GAM Task 13-025: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 1

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August 20, 2013

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GAM TASK 13-025: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 1

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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 Blaine, Dockum, Ogallala, (which includes the Rita Blanca Aquifer), and Seymour aquifers within Groundwater Management Area 1. Tables 1 through 8 summarize the total estimated recoverable storage required by the statute. Figures 2 through 5 indicate the extent of the groundwater availability models used to estimate the total recoverable storage.

DEFINITION OF TOTAL ESTIMATED RECOVERABLE STORAGE:

The total estimated recoverable storage is defined as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume. In other words, we assume that 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 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 of different water quality types. These values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction as the result of extracting groundwater from the aquifer.

METHODS:

To estimate the total recoverable storage of an aquifer, we first calculated the total storage in an aquifer within the official aquifer boundary. The total storage is the volume of groundwater removed by pumping that completely drains the aquifer.

Aquifers can be either unconfined or confined (Figure 1). A well screened in an unconfined aquifer will have a water level equal to the water level in the aquifer outside the well. Thus, unconfined aquifers have water levels within the aquifers. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure above the ambient atmospheric pressure. The water level at a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is also different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater removed by pumping that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is the groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic pressure in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. The second part, just like unconfined aquifer, is the groundwater released from the aquifer when the water level falls from the top to the bottom of the aquifer. Given the same aquifer area and water level drop, the amount of water released in the second part is much greater than the first part. The difference is quantified by two parameters: storativity related to confined aquifer and specific yield related to unconfined aquifer. For example, storativity values range from 10^{-5} to

10^{-3} for most confined aquifers, while the specific yield values can be 0.01 to 0.3 for most unconfined aquifers. The equations for calculating the total storage are presented below:

- for unconfined aquifers

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

- for confined aquifers

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

  - confined part

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

or

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

  - unconfined part

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

where:

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

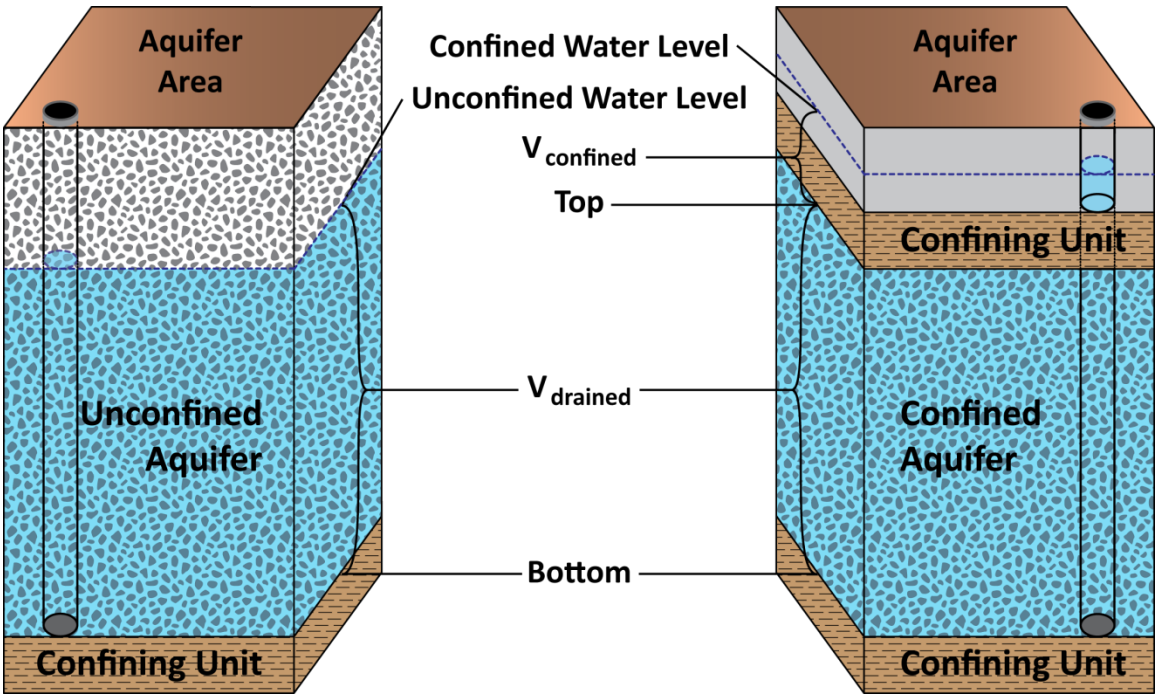

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

As presented in the equations, calculation of the total storage requires data, such as aquifer top, aquifer bottom, aquifer storage properties, and water level. For the Blaine, Dockum, Ogallala (which includes the Rita Blanca Aquifer), and Seymour aquifers in Groundwater Management Area 1, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. This information was contained in model input and output files on a cell-by-cell basis. In the absence of groundwater availability model(s), the total storage will be calculated using other approaches. Finally, the total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent.

PARAMETERS AND ASSUMPTIONS:

Seymour and Blaine aquifers

- We used version 1.01 of the groundwater availability model for the Seymour and Blaine aquifers. See Ewing and others (2004) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes two layers, representing the Seymour (layer 1) and Blaine (layer 2) aquifers. In areas where the Blaine Aquifer does not exist the model roughly replicates the various Permian units located in the study area.
- Of the two layers, total estimated recoverable storage was determined using the cells in the model that represent the Blaine Aquifer in layer 2.
- Because no active grid cells fell within Groundwater Management Area 1, total estimated recoverable storage values for the Seymour Aquifer were calculated by averaging the attributes of the two closest grid cells and applying them to the area the Seymour Aquifer covers in Groundwater Management Area 1.

Dockum Aquifer

- We used version 1.01 of the groundwater availability model for the Dockum Aquifer to estimate the total recoverable storage. See Ewing and others (2008) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes three layers which generally represent the younger geologic units overlying the Dockum Aquifer (layer 1), the upper portion of the Dockum Aquifer (layer 2), and the lower portion of the Dockum Aquifer (layer 3).
- Of the three layers, total estimated recoverable storage was determined and combined for layers representing the Dockum Aquifer (layers 2 and 3).
- The down-dip boundary of the Dockum 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 (Ewing and others, 2008). Consequently, the model extends into zones of brackish and brine groundwater.

The official extent of the Dockum Aquifer was used to exclude this area (George and others, 2011).

Southern portion of the Ogallala Aquifer

- We used version 2.01 of the groundwater availability model to estimate the total recoverable storages of the southern portion of the Ogallala and Edwards-Trinity (High Plains) aquifers. This model is an expansion on and update to the previously developed groundwater availability model for the southern portion of the Ogallala Aquifer described in Blandford and others (2003). See Blandford and others (2008) and Blandford and others (2003) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes 4 layers which represent the southern portion of the Ogallala (layer 1) and the Edwards-Trinity (High Plains) (primarily Edwards, Comanche Peak, and Antlers Sand formations; layers 2-4).
- Of the four layers, total estimated recoverable storage was determined for the Ogallala Aquifer (layer 1) in Groundwater Management Area 1.

Northern portion of the Ogallala Aquifer and Rita Blanca Aquifer

- We used version 3.01 of the groundwater availability model to estimate the total recoverable storage for the northern portion of the Ogallala Aquifer which includes the Rita Blanca Aquifer. This model is an update to the previously developed groundwater availability model for the northern portion of the Ogallala Aquifer described in Dutton and others (2001) and Dutton (2004). See Kelley and others (2010), Dutton (2004), and Dutton and others (2001) for assumptions and limitations of the model.
- The model for the northern portion of the Ogallala Aquifer has one layer which collectively represents the Ogallala and Rita Blanca aquifers combined.
- Total estimated recoverable storage was determined for the combined Ogallala and Rita Blanca aquifers (layer 1) in Groundwater Management Area 1.

RESULTS:

Tables 1 through 8 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded to two significant digits. Figures 2 through 5 indicate the extent of the groundwater availability models in Groundwater Management Area 1 for the Blaine, Dockum, Ogallala (which includes the Rita Blanca Aquifer), and Seymour aquifers from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BLAINE AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. 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)*
Wheeler	6,700,000	1,675,000	5,025,000
Total	**6,700,000**	**1,675,000**	**5,025,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE BLAINE AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Panhandle GCD	6,700,000	1,675,000	5,025,000
Total	**6,700,000**	**1,675,000**	**5,025,000**

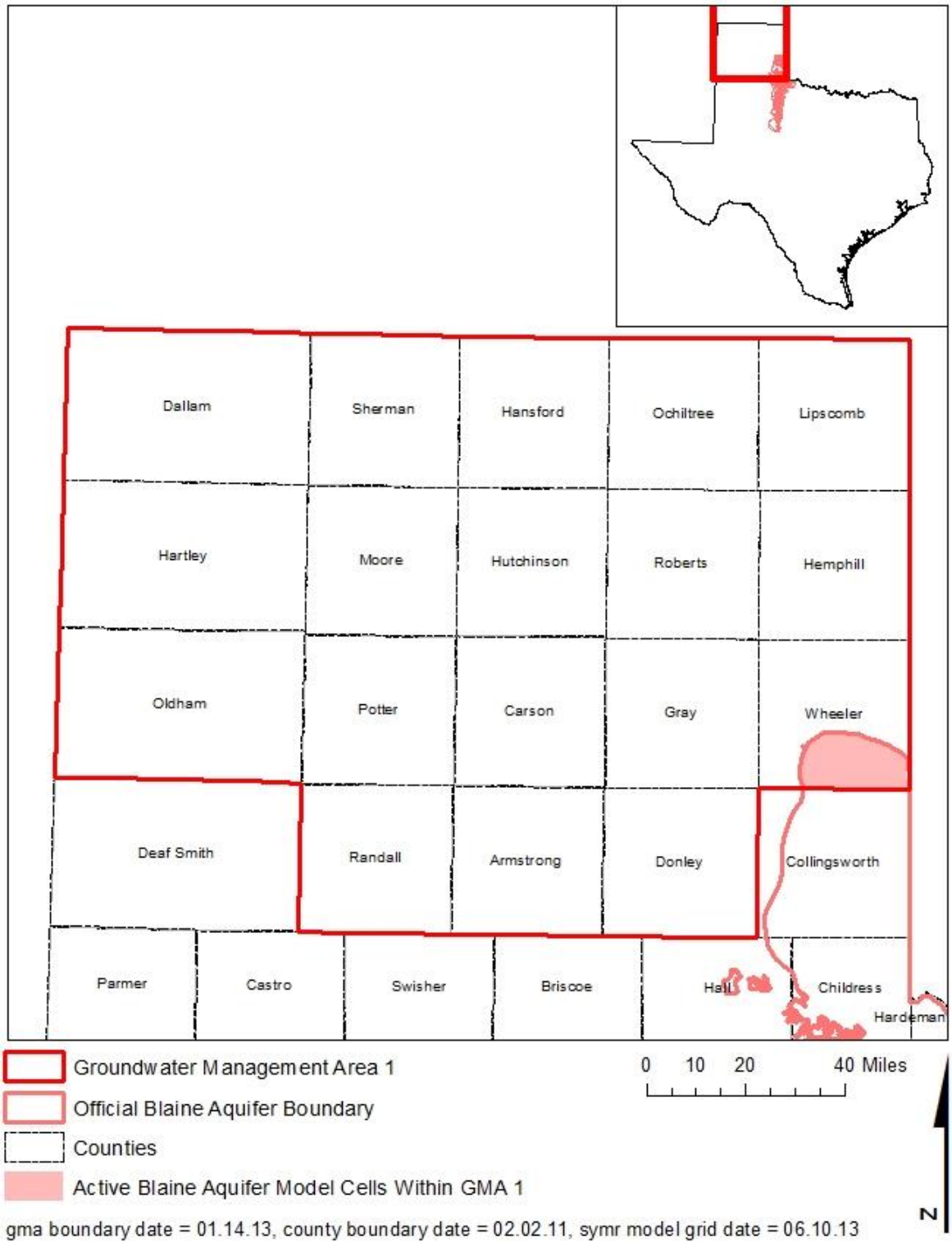

FIGURE 2. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE BLAINE AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. 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)***
Armstrong	10,000,000	2,500,000	7,500,000
Carson	1,800,000	450,000	1,350,000
Dallam	81,000,000	20,250,000	60,750,000
Hartley	93,000,000	23,250,000	69,750,000
Moore	11,000,000	2,750,000	8,250,000
Oldham	60,000,000	15,000,000	45,000,000
Potter	14,000,000	3,500,000	10,500,000
Randall	50,000,000	12,500,000	37,500,000
Sherman	1,200,000	300,000	900,000
Total	**322,000,000**	**80,500,000**	**241,500,000**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[1] FOR THE DOCKUM AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
High Plains UWCD[2] No.1	31,000,000	7,750,000	23,250,000
North Plains GCD	170,000,000	42,500,000	127,500,000
Panhandle GCD	20,000,000	5,000,000	15,000,000
No District	98,000,000	24,500,000	73,500,000
Total	**319,000,000**	**79,750,000**	**239,250,000**

[1] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant digits.
[2] UWCD is the abbreviation for Underground Water Conservation District.

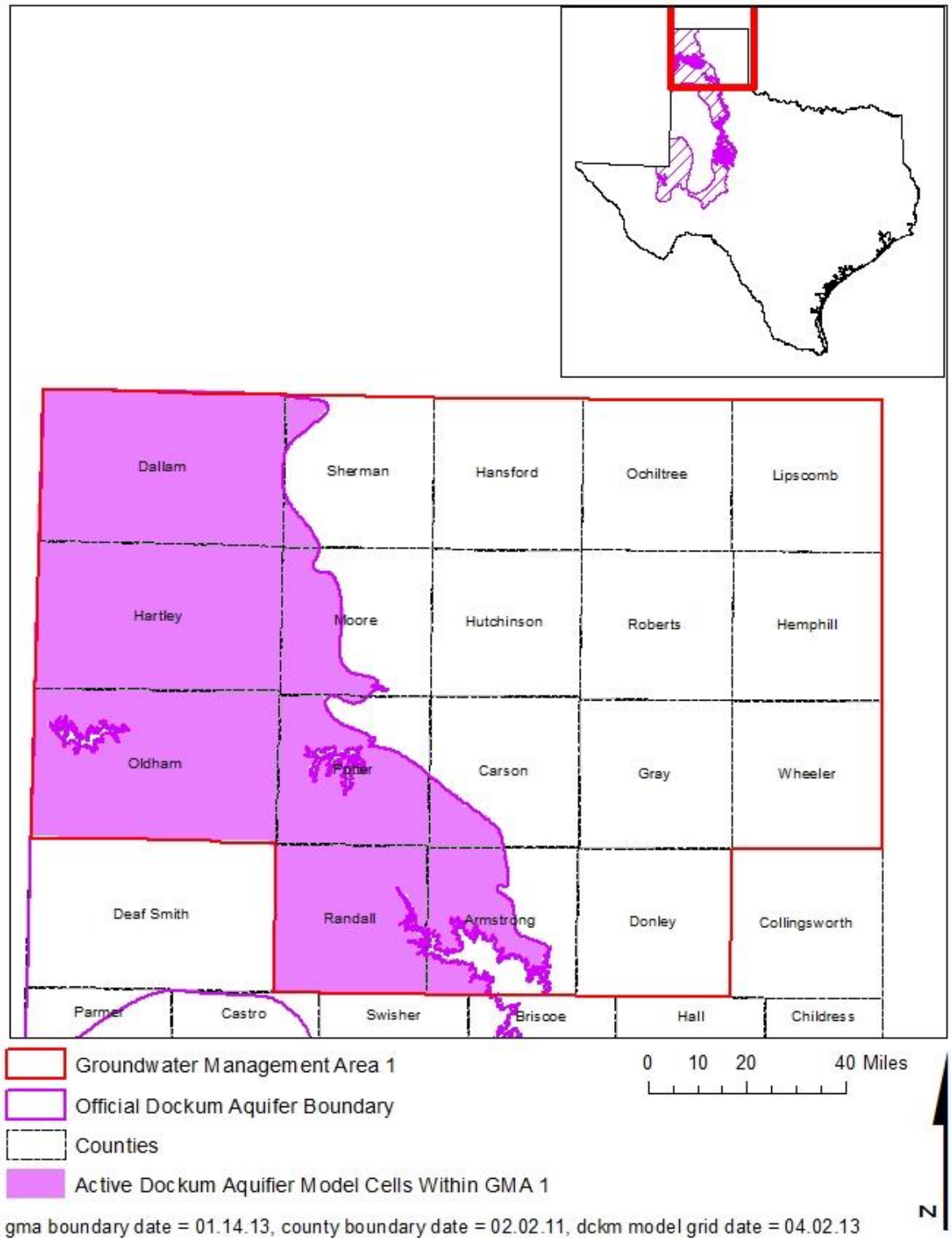

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE DOCKUM AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. 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)*
Armstrong	3,300,000	825,000	2,475,000
Carson	16,000,000	4,000,000	12,000,000
Dallam	22,000,000	5,500,000	16,500,000
Donley	5,000,000	1,250,000	3,750,000
Gray	13,000,000	3,250,000	9,750,000
Hansford	22,000,000	5,500,000	16,500,000
Hartley	27,000,000	6,750,000	20,250,000
Hemphill	15,000,000	3,750,000	11,250,000
Hutchinson	11,000,000	2,750,000	8,250,000
Lipscomb	21,000,000	5,250,000	15,750,000
Moore	12,000,000	3,000,000	9,000,000
Ochiltree	21,000,000	5,250,000	15,750,000
Oldham	2,600,000	650,000	1,950,000
Potter	2,400,000	600,000	1,800,000
Randall	6,100,000	1,525,000	4,575,000
Roberts	32,000,000	8,000,000	24,000,000
Sherman	20,000,000	5,000,000	15,000,000
Wheeler	7,700,000	1,925,000	5,775,000
Total	**259,100,000**	**64,775,000**	**194,325,000**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD)[3] FOR THE OGALLALA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Hemphill County UWCD[4]	15,000,000	3,750,000	11,250,000
High Plains UWCD No.1	4,600,000	1,150,000	3,345,000
North Plains GCD	150,000,000	37,500,000	112,500,000
Panhandle GCD	79,000,000	19,750,000	59,250,000
No District	13,000,000	3,250,000	9,750,000
Total	**261,600,000**	**65,400,000**	**196,200,000**

[3] The total estimated recoverable storages by groundwater conservation district and county aquifer may not be the same because the numbers have been rounded to two significant digits.
[4] UWCD is the abbreviation for Underground Water Conservation District.

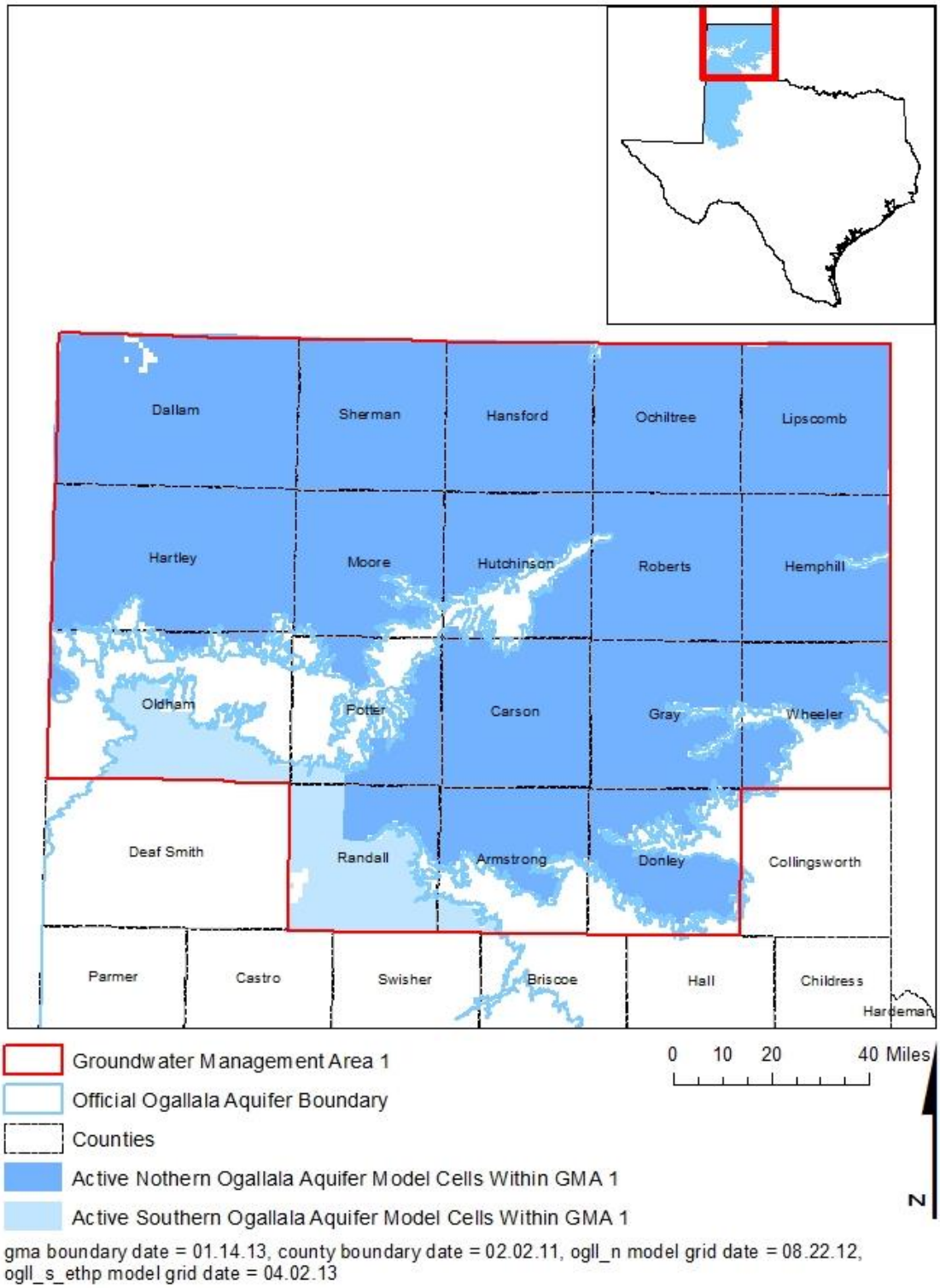

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODELS OF THE NORTHERN AND SOUTHERN PORTIONS OF THE OGALLALA AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 1.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Donley	760	190	570
Total	**760**	**190**	**570**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE SEYMOUR AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 1. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Panhandle GCD	760	190	570
Total	**760**	**190**	**570**

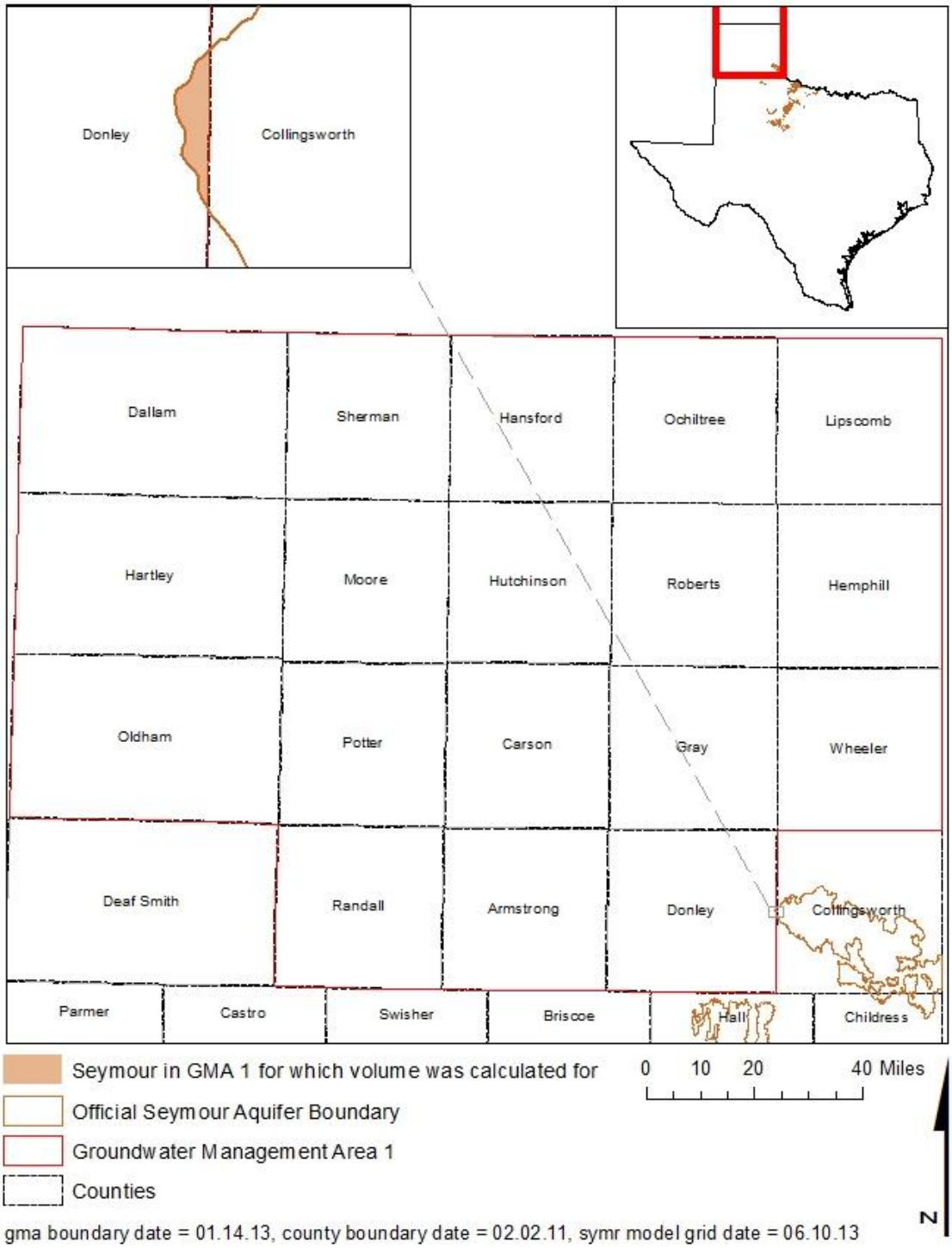

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL OF THE SEYMOUR AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA 1.

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:

Blandford, T.N., Blazer, D.J., Calhoun, K.C., Dutton, A.R., Naing, T., Reedy, R.C., and Scanlon, B.R., 2003, Groundwater availability of the southern Ogallala aquifer in Texas and New Mexico—Numerical simulations through 2050: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 158 p., http://www.twdb.texas.gov/groundwater/models/gam/ogll_s/OGLL_S_Full_Report.pdf.

Blandford, T.N., Kuchanur, M., Standen, A., Ruggiero, R., Calhoun, K.C., Kirby, P., and Shah, G., 2008, Groundwater availability model of the Edwards-Trinity (High Plains) Aquifer in Texas and New Mexico: Final report prepared for the Texas Water Development Board by Daniel B. Stephens & Associates, Inc., 176 p.,

http://www.twdb.texas.gov/groundwater/models/gam/ethp/ETHP_Model_Report.pdf.

Dutton, A., 2004, Adjustment of Parameters to Improve the Calibration of the Og-n Model of the Ogallala Aquifer, Panhandle Water Planning Area: Prepared for Freese and Nichols, Inc. and Panhandle Water Planning Group, 25 p., http://www.twdb.texas.gov/groundwater/models/gam/ogll_n/OGLL_N_Revision_Report.pdf.

Dutton, A.R., Reedy, R.C., and Mace, R.E., 2001, Saturated Thickness in the Ogallala Aquifer in the Panhandle Water Planning Area—Simulations of 2000 through 2050 Withdrawal Projections: Prepared for Panhandle Water planning Group, 130 p., http://www.twdb.texas.gov/groundwater/models/gam/ogll_n/OGLL_N_Model_Report.pdf.

Ewing, J.E., Jones, T.L., Pickens, J.F., Chastain-Howley, A., Dean, K.E., Spear, A.A., 2004, Groundwater availability model for the Seymour Aquifer: Final report prepared for the Texas Water Development Board by INTERA, Inc., 533 p., http://www.twdb.texas.gov/groundwater/models/gam/symr/SYMR_Model_Report.pdf.

Ewing, J.E., Jones, T.L., Yan, T., Vreugdenhil, A.M., Fryar, D.G., Pickens, J.F., Gordon, K., Nicot, J.P., Scanlon, B.R., Ashworth, J.B., and Beach, J., 2008, Groundwater Availability Model for the Dockum Aquifer – Final Report: contract report to the Texas Water Development Board, 510 p., http://www.twdb.texas.gov/groundwater/models/gam/dckm/DCKM_Model_Report.pdf.

Kelley, V.A., Jones [Dale], T., Fryar, D., Dutton, A.R., Deeds, N., 2010, Northern Ogallala Update to Support 2011 [Region A] Water Plan, 106 p., http://www.twdb.texas.gov/groundwater/models/gam/ogll_n/Appendix%20F%20_%20Update%20Northern%20Ogallala%20GAM.pdf.

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.

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