GAM Run 10-003

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EXECUTIVE SUMMARY:

Pumping was adjusted in the groundwater availability model for the Igneous and Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons aquifers to produce specified average 50-year drawdowns in Brewster County Groundwater Conservation District, Culberson County Groundwater Conservation District, Jeff Davis County Underground Water Conservation District, and Presidio County Underground Water Conservation District.

The specified average drawdowns and estimated pumping volumes are:

- In Culberson County Groundwater Conservation District, average drawdowns of 40 feet in the West Texas Bolsons and 50 feet in the Igneous aquifers with annual pumping of 24,921 and 626 acre-feet per year, respectively;

- In Jeff Davis County Underground Water Conservation District, average drawdowns of 20 feet for the West Texas Bolsons Aquifer and 10 feet for the Igneous Aquifer with annual pumping of 214 and 2,195 acre-feet per year, respectively;

- In Presidio County Underground Water Conservation District, average drawdown of 5 feet for both the West Texas Bolsons and Igneous aquifers with annual pumping of 509 and 1,093 acre-feet per year, respectively; and

- In Brewster County Groundwater Conservation District, average drawdown of 0 feet for the Igneous Aquifer with annual pumping of 1,373 acre-feet per year.

REQUESTOR:

Ms. Janet Adams of Jeff Davis County Underground Water Conservation District and Presidio County Underground Water Conservation District (on behalf of Groundwater Management Area 4).

DESCRIPTION OF REQUEST:

Ms. Janet Adams requested a model run to determine the amount of pumping that results in specified drawdowns in Groundwater Management Area 4 after 50 years. For the West Texas Bolsons Aquifer the drawdowns were specified as 40 feet for Culberson County Groundwater Conservation District, 20 feet for Jeff Davis County Underground Water Conservation District, and 5 feet for Presidio County Underground Water Conservation District. For the Igneous Aquifer the drawdowns were specified as zero feet for Brewster County Groundwater Conservation District, 50 feet for Culberson County Groundwater Conservation District, 10 feet for Jeff Davis County Underground Water Conservation District, and 5 feet for Presidio County Underground Water Conservation District.

METHODS:

The groundwater availability model for the Igneous and parts of the West Texas Bolsons Aquifers (Figure 1) was used to determine the maximum pumping that would result in the specified maximum drawdowns (Table 1). It should be noted that the parts of the West Texas Bolsons Aquifer in the groundwater availability model (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) are referred to in the model report (Beach and others, 2004) collectively as the Salt Basin Bolson Aquifer.

This request is a follow-up to an earlier request (Oliver, 2009). In that run, a pumping distribution that achieved all requested drawdowns was not physically possible, so two different pumping scenarios were developed. In Scenario 1 all requested drawdowns were met except the Jeff Davis County Underground Water Conservation District portion of the West Texas Bolsons Aquifer. In Scenario 2 all requested drawdowns were met except the Culberson County Groundwater Conservation District portion of the Igneous and West Texas Bolsons aquifers.

The results of the previous run were used as a starting point to estimate the amount of pumping resulting in the drawdowns specified for this run (Tables 1 and 2). We ran the model iteratively, adjusting pumping in each groundwater conservation district and in each aquifer until the specified average drawdowns were achieved. Dry cells were not taken into account in the calculation of average drawdown. The final pumping amounts were then adjusted up and down in order to show the relationship between pumping and drawdown in Groundwater Management Area 4. The total pumping for each scenario was multiplied by a factor to increase (factors of 1.3, 1.6 and 2.0) or decrease (factors of 0.8, 0.6, and 0.4).

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the model run using the groundwater availability model for the Igneous Aquifer and Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer are described below:

- Version 1.01 of the groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers was used. See Beach and others (2004) for assumptions and limitations of the model.
- Processing MODFLOW for Windows (PMWin) version 5.3 as the interface to process model output (Chiang and Kinzelbach, 2001) was used.
- The model includes three layers representing the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer (Layer 1), the Igneous Aquifer (Layer 2), and the underlying Cretaceous and Permian units (Layer 3). Also note that some areas of Layer 2 in the model outside the boundary of the Igneous Aquifer are active in order to allow flow between the West Texas Bolsons Aquifer of Layer 1 and the underlying Permian units of Layer 3.

- The Igneous Aquifer boundary used in the groundwater availability model run was the boundary around which the model was developed. This boundary is a generalized (or smoothed) and slightly smaller version of the official boundary of the Igneous Aquifer according to the 2007 State Water Plan. A comparison of these two boundaries, as well as the boundary for the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer, is shown in Figure 1.

- The mean absolute error (a measure of the difference between simulated and actual water levels during model calibration) of the entire model for the period of 1990 to 2000 is 64 feet, or four percent of the range of measured water levels (Beach and others, 2004).

- The head closure criterion (HCLOSE) in the Strongly Implicit Procedure package'was changed from 0.001 ft to 0.005 feet in order to allow the model to converge under the various pumping conditions of the model runs. This change did not result in any high (greater than 1 percent) water budget imbalances that would indicate a problem with the model run.

- The starting pumpage in the model was the last year of the historical/calibration portion of the model (2000) except for two minor changes. First, the total pumping in cells in the Igneous Aquifer near the city of Alpine that contained greater than 3 acre-feet per year of pumping was distributed evenly among those cells (20 cells total). This redistribution was done in order to prevent the cells with higher pumping from going dry. The second change was to remove pumping from a model cell that caused the model to not converge under the pumping scenarios described above (Layer 1, Row 79, Column 64). The pumping in this cell was less than 0.1 acre-feet per year and its removal is not considered to have any significant effect on the results below (Oliver, 2009).

Table 1. Requested average drawdowns and average drawdowns from the previous run request for comparison (Oliver, 2009).

	Scenario 1 GAM Run 09-25		**Scenario 2 GAM Run 09-25**		**Scenario 3 (this request)**	
Groundwater Conservation District	West Texas Bolsons Aquifer	Igneous Aquifer	West Texas Bolsons Aquifer	Igneous Aquifer	West Texas Bolsons Aquifer	Igneous Aquifer
Brewster County	--	20	--	20	--	0
Culberson County	50	50	0	13	40	50
Jeff Davis County	21	10	10	10	20	10
Presidio County	5	5	5	5	5	5

Table 2. Pumpage input into the groundwater availability model for the original year 2000 pumping and for pumping scenarios 1, 2, and 3. All pumpage is reported in acre-feet per year.

Aquifer	Groundwater Conservation District	Original 1997 Pumping	Scenario 1 Pumping (GAM Run 09-25 input)	Scenario 2 Pumping (GAM Run 09-25 input)	Scenario 3 Pumping (this request input)
West Texas Bolsons	Culberson County GCD	30,316	28,150	11,700	24,950
	Jeff Davis County UWCD	135	135	135	250
	Presidio County UWCD	790	510	540	510
Igneous	Culberson County GCD	0	325	0	630
	Jeff Davis County UWCD	932	2,215	2,525	2,215
	Presidio County UWCD	1,985	750	730	1,100
	Brewster County GCD	2,051	4,130	4,130	1,385
Total	**GMA 4 West Texas Bolsons and Igneous**	**36,209**	**36,215**	**19,760**	**31,040**

Table 3. County average drawdown values and corresponding pumping amounts from the model budget (input minus dry cell pumping).

Aquifer	Groundwater Conservation District	Average drawdown after 50 years	Scenario 3 Pumping (from water budget)
West Texas Bolsons	Culberson County GCD	40	24,921
	Jeff Davis County UWCD	20	214
	Presidio County UWCD	5	509
Igneous	Culberson County GCD	50	626
	Jeff Davis County UWCD	10	2,195
	Presidio County UWCD	5	1,093
	Brewster County GCD	0	1,373
Total	**GMA 4 West Texas Bolsons and Igneous**	--	**30,931**

RESULTS:

The amount of pumping input that results in the requested drawdown for each aquifer in each district is shown along with the results from the previous run (Oliver, 2009) in Table 2. The new analysis is refered to as Scenario 3. The relationship between total pumping and overall average drawdown for the Igneous and West Texas Bolsons Aquifers are shown in Figure 2. Model layer 3 and part of model layer 2 in Culberson County which represent underlying Cretaceous units are not included in the overall drawdown average. The requested drawdowns and corresponding pumping amounts are listed together in Table 3.

Charts for each of the major water budget terms for each year of the predictive model run are shown for Groundwater Management Area 4 in Appendix A along with the water budget terms for scenario 1 and 2 for comparison. Appendix B contains water budget tables for each scenario for each groundwater conservation district 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 falling on the outcrop (where the aquifer is exposed at land surface) areas of aquifers as well as inflow to the aquifer from alluvial fans and stream beds as described in Beach and others (2004). Recharge is always shown as “Inflow” into the water budget. Recharge is modeled using the MODFLOW Recharge package.

- 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 using the MODFLOW Evapotranspiration (EVT) package.

- Pumping—water produced from wells in each aquifer. This component is always shown as “Outflow” from the water budget, because all wells included in the model produce (rather than inject) water. Pumping is simulated in the model using the MODFLOW Well package.

- Streams and Springs—water that naturally discharges from an aquifer when water levels rise above the elevation of the stream or spring. This component is always shown as “Outflow,” or discharge, in the water budget. Stream and spring outflows are simulated in the model using the MODFLOW Drain package. Stream inflow was modeled using the MODFLOW Recharge package and is included in the recharge values described above.

- Change in Storage—changes in the water stored in the aquifer. Storage can be either and “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 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 district and adjacent districts. Lateral flow is not shown in Appendix A because those results reflect the model as a whole (i.e. not individual districts). However, lateral flow is included in the water budget tables presented in Appendix B.

- Vertical leakage (upward or downward)—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. In this model, the West Texas Bolsons Aquifer is not always underlain by the Igneous Aquifer and the Igneous Aquifer is not always overlain by the West Texas Bolsons Aquifer. For this reason, the amount of water exiting the West Texas Bolsons Aquifer may not equal the amount of water entering the Igneous Aquifer in Appendix B.

Figure A-1 in Appendix A shows the pumping for the three scenarios. Figure A-2 shows Net Recharge in the groundwater availability model for each stress period for each of the three scenarios. Here, “Net Recharge” refers to recharge sourced from precipitation minus evapotranspiration and outflow to springs and streams. Note that Net Recharge increases slightly before leveling off during the predictive model run. Though recharge from precipitation is constant in the model, as water levels decline due to the increased pumping, the amount of water removed from the aquifer by evapotranspiration and discharge to springs and streams is reduced.

Figure A-3 shows the Net Change in Storage in the groundwater availability model. The volume of water removed from storage in the aquifer each year for Scenario 3 lies between the amount for Scenarios 1 and 2.

Figures A-4 and A-5 show the magnitude and direction of flow between each of the model layers. Over the model area as a whole, water is flowing outward from Layer 2 – upward into Layer 1 and downward into the underlying Cretaceous and Permian units of Layer 3. Note that vertical flow is referred to by the layer number as opposed to the aquifer name because some portions of Layer 2 are active outside the Igneous Aquifer boundary in order to allow flow between the West Texas Bolsons Aquifer in Layer 1 and the underlying Cretaceous and Permian units in Layer 3.

The water budget tables in Appendix B show each of the water budget components for each groundwater conservation district. Note that the total amount of water pumped from an aquifer within a groundwater conservation district may differ from the values for Pumping in Table 1 above. This is due to the occurrence of dry cells. When the water level in a cell drops below the bottom of the aquifer in a cell, the cell goes dry and pumping can no longer occur. The total pumpage is, therefore, reduced.

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 county boundary 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:

Beach, J.A., Ashworth, J.B., Finch, Jr., S.T., Chastain-Howley, A., Calhoun, K., Urbanczyk, K.M., Sharp, J.M., and Olson, J., 2004, Groundwater availability model for the Igneous and parts of the West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) aquifers: contract report to the Texas Water Development Board, 208 p.

Chiang, W., and Kinzelbach, W., 2001, Groundwater Modeling with PMWIN, 346 p.

Oliver, W., 2009, GAM run 09-25: Texas Water Development Board, GAM Run 09-25 Report, 26 p.

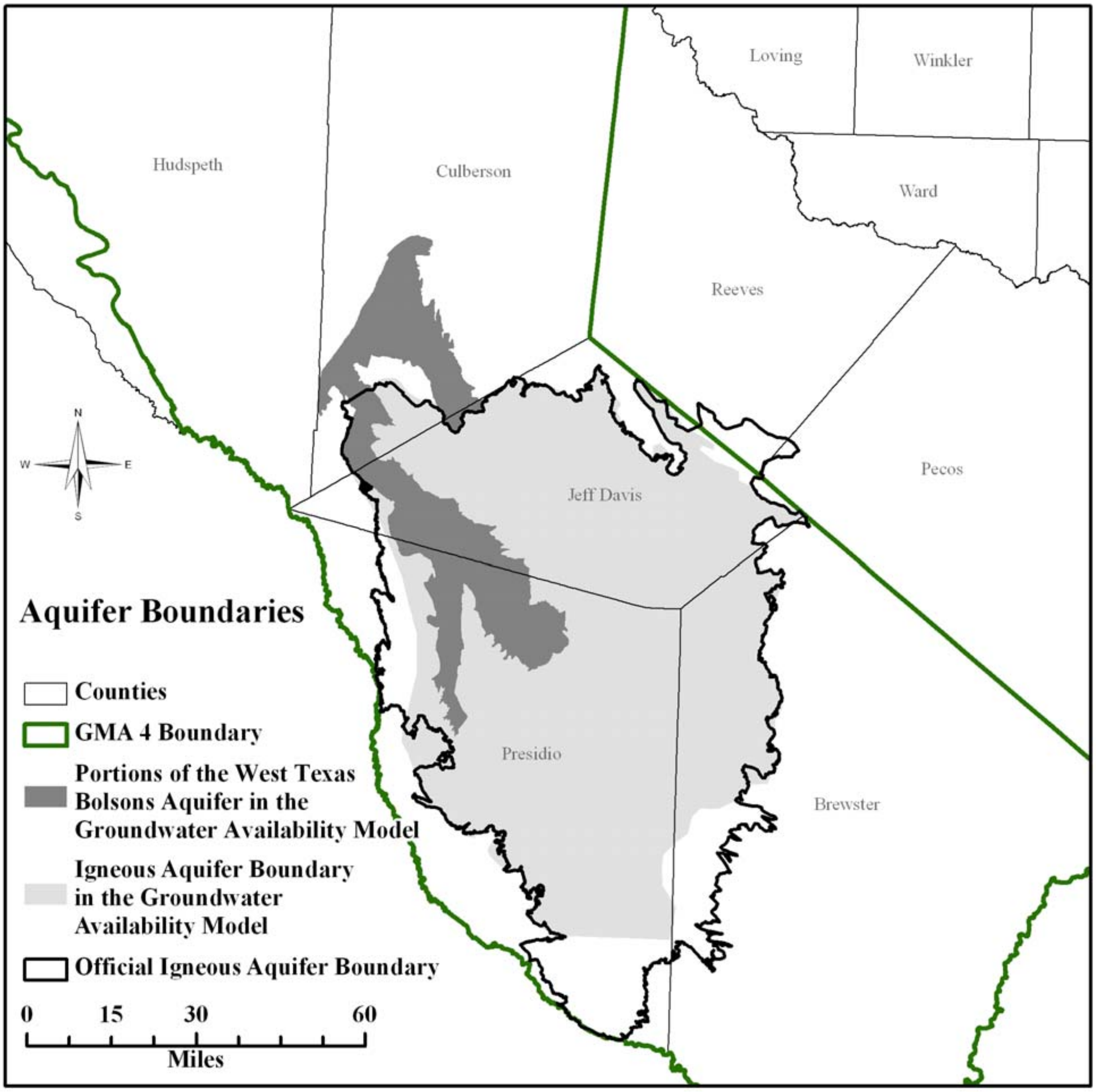

Figure 1. Aquifer boundaries for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer and the Igneous Aquifer used in the groundwater availability model run. The official boundary of the Igneous Aquifer is also included for comparison (From Oliver, 2009).

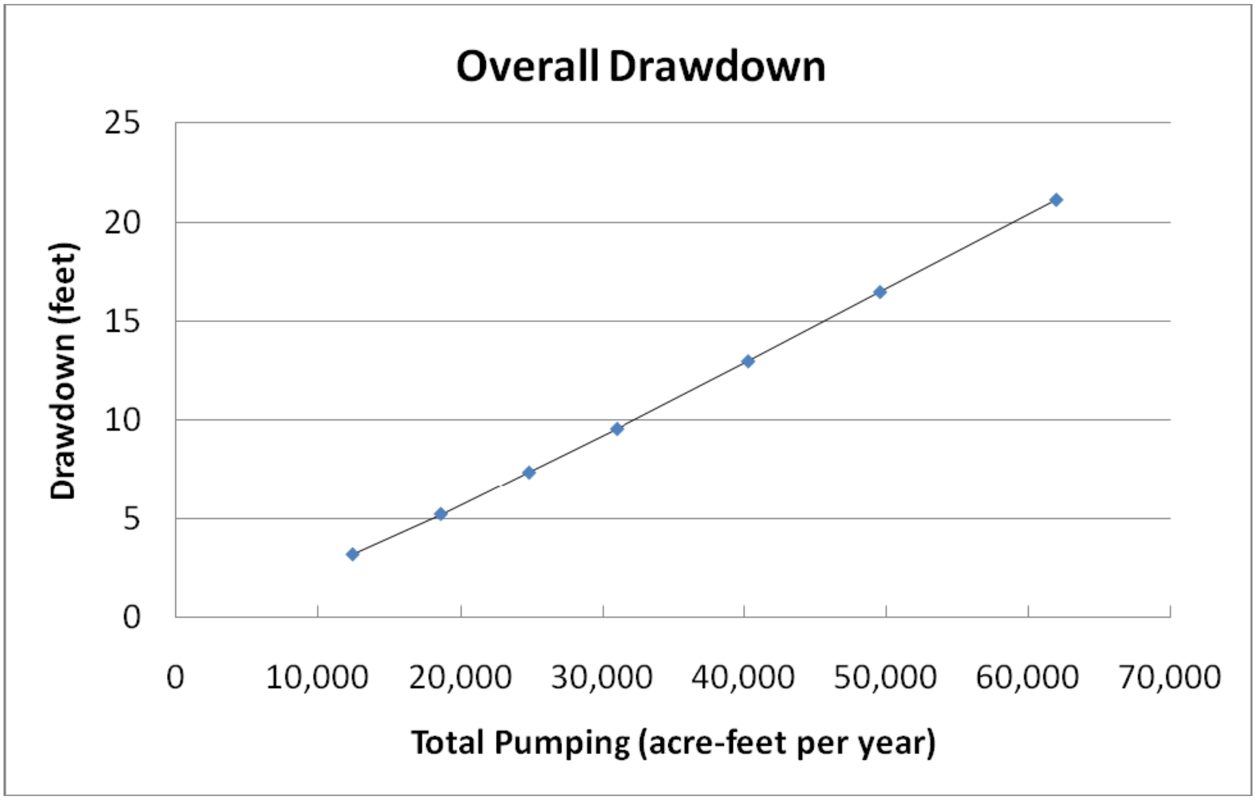

Figure 2. The relationship between pumping and drawdown in Groundwater Management Area 4. The total pumping for each scenario was multiplied by a factor to increase (factors of 1.3, 1.6 and 2.0) or decrease (factors of 0.8, 0.6, and 0.4). Model layer 3 and part of model layer 2 in Culberson County which represent underlying Cretaceous units are not included in the overall drawdown average.

Appendix A

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

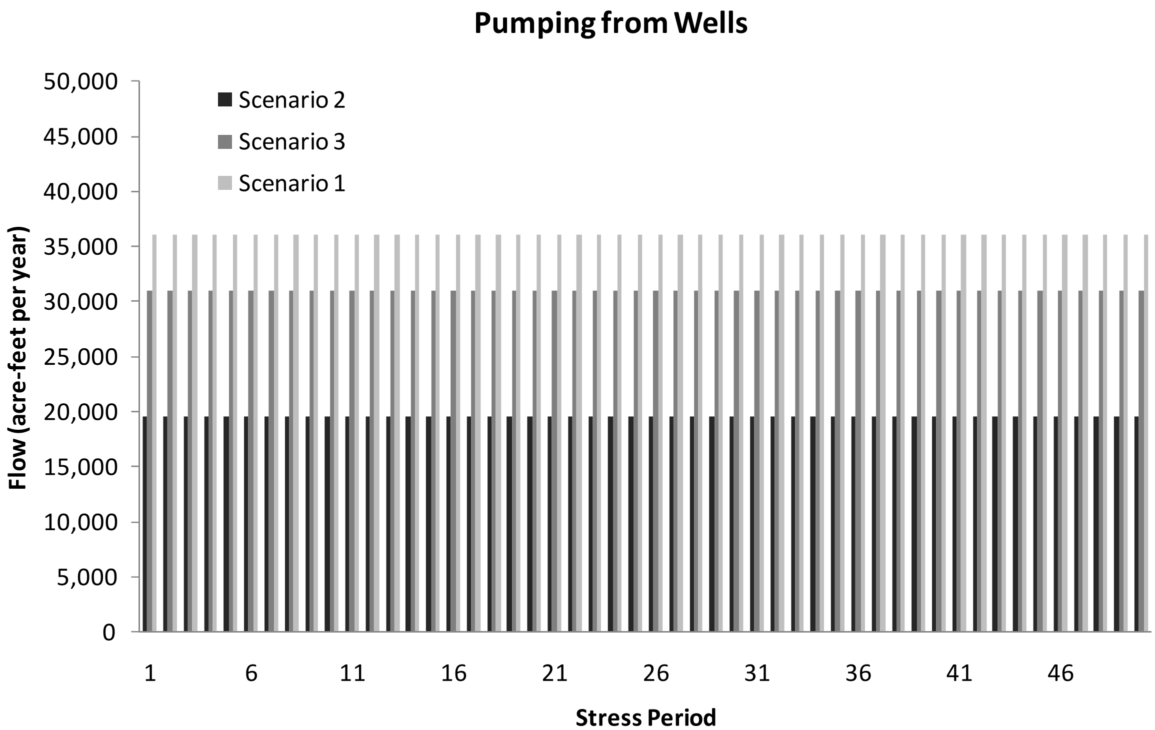

Figure A-1. Pumpage output from the groundwater availability model for all layers by stress period. Each stress period represents one year (Scenarios 1 and 2 from Oliver, 2009).

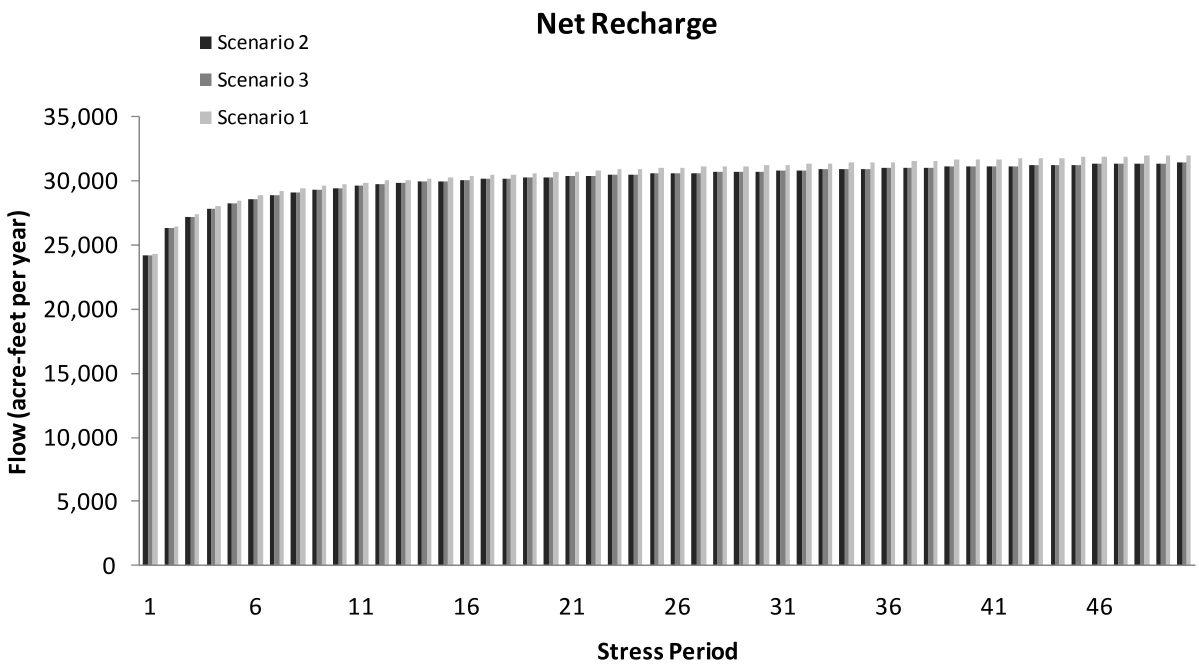

Figure A-2. Net recharge into the groundwater availability model for all layers by stress period. Each stress period represents one year. Note that net recharge refers to recharge to the aquifer sourced from precipitation minus evapotranspiration and outflow to springs (Scenarios 1 and 2 from Oliver, 2009).

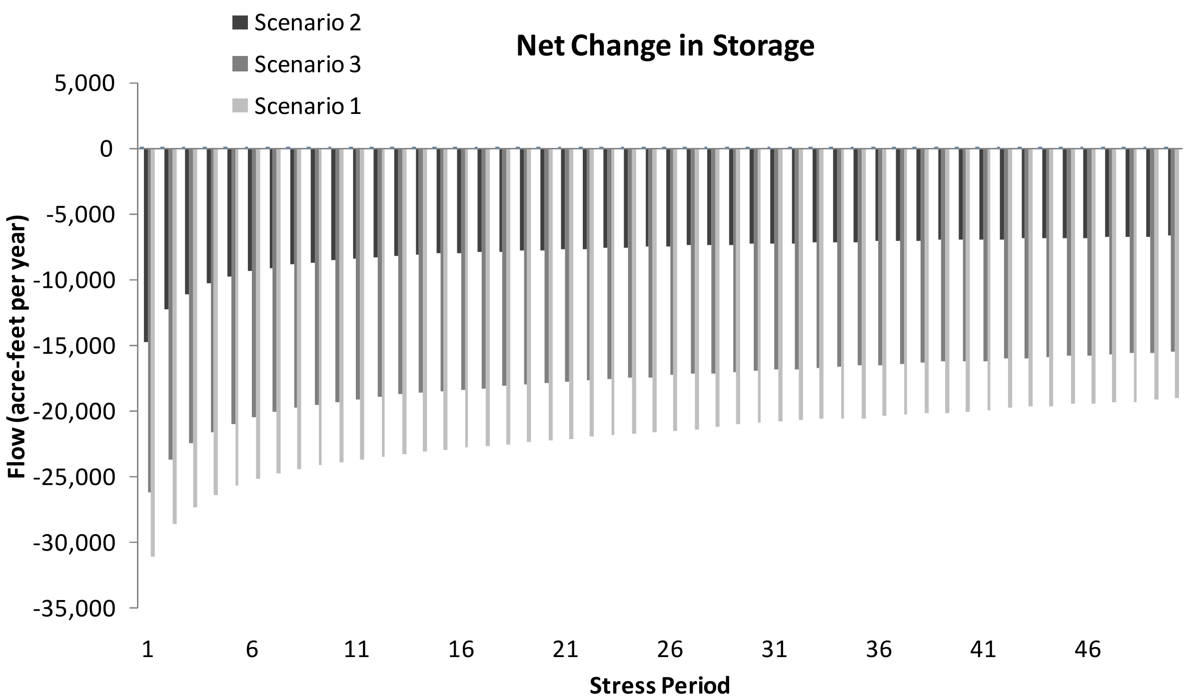

Figure A-3. Net change in storage (the volume of water stored in the aquifer) in the groundwater availability model for all layers by stress period. Each stress period represents one year (Scenarios 1 and 2 from Oliver, 2009).

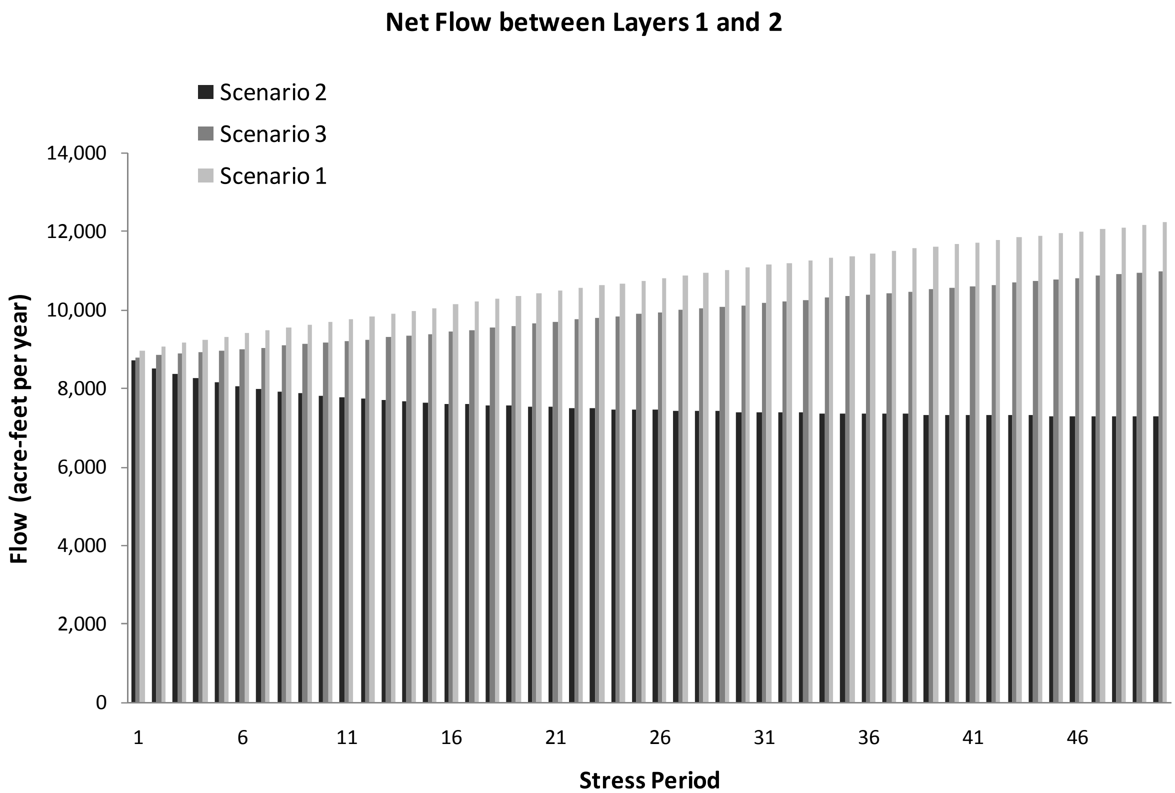

Figure A-4. Net vertical flow between Layer 1 and Layer 2 in the groundwater availability model by stress period. Each stress period represents one year. Note that vertical flow is referred to by the layer number as opposed to the aquifer name because some portions of Layer 2 outside the Igneous Aquifer boundary are active in the model in order to allow flow between the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer in Layer 1 and the underlying Cretaceous and Permian units in Layer 3 (Scenarios 1 and 2 from Oliver, 2009).

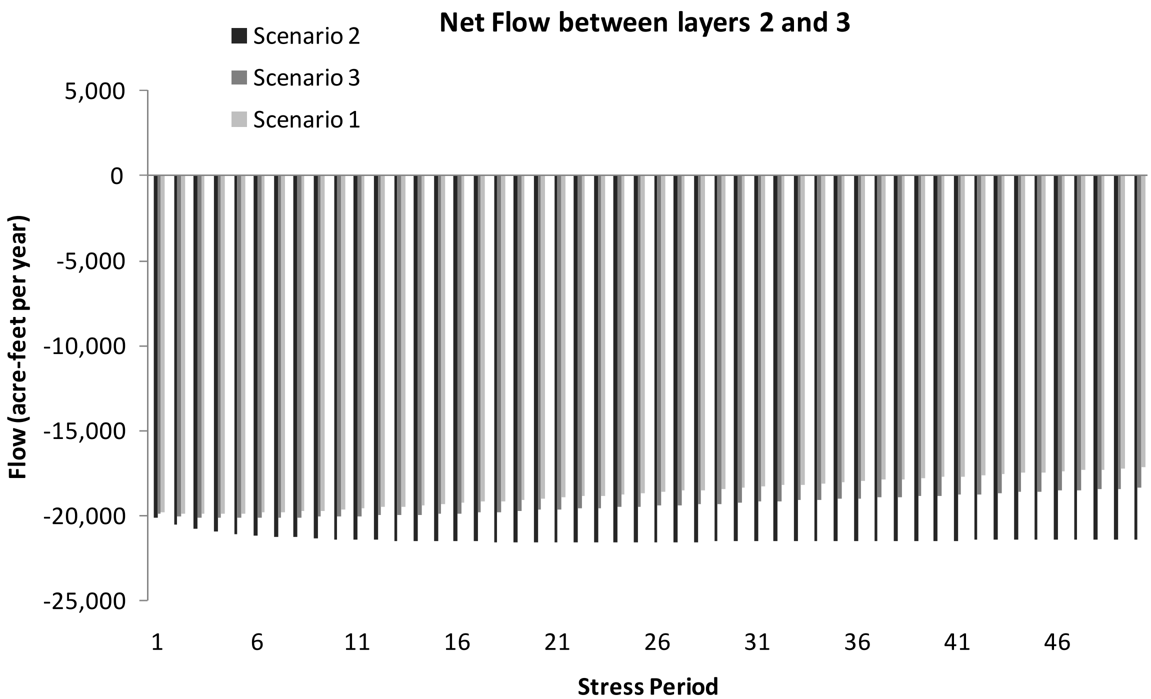

Figure A-5. Net vertical flow between Layer 2 and Layer 3 in the groundwater availability model by stress period. Each stress period represents one year. Note that vertical flow is referred to by the layer number as opposed to the aquifer name because some portions of Layer 2 outside the Igneous Aquifer boundary are active in the model in order to allow flow between the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer in Layer 1 and the underlying Cretaceous and Permian units in Layer 3 (Scenarios 1 and 2 from Oliver, 2009).

Appendix B

Water budget table for the last stress period of the model run

Table B-1. Water budgets for Scenario 3 for the last stress period of the groundwater availability model by groundwater conservation district. All values are reported in acre-feet per year.

	Culberson County GCD		Jeff Davis County UWCD		Presidio County UWCD		Brewster County GCD	
	West Texas Bolsons	**Igneous**	**West Texas Bolsons**	**Igneous**	**West Texas Bolsons**	**Igneous**	**West Texas Bolsons**	**Igneous**
Inflow								
Recharge	2,099	627	154	25,924	1,457	9,341	-	6,569
Vertical Leakage Upper	0	59	0	0	0	0	-	0
Vertical Leakage Lower	13,906	185	1,908	244	1,548	763	-	406
Lateral Flow	7,729	1,049	4,007	671	884	4,041	-	1,074
Head Dependant Flow	0	0	0	0	0	0		0
Total Inflow	*23,735*	*1,921*	*6,068*	*26,838*	*3,890*	*14,144*	-	*8,049*
Outflow								
Pumping	24,921	626	214	2,195	509	1,093	-	1,373
Springs and Streams	0	0	0	2,332	0	3,327	-	145
Evapotranspiration	0	0	0	2,940	0	966	-	1,377
Vertical Leakage Upper	0	441	0	1,908	0	1,548	-	0
Vertical Leakage Lower	6,381	1,299	0	14,689	0	7,047	-	3,969
Lateral Flow	0	3	8,613	4,043	4,007	1,444	-	1,238
Head Dependant Flow	0	0	0	0	0	0		0
Total Outflow	*31,302*	*2,370*	*8,827*	*28,107*	*4,515*	*15,425*	-	*8,102*
Inflow - Outflow	-7,568	-449	-2,760	-1,269	-626	-1,281	-	-53
Storage Change	-7,504	-449	-2,745	-1,270	-623	-1,292	-	-56
Model Error	-64	0	-14	1	-3	11		3
Model Error (%)	-0.20	-0.01	-0.16	0.00	-0.06	0.07	-	0.03