GAM Task 10-012 Model Run Report

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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 August 9, 2010.

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EXECUTIVE SUMMARY:

The newly released groundwater availability model for the Yegua-Jackson Aquifer was run from 1998 to 2060 assuming pumping from the 2007 State Water Plan, where applicable. In areas containing the Yegua-Jackson Aquifer but without pumping specified in the state water plan, pumping was left at the level during the last year of the historical period of the model (1997). Additionally, pumping in this "base" run was ramped up and down to investigate how the aquifer responds to different levels of pumping.

Results are presented by groundwater management area with the exception of Groundwater Management Area 16. Results for this area are not included because the Yegua-Jackson Aquifer is contained in a soon-to-be-released model specifically for Groundwater Management Area 16. The pumping above yields results ranging from an average water level increase of 2 feet in Groundwater Management Area 11 to an average decline of 3 feet in Groundwater Management Area 15. For the 0.4 scenario (pumping decreased by a factor of 0.4), results range from an average water level rise of 7 feet in Groundwater Management Area 11 to an average decline of 2 feet in Groundwater Management Area 15. For the 4.0 scenario (pumping increased by a factor of 4.0), results range from an average water level decline of 1 foot in Groundwater Management Area 12 to an average decline of 18 feet in Groundwater Management Area 11.

PURPOSE OF MODEL RUNS:

The model runs contained in this report were performed using the newly released groundwater availability model for the Yegua-Jackson Aquifer to determine how the model performs during predictive simulations. These runs will also serve as a source of information for groundwater management areas that need to establish desired future conditions for the Yegua-Jackson Aquifer.

DESCRIPTION OF MODEL RUNS:

A predictive simulation was run using pumping from the 2007 State Water Plan (TWDB, 2007) where applicable and pumping from the historical-calibration portion of the model elsewhere. This "base" scenario was then adjusted up and down to determine how the aquifer responds under different levels of pumping.

METHODS:

The groundwater availability model for the Yegua-Jackson Aquifer was extended from the end of the historical-calibration period (1997) to 2060. Each MODFLOW package in the model was changed as appropriate to enable predictive simulations through 2060. Some assumptions made during this process are discussed below:

- For the reservoir package, the average reservoir stage during the historical-calibration period of the model (1980 to 1997) was determined and held constant through the predictive period.

- The general-head boundary package is used to simulate flow from the Jasper Aquifer portion of the Gulf Coast Aquifer into the Catahoula unit represented by portions of layer 1 in the Yegua-Jackson Aquifer model. Though general-head boundary head values change through time in the historical period, the volume of flow that enters the top of the Upper Jackson (Layer 2) does not exhibit large fluctuations and is a relatively small portion of the overall budget (Deeds and others, 2010). For this reason the general-head boundary head values for 1997 (the stress period containing the median general-head boundary inflow between 1980, 1990, and 1997) were assigned to the predictive stress periods.

- For the well package, pumping from the last year of the historical-calibration period of the model was assigned to the interim period (1998 to 2009) prior to the predictive simulation. This was considered an appropriate assumption after a preliminary investigation of available water level measurements in the TWDB Groundwater Database. This investigation showed neither a consistent trend in water level changes nor a sufficient amount of information to support reevaluating the pumping distribution. For the predictive simulation (2010 to 2060), pumping was assigned as described below.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the model run using the groundwater availability model for the Yegua-Jackson Aquifer are described below:

- We used version 1.01 of the groundwater availability model for the Yegua-Jackson Aquifer. See Deeds and others (2010) for assumptions and limitations of the groundwater availability model.

- The model includes five layers representing the Yegua-Jackson Aquifer and the overlying Catahoula unit.

- As reported in Deeds and others (2010), the mean absolute errors (a measure of the difference between simulated and measured water levels during model calibration) for the Jackson Group (combined upper and lower Jackson units), Upper Yegua, and Lower Yegua portions of the Yegua-Jackson Aquifer for the historical-calibration period of the model are 31.1, 23.9, and 24.5 feet, respectively. These represent 10.3, 5.7 and 6.3 percent of the hydraulic head drop across each model area, respectively.

- Cells were assigned to individual counties and groundwater conservation districts as shown in the March 23, 2010 version of the model grid for the Yegua-Jackson Aquifer.

- The recharge used for the model run represents average recharge as described in Deeds and others (2010).

- The model results presented in this report were extracted from all areas of the model representing the units comprising the Yegua-Jackson Aquifer. This includes some areas outside the “official” boundary of the aquifer shown in the 2007 State Water

Plan (TWDB, 2007). For this reason, the reported drawdowns may reflect water of quality ranging from fresh to brackish and saline. This is especially true for the subcrop portions of the aquifer in groundwater management areas 14 and 15.

Pumping

The pumping values in the groundwater availability model in each county for the “base” predictive model run were determined using values in the 2007 State Water Plan, where applicable (TWDB, 2007). These values are shown in Table 1. In areas where the 2007 State Water Plan did not define pumping in the Yegua-Jackson Aquifer, pumping was kept at the levels in the model for the last year of the historical-calibration period (1997). When distributing the new pumping in each county, the percent of pumping in each model layer was preserved. Where a decrease from the 1997 level of pumping was required, the pumping for each cell in the county 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 in the layer that contained pumping during the last year of the historical-calibration portion of the model.

The one exception to the assignment of pumping described above was in Jim Hogg County. The 2007 State Water Plan specifies 100 acre feet of pumping per year for this area. However, the historical-calibration portion of the model did not contain any pumping in the county. Because the pumping volume was relatively small and only a small portion of the Yegua-Jackson Aquifer is present in Jim Hogg County, pumping was not applied for this analysis. Additionally, results for Jim Hogg County (part of Groundwater Management Area 16) are not presented in this report because this area of the Yegua-Jackson Aquifer is included in an upcoming model designed specifically for Groundwater Management Area 16.

The “base” pumping distribution described above was also adjusted up and down in order to provide insight into the relationship between pumping and drawdown in the Yegua-Jackson Aquifer. The pumping input to the model in each county was multiplied by a factor to increase (factors of 1.3, 1.6, 1.9, 2.5, 3.0, and 4.0) or decrease (factors of 0.8, 0.6, and 0.4) the pumping in these areas. These factors were chosen in order to provide results from a broad range of pumping between less than half of the “base” (the 0.4 scenario) to 4 times the base. The relationships generated are presented in the Results section below.

RESULTS:

Figure 1 below is a location map that shows the location of the Yegua-Jackson Aquifer and those areas included in the groundwater availability model. Figure 1 also includes the locations of each groundwater management area and county in the model area.

The pumping output from the model for each scenario described in the Pumping section above is shown in Table 2 for each groundwater management area in the model with the exception of Groundwater Management Area 16. Results for Groundwater Management Area 16 are not presented in this report because the Yegua-Jackson Aquifer in this area is modeled together with the Gulf Coast Aquifer in a separate groundwater availability model that is expected to be released shortly after this report. Pumping for the last year of the historical-calibration period is also included as a reference to indicate how the 2007 State Water Plan pumping compares to the estimated pumping for 1997 in the model.

Table 2 also includes the average drawdown between 2010 and 2060 for each scenario by groundwater management area. The drawdown values presented reflect the drop in water levels from the beginning of 2010 to the end of 2060 (a 51-year simulation period). Notice that some areas exhibit a water level decline under the base pumping scenario (for example, Groundwater Management Area 14). Other areas exhibit a water level rise (for example, Groundwater Management Area 11).

Though only a groundwater management area-wide summary of results is presented in Table 2, appendices to this report containing results for each groundwater management area have been included to provide more details on pumping and drawdown for each county. Appendices A, B, C, D, and E contain detailed predictive model run results for groundwater management areas 11, 12, 13, 14, and 15, respectively.

To better illustrate how the model responds through time during the “Base” run, each appendix also contains figures of each of the major water budget terms between 1998 and 2060 for the groundwater management area. The components of the water budget are described below:

- Recharge— areally distributed recharge due to precipitation. Recharge is always shown as “Inflow” into the water budget. Recharge is modeled using the MODFLOW Recharge package.

- Pumping—water produced from wells in the aquifer. This component is always shown as “Outflow” from the water budget.

- Net Change in Storage—changes in the water stored in the aquifer. 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). The “net” change in storage refers to the difference between the storage inflows and outflows.

- Evapotranspiration—water that naturally discharges from the aquifer by direct evaporation or transpiration through plants. This occurs in areas where the water level in the aquifer is near the land surface, primarily near rivers and streams. Evapotranspiration is always shown as an “Outflow” from the water budget and is modeled using the MODFLOW Evapotranspiration package.

- Net Surface Water Flow—describes the total interaction of the aquifer with surface water features such as streams, reservoirs, and springs. For streams and reservoirs, interaction with surface water can be either an inflow from the surface water (for example, a losing stream) or an outflow to the surface water (for example, a gaining stream). Springs, alternatively, can only be an outflow from the aquifer. Streams, reservoirs, and springs are modeled using the MODFLOW Stream, Reservoir, and Drain packages, respectively.

- Vertical Flow from Overlying Catahoula—describes the vertical flow, or leakage, between the overlying Catahoula unit and the Yegua-Jackson Aquifer. This flow is controlled by the water levels in each aquifer and aquifer properties that define the amount of leakage that can occur. The Catahoula unit overlies the subcrop portions of the Yegua-Jackson Aquifer and interacts with the Gulf Coast Aquifer that overlies it using the MODFLOW General-Head Boundary package.

- 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 management area).

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.

Groundwater Management Area 11

Results for Groundwater Management Area 11 are shown in Appendix A. Table A-1 shows the pumping and drawdown by county and for Groundwater Management Area 11 as a whole. Notice that the 2007 State Water Plan pumping was over 2000 acre-feet per year less than the pumping in 1997. This decline in pumping led to the overall increase in water levels of 2 feet between 2010 and 2060 over the area in the “base” scenario. Figure A-1 depicts these same values graphically, showing the trend between the average drawdown over Groundwater Management Area 11 and the annual pumping. Drawdown in Groundwater Management Area 11 is sensitive to pumping, increasing to 18 feet for the “4.0” scenario where pumping is 4 times higher than the “base” scenario.

The water budget figures for Groundwater Management Area 11 depict these same trends. Figure A-2 shows how the pumping was lowered in 2010 and kept constant throughout the predictive period. Figure A-3 shows recharge through time, which was kept constant in the model. Figure A-4 shows the net change in storage in the model through time. For the whole period water levels area rising. The rate of water level rise increases in 2010 as the pumping is reduced before slowly leveling off. Figure A-5 shows outflow by evapotranspiration, which increases through time corresponding to increasing water levels. Figure A-6, showing outflow to surface water, also increases through time for the same reason. Figure A-7 shows the net inflow from the overlying Catahoula unit, which increases slightly through time. This response is counterintuitive with rising water levels, but the magnitude of flow is very small and the flow only occurs in the subcrop portions of the Yegua-Jackson Aquifer, which are limited to the far southern portions of Trinity, Angelina, San Augustine, and Sabine counties. Finally, Figure A-8 shows the lateral flow from areas neighboring Groundwater Management Area 11. The net later flow is always inflow toward Groundwater Management Area 11, but the magnitude of the inflow decreases with time as water levels rise.

Groundwater Management Area 12

Results for Groundwater Management Area 12 are shown in Appendix B. Table B-1 shows the pumping and drawdown by county and for Groundwater Management Area 12 as a whole. Notice that the "base" scenario pumping was essentially the same as the 1997 pumping. This is because the 2007 State Water Plan does not specifically address pumping from the Yegua-Jackson Aquifer in these counties. Figure B-1 depicts the values in Table B-1 graphically, showing the trend between the average drawdown in Groundwater Management Area 12 and the annual pumping. In general the change in water levels is very small for the various scenarios, ranging from an increase of less than 1 foot to a decline of just over 1 foot.

The water budget figures for Groundwater Management Area 12 provide more insight into the response of the aquifer to the "base" pumping scenario. Figure B-2 shows that pumping was kept constant throughout the period. Figure B-3 shows recharge through time, which was kept constant in the model. Figure B-4 shows the net change in storage in the model through time. For the whole period water levels are rising, but the rate of water level rise declines with time. Figure B-5 shows outflow by evapotranspiration, which increases through time corresponding to increasing water levels.

Figure B-6, showing outflow to surface water, is relatively stable through the predictive period. Figure B-7 shows the net outflow to the overlying Catahoula unit, which increases slightly through time due to the increasing water levels. Lastly, Figure B-8 shows the lateral flow into Groundwater Management Area 12. The net lateral flow is always in inflow from neighboring areas and the magnitude of flow increases through time. Though an overall average water level rise should result in a reduction in lateral inflow (all else being equal), lateral flow is also dependent on the change in water level in neighboring areas and the water levels along the boundary of Groundwater Management Area 12.

Groundwater Management Area 13

Results for Groundwater Management Area 13 are shown in Appendix C. Table C-1 shows the pumping and drawdown by county and for Groundwater Management Area 13 as a whole. Notice that the 2007 State Water Plan pumping was almost 7000 acre-feet per year more than the pumping in 1997. This increase is not uniform, however, because the state water plan only defines pumping from the Yegua-Jackson Aquifer in Webb and Zapata counties in Groundwater Management Area 13. Figure C-1 depicts pumping and the associated drawdown for each of the scenarios. Drawdown over Groundwater Management Area 13 as a whole for the "base" scenario is less than half a foot and increases to almost 2 feet for the "4.0" scenario.

The water budget figures for Groundwater Management Area 13 provide more insight into the response of the aquifer to the "base" pumping scenario. Figure C-2 shows how the pumping was increased in 2010 and kept constant throughout the predictive period. Figure C-3 shows recharge through time, which was kept constant in the model. Figure C-4 shows the net change in storage in the model through time. During the period before the predictive model run, water levels were rising slowly. However, with the increased pumping beginning in 2010, water levels began to fall as shown by the net reduction in storage. Figure C-5 shows outflow by evapotranspiration, which decreases through time corresponding to declining water levels. Figure C-6 shows net outflow to surface water, which increases through time. Though this is a counterintuitive response for the groundwater management area as a whole, the increases in surface water outflow are restricted to McMullen County, which has very little pumping and exhibits slightly increasing water levels. Figure C-7 shows the net inflow from the overlying Catahoula unit, which shows a small increase before leveling out over time. Lastly, Figure C-8 shows the net lateral flow into Groundwater Management Area 13. The net lateral flow is always inflow toward Groundwater Management Area 13, but the magnitude of flow decreases before slowly rising toward the end of the predictive period. This is the opposite response one would expect with an increase in pumping, but it also is dependent on the changes in water levels in surrounding areas. While water levels in Groundwater Management Area 13 show a slight decline in the “base” scenario, water levels in surrounding areas are declining at faster rates (for example, Fayette, Lavaca, and DeWitt counties). This leads to the reduction in the rate of lateral inflow shown in Figure C-8.

Groundwater Management Area 14

Results for Groundwater Management Area 14 are shown in Appendix D. Table D-1 shows the pumping and drawdown by county and for Groundwater Management Area 14 as a whole. Notice that the 2007 State Water Plan pumping was over 6,000 acre-feet per year more than the pumping in 1997. This increase is not uniform, however, because the state water plan only defines pumping from the Yegua-Jackson Aquifer in Walker, Polk, and Tyler counties in Groundwater Management Area 14. Figure D-1 depicts pumping and the associated drawdown for each of the scenarios described in the Pumping section above. Drawdown over Groundwater Management Area 14 as a whole for the “base” scenario is approximately 3 feet and ranges between 2 feet and 7 feet for the various scenarios presented.

Notice that in Figure D-1, the line representing the relationship between pumping and drawdown bends downward between the “base” and “1.3” scenarios. This is due to a cell in the model with a large amount of pumping going “dry.” A cell goes dry when the water level in the cell drops below the bottom of the aquifer in the cell. In this situation pumping can no longer occur and the pumping output from the model is reduced.

The water budget figures for Groundwater Management Area 14 provide more insight into the response of the aquifer to the “base” pumping scenario. Figure D-2 shows how the pumping was increased in 2010 and kept constant throughout the predictive period. Figure D-3 shows recharge through time, which was kept constant in the model. Figure D-4 shows the net change in storage in the model through time. During the period before the predictive model run, water levels were rising slowly. However, with the increased pumping beginning in 2010, water levels began to fall as shown by the net reduction in storage.

Figure D-5 shows outflow by evapotranspiration which increases through time beginning in 2021 even though all inputs to the model are constant with time. As with the evapotranspiration for Groundwater Management Area 13 described above, this is due to the different locations of the pumping and the evapotranspiration. Evapotranspiration can only occur when the water level in the aquifer is close to the ground-surface. Most areas of the model exhibit a water level decline. However, Washington County, an area with relatively little pumping and portions of the Yegua-Jackson Aquifer outcrop, shows increasing water levels. The water levels in Washington County prior to 2021 were low enough such that no evapotranspiration could occur. However, beginning in 2021, water levels had raised enough to allow evapotranspiration, causing the increase in the middle of the predictive period shown in Figure D-5.

Figure D-6 shows net outflow to surface water, which declines through time with declining water levels. Figure D-7 shows the net inflow from the overlying Catahoula unit, which shows a slow increase as water levels decline in the subcrop portion of the aquifer in Groundwater Management Area 14. Finally, Figure D-8 shows the net lateral flow out of Groundwater Management Area 14. Though the direction of lateral flow is always outflow to adjacent areas, the magnitude of the outflow declines during the predictive period due to declining water levels.

Groundwater Management Area 15

Results for Groundwater Management Area 15 are shown in Appendix E. Table E-1 shows the pumping and drawdown by county for Groundwater Management Area 15 as a whole. Notice that the "base" scenario pumping is the same as the 1997 pumping. This is because the 2007 State Water Plan does not specifically address pumping from the Yegua-Jackson Aquifer in the counties in Groundwater Management Area 15. Figure E-1 depicts pumping and the associated drawdown for each of the scenarios described in the pumping section above. Drawdown over the area as a whole for the "base" scenario is approximately 3 feet and ranges from 2 to 5 feet between the "0.4" to "4.0" scenarios.

The water budget figures for Groundwater Management Area 15 provide more insight into the response of the aquifer to the "base" pumping scenario. Figure E-2 shows how the pumping was kept constant at levels from the historical-calibration portion of the model through the predictive period. Figure E-3 shows recharge through time, which was kept constant in the model. Figure E-4 shows the net change in storage in the model through time. Over the whole period water levels are declining. However, the rate of water-level decline slows with time during the predictive simulation. Figure E-5 shows that no evapotranspiration occurs from the Yegua-Jackson Aquifer in Groundwater Management Area 15 in the model. Figure E-6 shows the net inflow from surface water, which exclusively consists of inflow from streams in the model. The rate of inflow from streams increases slightly with time as water-levels decline. Figure E-7 shows the net inflow from the overlying Catahoula unit, which also shows a slow increase with time as water levels decline. Lastly, Figure E-8 shows the net lateral flow out of Groundwater Management Area 15. The net lateral flow is always an outflow to adjacent areas, but the magnitude of flow decreases with time as water levels decline.

REFERENCES:

Deeds, N.E., Yan, T., Singh, A., Jones, T.L., Kelley, V.A., Knox, P.R., Young, S.C., 2010, Groundwater availability model for the Yegua-Jackson Aquifer: Final report prepared for the Texas Water Development Board by INTERA, Inc., 582 p.

Texas Water Development Board, 2007, Water for Texas – 2007—Volumes I-III; Texas Water Development Board Document No. GP-8-1, 392 p.

Table 1. Annual pumping from the Yegua-Jackson Aquifer by county in the 2007 State Water Plan (TWDB, 2007). Pumping is in acre-feet per year.

County	Annual Pumping
Angelina	4,860
Houston	1,380
Jim Hogg	100
Nacogdoches	60
Polk	360
Sabine	1,100
San Augustine	540
Starr	2,000
Trinity	740
Tyler	180
Walker	6,400
Webb	5,000
Zapata	2,000

Table 2. Pumping and drawdown for each scenario for each groundwater management area (GMA) in the model. Pumping is in acre-feet per year. Drawdown is in feet. Negative values indicate a rise in water levels.

	1997	Pumping by Scenario									
GMA	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 11	10,833	3,470	5,204	6,939	8,673	11,275	13,637	15,998	20,722	24,658	32,145
GMA 12	4,612	1,844	2,765	3,687	4,610	5,995	7,380	8,766	11,537	13,846	18,463
GMA 13	1,006	3,173	4,759	6,345	7,931	10,310	12,689	15,067	19,825	23,789	31,718
GMA 14	1,637	3,117	4,676	6,234	7,793	8,231	10,131	12,030	15,829	18,995	25,327
GMA 15	685	274	411	548	685	889	1,094	1,298	1,706	2,047	2,728
		Drawdown by Scenario									
GMA 11		-7	-5	-4	-2	0	2	4	8	11	18
GMA 12		-1	-1	0	0	0	0	0	1	1	1
GMA 13		0	0	0	0	0	1	1	1	1	2
GMA 14		2	2	3	3	3	4	4	5	5	7
GMA 15		2	2	2	3	3	3	4	4	4	5

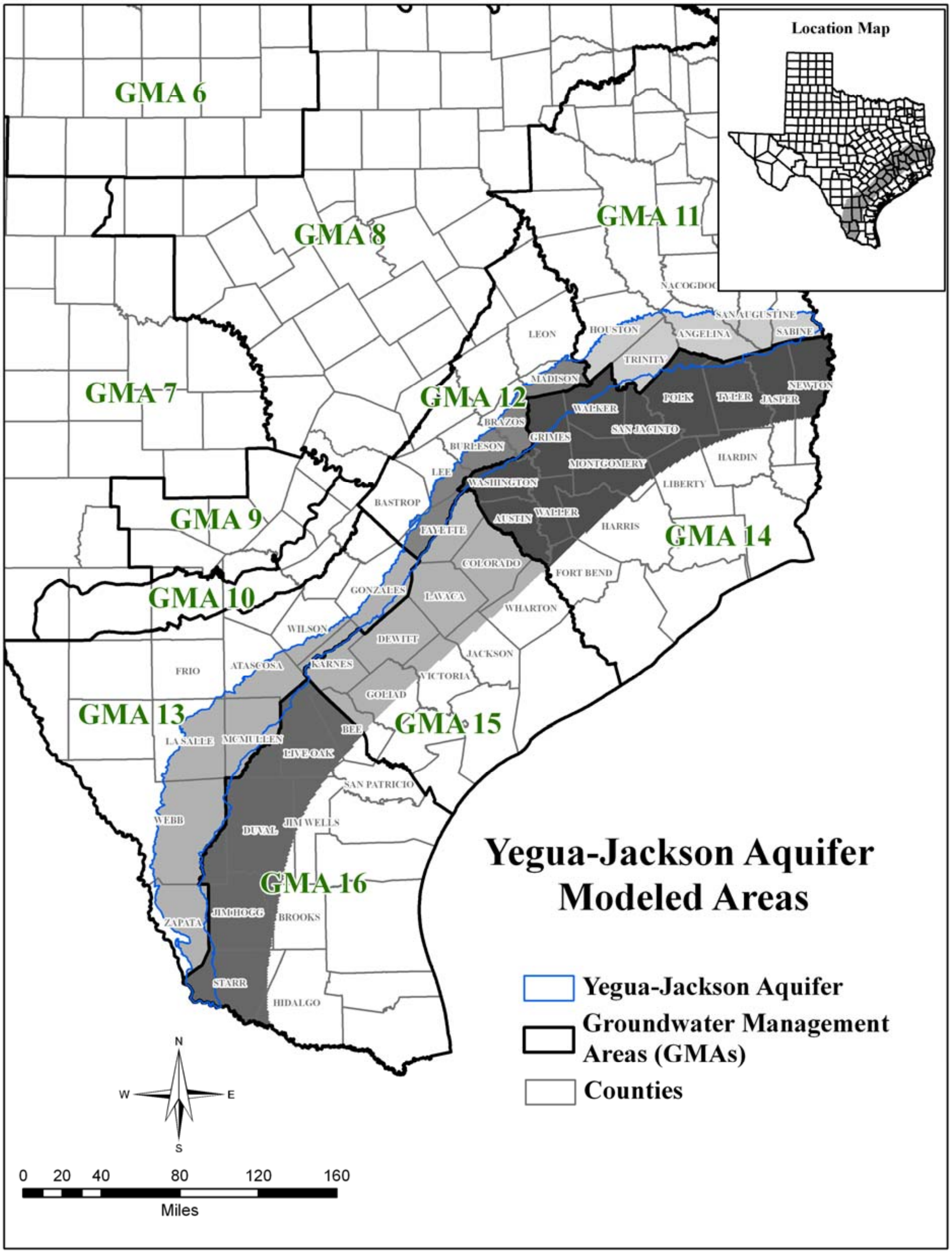

Figure 1. Location map showing model grid cells representing the Yegua-Jackson Aquifer, groundwater management areas, and the Yegua-Jackson Aquifer boundary.

Appendix A

Spread Analysis Results for Groundwater Management Area 11

Table A-1. Pumping and average drawdown between 2010 and 2060 for each county in Groundwater Management Area 11 (GMA 11) by scenario. Pumping is in acre-feet per year. Drawdown is in feet. Negative values indicate a rise in water levels.

		1997	Pumping by Scenario										Drawdown by Scenario									
GMA	**County**	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 11		10,833	3,470	5,204	6,939	8,673	11,275	13,637	15,998	20,722	24,658	32,145	-7	-5	-4	-2	0	2	4	8	11	18
	Angelina	6,313	1,942	2,913	3,884	4,855	6,311	7,528	8,745	11,178	13,206	16,876	-11	-9	-6	-4	0	4	8	15	22	33
	Houston	851	552	828	1,103	1,379	1,792	2,205	2,618	3,445	4,133	5,511	0	0	0	1	1	1	1	2	2	3
	Nacogdoches	104	24	36	48	60	78	96	114	150	180	240	-6	-5	-5	-4	-3	-2	-1	2	4	9
	Sabine	2,490	440	660	880	1,100	1,430	1,760	2,090	2,750	3,300	4,400	-13	-11	-10	-8	-6	-3	-1	4	8	16
	San Augustine	118	216	324	432	540	702	864	1,026	1,350	1,620	2,160	-11	-10	-8	-7	-5	-3	-1	3	7	14
	Trinity	956	296	444	592	740	962	1,184	1,406	1,849	2,219	2,958	-2	0	1	2	2	3	4	6	8	11

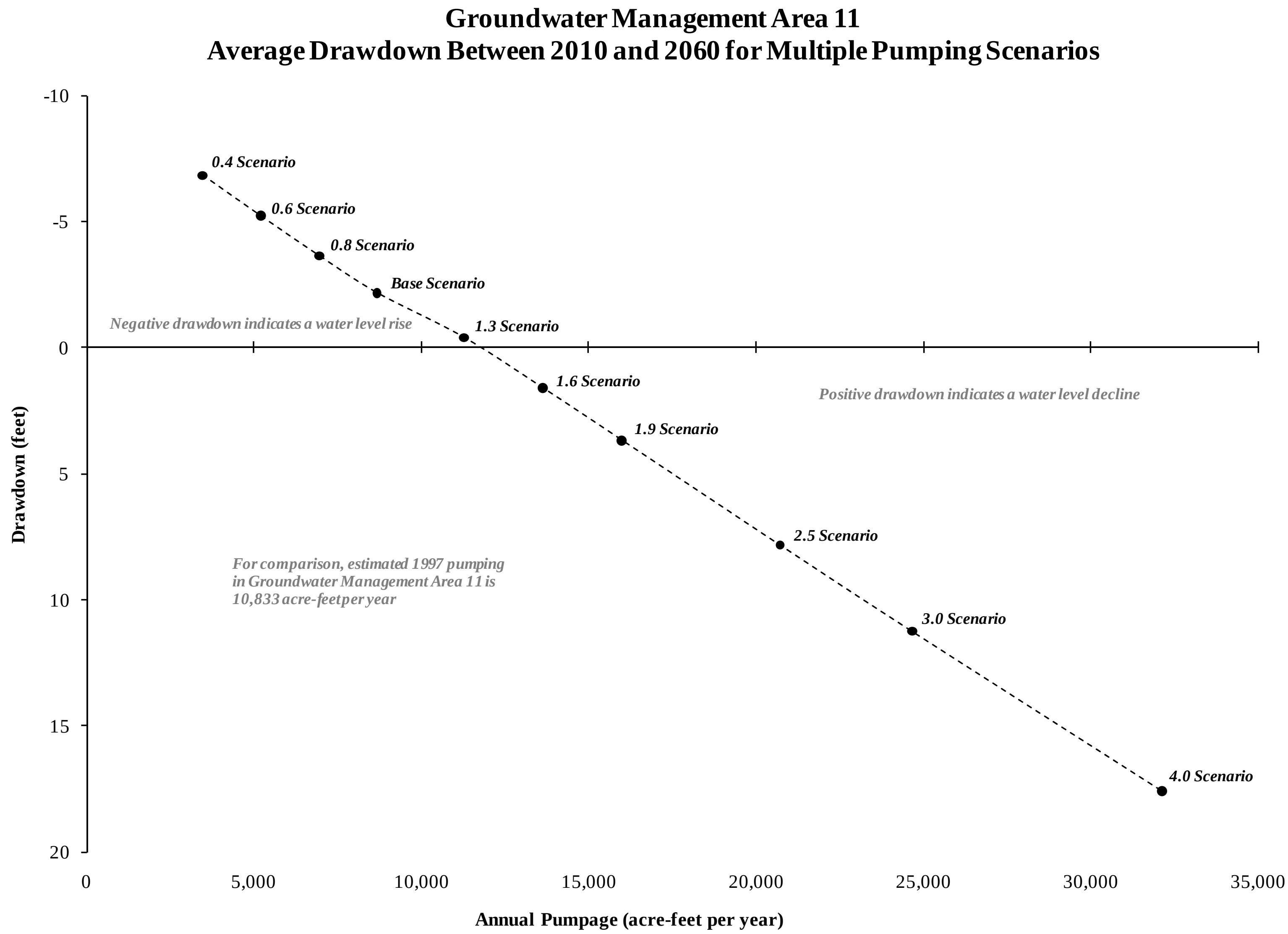

Figure A-1. Average drawdown (decline in water levels) between 2010 and 2060 in the Yegua-Jackson Aquifer for each pumping scenario for Groundwater Management Area 11.

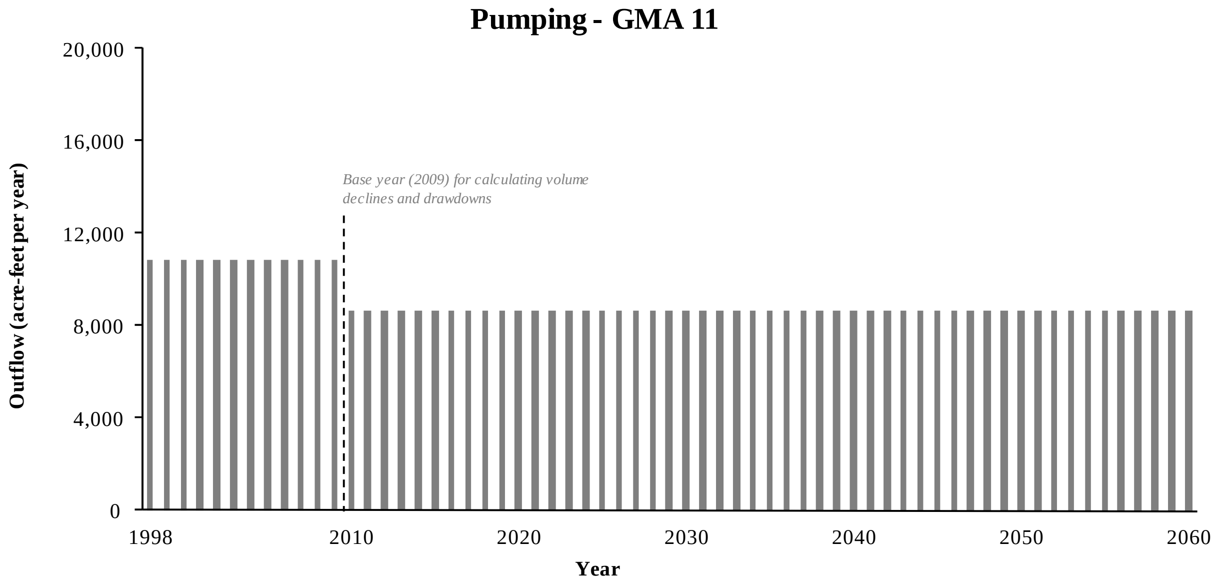

Figure A-2. Pumping output from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area (GMA) 11.

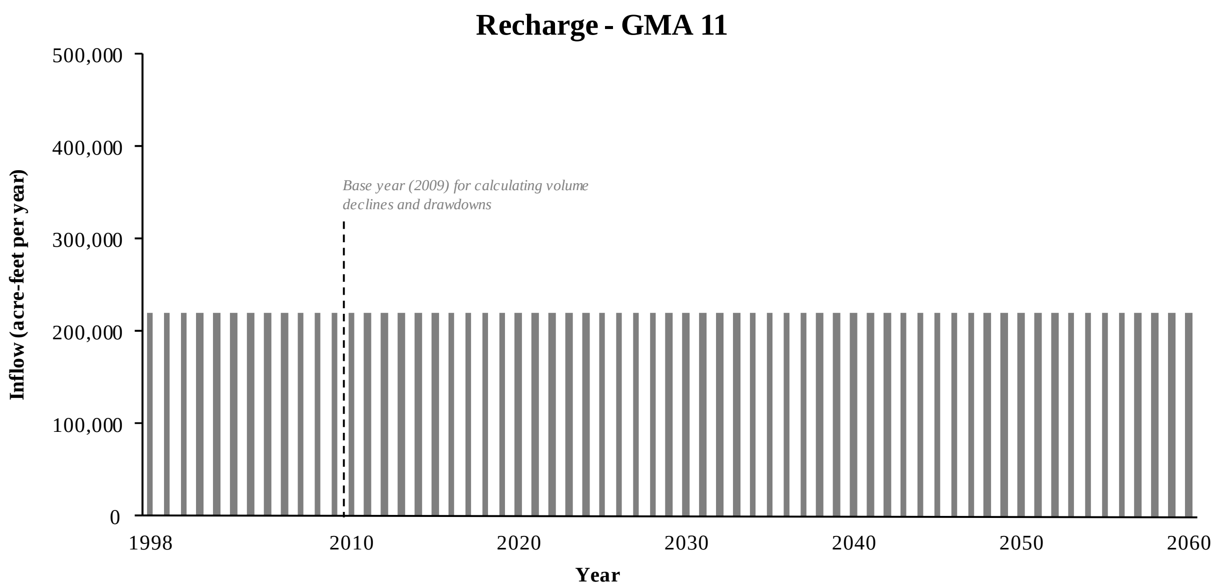

Figure A-3. Recharge into the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 11.

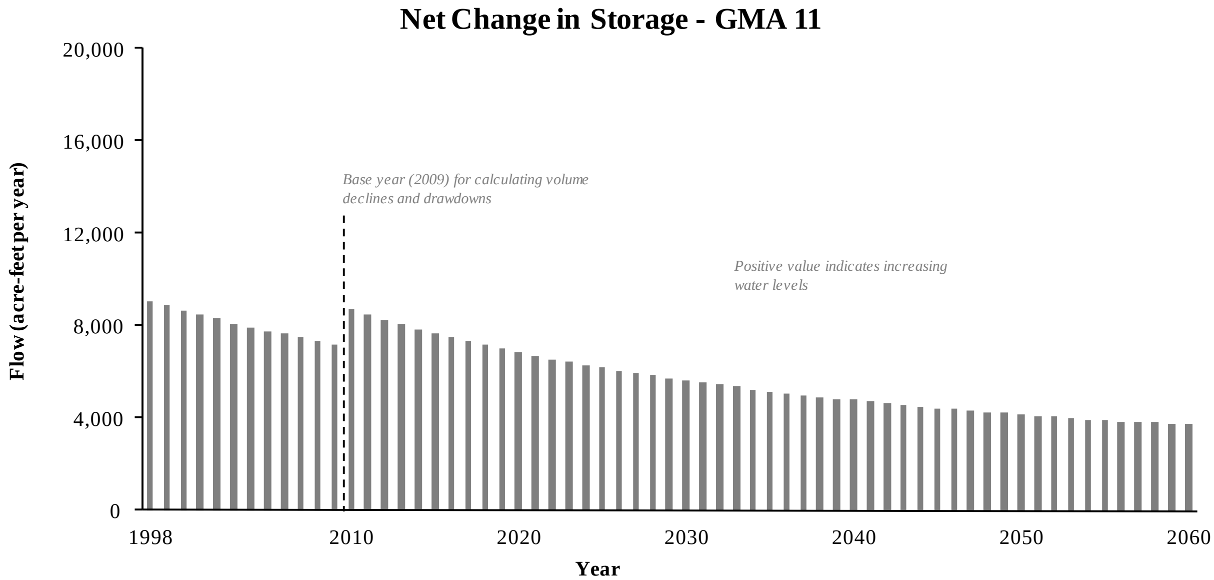

Figure A-4. Net change in storage (the volume of water stored in the aquifer) by year in the Yegua-Jackson Aquifer for the “base” scenario for Groundwater Management Area 11.

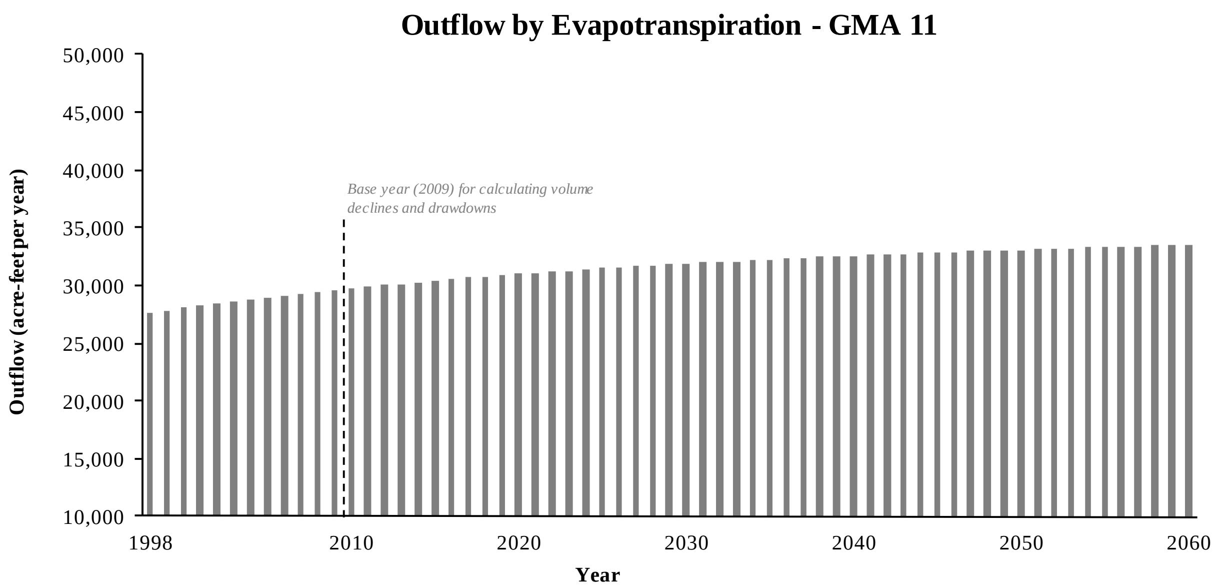

Figure A-5. Outflow by evapotranspiration from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 11.

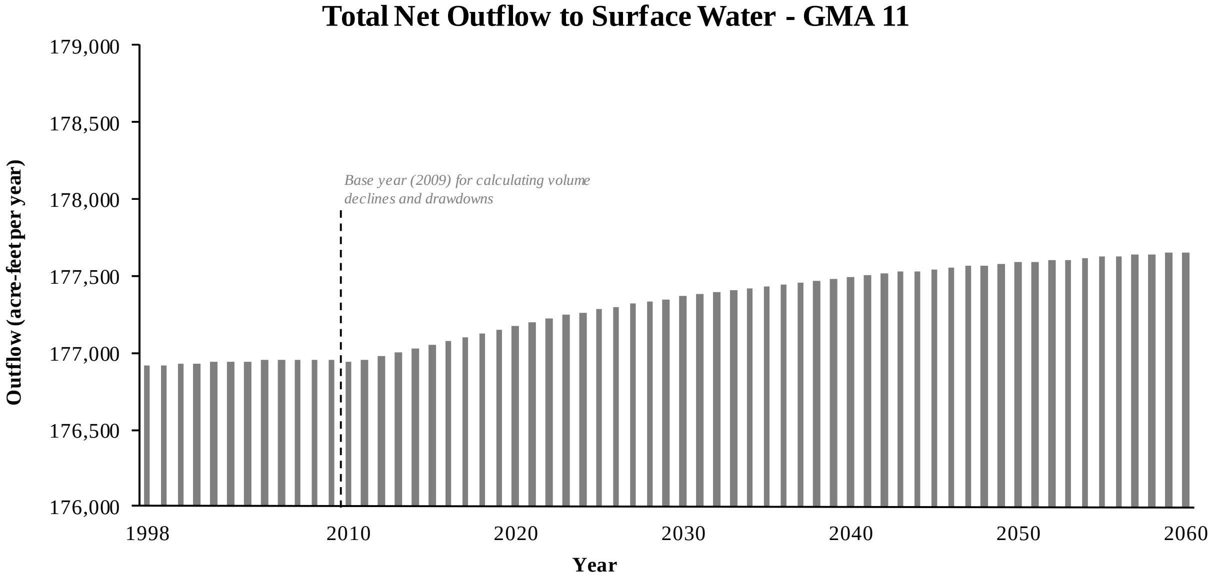

Figure A-6. Total net outflow to surface water from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 11. Total net outflow is the total flow to reservoirs, streams, and springs.

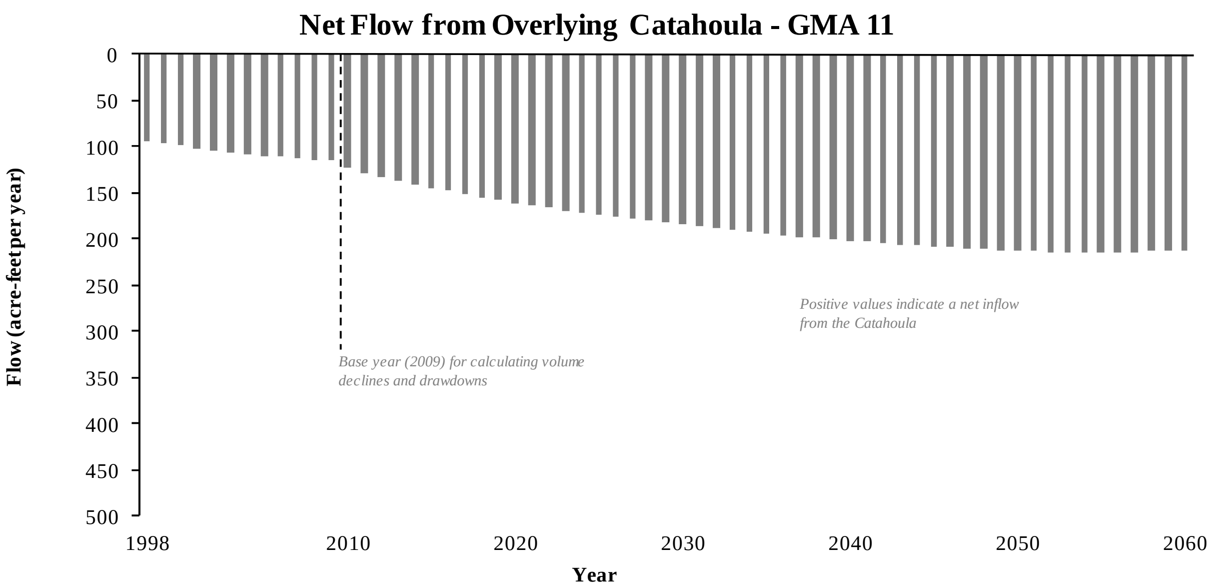

Figure A-7. Net inflow from the overlying Catahoula unit to the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 11.

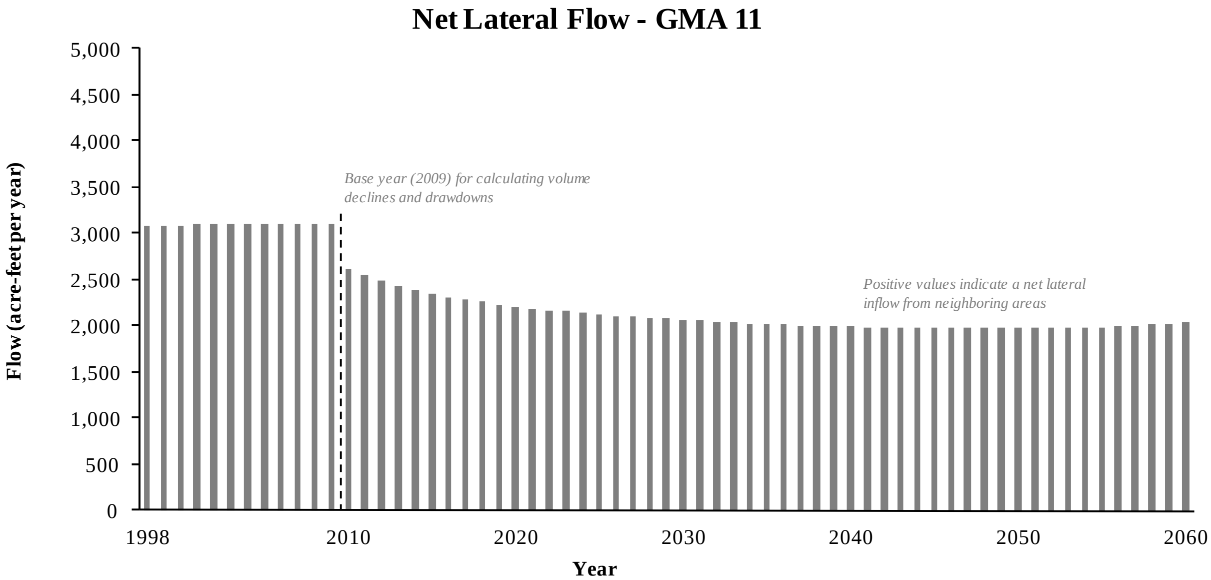

Figure A-8. Net lateral flow each year between Groundwater Management Area 11 and adjacent areas for the “base” scenario.

Appendix B

Spread Analysis Results for Groundwater Management Area 12

Table B-1. Pumping and average drawdown between 2010 and 2060 for each county in Groundwater Management Area 12 (GMA 12) by scenario. Pumping is in acre-feet per year. Drawdown is in feet. Negative values indicate a rise in water levels.

		1997	Pumping by Scenario										Drawdown by Scenario									
GMA	**County**	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 12		4,612	1,844	2,765	3,687	4,610	5,995	7,380	8,766	11,537	13,846	18,463	-1	-1	0	0	0	0	0	1	1	1
	Bastrop	28	11	16	22	27	35	43	51	67	81	108	0	0	0	0	0	0	0	0	0	1
	Brazos	1,658	663	995	1,326	1,658	2,155	2,653	3,150	4,145	4,974	6,632	-1	0	0	0	0	0	0	1	1	2
	Burleson	778	311	467	622	778	1,011	1,245	1,478	1,945	2,334	3,112	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1
	Fayette	404	161	242	322	403	525	648	771	1,017	1,221	1,631	0	0	0	1	1	1	1	2	2	2
	Lee	623	249	374	498	623	810	997	1,184	1,557	1,869	2,492	-1	-1	-1	-1	-1	-1	0	0	0	0
	Leon	4	2	2	3	4	5	6	8	10	12	16	0	0	0	0	0	1	1	1	2	2
	Madison	1,117	446	670	893	1,116	1,451	1,786	2,120	2,790	3,348	4,464	0	0	0	0	0	1	1	1	1	2

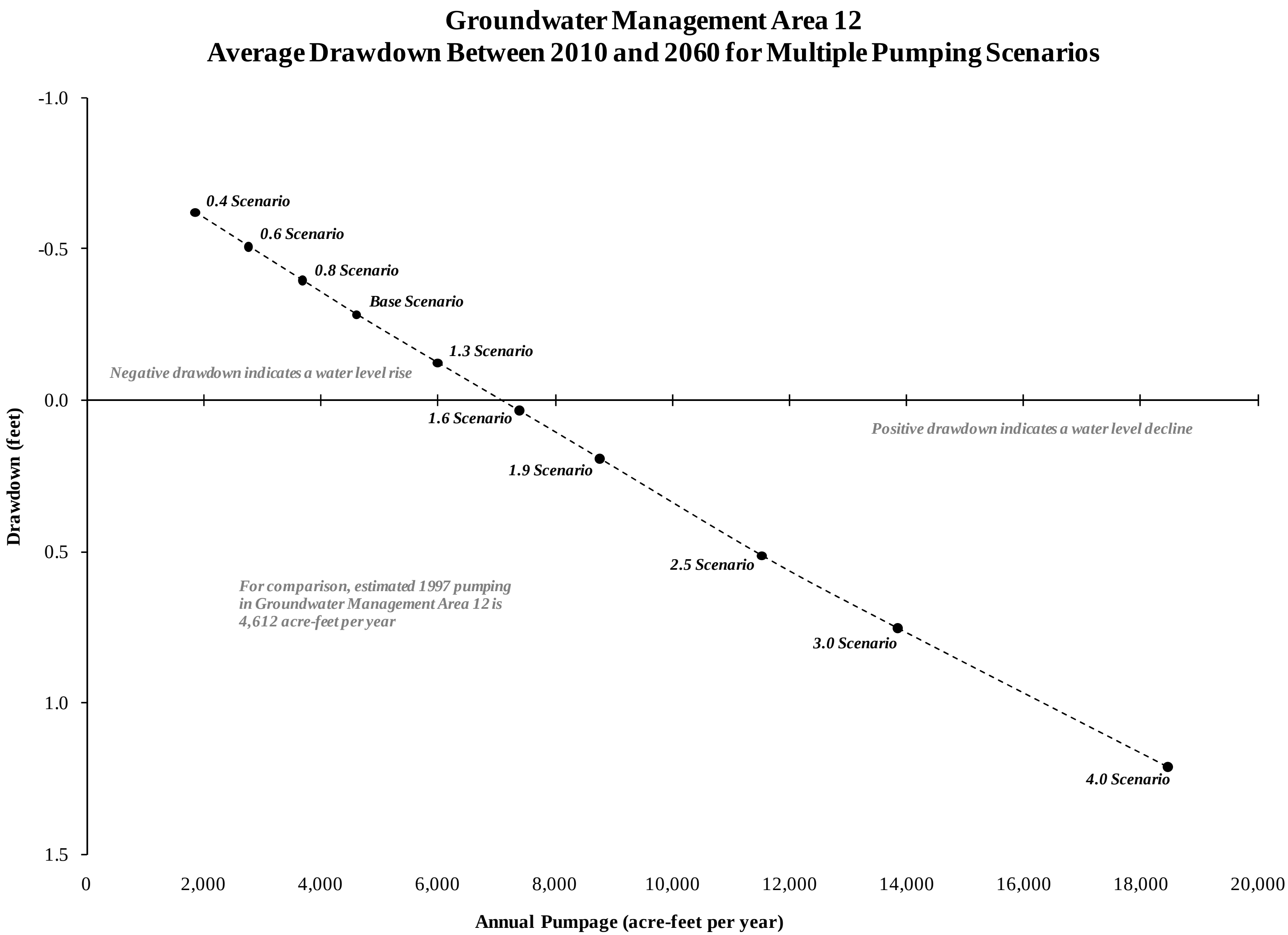

Figure B-1. Average drawdown (decline in water levels) between 2010 and 2060 in the Yegua-Jackson Aquifer for each pumping scenario for Groundwater Management Area 12.

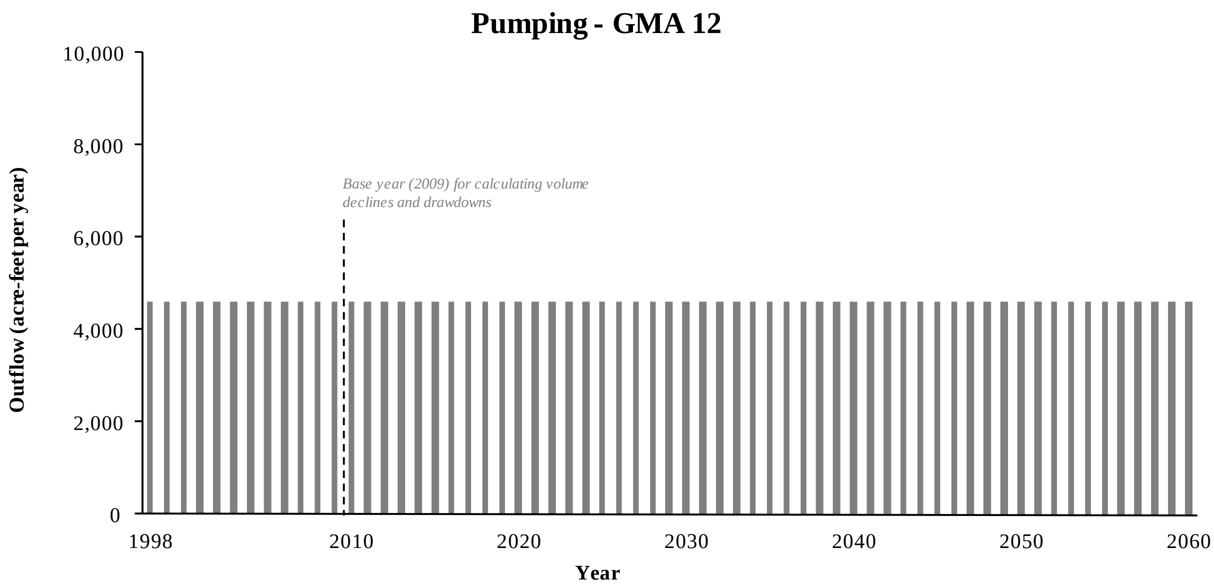

Figure B-2. Pumping output from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area (GMA) 12.

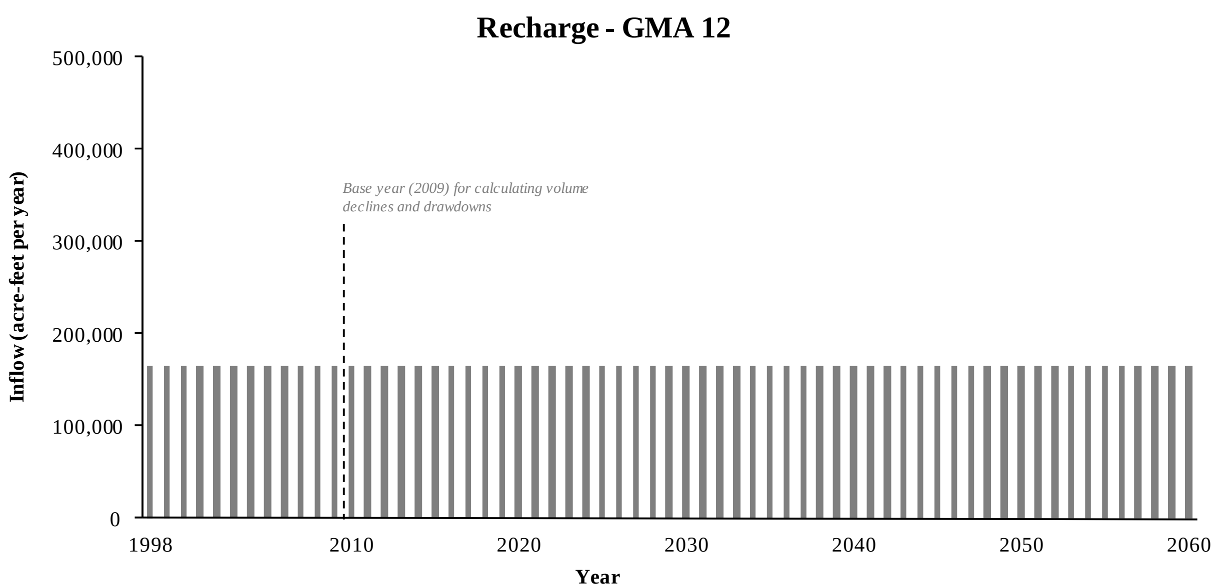

Figure B-3. Recharge into the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 12.

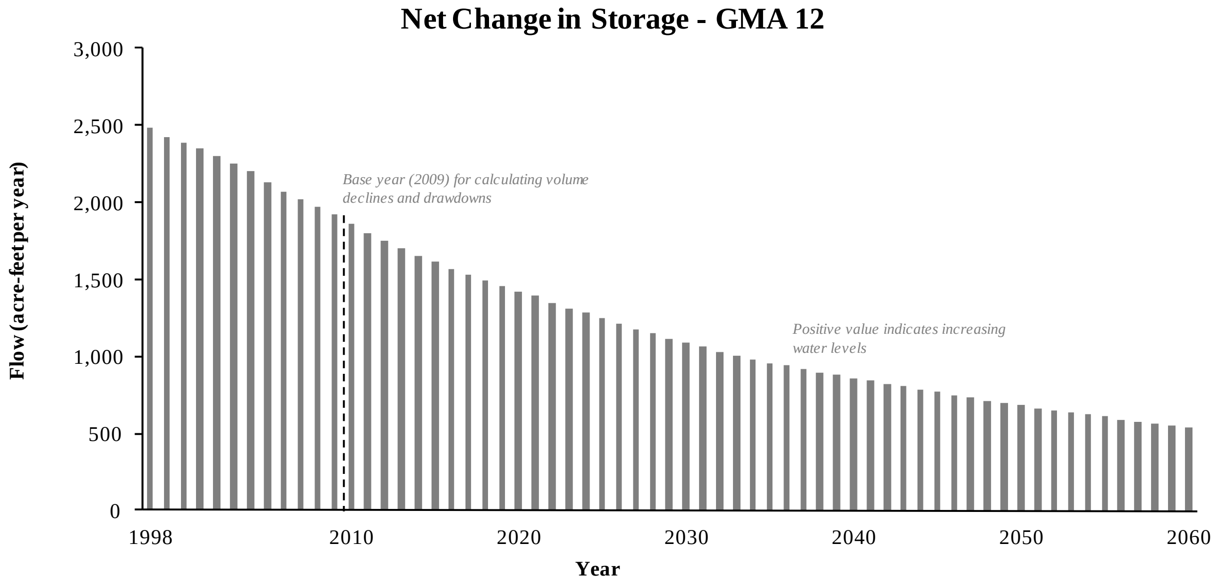

Figure B-4. Net change in storage (the volume of water stored in the aquifer) by year in the Yegua-Jackson Aquifer for the "base" scenario for Groundwater Management Area 12.

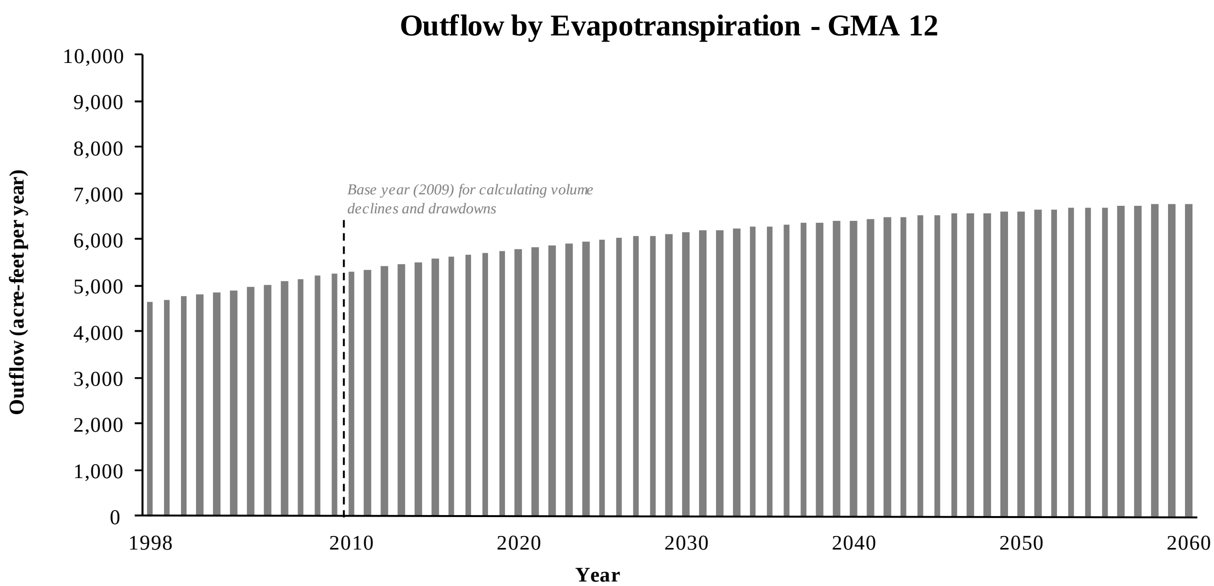

Figure B-5. Outflow by evapotranspiration from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 12.

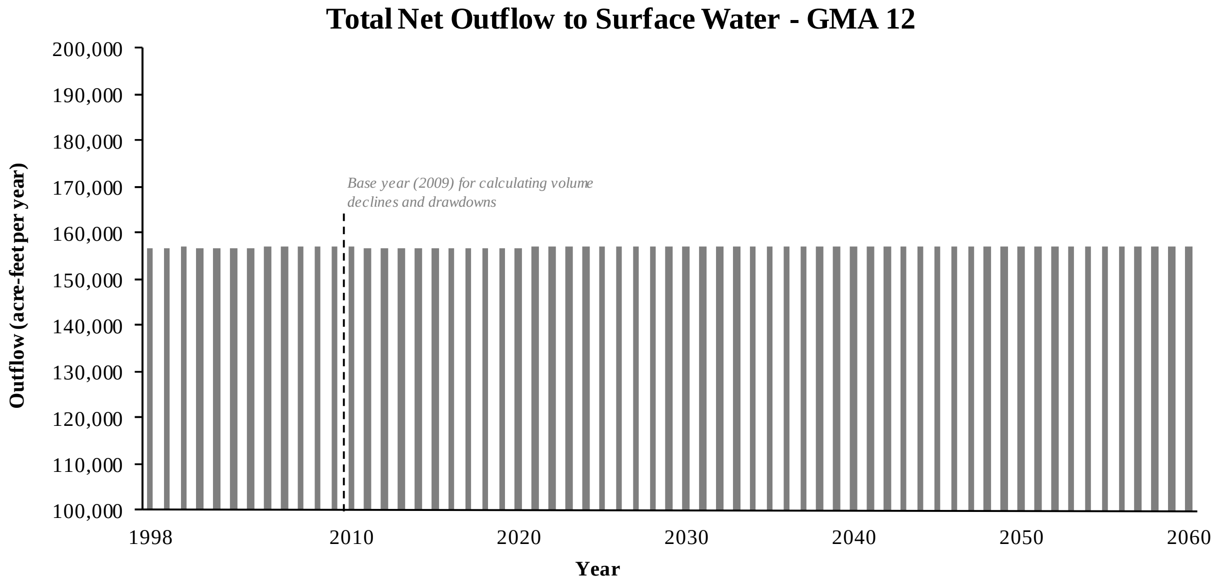

Figure B-6. Total net outflow to surface water from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 12. Total net outflow is the total flow to reservoirs, streams, and springs.

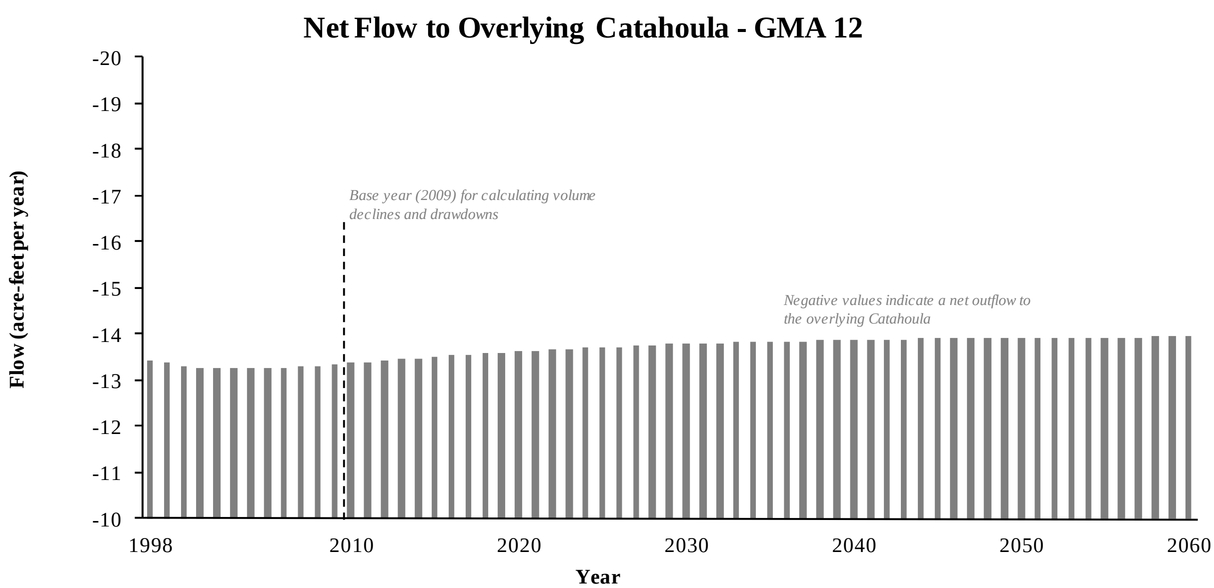

Figure B-7. Net flow to the overlying Catahoula unit from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 12.

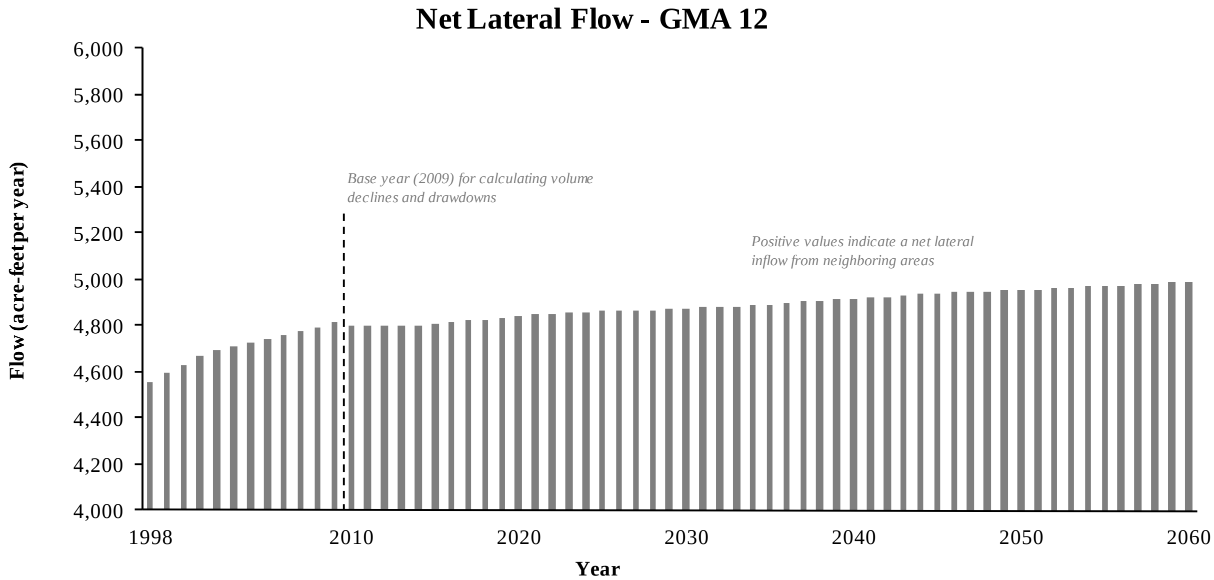

Figure B-8. Net lateral flow each year between Groundwater Management Area 12 and adjacent areas for the “base” scenario.

Appendix C

Spread Analysis Results for Groundwater Management Area 13

Table C-1. Pumping and average drawdown between 2010 and 2060 for each county in Groundwater Management Area 13 (GMA 13) by scenario. Pumping is in acre-feet per year. Drawdown is in feet.

		1997	Pumping by Scenario										Drawdown by Scenario									
GMA	**County**	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 13		1,006	3,173	4,759	6,345	7,931	10,310	12,689	15,067	19,825	23,789	31,718	0	0	0	0	0	1	1	1	1	2
	Atascosa	215	86	128	171	214	278	342	407	535	642	856	0	0	0	0	0	0	0	0	0	0
	Frio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Gonzales	245	97	146	195	244	317	390	463	609	731	975	0	1	1	1	1	1	1	1	1	1
	Karnes	196	78	118	157	196	254	312	370	486	583	776	0	0	0	0	0	0	0	0	1	1
	La Salle	24	9	14	18	23	30	37	44	57	69	92	0	0	0	0	0	0	0	0	0	0
	Mcmullen	46	18	27	36	45	58	72	85	112	135	180	0	0	0	0	0	0	0	0	0	0
	Webb	28	2,000	3,000	4,000	5,000	6,500	8,000	9,500	12,500	15,000	19,999	0	0	0	0	1	1	1	2	2	3
	Wilson	211	84	126	168	210	273	336	399	525	630	840	0	0	0	0	0	0	0	0	1	1
	Zapata	41	800	1,200	1,600	2,000	2,600	3,200	3,800	5,000	6,000	8,000	0	0	0	0	1	1	1	2	2	3

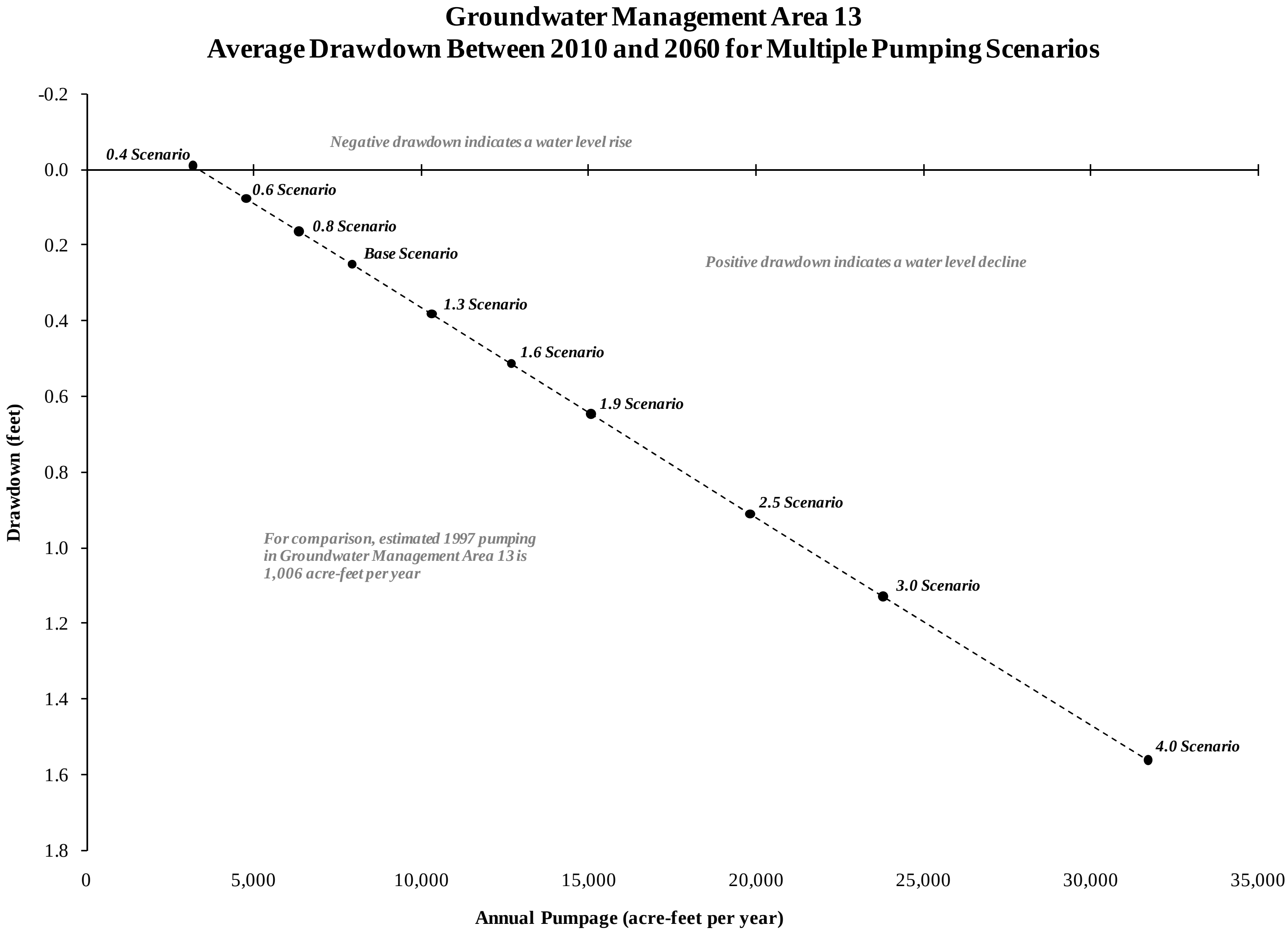

Figure C-1. Average drawdown (decline in water levels) between 2010 and 2060 in the Yegua-Jackson Aquifer for each pumping scenario for Groundwater Management Area 13.

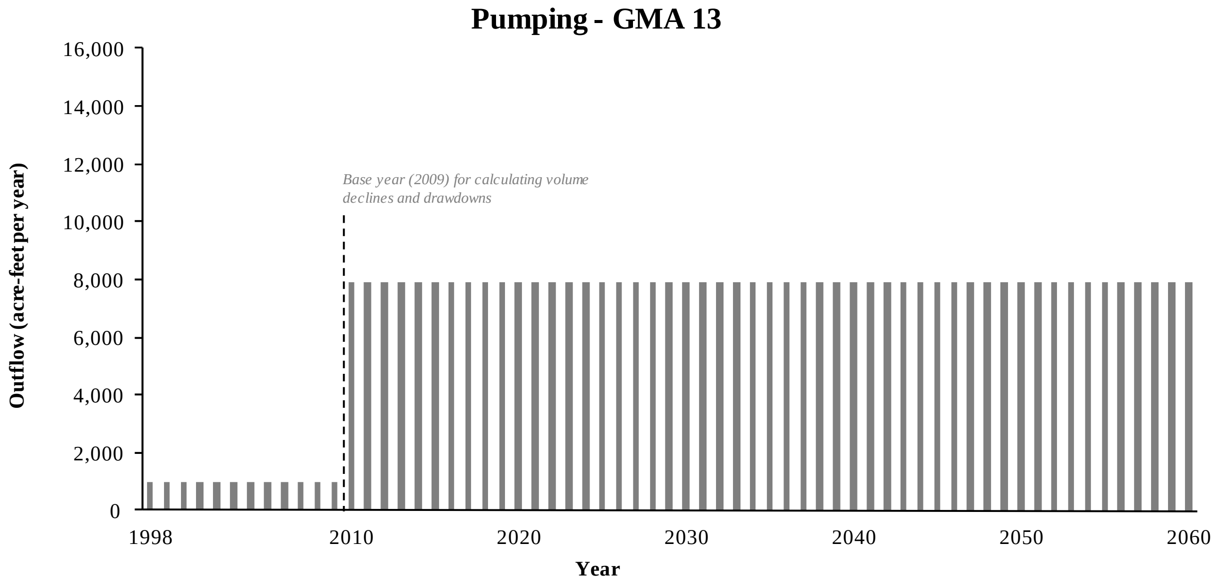

Figure C-2. Pumping output from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area (GMA) 13.

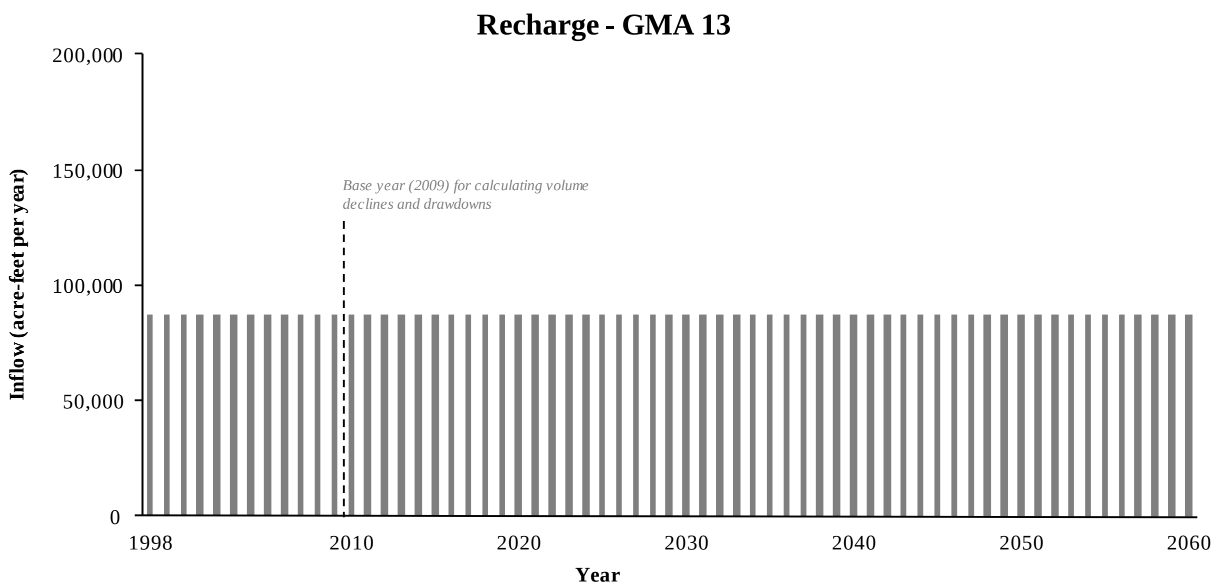

Figure C-3. Recharge into the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 13.

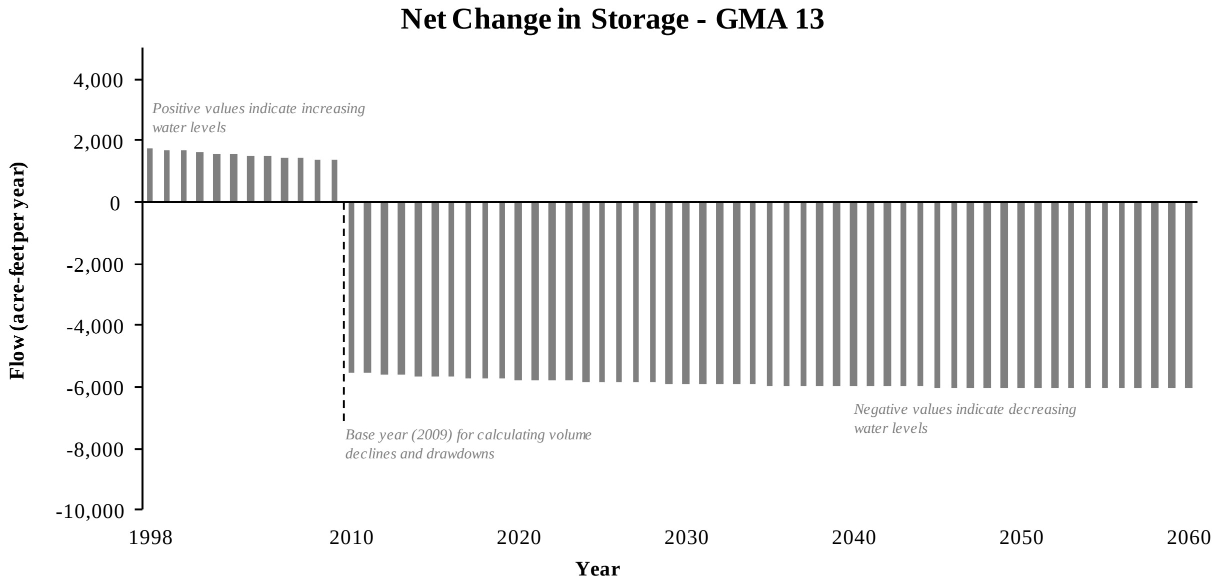

Figure C-4. Net change in storage (the volume of water stored in the aquifer) by year in the Yegua-Jackson Aquifer for the “base” scenario for Groundwater Management Area 13.

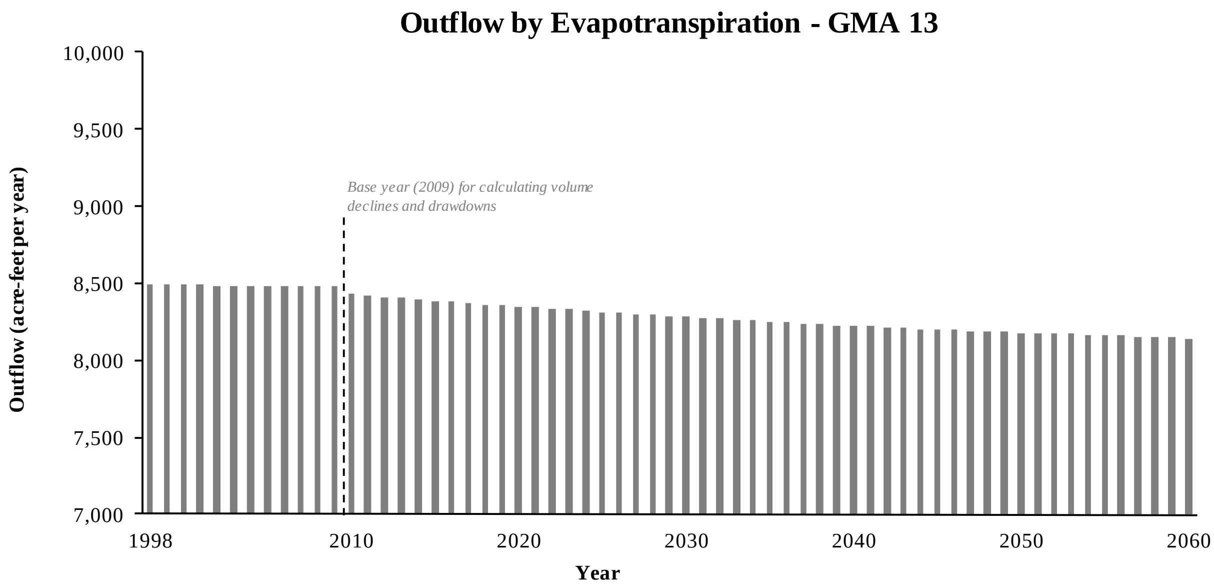

Figure C-5. Outflow by evapotranspiration from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 13.

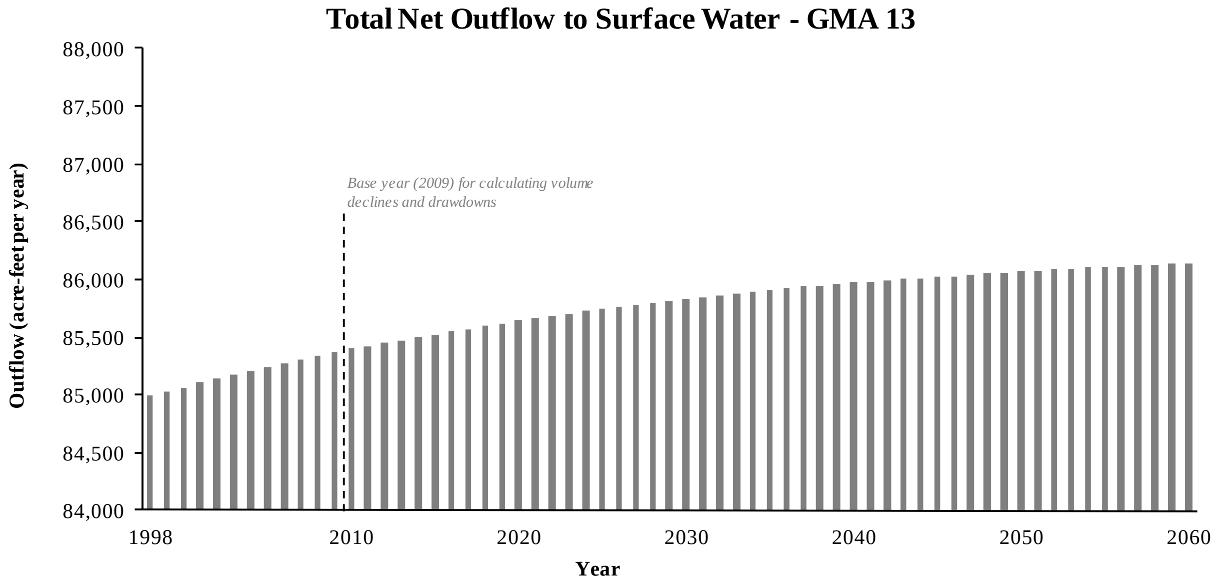

Figure C-6. Total net outflow to surface water from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 13. Total net outflow is the total flow to reservoirs, streams, and springs.

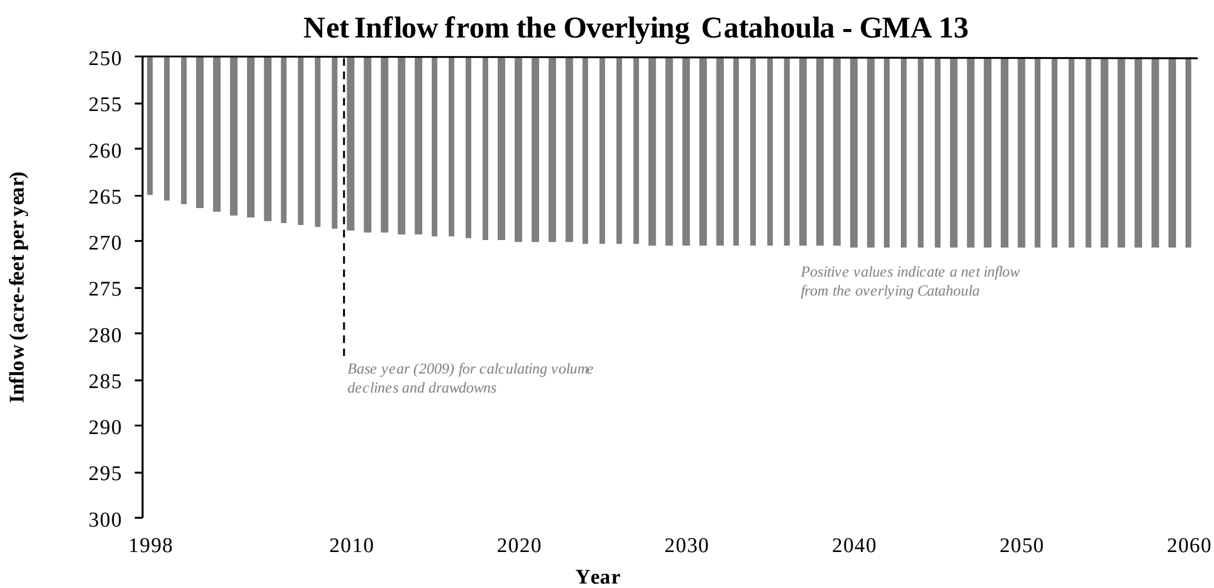

Figure C-7. Net flow from the overlying Catahoula unit into the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 13.

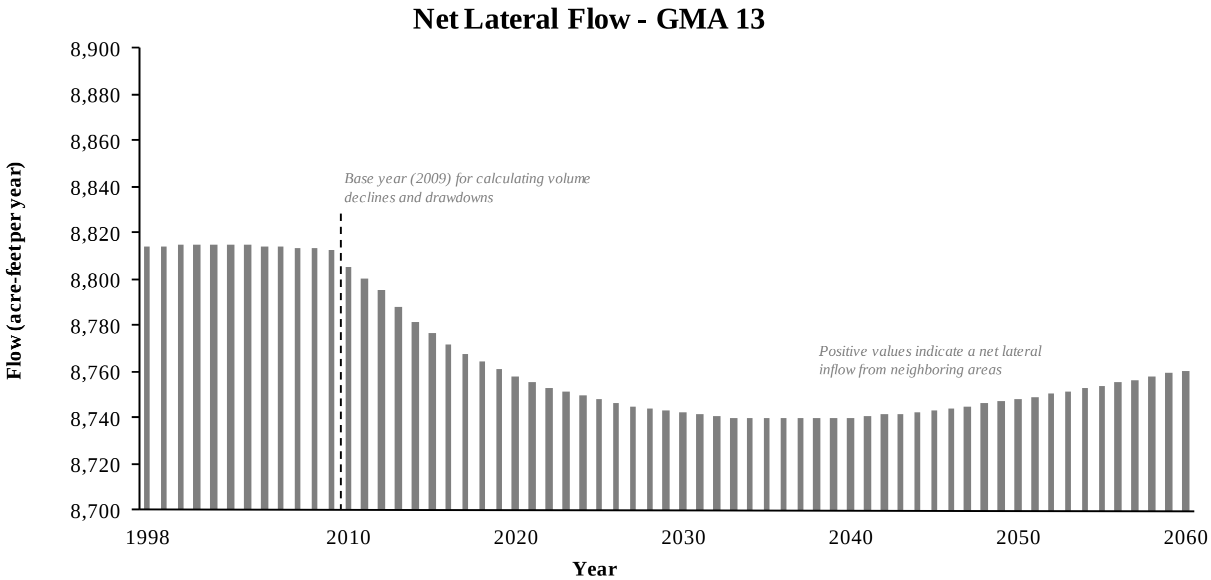

Figure C-8. Net lateral flow each year between Groundwater Management Area 13 and adjacent areas for the “base” scenario.

Appendix D

Spread Analysis Results for Groundwater Management Area 14

Table D-1. Pumping and average drawdown between 2010 and 2060 for each county in Groundwater Management Area 14 (GMA 14) by scenario. Pumping is in acre-feet per year. Drawdown is in feet. Negative values indicate a rise in water levels.

		1997	Pumping by Scenario										Drawdown by Scenario									
GMA	**County**	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 14		1,637	3,117	4,676	6,234	7,793	8,231	10,131	12,030	15,829	18,995	25,327	2	2	3	3	3	4	4	5	5	7
	Austin	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
	Brazos	0	0	0	0	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	0
	Fort Bend	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
	Grimes	720	288	431	575	719	935	1,150	1,366	1,797	2,157	2,876	1	1	1	1	1	1	1	1	1	1
	Hardin	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
	Harris	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5
	Jasper	0	0	0	0	0	0	0	0	0	0	0	-2	-1	-1	0	1	2	3	5	6	10
	Liberty	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	4
	Montgomery	0	0	0	0	0	0	0	0	0	0	0	8	8	8	8	8	8	8	8	8	8
	Newton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	5	7
	Polk	470	144	216	288	360	468	576	684	900	1,080	1,440	-1	0	1	2	4	6	7	9	12	15
	San Jacinto	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	6	6	6	6	7	7
	Tyler	0	72	108	144	180	234	288	342	450	540	720	1	1	2	2	3	4	4	6	7	9
	Walker	312	2,560	3,840	5,120	6,400	6,420	7,902	9,384	12,347	14,816	19,755	3	4	5	6	4	4	5	6	6	8
	Waller	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3
	Washington	134	54	80	107	134	174	214	255	335	402	536	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1

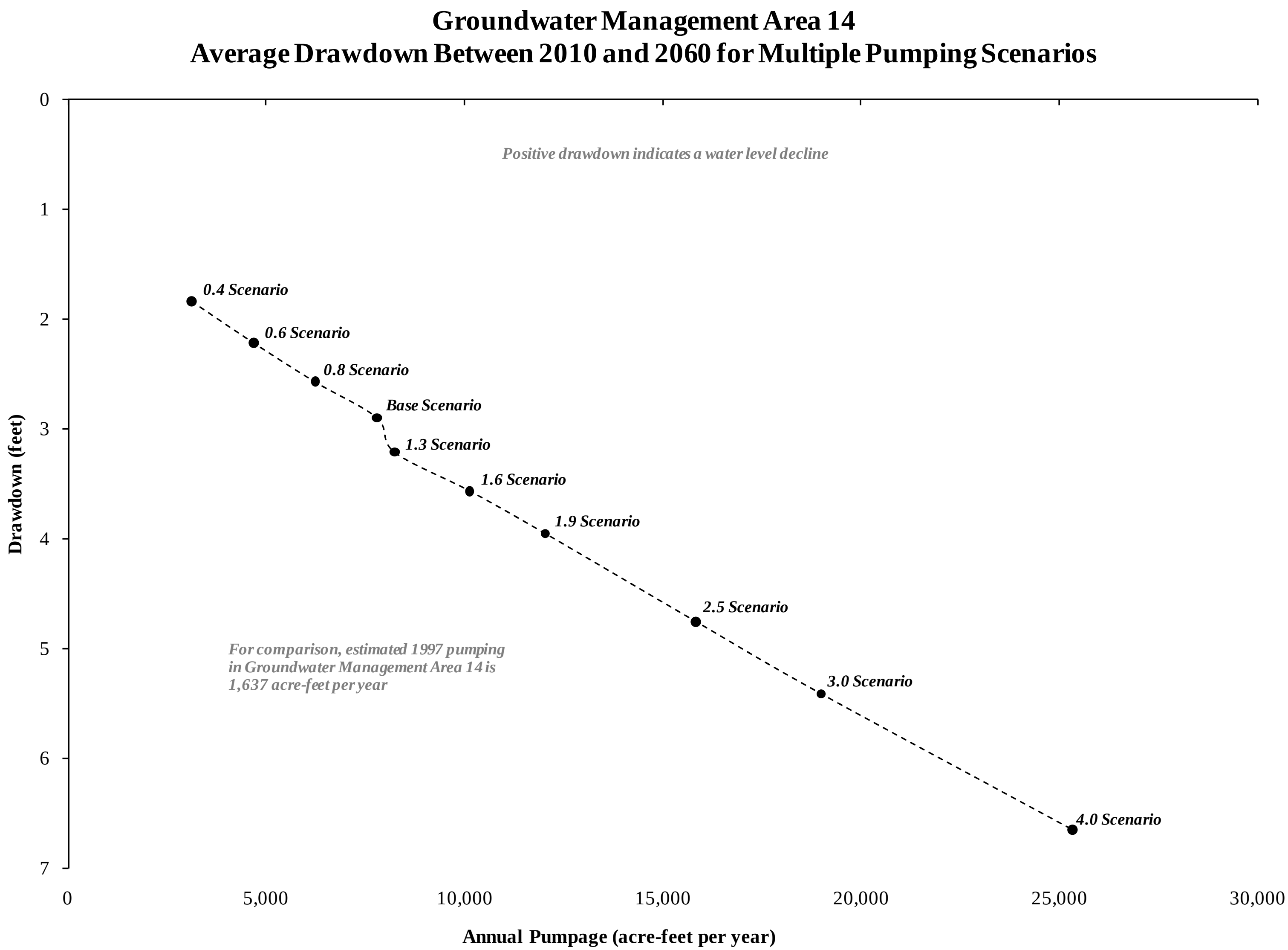

Figure D-1. Average drawdown (decline in water levels) between 2010 and 2060 in the Yegua-Jackson Aquifer for each pumping scenario for Groundwater Management Area 14.

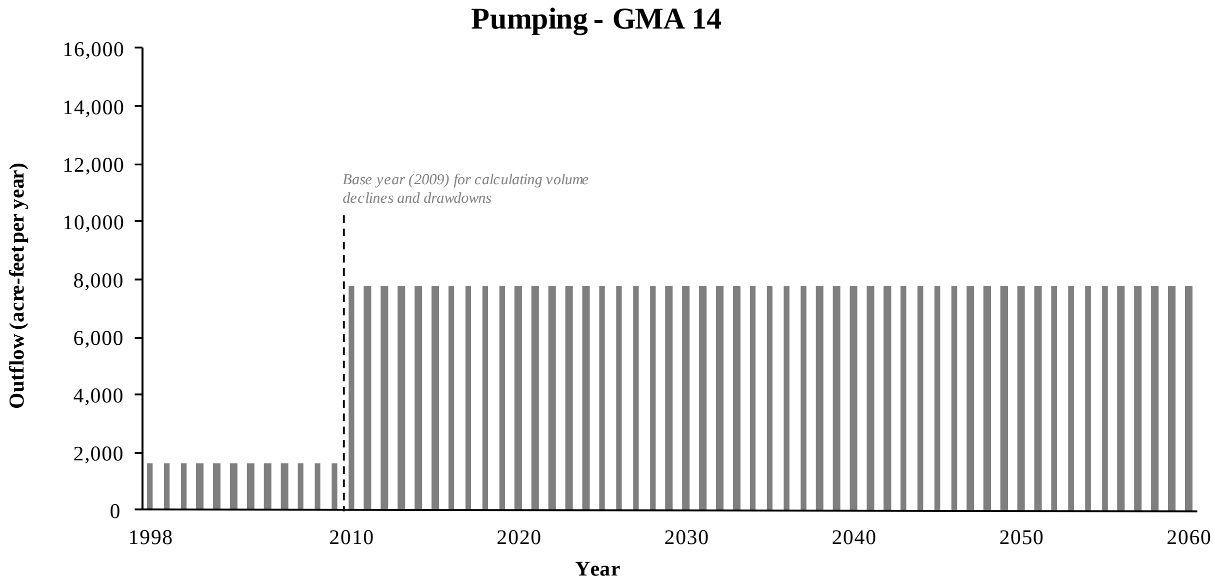

Figure D-2. Pumping output from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area (GMA) 14.

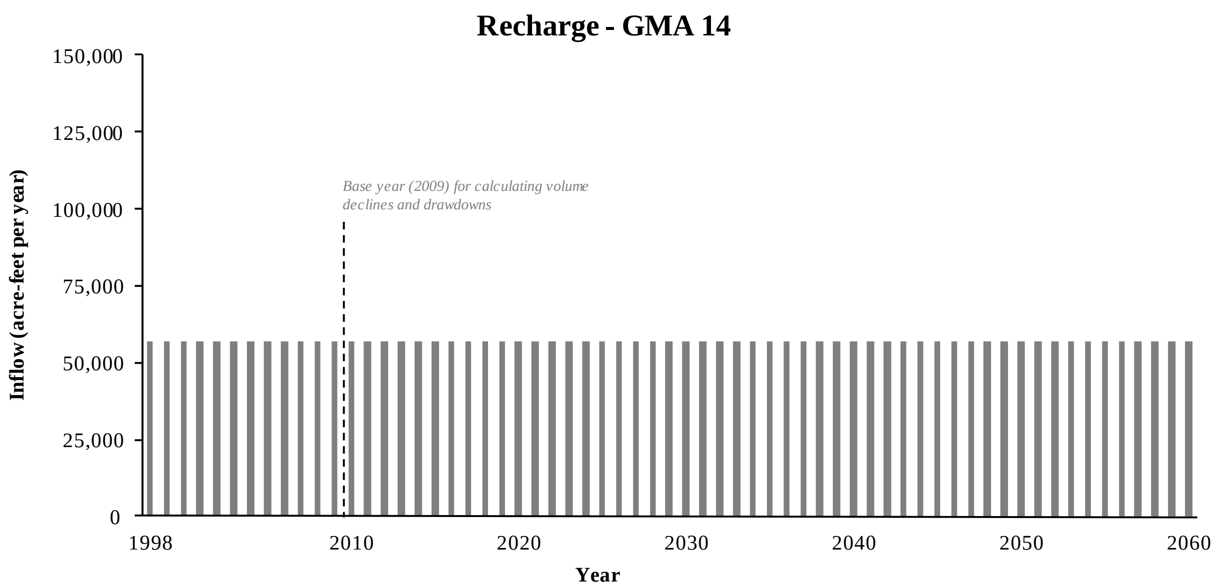

Figure D-3. Recharge into the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 14.

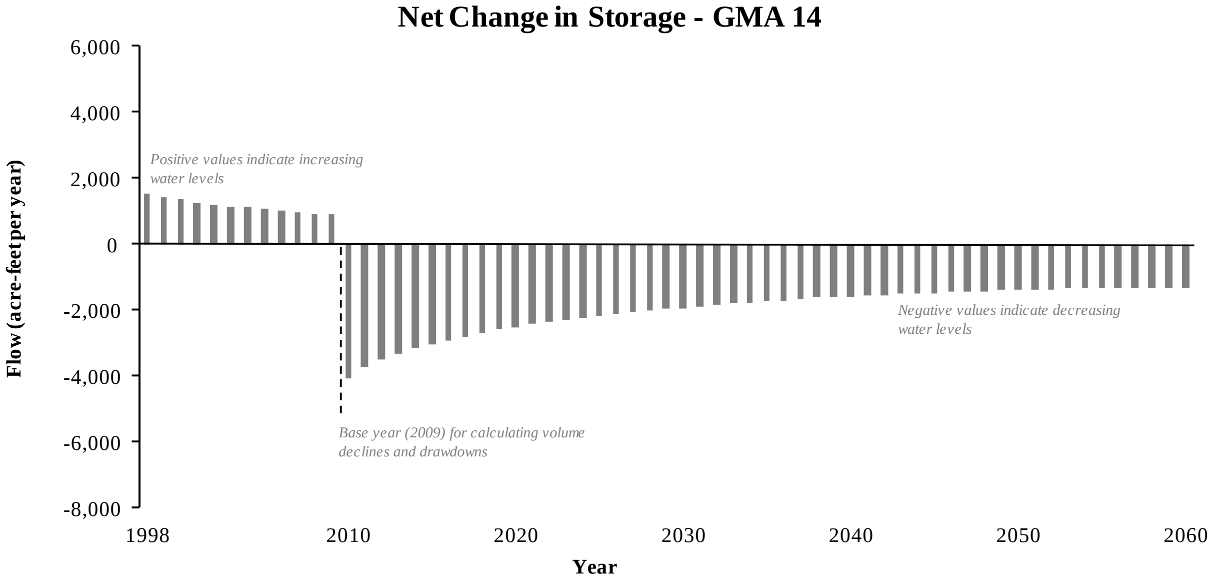

Figure D-4. Net change in storage (the volume of water stored in the aquifer) by year in the Yegua-Jackson Aquifer for the “base” scenario for Groundwater Management Area 14.

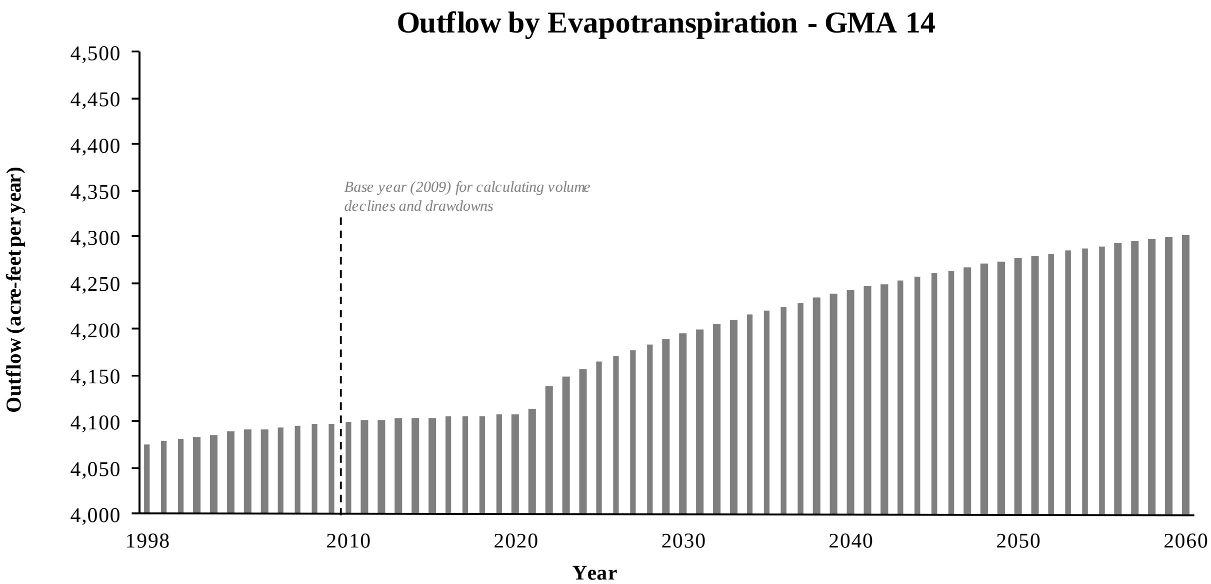

Figure D-5. Outflow by evapotranspiration from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 14.

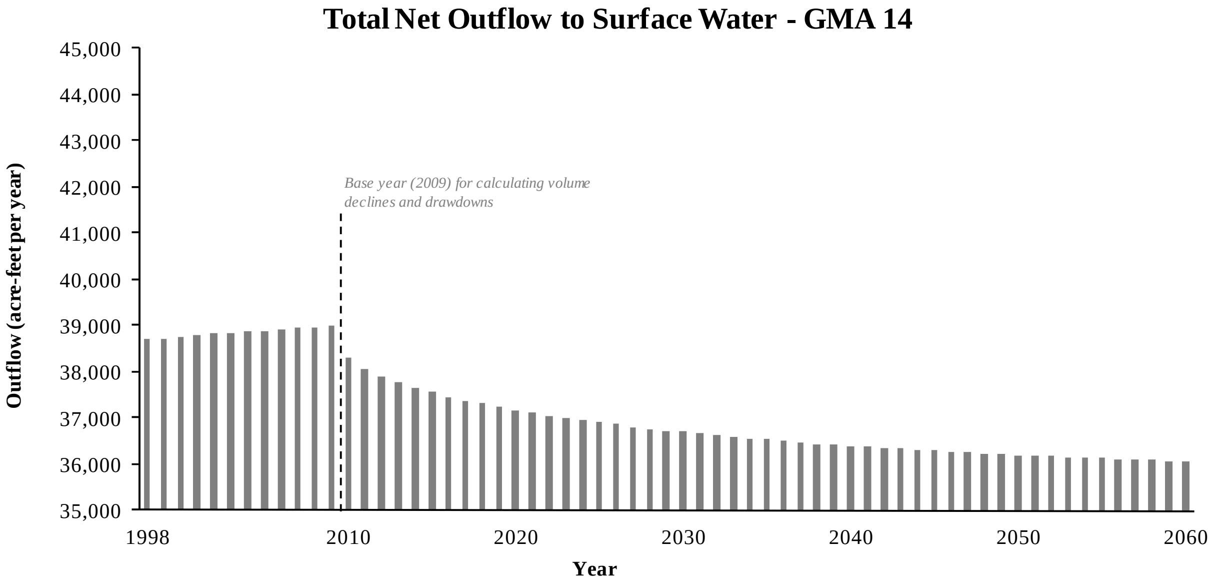

Figure D-6. Total net outflow to surface water from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 14. Total net outflow is the total flow to reservoirs, streams, and springs.

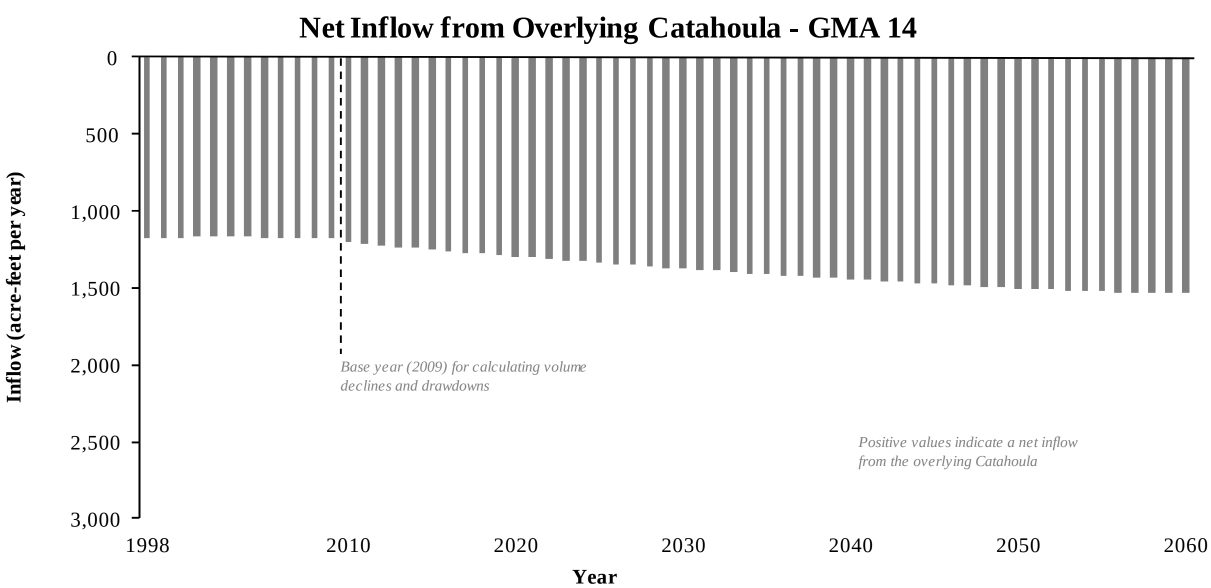

Figure D-7. Net flow from the overlying Catahoula unit into the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 14.

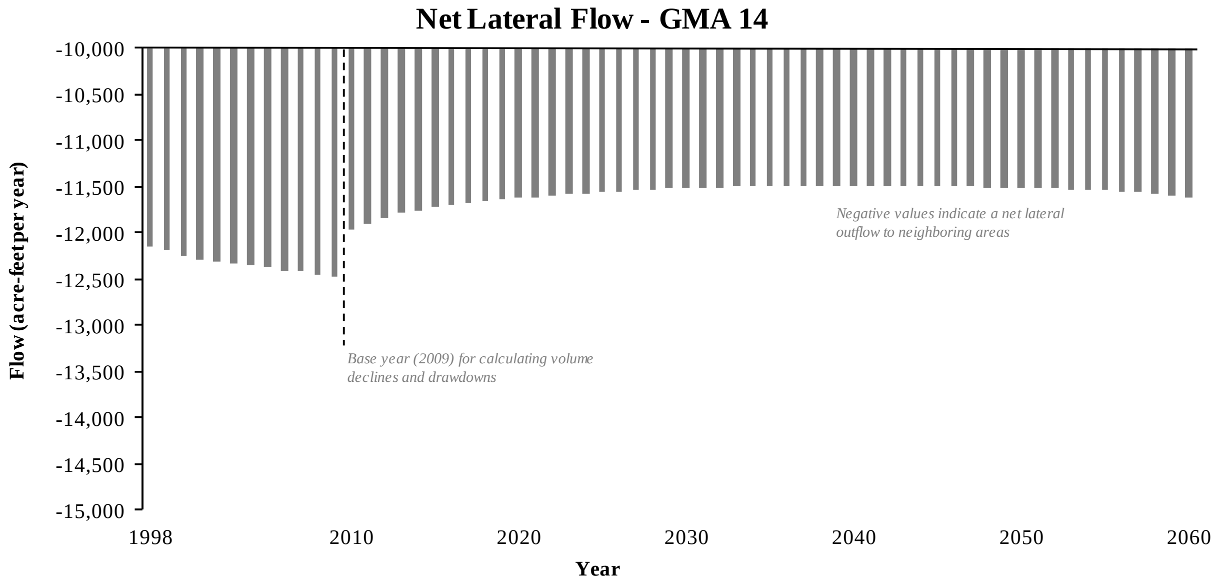

Figure D-8. Net lateral flow each year between Groundwater Management Area 14 and adjacent areas for the “base” scenario.

Appendix E

Spread Analysis Results for Groundwater Management Area 15

Table E-1. Pumping and average drawdown between 2010 and 2060 for each county in Groundwater Management Area 15 (GMA 15) by scenario. Pumping is in acre-feet per year. Drawdown is in feet.

		1997	Pumping by Scenario										Drawdown by Scenario									
GMA	**County**	**Pumping**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**	**0.4**	**0.6**	**0.8**	**Base**	**1.3**	**1.6**	**1.9**	**2.5**	**3**	**4**
GMA 15		685	274	411	548	685	889	1,094	1,298	1,706	2,047	2,728	2	2	2	3	3	3	4	4	4	5
	Bee	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
	Colorado	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	4	4	4	5	5	6
	Dewitt	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
	Fayette	677	271	406	542	677	878	1,079	1,280	1,682	2,018	2,688	0	1	2	3	4	6	7	10	12	15
	Goliad	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2
	Jackson	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3
	Karnes	3	1	2	2	3	5	6	8	11	14	20	1	1	1	1	1	1	1	1	1	1
	Lavaca	5	2	3	4	5	6	8	9	12	15	20	3	3	4	4	4	5	5	6	7	7
	Victoria	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3	3
	Wharton	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1

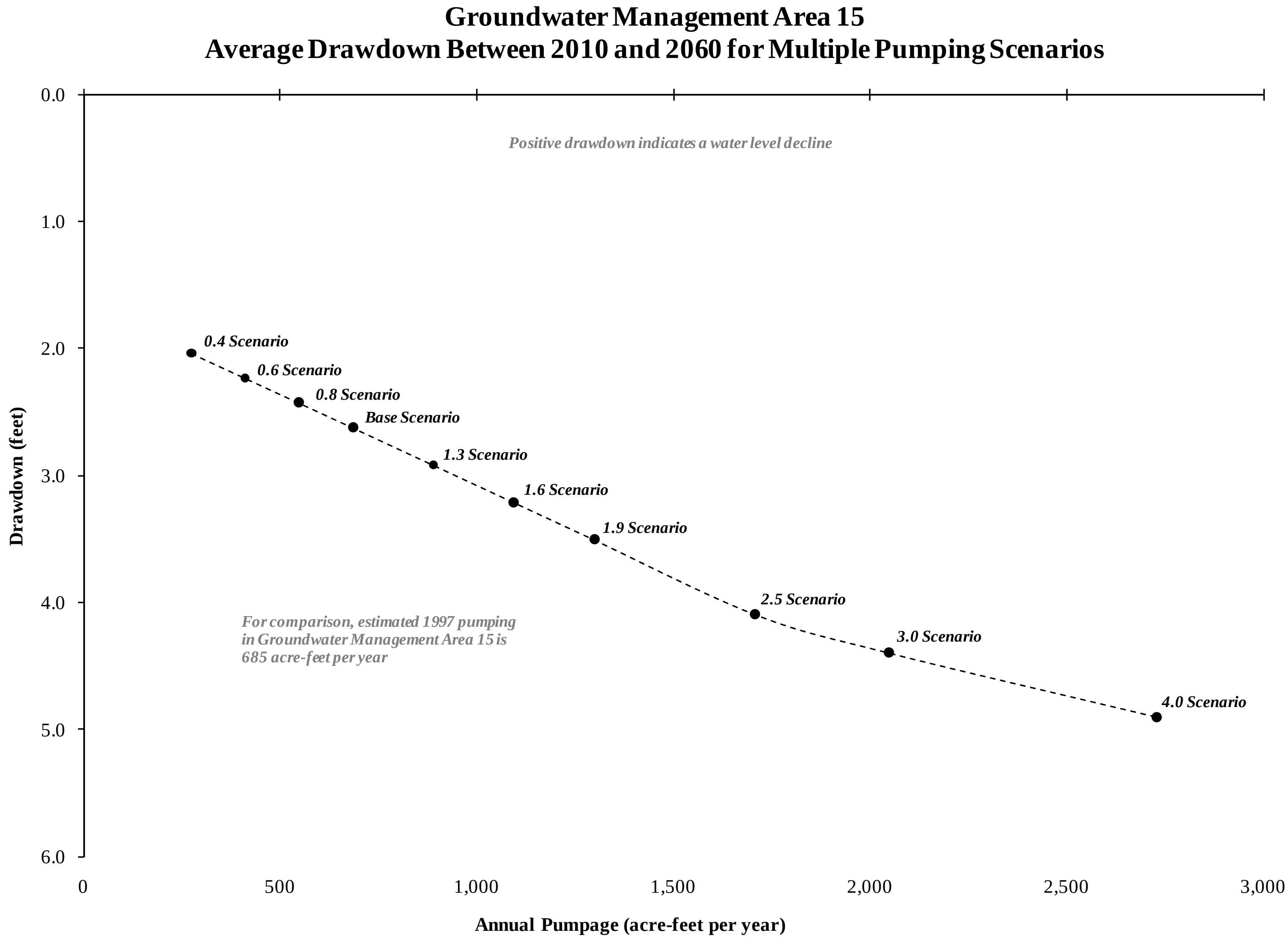

Figure E-1. Average drawdown (decline in water levels) between 2010 and 2060 in the Yegua-Jackson Aquifer for each pumping scenario for Groundwater Management Area 15.

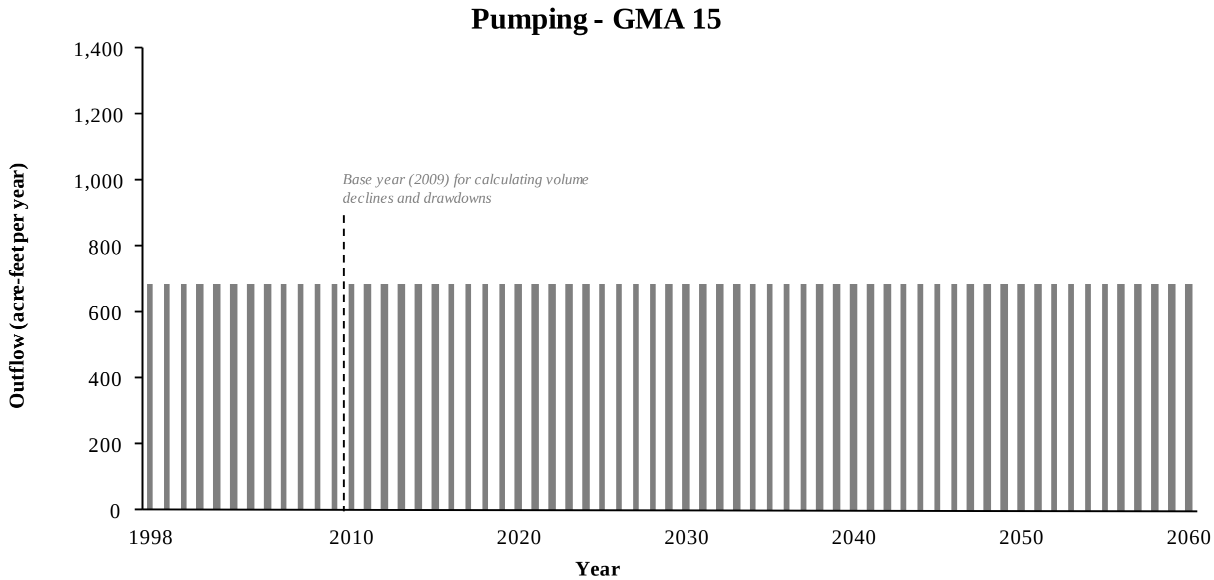

Figure E-2. Pumping output from the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area (GMA) 15.

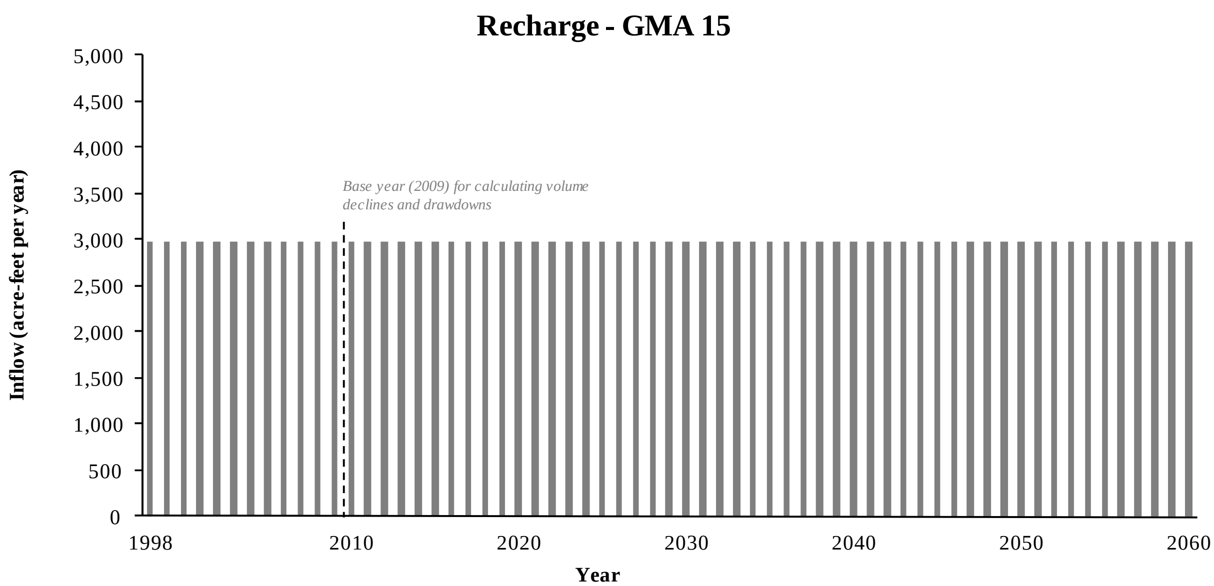

Figure E-3. Recharge into the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 15.

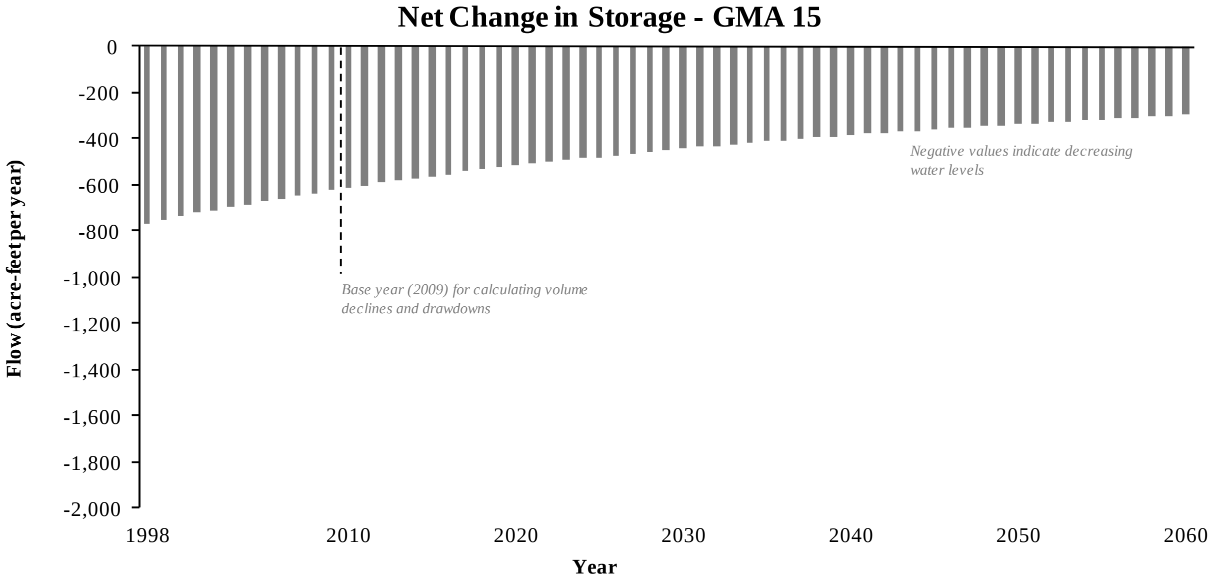

Figure E-4. Net change in storage (the volume of water stored in the aquifer) by year in the Yegua-Jackson Aquifer for the “base” scenario for Groundwater Management Area 15.

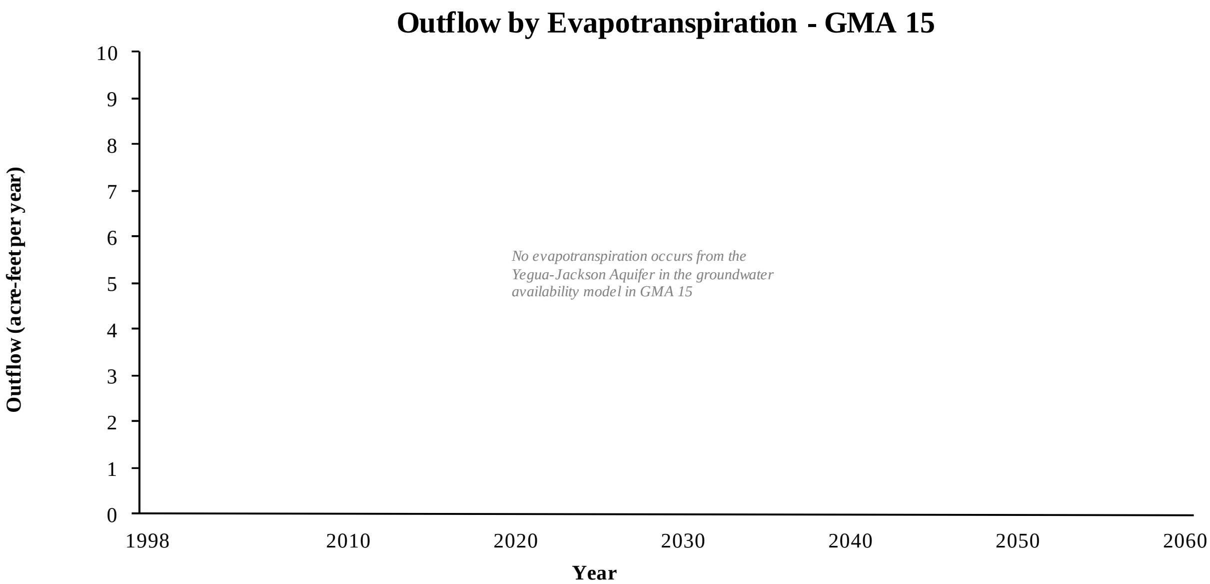

Figure E-5. Outflow by evapotranspiration from the Yegua-Jackson Aquifer for the “base” scenario by year for Groundwater Management Area 15. Note that no evapotranspiration occurs from the Yegua-Jackson Aquifer in the groundwater availability model in Groundwater Management Area 15.

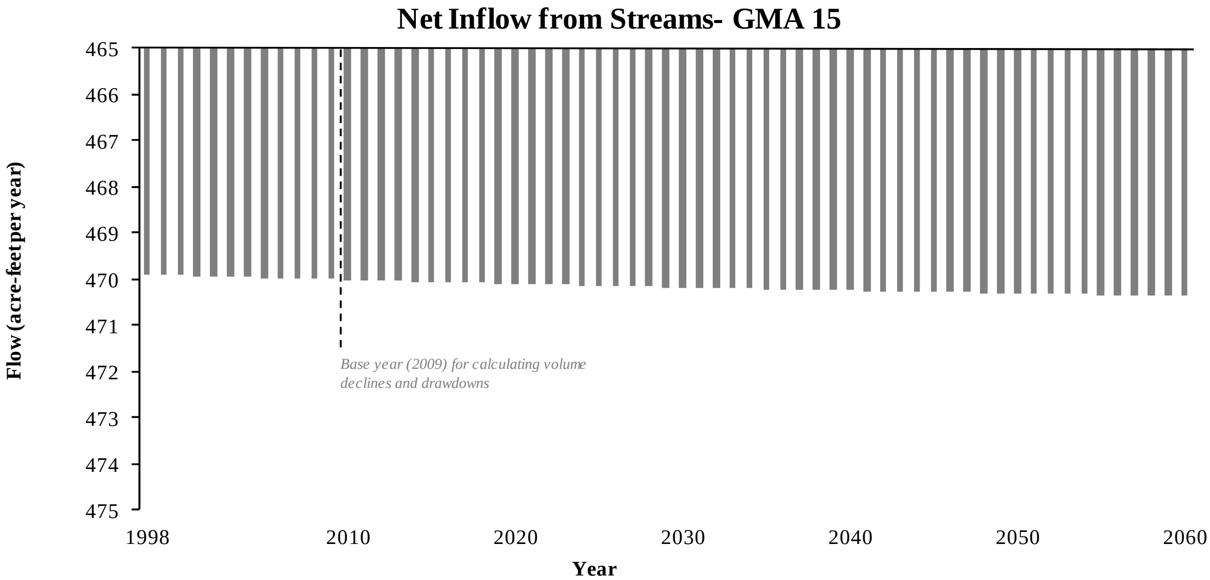

Figure E-6. Net inflow from streams to the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 15. Note that only streams are shown for surface water outflow because no reservoirs or springs are included in the groundwater availability model in Groundwater Management Area 15.

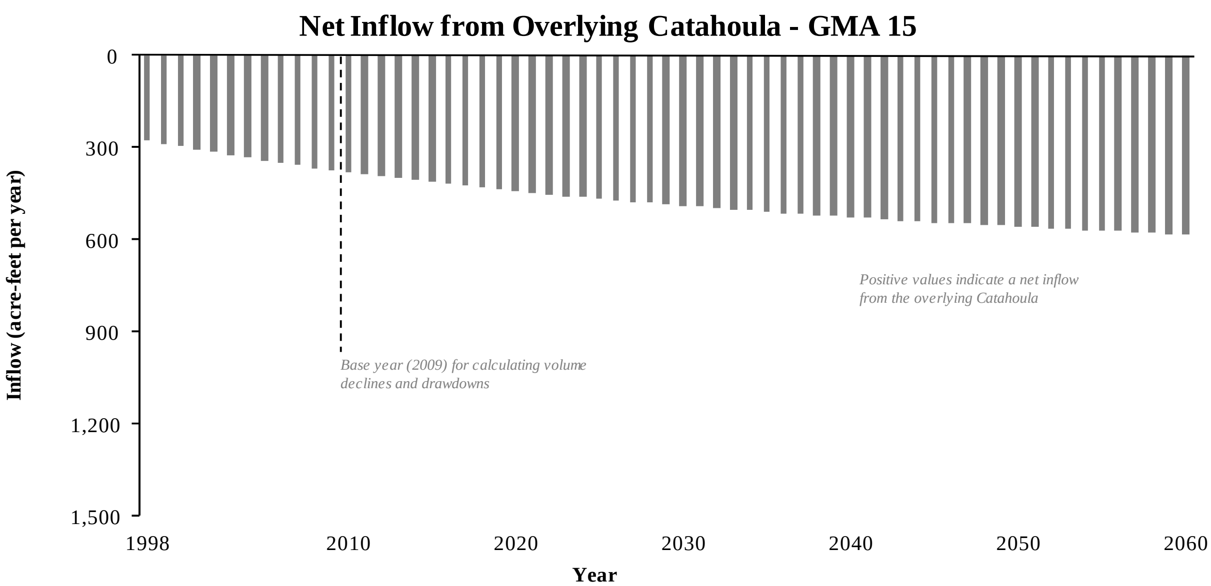

Figure E-7. Net flow from the overlying Catahoula unit into the Yegua-Jackson Aquifer for the "base" scenario by year for Groundwater Management Area 15.

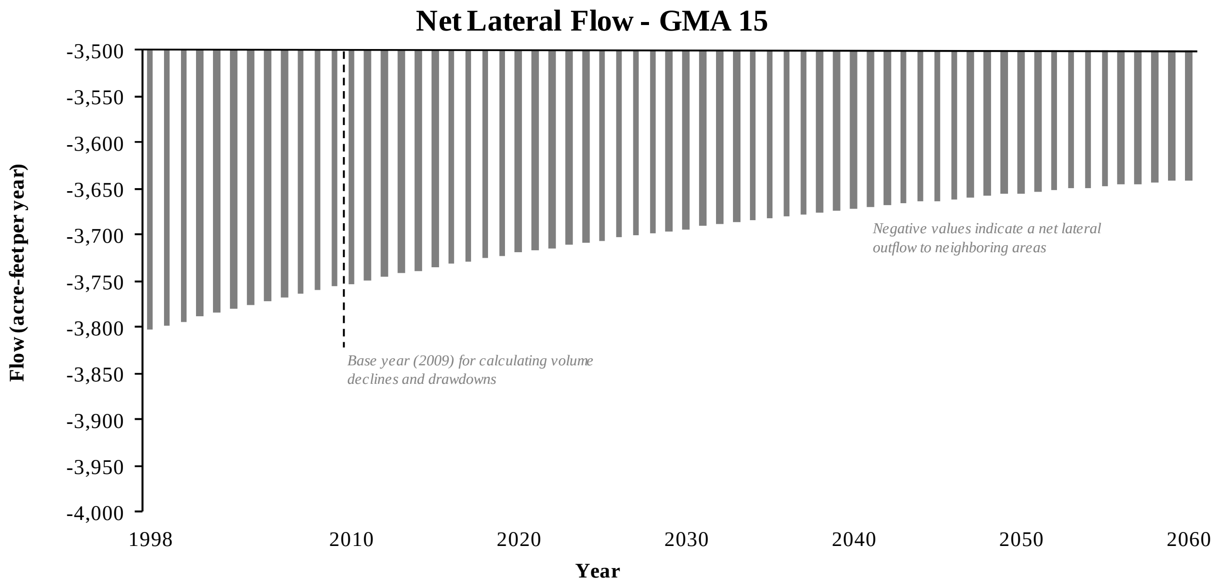

Figure E-8. Net lateral flow each year between Groundwater Management Area 15 and adjacent areas for the “base” scenario.