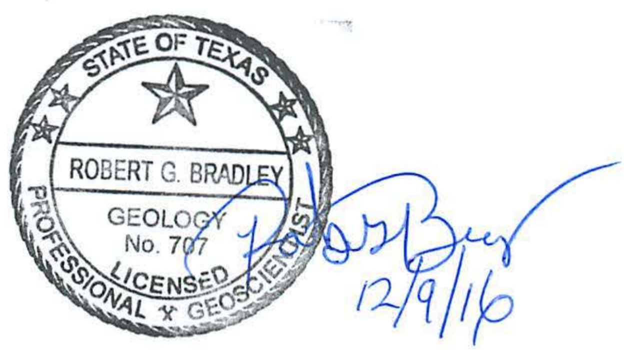
Aquifer Assessment 16-01: Supplemental report of Total Estimated Recoverable Storage for Groundwater Management Area 10

by Robert G. Bradley P.G.
Texas Water Development Board
Groundwater Division
512-936-0870
December 9, 2016



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AQUIFER ASSESSMENT 16-01: SUPPLEMENTAL REPORT OF TOTAL ESTIMATED RECOVERABLE STORAGE FOR GROUNDWATER MANAGEMENT AREA 10

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EXECUTIVE SUMMARY:

Texas Water Code, §36.108(d) 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). The total estimated recoverable storage defined in 31 Texas Administrative Code §356.10 is 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.

Groundwater Management Area 10 declared the Leona Gravel, Austin Chalk, and Buda Limestone aquifers in Uvalde County, and the saline Edwards (Balcones Fault Zone) Aquifer, relevant for joint planning purposes on August 23, 2010. This report is a supplement to GAM Task 13-033 (Jones and others, 2013). This report is a discussion on the methods, assumptions, and results for the Leona Gravel, Austin Chalk, and Buda Limestone aquifers in Uvalde County and the saline Edwards (Balcones Fault Zone) Aquifer in the northern subdivision of Groundwater Management Area 10. Members of Groundwater Management Area 10 designated the northern subdivision to distinguish between the Edwards (Balcones Fault Zone) Aquifer regulated by the Edwards Aquifer Authority and those portions falling within the Barton Springs/Edwards Aquifer Conservation District, Plum Creek Conservation District, and unregulated portions of the groundwater management area.

Tables 1 through 5 summarize the total estimated recoverable storage required by the statute. None of the aquifers in this report has a groundwater availability model.

DEFINITION OF TOTAL ESTIMATED RECOVERABLE STORAGE:

The definition of total estimated recoverable storage is the estimated amount of groundwater within an aquifer 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 is potentially drainable. The total estimated recoverable storage estimates are for the portion of the aquifers within Groundwater Management Area 10 designated as relevant for joint planning. Total estimated recoverable storage values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data is sparse and may be insufficient to differentiate between different water quality types. The total estimated recoverable storage values do not take into account possible land surface subsidence, degradation of water quality, any changes to surface water-groundwater interaction, or economic viability of removing the water.

METHODS:

To estimate the total recoverable storage of an aquifer, the total storage in an aquifer within the study area boundary is calculated. Total storage is the volume of groundwater that could be drained from 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. Low permeable geologic units at the top and bottom bound a confined aquifer, 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 drainable volume of groundwater that makes the water level fall to the aquifer bottom.

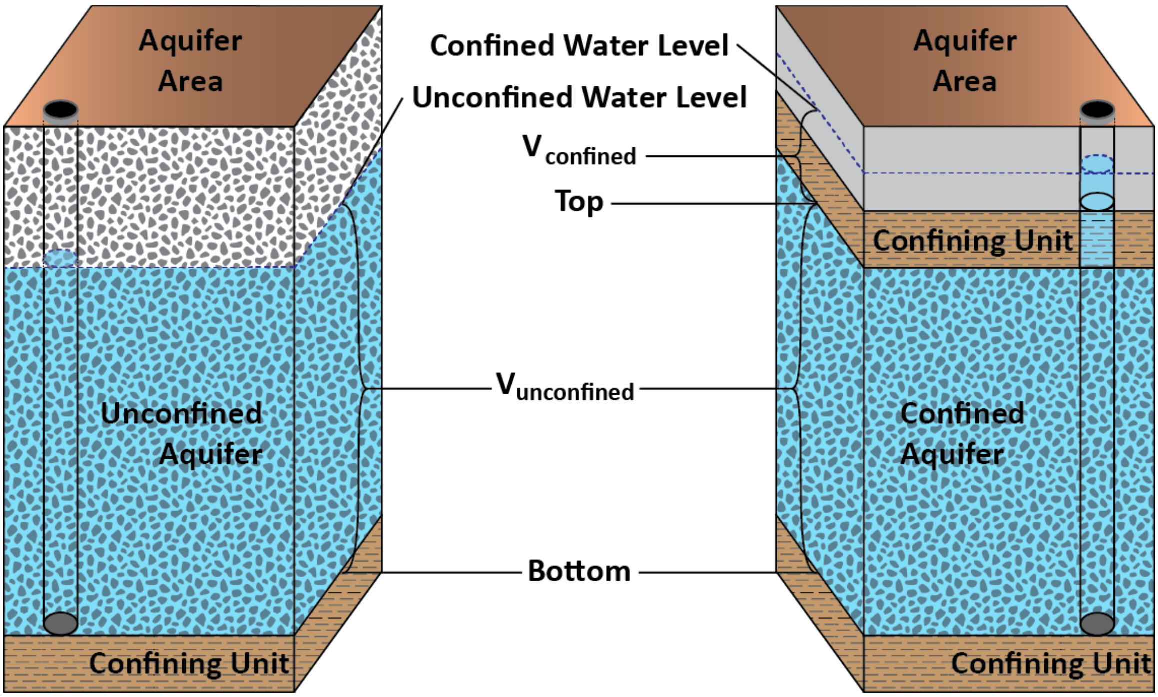

Figure 1. Schematic graph showing the difference between unconfined and confined aquifers.

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. This reduction of hydraulic pressure in the aquifer, a lowering the water level, causes expansion of water and compression of aquifer and confining unit solids. The aquifer is still fully saturated at this point. The second part, just like an 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: confined storativity related to confined conditions and specific yield, also called unconfined storativity, related to unconfined conditions. 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.

Here are the equations for calculating total storage:

- for unconfined aquifers

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

- for confined aquifers

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

  - confined part

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

  - unconfined part

$$V_{unconfined} =\ Area \times (Top - Bottom) \times S_y$$

where:

- $V_{unconfined}$ = storage volume due to water draining from an unconfined formation (acre-feet)
- $V_{confined}$ = storage volume due to elastic properties of the aquifer and water (acre-feet)
- *Area* = areal extent of the aquifer (acres)
- *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 = confined storativity (no units)

As presented in the equations, calculation of the total storage requires data, such as aquifer top, aquifer bottom, aquifer storage properties, and potentiometric surface (water levels). Details for the calculations are in the parameters and assumption section of this report.

The extent for the Leona Gravel Aquifer (Figure 2) in this report is from Aquifer Assessment Report 10-28 MAG (Bradley, 2013a). Specific data for this study is from the TWDB (2016a) groundwater database and the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database.

Water-level elevation (Figure 3) and aquifer base raster grids (Figure 4) are created to estimate the total recoverable storage as described in the parameters and assumptions. These maps led to creation of a saturated thickness raster grid (Figure 5) that is used to calculate the aquifer volume. The Austin Chalk (Figures 6 through 9) and Buda Limestone (Figures 10 through 13) are not fully water bearing throughout Uvalde County because of the variability of the lithology, faulting, fracturing, and numerous Cretaceous igneous intrusions within the units (Green and others, 2009; Smith and others, 2007; Welder and Reeves, 1962). Green and others (2009) published inferred extents for the water-bearing Austin Chalk and Buda Limestone; however, these are insufficient for the purposes of this study. This study delineated the Austin Chalk and Buda Limestone aquifer extents using the data described in the following section.

Data for these two aquifers are from TWDB databases (TWDB, 2016a; 2016b), the Texas Department of Licensing and Regulation Well Report Submission and Retrieval System database (TDLR, 2016), and Welder and Reeves (1962). After reviewing approximately 994 well records, 882 records provide the data relevant for this study, including structure and water levels, from wells completed in the Austin Chalk or Buda Limestone aquifers. The Austin Chalk and Buda Limestone aquifers’ areal extents are based on the presence of wells completed in those units (Figures 6 and 10). Total estimated recoverable storage is calculated for these delineated areas.

The calculations do not include some outlying wells; this is to reduce speculation of the groundwater conditions between areas of known production and these individual wells.

The saline Edwards (Balcones Fault Zone) Aquifer consists of the Kainer, Person, and Georgetown formations that are downdip of the official extent of the Edwards (Balcones Fault Zone) Aquifer (Flores, 1990) and within the northern subdivision of Groundwater Management Area 10 (Figure 14). This area is outside the active portions of current groundwater availability models so we used a non-model volumetric approach to calculate the total estimated recoverable storage. Most of the structure of the saline Edwards (Balcones Fault Zone) Aquifer is from the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer Groundwater Availability Model (Lindgren and others, 2004). In addition, individual well data (TDLR, 2016; TWDB, 2016a, 2016b) and information from published reports (Arnow, 1957; Core Laboratories, 1972a, 1972b; Flores, 1990) fill in the data gaps from areas that fall outside the model extent. The water-level data (TDLR 2016; TWDB, 2016a) provide data points to create an average potentiometric surface. The development of the raster grid representing the confined volume of the saline Edwards (Balcones Fault Zone) aquifer is by subtracting the average potentiometric surface raster grid from the top of the aquifer raster grid values (Figure 15).

PARAMETERS AND ASSUMPTIONS:

Here are the parameters and assumptions used to determine the total estimated recoverable storage by individual aquifer. Aquifers are listed in order by age from youngest to oldest.

Leona Gravel Aquifer

- The total area of the Leona Gravel Aquifer in Uvalde County, based on the Leona Formation (Figure 2) delineated by Bradley (2013a) and sourced from the 1:250,000 Digital Geological Atlas of Texas (USGS and TWDB, 2006), is approximately 57,500 acres.
- The TWDB (2016a) groundwater database and the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database provide data for this study. Additional water-level measurements from the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database are included to enhance the spatial distribution through increased data density. The water-level data is processed through Surfer™ to generate an average water-level surface raster grid.
- We processed the geologic data through Surfer™ to generate the aquifer bottom (Figure 3) and the water-level surfaces (Figure 4). The surfaces form unconfined drained volume raster grids processed through Surfer™ grid math to produce a saturated thickness raster grid (Figure 5).
- The saturated thickness grid (Figure 5) is multiplied by an assumed unconfined specific yield of 15 percent (Johnson, 1967; George, 2010) and is summed up using zonal statistics from Esri® ArcMap™ 10 to equal total storage.

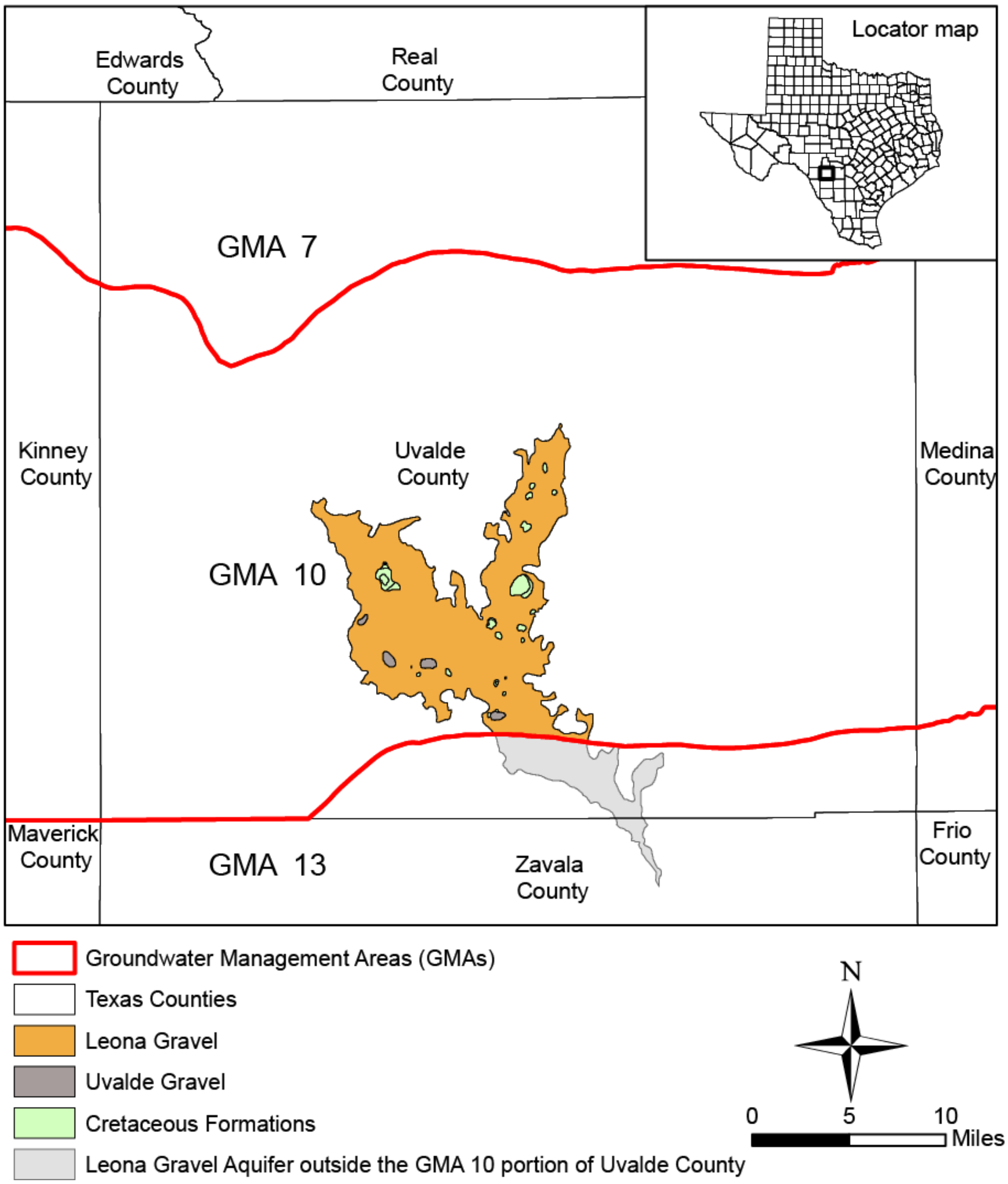

Figure 2. Extent of the Leona Gravel Aquifer in Uvalde County used to estimate total recoverable storage (Table 1) within Groundwater Management Area 10 (From Bradley, 2013a).

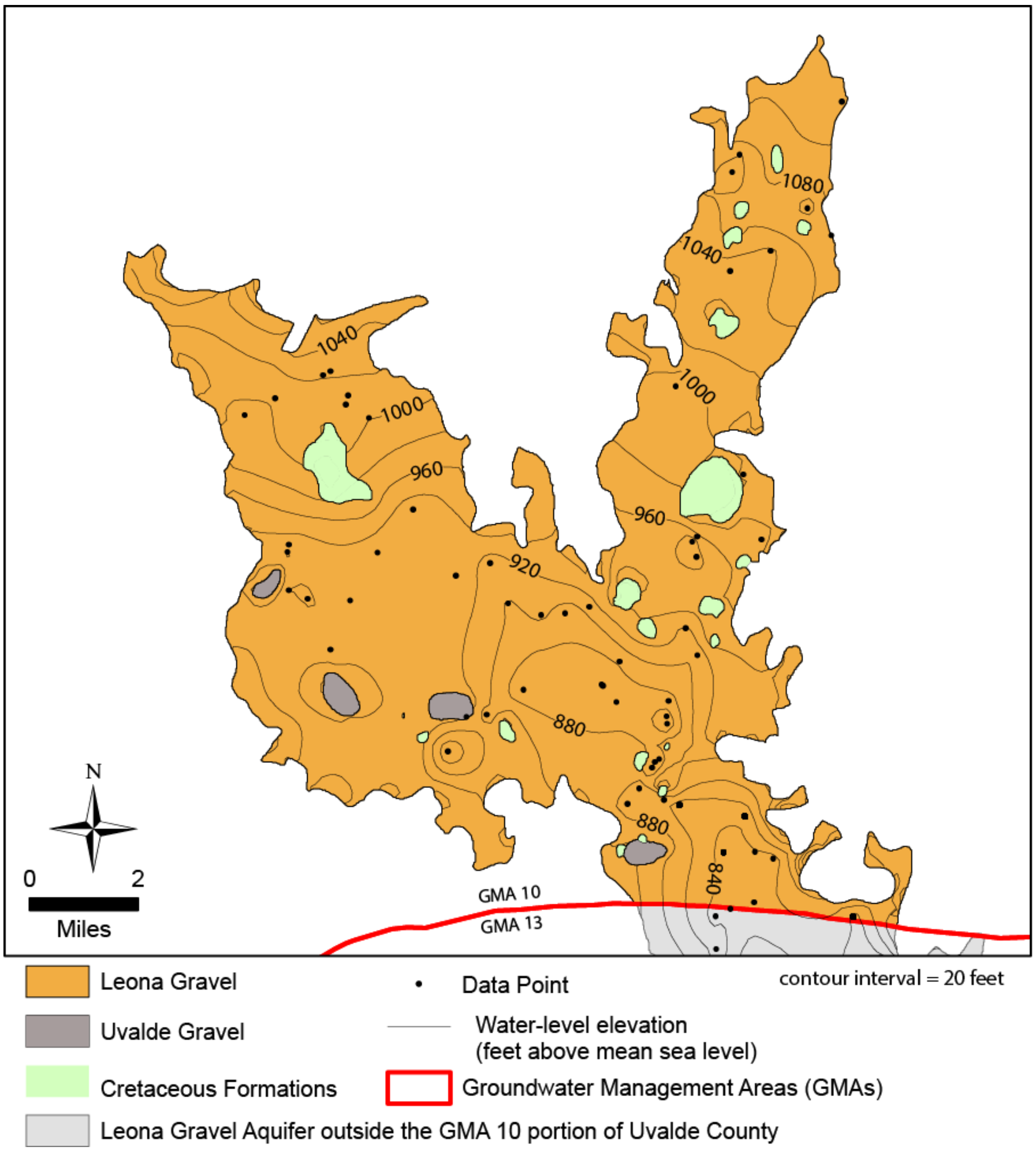

Figure 3. Average water-level elevation map for the Leona Gravel Aquifer in Uvalde County used to estimate total recoverable storage (Table 1) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a).

Figure 4. Base of the Leona Gravel Aquifer in Uvalde County used to estimate total recoverable storage (Table 1) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a).

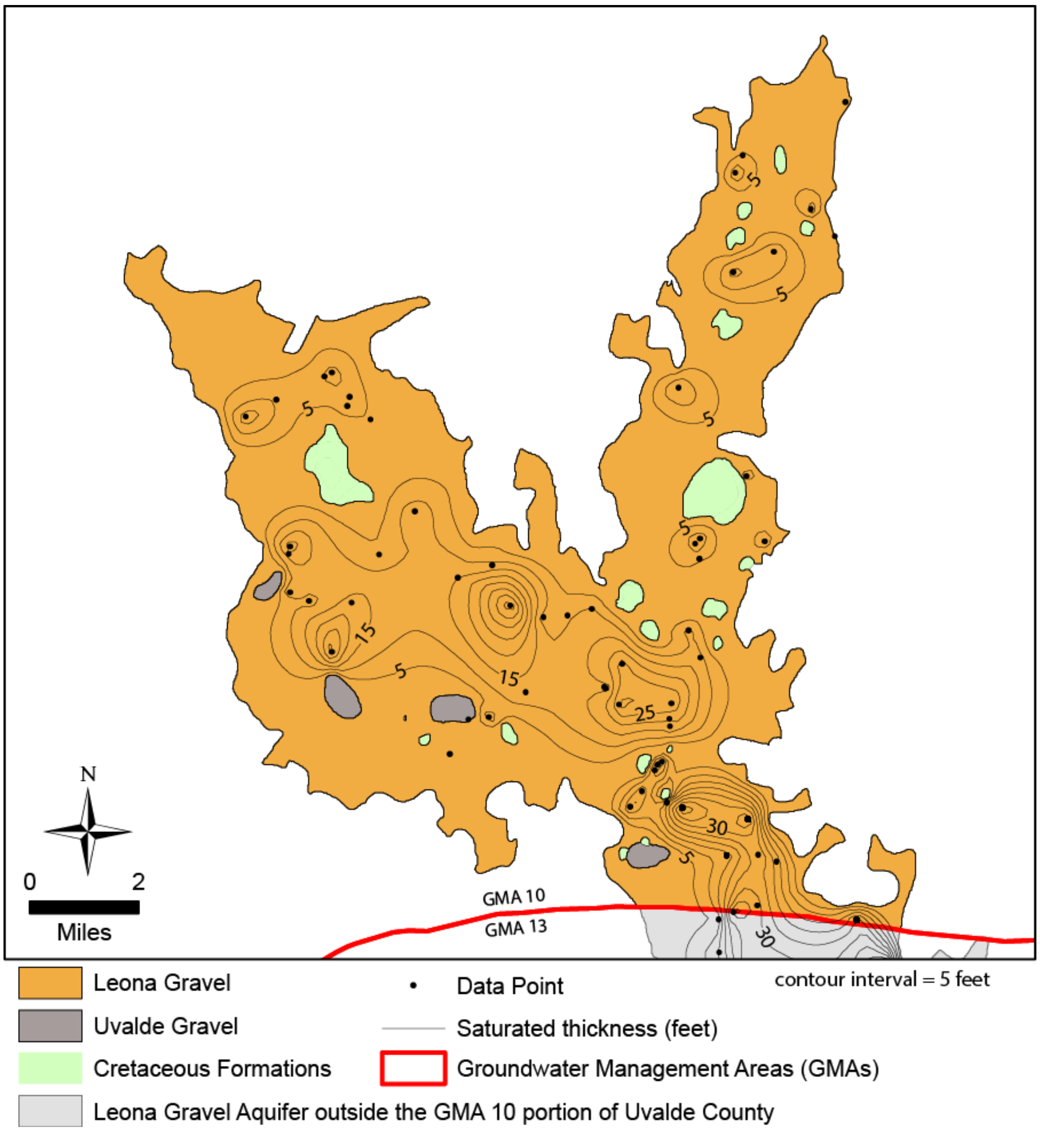

Figure 5. Saturated thickness of the Leona Gravel Aquifer in Uvalde County used to estimate total recoverable storage (Table 1) within Groundwater Management Area 10.

Austin Chalk Aquifer

- The total area of the Austin Chalk Aquifer in Uvalde County, based on productive wells completed in the Austin Chalk Formation (Figure 6), is approximately 66,700 acres.
- The data for this study is from the TWDB (2016a) groundwater database, the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database, and the TWDB Brackish Resources Aquifer Characterization System database (TWDB, 2016b).
- We processed the geologic data through Surfer™ to generate the aquifer top (Figure 7), bottom (Figure 8), and the water-level surfaces (Figure 9). These surfaces form confined head and unconfined drained volume raster grids that are processed through Surfer™ grid math to produce a saturated thickness raster grid. The saturated thickness grid is multiplied by an unconfined specific yield of 3 percent and confined storativity of 1.0×10^{-5}, and is summed up using zonal statistics from Esri® ArcMap™ 10 to equal total storage.
- The estimate of unconfined specific yield is based on low porosity and low groundwater production (American Society of Civil Engineers, 1996; Clark and Small, 1997; Welder and Reeves, 1962).
- The available water-level data are not spatially and temporally extensive at any one period in the TWDB groundwater database record. We included additional water-level measurements from the Texas Department of Licensing and Regulation (2016) Well Report database to enhance the spatial distribution through increased data density. Processing this data in Surfer™ produces a water-level surface raster grid (Figure 9).

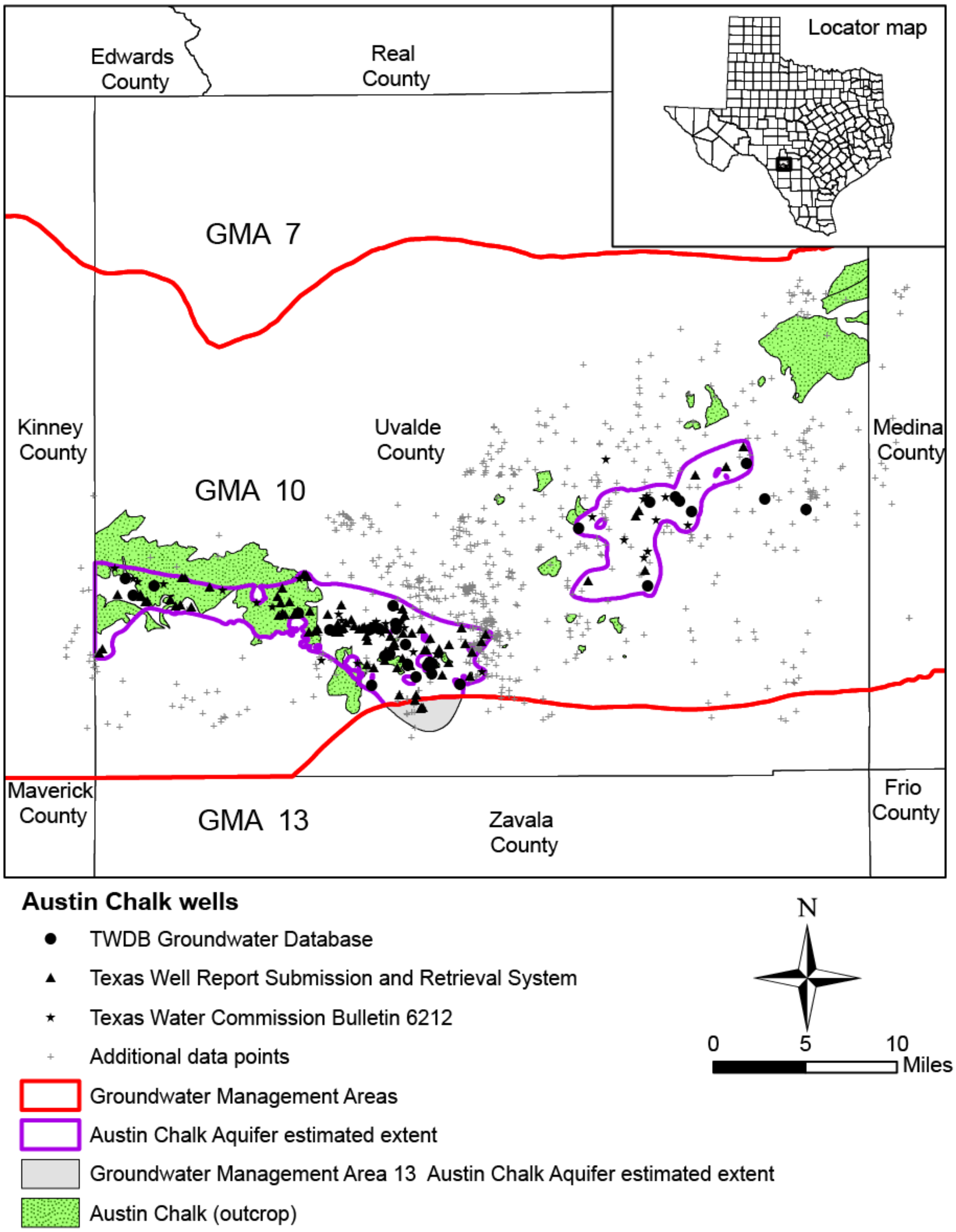

Figure 6. **Extent of the Austin Chalk Aquifer in Uvalde County used to estimate total recoverable storage (Table 2) within Groundwater Management Area 10.**

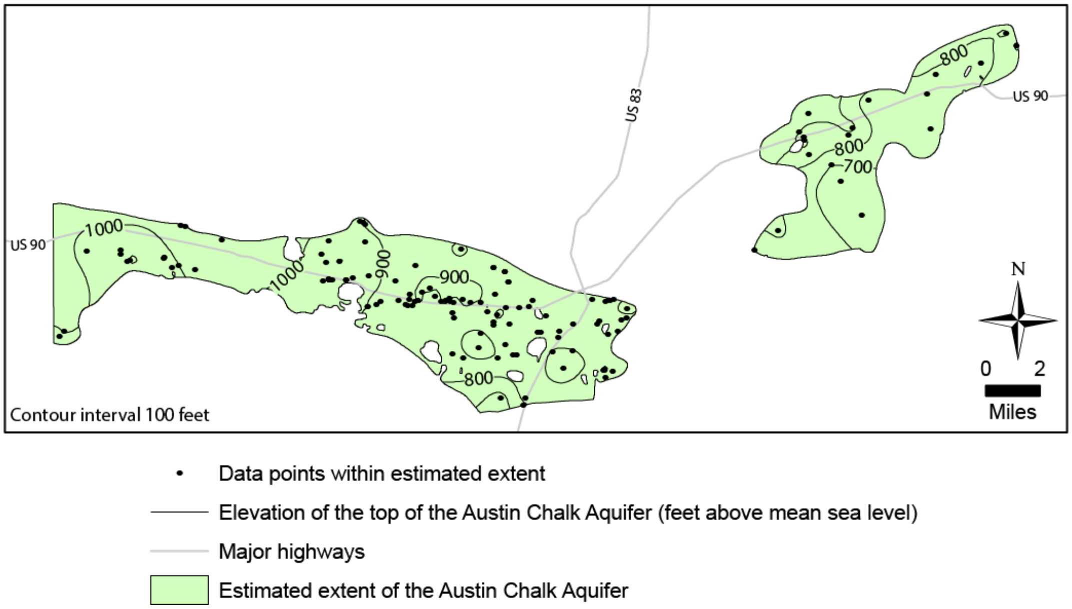

Figure 7. Top of the Austin Chalk Aquifer in Uvalde County used to estimate total recoverable storage (Table 2) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a, 2016b).

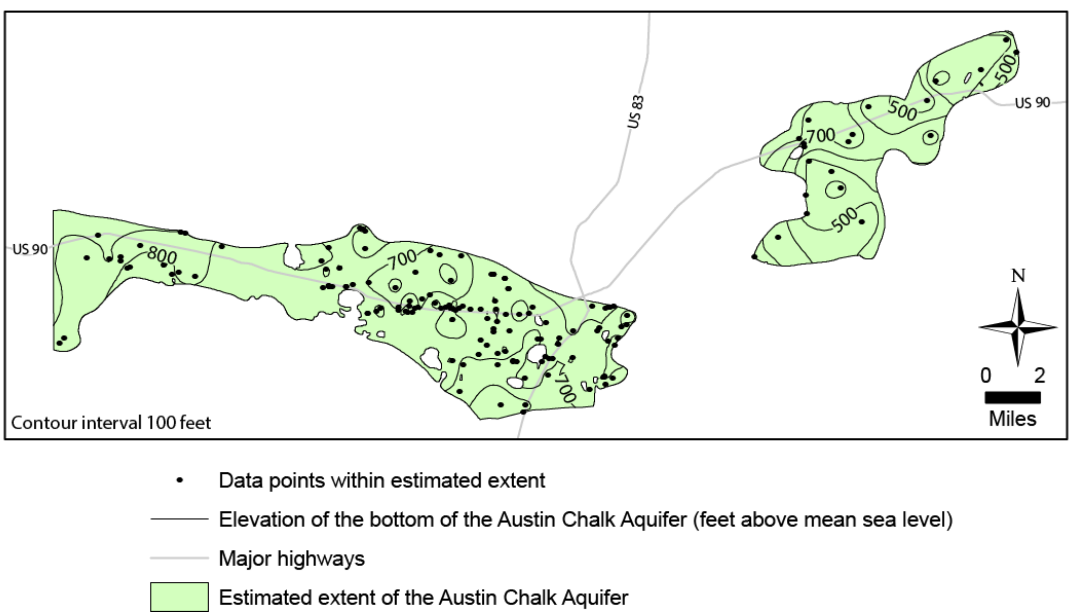

Figure 8. Base of the Austin Chalk Aquifer in Uvalde County used to estimate total recoverable storage (Table 2) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a, 2016b).

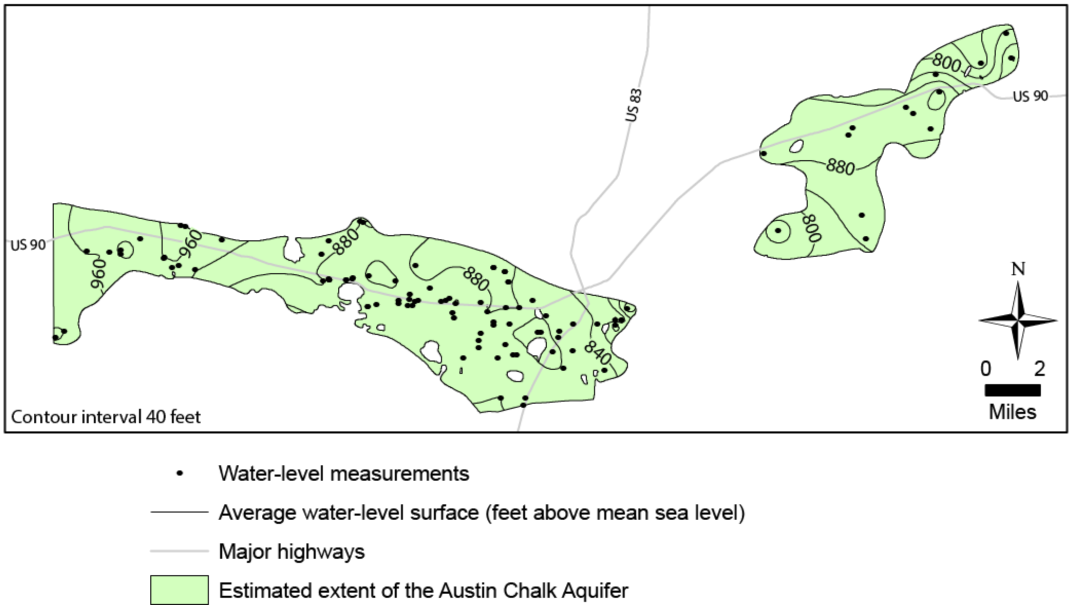

Figure 9. Average water-level elevation map for the Austin Chalk Aquifer in Uvalde County used to estimate total recoverable storage (Table 2) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a, 2016b).

Buda Limestone Aquifer

- The total areal extent of the Buda Limestone Aquifer in Uvalde County, based on productive wells completed in the Buda Formation (Figure 10), is approximately 38,600 acres.
- The data for this study is from the TWDB (2016a) groundwater database, the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database, and the TWDB Brackish Resources Aquifer Characterization System database (TWDB, 2016b).
- We processed the geologic data through Surfer™ to generate the aquifer top (Figure 11), bottom (Figure 12), and the water-level surfaces (Figure 13). These surfaces form confined head and unconfined drained volume raster grids processed through Surfer™ grid math to produce a saturated thickness raster grid.

The saturated thickness grid, multiplied by an unconfined specific yield of 3 percent and confined storativity of 1.0×10^{-5}, then summed up using zonal statistics from Esri® ArcMap™ 10, calculates a total storage volume.

- The estimate of unconfined specific yield is based on low porosity and low groundwater production (American Society of Civil Engineers, 1996; Clark and Small, 1997; Welder and Reeves, 1962).
- The available water-level data are not spatially and temporally extensive at any one period in the TWDB groundwater database record. We included additional water-level measurements from the Texas Department of Licensing and Regulation (2016) Well Report database to enhance the spatial distribution through increased data density. Processing this data in Surfer™ produces a water-level surface raster grid (Figure 13).

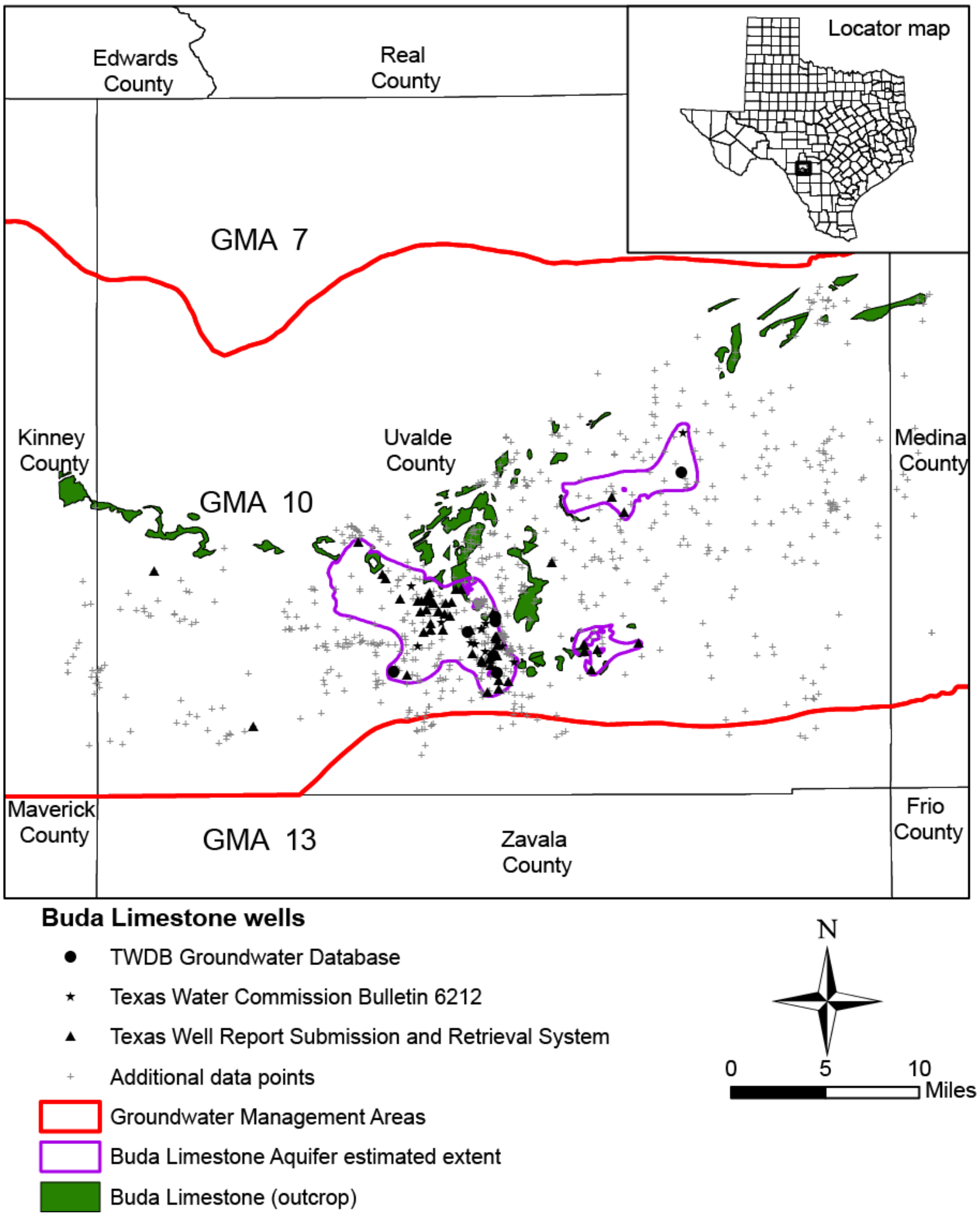

Figure 10. Extent of the Buda Limestone Aquifer in Uvalde County used to estimate total recoverable storage (Table 3) within Groundwater Management Area 10.

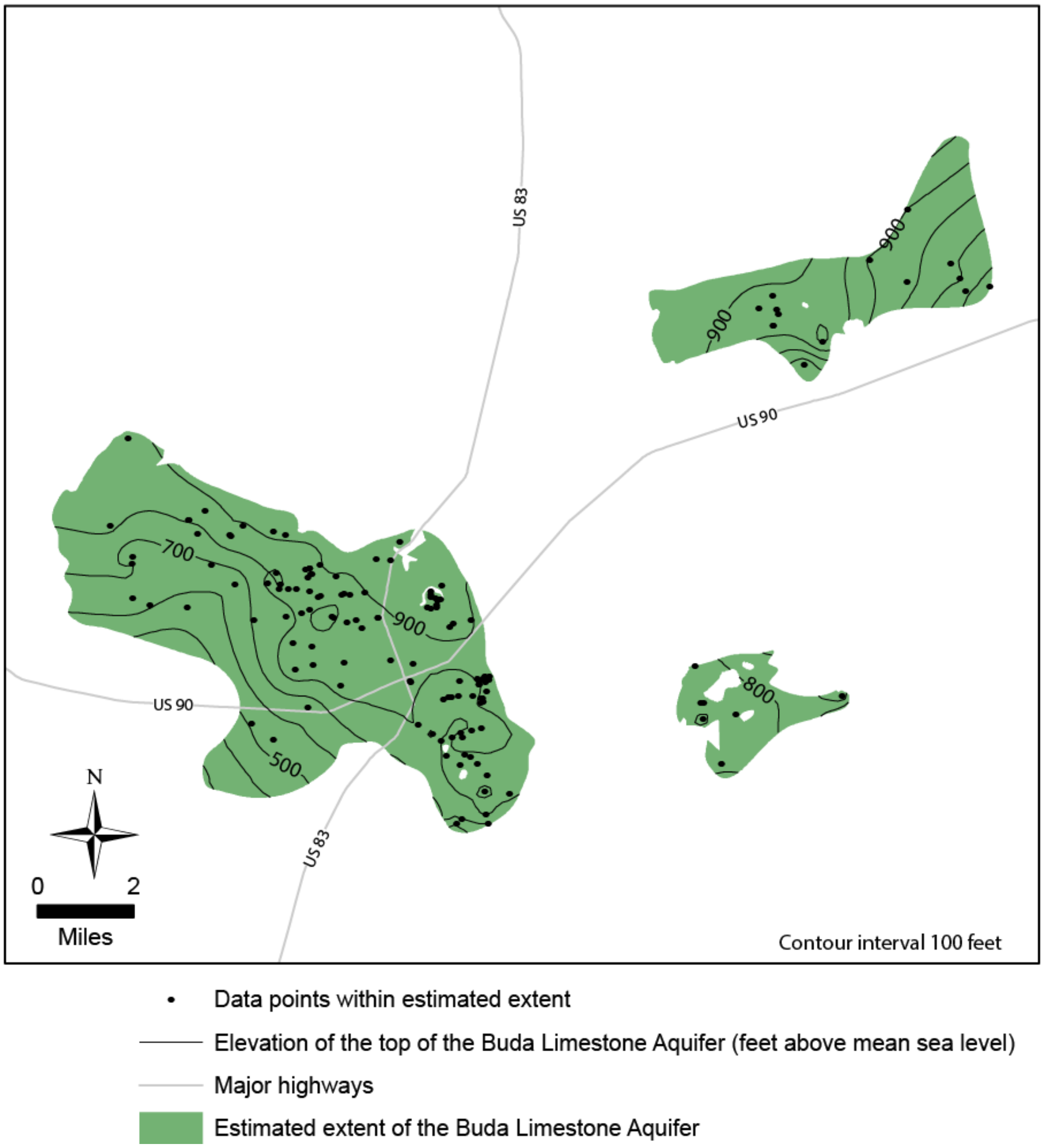

Figure 11. **Top of the Buda Limestone Aquifer in Uvalde County used to estimate total recoverable storage (Table 3) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a, 2016b).**

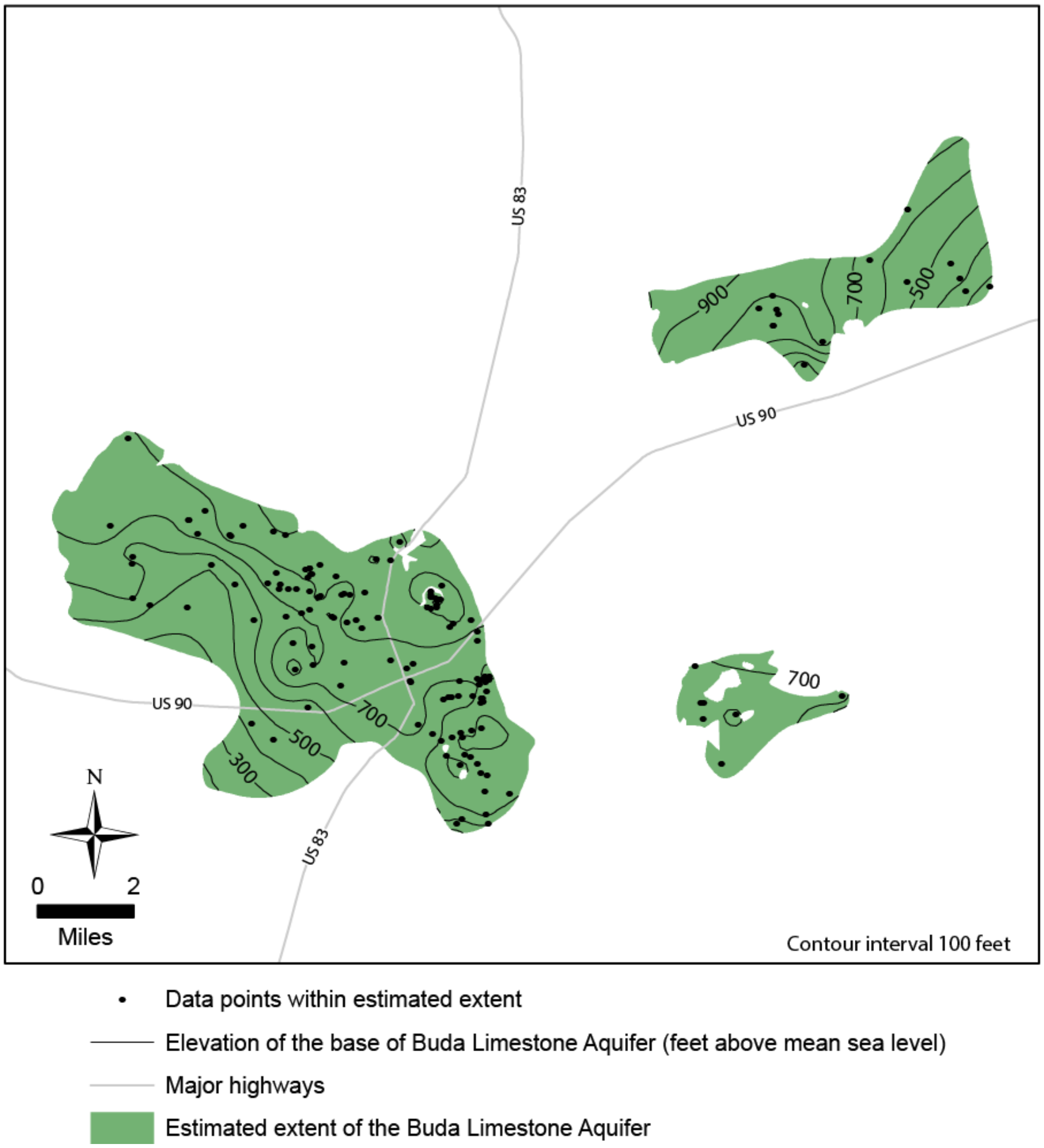

Figure 12. **Base of the Buda Limestone Aquifer in Uvalde County used to estimate total recoverable storage (Table 3) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a, 2016b).**

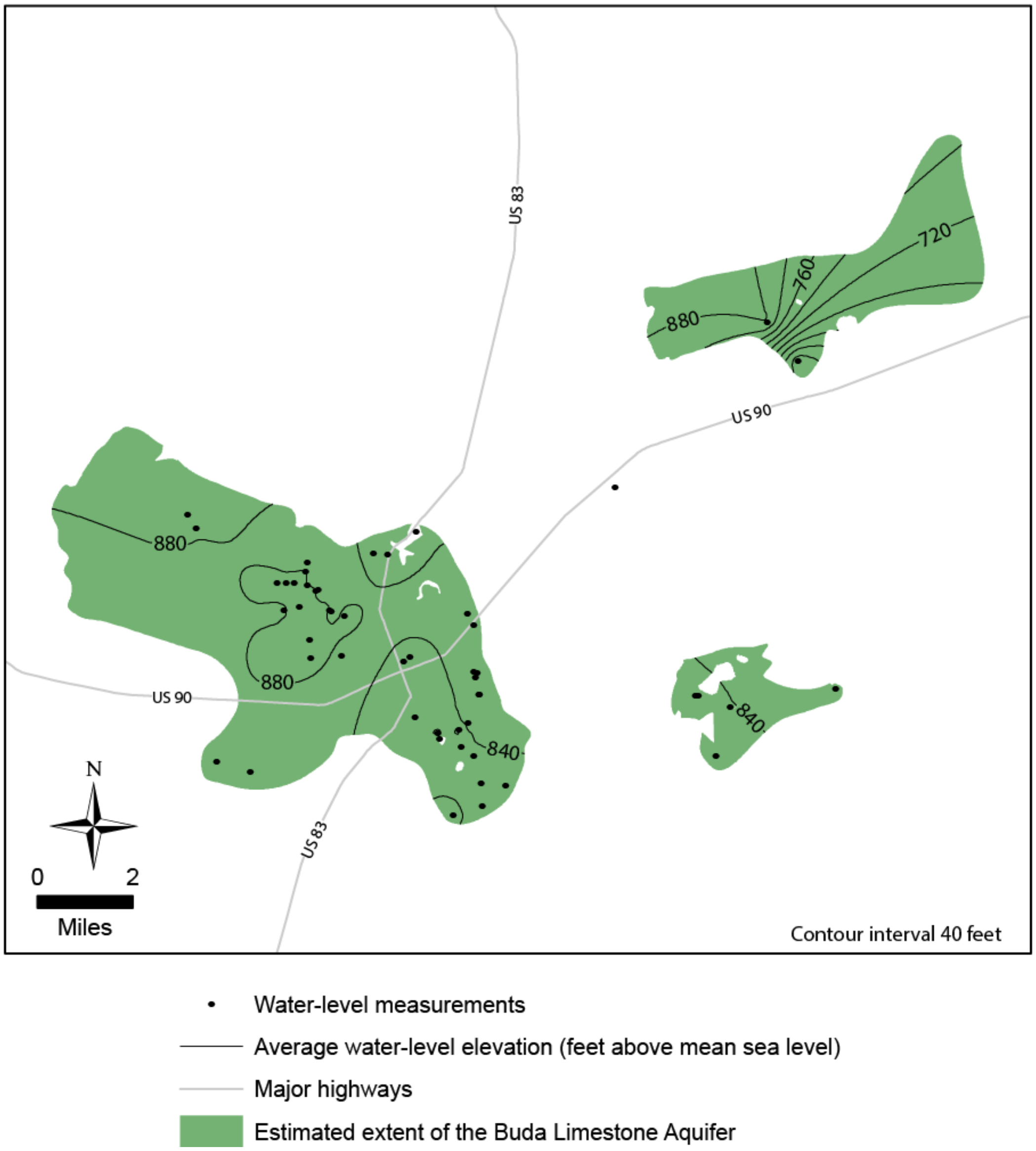

Figure 13. **Average water-level elevation map for the Buda Limestone Aquifer in Uvalde County used to estimate total recoverable storage (Table 3) within Groundwater Management Area 10 (TDLR, 2016; TWDB, 2016a).**

Saline Edwards (Balcones Fault Zone) Aquifer

- The study area boundary is from Bradley (2013b) and falls outside the official boundary of the Edwards (Balcones Fault Zone) Aquifer; the area is slightly more than 160,000 acres (Figure 14).
- The saline Edwards (Balcones Fault Zone) Aquifer in the northern subdivision of Groundwater Management Area 10 is under confined conditions throughout the area.
- Part of the structure (Figure 15) of the saline Edwards (Balcones Fault Zone) Aquifer is from the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer Groundwater Availability Model (Lindgren and others, 2004).
- Additional data for this study is from the TWDB (2016a) groundwater database, the Texas Department of Licensing and Regulation (2016) Well Report Submission and Retrieval System database, and the TWDB Brackish Resources Aquifer Characterization System database (TWDB, 2016b). We include additional water-level measurements from the Texas Department of Licensing and Regulation (2016) Well Report database to enhance the spatial distribution through increased data density (Figure 15).
- We processed the geologic data through Surfer™ to generate the aquifer top, bottom, and potentiometric surface raster grids. The gridded surfaces (Figure 15) for the top and bottom are from well logs and published data (Arnow, 1957; Core Laboratories, 1972a, 1972b; Flores, 1990; Lindgren and others, 2004; TDLR, 2016; TWDB, 2016a, 2016b). These surfaces form confined head and unconfined drained volume raster grids processed through Surfer™ grid math to produce a saturated thickness raster grid.
- The saturated thickness grid is multiplied by an average specific yield of 1.7 percent (Slade and others, 1986) and the total head thickness raster grid is multiplied by a confined storativity of 7.0×10^{-4} (Hunt and others, 2010), and both are summed up using zonal statistics from Esri® ArcMap™ 10 to equal total storage.

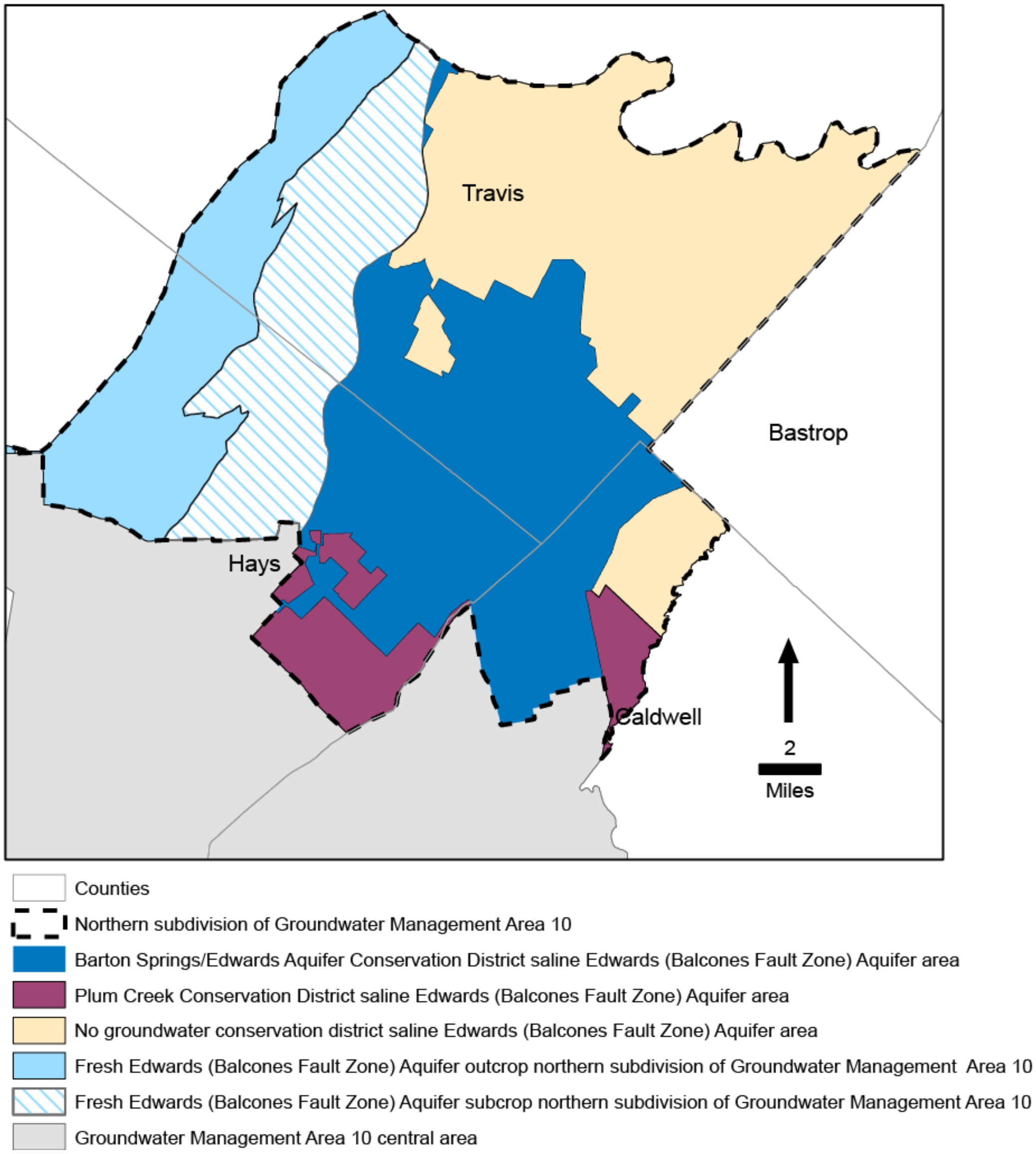

Figure 14. Extent of the saline Edwards (Balcones Fault Zone) Aquifer in the northern subdivision of Groundwater Management Area 10 (Bradley, 2013b).

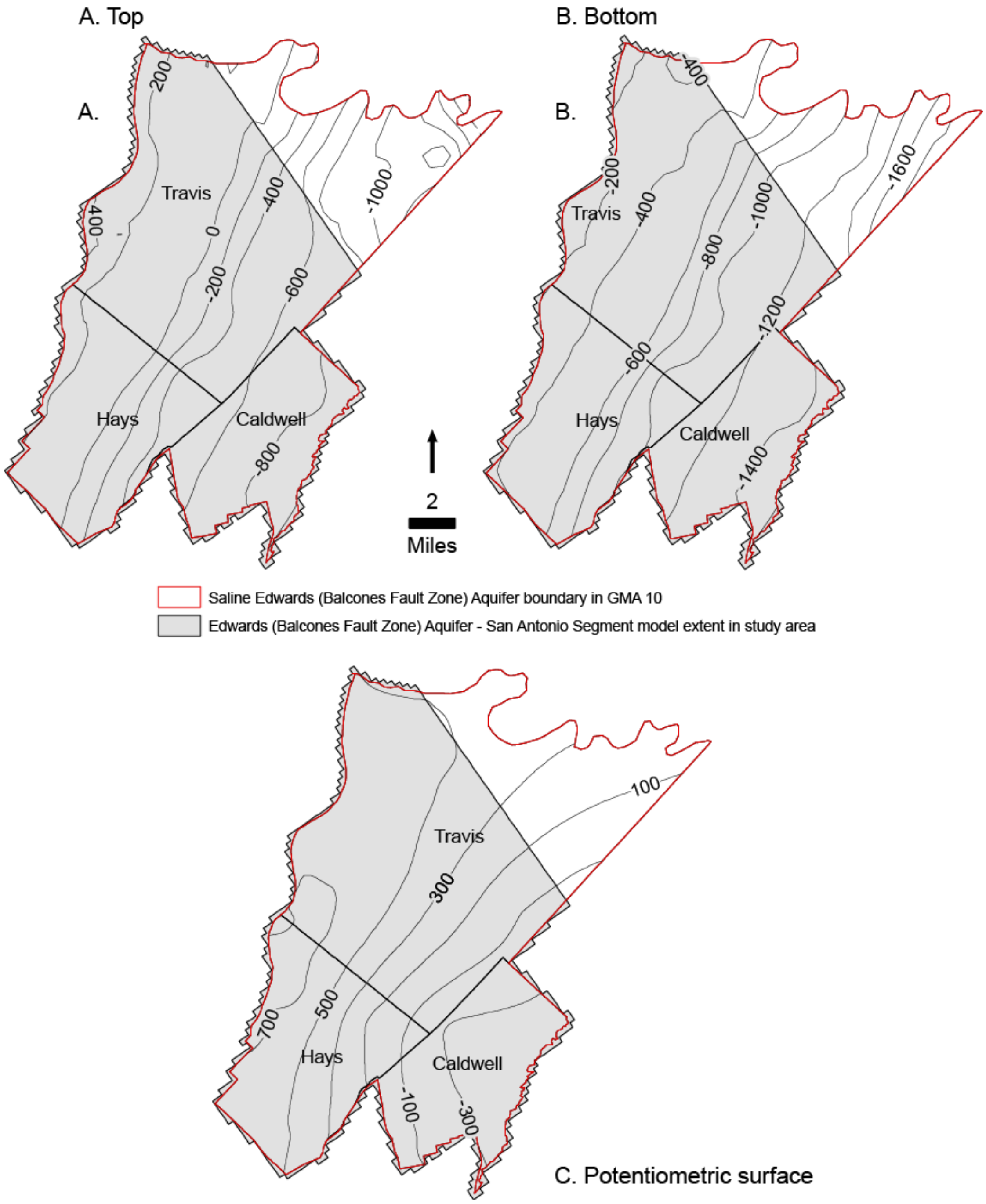

Figure 15. **Maps of the top (a), bottom (b), and average potentiometric surface (C) of the saline Edwards (Balcones Fault Zone) Aquifer for the northern subdivision within Groundwater Management Area 10 used to estimate total recoverable storage (Tables 4 and 5).**

RESULTS:

Tables 1 through 3 summarize the total estimated recoverable storage for the Leona Gravel, Austin Chalk, and Buda Limestone aquifers in Uvalde County. The Uvalde County Underground Water Conservation District is coextensive with Uvalde County and there is one table for each aquifer. Total estimated recoverable storage in Uvalde County ranges from 12,750 to 38,250 acre-feet for the Leona Gravel aquifer, 70,000 to 210,000 acre-feet for the Austin Chalk Aquifer, and 19,000 to 57,000 acre-feet for the Buda Limestone Aquifer.

Table 1. Total estimated recoverable storage for the Leona Gravel Aquifer for the Uvalde County Underground Water Conservation District within Groundwater Management Area 10. Rounding of the total storage estimates is to two significant figures.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Uvalde County Underground Water Conservation District	51,000	12,750	38,250

Table 2. Total estimated recoverable storage for The Austin Chalk Aquifer for the Uvalde County Underground Water Conservation District within Groundwater Management Area 10. Rounding of the total storage estimates is to two significant figures.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Uvalde County Underground Water Conservation District	280,000	70,000	210,000

Table 3. Total estimated recoverable storage for the Buda Limestone Aquifer for the Uvalde County Underground Water Conservation District within Groundwater Management Area 10. Rounding of the total storage estimates is to two significant figures.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Uvalde County Underground Water Conservation District	76,000	19,000	57,000

Tables 4 and 5 summarize the total estimated recoverable storage by county and groundwater conservation district for the saline Edwards (Balcones Fault Zone) Aquifer within the northern subdivision of Groundwater Management Area 10. The total estimated recoverable storage for saline Edwards (Balcones Fault Zone) Aquifer ranges from 365,000 to 1,095,000 acre-feet.

LIMITATIONS

Our analyses assume homogeneous and isotropic aquifers; however, the Leona Gravel, Austin Chalk, Buda Limestone, and saline Edwards (Balcones Fault Zone) aquifers may not behave uniformly. These analyses are sufficient to develop total estimated recoverable storage for these aquifers until further information is developed and evaluated to refine this estimate. All of these estimates will need further refinement as more data becomes available.

Table 4. Total estimated recoverable storage by county for the saline Edwards (Balcones Fault Zone) Aquifer within the northern subdivision of Groundwater Management Area 10. Rounding of total storage estimates is to two significant figures.

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Caldwell	270,000	67,500	202,500
Hays	320,000	80,000	240,000
Travis	870,000	217,500	652,500
Total	**1,460,000**	**365,000**	**1,095,000**

Table 5. Total estimated recoverable storage by groundwater conservation district for the saline Edwards (Balcones Fault Zone) Aquifer within the northern subdivision of Groundwater Management Area 10. Rounding of total storage estimates is to two significant figures.

Groundwater Conservation District	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Barton Springs/Edwards Aquifer Conservation District	690,000	172,500	517,500
Plum Creek Conservation District	150,000	37,500	112,500
no district	620,000	155,000	465,000
Total	**1,460,000**	**365,000**	**1,095,000**

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