GAM Run 08-42

by Shirley C. Wade, Ph.D, P.G.

Texas Water Development Board
Groundwater Availability Modeling Section
(512) 936-0883
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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 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 "low 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 60 feet in the Carrizo and upper Wilcox aquifers center around the intersection of Wilson, Gonzales, and Guadalupe counties; water level declines of over 90 feet are also centered near the outcrop in Frio County; and

- water level declines in the middle and lower Wilcox aquifers exceed 75 feet and 175 feet respectively due to a brackish well field added to the lower Wilcox aquifer in Atascosa, Bexar, and Wilson counties. Water level declines of over 50 feet are also suggested in Gonzales and Caldwell counties. Water level declines in the rest of these aquifers are generally less than 50 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 08-43 (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 low 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 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.

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- 42 specified pumpage		
County	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer
Atascosa	517	964	55,009	517	1,000	43,333
Bastrop	7	88	690	--	--	691
Bee	--	--	76	--	--	77
Bexar	--	--	16,871	--	--	26,982
Caldwell	--	132	3,634	--	10	26,209
DeWitt	--	--	1	--	--	1
Dimmit	--	--	4,477	--	--	3,359
Fayette	66	12	2	--	--	2
Frio	87	66	110,004	90	100	85,000
Gonzales	552	240	2,605	1,268	2,120	46,325
Guadalupe	--	--	6,072	--	--	15,432
Karnes	--	--	471	--	--	471
LaSalle	1,316	2	8,286	987	1	6,215
Lavaca	--	--	1	--	--	1
Live Oak	--	--	85	--	--	85
Maverick	--	--	3,298	--	--	3,298
McMullen	0	0	119	50	100	950
Medina	--	--	5,008	--	--	3,500
Uvalde	--	--	596	--	--	5,000
Webb	--	--	916	--	--	915
Wilson	504	170	17,376	500	100	31,556
Zavala	--	--	48,763	--	--	36,573

Specified Pumpage

The pumpage specified by the members of Groundwater Management Area 13 was based on the baseline 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 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 08-42 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	40,000	--	--	3,333
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	--	6,633	12,836
Caldwell	279	0	1,169	2,186	6,209	--	10,000	10,000
DeWitt	1	0	0	0	1	--	--	--
Dimmit	2,917	1,321	189	50	2,188	991	142	38
Fayette	2	0	0	0	2	--	--	--
Frio	99,802	6,049	4,089	64	80,000	--	--	5,000
Gonzales	2,538	1	66	0	32,271	1	4,053	10,000
Guadalupe	1,224	0	3,240	1,608	10,584	--	3,240	1,608
Karnes	471	0	0	0	471	--	--	--
LaSalle	5,684	2,602	0	0	4,263	1,952	--	--
Lavaca	1	0	0	0	1	--	--	--
Live Oak	85	0	0	0	85	--	--	--
Maverick	596	276	856	1,570	596	276	856	1,570
McMullen	119	0	0	0	800	50	50	50
Medina	1,477	31	980	2,520	--	--	--	3,500
Uvalde	358	0	120	118	1,250	3,750	--	--
Webb	896	13	6	1	896	13	6	1
Wilson	15,986	40	772	578	25,000	--	--	6,556
Zavala	34,731	8,629	4,901	502	26,048	6,472	3,676	377

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.

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	--	--	--	--	--	3,333
Bexar	San Antonio Water System	--	--	4,000	--	--	6,111
Caldwell	1	--	--	--	--	8,811	7,940
Caldwell	2	--	--	209	--	189	60
Caldwell	3	--	10	1,000	--	1,000	2,000
Caldwell	Aqua Water Supply	--	--	5,000	--	--	--
Gonzales	4	500	1,000	10,000	--	2,000	5,000
Gonzales	5	268	120	2,271	1	53	--
Gonzales	6	500	1,000	8,000	--	2,000	5,000
Gonzales	Schertz-Seguin	--	--	9,000	--	--	--
Gonzales	Canyon Regional	--	--	3,000	--	--	--
Guadalupe	Canyon Regional	--	--	1,260	--	--	--
Guadalupe	Spring Hills	--	--	2,250	--	--	--
Guadalupe	Schertz-Seguin	--	--	5,850	--	--	--
Wilson	San Antonio Water System	--	--	--	--	--	5,555

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 of up to 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 30 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 100 feet in southwestern Gonzales County. Declines of over 90 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 50 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 75 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 175 feet and drawdowns in the majority of the three county area exceeds 25 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 5,000 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 3,600 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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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.

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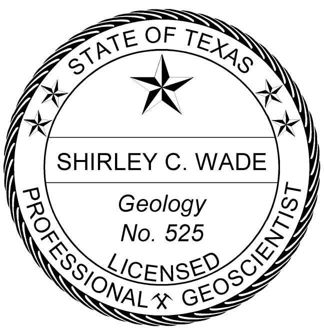

The seal appearing on this document was authorized by Shirley C. Wade, P.G. 525, on September 12, 2008.

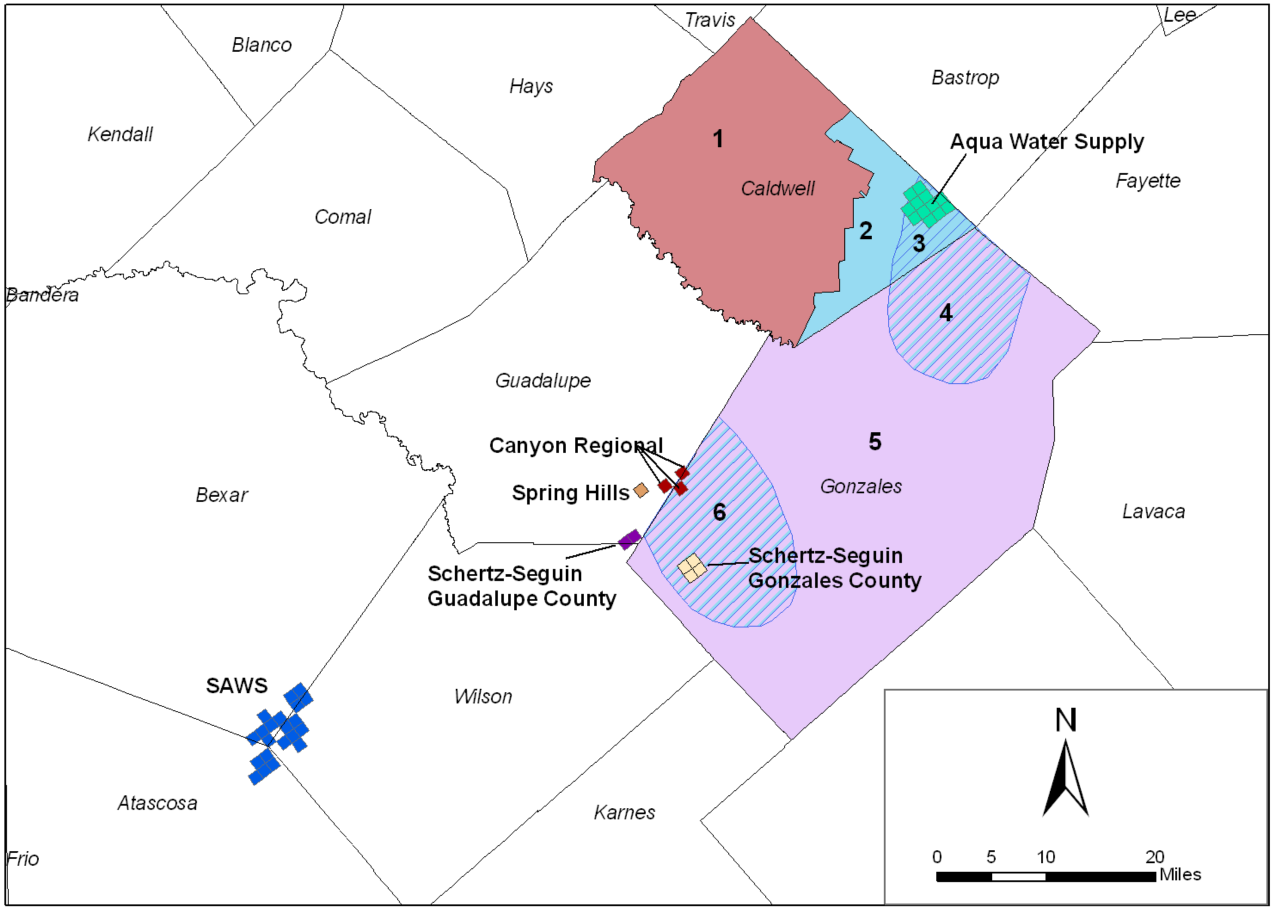

Figure 1. Well fields and specified pumpage areas.

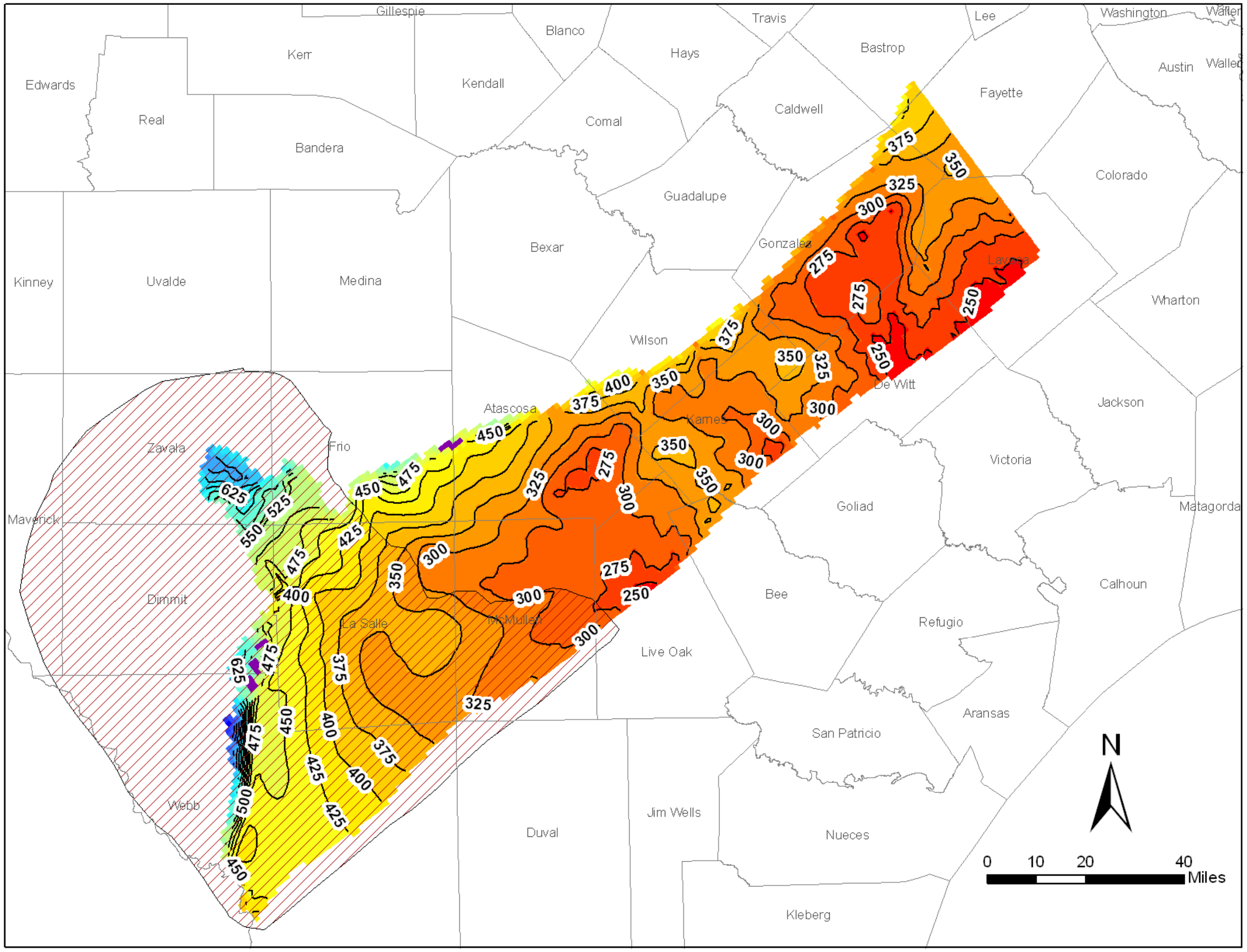

Figure 2. **Initial water level elevations for the predictive model run in the Sparta Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. The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

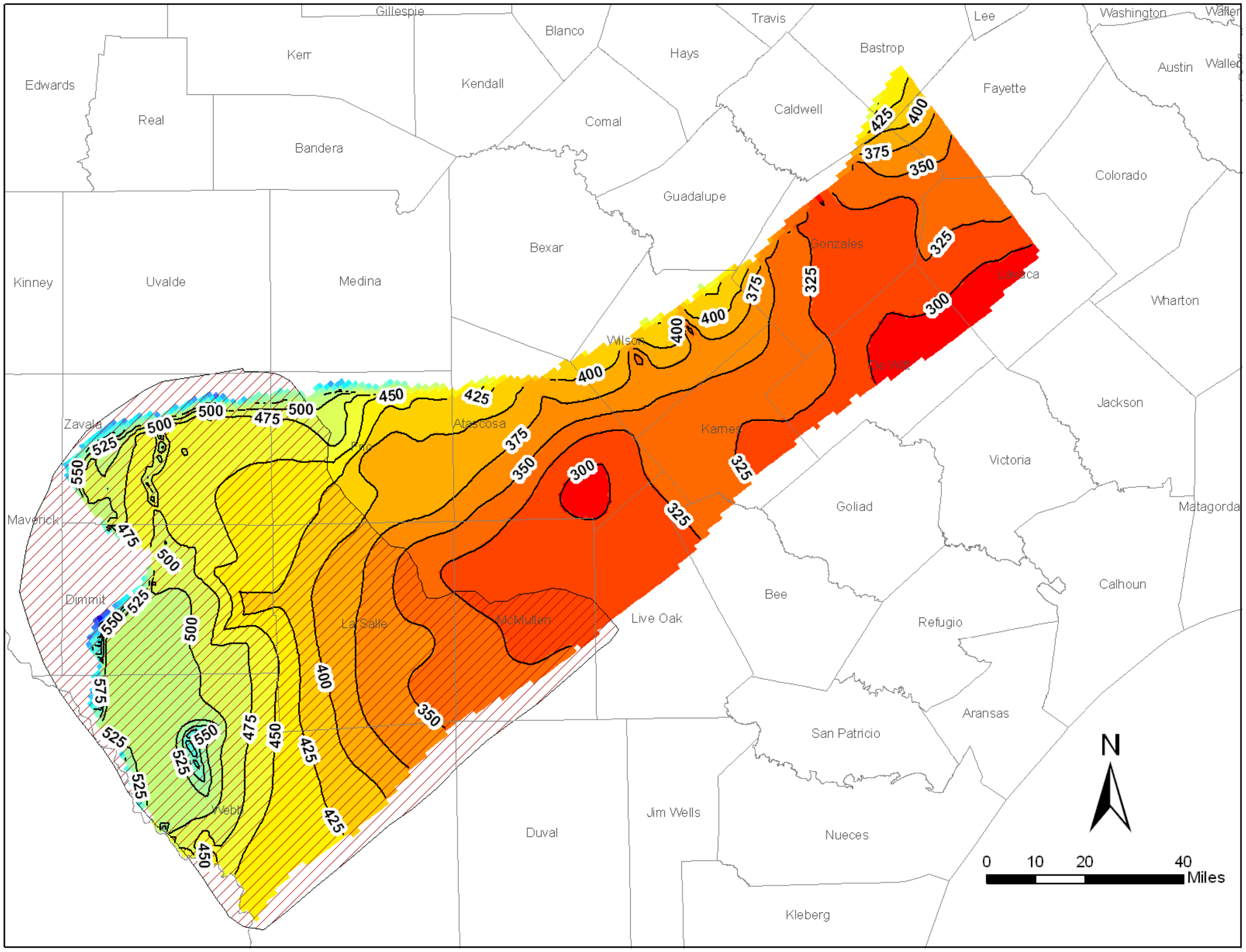

Figure 3. **Initial water level elevations for the predictive model run in the Queen City Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

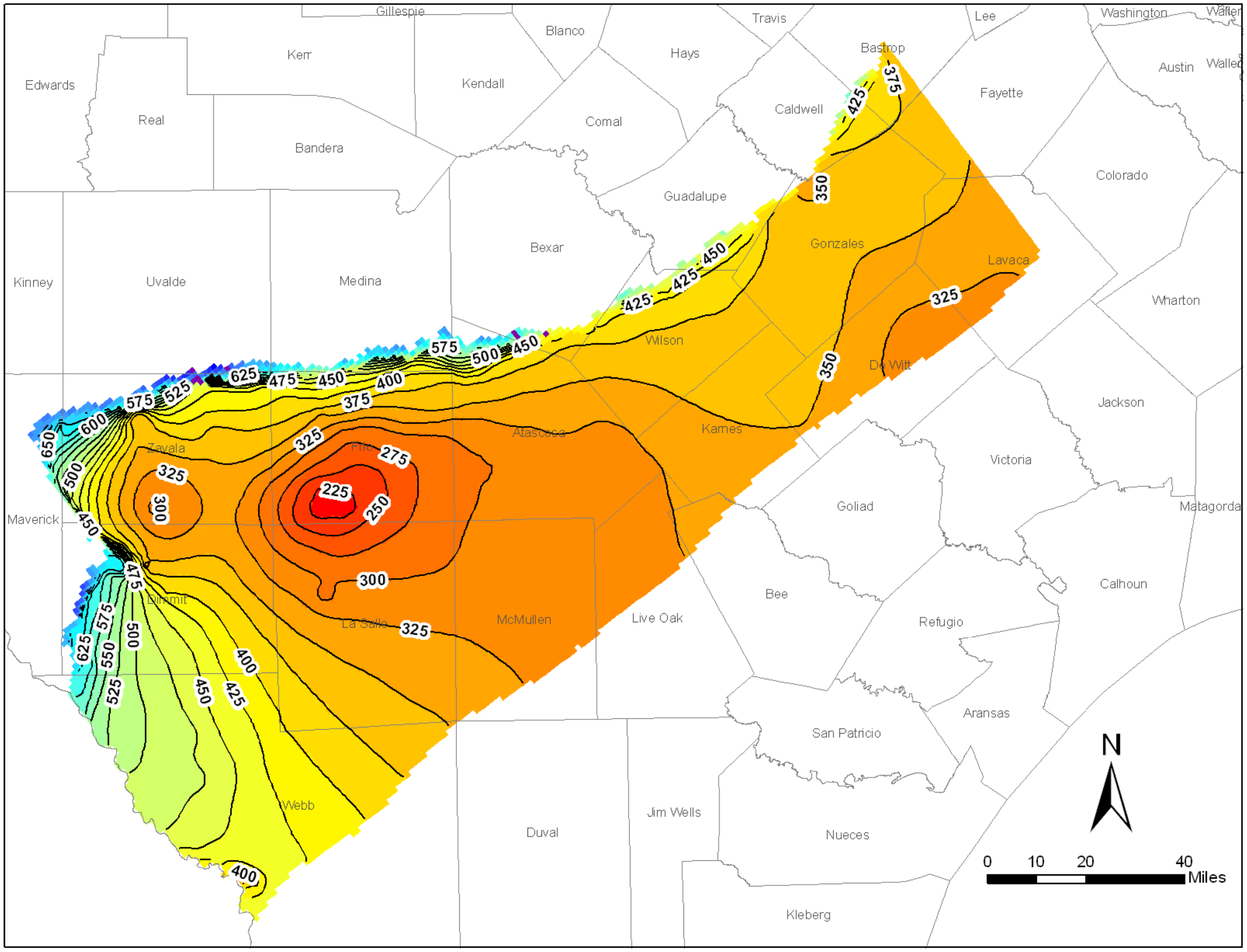

Figure 4. Initial water level elevations for the predictive model run in the Carrizo Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet. Dry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

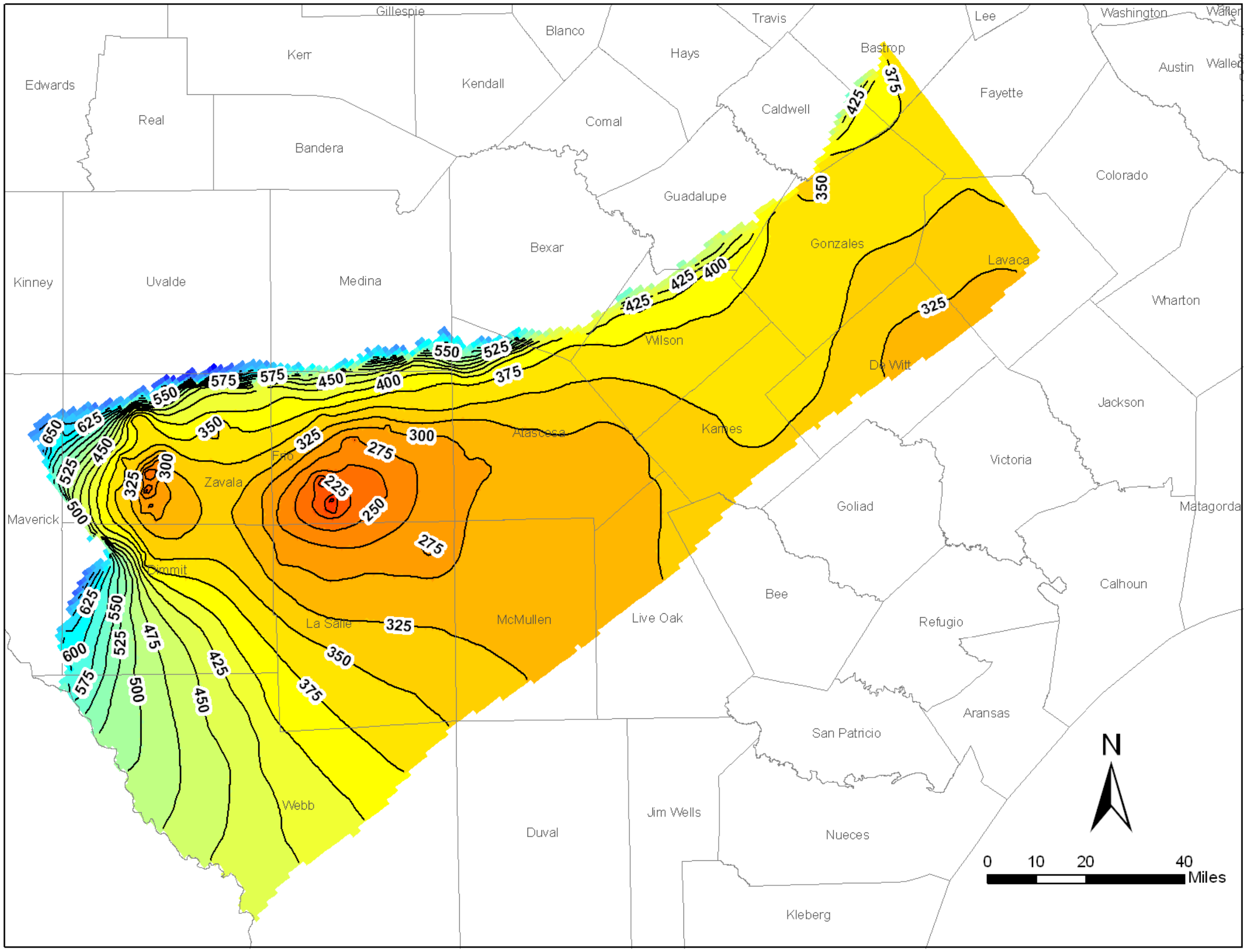

Figure 5. **Initial water level elevations for the predictive model run in the upper Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

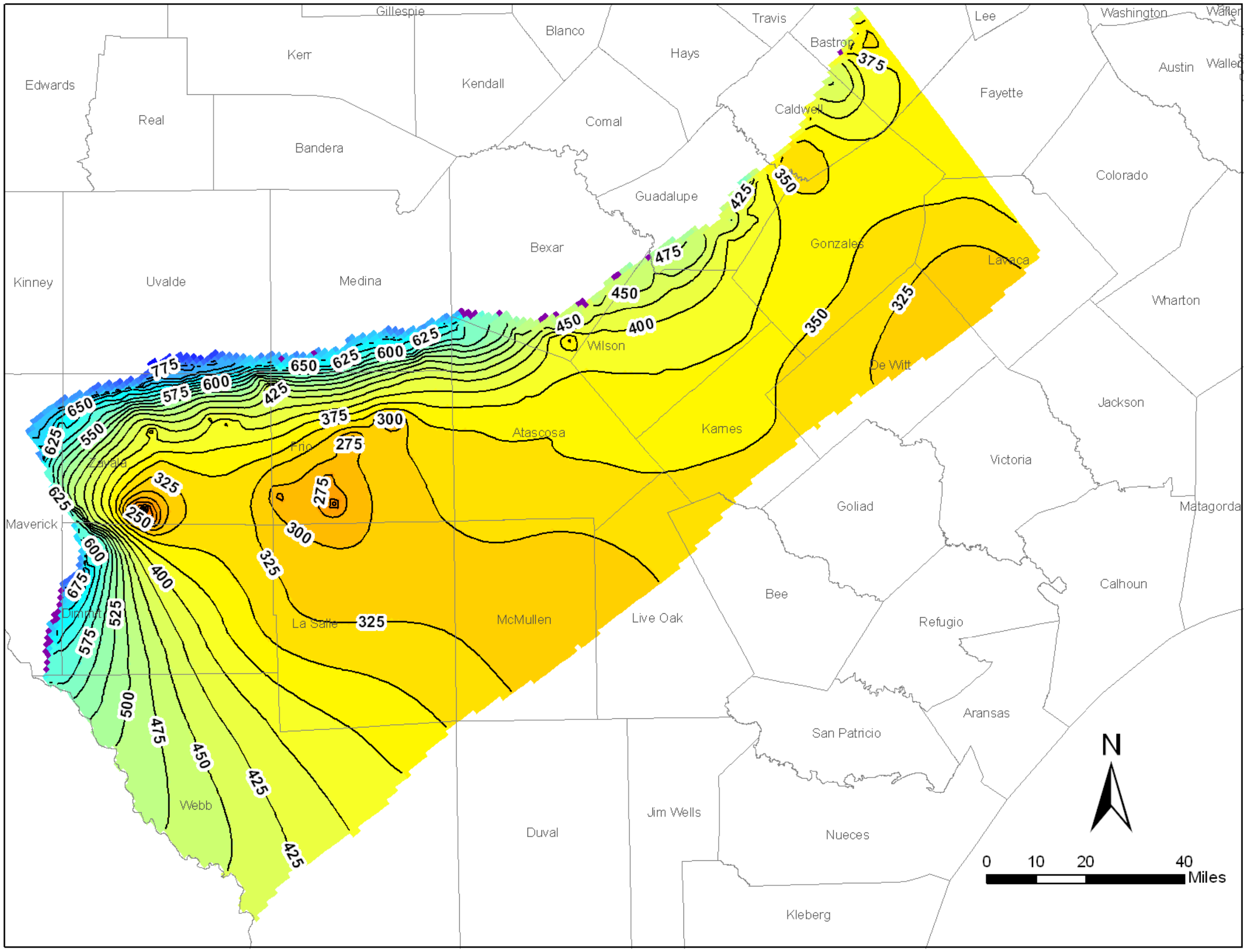

Figure 6. **Initial water level elevations for the predictive model run in the middle Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

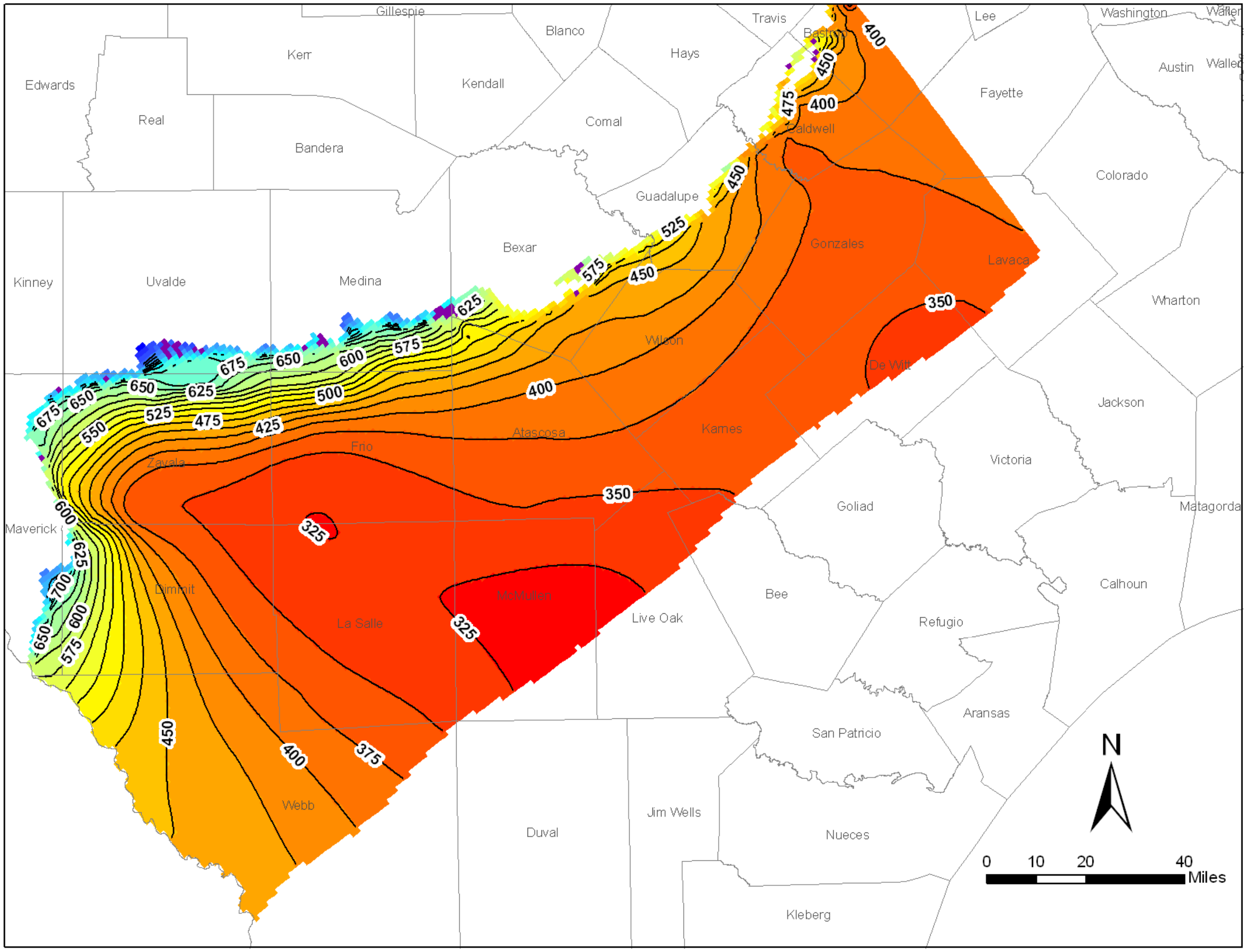

Figure 7. Initial water level elevations for the predictive model run in the lower Wilcox Aquifer from the groundwater availability model for the southern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Water level elevations are in feet above mean sea level. Contour interval is 25 feet.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

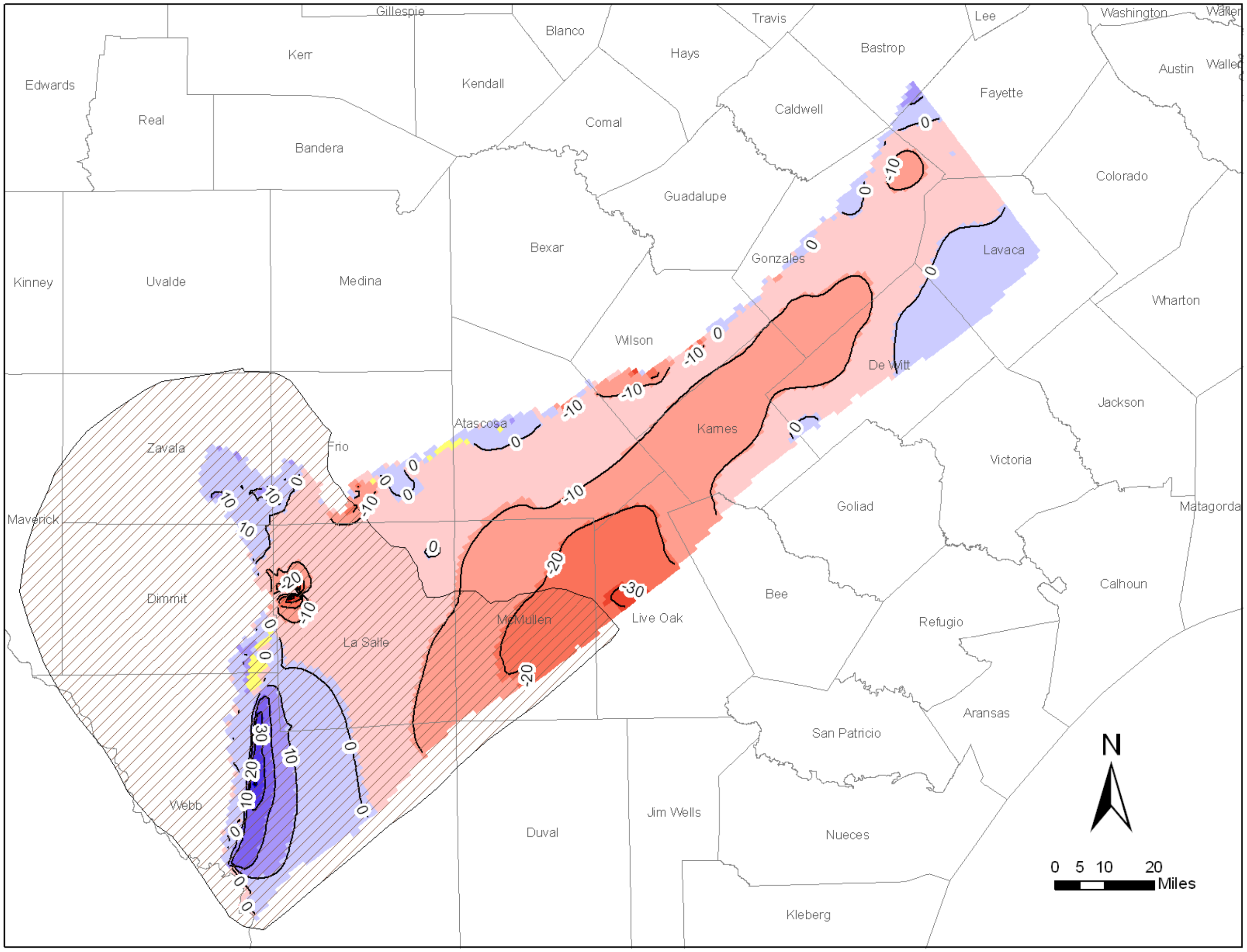

Figure 8. Water level changes after 60 years using the specified pumpage in the Sparta Aquifer. Water level changes are reported in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.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

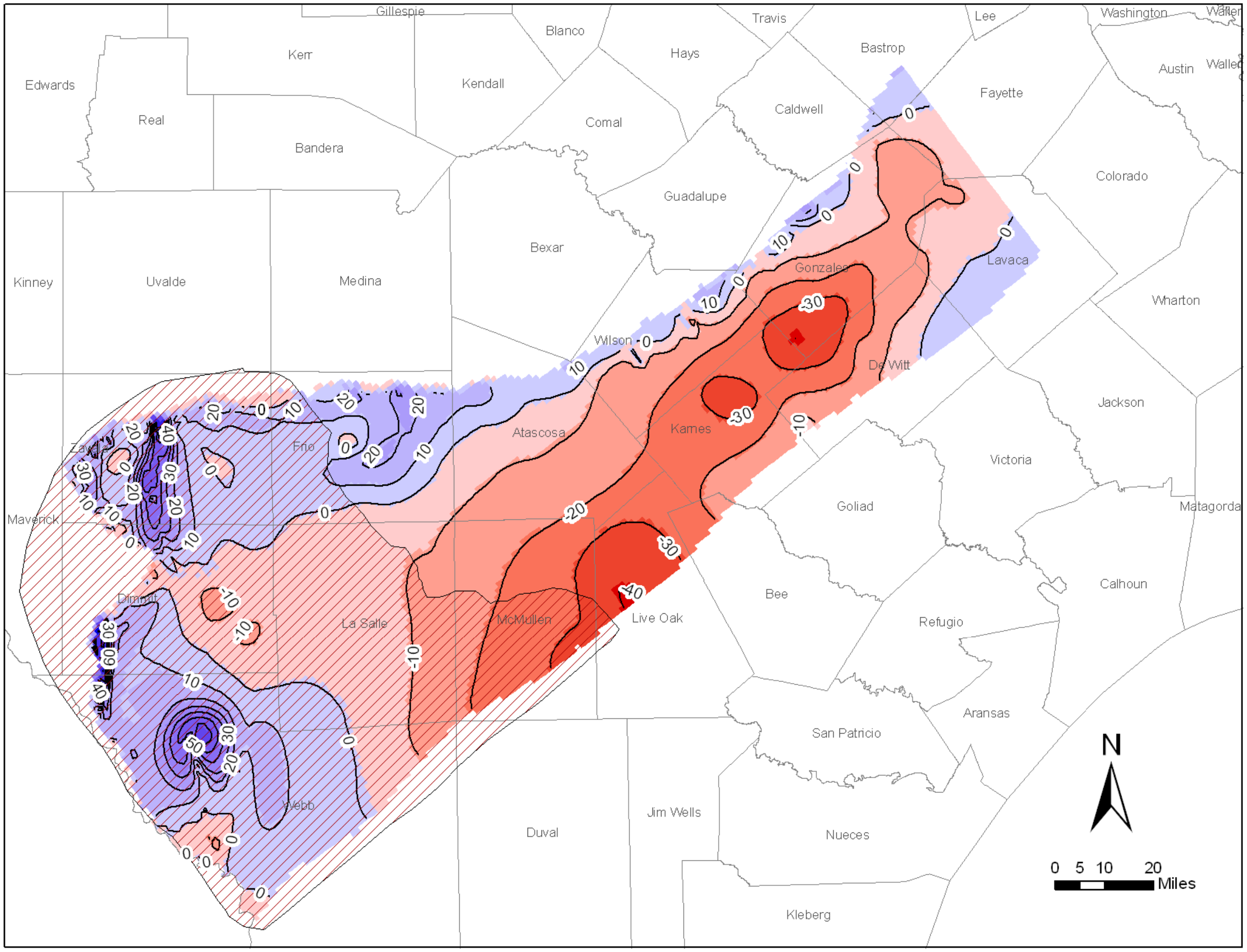

Figure 9. **Water level changes after 60 years using the specified pumpage in the Queen City Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.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

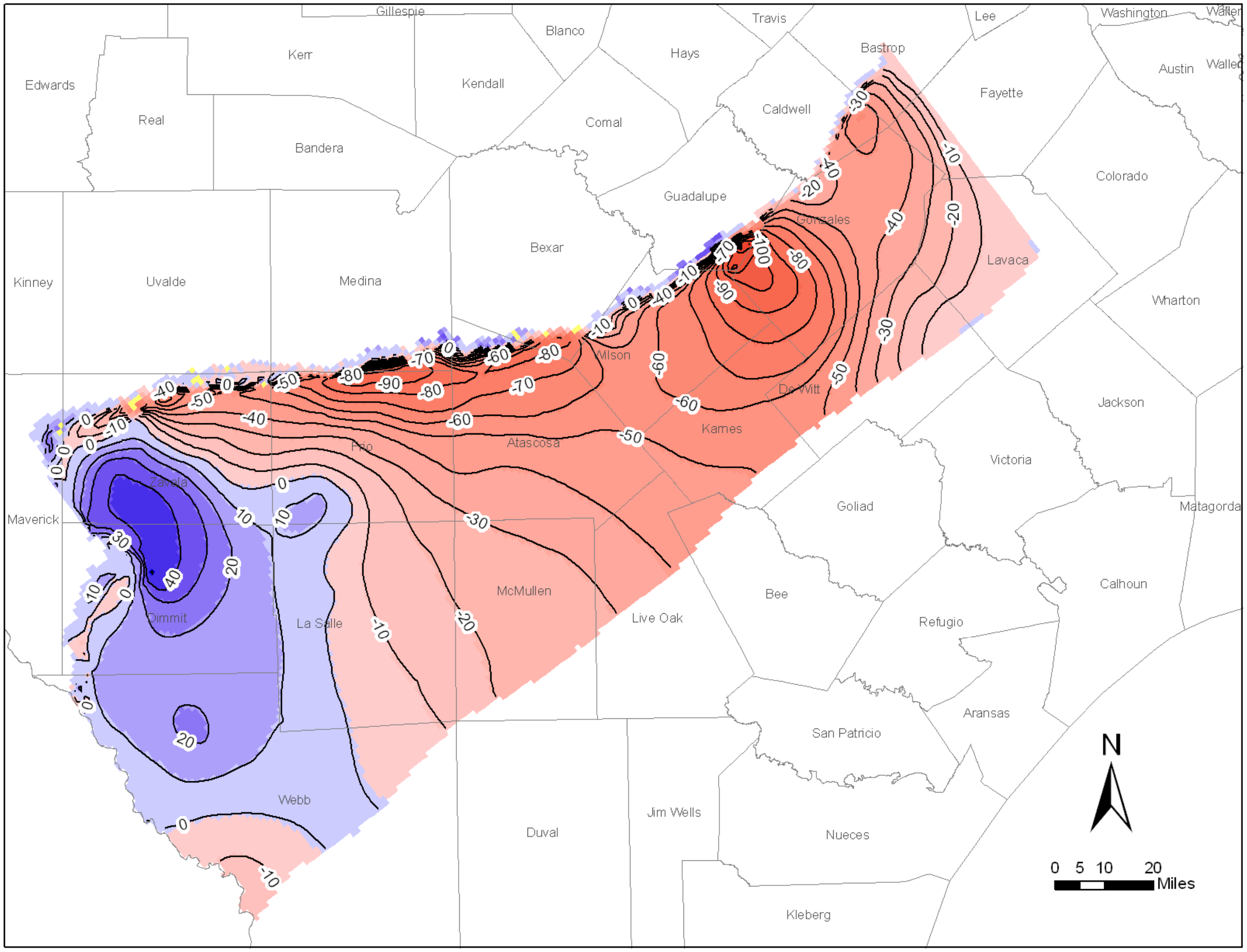

Figure 10. Water level changes after 60 years using the specified pumpage in the Carrizo Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

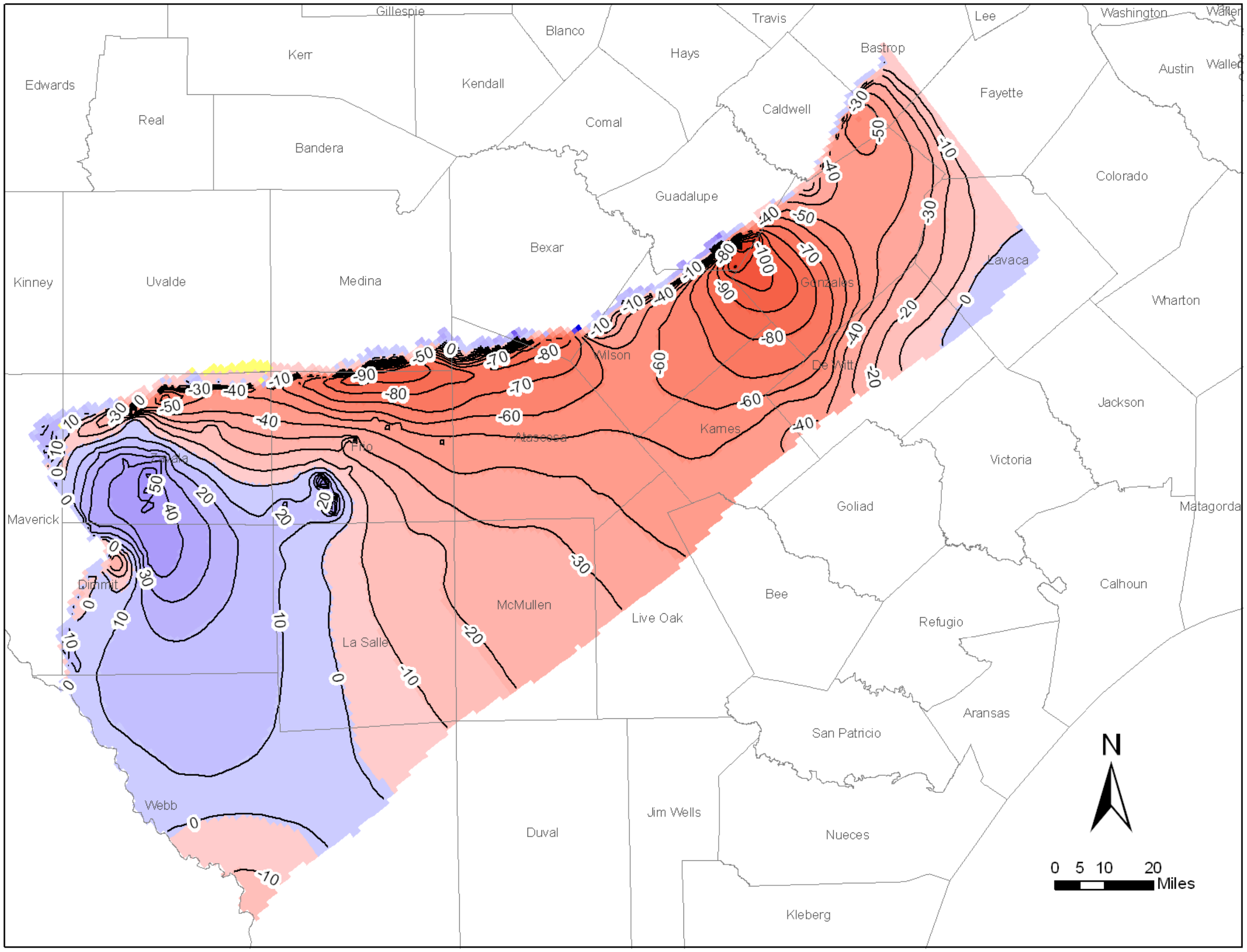

Figure 11. Water level changes after 60 years using the specified pumpage in the upper Wilcox Aquifer. Water level changes are in feet. Contour interval is 10 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

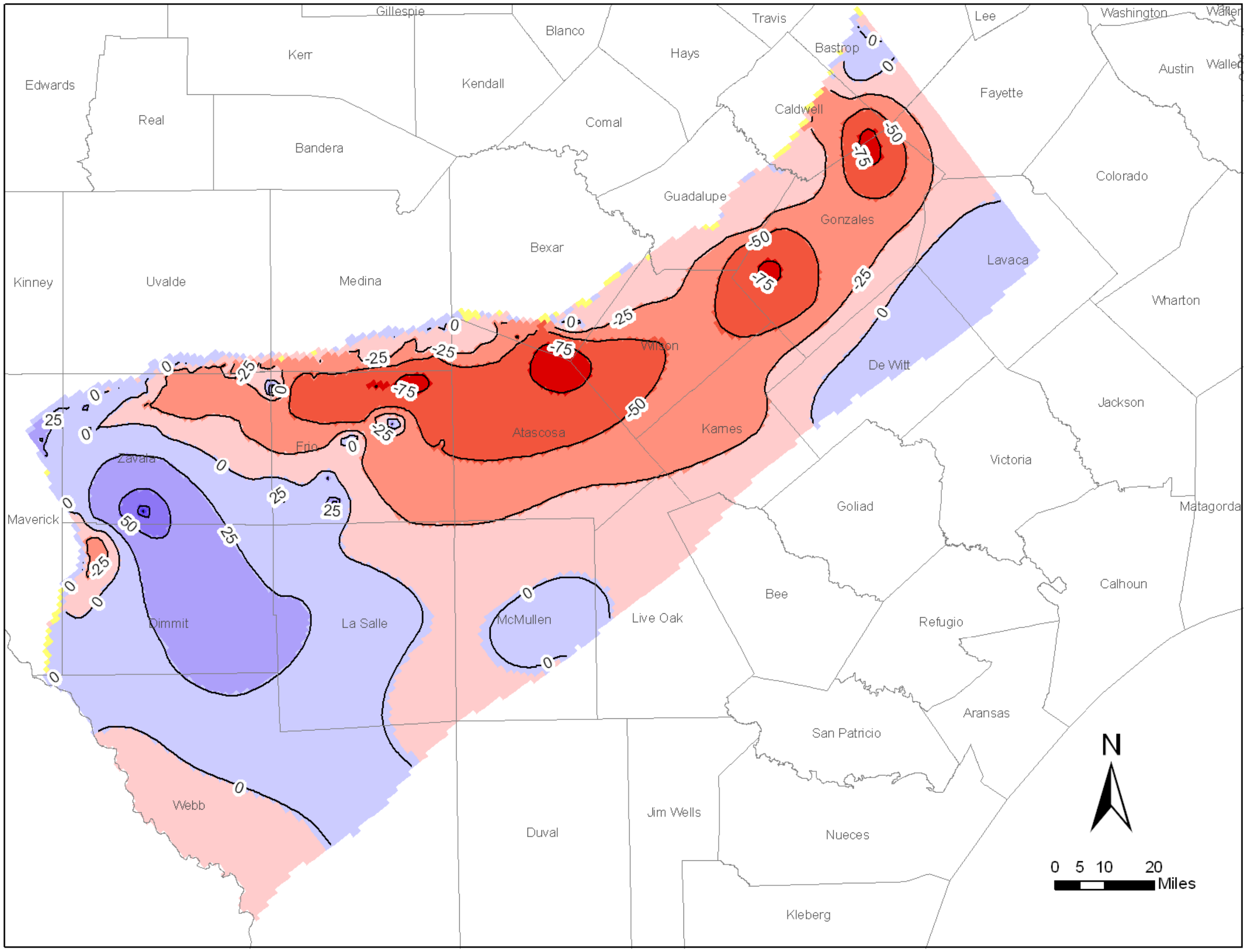

Figure 12. Water level changes after 60 years using the specified pumpage in the middle Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

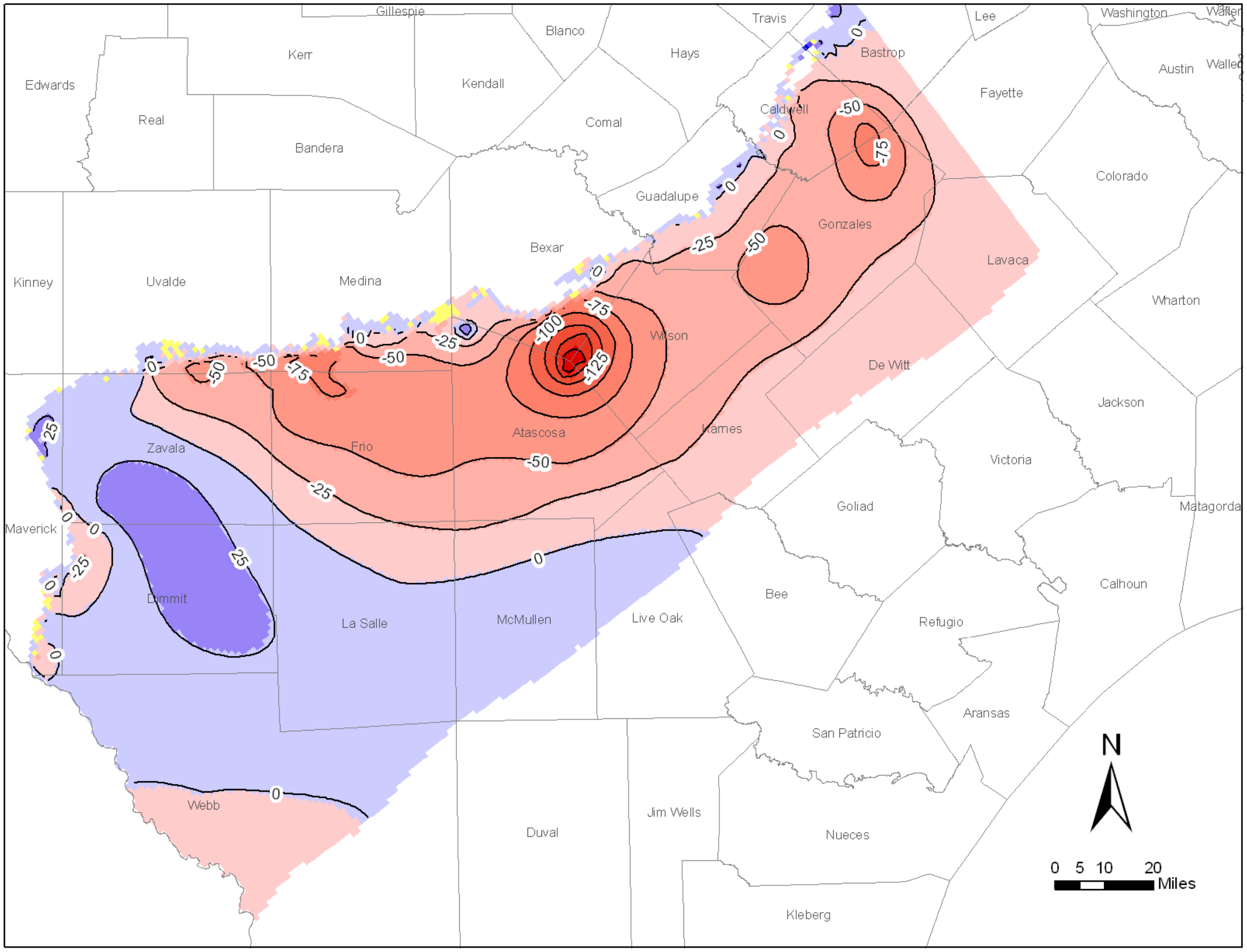

Figure 13. Water level changes after 60 years using the specified pumpage in the lower Wilcox Aquifer. Water level changes are in feet. Contour interval is 25 feet. Areas of increasing water levels are shown in blue. Areas of decreasing water levels are shown in red. Dry model cells are shown in yellow.

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 08-42 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	283	162	13	0	--	--	--	--	69	0	521	403	908	263
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	3,909	4,165	58	19	--	--	--	--	176	580	258	14	5,853	938
Wells	0	516	0	0	--	--	--	--	0	0	0	0	0	80
Rivers and streams (Stream Package)	219	495	0	0	--	--	--	--	0	0	486	931	368	223
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	708	220	2	1	--	--	--	--	12	19	334	567	327	2,128
Vertical leakage lower surface	2,263	4,131	11	64	--	--	--	--	512	169	3	2,835	7	8,033
Queen City														
Storage	510	802	29	0	--	--	40	25	161	0	1,567	9,433	85	9,243
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	999	0	0	--	--	0	10	0	0	0	0	0	97
Rivers and streams (Stream Package)	3,257	2,290	0	0	--	--	107	219	0	0	8,612	6,757	7,460	11
Recharge	5,166	0	0	0	--	--	1,144	0	0	0	11,146	0	13,821	0
Evapotranspiration	0	50	0	0	--	--	0	0	0	0	0	0	0	0
Vertical leakage upper surface	4,290	2,150	22	3	--	--	--	--	68	439	3,178	18	8,823	0
Lateral inflow	2,065	615	2	3	--	--	28	913	3	16	1,618	2,682	606	3,661
Vertical leakage lower surface	45	8,427	0	48	--	--	0	154	352	127	127	7,356	0	17,783

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	10,437	257	25	0	3,482	152	1,097	4	128	0	52	1,973	11,913	9
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	40,000	0	19	0	6,134	0	6,209	0	1	0	2,185	0	79,984
Rivers and streams (Stream Package)	1,411	18	0	0	2,116	0	75	0	0	0	841	0	536	0
Recharge	8,119	0	0	0	4,423	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	10,703	0	61	0	128	0	1,644	0	139	317	6,902	10	21,215	0
Lateral inflow	16,660	9,764	91	212	1,430	5,403	3,562	5,566	127	0	686	4,262	40,890	4,793
Vertical leakage lower surface	3,168	459	55	0	351	240	170	301	458	0	2,135	4,791	8,647	227
Upper Wilcox														
Storage	131	0	35	0	14	17	1	12	240	0	229	310	93	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	992	0	0
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	90	120	0	0
Recharge	0	0	0	0	361	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	459	3,168	0	55	240	351	301	170	0	458	4,791	2,135	227	8,647
Lateral inflow	323	70	5	13	8	102	4	29	93	43	1,113	2,595	1,551	112
Vertical leakage lower surface	2,593	267	47	0	52	206	2	97	168	0	999	1,416	6,912	23

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	1,713	0	43	0	2,276	2	2,396	0	226	15	913	33	487	0
Reservoirs (River Package)	0	0	0	0	1,718	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	0	0	88	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	5,507	0	9,124	0	0	0	141	0	0
Rivers and streams (Stream Package)	642	0	0	0	3,512	55	2,071	3,250	0	0	271	2	0	0
Recharge	622	0	0	0	2,839	0	4,073	0	0	0	724	0	0	0
Evapotranspiration	0	0	0	0	0	12	0	16	0	0	0	0	0	0
Vertical leakage upper surface	267	2,593	0	47	206	52	97	2	0	168	1,416	999	23	6,912
Lateral inflow	867	855	8	5	622	1,098	4,449	468	23	126	663	1,666	2,845	184
Vertical leakage lower surface	776	1,439	20	0	0	4,358	315	543	61	0	730	1,874	3,748	7
Lower Wilcox														
Storage	1,272	0	98	0	2,994	15	1,344	31	500	0	568	34	484	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	64	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	3,333	0	19	0	11,888	0	9,887	0	0	0	37	0	5,013
Rivers and streams (Stream Package)	0	0	0	0	4,146	412	2,059	99	0	0	193	0	0	0
Recharge	0	0	0	0	5,275	0	4,974	0	0	0	268	0	0	0
Evapotranspiration	0	0	0	0	0	165	0	168	0	0	0	0	0	0
Vertical leakage upper surface	1,439	776	0	20	4,358	0	543	315	0	61	1,874	730	7	3,748
Lateral inflow	5,411	4,012	26	85	4,216	8,460	3,114	1,469	251	690	2,019	4,120	8,773	502

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	185	59	--	--	126	0	2,523	36	15	0	87	0	--	--
Reservoirs (River Package)	0	0	--	--	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	22	--	--	0	0	0	0	0	0	0	0	--	--
General head boundary	671	4,965	--	--	754	814	8,051	7,166	193	654	13	574	--	--
Wells	0	1,268	--	--	0	0	0	987	0	0	0	0	--	--
Rivers and streams (Stream Package)	0	1,230	--	--	0	0	0	1,894	0	0	0	0	--	--
Recharge	3,081	0	--	--	0	0	1,923	0	0	0	0	0	--	--
Evapotranspiration	0	3	--	--	0	0	0	444	0	0	0	0	--	--
Lateral inflow	415	36	--	--	131	158	2,978	983	17	60	33	5	--	--
Vertical leakage lower surface	3,805	575	--	--	491	531	1,990	5,956	590	102	458	13	--	--
Queen City														
Storage	925	377	0	14	298	0	396	15	29	0	225	0	--	--
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	--	--
Springs (Drain Package)	0	23	0	0	0	0	0	0	0	0	0	0	--	--
General head boundary	0	0	0	0	0	0	0	0	1	0	0	0	--	--
Wells	0	2,121	0	0	0	0	0	1	0	0	0	0	--	--
Rivers and streams (Stream Package)	565	2,916	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	33	0	0	0	0	0	0	0	0	0	0	--	--
Vertical leakage upper surface	991	3,438	--	--	373	298	5,877	1,702	29	543	17	335	--	--
Lateral inflow	2,464	50	3	6	710	131	4,635	888	10	28	28	12	--	--
Vertical leakage lower surface	481	2,561	0	21	3	955	54	8,357	517	14	117	39	--	--

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	2,393	0	5,129	524	274	0	238	0	20	0	142	0	0	787
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	615	0	0	0	0	0
Wells	0	30,761	0	9,162	0	471	0	4,263	0	1	0	85	0	145
Rivers and streams (Stream Package)	714	235	359	0	0	0	0	0	0	0	0	0	440	97
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	5,086	274	625	0	1,163	0	9,132	11	1	551	121	27	46	0
Lateral inflow	23,234	2,072	2,813	6,353	1,452	3,227	5,266	11,403	952	1,484	546	1,103	4	770
Vertical leakage lower surface	709	199	376	473	812	2	1,963	923	449	0	405	0	46	846
Upper Wilcox														
Storage	29	0	2	0	196	0	300	0	66	0	187	0	0	113
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	436	0	0	0	0	0
Wells	0	0	0	0	0	0	0	1,952	0	0	0	0	0	137
Rivers and streams (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	51	34
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	199	709	473	376	2	812	923	1,963	0	449	0	405	846	46
Lateral inflow	90	10	14	87	19	30	3,192	1,402	11	96	72	106	21	110
Vertical leakage lower surface	559	157	167	194	625	0	904	1	32	0	253	0	51	615

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	769	0	1,444	0	357	0	193	30	56	68	153	0	1	85
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	139	0	0	0	0	0
Wells	0	4,053	0	2,996	0	0	0	0	0	0	0	0	0	260
Rivers and streams (Stream Package)	1,079	0	4,096	2,067	0	0	0	0	0	0	0	0	896	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	157	559	194	167	0	625	1	904	0	32	0	253	615	51
Lateral inflow	3,750	1,670	704	5,260	46	86	392	322	121	293	11	21	469	856
Vertical leakage lower surface	406	5	79	1,631	308	0	670	0	76	0	110	0	32	1,333
Lower Wilcox														
Storage	568	0	851	218	968	0	182	93	106	0	287	0	169	281
Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs (Drain Package)	0	0	0	41	0	0	0	0	0	0	0	0	0	0
General head boundary	0	0	0	0	0	0	0	0	706	27	0	0	0	0
Wells	0	9,992	0	1,550	0	0	0	0	0	0	0	0	0	992
Rivers and streams (Stream Package)	0	0	1,449	302	0	0	0	0	0	0	0	0	372	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	5	406	1,631	79	0	308	0	670	0	76	0	110	1,333	32
Lateral inflow	10,128	303	1,413	7,634	419	1,079	2,246	1,665	574	1,282	117	294	14	1,691

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta												
Storage	137	0	--	--	--	--	13	3,923	923	0	1	1,184
Reservoirs (River Package)	0	0	--	--	--	--	0	0	0	0	0	0
Springs (Drain Package)	0	0	--	--	--	--	0	0	0	133	0	0
General head boundary	727	1,839	--	--	--	--	5,127	838	1,336	3,125	0	0
Wells	0	48	--	--	--	--	0	0	0	500	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	3,938	2,156	119	397	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	497	153	--	--	--	--	246	758	97	438	34	145
Vertical leakage lower surface	1,189	510	--	--	--	--	821	3,471	743	1,020	0	3,254
Queen City												
Storage	549	0	--	--	--	--	60	20,062	1,639	466	120	18,139
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	101	--	--	--	--	0	0	0	100	0	0
Rivers and streams (Stream Package)	0	0	--	--	--	--	20,868	7,175	1,468	3,210	16,793	0
Recharge	0	0	--	--	--	--	10,787	0	7,482	0	10,722	0
Evapotranspiration	0	0	--	--	--	--	0	1,524	0	0	0	0
Vertical leakage upper surface	470	1,057	--	--	--	--	4,039	674	1,876	587	2,635	0
Lateral inflow	1,069	122	--	--	--	--	721	2,496	64	2,093	1,191	939
Vertical leakage lower surface	180	988	--	--	--	--	201	4,749	0	6,074	0	12,382

Table A-1. (continued)

	McMullen		Medina		Uvalde		Webb		Wilson		Zavala	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo												
Storage	214	0	3,718	267	1	2	9	155	8,521	203	5,632	952
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	802	0	0	0	821	0	896	0	28,601	0	24,641
Rivers and streams (Stream Package)	0	0	1,397	59	649	0	52	0	10,575	88	2,643	0
Recharge	0	0	8,726	0	1,223	0	529	0	8,696	0	6,639	0
Evapotranspiration	0	0	0	0	0	0	0	124	0	0	0	0
Vertical leakage upper surface	1,117	79	8	0	--	--	4,404	12	8,207	0	12,802	240
Lateral inflow	1,252	2,522	884	14,062	4	1,053	124	1,438	7,403	15,978	6,330	9,498
Vertical leakage lower surface	846	26	855	1,199	0	0	407	2,903	1,904	436	7,186	5,902
Upper Wilcox												
Storage	424	0	81	27	0	0	36	166	36	0	196	50
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	47	0	0	0	0	0	13	0	0	0	6,317
Rivers and streams (Stream Package)	0	0	0	0	0	0	15	205	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	26	846	1,199	855	0	0	2,903	407	436	1,904	5,902	7,186
Lateral inflow	655	629	34	431	0	0	729	2,351	109	17	621	413
Vertical leakage lower surface	416	0	662	663	0	0	22	576	1,472	131	8,155	1,212

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	225	0	2,783	21	874	5	49	104	1,015	0	1,133	456
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	47	0	0	0	0	0	6	0	0	0	3,694
Rivers and streams (Stream Package)	0	0	925	40	308	15	2,990	2,816	1,145	1,061	1,417	4
Recharge	0	0	2,619	0	1,191	0	82	0	968	0	969	0
Evapotranspiration	0	0	0	0	0	0	0	150	0	0	0	0
Vertical leakage upper surface	0	416	663	662	0	0	576	22	131	1,472	1,212	8,155
Lateral inflow	79	60	344	2,381	22	938	478	506	1,865	1,308	2,128	351
Vertical leakage lower surface	218	0	100	4,330	0	1,437	14	586	240	1,523	7,784	1,984
Lower Wilcox												
Storage	257	38	2,145	238	1,604	65	13	194	919	0	366	608
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	47	0	2,489	0	0	0	1	0	6,547	0	320
Rivers and streams (Stream Package)	0	0	113	194	350	16	0	135	207	0	788	86
Recharge	0	0	1,975	0	1,205	0	15	0	69	0	537	0
Evapotranspiration	0	0	0	273	0	6	0	42	0	0	0	0
Vertical leakage upper surface	0	218	4,330	100	1,437	0	586	14	1,523	240	1,984	7,784
Lateral inflow	430	384	768	6,038	323	4,833	1,720	1,948	8,723	4,655	6,739	1,614