GAM Task 13-033: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 10

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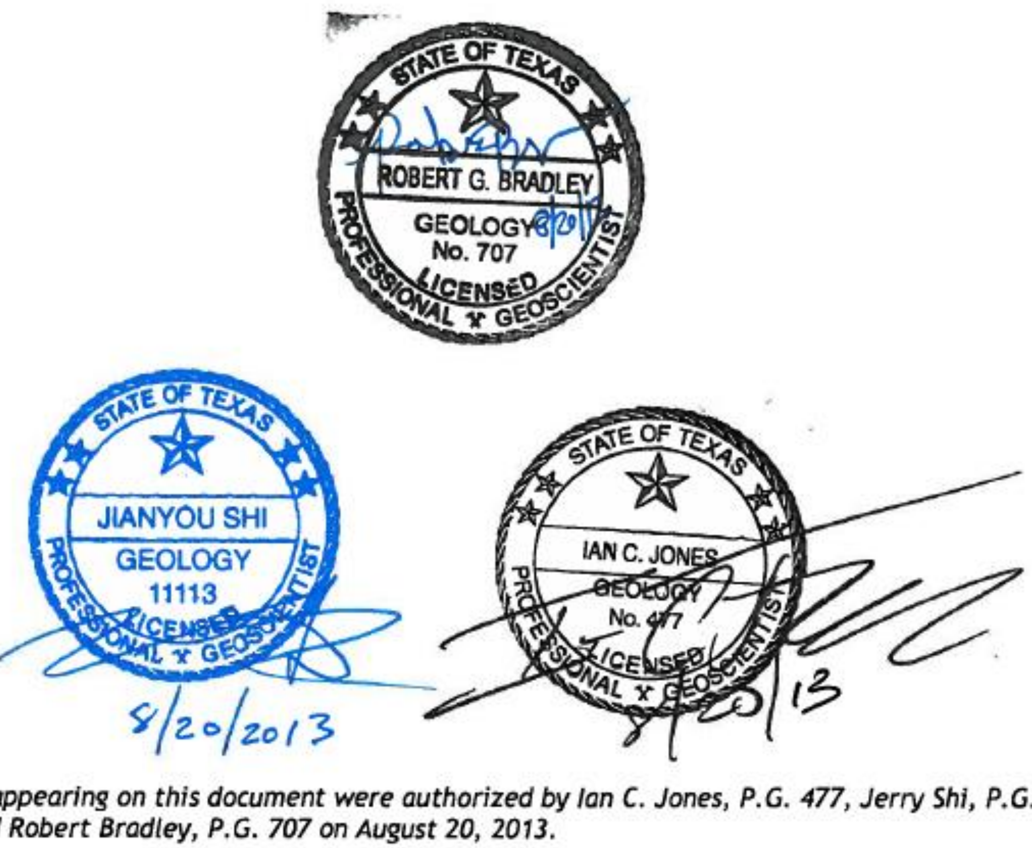

The seals appearing on this document were authorized by Ian C. Jones, P.G. 477, Jerry Shi, P.G. 11113, and Robert Bradley, P.G. 707 on August 20, 2013.

Ian Jones, Jerry Shi, and Robert Bradley calculated the total estimated recoverable storage for the Edwards (Balcones Fault Zone) Aquifer (excluding the Kinney County portion of the Aquifer), the Edwards (Balcones Fault Zone) Aquifer in Kinney County, and the confined portion of the Trinity Aquifer, respectively. Ian Jones also calculated the total estimated recoverable storage for the unconfined portion of the Trinity Aquifer.

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GAM TASK 13-033: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 10

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EXECUTIVE SUMMARY:

Texas Water Code, §36.108 (d) (Texas Water Code, 2011) states that, before voting on their 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 and Edwards (Balcones Fault Zone) aquifers within Groundwater Management Area 10. Tables 2 through 5 summarize the total estimated recoverable storage required by the statute. Figures 2 and 3 indicate the official extent of the aquifers in Groundwater Management Area 10 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

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percent of the porosity-adjusted aquifer volume. In other words, we assume that between 25 and 75 percent of groundwater held within an aquifer can be removed by pumping.

The total recoverable storage was estimated for the portion of the aquifer within Groundwater Management Area 10 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 due to pumping.

METHODS:

To estimate the total recoverable storage of an aquifer, we first calculated the total storage in an aquifer within the official aquifer boundary in the groundwater management area. The total storage is the volume of groundwater that can be removed by pumping completely draining 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—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 in a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is also different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater removed by pumping that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is the groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic pressure in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. The second part, just like unconfined aquifer, is the groundwater released from the aquifer when the water level falls from the top to the bottom of the aquifer. Given the same aquifer area and water level drop, the amount of water released in the second part is much greater than the first part. The difference is quantified by two parameters: storativity related to confined aquifer and specific yield related to unconfined aquifer. For example, storativity values range from 10^{-5} to 10^{-3} for most confined aquifers, while the specific yield values can be 0.01 to 0.3 for most unconfined aquifers. The equations for calculating the total storage are presented below:

- for unconfined aquifers

$$Total\ Storage\ = V_{drained} = Area \times S_y \times (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage\ = V_{confined} + V_{drained}$$

    - confined part

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

or

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

    - unconfined part

$$V_{drained} = \ Area \times \left[S_y \times (Top - Bottom)\right]$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $V_{confined}$ = storage volume due to elastic properties of the aquifer and water(acre-feet)
- *Area* = area of aquifer (acre)
- *Water Level* = groundwater elevation (feet above mean sea level)
- *Top* = elevation of aquifer top (feet above mean sea level)
- *Bottom* = elevation of aquifer bottom (feet above mean sea level)
- S_y = specific yield (no units)
- S_s = specific storage (1/feet)
- S = storativity or storage coefficient (no units)

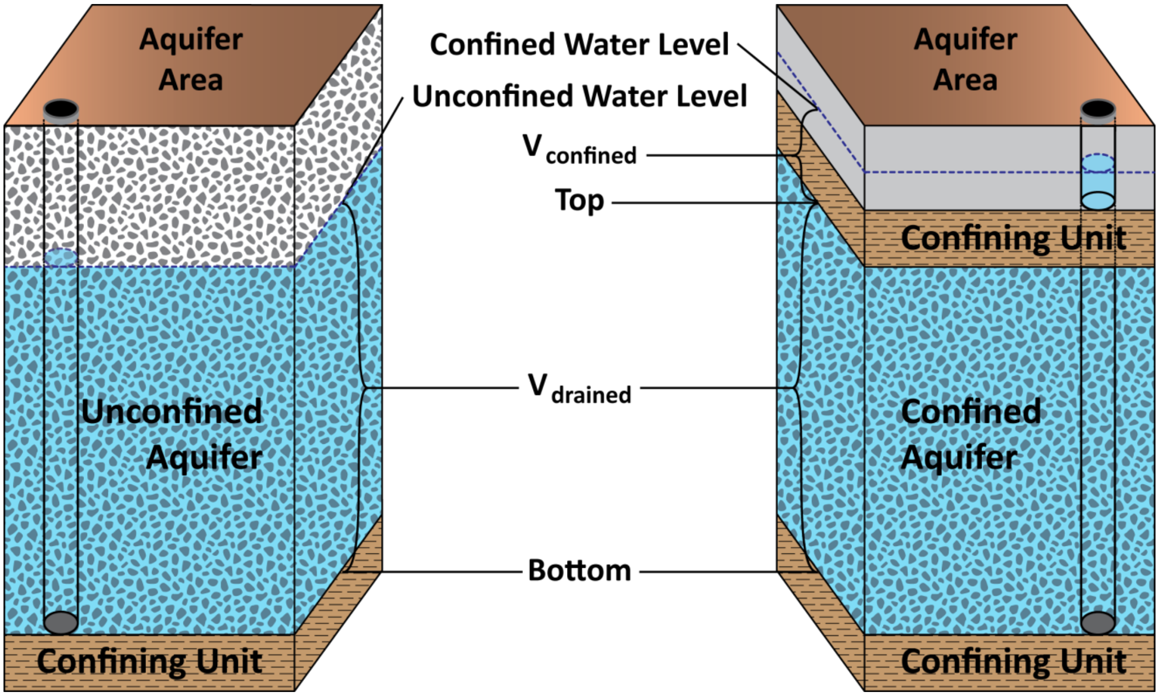

FIGURE 1. SCHEMATIC SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 unconfined part of the Trinity Aquifer and Edwards (Balcones Fault Zone) aquifers in Groundwater Management Area 10, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. For aquifers without groundwater availability model(s), an analogous approach is used. For the confined part of the Trinity Aquifer in Groundwater Management Area 10 we used Surfer® software to create surfaces for the water level, top of aquifer, and base of aquifer, using existing data or references. We then used these surfaces to make the volume calculations based on published estimates of storage coefficient and specific yield. Finally, the total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent.

In the case of Kinney County, a slightly different methodology was used to calculate total estimated recoverable storage based on data from the alternative groundwater flow model simulating the Edwards (Balcones Fault Zone) Aquifer in Kinney County (Hutchison and others, 2011). Because the Kinney County model simulated all units as confined, specific yield was not included in the model. As a result, a review was performed on previous studies and the results are summarized in Table 1. Though a specific value of 0.15 was used by Lindgren and Others (2004) for the Edwards (Balcones Fault Zone) Aquifer in Kinney County, that value was likely based on the porosity study of the aquifer by Hovorka and others (1996). As a result, that value was considered unrealistically high. For the total estimated recoverable storage calculation, a specific yield value of 0.05 was used for the Edwards (Balcones Fault Zone) Aquifer in Kinney County. This value was within the range of previous studies.

A FORTRAN-90 program was developed and used to expedite the storage calculation. The total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent.

TABLE 1. SUMMARY OF AQUIFER SPECIFIC YIELD (SY) AND POROSITY VALUES FROM PREVIOUS STUDIES FOR THE EDWARDS (BALCONES FAULT ZONE) AQUIFER.

Study	*Study Area*	*Study Area*	*Value*	*Study Method*
Maclay and Rettman (1973)	San Antonio	Outcrop	0.025 (average Sy)	recharge/discharge and water level fluctuation
Maclay and Small (1976)	San Antonio	Outcrop	*0.05 to 0.2 (porosity)*	borehole geophysical and laboratory data
Klemt and Others (1979)	San Antonio	Outcrop	0.06 (Sy)	groundwater flow model
Slade and Others (1985)	Austin	Outcrop	0.008 to 0.064 (Sy)	groundwater flow model
Maclay and Land (1988)	San Antonio	Outcrop	0.05 (Sy)	groundwater flow model
Hovorka and Others (1996)	Kinney	Outcrop and Confined	*0.1 to 0.2 (porosity)*	borehole geophysical and laboratory data
Lindgren and Others (2004)	Kinney	Outcrop	*0.15 (Sy)*	groundwater flow model; Sy based on porosity of Hovorka and Others (1996)

PARAMETERS AND ASSUMPTIONS:

Trinity Aquifer

- The Trinity Aquifer within Groundwater Management Area 10 is under confined conditions throughout the area.
- The potentiometric surface is based on the water-level measurements from several sources (Holt, C.L.R, 1956, p.129; Welder and Reeves, 1962, p. 129; TWDB, 2013, and Texas Department of Licensing and Regulation, 2013). Because all of the measurements are located north of the study area and not within the Groundwater Management Area 10 area, an estimate of the head at the southern boundary was made using the head gradient from the available water levels. These estimates were included with the water-level measurements to create a potentiometric surface grid in Surfer® software to estimate the total head above the top of the aquifer.
- We used the base of the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer from the associated groundwater availability model (Lindgren and others, 2004) as the top of the Trinity Aquifer within the area. The base of the Trinity Aquifer is from Plate 4 in Flawn and others (1961). These surfaces were created as grids in Surfer® software and used to calculate aquifer thickness.
- No storage data was discovered for the area, but because the calculations include all of the Trinity Aquifer as a whole, we used conservative estimates for a storage coefficient of 1×10^{-5} and a specific yield of 0.01 based on Trinity Aquifer references (Johnson, 1967; Jones and others, 2009; Hunt and others, 2010).
- The confined volume is calculated by taking the difference in the potentiometric surface and top of the Trinity Aquifer to estimate total estimated head. This value is multiplied by a storage coefficient of 1×10^{-5} resulting in the total storage volume for the portion above the top of the aquifer.
- The unconfined drained volume is calculated by taking the aquifer thickness and multiplied by a specific yield of 0.01.
- Zonal statistics in ArcMap 10.1 software summed the data from grid calculations by county.

Edwards (Balcones Fault Zone) Aquifer

- We used version 1.01 of the groundwater availability model for the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer to estimate the total recoverable storage for the aquifer. See Lindgren and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes one layer which represents the Edwards (Balcones Fault Zone) Aquifer.
- The confined portion of the Edwards (Balcones Fault Zone) Aquifer includes water ranging in total dissolved solids concentration from 250 milligrams per liter (mg/L) to more than 250,000 mg/L (Lindgren and others, 2004). The down-dip boundary of the model is based on the 10,000 mg/L total dissolved solids concentration line and is assumed to represent the limit of groundwater flow in the confined zone of the aquifer (Lindgren and others, 2004).

Edwards (Balcones Fault Zone) in Kinney County

- We used version 1.01 of the groundwater flow model for the Kinney County area to estimate the total recoverable storages for the Edwards (Balcones Fault Zone) Aquifer in Kinney County. See Hutchison and Others (2011) for assumptions and limitations of the alternative numerical groundwater flow model.
- This groundwater flow model includes four numerical layers which represent the Carrizo-Wilcox Aquifer (Layer 1), an Upper Cretaceous Unit (Layer 2), the Edwards Group (Layer 3), and the Trinity Group (Layer 4).
- Model Layer 3 was used to calculate the total estimated recoverable storage for the Edwards (Balcones Fault Zone) Aquifer in Groundwater Management Area 10 located in Kinney County.

RESULTS:

Tables 2 through 5 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded within one percent of the total. Figure 2 indicates the extent of the Trinity Aquifer in Groundwater

Management Area 10 used to estimate the total recoverable storage information. Figure 3 indicates the extent of the groundwater availability model in Groundwater Management Area 10 for the Edwards (Balcones Fault Zone) Aquifer from which the storage information was extracted.

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 10. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bexar	5,500,000	1,375,000	4,125,000
Caldwell	24,000	6,000	18,000
Comal	2,300,000	575,000	1,725,000
Guadalupe	43,000	10,750	32,250
Hays	2,400,000	600,000	1,800,000
Medina	11,000,000	2,750,000	8,250,000
Travis	690,000	172,500	517,500
Uvalde	1,100,000	275,000	825,000
Total	23,057,000	5,764,250	17,292,750

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[3] FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 10. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED WITHIN ONE PERCENT OF THE TOTAL.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	9,400,000	2,350,000	7,050,000
Barton Springs-Edwards Aquifer Conservation District	1,200,000	300,000	900,000
Edwards Aquifer Authority	96,000	24,000	72,000
Medina County CD	11,000,000	2,750,000	8,250,000
Plum Creek CD	270,000	67,500	202,500
Uvalde County Underground Water Conservation District	1,100,000	275,000	825,000
Total	23,066,000	5,766,500	17,299,500

[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 within one percent.

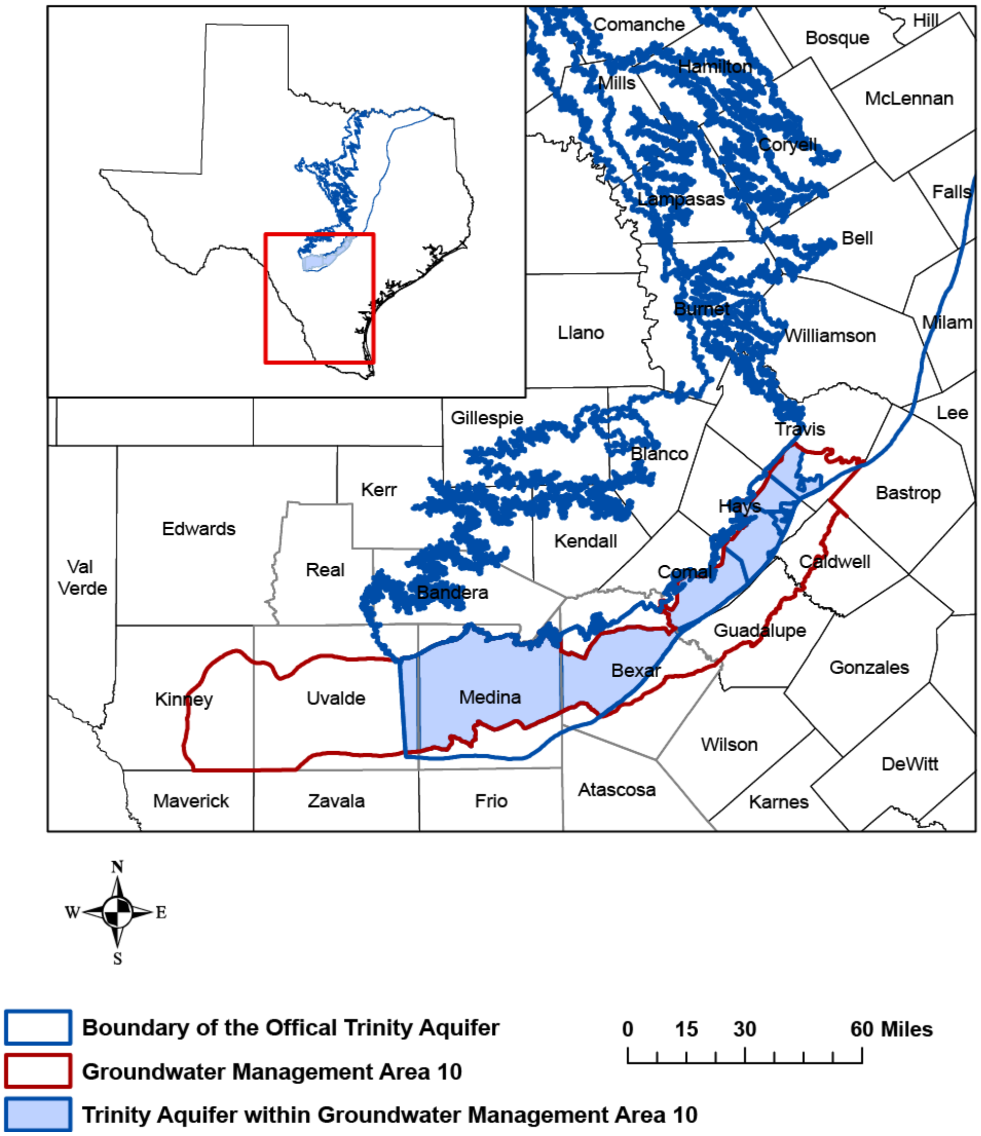

FIGURE 2. AREA OF THE TRINITY AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 2 AND 3) WITHIN GROUNDWATER MANAGEMENT AREA 10.

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE EDWARDS (BALCONES FAULT ZONE) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 10. COUNTY TOTAL ESTIMATES ARE ROUNDED WITHIN TWO SIGNIFICANT NUMBERS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bexar	880,000	220,000	660,000
Comal	420,000	105,000	315,000
Guadalupe	8,900	2,225	6,675
Hays	200,000	50,000	150,000
Kinney	3,100,000	775,000	2,325,000
Medina	3,200,000	800,000	2,400,000
Travis	69,000	17,250	51,750
Uvalde	15,000,000	3,750,000	11,250,000
Total	22,877,900	5,719,475	17,158,425

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[4] FOR THE EDWARDS (BALCONES FAULT ZONE) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 10. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED WITHIN TWO SIGNIFICANT NUMBERS.

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	3,500	10,500
Barton Springs/Edwards Aquifer Conservation District	130,000	32,500	97,500
Edwards Aquifer Authority	20,000,000	5,000,000	15,000,000
Kinney County Groundwater Conservation District	3,100,000	775,000	2,325,000
Total	23,244,000	5,811,000	17,433,000

[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 within one percent.

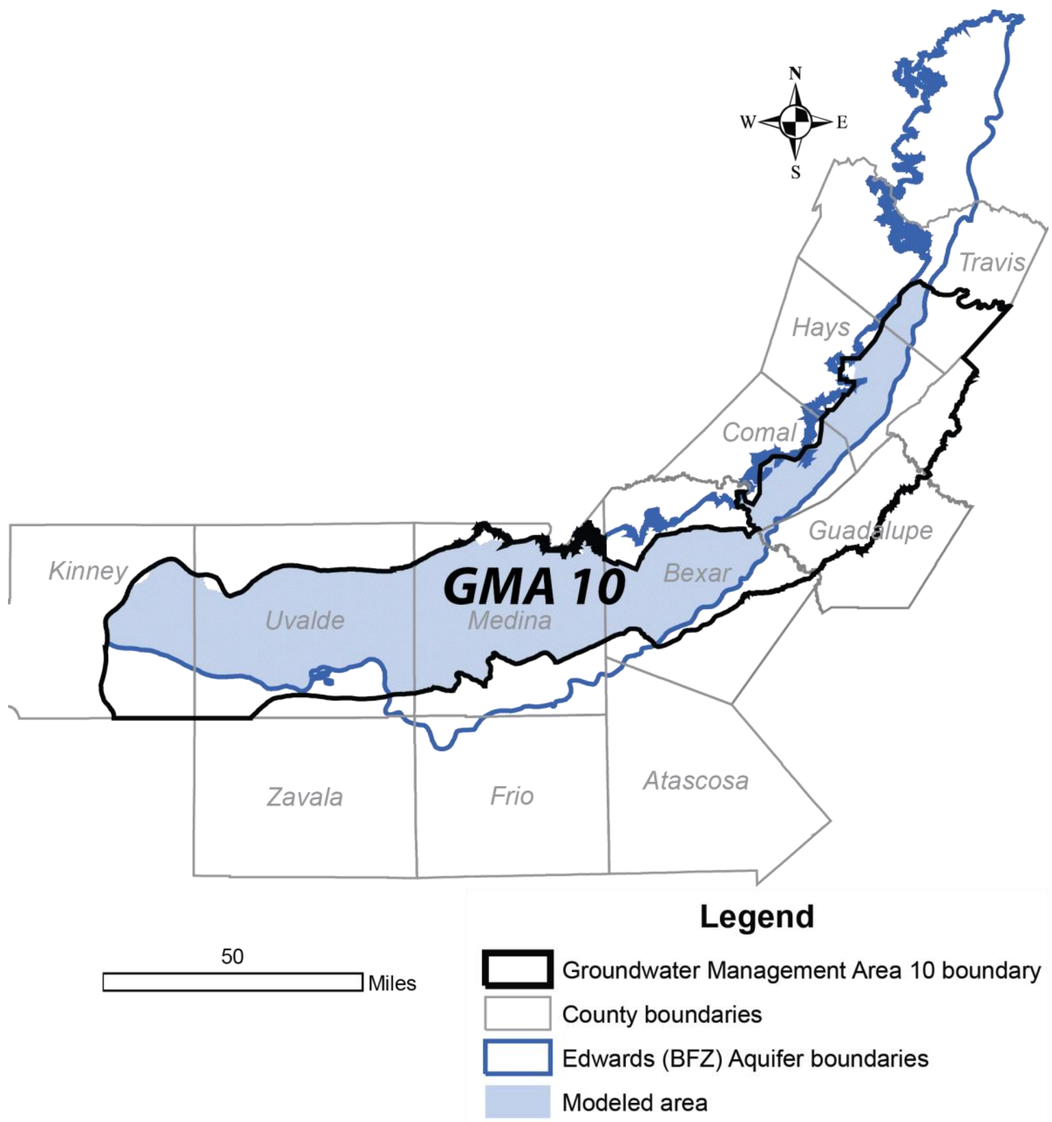

FIGURE 3. EXTENT OF THE GROUNDWATER MODELS FOR THE SAN ANTONIO AND BARTON SPRINGS SEGMENTS OF THE EDWARDS (BALCONES FAULT ZONE) AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE EDWARDS (BALCONES FAULT ZONE) AQUIFER (TABLES 4 AND 5) WITHIN GROUNDWATER MANAGEMENT AREA 10. TOTAL ESTIMATED RECOVERABLE STORAGE IN KINNEY COUNTY WAS CALCULATED USING THE ALTERNATIVE GROUNDWATER FLOW MODEL FOR THE KINNEY COUNTY PORTION OF THE AQUIFER (HUTCHISON AND OTHERS, 2011), WHILE TOTAL RECOVERABLE ESTIMATED STORAGE IN THE REMAINDER OF THE SAN ANTONIO AND BARTON SPRINGS SEGMENTS OF THE EDWARDS (BALCONES FAULT ZONE) AQUIFER WAS CALCULATED USING THE GROUNDWATER AVAILABILITY MODEL FOR THE SAN ANTONIO SEGMENT OF THE EDWARDS (BALCONES FAULT ZONE) AQUIFER (LINDGREN AND OTHERS, 2004).

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.

REFERENCES:

Flawn, P. T., Goldstein, A, King, P. B., and Weaver, C. E.,1961, The Ouachita System, University of Texas at Austin, Bureau of Economic Geology, Publication No. 6120 Plate 4, 401 p.

George, P. G., Mace, R. E., and Petrossian, R, 2011, Aquifers of Texas, Texas Water Development Board Report 380, http://www.twdb.texas.gov/groundwater/aquifer/index.asp

Holt, C. L. R., 1956, Geology and ground-water resources of Medina County, Texas Board of Water Engineers, Bulletin 5601, 278 p.

Hovorka, S.D., Dutton, A.R., Ruppel, S.C., and Yeh, J.S., 1996. Edwards aquifer ground-water resources: geologic controls on porosity development in platform carbonates, South Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 238, 75 p.

Hunt, B. B., Smith, B. A., Kromann, J, Wierman, D. A, and Mikels, J. K., 2010, Compilation of pumping tests in Travis and Hays Counties, Central Texas, Barton Springs/Edwards Aquifer Conservation District Data Series Report 2010-0701, p.

Hutchison, W.R. Shi, J. and Jigmond, J., 2011. Groundwater Flow Model of the Kinney County Area. http://www.twdb.texas.gov/groundwater/models/gam/trnt_n/TRNT_N_Model_Report.pdf.

Johnson, A. I., 1967, Specific yield – compilation of specific yields for various materials, U.S. Geological Survey, Water Supply Paper 1662-D, 74p.

Jones, I. C., Anaya, R. and Wade, S., 2009, Groundwater Availability Model for the Hill Country portion of the Trinity Aquifer System, Texas, Texas Water Development Board unpublished report, 193 p.

Klemt, W.B., Knowles, T.R., Elder, G. and Sieh, T.-W., 1979. Ground-water resources and model applications for the Edwards (Balcones Fault Zone) aquifer in the San Antonio region, Texas: Texas Department of Water Resources Report 239, 88 p.

Lindgren, R.J., Dutton, A.R., Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004. Conceptualization and Simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004–5277, 153 p.

Maclay, R.W. and Land, L.F., 1988. Simulation of flow in the Edwards aquifer, San Antonio region, Texas, and the refinements of storage and flow concepts: U.S. Geological Survey Water-Supply Paper 2336, 48 p.

Maclay, R.W. and Rettman, P.L., 1973. Regional specific yield of the Edwards and associated limestones in the San Antonio, Texas area: Edwards Underground Water District, 10 p.

Maclay, R.W. and Small, T.A., 1976. Progress report on geology of the Edwards aquifer, San Antonio area, Texas, and preliminary interpretation of borehole geophysical and laboratory data on carbonate rocks: U.S. Geological Survey Open-File Report 76-627, 94 p.

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Slade, R.M., Jr., Ruiz, L., and Slagle, D., 1985. Simulation of the flow system Barton Springs and associated Edwards aquifer in the Austin area, Texas: U.S. Geological Survey Water-Resources Investigations Report 85-4299, 49 p.

Texas Department of Licensing and Regulation, 2013, Texas Well Record Submission and Retrieval System: Texas Department of Licensing and Regulation, Water Well and Pump Installers program.

Texas Administrative Code, 2011, http://info.sos.state.tx.us/pls/pub/readtac$ext.viewtac

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf

Texas Water Development Board, 2013, Groundwater database: Texas Water Development Board, Water Science and Conservation Division.

Welder, F. A. and Reeves, R. D., 1962, Geology and Ground-water resources of Uvalde County, Texas, Texas Water Commission, Bulletin 6212, 252 p.