GAM Run 08-83

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EXECUTIVE SUMMARY:

Additional data analyses and discussion of results for GAM Run 08-64 are presented in this report. These additional analyses indicate that the greatest change in recharge, which is the largest component of the water budget, coincides with the simulated drought of record. The largest decrease in recharge beneath Comanche County occurs in the Hensell Aquifer where recharge conditions are purposely reduced (approximately 7,503 acre-feet per year, or 36 percent of the recharge for average conditions) in the Hensell Aquifer to simulate conditions from 1954 through 1956. Although a portion of this may be attributable to cells that converted to dry, the majority is due to the simulated drought. This is nearly double the pumpage quantities removed for Comanche County due to the conversion of cells to dry (3,994 acre-feet per year). The largest decrease in recharge beneath Erath County occurs in the Paluxy Aquifer and coincides with the simulated drought of record with a decrease of approximately 18,122 acre-feet per year, or 60 percent of recharge during average conditions. Prior to the simulated drought of record, recharge remains steady in the Paluxy Aquifer, Glen Rose Formation, Hensell Aquifer, and Hosston Aquifer, with no decrease in recharge due to the conversion of cells to dry.

REQUESTOR:

Ms. Cheryl Maxwell (of the Clearwater Underground Water Conservation District) a representative of Groundwater Management Area 8.

DESCRIPTION OF REQUEST:

Ms. Maxwell requested an addendum to GAM Run 08-64 that addresses the following:

Task 1 – Additional Data Analyses

- total number of dry cells in Comanche, Erath, and other counties at the beginning of 2000 and at 5-year increments thereafter;
- amount of pumping removed from the water budget in each county based on cells that converted to dry during the simulation;
- map of cells that converted to dry during the simulation;
- map showing the thickness of the potentiometric surface at the beginning of 2000 and at the conclusion of 2060;
- an explanation of how cells that convert to dry are included in the average drawdown calculations;

- calculation of average drawdown at 5-year increments for Erath and Comanche counties; and
- water budget calculations at 5-year increments for Erath and Comanche counties.

Task 2 – Additional Discussion of Results

- include a discussion of the possible and probable reasons for cells that converted to dry during the simulation in Comanche, Erath, and other counties;
- include a discussion of the likelihood that water levels will drop below the bottom of the aquifer;
- include a discussion on the changes in the water budget and drawdown over time with regard to groundwater availability and sustainability;
- include a discussion on the reliability of the model predictions and implications for future groundwater monitoring in areas where groundwater resources have been significantly depleted; and
- identify potential areas of concern with the groundwater availability model for the northern portion of the Trinity Aquifer System that could limit its availability to accurately estimate managed available groundwater from desired future conditions for specific counties.

METHODS:

The groundwater availability model for the northern portion of the Trinity Aquifer System and the pumping specifications provided by Groundwater Management Area 8 for GAM Run 08-64 (Hill, 2010a) were applied in these analyses. Specific details for GAM Run 08-64 are provided in Hill, 2010a. For this addendum, the predictive simulation extends from 2000 through 2060 (60-year predictive simulation), whereas GAM Run 08-64 consisted of 50 stress periods (years) and assumed differences between the 50 and 60-year predictive scenarios would not significantly affect the simulated results as is confirmed in this addendum. Data was extracted from the model simulation at 5 year increments and analyzed using ERSI ArcGIS software and Microsoft Office products.

PARAMETERS AND ASSUMPTIONS:

The groundwater availability model for the northern portion of the Trinity Aquifer System was used for this model run. A brief description of the model and caveats are listed below:

- version 1.01 of the groundwater availability model for the northern portion of the Trinity Aquifer System was used for this model run. See Bené and others (2004) for a detailed discussion of assumptions and limitations for the model;

- Groundwater Vistas (Environmental Simulations, Inc., 2007) version 5.30 build 10 was used as the interface to process model output;

- the groundwater availability model grid files (trnt_n_grid_poly), version 111808, were used to process model output;

- the 1999 spatial distribution of pumpage used with the calibrated historic model was used to generate pumpage for the predictive simulation. Pumpage was increased or decreased per specifications provided by Groundwater Management Area 8 (Hill, 2010a). Changes in pumpage between 2000 and 2010 are assumed to not significantly affect the predictive simulation’s results;

- the model includes seven layers, representing the Woodbine Aquifer (layer 1), the Washita and Fredericksburg Groups (layer 2), the Paluxy Aquifer (layer 3), the Glen Rose Formation (layer 4), the Hensell Aquifer (layer 5), the Pearsall/Cow Creek/Hammett/Sligo Members (layer 6), and the Hosston Aquifer (layer 7). The Woodbine Aquifer, Paluxy Aquifer, Hensell Aquifer, and Hosston Aquifer are the most productive water-bearing strata in the region;

- average annual recharge conditions based on climate data from 1980 to 1999 was used for the simulation. The last three years of the simulation used the drought-of-record recharge conditions, which were defined as the years from 1954 through 1956;

- the MODFLOW-96 groundwater flow simulator was used for this model run. MODFLOW-96 does not simulate three-dimensional, variable density groundwater flow that may arise in aquifers containing both fresh and non-fresh groundwater (such as the Woodbine Aquifer, Paluxy Aquifer, Hensell Aquifer, and Hosston Aquifer). See Bené and others (2004) for a detailed discussion on water quality in the aquifers;

- the Strongly Implicit Procedure (SIP) solver was used with MODFLOW-96. Therefore, model cells convert to dry when simulated water levels drop below the bottom of the model cell. Model cells that convert to dry during the simulation are removed from the groundwater flow calculations performed by MODFLOW-96 (Harbaugh and McDonald, 1996); and

- it should be noted that because the model is an approximation of reality (Anderson and Woessner, 2002) the calculated average changes in water levels and the water budget are approximations.

RESULTS:

Task 1 – Additional Data Analyses

Table 1 shows the number of cells that converted to dry at 5-year increments during the 60-year predictive simulation. The counties with the maximum number of cells converting to dry during the predictive simulation were Comanche County with a total of 52 dry cells, followed by Burnet County with 20 dry cells, and Lampasas County with 11 dry cells. The quantity of pumpage removed during the predictive simulation at 5-year increments due to cells converting to dry is provided in Table 2. The maximum quantities of pumpage removed due to cells converting to dry are 3,994 acre-feet per year for Comanche County, followed by Bosque County with 2,400 acre-feet per year, and Erath County with 2,293 acre-feet per year. The percent of pumpage removed at the conclusion of the predictive simulation relative to the specified total pumpage per county, indicates that Taylor County loses the largest percentage (37 percent) followed by Bosque County with 32 percent, and Comanche County with 16 percent (see Table 3). The increase in the percent of pumpage removed relative to the specified pumpage for Comanche County reported in Hill, 2010b (13 percent) and in this report (16 percent) is due to the increase in the predictive simulation from 50 to 60 years.

Figure 1 is a map with the locations of cells that converted to dry during the predictive simulation. Cells converted to dry primarily in the outcrop areas of the aquifers, but dry cells also occur in the subsurface areas underlying Tarrant, Johnson, and Bosque counties. Additionally, dry cells are located along the Coryell-Bell and Williamson-Travis county lines.

Figures 2 through 5 qualitatively show the thickness of the potentiometric surface relative to the base of the aquifer for the Woodbine Aquifer, Paluxy Aquifer, Hensell Aquifer, and the Hosston Aquifer at the start of the predictive simulation (2000) and at its conclusion (2060). A decrease in the thickness of the potentiometric surface, or a decrease in artesian head is predicted for the downdip portions of all four aquifers.

A quantitative summary of average water level changes in 5-year increments underlying Comanche and Erath counties for layers 3, 4, 5 and 7 is provided in Tables 4 and 5. Water level changes reported in Tables 4 and 5 were calculated as follows and represent the active areas of the aquifer footprint underlying a county:

- if the starting water levels for the predictive simulation did not convert to dry and the simulated water levels at the end of the 60-year predictive simulation did not convert to dry, then the difference between the starting water levels and simulated water levels at the end of the 60-year predictive simulation was calculated;

- if the starting water levels for the predictive simulation did not convert to dry, but the simulated water levels at the end of the 60-year predictive simulation converted to dry, then the difference between the starting water levels and the bottom elevation for cells that converted to dry was calculated; or

- if the starting water levels for the predictive simulation had converted to dry and the simulated water levels at the end of the 60-year predictive simulation remained dry (rewetting was not allowed), then these values were omitted from the county average water level changes reported in Tables 4 and 5.

Maximum decreases in average water level changes occurs in the Hosston Aquifer at the conclusion of the predictive simulation and coincides with the simulated drought of record and the maximum number of cells that convert to dry. Average water level decreases in the Hosston Aquifer underlying Comanche County are 11 feet and 27 feet for Erath County (1 foot greater than the average drawdown for the 50-year predictive simulation reported in GAM Run 08-64 (Hill, 2010a)).

Quantitative components of the water budget for Comanche and Erath counties at 5-year increments are shown in Appendix A. Components are divided into "in" and "out" and represent fluxes into and out of the aquifer footprint underlying each respective county. The calculated water budget is a summary of the groundwater flow simulator's (MODFLOW-96) calculations for water entering and leaving the model layers. Components of the water budget are described below:

- wells—refer to groundwater withdrawals. This component is shown as "out" in Appendix A, because the wells in the model for the northern portion of the Trinity Aquifer System withdraw (rather than inject) water. Wells are simulated using the MODFLOW Well Package. The pumpage reported in the water budget (Appendix A) will not match assigned total pumpage due to quantities removed for cells that converted to dry during the predictive simulation;

- recharge—represents the distributed precipitation falling on the outcrop areas. Recharge is shown as "in" in Appendix A. Recharge is simulated using the MODFLOW Recharge Package;

- evapotranspiration—accounts for water that flows out of an aquifer due to direct evaporation and plant transpiration. This component of the budget is shown as "out". Evapotranspiration is simulated using the MODFLOW Evapotranspiration Package. In the model for the northern portion of the Trinity Aquifer System, groundwater discharge via small seeps and springs and larger spring discharge to streams not specifically modeled by the Streamflow-Routing Package (abbreviated to Stream Package in Appendix A) are simulated using the Evapotranspiration Package (Bené and others, 2004);

- vertical leakage (upward or downward)—describes the vertical flow, or leakage, between two aquifers. Fluxes to an aquifer from an overlying or underlying aquifer are represented as "in" in Appendix A. Vertical leakage out of an aquifer are referred to as "out" in Appendix A;

- change in storage—refers to changes in the water stored within an aquifer. The storage component representing water that is removed from storage in the aquifer (that is, water level declines) is labeled as “in” in Appendix A. The storage component that is added back into storage within the aquifer (that is, water level increases) is labeled as “out” in Appendix A;

- lateral flow—describes lateral flow within an aquifer between a county and adjacent counties. Incoming flows are shown as “in” in Appendix A and outgoing flows are shown as “out”;

- rivers and streams—refer to water that flows between perennial rivers or streams and an aquifer. Flows into the aquifer and out of the stream are shown as “in” in Appendix A and flows out of the aquifer and into the stream are shown as “out” in Appendix A;

- reservoirs—refer to water that flows between reservoirs and an aquifer. Flows out of the reservoir and into the aquifer are shown as “in” in Appendix A. Flows out of the aquifer and into the reservoir are shown as “out” in Appendix A. Reservoirs are simulated using the MODFLOW River Package (Bené and others, 2004); and

- inter-aquifer flow—refers to fluxes between model cells with general-head boundaries. In the model for the northern portion of the Trinity Aquifer System, general head boundaries are used to simulate the flux of water between portions of the uppermost layer with the overlying mantle of younger deposits and between the model layers and the Colorado River (Bené and others, 2004). General head boundaries are simulated using the MODFLOW General Head Boundary (GHB) Package.

Table 1. Total number of model cells converted to dry at the beginning (2000) and at 5-year increments thereafter during the predictive simulation for Comanche, Erath and other counties. Only the counties for which model cells converted to dry are shown.

Year	Comanche	Erath	Bell	Bosque	Brown	Burnet	Coryell	Eastland	Johnson	Lampasas	Tarrant	Taylor	Williamson	Wise
2000	1	1	3	0	0	1	4	0	0	1	0	0	0	0
2005	1	1	3	0	0	2	4	1	0	2	0	0	0	0
2010	4	1	4	0	0	3	4	1	0	6	0	0	0	0
2015	7	1	5	0	0	4	4	1	0	6	0	0	1	0
2020	9	2	6	1	0	4	4	1	0	7	0	0	1	0
2025	14	3	6	1	0	6	5	2	0	7	0	0	1	0
2030	18	4	7	1	0	11	5	2	0	9	1	1	1	0
2035	23	6	7	1	0	11	5	3	0	9	1	1	1	1
2040	31	7	7	1	0	14	5	3	2	10	1	1	1	1
2045	35	7	7	1	0	15	5	3	4	10	1	1	1	1
2050	42	7	7	1	1	17	5	3	4	10	1	1	1	1
2055	46	7	7	1	1	19	5	3	5	11	1	1	1	1
2060	52	8	8	2	1	20	5	3	5	11	1	1	1	1

Table 2. Total pumping removed, reported in acre-feet per year per county, from the simulation at 5-year increments in response to cells converting to dry.

Year	Comanche	Erath	Bell	Bosque	Brown	Burnet	Coryell	Eastland	Johnson	Lampasas	Tarrant	Taylor	Williamson	Wise
2000	421	740	126	0	0	3	25	0	0	2	0	0	0	0
2005	421	740	126	0	0	5	25	31	0	5	0	0	0	0
2010	622	740	143	0	0	7	25	31	0	19	0	0	0	0
2015	887	740	183	0	0	9	25	31	0	19	0	0	114	0
2020	1,083	1,152	227	1,678	0	9	25	31	0	20	0	0	114	0
2025	1,497	1,169	227	1,678	0	13	32	98	0	20	0	0	114	0
2030	1,806	1,487	274	1,678	0	35	32	98	0	25	342	248	114	0
2035	2,121	2,018	274	1,678	0	35	32	140	0	25	342	248	114	209
2040	2,690	2,276	274	1,678	0	38	32	140	397	27	342	248	114	209
2045	2,925	2,276	274	1,678	0	41	32	140	802	27	342	248	114	209
2050	3,337	2,276	274	1,678	31	45	32	140	802	27	342	248	114	209
2055	3,629	2,276	274	1,678	31	53	32	140	1,021	28	342	248	114	209
2060	3,994	2,293	312	2,400	31	54	32	140	1,021	28	342	248	114	209

Table 3. Percent of pumpage removed due to cells converting to dry at the conclusion of the predictive simulation (2060) relative to specified pumpage per county. Specified pumpage is reported in acre-feet per year.

	Comanche	Erath	Bell	Bosque	Brown	Burnet	Coryell	Eastland	Johnson	Lampasas	Tarrant	Taylor	Williamson	Wise
Specified pumpage	25,000	30,000	9,144	7,509	2,085	3,602	3,770	4,853	21,081	3,176	19,615	679	6,321	8,414
Percent removed	16	8	3	32	1	1	1	3	5	1	2	37	2	2

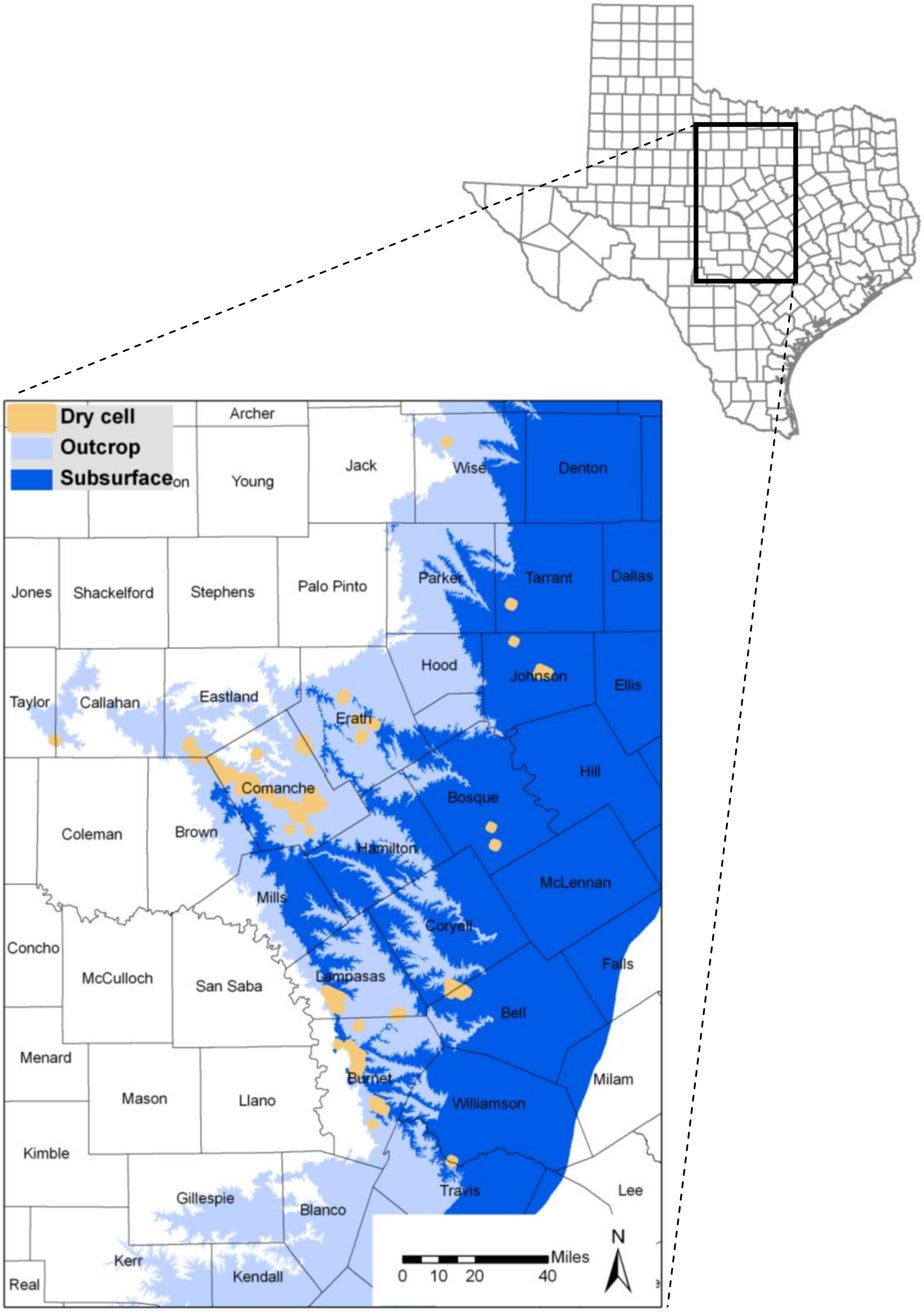


Figure 1. Map with location of model cells that converted to dry during the predictive simulation. Dry cells shown are a composite of layers containing dry cells.

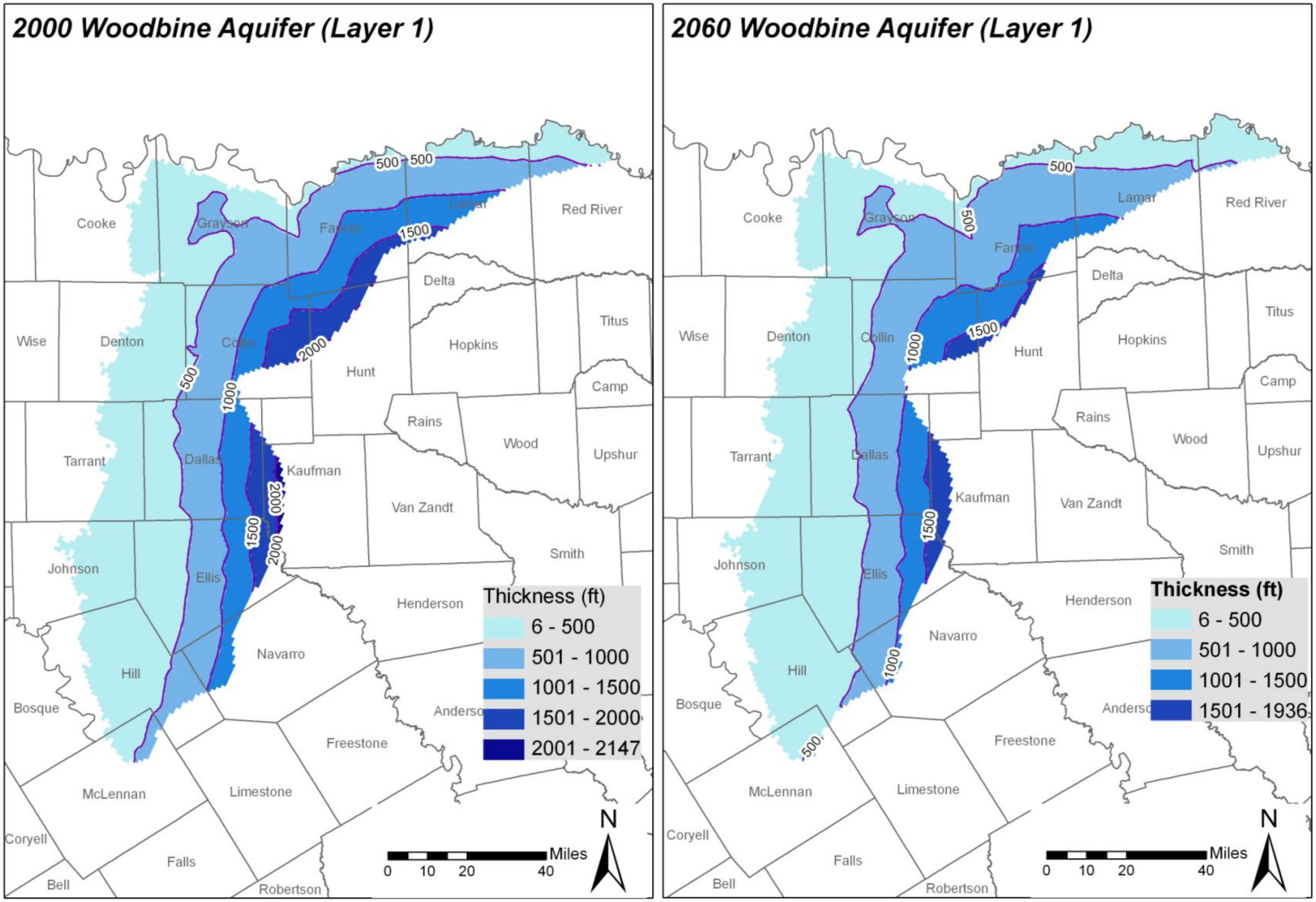


Figure 2. Thickness of the potentiometric surface for the Woodbine Aquifer, in feet, at the start of the predictive simulation (2000) and at its conclusion (2060).

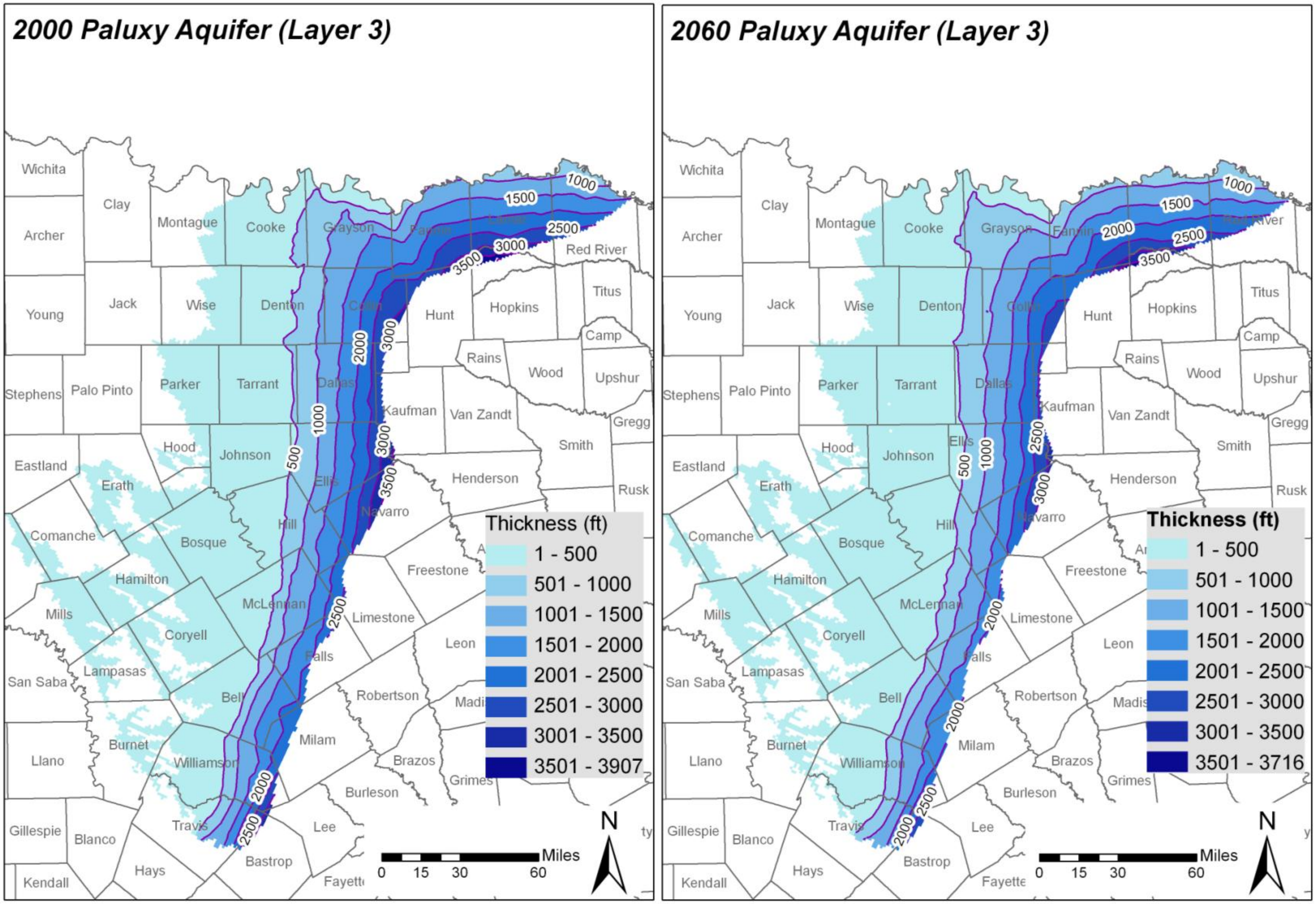


Figure 3. Thickness of the potentiometric surface for the Paluxy Aquifer, in feet, at the start of the predictive simulation (2000) and at its conclusion (2060).

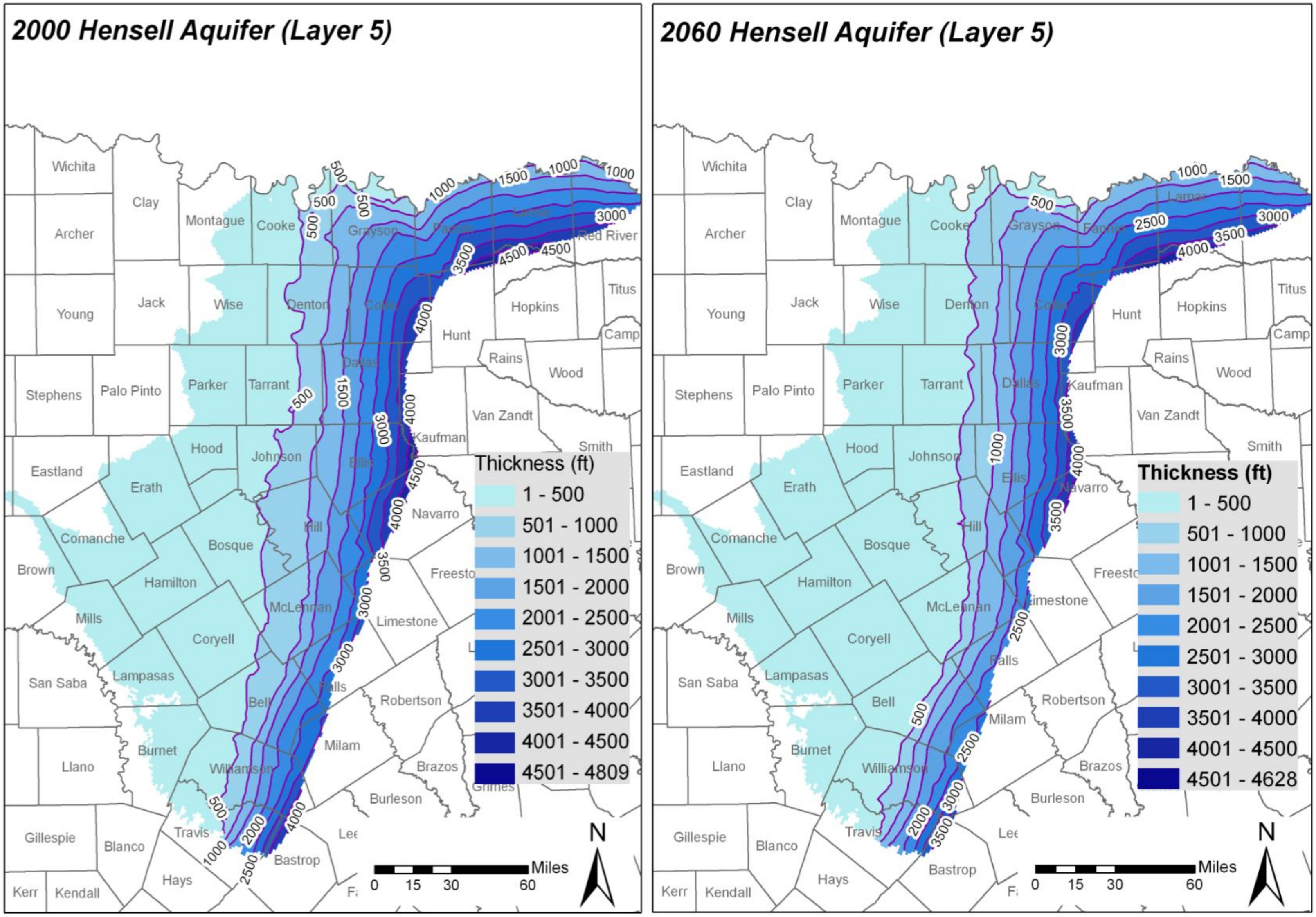
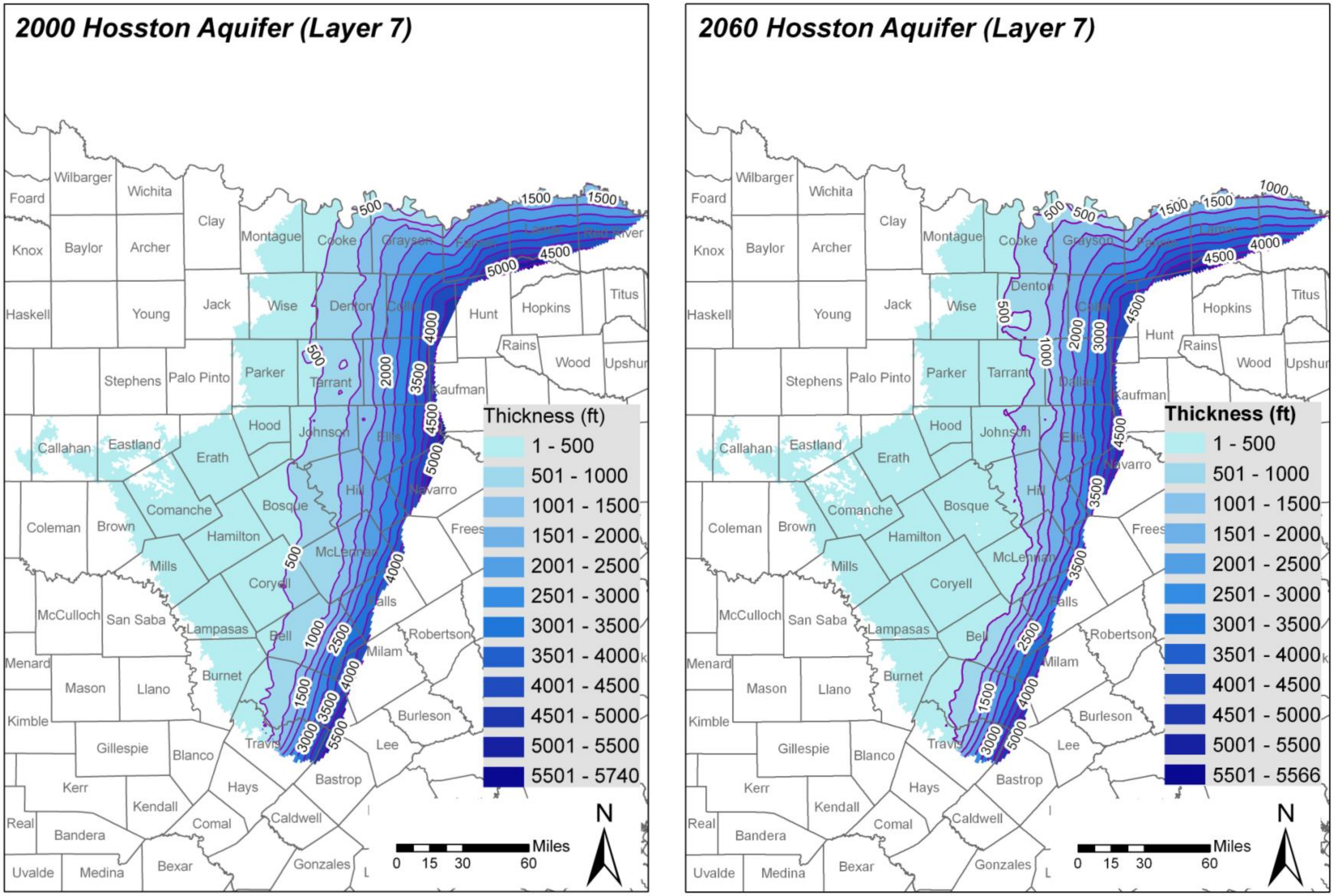


Figure 4. Thickness of the potentiometric surface for the Hensell Aquifer, in feet, at the start of the predictive simulation (2000) and at its conclusion (2060).



2000 Hosston Aquifer (Layer 7)

2060 Hosston Aquifer (Layer 7)

Figure 5. Thickness of the potentiometric surface for the Hosston Aquifer, in feet, at the start of the predictive simulation (2000) and at its conclusion (2060).

Table 4. Average water level changes (feet) in 5-year increments for Comanche County. Negative values indicate an average decrease in water levels.

Year	Comanche County			
	Paluxy Aquifer (Layer 3)	Glen Rose Formation (Layer 4)	Hensell Aquifer (Layer 5)	Hosston Aquifer (Layer 7)
2000	0	0	0	-2
2005	0	0	0	-3
2010	0	0	0	-4
2015	0	0	-1	-5
2020	0	0	-1	-6
2025	0	0	-1	-7
2030	0	0	-1	-7
2035	0	0	-2	-8
2040	0	0	-2	-9
2045	0	0	-2	-9
2050	0	0	-2	-10
2055	0	0	-2	-10
2060	0	0	-3	-11

Table 5. Average water level changes (feet) in 5-year increments for Erath County. Negative values indicate an average decrease in water levels.

Year	Erath County			
	Paluxy Aquifer (Layer 3)	Glen Rose Formation (Layer 4)	Hensell Aquifer (Layer 5)	Hosston Aquifer (Layer 7)
2000	0	0	-1	-10
2005	0	0	-3	-16
2010	0	0	-4	-19
2015	0	0	-5	-20
2020	0	0	-6	-21
2025	0	0	-7	-22
2030	0	0	-8	-23
2035	0	0	-9	-24
2040	-1	0	-9	-25
2045	-1	0	-10	-25
2050	-1	0	-11	-26
2055	-1	0	-12	-27
2060	-1	-1	-13	-27

Task 2 – Additional Discussion of Results

A cell converts to dry when the simulated water level drops below the cell's bottom elevation. The cell is then deactivated if rewetting is not permitted. That is, pumpage, recharge, as well as other components, are removed from the calculated water budget.

Bené and others (2004) report that aquifer depletion in the outcrop areas is plausible and therefore, they did not permit rewetting. The majority of cells that converted to dry during the predictive simulation are located in the outcrop areas. Bené and others (2004) note that the probable reasons for these cells converting to dry is due to the interaction between several factors: such as pumpage, aquifer properties, and the relatively thin saturated thickness of the model cells. If concentrated pumpage is the primary factor for a cell converting to dry, the model may be indicating that local pumping is too high.

Model cells that convert to dry also occur in the subsurface aquifer portions underlying Tarrant, Johnson, and Bosque counties. Additionally, dry cells occur along the Coryell-Bell and Williamson-Travis county lines. Concentration of pumpage and aquifer properties, are more probable reasons for cells converting to dry, as these portions of the aquifers are relatively thicker than the outcrop portions.

Technically, strata that compose an aquifer will retain some groundwater. For practical purposes however, an aquifer may become an uneconomical resource if water levels drop below the open interval of wells. In reality, the aquifer will probably not go dry because pumping will become uneconomical before the aquifer is fully dewatered in any particular area.

The U.S. Geological Survey is developing a solver that applies a Newton Raphson iteration scheme that is purported to resolve some of the issues related to the conversion of cells to dry. This new tool however, is not scheduled for release until later in 2009 (Niswonger, 2009).

Recharge and evapotranspiration are the largest components of the water budget for Comanche and Erath counties as shown in Appendix A. The largest decrease in recharge beneath Comanche County occurs in the Hensell Aquifer and coincides with the simulated drought of record, where recharge conditions are purposely reduced (approximately 7,503 acre-feet per year, or 36 percent of the recharge for average conditions in the Hensell Aquifer, see Appendix A) to simulate conditions from 1954 through 1956. Although a portion of this may be attributable to cells that converted to dry, the majority is due to the simulated drought. This is nearly double the pumpage quantities removed due to the conversion of cells to dry (3,994 acre-feet per year) for Comanche County. Prior to the simulated drought of record, recharge remained steady in the Paluxy Aquifer, Glen Rose Formation, and Hensell Aquifer. Decreases of approximately 76 acre-feet per year occur in the Hosston Aquifer, prior to the simulated drought of record, due to the conversion of cells to dry.

Evapotranspiration quantities beneath Comanche County are more variable relative to recharge during the predictive simulation. The maximum decrease (5,683 acre-feet per year) coincides with the simulated drought of record and occurs in the Hensell Aquifer. Prior to the drought of record, the largest difference between minimum and maximum values beneath Comanche County was approximately 909 acre-feet per year and occurs in the Hensell Aquifer (see Appendix A).

The percent of pumpage removed due to cells converting to dry relative to specified quantities for Comanche County begins at 2 percent at the conclusion of the first stress period for the predictive simulation and increases to a maximum of 16 percent during the simulated drought of record at the conclusion of the predictive simulation (calculated using values from Tables 2 and 3).

The largest decrease in recharge beneath Erath County occurs in the Paluxy Aquifer and coincides with the simulated drought of record. A decrease of approximately 18,122 acre-feet per year, or 60 percent of recharge during average conditions, see Appendix A. Prior to the simulated drought of record, recharge remains steady in the Paluxy Aquifer, Glen Rose Formation, Hensell Aquifer, and Hosston Aquifer, with no decrease in recharge due to the conversion of cells to dry.

Evapotranspiration quantities are more variable relative to recharge during the predictive simulation. The maximum decrease (14,567 acre-feet per year) occurs in the Paluxy Aquifer and coincides with the simulated drought of record. Prior to the drought of record, the largest difference between minimum and maximum values beneath Erath County is 1,681 acre-feet per year and occurs in the Paluxy Aquifer (see Appendix A).

The percent of pumpage removed due to cells converting to dry relative to specified pumpage for Erath County begins at 2 percent at the conclusion of the first stress period for the predictive simulation and increases to a maximum of 8 percent during the simulated drought of record at the conclusion of the predictive simulation (calculated using values from Tables 2 and 3).

Development of a long-term observation monitoring program in areas where groundwater resources may become significantly depleted would provide useful information to the groundwater conservation districts for managing groundwater resources. Additionally, this data would be useful in future refinements to the groundwater availability model for the northern portion of the Trinity Aquifer System.

Areas where the groundwater availability model overestimates, or underestimates observed water levels will affect its accuracy to estimate managed available groundwater from desired future conditions. However, this can be mitigated by: 1) developing a long-term observation monitoring program, 2) using data collected from the observation monitoring program in future refinements to the groundwater availability model for the northern portion of the Trinity Aquifer System, and 3) revisiting desired future conditions on a periodic basis as specified in Texas Water Code, Chapter 36 section 36.108.

Additional limitations and potential areas of concern with the groundwater availability model for the northern portion of the Trinity Aquifer System are discussed in Bené and others, 2004. Caveats are also listed in GAM Run reports 08-64 and 08-66 (Hill, 2010a; Hill, 2010b). Desired future conditions may be revised at any time per Groundwater Management Area 8’s request, see Texas Water Code, Chapter 36 section 36.108.

REFERENCES:

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Bené, J., Harden, B., O'Rourke, D., Donnelly, A., and Yelderman, J., 2004, Northern Trinity/Woodbine Groundwater Availability Model: contract report to the Texas Water Development Board by R.W. Harden and Associates, 391 p.

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Harbaugh, A.W. and McDonald, M.G., 1996, User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, U.S. Geological Survey Open-File Report 96-485, 56 p.

Hill, M.E., 2010a, GAM Run 08-64, Texas Water Development Board GAM Run Report, 46 p.

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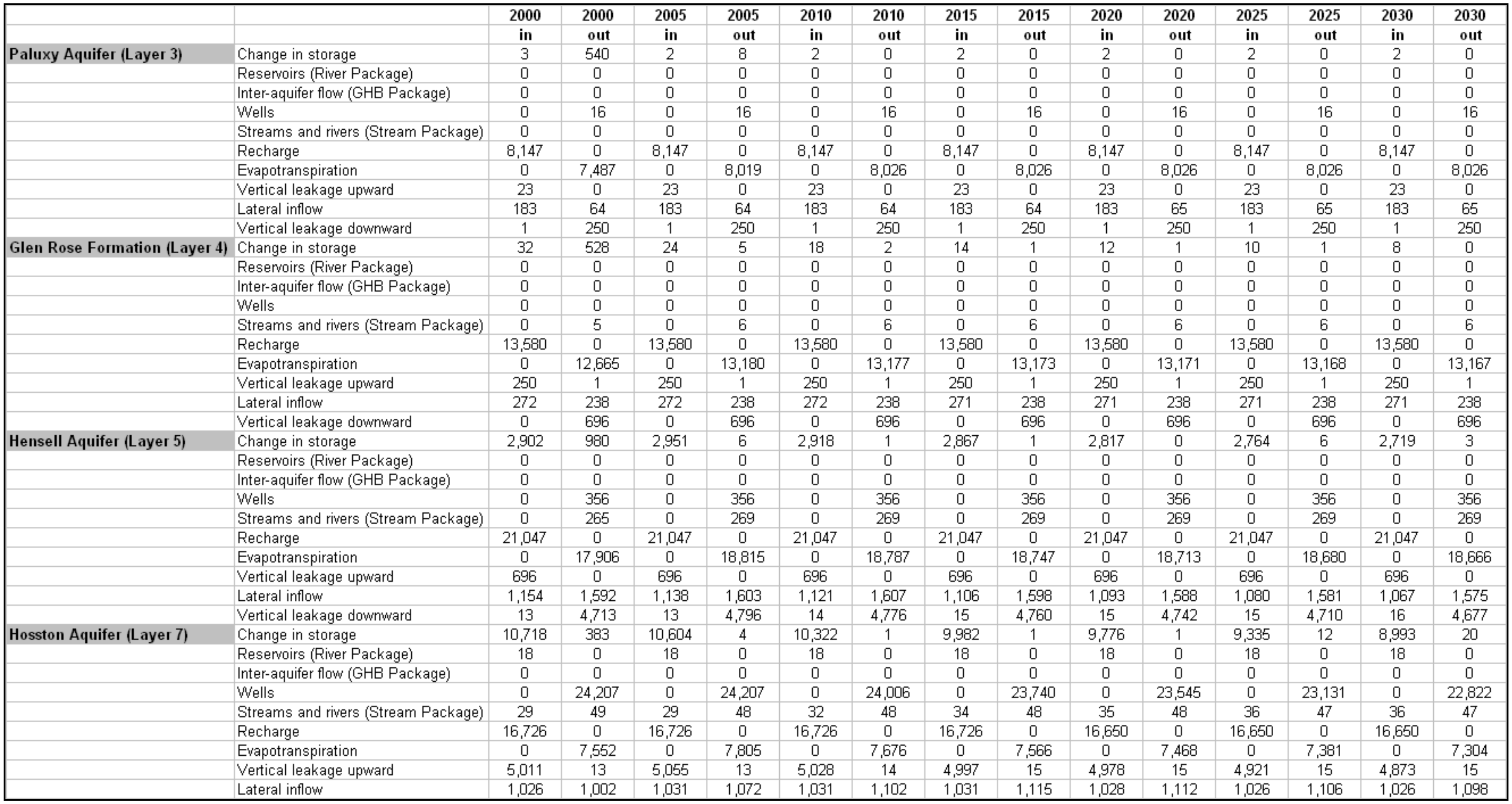
Niswonger, R., 2009, Written communication, February 12, Austin, Texas.

Appendix A

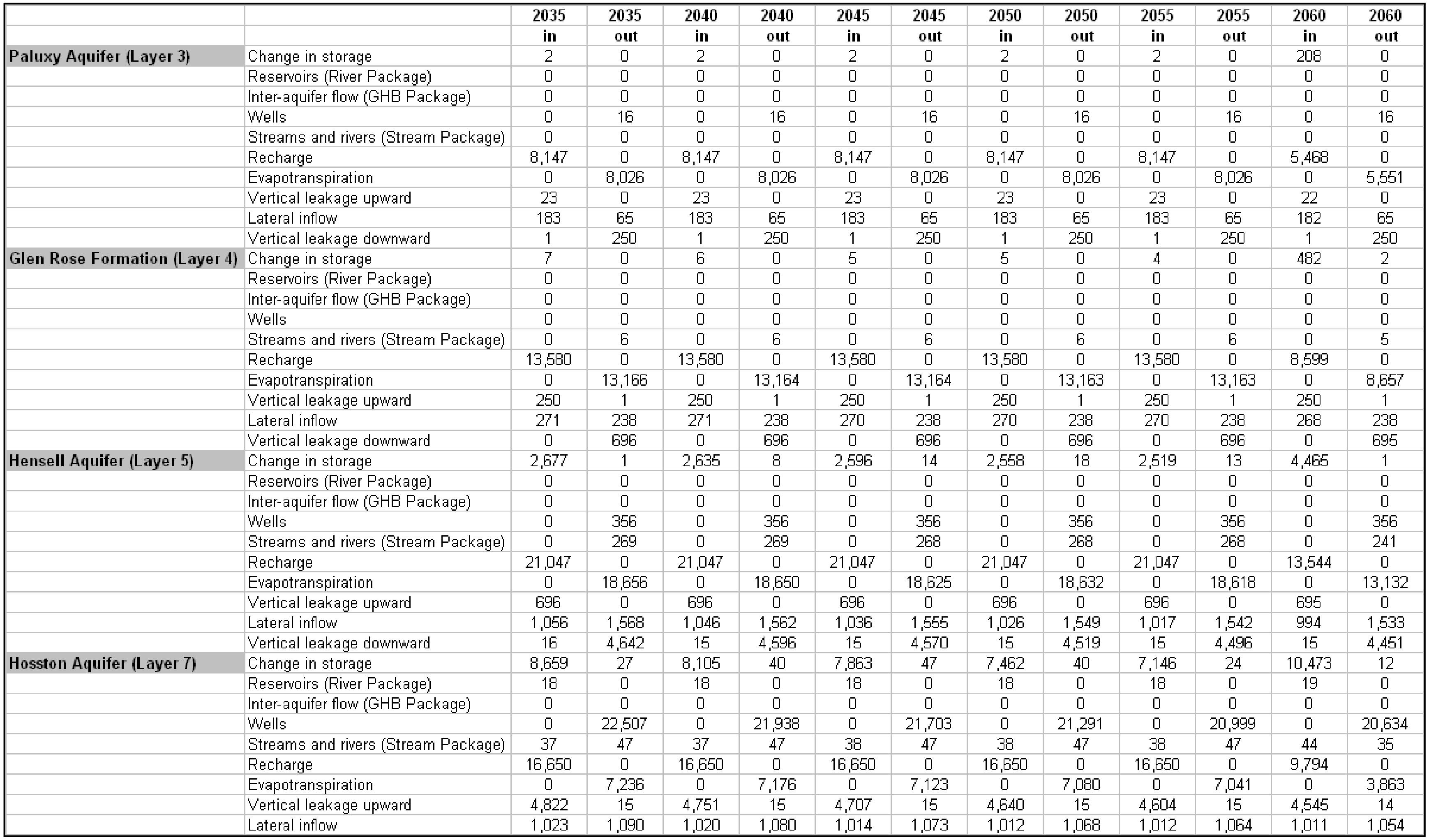
Water Budget for Comanche and Erath counties

Table A-1. Water budget for Comanche County at 5-year increments for layers 3, 4, 5, and 7. Values listed are in acre-feet per year.



		2000	2000	2005	2005	2010	2010	2015	2015	2020	2020	2025	2025	2030	2030
		in	out	in	out	in	out	in	out	in	out	in	out	in	out
Paluxy Aquifer (Layer 3)	Change in storage	3	540	2	8	2	0	2	0	2	0	2	0	2	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	16	0	16	0	16	0	16	0	16	0	16	0	16
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	8,147	0	8,147	0	8,147	0	8,147	0	8,147	0	8,147	0	8,147	0
	Evapotranspiration	0	7,487	0	8,019	0	8,026	0	8,026	0	8,026	0	8,026	0	8,026
	Vertical leakage upward	23	0	23	0	23	0	23	0	23	0	23	0	23	0
	Lateral inflow	183	64	183	64	183	64	183	64	183	65	183	65	183	65
	Vertical leakage downward	1	250	1	250	1	250	1	250	1	250	1	250	1	250
Glen Rose Formation (Layer 4)	Change in storage	32	528	24	5	18	2	14	1	12	1	10	1	8	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Streams and rivers (Stream Package)	0	5	0	6	0	6	0	6	0	6	0	6	0	6
	Recharge	13,580	0	13,580	0	13,580	0	13,580	0	13,580	0	13,580	0	13,580	0
	Evapotranspiration	0	12,665	0	13,180	0	13,177	0	13,173	0	13,171	0	13,168	0	13,167
	Vertical leakage upward	250	1	250	1	250	1	250	1	250	1	250	1	250	1
	Lateral inflow	272	238	272	238	272	238	271	238	271	238	271	238	271	238
	Vertical leakage downward	0	696	0	696	0	696	0	696	0	696	0	696	0	696
Hensell Aquifer (Layer 5)	Change in storage	2,902	980	2,951	6	2,918	1	2,867	1	2,817	0	2,764	6	2,719	3
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	356	0	356	0	356	0	356	0	356	0	356	0	356
	Streams and rivers (Stream Package)	0	265	0	269	0	269	0	269	0	269	0	269	0	269
	Recharge	21,047	0	21,047	0	21,047	0	21,047	0	21,047	0	21,047	0	21,047	0
	Evapotranspiration	0	17,906	0	18,815	0	18,787	0	18,747	0	18,713	0	18,680	0	18,666
	Vertical leakage upward	696	0	696	0	696	0	696	0	696	0	696	0	696	0
	Lateral inflow	1,154	1,592	1,138	1,603	1,121	1,607	1,106	1,598	1,093	1,588	1,080	1,581	1,067	1,575
	Vertical leakage downward	13	4,713	13	4,796	14	4,776	15	4,760	15	4,742	15	4,710	16	4,677
Hosston Aquifer (Layer 7)	Change in storage	10,718	383	10,604	4	10,322	1	9,982	1	9,776	1	9,335	12	8,993	20
	Reservoirs (River Package)	18	0	18	0	18	0	18	0	18	0	18	0	18	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	24,207	0	24,207	0	24,006	0	23,740	0	23,545	0	23,131	0	22,822
	Streams and rivers (Stream Package)	29	49	29	48	32	48	34	48	35	48	36	47	36	47
	Recharge	16,726	0	16,726	0	16,726	0	16,726	0	16,650	0	16,650	0	16,650	0
	Evapotranspiration	0	7,552	0	7,805	0	7,676	0	7,566	0	7,468	0	7,381	0	7,304
	Vertical leakage upward	5,011	13	5,055	13	5,028	14	4,997	15	4,978	15	4,921	15	4,873	15
	Lateral inflow	1,026	1,002	1,031	1,072	1,031	1,102	1,031	1,115	1,028	1,112	1,026	1,106	1,026	1,098

Table A-1. (continued).



		2035 in	2035 out	2040 in	2040 out	2045 in	2045 out	2050 in	2050 out	2055 in	2055 out	2060 in	2060 out
Paluxy Aquifer (Layer 3)	Change in storage	2	0	2	0	2	0	2	0	2	0	208	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	16	0	16	0	16	0	16	0	16	0	16
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	8,147	0	8,147	0	8,147	0	8,147	0	8,147	0	5,468	0
	Evapotranspiration	0	8,026	0	8,026	0	8,026	0	8,026	0	8,026	0	5,551
	Vertical leakage upward	23	0	23	0	23	0	23	0	23	0	22	0
	Lateral inflow	183	65	183	65	183	65	183	65	183	65	182	65
	Vertical leakage downward	1	250	1	250	1	250	1	250	1	250	1	250
Glen Rose Formation (Layer 4)	Change in storage	7	0	6	0	5	0	5	0	4	0	482	2
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	0	0	0	0	0	0	0	0	0	0	0
	Streams and rivers (Stream Package)	0	6	0	6	0	6	0	6	0	6	0	5
	Recharge	13,580	0	13,580	0	13,580	0	13,580	0	13,580	0	8,599	0
	Evapotranspiration	0	13,166	0	13,164	0	13,164	0	13,163	0	13,163	0	8,657
	Vertical leakage upward	250	1	250	1	250	1	250	1	250	1	250	1
	Lateral inflow	271	238	271	238	270	238	270	238	270	238	268	238
	Vertical leakage downward	0	696	0	696	0	696	0	696	0	696	0	695
Hensell Aquifer (Layer 5)	Change in storage	2,677	1	2,635	8	2,596	14	2,558	18	2,519	13	4,465	1
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	356	0	356	0	356	0	356	0	356	0	356
	Streams and rivers (Stream Package)	0	269	0	269	0	268	0	268	0	268	0	241
	Recharge	21,047	0	21,047	0	21,047	0	21,047	0	21,047	0	13,544	0
	Evapotranspiration	0	18,656	0	18,650	0	18,625	0	18,632	0	18,618	0	13,132
	Vertical leakage upward	696	0	696	0	696	0	696	0	696	0	695	0
	Lateral inflow	1,056	1,568	1,046	1,562	1,036	1,555	1,026	1,549	1,017	1,542	994	1,533
	Vertical leakage downward	16	4,642	15	4,596	15	4,570	15	4,519	15	4,496	15	4,451
Hosston Aquifer (Layer 7)	Change in storage	8,659	27	8,105	40	7,863	47	7,462	40	7,146	24	10,473	12
	Reservoirs (River Package)	18	0	18	0	18	0	18	0	18	0	19	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	22,507	0	21,938	0	21,703	0	21,291	0	20,999	0	20,634
	Streams and rivers (Stream Package)	37	47	37	47	38	47	38	47	38	47	44	35
	Recharge	16,650	0	16,650	0	16,650	0	16,650	0	16,650	0	9,794	0
	Evapotranspiration	0	7,236	0	7,176	0	7,123	0	7,080	0	7,041	0	3,863
	Vertical leakage upward	4,822	15	4,751	15	4,707	15	4,640	15	4,604	15	4,545	14
	Lateral inflow	1,023	1,090	1,020	1,080	1,014	1,073	1,012	1,068	1,012	1,064	1,011	1,054

Table A-2. Water budget for Erath County at 5-year increments for layers 3, 4, 5, and 7. Values listed are in acre-feet per year.

		2000	2000	2005	2005	2010	2010	2015	2015	2020	2020	2025	2025	2030	2030
		in	out	in	out	in	out	in	out	in	out	in	out	in	out
Paluxy Aquifer (Layer 3)	Change in storage	719	1,755	652	25	645	1	639	1	633	1	627	1	620	1
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	4,031	0	4,031	0	4,031	0	4,031	0	4,031	0	4,031	0	4,031
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	30,367	0	30,367	0	30,367	0	30,367	0	30,367	0	30,367	0	30,367	0
	Evapotranspiration	0	24,914	0	26,577	0	26,595	0	26,589	0	26,584	0	26,578	0	26,573
	Vertical leakage upward	36	0	36	0	36	0	36	0	36	0	36	0	36	0
	Lateral inflow	40	87	40	87	40	87	40	87	40	87	41	87	41	87
	Vertical leakage downward	0	378	0	377	0	377	0	377	0	376	0	376	0	375
Glen Rose Formation (Layer 4)	Change in storage	246	1,148	233	17	223	6	216	4	209	3	203	3	199	2
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	1	0	1	0	1	0	1	0	1	0	1	0	1
	Streams and rivers (Stream Package)	1	837	2	847	2	846	2	846	2	846	2	846	2	846
	Recharge	25,885	0	25,885	0	25,885	0	25,885	0	25,885	0	25,885	0	25,885	0
	Evapotranspiration	0	22,883	0	23,979	0	23,975	0	23,967	0	23,960	0	23,956	0	23,954
	Vertical leakage upward	378	0	377	0	377	0	377	0	376	0	376	0	375	0
	Lateral inflow	555	590	555	591	555	591	554	591	554	591	553	591	553	590
	Vertical leakage downward	1	1,607	1	1,619	1	1,624	1	1,625	1	1,626	1	1,624	1	1,622
Hensell Aquifer (Layer 5)	Change in storage	14,847	335	15,229	4	15,240	1	15,184	0	15,084	0	14,964	0	14,557	16
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	9,045	0	9,045	0	9,045	0	9,045	0	9,045	0	9,029	0	8,711
	Streams and rivers (Stream Package)	145	535	146	534	145	527	144	520	143	514	142	509	142	504
	Recharge	10,181	0	10,181	0	10,181	0	10,181	0	10,181	0	10,181	0	10,181	0
	Evapotranspiration	0	5,879	0	6,126	0	6,050	0	5,978	0	5,913	0	5,854	0	5,800
	Vertical leakage upward	1,607	1	1,619	1	1,624	1	1,625	1	1,626	1	1,624	1	1,622	1
	Lateral inflow	1,149	4,085	1,170	4,158	1,171	4,224	1,172	4,259	1,166	4,269	1,163	4,270	1,162	4,271
	Vertical leakage downward	0	8,048	0	8,475	0	8,512	0	8,502	0	8,457	0	8,412	0	8,362
Hosston Aquifer (Layer 7)	Change in storage	8,061	25	7,934	0	7,984	0	8,044	12	7,694	22	7,717	5	7,781	21
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	16,183	0	16,183	0	16,183	0	16,183	0	15,771	0	15,771	0	15,771
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	1,525	0	1,525	0	1,525	0	1,525	0	1,525	0	1,525	0	1,525	0
	Evapotranspiration	0	854	0	866	0	857	0	849	0	842	0	836	0	831
	Vertical leakage upward	8,424	0	8,624	0	8,654	0	8,647	0	8,606	0	8,566	0	8,522	0
	Lateral inflow	1,121	2,068	1,172	2,206	1,170	2,292	1,166	2,336	1,162	2,352	1,159	2,355	1,155	2,359

Table A-2. (continued).

		2035	2035	2040	2040	2045	2045	2050	2050	2055	2055	2060	2060
		in	out	in	out	in	out	in	out	in	out	in	out
Paluxy Aquifer (Layer 3)	Change in storage	615	1	609	1	603	1	598	1	593	1	4,191	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	4,031	0	4,031	0	4,031	0	4,031	0	4,031	0	4,031
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	30,367	0	30,367	0	30,367	0	30,367	0	30,367	0	12,245	0
	Evapotranspiration	0	26,568	0	26,563	0	26,558	0	26,553	0	26,548	0	12,028
	Vertical leakage upward	36	0	36	0	36	0	36	0	36	0	36	0
	Lateral inflow	41	86	41	86	41	86	41	86	41	86	41	86
	Vertical leakage downward	0	375	0	375	0	374	0	374	0	373	0	372
Glen Rose Formation (Layer 4)	Change in storage	195	1	192	1	189	1	187	1	184	1	3,312	2
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	1	0	1	0	1	0	1	0	1	0	1
	Streams and rivers (Stream Package)	2	846	2	846	2	846	2	846	2	846	10	732
	Recharge	25,885	0	25,885	0	25,885	0	25,885	0	25,885	0	10,743	0
	Evapotranspiration	0	23,951	0	23,947	0	23,945	0	23,943	0	23,940	0	12,039
	Vertical leakage upward	375	0	375	0	374	0	374	0	373	0	372	0
	Lateral inflow	553	590	553	590	553	590	553	590	553	589	540	587
	Vertical leakage downward	1	1,622	1	1,623	1	1,623	1	1,622	1	1,622	1	1,617
Hensell Aquifer (Layer 5)	Change in storage	14,416	0	14,302	0	14,194	0	14,088	0	13,976	0	17,279	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	8,711	0	8,711	0	8,711	0	8,711	0	8,711	0	8,694
	Streams and rivers (Stream Package)	141	499	141	495	140	491	140	488	139	484	126	410
	Recharge	10,181	0	10,181	0	10,181	0	10,181	0	10,181	0	4,030	0
	Evapotranspiration	0	5,749	0	5,703	0	5,659	0	5,619	0	5,582	0	2,891
	Vertical leakage upward	1,622	1	1,623	1	1,623	1	1,622	1	1,622	1	1,617	1
	Lateral inflow	1,161	4,271	1,159	4,269	1,159	4,266	1,158	4,261	1,157	4,249	1,152	4,230
	Vertical leakage downward	0	8,290	0	8,227	0	8,168	0	8,109	0	8,050	0	7,977
Hosston Aquifer (Layer 7)	Change in storage	7,298	4	7,094	0	7,141	0	7,186	0	7,232	0	7,754	0
	Reservoirs (River Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Inter-aquifer flow (GHB Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Wells	0	15,240	0	14,981	0	14,981	0	14,981	0	14,981	0	14,981
	Streams and rivers (Stream Package)	0	0	0	0	0	0	0	0	0	0	0	0
	Recharge	1,525	0	1,525	0	1,525	0	1,525	0	1,525	0	491	0
	Evapotranspiration	0	825	0	820	0	816	0	811	0	807	0	235
	Vertical leakage upward	8,456	0	8,399	0	8,350	0	8,300	0	8,249	0	8,188	0
	Lateral inflow	1,151	2,360	1,145	2,361	1,141	2,359	1,138	2,356	1,136	2,353	1,130	2,347