Identification of Potential Brackish Groundwater Production Areas - Blossom Aquifer

TWDB Contract Number 1600011951

Prepared By:

LBG-Guyton Associates

July 2017

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TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

1. Executive Summary

House Bill 30 was passed in 2015 by the 84th Texas Legislature with a goal to identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability of brackish groundwater that can be used to reduce the use of fresh groundwater. The goal of these studies is to identify potential production areas that can provide brackish water over a 30 to 50-year time period using the draft Blossom Aquifer Groundwater Availability Model and the application of best available science.

A potential production area may only exist in a location that meets the criteria of House Bill 30. House Bill 30 states that these areas:

- Are separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability or water quality in any area of the same or other aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids level of 1,000 milligrams per liter or less at the time of designation of the zones.
- Are not located in an aquifer, subdivision of an aquifer, or geologic stratum that has an average total dissolved solids level of less than 1,000 milligrams per liter and is serving as a significant source of water supply for municipal, domestic, or agricultural purposes at the time of designation of the zones, or in an area of a geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Chapter 27.
- Are not located in an area of the Edwards Aquifer subject to the jurisdiction of the Edwards Aquifer Authority; the boundaries of the Barton Springs-Edwards Aquifer Conservation District; the Harris-Galveston Subsidence District; or the Fort Bend Subsidence District.

Using the exclusion criteria stated in House Bill 30, three potential production areas were delineated in areas outlying the excluded areas. Potential pumping volumes from the potential production areas were estimated using low, medium and high volume pumping scenarios assuming both 30 and 50 years of production. The pumping rates selected for the Blossom Aquifer are 50, 100, and 300 acre-feet per year. Theis drawdown analysis was performed for the three potential production areas to understand the effect pumping in these areas would have on existing exclusion criteria. The resulting drawdown impact on the nearest downdip extent of the aquifer ranges from less than one foot (pumping 50 acre-feet per year for 30 years) to 12 feet (pumping 300 acre-feet per year for 50 years). Potential production area 1 appears to have the least impact to up-dip exclusion wells with less than one to ten feet of drawdown. No volumes were calculated for the production areas.

A volumetric analysis was also performed to estimate volumes in the Blossom Aquifer based upon salinity zone classifications. The volumes represent in-place volumes (groundwater in storage) within the project area, not recoverable volumes (groundwater that may be realistically produced from the aquifer) and are included in Table 1-1. These volume estimates evaluate the basal sand only. The in-place, slightly saline (1,000- 3,000 milligrams per liter of total dissolved solids) groundwater volume was estimated to be 529,247 acre-feet. The moderately saline (3,000- 10,000 milligrams per liter of total dissolved solids) groundwater volume was estimated at 1,268,483 acre-feet.

Table 1-1. Estimates of Blossom Aquifer brackish groundwater volumes (all units are in acre-feet).

Zone/ County	Lamar	Red River	Bowie	Delta	Titus	Frank-lin	Hop-kins	Total	Percent
Fresh	254,050	305,619						559,669	18%
Slightly Saline	127,769	387,087		14,391				529,247	17%
Moderately Saline	217,741	554,104	289,029	149,943	18,603	19,216	19,847	1,268,483	41%
Very Saline	10,975	279,650	362,694	31,349	14,844			699,512	23%
Total	610,535	1,526,460	651,723	195,683	33,447	19,216	19,847	3,056,911	100%

2. Introduction

House Bill 30 was passed in 2015 by the 84th Texas Legislature with a goal to identify and designate local or regional brackish groundwater production zones in areas of the state with moderate to high availability of brackish groundwater that can be used to reduce the use of fresh groundwater. This legislation was driven by the recent severe drought coupled with continuous population growth in Texas.

The first four aquifers to be evaluated include: the Carrizo-Wilcox Aquifer within GMA-13 (between the Colorado River and the Rio Grande), the Blaine, Rustler, and Gulf Coast Aquifers. These aquifer studies were finalized in August 2016. Evaluations for three additional aquifers – (Blossom, Nacatoch and Trinity) must be completed by August 2017. Any other aquifers with potential brackish production zones need to be evaluated by December 1, 2022.

The Blossom Aquifer is located in northeast Texas with an outcrop area that trends generally west to east across Lamar, Red River and Bowie Counties (Figure 2-1). The project area for the Blossom Aquifer includes the downdip portion of the Blossom Formation that is estimated to have a total dissolved solids concentration up to 10,000 milligrams per liter. This area incorporates all of the geophysical log locations that were analyzed for water quality estimates. The project area encompasses 1,850 square miles and extends south of the Blossom outcrop through southern Lamar County into the northern portion of Delta County, to the southern Red River County line, and across the northwestern quadrant of Bowie County. The boundary is shown in Figure 2-1.

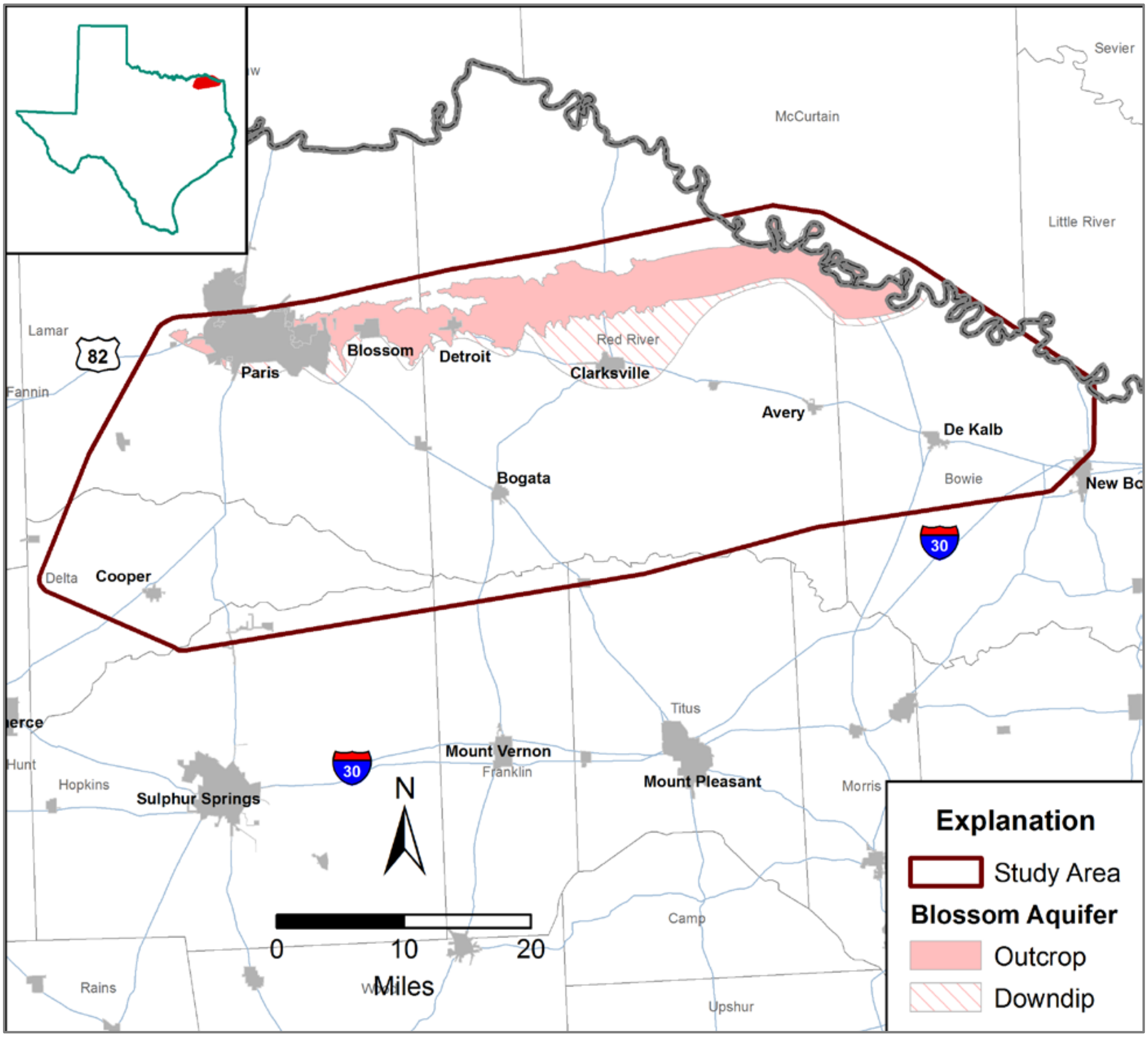

Figure 2-1. **Project area.**

3. Project Deliverables

Project deliverables include: this report, an ArcGIS geodatabase, and geophysical log metadata to be uploaded to the BRACS database. Data used for the completion of this project includes: water quality analytical data, geophysical logs, and water well reports from multiple sources. No geophysical logs or water quality results were used for this project from sources other than the TWDB, therefore none are provided with this project as a deliverable.

Metadata from geophysical log analyses have been provided in the BRACS database format that is structurally identical to Meyer (2014). The applicable source data has been integrated within an ESRI geodatabase format consistent with the TWDB's standard data model framework for delivery.

The results and evaluation of these data are discussed in this report. Any data that was incorporated into the results of this study have been provided to the TWDB with this report. This aquifer does not presently have an official groundwater availability model; therefore, volumetric analyses were performed using a preliminary draft version of the future groundwater model and best available science.

4. Project Area

The project area for the Blossom Aquifer includes the downdip portion of the Blossom Formation that is estimated to have a total dissolved solids concentration up to 10,000 milligrams per liter. This area incorporates all of the geophysical log locations that were analyzed for water quality estimates and has an area of 1,850 square miles. The City of Clarksville and the Red River County WCS both rely on the Blossom Aquifer for a portion of their municipal water supply. The City of Paris is located on the Blossom outcrop but relies upon surface water for municipal supply, according to the Texas Commission on Environmental Quality's Texas Drinking Water Watch database (TCEQ, 2016).

The Blossom Aquifer is located in the Blackland Prairie province (BEG, 1996). The Blackland Prairie province is characterized by low-rolling terrain with a dominant vegetation of short or bunch grass. An east-west trending ridge is the dominant land feature in this area, and divides surface drainage between the Red River basin to the north and the Sulphur River basin to the south (McLaurin, 1988). Precipitation in the outcrop area of the Blossom Aquifer averages about 47 inches annually (TWDB, 2016).

The width of the outcrop area ranges between one and six miles, with the narrowest outcrop in Fannin and western Lamar Counties. There is a layer of Quaternary alluvium overlying the Blossom Sand in easternmost Red River County and the outcrop of the aquifer does not extend eastward across the Red River into Bowie County.

The Blossom Aquifer is contained within Groundwater Management Area 8 (GMA-8) and Region D (North East Texas). There are no Groundwater Conservation Districts within the counties (Lamar, Red River and Bowie) that contain the Blossom Aquifer.

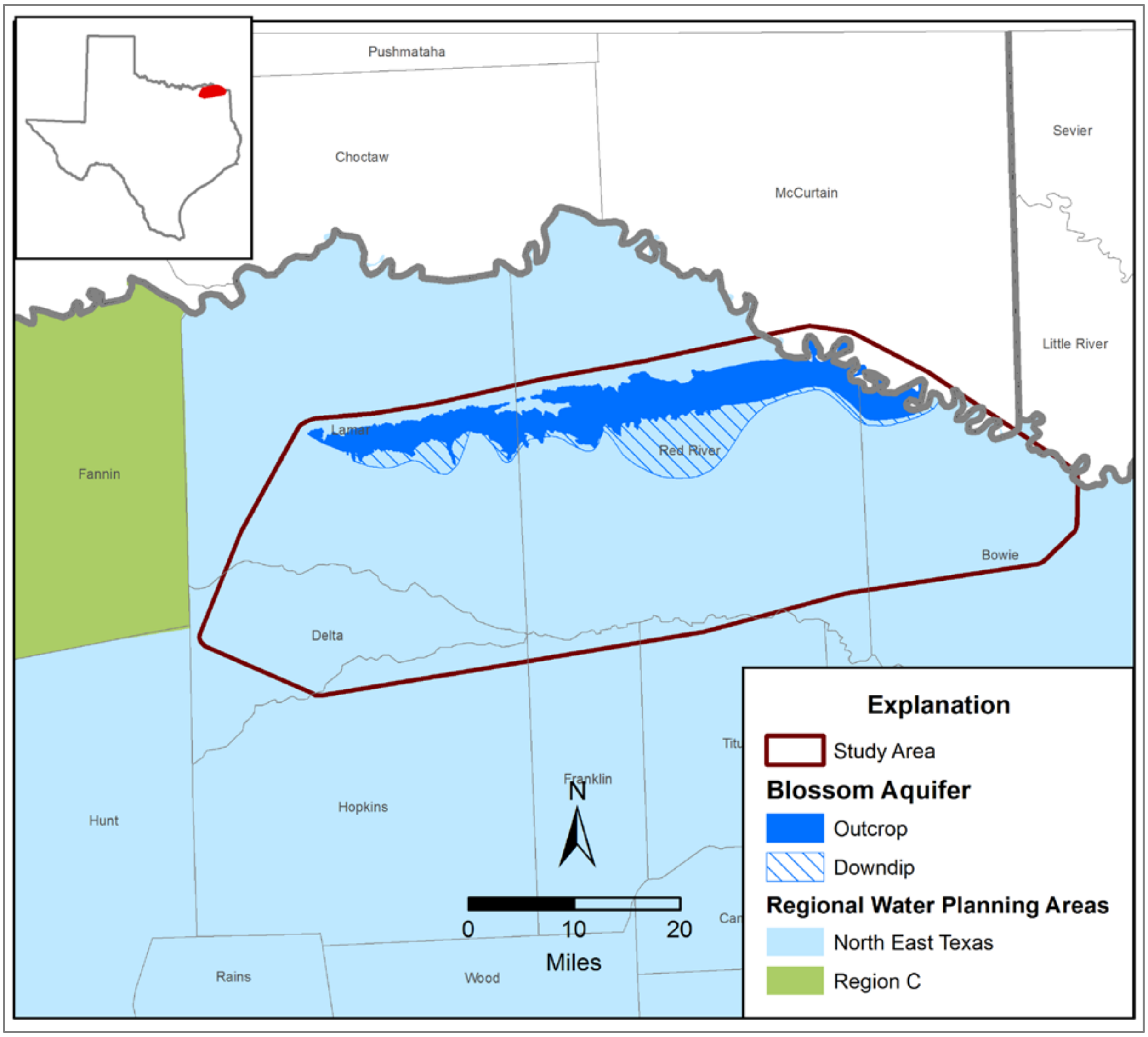

Figure 4-1. Regional water planning areas.

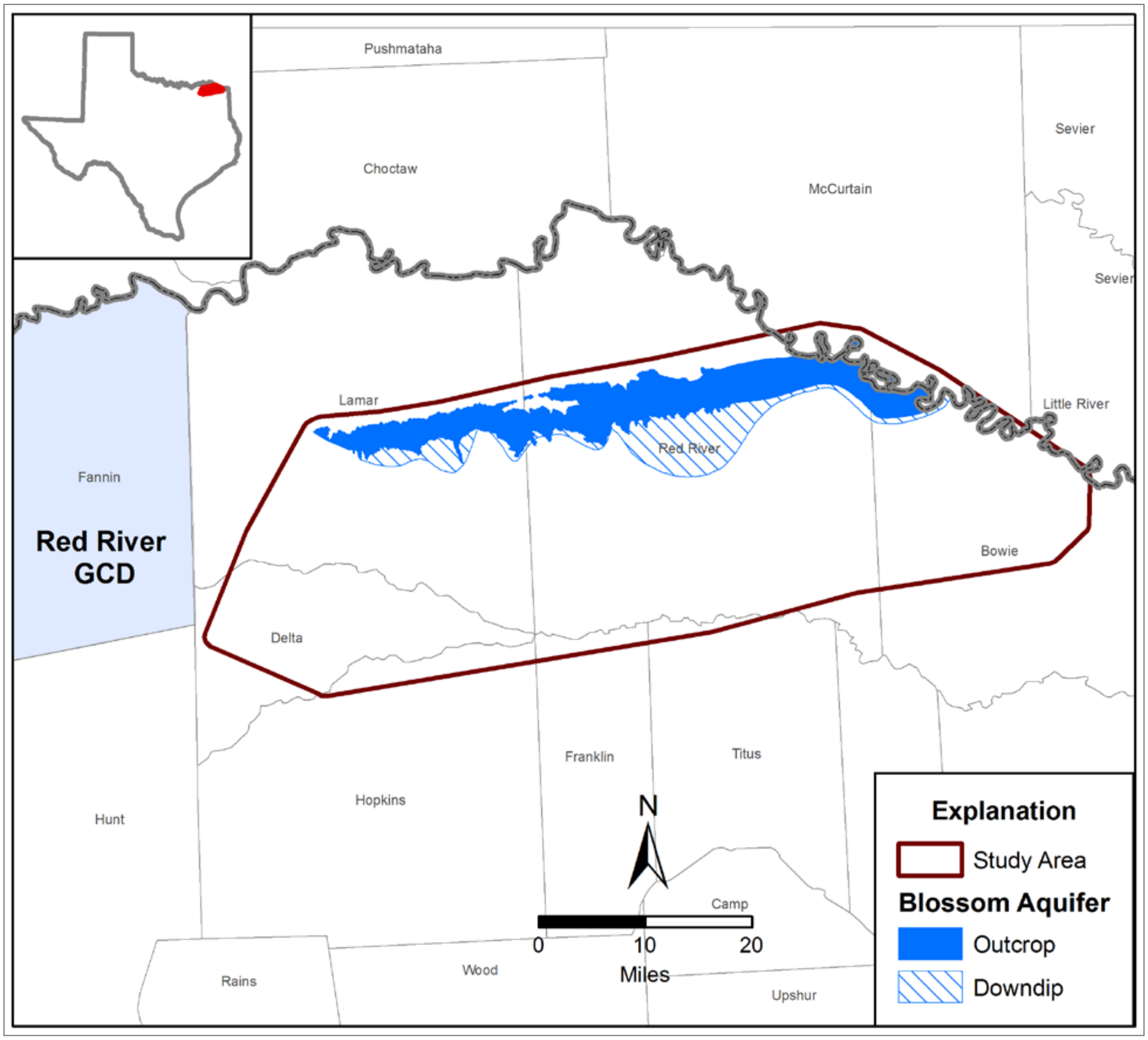

Figure 4-2. **Groundwater conservation districts.**

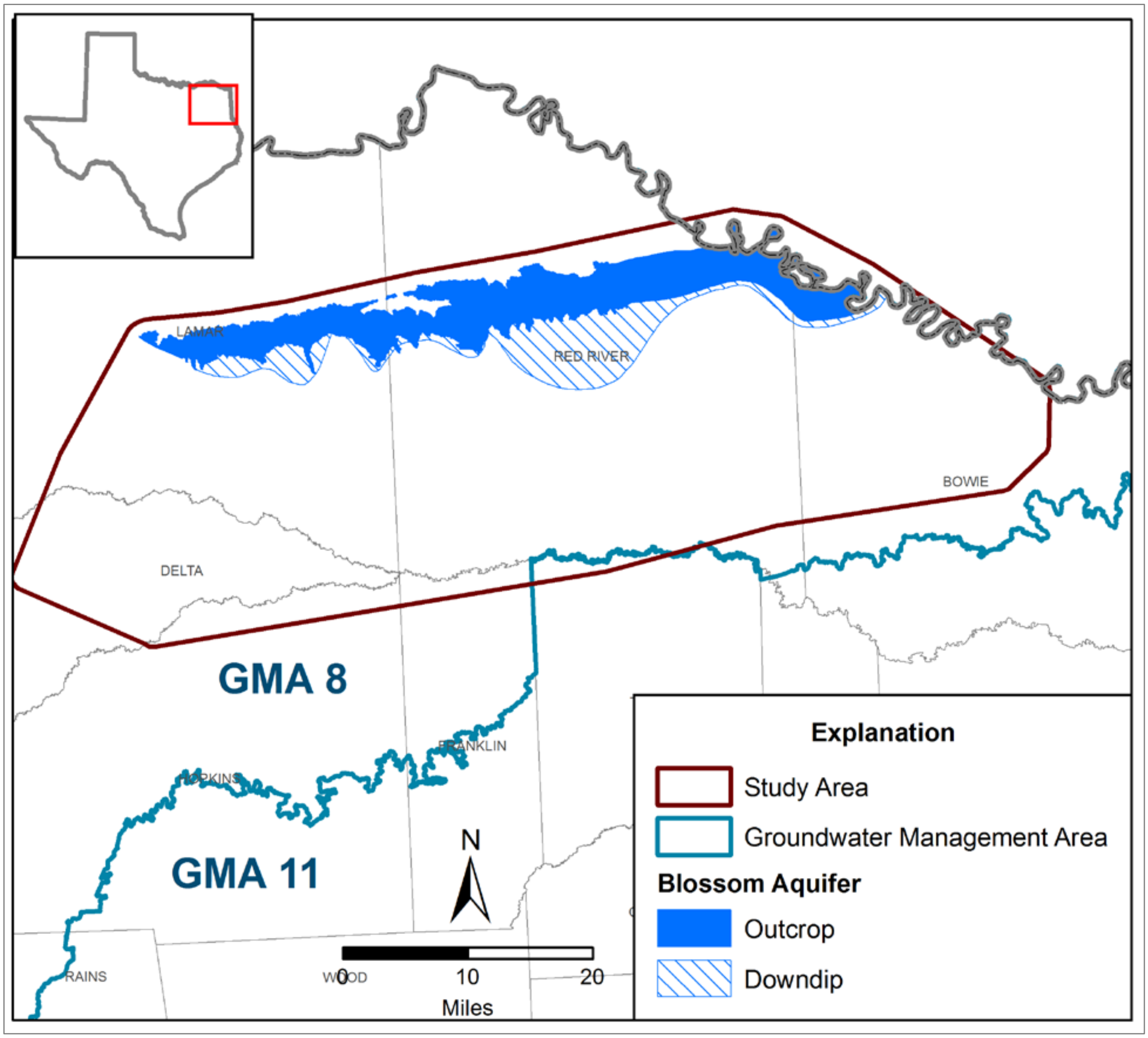

Figure 4-3. Groundwater management areas.

5. Hydrogeologic Setting

5.1. Geology

The Blossom Formation outcrops in a west –east trending belt across the middle of Fannin, Lamar, Red River, and Bowie Counties (Figure 5-1). The width of the outcrop area ranges between one and six miles, with the narrowest outcrop in Fannin and western Lamar Counties. There is a layer of Quaternary alluvium overlying the Blossom Sand in easternmost Red River County and the outcrop of the aquifer does not extend eastward across the Red River into Bowie County. On the western end of the outcrop, there is a facies change from sand to chalk and marl near the town of Bonham in central Fannin County.

The Blossom is primarily unconsolidated brown to light gray sandy, ferruginous, glauconitic beds interlaminated with thin beds of clay. Most of the formation is clay or marl and chalk, and less than 25 percent of the total thickness of the Blossom Formation consists of sand, with the thickest accumulations occurring at the top and the base of the formation, with essentially no hydrogeologic connectivity between them. The dip of the top of the formation averages about 95 feet per mile toward the south-southeast (Figure 5-2). Generally, the Mexia-Talco Fault Zone defines the southernmost extent of this study. The structure data were derived from the geophysical logs picks determined while estimating water quality.

The highest elevation of the top of the Blossom Formation within the outcrop is approximately 550 feet above mean sea level (amsl) in Red River County near the widest section of the outcrop. The lowest elevation of the top of the Blossom Formation identified in two logs is -1,800 feet above mean sea level near the Red River-Titus County line (northern edge of the Mexia-Talco Fault Zone). The depth to the top of the Blossom Formation (Figure 5-2) ranges from zero feet at the outcrop to nearly 2,200 feet below ground level (bgl).

The elevation of the base of the Blossom Formation varies from a high of 300 feet amsl near the city of Paris to -2,200 feet above mean sea level near the Red River- Titus County line. The depth to the base of the Blossom Formation ranges from 250 to 330 feet below ground level in the outcrop to nearly 2,600 feet below ground level at the Red River-Titus County line (Figure 5-3).

The thickness of the Blossom Formation increases from west to east. It is nearly 100 feet thick near the city of Paris and reaches a maximum thickness of about 360 feet in west-central Red River County (Table 5-1).

Table 5-1. Stratigraphic chart of the Blossom Aquifer and surrounding geologic units.

Era	System	Series	Group	Formation	Maximum thickness (feet)	Lithology
Cenozoic	Quaternary	Recent		Alluvium	75	Sand, silt, clay and gravel
		Pleistocene		Fluviatile, terrace deposits		
Mesozoic	Cretaceous	Gulf	Taylor	Marlbrook Marl, Pecan Gap Chalk, Wolfe City – Ozan Formation	1,500	Clay, marl, shale, chalk, mudstone, and sandstone, very fine-grained
			Austin	Gober Chalk	300	Chalk, discontinuous
				Brownstown	220	Clay or shale
				Blossom Sand	360	Fine to medium sand interbedded with marl and chalky marl
				Bonham	530	Clay or shale
				Ector	80	Chalk
			Eagle Ford		650	Shale with thin beds of sandstone and limestone

Source: Modified from McLaurin (1988).

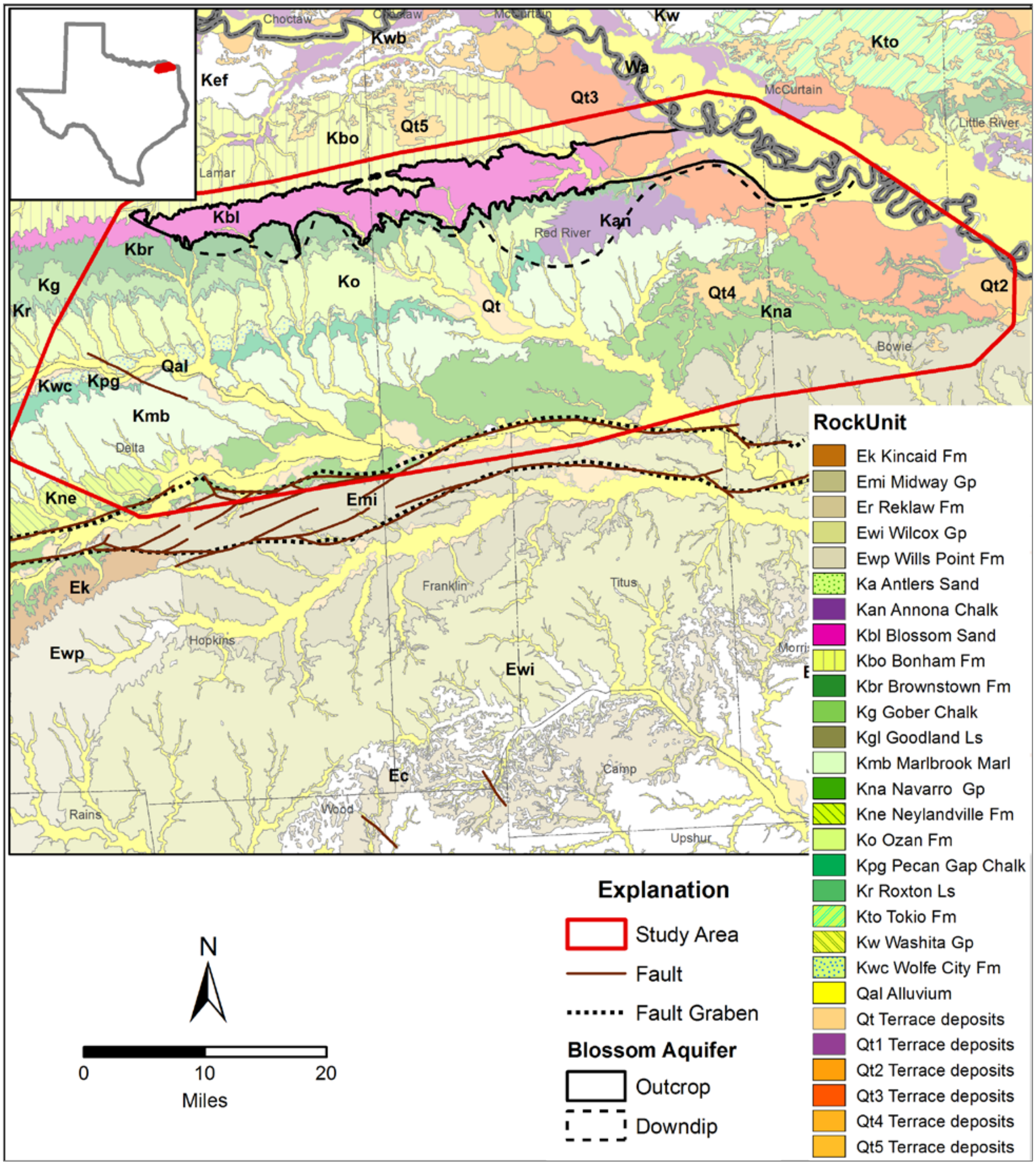

Figure 5-1. **Surface geology and faults in the Blossom Aquifer study area.**

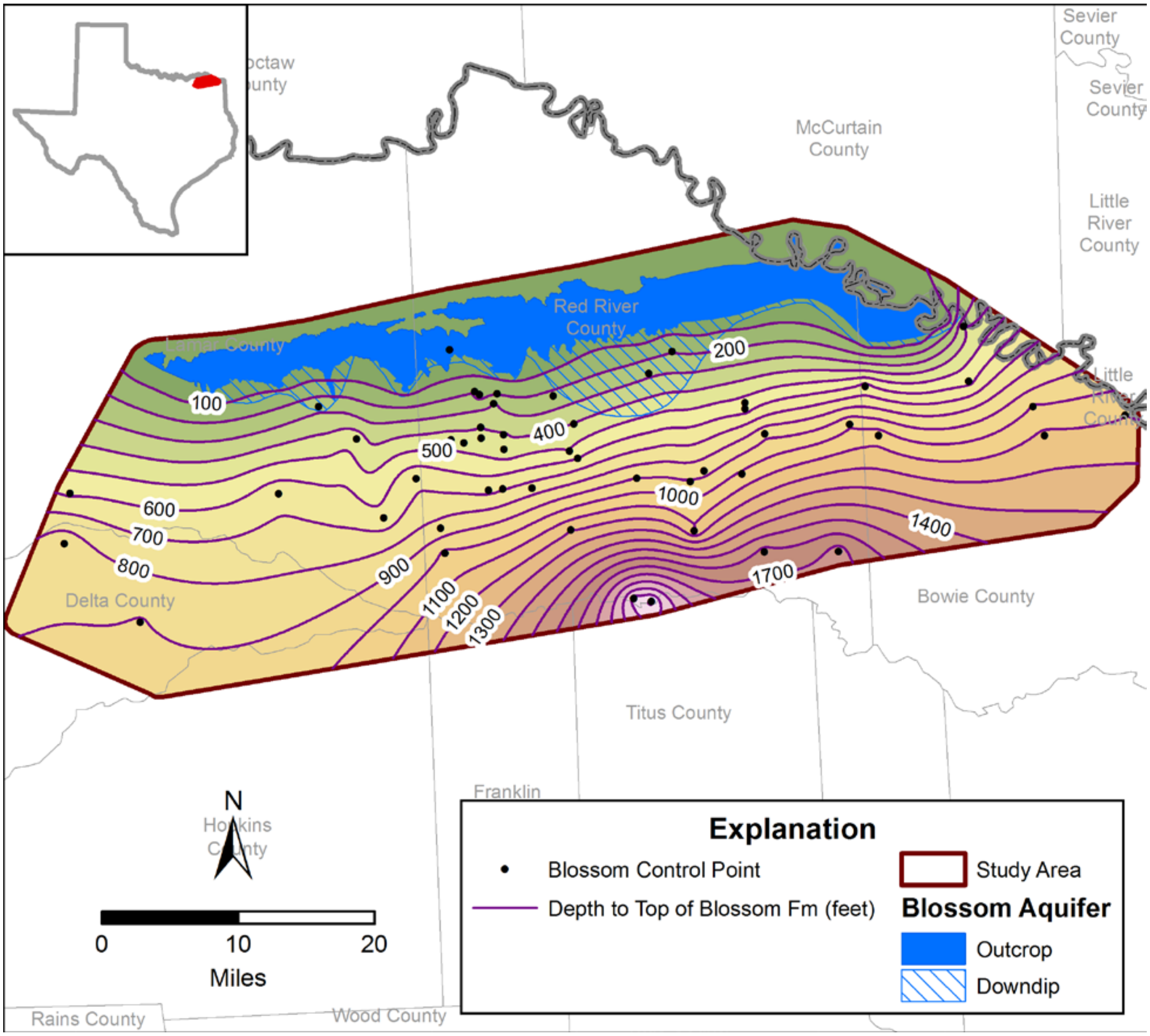

Figure 5-2. Depth to the top of the Blossom Formation.

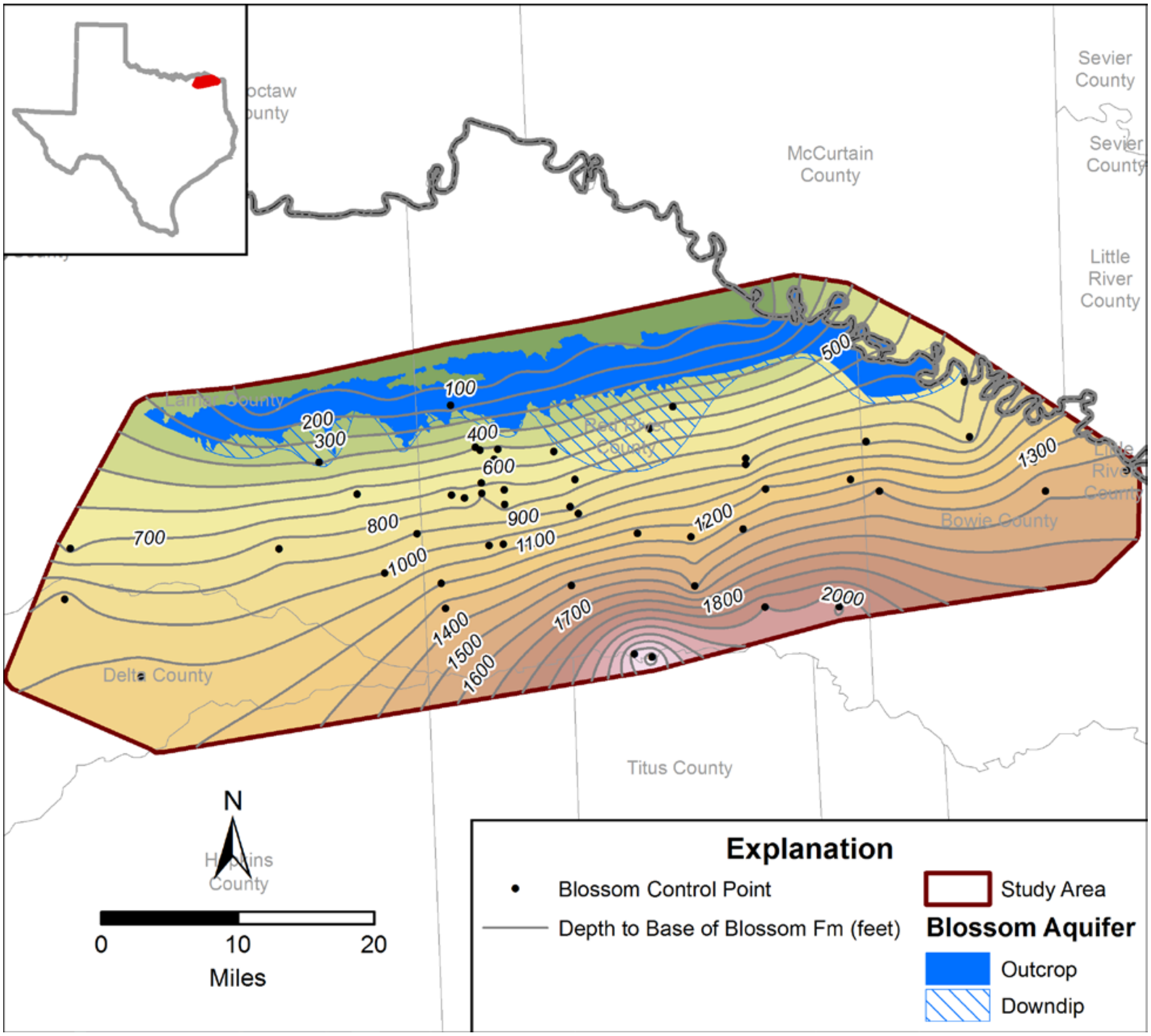

Figure 5-3. Depth to the base of the Blossom Formation.

5.2. Groundwater

The extent of the Blossom Aquifer does not include the portion of the outcrop that extends west of Paris to just east of the town of Bonham in Fannin County (Figure 5-1). Other designated aquifers that are located within the Blossom Aquifer brackish study area include the downdip extents of the Trinity and Woodbine aquifers, and the Nacatoch aquifer outcrop (Figure 5-4 and Figure 5-5).

Groundwater elevation contours were created for the year 2006, because it had the most available water level data measurements. The depth to water measurements ranged between -3.2 below ground level in a flowing well located on the outcrop and 305.5 feet below ground level in a downdip public supply well. Groundwater elevations are highest to the west (near Paris) and decrease in elevation to the east-southeast. It appears the natural direction of flow within the aquifer is from to the east-southeast, however pumping near the city of Clarksville has created a cone of depression (Figure 5-6).

Since the first Blossom Aquifer water well was drilled in the city of Clarksville in 1905 until 1960, water levels declined approximately 26 feet in the artesian portion of the aquifer, which is a rate of about 0.5 foot per year. Static levels were near the top of the aquifer in 1960, and because nearly all of the water supply wells completed in the Blossom Aquifer are screened in the lower sand at the base of the aquifer, water level declines have historically not been a concern. Prior to 1960, the majority of pumping from the Blossom Aquifer was for the city of Clarksville municipal supply in Red River County. Historically, the second greatest single water use of the Blossom Aquifer was the discharge from five flowing wells located in Lamar County near Paris, which supplied approximately 0.03 million gallons per day for livestock watering. Discharge by seepage into adjacent formations along the Luling-Mexia-Talco fault zone is likely to occur.

Recharge to the Blossom Aquifer outcrop has been calculated to be approximately 811 acre-feet per year based on previous calculations for the Nacatoch and similarities of the Blossom lithology to the Nacatoch lithology based on test hole cores. Where the Blossom Formation is overlain by high-level terrace alluvium in eastern Red River and western Bowie County, the alluvium likely recharges directly to the Blossom Sand. Approximately 30 percent of the outcrop contains rechargeable sand in western and central Red River County, and in eastern Lamar County, the net sand content of the formation drops to about 15 percent. Central and western Lamar County is primarily marl and recharge is not believed to be significant (McLaurin, 1988).

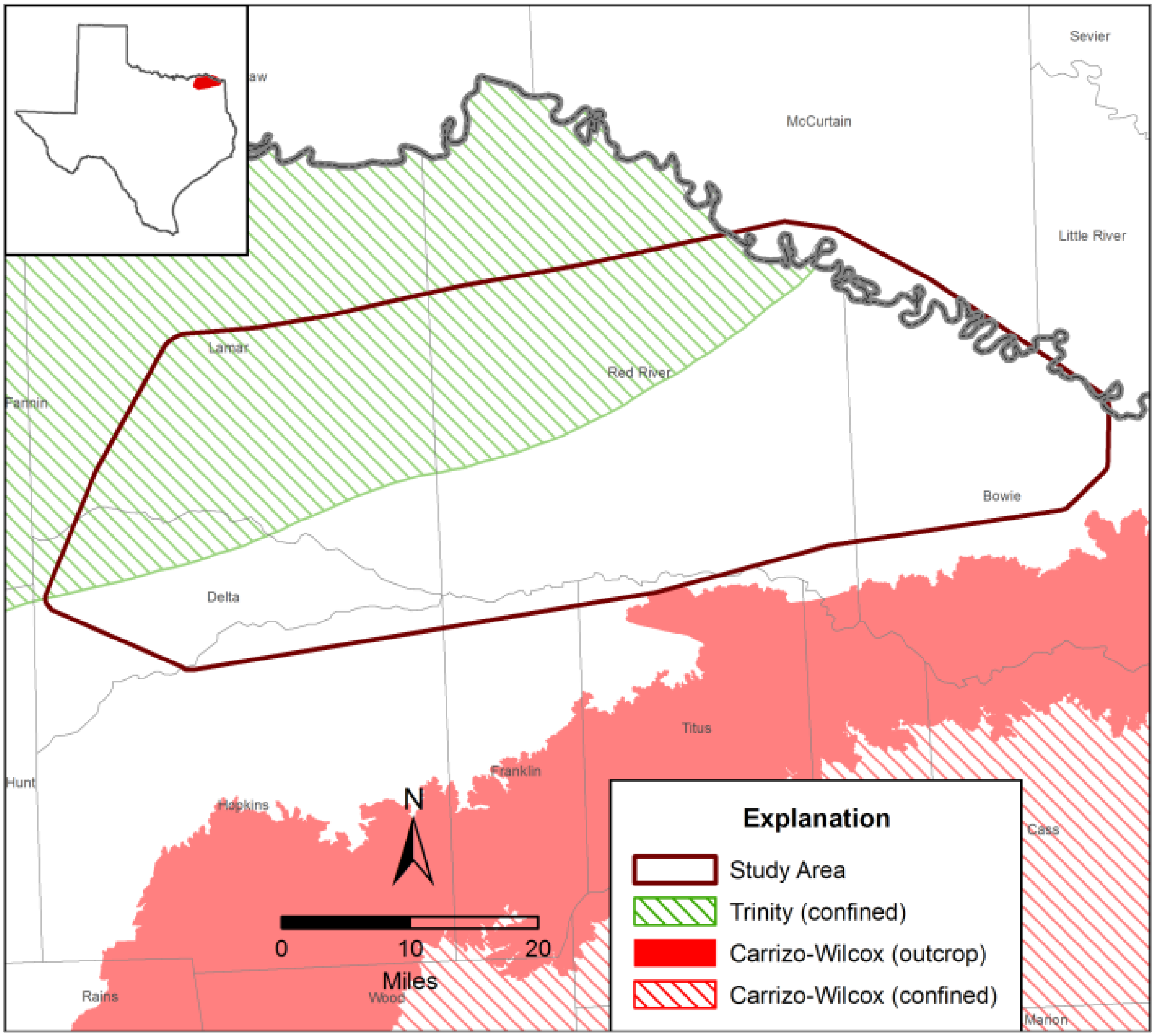

Figure 5-4. **Major aquifers near the study area.**

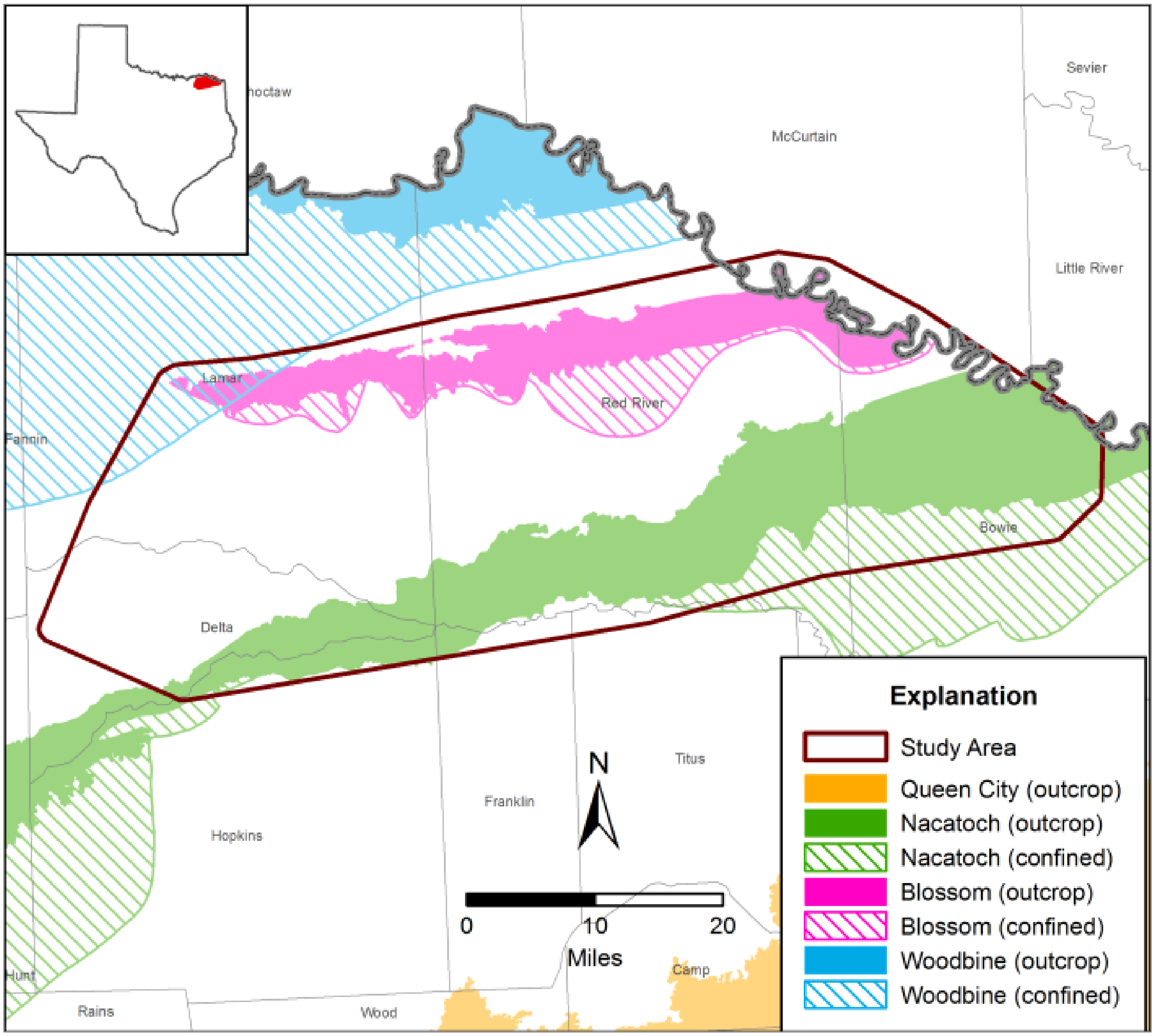

Figure 5-5. **Minor aquifers near the study area.**

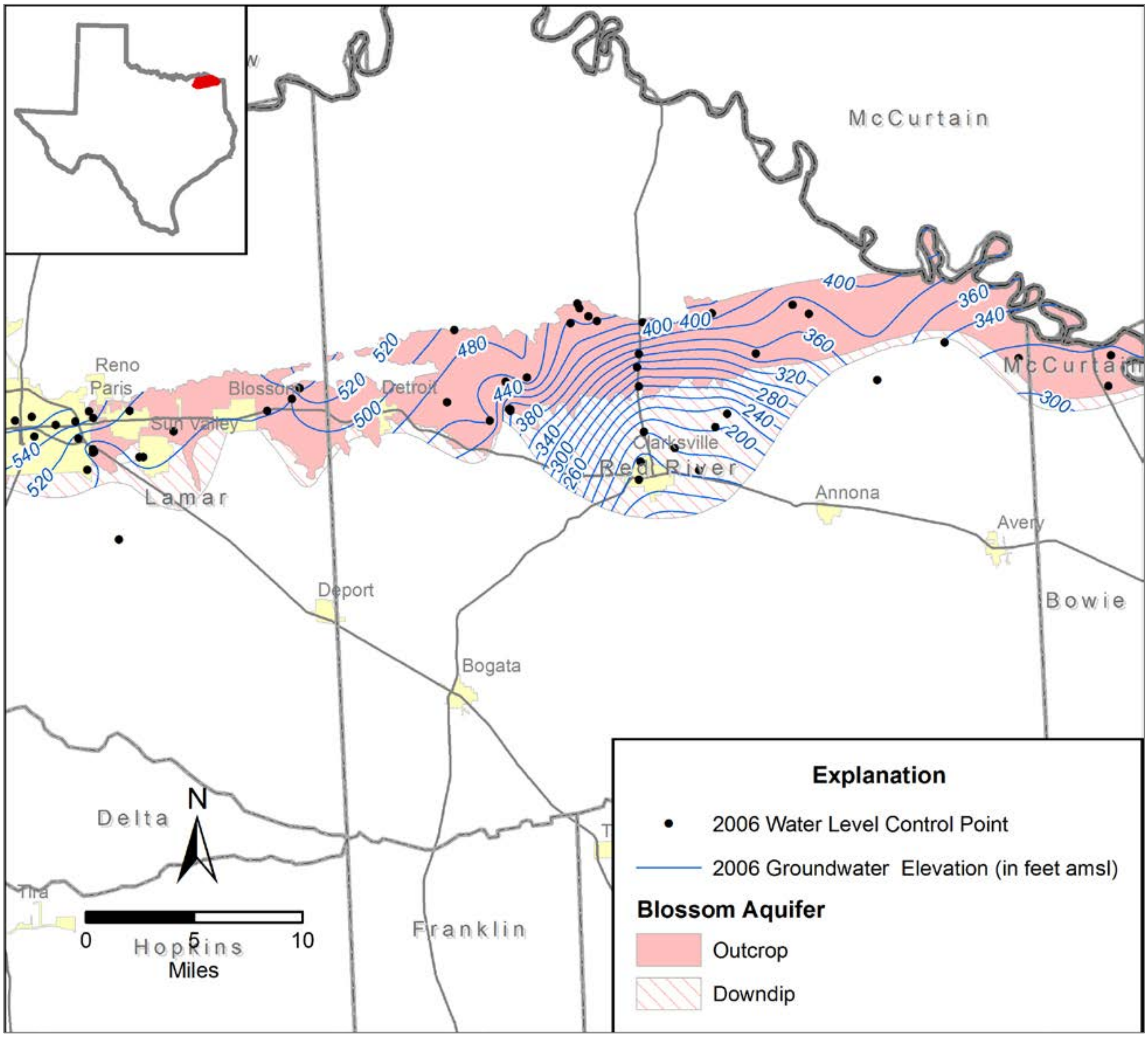

Figure 5-6. 2006 groundwater elevations.

6. Groundwater Salinity Zones

Groundwater salinity zones are listed in The distribution of the salinity zones in the Blossom Formation is also shown on Figure 6-2.

Table 6-1. This report has delineated groundwater salinity zone boundaries in the Blossom Aquifer up to 10,000 milligrams per liter total dissolved solids. Salinity zones have been defined using existing water quality analytical data (measured total dissolved solids) from wells completed in the Blossom Formation, stratigraphic units determined from geophysical logs for which reasonable total dissolved solids estimates were calculated, and the total dissolved solids estimates from geophysical logs. Figure 6-1 shows the distribution of the analytical sample data and total dissolved solids estimates from geophysical logs, as well as the downdip extent of 10,000 milligrams per liter total dissolved solids resulting from the log analyses. The distribution of the salinity zones in the Blossom Formation is also shown on Figure 6-2.

Table 6-1. Groundwater salinity classification summary.

Groundwater Salinity classification	Range in TDS[a] (mg/L)[b]
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	Over 35,000

[a] Total dissolved solids.
[b] Milligrams per liter.

Source: Modified from Winslow and Kister (1956).

6.1. Slightly Saline Zones

The downdip extent of the slightly saline zone, which contains groundwater with a total dissolved solids concentration ranging between 1,000 milligrams per liter and 3,000 milligrams per liter, was originally approximated by the TWDB for the 1988 report by developing an empirical relationship based on resistivity logs. The depth to the base of the slightly saline zone based on all data incorporated into this study varies from 30 to 675 feet within the extent of the 3,000 milligrams per liter delineated in McLaurin (1988). These depths are based upon water sample results. Results from this study suggest that in a few local areas, there are downdip occurrences of slightly saline waters at a depth of 800 to possibly 1,200 feet in depth. This study does not significantly change the delineation of the 3,000 milligrams per liter total dissolved solids line.

6.2. Moderately Saline Zones

Moderately saline zones are those zones with total dissolved solids concentrations between 3,000 and 10,000 milligrams per liter. The depth to the base of the slightly saline zone varies from 400 to 1,600 feet within the extent of the 10,000 milligrams per liter delineated in Figure 6-1. The depth to the top of the moderately saline Blossom Sand is approximately 300 feet in northern Red River County. Several schematic cross sections have been constructed through the Blossom Aquifer to illustrate the geometry of the formation, the basal sand, and the estimated water quality within the basal sand. These cross sections are included as Figure 6-3, Figure 6-4, and Figure 6-5.

6.3. Very Saline and Brine Zones

House Bill 30 only requires that the groundwater salinity zones in the Blossom Aquifer be delineated up to 10,000 milligrams per liter; therefore, very saline zones (10,000 to 35,000 milligrams per liter total dissolved solids) and brine zones (over 35,000 milligrams per liter total dissolved solids) are not within the scope of this project.

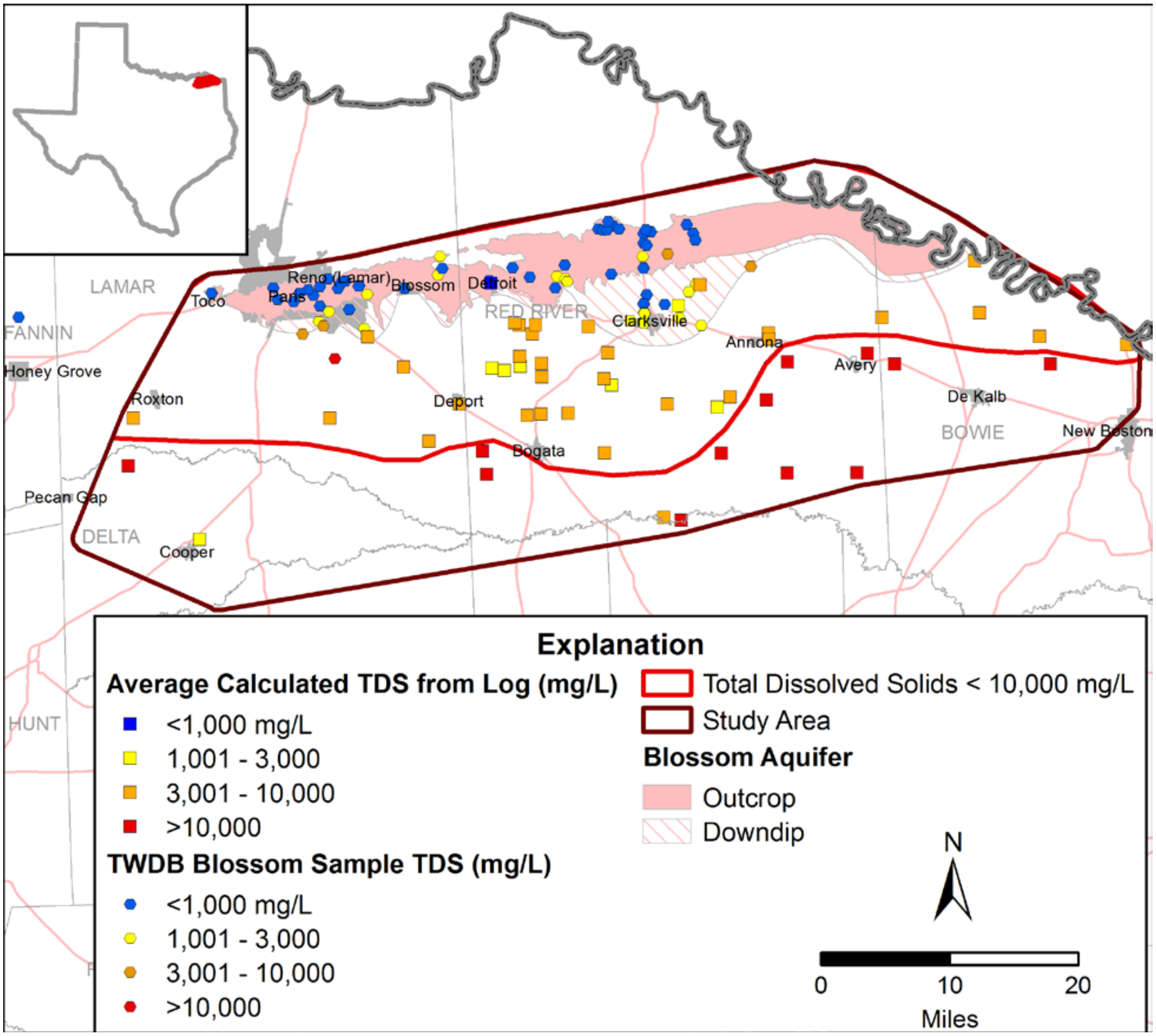

Figure 6-1. **Distribution of measured and estimated total dissolved solids values.**

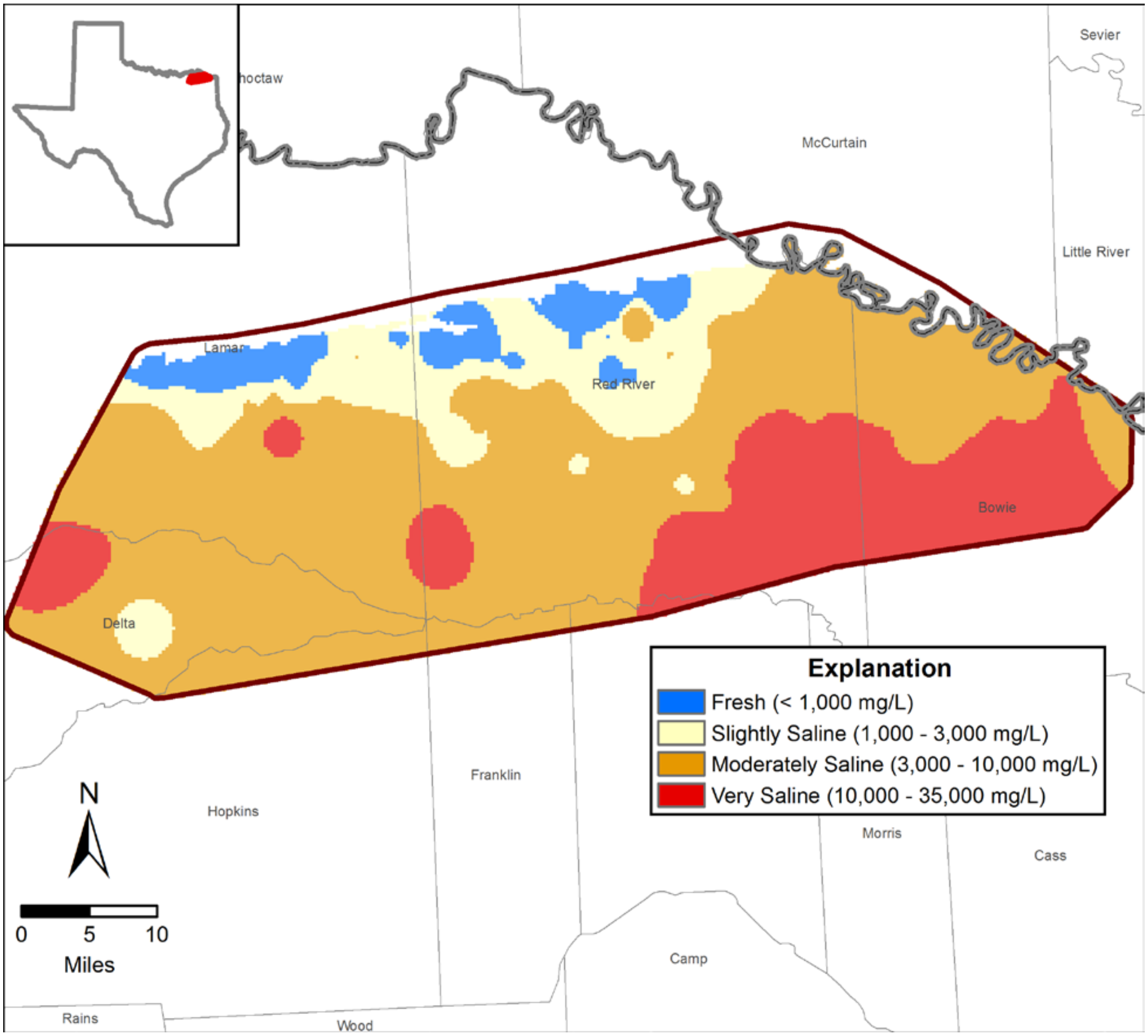

Figure 6-2. Blossom Aquifer salinity distribution.

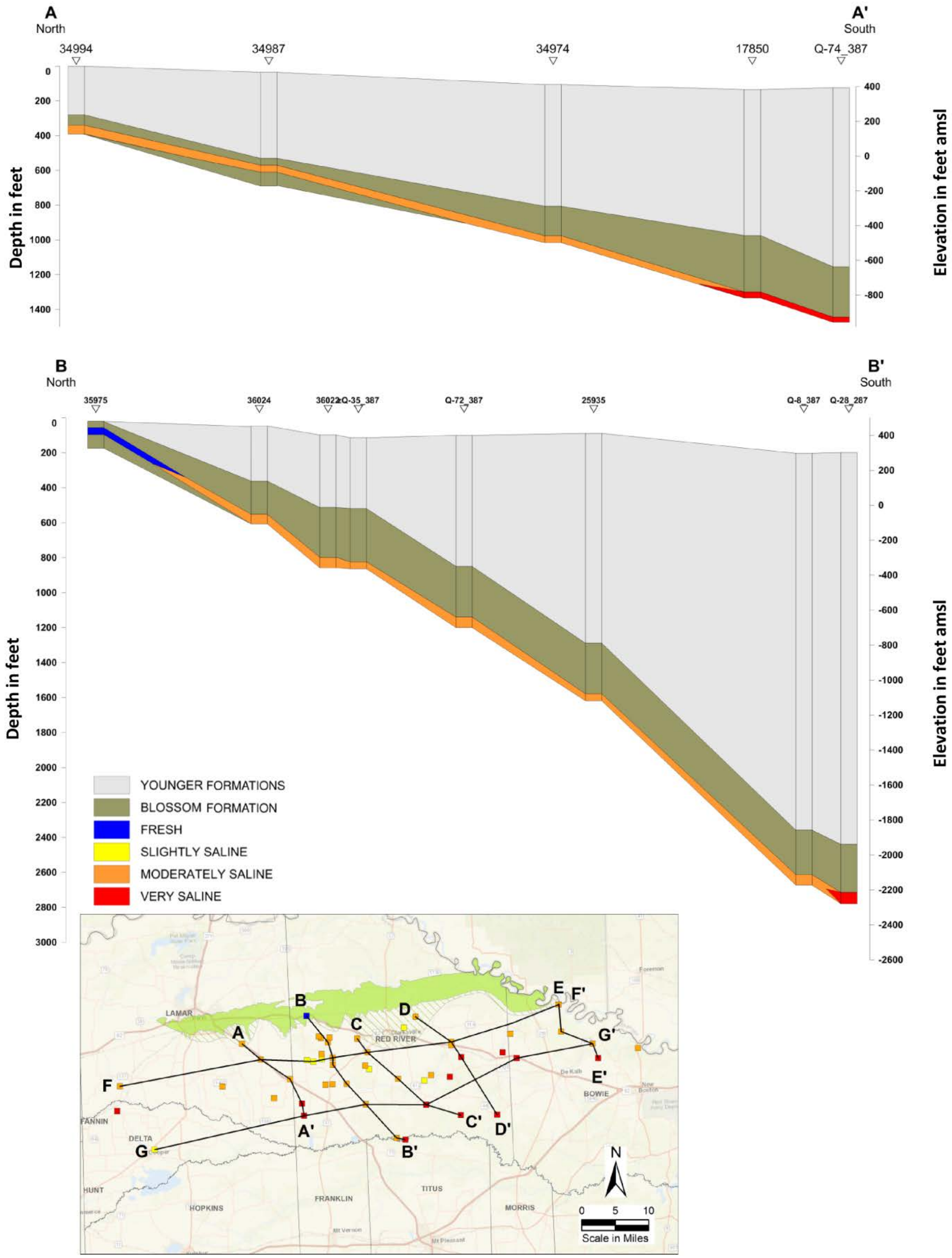

Figure 6-3. **Dip cross sections A-A' and B-B' with depth in feet and elevation in feet above mean sea level.**

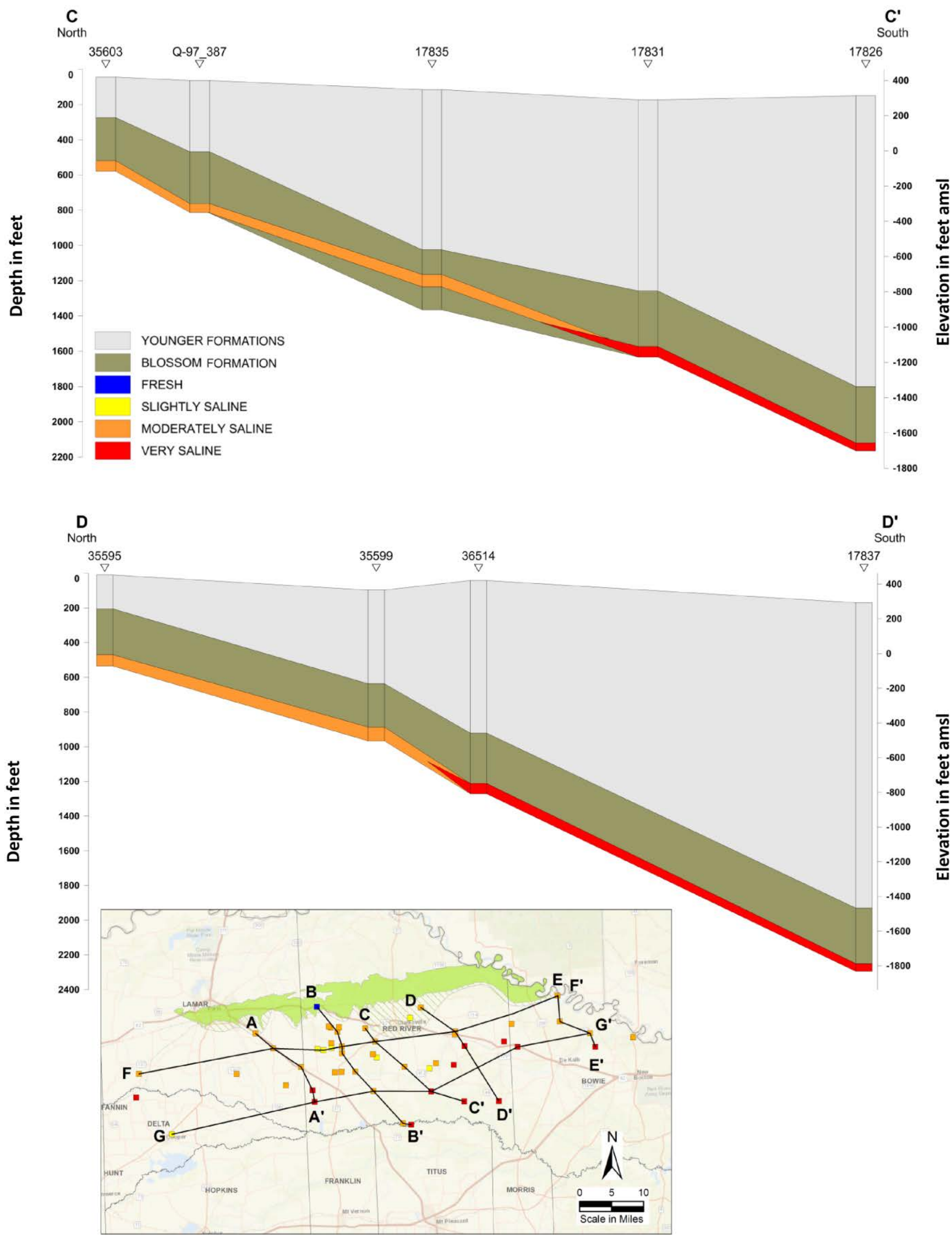

Figure 6-4. **Dip cross sections C-C’ and D-D’ with depth in feet and elevation in feet above mean sea level.**

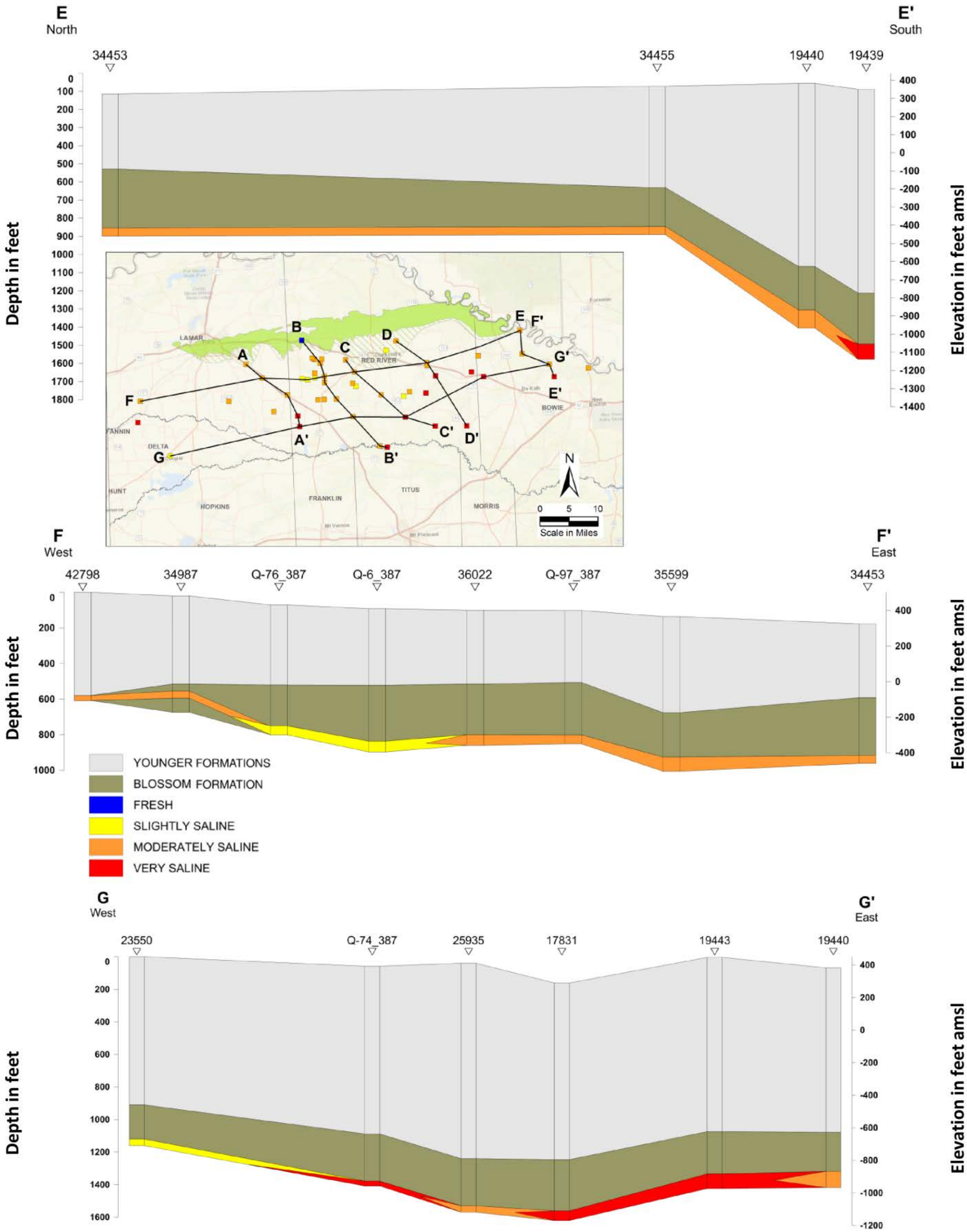

Figure 6-5. **Dip cross section E-E' and strike cross sections F-F' and G-G' with depth in feet and elevation in feet above mean sea level.**

7. Previous Investigations

In a U.S. Geological Survey hydrogeological study of Northern Louisiana and Southern Arkansas, Veatch (1906) initially identified the Blossom Sand as the sub-Clarksville Sand, named for the City of Clarksville water wells. Veatch's sub-Clarksville Sand included the overlying Brownstown clay/marl and the underlying Eagle Ford Formations.

Gordon (1911) performed a hydrogeological investigation of northeast Texas, and named the Blossom Sand after the town of Blossom in Lamar County, Texas. Gordon included the Blossom Sand with the Eagle Ford Group. He described the Upper Cretaceous rocks of northeastern Texas as being generally unconsolidated, except for the chalks, and noted that the contacts between formations were gradational and difficult to map. Gordon generally described the Blossom Formation as brown sandy ferruginous glauconitic beds interlaminated with thin beds of clay. Specifically, he described a section of Blossom outcrop located four miles north of Clarksville as follows: three feet of sand mixed with occasional marly clay, overlying six feet of blue marly clay over ten feet of hidden section, overlying ten feet of yellow sand with fossil impressions, overlying two feet of drab fissile clay, overlying 20 feet of yellow sand grading to drab arenaceous clay and containing iron concretions with impressions of fossils. He further noted that while the Blossom Sand may seem stratigraphically insignificant, it is the only (known) water-bearing horizon over a large portion of Lamar and Red River Counties.

Stephenson (1918) suggested that the Blossom belongs in the Austin Group and not the Eagle Ford Group, as proposed by Gordon. Correlation of fossil evidence indicates it is contemporaneous to the upper half of the Austin Chalk at its type locality in Travis County. Additionally, Stephenson (1927) established that the 200-plus feet of clay directly underlying the Blossom Formation that was formerly called Eagle Ford in northeast Texas is younger than true Eagle Ford clay and is also equivalent to the lower part of the Austin Chalk, and he named it the Bonham clay (marl). Sellards and others (1932) summarized the previous work by Veatch, Gordon and Stephenson. Baker and others (1963) performed a reconnaissance investigation of groundwater resources within the Red River, Sulphur River and Cypress Creek basins as part of a state-wide survey. This report provides a synopsis of Blossom geology, hydrogeology, aquifer properties, water quality and water use in the 1960s.

Stehli and Creath (1964) calculated the ratio of planktonic to benthonic foraminifera in Upper Cretaceous formations which are helpful in identifying large-scale regional changes in depositional environments. Analyses of these data indicate the presence of a water current boundary located along the Luling-Mexia-Talco fault zone which essentially acted as a barrier to flow. This suggests that a separate flow system entered the area from the southwest and that Upper Cretaceous formations once extended further to the west than their current extent.

McLaurin (1988) provided the most comprehensive characterization of the geology and hydrogeology of the Blossom Sand aquifer. A well inventory performed in the early 1980s found 139 wells completed in the Blossom Aquifer, with half of the wells designated as livestock and domestic wells and nearly half had been abandoned or destroyed. The TWDB drilled seven test holes to perform pump tests and determine aquifer characteristics. Cores were collected from sandy intervals in two of the test holes drilled in Red River County. The average porosity determined from these core data was 37 percent. Grain size analyses indicate that the D_{50} grain size averages between silt and fine-grained sand. Specific yield was found to be less than seven percent.

8. Data Collection and Analysis

8.1. Geophysical Log Data

The primary source of geophysical logs (Figure 8-1) is the TWDB BRACS database (175 logs). These log data include many of the old paper logs housed at the Railroad Commission of Texas Groundwater Advisory Unit (formerly the Texas Commission on Environmental Quality Surface Casing Division). The majority of these logs are spontaneous potential (SP) and resistivity/induction curves. Only one of the logs is a neutron log. A handful of logs were downloaded from the RRC well viewer (7 logs). Most of these logs are SP, gamma ray (GR), and resistivity logs. The Bureau of Economic Geology has over 350 logs in Bowie, Lamar and Red River Counties. Only about 30 of these have log tops that begin at 250 feet below ground level or less. Additionally, approximately 102 Q-logs that have not been incorporated into BRACS were considered for inclusion in this study.

8.1.1 Verification

External databases were not utilized for this project; therefore, verification of other data analyses was not applicable (except for the cation-anion balance described in the following section). Otherwise, verification of data imported into the BRACS Access dataset was cross-checked with the original data set compiled in Excel.

8.1.2 Level of Confidence

The level of confidence applied to the geophysical logs evaluated for this project were required to satisfy at least three of the following characteristics: 1) the log header contained the relevant data necessary to perform an estimate, 2) the log curve was legible and of sufficient quality, 3) the sand thickness of the target zone was at least 20 feet thick, 4) the bicarbonate concentration relative to total dissolved solids was less than 50 percent, and 5) the location was non-duplicative.

A total of 175 geophysical logs were available from the BRACS database and additional Q-logs, however after the level of confidence criteria were applied to these data, only 67 logs remained to estimate total dissolved solids. Most geophysical logs which satisfied at least three of the five components listed above were initially evaluated.

8.1.3 Self-Validation:

When the mud filtrate resistivity was not reported on the log header, it was calculated from the mud resistivity and the mud weight using the Overton and Lipson method for non-lignosulfonate muds or the Lowe and Dunlap relationship for fresh muds (Schlumberger, 2009). Out of 67 geophysical logs, 15 were omitted that did not pass this validation check. Additionally, when the SP method estimate exceeded 10,000 milligrams per liter total dissolved solids, the result was not used. 24 of the 52 remaining logs excluded the estimate using the SP method.

8.2. Water Quality Samples

A total of 137 water samples from 73 water wells completed in the Blossom Aquifer were found in the TWDB groundwater database. Most of the samples are from wells located in Red River and Lamar Counties, a few of these samples are from wells located in Fannin County (when the aquifer delineation extended further west and included a portion of Fannin County). Total dissolved solids range from 51 to 17,019 milligrams per liter, with an average concentration of 1,243 milligrams per liter. Bicarbonate concentrations range from 0 to 815 milligrams per liter, with an average concentration of 380 milligrams per liter. The percent of bicarbonate comprising the total dissolved solids was found to range from zero to 96 percent, with an average of 45 percent.

Laboratory measured total dissolved solids was compared to calculated total dissolved solids using Collier's (1993) Equation 3-1 which is given as:

$$TDS = total\ of\ ions + SiO_2 - (0.508) \times HCO_3$$

Using this equation, the measured total dissolved solids concentrations could be reproduced for all 137 samples. A cation–anion balance was performed for quality assurance of the sample data. Eight samples did not balance within five percent. The average constant relating conductance to total dissolved solids was derived from all of the water quality samples (C=0.601) for use in the water quality calculations.

8.3. Water Level Data

Water level data in the Blossom Aquifer and overlying alluvium is relatively sparse; therefore, the year 2006 was characterized because it had the greatest number of measurements reported in any year. Water levels for 56 wells were reported for the Blossom Aquifer and alluvium in 2006. Fifty-three of the TWDB measurements were flagged with a 'P' for publishable, and three were flagged with a 'Q' for questionable; however, the measurements flagged with a 'Q' did not appear anomalous when mapped so were included to characterize groundwater elevations.

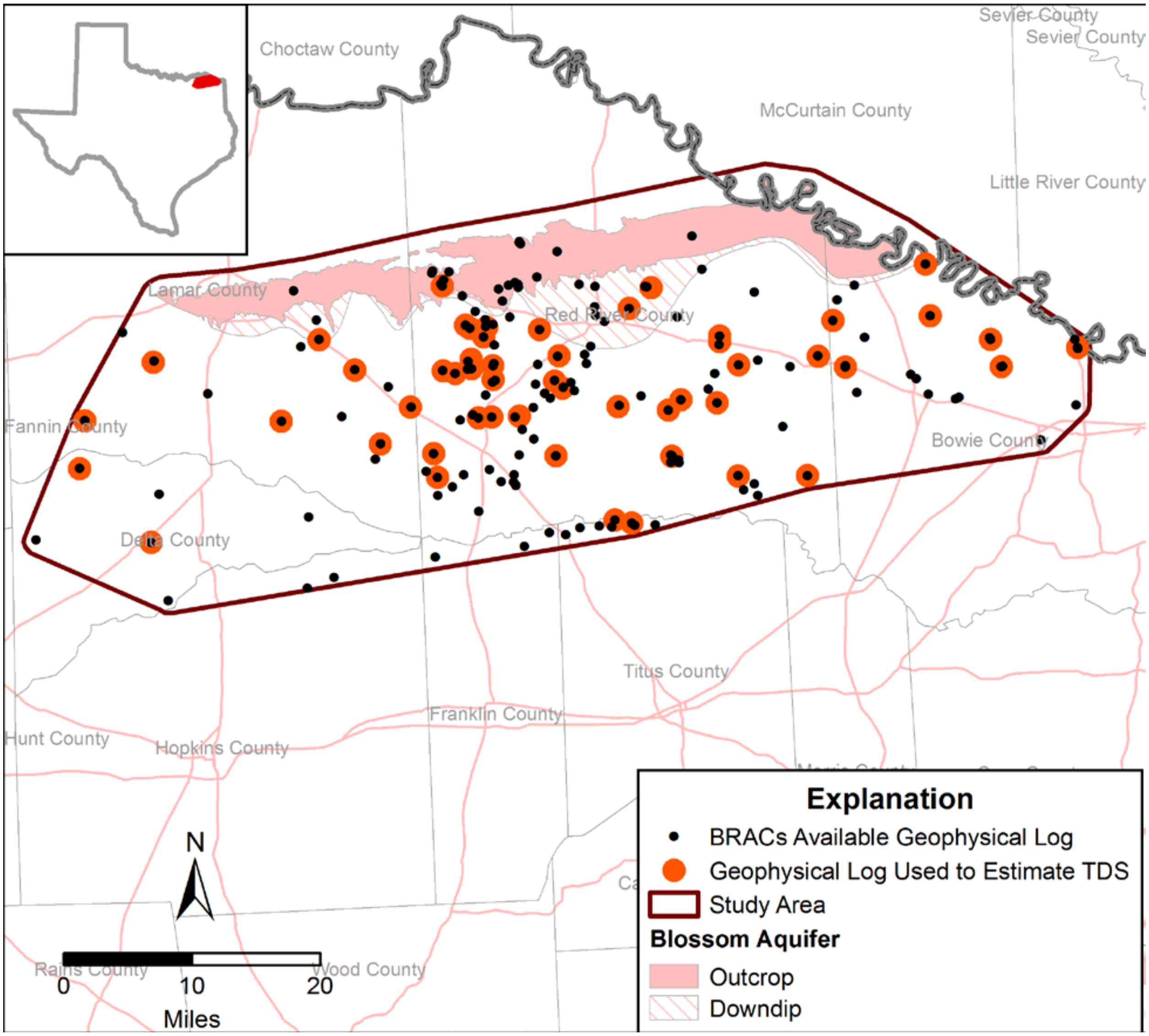

Figure 8-1. Geophysical log data.

9. Aquifer Hydraulic Properties

Hydraulic properties of the Blossom Aquifer derived from pumping tests are presented in Table 9-1 and Figure 9-1. Specific capacity ranges between 0.4 and 2.3 gallons per minute per foot of drawdown. Hydraulic conductivity ranges between 2.7 and 7.1 feet per day, and transmissivity ranges between 85 square feet per day in Lamar County to 530 square feet per day in Red River County. Note that the well yields and transmissivity increase with greater depth. These data were determined from pumping tests performed between 1942 and 1982. No long-term pumping tests performed since 1982 have been found or are publicly available.

Table 9-1. Pumping test results.

Well ID	Date	Screened interval (ft)[b]	Yield (gpm)[c]	Transmissivity (ft^2/day)[d]	Storage coefficient	Hydraulic conductivity (ft/d)[e]	Specific capacity (gal/min/ft)[f]
				Lamar County			
17-21-710	Aug-42	146-168	35	89[a]	-	4.0	0.4
17-21-711	Aug-42	164-190	38	85[a]	-	3.3	0.4
				Red River County			
16-17-402	Jul-65	91-166	10	235[a]	-	3.1	1.0
16-17-602	Sep-82	-	25	192	-	-	-
17-24-801	Oct-82	450-500	150	165	-	3.3	1.0
17-24-803	Dec-69	465-530	156	176	-	2.7	1.3
17-32-201	Aug-60	523-600	630	549	$7x10^{-5}$	7.1	-
17-32-203	Aug-60	510-603	630	494	$3x10^{-5}$	5.3	-
17-32-205	Jun-57	585-665	554	530[a]	-	6.6	2.3

[a] Transmissivity calculated using the Logan formula.
[b] Feet.
[c.] Gallons per minute.
[d] Square feet per day.
[e] Feet per day.
[f] Gallons per minute per foot.

Source: McLaurin, 1988.

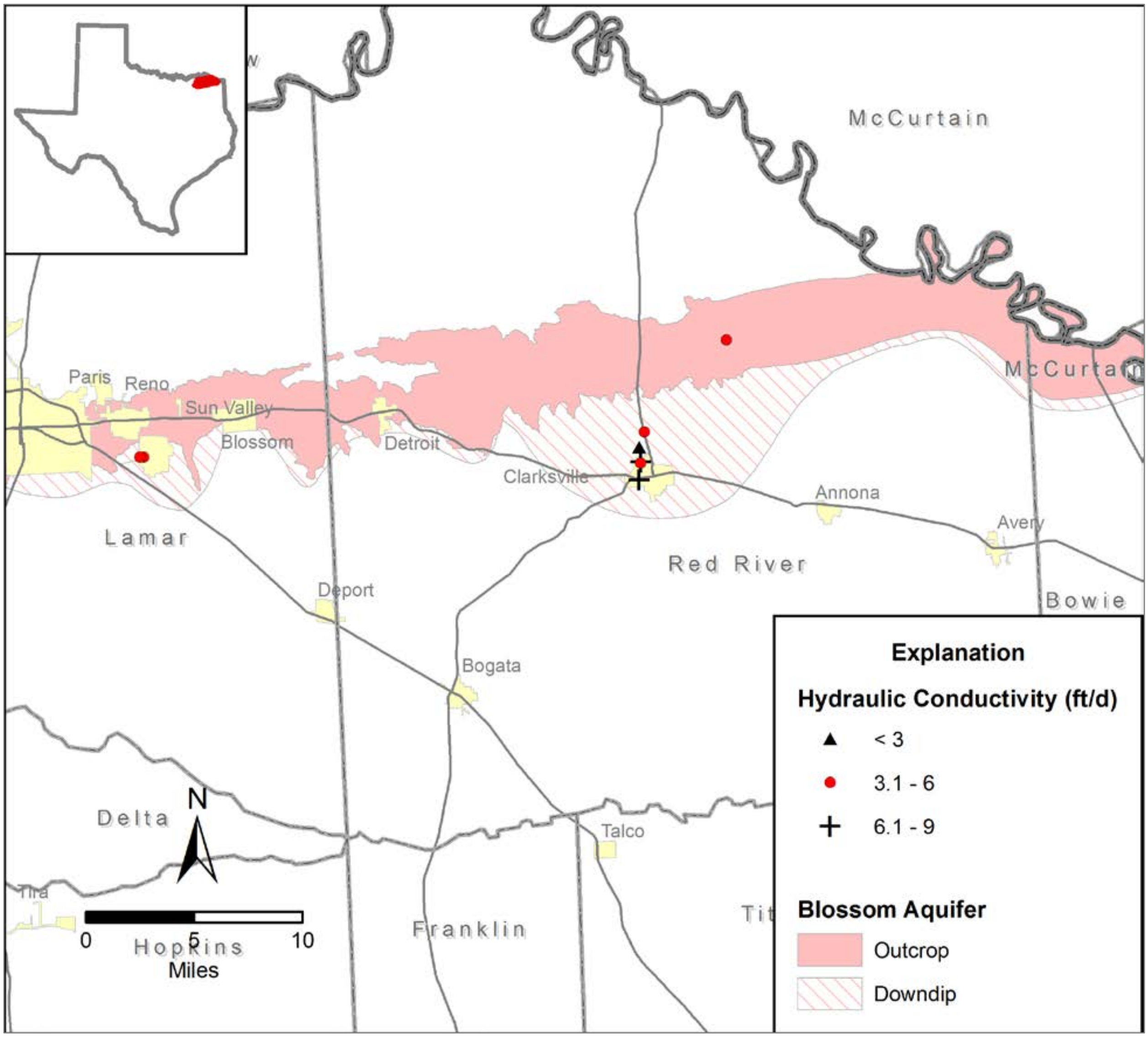

Figure 9-1. **Hydraulic conductivity.**

10. Water Quality Data

10.1. Dissolved Minerals

The average total dissolved solids concentration in Blossom samples is 1,244 milligrams per liter, and ranges between 51 and 17,019 milligrams per liter (fresh to very saline). A graph of specific conductance versus total dissolved solids is shown in Figure 10-1 for samples with a total dissolved solids less than 10,000 milligrams per liter. This relationship results in a conversion factor of 0.601 for Blossom samples. The percent of total dissolved solids that is made up of bicarbonate ranges between zero and 96 percent, with an average of 45 percent bicarbonate, which is high (Figure 10-2). The average pH is 8.2, which indicates slight alkalinity.

Table 10-1. Water quality summary.

	Concentration		
Constituent	**Average**	**Minimum**	**Maximum**
Silica	23	3	89
Calcium	30	1	496
Magnesium	10	0	630
Sodium	429	1	6,334
Potassium	4.5	1.0	22.3
Bicarbonate	380	0	815
Carbonate	16	0	90
Sulfate	215	1	5,239
Chloride	340	1	10,282
Fluoride	0.7	0.1	3.1
Nitrate	2.5	0.0	50.0
Total Dissolved Solids	1,244	51	17,019
Specific Conductance (micromhos at 25C)	2,358	41	37,044
Percent Bicarbonate	44.8	0.0	95.6
pH (standard units)	8.2	3.6	9.3
Sodium adsorption ratio (SAR)	41.5	0.1	129.5
Residual sodium carbonate (RSC) (milliequivalents per liter)	5.9	0.0	13.1

All results are in milligrams per liter unless specified.

Chloride concentrations average 340 milligrams per liter, which exceeds the drinking water standard of 250 milligrams per liter. The average residual sodium carbonate is 5.9, which exceeds the maximum contamination level of 2.5 milliequivalents per liter and is considered unsatisfactory for irrigation purposes.

Only one water sample was found for the Blossom Formation from the U.S. Geological Survey Produced Waters database (2016). No precise location data was provided; however, the sample had a total dissolved solids of 32,467 milligrams per liter and came from the Talco field located in Titus County near Talco, Texas within the Luling-Mexia-Talco fault zone.

Piper diagrams for the fresh, slightly saline, moderately and very saline groundwater classifications are included as Figure 10-3, Figure 10-4, and Figure 10-5. The samples were grouped based upon the total dissolved solids of the sample. These diagrams suggest that the groundwater chemistry transitions from predominantly calcium bicarbonate waters in the fresh zone, to sodium bicarbonate waters in the slightly saline zone to sodium chloride in the moderately and very saline zones.

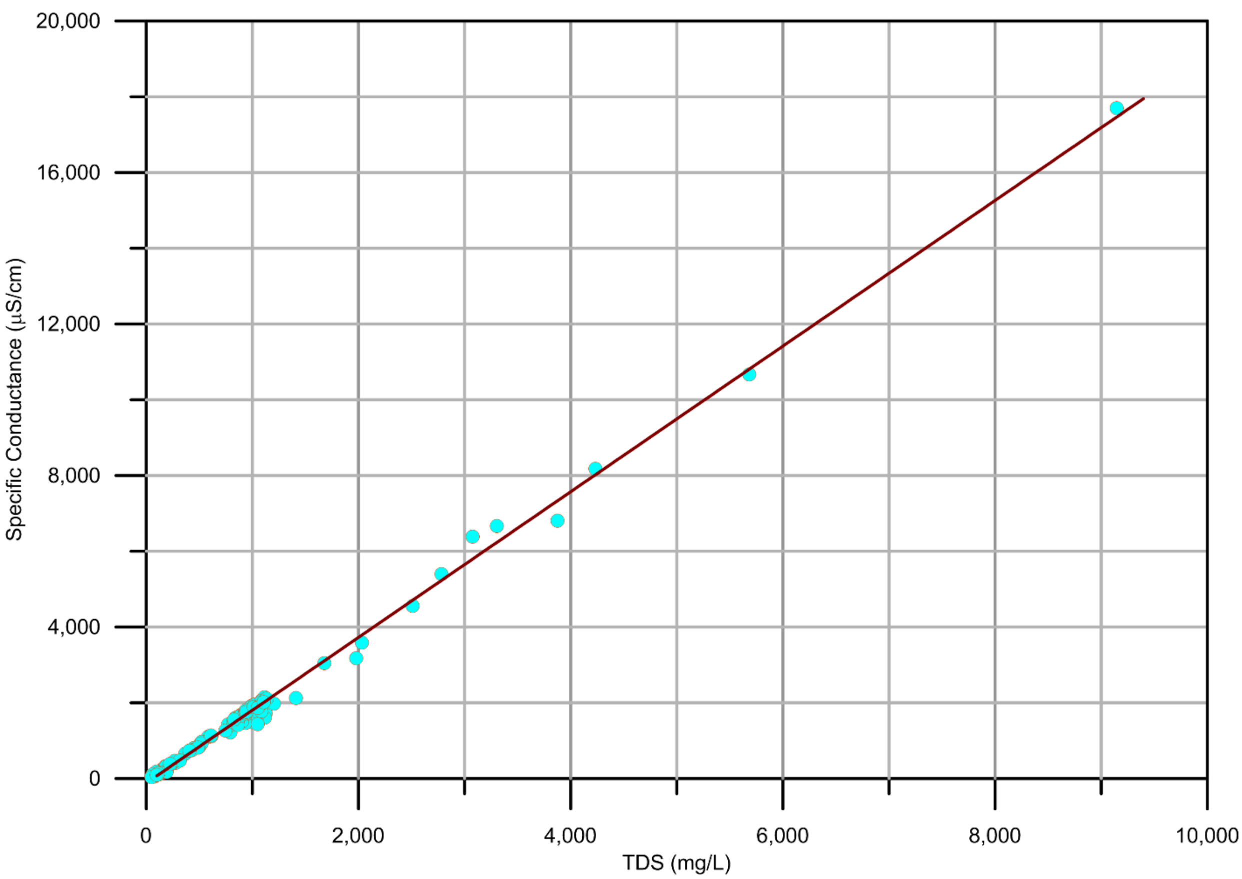

Figure 10-1. Graph of specific conductance versus total dissolved solids in Blossom Aquifer sample data.

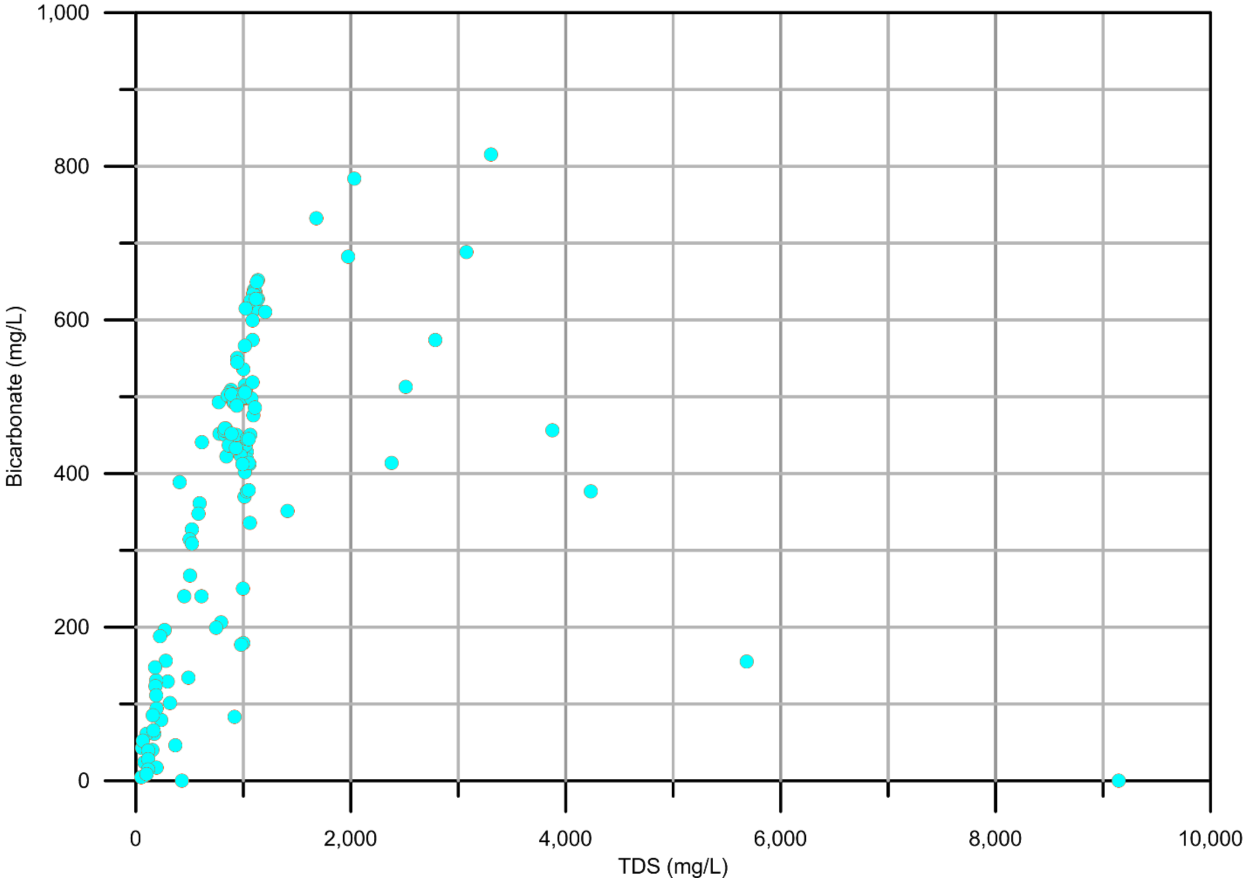

Figure 10-2. Graph of bicarbonate versus total dissolved solids results in Blossom Aquifer sample data.

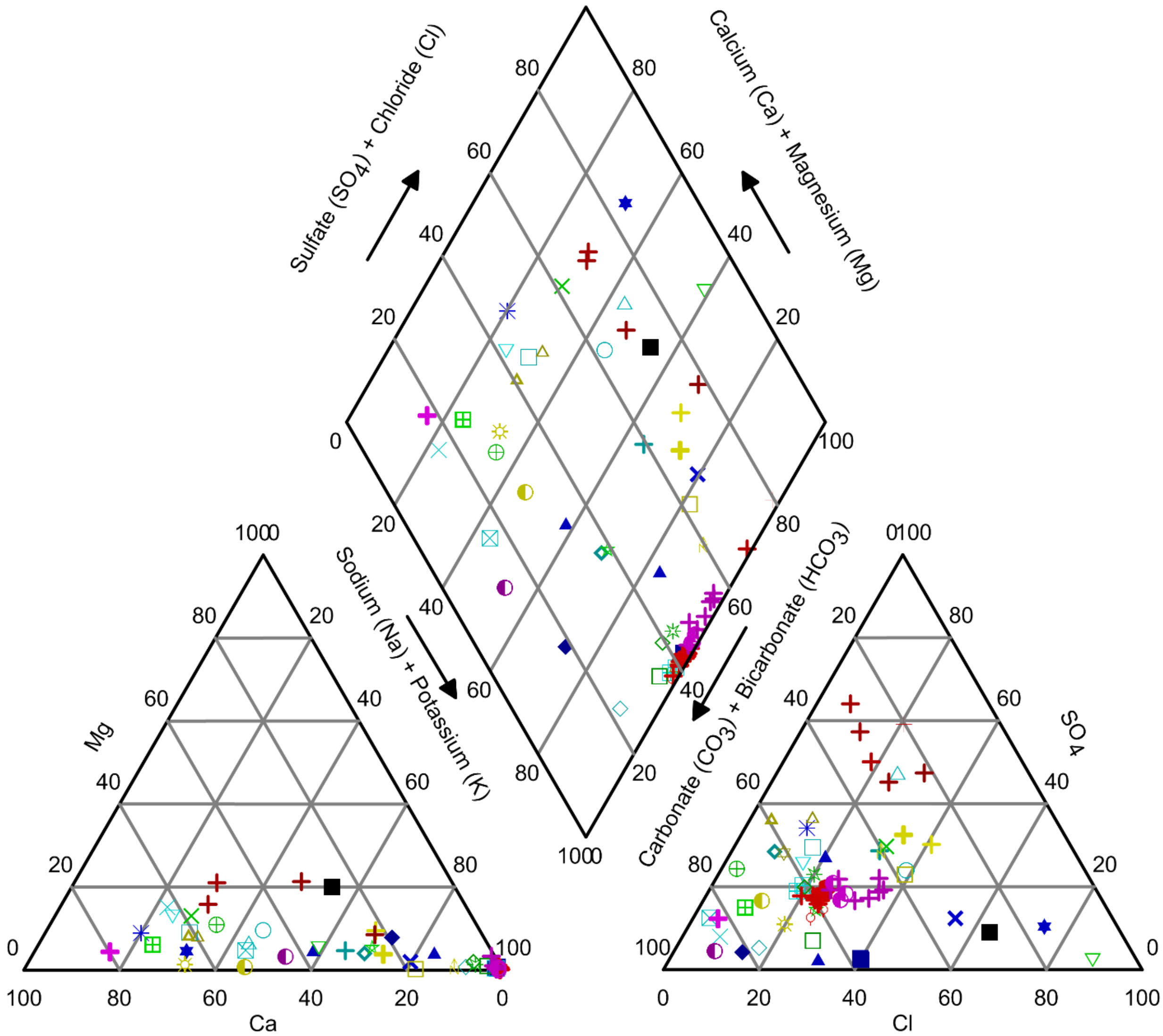

Figure 10-3. **Piper diagram of Blossom Aquifer sample results with total dissolved solids concentrations less than 1,000 milligrams per liter.**

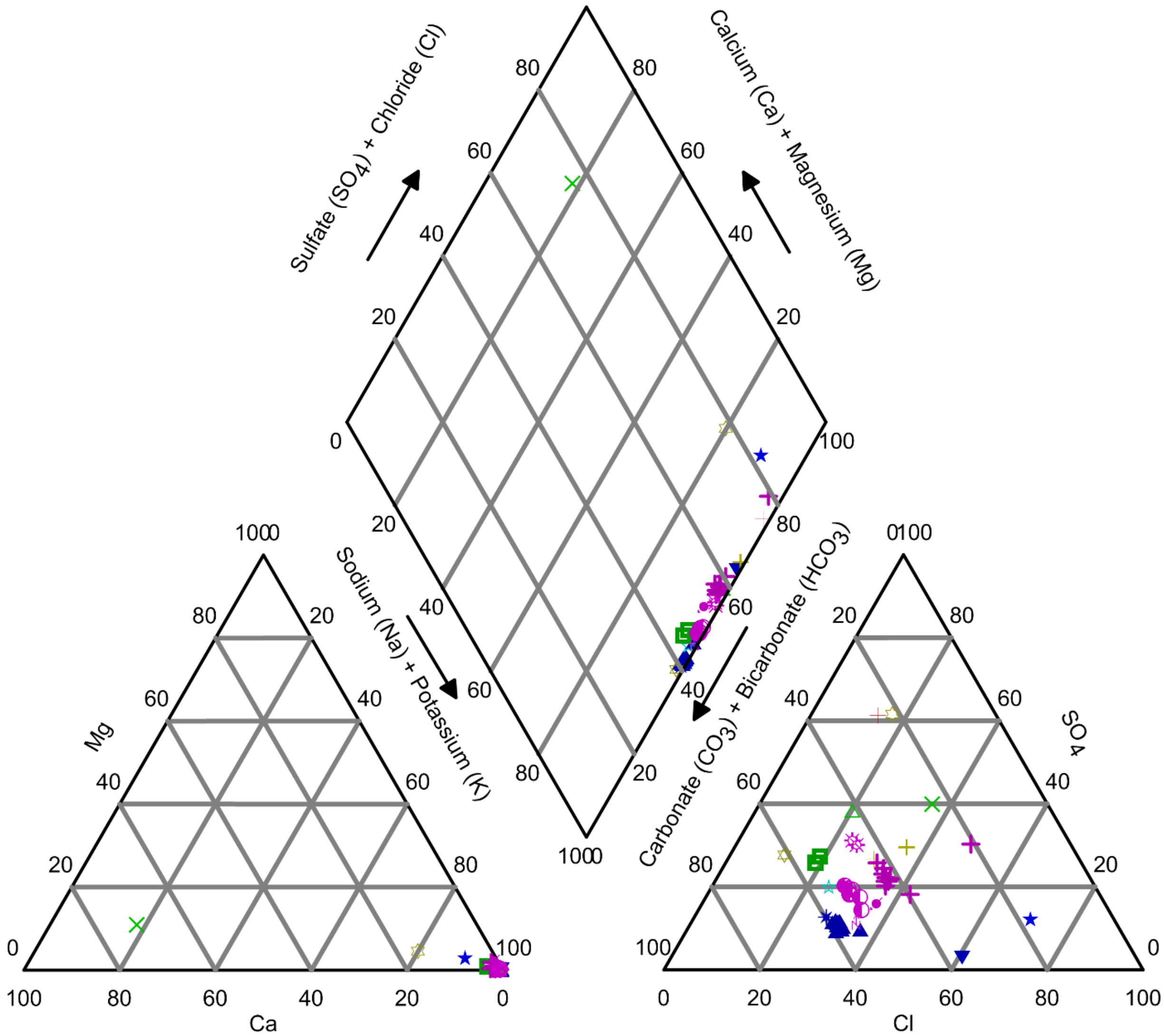

Figure 10-4. **Piper diagram of Blossom Aquifer sample results with total dissolved solids concentrations between 1,000 and 3,000 milligrams per liter.**

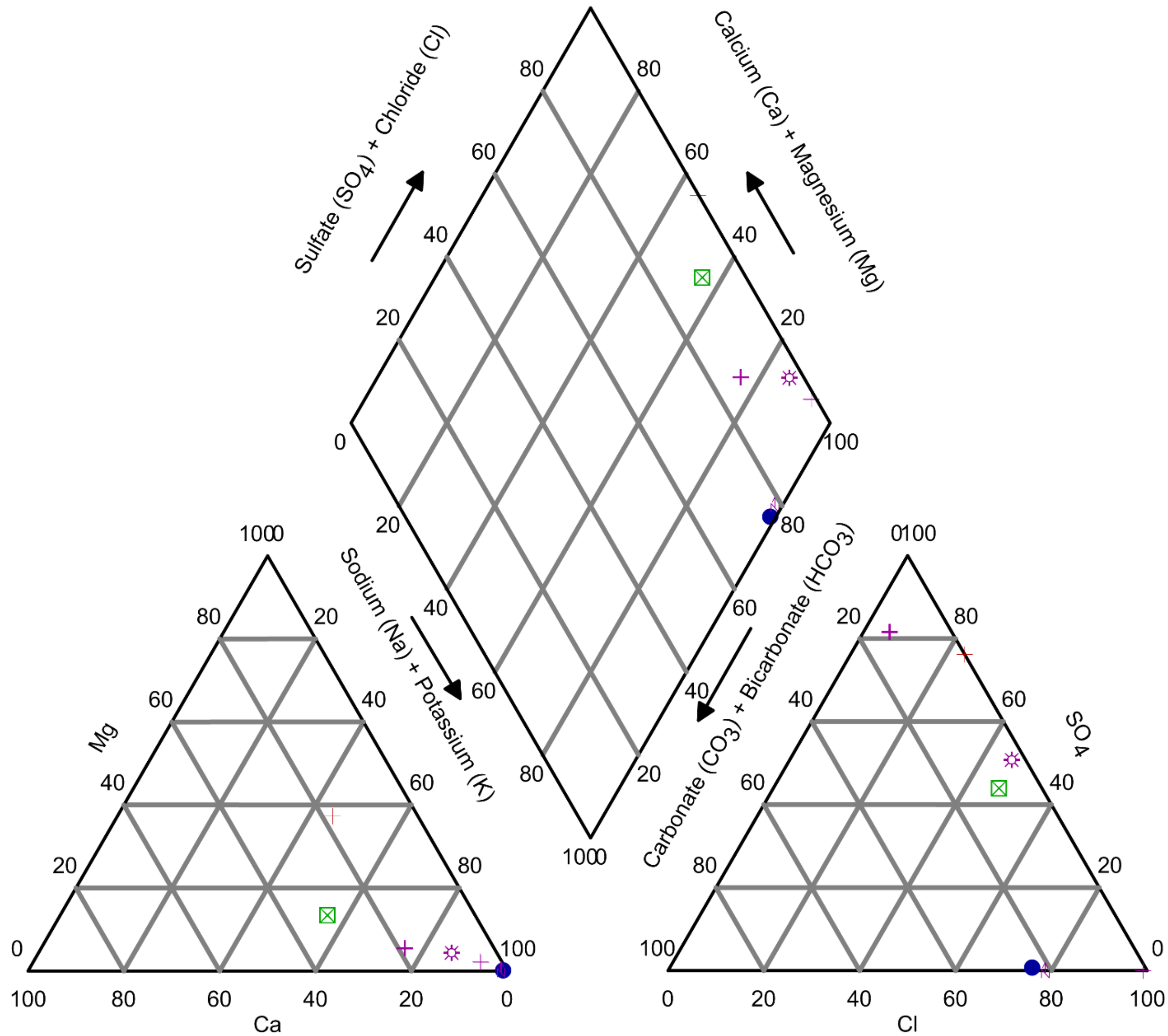

Figure 10-5. **Piper diagram of Blossom Aquifer sample results with total dissolved solids concentrations greater than 3,000 milligrams per liter.**

10.2. Radionuclides

Three wells sampled for gross alpha and gross beta had concentrations below the maximum contamination level of 15 and 50 picocuries per liter, respectively, for drinking water, as enforced by the Texas Commission on Environmental Quality (TCEQ). Two wells were tested for radium 226 and 228 and were below the maximum contamination level of five picocuries per liter. One well tested for dissolved uranium was found to have concentrations below the maximum contamination level of 30 micrograms per liter. A summary of results is included in Table 10-2.

Table 10-2. Radionuclide sample results from the Blossom Aquifer.

Well ID	Sample Date	Total Gross Alpha (pCi/L)[a]	Total Gross Beta (pCi/L)[a]	Dissolved Uranium (ug/L)[b]
		MCL = 15 pCi/L	MCL=50 pCI/L	MCL=30 ug/L
16-17-701	9/12/2001	0.4+-2.5	0.8+-3.1	--
16-17-701	7/9/2015	--	--	<1.00
17-24-801	9/13/2001	0.4+-2.2	1.5+-3.2	--
17-32-201	9/14/2001	3.6+-2.5	2.0+-2.9	--

[a] Picocuries per liter.

[b] Micrograms per liter.

11. Net Sand Analysis

Maps of both the basal sand total thickness and the basal sand net thickness, which is the portion of the basal sand that was selected as a target zone for water quality estimates are included as Figure 11-2Figure 11-1 and Figure 11-2. The basal sand total thickness represents that portion of the basal sand unit comprised of 100 percent sand, 65 percent sand with clay, and 35 percent clay with sand (the BRACS lithologic units defined for this project). The basal net sand thickness represents only that portion with lithology composed of 100 percent sand. The net sand intervals are equivalent to the clean sand intervals from the geophysical logs chosen for total dissolved solids estimates.

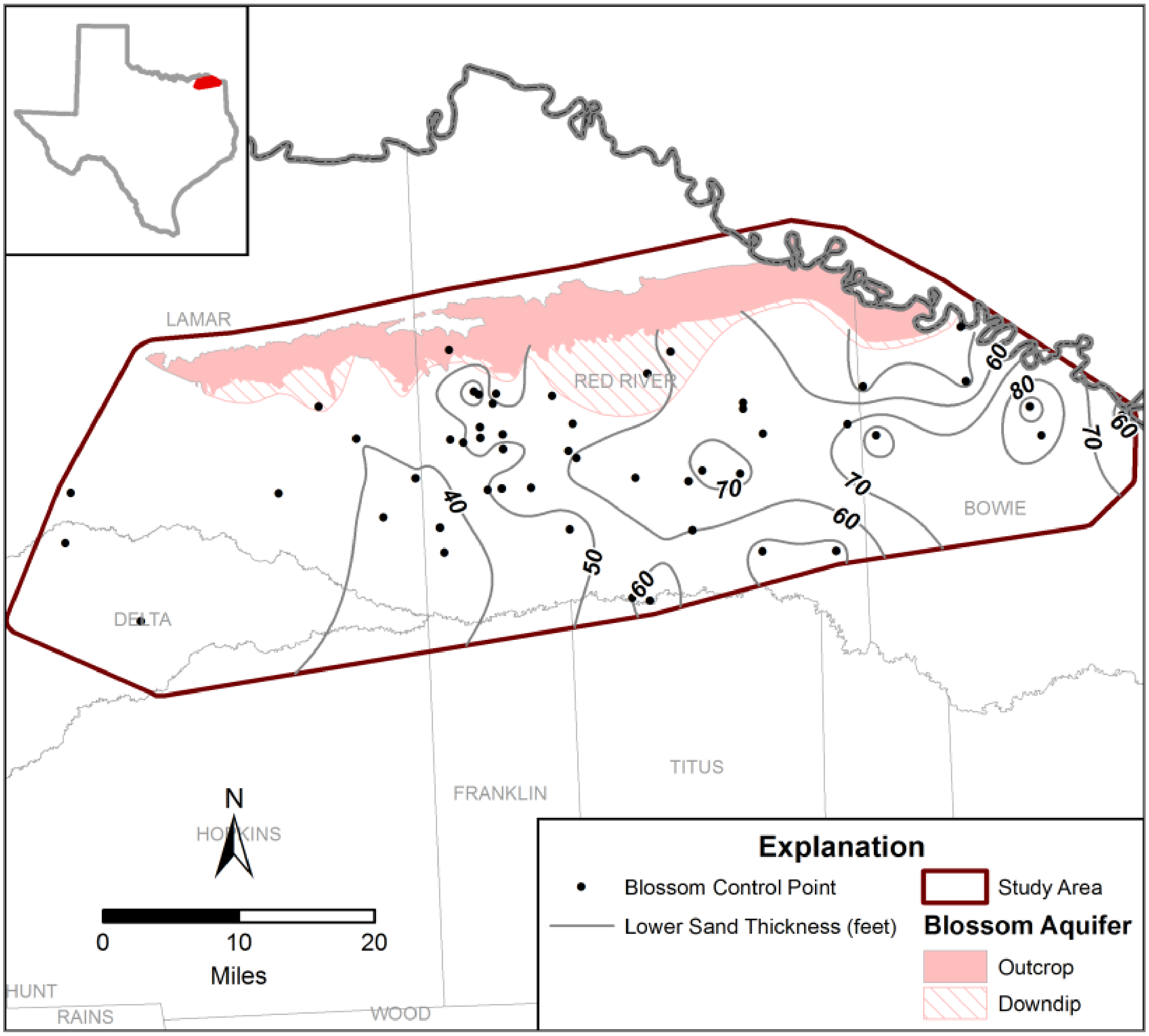

Figure 11-1. Basal sand total thickness.

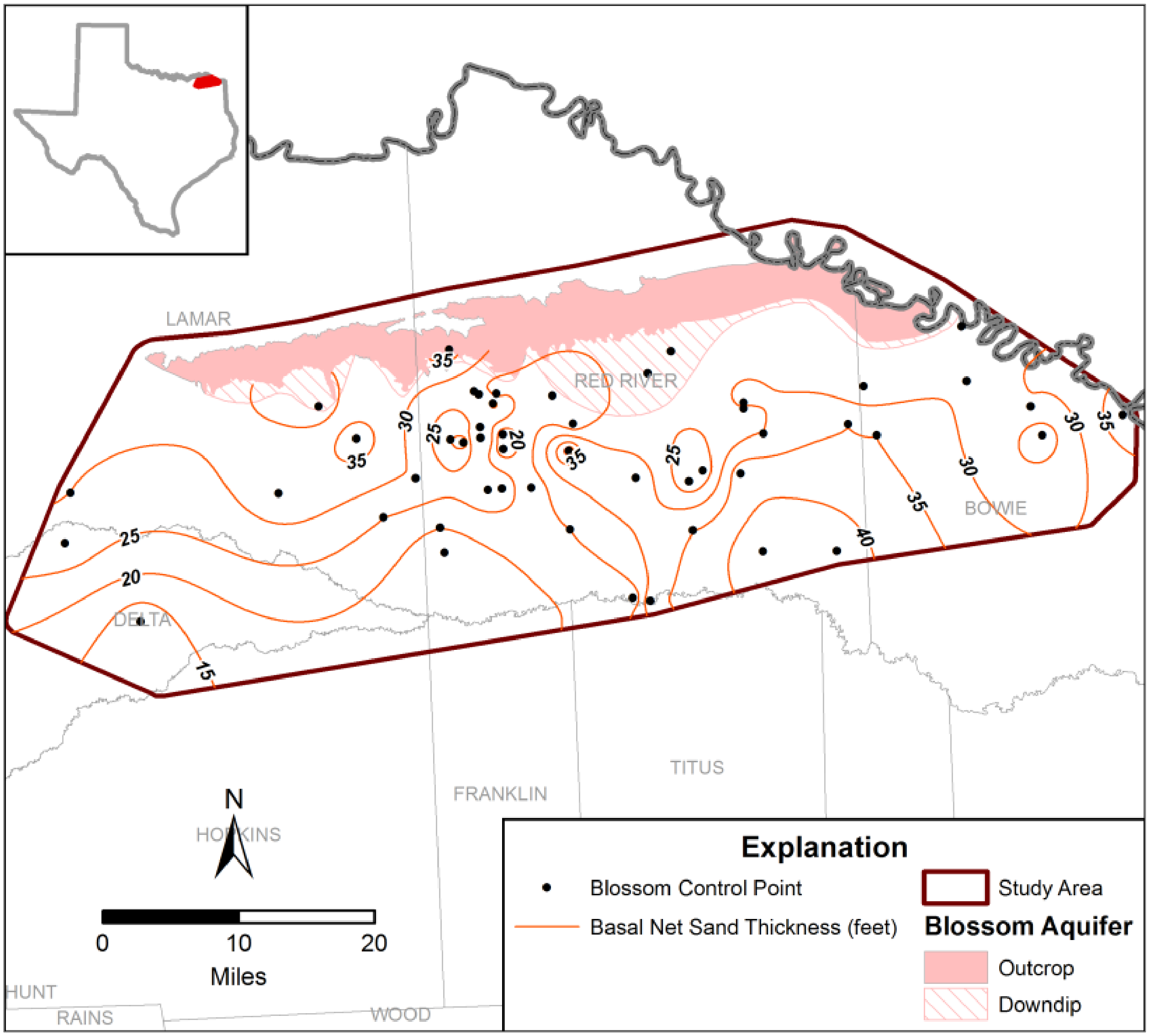

Figure 11-2. **Basal sand net thickness.**

12. Groundwater Volume Methodology

The primary assumption made for the Blossom Aquifer was that total dissolved solids values do not vary vertically, and that the only relevant portion of the aquifer is in the basal sand unit.

The Blossom Aquifer surfaces were interpolated using ArcGIS Pro's geostatistical analyst package using empirical bayesian kriging. Along with the aquifer itself, the top and bottom of the basal sand unit was also interpolated. The thickness for both the aquifer and the basal sand was determined by the interpolated surfaces. The assumption of no vertical change in total dissolved solids values allowed for the total dissolved solids point values to be interpolated using the same method, but was confined to only to the basal sand unit. The interpolated total dissolved solids values were then zoned into the four salinity categories.

With the total dissolved solids zones defined, the top, bottom, and thickness of each zone could be extracted. With these values, along with water level, specific yield, and specific storage the volumes for each zone could be estimated. The water level data came from the TWDB's groundwater database and was based on 2006 readings, which were interpolated for the entire area of the aquifer. The specific yield and specific storage values were extracted from the draft Blossom Aquifer groundwater availability model, taking the values from the third layer that represented the Basal sand unit. The method used to estimate the volumes is similar to the TERS calculations and was performed for each cell.

Volume Unconfined: Vunconfined =Area * Sy * (Water Level - Bottom)

Volume Confined: Total Volume = Vconfined + Vunconfined

Vconfined = Area * S * (Water level - Top)

Vunconfined = Area * Sy * Thickness

Variables:

Vunconfined	= storage volume due to water draining from the formation (Cubic feet)
Vconfined	= storage volume due to elastic properties of aquifer and water (Cubic feet)
Area	= area of the aquifer (square feet)
S	= storativity (unitless)
Sy	= specific yield (1/feet)
Water Level	= groundwater depth (feet)
Top	= top depth of aquifer (feet)
Bottom	= bottom depth of aquifer (feet)

The estimated volumes are split out by county and by salinity zone only. The volumes represent in-place volumes (groundwater in storage) within the project area, not recoverable volumes (groundwater that may be realistically produced from the aquifer) and are included in Table 12-1.

The modeling results indicate that over 3,056,000 ac-ft of in-place groundwater exist in the Blossom Formation in the project area. Of this total volume, approximately 40 percent of the available groundwater is within the moderately saline zone. Fresh and slightly saline water represent 18 and 17 percent of all available Blossom Aquifer groundwater and very saline groundwater contributes about 23 percent of the estimated volume located in the project area.

The in-place slightly saline (1,000- 3,000 milligrams per liter of total dissolved solids) groundwater volume was estimated to be 529,247 acre-feet and the moderately saline (3,000-10,000 milligrams per liter of total dissolved solids) groundwater volume was estimated at 1,268,483 acre-feet.

Table 12-1. Estimates of Blossom Aquifer brackish groundwater volumes (all units are acre-feet).

Zone/ County	Lamar	Red River	Bowie	Delta	Titus	Franklin	Hopkins	Total	Percent
Fresh	254,050	305,619						559,669	18%
Slightly Saline	127,769	387,087		14,391				529,247	17%
Moderately Saline	217,741	554,104	289,029	149,943	18,603	19,216	19,847	1,268,483	41%
Very Saline	10,975	279,650	362,694	31,349	14,844			699,512	23%
Total	610,535	1,526,460	651,723	195,683	33,447	19,216	19,847	3,056,911	100%

13. Geophysical Well Log Analysis and Methodology

13.1. Geophysical Log Total Dissolved Solids Interpretation and Direct Measurement from Samples

An Excel spreadsheet was created to perform calculations with parameter values read from the geophysical log using the following total dissolved solids methods: SP, Alger-Harrison (ratio), Estepp (modified ratio), and R_{wa} minimum (Estepp, 2010). Based on available log data, the most widely applicable methods are SP and Alger-Harrison. Porosity logs are rare, and therefore the R_{wa} minimum method is not applicable. The final calculated total dissolved solids is an average value derived from the methods used on any particular geophysical log. In most cases, this is an average based on SP and Alger-Harrison methods. However, if the total dissolved solids estimate using the SP method exceeded 10,000 milligrams per liter, then only the estimate calculated using the Alger-Harrison method was used. A sample calculation spreadsheet is shown on Figure 13-1 and Figure 13-2.

Surface temperature (T_s) is based upon 30-year normal data sets for the period of record 1981 through 2010 obtained from the National Oceanic and Atmospheric Administration National Centers for Environmental Information (2016). The average annual temperature was used for weather stations located in Paris, Clarksville and Dekalb for Lamar, Red River and Bowie Counties, respectively.

Bottom hole temperature (T_{bh}), and total depth of the hole (TD) are read from the log header. The average, or middle target zone depth is also determined from the log. Formation temperature (T_f) is derived by multiplying the temperature difference across the entire hole times the percent of total depth of the middle target zone. This value is then added to the surface temperature. $T_f = (T_{bh}-T_s)*(\text{target depth/total depth}) +T_s$. When T_{bh} was not available from the log header, T_{bh} was taken from nearby logs with similar total depths.

The Mean Ro method was determined to be non-applicable to the Blossom Aquifer due to the requirements of consistent porosity, cementation, lithology, and pore structure in the formation. The high bicarbonate concentrations found in the Blossom Formation may also disqualify this method.

Example geophysical logs with total dissolved solids estimations using the SP and Alger-Harrison methods are shown in Figure 13-3 and Figure 13-4. A step-by-step overview of the SP and Alger-Harrison calculations are included in this section. When the mud filtrate resistivity was not reported on the log header, it was calculated from the mud resistivity and the mud weight using the Overton and Lipson method for non-lignosulfonate muds or the Lowe and Dunlap relationship for fresh muds (Schlumberger Gen-3, 2009). A tabulation of relevant BRACS variables from the two example geophysical logs is included as Table 13-1.

13.1.1 Total Dissolved Solids Estimation Using the SP Method

1) Calculate the formation temperature (T_f) using the bottom hole temperature (BHT), the surface temperature (T_S), the depth of the target zone ($DEPTH$) and the total depth (TD):

$$T_f = (BHT - T_S)\ \frac{DEPTH}{TD} + \ T_S$$

2) Convert the mud filtrate resistivity R_{mf} to the mud filtrate resistivity at the formation temperature ($R_{mf_{T_f}}$) using the resistivity temperature on the log header (T_0):

$$R_{mf_{T_f}} = R_{mf}\left(\frac{T_0}{T_f}\right)$$

3) Correct the mud filtrate resistivity R_{mf} for mud type:

If $R_{mf} \geq 5.0\ \Omega m : freshwater\ mud : R_{mf}\ (cor) = 1.75\ R_{mf}$

4) Calculate the temperature dependent constant (K) at T_f:

$$K = 61 + 0.133\ T_f$$

5) Solve for the equivalent formation water resistivity (R_{we}) using the static spontaneous potential (SSP) and K:

$$R_{we} = 10^{\left[\frac{SSP+K\ (Log\ R_{mf})}{K}\right]}$$

6) Correct R_{we} for groundwater type; using either the sodium bicarbonate (1.33) or high bicarbonate constant (1.75) to calculate the formation water resistivity (R_W):

$$R_w = constant\ R_{we}$$

7) Convert (R_W) to the water resistivity at 75℉ (R_{w75}):

$$R_{w75} = \ R_W\ \left(\frac{T_f}{75}\right)$$

8) Convert $R_{mf_{75}}$ to the specific conductivity at 75 ̊F (Cw_{75}):

$$Cw_{75} = \frac{10{,}000}{R_{mf_{75}}}$$

9) Solve for total dissolved solids (TDS) using; using the TDS-C conversion factor (c_t):

$$TDS = c_t * C_{w_{75}}$$

13.1.2 Derivation of Alger-Harrison Method

This method is based upon the Archie formula for water saturation of an uninvaded zone (S_{xo}):

$$S_{xo} = \left(\frac{F * R_{mf}}{R_{xo}}\right)^{1/2}$$

where Rxo is the shallow resistivity read from the log, F is the formation factor, and R_{mf} is the mud filtrate resistivity read from the log header.

At 100 percent water saturation:

$$S_{xo} = \left(\frac{F * R_{mf}}{R_{xo}}\right)^{1/2} = 1 \text{ and } S_w = \left(\frac{F * R_w}{R_t}\right)^{1/2} = 1,$$

where R_w is formation water resistivity and R_t is the uninvaded formation resistivity therefore S_{xo} = S_w, and

$$\frac{F * R_{mf}}{R_{xo}} = \frac{F * R_w}{R_t}$$

And

$$\frac{R_{mf}}{R_{xo}} = \frac{R_w}{R_t}$$

So

$$R_{xo} * R_w = R_{mf} * R_t$$

R_w then becomes

$$R_w = \frac{R_{mf} * R_t}{R_{xo}}, or\ R_w = R_{mf}\left(\frac{R_t}{R_{xo}}\right),$$

The Alger-Harrison rearranges in terms of R_{xo}/R_t, which gives us:

$$R_w = R_{mf} \div \left(\frac{R_{xo}}{R_t}\right)$$

13.1.3 Total Dissolved Solids Estimation Using Alger-Harrison Method

1) Calculate the formation temperature (T_f) using the bottom hole temperature (BHT), the surface temperature (T_S), the depth of the target zone ($DEPTH$) and the total depth (TD):

$$T_f = (BHT - T_S)\ \frac{DEPTH}{TD} + T_S$$

2) Convert the mud filtrate resistivity.R_{mf} to the mud filtrate resistivity at the formation temperature ($R_{mf_{T_f}}$) using the resistivity at surface temperature:

$$R_{mf_{T_f}} = R_{mf_{T_S}} \left(\frac{T_S}{T_f}\right)$$

3) Correct R_{mf} for mud type:

$$R_{mf} \geq 5.0\ \Omega m : freshwater\ mud : R_{mf}\ (cor) = 1.75\ R_{mf}$$

4) Calculate (R_{xo}) / (R_t) ratio (an invasion corrections is optional)

$$\frac{R_{xo}}{R_t}$$

5) Calculate equivalent formation water resistivity (R_{we}):

$$R_w = R_{mf} \div \frac{R_{xo}}{R_t}$$

6) Correct R_{we} for groundwater type; using either the sodium bicarbonate (1.33) or high bicarbonate constant (1.75) to calculate the formation water resistivity (R_w):

$$R_{we} = constant\ R_w$$

7) Convert (R_W) to the water resistivity at 75℉ ($R_{w_{75}}$):

$$R_{w_{75}} = R_w\ \left(\frac{T_f}{75}\right)$$

8) Convert $R_{mf_{75}}$ to the specific conductivity at 75℉ (Cw_{75}):

$$C_{w_{75}} = \frac{10{,}000}{R_{mf_{75}}}$$

9) Solve for total dissolved solids (TDS) using; using the TDS-C conversion factor (c_t):

$$TDS = c_t\ *\ C_{w_{75}}$$

Bracs ID:	17845
API Num:	387-30234
County:	Red River
Formation:	Blossom
Date:	6/20/2016
Project:	Blossom Brackish
Log Type:	SP, dual ind,cond
Comments:	

Legend

(light blue)	Enter value from geophysical log
(light green)	Enter value from reference table
(tan)	Invasion correction
(orange)	Calculated Value
(yellow)	Calculated TDS

TEMP, DEPTHS			
Surface Temp, deg F:	30-yr normal	62.6	NOAA NCDC
Bottom Hole Temp, deg F:		137	Log header
Formation Temp (Tf), deg F:		77	Calc
Total Depth, ft:		5416	Log header
Average Zone Depth, ft:		1050	Log
Constant:	K	71	Calc
Cementation Exponent (range 1.3-2.4):	m	1.35	Table
Lithology Constant (default = 1):	a	1	Table
Fm Water Equivalent R/ Apparent Fm Water R			
SP Method	Rwe	0.49	Calc
Alger Harrison Method		0.65	Calc
Rwa Minimum TDS Method	Rwa	0.00	Calc
Groundwater Type Correction (Rw = C Rwe)			
SP Method	Rw	0.5	Calc
Alger Harrison Method	Rw	0.65	Calc
Rwa Minimum TDS Method	Rw	0.00	Calc
Constant a function of WQ	C	1	Table
Convert Rw to R at 75 deg F			
SP Method	R75	0.51	Calc
Alger Harrison Method	R75	0.67	Calc
Rwa Minimum TDS Method	R75	0.00	Calc
Specific Conductance @ 75 deg F, umhos-cm:			
SP Method	Cw	19712	Calc
Alger Harrison Method	Cw	14905	Calc
Rwa Minimum TDS Method	Cw	#DIV/0!	Calc
SC-TDS Conversion Factor	Ct	0.601	Table
		Blossom	
TDS = Ct x Cw, mg/L:			
SP Method	TDS	1	Calc
Alger Harrison Method	TDS	8958	Calc
Rwa Minimum TDS Method	TDS	#DIV/0!	Calc
Estepp	TDS	n/a	Calc
	calc avg	**8958**	

LOG CURVE VALUES		
SSP, zone, mV (include +-):	-37	Log
Rxo, shallow invaded zone, ohm-m:	5	Log
Rt, deep transition zone, ohm-m:	2	Log
Rxo/Rt	2.50	Calc
Invasion Correction (optional)	0	

POROSITY - Rwa METHOD only		
fn, neutron porosity	0	Log
fd, density porosity	0	Log
fND, Total porosity	0.00	Calc

==> Alger-Harrison:
Apply invasion correction to Rxo/Rt, if needed
(these are not built in to the spreadsheet)
Put your corrected Rxo/Rt here: ==> 0
If not doing a correction, enter a ZERO

==>

No Correction Factor Needed	*C = 1*
High Calcium Sulfate	*1.1*
Moderate Bicarbonate Waters	*1.33*
High Bicarbonate Waters (HCO3>50% TDS)	*1.75*

==> Estepp, 2010, Appendix C
default = 0.65

if SP>10,000 insert 0.9999

Figure 13-1. Calculation spreadsheet for water quality estimates (part 1).

Bracs ID:	17845
API Num:	387-30234
County:	Red River
Formation:	Blossom
Date:	42541
Project:	Blossom Brackish
Log Type:	SP, dual ind,cond
Comments:	

Legend

(blue)	Enter value from geophysical log
(green)	Enter value from reference table
(orange)	Calculated Value
(yellow)	Calculated TDS

MUD	spersene	
Rmf, ohm-m:	1.85	Log header
Rmf Temp (T0), deg F:	68	Log header
Rmf @ Tf, ohm-m:	1.63	Calc
Rmf(cor), ohm-m:	1.63	Calc

Freshwater Mud Correction:
If Rmf @Tf >= 5.0
Then Rmf(cor) = 1.75 Rmf

Rm, ohm-m:	2.10	Log header
Rm Temp (T0), deg F:	68	Log header

Check mud filtrate resistivity (TWDB contract)

	Mud Density, lbm/gal	9.5	Log header
	Km (from Schlumerger Gen-3)	0.927315	Log header
If 0.1<Rm<10	Rmf=Km(Rm)^1.07	2.1	calc- compare to M11
If 0.1<Rm<2	log(Rmf/Rm) = 0.396-(0.0475xrm)	1.8	calc- compare to M11

	DT_TopBlsm	DT_BotBlsm	BlsmTHk	LandELev	EL_Top Blsm	EL_BotBlsm
Fm	685	1055	370	408	-277	-647
Sd Ut	1000	1055	55			
Clean Sd	1025	1055	30	1.6	Lateral correction multiplier for AO	

Latitude, dec deg	33.511169
Longitude, dec deg	-95.206734

Figure 13-2. Calculation spreadsheet for water quality estimates (part 2).

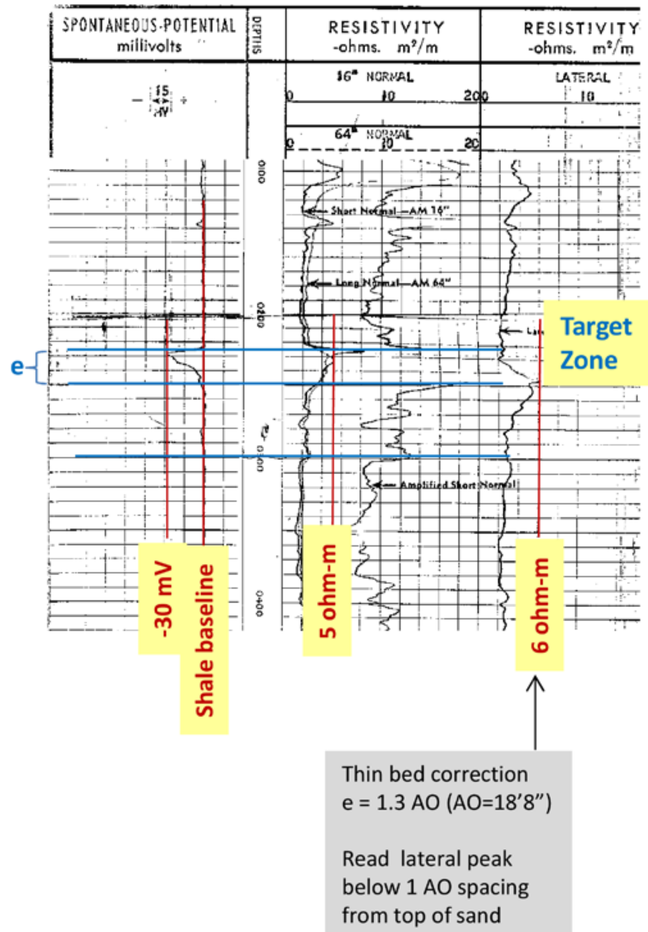

Figure 13-3. BRACS ID# 68163 geophysical log total dissolved solids estimation.

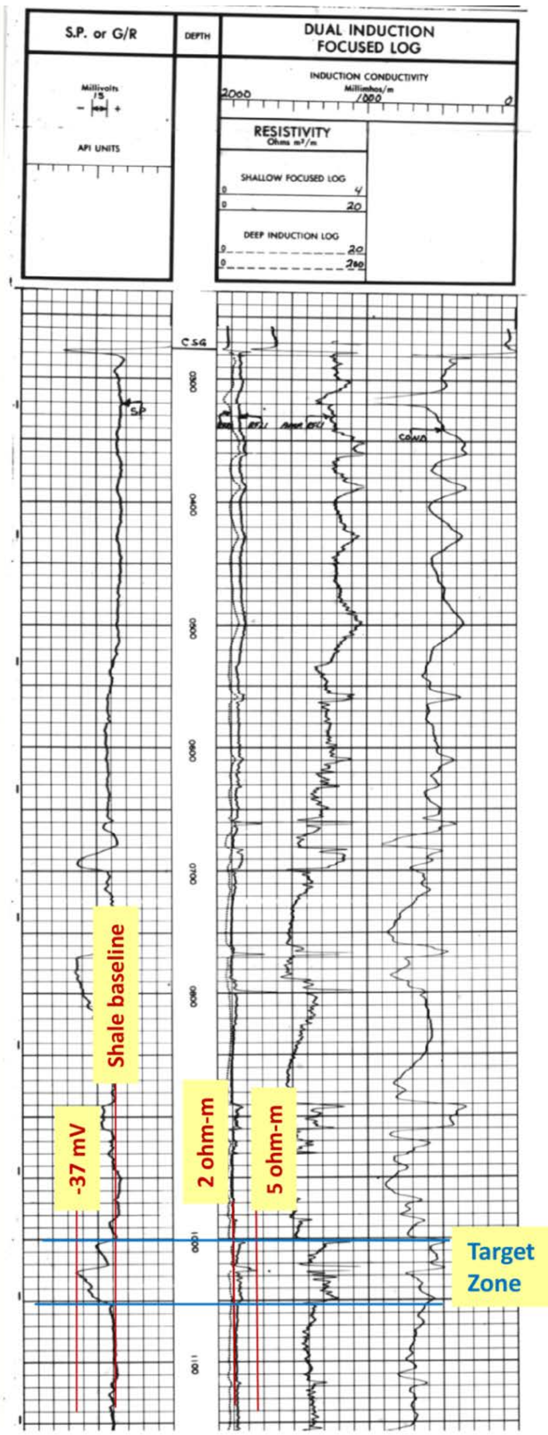

Figure 13-4. **BRACS ID #17845 geophysical log total dissolved solids estimation.**

Table 13-1. Total dissolved solids estimates from geophysical logs.

Field Description	Figure 13-4		Figure 13-3	
WELL_ID	17845	17845	68163	68163
FOR_KEY_*	387-30234	387-30234	Q-50	Q-50
CON_TDS_ METHOD	SP Method	Alger Harrison	SP Method	Alger Harrison
DF	1,050	1,050	230	230
TDS_INTERPRETED	>10,000	8,958	2,301	3,160
RXO	5.0	5.0	6.0	6.0
RO	2.0	2.0	5.0	5.0
RXO_RO	2.5	2.5	1.2	1.2
CT	0.6	0.6	0.6	0.6
RWE	0.49	0.65	1.62	3.62
RWE_RW_COR	1	1	1.75	1.75
RW	0.49	0.65	2.84	2.07
RW75	0.51	0.67	2.61	1.90
CW	19,712	14,905	3,829	5,258
SP	-37	0	-30	0
K	71.2	0	70.2	0
DT	5,416	5,416	1,316	1,316
RM	2.1	2.1	4.0	4.0
RM_TEMP	68	68	72	72
TS	62.6	62.6	62.6	62.6
TBH	137	137	99	99
RMF	1.85	1.85	4.16	4.16
RMF_TEMP	68	68	72	72
TF	77	77	69	69
RMF_TF	1.63	1.63	4.34	4.34

WELL_ID: BRACS unique well ID.

FOR_KEY_*: The foreign key in a text format or a numeric format assigned to this well record.

DF: Depth of the assessed formation of interest, not corrected for kelly bushing height. Units are feet below ground surface.

CON_TDS_METHOD: Method(s) used to determine TDS. Refers to a lookup table.

TDS_INTERPRETED: Interpreted total dissolved solids (TDS) concentration at the depth of formation. The units of are milligrams per liter total dissolved solids.

RXO: Resistivity of the invaded zone in units of ohm-meter.

RO: Resistivity of the saturated formation in units of ohm-meter. The formation should be 100 percent saturated with water.

RXO_RO: Calculated from: (RXO / RO). The value is dimensionless.

RWE: Resistivity of water equivalent in units of ohm-meter.

RWE_RW_COR: Correction factor for high anion waters using the SP Method and the Rwa Minimum Method (Estepp, 1998). The value units are dimensionless.

CT: Total dissolved solids divided by specific conductance. The field value is less than one and is dimensionless.

RW: Resistivity of the water as determined by geophysical well log analysis. Units are ohm-meters.

RW75: Resistivity of the water as determined by geophysical well log analysis corrected for 75 degrees Fahrenheit. Units are ohm-meters.

CW: Conductivity of the water as determined by geophysical well log analysis corrected for 75 degrees Fahrenheit. Units are microsiemens per meter.

SP: Spontaneous potential value in units of + or – millivolts.

K: The constant, K, which is dependent on temperature and is used in equations for the SP method (Estepp, 1998).

DT: The total depth of the log (not the total depth of the hole).

RM_TEMP: Temperature of the drilling mud when the drilling mud was tested for resistivity. Temperature is in units of degrees Fahrenheit.

RMF_COR: Correction factor for resistivity of the mud filtrate when using the SP method of analysis.

TS: Temperature is in units of degrees Fahrenheit and is a 30-year local climate normal.

TBH: Temperature at the bottom of the hole at the time the well was logged. Temperature is in units of degrees Fahrenheit.

RMF: Resistivity of the drilling mud filtrate when the well was logged. Resistivity is in units of ohm-meter.

RMF_TEMP: Temperature of the drilling mud filtrate when the drilling mud filtrate was tested for resistivity. Temperature is in units of degrees Fahrenheit.

TF: The temperature at the depth of formation of interest [DF]. Units are degrees Fahrenheit.

RMF_TF: Resistivity of the mud filtrate at the temperature of formation of interest. Resistivity is in units of ohm-meter.

13.2. Log Correction Factor Determination

The following corrections will likely be necessary to derive water quality from the available geophysical logs for the fresh and brackish portions of the Blossom Aquifer:

13.2.1 High Bicarbonate Correction

The Blossom water quality sample data indicates the portion of total dissolved solids that are due to bicarbonate ions ranges from zero to 96 percent and averages 45 percent. The percent varies quite significantly, therefore correction factors of 1.33 and 1.75 were used to correct the formation water apparent equivalent resistivity for groundwater type. In freshwater with bicarbonate concentrations exceeding 50 percent of total dissolved solids, 1.75 was used. If the bicarbonate percentage was between 20 and 50 percent, then 1.33 was used. The default was 1.0 (no correction) in the brackish portion of the aquifer. The chart of equivalent formation water resistivity (R_{we}) versus the true formation water resistivity (R_w) curve is modified from Schlumberger (Estepp 2010, Figure 1-1, p. 3).

13.2.2 Static SP Bed Thickness Correction Factor

In beds with approximately ten feet or less of thickness, the static (maximum) SP response can be attenuated due to a lack of a sufficiently thick target zone (clean sand) to allow adequate amount of time and/or space to record the maximum static SP. To correct, the maximum SP from the target zone is recorded and then corrected to static SP using either a chart or empirical equation (Asquith & Gibson, 1982). The spreadsheet currently incorporates the equation $SSP = -K \times \log (R_{mf}/R_o)$ in the SP method calculations. The average thickness of the clean sand within the (lower) Blossom Aquifer screened intervals is 26.5 feet. The clean sand portion of the lower Blossom Sand will be evaluated since it is typically the thickest sand and essentially defines the maximum vertical extent of the aquifer. The average thickness of the lower Blossom Sand unit is approximately 65 feet in the geophysical logs reviewed for this report. This correction will be incorporated where needed, although generally, bed thickness of the clean sand within the screened section of the Blossom is unlikely to require the correction.

13.2.3 Bed Thickness Correction

AO is the distance between lateral tool electrodes, and is typically 18.67 feet. In resistive formations with a bed thickness greater than one AO spacing the lateral curve will record lower resistivity near the top of the bed and higher resistivity in the lower portion of the bed. The lateral curve will also exhibit a decay zone, or dead zone at the top of a formation with a thickness greater than one AO-spacing. To accommodate this characteristic of the lateral tool, borehole corrections were made based upon the thickness of the zone of interest.

Corrections were made when reading deep resistivity from lateral curves. The resistivity was read from the lateral curve using bed thickness (e) = 1.3 AO on two logs and e = 1.5AO from 3 logs, depending on the thickness of the clean sand in that particular log. See Figure 13-3for an example of a bed thickness correction using e = 1.3 AO. If sand thickness was 1.3 times the AO spacing (approximately 25 feet), the lateral resistivity is read from the peak of the curve (below the dead zone). If sand thickness was equal to about 1.5 times the AO spacing (nearly 30 feet), the 2/3 rule was used, which takes the difference between the resistivity reading at the peak value and at one AO spacing from the top of the bed at the base of the dead zone (Estepp, 1998).

14. Potential Brackish Groundwater Production Area Analysis and Modeling Methodology

14.1. Exclusion Criteria

Potential production area may only exist in locations that meet the criteria of House Bill 30. House Bill 30 states that these areas:

- Are separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability or water quality in any area of the same or other aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids level of 1,000 milligrams per liter or less at the time of designation of the zones.
- Are not located in an aquifer, subdivision of an aquifer, or geologic stratum that has an average total dissolved solids level of more than 1,000 milligrams per liter and is serving as a significant source of water supply for municipal, domestic, or agricultural purposes at the time of designation of the zones, or in an area of a geologic stratum that is designated or used for wastewater injection through the use of injection wells or disposal wells permitted under Chapter 27.

Using these criteria for guidance, several public supply, irrigation, domestic, and injection wells were determined to qualify for exclusion. Two-mile buffer zones were applied to all Nacatoch wells. One-mile buffers were applied to wells for which reports were found in the state driller report database. The summary table (Table 14-1) lists the type of well and total count of the wells found by source. Alluvium wells completed within less than 200 feet of vertical separation from the top of the Blossom were excluded. Note there is overlap between the Texas Commission on Environmental Quality and the TWDB’s datasets for public supply wells. Tables of all excluded wells are included as Appendix 19-1. Any area between the 1,000 and 10,000 milligrams per liter total dissolved solids extents that were not excluded using these criteria were considered for evaluation as potential production areas (Figure 14-2).

Table 14-1. Exclusion wells summary

Source	Well Use	Count	Aquifer Designation
TCEQ	Public Supply	7	Blossom
TWDB GWDB	Domestic	48	Blossom
TWDB GWDB	Irrigation	6	Blossom
TWDB GWDB	Public Supply	5	Blossom
TWDB GWDB	Domestic	5	Alluvium
State Driller Report DB	Domestic	26	Blossom, Alluvium
State Driller Report DB	Irrigation	8	Blossom, Alluvium
State Driller Report DB	Public Supply	1	Blossom, Alluvium

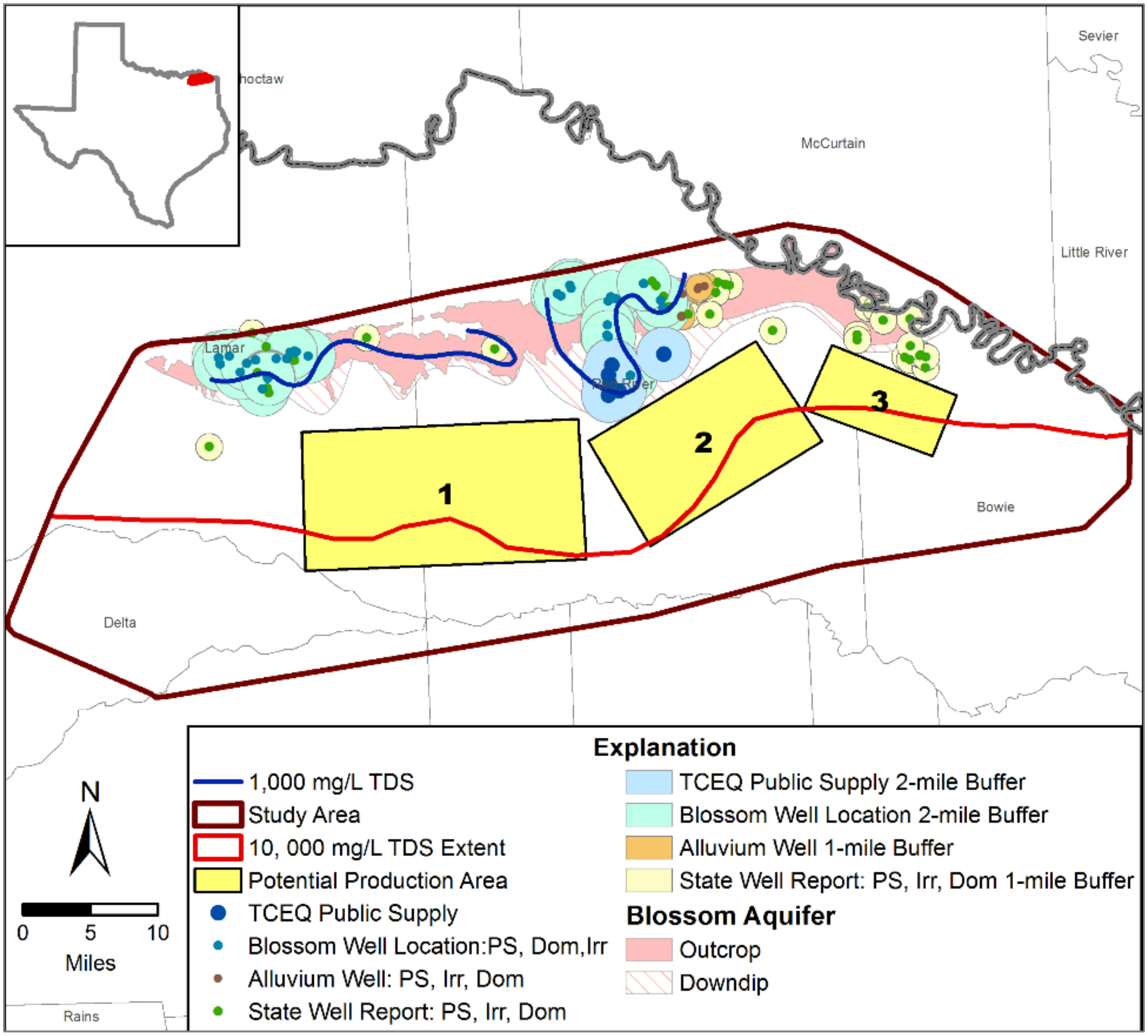

Figure 14-1. Combined exclusion areas and potential production areas.

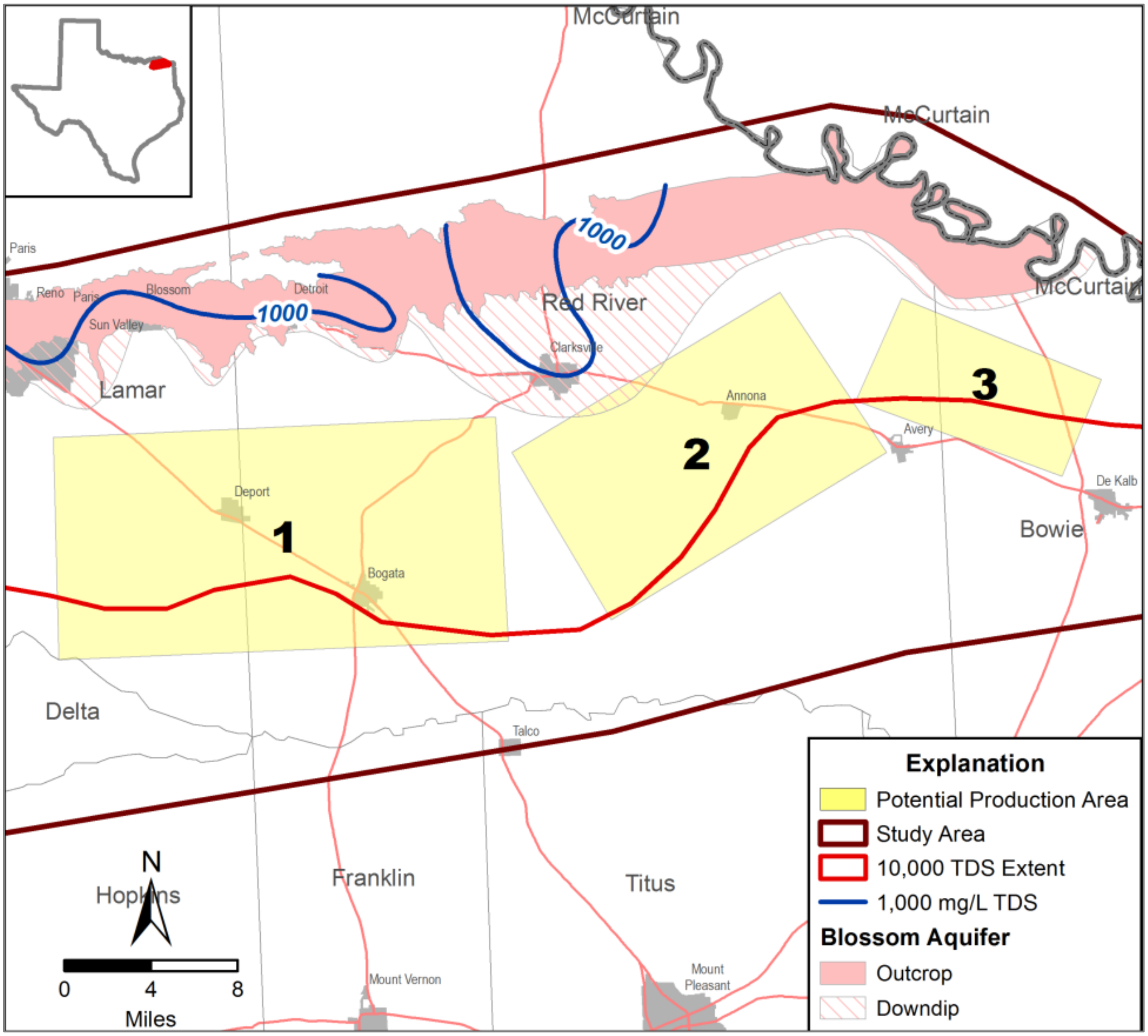

Figure 14-2. Potential production areas 1, 2 and 3.

14.2. Pumping Analysis and Results For 30- and 50-Year Periods

Theis drawdown analysis was performed for the three potential production areas to understand the effect pumping in these areas would have on nearby locations (Figure 14-3 through Figure 14-20). Each potential production area was pumped at a low, medium, and high rate and for a period of 30 and 50-years (Table 14-2).

Table 14-2. Blossom Aquifer simulated pumping volumes

Pumping Range	Pumping Volume (acre-feet per year)
Low	50
Medium	100
High	300

Numerous well fields were modeled for each potential production area. The well field set up was the same for each scenario, but placed in different locations throughout the potential production areas to understand the different effects they could have at various locations. The well field set up remained the same as a series of six wells offset by 4,000 ft. It was assumed that the wells fully screened the sand portions of the Blossom aquifer. The properties for the each potential production area were taken from the draft Blossom groundwater availability model and averaged over the potential production area. The storativity values were calculated as the average layer thickness within each potential production area times the average specific storage term for each cell. The transmissivity was calculated in the same way, but using the average hydraulic conductivity to get the transmissivity value (Table 14-3).

The well fields selected for each potential production area are those wellfields which have the least extensive amount of up-dip drawdown. The drawdown contours for each of the selected well fields and associated potential production areas are included as Figure 14-3 through Figure 14-20. The approximate minimum and maximum impact, in feet of drawdown, to the nearest exclusion wells at each of the potential production areas are summarized in Table 14-4. Minimum drawdowns are 100 acre-feet 30-year scenarios, and maximums are from 500 acre-feet 50-year scenarios. Potential production areas 1 appears to have the least impact to up-dip exclusion wells with less than one to ten feet of drawdown.

Table 14-3. Blossom Aquifer properties for the modeled potential production areas.

Potential Production Area	Storativity	Transmissivity (gallons per day per foot)
1	0.001	1,029
2	0.0014	1,441
3	0.0012	1,235

Table 14-4. Summary of estimated impact on nearest exclusion wells, in feet of drawdown

Potential production area	Minimum drawdown (feet)	Maximum drawdown (feet)
1	less than 1	10
2	3	12
3	7	50

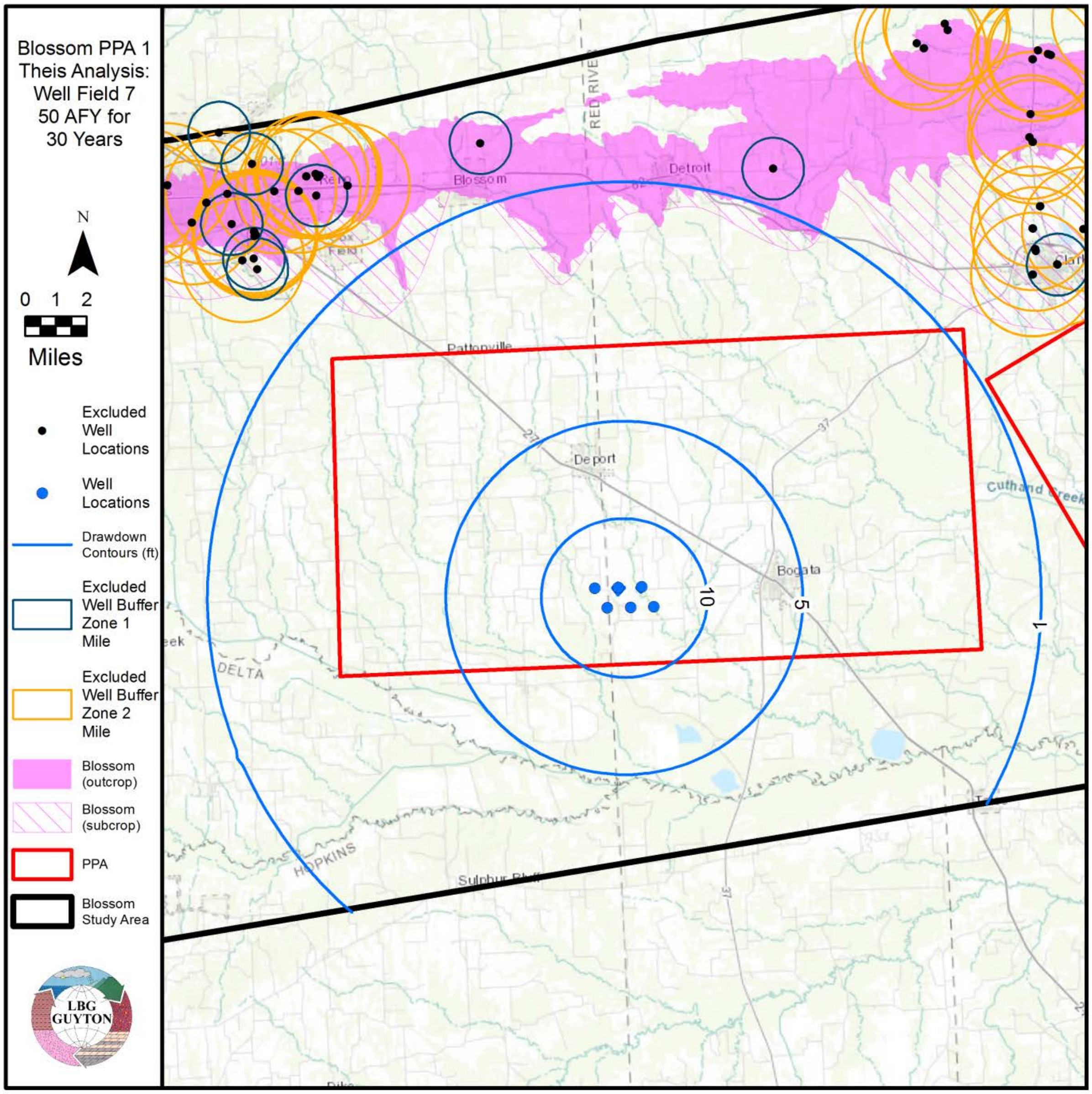

Figure 14-3. **Potential production area 1: 30-year drawdown at 50 acre-feet per year.**

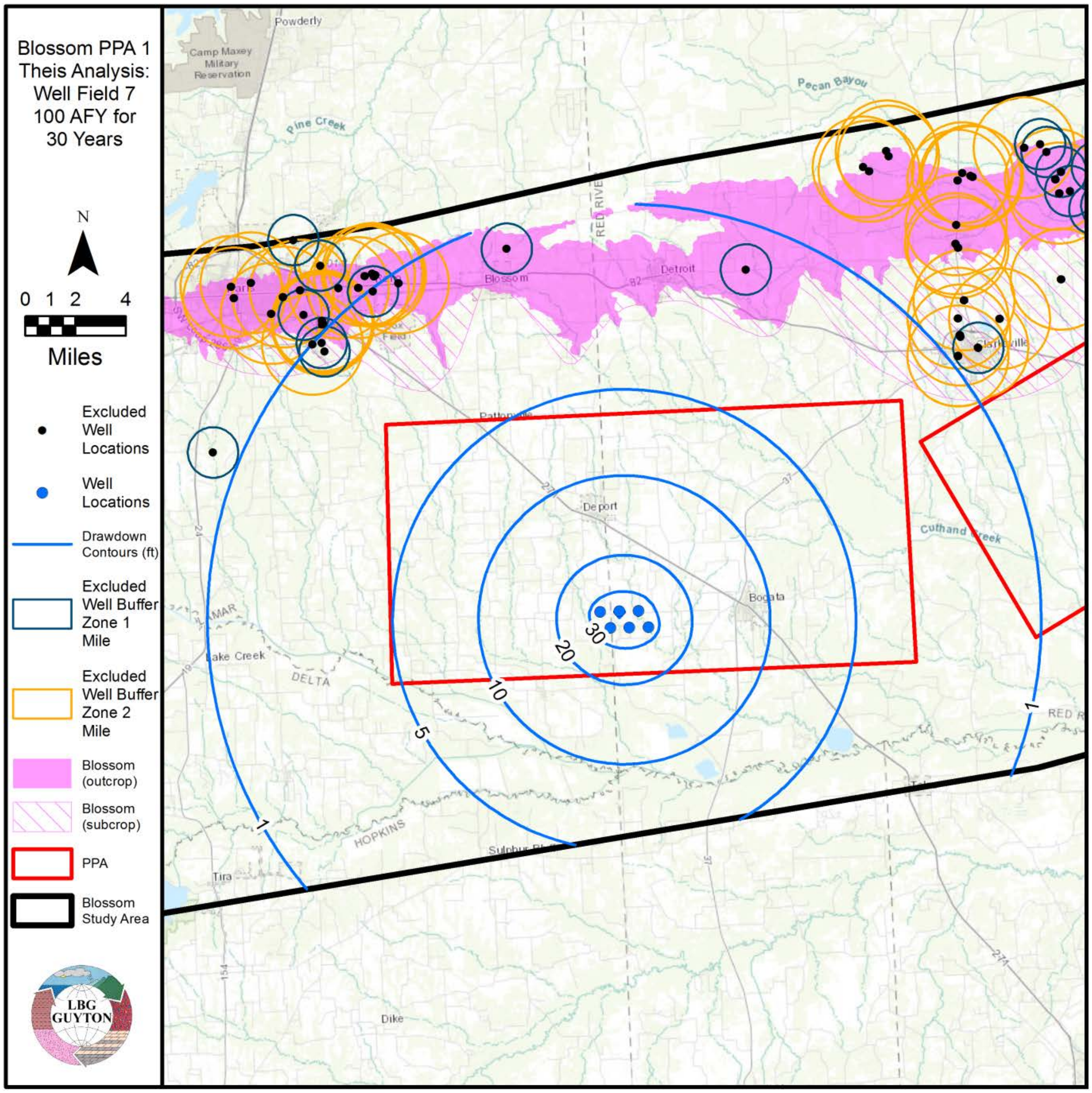

Figure 14-4. Potential production area 1: 30-year drawdown at 100 acre-feet per year.

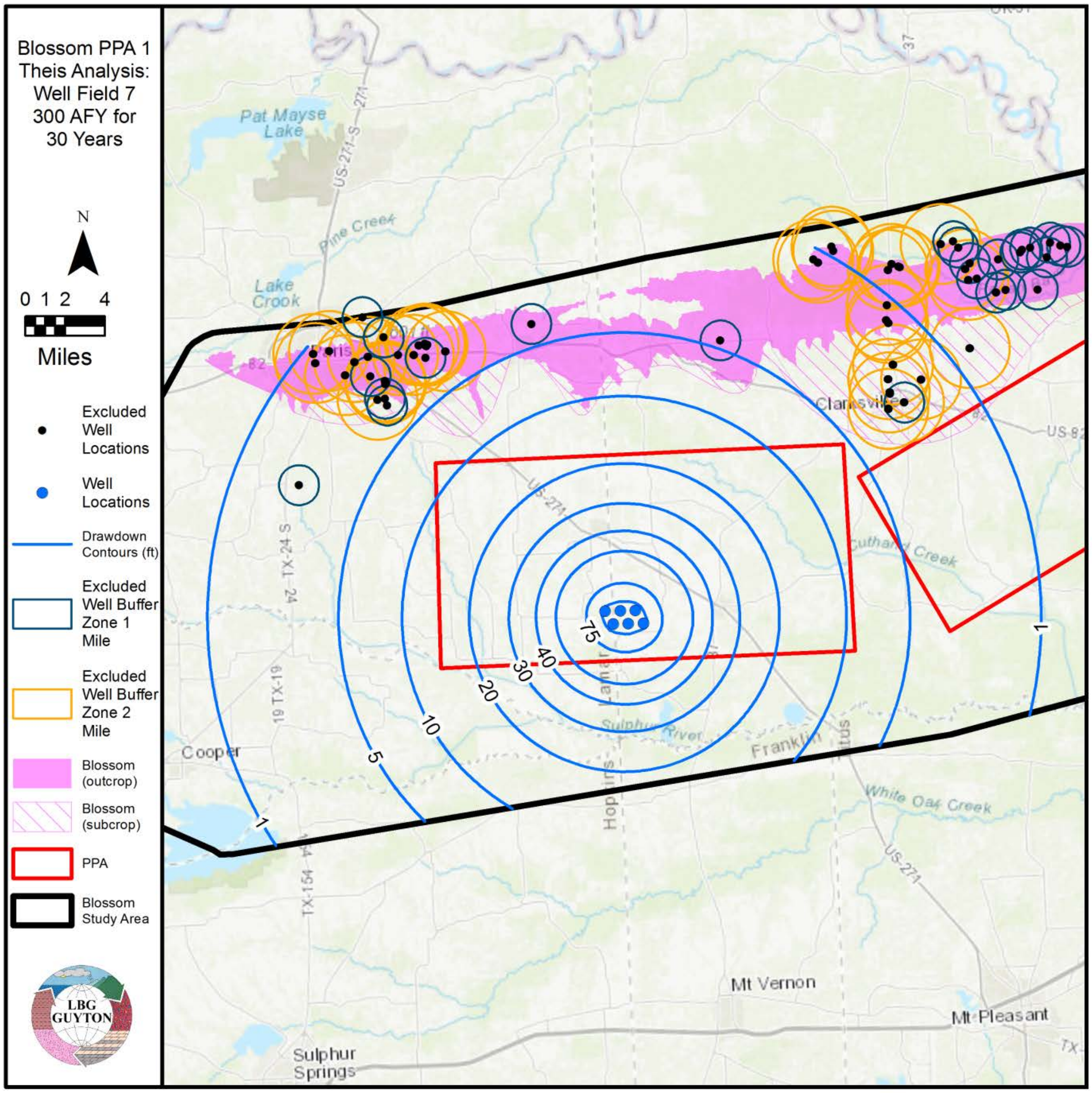

Figure 14-5. **Potential production area 1: 30-year drawdown at 300 acre-feet per year.**

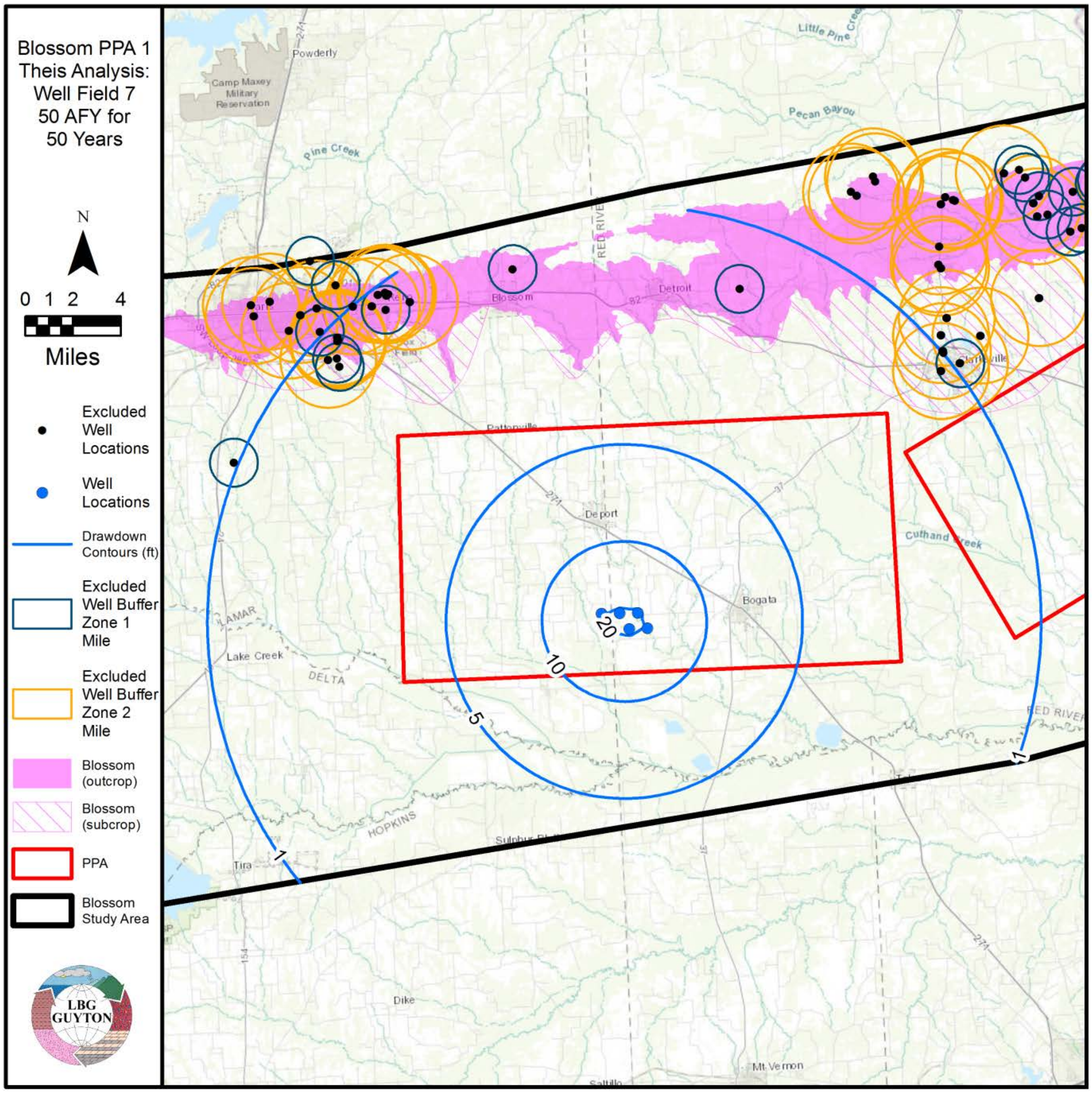

Figure 14-6. **Potential production area 1: 50-year drawdown at 50 acre-feet per year.**

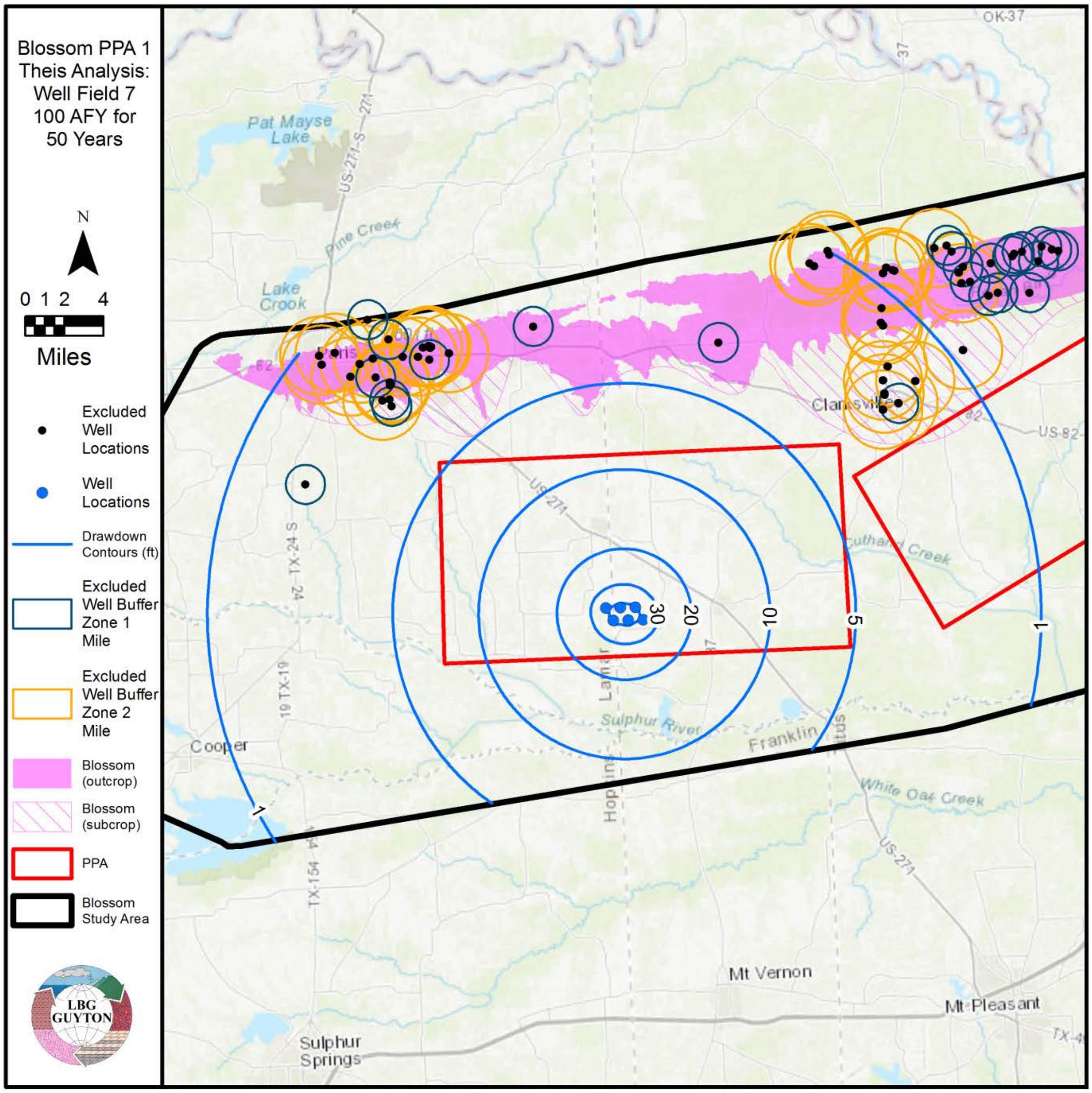

Figure 14-7. Potential production area 1: 50-year drawdown at 100 acre-feet per year.

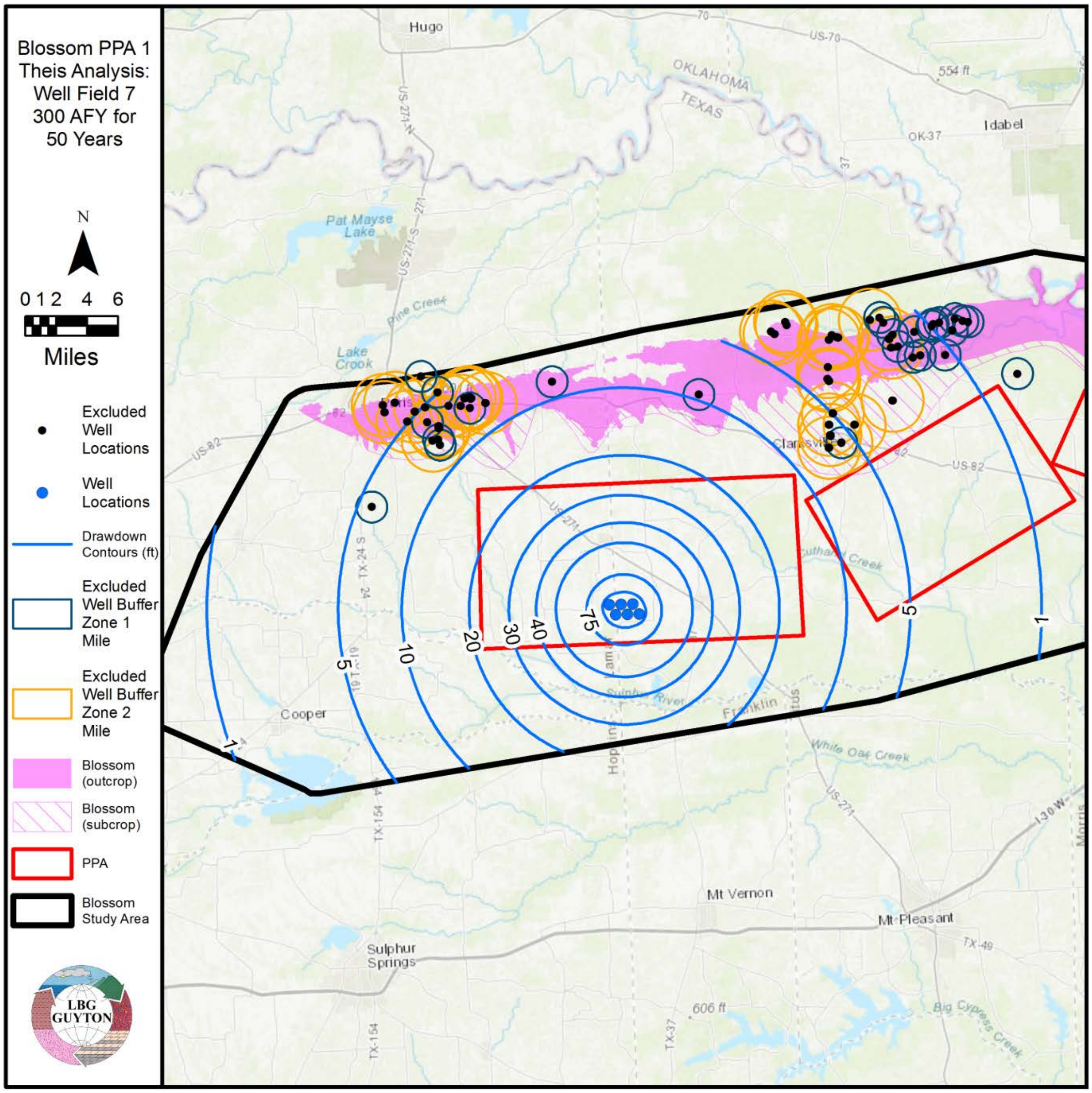

Figure 14-8. **Potential production area 1: 50-year drawdown at 300 acre-feet per year.**

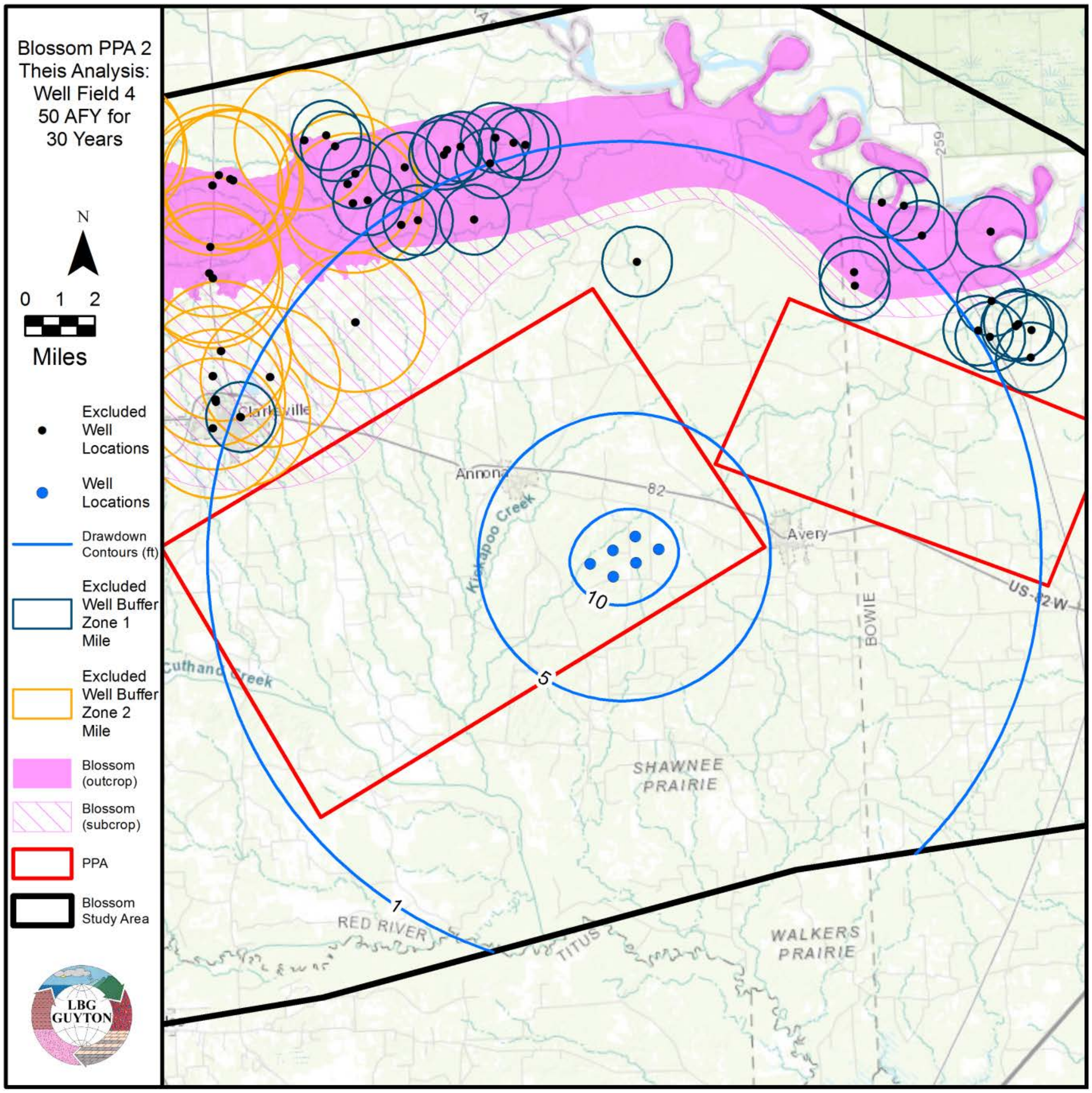

Figure 14-9. Potential production area 2: 30-year drawdown at 50 acre-feet per year.

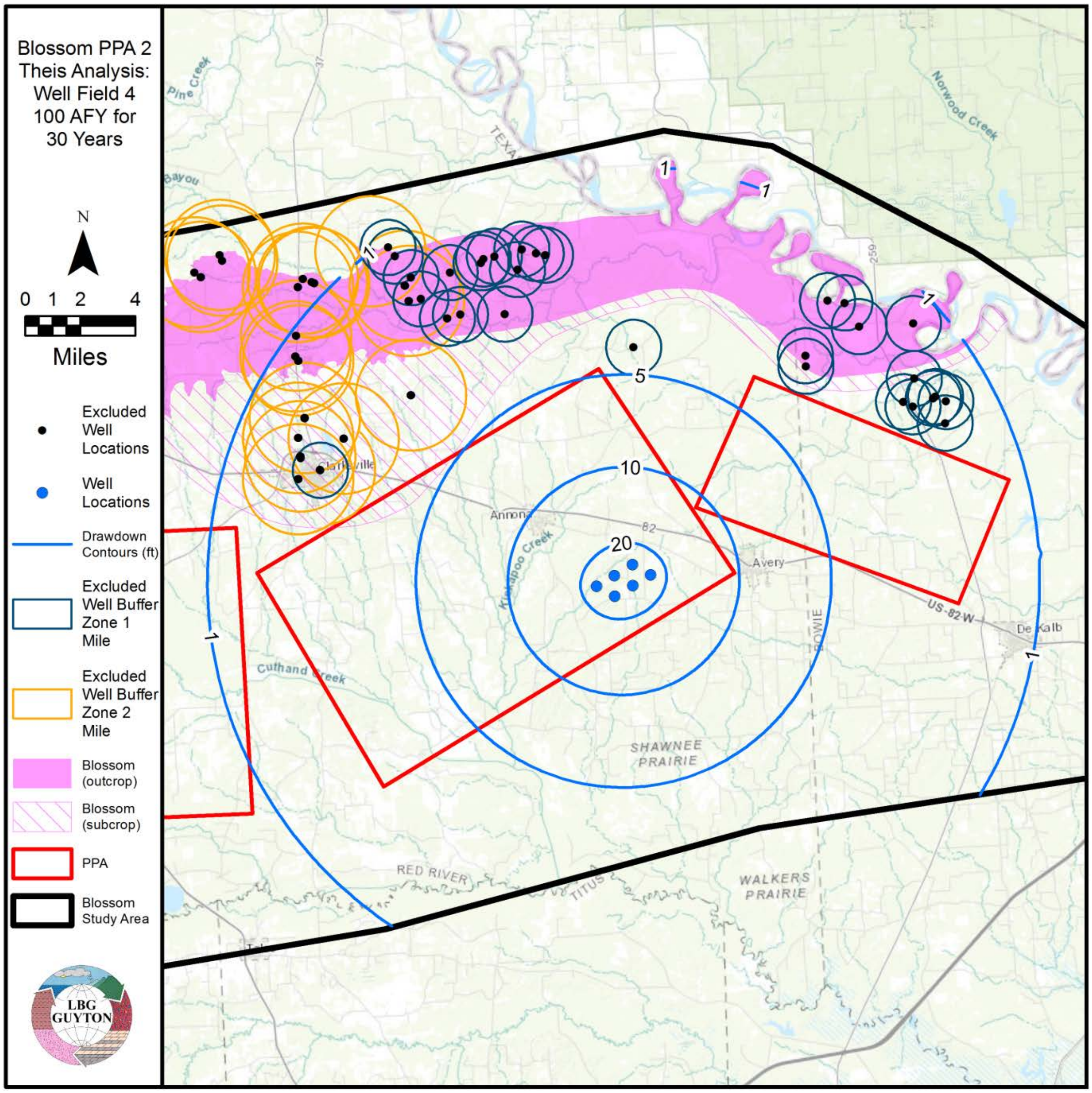

Figure 14-10. Potential production area 2: 30-year drawdown at 100 acre-feet per year.

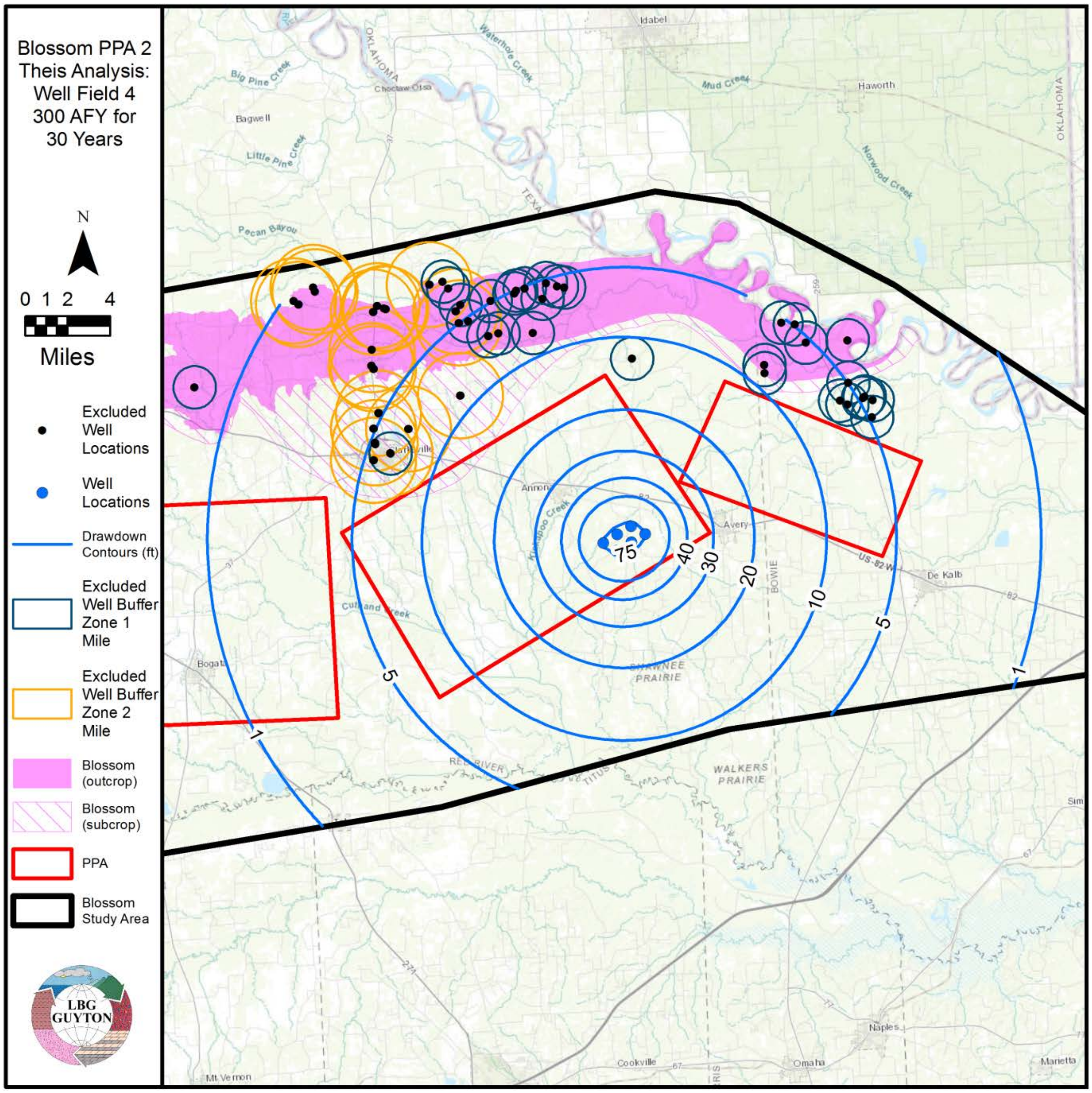

Figure 14-11. Potential production area 2: 30-year drawdown at 300 acre-feet per year.

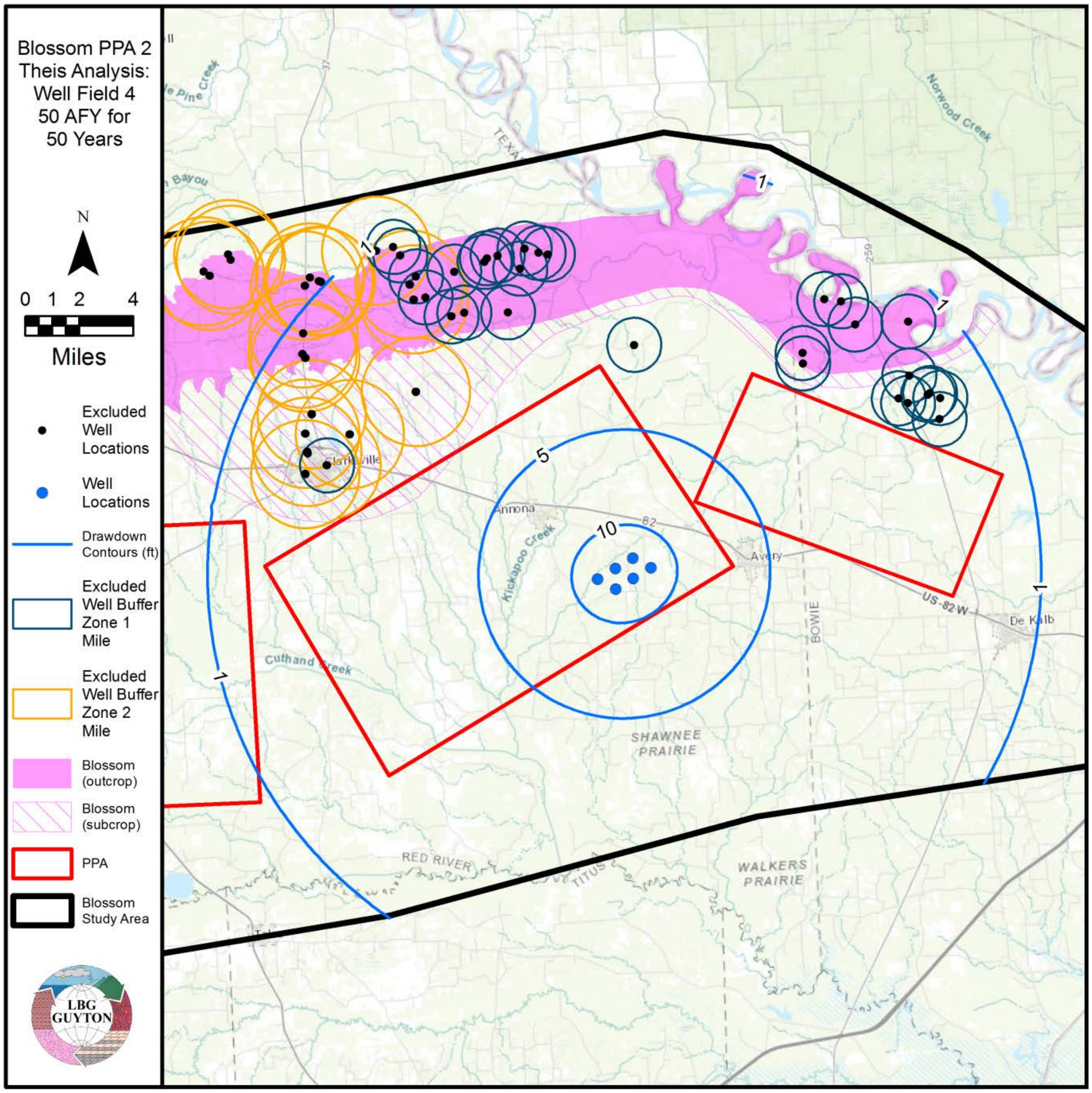

Figure 14-12. Potential production area 2: 50-year drawdown at 50 acre-feet per year.

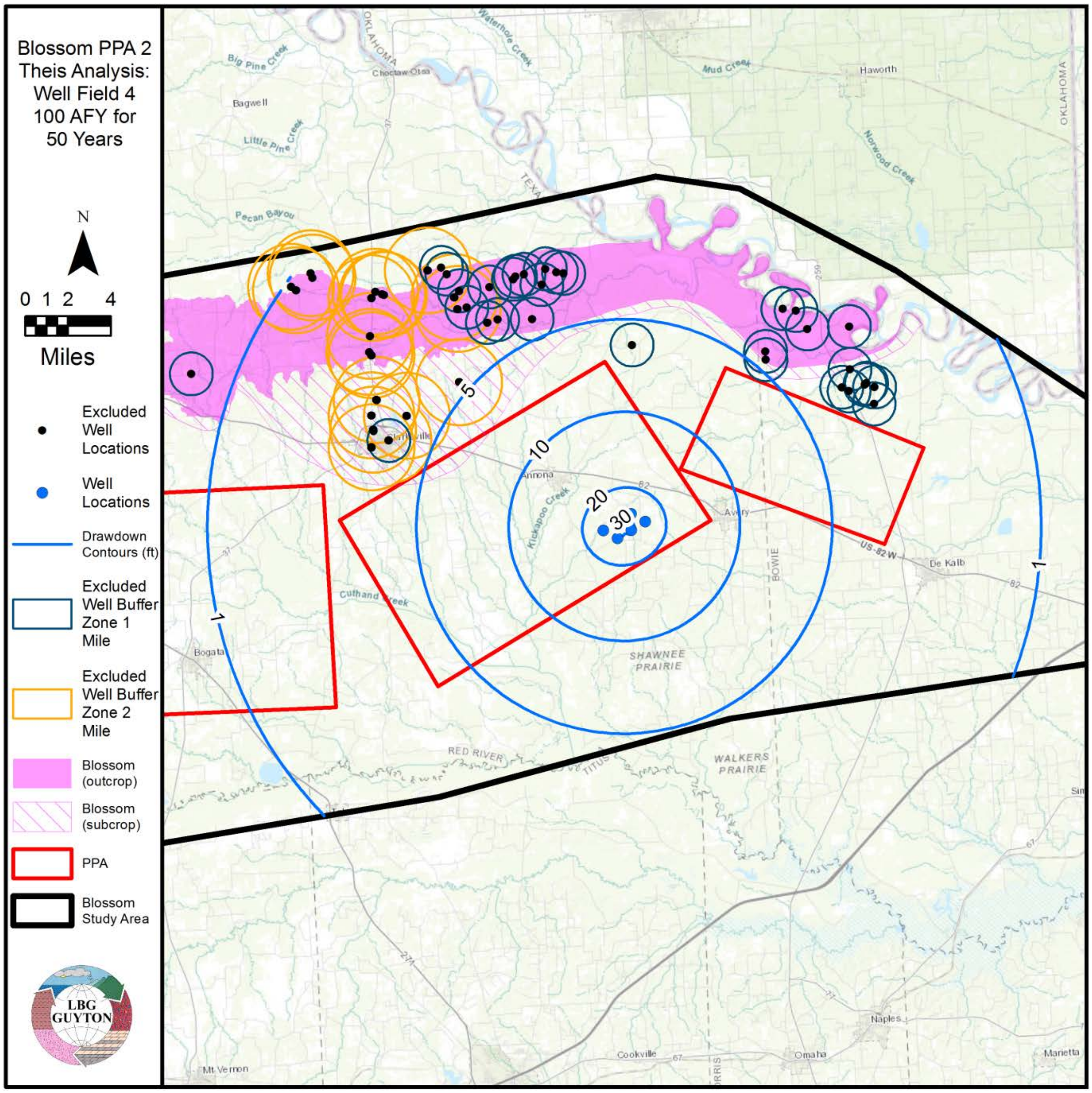

Figure 14-13. Potential production area 2: 50-year drawdown at 100 acre-feet per year.

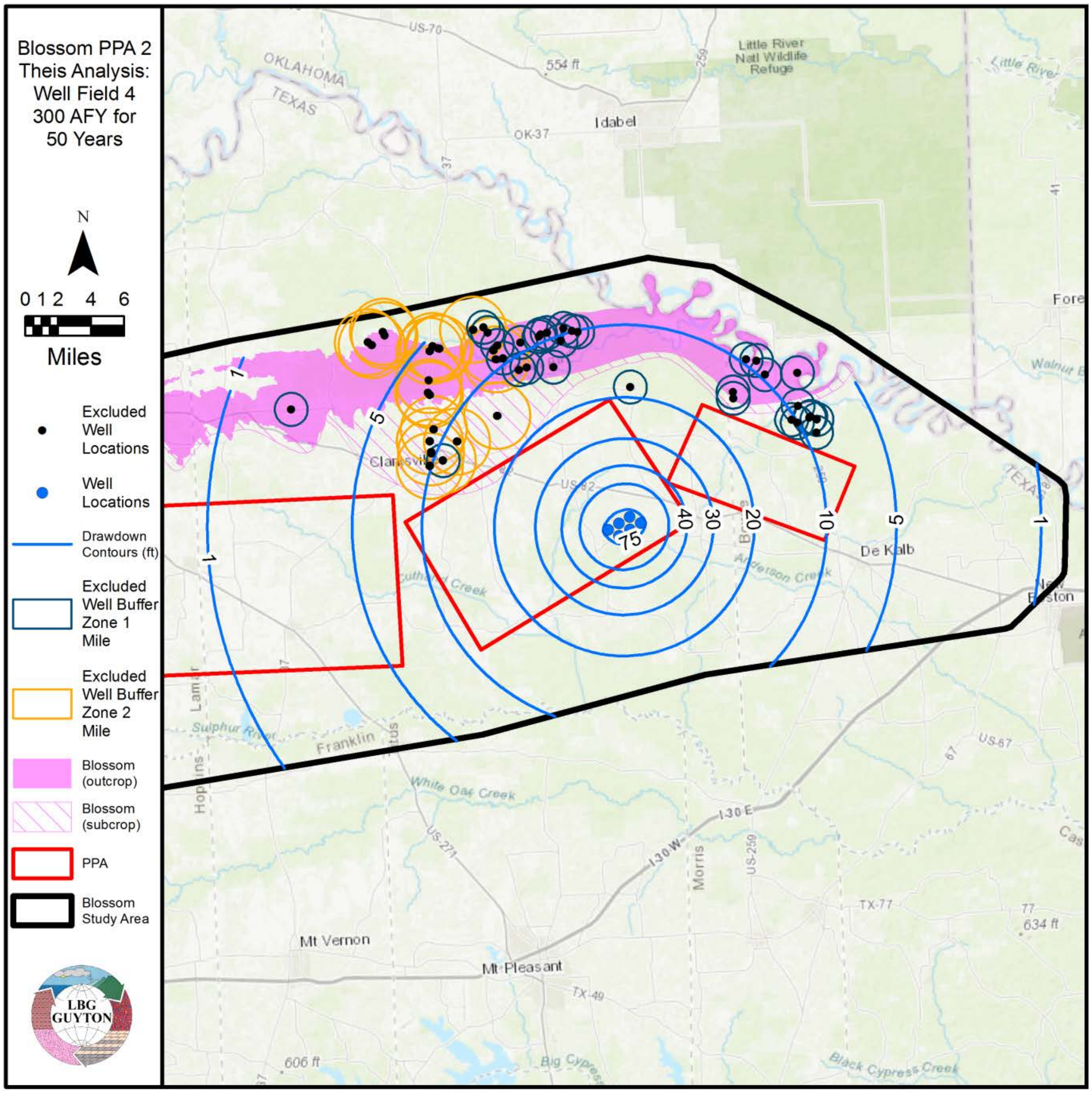

Figure 14-14. Potential production area 2: 50-year drawdown at 300 acre-feet per year.

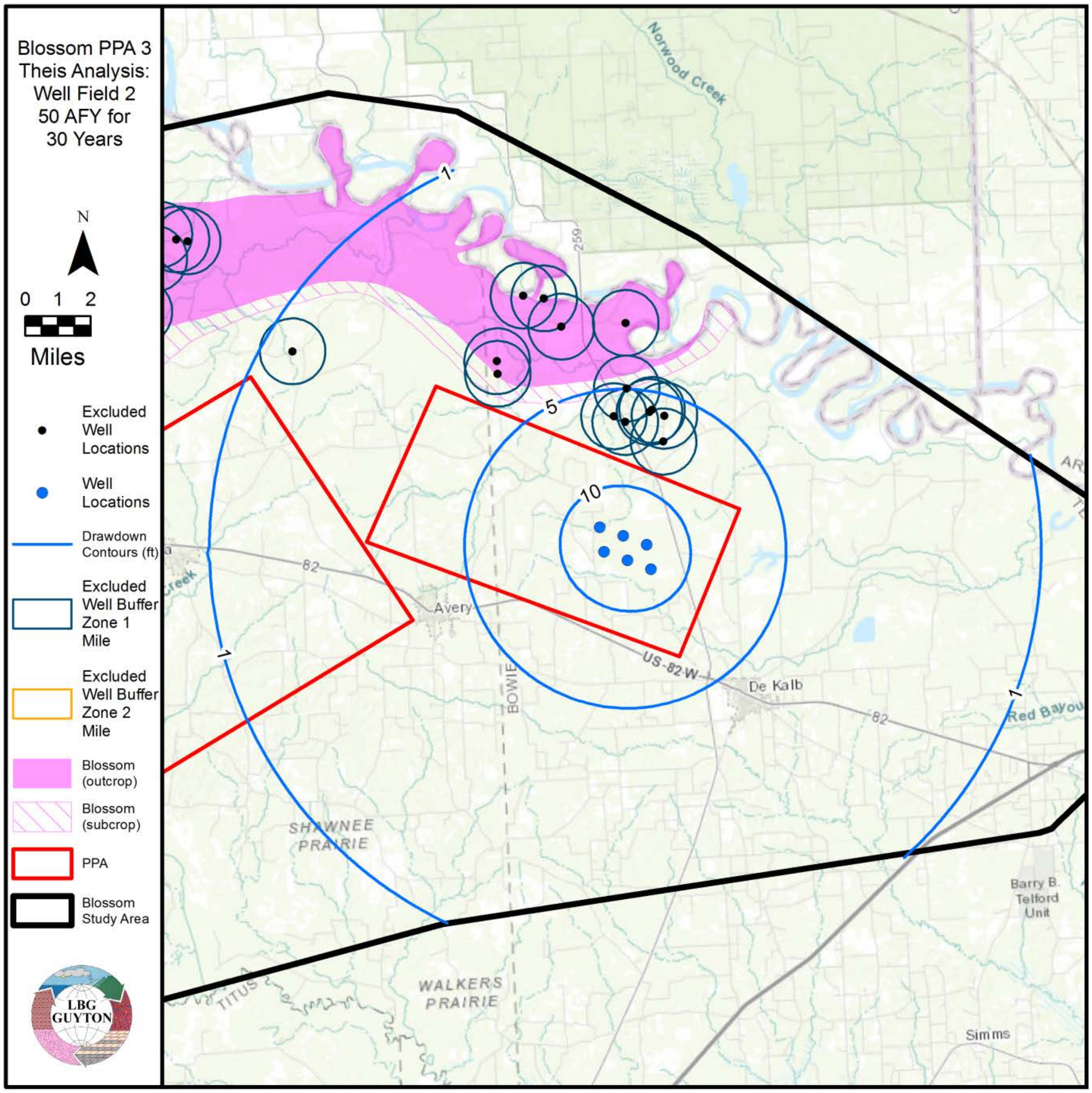

Figure 14-15. Potential production area 3:30-year drawdown at 50 acre-feet per year.

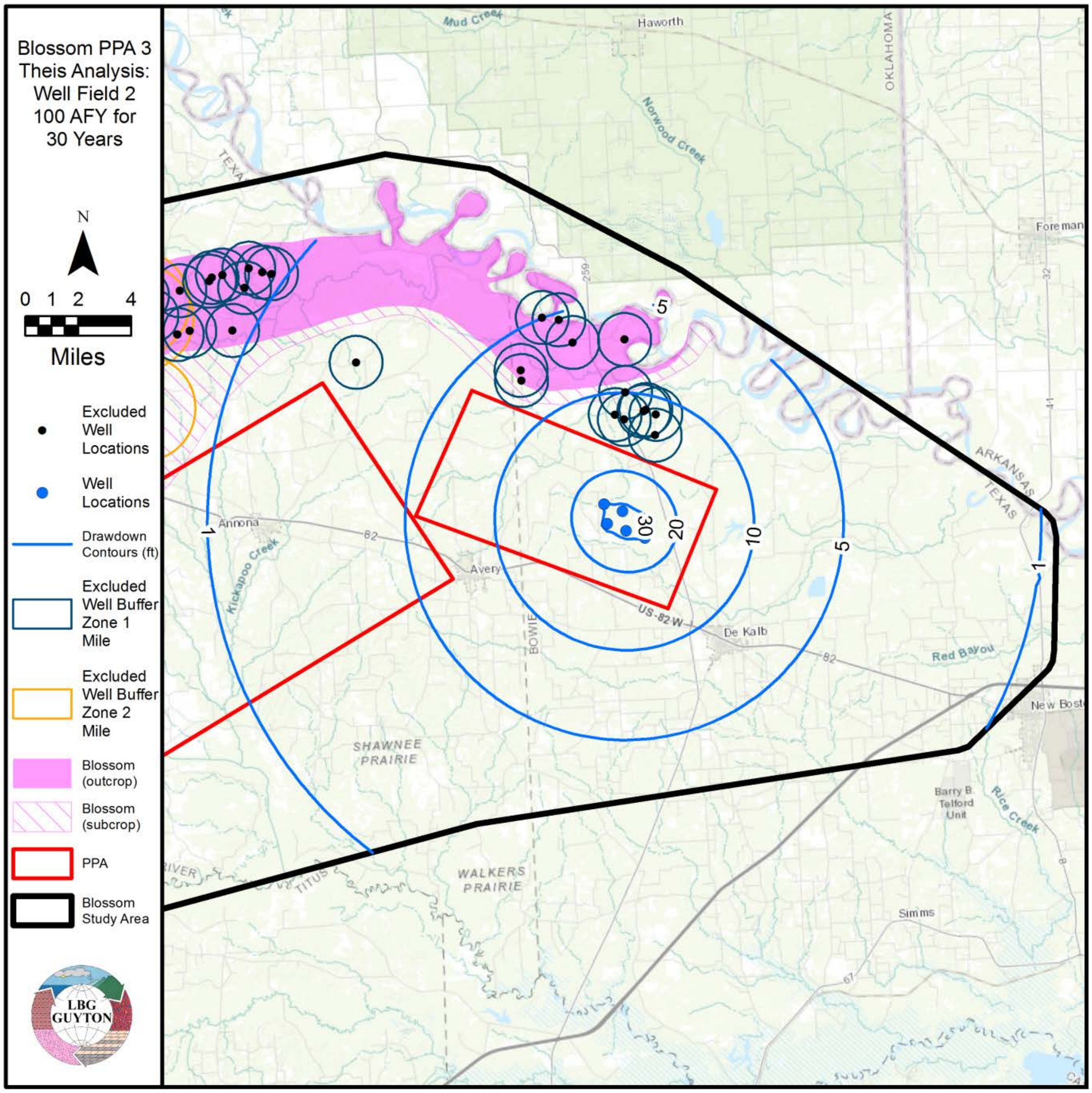

Figure 14-16. Potential production area 3: 30-year drawdown at 100 acre-feet per year.

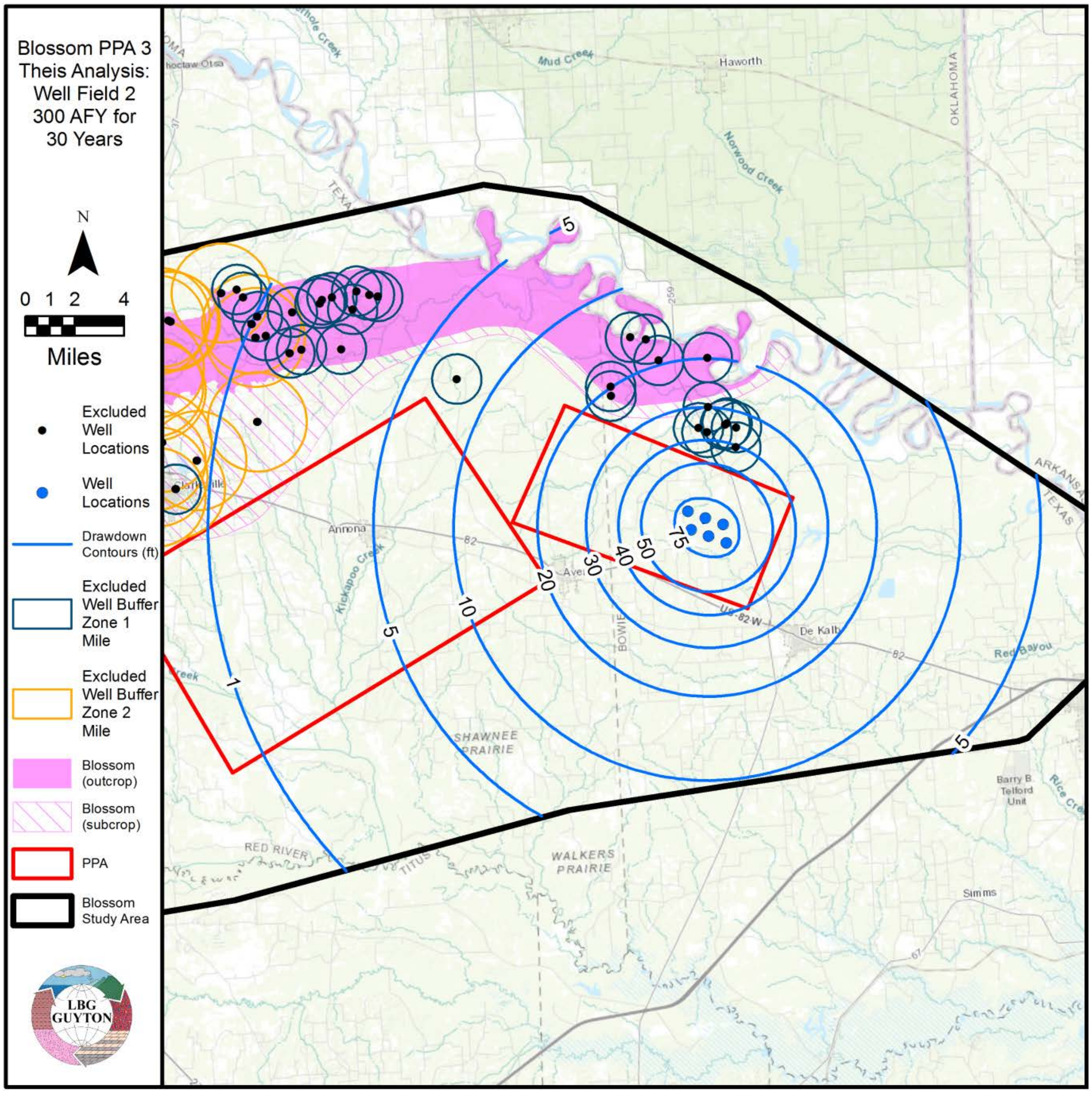

Figure 14-17. Potential production area 3: 30-year drawdown at 300 acre-feet per year.

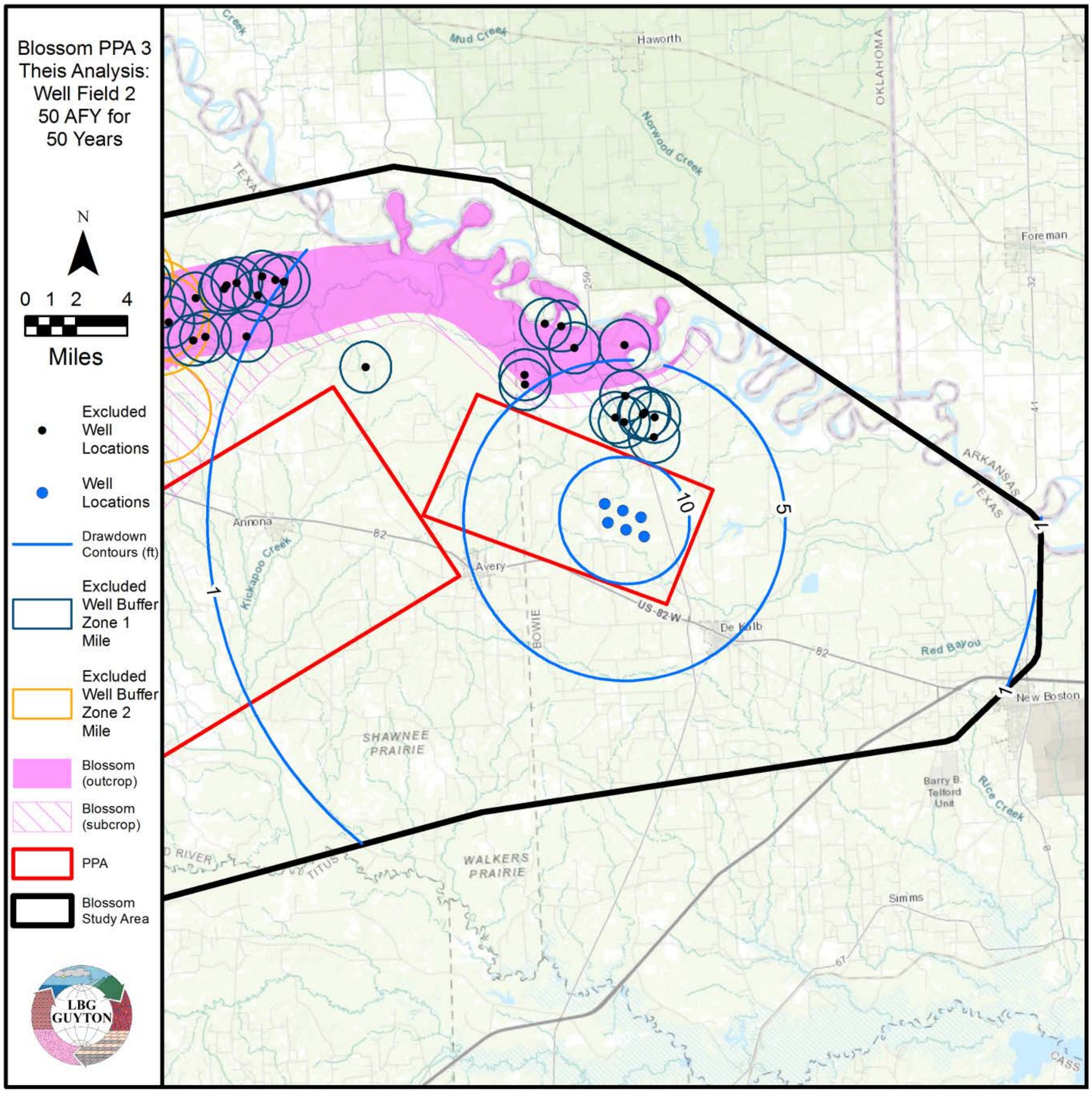

Figure 14-18. **Potential production area 3: 50-year drawdown at 50 acre-feet per year.**

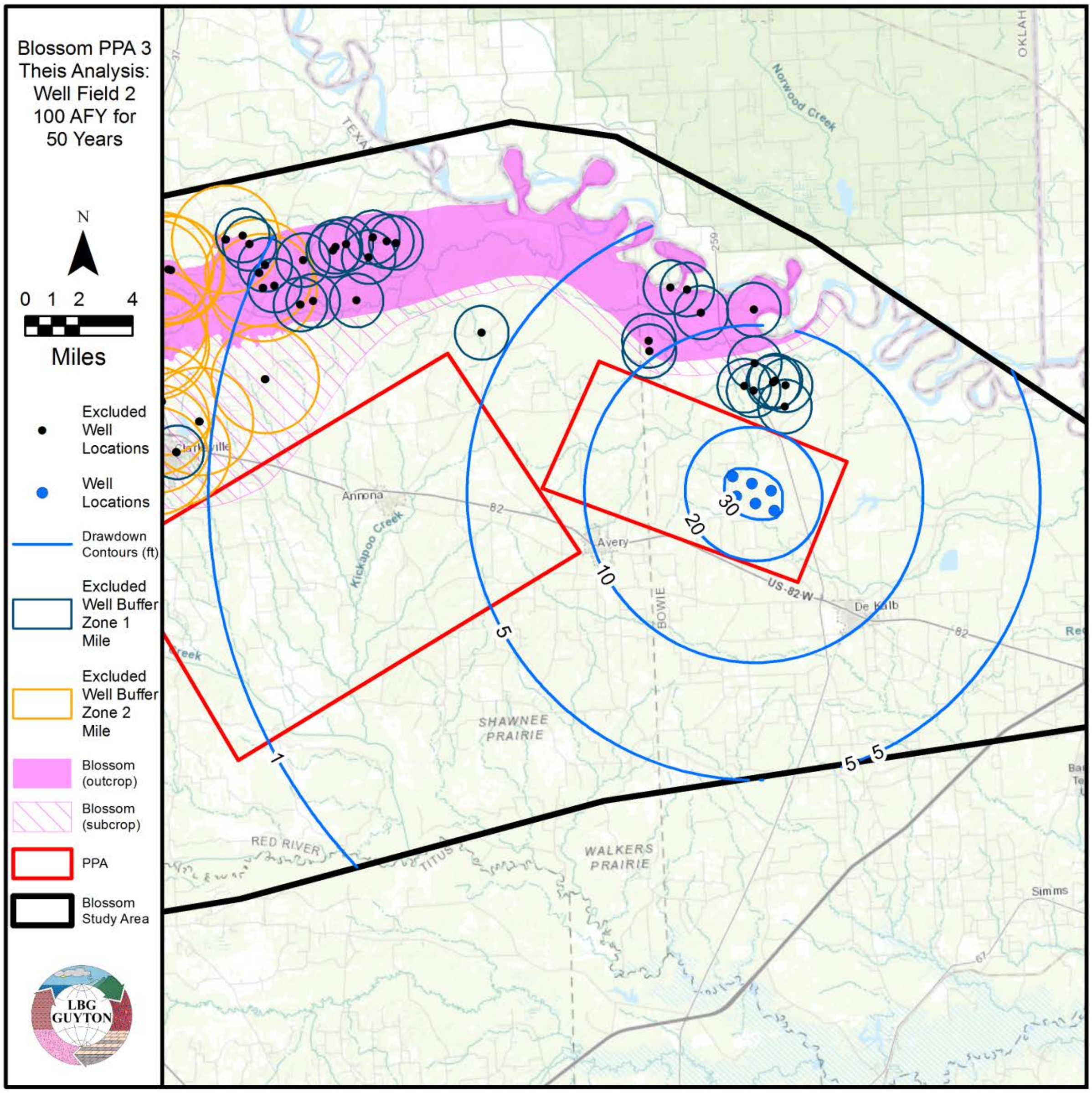

Figure 14-19. **Potential production area 3: 50-year drawdown at 100 acre-feet per year.**

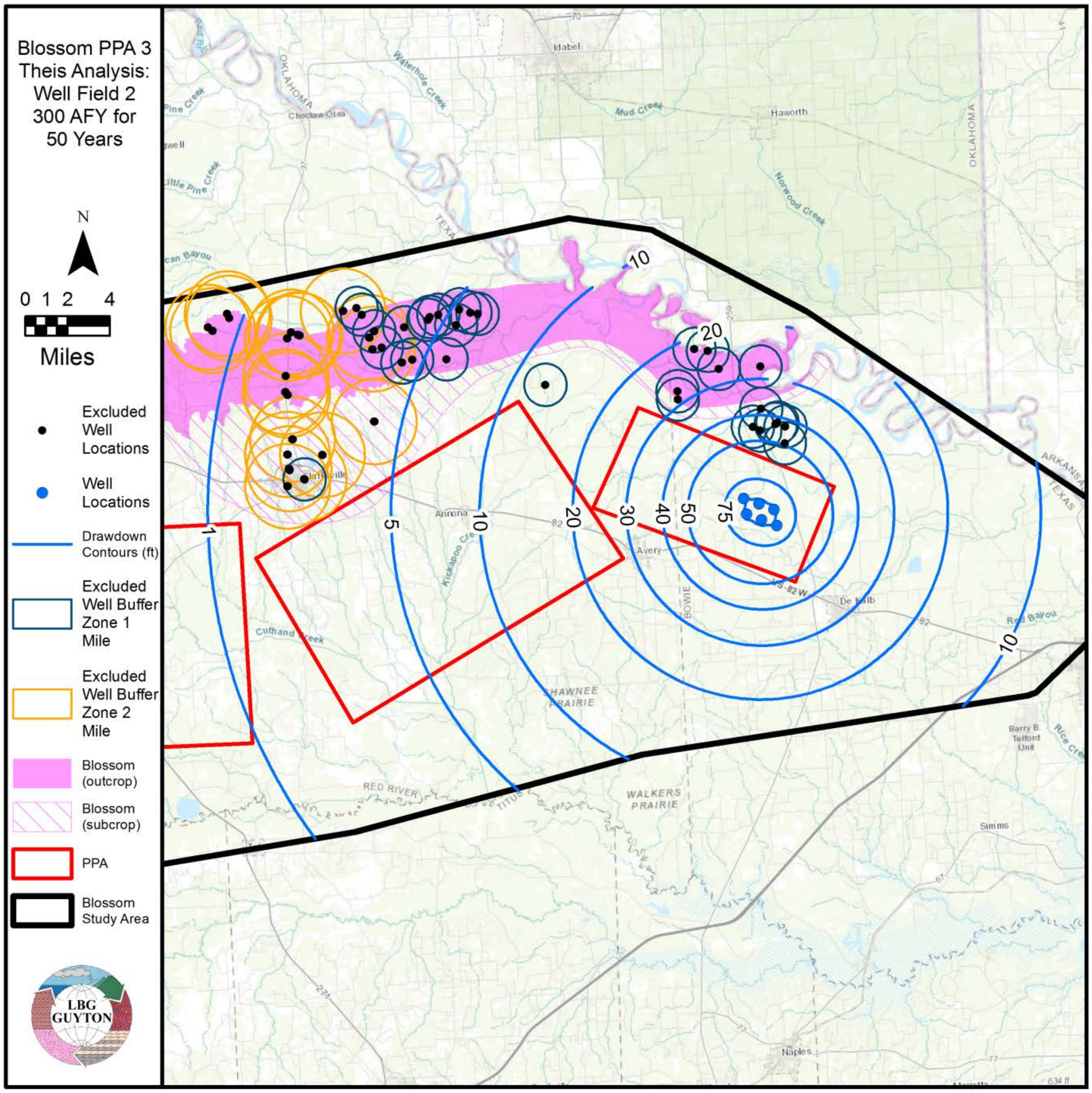

Figure 14-20. Potential production area 3: 50-year drawdown at 300 acre-feet per year.

14.3. Limitations

One major limitation of this study was the lack of geophysical log data and water sample data that were able to be paired for the calibration of total dissolved solids concentrations. Diligent effort was made to find any and all existing pairs for this purpose; however, resulting matches were very limited. Another major limitation is the lack of aquifer test data available for the Blossom aquifer. TDWB provided additional hydraulic properties based on some short-term pumping tests to help alleviate this limitation.

15. Future Improvements

Further investigative efforts that would be invaluable for the application of the results of this project would be test hole drilling and aquifer testing within the potential production areas to verify and/or revise the predicted production volumes that have been calculated for this project. Water quality sampling and geophysical logging of any test holes would also be essential to confirming and/or revising expected total dissolved solids concentrations.

16. Conclusions

Using the exclusion criteria stated in House Bill 30, three potential production areas were delineated in areas outlying the excluded areas. Potential pumping volumes from the potential production areas were estimated using low, medium and high volume pumping scenarios assuming both 30 and 50 years of production. The pumping rates selected for the Blossom Aquifer are 50, 100, and 300 acre-feet per year. Theis drawdown analysis was performed for the three potential production areas to understand the effect pumping in these areas would have on existing exclusion criteria. The resulting drawdown impact on the nearest downdip extent of the aquifer ranges from less than one foot (pumping 50 acre-feet per year for 30 years) to 12 feet (pumping 300 acre-feet per year for 50 years). Potential production areas 1 appears to have the least impact to up-dip exclusion wells with less than one to ten feet of drawdown. No volumes were calculated for the production areas.

A volumetric analysis was also performed to estimate volumes in the Blossom Aquifer based upon salinity zone classifications. The estimated volumes are broken out by county and by salinity zone only. The volumes represent in-place volumes (groundwater in storage) within the project area, not recoverable volumes (groundwater that may be realistically produced from the aquifer). These volume estimates evaluate the basal sand only. The modeling results indicate that over 3,056,000 acre-feet of in-place groundwater exists in the Blossom Formation in the project area. The in-place, slightly saline (1,000- 3,000 milligrams per liter of total dissolved solids) groundwater volume was estimated to be 529,247 acre-feet. The moderately saline (3,000- 10,000 milligrams per liter of total dissolved solids) groundwater volume was estimated at 1,268,483 acre-feet.

17. Acknowledgements

We would like to thank the Innovative Water Technologies staff at the TWDB for their guidance and patience during the preparation and completion of this project, specifically: Alan Andrews, Matthew Webb, John Meyer, and Ericka Mancha. We would also like to acknowledge the Texas State Legislature for providing the funding for this project and making this work possible.

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Appendix 19.1 TWDB wells that meet House Bill 30 exclusion criteria.

State Well Number	Aquifer	Well Depth (feet)	Primary Water Use
1617105	Alluvium	85	Domestic
1617201	Alluvium	86	Domestic
1617206	Alluvium	75	Domestic
1617209	Alluvium	90	Domestic
1617404	Alluvium	78	Domestic
1724502	Blossom	308	Domestic
1732205	Blossom	675	Public Supply
1721401	Blossom	60	Domestic
1721402	Blossom	63	Domestic
1724204	Blossom	60	Domestic
1732201	Blossom	602	Public Supply
1721701	Blossom	30	Domestic
1721702	Blossom	50	Domestic
1724205	Blossom	50	Domestic
1617402	Blossom	166	Domestic
1724901	Blossom	512	Domestic
1617701	Blossom	502	Public Supply
1724801	Blossom	538	Public Supply
1724803	Blossom	566	Public Supply
1724101	Blossom	31	Domestic
1724301	Blossom	74	Domestic
1617401	Blossom	83	Domestic
1724103	Blossom	57	Domestic
1720501	Blossom	70	Domestic
1720802	Blossom	60	Domestic
1720804	Blossom	80	Domestic
1720906	Blossom	80	Domestic
1720908	Blossom	70	Domestic
1720911	Blossom	135	Domestic
1720912	Blossom	60	Domestic
1721403	Blossom	70	Domestic
1721404	Blossom	80	Domestic

Appendix 19.1 TWDB wells that meet House Bill 30 exclusion criteria.

State Well Number	Aquifer	Well Depth (feet)	Primary Water Use
1721806	Blossom	85	Domestic
1724207	Blossom		Domestic
1724208	Blossom	40	Domestic
1724507	Blossom	280	Irrigation
1721713	Blossom	120	Irrigation
1721714	Blossom	115	Irrigation
1721715	Blossom	120	Irrigation
1721716	Blossom	110	Irrigation
1724108	Blossom	45	Domestic
1724109	Blossom	32	Domestic
1724506	Blossom	211	Domestic

Appendix 19.1 TWDB wells that meet House Bill 30 exclusion criteria.

PWS Label	System Name	State Well Number	Aquifer	Well Depth (feet)
G1940002A	CITY OF CLARKSVILLE	1732201	Blossom	602
G1940002B	CITY OF CLARKSVILLE	1732205	Blossom	675
G1940002C	CITY OF CLARKSVILLE	1732202	Blossom	600
G1940002D	CITY OF CLARKSVILLE		Blossom	624
G1940008A	RED RIVER COUNTY WSC	1617701	Blossom	502
G1940008B	RED RIVER COUNTY WSC	1724802	Blossom	538
G1940008C	RED RIVER COUNTY WSC	1724803	Blossom	566

Appendix 19-1. State Driller Reports that meet House Bill 30 exclusion criteria.

Tracking ID	Owner Name	County	City	Total Depth (feet)
13824	Trent Kelsoe Farm	Bowie		60
13825	Trent Kelsoe Farm	Bowie		55
26436	FORREST RORABACK	Red River	CLARKSVILLE	78
27705	Shatbeneau	Lamar	Paris	90
28353	ELECT.AIR SERVICE	Red River	CLARKSVILLE	72
39181	ANGELIA ROBERTS	Bowie	DEKALB	62
40057	JOHN HURD	Red River	AVERY	62
72001	MARION LOWE	Red River	CLARKSVILE	58
78930	DOUG HOWLETT	Red River	Bagwell	540
80662	JOHNNY MCCARY	Bowie	DEKALB	75
82981	LOUIE BOND	Red River	CLARKSVILE	52
90739	Nora Hardwick	Bowie	Dekalb	70
110828	HULBERT PERKINS	Red River	CLARKSVILE	0
119780	Clemons hamliton	Bowie	De Kalb	70
119783	white	Bowie	De Kalb	65
142136	NORVELL REED	Red River	CLARKSVILE	78
190937	Lee Farris Construction	Bowie	DeKalb	54
191150	Billy Mitchell	Bowie	De Kalb	65
203368	Glen Roberts	Lamar	Paris	403
209547	City of Clarksville	Red River	Clarksville	629
220843	Farris Contruction	Bowie	Dekalb	50
227780	Kerry Kirkland	Red River	Clarksville	210
227788	Bob Johns	Lamar	Paris	362
237852	Karen & David Sadler	Red River	Clarksville	66
278927	Shirley Thomas	Lamar	Blosom	182
281827	Gary Davis	Red River	Clarksville	360
284283	Gary Davidson	Red River	Clarksville	64
290969	RICHARD SPRADLING	Lamar	PARIS	212

Appendix 19-1. State Driller Reports that meet House Bill 30 exclusion criteria.

Tracking ID	Owner Name	County	City	Total Depth (feet)
295452	Folse's Farm	Bowie	De Kalb	50
312938	T L M Ranch	Lamar	Paris	195
336113	Price Hamilton	Bowie	De Kalb	90
336114	Hilda Perkins	Red River	Clarksville	100
347619	Jack Cleere	Lamar	Paris	142
349332	Steve Head	Lamar	Paris	202
352412	Tom Mitchell	Bowie	DeKalb	0

Appendix 19-2. GIS Datasets

GIS dataset descriptions have been included in the report text where applicable.

Appendix 19-3. GIS file names and codes

File Content	File Name	File Type
Alluvium Well 1-mile Buffer	ALVMwells_DomPSIrr_buffer1mi2	Polygon shapefile
Alluvium Well: PS, Irr, Dom	ALVMwells_DomPSIrr2	Point shapefile
Aquifer_properties	Aquifer_properties	Point shapefile
Blossom Water quality calculations	BlossomGWQcalcs_KL5	Point shapefile
Study Area	BlossomStudyArea	Polygon shapefile
Blossom Well Location 2-mile	BlossomWell2mileBuffer2	Polygon shapefile
Blossom Well Location: PS, Dom,	BlossomWells_PS_DOM_Irr	Point shapefile
Blossom Well Location: PS, Dom,	BlossomWells_PSdomIRRonly	Point shapefile
Blossom Well Samples	BlossomWellSamples	Point shapefile
Blossom Control Point	BLSMpts	Point shapefile
BRACS Available Geophysical Log	BRACSLogLocs_clip	Point shapefile
Towns and cities	Cities and Towns	Polygon shapefile
Counties	Counties	Polygon shapefile
Depth to Base of Blossom Fm	D_B_BLSM2contours_clip	Polyline shapefile
Depth to Top of Blossom Fm	D_T_BLSM2contours_clip	Polyline shapefile
Fault	Fault	Polyline shapefile
Fault Graben	Fault Grabens	Polyline shapefile
Groundwater Management Area	groundwater_ management_areas_apr09_dd	Polygon shapefile
Basal Net Sand Thickness	LWRSDNET contours_clip2	Polyline shapefile
Lower Sand Thickness	LWRSDTHKcontours_clip3	Polyline shapefile
Blossom aquifer	MinAq_BLOSSOM	Polygon shapefile
Major Aquifers	new_major_aquifers_dd	Polygon shapefile
Minor Aquifers	new_minor_aquifers_dd	Polygon shapefile
Potential Production Area	PPA5	Polygon shapefile
geologic Logs clipped	Qlogs_clip	Point shapefile
Regional Water Planning Areas	Regional_Water_Planning_areas	Polygon shapefile
Geological rock unit	Rock Unit	Polygon shapefile
State Well Report: PS, Irr, Dom 1-mile Buffer	SDRDB_Blossom_DomPSIrr_Only_buffer1mi2	Polygon shapefile

Appendix 19-3. GIS file names and codes

State Well Report: PS, Irr, Dom	SDRDBDomIrrPS_outcrop3	Point shapefile
TDS < 10,000 mg/L	T10000Kextent	Polygon shapefile
1,000 mg/L TDS	T1kTDS	Polygon shapefile
2003 Brackish 10Kcontour	T2003Brackish_10Kcontour	Polyline shapefile
2003Brackish_3Kcontour	T2003Brackish_3Kcontour	Polyline shapefile
2006_blossom_WLs	T2006_blossom_WLs	Point shapefile
TCEQ Public Supply	TCEQ_PS_BLSM	Point shapefile
TCEQ Public Supply 2-mile Buffer	TCEQ_PS_BLSM_buffer2mi	Polygon shapefile
Texas Cities	Texas_Cities	Point shapefile
Major Roads	Texas_Hwys	Polyline shapefile
Texas major highways	Texas_Major_Hwy_NAD_83	Polyline shapefile
State Line	Texas_outline_gamcopy	Polyline shapefile
TWDB Groundwater Conservation	TWDB_GCDs_082014	Polyline shapefile
2006 Groundwater Elevation	WLelevcontours_clip	Polyline shapefile

Appendix 19-3. GIS file names and codes

Surface description	Surface file
Depth to formation bottom, ft	blsm_fm_bot
Formation thickness, ft	blsm_fm_thk
Depth to formation top, ft	blsm_fm_top
Depth to basal sand bottom, ft	blsm_lt_bot
Basal sand thickness, ft	blsm_lt_thk
Depth to basal sand top, ft	blsm_lt_top
Depth to Bottom of Blossom Formation	d_b_blsm2_c
Depth to Top of Blossom Formation	d_t_blsm2_c
Fresh water bottom depth, ft	fr_bd
Fresh water top depth, ft	fr_td
Fresh water thickness, ft	fr_thk
Fresh water volume, ac-ft	fr_vol
Moderately saline bottom depth, ft	ms_bd
Moderately saline top depth, ft	ms_td
Moderately saline thickness, ft	ms_thk
Moderately saline volume, ac-ft	ms_vol
Snap grid file	snap_blsm
Slightly saline bottom depth, ft	ss_bd
Slightly saline top depth, ft	ss_td
Slightly saline thickness, ft	ss_thk
Slightly saline volume, ac-ft	ss_vol
2006 water levels	T2006_blos_wls
Total dissolved solids zones	TDS_zones
Volume of water, ac-ft	Vol_Total
Very saline bottom depth, ft	vs_bd

Appendix 19-4. Comments and Responses.

General Report Comments

1. Thank you for submitting the Draft Final Report.

    No response needed

2. Make all figures larger so that all text is legible. In general a full page should be dedicated for each figure.

    Complete

3. All captions must be made more descriptive of the figure they correspond with. Ensure that the associated caption in the List of Figures and List of Tables sections are updated as well.

    Complete

4. If text in a figure is illegible, the text should be made larger or the text should be removed from the figure.

    Complete

5. Please include an example of the spreadsheet or form used for carrying out calculations.

    Complete

6. Please replace all instances of referring to the Blossom Aquifer as just "Blossom" to "Blossom Aquifer."

    Complete

7. Please spell out all acronyms used in the report at least once.

    Complete

8. Replace "mg/l" with "milligrams per liter."

    Complete

9. Replace "ft bgl" with "feet below ground level."

    Complete

10. Replace "ft amsl" with "feet above mean sea level."

    Complete

11. Replace "mgd" with "millions of gallons per day."

    Complete

12. Replace "TDS" with "total dissolved solids."

    Complete

13. Replace "BRACs" with "BRACS."

    Complete

14. Please spell out House Bill 30 in the report to limit variations of abbreviations.

    Complete

15. Please fix grammatical errors.

    Complete

Specific Comments

1. Page 1. Executive Summary, Second paragraph: “Area” should be “areas.”

    Complete

2. Page 1. Executive Summary, Second bullet: In the first sentence, the word “more” should be replaced with “less.”

    Complete

3. Page 1. Executive Summary, last paragraph: Consider providing volumes of groundwater in acre-feet in addition to the percentage provided in the report.

    Complete

4. Page 2. Section 2, Second paragraph: Please rephrase the third sentence so that is grammatically correct.

    Complete

5. Page 4. Figure 4-1: Color chosen for Blossom formation does not adequately display the downdip extent of the aquifer on the map. Dedicate a page per figure.

    Blossom formation has been changed to a darker color.

6. Page 5. Table 5-1: Please adjust cell size so that words are not truncated by the lines of the cells. For example, under the “Formation” column, the word “deposits” is truncated.

    Tables have been adjusted.

7. Page 7. Figure 5-2: Please dedicate a full page for each figure. Please remove the surface artifacts that extend beyond the study area. The combination of symbology and color chosen to display the downdip portion of the Blossom Aquifer makes it difficult to see.

    Surface artifacts have been clipped to only the study area. Blossom formation has been change to a darker color.

8. Page 8. Figure 5-3: Please dedicate a full page for each figure and make sure all text is legible.

    Complete

9. Page 12. Figure 6-2: Please be consistent with the salinity classifications presented in Table 6-1.

    Complete

10. Page 13. Figure 6-3: Please change “FMS” to formations. Please describe axes and units in figures in the caption.

    Complete

11. Page 14. Figure 6-4: Please change “FMS” to formations. Please describe axes and units in figures in the caption.

Complete

12. Page 15. Figure 6-6: Please change "FMS" to formations. Please describe axes and units in figures in the caption.

    Complete

13. Page 17. Section 8.1: Please replace "TWDB Brackish Resources Aquifer characterization System BRACS Team" to "TWDB BRACS Database".

    Complete

14. Page 20. Section 10.1: Delete first paragraph. It is almost identical to the following paragraph.

    Complete

15. Page 22. First paragraph, first sentence: Please remove the "()" from the sentence.

    Complete

16. Pages 22, 23, and 24. Figures 10-1 to 10-4: All lines in crossplots and piper diagrams must be made darker. Please make captions more descriptive.

    Complete

17. Pages 22 and 24. Figure 10-3, Figure 10-4, and Figure 10-5: Please change "Blossom" to "Blossom Aquifer" in the caption.

    Complete

18. Page 25. Figure 11-1 and Figure 11-2: Please dedicate a full page for each figure. Please make caption more descriptive.

    Complete

19. Page 27. Table 12-1: Please change "Blossom" to "Blossom Aquifer" in the caption.

    Complete

20. Page 36. Figure 14-1 and Figure 14-2: Please dedicate a full page for each figure.

    Complete

21. Page 37. Section 14.2: Please provide drawdown tables for the three pumping scenarios for each potential production area.

    Summary table provided

22. Page 38, Page 39, and Page 40.

    a. All cone of depression figures need to be made much larger. The majority of the text in each figure is illegible, including items in the legend and labels in the maps themselves. Please dedicate one full page per figure.

    b. Cones of depression should not extend beyond updip extent of outcrop.

    c. Please fix the gap in the circles in the figures showing 50-year drawdown associated with pumping 300 acre-feet per year for PPA 1, PPA 2, and PPA 3.

d. Page number should appear on the bottom of the page.

e. Please consider providing additional figures that show exclusion wells and their buffers alongside the cones of depression from simulated pumping.

Complete

23. Page A-1. Appendices: Please reposition tables so that they appear below the title of the appendix section they are under, instead of how they currently are where they appear on the following page, as is the case with appendix 19.1 and appendix 19.3.

Complete

<u>Data Deliverables Comments</u>

1. Please organize files provided in such a way that links to source data in MXDs are not broken. Currently upon opening MXDs, no layers are displayed as links to source data are broken.

   The shapefile links now connect to each corresponding shapefile in the geodatabase.

2. Please provide all data linked in MXDs. The following files linked in MXDs are not present in the geodatabase provided:

   - 10000Kextent
   - County
   - counties_GAM
   - contourclip
   - LWRSDNET3
   - LWRSDTHK2
   - D_B_BLSM2
   - D_T_BLSM2
   - D_B_BLSM2contours_clip
   - D_T_BLSM2contours_clip
   - BlossomWells_PSdomIRRonly
   - SDRDB_Blossom_DomPSIrr_Only_buffer1mi2
   - 1k_TDS
   - 2006_blossom_WLs
   - Four_State_Ln
   - Cities
   - transect lines
   - StratMap_City_Polyv4

- RWPG
- 2003Brackish_3Kcontour
- 2003Brackish_10Kcontour
- Blossomwqcontoursbrackgamproj
- Revised3000tds
- AverageCaclulated TDS from Log (mg/l)
- City_polys_5cos

The shapefile links now connect to each corresponding shapefile in the geodatabase.

3. Please ensure that all GIS data provided adheres to the format requirements described in section 3 of Exhibit G of the contract.

   All shapefiles have been adjusted to follow Exhibit G of the contract.

4. Please make sure that all shapefiles and rasters have metadata describing their content. Currently, only some shapefiles and none of the rasters have associated metadata.

   Metadata has been added to all shapefiles and rasters.

5. Please submit shapefiles of cones of depression from modeled pumping scenarios.

   Complete

6. MXDs “Groundwater_Conversation_Districts_Blossom_10.2” and “Mgmt_Areas_Blossom_10.2” cannot be opened. Please save these using the same version of ArcMap that the other MXDs were saved with.

   MXD files “Groundwater_Conversation_Districts_Blossom_10.2” and “Mgmt_Areas_Blossom_10.2” have been back