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

Stakeholder Forum
Sorona, TX

Steve Young, URS

December 11, 2008

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Outline

- Purpose
- Project Overview
- Model Calibration
- PEST
- ETPVA GAM Calibration
- Summary

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] cited 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 *

1 4 summarized from TWDB RFQ

Stakeholder Forum Purpose

- Provide Public Awareness of GAM
- Update Interested Participants
- Solicit Data and Information
- Exchange Ideas
- Encourage and Receive Feedback

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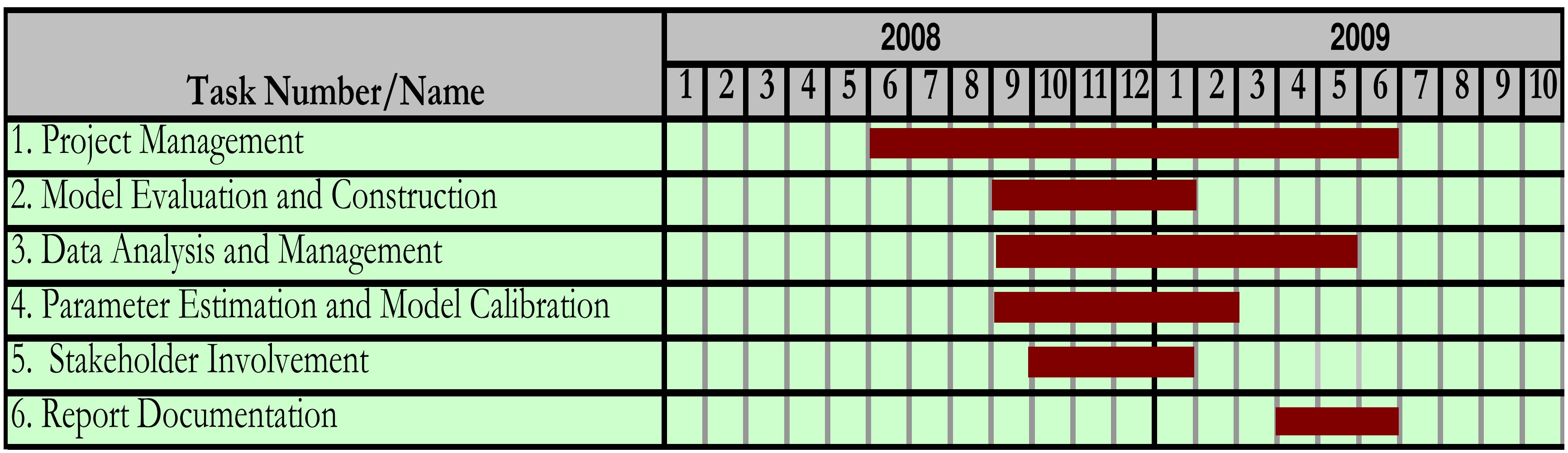
Project Overview: Schedule

- **Kickoff Meeting - July 2008**
- **Study Completion Date – July 2009**



Schedule for Stakeholder Involvement Focuses on Data Exchange

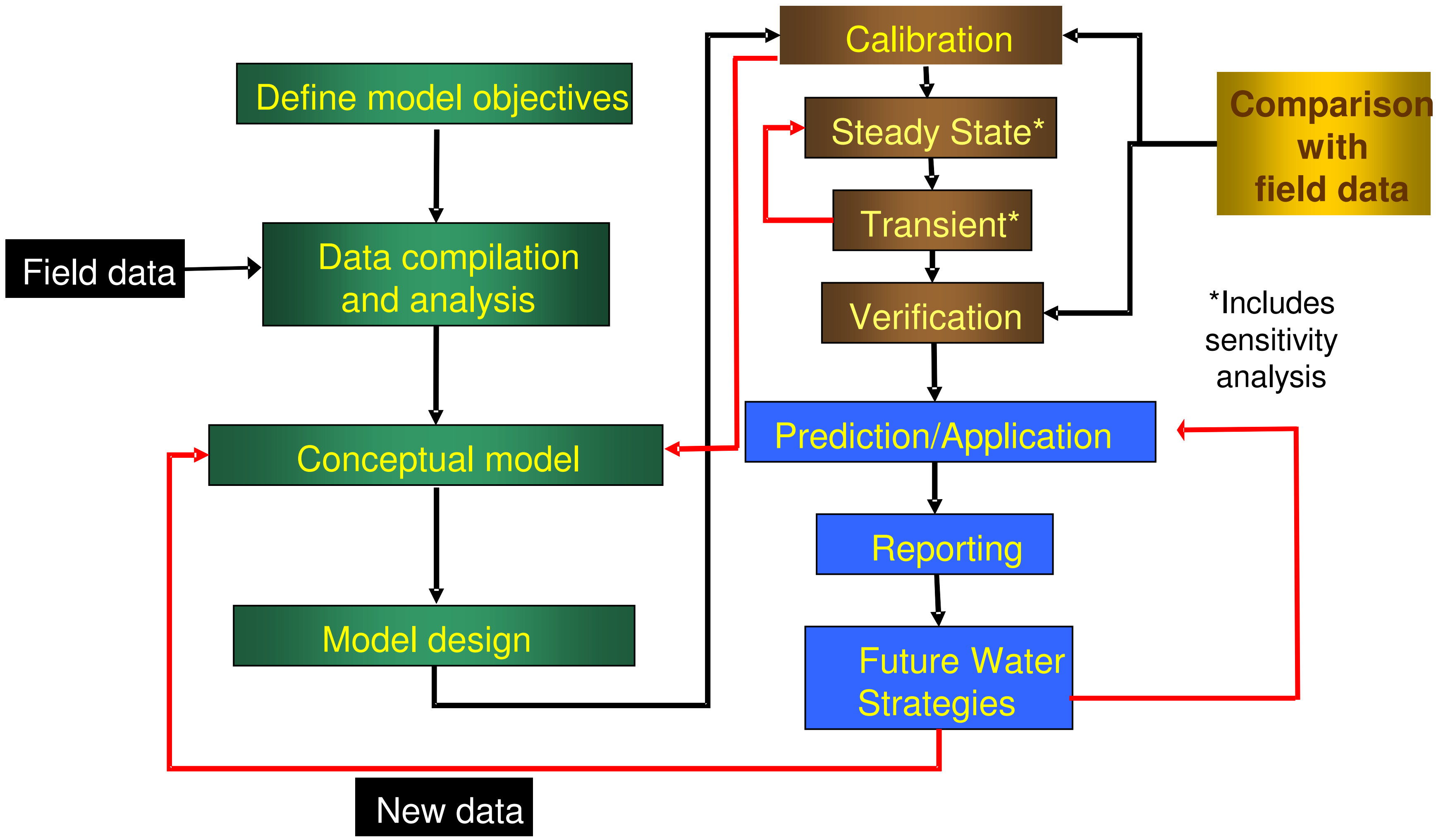
Project Overview: Team Members

Company/ Personnel	Responsibility/Expertise
URS	Project Management, Model Construction, Model Calibration, PEST Experience
Steve Young, PE, PG, PHD	
Trevor Budge, PHD	
WaterMark Consulting	PEST software, Parameter Estimation, Predictive Uncertainty
John Doherty, Ph.D	
INTERA, Inc	High Performance Network Clusters, GAM Development and Application, Model Calibration, PEST Experience
Van Kelley, PG	
Neil Deeds, PE, PHD	
Environmental Simulations, Inc.	Groundwater Vista Graphical User Interface for MODFLOW,
Jim Rumbaugh, PG	
Laura Raun Public Relations	Public Involvement
Laura Raun	

Model

Calibration

Tasks Associated with Model Development & Application



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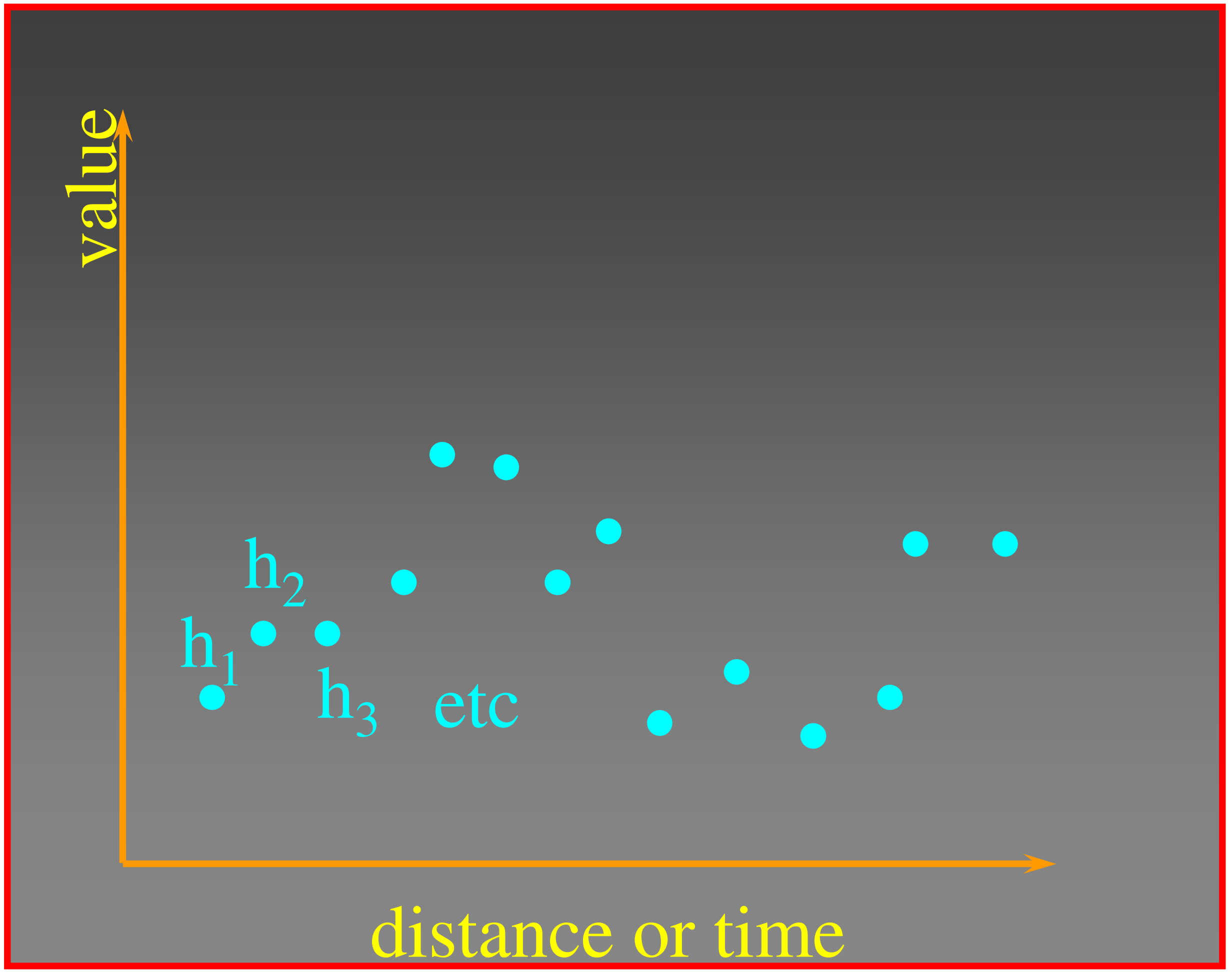
What is Model Calibration?

- The process of adjusting model inputs so that model calculations match what we measure in the real-world.
- Sometimes called “history matching”
- A good model calibration is not sufficient to develop a good model. Also need good data, a good conceptual model, and an adequate numerical grid.

Real World Data

Field or laboratory measurements



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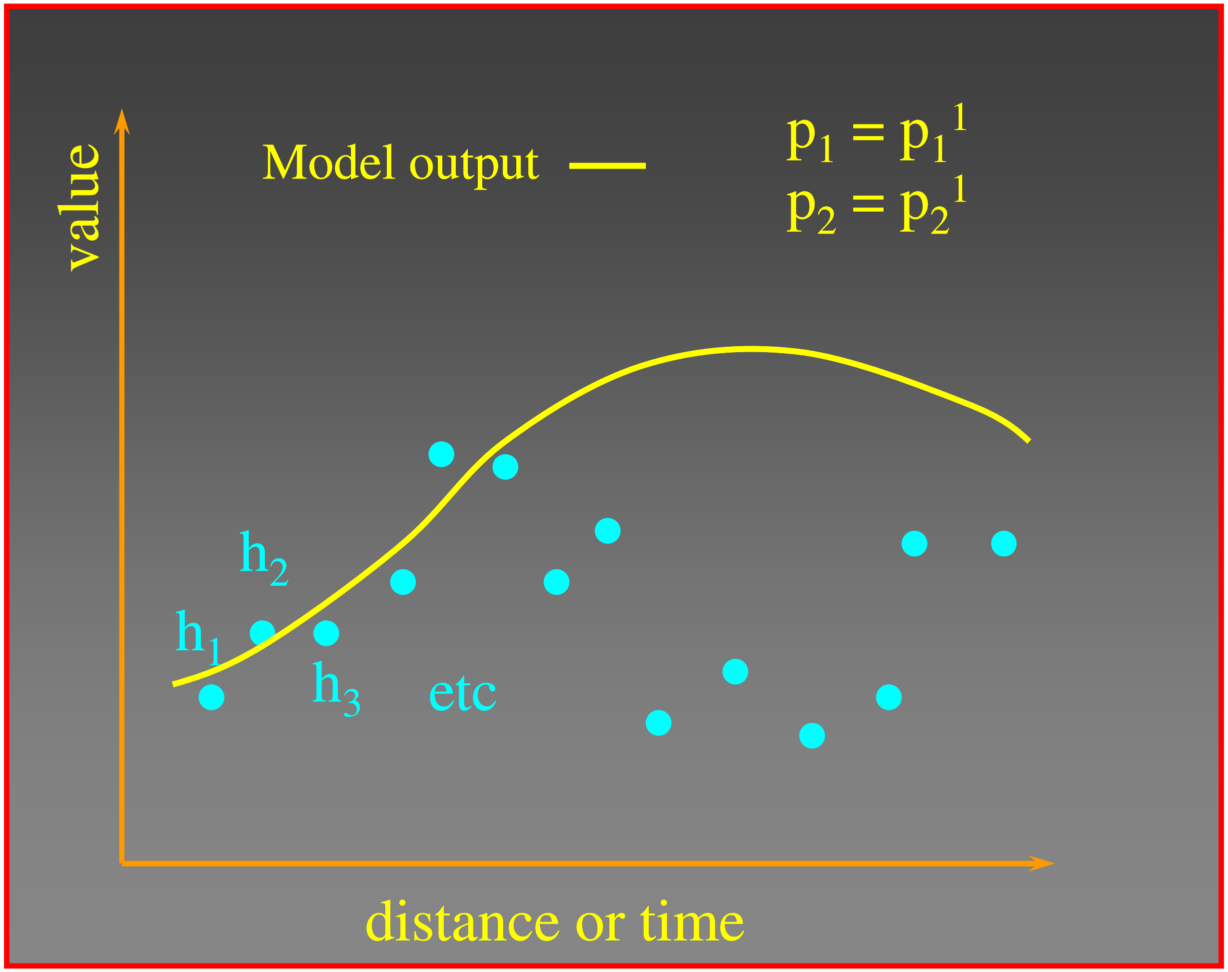
Attempt 1 for Model Calibration



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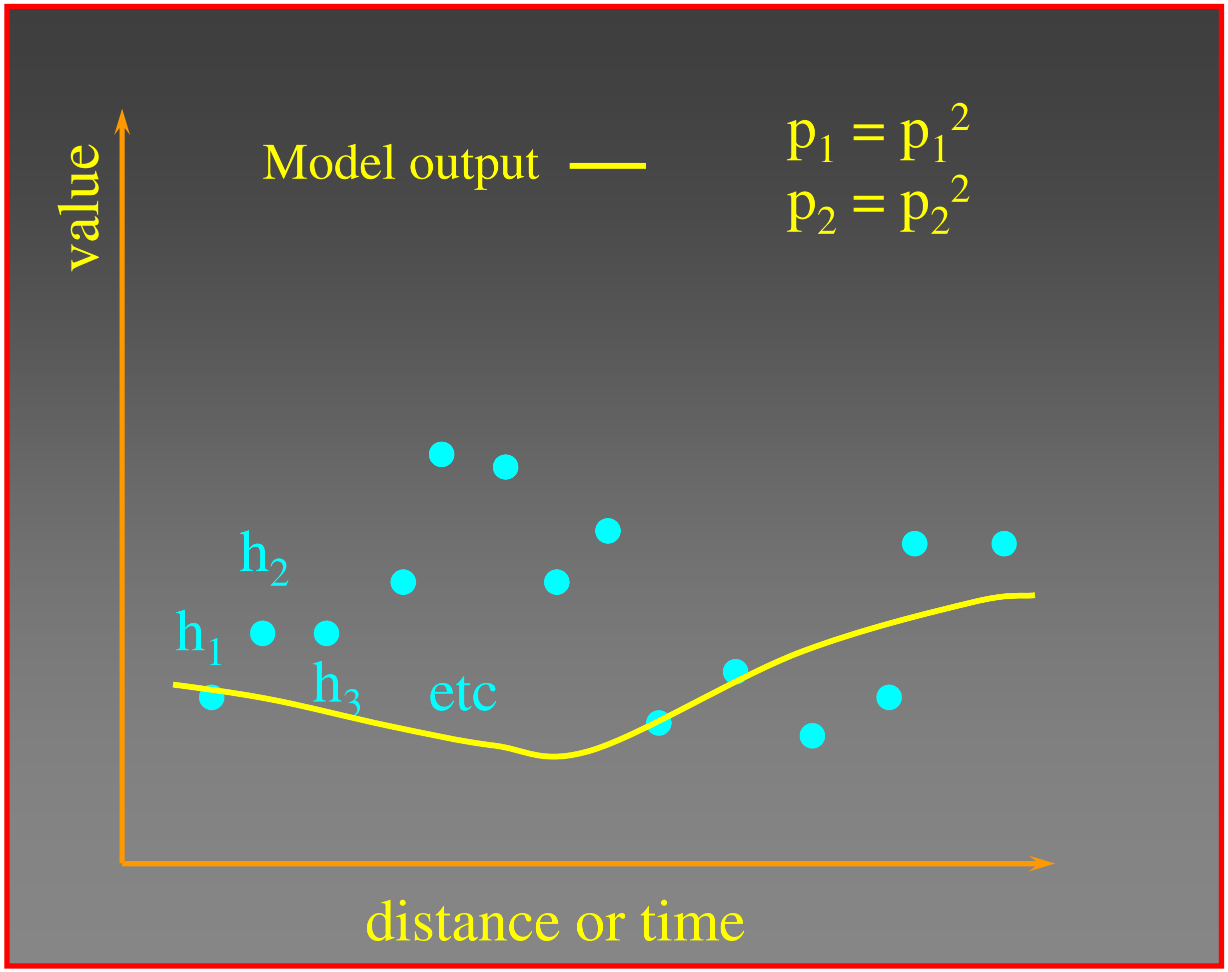
Attempt 2 for Model Calibration



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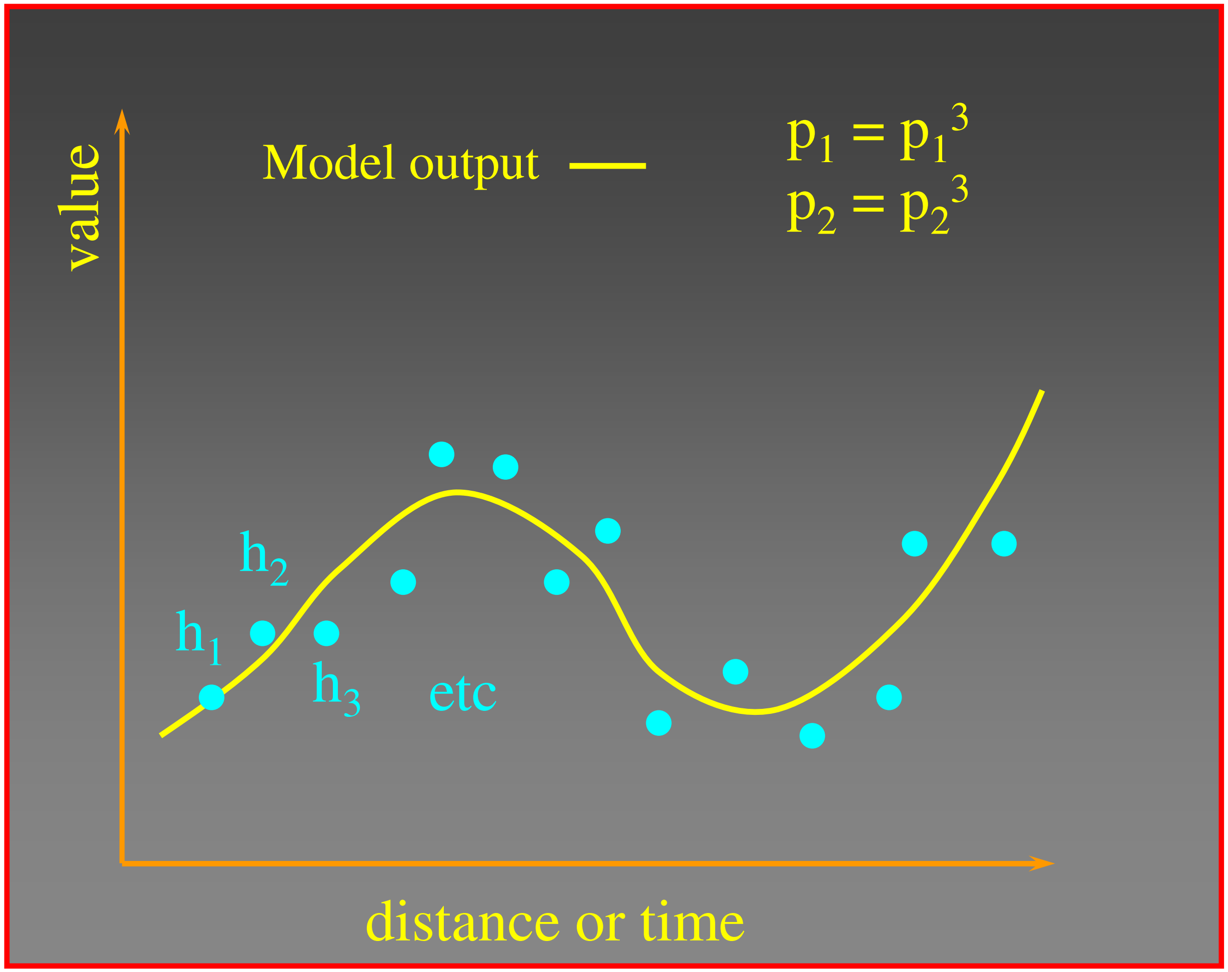
Attempt 3 for Model Calibration



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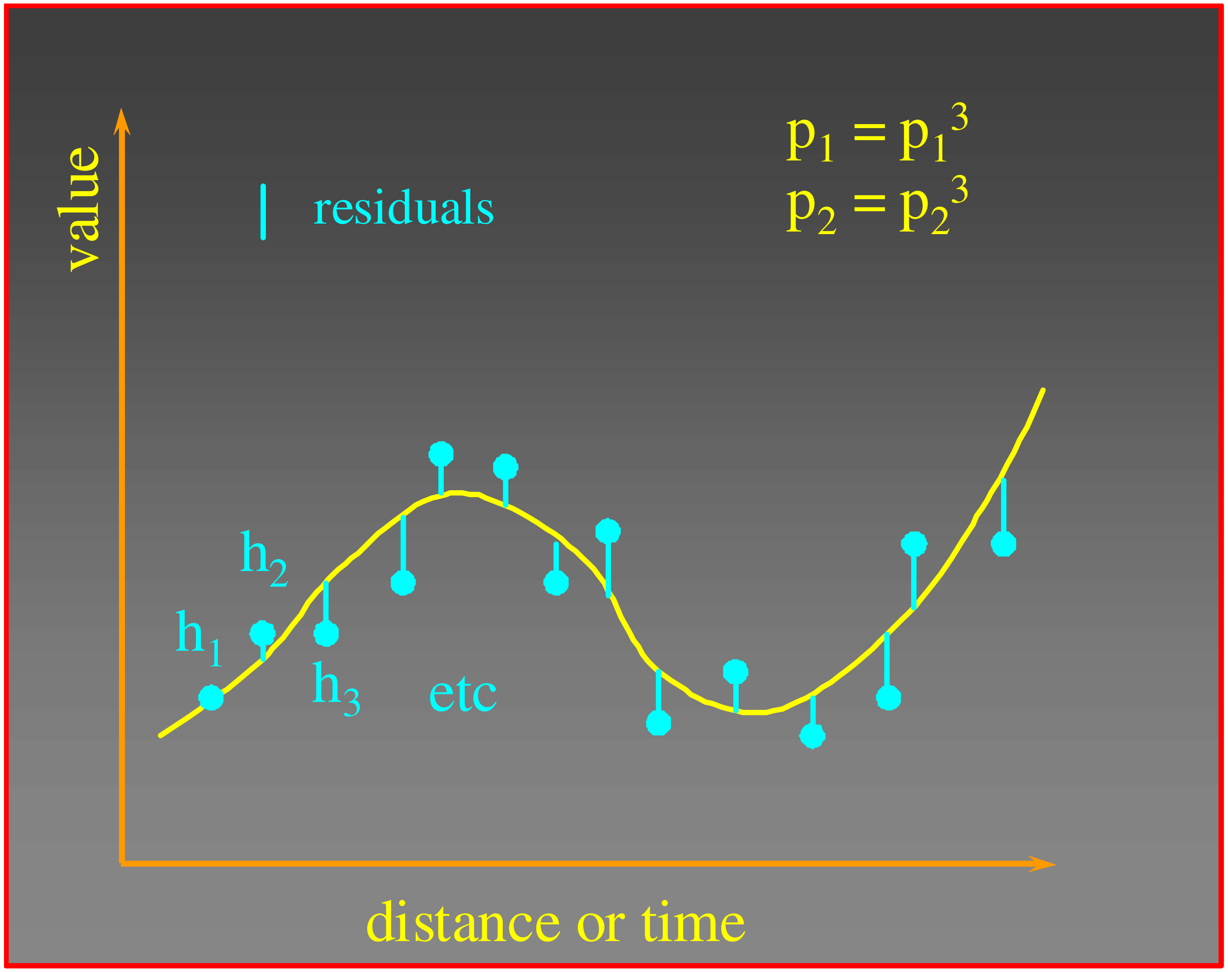
Calculation of Residuals for Model Calibration



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Statistical Measures Involving Residuals

- **Residual**
  - Difference between observed and simulated value
  - Negative value indicates the simulated value is higher than the observed value
- **Absolute Error**
  - Absolute value of difference between observed and simulated water level
- **Root mean squared error (RMSE)**
  - Square root of the average of the squared residuals
  - *Only applicable for multiple measurements

Well ID	Simulated	Observed	Residual	Absolute Error	RMS*
1	25.6	22.3	-3.3	3.3	
2	43.1	45.4	2.3	2.3	
3	35.2	30.1	-5.1	5.1	
4	24.3	24	-0.3	0.3	
			-1.6	2.75	3.251154

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Calibration Issues

- Model Objectives
  - What is intended use of model, required resolution?
- Calibration Targets
  - What do we compare the model to?
- Data Uncertainty
  - What is the data quality and error? How does it affect predictions?
- 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?
- Non-uniqueness
  - What is the sensitivity of model matches to changes in model inputs?
- Goals
  - How good is “good enough”?

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

Issue/Concern	Advantages
Calibration Targets	Automatic comparisons between measured and simulated values allow very quick and efficient calculations of residuals so there is essentially no limit on number of calibration targets
Data Uncertainty	Can incorporate supports 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	PEST is computer intensive and not labor intensive. After setting-up problem, PEST can be orders-of-magnitude more efficient. More efficient simulations allows more options to be explored and better calibrations achieved.
Non-uniqueness	PEST includes a comprehensive set of sensitivity analysis and correlation analyses that quickly inform the modeler on problems related to non-uniqueness
Goal	PEST provides several options to the modeler for evaluating how good is good enough so there is very little guessing on whether or not sufficient calibration has been performed for the given conditions

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PEST

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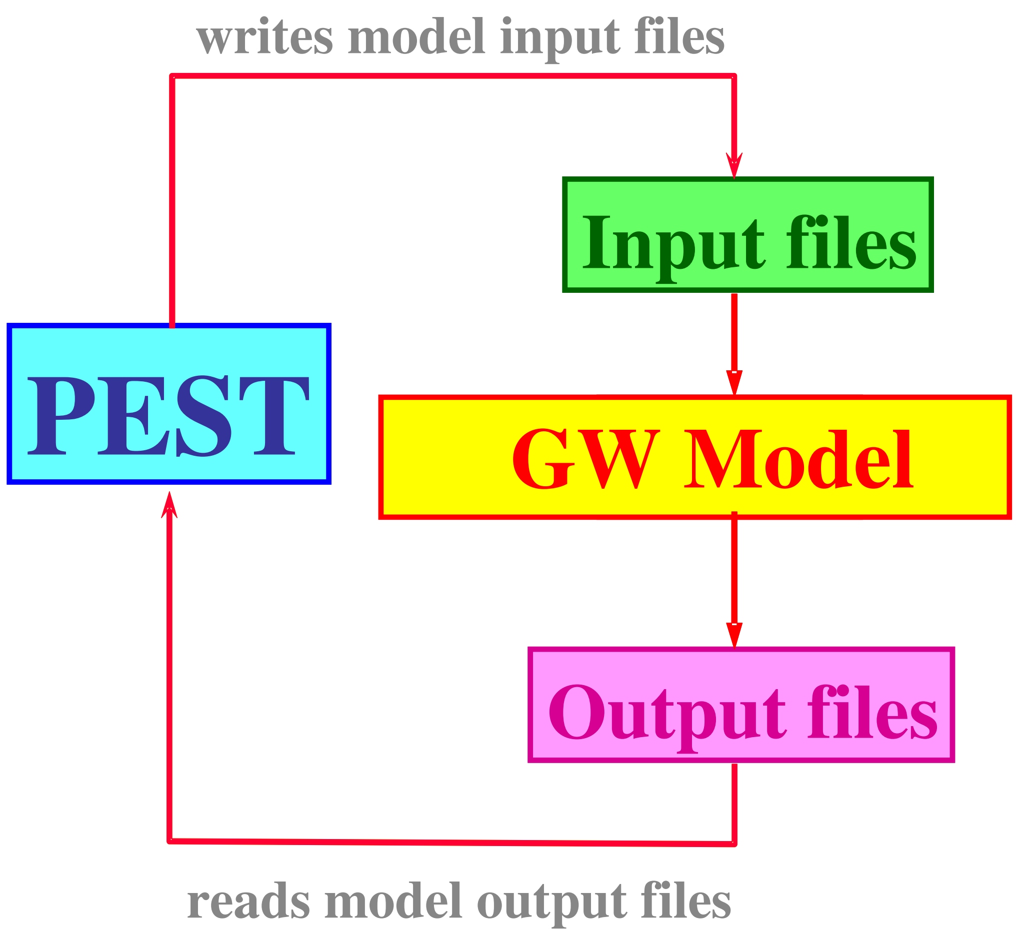
PEST
(Parameter Estimation Software)



- PEST
  - •Calculates sensitivities between model output and groups of specific model inputs
  - •Determines how uncertainty in input parameters affects specific model output
  - •Follows an objective, systematic, and reproducible approach for all aspects of model calibration and predictions

PEST Notes

- Developed by John Doherty in 1994
- Most widely used parameter estimation software for groundwater modeling
- Supported by MODFLOW Graphic User Interfaces
- Used Extensively to support the LCRA-SAWS Water Project
  - Parameter estimation
  - Predictive Uncertainty

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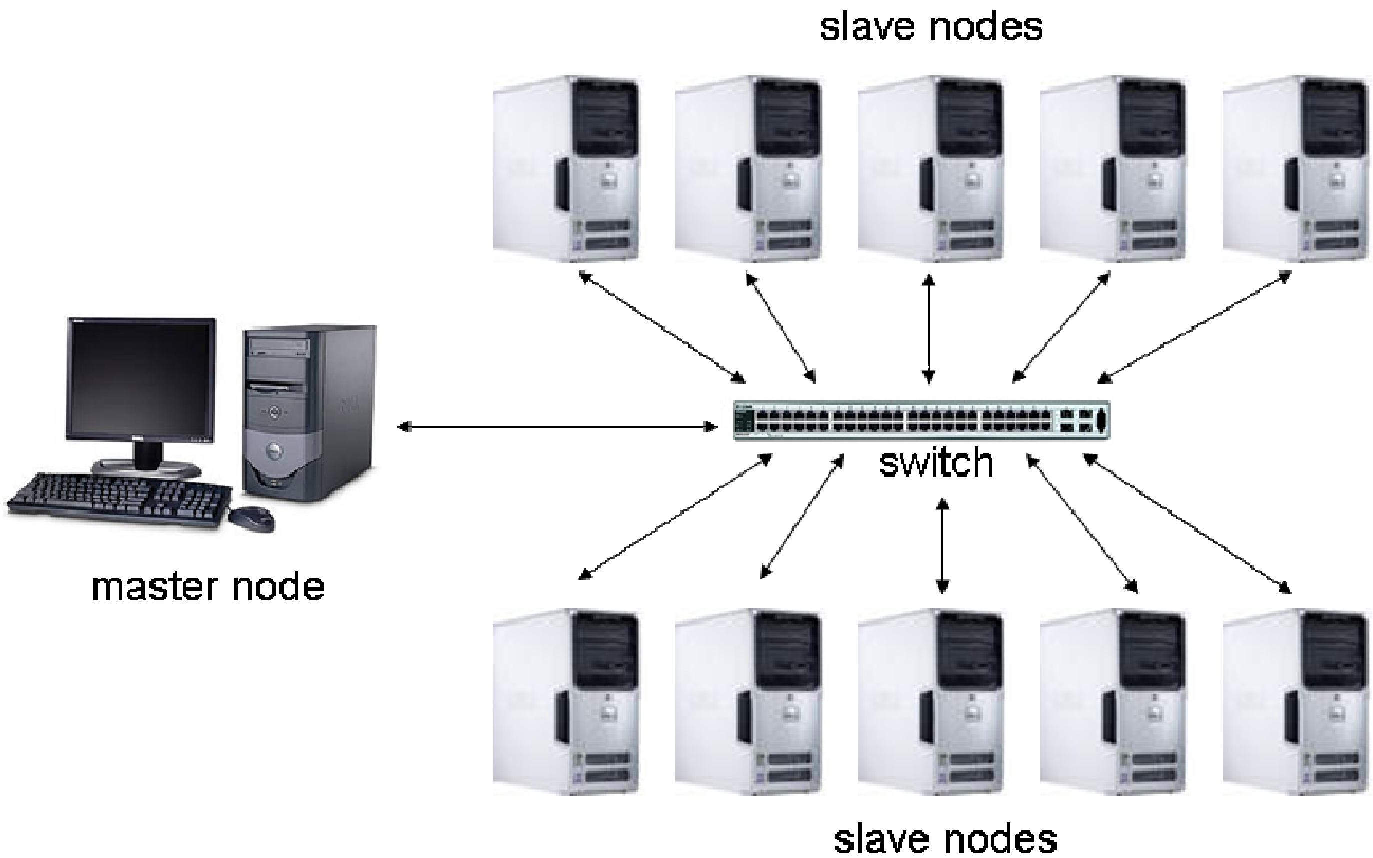
Parallel Processing With PEST



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Major PEST Inputs

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

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Issues Related to Modeling Variability

- Field data is typically available at discrete locations in space (see example, hydraulic conductivity measurements)
- The model requires an estimate of aquifer properties over the entire model domain.
- Thus, we must employ a method for estimating these properties away from field observed values.

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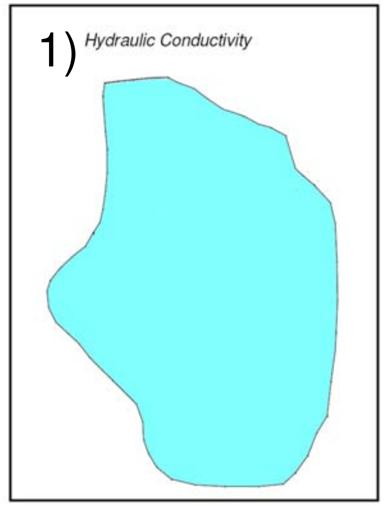
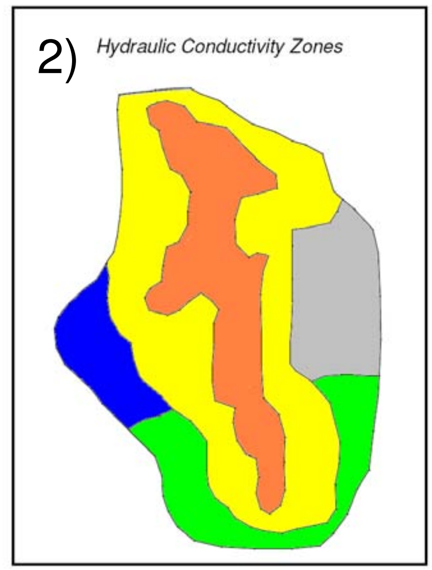
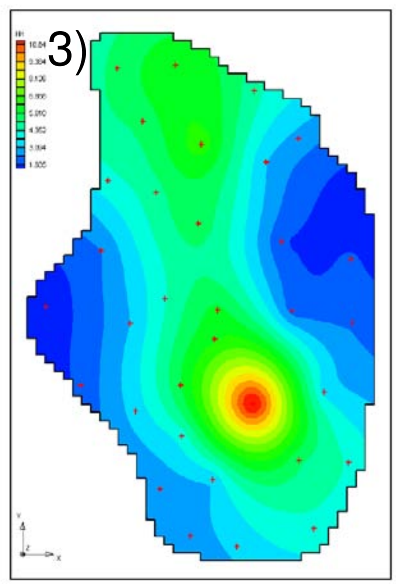
Methods Supported by PEST for Estimating Aquifer Properties

- 1) Assumed a Single Uniform Value
- 2)Zonation-Create zones and assume uniform properties in each zone
- 3)Pilot Points - Vary properties using a statistical model based kriging



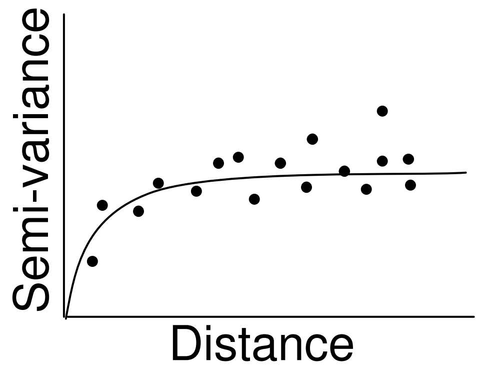


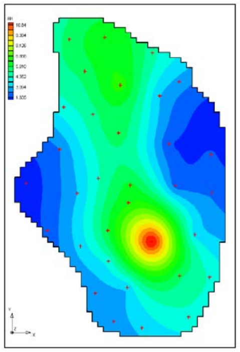


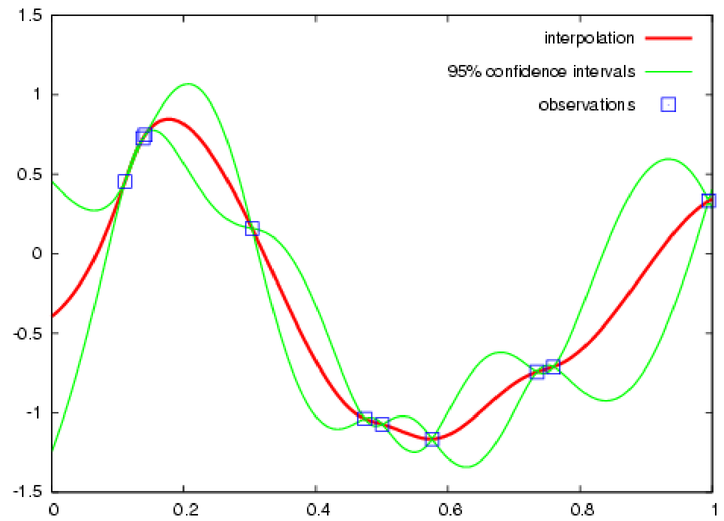
(Jones, 2008)

Pilot Point Method is Similar to Kriging

- **In 1951, Daniel G. Krige published a method for estimating geologic properties as a mining engineer in South Africa**
- **In 1960, George Matheson discovered that Krige's methods followed the statistics described by Gauss and called the method "kriging"**
- **Using "kriging", aquifer properties can be estimated throughout the model domain from discrete measurements locations**
- **Also it provides an estimate of the uncertainty that is in the estimates**







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Possible PEST Pitfalls

- Inadequate Conceptual Model
- Insufficient Numerical Discretization
- Insufficient Model Calibration Targets
- Improper Weighting of Calibration Targets
- Problems with Numerical Model Convergence
- Poor Initial Estimates of Model Parameters
- Large Uncertainty in Pumping

PEST is a tool to help extract maximum information from data. Its application does not necessarily equate to a adequately calibrated model

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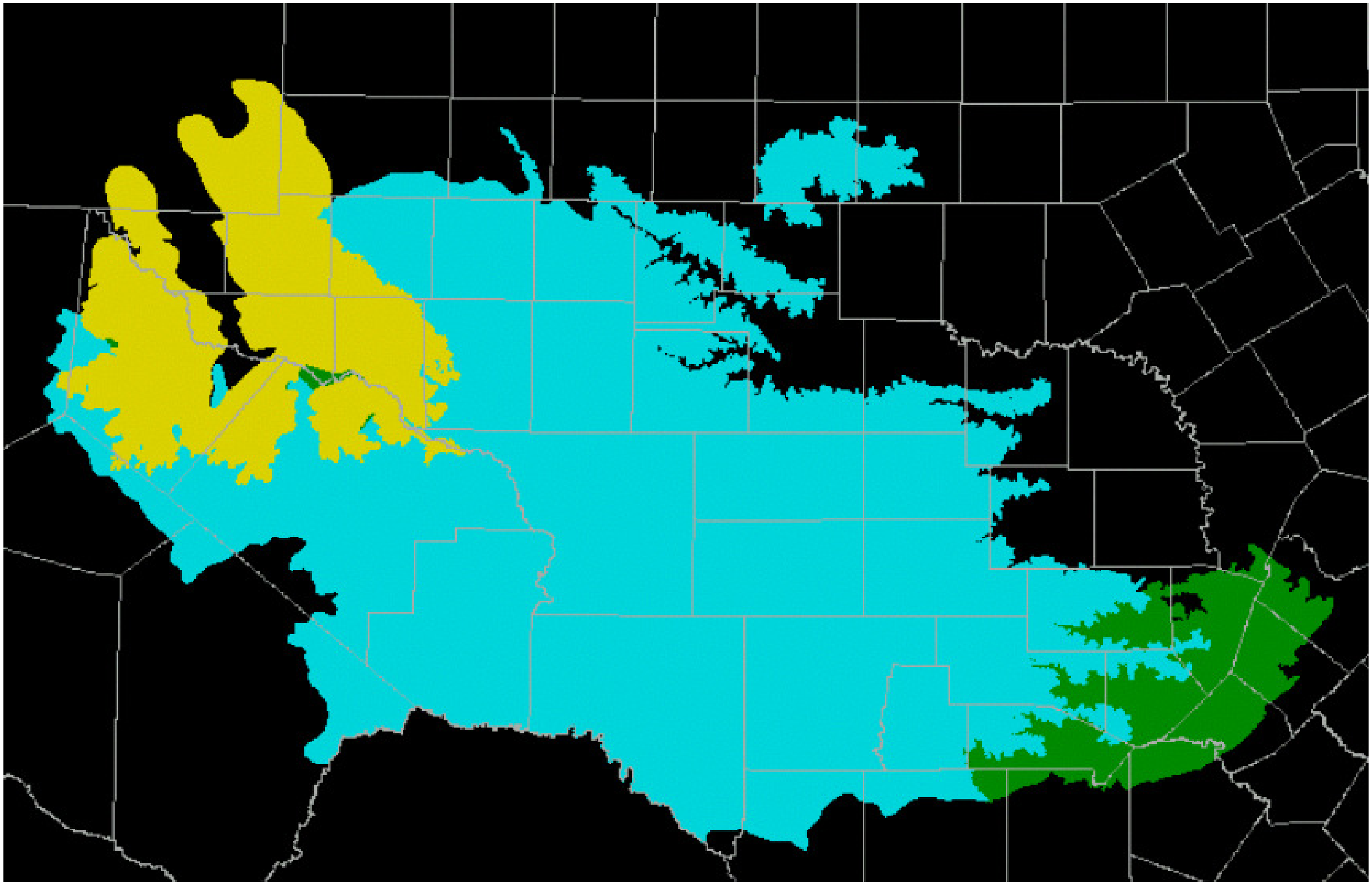
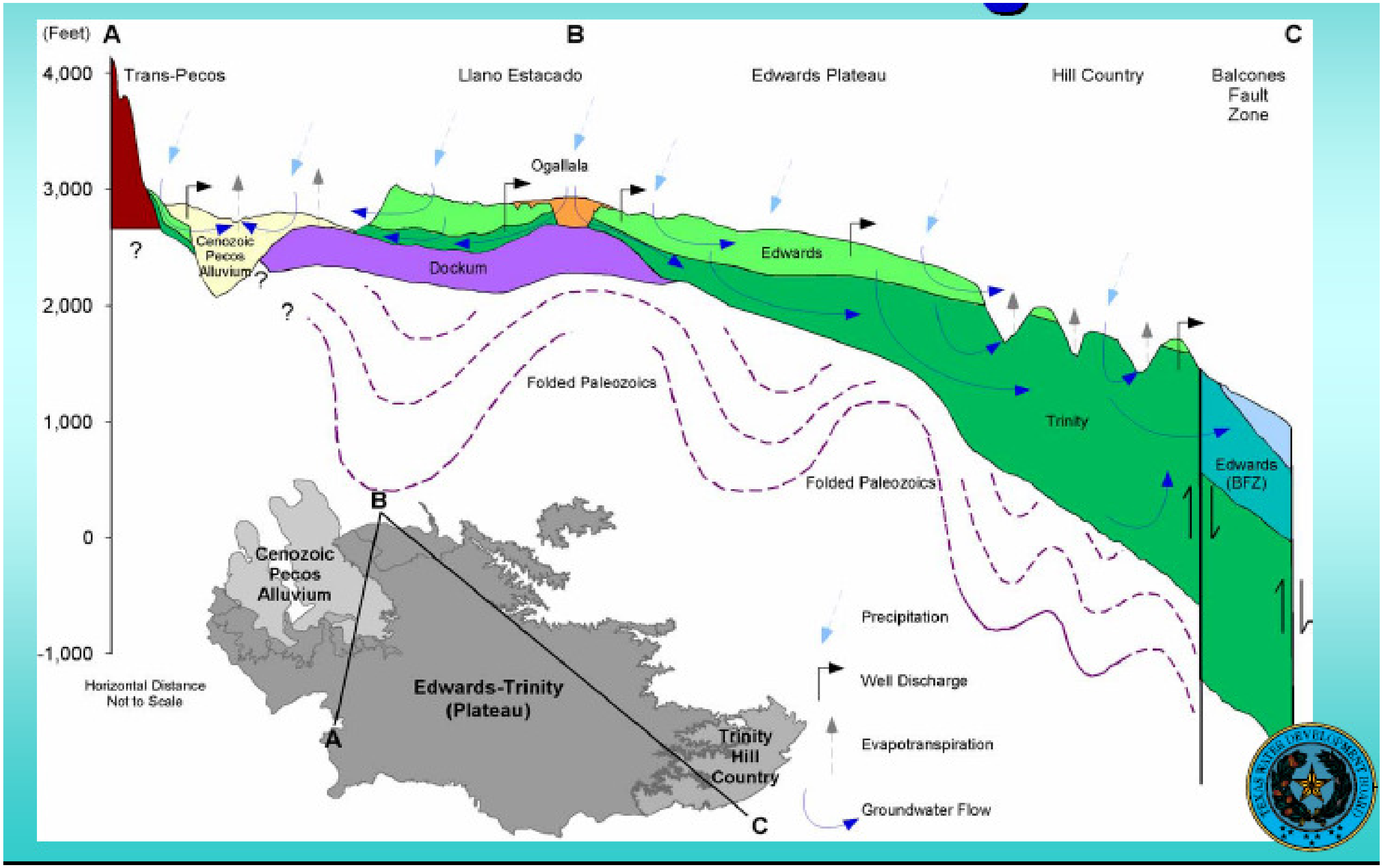
Edwards-Trinity (Plateau) and Pecos Valley Aquifers GAM

Spatial Extent of the ETPVA GAM



Conceptual Cross-Section



From SAF6_ET-p_part1.pdf

Calibration/Re-Calibration of Edwards-Trinity (Plateau) and Pecos Valley Aquifer GAM

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Objectives of Recalibration

- Improve Spatial and Temporal Distribution of Water Level Calibration Targets
- Improve Matches to Water Level Measurements
- Reduce Predictive Uncertainty of ETPVA GAM
- Demonstrate Feasibility of PEST Applications

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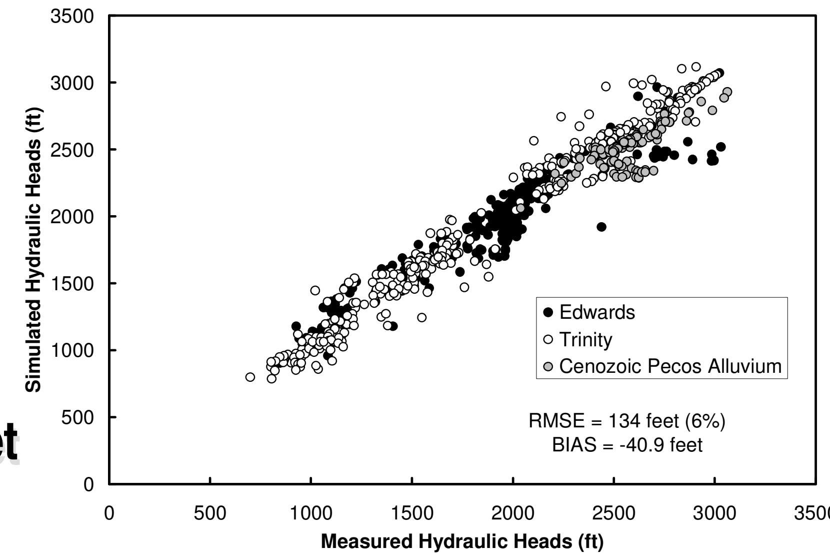
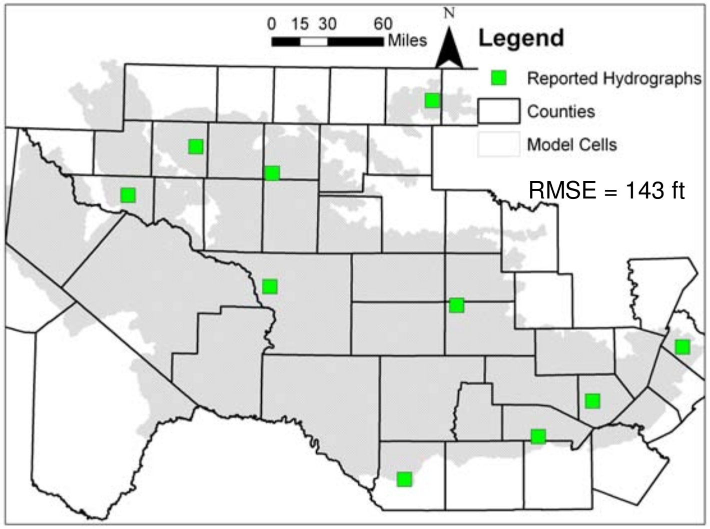
Calibration Targets for Water Levels Used for Current Calibration

- **Steady State**
  - Selected Measurements before 1980 were used to develop a steady state calibration water level target
- **Transient**
  - Ten Hydrographs with a total of 1567 measurements across the model domain were used to compare to simulated and observed water levels from 1980 to 2000





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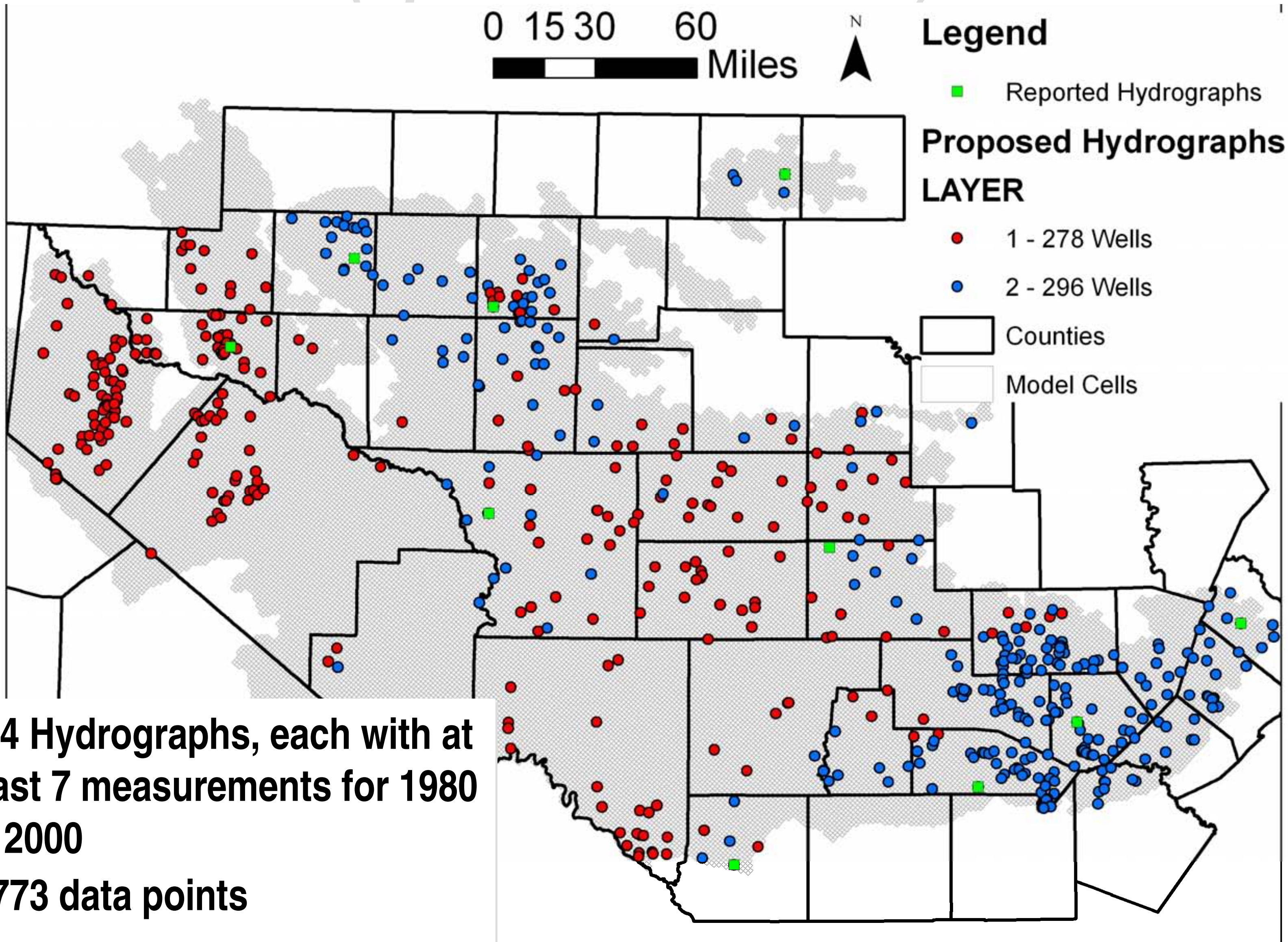
Proposed Water levels for Recalibration (Spatial Distribution)



- 574 Hydrographs, each with at least 7 measurements for 1980 to 2000
- 4,773 data points

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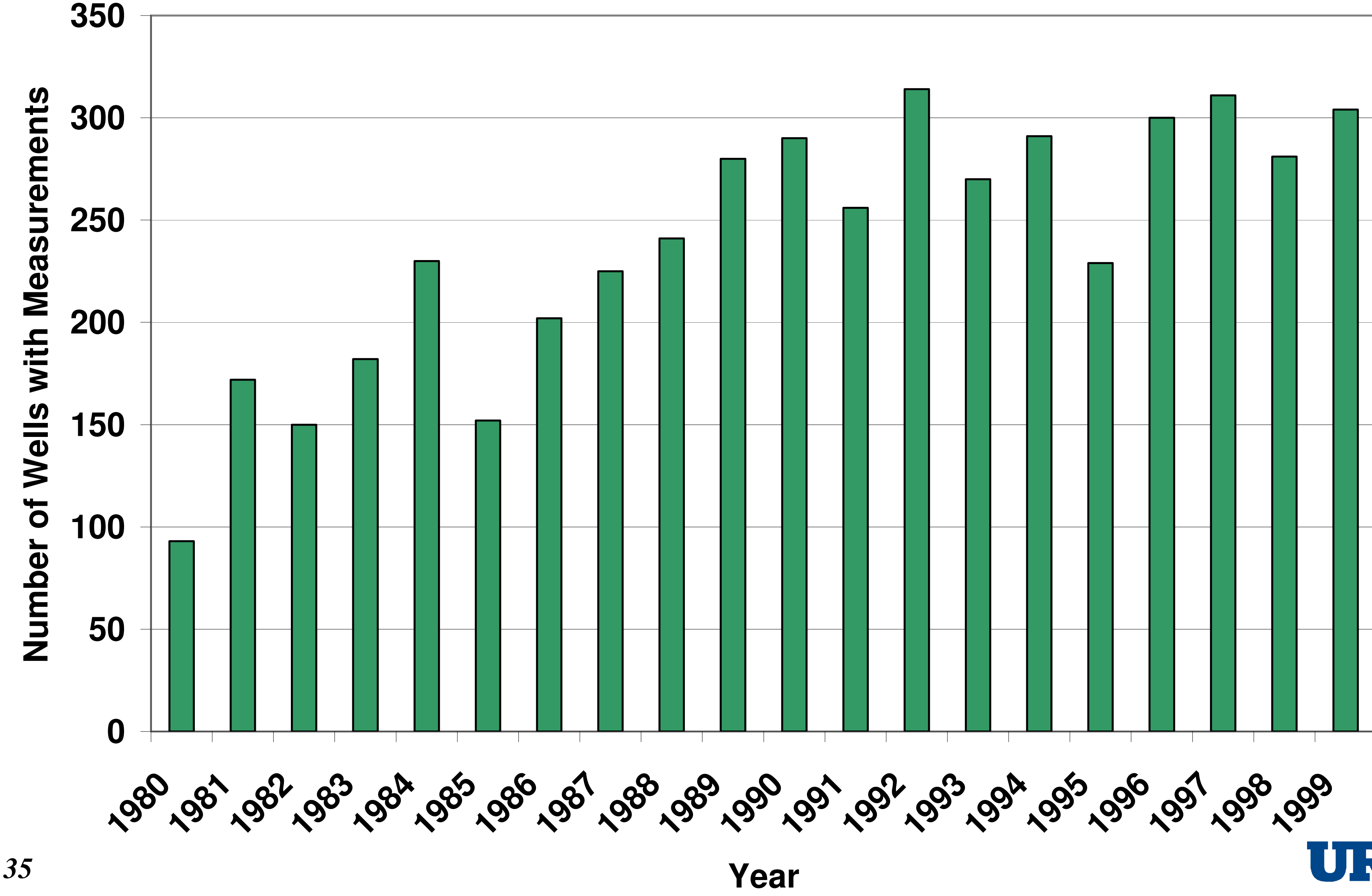
Proposed Water levels for Recalibration (Temporal Distribution)



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Residuals Statistics for Current Model Based for the 574 Hydrographs

County	RMS	Absolute Error	Average Residual	Number of Measurements	Number of Wells	County	RMS	Absolute Error	Average Residual	Number of Measurements	Number of Wells
All	401.0	250.4	-206.6	4773	574	Kinney	83.0	62.4	-59.5	52	6
Bandera	131.8	93.8	-57.2	267	40	Loving	15.3	15.3	-15.3	20	2
Bexar	172.3	129.6	-29.5	77	10	McCulloch	63.8	63.8	63.8	12	1
Blanco	199.6	180.1	-178.5	82	11	Menard	109.5	69.4	28.9	110	13
Brewster	1088.1	1088.1	-1088.1	6	1	Midland	86.1	79.8	-45.4	66	7
Comal	97.3	84.2	-68.2	34	8	Nolan	84.7	74.8	38.8	35	4
Concho	32.6	27.7	-8.4	30	4	Pecos	909.6	873.4	-873.4	333	31
Crane	55.6	55.4	-55.4	18	2	Reagan	175.6	144.3	79.6	168	21
Crockett	146.1	125.0	-123.8	191	27	Real	152.0	123.9	-46.1	91	9
Ector	79.2	75.0	-74.6	117	17	Reeves	848.5	794.7	-794.7	555	55
Edwards	128.8	79.6	-57.1	65	10	Schleicher	154.8	151.8	-151.8	126	15
Gillespie	122.7	108.5	-5.3	317	46	Sterling	68.7	60.5	23.8	19	2
Glasscock	169.3	147.4	59.2	249	23	Sutton	179.2	169.7	-168.8	159	17
Hays	201.2	195.2	-165.6	72	15	Terrell	225.4	177.8	-77.4	22	5
Irion	116.3	100.9	-98.5	66	7	Tom_Gree	82.3	71.8	-69.4	26	4
Jeff_Davis	599.1	598.0	-598.0	23	4	Travis	148.8	103.6	-84.2	62	7
Kendall	117.2	91.2	-59.2	246	31	Upton	70.7	61.7	36.3	72	6
Kerr	143.7	134.4	-127.2	213	31	Val_Verde	62.9	46.6	-29.1	197	23
Kimble	132.5	84.0	64.7	91	13	Ward	157.0	139.4	-139.2	369	34
						Winkler	198.2	175.6	-175.6	115	12

Primary Goal is to Reduce the RMS

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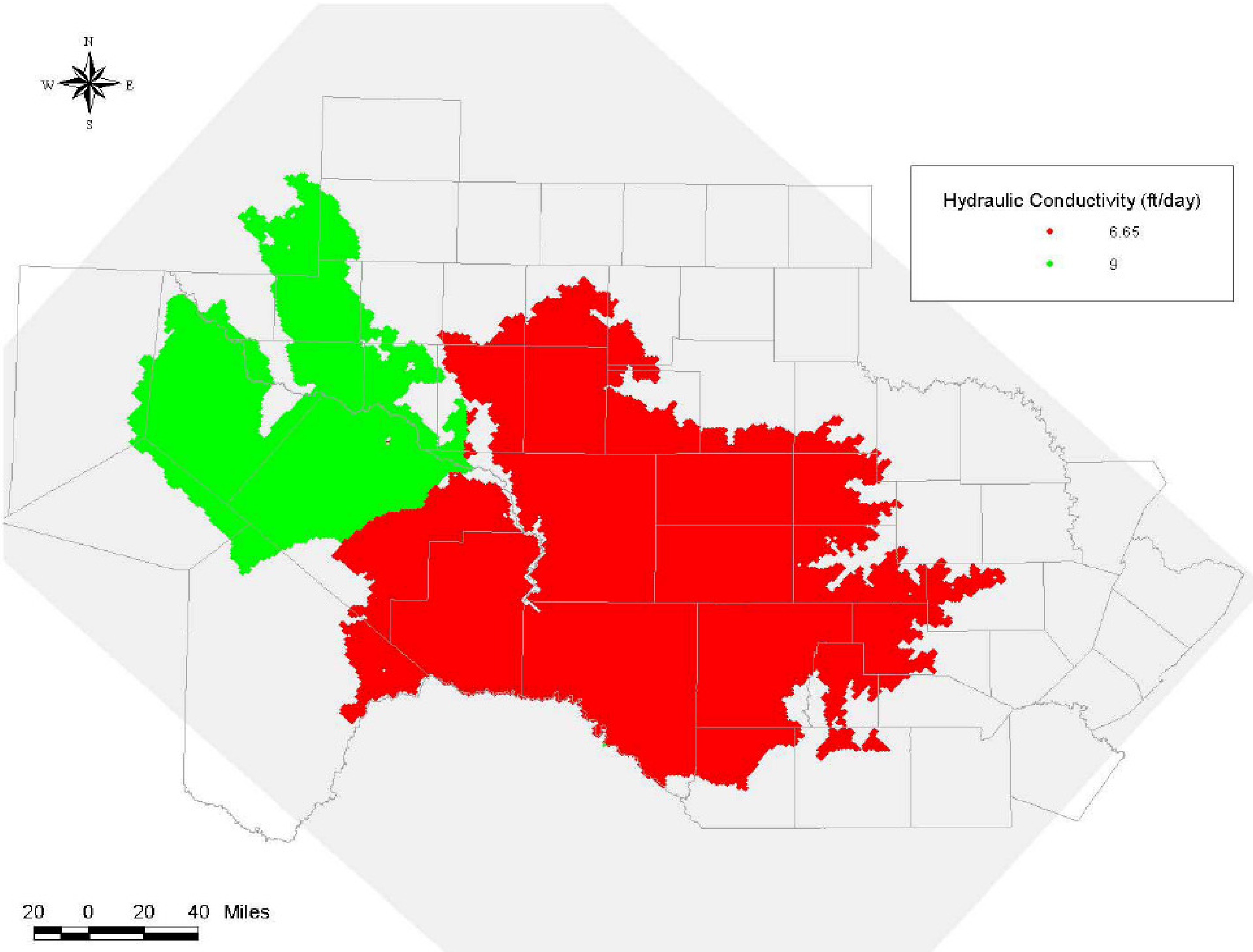
Aquifer Zones and Recharge Zones

- Aquifer Zones
  - Current model has five aquifer zones with uniform properties
  - Recalibrated model should have five zones with spatially variable properties
- Recharge Zones
  - Current model has 11 recharge zones with uniform properties
  - Recalibration model should have 11 recharge zones with uniform properties

Calibrated Hydraulic Conductivity Values: Two Zones in Model Layer 1



From SAF6_ET-p_part3.pdf

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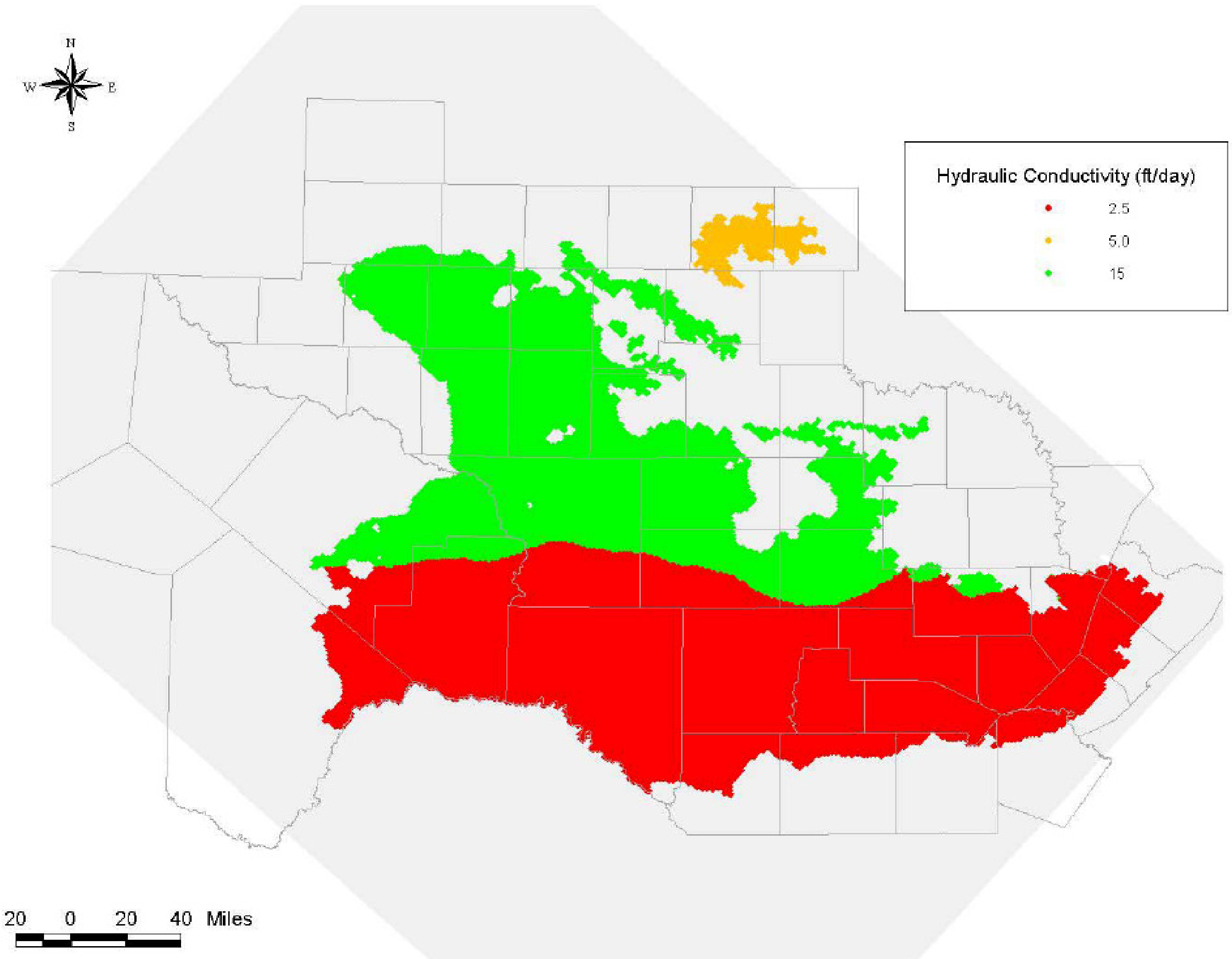
Calibrated Hydraulic Conductivity Values: Three Zones in Model Layer 2



From SAF6_ET-p_part3.pdf

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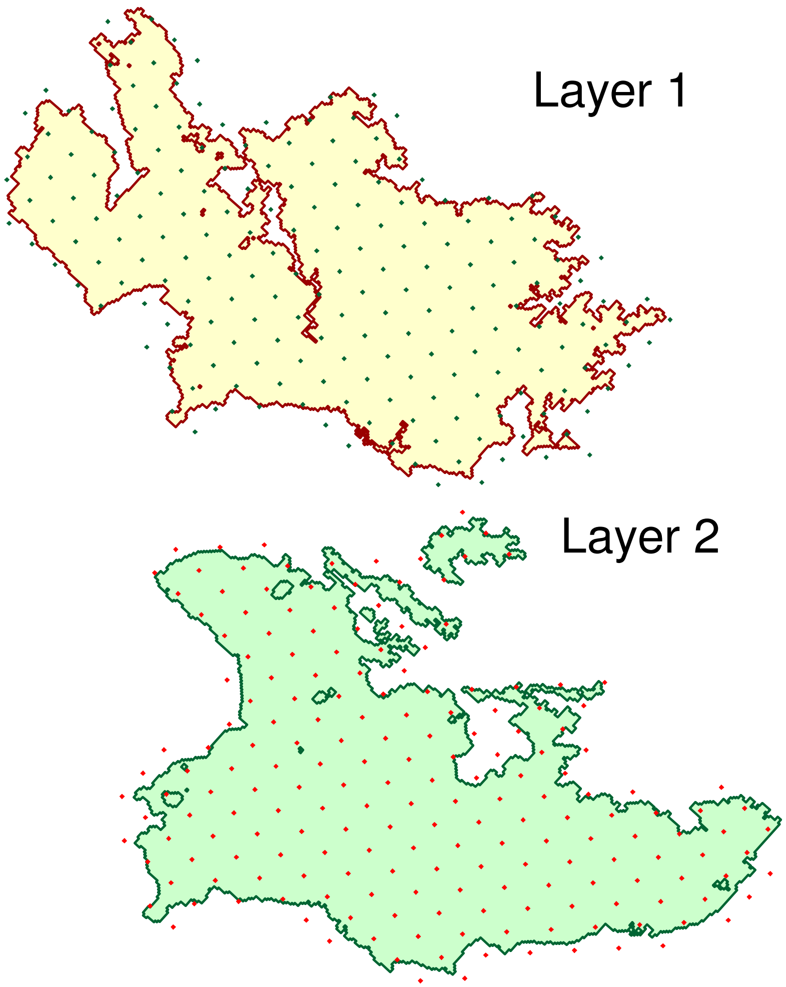
Location of Pilot Points for Recalibration

- Aquifer Properties will be estimated for the model grid by kriging points shown
- Based on the kriged surface the aquifer properties will be altered for the model simulation
- The statistics (average and standard deviation) of the original field data will be preserved
- The pilot points are roughly 20 km apart in both directions



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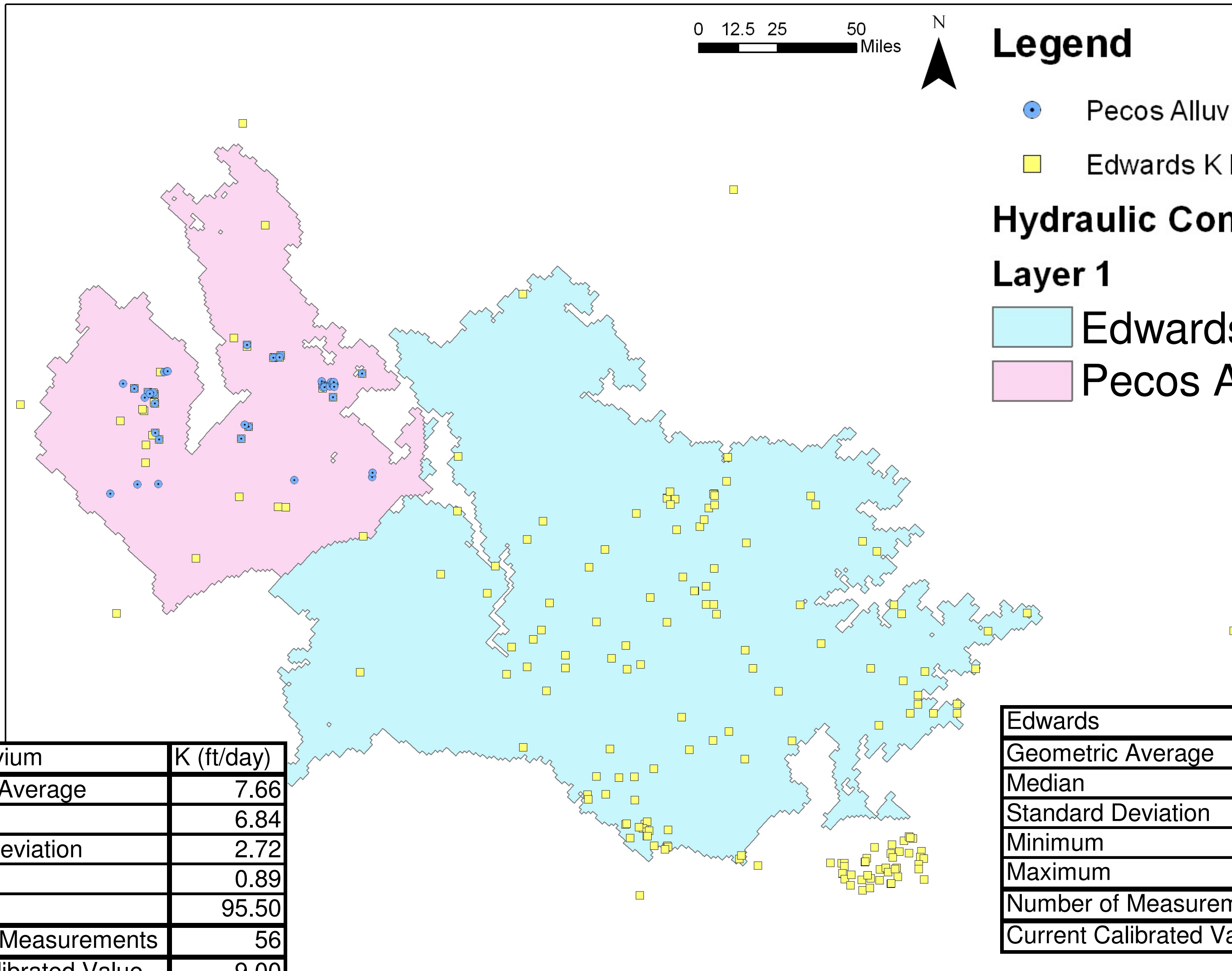
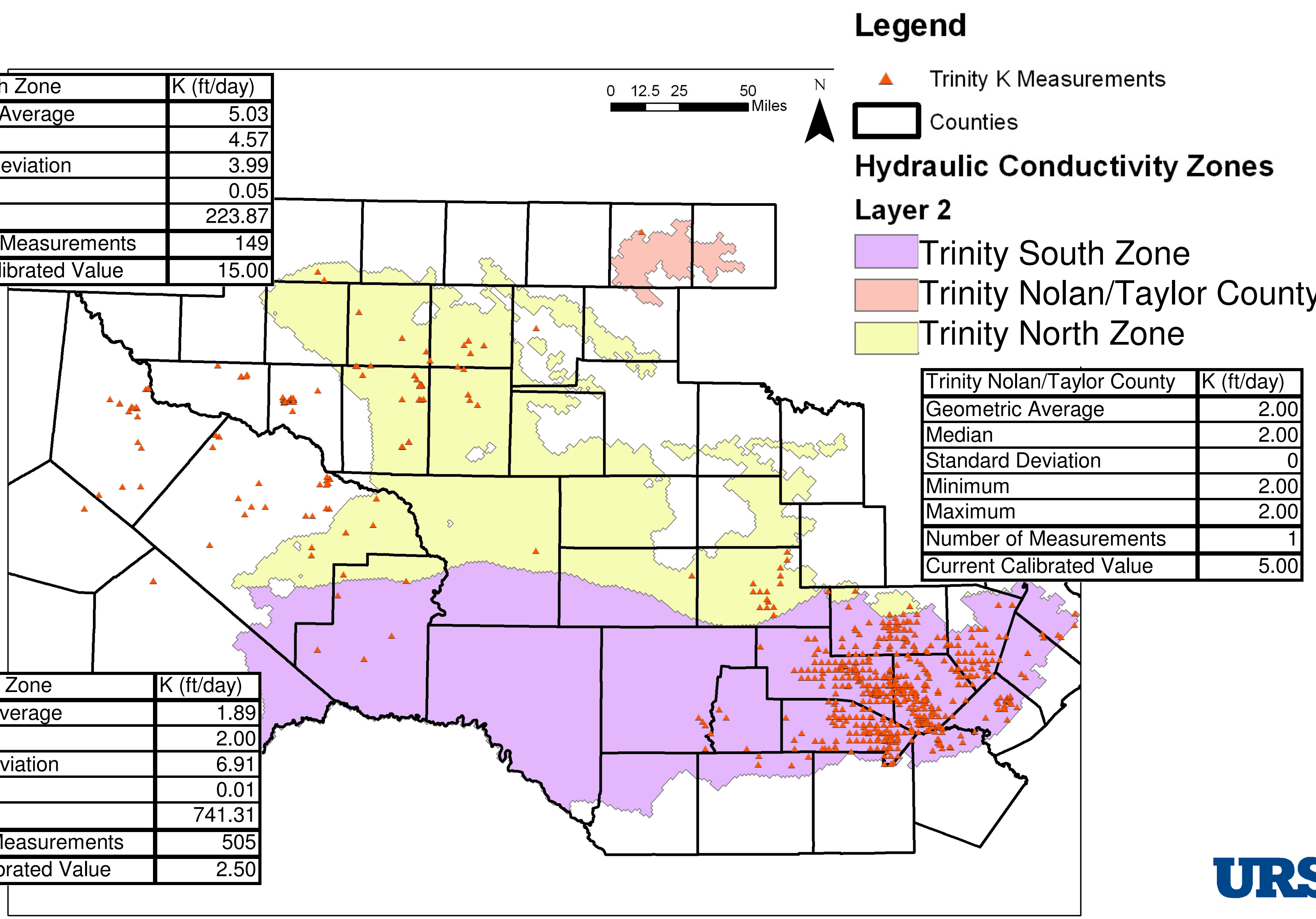
Statistical Analysis of Hydraulic Conductivity Data



Pecos Alluvium	K (ft/day)
Geometric Average	7.66
Median	6.84
Standard Deviation	2.72
Minimum	0.89
Maximum	95.50
Number of Measurements	56
Current Calibrated Value	9.00

Edwards	K (ft/day)
Geometric Average	6.66
Median	6.84
Standard Deviation	14.44
Minimum	0.00
Maximum	3548.13
Number of Measurements	190
Current Calibrated Value	6.66

Statistical Analysis of Hydraulic Conductivity Data



Trinity North Zone	K (ft/day)
Geometric Average	5.03
Median	4.57
Standard Deviation	3.99
Minimum	0.05
Maximum	223.87
Number of Measurements	149
Current Calibrated Value	15.00

Trinity Nolan/Taylor County	K (ft/day)
Geometric Average	2.00
Median	2.00
Standard Deviation	0
Minimum	2.00
Maximum	2.00
Number of Measurements	1
Current Calibrated Value	5.00

Trinity South Zone	K (ft/day)
Geometric Average	1.89
Median	2.00
Standard Deviation	6.91
Minimum	0.01
Maximum	741.31
Number of Measurements	505
Current Calibrated Value	2.50

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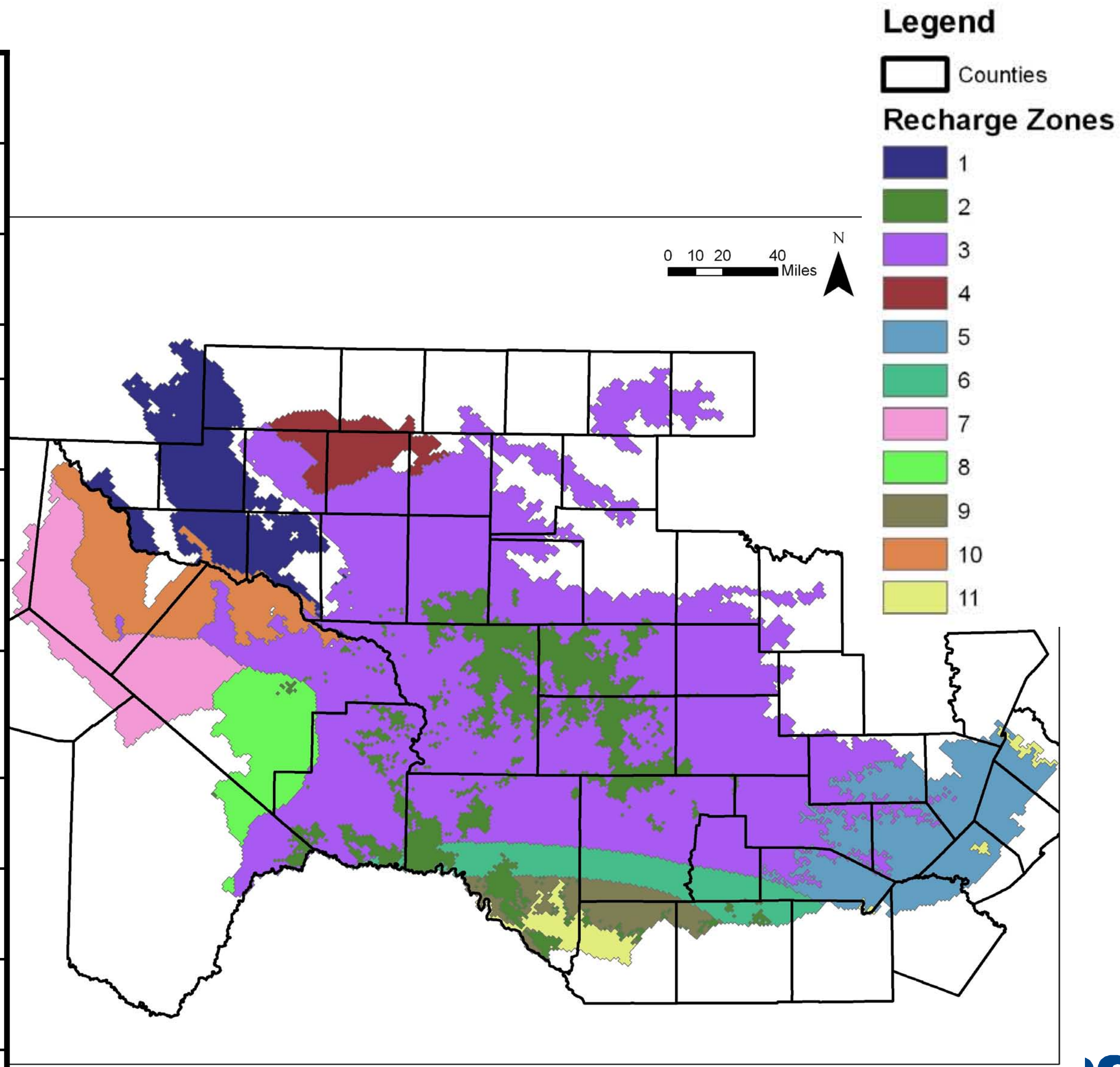
Eleven Zones Used to Simulate Recharge

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
11	No Recharge	0



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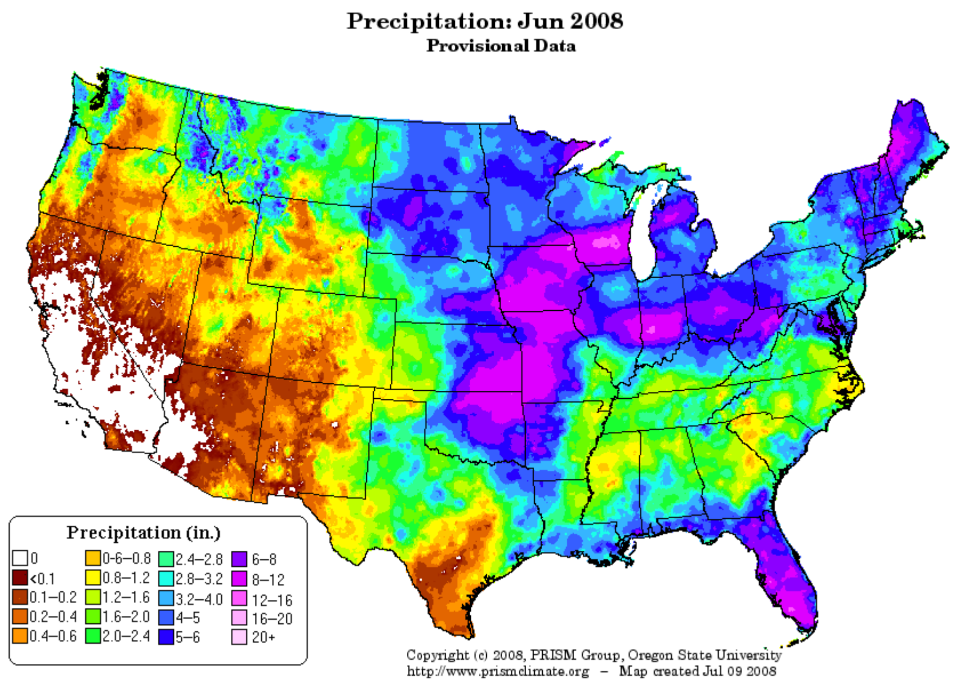
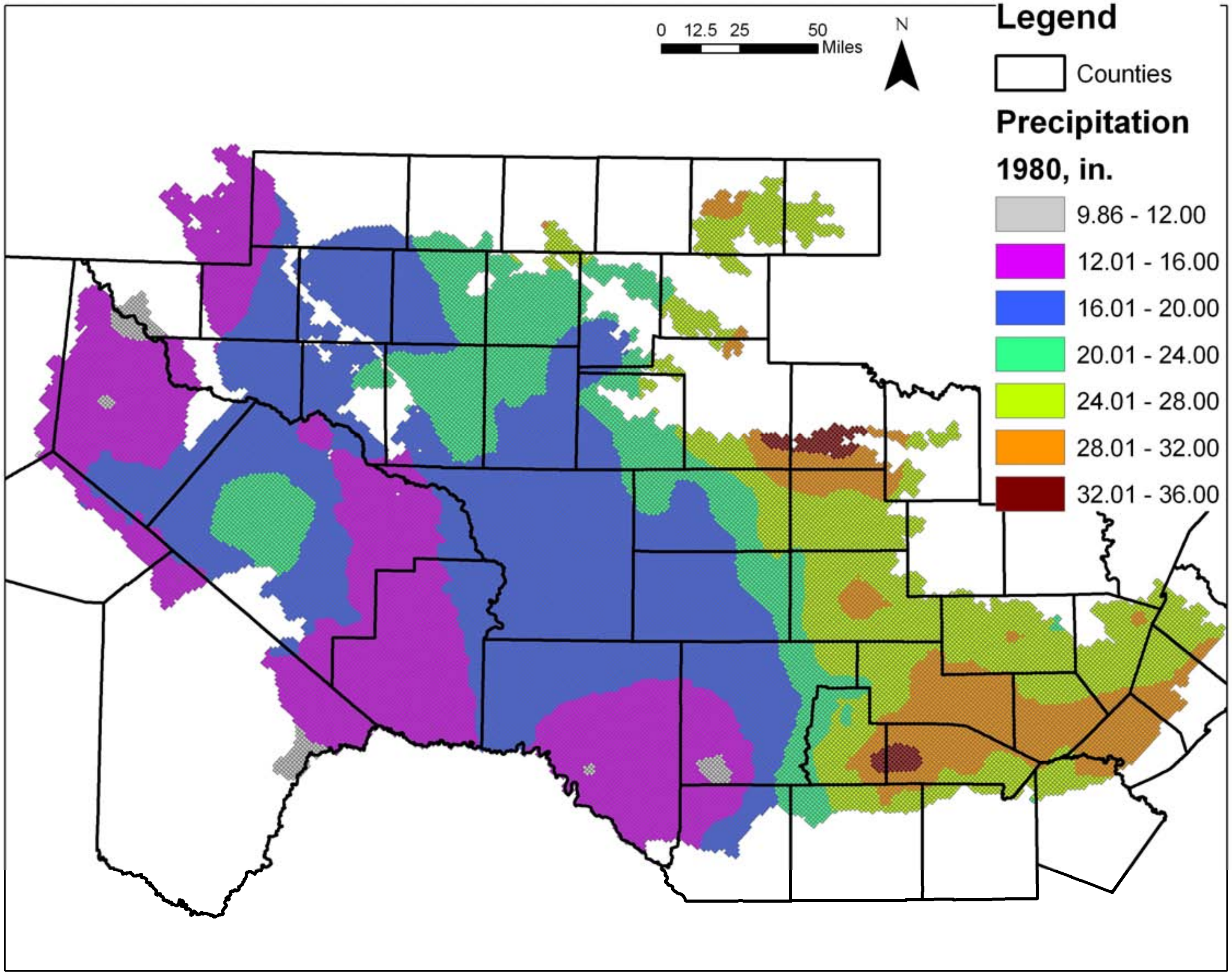
PRISM Rainfall Data Used for Recharge Calculations

- Developed by the PRISM group – http://www.prism.oregonstate.edu
- Based at Oregon State University
- 4km X 4km resolution
- Provide estimates of precipitation based on
  - Climatic Data
  - Regression Analysis
  - Orographic Effects
  - Expert Input
- Archival data from 1900 to present

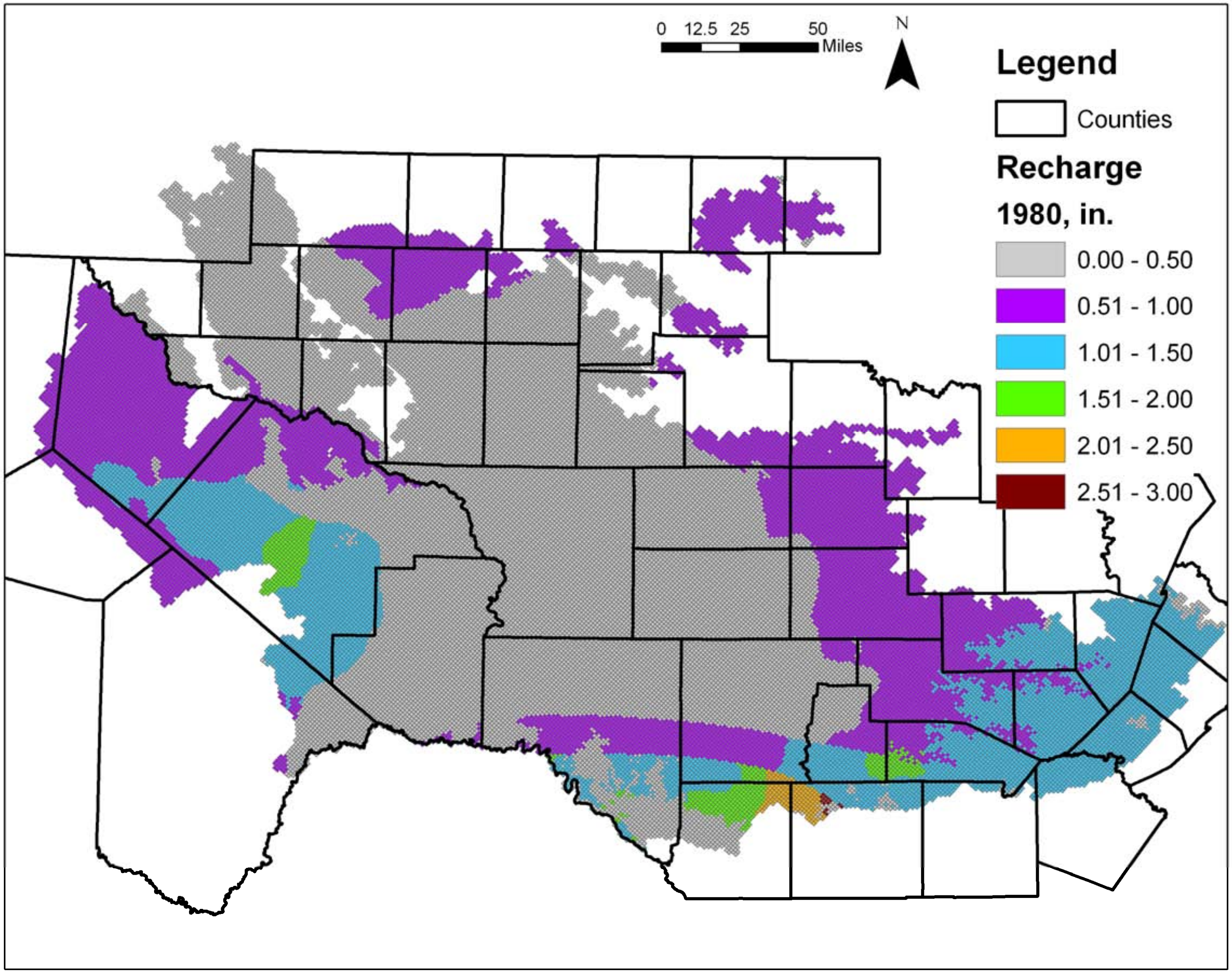


(Daly, 2008)

Example Precipitation Distribution

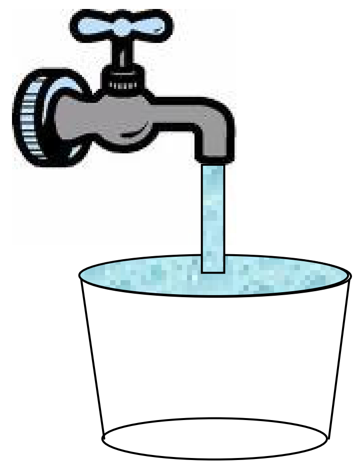


Example Recharge Distribution



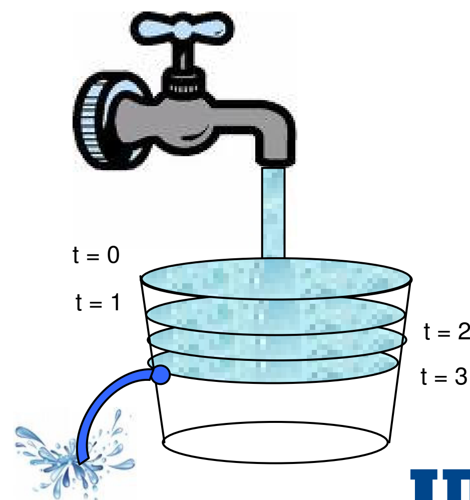
What is Steady State vs. Transient?

- Steady state refers to a system that doesn't change with time
  - Inflow = outflow
  - Water level is constant
- Transient describes a system that changes with time
- To explain the difference we will use the example of a bucket water faucet with a bucket catching water from it
- The amount of time it takes to for the water faucet and bucket to reach equilibrium depends on the many factors (e.g., bucket size, amount of water leaving the faucet, where the whole is placed in the bucket, etc.)



Steady State Situation Exists When Bucket is Over Flowing

Transient Situation Exists When Bucket Springs a Leak



Model Time Periods

Steady-State Conditions

- Groundwater systems are never truly steady state
- For purpose of building a model, it may be useful to approximate the real groundwater system using a steady state model because:
  - The amount of change in the system is limited
  - The amount of time for the system to adjust to new conditions is small versus scope of the total time
  - The changes only have local scale impacts and the modeling task is regional in scale
  - Limited data only allow for approximating one condition

Transient Conditions

- To approximate or model a groundwater system as transient requires more data than to model it as steady state
- These include:
  - Aquifer storage properties
  - Initial water levels in the aquifer
  - Temporal changes in aquifer stresses

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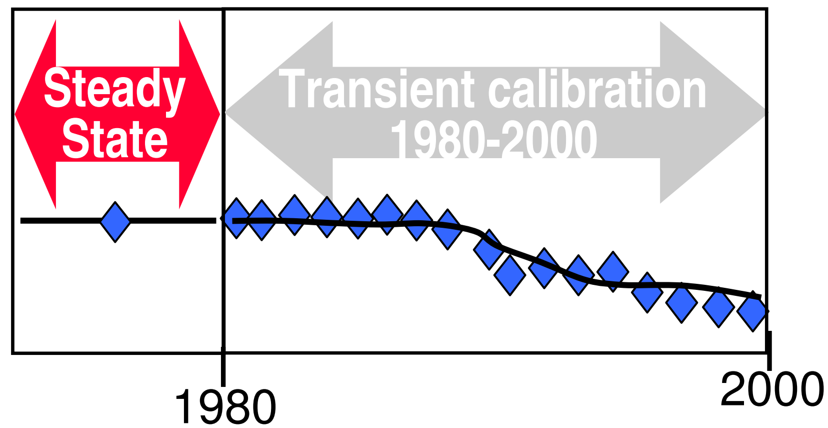
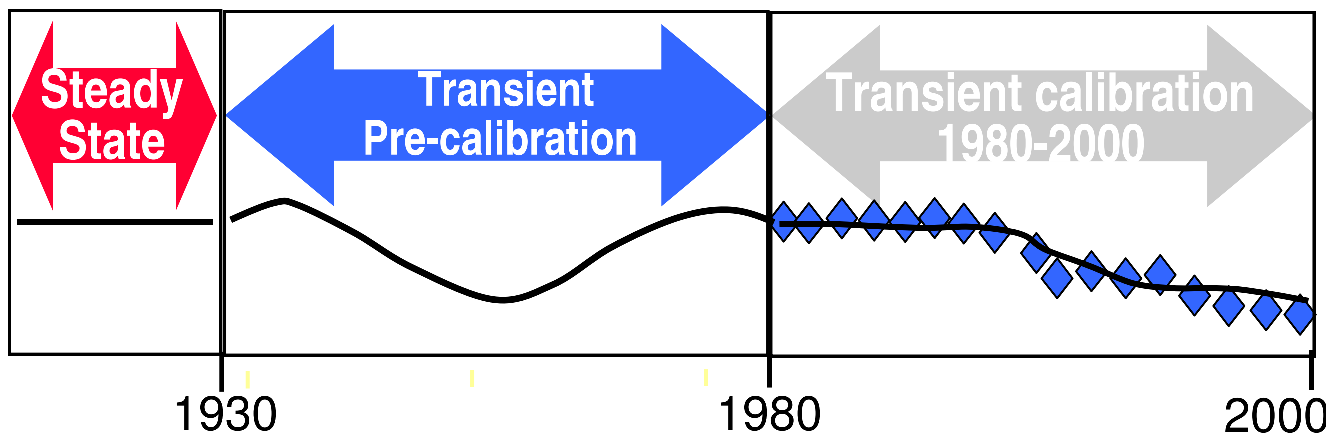
Model Time Periods

- Current Model Calibration Approach



- Proposed Re-Calibration Strategy



LEGEND
Observed Water Level
Model Water Level

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Addition of a Pre-calibration Pumping from 1930 to 1980

- In several counties, large changes in pumping occurred over time prior to 1980
- Water levels may not have been in equilbrium with pumping in 1980 so water levels may have been undergone significant change

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Historical Pumping in Reeves County

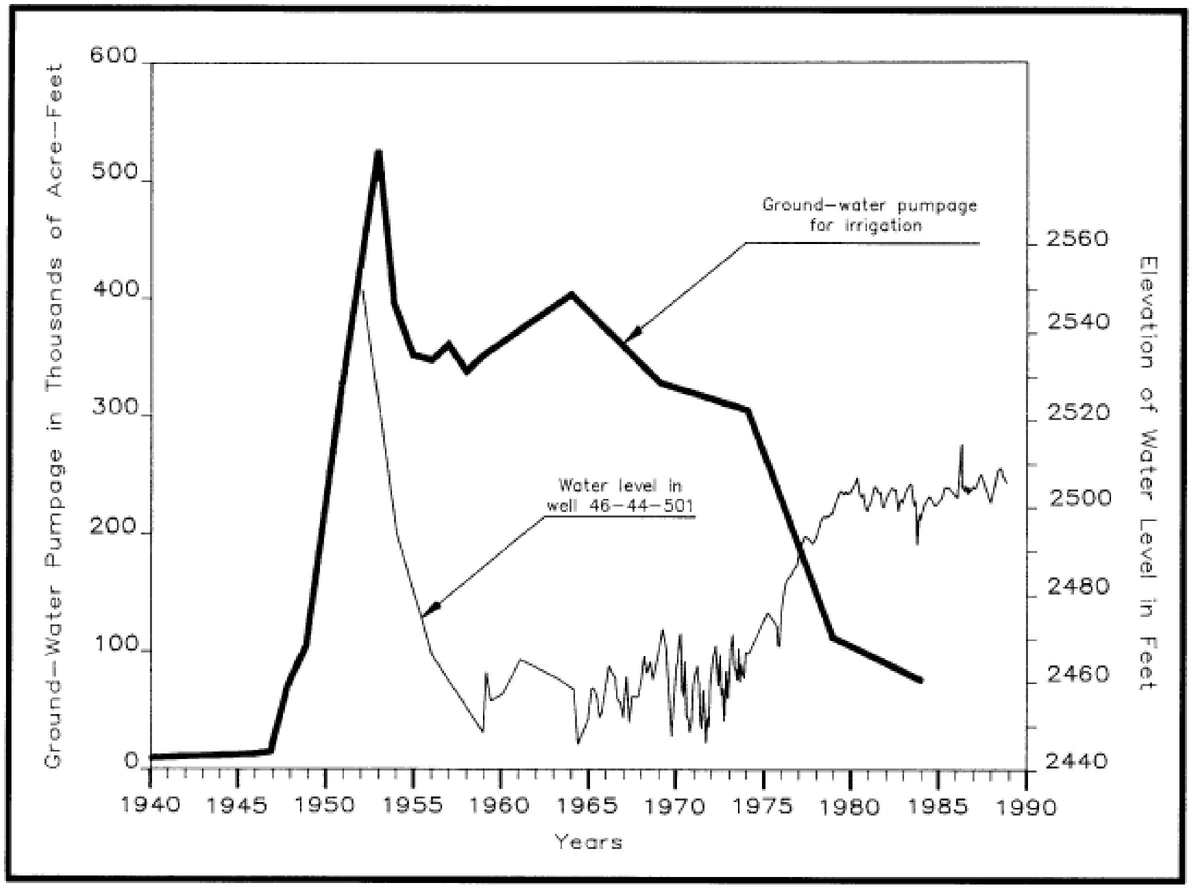

Figure 9

IRRIGATION PUMPAGE IN REEVES COUNTY VERSUS WATER–LEVEL CHANGE OVER TIME

TWDB Report 317, 1990

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Estimates Pre-calibration Pumping from 1930 to 1980

- Based on data from county reports, TWDB, National Agricultural Statistic Survey, and other sources
- Based on multiplication factors for “pumping” zones

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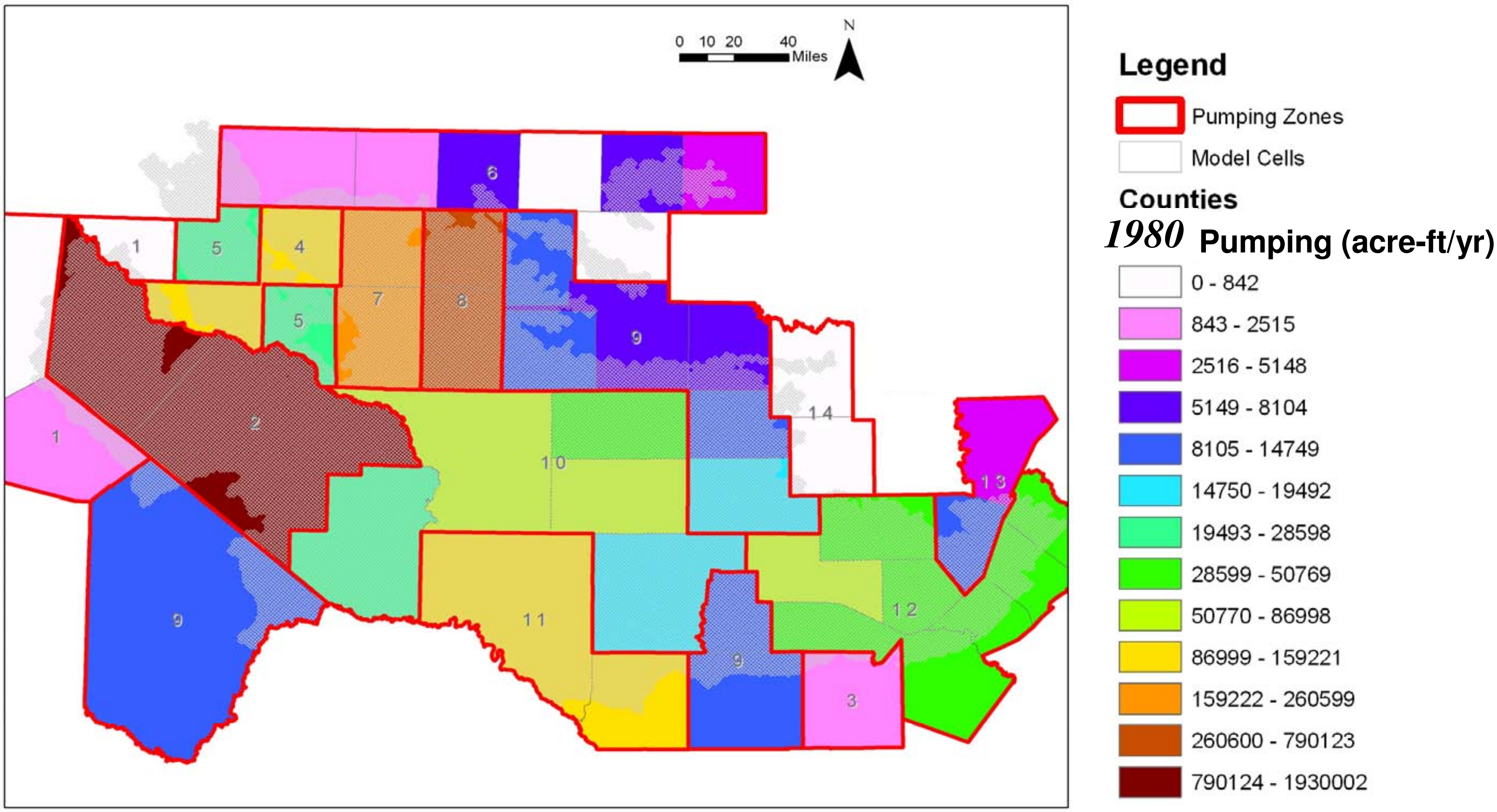
Pumping Zones



Summary

Key Highlights

- Good Model Calibration is a Prerequisite for Developing a Reliable Model for Assessing Groundwater Availability
- PEST is the Most Robust and Well Used Software for Calibrating Groundwater Models
- PEST Requires Expertise and Experience to Set Up but Provides Unmatched Capabilities for Model Calibration
- Project is Primarily a Demonstration to Evaluate PEST Applicability to GAM Program

Key Highlights (con't)

- Project will Produced an Improved ETPVA GAM but Improvements will be Primarily Limited to What can be Gained Through an Improved Model Calibration Technique
- Project will Provide Recommendations on how to Continue to Improve ETPVA GAM
- Project Will Benefit from Stakeholder contributions involving:
  - Water level measurements prior to 2000
  - Estimates of Aquifer Properties
  - Site Conceptual Model Information

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