Daniel B. Stephens & Associates, Inc.

MEMORANDUM

TO: Jim Totten, Lost Pines Groundwater Conservation District

FROM: Andy Donnelly

DATE: October 26, 2018

SUBJECT: GAM In-Kind Services, Task 3 - DFC Run Evaluation

STATE OF TEXAS
ANDREW C.A. DONNELLY
GEOLOGY
No. 737
LICENSED
PROFESSIONAL GEOSCIENTIST

Executive Summary

DBS&A compared model simulation results with the amount and distribution of predictive pumpage used in the previous GAM run for GMA 12 in the recently updated GAM. Because of differences of the model structure between the previous and updated GAMs, direct conversion of pumpage (represented by the well [WEL] file in MODFLOW) and comparison is not possible. Model differences include:

1. Implementation of two new model layers the represent the alluvial aquifers and the uppermost portion (the shallow flow system) of the deep regional aquifers
2. Update of the historic calibration time period to include years 2000 through 2010
3. Refinement of the model grid using an unstructured grid option now available for MODFLOW.

Because of these changes, different approaches and assumptions could be used when converting the previous GAM well file for use in the updated GAM.

Three different conversion approaches were used to convert the well file used in the previous GAM with that used in the updated GAM:

1. A well file with no pumpage in either of the two new model layers;
2. A well file with no pumpage in model Layer 2, which represents the shallow flow

systems within each of the deep, regional aquifers; and

3. A well file with pumpage distributed to all model layers.

The simulation results were analyzed in two ways: 1) only water levels representing the deep regional aquifers were used to calculate drawdowns, and water levels in the model layers representing the shallow flow systems were ignored; and 2) the maximum drawdown between the layer representing the shallow flow system and the layer representing the deeper flow system was used to calculate average drawdowns. We believe the use of the maximum drawdown of the vertically adjacent model cells that represent shallow and deep flow systems is more representative because in many locations, the drawdown in the shallow flow system was very small relative to that in the deeper flow system, and we did not want to bias the overall drawdowns if we took an average between the two systems.

Although three well files were created and two different methods were used to calculate drawdowns, the results from all of the simulations were similar, resulting in a narrow range of expected drawdowns with the updated GAM. However, by comparing results of the updated GAM with those of the old GAM, we note that calculated drawdowns of the Sparta and Queen City aquifers from the new GAM are significantly higher for GMA 12 than those from the previous GAM, although some GCDs had less drawdown than the previous DFCs. Calculated drawdowns in the Carrizo Aquifer for the new GAM were similar to the previous DFCs for GMA 12 as a whole, although individual GCDs had either higher or lower drawdowns. Calculated drawdowns in the Calvert Bluff, Simsboro, and Hooper aquifers were significantly lower in the updated GAM comparted to the previous DFCs for both GMA 12 as a whole and each individual GCD within the GMA.

The different assumptions used in both the creation of the well file and analysis of the output files returned similar results. These results are still slightly different from each other, however, indicating that a set of standard operating procedures should be developed to guide use of the updated GAM in future joint groundwater planning simulations. This approach would ensure that users of the updated GAM apply the same assumptions to create well files and analyze model results.

Introduction

As part of the in-kind services that Lost Pines Groundwater Conservation District (LPGCD) provided toward the development of the updated Queen City-Sparta groundwater availability model (GAM), Daniel B. Stephens & Associates, Inc. (DBS&A) conducted a comparison analysis of the recently updated GAM (developed under TWDB Contract 1548301856) with the previous GAM for the central portion of the Carrizo-Wilcox, Queen City, and Sparta aquifers. This task involved conducting simulations with the updated GAM using the same amount and distribution of pumpage from the previous round of joint groundwater planning to assess how predicted impacts from the updated GAM compare to the previous GAM.

The previous GAM used in this report (version 2.02) is documented in Kelley and others (2004). This GAM was used to determine the modeled available groundwater (MAG) estimates for Groundwater Management Area 12 (GMA 12) during the second round of joint groundwater planning completed in 2016. Table 1 summarizes the desired future conditions (DFCs) approved by GMA 12 in 2016.

Table 1. Desired Future Conditions approved by GMA 12 from the second round of joint groundwater planning.

GCD or County	**Average Aquifer Drawdown (ft) measured from January 2000 through December 2069**					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	12	12	61	125	295	207
Fayette County GCD	47	64	110	Declared as non-relevant		
Lost Pines GCD	5	15	62	100	240	165
Mid-East Texas GCD	5	2	80	90	138	125
Post Oak Savannah GCD	28	30	67	149	318	205
Falls County	--	--	--	--	-2	27
Limestone County	--	--	--	11	50	50
Navarro County	--	--	--	-1	3	3
Williamson County	--	--	--	-11	47	69
GMA-12	***16***	***16***	***75***	***114***	***228***	***168***

Model Differences

In order to compare the drawdowns calculated using the previous GAM with those calculated using the updated GAM for the same amount and distribution of pumpage, the MODFLOW well file used with the previous GAM had to be converted for use with the updated GAM. Due to the numerous differences in model structure and gridding between the two GAMs, a direct conversion is not possible. The main differences that had to be considered with respect to converting the well file used with the previous GAM for use with the updated GAM include:

1. Implementation of two additional shallow layers in the updated GAM.
2. Expansion of the historic calibration time period from 1999 to 2010. The previous GAM was calibrated through 1999, and therefore the years 2000 to 2010 were included in the predictive portion of the previous DFC model runs.
3. Refinement of the model grid from one mile square cells to either one-half mile square or one-quarter mile square cells using an unstructured grid implemented using the MODFLOW-USG code.

Each of these differences is discussed in detail below.

Additional Model Layers - The updated GAM includes two new layers. The first model layer (Layer 1) represents the shallow alluvial aquifers associated with the Brazos and Colorado Rivers. The addition of this layer in the model is fairly straightforward and does not complicate the conversion of the previous well file because the previous GAM did not include any alluvial aquifer pumpage. It is unclear whether pumpage in Layer 1 should be included in the converted well file when doing a direct comparison to the previous model run because pumpage in the alluvial aquifers was not included in the original GMA 12 well file. Because alluvial aquifer pumpage was included in the historic calibration well file for the updated GAM, elimination of this pumpage might impact predictive results if this pumpage was removed during the predictive simulations. Therefore, we conducted simulations for this comparison study both with and without pumpage in the new model Layer 1 to assess the impact of alluvial aquifer pumpage on the predictive simulation results.

The second new model layer (Layer 2) included in the updated GAM is a surficial layer intended to represent the shallow groundwater flow system portion of the deep regional aquifers that occurs in the aquifer outcrop areas. These regional aquifers include the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper Aquifers. There are also two aquitards, one between the Sparta and Queen City Aquifers and one between the Queen City and Carrizo aquifers. This new model Layer 2 varies in thickness, with the top surface set to ground surface or the base of the alluvium (where alluvium is present). The base of model Layer 2 is typically set to approximately 25 to 75 feet below the estimated pre-development water level surface. In much of the outcrop area for each aquifer, the Layer 2 model cell directly overlies another model cell that represents the deeper portion of the same aquifer.

The addition of model Layer 2 and the presence of vertically adjacent model cells that represent the same aquifer with no intervening confining unit creates two issues that had to be addressed in the current study. The first issue is the distribution of pumpage between the two model layers that represent the aquifer unit. The previous GAM contained only one cell representing the aquifer, and all pumpage from wells in that cell were assigned to it. The updated GAM contains many areas where two vertically connected model cells represent the same aquifer. Because the updated GAM historic calibration well file contains pumpage in both the shallow flow systems (e.g numerous shallow domestic and livestock wells assigned to model Layer2) and the deeper flow systems, a determination had to be made regarding how to distribute the previous GAM pumpage to the updated GAM well file where two vertically connected cells exist. The second issue that had to be addressed was which water levels/drawdowns should be used to calculate average drawdowns, since in the outcrop areas there are two model cells representing different portions of the same aquifer.

<u>Historic Calibration Period</u>- In the original GAM, the historic calibration period was 1975 through 1999. Because of this, DFCs were structured such that calculated drawdowns always started at the end of the calibration time period. Thus in the first round of joint groundwater planning the DFCs were defined as drawdown measured from 2000 to 2060, and in the second

round of joint groundwater planning the DFCs were defined as drawdown measured from January 2000 to December 2069.

In the updated GAM the historic calibration period is extended through 2010. Therefore, the predictive portion of the model run begins in 2011 rather than 2000. In order to avoid changing the historic calibration portion of the well file in the updated GAM, simulation results for tehe period 2000 through 2010 in the original GAM predictive simulations were ignored. This approach assumed that predictive drawdown is based on the starting water levels as of the beginning of 2011, instead of the beginning of 2000.

Grid Structure - The previous GAM used a regular, structured grid, where all model cells have an equal size of one mile by one mile, and only vary in their vertical thickness. The updated GAM uses an unstructured grid. This approach allows for the model grid size to be reduced or enlarged around features of interest. In the updated GAM, grid refinements were prescribed adjacent to the Brazos and Colorado Rivers, resulting in an irregular grid pattern. Grid refinements were done by dividing some of the previous 1 mile by 1 mile grid cells into either four grid cells (1/2 mile by 1/2 mile) or sixteen grid cells (1/4 mile by 1/4 mile). This change in cell size impacts the calculation of average water levels/drawdowns across a geographic area, because of the variation in grid cell size. For the updated GAM, averaging water levels for each model cell will overemphasize water levels/drawdowns in the regions of smaller model cells because there are more of them. In addition, a determination had to be made on how to divide up the pumpage in the original, one mile square, GAM grid cell into the smaller grid cells that comprise the same area in the updated model.

We understand that with the new MODFLOW-USG program, the term "cell" is no longer used, being replaced by the term "nodes". However, to avoid confusion in this report, the term "cell" is used when referring to nodes in the updated GAM.

Methods

In order to run a predictive simulation representing the previous round of joint groundwater planning DFCs, the previous well file had to be converted and the other input files for the updated GAM had to be extended through 2070. Each of these tasks is described below.

Conversion of the Well File

Conversion of the well file used in the previous GAM for use in the updated GAM was complicated and involved several steps. Each of the major steps is described below.

Layer 1 Pumpage - The original GAM does not include a model layer to represent pumpage from the Brazos and Colorado River alluvium. The updated GAM does contain this pumpage in model Layer 1. To include pumpage in Layer 1 in the predictive portion of the model simulation, we extended the 2010 pumpage in Layer 1 in the updated GAM historic calibration well file through the predictive time period. This approach was taken for two reasons:

1. There is not a significant amount of pumpage from the Colorado River alluvium. The only permitted pumpage that we are aware of is for the City of Bastrop, and the City of Bastrop is attempting to reduce pumping from the Colorado River alluvium in favor of pumping from the Simsboro Aquifer. Therefore, it seems unlikely that there will be a substantial increase in pumpage from the Colorado River alluvium over the next 50 to 60 years.

2. An evaluation of historic pumpage from the Brazos River alluvium indicates that this pumpage appears to have leveled off by 2010. This observation was confirmed in a phone conversation with John Seifert, consulting hydrologist for the Brazos Valley GCD, which is the GCD with the majority of production from the Brazos River alluvium. Mr. Seifert confirmed that the pumpage from the alluvium would probably not be increasing significantly from current levels, and might actually decrease slightly in the future.

Layer 2 Pumpage - In the updated GAM, model Layer 2 represents the shallow groundwater flow regime for each aquifer. This layer serves to further isolate the alluvial aquifers and shallow flow systems from the deep, regional aquifer flow systems. Layer 2 typically occurs from ground surface or the base of the alluvium to approximately 25 to 75 feet below the predevelopment water level elevation in each aquifer outcrop area (Young and others, 2018). Thus, the aquifer represented by model Layer 2 changes depending on the cell location. As noted above, at many locations an aquifer is represented by two model cells- the shallow flow system in the aquifer outcrop that is represented with a layer 2 model cell, and the deep flow system that is represented in a model cell in a different layer (i.e. model layers 3 to 10).

The following process was used to distribute the pumpage from the previous DFC run to the new model grid for the model simulation that includes pumpage in Layer 2:

1. Historic pumpage in model Layer 2 was evaluated for each county in the model domain for the period 1930 to 2010 in the updated model.

2. The trend of pumpage in Layer 2 was noted for each county, and a factor was assigned for each county that would increase the 2010 Layer 2 pumpage in accordance with the historical trend (Appendix A).

3. Based on the county in which each model cell is located, the 2010 pumpage in Layer 2 was increased for each year in the predictive simulation by the factor assigned in step 2 above. This pumpage was then subtracted from the total pumpage in that cell in the original GAM well file, and the remaining pumpage was assigned to the underlying model layer that represented that aquifer (Layer 3=Sparta; Layer 5=Queen City; Layer 7=Carrizo; Layer 8=Calvert Bluff; Layer 9=Simsboro; Layer 10=Hooper).

4. A comparison was done to ensure that the layer 2 pumpage for any aquifer in each county was not higher than the total aquifer pumpage for that county from the original DFC model run. If the Layer 2 pumpage for a county was higher than the total pumpage in the DFC model run, the Layer 2 pumpage was decreased to equal to the total pumpage from the original DFC model run, and zero pumpage was assigned to the deep aquifer model

layer for that particular aquifer.

5. For model cells divided into four or sixteen smaller cells, the pumpage from the original GAM model cell was divided evenly between all of the subdivided cells, rather than attempt to identify the model cell that individual high-production wells occur in. This approach was taken to more accurately replicate the pumpage distribution from the original GAM well file.

Due to the potential variations in the construction of a well file representive of the original GAM well file, three simulations were conducted to compare to the previous GMA-12 simulation for the calculation of MAGs. These include:

1. *Run 1- Zero pumpage in Layers 1 and 2-* This simulation may be the closest match to the previous GMA 12 simulation using the original GAM because the previous GAM did not include model Layers 1 and 2. In this simulation, no pumpage was included in the model layer representing the alluvial aquifers, and all of the pumpage for each of the remaining aquifers was placed into the model cells representing the deeper portions of the flow systems (i.e. model Layers 3 through 10).

2. *Run 2 - Zero pumpage in Layer 2* - This simulation includes pumpage in model Layer 1 representing the alluvial aquifers. Pumpage in Layer 1 in the predictive portion of the model was set to equal the 2010 pumpage as described above. No pumpage was assigned to model Layer 2 in this simulation, and all of the pumpage for each aquifer was assigned to the model cells representing the deep flow systems. This is the same as pumping Run 1 above, but pumping in the alluvial aquifers is included in the simulation.

3. *Run 3 - Pumpage assigned to all model layers-* This simulation assigned pumpage from the aquifers of interest to Layer 2, which represents the shallow flow system. The amount of pumpage assigned to Layer 2 was based on the amount of pumpage assigned to Layer 2 in the historic calibration time period, as described above. The remainder of the pumpage was assigned to the layer representing the deeper flow system for each aquifer (model Layers 3 through 10).

Extension of Other Input Files

Most of the input files for the updated GAM either remained unchanged or only had to be extended for an additional 60 stress periods. The Recharge (RCH) package and the General Head Boundary (GHB) package in the updated model had variations during the historic calibration period and also needed to be extended through 2070. The extension of these to packages through 2070 is discussed below.

Recharge Package - Recharge varied every year during the historic calibration period. For the predictive simulation period, an average recharge value was used. The initial time step in the historic calibration simulation, intended to represent steady-state conditions, used an average recharge value for each model cell. This steady-state recharge array was used for each year/stress period in the predictive simulation period.

General Head Boundary (GHB) Package - GHBs were used to represent vertical leakage between the Sparta and the overlying Yegua-Jackson Aquifer and lateral flow of groundwater across the northeastern and southwestern boundaries of the model; of these two applications most of the GHB cells used to represent the vertical leakage (Young and others, 2018). An evaluation of the historic GHB package indicated that assigned heads in GHB cells representing vertical flow between the Yegua-Jackson and Sparta aquifers varied throughout the historic time period and did not follow a consistent trend. For the predictive stress periods the 2010 assigned heads in these cells were assumed to continue throughout the predictive simulation.

Results

As discussed above, the presence of two vertically adjacent model cells representing different portions of the same aquifer results in multiple potential methods for calculating average drawdowns. Options for the resolution of this issue include:

1. Averaging the water levels in the vertically adjacent model cells and using either a straight or weighted average to calculate drawdown
2. Using the water level in the underlying layer representing the deeper flow systems and ignoring the water level in Layer 2 representing the shallow portion of the aquifer
3. Using the maximum drawdown of either the shallow or deep model cell in the average drawdown calculations.

Option 1 allows for consideration of all water levels modeled for an aquifer at a particular location. However, one of the water levels that will be included in the computation represents the shallow flow system not included in the previous GAM. In addition, small drawdown in Layer 2 compared to the underlying layer representing the deeper flow systems (or vice versa) could bias the overall results when an average is calculated. While Options 1 or 3 may be the best methodologies for calculating average water levels in future uses of the updated GAM, they may not be the best methodology for calculating average water levels for a comparison of drawdowns to the previous GAM, which is the purpose of this study.

For the purposes of this study, the three predictive simulations were assessed as follows. For Runs 1 and 2, neither of which contained pumpage in model Layer 2, only water levels in the deeper flow systems (Layers 3 to 10) were included in the drawdown calculations - this approach is Option 2 above. For Run 3, which did contain pumpage in model Layer 2, Options 2 and 3 are used.

The average drawdowns calculated for the three model simulations are summarized in Tables 2 through 5. The results presented in these tables indicate the following:

1. Drawdowns calculated for all three of the model simulations are fairly similar.

2. Calculated drawdowns in the Sparta and Queen City Aquifers were significantly higher for GMA 12 with the updated GAM as compared to the previous GAM, although some individual GCDs had less drawdown than the previous DFCs.

3. Calculated drawdowns in the Carrizo Aquifer were similar to the previous DFCs for GMA 12 as a whole, although individual GCDs had either higher or lower values.

4. Calculated drawdowns in the Calvert Bluff, Simsboro, and Hooper Aquifers were significantly lower with the updated GAM compared to the previous DFCs for both GMA 12 as a whole and each GCD within the GMA.

5. The exclusion of pumpage in the alluvial aquifers (Layer 1) decreases the amount of drawdown in the underlying aquifers by 0 to 8 feet over the 60-year predictive time period, most significantly in the Brazos Valley and Post Oak Savannah GCDs.

6. The exclusion of pumpage in the shallow flow system (Layer 2) increased the amount of drawdown in the underlying aquifers by 0 to 2 feet over the 60-year predictive period. This is likely because the elimination of pumpage in Layer 2 resulted in an increase in pumpage in the underlying model cell representing the deeper portion of the aquifers (Layers 3 to 10), which would result in increased drawdowns in those cells.

7. The inclusion of Layer 2 in the drawdown calculations decreases the calculated drawdown for the aquifers of interest by 0 to 6 feet over the 60-year predictive period, with the exception of Williamson County, which does not contain model cells representing the deep aquifer in the Calvert Bluff Aquifer.

Table 2. Calculated average aquifer drawdowns for model simulation with no pumpage in Layers 1 or 2 (Run 1) and only averaging water levels in the deep flow system (layers 3 to 10).

GCD or County	Average Aquifer Drawdown (feet) measured from January 2011 through December 2070					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	39	33	66	77	143	115
Fayette County GCD	35	65	134	Declared as non-relevant		
Lost Pines GCD	25	28	98	88	142	104
Mid-East Texas GCD	27	19	41	42	51	47
Post Oak Savannah GCD	63	33	103	110	193	147
Falls County	--	--	--	--	14	5
Limestone County	--	--	--	12	10	7
Navarro County	--	--	--	0.3	0.5	0.2
Williamson County	--	--	--	0	32	14
GMA-12	***37***	***35***	***82***	***80***	***128***	***104***

Table 3. Calculated average aquifer drawdowns for model simulation with no pumpage in Layer 2 (Run 2) and only averaging drawdown in the deep flow system (layers 3 to 10).

GCD or County	Average Aquifer Drawdown (feet) measured from January 2011 through December 2070					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	41	38	73	84	150	123
Fayette County GCD	35	65	135	Declared as non-relevant		
Lost Pines GCD	25	28	99	89	143	105
Mid-East Texas GCD	27	20	42	42	52	48
Post Oak Savannah GCD	64	33	107	114	198	152
Falls County	--	--	--	--	15	5
Limestone County	--	--	--	12	10	7
Navarro County	--	--	--	0.3	0.5	0.2
Williamson County	--	--	--	0	32	14
GMA-12	***37***	***36***	***84***	***83***	***131***	***107***

Table 4. Calculated average aquifer drawdowns for model simulation with pumpage in all layers (run 3) and only averaging drawdown in the deep flow system (layers 3 to 10).

GCD or County	**Average Aquifer Drawdown (feet) measured from January 2011 through December 2070**					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	39	37	72	83	149	121
Fayette County GCD	34	65	134	Declared as non-relevant		
Lost Pines GCD	24	27	98	88	142	103
Mid-East Texas GCD	26	19	41	41	51	47
Post Oak Savannah GCD	62	31	106	113	197	151
Falls County	--	--	--	--	15	5
Limestone County	--	--	--	12	10	7
Navarro County	--	--	--	0.2	0.4	0.2
Williamson County	--	--	--	0	32	14
GMA-12	***36***	***35***	***83***	***82***	***130***	***106***

Table 5. Calculated average aquifer drawdowns for model simulation with pumpage in all layers (Run 3) and using the maximum drawdown to calculate a water level when two vertically adjacent nodes are present that represent the same aquifer.

GCD or County	**Average Aquifer Drawdown (feet) measured from January 2011 through December 2070**					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	36	36	69	81	148	122
Fayette County GCD	34	65	134	Declared as non-relevant		
Lost Pines GCD	21	26	93	85	138	103
Mid-East Texas GCD	22	18	39	40	50	47
Post Oak Savannah GCD	56	30	105	110	191	151
Falls County	--	--	--	--	9	5
Limestone County	--	--	--	9	8	7
Navarro County	--	--	--	0.1	0.2	0.2
Williamson County	--	--	--	28	23	14
GMA-12	***33***	***34***	***80***	***79***	***126***	***106***

Summary

Due to the differences between the previous and updated GAMs, it was not possible to simulate the identical amount and distribution of pumpage used in the previous GAM in the updated GAM. This is because of the inclusion of two new layers in the updated GAM; the use of an unstructured grid to reduce the cell size in selected areas; the occurrence of a single aquifer simulated at the same location using two model layers; and the updating of the historic calibration time period from 2000 through 2010.

To evaluate the application of the previous GAM well file in the updated GAM, three model simulations were conducted to illustrate a range of potential outcomes. One simulation had no pumpage in either of the two new model layers, one simulation had no pumpage in the new model layer representing the shallow portion of the deep regional aquifers, and one simulation had pumpage in all model layers. The results from these three simulations are summarized in Table 6, which illustrates that the simulated average drawdowns are fairly similar despite the differences in the well files. The lower drawdowns in Table 6 are from Run 1, which eliminated all pumpage in the alluvial aquifers. This decrease in pumpage from the overall model run resulted in lower drawdowns throughout the model. The higher drawdowns in Table 6 are from Run 2, which did not distribute any pumpage to Layer 2, the layer representing the shallow flow systems in the model. Instead, this pumpage was assigned to the layers representing the deeper flow systems, which resulted in the increased overall simulated drawdowns.

The simulated drawdowns using the previous GAM well file in the previous GAM are summarized in Table 7. Comparison of the results in Tables 6 and 7 indicates the following:

1. Calculated drawdowns in the Sparta Aquifer are higher for GMA 12, and for all individual GCDs and counties except for Fayette County GCD, which had lower calculated drawdowns than with the previous GAM.

2. Calculated drawdowns in the Queen City Aquifer are higher for GMA 12, and for all individual GCDs and counties except for Post Oak Savannah and Fayette County GCDs, both of which had similar calculated drawdowns with the previous GAM.

3. Calculated drawdowns in the Carrizo Aquifer are higher for GMA 12, and for all individual GCDs and counties except for Fayette County GCD, which had lower calculated drawdowns than with the previous GAM.

4. Calculated drawdowns in the Calvert Bluff, Carrizo, and Hooper Aquifers are significantly lower for GMA 12 and for all GCDs compared to the previous GAM.

The third simulation was evaluated using two methodologies to calculate average drawdowns. The first method used water levels from the deep regional aquifers only, and the second method used the model cells representative of both the shallow and deep flow systems. A comparison of the results of the two approaches indicated that the overall average drawdowns decreased slightly when the simulated water levels in the shallow flow system were included in the computation.

This analysis illustrates the range of drawdowns that might be calculated under the premise of replicating the previous GMA 12 pumpage file. These results illustrate the need to develop a set of "standard operating procedures" where the updated GAM is used to calculate drawdowns for use in joint groundwater planning. These procedures should be developed and agreed upon by the GCDs and their consultants and the TWDB.

Table 6. Range of drawdowns calculated for the three simulations using the updated GAM.

GCD or County	**Average Aquifer Drawdown (feet) measured from January 2011 through December 2070**					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	39-41	33-38	66-73	77-84	143-150	115-123
Fayette County GCD	34-35	65	134-135	Declared as non-relevant		
Lost Pines GCD	24-25	27-28	98-99	85-89	138-143	103-105
Mid-East Texas GCD	26-27	19-20	41-42	40-42	50-52	47-48
Post Oak Savannah GCD	62-64	31-33	103-107	110-114	191-198	151-152
Falls County	--	--	--	--	9-15	5
Limestone County	--	--	--	9-12	8-10	7
Navarro County	--	--	--	0.1-0.3	0.2-0.5	0.2
Williamson County	--	--	--	28	23-32	14
GMA-12	***36-37***	***34-36***	***80-84***	***79-83***	***126-131***	***106-107***

Table 7. Drawdowns calculated using the previous GAM.

GCD or County	**Average Aquifer Drawdown (feet) measured from January 2011 through December 2070**					
	Sparta	**Queen City**	**Carrizo**	**Calvert Bluff**	**Simsboro**	**Hooper**
Brazos Valley GCD	12	12	61	125	295	207
Fayette County GCD	47	64	110	Declared as non-relevant		
Lost Pines GCD	4	16	68	110	251	181
Mid-East Texas GCD	1	-3.2	81	90	138	126
Post Oak Savannah GCD	28	30	67	149	322	206
Falls County	--	--	--	--	-2	27
Limestone County	--	--	--	11	51	53
Navarro County	--	--	--	-1	6	6
Williamson County	--	--	--	-11	47	68
GMA-12	***16***	***16***	***75***	***115***	***231***	***171***

References

Kelley, V. A., N. E. Deeds, D. G. Fryar, J-P Nicot, T. L Jones, A. R. Dutton, G. Bruehl, T. Unger-Holtz, J. L. Machin, 2004; Groundwater Availability Models for the Queen City and Sparta Aquifers; final report prepared for the Texas Water Development Board; October, 2004; 867 p.

Young, S., J. Jigmond, T. Jones, T. Ewing, S. Panday, RW Harden & Associates, and D. Lupton, 2018, Draft: Groundwater Availability Model for the Central Portion of the Sparta, Queen City, and Carrizo Aquifers; draft report prepared for the Texas Water Development Board; June, 2018; 2 vols., 914 p.

Appendix A

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Bexar	Comal	Hays	Travis	Williamson	Bell	Falls	McLennan	Limestone	Navarro	Henderson	Kaufman	Van Zandt	Guadalupe	Milam
2011	1	1	1	1	1.04	1	1.01	1	1.01	1.025	1.01	1	1.01	1.01	1.01
2012	1	1	1	1	1.08	1	1.02	1	1.02	1.05	1.02	1	1.02	1.02	1.02
2013	1	1	1	1	1.12	1	1.03	1	1.03	1.075	1.03	1	1.03	1.03	1.03
2014	1	1	1	1	1.16	1	1.04	1	1.04	1.1	1.04	1	1.04	1.04	1.04
2015	1	1	1	1	1.2	1	1.05	1	1.05	1.125	1.05	1	1.05	1.05	1.05
2016	1	1	1	1	1.24	1	1.06	1	1.06	1.15	1.06	1	1.06	1.06	1.06
2017	1	1	1	1	1.28	1	1.07	1	1.07	1.175	1.07	1	1.07	1.07	1.07
2018	1	1	1	1	1.32	1	1.08	1	1.08	1.2	1.08	1	1.08	1.08	1.08
2019	1	1	1	1	1.36	1	1.09	1	1.09	1.225	1.09	1	1.09	1.09	1.09
2020	1	1	1	1	1.4	1	1.1	1	1.1	1.25	1.1	1	1.1	1.1	1.1
2021	1	1	1	1	1.44	1	1.11	1	1.11	1.275	1.11	1	1.11	1.11	1.11
2022	1	1	1	1	1.48	1	1.12	1	1.12	1.3	1.12	1	1.12	1.12	1.12
2023	1	1	1	1	1.52	1	1.13	1	1.13	1.325	1.13	1	1.13	1.13	1.13
2024	1	1	1	1	1.56	1	1.14	1	1.14	1.35	1.14	1	1.14	1.14	1.14
2025	1	1	1	1	1.6	1	1.15	1	1.15	1.375	1.15	1	1.15	1.15	1.15
2026	1	1	1	1	1.64	1	1.16	1	1.16	1.4	1.16	1	1.16	1.16	1.16
2027	1	1	1	1	1.68	1	1.17	1	1.17	1.425	1.17	1	1.17	1.17	1.17
2028	1	1	1	1	1.72	1	1.18	1	1.18	1.45	1.18	1	1.18	1.18	1.18
2029	1	1	1	1	1.76	1	1.19	1	1.19	1.475	1.19	1	1.19	1.19	1.19
2030	1	1	1	1	1.8	1	1.2	1	1.2	1.5	1.2	1	1.2	1.2	1.2
2031	1	1	1	1	1.84	1	1.21	1	1.21	1.525	1.21	1	1.21	1.21	1.21
2032	1	1	1	1	1.88	1	1.22	1	1.22	1.55	1.22	1	1.22	1.22	1.22
2033	1	1	1	1	1.92	1	1.23	1	1.23	1.575	1.23	1	1.23	1.23	1.23
2034	1	1	1	1	1.96	1	1.24	1	1.24	1.6	1.24	1	1.24	1.24	1.24
2035	1	1	1	1	2	1	1.25	1	1.25	1.625	1.25	1	1.25	1.25	1.25
2036	1	1	1	1	2.04	1	1.26	1	1.26	1.65	1.26	1	1.26	1.26	1.26
2037	1	1	1	1	2.08	1	1.27	1	1.27	1.675	1.27	1	1.27	1.27	1.27
2038	1	1	1	1	2.12	1	1.28	1	1.28	1.7	1.28	1	1.28	1.28	1.28
2039	1	1	1	1	2.16	1	1.29	1	1.29	1.725	1.29	1	1.29	1.29	1.29
2040	1	1	1	1	2.2	1	1.3	1	1.3	1.75	1.3	1	1.3	1.3	1.3
2041	1	1	1	1	2.24	1	1.31	1	1.31	1.775	1.31	1	1.31	1.31	1.31
2042	1	1	1	1	2.28	1	1.32	1	1.32	1.8	1.32	1	1.32	1.32	1.32
2043	1	1	1	1	2.32	1	1.33	1	1.33	1.825	1.33	1	1.33	1.33	1.33
2044	1	1	1	1	2.36	1	1.34	1	1.34	1.85	1.34	1	1.34	1.34	1.34
2045	1	1	1	1	2.4	1	1.35	1	1.35	1.875	1.35	1	1.35	1.35	1.35
2046	1	1	1	1	2.44	1	1.36	1	1.36	1.9	1.36	1	1.36	1.36	1.36
2047	1	1	1	1	2.48	1	1.37	1	1.37	1.925	1.37	1	1.37	1.37	1.37
2048	1	1	1	1	2.52	1	1.38	1	1.38	1.95	1.38	1	1.38	1.38	1.38
2049	1	1	1	1	2.56	1	1.39	1	1.39	1.975	1.39	1	1.39	1.39	1.39
2050	1	1	1	1	2.6	1	1.4	1	1.4	2	1.4	1	1.4	1.4	1.4
2051	1	1	1	1	2.64	1	1.41	1	1.41	2.025	1.41	1	1.41	1.41	1.41
2052	1	1	1	1	2.68	1	1.42	1	1.42	2.05	1.42	1	1.42	1.42	1.42
2053	1	1	1	1	2.72	1	1.43	1	1.43	2.075	1.43	1	1.43	1.43	1.43
2054	1	1	1	1	2.76	1	1.44	1	1.44	2.1	1.44	1	1.44	1.44	1.44
2055	1	1	1	1	2.8	1	1.45	1	1.45	2.125	1.45	1	1.45	1.45	1.45
2056	1	1	1	1	2.84	1	1.46	1	1.46	2.15	1.46	1	1.46	1.46	1.46

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Bexar	Comal	Hays	Travis	Williamson	Bell	Falls	McLennan	Limestone	Navarro	Henderson	Kaufman	Van Zandt	Guadalupe	Milam
2057	1	1	1	1	2.88	1	1.47	1	1.47	2.175	1.47	1	1.47	1.47	1.47
2058	1	1	1	1	2.92	1	1.48	1	1.48	2.2	1.48	1	1.48	1.48	1.48
2059	1	1	1	1	2.96	1	1.49	1	1.49	2.225	1.49	1	1.49	1.49	1.49
2060	1	1	1	1	3	1	1.5	1	1.5	2.25	1.5	1	1.5	1.5	1.5
2061	1	1	1	1	3.04	1	1.51	1	1.51	2.275	1.51	1	1.51	1.51	1.51
2062	1	1	1	1	3.08	1	1.52	1	1.52	2.3	1.52	1	1.52	1.52	1.52
2063	1	1	1	1	3.12	1	1.53	1	1.53	2.325	1.53	1	1.53	1.53	1.53
2064	1	1	1	1	3.16	1	1.54	1	1.54	2.35	1.54	1	1.54	1.54	1.54
2065	1	1	1	1	3.2	1	1.55	1	1.55	2.375	1.55	1	1.55	1.55	1.55
2066	1	1	1	1	3.24	1	1.56	1	1.56	2.4	1.56	1	1.56	1.56	1.56
2067	1	1	1	1	3.28	1	1.57	1	1.57	2.425	1.57	1	1.57	1.57	1.57
2068	1	1	1	1	3.32	1	1.58	1	1.58	2.45	1.58	1	1.58	1.58	1.58
2069	1	1	1	1	3.36	1	1.59	1	1.59	2.475	1.59	1	1.59	1.59	1.59
2070	1	1	1	1	3.4	1	1.6	1	1.6	2.5	1.6	1	1.6	1.6	1.6

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Freestone	Caldwell	Wilson	Bastrop	Robertson	Lee	Anderson	Burleson	Leon	Gonzales	Karnes	Smith	Fayette	Cherokee	Brazos
2011	1	1.02	1.01	1.01	1.005	1.015	1.005	1.01	1	1.01	1	1.02	1	1.005	1
2012	1	1.04	1.02	1.02	1.01	1.03	1.01	1.02	1	1.02	1	1.04	1	1.01	1
2013	1	1.06	1.03	1.03	1.015	1.045	1.015	1.03	1	1.03	1	1.06	1	1.015	1
2014	1	1.08	1.04	1.04	1.02	1.06	1.02	1.04	1	1.04	1	1.08	1	1.02	1
2015	1	1.1	1.05	1.05	1.025	1.075	1.025	1.05	1	1.05	1	1.1	1	1.025	1
2016	1	1.12	1.06	1.06	1.03	1.09	1.03	1.06	1	1.06	1	1.12	1	1.03	1
2017	1	1.14	1.07	1.07	1.035	1.105	1.035	1.07	1	1.07	1	1.14	1	1.035	1
2018	1	1.16	1.08	1.08	1.04	1.12	1.04	1.08	1	1.08	1	1.16	1	1.04	1
2019	1	1.18	1.09	1.09	1.045	1.135	1.045	1.09	1	1.09	1	1.18	1	1.045	1
2020	1	1.2	1.1	1.1	1.05	1.15	1.05	1.1	1	1.1	1	1.2	1	1.05	1
2021	1	1.22	1.11	1.11	1.055	1.165	1.055	1.11	1	1.11	1	1.22	1	1.055	1
2022	1	1.24	1.12	1.12	1.06	1.18	1.06	1.12	1	1.12	1	1.24	1	1.06	1
2023	1	1.26	1.13	1.13	1.065	1.195	1.065	1.13	1	1.13	1	1.26	1	1.065	1
2024	1	1.28	1.14	1.14	1.07	1.21	1.07	1.14	1	1.14	1	1.28	1	1.07	1
2025	1	1.3	1.15	1.15	1.075	1.225	1.075	1.15	1	1.15	1	1.3	1	1.075	1
2026	1	1.32	1.16	1.16	1.08	1.24	1.08	1.16	1	1.16	1	1.32	1	1.08	1
2027	1	1.34	1.17	1.17	1.085	1.255	1.085	1.17	1	1.17	1	1.34	1	1.085	1
2028	1	1.36	1.18	1.18	1.09	1.27	1.09	1.18	1	1.18	1	1.36	1	1.09	1
2029	1	1.38	1.19	1.19	1.095	1.285	1.095	1.19	1	1.19	1	1.38	1	1.095	1
2030	1	1.4	1.2	1.2	1.1	1.3	1.1	1.2	1	1.2	1	1.4	1	1.1	1
2031	1	1.42	1.21	1.21	1.105	1.315	1.105	1.21	1	1.21	1	1.42	1	1.105	1
2032	1	1.44	1.22	1.22	1.11	1.33	1.11	1.22	1	1.22	1	1.44	1	1.11	1
2033	1	1.46	1.23	1.23	1.115	1.345	1.115	1.23	1	1.23	1	1.46	1	1.115	1
2034	1	1.48	1.24	1.24	1.12	1.36	1.12	1.24	1	1.24	1	1.48	1	1.12	1
2035	1	1.5	1.25	1.25	1.125	1.375	1.125	1.25	1	1.25	1	1.5	1	1.125	1
2036	1	1.52	1.26	1.26	1.13	1.39	1.13	1.26	1	1.26	1	1.52	1	1.13	1
2037	1	1.54	1.27	1.27	1.135	1.405	1.135	1.27	1	1.27	1	1.54	1	1.135	1
2038	1	1.56	1.28	1.28	1.14	1.42	1.14	1.28	1	1.28	1	1.56	1	1.14	1
2039	1	1.58	1.29	1.29	1.145	1.435	1.145	1.29	1	1.29	1	1.58	1	1.145	1
2040	1	1.6	1.3	1.3	1.15	1.45	1.15	1.3	1	1.3	1	1.6	1	1.15	1
2041	1	1.62	1.31	1.31	1.155	1.465	1.155	1.31	1	1.31	1	1.62	1	1.155	1
2042	1	1.64	1.32	1.32	1.16	1.48	1.16	1.32	1	1.32	1	1.64	1	1.16	1
2043	1	1.66	1.33	1.33	1.165	1.495	1.165	1.33	1	1.33	1	1.66	1	1.165	1
2044	1	1.68	1.34	1.34	1.17	1.51	1.17	1.34	1	1.34	1	1.68	1	1.17	1
2045	1	1.7	1.35	1.35	1.175	1.525	1.175	1.35	1	1.35	1	1.7	1	1.175	1
2046	1	1.72	1.36	1.36	1.18	1.54	1.18	1.36	1	1.36	1	1.72	1	1.18	1
2047	1	1.74	1.37	1.37	1.185	1.555	1.185	1.37	1	1.37	1	1.74	1	1.185	1
2048	1	1.76	1.38	1.38	1.19	1.57	1.19	1.38	1	1.38	1	1.76	1	1.19	1
2049	1	1.78	1.39	1.39	1.195	1.585	1.195	1.39	1	1.39	1	1.78	1	1.195	1
2050	1	1.8	1.4	1.4	1.2	1.6	1.2	1.4	1	1.4	1	1.8	1	1.2	1
2051	1	1.82	1.41	1.41	1.205	1.615	1.205	1.41	1	1.41	1	1.82	1	1.205	1
2052	1	1.84	1.42	1.42	1.21	1.63	1.21	1.42	1	1.42	1	1.84	1	1.21	1
2053	1	1.86	1.43	1.43	1.215	1.645	1.215	1.43	1	1.43	1	1.86	1	1.215	1
2054	1	1.88	1.44	1.44	1.22	1.66	1.22	1.44	1	1.44	1	1.88	1	1.22	1
2055	1	1.9	1.45	1.45	1.225	1.675	1.225	1.45	1	1.45	1	1.9	1	1.225	1
2056	1	1.92	1.46	1.46	1.23	1.69	1.23	1.46	1	1.46	1	1.92	1	1.23	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Freestone	Caldwell	Wilson	Bastrop	Robertson	Lee	Anderson	Burleson	Leon	Gonzales	Karnes	Smith	Fayette	Cherokee	Brazos
2057	1	1.94	1.47	1.47	1.235	1.705	1.235	1.47	1	1.47	1	1.94	1	1.235	1
2058	1	1.96	1.48	1.48	1.24	1.72	1.24	1.48	1	1.48	1	1.96	1	1.24	1
2059	1	1.98	1.49	1.49	1.245	1.735	1.245	1.49	1	1.49	1	1.98	1	1.245	1
2060	1	2	1.5	1.5	1.25	1.75	1.25	1.5	1	1.5	1	2	1	1.25	1
2061	1	2.02	1.51	1.51	1.255	1.765	1.255	1.51	1	1.51	1	2.02	1	1.255	1
2062	1	2.04	1.52	1.52	1.26	1.78	1.26	1.52	1	1.52	1	2.04	1	1.26	1
2063	1	2.06	1.53	1.53	1.265	1.795	1.265	1.53	1	1.53	1	2.06	1	1.265	1
2064	1	2.08	1.54	1.54	1.27	1.81	1.27	1.54	1	1.54	1	2.08	1	1.27	1
2065	1	2.1	1.55	1.55	1.275	1.825	1.275	1.55	1	1.55	1	2.1	1	1.275	1
2066	1	2.12	1.56	1.56	1.28	1.84	1.28	1.56	1	1.56	1	2.12	1	1.28	1
2067	1	2.14	1.57	1.57	1.285	1.855	1.285	1.57	1	1.57	1	2.14	1	1.285	1
2068	1	2.16	1.58	1.58	1.29	1.87	1.29	1.58	1	1.58	1	2.16	1	1.29	1
2069	1	2.18	1.59	1.59	1.295	1.885	1.295	1.59	1	1.59	1	2.18	1	1.295	1
2070	1	2.2	1.6	1.6	1.3	1.9	1.3	1.6	1	1.6	1	2.2	1	1.3	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	De Witt	Madison	Washington	Houston	Lavaca	Grimes	Goliad	Austin	Colorado	Rusk	Walker	Victoria	Nacogdoches	Waller	Montgomery
2011	1	1	1	1.01	1	1	1	1	1	1	1	1	1.005	1	1
2012	1	1	1	1.02	1	1	1	1	1	1	1	1	1.01	1	1
2013	1	1	1	1.03	1	1	1	1	1	1	1	1	1.015	1	1
2014	1	1	1	1.04	1	1	1	1	1	1	1	1	1.02	1	1
2015	1	1	1	1.05	1	1	1	1	1	1	1	1	1.025	1	1
2016	1	1	1	1.06	1	1	1	1	1	1	1	1	1.03	1	1
2017	1	1	1	1.07	1	1	1	1	1	1	1	1	1.035	1	1
2018	1	1	1	1.08	1	1	1	1	1	1	1	1	1.04	1	1
2019	1	1	1	1.09	1	1	1	1	1	1	1	1	1.045	1	1
2020	1	1	1	1.1	1	1	1	1	1	1	1	1	1.05	1	1
2021	1	1	1	1.11	1	1	1	1	1	1	1	1	1.055	1	1
2022	1	1	1	1.12	1	1	1	1	1	1	1	1	1.06	1	1
2023	1	1	1	1.13	1	1	1	1	1	1	1	1	1.065	1	1
2024	1	1	1	1.14	1	1	1	1	1	1	1	1	1.07	1	1
2025	1	1	1	1.15	1	1	1	1	1	1	1	1	1.075	1	1
2026	1	1	1	1.16	1	1	1	1	1	1	1	1	1.08	1	1
2027	1	1	1	1.17	1	1	1	1	1	1	1	1	1.085	1	1
2028	1	1	1	1.18	1	1	1	1	1	1	1	1	1.09	1	1
2029	1	1	1	1.19	1	1	1	1	1	1	1	1	1.095	1	1
2030	1	1	1	1.2	1	1	1	1	1	1	1	1	1.1	1	1
2031	1	1	1	1.21	1	1	1	1	1	1	1	1	1.105	1	1
2032	1	1	1	1.22	1	1	1	1	1	1	1	1	1.11	1	1
2033	1	1	1	1.23	1	1	1	1	1	1	1	1	1.115	1	1
2034	1	1	1	1.24	1	1	1	1	1	1	1	1	1.12	1	1
2035	1	1	1	1.25	1	1	1	1	1	1	1	1	1.125	1	1
2036	1	1	1	1.26	1	1	1	1	1	1	1	1	1.13	1	1
2037	1	1	1	1.27	1	1	1	1	1	1	1	1	1.135	1	1
2038	1	1	1	1.28	1	1	1	1	1	1	1	1	1.14	1	1
2039	1	1	1	1.29	1	1	1	1	1	1	1	1	1.145	1	1
2040	1	1	1	1.3	1	1	1	1	1	1	1	1	1.15	1	1
2041	1	1	1	1.31	1	1	1	1	1	1	1	1	1.155	1	1
2042	1	1	1	1.32	1	1	1	1	1	1	1	1	1.16	1	1
2043	1	1	1	1.33	1	1	1	1	1	1	1	1	1.165	1	1
2044	1	1	1	1.34	1	1	1	1	1	1	1	1	1.17	1	1
2045	1	1	1	1.35	1	1	1	1	1	1	1	1	1.175	1	1
2046	1	1	1	1.36	1	1	1	1	1	1	1	1	1.18	1	1
2047	1	1	1	1.37	1	1	1	1	1	1	1	1	1.185	1	1
2048	1	1	1	1.38	1	1	1	1	1	1	1	1	1.19	1	1
2049	1	1	1	1.39	1	1	1	1	1	1	1	1	1.195	1	1
2050	1	1	1	1.4	1	1	1	1	1	1	1	1	1.2	1	1
2051	1	1	1	1.41	1	1	1	1	1	1	1	1	1.205	1	1
2052	1	1	1	1.42	1	1	1	1	1	1	1	1	1.21	1	1
2053	1	1	1	1.43	1	1	1	1	1	1	1	1	1.215	1	1
2054	1	1	1	1.44	1	1	1	1	1	1	1	1	1.22	1	1
2055	1	1	1	1.45	1	1	1	1	1	1	1	1	1.225	1	1
2056	1	1	1	1.46	1	1	1	1	1	1	1	1	1.23	1	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	De Witt	Madison	Washington	Houston	Lavaca	Grimes	Goliad	Austin	Colorado	Rusk	Walker	Victoria	Nacogdoches	Waller	Montgomery
2057	1	1	1	1.47	1	1	1	1	1	1	1	1	1.235	1	1
2058	1	1	1	1.48	1	1	1	1	1	1	1	1	1.24	1	1
2059	1	1	1	1.49	1	1	1	1	1	1	1	1	1.245	1	1
2060	1	1	1	1.5	1	1	1	1	1	1	1	1	1.25	1	1
2061	1	1	1	1.51	1	1	1	1	1	1	1	1	1.255	1	1
2062	1	1	1	1.52	1	1	1	1	1	1	1	1	1.26	1	1
2063	1	1	1	1.53	1	1	1	1	1	1	1	1	1.265	1	1
2064	1	1	1	1.54	1	1	1	1	1	1	1	1	1.27	1	1
2065	1	1	1	1.55	1	1	1	1	1	1	1	1	1.275	1	1
2066	1	1	1	1.56	1	1	1	1	1	1	1	1	1.28	1	1
2067	1	1	1	1.57	1	1	1	1	1	1	1	1	1.285	1	1
2068	1	1	1	1.58	1	1	1	1	1	1	1	1	1.29	1	1
2069	1	1	1	1.59	1	1	1	1	1	1	1	1	1.295	1	1
2070	1	1	1	1.6	1	1	1	1	1	1	1	1	1.3	1	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Trinity	Jackson	Angelina	Refugio	Wharton	Harris	San Jacinto	Calhoun	Polk	Fort Bend	San Augustine	Aransas	Matagorda	Tyler	Liberty
2011	1	1	1.01	1	1	1	1	1	1	1	1.015	1	1	1	1
2012	1	1	1.02	1	1	1	1	1	1	1	1.03	1	1	1	1
2013	1	1	1.03	1	1	1	1	1	1	1	1.045	1	1	1	1
2014	1	1	1.04	1	1	1	1	1	1	1	1.06	1	1	1	1
2015	1	1	1.05	1	1	1	1	1	1	1	1.075	1	1	1	1
2016	1	1	1.06	1	1	1	1	1	1	1	1.09	1	1	1	1
2017	1	1	1.07	1	1	1	1	1	1	1	1.105	1	1	1	1
2018	1	1	1.08	1	1	1	1	1	1	1	1.12	1	1	1	1
2019	1	1	1.09	1	1	1	1	1	1	1	1.135	1	1	1	1
2020	1	1	1.1	1	1	1	1	1	1	1	1.15	1	1	1	1
2021	1	1	1.11	1	1	1	1	1	1	1	1.165	1	1	1	1
2022	1	1	1.12	1	1	1	1	1	1	1	1.18	1	1	1	1
2023	1	1	1.13	1	1	1	1	1	1	1	1.195	1	1	1	1
2024	1	1	1.14	1	1	1	1	1	1	1	1.21	1	1	1	1
2025	1	1	1.15	1	1	1	1	1	1	1	1.225	1	1	1	1
2026	1	1	1.16	1	1	1	1	1	1	1	1.24	1	1	1	1
2027	1	1	1.17	1	1	1	1	1	1	1	1.255	1	1	1	1
2028	1	1	1.18	1	1	1	1	1	1	1	1.27	1	1	1	1
2029	1	1	1.19	1	1	1	1	1	1	1	1.285	1	1	1	1
2030	1	1	1.2	1	1	1	1	1	1	1	1.3	1	1	1	1
2031	1	1	1.21	1	1	1	1	1	1	1	1.315	1	1	1	1
2032	1	1	1.22	1	1	1	1	1	1	1	1.33	1	1	1	1
2033	1	1	1.23	1	1	1	1	1	1	1	1.345	1	1	1	1
2034	1	1	1.24	1	1	1	1	1	1	1	1.36	1	1	1	1
2035	1	1	1.25	1	1	1	1	1	1	1	1.375	1	1	1	1
2036	1	1	1.26	1	1	1	1	1	1	1	1.39	1	1	1	1
2037	1	1	1.27	1	1	1	1	1	1	1	1.405	1	1	1	1
2038	1	1	1.28	1	1	1	1	1	1	1	1.42	1	1	1	1
2039	1	1	1.29	1	1	1	1	1	1	1	1.435	1	1	1	1
2040	1	1	1.3	1	1	1	1	1	1	1	1.45	1	1	1	1
2041	1	1	1.31	1	1	1	1	1	1	1	1.465	1	1	1	1
2042	1	1	1.32	1	1	1	1	1	1	1	1.48	1	1	1	1
2043	1	1	1.33	1	1	1	1	1	1	1	1.495	1	1	1	1
2044	1	1	1.34	1	1	1	1	1	1	1	1.51	1	1	1	1
2045	1	1	1.35	1	1	1	1	1	1	1	1.525	1	1	1	1
2046	1	1	1.36	1	1	1	1	1	1	1	1.54	1	1	1	1
2047	1	1	1.37	1	1	1	1	1	1	1	1.555	1	1	1	1
2048	1	1	1.38	1	1	1	1	1	1	1	1.57	1	1	1	1
2049	1	1	1.39	1	1	1	1	1	1	1	1.585	1	1	1	1
2050	1	1	1.4	1	1	1	1	1	1	1	1.6	1	1	1	1
2051	1	1	1.41	1	1	1	1	1	1	1	1.615	1	1	1	1
2052	1	1	1.42	1	1	1	1	1	1	1	1.63	1	1	1	1
2053	1	1	1.43	1	1	1	1	1	1	1	1.645	1	1	1	1
2054	1	1	1.44	1	1	1	1	1	1	1	1.66	1	1	1	1
2055	1	1	1.45	1	1	1	1	1	1	1	1.675	1	1	1	1
2056	1	1	1.46	1	1	1	1	1	1	1	1.69	1	1	1	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Trinity	Jackson	Angelina	Refugio	Wharton	Harris	San Jacinto	Calhoun	Polk	Fort Bend	San Augustine	Aransas	Matagorda	Tyler	Liberty
2057	1	1	1.47	1	1	1	1	1	1	1	1.705	1	1	1	1
2058	1	1	1.48	1	1	1	1	1	1	1	1.72	1	1	1	1
2059	1	1	1.49	1	1	1	1	1	1	1	1.735	1	1	1	1
2060	1	1	1.5	1	1	1	1	1	1	1	1.75	1	1	1	1
2061	1	1	1.51	1	1	1	1	1	1	1	1.765	1	1	1	1
2062	1	1	1.52	1	1	1	1	1	1	1	1.78	1	1	1	1
2063	1	1	1.53	1	1	1	1	1	1	1	1.795	1	1	1	1
2064	1	1	1.54	1	1	1	1	1	1	1	1.81	1	1	1	1
2065	1	1	1.55	1	1	1	1	1	1	1	1.825	1	1	1	1
2066	1	1	1.56	1	1	1	1	1	1	1	1.84	1	1	1	1
2067	1	1	1.57	1	1	1	1	1	1	1	1.855	1	1	1	1
2068	1	1	1.58	1	1	1	1	1	1	1	1.87	1	1	1	1
2069	1	1	1.59	1	1	1	1	1	1	1	1.885	1	1	1	1
2070	1	1	1.6	1	1	1	1	1	1	1	1.9	1	1	1	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Brazoria	Jasper	Zavala	Sabine	Hardin	Chambers	Galveston	Newton	Jefferson
2011	1	1	1	1	1	1	1	1	1
2012	1	1	1	1	1	1	1	1	1
2013	1	1	1	1	1	1	1	1	1
2014	1	1	1	1	1	1	1	1	1
2015	1	1	1	1	1	1	1	1	1
2016	1	1	1	1	1	1	1	1	1
2017	1	1	1	1	1	1	1	1	1
2018	1	1	1	1	1	1	1	1	1
2019	1	1	1	1	1	1	1	1	1
2020	1	1	1	1	1	1	1	1	1
2021	1	1	1	1	1	1	1	1	1
2022	1	1	1	1	1	1	1	1	1
2023	1	1	1	1	1	1	1	1	1
2024	1	1	1	1	1	1	1	1	1
2025	1	1	1	1	1	1	1	1	1
2026	1	1	1	1	1	1	1	1	1
2027	1	1	1	1	1	1	1	1	1
2028	1	1	1	1	1	1	1	1	1
2029	1	1	1	1	1	1	1	1	1
2030	1	1	1	1	1	1	1	1	1
2031	1	1	1	1	1	1	1	1	1
2032	1	1	1	1	1	1	1	1	1
2033	1	1	1	1	1	1	1	1	1
2034	1	1	1	1	1	1	1	1	1
2035	1	1	1	1	1	1	1	1	1
2036	1	1	1	1	1	1	1	1	1
2037	1	1	1	1	1	1	1	1	1
2038	1	1	1	1	1	1	1	1	1
2039	1	1	1	1	1	1	1	1	1
2040	1	1	1	1	1	1	1	1	1
2041	1	1	1	1	1	1	1	1	1
2042	1	1	1	1	1	1	1	1	1
2043	1	1	1	1	1	1	1	1	1
2044	1	1	1	1	1	1	1	1	1
2045	1	1	1	1	1	1	1	1	1
2046	1	1	1	1	1	1	1	1	1
2047	1	1	1	1	1	1	1	1	1
2048	1	1	1	1	1	1	1	1	1
2049	1	1	1	1	1	1	1	1	1
2050	1	1	1	1	1	1	1	1	1
2051	1	1	1	1	1	1	1	1	1
2052	1	1	1	1	1	1	1	1	1
2053	1	1	1	1	1	1	1	1	1
2054	1	1	1	1	1	1	1	1	1
2055	1	1	1	1	1	1	1	1	1
2056	1	1	1	1	1	1	1	1	1

Appendix A- Factors Used to Calculate Predictive Pumpage in Layer 2

	Brazoria	Jasper	Zavala	Sabine	Hardin	Chambers	Galveston	Newton	Jefferson
2057	1	1	1	1	1	1	1	1	1
2058	1	1	1	1	1	1	1	1	1
2059	1	1	1	1	1	1	1	1	1
2060	1	1	1	1	1	1	1	1	1
2061	1	1	1	1	1	1	1	1	1
2062	1	1	1	1	1	1	1	1	1
2063	1	1	1	1	1	1	1	1	1
2064	1	1	1	1	1	1	1	1	1
2065	1	1	1	1	1	1	1	1	1
2066	1	1	1	1	1	1	1	1	1
2067	1	1	1	1	1	1	1	1	1
2068	1	1	1	1	1	1	1	1	1
2069	1	1	1	1	1	1	1	1	1
2070	1	1	1	1	1	1	1	1	1