59.66
Maverick	MA	45	531	269	486	224	-7.26	-12.32
McMullen	MC	289	7,767	4,853	7,478	4,564	84.73	15.30
Medina	ME	1,835	2,607	2,611	772	776	4.69	-2.67
Uvalde	UV	7	0	0	-7	-7	-6.21	-10.59
Webb	WE	425	954	954	529	529	46.65	-14.91
Wilson	WI	23,956	39,213	118,043	15,257	94,087	25.37	93.53
Zavala	ZA	50,607	38,439	34,634	-12,168	-15,973	-62.98	-105.34

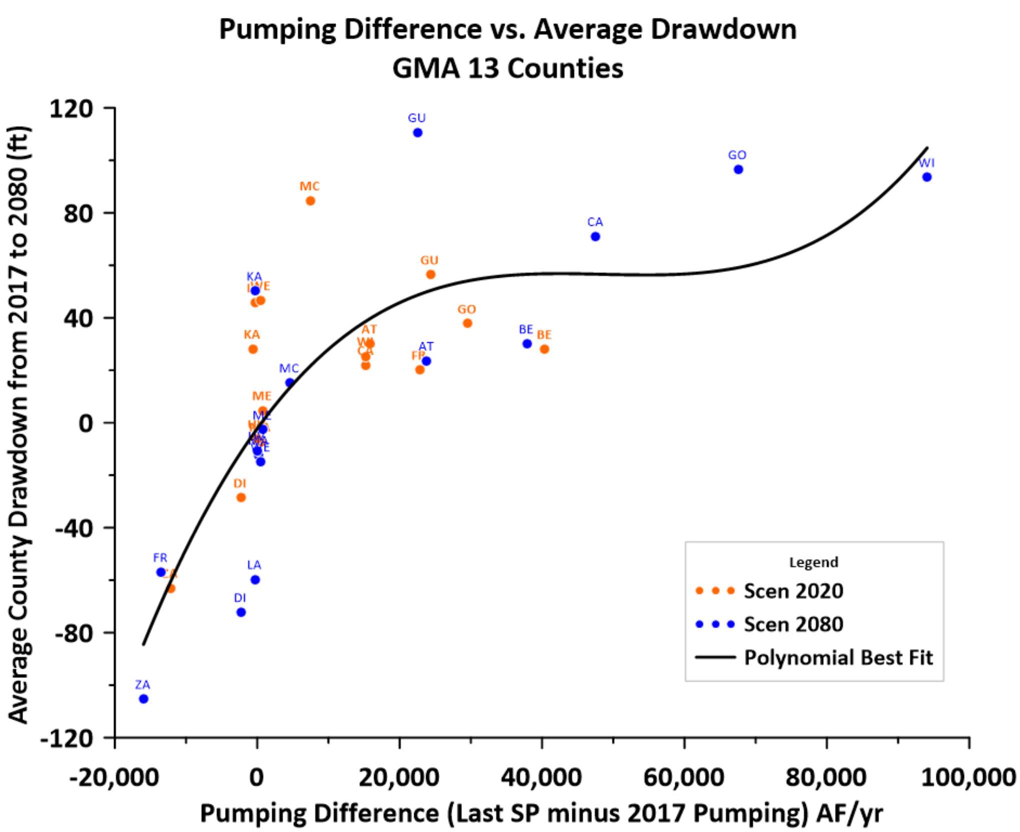


Figure 15. Summary of Pumping Differences and Average Drawdown

The results presented in Table 8 and Figure 15 generally demonstrate that when pumping increases from 2017 levels, drawdowns increase. Conversely, when pumping decreases from 2017 levels, groundwater recovery is calculated (negative average drawdowns). For example, pumping in Zavala County in both Scen2020 and Scen2080 is lower than 2017 pumping, and average drawdowns are negative, which represents a groundwater elevation recovery is calculated by the model. Please recall that the DFC drawdown for Zavala County is about 10 feet. This may the result of the limitation of the old GAM where groundwater declines persisted, even with reductions in pumping. From a conceptual standpoint, the new GAM correctly calculates a groundwater elevation recovery when pumping is reduced.

Another example is Wilson County. Please note that Scen2020 pumping (about 39,000 AF/yr) is lower than Scen2080 pumping (about 118,000 AF/yr). The average drawdown from 2017 to 2080 in Scen2020 is about 25 feet, while the average drawdown from 2017 to 2080 is about in Scen2080 is about 94 feet. The relative pumping in Caldwell County (about 20,000 in Scen2020 and about 52,000 in Scen2080) has the same effect on average drawdown (22 feet in Scen2020 and 71 feet in Scen2080). These relationships also are observed in Gonzales County (pumping increases from about 66,000 AF/yr to about 104,000 AF/yr and average drawdown increases from about 38 feet to 97 feet).

The results can also be used to observe impacts across county line. The most prominent example is Guadalupe County. Pumping in Scen2020 is about 28,000 AF/yr, while pumping in Scen2080 is slightly lower (about 24,000 AF/yr). Average drawdown in Guadalupe County, however, in Scen2020 is about 56 feet, and is about 111 feet in Scen2080. It appears that the pumping increases in Caldwell, Gonzales, and Wilson counties may be explanations to the increased drawdowns in Guadalupe County between Scen2020 and Scen2080 since the pumping in Guadalupe County is essentially the same between the two scenarios.

4.2.3 Comparison of Average Drawdowns

The average drawdowns for each county-aquifer unit for the DFC simulation using the old GAM and the predictive scenario simulations using the new GAM were compared to gain some additional insight on the performance of the new GAM. These results are presented as:

- Figure 16: Sparta Aquifer
- Figure 17: Queen City Aquifer
- Figure 18: Carrizo-Wilcox Aquifer

For these plots, the average drawdown for the DFC simulation using the old GAM are plotted on the x-axis, and the average drawdown for the two predictive simulations (Scen2020 and Scen2080) were plotted on the y-axis. A one-to-one line was also included to divide the plot into two areas:

- Points to the right or below the one-to-one line are counties where the old GAM average drawdown is greater than the new GAM average drawdown.
- Points to the left or above the one-to-one line are counties where the old GAM average drawdown is less than the new GAM average drawdown.

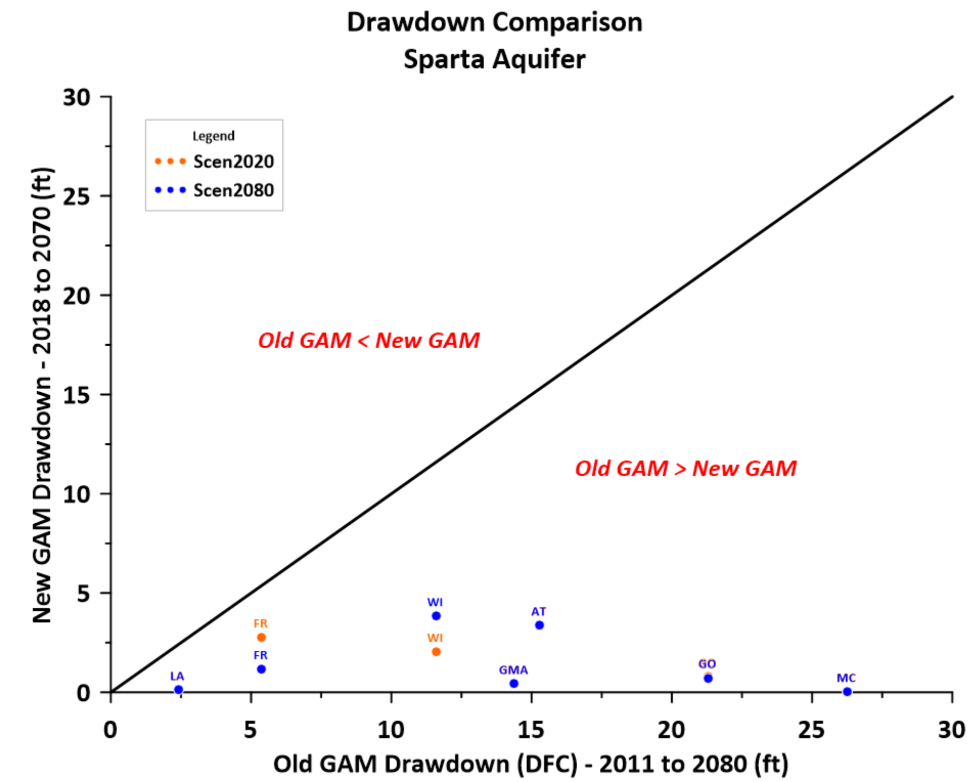


Figure 16. Drawdown Comparison: Sparta Aquifer

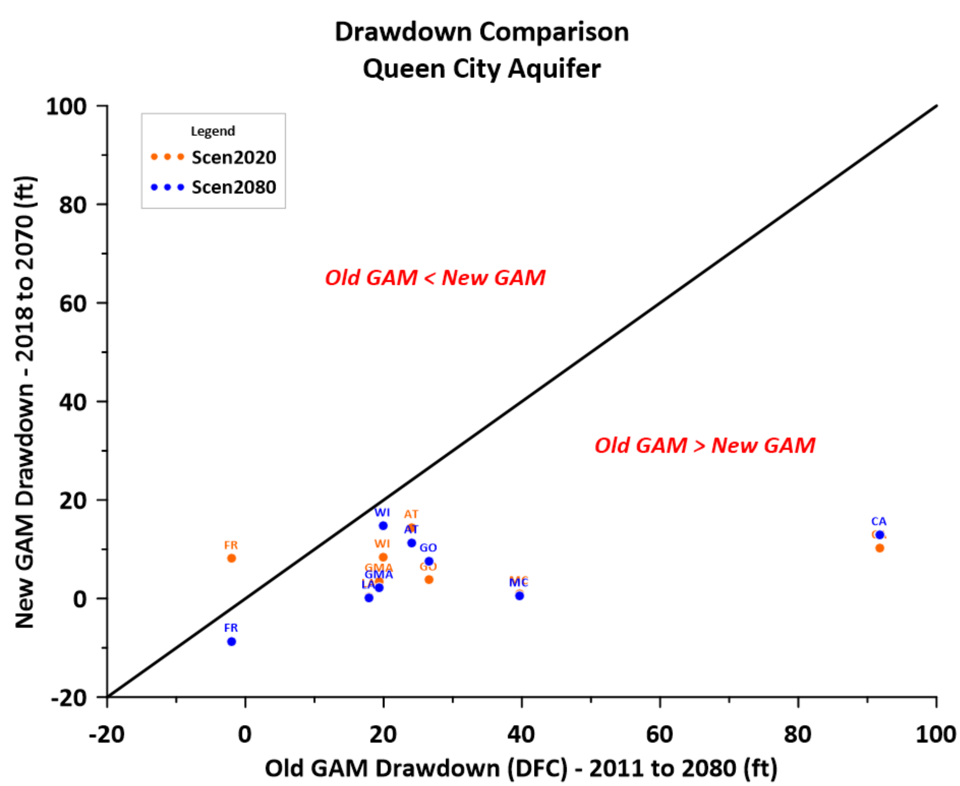


Figure 17. Drawdown Comparison: Queen City Aquifer

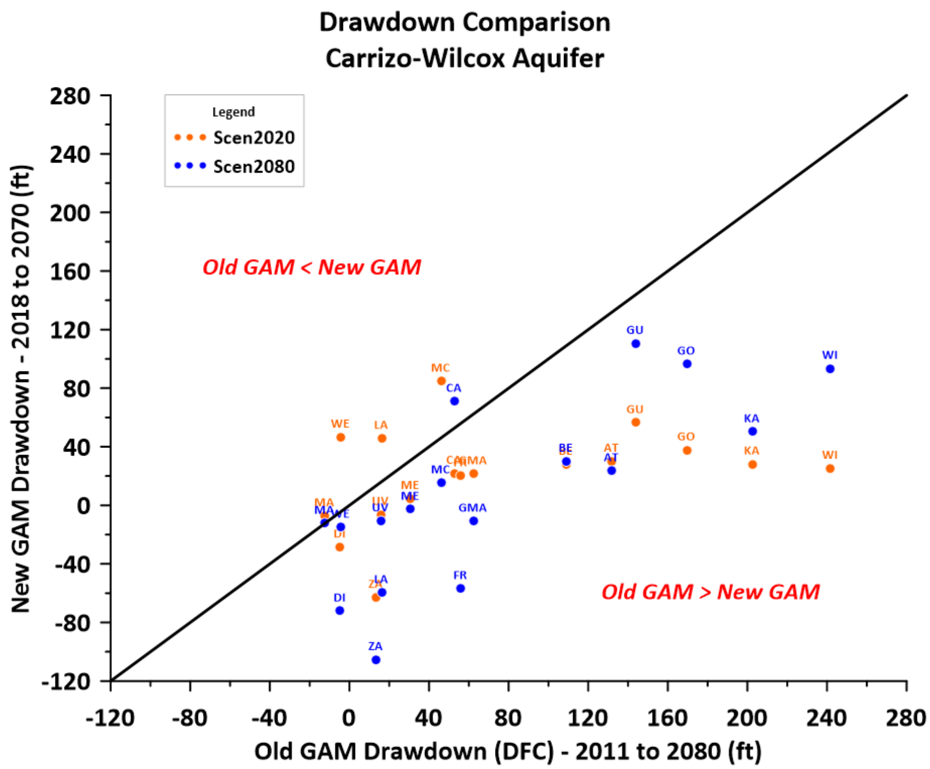


Figure 18. Drawdown Comparison: Carrizo-Wilcox Aquifer

Please note that for the Sparta Aquifer, all points lie to the right and below the one-to-one line, which means that the new GAM generally predicts higher drawdowns than the old GAM. For the Queen City Aquifer, only one point is to the left and above the one-to-one line (Frio County for Scen2020). For Scen2080, the point is to the right and below the one-to-one line. Pertinent pumping information for the Queen City pumping in Frio County needed to interpret these results is:

- MAG pumping: 6,755 AF/yr in 2020, decreasing to 3,970 AF/yr in 2080, leading to a groundwater level recovery of about 2 ft (DFC)
- 2017 pumping from calibrated model is 1,060 AF/yr
- Scen2020 pumping: 5,728 AF/yr in 2018 decreasing to 5,680 AF/yr, leading to a drawdown of about 8 feet.
- Scen2080 pumping: 3,493 AF/yr decreasing to 3,526 AF/yr in 2080, leading to a groundwater level recovery of about 9 feet.

The fact that pumping in Scen2020 and Scen2080 are both well above the 2017 pumping suggests that there should be a drawdown in the Queen City Aquifer in Frio County. However, the results suggest that the Queen City Aquifer is also impacted by the underlying Carrizo-Wilcox Aquifer. Please note that in Scen2020, there is about 20 feet of drawdown in the Carrizo-Wilcox in Frio County and there is about 57 feet of groundwater elevation recovery in the Carrizo-Wilcox in Frio County in Scen2080. This is due to:

- 2017 pumping in the Carrizo-Wilcox pumping in Frio County is about 92,000 AF/yr
- Scen2020 pumping in the Carrizo-Wilcox pumping in Frio County is about 110,000 AF/yr
- Scen2080 pumping in the Carrizo-Wilcox pumping in Frio County is about 76,000 AF/yr

Thus, it is clear that the increase in pumping simulated in Scen2020 (as compared to the 2017 pumping) results in drawdown in the Carrizo-Wilcox Aquifer in Frio County of about 20 feet, while a decrease in pumping simulated in Scen2080 (as compared to the 2017 pumping) results in a recovery of about 57 feet. The results in the Queen City suggest that the new GAM simulates cross-formational impacts between the Queen City and Carrizo-Wilcox in Frio County.

The Carrizo-Wilcox Aquifer drawdown comparison demonstrates that, in general, the old GAM drawdowns are greater than the new GAM drawdowns. Of note are the simulated groundwater recoveries in Scen2020 (Dimmit, Maverick, Uvalde, and Zavala counties) and in Scen2080 (Dimmit, Frio, LaSalle, Maverick, Uvalde, Webb, and Zavala). These are all associated with reductions in pumping as compared to 2017 pumping. As described earlier, these pumping amounts are based on the current MAG values, which may have been set based on reliance on the old GAM.

Please recall that the old GAM had a limitation with respect to persistently declining groundwater elevations, even with pumping reductions. It is possible that in order to achieve a desired future condition of a few feet of drawdown, pumping was reduced in the simulations to achieve the desired results. The following are the drawdowns in the Carrizo-Wilcox associated with the DFC simulation for these counties:

- Dimmit: -4.63 ft
- Frio: 47 ft
- LaSalle: 16 ft
- Maverick: -12 ft
- Uvalde: 16 ft
- Webb: -4 ft
- Zavala: 13 ft

This information will be useful to GMA 13 as they move forward in the next round of joint planning using the new GAM which appropriately simulates the effects of pumping increases and decreases (i.e. drawdown and recovery of groundwater elevations).

5.0 Limitations

The simulations, Scen2020 and Scen2080 were designed to the calculate drawdown from 2017 to 2080 with the new GAM that are similar to the DFC simulation that used the old GAM. Choosing to use a constant input pumping for these two scenarios is a limitation to a full comparison. Neither scenario fully matched the actual DFC/MAG simulation with the various increases and decreases that were included in the MAG report. The constant input approach was chosen to also evaluate the impacts of the WEL package's pumping reduction feature to better understand the limitations associated with impacts of declining groundwater elevations on pumping and gain a better understanding of the possibility to better simulate sustainable pumping scenarios.

As with all GAM simulations of this nature, the results are primarily useful for regional analyses (i.e. county-aquifer or GCD-aquifer scale). Smaller scale analyses should proceed with caution given the objectives of model development and calibration.

6.0 References

Furnans, J., 2022. Groundwater Availability Modeling Technical Elements, 2021 Joint Planning. Technical Memorandum to Groundwater Management Area 13. January 14, 2022, 5p.

Furnans, J. and Keester, M., 2020. 2021 Joint Planning Desired Future Conditions Explanatory Report. Prepared by Groundwater Management Area 13 Joint Planning Committee with technical assistance by Jordan Furnans and Michael Keester, LRE Water. January 14, 2022, 510p.

Wade, S.C., 2022. GAM Run 21-018MAG: Modeled Available Groundwater for the Carrizo-Wilcox, Queen City, Sparta, and Yegua-Jackson Aquifers in Groundwater Management Area 13. Texas Water Development Board, Groundwater Division, Groundwater Availability Modeling Department. July 25, 2022, 32p.

Appendix A

Modeled Available Groundwater for the Sparta, Queen City, and Carrizo-Wilcox Aquifers by County

Sparta Aquifer Modeled Available Groundwater by County
Groundwater Management Area 13
from Wade (2022)

County	2020	2030	2040	2050	2060	2070	2080
Atascosa	1,218	1,187	1,043	998	961	932	932
Bexar							
Caldwell							
Dimmit							
Frio	897	623	603	576	557	534	534
Gonzales	3,524	2,451	2,457	2,451	2,451	2,451	2,451
Guadalupe							
Karnes							
La Salle	0	0	0	0	0	0	0
Maverick							
McMullen	0	0	0	0	0	0	0
Medina							
Uvalde							
Webb							
Wilson	335	182	163	144	128	114	114
Zavala							
Total GMA 13	5,974	4,443	4,266	4,169	4,097	4,031	4,031

Queen City Aquifer Modeled Available Groundwater by County
Groundwater Management Area 13
from Wade (2022)

County	2020	2030	2040	2050	2060	2070	2080
Atascosa	4,070	4,525	4,537	4,495	4,390	4,285	4,285
Bexar							
Caldwell	4,842	4,829	4,557	4,545	4,545	3,977	3,977
Dimmit							
Frio	6,702	4,533	4,380	4,231	4,066	3,927	3,927
Gonzales	4,973	4,960	4,973	4,960	4,960	4,500	4,500
Guadalupe	0	0	0	0	0	0	0
Karnes							
La Salle	1	1	1	1	1	1	1
Maverick							
McMullen	3	3	3	3	3	3	3
Medina							
Uvalde							
Webb							
Wilson	2,631	1,423	1,267	1,123	1,000	892	892
Zavala							
Total GMA 13	23,222	20,274	19,718	19,358	18,965	17,585	17,585

Carrizo-Wilcox Aquifer Modeled Available Groundwater by County
Groundwater Management Area 13
from Wade (2022)

County	2020	2030	2040	2050	2060	2070	2080
Atascosa	51,924	54,397	55,329	56,828	58,406	59,982	59,982
Bexar	69,727	68,451	68,928	68,739	67,653	67,849	67,849
Caldwell	18,180	24,877	32,775	42,514	45,688	49,635	49,594
Dimmit	3,895	3,885	3,895	3,885	3,885	3,885	3,885
Frio	114,827	86,995	85,143	82,950	81,018	79,131	79,131
Gonzales	60,431	76,265	90,788	102,373	102,747	103,707	96,161
Guadalupe	55,637	39,563	41,668	43,315	42,118	42,199	41,659
Karnes	693	758	843	931	1,001	1,043	1,043
La Salle	6,554	6,536	6,554	6,536	6,536	6,536	6,536
Maverick	547	545	547	545	545	276	276
McMullen	7,789	7,768	4,867	4,854	4,854	4,854	4,854
Medina	2,635	2,628	2,635	2,628	2,628	2,628	2,628
Uvalde	0	0	0	0	0	0	0
Webb	912	910	912	910	910	910	910
Wilson	38,229	38,284	43,604	68,609	105,947	125,670	125,670
Zavala	38,303	36,675	35,399	35,204	35,006	34,831	34,540
Total GMA 13	470,283	448,537	473,887	520,821	558,942	583,136	574,718

Appendix B

Comparison of County-Aquifer Pumping Estimates: 2020 and 2080, MAG Report (Wade, 2022), Spreadsheet Calculations, WEL File Pre-Processor

Appendix B
Comparison of County-Aquifer Pumping Estimates: 2020 and 2080
MAG Report (Wade, 2020), Spreadsheet Calculations, WEL File Pre-Processor

County	Aquifer	2020 Pumping (AF/yr)			2080 Pumping (AF/yr)		
		MAG Report	Spreadsheet	WEL Input	MAG Report	Spreadsheet	WEL Input
Atascosa	Sparta	1,218	1,219	1,236	932	935	953
Frio	Sparta	897	931	944	534	556	569
Gonzales	Sparta	3,524	3,552	3,551	2,451	2,488	2,488
La Salle	Sparta	0	986	986	0	986	986
McMullen	Sparta	0	0	0	0	0	0
Wilson	Sparta	335	462	472	114	156	167
Atascosa	Queen City	4,070	4,072	4,129	4,285	4,299	4,356
Caldwell	Queen City	4,842	5,113	5,123	3,977	4,261	4,271
Frio	Queen City	6,702	6,755	6,790	3,927	3,971	4,007
Gonzales	Queen City	4,973	5,063	5,062	4,500	4,604	4,603
Guadalupe	Queen City	0	0	0	0	0	0
LaSalle	Queen City	1	12	12	1	12	12
McMullen	Queen City	3	0	0	3	0	0
Wilson	Queen City	2,631	2,778	2,814	892	944	980
Atascosa	Carrizo-Wilcox	51,924	51,780	52,995	59,982	59,982	61,196
Bexar	Carrizo-Wilcox	69,727	69,537	69,535	67,849	67,849	67,847
Caldwell	Carrizo-Wilcox	18,180	18,169	18,169	49,594	49,633	49,632
Dimmit	Carrizo-Wilcox	3,895	4,125	4,125	3,885	4,125	4,125
Frio	Carrizo-Wilcox	114,827	114,009	116,754	79,131	78,784	81,529
Gonzales	Carrizo-Wilcox	60,431	57,069	57,068	96,161	96,562	96,560
Guadalupe	Carrizo-Wilcox	55,637	50,352	50,369	41,659	40,519	40,523
Karnes	Carrizo-Wilcox	693	708	732	1,043	1,061	1,085
La Salle	Carrizo-Wilcox	6,554	6,536	6,536	6,536	6,536	6,536
Maverick	Carrizo-Wilcox	547	545	531	276	276	269
McMullen	Carrizo-Wilcox	7,789	7,768	7,767	4,854	4,854	4,853
Medina	Carrizo-Wilcox	2,635	2,658	2,660	2,628	2,647	2,649
Uvalde	Carrizo-Wilcox	0	0	0	0	0	0
Webb	Carrizo-Wilcox	912	909	910	910	909	910
Wilson	Carrizo-Wilcox	38,229	38,119	38,926	125,670	126,361	127,168
Zavala	Carrizo-Wilcox	38,303	38,440	38,440	34,540	34,634	34,634

Appendix C

Grid Cell Count and Acreage by County and Aquifer

Outcrop Area

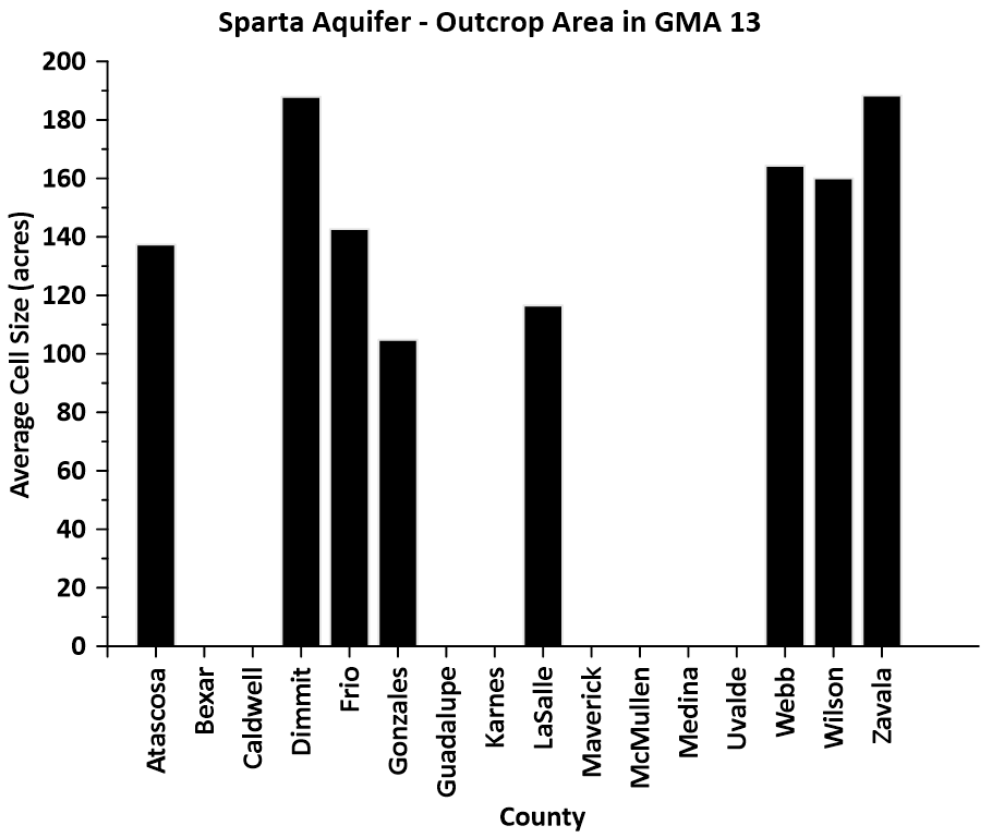
County Code	County Name	Cell Count			Area (Acres)			Average Cell Size (acres)		
		Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox
7	Atascosa	233	1,229	540	32,000	113,000	78,720	137	92	146
11	Bastrop	21	45	1,156	3,840	24,480	126,400	183	544	109
13	Bee	0	0	0	0	0	0	0	0	0
15	Bexar	0	0	2,022	0	0	207,360	0	0	103
28	Caldwell	0	90	1,615	0	10,560	205,600	0	117	127
59	DeWitt	0	0	0	0	0	0	0	0	0
64	Dimmit	417	3,759	991	78,360	477,480	157,000	188	127	158
75	Fayette	8	0	0	1,400	0	0	175	0	0
82	Frio	1,045	2,467	163	149,080	279,040	13,480	143	113	83
89	Gonzales	287	922	115	30,080	90,280	11,800	105	98	103
94	Guadalupe	0	4	1,125	0	640	218,880	0	160	195
128	Karnes	0	0	0	0	0	0	0	0	0
139	LaSalle	1,047	0	0	122,040	0	0	117	0	0
143	Lavaca	0	0	0	0	0	0	0	0	0
149	LiveOak	0	0	0	0	0	0	0	0	0
159	Maverick	0	0	1,180	0	0	130,120	0	0	110
162	McMullen	0	0	0	0	0	0	0	0	0
163	Medina	0	0	1,850	0	0	207,200	0	0	112
232	Uvalde	0	0	887	0	0	88,280	0	0	100
240	Webb	469	3,130	276	77,080	492,040	18,840	164	157	68
247	Wilson	148	967	662	23,680	140,560	85,760	160	145	130
254	Zavala	636	4,426	1,489	119,760	421,240	147,760	188	95	99
255	Mexico	237	323	890	57,720	59,960	152,720	244	186	172
999	GMA 13	4,485	17,204	13,062	686,520	2,078,480	1,629,360	153	121	125

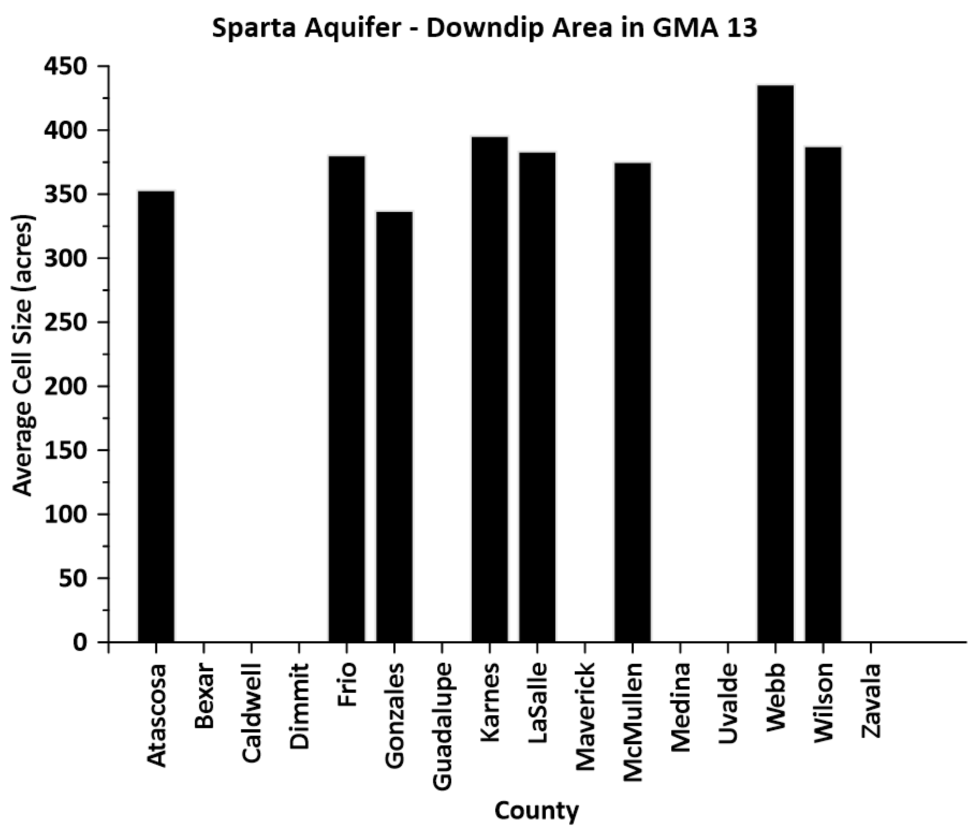
Downdip Area

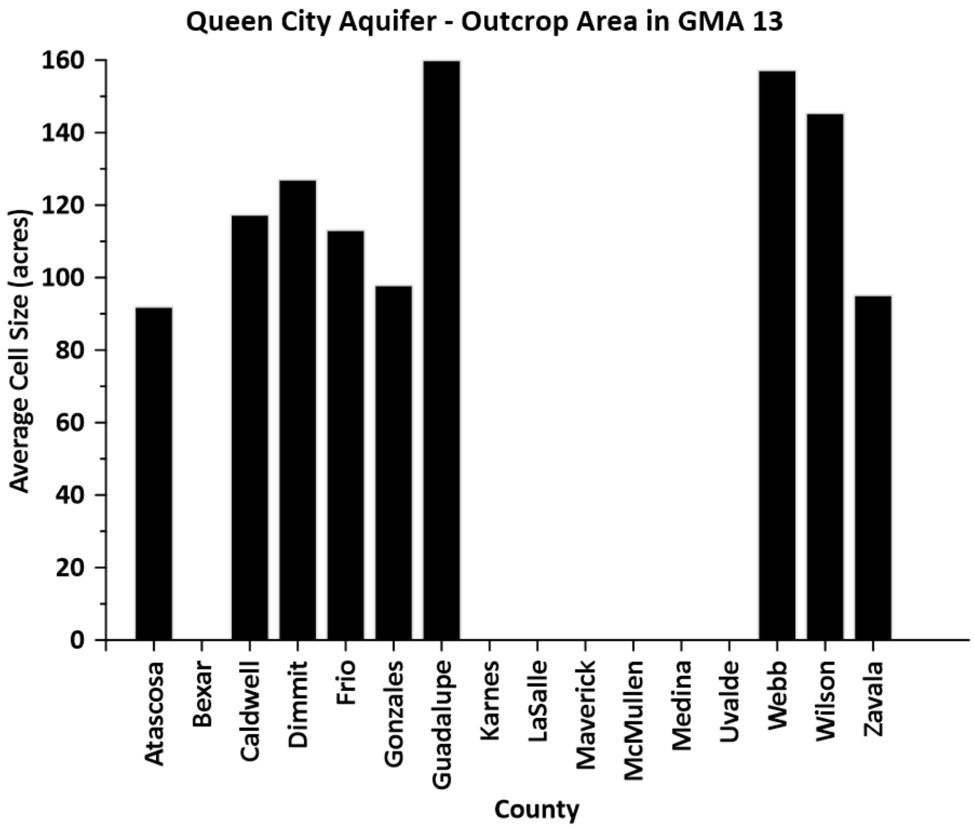
County Code	County Name	Cell Count			Area (Acres)			Average Cell Size (acres)		
		Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox
7	Atascosa	1,307	862	3,348	461,600	507,040	2,067,840	353	588	618
11	Bastrop	6	19	497	3,840	11,200	249,920	640	589	503
13	Bee	103	64	192	41,920	40,960	122,880	407	640	640
15	Bexar	0	0	239	0	0	96,320	0	0	403
28	Caldwell	0	0	537	0	0	231,840	0	0	432
59	DeWitt	883	543	1,629	350,080	347,520	1,042,560	396	640	640
64	Dimmit	0	192	3,473	0	104,640	2,091,200	0	545	602
75	Fayette	153	125	372	78,240	79,520	238,080	511	636	640
82	Frio	331	680	3,213	125,920	339,200	1,995,360	380	499	621
89	Gonzales	1,321	850	3,029	445,120	500,320	1,891,040	337	589	624
94	Guadalupe	0	0	330	0	0	160,800	0	0	487
128	Karnes	974	599	1,797	385,280	383,360	1,150,080	396	640	640
139	LaSalle	2,050	1,403	4,203	785,920	896,960	2,689,920	383	639	640
143	Lavaca	763	455	1,365	292,480	291,200	873,600	383	640	640
149	LiveOak	626	329	987	213,920	210,560	631,680	342	640	640
159	Maverick	0	0	140	0	0	41,120	0	0	294
162	McMullen	1,515	882	2,646	568,320	564,480	1,693,440	375	640	640
163	Medina	0	0	465	0	0	165,600	0	0	356
232	Uvalde	0	0	157	0	0	41,440	0	0	264
240	Webb	1,370	1,109	5,601	596,960	684,800	3,531,840	436	617	631
247	Wilson	443	394	2,201	171,680	217,600	1,322,240	388	552	601
254	Zavala	0	258	3,607	0	151,680	2,074,720	0	588	575
255	Mexico	597	664	3,130	294,720	414,400	1,890,880	494	624	604
999	GMA 13	8,770	7,071	35,498	3,338,560	4,240,800	21,479,360	381	600	605

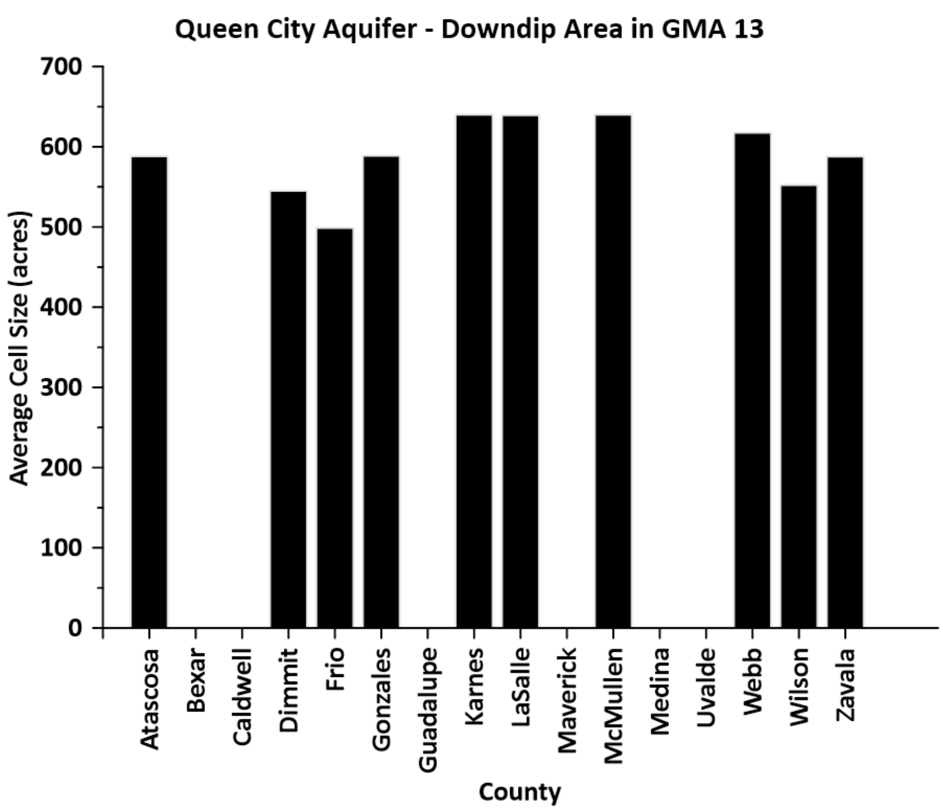
Total Area

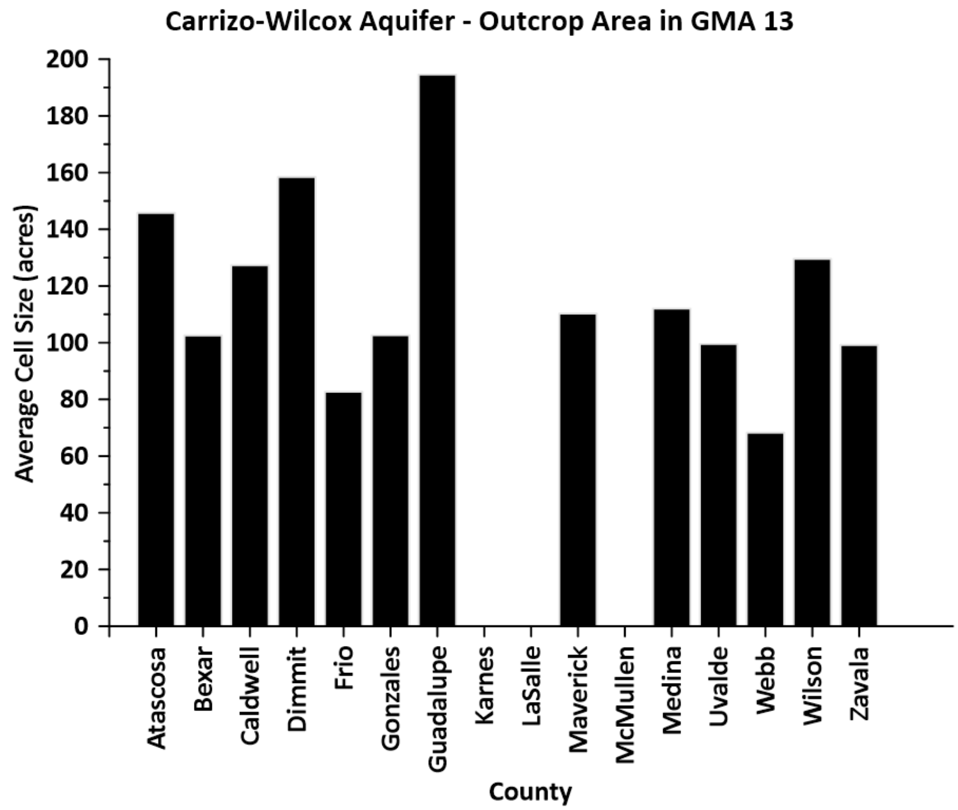
County Code	County Name	Cell Count			Area (Acres)			Average Cell Size (acres)		
		Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox	Sparta	Queen City	Carrizo-Wilcox
7	Atascosa	1,540	2,091	3,888	493,600	620,040	2,146,560	321	297	552
11	Bastrop	27	64	1,653	7,680	35,680	376,320	284	558	228
13	Bee	103	64	192	41,920	40,960	122,880	407	640	640
15	Bexar	0	0	2,261	0	0	303,680	0	0	134
28	Caldwell	0	90	2,152	0	10,560	437,440	0	117	203
59	DeWitt	883	543	1,629	350,080	347,520	1,042,560	396	640	640
64	Dimmit	417	3,951	4,464	78,360	582,120	2,248,200	188	147	504
75	Fayette	161	125	372	79,640	79,520	238,080	495	636	640
82	Frio	1,376	3,147	3,376	275,000	618,240	2,008,840	200	196	595
89	Gonzales	1,608	1,772	3,144	475,200	590,600	1,902,840	296	333	605
94	Guadalupe	0	4	1,455	0	640	379,680	0	160	261
128	Karnes	974	599	1,797	385,280	383,360	1,150,080	396	640	640
139	LaSalle	3,097	1,403	4,203	907,960	896,960	2,689,920	293	639	640
143	Lavaca	763	455	1,365	292,480	291,200	873,600	383	640	640
149	LiveOak	626	329	987	213,920	210,560	631,680	342	640	640
159	Maverick	0	0	1,320	0	0	171,240	0	0	130
162	McMullen	1,515	882	2,646	568,320	564,480	1,693,440	375	640	640
163	Medina	0	0	2,315	0	0	372,800	0	0	161
232	Uvalde	0	0	1,044	0	0	129,720	0	0	124
240	Webb	1,839	4,239	5,877	674,040	1,176,840	3,550,680	367	278	604
247	Wilson	591	1,361	2,863	195,360	358,160	1,408,000	331	263	492
254	Zavala	636	4,684	5,096	119,760	572,920	2,222,480	188	122	436
255	Mexico	834	987	4,020	352,440	474,360	2,043,600	423	481	508
999	GMA 13	13,255	24,275	48,560	4,025,080	6,319,280	23,108,720	304	260	476

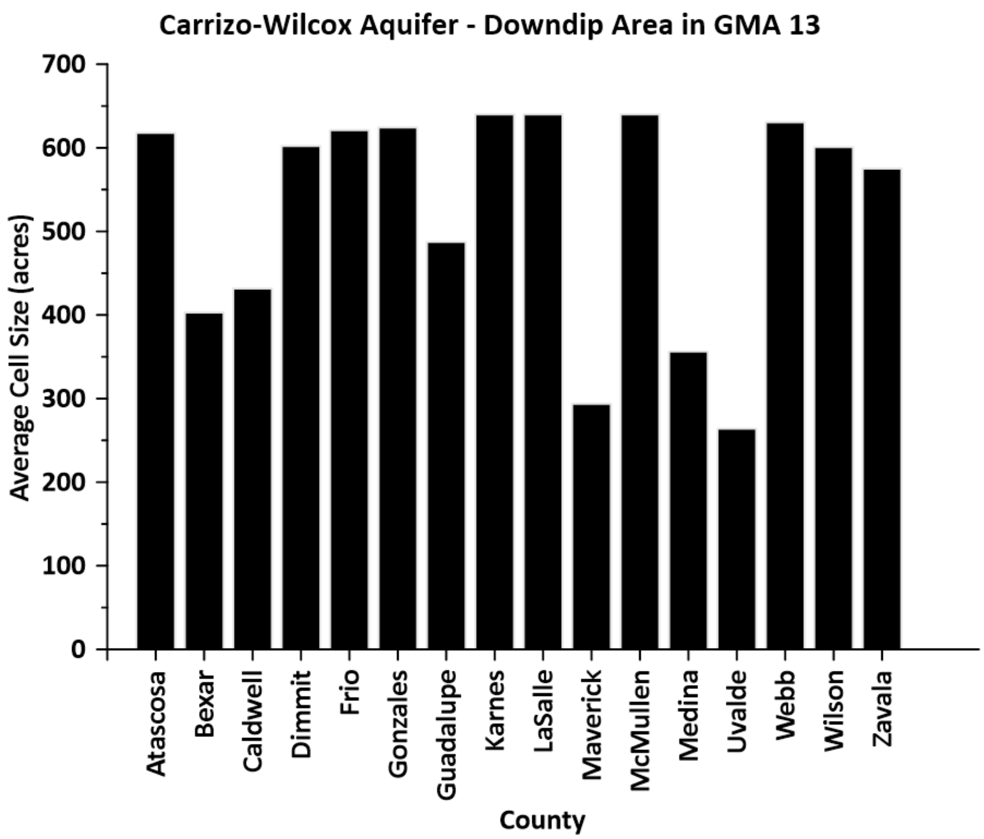

Sparta Aquifer - Outcrop Area in GMA 13
Average Cell Size (acres)
0
20
40
60
80
100
120
140
160
180
200
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County


Sparta Aquifer - Downdip Area in GMA 13
Average Cell Size (acres)
0
50
100
150
200
250
300
350
400
450
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County


Queen City Aquifer - Outcrop Area in GMA 13
Average Cell Size (acres)
0
20
40
60
80
100
120
140
160
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County

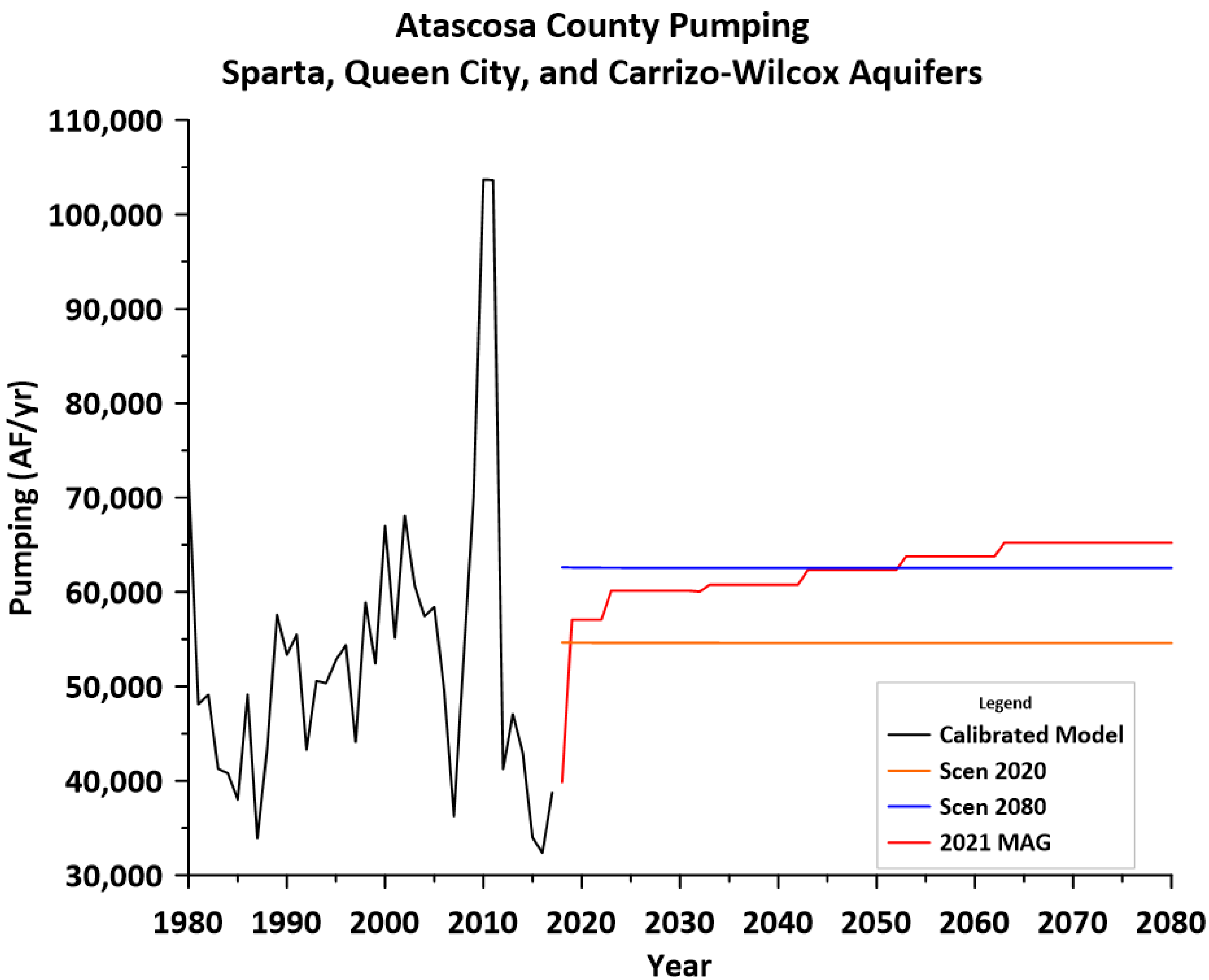

Queen City Aquifer - Downdip Area in GMA 13
Average Cell Size (acres)
0
100
200
300
400
500
600
700
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County

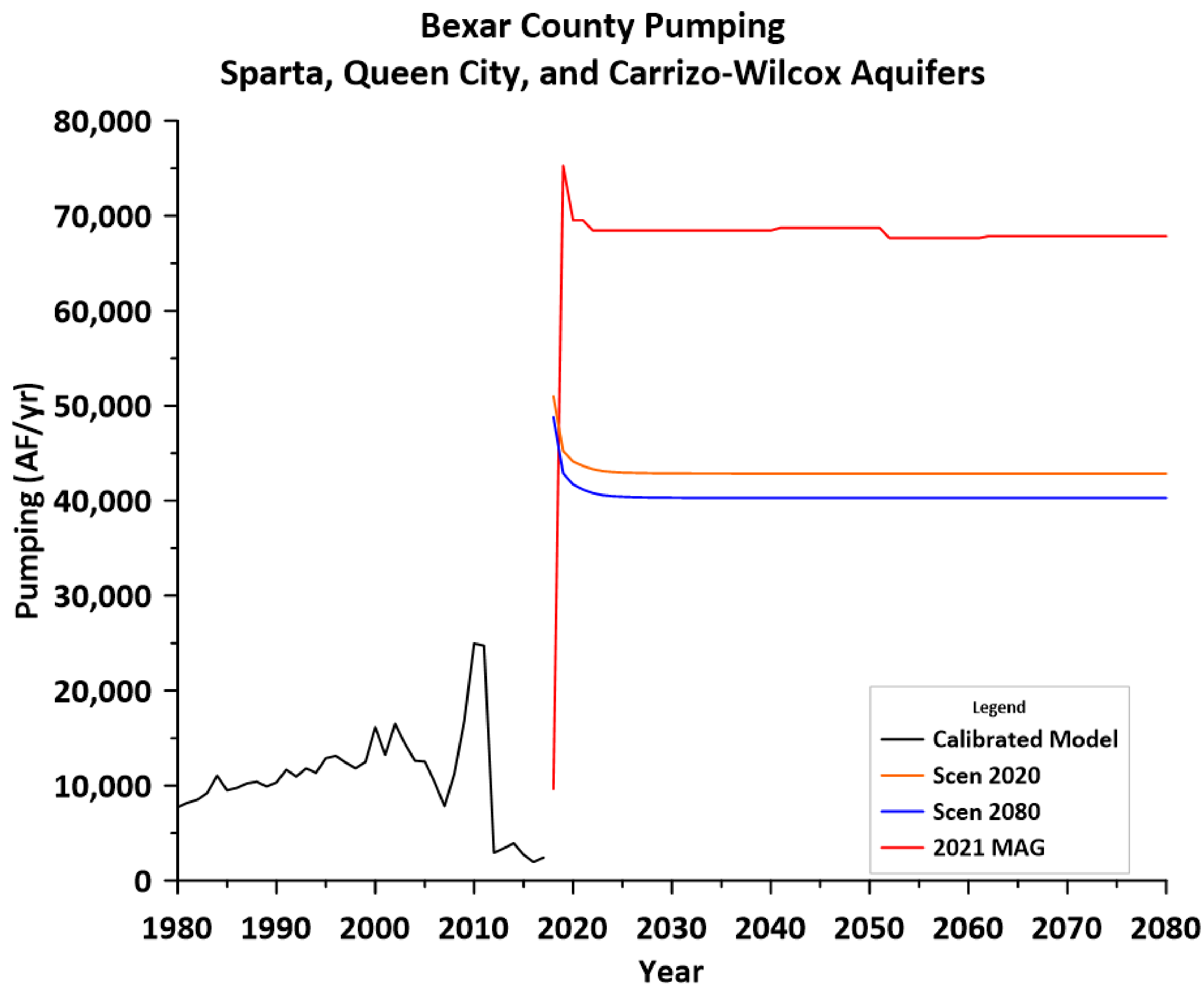

Carrizo-Wilcox Aquifer - Outcrop Area in GMA 13
Average Cell Size (acres)
0
20
40
60
80
100
120
140
160
180
200
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County

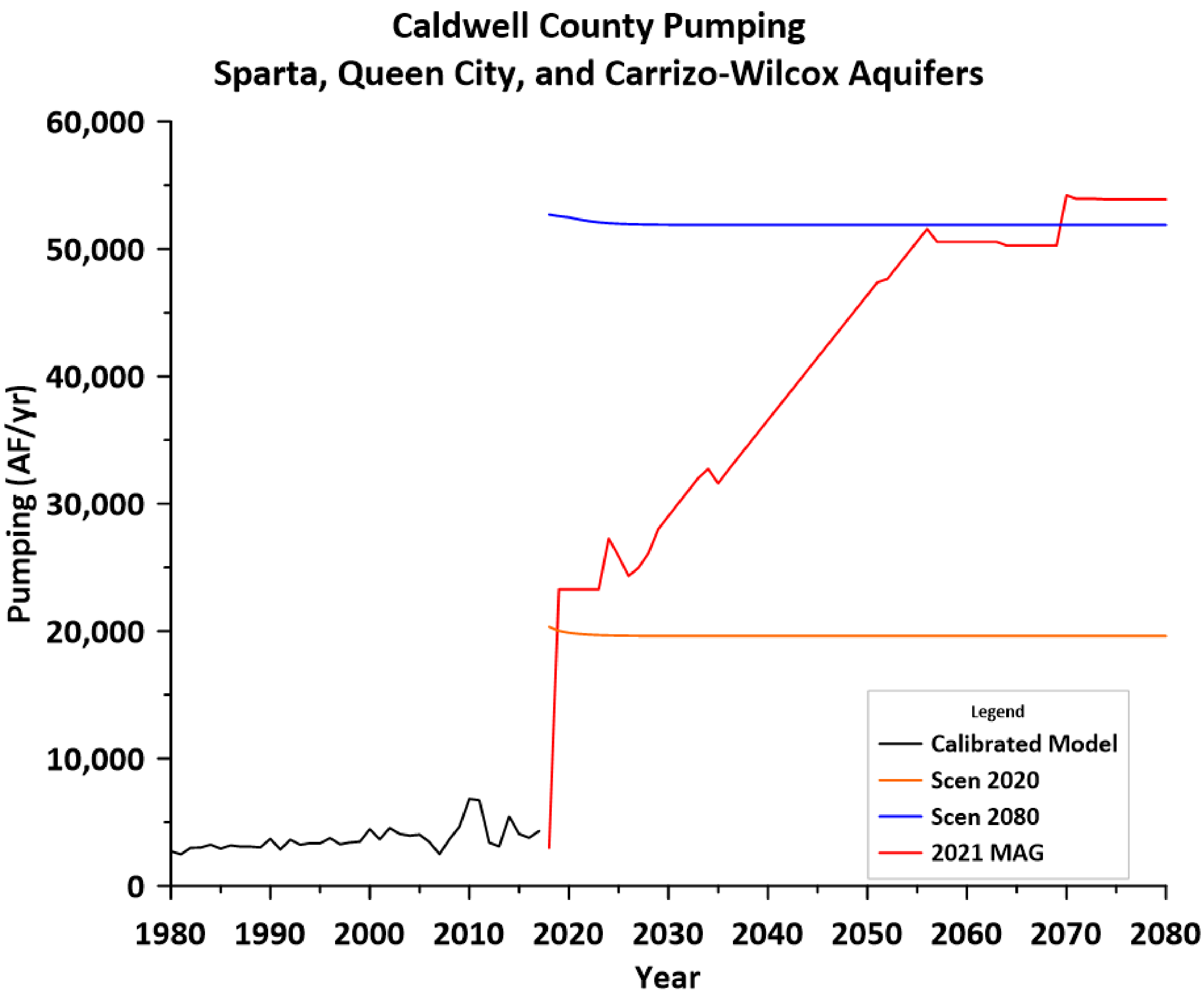

Carrizo-Wilcox Aquifer - Downdip Area in GMA 13
Average Cell Size (acres)
0
100
200
300
400
500
600
700
Atascosa
Bexar
Caldwell
Dimmit
Frio
Gonzales
Guadalupe
Karnes
LaSalle
Maverick
McMullen
Medina
Uvalde
Webb
Wilson
Zavala
County

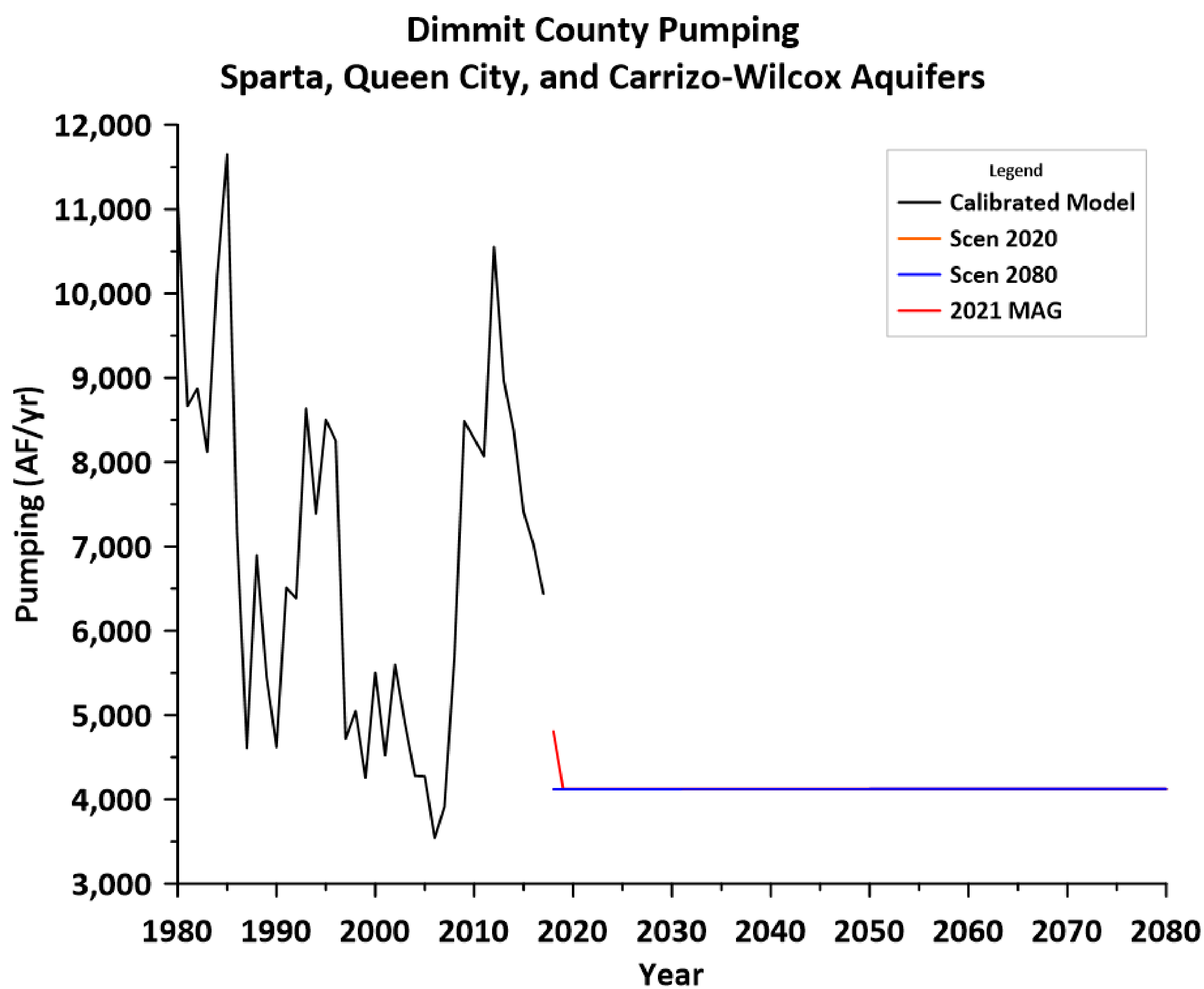
Appendix D

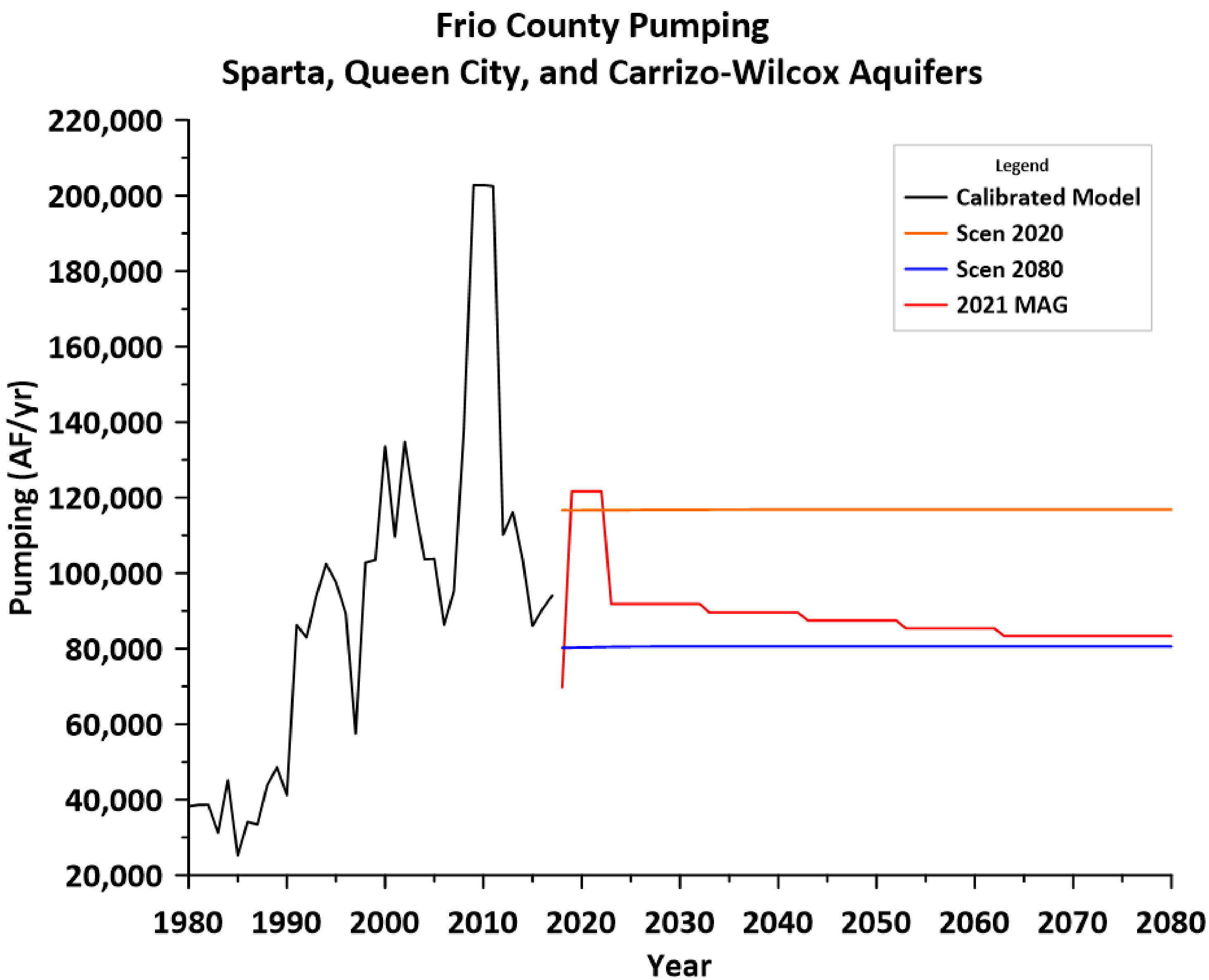
Output Pumping Comparisons (MAG, Scen2020, and Scen2080) with Current MAG

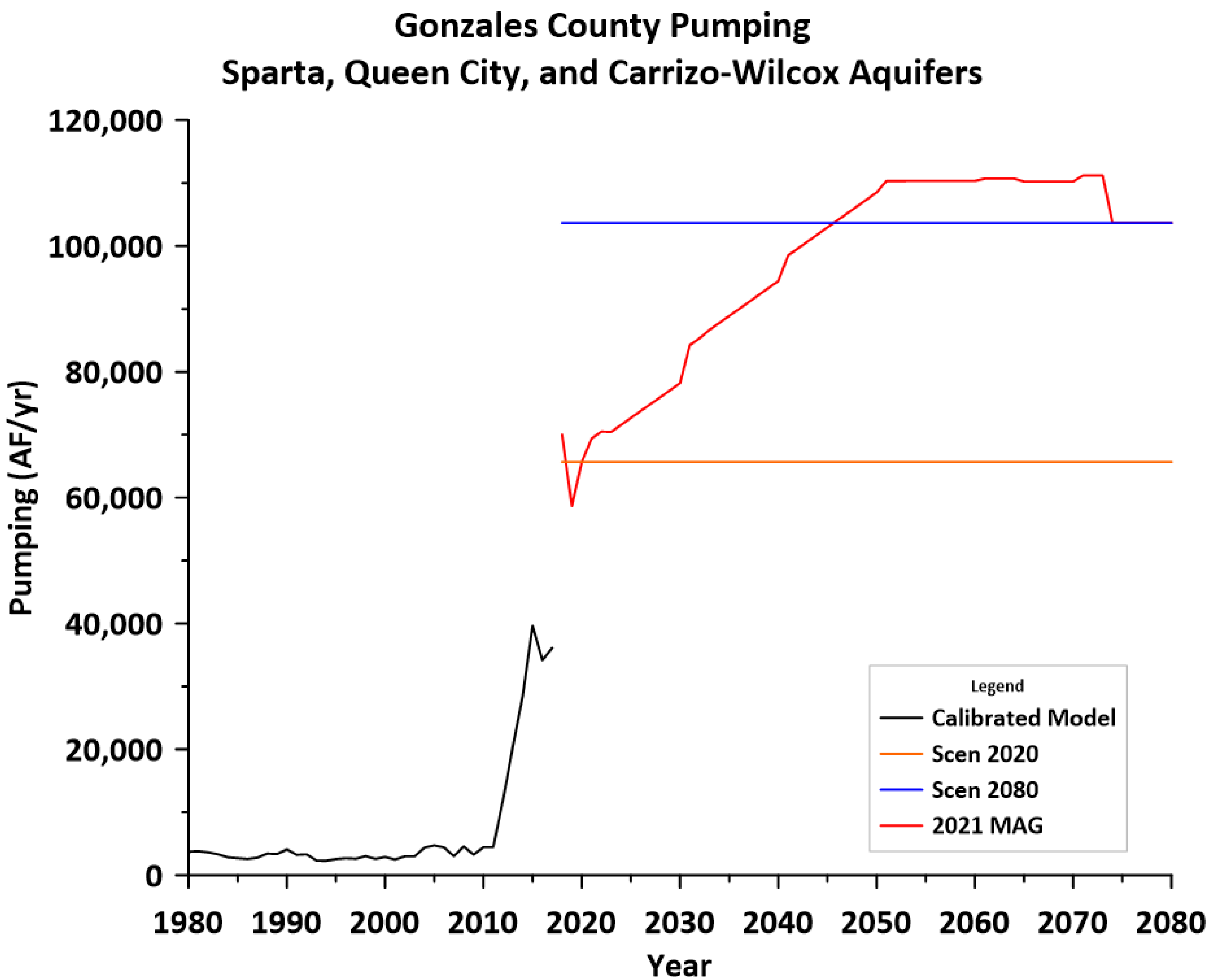

Atascosa County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

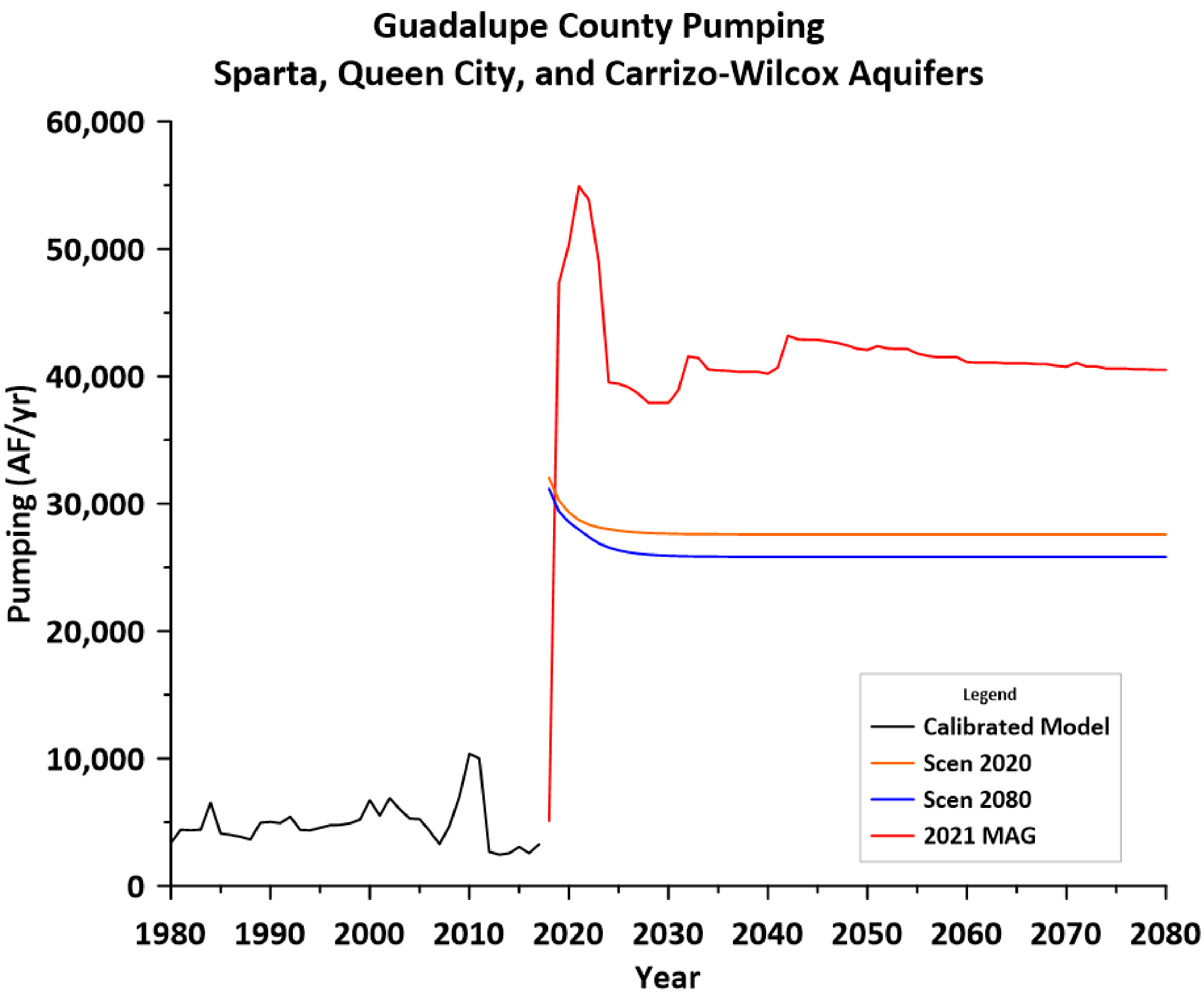

Bexar County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

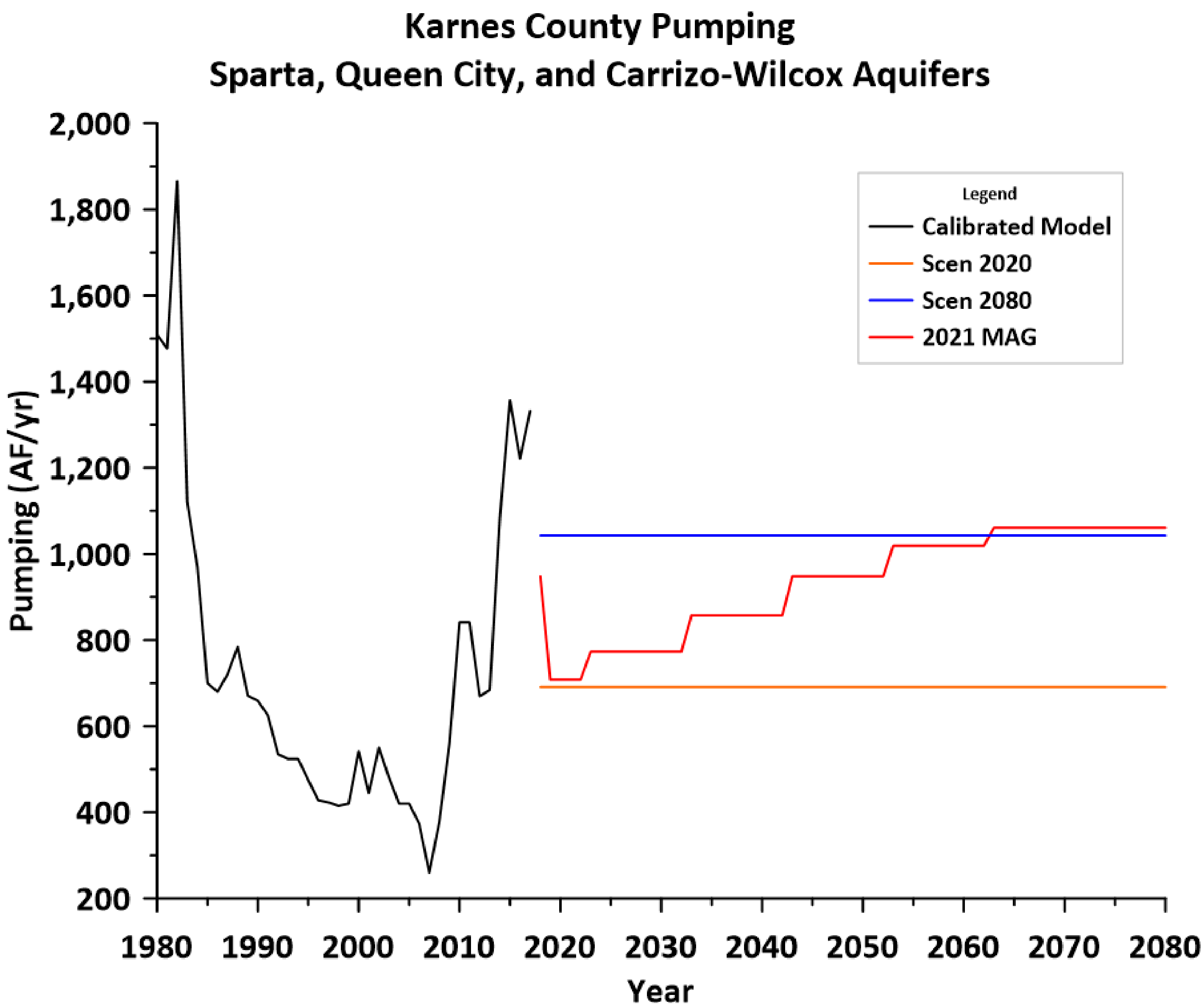

Caldwell County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
60,000
50,000
40,000
30,000
20,000
10,000
0
Pumping (AF/yr)
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG


Dimmit County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
Pumping (AF/yr)
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

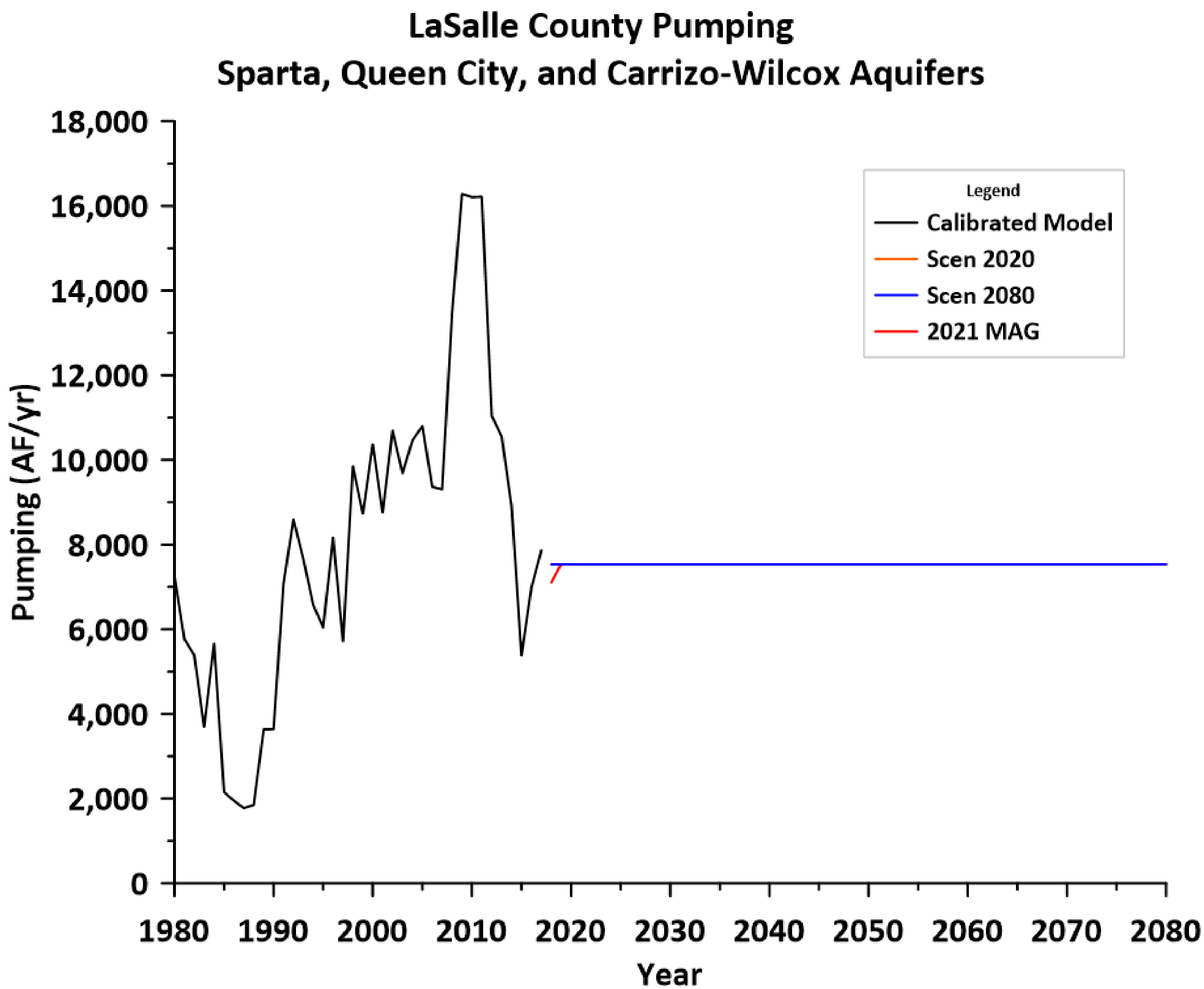

Frio County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

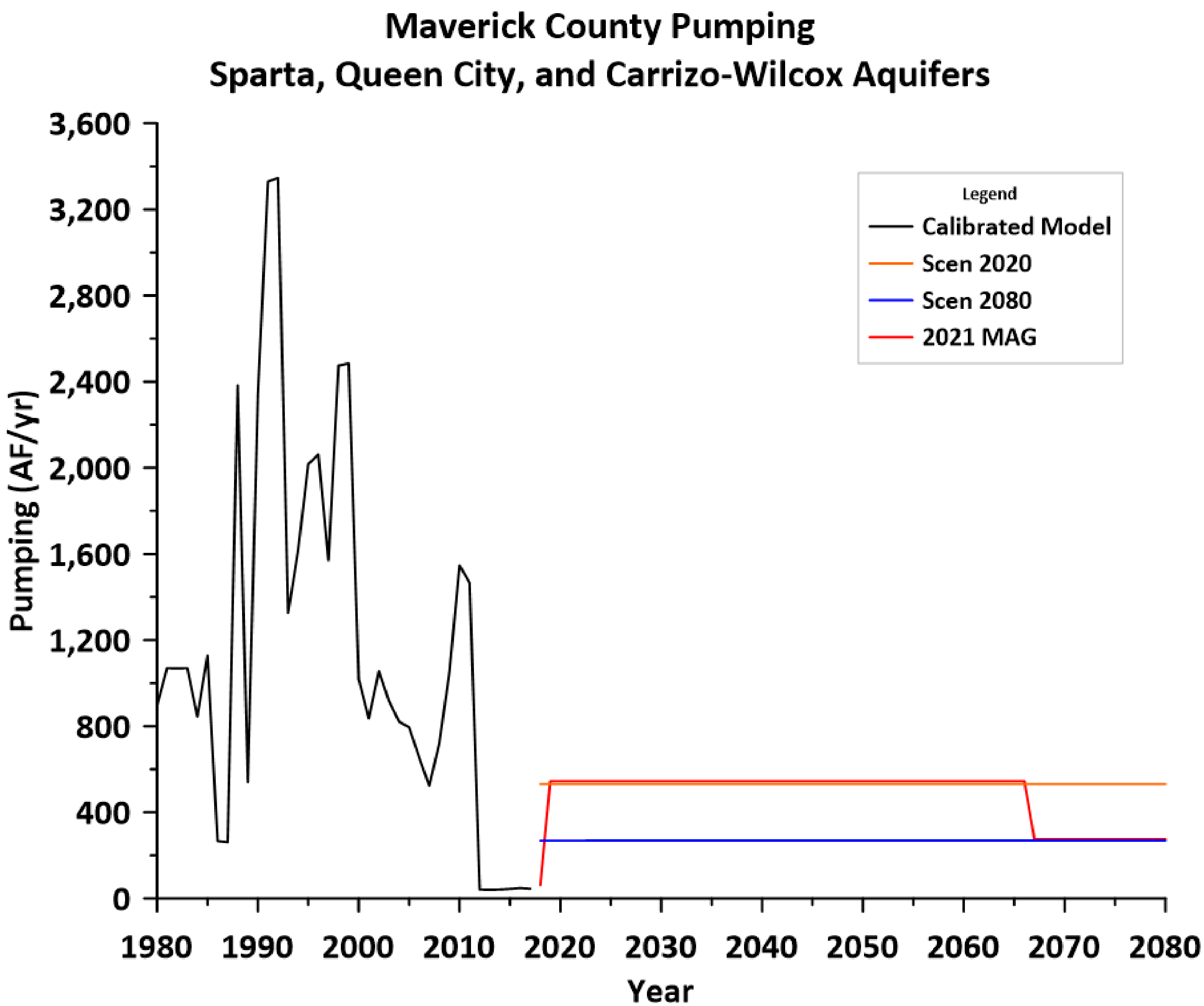

Gonzales County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
120,000
100,000
80,000
60,000
40,000
20,000
0
Pumping (AF/yr)
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

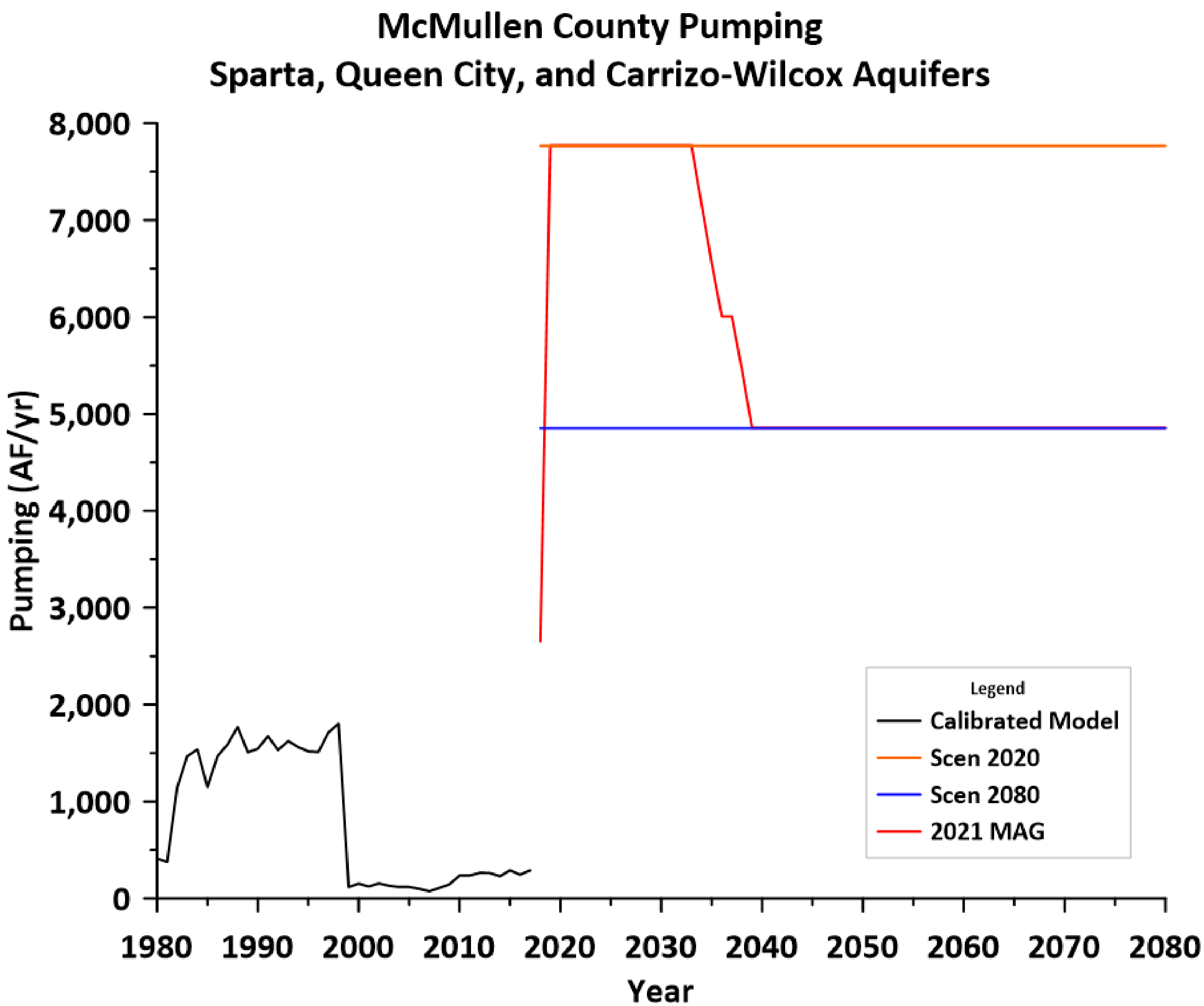

Guadalupe County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
60,000
50,000
40,000
30,000
20,000
10,000
0
Pumping (AF/yr)
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

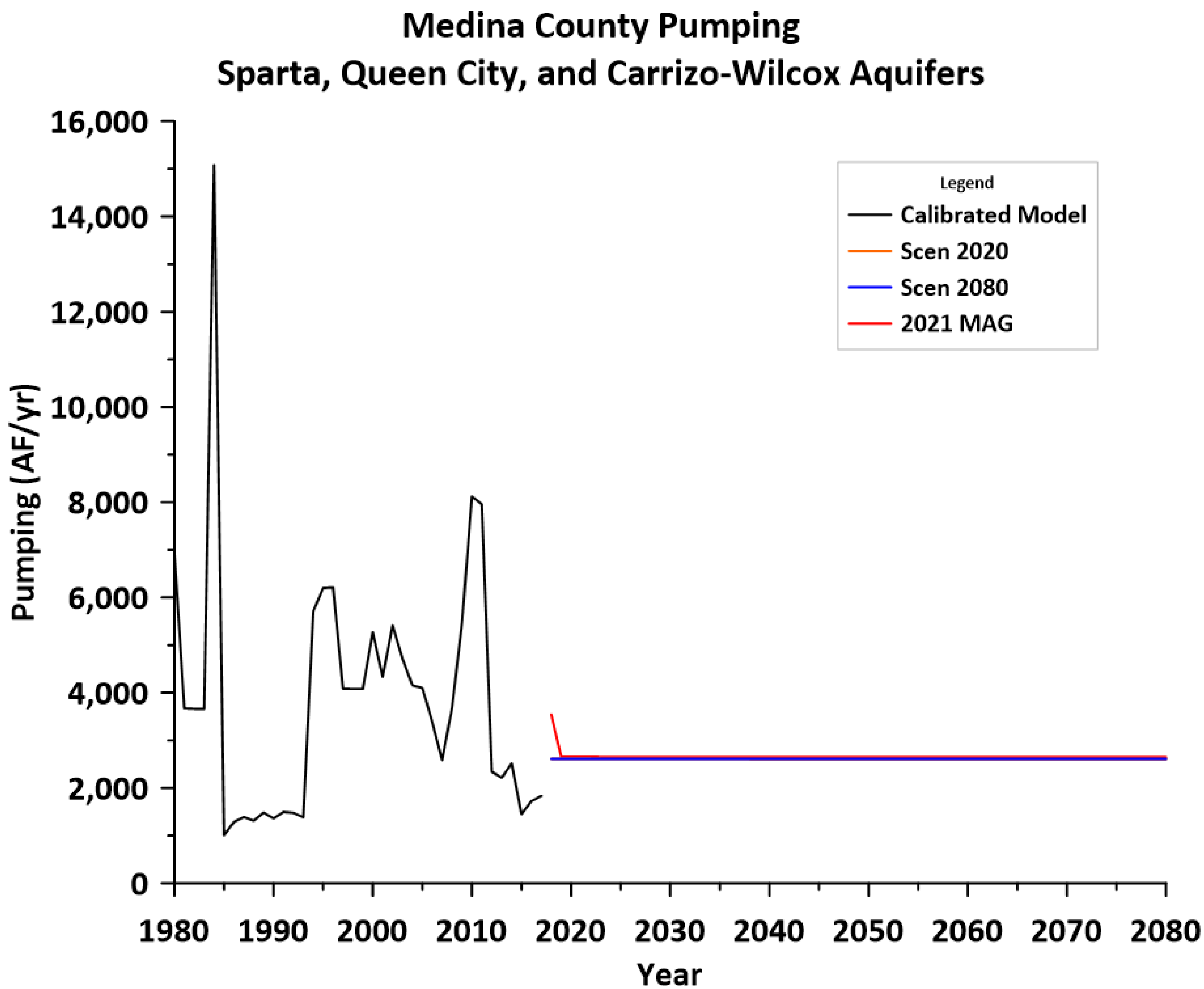


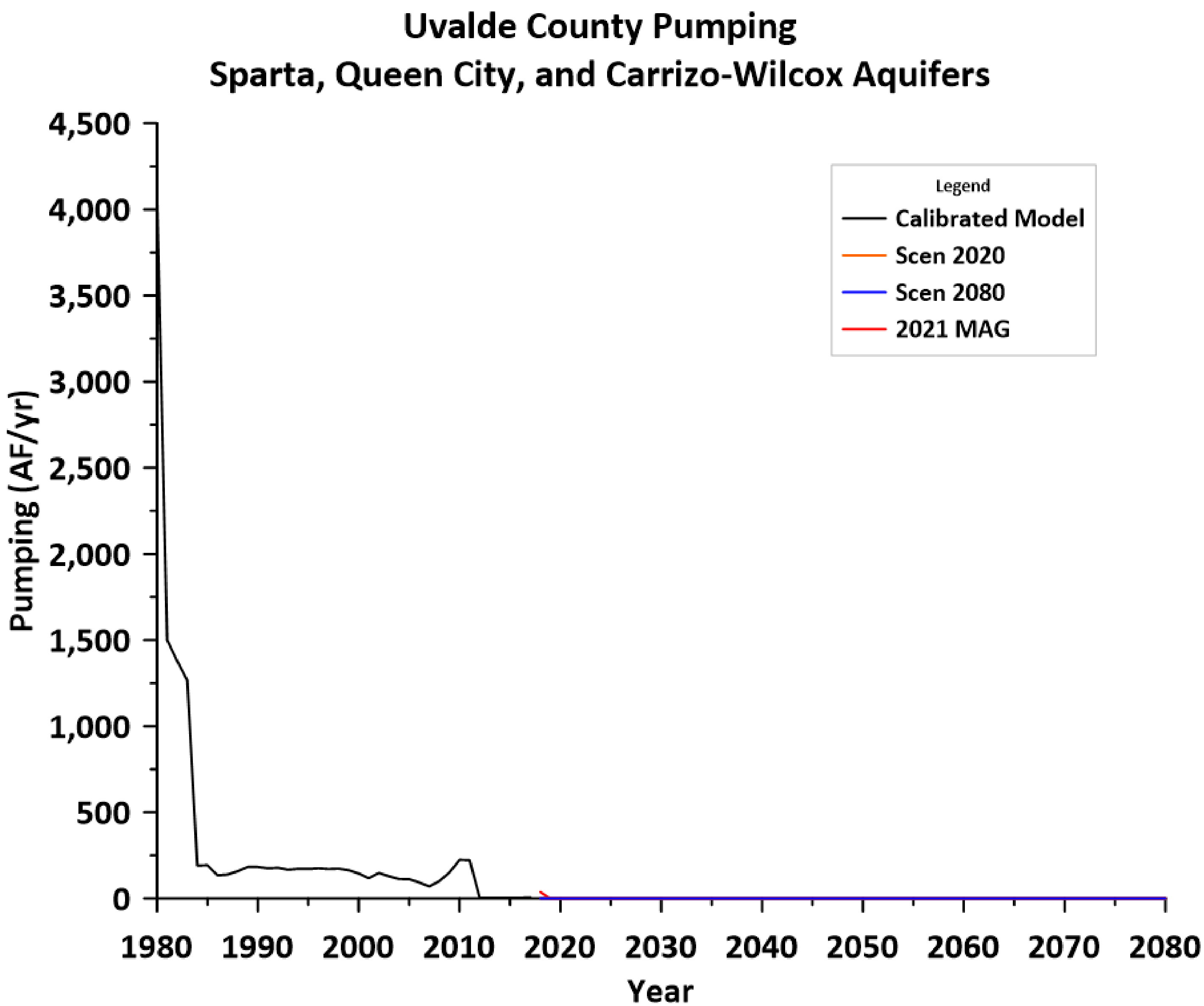
Karnes County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

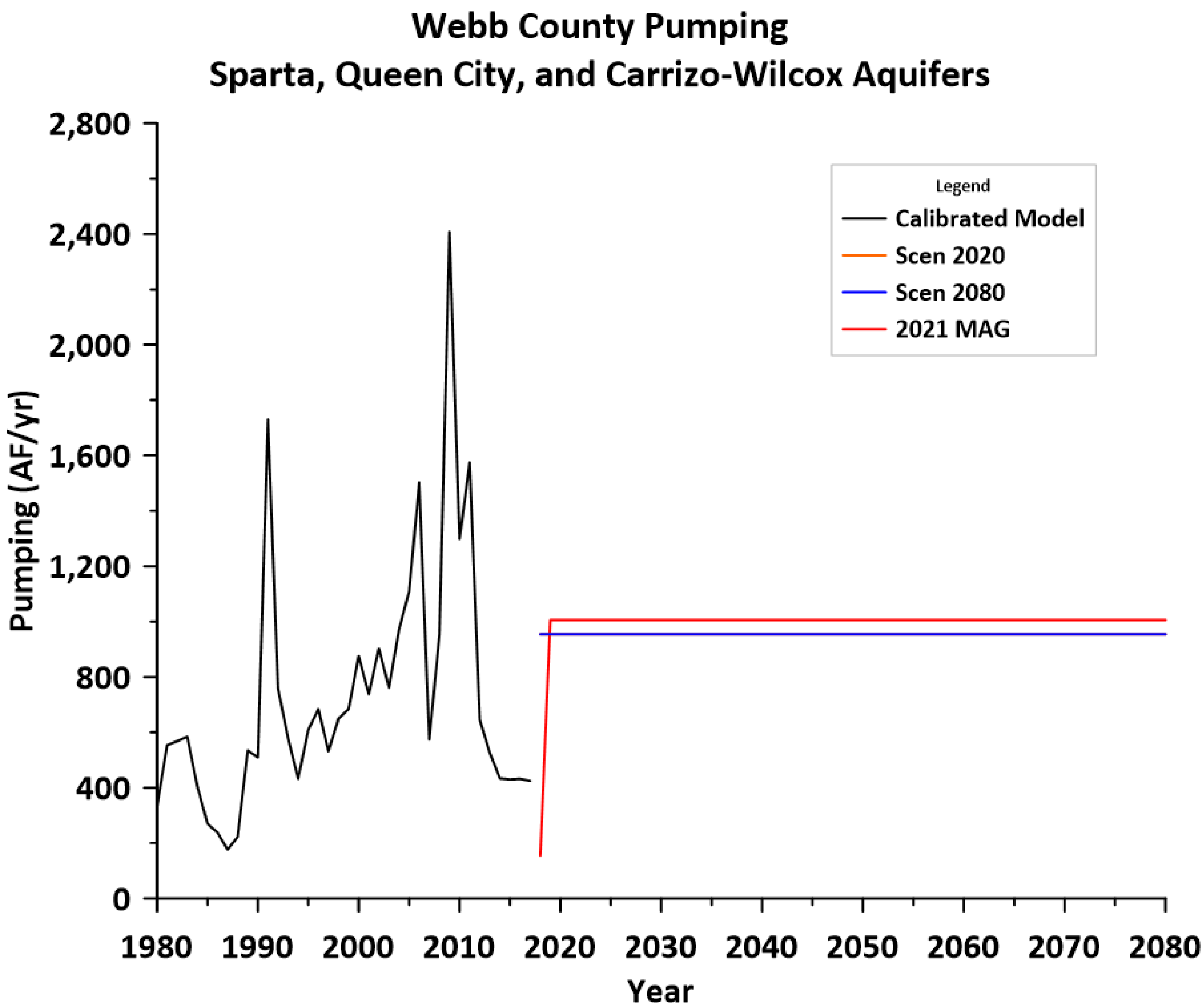

LaSalle County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

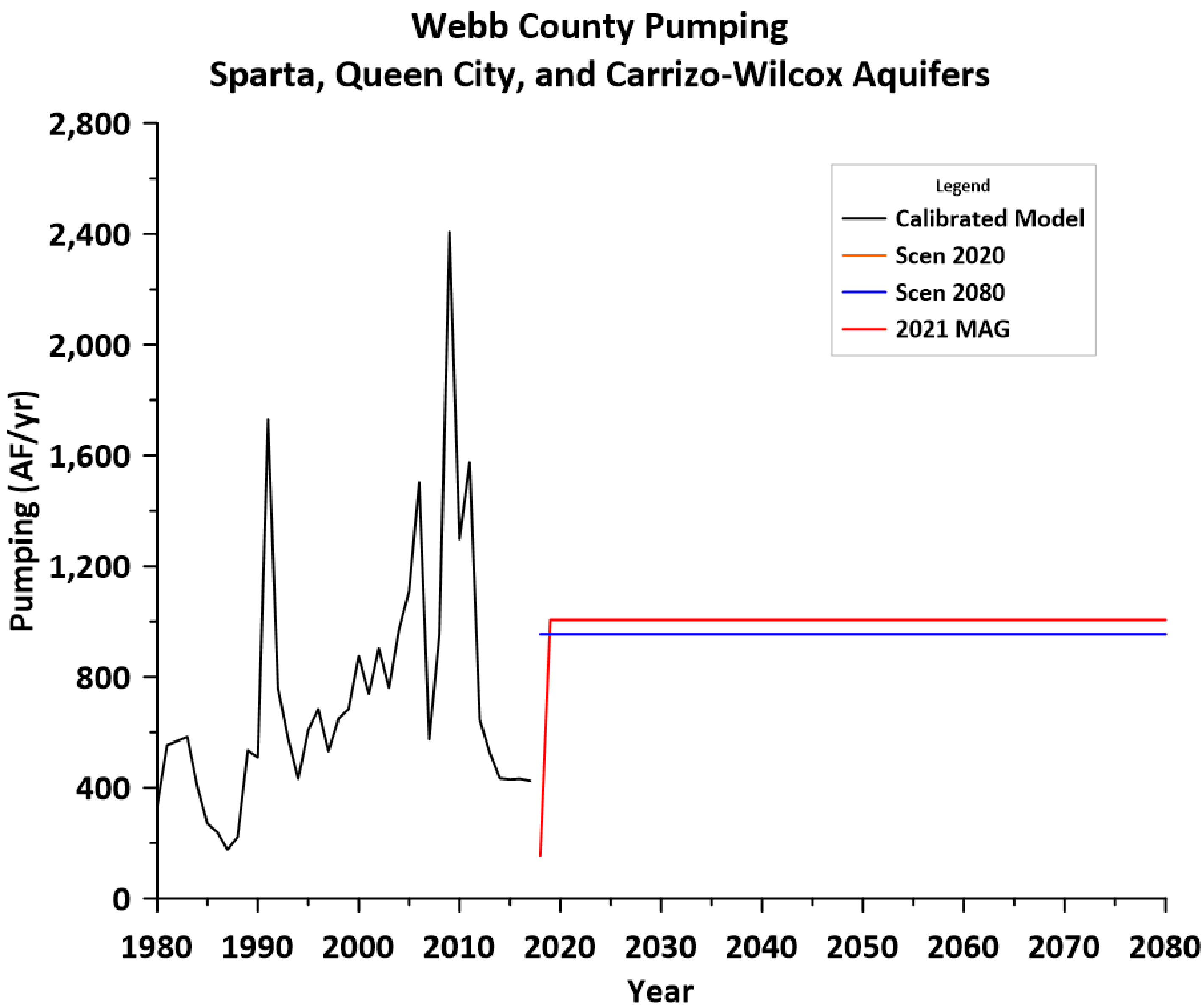

Maverick County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
3,600
3,200
2,800
2,400
2,000
1,600
1,200
800
400
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG


McMullen County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Pumping (AF/yr)
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG

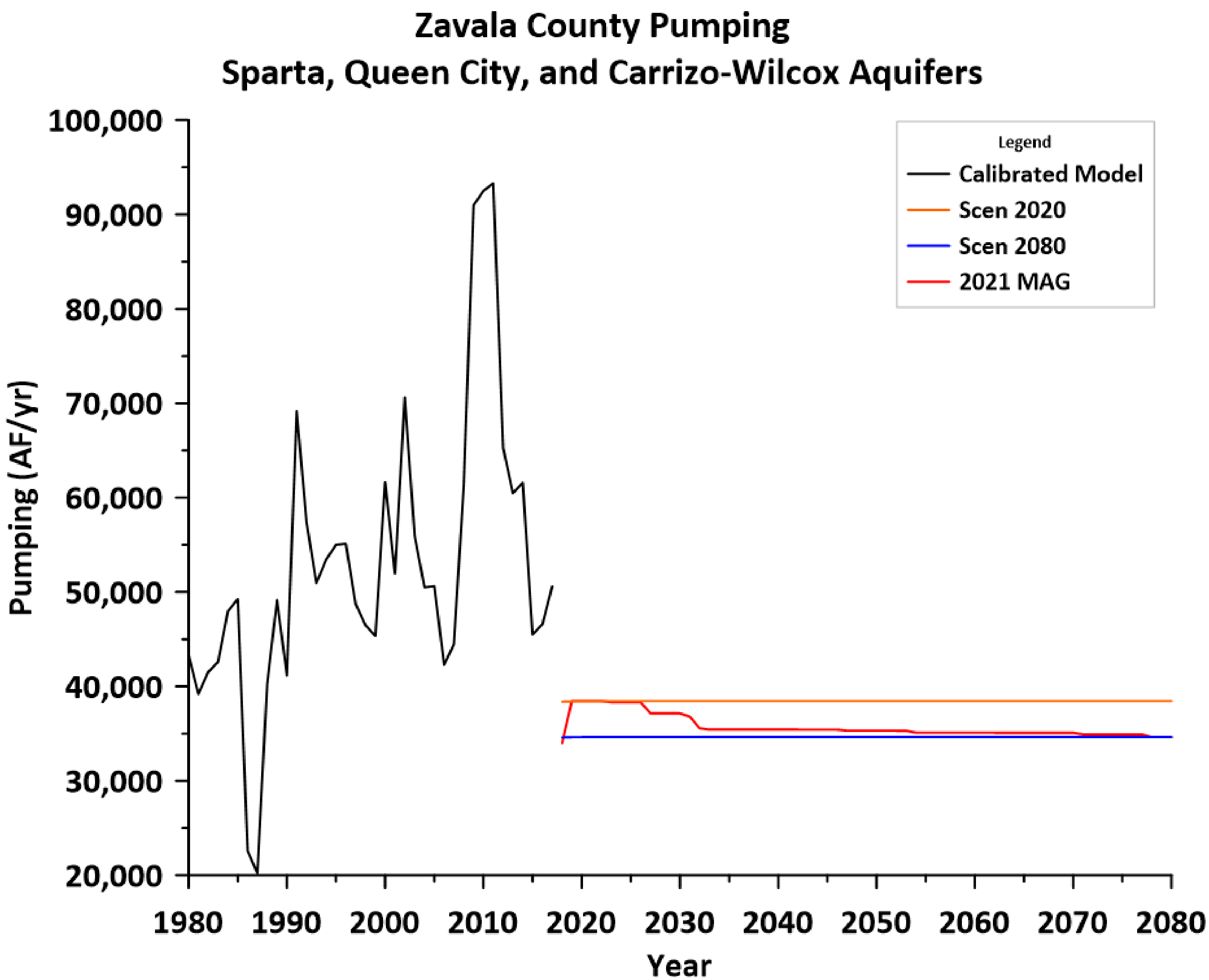

Medina County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG
Pumping (AF/yr)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year


Uvalde County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG
Pumping (AF/yr)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year


Webb County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG
Pumping (AF/yr)
2,800
2,400
2,000
1,600
1,200
800
400
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year



Webb County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
2,800
2,400
2,000
1,600
1,200
800
400
0
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG


Zavala County Pumping
Sparta, Queen City, and Carrizo-Wilcox Aquifers
Pumping (AF/yr)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
Year
Legend
Calibrated Model
Scen 2020
Scen 2080
2021 MAG