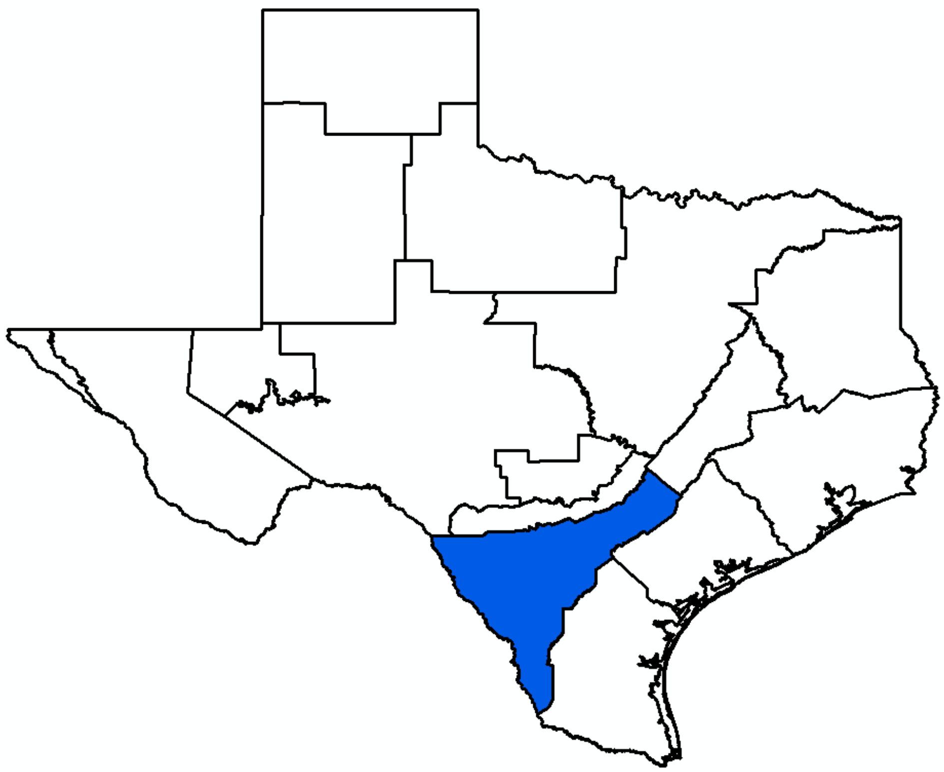
GMA 13 Technical Memorandum 16-03
Draft 1

GAM Predictive Scenarios 13 and 14
Simulations to Analyze Threshold Values for Saturated Thickness in Carrizo Aquifer and Wilcox Aquifer Outcrop Areas



Prepared for:
Groundwater Management Area 13

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1.0 Introduction

1.1 Background

At a result of discussions at the February 25, 2016 GMA 13 meeting, and in accordance with a scope-of-work dated February 29, 2016, the outcrop analysis that was the subject of the Technical Memorandum 16-02 has been extended to include simulations that were designed to maintain threshold values of saturated thickness in the outcrop areas of the Carrizo and Wilcox aquifers in GMA 13. The initial pumping for these simulations were the same as the values in Scenario 9 (please see Technical Memoranda 16-01 and 16-02 for more details).

During the discussion at the February 25, 2016 GMA 13 meeting, a simulation that maintained a 2070 saturated thickness of 75 percent of 2011 saturated thickness was discussed. As part of the scope of work dated February 29, 2016, there was a plan to also evaluate 70 percent and 65 percent threshold values.

Impacts to the outcrop area are important to consider for two reasons: 1) the shallow domestic wells that are completed in the outcrop are more sensitive to drawdown than wells completed in the confined portions of the aquifers, and 2) any impacts to surface water flow would occur in the outcrop areas. The issue of accuracy of the GAM in the outcrop area is acknowledged in this analysis. Comparative analyses are more appropriate given the limitations of the GAM, and strict reliance on the results is not recommended.

1.2 Outcrop Areas of the Carrizo and Wilcox Aquifers in GMA 13

The outcrop areas of the model were identified as those cells where overlying layers were inactive (i.e. if layers 1 to 4 in a particular row and column were inactive, but layer 5 was active, it was assumed that layer 5 outcropped at this location).

In GMA 13, there are 999 cells in the outcrop area of the Carrizo Aquifer (each cell is one square mile). Layer 5 of the model represents the Carrizo Aquifer. In GMA 13, there are 1,553 cells in the outcrop area of the Wilcox Aquifer (each cell is one square mile). Layers 6, 7, and 8 of the model represent the Wilcox Aquifer.

The analysis considered the 2011 saturated thickness in each model cell (the initial condition of the simulations), the saturated thickness in 2070 of each model cell for each of the simulations, the drawdown in each cell between 2011 and 2070, and the percentage of storage remaining in each cell by dividing the saturated thickness in 2070 by the saturated thickness in 2011 and multiplying the result by 100.

Scenario 13 consisted of 22 separate model runs. Eighteen of these runs included varying reductions in individual water management strategies from Scenario 9 (i.e. the reductions were made one-by-one to evaluate the sensitivity of each strategy to changes in outcrop area saturated thickness). The results showed that the saturated thickness in the outcrop area was insensitive to individual reductions. The other four runs were to test the sensitivity of overall reductions in the outcrop areas of the Carrizo and Wilcox aquifers separately.

Scenario 14 consisted of 16 separate model runs. Pumping reductions were applied to: 1) Carrizo Aquifer outcrop area, 2) Carrizo Aquifer downdip area, 3) Wilcox Aquifer outcrop area, and 4) Wilcox Aquifer downdip area.

In order to better interpret the results, the saturated thickness analysis was also applied to Scenarios 3, 4 and 8, and these results were compared to the results of the 16 runs of Scenario 14.

Before the discussion of the model runs, the method used to classify different areas within the outcrop area is discussed below.

2.0 Outcrop Area Classification

The outcrop area of the Carrizo and Wilcox aquifers was subdivided based on estimated 2011 saturated thickness. Table 1 summarizes the classification and the number of cells within each class.

Table 1. Summary of Outcrop Area Classification

Aquifer	2011 Saturated Thickness (ft)	Number of Model Cells in GMA 13
Carrizo	0 to 50	475
Carrizo	50 to 100	131
Carrizo	100 to 250	260
Carrizo	250 to 500	121
Carrizo	> 500	12
Wilcox	0 to 50	860
Wilcox	50 to 100	168
Wilcox	100 to 250	291
Wilcox	250 to 500	177
Wilcox	> 500	62

Model output was processed to calculate the saturated thickness in 2070 for each of these classes. The 2070 saturated thickness was then divided by the saturated thickness in 2011 (Table 1) and multiplied by 100 to develop an estimate of the saturated thickness remaining in 2070 as a percentage of the saturated thickness in 2011 for each class.

2.1 Results from Previous Scenarios

At the October 9, 2013 GMA 13 meeting, GMA 13 reviewed the initial seven GAM simulations. Scenarios 1 to 7 were developed based on the previous DFC and MAG. Scenario 4 was a "base case" which used the pumping in the previous MAG and specific input from SAWS and GCDs. Scenarios 1, 2 and 3 represented reductions from the base case, and Scenarios 5, 6, and 7 represented increases from the base case to provide an overall understanding of the changes in drawdown to changes in pumping. In terms of total pumping, Scenario 3 was most similar to the current MAG.

Scenario 8 was completed and presented at the March 13, 2014 GMA 13 meeting. Scenario 8 was developed on specific changes to Scenario 4 by individual groundwater conservation districts.

Scenario 9 was completed and presented at the January 22, 2016 GMA 13 meeting, and was documented in Technical Memorandum 16-01. This scenario included all Region L water management strategies (recommended and alternative).

To provide context to the results of Scenarios 13 and 14 below, the results of Scenarios 3, 4, 8, and 9 are summarized in Table 2.

Table 2. Outcrop Saturated Thickness Results for Scenarios 3, 4, 8, and 9

Run	Outcrop Area of Carrizo Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)					Outcrop Area of Wilcox Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)				
	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft
3	119.26	76.92	73.64	72.9	76.99	107.73	79.99	89.65	94.25	97.65
4	118.35	74.64	70.44	68.74	73.36	105.99	78.49	88.14	93.53	97.36
8	117.12	75.89	72.16	70.63	74.12	101.64	74.23	84.78	91.68	96.43
9	116.59	72.80	66.03	61.31	65.25	100.48	66.22	75.22	87.34	95.72

Please note that even under Scenario 3 (the lowest pumping of the scenarios presented), the 75 percent threshold cannot be maintained in all areas. A threshold of 70 percent can be maintained in Scenarios 3 and 8, but not in Scenario 4 or 9. A threshold of 65 percent can be maintained in Scenarios 3, 4, and 9, but not in Scenario 9. Scenario 9 results in maintaining 65 percent in all but one class (Carrizo 250 to 500 feet).

3.0 Scenario 13

3.1 Pumping Reductions from Scenario 9 Pumping

Scenario 13 consisted of 18 runs that tested the sensitivity of individual reductions in specific water management strategies that were included in Scenario 9. A summary of these runs are presented in Table 3.

Table 3. Scenario 13 Model Runs – Specific Strategy Reductions

Model Run	Water Management Strategy	Aquifer	Pumping Reduction from Scenario 9 (%)
13-1	SSLGC Expanded Carrizo Project	Carrizo	10
13-2	CVLGC Carrizo Project	Carrizo	10
13-3	CRWA Wells Ranch - Phase 2	Carrizo	10
13-4	SAWS Expanded Local Carrizo	Carrizo	10
13-5	Hays/Caldwell PUA Project	Carrizo	10
13-6	TWA Carrizo Project	Carrizo	10
13-7	SSLGC Expanded Carrizo Project	Carrizo	20
13-8	CVLGC Carrizo Project	Carrizo	20
13-9	CRWA Wells Ranch - Phase 2	Carrizo	20
13-10	SAWS Expanded Local Carrizo	Carrizo	20
13-11	Hays/Caldwell PUA Project	Carrizo	20
13-12	TWA Carrizo Project	Carrizo	20
13-13	SSLGC Brackish Wilcox	Wilcox	10
13-14	Brackish Wilcox for SS WSC	Wilcox	10
13-15	Brackish Wilcox Groundwater for CRWA	Wilcox	10
13-16	SSLGC Brackish Wilcox	Wilcox	20
13-17	Brackish Wilcox for SS WSC	Wilcox	20
13-18	Brackish Wilcox Groundwater for CRWA	Wilcox	20

The final four runs of Scenario 13 included the overall reduction in pumping in the outcrop areas of the Carrizo and Wilcox aquifers. Table 4 summarizes the pumping reductions for these runs.

Table 4. Scenario 13 Model Runs – Overall Outcrop Reductions

Model Run	Description	Pumping Reduction from Scenario 9 (%)
13-19	Reduction in Carrizo Aquifer Outcrop Area Pumping	10
13-20	Reduction in Carrizo Aquifer Outcrop Area Pumping	20
13-21	Reduction in Wilcox Aquifer Outcrop Area Pumping	10
13-22	Reduction in Wilcox Aquifer Outcrop Area Pumping	20

3.2 Results

Results from the runs are summarized in Table 5, which presents that saturated thickness in 2070 as a percentage of the saturated thickness for each sub area of the outcrop. The results demonstrate the overall insensitivity to reducing pumping in individual water management strategies. This appears to be due to the relatively small reductions in outcrop area pumping by considering any individual strategy. For reference purposes, the results of Scenario 9 are also presented.

Please note that as presented in Table 5, the areas with less than 50 feet of saturated thickness in 2070 are higher than in 2011. This is likely due to less pumping due to the general lack of saturated thickness, and the overall increase in recharge from 2011 (a relatively dry year) to the assumed average recharge simulated from 2012 to 2070.

Also in Table 5, it can be seen that the thicker portion of the outcrop of the Wilcox are above the 75 percent threshold value discussed at the February 25, 2016 GMA 13 meeting. In contrast, the thicker portions of the Carrizo outcrop are less than 70 percent in all runs.

Based on these results, Scenario 14 was developed to provide results that would be useful to the groundwater conservation districts in GMA 13 to evaluate the balance between maintaining the saturated thickness of the outcrop area above a certain threshold and the development of groundwater that satisfies all recommended and alternative strategies in the most recent Regional Water Plan.

Table 5. Scenario 13 Results

Run	Outcrop Area of Carrizo Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)					Outcrop Area of Wilcox Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)				
	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft
9	116.59	72.80	66.03	61.31	65.25	100.48	66.22	75.22	87.34	95.72
13-1	116.59	72.81	66.08	61.40	65.27	100.48	66.22	75.22	87.34	95.72
13-2	116.60	72.83	66.11	61.44	65.30	100.48	66.22	75.22	87.34	95.72
13-3	116.60	72.83	66.13	61.40	65.27	100.48	66.22	75.22	87.34	95.72
13-4	116.62	72.86	66.33	62.19	66.92	100.48	66.23	75.23	87.34	95.72
13-5	116.58	72.86	66.12	61.36	65.25	100.48	66.22	75.22	87.34	95.73
13-6	116.59	72.85	66.10	61.35	65.25	100.48	66.22	75.22	87.34	95.72
13-7	116.60	72.83	66.14	61.48	65.28	100.48	66.22	75.22	87.34	95.72
13-8	116.61	72.87	66.19	61.57	65.35	100.48	66.22	75.22	87.34	95.72
13-9	116.60	72.87	66.24	61.50	65.28	100.48	66.22	75.22	87.34	95.72
13-10	116.64	72.92	66.64	63.06	68.58	100.49	66.24	75.23	87.35	95.72
13-11	116.58	72.91	66.23	61.41	65.26	100.48	66.22	75.22	87.35	95.74
13-12	116.58	72.90	66.16	61.38	65.26	100.48	66.22	75.22	87.34	95.73
13-13	116.59	72.80	66.03	61.32	65.25	100.49	66.24	75.26	87.36	95.73
13-14	116.59	72.80	66.03	61.32	65.25	100.48	66.23	75.23	87.34	95.72
13-15	116.59	72.80	66.04	61.32	65.25	100.49	66.31	75.40	87.44	95.73
13-16	116.59	72.80	66.03	61.32	65.25	100.49	66.26	75.30	87.39	95.74
13-17	116.59	72.80	66.03	61.32	65.25	100.48	66.24	75.24	87.35	95.72
13-18	116.59	72.80	66.03	61.31	65.25	100.48	66.22	75.22	87.34	95.72
13-19	117.70	73.20	66.43	61.71	65.69	100.48	66.22	75.22	87.34	95.72
13-20	117.70	73.20	66.43	61.71	65.69	101.61	66.73	75.98	87.69	95.87
13-21	116.59	72.81	66.04	61.32	65.25	102.92	67.16	76.73	88.03	96.03
13-22	116.59	72.80	66.03	61.31	65.25	100.48	66.22	75.22	87.34	95.72

4.0 Scenario 14

4.1 Pumping Reductions from Scenario 9 Pumping

Based on the results of Scenario 13, Scenario 14 was designed to simulate the effects of pumping reductions of a larger scale and over a wider area than those in Scenario 13. Scenario 14 consisted of 16 runs of the model with pumping reductions in the Carrizo outcrop, Carrizo downdip, Wilcox outcrop, and Wilcox downdip areas as summarized in Table 6. As with Scenario 13, initial pumping was Scenario 9 pumping.

Table 6. Summary of Pumping Reductions in Scenario 14

Model Run	Pumping Reduction from Scenario 9 (percent)			
	Carrizo Outcrop	Carrizo Downdip	Wilcox Outcrop	Wilcox Downdip
14-1	20	0	0	0
14-2	40	0	0	0
14-3	60	0	0	0
14-4	0	20	0	0
14-5	0	40	0	0
14-6	0	60	0	0
14-7	0	0	20	0
14-8	0	0	40	0
14-9	0	0	60	0
14-10	0	0	0	20
14-11	0	0	0	40
14-12	0	0	0	60
14-13	20	20	0	0
14-14	40	40	0	0
14-15	0	0	20	20
14-16	0	0	40	40

The actual pumping amounts by county and model layer for Scenario 9, and broken out by outcrop and downdip area are presented in Appendix A. Appendix A also includes the pumping with 20 percent, 40 percent and 60 percent reductions.

Appendix B presents the outcrop and downdip pumping totals for Scenario 9 classified by water quality (<1,000 mg/l TDS, between 1,000 and 3,000 mg/l TDS, and > 3,000 mg/l TDS) by county and model layer. Maps of the water quality were previously developed and presented at the GMA 13 meeting of November 19, 2015, and are reproduced in Appendix C.

4.2 Results

The results of the 16 runs of Scenario 14 are summarized in Table 7, which presents that saturated thickness in 2070 as a percentage of the saturated thickness for each sub area of the outcrop. Scenario 9 results are also included for comparison.

Table 7. Scenario 14 Results

Run	Outcrop Area of Carrizo Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)					Outcrop Area of Wilcox Aquifer Saturated Thickness in 2070 (% of 2011 Saturated Thickness)				
	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft	0 to 50 ft	50 to 100 ft	100 to 250 ft	250 to 500 ft	> 500 ft
9	116.59	72.80	66.03	61.31	65.25	100.48	66.22	75.22	87.34	95.72
14-1	118.63	76.15	72.38	70.78	74.27	100.74	68.50	78.92	89.18	96.06
14-2	121.45	77.38	73.97	72.25	75.30	100.77	68.51	78.92	89.18	96.07
14-3	125.17	78.74	75.68	73.71	76.39	100.80	68.53	78.93	89.19	96.07
14-4	116.57	78.67	75.39	75.49	78.99	100.89	68.84	79.12	89.27	96.11
14-5	117.78	82.85	80.35	81.83	84.65	101.07	69.21	79.34	89.37	96.16
14-6	120.57	87.85	85.76	88.11	90.20	101.29	69.60	79.56	89.47	96.21
14-7	116.93	75.16	71.28	69.49	73.31	103.20	69.51	80.45	89.86	96.37
14-8	116.93	75.17	71.29	69.49	73.31	106.32	70.93	82.06	90.60	96.71
14-9	116.94	75.19	71.29	69.50	73.31	109.79	72.79	83.66	91.35	97.04
14-10	117.65	75.74	71.81	70.12	73.93	101.43	70.98	81.69	90.77	96.57
14-11	118.07	76.34	72.37	70.78	74.59	102.32	74.22	85.04	92.44	97.06
14-12	117.74	77.00	72.95	71.47	75.27	102.83	78.49	89.12	94.12	97.54
14-13	118.90	79.71	76.96	76.96	79.94	100.90	68.85	79.13	89.28	96.11
14-14	123.33	85.58	83.84	84.66	86.67	101.11	69.22	79.34	89.39	96.16
14-15	117.65	75.75	71.82	70.13	73.94	103.94	72.09	83.22	91.46	96.88
14-16	118.08	76.36	72.38	70.79	74.59	108.06	77.21	88.12	93.83	97.69

Please note that none of the runs result in 75 percent or greater saturated thickness remaining in all areas. However, there are five runs (14-10, 14-11, 14-12, 14-15, and 14-16) where the saturated thickness is 70 percent or greater. All the runs result in 65 percent or greater saturated thickness.

In contrast, the results of Scenario 9 show that in the Carrizo outcrop area with a saturated thickness of between 250 and 500 feet, the 2070 saturated thickness would be about 61 percent of the 2011 saturated thickness. All other areas (classes) would have greater than 65 percent.

4.3 Discussion of Results

As noted above, maintaining a 75 percent threshold was not maintained in any of the scenarios, even the one that is closest to the current MAG (Scenario 3). Although it is possible to craft a pumping scenario that could meet the 75 percent threshold, due to model limitations, it would not necessarily be useful to the development of desired future conditions.

Attention needs to be focused on the range of changes in saturated thickness in each of the classifications. As noted previously, the shallow portions of the outcrop area (where 2011 saturated thickness is less than 50 feet) shows a consistent rise in all scenarios. As discussed earlier, this is likely due to increased recharge from 2011 (a dry year) to the average recharge conditions from 2012 to 2070 that were assumed in the predictive simulations. Due to the lack of saturated thickness, this is also an area with minimal pumping.

In contrast, the thicker areas (greater than 50 feet in 2011) show various ranges of saturated thickness remaining. In the thicker portions of the Wilcox Aquifer outcrop (greater than 250 feet), the results of Scenario 14 show that in 2070, over 85 percent of that saturated thickness will remain, even in Scenario 9.

Based on these scenarios, Scenario 9 is consistent with a minimum threshold value of 60 percent. Scenario 9 is also consistent with a minimum threshold value of 60 percent in the Carrizo outcrop and a minimum threshold value of 65 percent in the Wilcox outcrop.

The minimum values of saturated thickness in 2070 from Table 7 are summarized in Table 8. The minimum of all Carrizo outcrops is in the column labeled Carrizo, the minimum of all Wilcox outcrops is in the column labeled Wilcox, and the overall minimum is in the column Carrizo and Wilcox.

Note that, in runs 14-1, 14-2 and 14-3 (reductions in Carrizo outcrop pumping) the impact to saturated thickness is less than reductions in Carrizo downdip pumping (runs 14-4, 14-5 and 14-6). Although the percentage reductions were the same (20, 40 and 60 percent), the total pumping reductions were larger in the downdip scenarios due to the larger pumping. A similar observation is made for the Wilcox Aquifer (runs 14-7 to 14-9 versus 14-10 to 14-12).

Based on the results of Scenario 14, if the DFC were to be set to maintain a minimum outcrop saturated thickness in 2070 of 60 percent of 2011 saturated thickness, Scenario 9 would be acceptable.

Based on the results of Scenario 14, if the DFC were to be set to maintain a minimum outcrop saturated thickness of 2070 of 70 percent of 2011 saturated thickness, Scenario 9 pumping in the outcrop area of the Carrizo and the Wilcox would have to be reduced by at least 20 percent, or pumping in the downdip area would have to be reduced by at least 20 percent.

Table 8. Summary of Saturated Thickness Minima for Scenario 9 and Scenario 14

Run	Minimum Outcrop Saturated Thickness in 2070 (% of 2011 Saturated Thickness)		
	Carrizo	Wilcox	Carrizo and Wilcox
9	61	66	61
14-1	71	69	69
14-2	72	69	69
14-3	74	69	69
14-4	75	69	69
14-5	80	69	69
14-6	86	70	70
14-7	69	70	69
14-8	69	71	69
14-9	70	73	70
14-10	70	71	70
14-11	71	74	71
14-12	71	78	71
14-13	77	69	69
14-14	84	69	69
14-15	70	72	70
14-16	71	77	71

Due to the limitations of the GAM, it would be unreasonable to draw precise conclusions or select precise numerical standards for establishment of desired future conditions. The model results are useful to demonstrate that reductions in pumping in the downdip area can result in changes to the saturated thickness in the outcrop area. This is likely the direct result of pumping in the downdip area that is close to the outcrop/downdip boundary. The implication of this result is that, if the maintenance of the outcrop saturated thickness is a policy goal, pumping in the outcrop area and in the downdip area near the outcrop/downdip boundary should be subject to closer review than pumping in downdip areas well removed from the outcrop area.

The comparison of the results of Scenario 14 runs with Scenario 3 (the scenario closest to the current MAG and DFC) show that a 75 percent threshold is not attainable unless further pumping reductions to the current MAG are made. Under Scenario 9, the largest changes from Scenario 3 are in the outcrop areas of the Carrizo and Wilcox where the 2011 saturated thickness 100 to 500 feet:

- In Scenario 3, in the Carrizo Aquifer outcrop, the saturated thickness in 2070 would be about 73 percent of 2011 saturated thickness in Scenario 3 as compared to about 64 percent in Scenario 9.
- In Scenario 3, in the Wilcox Aquifer outcrop, the saturated thickness in 2070 would be about 92 percent of the 2011 saturated thickness in Scenario 3 as compared to about 81 percent in Scenario 9.

This comparison is a key issue for the groundwater conservation districts in GMA 13. The groundwater conservation districts in GMA 13 must balance the highest practicable use of groundwater and the conservation of groundwater. The districts must also consider the water needs as expressed in the regional water plan. The limitations of the model must also be taken into consideration when evaluating the saturated thickness reductions associated with Scenario 9, and the improvements of saturated thickness associated with pumping reductions simulated in Scenario 14.

Groundwater conservation districts are obligated to manage to meet the desired future condition. However, the MAG is an important component of regional water planning. Desired future conditions are updated every five years, and it is possible that an improved Groundwater Availability Model will be in use for the next joint planning cycle (i.e. before the next proposed DFCs are due in 2021).

Based on the results of the comparative analysis completed, the drawdowns and saturated thickness results from Scenario 9 could be considered for a proposed desired future condition. Simulations that considered pumping reductions from Scenario 9 could also be used to form the basis of a DFC. Based on the simulations, it can be seen that substantial reductions would be needed to achieve the 75 percent threshold (2070 saturated thickness is 75 percent of 2011 saturated thickness in the outcrop area). Even setting a 70 percent minimum threshold would require relatively large reductions in pumping as compared to Scenario 9.

Given the model limitations, it is difficult to assess the quantitative accuracy the results. It is intuitively obvious that a reduction in pumping will result in more saturated thickness in 2070. It is also notable that reductions in downdip pumping will improve the saturated thickness conditions of the outcrop area. However, critics of the model will suggest that the model is unreliable and over-predicts drawdown in the outcrop area (an argument that is not completely true, but is nevertheless essentially true).

If the model over-predicts the drawdown in the outcrop area, then it can be reasoned that the saturated thickness of the outcrop area in 2070 would be more than that predicted by the model. In Scenario 9, the model predicts a minimum of 61 percent in one class (Carrizo Aquifer, initial saturated thickness between 250 and 500 feet), and over 65 percent in all other areas.

Appendix A
Outcrop and Downdip Pumping
(Scenario 9 and Reductions of 20%, 40% and 60%)

Table A-1. Scenario 9 GMA 13 Outcrop Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	1,018	0	4,084	0	9,353	0	249	0
Bexar	0	0	0	0	10,691	0	0	0
Caldwell	0	0	307	0	2,525	0	6,135	4,073
Dimmit	0	0	0	0	160	3	11	7
Frio	644	0	4,110	0	764	0	0	0
Gonzales	3,551	0	850	0	10	0	29	0
Guadalupe	0	0	0	0	4,908	0	7,242	2,653
Karnes	0	0	0	0	0	0	0	0
LaSalle	983	0	0	0	0	0	0	0
Maverick	0	0	0	0	544	0	747	1,192
McMullen	89	0	0	0	0	0	0	0
Medina	0	0	0	0	487	0	444	502
Uvalde	0	0	0	0	1,249	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	156	0	839	0	3,517	0	125	0
Zavala	0	0	0	0	2,487	0	122	91

Table A-2. 20 percent reduction in Scenario 9 GMA 13 Outcrop Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	814	0	3,267	0	7,482	0	199	0
Bexar	0	0	0	0	8,553	0	0	0
Caldwell	0	0	246	0	2,020	0	4,908	3,258
Dimmit	0	0	0	0	128	2	9	6
Frio	515	0	3,288	0	611	0	0	0
Gonzales	2,841	0	680	0	8	0	23	0
Guadalupe	0	0	0	0	3,926	0	5,794	2,122
Karnes	0	0	0	0	0	0	0	0
LaSalle	786	0	0	0	0	0	0	0
Maverick	0	0	0	0	435	0	598	954
McMullen	71	0	0	0	0	0	0	0
Medina	0	0	0	0	390	0	355	402
Uvalde	0	0	0	0	999	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	125	0	671	0	2,814	0	100	0
Zavala	0	0	0	0	1,990	0	98	73

Table A-3. 40 percent reduction in Scenario 9 GMA 13 Outcrop Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	611	0	2,450	0	5,612	0	149	0
Bexar	0	0	0	0	6,415	0	0	0
Caldwell	0	0	184	0	1,515	0	3,681	2,444
Dimmit	0	0	0	0	96	2	7	4
Frio	386	0	2,466	0	458	0	0	0
Gonzales	2,131	0	510	0	6	0	17	0
Guadalupe	0	0	0	0	2,945	0	4,345	1,592
Karnes	0	0	0	0	0	0	0	0
LaSalle	590	0	0	0	0	0	0	0
Maverick	0	0	0	0	326	0	448	715
McMullen	53	0	0	0	0	0	0	0
Medina	0	0	0	0	292	0	266	301
Uvalde	0	0	0	0	749	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	94	0	503	0	2,110	0	75	0
Zavala	0	0	0	0	1,492	0	73	55

Table A-4. 60 percent reduction in Scenario 9 GMA 13 Outcrop Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	407	0	1,634	0	3,741	0	100	0
Bexar	0	0	0	0	4,276	0	0	0
Caldwell	0	0	123	0	1,010	0	2,454	1,629
Dimmit	0	0	0	0	64	1	4	3
Frio	258	0	1,644	0	306	0	0	0
Gonzales	1,420	0	340	0	4	0	12	0
Guadalupe	0	0	0	0	1,963	0	2,897	1,061
Karnes	0	0	0	0	0	0	0	0
LaSalle	393	0	0	0	0	0	0	0
Maverick	0	0	0	0	218	0	299	477
McMullen	36	0	0	0	0	0	0	0
Medina	0	0	0	0	195	0	178	201
Uvalde	0	0	0	0	500	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	62	0	336	0	1,407	0	50	0
Zavala	0	0	0	0	995	0	49	36

Table A-5. Scenario 9 GMA 13 Downdip Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	215	0	48,978	249	0	16,993
Bexar	0	0	0	0	32,732	0	0	41,067
Caldwell	0	0	0	0	39,291	0	2,294	9,747
Dimmit	0	0	0	0	2,650	1,070	193	31
Frio	0	0	0	0	76,535	0	0	0
Gonzales	0	0	4,213	0	54,308	0	9,515	22,132
Guadalupe	0	0	0	0	14,943	0	3,458	20,487
Karnes	0	0	0	0	1,295	0	0	0
LaSalle	0	0	2	0	4,669	1,952	188	50
Maverick	0	0	0	0	52	277	109	377
McMullen	0	0	134	0	4,402	0	0	0
Medina	0	0	0	0	46	0	805	747
Uvalde	0	0	0	0	0	3,754	0	0
Webb	0	0	0	0	895	13	6	1
Wilson	0	0	105	0	35,122	125	0	72,132
Zavala	0	0	0	0	23,470	6,386	3,488	286

Table A-6. 20 percent reduction in Scenario 9 GMA 13 Downdip Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	172	0	39,182	199	0	13,594
Bexar	0	0	0	0	26,186	0	0	32,854
Caldwell	0	0	0	0	31,433	0	1,835	7,798
Dimmit	0	0	0	0	2,120	856	154	25
Frio	0	0	0	0	61,228	0	0	0
Gonzales	0	0	3,370	0	43,446	0	7,612	17,706
Guadalupe	0	0	0	0	11,954	0	2,766	16,390
Karnes	0	0	0	0	1,036	0	0	0
LaSalle	0	0	2	0	3,735	1,562	150	40
Maverick	0	0	0	0	42	222	87	302
McMullen	0	0	107	0	3,522	0	0	0
Medina	0	0	0	0	37	0	644	598
Uvalde	0	0	0	0	0	3,003	0	0
Webb	0	0	0	0	716	10	5	1
Wilson	0	0	84	0	28,098	100	0	57,706
Zavala	0	0	0	0	18,776	5,109	2,790	229

Table A-7. 40 percent reduction in Scenario 9 GMA 13 Downdip Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	129	0	29,387	149	0	10,196
Bexar	0	0	0	0	19,639	0	0	24,640
Caldwell	0	0	0	0	23,575	0	1,376	5,848
Dimmit	0	0	0	0	1,590	642	116	19
Frio	0	0	0	0	45,921	0	0	0
Gonzales	0	0	2,528	0	32,585	0	5,709	13,279
Guadalupe	0	0	0	0	8,966	0	2,075	12,292
Karnes	0	0	0	0	777	0	0	0
LaSalle	0	0	1	0	2,801	1,171	113	30
Maverick	0	0	0	0	31	166	65	226
McMullen	0	0	80	0	2,641	0	0	0
Medina	0	0	0	0	28	0	483	448
Uvalde	0	0	0	0	0	2,252	0	0
Webb	0	0	0	0	537	8	4	1
Wilson	0	0	63	0	21,073	75	0	43,279
Zavala	0	0	0	0	14,082	3,832	2,093	172

Table A-8. 60 percent reduction in Scenario 9 GMA 13 Downdip Pumping

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	86	0	19,591	100	0	6,797
Bexar	0	0	0	0	13,093	0	0	16,427
Caldwell	0	0	0	0	15,716	0	918	3,899
Dimmit	0	0	0	0	1,060	428	77	12
Frio	0	0	0	0	30,614	0	0	0
Gonzales	0	0	1,685	0	21,723	0	3,806	8,853
Guadalupe	0	0	0	0	5,977	0	1,383	8,195
Karnes	0	0	0	0	518	0	0	0
LaSalle	0	0	1	0	1,868	781	75	20
Maverick	0	0	0	0	21	111	44	151
McMullen	0	0	54	0	1,761	0	0	0
Medina	0	0	0	0	18	0	322	299
Uvalde	0	0	0	0	0	1,502	0	0
Webb	0	0	0	0	358	5	2	0
Wilson	0	0	42	0	14,049	50	0	28,853
Zavala	0	0	0	0	9,388	2,554	1,395	114

Appendix B

Scenario 9 Outcrop and Downdip Pumping Categorized by Water Quality

Table B-1. Scenario 9 GMA 13 Outcrop Pumping (TDS < 1,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	0	0	9,353	0	249	0
Bexar	0	0	0	0	10,659	0	0	0
Caldwell	0	0	0	0	2,525	0	6,133	4,050
Dimmit	0	0	0	0	160	3	9	0
Frio	0	0	0	0	764	0	0	0
Gonzales	183	0	0	0	10	0	29	0
Guadalupe	0	0	0	0	4,908	0	7,082	2,589
Karnes	0	0	0	0	0	0	0	0
LaSalle	0	0	0	0	0	0	0	0
Maverick	0	0	0	0	544	0	27	2
McMullen	0	0	0	0	0	0	0	0
Medina	0	0	0	0	487	0	444	478
Uvalde	0	0	0	0	1,249	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	0	0	0	0	3,517	0	125	0
Zavala	0	0	0	0	2,487	0	27	0

Table B-2. Scenario 9 GMA 13 Outcrop Pumping (TDS between 1,000 and 3,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	337	0	0	0	0	0	0	0
Bexar	0	0	0	0	0	0	0	0
Caldwell	0	0	0	0	0	0	0	23
Dimmit	0	0	0	0	0	0	2	7
Frio	644	0	0	0	0	0	0	0
Gonzales	2,983	0	0	0	0	0	0	0
Guadalupe	0	0	0	0	0	0	0	27
Karnes	0	0	0	0	0	0	0	0
LaSalle	982	0	0	0	0	0	0	0
Maverick	0	0	0	0	0	0	720	1,191
McMullen	41	0	0	0	0	0	0	0
Medina	0	0	0	0	0	0	0	0
Uvalde	0	0	0	0	0	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	113	0	0	0	0	0	0	0
Zavala	0	0	0	0	0	0	94	91

Table B-3. Scenario 9 GMA 13 Outcrop Pumping (TDS > 3,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	680	0	0	0	0	0	0	0
Bexar	0	0	0	0	0	0	0	0
Caldwell	0	0	0	0	0	0	0	0
Dimmit	0	0	0	0	0	0	0	0
Frio	0	0	0	0	0	0	0	0
Gonzales	386	0	0	0	0	0	0	0
Guadalupe	0	0	0	0	0	0	0	0
Karnes	0	0	0	0	0	0	0	0
LaSalle	0	0	0	0	0	0	0	0
Maverick	0	0	0	0	0	0	0	0
McMullen	48	0	0	0	0	0	0	0
Medina	0	0	0	0	0	0	0	0
Uvalde	0	0	0	0	0	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	43	0	0	0	0	0	0	0
Zavala	0	0	0	0	0	0	0	0

Table B-4. Scenario 9 GMA 13 Downdip Pumping (TDS < 1,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	0	0	48,978	249	0	5,664
Bexar	0	0	0	0	32,732	0	0	8,212
Caldwell	0	0	0	0	39,291	0	2,294	8,183
Dimmit	0	0	0	0	2,021	1,035	178	0
Frio	0	0	0	0	76,535	0	0	0
Gonzales	0	0	1,995	0	54,070	0	9,515	8,856
Guadalupe	0	0	0	0	14,943	0	3,458	20,362
Karnes	0	0	0	0	855	0	0	0
LaSalle	0	0	0	0	2,109	1,947	179	0
Maverick	0	0	0	0	52	277	26	119
McMullen	0	0	0	0	3,375	0	0	0
Medina	0	0	0	0	46	0	805	747
Uvalde	0	0	0	0	0	3,754	0	0
Webb	0	0	0	0	1	2	0	0
Wilson	0	0	0	0	34,941	125	0	30,483
Zavala	0	0	0	0	23,470	6,386	3,240	42

Table B-5. Scenario 9 GMA 13 Downdip Pumping (TDS between 1,000 and 3,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	0	0	0	0	0	11,329
Bexar	0	0	0	0	0	0	0	32,855
Caldwell	0	0	0	0	0	0	0	1,564
Dimmit	0	0	0	0	630	35	16	31
Frio	0	0	0	0	0	0	0	0
Gonzales	0	0	1,939	0	239	0	0	13,277
Guadalupe	0	0	0	0	0	0	0	125
Karnes	0	0	0	0	440	0	0	0
LaSalle	0	0	2	0	2,559	5	9	50
Maverick	0	0	0	0	0	0	83	257
McMullen	0	0	134	0	1,027	0	0	0
Medina	0	0	0	0	0	0	0	0
Uvalde	0	0	0	0	0	0	0	0
Webb	0	0	0	0	893	11	6	1
Wilson	0	0	0	0	181	0	0	41,649
Zavala	0	0	0	0	0	0	249	244

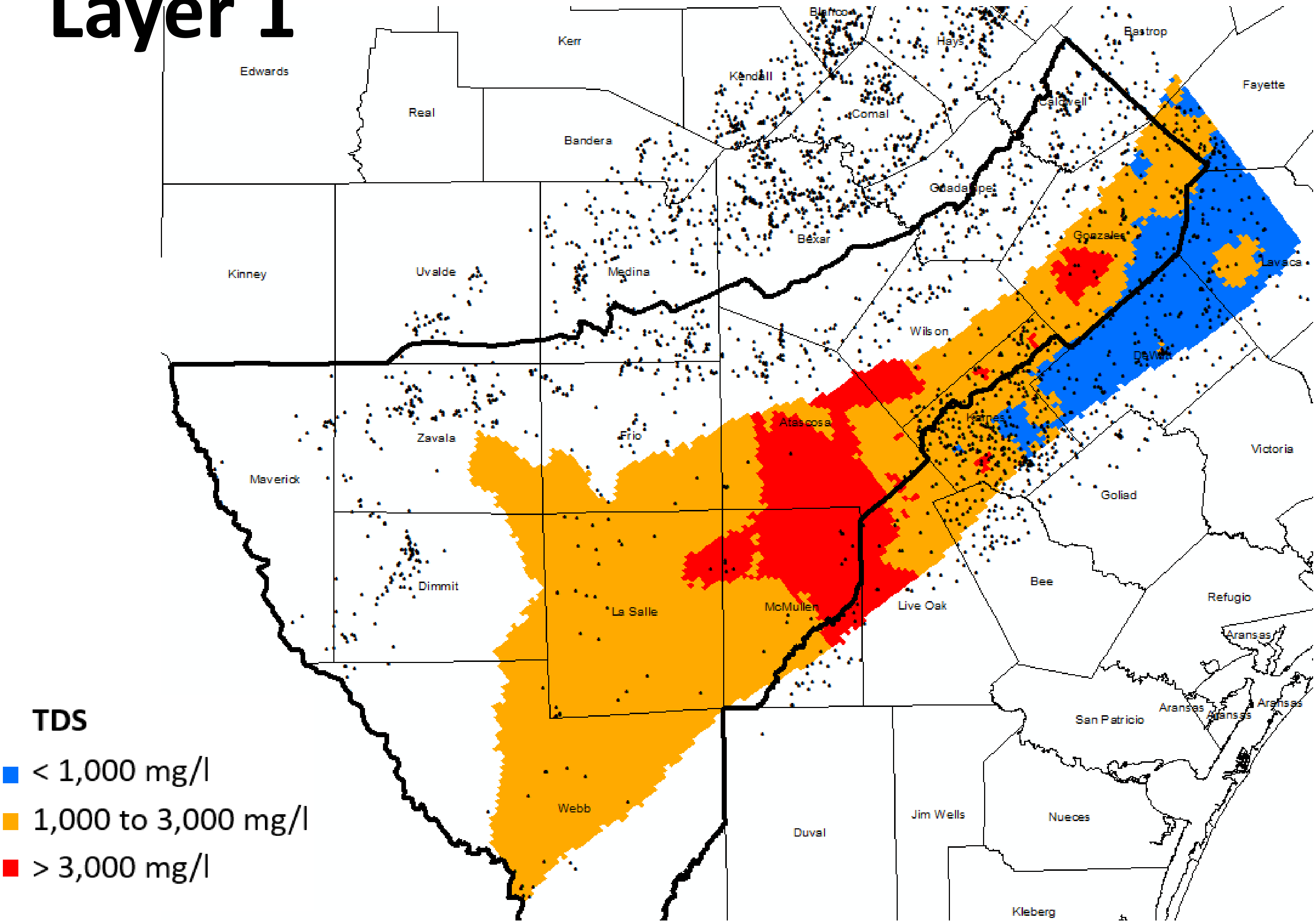
Table B-6. Scenario 9 GMA 13 Downdip Pumping (TDS > 3,000 mg/l)

County	Sparta Aquifer (Layer 1)	Weches (Layer 2)	Queen City (Layer 3)	Reklaw (Layer 4)	Carrizo (Layer 5)	Upper Wilcox (Layer 6)	Middle Wilcox (Layer 7)	Lower Wilcox (Layer 8)
Atascosa	0	0	0	0	0	0	0	0
Bexar	0	0	0	0	0	0	0	0
Caldwell	0	0	0	0	0	0	0	0
Dimmit	0	0	0	0	0	0	0	0
Frio	0	0	0	0	0	0	0	0
Gonzales	0	0	0	0	0	0	0	0
Guadalupe	0	0	0	0	0	0	0	0
Karnes	0	0	0	0	0	0	0	0
LaSalle	0	0	0	0	0	0	0	0
Maverick	0	0	0	0	0	0	0	0
McMullen	0	0	0	0	0	0	0	0
Medina	0	0	0	0	0	0	0	0
Uvalde	0	0	0	0	0	0	0	0
Webb	0	0	0	0	0	0	0	0
Wilson	0	0	0	0	0	0	0	0
Zavala	0	0	0	0	0	0	0	0

Appendix C

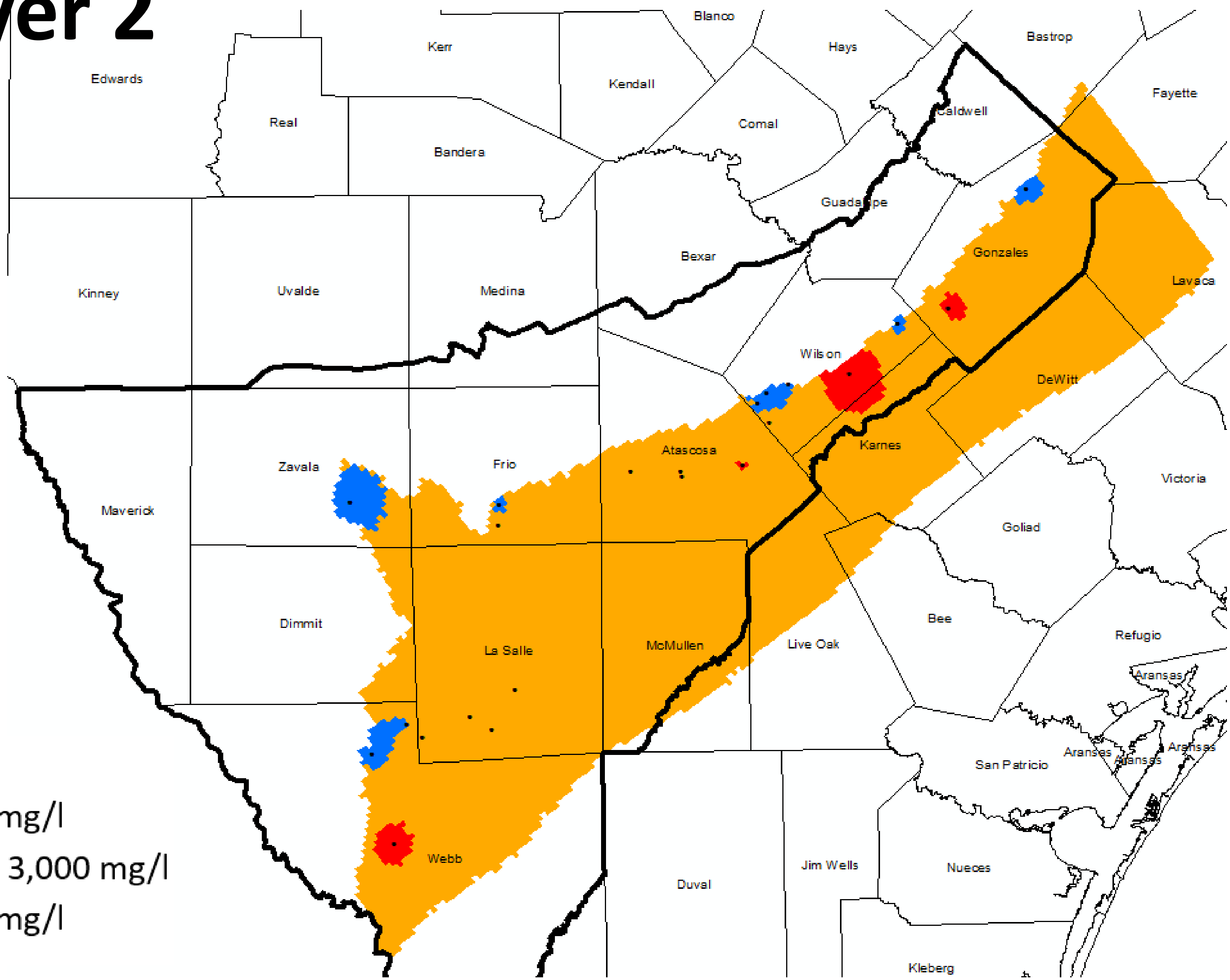
Maps Showing TDS by Model Layer

Layer 1



Edwards
Real
Kerr
Blanco
Hays
Bastrop
Fayette
Kendall
Comal
Caldwell
Bandera
Guadalupe
Bexar
Gonzales
Lavaca
Kinney
Uvalde
Medina
Wilson
DeWitt
Karnes
Atascosa
Frio
Zavala
Maverick
Victoria
Goliad
Dimmit
Bee
La Salle
McMullen
Live Oak
Refugio
Aransas
San Patricio
Webb
Duval
Jim Wells
Nueces
Kleberg
TDS
< 1,000 mg/l
1,000 to 3,000 mg/l
> 3,000 mg/l

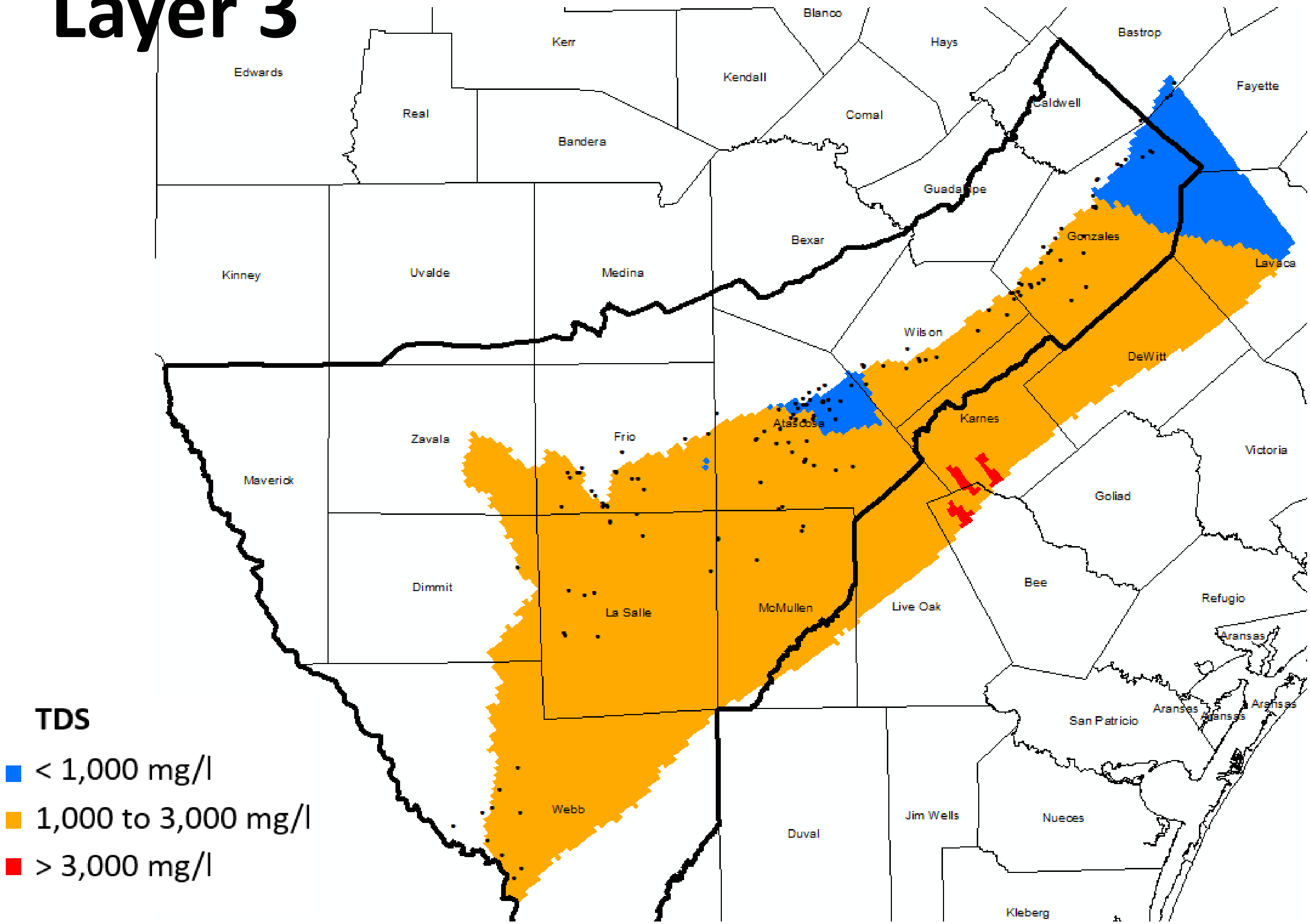
Layer 2



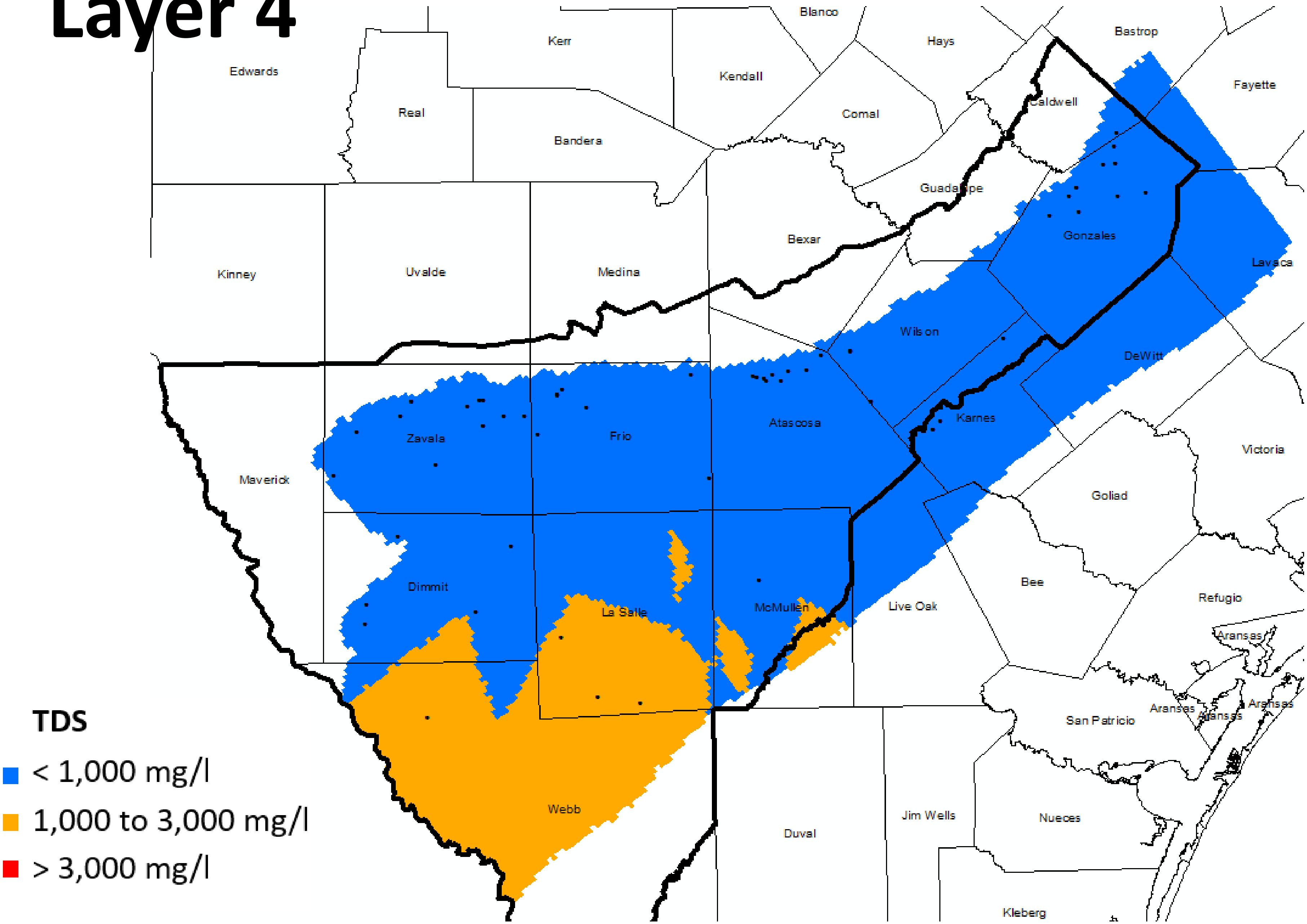
TDS

- < 1,000 mg/l
- 1,000 to 3,000 mg/l
- > 3,000 mg/l

Layer 3

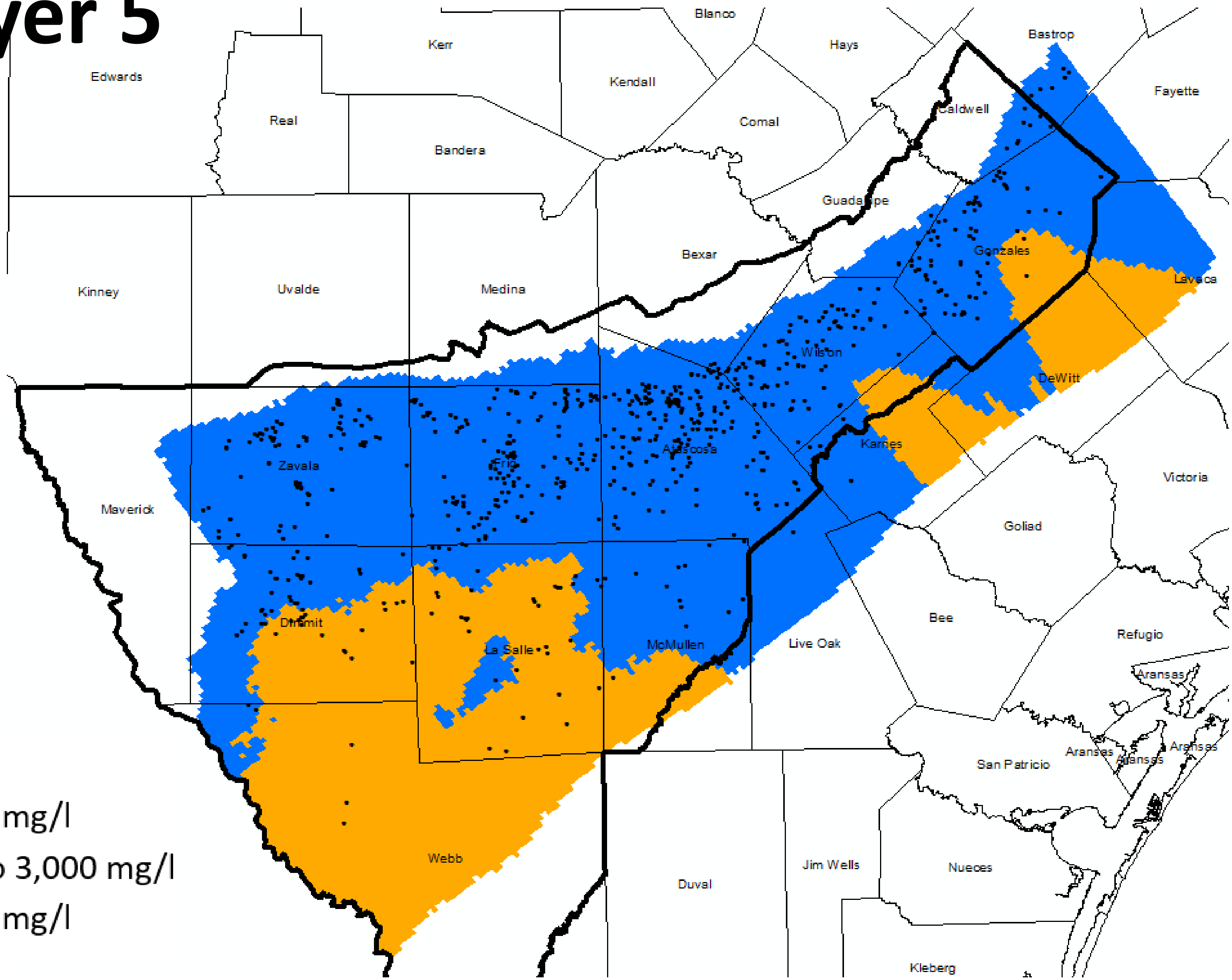

Edwards
Real
Kerr
Bandera
Kendall
Blanco
Hays
Comal
Bastrop
Caldwell
Fayette
Guadalupe
Bexar
Gonzales
Lavaca
Kinney
Uvalde
Medina
Wilson
DeWitt
Atascosa
Karnes
Victoria
Maverick
Zavala
Frio
Goliad
Dimmit
La Salle
McMullen
Live Oak
Bee
Refugio
Aransas
San Patricio
Webb
Duval
Jim Wells
Nueces
Kleberg
TDS
< 1,000 mg/l
1,000 to 3,000 mg/l
> 3,000 mg/l

Layer 4



Blanco
Kerr
Hays
Bastrop
Edwards
Kendall
Fayette
Caldwell
Real
Comal
Bandera
Guadalupe
Gonzales
Bexar
Lavaca
Kinney
Uvalde
Medina
Wilson
DeWitt
Zavala
Frio
Atascosa
Karnes
Victoria
Maverick
Goliad
Bee
Dimmit
La Salle
McMullen
Live Oak
Refugio
Aransas
San Patricio
Webb
Duval
Jim Wells
Nueces
Kleberg
TDS
< 1,000 mg/l
1,000 to 3,000 mg/l
> 3,000 mg/l

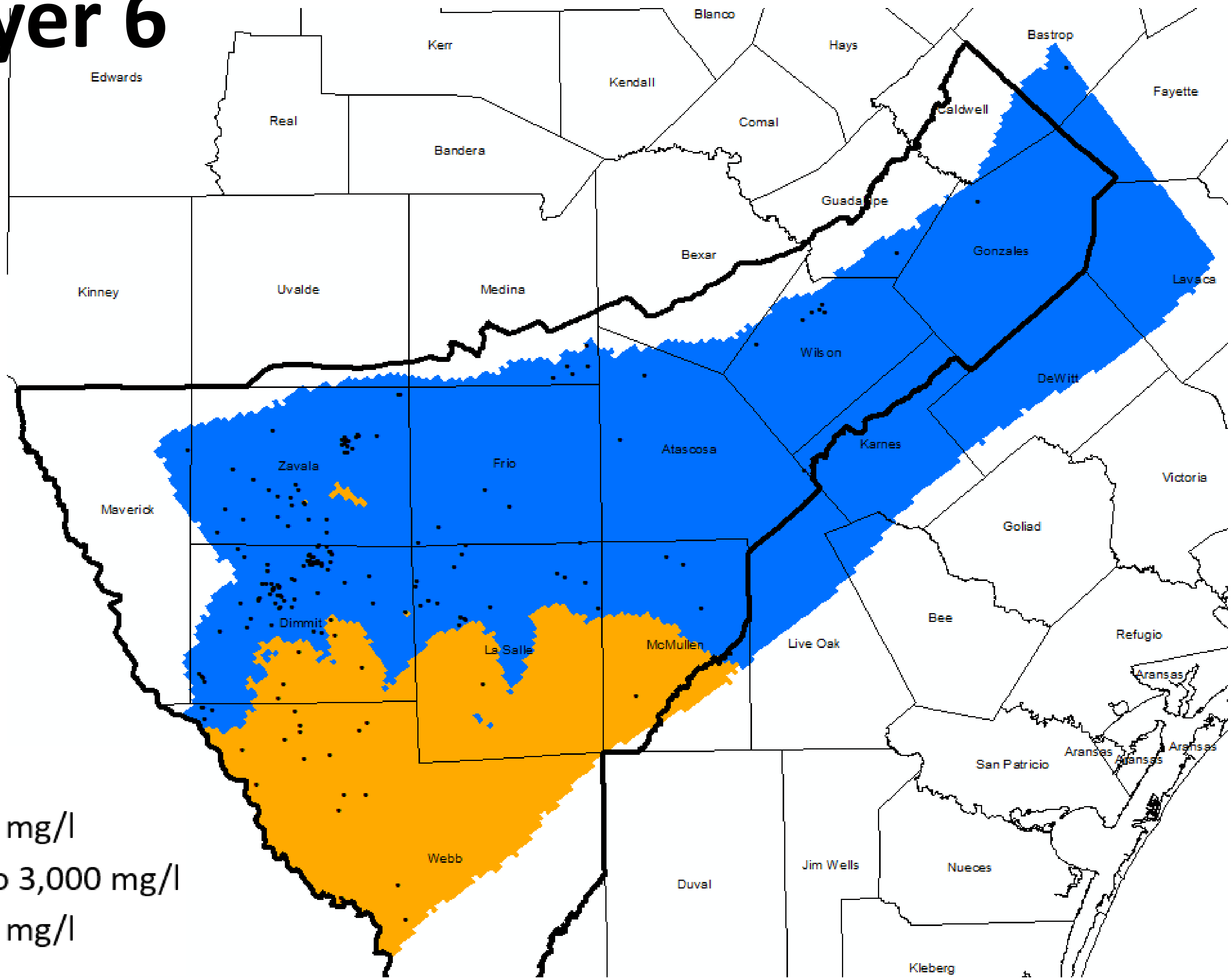
Layer 5



TDS

- < 1,000 mg/l
- 1,000 to 3,000 mg/l
- > 3,000 mg/l

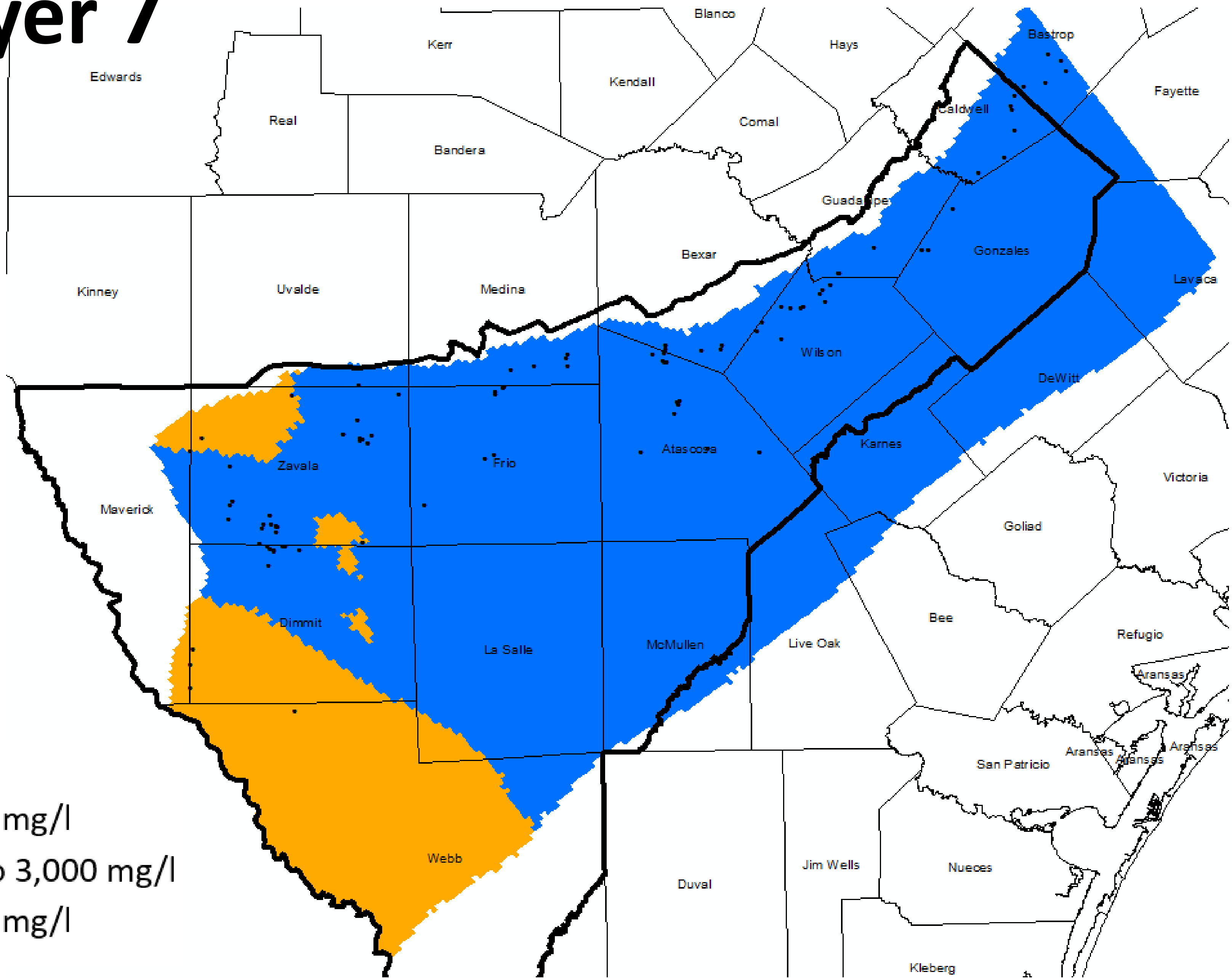
Layer 6



TDS

- < 1,000 mg/l
- 1,000 to 3,000 mg/l
- > 3,000 mg/l

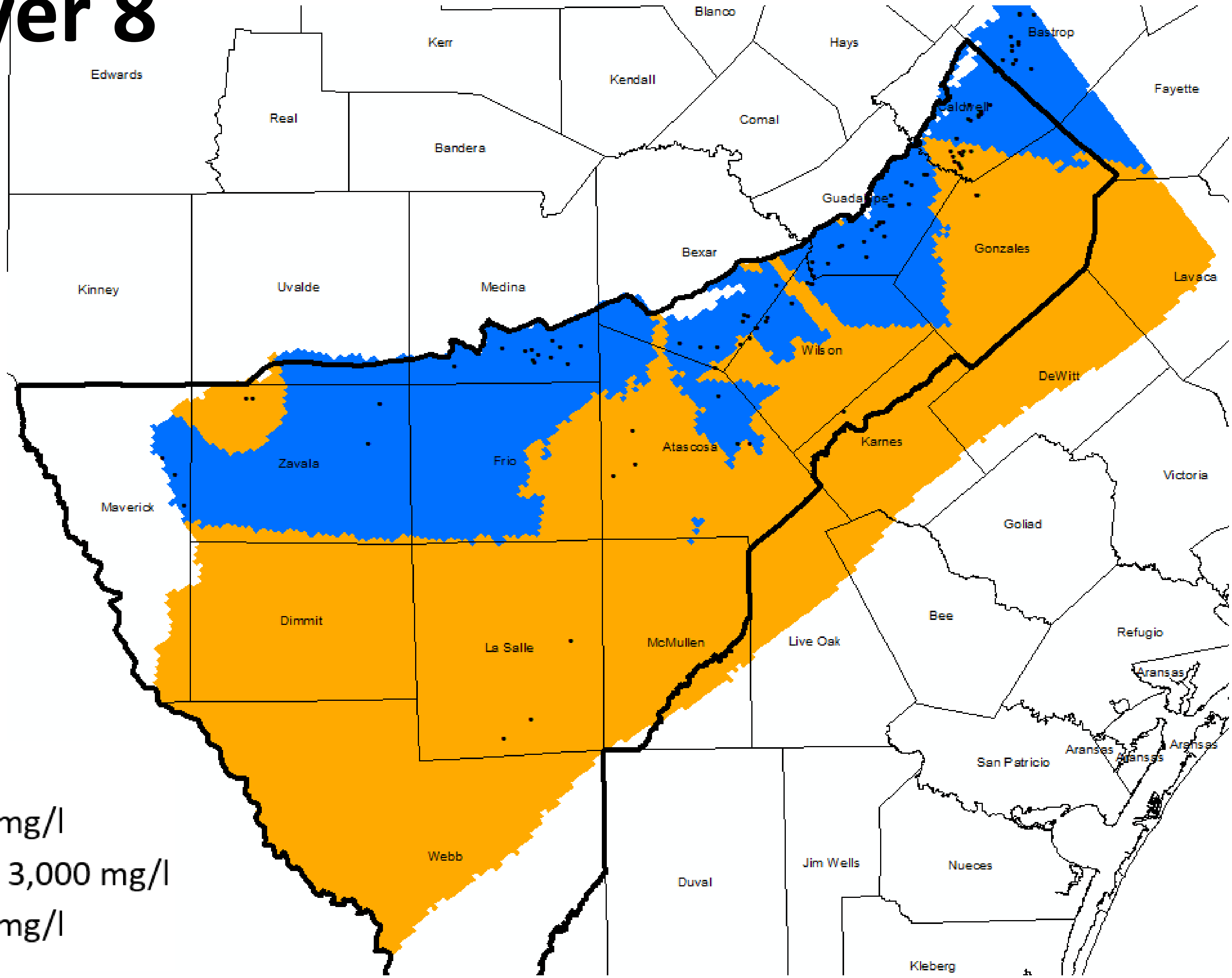
Layer 7



TDS

- < 1,000 mg/l
- 1,000 to 3,000 mg/l
- > 3,000 mg/l

Layer 8



TDS

- < 1,000 mg/l
- 1,000 to 3,000 mg/l
- > 3,000 mg/l