GAM Run 08-30

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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 water level recovery of up to 9 feet over most of the Edwards Group Aquifer and water level decline of up to 3 feet where the aquifer is thin. We adjusted pumpage for the Middle Trinity Aquifer to develop an average water level decline of 34 feet in Bandera, Blanco, Kendall, and Kerr counties; an average water level decline of 15 feet in Comal, Hays, and Travis counties; and an average water level decline of 44 feet in Bexar and Medina counties over the 60-year predictive simulation. Numerous dry cells in Bexar County limited the feasibility of simulating average water level declines of up to 55 feet in Bexar and Medina counties. The results of this model run indicate that achieving the above amount and distribution of water level declines results in a 10 to 80 percent reduction in baseflow to the local rivers, springs, and lakes/reservoirs that are located over the outcrop of the Middle Trinity Aquifer. Larger water level declines in the Upper and Middle Trinity aquifers occur in the northern parts of Bexar, Blanco, Travis, and western parts of Kerr counties. Comparison of baseline pumpage and adjusted pumpage for the above water level decline distribution shows that an additional 45,000 acre-feet of groundwater could potentially be pumped annually across most of Groundwater Management Area 9.

REQUESTOR:

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

DESCRIPTION OF REQUEST:

Mr. Ron Fieseler requested that we:

(1) adjust the baseline pumpage (Chowdhury, 2008a, b) to produce average water level declines of no more than 35 feet in the Middle Trinity Aquifer in Blanco, Bandera, Kerr and Kendall counties; average water level declines of no more than 15 feet in Comal, Hays, and Travis counties; and average water level declines of no more than 55 feet in Bexar and Medina counties with no decline in the water levels in the Edwards Group from 2008 to 2060;

(2) 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;

(3) 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

(4) 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. Details on this were discussed in GAM Run 8-15 (Chowdhury, 2008a) and GAM Run 8-20 (Chowdhury, 2008b). This baseline pumpage was then adjusted by trial and error in order to achieve the average declines requested. 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).

- 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's 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.

- 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.

- The pumpage specified by the districts in Groundwater Management Area 9 was developed using the spatially pattern of initial predictive pumpage included in the groundwater availability model (Mace and others, 2000).

- Average recharge was used throughout the predictive period for this model run. Average recharge in the model was estimated for normal climatic conditions by

- The model was run in Processing Modflow for Windows (version 5.3; Chiang and Kinzelbach, 1998).

RESULTS:

We developed a pumpage scenario that produced an average water level decline of 34 feet in Blanco, Bandera, Kerr and Kendall counties; an average water level decline of 15 feet in Comal, Hays, and Travis counties; and an average water level decline of 44 feet in Bexar and Medina counties in the Middle Trinity Aquifer by the end of 2060 with no appreciable decline in the water levels in the Edwards Group from 2008 to 2060. Because the assignment of additional pumpage was developing greater amount of dry cells in the northern parts of Bexar County, we have reported the pumpage amount that generated an average water level decline of 44 feet in Bexar and Medina counties instead of the requested 55 foot water level decline. In order to achieve the reported average water level declines per the requested geographic areas, it was necessary to significantly increase pumpage in all counties across Groundwater Management Area 9. More pumpage was assigned to counties with low historical pumpage compared to counties with high historical pumpage. Details of these pumpage estimates are presented in Table 1. Comparison of baseline pumpage and adjusted pumpage that produced the requested water level decline distribution shows a difference of about 45,000 acre-feet.

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 for specified water level declines per requested geographic areas
Bandera	4,215	7,268
Bexar	18,112	39,541
Blanco	1,564	4,538
Comal	6,255	9,542
Hays	4,842	7,335
Kendall	6,336	11,323
Kerr	7,513	8,540
Medina	403	2,928
Travis	5,596	8,461
Total	54,836	99,476

Groundwater Management Area 9 consists of all or parts 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 historically 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).

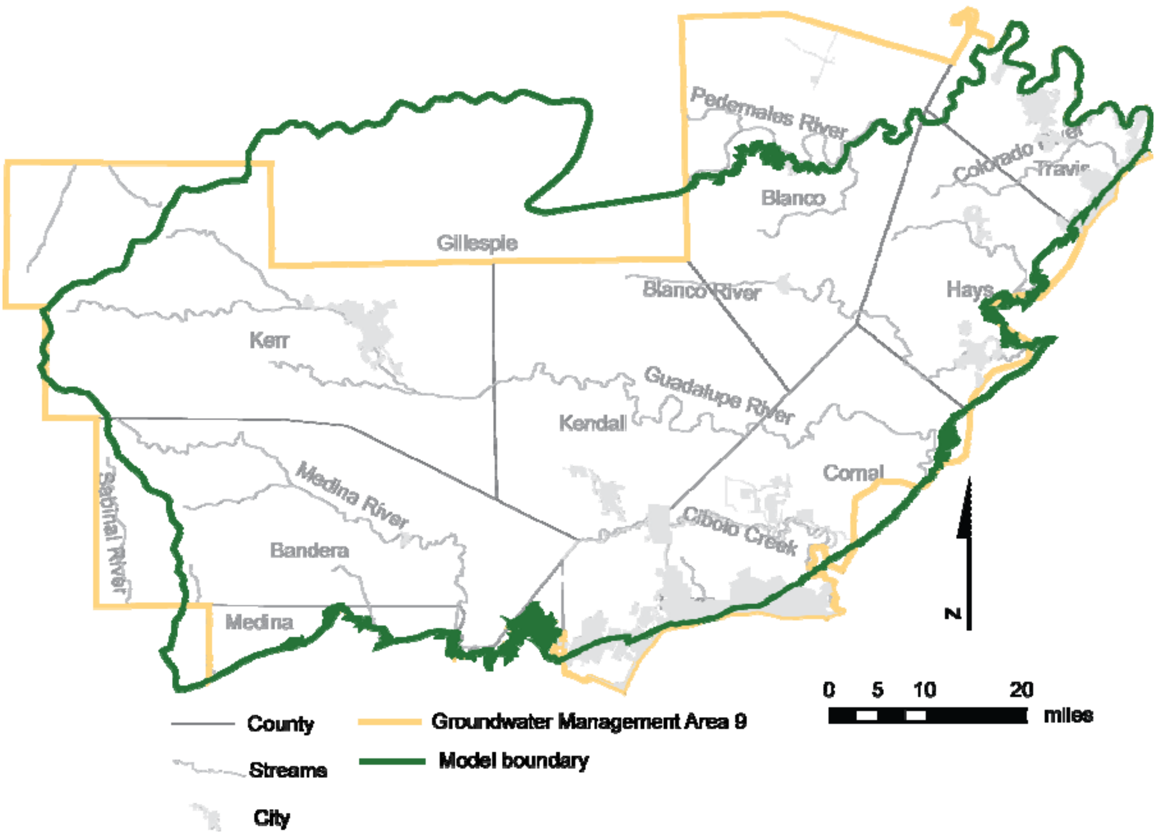

Figure 1. Map showing counties and streams in Groundwater Management Area 9. Outlines of Groundwater Management Area 9 and the model boundary are also shown. Note the groundwater model boundary also includes areas outside Groundwater Management Area 9.

Simulated water levels in the Middle Trinity Aquifer show significant changes between 2008 and 2060 (Figures 6 and 7). Simulated water levels show the greatest declines in Bexar, Kerr, Kendall, Travis, and Blanco counties. Simulated water level maps also show development of numerous dry cells in northern parts of Bexar County suggesting that the aquifer may not be able to readily sustain the specified pumpage in this area as spatially distributed. 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. For example, recent studies show that up to about 80,000 acre-feet of groundwater may annually recharge through infiltration of streamflow in the Cibolo Creek area and diffuse infiltration through adjacent soils and rock (Ockerman, 2007). Therefore, the water level decline results for northern Bexar County may not be representative of actual groundwater conditions in the area.

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 9 feet over the Edwards Group (Plateau) Aquifer and water level decline of up to about 3 feet in the east 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 5 feet in parts of Gillespie, Kerr, and Bexar counties and locally up to 15 feet in northern Bexar County (Figure 9). A water level change map for the Middle Trinity Aquifer shows a significant decrease (drawdown) of up to about 300 feet in the Middle Trinity Aquifer in the northern parts of Bexar County, up to about 80 feet in northern Kerr County, and up to about 50 feet in Blanco and Travis counties (Figure 10). However, these water level decreases average about 34 feet for the Middle Trinity Aquifer in Blanco, Bandera, Kendall, and Kerr counties; 15 feet in Comal, Hays and Travis counties; and 44 feet in Bexar and Medina counties. Water level changes for each of the counties within Groundwater Management Area 9 are presented in Table 2.

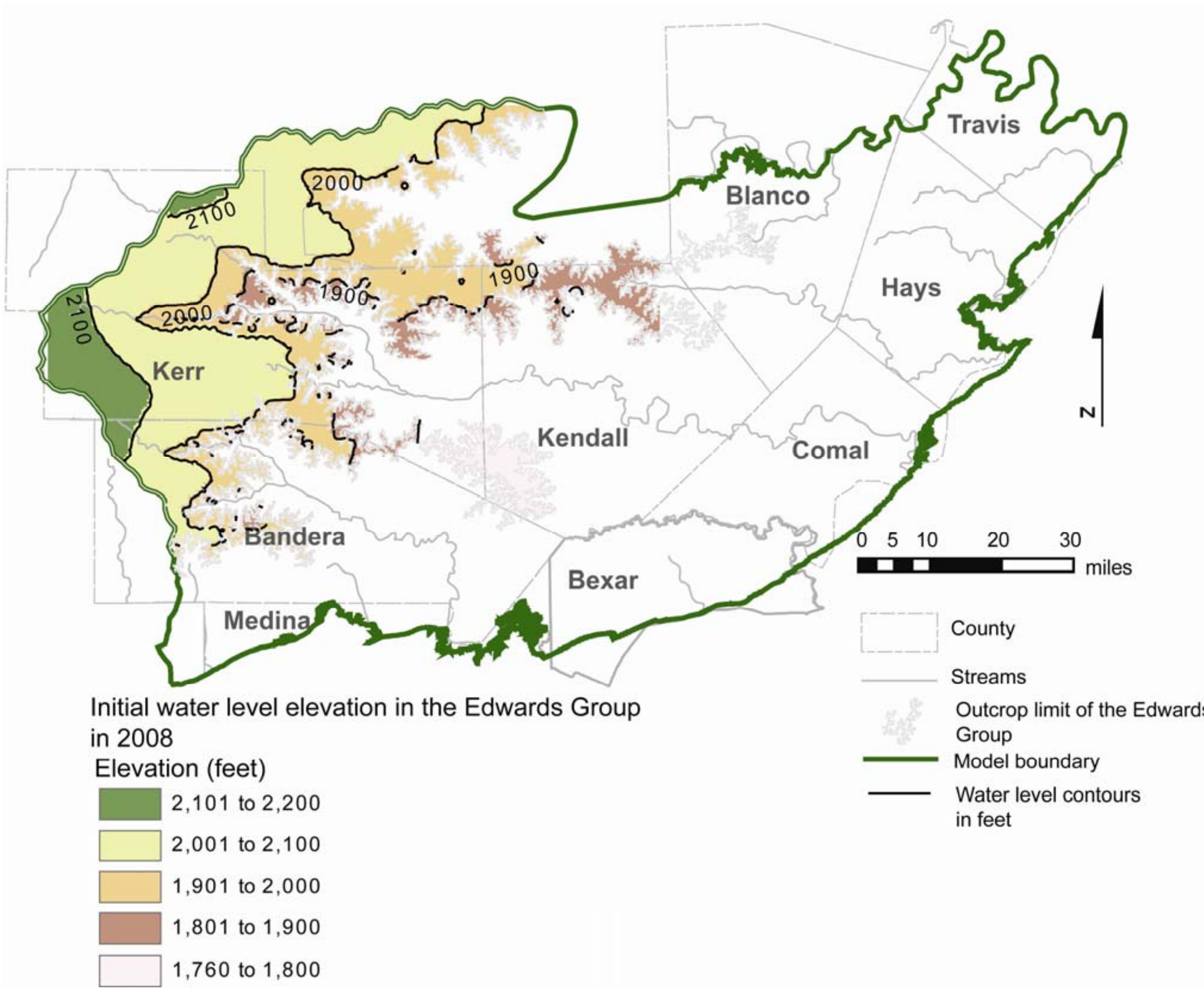

Figure 2. Initial water levels in the Edwards Group in 2008 for the beginning of the predictive period under baseline pumping from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Water level elevations are reported in feet above mean sea level. Contour interval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

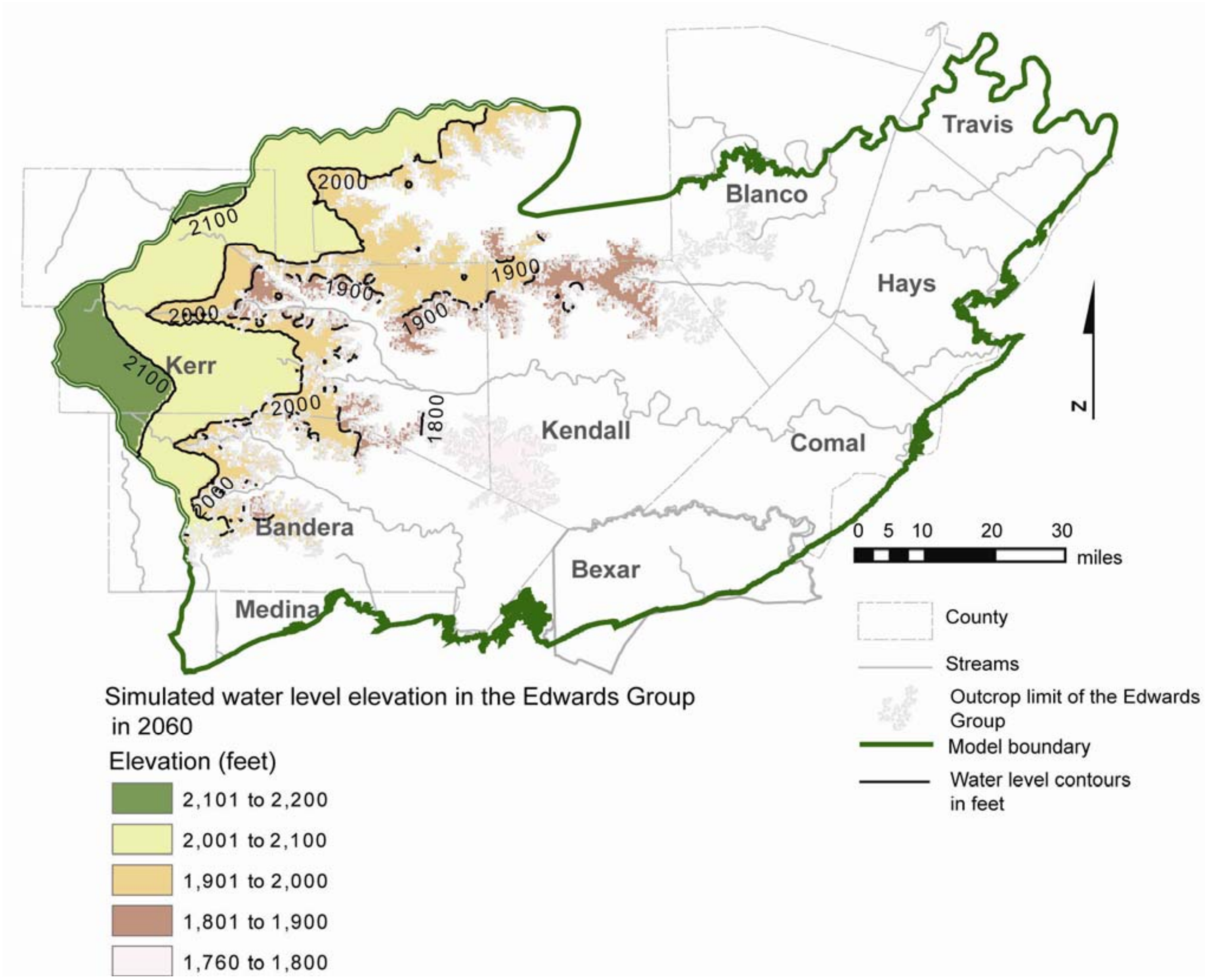

Figure 3. Water level elevations in the Edwards Group after 60 years of maintaining the same pumpage as baseline condition. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note only slight changes in water level elevations at the end of the predictive period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

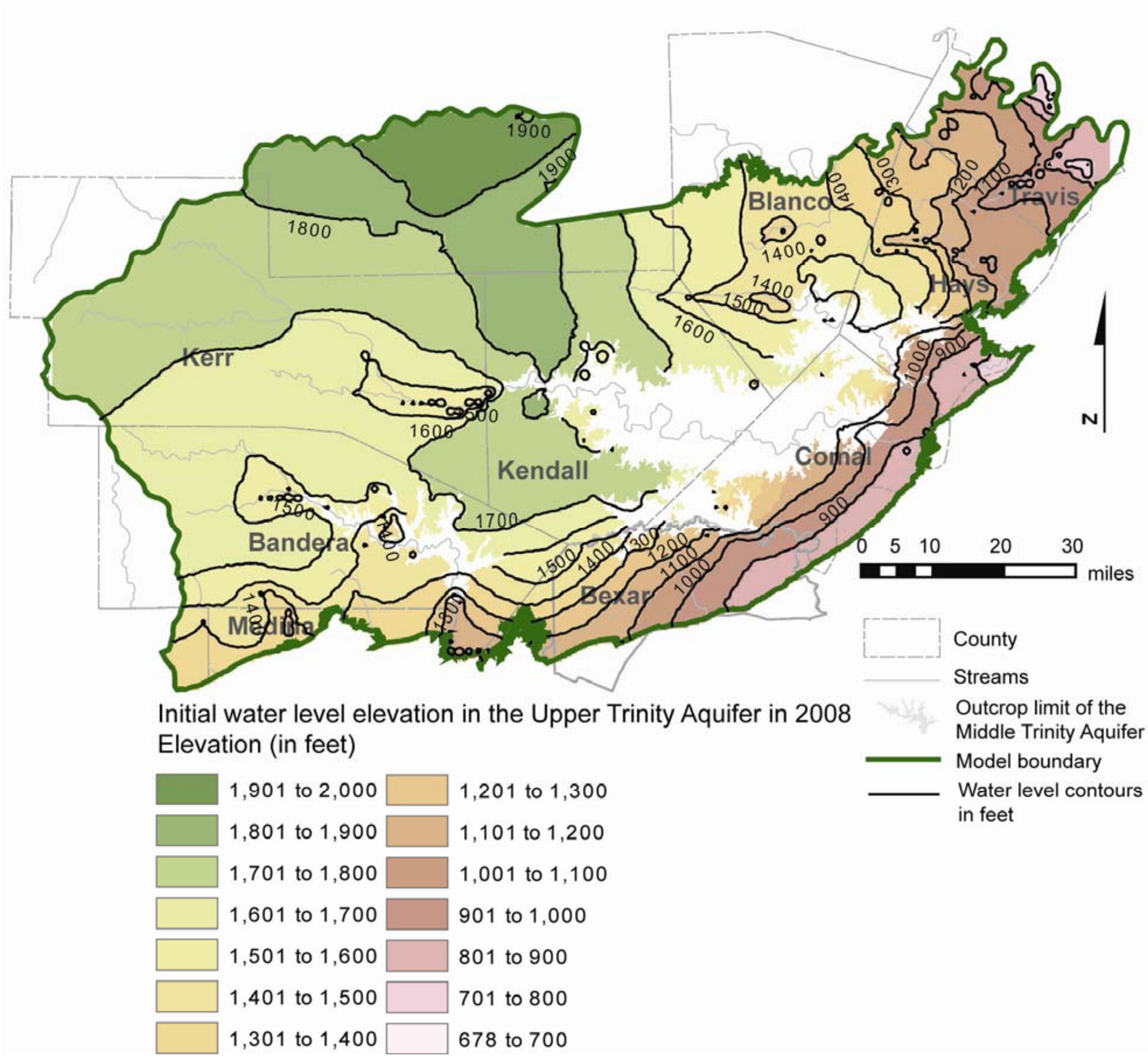

Figure 4. Initial water levels in the Upper Trinity Aquifer in 2008 for the beginning of the predictive period under baseline pumping from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Water level elevations are reported in feet above mean sea level. Contour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

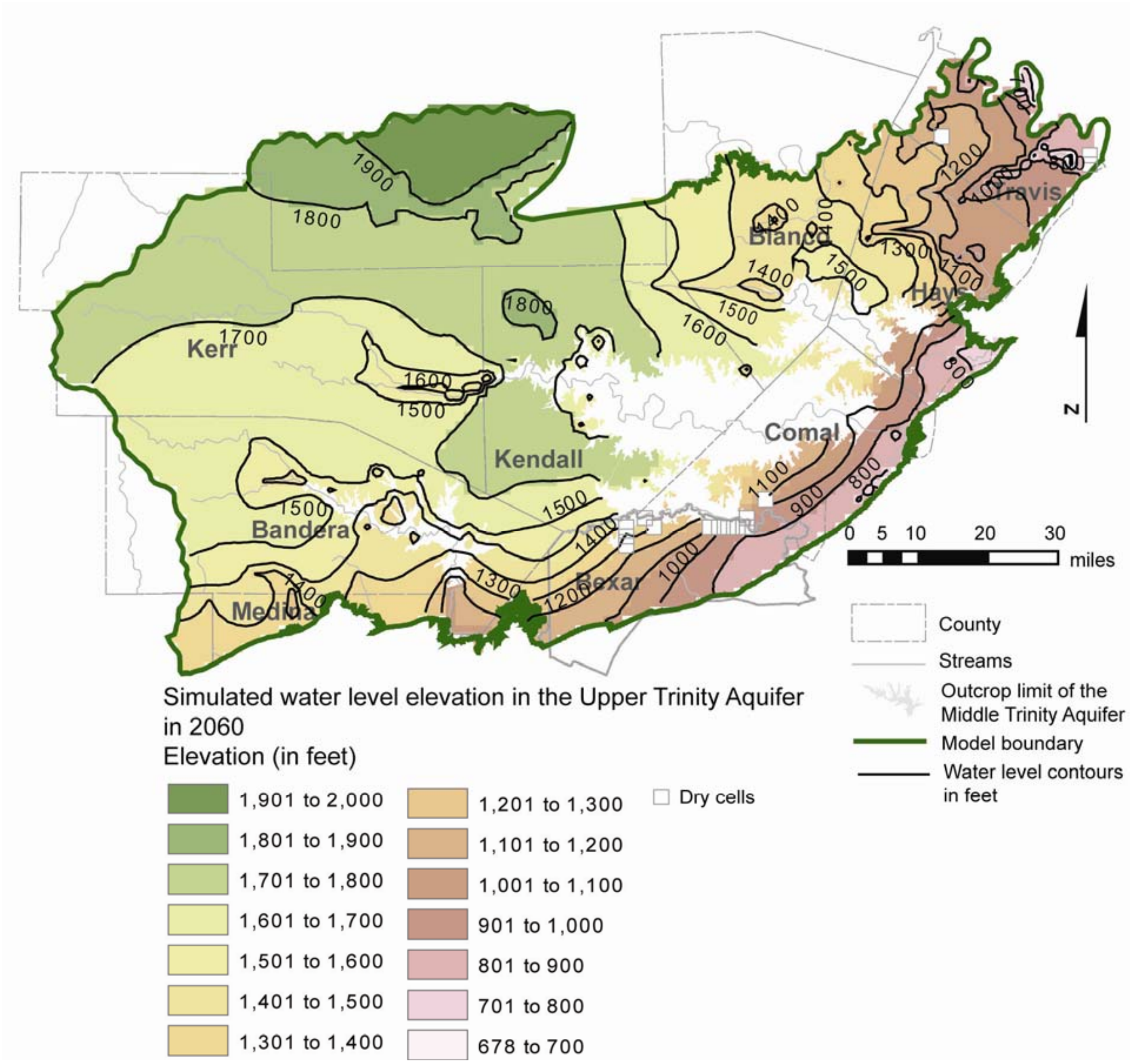

Figure 5. Water level elevations in the Upper Trinity Aquifer after 60 years of maintaining the same pumpage as baseline condition. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note changes to water level elevations in Gillespie, Kendall, Bexar, and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

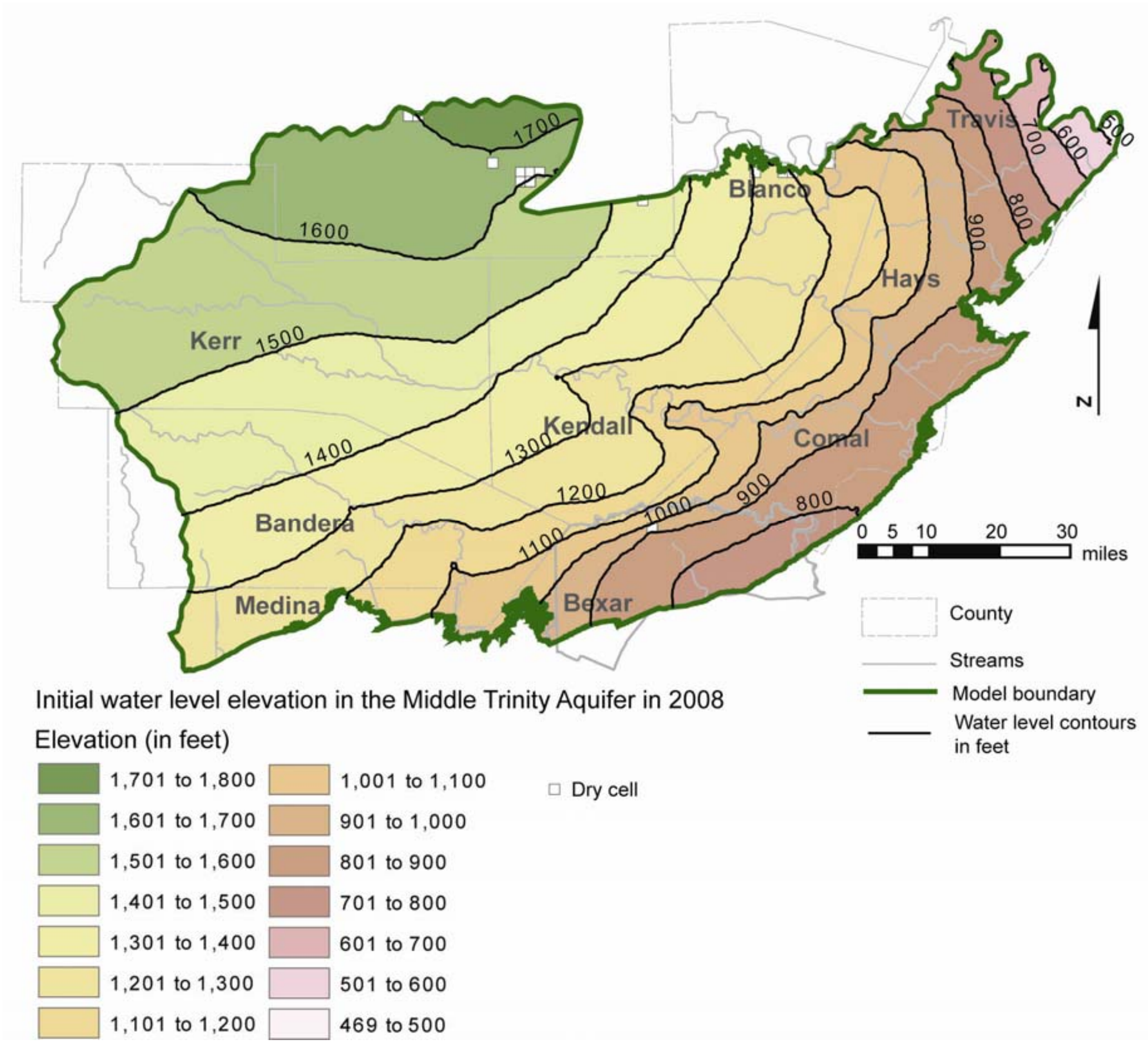

Figure 6. Initial water levels in the Middle Trinity Aquifer in 2008 for the beginning of the predictive period under baseline pumping condition from the groundwater availability model for the Hill Country portion of the Trinity Aquifer. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. 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.

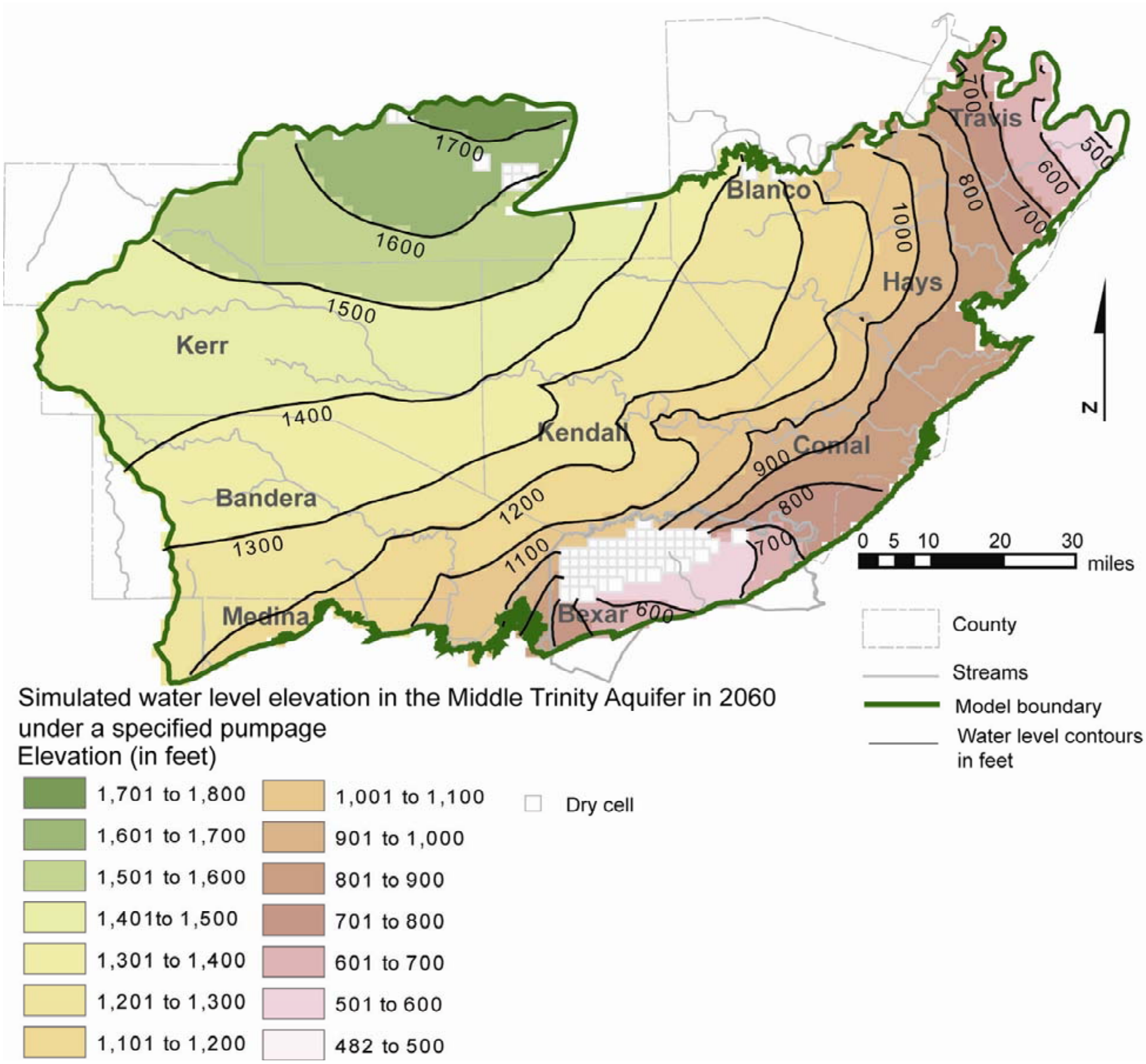

Figure 7. Water level elevations in the Middle Trinity Aquifer after 60 years using the adjusted specified pumpage. Water level elevations are reported in feet above mean sea level. Contour interval is 100 feet. Note several dry cells in Bexar, Kendall, and Gillespie counties. Note slight flattening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

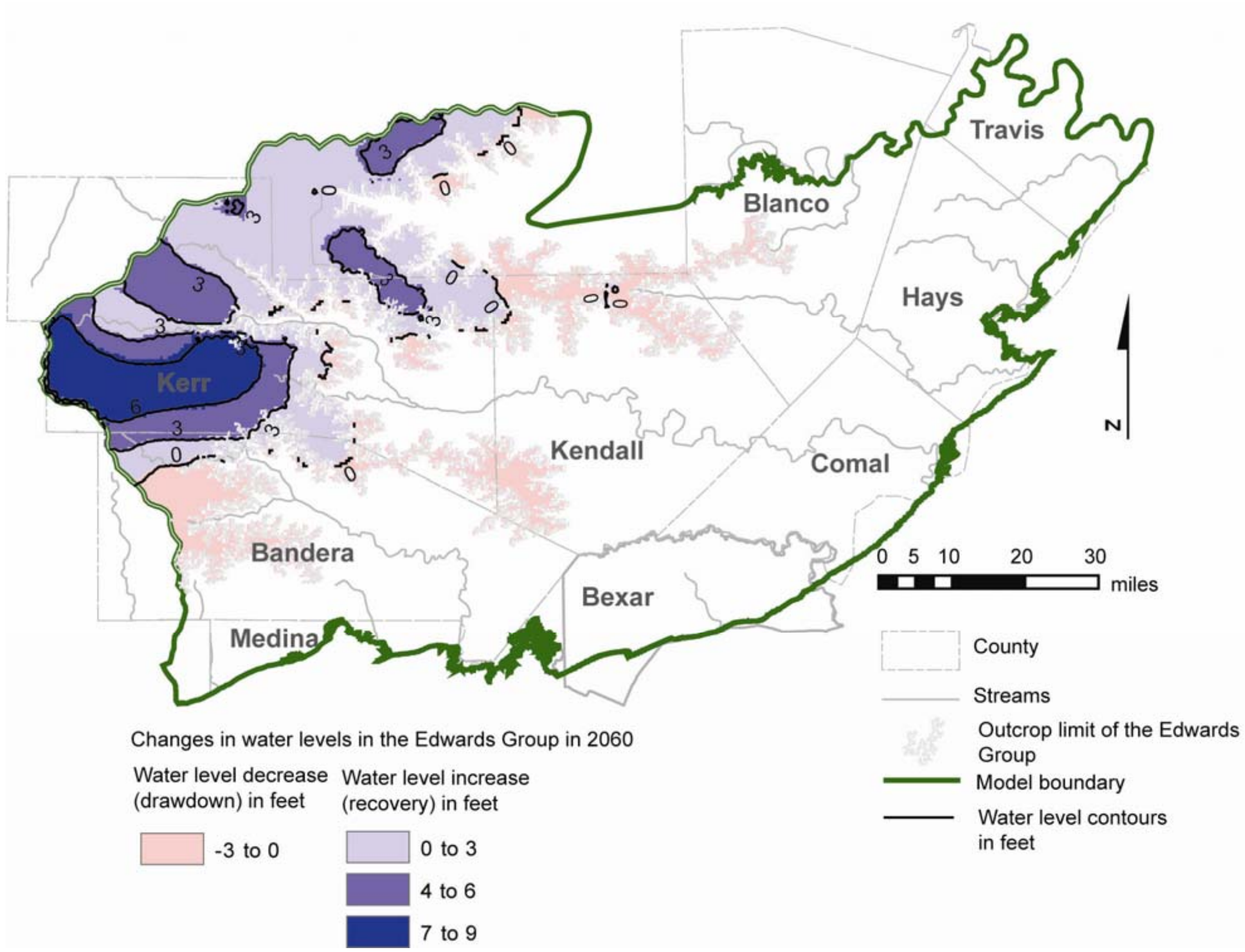

Figure 8. Changes in water levels after 60 years using the specified pumpage in the Edwards Group. Drawdown and water level recovery are reported in feet. Contour interval for drawdown is 3 foot and contour interval is 3 feet for water level recovery. Decreases in water levels are shown in red and increases are shown in blue.

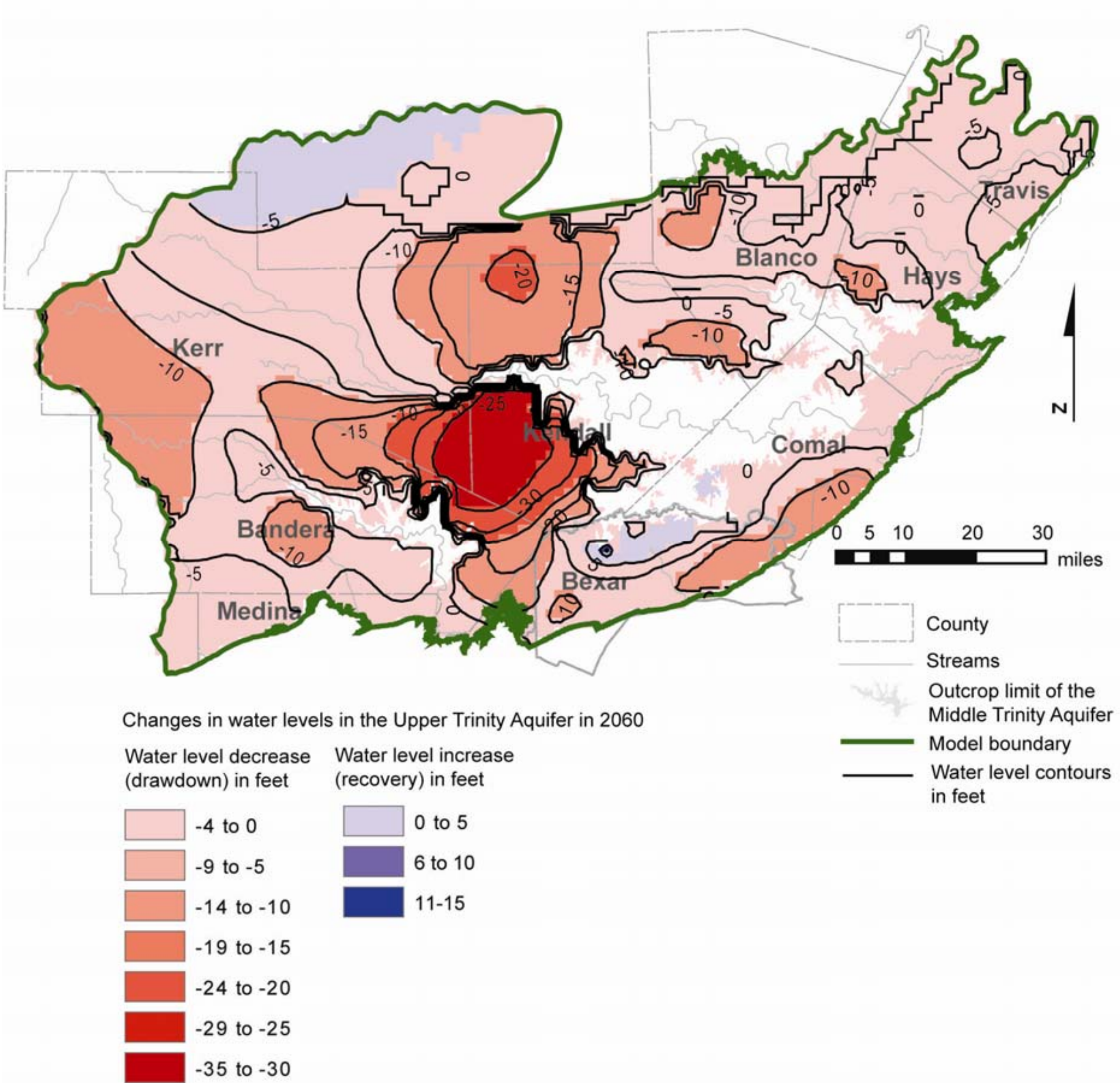

Figure 9. Changes in water levels after 60 years using the specified pumpage in the Upper Trinity Aquifer. Drawdowns and water level recovery are reported in feet. Contour interval for drawdown is 5 feet. Decreases in water levels are shown in red and increases are shown in blue.

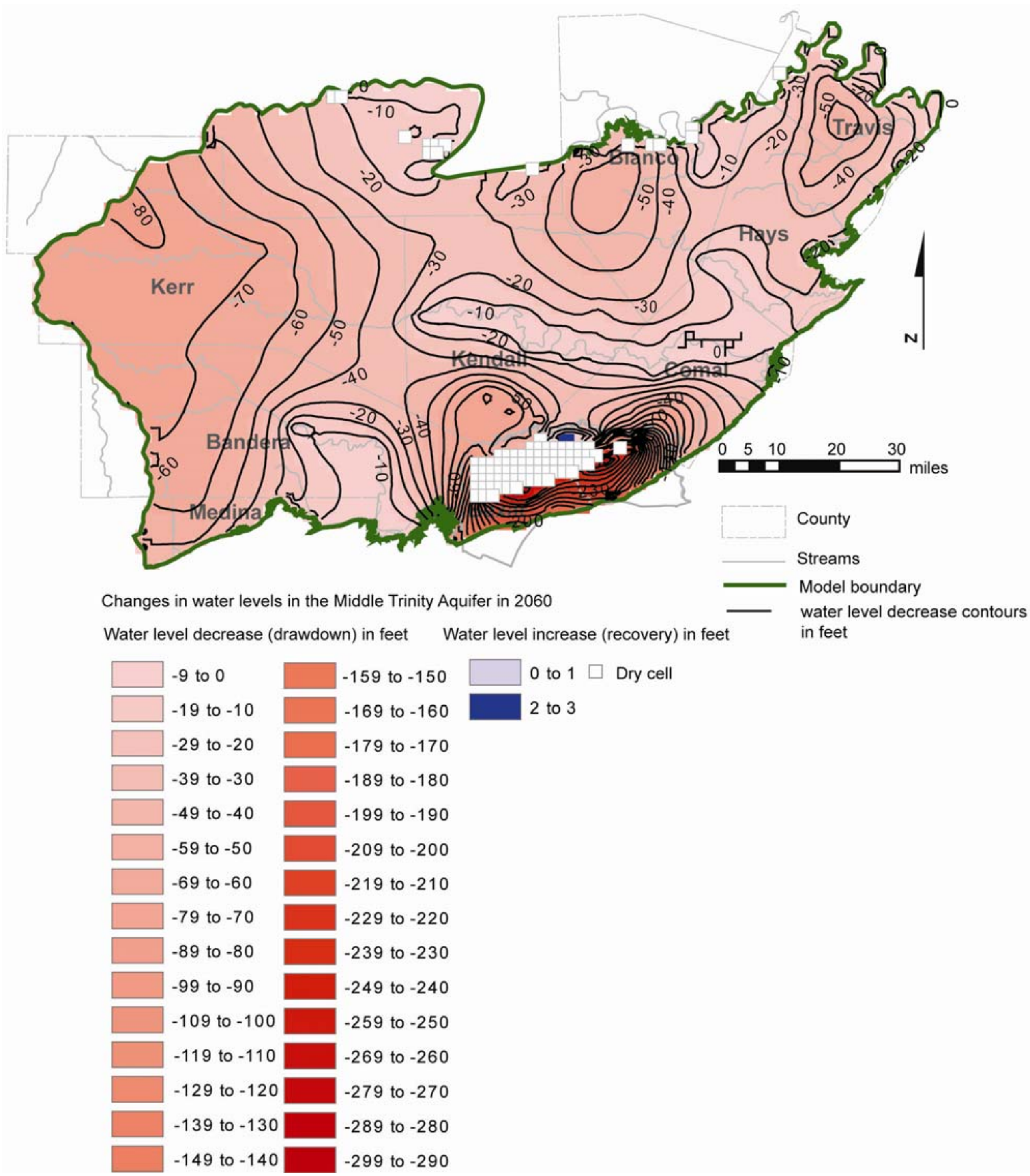

Figure 10. Changes in water levels after 60 years using the specified pumpage in the Middle Trinity Aquifer. Drawdowns are in feet. Contour interval is 10 feet. Decreases in water levels are shown in red. Increases in water levels for two cells in the northwestern parts of Bexar County are shown in blue. Numerous dry cells occur in Bexar County. 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 of an average of about 34 feet for the Middle Trinity Aquifer in Blanco, Bandera, Kendall, and Kerr counties; 15 feet in Comal, Hays and Travis counties; and 44 feet in Bexar and Medina counties. 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 (Bandera, Kendall, and Kerr)	**+1**	**-3**	**+5**
Upper Trinity Aquifer			
Bandera	-8	-32	0
Bexar	-3	-14	+11
Blanco	-3	-11	0
Comal	-2	-14	0
Hays	-2	-11	0
Kendall	-12	-35	0
Kerr	-8	-34	+2
Medina	-2	-15	0
Travis	-2	-20	0
Average (Bandera, Bexar, Blanco, Comal, Hays, Kendall, Kerr, Medina, and Travis)	**-5**	**-20**	**+1**
Middle Trinity Aquifer			
Bandera	-38	-82	0
Blanco	-18	-59	0
Kendall	-31	-82	0
Kerr	-51	-81	0
Average (Bandera, Blanco, Kendall, and Kerr)	**-34**	**-76**	**0**
Comal	-18	-174	0
Hays	-12	-46	0
Travis	-14	-54	0
Average (Comal, Hays, and Travis)	**-15**	**-91**	**0**
Bexar*	-69	-299	+3
Medina	-18	-126	0
Average (Bexar and Medina)	**-44**	**-212**	**+1**

* DISCLAIMER: Numerous dry cells occur in Bexar County in this model run that were not considered in the reported water level decline calculations; therefore, the reported water level decline may not be representative of actual groundwater conditions for Bexar County. Recent studies show that up to about 80,000 acre-feet of groundwater may annually recharge through

infiltration of streamflow in the Cibolo Creek area and diffuse infiltration through adjacent soils and rock (Ockerman, 2007), which was not considered during model simulation.

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. 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 drains also represent discharge from the aquifer to rivers.

- 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. The storage component that is included in “Inflow” is water that is removed from storage in the aquifer (that is, water levels decline). The storage component that is included in “Outflow” is water that is added back into storage in the aquifer (that is, water levels increase).

The water budgets included in Appendix 1 are for 2008 and 2060. This comparison of water budget results for 2008 and 2060 indicates how the amount 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 only show less than 1 to 12 percent decrease between 2008 and 2060 due to application of a constant pumpage through the 60 year simulation period (Appendix 1). However, baseflow and spring discharges for the rivers that flow over the Edwards Group in Kerr County show about 4 percent 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. Water budget results for the Middle Trinity Aquifer show considerable decrease for various components of flow to compensate for a substantial increase in pumpage in the aquifer (Appendix 1). Baseflow discharges into the rivers that flow over the Middle Trinity Aquifer decrease from 10 to about 80 percent in several areas including Travis, Bandera, Kendall, Comal, and Hays counties (Appendix 1). Spring discharge in the Middle Trinity Aquifer also decreases by as much as 68 percent in Kendall County and 20 percent in Hays County. However, it must be noted that water budget results reported for spring discharge are based on 14 springs explicitly represented in the model. The rivers in the area are largely fed by baseflow and discharge 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).

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:

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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.

Ockerman, D. J., 2007, Simulation of streamflow and estimation of groundwater recharge in the Upper Cibolo Creek watershed, south central Texas, U.S. Geological Survey Scientific Investigations Report 2007-5202, 31 p.

The seal appearing on this document was authorized by Ali H. Chowdhury, P.G., on August 19, 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. 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	2,364	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	12,877
		Recharge	11,588	0	11,588	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	13,958	13,960	13,952	13,953
Upper Trinity	Bandera	Storage	1,763	1	0	0
		Lakes/reservoirs (Constant Head)	2	2,586	2	2,464
		Lateral flow	5,692	10,147	5,057	9,396
		Vertical flow (upward)	458	0	459	0
		Vertical flow (downward)	18	14,147	0	13,621
		Pumping	0	270	0	270
		Rivers (Drain)	0	13,403	0	12,458
		Recharge	33,368	0	33,368	0
		Balcones Fault Zone (General Head Boundary)	14	402	19	357
		Springs (Drain)	0	359	0	339
		Total	41,314	41,315	38,905	38,904
Middle Trinity	Bandera	Storage	1,804	0	22	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	8,672	11,713	7,558	11,701
		Vertical flow (upward)	14,147	18	13,621	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	3,347	0	6,398
		Rivers (Drain)	0	12,694	0	7,452
		Recharge	4,432	0	4,432	0
		Balcones Fault Zone (General Head Boundary)	222	1,520	435	874
		Total	29,277	29,292	26,068	26,424

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	3,423	1,798
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	7,931	0	7,862
		Pumping	0	77	0	77
		Rivers (Drain)	0	13,745	0	12,867
		Recharge	19,175	0	19,175	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	23,647	23,659	22,598	22,604
Middle Trinity	Blanco	Storage	902	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	4,904	8,993	4,227	7,526
		Vertical flow (upward)	7,931	0	7,862	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	1,469	0	4,406
		Rivers (Drain)	0	12,443	0	9,322
		Recharge	9,206	0	9,206	0
		Balcones Fault Zone (General Head Boundary)	197	197	0	0
		Springs (Drain)	0	30	0	23
		Total	23,140	23,132	21,295	21,277
Upper Trinity	Comal	Storage	546	2	0	0
		Lakes/reservoirs (Constant Head)	174	254	205	225
		Lateral flow	1,825	2,611	1,772	2,553
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	61	3,674	49	3,697
		Pumping	0	473	0	473
		Rivers (Drain Package)	0	1,005	0	927
		Recharge	14,479	0	14,479	0
		Balcones Fault Zone (General Head Boundary)	0	9,066	0	8,629
		Total	17,084	17,084	16,504	16,504

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	3,042	3,237
		Lateral flow	9,411	9,924	7,488	9,058
		Vertical flow (upward)	3,674	61	3,697	49
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,741	0	9,144
		Rivers (Drain Package)	0	6,818	0	5,348
		Recharge	13,278	0	13,278	0
		Balcones Fault Zone (General Head Boundary)	0	3,044	775	1,445
		Total	29,696	29,696	28,279	28,279
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	5,489
		Pumping	0	551	0	551
		Rivers (Drain)	0	5,081	0	4,917
		Recharge	12,629	0	12,629	0
		Balcones Fault Zone (General Head Boundary)	0	1,218	0	1,136
		Springs (Drain)		0		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	1,130	3,323
		Lateral flow	3,181	144	2,962	100
		Vertical flow (upward)	5,620	0	5,489	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,104	0	7,884
		Rivers (Drain)	0	619	0	107
		Recharge	2,515	0	2,456	0
		Balcones Fault Zone (General Head Boundary)	0	1,092	0	627
		Total	12,422	12,431	12,037	12,040

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	1,719	8,441
		Vertical flow (upward)	43	6	49	1
		Vertical flow (downward)	8	15,728	0	15,142
		Pumping	0	307	0	307
		Rivers (Drain)	0	5,183	0	4,511
		Recharge	26,627	0	26,627	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	30,676	30,679	28,395	28,402
Middle Trinity	**Kendall**	**Storage**	1,859	0	2	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	9,205	12,810	7,299	9,757
		Vertical flow (upward)	15,728	8	15,142	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	5,546	0	10,395
		Rivers (Drain)	0	24,500	0	18,851
		Recharge	16,761	0	16,761	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Springs (Drain)		690	0	222
		Total	43,553	43,554	39,203	39,225

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	3,254	2,537
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	53	7,923	31	7,802
		Pumping	0	408	0	408
		Rivers (Drain Package)	0	15,309	0	14,847
		Recharge	24,929	0	24,929	0
		Balcones Fault Zone (General Head Boundary)	14	2,688	16	2,569
		Springs (Drain)		81	0	68
		Total	29,005	29,006	28,230	28,231
Middle Trinity	**Hays**	**Storage**	440	49	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	9,059	7,159	8,045	6,446
		Vertical flow (upward)	7,923	53	7,802	31
		Vertical flow (downward)	0	0	0	0
		Pumping	0	4,273	0	6,687
		Rivers (Drain Package)	0	8,738	0	6,782
		Recharge	5,802	0	5,802	0
		Balcones Fault Zone (General Head Boundary)	0	2,509	51	1,397
		Springs (Drain)		450		363
		Total	23,224	23,231	21,701	21,706
Edwards Group	**Kerr**	**Storage**	23	1,330	0	7
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	2,761	4,266	2,877	4,590
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	3,401	0	3,487
		Pumping	0	1,036	0	1,036
		Rivers (Drain)	0	21,248	0	22,189
		Recharge	29,478	0	29,478	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Drains (Springs)		986		1,041
		Total	32,262	32,266	32,355	32,351

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	2,738	1,641
		Vertical flow (upward)	3,401	0	3,487	0
		Vertical flow (downward)	10	8,507	0	8,718
		Pumping	0	213	0	213
		Rivers (Drain)	0	13,704	0	12,425
		Recharge	16,771	0	16,771	0
		Balcones Fault Zone (General Head Boundary)	0	0	0	0
		Total	24,325	24,327	22,996	22,996
Middle Trinity	**Kerr**	**Storage**	1,786	0	57	0
		Lakes/reservoirs (Constant Head Package)	0	0	0	0
		Lateral flow	4,384	8,455	4,443	6,632
		Vertical flow (upward)	8,507	10	8,718	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	6,259	0	7,386
		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	13,218	14,019
Upper Trinity	**Medina**	**Storage**	216	0	0	0
		Lakes/reservoirs (Constant Head)	1	3,580	1	3,448
		Lateral flow	7,039	3,619	6,673	3,415
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	20	1,084	0	1,217
		Pumping	0	43	0	43
		Rivers (Drain)	0	2,032	0	1,959
		Recharge	7,805	0	7,805	0
		Balcones Fault Zone (General Head Boundary)	128	4,850	141	4,539
		Total	15,209	15,209	14,621	14,621

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	9,997	6,631
		Vertical flow (upward)	1,084	20	1,217	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	360	0	2,884
		Rivers (Drain)	0	0	0	0
		Recharge	0	0	0	0
		Balcones Fault Zone (General Head Boundary)	214	6,913	1,801	3,521
		Total	11,256	11,256	13,016	13,035
Upper Trinity	Bexar	Storage	623	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	6,160	1,642	5,577	1,591
		Vertical flow (upward)	0	0	0	0
		Vertical flow (downward)	0	1,731	0	1,699
		Pumping	0	924	0	916
		Rivers (Drain Package)	0	2,354	0	1,905
		Recharge	10,242	0	10,193	0
		Balcones Fault Zone (General Head Boundary)	0	10,374	0	9,659
		Total	17,025	17,025	15,771	15,771
Middle Trinity	Bexar	Storage	3,441	0	0	0
		Lakes/reservoirs (Constant Head)	0	0	0	0
		Lateral flow	11,981	1,194	12,888	634
		Vertical flow (upward)	1,731	0	1,699	0
		Vertical flow (downward)	0	0	0	0
		Pumping	0	16,893	0	26,232
		Rivers (Drain)	0	0	0	0
		Recharge	1,638	0	1,348	0
		Balcones Fault Zone (General Head Boundary)	129	834	10,933	0
		Total	18,920	18,920	26,868	26,867