GAM Task 13-029: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 6

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Groundwater Resources Division
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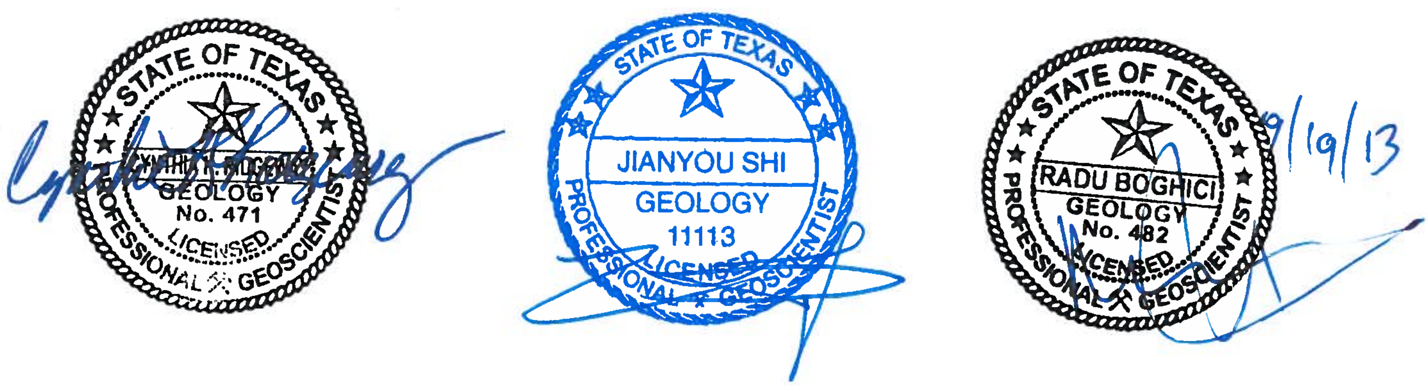
September 19, 2013



Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by William Kohlrenken under her direct supervision. The seals appearing on this document were authorized by Cynthia K. Ridgeway, P.G. 471, Radu Boghici, P.G. 482, and Jerry Shi, P.G. 11113 on September 19, 2013.

The total estimated recoverable storage in this report was calculated as follows: the Dockum and Ogallala aquifers (William Kohlrenken); the Seymour and Blaine aquifers (Radu Boghici); and the Trinity Aquifer (Jerry Shi).

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[1] This is the office telephone number for William Kohlrenken

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EXECUTIVE SUMMARY:

Texas Water Code, § 36.108 (d) (Texas Water Code, 2011) states that, before voting on the proposed desired future conditions for a relevant aquifer within a groundwater management area, the groundwater conservation districts shall consider the total estimated recoverable storage as provided by the executive administrator of the Texas Water Development Board (TWDB) along with other factors listed in §36.108 (d). Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the total estimated recoverable storage as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume.

This report discusses the methods, assumptions, and results of an analysis to estimate the total recoverable storage for the Blaine, Dockum, Trinity, Ogallala, and Seymour aquifers within Groundwater Management Area 6. Tables 1 through 10 summarize the total estimated recoverable storage required by the statute. Figures 2 through 6 indicate the extent of the groundwater availability models used to estimate the total recoverable storage.

DEFINITION OF TOTAL ESTIMATED RECOVERABLE STORAGE:

The total estimated recoverable storage is defined as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume. In other words, we assume that between 25 and 75 percent of groundwater held within an aquifer can be removed by pumping.

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[2] This is the office telephone number for William Kohlrenken

The total recoverable storage was estimated for the portion of each aquifer within Groundwater Management Area 6 that lies within the official lateral aquifer boundaries as delineated by George and others (2011). Total estimated recoverable storage values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data and the existing groundwater availability models do not permit the differentiation of different water quality types. These values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction as the result of extracting groundwater from the aquifer.

METHODS:

To estimate the total recoverable storage of an aquifer, we first calculated the total storage in an aquifer within the official aquifer boundary in the groundwater management area. The total storage is the volume of groundwater that can be removed by completely draining the aquifer.

Aquifers can be either unconfined or confined (Figure 1). A well screened in an unconfined aquifer will have a water level equal to the water level in the aquifer outside the well. Thus, unconfined aquifers have water levels within the aquifers. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure above the ambient atmospheric pressure. The water level at a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is also different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is the groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic pressure in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. The second part, just like unconfined aquifer, is the groundwater released from the aquifer when the water level falls from the top to the bottom of the aquifer. Given the same aquifer area and water level drop, the amount of water released in the second part is much greater than the first part. The difference is quantified by two parameters: storativity related to confined aquifer and specific yield related to unconfined aquifer. For example, storativity values range from 10^{-5} to 10^{-3} for most confined aquifers, while the specific yield values can be 0.01 to 0.3 for most unconfined aquifers. The equations for calculating the total storage are presented below:

- for unconfined aquifers

$$Total\ Storage\ = V_{drained} = Area \times S_y \times (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage\ = V_{confined} + V_{drained}$$

  - confined part

$$V_{confined} = \ Area \times [\ S \times (Water\ Level - Top)]$$

or

$$V_{confined} = \ Area \times [\ S_s\ \times (\mathrm{Top} - \mathrm{Bottom}) \times (Water\ Level - Top)]$$

  - unconfined part

$$V_{drained} = \ Area \times \left[S_y \times (Top - Bottom)\right]$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $V_{confined}$ = storage volume due to elastic properties of the aquifer and water(acre-feet)
- *Area* = area of aquifer (acre)
- *Water Level* = groundwater elevation (feet above mean sea level)
- *Top* = elevation of aquifer top (feet above mean sea level)
- *Bottom* = elevation of aquifer bottom (feet above mean sea level)
- S_y = specific yield (no units)
- S_s = specific storage (1/feet)
- S = storativity or storage coefficient (no units)

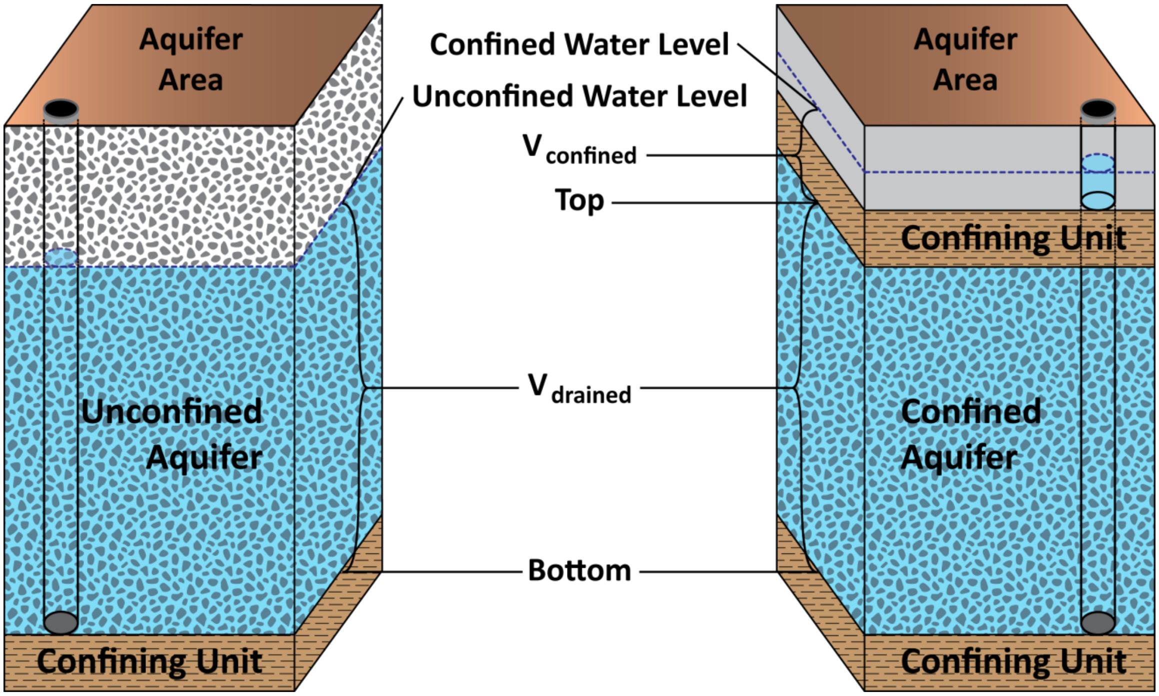

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

As presented in the equations, calculation of the total storage requires data, such as aquifer top, aquifer bottom, aquifer storage properties, and water level. For the Blaine, Dockum, Trinity, Ogallala, and Seymour aquifers in Groundwater Management Area 6, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. In the absence of groundwater availability model(s), the total storage will be calculated using other approaches.

Python scripts and a FORTRAN-90 program were developed and used to expedite the storage calculation. The total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent.

PARAMETERS AND ASSUMPTIONS:

Seymour and Blaine aquifers

- We used version 1.01 of the groundwater availability model for the Seymour and Blaine aquifers. See Ewing and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes two layers, representing the Seymour (Layer 1) and Blaine (Layer 2) aquifers. In areas where the Blaine Aquifer does not exist the model roughly replicates the various Permian units located in the study area.
- Total estimated recoverable storage was determined using the cells in the model that represent the Seymour (Layer 1) and Blaine (Layer 2) aquifers.

Dockum Aquifer

- We used version 1.01 of the groundwater availability model for the Dockum Aquifer to estimate the total recoverable storage. See Ewing and others (2008) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes three layers which generally represent the younger geologic units overlying the Dockum Aquifer (Layer 1), the upper portion of the Dockum Aquifer (Layer 2), and the lower portion of the Dockum Aquifer (Layer 3).
- Of the three layers, total estimated recoverable storage was determined and combined for layers representing the Dockum Aquifer (layers 2 and 3).
- The down-dip boundary of the Dockum Aquifer in this model was set to approximately coincide with the extent of the available geologic data, well beyond any active portion (groundwater use) of the aquifer (Ewing and others, 2008). Consequently, the model extends into zones of brackish and brine groundwater. The official extent of the Dockum Aquifer was used to exclude this area (George and others, 2011).

Trinity Aquifer

- We used version 1.01 of the groundwater availability model for the northern part of the Trinity Aquifer and the Woodbine Aquifer to estimate the total recoverable storage for the Trinity Aquifer. The Woodbine Aquifer is not present in Groundwater Management Area 6. See Bené and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes seven layers which generally represent the Woodbine Aquifer (Layer 1), the Washita and Fredericksburg Confining Unit (Layer 2), the Paluxy Aquifer Unit of the Trinity Aquifer (Layer 3), the Glen Rose Confining Unit of the Trinity Aquifer (Layer 4), the Hensell Sand Aquifer Unit of the Trinity Aquifer (Layer 5), the Twin Mountains Confining Units of the Trinity Aquifer (Layer 6), and the Hosston Aquifer Unit of the Trinity Aquifer (Layer 7). To develop the estimates for the total estimated recoverable storage, we used layers 3 through 7 (the Trinity Aquifer).
- The down-dip boundary of the model is considered the Luling-Mexia-Talco Fault Zone, which probably allows minimal groundwater flow across the fault zone (Bené and others, 2004). The groundwater in the official extent of the northern portion of the Trinity Aquifer aquifers ranges from fresh to moderately saline (brackish) in composition (Bené and others, 2004).

Southern portion of the Ogallala Aquifer

- We used version 2.01 of the groundwater availability model to estimate the total recoverable storages of the southern portion of the Ogallala and Edwards-Trinity (High Plains) aquifers. This model is an expansion on and update to the previously developed groundwater availability model for the southern portion of the Ogallala Aquifer described in Blandford and others (2003). See Blandford and others (2008) and Blandford and others (2003) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes 4 layers which represent the southern portion of the Ogallala (Layer 1) and the Edwards-Trinity (High Plains) (primarily Edwards, Comanche Peak, and Antlers Sand formations; layers 2-4).
- Of the four layers, total estimated recoverable storage was determined for the Ogallala Aquifer (Layer 1) in Groundwater Management Area 6.

Northern portion of the Ogallala Aquifer

- We used version 3.01 of the groundwater availability model to estimate the total recoverable storage for the northern portion of the Ogallala Aquifer which includes the Rita Blanca Aquifer where it occurs in the model area. However, the Rita Blanca Aquifer does not exist in Groundwater Management Area 6. This model is an update to the previously developed groundwater availability model for the northern portion of the Ogallala Aquifer described in Dutton and others (2001) and Dutton (2004). See Kelley and others (2010), Dutton (2004), and Dutton and others (2001) for assumptions and limitations of the model.
- The model for the northern portion of the Ogallala Aquifer has one layer which for Groundwater Management Area 6 represents the Ogallala Aquifer.
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RESULTS:

Tables 1 through 10 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded to two significant figures. Figures 2 through 6 indicate the extent of the groundwater availability models in Groundwater Management Area 6 for the Blaine, Dockum, Trinity, Ogallala, and Seymour aquifers from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BLAINE AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Childress	18,000,000	4,500,000	13,500,000
Collingsworth	29,000,000	7,250,000	21,750,000
Cottle	22,000,000	5,500,000	16,500,000
Dickens	35,000	8,750	26,250
Foard	5,900,000	1,475,000	4,425,000
Hall	2,500,000	625,000	1,875,000
Hardeman	10,000,000	2,500,000	7,500,000
King	24,000,000	6,000,000	18,000,000
Knox	810,000	202,500	607,500
Motley	110,000	27,500	82,500
Fisher	15,000,000	3,750,000	11,250,000
Kent	490,000	122,500	367,500
Stonewall	36,000,000	9,000,000	27,000,000
Jones	880,000	220,000	660,000
Wilbarger	1,400	350	1,050
Total	**164,726,400**	**41,181,600**	**123,544,800**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[3] FOR THE BLAINE AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Clear Fork GCD	15,000,000	3,750,000	11,250,000
Gateway GCD	56,000,000	14,000,000	42,000,000
Mesquite GCD	31,000,000	7,750,000	23,250,000
Rolling Plains GCD	810,000	202,500	607,500
No District	61,000,000	15,250,000	45,750,000
Total	**163,810,000**	**40,952,500**	**122,857,500**

[3] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.

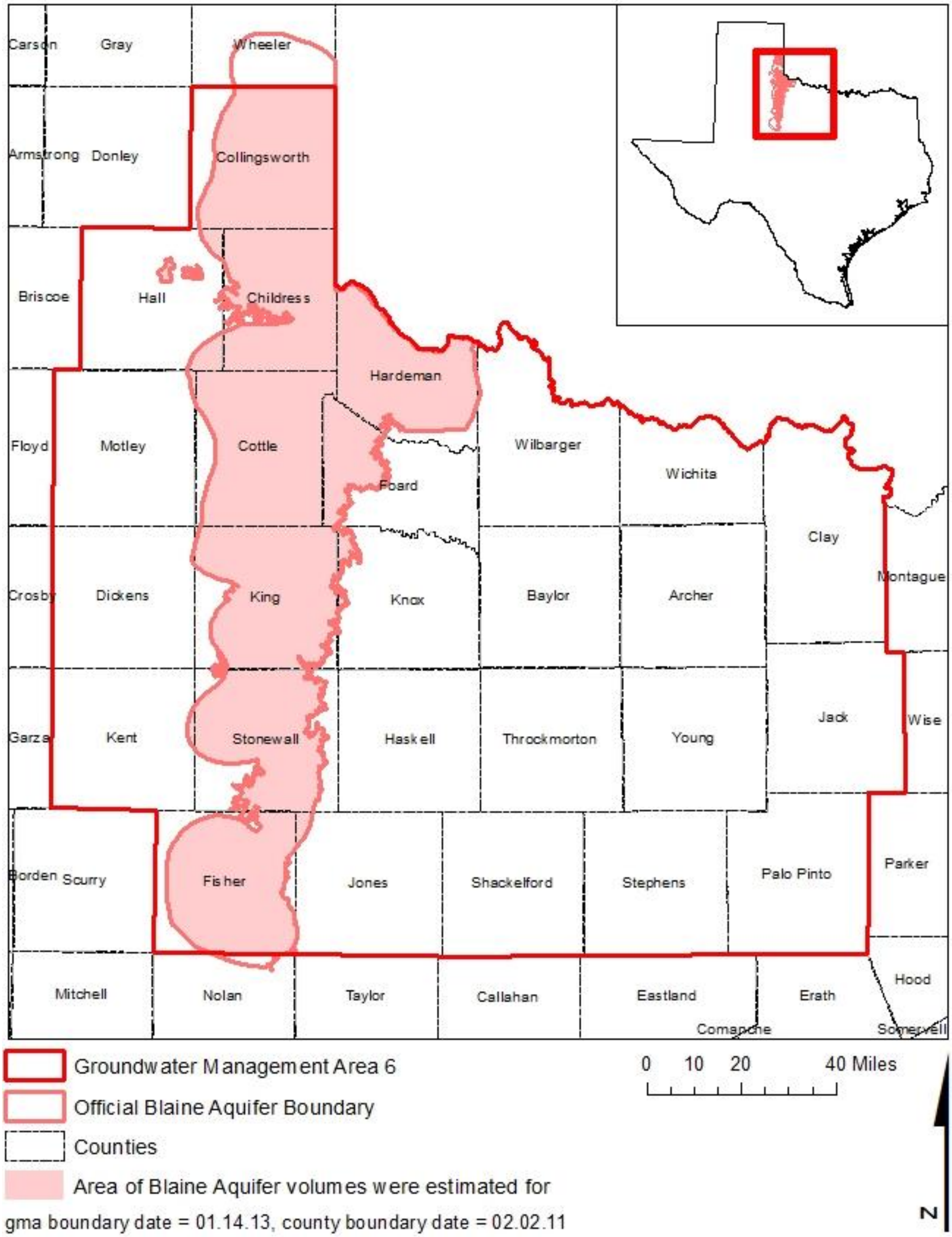

FIGURE 2. EXTENT OF THE BLAINE AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 6.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Dickens	3,400,000	850,000	2,550,000
Fisher	1,300,000	325,000	975,000
Kent	1,400,000	350,000	1,050,000
Motley	1,800,000	450,000	1,350,000
Total	**7,900,000**	**1,975,000**	**5,925,000**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Clear Fork GCD	1,300,000	325,000	975,000
Gateway GCD	1,800,000	450,000	1,350,000
No District	4,800,000	1,200,000	3,600,000
Total	**7,900,000**	**1,975,000**	**5,925,000**

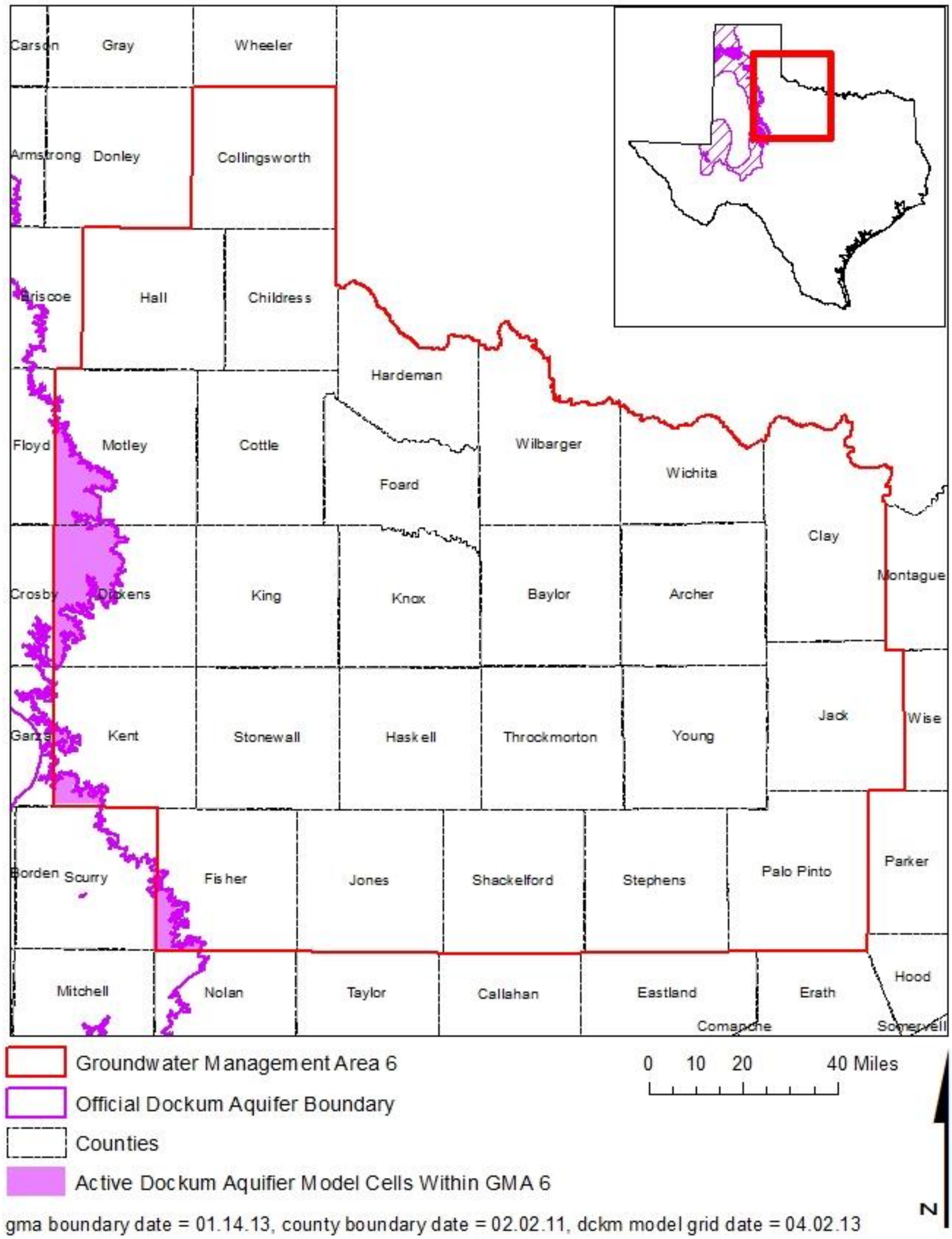

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE DOCKUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 6.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Jack	420,000	105,000	315,000
Palo Pinto	51,000	12,750	38,250
Total	**471,000**	**117,750**	**353,250**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[4] FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	470,000	117,500	352,500
Total	**470,000**	**117,500**	**352,500**

[4] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.

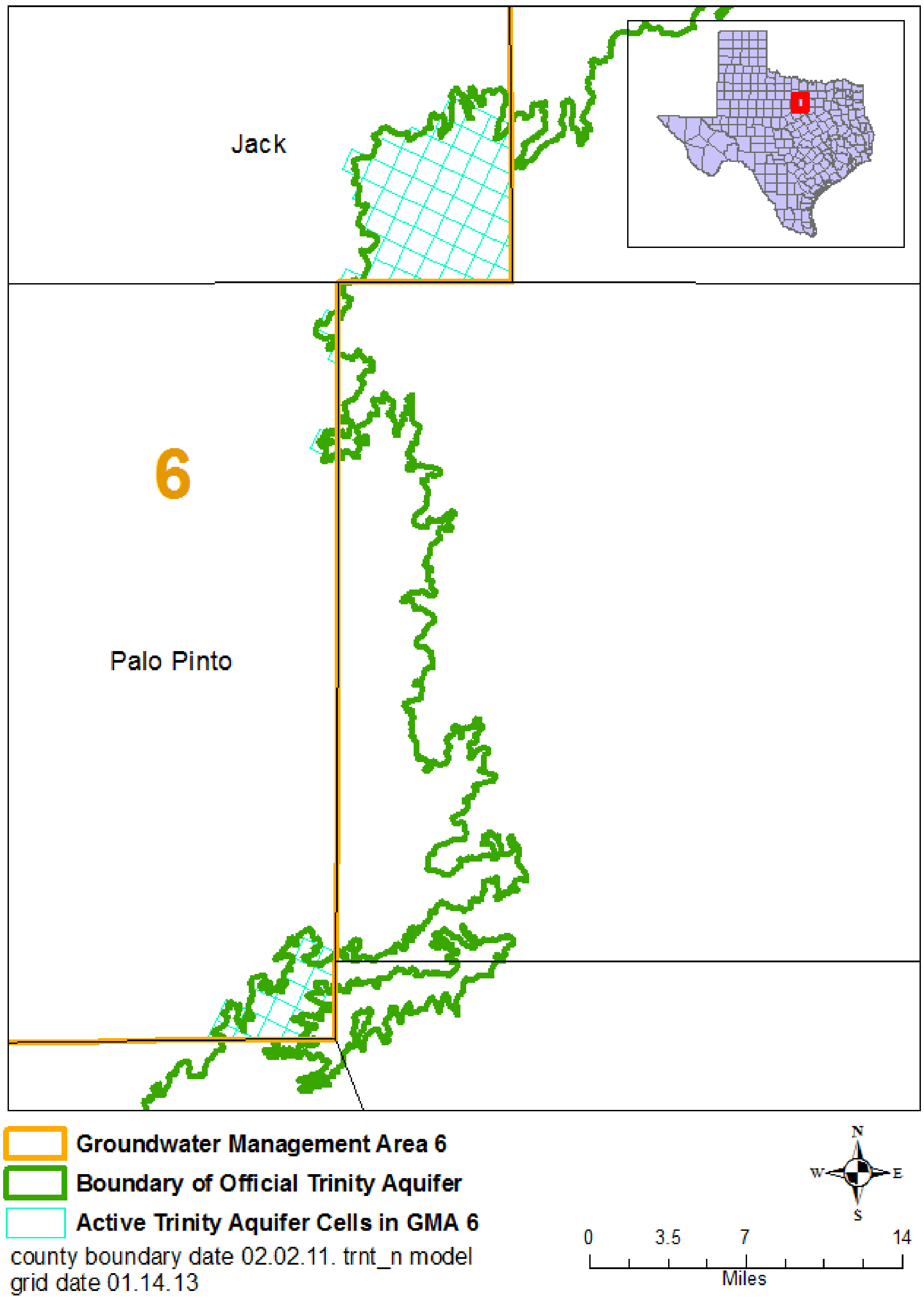

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE TRINITY AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 6.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Collingsworth	85,000	21,250	63,750
Dickens	1,200,000	300,000	900,000
Motley	1,000,000	250,000	750,000
Total	**2,285,000**	**571,250**	**1,713,750**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Gateway GCD	1,000,000	250,000	750,000
Mesquite GCD	85,000	21,250	63,750
No District	1,200,000	300,000	900,000
Total	**2,285,000**	**571,250**	**1,713,750**

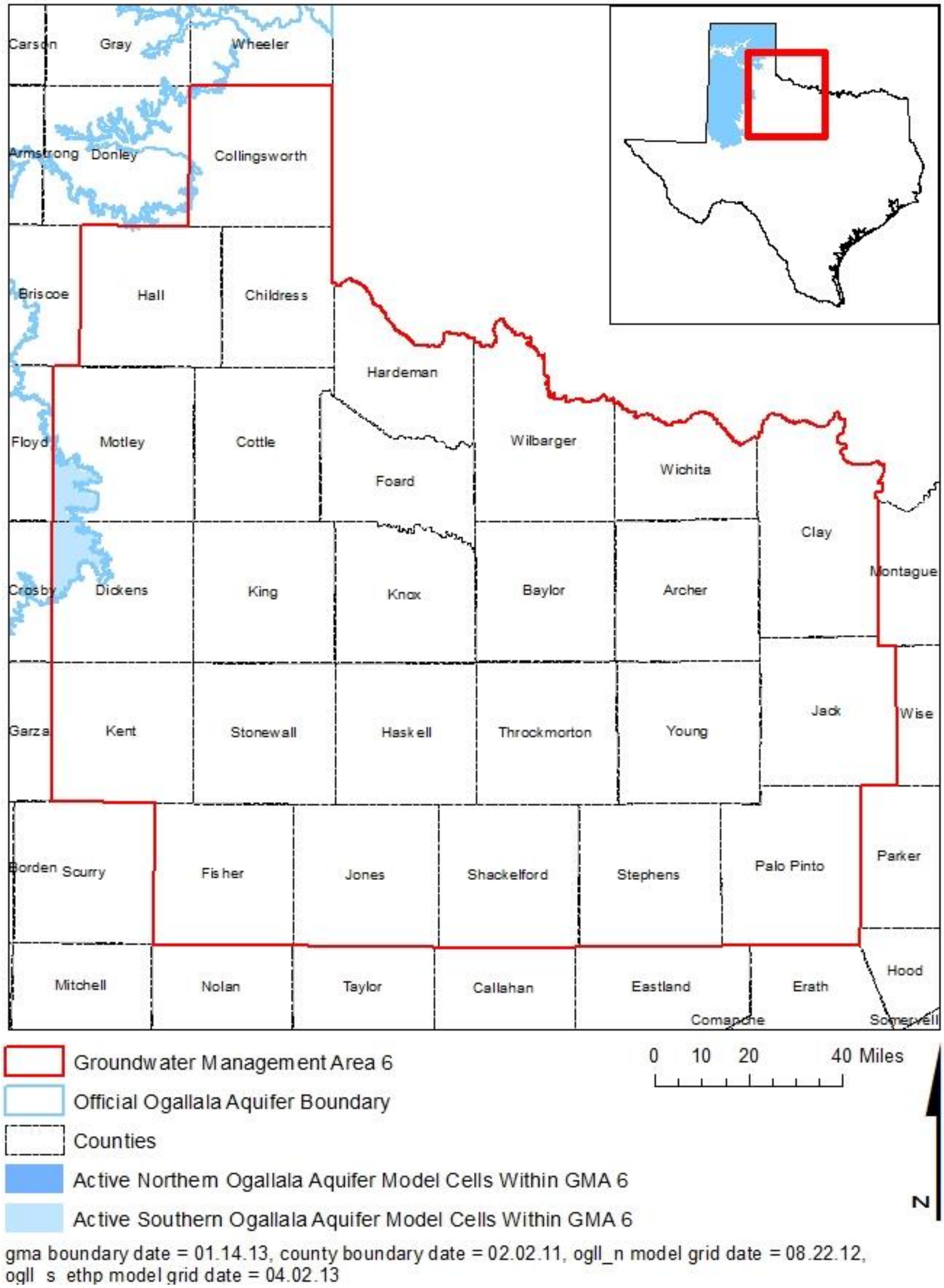

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODELS FOR THE SOUTHERN AND NORTHERN PORTIONS OF THE OGALLALA AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 6.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Archer	4,800	1,200	3,600
Baylor	220,000	55,000	165,000
Childress	100,000	25,000	75,000
Clay	170,000	42,500	127,500
Collingsworth	480,000	120,000	360,000
Fisher	260,000	65,000	195,000
Foard	220,000	55,000	165,000
Hall	200,000	50,000	150,000
Hardeman	450,000	112,500	337,500
Haskell	570,000	142,500	427,500
Jones	590,000	147,500	442,500
Kent	94,000	23,500	70,500
Knox	400,000	100,000	300,000
Motley	72,000	18,000	54,000
Stonewall	44,000	11,000	33,000
Throckmorton	29,000	7,250	21,750
Wichita	270,000	67,500	202,500
Wilbarger	890,000	222,500	667,500
Young	6,300	1,575	4,725
Total	**5,070,100**	**1,267,525**	**3,802,575**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[5] FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 6. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Clear Fork GCD	260,000	65,000	195,000
Gateway GCD	850,000	212,500	637,500
Mesquite GCD	680,000	170,000	510,000
Rolling Plains GCD	1,200,000	300,000	900,000
No District	2,100,000	525,000	1,575,000
Total	**5,090,000**	**1,272,500**	**3,817,500**

[5] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant figures.

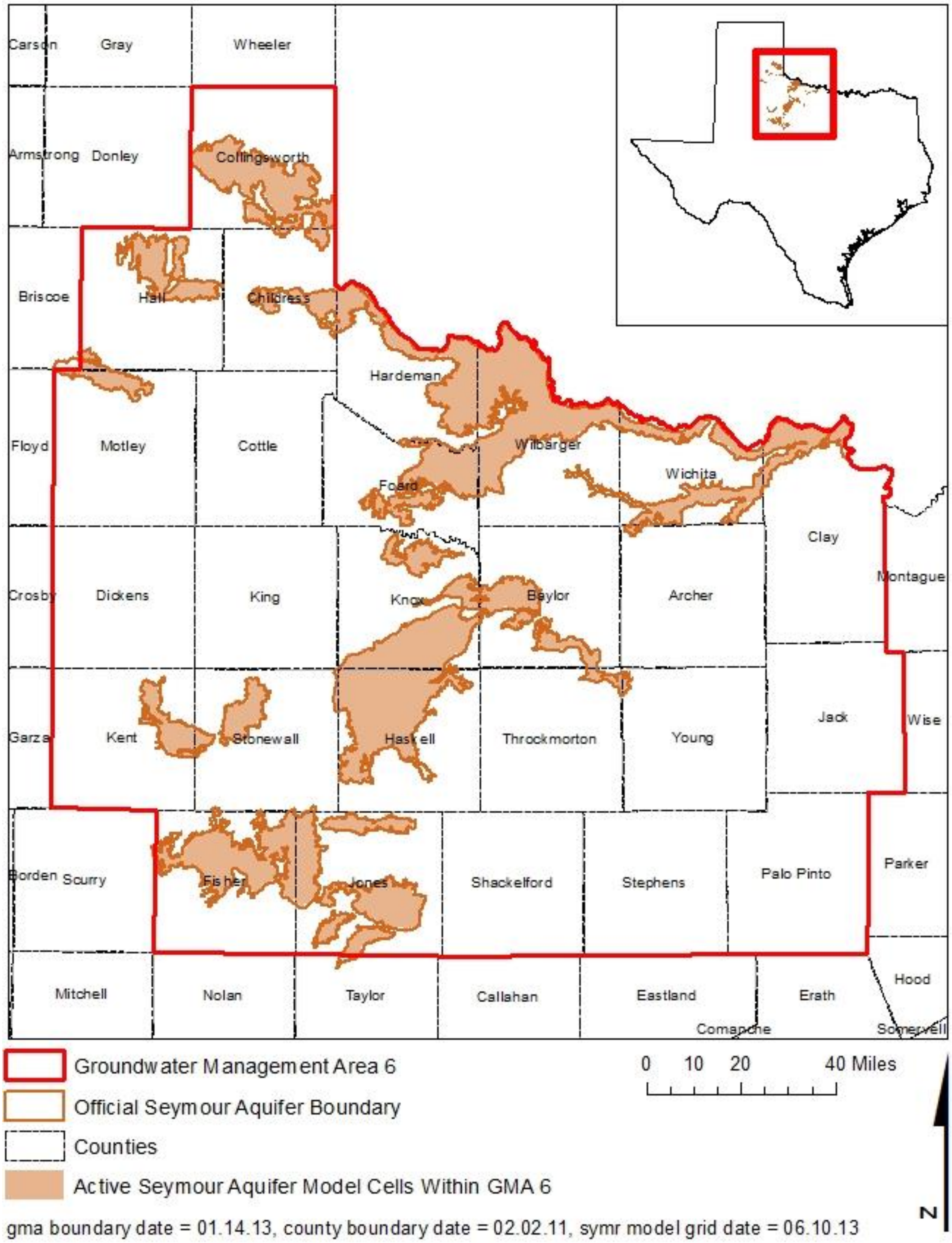

FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE SEYMOUR AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 6.

LIMITATIONS

The groundwater models used in completing this analysis are the best available scientific tools that can be used to meet the stated objective(s). To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time.

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