Stakeholder Advisory Forum - 3

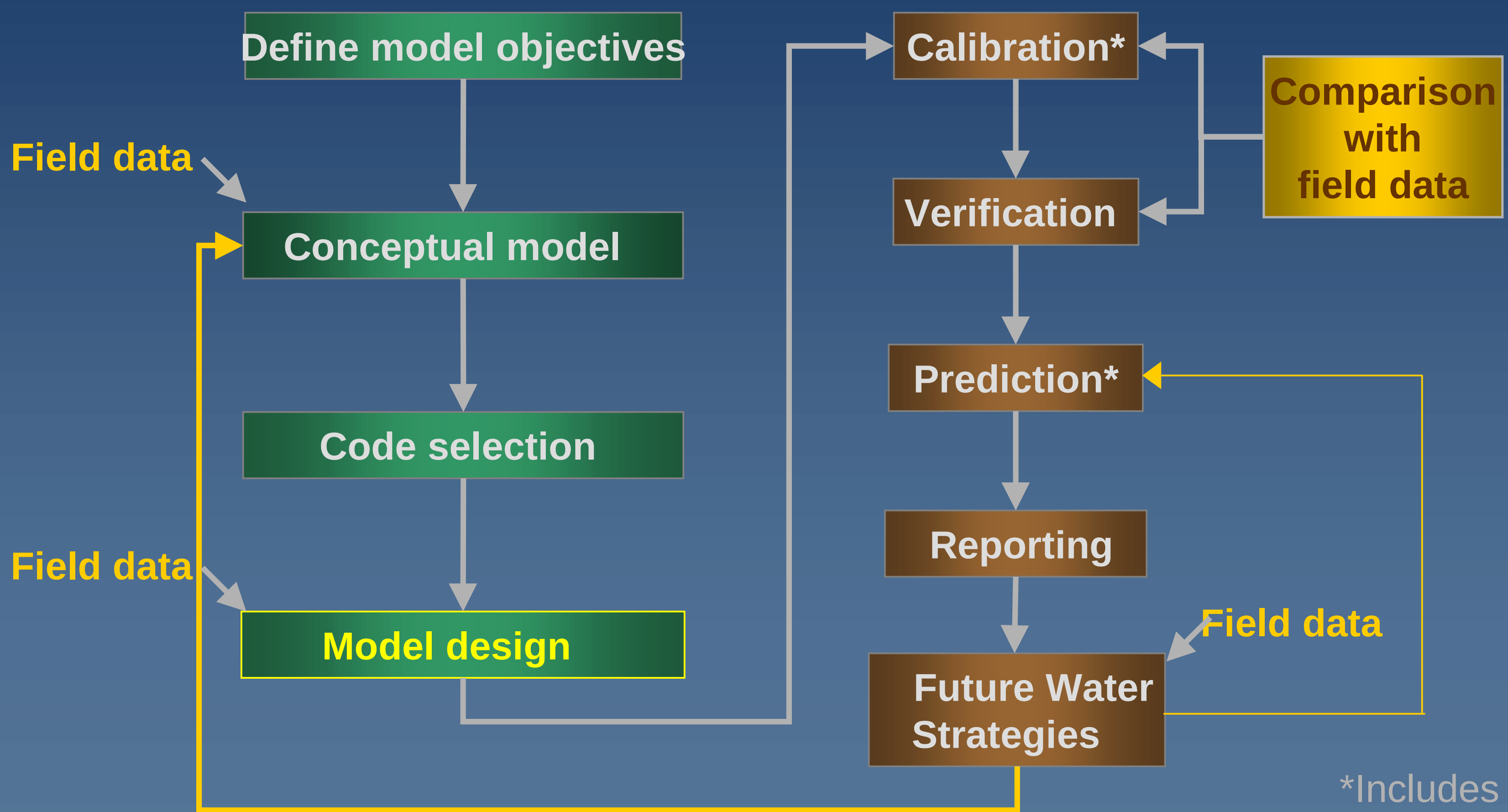
Groundwater Availability Modeling (GAM) for the Northern Carrizo-Wilcox Aquifer

Temple Inland Facility
Diboll, Texas
Angelina County

GAM Objectives

- **Develop realistic and scientifically accurate GW flow models representing the physical characteristics of the aquifer and incorporating the relevant processes**
- **The models are designed as tools to help GWCD, RWPGs, and individuals assess groundwater availability**
- **Stakeholder participation is important to ensure that the model is accepted as a valid model of the aquifer**

Modeling Protocol



*Includes sensitivity analysis

Northern GAM Schedule

2001

- SAF 1 — May 9
- SAF 2 — Aug 1
- SAF 3 — Nov 19

- Feb. 26 — Kickoff Meeting
- Aug 14 — Conceptual Model
- Dec. —Initial model design

2002

- SAF 4 — Feb.
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- SAF 7 — Sept.

- Jan. —Calibrate steady-state model
- Mar. —Calibrate transient model
- Jun. —Complete model predictions
- Sept. —Prepare draft report
- Dec. —Present SAF Model Seminar

2003

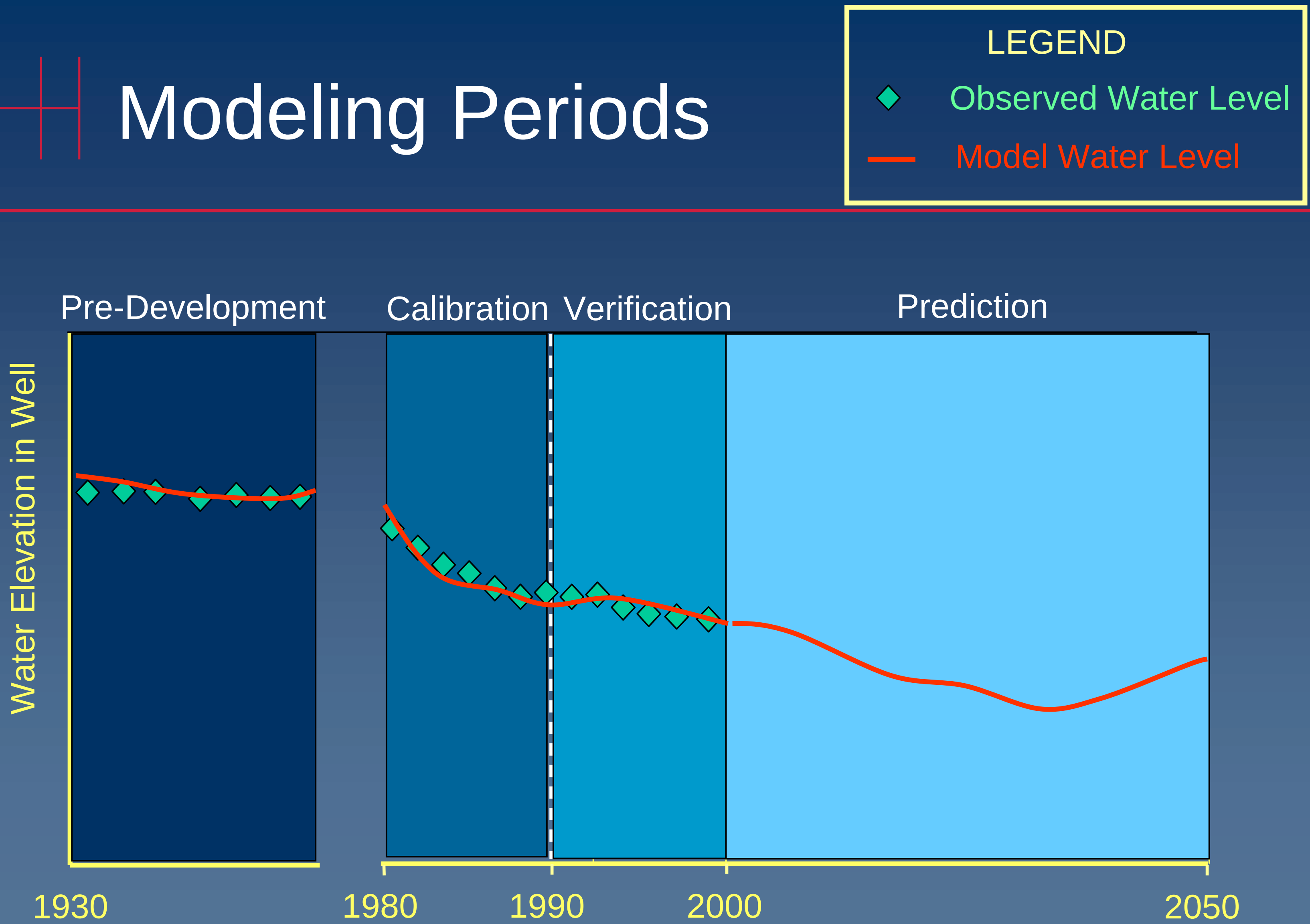
- SAF 8 — Jan.

- Deliver Final Product

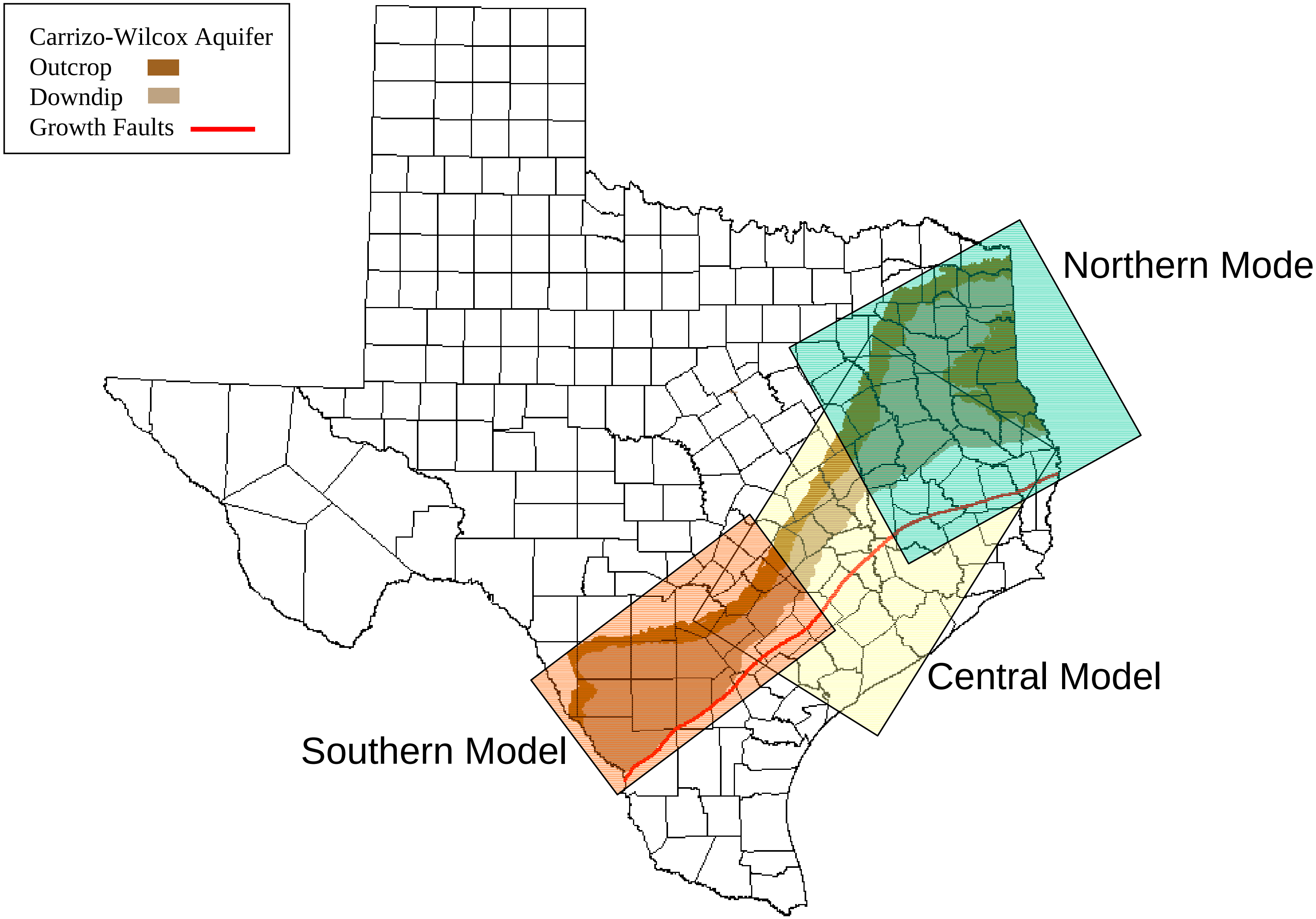
Model Specifications

- Three dimensional (MODFLOW-96)
- Regional scale (100's of mi2)
- Include Groundwater/surface water interaction (Stream routing, Prudic 1988)
- Properly implement recharge via factors
- Grid spacing of 1 square mile
- Stress periods as small as 1 month

Modeling Periods



Carrizo-Wilcox GAM Model Domains

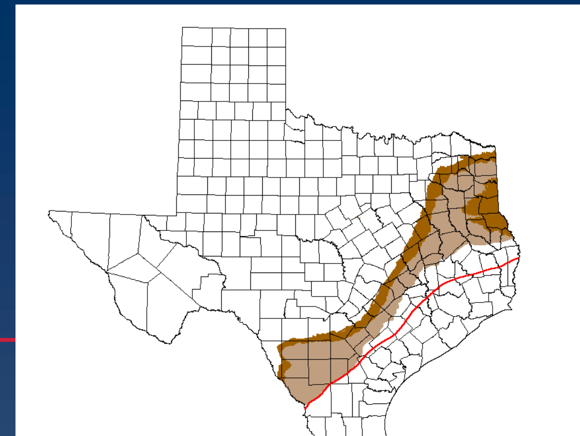


Model Design

- **Aquifer geometry**
  - **Hydrostratigraphy**
  - **Geology, structure, model grid, and boundaries**
- **Aquifer properties**
- **Water levels and regional groundwater flow**
- **Recharge**
- **Surface/groundwater interaction**

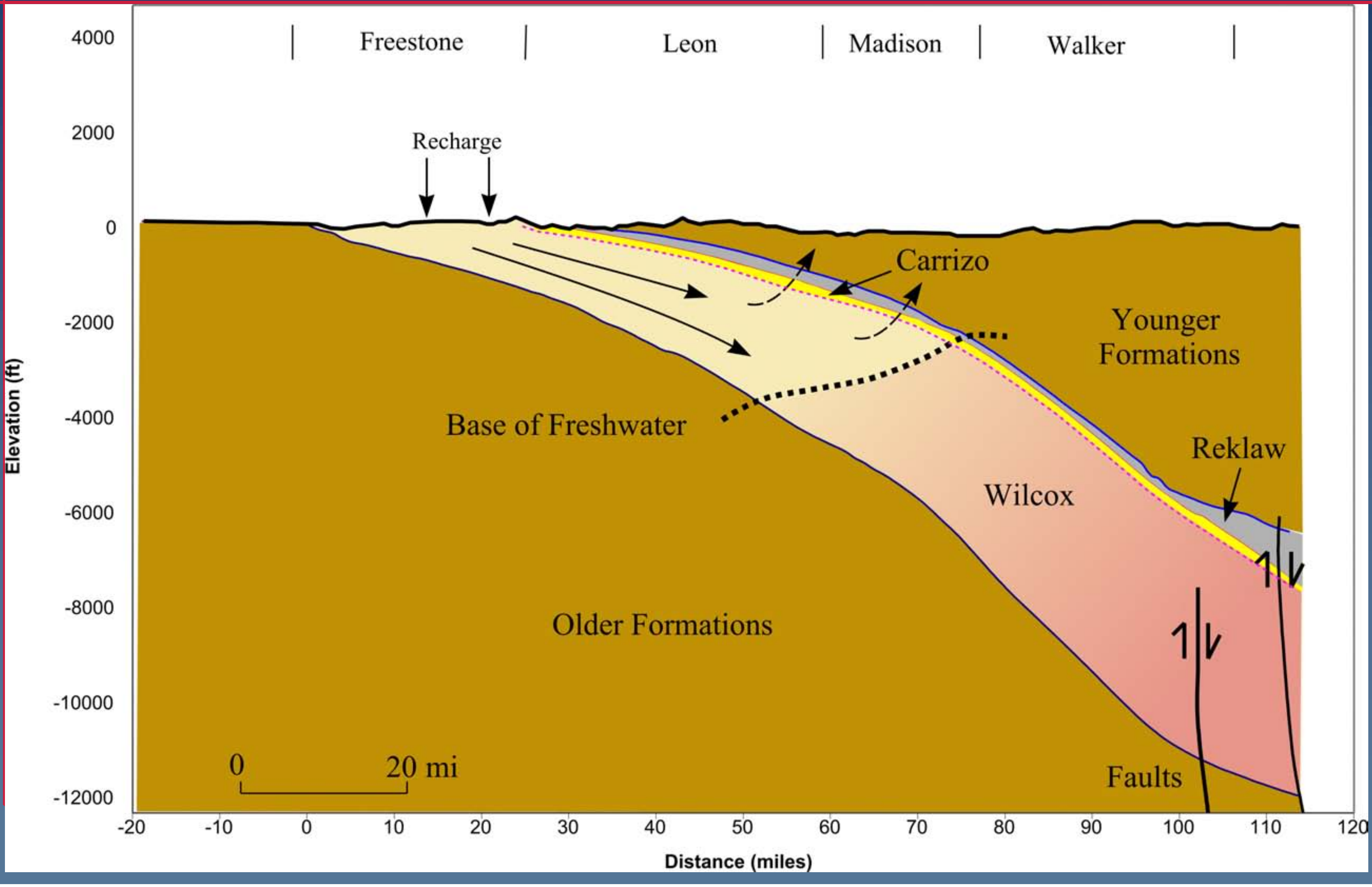
Aquifer Geometry

Geologic Framework — Stratigraphy



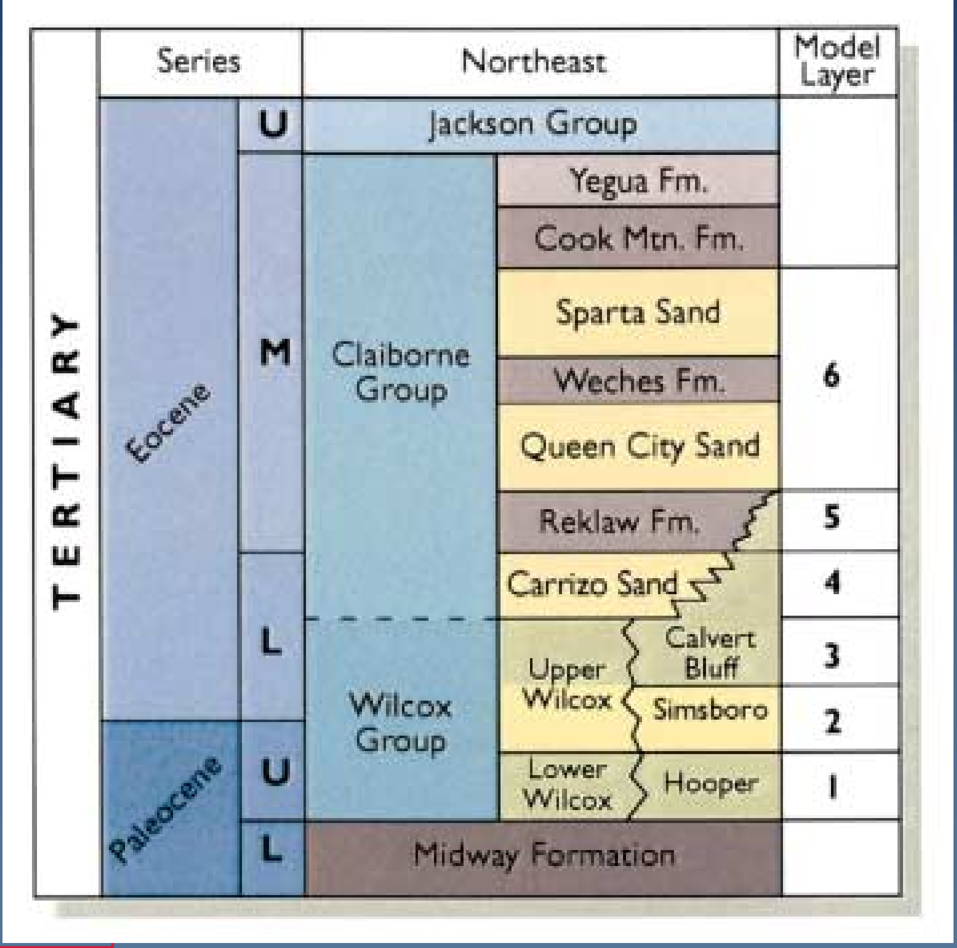
	Series			South Texas	Central Texas	Sabine Uplift
Tertiary	Eocene	U	Jackson Group		→	→
		M	Claiborne Group	Yegua Formation	→	→
				Cook Mtn. Fm.	→	→
				Sparta Sand	→	→
				Weches Formation	→	→
				Queen City Sand	→	→
				Recklaw Formation	→	→
		L	Wilcox Group	Carrizo Sand / Upper Wilcox	Carrizo Sand	Carrizo Sand
					Calvert Bluff Formation	Upper Wilcox
	Paleocene	U		Middle Wilcox	Simsboro Formation	Middle Wilcox
				Lower Wilcox	Hooper Formation	Lower Wilcox
		L		Midway Formation	→	→

Geologic Framework: X-Section



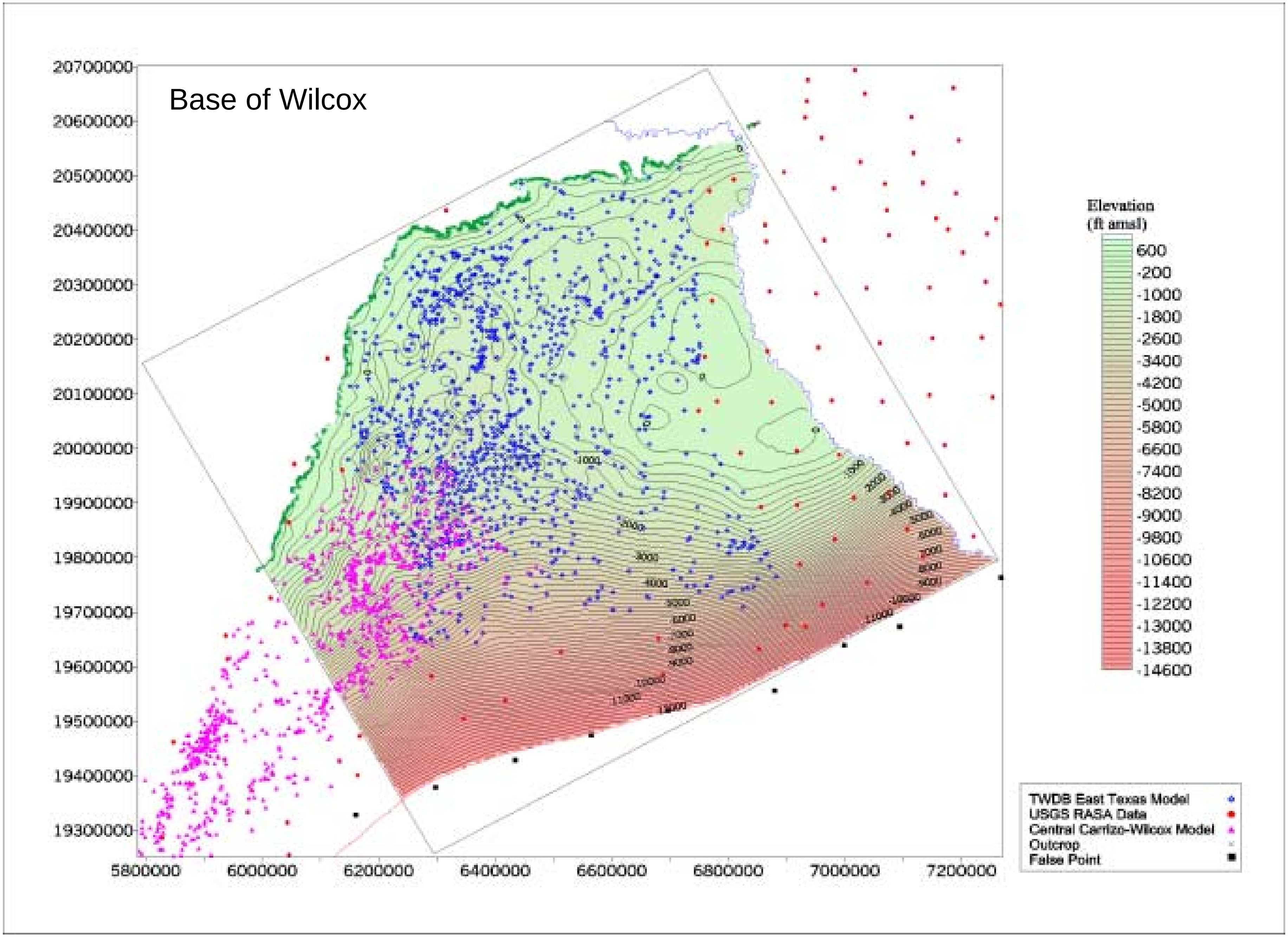
Model Layers

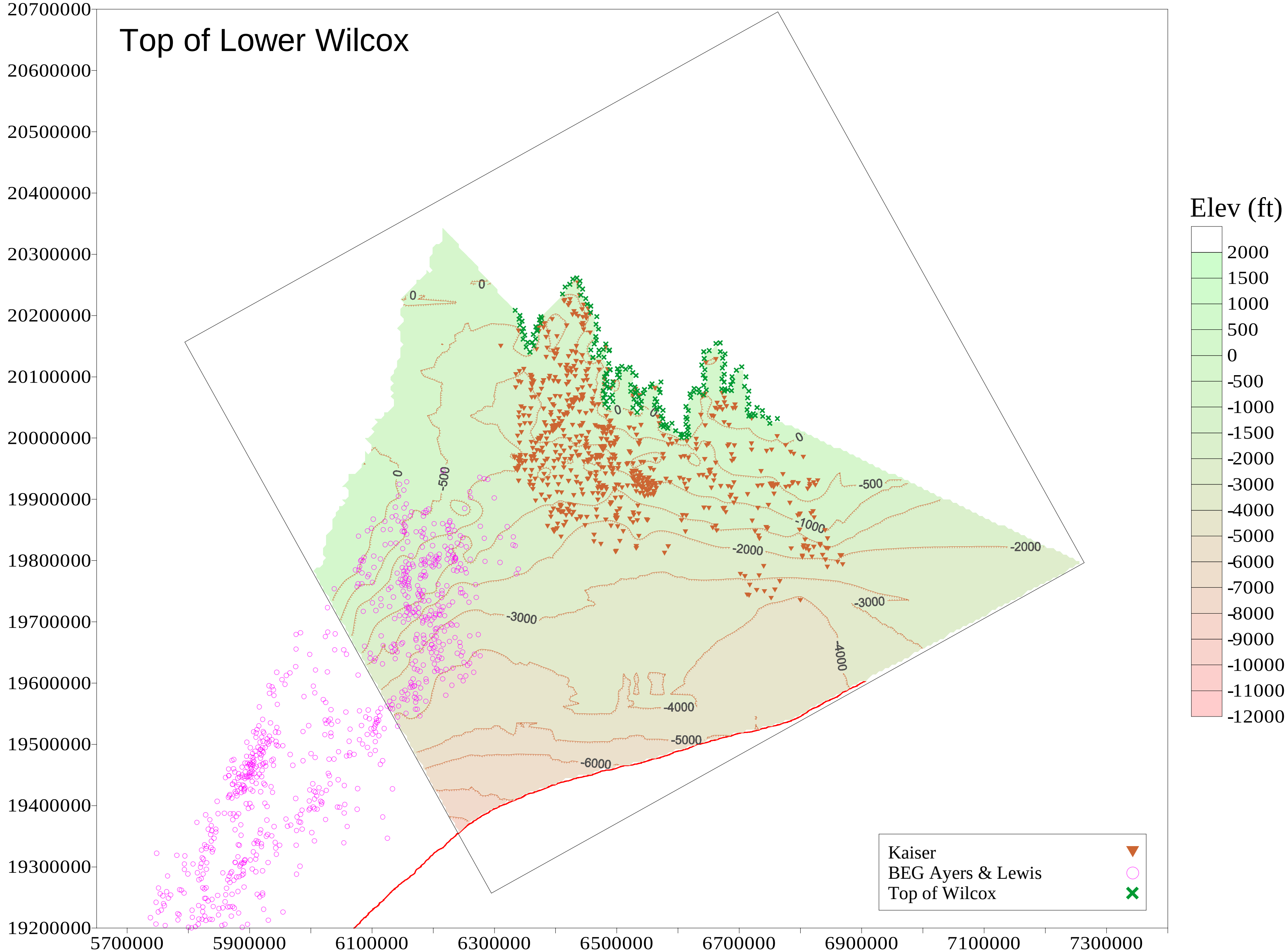
- **Total of six layers**
  - **Lower Wilcox (Hooper)**
  - **Middle Wilcox (Simsboro)**
  - **Upper Wilcox (Calvert Bluff)**
  - **Carrizo Sand**
  - **Reklaw Fm**
  - **Shallow aquifers**
    - **(QC, W, S)**



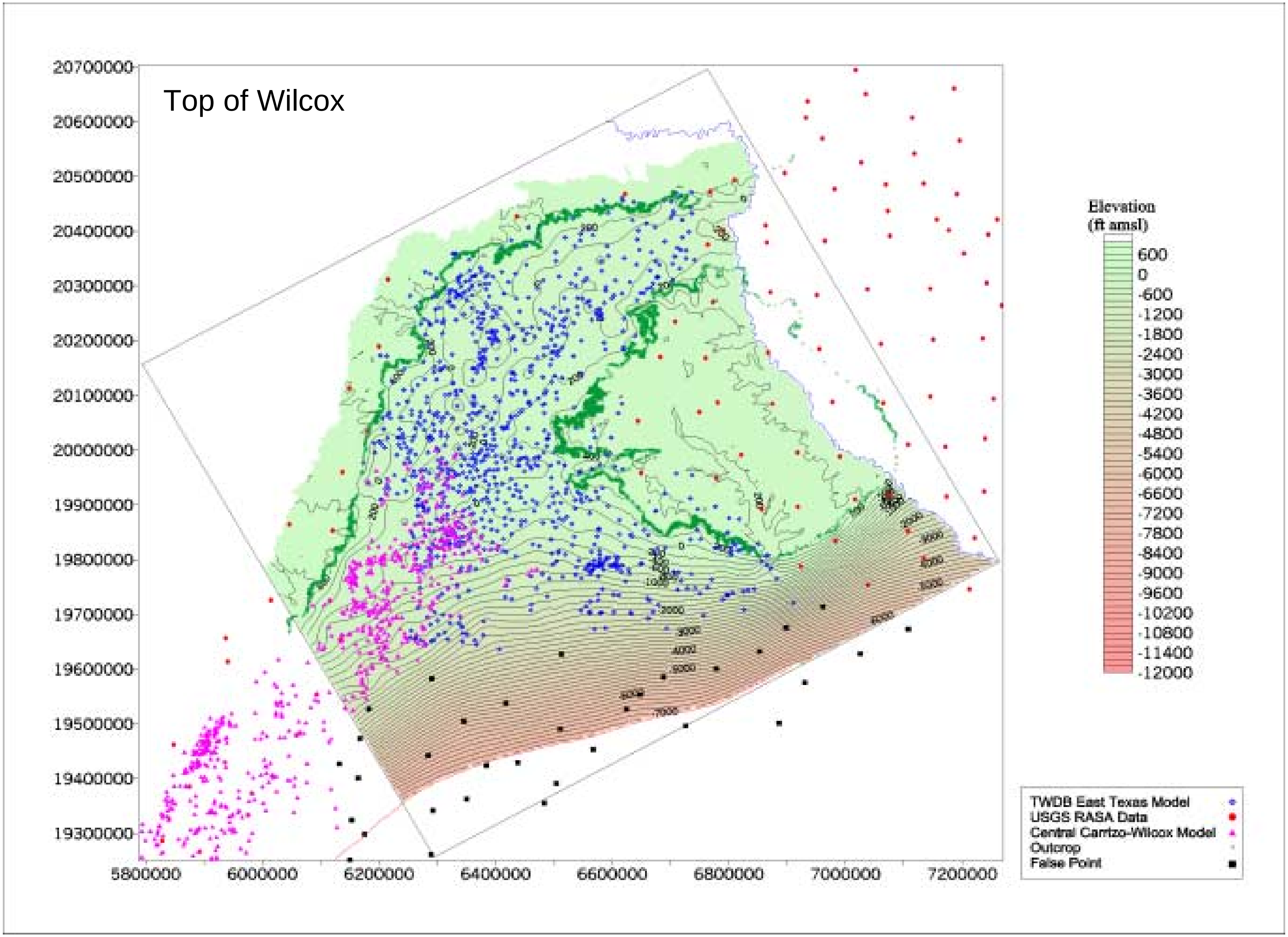
Stratigraphic Data Sources

- **TWDB East Texas Model**
  - **Wilcox, Carrizo, Reklaw, Queen City, Weches, Sparta**
- **USGS RASA (Texas - LA - MS)**
  - **Lower Claiborne-Upper Wilcox (NE: Carrizo)**
  - **Middle Wilcox (TX: entire Wilcox)**
- **Kaiser (1990) (Sabine Uplift)**
  - **2 layers for Wilcox**
- **Kaiser et al. (1978) (East Texas)**
  - **undivided Wilcox**
- **Bebout et al. (1982) (Texas)**
  - **3 layers for Wilcox**

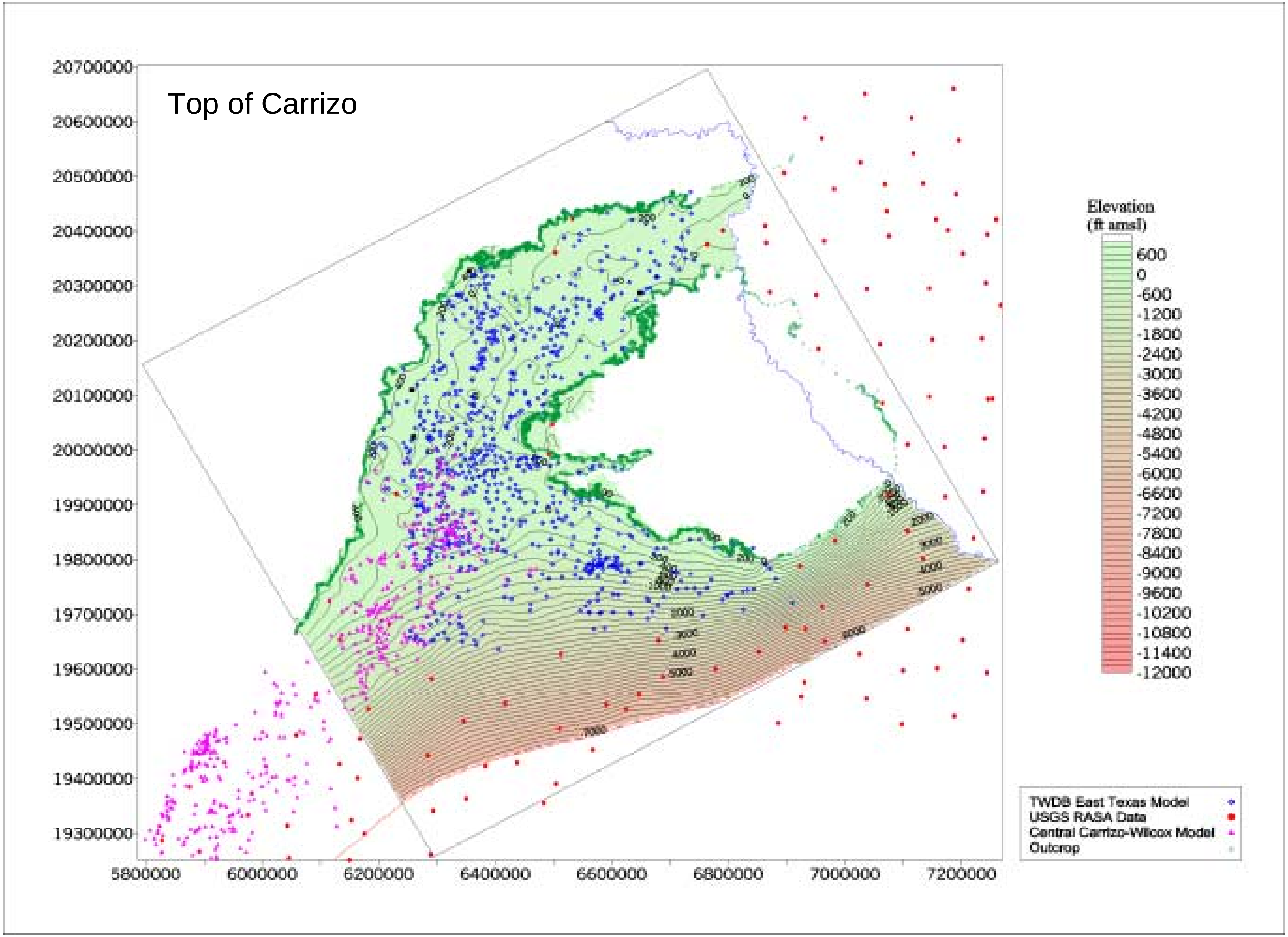

Base of Wilcox
Elevation (ft amsl)
600
-200
-1000
-1800
-2600
-3400
-4200
-5000
-5800
-6600
-7400
-8200
-9000
-9800
-10600
-11400
-12200
-13000
-13800
-14600
TWDB East Texas Model
USGS RASA Data
Central Carrizo-Wilcox Model
Outcrop
False Point
20700000
20600000
20500000
20400000
20300000
20200000
20100000
20000000
19900000
19800000
19700000
19600000
19500000
19400000
19300000
5800000
6000000
6200000
6400000
6600000
6800000
7000000
7200000



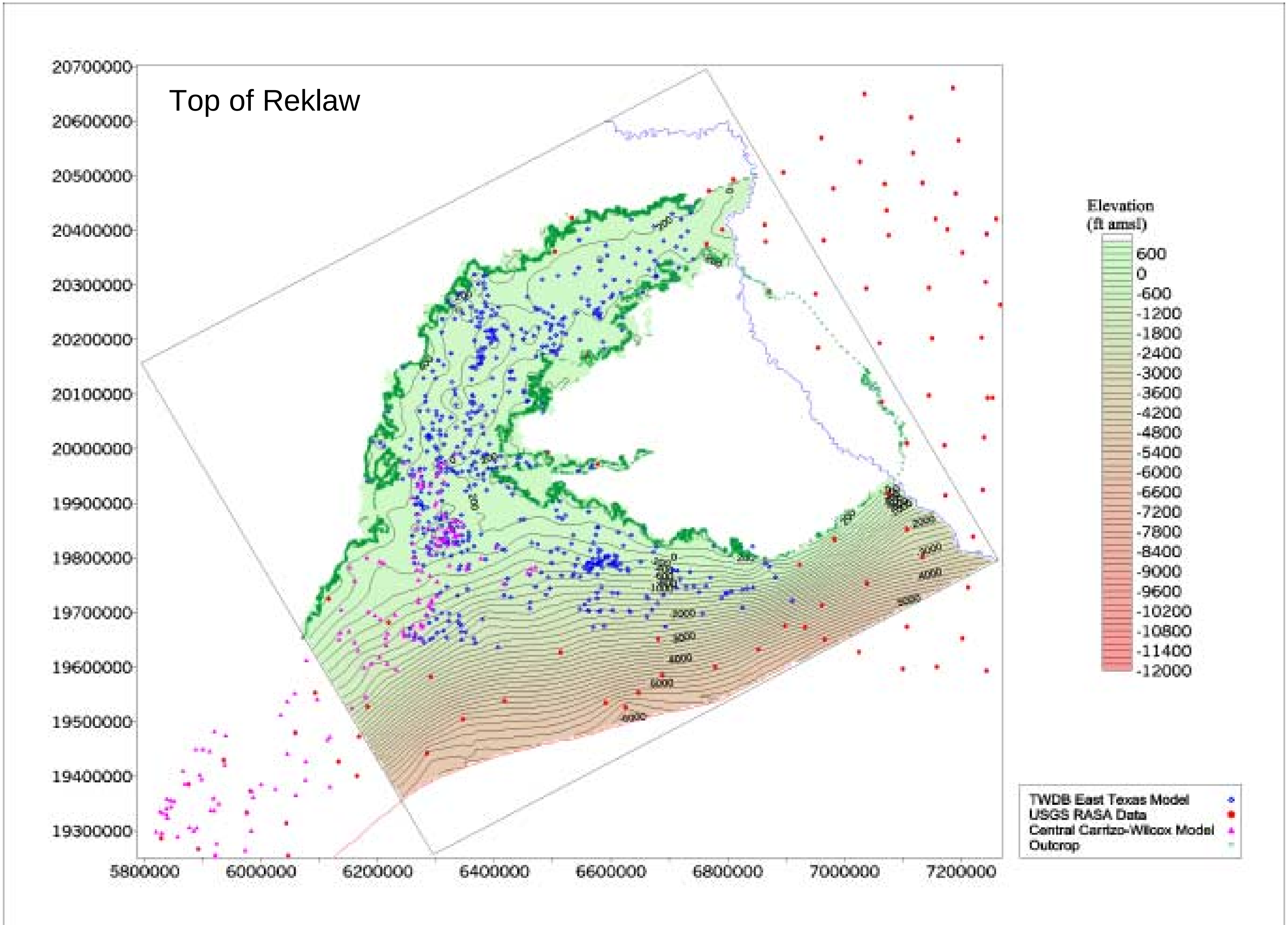
Top of Lower Wilcox



Top of Wilcox
Elevation (ft amsl)
600
0
-600
-1200
-1800
-2400
-3000
-3600
-4200
-4800
-5400
-6000
-6600
-7200
-7800
-8400
-9000
-9600
-10200
-10800
-11400
-12000
TWDB East Texas Model
USGS RASA Data
Central Carrizo-Wilcox Model
Outcrop
False Point
20700000
20600000
20500000
20400000
20300000
20200000
20100000
20000000
19900000
19800000
19700000
19600000
19500000
19400000
19300000
5800000
6000000
6200000
6400000
6600000
6800000
7000000
7200000

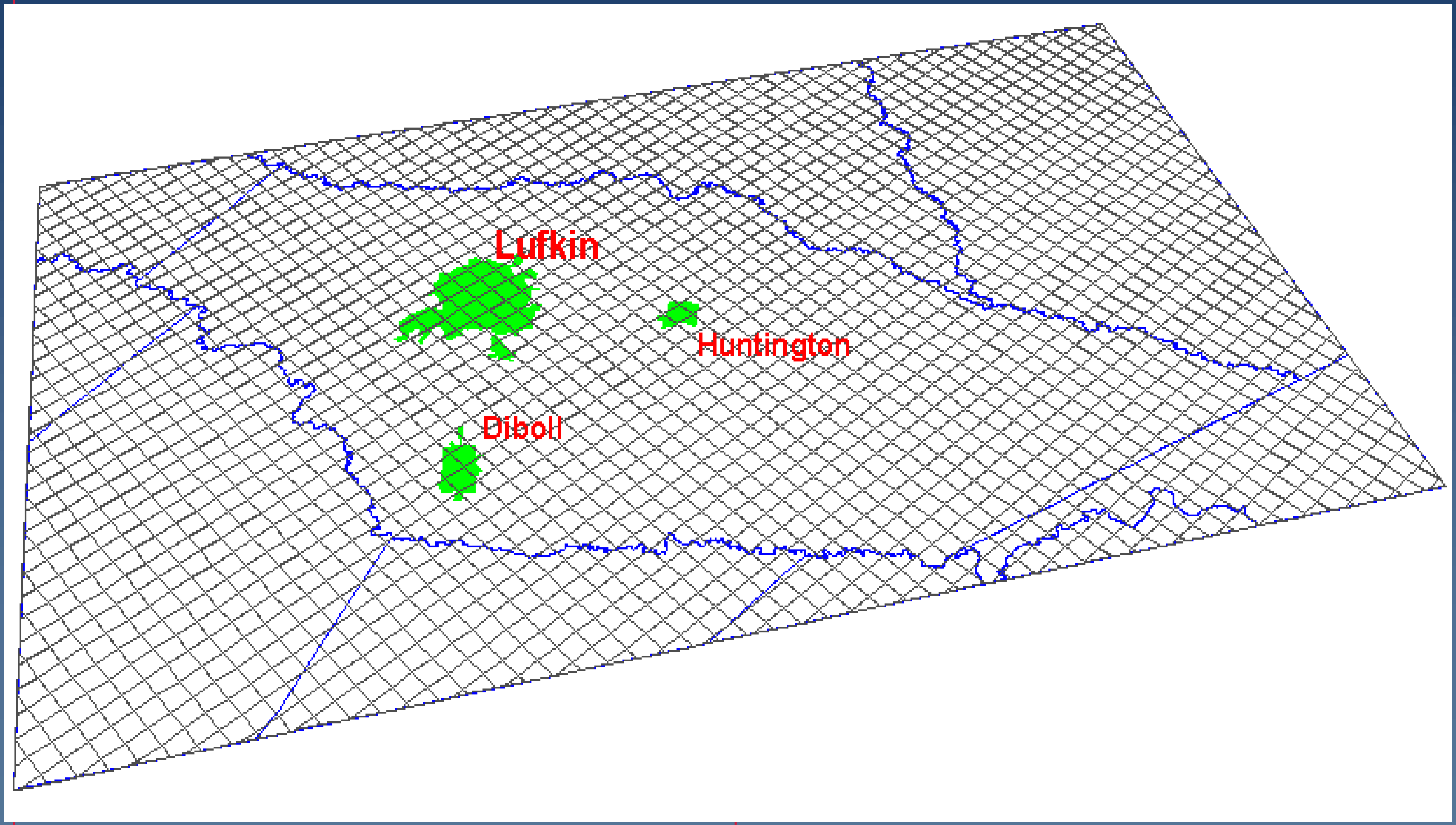


Top of Carrizo
20700000
20600000
20500000
20400000
20300000
20200000
20100000
20000000
19900000
19800000
19700000
19600000
19500000
19400000
19300000
5800000
6000000
6200000
6400000
6600000
6800000
7000000
7200000
Elevation
(ft amsl)
600
0
-600
-1200
-1800
-2400
-3000
-3600
-4200
-4800
-5400
-6000
-6600
-7200
-7800
-8400
-9000
-9600
-10200
-10800
-11400
-12000
TWDB East Texas Model
USGS RASA Data
Central Carrizo-Wilcox Model
Outcrop



Top of Reklaw
20700000
20600000
20500000
20400000
20300000
20200000
20100000
20000000
19900000
19800000
19700000
19600000
19500000
19400000
19300000
5800000
6000000
6200000
6400000
6600000
6800000
7000000
7200000
Elevation (ft amsl)
600
0
-600
-1200
-1800
-2400
-3000
-3600
-4200
-4800
-5400
-6000
-6600
-7200
-7800
-8400
-9000
-9600
-10200
-10800
-11400
-12000
TWDB East Texas Model
USGS RASA Data
Central Carrizo-Wilcox Model
Outcrop

Model Grid Scale

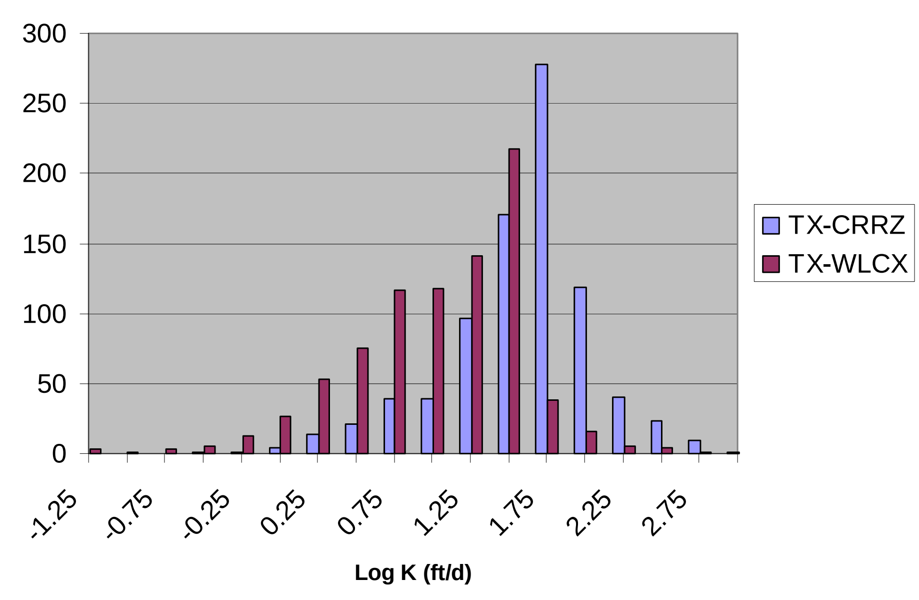


Aquifer Properties

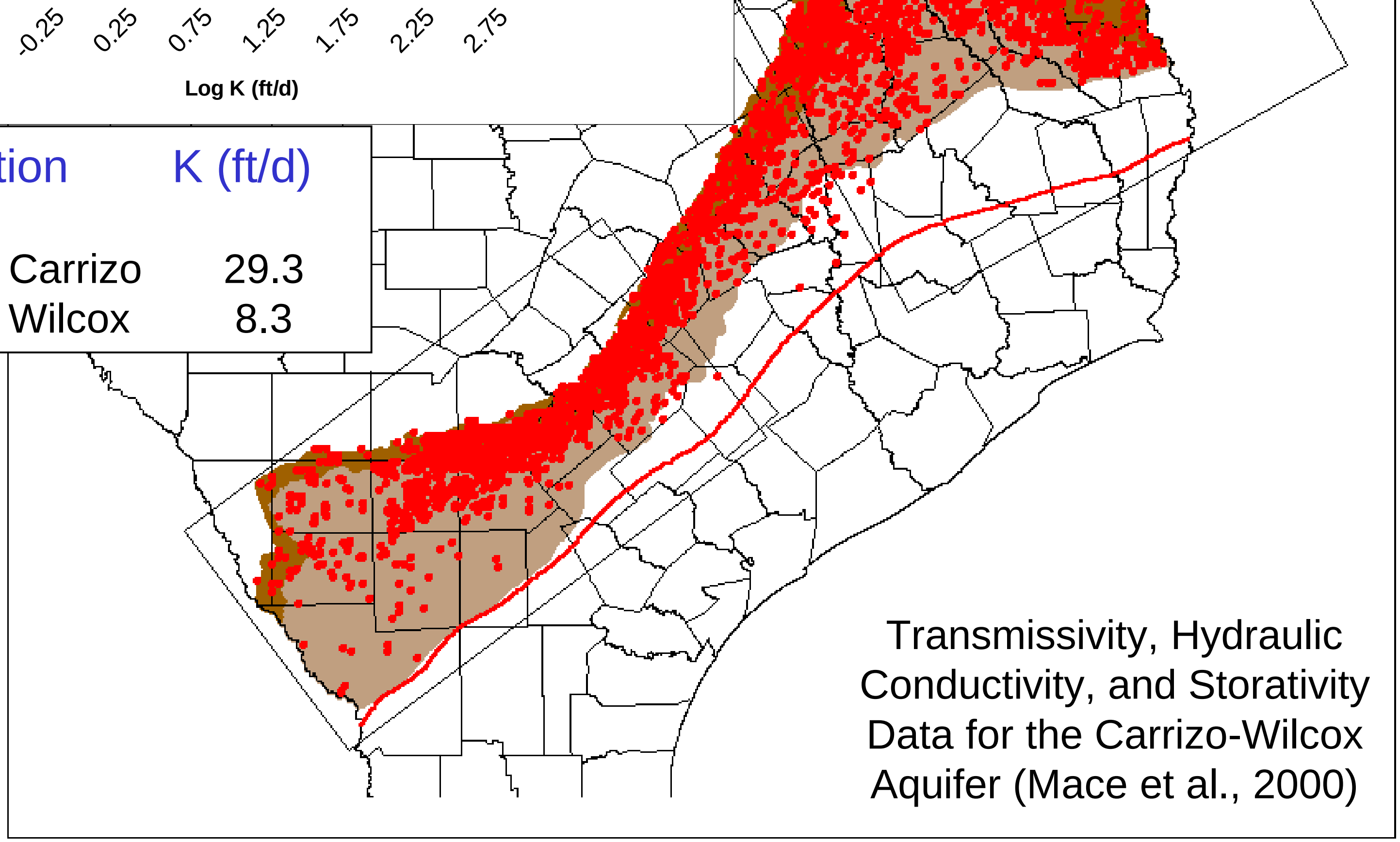
Hydraulic Properties

- A good distribution of point measurements for K are available (Mace et al, 2000)
- Measurements tend to be biased to the high side (well completion in sand)
- Hydraulic property related to depositional environments
- Must scale K_h and K_v to regional grid scale while preserving underlying data

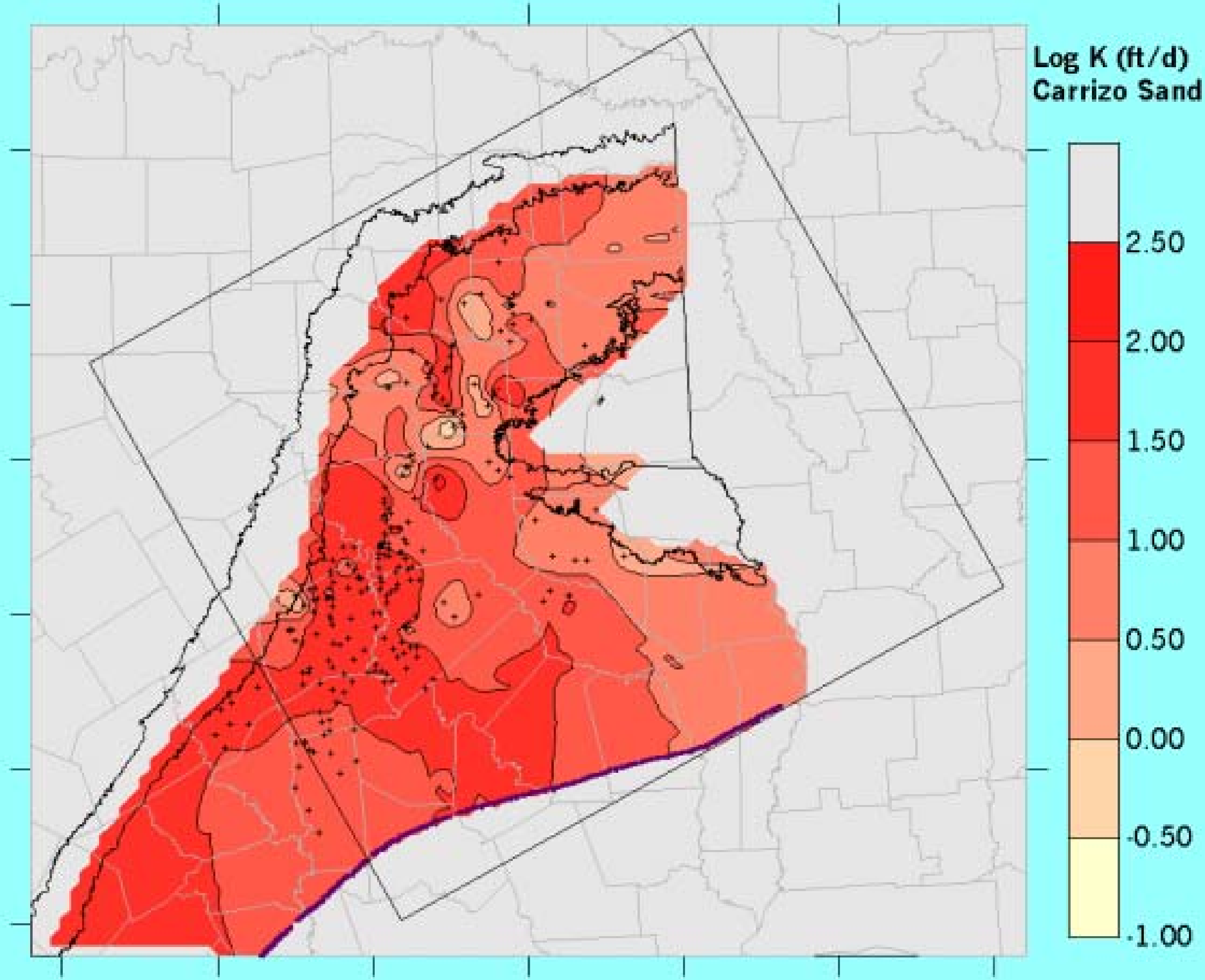
Hydraulic Conductivity Data Sources

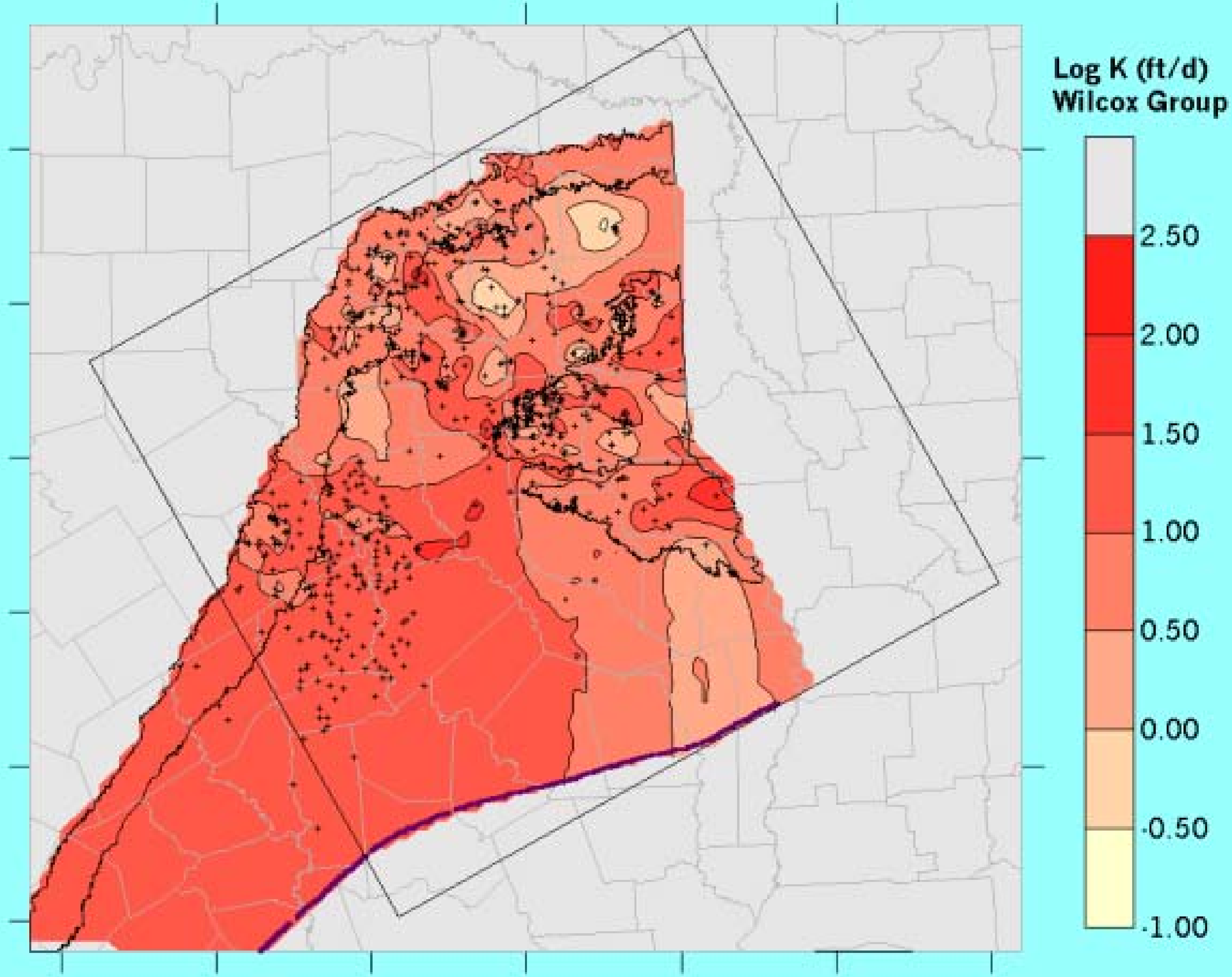


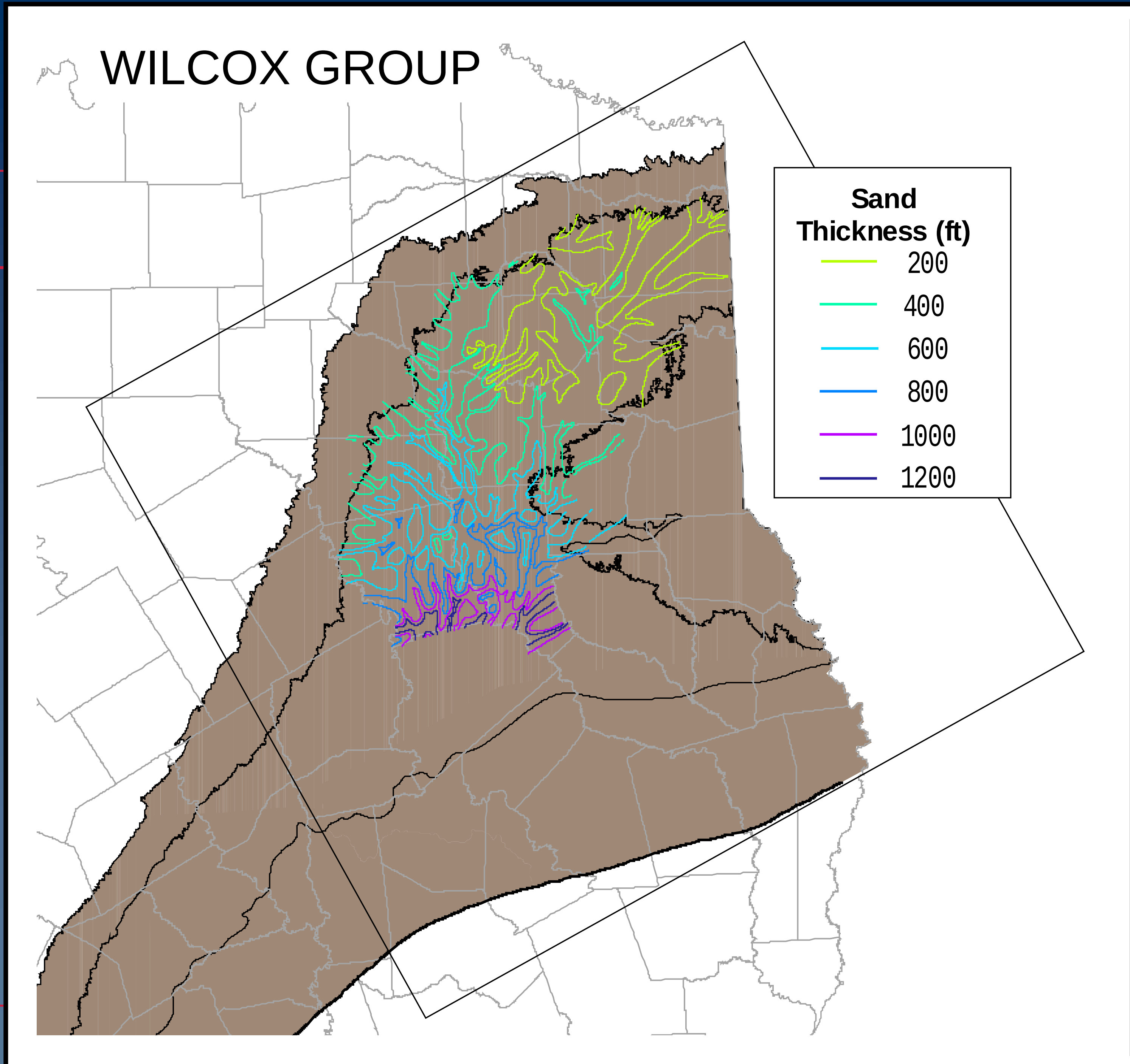
Formation	K (ft/d)
Texas - Carrizo	29.3
Texas - Wilcox	8.3

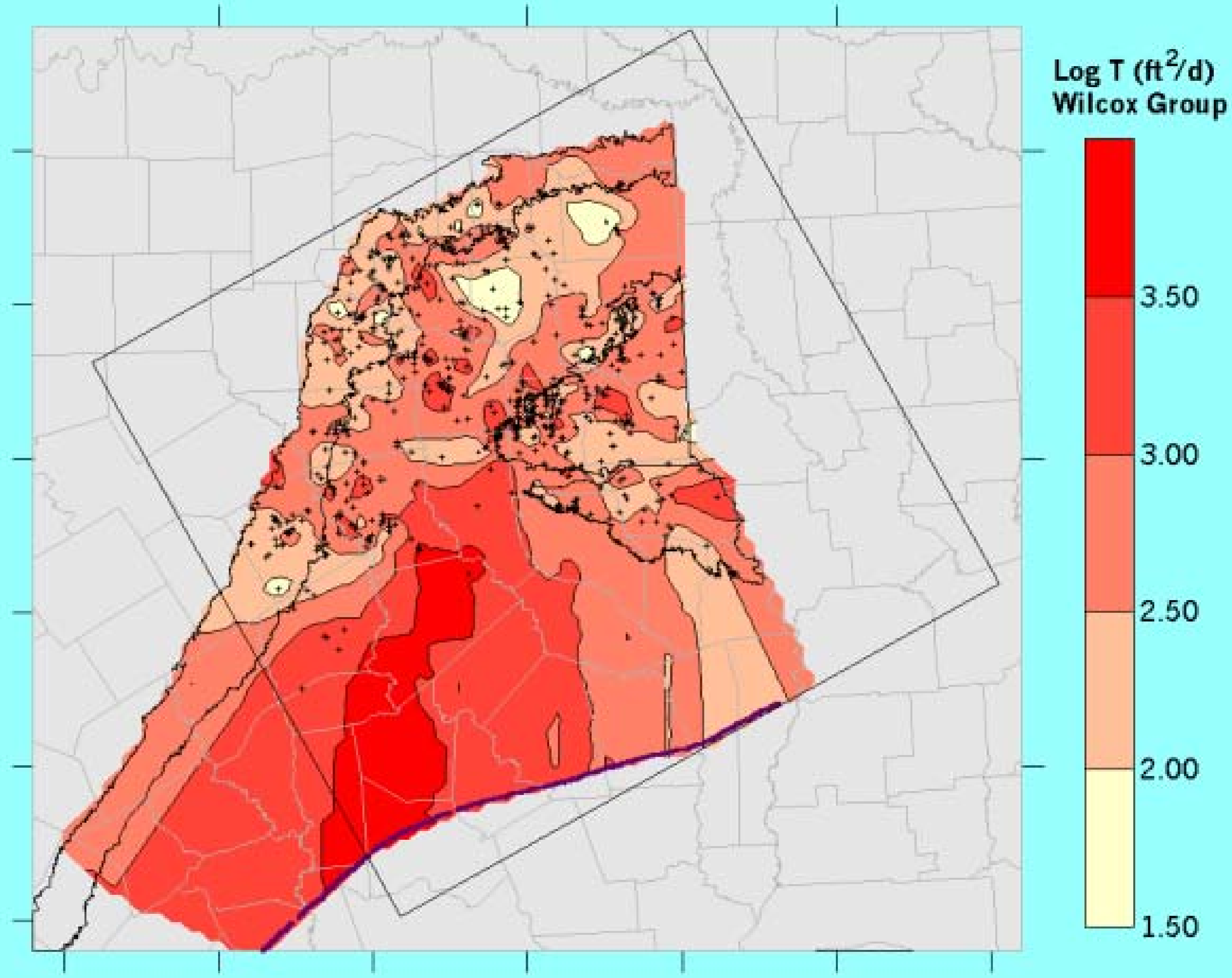


Transmissivity, Hydraulic Conductivity, and Storativity Data for the Carrizo-Wilcox Aquifer (Mace et al., 2000)


Log K (ft/d)
Carrizo Sand
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00


Log K (ft/d)
Wilcox Group
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00


WILCOX GROUP
Sand Thickness (ft)
200
400
600
800
1000
1200



Log T (ft²/d)
Wilcox Group
3.50
3.00
2.50
2.00
1.50

Effective Horizontal Conductivity

- **Estimate block center K through kriging (BLUE)**
- **Calculate a weighted-arithmetic mean K**
- **Preserves measured transmissivity W**

$$K_h \text{ effective} = \frac{(\text{net sand})(K_{sand}) + (\text{layer b} - \text{net sand})(K_{other})}{\text{layer b}}$$

K_{sand} = kriged value

$K_{clay} \le K_{other} < K_{sand}$

Effective Vertical Conductivity

- **Calibrate Kv/Kh effective based upon**
  - **Water-level vs. depth profiles**
  - **X-formational flow by 10,000 ppm**
  - **Specification of recharge**
- **Use supporting geologic information**
  - **Depositional environments**
  - **Maximum sand thickness / net sand**
  - **Maximum sand thickness / layer thickness**
  - **Percent sand**

Water Levels and Regional Groundwater Flow

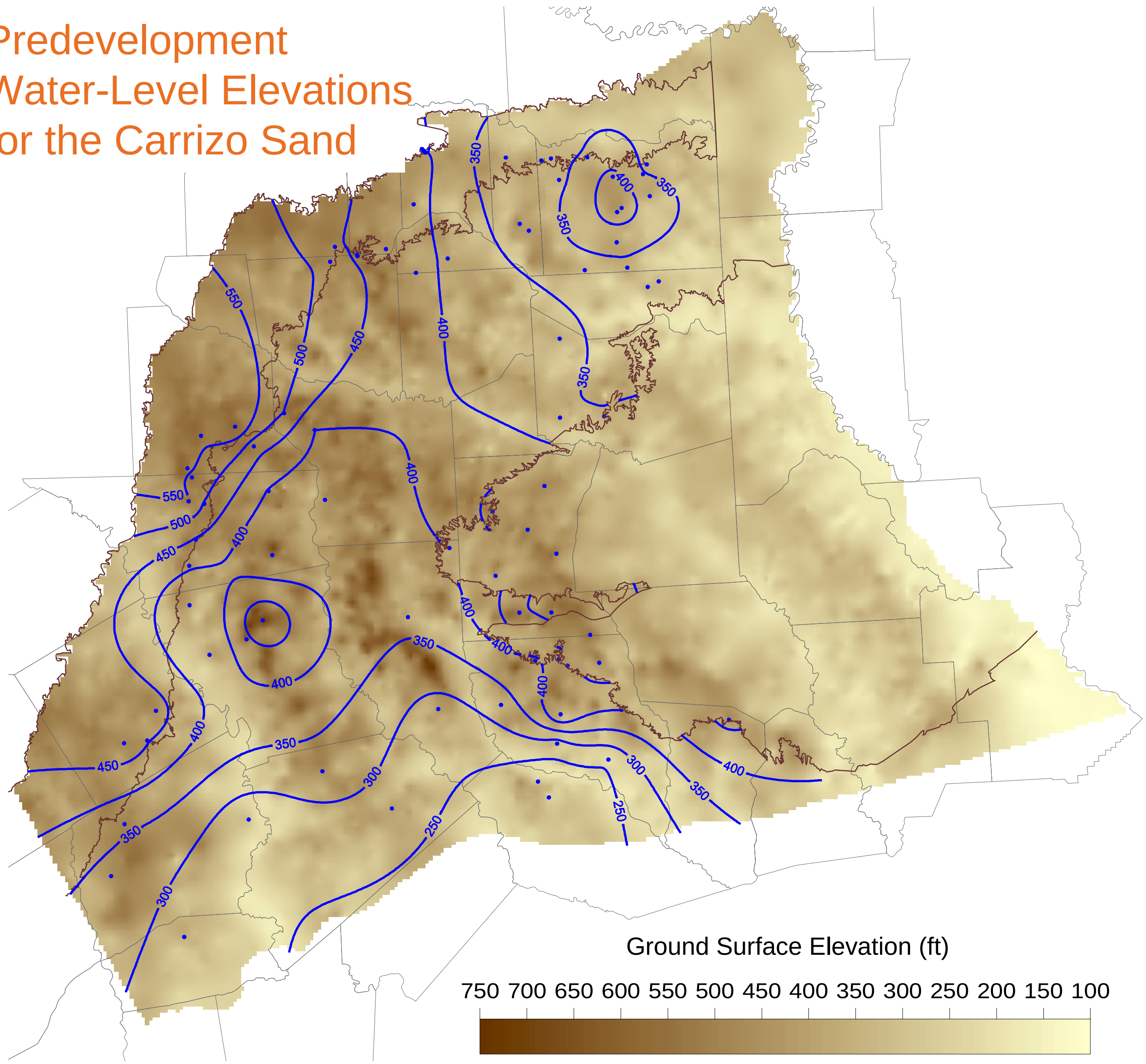
Water Levels and Regional Groundwater Flow

- **Objectives**
  - Develop potentiometric contours of water-level elevation
    - Predevelopment levels for model initialization
    - 1990 levels for model calibration
    - 2000 levels for model verification
  - Select hydrographs for use as calibration targets
  - Generate transient water level changes for use as boundary conditions
  - Evaluate cross-formational flow

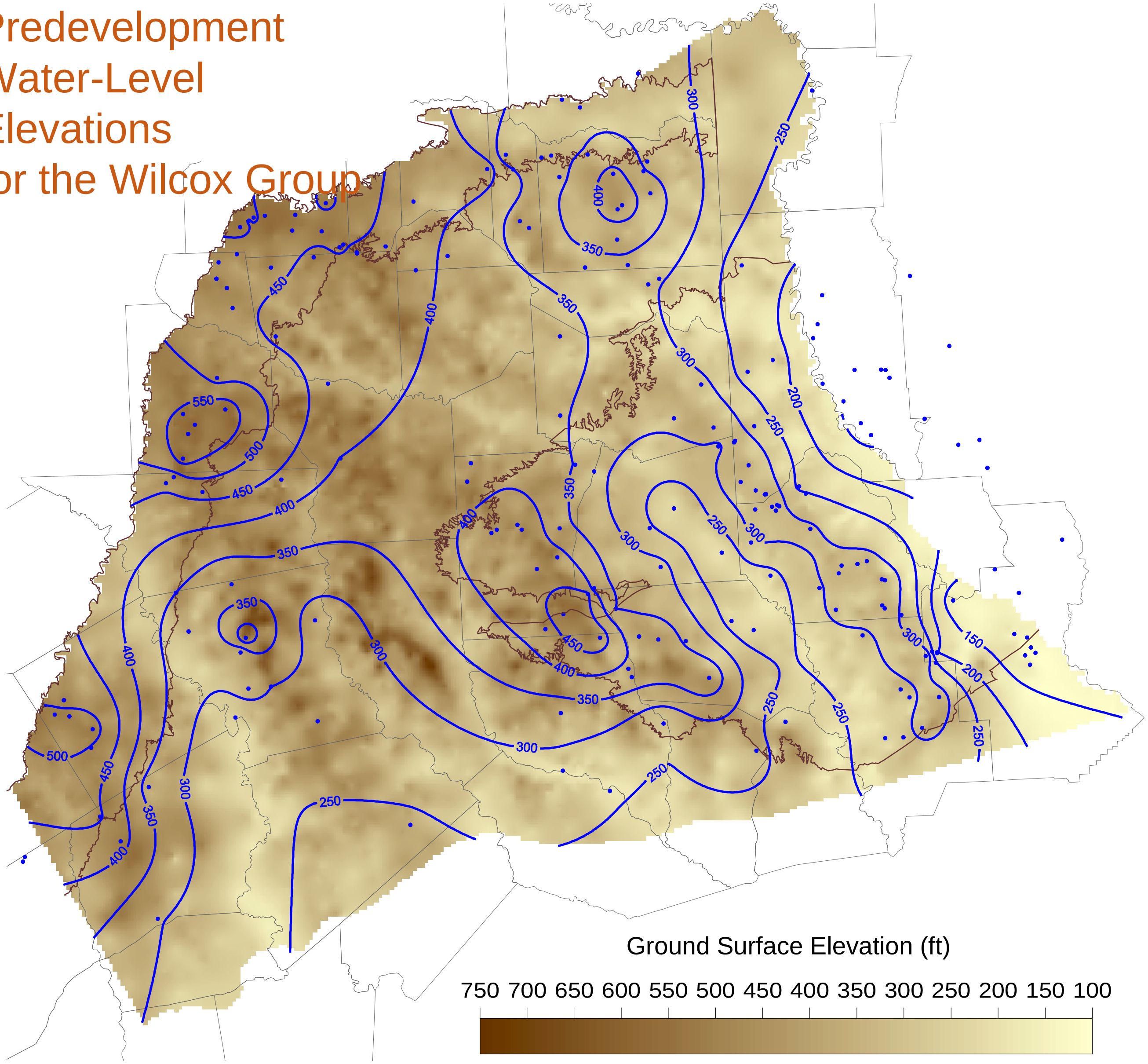
Water Levels and Regional Groundwater Flow (cont.)

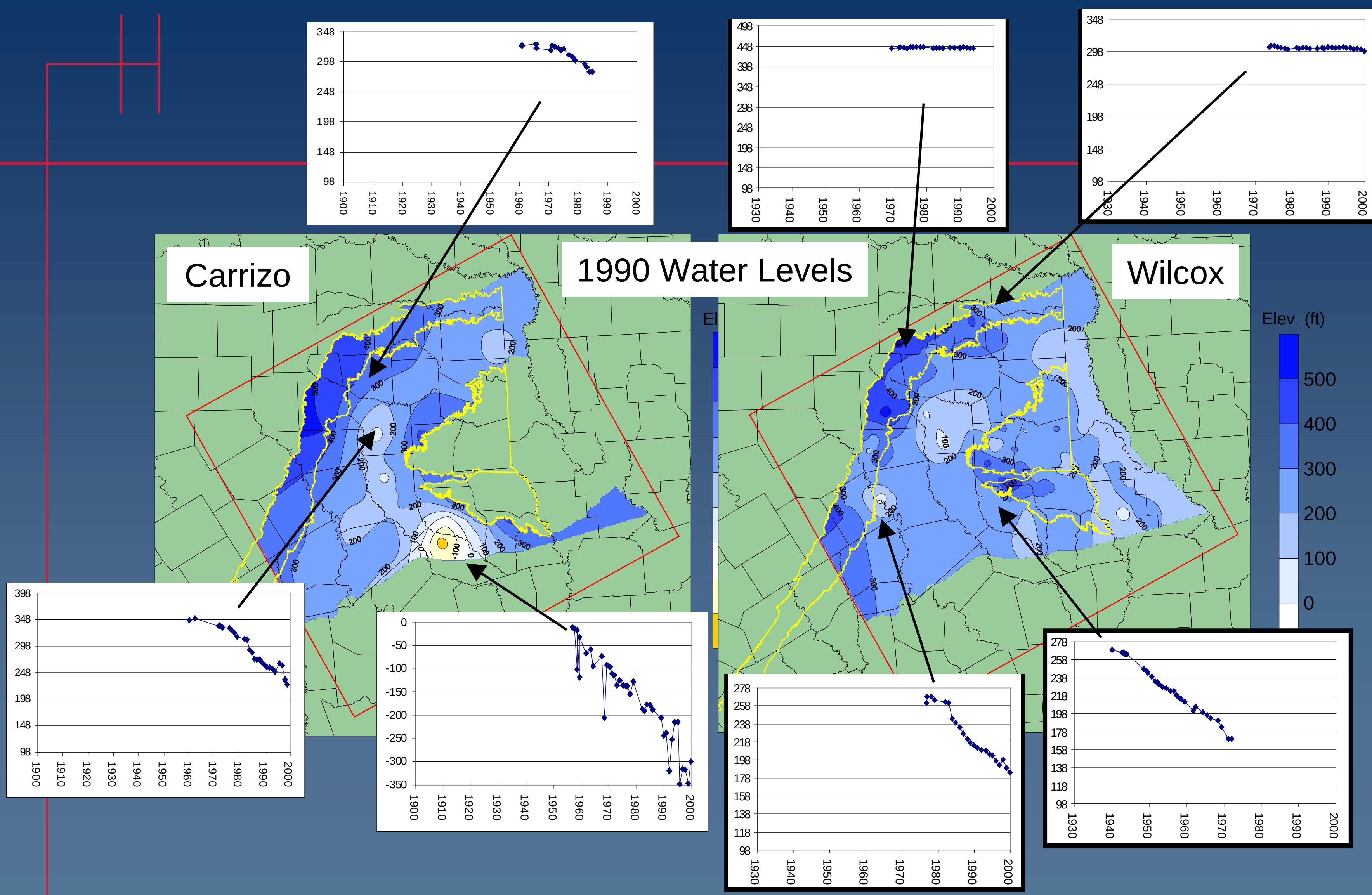
- **Sources of Data**
  - **Texas Water Levels**
    - **Texas Water Development Board database**
  - **Louisiana and Arkansas Water Levels**
    - **U.S. Geological Survey National Water Information System**
    - **Louisiana Department of Transportation and Development**

Predevelopment Water-Level Elevations for the Carrizo Sand



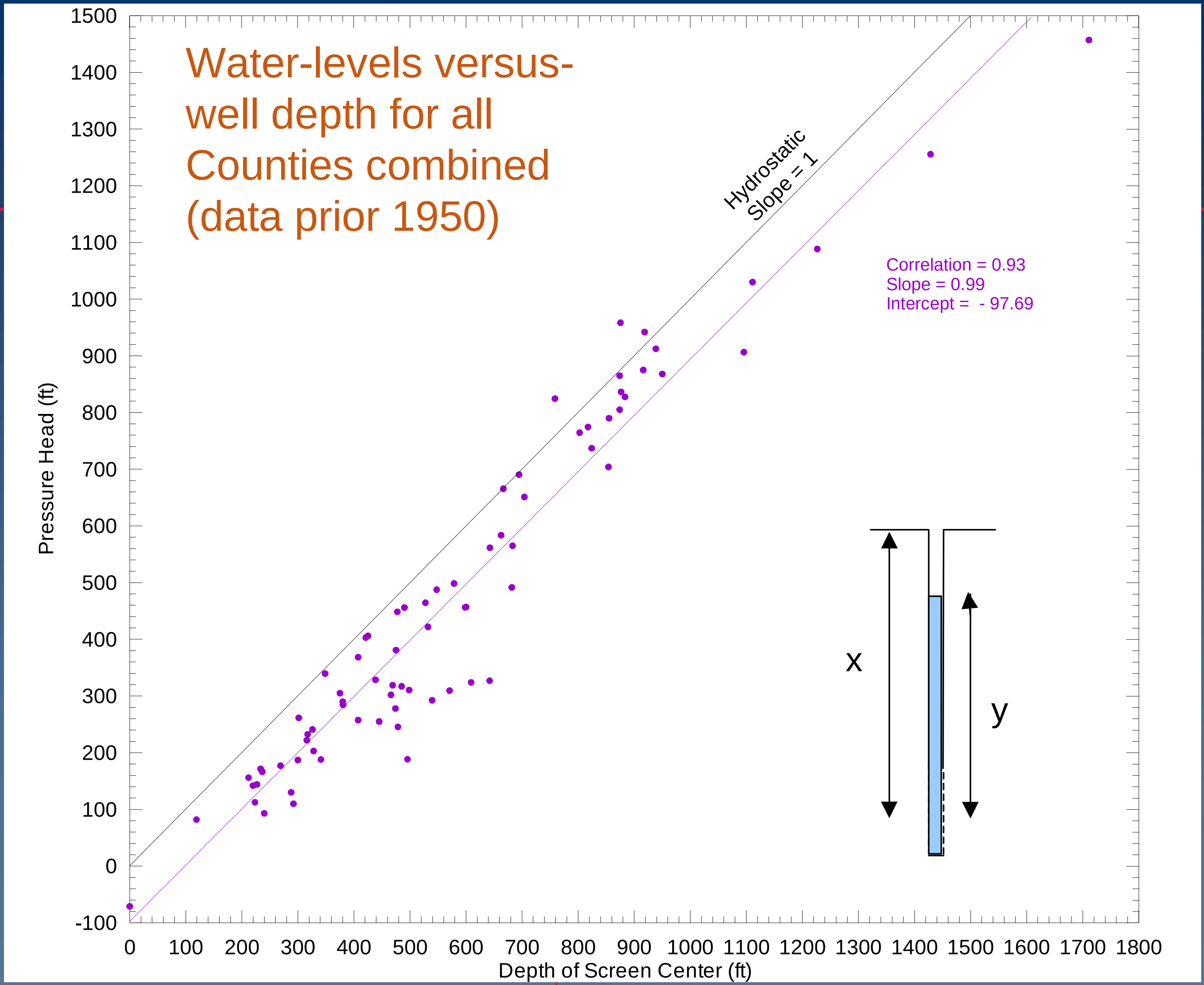
Predevelopment Water-Level Elevations for the Wilcox Group



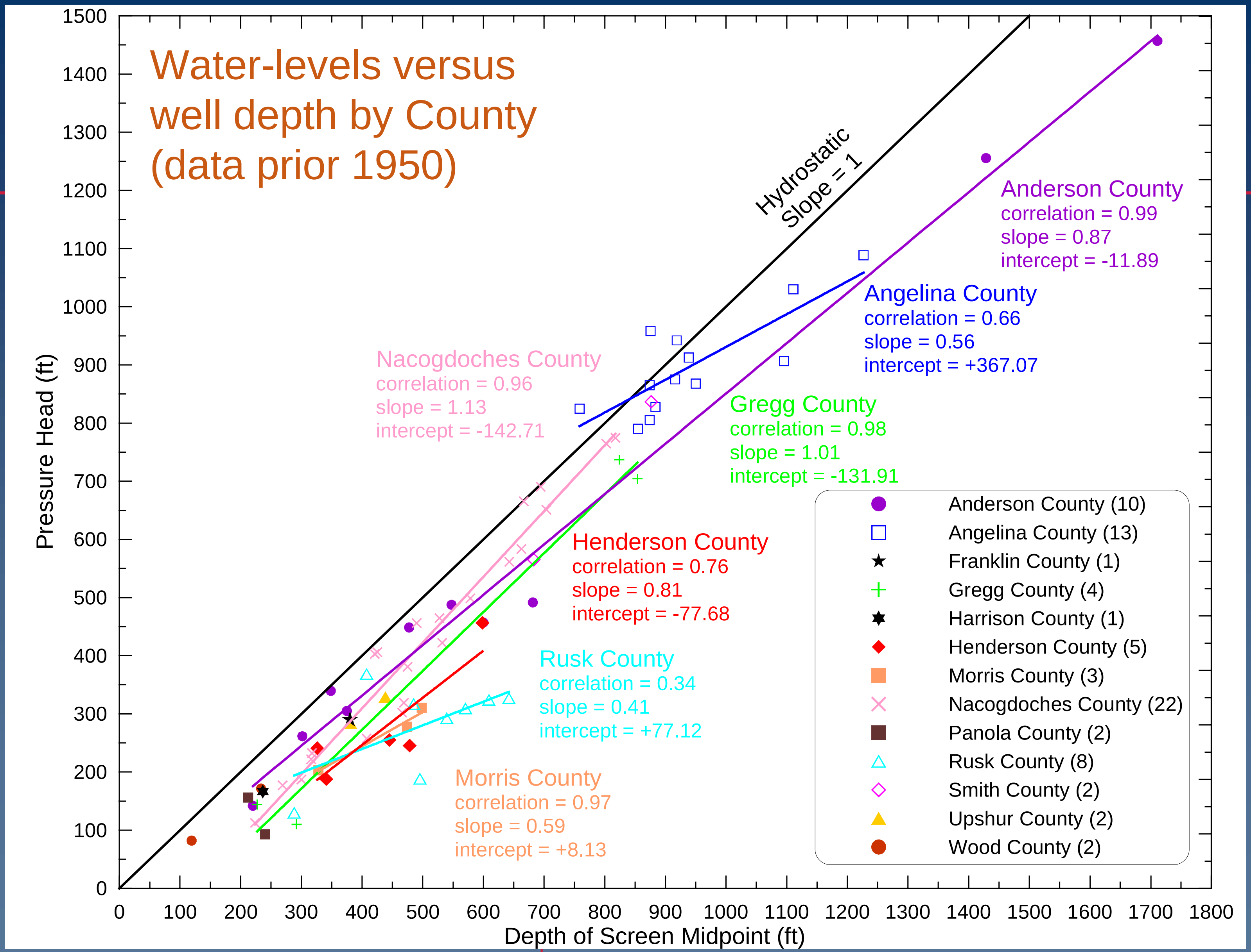

1990 Water Levels
Carrizo
Wilcox
Elev. (ft)
500
400
300
200
100
0

Water Levels and Regional Groundwater Flow (cont.)

- **Approach for Pressure-versus-Depth Analysis**
  - **Obtained water-level and well data prior to 1950 from the TWDB database**
  - **Compared WL vs. depth trends for different areas (e.g., counties)**
  - **Only data from Texas have been examined**



Water-levels versus-well depth for all Counties combined (data prior 1950)
Hydrostatic
Slope = 1
Correlation = 0.93
Slope = 0.99
Intercept = - 97.69
x
y
Pressure Head (ft)
Depth of Screen Center (ft)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800



Water-levels versus well depth by County (data prior 1950)
Hydrostatic Slope = 1
Anderson County
correlation = 0.99
slope = 0.87
intercept = -11.89
Angelina County
correlation = 0.66
slope = 0.56
intercept = +367.07
Nacogdoches County
correlation = 0.96
slope = 1.13
intercept = -142.71
Gregg County
correlation = 0.98
slope = 1.01
intercept = -131.91
Henderson County
correlation = 0.76
slope = 0.81
intercept = -77.68
Rusk County
correlation = 0.34
slope = 0.41
intercept = +77.12
Morris County
correlation = 0.97
slope = 0.59
intercept = +8.13
Anderson County (10)
Angelina County (13)
Franklin County (1)
Gregg County (4)
Harrison County (1)
Henderson County (5)
Morris County (3)
Nacogdoches County (22)
Panola County (2)
Rusk County (8)
Smith County (2)
Upshur County (2)
Wood County (2)
Pressure Head (ft)
Depth of Screen Midpoint (ft)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

Recharge

Recharge

- **Recharge is a complex function of precipitation, evapotranspiration, and runoff**
- **Recharge is not directly measurable on a model scale**
- **Recharge varies as a function of time and space**

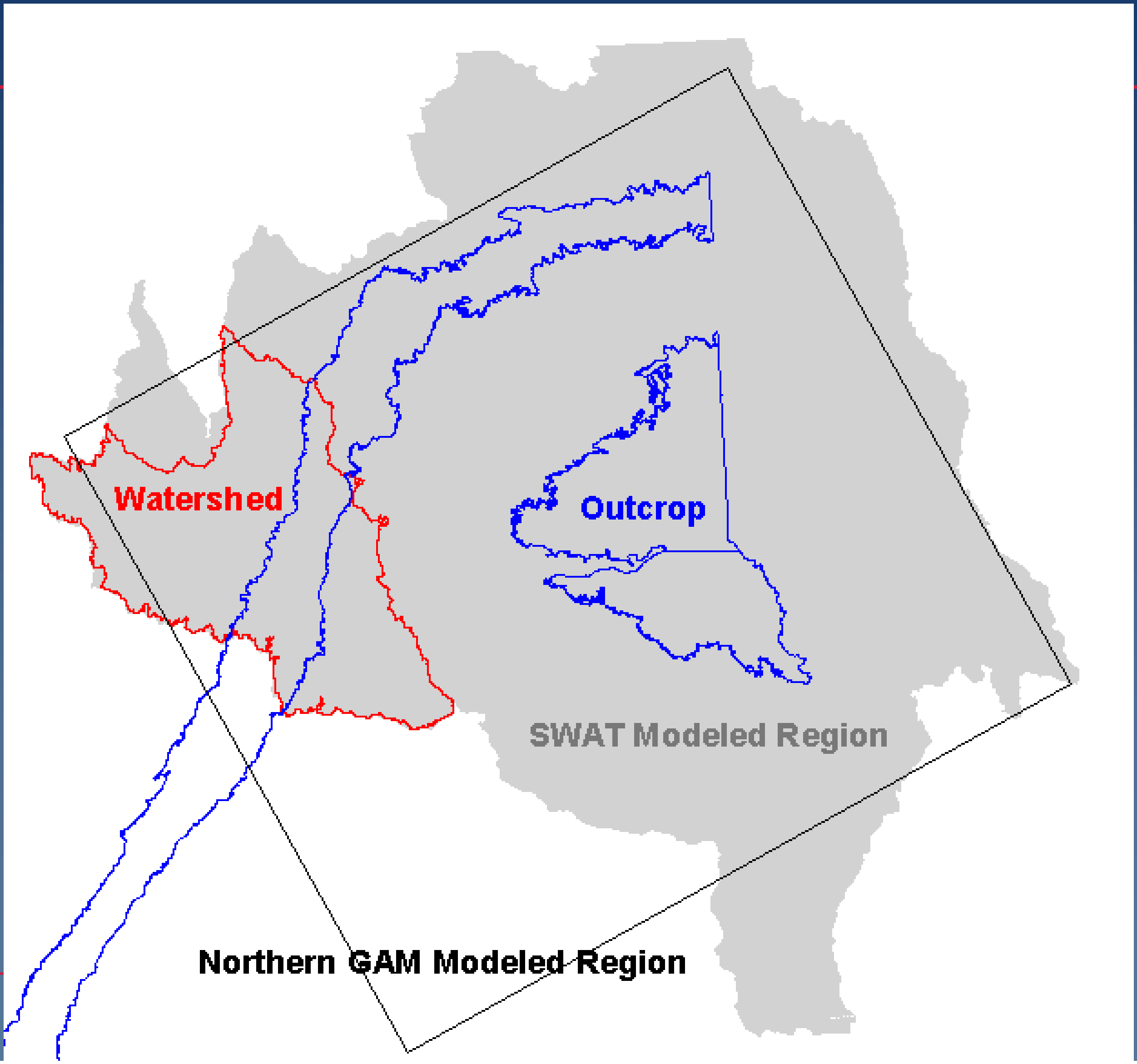
Soil and Water Assessment Tool

- **SWAT (Blacklands Research Center)**
- **Physically based (primarily) watershed scale model**
- **Infiltration/runoff based on SCS Curve Number method (daily timestep)**
  - **Land use**
  - **Soil type**
  - **Antecedent soil condition**
- **Recharge = Infiltration - Evapotranspiration**

Evapotranspiration in SWAT

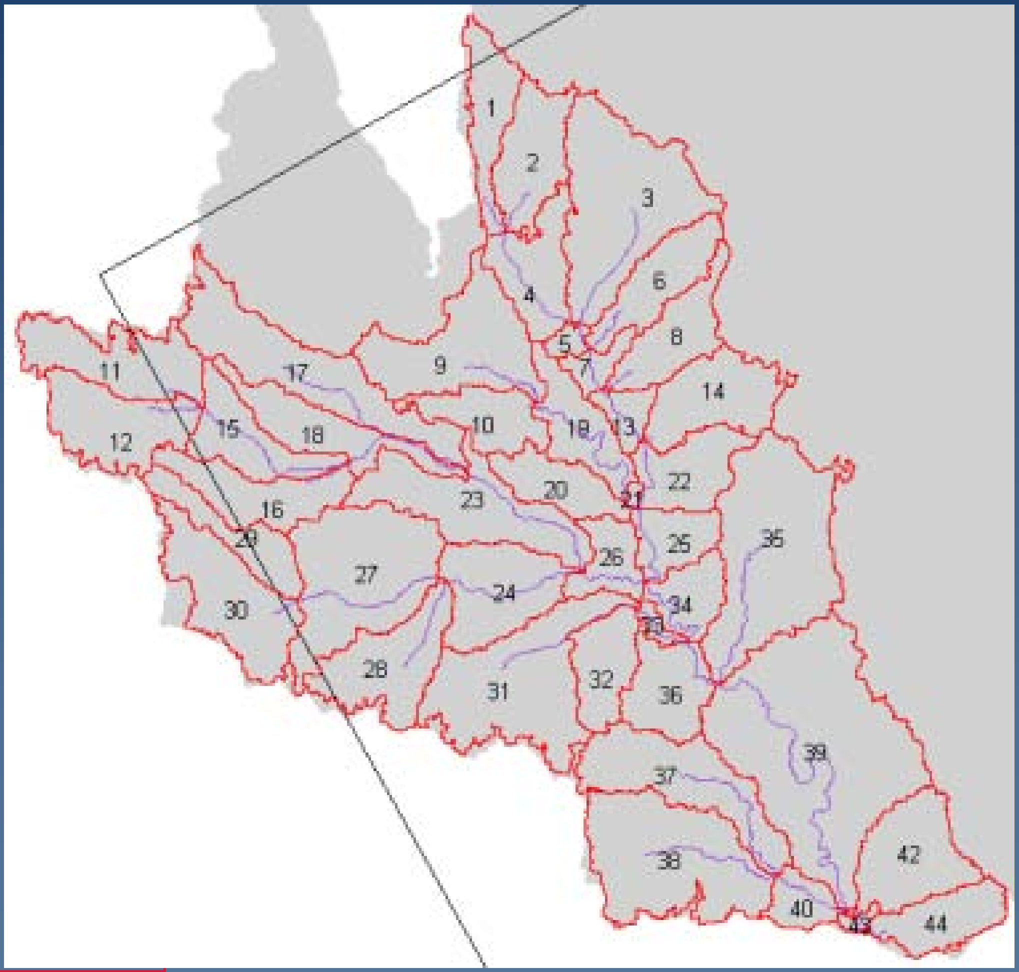
- Canopy Storage
- Potential Evapotranspiration
  - Hargreaves method (Penman, Priestley available)
- Actual Evapotranspiration
  - Evaporation of intercepted rainfall
  - Sublimation and evaporation from the soil
  - Transpiration
    - Maximum transpiration linear function of LAI and PET
    - Actual transpiration based on soil water uptake

SWAT GIS Interface



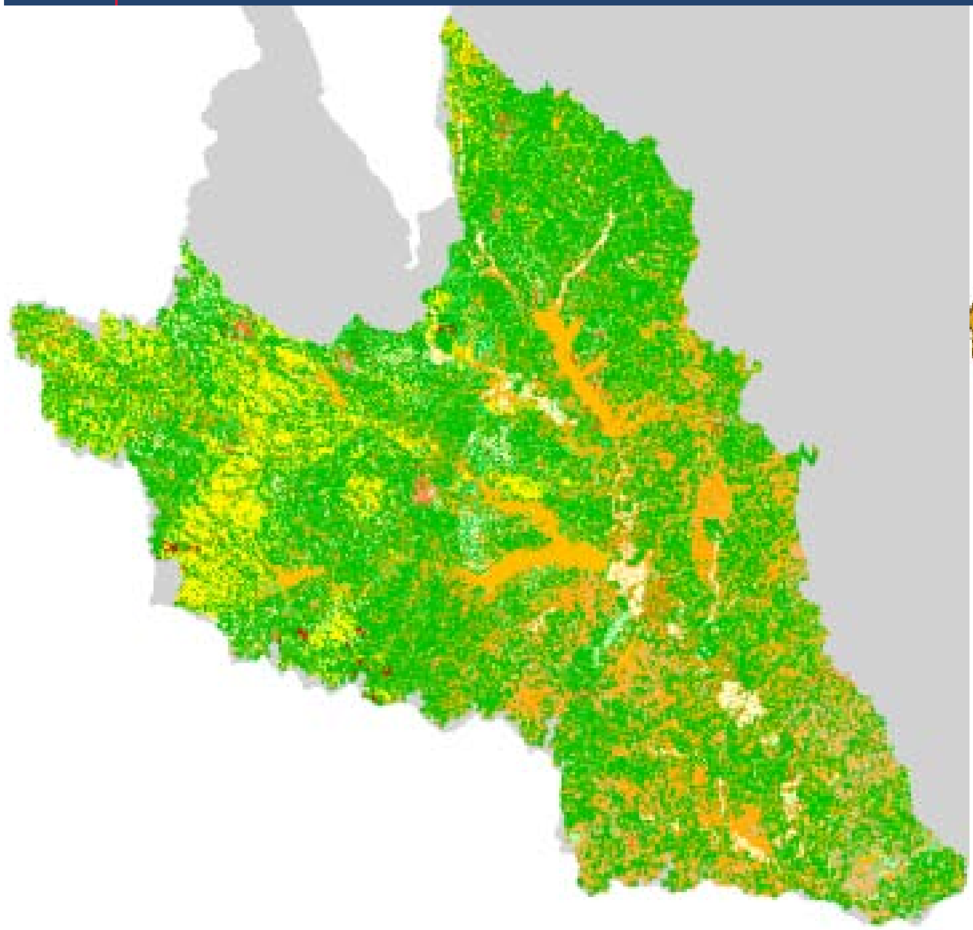
SWAT Inputs

- Sub-basins are delineated
- Stream routing segments established
- Stream volumes can be compared to gage values

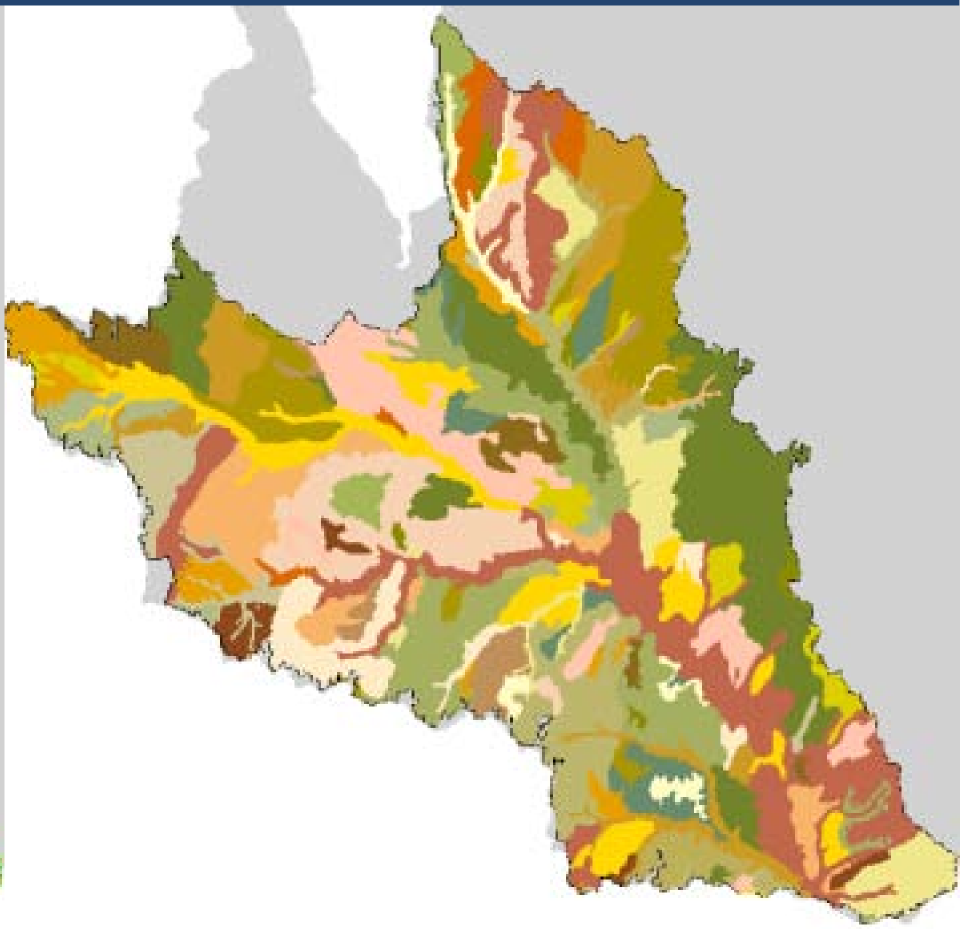


Inputs - Land Use / Soil

Land Use

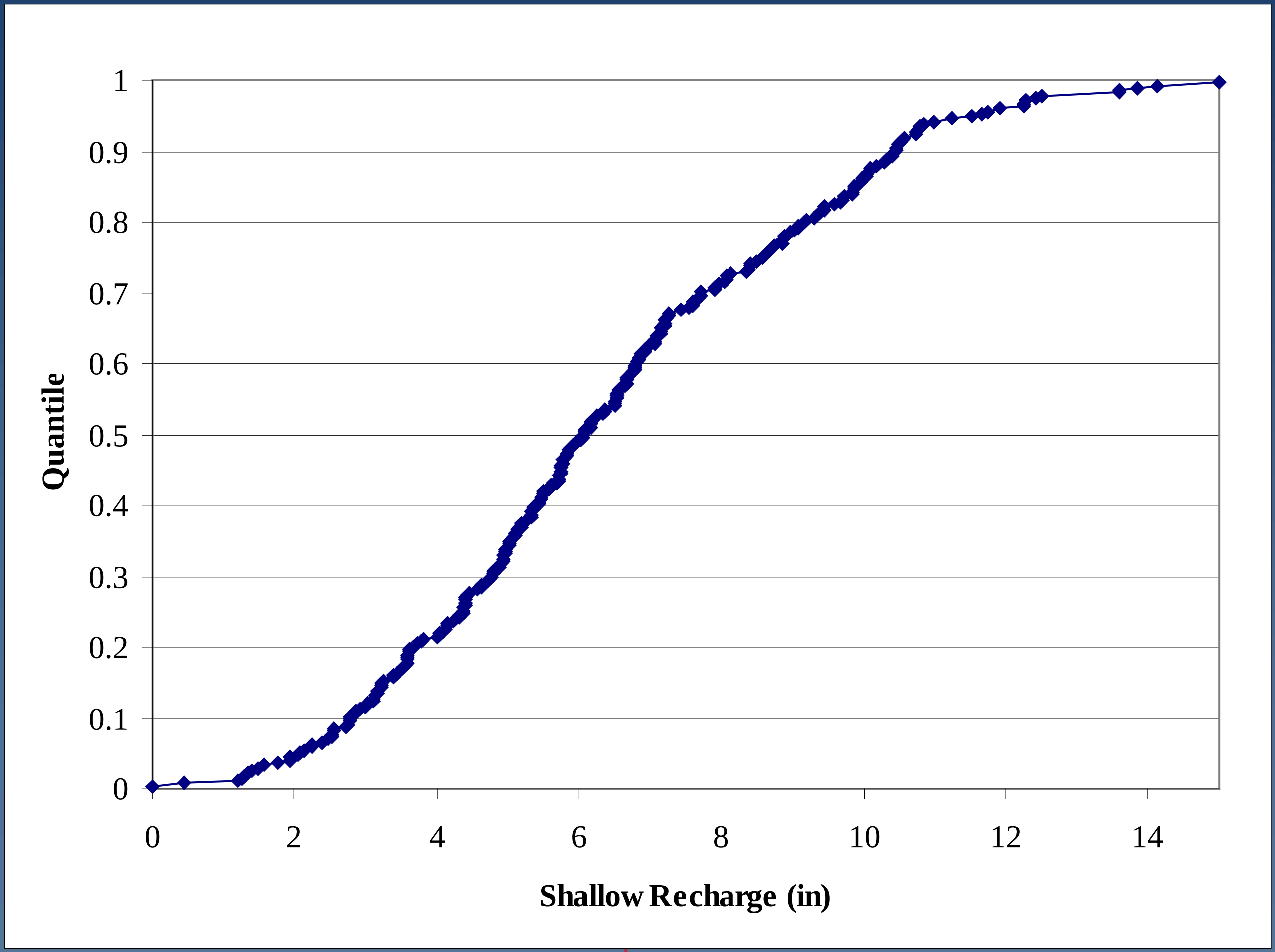


Soil Type

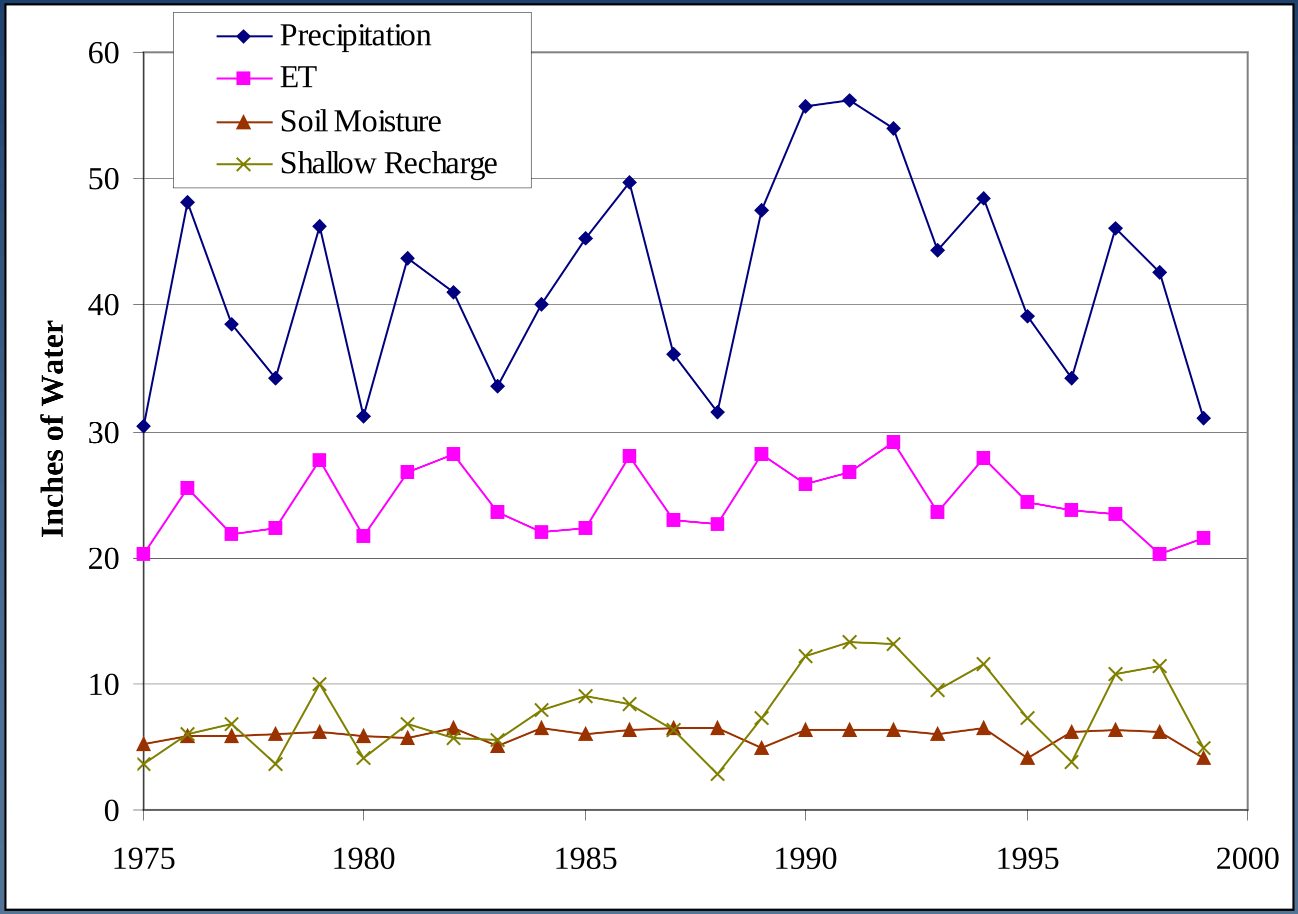


SWAT - Example Results

20-year average annual *shallow* recharge



SWAT - Example Results



Completion Status

- **Initial SWAT Runs Complete**
- **Work in Progress**
  - **Variable importance analysis (i.e. what drives recharge)**
  - **Results testing with MODFLOW model**

Surface/Groundwater Interaction

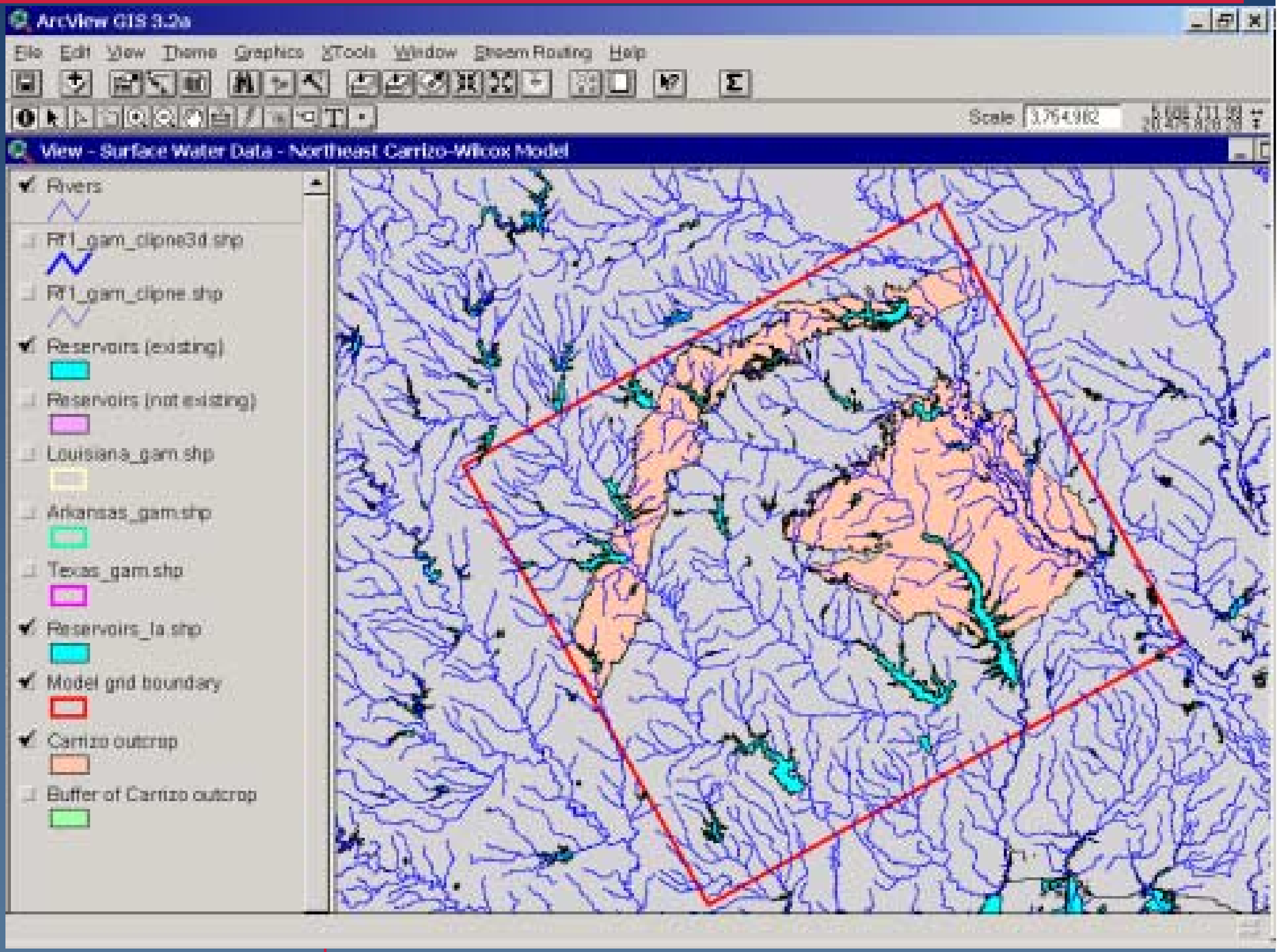
Stream-routing

Stream Routing

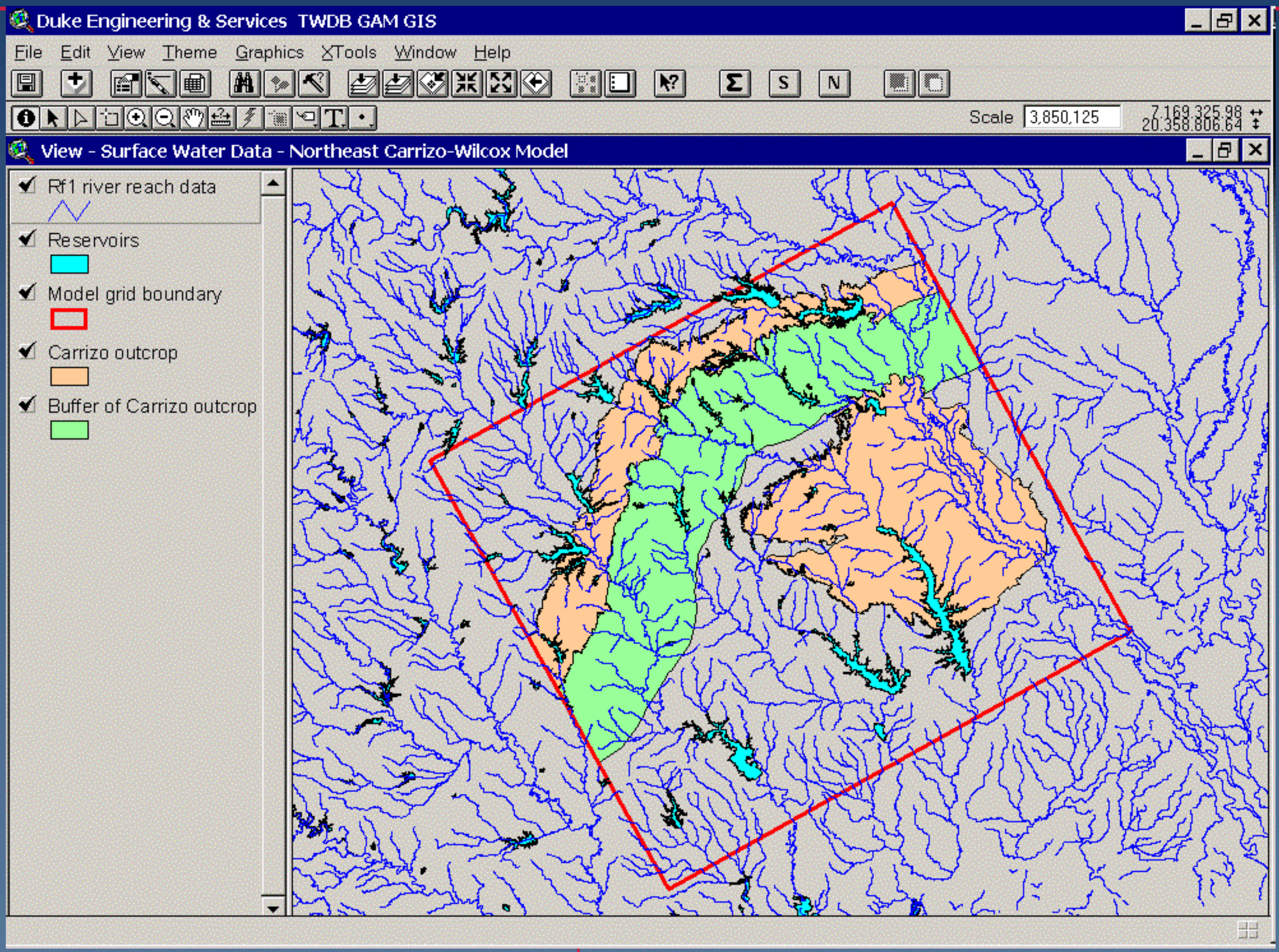
- **Use MODFLOW Stream Routing Package (Prudic, 1988)**
- **Stream stages are calculated using Manning's equation**
- **Stream-routing package routes surface water and calculates stream/aquifer interaction (gaining/losing)**

EPA River Reach Data

EPA river reach data include many attributes needed in MODFLOW: width, depth, stage, roughness, etc.

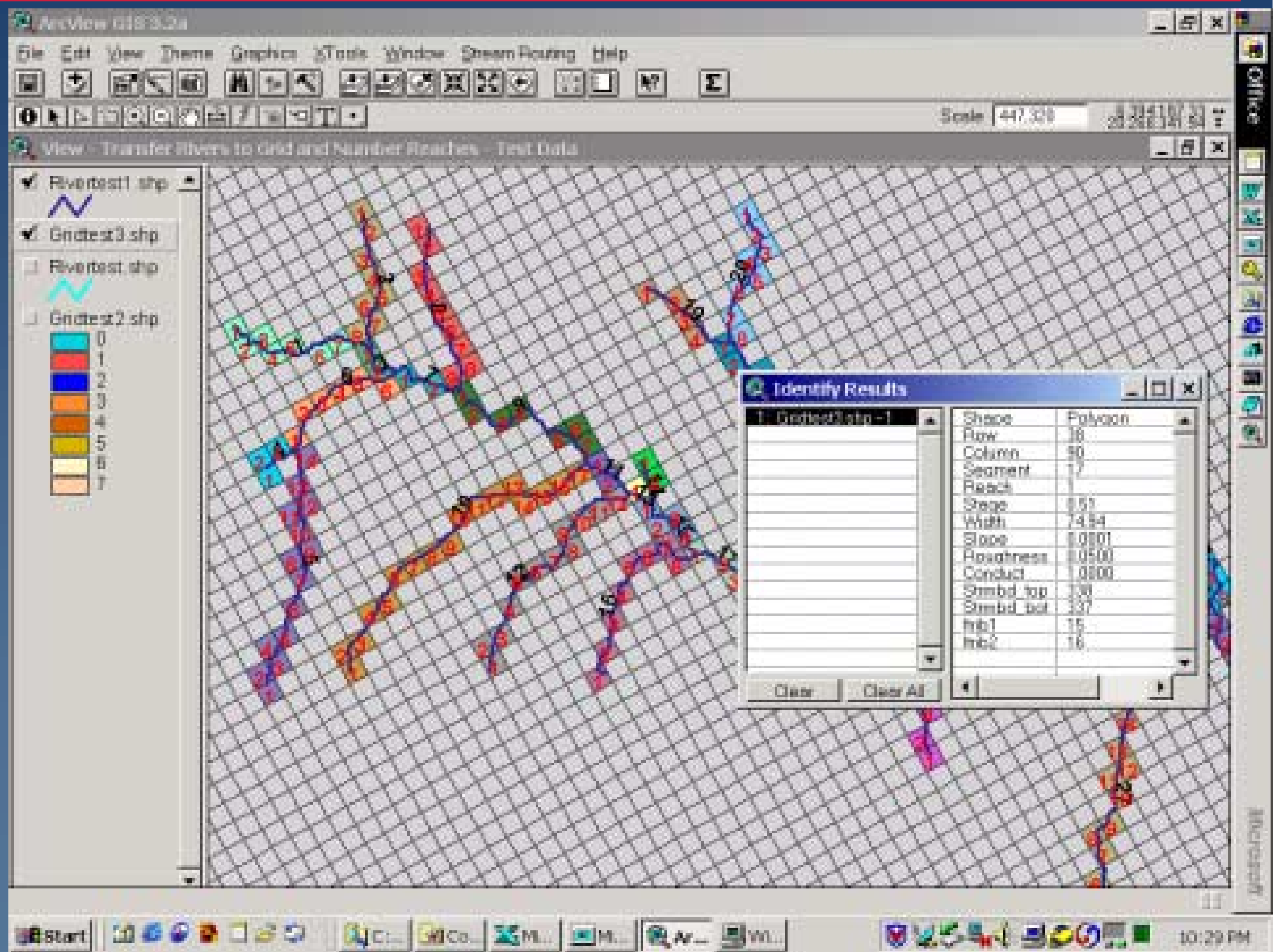


Selection of Rivers to Simulate



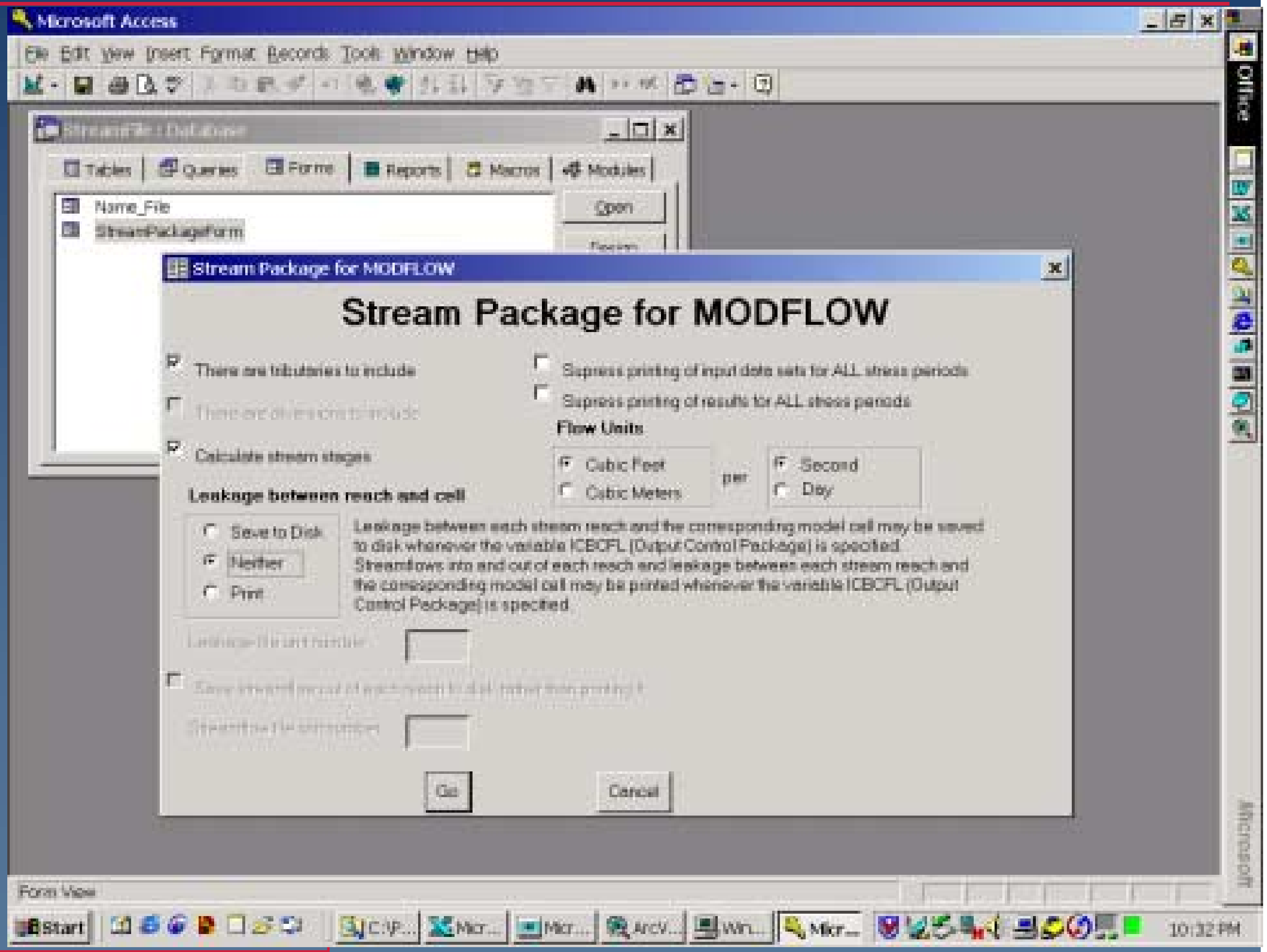
ArcView to MODFLOW input

Stream and reach numbering are done auto - matically using ArcView



ArcView to MODFLOW input

- Then, Access is used to read the ArcView data and convert it directly into MODFLOW text input files.



Stream Routing: Status

- **Automated routines have been developed that will allow flexibility in determining which streams are simulated**
- **In progress: Include model layer information**

Northern GAM Schedule

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Expected SAF-4 Discussion

- **Initial steady-state calibration (pre-development conditions)**
- **Further definition of model design**
- **Emphasis on pumping demand distributions**

NORTHERN CARRIZO WILCOX GAM STAKEHOLDERS ATTENDENCE LIST
Stakeholders Advisory Forum
Held
November 19, 2001 in Diboll, Texas

Name	Affiliation
Mary Ambrose	TNRCC
James Beach	LBG-Guyton
Sanjeev Kalaswad	TWDB
Buzz Patrick	Temple-Inland FPC
John Pickens	DE&S Project Team
Bill Roberts	TWDB
Walt Sears	Northeast Texas MWD
Rainer Senger	DE&S
David B. Smith	City of Nacogdoches
Tommy Spruill	Titus County FWSD #1
Burgess Stengl	Schaumburg Polk, Inc.
Nate Worthy	Pilgrim's Pride

Questions & Responses from
Northern Carrizo-Wilcox GAM
Stakeholder Advisory Forum #3
Held at Diboll, Texas
November 19, 2001

Meeting Questions & Responses

1. Is the "bad water" line at 10,000 ppm or at 3,000 ppm?

Response: Most studies depict the bad water line between fresh and saline water at being at 3,000 ppm total dissolved solids (TDS) concentration, as shown on the TWDB's map of major aquifers.

2. How does the structure adopted for the conceptual model compare with that in the TWDB East Texas Model described at the beginning of the project?

Response: We use the same number of layers for the Wilcox, Carrizo, and overlying Reklaw. However, we only use a single layer for representing the shallower units, which include the Queen City, Weches, and Sparta. Furthermore, the subdivision of the Wilcox follows that given in Kaiser (1990), which subdivided the Wilcox into a lower and upper unit, whereby the top of the lower unit corresponds to the top of the Hooper Formation in the central GAM area. The Simsboro Formation, representing the middle Wilcox unit in the central GAM area will be extrapolated into the northeast GAM area, having the same hydraulic properties as the upper Wilcox. There has been no reinterpretation of geophysical logs to determine structure. The various data sources used are listed on the presentation slides.

3. If we can't get a good calibration, how much of the modeling methodology will be repeated?

Response: Hydraulic conductivity will be scaled to the layers (hydraulic conductivity distribution is reasonably well known for the sand; hydraulic conductivity of the non-sand material will be changed to modify transmissivity). In certain areas, we will take a closer look at features that may have been missed because of the 1-mile grid scale. Vertical hydraulic conductivity and recharge are linked. Provided that we obtain a good estimate for recharge, we then can calibrate the model to get a good vertical hydraulic conductivity distribution.

4. How many Carrizo wells were used to prepare the predevelopment water level map?

Response: 84 wells were used for the predevelopment water-level map for the Carrizo, and 208 wells for the Wilcox**.**

5. How did you determine the correct geologic formation for the wells for the early water levels?

Response: Total well depth or screen interval was compared to depths of each of the formation layers.

6. How many of these wells are nested?

Response: We are in the process of identifying and evaluating nested wells for pressure-depth trends.

7. Will results from SWAT (Soil and water Analysis Tool) be compared with WAM being developed by the TNRCC?

Response: Yes. Also, SWAT results for an example watershed compared favorably with the published Texas recharge summary published by Bridget Scanlon (TBEG) on the TWDB website.

8. Will soil moisture below the root zone be considered as recharge?

Response: Yes, it is considered shallow recharge, but not all of it will enter the deeper groundwater flow system.

9. Is a shallow recharge study of any value to the Northern Carrizo-Wilcox GAM project since it mainly involves a confined aquifer?

Response: It is particularly important in the outcrop areas for the Carrizo Wilcox aquifer. In the outcrop areas, it is not confined.

10. What is the temporal discretization for SWAT?

Response: Daily.

11. Is the SWAT level of data as input to GAM warranted in terms of how the Queen City is handled, or is the detail lost when looking at what really gets into the Carrizo Wilcox aquifer?

Response: The use of SWAT is particularly important in developing physically based recharge estimates for the outcrop areas for the Carrizo-Wilcox aquifer in order to better constrain model calibration. Recharge rates and hydraulic conductivities in the aquifer (specifically vertical permeability) are typically highly correlated; that is, uncertainties in one produces large uncertainties in the other and vice versa.

12. Are the effects of wastewater discharge on stream flow being considered in the model?

Response: The wastewater discharge is included to the extent that it is included at stream gage stations. The feasibility of extracting the specific information from the WAM study is being investigated.

13. Will demand projections from the last (2002) State Water Plan be used in the model?

Response: Yes.

14. What is the importance of aquifer heterogeneity in the 1 square mile grid and how can you include it?

Response: We do not need to scale up small-scale heterogeneities to 1-mile grid.

15. What about tying together steady state and transient during calibration?

Response: We will have a calibration of the predevelopment water levels, then calibrate to transient conditions from 1980 – 1990. During the calibration, we will compare the transient to predevelopment calibration and modify both as necessary.

16. Will boundary conditions (faults, etc.) be considered in the model?

Response: Yes. The block hydraulic conductivity can be modified at the location of these features. Some salt domes are several square miles in area. The hydraulic conductivity can be modified at these locations.

17. What is the status of water quality mapping being undertaken in the project?

Response: The water quality data source was principally from the TWDB website, and also from TNRCC files. Simple plots with shading corresponding to ranges of TDS concentration have been prepared. In addition, we have been looking at iron concentrations, though we are also trying to establish a depth dependency.

Meeting Comments

1. SWAT is best used in studies where stream gauging stations are not available.

2. TDS values could perhaps be determined for each layer of the model on a grid block basis and displayed in this fashion instead of being grouped together.

3. General discussion of uncertainty and sparseness of water quality data that is available. Wells may have not been completed because of poor water quality, and the water quality information may not have been entered into any database. Water quality can vary horizontally and vertically in each layer over relatively short distances.

4. Poorer quality water may be used in the future as a result of water blending or desalinization.