GAM Run 08-43

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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 "medium 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 zero to 30 feet in most of the Sparta and Queen City aquifers, with higher drawdowns observed in areas with increased pumping (Gonzales County) and lower hydraulic conductivities (McMullen and Live Oak counties);

- water level declines of at least 100 feet in the Carrizo and upper Wilcox aquifers center around the intersection of Wilson, Gonzales, and Guadalupe counties; water level declines of over 110 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 250 feet respectively due to a brackish well field added to the lower Wilcox aquifers in Atascosa, Bexar, and Wilson counties. Water level declines of over 100 feet are also suggested in Gonzales and Caldwell counties. Water level declines in the rest of these aquifers are generally less than 75 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), 07-17 (Donnelly 2007c), 08-41 (Wade, 2008a) and 08-42 (Wade, 2008b).

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 medium 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. Simulated 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 layers 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.

Specified Pumpage

The pumpage specified by the members of Groundwater Management Area 13 was based on the baseline pumpage developed 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).

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 decreased relative to the baseline in a county, the pumpage in each cell was proportionately reduced.

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 summed together and 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- 43 specified pumpage		
County	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer
Atascosa	517	964	55,009	750	3,000	54,444
Bastrop	7	88	690	--	--	690
Bee	--	--	76	--	--	76
Bexar	--	--	16,871	--	--	29,019
Caldwell	--	132	3,634	--	30	38,209
DeWitt	--	--	1	--	--	1
Dimmit	--	--	4,477	--	--	5,037
Fayette	66	12	2	66	12	2
Frio	87	66	110,004	750	3,000	97,500
Gonzales	552	240	2,605	2,268	5,120	72,325
Guadalupe	--	--	6,072	--	--	16,472
Karnes	--	--	471	--	--	471
LaSalle	1,316	2	8,286	1,481	2	9,322
Lavaca	--	--	1	--	--	1
Live Oak	--	--	85	--	--	85
Maverick	--	--	3,298	--	--	3,298
McMullen	0	0	119	100	150	1,900
Medina	--	--	5,008	--	--	5,500
Uvalde	--	--	596	--	--	7,475
Webb	--	--	916	--	--	916
Wilson	504	170	17,376	750	3,000	43,907
Zavala	--	--	48,763	--	--	54,859

Table 2. Baseline pumpage and pumpage used in the current model run in each layer of the Carrizo-Wilcox Aquifer. Pumpage totals are in reported 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 08-43 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	--	--	--	4,444
Bastrop	100	60	309	221	100	60	309	221
Bee	19	19	19	19	19	19	19	19
Bexar	3,513	--	6,633	6,725	7,513	--	6,633	14,873
Caldwell	279	--	1,169	2,186	8,209	--	15,000	15,000
DeWitt	1	--	--	--	1	--	--	--
Dimmit	2,917	1,321	189	50	3,282	1,486	213	56
Fayette	2	--	--	--	2	--	--	--
Frio	99,802	6,049	4,089	64	90,000	--	--	7,500
Gonzales	2,538	1	66	--	42,271	1	10,053	20,000
Guadalupe	1,224	--	3,240	1,608	11,624	--	3,240	1,608
Karnes	471	--	--	--	471	--	--	--
LaSalle	5,684	2,602	--	--	6,395	2,927	--	--
Lavaca	1	--	--	--	1	--	--	--
Live Oak	85	--	--	--	85	--	--	--
Maverick	596	276	856	1,570	596	276	856	1,570
McMullen	119	--	--	--	1,600	100	100	100
Medina	1,477	31	980	2,520	--	--	--	5,500
Uvalde	358	--	120	118	1,875	5,600	--	--
Webb	896	13	6	1	896	13	6	1
Wilson	15,986	40	772	578	35,000	--	--	8,907
Zavala	34,731	8,629	4,901	502	39,072	9,708	5,514	565

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 reported 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	--	--	--	--	--	4,444
Bexar	San Antonio Water System	--	--	4,000	--	--	8,148
Caldwell	1	--	--	--	--	12,811	10,940
Caldwell	2	--	--	209	--	189	60
Caldwell	3	--	30	3,000	--	2,000	4,000
Caldwell	Aqua Water Supply	--	--	5,000	--	--	--
Gonzales	4	1,000	2,500	15,000	--	5,000	10,000
Gonzales	5	268	120	2,271	1	53	--
Gonzales	6	1,000	2,500	13,000	--	5,000	10,000
Gonzales	Schertz-Seguin	--	--	9,000	--	--	--
Gonzales	Canyon Regional	--	--	3,000	--	--	--
Guadalupe	Canyon Regional	--	--	1,400	--	--	--
Guadalupe	Spring Hills	--	--	2,500	--	--	--
Guadalupe	Schertz-Seguin	--	--	6,500	--	--	--
Wilson	San Antonio Water System	--	--	--	--	--	7,407

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 20 feet, with larger declines exceeding 30 feet centered on McMullen and Live Oak counties. These declines are a result of low hydraulic conductivities (less than 1 foot per day) rather than high pumpage in those areas (Kelley and others, 2004, Figure 4.3.11).

- Water level declines in the Queen City Aquifer (Figure 9) range from zero to 30 feet in most of the model area. As with the Sparta Aquifer, areas of greater drawdown are centered on the corners of McMullen and Live Oak counties and also Gonzales and Karnes counties, with declines of over 40 feet. Areas of higher declines are in response to increased pumpage in certain counties in the Queen City Aquifer, as shown in Table 1 and, in the case of McMullen and Live Oak counties, low hydraulic conductivities (Kelley and others, 2004, Figure 4.3.10). Areas of recovery are shown in northern Webb, Frio, 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 10 feet over most of the model area and are over 130 feet in southwestern Gonzales County. Declines of over110 feet are also centered near the outcrop in Frio County. These declines are in response to 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 a drawdown cone focused around Gonzales County, and declines of more than 10 feet in most of the rest of the model area.

- Water level declines in the middle Wilcox Aquifer (Figure 12) are between zero and 75 feet for most of the model area, with focused areas of decline in Atascosa, Frio, and Gonzales counties. Four cones of depression in Gonzales County, Bexar, Atascosa, Wilson, and Frio counties exceed 100 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 the wellfield (Figure 1) are over 250 feet and drawdowns in the majority of the three county area exceeds 50 feet. 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 flow to overlying and underlying formations along the upper and lower faces of the model layer as well as lateral inflow from adjacent counties. Future model runs can be compared to these water budgets to determine the impact of additional pumpage on the aquifer water levels 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 the occurrences of dry cells. Where dry cells occur the pumping for that cell is turned off, so the county total pumping is reduced. Uvalde County is the most extreme example where all model cells in the upper Wilcox and most cells in the Carrizo aquifers were converted to dry cells during the model run; therefore, the pumping calculated from the water budget and listed in Appendix A is very low for those two layers even though they were specified to have a total of 7,475 acre-feet per year (Table 2). In three 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 3,900 acre-feet per year), and in the Carrizo Aquifer from Gonzales to Guadalupe counties (1,500 acre-feet per year).

REFERENCES:

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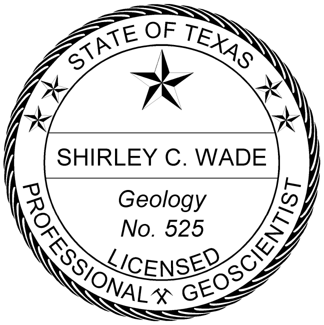

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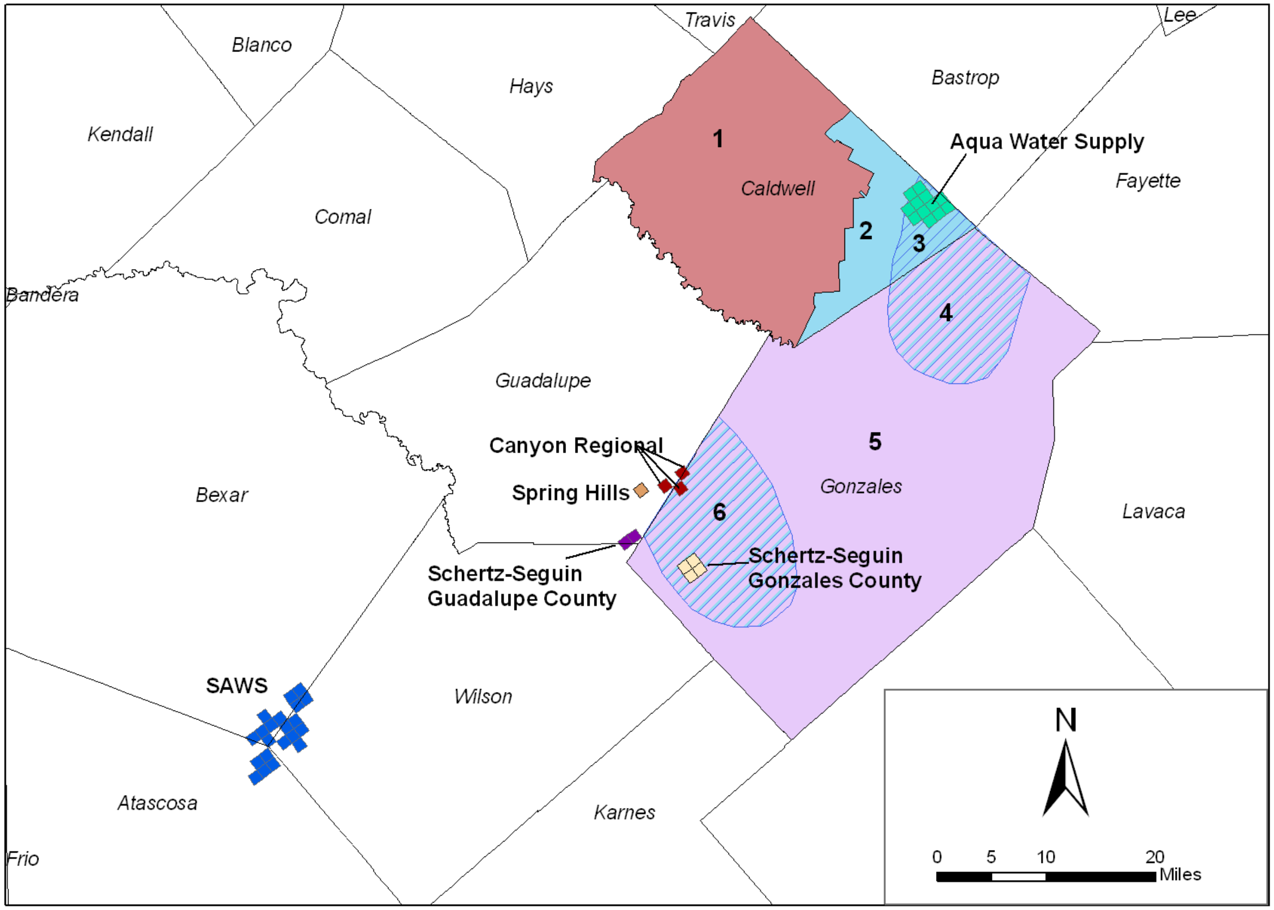

Figure 1. Well fields and specified pumpage areas.

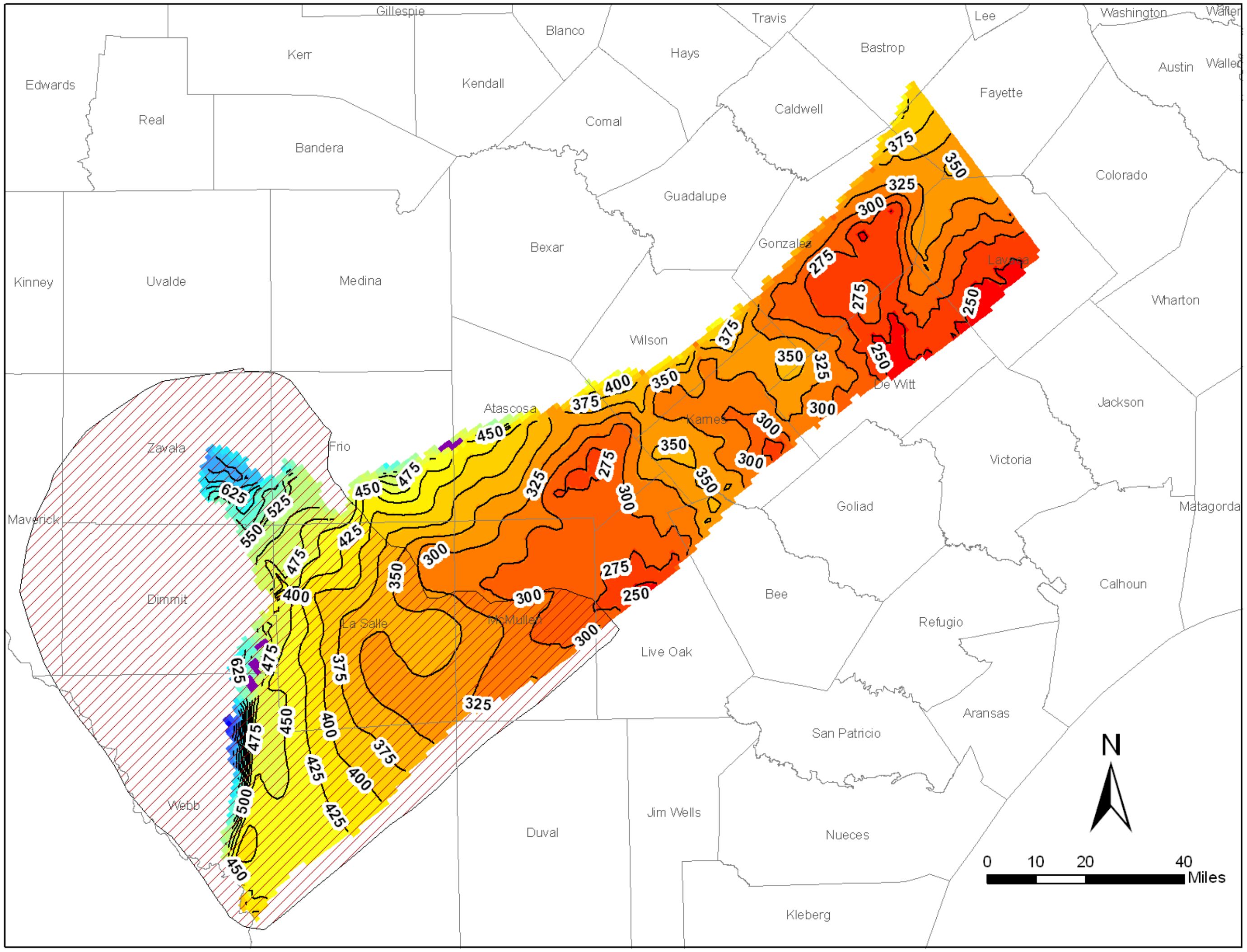

Figure 2. **Initial water level elevations for the predictive model run in the Sparta Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. The 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.**

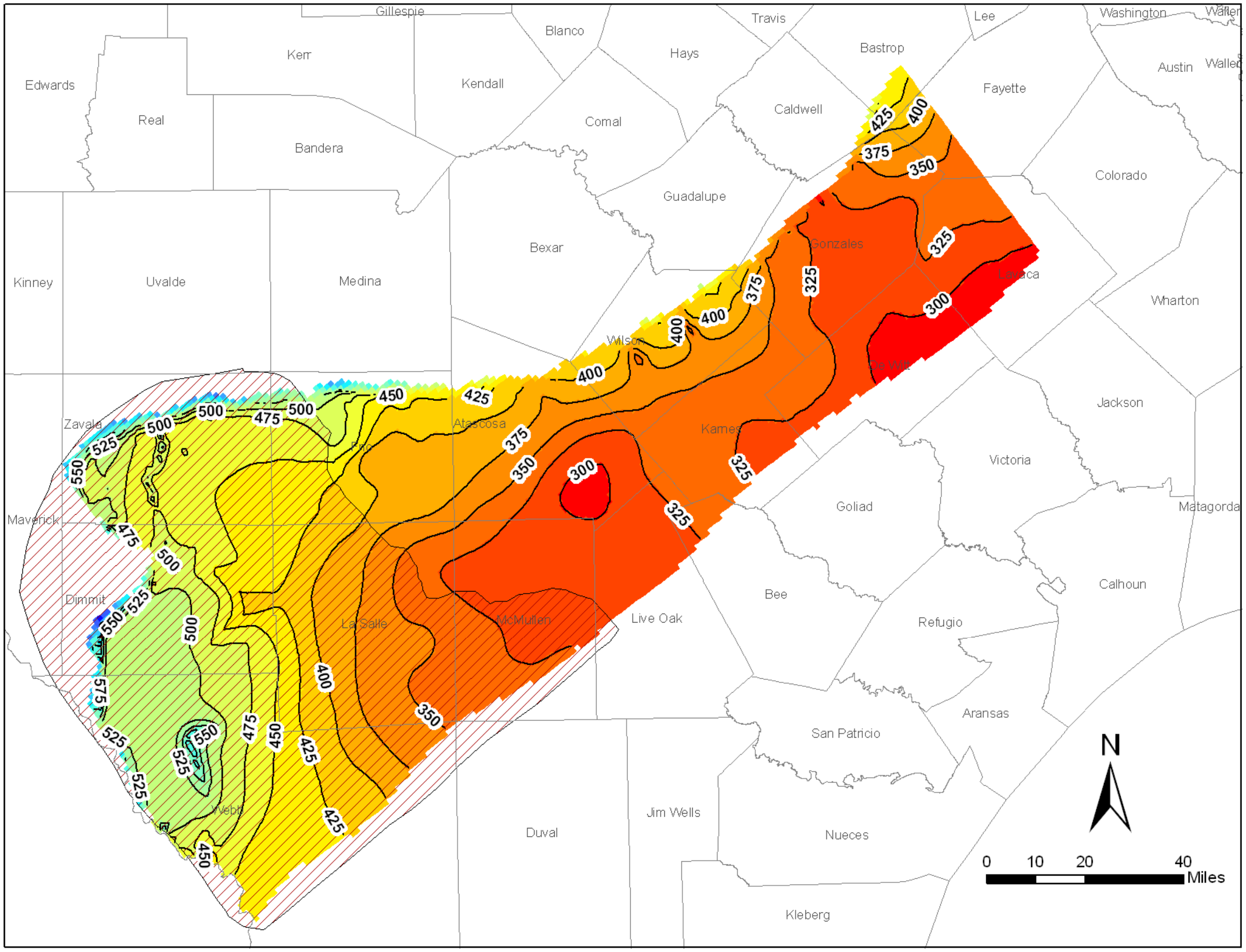

Figure 3. **Initial water level elevations for the predictive model run in the Queen City Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. 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.**

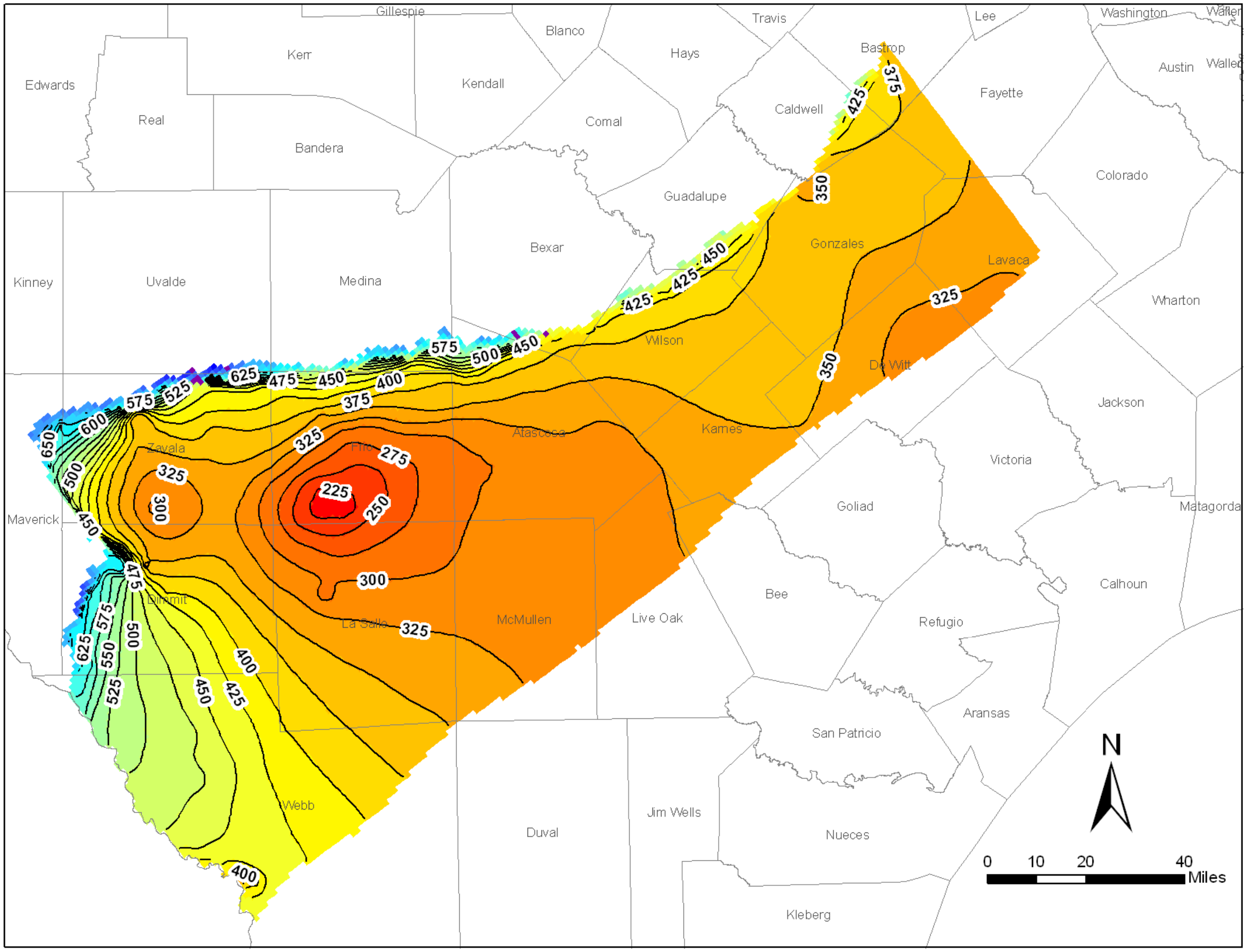

Figure 4. Initial water level elevations for the predictive model run in the Carrizo Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry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

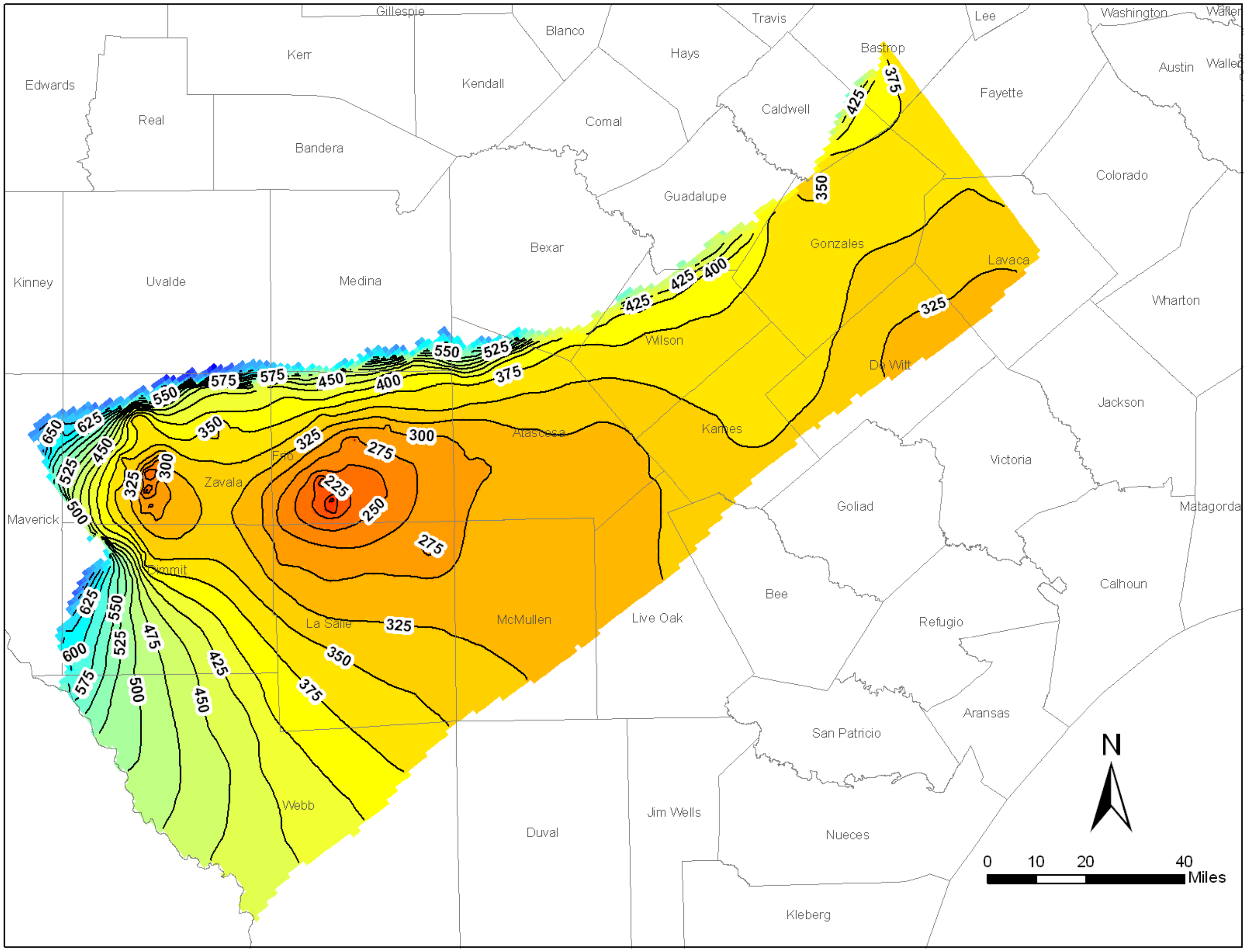

Figure 5. **Initial water level elevations for the predictive model run in the upper Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

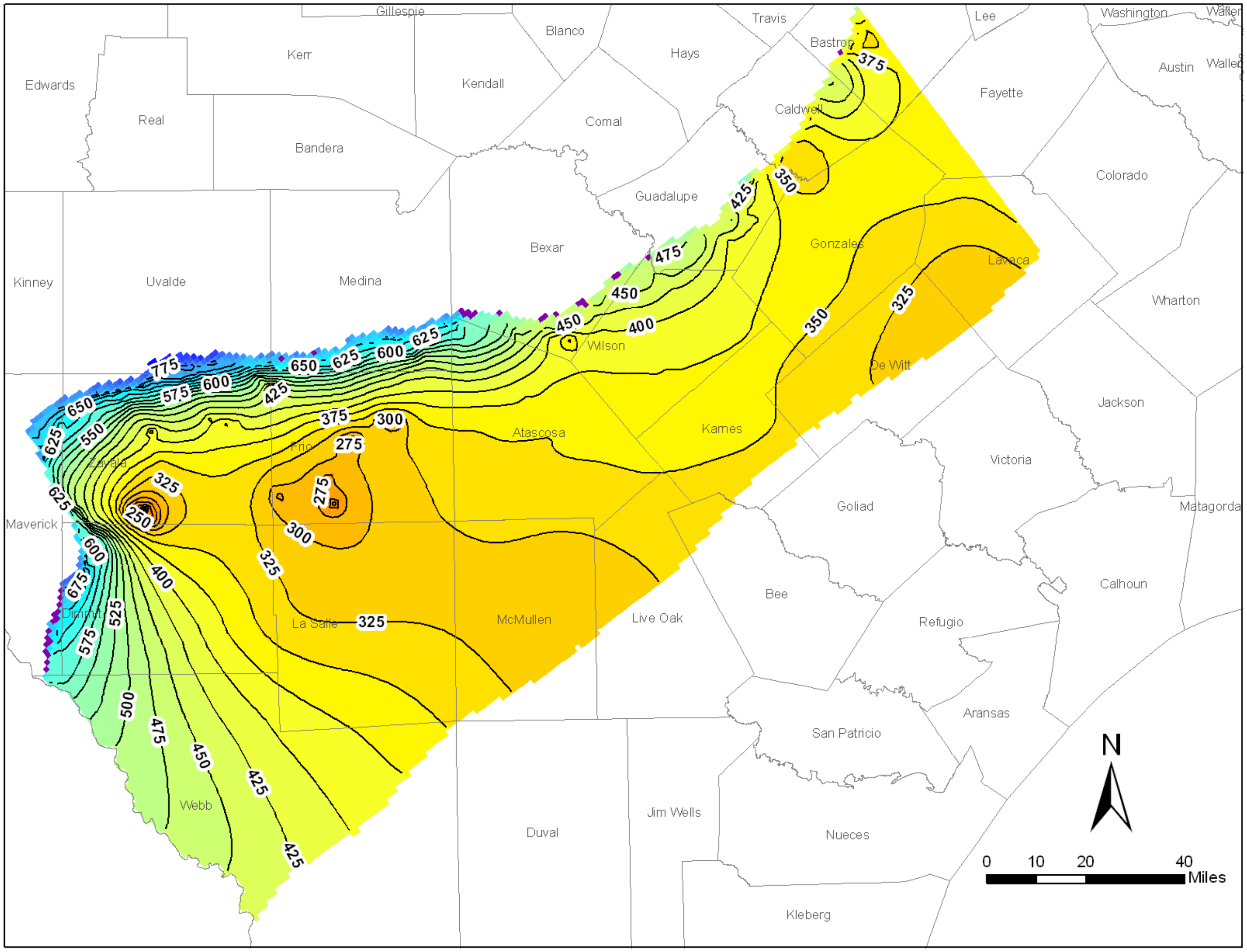

Figure 6. **Initial water level elevations for the predictive model run in the middle Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

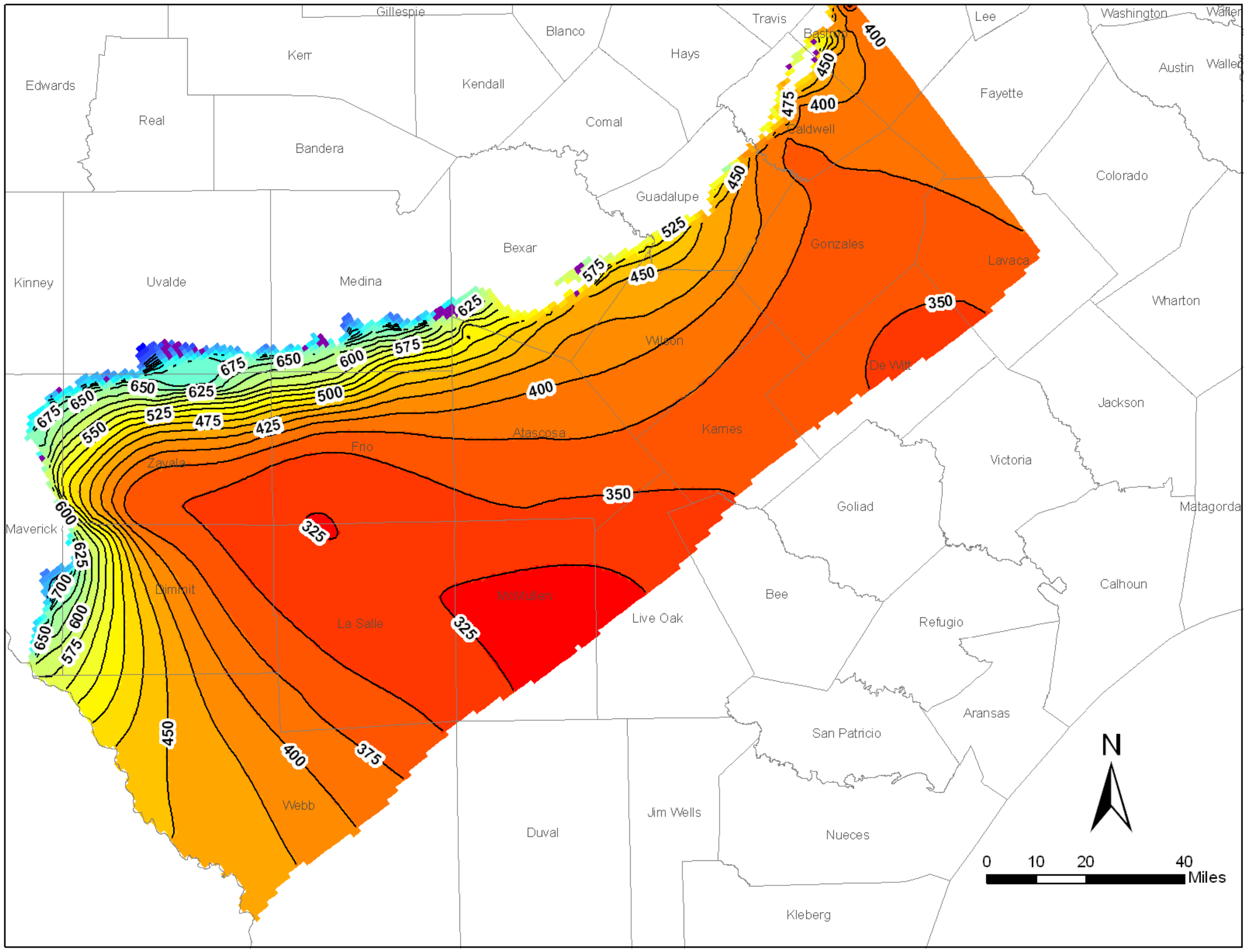

Figure 7. Initial water level elevations for the predictive model run in the lower Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

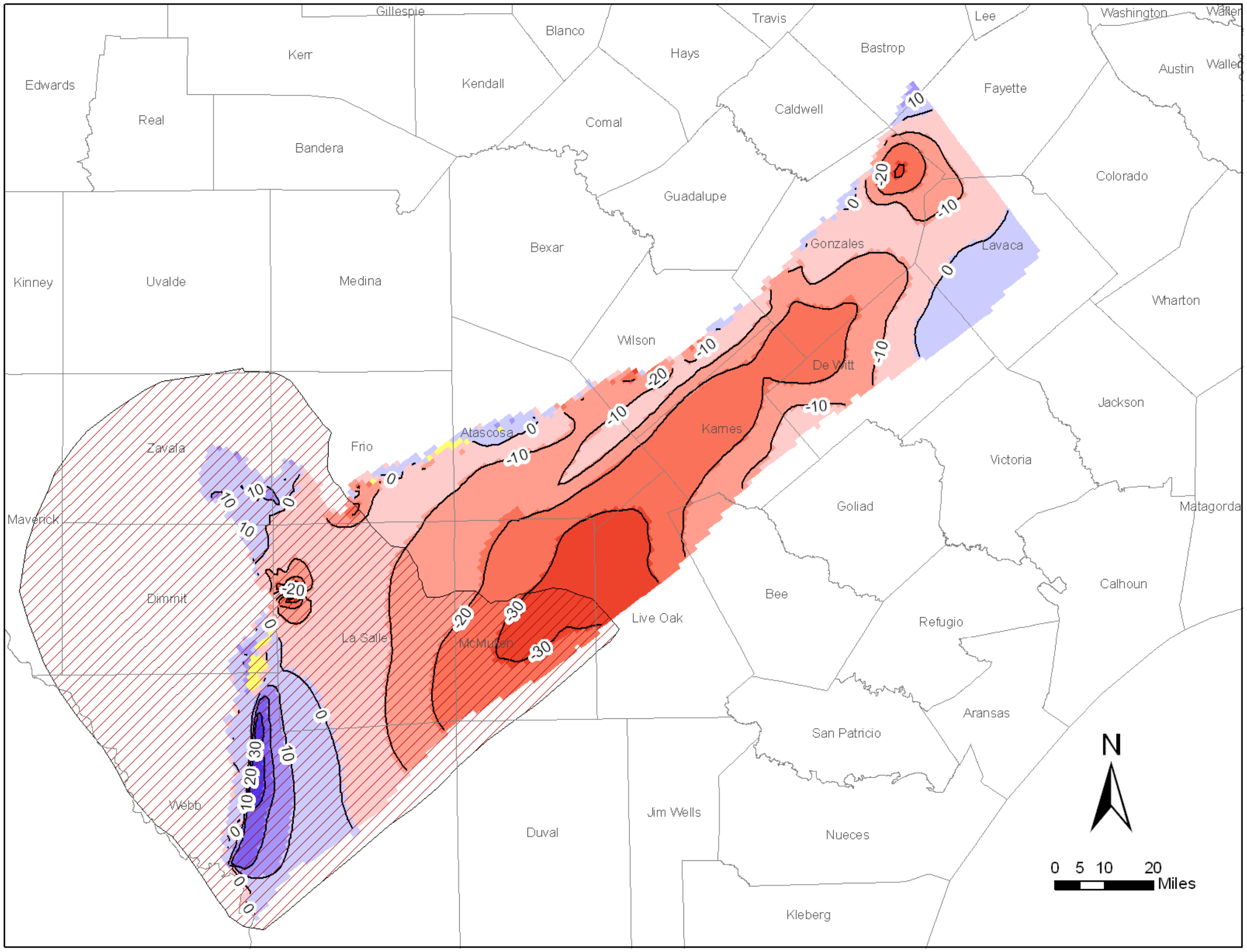

Figure 8. **Water level changes after 60 years using the specified pumpage in the Sparta Aquifer. Water level changes are reported in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in 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.**

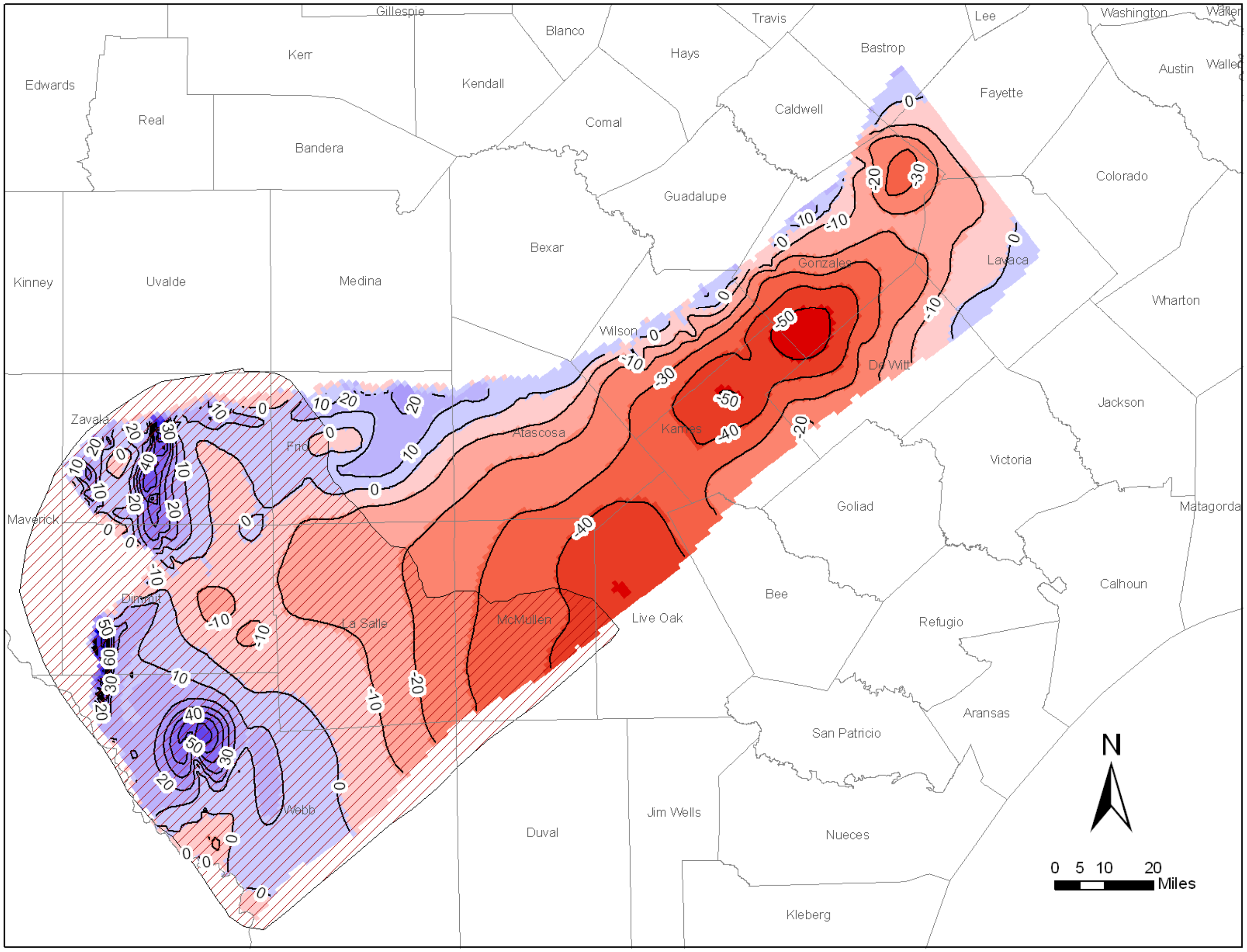

Figure 9. **Water level changes after 60 years using the specified pumpage in the Queen City Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow. 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.**

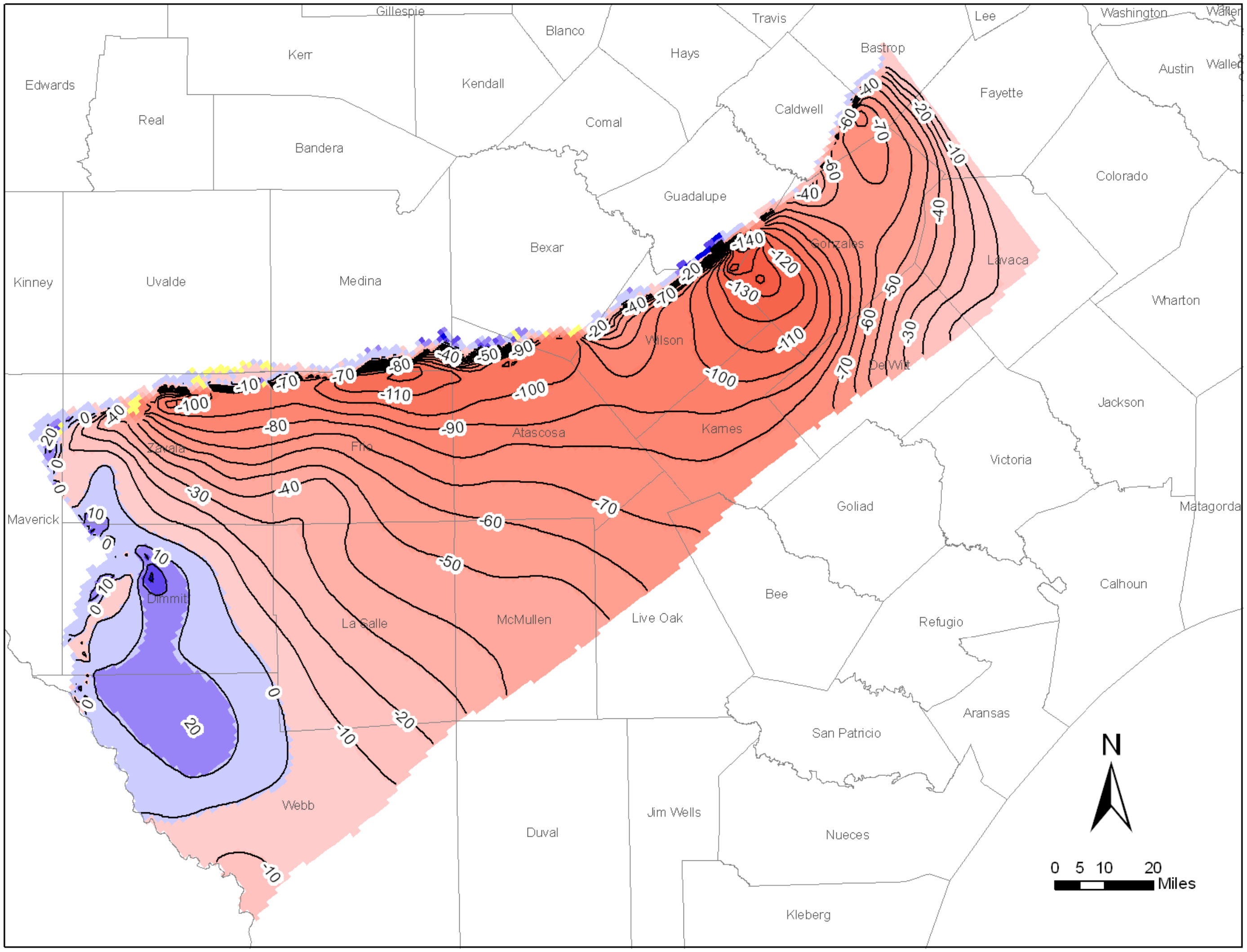

Figure 10. Water level changes after 60 years using the specified pumpage in the Carrizo Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

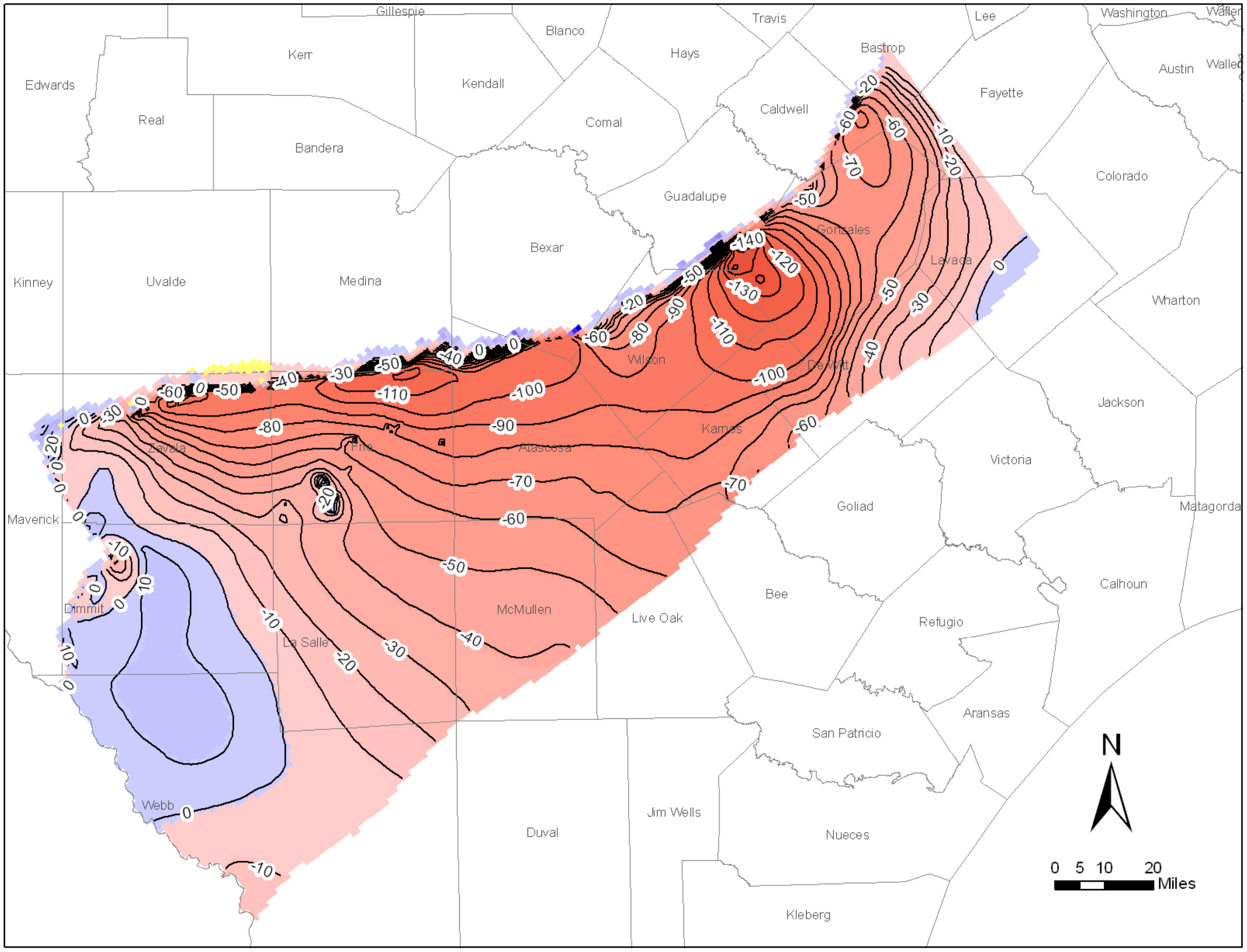

Figure 11. Water level changes after 60 years using the specified pumpage in the upper Wilcox Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

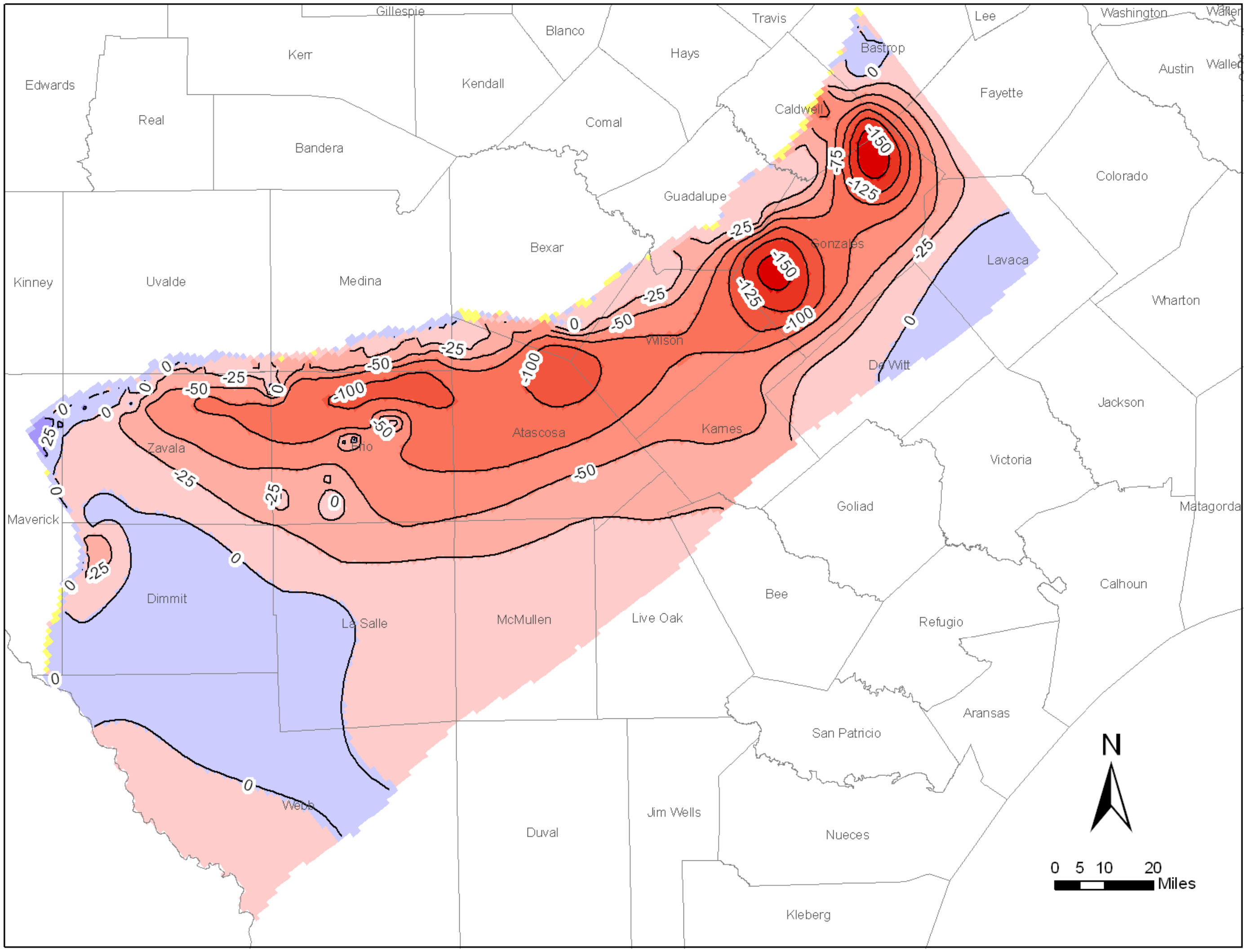

Figure 12. Water level changes after 60 years using the specified pumpage in the middle Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

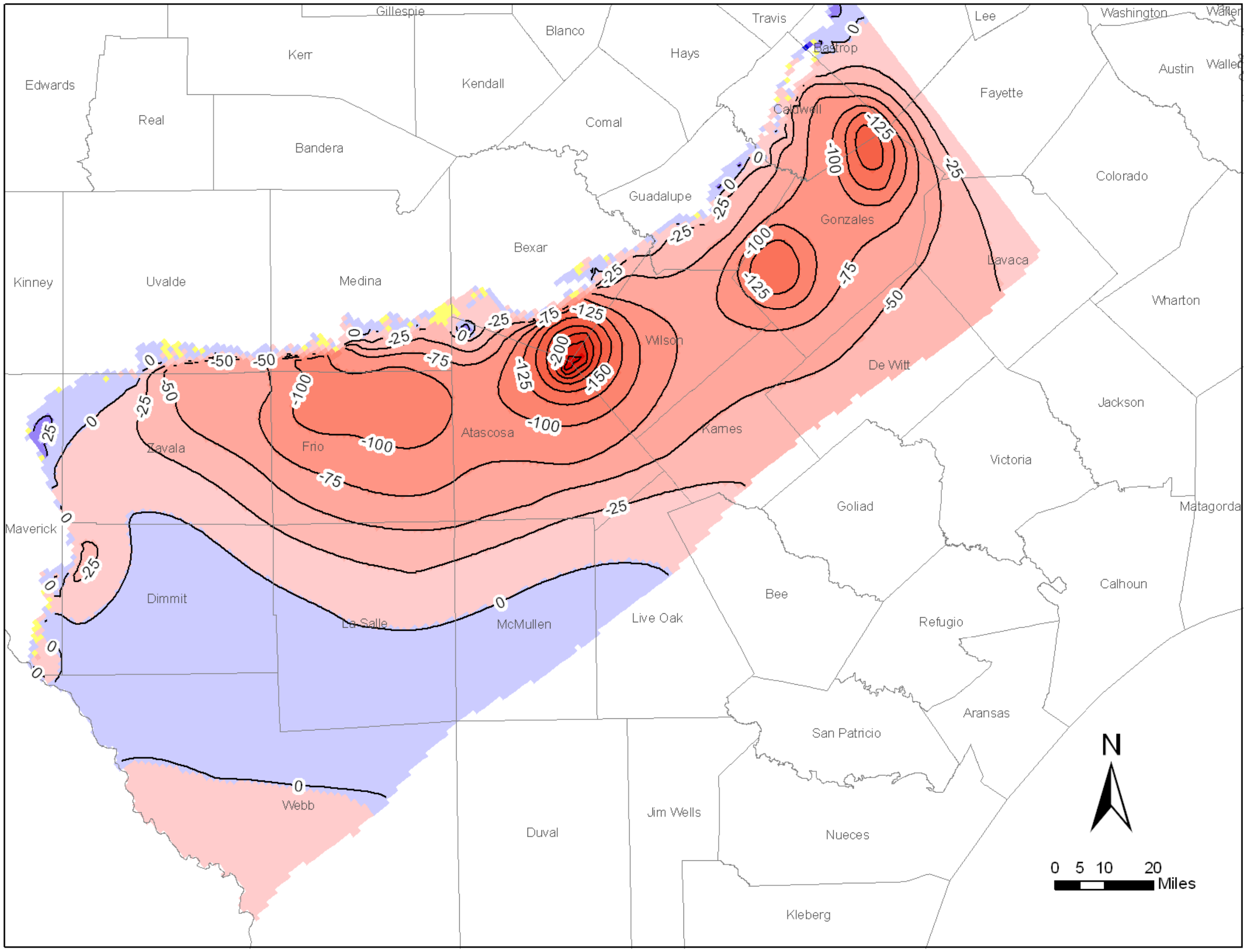

Figure 13. Water level changes after 60 years using the specified pumpage in the lower Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

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 08-43 using the specified pumpage in the groundwater availability model for the southern part of the Queen City, Sparta Aquifer, 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	476	127	19	0	--	--	--	--	108	0	556	399	1,156	243
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	4,957	3,075	67	14	--	--	--	--	226	502	259	14	6,727	726
Wells	0	748	0	0	--	--	--	--	0	0	0	0	0	725
Rivers and streams (Stream Package)	225	455	0	0	--	--	--	--	0	0	487	913	371	205
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	704	219	2	1	--	--	--	--	12	19	332	570	337	2,135
Vertical leakage lower surface	1,333	5,378	5	78	--	--	--	--	416	241	2	2,888	0	8,760
Queen City														
Storage	1,520	351	44	0	--	--	120	15	247	0	2,257	8,763	889	5,054
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	2,999	0	0	--	--	0	30	0	0	0	0	0	2,996
Rivers and streams (Stream Package)	3,390	1,884	0	0	--	--	176	95	0	0	8,820	6,306	7,468	8
Recharge	5,166	0	0	0	--	--	1,144	0	0	0	11,146	0	13,821	0
Evapotranspiration	0	19	0	0	--	--	0	0	0	0	0	0	0	0
Vertical leakage upper surface	5,635	1,209	39	0	--	--	--	--	133	321	3,304	14	9,720	0
Lateral inflow	2,109	631	2	3	--	--	5	1,124	3	19	1,619	2,886	707	3,741
Vertical leakage lower surface	2	10,730	0	82	--	--	0	181	221	264	105	9,280	0	20,806

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	14,516	237	38	0	4,709	174	1,665	3	200	0	178	703	17,090	14
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	50,000	0	19	0	5,968	0	8,206	0	1	0	3,283	0	89,992
Rivers and streams (Stream Package)	1,438	12	0	0	2,488	0	75	0	0	0	841	0	538	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	13,520	0	106	0	131	0	1,821	0	297	201	9,151	2	24,943	0
Lateral inflow	20,005	10,574	91	298	1,262	6,929	4,938	5,565	168	12	413	6,042	42,751	5,829
Vertical leakage lower surface	3,725	499	83	0	394	263	175	432	617	0	2,285	5,201	8,945	244
Upper Wilcox														
Storage	193	0	53	0	7	15	9	19	389	0	596	231	138	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	1,487	0	0
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	96	117	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	499	3,725	0	83	263	394	432	175	0	617	5,201	2,285	244	8,945
Lateral inflow	450	80	5	22	8	122	5	32	112	78	1,235	2,957	1,706	114
Vertical leakage lower surface	2,955	292	66	0	53	234	0	221	195	0	1,141	1,537	7,004	32

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	2,433	0	72	0	2,893	2	4,552	4	649	0	1,264	1	787	0
Reservoirs (River Package)	0	0	0	0	1,776	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	69	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	13,290	0	0	0	211	0	0
Rivers and streams (Stream Package)	642	0	0	0	4,052	0	2,915	1,132	0	0	271	2	0	0
Recharge	622	0	0	0	2,816	0	3,966	0	0	0	724	0	0	0
Evapotranspiration	0	0	0	0	0	11	0	9	0	0	0	0	0	0
Vertical leakage upper surface	292	2,955	0	66	234	53	221	0	0	195	1,537	1,141	32	7,004
Lateral inflow	979	918	2	8	625	1,315	5,281	1,040	40	419	699	2,006	3,251	225
Vertical leakage lower surface	711	1,804	19	0	0	5,486	9	1,469	1	76	896	2,030	3,195	36
Lower Wilcox														
Storage	2,060	0	187	0	4,364	15	3,178	7	1,086	0	875	9	787	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	32	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	4,444	0	19	0	13,925	0	14,751	0	0	0	50	0	7,511
Rivers and streams (Stream Package)	0	0	0	0	4,413	374	3,158	28	0	0	193	0	0	0
Recharge	0	0	0	0	5,298	0	5,015	0	0	0	268	0	0	0
Evapotranspiration	0	0	0	0	0	165	0	81	0	0	0	0	0	0
Vertical leakage upper surface	1,804	711	0	19	5,486	0	1,469	9	76	1	2,030	896	36	3,195
Lateral inflow	6,558	5,267	1	150	5,352	10,385	5,384	3,295	626	1,788	2,338	4,749	10,366	483

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	485	6	--	--	191	0	2,784	25	26	0	129	0	--	--
Reservoirs (River Package)	0	0	--	--	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	19	--	--	0	0	0	0	0	0	0	0	--	--
General head boundary	1,048	3,992	--	--	963	598	9,243	6,234	227	612	24	502	--	--
Wells	0	2,268	--	--	0	0	0	1,477	0	0	0	0	--	--
Rivers and streams (Stream Package)	7	935	--	--	0	0	0	1,849	0	0	0	0	--	--
Recharge	3,081	0	--	--	0	0	1,923	0	0	0	0	0	--	--
Evapotranspiration	0	3	--	--	0	0	0	436	0	0	0	0	--	--
Lateral inflow	479	39	--	--	170	136	3,019	984	19	64	29	6	--	--
Vertical leakage lower surface	2,854	692	--	--	222	812	1,579	7,543	543	140	362	36	--	--
Queen City														
Storage	2,202	228	0	13	453	0	729	5	50	0	333	0	--	--
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	11	0	0	0	0	0	0	0	0	0	0	--	--
General head boundary	0	0	0	0	0	0	0	0	3	0	0	0	--	--
Wells	0	5,119	0	0	0	0	0	2	0	0	0	0	--	--
Rivers and streams (Stream Package)	696	1,766	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	6	0	0	0	0	0	0	0	0	0	0	--	--
Vertical leakage upper surface	1,328	2,449	--	--	707	48	7,525	1,321	61	485	45	239	--	--
Lateral inflow	2,885	56	2	8	635	142	4,871	924	12	33	23	30	--	--
Vertical leakage lower surface	206	3,775	0	21	0	1,605	2	10,875	448	56	2	134	--	--

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	4,055	0	6,940	479	414	0	421	0	34	0	215	0	22	654
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	1,129	0	0	0	0	0
Wells	0	40,763	0	9,877	0	471	0	6,398	0	1	0	85	0	145
Rivers and streams (Stream Package)	2,735	0	506	0	0	0	0	0	0	0	0	0	450	93
Recharge	1,406	0	7,210	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	7,008	67	617	0	1,928	0	11,893	0	19	468	345	0	46	0
Lateral inflow	28,353	2,154	2,786	7,520	1,162	4,080	6,240	13,201	1,484	2,802	664	1,728	3	853
Vertical leakage lower surface	311	884	347	530	1,049	2	2,241	1,197	606	2	589	0	26	910
Upper Wilcox														
Storage	49	0	3	0	301	0	564	0	125	0	284	0	0	109
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	572	0	0	0	0	0
Wells	0	0	0	0	0	0	0	2,927	0	0	0	0	0	137
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	52	33
Recharge	0	0	0	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	884	311	530	347	2	1,049	1,197	2,241	2	606	0	589	910	26
Lateral inflow	133	12	15	105	30	30	3,784	1,640	21	128	114	170	20	119
Vertical leakage lower surface	120	864	128	223	746	0	1,263	0	26	11	361	0	35	680

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	1,554	0	2,249	1	604	0	566	0	233	4	268	0	4	74
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	222	0	0	0	0	0
Wells	0	10,074	0	2,996	0	0	0	0	0	0	0	0	0	260
Rivers and streams (Stream Package)	1,354	0	5,588	1,478	0	0	0	0	0	0	0	0	906	19
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	864	120	223	128	0	746	0	1,263	11	26	0	361	680	35
Lateral inflow	7,722	1,734	679	6,735	91	201	451	454	259	728	8	35	464	865
Vertical leakage lower surface	423	113	61	3,069	252	1	700	0	39	6	120	0	23	1,414
Lower Wilcox														
Storage	1,234	0	1,750	163	1,776	0	637	0	255	0	586	0	190	270
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	40	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	1,300	8	0	0	0	0
Wells	0	19,986	0	1,550	0	0	0	0	0	0	0	0	0	992
Rivers and streams (Stream Package)	0	0	2,039	220	0	0	0	0	0	0	0	0	376	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	113	423	3,069	61	1	252	0	700	6	39	0	120	1,414	23
Lateral inflow	19,597	535	2,355	11,659	592	2,117	2,664	2,601	1,082	2,596	78	545	14	1,817

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta												
Storage	219	0	--	--	--	--	23	3,869	1,125	0	2	1,183
Reservoirs (River Package)	0	0	--	--	--	--	0	0	0	0	0	0
Springs (Drain Package)	0	0	--	--	--	--	0	0	0	117	0	0
General head boundary	1,086	1,312	--	--	--	--	5,161	779	1,824	2,487	0	0
Wells	0	101	--	--	--	--	0	0	0	749	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	3,938	2,155	174	360	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	502	159	--	--	--	--	240	781	74	470	34	146
Vertical leakage lower surface	682	917	--	--	--	--	754	3,533	247	1,657	0	3,253
Queen City												
Storage	881	0	--	--	--	--	114	19,790	3,574	160	313	15,265
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	148	--	--	--	--	0	0	0	2,998	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	20,886	7,172	1,510	2,529	16,876	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	878	523	--	--	--	--	4,116	608	2,743	122	2,636	0
Lateral inflow	1,077	143	--	--	--	--	738	2,575	77	1,930	1,177	970
Vertical leakage lower surface	1	2,023	--	--	--	--	158	5,136	0	7,646	0	15,489

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo												
Storage	332	0	4,415	270	4	8	37	123	14,098	106	9,865	300
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	1,601	0	0	0	486	0	896	0	38,919	0	36,043
Rivers and streams (Stream Package)	0	0	1,402	54	543	0	55	0	11,084	65	2,649	0
Recharge	0	0	8,726	0	436	0	529	0	8,696	0	6,602	0
Evapotranspiration	0	0	0	0	0	0	0	124	0	0	0	0
Vertical leakage upper surface	2,308	0	8	0	--	--	4,855	1	10,304	0	18,042	1
Lateral inflow	1,477	3,605	896	14,570	0	490	93	1,742	9,576	16,310	7,945	8,112
Vertical leakage lower surface	1,117	29	759	1,313	0	0	413	3,096	2,114	472	7,092	7,738
Upper Wilcox												
Storage	678	0	82	26	0	0	134	92	55	0	364	40
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	101	0	0	0	0	0	13	0	0	0	9,371
Rivers and streams (Stream Package)	0	0	0	0	0	0	15	199	0	0	0	0
Recharge	0	0	0	0	0	0	82	0	0	0	304	0
Evapotranspiration	0	0	0	0	0	0	0	69	0	0	0	0
Vertical leakage upper surface	29	1,117	1,313	759	0	0	3,096	413	472	2,114	7,738	7,092
Lateral inflow	773	899	36	461	0	0	663	2,722	137	18	851	366
Vertical leakage lower surface	638	0	569	755	0	0	56	539	1,590	121	8,985	1,375

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	505	0	3,469	24	668	5	102	21	1,603	0	1,533	288
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	101	0	0	0	0	0	6	0	0	0	5,536
Rivers and streams (Stream Package)	0	0	924	40	308	15	3,004	2,811	1,287	729	1,417	4
Recharge	0	0	2,619	0	1,978	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	638	755	569	0	0	539	56	121	1,590	1,375	8,985
Lateral inflow	90	105	396	2,628	12	1,224	463	539	2,240	1,946	2,771	359
Vertical leakage lower surface	248	0	53	4,954	0	1,721	17	624	213	2,166	9,231	2,162
Lower Wilcox												
Storage	711	0	3,270	181	1,865	81	65	2	1,527	0	705	477
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	101	0	4,299	0	0	0	1	0	8,906	0	483
Rivers and streams (Stream Package)	0	0	119	136	345	16	0	132	207	0	790	83
Recharge	0	0	1,975	0	1,205	0	15	0	69	0	537	0
Evapotranspiration	0	0	0	169	0	6	0	42	0	0	0	0
Vertical leakage upper surface	0	248	4,954	53	1,721	0	624	17	2,166	213	2,162	9,231
Lateral inflow	464	825	910	6,390	248	5,281	1,667	2,178	11,310	6,160	7,741	1,660