GAM Run 12-025: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 16

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March 28, 2013

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EXECUTIVE SUMMARY:

Texas Water Code, § 36.108 (d) 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 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 Carrizo-Wilcox, Yegua-Jackson, and Gulf Coast (including parts of the Catahoula Formation) aquifers within groundwater management area 16. Tables 1 through 7 summarize the total estimated recoverable storage required by the statute. Figures 2 through 4 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 only 25 to 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 published in the 2007 State Water Plan. 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.

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 outside the well or in the aquifer. 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

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

  - 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)

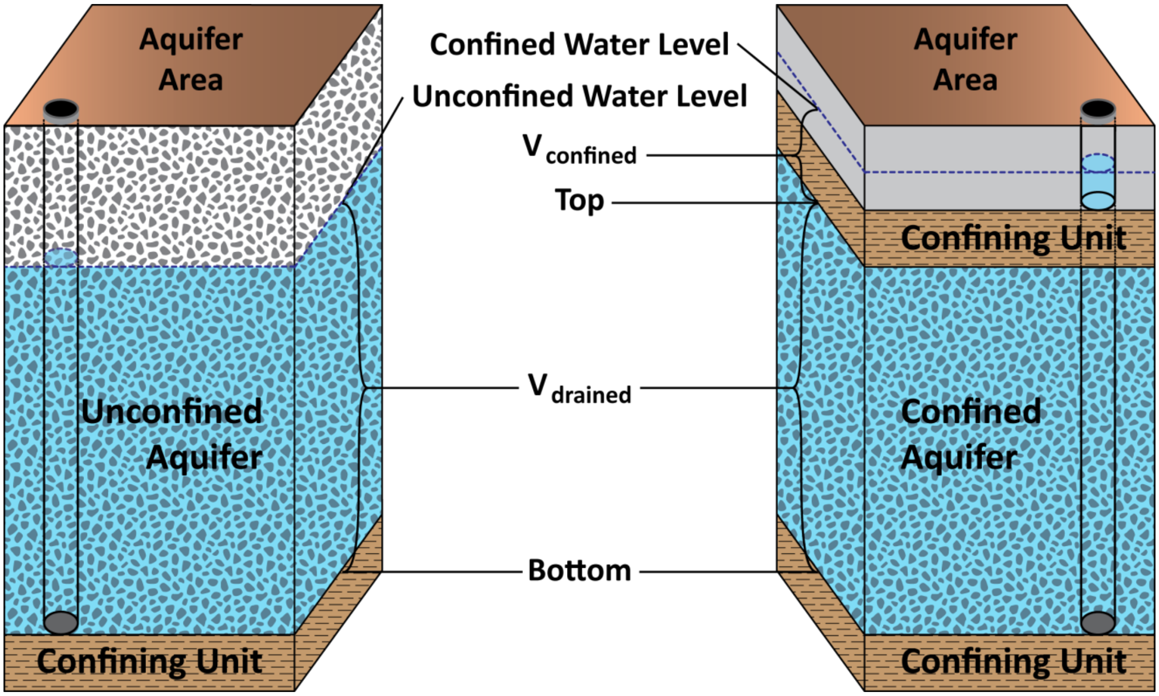

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 groundwater management area 16, we extracted this information from existing groundwater availability models. This information was contained in 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. 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:

Carrizo-Wilcox, Queen City, and Sparta aquifers

- We used version 2.01 of the groundwater availability model for the southern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers to estimate the total recoverable storage of the Carrizo-Wilcox Aquifer. The Sparta and Queen City aquifers are not present in groundwater management area 16, so these aquifers were not included in this analysis. See Deeds and others (2003) and Kelley and others (2004) for assumptions and limitations of the groundwater availability model for the southern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers.
- This groundwater availability model includes eight layers which generally represent the Sparta Aquifer (Layer 1), the Weches Confining Unit (Layer 2), the Queen City Aquifer (Layer 3), the Reklaw Confining Unit (Layer 4), the Carrizo Aquifer (Layer 5), the Upper Wilcox Formation (Layer 6), the Middle Wilcox Formation (Layer 7), and the Lower Wilcox Formation (Layer 8). To develop the estimates for the total estimated recoverable storage, we used layers 5 through 8 (Carrizo-Wilcox Aquifer system).
- The down-dip boundary of the model is based on the location of the Wilcox Growth Fault Zone which is considered to be a barrier to flow (Kelley and others, 2004). This boundary is relatively deep and in the portion of the aquifer that is characterized as brackish to saline; consequently, the model includes parts of the formation beyond potable portions of the aquifer. The groundwater in the Carrizo-Wilcox, Queen City, and Sparta aquifers ranges from fresh to brackish in composition (Kelley and others, 2004).

Yegua-Jackson Aquifer

- We used version 1.01 of the groundwater availability model to estimate the total recoverable storages of the Yegua-Jackson Aquifer and the Catahoula Formation. See Deeds and others (2010) for assumptions and limitations of the groundwater availability model.

- This groundwater availability model includes five layers which represent the outcrop section for the Yegua-Jackson Aquifer and the Catahoula Formation and other younger overlying units (Layer 1), the upper portion of the Jackson Group (Layer 2), the lower portion of the Jackson Group (Layer 3), the upper portion of the Yegua Group (Layer 4), and the lower portion of the Yegua Group (Layer 5). To develop the estimates for the total estimated recoverable storage in the Yegua-Jackson Aquifer, we used layers 1 through 5; however, we only used model cells in layer 1 that represent the outcrop area of the Yegua-Jackson Aquifer. We also used selected model cells in layer 1 to develop the estimates for the total estimated recoverable storage in the Catahoula Formation, which is considered part of the Gulf Coast Aquifer system.
- The down-dip boundary for the Yegua-Jackson 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 (Deeds and others, 2010). Consequently, the model extends into zones of brackish and saline groundwater.

Gulf Coast Aquifer

- We used the alternative model (of the Gulf Coast Aquifer) for groundwater management area 16 to estimate the total recoverable storage of the Gulf Coast Aquifer. See Hutchison and others (2011) for assumptions and limitations of the model.
- The groundwater flow model encompasses the boundaries of groundwater management area 16. The model includes portions of the underlying Gulf Coast, Yegua-Jackson, and Sparta, Queen City, and Carrizo-Wilcox aquifer systems. Layers 1 through 4 represent the Gulf Coast Aquifer system which is comprised of the Chicot Aquifer, Evangeline Aquifer, Burkeville confining unit, and Jasper Aquifer in descending order. Layer 5 is a bulk representation of the Yegua-Jackson Aquifer System including parts of the Catahoula Formation and layer 6 is a bulk representation of the Sparta, Queen-City, Carrizo-Wilcox aquifers (Hutchison and others, 2011).To develop the estimate for the total estimated recoverable storage, we used layers 1 through 4 (Gulf Coast Aquifer system). We used the Yegua-

Jackson Aquifer model for the Catahoula Formation, which is considered part of the Gulf Coast Aquifer system. These values are reported separately.

- The down-dip extents for all aquifer systems in this model are based on previously developed groundwater availability models of the Gulf Coast Aquifer central (Chowdhury and others, 2004) and southern (Chowdhury and Mace, 2007) portions, Yegua-Jackson Aquifer (Deeds and others, 2010), and Sparta, Queen City, and Carrizo-Wilcox aquifers southern portion (Kelley and others, 2004). As such, these model layers extend well past the slightly saline water line and into zones of brackish and saline groundwater.

RESULTS:

Tables 1 through 7 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded within one percent of the total. Figures 2 through 4 indicate the area of the groundwater availability models from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY AND GROUNDWATER CONSERVATION DISTRICT FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	4,700,000	1,175,000	3,525,000
Live Oak	89,000,000	22,250,000	66,750,000
McMullen	11,000,000	2,750,000	8,250,000
Total	**104,700,000**	**26,175,000**	**78,525,000**

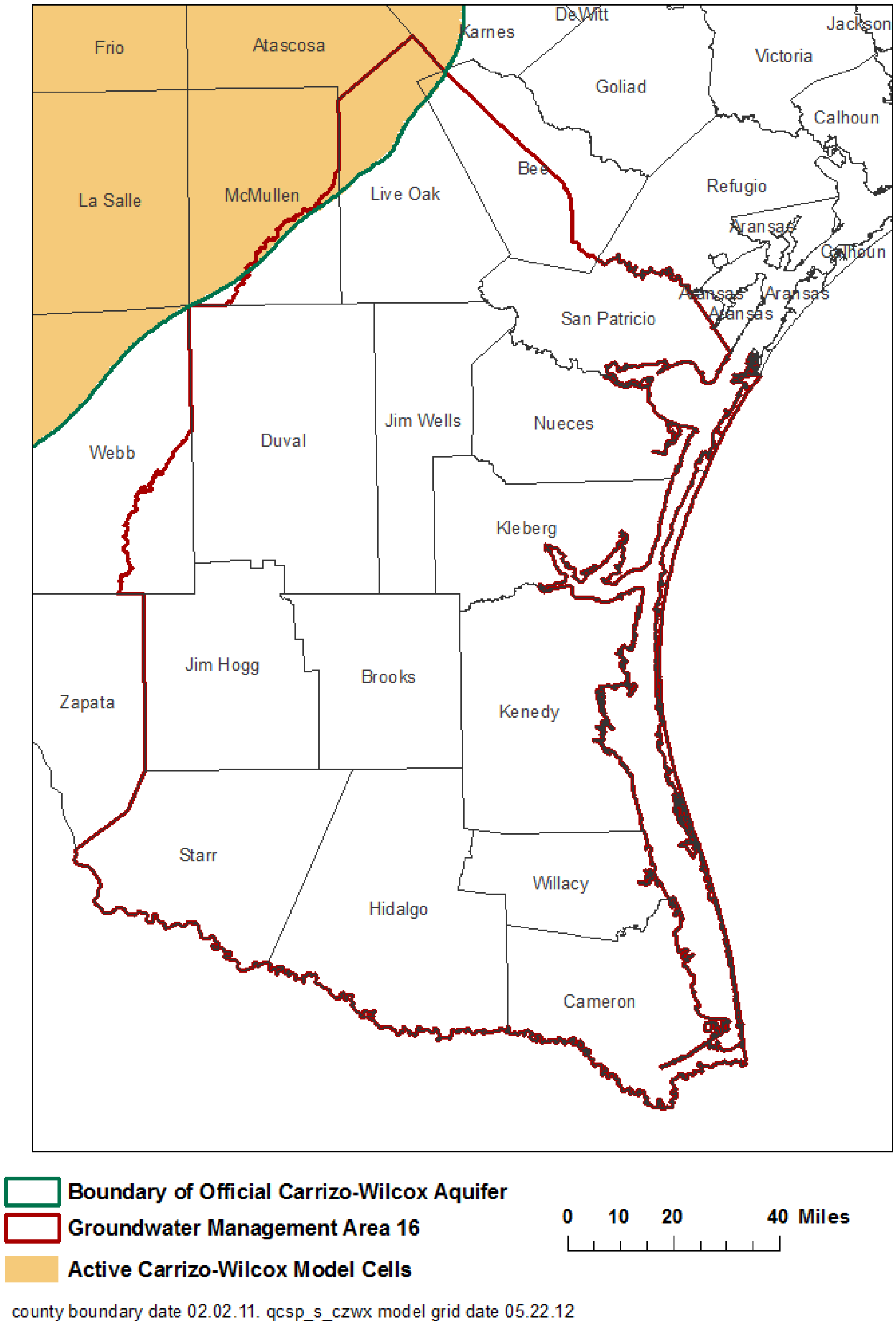

FIGURE 2. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLE 1) FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16.

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Duval	7,200,000	1,800,000	5,400,000
Jim Hogg	3,000,000	750,000	2,250,000
Live Oak	11,000,000	2,750,000	8,250,000
Starr	46,000,000	11,500,000	34,500,000
Webb	820,000	205,000	615,000
Total	**68,020,000**	**17,005,000**	**51,015,000**

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Brush Country	3,000,000	750,000	2,250,000
Duval County	7,200,000	1,800,000	5,400,000
Live Oak	11,000,000	2,750,000	8,250,000
Starr County	46,000,000	11,500,000	34,500,000
No District	820,000	205,000	615,000
Total	**68,020,000**	**17,005,000**	**51,015,000**

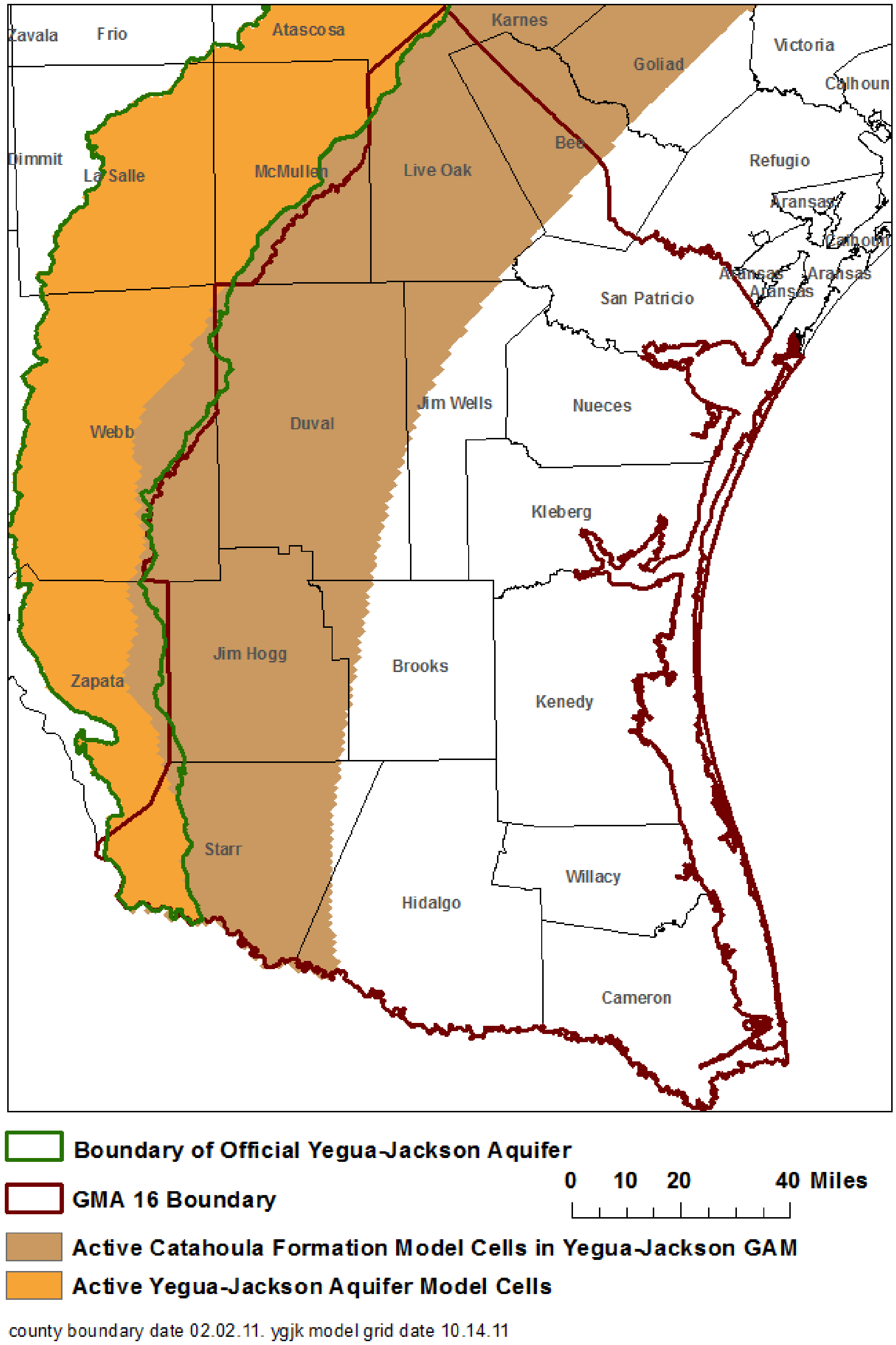

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE YEGUA-JACKSON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE YEGUA-JACKSON AQUIFER (TABLES 2 AND 3) AND CATAHOULA FORMATION (TABLES 4 AND 5) WITHIN GROUNDWATER MANAGEMENT AREA 16.

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CATAHOULA FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 16. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	60,000,000	15,000,000	45,000,000
Brooks	32,000,000	8,000,000	24,000,000
Duval	280,000,000	70,000,000	210,000,000
Hidalgo	21,000,000	5,250,000	15,750,000
Jim Hogg	220,000,000	55,000,000	165,000,000
Jim Wells	50,000,000	12,500,000	37,500,000
Live Oak	140,000,000	35,000,000	105,000,000
McMullen	21,000,000	5,250,000	15,750,000
Starr	170,000,000	42,500,000	127,500,000
Webb	24,000,000	6,000,000	18,000,000
Total	**1,018,000,000**	**254,500,000**	**763,500,000**

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[1] FOR THE CATAHOULA FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 16. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	58,000,000	14,500,000	43,500,000
Brush Country	310,000,000	77,500,000	232,500,000
Duval County	280,000,000	70,000,000	210,000,000
Live Oak	140,000,000	35,000,000	105,000,000
McMullen	21,000,000	5,250,000	15,750,000
Starr County	170,000,000	42,500,000	127,500,000
No District	47,000,000	11,750,000	35,250,000
Total	**1,026,000,000**	**256,500,000**	**769,500,000**

[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 within one percent.

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE GULF COAST AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL. NOTE: WE REPORT THE CATAHOULA FORMATION SEPARATELY IN TABLE 4.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	25,000,000	6,250,000	18,750,000
Brooks	90,000,000	22,500,000	67,500,000
Cameron	49,000,000	12,250,000	36,750,000
Duval	45,000,000	11,250,000	33,750,000
Hidalgo	160,000,000	40,000,000	120,000,000
Jim Hogg	40,000,000	10,000,000	30,000,000
Jim Wells	61,000,000	15,250,000	45,750,000
Kenedy	210,000,000	52,500,000	157,500,000
Kleberg	110,000,000	27,500,000	82,500,000
Live Oak	35,000,000	8,750,000	26,250,000
McMullen	2,100,000	525,000	1,575,000
Nueces	76,000,000	19,000,000	57,000,000
San Patricio	51,000,000	12,750,000	38,250,000
Starr	15,000,000	3,750,000	11,250,000
Webb	250,000	62,500	187,500
Willacy	45,000,000	11,250,000	33,750,000
Total	**1,014,350,000**	**253,587,500**	**760,762,500**

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[2] FOR THE GULF COAST AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16 . GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL. NOTE: WE REPORT THE CATAHOULA FORMATION SEPARATELY IN TABLE 5.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	25,000,000	6,250,000	18,750,000
Brush Country	150,000,000	37,500,000	112,500,000
Corpus Christi ASRCD	6,000,000	1,500,000	4,500,000
Duval County	45,000,000	11,250,000	33,750,000
Kenedy County	360,000,000	90,000,000	270,000,000
Live Oak	35,000,000	8,750,000	26,250,000
McMullen	2,100,000	525,000	1,575,000
Red Sands	3,100,000	775,000	2,325,000
San Patricio County	51,000,000	12,750,000	38,250,000
Starr County	15,000,000	3,750,000	11,250,000
No District	310,000,000	77,500,000	232,500,000
Total	**1,002,200,000**	**250,550,000**	**751,650,000**

[2] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to within one percent.

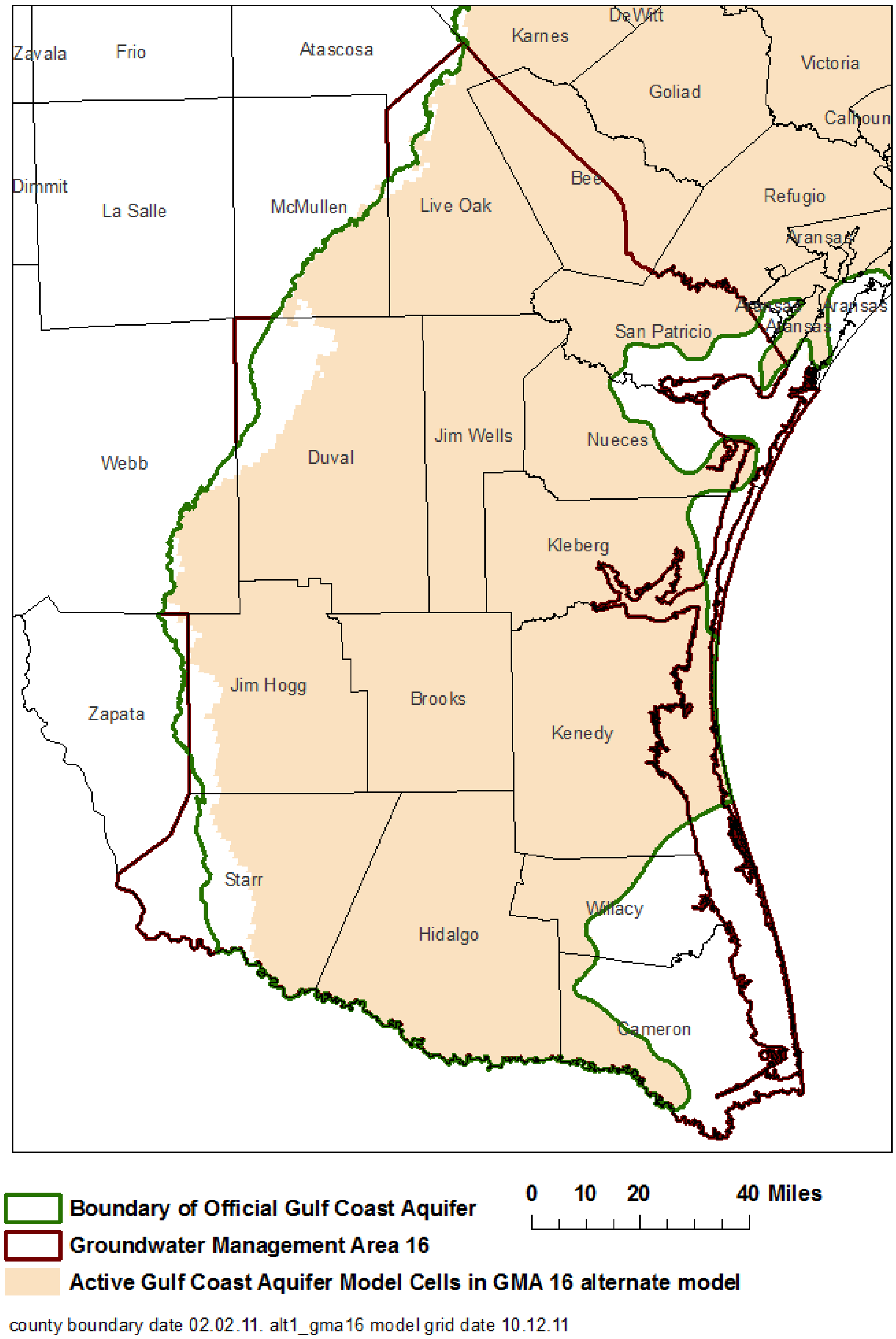

FIGURE 4. EXTENT OF THE ALTERNATIVE MODEL FOR GROUNDWATER MANAGEMENT AREA 16 USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 6 AND 7) FOR THE GULF COAST AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 16.

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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