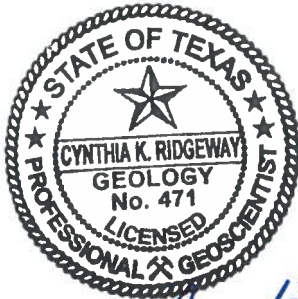

GAM TASK 15-006: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 1

by William Kohlrenken, GISP
Texas Water Development Board
Groundwater Resources Division
Groundwater Availability Modeling Section
(512) 463-8279
December 17, 2015



A handwritten signature in blue ink that reads "Cynthia K. Ridgeway".

Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by William Kohlrenken, GISP, under her direct supervision. The seal appearing on this document was authorized by Cynthia K. Ridgeway, P.G. 471 on December 17, 2015.

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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, Rita Blanca, Ogallala, and Seymour aquifers within Groundwater Management Area 1. 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.

On November 19, 2015, the four districts in Groundwater Management Area 1 requested that the Texas Water Development Board (letter dated November 19, 2015, from Kyle G. Ingham to Larry French) update the total estimated recoverable storage for the aquifers within the groundwater management area using the newly adopted High Plains Aquifer System Groundwater Availability Model. The High Plains Aquifer System Groundwater Availability Model was completed in 2015 and replaces three previous groundwater availability models: the northern portion of the Ogallala Aquifer, which includes the Rita Blanca Aquifer (version

3.01); the southern portion of the Ogallala Aquifer, which includes the Edwards-Trinity (High Plains) Aquifer (version 2.01); and the and the Dockum Aquifer (version 1.01) groundwater availability models. This report replaces the results of the previous report GAM Task 13-025 (Kohlrenken, 2013).

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.

The total recoverable storage was estimated for the portion of the aquifer 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. The total storage is the volume of groundwater removed by pumping that completely drains 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 removed by pumping 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

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

- unconfined part

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

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)

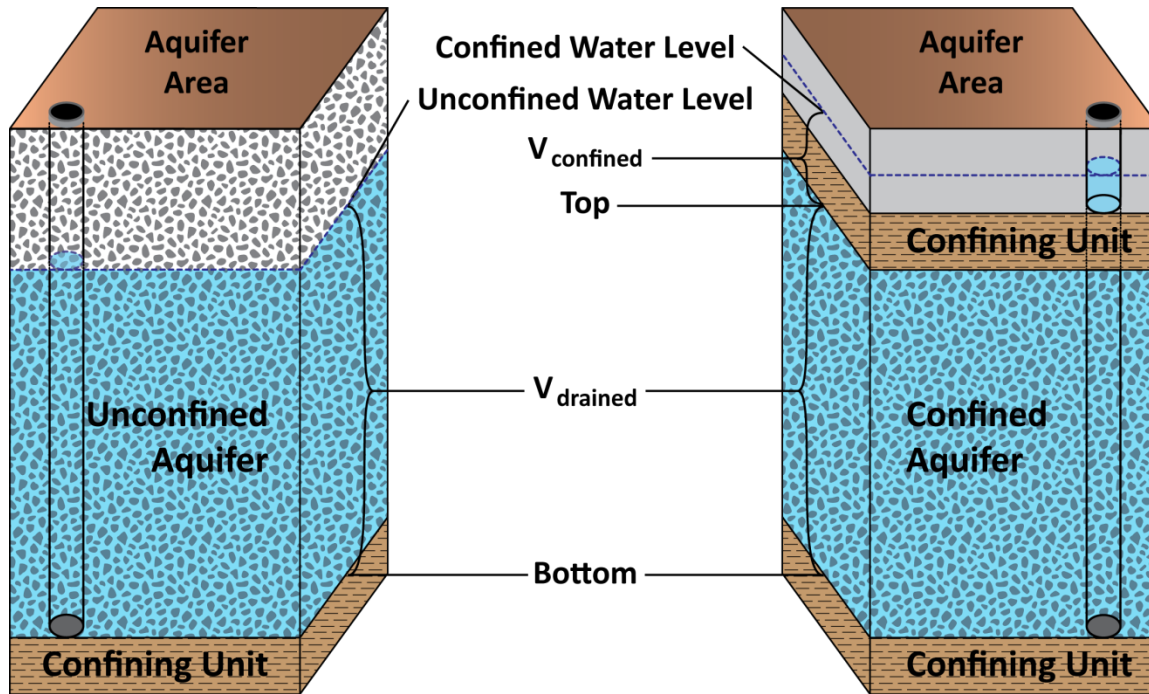


FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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, Rita Blanca, Ogallala, and Seymour aquifers in Groundwater Management Area 1, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. Finally, 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.
- Of the two layers, total estimated recoverable storage was determined using the cells in the model that represent the Blaine Aquifer in layer 2.
- Because no active grid cells fell within Groundwater Management Area 1, total estimated recoverable storage values for the Seymour Aquifer were calculated by averaging the attributes of the two closest grid cells and applying them to the area the Seymour Aquifer covers in Groundwater Management Area 1.

High Plains Aquifer System: Dockum, Edwards-Trinity (High Plains), Rita Blanca, and Ogallala aquifers

- We used version 1.01 of the groundwater availability model for the High Plains Aquifer System to estimate the total recoverable storage. See Deeds and Jigmond (2015) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes 4 layers which generally represent the Ogallala Aquifer and other younger geologic units overlying the Dockum Aquifer (layer 1), the Rita Blanca and Edwards-Trinity (High Plains) aquifers (layer 2), upper portion of the Dockum Aquifer (layer 3), and the lower portion of the Dockum Aquifer (layer 4).
- Of the 4 layers, total estimated recoverable storage was determined and combined for layers representing the Ogallala Aquifer (layer 1), Rita Blanca Aquifer (layer 2), and Dockum Aquifer (layers 3 and 4).

- 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 (Deed and others, 2015). 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).

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 digits. Figures 2 through 6 indicate the extent of the groundwater availability models in Groundwater Management Area 1 for the Blaine, Dockum, Rita Blanca, 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 1. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>County</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
Wheeler	6,700,000	1,675,000	5,025,000
Total	6,700,000	1,675,000	5,025,000

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE BLAINE AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT (GCD) TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>Groundwater Conservation District</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
Panhandle GCD	6,700,000	1,675,000	5,025,000
Total	6,700,000	1,675,000	5,025,000

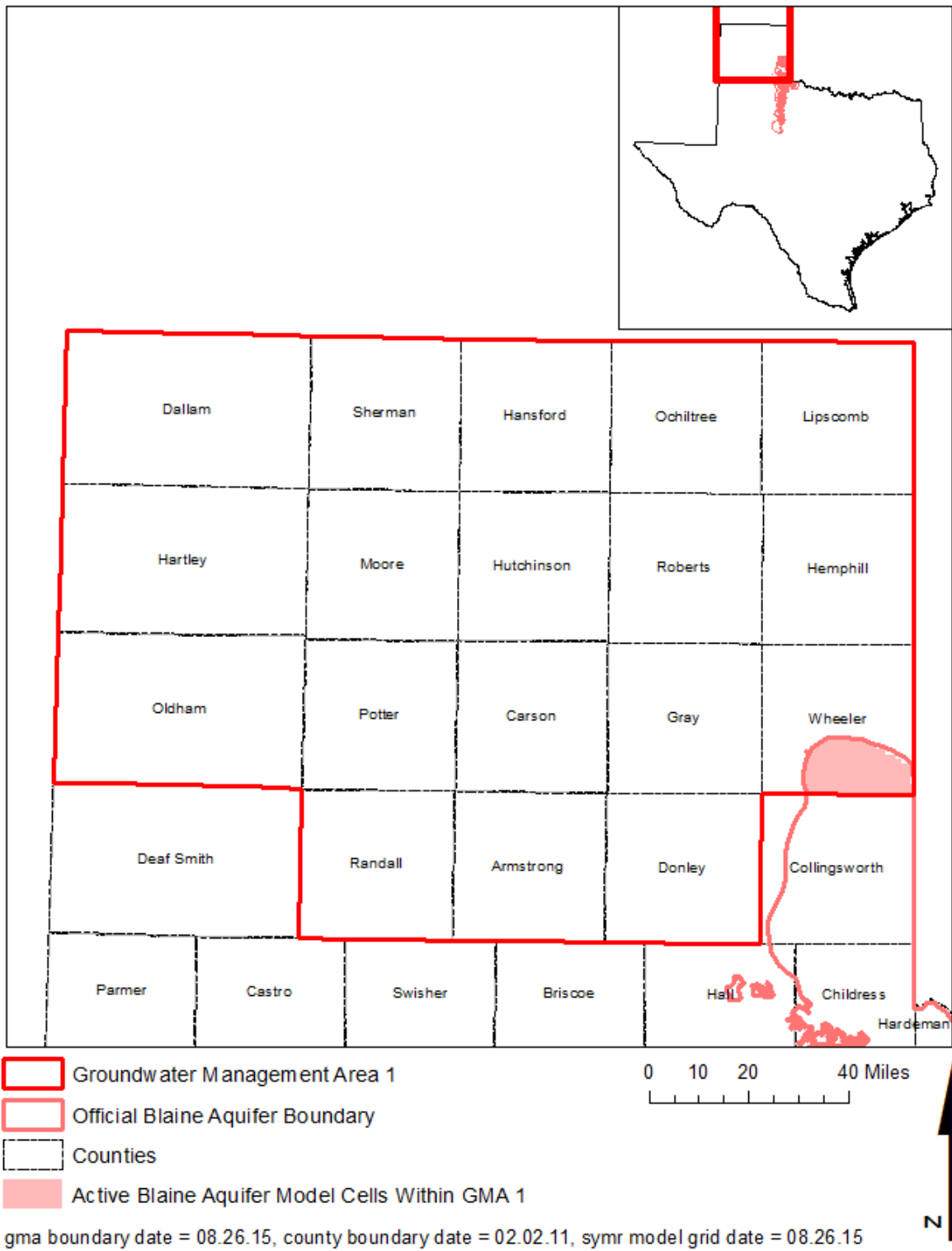


FIGURE 2. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE BLAINE AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 1.

**TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE DOCKUM AQUIFER
 WITHIN GROUNDWATER MANAGEMENT AREA 1. COUNTY TOTAL ESTIMATES ARE ROUNDED
 TO TWO SIGNIFICANT DIGITS.**

<i>County</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
Armstrong	7,000,000	1,750,000	5,250,000
Carson	1,900,000	475,000	1,425,000
Dallam	80,000,000	20,000,000	60,000,000
Hartley	96,000,000	24,000,000	72,000,000
Moore	7,400,000	1,850,000	5,550,000
Oldham	43,000,000	10,750,000	32,250,000
Potter	10,000,000	2,500,000	7,500,000
Randall	46,000,000	11,500,000	34,500,000
Sherman	540,000	135,000	405,000
Total	291,840,000	72,960,000	218,880,000

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)¹ FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>Groundwater Conservation District</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
High Plains UWCD ² No.1	28,000,000	7,000,000	21,000,000
North Plains GCD	170,000,000	42,500,000	127,500,000
Panhandle GCD	15,000,000	3,750,000	11,250,000
No District	77,000,000	19,250,000	57,750,000
Total	290,000,000	72,500,000	217,500,000

¹ 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 digits.

² UWCD is the abbreviation for Underground Water Conservation District.

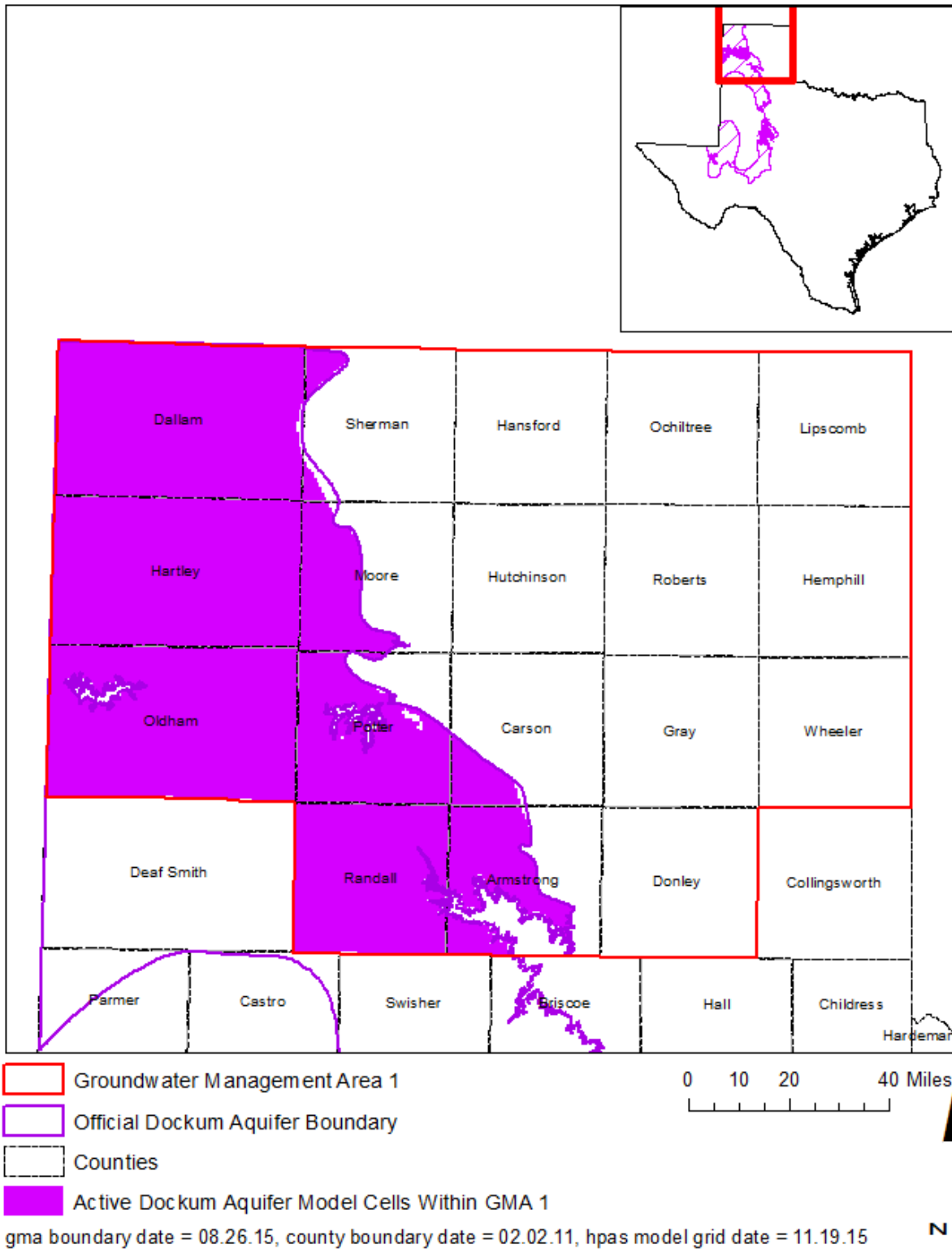


FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE DOCKUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE RITA BLANCA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>County</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
Dallam	9,800,000	2,450,000	7,350,000
Hartley	1,300,000	325,000	975,000
Total	11,100,000	2,775,000	8,325,000

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)³ FOR THE RITA BLANCA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>Groundwater Conservation District</i>	<i>Total Storage (acre-feet)</i>	<i>25% of Total Storage (acre-feet)</i>	<i>75% of Total Storage (acre-feet)</i>
North Plains GCD	11,000,000	2,750,000	8,250,000
No District	5,500	1,375	4,125
Total	11,005,500	2,751,375	8,254,125

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 digits.

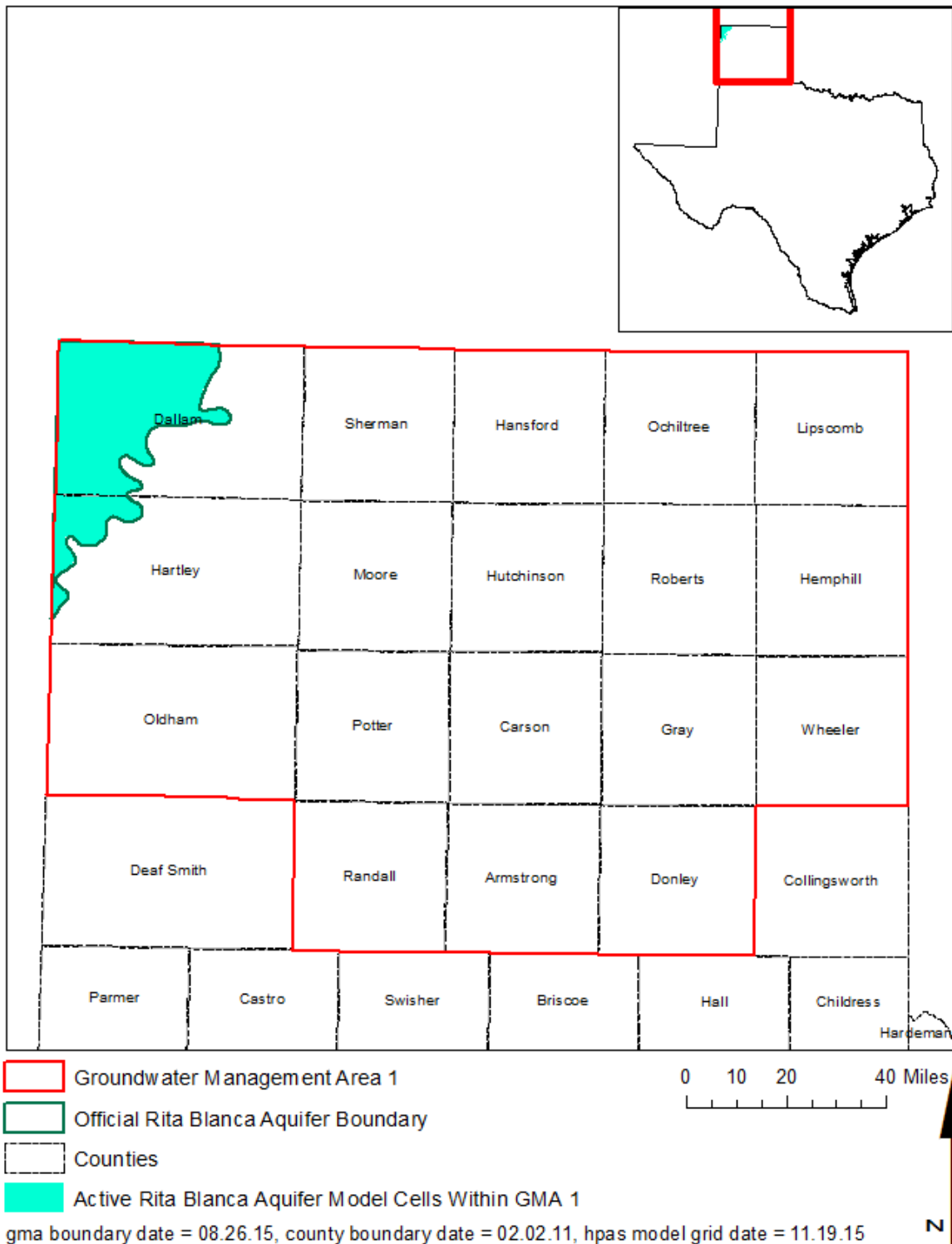


FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODELS OF THE RITA BLANCA AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>County</i>	<i>Total Storage (acre-feet)</i>	<i>25 percent of Total Storage (acre-feet)</i>	<i>75 percent of Total Storage (acre-feet)</i>
Armstrong	4,600,000	1,150,000	3,450,000
Carson	15,000,000	3,750,000	11,250,000
Dallam	15,000,000	3,750,000	11,250,000
Donley	4,400,000	1,100,000	3,300,000
Gray	14,000,000	3,500,000	10,500,000
Hansford	24,000,000	6,000,000	18,000,000
Hartley	17,000,000	4,250,000	12,750,000
Hemphill	15,000,000	3,750,000	11,250,000
Hutchinson	11,000,000	2,750,000	8,250,000
Lipscomb	18,000,000	4,500,000	13,500,000
Moore	10,000,000	2,500,000	7,500,000
Ochiltree	21,000,000	5,250,000	15,750,000
Oldham	2,000,000	500,000	1,500,000
Potter	1,900,000	475,000	1,425,000
Randall	4,800,000	1,200,000	3,600,000
Roberts	30,000,000	7,500,000	22,500,000
Sherman	18,000,000	4,500,000	13,500,000
Wheeler	7,000,000	1,750,000	5,250,000
Total	232,700,000	58,175,000	174,525,000

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)⁴ FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>Groundwater Conservation District</i>	<i>Total Storage (acre-feet)</i>	<i>25% of Total Storage (acre-feet)</i>	<i>75% of Total Storage (acre-feet)</i>
Hemphill County UWCD ⁵	15,000,000	3,750,000	11,250,000
High Plains UWCD No.1	3,100,000	775,000	2,325,000
North Plains GCD	130,000,000	32,500,000	97,500,000
Panhandle GCD	77,000,000	19,250,000	57,750,000
No District	9,600,000	2,400,000	7,200,000
Total	234,700,000	58,675,000	176,025,000

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 digits.

⁵ UWCD is the abbreviation for Underground Water Conservation District.

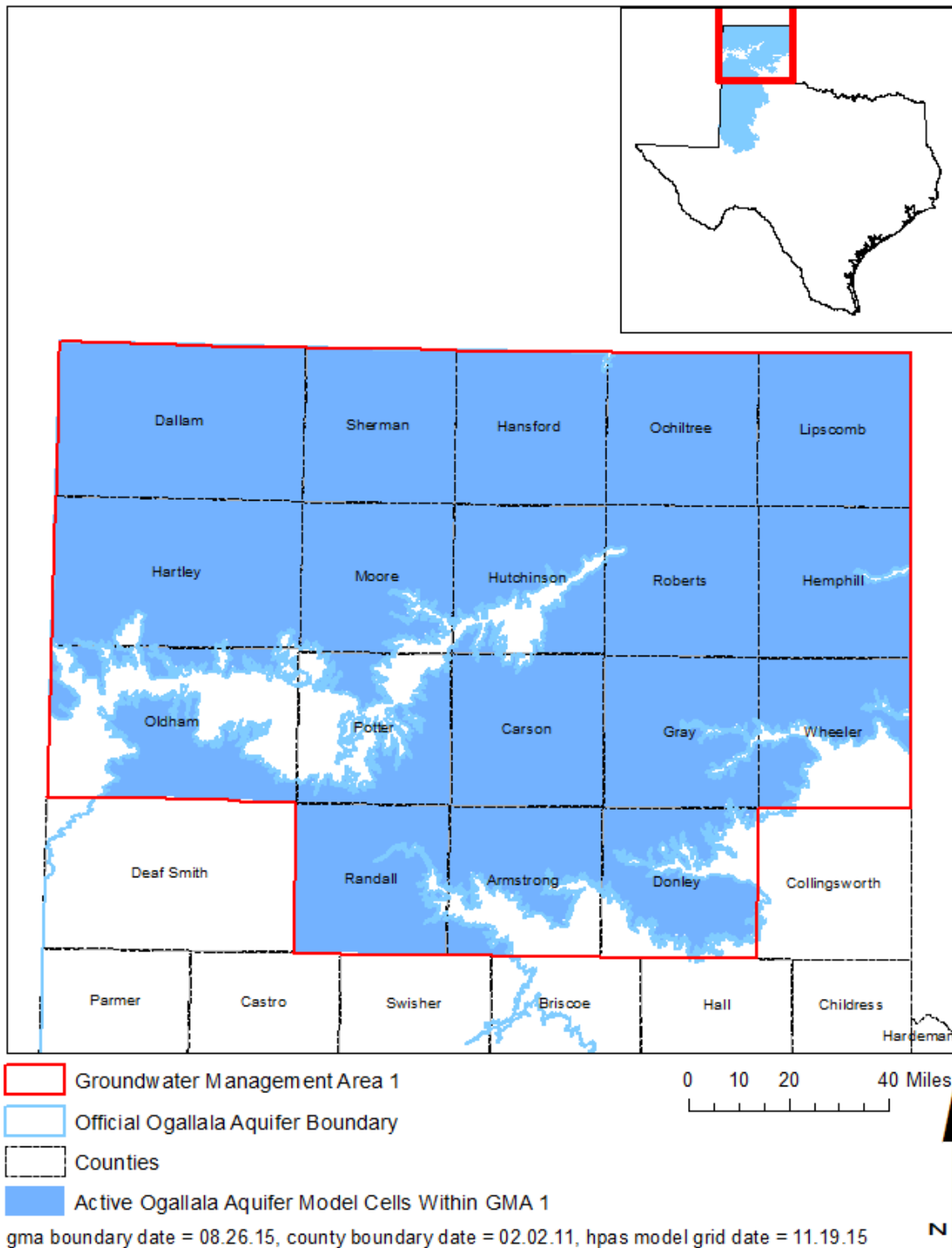


FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODELS OF OGALLALA AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>County</i>	<i>Total Storage (acre-feet)</i>	<i>25% of Total Storage (acre-feet)</i>	<i>75% of Total Storage (acre-feet)</i>
Donley	760	190	570
Total	760	190	570

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

<i>Groundwater Conservation District</i>	<i>Total Storage (acre-feet)</i>	<i>25% of Total Storage (acre-feet)</i>	<i>75% of Total Storage (acre-feet)</i>
Panhandle GCD	760	190	570
Total	760	190	570

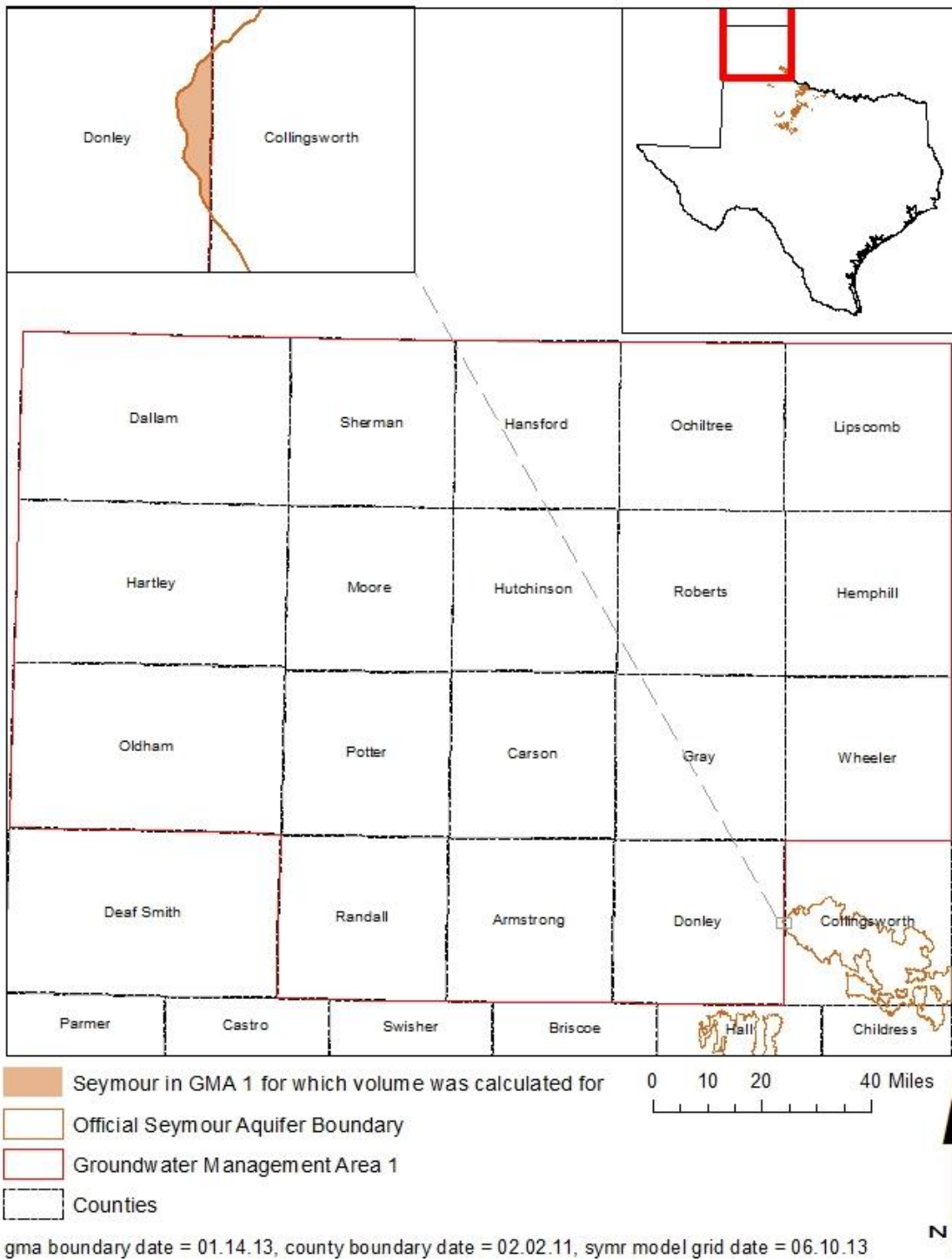


FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE SEYMOUR AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA 1.

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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