Draft 2023 Assessment of Compliance with Desired Future Conditions and Protective Drawdown Limits, Post Oak Savannah Groundwater Conservation District

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November 2023

Version 1.0

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EXECUTIVE SUMMARY

The report documents Post Oak Savannah Groundwater Conservation District (POSGCD) 2023 assessment of compliance with its Desired Future Conditions (DFCs) and the Protective Drawdown Limits (PDLs). Consistent with adopted DFCs in GMA 12, POSGCD defined the DFCs listed in Tables **ES-1** and **ES-2** for seven aquifers. The DFCs are expressed as an average drawdown that occurs across the entire extent of each aquifer within POSGCD boundaries. Throughout the report the ending time of December 2069 is often referred to as 2070, meaning January 1, 2070.

Table ES-1 GMA 12 and POSGCD adopted DFCs based on the average drawdown that occurs between January 2011 and December 2069

Aquifer	Drawdown (ft)
Sparta	32
Queen City	30
Carrizo	146
Upper Wilcox (Calvert Bluff Fm)	156
Middle Wilcox (Simsboro Fm)	278
Lower Wilcox (Hooper Fm)	178

Table ES-2 GMA 12 and POSGCD adopted DFCs based on the average drawdown that occurs between January 2011 and December 2069

Aquifer	Drawdown (ft)
Yegua-Jackson	61

POSGCD has divided most of the DFC Management Zones into two to three management areas. Most of the management areas are regulated by PDLs. Management Areas were created for the purpose of improving the District's ability to manage and regulate water level change across the portion of the District's aquifers where the majority of wells are located. The up-dip most area of the aquifer that includes the aquifer outcrop is represented by PDL Management Area 1. Management Area 1 has the largest proportion of the monitoring well network, and thus the highest confidence in the estimated water level and drawdown surfaces. **Table ES-3** summarizes the PDLs that have been adopted by POSGCD.

Table ES-3 PDLs for Management Areas

Aquifer	Average Drawdown Measured from January 2011 to December 2070	
	Management Area 1	Management Area 2
Sparta	28	N/A
Queen City	19	N/A
Carrizo	75	175
Calvert Bluff	88	223
Simsboro	91	335
Hooper	210	N/A

To help ensure that management actions can occur prior to DFCs and PDLs being violated, the POSGCD have defined action levels (identified in POSGCD Groundwater Rule 16.4). Threshold Level 1 is triggered when the average drawdown calculated from the measured water levels are greater than 50 percent of an DFC or 50 percent of a PDL. Threshold Level 2 is triggered by either an average drawdown that is greater than 60 percent of a DFC or 60 percent of a PDL. If Threshold Level 1 is triggered, then hydrogeologic studies will be performed. A possible outcome of these studies is that schedules may be developed to curtail groundwater production in the affected management areas and/or zones. If Threshold Level 2 is triggered, the District may notify well owners of possible plans of curtailment of productions in affected management zones pending results from the Threshold Level 1 studies.

The data required to assess compliance with DFCs is water level data measured from POSGCD monitoring wells. The POSGCD Monitoring Well network currently consists of the 447 wells and the network is continually being reviewed and updated to include additional monitoring wells to improve the ability to monitor aquifer conditions. Table ES-4 summarize the evaluation of DFC compliance for the seven aquifers that were evaluated.

Table ES-4 Evaluation of DFC Compliance based on Comparison with Average Drawdown Calculated from the DFC base year until 2023 using Measured Water Levels

Management Zone	2070 DFC (ft)	Avg. Drawdown (ft) / % of DFC	Compliant With DFC
Sparta	32	11.8 (37%)	Yes
Queen City	30	14.3 (47.6%)	Yes
Carrizo	146	73.2 (50.1%)	No
Calvert Bluff (Upper Wilcox)	156	60 (38.5%)	Yes
Simsboro (Middle Wilcox)	278	69.3 (24.9%)	Yes
Hooper (Lower Wilcox)	178	18.1 (10.2%)	Yes
Yegua-Jackson	61	-26.1 (-42.8%)	Yes

The evaluation shows that six of the seven aquifers for which there are drawdown-based DFCs are compliant with the DFCs. For the 2023 measured water level values, the aquifer with the greatest amount of drawdown relative to the aquifer's DFC is the Carrizo, which had an average drawdown of 73.2 ft in 2023. This drawdown represents 50.1% of the Carrizo 146 ft DFC average drawdown in 2070, which exceeds the Threshold Level 1. The remaining six aquifers maintain 2023 average drawdown values below the 50% aquifer DFC threshold values.

Table ES-5 summarizes the evaluation compliance in 2023 for the six aquifers with PDLs. The evaluation shows that five of the six aquifers for which there are drawdown based PDLs are compliant with the PDLs. For the 2023 measured water level values, the aquifer with the greatest amount of drawdown relative to the aquifer's PDL is the Carrizo Management Area #2, which had an average drawdown of 98.3 ft or 56.2% of the 175 ft PDL in 2070. This average drawdown for the Carrizo Management Area #2 exceeds 60% of the PDL, which is the Threshold Level 2. The remaining five aquifers maintain 2023 average drawdown values below the 50% aquifer PDL threshold values.

Table ES-5 Evaluation of PDL Compliance based on Comparison with Average Drawdown Calculated from the DFC base year until 2023 using Measured Water Levels

Management Area		2070 PDF (ft)	Avg. Drawdown (ft) / % of DFC	Compliant With PDL
Sparta	Area 1	28	-2.1 (-7.6%)	Yes
Queen City	Area 1	75	-4.2 (-22.1%)	Yes
Carrizo	Area 1	75	17.1 (22.8%)	Yes
	Area 2	175	98.3 (56.2%)	No
Calvert Bluff (Upper Wilcox)	Area 1	88	23.6 (26.8%)	Yes
	Area 2	223	65.4 (29.3%)	Yes
Simsboro (Middle Wilcox)	Area 1	91	-10.1 (-11.1%)	Yes
	Area 2	335	100.7 (30.1%)	Yes
Hooper (Lower Wilcox)	Area 1	210	20.6 (9.8%)	Yes

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ACROYNMS AND ABBREVIATIONS

%	percent
DFC	Desired Future Condition
ft	feet
GAM	groundwater availability model
GCD	groundwater conservation district
GMA	groundwater management area
HB	house bill
PDL	Protective Drawdown Limit
POSGCD	Post Oak Groundwater Conservation District
TWC	Texas Water Code
TWDB	Texas Water Development Board

1.0 INTRODUCTION

This report documents the 2023 assessment of compliance with the Post Oak Savannah Groundwater Conservation District (POSGCD) Desired Future Conditions (DFCs) and the Protective Drawdown Limits (PDLs). The methods used to assess compliance in this report were documented in a report entitled “Post Oak Savannah Guidance Document for Evaluating Compliance with Desired Future Conditions and Protective Drawdown Limits” and completed in 2021 (INTERA, 2021). The methodologies used in this assessment and documented in the 2021 report were discussed throughout a series of presentations at POSGCD DFC committee and board meetings from 2019 through 2023. The assessment approach is meant to be adaptive and subject to improvements in response to new information and changes in site conditions.

1.1 Post Oak Savannah Groundwater Conservation District

The POSGCD was created in Milam and Burleson counties by House Bill (HB) 1784, 77th Legislature, 2001, and a local confirmation election in November 2002. The purpose of this bill is to provide a locally controlled groundwater district to conserve and preserve groundwater, protect groundwater users, protect and recharge groundwater, prevent pollution or waste of groundwater in the central Carrizo-Wilcox area, control subsidence caused by withdrawal of water from the groundwater reservoirs in that area, and regulate the transport of water out of the boundaries of the districts.

The POSGCD is a member of GMA 12 and GMA 8, whose areal extents are shown in **Figure 1-1**. To help establish DFCs for the relevant aquifers within the boundaries of Groundwater Management Areas (GMAs) 8 and 12, POSGCD will consider groundwater availability models (GAMs) and other data or information. As part of the joint planning process, POSGCD will establish management goals and objectives that are consistent with the DFCs adopted by GMA 8 and GMA 12.

Table 1-1 provides stratigraphic column of the formations and aquifers located within the District boundaries. **Figure 1-2** shows the locations of the outcrops of these formation and aquifers based on the surface geology mapped by Young and others (2018), Ewing and Jigmond (2016), and Deeds and others (2010). An outcrop is where an aquifer is present at ground surface. The aquifers in the District generally dip to the southeast at slopes of about 100 to 150 feet (ft) per mile. Within the District, the Trinity Aquifer does not outcrop and is overlaid primarily by the Midway Formation. The Midway Formation outcrops in the northwestern portion of Milam County. The Midway Formation is an aquitard separating the older Northern Trinity Aquifer from the younger Carrizo-Wilcox Aquifer. An aquitard is a formation that is composed primarily of clayey deposits that allows only small amounts of groundwater to flow. As a general rule, aquitards do not contain sufficiently permeable deposits to support sustained pumping. Therefore, the District has not established DFCs for the Midway formation and the two other aquicludes listed in Table 1-1, which are the Reklaw and Weches formations.

Table 1-1 Generalized stratigraphic column for POSGCD

ERA	Period	Age (M.Y.)	Hydrostratigraphic Unit	Hydrogeologic Unit
Cenozoic	Tertiary	33.9	Jackson	Yegua-Jackson Aquifer
			Yegua	
			Sparta	Sparta Aquifer
			Weches	Aquitard (mud)
			Queen City	Queen City Aquifer
			Reklaw	Aquitard (mud)
		55.8	Carrizo	Carrizo-Wilcox Aquifer
			Upper Wilcox/Calvert Bluff	
			Middle Wilcox/Simsboro	
			Lower Wilcox/Hooper	
		65.5	Midway	Aquitard (mud)
Mesozoic	Cretaceous		Trinity	Trinity Aquifer

The only relevant aquifer in the District in GMA 8 is the Northern Trinity Aquifer. The Midway aquitard overlying the Trinity Aquifer outcrops in the far northwestern portions of Milam County, but the Trinity Aquifer is only present in the subsurface and is not considered a relevant aquifer in the District and therefore is not covered in this document.

The District is divided into groundwater management zones and management areas for the purpose of evaluating and managing groundwater resources recognizing the different characteristics and anticipated future development of the aquifers in the District. Each of the District's Management Zones the District has adopted DFCs through the joint planning process. For several of the management areas the District has adopted PDLs. Currently, the District's DFCs and PDLs represent drawdown limits over fixed time intervals.

The objective of this report is to assess the District's compliance with its DFCs and PDLs. The report assembles and analyzes measured water levels to determine the amount of drawdown that has occurred across management zones with drawdown-based DFCs and management areas with a PDL that occur in GMA 12. The report is a scientific report. Because the joint-planning process and the District Management Plan are adaptive in nature, this report will end with a section on considerations on future improvement of monitoring data and collection and the assessment methodology and associated assumptions.

1.1.1 DFC Management Zones

Chapter 36 of the Texas Water Code (TWC) provides the statutory guidance for groundwater conservation districts (GCDs). Chapter 36.108 describes the GCD requirements for joint-planning and compliance with DFCs. For permitting of groundwater within the District, Chapter 36.1132(b) states that districts "shall manage total groundwater production on a long-term basis to achieve an applicable desired future condition." In response to these duties, the District Groundwater Management Plan requires that the District assess compliance with DFCs at least every three years using water levels measured in the District monitoring wells.

The principal aquifers that are managed by the District include the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers. The boundaries for the management zones for these six aquifer are conterminous with boundaries of the aquifers they represent. The monitoring well network for each total management zones is used to estimate a drawdown surface. This drawdown surface is then averaged over the total management zone and evaluated relative to the DFC. The methods in which DFCs are assessed are further discussed in Section 4.

1.1.2 PDL Management Areas

The District has subdivided the DFC Management Zones of its six principal aquifers into two to three management areas. The creation of the management areas was performed with heavy consideration for the spatial distribution of the existing wells and especially monitoring wells across each aquifer. As a general rule, the upmost dip portion of the aquifers have the highest number and distribution of monitoring wells (PDL Management Area 1). By carving out a PDL management area that contain a greater density of monitoring wells than contained across a DFC management zone for a specific aquifer, the District has developed an area across which the average drawdown based on monitoring data can be determined with greater accuracy and higher confidence than the average drawdown for the larger zone containing the area. There are no statutory requirements in Chapter 36 for PDLs. The current set of District rules require that PDL compliance be assessed at the same schedule as the District is required to assess DFC compliance. The methods in which PDLs are assessed are discussed in Section 4.

1.2 Report Organization

The report will be organized starting in Section 2 with a review of the key management plan concepts as they relate to the long-term compliance with the DFCs and a discussion of the PDLs developed to protect production capacity of existing wells in the shallow unconfined portions of District aquifers. The fundamental data used to assess compliance is drawdown, which is the mathematical difference between two well water levels measured in the same well at two different times. Water levels are monitored by the District through a monitoring well program, and Section 3 of the report will describe the monitoring network and the associated measurements. Section 4 of the report will provide the details of the assessment for both DFCs and PDLs. Section 5 will complete the report by making observations and recommendations for improving both the collection and the use of water levels to assess future compliance with DFCs and PDLs.

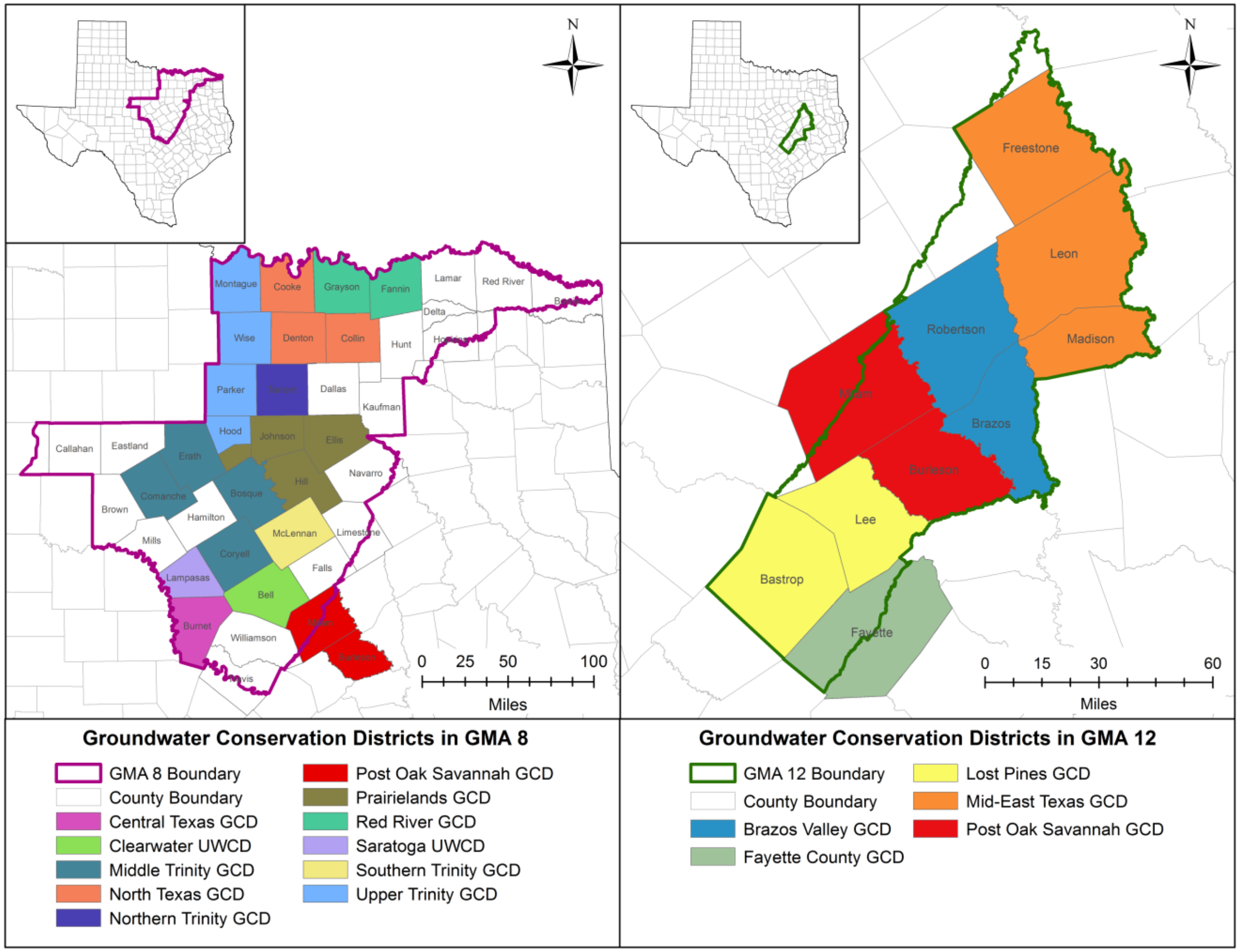

Figure 1-1 Counties and groundwater districts associated with Groundwater Management Areas 8 and 12

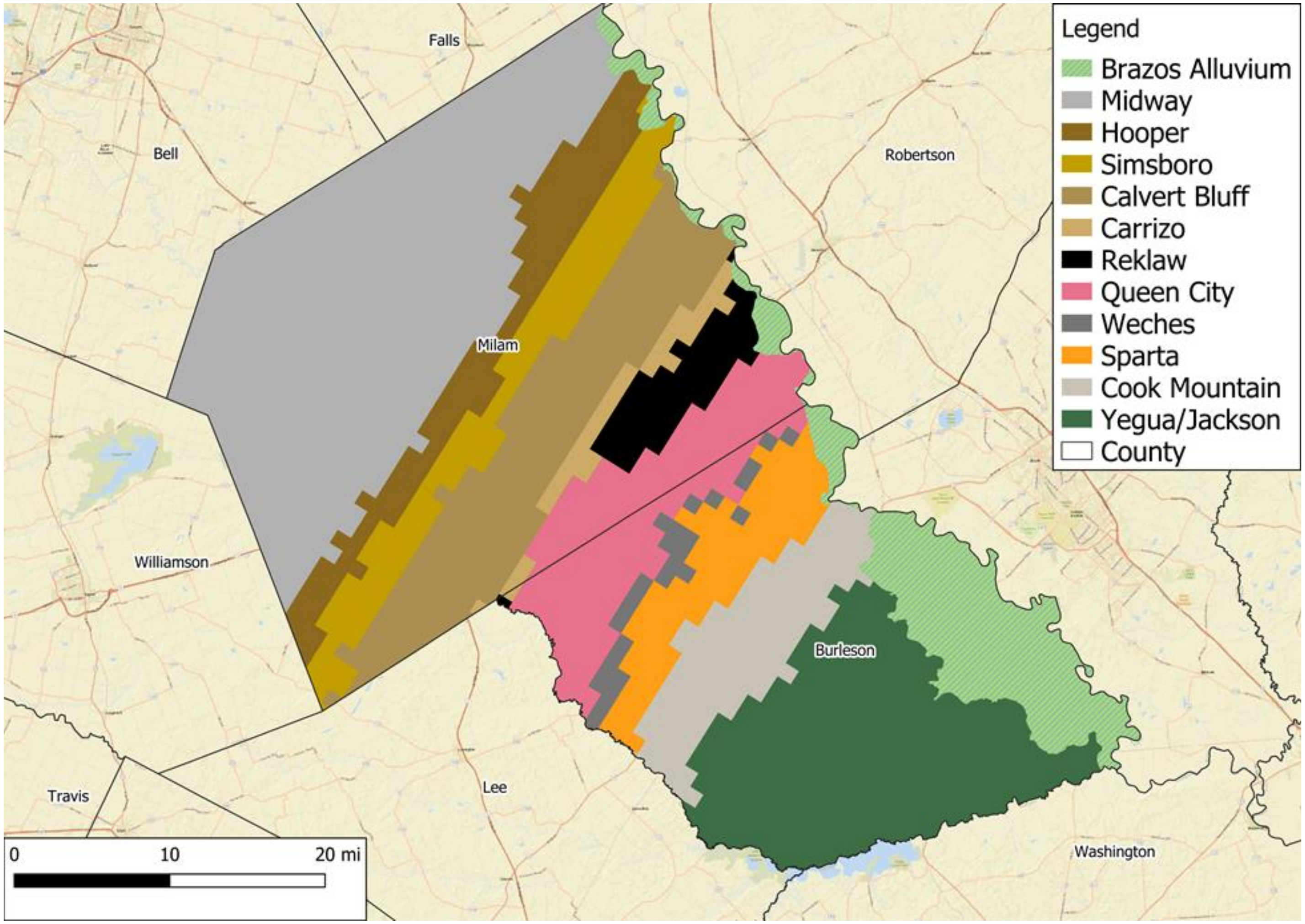

Figure 1-2 Map of aquifer outcrops based on information extracted from Groundwater Availability Models

2.0 GROUNDWATER MANAGEMENT PLAN

Chapter 36.1071 of the TWC requires that a District develop a Groundwater Management Plan that addresses several possible management goals, including the management goals for addressing the DFCs adopted by the District under Chapter 36.108. Consistent with these requirements, the District will use measured water levels from its monitoring wells to determine compliance with its DFCs at least once every three years. This commitment is stated in Section 17.10 of POSGCD's Management Plan (POSGCD, 2022) titled "Desired Future Conditions and Protective Drawdown Limits." **Exhibit 1** is an image of Section 17.10 of POSGCD Management Plan.

Section 17.10 requires POSGCD to assess their compliance with both DFCs and PDLs at least once every three years.

> **17.10 Desired Future Conditions and Protective Drawdown Limits**
>
> Management Objective:
>
> At least once every three years, the District will monitor water levels and evaluate whether the change in water levels is in conformance with the DFCs and PDLs adopted by the District. The District will estimate total annual groundwater production for each aquifer based on the water use reports, estimated exempted use, and other relevant information, and compare these production estimates to the MAGs listed in Table 8-1.
>
> Performance Standards:
>
> 1. At least once every three years, the general manager will report to the Board the measured water levels obtained from the monitoring wells within each Management Zone/Area, the average measured drawdown for each Management Zone/Area calculated from the measured water levels of the monitoring wells within the Management Zone/Area, a comparison of the average measured drawdowns for each Management Zone with the DFCs/PDLs for each Management Zone/Area, and the District's progress in conforming with the DFCs/PDLs.
> 2. At least once every three years, the general manager will report to the Board the total permitted production and the estimated total annual production for each aquifer and compare these amounts to the MAGs listed in Table 8-1 for each aquifer.

Exhibit 1 Section 17.10 Desired Future Conditions and Protective Drawdown Limits from Post Oak Savannah Management Plan (POSGCD, 2022)

2.1 DFC Management Zones and PDL Management Areas

Figure 2-1 shows DFC Management Zones for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro and Hooper aquifers. **Figure 2-2** shows the management areas for these six aquifers. The DFCs and the PDLs were developed to be consistent with the simulated drawdowns from Groundwater Management Area 12 simulations that are described in the GMA 12 Explanatory Report (D.B Stephens & Associates and others, 2022). The DFCs and the PDLs are described in the next two subsections.

2.2 Desired Future Conditions

Table 2-1 lists the POSGCD DFCs for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers. These DFCs were developed as part of GMA 12 joint planning process and are based on a GAM simulation using pumping file S-19 (D.B Stephens & Associates and others, 2022). Pumping file S-19 was assembled by GMA 12 to represent the pumping associated with the aforementioned six aquifers from 2011 to 2070. The pumping estimate began in 2010 because the calibration of the GAM (Young and others, 2018) for the six aquifers end in 2011.

Table 2-1 POSGCD DFCs for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper Aquifers

Aquifer	2021 Joint Planning
	Average Drawdown (ft) between January 2011 and January 2070
Sparta	32
Queen City	30
Carrizo	146
Calvert Bluff (Upper Wilcox)	156
Simsboro (Middle Wilcox)	278
Hooper (Lower Wilcox)	178

Table 2-2 lists the POSGCD DFCs for the Yegua Jackson Aquifer. The DFC was developed as part of GMA 12 joint planning process and are based on a GAM simulation using pumping file YGSK-PS2 (D.B Stephens & Associates and others,2022). Pumping file YGSK-PS2 was assembled by GMA 12 to represent the pumping associated with Yegua-Jackson Aquifer from 1998 to 2070. The pumping estimate began in 1998 because the calibration of the GAM (Deeds and others, 2010) for the six aquifers ended in 1997.

Table 2-2 Adopted DFCs for the Yegua-Jackson Aquifer

Aquifer	2021 Joint Planning
	Average Drawdown between January 2010 and January 2070 (ft)
Yegua-Jackson	61

2.3 Protective Drawdown Limits

For several management areas, the District has adopted a PDL, which represents an average drawdown across the management area measured from January 2011 to December 2070. The PDLs were adopted to improve the District's ability to manage and regulate water level change across the portion of the District's aquifers where the majority of wells are located. The PDLs were developed using GMA 12 pumping file S-19, which is the pumping file used by GMA 12 to develop the DFCs for each of the management zones that have been divided into management areas. The PDLs are therefore considered to be physical compatible with all the DFCs adopted by GMA 12. **Table 2-3** lists the PDLs for selected management areas , which are illustrated in Figure 2-2.

Table 2-3 Protective Drawdown Limits (PDLs) for Management Areas

Aquifer	Average Drawdown Measured from January 2010 to December 2070	
	Management Area 1	Management Area 2
Sparta	28	N/A
Queen City	19	N/A
Carrizo	75	175
Calvert Bluff	88	223
Simsboro	91	335
Hooper	210	N/A

2.4 Threshold Limits for DFCs and PDLs

POSGCD has established three threshold levels (identified in POSGCD Groundwater Rule 16.4) to help achieve its DFCs and PDLs and to conserve and preserve groundwater availability and protect groundwater users. In evaluating compliance for their DFCs and PDLs, POSGCD is evaluating whether any of the thresholds have been exceeded.

Threshold Level 1 is triggered by an average drawdown that is greater than 50 percent (%) of the DFC or 50% of the PDL. Threshold Level 2 is triggered by either an average drawdown that is greater than 60% of the aquifer DFC or 60% of the aquifer PDL. If a Threshold Level 1 is triggered, then hydrogeologic studies will be performed to address potential concerns about the data analysis, the cause for the drawdown, and the potential impact of the drawdown on production from the aquifer. A possible outcome of these studies is that schedules may be developed to curtail groundwater production in the affected management zones. If Threshold Level 2 is triggered, the District may notify well owners of possible plans for curtailing productions in affected management zones pending results from the Threshold Level 1 studies.

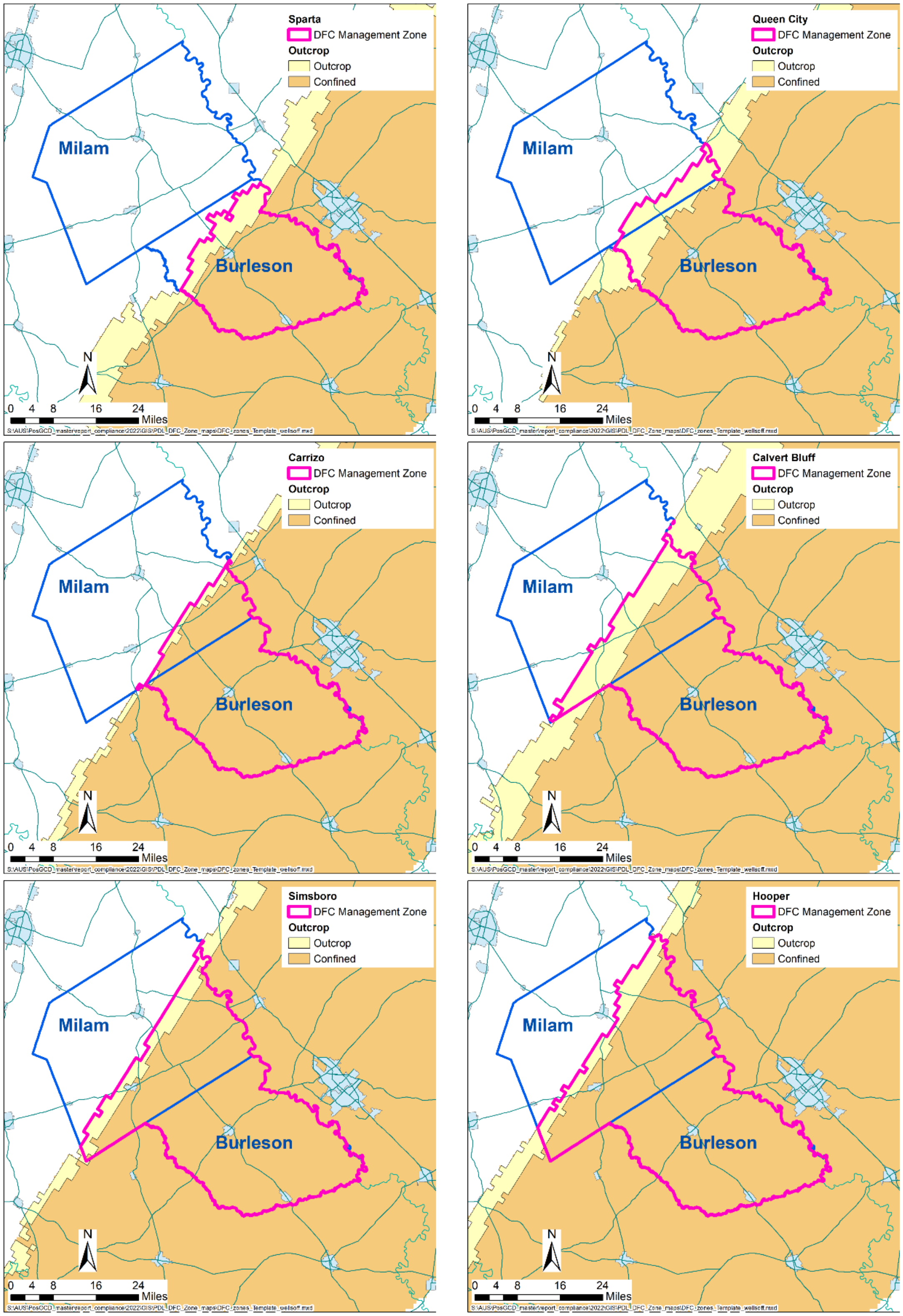

Figure 2-1 POSGCD total aquifer management zones for evaluating GMA 12 DFCs

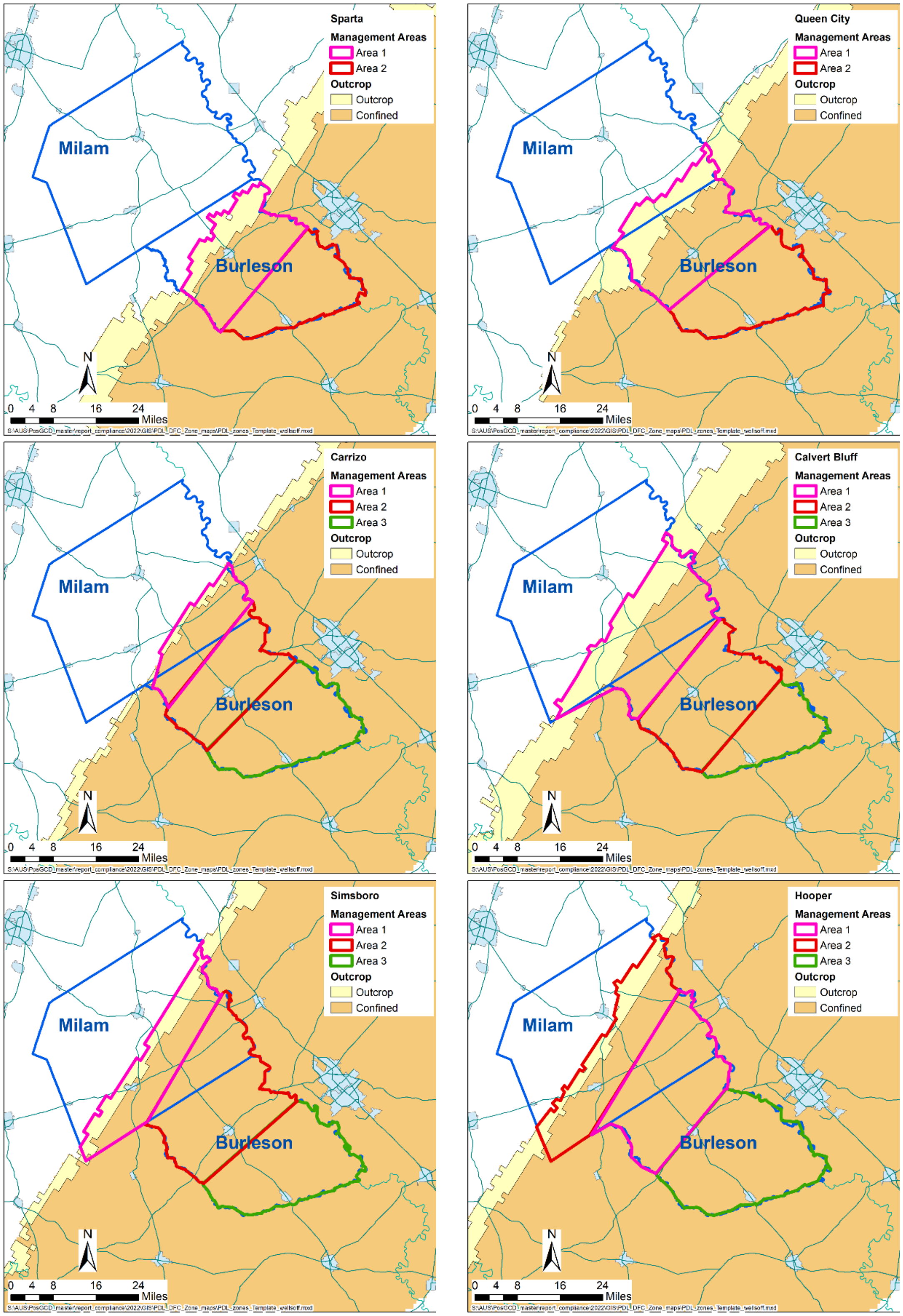

Figure 2-2 POSGCD PDL Management Areas for evaluating District PDLs

3.0 POSGCD WATER LEVEL MONITORING WELL NETWORK

This section describes the monitoring network of groundwater wells that the District uses to measure changes in water levels over time.

3.1 Monitor Well Network

The POSGCD network of groundwater wells is continually expanding by the addition of wells. The POSGCD Monitoring Well network currently consists of the 447 wells shown in **Figure 3-1.** The POSGCD monitoring database includes the following information for each monitoring well: spatial coordinates, well depth, screened interval, and aquifer assignment. POSGCD annually reviews and verifies aquifer assignments according to the latest data available and through collaboration with neighboring GCDs and the Texas Water Development Board (TWDB). Diagrams of the constructions for most of the monitoring wells are presented in the POSGCD monitoring guidance document (INTERA, 2021). The POSGCD monitoring guidance document provides guidelines for the collection and analysis of measured water levels. Updates to the well construction diagrams occur when the guidance document is revised.

Figure 3-2 shows the monitoring wells that were used to map annual changes in water level in 2023. The monitoring network includes two well of groups. One well group consists of POSGCD monitoring wells that have more than 70% of their wells screen intersecting a single aquifer. The other well group consists of monitoring wells from the Lost Pine GCD or the Brazos Valley GCD monitoring network. As funding becomes available, POSGCD will expand the seasonal and continual measurements of water levels at its monitoring wells.

3.2 Measurement of Water Levels

The water levels used in the compliance evaluation of DFCs and PDLs were measured between January 1st and April 31st. During this 4-month interval, the water levels are typically at their highest elevation and pumping rates are near their annual lows. The majority of the water levels are measured manually with an e-line tape. The majority of water levels are measured by GCD employees. The monitoring protocols used by POSGCD for measuring water levels are described by INTERA (2022). Approximately 120 POSGCD wells are equipped with either a transducer and data logger or WellIntel equipment to measure and record water levels regularly at 4-hours interval or less. The 2023 DFC evaluation, for the first time, incorporates continuous monitoring of Carrizo and/or Simsboro water levels in the Vista Ridge, Blue Water 130 Project, and SLR pumping wells to better assess the influence of these pumping centers on local to regional aquifer drawdown.

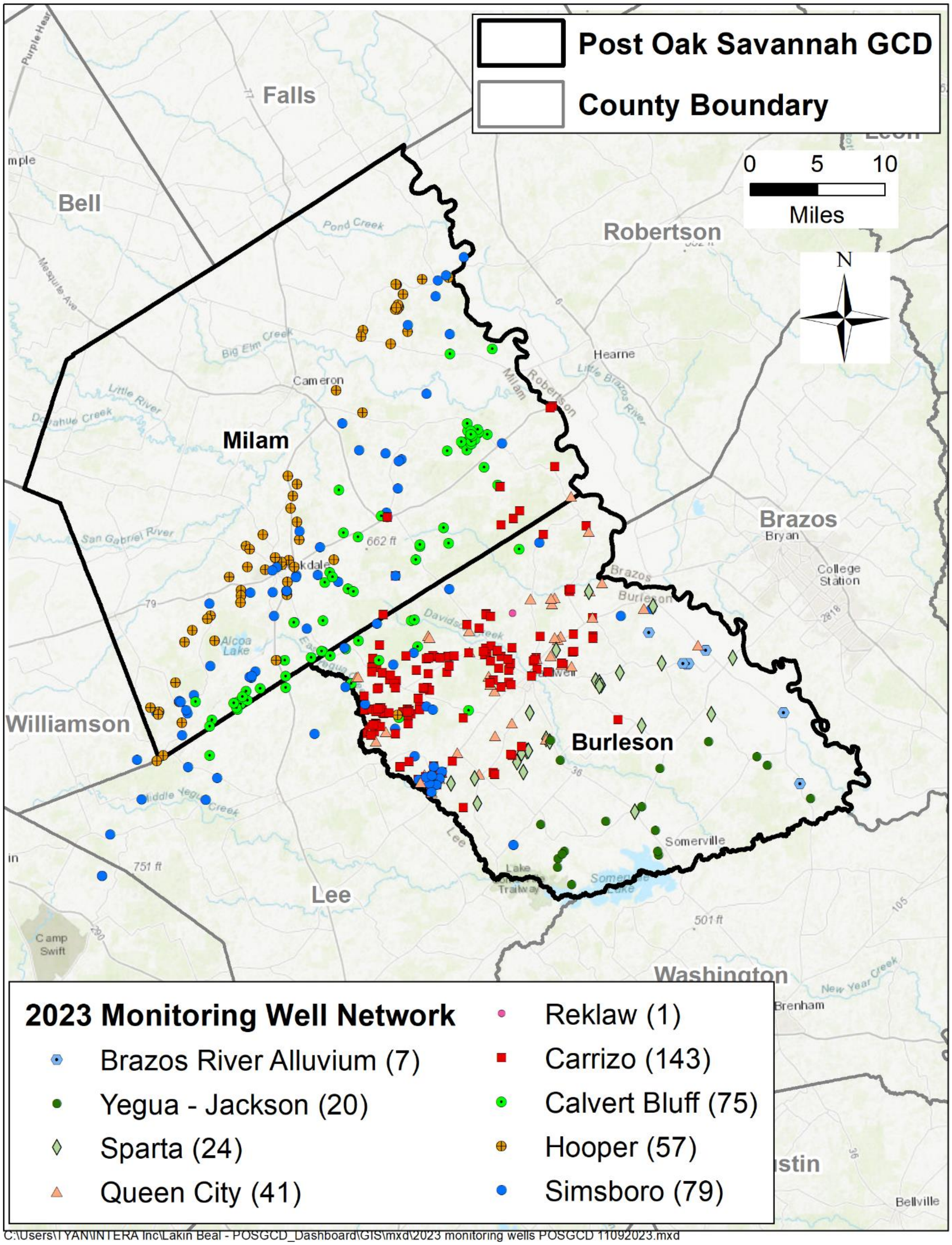

Figure 3-1 POSGCD monitoring well network consisting of 447 wells

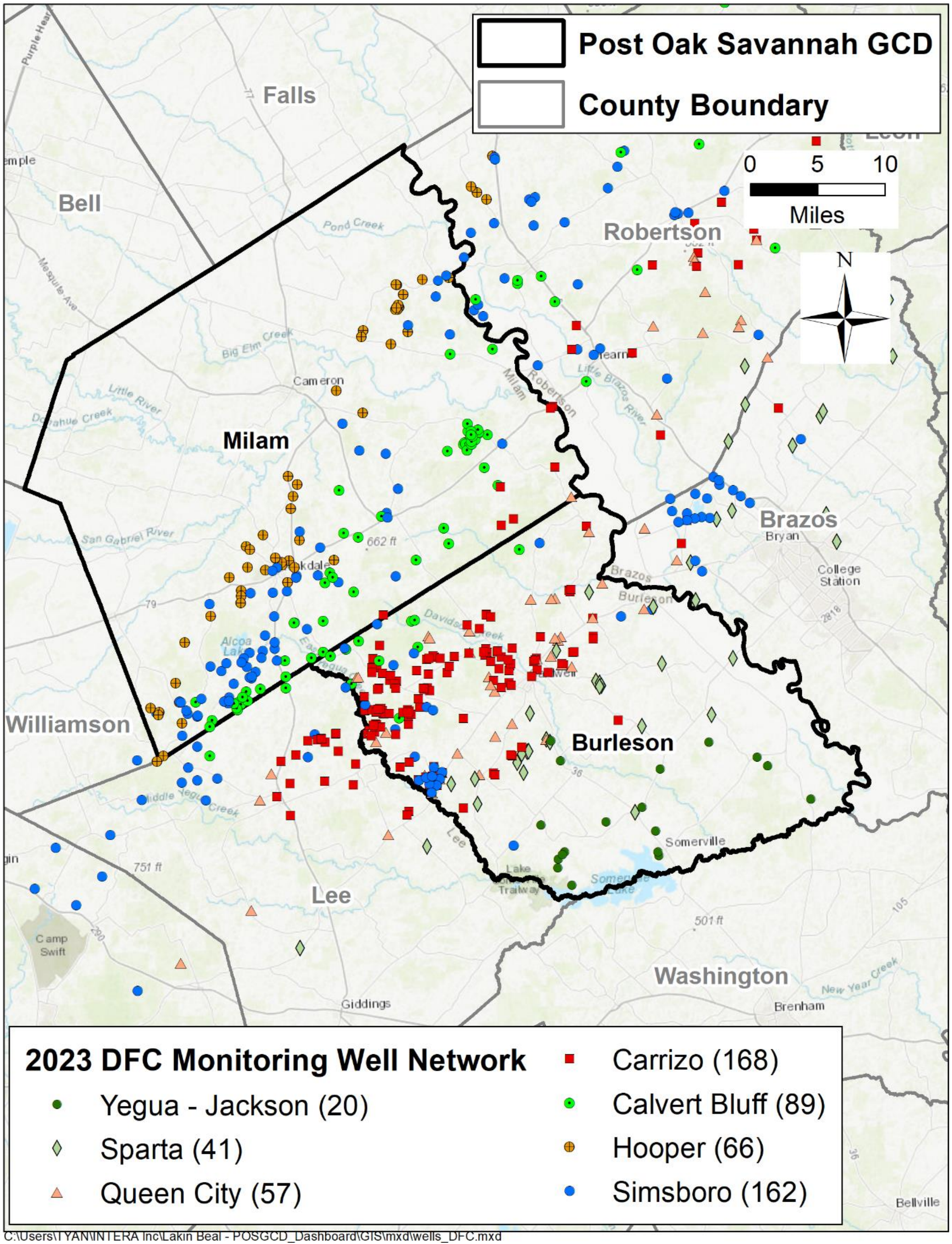

Figure 3-2 Monitoring well locations used in the DFC drawdown calculation for 2011 to 2023.

4.0 COMPLIANCE EVALUATION

This section provides a discussion of the DFC and PDL compliance evaluation. For each evaluation, the section explains the methodology and provides the results of the evaluation.

4.1 DFC Compliance Evaluation

Districts have a requirement under TWC Chapter 36.1132(b) to manage total groundwater production on a long-term basis to achieve DFCs. The DFCs for aquifers within the District are long-term management goals that are expressed as average aquifer drawdown that has occurred since the start of the DFC compliance period. For all aquifers in GAM 12, the start of the DFC compliance period is January 2011 except for the Yegua-Jackson Aquifer. The start of the DFC compliance period for the Yegua-Jackson Aquifer is January 2010.

The POSGD evaluation can be divided into the following five steps:

1) Identify which of the measured water levels are appropriate for the evaluation and determine a single value for each well by averaging multiple measurements, if they exist;
2) Calculate a three-year moving average for each well to be used for the interpolation process;
3) Interpolate the measured water levels by aquifer to produce a continuous set of values and contours of water level elevation across the entire aquifer for the DFC baseline year (i.e., 2011) and for the current year (i.e. 2023);
4) Generate a continuous set of drawdown values and drawdown contours across the entire aquifer based on the difference in water levels for the DFC baseline year and the current year;
5) Determine the amount the change in the average water since the baseline year

Figure 4-1 illustrates the application of Steps 3, 4, and 5 that was performed to determine the average drawdown that had occurred in the Simsboro aquifer over the period from 2000 to 2021.

4.1.1 Methods for Spatial Interpolation of Measured Water Levels

Spatial interpolation of measured water levels is performed in order to generate a continuous set of water level values and contours of water levels across an aquifer. Since 2008, POSGCD has evaluated multiple methods for interpolating water levels and is currently using three methods. Differences among the spatial interpolations can occur because of differences in their underlying assumptions regarding the statistical properties of the points being interpolated and with the sophistication in the algorithms used to implement mathematical analysis. Testing of these three methods has shown that the similarity in the predictions of the three methods increases as the density and coverage provided by the measured water levels increases. Our testing has also led to the conclusion that there is benefit in using multiple methods for evaluating because of the differences in water level conditions and monitoring network among the aquifers.

Currently, POSGCD's research indicates that two spatial interpretation methods are suitable for application for the seven aquifers with DFCs listed in Tables 2-1 and 2-2. These two methods are topo to raster, which is abbreviated as T2R, and ordinary kriging of water levels, which is abbreviated as KWL. For aquifers for which there is a GAM that is current with production rates and shown to be reasonable accurate for the POSGCD area, POSGCD's research suggests that a third of spatial method is suitable for application. The third method is called an ordinary kriging with residuals, and is abbreviated as KRS. A brief description of the three methods is provided below:

- Topo to Raster (T2R) - The method applies inverse distance weighting (IDW) to weight the influence of measure points at unmeasured locations. In general, the mathematical influence (weight) of measured points is proportional to the distance to the unsampled location. This approach is widely used because of the relatively simple set of equations needed to estimate values at unsampled locations. A concern with using T2R is that it ignores information regarding spatial statistics (e.g. variance and correlation) and the groundwater flow patterns. Another concern is that its implementation is through a proprietary program in ArcGIS (ESRI, 2020), for which the source code is not available for review by the public.
- Ordinary Kriging with Water Levels (KWL) – Ordinary kriging is a geostatistical method that determines the influence (weight) of measured points based on the correlation coefficient at varying spatial configurations relative to unmeasured points. Ordinary kriging assumes that the data is both normally distributed and has not spatial trend (Deutsch and Journel, 1998). A concern with using ordinary kriging with water levels is that there usually is a spatial trend in the water level data in POSGCD that is manifested as a regional water level gradients toward a hydraulic boundary condition such as the Gulf of Mexico, the Brazos River, or a well field with large production such as Vista Ridge or the City of Bryan wellfields.
- Ordinary Kriging with Residuals (KRS) – A first step in applying the KRS method is to develop an estimate of the water surface trend surface by smoothing a prediction of the groundwater water level from a groundwater model. The second step is to transform the set of measured water levels into a set of residuals by subtracting the water level elevation predicted by the surface trend at each well location from the measured water level elevation at the well location. Transforming the water levels into residuals is performed so that values being kriged would be more likely would be closer to a normal distribution and exhibit stationarity than the set of measured water levels.

Contours of the water level elevation based on the measured 2023 water levels are provided in Appendices A, B and C for the six aquifers with DFCs listed in Table 2-1. Appendices A, B, and C present results based on the spatial interpolation methods T2R, KWL, and KRS, respectively.

For the last three years, the water levels in the Carrizo Aquifer have been of primary interest to POSGCD because of the large drawdowns that have occurred since the Vista Ridge wellfield started production. The upper three plots in **Figure 4-1** show the drawdown contours generated for the Carrizo aquifer over the time period from 2011 to 2023 using the three spatial interpolation methods discussed above: T2R, KWL, and KRS. All three methods produced generally similar shaped drawdown contours and drawdown values for radial distances of more than 10 miles from the Vista Ridge well field.

4.1.2 Evaluation of Water Levels for DFC Compliance

Table 4-1 lists the key metrics associated with the DFC 2023 compliance evaluation for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers. For these six aquifers, the average drawdown is measured from the baseline year 2011 and the average drawdown is calculated as the average of the three interpolation methods. Table 4-1 lists the average drawdown determined from each of the three interpolation methods for 2023 and provides the average drawdown for the three methods. For example, the T2R, KWL, and KRS interpolation methods for the Carrizo Aquifer yield 72, 69.1, 78.5 feet (ft) for drawdown from 2011 to 2023, respectively. These three values produce an average drawdown of 73.2 ft. Since 50% of the Carrizo DFC of 146 ft is 73 ft, Threshold Level 1 is exceeded and therefore, the Carrizo Aquifer is considered noncompliant with the DFC. The remaining five aquifers have average 2023 drawdown values that are maintained below the DFC thresholds.

Table 4-2 summarizes the DFC compliance evaluation for years 2016 through 2023 using the average drawdown calculated from the three interpolation methods. The table shows seven instances through time where the average drawdown from the three interpolation methods exceeds a Threshold Level. Two exceedances occur for the 2017 and 2018 water level data for the Sparta Aquifer. The average Sparta drawdown for 2017 and 2018 is 18.2 and 18.5 ft, respectively. For both 2017 and 2018 , The threshold of 50% for Level 1 was exceeded. Four threshold exceedances occur for the Queen City Aquifer's 2018, 2019, 2020, and 2021 water levels. The average Queen City drawdowns for 2018, 2019, 2020 , and 2021 are 18.1, 22.5, 20.0, and 16.0 ft, respectively. The 75% threshold for Level 3 was exceeded in 2019. In 2018 and 2020, the Threshold Level 2 of 60% was exceeded. The average Carrizo drawdown for 2023 is 73.2 ft, which exceeds the Threshold Level 1 of 50%.

Figure 4-3 shows the DFC management zone average drawdown values for the three interpolation methods and the average of the three methods (black points) through time. These values are compared to the Threshold Level 1, 2, and 3 values, which are depicted as horizontal lines.

Table 4-3 lists the key metrics associated with the DFC 2023 compliance evaluation for the Yegua-Jackson aquifer. For the Yegua-Jackson aquifer the KRS spatial interpolation method is not used because the Yegua-Jackson GAM (Deeds and others, 2004) has not been adequately updated since its development to be used for implementing the KRS method. As a result, Table 4-3 only includes spatial interpolation results for the TWR and the KWL method. In 2023, the average 2011 to 2023 drawdown for the Yegua-Jackson Aquifer is -30.2 ft, indicating a higher average groundwater table in 2023 relative to 2010. **Table 4-4** shows the DFC compliance evaluation for years 2016 through 2023 does not violated and Threshold Levels.

Table 4-1 Evaluation of DFC compliance for 2023 based on the three Threshold limits for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers.

Management Zone	DFC	2011 to 2023 Drawdown: Avg. Drawdown (ft) / % of DFC; Drawdown values from the T2R, KWL, and KRS methods	Compliant with DFC
Sparta	32	11.8 (37%)	Yes
		10.6, 12.6, 12.4	
Queen City	30	14.3 (47.6%)	Yes
		12.2, 2.7, 28	
Carrizo	146	73.2 (50.1%)	No
		72, 69.1, 78.5	
Calvert Bluff (Upper Wilcox)	156	60 (38.5%)	Yes
		72.2, 36.5, 71.4	
Simsboro (Middle Wilcox)	278	69.3 (24.9%)	Yes
		74, 53.5, 80.3	
Hooper (Lower Wilcox)	178	18.1 (10.2%)	Yes
		14.6, 7.5, 32.3	

Threshold 1 = 50% PDL Threshold 2 = 60% PDL

Threshold 3 = 75% DFC

Table 4-2 Evaluation of DFC compliance for 2016 to 2023 based on the three Threshold limits for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers. Note: black text indicates compliance; blue text indicates at or above Threshold Level 1; orange indicates at or above Threshold Level 2, green indicates at or above Threshold Level 3

Management Zone	DFC	Drawdown from 2011 to 2016	Drawdown from 2011 to 2017	Drawdown from 2011 to 2018	Drawdown from 2011 to 2019	Drawdown from 2011 to 2020	Drawdown from 2011 to 2021	Drawdown from 2011 to 2022	Drawdown from 2011 to 2023
Sparta	32	13.2	18.2	18.5	15.8	14.2	12.5	12.0	11.8
		41.4%	56.8%	57.9%	49.3%	44.4%	39.0%	37.6%	37.0%
		1, -, -	2, 1, -	2, 2, -	1, 1, -	1, 1, -	-, 1, -	-, 1, -	-, -, -
Queen City	30	5.5	11.8	18.1	22.5	20.9	16.0	13.1	14.3
		18.3%	39.2%	60.4%	75.1%	69.8%	53.3%	43.5%	47.6%
		-, -, -	-, 2, -	-, 3, -	-, 3, -	-, 3, -	-, 3, -	-, 2, -	-, -, 3
Carrizo	146	-1.9	5.8	14.8	30.2	36.7	51.3	51.6	73.2
		-1.3%	4.0%	10.1%	20.7%	25.1%	35.1%	35.4%	50.1%
		-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	3, -, 1
Calvert Bluff (Upper Wilcox)	156	-1.9	8.4	6.7	14.9	26.6	33.7	40.8	60.0
		-1.2%	5.4%	4.3%	9.6%	17.1%	21.6%	26.2%	38.5%
		-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	1, -, -
Simsboro (Middle Wilcox)	278	7.8	1.6	-2.2	-0.2	18.7	36.1	38.9	69.3
		2.8%	0.6%	-0.8%	-0.1%	6.7%	13.0%	14.0%	24.9%
		-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
Hooper (Lower Wilcox)	178	-7.2	-15.5	-12.2	-12.8	-0.8	6.5	11.6	18.1
		-4.1%	-8.7%	-6.9%	-7.2%	-0.5%	3.7%	6.5%	10.2%
		-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -

Threshold 1 = 50% DFC   Threshold 2 = 60% DFC   Threshold 3 = 75% DFC

Table 4-3 Evaluation of DFC compliance for 2023 for Yegua-Jackson aquifer.

Management Zone	2070 DFC (ft)	2010 to 2023 Drawdown Avg. Drawdown (ft) / % of DFC Drawdown values from the T2R, and KWL	Compliant With DFC
Yegua-Jackson	61	-30.2 (-49.4%) **-27.0, -33.3**	Yes

Threshold 1 = 50% DFC Threshold 2 = 60% DFC
Threshold 3 = 75% DFC

Note: black text indicates compliance; blue text indicates at or above Threshold Level 1; orange indicates at or above Threshold Level 2, green indicates at or above Threshold Level 3

Table 4-4 Evaluation of DFC compliance for 2016 to 2023 based for the Yegua-Jackson aquifer.

Management Zone	DFC (ft)	From 2010 to 2016	From 2010 to 2017	From 2010 to 2018	From 2010 to 2019	From 2010 to 2020	From 2010 to 2021	From 2010 to 2022	From 2010 to 2023
		Avg. Drawdown (ft) / % of DFC / Maximum Threshold Level Violation for T2R and KWL							
Yegua-Jackson	61	-8.1	-13.5	-18.5	-14.8	-14.6	-14.3	-16.3	-30.2
		-13.3%	-22.2%	-30.3%	-24.2%	-23.9%	-23.4%	-26.7%	-49.4%
		-, -	-, -	-, -	-, -	-, -	-, -	-, -	-, -

Threshold 1 = 50% DFC Threshold 2 = 60% DFC
Threshold 3 = 75% DFC

Note: black text indicates compliance; blue text indicates at or above Threshold Level 1; orange indicates at or above Threshold Level 2, green indicates at or above Threshold Level 3

4.2 PDL Compliance Evaluation

The PDL compliance evaluations are performed using the same workflow, data, codes, algorithms, threshold levels, and analysis that are used to perform the DFC evaluation. The primary difference is that the PDL evaluations are performed for management areas, whereas the DFC evaluations are performed for management zones.

4.2.1 Method

The method used to calculate average drawdown in the PDL Management Areas is identical to the method employed for compliance with the DFC Management Zones in which they are located. To perform the PDL evaluations, the spatial interpolations generated for the DFC evaluations are used. The only difference is that where a DFC average drawdown is calculated across a management zone (see Figure 2-1) a PDL average drawdown is calculated across a management area (see Figure 2-2).

As previously discussed, there are a total of nine management areas for which POSGCD has adopted PDLs. Each of the Sparta, Queen City, and the Hooper aquifers have one PDL management area each. Each of the Carrizo, Calvert Bluff, and Simsboro aquifers have two PDF management areas each.

4.2.2 Evaluation of Water Levels for PDL Compliance

Table 4-5 lists the key metrics associated with the PDL 2023 compliance evaluation for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers. For these six aquifers, the average drawdown is measured from the baseline year 2011 and the average drawdown is calculated as the average of the three interpolation methods. Table 4-5 lists the average drawdown determined from each of the three interpolation methods for 2023 and provides the average drawdown for the three methods. For example, the T2R, KWL, and KRS interpolation methods for the Carrizo Aquifer PDL Management Area 2 yields 107.6, 93.3, 93.9 ft drawdown from 2011 to 2023, respectively. These three values produce an average drawdown of 98.3 ft. Since 50% of the Carrizo PDL Management Area 2 of 175 ft is 87.5 ft, Threshold Level 1 is exceeded and therefore, the Carrizo Aquifer is considered PDL complaint for Management Area 2. The remaining eight PDL Management Areas, spanning all six aquifers, have average 2023 drawdown values that are maintained below the PDL thresholds.

Table 4-6 summarizes the PDL compliance evaluation for years 2016 through 2023 using the average drawdown calculated from the three interpolation methods. Table 4-6 shows two instances through time where the average drawdown for the three interpolation methods exceeds a threshold level. The first violation is for the 2017 water level data for the Sparta Aquifer. The average Sparta drawdown for Management Area 1 in 2017 is 16.7 ft, which violates Threshold Level 1. The average Carrizo drawdown for Management Area 2 in 2023 is 98.3 ft, which exceeds the Threshold Level 1 of 50%.

Figure 4-5 shows the PDL Management Area 1 average drawdown values for the three interpolation methods and the average value of the three methods (black points) through time. These values are compared to the Threshold Level 1, 2, and 3 values, which are depicted as horizontal lines.

Figure 4-6 shows the PDL Management Area 2 average drawdown values for the three interpolation methods and the average value of the three methods (black points) through time. These values are compared to the Threshold Level 1, 2, and 3 values, which are depicted as horizontal lines.

Table 4-5 Evaluation of PDL compliance for 2023 based on the three Threshold limits for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers.

Management Area		2070 PDL (ft)	2011 to 2022 Drawdown: Avg. Drawdown (ft) / % of DFC Drawdown values from the T2R, KWL, and KRS methods	Compliant with PDL
Sparta	Area 1	28	-2.1 (-7.6%) 1.9, 0.7, -9	Yes
Queen City	Area 1	19	-4.2 (-22.1%) -6.4, -0.5, -5.7	Yes
Carrizo	Area 1	75	17.1 (22.8%) 0.3, 8.9, 42.1	Yes
	Area 2	175	98.3 (56.2%) 107.6, 93.3, 93.9	No
Calvert Bluff (Upper Wilcox)	Area 1	88	23.6 (26.8%) 19.2, 24.5, 27.1	Yes
	Area 2	223	65.4 (29.3%) 39.3, 47.1, 109.8	Yes
Simsboro (Middle Wilcox)	Area 1	91	-10.1 (-11.1%) -3.6, -8.6, -18	Yes
	Area 2	335	100.7 (30.1%) 101.1, 98, 103.1	Yes
Hooper (Lower Wilcox)	Area 1	210	20.6 (9.8%) 22.5, 4.2, 35.2	Yes

Threshold 1 = 50% PDL Threshold 2 = 60% PDL
Threshold 3 = 75% DFC

Note: black text indicates compliance; blue text indicates at or above Threshold Level 1; orange indicates at or above Threshold Level 2, green indicates at or above Threshold Level 3

Table 4-6 Evaluation of PDL compliance for 2016 to 2023 based on the three Threshold limits for the Sparta, Queen City, Carrizo, Calvert Bluff, Simsboro, and Hooper aquifers.

Management Area		PDL	Drawdown from 2011 to 2016	Drawdown from 2011 to 2017	Drawdown from 2011 to 2018	Drawdown from 2011 to 2019	Drawdown from 2011 to 2020	Drawdown from 2011 to 2021	Drawdown from 2011 to 2022	Drawdown from 2011 to 2023
			Avg. of Drawdown (ft)							
			% of DFC							
			Threshold Violation: T2R, KWL, KRS							
Sparta	Area 1	28	11.2	16.7	10.3	8.7	7.2	3.8	2.9	-2.1
			39.9%	59.6%	36.7%	31.1%	25.5%	13.7%	10.2%	-7.6%
			1, -, -	3, 1, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
Queen City	Area 1	75	2.6	1.2	3.1	4.4	3.9	1.0	0.1	-4.2
			3%	2%	4%	6%	5%	1%	0%	-6%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
Carrizo	Area 1	75	-3.1	-1.3	3.4	0.6	16.3	11.9	9.7	17.1
			-4%	-2%	5%	1%	22%	16%	13%	23%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, 1
	Area 2	175	-0.3	9.2	15.0	32.2	53.6	69.5	74.5	98.3
			0%	5%	9%	18%	31%	40%	43%	56.2%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	2, 1, 1
Calvert Bluff (Upper Wilcox)	Area 1	88	-0.8	3.0	3.3	2.7	5.5	8.2	11.9	23.6
			-1%	3%	4%	3%	6%	9%	14%	27%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
	Area 2	223	-1.1	14.2	11.2	26.4	45.7	57.7	69.7	65.4
			0%	6%	5%	12%	20%	26%	31%	29%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
Simsboro (Middle Wilcox)	Area 1	91	4.3	-7.3	-11.9	-13.3	-9.9	-6.6	-6.0	-10.1
			5%	-8%	-13%	-15%	-11%	-7%	-7%	-11%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
	Area 2	335	11.7	10.7	10.5	12.2	33.2	53.1	64.2	100.7
			4%	3%	3%	4%	10%	16%	19%	30%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -
Hooper (Lower Wilcox)	Area 1	210	-7.0	-19.0	-14.9	-16.6	-4.5	4.6	11.9	20.6
			-3%	-9%	-7%	-8%	-2%	2%	6%	10%
			-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -	-, -, -

Threshold 1 = 50% DFC Threshold 2 = 60% DFC Threshold 3 = 75% DFC

Note: black text indicates compliance; blue text indicates at or above Threshold Level 1; orange indicates at or above Threshold Level 2, green indicates at or above Threshold Level 3

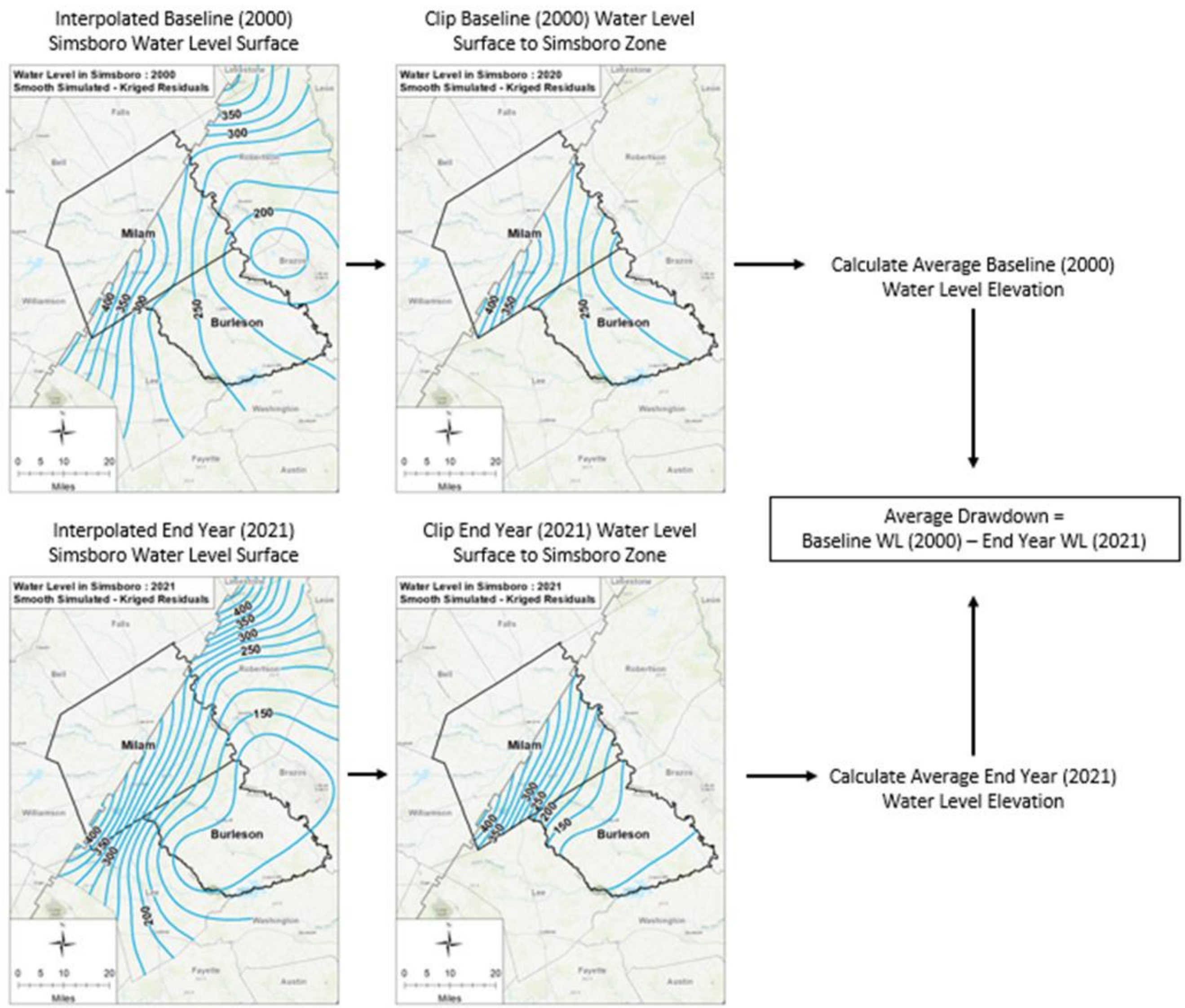

Figure 4-1 Diagram showing the process of interpolation of measured water levels in the Simsboro Aquifer to determine the average drawdown from 2000 to 2021.

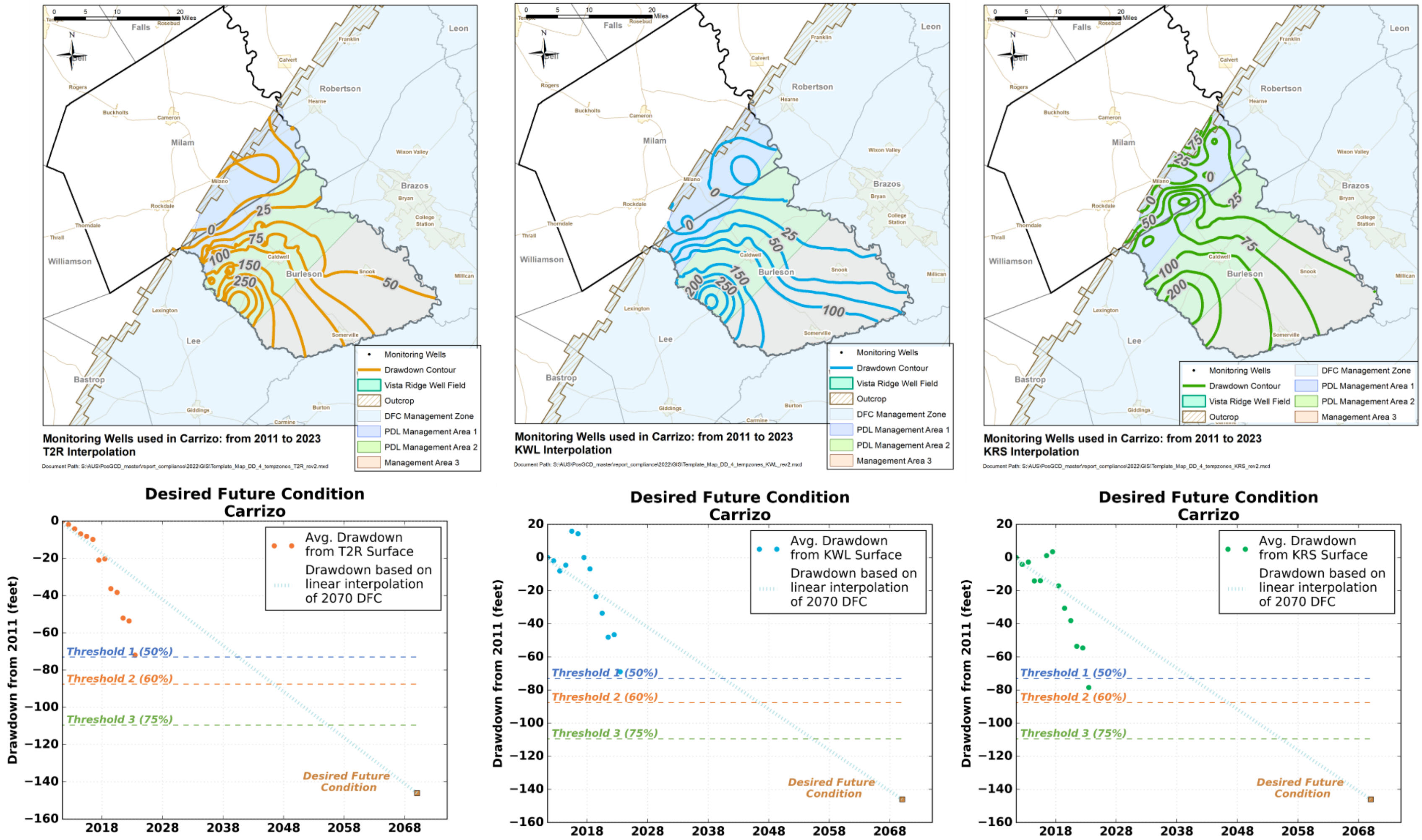

Figure 4-2 Comparison of drawdown generated for the Carrizo for the time interval 2011 to 2023 by three different spatial interpolation methods: topo2raster (T2R), ordinary kriging with water levels (KWL), and ordinary kriging with residuals (KRS). The upper three plots compare contours of drawdown and the lower three plots how average drawdown of the three methods over time as determined from the base year 2011

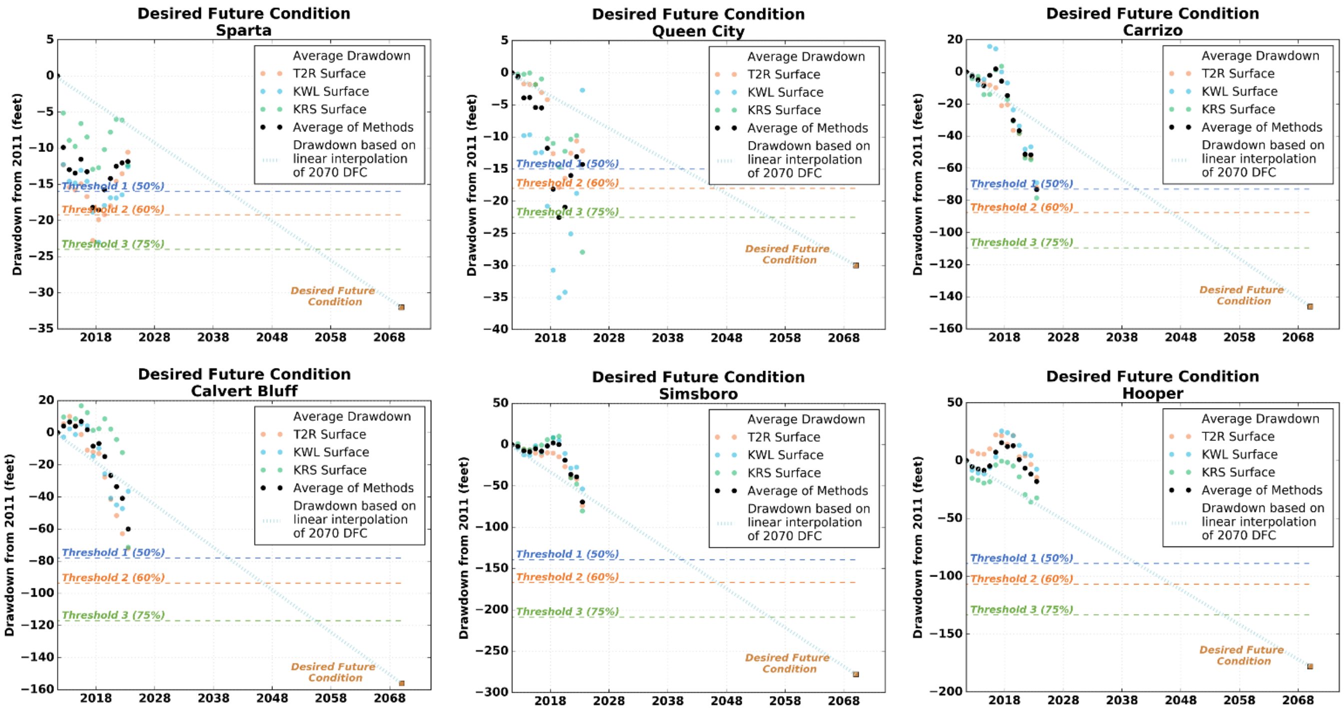

Figure 4-3 Comparison of average drawdown and drawdowns calculated from the year 2011 using the spatial interpolation methods topo to raster (T2R), kriging with water levels (KWL), and kriging with residuals (KRS) for the Sparta, Queen City, Carrizo, Calver Bluff, Simsboro, and Hooper aquifers Management Zones

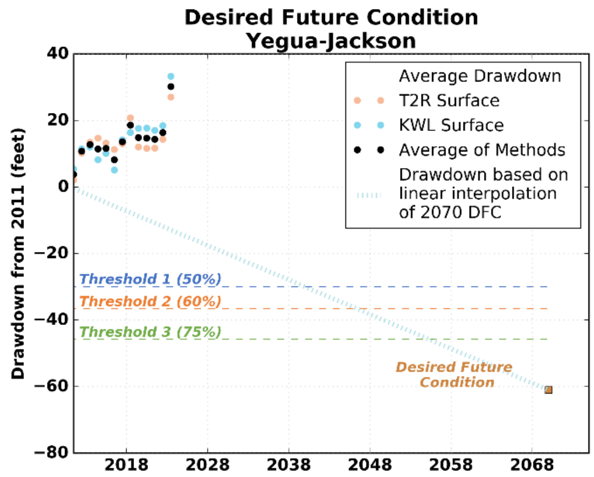

Figure 4-4 Comparison of average drawdown and drawdowns calculated from the year 2010 using the spatial interpolation methods topo to raster (T2R) and kriging with water levels (KWL) Yegua-Jackson aquifer Management Zone.

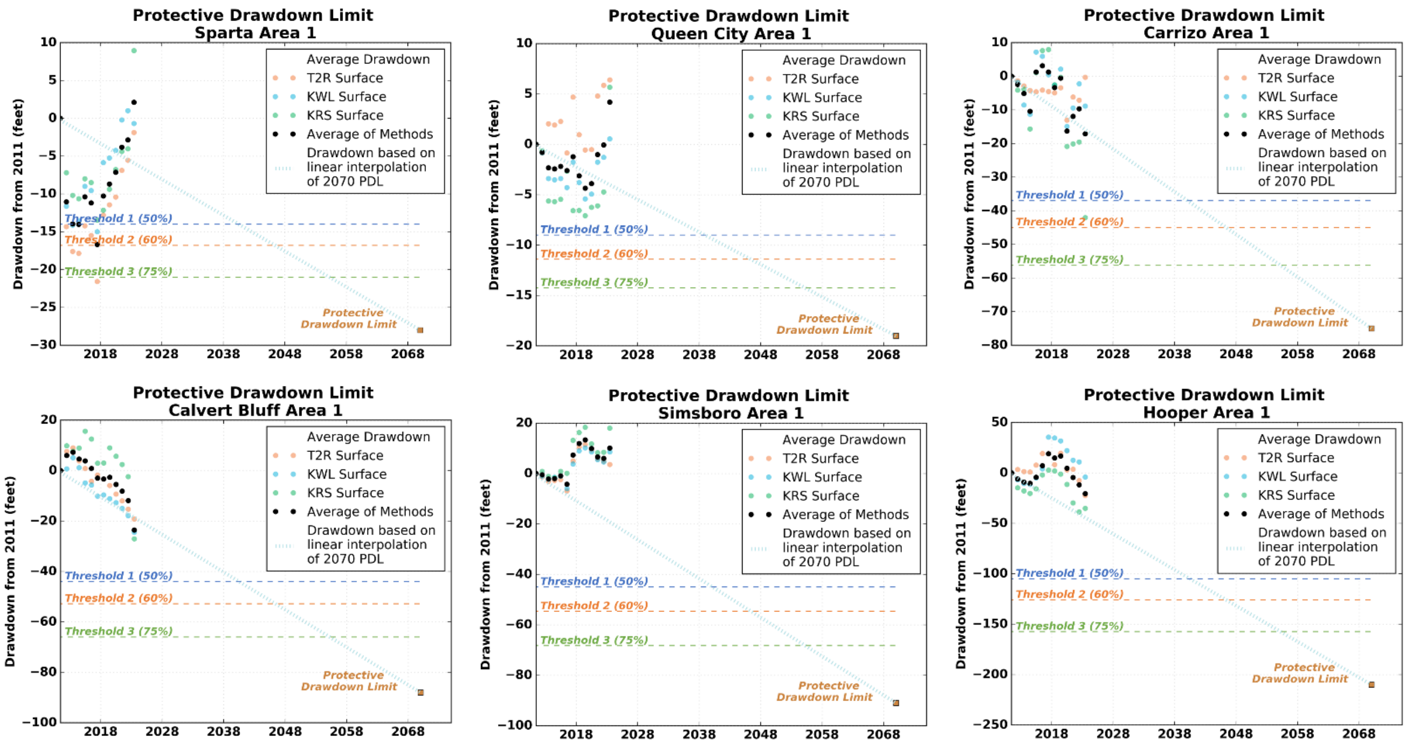

Figure 4-5 Comparison of average drawdown and drawdowns calculated from the year 2011 using the spatial interpolation methods topo to raster (T2R), kriging with water levels (KWL), and kriging with residuals (KRS) for Management Area 1 for the Sparta, Queen City, Carrizo, Calver Bluff, Simsboro, and Hooper aquifers.

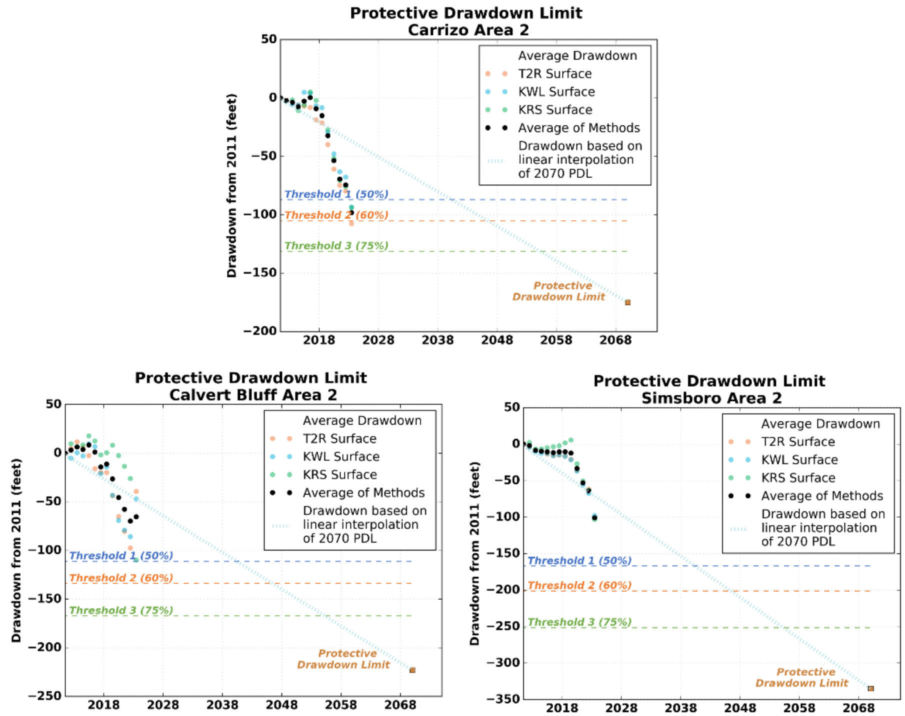

Figure 4-6 Comparison of average drawdown and drawdowns calculated from the year 2011 using the spatial interpolation methods topo to raster (T2R), kriging with water levels (KWL), and kriging with residuals (KRS) for the Management Area 2 for the Sparta, Queen City, Carrizo, Calver Bluff, Simsboro, and Hooper aquifers.

5.0 REFERENCES

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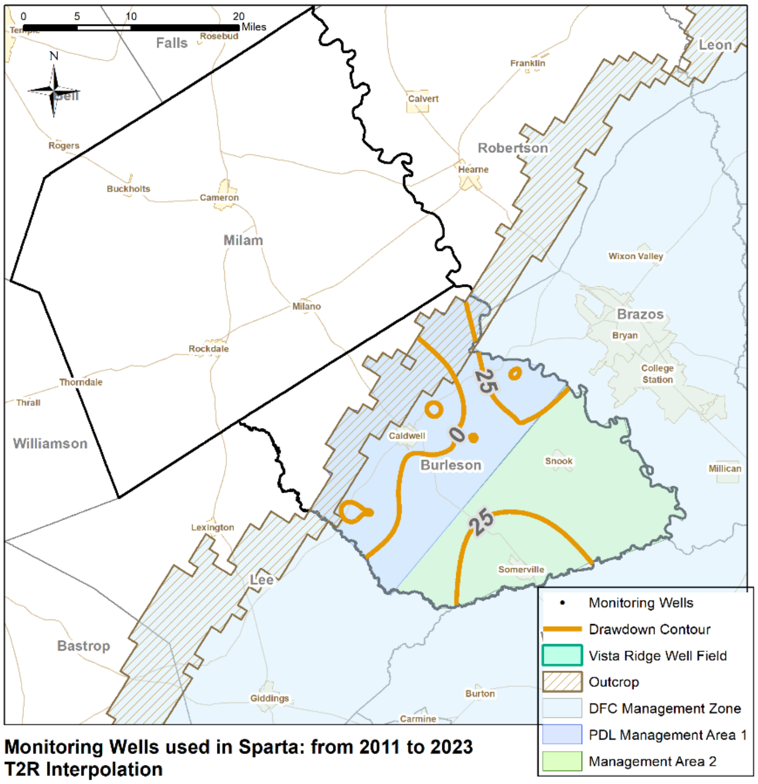
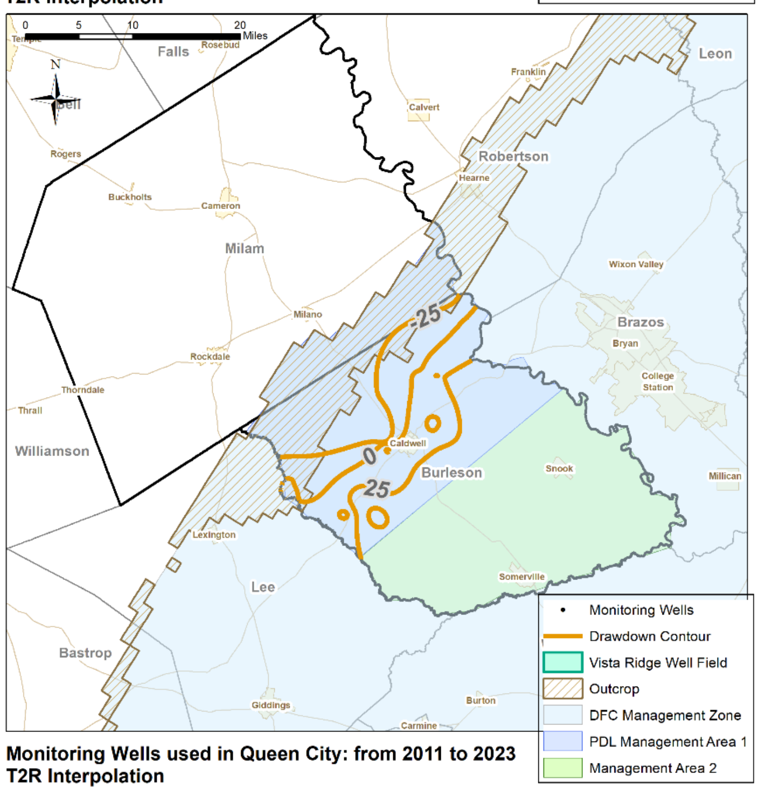
APPENDIX A

2023 Water Level Surfaces Created by Applying Topo to Raster to Water Levels



Monitoring Wells used in Sparta: from 2011 to 2023
T2R Interpolation



Monitoring Wells used in Queen City: from 2011 to 2023
T2R Interpolation

Figure A-1 2023 drawdown contours for the Sparta and Queen City Aquifers Based on Interpolation using Topo to Raster

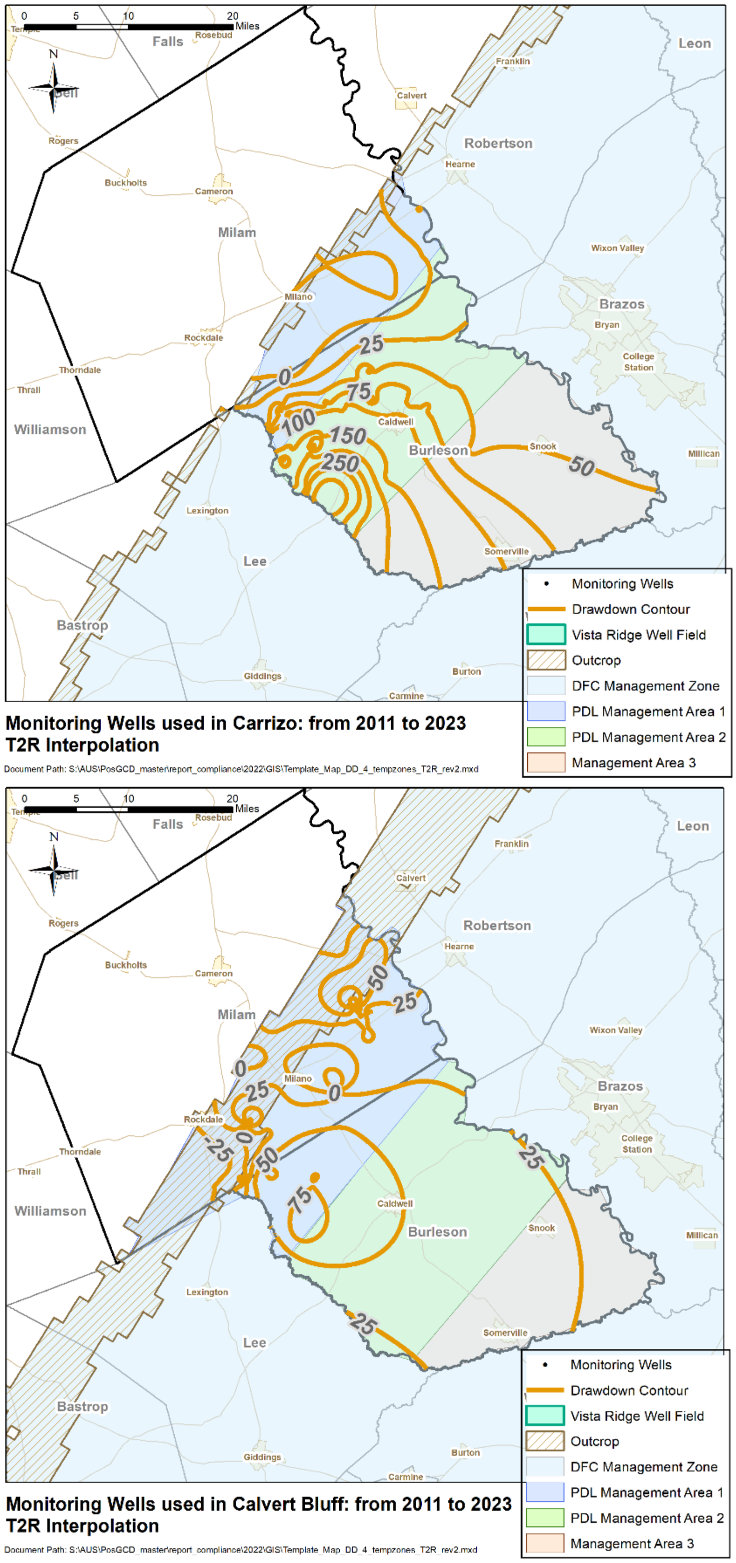


Figure A-2 2023 drawdown contours for the Carrizo and Calvert Bluff Aquifers Based on Interpolation using Topo to Raster

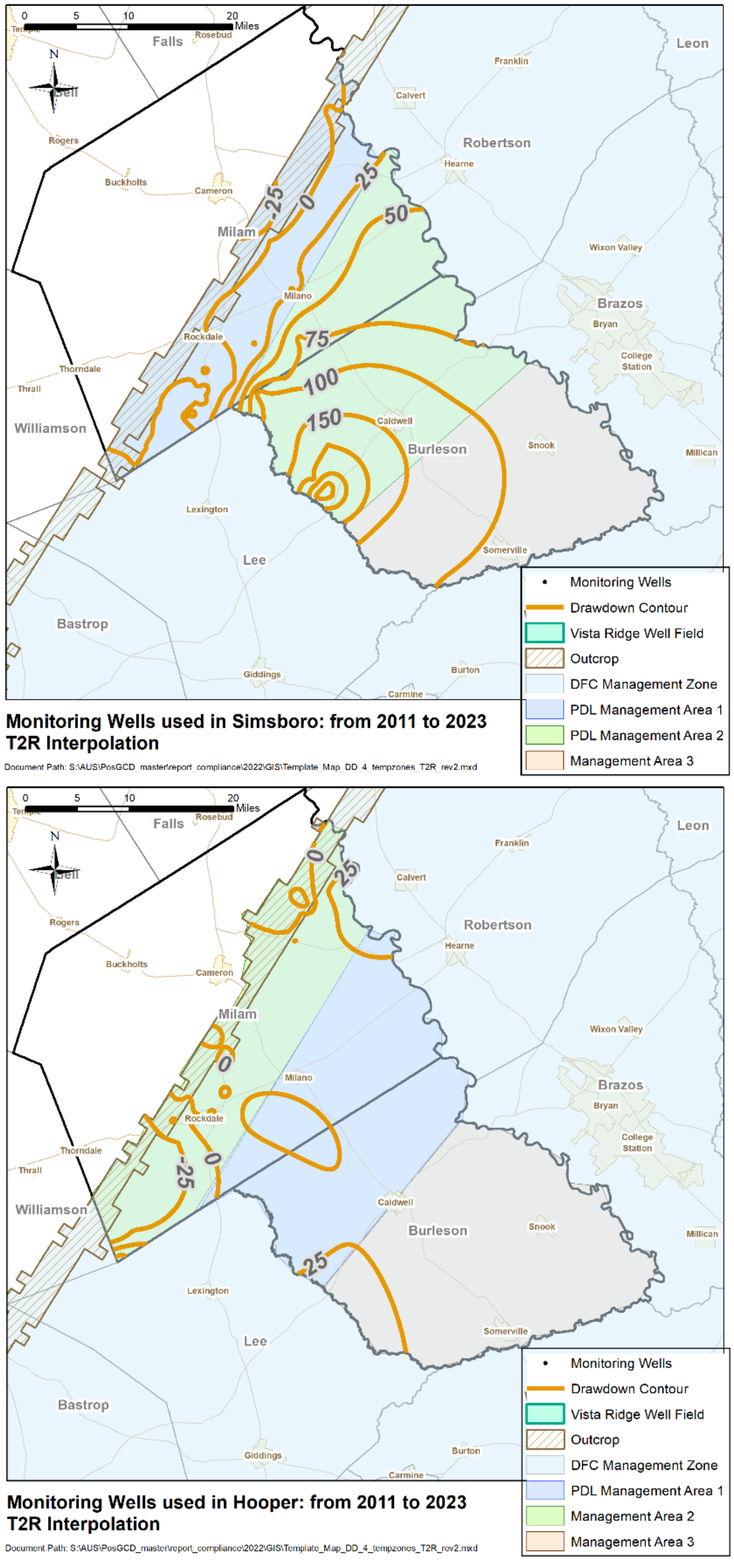


Figure A-3 2023 drawdown contours for the Simsboro and Hooper Aquifers Based on Interpolation using Topo to Raster

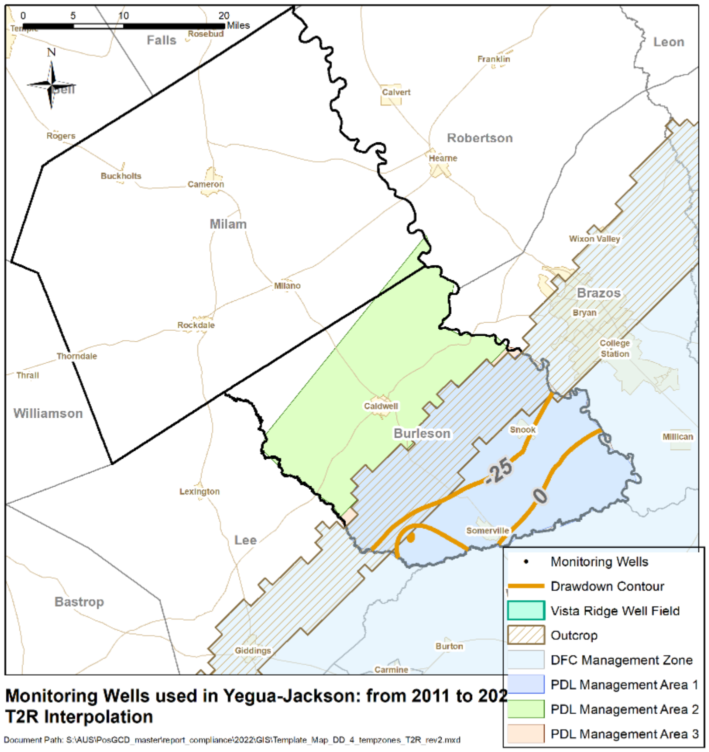


Figure A-4 2023 drawdown contours for Yegua-Jackson Aquifer Based on Interpolation using Topo to Raster

APPENDIX B

2023 Water Level Surfaces Created by Applying Ordinary Kriging to Water Levels

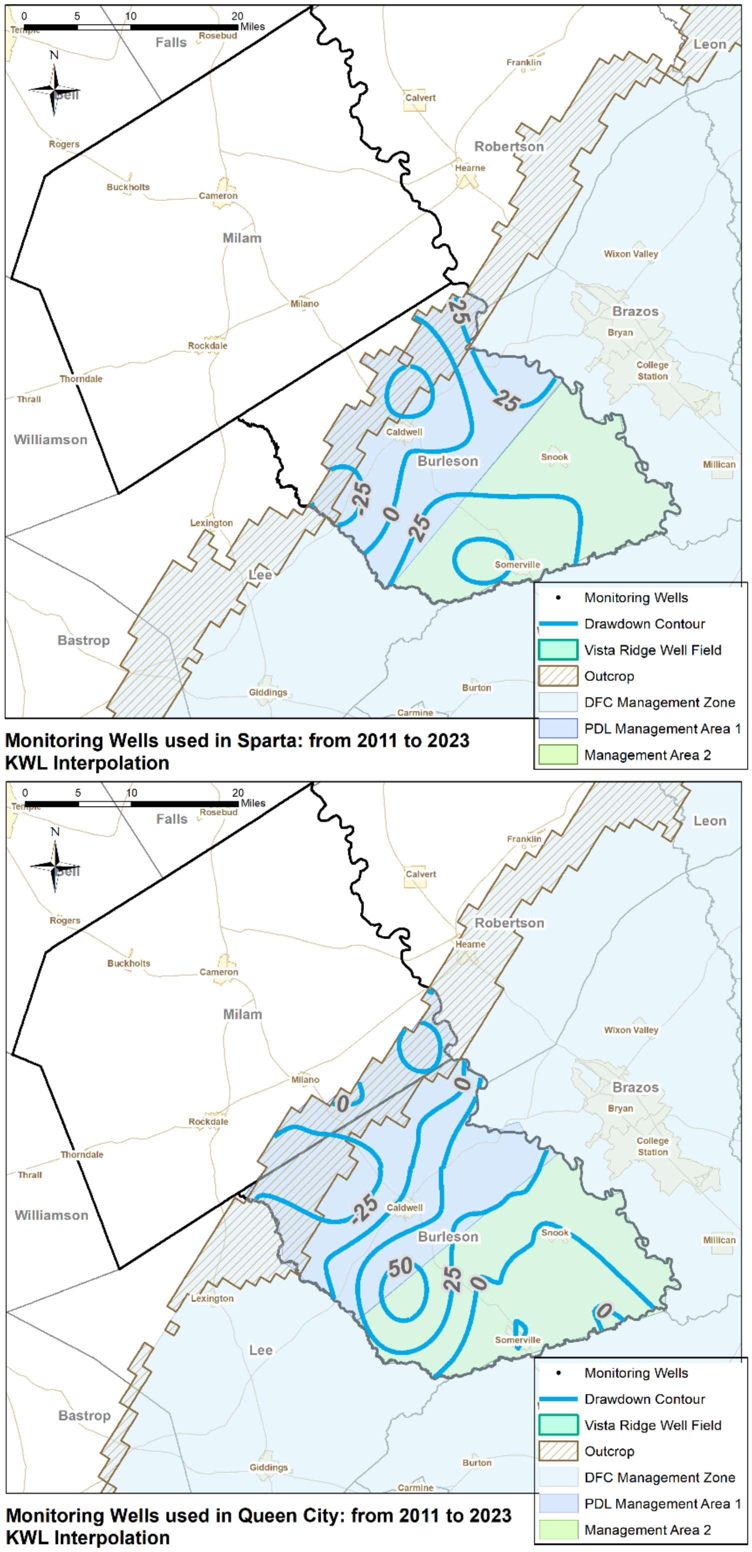


Figure B-1 2023 drawdown contours for the Sparta and Queen City Aquifers Based on Interpolation using Ordinary Kriging with Water Levels

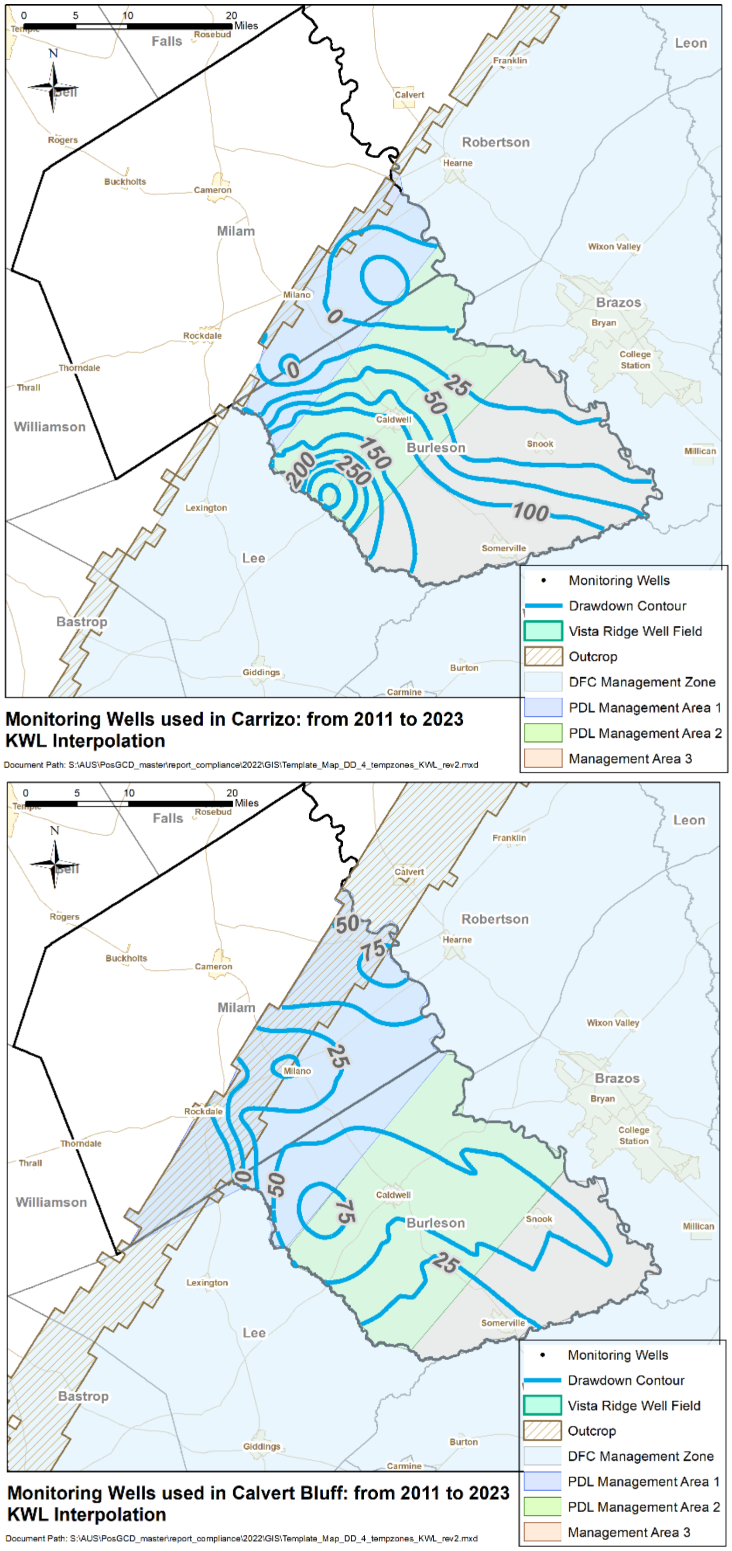


Figure B-2 2023 drawdown contours for the Carrizo and Calvert Bluff Aquifers Based on Interpolation using Ordinary Kriging with Water Levels

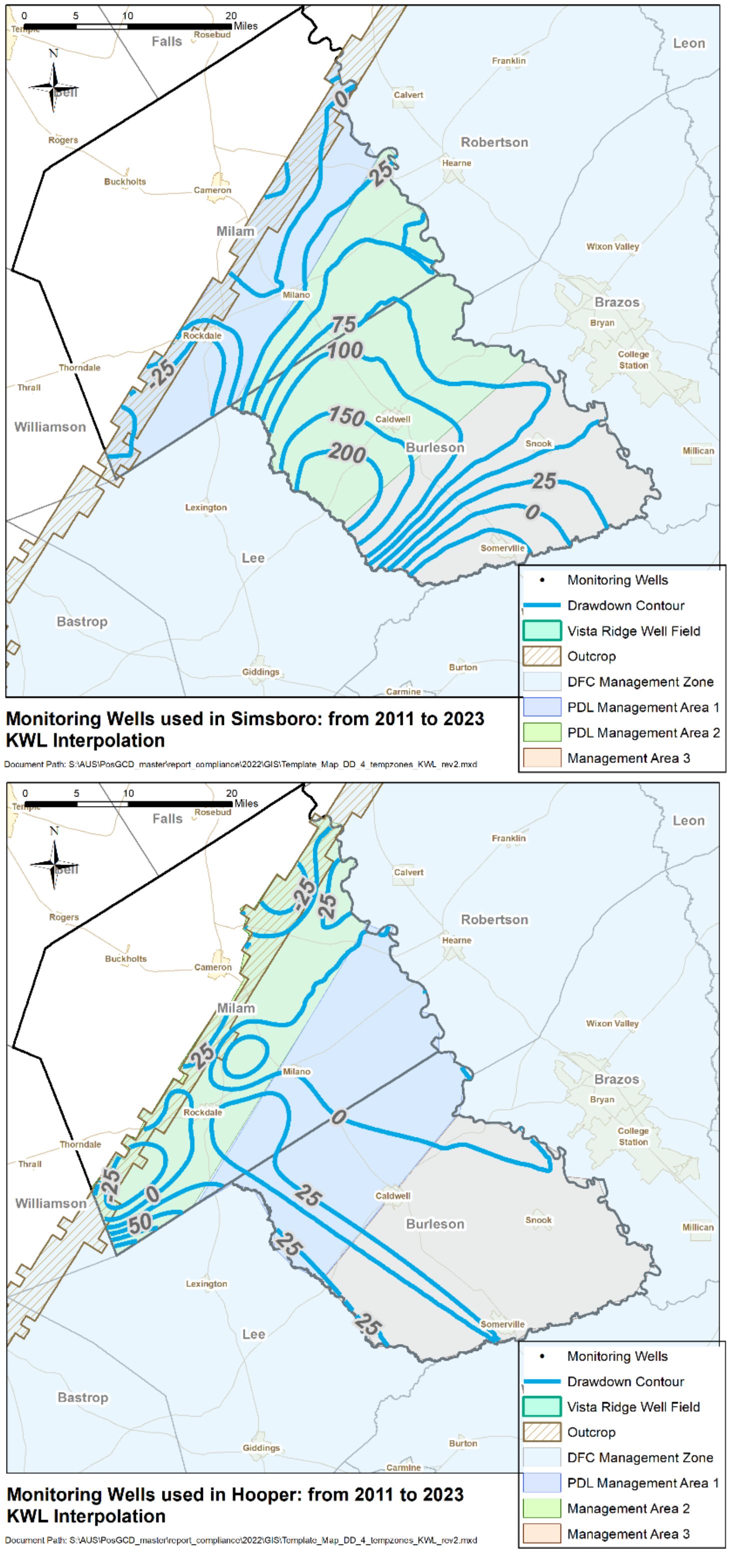


Figure B-3 2023 drawdown contours for the Simsboro and Hooper Aquifers Based on Interpolation using Ordinary Kriging with Water Levels

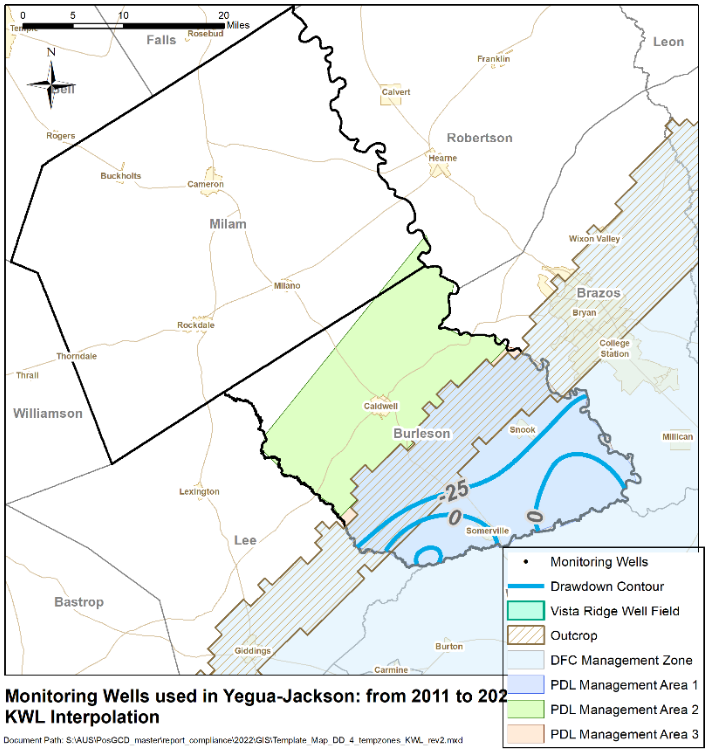
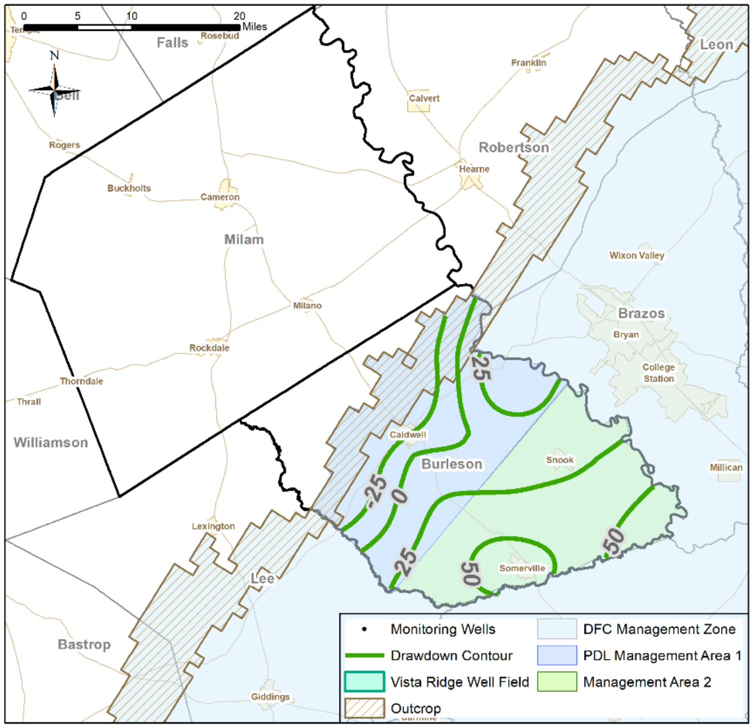


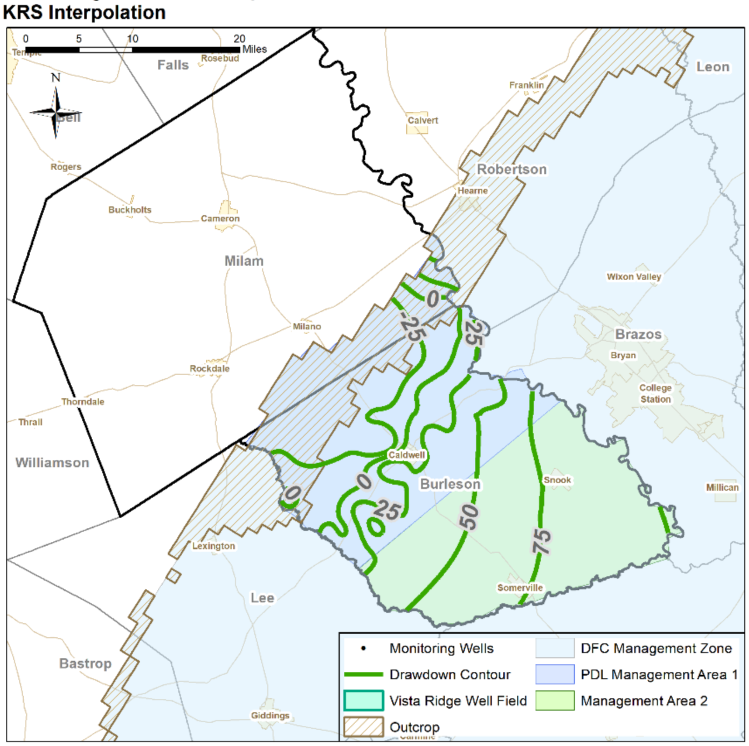
Figure B-4 2023 drawdown contours for the Yegua-Jackson Aquifer Based on Interpolation using Ordinary Kriging with Water Levels

APPENDIX C

2023 Water Level Surfaces Created by Applying Ordinary Kriging to Water Level Residuals

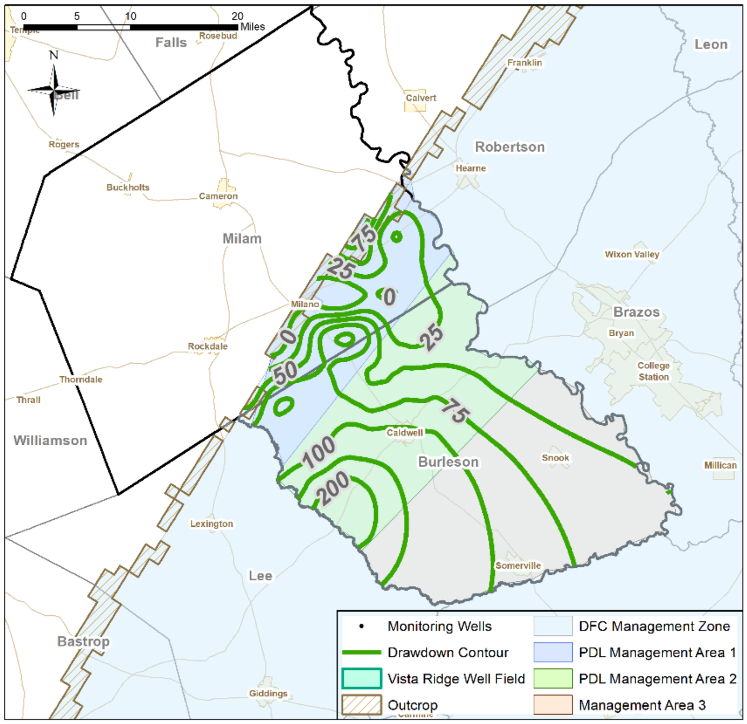


Monitoring Wells used in Sparta: from 2011 to 2023
KRS Interpolation

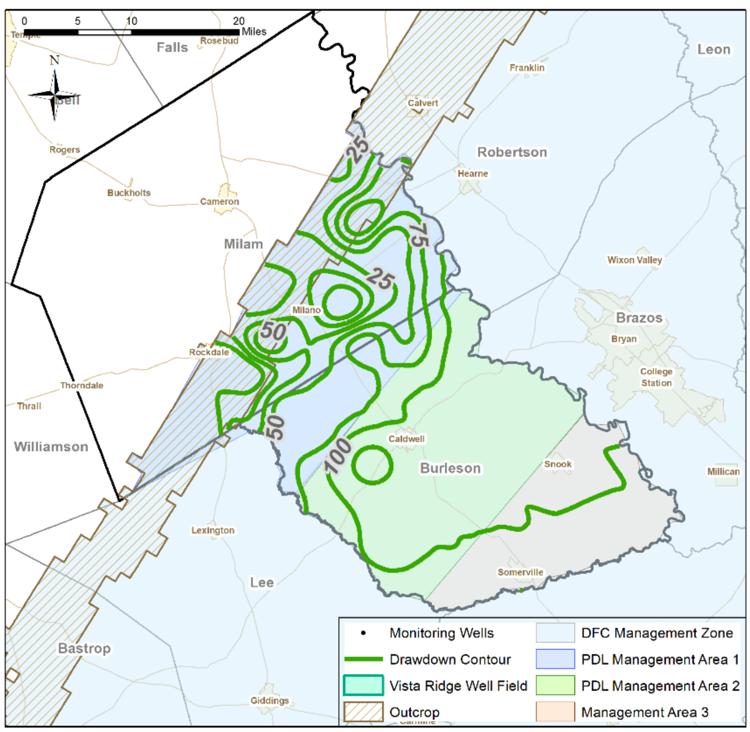


Monitoring Wells used in Queen City: from 2011 to 2023
KRS Interpolation

Figure C-1 2023 drawdown contours for the Sparta and Queen City Aquifers Based on Interpolation using Ordinary Kriging with Residuals

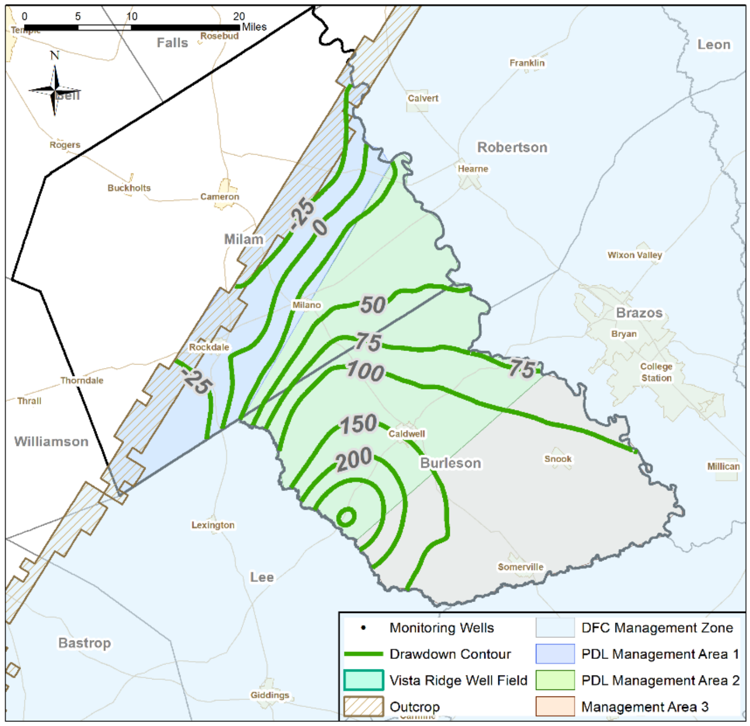


Monitoring Wells used in Carrizo: from 2011 to 2023
KRS Interpolation

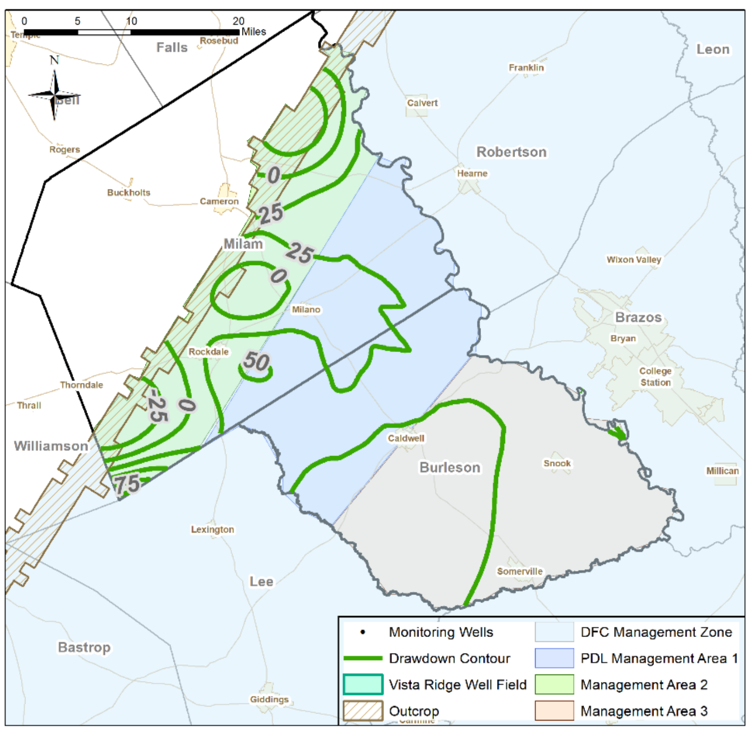


Monitoring Wells used in Calvert Bluff: from 2011 to 2023
KRS Interpolation

Figure C-2 2023 drawdown contours for the Carrizo and Calvert Bluff Aquifers Based on Interpolation using Ordinary Kriging with Residuals



Monitoring Wells used in Simsboro: from 2011 to 2023
KRS Interpolation



Monitoring Wells used in Hooper: from 2011 to 2023
KRS Interpolation

Figure C-3 2023 drawdown contours for the Simsboro and Hooper Aquifers Based on Interpolation using Ordinary Kriging with Residuals