Re-Calibration the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers (ETPVA)

GMA-7 Meeting
Fredericksburg, TX

Steve Young, URS

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Outline

- Purpose
- Project Purpose
- Model Calibration
- PEST Overview
- PEST Application
- ETPVA GAM Re-Calibration Results
- Report Summary
- Recommended Model Improvements

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Project Purpose

"Re-calibrate the GAM for the ETPVA using parameter estimation (PEST) techniques with a high-performance computer cluster (HPC) to determine the feasibility of the groundwater availability modeling program using this approach and equipment "[1]

[1] from TWDB RFQ

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Project Purpose

- Update an Existing Model
- Examine Feasibility of PEST for expediting the calibration process
- Provide GAM program with equipment to use parallel processing to expedite model calibration and/or simulation

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Model Calibration

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Groundwater Modeling 101

Model Development	Major Activity
Data Collection	Collect data points
Site Conceptual Model	Develop generalized pictures from the points
Numerical Model	Convert the generalized pictures into equations
Model Calibration	Adjust the points used in the model equations to match the data points - input (recharge and aquifer properties) - output (groundwater elevations and flows)

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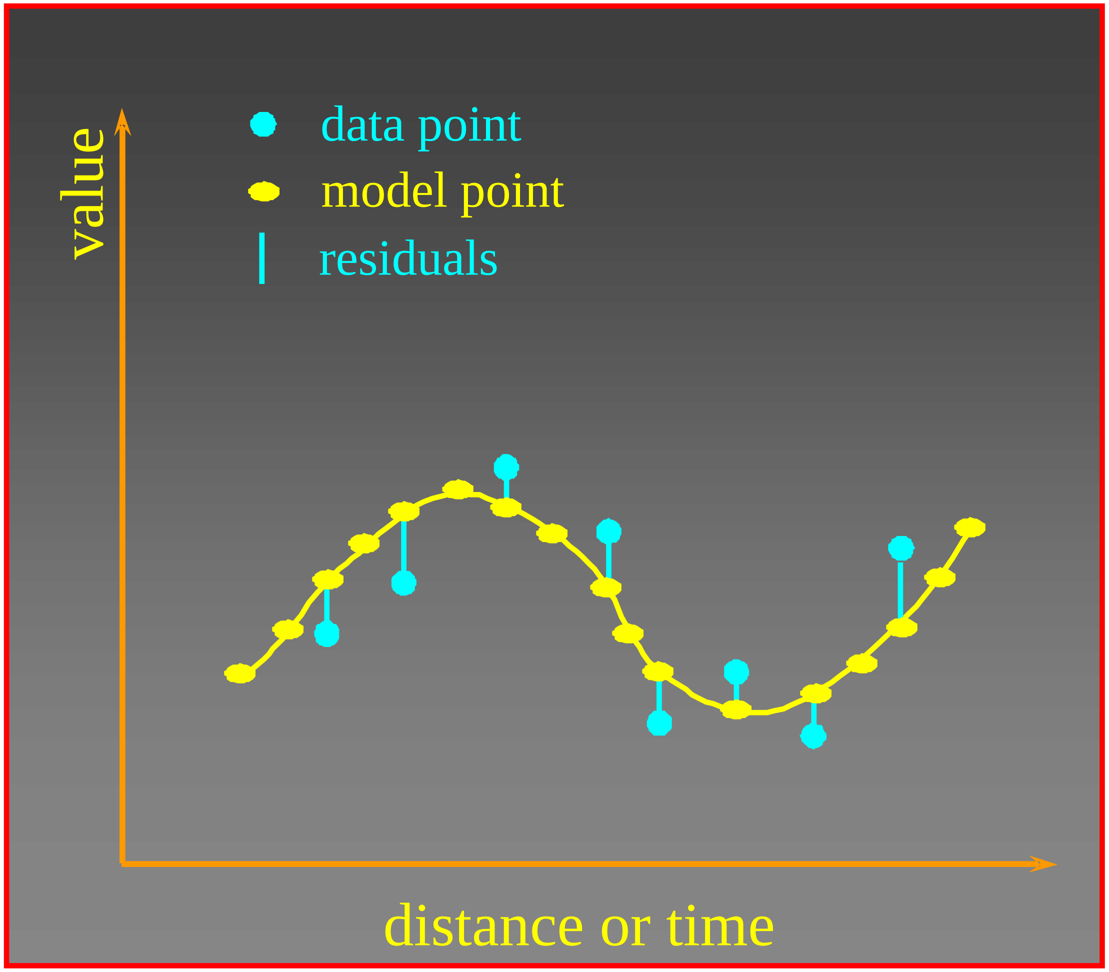
Model Calibration: Matching Model Points to Data Points



Key Questions

Why these data points?

Are there enough data points?

What data points are important to match?

What confidence do we have in the data points?

Do the model points match the data points well enough?

Should another conceptual model be considered?

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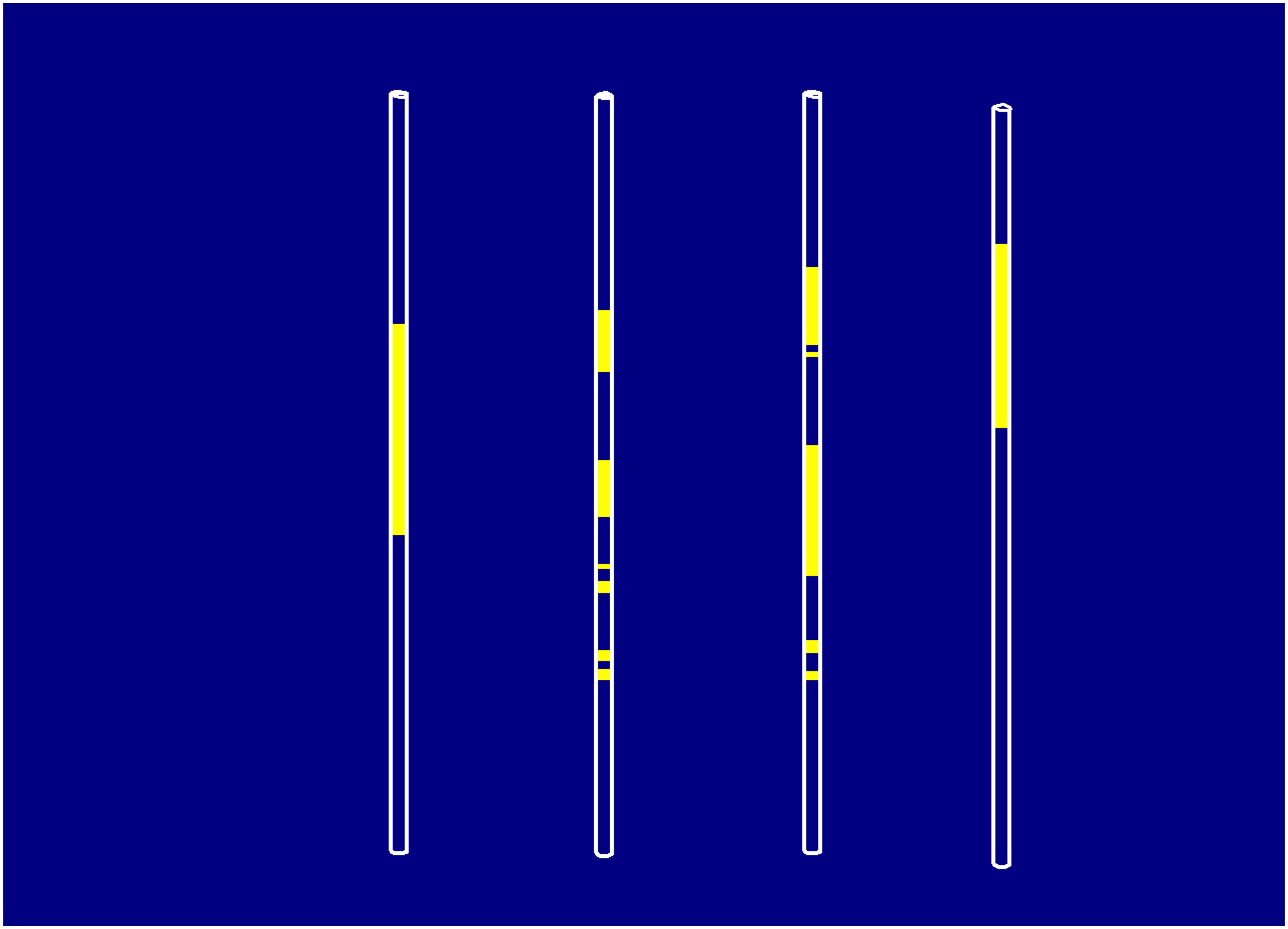
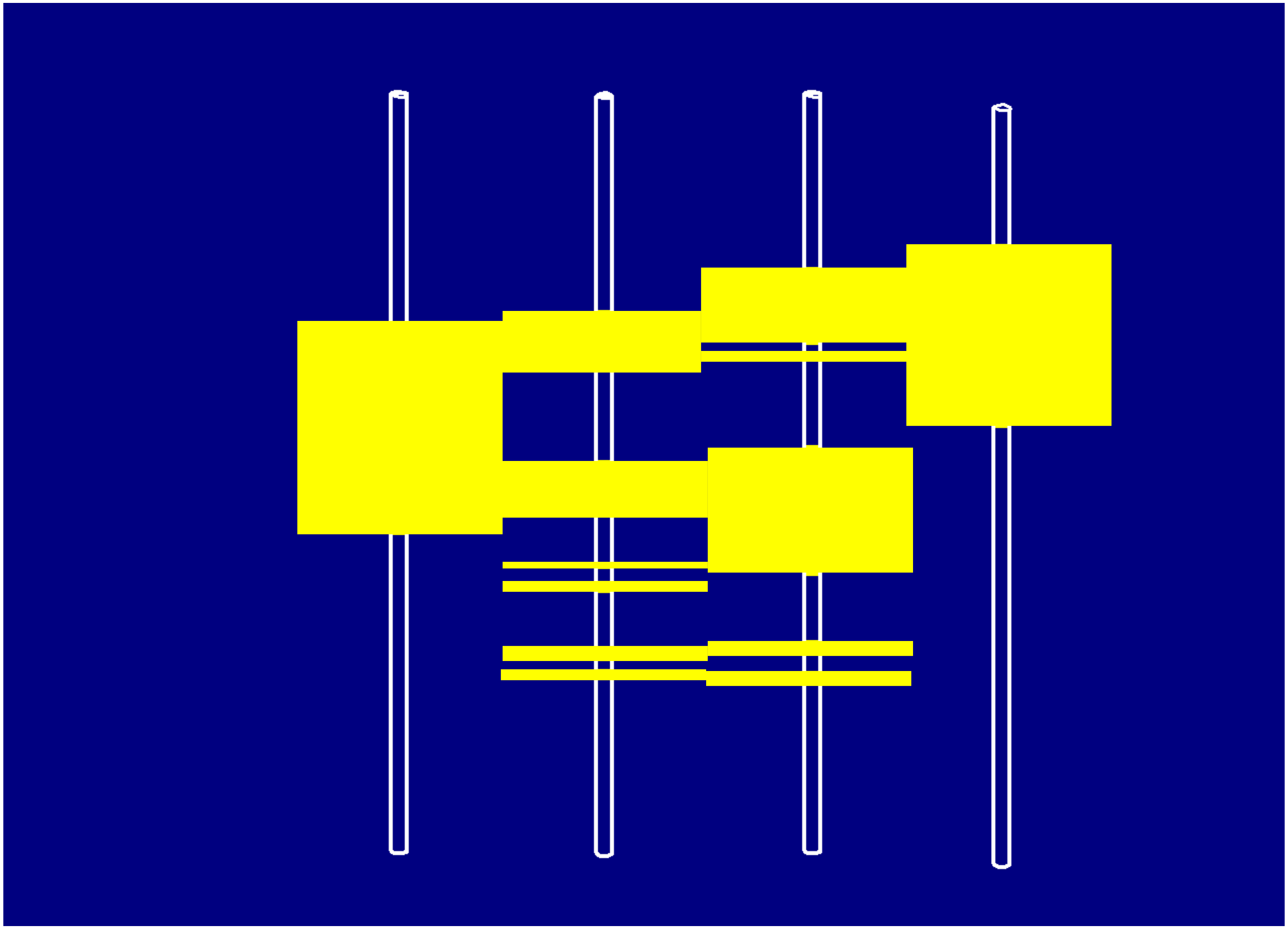
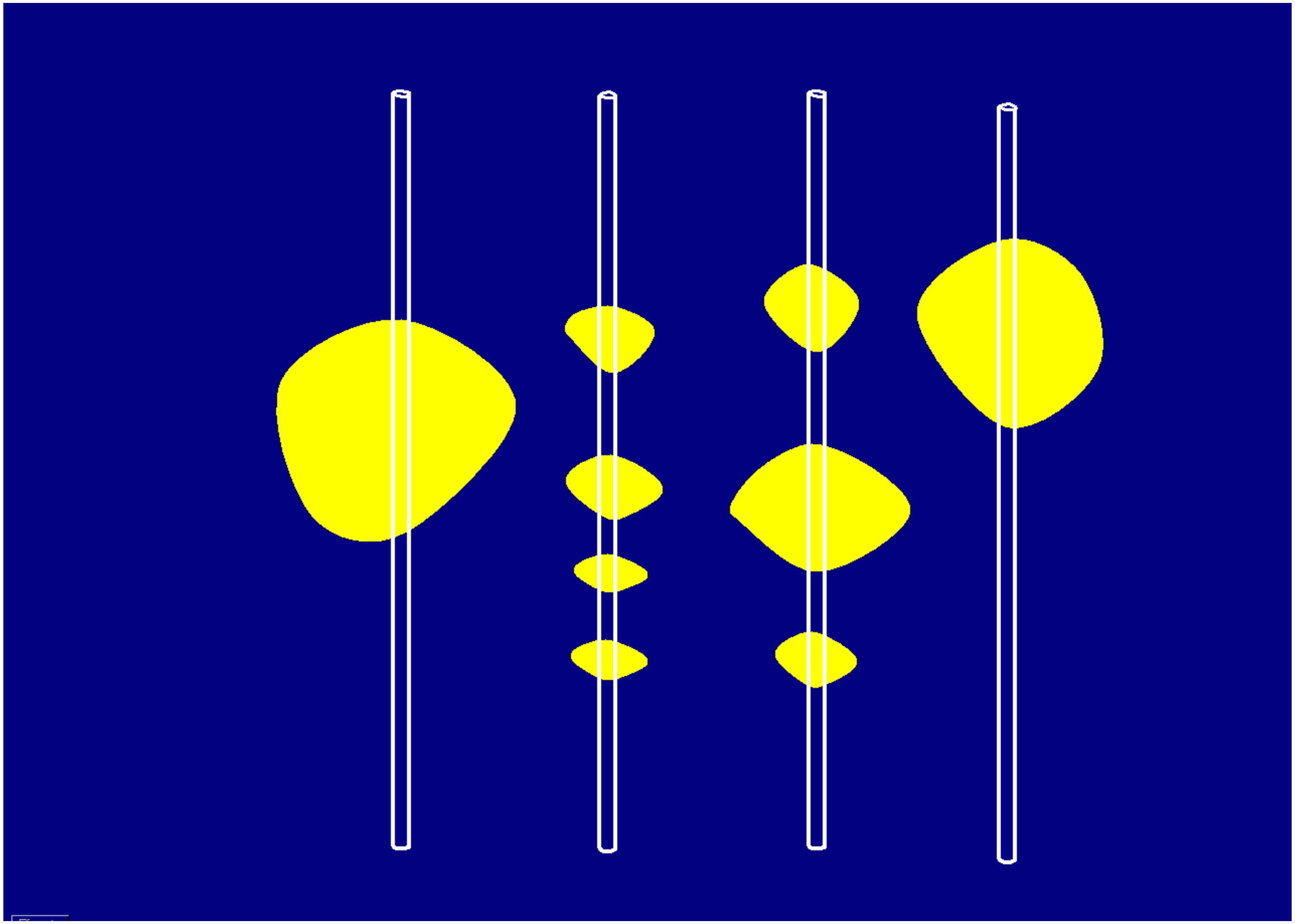
Model Calibration: Example for Interpreting Data Points for Sand Thickness



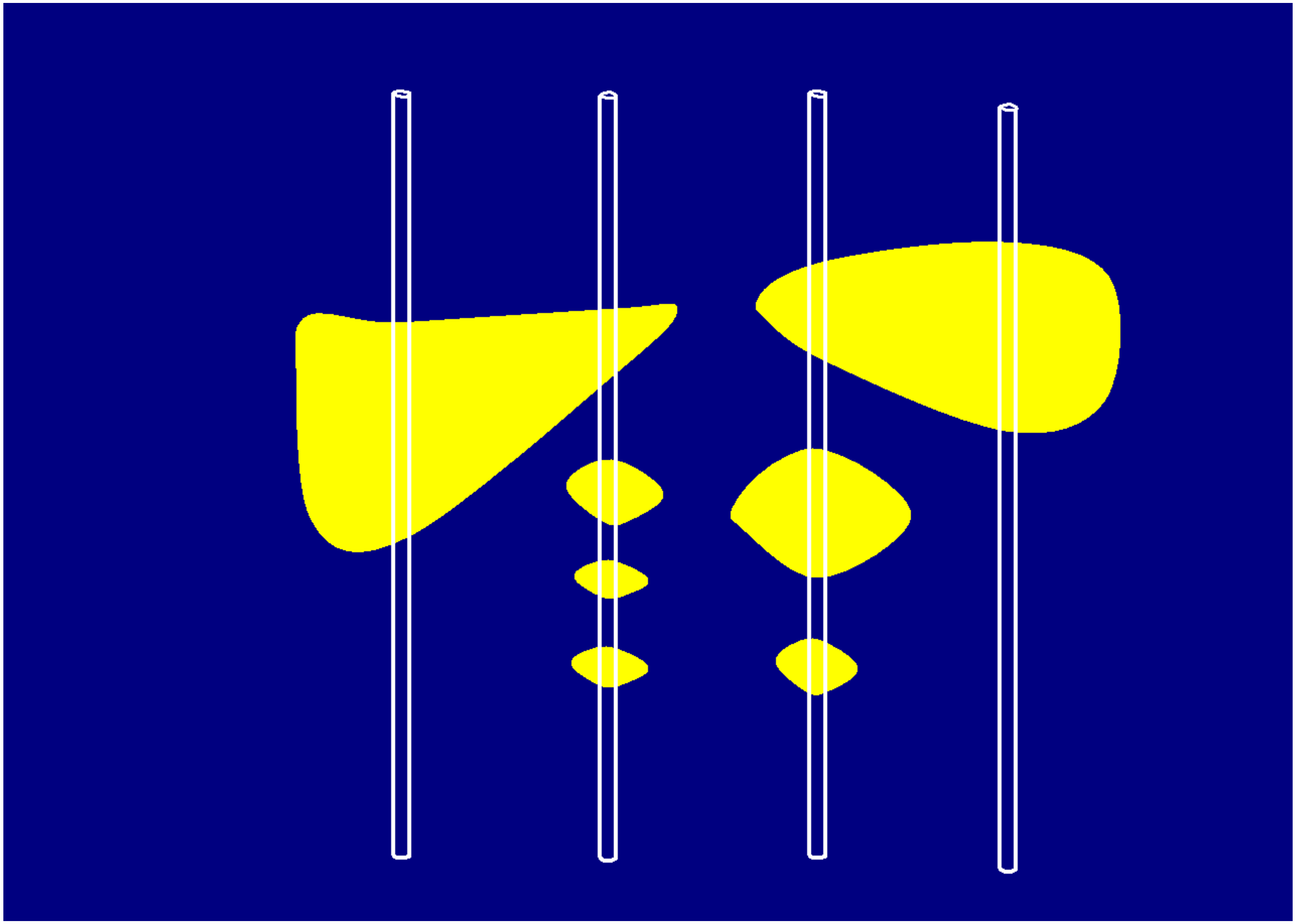
An Engineer Providing a Geologic Interpretation: No Interpolation Between Data Points



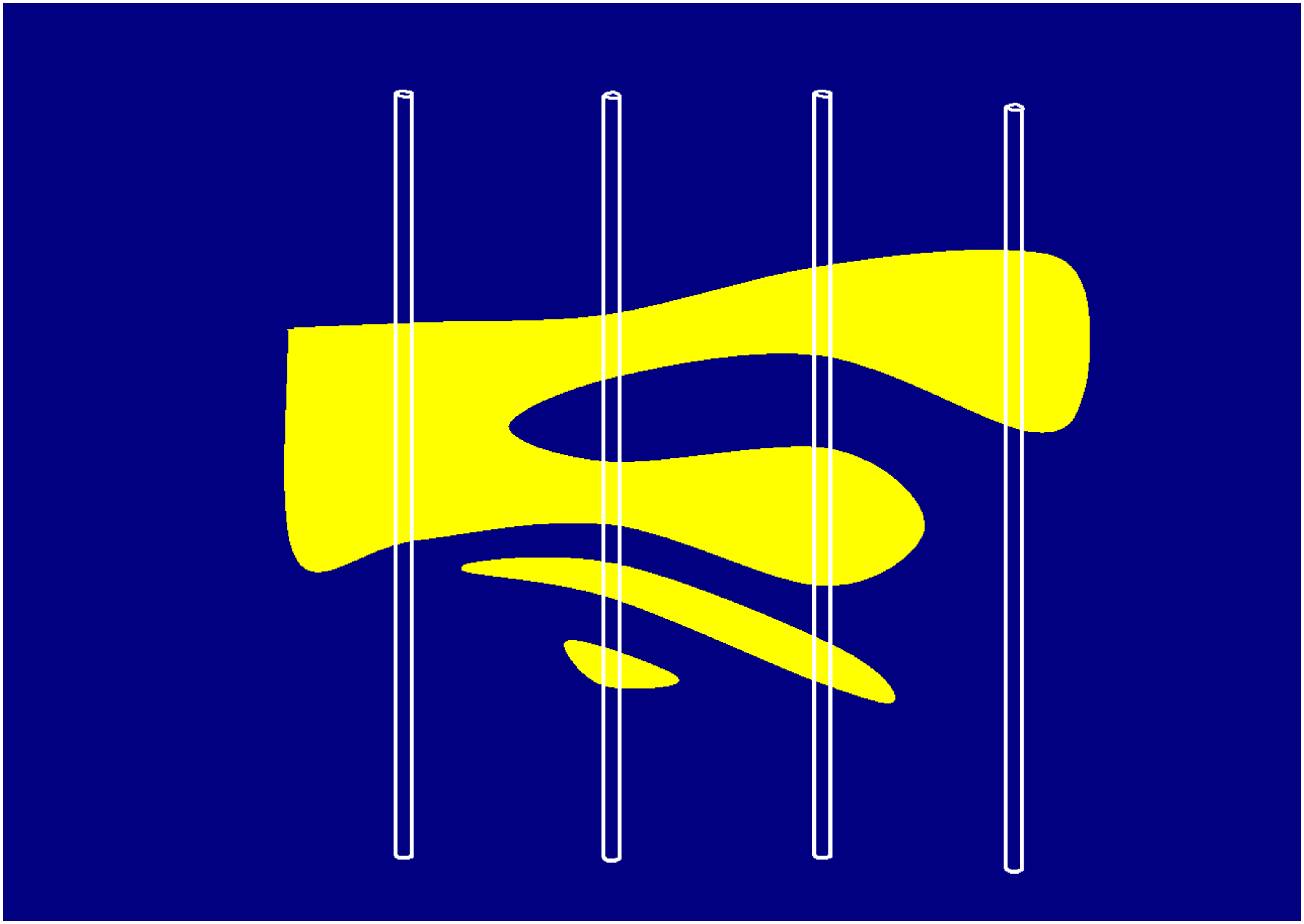
A Very Conservative Geologist's Interpretation: No Connection Among The Sands



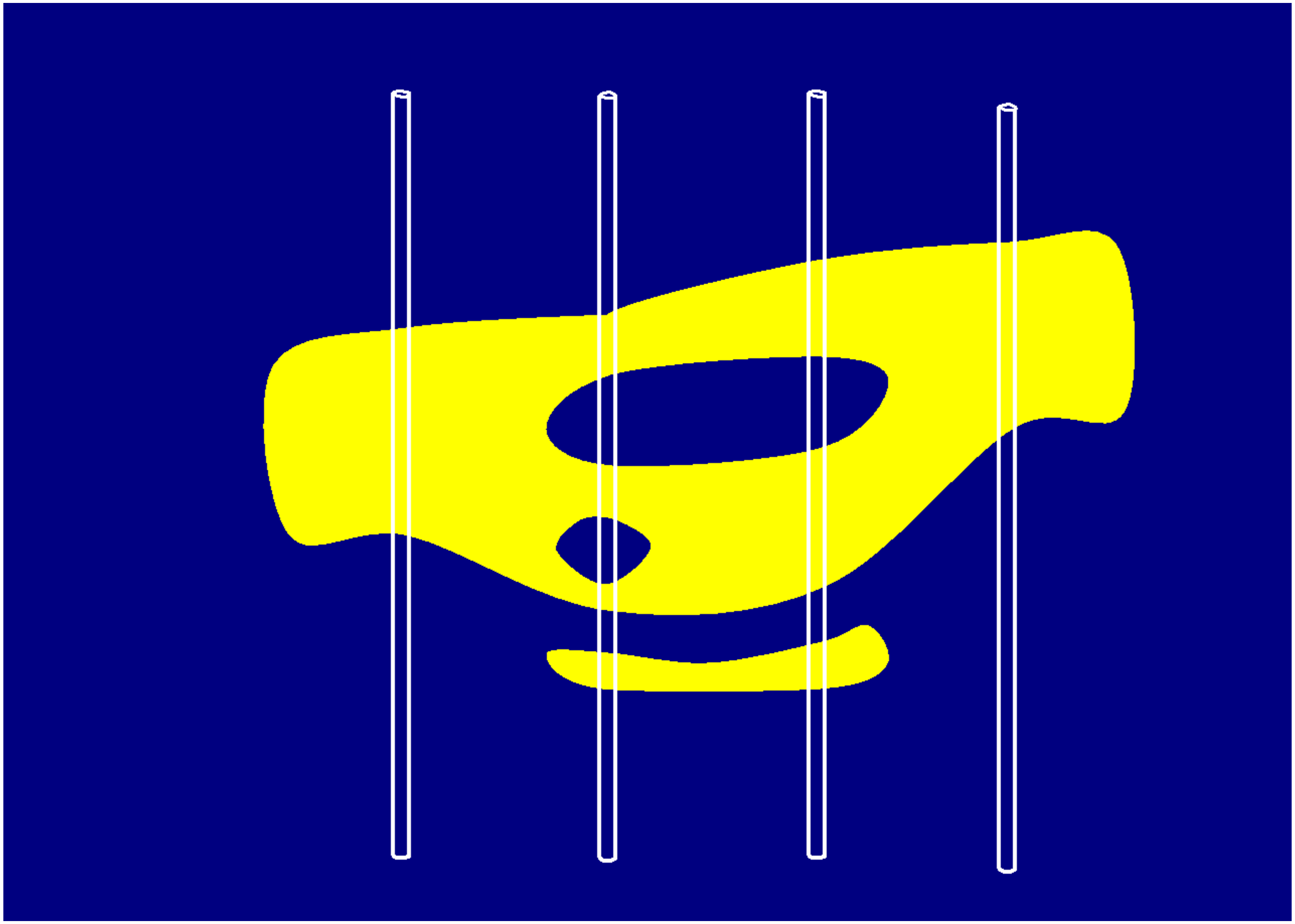
A Conservative Geologist's Interpretation: Limited Connection Among The Sands



An Optimistic Geologist's Interpretation: Moderate Connections Among The Sands



A Very Optimistic Geologist's Interpretation: Sands are Highly Interconnected



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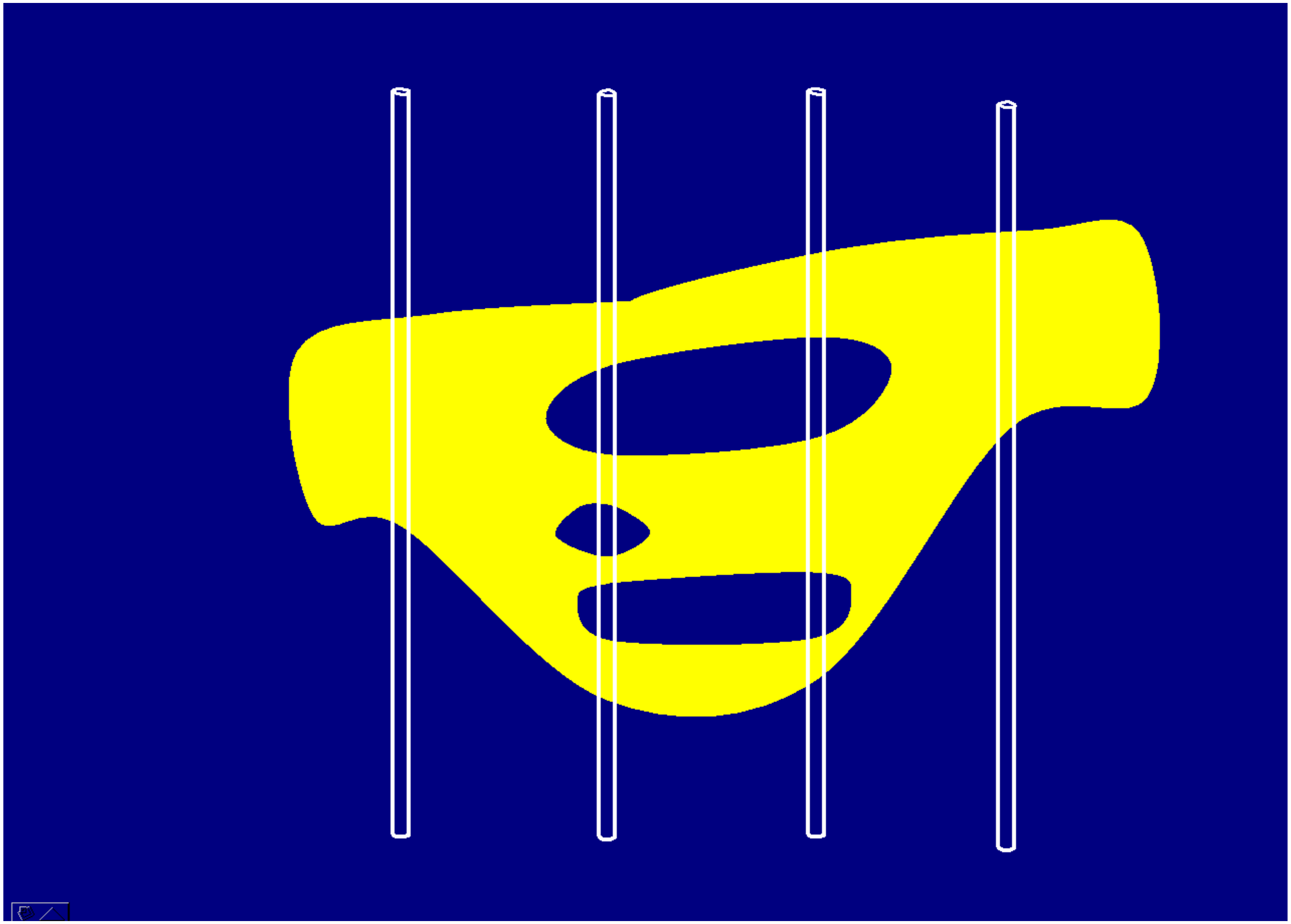
An Extremely Optimistic Geologist Interpretation: All Sands Are Interconnected



Model Calibration: The Big Picture

- Model calibration involves selecting and interpreting lots of data points
- Different approaches can produce very different results
- Calibration approaches should be selected based on how well they address key technical issues
- The ETPVA GAM is among the largest and most complex aquifers – data interpolation will be inherently very difficult

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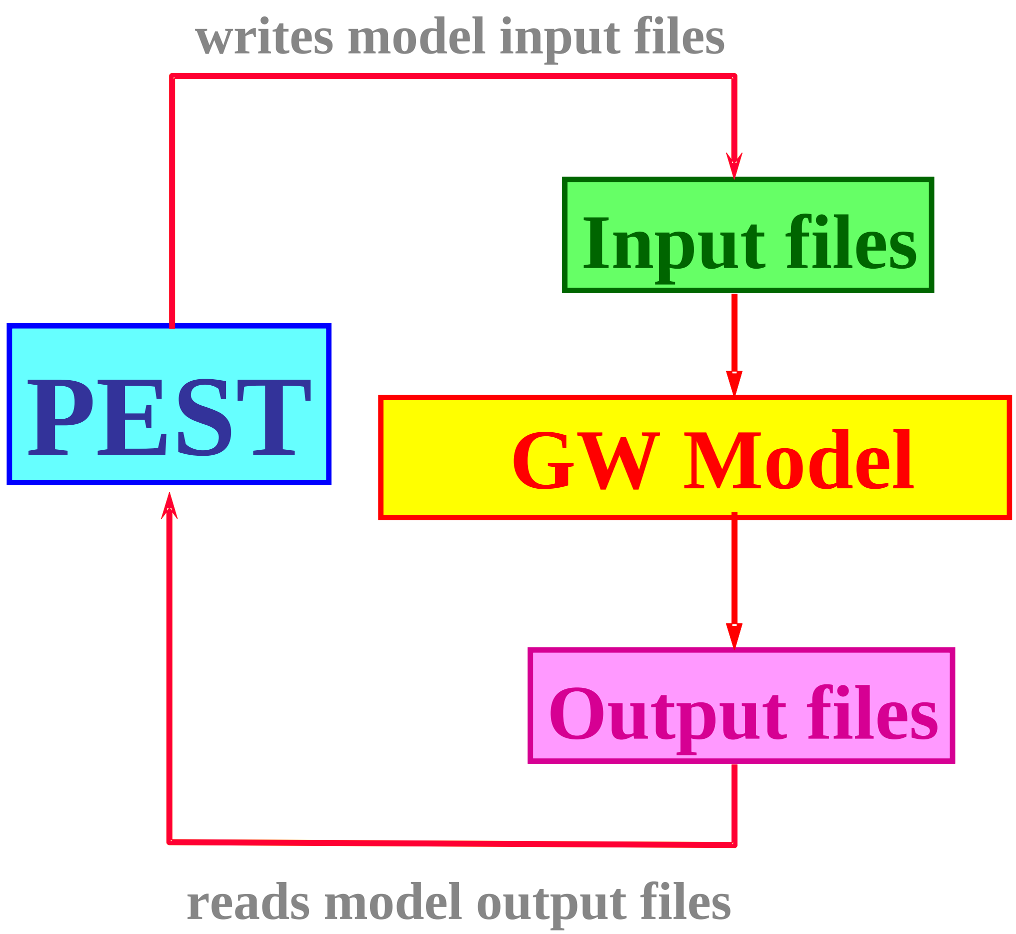
Key Calibration Issues from a Technical Perspective

- Model Objectives
  - What is intended use of model, required resolution?
- Calibration Targets
  - What do we compare the model to? What date should calibration begin?
- Non-uniqueness & Data Uncertainty
  - What is the sensitivity of model matches to changes in model inputs?
  - What is the data quality and error? How does it affect predictions?
  - Has maximum information been extracted from the data
- Transparency
  - Are adjustments from field data to model inputs traceable?
- Reproducibility
  - Are objective and systematic procedures being used?
- Resources
  - What are schedule and man power constraints?
- Goals
  - How good is “good enough”?

PEST OVERVIEW

PEST
(Parameter Estimation Software)



- PEST is a series of programs developed by John Doherty
- PEST requires that programs be tailored to each specific application
- PEST receives most of its instructions through a single control file
- PEST code is “free”

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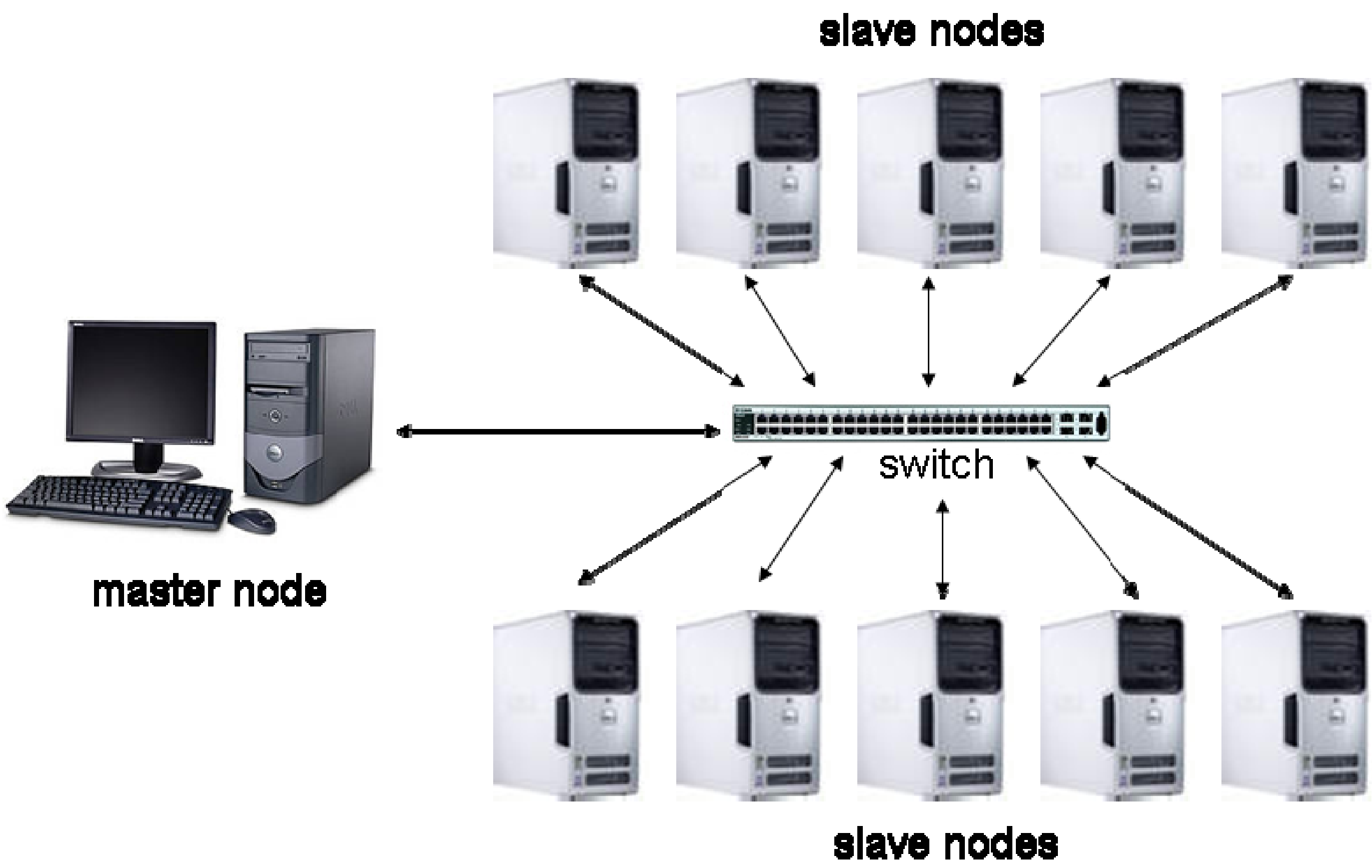
Parallel Processing With PEST



Advantage of Using PEST Compared to Conventional Trail-and-Error Approach

Issue/Concern	Advantages
Calibration Targets	Efficient calculations of residuals so there is essentially no limit on number of calibration targets
Data Uncertainty	Can incorporate several different options for weighting data and estimates. Includes routines to calculated how parameter uncertainty translates to predictive uncertainty.
Transparency	PEST instruction files provide a complete history of the conditions imposed to achieve calibration
Reproducibility	PEST operates in a systematic fashion so that any modeler will produce the same result using the same PEST files.
Resources	After model calibration set-up, PEST can be orders-of-magnitude more efficient than manual calibration. More efficient simulations allows more options to be explored and better calibrations achieved.
Non-uniqueness	PEST includes a comprehensive set of statistical analyses that quickly inform the modeler on potential problems related to non-uniqueness
Goal	PEST provides objective measures for evaluating how good is good enough.

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Possible Pitfalls that Could Render a PEST Application Unsatisfying

- Inadequate Conceptual Model
- Insufficient Numerical Discretization
- Insufficient Model Calibration Targets Available for Calibration
- Improper Weighting of Calibration Targets
- Problems with the Groundwater Code
- Poor Initial Estimates of Model Parameters
- Large Uncertainty in Historical Pumping

PEST is a tool to help extract maximum information from data. Its application does not necessarily guarantee a model will be a good predictor

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PEST APPLICATION

Summary of Calibration Approach

- Same conceptual model and modeling approach for original GAM with two exceptions
  - Changed start of model from 1980 to 1930
  - Increased number of groundwater measurements used for model calibration
- Same MODFLOW model so transmissivity does not vary with saturated thickness
- Same recharge zones and locations for hydraulic boundary conditions
- Same pumping values for 1980 to 2000
- Same hydraulic conductivity zones but zones do not have an uniform value

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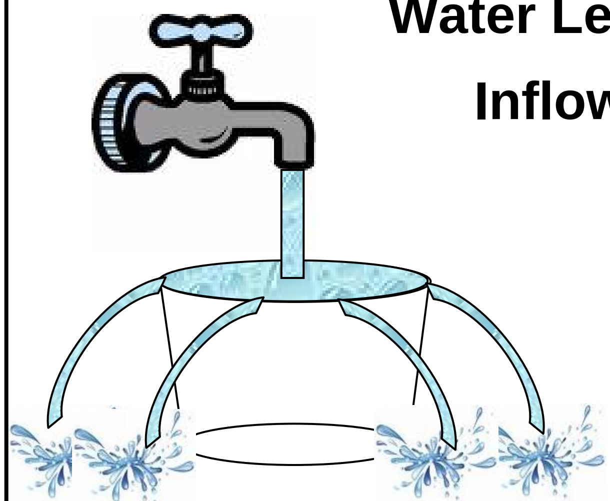
What is Steady State vs. Transient?

Steady State Condition: Bucket Overflow

Water Level Constant

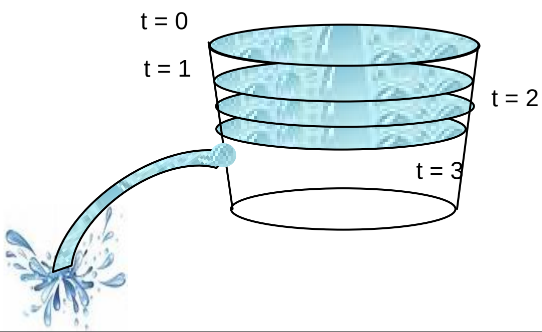
Inflow = Outflow

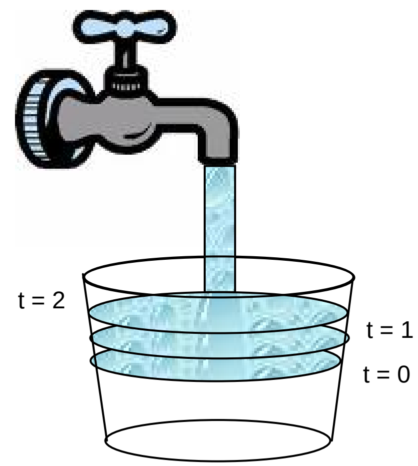


Transient Condition: Bucket Filling or Bucket Draining

Water Level Changing

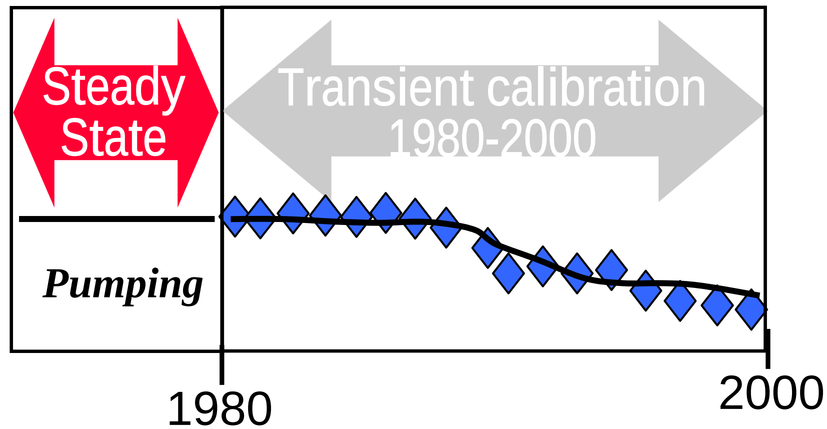
Inflow ≠ Outflow



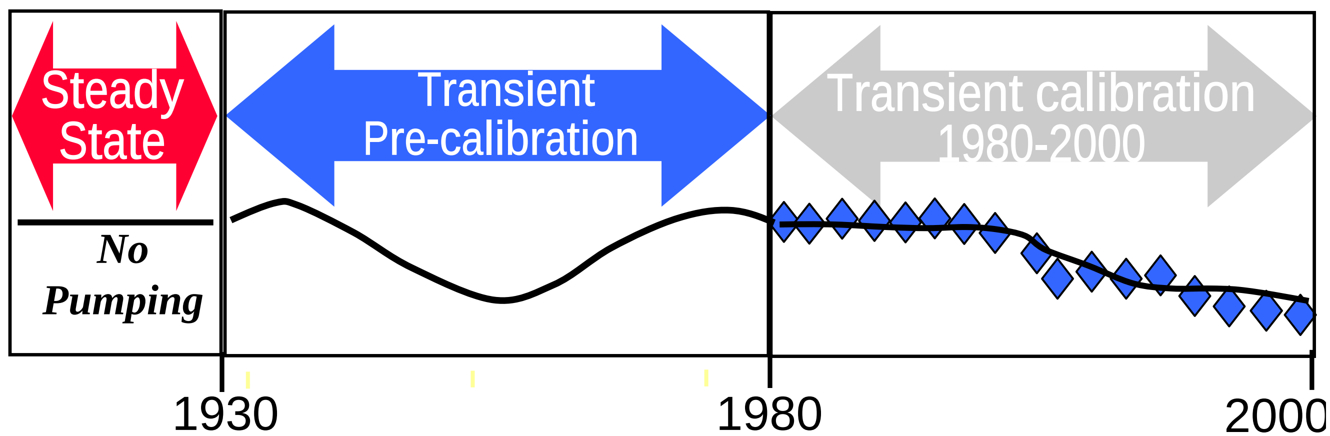


Difference in the Modeling Periods

- Original GAM



- Re-Calibrated GAM

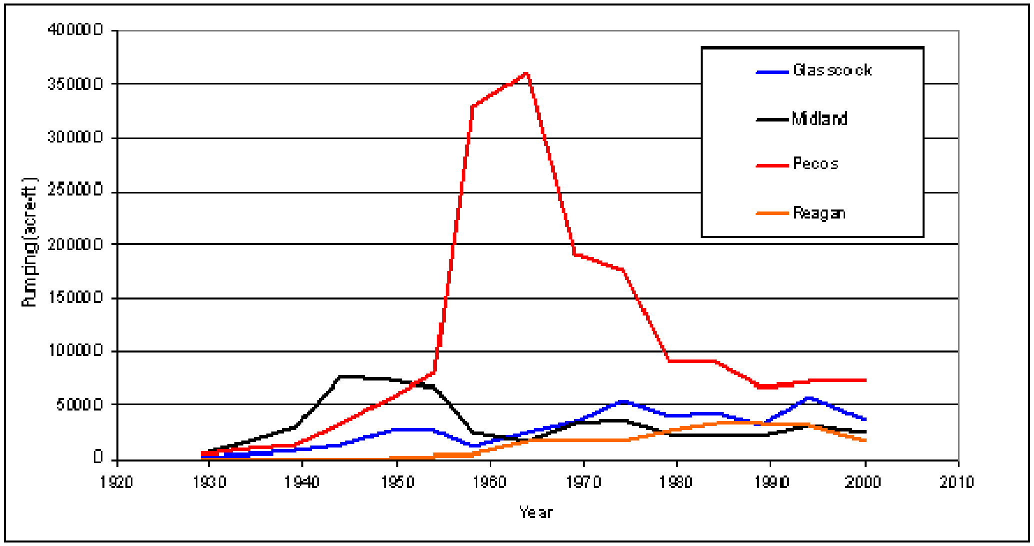


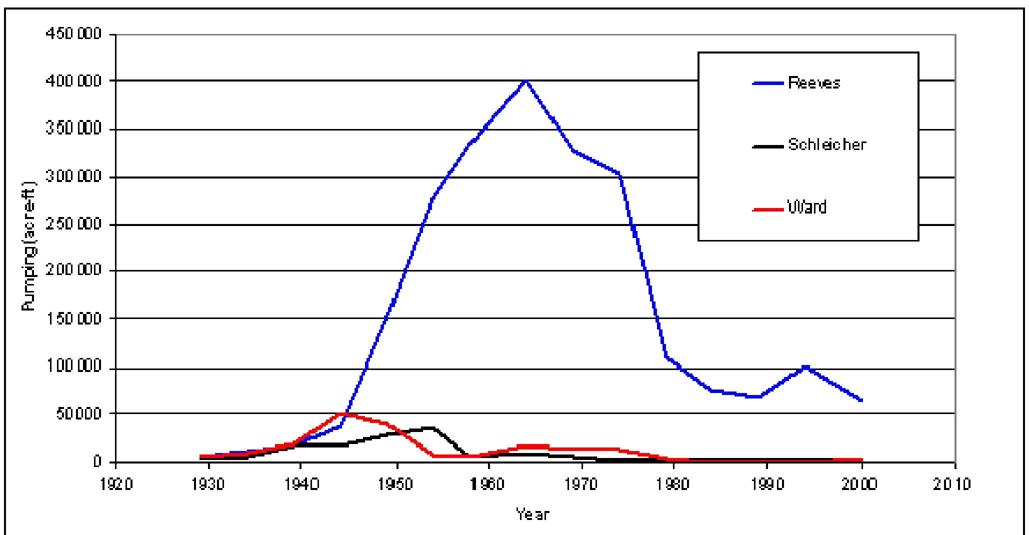
LEGEND

Observed Water Level

Model Water Level

Approach for Estimating Historical Pumping from 1930 to 1980





- Identify counties that have greatest pumping from 1930 to 1980
- Blend TWDB data and US Agricultural Surveys to estimate pumping rates

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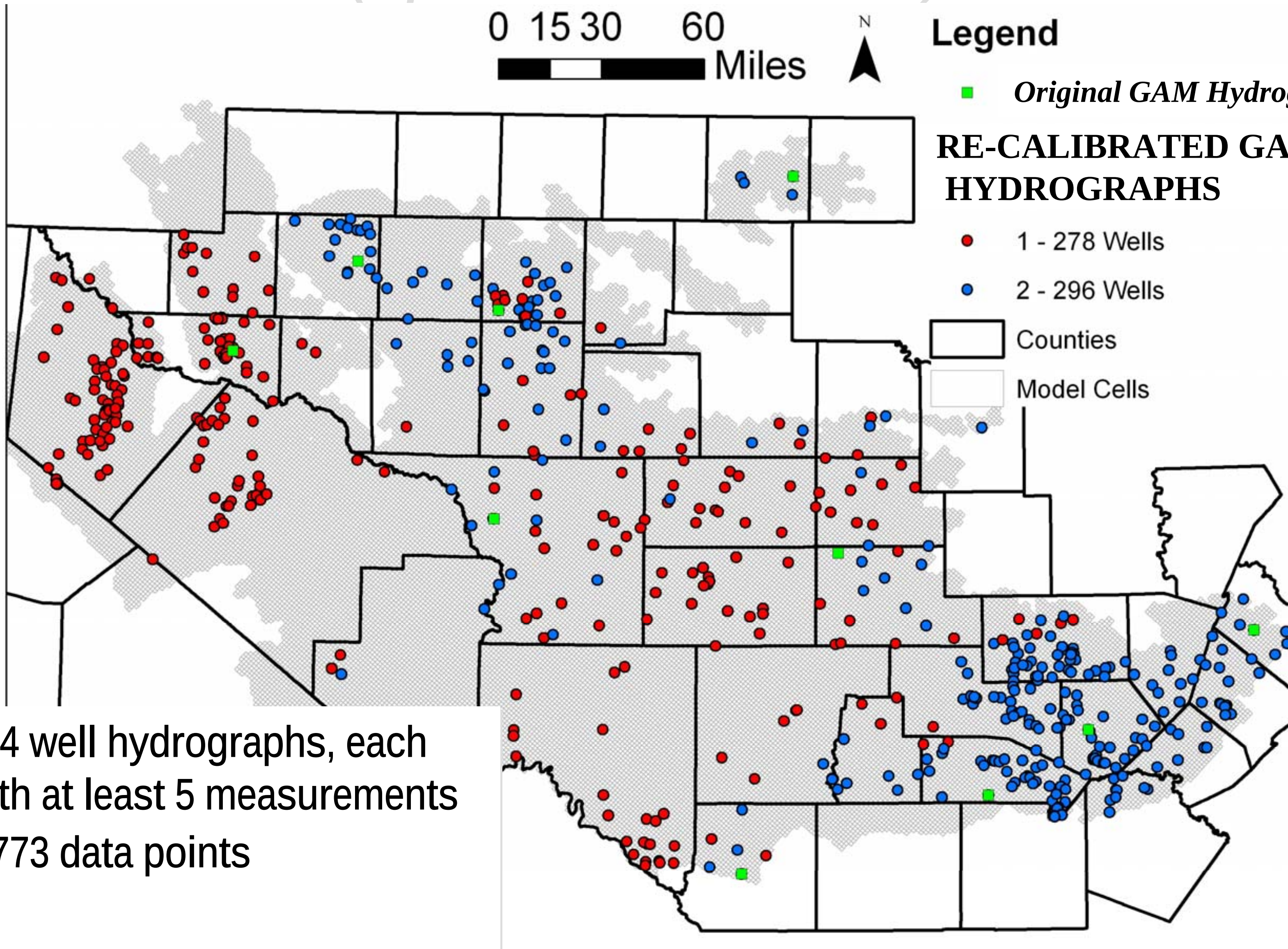
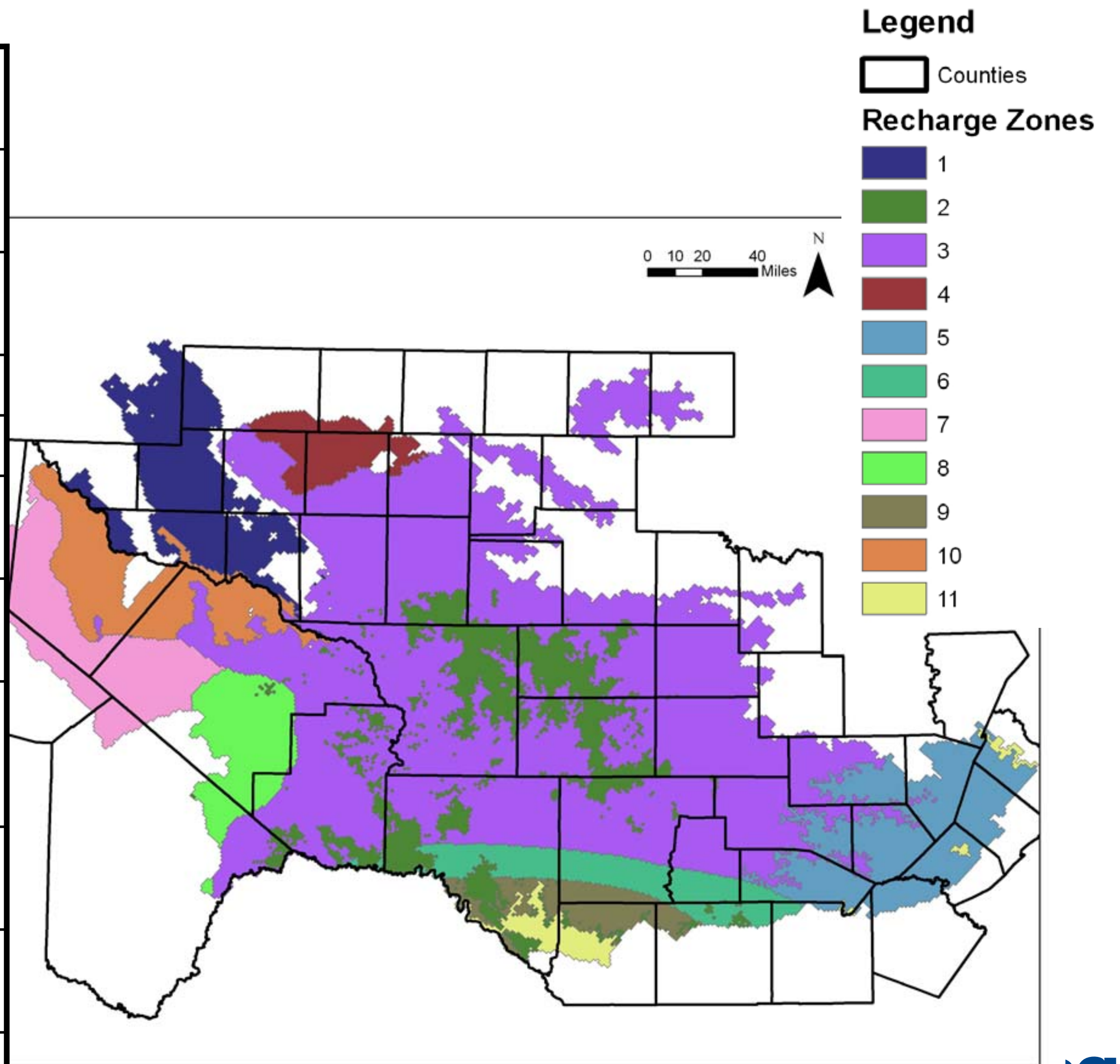
Difference in the Hydrographs (Spatial Distribution)



- 574 well hydrographs, each with at least 5 measurements
- 4,773 data points

Original GAM Recharge Zones

Zone Number	Recharge Zone	Percent Rainfall
1	Cenozoic Pecos Alluvium North	1
2	Buda Limestone or Del Rio Formation	1
3	Edwards Group	2
4	Ogallala Sediments	3
5	Hill Country Trinity Group	4.7
6	Edwards – Devil's River Formation	5
7	Edwards – Trans-Pecos Basin and Range	6.0
8	Edwards – Stockton Plateau	8
9	Edwards – Maverick Basin	10.2
10	Cenozoic Pecos Alluvium South	5



Constraints on Uniform Rates for Recharge Zones

Assumed Re-calibrated GAM values should be close to Original GAM estimates

Recharge Zone		Preferred recharge factor	Lower bound	Upper bound
Number	**Name**			
1	Cenozoic Pecos – Alluvium North	0.01	0.0009	0.020
2	Buda Limestone or Del Rio Formation	0.01	0.0009	0.020
3	Edwards Group	0.02	0.016	0.04
4	Ogallala Sediments	0.03	0.02	0.06
5	Hill County Trinity Group	0.047	0.037	0.057
6	Edwards – Devil's River Formation	0.05	0.04	0.07
7	Edwards-Trans-Pecos Basin and Range	0.06	0.04	0.08
8	Edwards – Stockton Plateau	0.08	0.06	0.10
9	Edwards – Maverick Basin	0.102	0.08	0.12
10	Cenzoic Pecos Alluvium South	0.05	0.04	0.07

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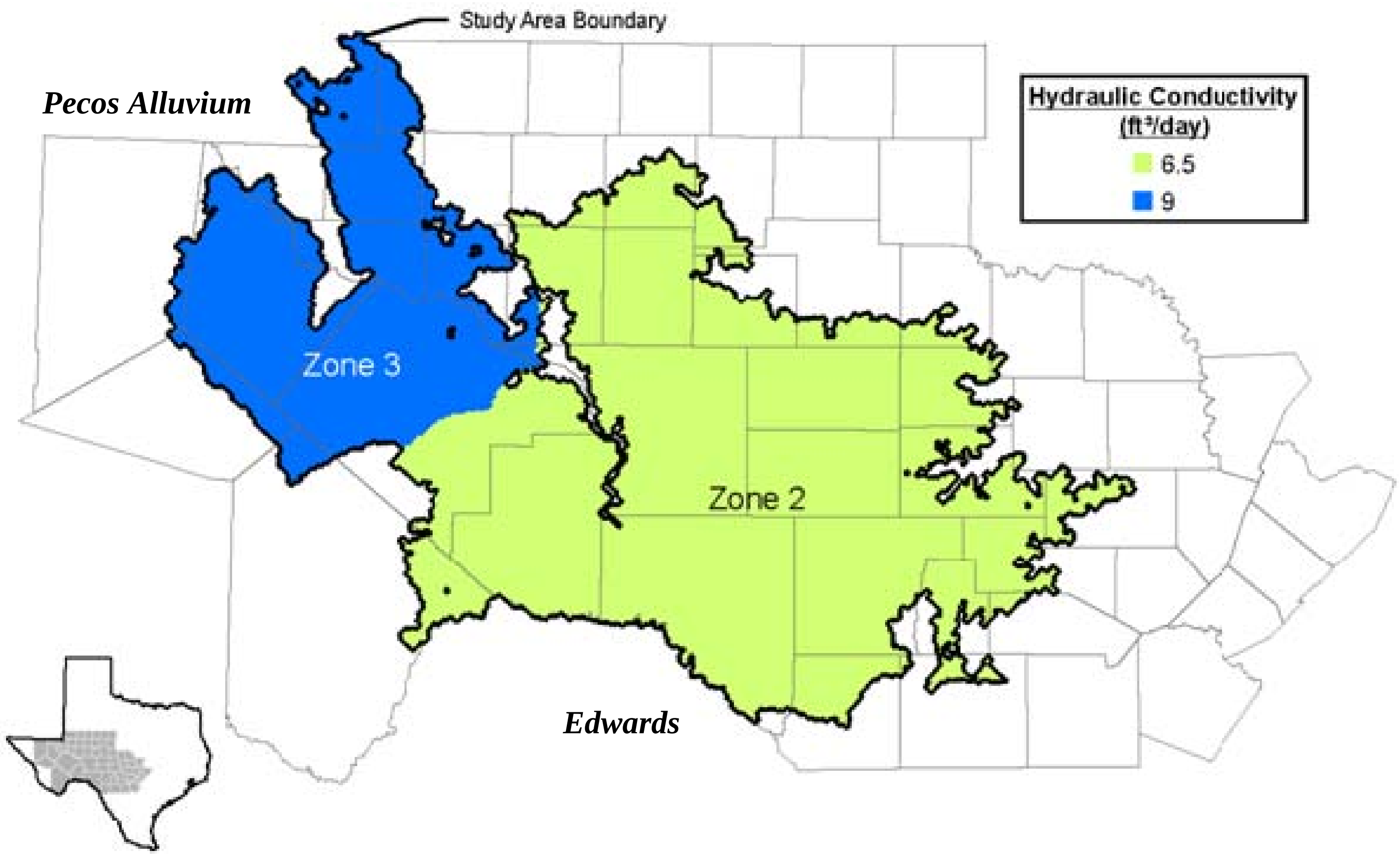
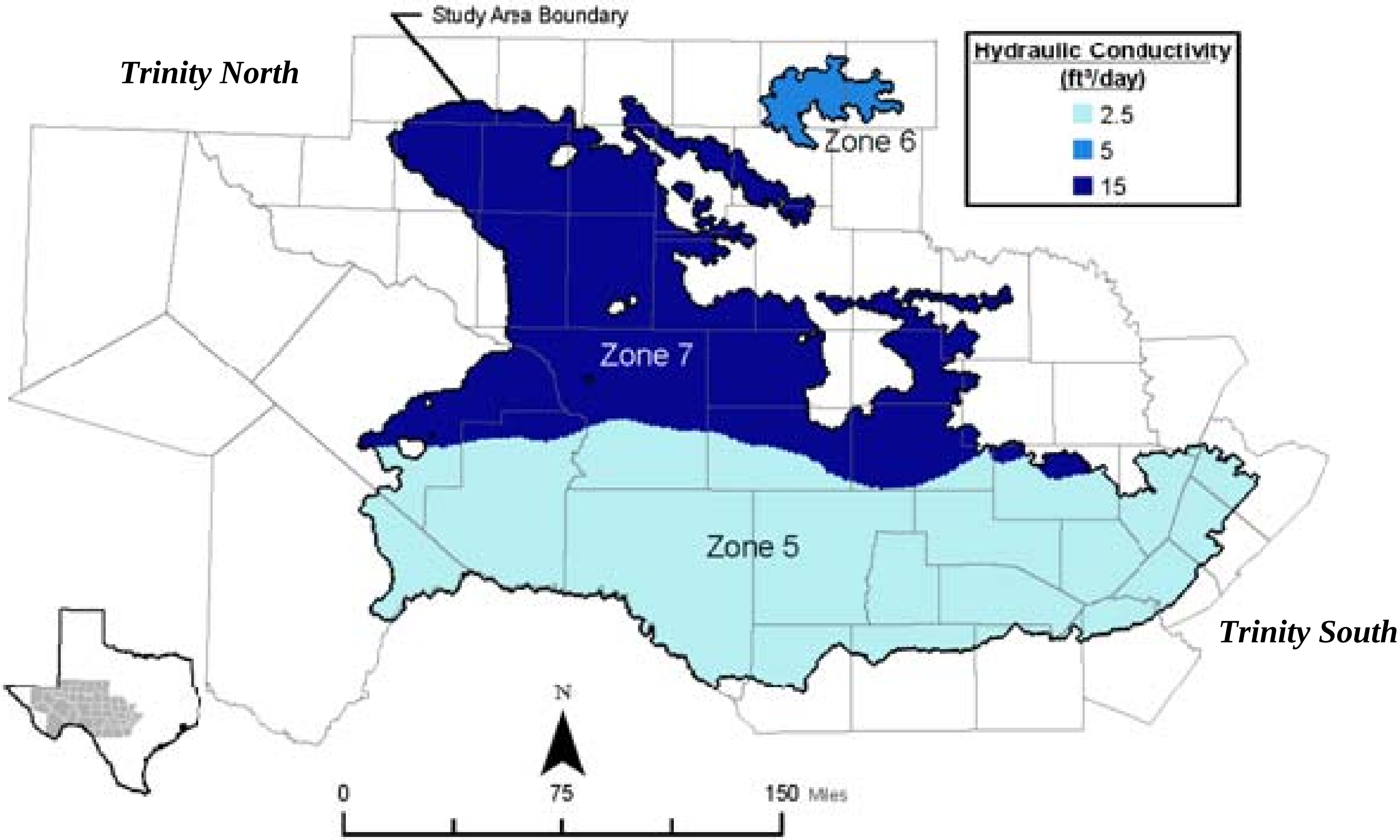
Original GAM Hydraulic Conductivity Zones in Model Layer 1



Original GAM Hydraulic Conductivity Zones in Model Layer 2



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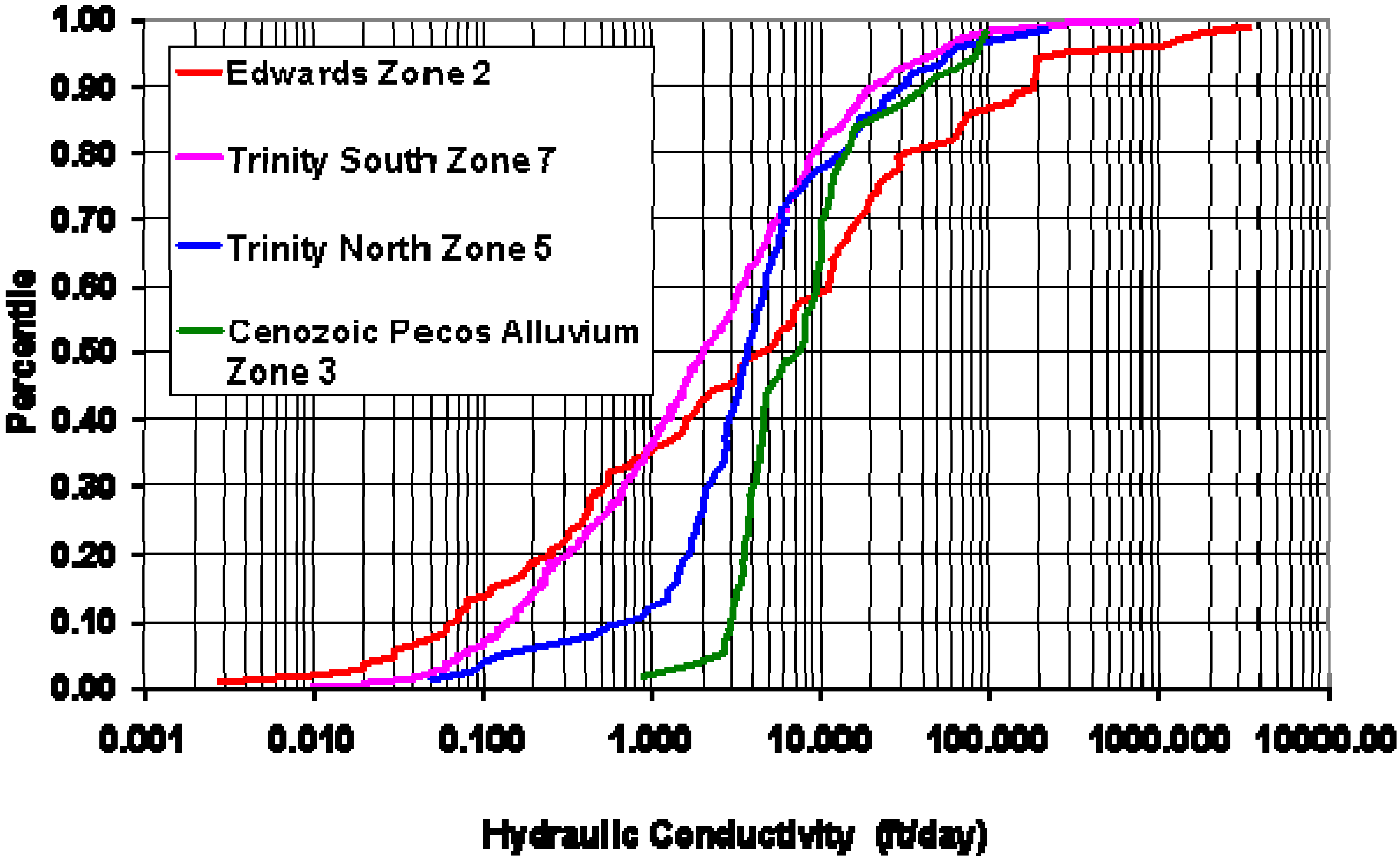
Distribution of Hydraulic Conductivity Values for Each Zone*



* Project did not perform QA/QC on data

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Constraints Placed on Hydraulic Conductivity Zones

Constraints on Average for Each Zone

Zone number	Preferred zonal average (median value)	Zonal lower bound (40% percentile)	Zonal upper bound (60% percentile)	Number of data points	Original GAM
2	4.72	1.54	11.16	105	6.5
3	7.54	4.72	9.34	55	9
5	1.77	1.24	3.4	504	2.5
6	3.74	2.85	4.8	-	5
7	3.74	2.85	4.8	74	15

Constraints on Value for Each Grid Cell

Limit on Hydraulic Conductivity	Aquifer Zone				
	2	3	5	6	7
Lower	8	5	1	1.6	1
Upper	16	13	7	7	6

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Information in PEST Control File

- Ranges for Model Inputs
  - Preferred Value
  - Minimum and Maximum Values
  - Allowed Amount and Type of Spatial Variability
- Weighting Factors for Calibration Targets
  - Includes both
  - Account for different type of data
  - Account for measurement error
- Optimization Approach
  - Estimation technique
  - Method accounts for correlation among model parameters
  - Closure criteria

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Example Listing of PEST Control File

Hydraulic Conductivity Zone Constraints

hk1_zone2	log	factor	4.72	1.54	11.16	hkzone
hk1_zone3	log	factor	7.54	4.72	9.34	hkzone
hk2_zone5	log	factor	1.99	1.24	3.4	hkzone

Recharge Zone Constraints

rf_zone1	log factor	0.01	0.0009	0.020	rfzone
rf_zone2	log factor	0.01	0.0009	0.020	rfzone
rf_zone3	log factor	0.02	0.016	0.04	rfzone
rf_zone4	log factor	0.03	0.02	0.06	rfzone

Preferred Value

Upper Limit

Lower Limit

Groundwater Elevations

h_4421403_01	2475.880	5.292556E-03	heads_lay2
h_4421403_02	2482.800	5.292556E-03	heads_lay2
h_4421403_03	2480.700	5.292556E-03	heads_lay2
h_4421403_04	2460.300	5.292556E-03	heads_lay2
h_4421403_05	2464.100	5.292556E-03	heads_lay2

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ETPVA GAM

Re-Calibration Results

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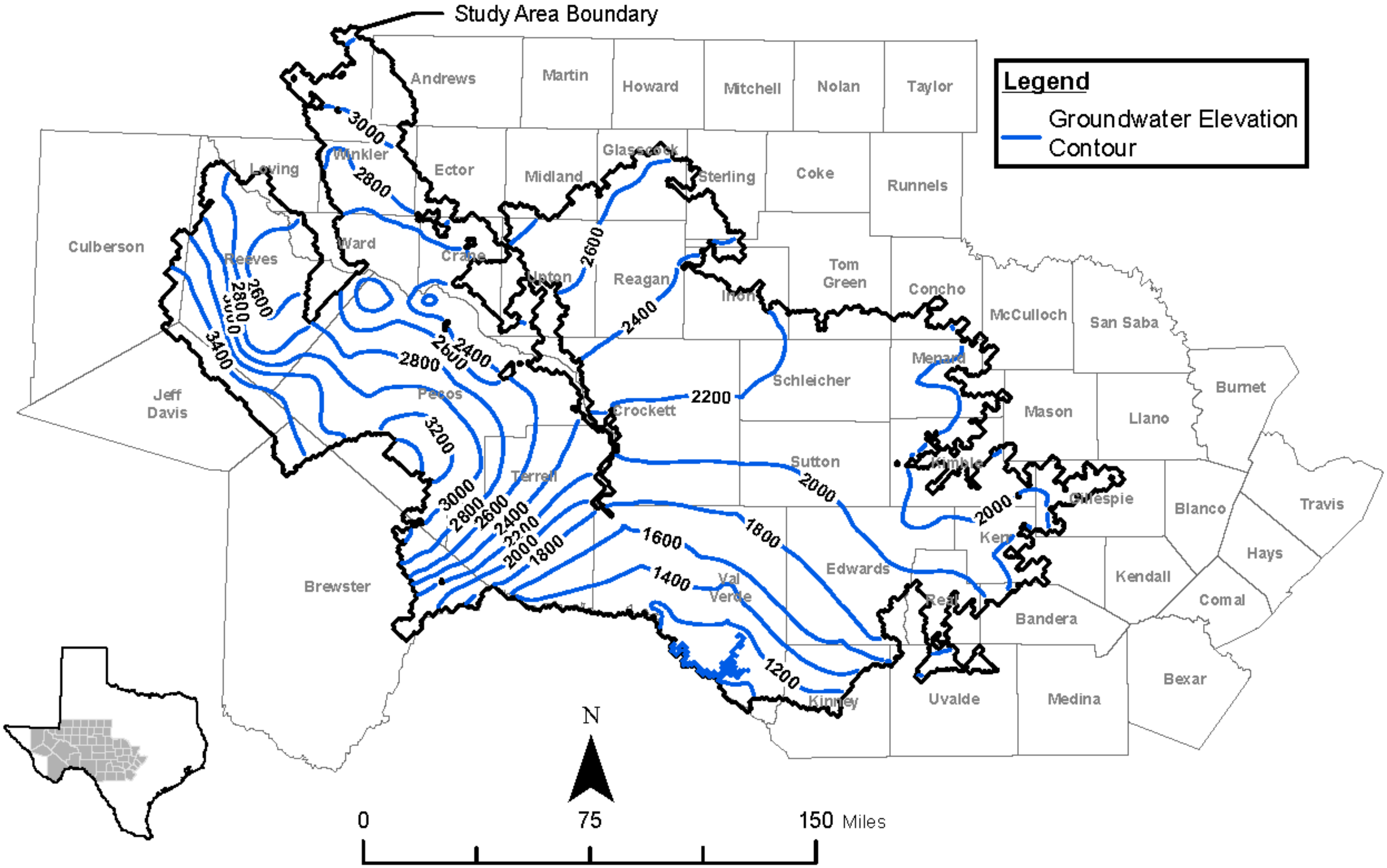
Simulated Groundwater Elevations by Re-calibrated GAM: Layer 1



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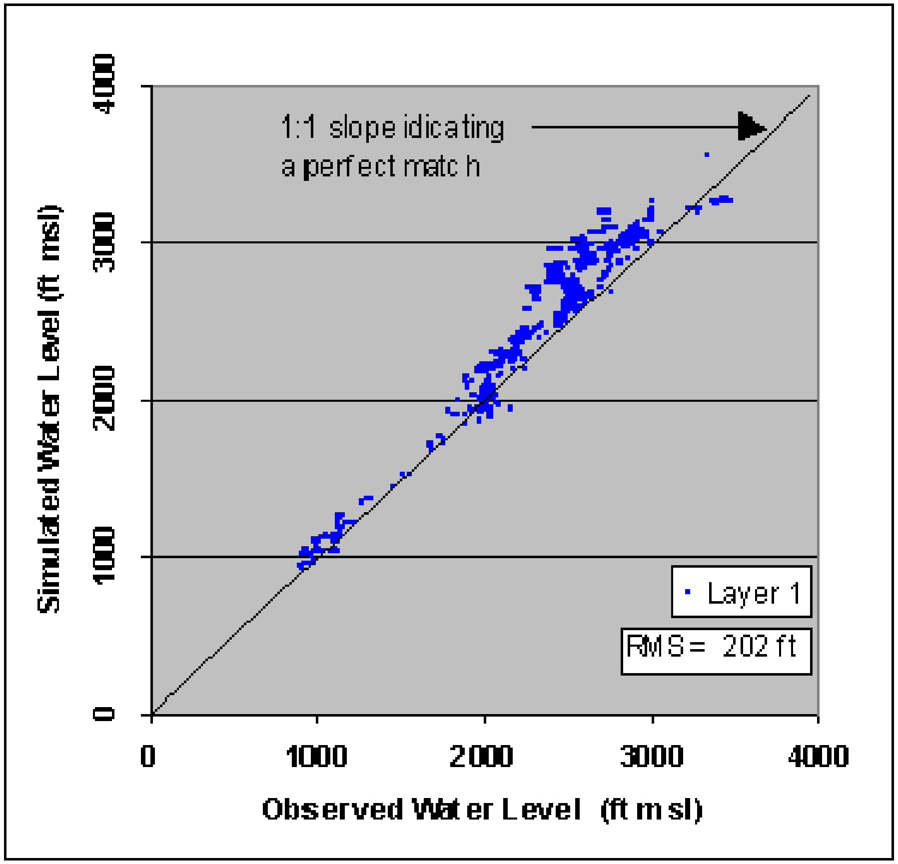
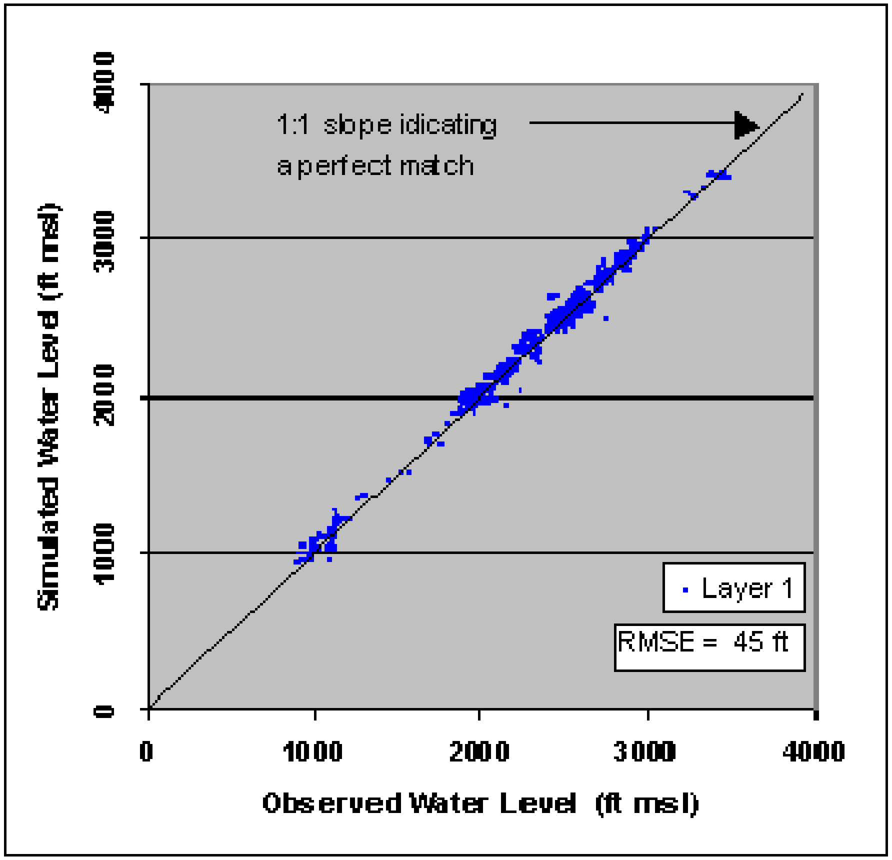
Matches to 1980-2000 Well Hydrographs by County: Layer 1

Original GAM



Re-calibrated GAM



Note: 1.)RMS & RMSE = Root-Mean Square Error
2.)RMS for original GAM is based on the 574 hydrographs selected for this project. Original GAM calibration report had a RMS of about 140 feet

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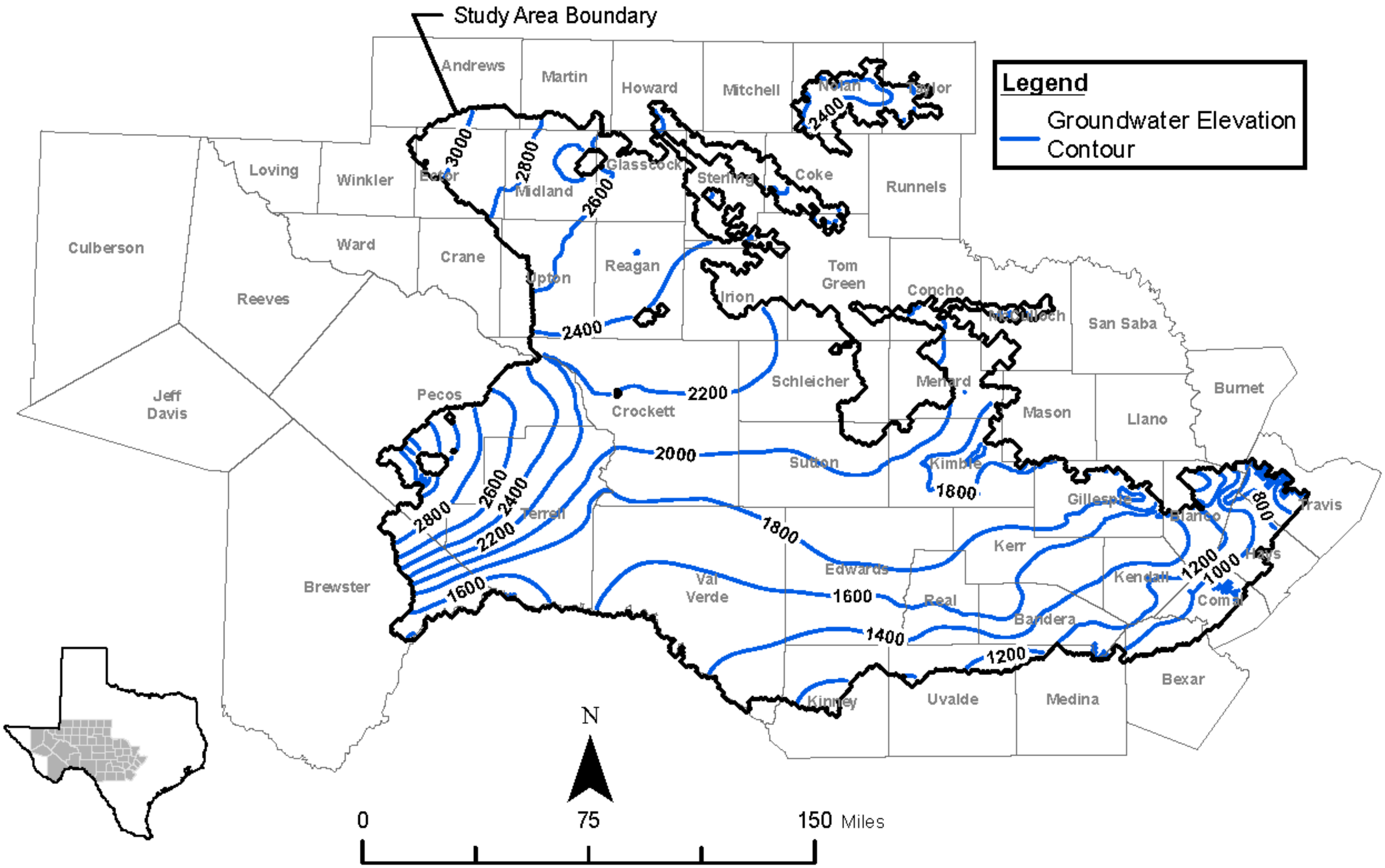
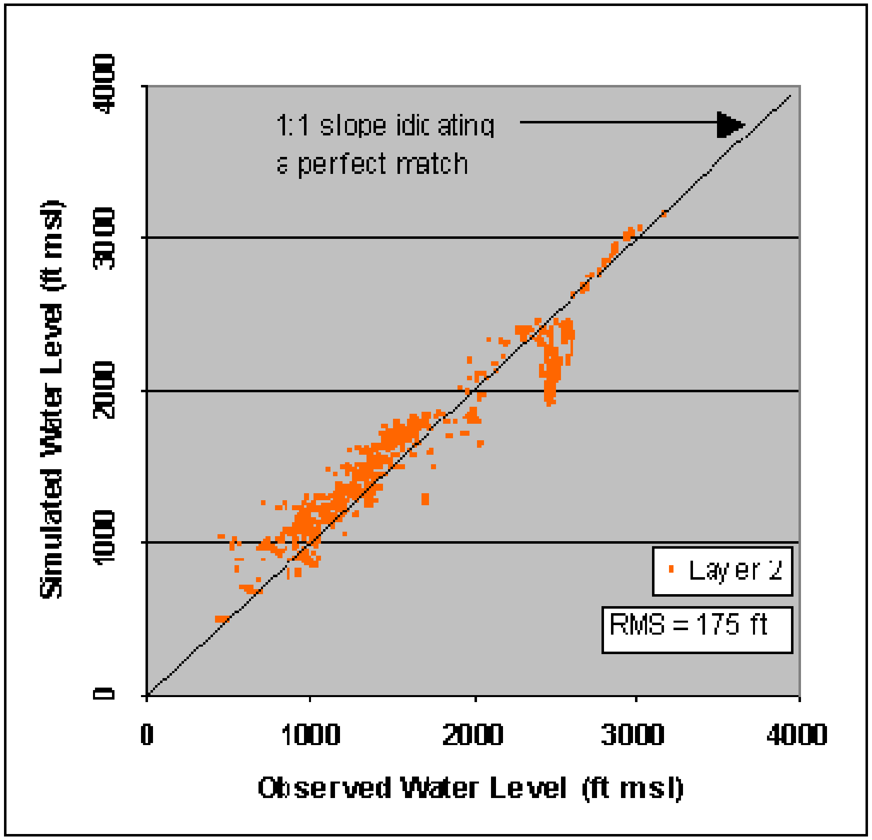
Matches to 1980-2000 Well Hydrographs by County: Layer 2

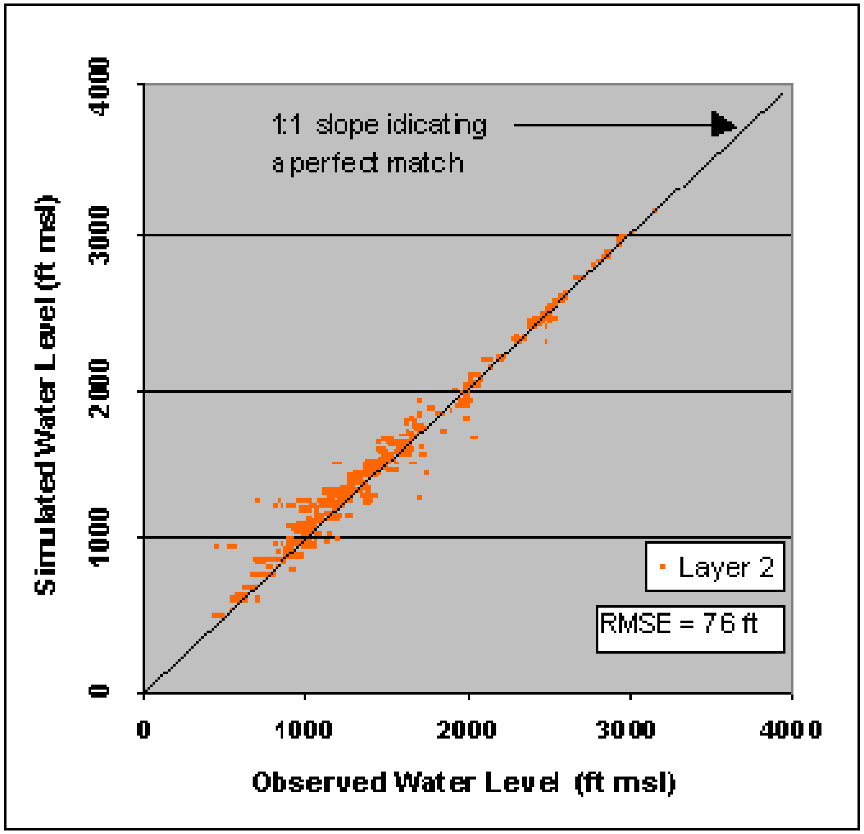


Matches to 1980-2000 Well Hydrographs by County: Layer 2

Original GAM



Re-calibrated GAM



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History Matches to Well Hydrographs by County

County	Root-Mean Square Error for GAM		Num. of Points	Number of Wells	County	Root-Mean Square Error for GAM		Num. of Points	Number of Wells
	Re-Calibrated	Original				Re-Calibrated	Original		
All	60.4	182.9	4773	574	Kinney	52.0	79.6	52	6
Bandera	121.2	131.9	267	40	Loving	5.8	19.2	20	2
Bexar	128.5	172.0	77	10	McCulloch	13.7	63.9	12	1
Blanco	73.9	200.1	82	11	Menard	18.9	109.3	110	13
Brewster	9.6	225.9	6	1	Midland	12.3	135.0	66	7
Comal	55.4	97.3	34	8	Nolan	40.8	84.7	35	4
Concho	32.2	32.6	30	4	Pecos	39.5	230.8	333	31
Crane	7.3	25.3	18	2	Reagan	23.4	268.9	168	21
Crockett	31.7	139.7	191	27	Real	93.4	151.9	91	9
Ector	9.1	50.1	117	17	Reeves	53.1	301.6	555	55
Edwards	126.9	128.8	65	10	Schleicher	32.6	153.1	126	15
Gillespie	71.6	122.8	317	46	Sterling	23.7	82.9	19	2
Glasscock	29.5	279.8	249	23	Sutton	54.4	177.8	159	17
Hays	87.0	201.4	72	15	Terrell	83.9	196.4	22	5
Irion	41.4	110.3	66	7	Travis	30.4	149.0	62	7
Kendall	83.8	117.1	246	31	Upton	9.4	176.8	72	6
Kerr	66.5	143.8	213	31	Ward	16.2	111.9	369	34
Kimble	55.1	132.4	91	13	Winkler	31.5	133.8	115	12

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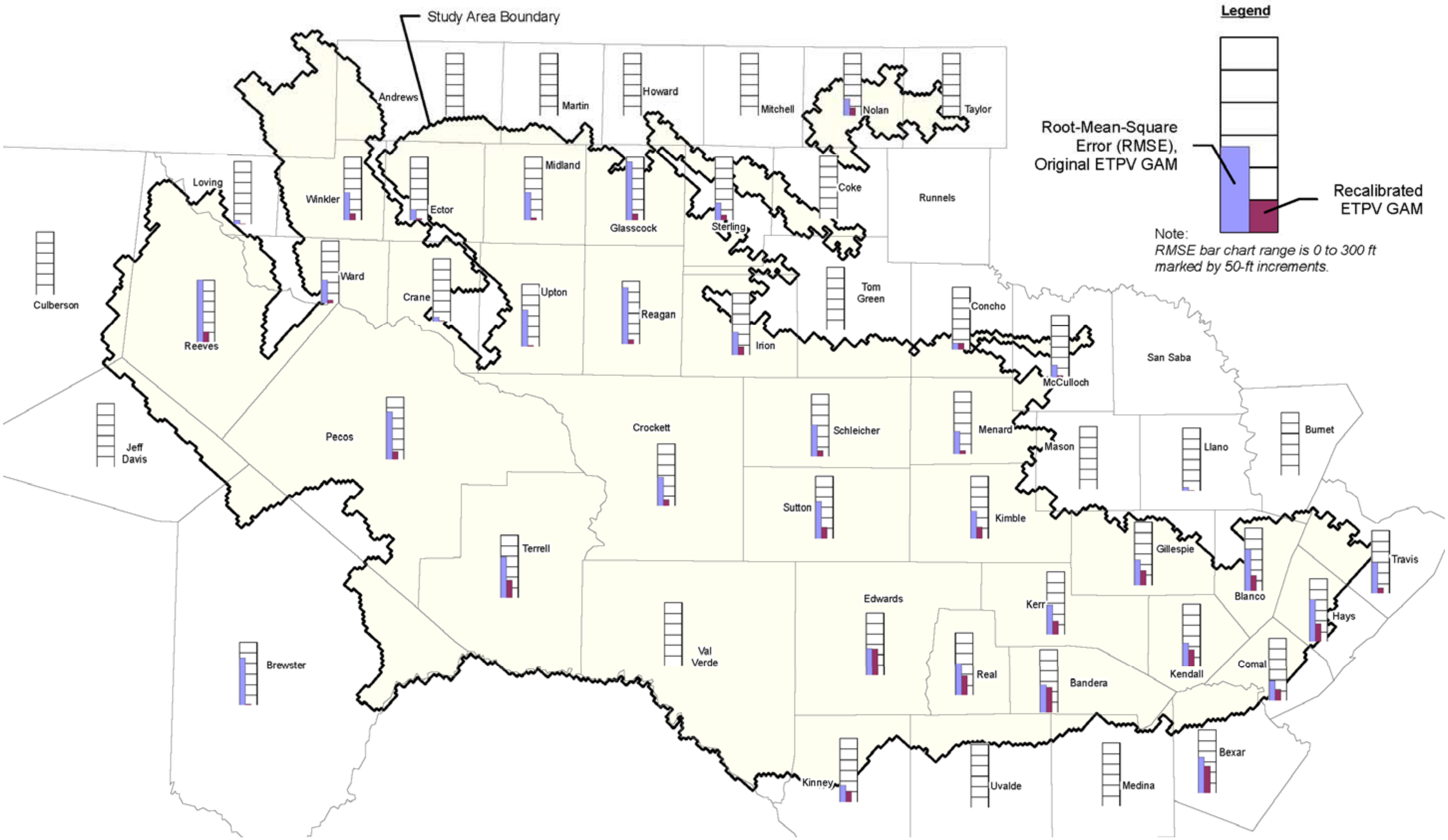
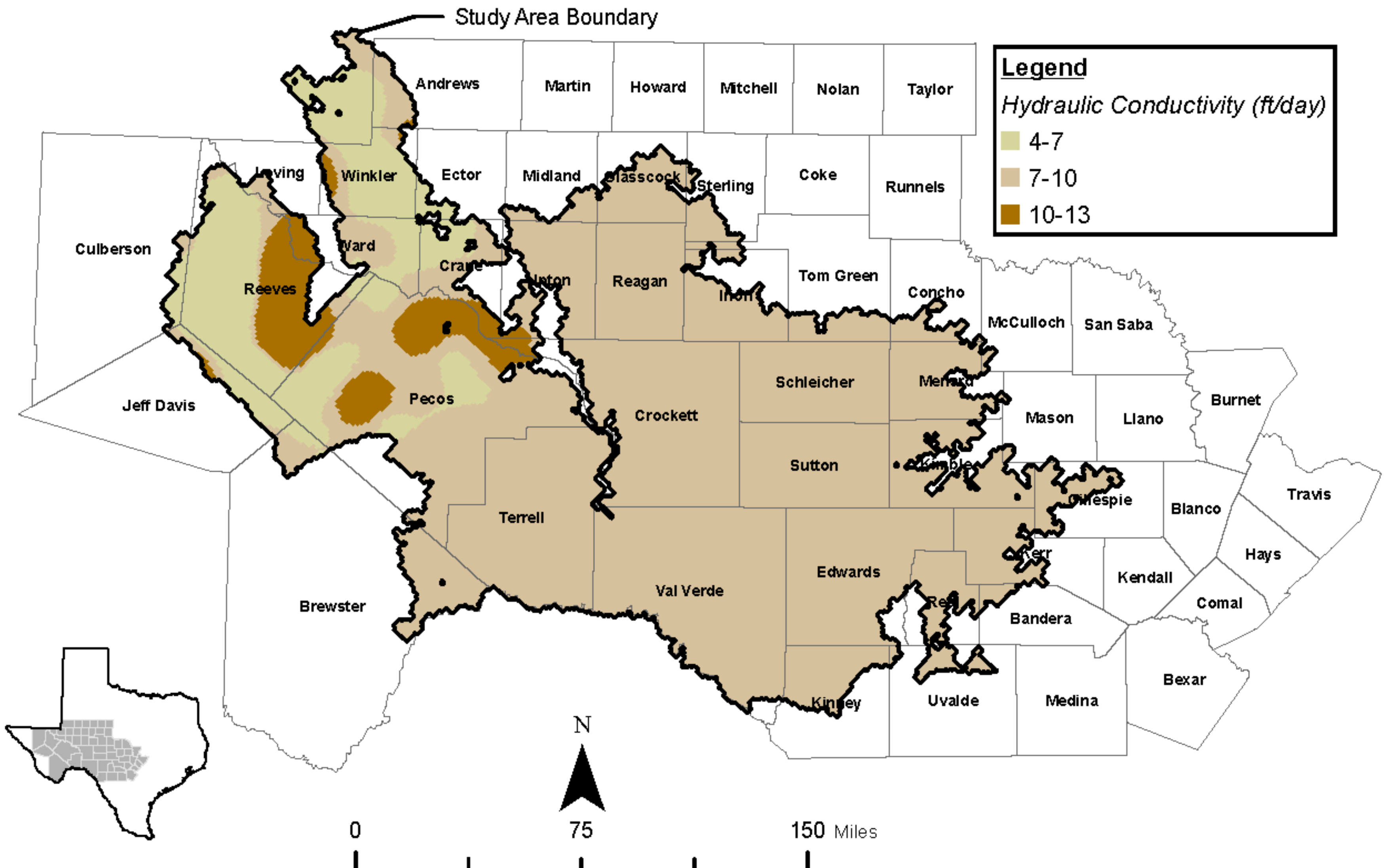
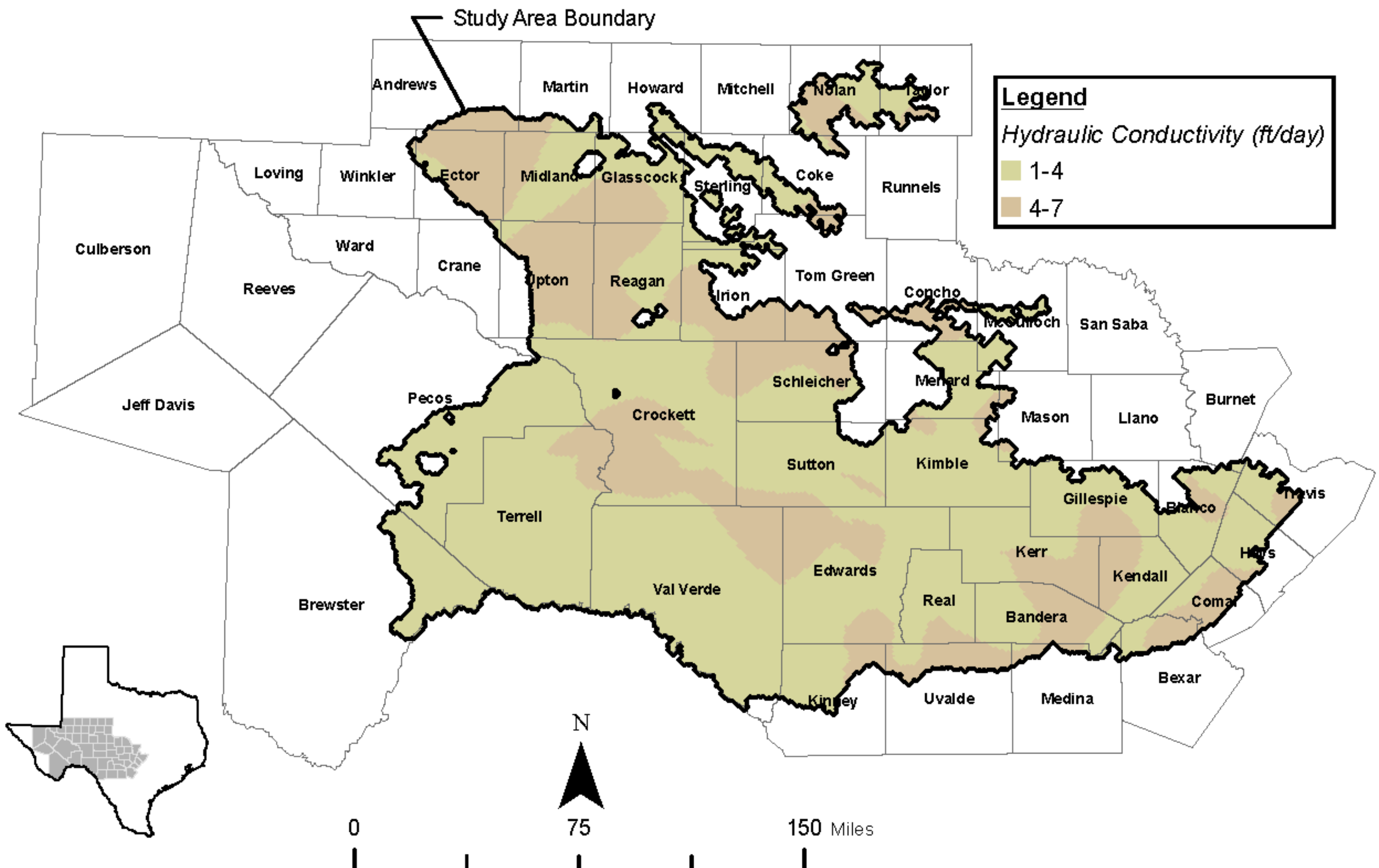
History Matches to Well Hydrographs by County



Re-calibrated GAM Hydraulic Conductivity Field: Layer 1



Re-calibrated GAM Hydraulic Conductivity Field: Layer 2



GAMs' Hydraulic Conductivity Field: Summary

Aquifer parameter			Zone 2 Edwards	Zone 3 Pecos Valley	Zone 5 Trinity South	Zone 6 Trinity North	Zone 7 Trinity North
Horizontal Hydraulic Conductivity (ft/day)	ReCalibrated GAM	Arithmetic average	8.0	7.6	2.9	3.3	3.9
		Median	8.0	7.1	2.1	3.7	3.7
		Minimum	8.0	4.0	1.0	1.0	1.0
		Maximum	8.9	13.0	7.0	6.9	7.0
	Original GAM	Uniform Value	6.5	9	2.5	5	15
	Field Data	Median	4.72	7.54	1.77	3.74	3.74
		40% Percentile	1.54	4.72	1.24	2.85	2.85
		60% Percentile	11.16	9.34	3.4	4.8	4.8

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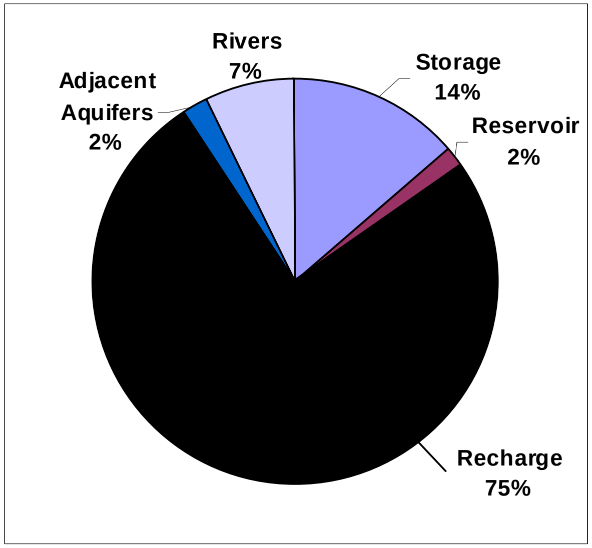
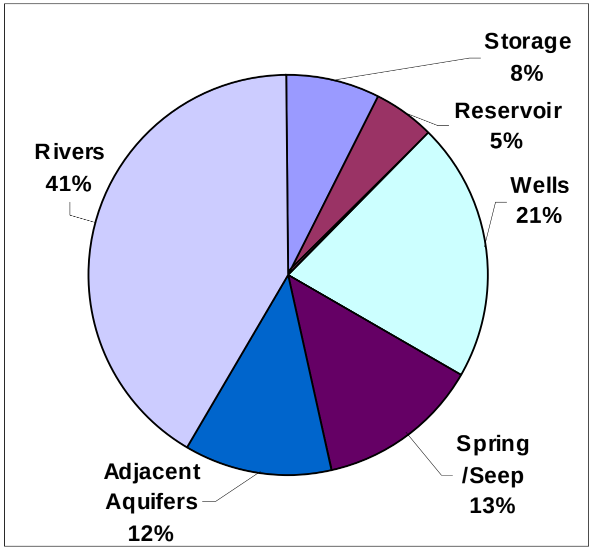
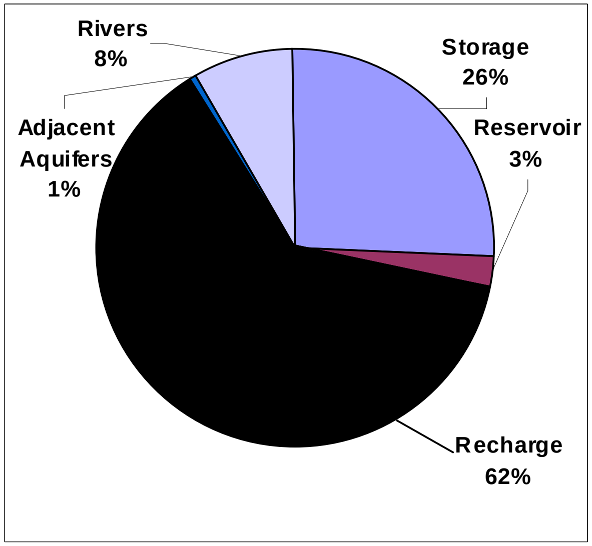
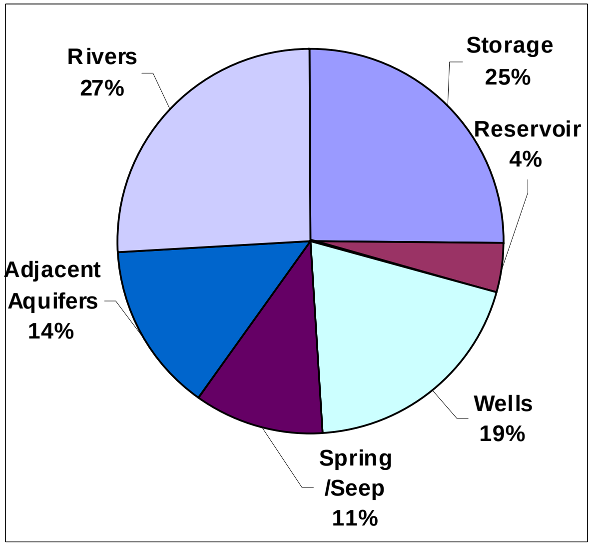
GAMs Water Budget Summary

	Sources	Sinks
Original GAM		
Re-Calibrated GAM		

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Summary of Report

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Report Summary

- Thorough Technical Discussions on PEST Capabilities and Model Calibration Process
- Detailed Description of the Files Used to Run PEST for the ETPVA GAM Re-calibration
  - utility programs
  - model input and output files
- Listing of Wells used for the model Calibration
- Figures Illustrate Results from Original and Re-Calibration ETPVA GAM

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Report Summary

- Description of the High-Performance HPC Cluster
  - Six Duo Core HP Desktops
  - Linux operating system
- PEST application is significantly more advanced than PEST utilities available through MODFLOW GUIs
- PEST optimized on 2485 model parameters – complete simuation required about 3 days of run time

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Recommended Model Improvements

Recommended Model Improvements

- Subdivide GAM into smaller more regional models
- Develop improved site conceptual models
- Mine the literature for additional pumping tests
- Replace MODFLOW96 so transmissivity can vary with changes groundwater levels
- Revised grid sizes for improved capability to accurately simulate groundwater- surface water interactions and impacts from pumping

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Recommend PEST Be Considered for Future Use

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Reproducibility	PEST operates in a systematic fashion so that any modeler will produce the same result using the same PEST files.
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Non-uniqueness	PEST includes a comprehensive set of statistical analyses that quickly inform the modeler on potential problems related to non-uniqueness
Goal	PEST provides objective measures for evaluating how good is good enough.

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Additional Benefit of a PEST Model

- Provides platform to quickly investigate different assumption in model parameters
  - Change values in the PEST control file
  - Type "pest jobname.pst"
- Provides a transparent platform for others to review or to enhance
- Provide comprehensive documentation of assumptions and constrains

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