GAM Task 13-035 Version 2: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 12

by Shirley Wade, Ph.D., P.G. and Jerry Shi, Ph.D., P.G.
Texas Water Development Board
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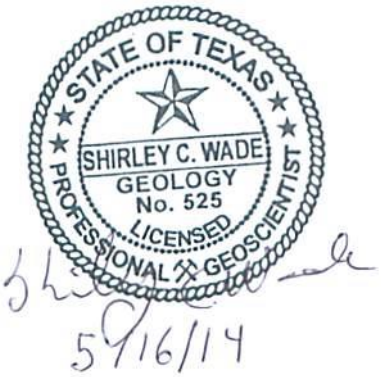
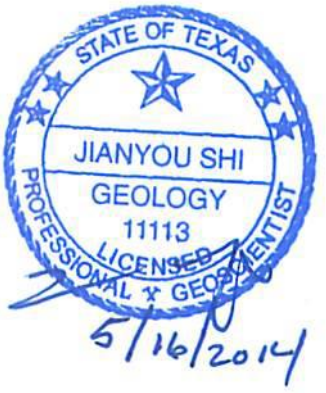
(512) 936-0883
May 16, 2014





The seals appearing on this document were authorized by Shirley C. Wade, P.G. 525, and Jianyou (Jerry) Shi, P.G. 11113 on May 16, 2014.

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

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GAM TASK 13-035 VERSION 2: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 12

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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 Trinity, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, Brazos River Alluvium, and Gulf Coast aquifers within Groundwater Management Area 12. 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 12 used to estimate the total recoverable storage. Tables 15 through 22 summarize total estimated recoverable storage for the Carrizo-Wilcox Aquifer by model layer, as requested by the coordinator for Groundwater Management Area 12.

On November 25, 2013, the TWDB Executive Administrator approved a boundary change between Groundwater Management Areas 12 and 14. That boundary change consisted of removing a small portion of Brazos County from Groundwater Management Area 14 and assigning it to Groundwater Management Area 12 such that Brazos County is now completely within Groundwater Management Area 12. This report (version 2) reflects those changes.

Updates to this report from version 1 include, (1) addition of total estimated recoverable storage volumes for the Gulf Coast Aquifer System, (2) updates to total estimated recoverable storage volumes for the Brazos River Alluvium Aquifer, and (3) updates to all maps showing the boundary of Groundwater Management Area 12.

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 12 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 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 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)

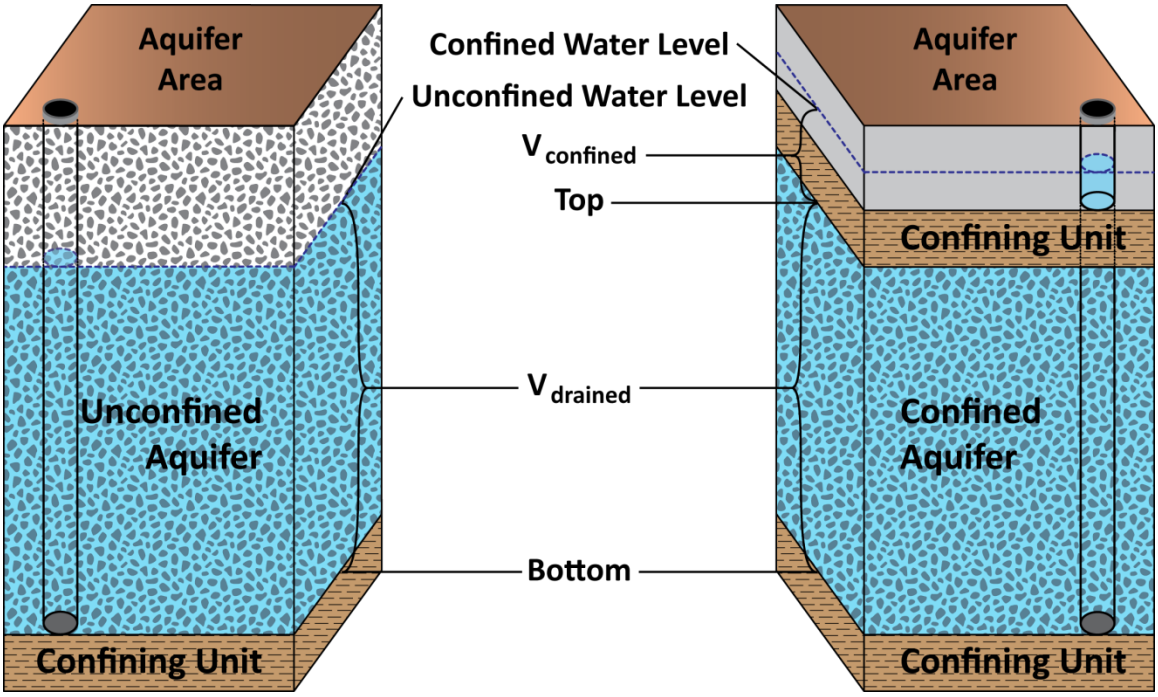

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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

For the Brazos River Alluvium Aquifer, which does not yet have a groundwater availability model, we used an analytical approach. For each county, ArcMAP™ was used to estimate the Brazos River Alluvium Aquifer thickness (assuming base of the alluvium and land surface) and average water table depth. Average Brazos River Alluvium Aquifer saturated thickness for

each county was then calculated from average thickness minus average water table depth. Finally we estimated the total storage of the Brazos River Alluvium Aquifer from average saturated thickness multiplied with area and an assumed specific yield value.

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 12. See Bené and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes seven layers which generally represent the Woodbine Aquifer (Layer 1), the Washita and Fredericksburg Confining Unit (Layer 2), the Paluxy Aquifer Unit of the Trinity Aquifer (Layer 3), the Glen Rose Confining Unit of the Trinity Aquifer (Layer 4), the Hensell Sand Aquifer Unit of the Trinity Aquifer (Layer 5), the Twin Mountains Confining Units of the Trinity Aquifer (Layer 6), and the Hosston Aquifer Unit of the Trinity Aquifer (Layer 7). To develop the estimates for the total estimated recoverable storage, we used Layers 3 through 7 (the Trinity Aquifer).
- The down-dip boundary of the model is considered the Luling-Mexia-Talco Fault Zone, which probably allows minimal groundwater flow across the fault zone (Bené and others, 2004). The groundwater in the official extent of the northern portion of the Trinity Aquifer aquifers ranges from fresh to moderately saline (brackish) in composition (Bené and others, 2004).

Carrizo-Wilcox, Queen City, and Sparta aquifers

- We used version 2.02 of the groundwater availability model for the central part of the Carrizo-Wilcox, Queen City, and Sparta aquifers to estimate the total recoverable

storage for the Carrizo-Wilcox, Queen City, and Sparta aquifers. See Dutton and others (2003) and Kelley and others (2004) for assumptions and limitations of the groundwater availability model.

- 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 Formation (Layer 5), the Upper Wilcox Formation or Calvert Bluff Formation (Layer 6), the Middle Wilcox Formation or Simsboro Formation (Layer 7), and the Lower Wilcox Formation or Hooper Formation (Layer 8). To develop the estimates for the total estimated recoverable storage, we used Layer 1 (Sparta Aquifer), Layer 3 (Queen City Aquifer), and 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 (Dutton and others, 2003). The groundwater in the official extent of the Carrizo-Wilcox, Queen City, and Sparta aquifers ranges from fresh to brackish in composition (Kelley and others, 2004).

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 storage of the Yegua-Jackson Aquifer. 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.

- 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. 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).

Brazos River Alluvium Aquifer

- The Brazos River Alluvium Aquifer is under water table conditions in most places (George and others, 2011).
- The thickness of the Brazos River Alluvium Aquifer is based on a U.S. Geological Survey electromagnetic and resistivity imaging project (Shah and others, 2007).
- Water levels are from the TWDB groundwater database http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp accessed in July 2013. The three latest years of water level data were used to estimate the average water table depth for each county.
- We used a specific yield value of 0.15 from Cronin and others (1967).

RESULTS:

Tables 1 through 14 summarize the total estimated recoverable storage required by statute. Tables 15 through 22 in Appendix A summarize the total estimated recoverable storage for the formations making up the Carrizo-Wilcox Aquifer: the Hooper, the Simsboro, the Calvert Bluff, and the Carrizo formations. The county and groundwater conservation district total storage estimates are rounded to two significant digits. Figures 2 through 7 indicate the extent of the groundwater availability models in Groundwater Management Area 12 for the Trinity, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers from which the storage information was extracted. Figure 8 indicates the extent of the Brazos River Alluvium Aquifer in Groundwater Management Area 12 used to estimate the total recoverable storage. Figures 9 through 12 in Appendix A indicate the extent of the groundwater availability model for the central portion of the Carrizo-Wilcox Aquifer from which the storage information for the Hooper, Simsboro, Calvert Bluff, and Carrizo formations was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	9,000,000	2,250,000	6,750,000
Lee	500,000	125,000	375,000
Williamson	1,600,000	400,000	1,200,000
Total	**11,100,000**	**2,775,000**	**8,325,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[1] FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	1,600,000	400,000	1,200,000
Lost Pines GCD	9,500,000	2,375,000	7,125,000
Total	**11,100,000**	**2,775,000**	**8,325,000**

[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.

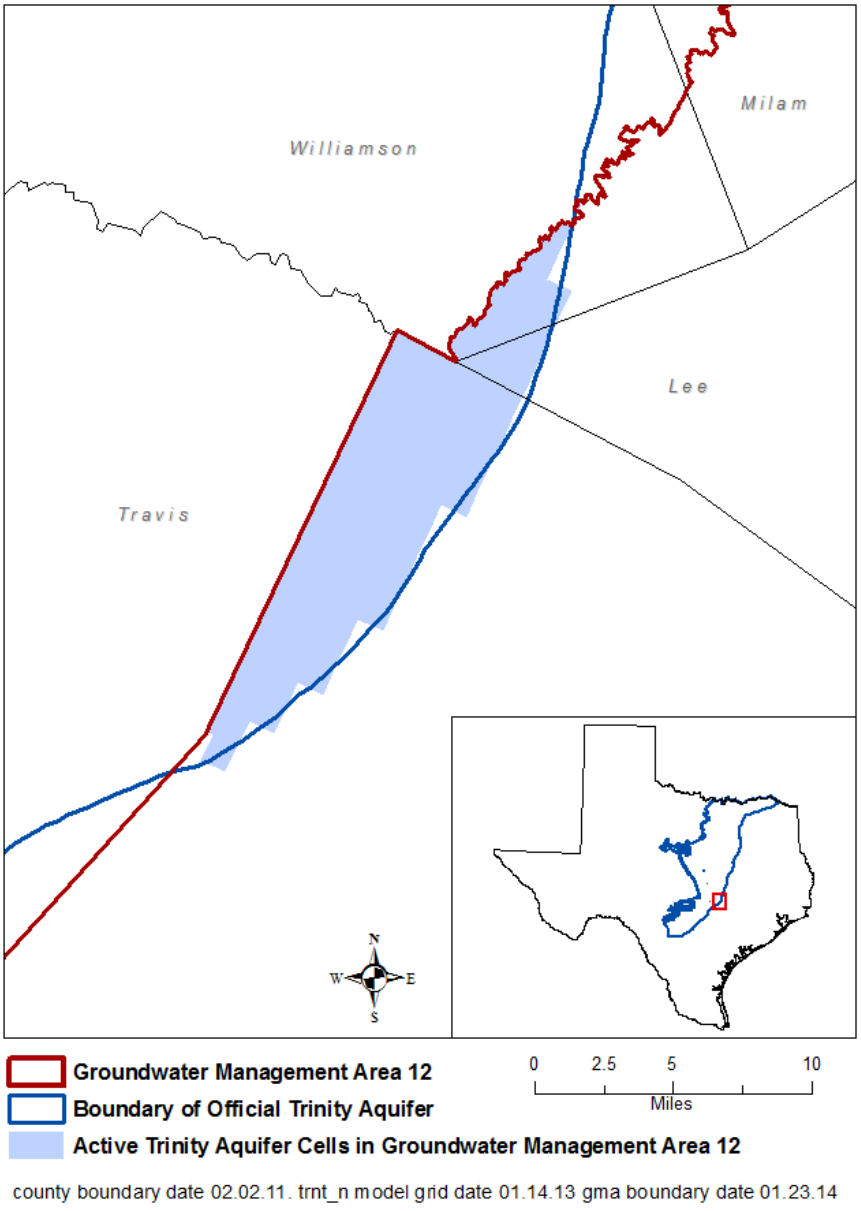

FIGURE 2. AREA OF THE TRINITY AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	98,000,000	24,500,000	73,500,000
Brazos	69,000,000	17,250,000	51,750,000
Burleson	120,000,000	30,000,000	90,000,000
Falls	820,000	205,000	615,000
Fayette	95,000,000	23,750,000	71,250,000
Freestone	46,000,000	11,500,000	34,500,000
Lee	130,000,000	32,500,000	97,500,000
Leon	180,000,000	45,000,000	135,000,000
Limestone	12,000,000	3,000,000	9,000,000
Madison	110,000,000	27,500,000	82,500,000
Milam	47,000,000	11,750,000	35,250,000
Navarro	1,000,000	250,000	750,000
Robertson	110,000,000	27,500,000	82,500,000
Williamson	500,000	125,000	375,000
Total	1,019,320,000	254,830,000	764,490,000

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT [2] FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	14,000,000	3,500,000	10,500,000
Brazos Valley GCD	180,000,000	45,000,000	135,000,000
Fayette County GCD	95,000,000	23,750,000	71,250,000
Lost Pines GCD	220,000,000	55,000,000	165,000,000
Mid-East Texas GCD	340,000,000	85,000,000	255,000,000
Post Oak Savannah GCD	170,000,000	42,500,000	127,500,000
Total	1,019,000,000	254,750,000	764,250,000

[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.

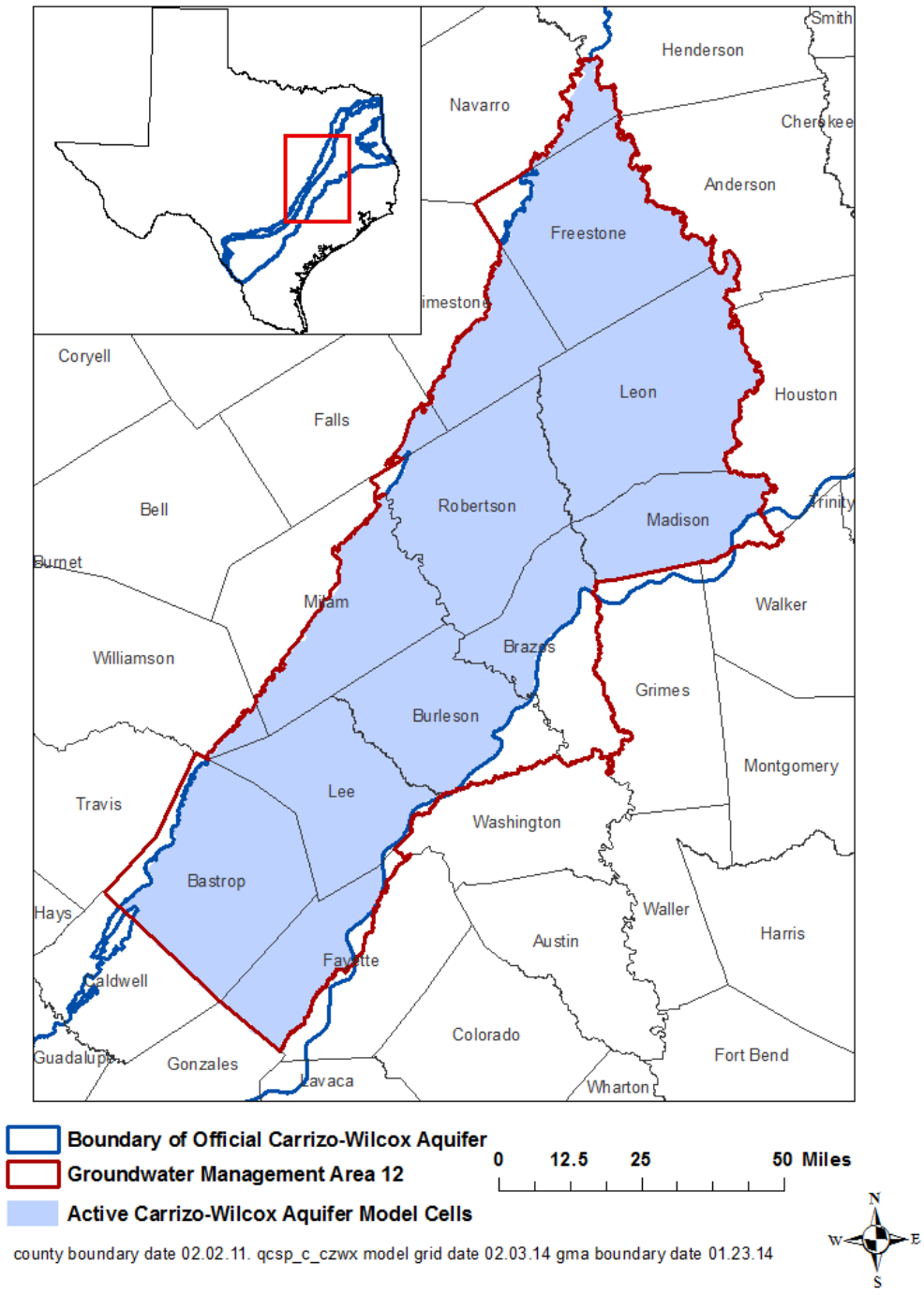

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CARRIZO-WILCOX AQUIFER (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	9,500,000	2,375,000	7,125,000
Brazos	25,000,000	6,250,000	18,750,000
Burleson	29,000,000	7,250,000	21,750,000
Fayette	19,000,000	4,750,000	14,250,000
Freestone	290,000	72,500	217,500
Lee	23,000,000	5,750,000	17,250,000
Leon	25,000,000	6,250,000	18,750,000
Madison	20,000,000	5,000,000	15,000,000
Milam	650,000	162,500	487,500
Robertson	8,800,000	2,200,000	6,600,000
Total	160,240,000	40,060,000	120,180,000

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[3] FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos Valley GCD	34,000,000	8,500,000	25,500,000
Fayette County GCD	19,000,000	4,750,000	14,250,000
Lost Pines GCD	32,000,000	8,000,000	24,000,000
Mid-East Texas GCD	45,000,000	11,250,000	33,750,000
Post Oak Savannah GCD	30,000,000	7,500,000	22,500,000
Total	160,000,000	40,000,000	120,000,000

[3] 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.

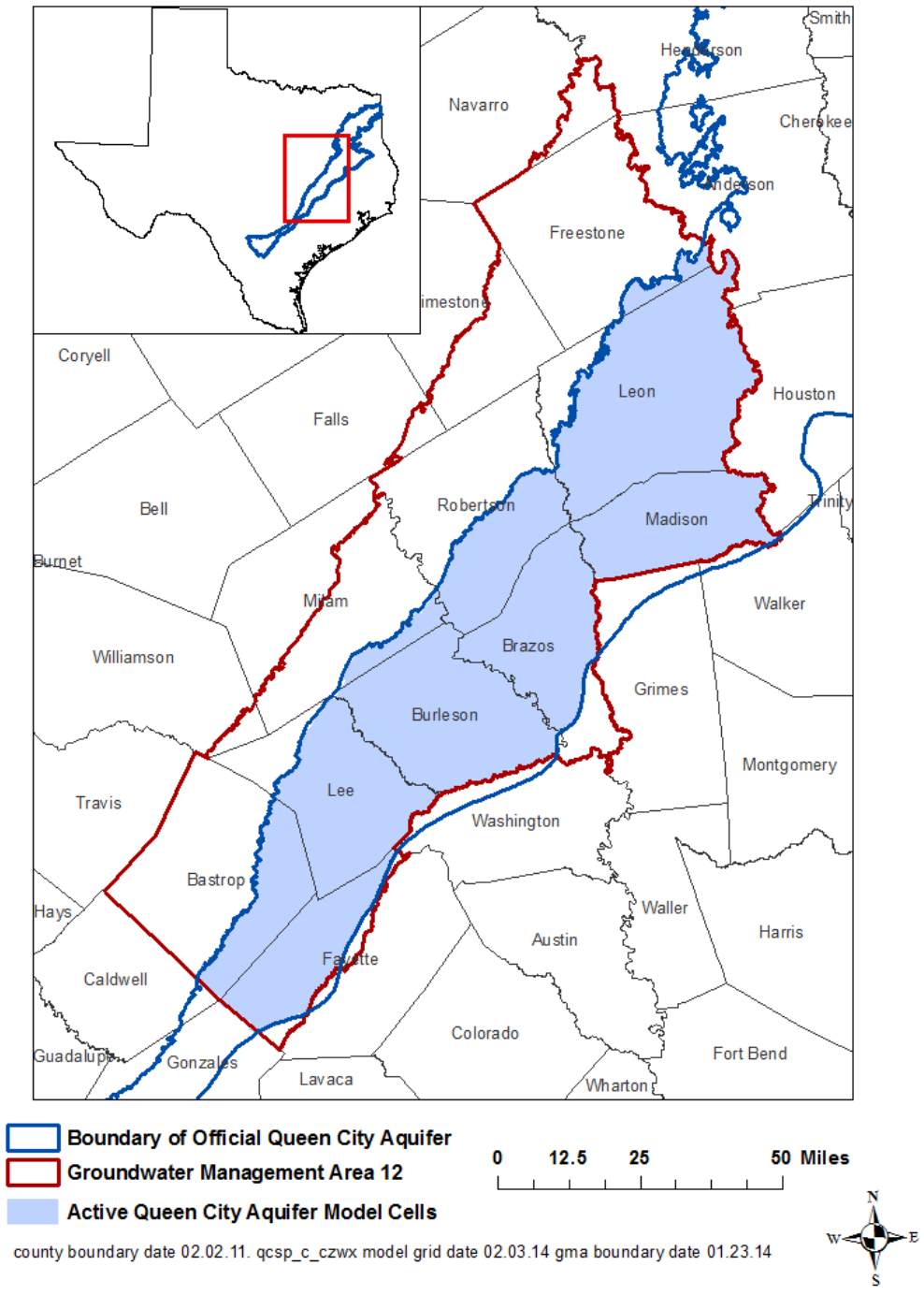

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE QUEEN CITY AQUIFER (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	2,500,000	625,000	1,875,000
Brazos	17,000,000	4,250,000	12,750,000
Burleson	16,000,000	4,000,000	12,000,000
Fayette	12,000,000	3,000,000	9,000,000
Lee	10,000,000	2,500,000	7,500,000
Leon	4,600,000	1,150,000	3,450,000
Madison	16,000,000	4,000,000	12,000,000
Robertson	1,300,000	325,000	975,000
Total	79,400,000	19,850,000	59,550,000

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[4] FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos Valley GCD	18,000,000	4,500,000	13,500,000
Fayette County GCD	12,000,000	3,000,000	9,000,000
Lost Pines GCD	13,000,000	3,250,000	9,750,000
Mid-East Texas GCD	21,000,000	5,250,000	15,750,000
Post Oak Savannah GCD	16,000,000	4,000,000	12,000,000
Total	80,000,000	20,000,000	60,000,000

[4] 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.

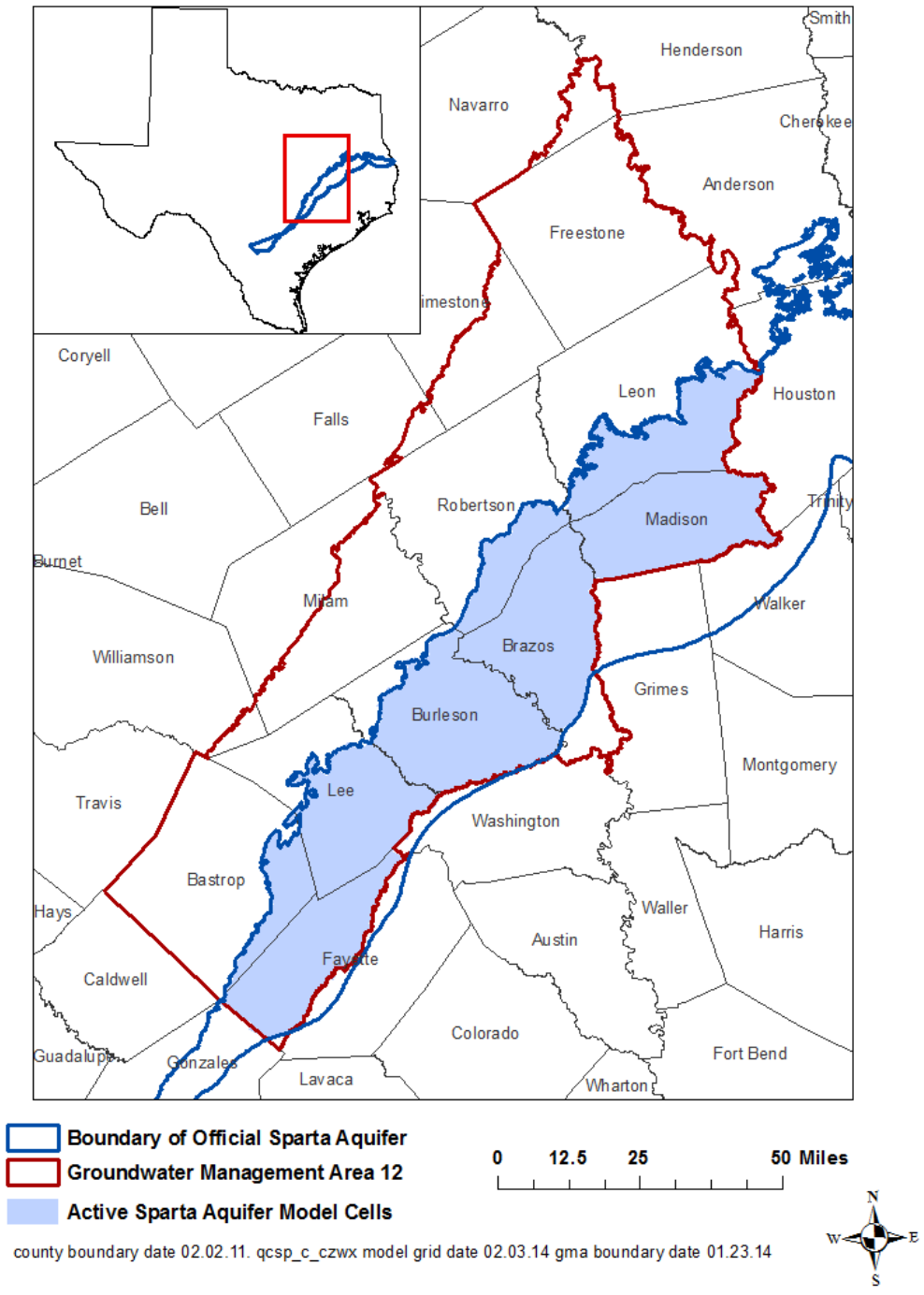

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE SPARTA AQUIFER (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	290,000	72,500	217,500
Brazos	30,000,000	7,500,000	22,500,000
Burleson	27,000,000	6,750,000	20,250,000
Fayette	27,000,000	6,750,000	20,250,000
Lee	10,000,000	2,500,000	7,500,000
Leon	76,000	19,000	57,000
Madison	15,000,000	3,750,000	11,250,000
Total	109,366,000	27,341,500	82,024,500

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[5] FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos Valley GCD	30,000,000	7,500,000	22,500,000
Fayette County GCD	27,000,000	6,750,000	20,250,000
Lost Pines GCD	10,000,000	2,500,000	7,500,000
Mid-East Texas GCD	15,000,000	3,750,000	11,250,000
Post Oak Savannah GCD	27,000,000	6,750,000	20,250,000
Total	109,000,000	27,250,000	81,750,000

[5] 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.

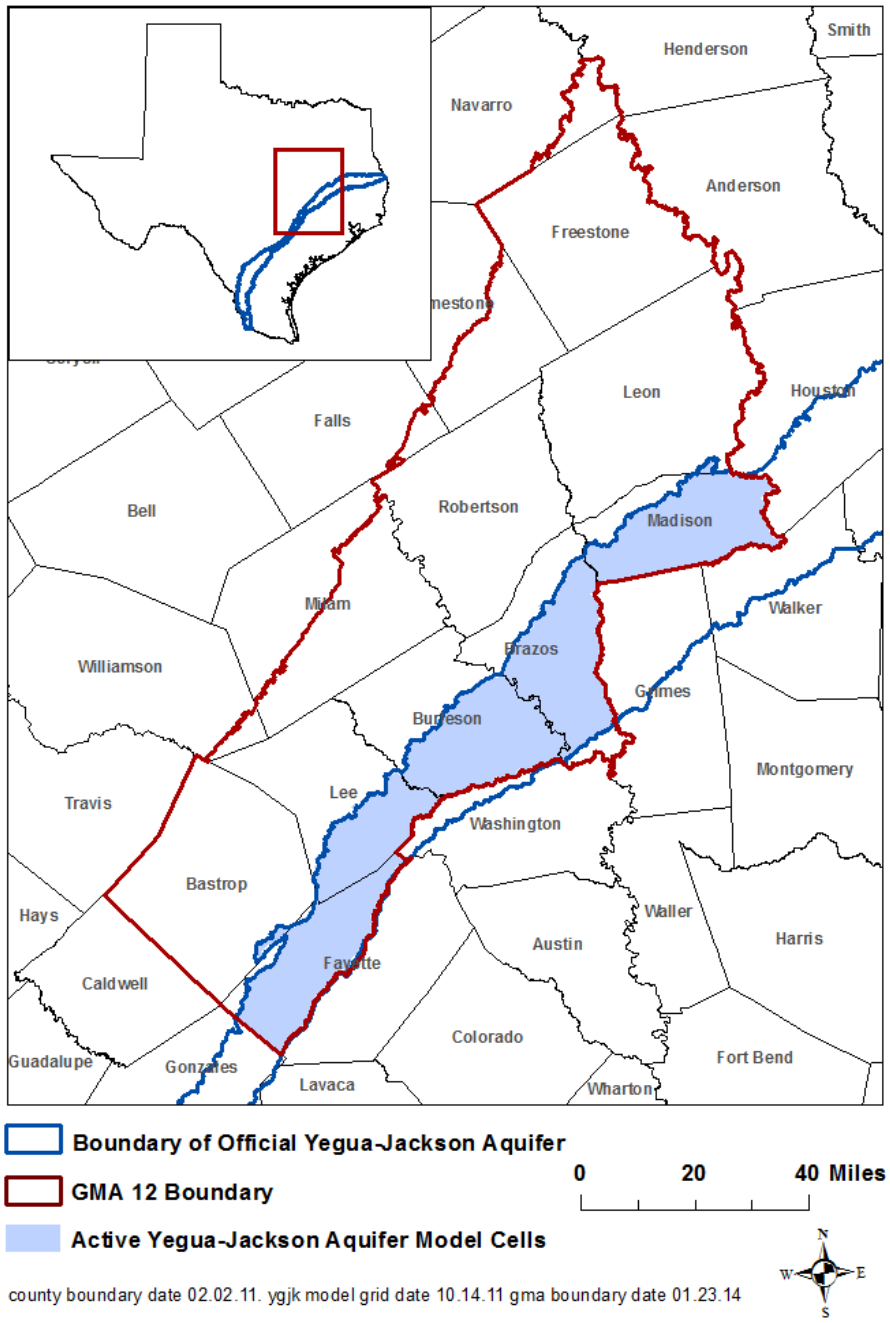

FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE YEGUA-JACKSON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos	450,000	112,500	337,500
Total	450,000	112,500	337,500

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[6] FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos Valley GCD	450,000	112,500	337,500
Total	450,000	112,500	337,500

[6] 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.

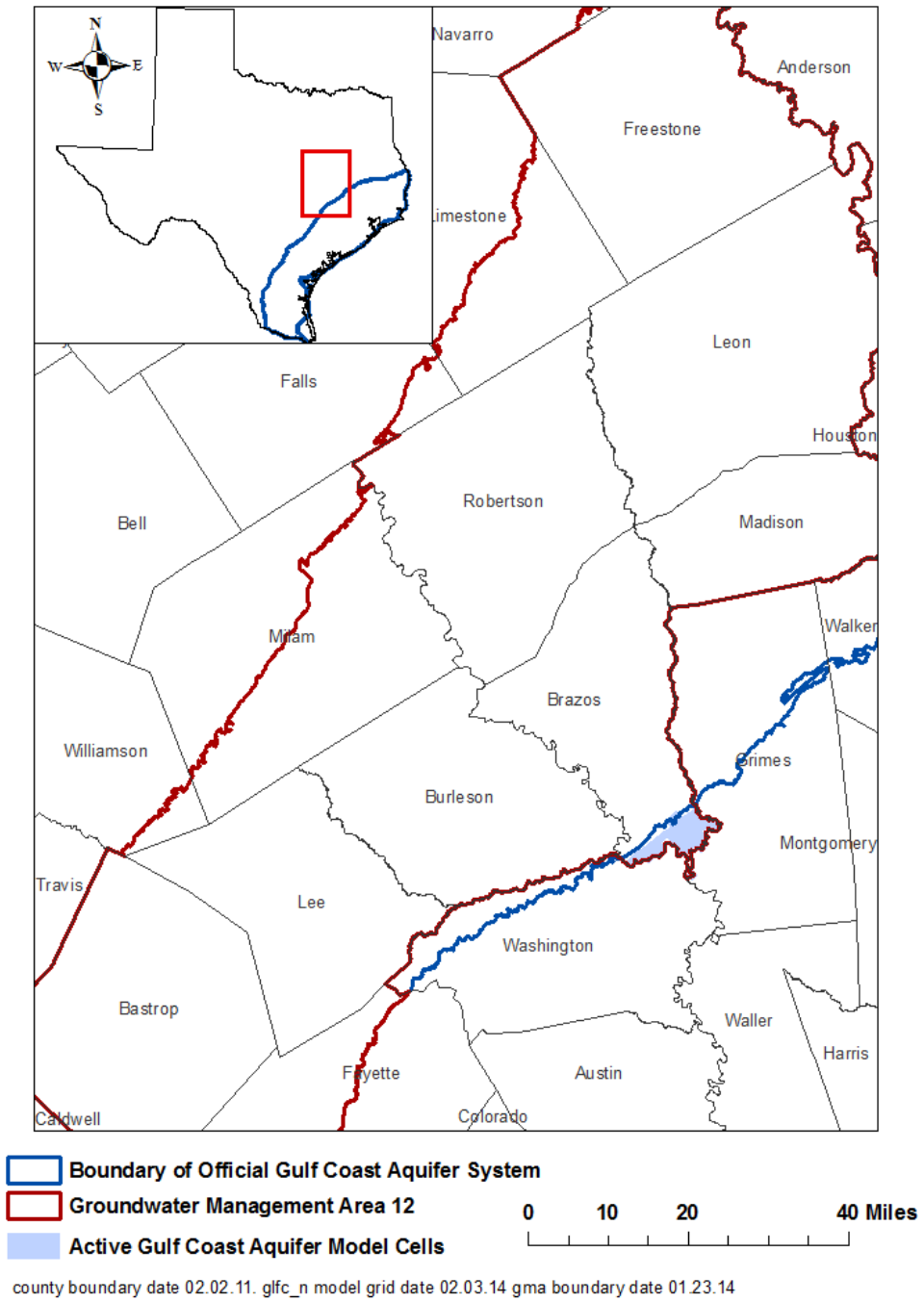

FIGURE 7. AREA USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Brazos	290,000	72,500	217,500
Burleson	450,000	112,500	337,500
Falls	140	35	105
Milam	28,000	7,000	21,000
Robertson	270,000	67,500	202,500
Total	1,038,140	259,535	778,605

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[7] FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	140	35	105
Brazos Valley GCD	560,000	140,000	420,000
Post Oak Savannah GCD	480,000	120,000	360,000
Total	1,040,140	260,035	780,105

[7] 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.

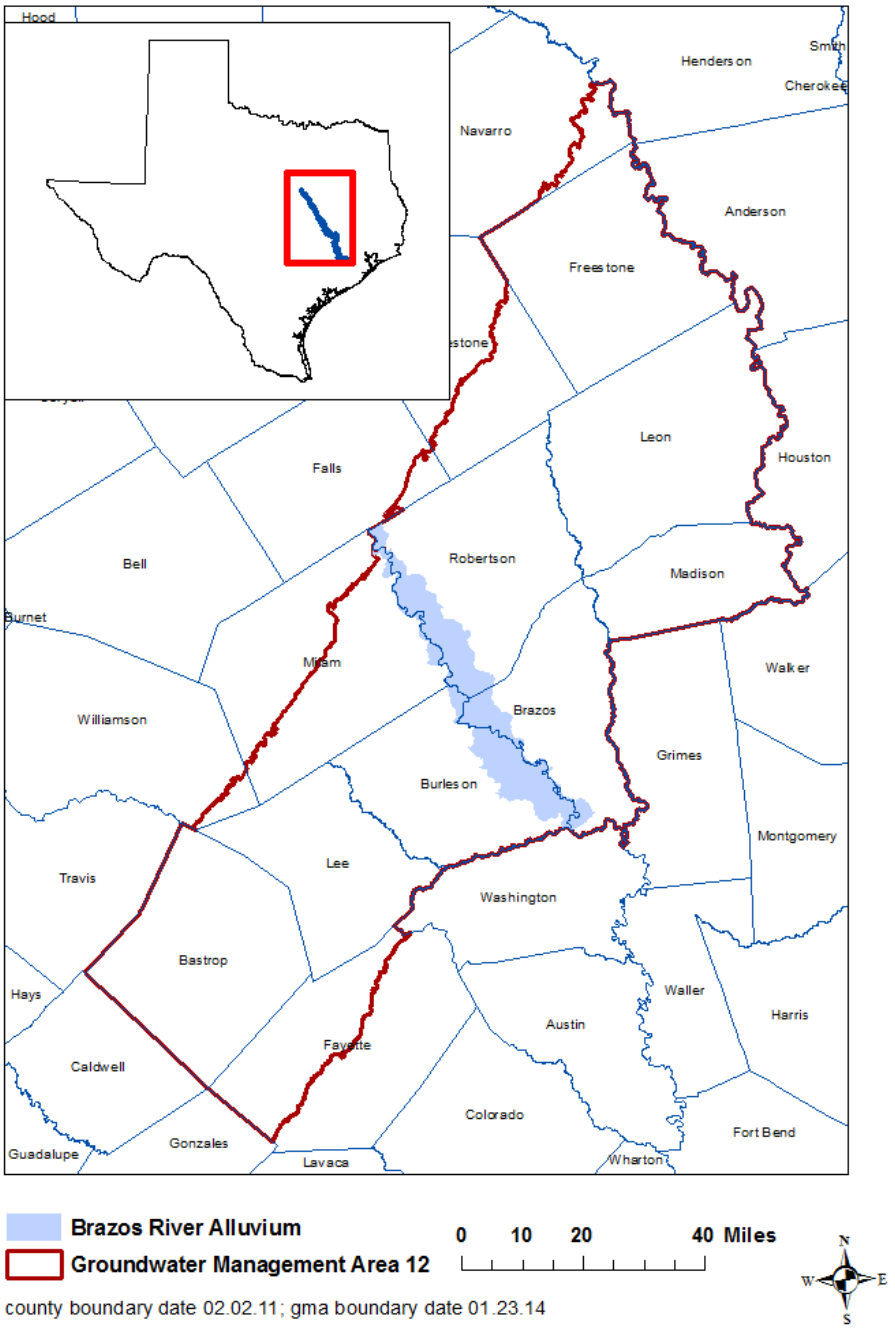

FIGURE 8. AREA USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 AND 14) FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 12.

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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APPENDIX A Total Estimated Recoverable Storage for the Hooper, Simsboro, Calvert Bluff, and Carrizo Formations of the Carrizo-Wilcox Aquifer

TABLE 15. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE HOOPER FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	35,000,000	8,750,000	26,250,000
Brazos	18,000,000	4,500,000	13,500,000
Burleson	30,000,000	7,500,000	22,500,000
Falls	760,000	190,000	570,000
Fayette	25,000,000	6,250,000	18,750,000
Freestone	17,000,000	4,250,000	12,750,000
Lee	34,000,000	8,500,000	25,500,000
Leon	42,000,000	10,500,000	31,500,000
Limestone	7,200,000	1,800,000	5,400,000
Madison	32,000,000	8,000,000	24,000,000
Milam	15,000,000	3,750,000	11,250,000
Navarro	850,000	212,500	637,500
Robertson	31,000,000	7,750,000	23,250,000
Williamson	450,000	112,500	337,500
Total	288,260,000	72,065,000	216,195,000

TABLE 16. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[8] FOR THE HOOPER FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	9,300,000	2,325,000	6,975,000
Brazos Valley GCD	49,000,000	12,250,000	36,750,000
Fayette County GCD	25,000,000	6,250,000	18,750,000
Lost Pines GCD	68,000,000	17,000,000	51,000,000
Mid-East Texas GCD	92,000,000	23,000,000	69,000,000
Post Oak Savannah GCD	45,000,000	11,250,000	33,750,000
Total	288,300,000	72,075,000	216,225,000

[8] 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.

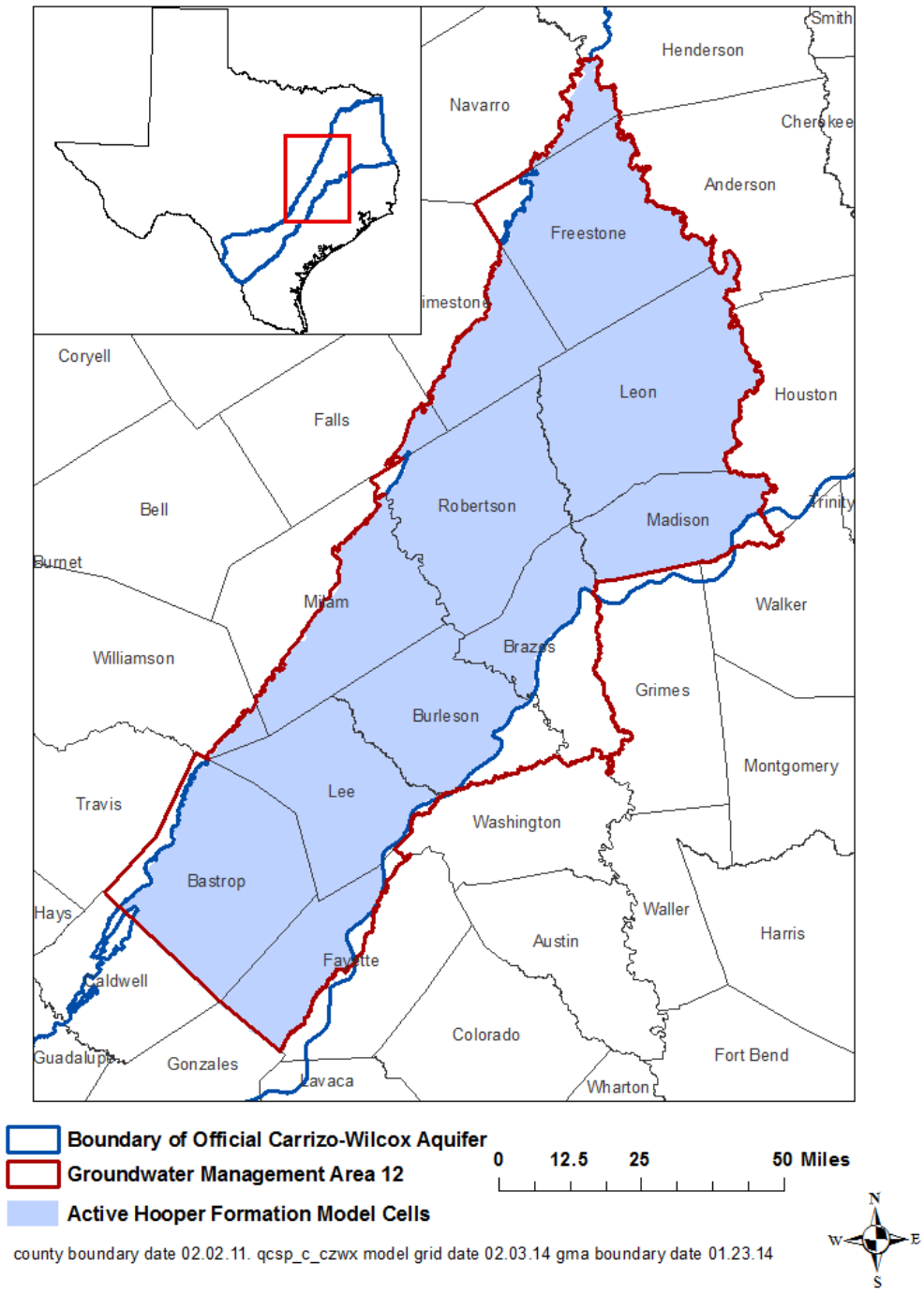

FIGURE 9. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE HOOPER FORMATION (TABLES 15 AND 16) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 17. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SIMSBORO FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	18,000,000	4,500,000	13,500,000
Brazos	19,000,000	4,750,000	14,250,000
Burleson	30,000,000	7,500,000	22,500,000
Falls	66,000	16,500	49,500
Fayette	14,000,000	3,500,000	10,500,000
Freestone	9,600,000	2,400,000	7,200,000
Lee	28,000,000	7,000,000	21,000,000
Leon	35,000,000	8,750,000	26,250,000
Limestone	3,100,000	775,000	2,325,000
Madison	19,000,000	4,750,000	14,250,000
Milam	17,000,000	4,250,000	12,750,000
Navarro	140,000	35,000	105,000
Robertson	36,000,000	9,000,000	27,000,000
Williamson	49,000	12,250	36,750
Total	228,955,000	57,238,750	171,716,250

TABLE 18. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[9] FOR THE SIMSBORO FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	3,400,000	850,000	2,550,000
Brazos Valley GCD	55,000,000	13,750,000	41,250,000
Fayette County GCD	14,000,000	3,500,000	10,500,000
Lost Pines GCD	46,000,000	11,500,000	34,500,000
Mid-East Texas GCD	64,000,000	16,000,000	48,000,000
Post Oak Savannah GCD	47,000,000	11,750,000	35,250,000
Total	229,400,000	57,350,000	172,050,000

[9] 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.

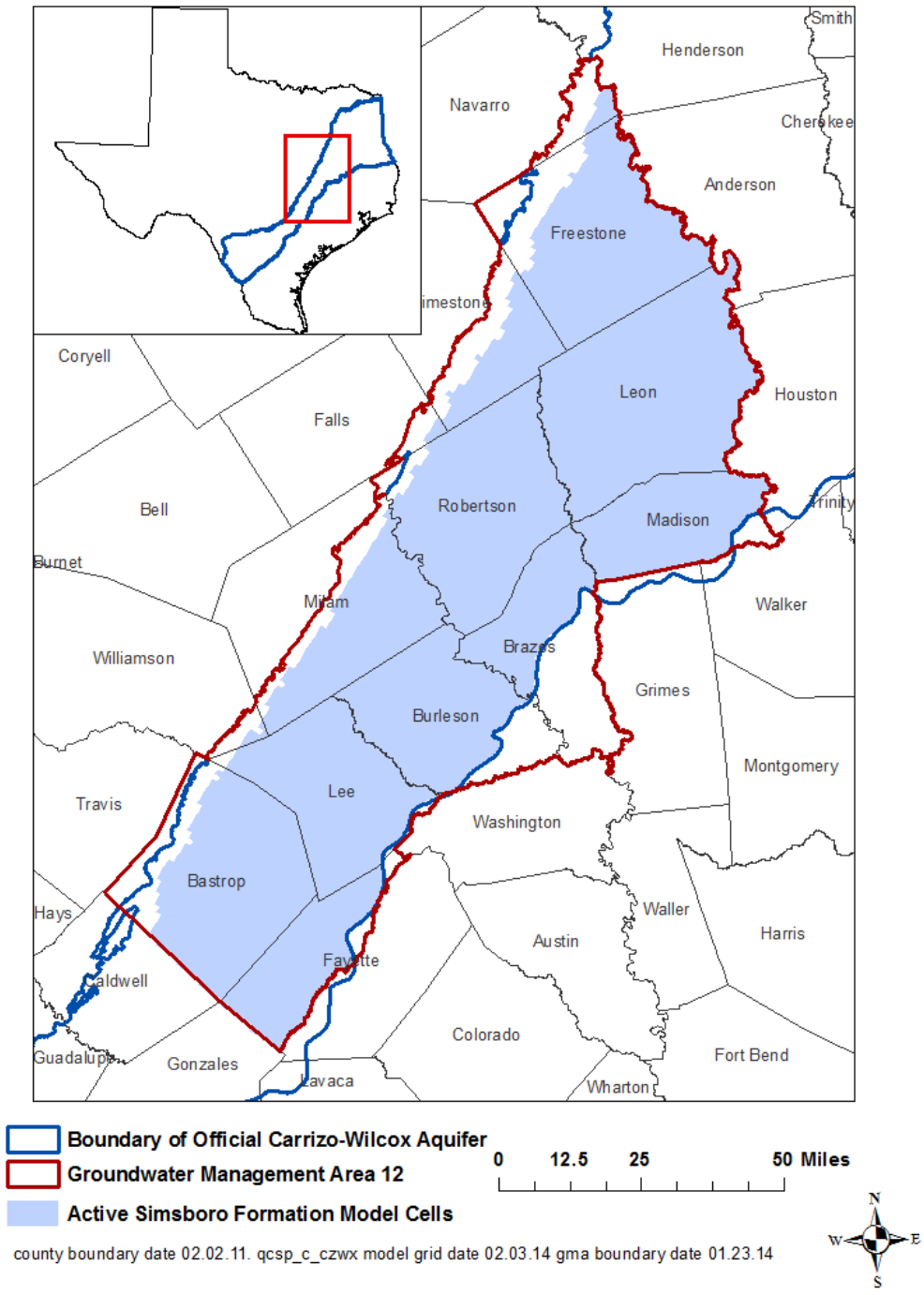

FIGURE 10. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE SIMSBORO FORMATION (TABLES 17 AND 18) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 19. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CALVERT BLUFF FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	33,000,000	8,250,000	24,750,000
Brazos	22,000,000	5,500,000	16,500,000
Burleson	40,000,000	10,000,000	30,000,000
Falls	0	0	0
Fayette	36,000,000	9,000,000	27,000,000
Freestone	17,000,000	4,250,000	12,750,000
Lee	43,000,000	10,750,000	32,250,000
Leon	81,000,000	20,250,000	60,750,000
Limestone	1,300,000	325,000	975,000
Madison	51,000,000	12,750,000	38,250,000
Milam	12,000,000	3,000,000	9,000,000
Navarro	39,000	9,750	29,250
Robertson	32,000,000	8,000,000	24,000,000
Williamson	1,800	450	1,350
Total	368,340,800	92,085,200	276,255,600

TABLE 20. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[10] FOR THE CALVERT BLUFF FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	1,400,000	350,000	1,050,000
Brazos Valley GCD	54,000,000	13,500,000	40,500,000
Fayette County GCD	36,000,000	9,000,000	27,000,000
Lost Pines GCD	77,000,000	19,250,000	57,750,000
Mid-East Texas GCD	150,000,000	37,500,000	112,500,000
Post Oak Savannah GCD	52,000,000	13,000,000	39,000,000
Total	370,400,000	92,600,000	277,800,000

[10] 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.

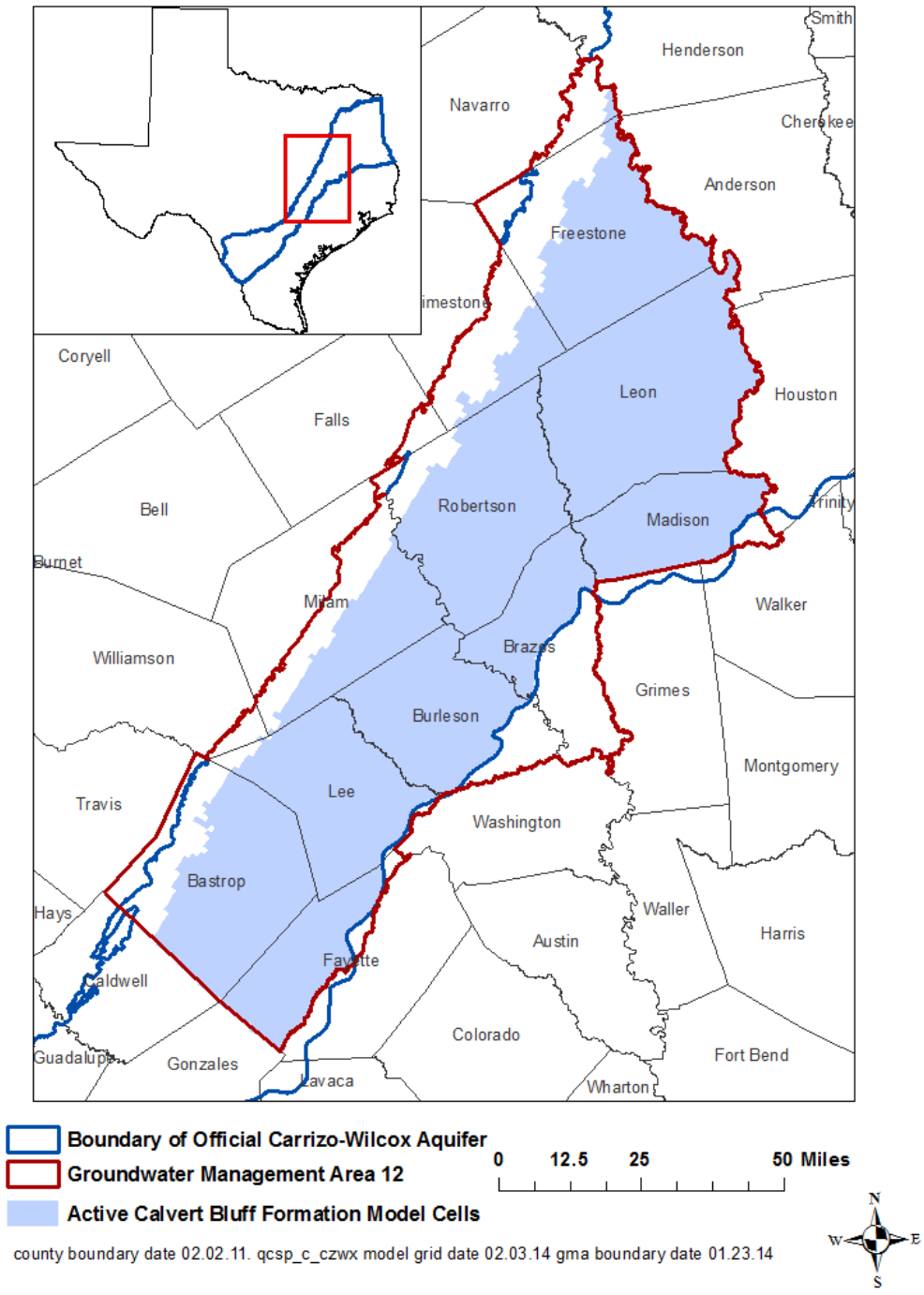

FIGURE 11. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CALVERT BLUFF FORMATION (TABLES 19 AND 20) WITHIN GROUNDWATER MANAGEMENT AREA 12.

TABLE 21. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CARRIZO FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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)*
Bastrop	12,000,000	3,000,000	9,000,000
Brazos	9,800,000	2,450,000	7,350,000
Burleson	21,000,000	5,250,000	15,750,000
Falls	0	0	0
Fayette	20,000,000	5,000,000	15,000,000
Freestone	2,000,000	500,000	1,500,000
Lee	21,000,000	5,250,000	15,750,000
Leon	20,000,000	5,000,000	15,000,000
Limestone	0	0	0
Madison	9,500,000	2,375,000	7,125,000
Milam	2,900,000	725,000	2,175,000
Navarro	0	0	0
Robertson	9,500,000	2,375,000	7,125,000
Williamson	0	0	0
Total	127,700,000	31,925,000	95,775,000

TABLE 22. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[11] FOR THE CARRIZO FORMATION WITHIN GROUNDWATER MANAGEMENT AREA 12. 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	0	0	0
Brazos Valley GCD	19,000,000	4,750,000	14,250,000
Fayette County GCD	20,000,000	5,000,000	15,000,000
Lost Pines GCD	33,000,000	8,250,000	24,750,000
Mid-East Texas GCD	31,000,000	7,750,000	23,250,000
Post Oak Savannah GCD	23,000,000	5,750,000	17,250,000
Total	126,000,000	31,500,000	94,500,000

[11] 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.

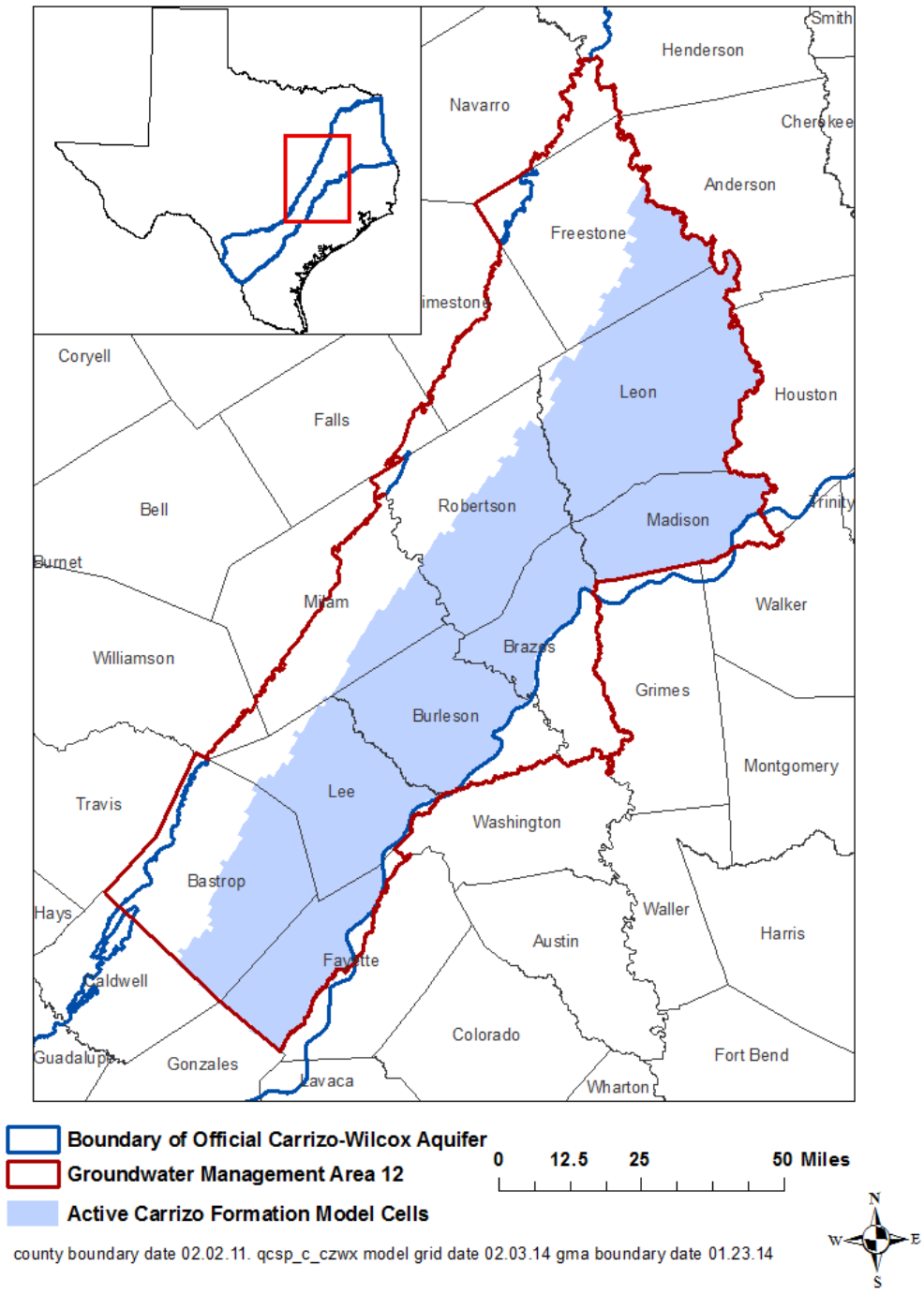

FIGURE 12. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CARRIZO FORMATION (TABLES 21 AND 22) WITHIN GROUNDWATER MANAGEMENT AREA 12.