GAM TASK 13-037: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 14

by Shirley Wade, Ph.D., P.G., David Thorkildsen, P.G., and Roberto Anaya, P.G.
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Groundwater Resources Division
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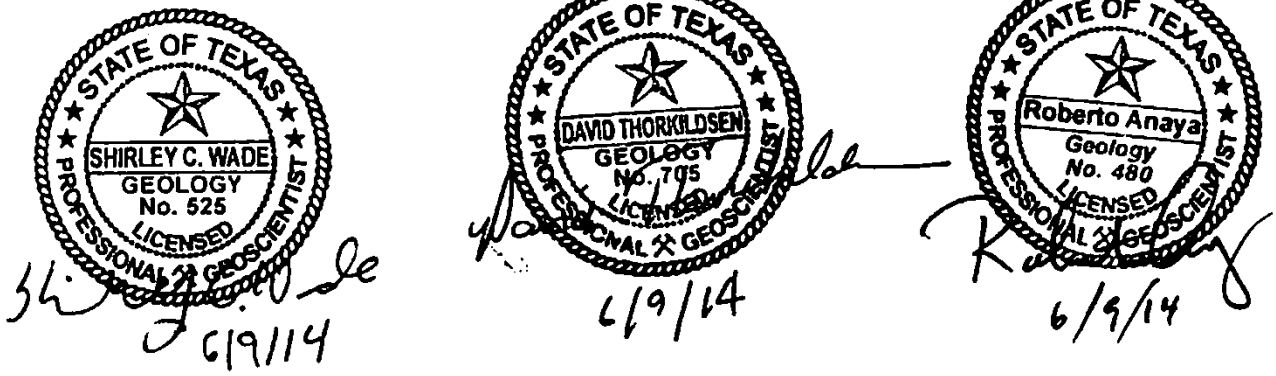
June 09, 2014



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The total estimated recoverable storage in this report was calculated as follows: the Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson aquifers, the Gulf Coast Aquifer System and the Brazos River Alluvium Aquifer (Shirley Wade); and the San Bernard, Navasota, San Jacinto, and Trinity river alluviums determined as relevant (David Thorkildsen), quality assurance and report preparation (Roberto Anaya).

[1] Contact information is for Roberto Anaya

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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 Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, Gulf Coast, and Brazos River Alluvium aquifers in addition to water-bearing alluvial sediments determined as relevant by Groundwater Management Area 14 groundwater conservation districts for the San Bernard, Navasota, San Jacinto, and Trinity rivers within Groundwater Management Area 14. Tables 1 through 20 summarize the total estimated recoverable storage required by the statute. The total estimated recoverable storage values are for areas within the official extent of the aquifers (and other portions deemed relevant by the groundwater conservation districts) in Groundwater Management Area 14. In addition, areas that currently have adopted desired future conditions but may be declared to be non-relevant are included

[1] Contact information is for Roberto Anaya

as the total estimated recoverable storage values are needed for the associated explanatory report per Texas Administrative Code Rule §356.31 (b) (Texas Administrative Code, 2011).

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 aquifers within Groundwater Management Area 14 that lie within the official lateral aquifer boundaries as delineated by George and others (2011). If portions of aquifers outside these boundaries were defined as relevant in the resolution dated August 25, 2010, that adopted the current desired future conditions, then estimates of total recoverable storage reported here include these specific areas. 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 and/or relevant 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)

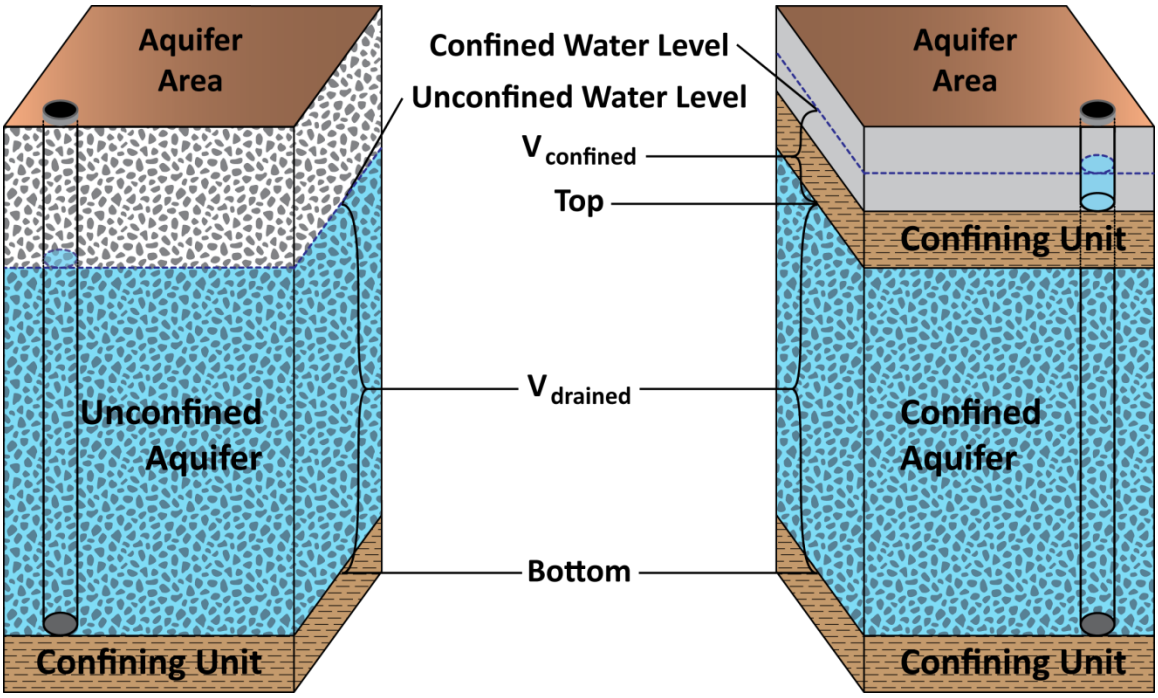

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 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 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 (Shah and others, 2007; TWDB, 2013). 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.

For the water bearing alluvial sediments determined as relevant for the San Bernard, Navasota, San Jacinto, and Trinity rivers, which do not have a groundwater availability model, we used an analytical approach. For each county, ArcMAP™ was used to calculate the acreage area for the delineated spatial extents of each of the river alluvia. The saturated thickness was then estimated based on water well and water-level data from the TWDB groundwater database for each of the acreage areas of the water bearing alluvial sediments determined as relevant (TWDB, 2011). Finally, we estimated the total storage for each of the river alluvia using average saturated thicknesses multiplied with associated areas and an assumed uniformly distributed specific yield values reported in the literature (Baker and others, 1974; Bradley, 2011; Cronin and Wilson, 1967; Johnson, 1967; Wilson, 1967).

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:

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).
- The groundwater availability model for the northern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers was not considered for analysis because the active model area was more adequately covered by the overlap of the active model area for the central part of the Carrizo-Wilcox, Queen City, and Sparta aquifers.

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. 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).

- For Jasper, Newton, Polk, Tyler, and Washington counties we used the official active areas of the groundwater availability model to estimate the total recoverable storage for the Yegua-Jackson Aquifer. However, for Grimes and Walker counties the desired future condition statement adopted on August 25, 2010,o included confined and brackish confined areas outside of the official aquifer area. Geographic information for those areas was submitted with the desired future condition statement. We used that information in this assessment to estimate the total recoverable storage for Grimes and Walker counties for layers 2 through 5 which represent the confined parts of the Yegua-Jackson units.

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 (defined in this case to be 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).

San Bernard River Alluvium

- The areal extent of the San Bernard River Alluvium within Austin County was calculated to be 2,792 acres (USGS and TWDB, 2006).
- Average saturated thickness of the water bearing alluvium determined as relevant was calculated to be 20 feet (Thorkildsen and Backhouse, 2011).
- We used a specific yield value of 0.15 (Wilson, 1967).

Navasota River Alluvium

- The areal extent of the Navasota River Alluvium within Grimes County was calculated to be 12,004 acres (USGS and TWDB, 2006).
- Based on water well and water-level data from the TWDB groundwater database near the confluence of the Navasota and Brazos Rivers the water bearing alluvium determined as relevant has an average saturated thickness of 32 feet (TWDB, 2011).
- We used a specific yield value of 0.15 (Baker and others, 1974; Bradley, 2011; Johnson, 1967).

San Jacinto River Alluvium

- The areal extent of the San Jacinto River Alluvium within Walker County was calculated to be 7,399 acres (USGS and TWDB, 2006).
- Based on water well and water-level data from the TWDB groundwater database the water bearing alluvium determined as relevant has an average saturated thickness of 20 feet (TWDB, 2011).
- We used a specific yield value of 0.15 (Cronin and Wilson, 1967; Johnson, 1967).

Trinity River Alluvium

- The areal extent of the Trinity River Alluvium within Walker County was calculated to be 19,873 acres (USGS and TWDB, 2006).
- Based on water well and water-level data from the TWDB groundwater database the water bearing alluvium determined as relevant has an average saturated thickness of 23 feet (TWDB, 2011).

- We used a specific yield value of 0.15 (Cronin and Wilson, 1967; Johnson, 1967).

RESULTS:

Tables 1 through 20 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total storage estimates are rounded to two or three significant digits. Figures 2 through 11 indicate the extent of the groundwater availability models or aquifer boundaries deemed relevant by the groundwater conservation districts in Groundwater Management Area 14 for the Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, Gulf Coast, and Brazos River Alluvium aquifers as well as the water bearing alluvial sediments determined as relevant by Groundwater Management Area 14 groundwater conservation districts for the San Bernard, Navasota, San Jacinto, and Trinity rivers.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. COUNTY TOTAL ESTIMATES ARE ROUNDED TO THREE SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Grimes	14,500,000	3,625,000	10,875,000
Walker	5,040,000	1,260,000	3,780,000
Washington	264,000	66,000	198,000
Total	19,804,000	4,951,000	14,853,000

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[2] FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO THREE 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	264,000	66,000	198,000
Bluebonnet GCD	19,500,000	4,875,000	14,625,000
Total	19,764,000	4,941,000	14,823,000

[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 three significant digits.

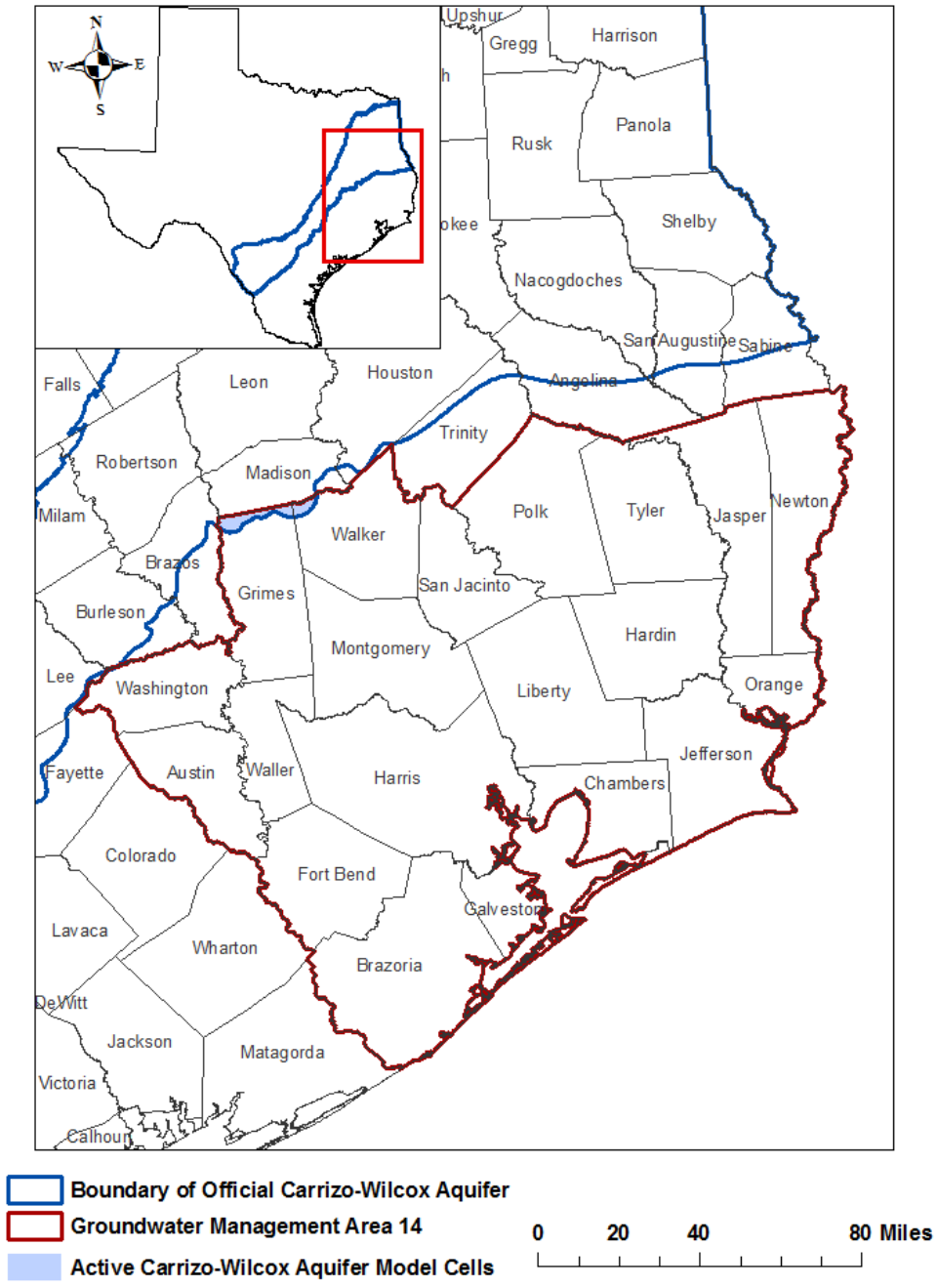

FIGURE 2. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CARRIZO-WILCOX AQUIFER (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. COUNTY TOTAL ESTIMATES ARE ROUNDED TO THREE SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Grimes	4,970,000	1,242,500	3,727,500
Walker	624,000	156,000	468,000
Washington	4,330,000	1,082,500	3,247,500
Total	9,924,000	2,481,000	7,443,000

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[3] FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO THREE 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	4,330,000	1,082,500	3,247,500
Bluebonnet GCD	5,590,000	1,397,500	4,192,500
Total	9,920,000	2,480,000	7,440,000

[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 three significant digits.

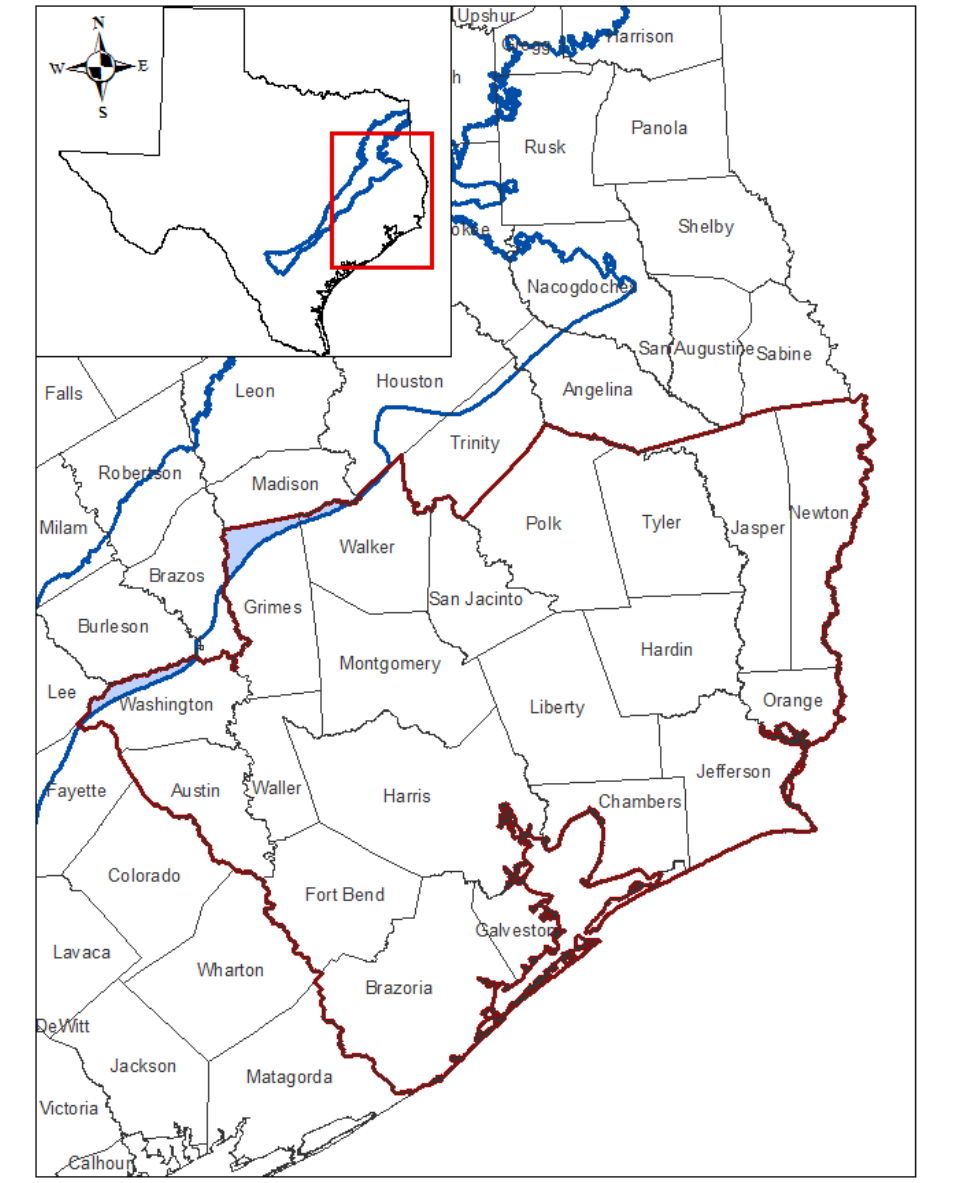

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE QUEEN CITY AQUIFER (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. COUNTY TOTAL ESTIMATES ARE ROUNDED TO THREE SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Grimes	11,600,000	2,900,000	8,700,000
Walker	8,550,000	2,137,500	6,412,500
Washington	1,860,000	465,000	1,395,000
Total	22,010,000	5,502,500	16,507,500

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[4] FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO THREE 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	1,860,000	465,000	1,395,000
Bluebonnet GCD	20,100,000	5,025,000	15,075,000
Total	21,960,000	5,490,000	16,470,000

[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 three significant digits.

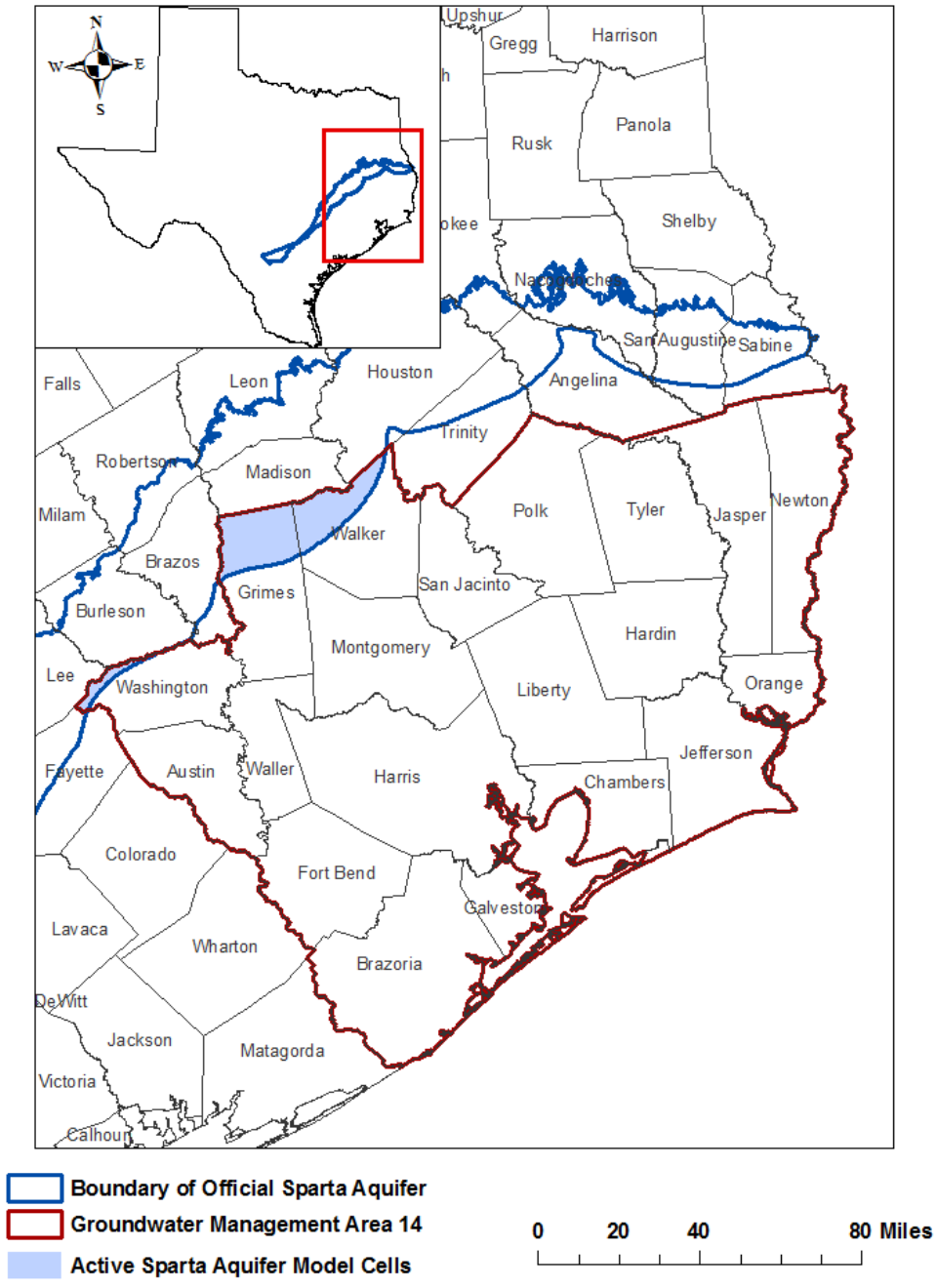

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE SPARTA AQUIFER (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. COUNTY TOTAL ESTIMATES ARE ROUNDED TO THREE SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Grimes	94,900,000	23,725,000	71,175,000
Jasper	6,930,000	1,732,500	5,197,500
Newton	1,270,000	317,500	952,500
Polk	27,900,000	6,975,000	20,925,000
Tyler	8,650,000	2,162,500	6,487,500
Walker	103,000,000	25,750,000	77,250,000
Washington	12,400,000	3,100,000	9,300,000
Total	255,050,000	63,762,500	191,287,500

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[5] FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO THREE 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	12,400,000	3,100,000	9,300,000
Bluebonnet GCD	198,000,000	49,500,000	148,500,000
Lower Trinity GCD	28,000,000	7,000,000	21,000,000
Southeast Texas GCD	16,900,000	4,225,000	12,675,000
Total	255,300,000	63,825,000	191,475,000

[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 three significant digits.

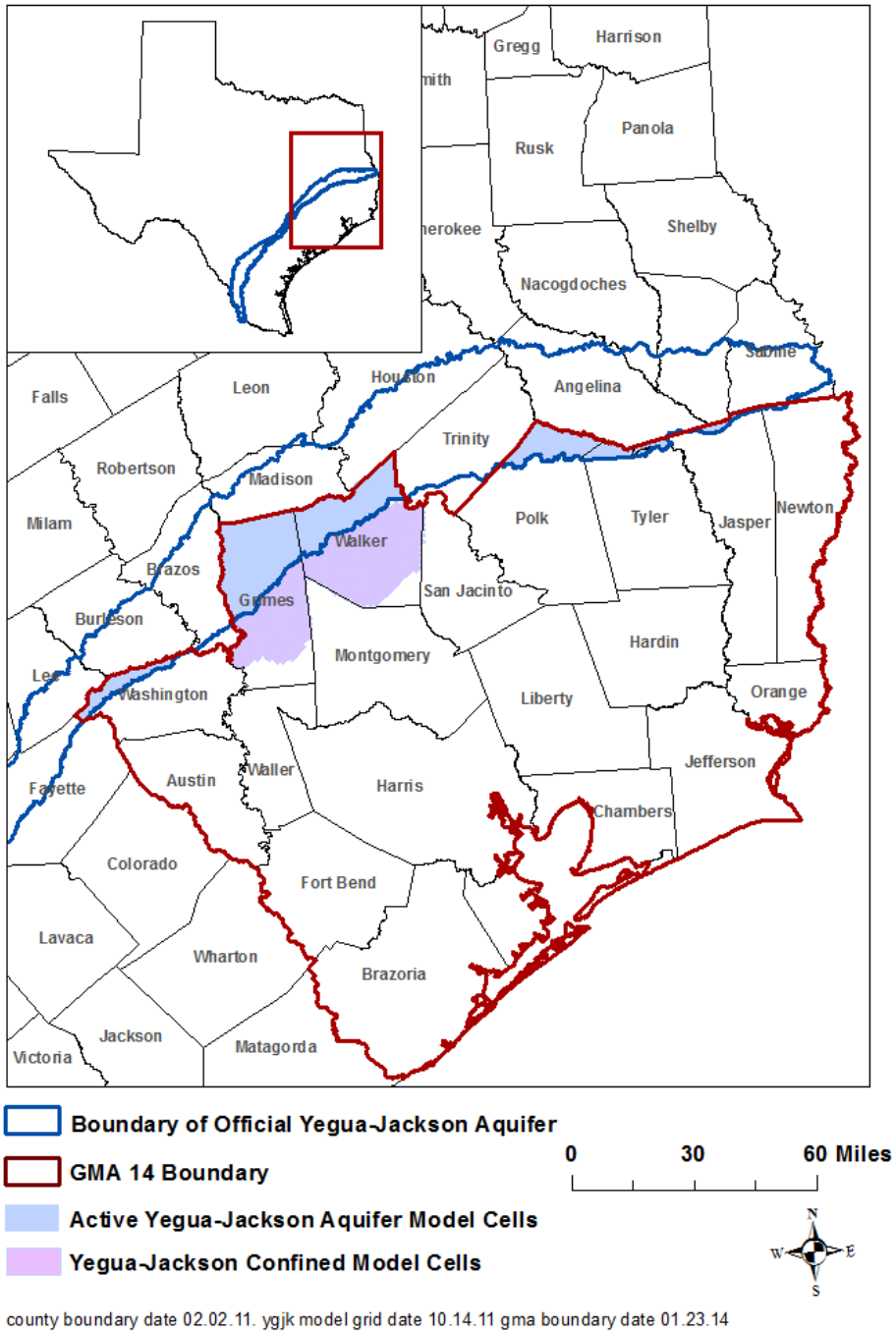

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE YEGUA-JACKSON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Austin	80,000,000	20,000,000	60,000,000
Brazoria	330,000,000	82,500,000	247,500,000
Chambers	130,000,000	32,500,000	97,500,000
Fort Bend	170,000,000	42,500,000	127,500,000
Galveston	81,000,000	20,250,000	60,750,000
Grimes	35,000,000	8,750,000	26,250,000
Hardin	190,000,000	47,500,000	142,500,000
Harris	380,000,000	95,000,000	285,000,000
Jasper	140,000,000	35,000,000	105,000,000
Jefferson	170,000,000	42,500,000	127,500,000
Liberty	250,000,000	62,500,000	187,500,000
Montgomery	180,000,000	45,000,000	135,000,000
Newton	120,000,000	30,000,000	90,000,000
Orange	61,000,000	15,250,000	45,750,000
Polk	110,000,000	27,500,000	82,500,000
San Jacinto	95,000,000	23,750,000	71,250,000
Tyler	120,000,000	30,000,000	90,000,000
Walker	32,000,000	8,000,000	24,000,000
Waller	80,000,000	20,000,000	60,000,000
Washington	22,000,000	5,500,000	16,500,000
Total	2,776,000,000	694,000,000	2,082,000,000

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[6] FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 14. 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	640,000,000	160,000,000	480,000,000
Bluebonnet GCD	230,000,000	57,500,000	172,500,000
Brazoria County GCD	330,000,000	82,500,000	247,500,000
Fort Bend Subsidence District	170,000,000	42,500,000	127,500,000
Harris-Galveston Coastal Subsidence District	460,000,000	115,000,000	345,000,000
Lone Star GCD	180,000,000	45,000,000	135,000,000
Lower Trinity GCD	200,000,000	50,000,000	150,000,000
Southeast Texas GCD	570,000,000	142,500,000	427,500,000
Total	2,780,000,000	695,000,000	2,085,000,000

[6] 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.

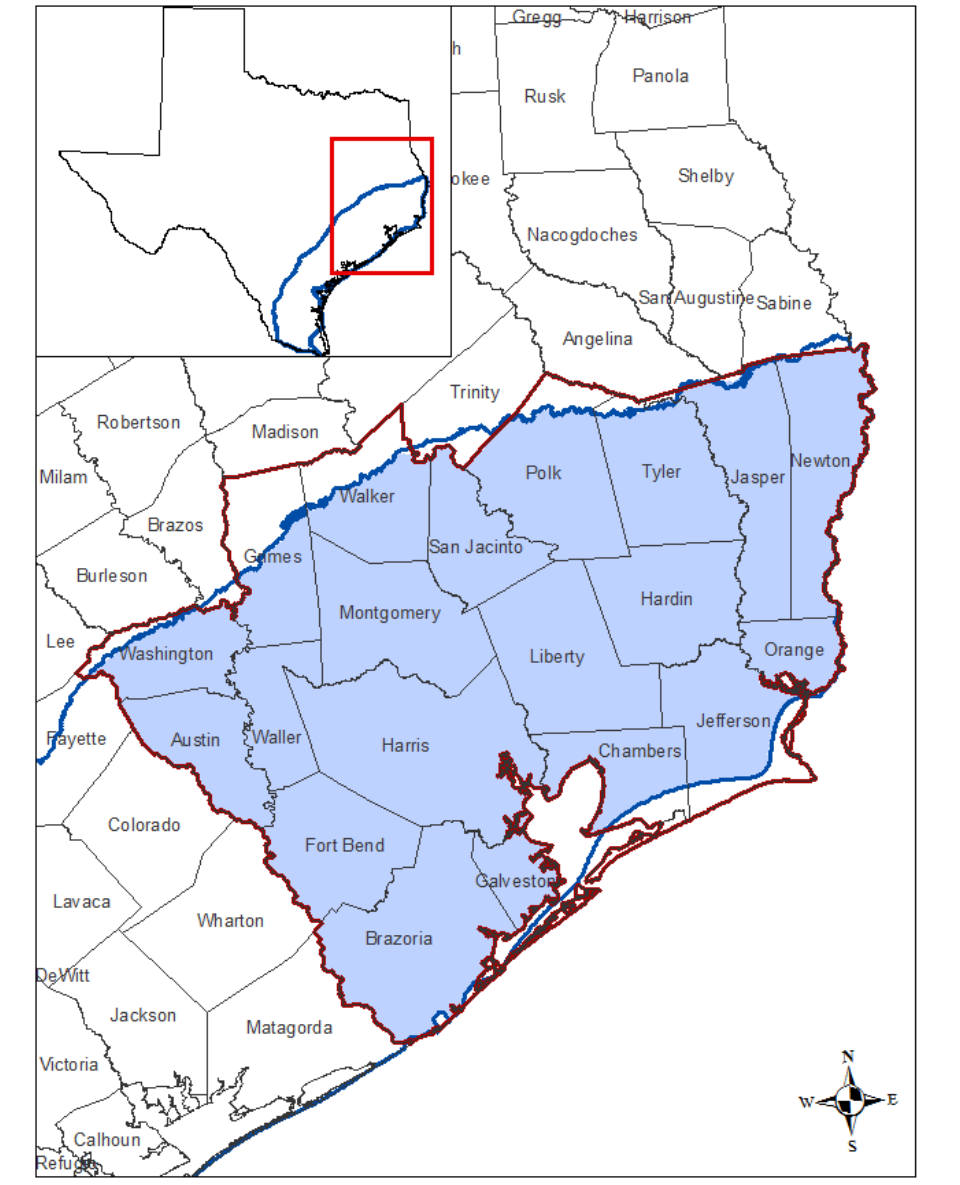

FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN PART OF THE GULF COAST AQUIFER SYSTEM USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. COUNTY TOTAL ESTIMATES ARE ROUNDED TO THREE SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Austin	220,000	55,000	165,000
Fort Bend	1,010,000	252,500	757,500
Grimes	74,700	18,675	56,025
Waller	412,000	103,000	309,000
Washington	179,000	44,750	134,250
Total	1,895,700	473,925	1,421,775

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[7] FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO THREE 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	179,140	179,000	44,750
Bluebonnet GCD	707,000	176,750	530,250
Fort Bend Subsidence District	1,010,000	252,500	757,500
Total	1,896,000	474,000	1,422,000

[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 three significant digits.

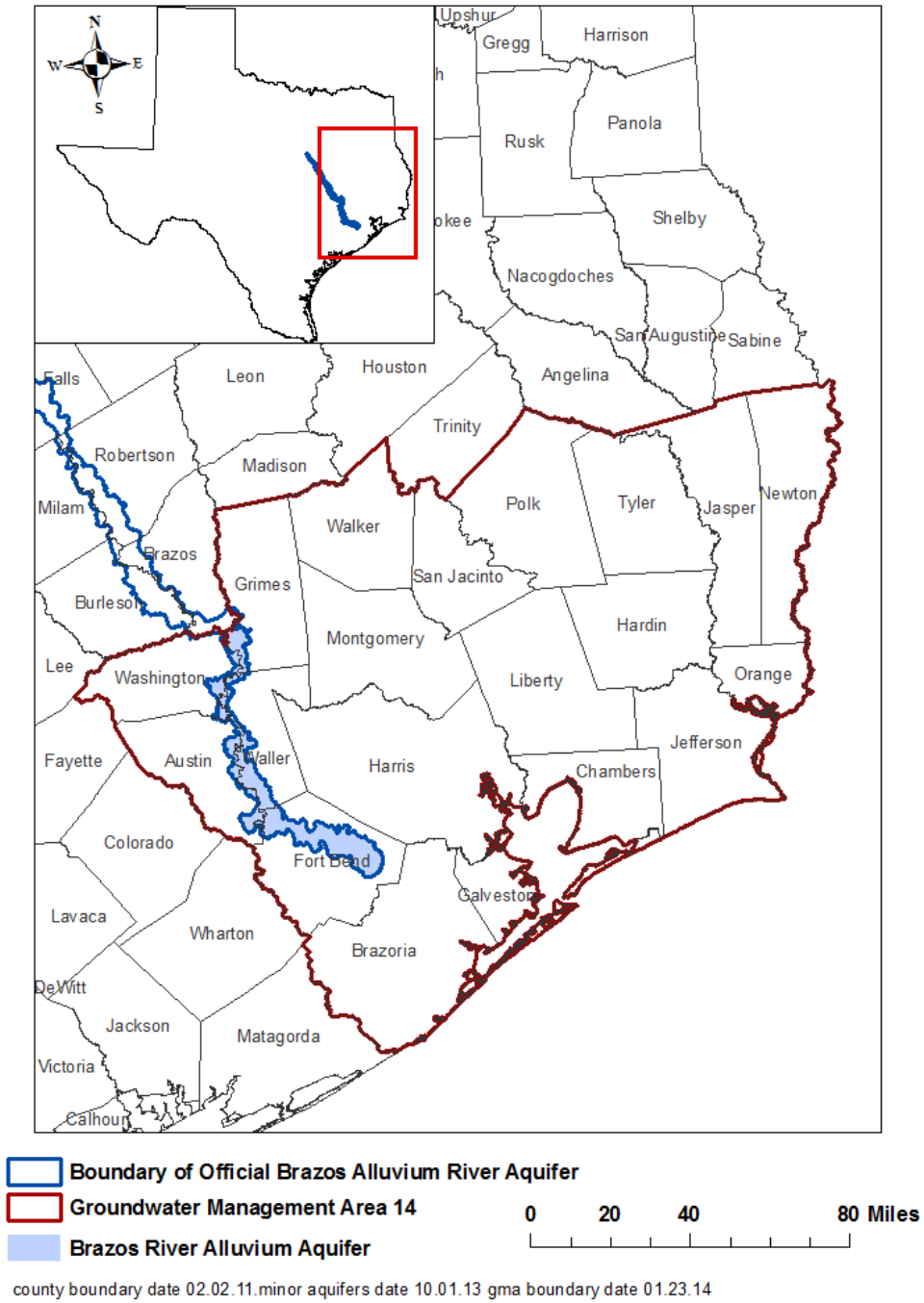

FIGURE 7. EXTENT OF THE BRAZOS RIVER ALLUVIUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) FOR THE BRAZOS RIVER ALLUVIUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SAN BERNARD RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Austin	8,400	2,100	6,300
Total	8,400	2,100	6,300

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE SAN BERNARD RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Bluebonnet GCD	8,400	2,100	6,300
Total	8,400	2,100	6,300

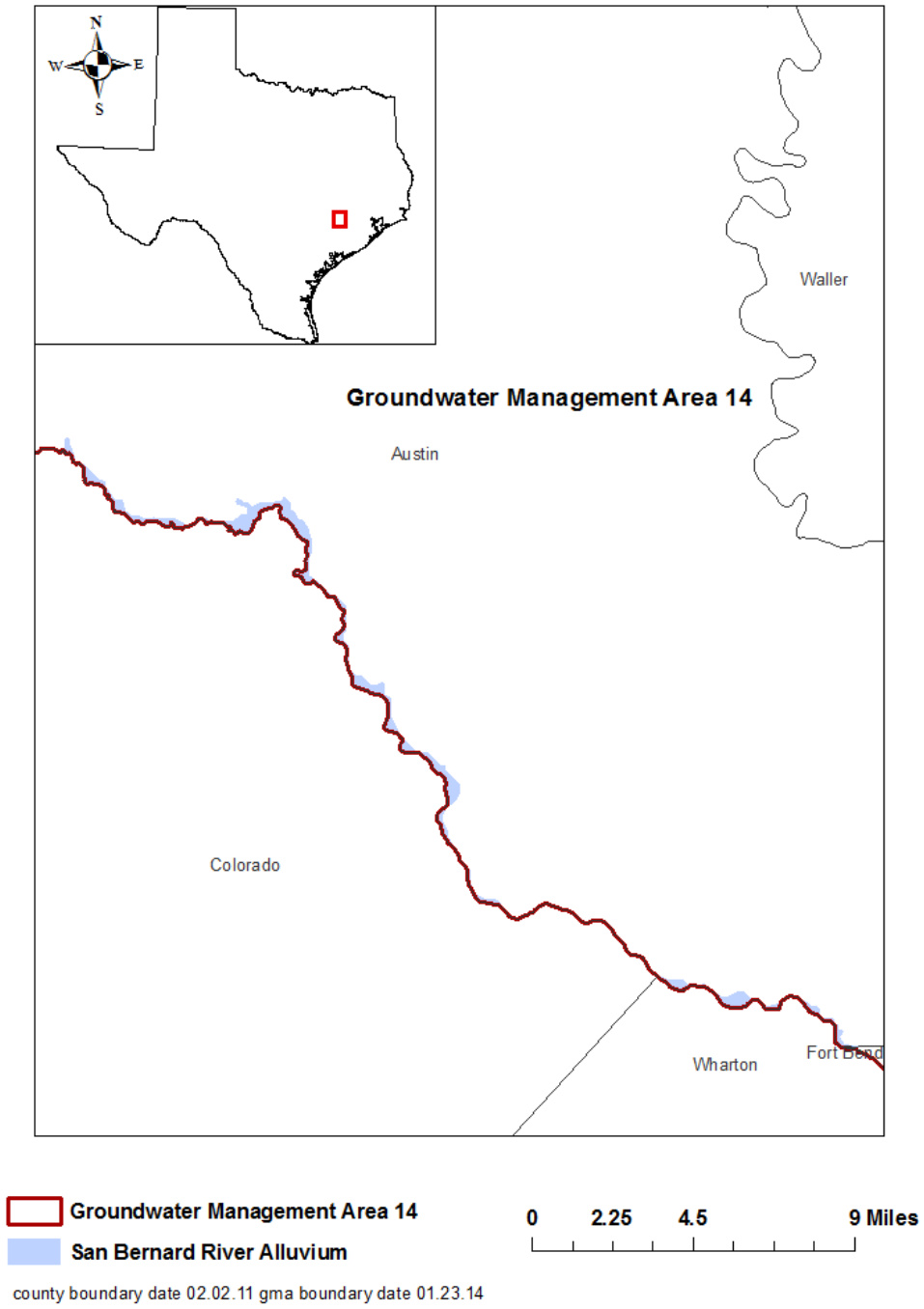

FIGURE 8. EXTENT OF THE SAN BERNARD RIVER ALLUVIUM DETERMINED AS RELEVANT IN AUSTIN COUNTY USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 AND 14) FOR THE SAN BERNARD RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 15. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE NAVASOTA RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Grimes	58,000	14,500	43,500
Total	58,000	14,500	43,500

TABLE 16. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE NAVASOTA RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Bluebonnet GCD	58,000	14,500	43,500
Total	58,000	14,500	43,500

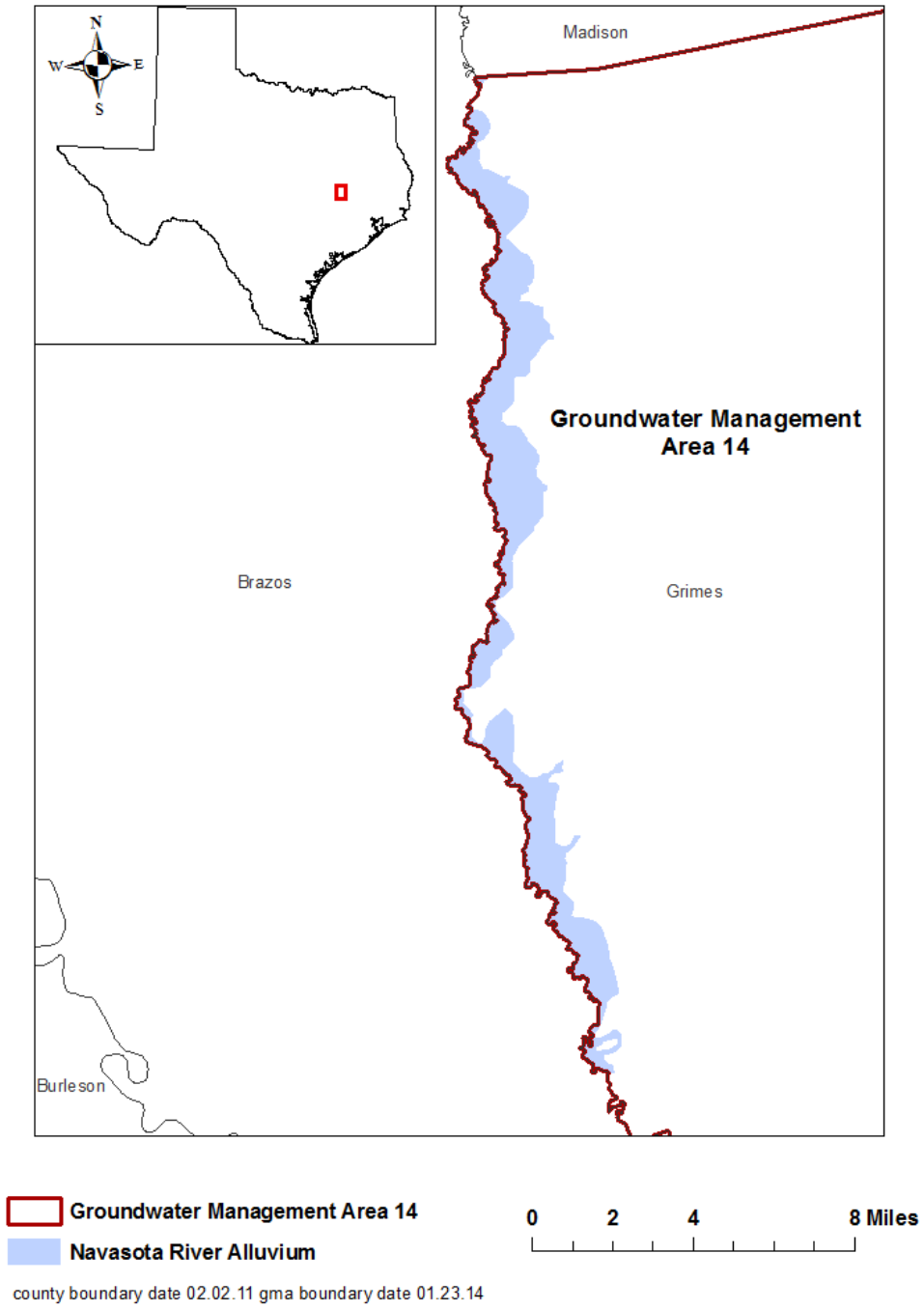

FIGURE 9. EXTENT OF THE NAVASOTA RIVER ALLUVIUM DETERMINED AS RELEVANT IN GRIMES COUNTY USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 15 AND 16) FOR NAVASOTA RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 17. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SAN JACINTO RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Walker	22,000	5,500	16,500
Total	22,000	5,500	16,500

TABLE 18. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE SAN JACINTO RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Bluebonnet GCD	22,000	5,500	16,500
Total	22,000	5,500	16,500

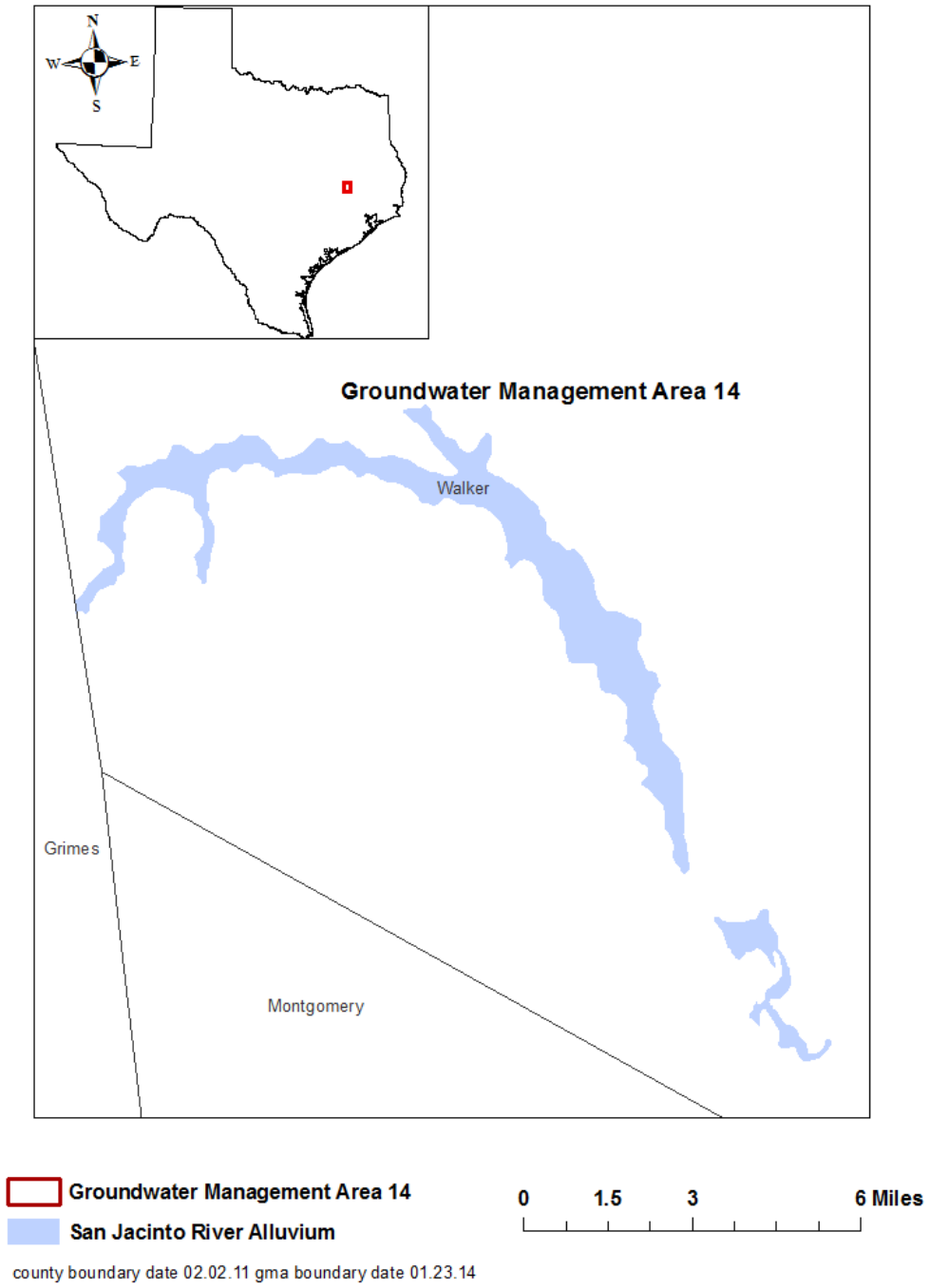

FIGURE 10. EXTENT OF THE SAN JACINTO RIVER ALLUVIUM DETERMINED AS RELEVANT IN WALKER COUNTY USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 17 AND 18) FOR THE SAN JACINTO RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14.

TABLE 19. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Walker	69,000	17,250	51,750
Total	69,000	17,250	51,750

TABLE 20. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE TRINTY RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14. 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)*
Bluebonnet GCD	69,000	17,250	51,750
Total	69,000	17,250	51,750

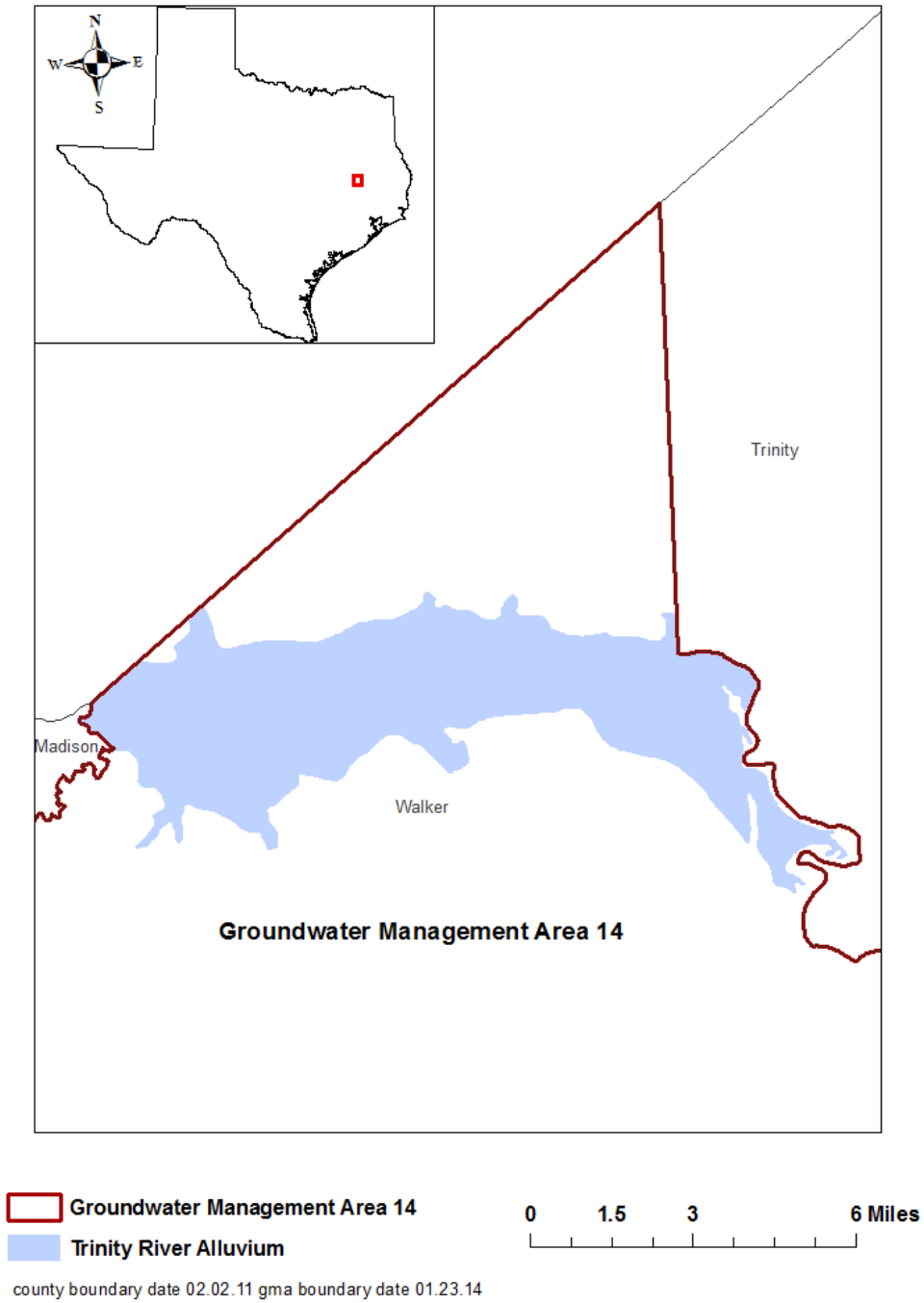

FIGURE 11. EXTENT OF THE TRINITY RIVER ALLUVIUM DETERMINED AS RELEVANT IN WALKER COUNTY USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 19 AND 20) FOR THE TRINITY RIVER ALLUVIUM DETERMINED AS RELEVANT WITHIN GROUNDWATER MANAGEMENT AREA 14.

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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