Introduction
Texas Water Development Board (TWDB) Groundwater Availability Modeling (GAM) Program

- Cindy Ridgeway, P.G.
- Contract Manager and GAM Manager

Texas Water Development Board

Disclaimer

The following presentation is based upon professional research and analysis within the scope of the Texas Water Development Board's statutory responsibilities and priorities but, unless specifically noted, does not necessarily reflect official Board positions or decisions.

Groundwater Availability Modeling Program

- **Aim**: Produce groundwater flow models for the major and minor aquifers of Texas.
- **Purpose**: Develop various tools that can be used to aid in groundwater resources management by stakeholders.
- **Public process**: Stakeholder involvement during model development process and during associated aquifer related projects-as applicable.
- **Models**: Freely available, standardized, thoroughly documented. Reports available over the internet.
- **Living tools**: Periodically updated.

How we use Groundwater Models?

Per Statute:

- TWDB provides groundwater conservation districts with water budget data for their management plans.
- Groundwater management areas can use to assist in determining desired future conditions.
- TWDB uses when calculating estimated Modeled Available Groundwater.
- TWDB uses when calculating Total Estimated Recoverable Storage.

Why Stakeholder Advisory Forums?

- Keep stakeholders updated about progress of the model-related project
- Provide stakeholders with the opportunity to provide input and data to assist with model-related project development
- Discuss limitations and applications of the project

Contact Information

Cindy Ridgeway, P.G.
Groundwater Availability Modeling Section
512-936-2386
Cindy.ridgeway@twdb.texas.gov

Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

Web information (includes meeting information):
http://www.twdb.texas.gov/groundwater/models/gam/czwx_c/czwx_c.asp
Accepting comments on Fault Study through May 4, 2017

Effect of Faults on Groundwater Flow in the Carrizo-Wilcox Aquifer in Central Texas: Update the Central GAM for Sparta, Queen City, Carrizo-Wilcox Aquifers

Stakeholder Meeting #2
April 27, 2017

Post Oak Savannah GCD Office
Milano, TX

Presented by:
Steve Young, INTERA

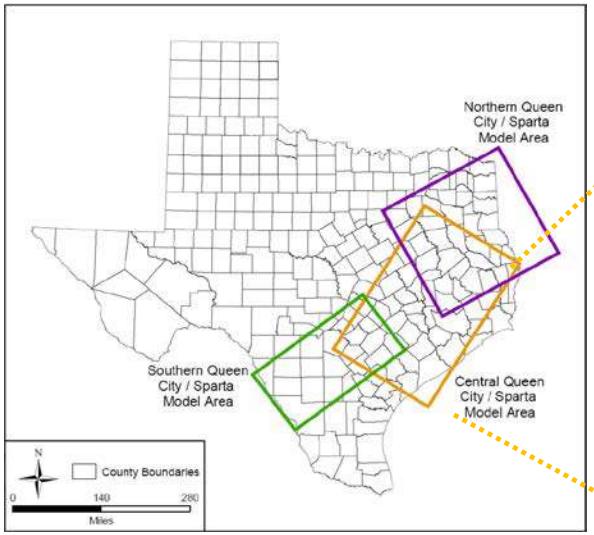
Agenda

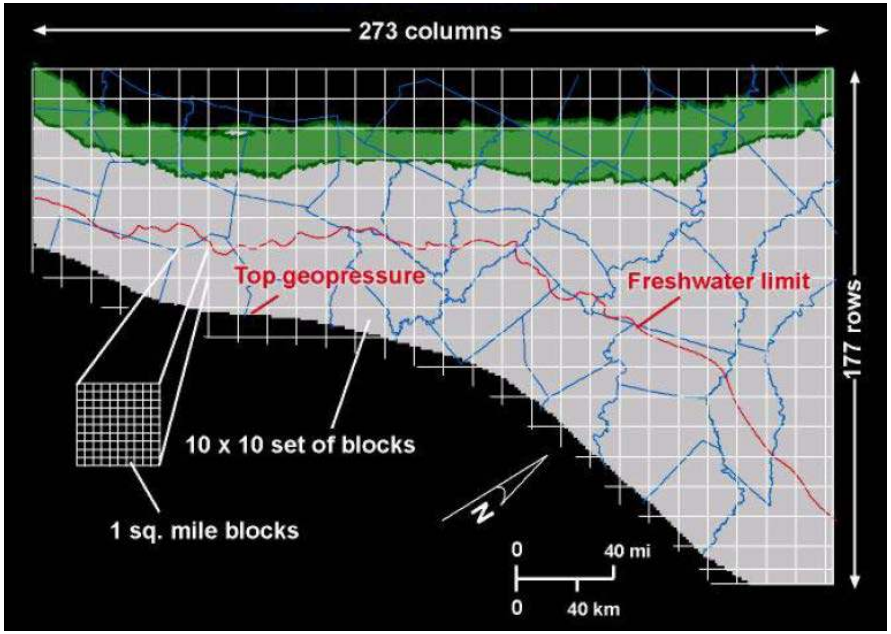
- Project Objectives
- Review Extent of QCSP GAM
- Overview Milano Fault Zone
- Assessment of Milano Fault Zone for a Revised GAM
  - Analysis of Geophysical Logs
  - GAM Sensitivity Analysis to Fault Representations
  - Analysis of Pumping Tests
- Recommendation Regarding Representation of Milano Fault Zone into a Revised GAM
- Update on Development of MODFLOW-USG Model
- Project Schedule

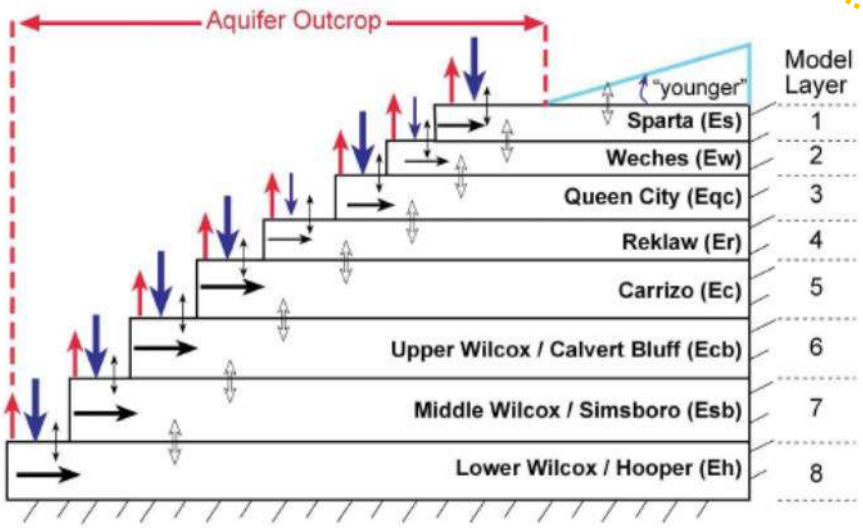
Project Objectives for an the Central QCSP GAM

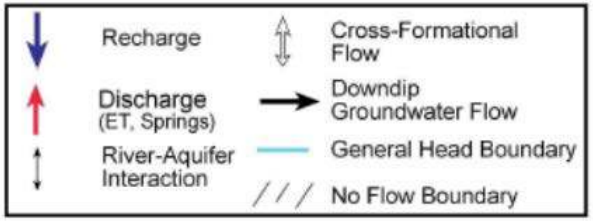
- Update from MODFLOW-96 to MODFLOW-2005 or to more recent MODFLOW-USG
- Update the representation of the Milano Fault zone in the GAM based on analysis of geophysical logs, analysis of pumping tests, and comparison of simulated and measured water levels.
- Improve the GAM capability to represent GW-SW interactions by reducing the grid cell size near Colorado and Brazos Rivers and adding shallow model layers.
- Review and update the application of recharge in the model outcrop areas to eliminate anomalies.
- The calibration period will be extended from 1999 to 2010 or later and historical pumping will be updated. Currently we plan to extend the calibration period from 1975 to 2000 to 1950 to 2010.
- Based on model sensitivity analyses comparing measured water levels and aquifer tests to the effect of faults on the groundwater flow system, faults in the GAM will be updated.

Review of QCSP Model Extent

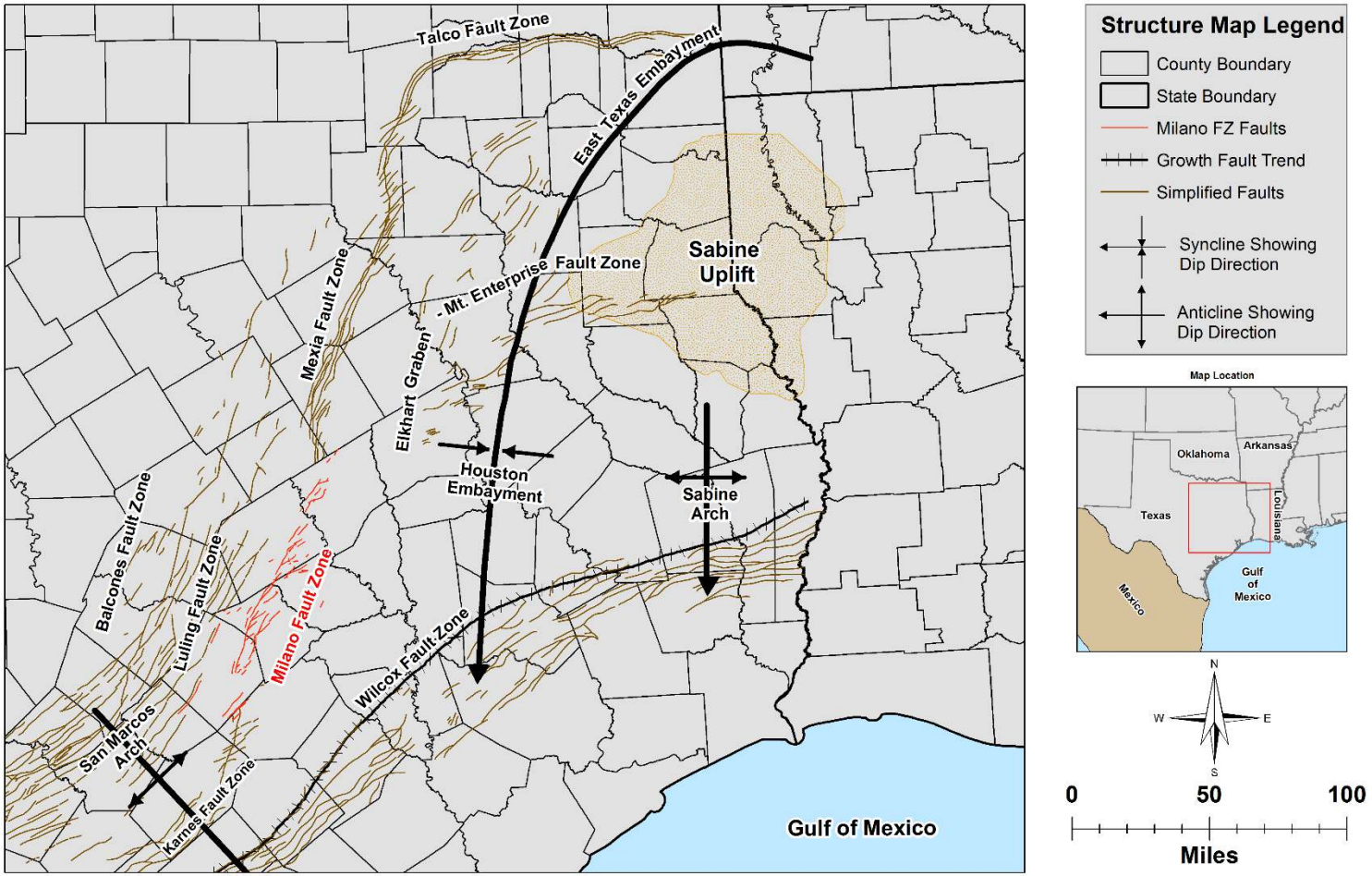








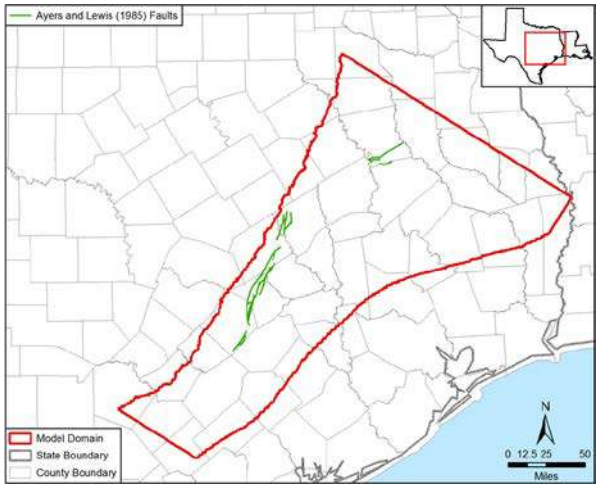
Review Milano Fault Zone



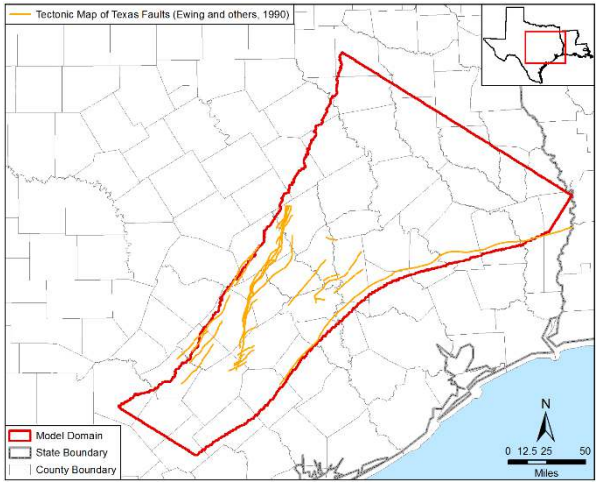
Milano Fault Zone Studies

- Three studies mapped location of faults
  - All three performed by Bureau of Economic Geology staff
  - Similar fault locations in area of interest
  - GAM faults most closely aligned with Ewing and others (1990)
- No assessment on impact to groundwater flow
  - No mapping of offsets
  - No assignment of conductances

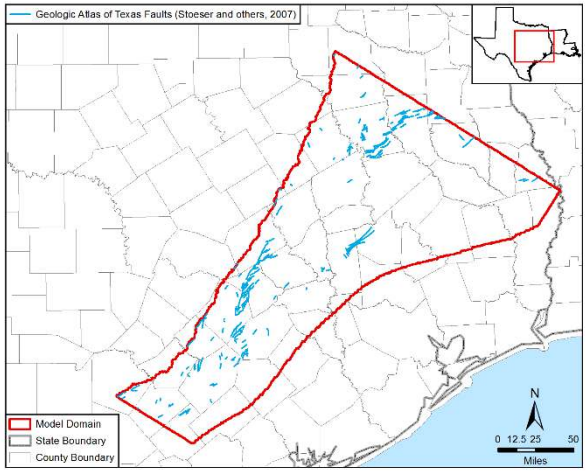
Ayers and Lewis (1985)



Ewing and others (1990)

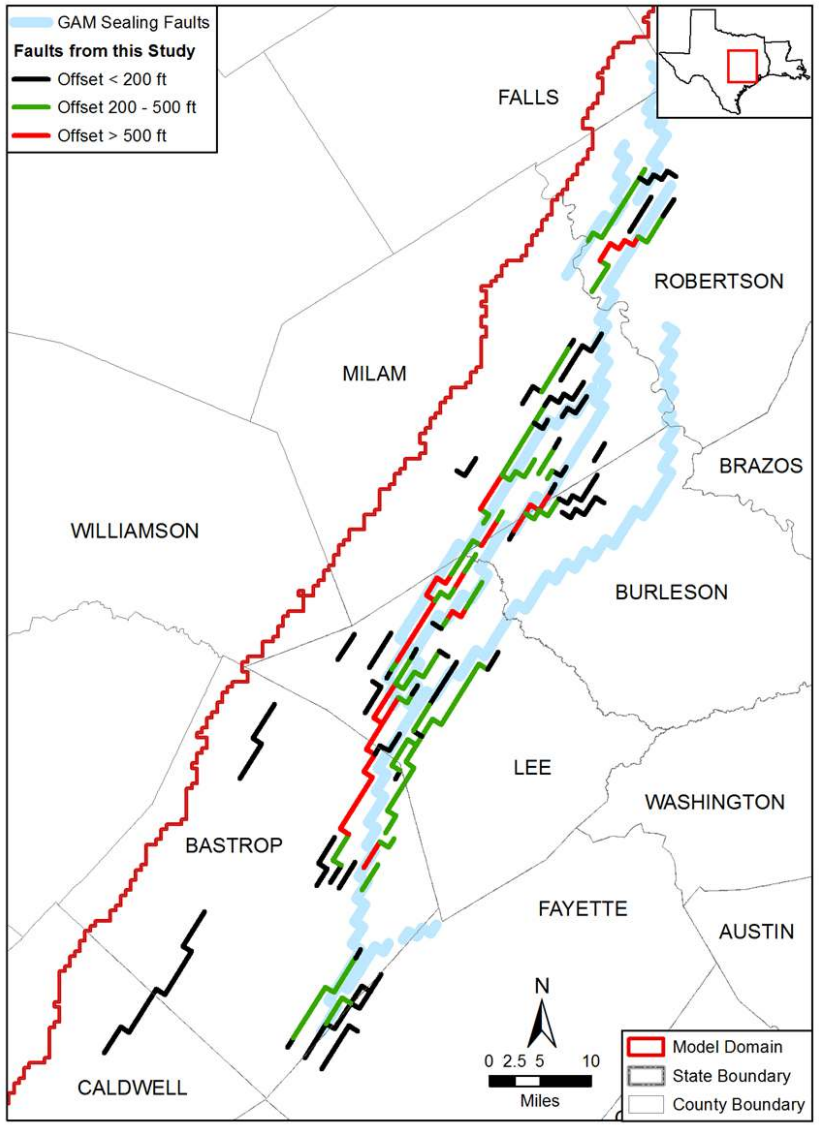


Stoeser and others (2007)

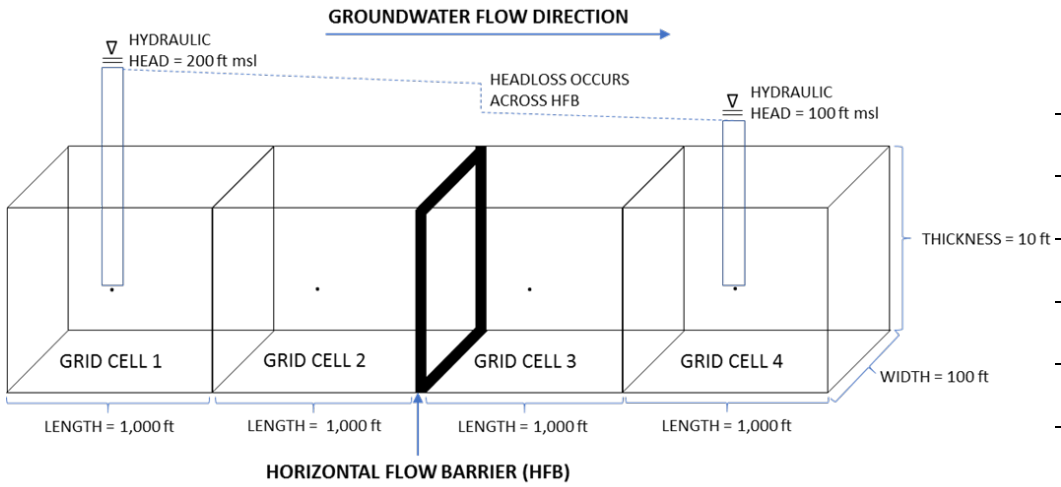


Geophysical Analysis

- Performed by Dr. Tom Ewing
- Mapped offsets at top of Navarro
- Project faults to Simsboro Formation
- Characterized the Milano Fault Zone as a series of Grabens
- Revised fault zone has considerable fewer sealing faults than current GAM



MODFLOW Horizontal Flow Barrier(HFB) Package Used to Represent Faults



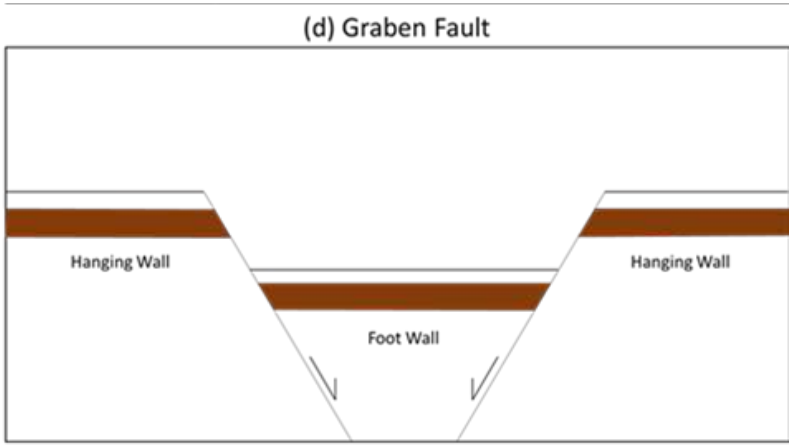
Hydraulic Conductivity (feet/day)	Groundwater Flow Rate (ft^3/day)	Percent of GW Flow to Case without HFB (percent)
no HFB	333.3	100
10	333.3	100
1	333.3	100
0.1	322.6	97
0.01	250.0	75
0.001	76.9	23
0.0001	9.7	3
0.00001	1.0	<1

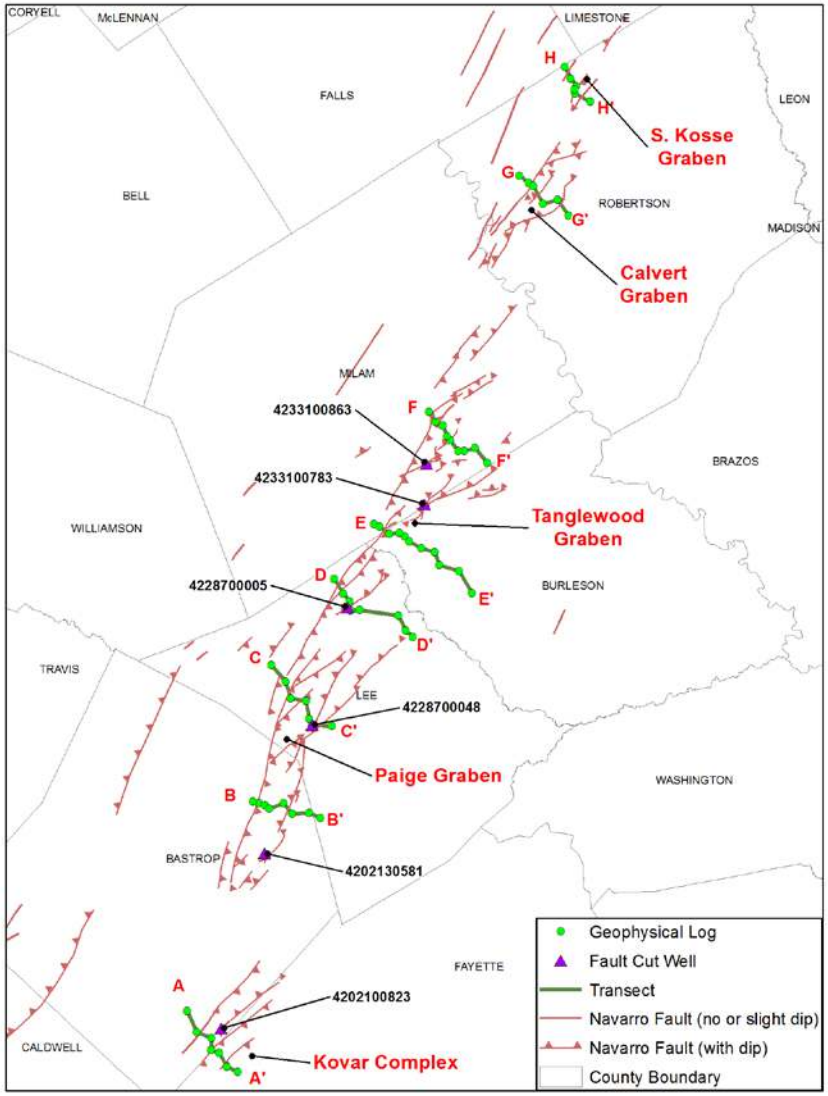
sealing

Hydraulic conductivity of aquifer = 10 ft/day
Horizontal Barrier Thickness = 1 feet

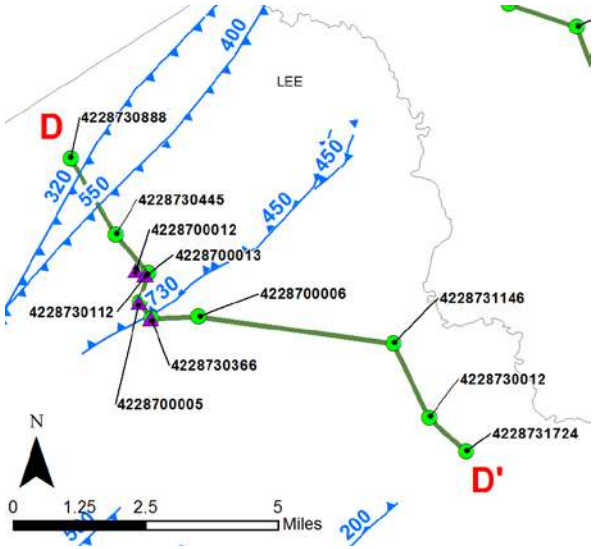
Faults Comprising the Milano Fault Zone

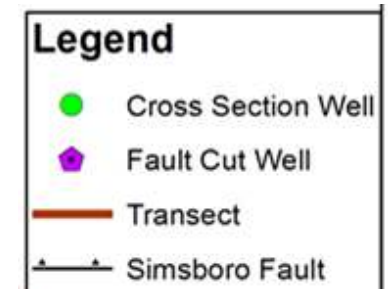
- Milano Fault Zone
  - Four Grabens and One Complex
  - Offsets supported by logs that intersect the Fault
- Grabens
  - Named for nearby towns
  - Constructed cross-sections

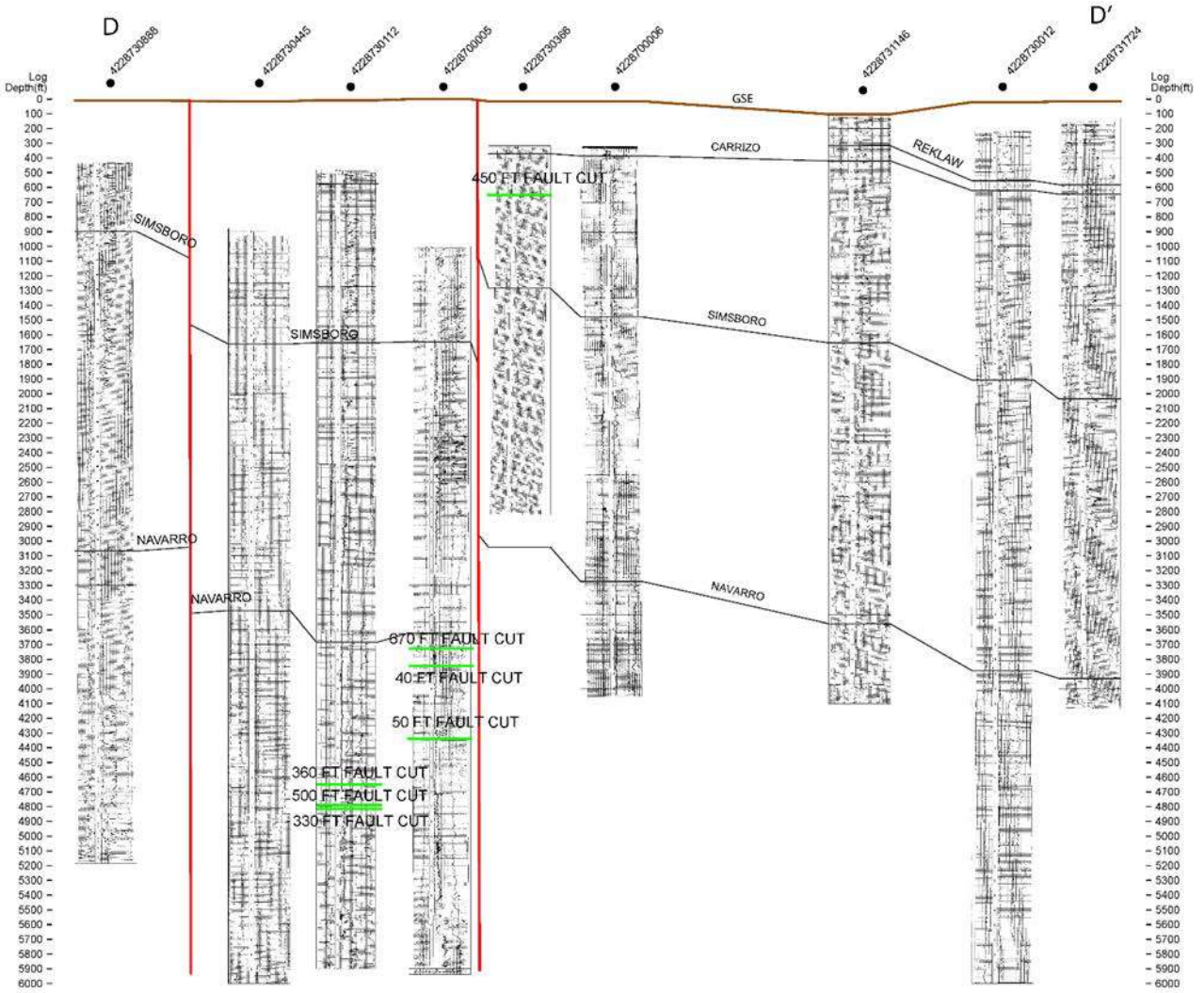




Example Cross Sections Through a Graben: Tanglewood in Lee County







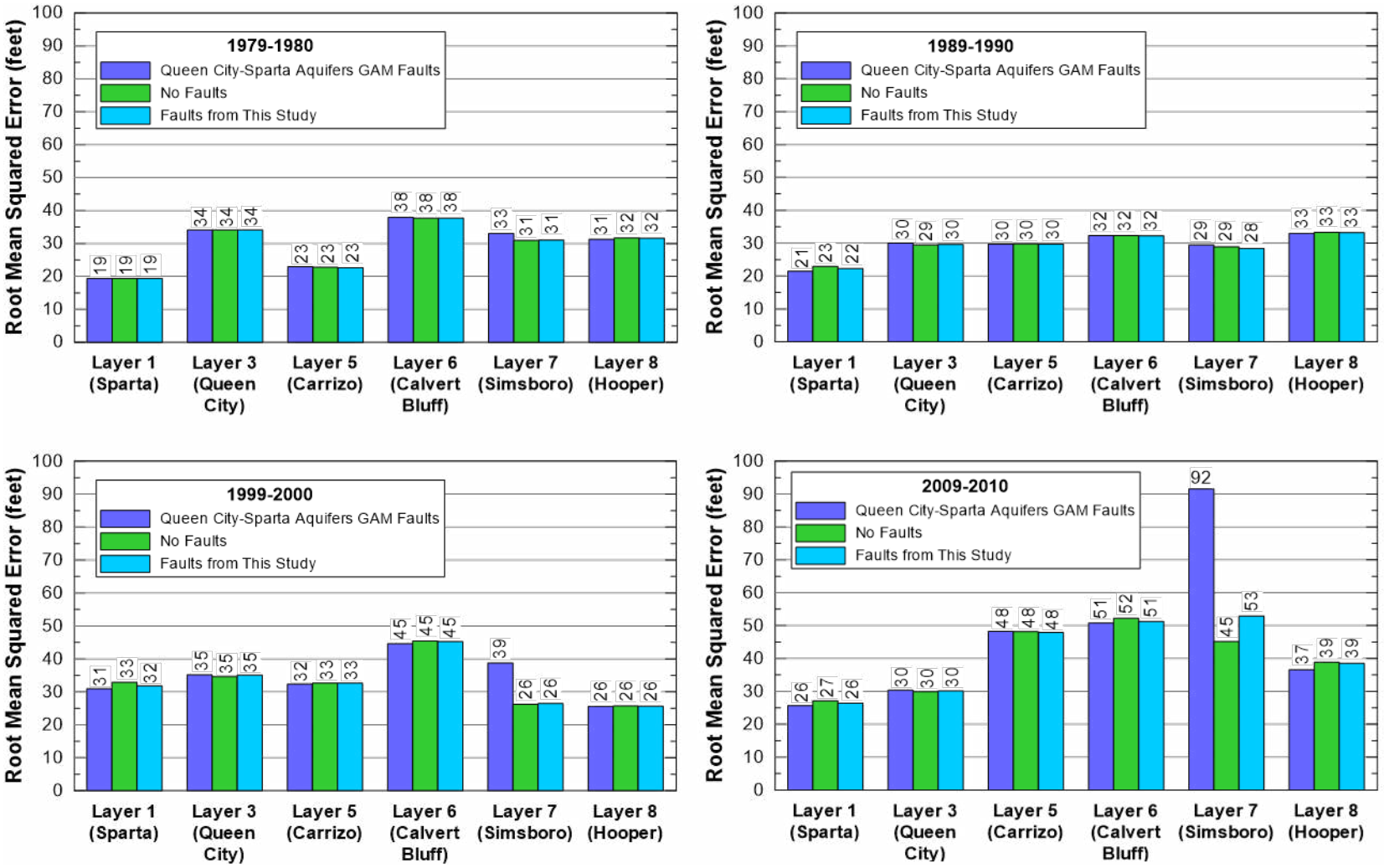
Findings from Analysis of Geophysical Logs

- Several long and continuous faults are replaced by a series of smaller and separated faults
- Significantly less number of sealing faults
- Smaller footprint for fault zone especially in Burleson County
- Numerous more “windows” or “gates” in the fault zone to allow groundwater to flow between outcrop areas and down dip areas
- Conceptualization of fault zone using MODFLOW-HFB package is acceptable

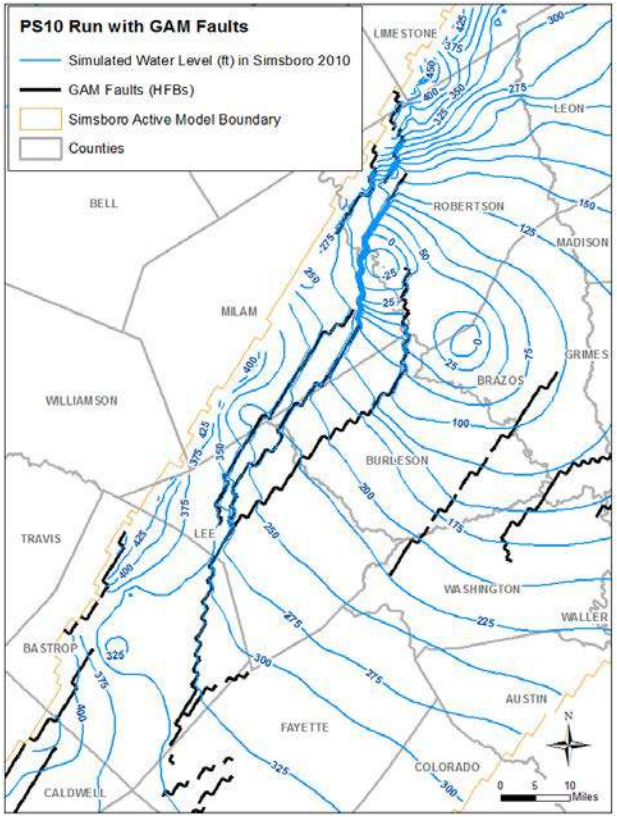
Sensitivity Analysis Approach

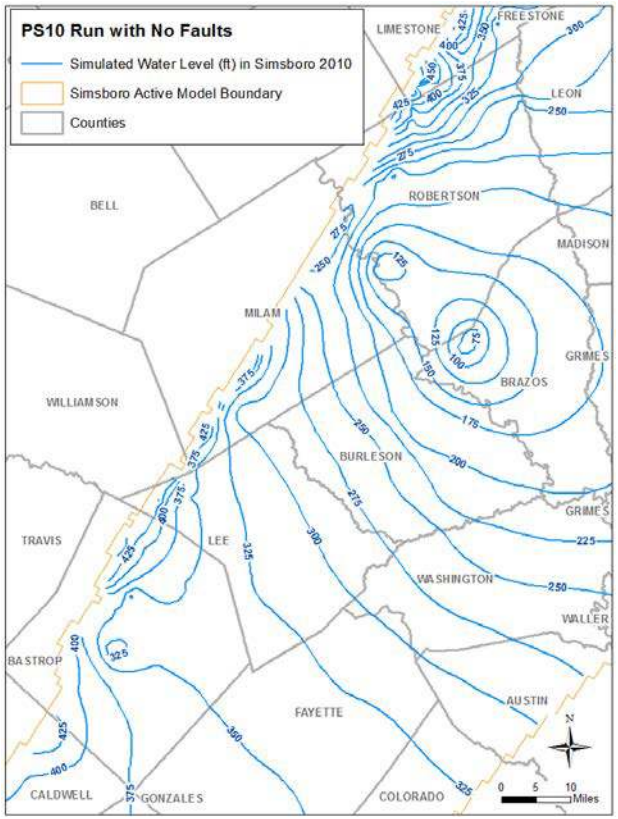
- Run GAM using GMA 12 Pumping Scenario PS 10 using three assumptions for faults
  - Current GAM faults (as is)
  - No faults (HFB package is omitted)
  - This study's faults
- Compare drawdown contours and fits to statistics of measured and modeled water levels for the years:
  - 1990
  - 2000
  - 2010
  - 2070
- Compare hydrographs of measured and modeled water levels for wells near faults

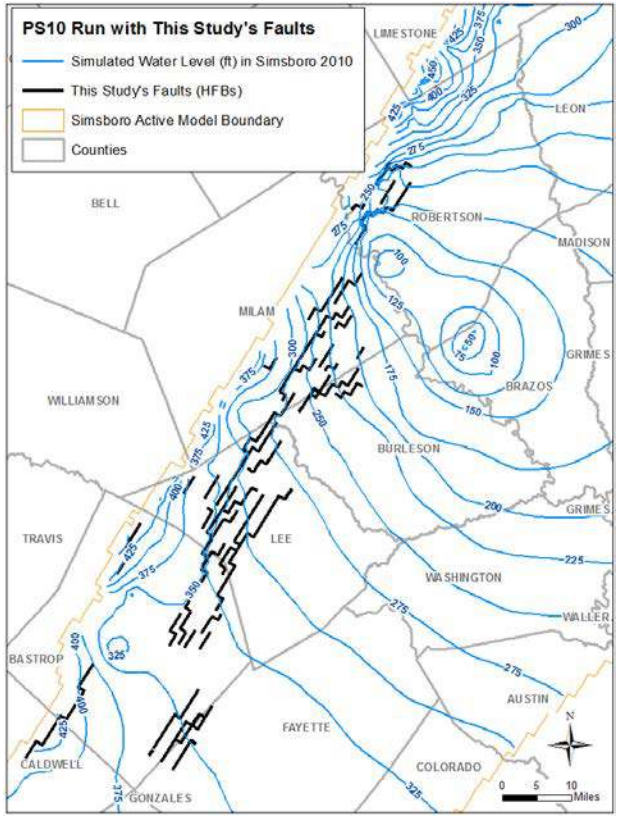
Average Error Between Measured and Modeled Elevations for Water Levels for the Entire Model Domain



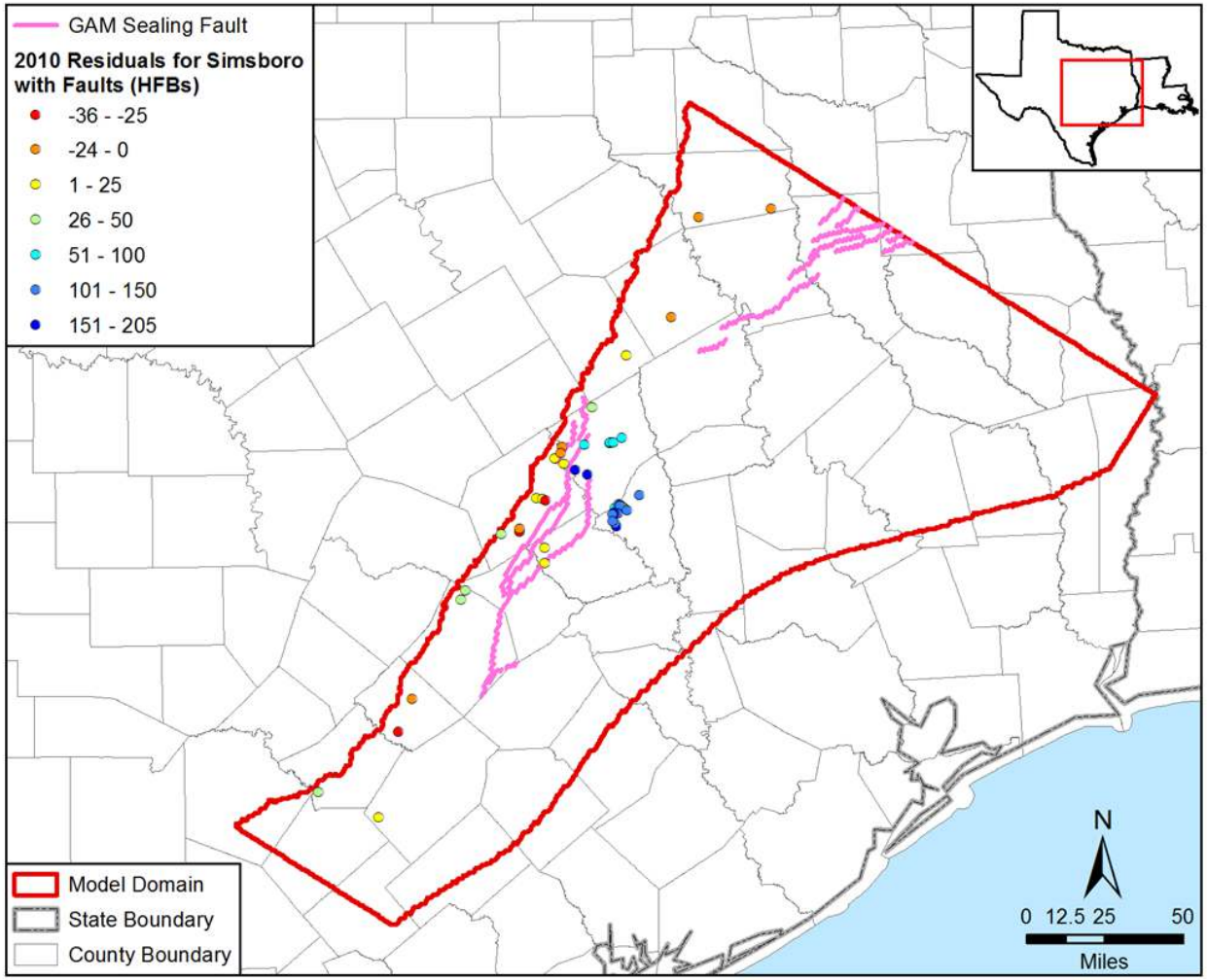
Comparison of Simsboro Drawdowns for PS10 Pumping in 2010



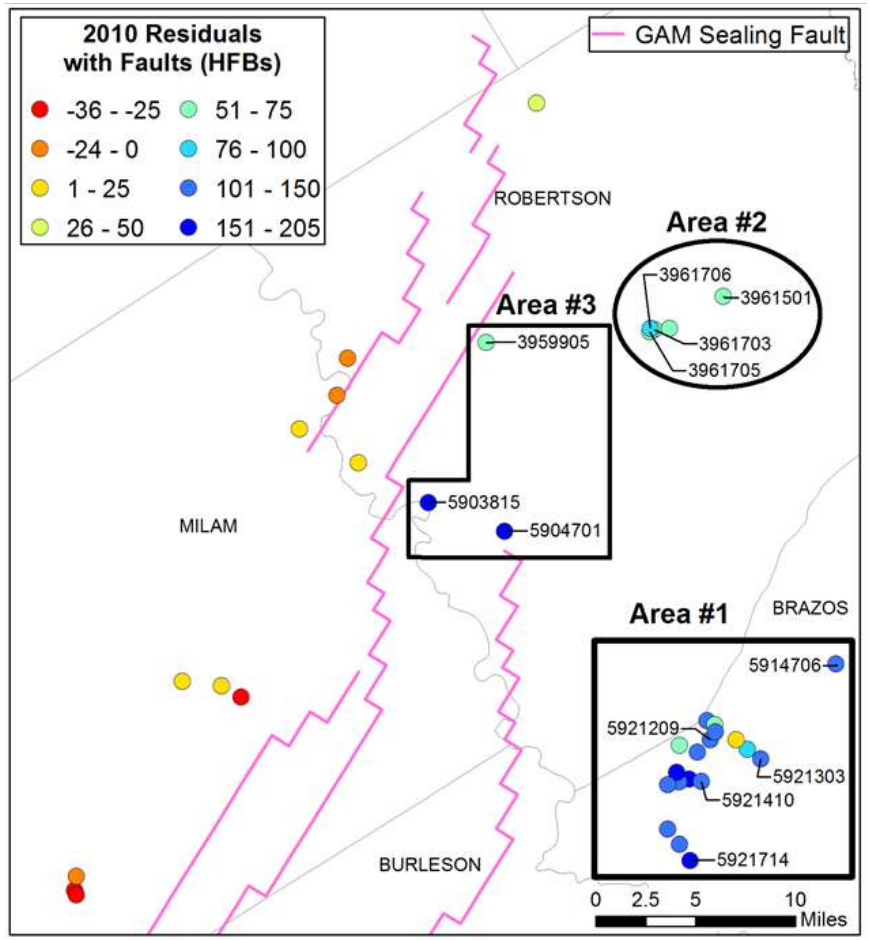


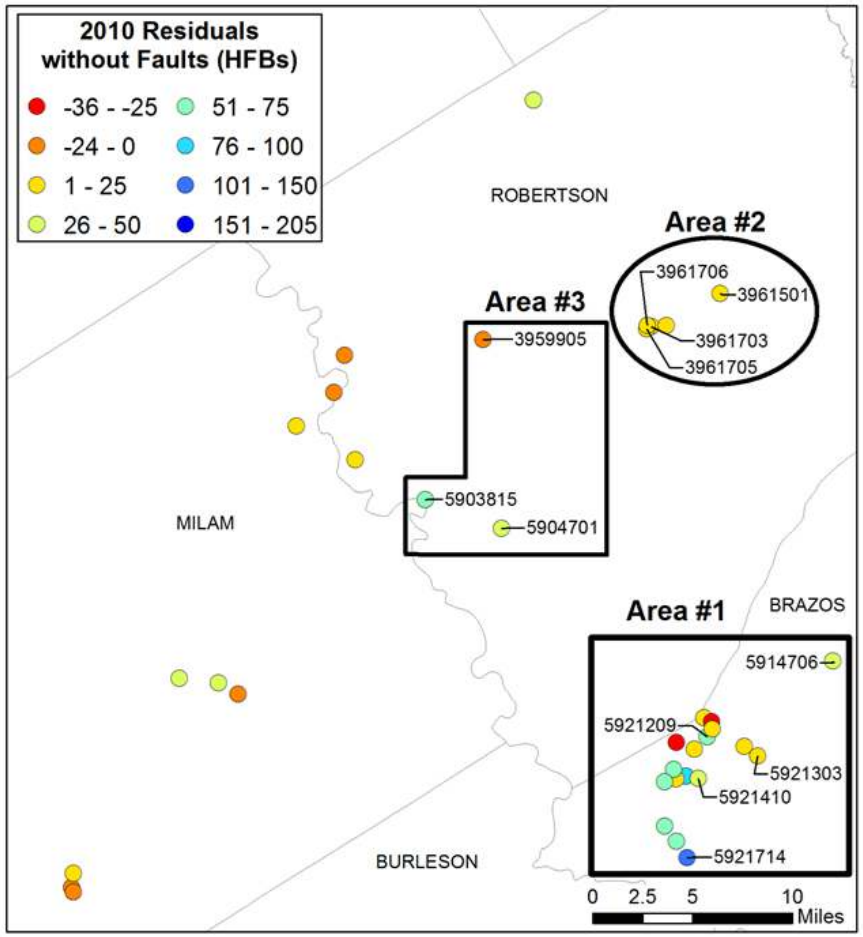


Differences Between Measured and Modeled Water Levels for 2010

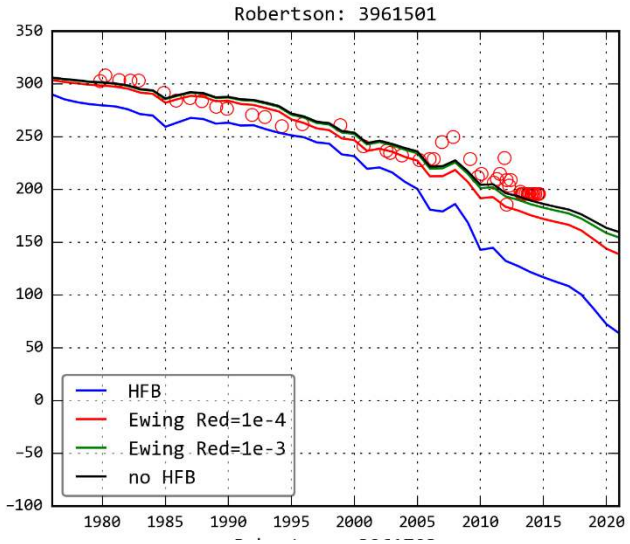


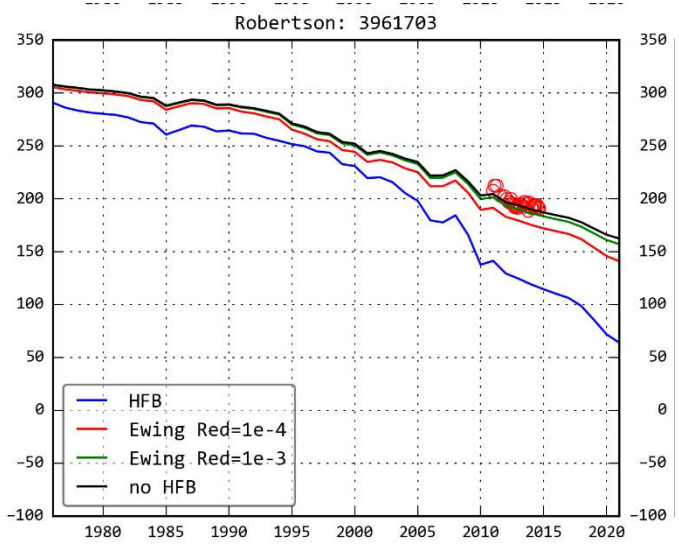
Differences Between Measured and Modeled Water Levels for 2010 Near Brazos River

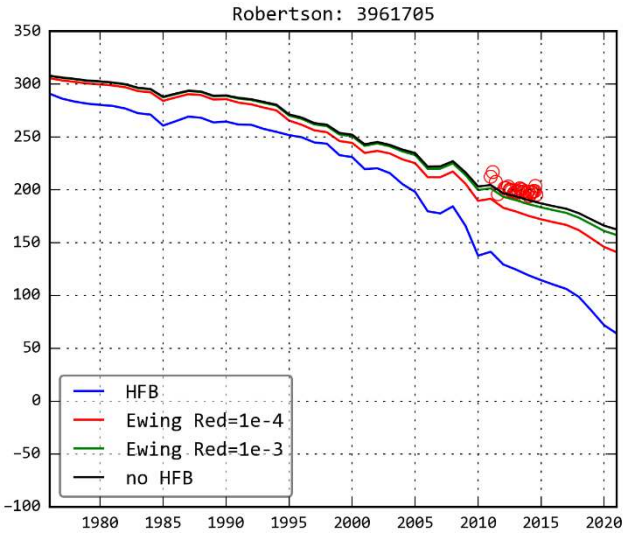


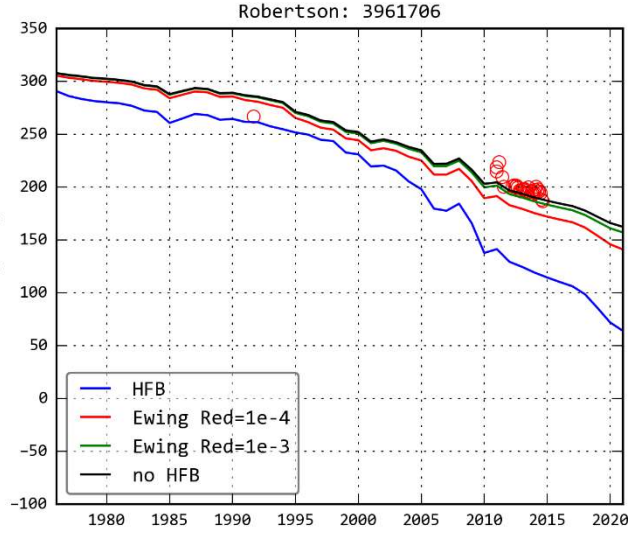


Hydrographs for Wells in Area #1 (near City of Bryan)

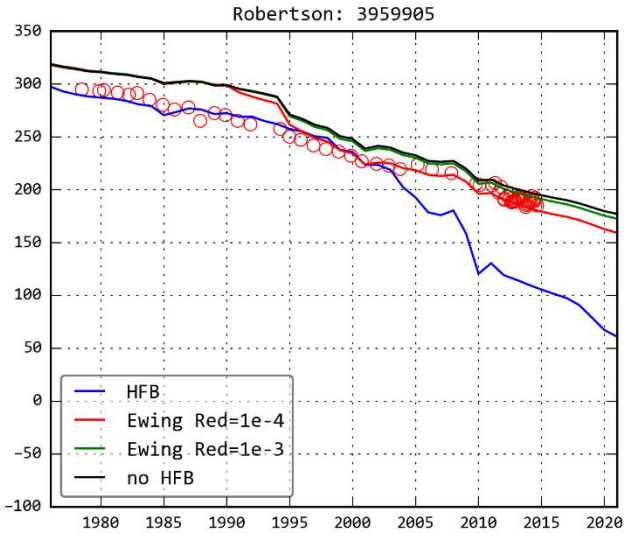


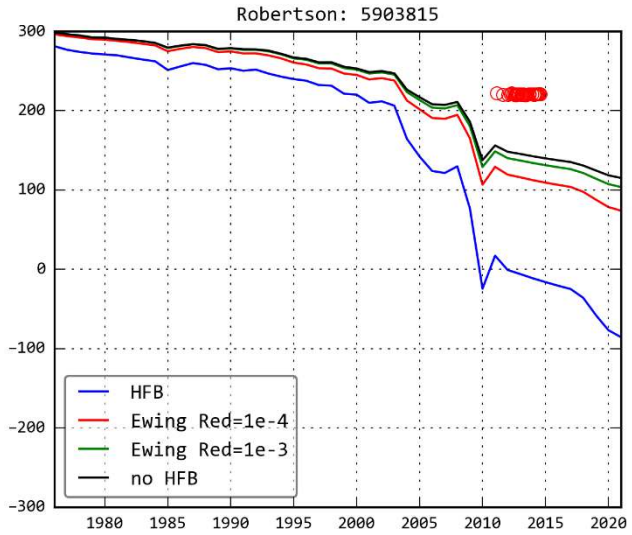


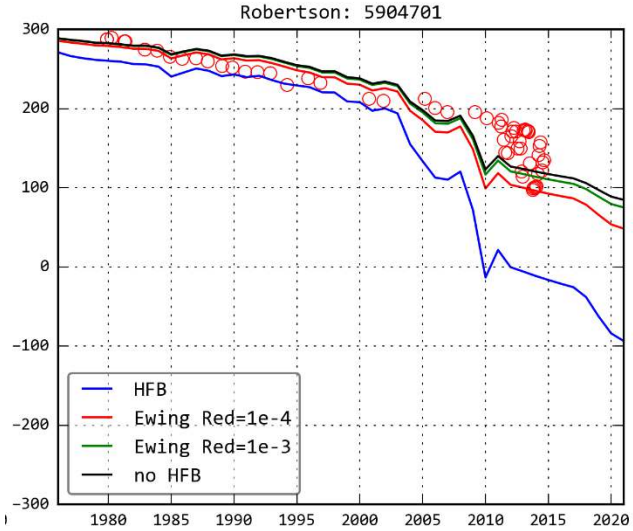




Hydrographs for Wells in Area #2 (near center of Robertson County)





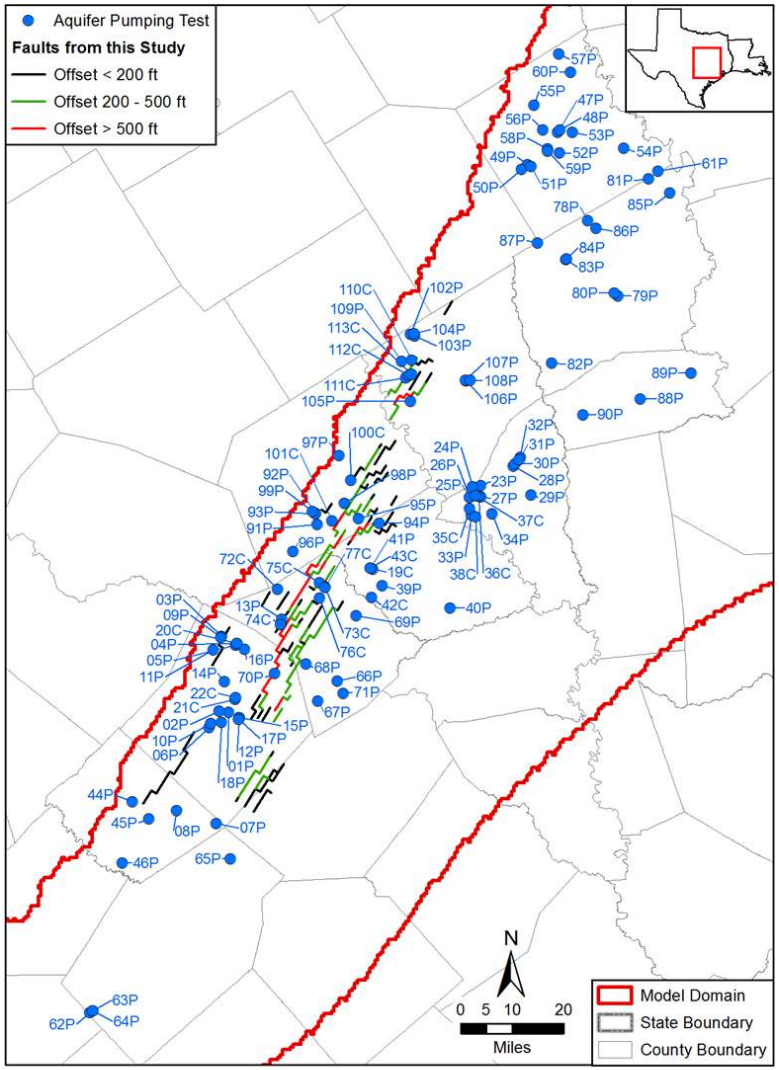


Summary of Findings From Comparison of Modeled and Measured Water Levels from 1975 to 2010

- Wells in Robertson and Brazos Counties
  - Substantial pumping down dip of current HFBs in GAM
  - Several wells with long-term set of water level measurements
- Comparison of measured & modeled water levels suggest that existing HFBs are in wrong locations and/or have resistances too high
- Measured water levels down gradient of faults are in relatively good agreement with model results using this study's faults and using no faults (HFBs)

Analyzed 113 Pumping Tests for Evidence of Faults Affecting GW Flow

- Data Source
  - Majority of pumping tests from TCEQ PWS file
  - Some pumping tests performed for End Op, Forestar, Alcoa, and Blue Water
- All single well pumping tests
- Examine plots of drawdown versus time
  - Straight-lines suggests homogeneous aquifer conditions
  - Lines with kinks and bend to a steeper slope is evidence of a possible fault
  - Limited time to 2 days
- Analysis is called a Cooper-Jacob Straight-line (CJSL) Analysis



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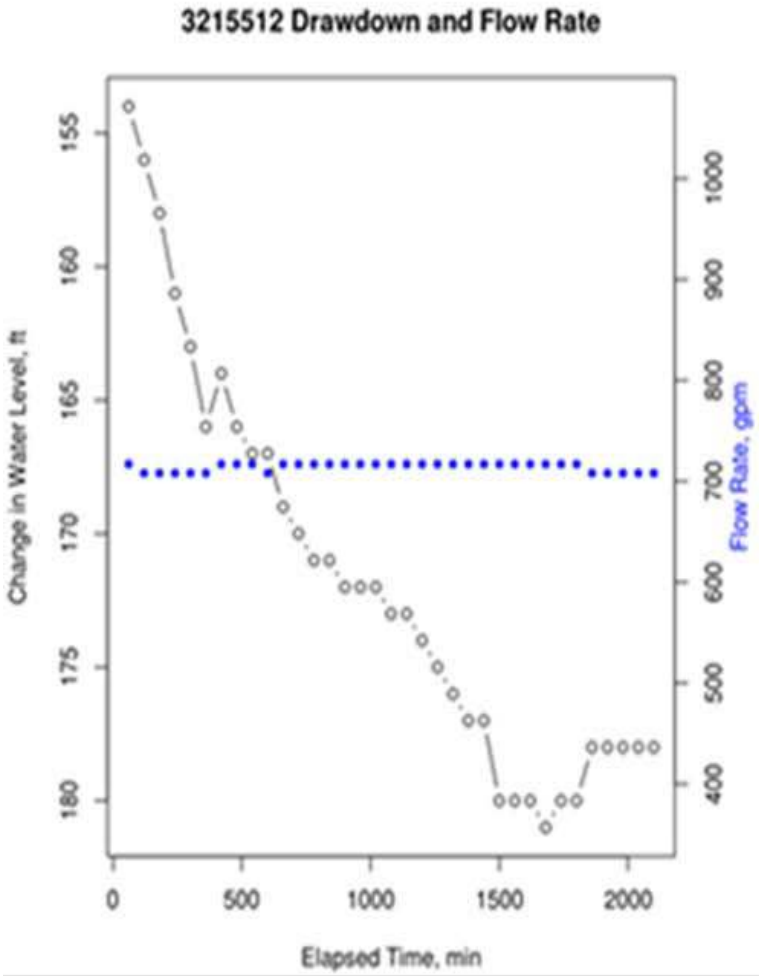
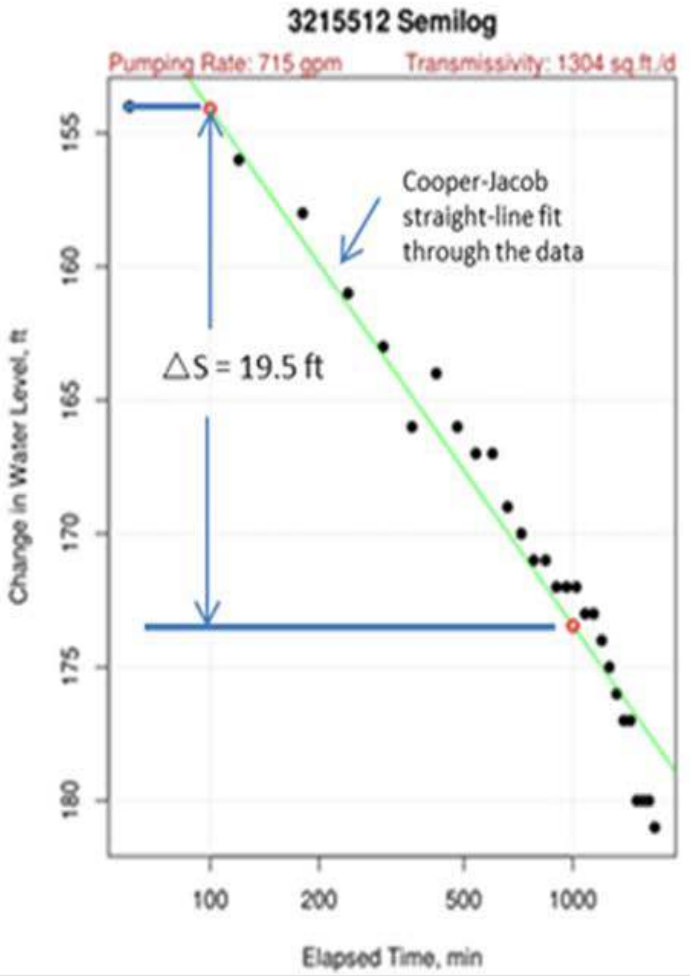
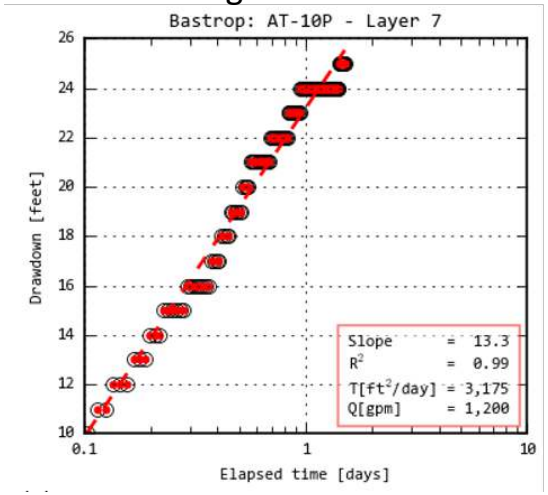
Example of a Cooper-Jacob Straight-Line Analysis



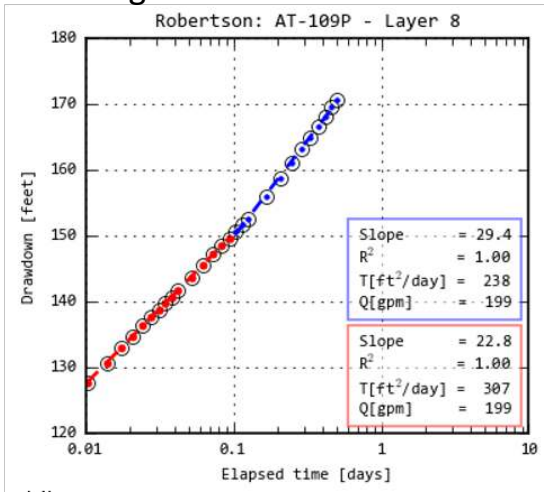


Four Categories Used to Classify Pumping Tests Based on Change in Transmissivity (T)

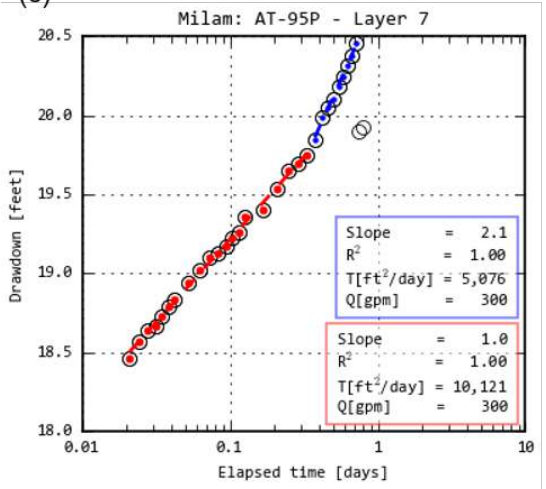
(a) No change in T with time



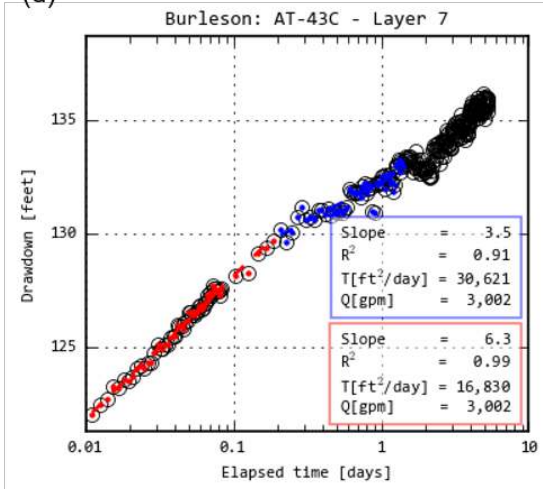
(b) Slight Decrease in T with time



(c) Large Decrease in T with time

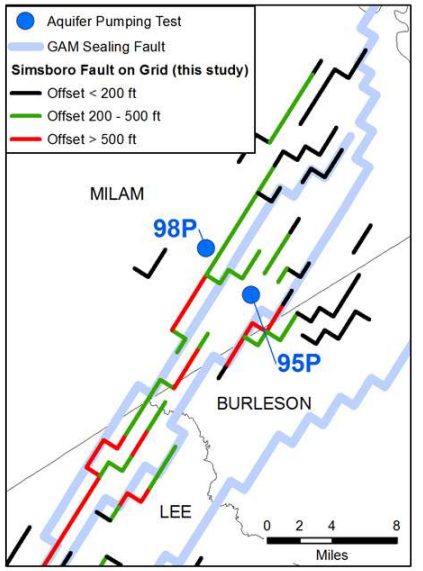


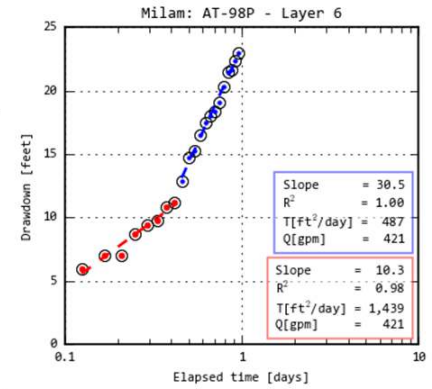
(d) Increase in T with time

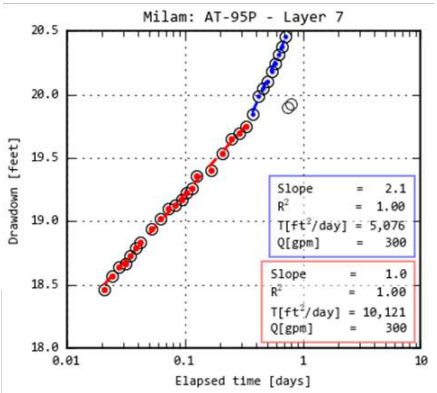


Example of CJSL Plots that Provide Evidence of Faults Affecting GW Flow

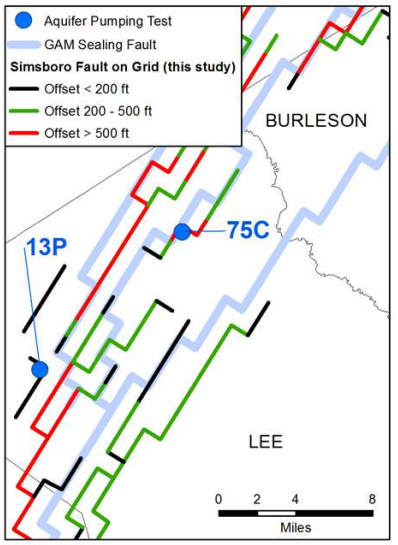
Milam County

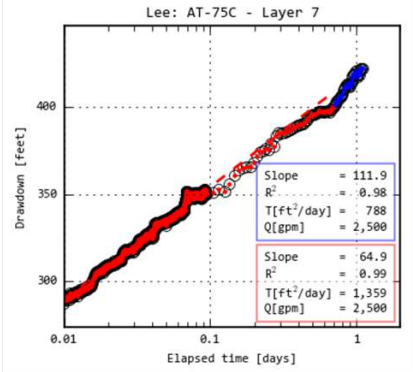


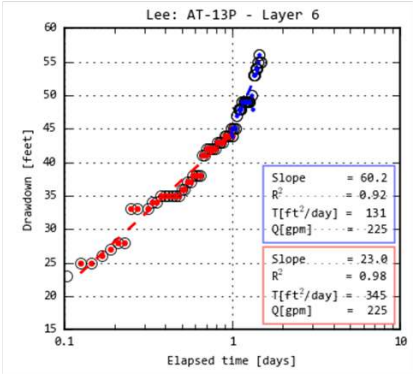




Lee County







Percentage of Pumping Tests with a T_{late} Lower than T_{early}

Fault Type	Fault Offset (feet)	Distance from Closest Fault (miles)	Total Number of Wells	Percentage of Wells with T_{late}/T_{early} Ratio < 0.65	Percentage of Wells with T_{late}/T_{early} Ratio < 0.85
This Study Faults	> 500	2	10	50%	70%
	> 200		17	35%	53%
GAM Faults			23	26%	39%
This Study Faults	> 500	4	16	38%	63%
	> 200		20	30%	55%
GAM Faults			30	20%	33%
This Study Faults	> 500	6	24	29%	50%
	> 200		34	21%	38%
GAM Faults			38	24%	39%
This Study Faults	> 500	> 8	58	3%	5%
	> 200		48	2%	4%
GAM Faults			47	6%	9%

Options for Simulating Faults: Concerns with Using Existing GAM

- Built as a regional flow model, not designed to simulate individual 1-day long, aquifer pumping tests
- Calibrated using very limited measurements of hydraulic conductivity at locations near faults
- No steady state solution available – model will not converge
- Grid cells are 1-mile by 1-mile – too coarse to accurately represent hydraulic gradients or fault locations
- Improper representation of spatial variation in aquifer properties could mask impact of fault zone
- Most well screens have significantly shorter lengths than GAM model layers and intersect a sand unit with hydraulic properties not reflective of the bulk properties aquifer represented by the model layer

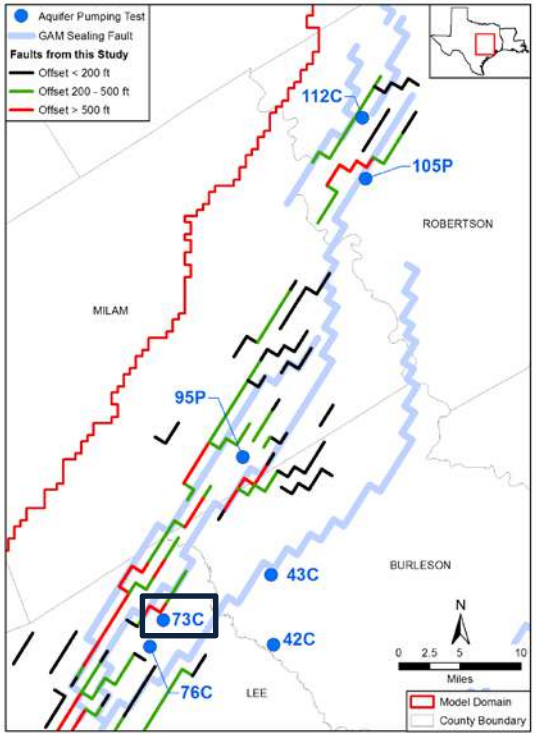
Summary of Measured and Simulated Time versus Drawdown Data for Six Aquifer Pumping Tests

Aquifer Test ID	From Interpretation of Observed Data	From Interpretation of TTim Simulated Data	
	T_{late}/T_{early}	This Study Faults	GAM Faults
		T_{late}/T_{early}	T_{late}/T_{early}
AT-73P	0.72	0.73	0.71
AT-76C	0.59	0.86	0.64
AT-112C	0.82	0.76	0.97
AT-105P	0.50	0.68	0.99
AT-43C	1.00	1.00	0.52
AT-42C	1.00	0.91	0.65

Note: ID = identification; GAM = groundwater availability model

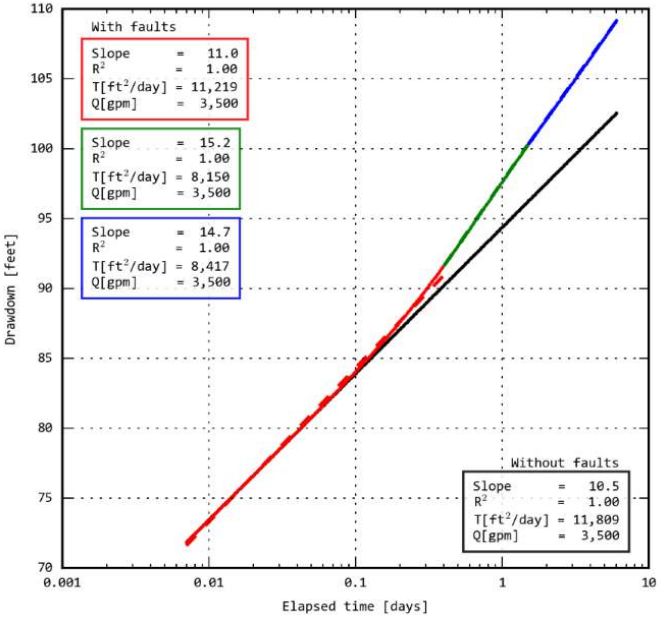
Note: Placement of faults into GAM introduces uncertainty of up to 0.5 miles

Comparison Time versus Drawdown for Pumping Test AT-73C (T_{late}/T_{early} = 0.72)



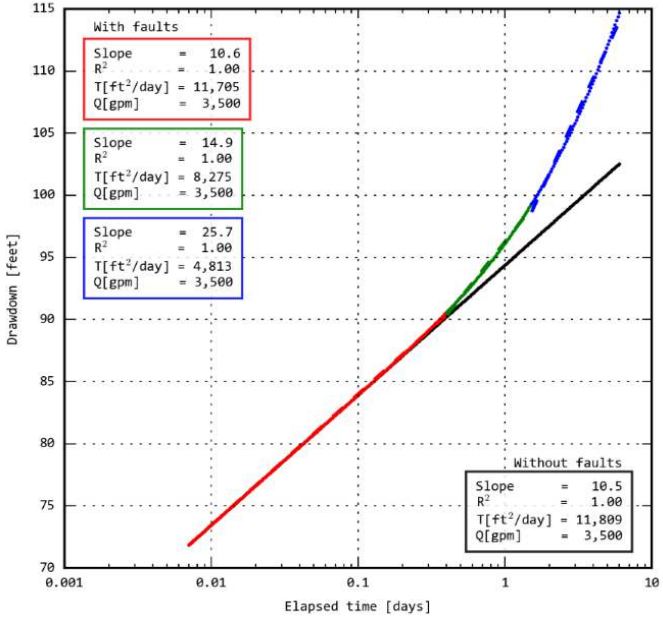
T_{late}/T_{early} = 0.73

(a) This study faults



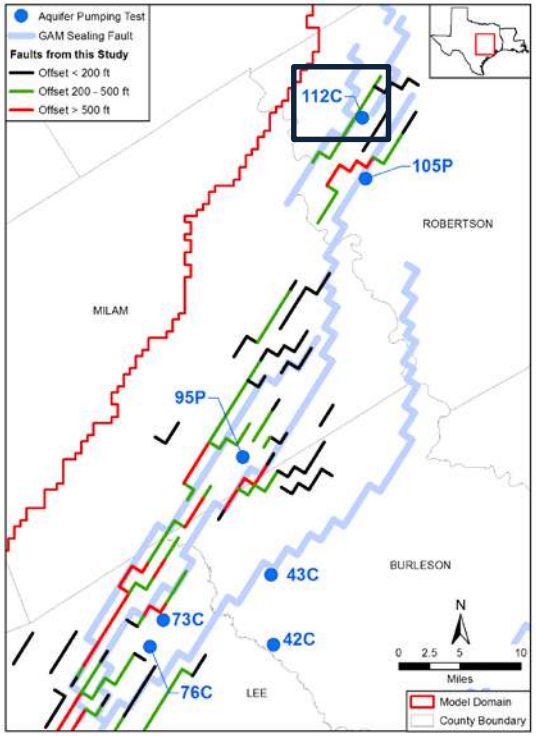
T_{late}/T_{early} = 0.71

(b) GAM faults



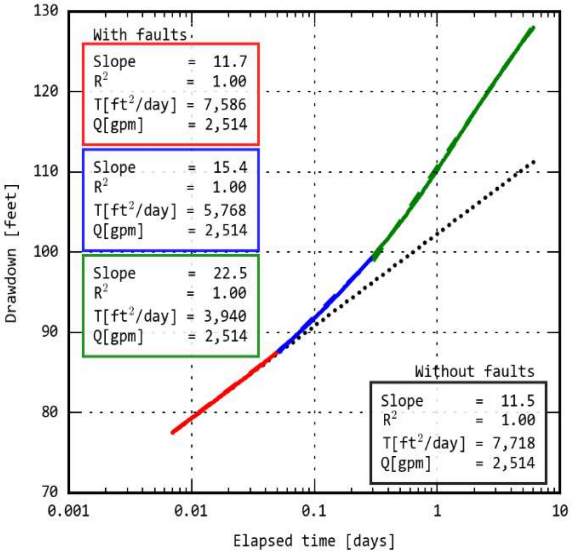
Simulations based on TTIM runs using transmissivity from aquifer pumping tests and storativity from the GAM at well location

Comparison Time versus Drawdown for Pumping Test AT-112C (T_{late}/T_{early} = 0.82)



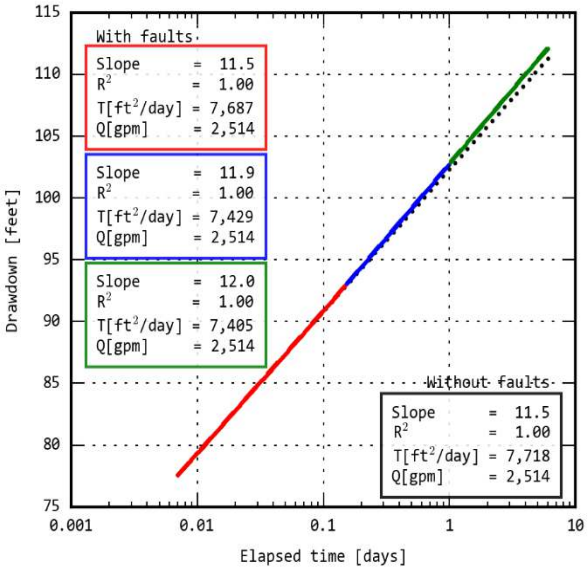
T_{late}/T_{early} = 0.76

(a) This study faults



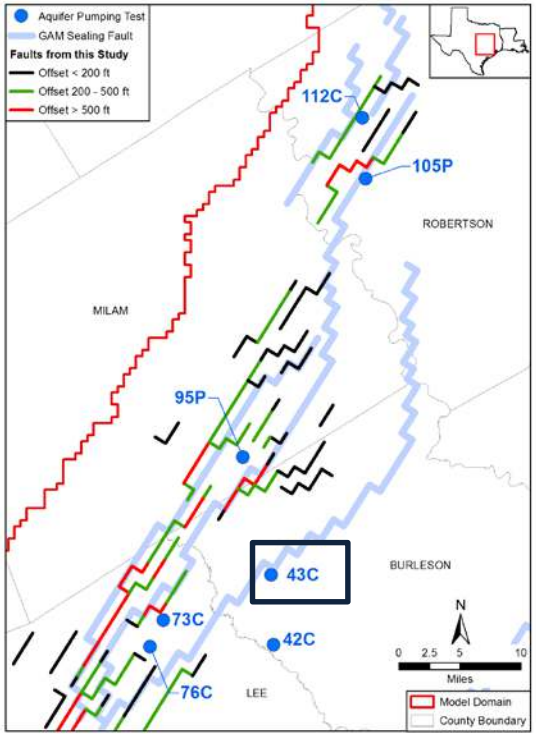
T_{late}/T_{early} = 0.97

(b) GAM faults

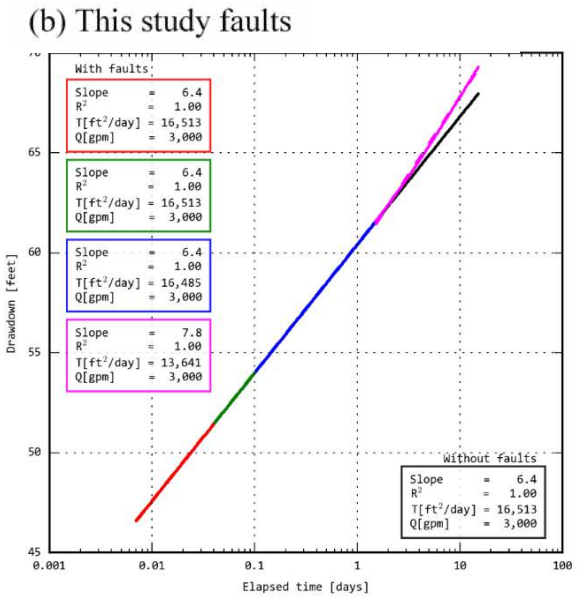


Simulations based on TTIM runs using transmissivity from aquifer pumping tests and storativity from the GAM at well location

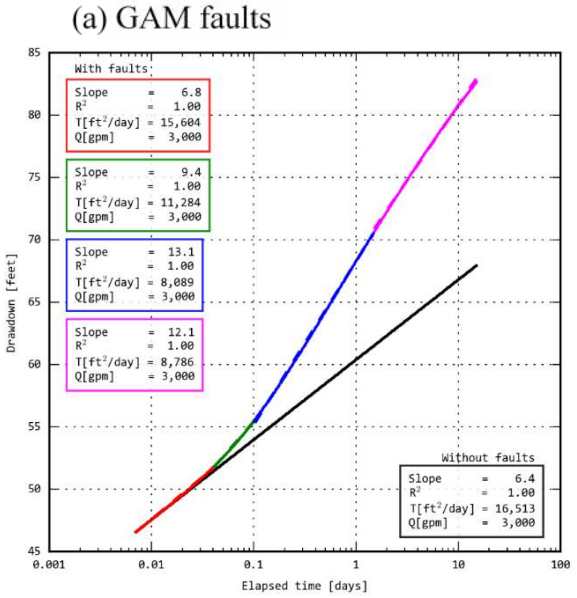
Comparison Time versus Drawdown for Pumping Test AT-43C (T_{late}/T_{early} = 1.00)



T_{late}/T_{early} = 1.00



T_{late}/T_{early} = 0.52



Simulations based on TTIM runs using transmissivity from aquifer pumping tests and storativity from the GAM at well location

Summary of Findings from The Analysis of Aquifer Pumping Tests

- Considerable evidence
  - That faults have a significant impact on groundwater flow in the vicinity of the Milano Fault Zone
  - Supporting fault locations from this study more so than in current GAM
  - Against the GAM fault line that dips south near Caldwell and then toward Robertson County
- Modeling
  - GAM in its current state is not an appropriate tool for modeling and analyzing pumping tests. At a minimum, additional grid cell and model refinement is needed
  - Analytical element model is an appropriate tool for modeling and analyzing pumping tests

Recommendation Regarding Representation of Milano Fault Zone in a Revised GAM

- Replace Current GAM Faults with This Study Faults
- Continue using HFB Package to Represent the Fault Locations
- Investigate Modifications to Conductances Assigned to Fault Offsets during Model Calibration

Update on Development of MODFLOW-USG Model

- Converted MODFLOW 96 to MODFLOW-USG
  - Establish steady state conditions
  - Confirmed conversion by comparing water levels and water balances
  - Tested grid cell refinement capabilities
- Evaluated Options for Representing Groundwater-Surface Water Interaction
  - Mapped alluvial deposits associated with Colorado River
  - Obtained similar results between river package and stream package
  - Opted to use river package instead of stream package
  - River package supports gain-loss evaluation along river reaches

Data Analysis: Wells Information from TWDB Databases

Estimate Base of Alluvium

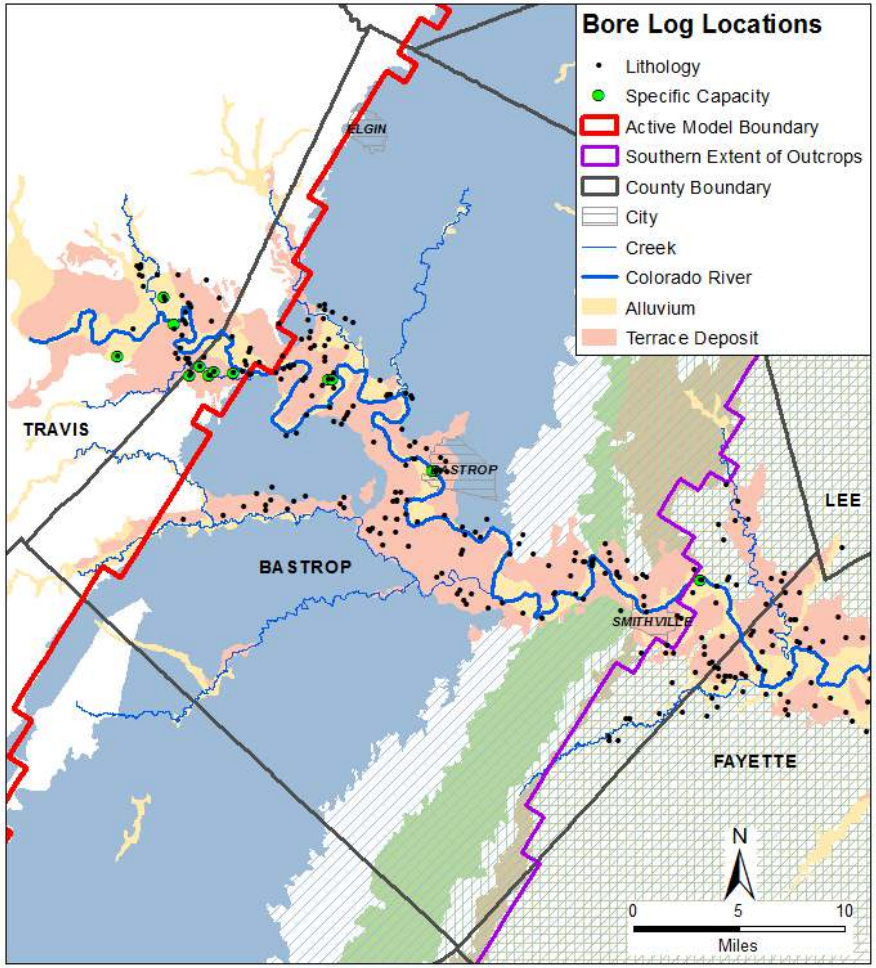
- 261 lithology profiles
- Base of gravel or coarse sandy deposit or top of a muddy/silty sequence

TDLR Well 156938		
Depth Interval (Ft.)	**Description**	**Unit**
0 - 11	Top Brown Sand	Alluvial System
11 - 20	Coarse Sand / Brown Clay	Alluvial System
20 - 45	Pea Gravel	Alluvial System
45 - 60	Pea Gravel / Large Gravel	Alluvial System
60 - 105	Gray Shale / Sandy Green Shale	Weches Formation
105 - 125	Grow-Brown Shale	Weches Formation
125 - 158	Gray-Brown Sand / Iron Rock	Weches Formation

Estimate of Transmissivity (ft^2/day)

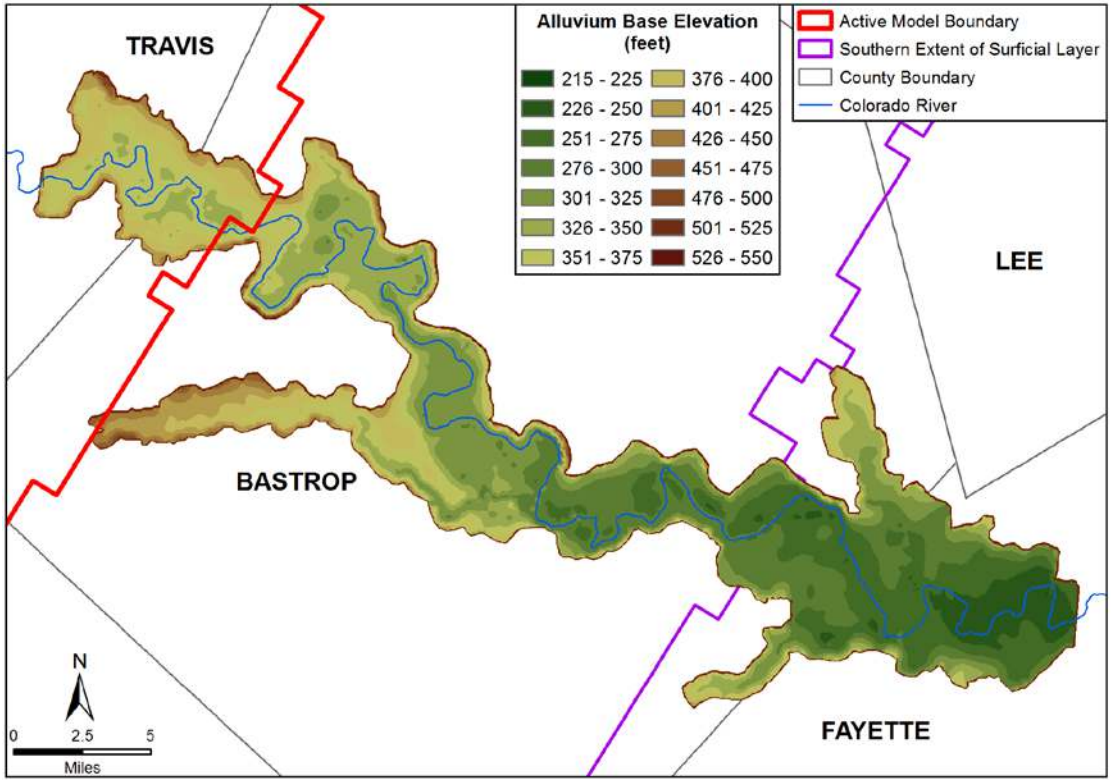
- 14 values
- Geometric mean of hydraulic conductivity is 75 ft/day

Alluvium Wells



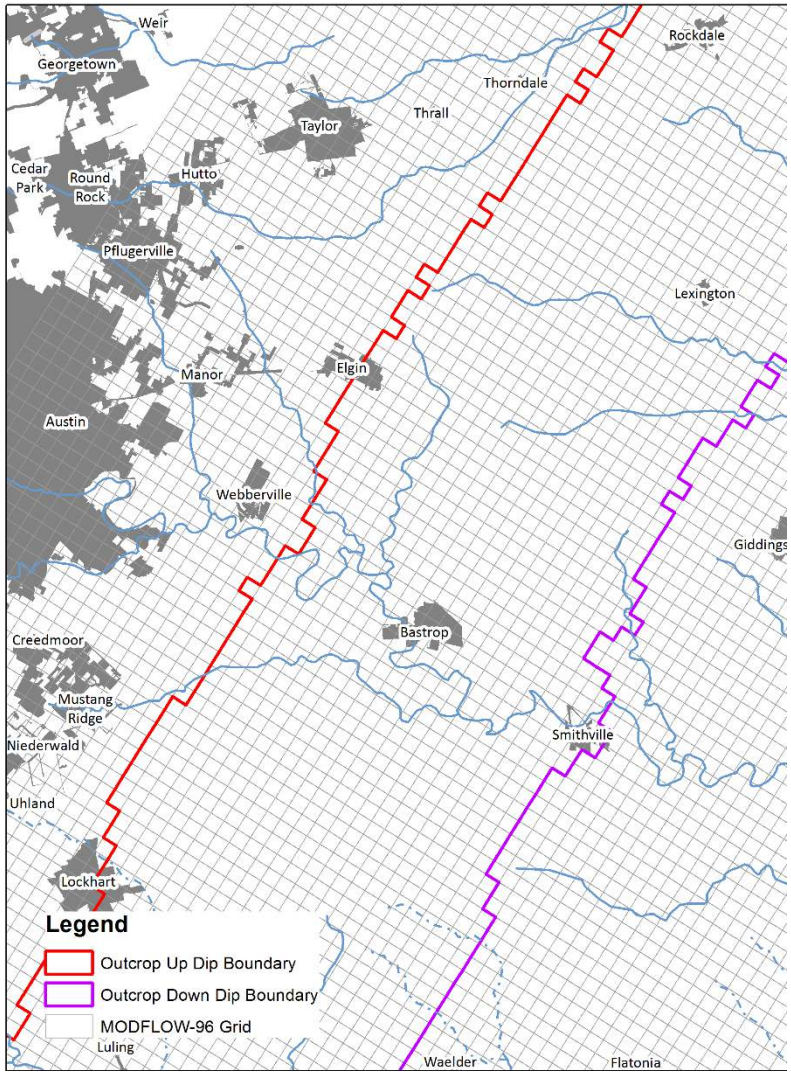
Colorado Alluvium: Base Elevations

- Data
  - 260 well locations
  - Bathymetry from LCRA terrain map
  - Added control points where coverage was sparse. Depth estimated based on hydrogeologic studies
- Map
  - 0.25-mile by 0.25-mile grid cells
  - Area between red and purple lines will be represented in updated GAM

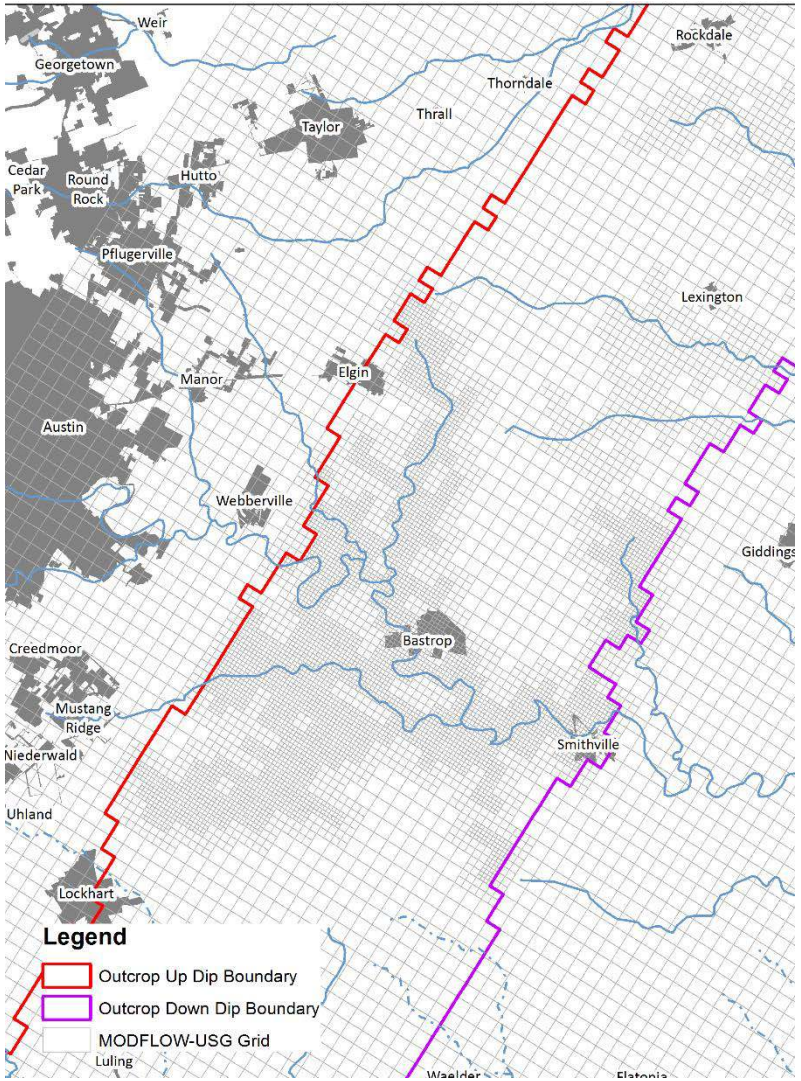


Comparison of Model Grid Cells in Vicinity of Colorado River: MODFLOW 96 and MODFLOW-USG

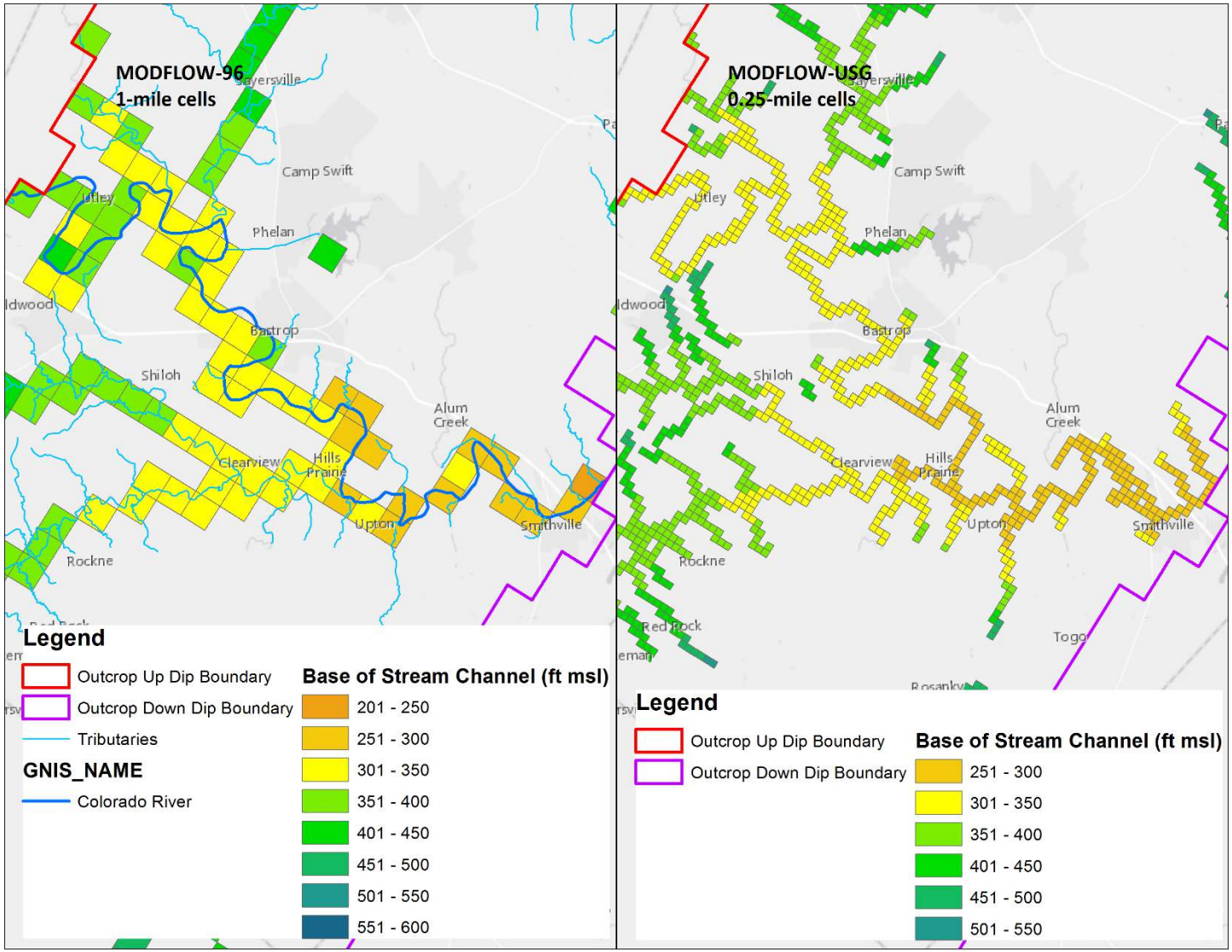
MODFLOW 96 Grid



MODFLOW-USG Grid



Comparison of Colorado River Location: MODFLOW 96 and MODFLOW-USG



Project Schedule

- Draft Model Report Due January 31, 2018

- Final Report Deadline April 30, 2018


QUESTIONS