GAM Run 07-20

by Richard M. Smith, P.G. and
Shirley Wade, P.G.
Texas Water Development Board
Groundwater Availability Modeling Section
(512) 936-0877
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EXECUTIVE SUMMARY:

We ran the groundwater availability model for the northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers for a 50-year predictive period using 1999 pumping rates and pumping locations along with average recharge rates, evapotranspiration rates, and initial streamflows. The results show minimal water level declines in the Sparta and Queen City aquifers (mostly less than 10 feet) and moderate declines (less than 40 feet) in the Carrizo, Upper and Middle Wilcox aquifers within Groundwater Management Area 11 using 1999 water levels as a comparison. Some areas show water levels recovering or rebounding when compared to the 1999 water levels.

REQUESTOR:

Mr. David Alford of the Piney Woods Groundwater Conservation District (on behalf of Groundwater Management Area 11).

DESCRIPTION OF REQUEST:

Mr. Alford requested we use the groundwater availability model for the northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers to make a baseline run for a 50-year predictive simulation.

METHODS:

To address the request, we:

- used the 1999 estimated pumpage from the transient calibration-verification model run as the baseline pumpage on an annual basis throughout the model simulation;
- ran the model for 50 years;
- extracted county water budgets after 50 years of simulation time;
- generated maps of initial water levels in 1999; and

- generated maps of water levels and water level differences in the aquifers of interest (the Sparta, Queen City, Carrizo, and Upper Wilcox aquifers) for Groundwater Management Area 11 after 50 years.

PARAMETERS AND ASSUMPTIONS:

- We used version 2.01 of the groundwater availability model for the northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

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

- The model includes eight layers, representing:

    1. Sparta Aquifer (Layer 1)
    2. Weches confining unit (Layer 2)
    3. Queen City Aquifer (Layer 3)
    4. Reklaw confining unit (Layer 4)
    5. Carrizo Aquifer (Layer 5)
    6. Upper Wilcox Aquifer (Layer 6)
    7. Middle Wilcox (Layer 7)
    8. Lower Wilcox (Layer 8)

- In the Sabine Uplift area, the Simsboro Formation (Middle Wilcox aquifer) is not distinguishable and the Wilcox is informally divided into the Upper Wilcox and the Lower Wilcox aquifers (Fryar and others, 2003). In the model, layers 6 and 7 represent the Upper Wilcox and Lower Wilcox aquifers in this area. Layer 8 is included in the model in this area, but it is of nominal thickness and is not intended to represent the Lower Wilcox aquifer. The original Carrizo-Wilcox model for this area did not include a third (bottom) layer for the Wilcox aquifer in the Sabine Uplift area.

- The mean absolute error (a measure of the difference between simulated and actual water levels during model calibration) in the groundwater availability model is 16 feet for the Sparta Aquifer, 21 feet for the Queen City Aquifer, 25 feet for the Carrizo Aquifer, and 21 feet for the Upper Wilcox Aquifer for the calibration period (1980-89) and 15, 24, 28, and 24 feet for the same aquifers respectively in the verification period (1990-99), or between five and eight percent of the range of measured water levels (Kelley and others, 2004).

- Recharge rates are based on average (1961 – 1990) precipitation (Kelley and others, 2004).

- Evaporation rates and initial streamflow rates are based on long-term steady-state conditions (Kelley and others, 2004).

- Baseline pumpage is 1999 pumping rates and pumping locations. Tables and graphs of the total pumping by county used in the transient calibration are shown in Appendix A.

RESULTS:

The components of the water budget (Table 1) are described below.

- Storage—This component is 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 county-wide 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).

- Reservoirs – This is water that leaks from reservoirs into the aquifer or from the aquifer into the reservoir. This component can be shown as "Inflow" or "Outflow" in the budget. Reservoirs in this model are modeled with the river package which uses the same mathematical calculations as the reservoir package.

- Springs and seeps—This is water that drains from an aquifer if water levels are above the elevation of the spring or seep. This component is always shown as "Outflow", or discharge, from an aquifer. Springs and seeps are modeled in the model using the MODFLOW Drain package.

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

- Wells—This is water produced from wells in each aquifer. In the model for the northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers, this component is always shown as "Outflow" from an aquifer, because all wells included in the model produce (rather than inject) water. Wells are modeled in the model using the MODFLOW Well package.

- Rivers and Streams—This is 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.

- Recharge—This component simulates areally distributed recharge due to precipitation falling on the outcrop areas of aquifers. Recharge is always shown as "Inflow" into an aquifer. This component does not include runoff from precipitation events that may later recharge an aquifer as stream losses, which is included in the model using the stream (or river) package. Recharge is modeled in the model for the northern portion of the Queen City, Sparta, and Carrizo-Wilcox aquifers using the MODFLOW Recharge package.

- Evapotranspiration—This is 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.

- Lateral flow between counties—This component describes lateral flow within the aquifer between adjacent counties.

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

It is important to note that sub-regional water budgets for individual counties are not exact. This is due to the one-mile spacing of the model grid and because we assumed each model cell is assigned to a single county. The water budgets for an individual cell containing a county boundary are assigned to either one county or the other and therefore very minor variations in the county-wide budgets may be observed.

Figures 1 through 5 provide the initial water levels for the Sparta Aquifer (layer 1, Figure 1), the Queen City Aquifer (layer 3, Figure 2), the Carrizo Aquifer (layer 5, Figure 3), the Upper Wilcox Aquifer (layer 6, Figure 4), and the Middle and/or Lower Wilcox Aquifer (layer 7, Figure 5). Water levels after 50 years are shown in Figures 6 through 10 for the Sparta Aquifer (layer 1, Figure 6), the Queen City Aquifer (layer 3, Figure 7), the Carrizo Aquifer (layer 5, Figure 8), the Upper Wilcox Aquifer (layer 6, Figure 9) and the Middle and/or Lower Wilcox (layer 7, Figure 10). We do not show figures for layer 8 because it only includes about five percent of the model pumpage and water level declines are less than 10 feet over most of Groundwater Management Area 11. In addition layer 8 does not represent the Lower Wilcox in most of the Sabine Uplift area.

Water level differences in the Sparta Aquifer (layer 1) after 50 years are shown in Figure 11. The Sparta Aquifer for the most part maintains the same level as in 1999 with only slight water declines and slight rebound (less than 10 feet) across the extent of the model area (Figure 11). Throughout most of Groundwater Management Area 11 water levels in

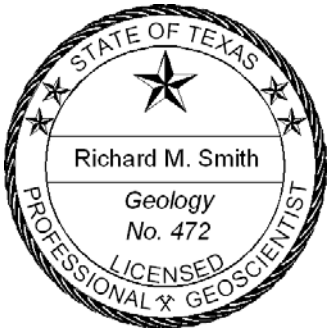
the Queen City Aquifer (layer 3) after 50 years also show little change (Figure 12); however, small areas in the outcrop show rebounds in excess of 30 feet.

Water level differences after 50 years in the Carrizo Aquifer (layer 5) are shown in Figure 13. This figure indicates a large area of moderate (less than 30 feet) water level rebounds centered between Angelina and Nacogdoches counties. The rebound occurs because earlier historical pumping levels in those two counties were greater than 1999 pumping (Appendix A). An area of moderate water level declines (less than 40 feet) is centered on Smith and Upshur counties to the north. The Wilcox layers (layer 6 and 7) mirror the Carrizo Aquifer as can be seen in Figures 14 and 15. Areas of rebound are centered in Angelina County and declines are seen in Smith and Upshur counties. Along the southwestern lateral boundary water level declines of up to 80 feet occur in the Upper Wilcox Aquifer (Figure 14) and up to 150 feet in the Middle Wilcox Aquifer (Figure 15) outside of Groundwater Management Area 11. These declines are due to pumping in the Bryan-College Station area represented by declining water levels in the general head boundary package (Kelley and others, 2004).

REFERENCES:

Fryar, D., Senger, R., Deeds, N., Pickens, J., Jones, T., Whallon, A. J., and Dean, K. E., 2003, Groundwater Availability Model for the Northern Carrizo-Wilcox Aquifer: contract report to the Texas Water Development Board, 529 p.

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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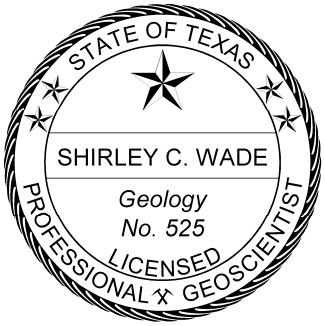

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Table 1. Annual water budgets for each county in Groundwater Management Area 11 at the end of the 50-year predictive model run using 1999 pumpage in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers. Values are reported in acre-feet per year.

	Anderson		Angelina		Bowie		Camp		Cass		Cherokee		Franklin	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta														
Storage	5	308	56	7	--	--	--	--	--	--	377	190	--	--
Reservoirs	0	0	0	0	--	--	--	--	--	--	0	0	--	--
Springs and seeps	0	0	0	0	--	--	--	--	--	--	0	0	--	--
General Head Boundary	0	0	2,956	1,750	--	--	--	--	--	--	205	162	--	--
Well	0	149	0	293	--	--	--	--	--	--	0	213	--	--
Rivers and Streams	0	3,069	0	2,103	--	--	--	--	--	--	82	2,257	--	--
Recharge	11,542	0	578	0	--	--	--	--	--	--	9,740	0	--	--
Evapotranspiration	0	4,866	0	0	--	--	--	--	--	--	0	1,879	--	--
Lateral Inflow	594	98	2,041	393	--	--	--	--	--	--	179	1,804	--	--
Vertical Leakage Downward	195	3,846	445	1,530	--	--	--	--	--	--	272	4,349	--	--
Queen City														
Storage	2,361	2,179	2	17	--	--	98	193	119	6,410	1,366	4,092	--	--
Reservoirs	740	0	0	0	--	--	333	0	0	0	734	0	--	--
Springs and seeps	0	206	0	0	--	--	0	21	0	33	0	127	--	--
General Head Boundary	0	0	0	0	--	--	0	0	0	0	0	0	--	--
Well	0	774	0	98	--	--	0	132	0	536	0	905	--	--
Rivers and Streams	542	23,356	0	0	--	--	65	2,243	135	16,449	372	9,820	--	--
Recharge	31,368	0	0	0	--	--	2,077	0	41,132	0	27,454	0	--	--
Evapotranspiration	0	14,122	0	0	--	--	0	815	0	15,627	0	10,634	--	--
Vertical Leakage Upward	4,497	143	1,394	251	--	--	--	--	--	--	5,190	223	--	--
Lateral Inflow	5,253	2,487	291	32	--	--	1,225	221	1,023	1,192	884	5,176	--	--
Vertical Leakage Downward	132	1,626	12	1,300	--	--	34	206	32	2,194	58	5,083	--	--

Table 1. Continued

	Anderson		Angelina		Bowie		Camp		Cass		Cherokee		Franklin	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	280	7	0	50	--	--	46	426	106	195	219	518	0	575
Reservoirs	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	--	--	0	0	0	0	0	0	0	151
General Head Boundary	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Well	0	3,281	0	17,736	--	--	0	632	0	1,578	0	3,928	0	214
Rivers and Streams	58	1,062	0	0	--	--	0	47	0	0	8	950	18	1,297
Recharge	311	0	0	0	--	--	1,518	0	0	0	1,946	0	4,655	0
Evapotranspiration	0	0	0	0	--	--	0	485	0	0	0	230	0	1,587
Vertical Leakage Upward	1,694	70	1,575	4	--	--	933	4	2,613	0	6,226	373	102	0
Lateral Inflow	4,555	2,654	15,309	2,198	--	--	497	693	115	262	2,982	2,315	577	609
Vertical Leakage Downward	643	466	3,104	0	--	--	4	711	178	977	620	3,687	15	935
Upper Wilcox														
Storage	193	73	0	728	0	27	0	956	56	1,981	14	204	0	140
Reservoirs	0	0	0	0	0	0	784	37	0	0	0	0	26	105
Springs and seeps	0	0	0	0	0	0	0	223	0	0	0	0	0	90
General Head Boundary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1,039	0	2,154	0	252	0	355	0	777	0	3,977	0	134
Rivers and Streams	0	293	0	0	172	27	0	500	164	323	0	0	0	1,038
Recharge	361	0	0	0	81	0	293	0	3,059	0	0	0	1,715	0
Evapotranspiration	0	104	0	0	0	36	0	437	0	506	0	0	0	612
Vertical Leakage Upward	466	643	0	3,104	--	--	711	4	977	178	3,687	620	935	15
Lateral Inflow	2,510	1,990	6,149	1,629	161	80	1,014	507	774	689	3,103	2,498	393	822
Vertical Leakage Downward	956	345	1,466	0	12	4	246	29	153	728	1,235	739	47	161

Table 1. Continued

	Anderson		Angelina		Bowie		Camp		Cass		Cherokee		Franklin	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	10	106	0	1,041	1	1,441	0	55	0	324	1	391	0	2,169
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	235	0	0	0	0	0	0	0	23
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	160	0	0	0	1,175	0	312	0	396	0	16	0	596
Rivers and Streams	0	0	0	0	34	2,785	0	0	0	0	0	0	0	1,473
Recharge	5	0	0	0	10,177	0	0	0	107	0	0	0	5,923	0
Evapotranspiration (ET)	0	0	0	0	0	3,989	0	0	0	0	0	0	0	767
Vertical Leakage Upward	345	956	0	1,466	4	12	29	246	728	153	739	1,235	161	47
Lateral Inflow	1,590	1,526	2,310	171	822	1,038	1,455	905	1,163	970	2,043	1,536	531	1,231
Vertical Leakage Downward	815	17	368	0	582	947	34	0	41	196	539	144	182	491
Lower Wilcox														
Storage	0	162	0	279	2	1	0	2	0	4	0	206	0	6
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	126	0	0	0	273	0	2	0	176	0	0	0	287
Rivers and Streams	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0	0	0	82	0
Evapotranspiration (ET)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vertical Leakage Upward	17	815	0	368	947	582	0	34	196	41	144	539	491	182
Lateral Inflow	2,306	1,220	688	41	39	133	98	60	90	90	1,197	1,197	61	159

Table 1. Continued

	Gregg		Harrison		Henderson		Hopkins		Houston		Marion		Morris	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Sparta														
Storage	--	--	--	--	--	--	--	--	288	510	--	--	--	--
Reservoirs	--	--	--	--	--	--	--	--	0	0	--	--	--	--
Springs and seeps	--	--	--	--	--	--	--	--	0	0	--	--	--	--
General Head Boundary (GHB)	--	--	--	--	--	--	--	--	5,844	4,973	--	--	--	--
Well	--	--	--	--	--	--	--	--	0	694	--	--	--	--
Rivers and Streams	--	--	--	--	--	--	--	--	79	9,808	--	--	--	--
Recharge	--	--	--	--	--	--	--	--	22,975	0	--	--	--	--
Evapotranspiration	--	--	--	--	--	--	--	--	0	8,563	--	--	--	--
Lateral Inflow	--	--	--	--	--	--	--	--	2,628	1,785	--	--	--	--
Vertical Leakage Downward	--	--	--	--	--	--	--	--	2,504	7,985	--	--	--	--
Queen City														
Storage	87	997	0	4,566	175	4,097	--	--	426	115	66	1,597	46	2,268
Reservoirs	0	0	0	0	1,027	0	--	--	0	0	3	163	0	0
Springs and seeps	0	46	0	15	0	309	--	--	0	0	0	58	0	65
General Head Boundary (GHB)	0	0	0	0	0	0	--	--	0	0	0	0	0	0
Well	0	306	0	416	0	797	--	--	0	240	0	149	0	197
Rivers and Streams	0	1,095	4	1,132	73	4,388	--	--	291	6,905	18	1,865	0	1,151
Recharge	6,973	0	11,818	0	17,628	0	--	--	2,225	0	8,223	0	5,773	0
Evapotranspiration	0	4,289	0	4,656	0	11,409	--	--	0	480	0	4,726	0	1,394
Vertical Leakage Upward	--	--	--	--	--	--	--	--	7,831	2,568	--	--	--	--
Lateral Inflow	761	435	210	451	4,500	920	--	--	2,656	2,229	1,209	472	357	851
Vertical Leakage Downward	11	665	10	806	6	1,490	--	--	238	1,131	26	513	21	271

Table 1. Continued

	Gregg		Harrison		Henderson		Hopkins		Houston		Marion		Morris	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	389	0	780	304	1,201	75	0	333	18	18	79	107	1	250
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1,510	0	2,479	0	3,568	0	380	0	838	0	762	0	567
Rivers and Streams	34	209	0	452	0	597	0	362	0	0	0	0	0	0
Recharge	120	0	3,621	0	5,033	0	2,443	0	0	0	0	0	355	0
Evapotranspiration	0	0	0	1,311	0	441	0	416	0	0	0	0	0	42
Vertical Leakage Upward	890	34	2,348	1	1,877	0	30	0	861	55	944	29	531	5
Lateral Inflow	682	271	151	142	1,537	2,793	203	442	4,367	4,459	139	67	171	154
Vertical Leakage Downward	315	405	225	2,436	155	2,331	0	741	306	182	184	381	255	295
Upper Wilcox														
Storage	9	0	100	3,738	110	724	0	1,195	179	331	8	1,035	143	5
Reservoirs	0	0	0	0	0	0	0	0	0	0	16	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	194
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	854	0	795	0	1,428	0	181	0	11	0	235	0	200
Rivers and Streams	0	0	166	2,335	25	1,274	0	333	0	0	16	563	0	302
Recharge	0	0	7,379	0	6,370	0	2,252	0	0	0	1,972	0	2,727	0
Evapotranspiration	0	0	0	1,518	0	2,018	0	403	0	0	0	433	0	781
Vertical Leakage Upward	405	315	2,436	225	2,331	155	741	0	182	306	381	184	295	255
Lateral Inflow	1,434	663	517	925	997	2,164	60	702	2,157	1,964	654	401	512	983
Vertical Leakage Downward	206	222	414	1,475	234	2,304	0	241	203	110	227	424	29	985

Table 1. Continued

	Gregg		Harrison		Henderson		Hopkins		Houston		Marion		Morris	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	3	6	3	5,232	858	218	0	5,860	117	348	5	93	166	33
Reservoirs	0	0	101	72	0	4	0	0	0	0	61	0	0	0
Springs and seeps	0	0	0	227	0	0	0	362	0	0	0	3	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	400	0	527	0	1,087	0	1,279	0	2	0	175	0	461
Rivers and Streams	0	0	473	4,541	5	1,770	84	3,544	0	0	0	59	290	2,388
Recharge	0	0	21,854	0	3,688	0	16,504	0	0	0	147	0	680	0
Evapotranspiration	0	0	0	9,582	0	942	0	2,037	0	0	0	562	0	0
Vertical Leakage Upward	222	206	1,475	414	2,304	234	241	0	110	203	424	227	985	29
Lateral Inflow	897	529	1,183	4,138	1,309	1,678	80	1,793	983	960	935	485	1,372	658
Vertical Leakage Downward	28	8	372	728	306	2,536	344	2,378	303	0	64	31	127	51
Lower Wilcox														
Storage	0	0	0	6	16	2,169	0	52	138	309	0	2	0	1
Reservoirs	0	0	0	0	1,624	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	204	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	0	0	212	0	1,257	0	2,203	0	0	0	3	0	5
Rivers and Streams	0	0	0	0	61	1,076	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	1,372	0	363	0	0	0	0	0	0	0
Evapotranspiration	0	0	0	0	0	841	0	0	0	0	0	0	0	0
Vertical Leakage Upward	8	28	728	372	2,536	306	2,378	344	0	303	31	64	51	127
Lateral Inflow	45	25	73	210	1,205	198	14	157	1,152	599	72	38	122	42

Table 1. Continued

	Nacogdoches		Panola		Rains		Rusk		Sabine		San Augustine		Shelby	
Sparta	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
Storage	278	901	--	--	--	--	3	7	0	551	0	2,150	--	--
Reservoirs	0	0	--	--	--	--	0	0	104	35	0	0	--	--
Springs and seeps	0	1	--	--	--	--	0	0	0	74	0	0	--	--
General Head Boundary (GHB)	243	220	--	--	--	--	0	0	808	610	930	1,383	--	--
Well	0	331	--	--	--	--	0	0	0	66	0	61	--	--
Rivers and Streams	220	5,045	--	--	--	--	0	0	19	2,842	0	2,540	--	--
Recharge	17,768	0	--	--	--	--	443	0	3,516	0	7,936	0	--	--
Evapotranspiration (ET)	0	4,480	--	--	--	--	0	165	0	568	0	2,225	--	--
Lateral Inflow	503	1,377	--	--	--	--	--	--	606	584	611	713	--	--
Vertical Leakage Downward	280	6,939	--	--	--	--	0	274	480	204	265	671	--	--
Queen City														
Storage	327	2,872	0	0	--	--	34	1,042	0	4	0	103	0	4
Reservoirs	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	--	--	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Well	0	313	0	0	--	--	0	68	0	0	0	0	0	0
Rivers and Streams	0	1,176	0	0	--	--	0	629	0	0	0	0	0	0
Recharge	8,200	0	50	0	--	--	5,273	0	0	0	145	0	220	0
Evapotranspiration (ET)	0	3,590	0	49	--	--	0	2,115	0	0	0	72	0	192
Vertical Leakage Upward	9,106	325	--	--	--	--	278	0	261	286	831	62	--	--
Lateral Inflow	447	132	3	0	--	--	94	230	2	1	3	2	0	3
Vertical Leakage Downward	58	9,729	0	4	--	--	23	1,618	274	244	39	779	0	21

Table 1. Continued

	Nacogdoches		Panola		Rains		Rusk		Sabine		San Augustine		Shelby	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	96	767	2	4	--	--	810	1,131	0	770	0	309	47	14
Reservoirs	0	0	0	0	--	--	0	0	0	160	0	0	0	0
Springs and seeps	0	0	0	0	--	--	0	416	0	47	0	125	0	0
General Head Boundary (GHB)	0	0	0	0	--	--	0	0	0	0	0	0	0	0
Well	0	9,361	0	283	--	--	0	2,612	0	464	0	414	0	957
Rivers and Streams	0	4,816	0	0	--	--	37	17,683	0	0	28	1,702	0	0
Recharge	19,358	0	1,139	0	--	--	44,576	0	4,029	0	9,465	0	1,828	0
Evapotranspiration	0	8,834	0	635	--	--	0	17,176	0	632	0	5,763	0	782
Vertical Leakage Upward	11,485	192	6	0	--	--	3,205	278	377	259	820	41	90	1
Lateral Inflow	4,251	8,568	207	260	--	--	1,307	2,953	1,163	2,419	2,450	3,262	206	116
Vertical Leakage Downward	2,473	5,124	21	194	--	--	32	7,719	0	816	63	1,211	85	385
Upper Wilcox														
Storage	34	2,534	115	62	132	95	608	5,932	2	439	11	1,266	118	2,990
Reservoirs	0	0	299	0	0	0	157	55	2,151	29	0	0	400	0
Springs and seeps	0	0	0	81	0	0	0	126	0	3,079	0	0	0	599
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	4,090	0	331	0	315	0	1,897	0	200	0	236	0	894
Rivers and Streams	65	858	0	1,583	7	0	279	5,650	0	2,621	0	1,731	91	10,094
Recharge	2,612	0	6,797	0	481	0	20,634	0	4,107	0	3,407	0	27,588	0
Evapotranspiration	0	1,028	0	4,674	0	52	0	3,223	0	1,203	0	437	0	8,227
Vertical Leakage Upward	5,124	2,473	194	21	--	--	7,719	32	816	0	1,211	63	385	85
Lateral Inflow	6,556	3,902	984	502	2,845	2,427	1,122	5,339	1,739	1,142	3,270	3,713	980	3,881
Vertical Leakage Downward	1,251	756	96	1,232	0	69	128	8,393	62	165	67	519	8	2,799

Table 1. Continued

	Nacogdoches		Panola		Rains		Rusk		Sabine		San Augustine		Shelby	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	0	1,500	793	4,148	0	3,161	0	357	47	51	0	314	333	2,147
Reservoirs	0	0	68	0	0	114	0	0	0	0	0	0	1,953	15
Springs and seeps	0	0	0	34	0	61	0	0	0	0	0	0	0	1,714
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	315	0	2,212	0	434	0	3,190	0	51	0	1	0	1,337
Rivers and Streams	16	33	1,040	24,781	84	1,360	0	0	0	0	0	0	337	9,770
Recharge	408	0	29,996	0	7,100	0	0	0	0	0	0	0	15,655	0
Evapotranspiration (ET)	0	0	0	6,463	0	1,183	0	0	0	0	0	0	0	3,193
Vertical Leakage Upward	756	1,251	1,232	96	69	0	8,393	128	165	62	519	67	2,799	8
Lateral Inflow	3,672	1,780	6,233	1,288	233	874	659	4,563	507	520	1,395	1,439	1,434	3,800
Vertical Leakage Downward	211	184	863	1,202	185	484	60	875	2	36	24	118	348	874
Lower Wilcox														
Storage	0	305	1	7	10	36	0	64	5	30	0	121	0	53
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1	0	530	0	283	0	0	0	51	0	0	0	27
Rivers and Streams	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	181	0	0	0	0	0	0	0	0	0
Evapotranspiration	0	0	0	0	0	118	0	0	0	0	0	0	0	0
Vertical Leakage Upward	184	211	1,202	863	484	185	875	60	36	2	118	24	874	348
Lateral Inflow	811	478	290	92	31	80	123	875	140	97	386	358	123	568

Table 1. Continued

	Smith		Titus		Trinity		Upshur		Van Zandt		Walker		Wood	
Sparta	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**
Storage	45	3,221	--	--	0	14	1	112	--	--	17	0	2	551
Reservoirs	0	0	--	--	0	0	0	0	--	--	0	0	0	0
Springs and seeps	0	4	--	--	0	0	0	0	--	--	0	0	0	12
General Head Boundary (GHB)	0	0	--	--	953	865	0	0	--	--	997	908	0	0
Well	0	0	--	--	0	18	0	0	--	--	0	2	0	0
Rivers and Streams	0	2,559	--	--	0	0	0	0	--	--	0	0	0	108
Recharge	22,484	0	--	--	0	0	1,488	0	--	--	0	0	3,750	0
Evapotranspiration	0	2,187	--	--	0	0	0	0	--	--	0	0	0	474
Lateral Inflow	23	6	--	--	525	282	11	66	--	--	309	285	66	11
Vertical Leakage Downward	71	14,646	--	--	175	474	0	1,322	--	--	399	528	0	2,662
Queen City														
Storage	651	8,060	11	79	0	21	108	8,240	21	170	8	0	587	5,864
Reservoirs	499	0	0	0	0	0	0	124	0	0	0	0	0	0
Springs and seeps	0	32	0	0	0	0	0	99	0	0	0	0	0	11
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1,347	0	0	0	1	0	1,278	0	228	0	0	0	1,238
Rivers and Streams	905	25,816	0	91	0	0	316	5,819	0	271	0	0	696	5,110
Recharge	30,169	0	473	0	0	0	23,410	0	5,333	0	0	0	14,429	0
Evapotranspiration	0	9,989	0	183	0	0	0	6,514	0	3,261	0	0	0	3,114
Vertical Leakage Upward	14,347	15	--	--	--	--	1,293	0	--	--	305	231	2,604	0
Lateral Inflow	4,589	4,332	51	85	165	40	1,220	2,869	329	1,389	70	59	981	3,095
Vertical Leakage Downward	31	1,600	3	99	42	432	11	1,416	0	364	151	244	14	877

Table 1. Continued

	Smith		Titus		Trinity		Upshur		Van Zandt		Walker		Wood	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Carrizo														
Storage	2,335	401	67	247	2	18	347	568	240	148	52	0	108	1,197
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	216
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	6,028	0	319	0	32	0	2,635	0	1,155	0	0	0	2,712
Rivers and Streams	46	251	0	169	0	0	54	27	27	1,312	0	0	76	930
Recharge	1,556	0	1,392	0	0	0	697	0	4,617	0	0	0	6,991	0
Evapotranspiration	0	0	0	375	0	0	0	0	0	246	0	0	0	1,043
Vertical Leakage Upward	2,182	2	211	0	404	13	1,114	0	506	0	169	69	1,276	6
Lateral Inflow	2,224	1,205	23	153	3,493	4,053	1,034	346	735	2,125	1,539	1,611	1,225	1,183
Vertical Leakage Downward	1,689	2,145	37	468	256	39	1,071	742	70	1,211	3	82	401	2,789
Upper Wilcox														
Storage	258	1	365	151	5	470	4	11	279	2,415	1,716	0	9	3,031
Reservoirs	0	0	605	8	0	0	0	0	0	0	0	0	1,315	15
Springs and seeps	0	0	0	273	0	0	0	0	0	0	0	0	0	647
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	5,514	0	299	0	0	0	1,466	0	806	0	0	0	1,237
Rivers and Streams	0	433	40	1,800	0	0	0	0	160	1,193	0	0	37	912
Recharge	65	0	3,398	0	0	0	0	0	9,791	0	0	0	3,771	0
Evapotranspiration	0	0	0	1,323	0	0	0	0	0	3,371	0	0	0	1,090
Vertical Leakage Upward	2,145	1,689	468	37	39	256	742	1,071	1,211	70	82	3	2,789	401
Lateral Inflow	3,849	865	373	1,141	1,639	1,276	915	249	720	2,285	734	2,366	1,492	1,008
Vertical Leakage Downward	2,914	729	148	364	321	0	1,252	115	26	2,046	1	164	323	1,395

Table 1. Continued

	Smith		Titus		Trinity		Upshur		Van Zandt		Walker		Wood	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Middle Wilcox														
Storage	61	5	13	4,426	21	434	2	38	194	2,304	1,888	0	1	3,931
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	149	0
Springs and seeps	0	0	0	228	0	0	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1,835	0	1,005	0	0	0	339	0	2,001	0	0	0	480
Rivers and Streams	0	0	17	3,568	0	0	0	0	246	4,202	0	0	85	22
Recharge	0	0	11,581	0	0	0	0	0	10,566	0	0	0	2,929	0
Evapotranspiration (ET)	0	0	0	1,560	0	0	0	0	0	1,573	0	0	0	0
Vertical Leakage Upward	729	2,914	364	148	0	321	115	1,252	2,046	26	164	1	1,395	323
Lateral Inflow	3,703	738	750	1,751	1,035	542	1,792	361	993	2,333	392	2,681	2,545	2,318
Vertical Leakage Downward	1,245	245	627	665	241	0	107	27	251	1,857	238	0	63	92
Lower Wilcox														
Storage	26	1	0	5	21	146	1	2	10	1,068	2,041	0	0	8
Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Springs and seeps	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General Head Boundary (GHB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well	0	1	0	33	0	0	0	0	0	1,121	0	0	0	2
Rivers and Streams	0	0	0	0	0	0	0	0	0	2,198	0	0	0	0
Recharge	0	0	16	0	0	0	0	0	6,494	0	0	0	0	0
Evapotranspiration (ET)	0	0	0	0	0	0	0	0	0	2,602	0	0	0	0
Vertical Leakage Upward	245	1,245	665	627	0	241	27	107	1,857	251	0	238	92	63
Lateral Inflow	1,193	217	118	136	426	272	131	50	347	1,468	237	2,040	166	185

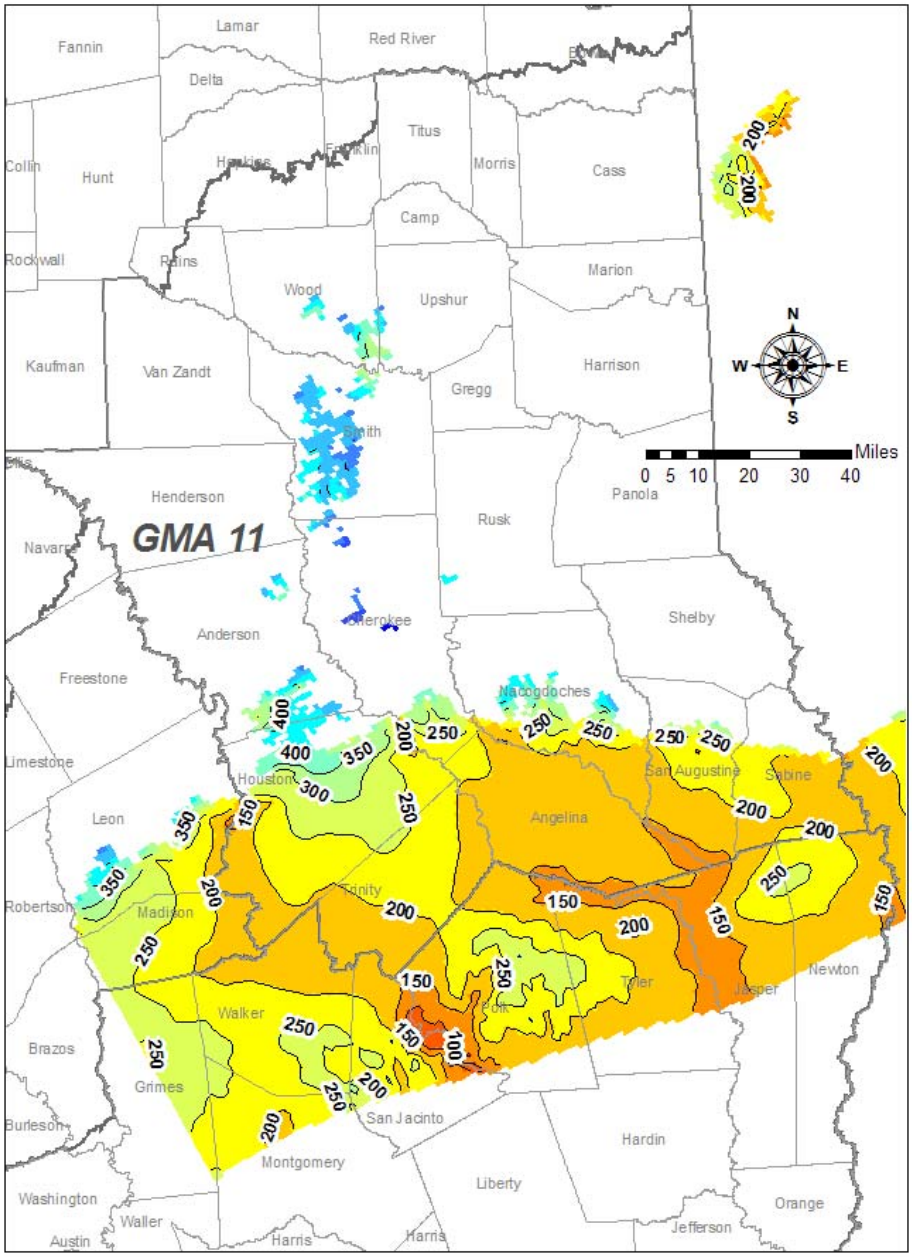

Figure 1: Water levels (in feet above mean sea level) in the Sparta Aquifer (layer 1) in 1999. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

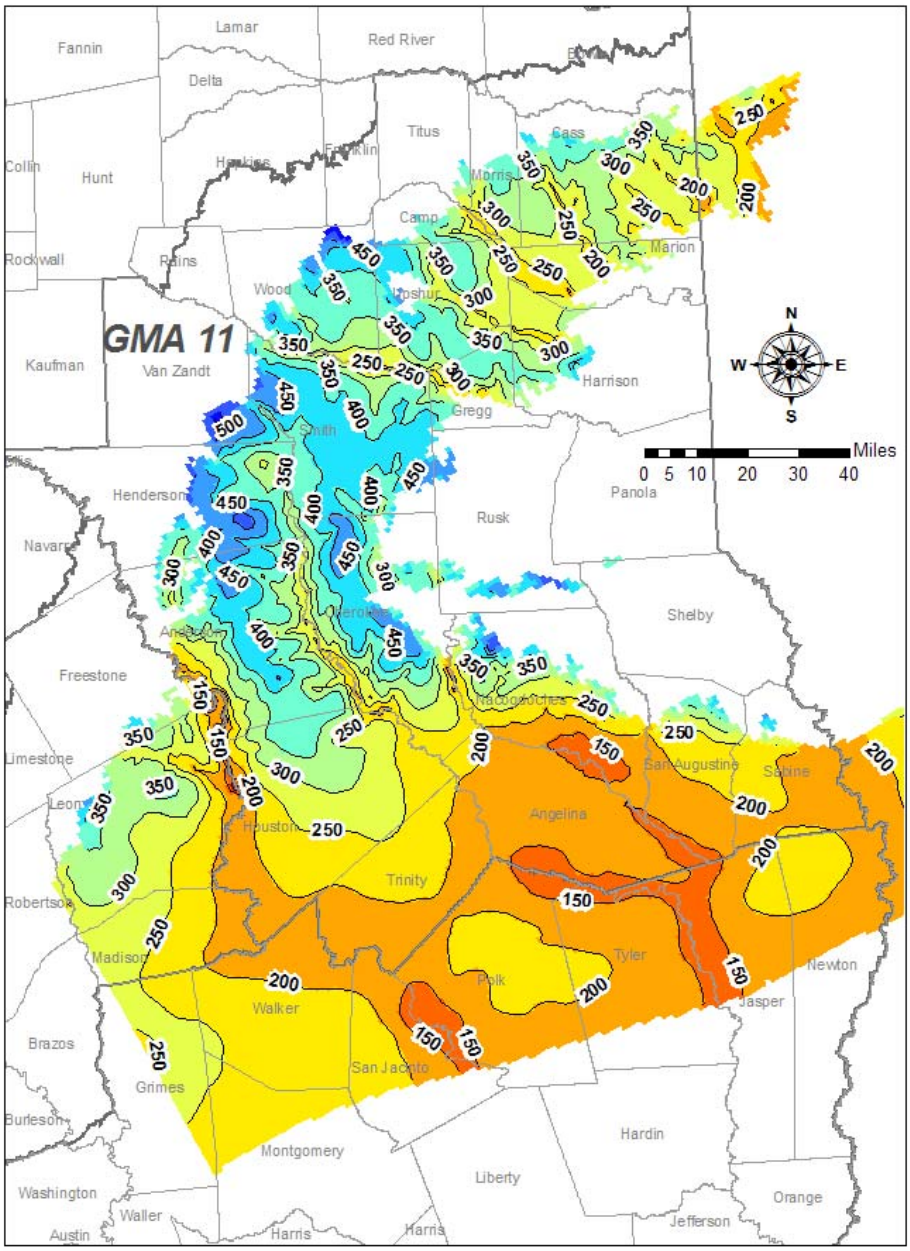

Figure 2: Water levels in the Queen City Aquifer (layer 3) in 1999. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

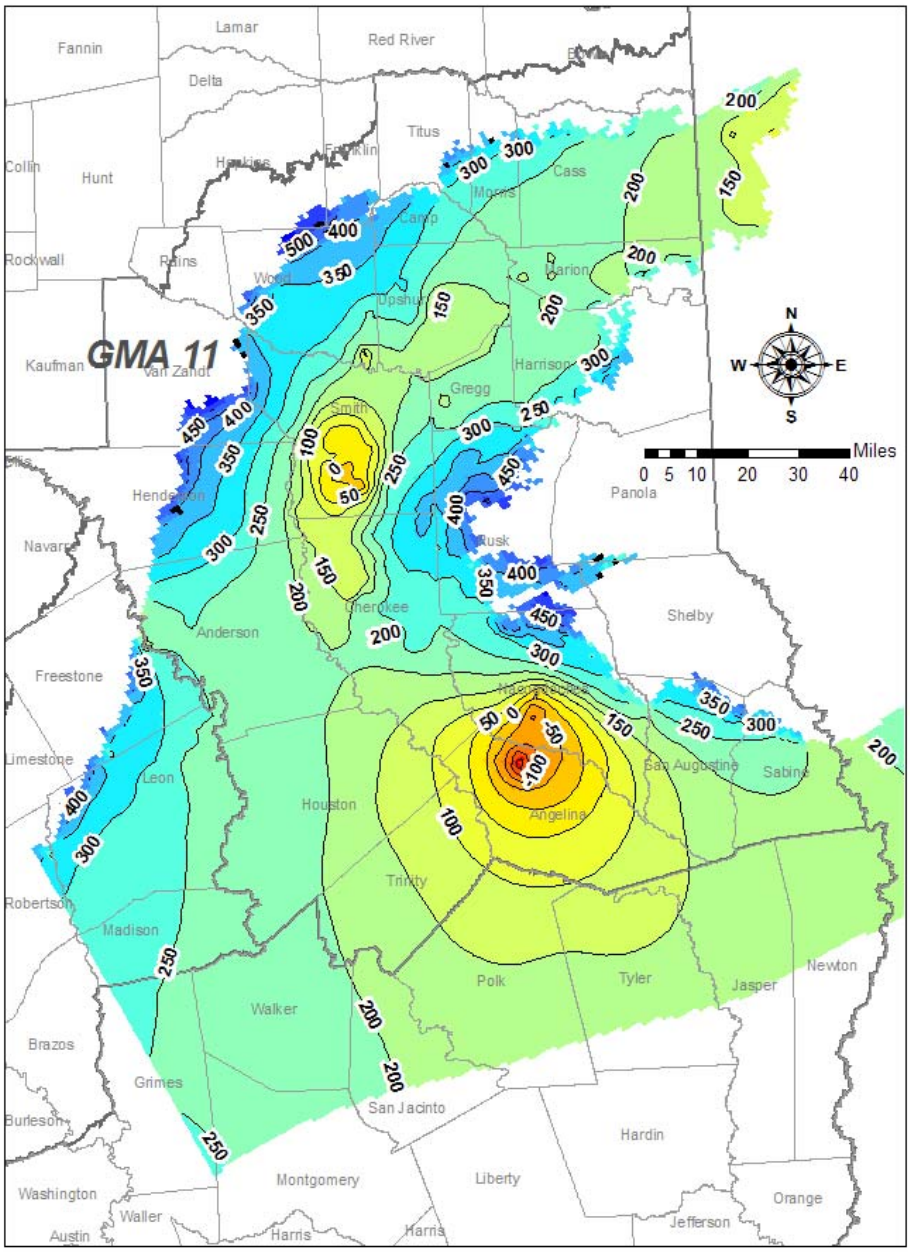

Figure 3: Water levels in the Carrizo Aquifer (layer 5) in 1999. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

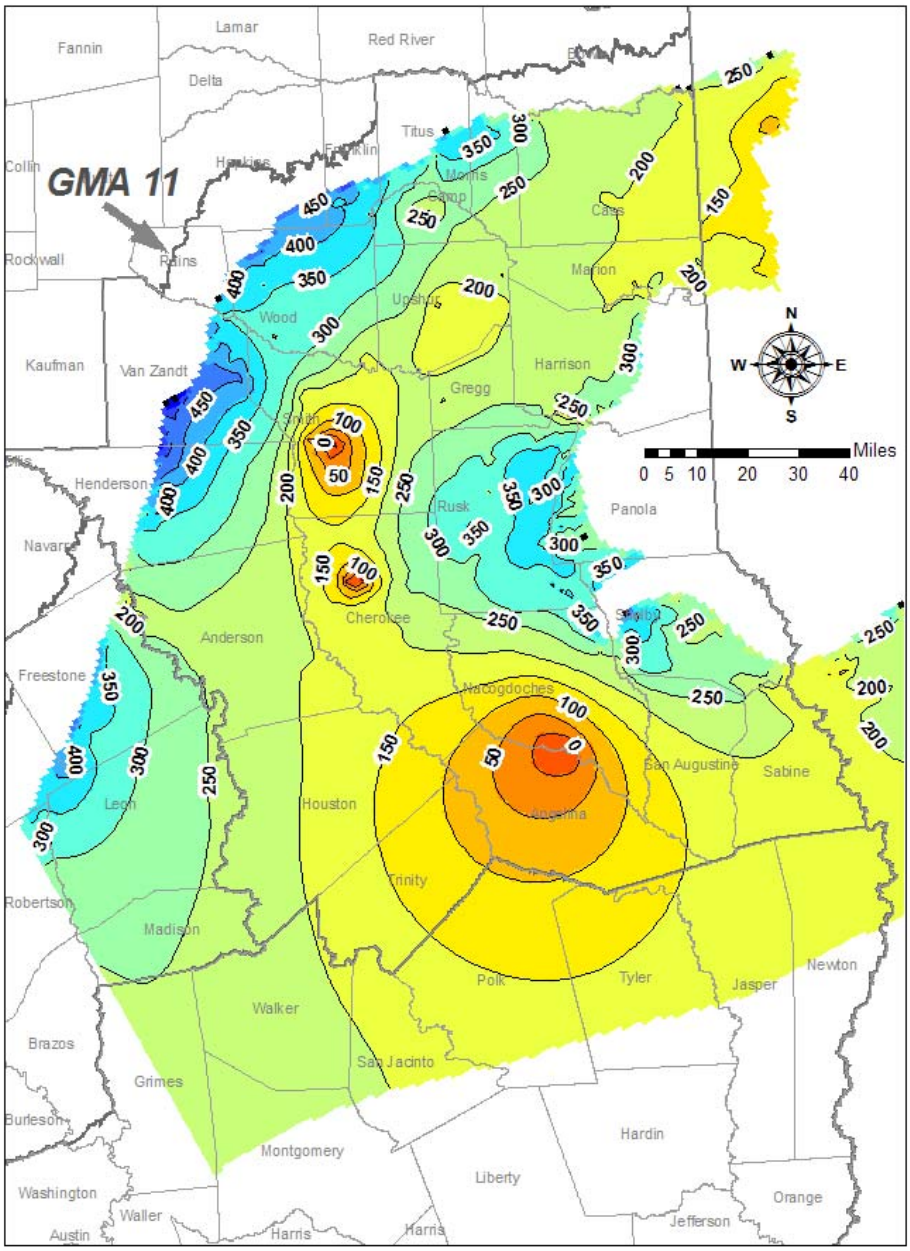

Figure 4: Water levels in the Upper Wilcox Aquifer (layer 6) in 1999. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet (Figure updated September 10, 2008).

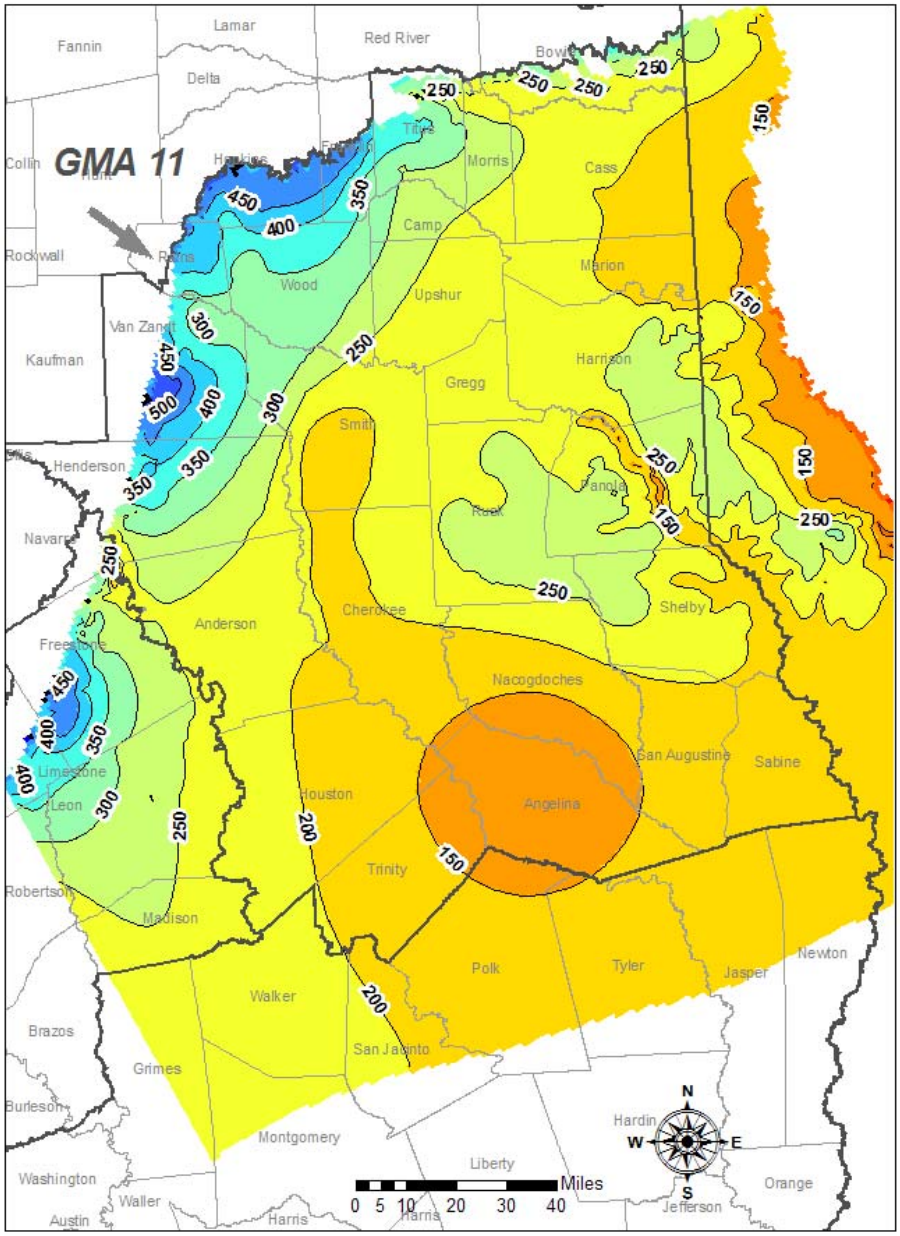

Figure 5: Water levels in the Middle and/or Lower Wilcox Aquifer (layer 7) in 1999. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

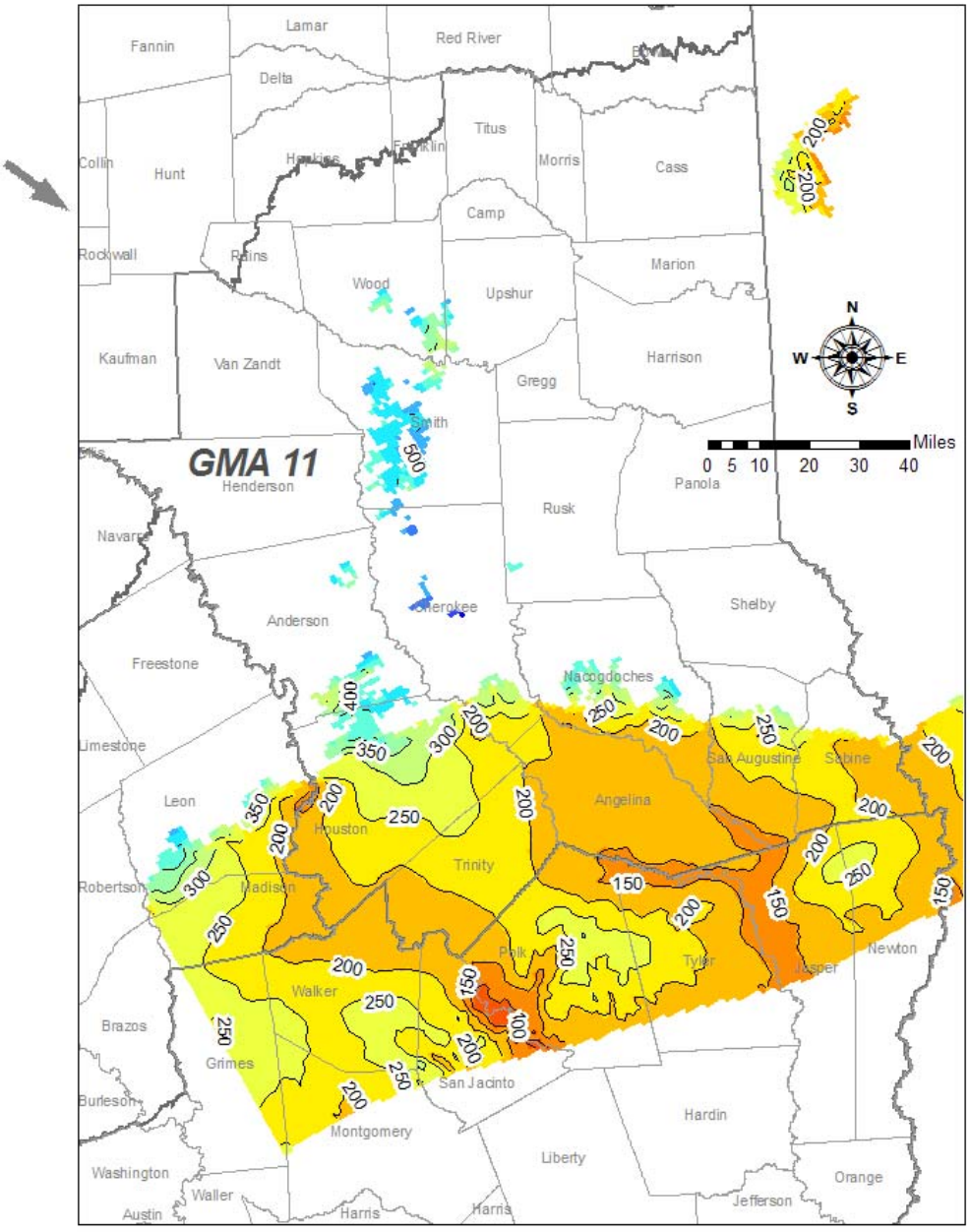

Figure 6: Water levels in the Sparta Aquifer after 50 years of 1999 pumpage. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

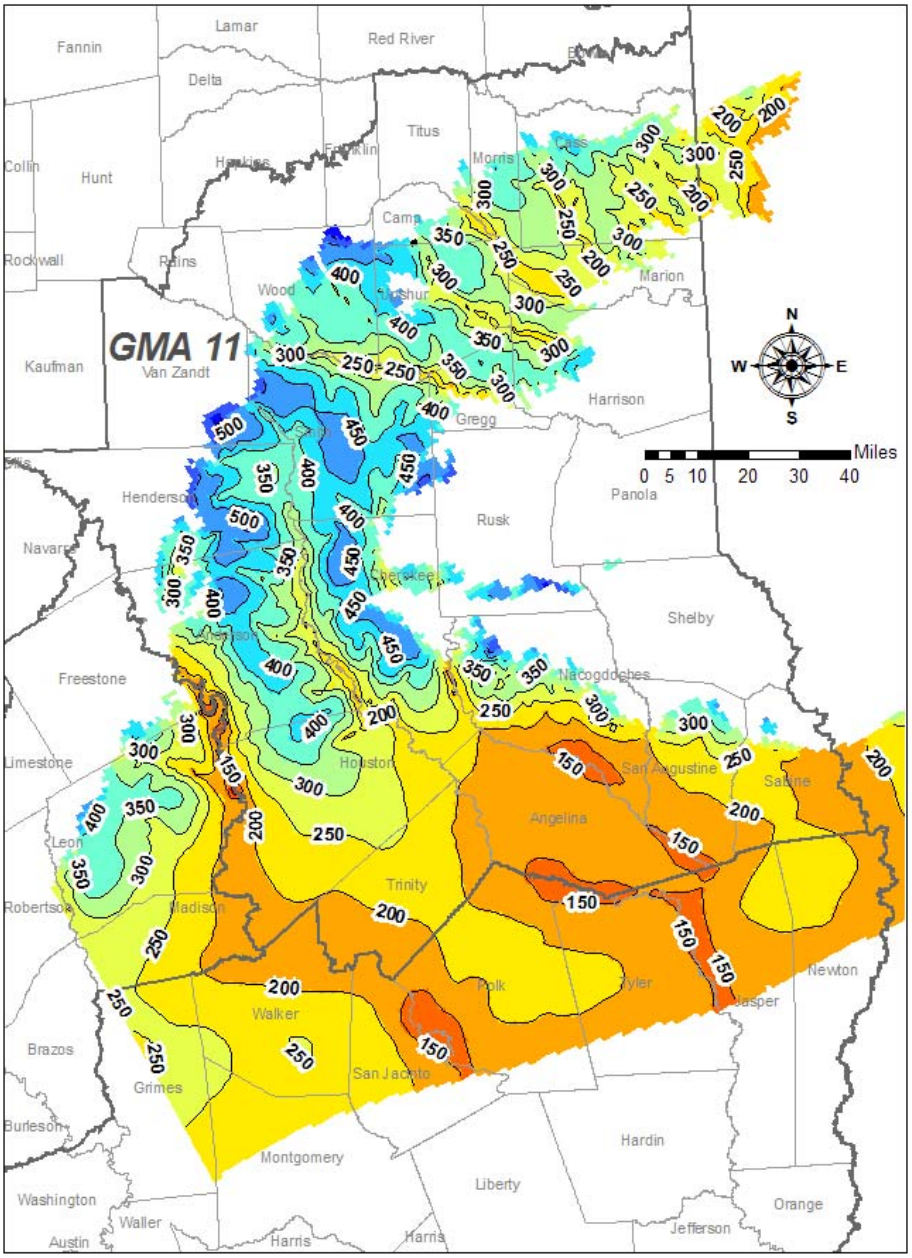

Figure 7: Water levels in the Queen City Aquifer after 50 years of 1999 pumpage. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

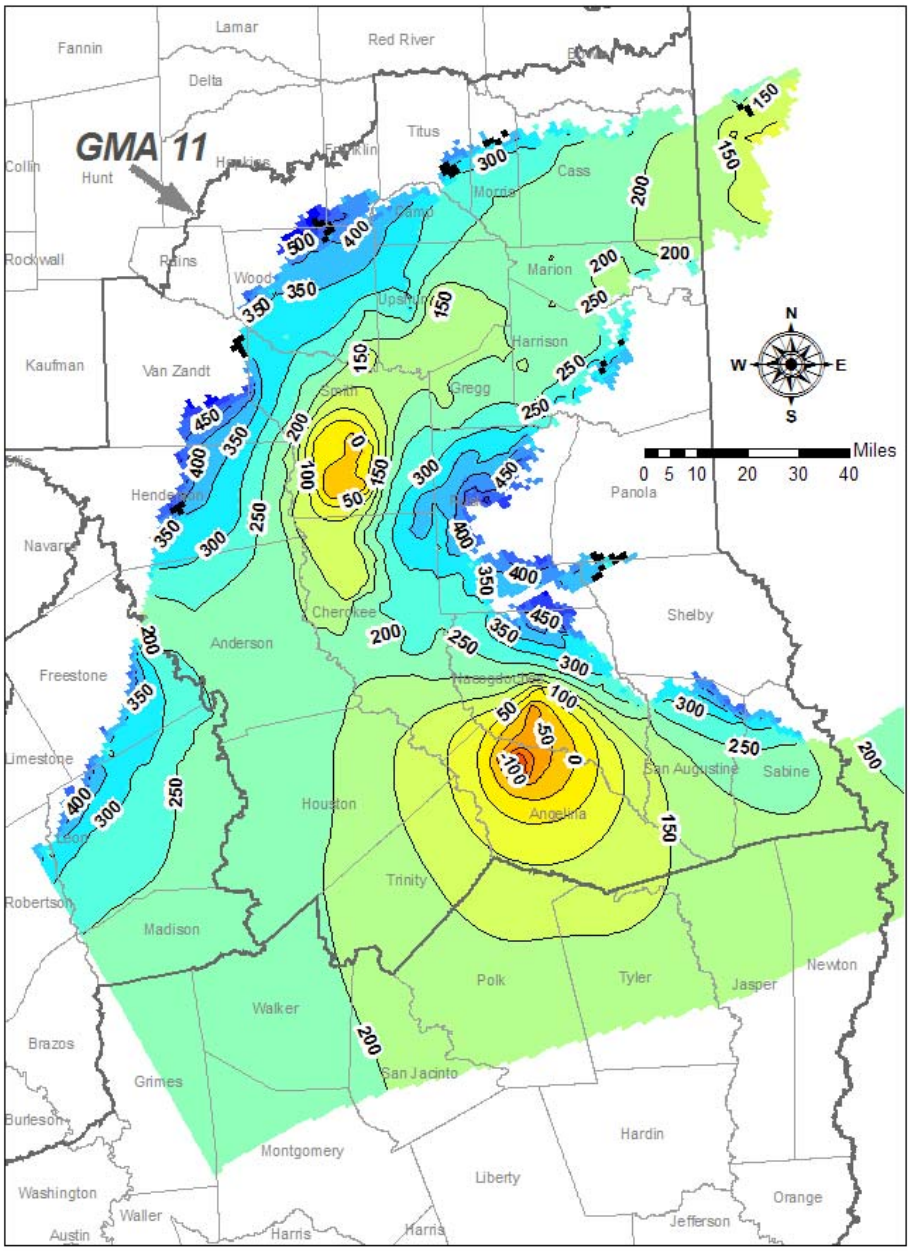

Figure 8: Water levels in the Carrizo Aquifer after 50 years of 1999 pumpage. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

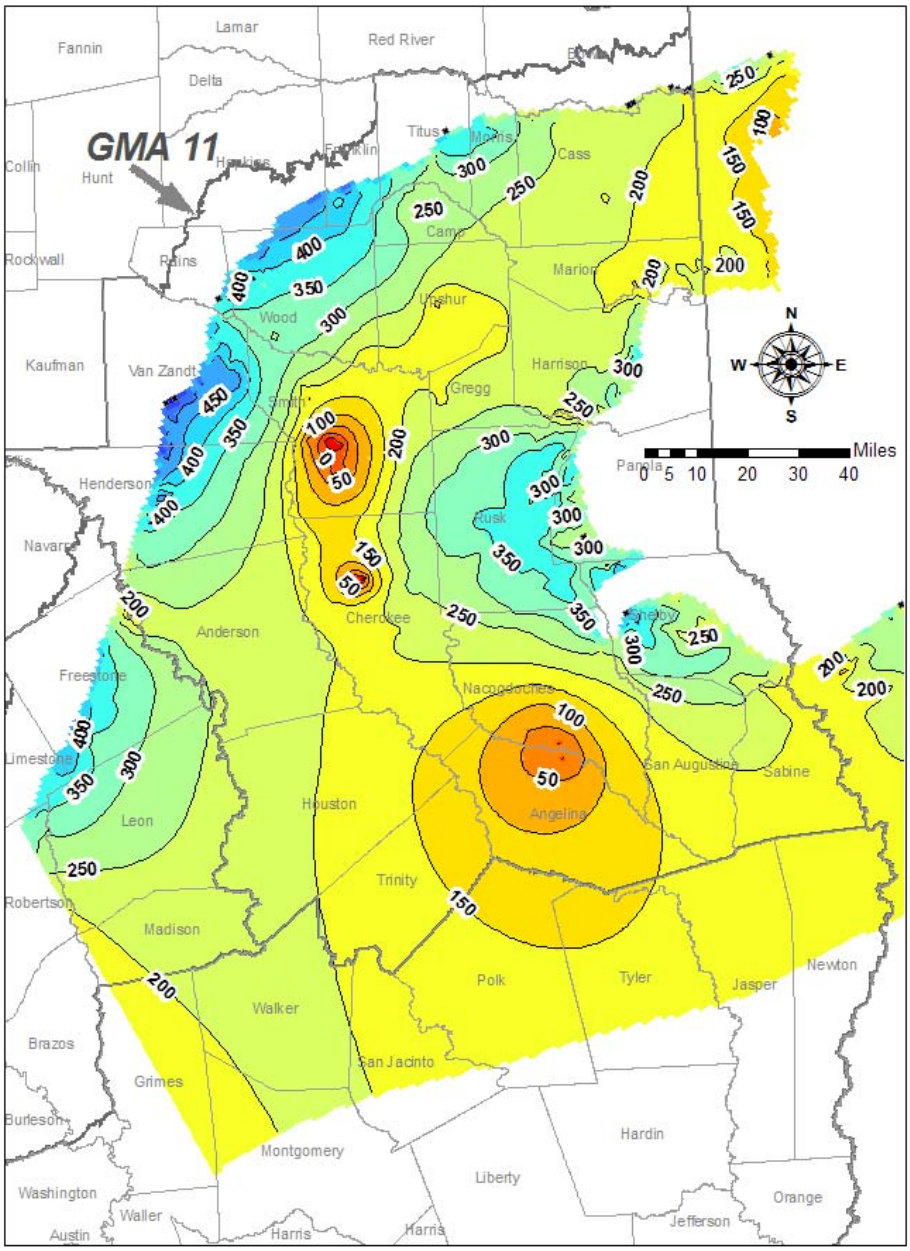

Figure 9: Water levels in the Upper Wilcox Aquifer after 50 years of 1999 pumpage. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

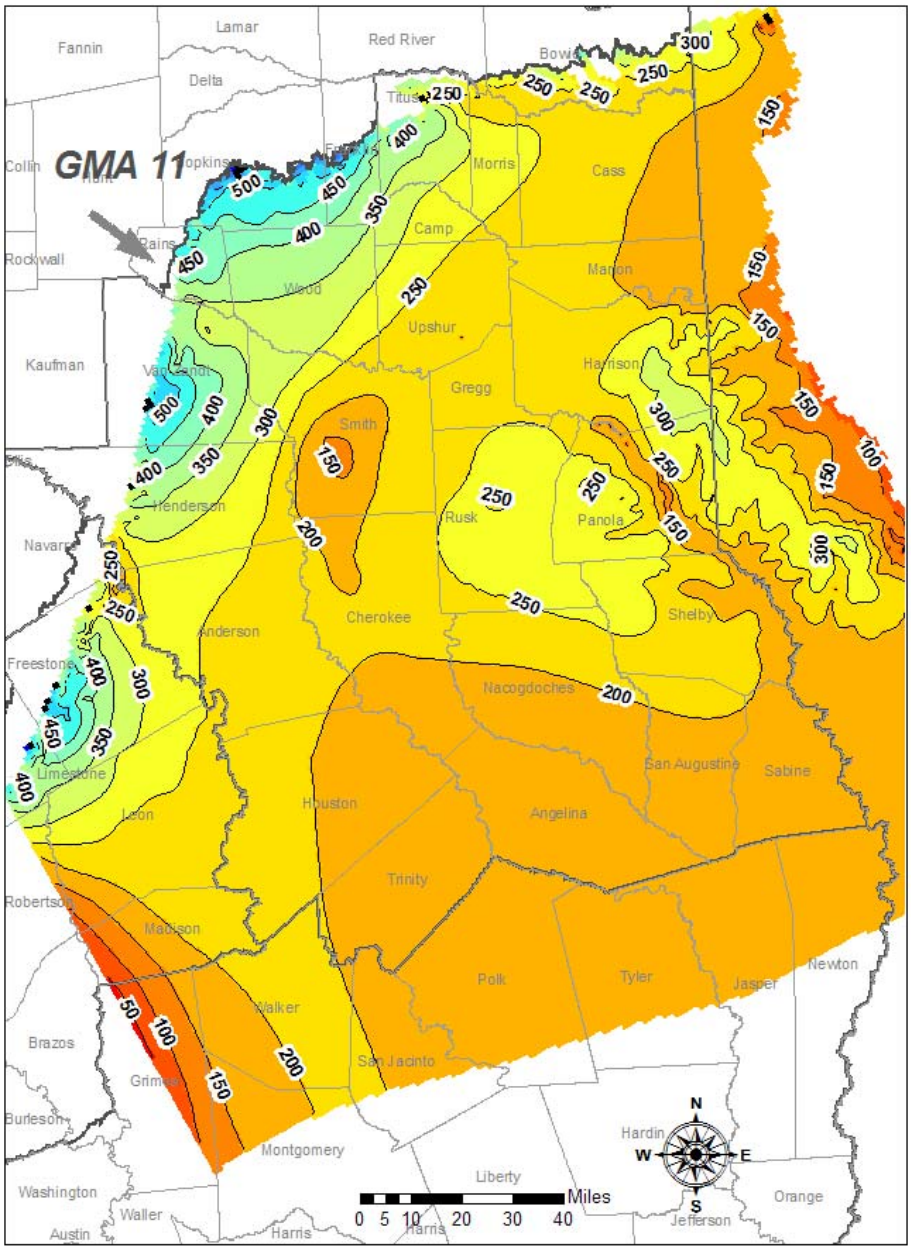

Figure 10: Water levels in the Middle and/or Lower Wilcox Aquifer after 50 years of 1999 pumpage. Dry cells are shown as black squares. Counties outlined in dark gray indicate groundwater management area (GMA) boundaries. Contour interval is 50 feet.

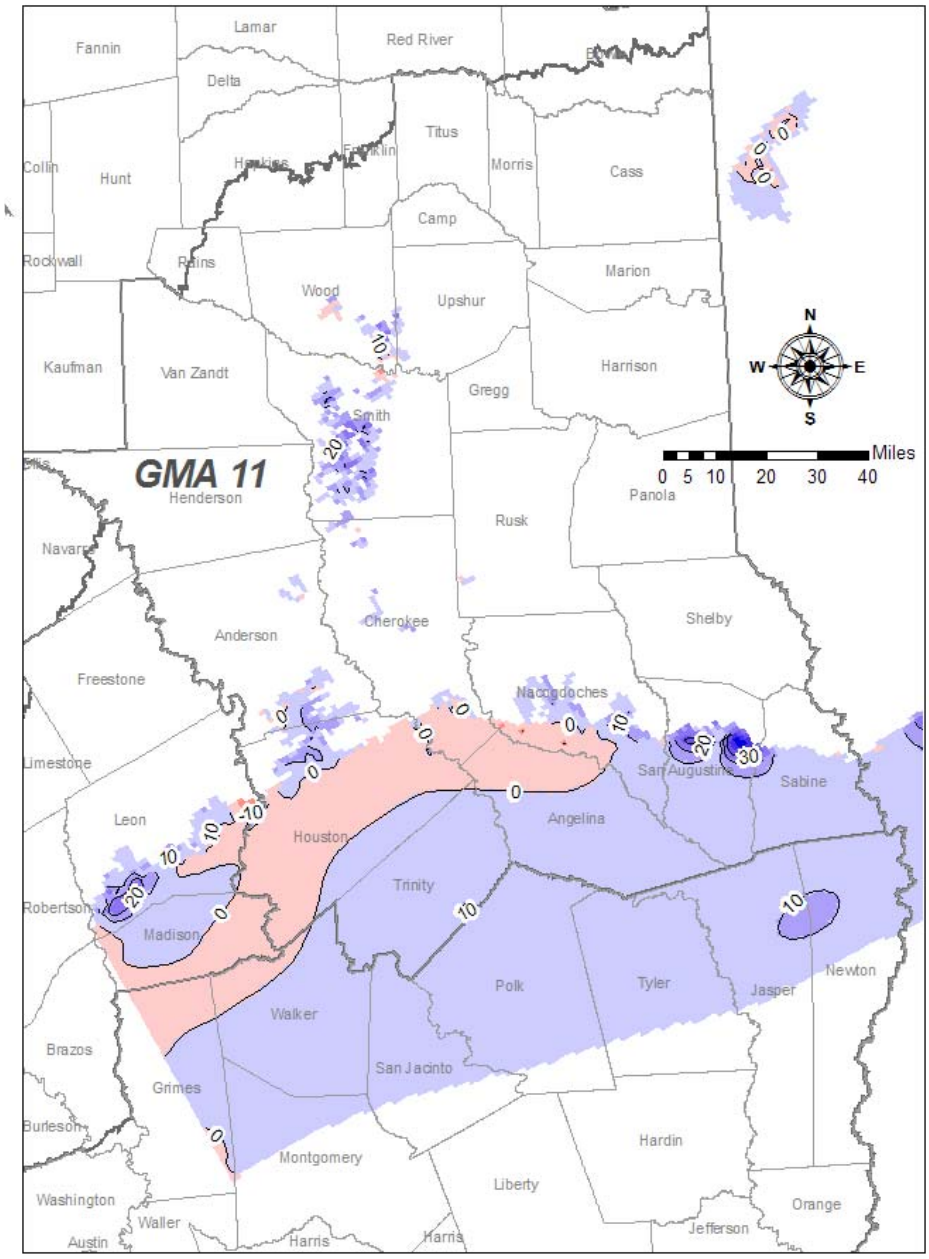

Figure 11: Water level differences in the Sparta Aquifer after 50 years of 1999 pumpage and using 1999 water levels as a baseline. Positive numbers indicate rebound (blue areas) and negative numbers show decline (red areas). Contour interval is 10 feet. Counties outlined in dark gray indicate groundwater management area (GMA).

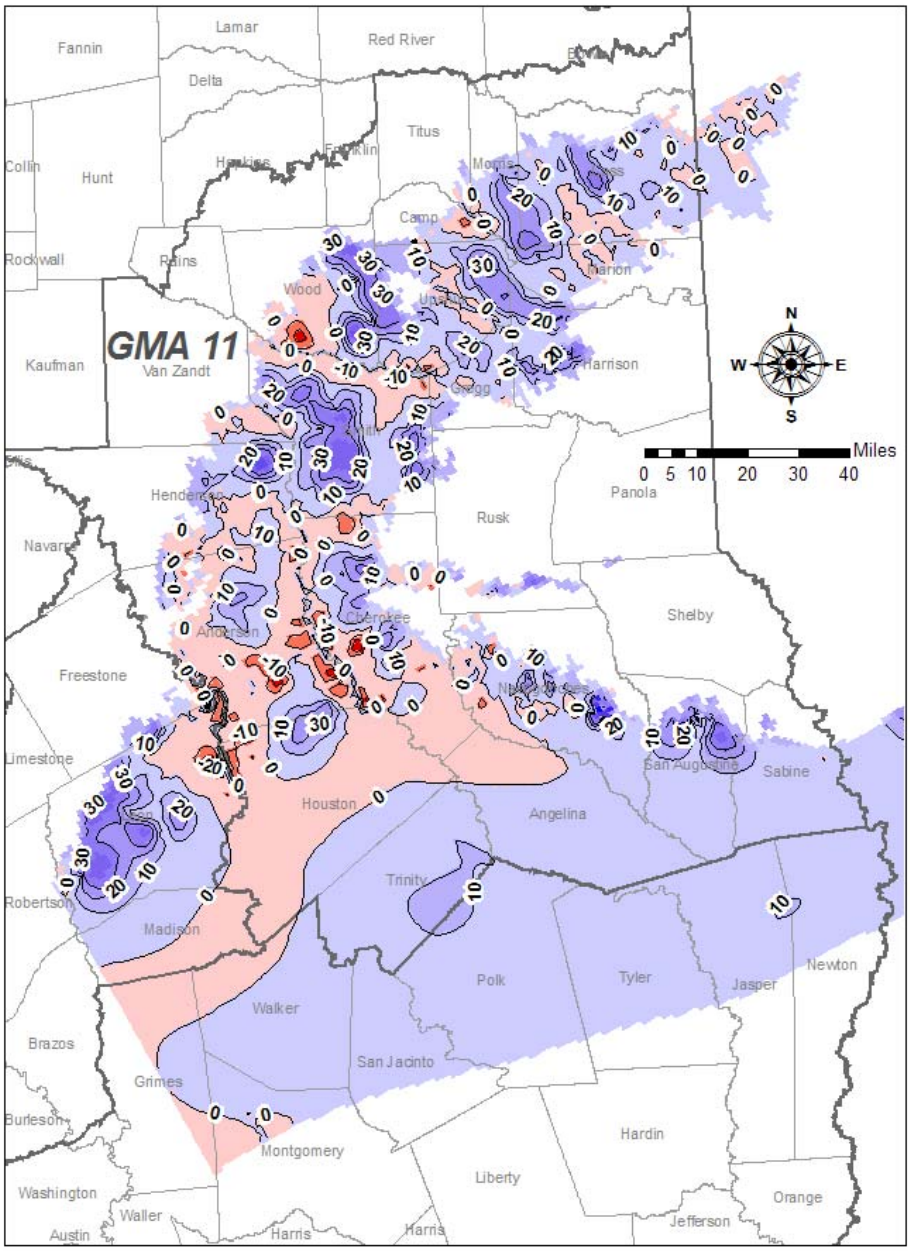

Figure 12: Water level differences in the Queen City Aquifer after 50 years of 1999 pumpage and using 1999 water levels as a baseline. Positive numbers indicate rebound (blue areas) and negative numbers show decline (red areas). Contour interval is 10 feet. Counties outlined in dark gray indicate groundwater management area (GMA)

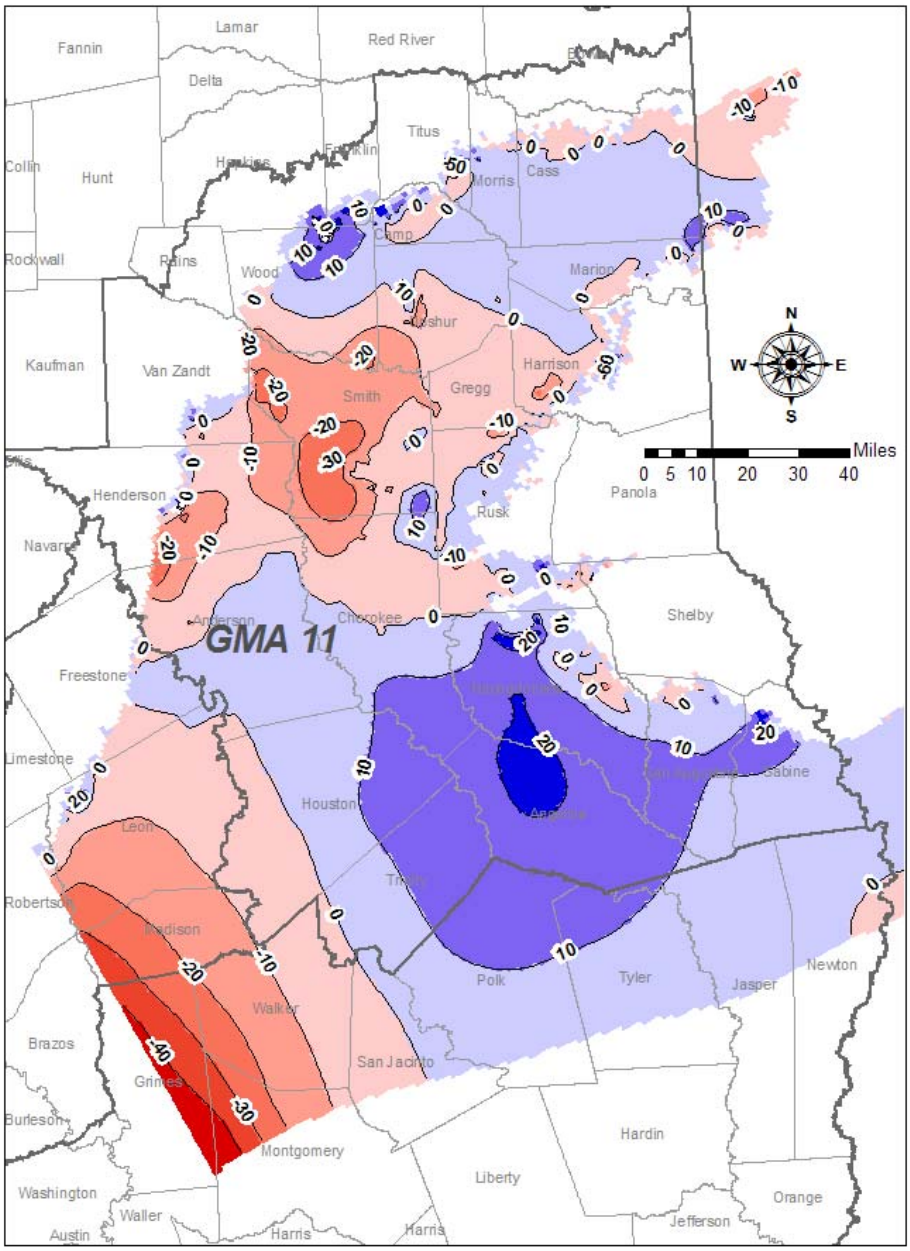

Figure 13: Water level differences in the Carrizo Aquifer after 50 years of 1999 pumpage and using 1999 water levels as a baseline. Positive numbers indicate rebound (blue areas) and negative numbers show decline (red areas). Contour interval is 10 feet. Counties outlined in dark gray indicate groundwater management area (GMA)

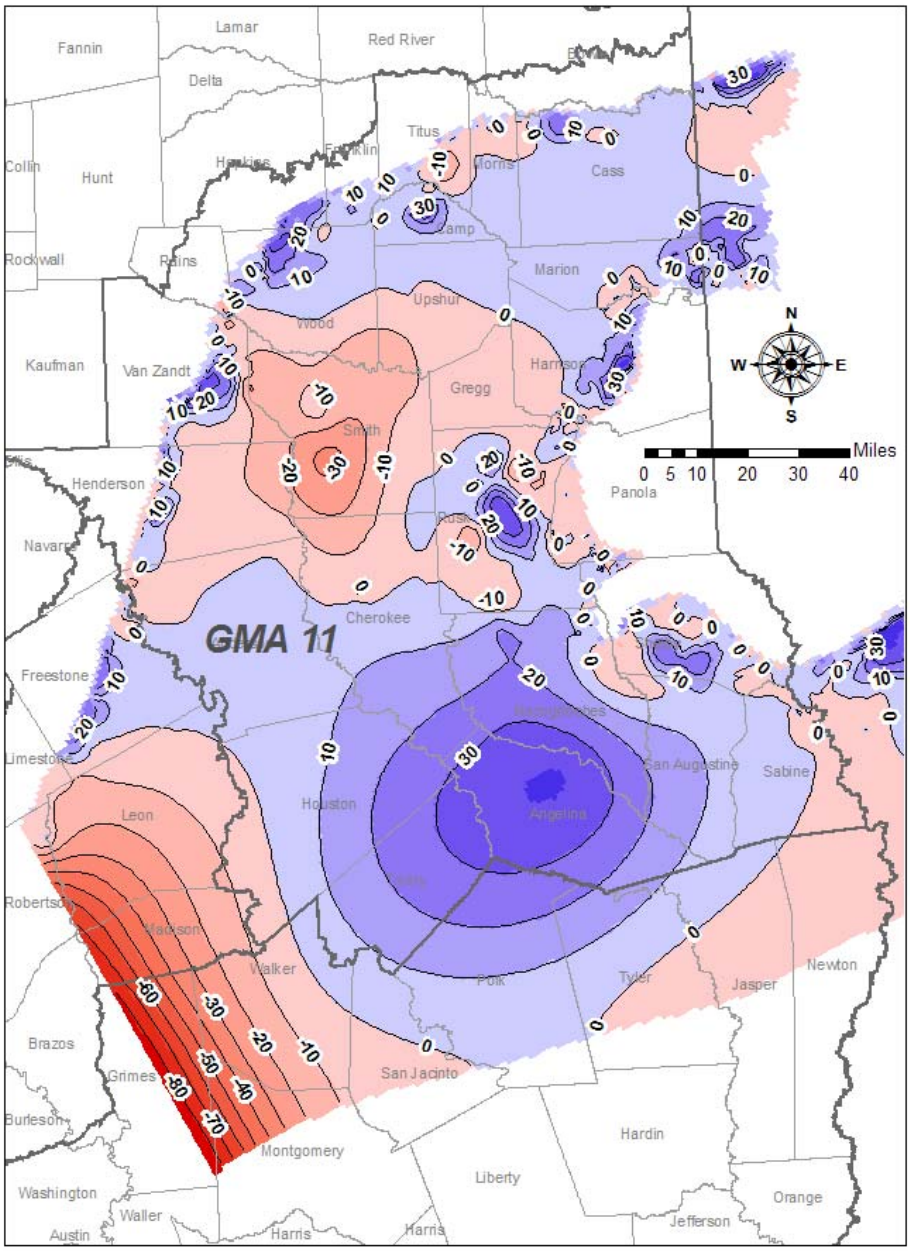

Figure 14: Water level differences in the Upper Wilcox Aquifer after 50 years of 1999 pumpage and using 1999 water levels as a baseline. Positive numbers indicate rebound (blue areas) and negative numbers show decline (red areas). Contour interval is 10 feet. Counties outlined in dark gray indicate groundwater management area (GMA).

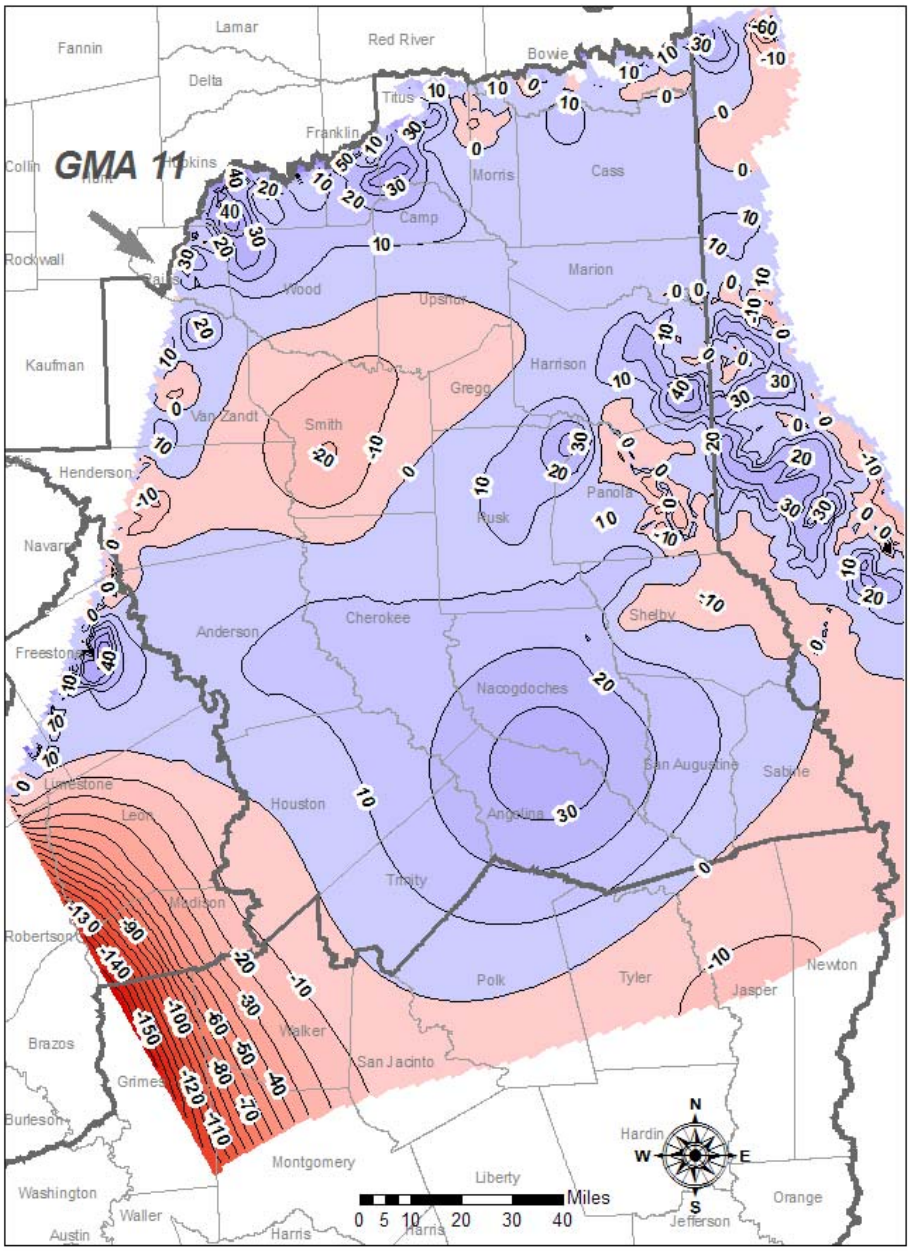

Figure 15: Water level differences in the Upper and/or Lower Wilcox Aquifer after 50 years of 1999 pumpage and using 1999 water levels as a baseline. Positive numbers indicate rebound (blue areas) and negative numbers show decline (red areas). Contour interval is 10 feet. Counties outlined in dark gray indicate groundwater management area (GMA).

Appendix A

Summary of Historic Pumpage in the GAM for the Northern part of the Queen City and Sparta Aquifers

Table A-1. Summary of estimated historic pumpage included in the groundwater availability model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers (in acre-feet per year).

Year	Total	Anderson	Angelina	Bowie	Camp	Cass	Cherokee	Franklin	Freestone	Gregg	Harrison	Henderson
1980	**140,630**	3,784	21,231	2,847	1,559	4,228	7,733	1,264	2,298	3,221	3,792	4,904
1981	**142,237**	4,190	19,910	3,000	1,621	4,397	7,829	1,336	2,455	3,396	4,220	4,165
1982	**143,514**	4,282	20,335	3,068	1,587	4,643	7,404	1,370	2,610	3,499	4,339	5,016
1983	**145,285**	4,332	19,876	3,166	1,639	4,660	7,514	1,392	2,617	3,223	4,523	5,289
1984	**153,627**	4,668	20,931	3,280	1,915	4,718	7,730	1,440	2,702	3,195	4,651	6,815
1985	**151,516**	4,602	20,961	3,287	1,844	4,685	7,571	1,453	2,850	3,048	4,784	7,326
1986	**148,965**	4,583	20,293	3,248	1,780	4,531	7,752	1,455	2,561	2,718	4,566	7,364
1987	**149,847**	4,502	19,904	3,261	1,786	4,528	8,160	1,419	2,566	2,650	4,784	6,846
1988	**166,795**	4,773	18,452	3,213	1,836	4,610	8,257	1,448	2,656	2,805	4,603	7,404
1989	**167,258**	4,915	23,114	3,424	1,763	4,599	8,189	1,448	2,500	2,688	4,436	7,326
1990	**163,078**	4,962	18,457	3,551	1,876	4,553	8,227	1,546	2,627	2,707	4,543	7,351
1991	**159,741**	4,915	17,654	3,580	1,974	4,179	7,523	1,622	2,458	2,806	4,478	7,134
1992	**165,288**	5,143	17,788	3,434	1,637	3,664	8,242	1,727	2,636	2,787	4,277	7,090
1993	**165,637**	5,390	17,443	3,574	1,660	3,593	8,483	1,791	2,658	2,926	4,592	7,509
1994	**167,512**	5,224	17,559	3,577	1,767	3,568	8,837	1,735	2,727	2,951	4,438	7,567
1995	**171,286**	5,408	18,269	3,651	1,630	3,693	8,814	1,724	2,842	2,977	4,356	7,910
1996	**172,809**	5,535	18,416	3,715	1,589	3,596	8,681	1,745	2,984	2,997	4,402	8,033
1997	**170,142**	5,701	18,308	3,714	1,646	3,643	8,926	1,199	2,872	2,921	4,470	8,013
1998	**175,481**	5,864	20,117	3,689	1,654	3,621	9,298	1,463	2,987	2,558	4,504	8,373
1999	**173,399**	5,549	19,776	3,531	1,572	3,296	8,983	1,490	2,960	3,008	4,403	8,389

Table A-1. continued

Year	Hopkins	Houston	Leon	Limestone	Madison	Marion	Morris	Nacogdoches	Navarro	Panola	Rains	Robertson
1980	3,147	1,567	2,551	819	1,763	982	1,991	16,532	982	3,487	620	158
1981	2,993	1,591	2,576	852	1,856	1,095	2,169	15,386	1,095	3,404	693	161
1982	3,101	1,673	2,857	933	1,908	1,132	2,188	15,555	1,132	3,574	726	164
1983	3,275	1,671	2,951	979	2,302	1,154	1,970	15,536	1,154	3,349	750	167
1984	3,657	1,744	3,867	1,139	2,261	1,133	2,002	16,461	1,133	3,796	821	176
1985	3,667	1,759	3,763	1,725	2,315	1,085	1,819	16,276	1,085	3,947	825	193
1986	3,517	1,549	3,529	1,944	2,463	1,007	1,658	16,470	1,007	4,210	808	188
1987	3,608	1,705	3,748	1,794	1,752	1,027	1,590	16,407	1,027	4,327	830	175
1988	3,350	1,772	3,977	1,825	1,905	1,027	1,633	15,928	1,027	4,456	888	237
1989	3,346	1,578	3,679	2,219	1,955	1,082	7,870	19,501	1,082	4,427	914	162
1990	4,297	1,423	3,750	2,282	1,966	1,090	7,841	15,244	1,090	4,647	997	160
1991	4,359	1,379	3,669	2,146	2,086	1,064	7,836	14,449	1,064	4,646	1,013	173
1992	4,676	1,342	3,594	1,961	1,705	1,042	1,503	14,172	1,042	4,677	955	180
1993	4,683	1,742	3,686	1,971	1,743	1,172	1,479	15,511	1,172	4,729	983	185
1994	4,940	1,832	3,546	1,973	1,891	1,149	1,549	15,485	1,149	4,986	1,029	183
1995	4,735	1,750	3,733	1,849	1,818	1,156	1,580	16,030	1,156	5,034	1,047	227
1996	4,671	1,838	3,628	2,026	2,003	1,156	1,521	14,672	1,156	5,760	1,064	186
1997	4,561	1,750	4,115	1,990	1,773	1,241	1,481	14,333	1,241	5,712	1,082	202
1998	4,946	1,822	4,046	1,939	1,877	1,246	1,552	14,204	1,246	5,099	1,132	59
1999	4,990	1,789	3,988	1,953	1,942	1,276	1,473	14,872	1,276	4,461	1,138	59

Table A-1. continued

Year	Rusk	Sabine	San Augustine	Shelby	Smith	Titus	Trinity	Upshur	Van Zandt	Walker	Wood
1980	7,286	569	692	2,979	12,012	1,521	23	4,096	4,989	1	7,001
1981	7,369	619	656	2,904	13,682	1,634	25	4,438	4,960	1	7,036
1982	7,462	634	703	2,976	13,651	1,649	27	4,562	5,238	1	7,167
1983	7,270	660	686	3,072	13,801	1,748	28	4,487	5,159	1	7,327
1984	7,016	694	869	3,712	14,542	1,747	31	4,649	5,642	1	7,308
1985	7,623	679	760	3,058	14,411	1,873	32	4,508	5,369	1	7,160
1986	7,495	676	752	3,002	13,770	1,730	33	4,571	5,644	1	6,448
1987	7,431	684	729	3,044	14,151	1,756	33	4,746	5,671	1	6,119
1988	8,081	753	810	3,178	21,035	1,736	34	4,792	5,843	1	5,883
1989	7,828	731	712	3,036	13,965	1,928	34	4,582	5,630	1	6,257
1990	7,961	756	712	3,177	12,376	1,910	36	4,677	5,614	1	5,491
1991	7,730	739	609	3,189	13,016	1,808	36	4,678	5,753	1	5,138
1992	7,773	735	610	3,404	13,544	1,692	37	5,022	5,687	1	5,013
1993	8,082	787	707	3,235	14,393	1,741	39	5,446	5,912	1	5,057
1994	7,736	752	675	3,558	14,431	2,033	39	5,555	5,824	1	5,363
1995	8,353	749	696	3,508	14,834	2,001	39	5,253	5,987	1	5,443
1996	8,870	767	650	3,570	14,334	2,032	40	5,602	6,308	1	5,496
1997	8,623	798	683	3,566	14,177	1,935	40	5,374	6,194	1	5,453
1998	8,448	798	686	3,515	15,055	1,934	41	5,913	6,602	1	5,842
1999	7,686	807	691	3,561	14,682	1,976	42	5,843	6,031	1	5,901

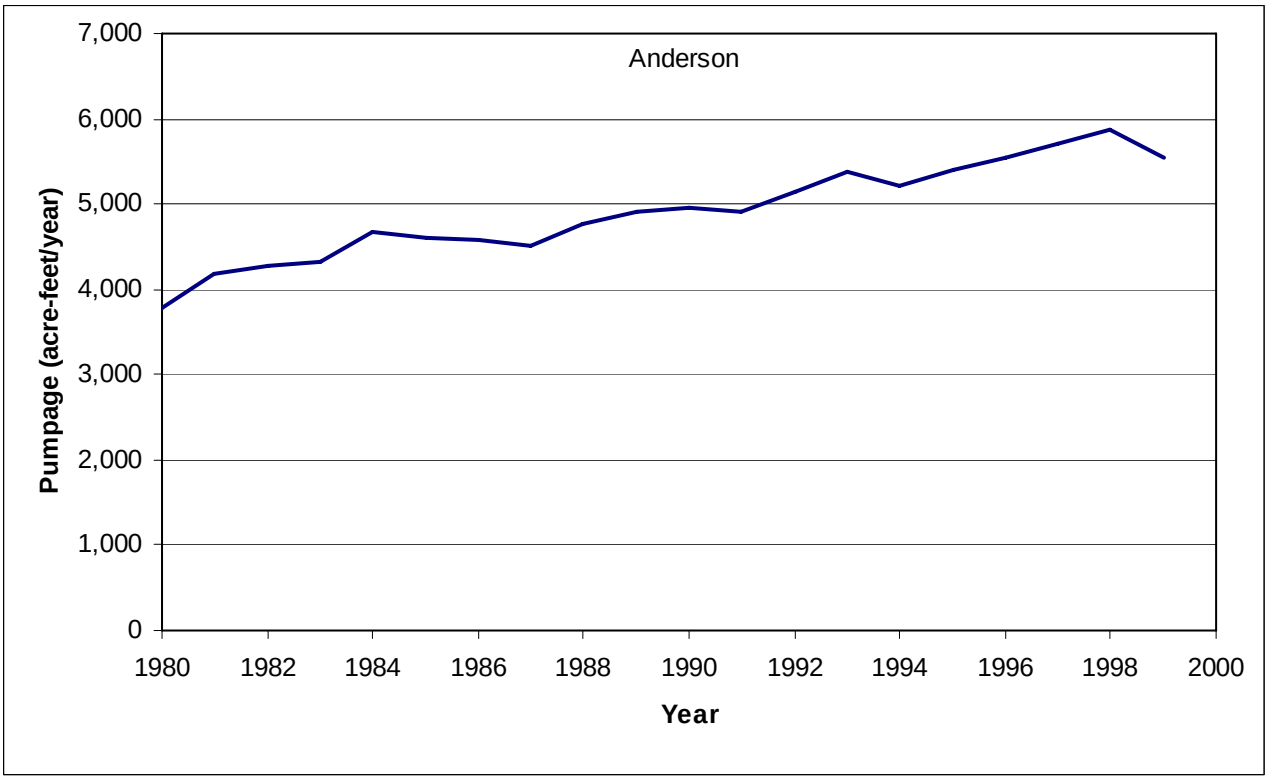

Figure A-1- Pumpage in Anderson County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

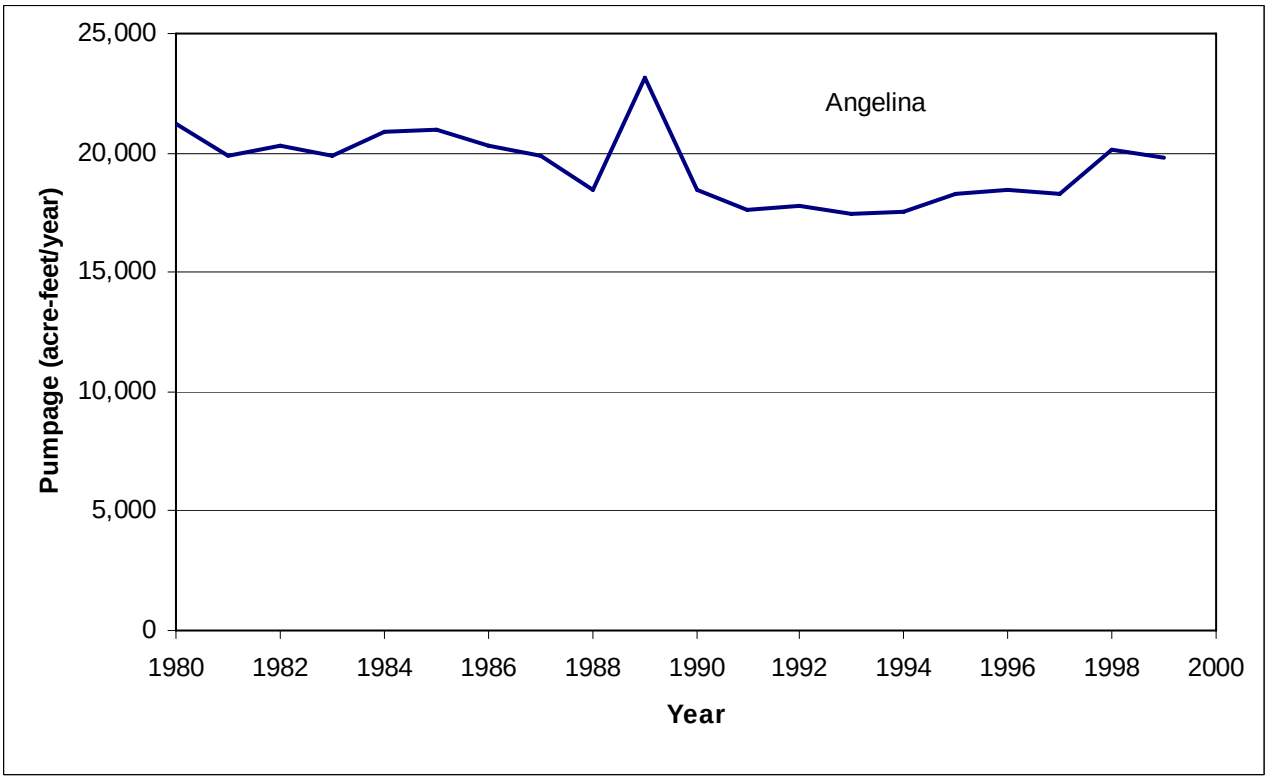

Figure A-2- Pumpage in Angelina County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

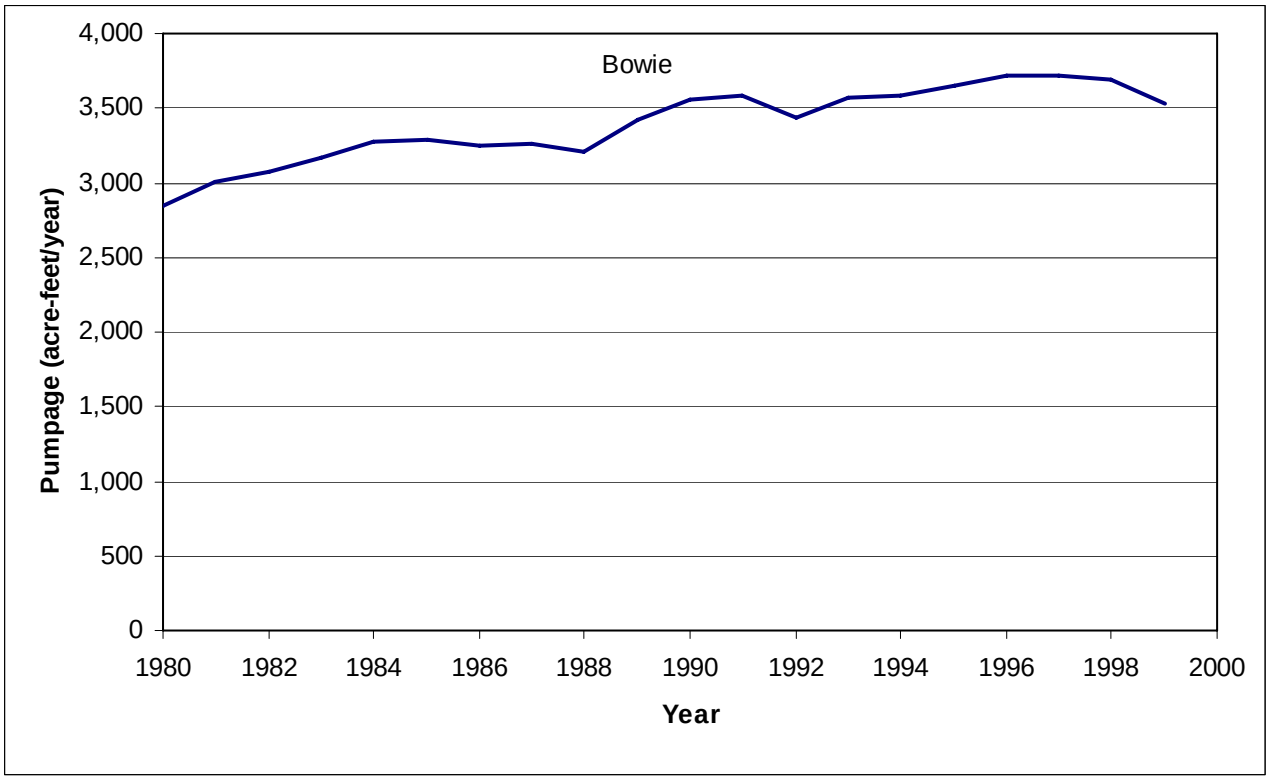

Figure A-3- Pumpage in Bowie County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

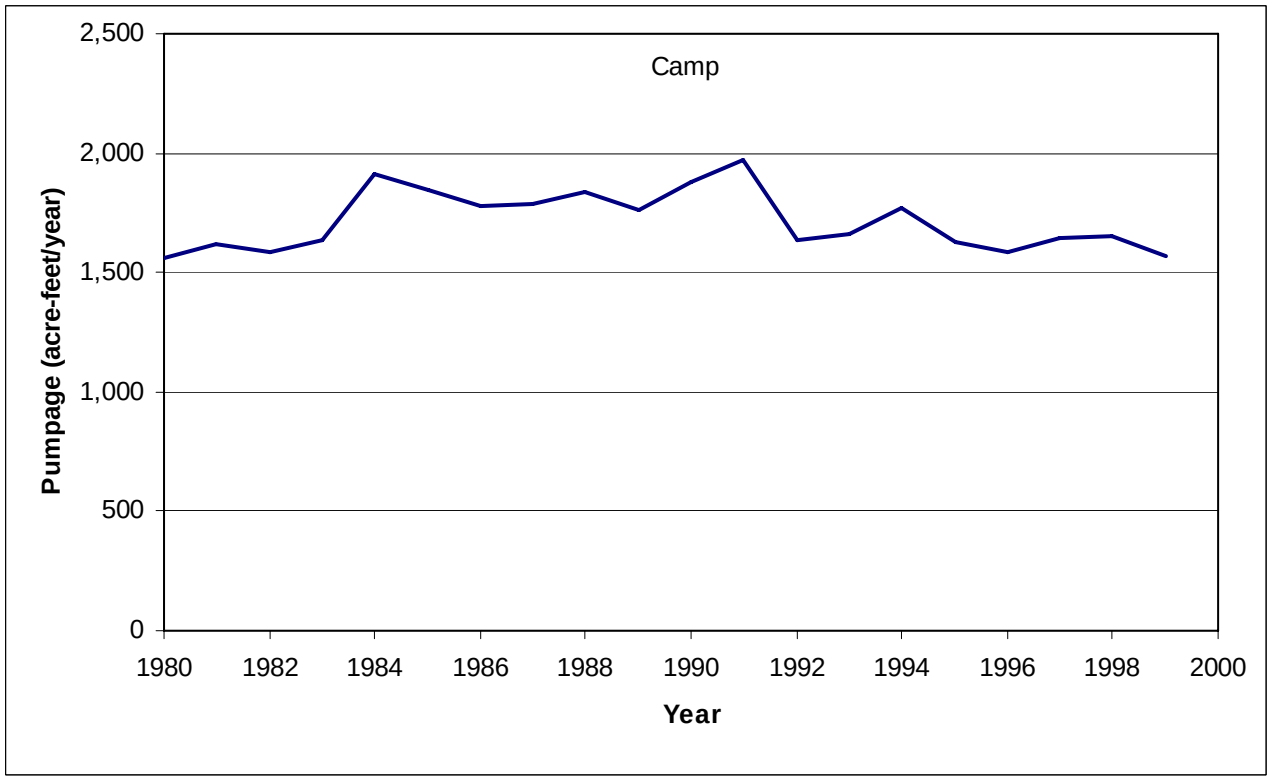

Figure A-4- Pumpage in Camp County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

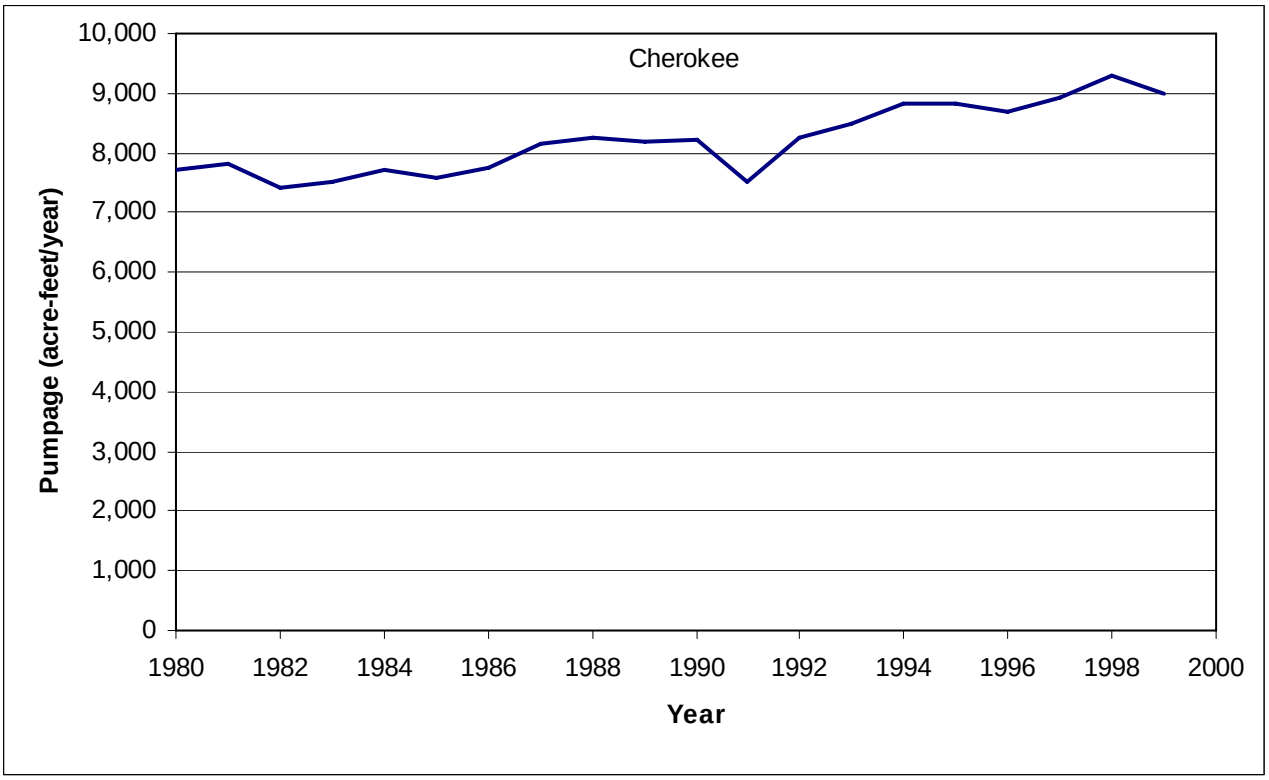

Figure A-7- Pumpage in Cherokee County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

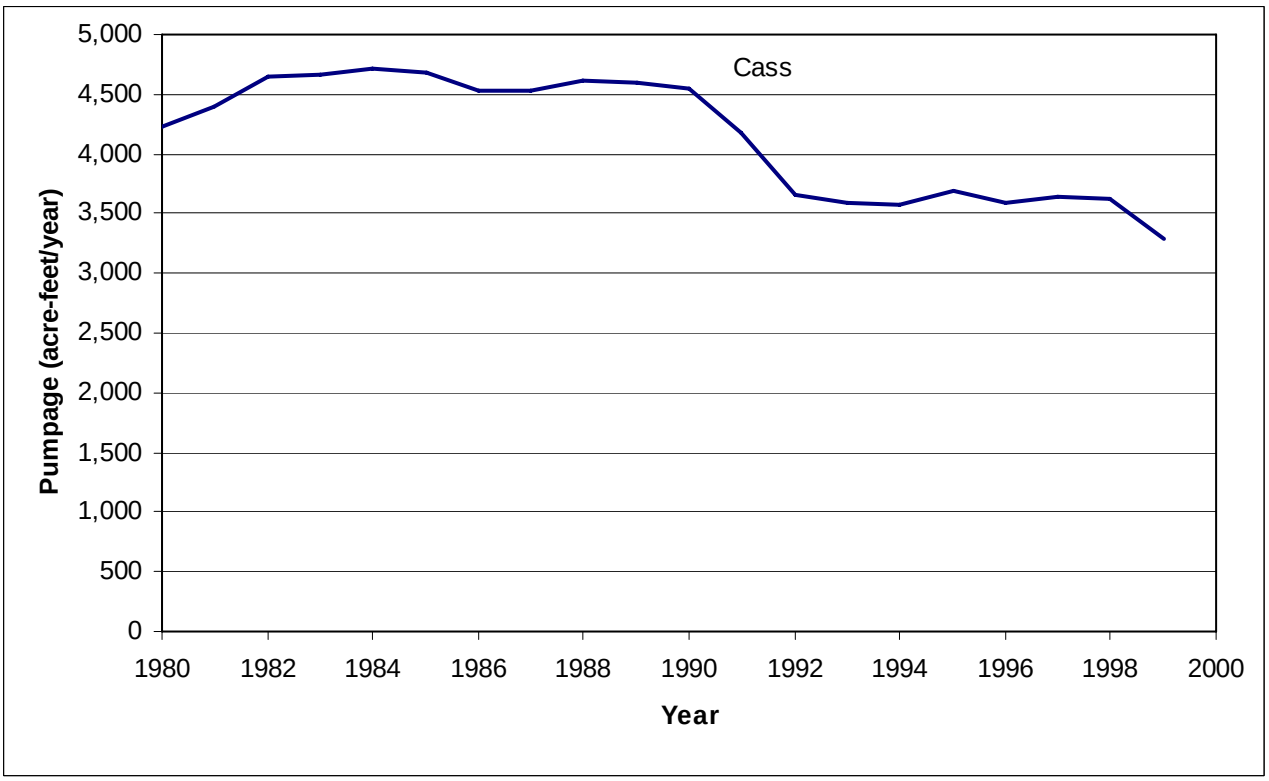

Figure A-6- Pumpage in Cass County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

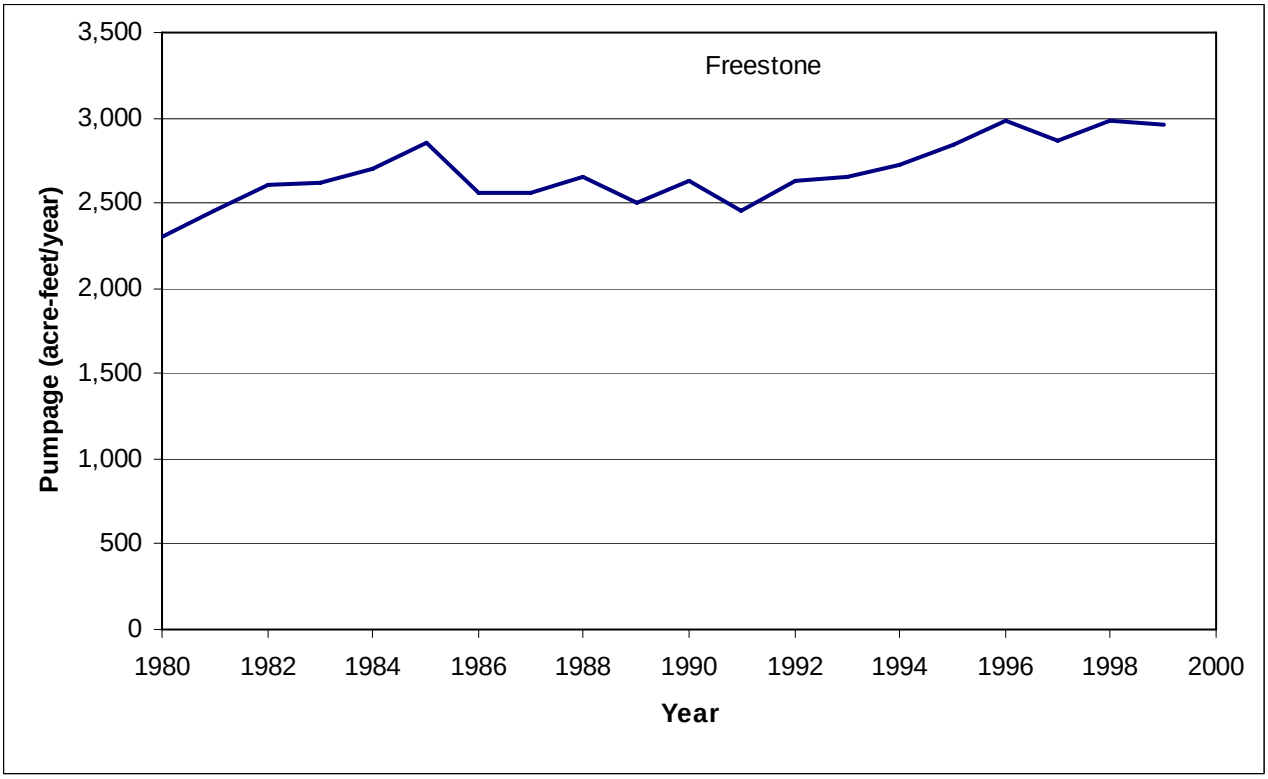

Figure A-9- Pumpage in Freestone County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

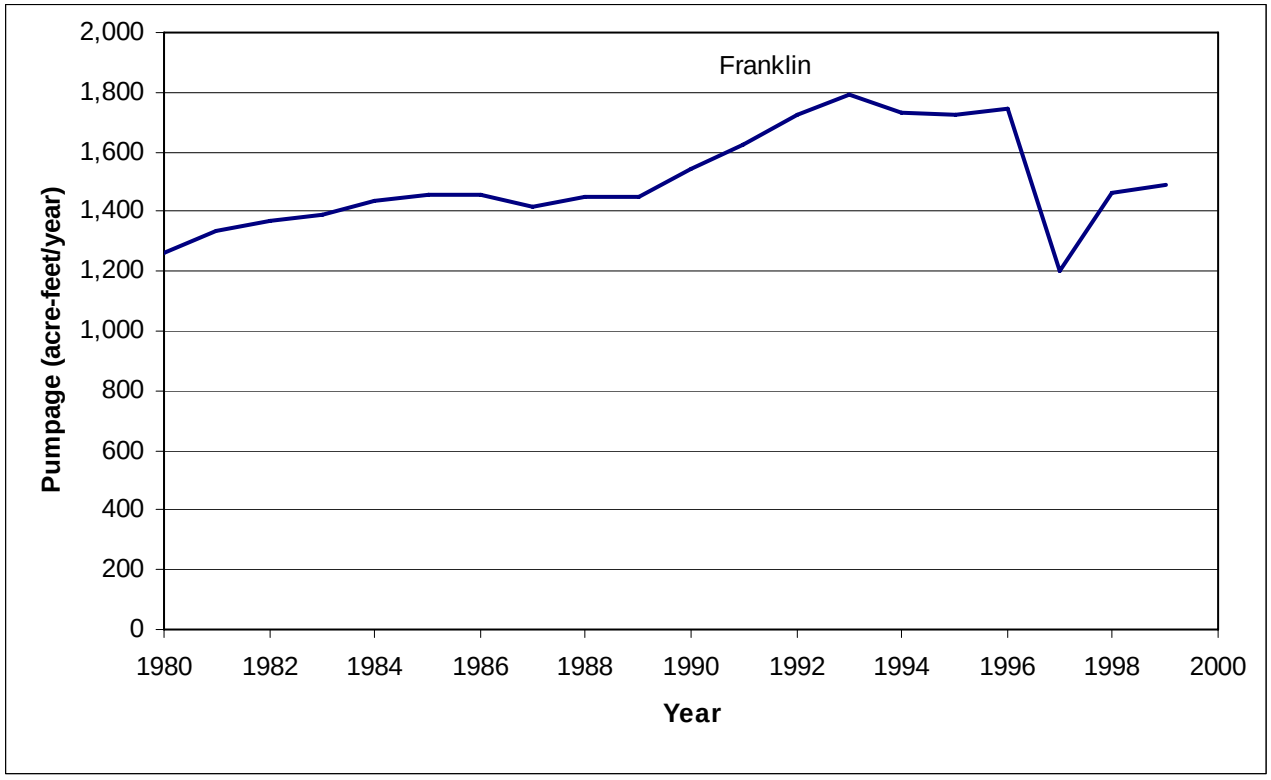

Figure A-8- Pumpage in Franklin County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

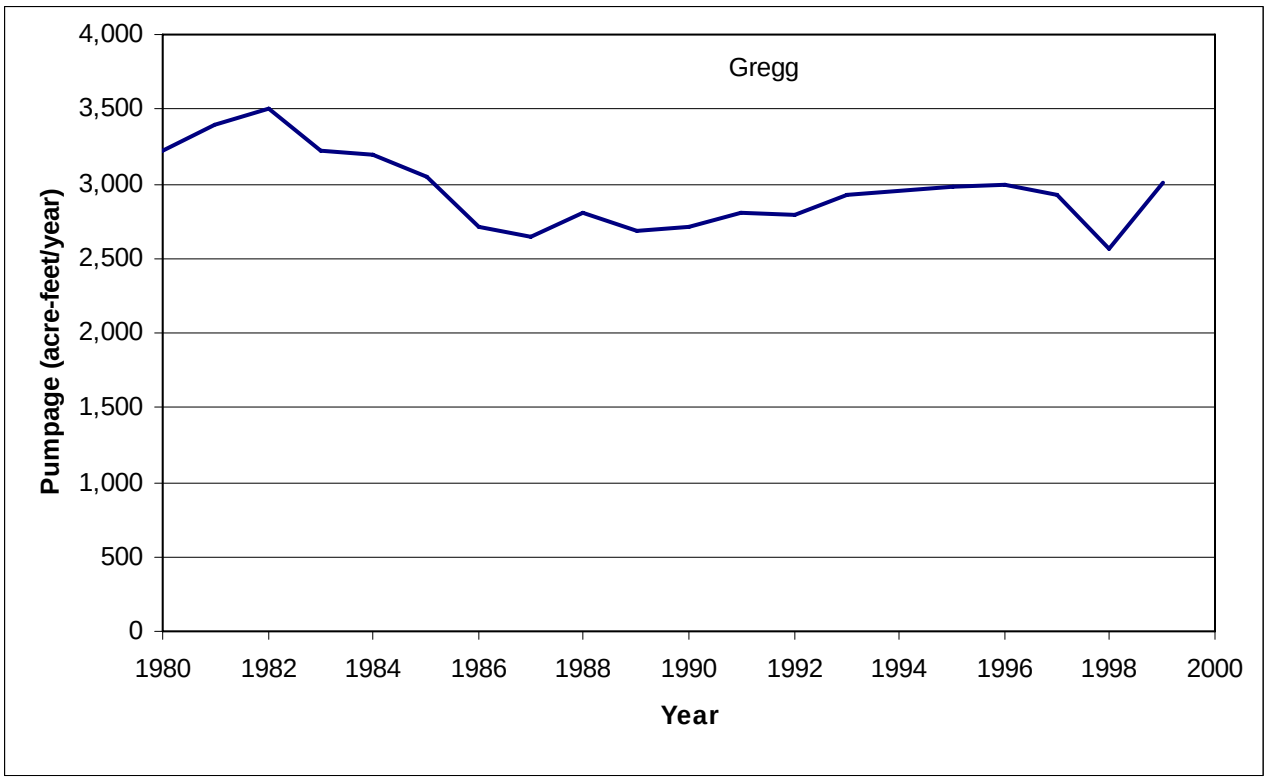

Figure A-10- Pumpage in Gregg County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

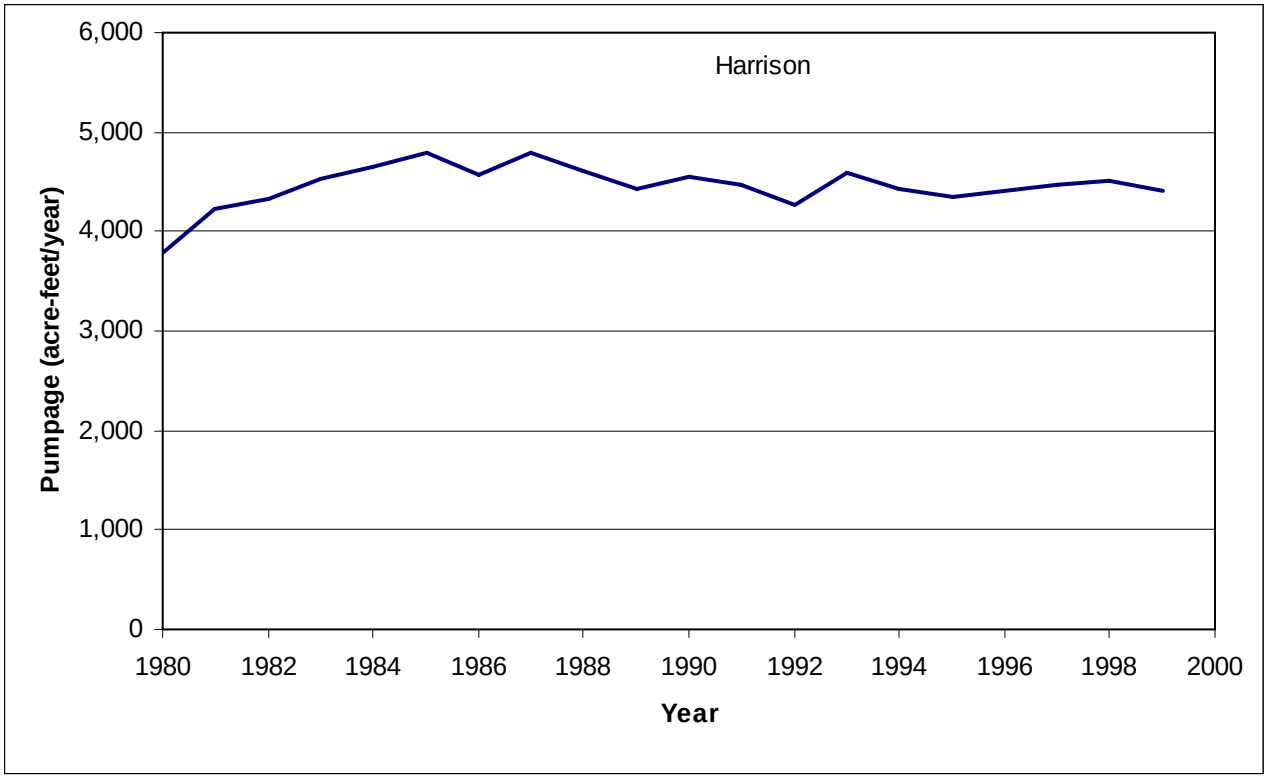

Figure A-11- Pumpage in Harrison County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

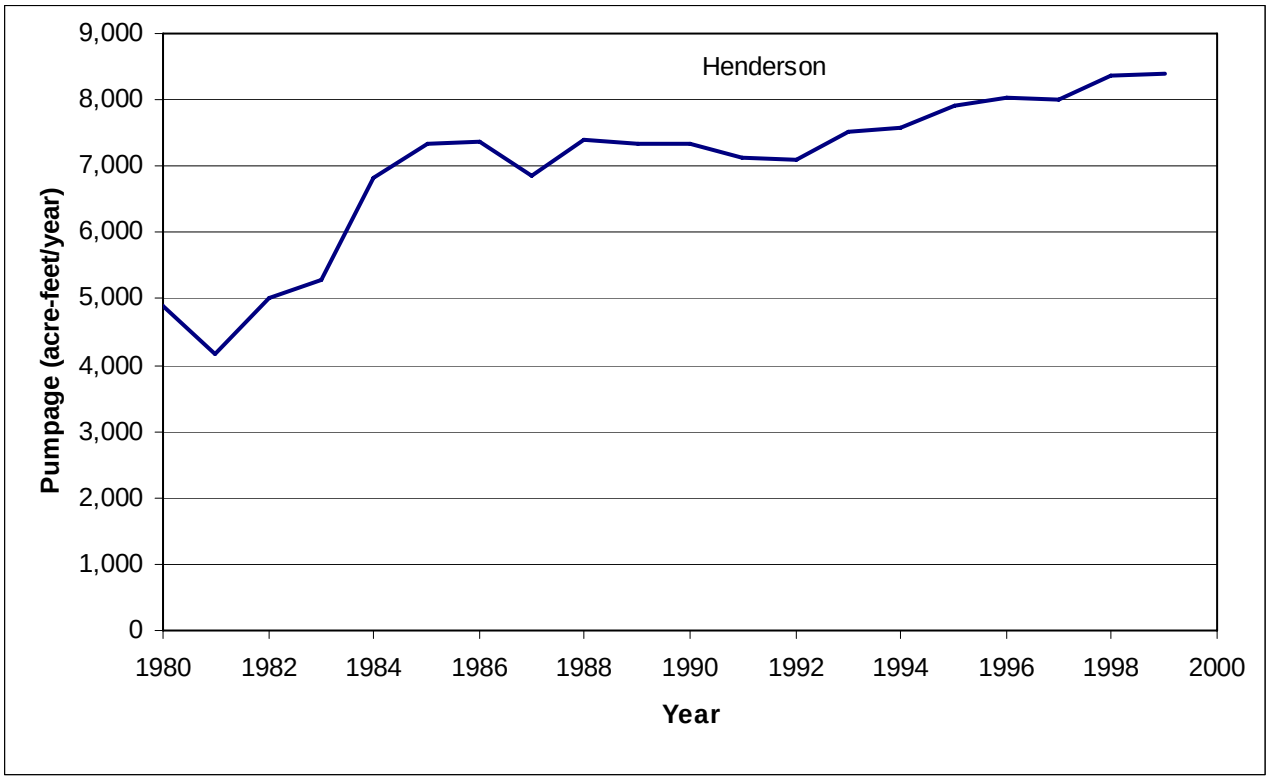

Figure A-12- Pumpage in Henderson County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

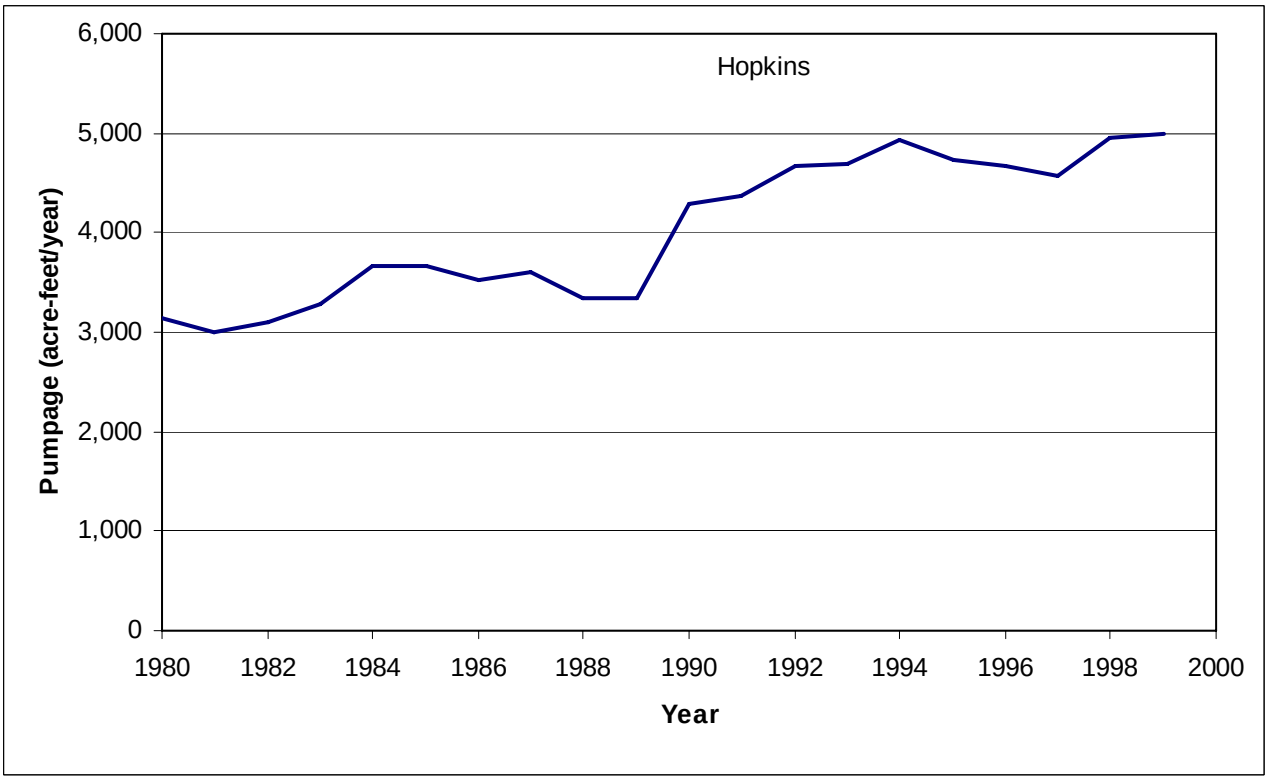

Figure A-13- Pumpage in Hopkins County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

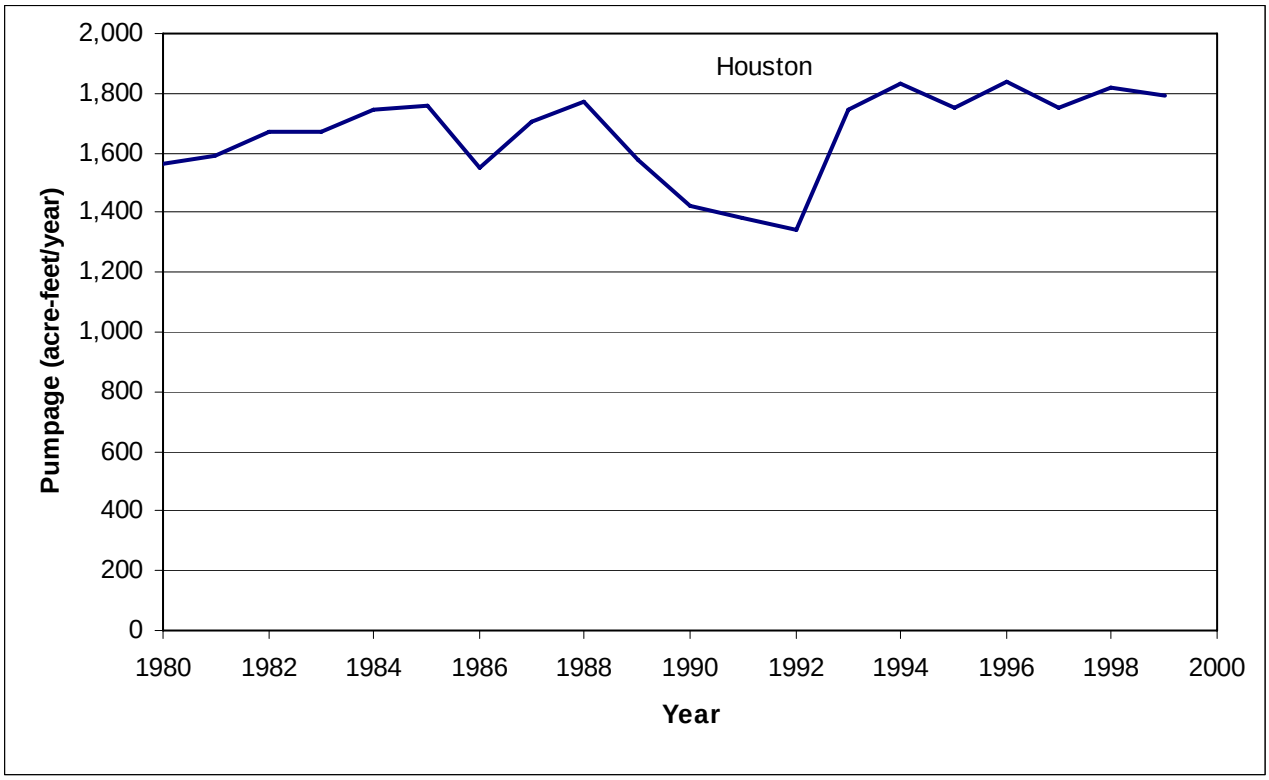

Figure A-14- Pumpage in Houston County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

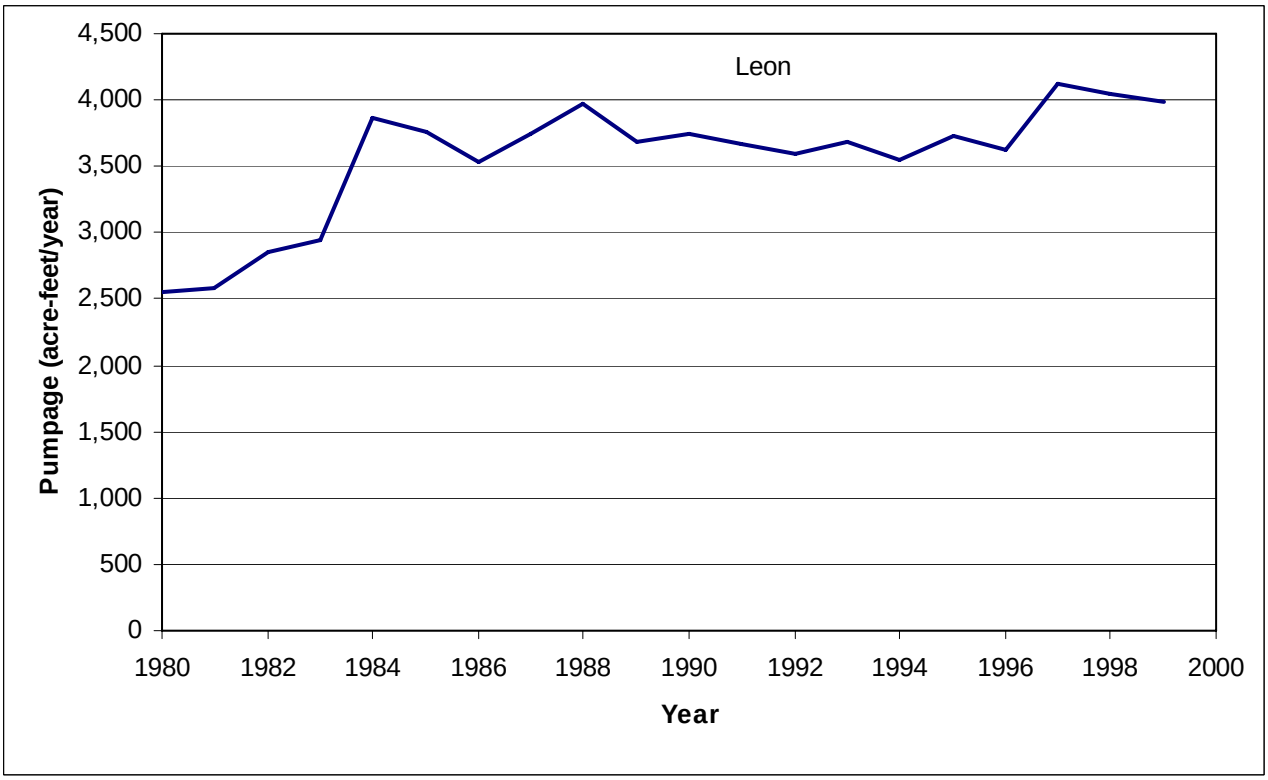

Figure A-15- Pumpage in Leon County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

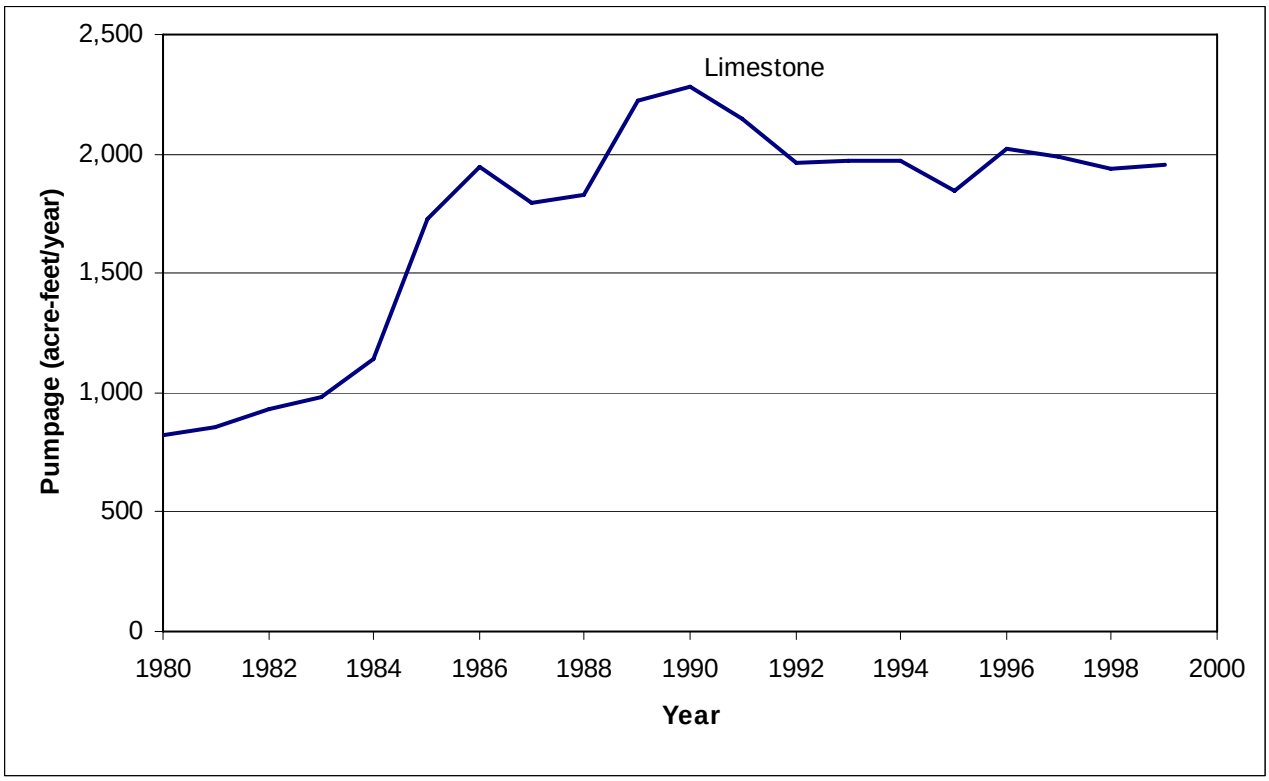

Figure A-16- Pumpage in Limestone County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

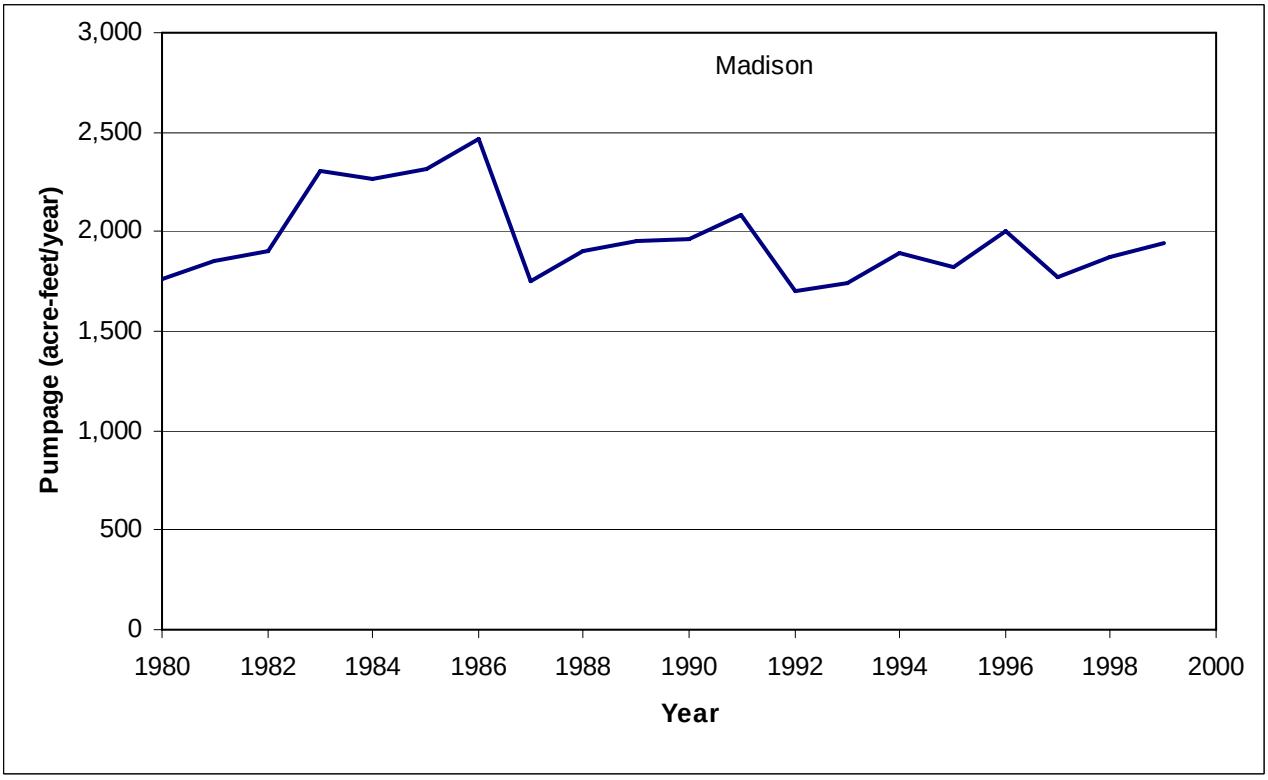

Figure A-17- Pumpage in Madison County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

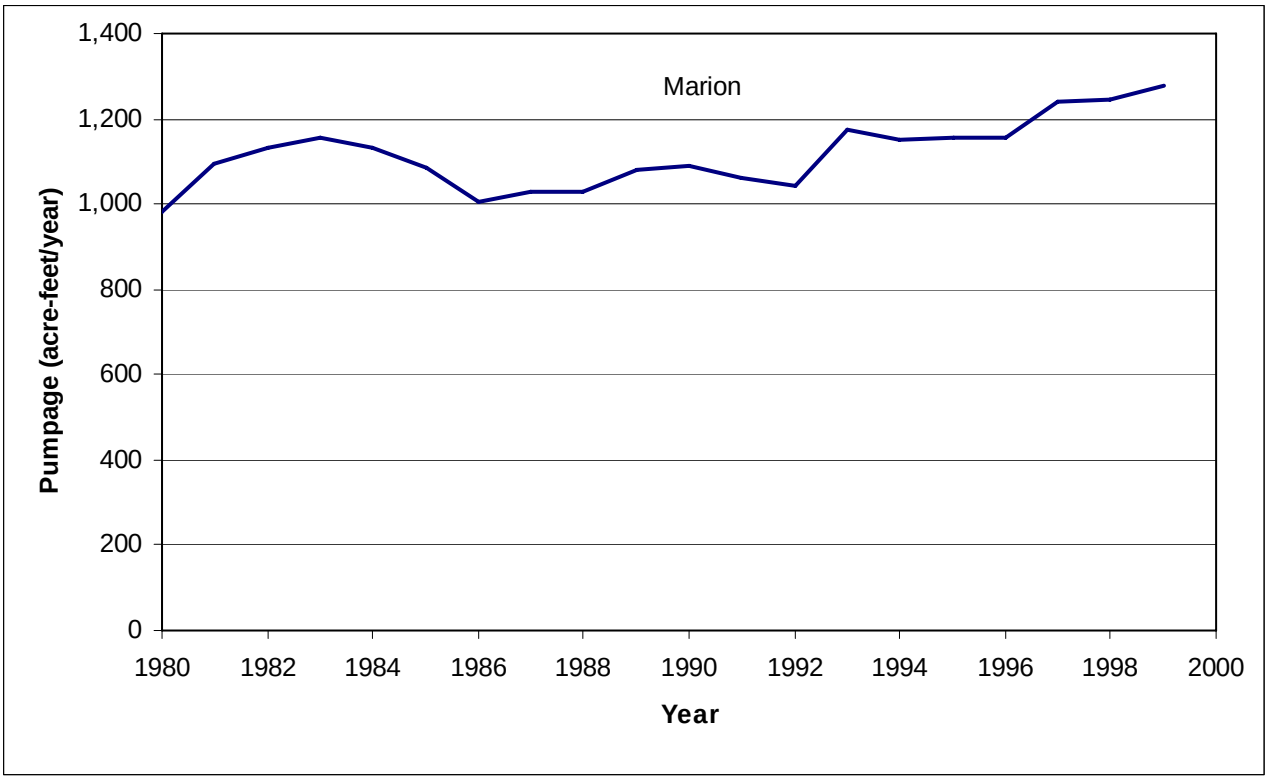

Figure A-18- Pumpage in Marion County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

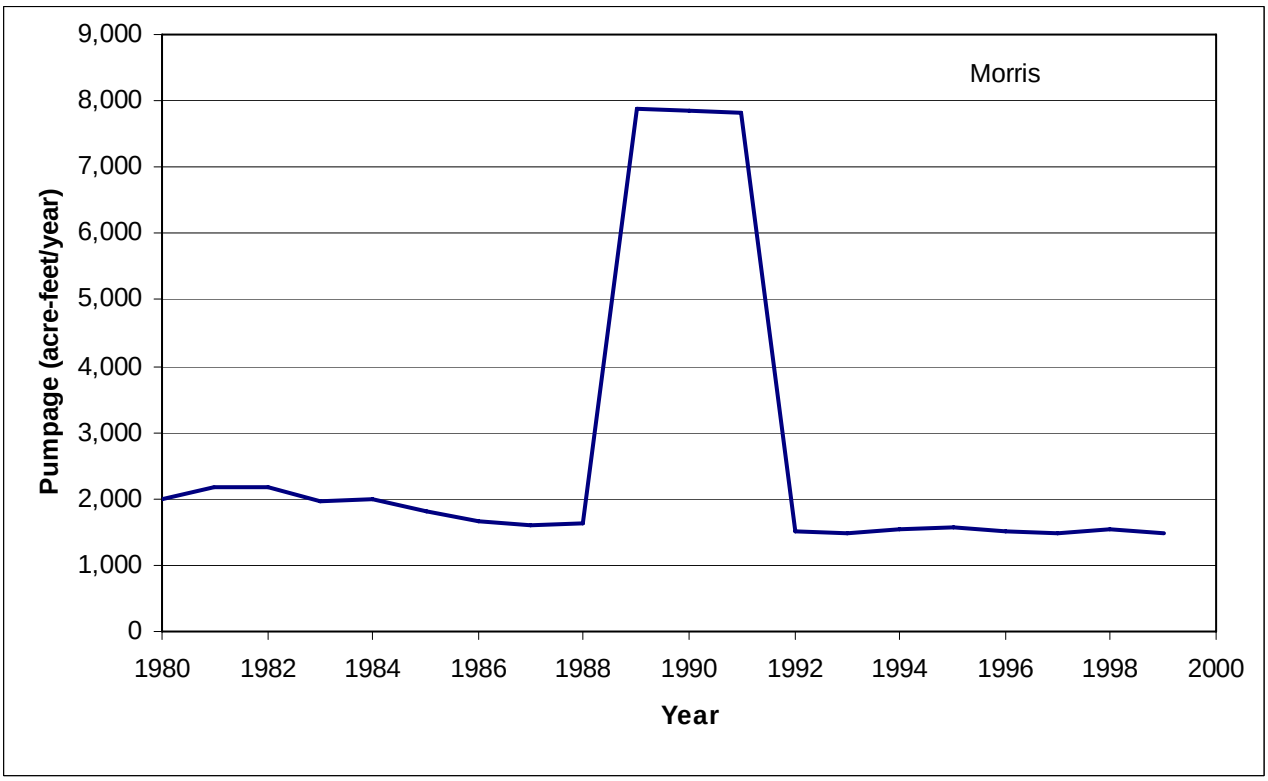

Figure A-19- Pumpage in Morris County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

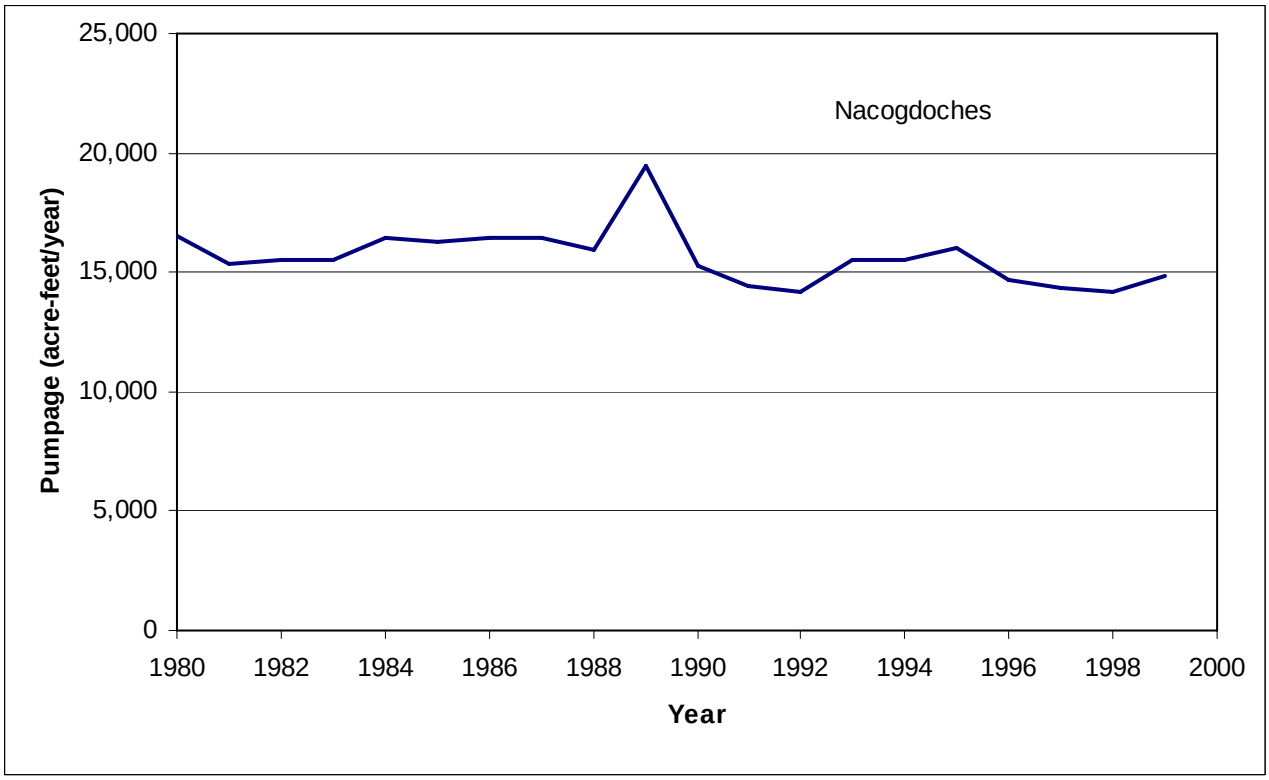

Figure A-20- Pumpage in Nacogdoches County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

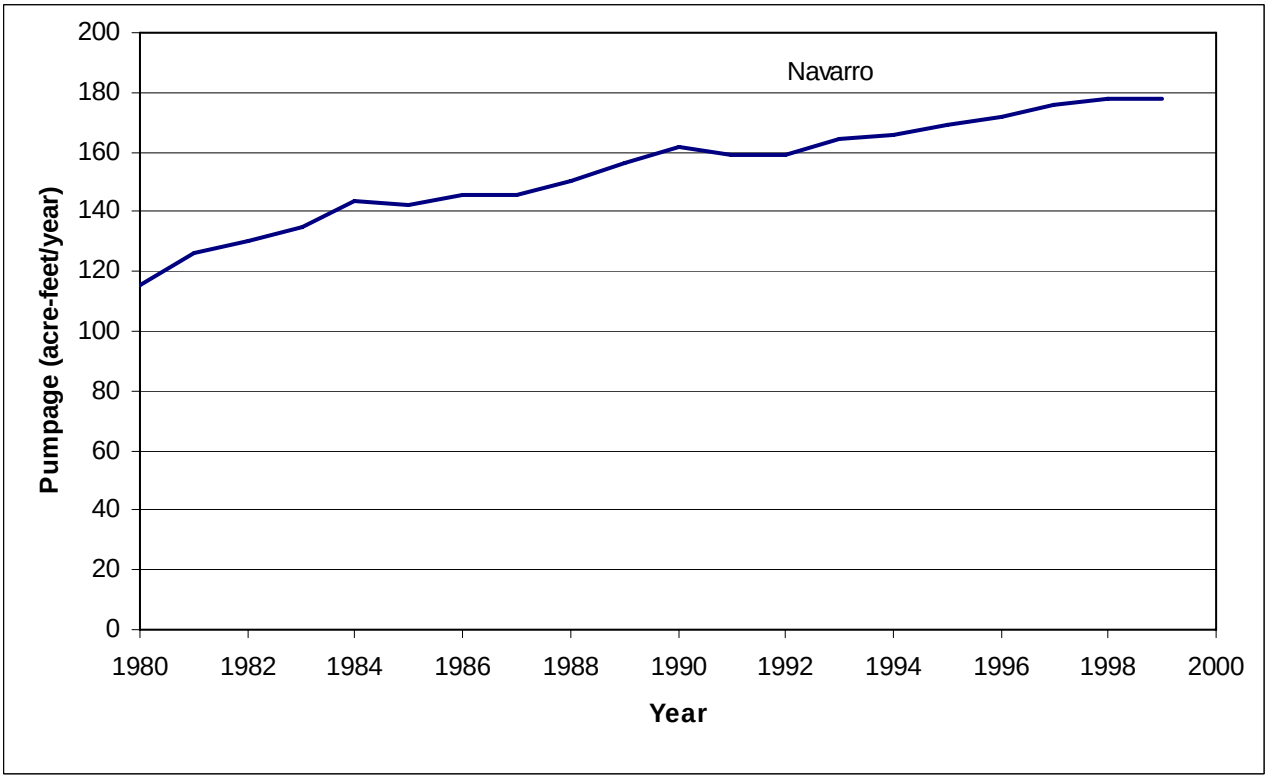

Figure A-21- Pumpage in Navarro County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

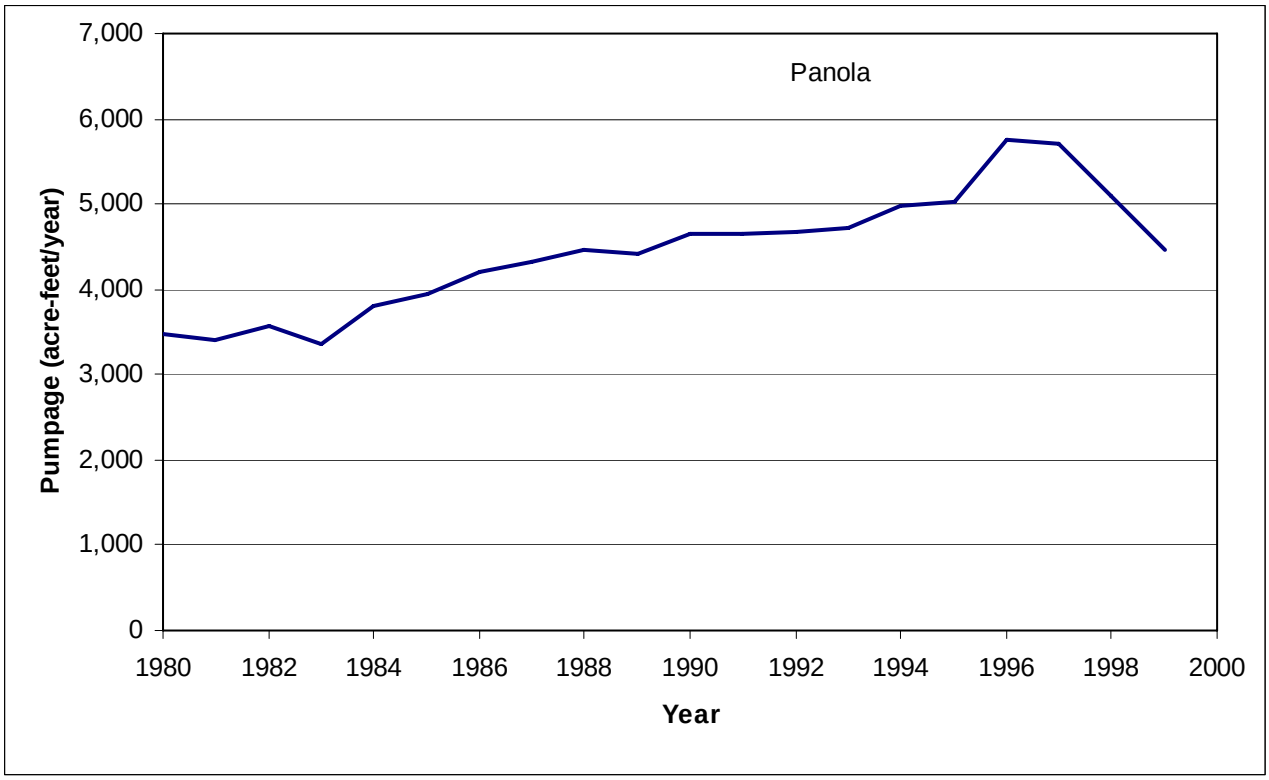

Figure A-22- Pumpage in Panola County included in the GAM for the Northern part of the Queen City and Sparta Aquifers.

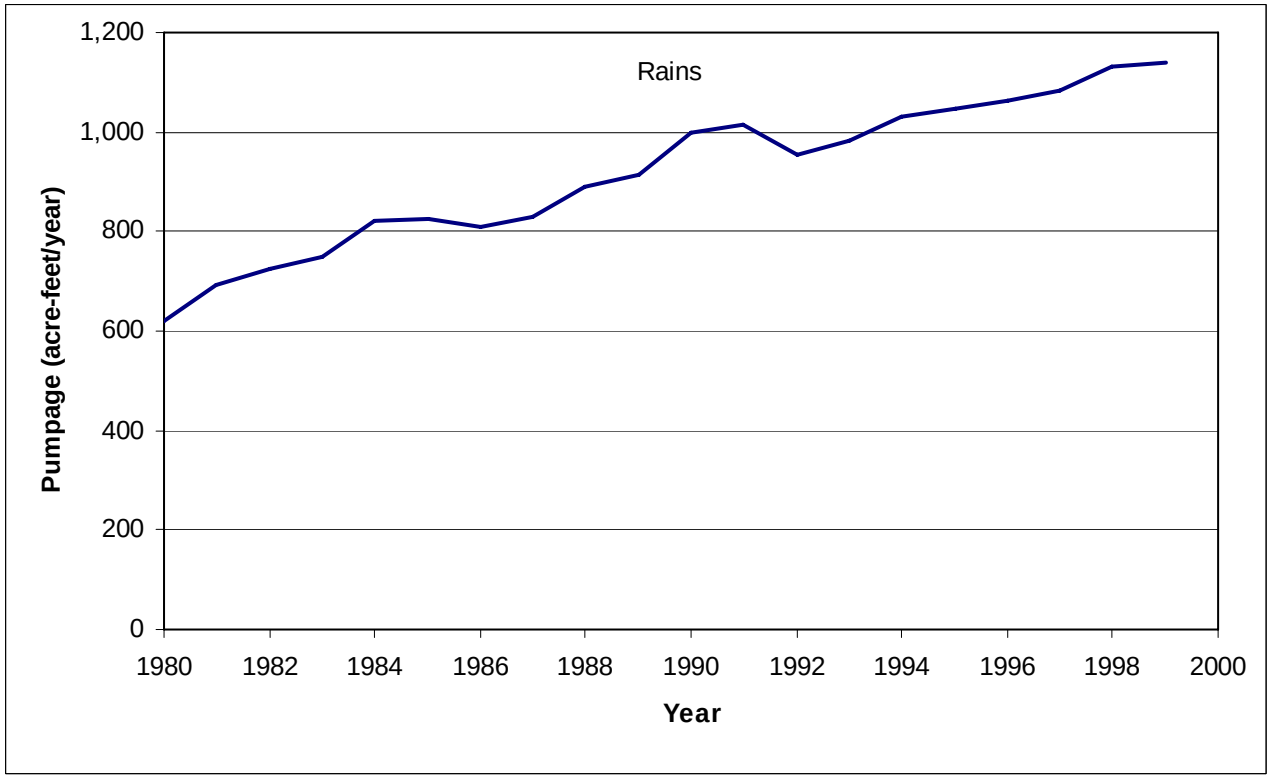

Figure A-23- Pumpage in Rains County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

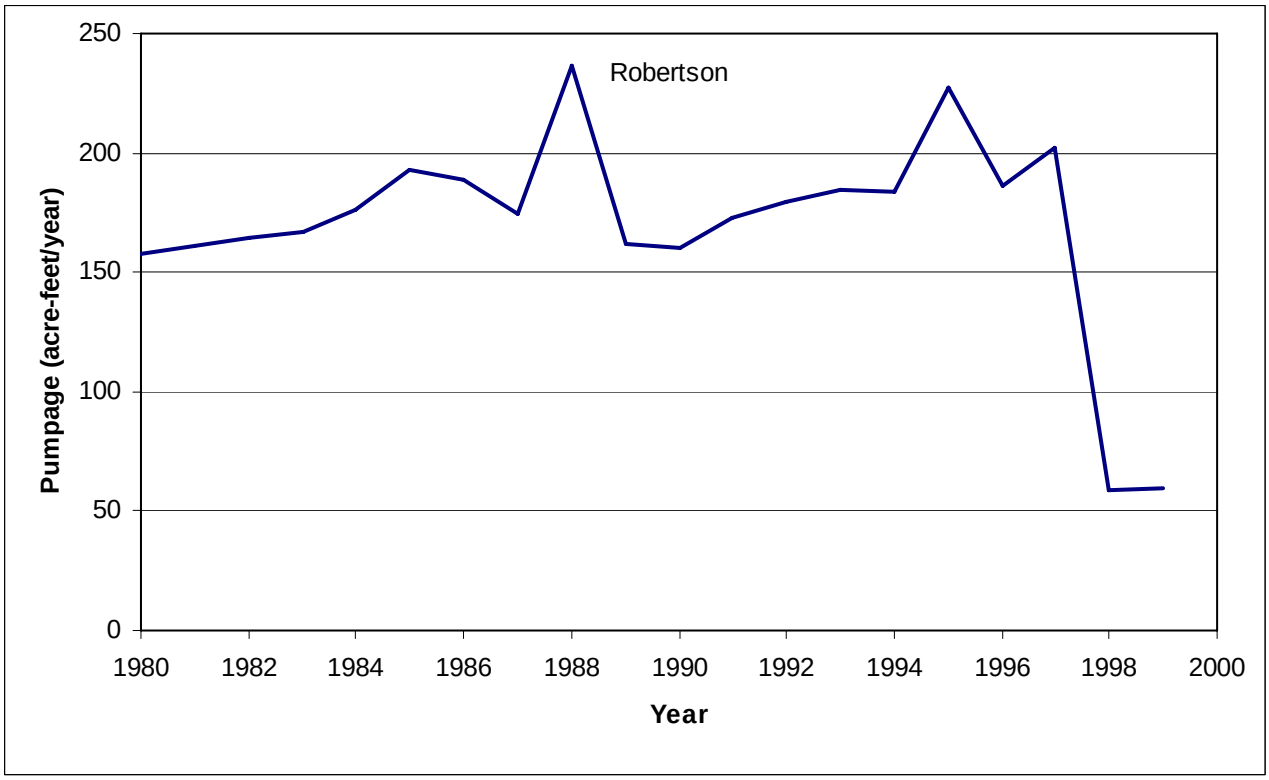

Figure A-24- Pumpage in Robertson County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

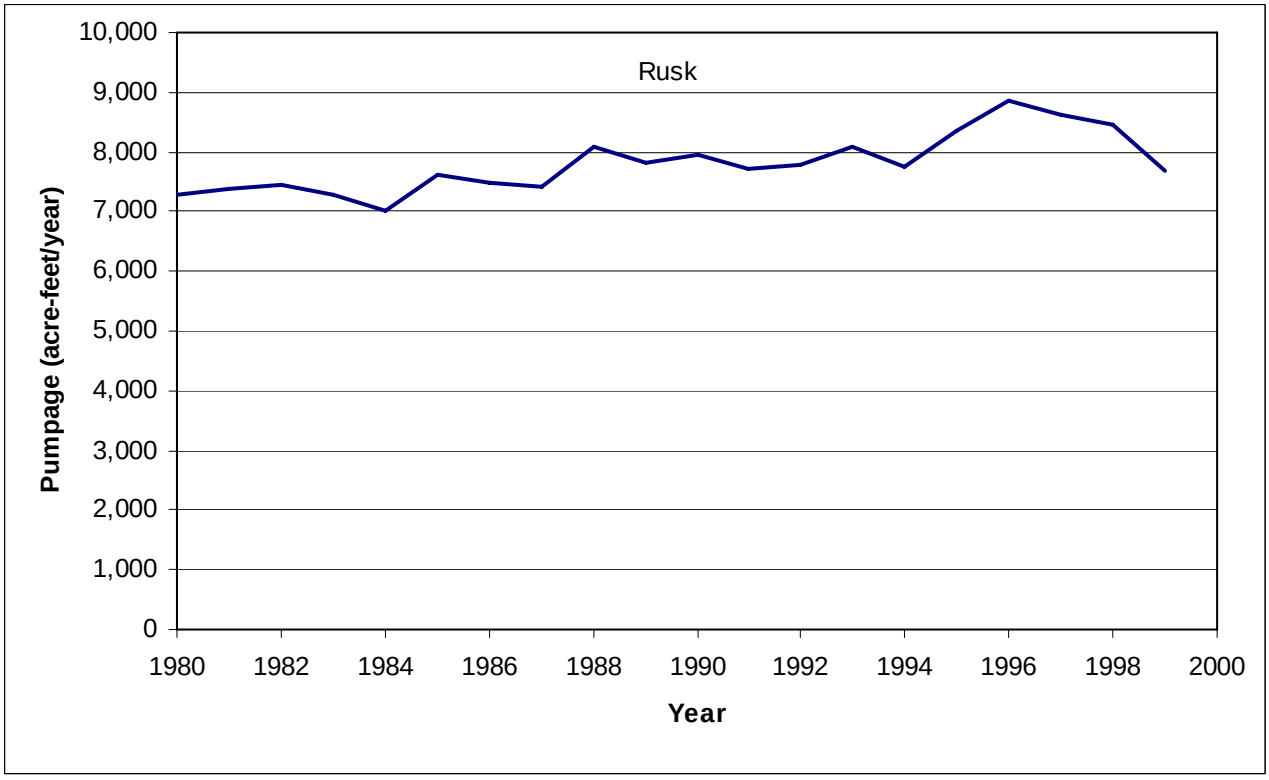

Figure A-25- Pumpage in Rusk County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

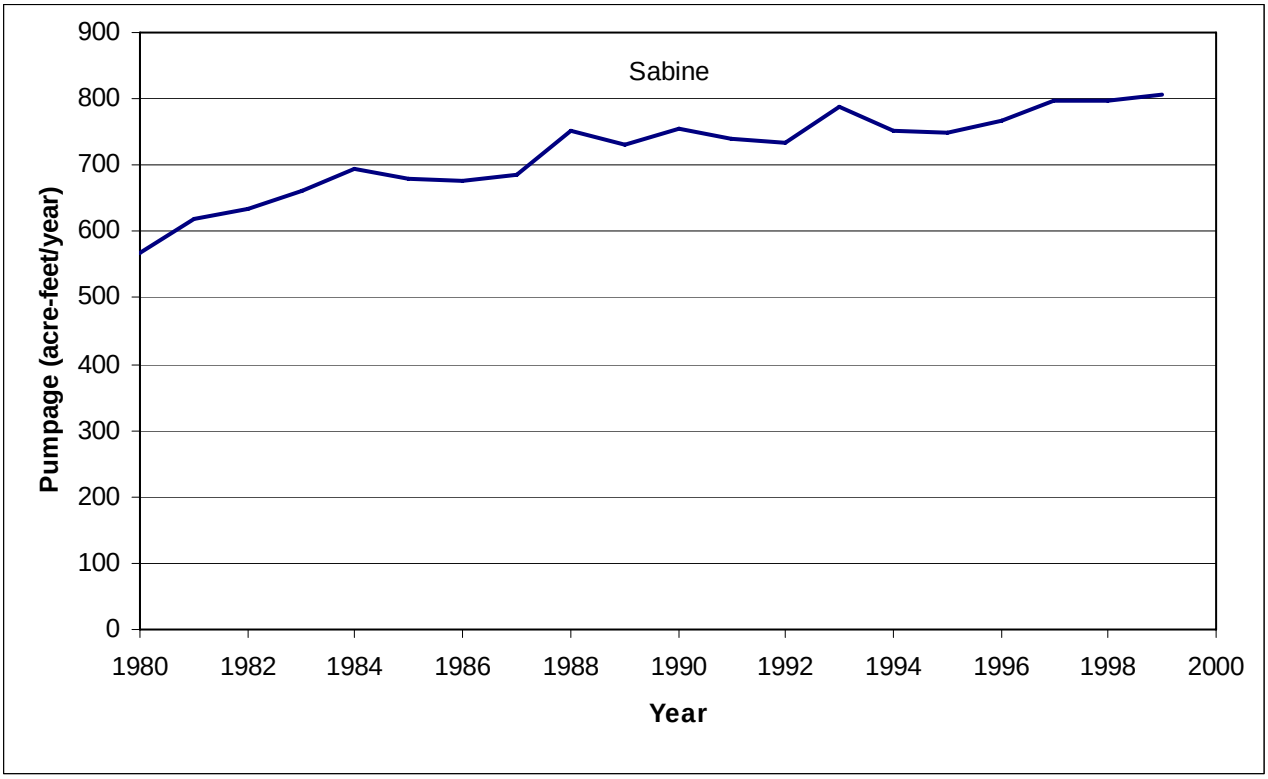

Figure A-26- Pumpage in Sabine County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

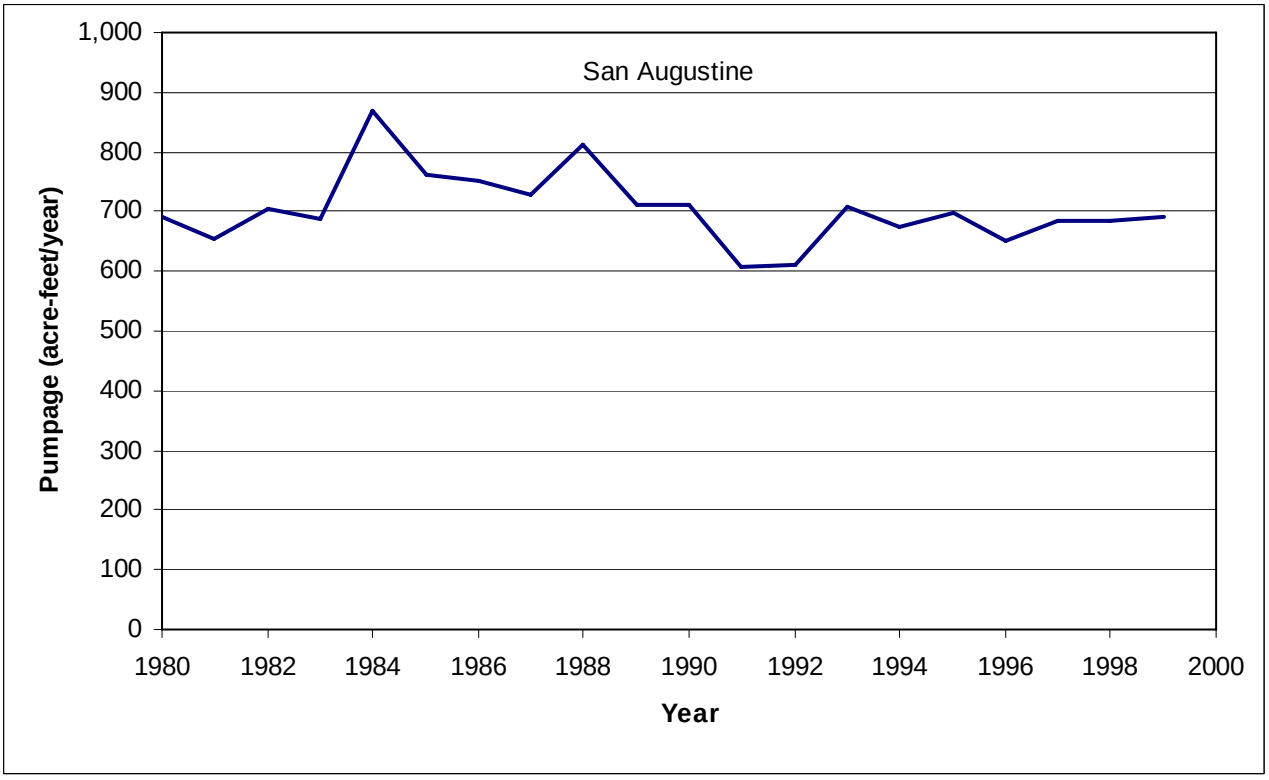

Figure A-27- Pumpage in San Augustine County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

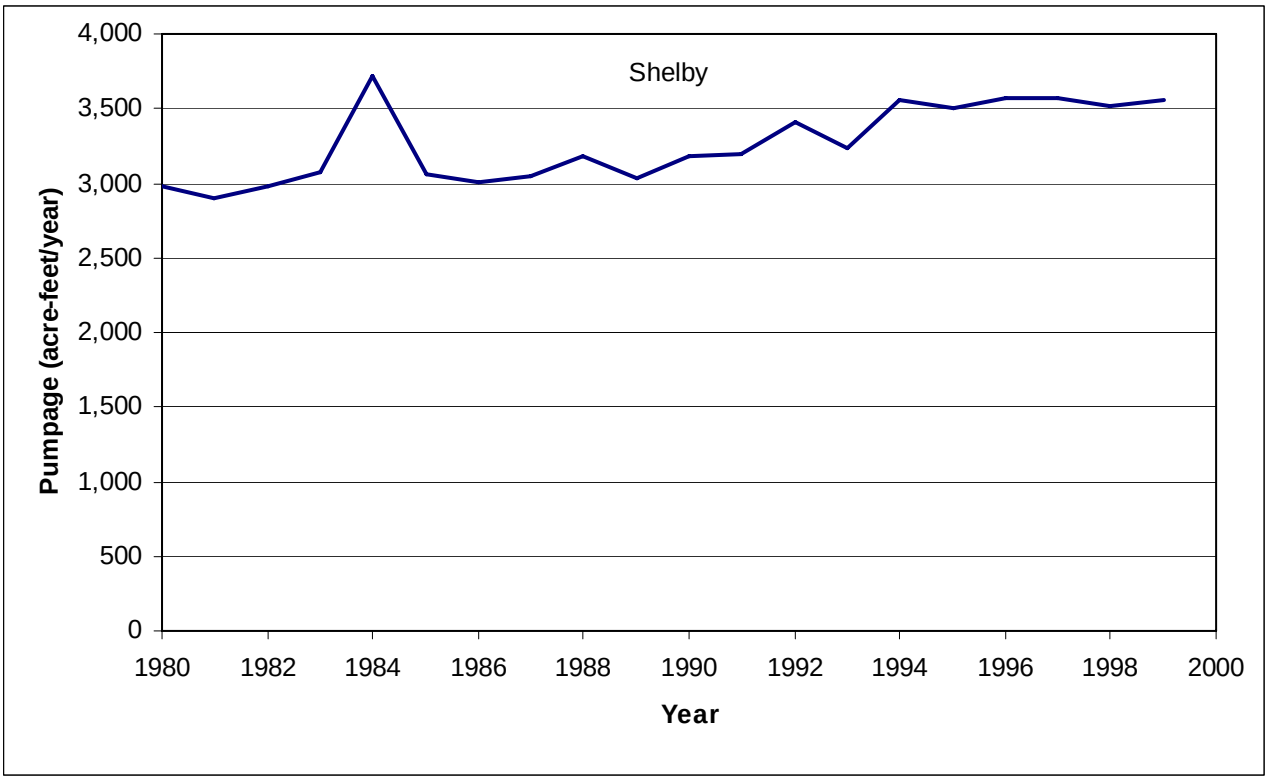

Figure A-27- Pumpage in Shelby County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

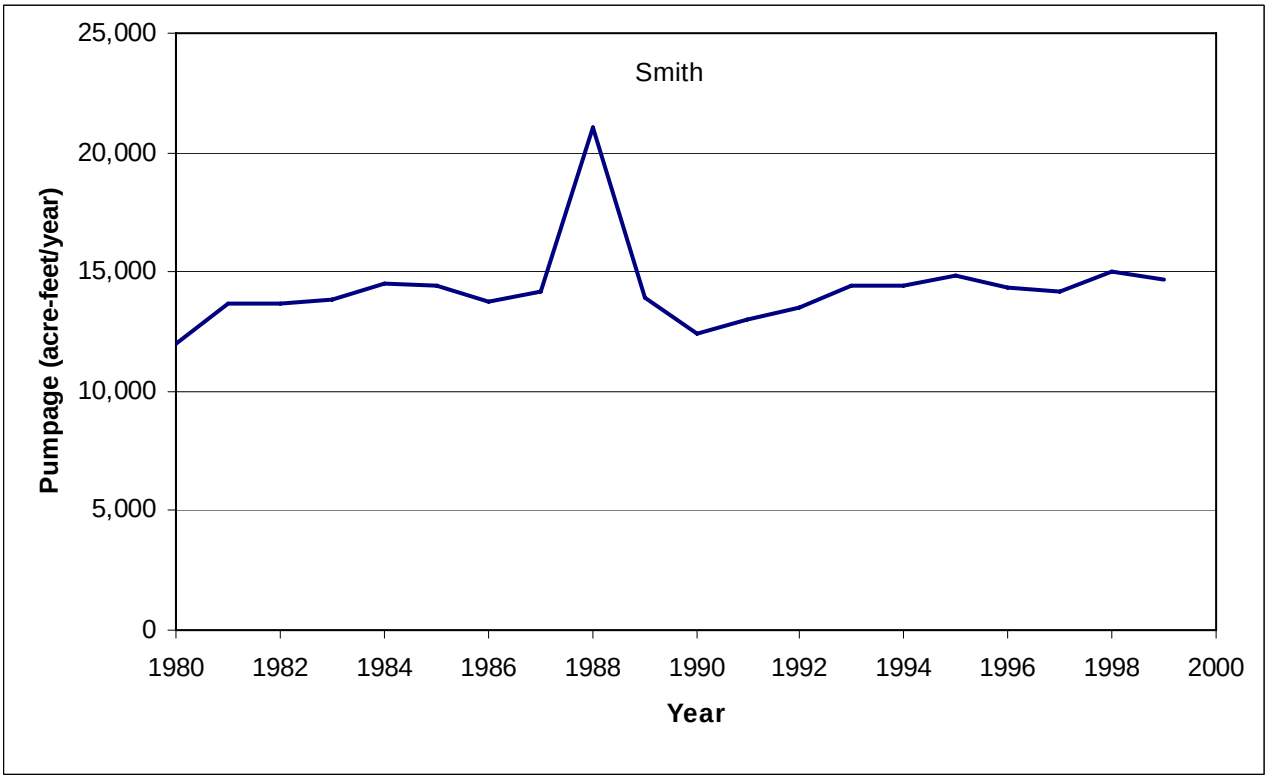

Figure A-28- Pumpage in Smith County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

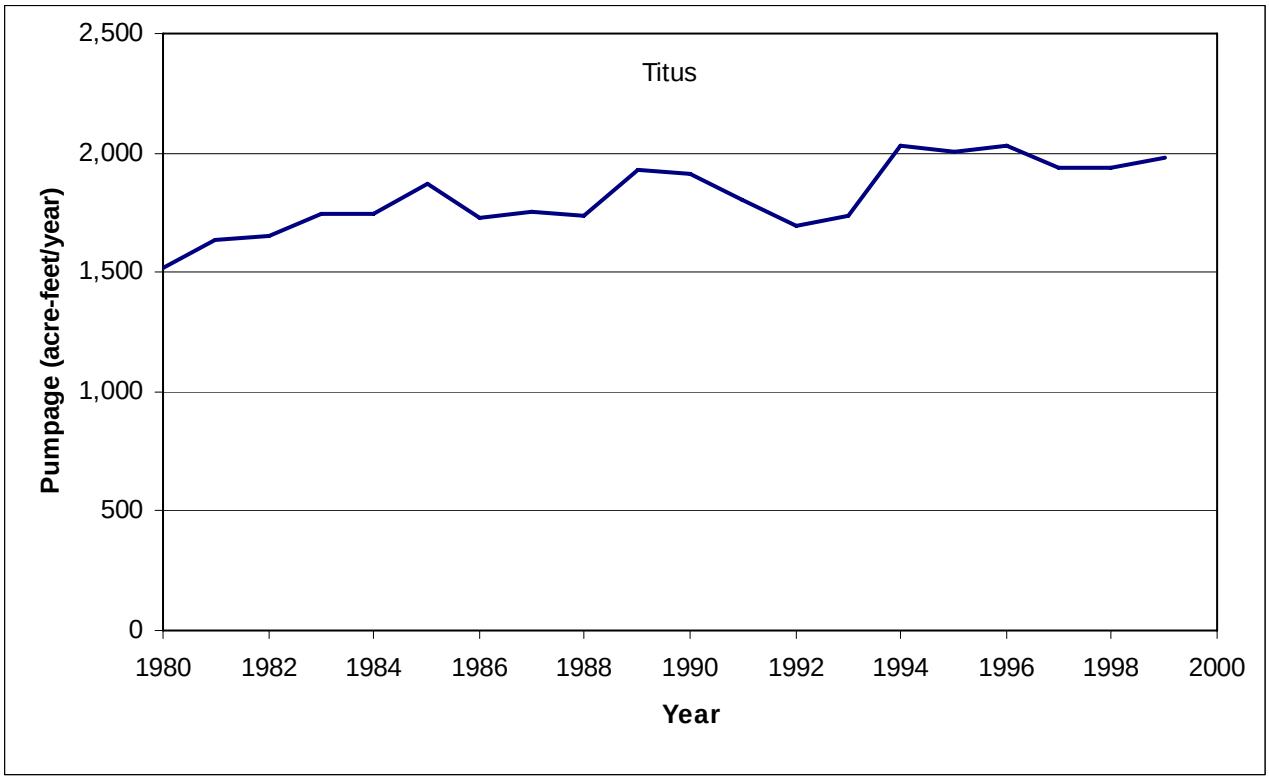

Figure A-29- Pumpage in Titus County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

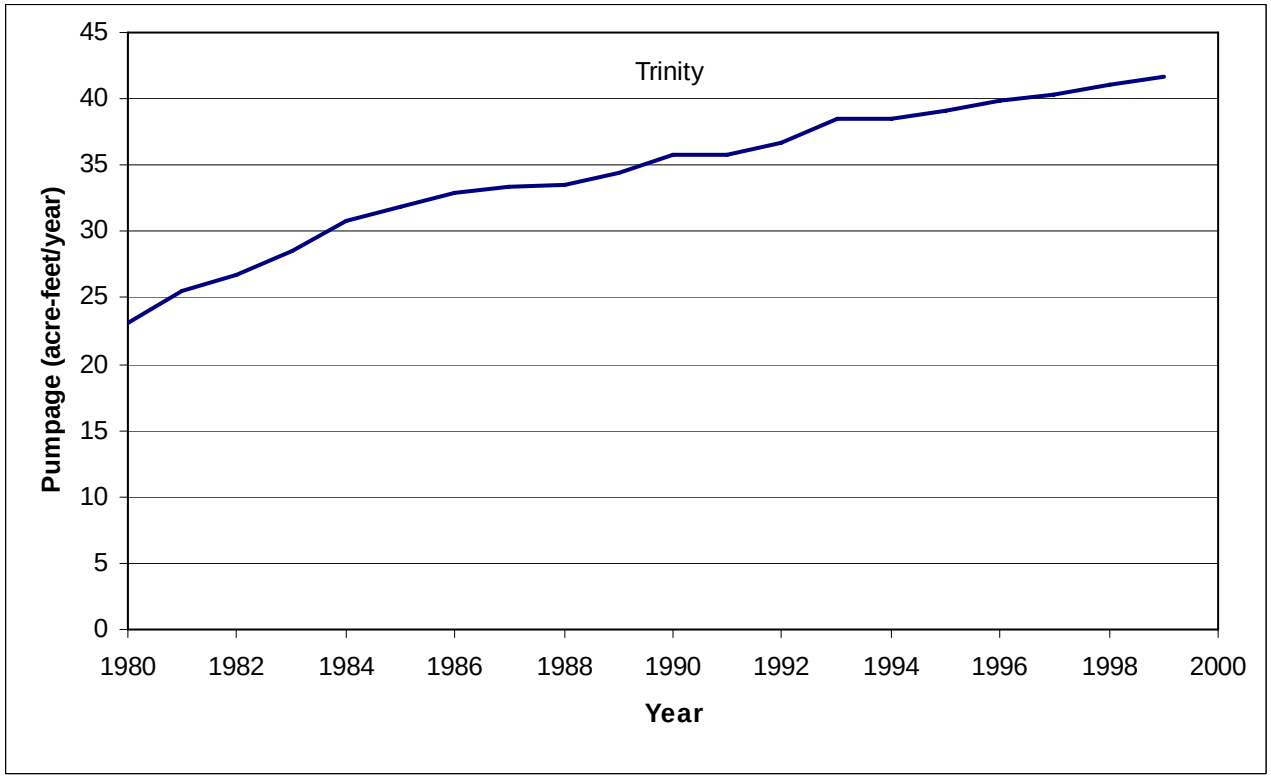

Figure A-30- Pumpage in Trinity County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

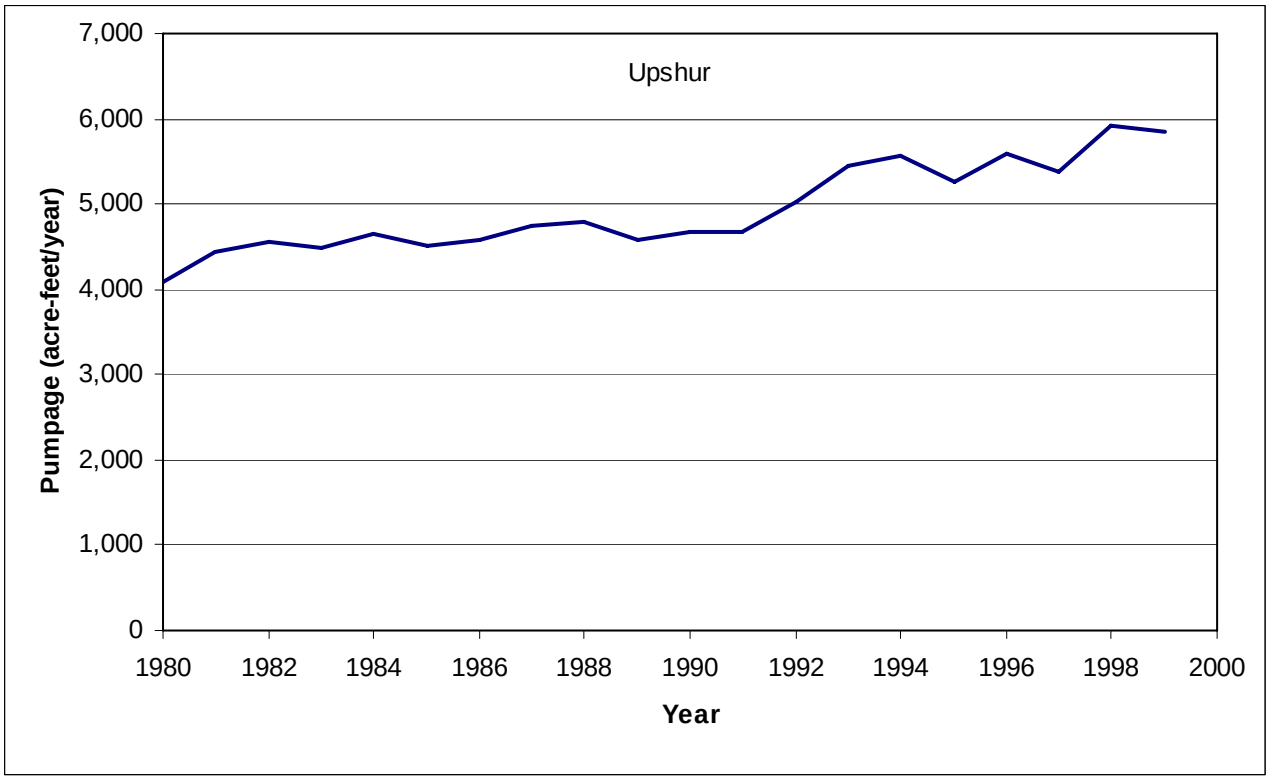

Figure A-31- Pumpage in Upshur County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

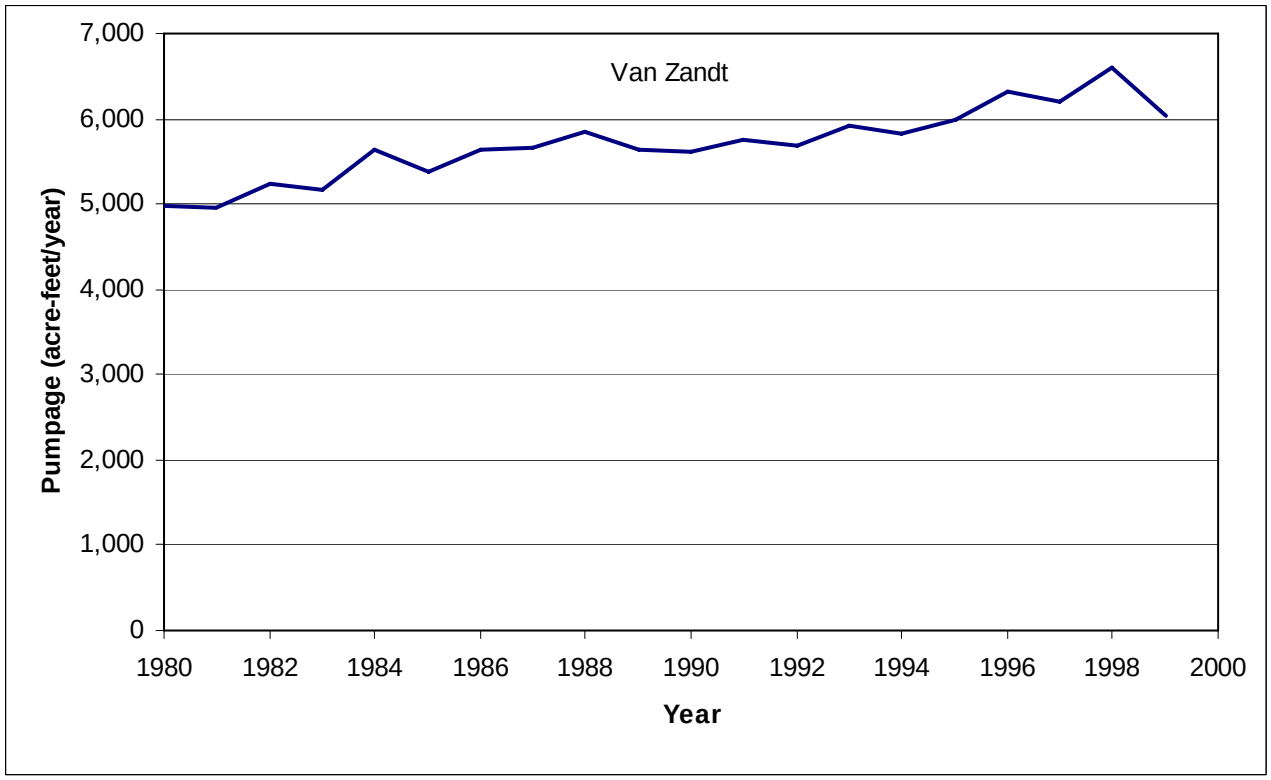

Figure A-32- Pumpage in Van Zandt County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

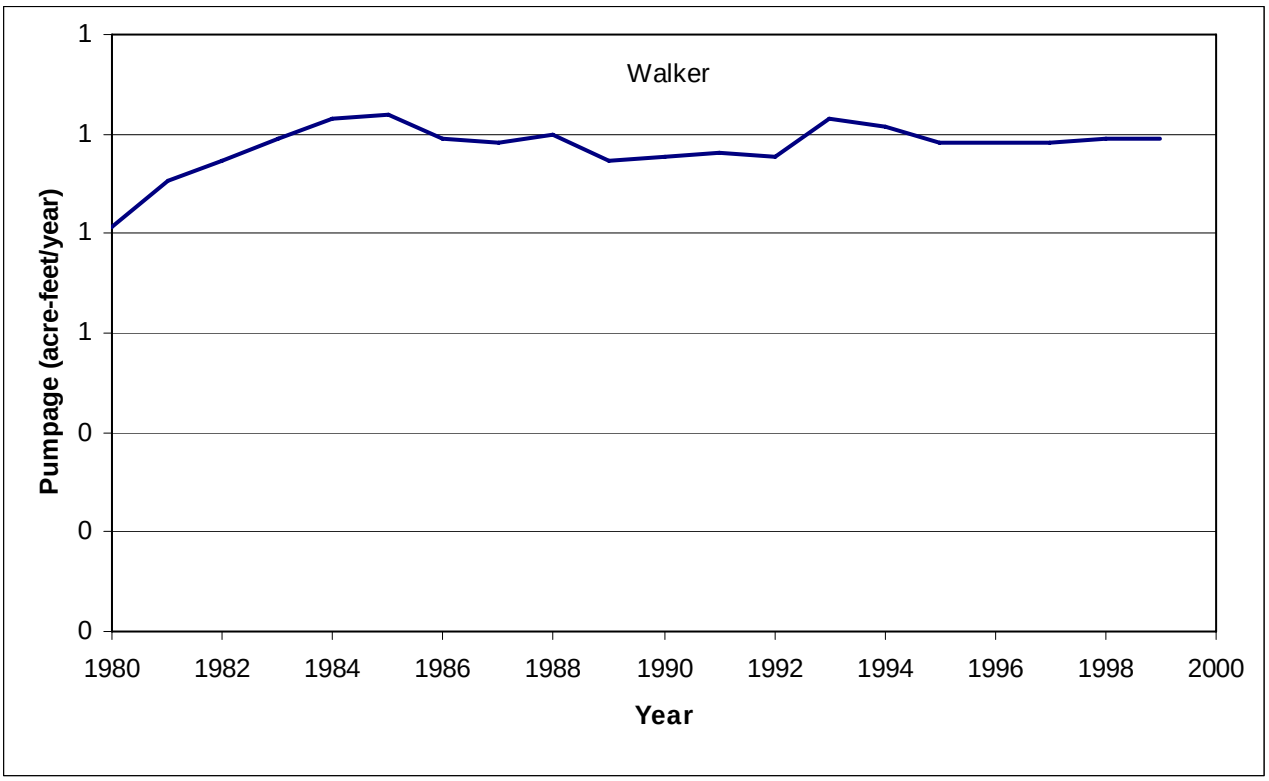

Figure A-33- Pumpage in Walker County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.

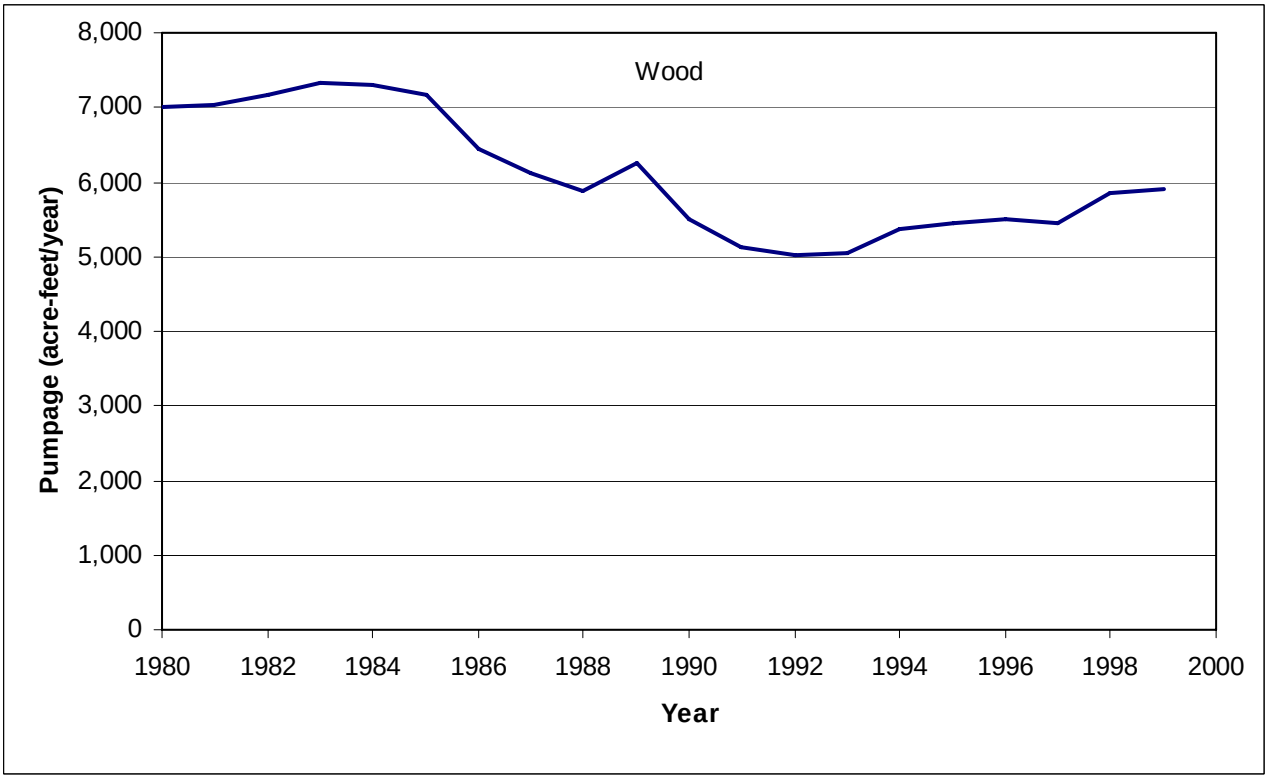

Figure A-34- Pumpage in Wood County included in the model for the northern part of the Queen City, Sparta, and Carrizo-Wilcox aquifers.