GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11

by Shirley Wade, Ph.D., P.G., Jerry Shi, Ph.D., P.G.,
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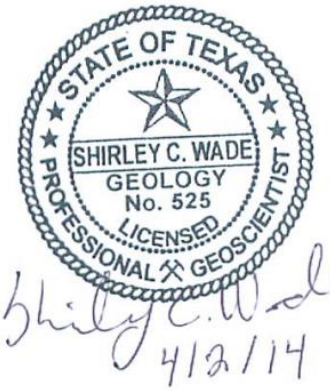
April 2, 2014



The seals appearing on this document were authorized by Shirley C. Wade, P.G. 525, Jianyou (Jerry) Shi, P.G. 11113, and Cynthia K. Ridgeway, P.G. 471 on April 2, 2014. Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by Chelsea Seiter-Weatherford under her direct supervision.

The total estimated recoverable storage in this report was calculated as follows: the Trinity Aquifer (Jerry Shi), the Nacatoch Aquifer (Chelsea Seiter-Weatherford), and the Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers (Shirley Wade).

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GAM TASK 13-034: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 11

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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(24) (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 Trinity, Nacatoch, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers within Groundwater Management Area 11. Tables 1 through 14 summarize the total estimated recoverable storage required by the statute. Figures 2 through 8 indicate the official extent of the aquifers in Groundwater Management Area 11 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 Groundwater Management Area 11 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 between different water quality types. The total estimated recoverable storage values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction that may occur 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. 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 in a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is 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 aquifers and specific yield related to unconfined aquifers. 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)

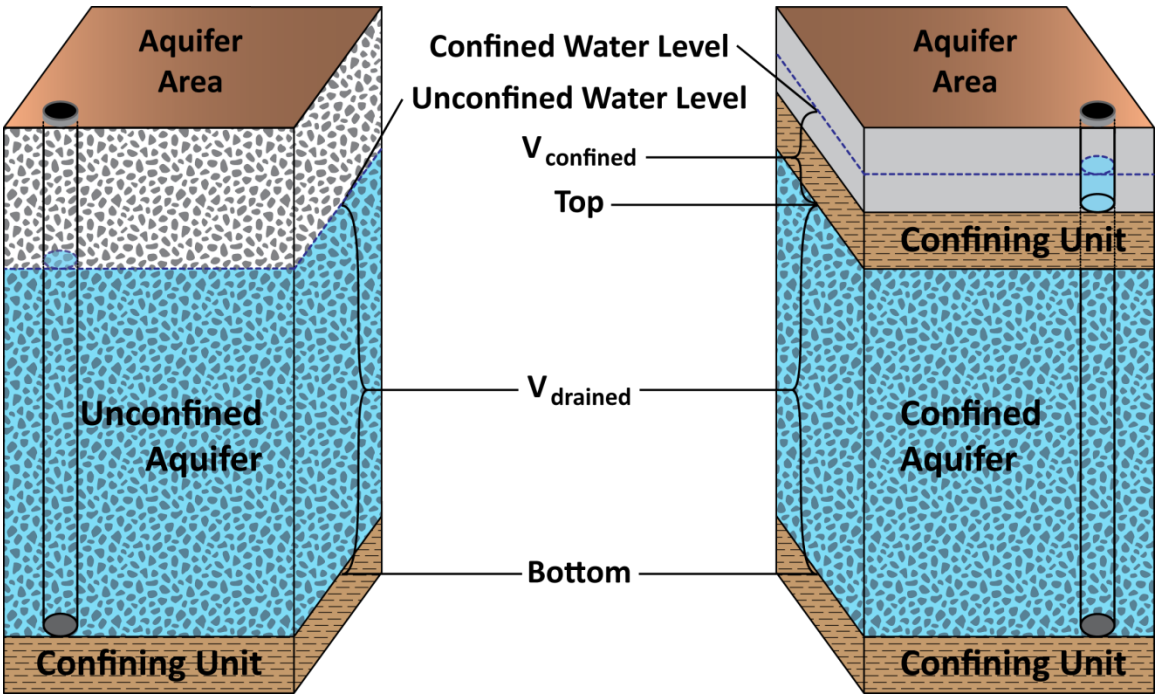

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 Trinity, Nacatoch, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers within Groundwater Management Area 11 we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis.

The recoverable storage for each of the aquifers listed above was the product of its total storage and an estimated factor ranging from 25 percent to 75 percent.

PARAMETERS AND ASSUMPTIONS:

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 11. 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 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).

Nacatoch Aquifer

- We used version 1.01 of the groundwater availability model for the Nacatoch Aquifer. See Beach and others (2009) for assumptions and limitations of the groundwater availability model for the Nacatoch Aquifer.
- This groundwater availability model includes two layers which represent the Midway Group, and alluvium and terrace deposits (Layer 1), and the Nacatoch Aquifer (Layer 2).
- The total estimated recoverable storage for the Nacatoch Aquifer was calculated using Layer 2.
- Groundwater in the Nacatoch Aquifer is generally fresh within Groundwater Management Area 11 (Beach and others, 2009). Groundwater with total dissolved solids of less than 1,000 milligrams per liter is defined as fresh. Groundwater with total dissolved solids between 1,000 to 10,000 milligrams per liter is defined as brackish, and groundwater with total dissolved solids between 10,000 and 35,000 milligrams per liter is defined as saline (George and others, 2011).

Carrizo-Wilcox, Queen City, and Sparta aquifers

- We used Version 2.01 of the groundwater availability model for the northern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers. See Fryar and others (2003) and Kelley and others (2004) for assumptions and limitations of the groundwater availability model for the northern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers.
- The groundwater availability model includes eight layers that generally correspond to 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 Aquifer (Layer 6), the Middle Wilcox Aquifer (Layer 7), and the Lower Wilcox Aquifer (Layer 8).
- In the Sabine Uplift area, the Simsboro Formation (Middle Wilcox Aquifer) is not distinguishable and the Wilcox Group is informally divided into the Upper Wilcox and the Lower Wilcox aquifers (Fryar and others, 2003). In the current version of the groundwater availability model, layers 6 and 7 represent the Upper Wilcox and Lower Wilcox aquifers in this area. Layer 8 is included in the model in this area, but it is of nominal thickness and is not intended to represent the Lower Wilcox aquifer.

Yegua-Jackson Aquifer and the Catahoula Formation portion of the Gulf Coast Aquifer System

- We used version 1.01 of the groundwater availability model for the Yegua-Jackson Aquifer to estimate the total recoverable storages of the Yegua-Jackson Aquifer and parts of 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 to evaluate the outcrop area of the Yegua-Jackson Aquifer.

- 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, much deeper than any portion of the aquifer that is used for groundwater supply (Deeds and others, 2010). Consequently, the model extends into zones of brackish and saline groundwater. The groundwater in the official extent of the Yegua-Jackson Aquifer ranges from fresh to brackish in composition (Deeds and others, 2010).

Gulf Coast Aquifer System

- We used version 3.01 of the groundwater availability model for the northern portion of the Gulf Coast Aquifer system for this analysis. See Kasmarek (2013) for assumptions and limitations of the model.
- The model has four layers which represent the Chicot Aquifer (Layer 1), the Evangeline Aquifer (Layer 2), the Burkeville confining unit (Layer 3), and the Jasper Aquifer and parts of the Catahoula Formation in direct hydrologic communication with the Jasper Aquifer (Layer 4).
- The southeastern boundary of flow in each hydrogeologic unit of the model was set at the down-dip limit of freshwater (up to 10,000 milligrams per liter of total dissolved solids; Kasmarek, 2013).

RESULTS:

Tables 1 through 14 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total storage estimates are rounded to two significant digits. Figures 2 through 8 indicate the extent of the groundwater availability models in Groundwater Management Area 11 from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Henderson	500,000	125,000	375,000
Total	**500,000**	**125,000**	**375,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Neches & Trinity Valleys GCD	500,000	125,000	375,000
Total	**500,000**	**125,000**	**375,000**

FIGURE 2 EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN TRINITY AND WOODBINE AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE TRINITY AQUIFER (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE NACATOCH AQUIFER IN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bowie	140,000	35,000	105,000
Henderson	9,800	2,450	7,350
Morris	2,900	725	2,175
Red River	11,000	2,750	8,250
Titus	15,000	3,750	11,250
Total	**178,700**	**44,675**	**134,025**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[1] FOR THE NACATOCH AQUIFER IN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	160,000	40,000	120,000
Neches & Trinity Valleys GCD	9,800	2,450	7,350
Total	**169,800**	**42,450**	**127,350**

[1] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.

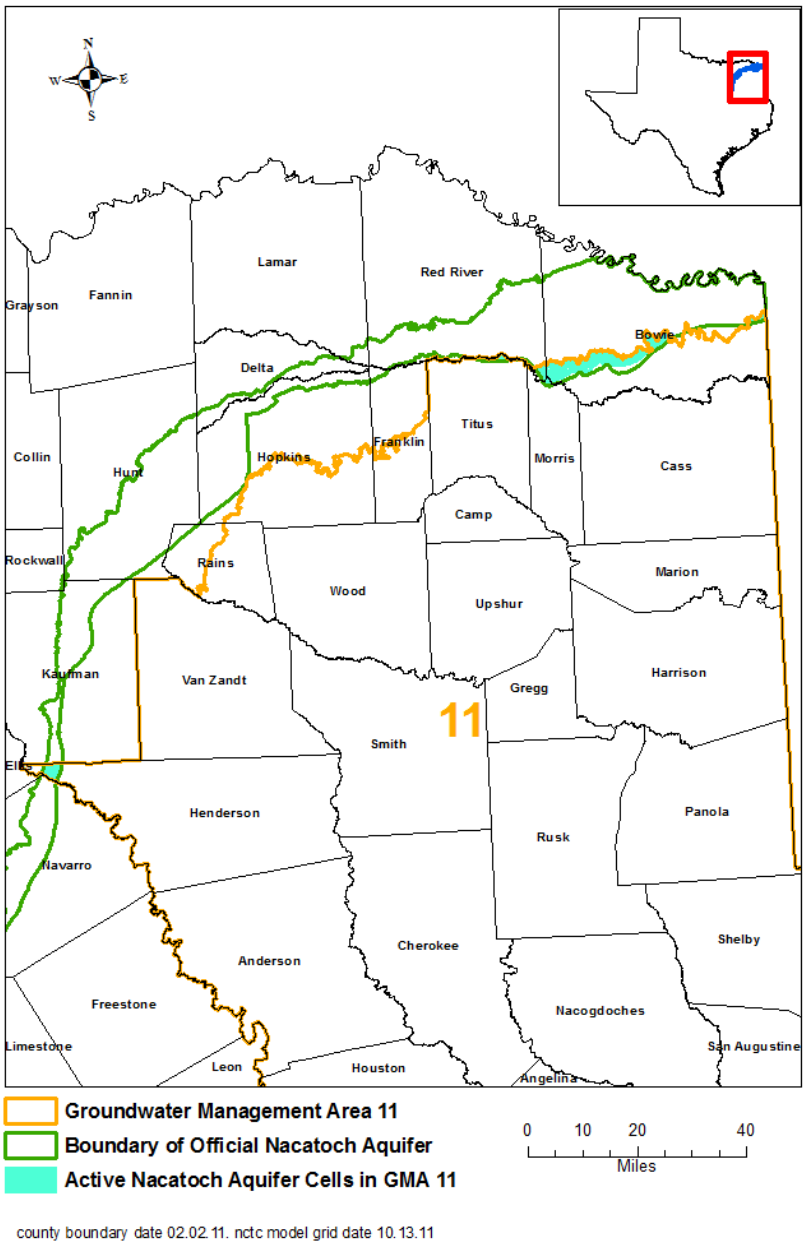

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NACATOCH AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE NACATOCH AQUIFER (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Anderson	170,000,000	42,500,000	127,500,000
Angelina	130,000,000	32,500,000	97,500,000
Bowie	6,400,000	1,600,000	4,800,000
Camp	15,000,000	3,750,000	11,250,000
Cass	60,000,000	15,000,000	45,000,000
Cherokee	200,000,000	50,000,000	150,000,000
Franklin	6,000,000	1,500,000	4,500,000
Gregg	21,000,000	5,250,000	15,750,000
Harrison	40,000,000	10,000,000	30,000,000
Henderson	66,000,000	16,500,000	49,500,000
Hopkins	7,000,000	1,750,000	5,250,000
Houston	390,000,000	97,500,000	292,500,000
Marion	25,000,000	6,250,000	18,750,000
Morris	16,000,000	4,000,000	12,000,000
Nacogdoches	210,000,000	52,500,000	157,500,000
Panola	33,000,000	8,250,000	24,750,000
Rains	3,200,000	800,000	2,400,000
Red River	33,000	8,250	24,750
Rusk	100,000,000	25,000,000	75,000,000
Sabine	78,000,000	19,500,000	58,500,000

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
San Augustine	110,000,000	27,500,000	82,500,000
Shelby	85,000,000	21,250,000	63,750,000
Smith	100,000,000	25,000,000	75,000,000
Titus	13,000,000	3,250,000	9,750,000
Trinity	43,000,000	10,750,000	32,250,000
Upshur	45,000,000	11,250,000	33,750,000
Van Zandt	35,000,000	8,750,000	26,250,000
Wood	54,000,000	13,500,000	40,500,000
Total	**2,061,633,000**	**515,408,250**	**1,546,224,750**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT [2] FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	890,000,000	222,500,000	667,500,000
Anderson County UWCD[3]	7,600,000	1,900,000	5,700,000
Deep East Texas GCD[4]	270,000,000	67,500,000	202,500,000
Neches & Trinity Valleys GCD	430,000,000	107,500,000	322,500,000
Panola County GCD	33,000,000	8,250,000	24,750,000
Pineywoods GCD	340,000,000	85,000,000	255,000,000
Rusk County GCD	100,000,000	25,000,000	75,000,000
Total	**2,070,600,000**	**517,650,000**	**1,552,950,000**

[2] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.
[3] UWCD stands for Underground Water Conservation District
[4] Deep East Texas Groundwater Conservation District is pending confirmation.

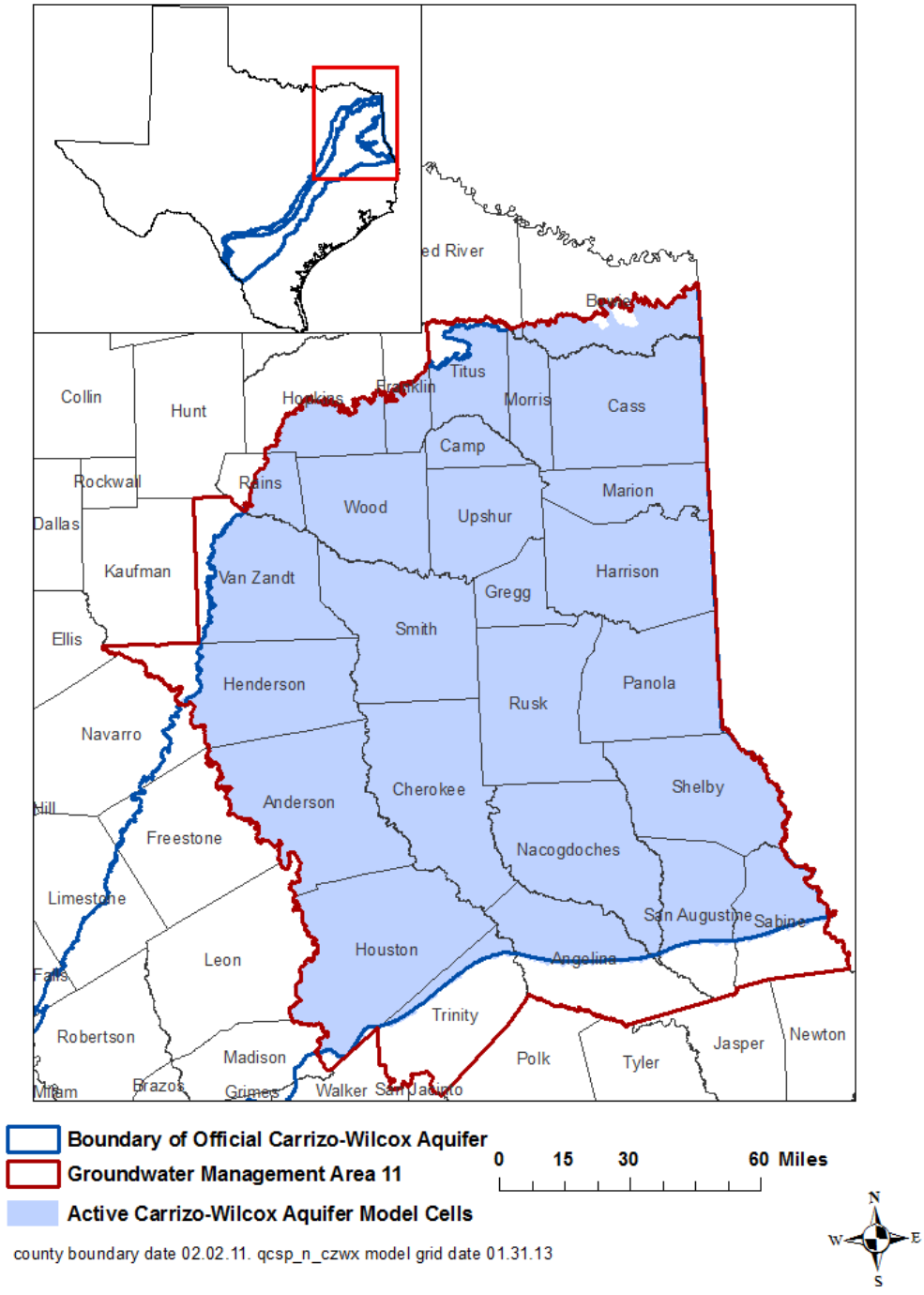

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CARRIZO-WILCOX AQUIFER (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Anderson	19,000,000	4,750,000	14,250,000
Angelina	2,000,000	500,000	1,500,000
Camp	600,000	150,000	450,000
Cass	8,000,000	2,000,000	6,000,000
Cherokee	15,000,000	3,750,000	11,250,000
Gregg	1,500,000	375,000	1,125,000
Harrison	1,200,000	300,000	900,000
Henderson	6,700,000	1,675,000	5,025,000
Houston	37,000,000	9,250,000	27,750,000
Marion	2,500,000	625,000	1,875,000
Morris	1,300,000	325,000	975,000
Nacogdoches	4,500,000	1,125,000	3,375,000
Rusk	58,000	14,500	43,500
Smith	23,000,000	5,750,000	17,250,000
Titus	63,000	15,750	47,250
Trinity	1,900,000	475,000	1,425,000
Upshur	7,800,000	1,950,000	5,850,000
Van Zandt	1,200,000	300,000	900,000
Wood	8,700,000	2,175,000	6,525,000
Total	**142,021,000**	**35,505,250**	**106,515,750**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[5] FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	95,000,000	23,750,000	71,250,000
Anderson County UWCD[6]	550,000	137,500	412,500
Neches & Trinity Valleys GCD	40,000,000	10,000,000	30,000,000
Pineywoods GCD	6,500,000	1,625,000	4,875,000
Rusk County GCD	58,000	14,500	43,500
Total	**142,108,000**	**35,527,000**	**106,581,000**

[5] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.
[6] UWCD stands for Underground Water Conservation District

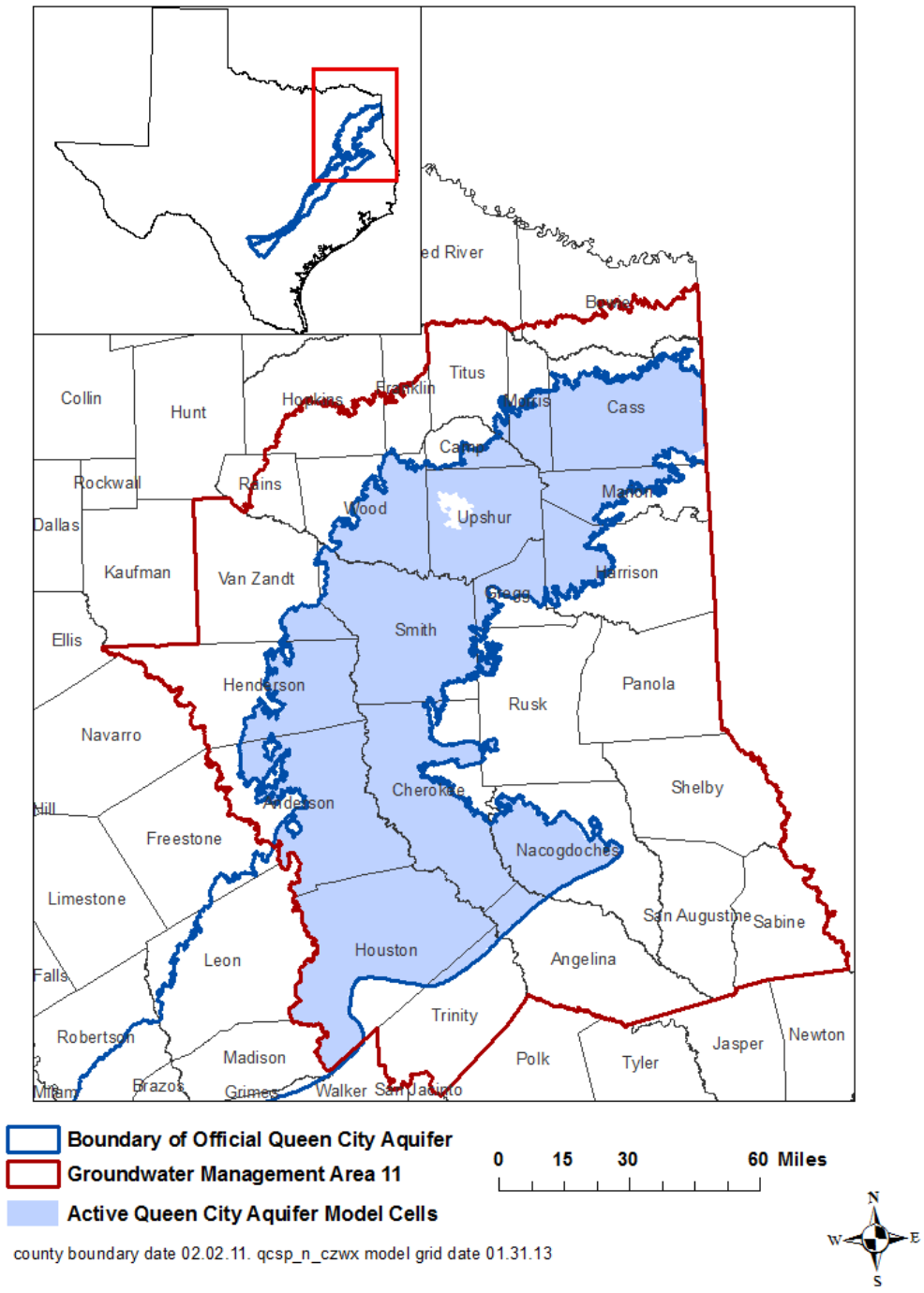

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE QUEEN CITY AQUIFER (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Anderson	640,000	160,000	480,000
Angelina	5,200,000	1,300,000	3,900,000
Cherokee	1,700,000	425,000	1,275,000
Houston	25,000,000	6,250,000	18,750,000
Nacogdoches	3,900,000	975,000	2,925,000
Sabine	6,000,000	1,500,000	4,500,000
San Augustine	6,800,000	1,700,000	5,100,000
Trinity	6,100,000	1,525,000	4,575,000
Total	**55,340,000**	**13,835,000**	**41,505,000**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[7] FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	32,000,000	8,000,000	24,000,000
Deep East Texas GCD[8]	13,000,000	3,250,000	9,750,000
Neches & Trinity Valleys GCD	2,300,000	575,000	1,725,000
Pineywoods GCD	9,100,000	2,275,000	6,825,000
Total	**56,400,000**	**14,100,000**	**42,300,000**

[7] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.
[8] Deep East Texas Groundwater Conservation District is pending confirmation.

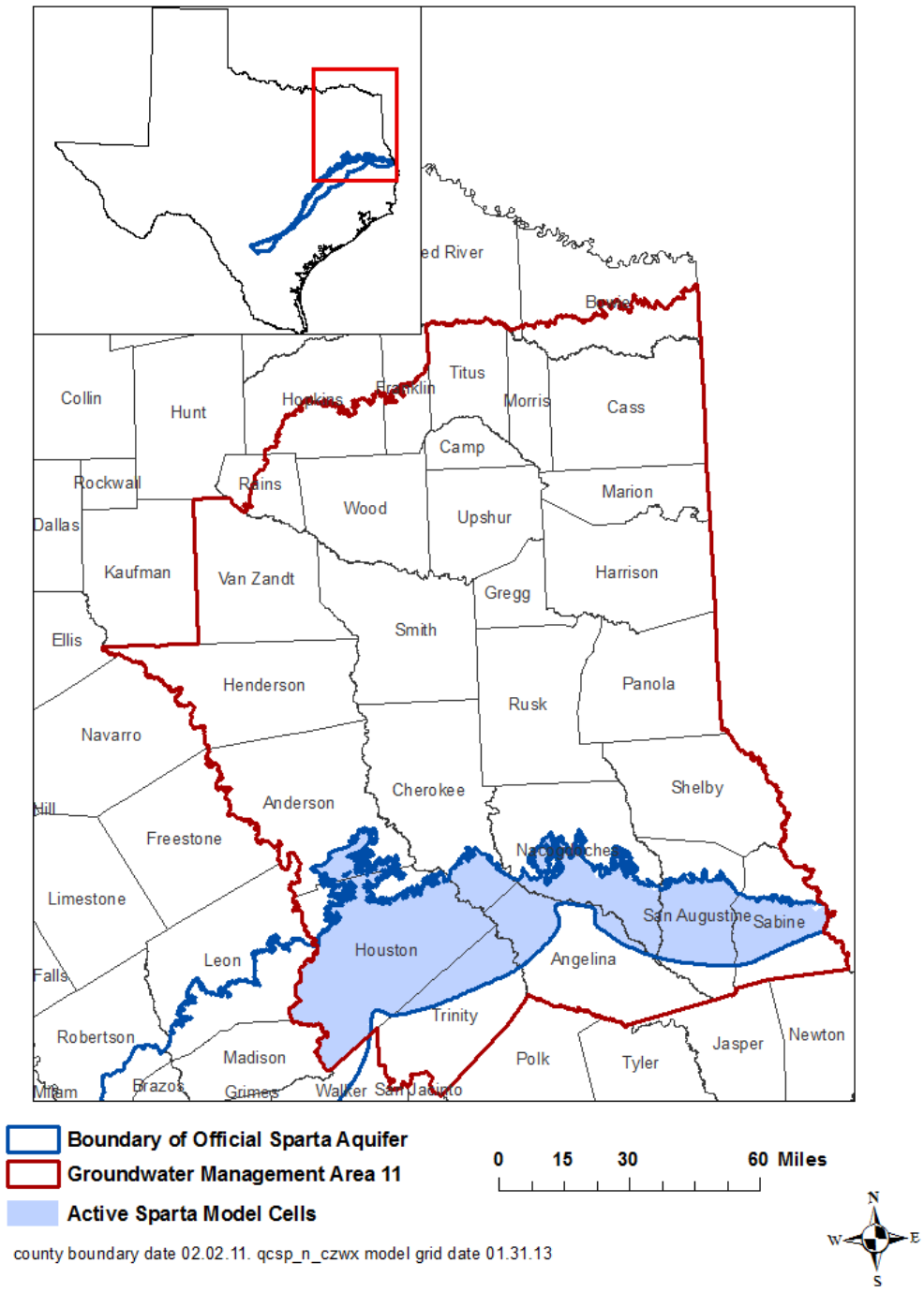

FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE SPARTA AQUIFER (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Angelina	72,000,000	18,000,000	54,000,000
Houston	21,000,000	5,250,000	15,750,000
Nacogdoches	1,400,000	350,000	1,050,000
Sabine	30,000,000	7,500,000	22,500,000
San Augustine	19,000,000	4,750,000	14,250,000
Trinity	83,000,000	20,750,000	62,250,000
Total	**226,400,000**	**56,600,000**	**169,800,000**

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[9] FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25percent of Total Storage (acre-feet)*	*75percent of Total Storage (acre-feet)*
No District	100,000,000	25,000,000	75,000,000
Deep East Texas GCD[10]	49,000,000	12,250,000	36,750,000
Pineywoods GCD	74,000,000	18,500,000	55,500,000
Total	**223,000,000**	**55,750,000**	**167,250,000**

[9] The total estimated recoverable storages values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.
[10] Deep East Texas Groundwater Conservation District is pending confirmation.

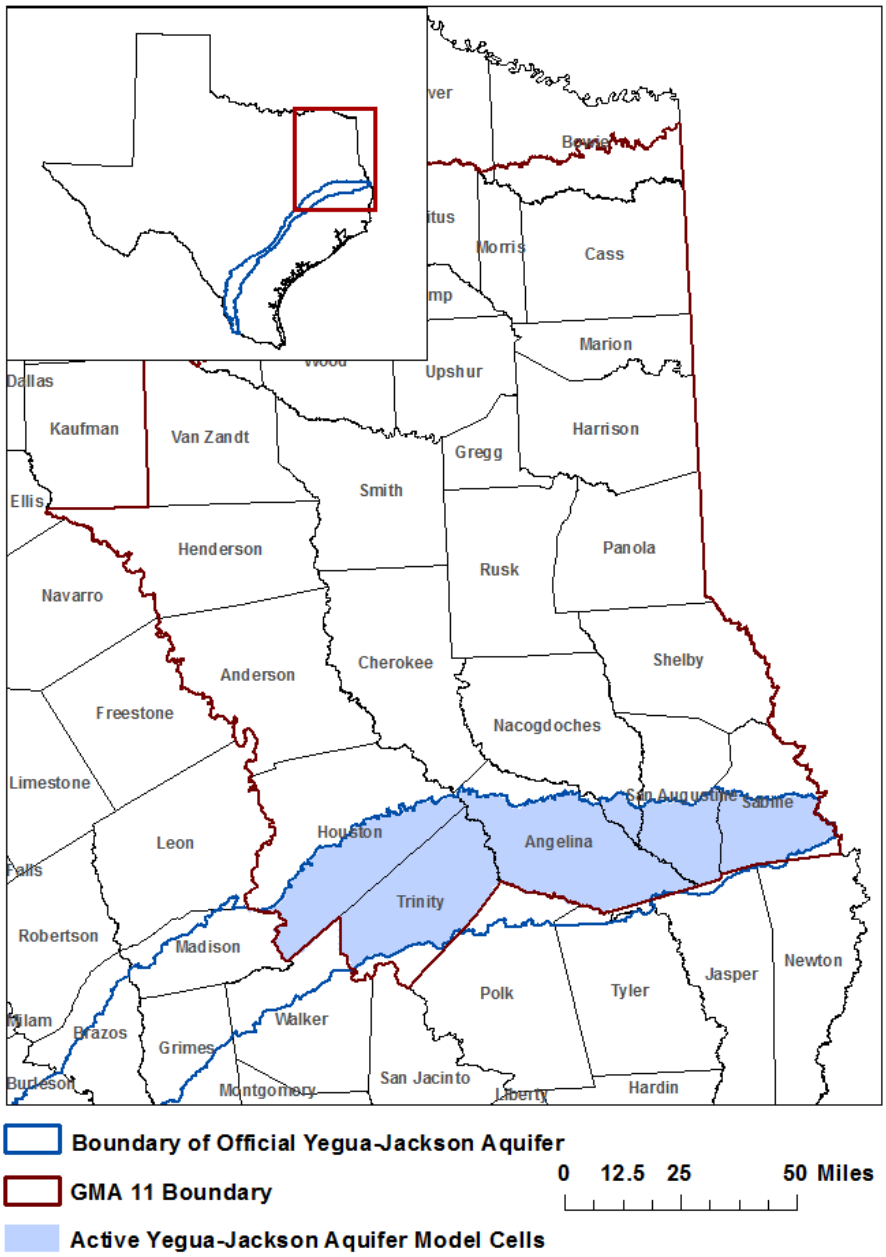

FIGURE 7. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE YEGUA-JACKSON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Angelina	27,000	6,750	20,250
Sabine	120,000	30,000	90,000
Trinity	1,300,000	325,000	975,000
Total	**1,447,000**	**361,750**	**1,085,250**

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[11] FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25percent of Total Storage (acre-feet)*	*75percent of Total Storage (acre-feet)*
No District	1,400,000	350,000	1,050,000
Pineywoods GCD	27,000	6,750	20,250
Total	**1,427,000**	**356,750**	**1,070,250**

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

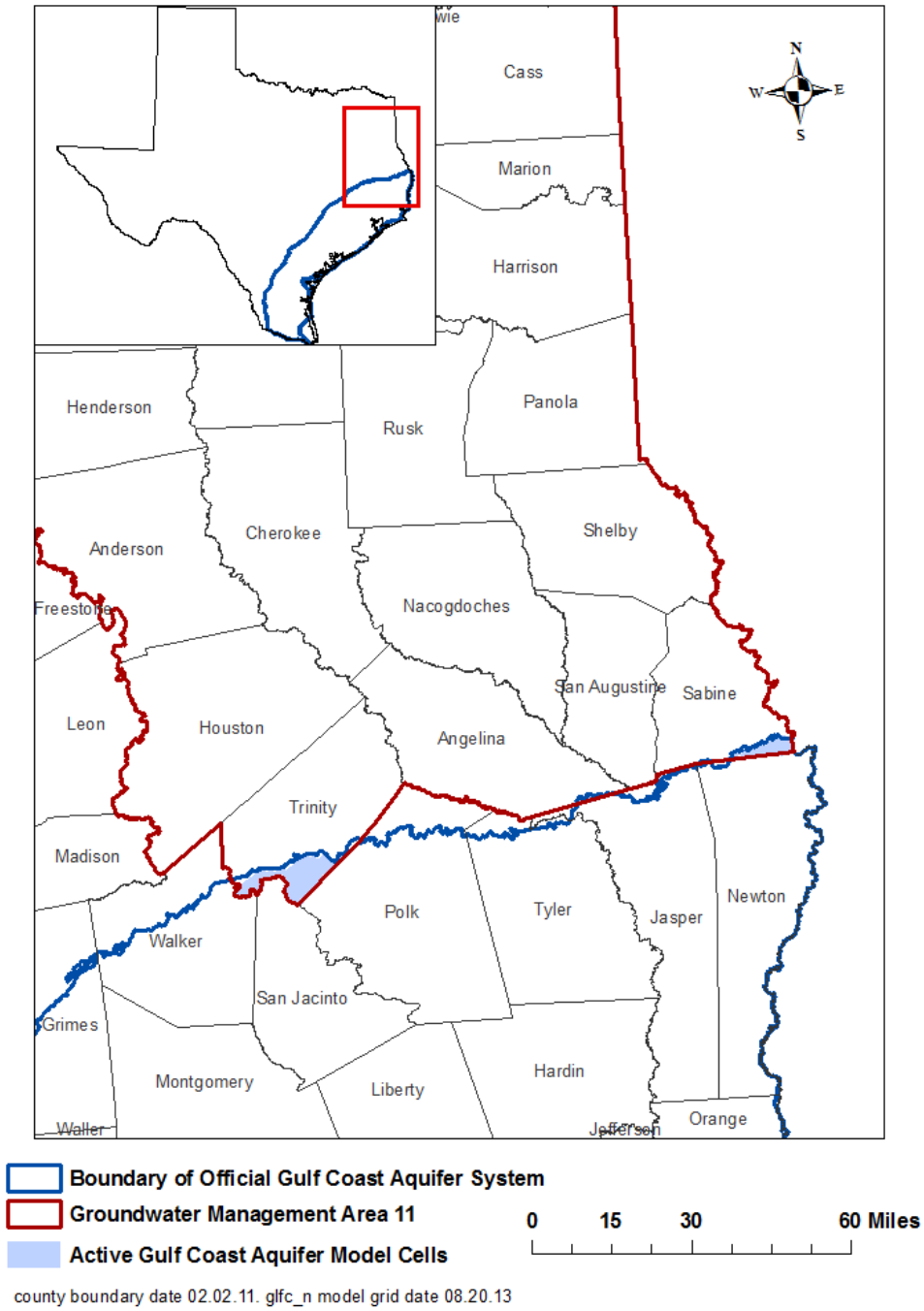

FIGURE 8. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE GULF COAST AQUIFER SYSTEM USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 AND 14) FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11.

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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