Proposed Brackish Groundwater Production Zones for the Southern Portion of the Trinity Aquifer and Trinity Group Formations, Texas

Open File Report 25-01

November 2025

Mark Robinson, P.G

Brackish Resources Aquifer Characterization System (BRACS) Department, Groundwater Division

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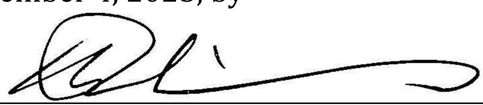

Mark C. Robinson

Table of Contents

List of Tables

List of Figures

Executive summary

The Texas Water Development Board (TWDB) conducted a study to identify and propose brackish groundwater production zones in the southern portion of the Trinity Aquifer, also known as the Hill County Trinity aquifer. This work fulfills requirements outlined in Texas Water Code § 16.060, which directs the TWDB to identify and designate brackish groundwater production zones that are suitable for production while minimizing impacts to existing water users. As part of this study, the TWDB is also required to report estimated 30- and 50-year production volumes and recommend reasonable monitoring strategies.

Proposed brackish groundwater production zones were identified using a combination of mapped salinity distributions from *Brackish Groundwater Study of the Hill Country Trinity Aquifer and Downdip Trinity Group Formations* (Robinson and others, 2022), aquifer productivity parameters, protective buffer distances to meet the statutory criteria of zones outlined in Texas Water Code § 16.060(b)(5), and a simplified groundwater flow model. The TWDB proposes four brackish groundwater production zones in the southern portion of the Trinity Aquifer:

- two in the upper Trinity formation (HCTU1 and HCTU2; see Table 15, Table 16, and Figure 10),
- one in the middle Trinity formation (HCTM1; see Table 17 and Figure 11), and
- one in the lower Trinity formation (HCTL1; see Table 18 and Figure 12).

Estimated brackish groundwater production volumes from the proposed zones range from 41,803 to 261,374 acre-feet over a 50-year period (Table ES-1).

Table ES-1. Proposed brackish groundwater production zone volumes.

Zone ID	Annual production volume (acre-feet per year)	30-year production volume (acre-feet)	50-year production volume (acre-feet)
HCTU1	1,679	50,412	84,024
HCTU2	835	25,081	41,803
HCTM1	2,699	80,699	134,476
HCTL1	5,238	156,844	261,374

These volumes stipulate constant production at average per-well rates of 76 to 152 gallons per minute over a 50-year period. These estimated production rates are not expected to significantly impact fresh groundwater or existing groundwater wells being used as a source of water supply for municipal, domestic, or agricultural purposes. Note that these estimates do not consider the effects of land surface subsidence, degradation of water quality, or any changes to groundwater-surface water interaction that may result from extracting groundwater from the aquifer.

The per-well production rates represent a maximum recommended for a well at the edge of a brackish groundwater production zone at the closest point to protected fresh groundwater or existing wells. Higher production rates could be possible for wells located within brackish groundwater production zones at greater distances from protected fresh groundwater or existing wells. For any brackish groundwater development projects from the proposed zones, the TWDB recommends monitoring in both the Trinity Aquifer and the overlying Edwards (Balcones Fault Zone) Aquifer to ensure that production activities do not compromise freshwater resources.

The TWDB identifies brackish groundwater production zones using the best publicly available data at the time of the analysis. As brackish groundwater production zones become developed over time and more becomes known about the aquifer properties in the brackish parts of the southern portion of the Trinity Aquifer, the cumulative subsurface data will provide greater insight into possible production volumes and optimum production rates.

Introduction

The TWDB evaluated the Trinity Aquifer, a major aquifer in central Texas, for brackish groundwater resources and potential brackish groundwater production zones. Texas Water Code § 16.060 requires the Texas Water Development Board (TWDB) to:

1) identify and designate brackish groundwater production zones in the state,
2) determine the volumes of groundwater that a brackish groundwater production zone can produce over 30-year and 50-year periods without causing significant impact to existing specified well users water availability or water quality,
3) make recommendations on reasonable monitoring to observe the effects of brackish groundwater production within the zone,
4) work with groundwater conservation districts and stakeholders in general, and
5) provide a summary of brackish groundwater production zone designations in the biennial report due December 1 of each even-numbered year.

The Trinity Aquifer is one of the nine major aquifers in Texas and is an important source of fresh water for millions of people across a large part of Central Texas. The southern portion of the Trinity Aquifer is divided from the northern portion along the Colorado River. This division is based primarily upon geographic considerations but also represents possible hydrogeologic and geologic changes within the Trinity Aquifer (Brune and Duffin, 1983; George and others, 2011). Because of the large geographic extent of the Trinity Aquifer, the TWDB Brackish Resources Aquifer Characterization System (BRACS) Program divided the aquifer into northern and southern study areas. The southern portion of the Trinity Aquifer is also known as the Hill Country Trinity aquifer.

In 2019, the BRACS Program completed a brackish groundwater study for the northern portion of the Trinity Aquifer (Robinson and others, 2019) that resulted in 15 brackish groundwater production zone designations. In 2022, the BRACS Program completed a brackish groundwater study of the Hill Country Trinity aquifer and downdip Trinity Group Formations (Robinson and others, 2022). The work presented in this report utilizes the results from the previous report and consideration of the statutory criteria in Texas Water Code § 16.060(b)(5) to identify proposed brackish groundwater production zones in the southern portion of the Trinity Aquifer (Hill Country Trinity aquifer).

The southern portion of the Trinity Aquifer study area (Figure 1) covers approximately 15,500 square miles in Central Texas and includes all or part of 24 counties (Table 1). The study area includes all the TWDB-defined Trinity Aquifer outcrop and subcrop areas in the Texas Hill Country region. The study area extent varies, primarily in the downdip direction, from the recently completed conceptual model for the southern portion of the Trinity Aquifer groundwater availability model (Toll and others, 2018). Additional area was included in the southern portion of the Trinity Aquifer brackish groundwater study area to minimize edge effects and map the deeper downdip portions of the Trinity Group formations. Portions of other aquifers that overlie the Trinity Aquifer in the study area are the Carrizo-Wilcox, Edwards (Balcones Fault Zone), and Edwards-Trinity (Plateau) aquifers. The Ellenberger-San Saba and the Hickory aquifers are overlain in part by the Trinity Aquifer, primarily in the northwestern part of the study area.

Table 1. Counties in the study area.

Atascosa	Frio	Llano
Bandera	Gillespie	Maverick
Bastrop	Gonzales	Medina
Bexar	Guadalupe	Real
Blanco	Hays	Travis
Burnet	Kendall	Uvalde
Caldwell	Kerr	Wilson
Comal	Kinney	Zavala

The ground surface elevation ranges from 278 to 2,342 feet above mean sea level across the study area. Half of the study area, located northwest of the Balcones Fault Zone, has significant topographic changes of several hundred feet from hilltops to canyon floors. The southeastern portion of the study area adjacent to the Balcones Fault Zone is the northwestern edge of the upper coastal plain, which exhibits less dramatic topography and an average elevation change of about 50 feet every 10 miles.

Background

We used the data and findings of the brackish groundwater study of the Hill Country Trinity aquifer (Robinson and others, 2022) for our evaluation of the proposed brackish groundwater production zones in this report. We encourage those who are interested in the detailed methodology of defining groundwater salinity zones to read the Hill Country Trinity aquifer brackish groundwater study. Statutory criteria in Texas Water Code § 16.060 require us to also evaluate existing water wells, aquifer producibility, and potential water level drawdown. We are also required to describe any portion of the aquifer within a brackish groundwater production zone that is potentially impacted by injection wells.

Stratigraphy and lithology

The southern portion of the Trinity Aquifer is a thick sedimentary wedge of calcareous sandstone, shale, limestone, dolomite, and evaporites belonging to the Cretaceous Trinity Group that was deposited upon an eroded shelf of Paleozoic rocks. This wedge thickens from 0 to 5,000 feet in a northwest to southeast direction. The Trinity Group is heavily faulted in the study area by the Balcones and the Luling Fault Zones. These fault zones tend to restrict the downdip flow of groundwater through water bearing units (Figure 2). Faults in some portions of the study area may form a boundary between the relatively fresh or slightly saline groundwater in relatively shallow updip portions of the Trinity Aquifer and the more moderate to very saline groundwater in deeper downdip portions of the southern portion of the Trinity Aquifer (Robinson and others, 2022).

The stratigraphic framework and geologic column used for this study is shown in Figure 3. The terminology for mappable geologic units of the Trinity Group varies according to geographic location. The hydrostratigraphic nomenclature used in this study is based upon the stratigraphic terminology used to describe the Trinity Group in the subsurface and in outcrops by previous studies in Hays, Travis, Blanco, and Gillespie counties (Wierman and others, 2010; Hunt and others, 2020). The hydrologic unit designations of upper, middle, and lower Trinity were first utilized by Ashworth (1983) based upon observed differences in groundwater heads in wells that were completed in different portions of the Trinity Aquifer. From these observations, Ashworth proposed the existence of aquitards between the 1) Upper Glen Rose limestone and Lower Glen Rose limestone and 2) between the Cow Creek limestone and Sligo limestone.

Salinity classes

Robinson and others (2022) used both measured and calculated groundwater salinity values to map the distribution of brackish groundwater in the southern portion of the Trinity Aquifer study area. The salinity distribution for each of the six hydrostratigraphic units was mapped using the classification system of Winslow and Kister (1956) shown in Table 2. For this analysis we decided to utilize the three-part division of the Trinity (upper, middle, and lower) as first defined by Ashworth (1983). The upper Trinity salinity map (Figure 4) is composed of the upper Glen Rose limestone. We combined the lower Glen Rose limestone, Hensell sandstone, and Cow Creek limestone salinity maps to create a middle Trinity salinity map (Figure 5). The Sligo limestone and Hosston sandstone salinity maps were combined to form a lower Trinity salinity map (Figure 6).

Table 2. Groundwater salinity classification used in the study. (Winslow and Kister, 1956). Colors used in this table for each salinity classification are consistent throughout the report and GIS datasets.

Groundwater salinity classification	Total dissolved solids concentration (units: milligrams per liter)
Fresh	0 to 999
Slightly saline	1,000 to 2,999
Moderately saline	3,000 to 9,999
Very saline	10,000 to 34,999
Brine	Greater than 35,000

As a result of combining the hydrostratigraphic salinity zone maps into the salinity distribution maps for the middle and lower Trinity we created “mixed zones” that combine two of the five classifications wherever they were found to overlap. A mixed salinity zone is one that contains brackish groundwater from two adjacent salinity classifications. Volume calculations were made for the mixed zones. However, we did not attempt to separate and quantify the volume of groundwater from the two component "mixed zones" into the classifications shown in Table 2. Appendix A includes total in-place groundwater volumes for each brackish groundwater production zone, split out by salinity classification and tabulated by county and by GCD. Total in-place groundwater volumes are significantly greater than the estimated production volumes. Estimated production rates and associated volumes are not expected to significantly impact fresh groundwater or existing groundwater wells being used as a source of water supply for municipal, domestic, or agricultural purposes.

Brackish groundwater production zones

Texas Water Code § 16.060 requires the TWDB to identify and designate local or regional brackish groundwater production zones, make reasonable monitoring recommendations to observe the effects of production in zones, work with stakeholders, and report zone designations in a biennial report to the Texas Legislature. We additionally provide the volumes of brackish groundwater that zones can produce in each county and each groundwater conservation district to help facilitate water planning.

The TWDB BRACS Program proposes four brackish groundwater production zones in the southern portion of the Trinity Aquifer study area: HCTU1, HCTU2, HCTM1, and HCTL1.[1] The combined area of these overlapping brackish groundwater production zones is 4,563,975 acres.

Zone designation considerations

Brackish groundwater production zones are proposed in accordance with the criteria outlined in Texas Water Code § 16.060. These criteria include aquifer availability and productivity, fresh and brackish groundwater locations, hydrogeologic barriers, administrative jurisdictions, existing water well use, and potential pumping impacts. After the proposed zones are presented to groundwater conservation districts and other stakeholders, the TWDB officially designates the brackish groundwater production zones by Board approval. This open file report will be updated as necessary to indicate when recommendations become designated zones.

The southern portion of the Trinity Aquifer in the study area is assumed to be available and productive because active water wells are in the updip portions of the aquifer. We can also assume that downdip portions of the aquifer have the potential to produce groundwater because of the presence of oil and gas wells, which require significant formation porosity and permeability to be commercial. No public aquifer test data were found in the proposed

[1] The naming convention for zones includes an aquifer abbreviation, a hydrologic indicator, and a number. For example, the HCTU2 indicates the second zone in the upper Trinity unit of the southern portion of the Trinity Aquifer.

brackish groundwater production zones, so the aquifer productivity could not be verified. The location of fresh and brackish groundwater was identified during the salinity class mapping (Robinson and others, 2022).

Significant vertical hydrologic barriers exist above and below the Trinity Aquifer. The lower Trinity hydrologic unit sits above much older and less transmissive Paleozoic rocks throughout much of the study area. The basal units of the Edwards Group overlie the upper Trinity hydrologic unit. In updip portions of the study area, it has been observed that groundwater can flow between the Edwards Aquifer and the upper Trinity (Smith and Hunt, 2009; Wong and others, 2014). No data exists with regard to this groundwater interaction for the downdip portions of the aquifers. However, geophysical well logs show that the Walnut (clay) Formation or equivalent shale, at the base of the Edwards Group, is 20 to 40 feet thick and may represent a significant aquitard for the top of the Trinity Aquifer.

The distance from a proposed brackish groundwater production zone to existing water wells is referred to as a horizontal distance hydrogeologic barrier. Geologic maps show that both normal and reverse geologic faults exist between portions of the brackish groundwater production zones and updip fresh groundwater which may also act as hydrogeologic barriers.

Methodology

To identify areas suitable for brackish groundwater production zone designations we first calculated buffer distances for the upper Trinity, middle Trinity, and lower Trinity. Then using ESRI ArcGIS Pro we applied the buffer distances around the following:

1) Existing domestic, agricultural, and public supply water wells that produce from the Trinity Aquifer.
2) Known Trinity Aquifer fresh groundwater zones.
3) The Edwards Aquifer Authority and Barton Springs/Edwards Aquifer Conservation District jurisdictional boundaries.

The buffer distances are based upon aquifer hydrologic properties and proposed production rates using the Cooper-Jacob approximation of the Theis Method, which has many simplifying assumptions, including that the aquifer has infinite extent, is homogeneous, has uniform thickness, is non-leaky confined, groundwater flow is horizontal, and wells are fully penetrating. To validate the buffer distances from this method, we developed a simple groundwater flow model using MODFLOW (based on the current TWDB groundwater availability model) and compared the calculated drawdown curves, resulting in a confirmation that the analytical method was an effective approach.

The transmissivity, well yield, and storativity data used in the analytical method are from Robinson and others (2022). We determined that the statistical median values for transmissivity and storativity were most representative because the mean values were impacted by a few very high values. For well yield, we generated a probability plot of the available data and based upon the generated curve used values in the 60 to 70 percentile range. The aquifer parameters used to calculate buffer distances are given in Table 3.

For each Trinity Aquifer interval, we calculated the radial distance needed for a 20-foot drawdown from a well producing at a constant rate for 50 years. As discussed below, the 20-foot drawdown would represent a maximum 1 to 4 percent drop in head outside the proposed production zones at the calculated buffer distances. The calculated 20-foot drawdown lateral buffers, which range from 5.5 to 6.5 miles, are also given in Table 3, along with the aquifer parameters used to calculate the buffers. Because there is no significant hydrogeological isolation between existing freshwater users and brackish groundwater production zones in these aquifer formations, the lateral buffer distances function as hydrogeological separation. As a result, the available drawdown assumptions and production volumes are conservative. If a brackish wellfield is planned in the future, pumping well tests and monitor wells will provide improved production, well spacing, and drawdown estimates that can be used to refine wellfield design.

TWDB staff evaluated injection wells in the Trinity Group within the study area using the Class II Well Injection Mapping Tool developed for the TWDB. We identified 54 Class II injection wells[2] within the study area that could potentially impact a Trinity Aquifer brackish groundwater production zone. No Class I or IV injection wells were identified. The tool calculated injection well buffer distances that ranged from 0.05 to 4.27 miles for all 54 Class II injection wells. Only one of the 54 Class II injection wells is located within a proposed brackish groundwater production zone that potentially impacts a portion of the Trinity Aquifer (Figure 4).

[2] A Class II injection well is a type of well used for underground injection of waste associated with oil and gas production. The Texas Railroad Commission regulates Class II disposal and injection wells.

Table 3. Parameters used to model drawdown for hypothetical brackish groundwater production zone wells and resulting buffer distance from hypothetical production wells.

Parameters	HCTU1	HCTU2	HCTM1	HCTL1
Well yield per well (gallons per minute)	152	152	76	99
Storage coefficient (storativity)	0.00017	0.00017	0.00015	0.00032
Transmissivity (feet^2/day)	601	601	232	267
Transmissivity (gallons per day/foot)	4,496	4,496	1,735	1,997
Specific yield	0.054	0.054	0.108	0.120
Buffer distance: Calculated radius (miles) from well pumping for 50 years where drawdown equals 20 feet	5.5	5.5	6.5	6
Area of proposed brackish groundwater production zone (acres)	122,520	207,632	1,864,035	2,369,788
Area of single **buffer distance** circle (acres)	60,821	60,821	84,949	72,382
50-year single well cumulative production (acre-feet)	12,250	12,250	6,150	8,000
30-year single well cumulative production (acre-feet)	7,350	7,350	3,690	4,800
Annual single well cumulative production (acre-feet)	245	245	123	160

Results

Estimated single well production volumes for each proposed brackish groundwater production zone and calculated parameters that define the physical dimensions of the proposed brackish groundwater production zones are detailed in Table 4. Because the minimum hydraulic head for the proposed brackish groundwater production zones ranges from 493 feet to 1,962 feet, we determined that a 20-foot drawdown would represent only a 1 to 4 percent drop in head and should not represent a significant impact to existing Trinity Aquifer wells (public supply, domestic, and agricultural) closest to the proposed brackish groundwater production zones.

Figure 7 shows the proposed brackish groundwater production zones for the upper Trinity. The map shows the 5.5-mile buffers used to constrain the proposed brackish groundwater production zones. Buffered areas included the 1) Edwards Aquifer Authority; 2) Barton Springs/Edwards Aquifer Conservation District; 3) known area of fresh water; and 4) existing domestic, public, and agricultural wells. We also excluded the northern portion of the Trinity Aquifer and areas with total dissolved solids concentrations greater than 10,000 milligrams per liter.

Figure 8 shows the proposed brackish groundwater production zone for the middle Trinity. The map shows the 6.5-mile buffers used to constrain the proposed brackish groundwater production zone. Buffered areas included the 1) known area of fresh water and 2) existing domestic, public, and agricultural wells. We also excluded the northern portion of the

Trinity Aquifer and areas with total dissolved solids concentrations greater than 10,000 milligrams per liter.

Figure 9 shows the proposed brackish groundwater production zone for the lower Trinity. The map shows the 6.0-mile buffers used to constrain the proposed brackish groundwater production zone. Buffered areas included the 1) known area of fresh water and 2) existing domestic, public, and agricultural wells. We also excluded the northern portion of the Trinity Aquifer and areas with total dissolved solids concentrations greater than 10,000 milligrams per liter.

Table 4. Estimated zone production volumes, minimum, maximum, and average depth, thickness, and hydraulic head for the proposed brackish groundwater production zones.

Parameters	HCTU1	HCTU2	HCTM1	HCTL1
50-year **zone maximum** cumulative production (acre-feet)	24,695	41,850	134,489	261,395
30-year **zone maximum** cumulative production (acre-feet)	14,816	25,109	80,707	156,857
Minimum depth (feet)	1,451	3,942	950	941
Maximum depth (feet)	5,810	7,019	7,714	7,165
Average depth (feet)	2,932	5,020	3,353	3,558
Minimum thickness (feet)	504	853	464	400
Maximum thickness (feet)	961	1,134	1,519	1,906
Average thickness (feet)	670	912	719	1,011
Minimum hydraulic head (feet)	718	1,962	493	622
Maximum hydraulic head (feet)	2,937	3,509	3,994	4,785
Average hydraulic head (feet)	1,633	2,262	2,065	2,168

The HCTU1 proposed brackish groundwater production zone only contains one Class II injection well (BRACS#89648) in Figure 7. This well appears to have been injecting produced water from oilfield activities into the Edwards Group formations at a rate of 500 to 1,500 barrels per month since 1991. This well was determined to be of concern even though the injection interval is almost 200 feet above the Trinity Aquifer. Previous studies (Smith and Hunt, 2009; Wong and others, 2014) have indicated the possibility of communication between the lower Edwards and the upper Glen Rose formations. Studies have also highlighted the karstic nature of the upper Trinity (Smith and Hunt, 2009). These previous studies informed the decision to create a 3,600-foot buffer around this Class II injection well, which is more than double the calculated maximum migration distance calculated use the TWDB injection buffer tool.

Zone production volumes

As discussed earlier, the calculation of the buffer distances shown in Table 3 required us to identify a maximum well yield for production without having a significant impact on fresh groundwater resources and various existing brackish groundwater wells. These production rates were then used to calculate a per well production volume that would be possible if the well was produced for a 30 and 50-year permit term Table 3). In an effort to provide estimates on the total producible volume of brackish groundwater from the proposed production zones, we calculated the maximum number of wells that could potentially be developed by assuming that each well required the area of a circle with a radius equal to the appropriate buffer distance and divided the total area of the zone by this value to derive the hypothetical number of possible wells for each zone (Figure 4). The production volumes for 30- and 50-year time frames for each zone, given the maximum hypothetical number of wells distributed in each zone, is given in Table 4. Tables 5 through 8 summarize the calculated production estimates by county and river basins within each county. The production volumes in Tables 5 through 8 are split by both county and river basin to conform with regional water planning standards. The additional subdivision creates smaller areas with smaller groundwater availability volumes. These volumes result in the production of only one percent of the in place brackish groundwater estimated for each proposed production zone. This low percentage is a result of the constraint that there be no significant impact on fresh groundwater resources. Because there is no physical hydrogeological isolation between existing freshwater users and brackish groundwater production zones in these aquifer formations, the lateral buffer distances function as hydrogeological separation. Therefore, the available drawdown assumptions and production volumes are conservative.

Table 5. Estimated volume of brackish groundwater that could be produced from proposed brackish groundwater production zone HCTU1 (upper Trinity). Data organized by county and river basin. Volumes are in acre-feet.

HCTU1: Proposed upper Trinity brackish groundwater production zone				
County	River basin	Annual volume	30-Year volume	50-year volume
Bastrop	Colorado	781	23,453	39,091
Bastrop	Guadalupe	210	6,315	10,525
Caldwell	Colorado	224	6,717	11,195
Caldwell	Guadalupe	271	8,143	13,573
Travis	Colorado	193	5,784	9,641
Total		1,679	50,412	84,024

Table 6. Estimated volume of brackish groundwater that could be produced from proposed brackish groundwater production zone HCTU2 (upper Trinity). Data organized by county and river basin. Volumes are in acre-feet.

HCTU2: Proposed upper Trinity brackish groundwater production zone				
County	River basin	Annual volume	30-Year volume	50-year volume
Zavala	Nueces	835	25,081	41,803

Table 7. Estimated volume of brackish groundwater that could be produced from proposed brackish groundwater production zone HCTM1 (middle Trinity). Data organized by county and river basin. Volumes are in acre-feet.

HCTM1: Proposed -middle Trinity brackish groundwater production zone				
County	River basin	Annual volume	30-Year volume	50-year volume
Bastrop	Colorado	179	5,363	8,936
Caldwell	Colorado	92	2,753	4,588
Caldwell	Guadalupe	166	4,952	8,252
Guadalupe	Guadalupe	151	4,521	7,533
Guadalupe	San Antonio	100	2,997	4,993
Bexar	San Antonio	388	11,606	19,340
Bexar	Nueces	114	3,419	5,697
Atascosa	San Antonio	110	3,301	5,501
Atascosa	Nueces	122	3,635	6,057
Medina	San Antonio	118	3,524	5,872
Medina	Nueces	383	11,447	19,075
Uvalde	Nueces	462	13,804	23,003
Zavala	Nueces	314	9,378	15,628
Total		2,699	80,699	134,476

Table 8. Estimated volume of brackish groundwater that could be produced from proposed brackish groundwater production zone HCTL1 (lower Trinity). Data organized by county and river basin. Volumes are in acre-feet.

HCTL1: Proposed upper Trinity brackish groundwater production zone				
County name	River basin	Annual volume	30-Year volume	50-year volume
Travis	Colorado	143	4,289	7,147
Bastrop	Colorado	311	9,324	15,539
Caldwell	Colorado	175	5,250	8,749
Caldwell	Guadalupe	198	5,942	9,903
Guadalupe	Guadalupe	215	6,427	10,710
Guadalupe	San Antonio	155	4,630	7,715
Wilson	San Antonio	211	6,310	10,516
Bexar	San Antonio	651	19,487	32,474
Bexar	Nueces	156	4,673	7,787
Atascosa	San Antonio	170	5,093	8,487
Atascosa	Nueces	196	5,858	9,761
Medina	San Antonio	177	5,298	8,829
Medina	Nueces	722	21,612	36,015
Uvalde	Nueces	944	28,269	47,109
Zavala	Nueces	424	12,708	21,177
Frio	Nueces	294	8,816	14,692
Comal	Guadalupe	96	2,860	4,766
Total		5,238	156,844	261,374

Groundwater monitoring recommendations

It is generally recommended that groundwater monitoring be performed in the Trinity Aquifer and the overlying Edwards (Balcones Fault Zone) Aquifer. It has been shown that groundwater can move between the lower Edwards and upper Trinity formations in updip portions of the aquifers. In the downdip areas, monitoring in wells completed in these aquifers would ensure that the lower Edwards shales provide an adequate hydrologic barrier separating the Trinity and Edwards (Balcones Fault Zone) aquifers.

Fresh-water resources of the Trinity Aquifer, updip from the proposed zones, should also be monitored to ensure that significant impact caused by the production of brackish groundwater is prevented. Monitoring is not required below the Hosston sand unit of the Trinity Aquifer because there are no known fresh or brackish aquifers that would be impacted by pumping in these formations. Future wellfields in the proposed brackish zones should include monitor wells to track water levels and water quality during production.

Stakeholder engagement

The four proposed brackish groundwater production zones defined for the southern portion of the Trinity Aquifer intersect four groundwater management areas and nine groundwater conservation districts (Tables 9 and 10). We show the proposed brackish groundwater production zones superimposed on the outlines of impacted groundwater conservation districts in Figures 10 through 12.

Five stakeholder meetings were held in 2019 for the Hill Country Trinity aquifer brackish groundwater study (Robinson and others, 2022). Additional stakeholder meetings will be held after this report is released, prior to brackish groundwater production zone designation by the TWDB. All information related to the Hill Country Trinity aquifer study is available on the TWDB website. After engaging and soliciting feedback on the proposed zones from stakeholders, the proposed zones may be considered by the Board for designation during a public meeting.

Table 9. Groundwater management areas intersected by proposed brackish groundwater production zones.

Proposed brackish groundwater production zone	Groundwater management area
HCTU1	10, 12, 13
HCTU2	13
HCTM1	10, 12, 13
HCTL1	7, 10, 12, 13

Table 10. Groundwater conservation districts intersected by proposed brackish groundwater production zones.

Proposed brackish groundwater production zone	Groundwater conservation district
HCTU1	Gonzales County UWCD
	Lost Pines GCD
	Plum Creek CD
HCTU2	Wintergarden GCD
HCTM1	Evergreen UWCD
	Gonzales County UWCD
	Guadalupe County GCD
	Lost Pines GCD
	Medina County GCD
	Plum Creek GCD
	Uvalde County UWCD
	Wintergarden GCD
HCTL1	Comal Trinity GCD
	Evergreen UWCD
	Gonzales County UWCD
	Guadalupe County GCD
	Lost Pines GCD
	Medina County GCD
	Plum Creek GCD
	Uvalde County UWCD
	Wintergarden GCD

Limitations

The TWDB proposes brackish groundwater production zones using the best publicly available data at the time of the analysis. All interpretations and calculations used for mapping are stored and available in the BRACS Database and Geographic Information System files posted on the TWDB website. As more wells are drilled and monitored and more data becomes available, recommendations may change.

Figures

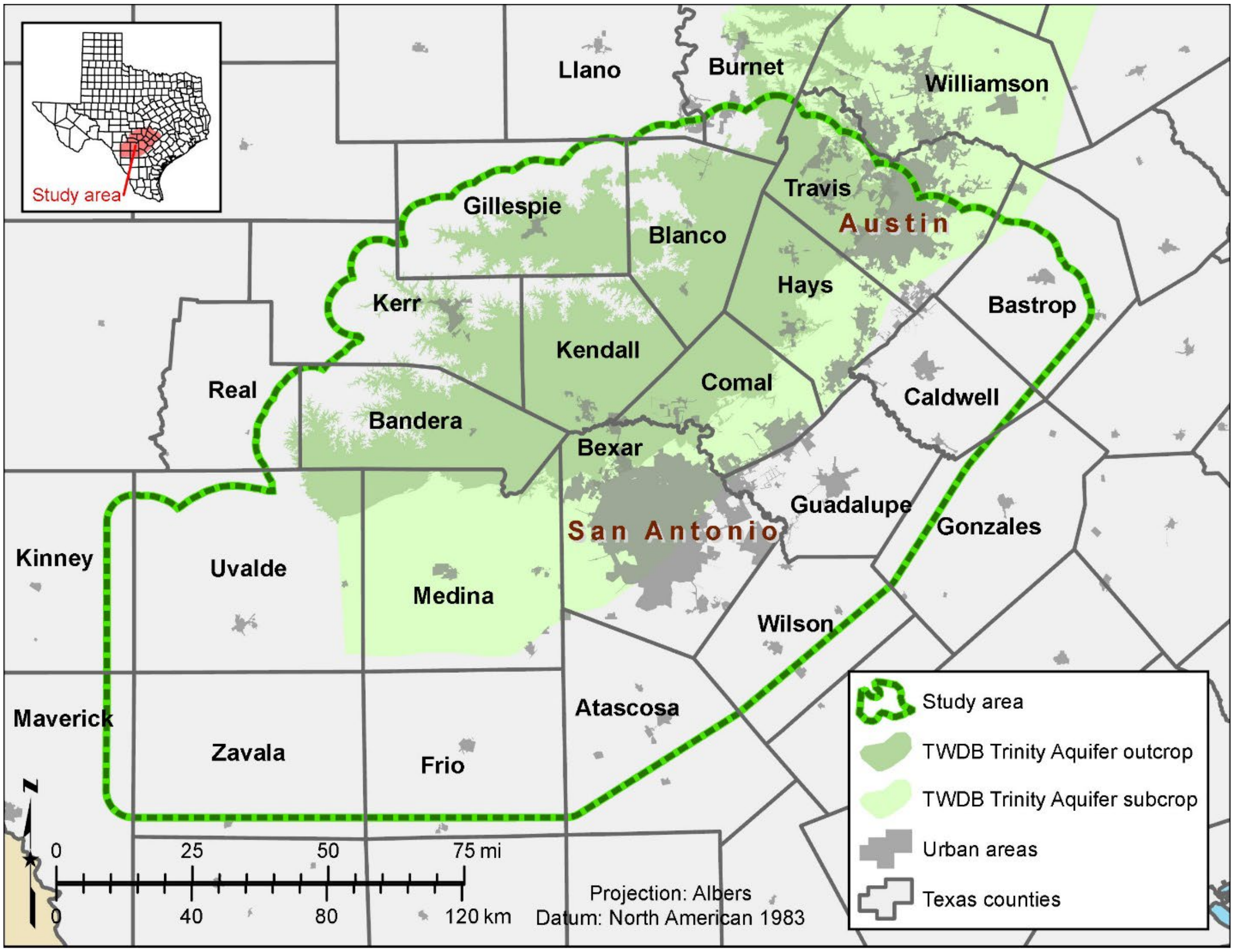

Figure 1. **Study area boundary which includes the southern portion of the Trinity Aquifer (Hill Country Trinity aquifer) as well as Trinity Group formations outside the official Trinity Aquifer boundary.**

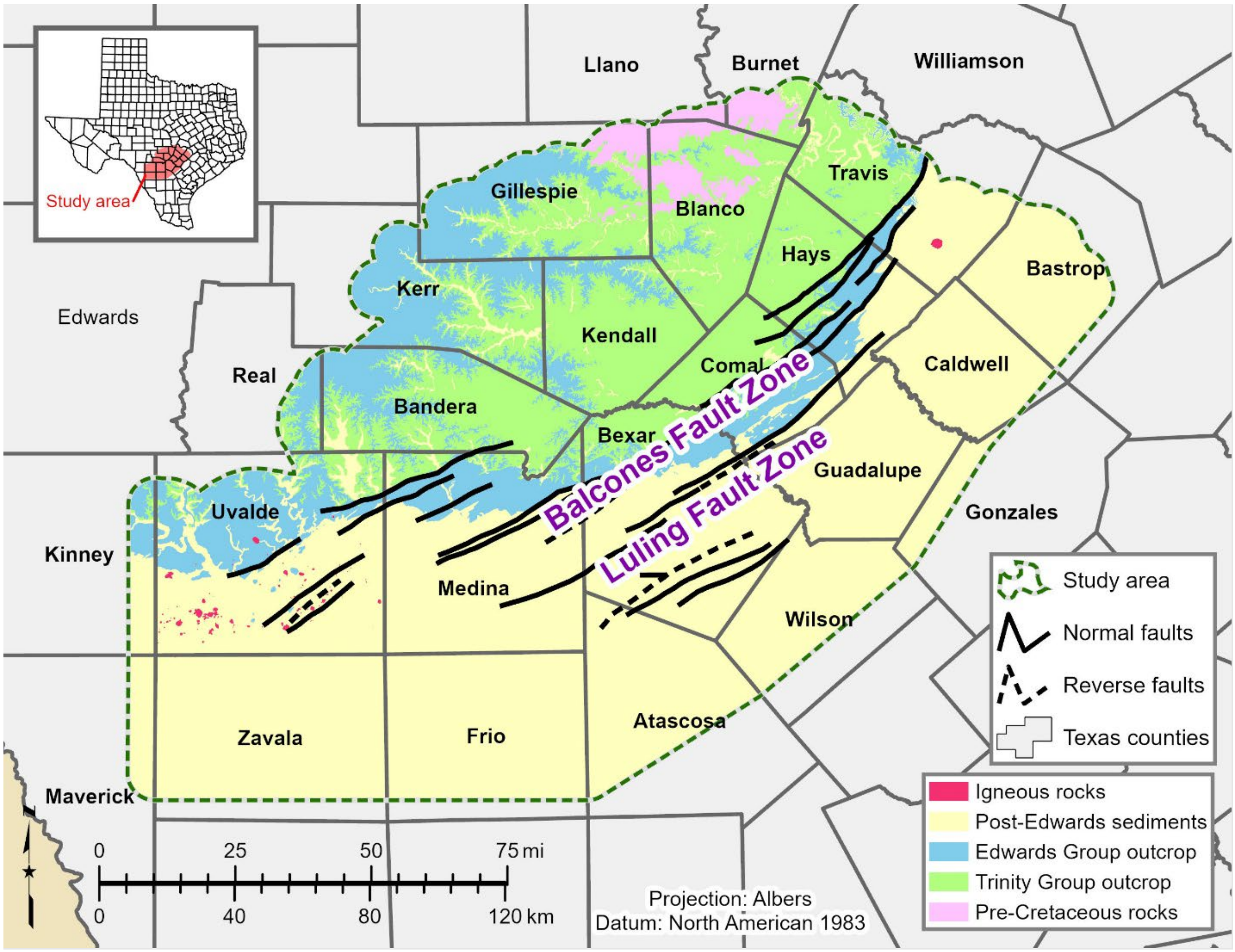

Figure 2. Southern portion of the Trinity Group simplified geologic setting (Geology from TWDB, 2007).

<table>
<tr><th>Era</th><th>System</th><th>Group</th><th colspan="2">Stratigraphic unit</th><th colspan="2">Hydrologic unit</th></tr>
<tr><td>Cenozoic</td><td>Quaternary</td><td></td><td colspan="2">Alluvium</td><td colspan="2">Alluvium</td></tr>
<tr><td rowspan="9">Mesozoic</td><td rowspan="9">Cretaceous</td><td rowspan="2">Edwards</td><td colspan="2">Segovia Formation</td><td colspan="2" rowspan="2">Edwards Group</td></tr>
<tr><td colspan="2">Fort Terrett Formation</td></tr>
<tr><td rowspan="7">Trinity</td><td rowspan="2">Glen Rose Limestone</td><td>Upper Member</td><td rowspan="7">Trinity Aquifer System</td><td>Upper Trinity</td></tr>
<tr><td>Lower Member</td><td rowspan="3">Middle Trinity</td></tr>
<tr><td colspan="2">Hensell Sand/Bexar Shale</td></tr>
<tr><td colspan="2">Cow Creek Limestone</td></tr>
<tr><td colspan="2">Hammett Shale</td><td>Confining unit</td></tr>
<tr><td colspan="2">Sligo Formation</td><td rowspan="2">Lower Trinity</td></tr>
<tr><td colspan="2">Sycamore Sand/Hosston Formation</td></tr>
<tr><td colspan="3">Paleozoic</td><td colspan="2">Undifferentiated Pre-Cretaceous rock</td><td colspan="2"></td></tr>
</table>

Figure 3. Stratigraphic and hydrostratigraphic column (from Jones and others, 2011).

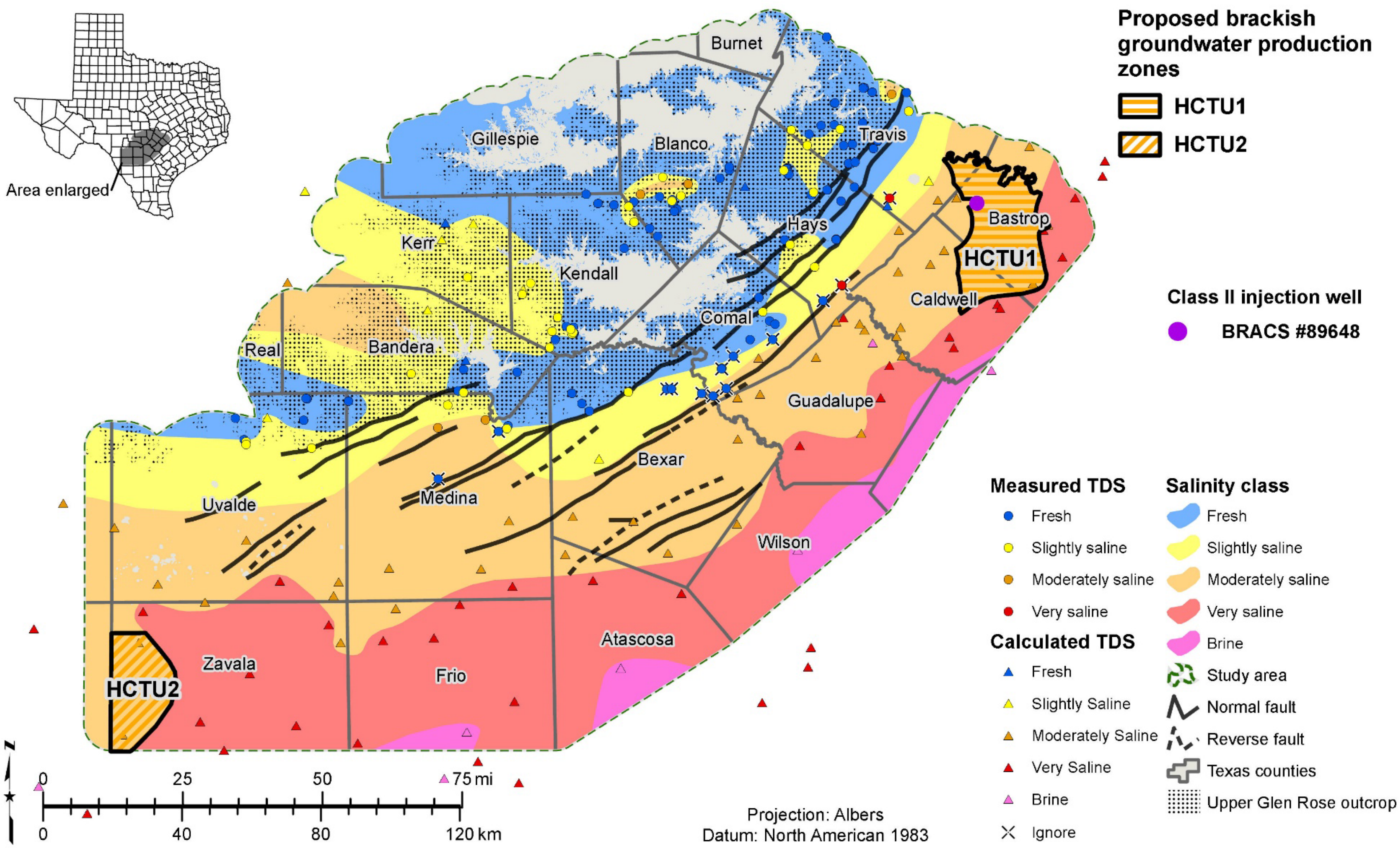

Figure 4. **Proposed brackish groundwater production zones, salinity classes, and well control for the upper Trinity aquifer (upper Glen Rose limestone).**

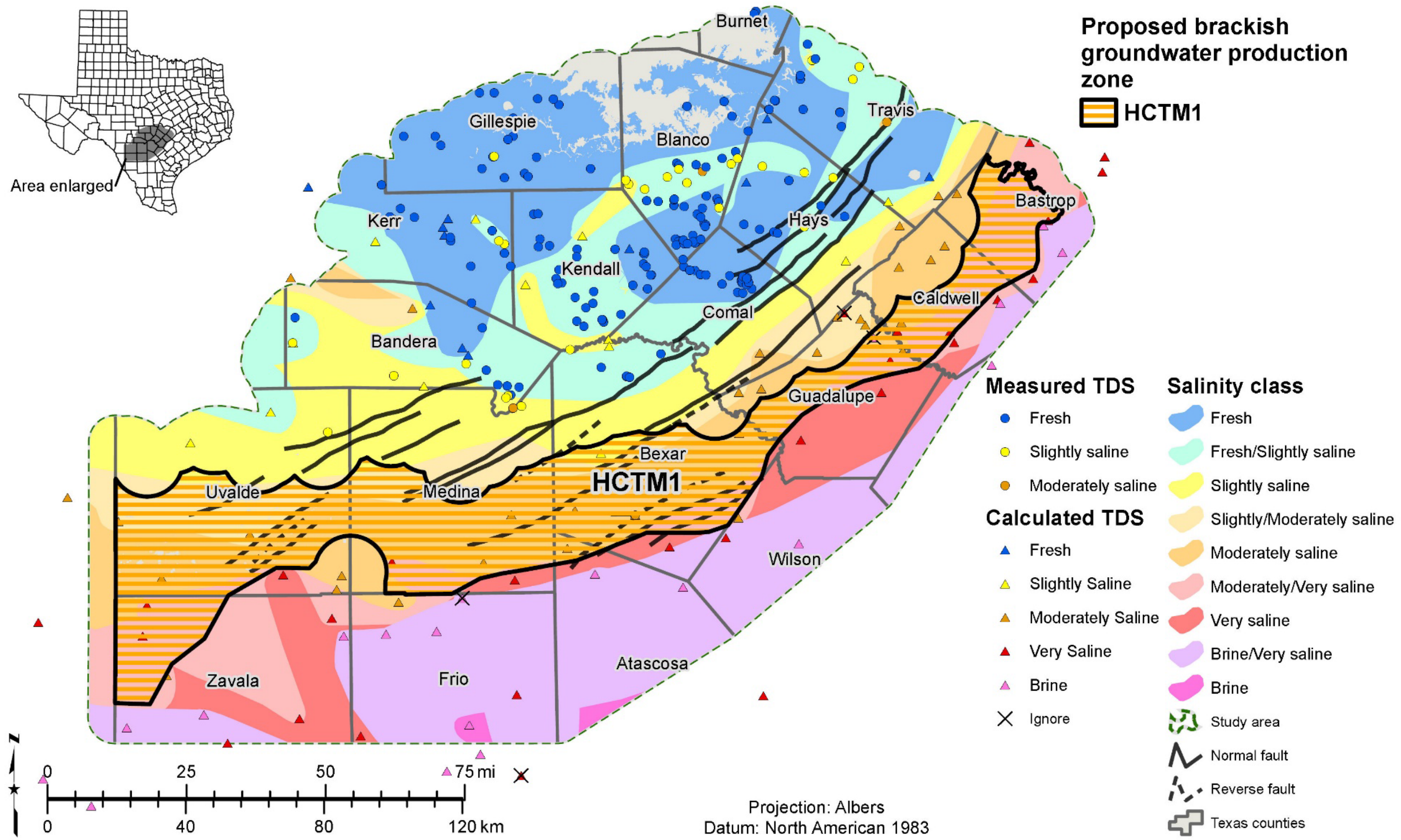

Figure 5. Proposed brackish groundwater production zone, salinity classes, and well control in the middle Trinity aquifer (lower Glen Rose limestone, Hensell sandstone, and Cow Creek limestone).

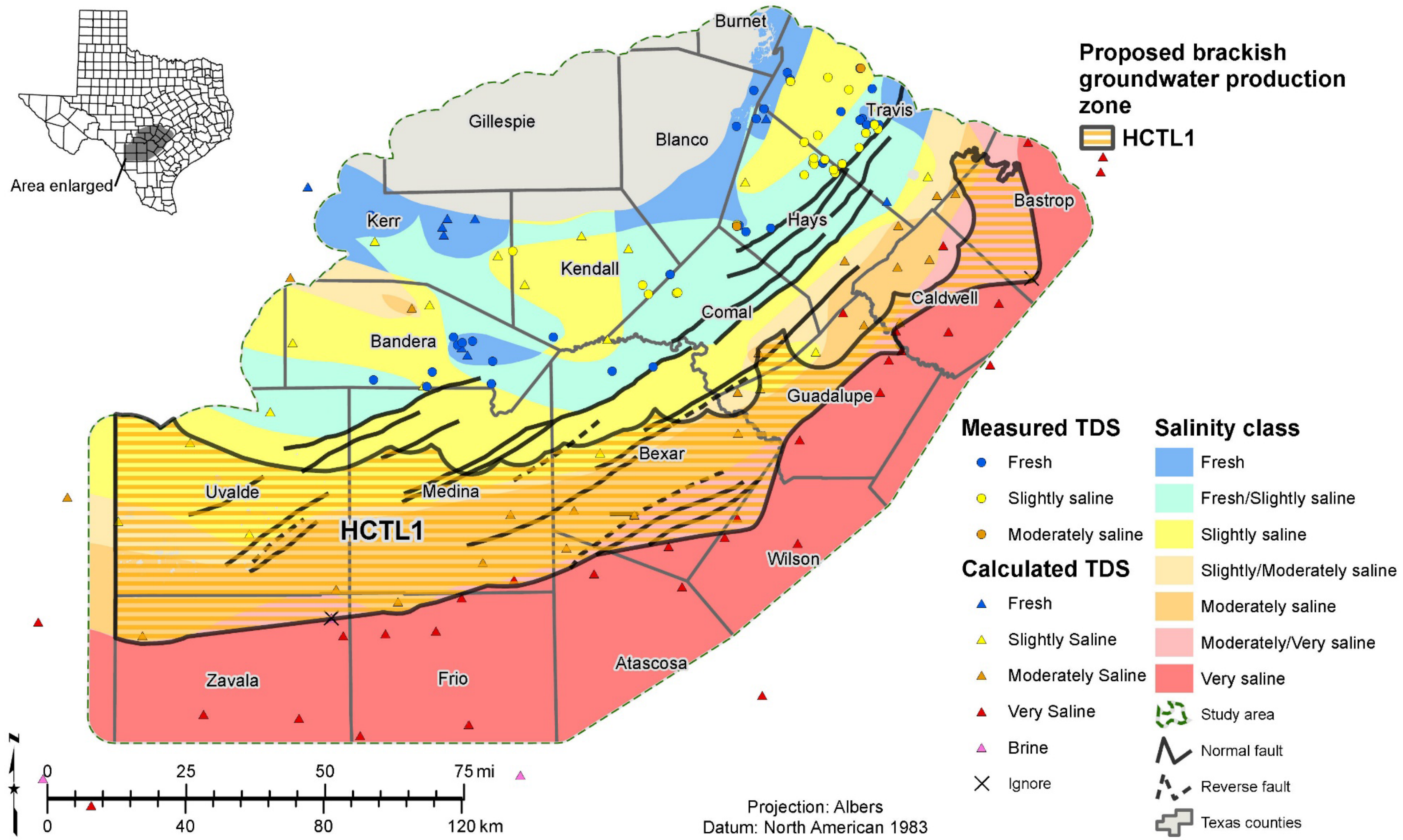

Figure 6. **Proposed brackish groundwater production zone, salinity classes, and well control in the lower Trinity (Sligo limestone, and Hosston sandstone).**

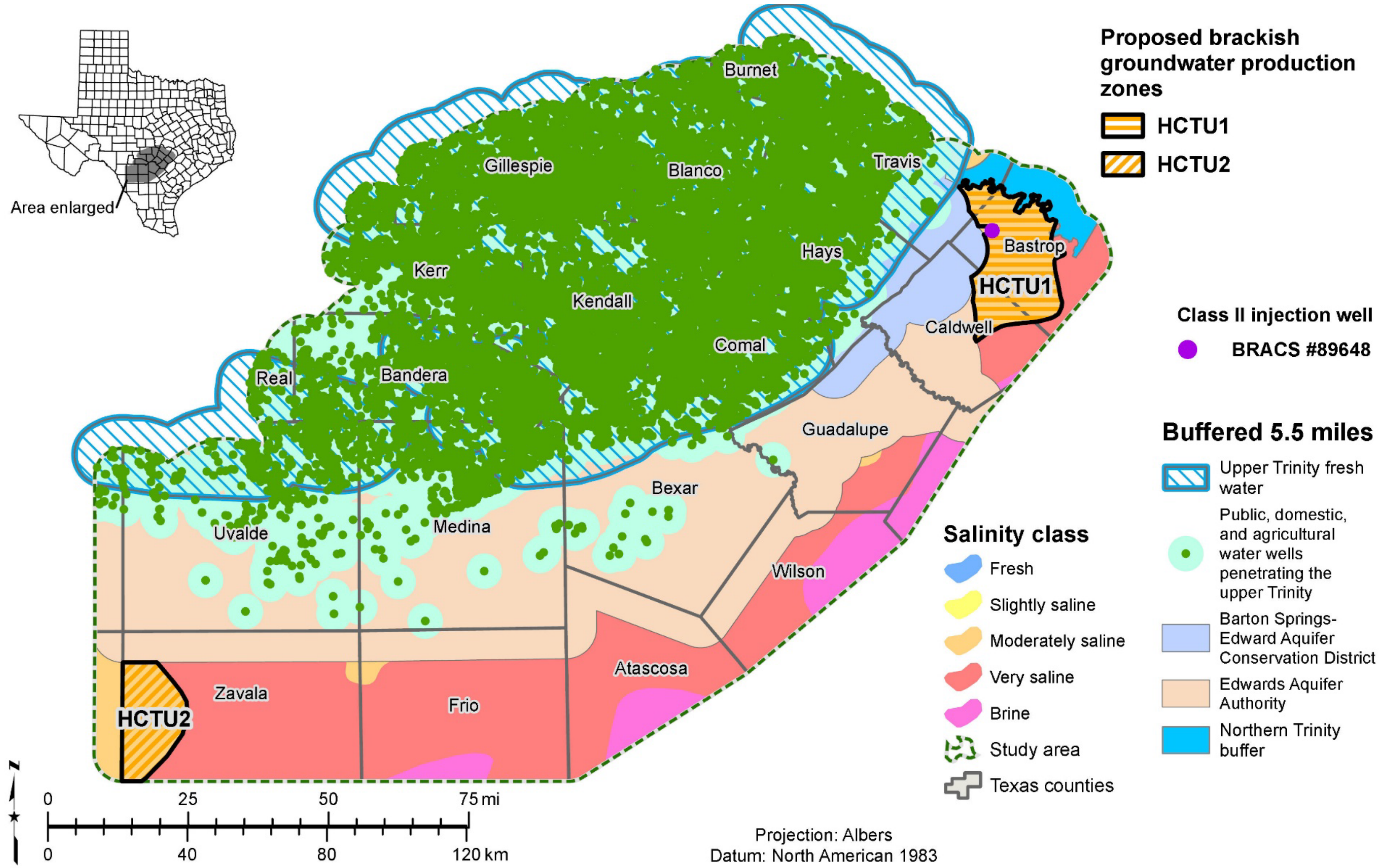

Figure 7. **Map showing the upper Trinity 5.5-mile buffer around fresh water, key water wells, Barton Springs-Edwards Aquifer Conservation District, and Edwards Aquifer Authority.**

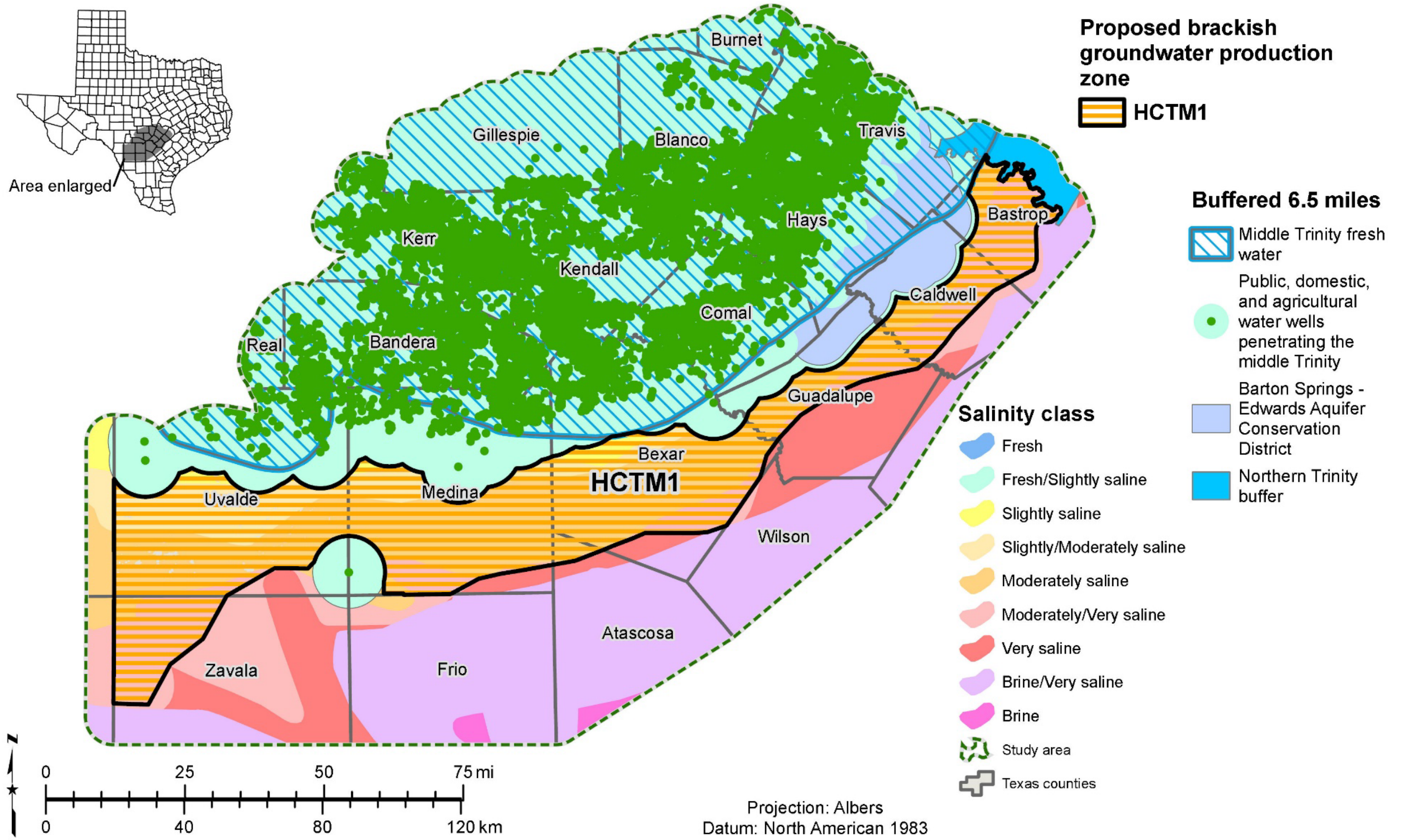

Figure 8. Map showing the middle Trinity 6.5-mile buffer around fresh water, key water wells, and Barton Springs-Edwards Aquifer Conservation District.

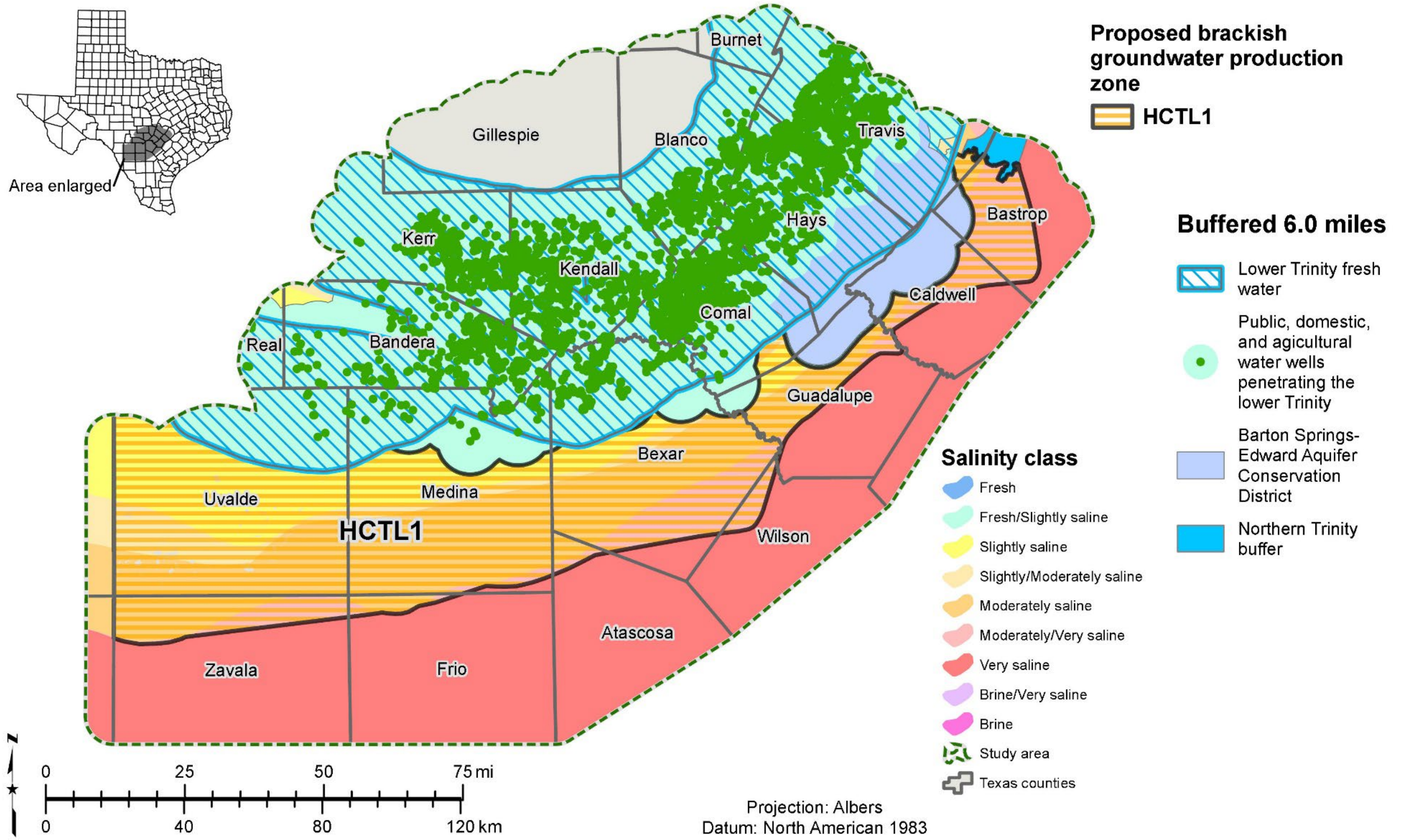

Figure 9. Map showing the lower Trinity 6.0-mile buffer around fresh water, key water wells, and Barton Springs-Edwards Aquifer Conservation District.

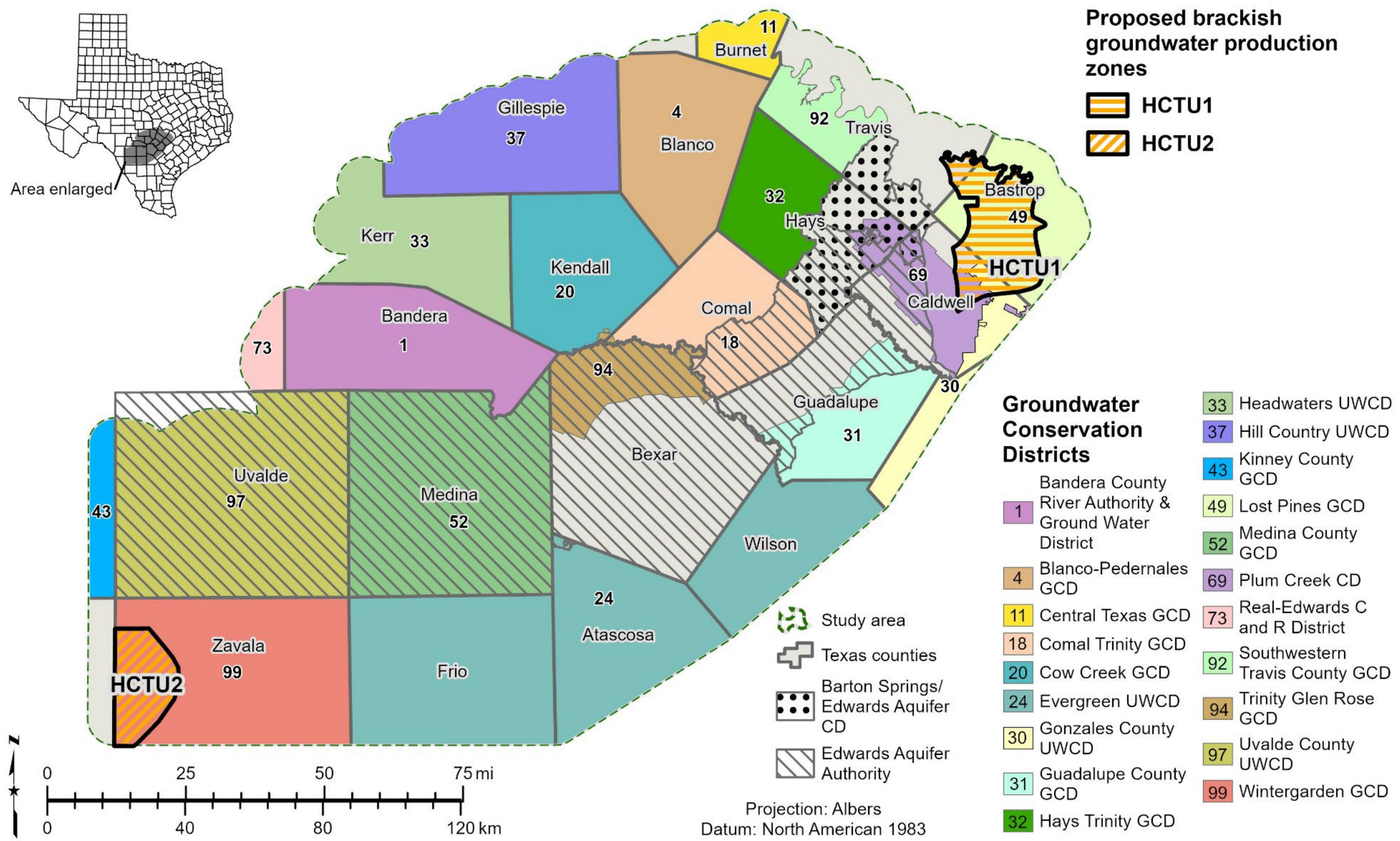

Figure 10. Upper Trinity aquifer proposed brackish groundwater production zones (HCTU1 and HCTU2) and groundwater conservation districts (GCDs).

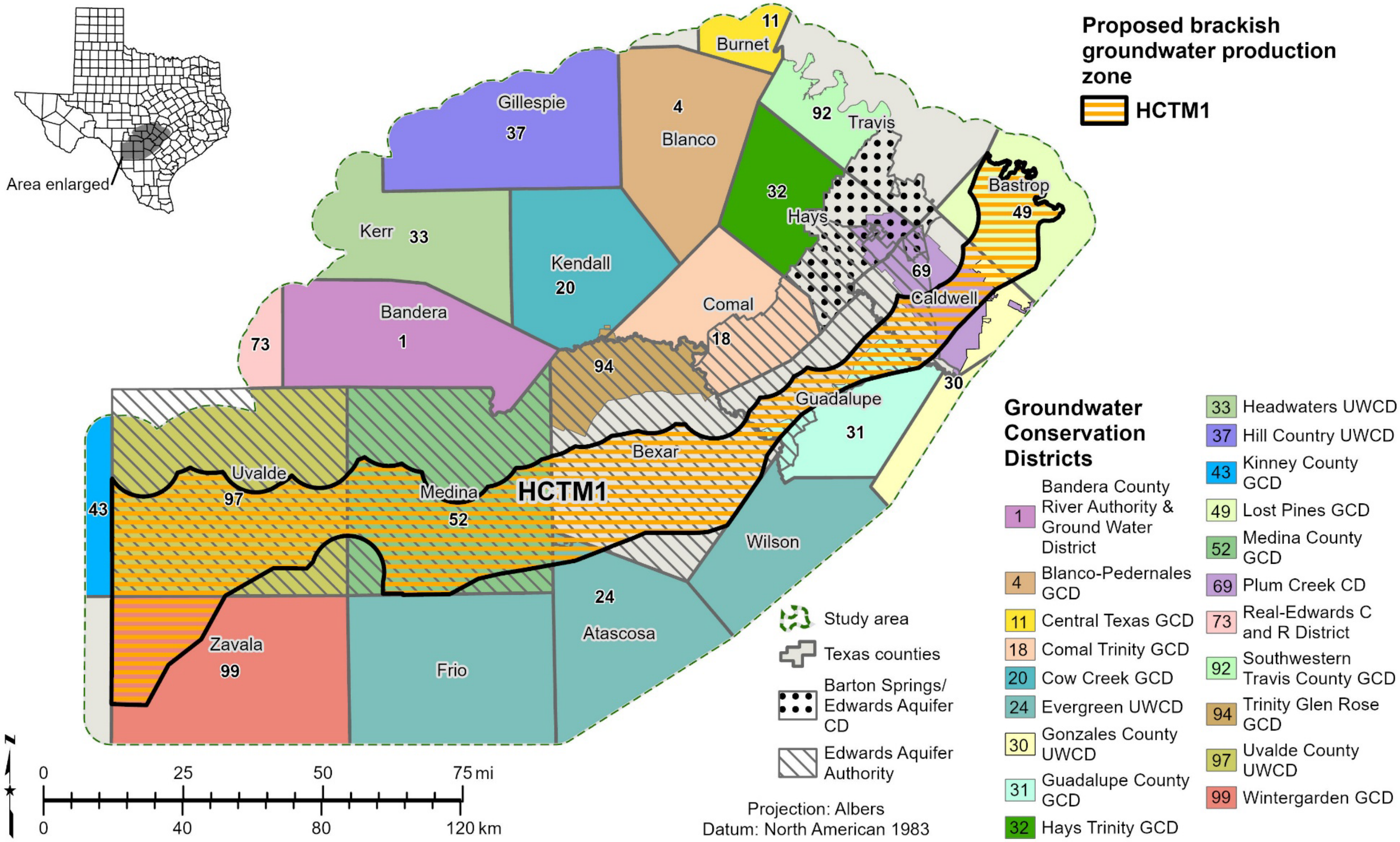

Figure 11. Middle Trinity aquifer proposed brackish groundwater production zone (HCTM1) and groundwater conservation districts (GCDs).

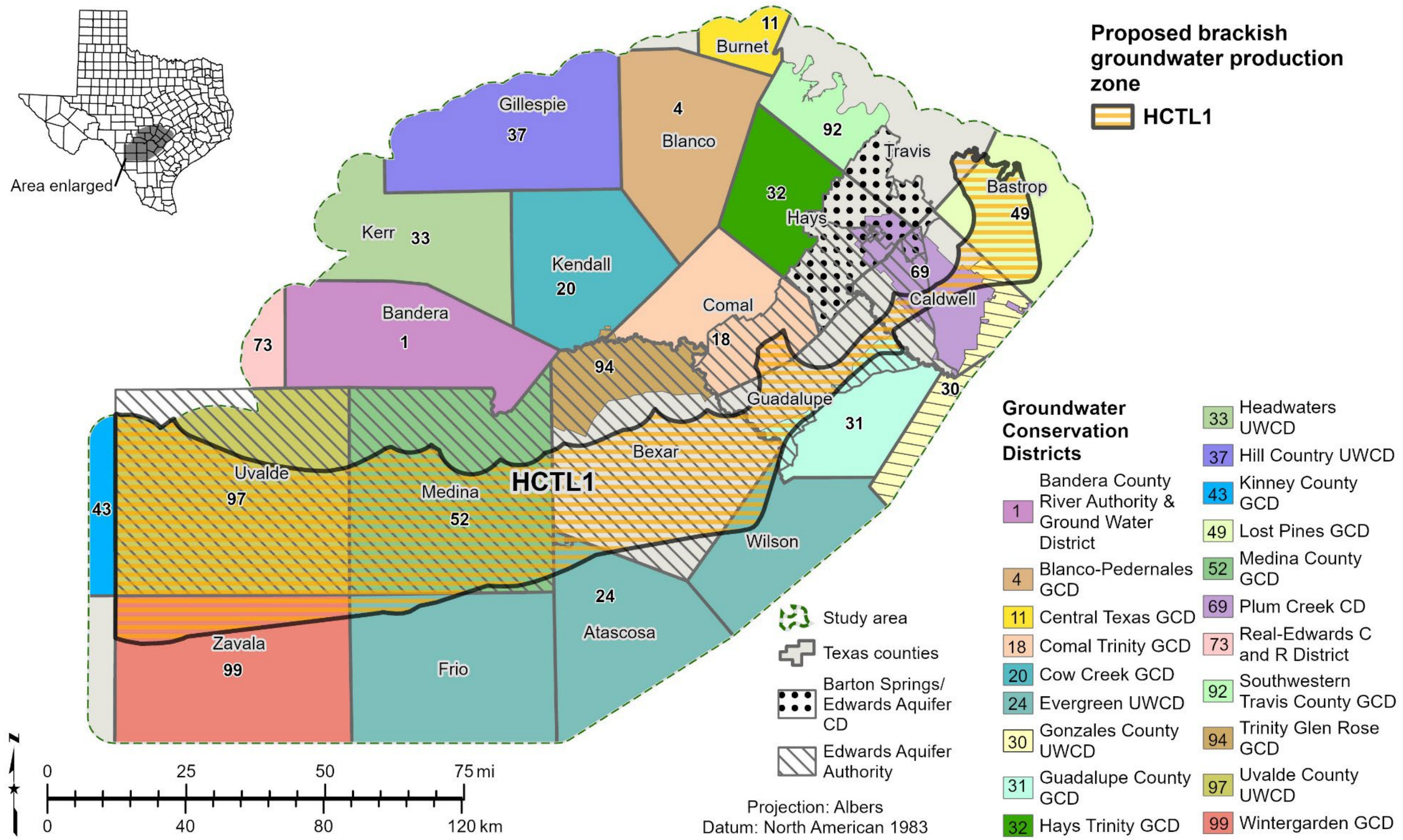

Figure 12. Lower Trinity aquifer proposed brackish groundwater production zone (HCTL1) and groundwater conservation districts (GCDs).

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Appendix A: Total in-place storage volumes

We used a 250-foot grid to calculate brackish groundwater volumes for total aquifer storage. We calculated both confined storage and unconfined drained storage for each of the three hydrologic units of the southern portion of the Trinity Aquifer: upper Trinity, middle Trinity, and lower Trinity. We calculated the unconfined drained groundwater storage and the confined groundwater storage using the methods demonstrated by Shi and others (2014).

We performed volume calculations using a Python script (Robinson and others, 2022), which processes the study area using 250-foot by 250-foot grid cells and multiplies them by the interval thickness to derive total grid cell volume. Each grid cell volume is then 1) multiplied by specific yield to get drainable (unconfined) volume and 2) multiplied by water-level head and storativity to get confined volume. The sum of the confined and drainable volumes represents groundwater storage for the grid cell. The script then uses ArcGIS to identify grid cells located in the proposed brackish groundwater production zones. The process is applied to each of the three Trinity Aquifer intervals.

All data used in the calculations are from Robinson and others (2022). We used the three static water level surfaces developed for the study and four of the raster surfaces created for the study to define the three Trinity Aquifer intervals used in this report (Figure 3). The raster surface for the top of the upper Glen Rose limestone was used to define the top of the upper Trinity. The raster surface for the top of the lower Glen Rose limestone was used as the base of the upper Trinity and the top of the middle Trinity. The raster surface for the top of the Hammett shale was used as the base of the middle Trinity. The raster surface for the top of the Sligo limestone was used for the top of the lower Trinity and the raster surface for the base of the Cretaceous was used as the base of the lower Trinity.

Total in-place groundwater volumes were calculated for those portions of the Trinity Aquifer located within the boundaries of the proposed brackish groundwater production zones. Table A1 shows the aquifer storage properties used in volume calculations. Aquifer storage properties were determined from both core analyses (Standen and Murphy, 2021) and published aquifer tests.

Table A1. Specific yield and storativity values used for volume calculations (from Robinson and others [2022]).

Hydrogeologic unit	Specific yield unconfined (unitless)	Specific yield confined (unitless)	Storativity (unitless)
Upper Trinity	0.054	0.027	1.7x10-4
Middle Trinity	0.108	0.054	1.5x10-4
Lower Trinity	0.120	0.060	3.2x10-4

Table A2 shows the total in-place groundwater volume in each zone by salinity class. The upper Trinity zones contain only moderately saline groundwater (3,000 to 9,999 milligrams per liter total dissolved solids). The middle and lower Trinity zones contain slightly saline groundwater (1,000 to 2,999 milligrams per liter of total dissolved solids), moderately saline groundwater (3,000 to 9,999 milligrams per liter total dissolved solids), and mixed salinity groundwater.

Table A2. Volume of total in-place groundwater in the proposed brackish groundwater production zones for the southern portion of the Trinity Aquifer. Volumes are in acre-feet.

Proposed brackish groundwater production zone	SS	SS-MS	MS	MS-VS	Total
HCTU1	-	-	3,984,000	-	3,579,000
HCTU2	-	-	3,579,000	-	3,984,000
HCTM1	1,624,000	10,974,000	39,068,000	24,211,000	75,877,000
HCTL1	28,542,000	11,393,000	78,262,000	35,832,000	154,029,000
Total	30,166,000	22,367,000	124,893,000	60,043,000	237,469,000

Notes:

Volumes are rounded to the nearest 1,000-acre-foot.

SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids

Tables A3 through A6 show the volumes by salinity class and county. The proposed brackish groundwater production zone with the largest calculated volume is HCTL1 with a volume of more than 154 million acre-feet. Uvalde County has the greatest calculated total volume of more than 66 million acre-feet, of which almost 19 million acre-feet is classified as slightly saline groundwater (1,000 to 2,999 milligrams per liter).

Table A3. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTU1 (upper Trinity). Data organized by county and salinity. Volumes are in acre-feet.

County	SS	SS-MS	MS	MS-VS	Total
Bastrop	-	-	3,001,000	-	3,001,000
Caldwell	-	-	772,000	-	772,000
Travis	-	-	211,000	-	211,000
Total	-	-	3,984,000	-	3,984,000
Percent	-	-	100.0%	-	100.0%

Notes:
Volumes are rounded to the nearest 1,000-acre-foot.
SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids

Table A4. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTU2 (upper Trinity). Data organized by county and salinity. Volumes are in acre-feet.

County	SS	SS-MS	MS	MS-VS	Total
Zavala	-	-	3,579,000	-	3,579,000
Total	-	-	3,579,000	-	3,579,000
Percent	-	-	100.0%	-	100.0%

Notes:
Volumes are rounded to the nearest 1,000-acre-foot.
SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids

Table A5. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTM1 (middle Trinity). Data organized by county and salinity. Volumes are in acre-feet.

County	SS	SS-MS	MS	MS-VS	Total
Atascosa	-	-	665,000	101,000	766,000
Bastrop	-	-	706,000	3,396,000	4,102,000
Bexar	976,000	1,145,000	9,751,000	2,209,000	14,081,000
Caldwell	-	-	1,278,000	2,641,000	3,919,000
Guadalupe	-	-	2,384,000	1,353,000	3,737,000
Medina	206,000	1,949,000	12,028,000	2,388,000	16,571,000
Uvalde	442,000	7,880,000	11,475,000	1,063,000	20,860,000
Zavala	-	-	781,000	11,060,000	11,841,000
Total	1,624,000	10,974,000	39,068,000	24,211,000	75,877,000
Percent	2.1%	14.5%	51.5%	31.9%	100.0%

Notes:

Volumes are rounded to the nearest 1,000-acre-foot.

SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids

Table A6. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTL1 (lower Trinity). Data organized by county and salinity. Volumes are in acre-feet.

County	SS	SS-MS	MS	MS-VS	Total
Atascosa	-	-	1,054,000	735,000	1,789,000
Bastrop	-	-	443,000	8,811,000	9,254,000
Bexar	2,644,000	1,287,000	12,437,000	9,822,000	26,190,000
Caldwell	-	-	394,000	3,584,000	3,978,000
Comal	404,000	111,000	147,000	-	662,000
Frio	-	-	2,420,000	1,175,000	3,595,000
Guadalupe	663,000	214,000	4,528,000	1,038,000	6,443,000
Medina	6,733,000	2,099,000	26,664,000	1,556,000	37,052,000
Travis	-	49,000	542,000	-	591,000
Uvalde	18,098,000	7,633,000	19,507,000	143,000	45,381,000
Wilson	-	-	-	2,187,000	2,187,000
Zavala	-	-	10,126,000	6,781,000	16,907,000
Total	28,542,000	11,393,000	78,262,000	35,832,000	154,029,000
Percent	18.5%	7.4%	50.8%	23.3%	100.0%

Notes:

Volumes are rounded to the nearest 1,000-acre-foot.

SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids

We also calculated the total in-place volume of groundwater for conservation districts that were intersected by the proposed brackish groundwater production zones. Tables A7 through A10 show the volumes by salinity class and groundwater conservation district.

Table A7. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTU1 (upper Trinity). Data organized by groundwater conservation district and salinity class. Volumes are in acre-feet.

Groundwater conservation district	SS	SS-MS	MS	MS-VS	Total
GCUWCD	-	-	278,000	-	278,000
LPGCD	-	-	3,000,000	-	3,000,000
PCCD	-	-	307,000	-	307,000
No GCD	-	-	399,000	-	399,000
Total	-	-	3,984,000	-	3,984,000
Percent	-	-	100.0%	-	100.0%

Notes:
Volumes are rounded to the nearest 1,000-acre-foot.
SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids
GCUWCD = Gonzales County Underground Water Conservation District
LPGCD = Lost Pines Groundwater Conservation District
PCCD = Plum Creek Conservation District

Table A8. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTU2 (upper Trinity). Data organized by groundwater conservation district and salinity class. Volumes are in acre-feet.

Groundwater conservation district	SS	SS-MS	MS	MS-VS	Total
WGCD	-	-	3,579,000	-	3,579,000
Total	-	-	3,579,000	-	3,579,000
Percent	-	-	100.0%	-	100.0%

Notes:
Volumes are rounded to the nearest 1,000-acre-foot.
SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids
WGCD = Wintergarden Groundwater Conservation District

Table A9. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTM1 (middle Trinity). Data organized by groundwater conservation district and salinity class. Volumes are in acre-feet.

Groundwater conservation district	SS	SS-MS	MS	MS-VS	Total
EUWCD	-	-	667,000	102,000	769,000
GCGCD	-	-	485,000	1,042,000	1,527,000
GCUWCD	-	-	-	377,000	377,000
LPGCD	-	-	706,000	3,396,000	4,102,000
MCGCD	206,000	1,949,000	12,028,000	2,388,000	16,571,000
PCCD	-	-	727,000	1,471,000	2,198,000
UCUWCD	442,000	7,880,000	11,475,000	1,063,000	20,860,000
WGCD	-	-	781,000	11,061,000	11,842,000
No GCD	976,000	1,145,000	12,199,000	3,311,000	17,631,000
Total	1,624,000	10,974,000	39,068,000	24,211,000	75,877,000
Percent	2.1%	14.5%	51.5%	31.9%	100.0%

Notes:

Volumes are rounded to the nearest 1,000-acre-foot.

SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids
EUWCD = Evergreen Underground Water Conservation District
GCGCD = Guadalupe County Groundwater Conservation District
GCUWCD = Gonzales County Underground Water Conservation District
LPGCD = Lost Pines Groundwater Conservation District
MCGCD = Medina County Groundwater Conservation District
PCCD = Plum Creek Conservation District
UCUWCD = Uvalde County Underground Water Conservation District
WGCD = Wintergarden Groundwater Conservation District

Table A10. Volume of total in-place groundwater in proposed brackish groundwater production zone HCTL1 (lower Trinity). Data organized by groundwater conservation district and salinity class. Volumes are in acre-feet.

Groundwater conservation district	SS	SS-MS	MS	MS-VS	Total
CoTGCD	370,000	111,000	147,000	-	628,000
EUWCD	-	-	3,474,000	4,097,000	7,571,000
GCGCD	-	-	771,000	942,000	1,713,000
GCUWCD	-	-	-	767,000	767,000
LPGCD	-	-	443,000	8,811,000	9,254,000
MCGCD	6,726,000	2,099,000	26,664,000	1,556,000	37,045,000
PCCD	-	-	110,000	1,895,000	2,005,000
UCUWCD	18,098,000	7,633,000	19,506,000	143,000	45,380,000
WGCD	-	-	10,126,000	6,781,000	16,907,000
No GCD	3,348,000	1,550,000	17,021,000	10,840,000	32,759,000
Total	28,542,000	11,393,000	78,262,000	35,832,000	154,029,000
Percent	18.5%	7.4%	50.8%	23.3%	100.0%

Notes:

Volumes are rounded to the nearest 1,000-acre-foot.

SS (Slightly saline) = 1,000 to 2,999 milligrams per liter total dissolved solids
SS-MS = area with a mix of slightly and moderately saline measurements and calculations
MS (Moderately saline) = 3,000 to 9,999 milligrams per liter total dissolved solids
MS-VS = area with a mix of moderate and very saline measurements and calculations
VS (Very saline) = 10,000 to 35,000 milligrams per liter total dissolved solids
CoTGCD = Comal Trinity Groundwater Conservation District
EUWCD = Evergreen Underground Water Conservation District
GCGCD = Guadalupe County Groundwater Conservation District
GCUWCD = Gonzales County Underground Water Conservation District
LPGCD = Lost Pines Groundwater Conservation District
MCGCD = Medina County Groundwater Conservation District
PCCD = Plum Creek Conservation District
UCUWCD = Uvalde County Underground Water Conservation District
WGCD = Wintergarden Groundwater Conservation District

Note that the calculated volumes do not consider the effects of land surface subsidence, degradation of water quality, or any changes to groundwater-surface water interaction that may result from extracting groundwater from the aquifer. These volumes should not be used for joint groundwater planning or evaluation of achieving adopted desired future conditions in the same way total estimated recoverable storage (TERS) and modeled available groundwater (MAG) are used according to the joint planning process described in Texas Water Code §36.108. Volumes calculated for brackish aquifer studies in the BRACS Program differ from TERS volumes determined by the TWDB Groundwater Modeling Program (Wade and Bradley, 2013; Shi and others, 2014) because of differences in the area, saturated thickness, and storage parameters used in the calculations.