GAM Task 13-028: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 4

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January 15, 2014

The seals appearing on this document were authorized on January 10, 2014 by Radu Boghici, P.G. 482; Robert G. Bradley, P.G. 707; Ian C. Jones, P.G. 477; Jerry Shi, P.G. 11113; David Thorkildsen, P.G. 705; Cynthia K. Ridgeway, P.G. 471; and Rima Petrossian, P.G. 467. Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by Rohit Raj Goswami under her direct supervision. Rima Petrossian is the Manager of the Groundwater Technical Assistance Section and is responsible for oversight of work performed by Sarah Backhouse under her direct supervision.

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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 Igneous, West Texas Bolsons, Bone Spring-Victorio Peak, Capitan Reef Complex, Marathon, Upper Salt Basin, Edwards Trinity (Plateau), Pecos Valley, and Rustler aquifers within Groundwater Management Area 4. Tables 1 through 18 summarize the total estimated recoverable storage required by the statute. Figures 3 through 10 indicate the extent of the groundwater availability models, and/or of the non-modeled areas, 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.

The total recoverable storage was estimated for the portion of each aquifer within Groundwater Management Area 4 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, PARAMETERS, AND ASSUMPTIONS:

To estimate the total recoverable storage of an aquifer, we calculated the total volume of water within the official aquifer boundary in the groundwater management area.

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 less than the top of the aquifers. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure higher than 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

$$Total\ Storage \quad V_{drained} \quad Area \quad S \quad (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage \quad V_{confined} \quad V_{drained}$$

  - confined part

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

or

$$V_{confined} \quad Area \quad [\,S_s \quad (\ \ \mathrm{op} - \mathrm{Bottom}) \quad (Water\ Level - Top)]$$

  - unconfined part

$$V_{drained} \quad Area \quad [S \quad (Top - Bottom)]$$

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)

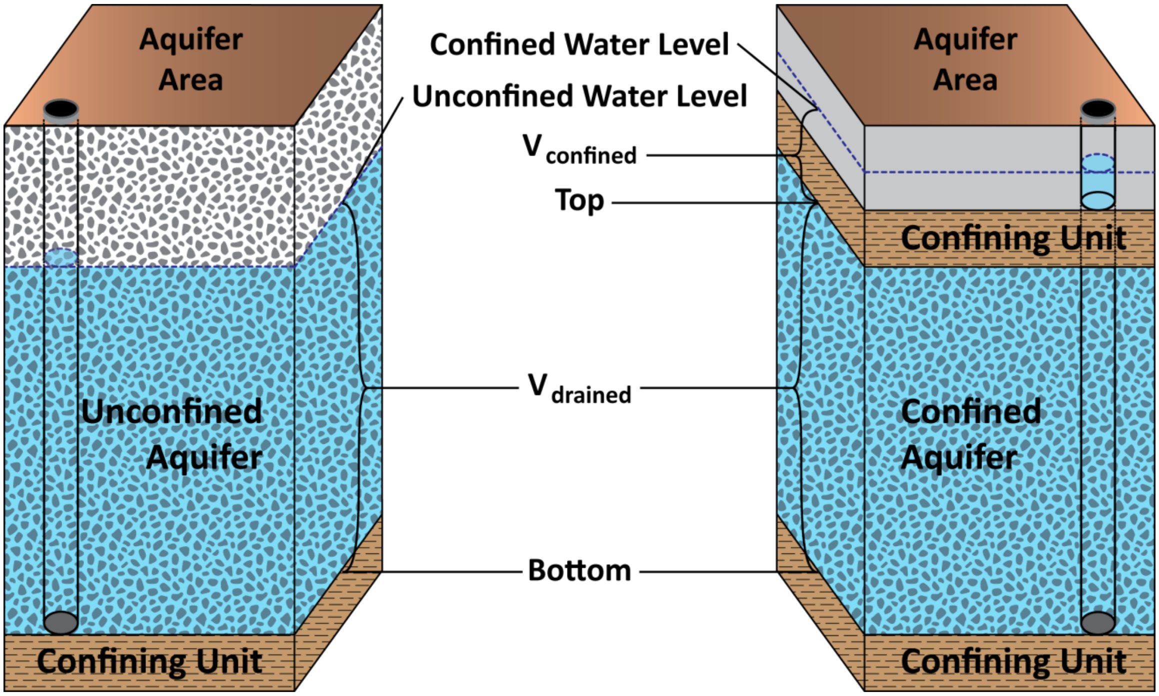

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 aquifers that had groundwater availability models in Groundwater Management Area 4, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. 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 of the total storage.

In the absence of groundwater availability models, the total storage was calculated using other approaches (see the methodologies used for the Capitan Reef Complex Aquifer, Marathon Aquifer, the Upper Salt Basin Formation, and marginal parts of the Igneous, West Texas Bolsons, Pecos Valley, Edwards-Trinity (Plateau), and Rustler aquifers). These approaches and methods are described on the following pages for each aquifer or set of multiple aquifers, as appropriate.

IGNEOUS AND WEST TEXAS BOLSONS (WILD HORSE FLAT, MICHIGAN FLAT, RYAN FLAT, LOBO FLAT, PRESIDIO AND REDFORD) AQUIFERS

To determine the total estimated recoverable storage in the areas covered by groundwater availability models, we used version 1.01 of the groundwater availability model for the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat) Aquifer and version 1.01 of the groundwater availability model for the West Texas Bolsons (Presidio and Redford) Aquifer. See Beach and others (2004), and Wade and Jigmond (2013) for assumptions and limitations of these models. The groundwater availability model for the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat) Aquifer includes three layers, representing the West Texas Bolsons (layer 1) and Igneous (layer 2) aquifers, and the underlying units (layer 3). Total estimated recoverable storage was determined using the cells in the model that represent the West Texas Bolsons (layer 1) and Igneous Aquifer (layer 2). The groundwater availability model for the West Texas Bolsons (Presidio and Redford) Aquifer includes three layers which generally represent the Rio Grande Alluvium (layer 1), the Presidio and Redford Bolsons (layer 2), and the underlying older rocks (layer 3). To develop the estimates for the total estimated recoverable storage, we used layer2 (the Presidio and Redford Bolsons).

We employed an alternate method, herein named *"The Method of the Wedges"*, to calculate total storage for parts of the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Presidio and Redford) Aquifer in Groundwater Management Area 4 that are within the official aquifer boundaries, but are not within the area of a groundwater availability model. The "Method of the Wedges" is based on the assumption that the non-modeled areas approximate the form of a right-wedge (Figure 2). These areas were not included in their respective groundwater availability models because they occur along the margins of the aquifers where the aquifer pinches out and is difficult to model (see Figures 3 and 4). Total storage was calculated by multiplying the volume of the assumed right-wedge by specific yields extracted from the model files, values ranging from 0.01 to 0.15.

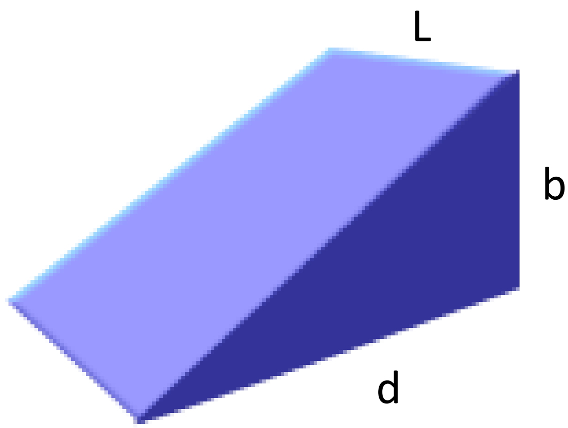

FIGURE 2. A SCHEMATIC OF THE RIGHT-WEDGE USED TO CALCULATE TOTAL STORAGE IN THE IGNEOUS AQUIFER IN GROUNDWATER MANAGEMENT AREA 4.

The volume of the right-edge was calculated using the formula:

$$V \quad 0.5 \quad b \quad L \quad d$$

Where:

- *b* = the average saturated thickness of the last row of active model cells bordering the "wedge";
- *L* = the length of the last row of active model cells bordering the "wedge"; and
- *d* = the average distance between the last row of active model cells and the aquifer boundary.

We computed the non-modeled areas' storage as by using *The Method of the Wedges*, and we added it to the groundwater availability model-derived storage.

West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) aquifer

To determine the total estimated recoverable storage in the areas covered by groundwater availability models, we used version 1.01 of the groundwater availability model for the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) Aquifer. See Beach and others (2008) for assumptions and limitations of the groundwater availability model. This groundwater availability model includes three layers. Layer 1 represents the bolson aquifer, while layers 2 and 3 represent strata underlying the bolson deposits of layer 1. Of the three layers, total estimated recoverable storage was determined for layer 1.

For the non-modeled portions of the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) aquifers, the aquifer structure and water level data were projected from modeled areas into the non-modeled areas. Recoverable storage in areas outside of the model but within the official aquifer boundaries (see Figure 4) was estimated by first establishing a relationship between aquifer thickness and saturated thickness. The aquifer thickness is the difference between the elevations of the aquifer top and base, and saturated thickness is the difference between the water table and aquifer base elevations. We determined that there is a polynomial relationship between aquifer thickness and saturated thickness in the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) Aquifer. The relationship between saturated thickness (*Hsat*) and aquifer thickness (*H*) is described by the following equation:

$$Hsat = 0.0001 \times H^2 + 0.485 \times H$$

We computed the non-modeled areas' storage by multiplying *Hsat* by the aquifer surface area by a specific yield of 0.06, which was derived from the model files. We added the non-modeled areas storage to the groundwater availability model-derived storage.

The combined storage estimates for West Texas Bolsons (Red Light Draw, Green River Valley, Eagle Flat, Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Presidio and Redford) Aquifer, calculated as described here and in the preceding section, are shown in Tables 3 and 4.

BONE SPRING-VICTORIO PEAK AQUIFER

We used the preliminary groundwater flow model for the Dell City Area (Hudspeth and Culberson counties, Texas) developed by El Paso Water Utilities (Hutchinson, 2008) to estimate the total recoverable storage for the Bone Spring-Victorio Peak Aquifer (Figure 5). See Hutchison (2008) for assumptions and limitations of this groundwater flow model. This groundwater flow model includes one layer, which represents the confined Bone Spring-Victorio Peak Aquifer. The specific yield values were not included in the model Layer-Property Flow package as the groundwater flow model simulated all hydrostratigraphic units as confined aquifers. The specific yield values for the Bone Springs-Victorio Peak Aquifer were obtained from groundwater storage zones database provided with groundwater modeling files by

Hutchison (2008). The specific yield values ranged from 0.01 to 0.019 and were assigned to the various cells as per their respective zonation.

The total estimated recoverable storage was initially determined for the Bone Spring-Victorio Peak Aquifer (layer 1) as volumes for three alternative scenarios (see Hutchison, 2008). These alternative-scenario volumes were then averaged to obtain the total estimated recoverable storage presented in this report, as product of storage volume and an estimated factor ranging from 25 percent to 75 percent.

CAPITAN REEF COMPLEX AQUIFER

The Capitan Reef Complex Aquifer in Groundwater Management Area 4 does not yet have a groundwater availability model. For this aquifer, we used surfaces for the aquifer top and base constructed by Standen and others (2009). Due to insufficient water-level data to construct a water-level map we calculated total storage for the Capitan Reef Complex Aquifer assuming that $V_{confined}$ is very small relative to $V_{drained}$ and is, therefore, insignificant. The justification for this assumption is that the aquifer thickness and specific yield used to calculate the unconfined part of the total storage are much larger than the confined head—difference between the water level and aquifer top elevations—and the storativity or specific storage used to calculate the confined part of the total storage. No storage data were available for the area. We estimated the specific yield to be 0.05 based on borehole geophysics data for the Capitan Reef Complex Aquifer (Garber and others, 1989).

The total storage was calculated for each cell by multiplying cell area, aquifer thickness and the specific yield of 0.05.We extracted the aquifer top and base data using a grid with 1 square mile cells (Figure 6) and calculated total storage for each cell.

MARATHON AQUIFER

The Marathon Aquifer (Figure 7) occurs entirely within north-central Brewster County within Groundwater Management Area 4.Water in the aquifer is under unconfined conditions within fractures, joints, and cavities (George and others, 2011).

We used an estimated average saturated thickness of 200 feet and specific yield of 0.03 (Far West Texas RWPG, 2001) to calculate total estimated recoverable storage by multiplying the aquifer areal extent by the saturated thickness and by the specific yield.

THE UPPER SALT BASIN FORMATION

The delineation of the Upper Salt Basin Formation (Figure 8) was based on information provided by the Culberson County Underground Water Conservation District. The Upper Salt Basin Formation does not have a groundwater availability model.

The Upper Salt Basin Formation within Groundwater Management Area 4 is assumed to be under water-table conditions within Culberson County. The aquifer-wide saturated thickness was estimated to be 440 feet, based on the minimum saturated thickness calculated in each well. The specific yield of the aquifer was estimated as 0.06 based on values from the adjacent groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers (Beach and others 2004). The saturated thickness of the aquifer was calculated by subtracting the elevation of the base of the Upper Salt Basin (see Beach and others 2004; Gates and others, 1980; Standen and others, 2009; and TWDB, 2013 for base elevations) from the elevation of each water level measurement available in the TWDB groundwater database wells (2013).

The total estimated recoverable storage was calculated by multiplying the aquifer areal extent by the saturated thickness and by the specific yield.

EDWARDS-TRINITY (PLATEAU) AND PECOS VALLEY AQUIFERS

We first used the alternative one-layer numerical flow model (Hutchison and others, 2011) to compute the recoverable storage in the modeled areas of the Edwards-Trinity (Plateau) and Pecos Valley Aquifers. Specific yield values were obtained from the storage values database from groundwater modeling files (Hutchison and others, 2011).

Some portions of the Pecos Valley and Edwards-Trinity (Plateau) aquifers in Groundwater Management Area 4 were not included in the one-layer alternative groundwater flow model covering these aquifers (Hutchison and others, 2011). The aquifers in these areas (see Figure 9) are relatively thin and mostly restricted to the western margins of the area. As was done for the West Texas Bolsons, the recoverable storage in the Pecos Valley and Edwards-Trinity

(Plateau) aquifers outside of the model but within the official aquifer boundaries was estimated by first establishing a relationship between aquifer thickness and saturated thickness. In the Edwards-Trinity (Plateau) and Pecos Valley aquifers there is a generally linear relationship between aquifer thickness (*H*) and saturated thickness (*Hsat*). We found that the relationship between saturated thickness (*Hsat*)and aquifer thickness (*H*) is described by the following equation for the Edwards-Trinity (Plateau) Aquifer:

$Hsat = 0.9 \times H$

and by the following equation for the Pecos Valley Aquifer:

$Hsat = 0.8 \times H$

The non-modeled portions of the Pecos Valley and Edwards-Trinity (Plateau) aquifers were assumed to be unconfined. Consequently, storage in each model cell representing parts of the respective aquifers excluded from the groundwater flow model was estimated using the following equation:

$$Total\ Storage = V_{drained} = Area \times S_y \times H_{sat}$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- *Area* = area of aquifer (acre)
- S_y = specific yield (no units)
- H_{sat} = estimated saturated thickness (feet)

Storage volumes estimated using this method were added to the storage volumes from the modeled area, where applicable, to estimate the total recoverable storage for the entire aquifers.

Rustler Aquifer

For the Rustler Aquifer, we used version 1.01 of the groundwater availability model for the Rustler Aquifer to estimate the total recoverable storage. See Ewing and others (2012) for assumptions and limitations of the groundwater availability model. This groundwater availability model includes two numerical layers which represent Dockum Aquifer/Dewey Lake

Formation (Layer 1) and Rustler Aquifer (Layer 2). Model Layer 2 was used to calculate the total estimated recoverable storage for the Rustler Aquifer.

Parts of the Rustler Aquifer in Brewster and Jeff Davis counties that are not included in the modeled area in Groundwater Management Area 4 (see Figure 10) were addressed using an analytical method as follows:

First, we calculated the total aquifer volume by using the equation:

$$\textit{Total Aquifer Volume} = \textit{Aquifer Area} \times \textit{Aquifer Average Thickness}$$

The aquifer area was estimated using ArcGIS 10 and the aquifer average thickness was estimated to be approximately 50 feet, based on the Rustler Groundwater Availability Model report. Next, we calculated the total aquifer storage using the following equation:

$$\textit{Total Aquifer Storage} = \textit{Total Aquifer Volume} \times \textit{Aquifer Specific Yield}$$

The specific yield was assigned a value of 0.03 (see LBG-Guyton Associates, 2003).

We computed the non-modeled areas' storage as by using the analytical method described above, and we added it to the groundwater availability model-derived storage.

RESULTS:

Tables 1 through 18 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded to two significant figures. Figures 3 through 10 indicate the extent of the groundwater availability models and/or of the non-modeled areas in Groundwater Management Area 4 for the Igneous Aquifer and West Texas Bolsons Aquifer (Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Red Light Draw, Green River Valley, Eagle Flat, Presidio and Redford bolsons), Bone Spring-Victorio Peak Aquifer, Capitan Reef Complex, Marathon Aquifer, Upper Salt Basin, Edwards-Trinity (Plateau) Aquifer, Pecos Valley Aquifer, and Rustler Aquifer from which the storage information was calculated.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE IGNEOUS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster	5,300,000	1,325,000	3,975,000
Culberson	760,000	190,000	570,000
Jeff Davis	24,000,000	6,000,000	18,000,000
Presidio	34,000,000	8,500,000	25,500,000
Total	**64,060,000**	**16,015,000**	**48,045,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE IGNEOUS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster County GCD	5,300,000	1,325,000	3,975,000
Culberson County GCD	760,000	190,000	570,000
Jeff Davis Co. UWCD[2]	24,000,000	6,000,000	18,000,000
Presidio County UWCD	34,000,000	8,500,000	25,500,000
Total	**64,060,000**	**16,015,000**	**48,045,000**

[2] UWCD is the abbreviation for Underground Water Conservation District

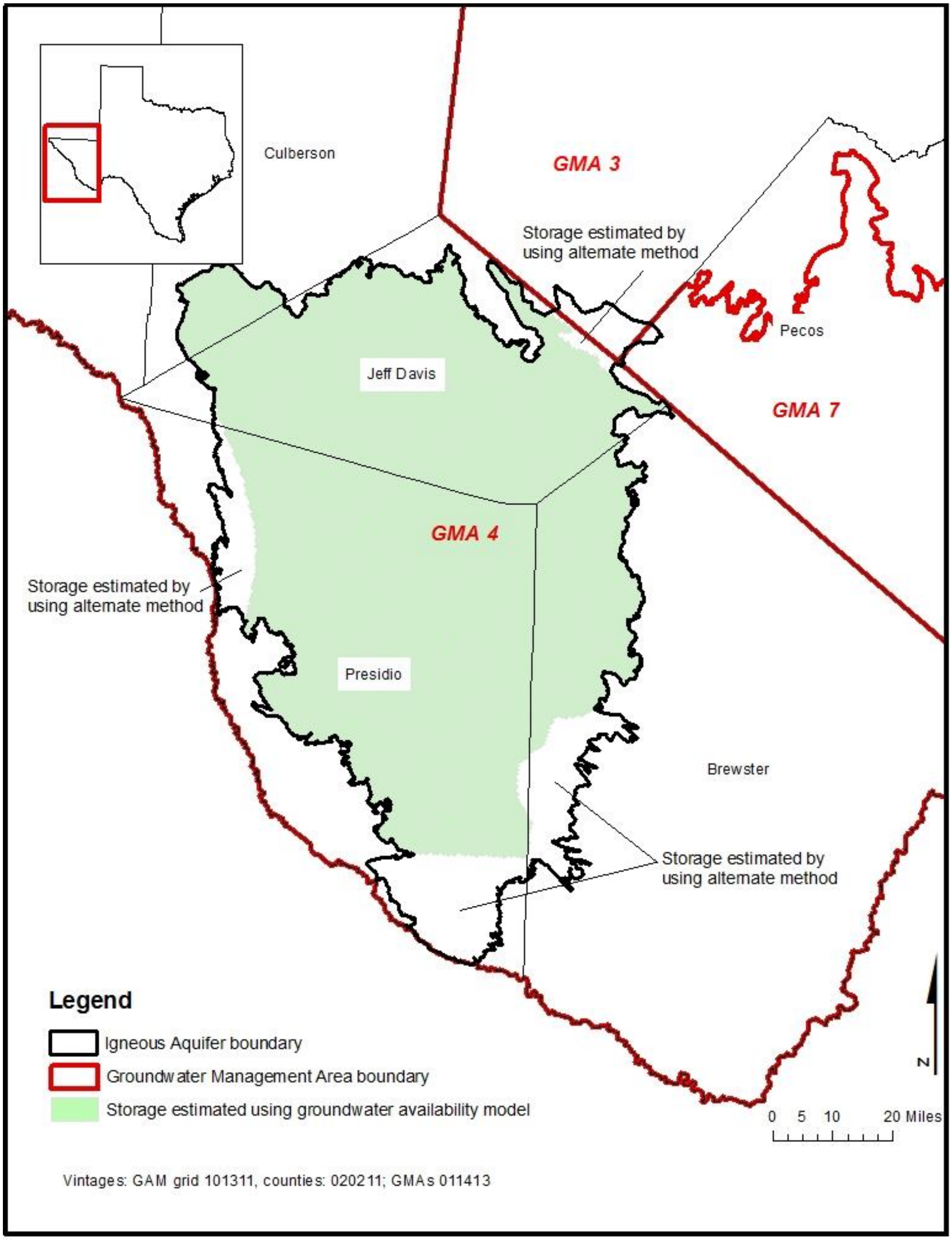

FIGURE 3. EXTENT OF THE IGNEOUS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 4.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE WEST TEXAS BOLSONS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Culberson	5,400,000	1,350,000	4,050,000
Hudspeth	6,800,000	1,700,000	5,100,000
Jeff Davis	4,200,000	1,050,000	3,150,000
Presidio	35,000,000	8,750,000	26,250,000
Total	**51,400,000**	**12,850,000**	**38,550,000**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE WEST TEXAS BOLSONS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Culberson County GCD	5,400,000	1,350,000	4,050,000
Jeff Davis Co. UWCD[3]	4,200,000	1,050,000	3,150,000
Presidio County UWCD	35,000,000	8,750,000	26,250,000
No District	6,800,000	1,700,000	5,100,000
Total	**51,400,000**	**12,850,000**	**38,550,000**

[3] UWCD is the abbreviation for Underground Water Conservation District

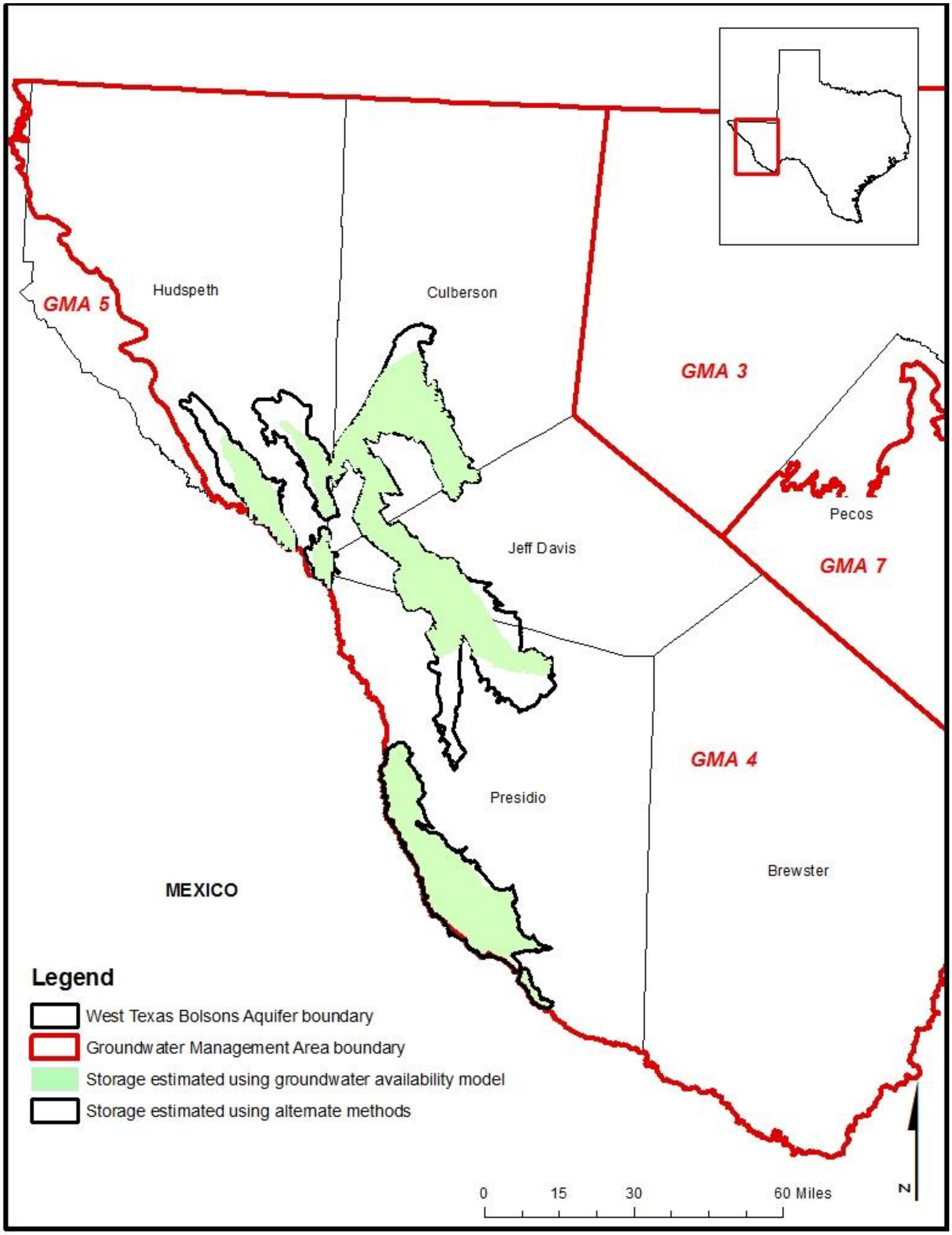

FIGURE 4. EXTENT OF THE WEST TEXAS BOLSONS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 4.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BONE SPRING-VICTORIO PEAK AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT 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)*
Hudspeth	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE BONE SPRING-VICTORIO PEAK AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Hudspeth County UWCD[4] No. 1	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

[4] UWCD is the abbreviation for Underground Water Conservation District

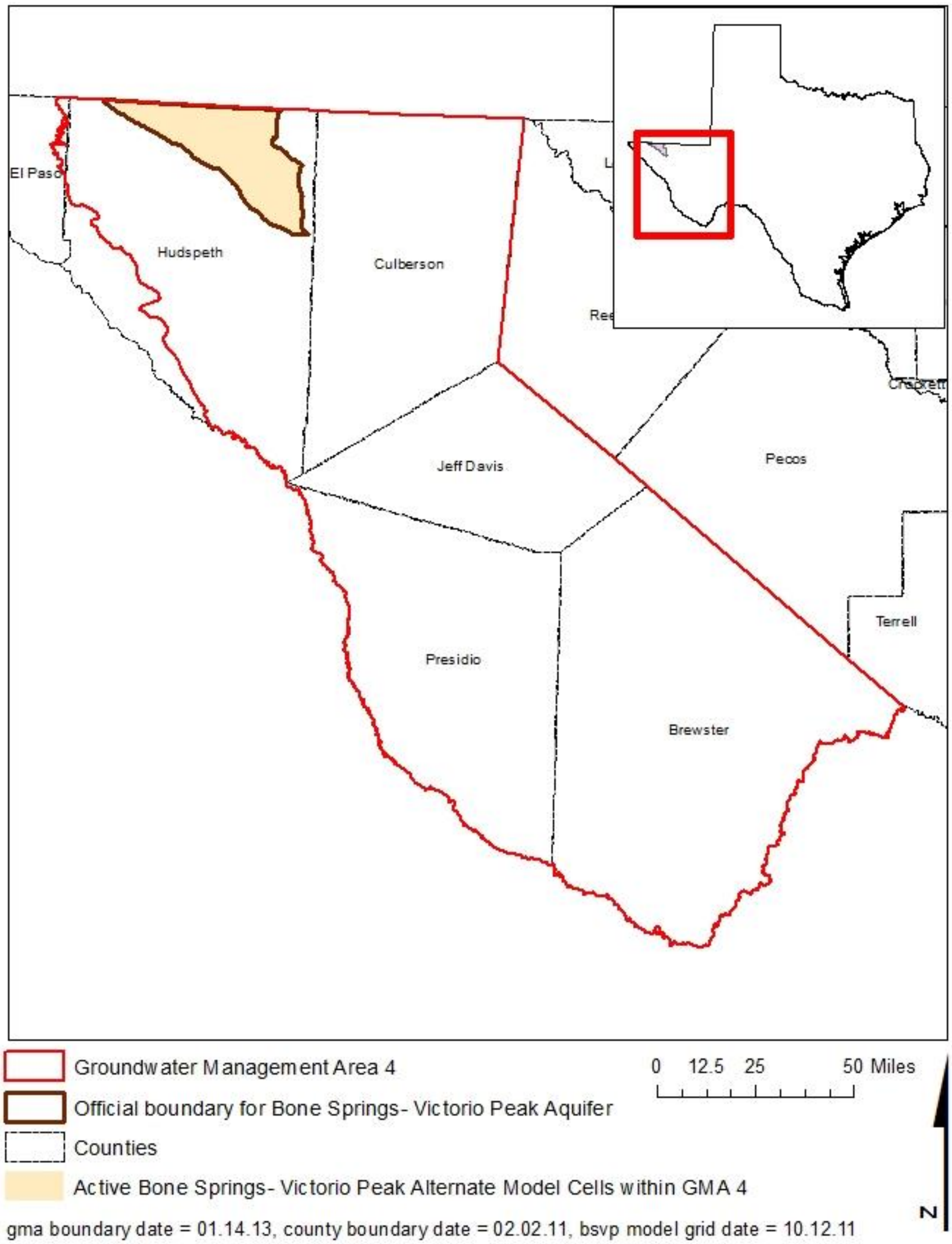

FIGURE 5. EXTENT OF THE BONE SPRING-VICTORIO PEAK AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CAPITAN AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster	2,500,000	625,000	1,875,000
Culberson	21,000,000	5,250,000	15,750,000
Hudspeth	1,100,000	275,000	825,000
Jeff Davis	760,000	190,000	570,000
Total	**25,360,000**	**6,340,000**	**19,020,000**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE CAPITAN AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster County GCD	2,500,000	625,000	1,875,000
Culberson County GCD	15,000,000	3,750,000	11,250,000
Jeff Davis Co. UWCD[5]	760,000	190,000	570,000
No District	7,300,000	1,825,000	5,475,000
Total	**25,560,000**[6]	**6,390,000**	**19,170,000**

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[5] UWCD is the abbreviation for Underground Water Conservation District

[6] Note: Due to rounding to two significant figures, the total storage by county differs from the total storage by groundwater conservation district.

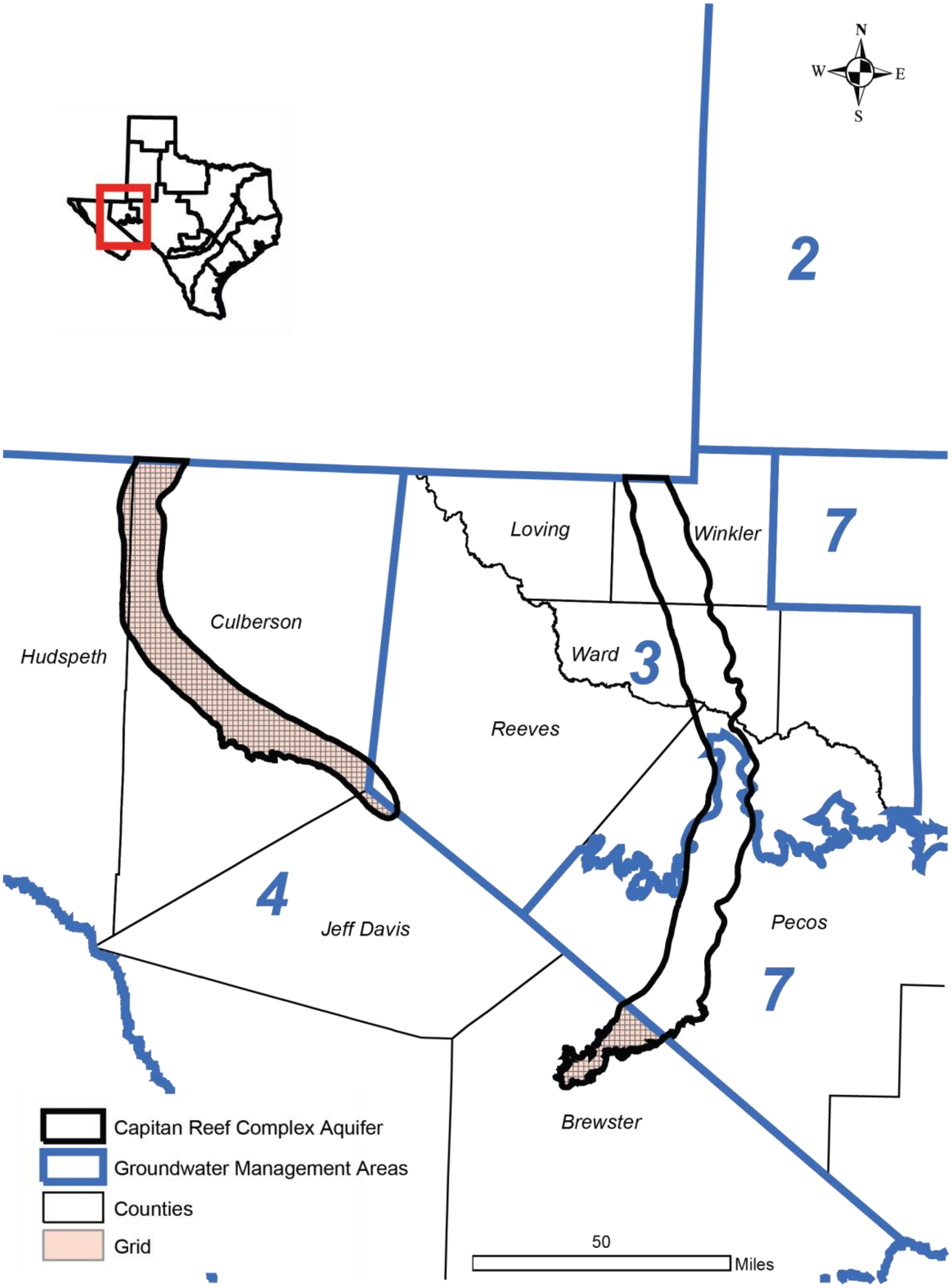

FIGURE 6. EXTENT OF THE THE CAPITAN REEF COMPLEX AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE MARATHON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster	1,500,000	375,000	1,125,000
Total	**1,500,000**	**375,000**	**1,125,000**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE MARATHON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster County GCD	1,500,000	375,000	1,125,000
Total	**1,500,000**	**375,000**	**1,125,000**

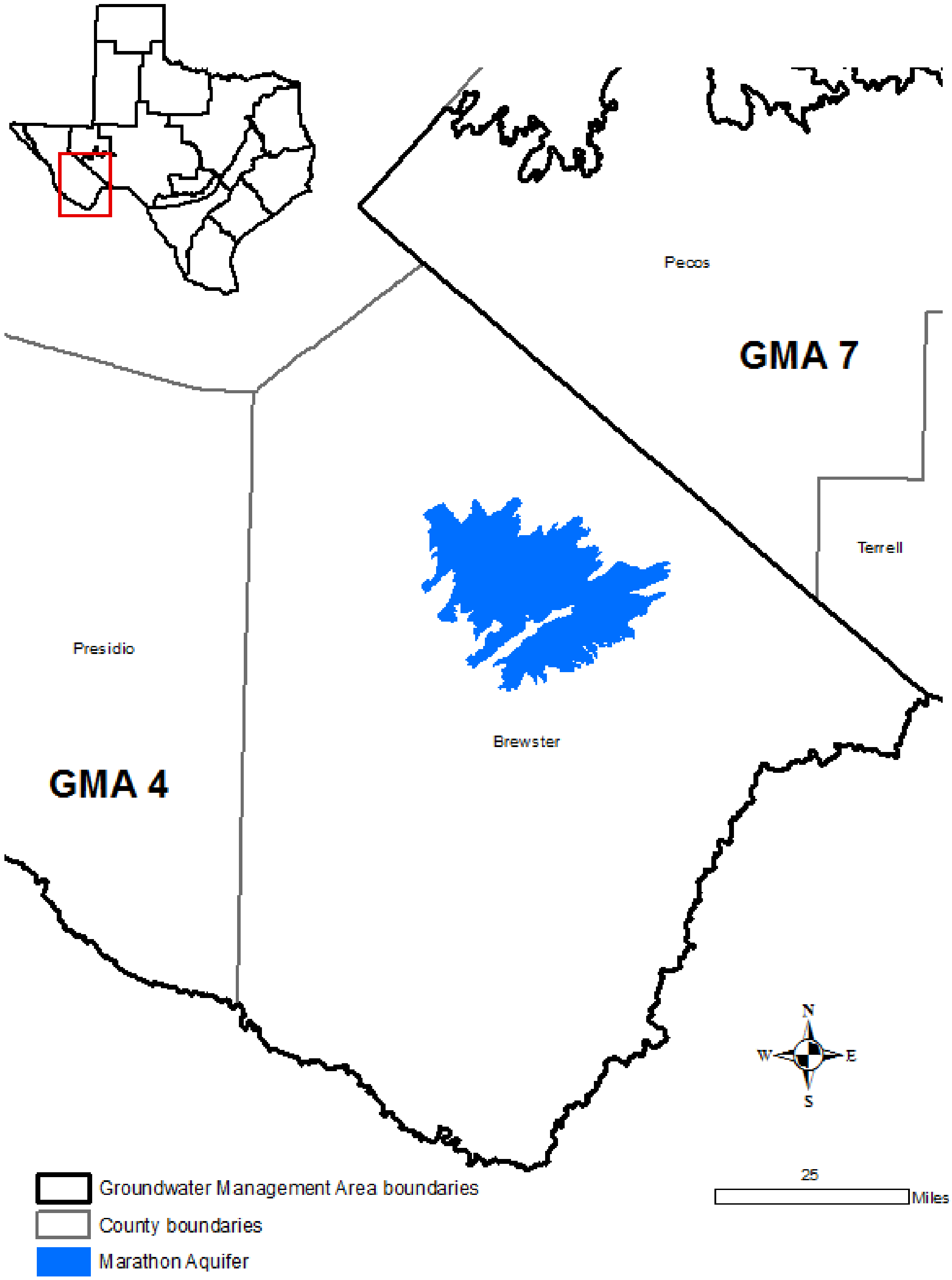

FIGURE 7. EXTENT OF THE MARATHON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE UPPER SALT BASIN WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT 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)*
Culberson	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE UPPER SALT BASIN WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Culberson County GCD	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

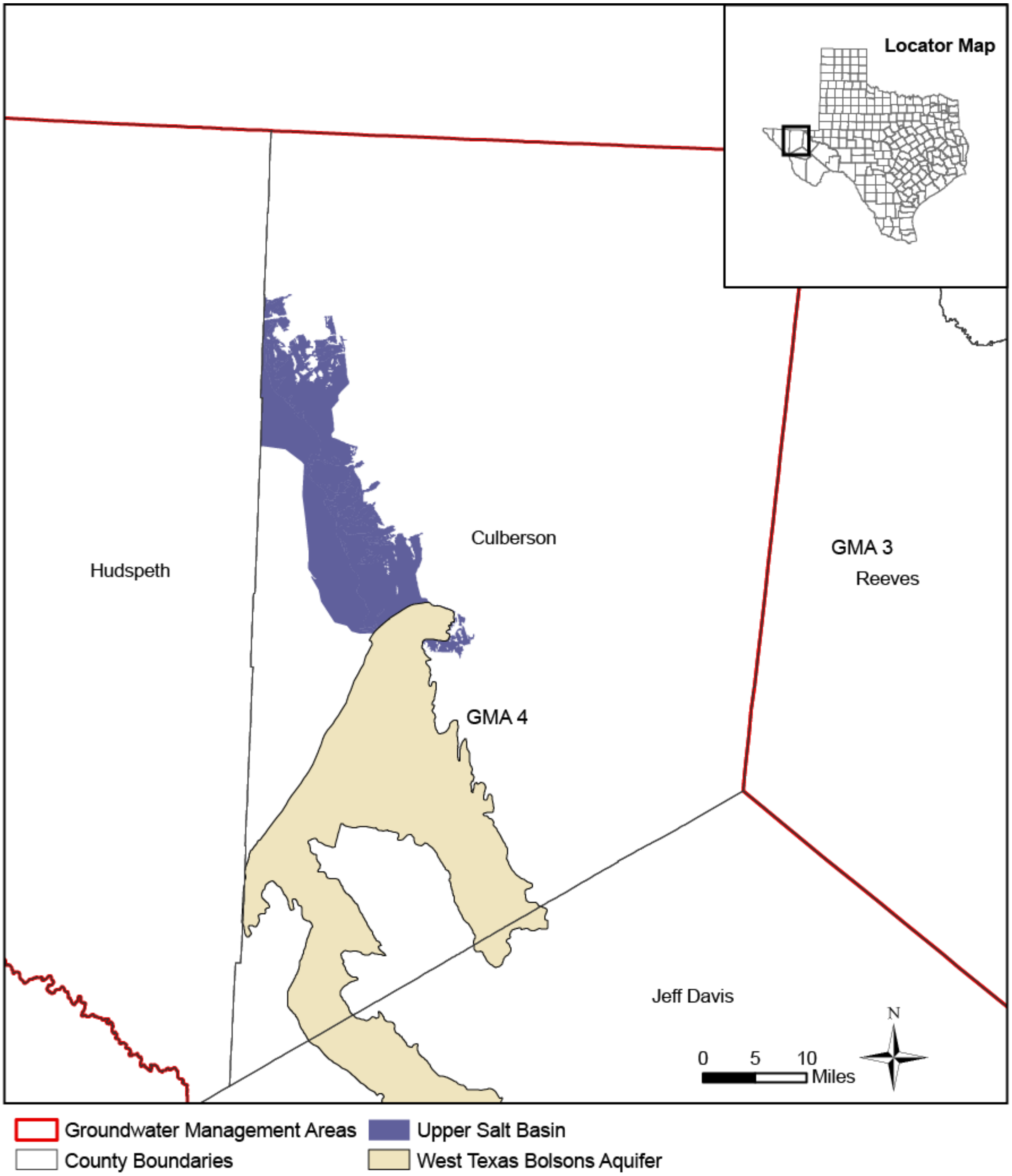

FIGURE 8. EXTENT OF THE UPPER SALT BASIN USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster	2,600,000	650,000	1,950,000
Culberson	470,000	117,500	352,500
Jeff Davis	710,000	177,500	532,500
Total	**3,780,000**	**945,000**	**2,835,000**

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster County GCD	2,600,000	650,000	1,950,000
Culberson County GCD	210,000	52,500	157,500
Jeff Davis Co. UWCD[7]	710,000	177,500	532,500
No District	260,000	65,000	195,000
Total	**3,780,000**	**945,000**	**2,835,000**

[7] UWCD is the abbreviation for Underground Water Conservation District

TABLE 15. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Culberson	750,000	187,500	562,500
Jeff Davis	740,000	185,000	555,000
Total	**1,490,000**	**372,500**	**1,117,500**

TABLE 16. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Jeff Davis Co. UWCD[8]	740,000	185,000	555,000
No District	750,000	187,500	562,500
Total	**1,490,000**	**372,500**	**1,117,500**

[8] UWCD is the abbreviation for Underground Water Conservation District

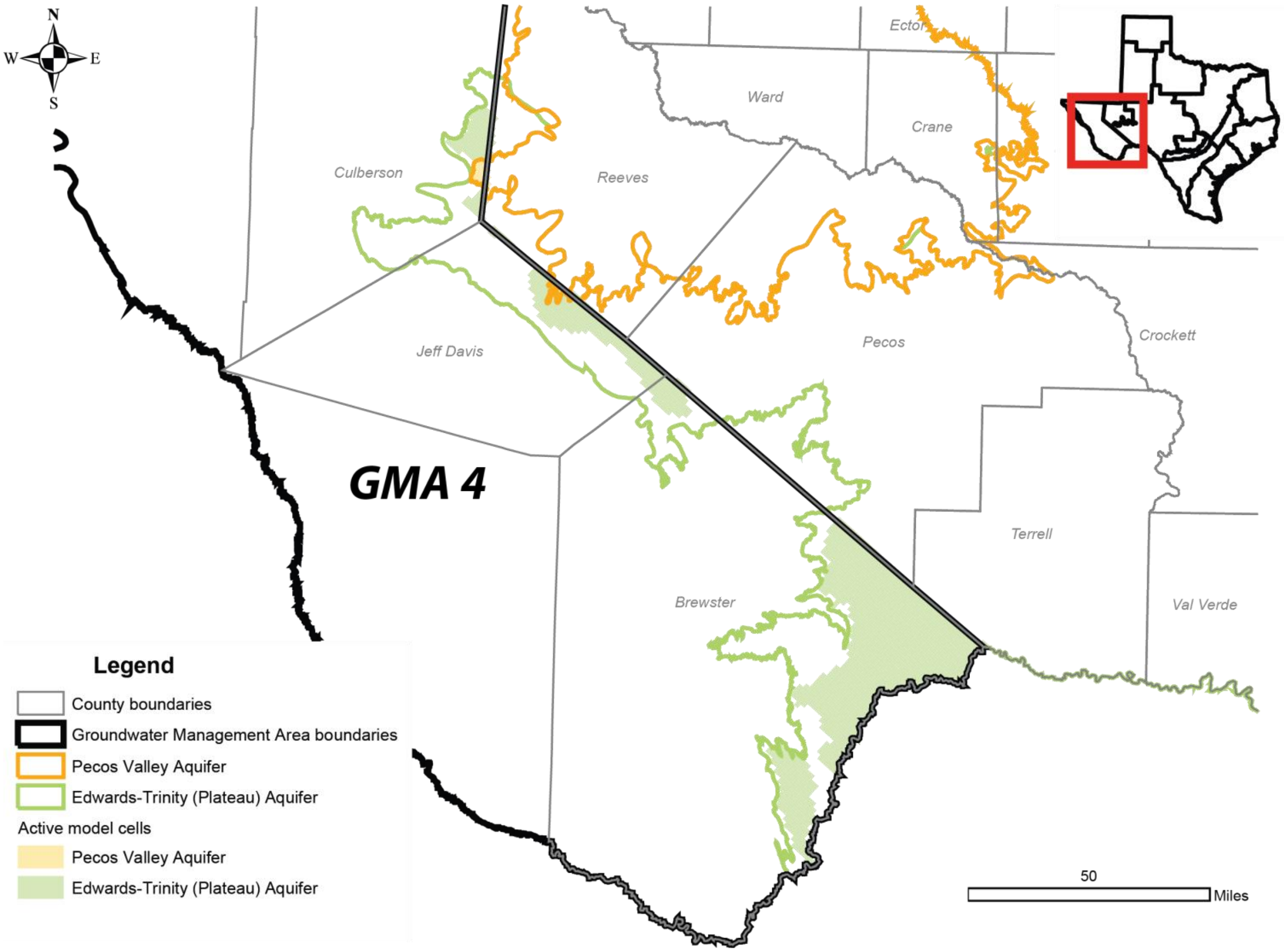

FIGURE 9. EXTENT OF THE EDWARDS-TRINITY (PLATEAU) AND PECOS VALLEY AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 THROUGH 16) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 17. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE RUSTLER AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster	53,000	13,250	39,750
Culberson	4,200,000	1,050,000	3,150,000
Jeff Davis	670,000	167,500	502,500
Total	**4,923,000**	**1,230,750**	**3,692,250**

TABLE 18. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE RUSTLER AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. 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)*
Brewster County GCD	53,000	13,250	39,750
Jeff Davis Co. UWCD[9]	670,000	167,500	502,500
No District	4,200,000	1,050,000	3,150,000
Total	**4,923,000**	**1,230,750**	**3,692,250**

[9] UWCD is the abbreviation for Underground Water Conservation District

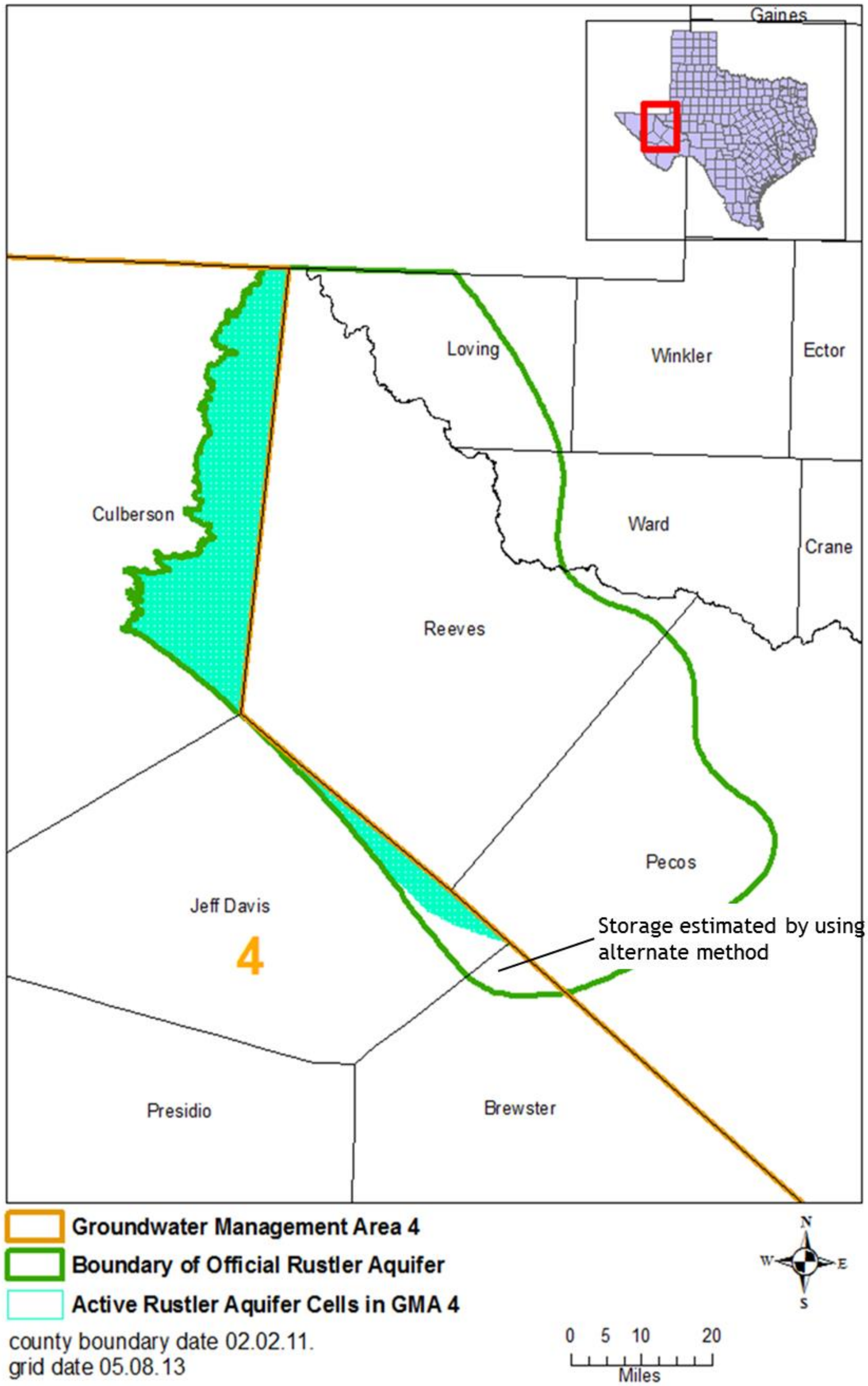

FIGURE 10. EXTENT OF THE RUSTLER AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 17 AND 18) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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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