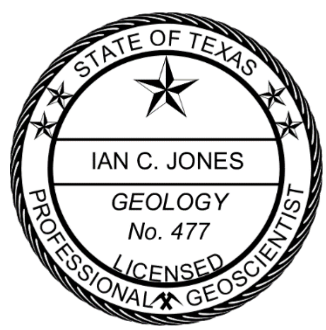
GAM RUN 23-004: HILL COUNTRY UNDERGROUND WATER CONSERVATION DISTRICT MANAGEMENT PLAN

Ian C. Jones, Ph.D., P.G.
Texas Water Development Board
Groundwater Division
Groundwater Modeling Department
512-463-6641
May 31, 2023



5/31/2023

This page is intentionally blank

GAM RUN 23-004: HILL COUNTRY UNDERGROUND WATER CONSERVATION DISTRICT MANAGEMENT PLAN

Ian C. Jones, Ph.D., P.G.
Texas Water Development Board
Groundwater Division
Groundwater Modeling Department
512-463-6641
May 31, 2023

EXECUTIVE SUMMARY:

Texas Water Code §36.1071 (h), 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 Hill Country Underground Water 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, which includes:

1. the annual amount of recharge from precipitation, if any, to the groundwater resources within the district;
2. the annual volume of water that discharges from the aquifer to springs and any surface-water bodies, including lakes, streams, and rivers, for each aquifer within the district; 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 Hill Country Underground Water Conservation District should be adopted by the district on or before July 20, 2023 and submitted to the executive administrator of the TWDB on or before August 19, 2023. The current management plan for the Hill Country Underground Water Conservation District expires on October 18, 2023.

We used the groundwater availability models for the Edwards-Trinity (Plateau) and Pecos Valley aquifers (Anaya and Jones, 2009) and the minor aquifers of the Llano Uplift region (Shi and others, 2016) to estimate the management plan information for the Edwards-Trinity (Plateau), Trinity, Ellenburger-San Saba, and Hickory aquifers within the Hill Country Underground Water Conservation District.

This report replaces the results of GAM Run 17-009 (Anaya, 2018). Values may differ from the previous report as a result of routine updates to the spatial grid file 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. Tables 1, 2, 3, and 4 summarize the groundwater availability model data required by statute. Figures 1, 3, 5, and 7 show the area of the model from which the values in Tables 1, 2, 3, and 4 were extracted. Figures 2, 4, 6, and 8 provide a generalized diagram of the groundwater flow components provided in Tables 1, 2, 3, and 4. If the Hill Country Underground Water Conservation District determines that the district boundaries used in the assessment do not reflect current conditions after reviewing the figures, please notify the TWDB Groundwater Modeling Department at your earliest convenience.

The flow components presented in this report do not represent the full groundwater budget. If additional inflow and outflow information would be helpful for planning purposes, the district may submit a request in writing to the TWDB Groundwater Modeling Department for the full groundwater budget.

METHODS:

In accordance with the provisions of the Texas Water Code § 36.1071 (h), the groundwater availability model mentioned above was used to estimate information for the Hill Country Underground Water Conservation District management plan. Water budgets were extracted for the historical model periods in the respective groundwater availability models. For the Edwards-Trinity (Plateau) and Trinity aquifers, the historical calibration period is 1981 through 2000, while for the Ellenburger-San Saba and Hickory aquifers the historical calibration period is 1981 through 2010. Water budgets were extracted over the historical calibration periods using ZONEBUDGET Version 3.01 (Harbaugh, 2009) and

ZONEBUDGET USG Version 1.00 (Panday and others, 2013), respectively. 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:

Edwards-Trinity (Plateau) and Trinity aquifers

- We used version 1.01 of the groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Valley aquifers (Anaya and Jones, 2009) to analyze the Edwards-Trinity (Plateau) and Trinity aquifers. See Anaya and Jones (2009) for assumptions and limitations of the model.

- The groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Valley aquifers contains the following two layers in the Hill Country Underground Water Conservation District:

    - Layer 1 represents the Edwards Group and equivalent limestone hydrostratigraphic units of the Edwards-Trinity (Plateau) Aquifer, and

    - Layer 2 represents the Trinity Group hydrostratigraphic units or equivalent units of the Edwards-Trinity (Plateau) and Trinity aquifers.

- The two layers were combined for calculating water budget flows in the Edwards-Trinity (Plateau) Aquifer within the district and were divided into zones representing the lateral extents of the Edwards-Trinity (Plateau) and Trinity aquifers.

- We used the groundwater availability model for the Edwards-Trinity (Plateau) Aquifer instead of the groundwater availability model for the Hill Country portion of the Trinity Aquifer because the Edwards-Trinity (Plateau) Aquifer model covers the entire geographical area of the district. Both groundwater availability models are aligned with different model grid orientations which prevent combining the results from each without double-accounting or omitting important water budget information.

- Water budget terms were averaged for the period 1981 through 2000 (stress periods 2 through 21).

- The model was run with MODFLOW-96 (Harbaugh and McDonald, 1996).

Ellenburger-San Saba and Hickory aquifers

- We used version 1.01 of the groundwater availability model for the Minor Aquifers in the Llano Uplift Region (Shi and others, 2016) to analyze the Ellenburger-San Saba and Hickory aquifers. See Shi and others (2016) for assumptions and limitations of the model.

- The groundwater availability model for the Minor Aquifers in the Llano Uplift Region contains eight layers:

    - Layer 1 — the Trinity Aquifer, Edwards-Trinity (Plateau) Aquifer, and younger alluvium deposits
    - Layer 2 — confining units
    - Layer 3 — the Marble Falls Aquifer and equivalent
    - Layer 4 — confining units
    - Layer 5 — the Ellenburger-San Saba Aquifer and equivalent
    - Layer 6 — confining units
    - Layer 7 — the Hickory Aquifer and equivalent
    - Layer 8 — confining (Precambrian) units

- Perennial rivers and reservoirs were simulated using the MODFLOW-USG river package. Springs were simulated using the MODFLOW-USG drain package. For this management plan, groundwater discharge to surface water includes groundwater leakage to the river and drain boundaries.

- Water budget terms were averaged for the period 1981 through 2010 (stress periods 2 through 31).

- The model was run with MODFLOW-USG (Panday and others, 2013).

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 Edwards-Trinity (Plateau), Trinity, Ellenburger-San Saba, and Hickory aquifers located within the Hill Country Underground Water Conservation District and averaged over the historical calibration period, as shown in Tables 1, 2, 3 and 4.

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, 2, 3, and 4. Figures 1, 3, 5, and 7 show the area of the model from which the values in Tables 1, 2, 3, and 4 were extracted. Figures 2, 4, 6, and 8 provide a generalized diagram of the groundwater flow components provided in Tables 1, 2, 3, and 4. 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 Edwards-Trinity (Plateau) Aquifer that is needed for the Hill Country Underground Water Conservation District 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	Edwards-Trinity (Plateau) Aquifer	17,396
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Edwards-Trinity (Plateau) Aquifer	16,814
Estimated annual volume of flow into the district within each aquifer in the district	Edwards-Trinity (Plateau) Aquifer	4,429
Estimated annual volume of flow out of the district within each aquifer in the district	Edwards-Trinity (Plateau) Aquifer	8,805
Estimated net annual volume of flow between each aquifer in the district	To Edwards-Trinity (Plateau) Aquifer from Trinity Aquifer	1,071
	From Edwards-Trinity (Plateau) Aquifer to Ellenburger-San Saba Aquifer	535[1]
	From Edwards-Trinity (Plateau) Aquifer to Hickory Aquifer	11[1]

[1] The estimated net annual volume of flow between the Edwards-Trinity (Plateau) and the Ellenburger-San Saba aquifers was calculated from version 1.01 of the groundwater availability model for the minor aquifers in the Llano Uplift Region.

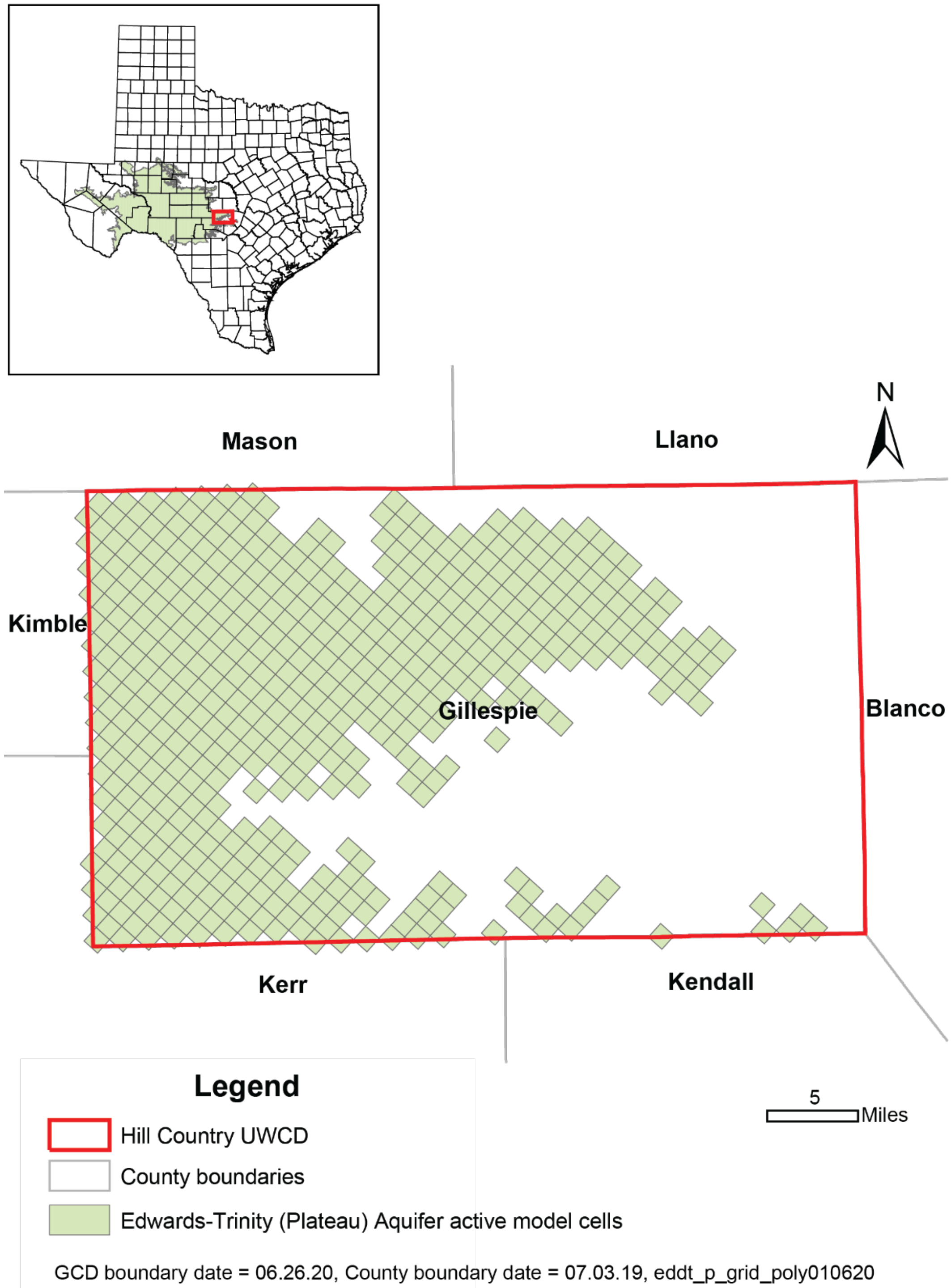
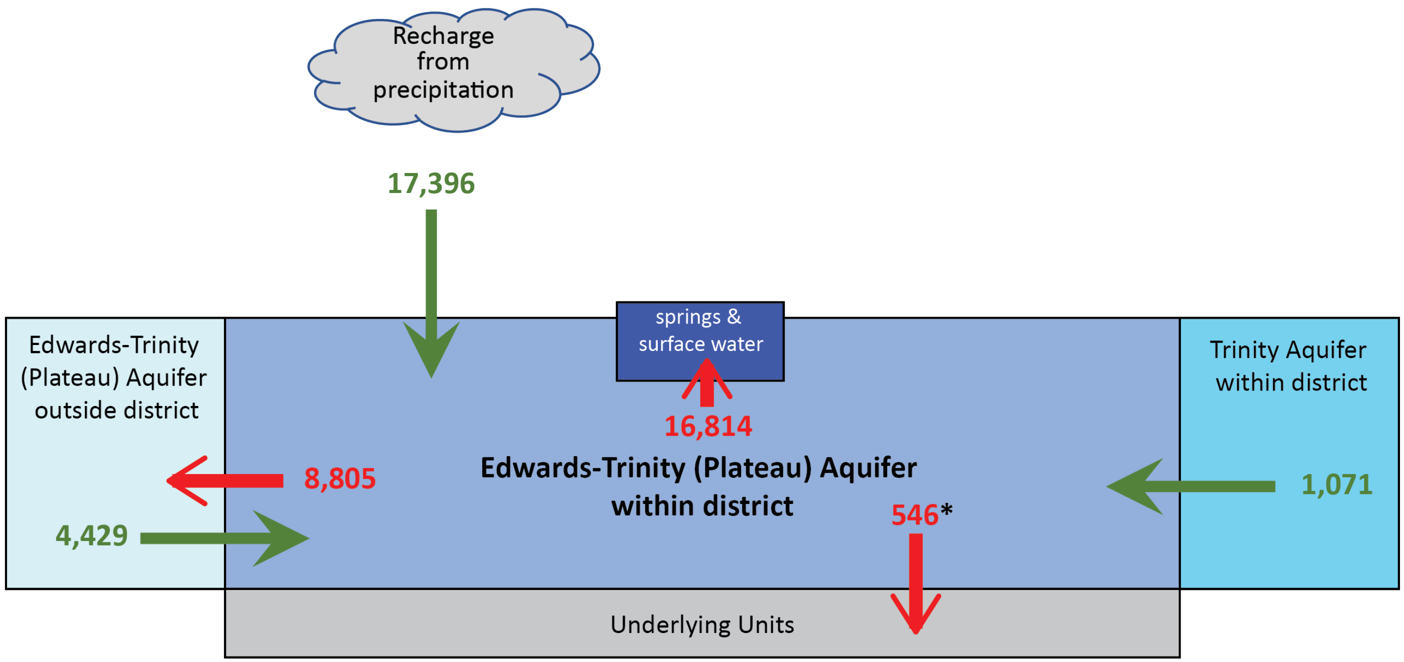


Figure 1: Area of the Edwards-Trinity (Plateau) and Pecos Valley aquifers groundwater availability model from which the information in Table 1 was extracted (the Edwards-Trinity (Plateau) Aquifer extent within the district boundary).



* Flow to underlying units includes net outflow of 535 acre-feet per year to Ellenburger-San Saba Aquifer, and 11 acre-feet per year to Hickory Aquifer. Values come from the groundwater availability model for the minor aquifers of the Llano Uplift.

Caveat: This diagram only includes the water budget items provided in Table 1. A complete water budget would include additional inflows and outflows. For a full groundwater budget, please submit a request in writing to the Groundwater Modeling Department.

Figure 2: Generalized diagram of the summarized budget information from Table 1, representing directions of flow for the Edwards-Trinity (Plateau) Aquifer within the Hill County Underground Water Conservation District. Flow values are expressed in acre-feet per year.

Table 2: Summarized information for the Trinity Aquifer that is needed for the Hill Country Underground Water Conservation District 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	28,839
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Trinity Aquifer	25,625
Estimated annual volume of flow into the district within each aquifer in the district	Trinity Aquifer	409
Estimated annual volume of flow out of the district within each aquifer in the district	Trinity Aquifer	1,545
Estimated net annual volume of flow between each aquifer in the district	From Trinity Aquifer to Edwards-Trinity (Plateau) Aquifer	1,071
	From Trinity Aquifer to Ellenburger-San Saba Aquifer	60[2]

[2] The estimated net annual volume of flow between the Trinity and the Ellenburger-San Saba aquifers was calculated from version 1.01 of the groundwater availability model for the minor aquifers in the Llano Uplift Region.

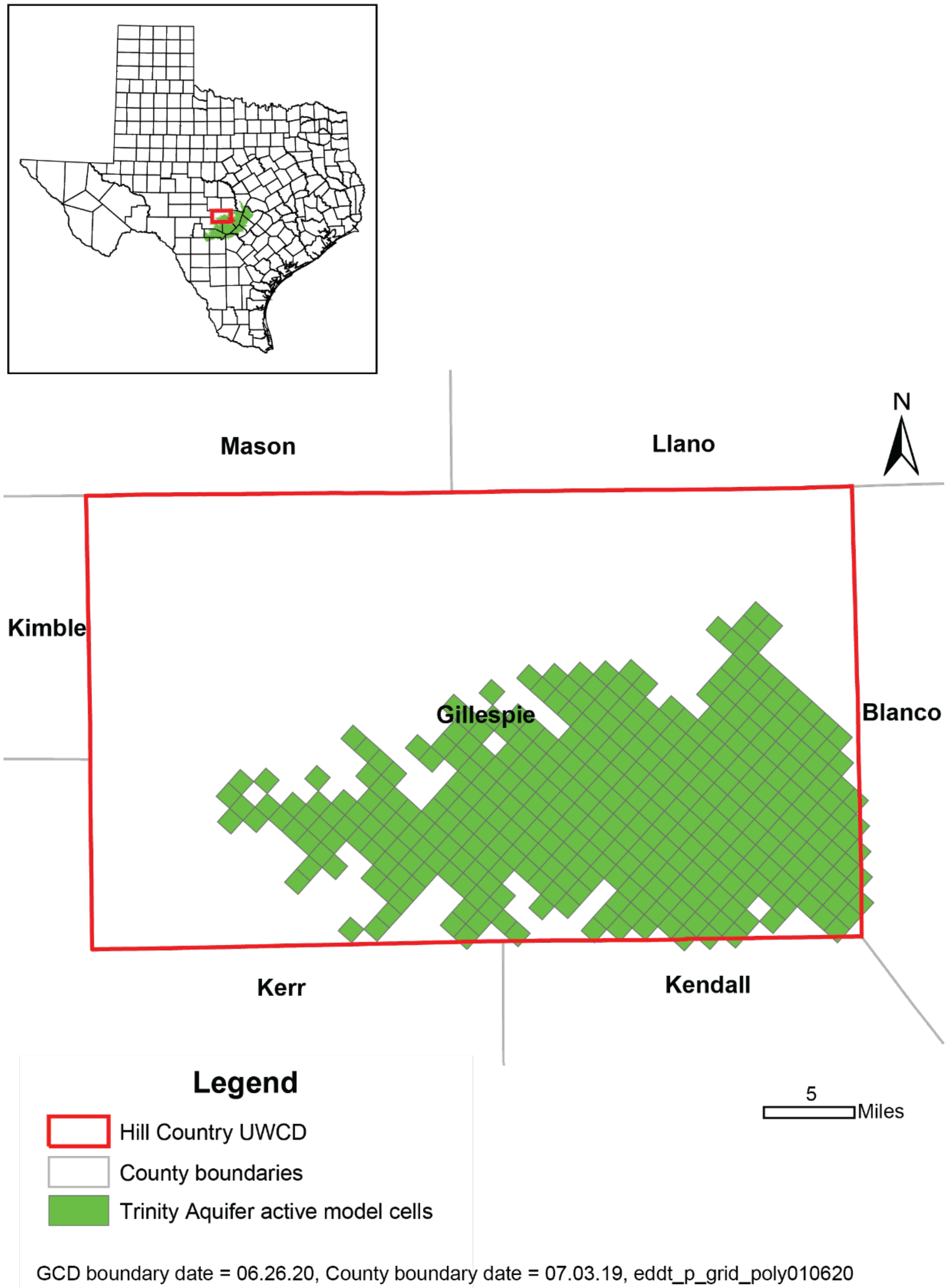
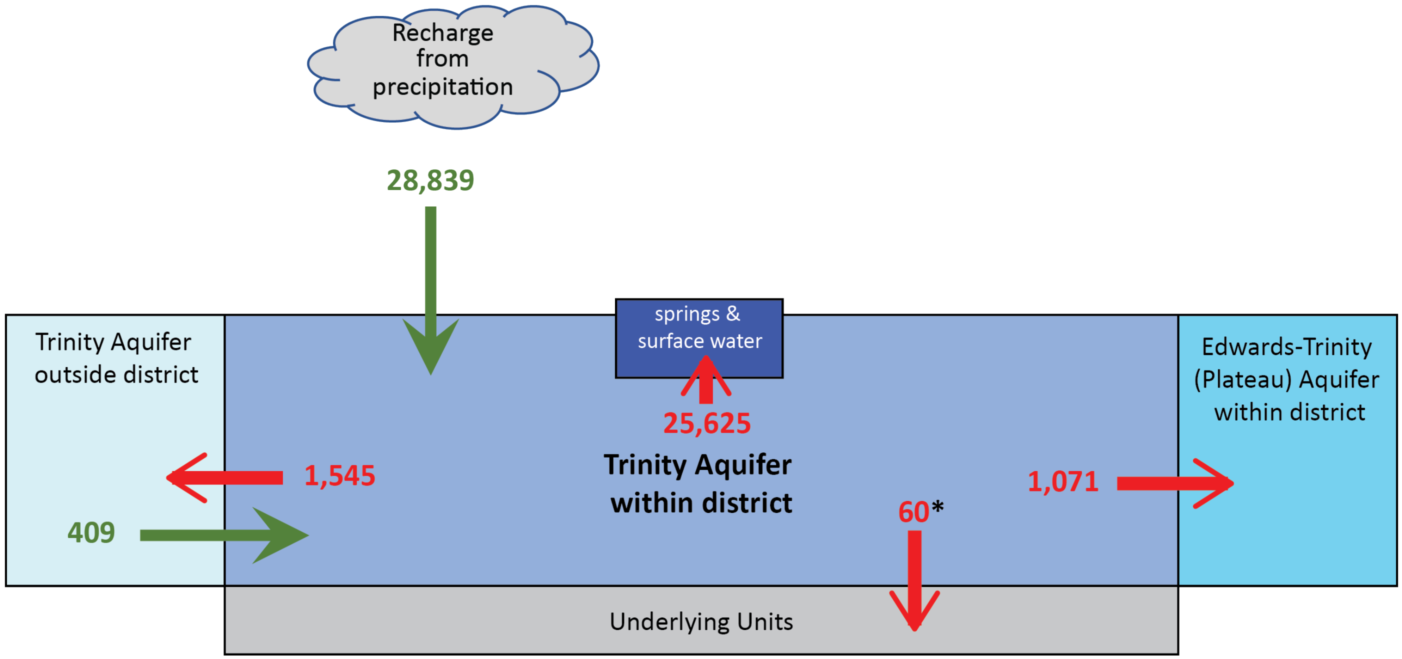


Figure 3: Area of the Edwards-Trinity (Plateau) and Pecos Valley aquifers groundwater availability model from which the information in Table 2 was extracted (the Trinity Aquifer extent within the district boundary).



* Flow to underlying units includes net outflow of 60 acre-feet per year to Ellenburger-San Saba Aquifer. Values come from the groundwater availability model for the minor aquifers of the Llano Uplift.

Caveat: This diagram only includes the water budget items provided in Table 2. A complete water budget would include additional inflows and outflows. For a full groundwater budget, please submit a request in writing to the Groundwater Modeling Department.

Figure 4: Generalized diagram of the summarized budget information from Table 2, representing directions of flow for the Trinity Aquifer within the Hill Country Underground Water Conservation District. Flow values are expressed in acre-feet per year.

Table 3: Summarized information for the Ellenburger-San Saba Aquifer that is needed for the Hill Country Underground Water Conservation District 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	Ellenburger-San Saba Aquifer	940
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Ellenburger-San Saba Aquifer	1,593
Estimated annual volume of flow into the district within each aquifer in the district	Ellenburger-San Saba Aquifer	612
Estimated annual volume of flow out of the district within each aquifer in the district	Ellenburger-San Saba Aquifer	8,183
Estimated net annual volume of flow between each aquifer in the district	To Ellenburger-San Saba Aquifer from Edwards-Trinity (Plateau) Aquifer	535
	To Ellenburger-San Saba Aquifer from Trinity Aquifer	60
	To Ellenburger-San Saba Aquifer from Pennsylvanian confining units	54
	From Ellenburger-San Saba Aquifer to Marble Falls Formation	348
	To Ellenburger-San Saba Aquifer from Mississippian confining units	33,683
	From Ellenburger-San Saba Aquifer to Ellenburger-San Saba Aquifer equivalent units	1,207
	From Ellenburger-San Saba Aquifer to Cambrian confining units	23,738
	To Ellenburger-San Saba Aquifer from Hickory Aquifer	3,381
	To Ellenburger-San Saba Aquifer from Pre-Cambrian confining units	629

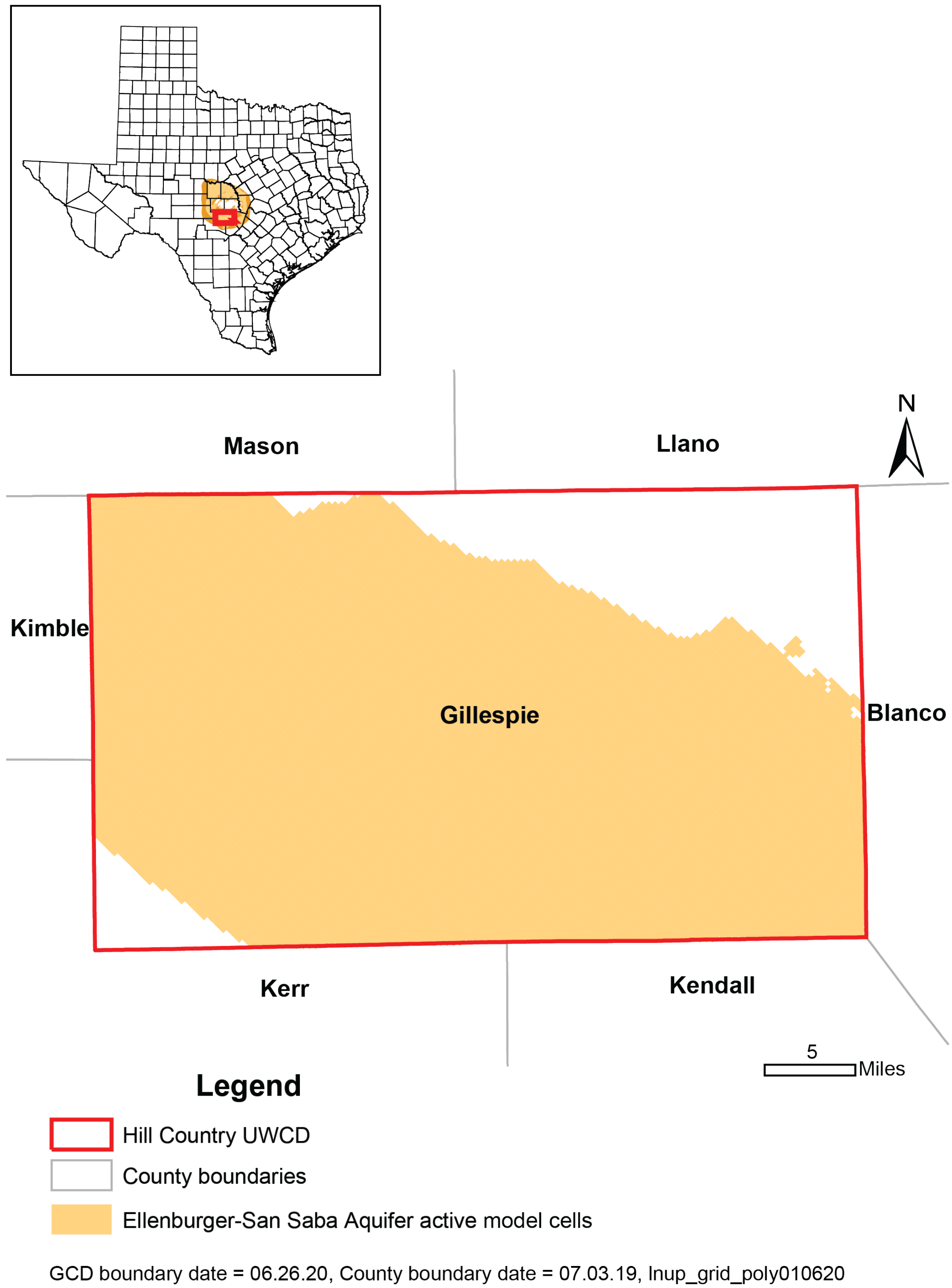
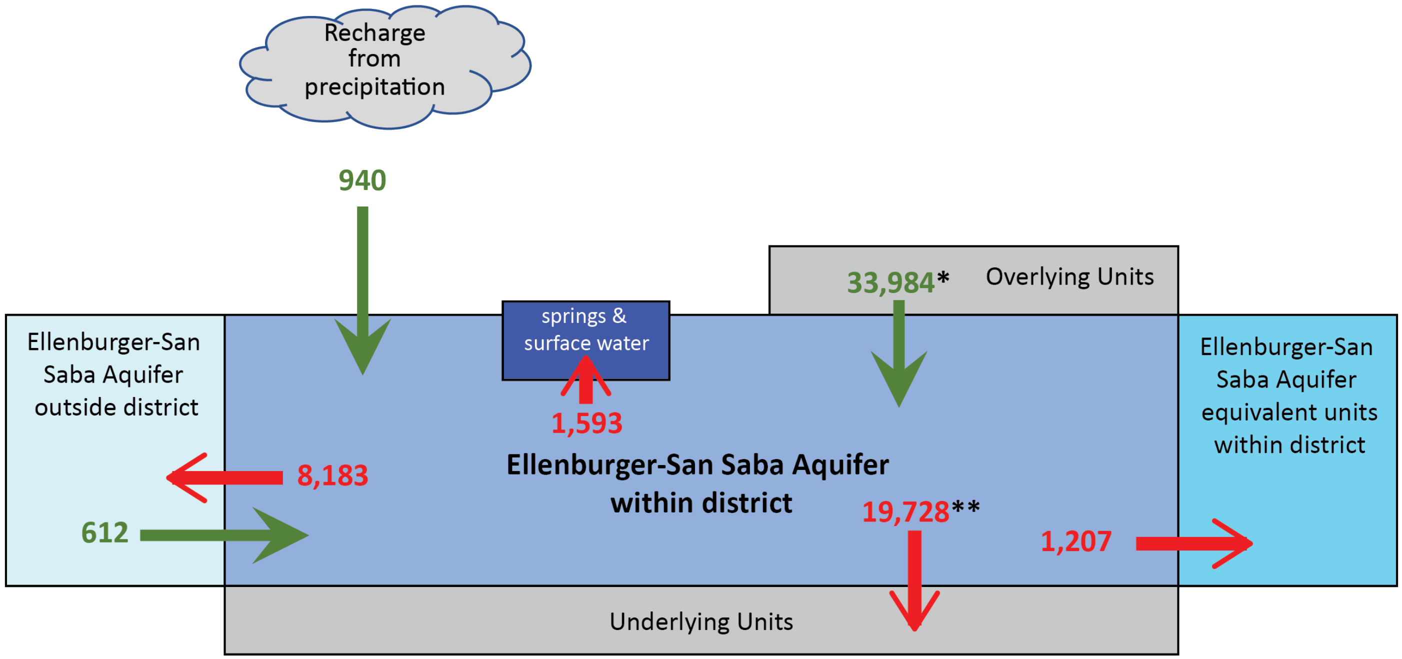


Figure 5: Area of the Minor Aquifers of the Llano Uplift groundwater availability model from which the information in Table 3 was extracted (the Ellenburger-San Saba Aquifer extent within the district boundary).



* Flow from overlying units includes net inflow of 535 acre-feet per year from Edwards-Trinity (Plateau) Aquifer, 60 acre-feet per year from Trinity Aquifer, and 33,737 acre-feet per year from overlying confining units, and net outflow of 348 acre-feet per year to Marble Falls Formation equivalent units.
** Flow to underlying units includes net inflow of 3,381 acre-feet per year from Hickory Aquifer and 629 acre-feet per year from Pre-Cambrian confining unit, and net outflow of 23,738 to underlying 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. For a full groundwater budget, please submit a request in writing to the Groundwater Modeling Department.

Figure 6: Generalized diagram of the summarized budget information from Table 3, representing directions of flow for the Ellenburger-San Saba Aquifer within the Hill County Underground Water Conservation District. Flow values are expressed in acre-feet per year.

Table 4: Summarized information for the Hickory Aquifer that is needed for the Hill Country Underground Water Conservation District 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	Hickory Aquifer	263
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Hickory Aquifer	0
Estimated annual volume of flow into the district within each aquifer in the district	Hickory Aquifer	1,472
Estimated annual volume of flow out of the district within each aquifer in the district	Hickory Aquifer	17,801
Estimated net annual volume of flow between each aquifer in the district	To Hickory Aquifer from Edwards-Trinity (Plateau) Aquifer	11
	From Hickory Aquifer to Marble Falls Formation	132
	From Hickory Aquifer to Mississippian confining units	22
	From Hickory Aquifer to Ellenburger-San Saba Aquifer	3,381
	To Hickory Aquifer from Ellenburger-San Saba Aquifer equivalent units	291
	To Hickory Aquifer from Cambrian confining units	25,363
	From Hickory Aquifer to Hickory Aquifer equivalent units	280
	From Hickory Aquifer to Pre-Cambrian confining units	5,014

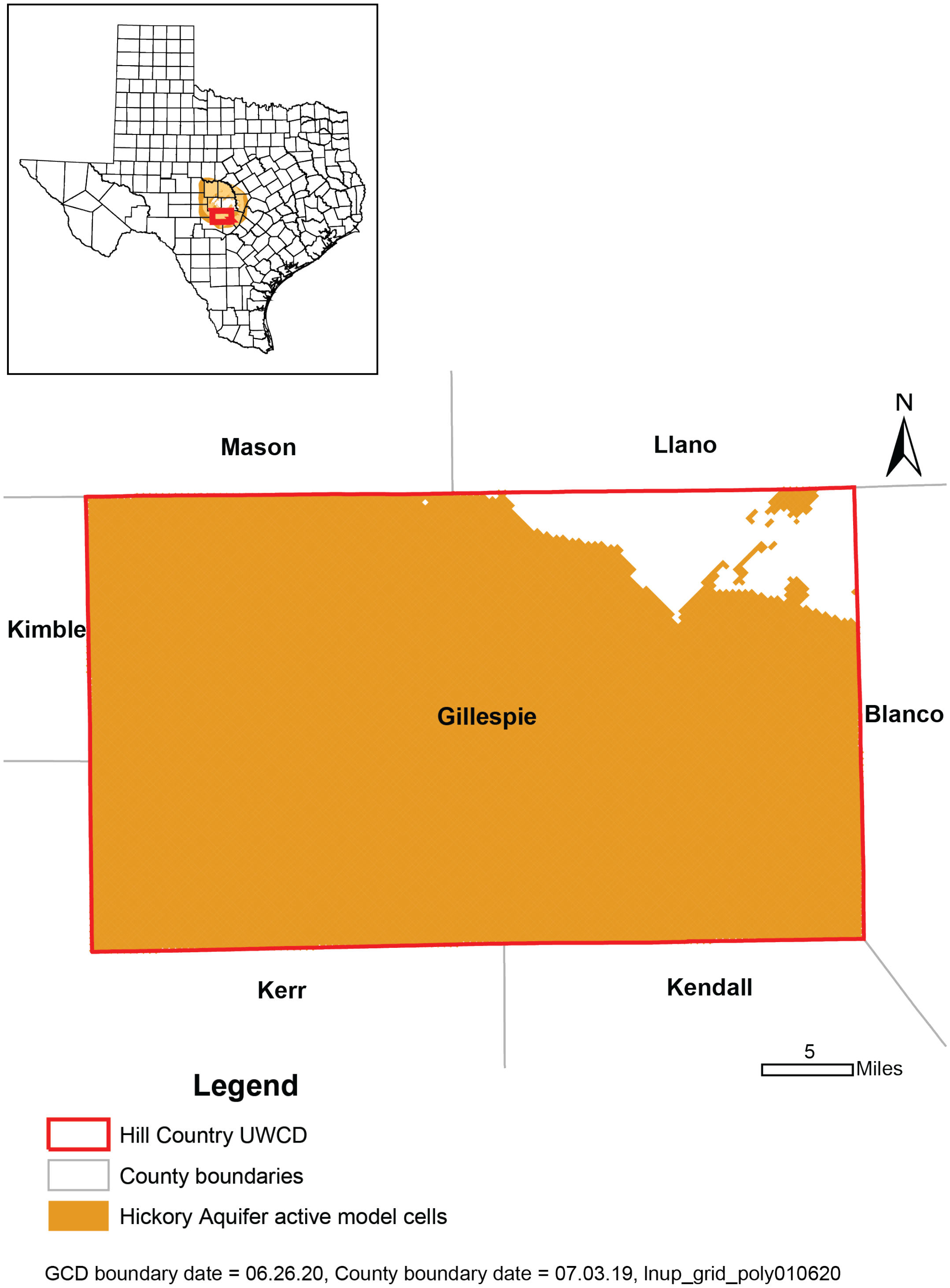
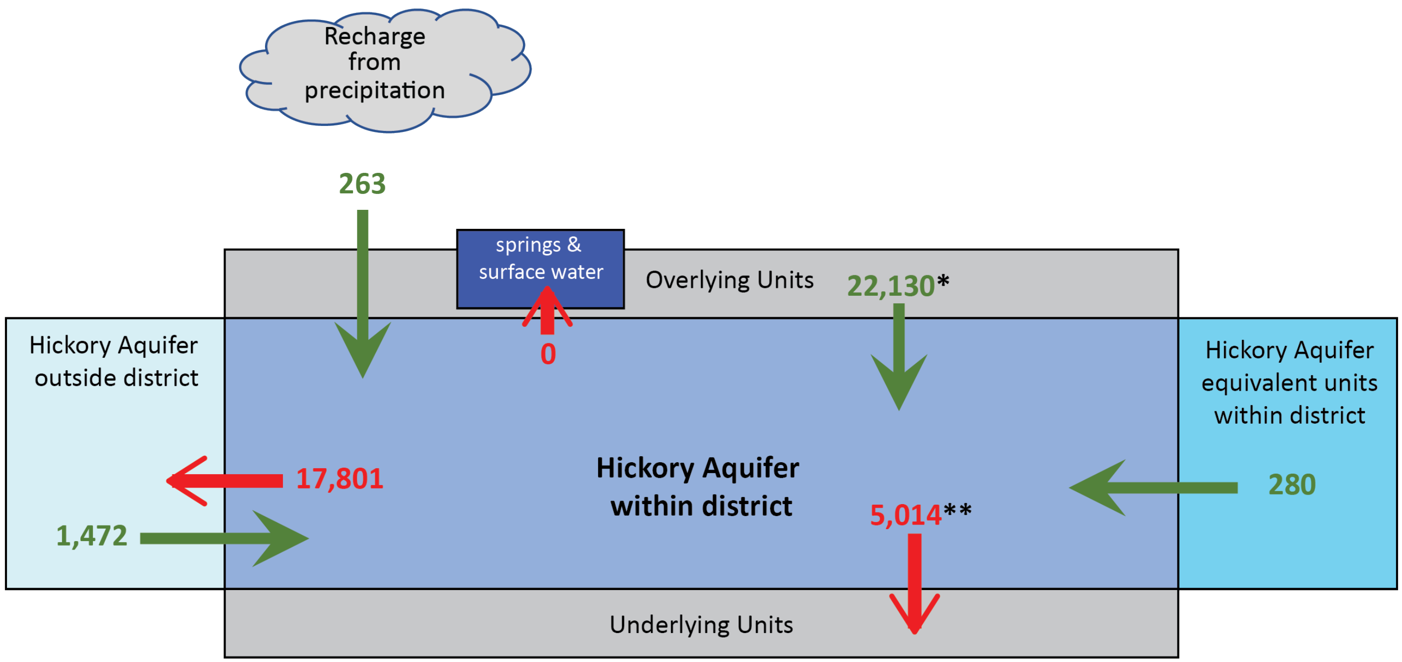


Figure 7: Area of the Minor Aquifers of the Llano Uplift groundwater availability model from which the information in Table 4 was extracted (the Hickory Aquifer extent within the district boundary).



* Flow from overlying units includes net inflow of 11 acre-feet per year from Edwards-Trinity (Plateau) Aquifer, 291 acre-feet per year from Ellenburger-San Saba Aquifer equivalent units, and 25,363 acre-feet per year from overlying confining units, and net outflow of 132 acre-feet per year to Marble Falls Formation equivalent units, 22 acre-feet per year to overlying confining unit, and 3,381 acre-feet per year to Ellenburger-San Saba Aquifer.
** Flow to underlying units includes net outflow of 5,014 acre-feet per year to Pre-Cambrian 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. For a full groundwater budget, please submit a request in writing to the Groundwater Modeling Department.

Figure 8: Generalized diagram of the summarized budget information from Table 4, representing directions of flow for the Hickory Aquifer within the Hill County Underground Water Conservation District. Flow values are expressed in acre-feet per year.

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:

Anaya, R., and Jones, I., 2009, Groundwater availability model for the Edwards-Trinity (Plateau) and Pecos Valley aquifers of Texas: Texas Water Development Board, Report 373, 103 p.

Anaya, R., 2018, GAM Run 17-009: Texas Water Development Board, GAM Run 17-009 Report, 17 p., https://www.twdb.texas.gov/groundwater/docs/GAMruns/GR17-009.pdf.

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.

Harbaugh, A. W., and McDonald, M.G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96–485, 56 p

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.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D., 2013, MODFLOW–USG version 1: 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 Techniques and Methods, book 6, chap. A45, 66 p.

Shi, J., Boghici, R., Kohlrenken, W., and Hutchison, W.R., 2016, Numerical Model Report: Minor Aquifers of the Llano Uplift Region of Texas (Marble Falls, Ellenburger-San Saba, and Hickory). Texas Water Development Board, 403p.

Texas Water Code § 36.1071 , 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf