Draft Technical Memorandum 5

Calculation of Future Pumping from Existing Modeled Available Groundwater Using Updated Groundwater Availability Model

Prepared for:
GSI Environmental, Inc.
9600 Great Hills Trail, Suite 350
Austin, TX 78759
512-346-4474

Prepared by:
William R. Hutchison, Ph.D., P.E., P.G.
Independent Groundwater Consultant
9305 Jamaica Beach
Jamaica Beach, TX 77554
512-745-0599
billhutch@texasgw.com

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Professional Engineer and Professional Geoscientist Seals

This report was prepared by William R. Hutchison, Ph.D., P.E., P.G., who is licensed in the State of Texas as follows:

- Professional Engineer (Geological and Civil) No. 96287
- Engineering Firm Registration No. 14526
- Professional Geoscientist (Geology) No. 286

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1.0 Executive Summary

The simulations completed for this technical memorandum involved adjusting pumping to achieve a target set of drawdowns. Initial pumping was the MAG calculated from the most recent joint planning process. The target drawdowns were calculated from the DFC run of the simulation used to set the secondary DFC of GMA 13. Adjustments to pumping were completed on a county-aquifer basis using PEST (parameter estimation software that is an industry standard application).

In general, and as expected given the results of the simulations documented in Technical Memorandum 4, the new GAM suggests that the pumping higher than the existing MAG is required to meet the secondary DFC drawdown. Quantitatively matching the drawdowns leads to potentially unreasonable pumping amounts, which may point more to the limitations of the old GAM than to potential limitations of the new GAM. Please recall that the calculated pumping increases in PEST Simulation 4f were not as high the calculated pumping increases in PEST Simulation 3f. This was largely due to the elimination of Sparta and Queen City aquifer pumping adjustments in PEST Simulation 4f.

As discussed in the evaluation of Scenarios 3f and 4f, it appears that the persistent lowering of groundwater levels in the old GAM led to DFC drawdowns in some counties to be unreasonably low. However, initial public comments received on the new GAM include potential issues with:

- Calibration period pumping in some counties
- Transmissivity values in some areas
- Storativity/specific yield values in some areas

The results of these simulations (and the simulations associated with Technical Memorandum 4) are not dispositive with respect to addressing these issues. However, the results of these simulations are consistent with pointing to a potential issue with calibration pumping in the southwestern counties, and aquifer parameters in the Queen City Aquifer.

Additional analyses are needed to address the initial public comments, but these simulations provide a solid foundation for understanding the dynamics between variations in pumping and the resulting variation in groundwater levels.

The results of the simulations also point to the limitations of evaluating alternative DFCs in using a "project-centric" approach and provide a means to complete simulations in a "aquifer-availability" approach. It is recognized that the "project-centric" approach evolved during a time when DFCs and MAGs had different statutory meanings than they do today. Given the capabilities of the new GAM, it would be advisable to focus more on "aquifer-availability" simulations similar to those documented in the technical memorandum in the future.

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 pumping necessary to achieve desired future conditions drawdown using the updated groundwater availability model.

3.0 Parameters and Assumptions

The simulations completed for this technical memorandum involved adjusting pumping to achieve a target set of drawdowns. Initial pumping was the MAG calculated from the most recent joint planning process. The target drawdowns were calculated from the DFC run of the simulation used to set the secondary DFC of GMA 13.

Adjustments to pumping were completed on a county-aquifer basis using PEST (parameter estimation software that is an industry standard application). Documentation of the approach to adjust pumping follows the documentation on the target drawdowns used and the calculation of drawdowns from the simulations.

3.1 Drawdown Calculations

3.1.1 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 *getddtarget.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 1, 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.

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.

Table 1. 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

3.1.2 Scenario Drawdown

The program named *getddpest.exe* was written to calculate county-aquifer drawdowns in 2080 that were used to compare with the targets. Output from this FORTRAN program is named *scen2020ddlist.dat* and is compared to the DFC drawdown targets in accordance with the PEST instruction file named *scendd.ins*.

Table 2 presents *scenddlist.dat* plus additional identifying information for each county-aquifer unit pertinent to this analysis:

- County Code (used by TWDB in model grid file)
- County Name
- Aquifer (i.e. Sparta, Queen City, or Carrizo-Wilcox)
- New GAM Layers (please note that Carrizo-Wilcox is covered by three layers)
- PEST Observation Number (used in PEST to identify target drawdown)
- Plotting Code (consists of first two letters of county name followed by aquifer designation of either one or two letters). These are used to assist in the interpretation of cross-plots of drawdown (DFC vs scenario).

Table 2. County-Aquifer Drawdown Summary Information

County Code	County Name	Aquifer	New GAM Layers	PEST Obervation Number	Plotting Code
7	Atascosa	Sparta	3	o1	ATS
7	Atascosa	Queen City	5	o2	ATQ
7	Atascosa	Carrizo-Wilcox	7, 8, and 9	o3	ATCW
15	Bexar	Carrizo-Wilcox	7, 8, and 9	o4	BECW
28	Caldwell	Queen City	5	o5	CAQ
28	Caldwell	Carrizo-Wilcox	7, 8, and 9	o6	CACW
64	Dimmit	Queen City	5	o7	DIQ
64	Dimmit	Carrizo-Wilcox	7, 8, and 9	o8	DICW
82	Frio	Sparta	3	o9	FRS
82	Frio	Queen City	5	o10	FRQ
82	Frio	Carrizo-Wilcox	7, 8, and 9	o11	FRCW
89	Gonzales	Sparta	3	o12	GOS
89	Gonzales	Queen City	5	o13	GOQ
89	Gonzales	Carrizo-Wilcox	7, 8, and 9	o14	GOCW
94	Guadalupe	Queen City	5	o15	GUQ
94	Guadalupe	Carrizo-Wilcox	7, 8, and 9	o16	GUCW
128	Karnes	Queen City	5	o17	KAQ
128	Karnes	Carrizo-Wilcox	7, 8, and 9	o18	KACW
139	LaSalle	Sparta	3	o19	LAS
139	LaSalle	Queen City	5	o20	LAQ
139	LaSalle	Carrizo-Wilcox	7, 8, and 9	o21	LACW
159	Maverick	Carrizo-Wilcox	7, 8, and 9	o22	MACW
162	McMullen	Sparta	3	o23	MCS
162	McMullen	Queen City	5	o24	MCQ
162	McMullen	Carrizo-Wilcox	7, 8, and 9	o25	MCCW
163	Medina	Carrizo-Wilcox	7, 8, and 9	o26	MECW
232	Uvalde	Carrizo-Wilcox	7, 8, and 9	o27	UVCW
240	Webb	Queen City	5	o28	WEQ
240	Webb	Carrizo-Wilcox	7, 8, and 9	o29	WECW
247	Wilson	Sparta	3	o30	WIS
247	Wilson	Queen City	5	o31	WIQ
247	Wilson	Carrizo-Wilcox	7, 8, and 9	o32	WICW
254	Zavala	Queen City	5	o33	ZAQ
254	Zavala	Carrizo-Wilcox	7, 8, and 9	o34	ZACW

3.2 Pumping

3.2.1 2080 Output Pumping from Scen2020

As documented in Technical Memorandum 4, two pumping scenarios were evaluated, one with that was based on MAG pumping from 2020 (Scen2020) and one that was based on MAG pumping from 2080 (Scen2080). For this analysis, the 2080 pumping from Scen2020 was used as the base pumping that was adjusted to match DFC targets.

The FORTRAN program *s2020pump.exe* was written to read the output pumping from 2080 pumping from Scen2020 (*2080pumpout.dat*) and summarize the county-layer pumping in both list format (*sumpump2080list.dat*) and array format (*sumpump2080array.dat*). Table 3 presents the output in array format.

Table 3. 2080 County-Layer Pumping from Scen2020

County Code	County Name	Pumping (AF/yr)				
		Layer 3	Layer 5	Layer 7	Layer 8	Layer 9
7	Atascosa	900	3,770	48,590	154	1,180
15	Bexar	0	0	17,132	56	25,655
28	Caldwell	0	3,726	439	3,625	11,823
64	Dimmit	0	0	3,880	205	38
82	Frio	791	5,680	110,390	0	0
89	Gonzales	3,551	5,058	47,514	9,547	0
94	Guadalupe	0	0	7,366	2,782	17,442
128	Karnes	0	0	691	0	0
139	LaSalle	986	12	6,536	0	0
159	Maverick	0	0	527	2	2
162	McMullen	0	0	7,767	0	0
163	Medina	0	0	512	1,247	847
232	Uvalde	0	0	0	0	0
240	Webb	44	0	909	1	0
247	Wilson	442	2,552	34,690	113	1,417
254	Zavala	0	0	34,502	3,610	328

3.2.2 Scenario Pumping Adjustments

The FORTRAN program *ScenWEL.exe* was written to adjust the base pumping and write an updated WEL file. The program:

- Reads a list of county names (and codes)
- Reads the factors that adjust pumping on a county-layer basis (PEST updates the factors during the simulations)

- Reads the 2080 output pumping from Scen2020 (*2080pumpout.dat*) and applies the adjustment factors to each cell based on the county-layer factors
- Writes an updated list of base pumping and adjusted pumping on a county-layer basis (*pumporigadj.dat*)
- Reads the text portion of the WEL file
- Writes a WEL file (*ScenMAG.wel*)

The baseline *pumporigadj.dat* file is presented in Table 4.

Please note that these values are the input pumping that may be reduced during the simulation as a result of inadequate saturated thickness. Details of the output pumping are provided in the results section.

Table 4. Baseline *pumporigadj.dat* File

County Code	County Name	Layer	Base Pumping (AF/yr)	Adjustment Factor	Scenario Pumping (AF/yr)
7	Atascosa	3	900	1.00	900
7	Atascosa	5	3,770	1.00	3,770
7	Atascosa	7	48,590	1.00	48,590
7	Atascosa	8	154	1.00	154
7	Atascosa	9	1,180	1.00	1,180
15	Bexar	7	17,132	1.00	17,132
15	Bexar	8	56	1.00	56
15	Bexar	9	25,655	1.00	25,655
28	Caldwell	5	3,726	1.00	3,726
28	Caldwell	7	439	1.00	439
28	Caldwell	8	3,625	1.00	3,625
28	Caldwell	9	11,823	1.00	11,823
64	Dimmit	7	3,880	1.00	3,880
64	Dimmit	8	205	1.00	205
64	Dimmit	9	38	1.00	38
82	Frio	3	791	1.00	791
82	Frio	5	5,680	1.00	5,680
82	Frio	7	110,390	1.00	110,390
89	Gonzales	3	3,551	1.00	3,551
89	Gonzales	5	5,058	1.00	5,058
89	Gonzales	7	47,514	1.00	47,514
89	Gonzales	8	9,547	1.00	9,547
94	Guadalupe	7	7,366	1.00	7,366
94	Guadalupe	8	2,782	1.00	2,782
94	Guadalupe	9	17,442	1.00	17,442
128	Karnes	7	691	1.00	691
139	LaSalle	3	986	1.00	986
139	LaSalle	5	12	1.00	12
139	LaSalle	7	6,536	1.00	6,536
159	Maverick	7	527	1.00	527
159	Maverick	8	2	1.00	2
159	Maverick	9	2	1.00	2
162	McMullen	7	7,767	1.00	7,767
163	Medina	7	512	1.00	512
163	Medina	8	1,247	1.00	1,247
163	Medina	9	847	1.00	847
240	Webb	3	44	1.00	44
240	Webb	7	909	1.00	909
240	Webb	8	1	1.00	1
247	Wilson	3	442	1.00	442
247	Wilson	5	2,552	1.00	2,552
247	Wilson	7	34,690	1.00	34,690
247	Wilson	8	113	1.00	113
247	Wilson	9	1,417	1.00	1,417
254	Zavala	7	34,502	1.00	34,502
254	Zavala	8	3,610	1.00	3,610
254	Zavala	9	328	1.00	328

3.3 Model Files

3.3.1 Files Unchanged from Calibrated Model

Table 5 presents the model files that were unchanged from the calibration run of the model.

Table 5. 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

3.3.2 Files Modified from the Calibrated Model

Table 6 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 6. 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.

4.0 Methods and Results

As noted above, the objective of the simulations documented in this technical memorandum was to use PEST to adjust pumping in an attempt to match drawdowns on a county-layer basis to the DFC drawdowns. PEST calculates the difference between a simulation county-layer drawdown and a DFC drawdown for the same county-layer unit. The difference is squared for each target, and the sum of all the squared differences (i.e. all county-layer units) is the PEST "objective function" called *phi*.

The PEST simulations completed for this effort are documented below. All files are included in the directory *Model*.

4.1 PEST Simulation 1

The initial simulation PEST input file is named *MAGSim01.pst*. The initial pumping adjustment factors were all set to 1.0, with a variation rage set between 0.0001 and 10.00. Please note that prior to running the first simulation, a test run with zero PEST iterations was run to verify that all file connections and names were correct (*MAGSim01-0.pst*). The number of adjustable county-layer pumping factors for this simulation was 41, and there were 34 target drawdowns.

After a single PEST iteration, it was noticed that the Sparta Aquifer pumping in Webb County had no impact on the simulation. Also, an input error in the initial factor for the layer 7 factor in Bexar County was discovered. Consequently, the simulation was terminated after one PEST iteration.

The initial *phi* was 194,764. After a single PEST iteration, the *phi* was lowered to 59,389. The summary output file for this simulation is *magsim01.rec*.

4.2 PEST Simulation 2

Simulation 2 (*MAGSim02.pst*) used the factors from Simulation 1 as input and fixed the factor for Layer 3 in Webb County at 1.0. Thus, the number of adjustable county-layer pumping factors for this simulation was 40, and there were 34 target drawdowns. The initial *phi* for this simulation was 59,921 (slightly different than the end *phi* of Simulation1 due to corrections to the input file noted earlier).

After five PEST iterations and 416 model runs, *phi* had been reduced to 37,903. However, the pumping adjustment factor for several county-layer units had reach the pre-defined limit of 10, suggesting that pumping needed to be higher in order to better match the target drawdowns. The simulation was terminated after the fifth PEST iteration to modify the pumping factor limits. The summary output for this simulation is *magsim02.rec*.

4.3 PEST Simulation 3

Simulation 3 (*MAGSim03.pst*) used the final factors from Simulation 2 as input. Pumping limits were also increased to 100 for eight county-layer units based on the results of Simulation 2. As in

PEST simulation 2, the number of adjustable county-layer pumping factors for this simulation was 40, and there were 34 target drawdowns. The initial *phi* for this simulation was 37,904 (essentially the same as the end *phi* of Simulation 2 considering rounding errors associated with factor specification in the input file).

After four PEST iterations and 333 model runs, the *phi* had lowered to 30,546. Pumping factors were at the limits for five county-aquifer units. The minor lowering of *phi* suggested that further improvement in *phi* with additional factor limit adjustments would not be useful, especially given the fact that pumping amounts in some county-layer units were potentially unreasonable.

The PEST simulation was terminated after four PEST iterations. The summary output for this simulation is *magsim03.rec*.

4.4 PEST Simulation 3f

To obtain a clean set of output files, a final run of PEST Simulation 3 (*MAGSim03f.pst*) was run using the pumping factors from the fourth PEST iteration of Simulation 3. The PEST input file was modified to complete zero iterations to obtain the drawdown comparison with pumping adjustments at the end of PEST Simulation 3. The output file for this simulation is *magsim03f.rec*.

The initial (and final) *phi* for this simulation was 30,643 (essentially the same as the end *phi* of Simulation 3 considering rounding errors associated with factor specification in the input file).

4.4.1 Drawdown Results

Drawdown calculations for this simulation were obtained from the FORTRAN program *getdd3f.exe*. Summary drawdown results are summarized in Table 7 and Figure 1. Please note that the county-aquifer plotting code in Table 7 appears as point labels in Figure 1 to denote the county-aquifer unit represented by each point. Also please note that a one-to-one line is plotted to facilitate comparison of the average drawdowns between the two simulations:

- A point that lies on the line represents the same average drawdown in both simulations
- A point that lies above or to the left of the line represents an average drawdown in Scenario 3f that is higher than the DFC average drawdown
- A point that lies below or to the right of the line represents an average drawdown in Scenario 3f that is lower than the DFC average drawdown

Please note that most of the points that are furthest away from the line are in the Queen City Aquifer. Because the Carrizo-Wilcox Aquifer has a higher significance in the context of the groundwater planning and management to the groundwater conservation districts in Groundwater Management Area 13, these results suggested that an additional simulation that focused only on the Carrizo-Wilcox may be useful to provide further insight.

Table 7. Drawdown Comparison: DFC and Scenario 3f

County Code	County Name	Aquifer	New GAM Layers	PEST Obervation Number	Plotting Code	Drawdown (ft) DFC	Drawdown (ft) Scenario 3f
7	Atascosa	Sparta	3	o1	ATS	21	28
7	Atascosa	Queen City	5	o2	ATQ	86	93
7	Atascosa	Carrizo-Wilcox	7, 8, and 9	o3	ATCW	127	115
15	Bexar	Carrizo-Wilcox	7, 8, and 9	o4	BECW	107	107
28	Caldwell	Queen City	5	o5	CAQ	24	32
28	Caldwell	Carrizo-Wilcox	7, 8, and 9	o6	CACW	45	49
64	Dimmit	Queen City	5	o7	DIQ	-4	0
64	Dimmit	Carrizo-Wilcox	7, 8, and 9	o8	DICW	-5	-7
82	Frio	Sparta	3	o9	FRS	6	6
82	Frio	Queen City	5	o10	FRQ	36	49
82	Frio	Carrizo-Wilcox	7, 8, and 9	o11	FRCW	53	34
89	Gonzales	Sparta	3	o12	GOS	23	20
89	Gonzales	Queen City	5	o13	GOQ	85	61
89	Gonzales	Carrizo-Wilcox	7, 8, and 9	o14	GOCW	181	176
94	Guadalupe	Queen City	5	o15	GUQ	6	111
94	Guadalupe	Carrizo-Wilcox	7, 8, and 9	o16	GUCW	147	106
128	Karnes	Queen City	5	o17	KAQ	118	19
128	Karnes	Carrizo-Wilcox	7, 8, and 9	o18	KACW	214	221
139	LaSalle	Sparta	3	o19	LAS	11	0
139	LaSalle	Queen City	5	o20	LAQ	23	4
139	LaSalle	Carrizo-Wilcox	7, 8, and 9	o21	LACW	11	6
159	Maverick	Carrizo-Wilcox	7, 8, and 9	o22	MACW	-13	1
162	McMullen	Sparta	3	o23	MCS	33	0
162	McMullen	Queen City	5	o24	MCQ	64	6
162	McMullen	Carrizo-Wilcox	7, 8, and 9	o25	MCCW	34	53
163	Medina	Carrizo-Wilcox	7, 8, and 9	o26	MECW	31	34
232	Uvalde	Carrizo-Wilcox	7, 8, and 9	o27	UVCW	18	5
240	Webb	Queen City	5	o28	WEQ	-7	1
240	Webb	Carrizo-Wilcox	7, 8, and 9	o29	WECW	-4	18
247	Wilson	Sparta	3	o30	WIS	20	25
247	Wilson	Queen City	5	o31	WIQ	88	91
247	Wilson	Carrizo-Wilcox	7, 8, and 9	o32	WICW	269	249
254	Zavala	Queen City	5	o33	ZAQ	-5	-1
254	Zavala	Carrizo-Wilcox	7, 8, and 9	o34	ZACW	14	17

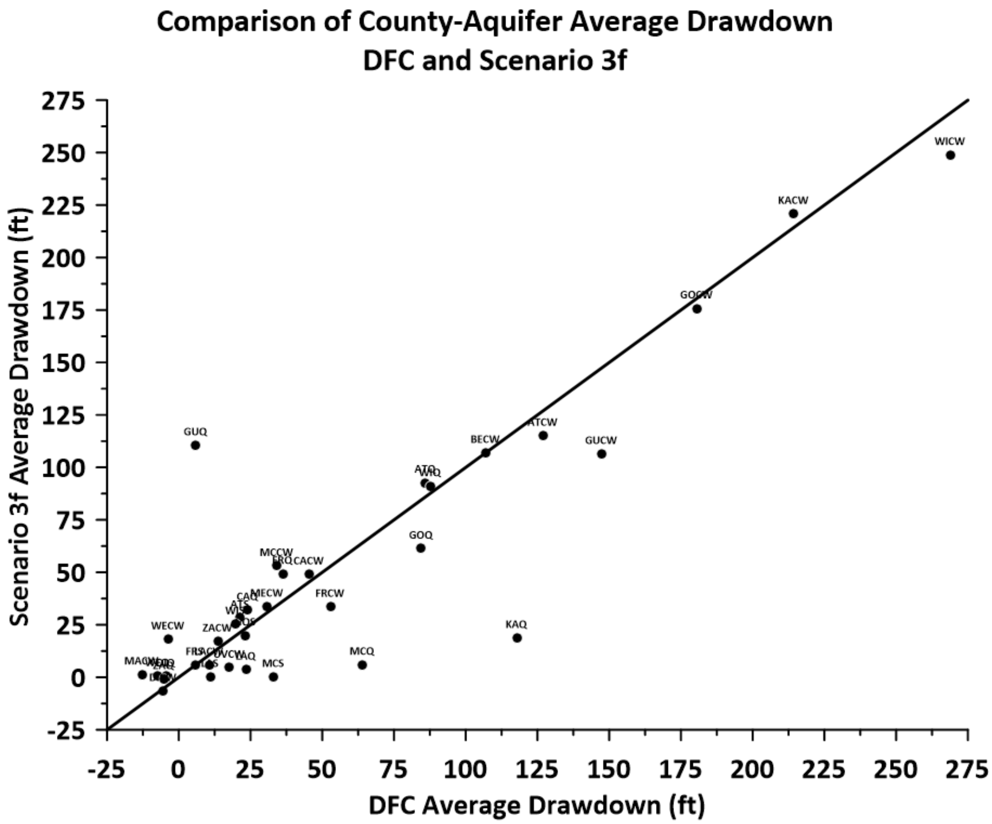

Figure 1. Drawdown Comparison: DFC and Scenario 3f

4.4.2 Pumping Results

Output pumping calculations for this simulation were obtained from the FORTRAN program *getpump3f.exe*. Summary pumping results are summarized in Table 8 and Figure 2. Please note that, for purposes of this summary, all pumping (Sparta, Queen City, and Sparta) is included in the summary table, although the detailed output from *getpump3f.exe* includes detailed pumping for the outcrop area, downdip area, and total pumping for each aquifer.

Please note that the pumping in Figure 2 is plotted on a logarithmic scale to facilitate comparisons across all counties. A comparison plot using linear axes clusters low pumping counties near the origin and makes it difficult to visualize where pumping is above or below the one-to-one line. The one-to-one line can be used compare MAG pumping and scenario pumping as follows:

- A point that lies on the line represents the same pumping in both simulations
- A point that lies above or to the left of the line represents scenario pumping higher than MAG pumping
- A point that lies below or to the right of the line represents scenario pumping lower than MAG pumping

Table 8. Pumping Comparison: MAG and Scenario 3f

County	Plotting Code	Pumping (AF/yr)	
		MAG	Scenario 3f
Atascosa	AT	65,217	147,815
Bexar	BE	67,849	306,953
Caldwell	CA	53,893	18,359
Dimmit	DI	4,124	1,218
Frio	FR	83,311	152,468
Gonzales	GO	103,653	801,185
Guadalupe	GU	40,519	33,472
Karnes	KA	1,061	14,631
LaSalle	LA	7,534	1,425
Maverick	MA	276	123
McMullen	MC	4,856	30
Medina	ME	2,646	10,537
Uvalde	UV	0	0
Webb	WE	1,006	64
Wilson	WI	127,461	375,541
Zavala	ZA	34,634	60,466
GMA 13	GMA	598,040	1,924,287

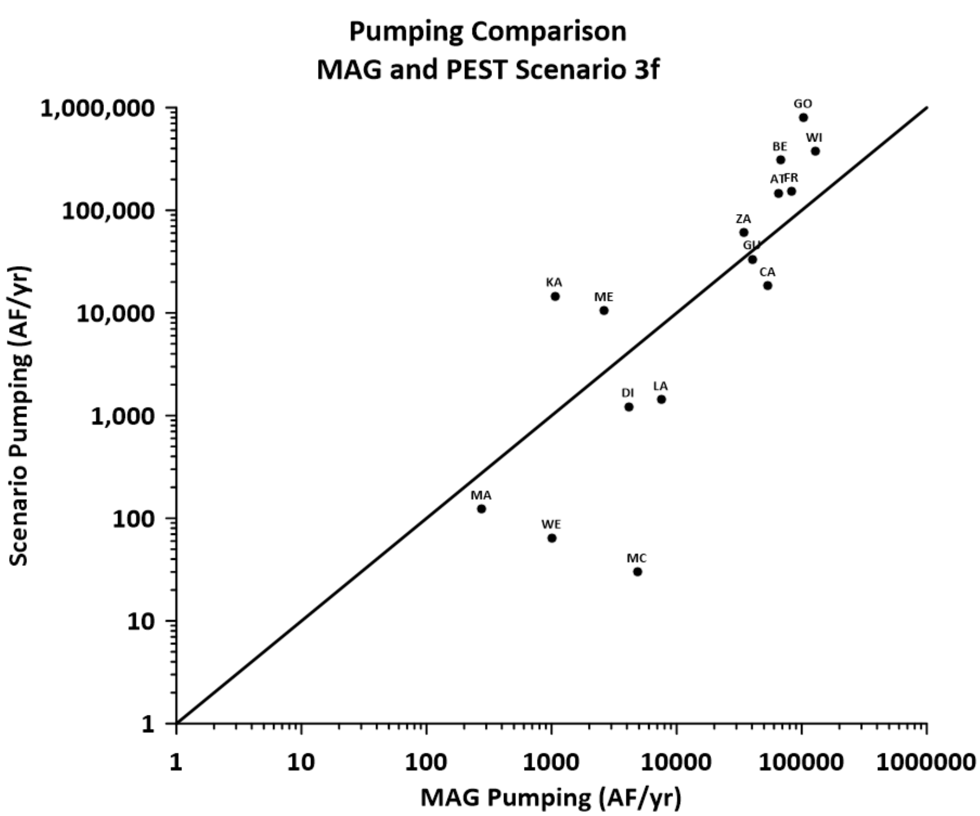

Figure 2. Pumping Comparison: MAG and Scenario 3f

Please note that scenario pumping in some counties (e.g. Atascosa, Bexar, Gonzales, and Wilson counties) are significantly higher than the MAG pumping. Some of these pumping amounts might be considered unreasonable. It should be noted that the adjustments to pumping in this scenario were made with the objective of matching DFC drawdowns in these counties. To the extent that the DFC drawdowns were derived from the previous GAM which had a known limitation of persistently declining groundwater levels, even under scenarios of reduced pumping, it would be unreasonable to take the results literally. It is far more valuable to interpret the results that the large drawdowns associated with the current DFC may need reevaluation.

GMA 13 used a "project-centric" approach to establishing the DFCs beginning in the first round of joint planning (i.e. 2005 to 2010). GMA 13 continued this basic approach during the second and third rounds of joint planning. This approach involved identifying potential locations and amounts of future pumping, then running the model to estimate the average drawdown over county-aquifer, county-layer, district-aquifer, or district-layer units as well as over all of GMA 13. Critics of this approach have labeled it "reverse engineering" the DFCs. An alternative to this approach is develop simulations that focus more on a "aquifer-availability" approach. The new GAM appears to be more capable to complete aquifer-availability scenarios than the old GAM because the limitation of persistently lowering groundwater levels has been addressed in the new GAM.

One other related issue are the public comments received to date about perceived issues and/or errors of the new GAM related to specified transmissivity and storativity values. These simulations are useful, but not dispositive in resolving this issue. Although the drawdowns and pumping results demonstrate that the new GAM has less drawdown than the old GAM for a given pumping, it is not possible to clearly state that it represents a flaw in the new GAM. The results of Scenario 4f are useful to explore this issue further.

4.5 PEST Simulation 4

This simulation limited the drawdown to Carrizo-Wilcox Aquifer units and allowed pumping variations to the MAG only in Carrizo-Wilcox Aquifer units. From a drawdown target perspective, the weight to all Sparta Aquifer and Queen City Aquifer targets was set to 1.0E-06 to effectively remove them from the objective function. Pumping in all Sparta Aquifer and Queen City Aquifer county-layer units were fixed to MAG values. Thus, only Carrizo-Wilcox pumping was adjusted in an attempt to match Carrizo-Wilcox drawdown targets.

Simulation 4 (*MAGSim04.pst*) reset all initial pumping factors to 1.0. All pumping factor upper limits were set to 10. The number of adjustable county-layer pumping factors for this simulation was 30, and there were 34 target drawdowns with weighting adjusted as described above. The initial *phi* for this simulation was 154,374, which is different than the initial *phi* for Simulation 1 due to the effects of different weighting.

After four PEST iterations and 245 model runs, the *phi* had lowered to 10,350. Most of the improvement in *phi* was realized in the first PEST iteration. The minor lowering of *phi* in the last three PEST iterations suggested that further improvement in *phi* with additional factor limit adjustments would not be useful. Therefore, the PEST simulation was terminated after four PEST iterations. The summary output for this simulation is *magsim04.rec*.

4.6 PEST Simulation 4f

To obtain a clean set of output files, a final run of PEST Simulation 4 (*MAGSim04f.pst*) was run using the pumping factors from the fourth PEST iteration of Simulation 4. The PEST input file was modified to complete zero iterations to obtain the drawdown comparison with pumping adjustments at the end of PEST Simulation 4. The output file for this simulation is *magsim04f.rec*.

The initial (and final) *phi* for this simulation was 10,220 (essentially the same as the end *phi* of Simulation 4 considering rounding errors associated with factor specification in the input file).

4.6.1 Drawdown Results

Drawdown calculations for this simulation were obtained from the FORTRAN program *getdd4f.exe*. Please recall that this simulation pumping adjustments and drawdown targets only focused on Carrizo-Wilcox units. Summary results for the Carrizo-Wilcox units are presented in Table 9 and Figure 3.

Please note that the county-aquifer plotting code in Table 9 appears as point labels in Figure 3 to denote the county-aquifer unit represented by each point. Also please note that a one-to-one line is plotted to facilitate comparison of the average drawdowns between the two simulations:

- A point that lies on the line represents the same average drawdown in both simulations
- A point that lies above or to the left of the line represents an average drawdown in Scenario 4f that is higher than the DFC average drawdown
- A point that lies below or to the right of the line represents an average drawdown in Scenario 4f that is lower than the DFC average drawdown

Please note that in Figure 3, all but three of the points are near the one-to-one line. The exceptions are LaSalle, McMullen, and Webb counties. These point fall above the one-to-one line which means that the Scenario 4f drawdown is higher than the DFC drawdown. This observation is discussed further after presenting the pumping comparison for this simulation.

Table 9. Drawdown Comparison: DFC and Scenario 4f

Included in Objective Function

County Code	County Name	Aquifer	New GAM Layers	PEST Obervation Number	Plotting Code	Drawdown (ft)	
						DFC	Scenario 4f
7	Atascosa	Carrizo-Wilcox	7, 8, and 9	o3	ATCW	127	134
15	Bexar	Carrizo-Wilcox	7, 8, and 9	o4	BECW	107	102
28	Caldwell	Carrizo-Wilcox	7, 8, and 9	o6	CACW	45	43
64	Dimmit	Carrizo-Wilcox	7, 8, and 9	o8	DICW	-5	5
82	Frio	Carrizo-Wilcox	7, 8, and 9	o11	FRCW	53	58
89	Gonzales	Carrizo-Wilcox	7, 8, and 9	o14	GOCW	181	175
94	Guadalupe	Carrizo-Wilcox	7, 8, and 9	o16	GUCW	147	140
128	Karnes	Carrizo-Wilcox	7, 8, and 9	o18	KACW	214	204
139	LaSalle	Carrizo-Wilcox	7, 8, and 9	o21	LACW	11	61
159	Maverick	Carrizo-Wilcox	7, 8, and 9	o22	MACW	-13	1
162	McMullen	Carrizo-Wilcox	7, 8, and 9	o25	MCCW	34	97
163	Medina	Carrizo-Wilcox	7, 8, and 9	o26	MECW	31	40
232	Uvalde	Carrizo-Wilcox	7, 8, and 9	o27	UVCW	18	4
240	Webb	Carrizo-Wilcox	7, 8, and 9	o29	WECW	-4	49
247	Wilson	Carrizo-Wilcox	7, 8, and 9	o32	WICW	269	270
254	Zavala	Carrizo-Wilcox	7, 8, and 9	o34	ZACW	14	9

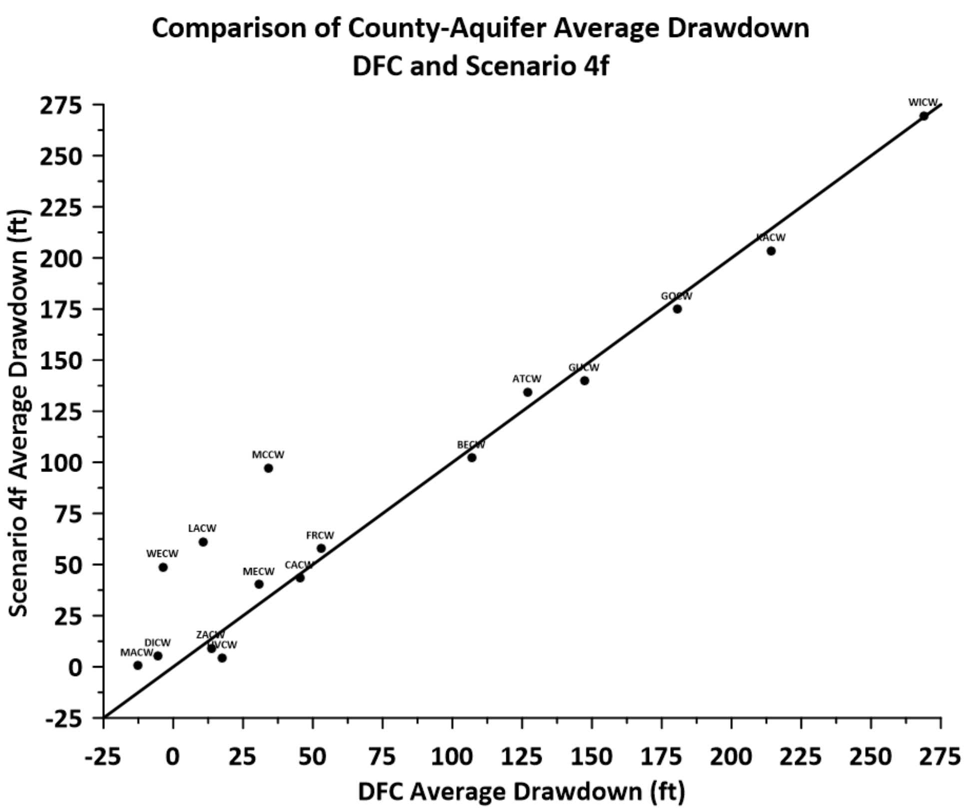

Figure 3. Drawdown Comparison: DFC and Scenario 4f

4.6.2 Pumping Results

Output pumping calculations for this simulation were obtained from the FORTRAN program *getpump4f.exe*. Summary pumping results are summarized in Table 10 and Figure 4. Please note that, for purposes of this summary, all pumping (Sparta, Queen City, and Sparta) is included in the summary table, although the detailed output from *getpump4f.exe* includes detailed pumping for the outcrop area, downdip area, and total pumping for each aquifer.

Please note that the pumping in Figure 4 is plotted on a logarithmic scale to facilitate comparisons across all counties. A comparison plot using linear axes clusters low pumping counties near the origin and makes it difficult to visualize where pumping is above or below the one-to-one line. The one-to-one line can be used compare MAG pumping and scenario pumping as follows:

- A point that lies on the line represents the same pumping in both simulations
- A point that lies above or to the left of the line represents scenario pumping higher than MAG pumping
- A point that lies below or to the right of the line represents scenario pumping lower than MAG pumping

Table 10. Pumping Comparison: MAG and Scenario 4f

County	Plotting Code	Pumping (AF/yr)	
		MAG	Scenario 4f
Atascosa	AT	65,217	138,141
Bexar	BE	67,849	283,306
Caldwell	CA	53,893	23,924
Dimmit	DI	4,124	1,351
Frio	FR	83,311	123,398
Gonzales	GO	103,653	170,220
Guadalupe	GU	40,519	56,555
Karnes	KA	1,061	6,909
LaSalle	LA	7,534	1,042
Maverick	MA	276	107
McMullen	MC	4,856	423
Medina	ME	2,646	9,240
Uvalde	UV	0	0
Webb	WE	1,006	51
Wilson	WI	127,461	335,691
Zavala	ZA	34,634	55,874
GMA 13	GMA	598,040	1,206,232

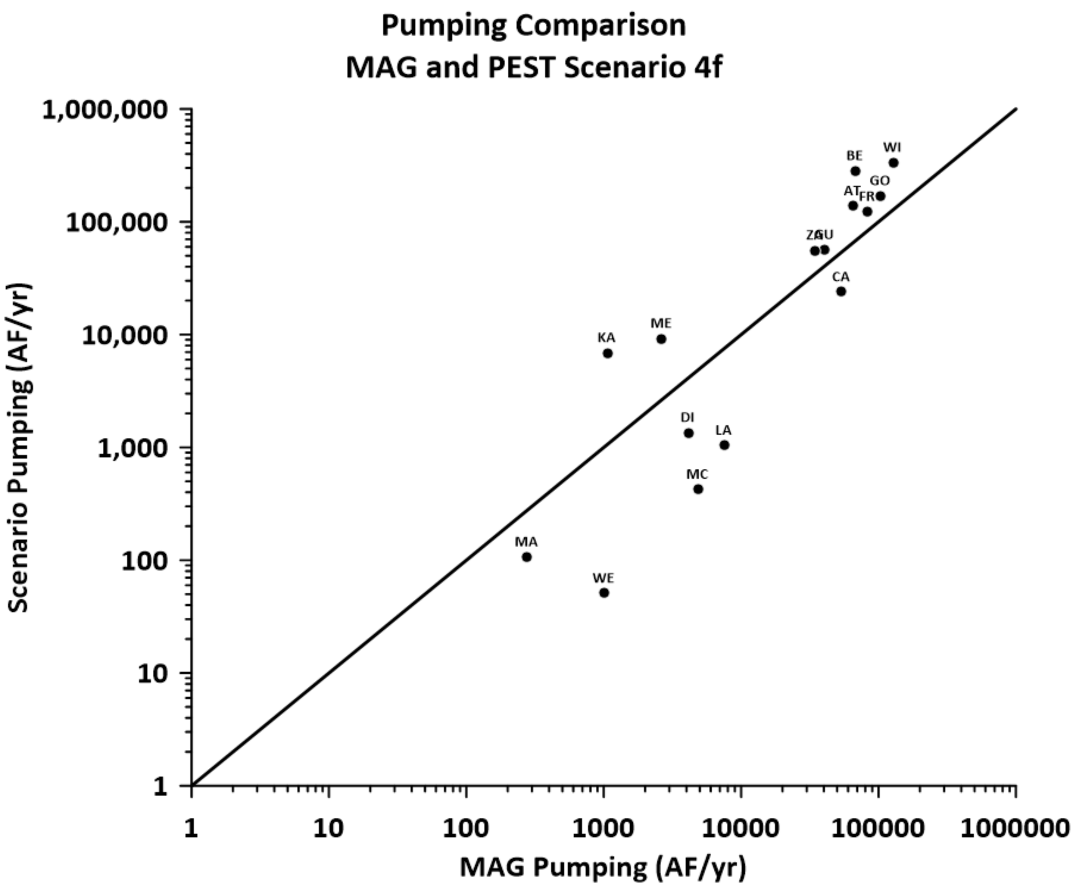

Figure 4. Pumping Comparison: MAG and Scenario 4f

Please note that the points for the five counties in the (Dimmit, LaSalle, Maverick, McMullen, and Webb) are below and to the right of the one-to-one line. This means that Scenario 4f pumping is lower than the MAG pumping. However, the drawdown in three of these counties (LaSalle, McMullen, and Webb) were significantly higher than the DFC drawdown. Thus, scenario pumping is lower than the MAG, yet the scenario drawdown is higher than the DFC. This suggests that another public comment received on the draft model related to calibration period pumping may have played a role during calibration to erroneously lower hydraulic conductivity values to match observed declines in groundwater elevation targets. Additional work is needed to confirm this possibility.

Similar to the results of Scenario 3f, there are several counties (Atascosa, Bexar, Gonzales, Medina, and Wilson) where pumping in Scenario 4f is significantly higher than the MAG pumping in order to obtain a good match to the drawdown. However, please note, for example, that the pumping in Gonzales County is 170,220 AF/yr in Scenario 4f, which is higher than the MAG pumping (103,653 AF/yr), but considerably less than the pumping in Scenario 3f (801,185 AF/yr). Please recall that Scenario 4f only considered Carrizo-Wilcox pumping, while Scenario 3f also involved adjusting pumping to hit targets in the Sparta and Queen City aquifers. These results may suggest that evaluation of the transmissivity values raised in the public comments for the Carrizo-Wilcox Aquifer should be also extended to the Queen City Aquifer.

4.7 Discussion of Results

In general, and as expected given the results of the simulations documented in Technical Memorandum 4, the new GAM suggests that the pumping higher than the existing MAG is required to meet the secondary DFC drawdown. Quantitatively matching the drawdowns leads to potentially unreasonable pumping amounts, which may point more to the limitations of the old GAM than to potential limitations of the new GAM. Please recall that the calculated pumping increases in PEST Simulation 4f were not as high the calculated pumping increases in PEST Simulation 3f. This was largely due to the elimination of Sparta and Queen City aquifer pumping adjustments in PEST Simulation 4f.

As discussed in the evaluation of Scenarios 3f and 4f, it appears that the persistent lowering of groundwater levels in the old GAM led to DFC drawdowns in some counties to be unreasonably low. However, initial public comments received on the new GAM include potential issues with:

- Calibration period pumping in some counties
- Transmissivity values in some areas
- Storativity/specific yield values in some areas

The results of these simulations (and the simulations associated with Technical Memorandum 4) are not dispositive with respect to addressing these issues. However, the results of these simulations are consistent with pointing to a potential issue with calibration pumping in the southwestern counties, and aquifer parameters in the Queen City Aquifer.

Additional analyses are needed to address the initial public comments, but these simulations provide a solid foundation for understanding the dynamics between variations in pumping and the resulting variation in groundwater levels.

The results of the simulations also point to the limitations of evaluating alternative DFCs in using a "project-centric" approach and provide a means to complete simulations in a "aquifer-availability" approach. It is recognized that the "project-centric" approach evolved during a time when DFCs and MAGs had different statutory meanings than they do today. Given the capabilities of the new GAM, it would be advisable to focus more on "aquifer-availability" simulations similar to those documented in the technical memorandum in the future.

5.0 Limitations

The simulations completed as part of this Technical Memorandum were designed to the calculate drawdown from 2017 to 2080 with the new GAM and compare the results with the DFC simulation that used the old GAM. Choosing to use a constant input pumping for these 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.

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