GAM Run 09-027

by Mr. Wade Oliver

Texas Water Development Board
Groundwater Availability Modeling Section
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June 21, 2010

Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by employees under her direct supervision. The seal appearing on this document was authorized by Cynthia K. Ridgeway, P.G. 471 on June 21, 2010.

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EXECUTIVE SUMMARY:

We ran the groundwater availability model for the southern portion of the Ogallala Aquifer (which includes the Edwards-Trinity High Plains Aquifer), adjusting annual pumping to achieve a 50 percent decline in the Ogallala Aquifer volume in each county in Groundwater Management Area 7 between 2009 and 2060. For comparison, we also calculated the pumping volume required to match the requested 50 percent decline using a water balance approach.

To set the initial volume of water for the above model run and water balance investigation, the volume of water in the Groundwater Management Area 2 portion of the Ogallala Aquifer in the model for 2008 was compared to the volume of water calculated from water level measurements representing the same area and time period. Groundwater Management Area 2 was used for this comparison (as opposed to Groundwater Management Area 7) because it covers the majority of the southern portion of the Ogallala Aquifer and contained a sufficient number of water level measurements to calculate the volume. From this analysis, it was found that the value calculated from water level measurements was 8.7 percent less than the volume in the model. To account for this discrepancy, a correction factor was applied to the pumping output from the model in order to more closely reflect the most current conditions represented by the water level measurements.

Results from the model run indicate that the total pumping that yields a 50 percent reduction in the Ogallala Aquifer volume within Groundwater Management Area 7 will decline from approximately 70,000 acre-feet per year to 53,000 acre-feet per year between 2009 and 2060.

Using the water balance approach, the total pumping in Groundwater Management Area 7 that achieves the requested 50 percent reduction in the Ogallala Aquifer volume is approximately 64,000 acre-feet per year using the initial volume in the model adjusted by the 8.7 percent correction factor. The results using this approach are similar to the results from the model run. However, it does not account for the dynamic responses of the aquifer to pumping such as decreased spring flow and changes in lateral and vertical flows or likely decreases in pumping through time due to declining water levels.

REQUESTOR:

Ms. Caroline Runge of Menard County Underground Water Conservation District on behalf of Groundwater Management Area 7.

DESCRIPTION OF REQUEST:

Ms. Runge asked us to perform a groundwater availability model run that results in a 50 percent decline in the volume of the southern portion of the Ogallala Aquifer in each county of Groundwater Management Area 7 by 2060. The southern portion of the Ogallala Aquifer and nearby groundwater management areas are shown in Figure 1.

METHODS:

In order to determine the pumping required to achieve the requested 50 percent reduction in the volume of the Ogallala Aquifer, we used the groundwater availability model for the southern portion of the Ogallala Aquifer, which also includes the Edwards-Trinity (High Plains) Aquifer. The pumping between 2009 and 2060 was then determined iteratively by adjusting the pumping values in each county to obtain the requested decline.

To set the initial volume for the model run, the model was first run with pumping held constant at year 2000 levels (the last year of the historical/calibration portion of the model) between 2001 and 2008. The volume of water in the model for 2008 in the Ogallala Aquifer within Groundwater Management Area 2 was then calculated at approximately 134,730,000 acre-feet. For comparison, water levels for the same time period were taken from the Texas Water Development Board Groundwater Database and kriged to create a water level surface for the Ogallala Aquifer over Groundwater Management Area 2. The locations of these water level measurements and the resulting water level surface are shown in Figure 2. After merging the surface with the model grid, the volume of water in each grid cell was calculated using the storage properties and base of the Ogallala Aquifer from the model. Note that Groundwater Management Area 2 was used (as opposed to Groundwater Management Area 7) because it covers the majority of the southern portion of the Ogallala Aquifer and contained a sufficient distribution of water level measurements to create a water level surface for 2008.

The volume in Groundwater Management Area 2 calculated from measured water levels was approximately 123,017,000 acre-feet, or 8.7 percent less than the volume calculated in the Groundwater Management Area 2 portion of the model. Since the initial volume in the model was 8.7 percent more than the approach using measured water levels, the pumping output from the model for each decade was reduced by 8.7 percent to correct for the initial volume (described above).

A water balance approach was also employed for comparison to the model results. The initial volume for Groundwater Management Area 7 from the model (approximately 6,657,000 acre-feet) was reduced by the 8.7 percent correction factor for the initial aquifer volume in each county. Then, using average recharge (taken from the year 2008 in the model), the pumping required to achieve the requested 50 percent reduction in volume between 2009 and 2060 was calculated.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the model run using the groundwater availability model for the southern portion of the Ogallala Aquifer are described below:

- We used version 2.01 of the groundwater availability model for the southern portion of the Ogallala Aquifer and the Edwards-Trinity (High Plains) Aquifer. This model is an expansion on and update to the previously developed groundwater availability model for the southern portion of the Ogallala Aquifer described in Blandford and others (2003). See Blandford and others (2008) and Blandford and others (2003) for assumptions and limitations of the groundwater availability model.

- The model includes four layers representing the southern portion of the Ogallala Aquifer and the Edwards-Trinity (High Plains) Aquifer. The units comprising the Edwards-Trinity (High Plains) Aquifer (primarily Edwards, Comanche Peak, and Antlers Sand formations) are separated from the overlying Ogallala Aquifer by a layer of Cretaceous shale, where present. Note that, though the Edwards-Trinity (High Plains) Aquifer is included in the model, it is not present within Groundwater Management Area 7.

- The mean absolute error (a measure of the difference between simulated and measured water levels during model calibration) for the Ogallala Aquifer in 2000 is 33 feet. The mean absolute error for the Edwards-Trinity (High Plains) Aquifer in 1997 is 25 feet (Blandford and others, 2008). This represents 1.8 and 3.0 percent of the hydraulic head drop across the model area for each aquifer, respectively.

- We used Groundwater Vistas version 5.36 Build 10 (Environmental Simulations, Inc., 2007) as the interface to process model output.

- Cells were assigned to individual counties and groundwater conservation districts as shown in the September 14, 2009 version of the model grid for the southern portion of the Ogallala Aquifer and the Edwards-Trinity (High Plains) Aquifer.

- The recharge used for the model run represents average recharge as described in Blandford and others (2003).

- The pumping used for the predictive simulations was determined iteratively to match the requested decline in volume by members of Groundwater Management Area 7. Details on this pumping are given below.

Pumping

The pumping values in the groundwater availability model in each county were determined using an iterative process. The pumping in the model for the year 2000 (the last year of the historical/calibration portion of the model) was held constant between 2001 and 2008. Beginning in 2009, this pumping distribution was adjusted up or down and then held constant for each year through 2060. After running the model, the decline in the volume of the aquifer between 2009 and 2060 was calculated. Where a decrease in pumping was required, the pumping value for each cell in the model was decreased by a uniform factor, preserving the original pumping distribution. Where an increase in pumping was required, pumping was uniformly increased over all model cells that contained pumping during the last year of the historical/calibration portion of the model. This process was repeated until the decline in aquifer volume in each county matched the requested decline.

Pumping in neighboring Groundwater Management Area 2 was also adjusted at their request to match a 50 percent decline between 2009 and 2060. Pumping in areas outside groundwater management areas 2 and 7 was held constant at 2000 levels through the predictive period. Further assumptions and results for areas outside Groundwater Management Area 7 are presented in GAM Run 09-023 (Oliver, 2010).

The "base" pumping distribution that met the above request was also adjusted up and down in order to provide insight into the relationship between pumping and drawdown in Groundwater Management Area 7. The pumping input to the model in groundwater management areas 2 and 7 was multiplied by a factor to increase (factors of 1.3, 1.6 and 1.9) or decrease (factors of 0.8, 0.6, and 0.4) the pumping in these areas. The relationships generated are presented in the Results section below.

RESULTS:

As described above, the pumping distribution for the last year of the historical/calibration portion of the model was held constant between 2001 and 2008 and then set to a level resulting in a decline in volume in the Ogallala Aquifer of 50 percent between 2009 and 2060 for each county in Groundwater Management Area 7. The pumping output from the model for each decade, which has been reduced by 8.7 percent to correct for the initial volume (described above) and accounts for pumping lost due to cells going inactive, is shown in Table 1. This includes results for each county and groundwater conservation district, as well as Groundwater Management Area 7 as a whole. The pumping for Groundwater Management Area 2 has also been included for comparison. A model cell goes inactive when the water level in a cell drops below the bottom of the aquifer. In this situation, pumping can no longer occur.

Table 1 also includes the percent volume remaining in each area and the average drawdown by decade. In each county in Groundwater Management Area 7, the percent volume remaining declines to 50 percent of the volume in 2008. The average county-wide drawdowns required to achieve this decline range from 22 feet in Ector County to 62 feet in Glasscock County.

As described in the Pumping section above, the base pumping distribution was adjusted up and down to provide insight into how the model responds under different levels of pumping. Tables similar to Table 1, but showing pumping, volume, and drawdown results for each of the scenarios where pumping was adjusted are shown in Appendix A. In addition, Figure 3 shows the percent volume remaining in Groundwater Management Area 7 through time for each of the pumping scenarios. Figure 4 shows the average drawdown in Groundwater Management Area 7 through time for each of the pumping scenarios. In Figure 3, notice that in the highest pumping scenario (the "1.9 Scenario" where pumping is increased to 190 percent of the base pumping), annual pumping begins over 135,000 acre-feet per year, but declines rapidly to almost 50,000 acre-feet per year by 2060 due to cells going inactive, with approximately 18 percent of the 2008 aquifer volume remaining at the end of the model run. In the lowest pumping scenario, the amount of pumping also decreases through time due to cells going inactive, but the decline is from approximately 24,400 acre-feet per year to 22,400 acre-feet per year, with more than 80 percent of the 2008 aquifer volume remaining in 2060. A similar comparison can be made with drawdown in Figure 4, where the average drawdown in 2060 in Groundwater Management Area 7 ranges from 12 feet in the lowest pumping scenario to over 75 feet in the highest pumping scenario.

Table 2 shows the results of two separate water balance analyses for each county in Groundwater Management Area 7 and for the area as a whole. The two analyses were performed using the initial volume calculated from the model adjusted by the 8.7 percent correction factor described in the Methods section above. The first analysis shows the annual constant pumping required to reduce the volume by 50 percent over 52 years (2009 to 2060), taking into account average recharge each year. The second analysis shows the percent of the original volume remaining using the the pumping output from the "Base" model run for each year of the predictive simulation. This also takes into account the average recharge and includes the 8.7 percent correction factor.

As mentioned above, the water balance analysis does not reflect spring flow or interaction of the aquifer with neighboring groundwater management areas. Additionally, this approach does not show the decrease in pumping through time with decreasing water levels that one would expect. Despite this, over Groundwater Management Area 7 as a whole, the pumping calculated from the water balance analysis (63,995 acre feet per year) is similar to the pumping calculated from the model, which starts at 69,752 acre-feet per year and declines steadily to 52,919 acre-feet per year.

To better illustrate how the model responds through time during the "Base" run, Appendix B contains charts for each of the major water budget terms for each year of the predictive model run. Note that these charts only reflect the Ogallala Aquifer within Groundwater Management Area 7. Appendix C contains water budget tables for each county and groundwater conservation district, as well as Groundwater Management Area 7 as a whole for the last stress period of the model run. The components of the water budget are described below:

- Recharge— areally distributed recharge due to precipitation as well as inflow to the aquifer from playa lakes. Recharge is always shown as "Inflow" into the water budget. Recharge is modeled using the MODFLOW Recharge package, except in Lubbock County, where it is also modeled using the MODFLOW well package.

- Pumping—water produced from wells in the aquifer. This component is always shown as "Outflow" from the water budget, except in Lubbock County, where the MODFLOW Well package is also used to simulate recharge inflow from playa lakes.

- Springs and Seeps—water that naturally discharges from an aquifer when water levels rise above the elevation of the spring or seep. This component is always shown as "Outflow," or discharge, in the water budget. Spring and seep outflows are simulated in the model using the MODFLOW Drain package. In Appendix B, outflow to springs and seeps is subtracted from recharge to show "Net Recharge."

- Change in Storage—changes in the water stored in the aquifer. Storage can be either an "inflow" (that is, water levels decline) or an "outflow" (that is, water levels increase). This component of the budget is often seen as water both going into and out of the aquifer because water levels may decline in some areas (water is being removed from storage) and rise in others (water is being added to storage).

- Lateral flow—describes lateral flow within an aquifer between one area and an adjacent area (for example, lateral flow into and out of a groundwater conservation district).

- Vertical flow or leakage (upper or lower)—describes the vertical flow, or leakage, between two aquifers. This flow is controlled by the water levels in each aquifer and aquifer properties that define the amount of leakage that can occur. “Upper” refers to interaction between an aquifer and the aquifer overlying it. “Lower” refers to interaction between an aquifer and the aquifer below it. Though this model does contain multiple layers, only the Ogallala Aquifer is present in Groundwater Management Area 7. For this reason, vertical flow is not shown in appendices B and C.

Figure B-1 in Appendix B shows the pumping through time for the “Base” scenario, which meets the requested volume remaining in 2060. Note that the pumping values in this figure have not been adjusted using the 8.7 percent correction factor.

Figure B-2 shows Net Recharge in the groundwater availability model for each year. Here, “Net Recharge” refers to recharge sourced from precipitation minus outflow to springs and seeps. Though recharge from precipitation input to the model is constant, as water levels decline and cells become inactive, the amount of water entering the aquifer through precipitation and removed from the aquifer by springs and seeps is reduced.

Figure B-3 shows the Net Change in Storage in the groundwater availability model. Note that the amount of water removed from storage increases in 2009 due to the increase in pumping shown in Figure B-1.

Figure B-4 shows the net lateral flow between Groundwater Management Area 7 and Groundwater Management Area 2. Notice that the direction of flow changes from a net outflow between 2001 and 2010 to a net inflow from 2011 to 2060 due to declining water levels in Groundwater Management Area 7.

It is important to note that sub-regional water budgets are not exact. This is due to the size of the model cells and the approach used to extract data from the model. To avoid double accounting, a model cell that straddles a political boundary (e.g. a county) is assigned to one side of the boundary based on the location of the centroid of the model cell. For example, if a cell contains two counties, the cell is assigned to the county where the centroid of the cell is located.

REFERENCES AND ASSOCIATED MODEL RUNS:

Blandford, T.N., Blazer, D.J., Calhoun, K.C., Dutton, A.R., Naing, T., Reedy, R.C., and Scanlon, B.R., 2003, Groundwater availability of the southern Ogallala aquifer in Texas and New Mexico—Numerical simulations through 2050: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 158 p.

Blandford, T.N., Kuchanur, M., Standen, A., Ruggiero, R., Calhoun, K.C., Kirby, P., and Shah, G., 2008, Groundwater availability model of the Edwards-Trinity (High Plains) Aquifer in Texas and New Mexico: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 176 p.

Environmental Simulations, Inc., 2007, Guide to using Groundwater Vistas Version 5, 381 p.

Oliver, W., 2010, GAM run 09-023: Texas Water Development Board, GAM Run 09-023 Report, 30 p.

Table 1. Pumping (reduced by an 8.7 percent correction factor), remaining volume, and drawdown by decade by county, groundwater conservation district (GCD), and groundwater management area (GMA). Pumping is in acre-feet per year. Drawdown is in feet.

Base scenario	Pumping reduced by 8.7 percent correction factor						Percent volume remaining						Average drawdown					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
County																		
Ector	8,665	8,026	7,730	7,171	7,135	6,727	98	88	78	68	59	50	1	5	10	14	18	22
Glasscock	21,773	21,322	20,875	19,691	17,289	14,868	98	87	77	67	58	50	2	15	27	39	50	62
Midland	39,149	38,388	36,824	34,623	32,693	31,325	98	87	77	68	58	50	2	9	17	24	31	38
District																		
Glasscock GCD	21,773	21,322	20,875	19,691	17,289	14,868	98	87	77	67	58	50	2	15	27	39	50	62
Management Area																		
GMA 2	2,175,279	2,011,192	1,869,880	1,724,743	1,567,632	1,430,799	98	86	76	66	58	50	2	10	18	25	32	38
GMA 7	69,587	67,737	65,429	61,485	57,117	52,919	98	87	77	67	58	50	2	10	17	25	32	39

Table 2. Recharge, pumping and groundwater storage volume analyses by county in Groundwater Management Area (GMA) 7 using the initial volume calculated from the model (reduced by an 8.7 percent correction factor). The two water balance analyses here show the percent volume remaining using 1) pumping calculated to achieve the reduction to 50 percent by 2060, and 2) pumping output from the model for each year. Pumping and recharge are in acre-feet per year. Volume is in acre-feet.

Volume source		**Model (adjusted by 8.7 percent correction factor)**			
Pumping source			**Calculated to match 50 percent volume**		**Model run (adjusted to 8.7 percent correction factor)**
	Recharge	**Volume**	**Pumping**	**Percent remaining**	**Percent remaining**
GMA 2	5,553	6,077,994	63,995	50	51
Ector	384	775,079	7,837	50	52
Glasscock	1,031	1,920,745	19,499	50	50
Midland	4,138	3,382,171	36,659	50	52

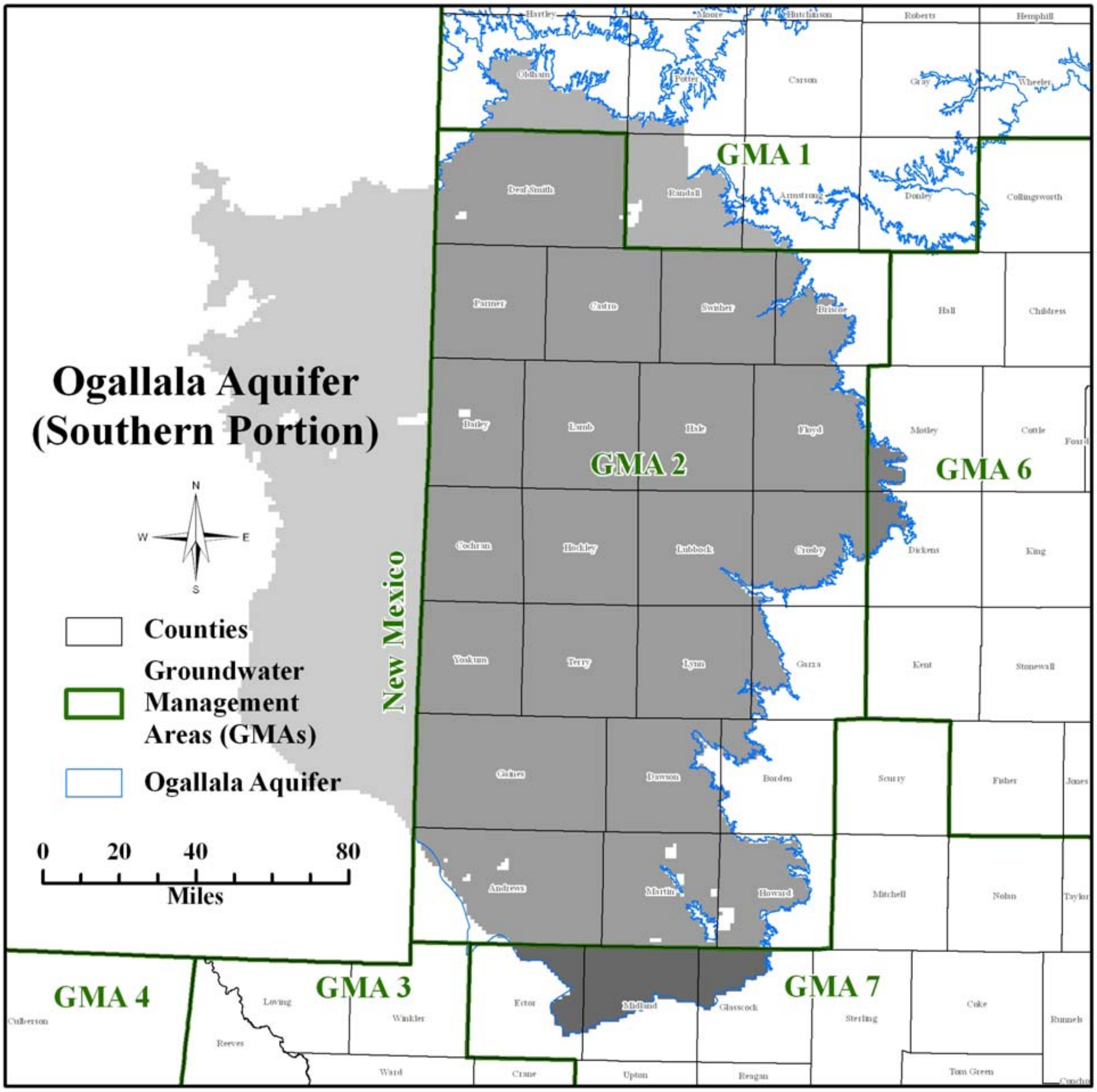

Figure 1. Location map showing model grid cells representing the southern portion of the Ogallala Aquifer, groundwater management areas, and the Ogallala Aquifer boundary.

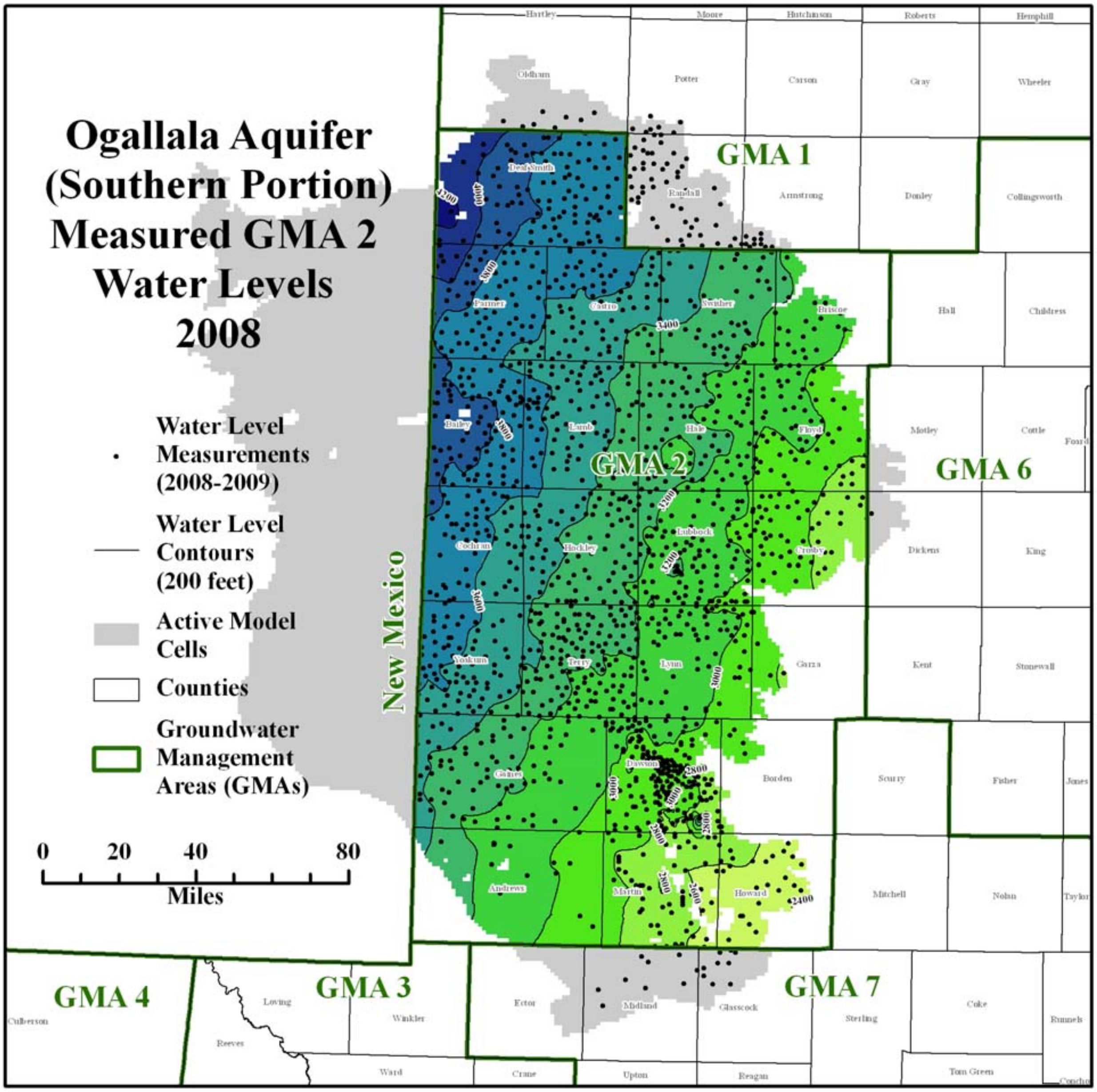

Figure 2. Water level measurements used to create a surface representing 2008 water levels and to estimate the initial Ogallala Aquifer volume within Groundwater Management Area 2. This volume was compared to the volume for the same area in the model and used to determine a correction factor for pumping which was applied to Groundwater Management Area 7 results.

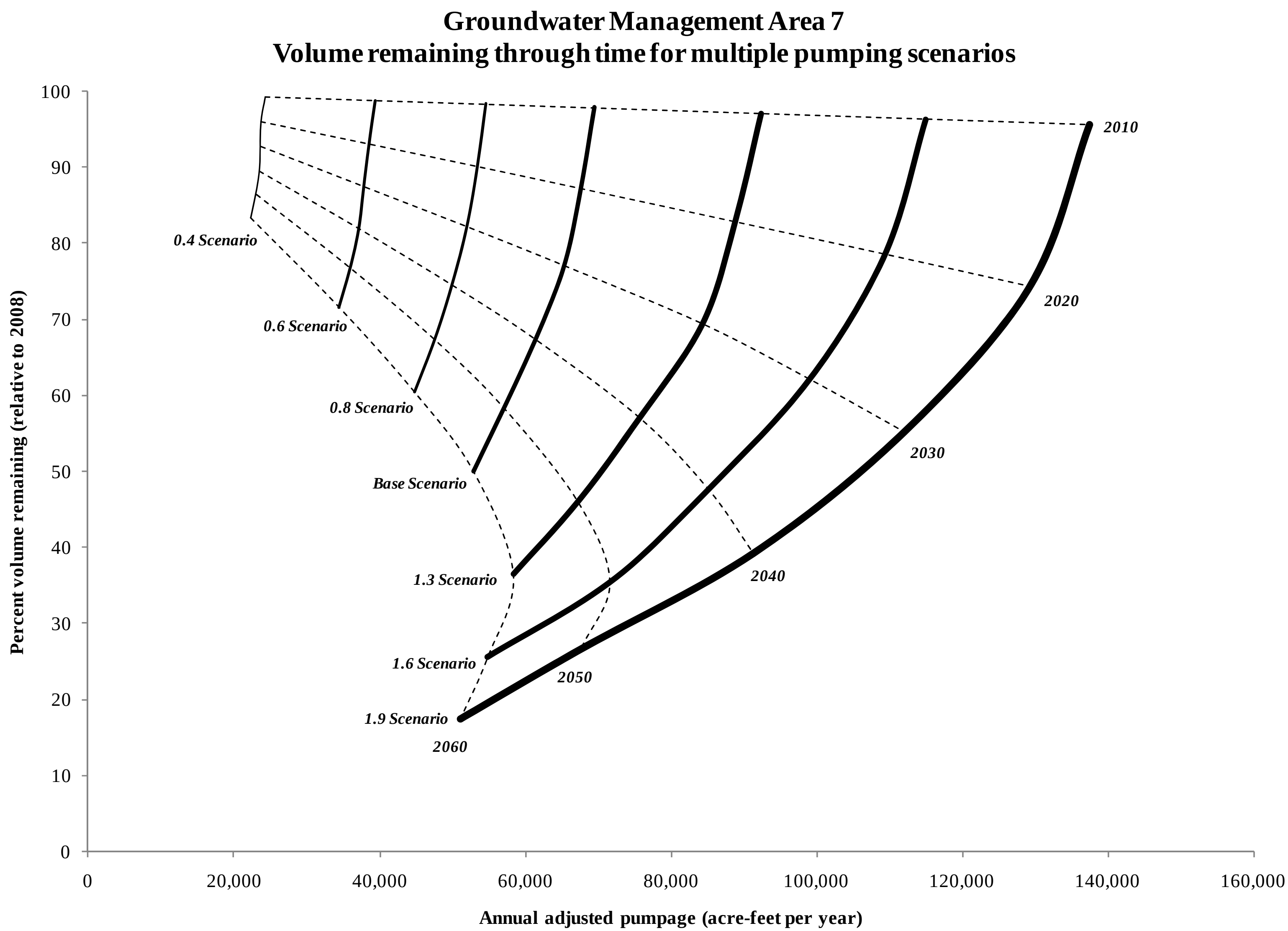

Figure 3. Percent of the Ogallala Aquifer volume remaining through time for each pumping scenario for Groundwater Management Area 7.

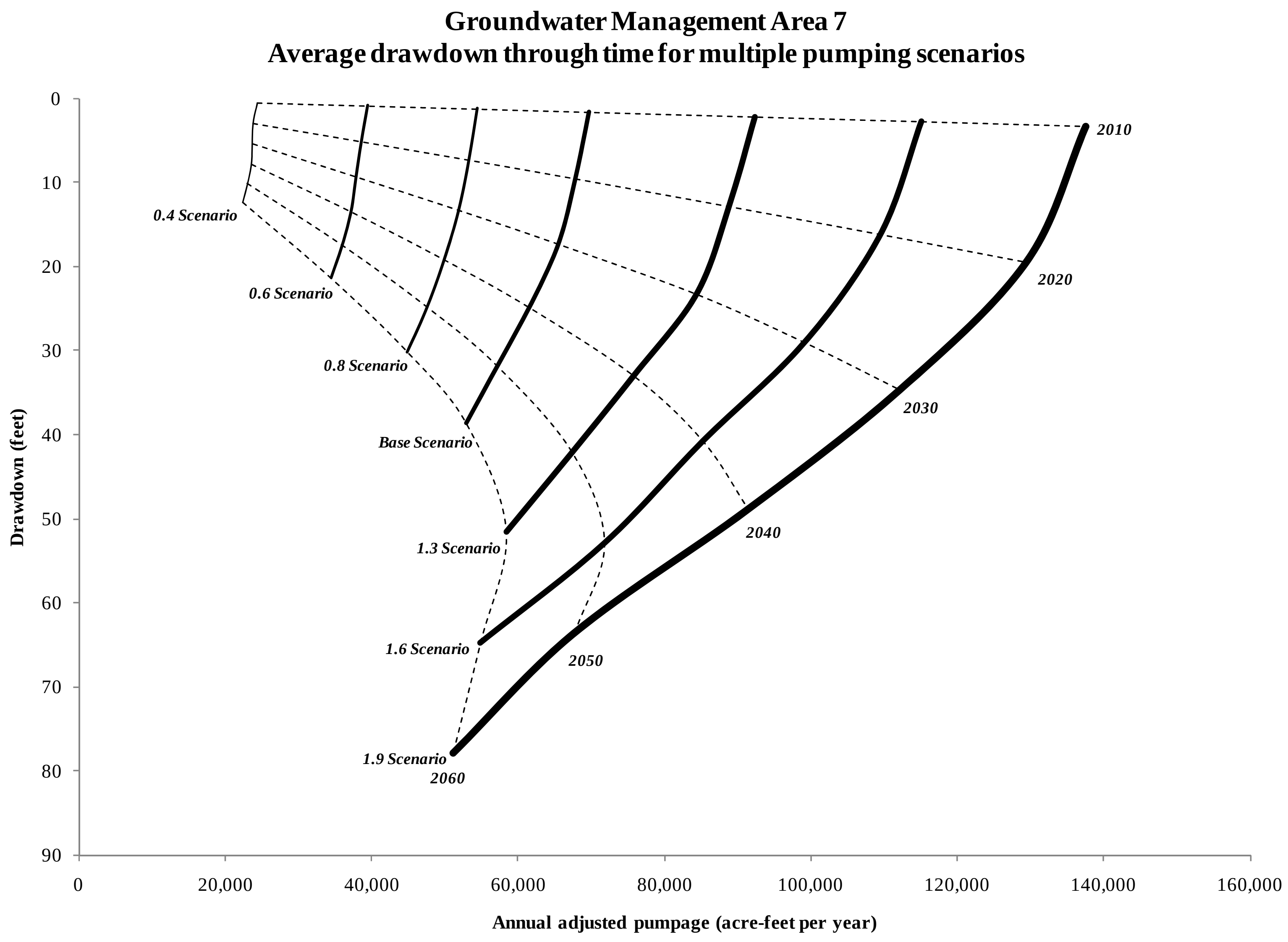

Figure 4. Average drawdown (decline in water levels) for the Ogallala Aquifer through time for each pumping scenario for Groundwater Management Area 7.

Appendix A

Pumping, remaining volume, and drawdown for each pumping scenario by decade

Table A-1. Pumping (reduced by an 8.7 percent correction factor), remaining volume, and average drawdown for the pumping scenarios with reduced pumping relative to the "base" by decade by county, groundwater conservation district, and groundwater management area. Pumping is in acre-feet per year. Volume is a percent of the 2008 volume in the model. Drawdown is in feet.

	Pumping reduced by 8.7 percent correction factor						Percent volume remaining						Average drawdown					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
Pumping 40 percent of base scenario																		
County																		
Ector	1,907	1,371	1,371	1,371	1,260	1,260	100	98	97	95	93	92	0	1	1	2	3	3
Glasscock	7,426	7,426	7,355	7,355	7,279	7,242	99	96	92	89	85	82	1	5	9	13	16	20
Midland	15,067	15,003	14,973	14,851	14,516	13,887	99	96	92	89	85	82	1	3	6	8	11	13
District																		
Glasscock GCD	7,426	7,426	7,355	7,355	7,279	7,242	99	96	92	89	85	82	1	5	9	13	16	20
Management Area																		
GMA 2	902,035	860,519	840,656	824,860	811,808	799,164	100	98	97	96	95	94	0	1	2	3	4	4
GMA 7	24,401	23,800	23,699	23,577	23,056	22,390	99	96	93	89	86	83	1	3	5	8	10	12
Pumping 60 percent of base scenario																		
County																		
Ector	4,047	3,457	3,457	3,328	3,146	2,892	99	95	91	86	82	78	0	2	4	6	7	9
Glasscock	12,209	12,086	11,960	11,775	11,715	11,188	99	93	87	81	76	70	1	8	15	21	28	34
Midland	23,150	23,005	22,411	22,048	21,087	20,344	99	93	87	81	76	71	1	5	9	14	18	21
District																		
Glasscock GCD	12,209	12,086	11,960	11,775	11,715	11,188	99	93	87	81	76	70	1	8	15	21	28	34
Management Area																		
GMA 2	1,316,163	1,239,989	1,192,806	1,152,708	1,116,516	1,082,217	99	94	90	86	82	78	1	4	7	10	13	15
GMA 7	39,405	38,549	37,828	37,151	35,948	34,424	99	93	87	82	77	72	1	5	9	13	17	21
Pumping 80 percent of base scenario																		
County																		
Ector	6,356	5,742	5,694	5,311	5,008	5,008	98	91	84	77	70	64	1	4	7	10	13	16
Glasscock	16,991	16,818	16,380	16,209	15,314	13,612	98	90	82	74	66	59	2	11	21	30	39	48
Midland	31,161	30,808	29,877	28,430	27,265	26,247	98	90	82	74	67	60	1	7	13	19	24	30
District																		
Glasscock GCD	16,991	16,818	16,380	16,209	15,314	13,612	98	90	82	74	66	59	2	11	21	30	39	48
Management Area																		
GMA 2	1,735,181	1,609,707	1,524,694	1,444,554	1,354,242	1,269,395	98	90	83	76	70	64	1	7	12	17	22	26
GMA 7	54,508	53,368	51,951	49,949	47,586	44,866	98	90	82	75	67	60	1	7	13	19	25	30

Table A-2. Pumping (reduced by an 8.7 percent correction factor), remaining volume, and average drawdown for the pumping scenarios with increased pumping relative to the "base" by decade by county, groundwater conservation district, and groundwater management area. Pumping is in acre-feet per year. Volume is a percent of the 2008 volume in the model. Drawdown is in feet.

	Pumping reduced by 8.7 percent correction factor						Percent volume remaining						Average drawdown					
	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060	2010	2020	2030	2040	2050	2060
Pumping 130 percent of base scenario																		
County																		
Ector	12,128	11,345	10,732	10,253	9,516	8,211	97	82	68	55	42	31	1	8	14	20	26	32
Glasscock	28,947	28,045	27,151	22,762	17,989	15,145	97	83	69	57	47	39	3	20	36	51	67	82
Midland	51,223	49,372	46,419	42,701	39,778	35,028	97	83	70	58	46	36	2	12	22	32	42	51
District																		
Glasscock GCD	28,947	28,045	27,151	22,762	17,989	15,145	97	83	69	57	47	39	3	20	36	51	67	82
Management Area																		
GMA 2	2,854,440	2,595,599	2,333,080	2,029,256	1,744,465	1,443,545	96	80	65	52	41	32	3	15	27	37	47	56
GMA 7	92,298	88,761	84,302	75,716	67,282	58,385	97	83	69	57	46	36	2	13	23	33	42	52
Pumping 160 percent of base scenario																		
County																		
Ector	15,592	14,518	13,440	12,377	10,110	6,795	96	77	59	43	28	17	2	10	18	26	34	41
Glasscock	36,120	34,801	30,701	23,025	18,903	13,953	96	79	62	49	38	30	4	25	45	64	83	102
Midland	63,296	60,124	54,929	49,789	42,695	34,110	96	79	63	48	36	25	3	15	28	40	52	63
District																		
Glasscock GCD	36,120	34,801	30,701	23,025	18,903	13,953	96	79	62	49	38	30	4	25	45	64	83	102
Management Area																		
GMA 2	3,519,787	3,149,870	2,666,644	2,191,316	1,680,623	1,155,097	95	74	55	40	27	19	3	20	35	49	62	70
GMA 7	115,008	109,443	99,070	85,192	71,708	54,858	96	79	62	48	35	26	3	16	29	41	53	65
Pumping 190 percent of base scenario																		
County																		
Ector	19,055	17,763	16,084	13,426	8,451	5,280	95	72	50	31	17	8	2	12	22	32	41	49
Glasscock	43,068	41,259	33,253	23,332	17,472	14,334	96	74	55	42	31	23	5	30	53	77	100	122
Midland	75,370	70,343	62,728	54,588	41,789	31,528	96	75	56	40	26	16	3	18	33	48	61	73
District																		
Glasscock GCD	43,068	41,259	33,253	23,332	17,472	14,334	96	74	55	42	31	23	5	30	53	77	100	122
Management Area																		
GMA 2	4,182,869	3,638,312	2,916,746	2,200,452	1,369,585	816,688	94	68	46	29	17	10	4	25	44	62	74	82
GMA 7	137,493	129,365	112,064	91,346	67,712	51,142	96	74	55	39	27	18	3	19	35	49	64	78

Appendix B

Water budgets for each stress period of the predictive groundwater availability model run

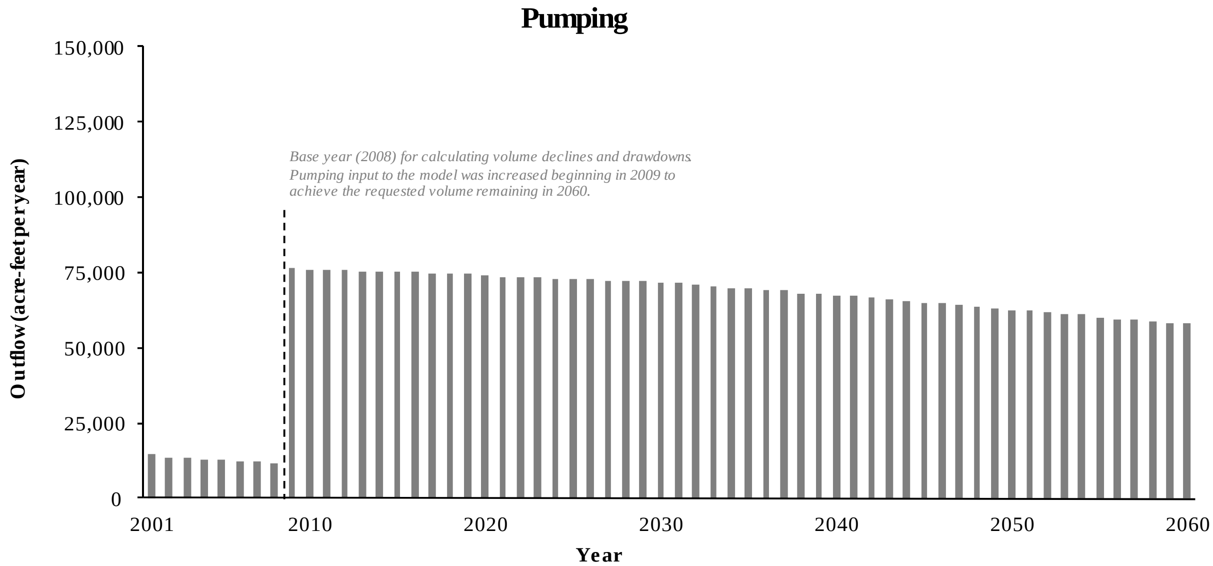

Figure B-1. Pumping output from the Ogallala Aquifer by year in the groundwater availability model for Groundwater Management Area 7. Note that these pumping values have not been adjusted using the 8.7 percent correction factor.

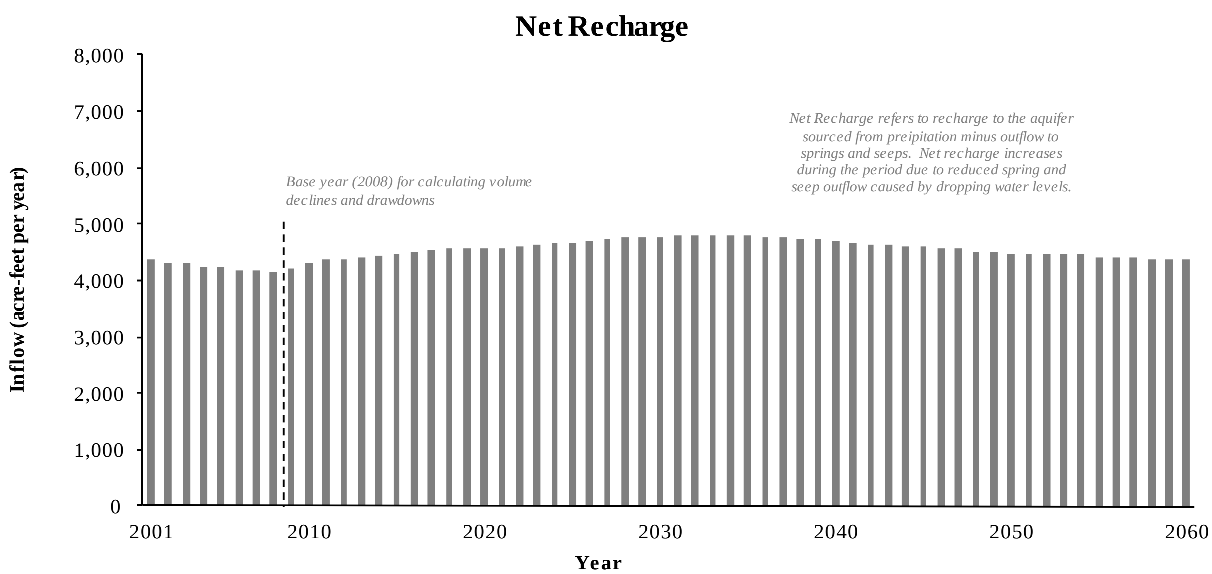

Figure B-2. Net recharge to the Ogallala Aquifer by year in the groundwater availability model for Groundwater Management Area 7. Note that net recharge refers to recharge to the aquifer sourced from precipitation minus outflow to springs and seeps.

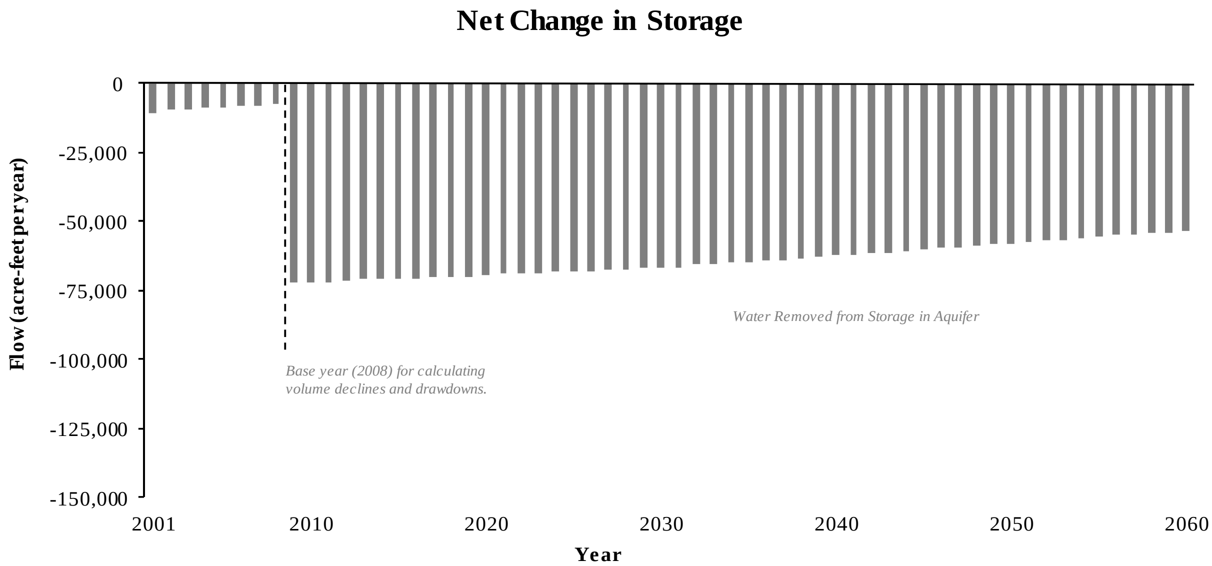

Figure B-3. Net change in storage (the volume of water stored in the aquifer) by year in the Ogallala Aquifer for Groundwater Management Area 7.

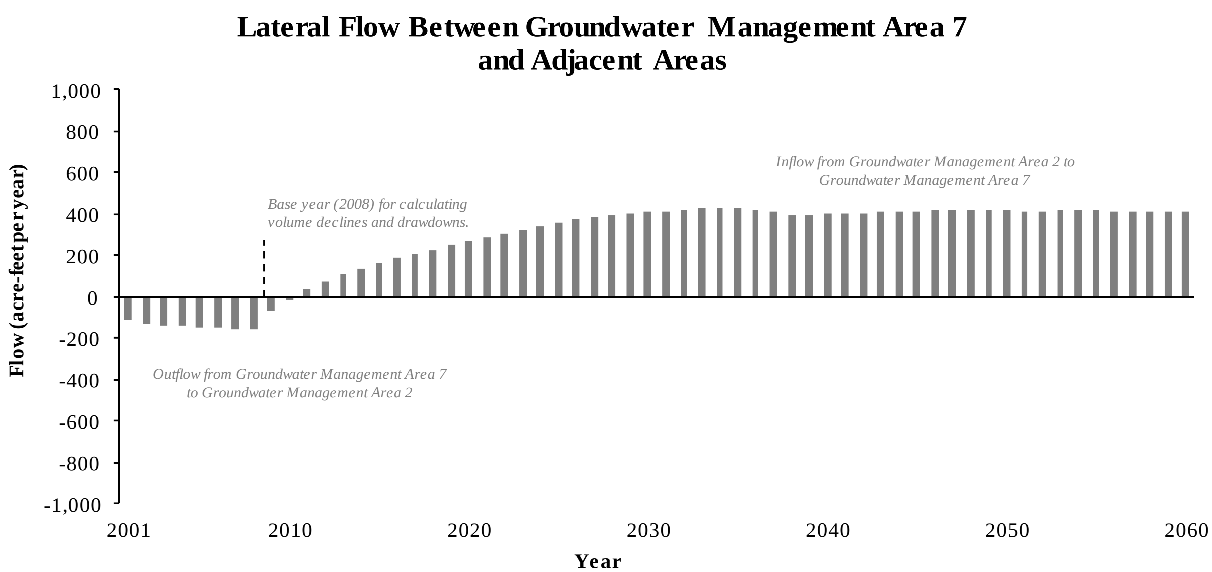

Figure B-4. Net lateral flow each year between Groundwater Management Area 7 and adjacent areas (that is, Groundwater Management Area 2).

Appendix C

Water budget tables by county, groundwater conservation district, and groundwater management area for the 2009-2060 predictive model run

Table C-1. Water budgets by county, groundwater conservation district (GCD), and groundwater management area (GMA) for the last stress period of the groundwater availability model run (2060). All values are reported in acre-feet per year.

	Ector	Glasscock	Midland	Glasscock GCD	GMA 2	GMA 7
Inflow						
Constant Head	0	0	0	0	0	0
Wells	0	0	0	0	11,459	0
Recharge	243	706	3,619	706	604,546	4,568
Multi-Node Wells	0	0	0	0	0	0
Vertical Leakage Lower	0	0	0	0	15,782	0
Lateral Flow	182	803	504	803	4,601	597
Total Inflow	*425*	*1,509*	*4,123*	*1,509*	*636,388*	*5,165*
Outflow						
Constant Head	0	0	0	0	0	0
Wells	7,368	16,284	34,310	16,284	1,547,196	57,962
Drains	0	206	0	206	11,318	206
Multi-Node Wells	0	0	0	0	19,945	0
Vertical Leakage Lower	0	0	0	0	28,502	0
Lateral Flow	417	146	516	146	2,969	186
Total Outflow	7,785	16,636	34,826	16,636	1,609,930	58,354
Inflow - Outflow	**-7,360**	**-15,127**	**-30,703**	**-15,127**	**-973,542**	**-53,189**
Storage Change	**-7,367**	**-15,128**	**-30,715**	**-15,128**	**-973,756**	**-53,211**
Model Error	**7**	**1**	**12**	**1**	**214**	**22**
Model Error (percent)	**0.09%**	**0.01%**	**0.03%**	**0.01%**	**0.01%**	**0.04%**