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DRAFT TECHNICAL MEMORANDUM

To: Daryn Hardwick, Groundwater Modeling Manager, Texas Water Development Board

From: Stephanie J. Moore, PG, INTERA Incorporated

Date: April 30, 2025

Re: Final Stakeholder Advisory Forum for Development of the Cross Timbers Aquifer Numerical Model

1 Overview

The second and final Stakeholder Advisory Forum (SAF) for development of the Cross Timbers Aquifer Groundwater Availability Model (GAM) was held on April 16, 2025. The purpose of the SAF was to provide an update on status of model development, share information regarding the current draft numerical model report, and seek public comment on the draft model and report. The agenda included a summary of (1) the Cross Timbers Aquifer Numerical Model, (2) model calibration, (3) sensitivity analysis, (4) model limitations, and (5) discussion.

INTERA, Inc. was retained by the Texas Water Development Board (TWDB) to develop the numerical model for the Cross Timbers Aquifer. INTERA hosted the SAF online via Microsoft Teams. A total of 26 people in attended the meeting. Names and affiliations for each attendee is provided in **Attachment 1**.

Daryn Hardwick of TWDB began the meeting by sharing the location to find all meeting materials for the Cross Timbers Aquifer (https://www.twdb.texas.gov/groundwater/models/gam/cstb/cstb.asp) and an overview of the TWDB Stakeholder Advisory Forums.

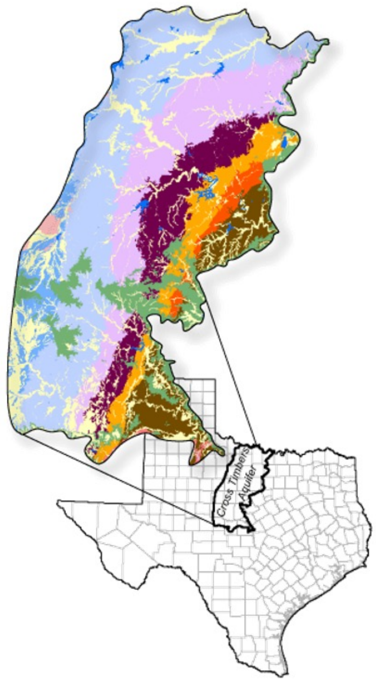
Stephanie Moore of INTERA continued with review of the meeting agenda and introduction of the project team. Stephanie Moore, Ryan Harmon, and Savannah Miller of INTERA continued with presentation of the technical details of the study area and numerical model. The complete PowerPoint presentation is provided as **Attachment 2**. An audio and video recording is available at the link listed in the above paragraph.

Upon conclusion of the technical presentations, the project team took questions from the audience. A summary of questions and answers is provided in **Attachment 3**. Finally, Stephanie wrapped up the meeting with reminder that the draft report is currently available for public review through June 16, 2025 (60 days from date of the meeting) and comments should be submitted to gam@twdb.texas.gov.

Attachment 1. Attendees

Number	Name	Affiliation
1	Roberto Anaya	TWDB
2	Natalie Ballew	TWDB
3	Neil Blandford	Geo-Logic Associates
4	Robert Bradley	TWDB
5	Ray Brady	Unknown
6	Amy Bush	Consultant
7	Tim Cawthon	TWDB
8	Bence Close	Unknown
9	Neil E. Deeds	INTERA
10	John Ellis	INTERA
11	Jevon Harding	TWDB
12	Daryn Hardwick	TWDB
13	Ryan Harmon	INTERA
14	Ian Jones	TWDB
15	Kristie Laughlin	TWDB
16	Adam Lee	TWDB
17	Saheli Majumdar	TWDB
18	Savannah Miller	INTERA
19	Stephanie Moore	INTERA
20	Micaela Pedrazas	TWDB
21	Doug Shaw	Upper Trinity GCD
22	Lynn Smith	Rolling Plains GCD
23	Evan Strickland	TWDB
24	Todd Umstot	Geo-Logic Associates
25	Shirley Wade	TWDB
26	Jeremy White	INTERA

Attachment 2. PowerPoint Slides from SAF#2



Stakeholder Advisory Forum (SAF #2):

Cross Timbers Groundwater Availability Model

April 16th, 2025

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Meeting information

- An audio and video recording of the meeting, presentation, and the report summarizing the meeting will be made available on the project's TWDB webpage
- https://www.twdb.texas.gov/groundwater/models/gam/cstb/cstb.asp

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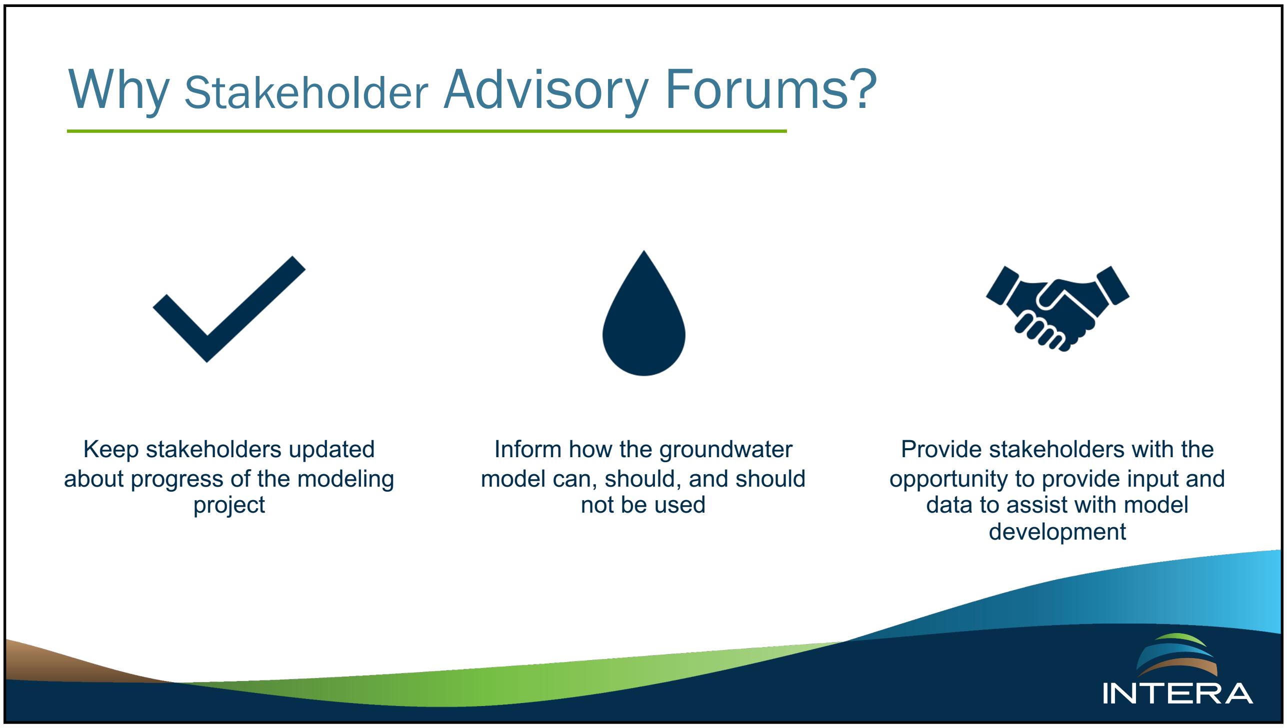
Why Stakeholder Advisory Forums?
Keep stakeholders updated about progress of the modeling project
Inform how the groundwater model can, should, and should not be used
Provide stakeholders with the opportunity to provide input and data to assist with model development
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Agenda
1 Cross Timbers Aquifer Model Review
2 Model Calibration
3 Sensitivity Analysis
4 Model Limitations
5 Discussion
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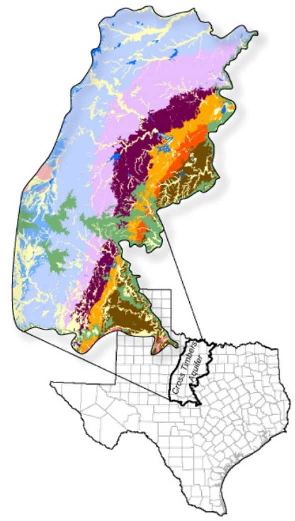
Project Team

- Ryan Harmon
- Savannah Miller, PG
- Stephanie J. Moore, PG
- Jeremy White, PhD
- John Ellis, PG

- PIC: Neil Deeds, PhD, PE, PG
- TWDB PM: Daryn Hardwick, PhD



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Study Objectives

1. Improve conceptual understanding of the Cross Timbers Aquifer
2. Provide tool for assessing desired future condition (DFC) of the aquifer and modeled available groundwater (MAG)
3. Create a numerical model that can be used for water planning at regional scale by both public and private entities

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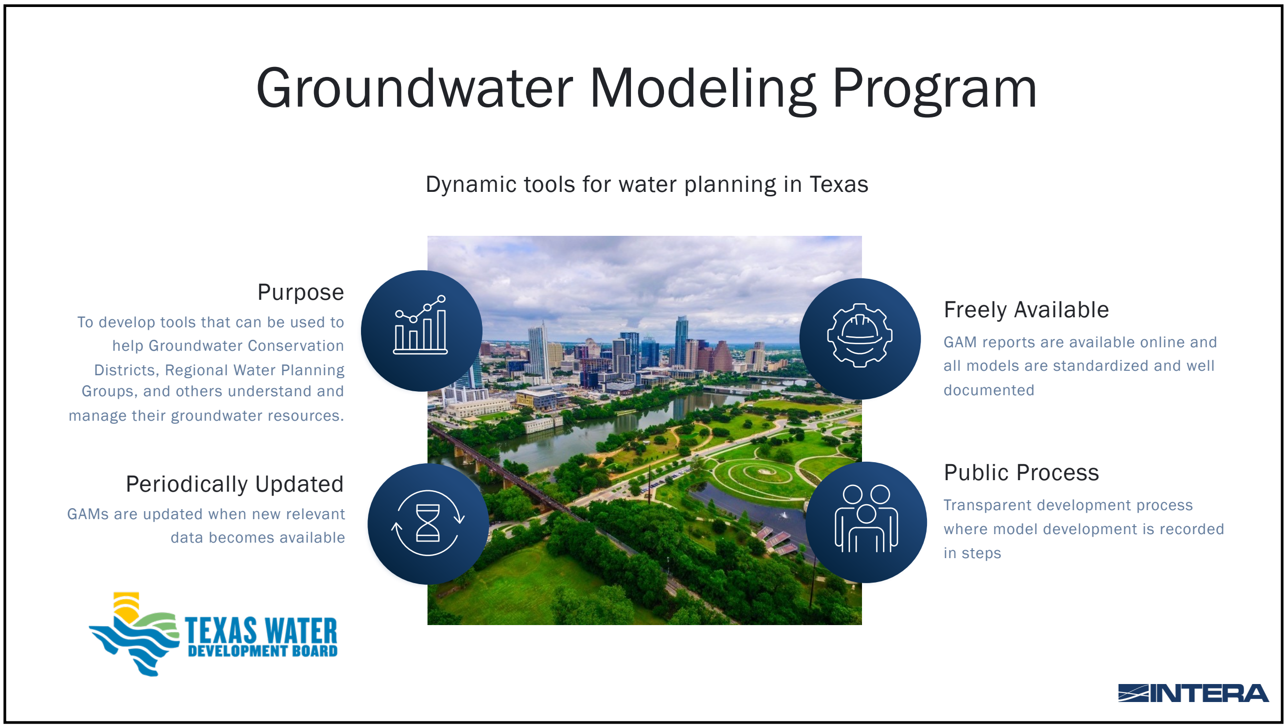
Groundwater Modeling Program
Dynamic tools for water planning in Texas
Purpose
To develop tools that can be used to help Groundwater Conservation Districts, Regional Water Planning Groups, and others understand and manage their groundwater resources.
Periodically Updated
GAMs are updated when new relevant data becomes available
Freely Available
GAM reports are available online and all models are standardized and well documented
Public Process
Transparent development process where model development is recorded in steps
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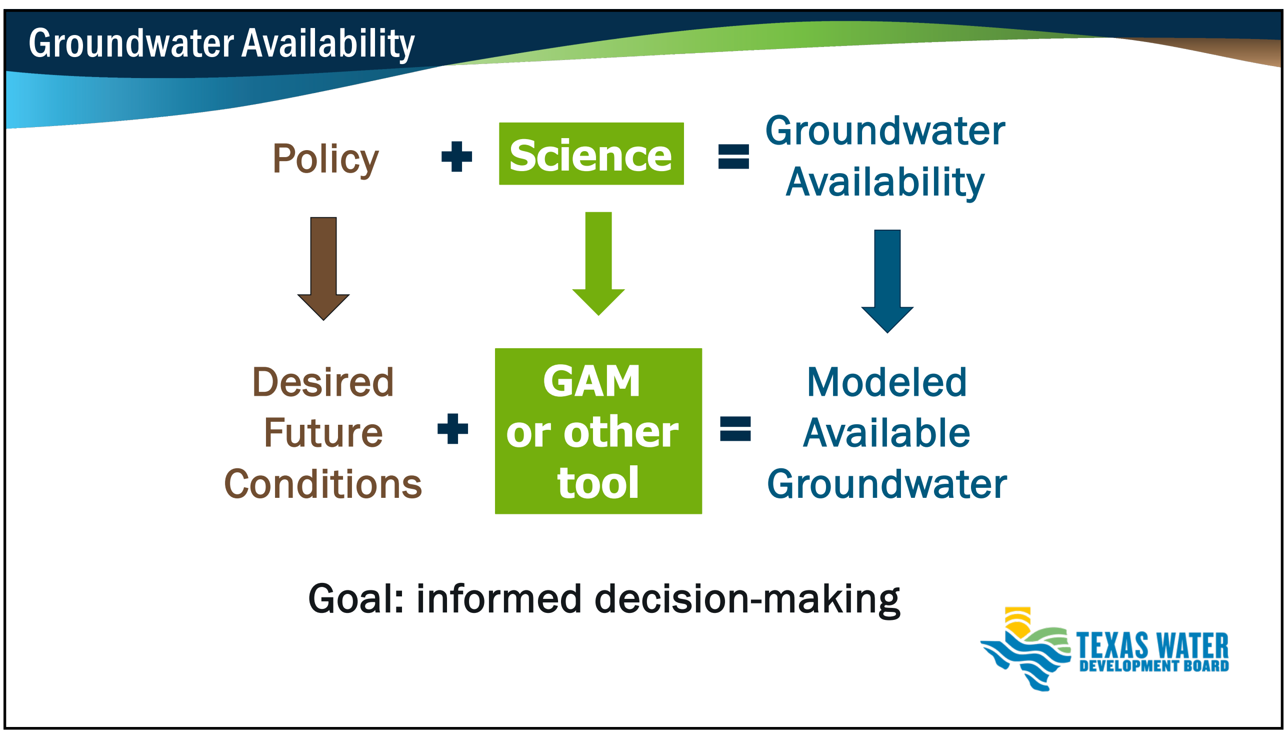
Groundwater Availability
Policy
+
Science
=
Groundwater Availability
Desired Future Conditions
+
GAM or other tool
=
Modeled Available Groundwater
Goal: informed decision-making
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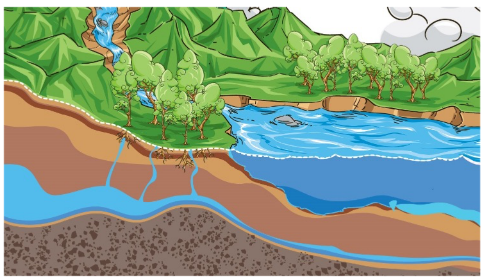
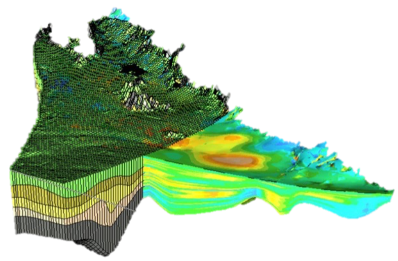
Groundwater Models

- Domenico (1972) defined a model as a representation of reality that attempts to explain the behavior of some aspect of reality and is always **less complex** than the real system it represents
- Wang & Anderson (1982) defined a model as a tool designed to represent a **simplified** version of reality





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Why Groundwater Flow Models?

- In contrast to surface water, groundwater flow is difficult to observe
- Aquifers are complex in terms of spatial extent and hydrogeological characteristics
- A groundwater model provides the only means for integrating available data for the prediction of groundwater flow at the scale of interest

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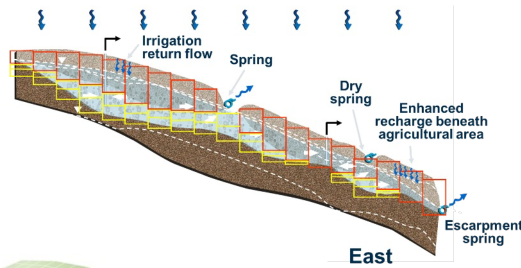
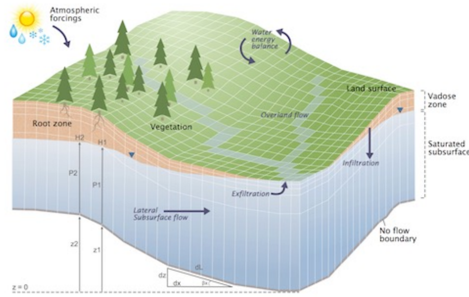
Numerical Flow Models

- Mathematical representation of an aquifer
- Employs basic laws of physics that govern groundwater flow
- Calculates the hydraulic head at discrete locations (determined by the grid)
- Compare calculated hydraulic heads to measured hydraulic heads





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MODFLOW

- Code developed by the U.S. Geological Survey
- Selected by TWDB for all GAMs
- Handles the relevant processes
- Comprehensive documentation
- Public domain – non-proprietary
- Most widely used groundwater modeling code
- Supporting interface programs available
- Using MODFLOW-6 – most recent standard version

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science for a changing world

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Model Types: Deterministic vs. Probabilistic

- **Deterministic** model: provides a single answer given a single set of input values
    - Does not incorporate randomness (which in our case are unknowns/uncertainties)

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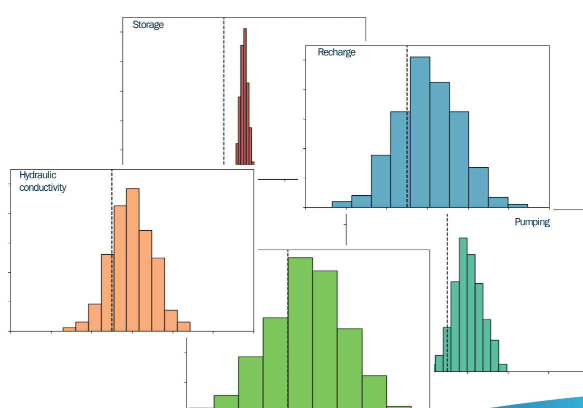
Model Types: Deterministic vs. Probabilistic

- **Deterministic** model: provides a single answer given a single set of input values
    - Does not incorporate randomness (which in our case are unknowns/uncertainties)
- **Probabilistic** model: incorporates unknowns (or *uncertainties*) in model inputs which leads to a range in outputs
    - Model input & output uncertainties are reflected as probability distribution functions (pdf)
    - **Also known as Uncertainty Analysis**



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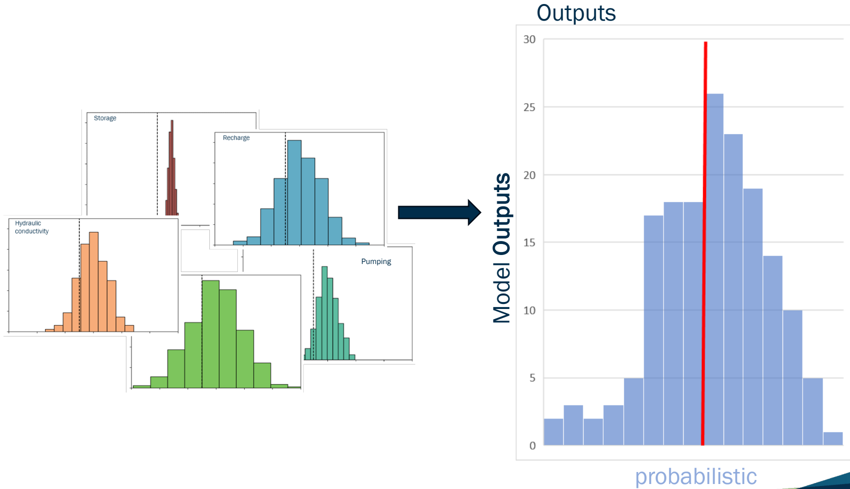
Model Types: Deterministic vs. Probabilistic



Probabilistic or Uncertainty Analysis incorporates the unknowns and provides more robust models.

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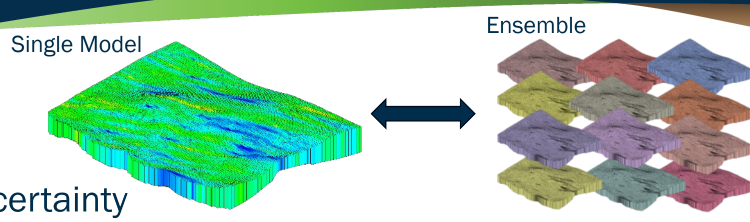
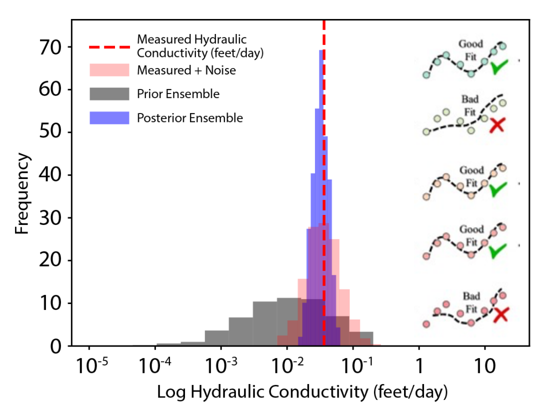
PESTPP-IES



Parameter estimation and uncertainty analysis method, compatible with MODFLOW6

- Ensemble (i.e., suite) based approach: Uses a collection (ensemble) of parameter sets to explore uncertainty and update model parameters iteratively.
- Iterative Updating: Updates parameter estimates multiple times using an ensemble smoother approach to improve calibration. (Prior to Posterior Distributions)
- Uncertainty Quantification: Provides insights into parameter uncertainty and predictive uncertainty.



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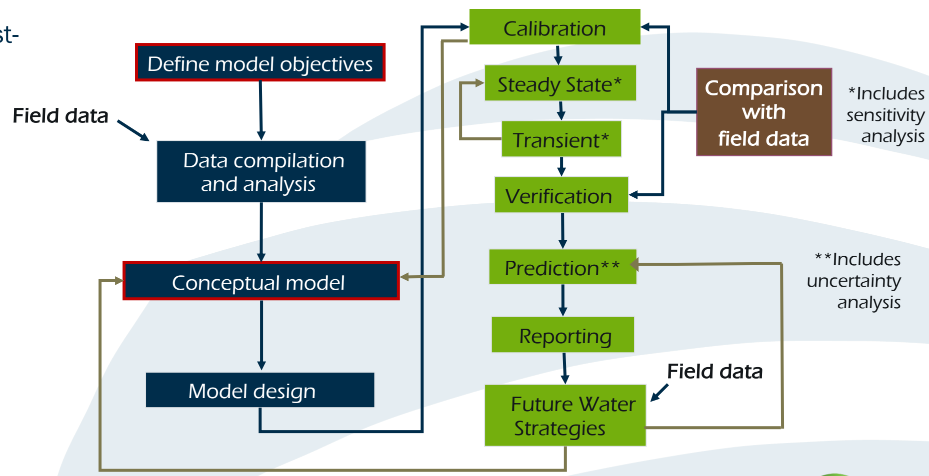
Modeling Protocol

- Model build, pre-, and post-processing all scripted in Python
- Many advantages to scripted workflow:
  - Automation & efficiency
  - Transparency
  - Reproducibility
  - Flexibility
  - Error reduction
  - Documentation & collaboration



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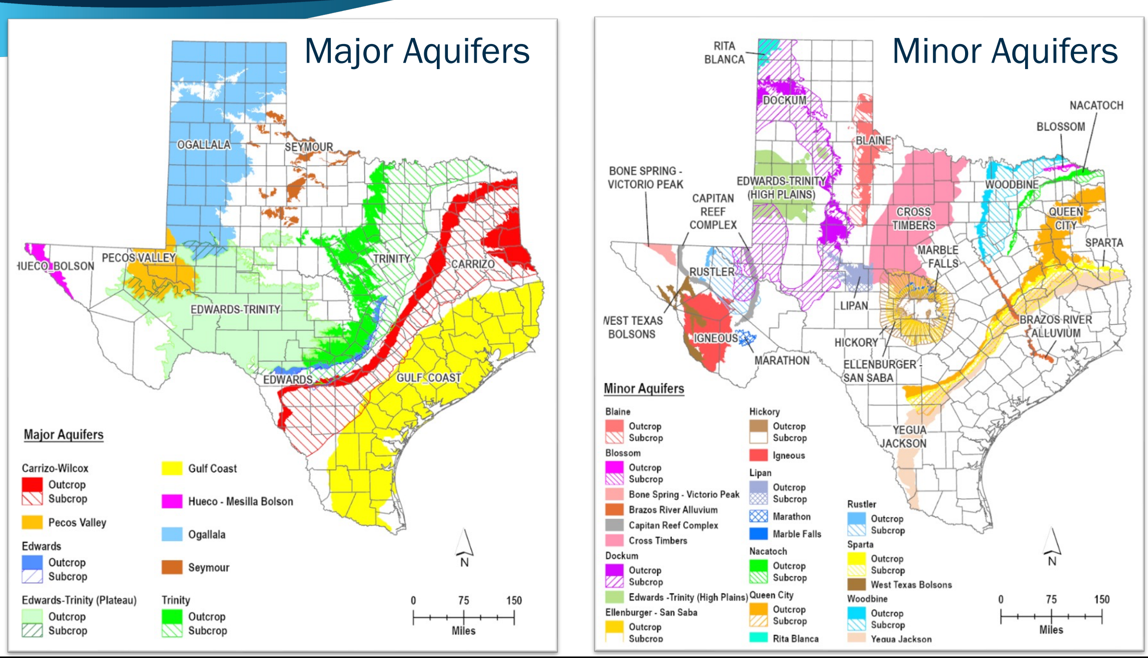
Aquifers of Texas



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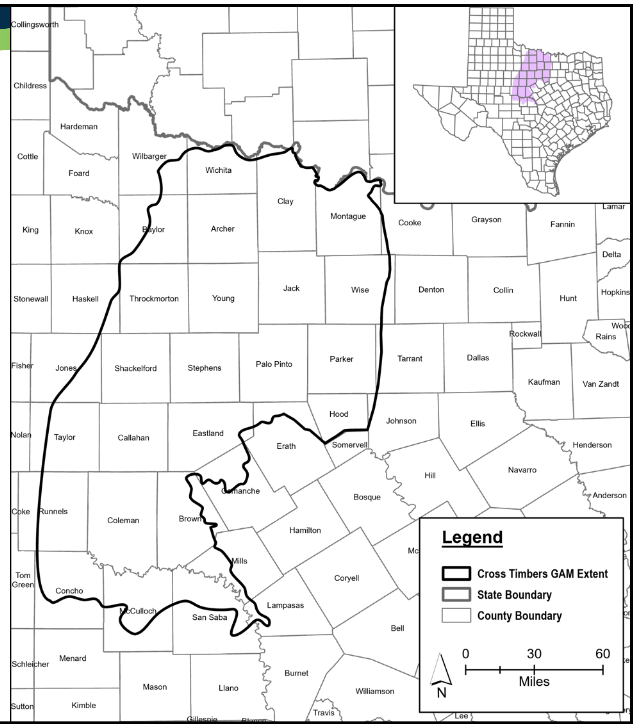
Study Area

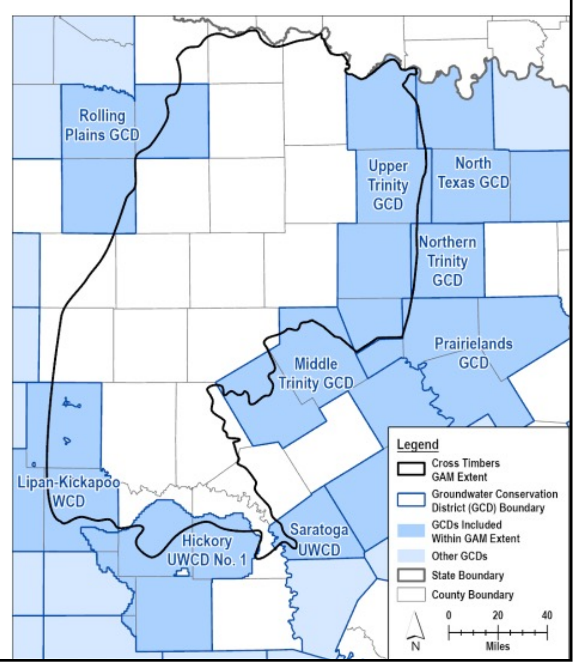
Cross Timbers Aquifer
- 17,800 square miles
- 33 counties

Previous Investigations
- Blanford and others, 2021
- Ballew and French, 2019
- Oliver and Kelley, 2014
- Nicot and others, 2011



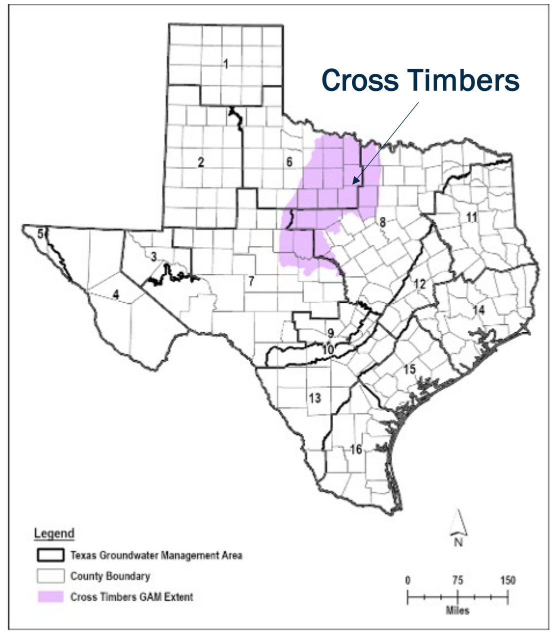
Groundwater Conservation Districts

1. Upper Trinity GCD
2. Rolling Plains GCD
3. Lipan-Kickapoo WCD
4. Hickory UWCD No. 1
5. Saratoga UWCD
6. Middle Trinity GCD
7. North Texas GCD
8. Northern Trinity GCD
9. Prairielands GCD



Groundwater Management Areas

1. GMA 6
2. GMA 7
3. GMA 8



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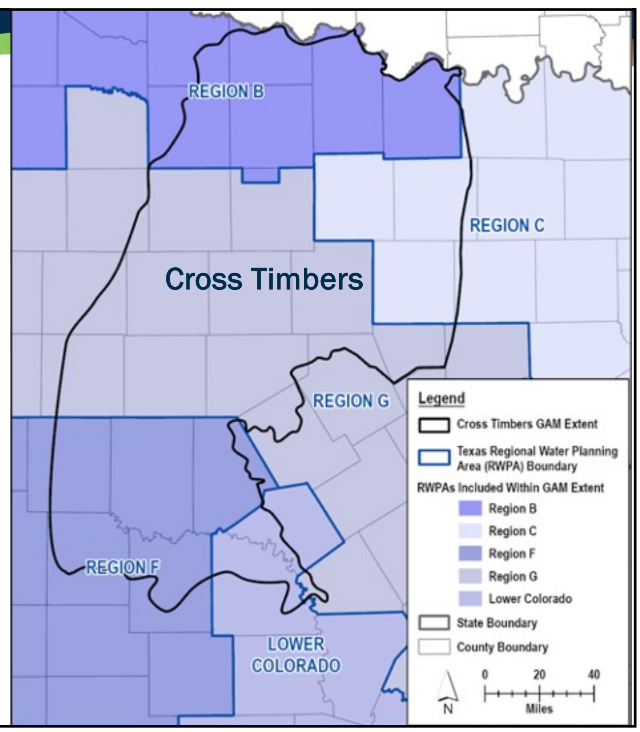
Regional Water Planning Areas

1. Region B (Red River)
2. Region C (North Central Texas including the DFW Metroplex)
3. Region F (West Texas)
4. Region G (Brazos)
5. Region K (Lower Colorado)



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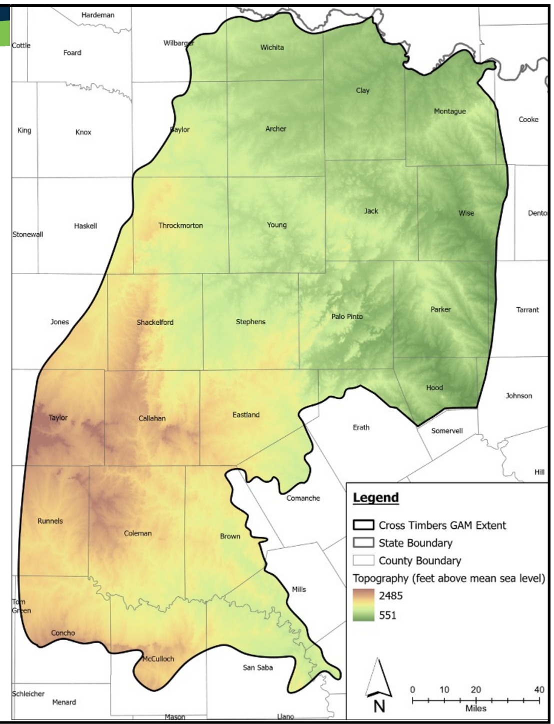
Topography & Physiography

- Elevation range
  - 551 to 2,485 ft amsl
  - Highest elevations in southwest plateaus
- Central Lowlands Physiographic Province
  - Low-relief terrain with broad plains, rolling hills, and river valleys
  - Dominated by Paleozoic sedimentary rocks
- Great Plains Physiographic Province
  - Extensive elevated plateaus with flatlands and rolling hills
  - Thick layers of sedimentary rocks



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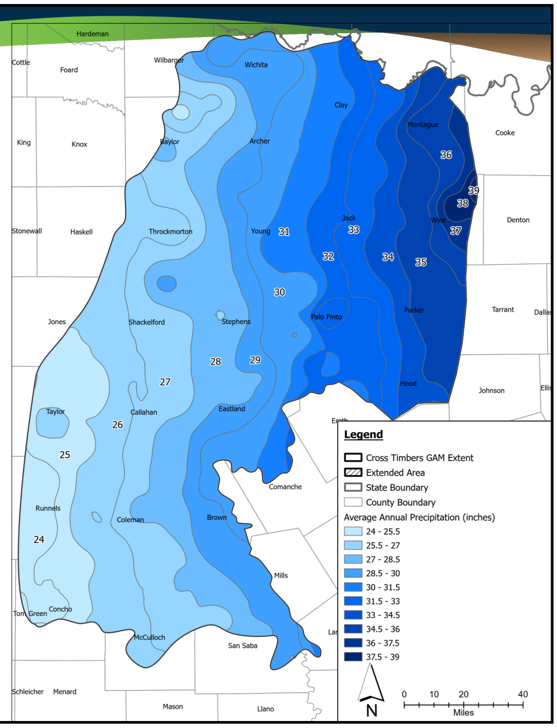
Precipitation

Average annual precipitation is 24 to 39 inches per year



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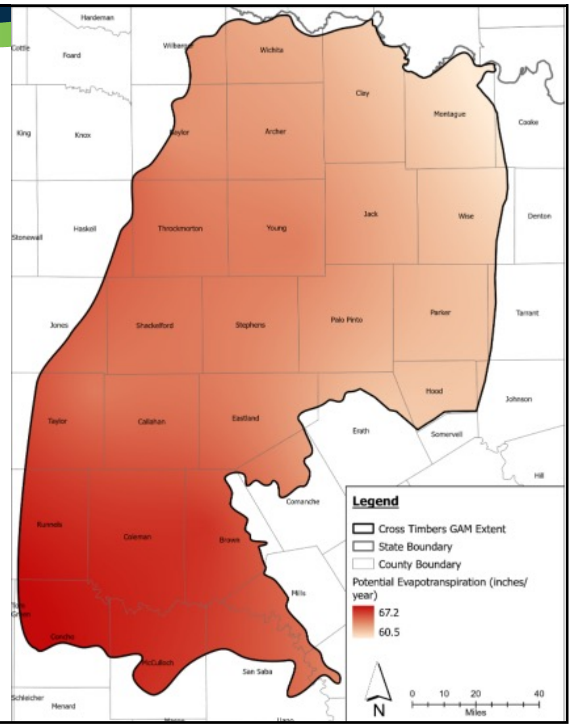
Potential Evapotranspiration

Potential evapotranspiration (PET) ranges from 60 to 67 inches per year



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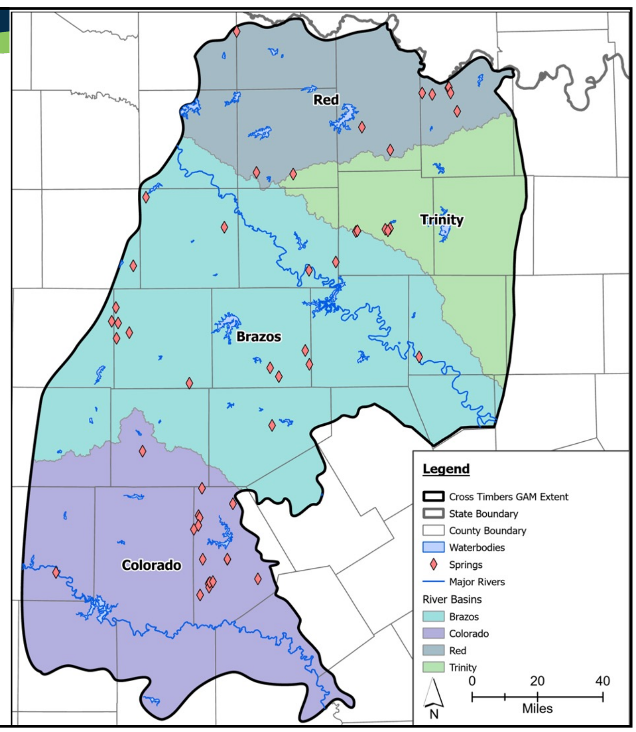
Surface Water Features

Four main river basins:

- Red River
- Trinity River
- Brazos River
- Colorado River



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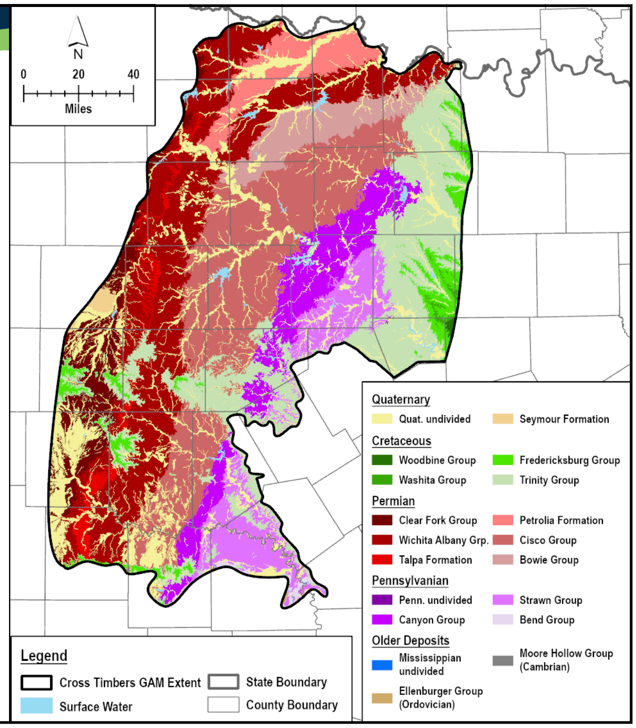
Surface Geology

- Paleozoic Formations:
  - Clear Fork Group (youngest)
  - Wichita-Albany Group
  - Cisco Group
  - Canyon Group
  - Strawn Group
  - Atoka (Bend) Group (oldest)
- Generally:
  - Youngest formations outcrop in west
  - Oldest formations outcrop in the east (exception is Trinity)



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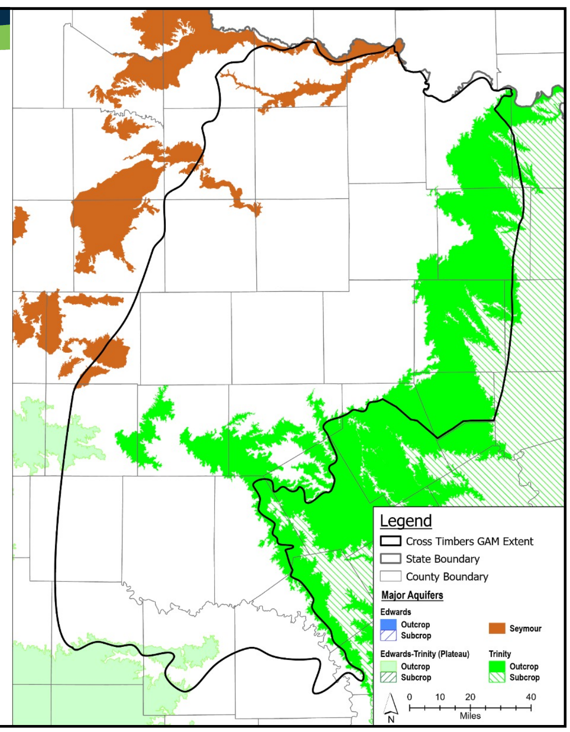
Adjacent Aquifers

- Seymour Aquifer (Quaternary)
- Trinity Aquifer (Cretaceous)



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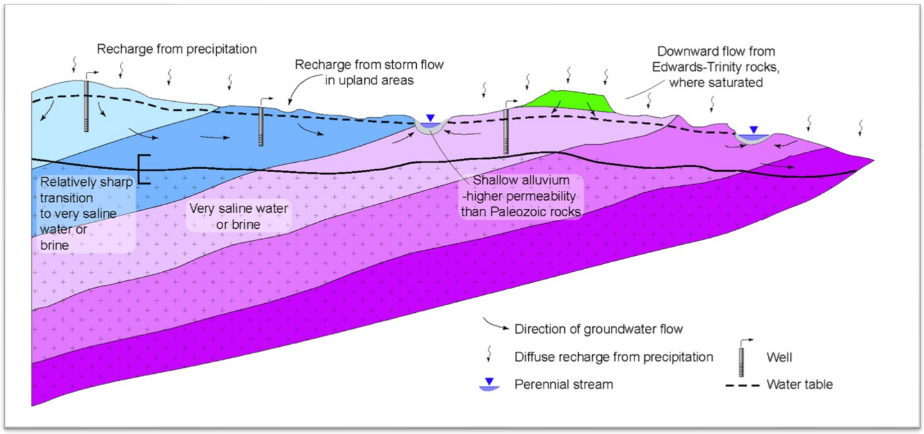
Conceptual Model

Major Updates:

- Model area, layering, grid properties
- Recharge

Minor Updates:

- Historical Pumping
- 2019 to 2022 data



From Blandford and others (2021)

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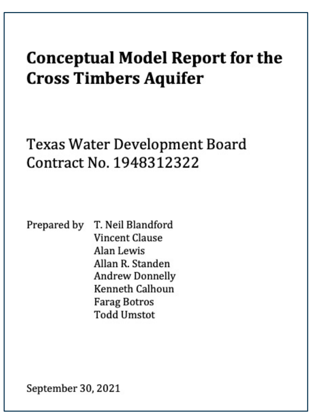
Model Boundary

Model area and extended model boundary

- Ballew and French (2019)
- Blandford and others (2021)

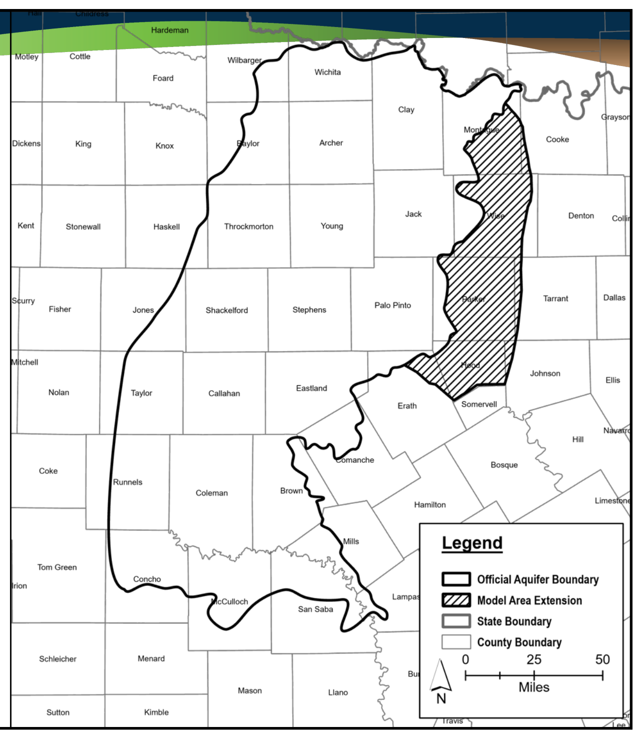


Conceptual Model Report for the Cross Timbers Aquifer

Texas Water Development Board
Contract No. 1948312322

Prepared by T. Neil Blandford
Vincent Clause
Alan Lewis
Allan R. Standen
Andrew Donnelly
Kenneth Calhoun
Farag Botros
Todd Umstot

September 30, 2021



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Model Configuration

- Conceptual Model suggested ¼ mile by ¼ mile, aligned with Northern Trinity Aquifer GAM (Kelley and others, 2014)
- Numerical Model is one mile by one mile on State Plane Coordinate System (not rotated)
  - 220 rows (y direction) by 160 columns (x direction)
  - 11 layers
  - Total of 387,200 cells
- Time Discretization
  - 1979: Steady State (Predevelopment)
  - 1980–2042: Annual transient stress periods
  - Calibrated to data through 2022, extended from 2019 in the Conceptual Model

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Stratigraphy

Two additional layers to those suggested in Conceptual Model

- Layer 2 is the primary aquifer (shallow flow system) – not geologic unit but represents shallow, up-dip portions of Conceptual Model layers 2 through 8
- Layer 9 is the reef complex

Million Years Ago (Ewing, 2016)	Era	System	Series or Stage	Group	Formation	Reef	Member or Limesone	Suggested Model Layer	Assigned Model Layer
2	Ceno-zoic	Quaternary - Pleistocene			Alluvium			1A	1
					Seymour				
	Mesozoic	Cretaceous		Fredericks-burg	Edwards Comanche Peak Walnut			1B	
130				Trinity	Antlers / Paluxy Glen Rose Twin Mountains				
275	Paleozoic	Permian	Leonard	Clear Fork	Choza		Lytle	2	3
					Vale		Bullwagon		
					Arroyo		Standpipe		
280				Wichita - Albany	**Leuders**			3	4
					Clyde, Waggoner Ranch (GAT)		Talpa		
							Grape Creek		
			Wolfcamp		Belle Plains, Petrolia (GAT)		Bead Mountain		
							Jagger Bend, Valera		
							Elm Creek		
					Putnam, Nocona (GAT)		Admiral		
292							**Coleman Junction**		
				Cisco	Santa Anna Branch			4	5
					Sedwick				
					Moran		Dothan, Camp Colorado		
					Pueblo		Stockwether, Saddle Creek		
		Pennsylvanian	Virgilian		Harpersville		Crystal Falls		
							Breckenridge	5	6
300					Thrifty	**Carbonate banks**	Blach Ranch		
							Ivan		
					Graham		Gunsight, Bunger		
303			Missourian	Canyon	Caddo Creek		**Home Creek**	6	7
							Colony Creek		
					Brad		Ranger		
							Clear Creek, Cedarton		
					Placid				
					Winchell				
					Wolf Mountain				
					Palo Pinto		Wiles, Wynn	7	8
307				Strawn	Mineral Wells		**Dog Bend**	8	10
			Desmoin-esian		Brazos River				
					Mingus		Capps, Dobbs Valley		
					Grindstone Creek		Buck Creek		
					Lazy Bend				
			Atokian	Atoka	Smithwick				
320			Morrowan	Morrow	**Marble Falls**		Marble Falls	9	11

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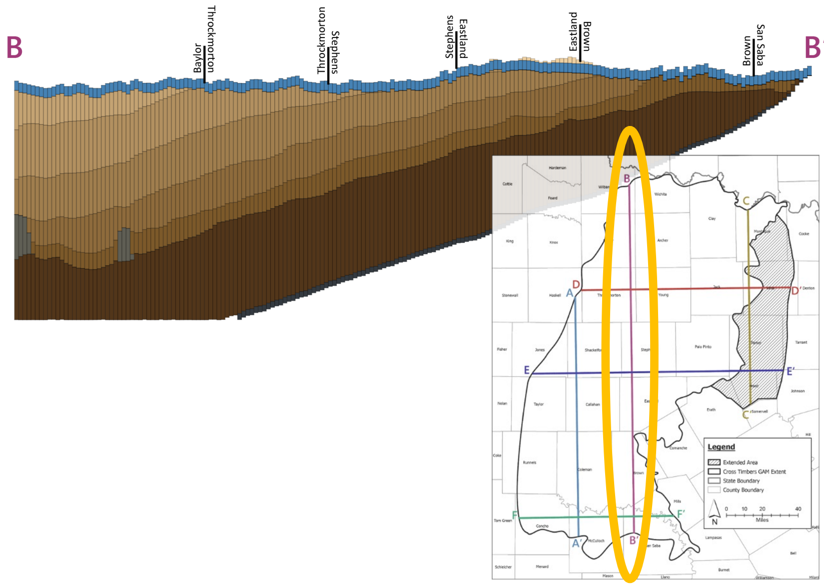
Structure

Model Layering

Layer 1	Seymour & Trinity Aquifers
Layer 2	Primary Aquifer
Layer 3	Clear Fork Group
Layer 4	Wichita Albany Group
Layer 5	Upper Cisco Group
Layer 6	Lower Cisco Group
Layer 7	Canyon Group
Layer 8	Palo Pinto Formation
Layer 9	Reef Formation
Layer 10	Strawn Atoka Group
Layer 11	Marble Falls Formation



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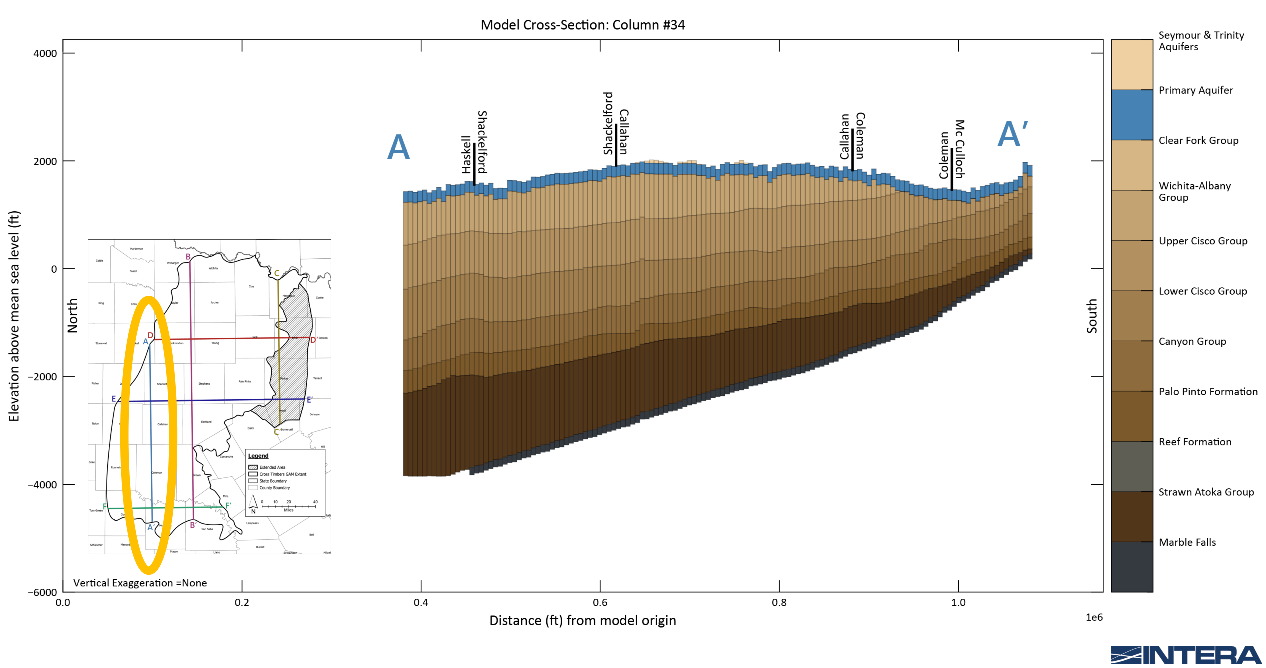

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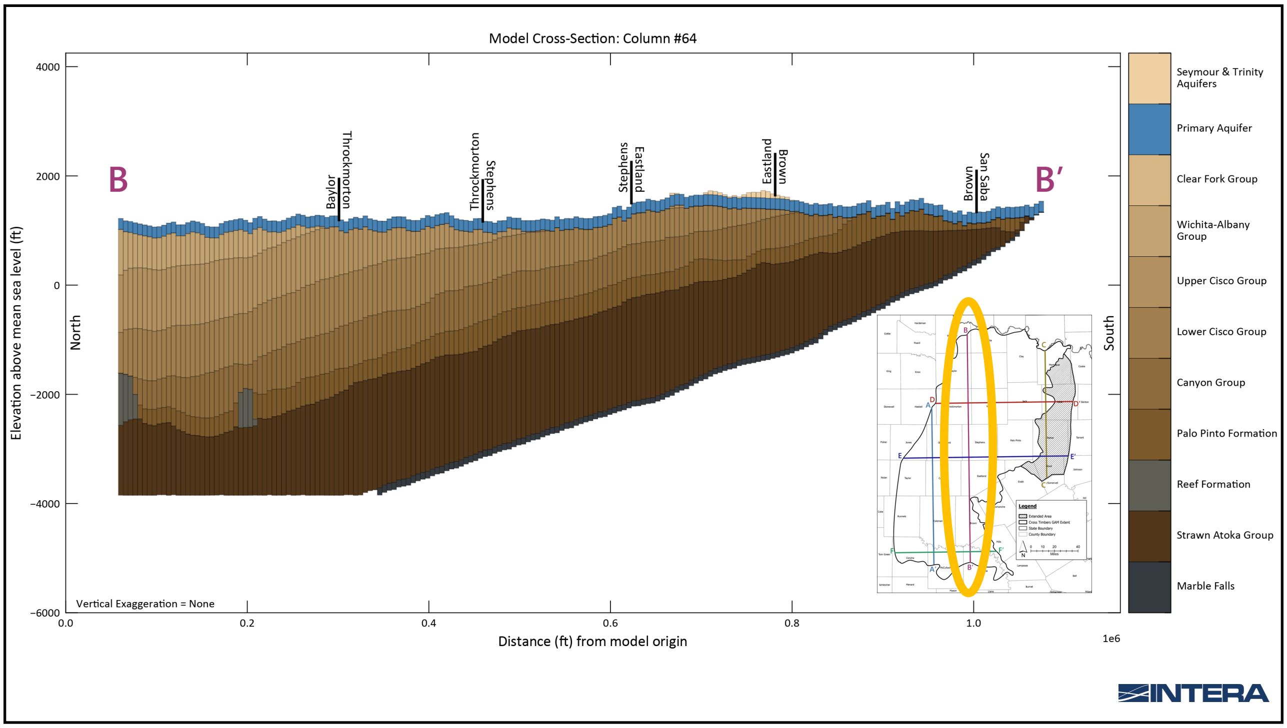
Model Cross-Section: Column #64
B
B′
Baylor
Throckmorton
Throckmorton
Stephens
Stephens
Eastland
Eastland
Brown
Brown
San Saba
North
South
Elevation above mean sea level (ft)
Distance (ft) from model origin
1e6
Vertical Exaggeration = None
Seymour & Trinity Aquifers
Primary Aquifer
Clear Fork Group
Wichita-Albany Group
Upper Cisco Group
Lower Cisco Group
Canyon Group
Palo Pinto Formation
Reef Formation
Strawn Atoka Group
Marble Falls
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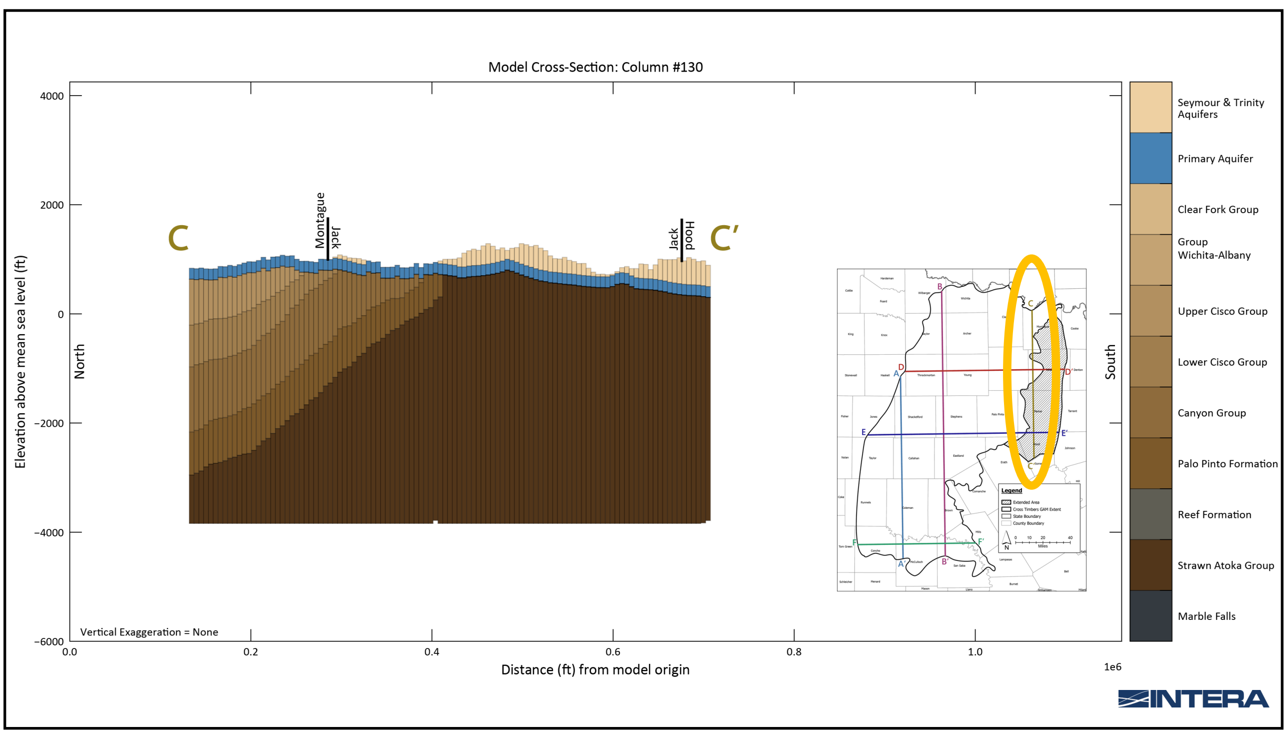
Model Cross-Section: Column #130
C
C′
Montague
Jack
Jack
Hood
North
South
Elevation above mean sea level (ft)
Distance (ft) from model origin
1e6
Vertical Exaggeration = None
Seymour & Trinity Aquifers
Primary Aquifer
Clear Fork Group
Group Wichita-Albany
Upper Cisco Group
Lower Cisco Group
Canyon Group
Palo Pinto Formation
Reef Formation
Strawn Atoka Group
Marble Falls
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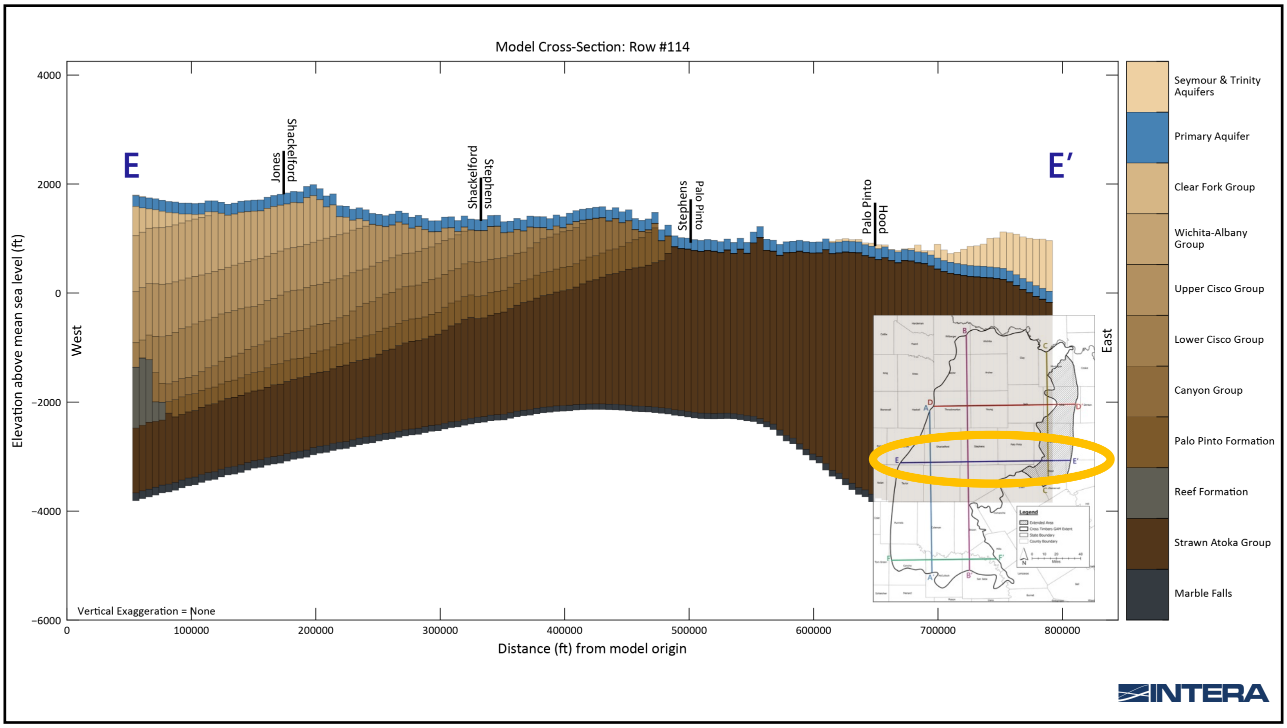

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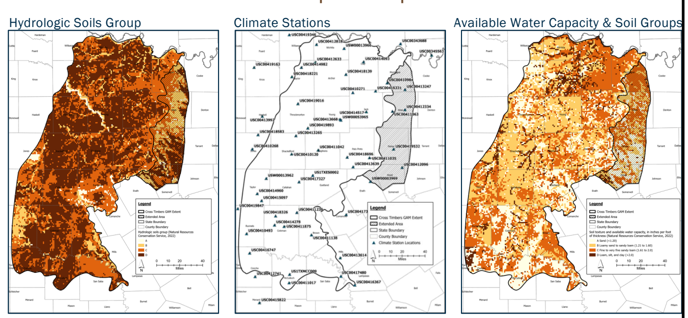
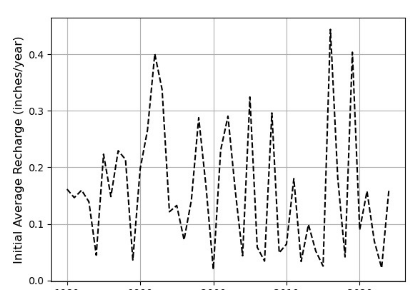
Recharge

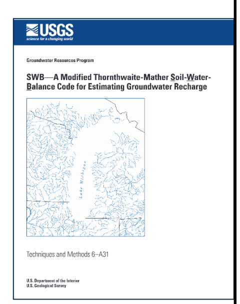
Recharge = infiltration into the deeper aquifer system

- Conceptual report recharge values:
  - 0.19–0.45 in/yr (with alluvium), 0.16–0.32 in/yr (excluding alluvium).
  - Estimates biased high
  - Concentrated around alluvium
  - Some recharge estimates > precipitation
- **Soil Water Balance (SWB)** Model for revised spatial and temporal recharge estimates (1980–2023).
  - Some inputs include: local climate stations, soil texture, available water capacity, hydrologic soil groups
  - Scaled to estimate deeper infiltration, ranging from: 0.02–0.44 in/yr.

SWB Spatial Inputs







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1 Cross Timbers Aquifer Model Review
2 Model Calibration
3 Sensitivity Analysis
4 Model Limitations
5 Discussion
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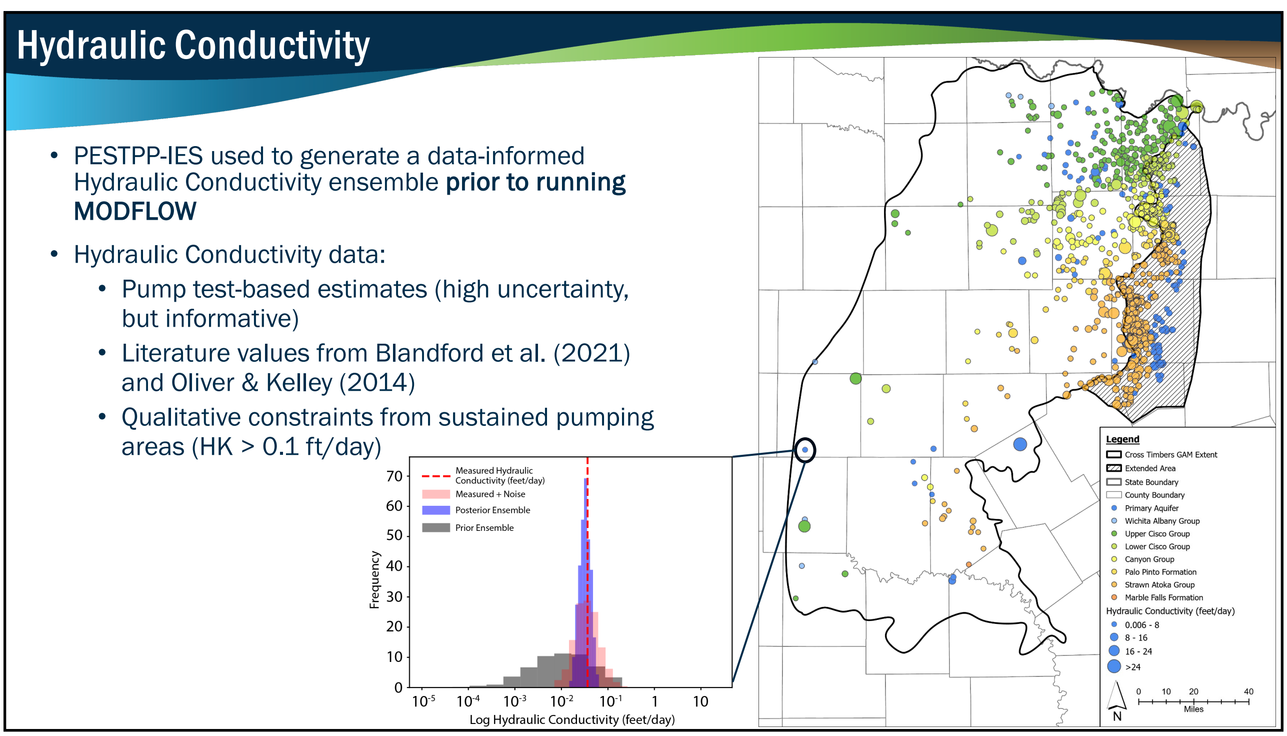
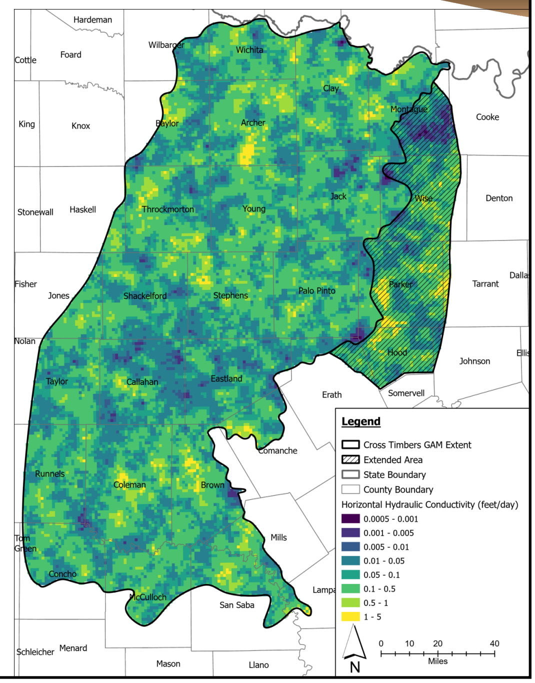

Hydraulic Conductivity
• PESTPP-IES used to generate a data-informed Hydraulic Conductivity ensemble prior to running MODFLOW
• Hydraulic Conductivity data:
• Pump test-based estimates (high uncertainty, but informative)
• Literature values from Blandford et al. (2021) and Oliver & Kelley (2014)
• Qualitative constraints from sustained pumping areas (HK > 0.1 ft/day)
Measured Hydraulic Conductivity (feet/day)
Measured + Noise
Posterior Ensemble
Prior Ensemble
Frequency
70
60
50
40
30
20
10
0
10-5
10-4
10-3
10-2
10-1
1
10
Log Hydraulic Conductivity (feet/day)
Legend
Cross Timbers GAM Extent
Extended Area
State Boundary
County Boundary
Primary Aquifer
Wichita Albany Group
Upper Cisco Group
Lower Cisco Group
Canyon Group
Palo Pinto Formation
Strawn Atoka Group
Marble Falls Formation
Hydraulic Conductivity (feet/day)
0.006 - 8
8 - 16
16 - 24
>24
0 10 20 40
Miles
N

40

Hydraulic Conductivity

Final hydraulic conductivity distribution informed by prior ensemble, but incorporated groundwater data as well

Layer	Average	Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
Seymour and Trinity Aquifers	8.6E+00	2.5E+00	1.9E-01	8.0E+00	1.0E+01	1.0E+01	1.0E+01
Primary Aquifer	**1.9E-01**	**2.2E-01**	**4.9E-04**	**4.7E-02**	**1.1E-01**	**2.4E-01**	**2.0E+00**
Clear Fork Group	4.9E-01	3.9E-02	9.1E-02	5.0E-01	5.0E-01	5.0E-01	5.0E-01
Wichita Albany Group	3.4E-01	1.7E-01	3.6E-03	1.8E-01	4.2E-01	5.0E-01	5.0E-01
Upper Cisco Group	2.7E-01	1.9E-01	4.7E-04	8.6E-02	2.3E-01	5.0E-01	5.0E-01
Lower Cisco Group	4.2E-01	1.5E-01	2.1E-03	3.8E-01	5.0E-01	5.0E-01	5.0E-01
Canyon Group	2.5E-01	1.9E-01	6.1E-04	7.7E-02	2.1E-01	5.0E-01	5.0E-01
Palo Pinto Formation	2.7E-01	2.0E-01	3.9E-04	7.5E-02	2.6E-01	5.0E-01	5.0E-01
Reef Formation	4.9E-01	3.8E-02	1.3E-01	5.0E-01	5.0E-01	5.0E-01	5.0E-01
Strawn Atoka Group	2.9E-01	1.9E-01	6.4E-04	1.1E-01	2.8E-01	5.0E-01	5.0E-01
Marble Falls Formation	4.3E-01	1.4E-01	2.8E-03	4.8E-01	5.0E-01	5.0E-01	5.0E-01



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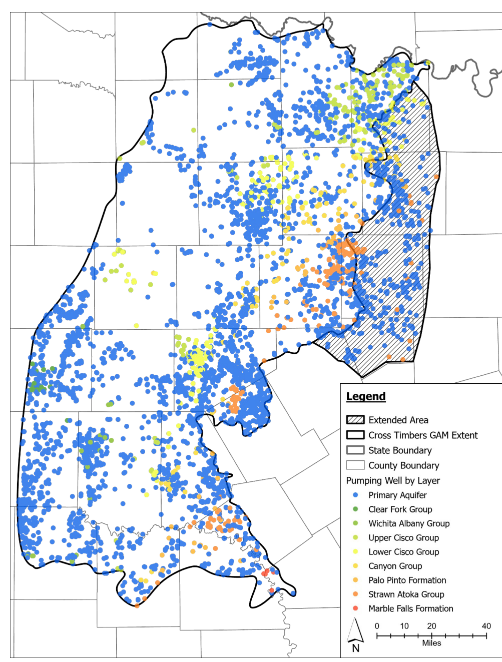
Pumping Wells

- Pumping estimates developed for six use types:
  - Irrigation
  - Mining
  - Municipal
  - Domestic
  - Livestock
  - Manufacturing
- Non-domestic wells assigned to model layers using screen info when available; otherwise, based on fraction of total well depth.
  - Wells < 250 ft: assigned to aquifer at 80% of depth
  - Wells > 250 ft: assigned to unit 50 ft above well bottom
- Domestic pumping was assigned to aquifer that is in outcrop



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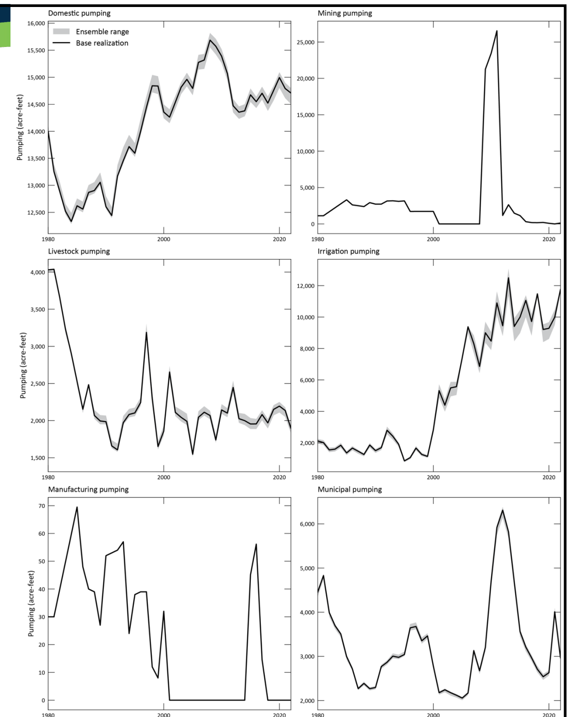
Pumping Rates

- TWDB data (1980–2022) used for municipal, industrial, mining, manufactoring, irrigation, and livestock pumping (1980–1984 interpolated).
- Domestic pumping rates based off population distributions and an assumed per capita rate of 100 gpd/person
- Pumping allocated to wells by use type, scaled by reported or estimated well yields.
- Calibration incorporates spatial uncertainty in well-based pumping rates.



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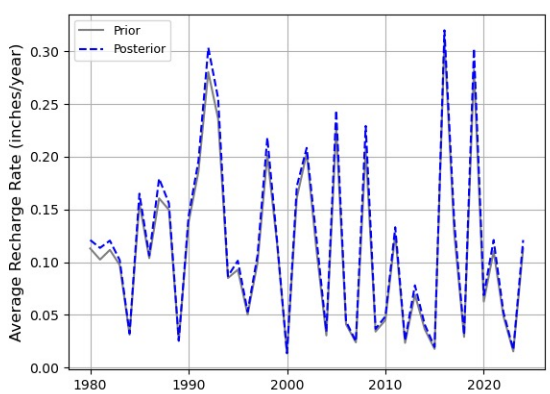
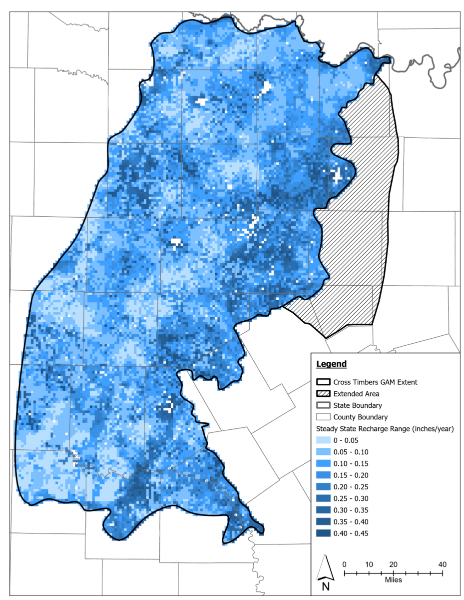
Recharge

- Calibrated recharge increased
  - Volume: ~100,000 ac-ft/yr to 130,000 ac-ft/year
  - Avg Rate: 0.11 inches/year to 0.12 inches/year





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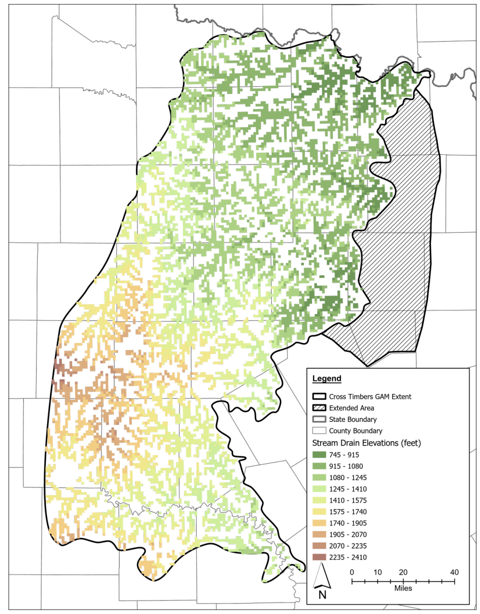
Stream Drains

Stream Drain (DRN) Package

- Intermittent and ephemeral streams
- Groundwater discharge
- Ensure topographic nature of groundwater table
- On average streamflow discharge increased during calibration by ~15,000 ac-ft/year



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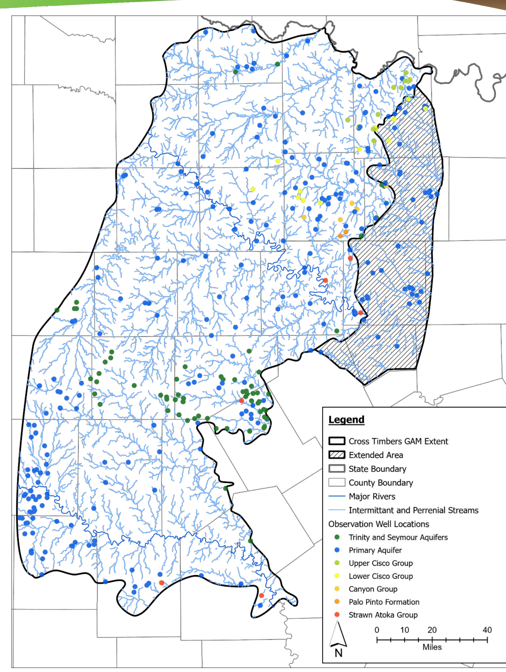
Water Level Targets

- Water level data obtained from TWDB and USGS
- 368 wells used as water level observations for the transient model calibration, 108 for steady state calibration
- Water level records varied in quality, longer record and higher frequency wells were weighted higher



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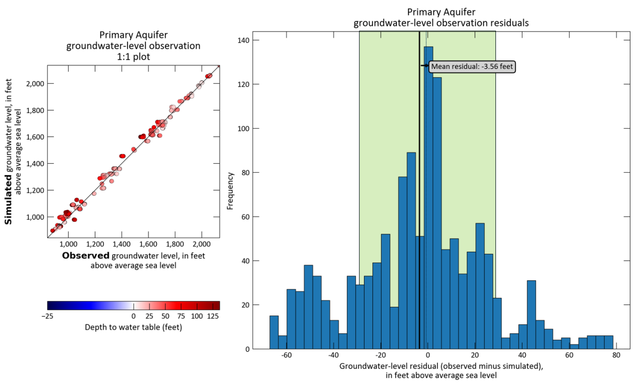
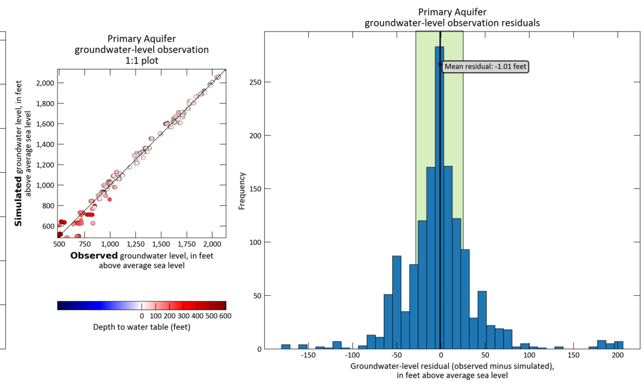
Water Level Targets

Primary Aquifer (no extended area)



Primary Aquifer (with extended area)



Added noise =+/- 10 to 30 feet

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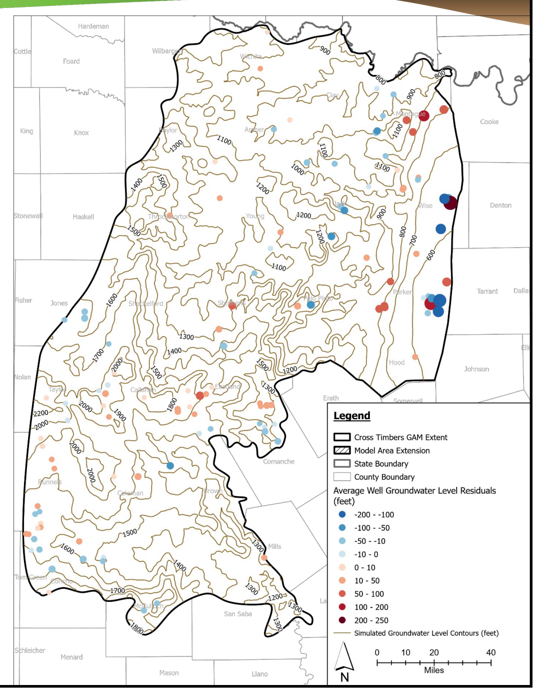
Water Level Targets

	Hydrogeologic Unit	Count	Average Residual (feet)	Median Residual (feet)	Root Mean Square Error (feet)	Mean Absolute Error (feet)	Measured Range (feet)	RMSE Range (<10%)
Over Official Aquifer Boundary	Seymour & Trinity Aquifers	650	-6.4	-1.6	33.4	25.9	783.1	4.3%
	Primary Aquifer	1276	19.8	18.5	50.7	39.2	1330.1	3.8%
Over Entire Model Study Area	Primary Aquifer	1433	17.4	17.5	59.7	44.7	1834.3	3.3%



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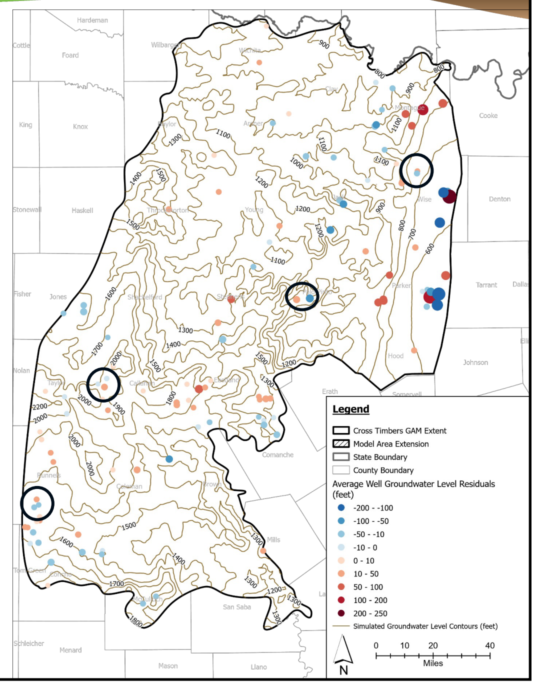
Water Level Targets

	Hydrogeologic Unit	Count	Average Residual (feet)	Median Residual (feet)	Root Mean Square Error (feet)	Mean Absolute Error (feet)	Measured Range (feet)
Over Official Aquifer Boundary	Seymour & Trinity Aquifers	650	-6.4	-1.6	33.4	25.9	783.1
	Primary Aquifer	1276	19.8	18.5	50.7	39.2	1330.1
Over Entire Model Study Area	Primary Aquifer	1433	17.4	17.5	59.7	44.7	1834.3



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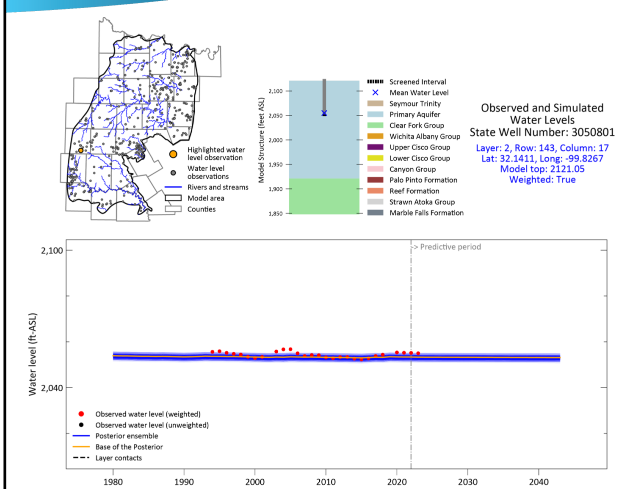
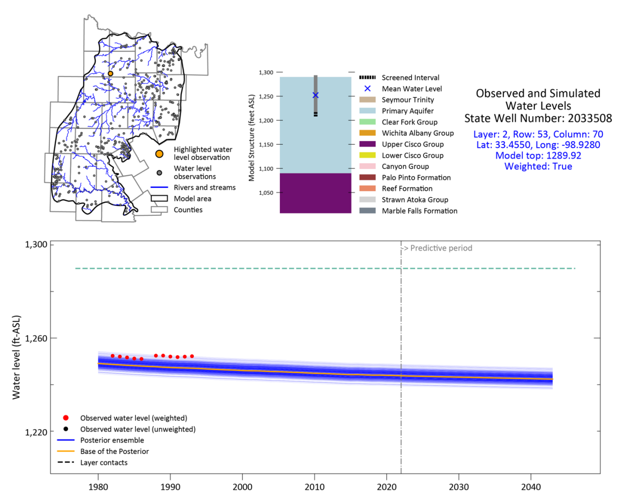
Simulated vs. Observed





INTERA

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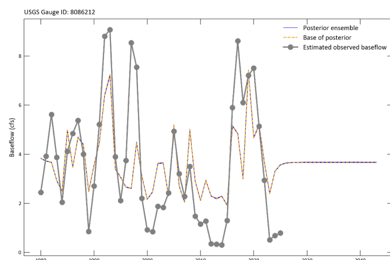
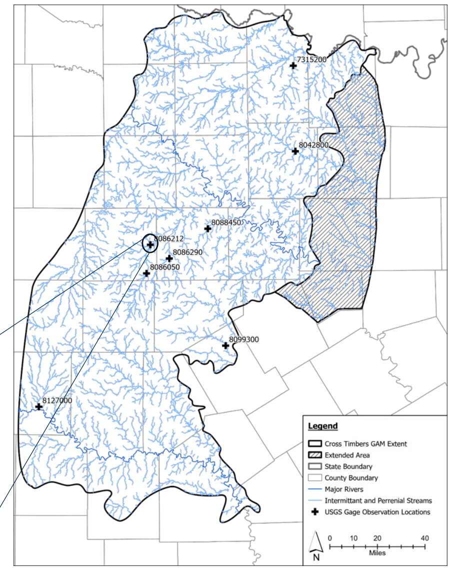
Baseflow Level Targets

- Statistical comparison with conceptual report (Table 4-10 vs. CR Table 4-8):
  - Average and median values in good agreement
  - Min and max values differ due to model smoothing effects
- Despite low weighting, the model captures general trends in groundwater discharge to streams.





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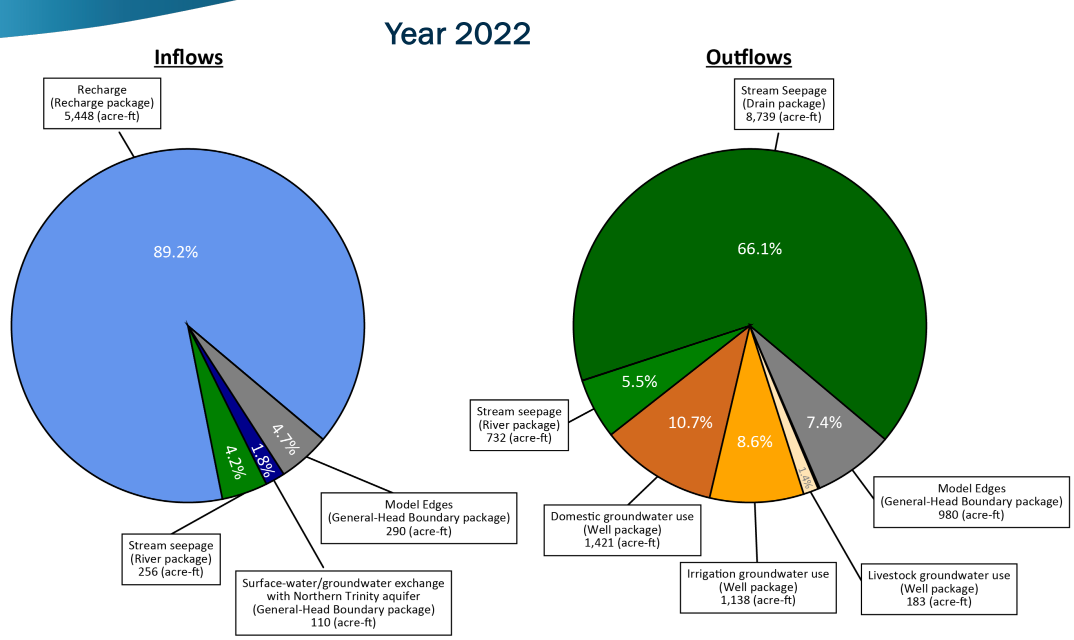
Water Budget



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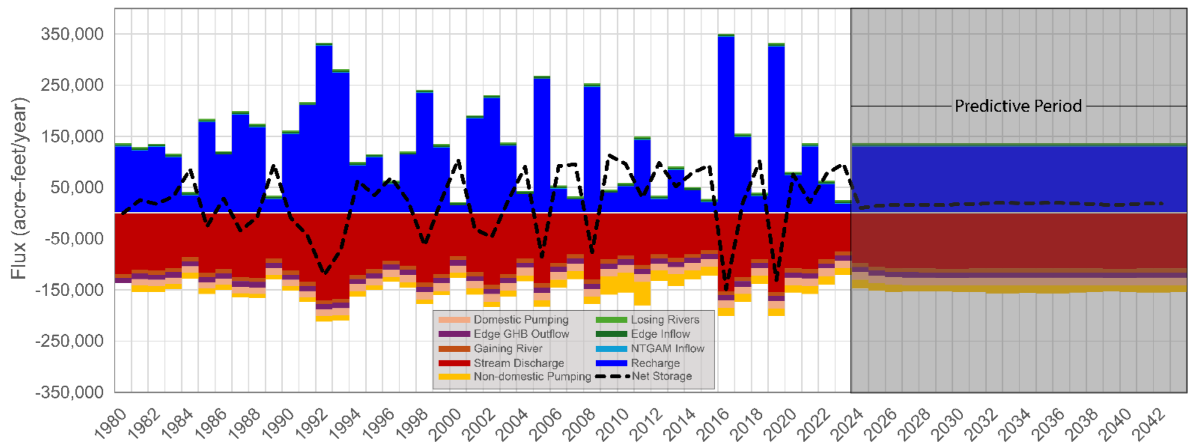
Water Budget



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Agenda

1. Cross Timbers Aquifer Model Review
2. Model Calibration
3. **Sensitivity Analysis**
4. Model Limitations
5. Discussion

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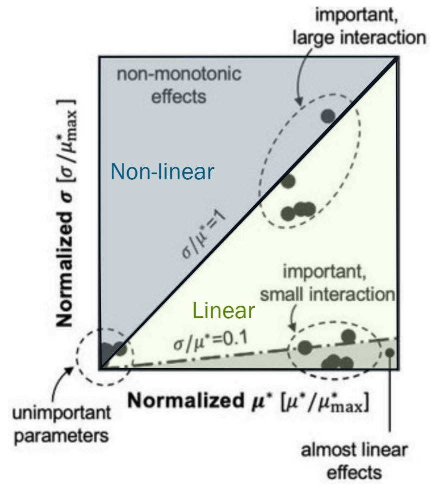
Model Sensitivity

- Method of Morris (Morris, 1991) for Global Sensitivity Analysis
  - Overall model sensitivity
  - Sensitivity by observation group
- Each parameter sampled four times within its posterior distribution

Parameter	Type	Layer(s)	Runs
Horizontal Hydraulic Conductivity	constant	1, 3-11	40
Horizontal Hydraulic Conductivity	zone	2	4
Vertical Hydraulic Conductivity	constant	3-11	36
Vertical Hydraulic Conductivity	zone	2	4
Specific Storage	constant	2-11	40
Specific Yield	constant	1	4
Specific Yield	zone	2	4
Recharge Rates	constant	1-2	4
River Conductance	constant	1-2	4
Stream Drain Conductance	constant	1-2	4
Drain Edge Conductance	constant	3-11	4
Domestic Pumping Rates	constant	1-2	4
Municipal Pumping Rates	constant	1-2	4
Livestock Pumping Rates	constant	1-2	4
Irrigation Pumping Rates	constant	1-2	4
Total Runs			164



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Steady-State Sensitivity

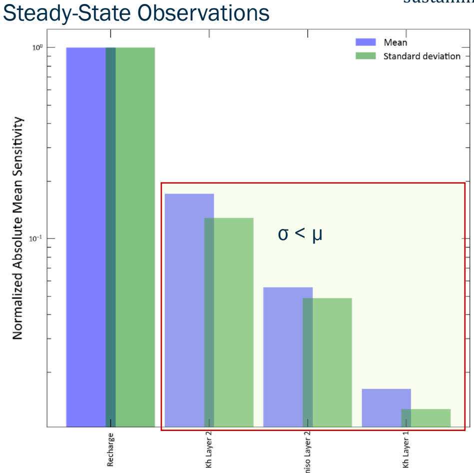
Steady-State Observation Sensitivity

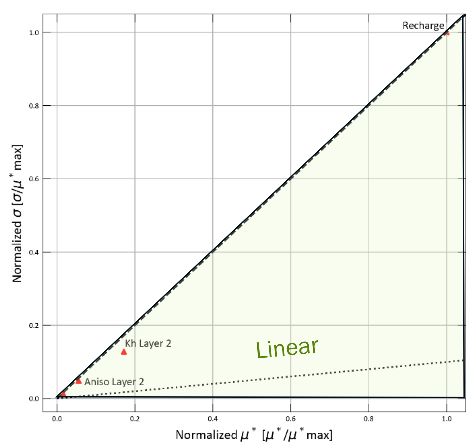
1. Recharge
2. Hydraulic Conductivity

Pre-development conditions, are simulated in equilibrium, inflows match outflows.

Balancing recharge and hydraulic conductivity during the steady-state period is essential for sustaining groundwater elevations.

Steady-State Observations





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Overall Model Sensitivity

High Frequency Groundwater Elevation Sensitivity

1. Recharge
2. Horizontal Hydraulic Conductivity
3. Specific Yield

"The sensitivity of groundwater levels throughout the primary aquifer to recharge and horizontal hydraulic conductivity is expected, as the balance of the two correlated parameters directly controls simulated groundwater levels."

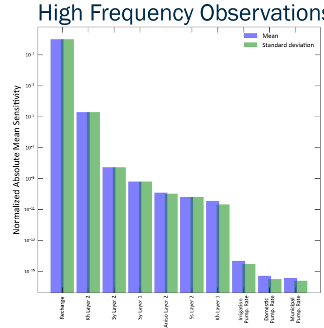
Baseflow Observation Sensitivity

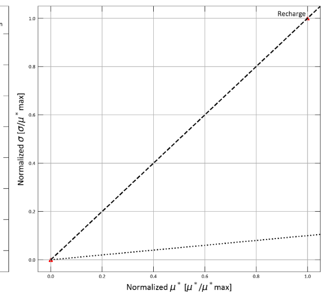
1. Recharge
2. Specific Yield
3. Specific Storage

"Recharge is the main inflow component, directly influences the total discharge volume."

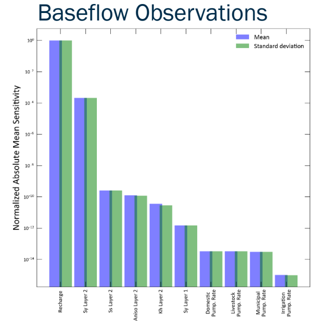
"Lower storage values lead to flashy baseflow responses to recharge fluctuations. In contrast, higher storage values support more sustained baseflows during dry periods. "

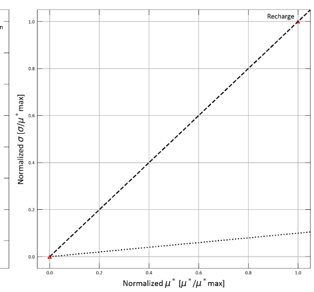
High Frequency Observations





Baseflow Observations





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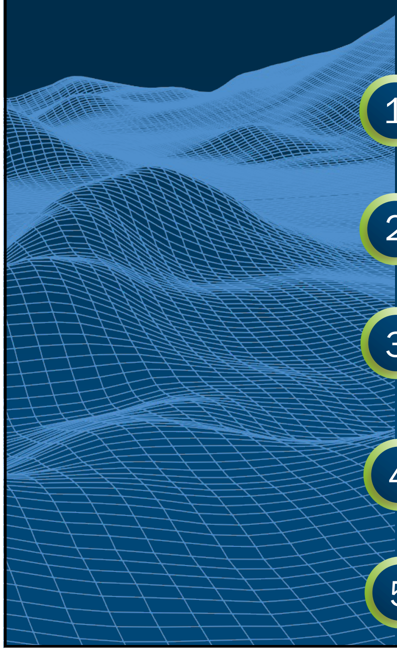

Agenda

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5. Discussion

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Model Limitations

- The GAM is a tool for making groundwater availability assessments only on regional basis
- The GAM is not capable of predicting aquifer responses at small scales (e.g., individual wells)
- Hydraulic properties and scale issues:
  - Limited data availability
  - The primary aquifer layer is highly heterogeneous but represented as one layer (layer 2) with averaged hydraulic properties
- Recharge estimates
- Multi-layer well completions
- Historical pumping

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Final Thoughts

- Well calibrated model, despite data limitations
- Aligns with conceptual understanding, while also providing more spatial and temporal understanding
- Scripted workflow, dynamic tool, easily updated with new data/conceptual understanding
- Robust uncertainty analysis will provide better predictive capabilities and additional confidence in management decisions.

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Agenda

1. Cross Timbers Aquifer Model Review
2. Model Calibration
3. Sensitivity Analysis
4. Model Limitations
5. **Discussion**

INTERA

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Contact information

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Web information:
https://www.twdb.texas.gov/groundwater/models/gam/cstb/cstb.asp

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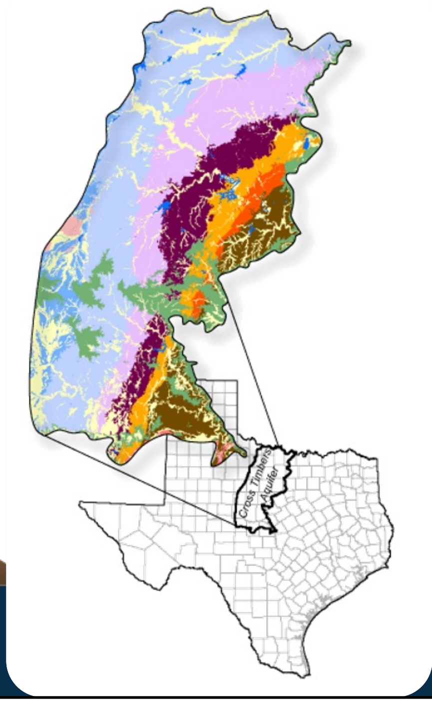

Discussion

Thank you for your attention, thoughts, and feedback!

Questions?

INTERA

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Attachment 3. Summary of Questions and Answers

1. **Roberto Anaya asked: Why was a Texas State Plane Coordinate System (a Lambert Conic Conformal projection optimized for most accurate shapes and directions) used instead of the GAM coordinate system (an Albers Equal Area projection used to optimize area)? Our TWDB calculations rely on most accurate area such as acre-foot units.**

   Response: At the time this project began, the GAM coordinate system had not yet been established with the European Petroleum Survey Group (EPSG) code by TWDB. EPSG codes provide a standardized, easy-to-reference system for specifying coordinate reference systems, ensuring consistent and accurate mapping across different software and datasets, and are especially useful in coding contexts where quick, unambiguous spatial references are needed. An EPSG code for the GAM coordinate system was not developed until the Cross Timbers numerical model development was well under way.

   Within the living, scripted workflow, there is a function that will change the coordinate system of anyone of the datasets on the fly.

2. **Michaela Pedrazas asked: Regarding the water level targets, 1) When averaging water levels to get annual values, did you filter water levels to just winter water levels to avoid including the effect of pumping? 2) What are you hanging the water levels from? (10m DEM?)**

   Response: For averaging annual water levels, we used a rolling average technique with the goal of smoothing out any impacts from pumping. We have an appendix in the report with all the hydrographs of raw data. Most of our water levels are actually collected during winter months so we had minimized any bias from pumping.

   Yes, water levels are hung from the 10-m DEM. Often, elevation data provided by drillers is inaccurate (often ready by handheld GPS units), so we re-sampled our well locations to the DEM, which has a 30-foot by 30-foot resolution.

3. **Neil Blandford had comment: The way we had done the conceptual model, is that the recharge can exceed precipitation at a given location if it's focused recharge, where runoff is focused to a particular location. It can and often does exceed the precipitation at that location.**

   Response: Yes, we understand that recharge has very high level of uncertainty because of lack of data. There is a large amount of variability in diffuse and focused recharge and relatively little data, particularly for the Cross Timbers study area. Better data for recharge is one of the areas that we specifically call out as having room for future improvement.

   A good amount of focused recharge spots ended up aligning with our rivers and drain cells. The river package specifically would still allow focused recharge to happen (where the river is losing water) in quantities greater than precipitation.

4. **Neil Blandford asked: Have you done any type of sensitivity on the sharp interface boundary which is essentially a hydraulic boundary of sorts, which I think would lie pretty much at the**

bottom of your layer 2? And the way I understand the system, you're recharge and pretty much all the pumping base flow, et cetera is really happening in that layer 2. And I'm wondering if you've done any type of sensitivity on that, which would, you know, basically be cutting off all of the model below layer 2?

Response: Yes, we have done sensitivity analysis and overall sensitivity is minimal. Additional details are available in the model report. We have drain edge parameters at the edge of the model and at the bottom of layer 2 (the primary aquifer). We used those to represent the interface at the bottom to see if we had heads in deeper layers that were building up too much, essentially allowing water into the primary aquifer (layer 2) and pushing that interface up or down. The overall sensitivity of those edge drains was minimal.

Additionally, we did particle tracking in deeper layers just to see that those particles remained in the deeper layers. We wanted to be sure that we didn't see a particle go from one of those deep layers up into the shallow flow system over the simulation period of 60 years.

One of the major challenges of this model is knowing where that interface sits because we do not have much spatial coverage and data to show where the fresh-saline interface is located. As you showed in the conceptual model, there are some locations where it may be as deep as 500 feet, but overall, it is closer to 200 feet. Additional data regarding the fresh-saline interface is big area for future model improvements.