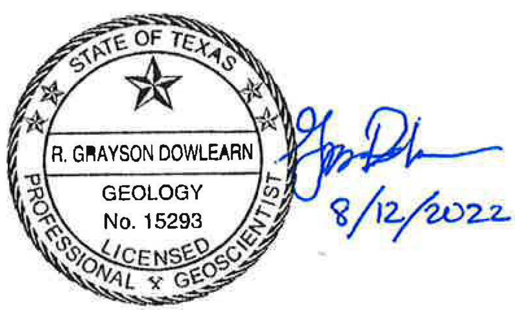
GAM Run 22-008: Lost Pines Groundwater Conservation District Management Plan

Grayson Dowlearn, P.G.
Texas Water Development Board
Groundwater Division
Groundwater Modeling Department
(512) 475-1552

August 12, 2022



This page is intentionally blank

GAM Run 22-008: Lost Pines Groundwater Conservation District Management Plan

Grayson Dowlearn, P.G.
Texas Water Development Board
Groundwater Division
Groundwater Modeling Department
(512) 475-1552
August 12, 2022

EXECUTIVE SUMMARY:

Texas State Water Code, Section 36.1071, Subsection (h) (Texas Water Code, 2011), states that, in developing its groundwater management plan, a groundwater conservation district shall use groundwater availability modeling information provided by the Executive Administrator of the Texas Water Development Board (TWDB) in conjunction with any available site-specific information provided by the district for review and comment to the Executive Administrator.

The TWDB provides data and information to the Lost Pines Groundwater Conservation District in two parts. Part 1 is the Estimated Historical Water Use/State Water Plan dataset report, which will be provided to you separately by the TWDB Groundwater Technical Assistance Department. Please direct questions about the water data report to Mr. Stephen Allen at 512-463-7317 or stephen.allen@twdb.texas.gov. Part 2 is the required groundwater availability modeling information and this information includes:

1. the annual amount of recharge from precipitation, if any, to the groundwater resources within the district;
2. for each aquifer within the district, the annual volume of water that discharges from the aquifer to springs and any surface-water bodies, including lakes, streams, and rivers; and
3. the annual volume of flow into and out of the district within each aquifer and between aquifers in the district.

The groundwater management plan for the Lost Pines Groundwater Conservation District should be adopted by the district on or before October 26, 2022 and submitted to the executive administrator of the TWDB on or before November 25, 2022. The current management plan for the Lost Pines Groundwater Conservation District expires on January 24, 2023.

Five modeled aquifers are located within Lost Pines Groundwater Conservation District, which include the following: Trinity, Carrizo-Wilcox, Queen City, Sparta, and Yegua-Jackson aquifers. We used three groundwater availability models to estimate the management plan information for the aquifers within the Lost Pines Groundwater Conservation District. We used the groundwater availability models for the northern portion of the Trinity Aquifer and the Woodbine Aquifer (Kelley and others, 2014), the central portion of the Carrizo-Wilcox, Queen City, and Sparta aquifers (Young and others, 2018 and Young and Kushnereit, 2020), and the Yegua-Jackson Aquifer (Deeds and others, 2010) to estimate the groundwater management plan information for the Lost Pines Groundwater Conservation District.

This report replaces the results of GAM Run 16-014 (Wade, 2017) because it includes results from the updated groundwater availability model for the central portion of the Carrizo-Wilcox, Queen City, and Sparta aquifers (Young and Kushnereit, 2020). Values may also differ from the previous report as a result of routine updates to the spatial grid files used to define county, groundwater conservation district, and aquifer boundaries, which can impact the calculated water budget values. Additionally, the approach used for analyzing model results is reviewed during each update and may have been refined to better delineate groundwater flows. This report also includes a new figure not included in the previous report to help groundwater conservation districts better visualize water budget components. Tables 1 through 5 summarize the groundwater availability model data required by statute and Figures 1, 3, 5, 7, and 9 show the area of the models from which the values in Tables 1 through 5 were extracted. Figures 2, 4, 6, 8, and 10 provide generalized diagrams of the groundwater flow components provided in Tables 1 through 5. If, after review of the figures, the Lost Pines Groundwater Conservation District determines that the district boundaries used in the assessment do not reflect current conditions, please notify the TWDB at your earliest convenience.

METHODS:

In accordance with the provisions of the Texas State Water Code, Section 36.1071, Subsection (h), the groundwater availability models mentioned above were used to estimate information for the Lost Pines Groundwater Conservation District management plan. Water budgets were extracted for the historical model periods for the Trinity Aquifer (1980 through 2012) and the Yegua-Jackson Aquifer (1980 through 1997) using ZONEBUDGET Version 3.01 (Harbaugh, 2009). Water budgets were extracted for the historical model periods for the Carrizo-Wilcox, Queen City, and Sparta aquifers (1980 through 2010) using ZONEBUDGET USG Version 1.00 (Panday and others, 2015). The average annual water budget values for recharge, surface-water outflow, inflow to the district, outflow from the district, and the flow between aquifers within the district are summarized in this report.

PARAMETERS AND ASSUMPTIONS:

Trinity Aquifer

- We used version 2.01 of the groundwater availability model for the northern portion of the Trinity Aquifer and the Woodbine Aquifer. See Kelley and others (2014) for assumptions and limitations of the model.
- The groundwater availability model for the northern portion of the Trinity Aquifer and Woodbine Aquifer contains eight layers that generally represent the following: Layer 1 (the surficial outcrop area of the units in layers 2 through 8 and units younger than Woodbine Aquifer), Layer 2 (Woodbine Aquifer), Layer 3 (Washita and Fredericksburg Groups, and the Edwards [Balcones Fault Zone] Aquifer), and Layers 4 through 8 (Trinity Aquifer). Layers 2 through 7 also include pass-through cells. The Woodbine Aquifer does not occur within the Lost Pines Groundwater Conservation District and therefore no groundwater budget values are included for it in this report.
- Perennial rivers and reservoirs were simulated using the MODFLOW River package. Ephemeral streams, flowing wells, springs, and evapotranspiration in riparian zones along perennial rivers were simulated using the MODFLOW Drain package.
- Water budget terms were averaged for the period 1980 through 2012 (stress periods 92 through 124)
- The model was run using MODFLOW-NWT (Niswonger and others, 2011).

Carrizo-Wilcox, Queen City, and Sparta aquifers

- We used version 3.02 of the groundwater availability model for the central portion of the Carrizo-Wilcox, Queen City, and Sparta aquifers. See Young and

Kushnereit (2020) and Young and others (2018) for assumptions and limitations of the model.

- The groundwater availability model for the central portion of the Carrizo-Wilcox, Queen City, and Sparta aquifers contains ten layers that generally represent the following: Layer 1 (Colorado River and Brazos River alluvium), Layer 2 (shallow flow system of all units in layers 3 through 10), Layer 3 (Sparta Aquifer and equivalent units), Layer 4 (Weches Formation), Layer 5 (Queen City Aquifer and equivalent units), Layer 6 (Reklaw Formation), and Layers 7 through 10 (Carrizo-Wilcox Aquifer and equivalent units).

- The MODFLOW River package was used to simulate groundwater exchange with major rivers and perennial streams. Outflow from ephemeral streams, intermittent streams, and seeps were simulated using the MODFLOW Drain package. The evapotranspiration package was used to simulate groundwater evapotranspiration from the model.

- Water budget terms were averaged for the period 1980 through 2010 (stress periods 52 through 82).

- The model was run with MODFLOW-USG (unstructured grid; Panday and others, 2015).

Yegua-Jackson Aquifer

- We used version 1.01 of the groundwater availability model for the Yegua-Jackson Aquifer. See Deeds and others (2010) for assumptions and limitations of the groundwater availability model.

- This groundwater availability model includes five layers, which represent the following: Layer 1 (Yegua-Jackson Aquifer outcrop and the Catahoula Formation and other younger overlying units), Layer 2 (the upper portion of the Jackson Group), Layer 3 (the lower portion of the Jackson Group), Layer 4 (the upper portion of the Yegua Group), and Layer 5 (the lower portion of the Yegua Group).

- An overall water budget for the district was determined for the Yegua-Jackson Aquifer (Layer 1 through Layer 5, collectively, for the portions of the model that represent the Yegua-Jackson Aquifer).

- Water budget terms were averaged for the period 1980 through 1997 (stress periods 10 through 27).

- The model was run with MODFLOW-2000 (Harbaugh and others, 2000).

RESULTS:

A groundwater budget summarizes the amount of water entering and leaving the aquifer according to the groundwater availability model. Selected groundwater budget components listed below were extracted from the groundwater availability model results for the Trinity, Carrizo-Wilcox, Queen City, Sparta, and Yegua-Jackson aquifer located within the Lost Pines Groundwater Conservation District and averaged over the historical calibration period, as shown in Tables 1 through 5.

1. Precipitation recharge—the areally distributed recharge sourced from precipitation falling on the outcrop areas of the aquifers (where the aquifer is exposed at land surface) within the district.

2. Surface-water outflow—the total water discharging from the aquifer (outflow) to surface-water features such as streams, reservoirs, and springs.

3. Flow into and out of district—the lateral flow within the aquifer between the district and adjacent counties.

4. Flow between aquifers—the net vertical flow between the aquifer and adjacent aquifers or confining units. This flow is controlled by the relative water levels in each aquifer and aquifer properties of each aquifer or confining unit that define the amount of leakage that occurs.

The information needed for the district's management plan is summarized in Tables 1 through 5. It is important to note that sub-regional water budgets are not exact. This is due to the size of the model cells and the approach used to extract data from the model. To avoid double accounting, a model cell that straddles a political boundary, such as a district or county boundary, is assigned to one side of the boundary based on the location of the centroid of the model cell. For example, if a cell contains two counties, the cell is assigned to the county where the centroid of the cell is located.

TABLE 1: SUMMARIZED INFORMATION FOR THE TRINITY AQUIFER THAT IS NEEDED FOR THE LOST PINES GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Trinity Aquifer	0
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Trinity Aquifer	0
Estimated annual volume of flow into the district within each aquifer in the district	Trinity Aquifer	355
Estimated annual volume of flow out of the district within each aquifer in the district	Trinity Aquifer	135
Estimated net annual volume of flow between each aquifer in the district	From the Trinity Aquifer to Trinity equivalent units	242
	From the Trinity Aquifer to overlying units	2
The model assumes a no-flow boundary at the base of the Trinity Aquifer.		

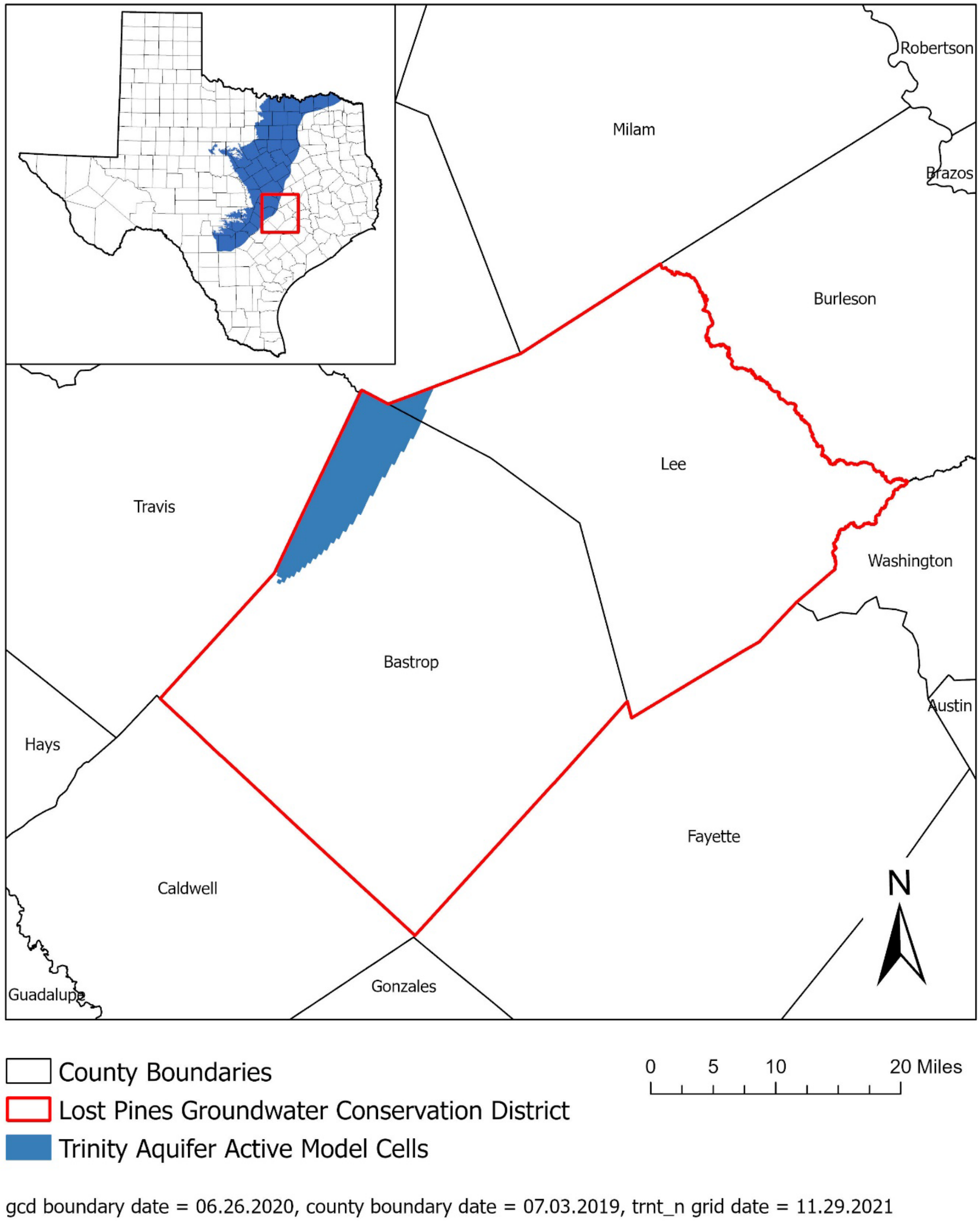
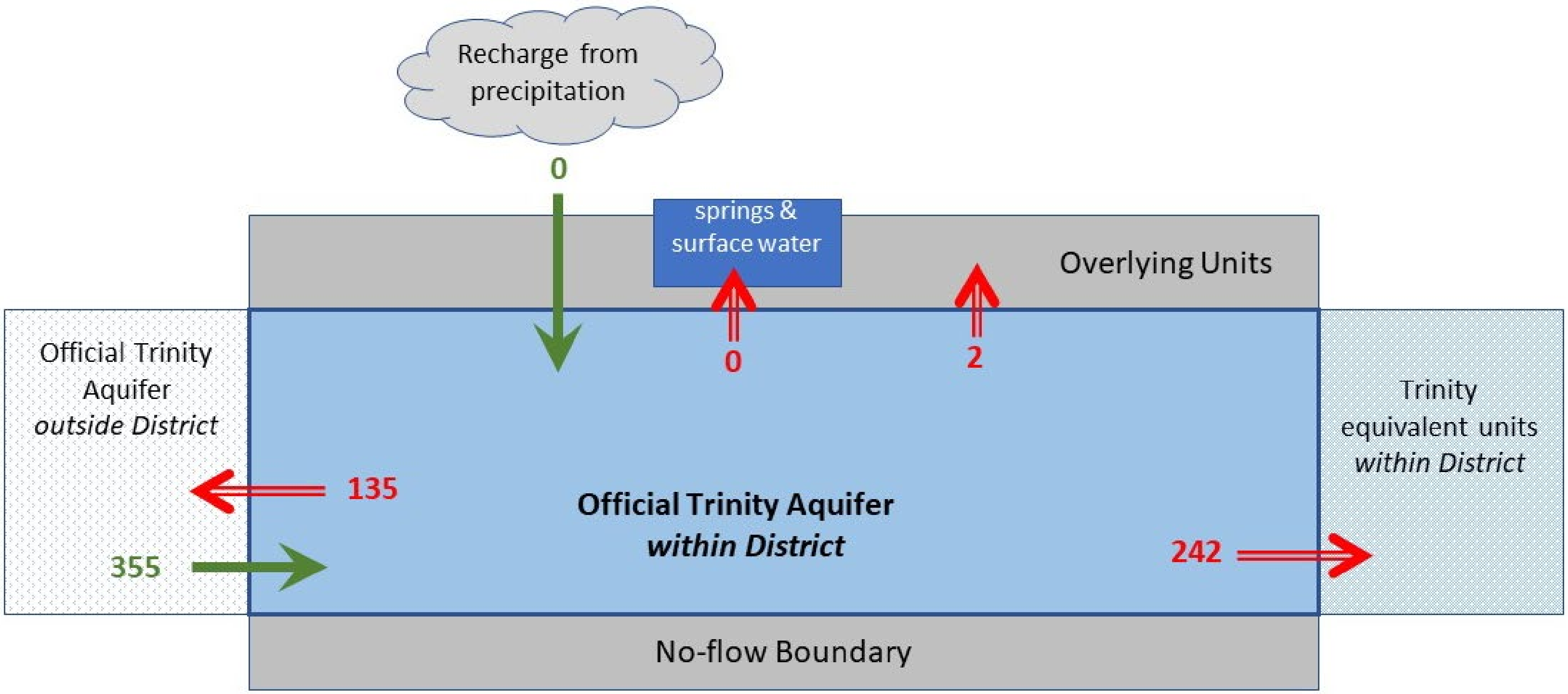


FIGURE 1: AREA OF THE NORTHERN TRINITY AND WOODBINE AQUIFER GROUNDWATER AVAILABILITY MODEL FROM WHICH THE INFORMATION IN TABLE 1 WAS EXTRACTED (THE TRINITY AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).



Caveat: This diagram only includes the water budget items provided in Table 1. A complete water budget would include additional inflows and outflows. If the District requires values for additional water budget items, please contact TWDB.

FIGURE 2: GENERALIZED DIAGRAM OF THE SUMMARIZED BUDGET INFORMATION FROM TABLE 1, REPRESENTING DIRECTIONS OF FLOW FOR THE TRINITY AQUIFER WITHIN LOST PINES GROUNDWATER CONSERVATION DISTRICT. FLOW VALUES EXPRESSED IN ACRE-FEET PER YEAR (AFY).

TABLE 2: SUMMARIZED INFORMATION FOR THE CARRIZO-WILCOX AQUIFER THAT IS NEEDED FOR THE LOST PINES GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Carrizo-Wilcox Aquifer	42,520
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Carrizo-Wilcox Aquifer	64,202
Estimated annual volume of flow into the district within each aquifer in the district	Carrizo-Wilcox Aquifer	12,454
Estimated annual volume of flow out of the district within each aquifer in the district	Carrizo-Wilcox Aquifer	13,228
Estimated net annual volume of flow between each aquifer in the district	To the Carrizo-Wilcox Aquifer from Carrizo-Wilcox equivalent units	596
	To the Carrizo-Wilcox Aquifer from the Reklaw confining unit	452
	From the Carrizo-Wilcox Aquifer to the Queen City Aquifer	625
	From the Carrizo-Wilcox Aquifer to the Weches confining unit	331
	From the Carrizo-Wilcox Aquifer to overlying alluvium	18,490
The model assumes a no-flow boundary at the base of the Carrizo-Wilcox Aquifer.		

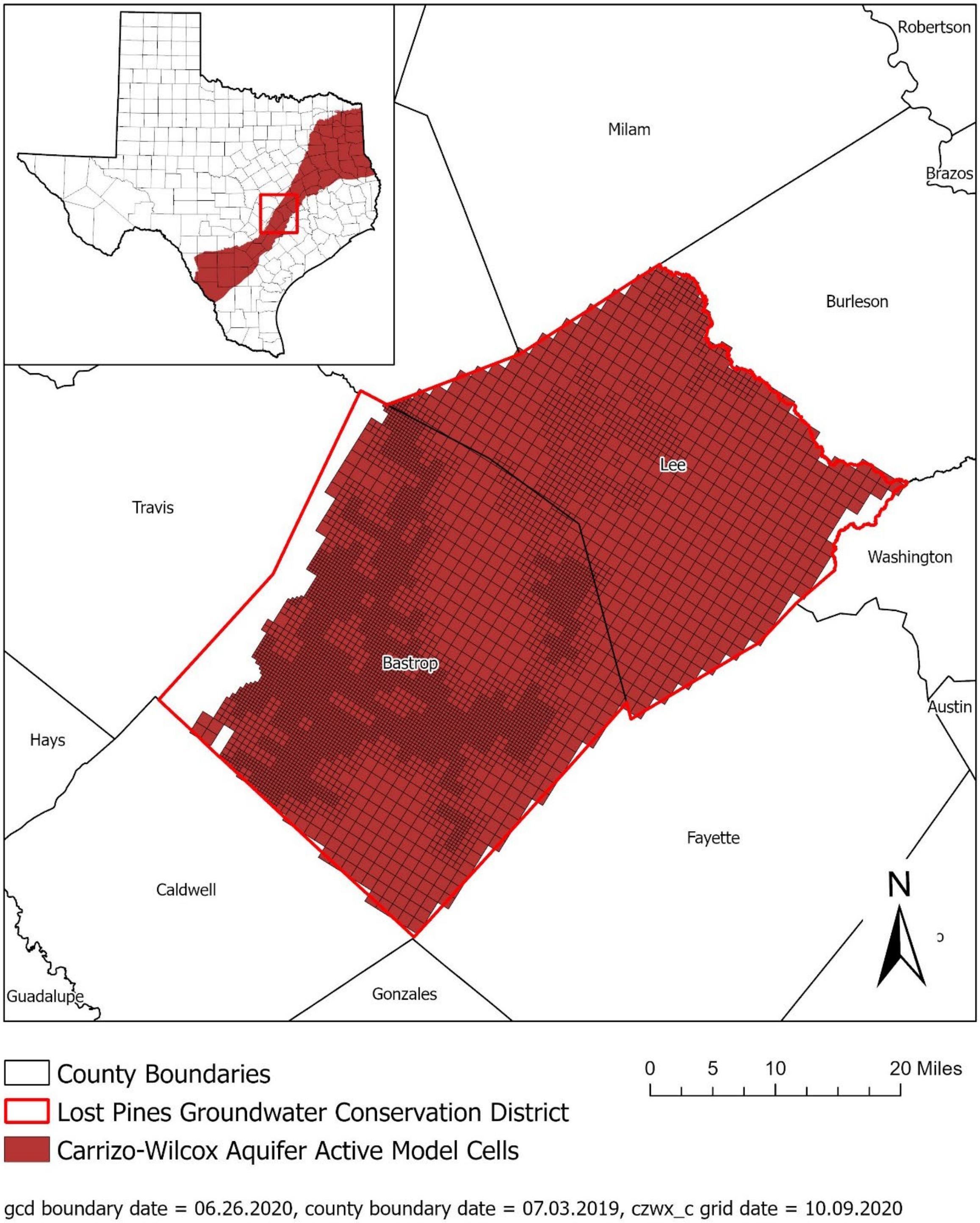
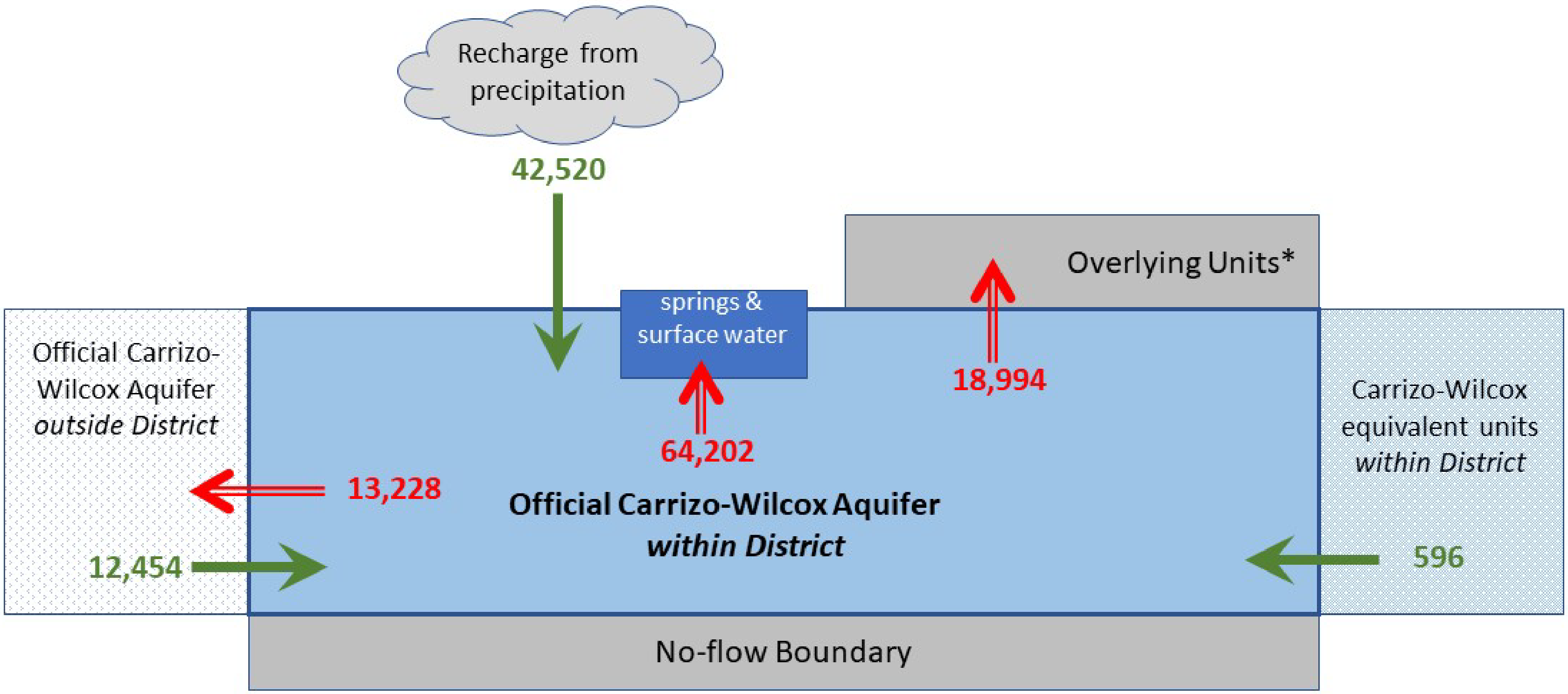


FIGURE 3: AREA OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS GROUNDWATER AVAILABILITY MODEL FROM WHICH THE INFORMATION IN TABLE 2 WAS EXTRACTED (THE CARRIZO-WILCOX AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).



* Flow to overlying units includes net inflow of 452 acre-feet per year from Reklaw confining unit, net outflow of 625 acre-feet per year to the Queen City Aquifer, net outflow of 331 acre-feet per year to the Weches confining unit, net outflow of 15,582 acre-feet per year to the Colorado River Alluvium, and net outflow of 2,908 acre-feet per year to other alluvium aquifers.

Caveat: This diagram only includes the water budget items provided in Table 2. A complete water budget would include additional inflows and outflows. If the District requires values for additional water budget items, please contact TWDB.

FIGURE 4: GENERALIZED DIAGRAM OF THE SUMMARIZED BUDGET INFORMATION FROM TABLE 2, REPRESENTING DIRECTIONS OF FLOW FOR THE CARRIZO-WILCOX AQUIFER WITHIN LOST PINES GROUNDWATER CONSERVATION DISTRICT. FLOW VALUES EXPRESSED IN ACRE-FEET PER YEAR (AFY).

TABLE 3: SUMMARIZED INFORMATION FOR THE QUEEN CITY AQUIFER THAT IS NEEDED FOR THE LOST PINES GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Queen City Aquifer	11,188
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Queen City Aquifer	7,802
Estimated annual volume of flow into the district within each aquifer in the district	Queen City Aquifer	2,371
Estimated annual volume of flow out of the district within each aquifer in the district	Queen City Aquifer	3,380
Estimated net annual volume of flow between each aquifer in the district	To the Queen City Aquifer from the Carrizo-Wilcox Aquifer	625
	From the Queen City Aquifer to the Reklaw confining unit	3,240
	From the Queen City Aquifer to Queen City equivalent units	624
	To the Queen City Aquifer from the Weches confining units	818
	From the Queen City Aquifer to the Sparta Aquifer	1,057
	From the Queen City Aquifer to overlying alluvium	1,957

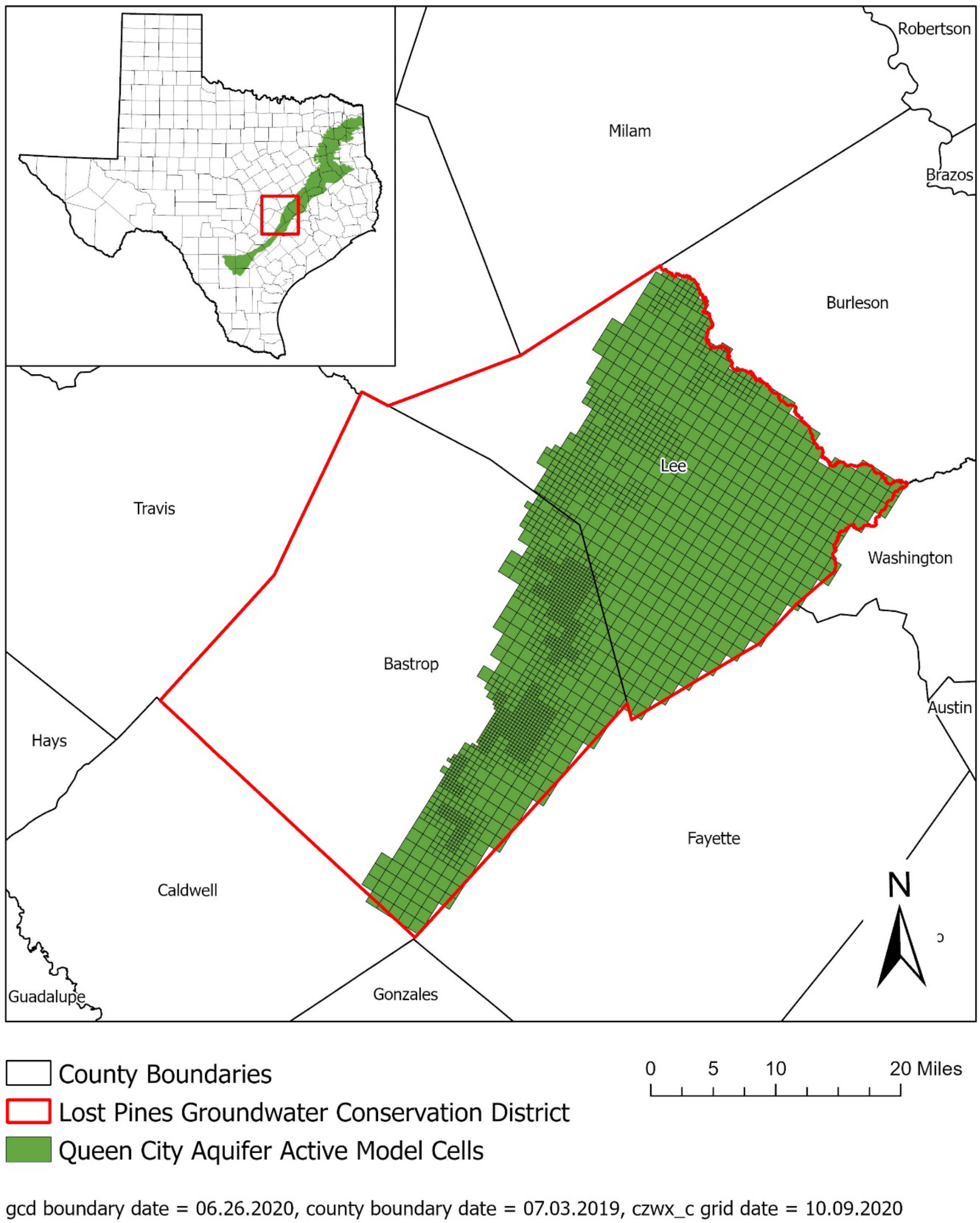
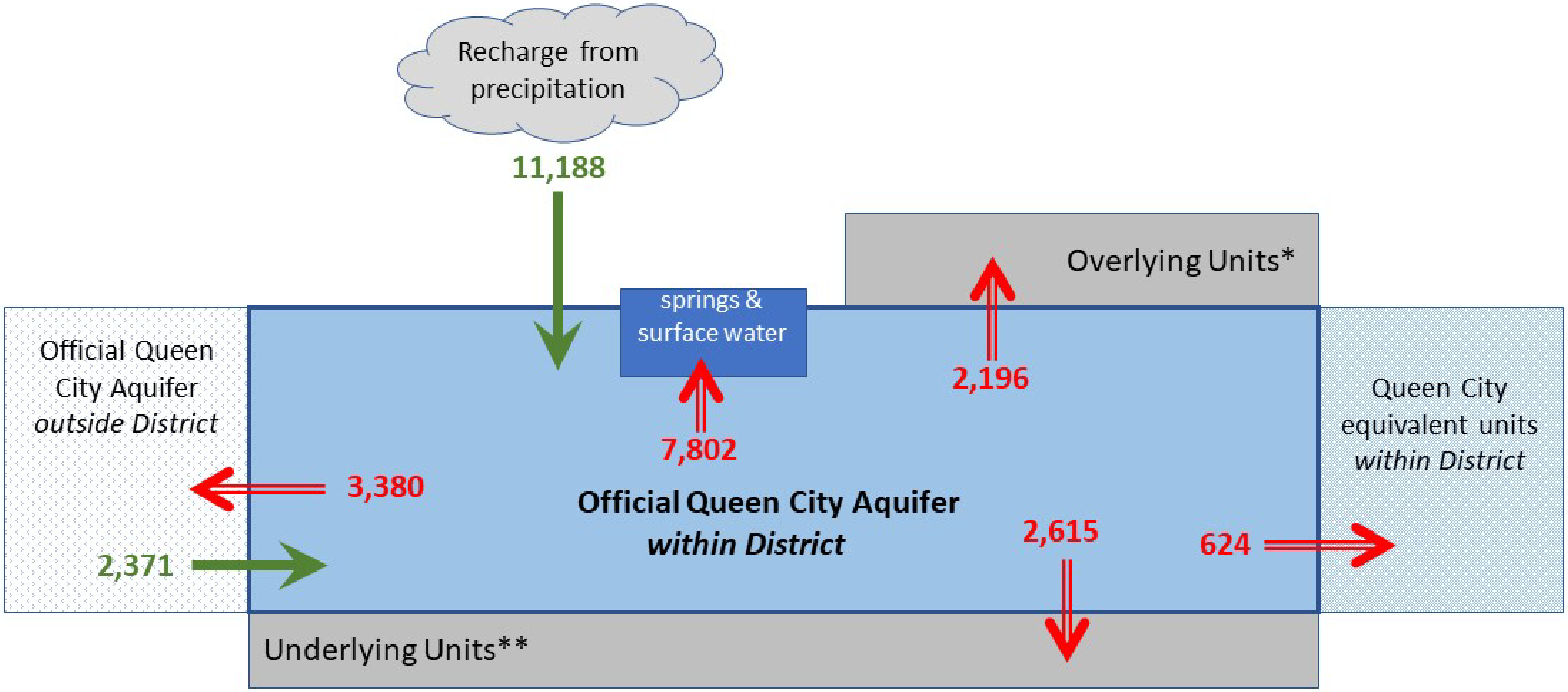


FIGURE 5: AREA OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS GROUNDWATER AVAILABILITY MODEL FROM WHICH THE INFORMATION IN TABLE 3 WAS EXTRACTED (THE QUEEN CITY AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).



* Flow to overlying units includes net inflow of 818 acre-feet per year from the Weches confining unit, net outflow of 1,057 acre-feet per year to the Sparta Aquifer, and net outflow of 1,957 acre-feet per year to the Colorado River Alluvium.

** Flow to underlying units includes net inflow of 625 acre-feet per year from the Carrizo-Wilcox Aquifer and net outflow of 3,240 acre-feet per year to the Reklaw confining unit.

Caveat: This diagram only includes the water budget items provided in Table 3. A complete water budget would include additional inflows and outflows. If the District requires values for additional water budget items, please contact TWDB.

FIGURE 6: GENERALIZED DIAGRAM OF THE SUMMARIZED BUDGET INFORMATION FROM TABLE 3, REPRESENTING DIRECTIONS OF FLOW FOR THE QUEEN CITY AQUIFER WITHIN LOST PINES GROUNDWATER CONSERVATION DISTRICT. FLOW VALUES EXPRESSED IN ACRE-FEET PER YEAR (AFY).

TABLE 4: SUMMARIZED INFORMATION FOR THE SPARTA AQUIFER THAT IS NEEDED FOR THE LOST PINES GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Sparta Aquifer	8,702
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Sparta Aquifer	13,664
Estimated annual volume of flow into the district within each aquifer in the district	Sparta Aquifer	434
Estimated annual volume of flow out of the district within each aquifer in the district	Sparta Aquifer	1,975
Estimated net annual volume of flow between each aquifer in the district	To the Sparta Aquifer from the Reklaw confining unit	26
	To the Sparta Aquifer from the Queen City Aquifer	1,057
	To the Sparta Aquifer from the Weches confining unit	2,321
	To the Sparta Aquifer from Sparta equivalent units	538
	From the Sparta Aquifer to the Cook Mountain confining unit	2,555
	From the Sparta Aquifer to overlying alluvium	1,529

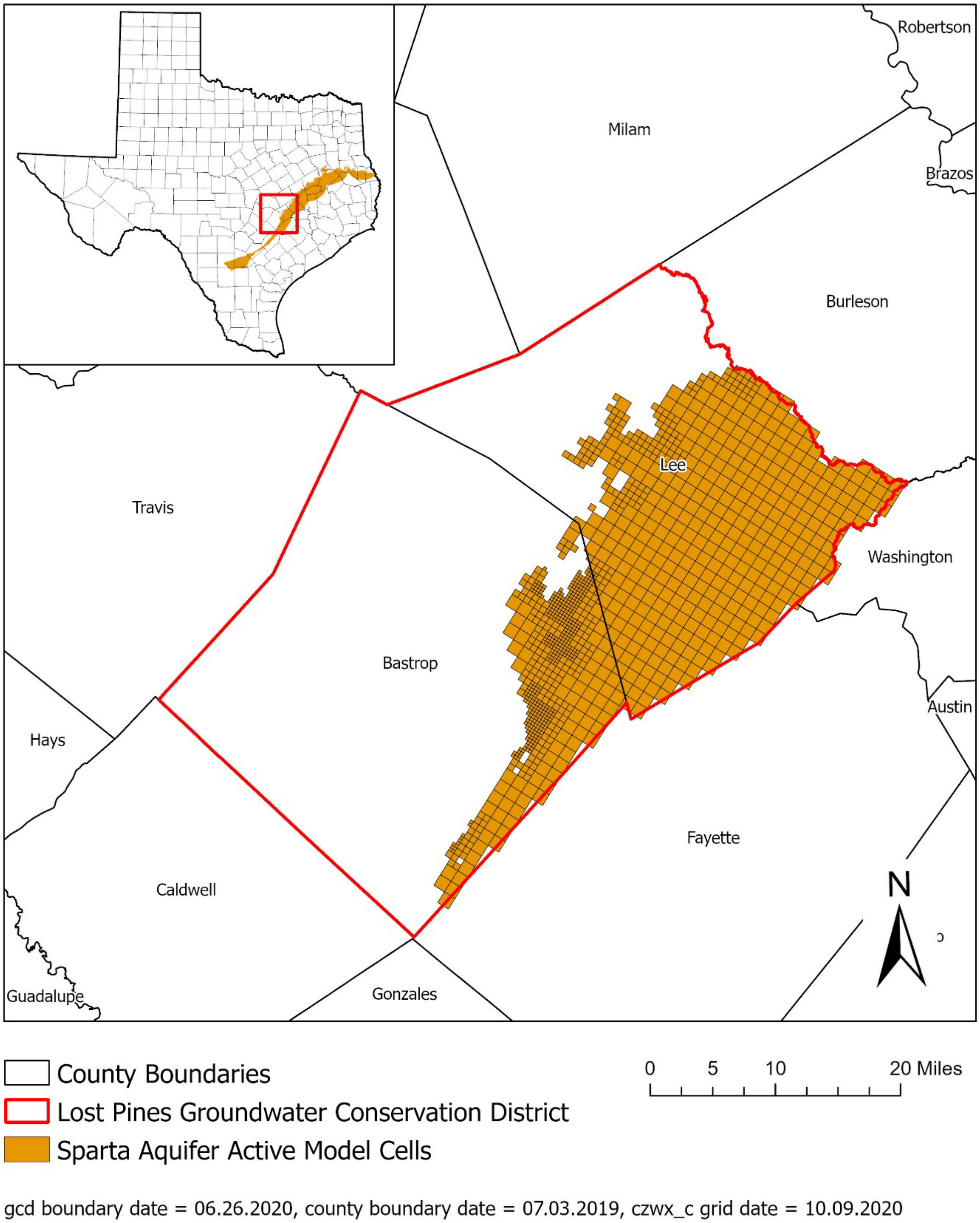
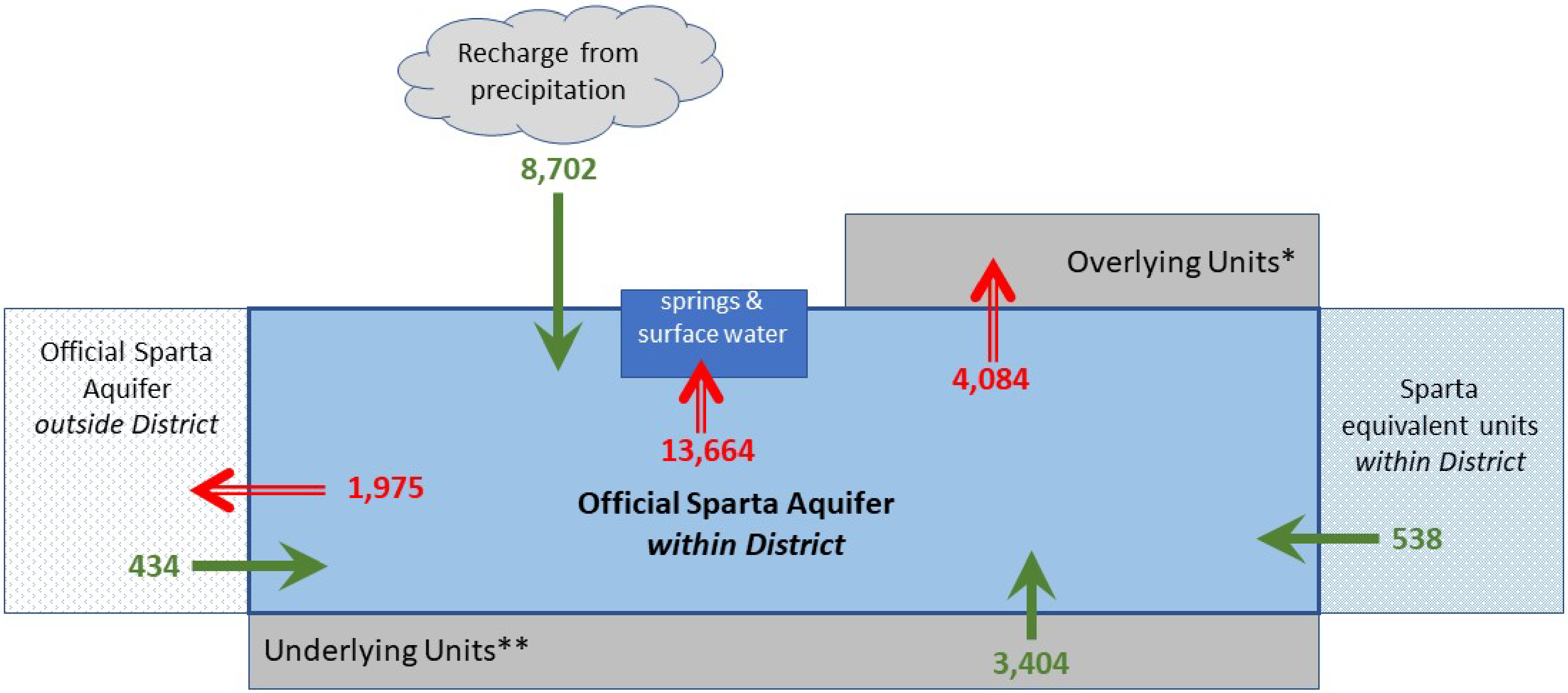


FIGURE 7: AREA OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS GROUNDWATER AVAILABILITY MODEL FROM WHICH THE INFORMATION IN TABLE 4 WAS EXTRACTED (THE SPARTA AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).



* Flow to overlying units includes net outflow of 2,555 acre-feet per year from the Cook Mountain confining unit and net outflow of 1,529 acre-feet per year to the Colorado River Alluvium.

** Flow from underlying units includes net inflow of 26 acre-feet per year from the Reklaw confining unit, net inflow of 1,057 acre-feet per year from the Queen City Aquifer, and new inflow of 2,321 acre-feet per year from the Weches confining unit.

Caveat: This diagram only includes the water budget items provided in Table 4. A complete water budget would include additional inflows and outflows. If the District requires values for additional water budget items, please contact TWDB.

FIGURE 8: GENERALIZED DIAGRAM OF THE SUMMARIZED BUDGET INFORMATION FROM TABLE 4, REPRESENTING DIRECTIONS OF FLOW FOR THE SPARTA AQUIFER WITHIN LOST PINES GROUNDWATER CONSERVATION DISTRICT. FLOW VALUES EXPRESSED IN ACRE-FEET PER YEAR (AFY).

TABLE 5: SUMMARIZED INFORMATION FOR THE YEGUA-JACKSON AQUIFER THAT IS NEEDED FOR THE LOST PINES GROUNDWATER CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Yegua-Jackson Aquifer	38,860
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Yegua-Jackson Aquifer	35,781
Estimated annual volume of flow into the district within each aquifer in the district	Yegua-Jackson Aquifer	5,882
Estimated annual volume of flow out of the district within each aquifer in the district	Yegua-Jackson Aquifer	10,154
The model assumes a no-flow boundary at the base of the Yegua-Jackson Aquifer.		

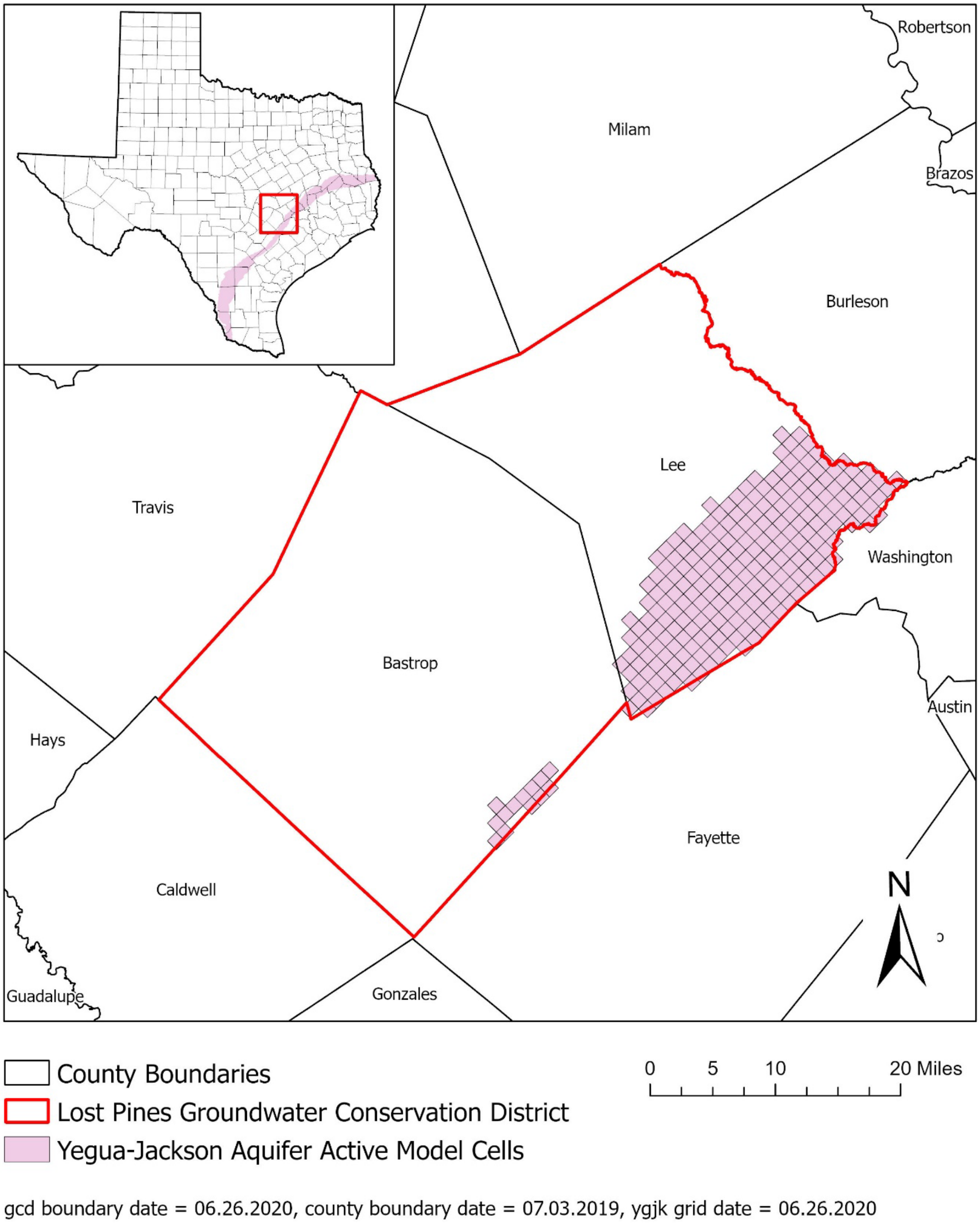
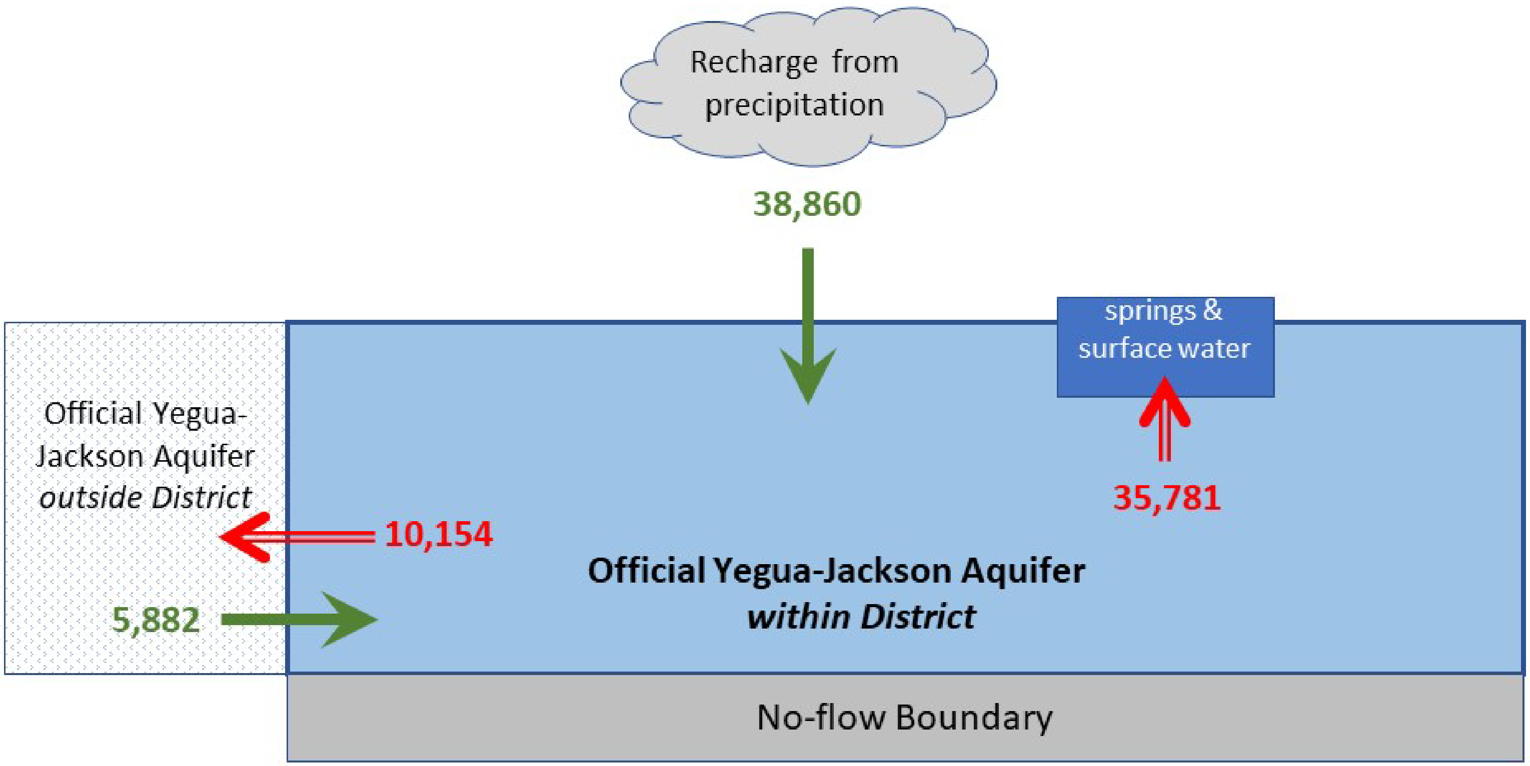


FIGURE 9: AREA OF THE YEGUA-JACKSON AQUIFER GROUNDWATER AVAILABILITY MODEL FROM WHICH THE INFORMATION IN TABLE 5 WAS EXTRACTED (THE YEGUA-JACKSON AQUIFER EXTENT WITHIN THE DISTRICT BOUNDARY).



Caveat: This diagram only includes the water budget items provided in Table 5. A complete water budget would include additional inflows and outflows. If the District requires values for additional water budget items, please contact TWDB.

FIGURE 10: GENERALIZED DIAGRAM OF THE SUMMARIZED BUDGET INFORMATION FROM TABLE 5, REPRESENTING DIRECTIONS OF FLOW FOR THE YEGUA-JACKSON AQUIFER WITHIN LOST PINES GROUNDWATER CONSERVATION DISTRICT. FLOW VALUES EXPRESSED IN ACRE-FEET PER YEAR (AFY).

LIMITATIONS:

The groundwater models used in completing this analysis are the best available scientific tools that can be used to meet the stated objectives. To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

A key aspect of using the groundwater model to evaluate historic groundwater flow conditions includes the assumptions about the location in the aquifer where historic pumping was placed. Understanding the amount and location of historical pumping is as important as evaluating the volume of groundwater flow into and out of the district, between aquifers within the district (as applicable), interactions with surface water (as applicable), recharge to the aquifer system (as applicable), and other metrics that describe the impacts of that pumping. In addition, assumptions regarding precipitation, recharge, and interaction with streams are specific to particular historic time periods.

Because the application of the groundwater models was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations related to the actual conditions of any aquifer at a particular location or at a particular time.

It is important for groundwater conservation districts to monitor groundwater pumping and overall conditions of the aquifer. Because of the limitations of the groundwater model and the assumptions in this analysis, it is important that the groundwater conservation districts work with the TWDB to refine this analysis in the future given the reality of how the aquifer responds to the actual amount and location of pumping now and in the future. Historic precipitation patterns also need to be placed in context as future climatic conditions, such as dry and wet year precipitation patterns, may differ and affect groundwater flow conditions.

REFERENCES:

Deeds, N. E., Yan, T., Singh, A., Jones, T. L., Kelley, V. A., Knox, P. R., and Young, S. C., 2010, Groundwater availability model for the Yegua-Jackson Aquifer: Final report prepared for the Texas Water Development Board by INTERA, Inc., 582 p., http://www.twdb.texas.gov/groundwater/models/gam/ygjk/YGJK_Model_Report.pdf.

Harbaugh, A. W., Banta, E. R., Hill, M. C., and McDonald, M. G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Harbaugh, A. W., 2009, Zonebudget Version 3.01, A computer program for computing subregional water budgets for MODFLOW ground-water flow models, U.S. Geological Survey Groundwater Software.

Kelley, V.A., Ewing, J., Jones, T.L., Young, S.C., Deeds, N., and Hamlin, S., 2014, Updated Groundwater Availability Model of the Northern Trinity and Woodbine Aquifers – Final Model Report, 984 p., http://www.twdb.texas.gov/groundwater/models/gam/trnt_n/Final_NTGAM_Vol%20I%20Aug%202014_Report.pdf

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Niswonger, R.G., Panday, S., and Ibaraki, M., 2011, MODFLOW-NWT, a Newton formulation for MODFLOW-2005: USGS, Techniques and Methods 6-A37, 44 p.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D., 2015, MODFLOW-USG version 1.3.00: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Software Release, 01 December 2015, 66p., http://dx.doi.org/10.5066/F7R20ZFJ

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf

Wade, S., 2017, GAM Run 16-014: Texas Water Development Board, GAM Run 16-014 Report, 20 p., https://www.twdb.texas.gov/groundwater/docs/GAMruns/GR16-014.pdf.

Young, S., Jigmond, M., Jones, T., Ewing, T., Panday, S., Harden, R. W, and Lupton, D., 2018, Final Report: Groundwater Availability Model for the Central Portion of the Sparta, Queen City, and Carrizo-Wilcox Aquifers, 942 p., https://www.twdb.texas.gov/groundwater/models/gam/hpas/HPAS_GAM_Conceptual_Report.pdf

Young, S.C., and Kushnereit, R., 2020, GMA 12 Update to the Groundwater Availability Model for the Central Portion of the Sparta, Queen City, and Carrizo-Wilcox Aquifers, Update to Improve Representation of the Transmissive Properties of the Simsboro Aquifer in the Vicinity of the Vista Ridge Well Field, 39 p., http://www.twdb.texas.gov/groundwater/models/gam/czwx_c/PE_Report_GMA12_final_october_2020_merge.pdf