GAM Run 08-20

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EXECUTIVE SUMMARY:

We ran the groundwater availability model for the Hill Country portion of the Trinity Aquifer using average recharge rates with a specified annual baseline pumpage for a 60-year predictive simulation. Model run results indicate up to 10 foot water level recovery over most of the Edwards Group and up to 3 feet water level decline where the aquifer is thin. We adjusted pumpage to try to achieve an average 15 foot water level decline across Groundwater Management Area 9 over the 60-year predictive simulation for the Middle Trinity Aquifer. We were able to adjust pumpage to produce about a 13 foot average water level decline in the Middle Trinity Aquifer (the most widely used aquifer in the area) across Groundwater Management Area 9. The results of this model run indicate that achieving an average 13 foot water level decline results in a slight reduction in baseflow to the local rivers, springs, and lakes/reservoirs. Larger water level declines in the Upper and Middle Trinity aquifers occur in the northern parts of Bexar and western parts of Kerr counties. Comparison of baseline pumpage and adjusted pumpage for an average of 13 feet of water level decline shows that an additional 1,540 acre-feet of groundwater could potentially be pumped regionally across most of Groundwater Management Area 9. In other words, pumpage that is close to current annual pumping volumes, as described by the districts in the baseline run, may produce an average of 13 feet of water level decline if pumping is continued at the same level through 2060 assuming average recharge conditions.

REQUESTOR:

Mr. Ron Fieseler, General Manager of the Blanco-Pedernales Groundwater Conservation District, on behalf of the groundwater conservation districts (GCDs) in Groundwater Management Area 9.

DESCRIPTION OF REQUEST:

Mr. Ron Fieseler requested that we:

(1) update the baseline pumpage in the groundwater availability model of the Hill Country portion of the Trinity Aquifer (Mace and others, 2000) based on input from the districts in Groundwater Management Area 9, which also included revised pumpage data

for Hays County from the Hays Trinity Groundwater Conservation District and redistributed pumpage for the Middle Trinity Aquifer in Travis County;

(2) adjust this baseline pumpage to produce average water level declines of no more than 15 feet in the Middle Trinity Aquifer across Groundwater Management Area 9 with no decline in the water levels in the Edwards Group from 2008 to 2060;

(3) extract water levels and water budgets for the beginning of the simulation (2008) using the baseline pumpage and the end of the predictive period (2060) using the adjusted pumpage that would produce the requested water level decline;

(4) develop water level change maps using the 2008 baseline model results compared against the results at the end of the predictive period (2060) using the adjusted pumpage; and

(5) provide managed available groundwater estimates by decade for each Groundwater Conservation District and for Groundwater Management Area 9 .

METHODS:

We updated the predictive pumpage in the groundwater availability model for the Hill Country portion of Trinity Aquifer (Mace and others, 2000) to closely match current county total pumpage use according to the districts. This effort included (1) replacing pumpage data for the Middle Trinity Aquifer in Hays County with the cell by cell pumpage data provided by Hays-Trinity Groundwater Conservation District, (2) redistributing pumpage for the Middle Trinity Aquifer in Travis County ensuring no additional pumpage is assigned close to Lake Travis and Lake Austin, and (3) adjusting county total pumpage to match current county groundwater use as supplied by the districts in the groundwater management area. This formed the baseline pumpage. The model was run in Processing Modflow for Windows (version 5.3: Chiang and Kinzelbach, 1998) using the baseline pumpage and the simulated water levels were compared to current water level conditions in the aquifer. The simulated water levels from this model run for 2008 formed the reference for comparison to current water level conditions in the aquifers. This baseline pumpage was then adjusted by trial and error to produce average water level declines of about 15 feet in the Middle Trinity Aquifer by the end of 2060 and 0 feet drawdown in the Edwards Group by the end of 2060 across the Groundwater Management Area 9. No further adjustments were made to the baseline pumpage for the Edwards Group or Upper Trinity Aquifer.

We extracted and contoured the simulated water levels for 2008 and 2060 in ArcMap© for both the baseline and adjusted pumpage. To improve the quality of the illustration, simulated water level and drawdown maps were finalized in Adobe Illustrator. We obtained county drawdown values by subtracting the simulated water levels produced by the adjusted pumpage condition at the end of 2060 from the 2008 simulated water levels under the baseline pumpage condition. We spatially joined the model grid with the simulated water levels and drawdown values to determine their distribution by county and model cell numbers. We exported the attributed ArcMap© datasets generated from this join and calculated the average, minimum, and maximum drawdown values in a spreadsheet. We also extracted water budget information for the beginning (2008) of the predictive period using the baseline pumpage and the end (2060) of the predictive period using the adjusted pumpage from the zoned water budget output data in Processing Modflow for Windows. This was done because the predictive pumpage was kept constant through the 60 years simulation run and decade by decade water budget flow terms would essentially be the same.

PARAMETERS AND ASSUMPTIONS:

- We used the groundwater availability model developed by Mace and others (2000) and only modified the predictive pumpage as described above.

- See Mace and others (2000) for details on model construction, recharge, discharge, assumptions and limitation of the model. A slightly updated version of this model (version 1.03) was used for this run (Chowdhury, 2007).

- The model has three layers: layer 1 represents the Edwards Group, layer 2 represents the Upper Trinity Aquifer, and layer 3 represents the Middle Trinity Aquifer.

- The model has a total of 79 stress periods with 2 stress periods representing pre-development conditions, 24 monthly stress periods for representing transient conditions (1996 to 1997), and 53 predictive annual stress periods (2008 to 2060).

- The calibrated model has a root-mean squared error of 56 feet .The root-mean squared error means that, on average, the simulated water level differs by about 56 feet. This root-mean squared error is about 5 percent of the total hydraulic head drop across the modeled area.

- The rivers, streams, and springs were simulated in the model using MODFLOW’s Drain package.

- MODFLOW Drain package was also used to simulate spring flow along bedding contacts of the Edwards Group and the Upper Trinity Aquifer in the northwestern parts of the model area. This resulted in the assignment of numerous drain cells along this outcrop contact.

- Reservoirs/lakes in the model area were simulated using constant heads.

- Pumpage used for the predictive period was developed as per instruction of the districts in Groundwater Management Area 9. Details on adjustments made to the pumpage are provided below.

- We assigned the baseline pumpage to the first predictive stress period in the model to represent 2008 pumping conditions. This was done with the assumption that the aquifers in the area recharges rapidly and groundwater movement is fast enough to bring about a dynamic equilibrium relatively quickly. Comparison of water level changes in selected hydrographs in the predictive period suggests that the aquifer attains a dynamic equilibrium within a year.

- Average recharge was used throughout the predictive period for this model run. Average recharge in the model was estimated for normal climatic conditions by using the average precipitation for the period 1960 to 1990 and the recharge coefficients estimated from baseflow analyses for each model cell (Mace and others, 2000).

RESULTS:

The pumpage specified by the districts in Groundwater Management Area 9 was developed using the initial predictive pumpage included in the groundwater availability model (Mace and others, 2000). This pumpage amount was adjusted using instructions by the groundwater conservation districts in Groundwater Management Area 9 such that the baseline pumpage reflected current county total pumpage use estimated by the districts. This baseline pumpage was then adjusted by trial and error to develop pumpage that produced an average of about 13 feet of water level decline in the Middle Trinity Aquifer across the groundwater management area. Repeated model runs with different scenarios of adjusted pumpage produced average water level declines exceeding 15 feet; therefore, we selected the results from the run that most closely achieved an average of 15 feet of water level declines without exceeding this directive. In order to achieve this, it was necessary to maintain current pumpage in counties with high historical pumping and drawdown and allow slightly increased pumpage over most of the remaining counties. Details of these pumpage estimates are presented in Table 1. Comparison of baseline pumpage and adjusted pumpage for the averaged 13 foot water level decline shows a difference of 1,540 acre-feet of groundwater.

Table 1. Estimated total county pumpage reported in acre feet per year. Total county pumpage is the sum of pumpage from the Edwards Group, Upper Trinity Aquifer, and Middle Trinity Aquifer.

Counties	**Baseline pumpage developed per instructions by Groundwater Management Area 9**	**Baseline pumpage adjusted to achieve an average 13 foot water level decline**
Bandera	4,215	4,550
Bexar	18,112	18,112
Blanco	1,564	1,713
Comal	6,255	6,834
Hays	4,842	5,282
Kendall	6,336	6,336
Kerr	7,513	7,513
Medina	403	439
Travis	5,596	5,596
Total	54,836	56,375

Groundwater Management Area 9 consists of Kerr, Bandera, Medina, Kendall, Bexar, Comal, Blanco, Hays, and Travis counties (Figure 1). Groundwater Management Area 9 contains numerous rivers and creeks, most of which gain groundwater from the aquifer, indicated by water level elevation contours that bend upstream along the length of the streams. Baseflow discharge that feeds most of the water courses in the area is a large component of streamflow (Mace and others, 2000).

Simulated water level elevation maps for the Edwards Group (Plateau), Upper Trinity, and Middle Trinity aquifers suggest that groundwater flows from the north to the south and from the west to the east (Figures 2, 3, 4, 5, 6, and 7) as observed from the measured water levels (Mace and others, 2000). We observed a minor rise in the simulated water levels in the Edwards Group between 2008 and 2060 across Groundwater Management Area 9 (Figures 2 and 3). Simulated water levels in the Upper Trinity Aquifer also remained relatively uniform between 2008 and 2060 with the exception of water level declines in northern parts of Kerr, Kendall, and Travis counties (Figures 4 and 5).

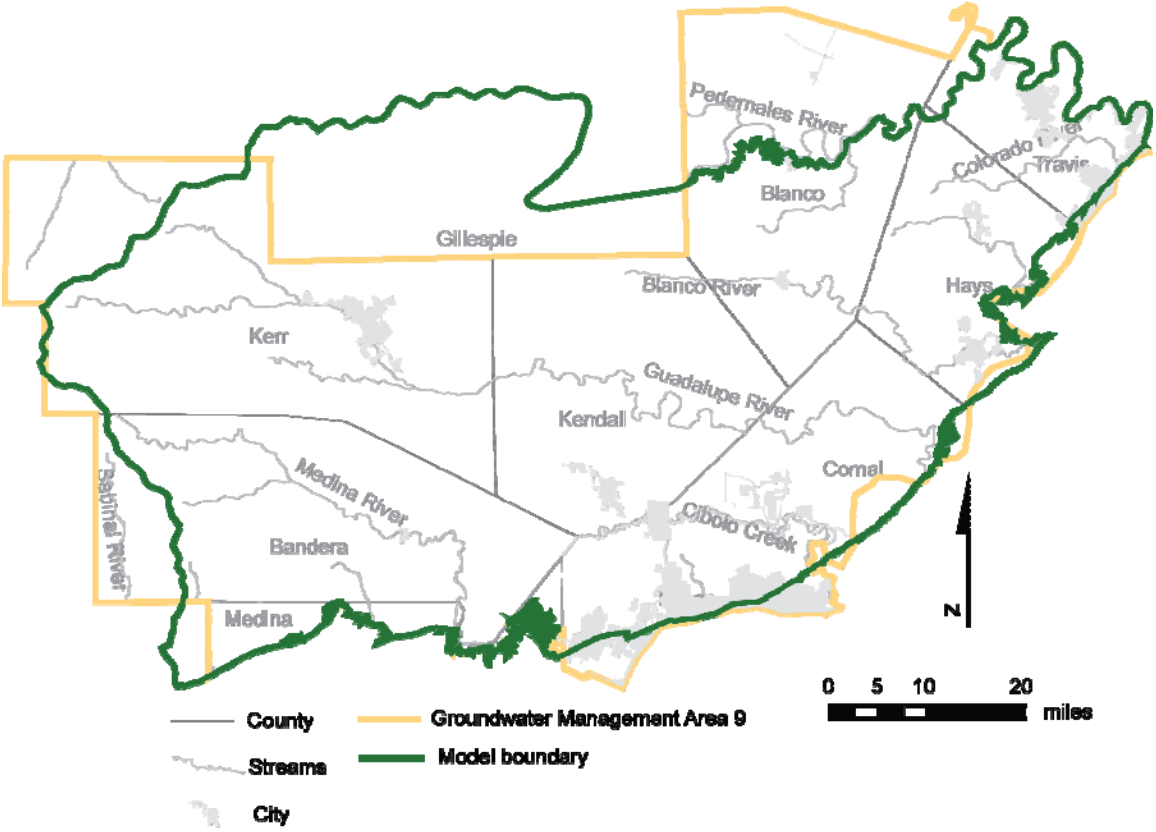

Figure 1. Map showing counties and streams in Groundwater Management Area 9. Outlines of Groundwater Management Area 9 and the model boundary are also shown. Note the groundwater model boundary also includes areas outside Groundwater Management Area 9.

Simulated water levels in the Middle Trinity Aquifer show significant changes between 2008 and 2060 (Figures 6 and 7). Simulated water levels show the most declines in Kerr, Kendall, Travis, Comal, and Bexar counties. Simulated water level maps also show development of numerous dry cells in southern Kendall and northern Bexar counties suggesting that the aquifer may not be able to readily sustain the specified pumpage in this area. However, note that the model does not accurately represent recharge to the Trinity Aquifer in northern Bexar County through stream flow losses in Cibolo Creek; therefore, these results for northern Bexar County may not be accurate.

Water level change maps were developed for the Edwards Group (Plateau), Upper Trinity, and Middle Trinity aquifers (Figures 8, 9, and 10). These water level change maps were generated by subtracting simulated water levels in 2008 under baseline pumpage from simulated water levels in 2060 under adjusted pumpage. We note that the water levels increase (recover) by up to about 10 feet over most of the Edwards Group (Plateau) Aquifer except in the eastern portions where water level decrease (drawdown) by up to 3 feet where the aquifer is thin. Water levels decrease by up to about 35 feet in the Upper Trinity Aquifer in the south western parts of Kendall County. Water levels also increase (recover) in the Upper Trinity Aquifer by up to 3 feet in parts of Gillespie, Kerr, and Bexar counties (Figure 9). A water level change map for the Middle Trinity Aquifer shows a significant decrease (drawdown) of up to about 100 feet in the Middle Trinity Aquifer in the northern parts of Bexar County (Figure 10). However, these water level decreases average about 13 feet for the Middle Trinity Aquifer over most of the Groundwater Management Area 9. Water level changes for each of the counties within Groundwater Management Area 9 are presented in Table 2.

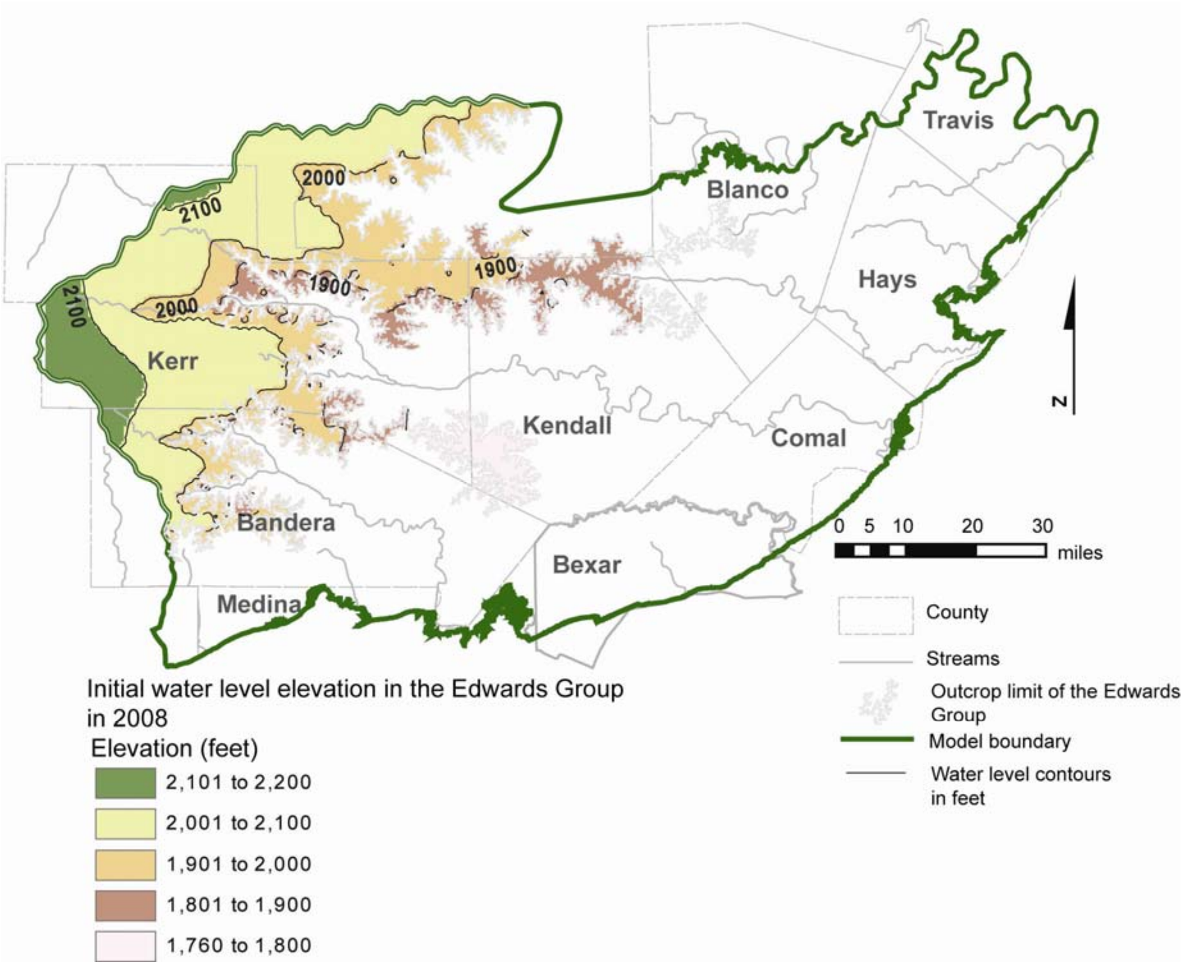

Figure 2. Initial water levels in the Edwards Group in 2008 for the beginning of the predictive period under baseline pumping from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note the water levels decrease from the west to the east following the land surface elevation.

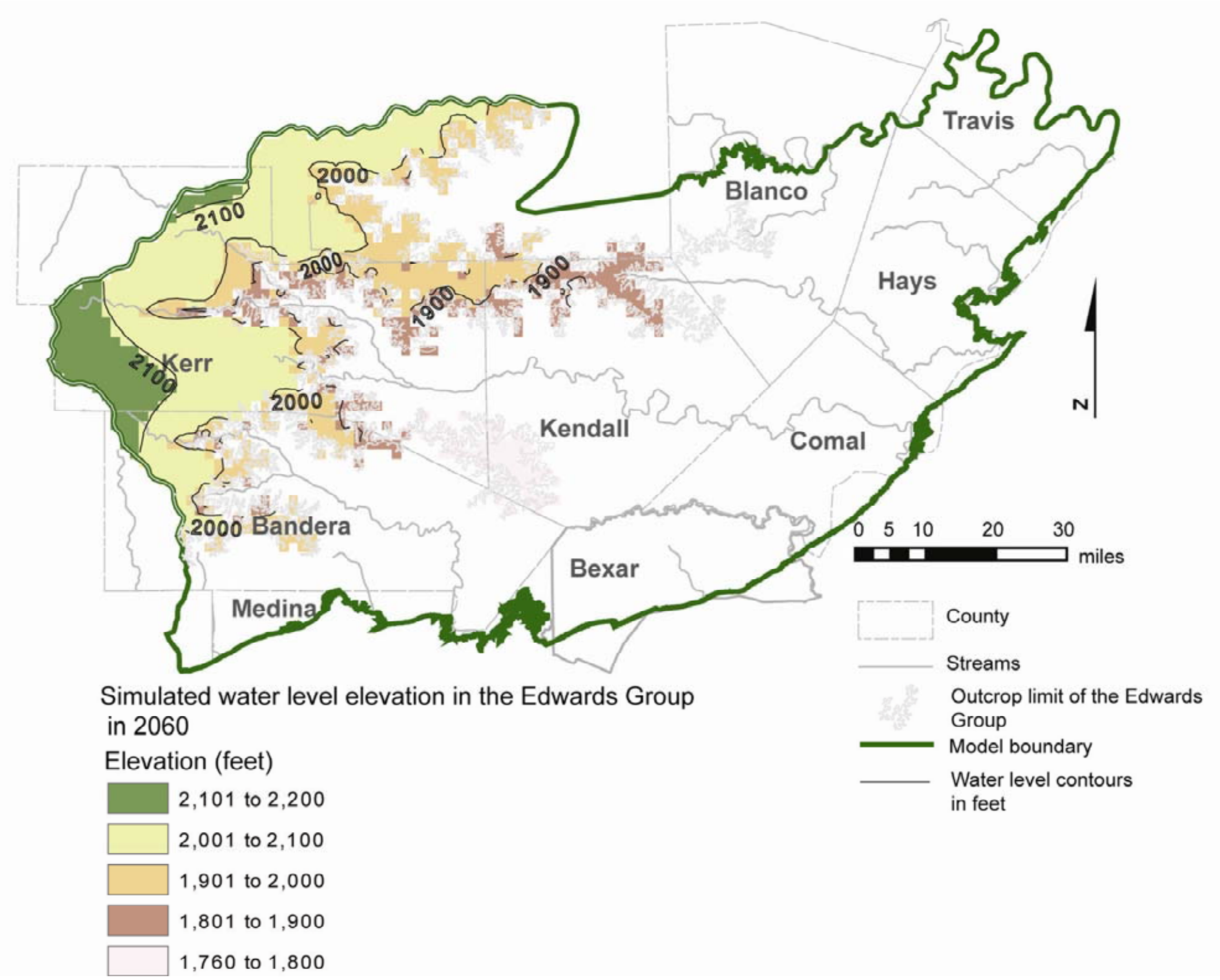

Figure 3. Water level elevations in the Edwards Group after 60 years of maintaining the same pumpage as baseline condition. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note only slight changes in water level elevations at the end of the predictive period in 2060.

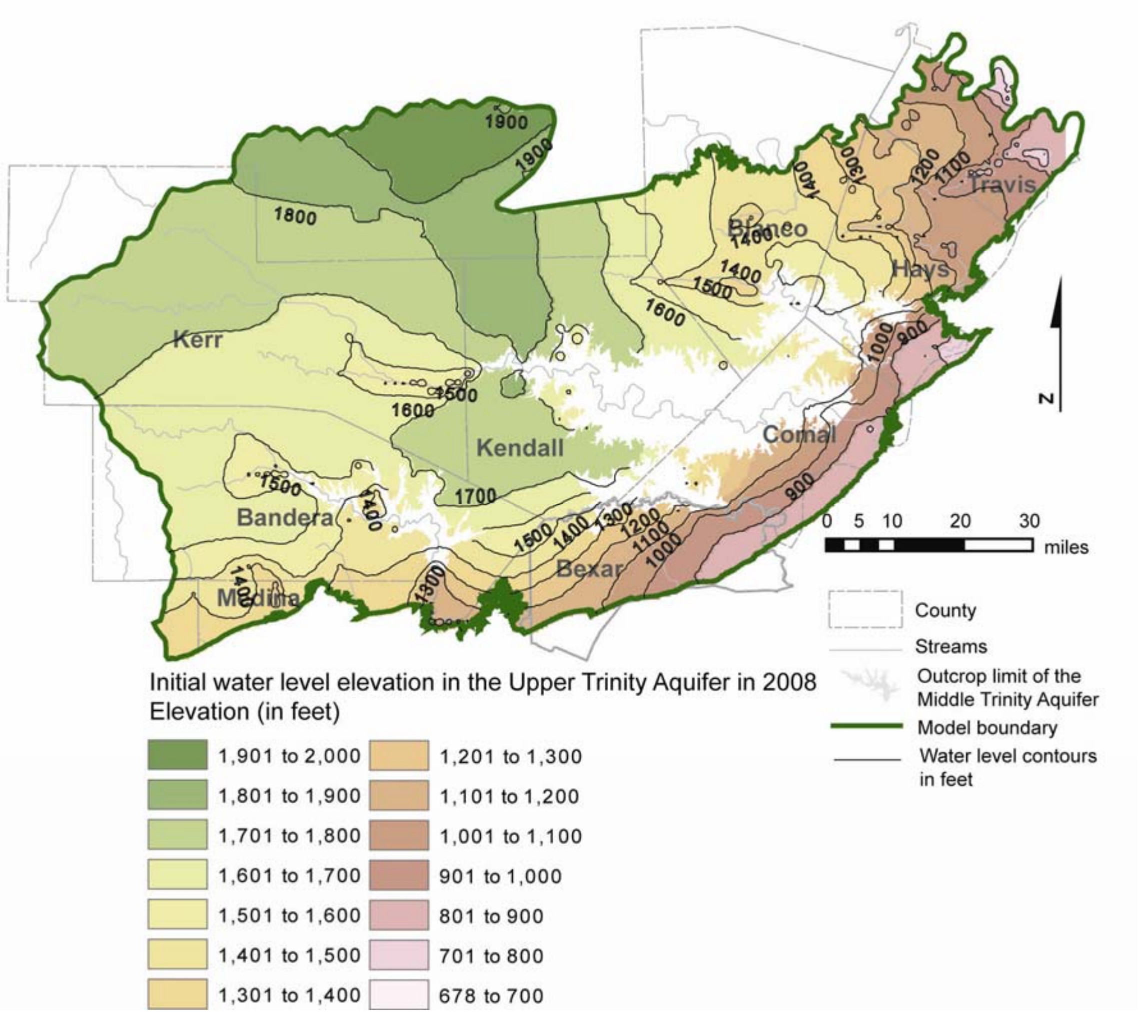

Figure 4. Initial water levels in the Upper Trinity Aquifer in 2008 for the beginning of the predictive period under baseline pumping from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet.

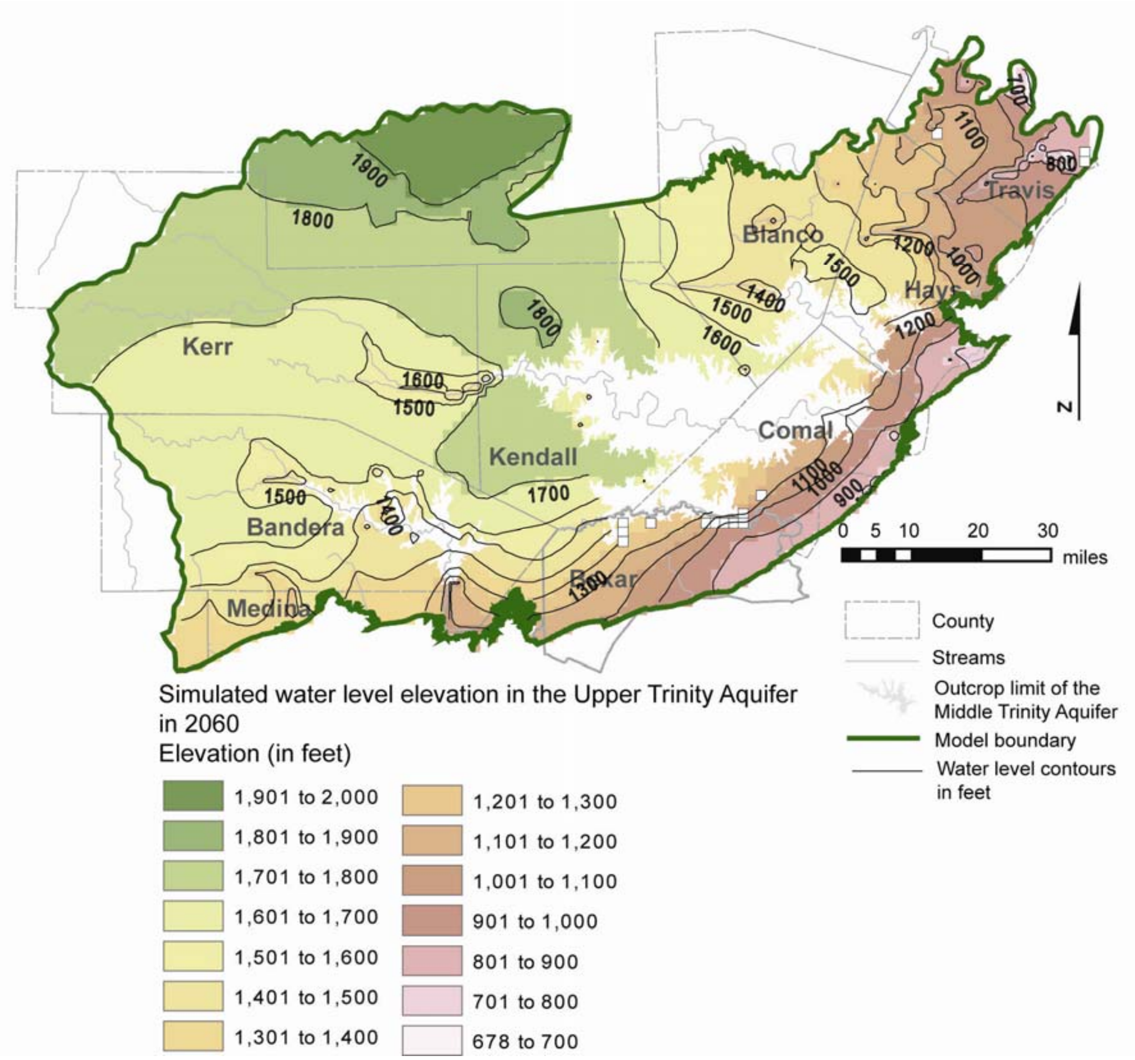

Figure 5. Water level elevations in the Upper Trinity Aquifer after 60 years of maintaining the same pumpage as baseline condition. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note changes to water level elevations in Gillespie, Kendall, Bexar, and Travis counties. Several dry cells also occur in Comal and Bexar counties.

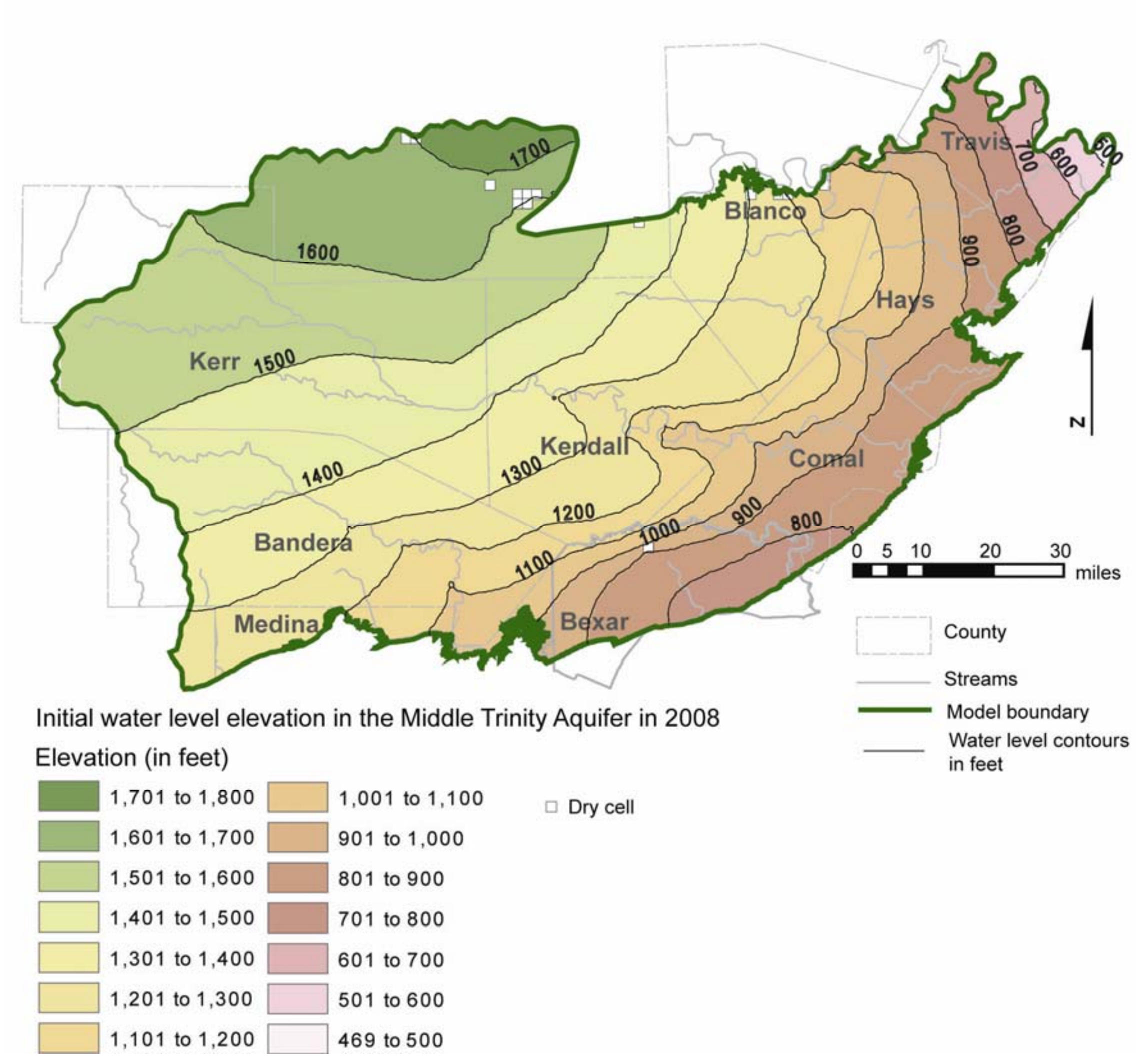

Figure 6. Initial water levels in the Middle Trinity Aquifer in 2008 for the beginning of the predictive period under baseline pumping condition from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Note groundwater flow is directed from the north to the south and from the west to the east with most of the water level contours bending upstream when the contours cross the rivers which suggests gaining nature of the rivers.

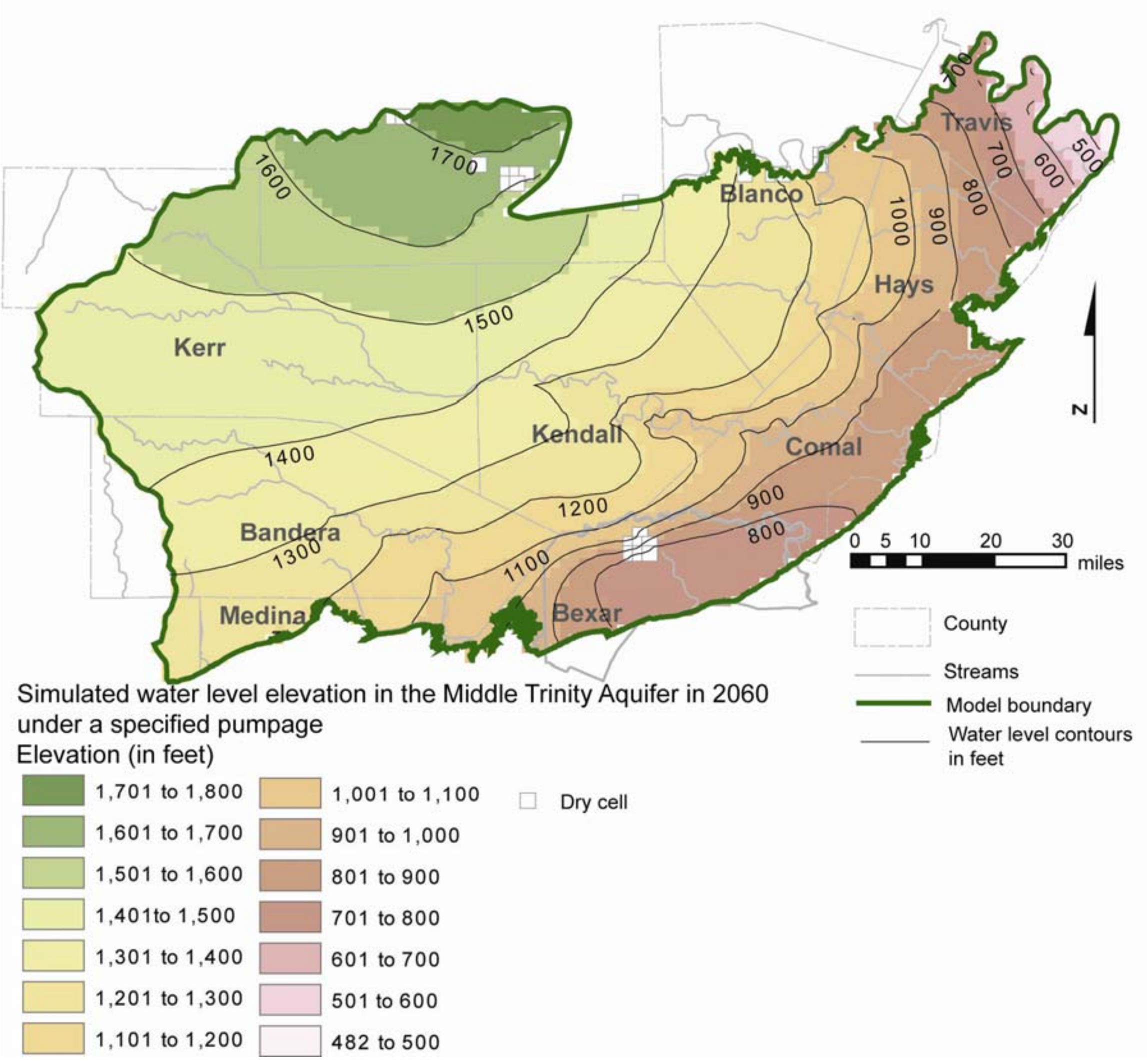

Figure 7. Water level elevations in the Middle Trinity Aquifer after 60 years using the adjusted specified pumpage. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note several dry cells in Bexar, Kendall, and Gillespie counties. Note slight flattening of the water level contours when they cross the rivers suggesting decreased baseflow under the specified pumpage condition.

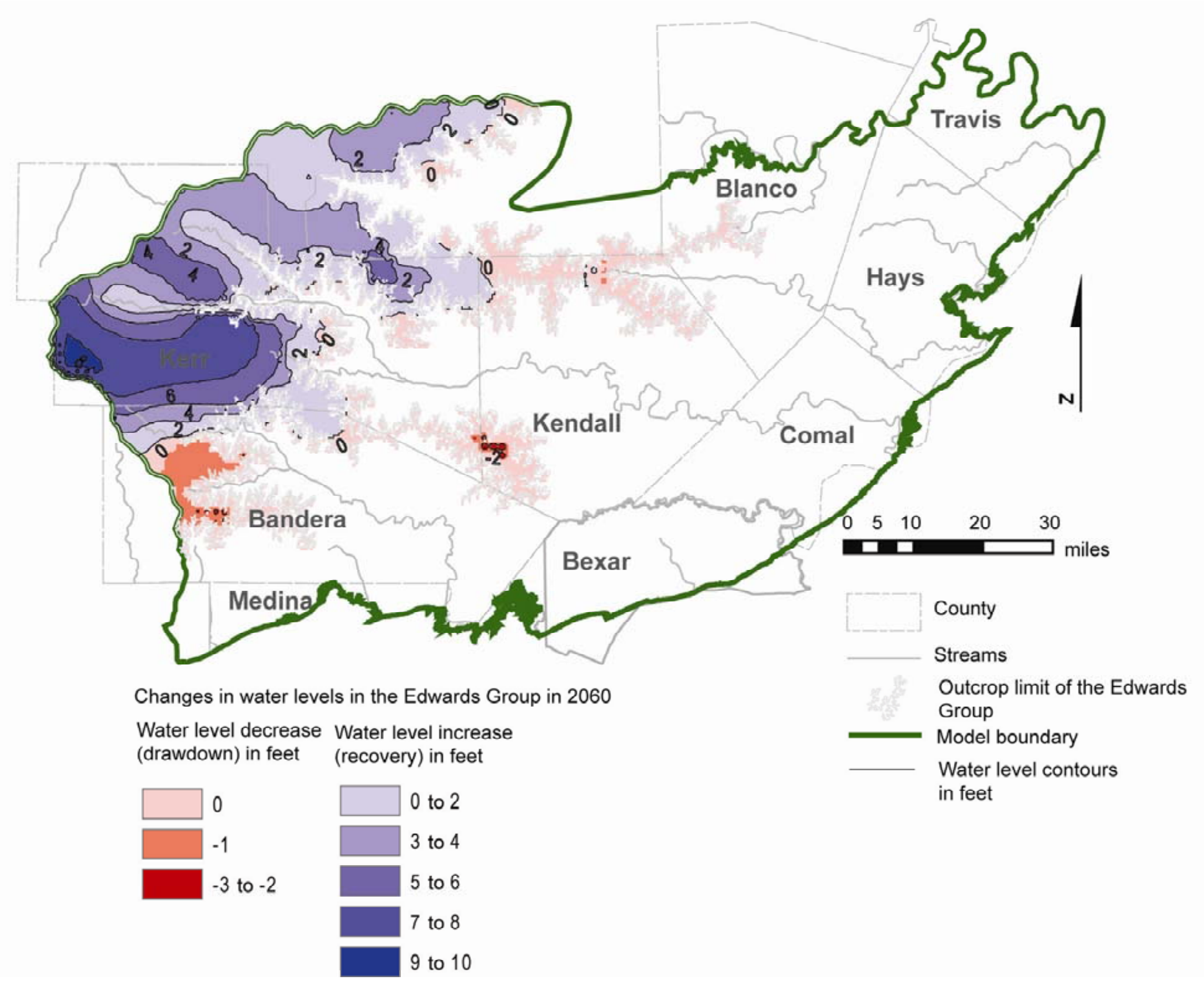

Figure 8. Changes in water levels after 60 years using the specified pumpage in the Edwards Group. Drawdown and water level recovery are reported in feet. Contour interval for drawdown is 1 foot and contour interval is 2 feet for water level recovery. Decreases in water levels are shown in red and increases are shown in blue.

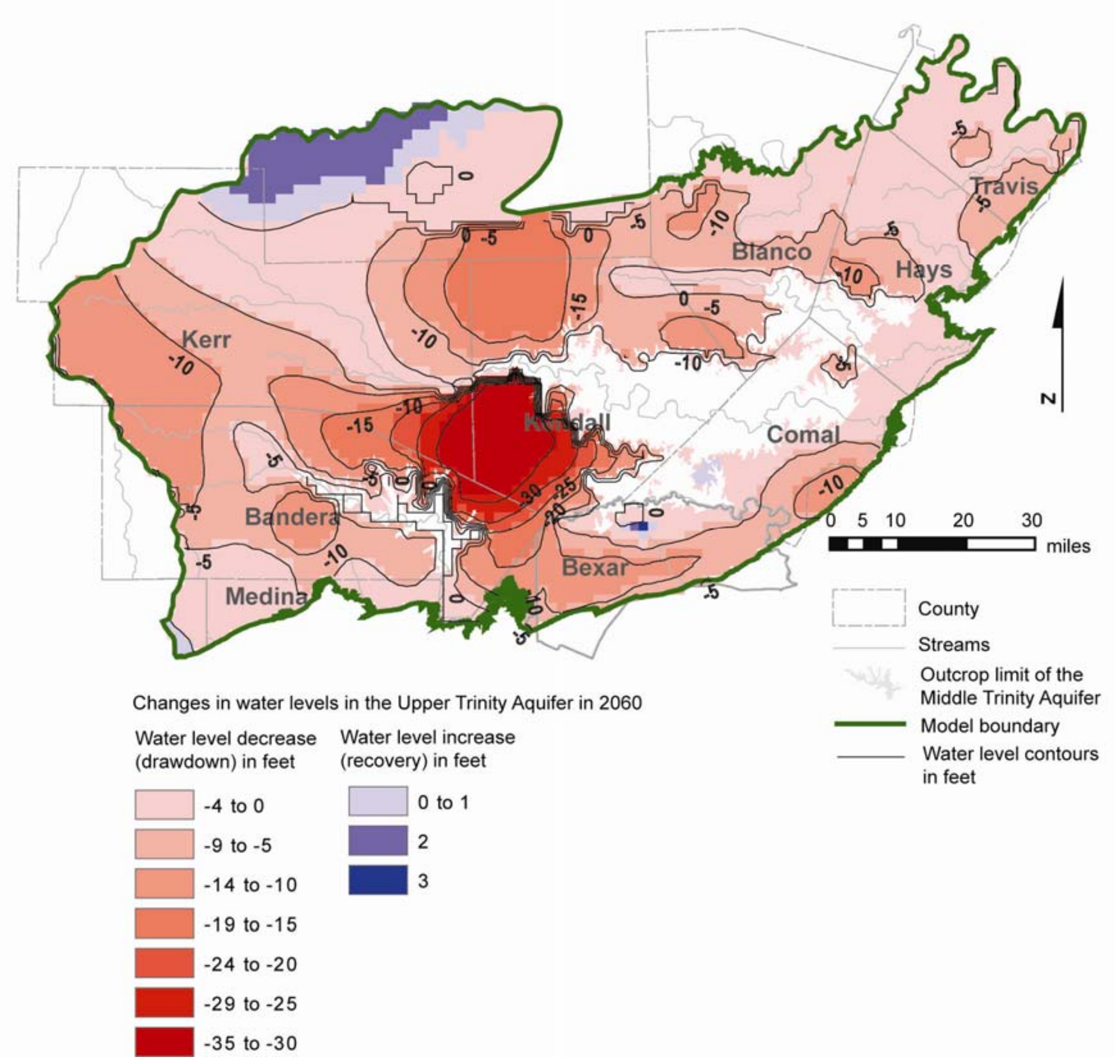

Figure 9. Changes in water levels after 60 years using the specified pumpage in the Upper Trinity Aquifer. Drawdowns and water level recovery are reported in feet. Contour interval for drawdown is 5 feet. Decreases in water levels are shown in red and increases are shown in blue.

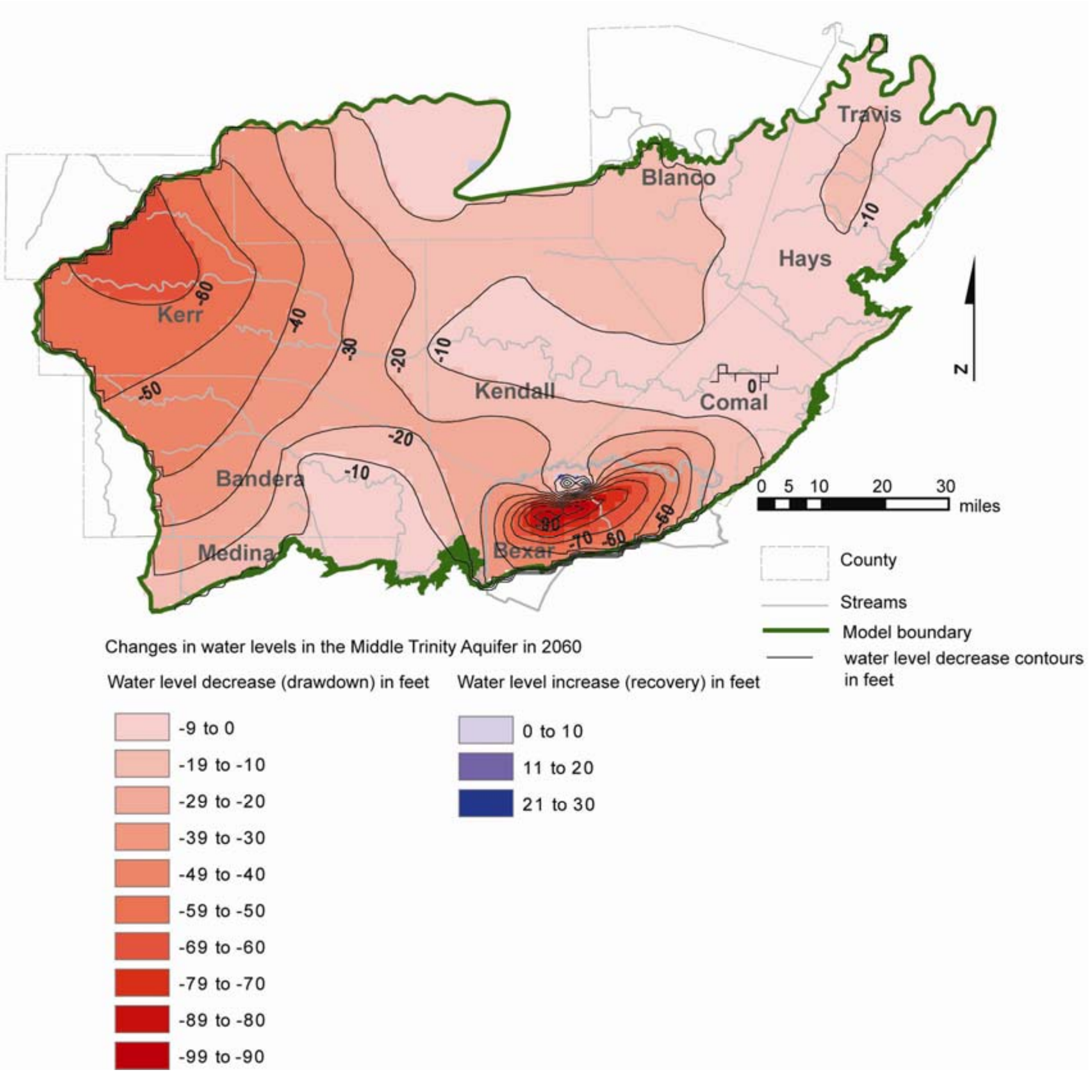

Figure 10. Changes in water levels after 60 years using the specified pumpage in the Middle Trinity Aquifer. Drawdowns are in feet. Contour interval is 10 feet. Decreases in water levels are shown in red. Increases in water levels for two cells in the northwestern parts of Bexar County are shown in blue. Numerous dry cells occur in Bexar and Kendall counties. A few dry cells also occur along the model boundaries due to thin model layer thickness along these areas.

Table 2. Water level changes in the Edwards Group, Upper Trinity, and Middle Trinity aquifers of the Hill Country area reported by county and aquifer. Negative values indicate a lowering of the water levels between 2008 under baseline pumping conditions and 2060 under increased pumping condition such that it produces water level declines by an average of about 13 feet for the Middle Trinity Aquifer across the Groundwater Management Area 9. Positive values indicate a recovery in the water levels in 2060 under the specified pumpage condition.

County	**Water level decline (feet) in 2060 using specified pumpage**		
	Average	Maximum	Minimum
Edwards Group Aquifer			
Bandera	0	-3	+5
Kendall	0	-3	0
Kerr	2	-2	+9
Average	+1	-3	+5
Upper Trinity Aquifer			
Bandera	-8	-32	0
Bexar	-4	-15	+3
Blanco	-2	-11	0
Comal	-2	-12	0
Hays	-2	-11	0
Kendall	-12	-35	0
Kerr	-7	-34	+2
Medina	-2	-16	0
Travis	-2	-10	0
Average	-5	-20	+1
Middle Trinity Aquifer			
Bandera	-21	-52	0
Bexar	-24	-99	+22
Blanco	-6	-18	0
Comal	-7	-43	0
Hays	-4	-12	0
Kendall	-12	-30	0
Kerr	-36	-67	0
Medina	-6	-31	0
Travis	-3	-11	0
Average	-13	-40	+2

Estimates of the water budget are included in Appendix 1. Various components of the water budget results presented in the appendix are described below.

- Recharge—Describes amount of water that infiltrates into the aquifer from rainfall in the outcrop and leakage from rivers and lakes. Recharge is always positive as water is added into the aquifer.

- River—Describes amount of water that flows between the rivers and an aquifer. When the water levels in an aquifer lie at a higher elevation than the river stage, water discharges (negative) from the aquifer into the river as baseflow. Conversely, if the water levels in an aquifer lie at a lower elevation than the river stage, water leaks into the aquifer (positive) from the river. Rivers are simulated in the model using the MODFLOW Drain Package. The Drain Package was used because the rivers in the Hill Country area are gaining and assigning the drains will only allow the rivers to receive water from the aquifer.

- Balcones Fault Zone (General Head Boundary Package)—General head boundary was assigned in the east of the model area in model layers 2 and 3 to estimate movement of water from the Upper and Middle Trinity aquifers into the Edwards (Balcones Fault Zone) Aquifer.

- Springs—Describes flow through the discrete springs simulated in the model using the MODFLOW Drain Package. Note that spring flow is also included in the River budget item.

- Lakes/reservoirs—Describes flow through the lakes/reservoirs simulated in the model using the MODFLOW Constant head package.

- Pumping—Describes amount of water produced from wells in each aquifer. This component of flow is reported negative as water is withdrawn from the aquifer. Pumping is represented in the model using the MODFLOW Well package.

- Vertical flow (Upper and Lower)—Describes amount of cross-formational flow along the contacts of the model layers between two aquifers. This flow is controlled by the water level elevations in each aquifer and aquifer properties of each aquifer.

- Lateral flow —Describes amount of groundwater flowing laterally along the horizontal direction in the aquifer.

- Storage—Describes net water stored in the aquifer. This component of the budget is often seen as water both going into and out of the aquifers. Positive sign indicates that water levels will rise (water added to storage) and negative sign indicates water level will decline (water removed from storage).

We present the water budget results as “In” and “Out” for 2008 and 2060 (Appendix 1). This comparison of water budget results for 2008 and 2060 indicates how the amounts of groundwater movement between the aquifers, rivers, springs, and lakes/reservoirs will likely change through time if it is decided that pumping from the aquifers will increase from a baseline to an adjusted specified pumpage condition. The column of results under “In” indicates the amount of water that is coming into the aquifer and the column of results under “Out” indicates the amount of water that is leaving the aquifer. Recharge is always found under the “In” column as recharge infiltrates into the aquifer. Similarly, pumping is always in the “Out” column as groundwater is pumped out of the aquifer.

Some parameters, such as rivers and vertical and lateral flow could occur in both “In” and “Out” columns given the variation in local hydrogeologic conditions of the aquifer.

Water budget results indicate that various components of flow for the Edwards Group and the Upper Trinity aquifers increase between 2008 and 2060 due to application of a constant pumpage through the 60 year simulation period (Appendix 1). For example, baseflow discharges for the rivers that flow over the Edwards Group and the Upper Trinity aquifers actually show a gain in flow (Appendix 1). This is because water levels in the area increase resulting in a higher hydraulic gradient causing more water to discharge to the river. Springs in these two aquifers also show gain in flow (Appendix 1). However, water budget results for the Middle-Trinity Aquifer show some decrease for various components of flow to compensate for a slight increase in pumpage (Appendix 1). Baseflow discharges into the rivers that flow over the Middle Trinity Aquifer decrease by up to about 20 percent in several areas including Blanco, Kendall, and Hays counties (Appendix 1). Spring discharges in the Middle Trinity Aquifer also decrease by 1 to 14 percent in Blanco and Hays counties and by about 26 percent in Kendall County. However, it must be noted that water budget results reported for spring discharges are based on a total of only 14 springs across the entire model area. The rivers in the area are largely fed by baseflow and discharges through springs along the river beds. However, only the larger springs could be included in the model as the model was constructed with 1 mile by 1 mile grid sizes to simulate regional flow conditions. Therefore, reported baseflow discharges along the long stretches of the rivers are probably a more reliable indicator of pumpage effects on natural flow to the rivers and springs. The reported decreases in baseflow discharges to the rivers and springs may not have a significant impact on changing groundwater flow direction in the aquifers regionally or changing the rivers from gaining to losing which is supported from simulated water level contours that still bend upstream along the course of the rivers after 60 years of specified pumping (Figures 6 and 7).

For Bexar, Comal, and Kendall counties, occurrences of a few dry cells may inherently affect the water budget values between 2008 and 2060. If dry cells appear, the cell is shut off and is not included in the water budget calculation. Dry cells may only appear towards the end of the predictive period and not at the beginning giving minor mismatch for “In” and “Out” values between 2008 and 2060 for some flow parameters.

REFERENCES:

Chiang, W.H. and Kinzelbach, W., 1998, Processing Modflow: A simulation system for modeling groundwater flow and pollution: Hamburgh, Zurich, variously paginated.

Chowdhury, A.H., 2007, GAM Run 7-18, Texas Water Development Board unpublished report, 30 p.

Mace, R.E., Chowdhury, A.H., Anaya, R., and Way, S-C., 2000, Groundwater availability of the Trinity Aquifer, Hill Country Area, Texas—Numerical simulations through 2050: Texas Water Development Board Report 353, 119 p.

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The seal appearing on this document was authorized by Ali H. Chowdhury, P.G., on July 28, 2008.

Appendix 1. Annual water budgets for each county at the beginning (2008) of the predictive period under baseline pumping and at the end (2060) of the predictive model run using adjusted specified pumpage in the groundwater availability model for the Hill Country portion of the Trinity Aquifer such that water level declines by about 15 feet in the Middle Trinity Aquifer across the Groundwater Management Area 9. Water budget values are reported in acre-feet per year. Water budgets for Kerr, Gillespie, Blanco, Medina, Kimble, Uvalde, and Bexar counties represent only the portions of those counties located in the active portion of the model. Note that the "spring" item only refers to springs discretely represented in the model. The "Rivers" term includes other spring flow.

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Edwards Group	Bandera	Storage	213	6	0	1
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	2,158	20	2,366	20
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	458	0	459
		Pumping	0	596	0	596
		Rivers (Drain)	0	12,880	0	12,879
		Recharge	11,588	0	11,588	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	13,958	13,960	13,953	13,955
Upper Trinity	Bandera	Storage	1,763	1	0	0
		Lakes/reservoirs (Constant Head)	2	2,586	2	2,475
		Lateral flow	5,692	10,147	5,066	9,397
		Vertical flow (upward)	458	0	459	0
		Vertical flow (downward)	18	14,147	0	13,594
		Pumping	0	270	0	270
		Rivers (Drain)	0	13,403	0	12,480
		Recharge	33,368	0	33,368	0
		Balcones Fault Zone (General Head Boundary)	14	402	19	358
		Springs (Drain)	0	359		339
		Total	41,314	41,315	38,913	38,913
Middle Trinity	Bandera	Storage	1,804	0	5	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	8,672	11,713	7,585	10,911
		Vertical flow (upward)	14,147	18	13,594	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	3,347	0	3,681
		Rivers (Drain)	0	12,694	0	10,056
		Recharge	4,432	0	4,432	0
		Balcones Fault Zone (General Head Boundary)	222	1,520	267	1,270
		Total	29,277	29,292	25,883	25,918

Appendix 1 continued.

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Upper Trinity	**Blanco**	**Storage**	911	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	3,561	1,906	3,422	1,802
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	7,931	0	7,782
		Pumping	0	77	0	77
		Rivers (Drain)	0	13,745	0	12,945
		Recharge	19,175	0	19,175	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	23,647	23,659	22,597	22,605
Middle Trinity	**Blanco**	**Storage**	902	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	4,904	8,993	4,625	8,568
		Vertical flow (upward)	7,931	0	7,782	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	1,469	0	1,615
		Rivers (Drain)	0	12,443	0	11,400
		Recharge	9,206	0	9,206	0
		Balcones Fault Zone (General Head Boundary)	197	197	0	0
		Springs (Drain)		30		28
		Total	23,140	23,132	21,613	21,612
Upper Trinity	**Comal**	**Storage**	546	2	0	0
		Lakes/reservoirs (Constant Head)	174	254	200	230
		Lateral flow	1,825	2,611	1,779	2,553
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	61	3,674	61	3,620
		Pumping	0	473	0	473
		Rivers (Drain Package)	0	1,005	0	944
		Recharge	14,479	0	14,479	0
		Balcones Fault Zone (General Head Boundary)	0	9,066	0	8,698
		Total	17,084	17,084	16,518	16,518

Appendix 1 continued.

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Middle Trinity	**Comal**	**Storage**	1,213	91	0	0
		Lakes/reservoirs (Constant Head)	2,121	4,018	2,341	3,738
		Lateral flow	9,411	9,924	8,580	9,040
		Vertical flow (upward)	3,674	61	3,620	61
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,741	0	6,293
		Rivers (Drain Package)	0	6,818	0	6,203
		Recharge	13,278	0	13,278	0
		Balcones Fault Zone (General Head Boundary)	0	3,044	0	2,485
		Total	29,696	29,696	27,819	27,819
Upper Trinity	**Travis**	**Storage**	419	0	0	0
		Lakes/reservoirs (Constant Head)	0	1,007	0	988
		Lateral flow	1,348	918	1,315	862
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	5,620	0	5,488
		Pumping	0	551	0	551
		Rivers (Drain)	0	5,081	0	4,918
		Recharge	12,629	0	12,629	0
		Balcones Fault Zone (General Head Boundary)	0	1,218	0	1,136
		Springs (Drain)		0		
		Total	14,396	14,396	13,943	13,944
Middle Trinity	**Travis**	**Storage**	389	71	0	0
		Lakes/reservoirs (Constant Head)	718	5,401	750	4,988
		Lateral flow	3,181	144	3,037	135
		Vertical flow (upward)	5,620	0	5,488	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,104	0	5,110
		Rivers (Drain)	0	619	0	534
		Recharge	2,515	0	2,515	0
		Balcones Fault Zone (General Head Boundary)	0	1,092	0	1,031
		Total	12,422	12,431	11,789	11,798

Appendix 1 continued

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Edwards Group	**Kendall**	**Storage**	65	7	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	111	215	113	208
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	6	43	1	49
		Pumping	0	318	0	318
		Rivers (Drain)	0	5,509	0	5,449
		Recharge	5,908	0	5,908	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	6,091	6,093	6,022	6,024
Upper Trinity	**Kendall**	**Storage**	1,951	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	2,046	9,455	1,728	8,453
		Vertical flow (upward)	43	6	49	1
		Vertical flow (downward)	8	15,728	0	15,086
		Pumping	0	307	0	307
		Rivers (Drain)	0	5,183	0	4,562
		Recharge	26,627	0	26,627	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	30,676	30,679	28,404	28,409
Middle Trinity	**Kendall**	**Storage**	1,859	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	9,205	12,810	8,176	11,768
		Vertical flow (upward)	15,728	8	15,086	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,546	0	5,546
		Rivers (Drain)	0	24,500	0	22,200
		Recharge	16,761	0	16,761	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Springs (Drain)		690	0	511
		Total	43,553	43,554	40,022	40,025

Appendix 1 continued

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Upper Trinity	**Hays**	**Storage**	620	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	3,388	2,597	3,258	2,537
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	53	7,923	48	7,778
		Pumping	0	408	0	408
		Rivers (Drain Package)	0	15,309	0	14,886
		Recharge	24,929	0	24,929	0
		Balcones Fault Zone (General Head Boundary)	14	2,688	16	2,575
		Springs (Drain)		81	0	68
		Total	29,005	29,006	28,251	28,252
Middle Trinity	**Hays**	**Storage**	440	49	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	9,059	7,159	8,719	6,826
		Vertical flow (upward)	7,923	53	7,778	48
		Vertical flow (downward)	0	0	0	0
		Pumping	0	4,273	0	4,700
		Rivers (Drain Package)	0	8,738	0	8,097
		Recharge	5,802	0	5,802	0
		Balcones Fault Zone (General Head Boundary)	0	2,509	0	2,215
		Springs (Drain)		450	0	416
		Total	23,224	23,231	22,299	22,302
Edwards Group	**Kerr**	**Storage**	23	1,330	0	6
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	2,761	4,266	2,878	4,592
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	3,401	0	3,488
		Pumping	0	1,036	0	1,036
		Rivers (Drain)	0	21,248	0	22,193
		Recharge	29,478	0	29,478	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Drains (Springs)		986		1,042
		Total	32,262	32,266	32,355	32,357

Appendix 1 continued.

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Upper Trinity	**Kerr**	**Storage**	1,160	27	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	2,984	1,876	2,747	1,643
		Vertical flow (upward)	3,401	0	3,488	0
		Vertical flow (downward)	10	8,507	0	8,655
		Pumping	0	213	0	213
		Rivers (Drain)	0	13,704	0	12,495
		Recharge	16,771	0	16,771	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	24,325	24,327	23,006	23,005
Middle Trinity	**Kerr**	**Storage**	1,786	0	13	0
		Lakes/reservoirs (Constant Head Package)	0	0	0	0
		Lateral flow	4,384	8,455	4,447	6,935
		Vertical flow (upward)	8,507	10	8,655	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	6,259	0	6,259
		Rivers (Drain)	0	0	0	0
		Recharge	0	0	0	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	14,676	14,725	13,115	13,195
Upper Trinity	**Medina**	**Storage**	216	0	0	0
		Lakes/reservoirs (Constant Head)	1	3,580	1	3,452
		Lateral flow	7,039	3,619	6,670	3,463
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	20	1,084	9	1,107
		Pumping	0	43	0	43
		Rivers (Drain)	0	2,032	0	1,992
		Recharge	7,805	0	7,805	0
		Balcones Fault Zone (General Head Boundary)	128	4,850	140	4,568
		Total	15,209	15,209	14,625	14,625

Appendix 1 continued.

Aquifer	County	Flow parameters	Water budget for 2008		Water budget for 2060	
			In	Out	In	Out
Middle Trinity	**Medina**	**Storage**	198	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	9,760	3,963	9,141	4,569
		Vertical flow (upward)	1,084	20	1,107	9
		Vertical flow (downward)	0	0	0	0
		Pumping	0	360	0	397
		Rivers (Drain)	0	0	0	0
		Recharge	0	0	0	0
		Balcones Fault Zone (General Head Boundary)	214	6,913	435	5,711
		Total	11,256	11,256	10,682	10,684
Upper Trinity	**Bexar**	**Storage**	623	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	6,160	1,642	5,598	1,599
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	1,731	0	1,759
		Pumping	0	924	0	924
		Rivers (Drain Package)	0	2,354	0	1,859
		Recharge	10,242	0	10,242	0
		Balcones Fault Zone (General Head Boundary)	0	10,374	0	9,699
		Total	17,025	17,025	15,840	15,840
Middle Trinity	**Bexar**	**Storage**	3,441	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	11,981	1,194	11,663	834
		Vertical flow (upward)	1,731	0	1,759	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	16,893	0	16,365
		Rivers (Drain)	0	0	0	0
		Recharge	1,638	0	1,638	0
		Balcones Fault Zone (General Head Boundary)	129	834	2,275	136
		Total	18,920	18,920	17,335	17,335