GAM Run 08-41

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EXECUTIVE SUMMARY:

We ran the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers, using a specified annual pumpage requested by Groundwater Management Area 13 for a 60-year predictive simulation along with average recharge, evapotranspiration rates, and initial streamflows. Groundwater Management Area 13 initially requested three specified pumpage scenarios to reflect high, low, and medium groundwater use. This model run represents the "high pumpage scenario" and indicates that assigning this amount of pumpage in the model for the predictive period results in the following:

- water level declines of 10 to 50 feet in most of the Sparta and Queen City aquifers, with higher drawdowns in areas where additional pumpage was added to these aquifers (mainly Gonzales, Atascosa, Wilson, and McMullen counties);

- maximum water level declines of at least 170 feet in the Carrizo and upper Wilcox aquifers around Caldwell, Gonzales, and Guadalupe counties; water level declines of over 140 feet are also centered near the outcrop in Frio County; and

- water level declines in the middle and lower Wilcox aquifers exceed 100 feet and 200 feet respectively due to a brackish well field added to the lower Wilcox aquifer in Atascosa, Bexar, and Wilson counties. Declines of over 200 feet are also suggested in Gonzales and Caldwell counties. Water level declines in the rest of these aquifers are generally less than 100 feet.

This model run is one of multiple model runs that will aid Groundwater Management Area 13 in developing their desired future conditions for the southern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Other previously completed model runs for this portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers are GAM runs 06-29 (Donnelly, 2007a), 07-16 (Donnelly, 2007b), and 07-17 (Donnelly 2007c).

REQUESTOR:

Mr. Mike Mahoney from the Evergreen Underground Water Conservation District (on behalf of Groundwater Management Area 13).

DESCRIPTION OF REQUEST:

Mr. Mahoney asked us to perform three model runs using the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers using a high, medium, and low pumpage scenario. This model run represents the high pumpage scenario held constant for a 60-year simulation using initial water levels from the end of the historic calibration period and average recharge conditions. The model run would use pumpage specified by the members of Groundwater Management Area 13.

METHODS:

The simulation was set up using average recharge and evapotranspiration rates and initial streamflows based on the historic calibration-verification runs, representing 1981 to 1999. These averages were then used for each year of the 60-year predictive simulation along with the specified pumpage. Resulting water levels and water level declines were then evaluated and are described in the results section below.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers are described below:

- We used Version 2.01 of the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

- We used Groundwater Vistas Version 5 (Environmental Simulations, Inc. 2007) as the interface to process model output results.

- See Deeds and others (2003) and Kelley and others (2004) for assumptions and limitations of the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

- The model includes eight layers representing:

    1. the Sparta Aquifer (layer 1),
    2. the Weches Formation (layer 2),
    3. the Queen City Aquifer (layer 3),
    4. the Reklaw Formation (layer 4),
    5. the Carrizo Aquifer (layer 5),
    6. the upper Wilcox Aquifer (layer 6),
    7. the middle Wilcox Aquifer (layer 7), and
    8. the lower Wilcox Aquifer (layer 8).

- Although the layer representing the Sparta Aquifer (layer 1) and the Queen City Aquifer (layer 3) extend to the Rio Grande in the model, the portion of these layers west of the Frio River are not recognized as part of either aquifer. No pumpage was assigned to these layers west of the Frio River, and although results (water levels) are shown for the entire layer in the figures, evaluation of impacts in these areas should be done with care.

- As described by Kalaswad and Arroyo (2006) and Kelly and others (2004) groundwater in the groundwater availability model for the southern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers ranges from fresh to saline. The reported values in this report for flow terms in the water budget (Appendix A) include fresh (less than 1,000 milligrams per liter total dissolved solids), brackish (1,000 to 10,000 milligrams per liter total dissolved solids), and saline (greater than 10,000 milligrams per liter total dissolved solids) groundwater.

- The root mean square error (a measure of the difference between simulated and measured water levels during model calibration) in the entire model for 1999 is 23 feet for the Sparta Aquifer, 18 feet for the Queen City aquifer, and 33 feet for the Carrizo aquifer (Kelley and others, 2004).

- Recharge rates, evapotranspiration rates, and initial streamflows are averages of historic estimates from 1981 to 1999.

- Pumpage used for each year of the 60-year predictive simulation was specified by members of Groundwater Management Area 13. Details on this pumpage are given below.

Table 1. Baseline pumpage and pumpage used in the current model run. Pumpage is reported in acre-feet per year.. For comparison, the Carrizo Aquifer (layer 5), the upper Wilcox Aquifer (layer 6), the middle Wilcox Aquifer (layer 7), and the lower Wilcox Aquifer (layer 8) are reported as the Carrizo-Wilcox Aquifer. Please note that Lavaca, Fayette, and Bastrop counties are only partially contained within the active part of the model and pumpage for these counties does not represent full county use.

	GAM Run 06-29 (1999- baseline) pumpage			GAM Run 08- 41 specified pumpage		
County	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer
Atascosa	517	964	55,009	1,000	6,000	65,556
Bastrop	7	88	690	--	--	691
Bee	--	--	76	--	--	77
Bexar	--	--	16,871	--	--	31,056
Caldwell	--	132	3,634	--	50	50,259
DeWitt	--	--	1	--	--	1
Dimmit	--	--	4,477	--	--	5,596
Fayette	66	12	2	--	--	2
Frio	87	66	110,004	1,000	6,000	110,000
Gonzales	552	240	2,605	4,268	10,120	102,325
Guadalupe	--	--	6,072	--	--	17,512
Karnes	--	--	471	--	--	471
LaSalle	1,316	2	8,286	1,645	3	10,358
Lavaca	--	--	1	--	--	1
Live Oak	--	--	85	--	--	85
Maverick	--	--	3,298	--	--	3,298
McMullen	0	0	119	200	300	3,950
Medina	--	--	5,008	--	--	7,500
Uvalde	--	--	596	--	--	10,500
Webb	--	--	916	--	--	915
Wilson	504	170	17,376	1,000	6,000	56,259
Zavala	--	--	48,763	--	--	60,954

Specified Pumpage

The pumpage specified by the members of Groundwater Management Area 13 was based on the pumpage constructed for GAM Run 06-29 (Donnelly, 2007a). The assumptions used to create the baseline pumpage are detailed in the GAM Run 06-29 report (http://www.twdb.state.tx.us/gam/GAMruns/GR06-29.pdf) and will not be repeated in this report.

Several modifications were made to the baseline pumpage to create the specified pumpage used in this simulation. County pumpage totals were increased or decreased to amounts specified by members of the groundwater management area (Tables 1 and 2), several well fields were added (Figure 1 and Table 3), and in two counties the pumpage distribution was adjusted. For several counties, the pumpage remained at baseline levels (Tables 1 and 2).

Table 2. Baseline pumpage and pumpage used in the current model run in each layer of the Carrizo-Wilcox Aquifer. Pumpage totals are in acre-feet per year. Please note that Lavaca, Fayette, and Bastrop counties are only partially contained within the active part of the model and pumpage for these counties does not represent full county use.

	GAM Run 06-29 (1999- baseline) pumpage				GAM Run 08-41 specified pumpage			
County	Carrizo Aquifer	Upper Wilcox Aquifer	Middle Wilcox Aquifer	Lower Wilcox Aquifer	Carrizo Aquifer	Upper Wilcox Aquifer	Middle Wilcox Aquifer	Lower Wilcox Aquifer
Atascosa	52,419	36	598	1,956	60,000	--	--	5,556
Bastrop	100	60	309	221	100	60	309	221
Bee	19	19	19	19	19	19	19	19
Bexar	3,513	0	6,633	6,725	7,513	0	6,633	16,910
Caldwell	279	0	1,169	2,186	10,209	0	20,000	20,000
DeWitt	1	0	0	0	1	0	0	0
Dimmit	2,917	1,321	189	50	3,646	1,651	236	63
Fayette	2	0	0	0	2	0	0	0
Frio	99,802	6,049	4,089	64	100,000	0	0	10
Gonzales	2,538	1	66	0	52,271	1	20,053	30,000
Guadalupe	1,224	0	3,240	1,608	12,664	0	3,240	1,608
Karnes	471	0	0	0	471	0	0	0
LaSalle	5,684	2,602	0	0	7,105	3,253	0	0
Lavaca	1	0	0	0	1	0	0	0
Live Oak	85	0	0	0	85	0	0	0
Maverick	596	276	856	1,570	596	276	856	1,570
McMullen	119	0	0	0	3,200	250	250	250
Medina	1,477	31	980	2,520	0	0	0	7,500
Uvalde	358	0	120	118	2,500	8,000	0	0
Webb	896	13	6	1	896	13	6	1
Wilson	15,986	40	772	578	45,000	0	0	11,259
Zavala	34,731	8,629	4,901	502	43,414	10,786	6,126	628

In order to increase the pumpage from the baseline total to the specified total, pumpage was distributed evenly to all active cells in the county, or an area specified by members of the groundwater management area. In cases where pumpage was specified to decrease relative to the baseline in a county, the pumpage in each cell was proportionately reduced.

In addition to increasing or in some cases reducing the county pumpage totals, several other modifications were made to the baseline pumpage to create the specified pumpage data set for this simulation. These modifications include:

- Pumpage was added in the Carrizo and lower Wilcox aquifers in Atascosa, Bexar, and Wilson counties to represent San Antonio Water System well fields (Figure 1).

- An Aqua Water Supply well field was added to the Carrizo Aquifer in southeastern Caldwell County and Schertz-Seguin well fields were added to Gonzales and Guadalupe counties (Figure 1).

- Canyon Regional wells and the Spring Hills well fields were added to Guadalupe and Gonzales counties (Figure 1).

- Caldwell County was separated into three pumpage areas: area 1 (Figure 1) covers the part of the county not included in Gonzales County Underground Water Conservation District, area 3 includes the far southeastern corner of the county which has specified pumpage values and area 2 includes the remainder of Caldwell County included in Gonzales Underground Water Conservation District with baseline pumpage assigned.

- Gonzales County was separated into three pumpage areas: area 4 has specified pumpage and is the northwest corner next to Caldwell County, area 6 is in the southwest corner next to Guadalupe County and has specified pumpage, and area 5 is the remainder of the county with baseline pumpage.

Table 3.Wellfield and specified area pumpage used for each aquifer layer in the model run. Pumpage totals are in acre-feet per year.

County	Area number or wellfield	Sparta Aquifer	Queen City Aquifer	Carrizo Aquifer	Upper Wilcox Aquifer	Middle Wilcox Aquifer	Lower Wilcox Aquifer
Atascosa	San Antonio Water System	--	--	--	--	--	5,556
Bexar	San Antonio Water System	--	--	4,000	--	--	10,185
Caldwell	1	--	--	--	--	16,311	13,940
Caldwell	2	--	--	209	--	189	60
Caldwell	3	--	50	5,000	--	3,500	6,000
Caldwell	Aqua Water Supply	--	--	5,000	--	--	--
Gonzales	4	2,000	5,000	20,000	--	10,000	15,000
Gonzales	5	268	120	2,271	1	53	--
Gonzales	6	2,000	5,000	18,000	--	10,000	15,000
Gonzales	Schertz-Seguin	--	--	9,000	--	--	--
Gonzales	Canyon Regional	--	--	3,000	--	--	--
Guadalupe	Canyon Regional	--	--	1,540	--	--	--
Guadalupe	Spring Hills	--	--	2,750	--	--	--
Guadalupe	Schertz-Seguin	--	--	7,150	--	--	--
Wilson	San Antonio Water System	--	--	--	--	--	9,259

RESULTS:

Included in Appendix A are estimates of the water budgets after running the model for 60 years. The components of the water budget are described below.

- Wells—water produced from wells in each aquifer. In the model this component is always shown as "Outflow" from the water budget, because all wells included in the model produce (rather than inject) water. Wells are simulated in the model using the MODFLOW Well package. It is important to note that values in Appendix A for wells in the water budget may not precisely match the pumpage amounts requested in Tables 1 and 2 because of dry cells and slight deviations generated by the programs written to create the well package.

- Springs—water that naturally discharges from an aquifer when water levels rise above the elevation of the spring. This component is always shown as "Outflow", or discharge, from the water budget. Spring flows are simulated in the model using the MODFLOW Drain package.

- Recharge—simulates areally distributed recharge due to precipitation falling on the outcrop (where the aquifer is exposed at land surface) areas of aquifers. Recharge is always shown as "Inflow" into the water budget.

- Vertical leakage—describes the vertical flow, or leakage, between two layers (aquifers or confining units) in the model. This flow is controlled by the water levels in each of the layers and aquifer properties of each layer that define the amount of leakage that can occur. "Inflow" to an aquifer from an overlying or underlying layer will always equal the "Outflow" from the other layer.

- Storage—water stored in the aquifer. The storage component that is included in "Inflow" is water that is removed from storage in the aquifer (that is, water levels decline). The storage component that is included in "Outflow" is water that is added back into storage in the aquifer (that is, water levels increase). This component of the budget is often seen as water both going into and out of the aquifer because this is a regional budget, and water levels will decline in some areas (water is being removed from storage) and will rise in others (water is being added to storage).

- Lateral flow—describes lateral flow within an aquifer between a county and adjacent counties.

- Evapotranspiration—water that flows out of an aquifer due to direct evaporation and plant transpiration. This component of the budget will always be shown as "Outflow". Evapotranspiration is modeled in the model using the MODFLOW Evapotranspiration (EVT) package.

- Rivers and Streams—water that flows between streams and rivers and an aquifer. The direction and amount of flow depends on the water level in the stream or river and the aquifer. In areas where water levels in the stream or river are above the water level in the aquifer, water flows into the aquifer and is shown as "Inflow" in the budget. In areas where water levels in the aquifer are above the water level in the stream or river, water flows out of the aquifer and into the stream and is shown as "Outflow" in the budget. Rivers and streams are modeled in the model using the MODFLOW Stream package.

- General-Head Boundary (GHB)—The model uses general head boundaries to simulate groundwater flow across the lateral aquifer boundaries. In addition, vertical movement of groundwater between the Sparta Aquifer (layer 1) and younger sediments that overlie the Sparta Aquifer in the downdip portions (areas where the layer is confined or covered by other aquifers or geologic formations) are simulated using general head boundaries.

The results are described for the four aquifers in the model area; the Sparta Aquifer (layer 1 in the model), the Queen City Aquifer (layer 3), the Carrizo Aquifer (layer 5), and the Wilcox Aquifer (layers 6, 7, and 8). Results for the other layers included in the model are not discussed because they are not considered to be aquifers in the region.

A small number of model cells went dry during the model run. Dry cells occur when the water level in a cell falls below the bottom of the cell. When this occurs the cell is deactivated. If high pumpage is the primary factor for a cell going dry, the model is saying that the pumping may be too great for the aquifer in this area. In the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers, when the model deactivates a cell, that cell is inactive for the rest of the simulation, and it is important to identify why a cell went dry and address the causes. In reality, the aquifer will probably not go dry because pumping will become uneconomical before the aquifer actually is fully dewatered in any particular area. Some of these cells went dry during the historic calibration period, and therefore, are not caused by conditions set for this predictive model run. All model cells that went dry during the run are located in the outcrop portions of the model, where the aquifer is thin and lies under unconfined conditions.

Initial water levels (which are from the end of the transient calibration run—the end of 1999) for the Sparta, Queen City, Carrizo, upper Wilcox, middle Wilcox, and lower Wilcox aquifers are shown in Figures 2 to 7. These figures show the starting water levels for this 60-year predictive model run. These figures all show that water level elevations are highest in the outcrop areas to the north and/or west, and water levels decrease as groundwater flows downdip, generally to the south and/or east. Initial water levels in the Carrizo and Wilcox aquifers show a large cone of depression in Frio, LaSalle, Dimmit, and Zavala counties.

Water level changes over the 60-year predictive simulation for the Sparta, Queen City, Carrizo, upper Wilcox, middle Wilcox, and lower Wilcox aquifers are shown in Figures 8 to 13. These figures indicate the following:

- Water level declines throughout most of Groundwater Management Area 13 in the Sparta Aquifer (Figure 8) range from zero to forty feet, with larger declines of up to 50 feet centered on McMullen and Gonzales counties. These declines are in response to increased pumpage in certain counties in the Sparta and Queen City aquifers, as shown in Table 1.

- Water level declines in the Queen City Aquifer (Figure 9) range from zero to fifty feet in most of the model area. As with the Sparta Aquifer, areas of greater drawdown are centered on the corners of McMullen and Atascosa counties and between Wilson and Karnes counties, with declines of over 60 feet. Other areas of greater drawdown are in Gonzales County. Areas of higher declines are in response to increased pumpage in certain counties in the Queen City Aquifer, as shown in Table 1. An area of recovery is shown in northern Webb and Zavala counties, which was also seen in the baseline model run (Donnelly, 2007a).

- Water level declines in the Carrizo Aquifer (Figure 10) over the next 60 years are predicted to exceed 50 feet over most of the model area and are over 170 feet in southwestern Gonzales County. Declines of over 140 feet are also centered near the outcrop in Frio County. These declines are in response to significant increases in pumpage in this model run.

- Water level declines in the upper Wilcox Aquifer (Figure 11) show similar patterns as the Carrizo Aquifer, with large water level declines focused around Gonzales County, and declines of more than 50 feet in most of the rest of the model area.

- Water level declines in the middle Wilcox Aquifer (Figure 12) are between 25 and 125 feet for most of the model area, with focused areas of decline in Atascosa, Frio, and Gonzales counties. Two cones of depression in Gonzales County exceed 250 feet.

- Water level declines in the lower Wilcox Aquifer (Figure 13) are dominated by pumpage added in Atascosa, Bexar, and Wilson counties for a brackish well field. Drawdowns in the center of this area are over 300 feet and drawdowns in Atascosa, Bexar, and Wilson counties exceed 100 feet over the majority of the three county area. Two drawdown cones are also predicted to occur in western and eastern Gonzales County and eastern Caldwell County.

Because some of the desired future conditions for the groundwater management area may be based on discharge to springs or baseflow to rivers and streams, we also reported the water budgets for each of these components for each county in the model area. These budgets are provided in Appendix A. The components of the water budget are divided up into “In” and “Out”, representing water that is coming into and leaving from the budget. As might be expected, water from wells is only in the “Out” column, representing water that is pulled out of the budget or aquifer system from wells. Likewise, recharge is only found in the “In” column. Streams and rivers, however, have values in both the “In” and “Out” columns. This is because some streams lose water to the aquifer, and some gain water from the aquifer depending on the water levels in the aquifer. Also included in these budgets are values for vertical leakage to overlying and underlying formations as well as lateral inflow from adjacent counties. Future model runs can be compared to these budgets to determine the impact of additional pumpage compared to this pumpage scenario simulation.

Some of the county pumping totals (Wells) listed in Appendix A differ from the amounts listed in Tables 1 and 2 for two reasons. In most cases the difference is due to dry cells. Where dry cells occur the pumping for that cell is turned off, so the county total is reduced. Uvalde County is the most extreme example where all model cells in the upper Wilcox and most cells in the Carrizo converted to dry during the model run; therefore, the model pumping listed in Appendix A is very low for those two layers even though they were specified to have a total of 10,500 acre-feet per year (Table 2). In two cases, for well field pumping, wells are located in one county, but the center of the model grid cell where they are located is in an adjoining county. Therefore in the water budget the "wells" value for that well field or portion of a well field will be assigned to the adjoining county. This shift occurs in the Carrizo Aquifer in Bexar and Guadalupe to Wilson counties (about 4,242 acre-feet per year), and in the Carrizo from Gonzales to Guadalupe (1,500 acre-feet per year).

REFERENCES:

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

The seal appearing on this document was authorized by Shirley C. Wade, P.G. 525, on September 17, 2008.

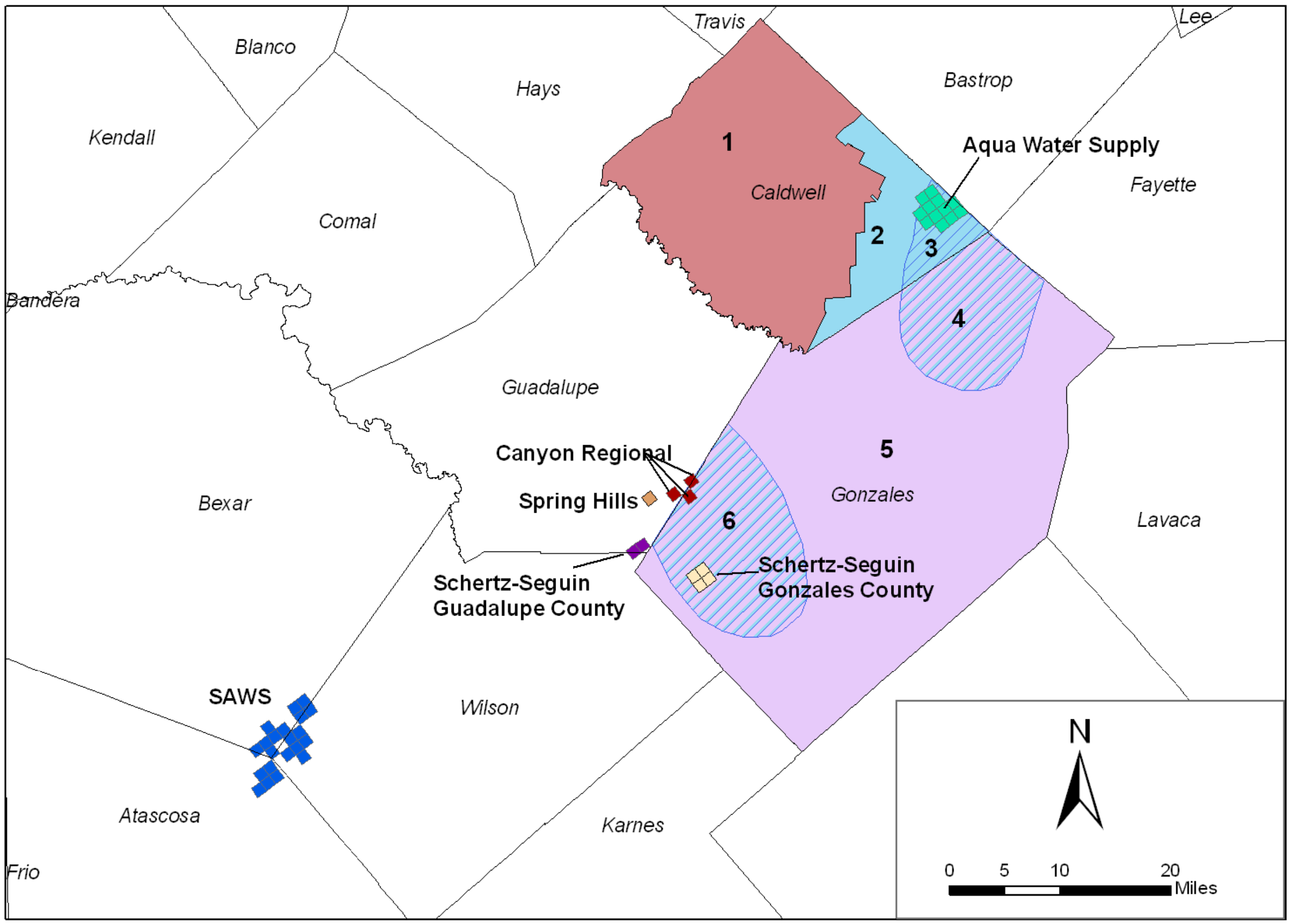

Figure 1. Well fields and specified pumpage areas.

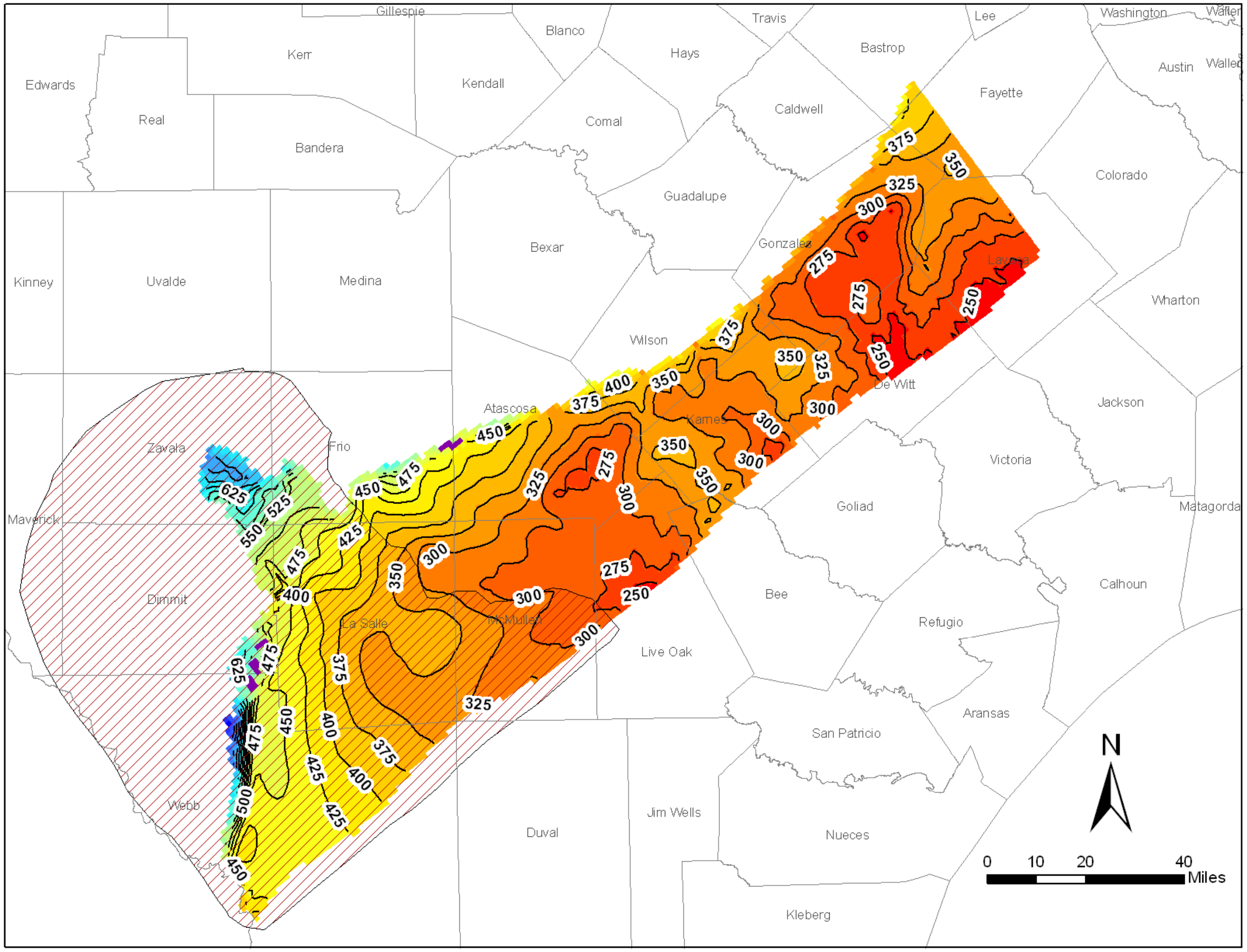

Figure 2. Initial water level elevations for the predictive model run in the Sparta Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. The area west of the Frio River (shown in hatched area) is not considered to be part of the Sparta Aquifer and does not have any pumpage assigned to it. Dry cells are shown in purple.

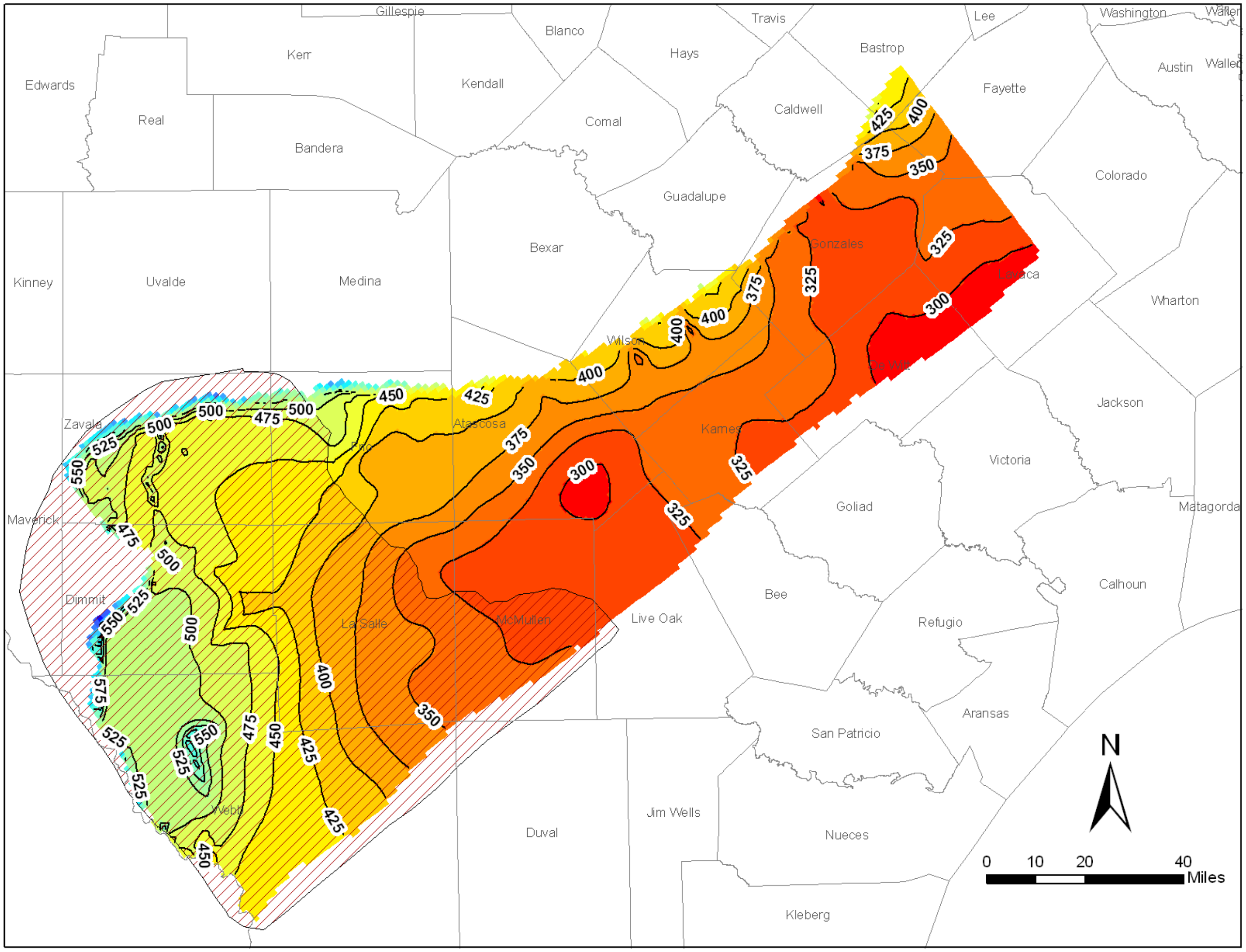

Figure 3. Initial water level elevations for the predictive model run in the Queen City Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. The area west of the Frio River (hatched area) is not considered to be part of the Queen City Aquifer and does not have any pumpage assigned to it. Dry model cells are shown in purple.

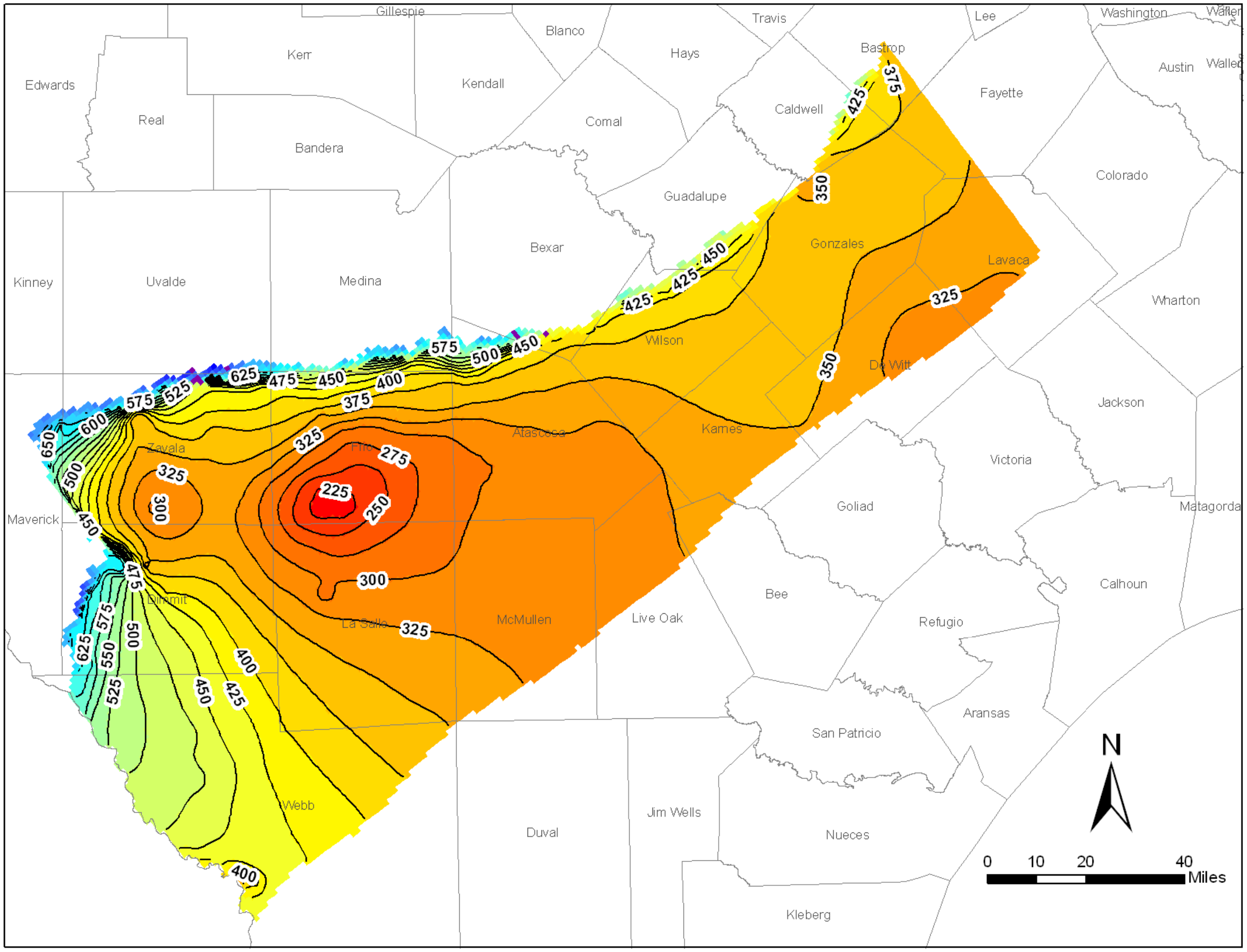

Figure 4. Initial water level elevations for the predictive model run in the Carrizo Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry model cells are shown in purple.

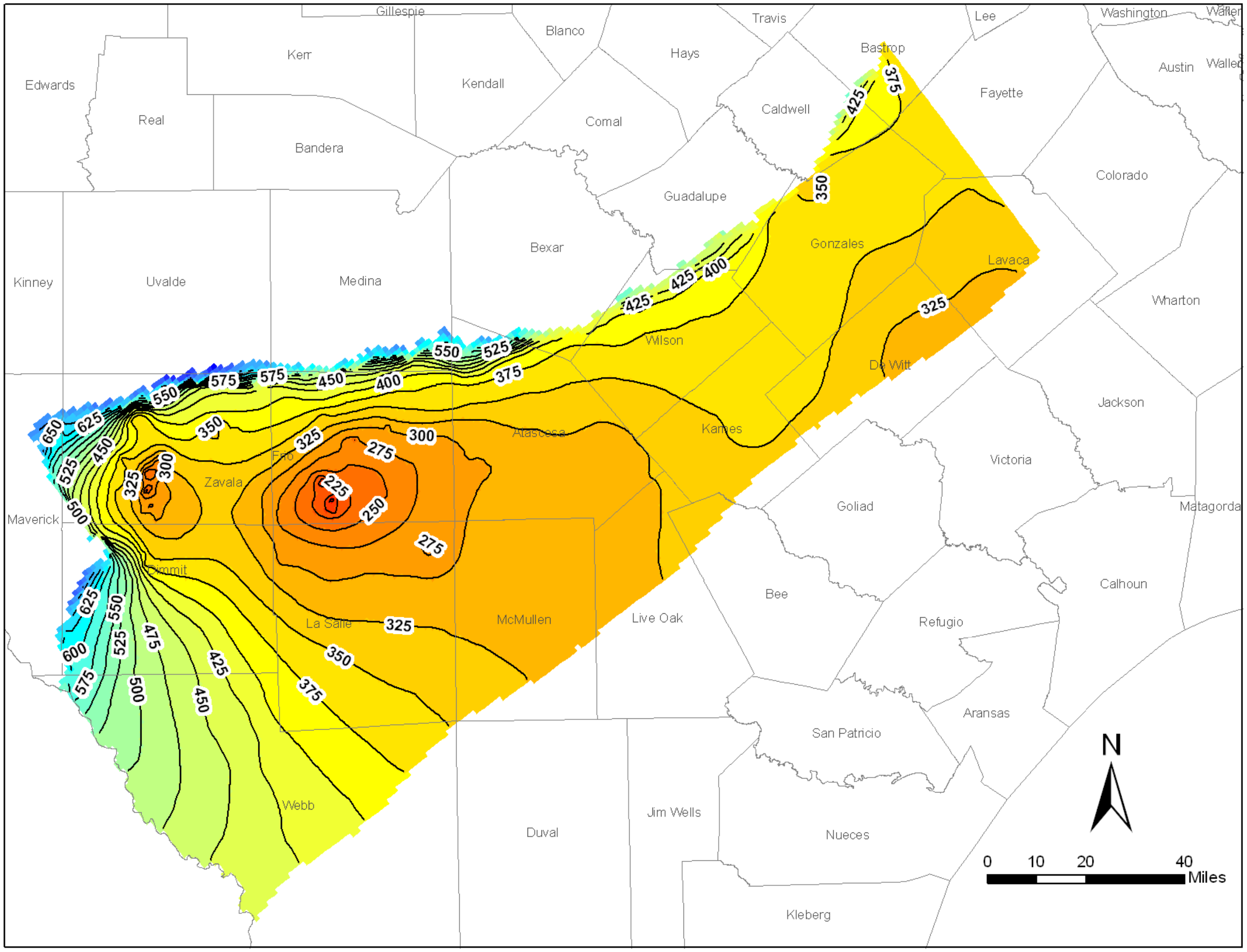

Figure 5. Initial water level elevations for the predictive model run in the upper Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry model cells are shown in purple.

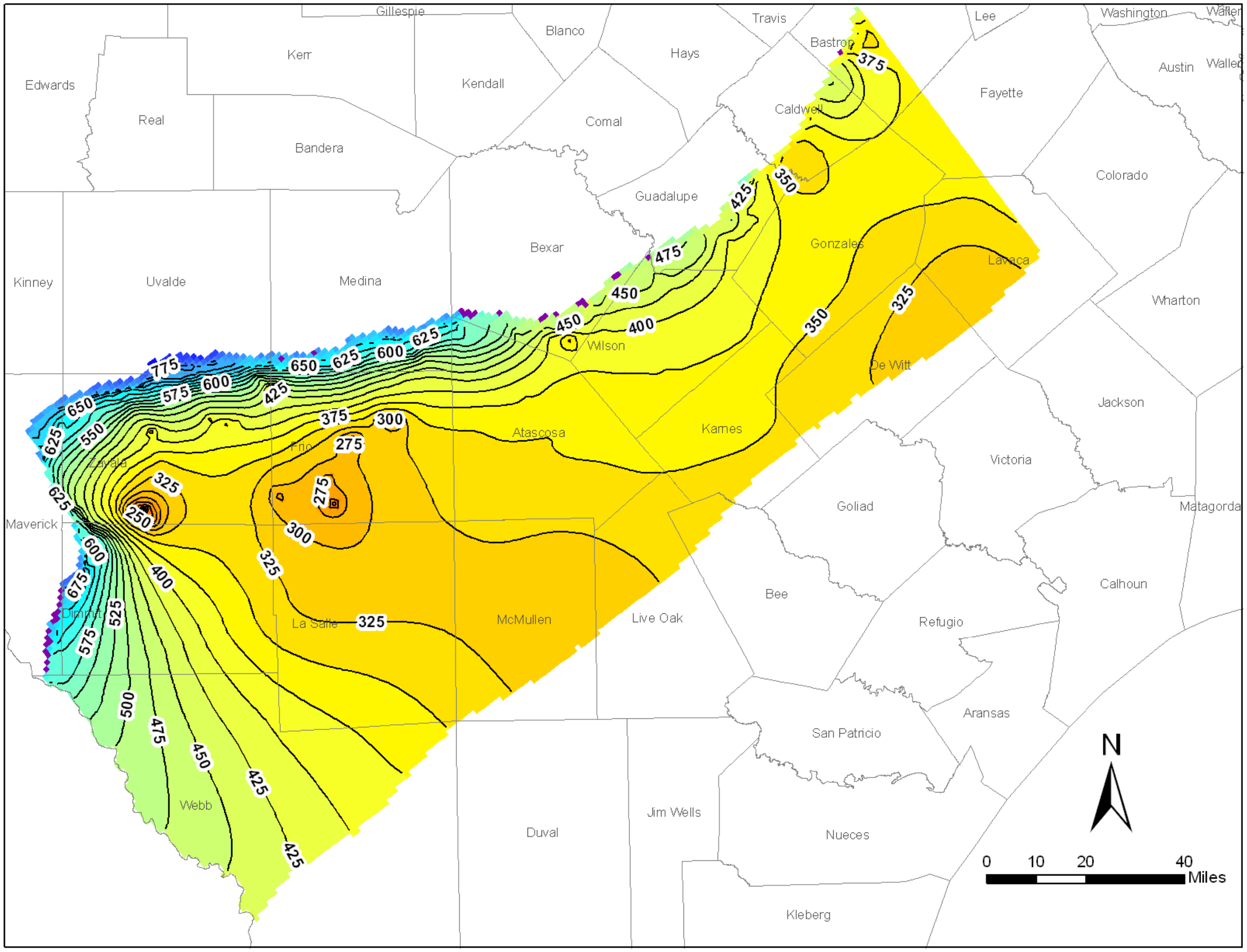

Figure 6. Initial water level elevations for the predictive model run in the middle Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry model cells are shown in purple.

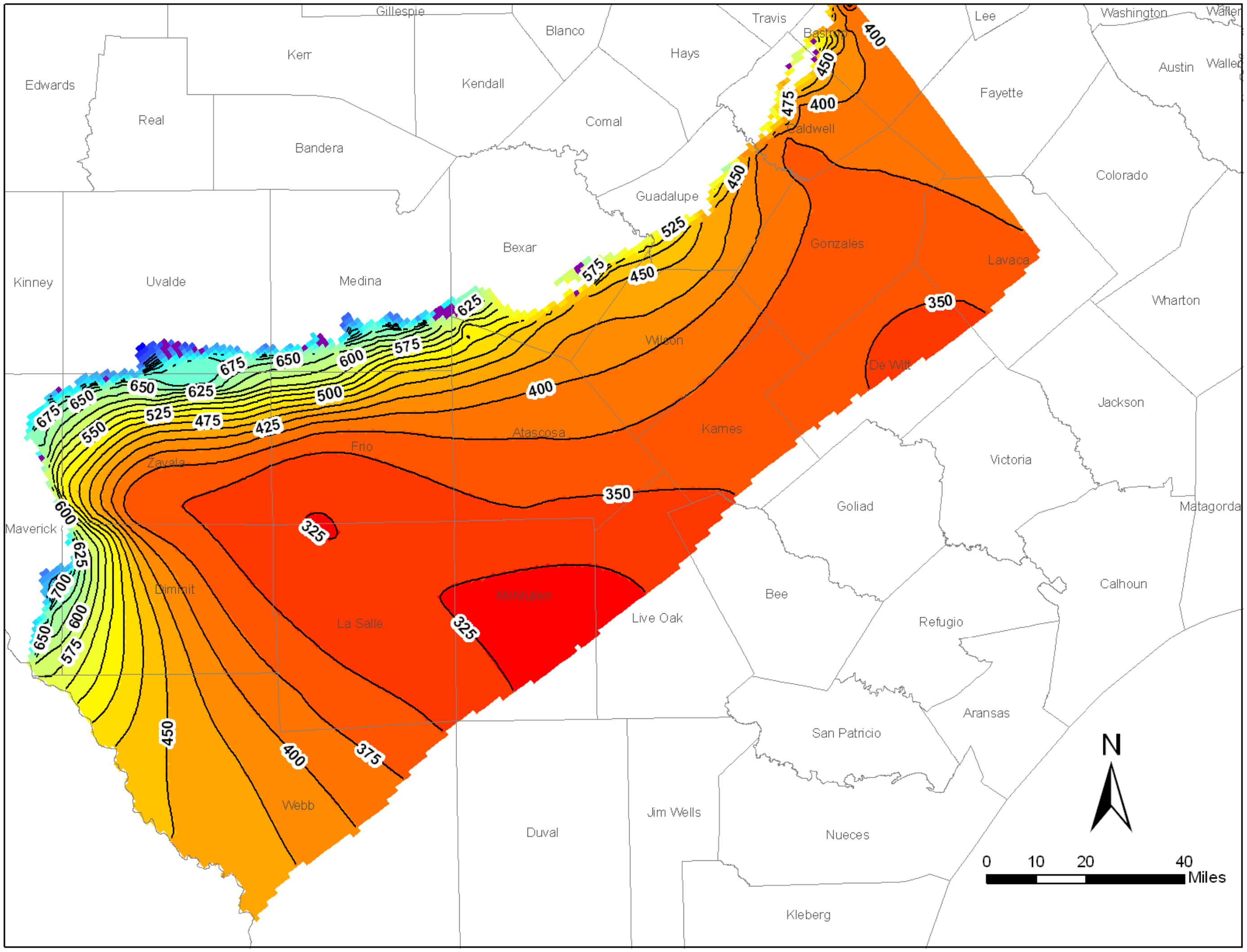

Figure 7. Initial water level elevations for the predictive model run in the lower Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry model cells are shown in purple.

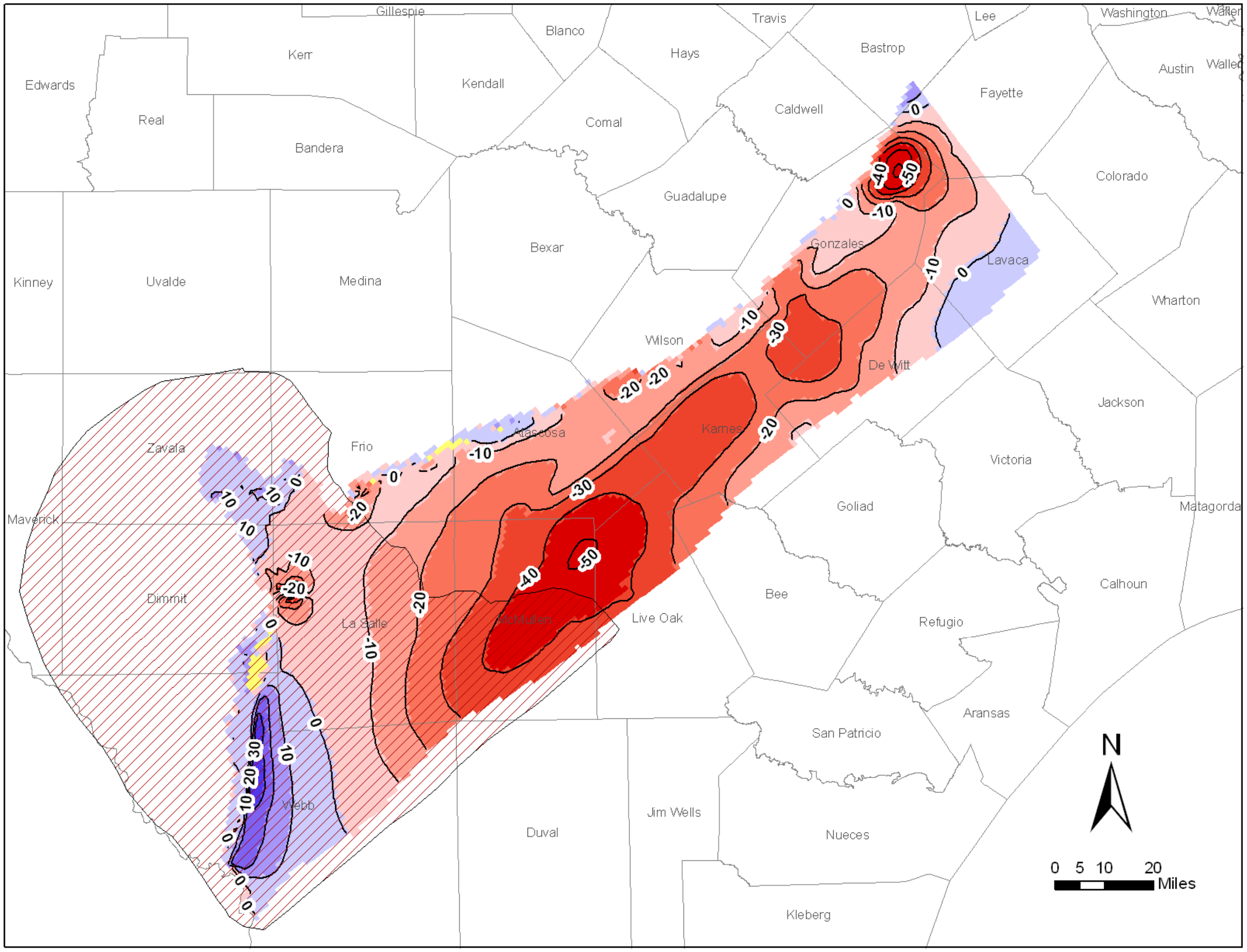

Figure 8. Water level changes after 60 years using the specified pumpage in the Sparta Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow. The area west of the Frio River (hatched area) is not considered to be part of the Sparta Aquifer and does not have any pumpage assigned to it.

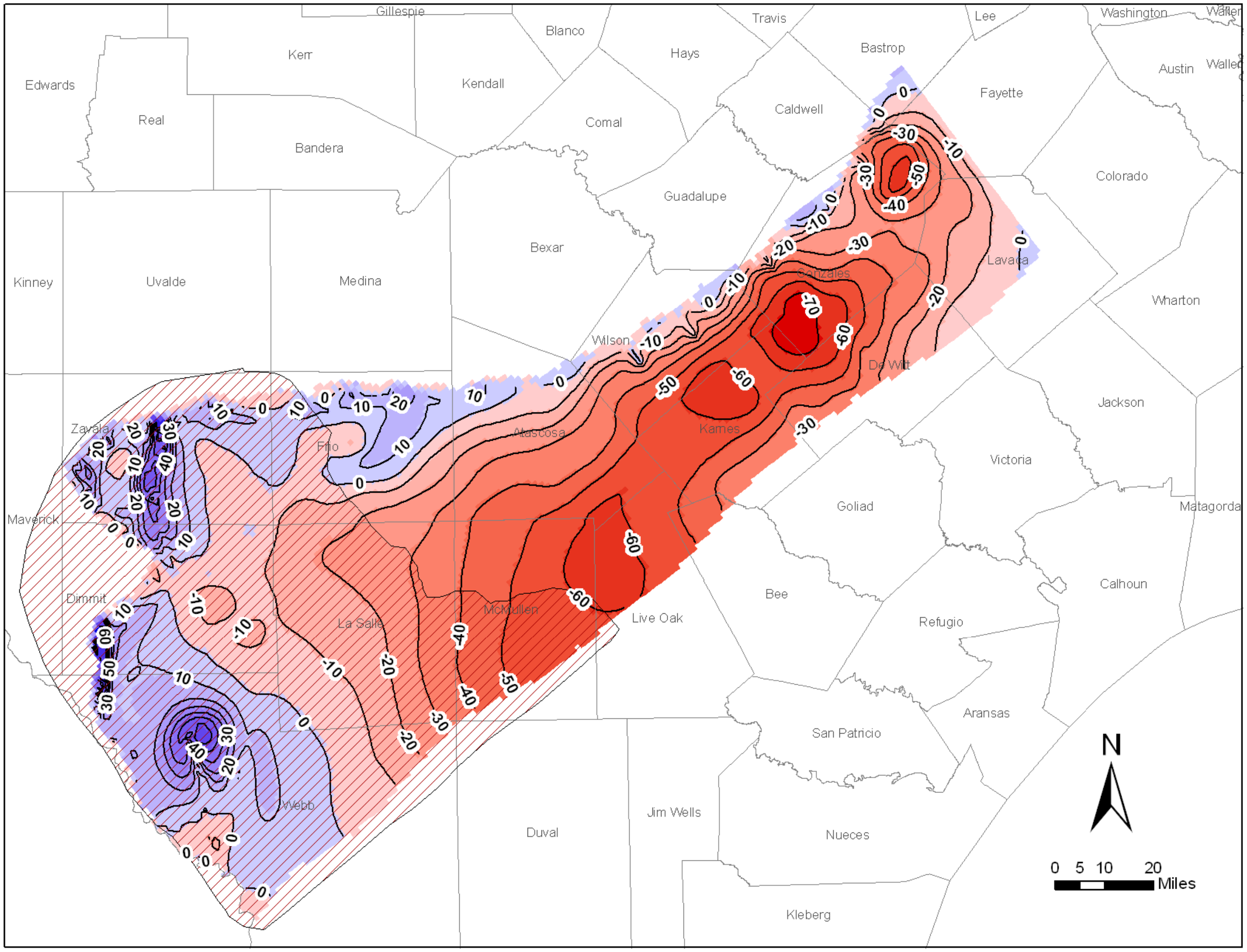

Figure 9. Water level changes after 60 years using the specified pumpage in the Queen City Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow. The area west of the Frio River (hatched area) is not considered to be part of the Queen City Aquifer and does not have any pumpage assigned to it.

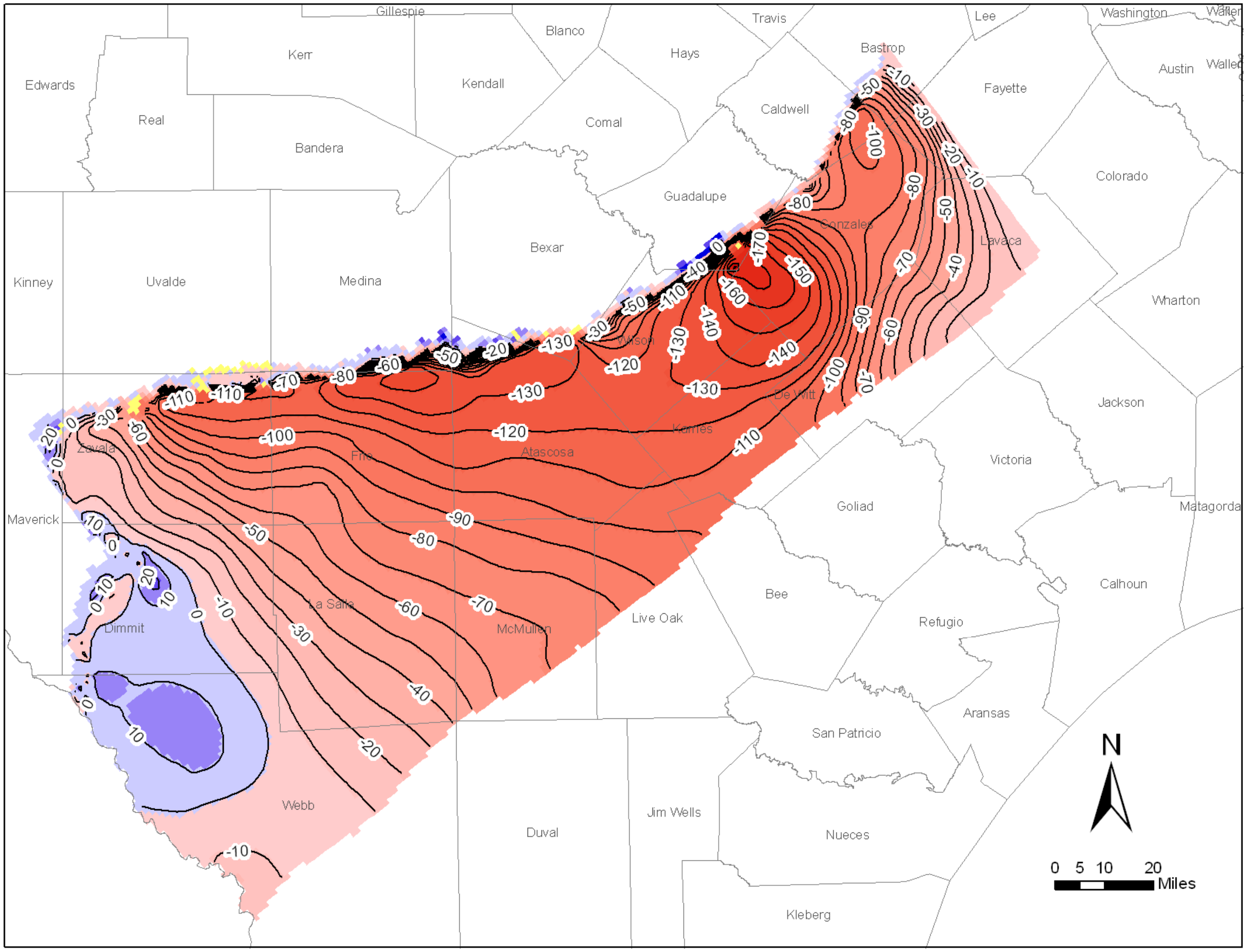

Figure 10. Water level changes after 60 years using the specified pumpage in the Carrizo Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

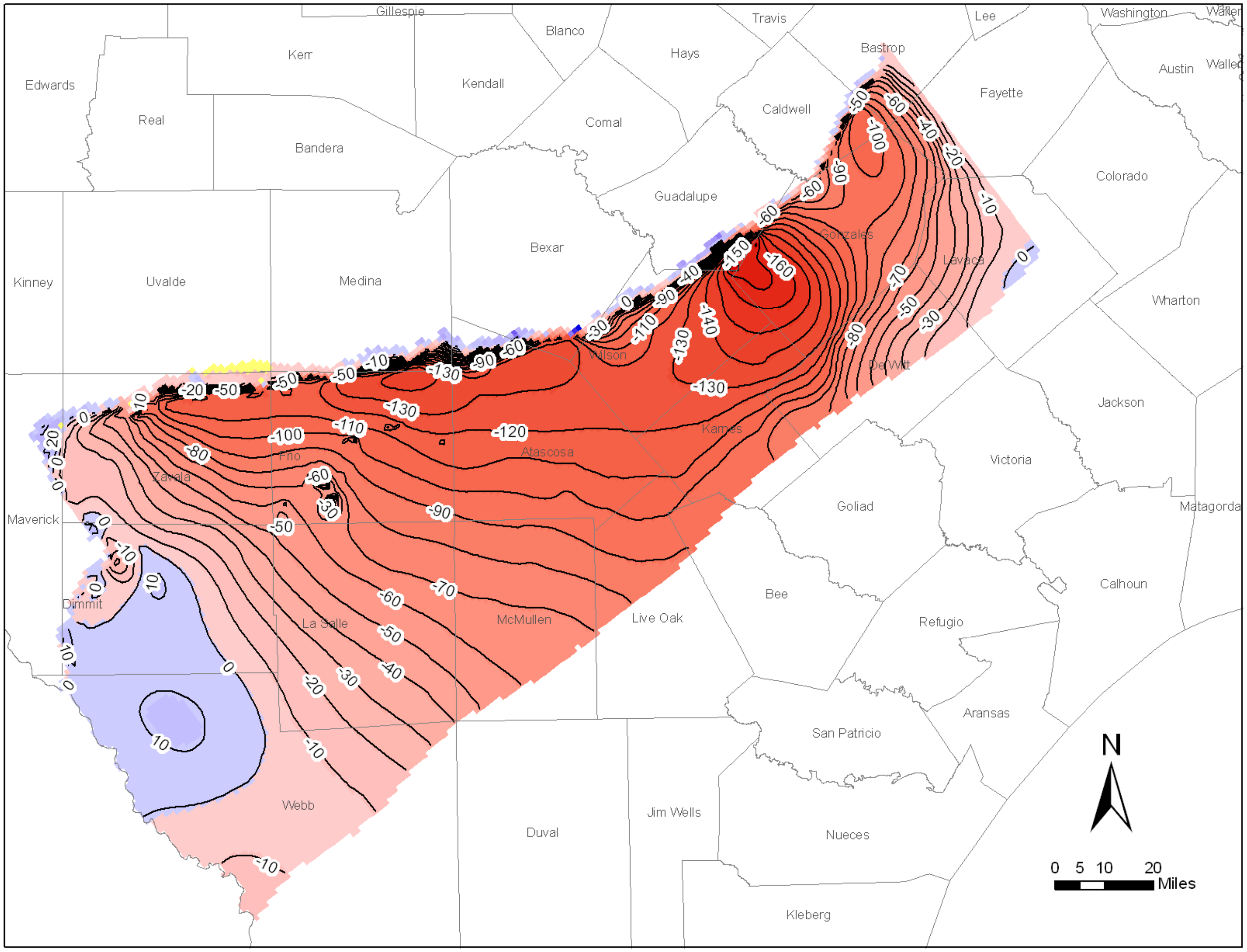

Figure 11. Water level changes after 60 years using the specified pumpage in the upper Wilcox Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

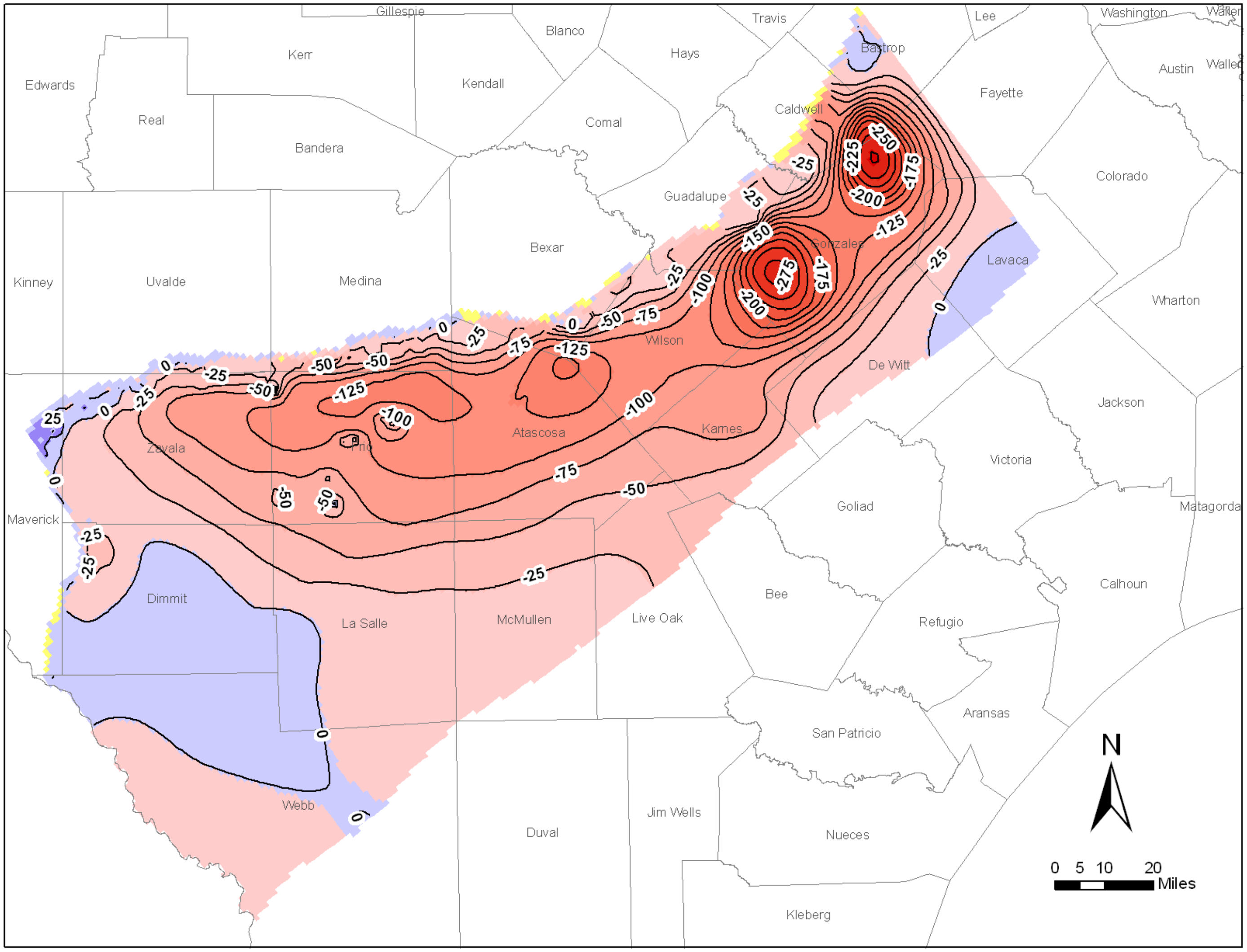

Figure 12. Water level changes after 60 years using the specified pumpage in the middle Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

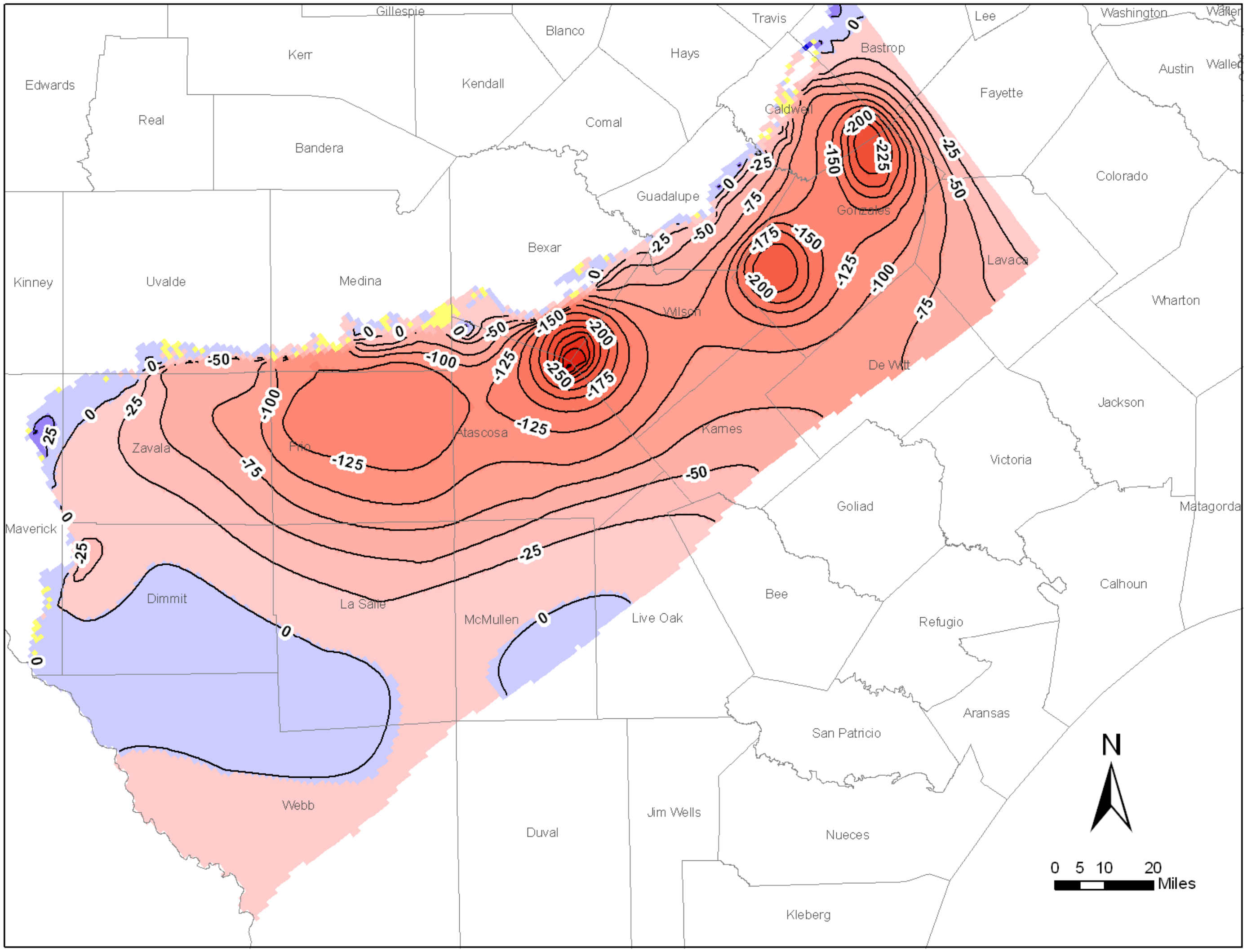

Figure 13. Water level changes after 60 years using the specified pumpage in the lower Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

Appendix A

Summary of Budgets After 60 Years

Table A-1. Annual water budgets for each county in Groundwater Management Area 13 at the end of the 60-year predictive model run 08-41 using the specified pumpage in the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Values are reported in acre-feet per year. Please note that Lavaca, Fayette, and Bastrop counties are only partially contained within the active part of the model and water budgets for these counties does not represent full county use.

	Atascosa		Bee		Bexar		Caldwell		De Witt		Dimmit		Frio	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta														
Storage	720	118	26	0	--	--	--	--	152	0	577	397	1,340	237
Reservoirs (River Package)	0	0	0	0	--	--	--	--	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	--	--	--	--	0	0	0	0	0	0
General head boundary	6,441	2,033	78	9	--	--	--	--	292	426	259	14	7,432	621
Wells	0	994	0	0	--	--	--	--	0	0	0	0	0	967
Rivers and streams (Stream Package)	233	409	0	0	--	--	--	--	0	0	488	901	372	197
Recharge	2,306	0	0	0	--	--	--	--	0	0	3,302	0	4,277	0
Evapotranspiration	0	0	0	0	--	--	--	--	0	0	0	154	0	74
Lateral inflow	732	222	2	1	--	--	--	--	13	19	330	573	343	2,168
Vertical leakage lower surface	440	7,095	2	97	--	--	--	--	325	336	1	2,919	0	9,500
Queen City														
Storage	3,031	151	60	0	--	--	290	10	346	0	2,717	8,559	3,123	2,781
Reservoirs (River Package)	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	--	--	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Wells	0	5,998	0	0	--	--	0	50	0	0	0	0	0	6,002
Rivers and streams (Stream Package)	3,596	1,493	0	0	--	--	312	53	0	0	8,900	6,077	7,477	5
Recharge	5,166	0	0	0	--	--	1,144	0	0	0	11,146	0	13,821	0
Evapotranspiration	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Vertical leakage upper surface	7,429	330	61	0	--	--	--	--	228	213	3,384	12	10,567	0
Lateral inflow	2,328	647	2	4	--	--	0	1,424	3	24	1,629	3,036	814	3,856
Vertical leakage lower surface	0	12,931	0	120	--	--	0	210	104	444	96	10,187	0	23,157

Table A-1. (continued)

	Atascosa		Bee		Bexar		Caldwell		De Witt		Dimmit		Frio	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	18,622	185	51	0	5,904	157	2,765	6	281	0	406	436	21,718	24
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	59,995	0	19	0	5,968	0	10,211	0	1	0	3,639	0	99,992
Rivers and streams (Stream Package)	1,478	0	0	0	2,582	0	75	0	0	0	841	0	539	0
Recharge	8,119	0	0	0	4,350	0	5,531	0	0	0	5,490	0	1,811	0
Evapotranspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical leakage upper surface	16,217	0	155	0	135	0	1,979	0	503	104	10,209	0	27,872	0
Lateral inflow	23,163	11,175	115	415	1,316	8,274	6,386	6,074	215	27	328	6,775	45,780	6,521
Vertical leakage lower surface	4,285	528	114	0	408	295	190	634	790	0	2,357	5,375	9,086	269
Upper Wilcox														
Storage	255	0	72	0	7	14	30	23	560	0	776	208	172	0
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	0	0	19	0	0	0	0	0	0	0	1,654	0	0
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	100	114	0	0
Recharge	0	0	0	0	434	0	0	0	0	0	345	0	0	0
Evapotranspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical leakage upper surface	528	4,285	0	114	295	408	634	190	0	790	5,375	2,357	269	9,086
Lateral inflow	585	76	6	33	8	141	7	43	137	120	1,315	3,193	1,886	105
Vertical leakage lower surface	3,303	310	88	0	55	237	0	416	212	0	1,198	1,584	6,901	37

Table A-1. (continued)

	Atascosa		Bee		Bexar		Caldwell		De Witt		Dimmit		Frio	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	3,130	1	103	0	3,425	3	6,981	0	1,201	0	1,434	1	1,038	0
Reservoirs (River Package)	0	0	0	0	1,818	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	55	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	0	0	19	0	5,459	0	16,804	0	0	0	232	0	0
Rivers and streams (Stream Package)	642	0	0	0	4,532	0	4,413	0	0	0	271	2	0	0
Recharge	622	0	0	0	2,816	0	3,723	0	0	0	724	0	0	0
Evapotranspiration	0	0	0	0	0	10	0	2	0	0	0	0	0	0
Vertical leakage upper surface	310	3,303	0	88	237	55	416	0	0	212	1,584	1,198	37	6,901
Lateral inflow	1,094	964	1	17	632	1,528	5,969	2,145	61	845	718	2,097	3,615	238
Vertical leakage lower surface	664	2,194	19	0	0	6,348	28	2,580	0	205	902	2,102	2,539	90
Lower Wilcox														
Storage	2,842	0	281	0	6,155	21	5,412	1	1,737	0	1,048	9	1,033	0
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	48	0	15	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	5,556	0	19	0	15,962	0	19,111	0	0	0	61	0	10,010
Rivers and streams (Stream Package)	0	0	0	0	4,591	341	3,443	0	0	0	193	0	0	0
Recharge	0	0	0	0	5,298	0	4,855	0	0	0	268	0	0	0
Evapotranspiration	0	0	0	0	0	165	0	30	0	0	0	0	0	0
Vertical leakage upper surface	2,194	664	0	19	6,348	0	2,580	28	205	0	2,102	902	90	2,539
Lateral inflow	7,720	6,535	42	284	6,497	12,351	7,801	4,905	1,038	2,980	2,552	5,192	11,849	423

Table A-1. (continued)

	Gonzales		Guadalupe		Karnes		La Salle		Lavaca		Live Oak		Maverick	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta														
Storage	1,067	1	--	--	261	0	2,987	19	42	0	176	0	--	--
Reservoirs (River Package)	0	0	--	--	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	15	--	--	0	0	0	0	0	0	0	0	--	--
General head boundary	1,896	2,788	--	--	1,244	417	10,238	5,588	274	566	48	420	--	--
Wells	0	4,268	--	--	0	0	0	1,650	0	0	0	0	--	--
Rivers and streams (Stream Package)	33	474	--	--	0	0	0	1,817	0	0	0	0	--	--
Recharge	3,081	0	--	--	0	0	1,923	0	0	0	0	0	--	--
Evapotranspiration	0	2	--	--	0	0	0	432	0	0	0	0	--	--
Lateral inflow	597	42	--	--	225	127	3,040	1,004	20	72	24	9	--	--
Vertical leakage lower surface	1,817	900	--	--	90	1,275	1,299	8,975	493	190	262	81	--	--
Queen City														
Storage	4,404	151	0	11	616	0	1,017	2	80	0	454	0	--	--
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	--	--
General head boundary	0	0	0	0	0	0	0	0	5	0	0	0	--	--
Wells	0	10,120	0	0	0	0	0	2	0	0	0	0	--	--
Rivers and streams (Stream Package)	1,549	911	0	0	0	0	0	0	0	0	0	0	--	--
Recharge	6,094	0	39	0	0	0	0	0	0	0	0	0	--	--
Evapotranspiration	0	4	0	0	0	0	0	0	0	0	0	0	--	--
Vertical leakage upper surface	1,862	1,402	--	--	1,292	4	9,005	1,070	112	429	97	141	--	--
Lateral inflow	3,630	63	1	9	565	172	4,986	1,026	15	44	23	65	--	--
Vertical leakage lower surface	49	4,938	0	21	0	2,296	0	12,908	382	122	0	368	--	--

Table A-1. (continued)

	Gonzales		Guadalupe		Karnes		La Salle		Lavaca		Live Oak		Maverick	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	6,776	0	6,279	545	555	0	575	0	55	0	289	0	64	614
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	1,741	0	0	0	0	0
Wells	0	50,768	0	7,287	0	471	0	7,112	0	1	0	85	0	145
Rivers and streams (Stream Package)	2,919	0	644	0	0	0	0	0	0	0	0	0	456	91
Recharge	1,406	0	7,112	0	0	0	0	0	0	0	0	0	2,108	0
Evapotranspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical leakage upper surface	9,087	2	611	0	2,727	0	14,063	0	70	399	629	0	46	0
Lateral inflow	35,245	2,206	2,635	9,172	1,140	5,233	6,815	15,587	2,135	4,389	841	2,457	3	900
Vertical leakage lower surface	252	2,708	317	594	1,284	2	2,448	1,203	796	8	783	0	19	946
Upper Wilcox														
Storage	70	0	3	0	411	0	787	0	207	0	385	0	0	107
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	732	0	0	0	0	0
Wells	0	0	0	0	0	0	0	3,253	0	0	0	0	0	135
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	53	33
Recharge	0	0	97	0	0	0	0	0	0	0	0	0	85	0
Evapotranspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical leakage upper surface	2,708	252	594	317	2	1,284	1,203	2,448	8	796	0	783	946	19
Lateral inflow	194	13	16	129	44	35	4,140	1,947	32	165	150	239	20	124
Vertical leakage lower surface	34	2,741	30	293	863	2	1,518	0	24	42	488	0	30	715

Table A-1. (continued)

	Gonzales		Guadalupe		Karnes		La Salle		Lavaca		Live Oak		Maverick	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	2,575	0	3,212	1	876	0	902	0	551	0	396	0	8	71
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	340	0	0	0	0	0
Wells	0	20,062	0	2,996	0	0	0	0	0	0	0	0	0	260
Rivers and streams (Stream Package)	1,346	0	7,529	1,115	0	0	0	0	0	0	0	0	910	18
Recharge	125	0	5,606	0	0	0	0	0	0	0	0	0	591	0
Evapotranspiration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical leakage upper surface	2,741	34	293	30	2	863	0	1,518	42	24	0	488	715	30
Lateral inflow	14,032	1,581	827	8,926	162	395	502	589	464	1,377	10	58	462	871
Vertical leakage lower surface	1,080	223	88	4,487	228	10	702	0	40	36	140	0	21	1,457
Lower Wilcox														
Storage	2,016	0	3,046	133	2,632	0	1,079	0	425	0	903	0	199	265
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	39	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	1,949	0	0	0	0	0
Wells	0	29,992	0	1,550	0	0	0	0	0	0	0	0	0	992
Rivers and streams (Stream Package)	0	0	2,852	155	0	0	0	0	0	0	0	0	378	49
Recharge	0	0	4,546	0	0	0	0	0	0	0	0	0	1,353	0
Evapotranspiration	0	0	0	66	0	0	0	0	0	0	0	0	0	195
Vertical leakage upper surface	223	1,080	4,487	88	10	228	0	702	36	40	0	140	1,457	21
Lateral inflow	29,630	798	3,003	15,902	1,013	3,427	3,052	3,428	1,631	4,000	144	907	14	1,878

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta												
Storage	305	0	--	--	--	--	34	3,833	1,330	0	2	1,183
Reservoirs (River Package)	0	0	--	--	--	--	0	0	0	0	0	0
Springs (Drain Package)	0	0	--	--	--	--	0	0	0	101	0	0
General head boundary	1,630	829	--	--	--	--	5,185	733	2,423	1,882	0	0
Wells	0	202	--	--	--	--	0	0	0	999	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	3,939	2,155	216	322	247	62
Recharge	0	0	--	--	--	--	3,201	0	2,403	0	4,362	0
Evapotranspiration	0	0	--	--	--	--	0	2,202	0	6	0	0
Lateral inflow	525	156	--	--	--	--	242	795	62	523	34	146
Vertical leakage lower surface	318	1,591	--	--	--	--	700	3,584	23	2,623	0	3,253
Queen City												
Storage	1,226	0	--	--	--	--	173	19,621	6,001	64	813	14,382
Reservoirs (River Package)	0	0	--	--	--	--	0	0	0	0	0	0
Springs (Drain Package)	0	0	--	--	--	--	0	0	0	0	0	0
General head boundary	0	0	--	--	--	--	0	0	0	0	0	0
Wells	0	300	--	--	--	--	0	0	0	6,002	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	20,898	7,170	1,572	1,866	16,895	0
Recharge	0	0	--	--	--	--	10,787	0	7,482	0	10,722	0
Evapotranspiration	0	0	--	--	--	--	0	1,523	0	0	0	0
Vertical leakage upper surface	1,601	171	--	--	--	--	4,176	554	3,948	12	2,635	0
Lateral inflow	1,143	173	--	--	--	--	755	2,639	93	1,913	1,162	1,017
Vertical leakage lower surface	0	3,327	--	--	--	--	146	5,432	0	9,239	0	16,829

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo												
Storage	449	0	4,875	276	1	0	68	111	19,632	36	12,007	189
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	3,199	0	0	0	428	0	896	0	49,219	0	40,129
Rivers and streams (Stream Package)	0	0	1,408	49	440	0	56	0	11,627	42	2,641	0
Recharge	0	0	8,726	0	271	0	529	0	8,696	0	6,558	0
Evapotranspiration	0	0	0	0	0	0	0	124	0	0	0	0
Vertical leakage upper surface	3,691	0	8	0	--	--	5,187	1	12,421	0	20,306	0
Lateral inflow	2,081	4,510	896	14,831	0	284	84	1,986	11,637	16,427	8,554	8,420
Vertical leakage lower surface	1,514	26	673	1,429	0	0	418	3,226	2,242	532	6,658	7,986
Upper Wilcox												
Storage	930	0	82	26	0	0	238	63	78	1	451	27
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	249	0	0	0	0	0	13	0	0	0	10,447
Rivers and streams (Stream Package)	0	0	0	0	0	0	15	197	0	0	0	0
Recharge	0	0	0	0	0	0	82	0	0	0	348	0
Evapotranspiration	0	0	0	0	0	0	0	69	0	0	0	0
Vertical leakage upper surface	26	1,514	1,429	673	0	0	3,226	418	532	2,242	7,986	6,658
Lateral inflow	974	1,036	37	488	0	0	638	3,016	162	19	977	374
Vertical leakage lower surface	869	0	485	846	0	0	95	518	1,627	136	9,108	1,363

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox												
Storage	817	0	4,006	123	656	6	181	4	2,295	0	1,765	214
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	248	0	0	0	0	0	6	0	0	0	6,161
Rivers and streams (Stream Package)	0	0	921	45	308	15	3,011	2,808	1,294	335	1,418	3
Recharge	0	0	2,619	0	2,143	0	82	0	968	0	1,006	0
Evapotranspiration	0	0	0	0	0	0	0	150	0	0	0	0
Vertical leakage upper surface	0	869	846	485	0	0	518	95	136	1,627	1,363	9,108
Lateral inflow	125	134	422	2,842	16	1,260	457	565	2,759	2,968	2,886	389
Vertical leakage lower surface	309	0	24	5,342	0	1,842	21	644	281	2,803	9,647	2,211
Lower Wilcox												
Storage	1,220	0	4,422	193	2,011	104	228	0	2,200	0	874	425
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	0	0	0	0
Wells	0	248	0	5,781	0	0	0	1	0	11,233	0	548
Rivers and streams (Stream Package)	0	0	135	86	344	16	0	130	206	0	790	83
Recharge	0	0	1,866	0	1,205	0	15	0	69	0	537	0
Evapotranspiration	0	0	0	90	0	6	0	42	0	0	0	0
Vertical leakage upper surface	0	309	5,342	24	1,842	0	644	21	2,803	281	2,211	9,647
Lateral inflow	561	1,223	1,014	6,606	223	5,498	1,659	2,352	14,120	7,885	8,206	1,914