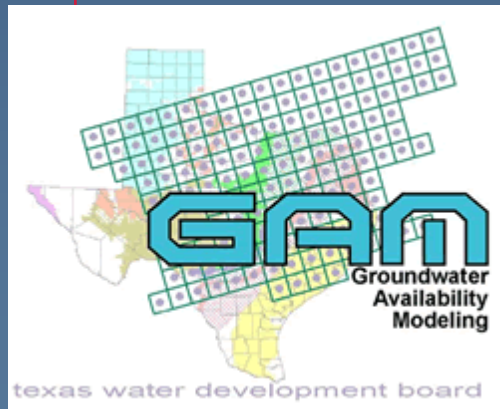


Stakeholder Advisory Forum - 5

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



Temple Inland Facility
Diboll, Texas
Angelina County
May 21, 2002



Presentation Outline

- GAM review
- Conceptual Model Review
- Hydraulic Properties
- Pre-Development Hydraulic Heads
- Recharge Estimation
- Steady-State Model Results
- Future SAF meeting

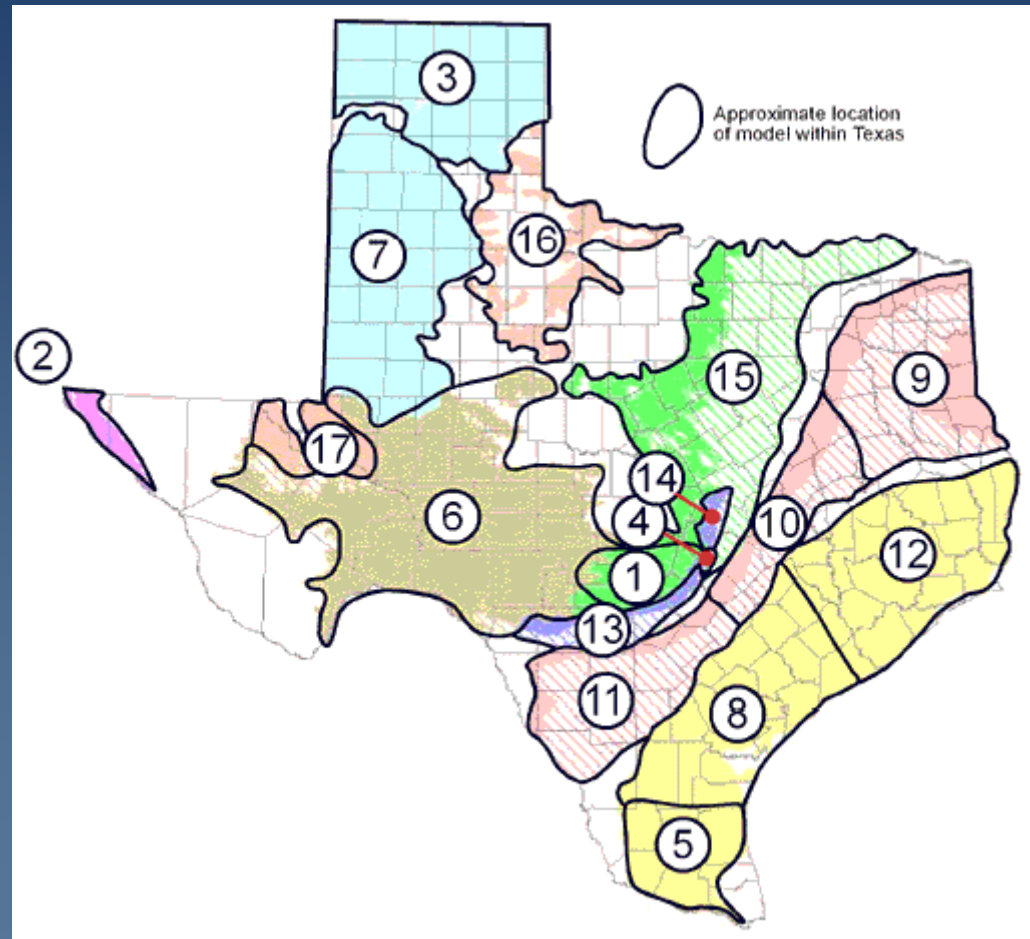
GAM Models

■ Ongoing:

- Carrizo-Wilcox (9-11)
- Ogallala south (7)
- Gulf Coast central (8)
- Gulf Coast north (12)
- Lower Rio Grande (5)
- Edwards Trinity (6)

■ Completed:

- Trinity HC (1)
- Hueco Bolson (2)
- Ogallala north (3)
- Edwards - BS (4)



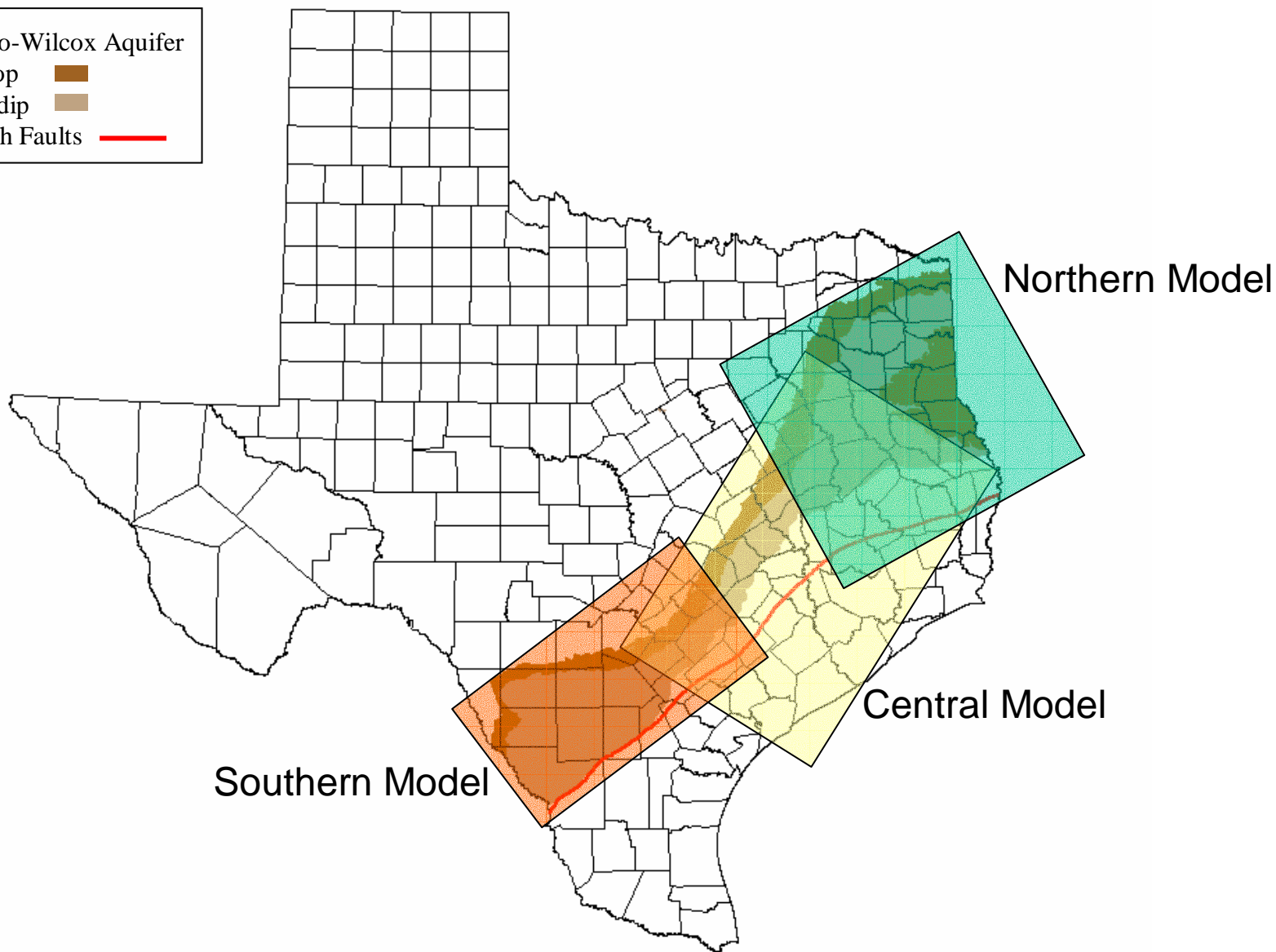
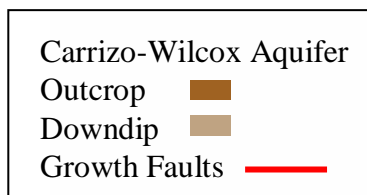
GAM Objectives

- 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

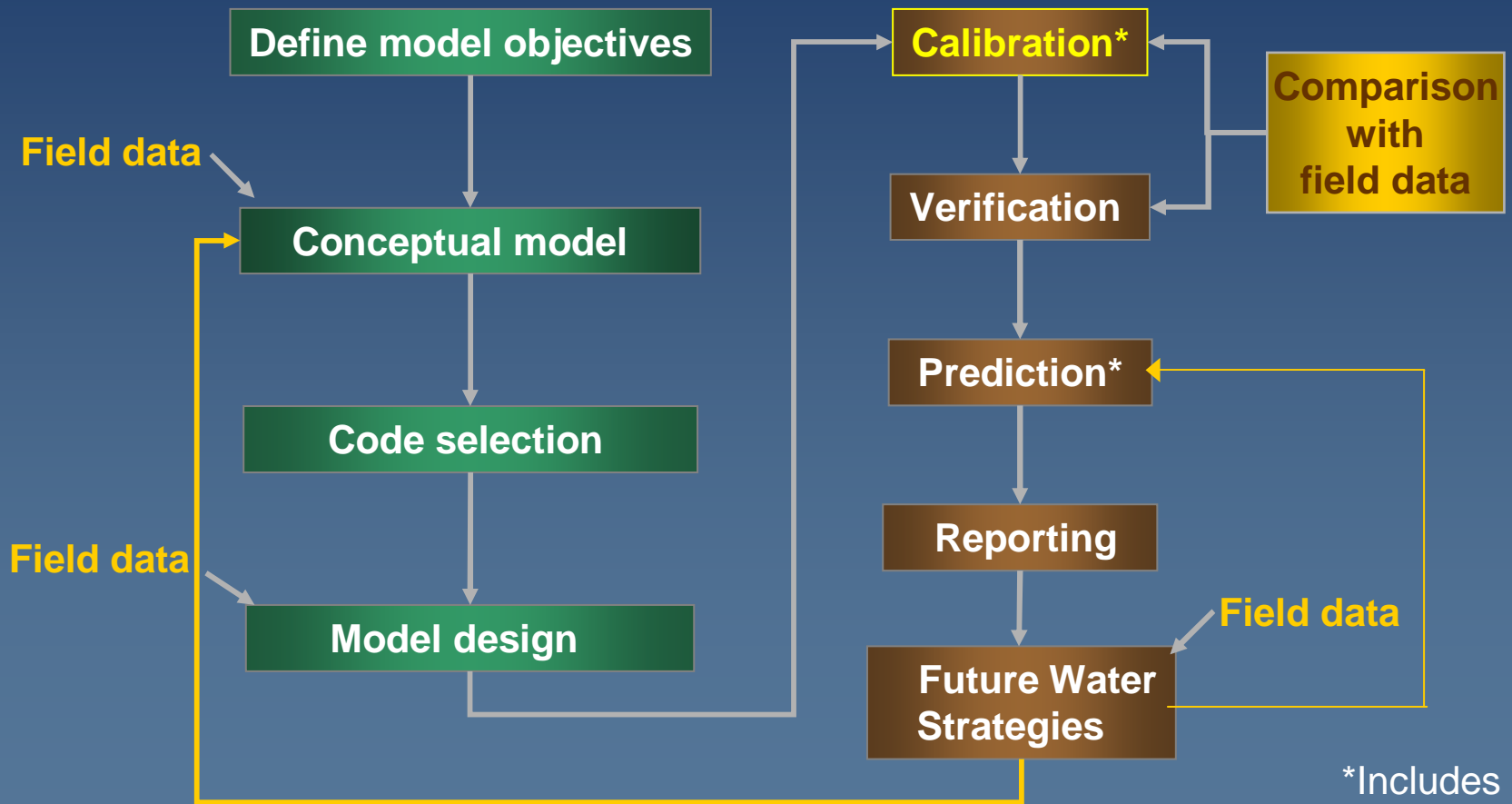
Model Specifications

- Three dimensional (MODFLOW-96)
- Regional scale (100's of mi²)
- Grid spacing of 1 square mile
- Include Groundwater/surface water interaction (Stream routing, Prudic 1988)
- Properly implement recharge
- Stress periods as small as 1 month
- Calibration to within 10% of head drop

Carrizo-Wilcox GAM Model Domains



Modeling Protocol

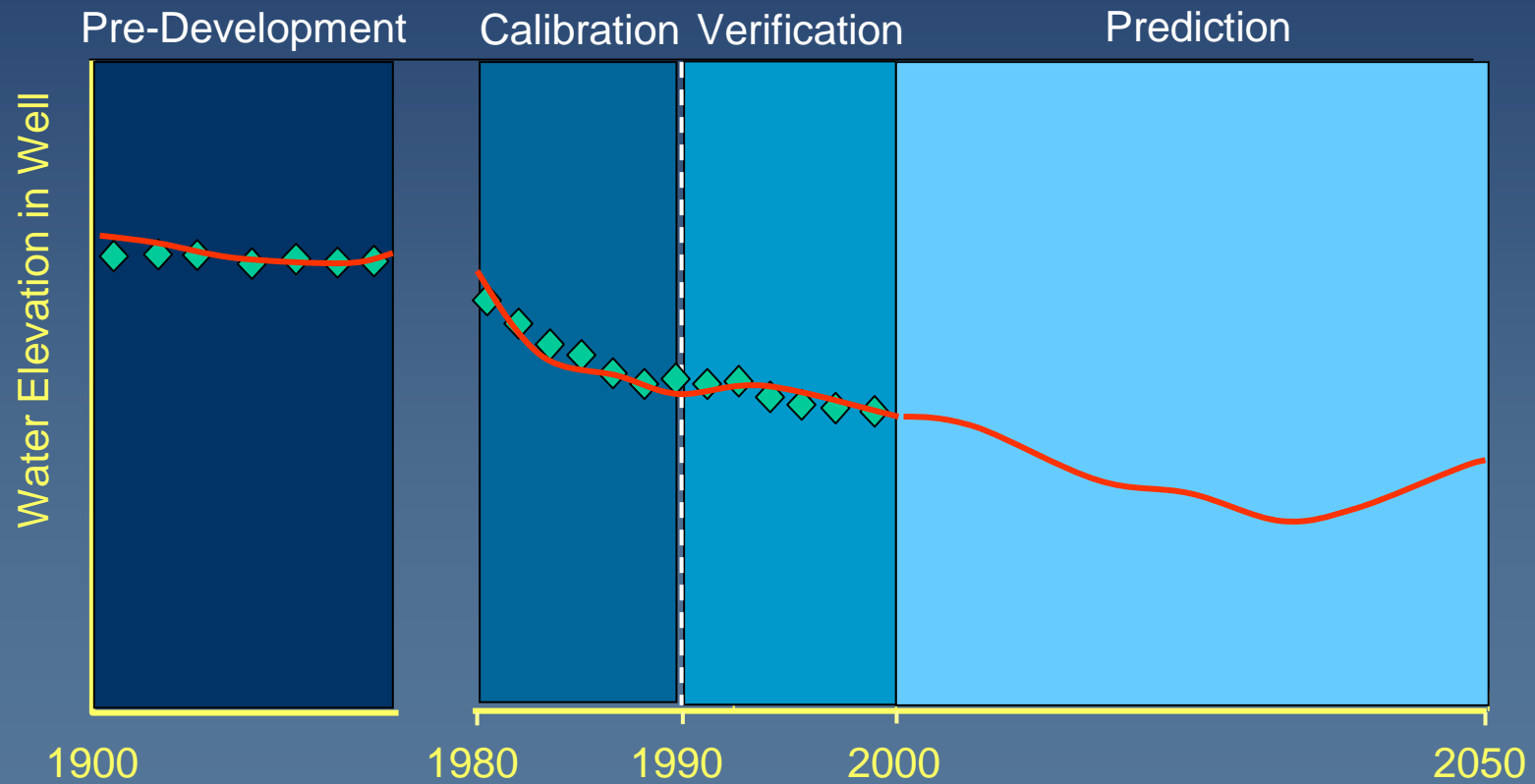


*Includes sensitivity analysis

Modeling Periods

LEGEND

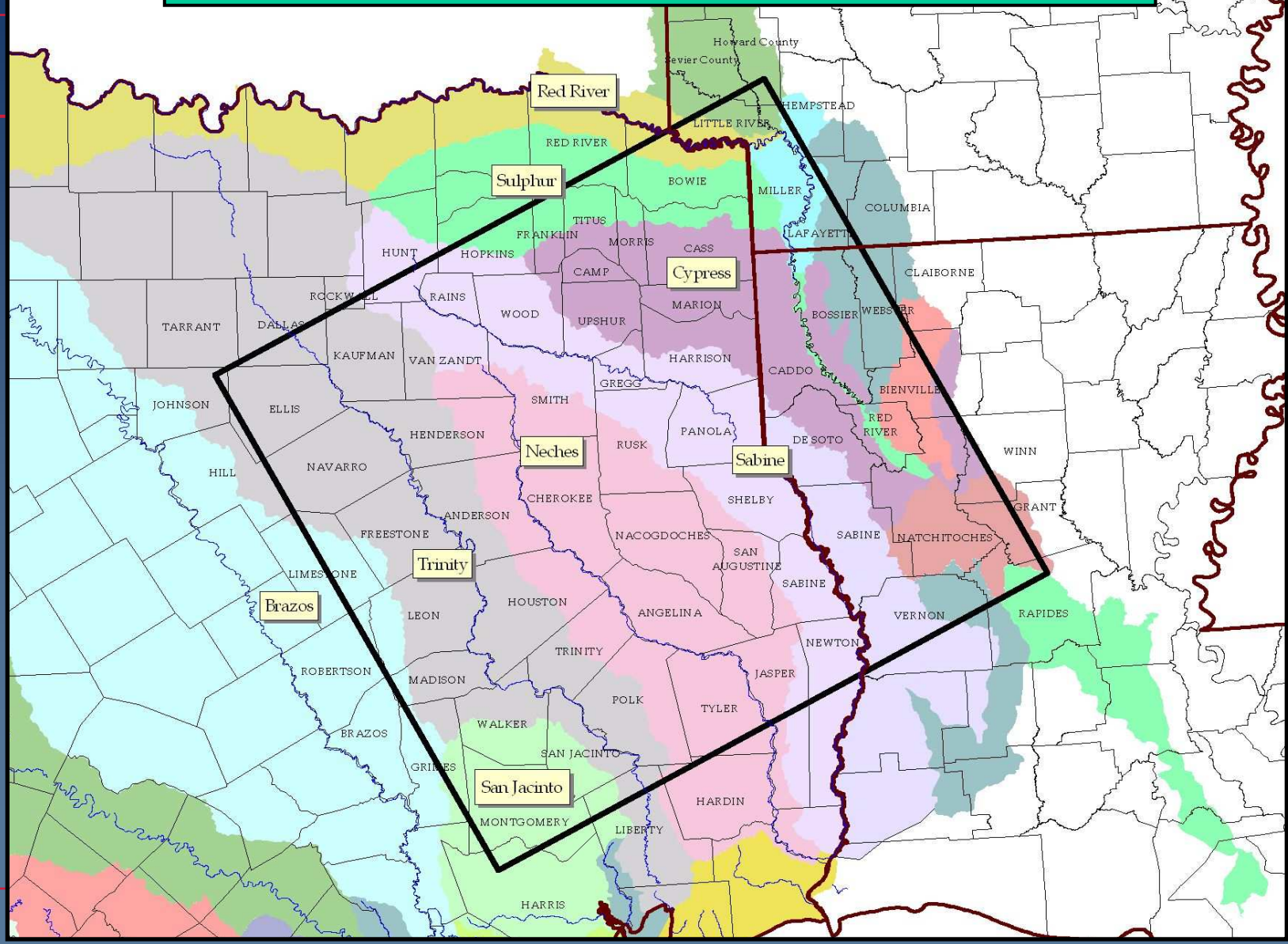
- ◆ Observed Water Level
- Model Water Level

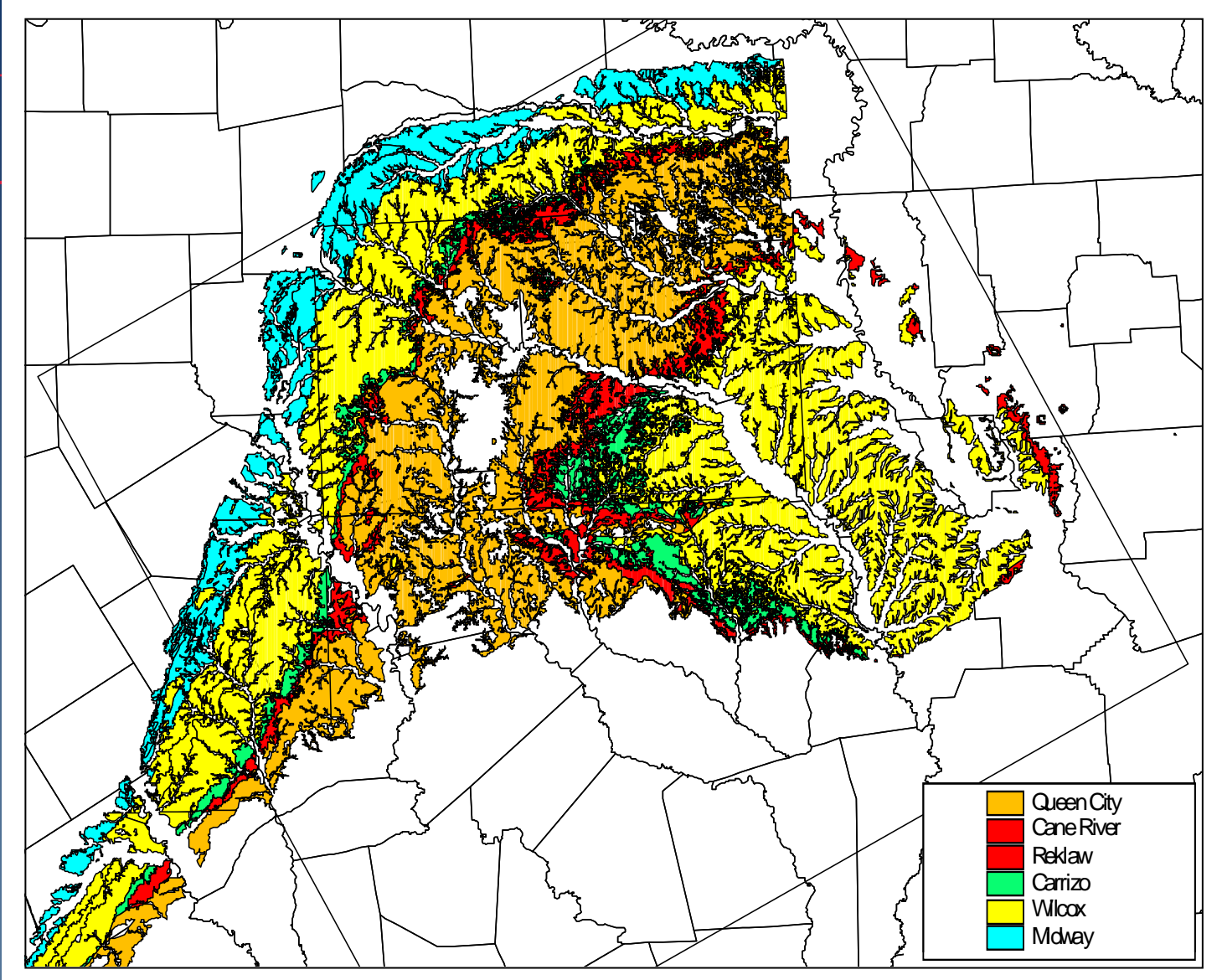


Presentation Outline

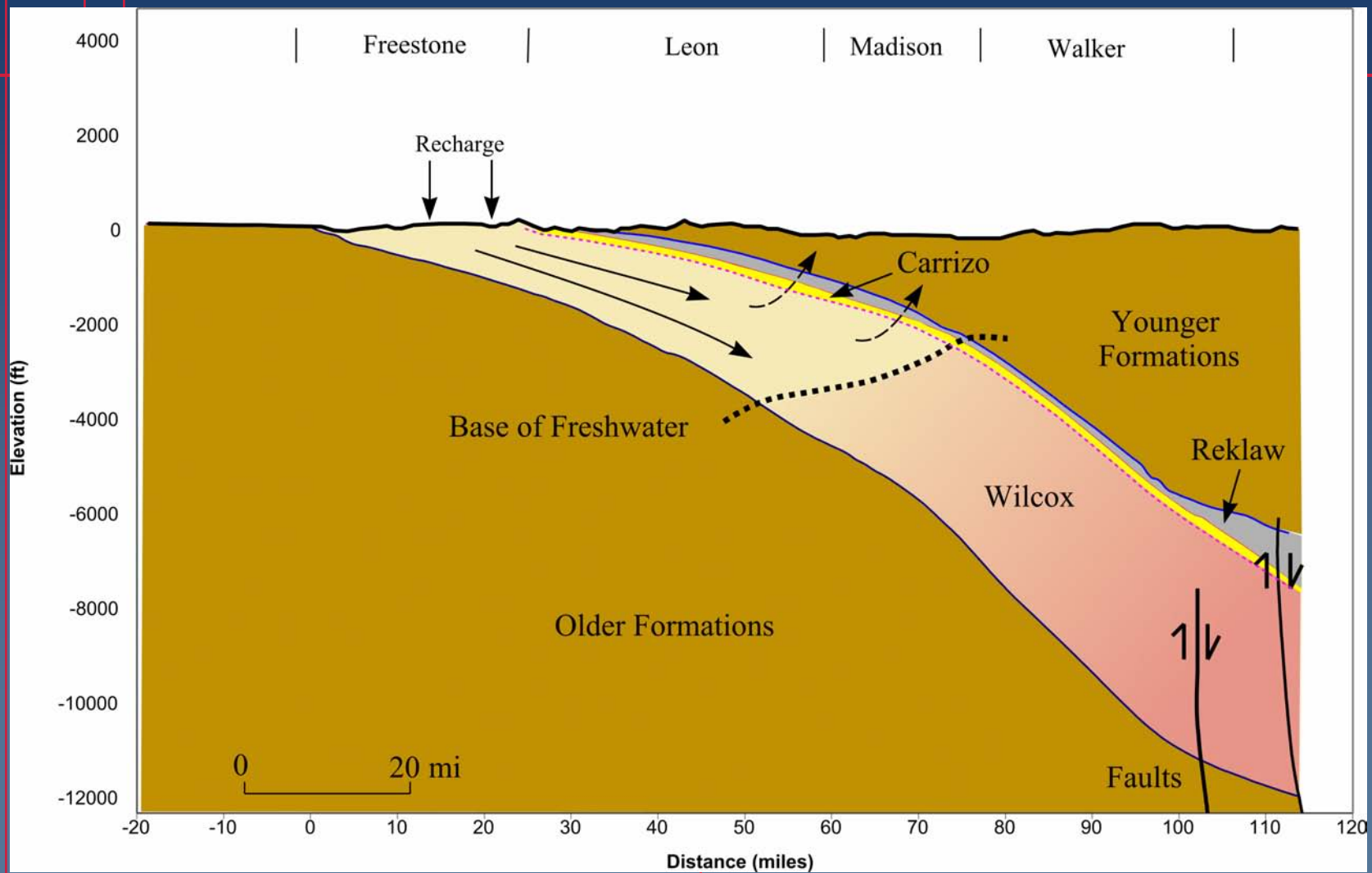
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Counties & River Basins in the Northern Carrizo-Wilcox Region





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)

	Series		Northeast		Model Layer
TERTIARY	Eocene	U	Jackson Group		
		M		Yegua Fm.	
				Cook Mtn. Fm.	
				Sparta Sand	6
				Weches Fm.	
			Queen City Sand		
		Reklaw Fm.	5		
	Paleocene	L		Carrizo Sand	4
				Upper Wilcox	Calvert Bluff
		U		Lower Wilcox	Simsboro
				Hooper	1
	L	Midway Formation			

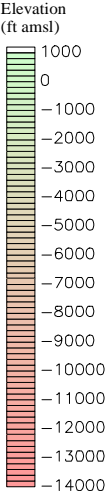
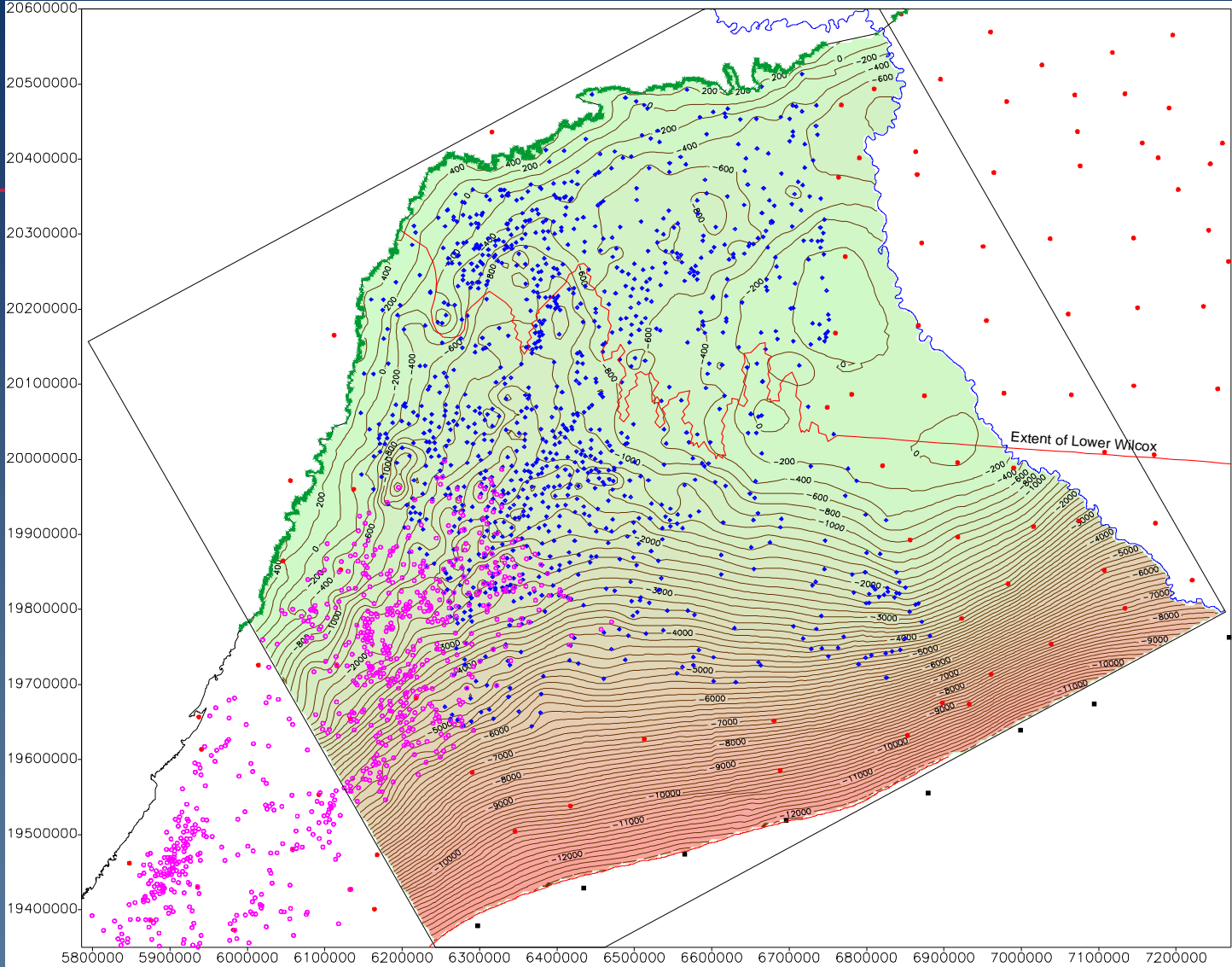
Data Sources: Structure

Model Layer Boundary	East Texas Model (unpublished) (TWDB)	Wilson and Hosman (1987) (USGS)	Kaiser (1990)	Central Carrizo-Wilcox GAM Model	Surface Elevations (USGS)
Top of Queen City	X				X
Top of Reklaw	X	X		X	X
Top of Carrizo	X	X		X	X
Top of Wilcox	X	X		X	X
Top of Middle Wilcox	X			X	X
Top of Lower Wilcox	X		X	X	X
Base of Wilcox	X	X		X	X

Data Format for the Various Sources:

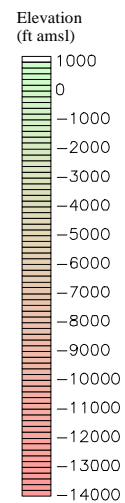
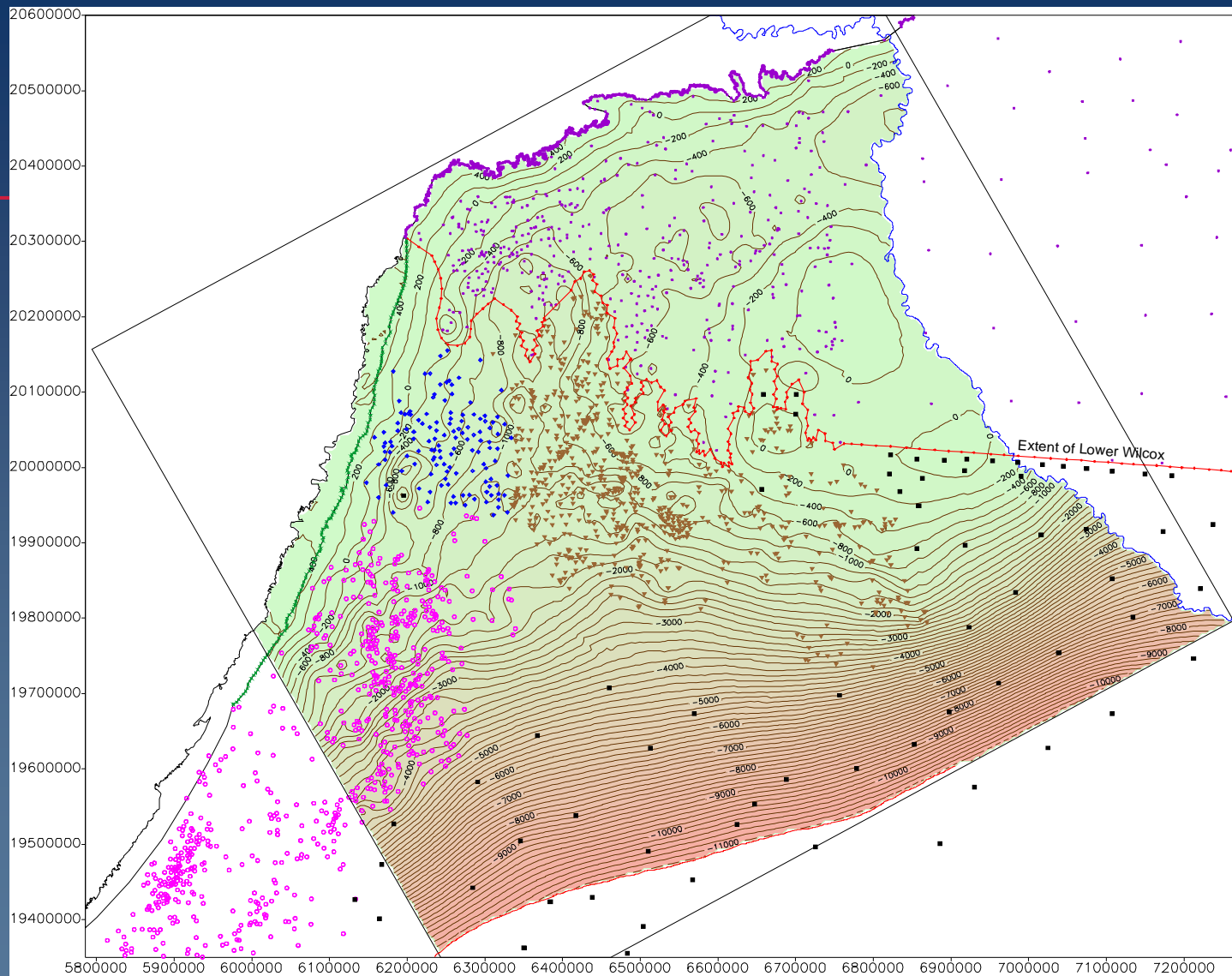
Data Source	Report Number	Format
TWDB (unpublished)		Text files containing x, y, and elevation.
Wilson and Hosman (1987)	USGS Open-File Report 87-677	Printed tables.
Kaiser (1990)	BEG	Printed tables.
Central Carrizo-Wilcox GAM Model		Text files containing x, y, and elevation.
Surface Elevations		DEM files.

Base of Wilcox



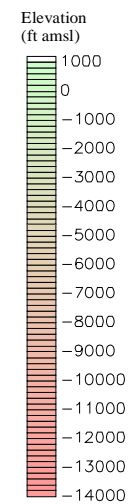
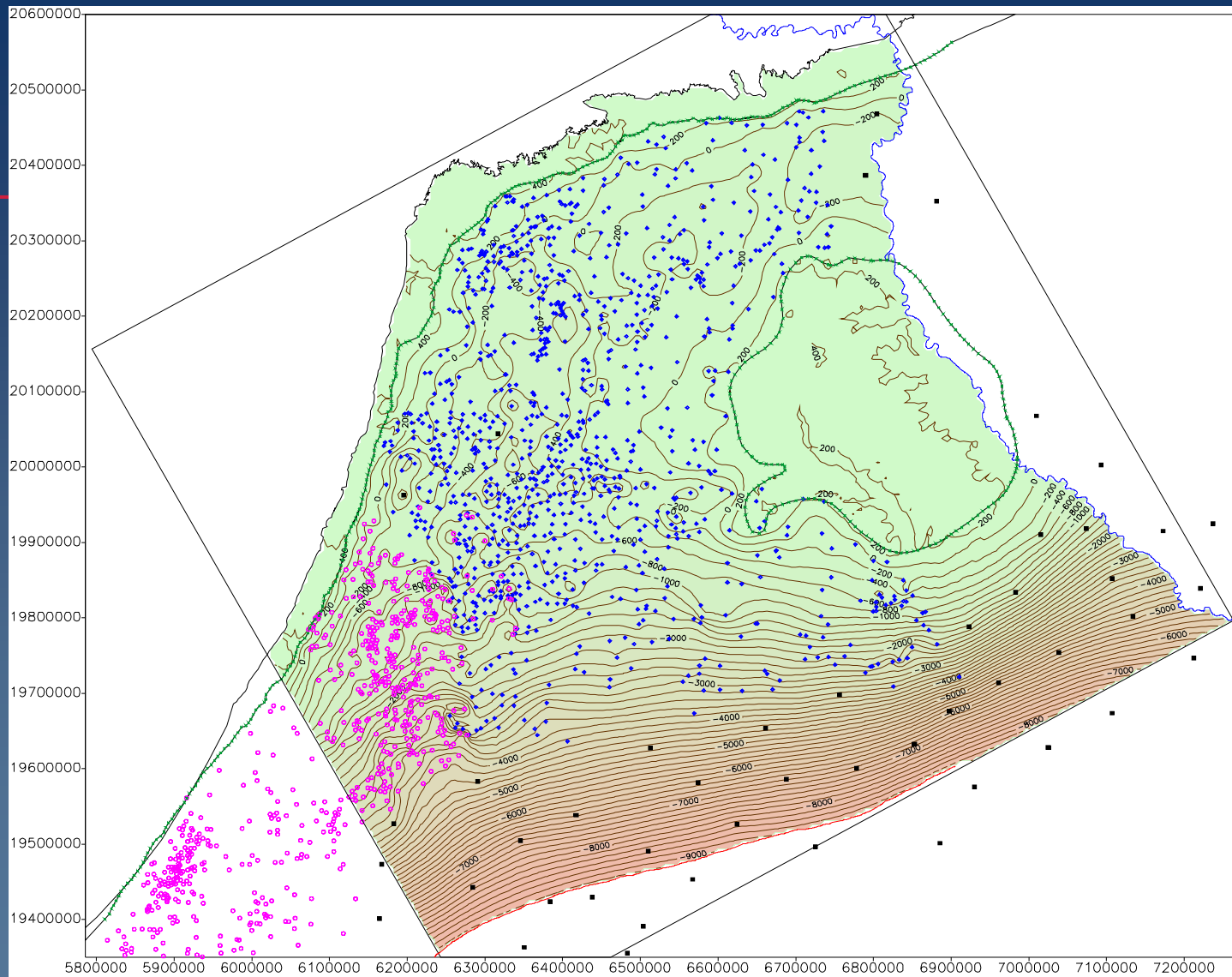
- TWDB East Texas Model ◆
- USGS RASA Data ●
- Central Carrizo-Wilcox Model ●
- Outcrop ×
- False Point ■

Top of Lower Wilcox



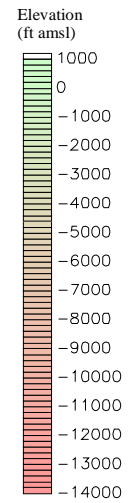
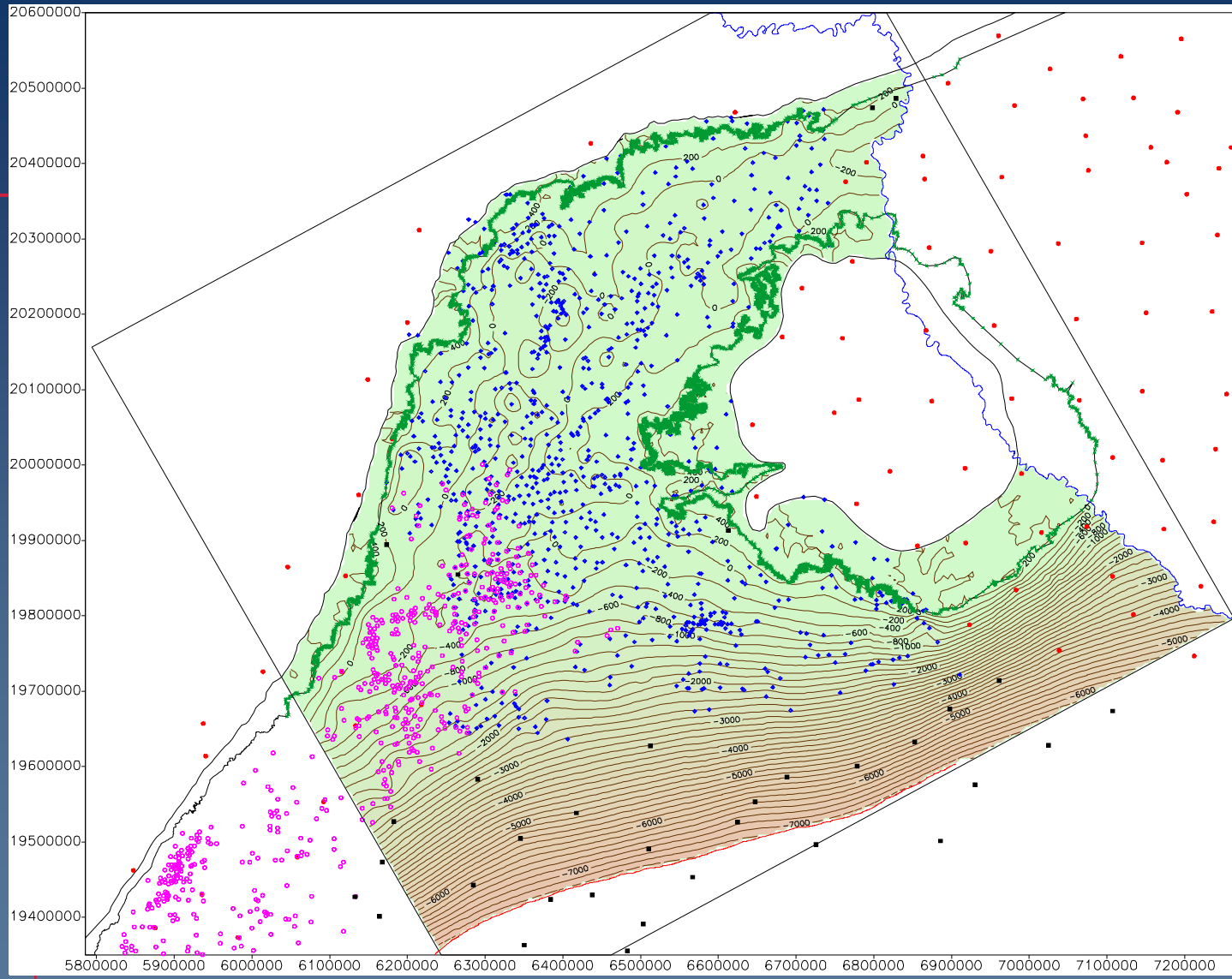
- Kaiser
- Central Carrizo-Wilcox Model
- Extent of Lower Wilcox
- TWDB East Texas Model
- Outcrop
- Base of Wilcox
- False Point

Top of Middle Wilcox



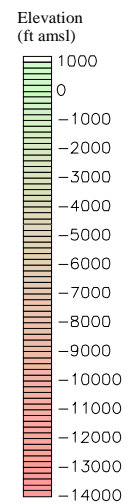
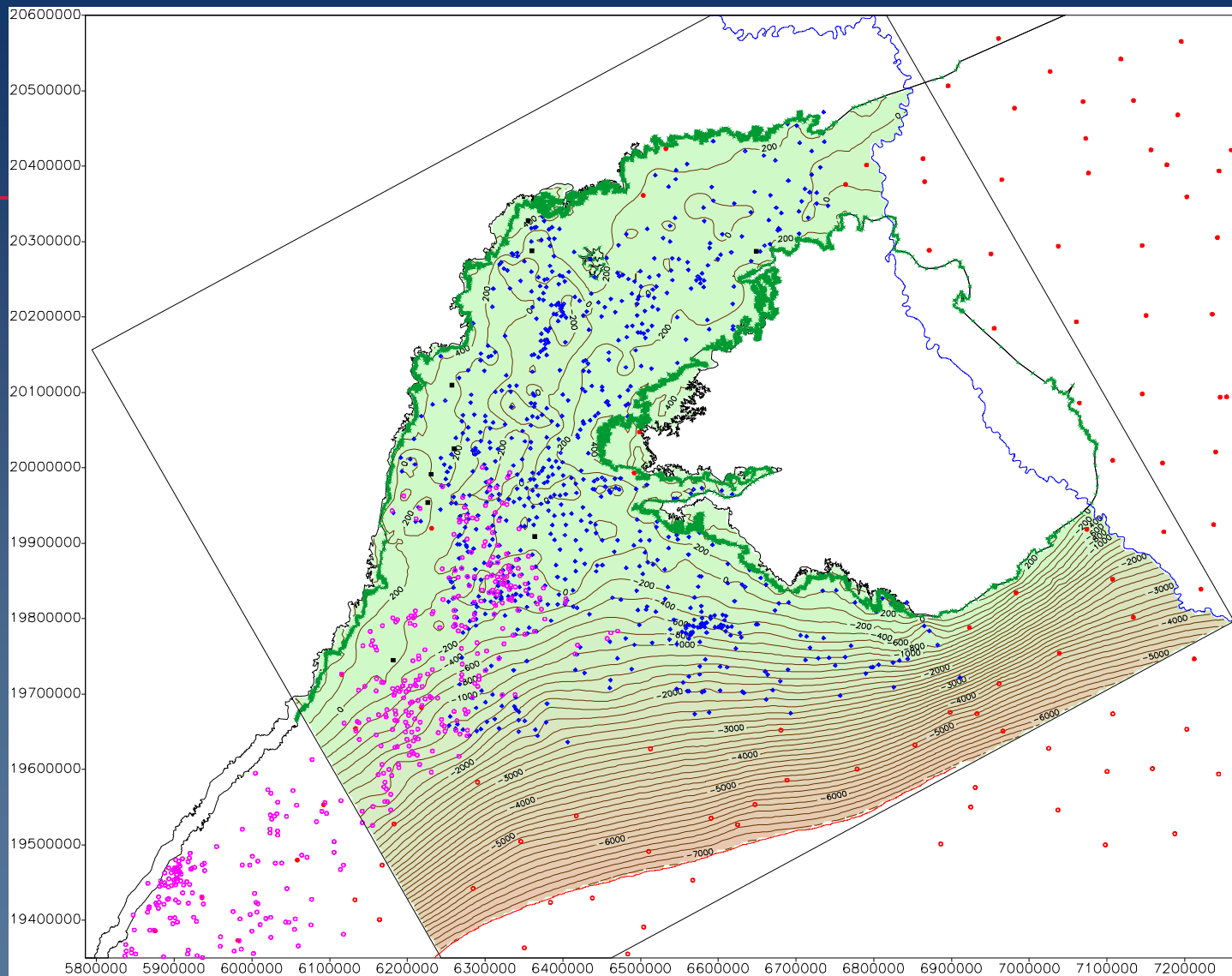
- TWDB East Texas Model
- Central Carrizo-Wilcox Model
- Outcrop
- False Point

Top of Wilcox



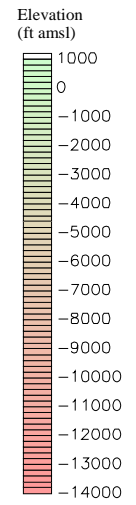
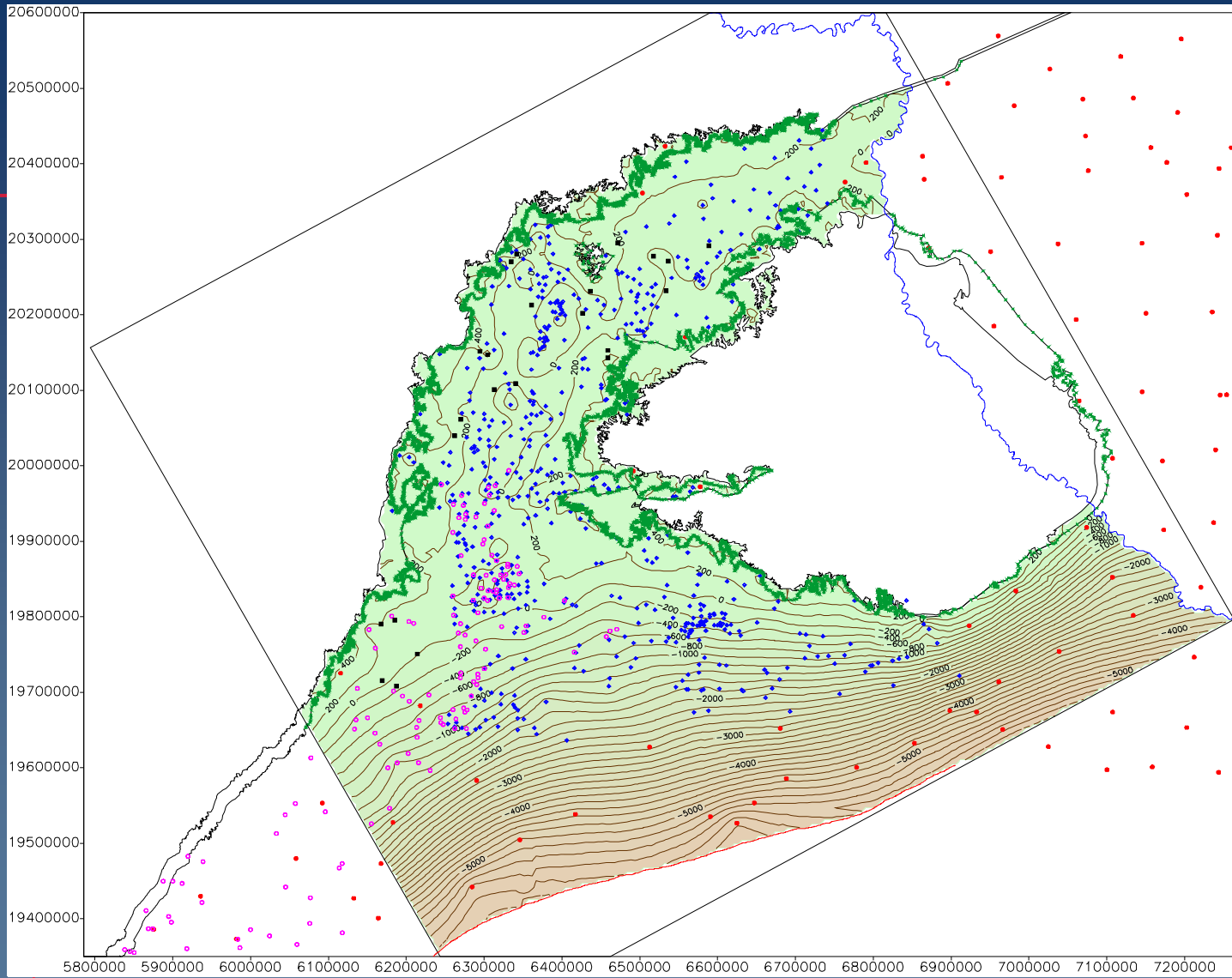
- TWDB East Texas Model ◆
- USGS RASA Data ●
- Central Carrizo-Wilcox Model ○
- Outcrop ✕
- False Point ■

Top of Carrizo



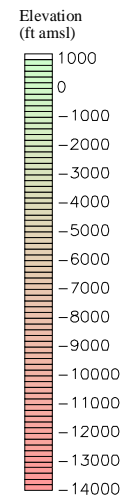
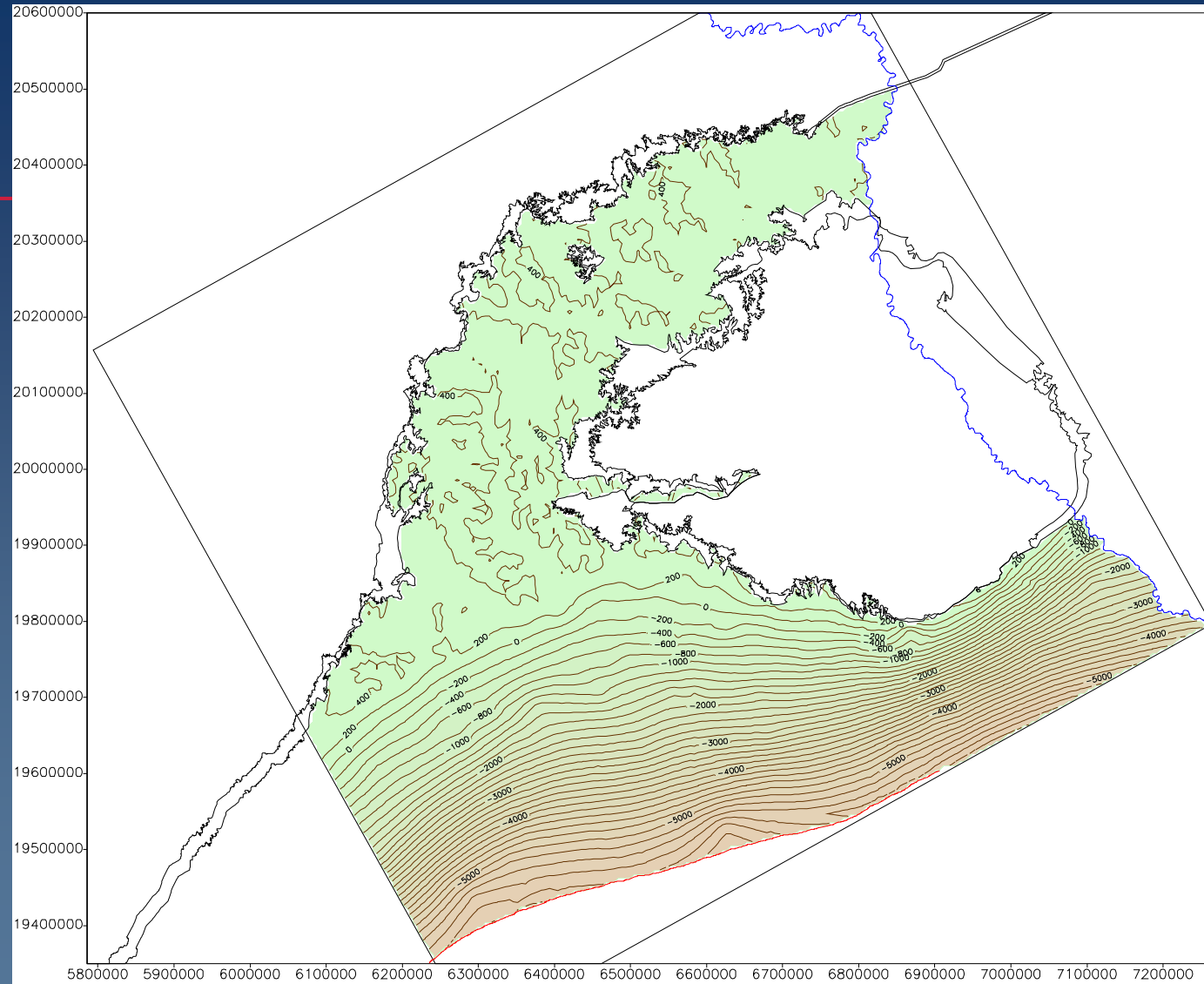
- TWDB East Texas Model
- USGS RASA Data (Layer 4)
- USGS RASA Data (Layer 3)
- Central Carrizo-Wilcox Model
- Outcrop
- False Point

Top of Reklaw



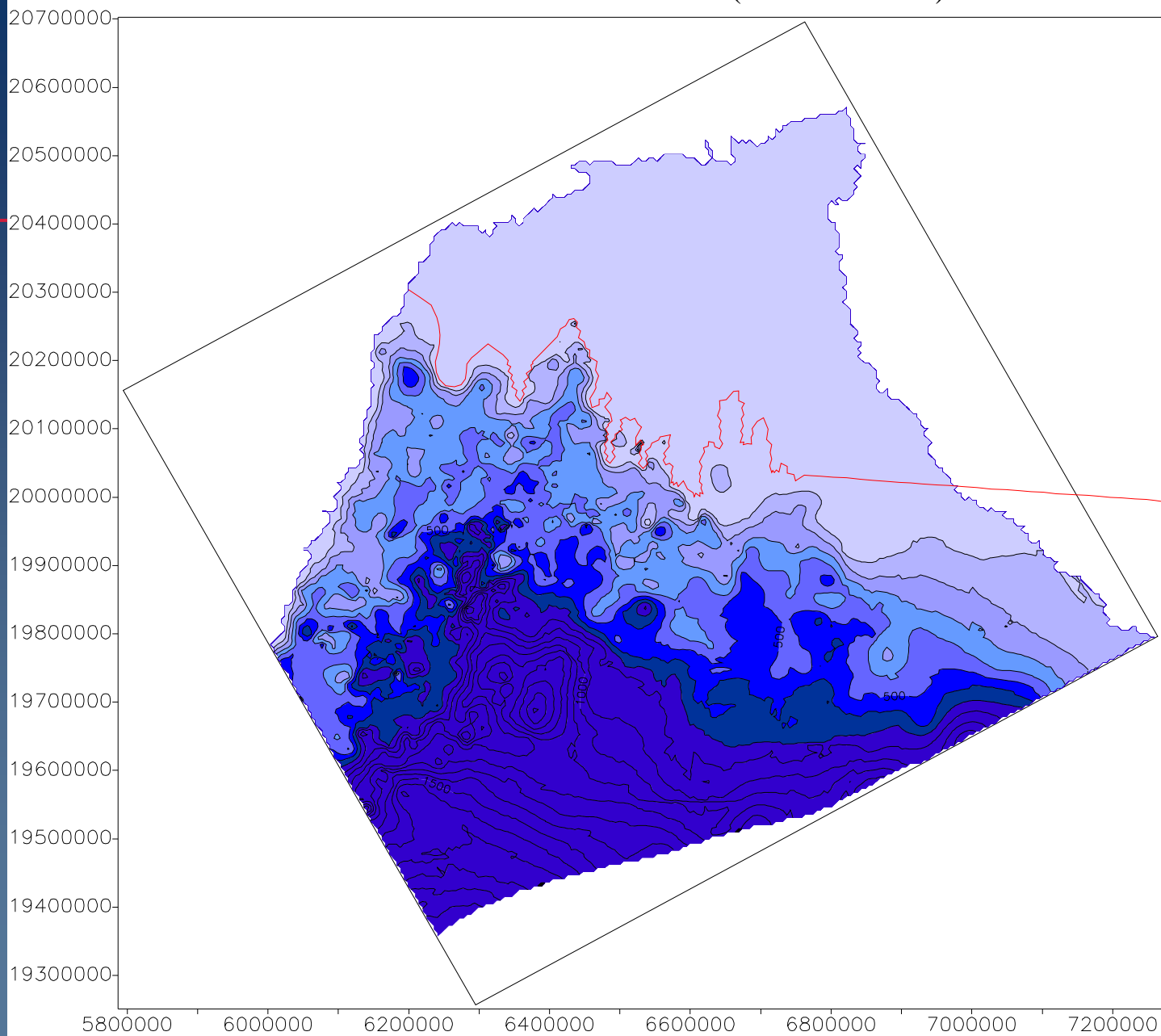
- TWDB East Texas Model
- USGS RASA Data
- Central Carrizo-Wilcox Model
- Outcrop
- False Point

Top of Queen City

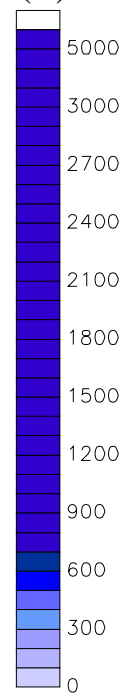


- TWDB East Texas Model
- Outcrop
- False Point

Thickness of Lower Wilcox (TLW14-BW11)

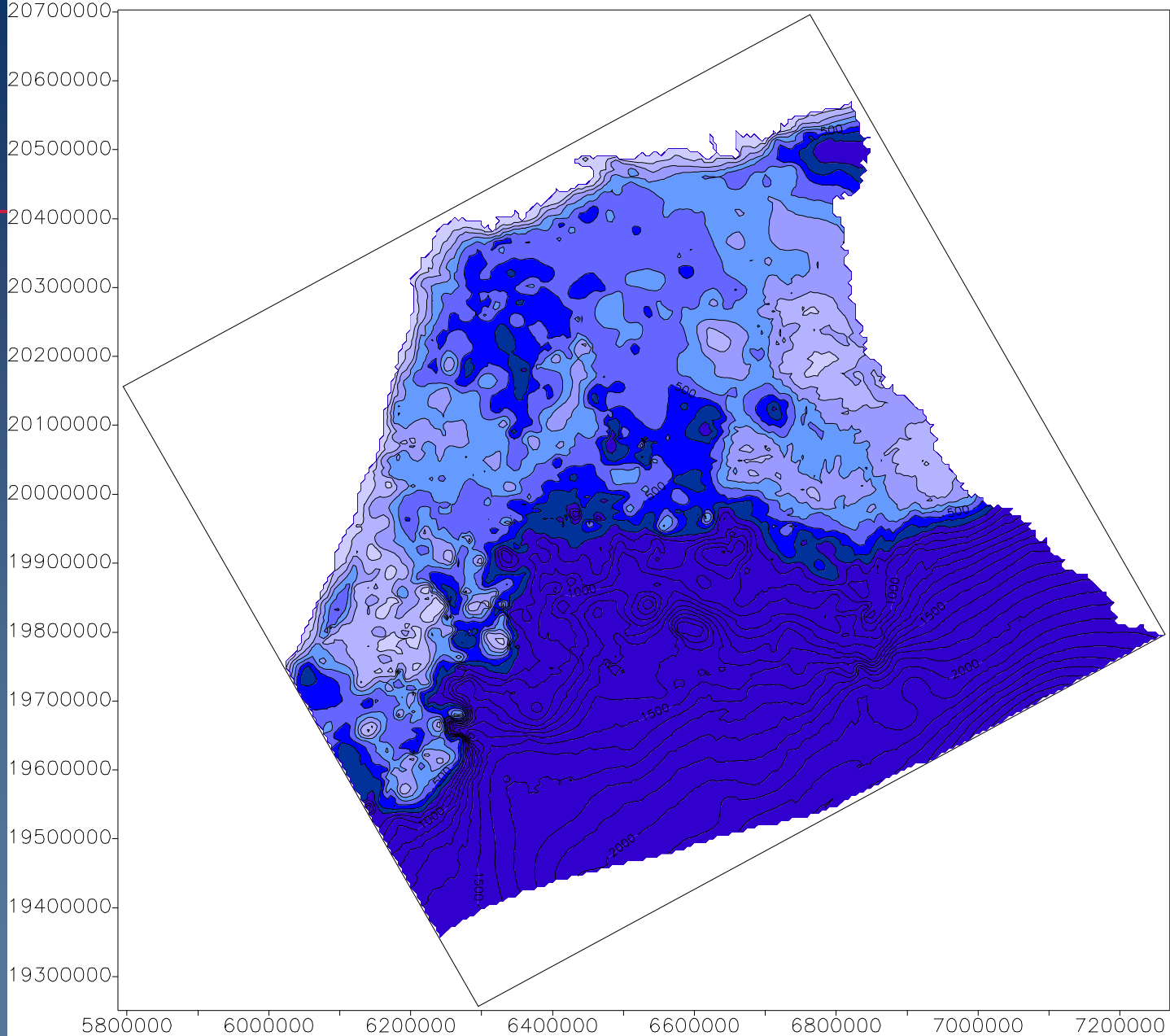


Thickness
(ft)

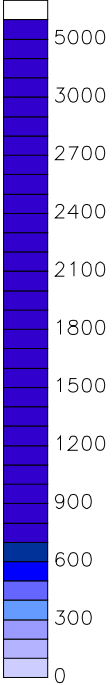


Min 20
Max 2053

Thickness of Middle Wilcox (TMW6-TLW14)

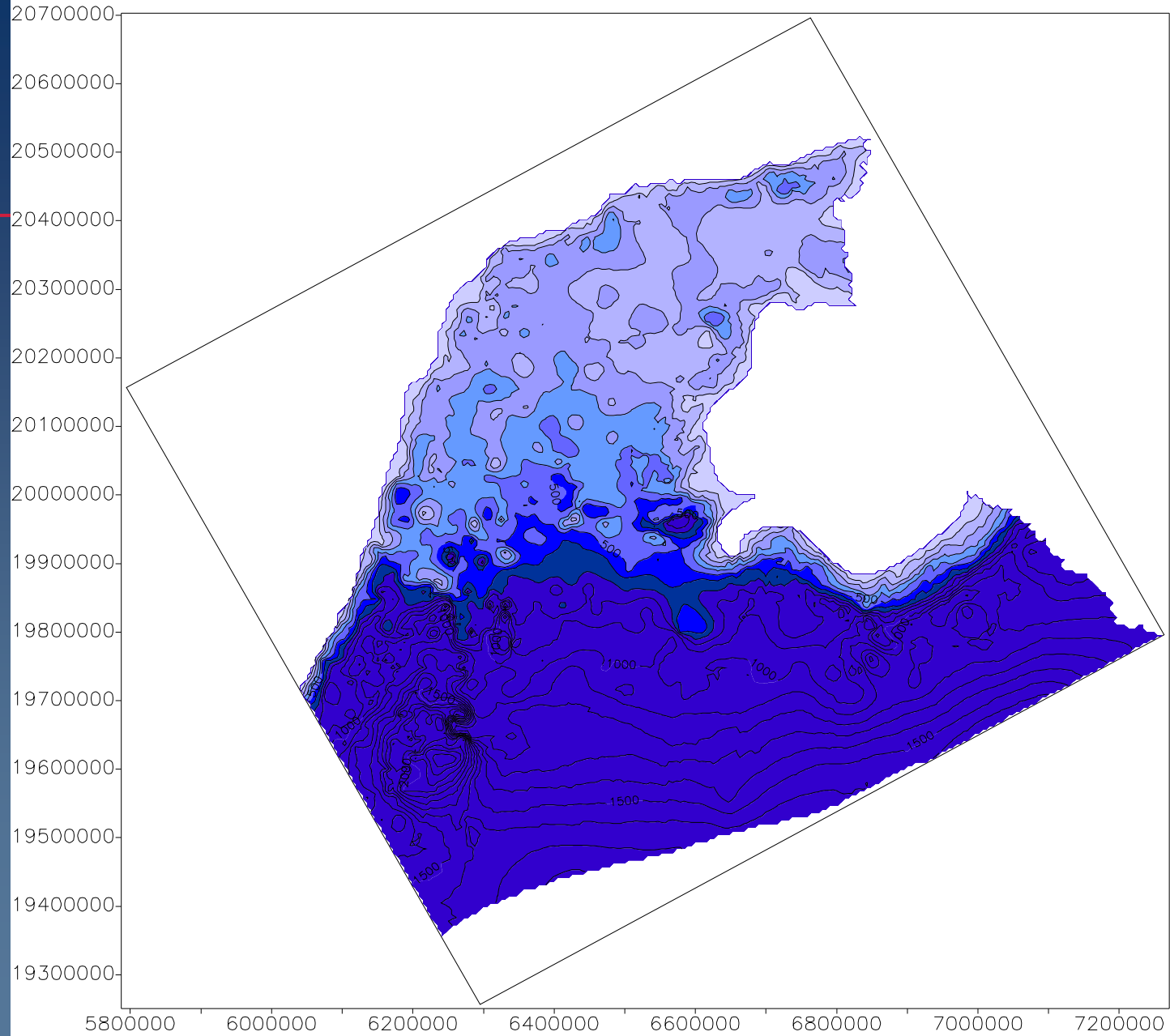


Thickness
(ft)

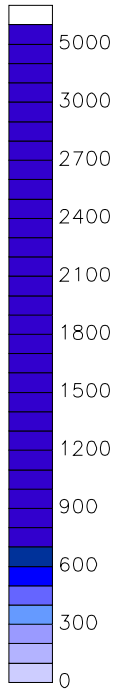


Min 20
Max 2842

Thickness of Upper Wilcox (TW16-TMW6)

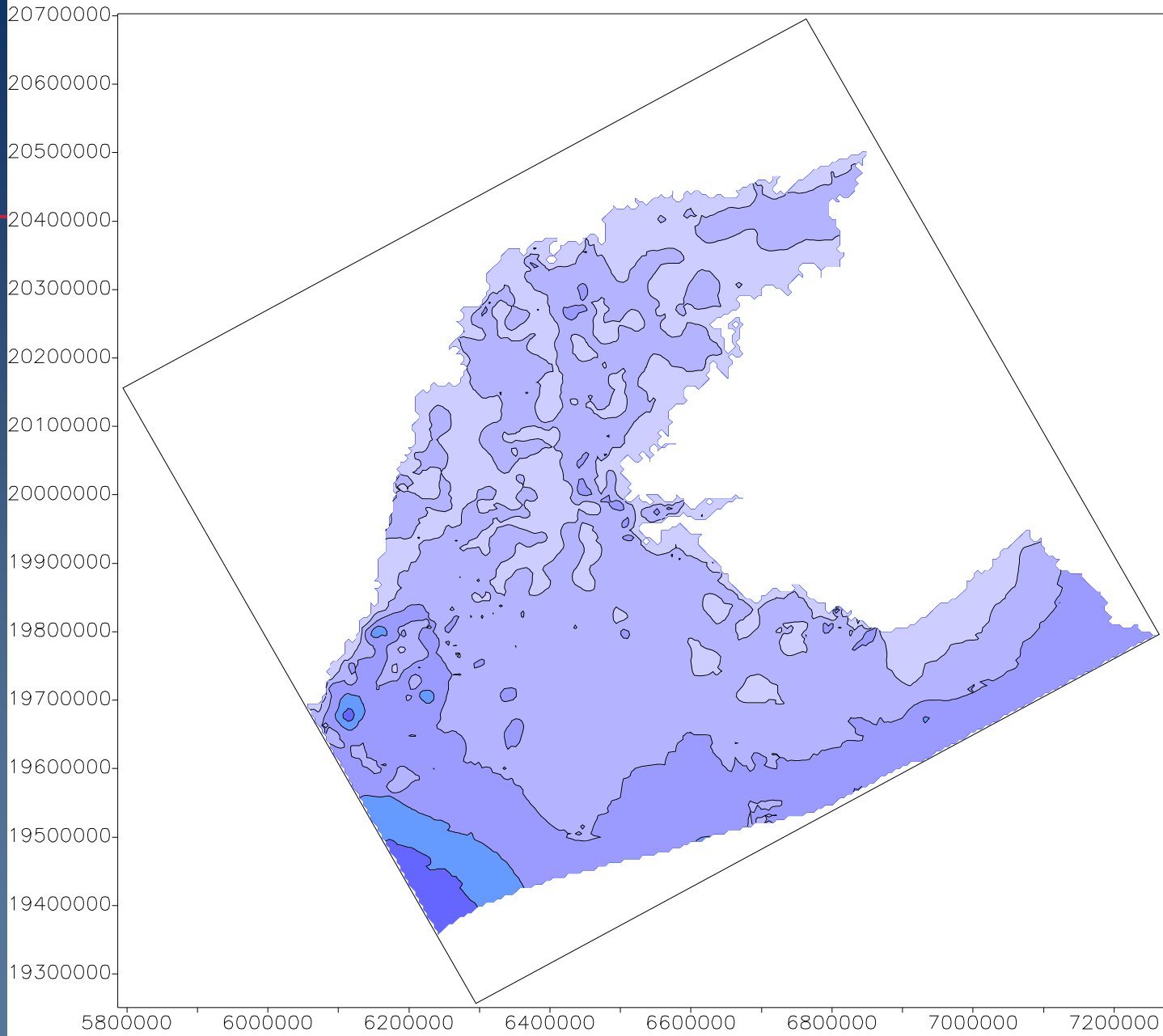


Thickness
(ft)

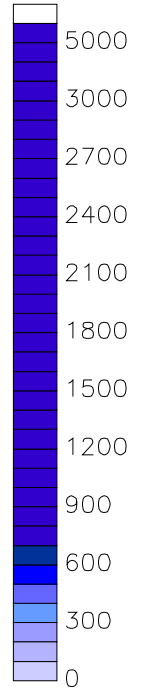


Min 20
Max 2400

Thickness of Carrizo (TC17-TW16)

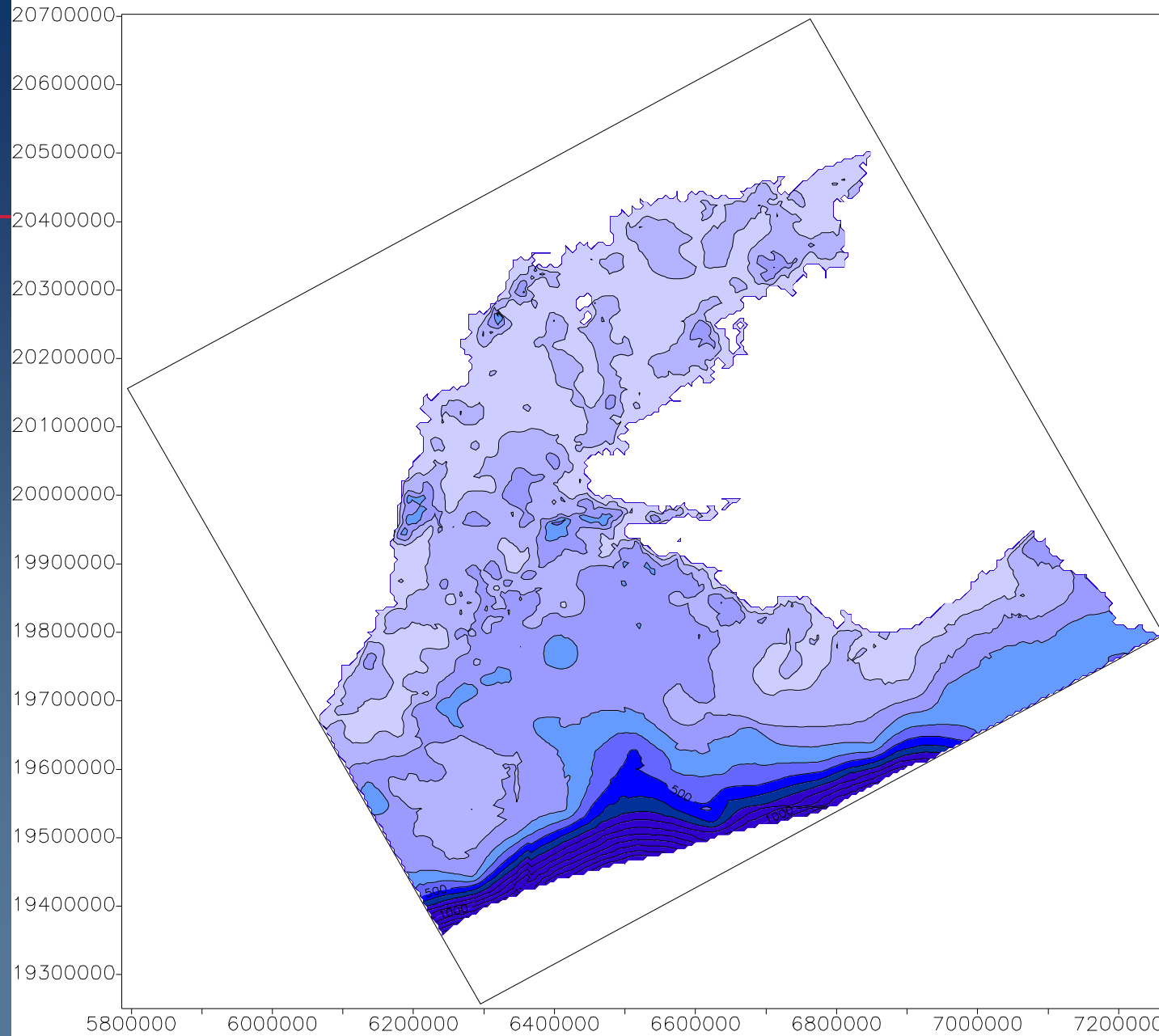


Thickness
(ft)

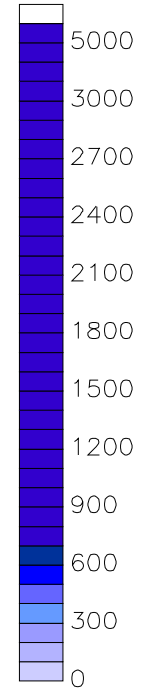


Min 20
Max 471

Thickness of Reklaw (TR12-TC17)

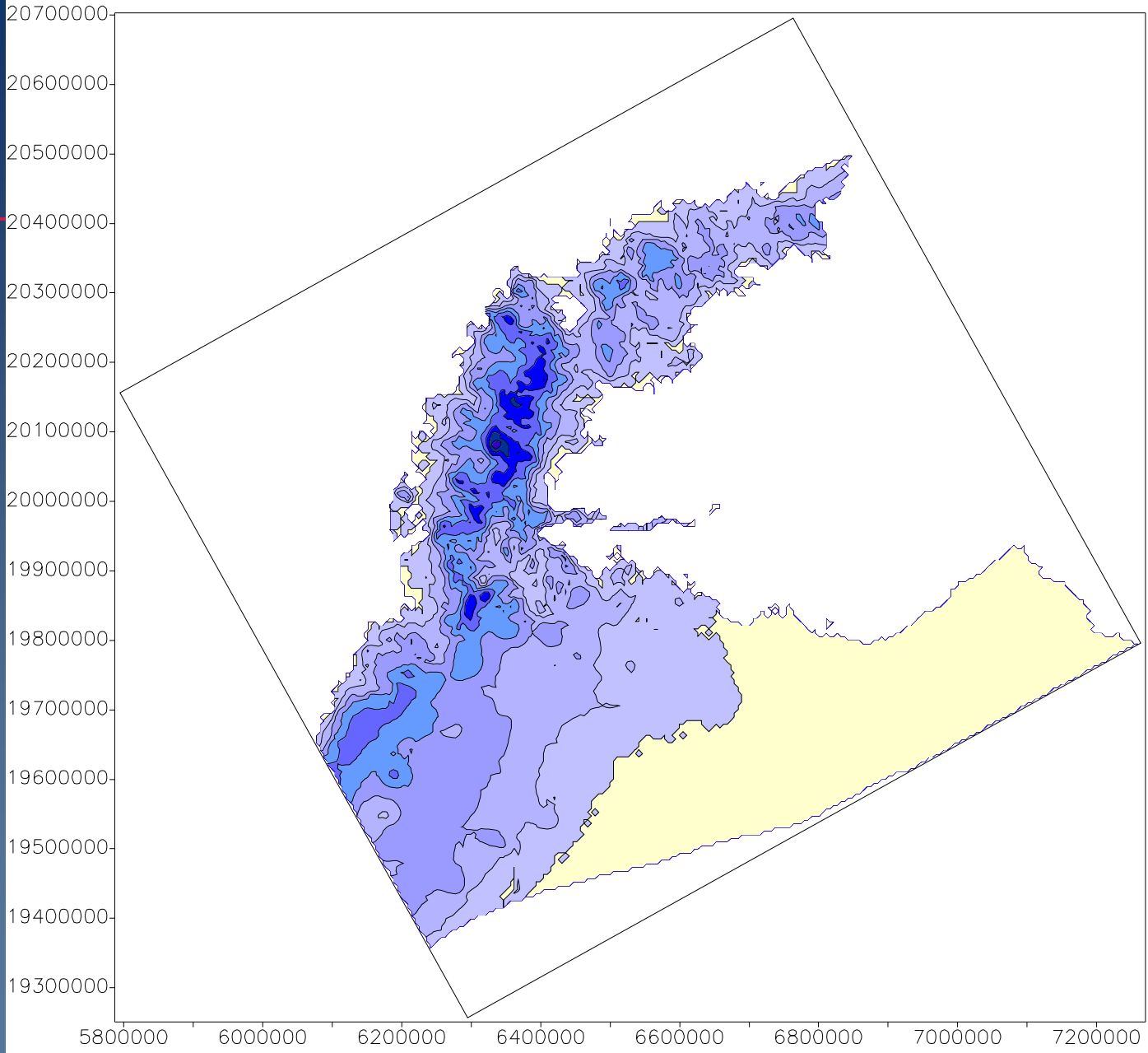


Thickness
(ft)

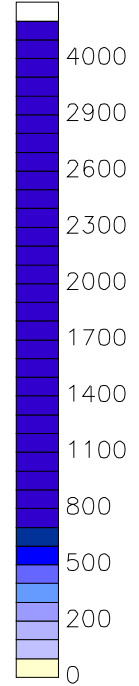


Min 20
Max 1500

Thickness of Queen City (TQC14-TR12)

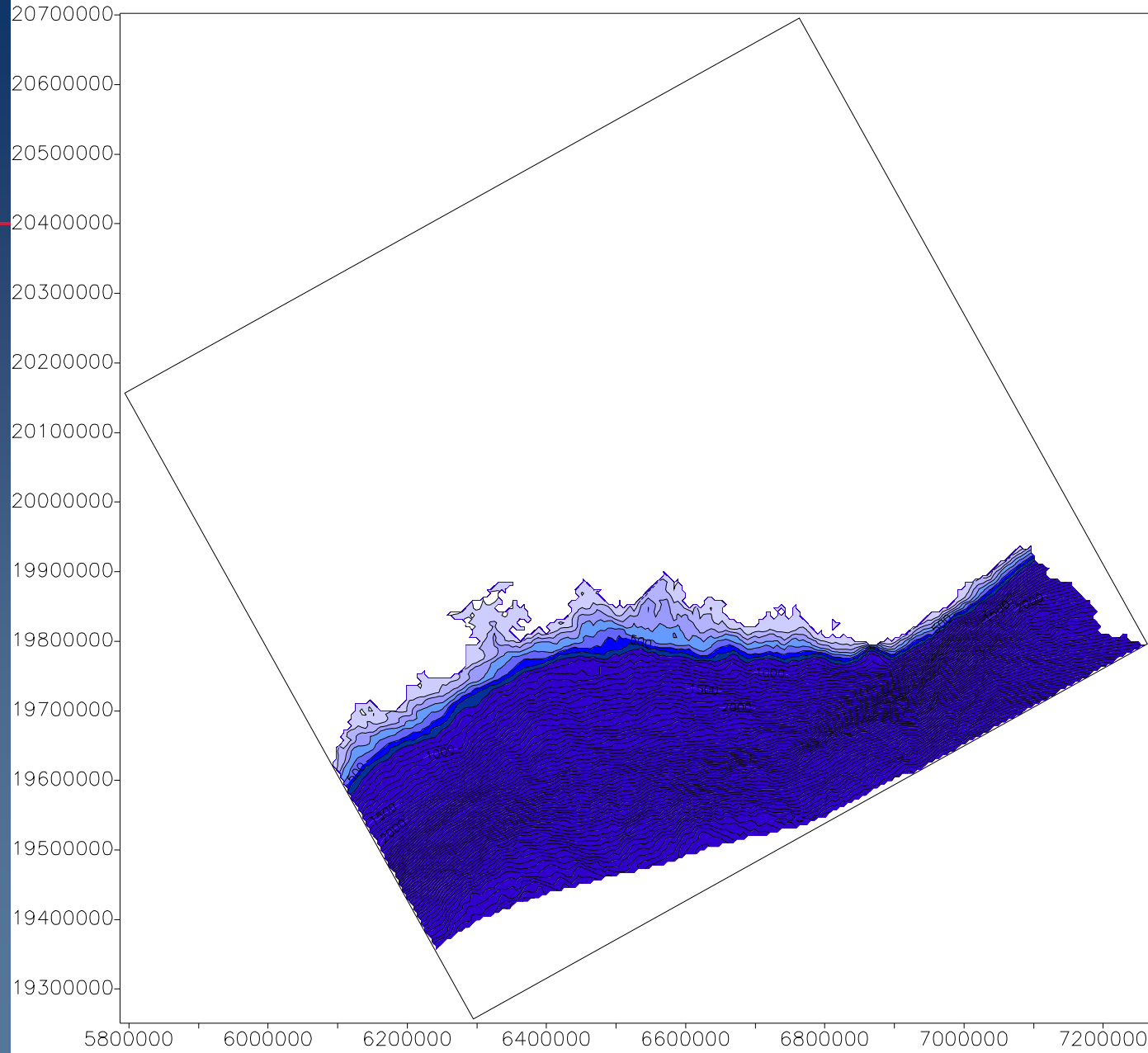


Thickness
(ft)

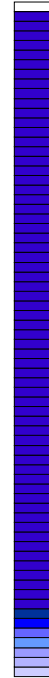


Min 20
Max 802

Thickness of Younger Sediments (TY4-TQC14)



Thickness
(ft)



Min 20
Max 6422

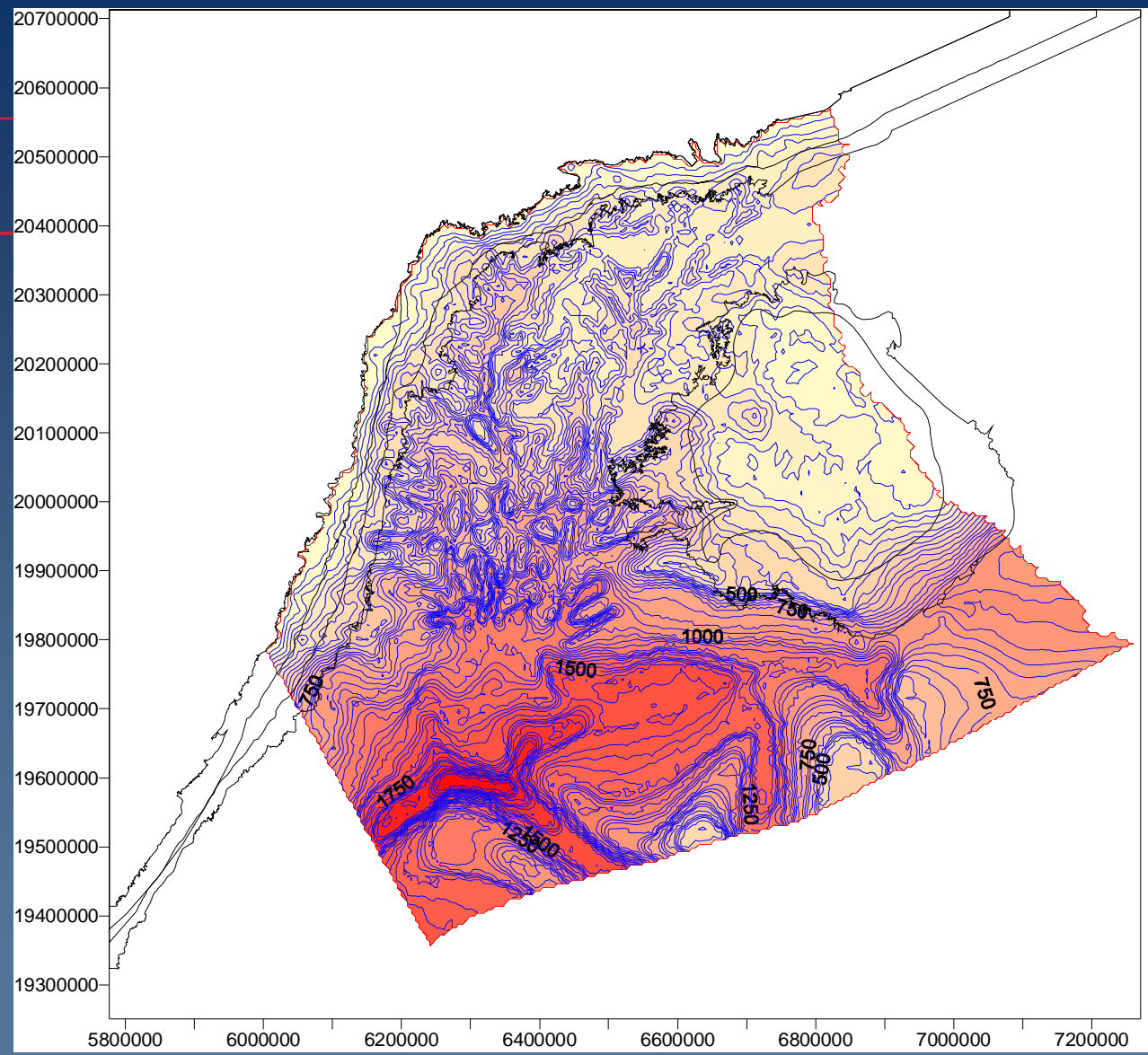
Presentation Outline

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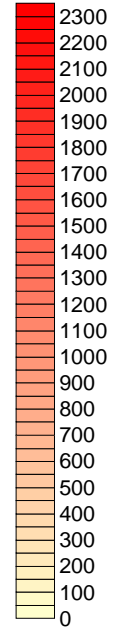
Sand Distributions

- Based on sand thickness maps from Kaiser et. al. (1978) and Fisher and McGowen (1967)
- Split out between Upper, Middle, and Lower Wilcox by percent; 37.5, 37.5, and 25, respectively.
- Carrizo assumed to be approximately 100 percent sand.

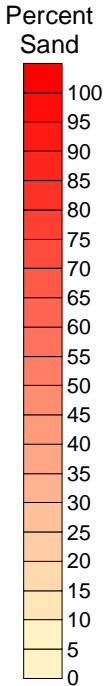
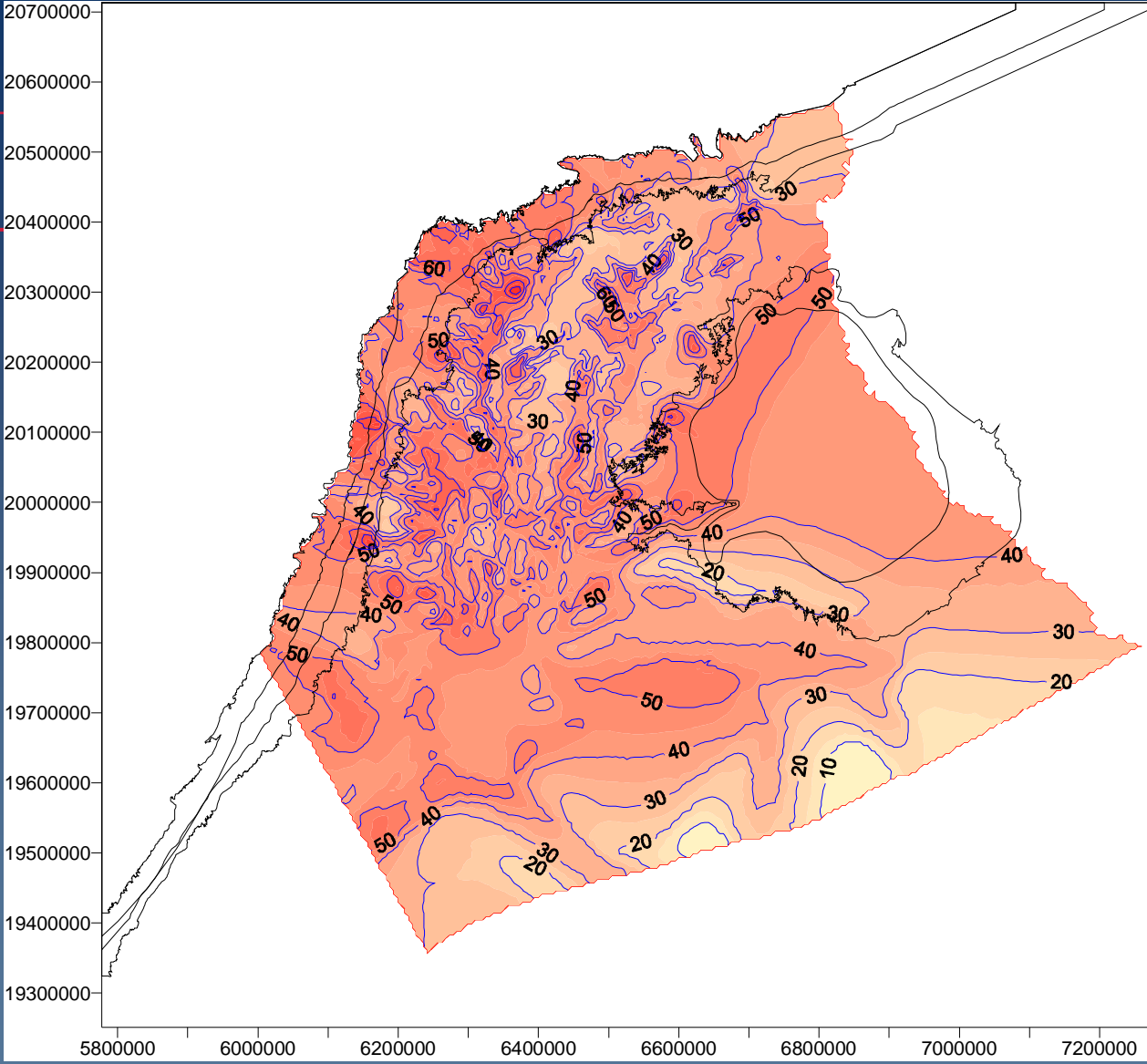
Total Wilcox Sand Thickness



Thickness (ft)



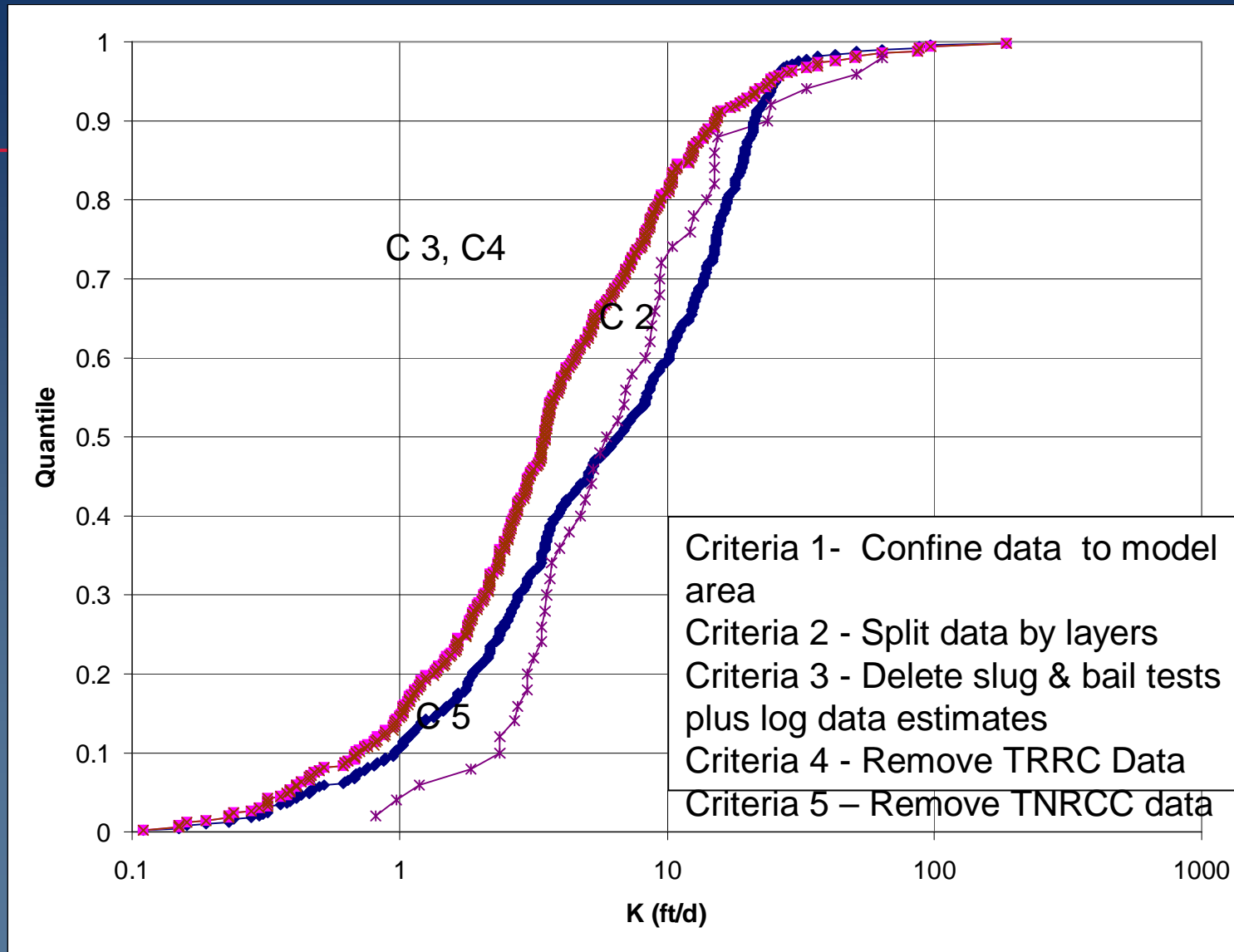
Total Wilcox Percent Sand



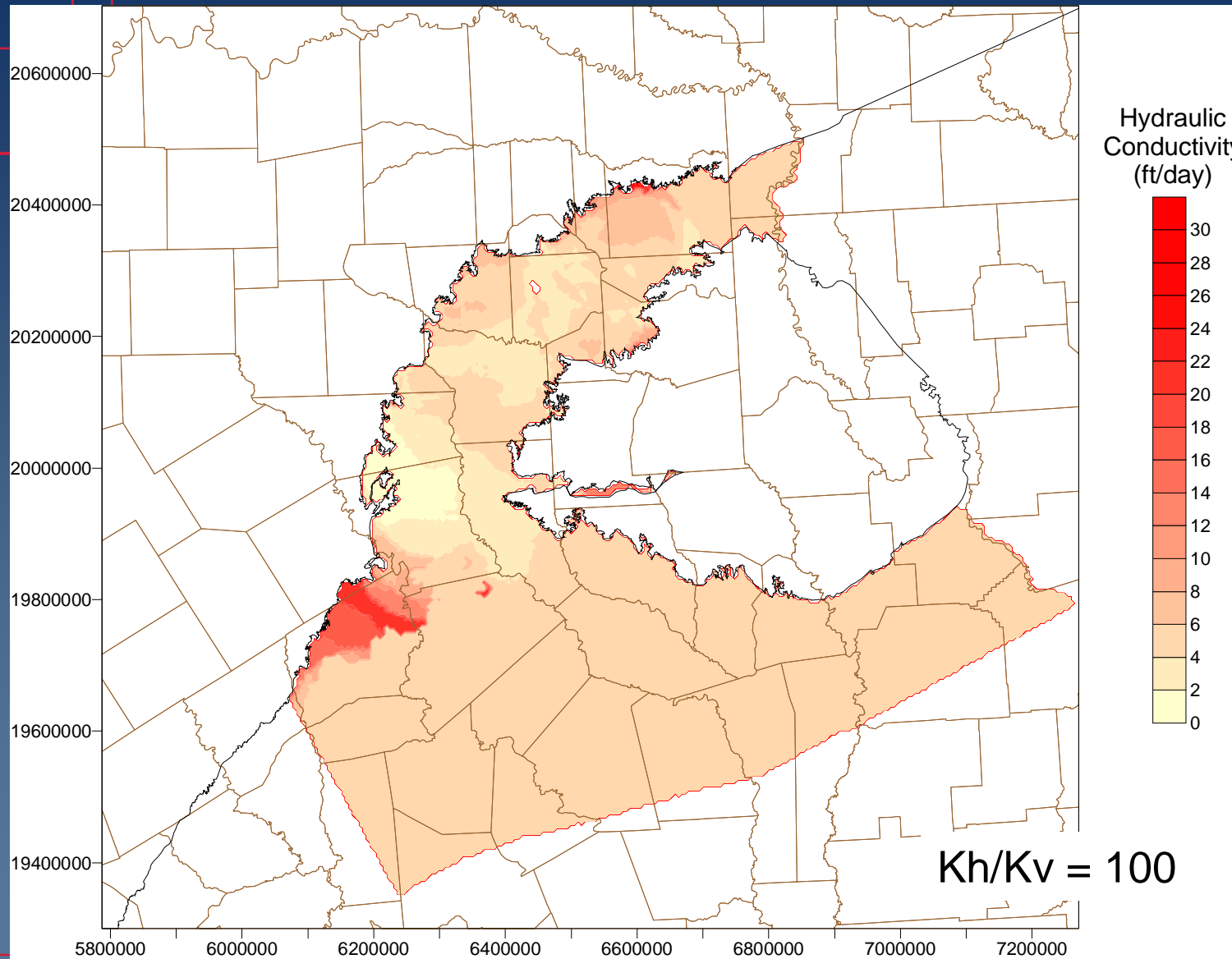
Hydraulic Conductivity

- A good distribution of point measurements are available (Mace et al, 2000)
- Poor correlation between measured values and estimated sand patterns
- Must scale K_h and K_v to regional grid scale

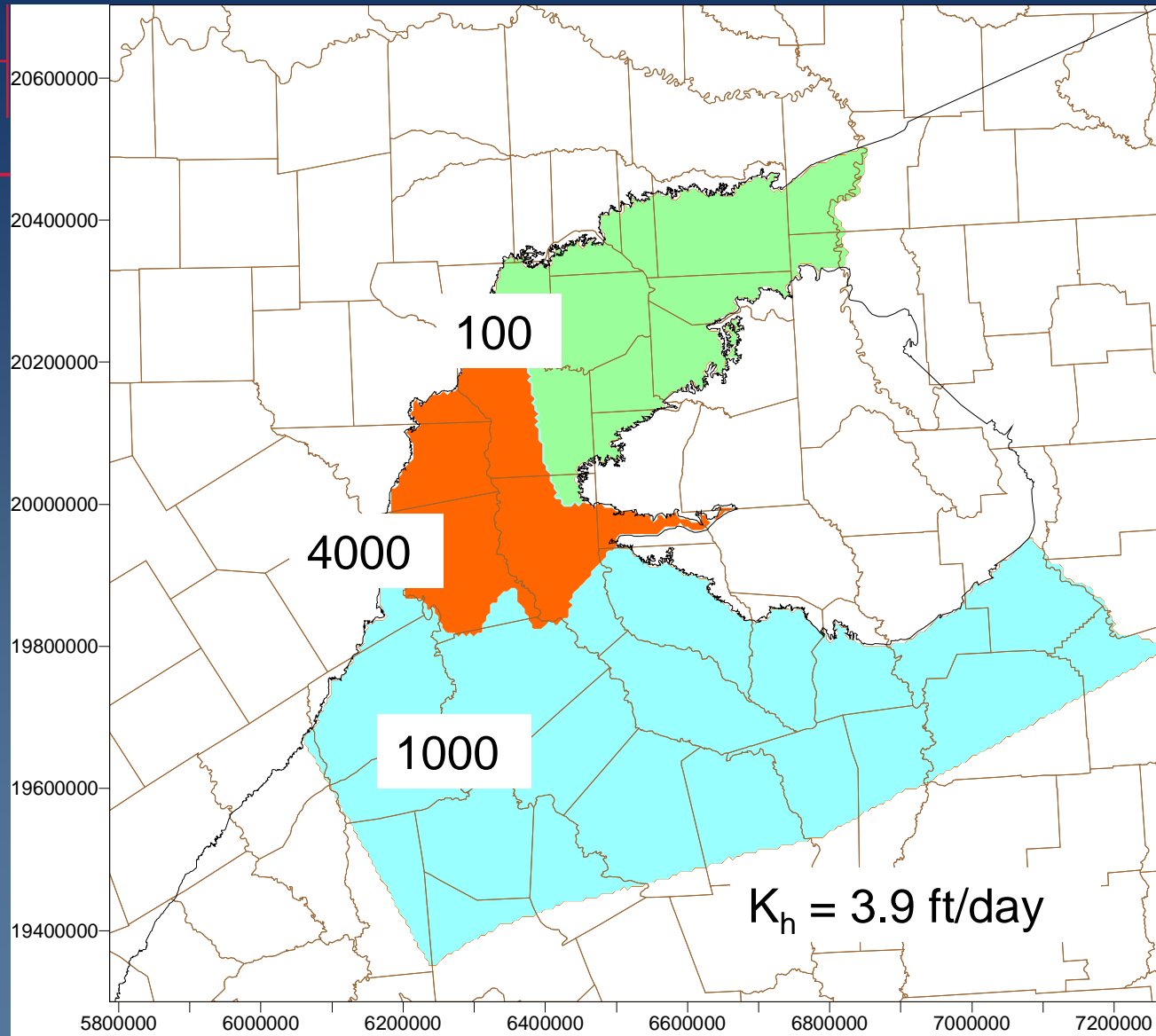
Comparison of Criteria for Carrizo-Wilcox



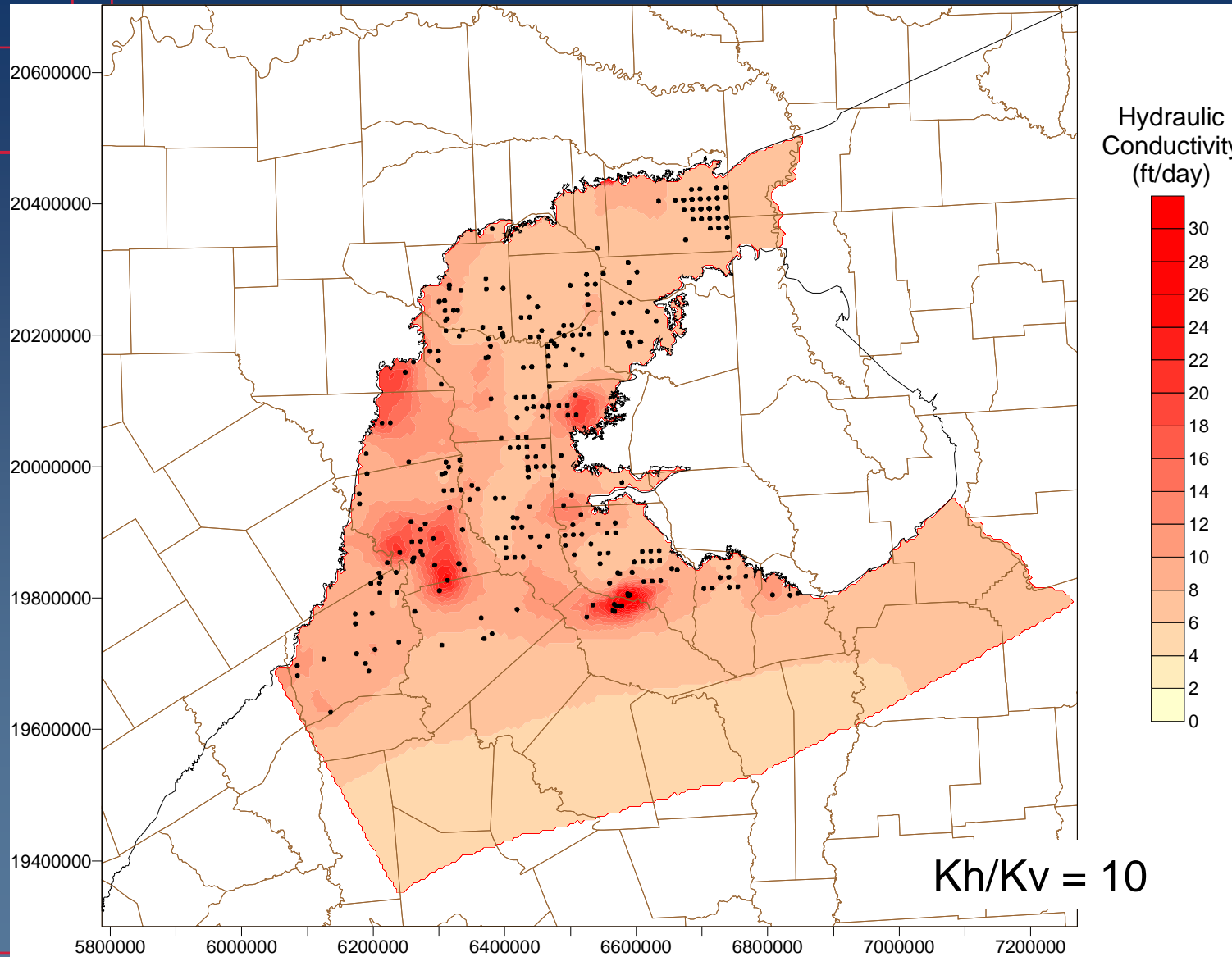
Queen City Hydraulic Conductivities



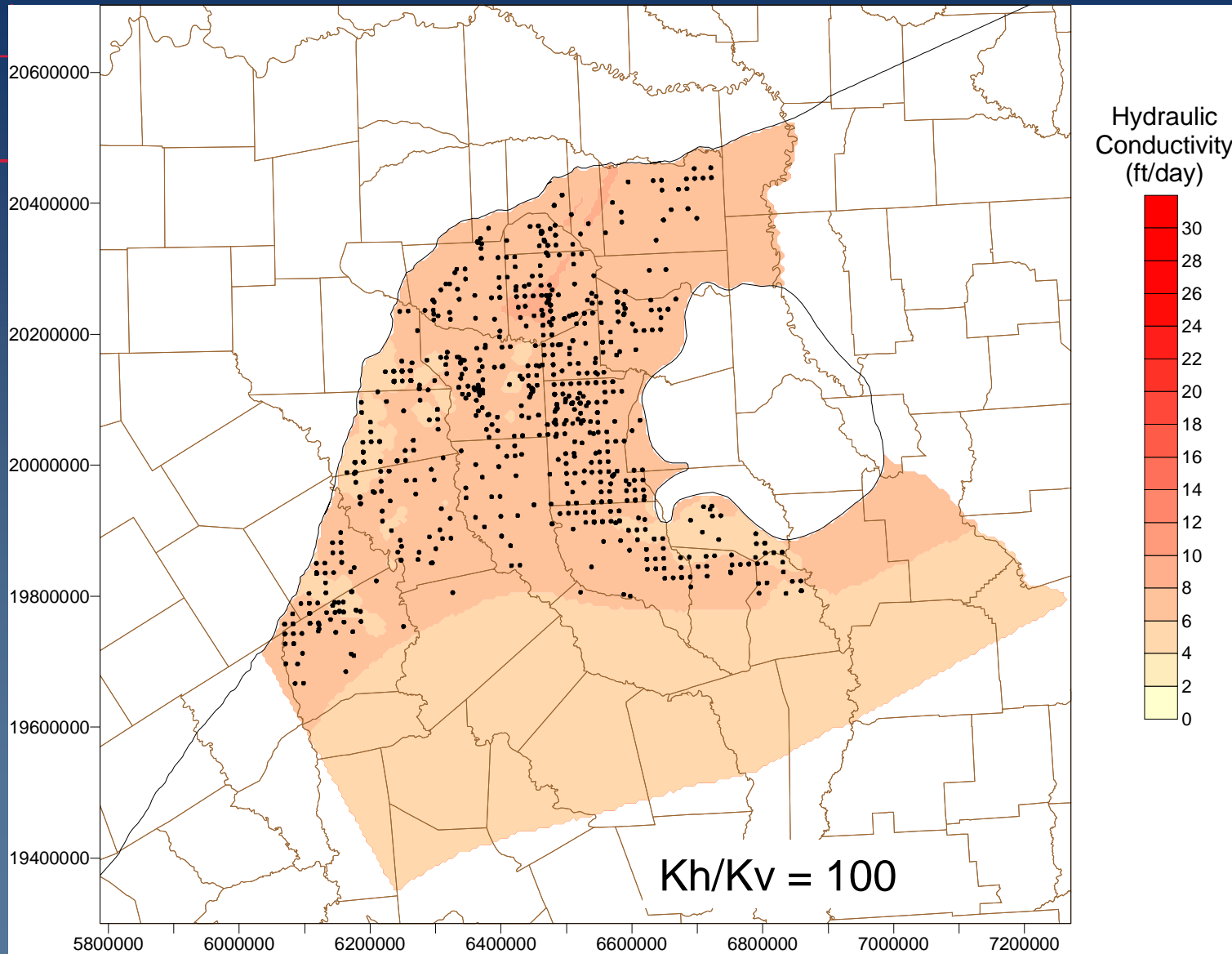
Reklaw K_h/K_v



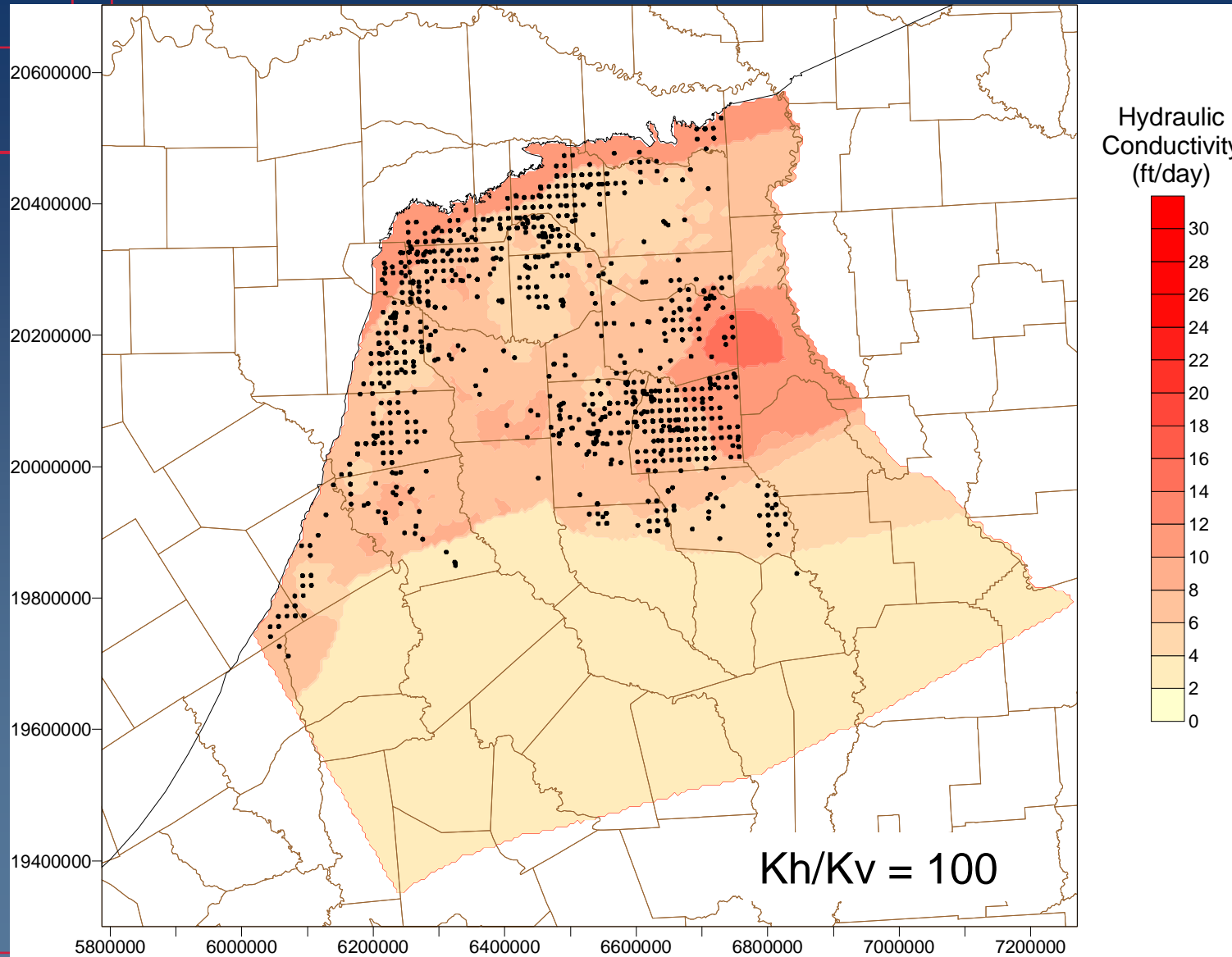
Carrizo Hydraulic Conductivities



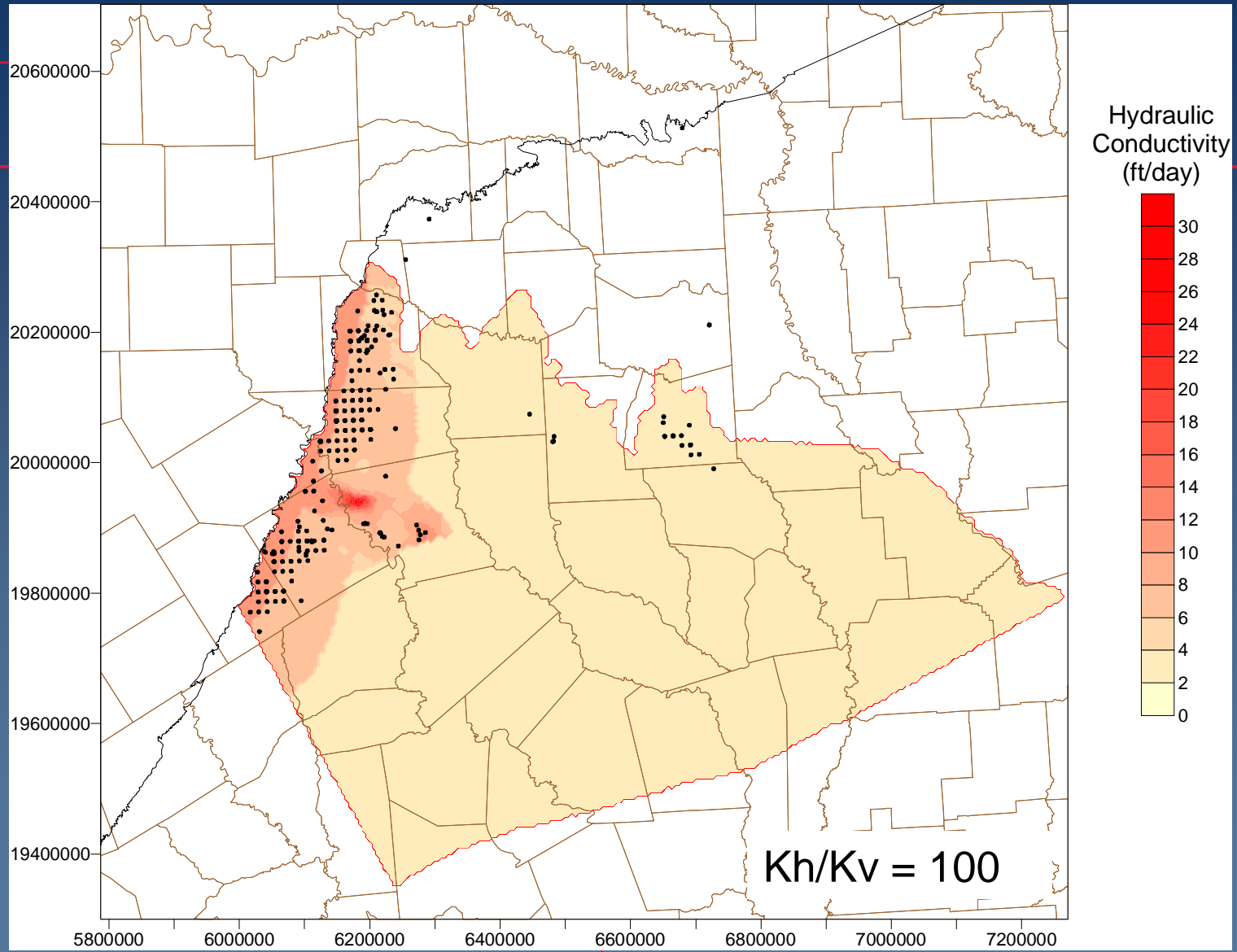
Upper Wilcox Hydraulic Conductivities



Middle Wilcox Hydraulic Conductivities



Lower Wilcox Hydraulic Conductivities

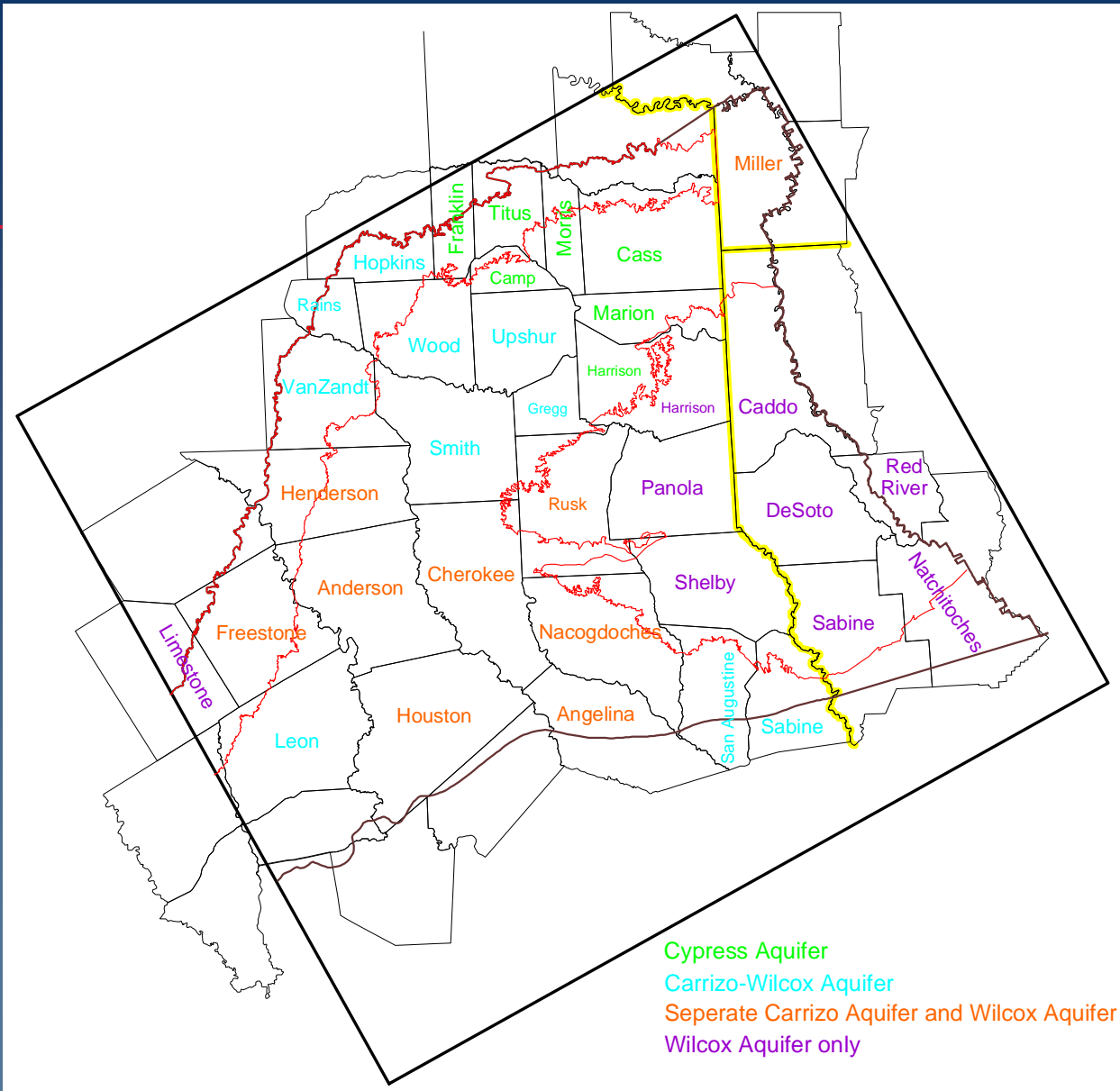


Presentation Outline

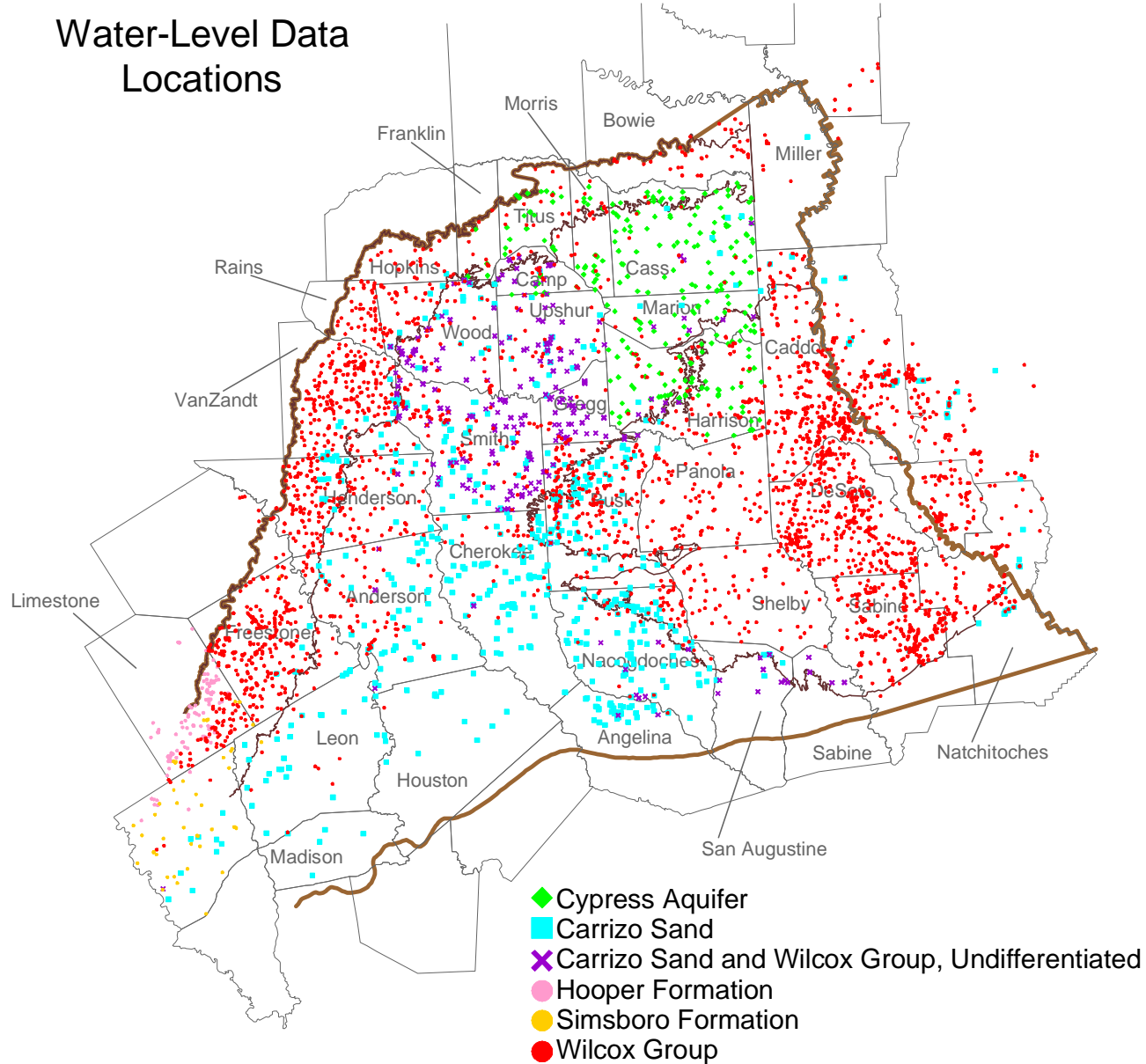
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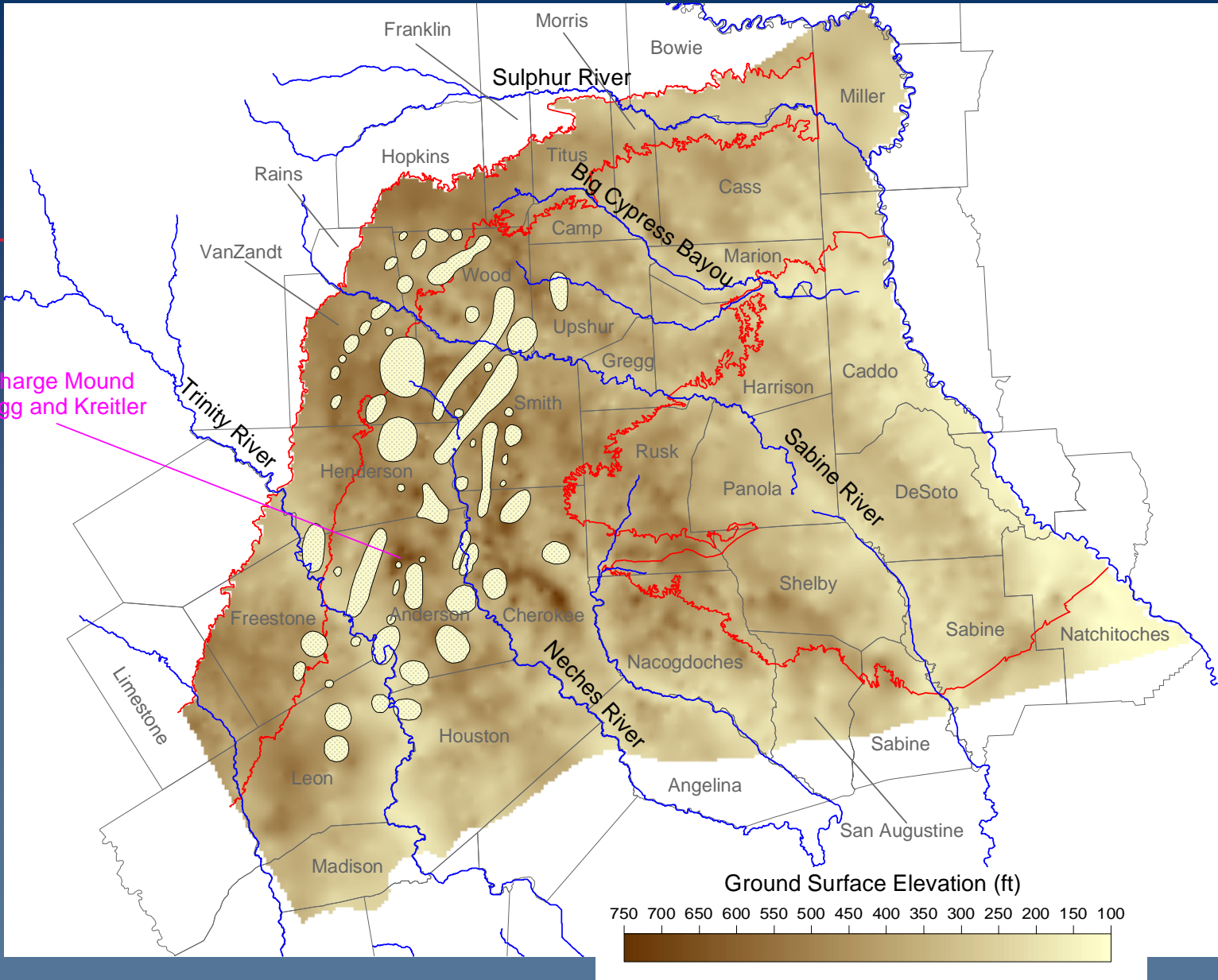
Predevelopment Heads

- Evaluated water-level data on a county by county basis
- Conducted a literature review on the historical development of the Carrizo and Wilcox in each county
- For each county, determined the hydraulic connectiveness of the Carrizo and Wilcox based on a review of the county reports



Water-Level Data Locations

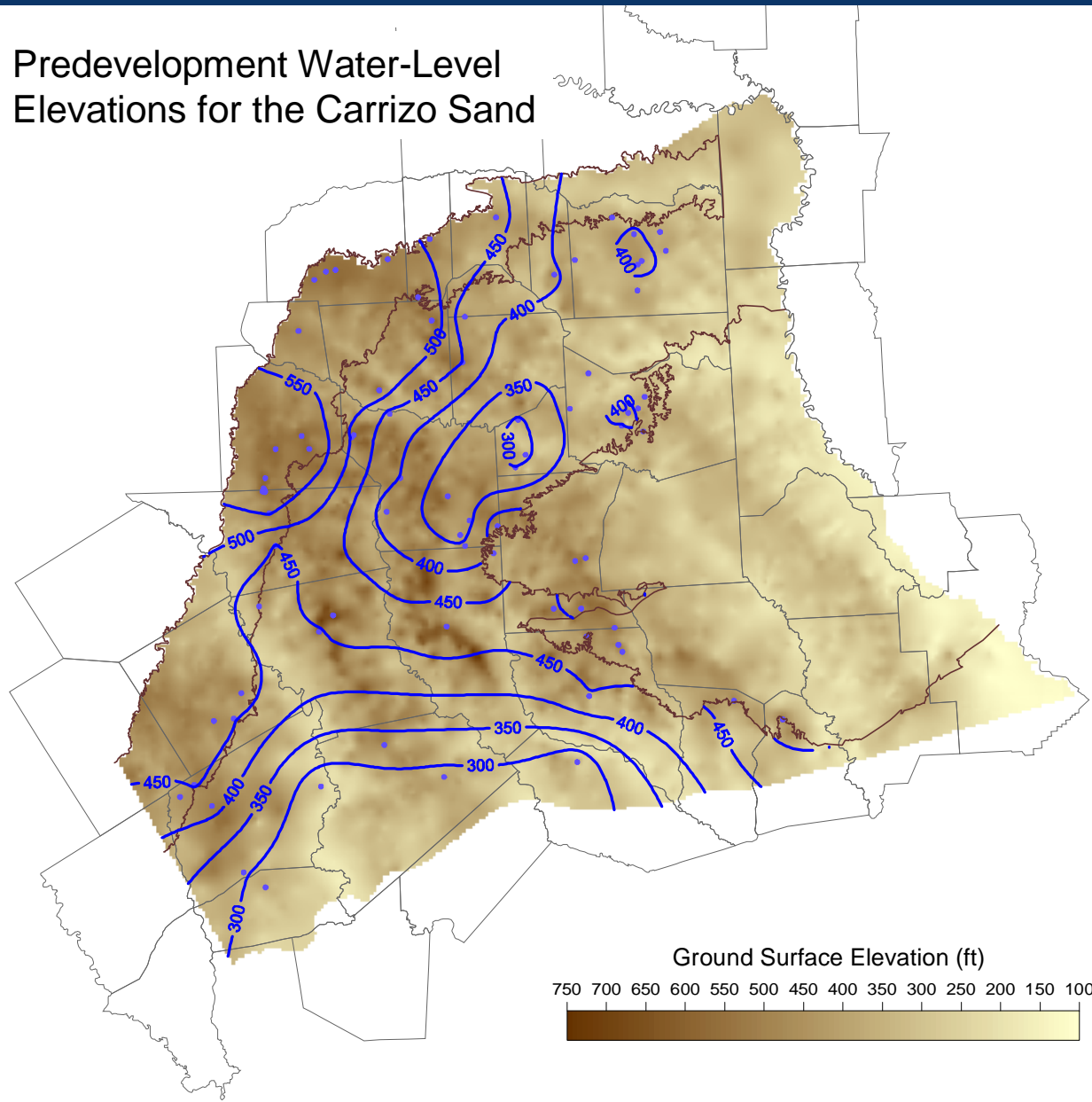




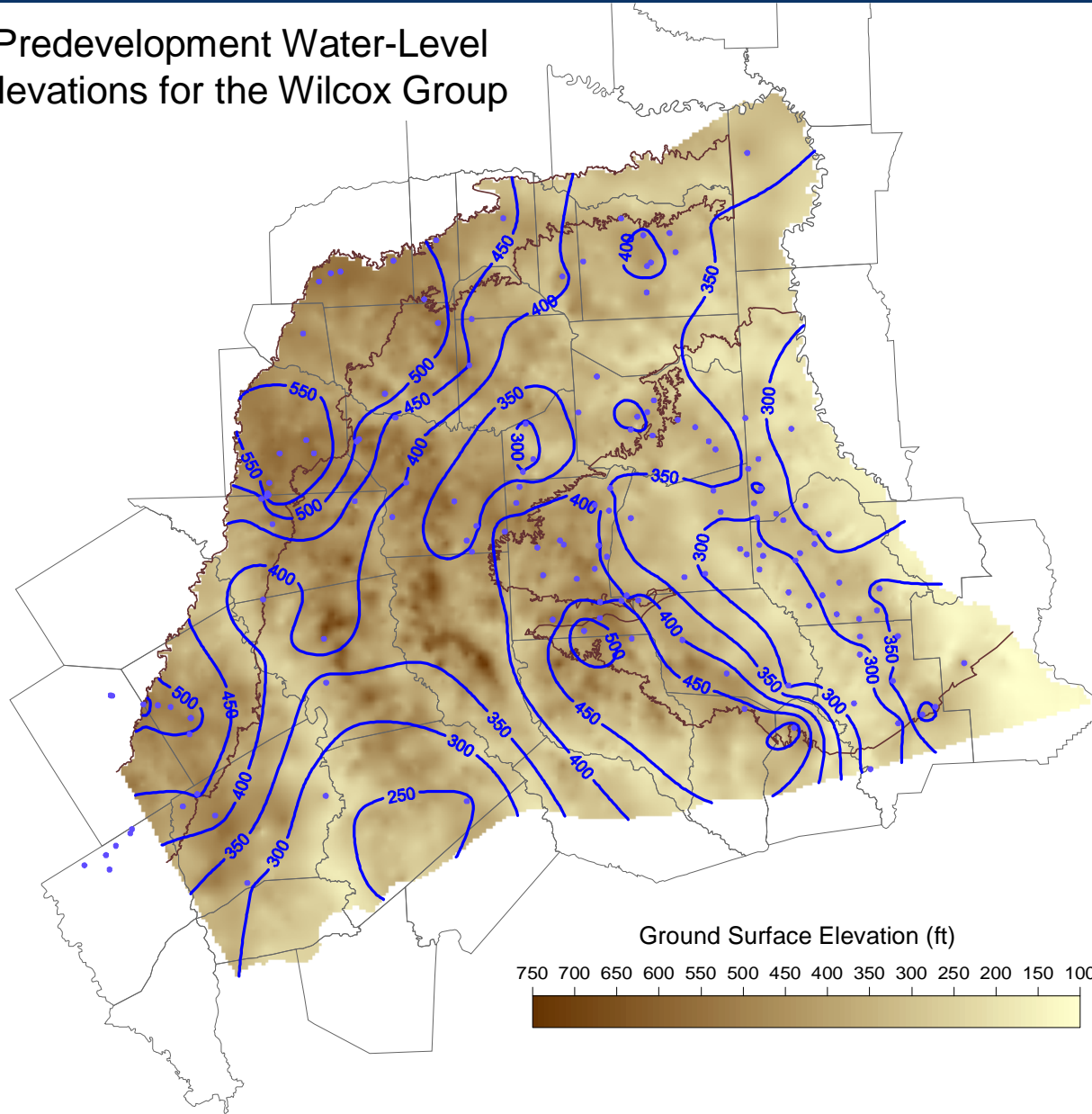
Methodology (continued)

- Attempted adequate coverage of water-level elevations across each county
- Used maximum water-level elevations (regardless of date measured) in each area of the county
- Used water-level measurements made at early dates when they were not considered to reflect pumpage effects

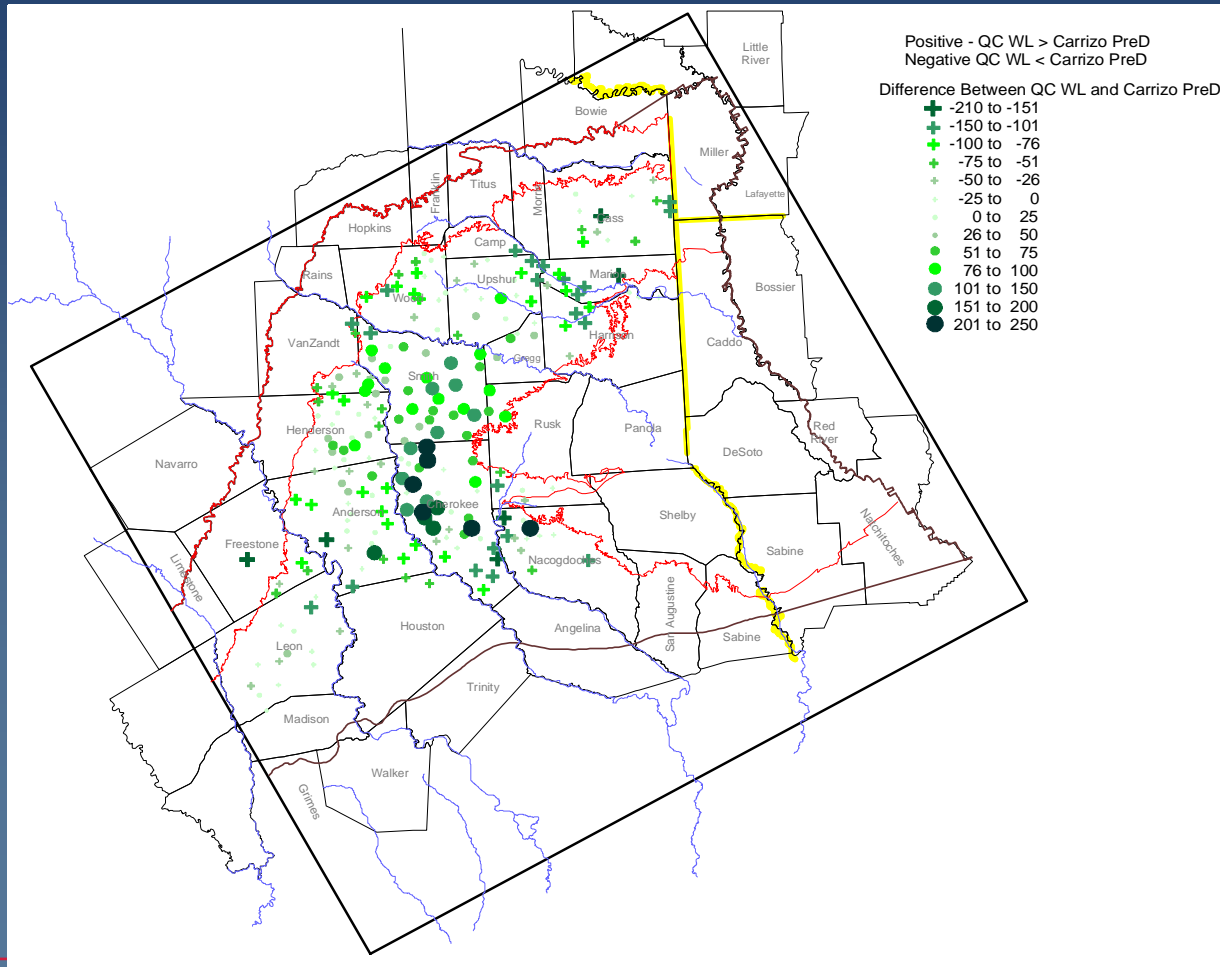
Predevelopment Water-Level Elevations for the Carrizo Sand



Predevelopment Water-Level Elevations for the Wilcox Group



Head Difference: QC - Carrizo

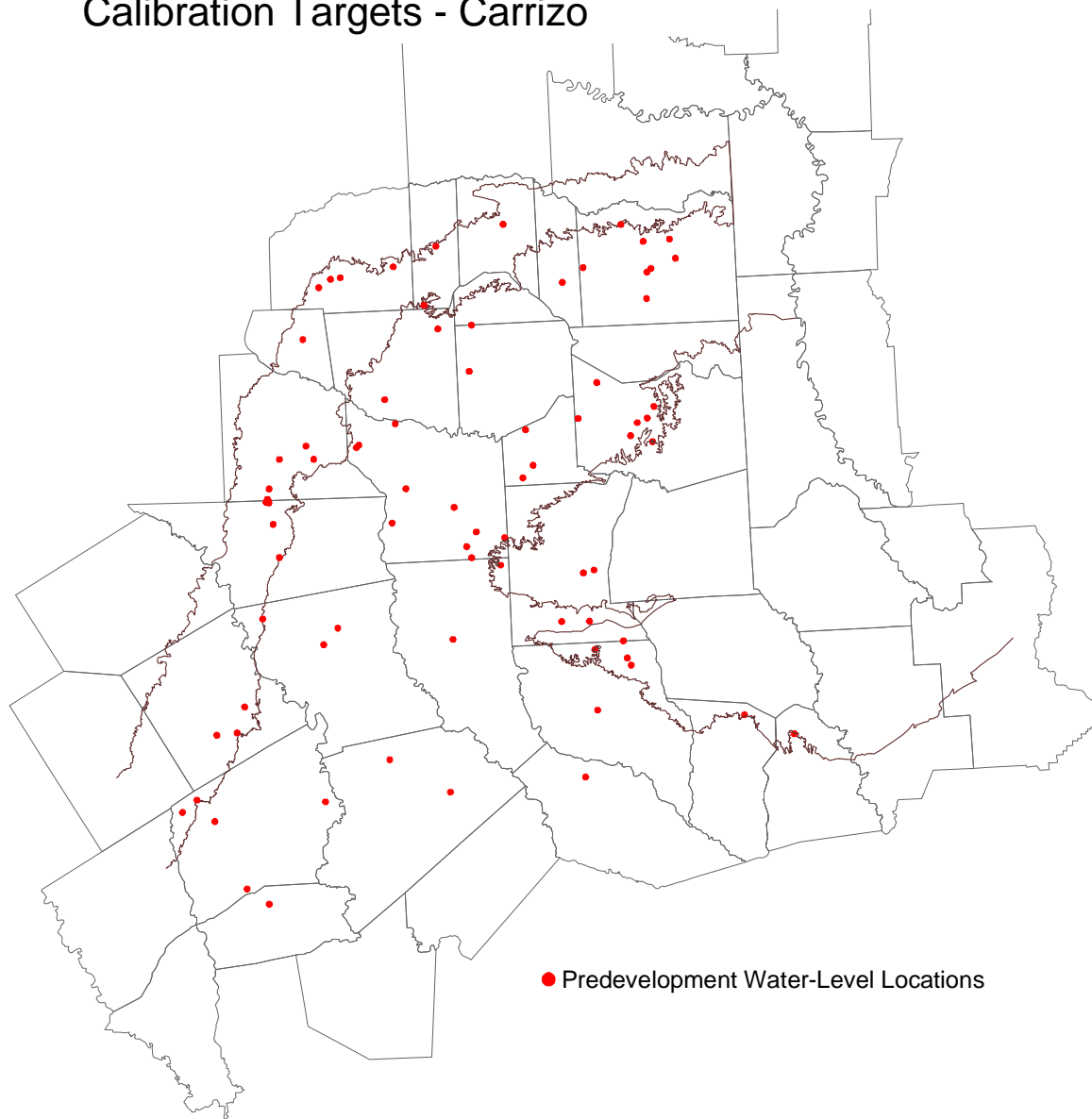


Calibration Targets

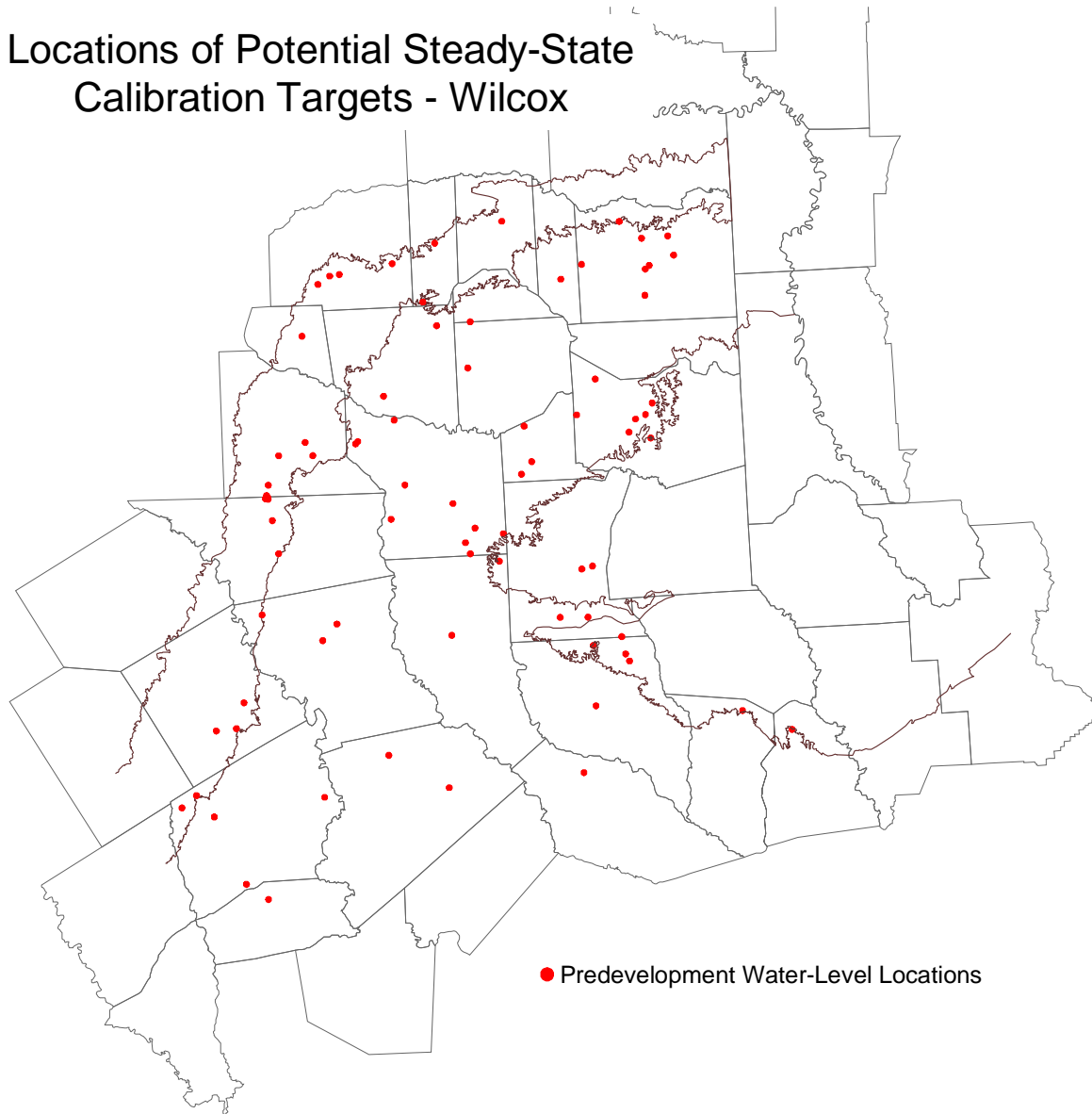
■ Steady-State Calibration

- Calibration targets consist of selected predevelopment water-level elevations in both the outcrop and artesian areas of the Carrizo Sand and the Wilcox Group

Locations of Potential Steady-State Calibration Targets - Carrizo



Locations of Potential Steady-State Calibration Targets - Wilcox



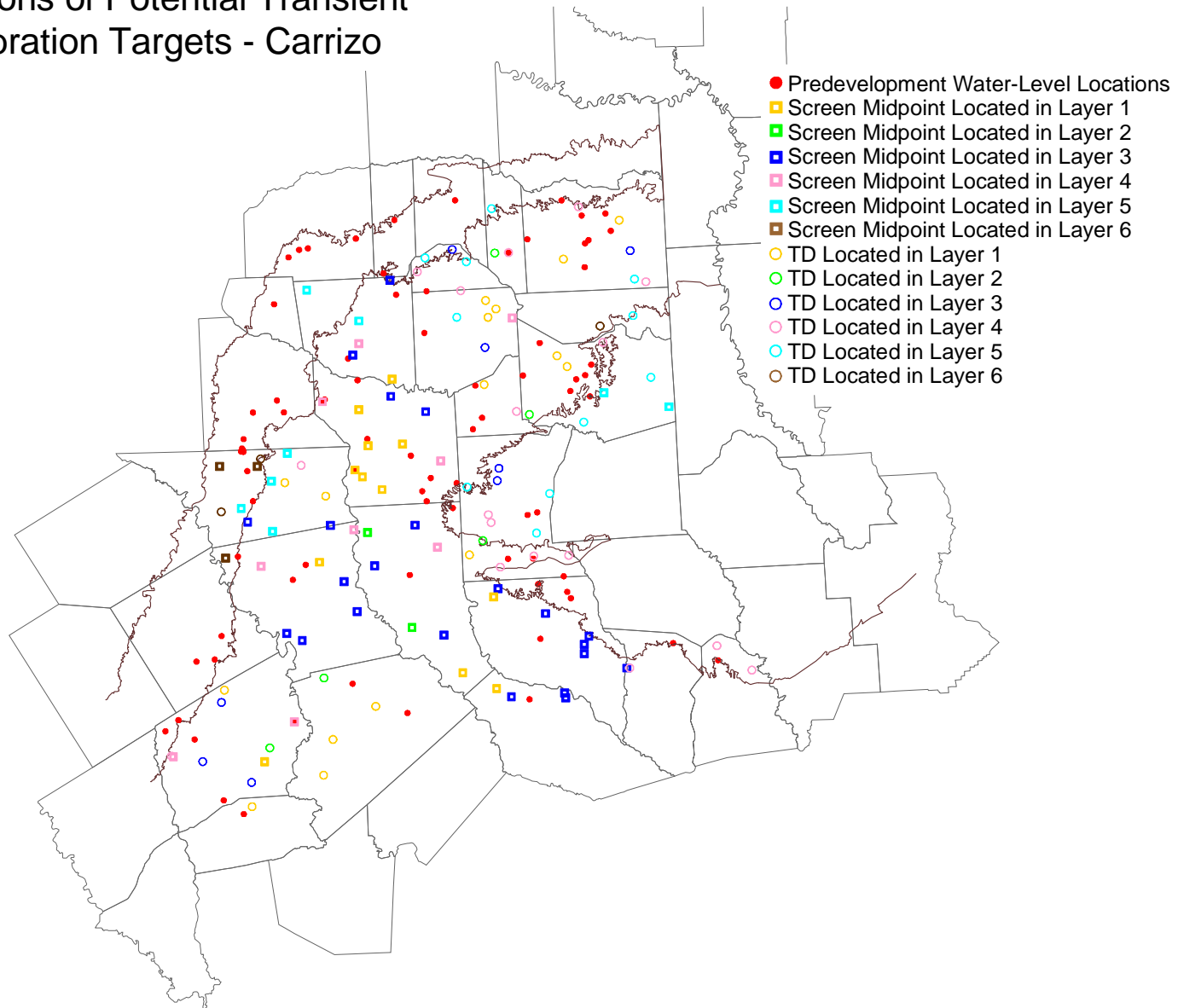
● Predevelopment Water-Level Locations

Calibration Targets

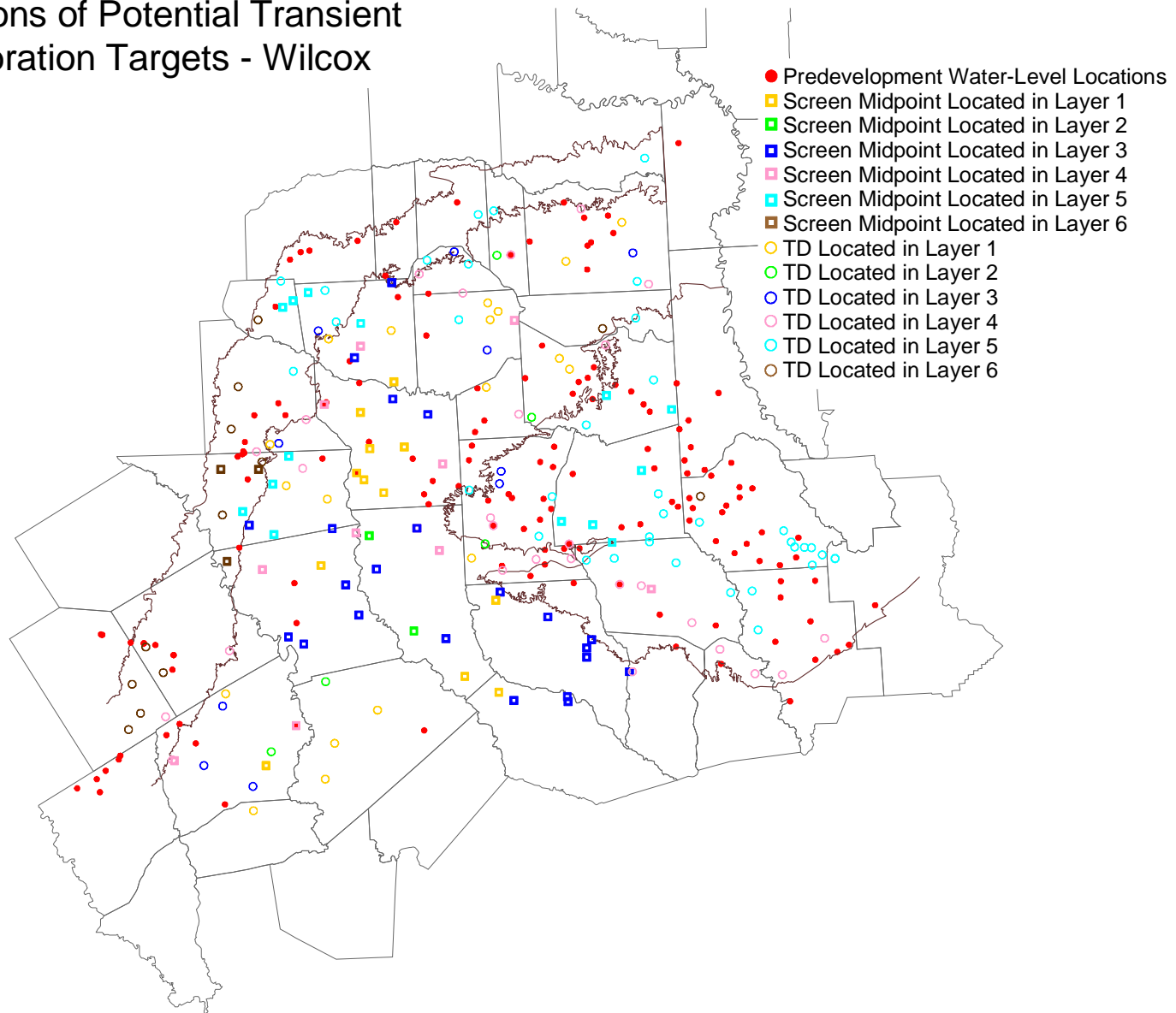
■ Transient Calibration

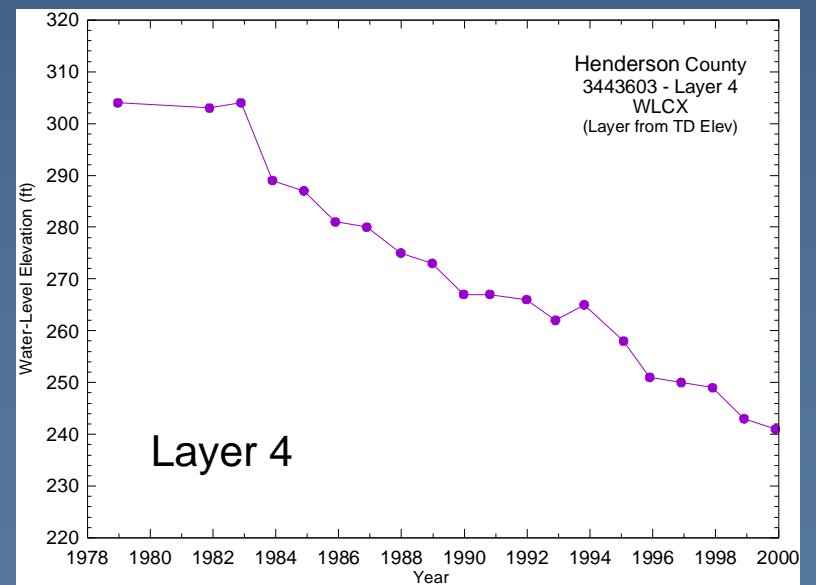
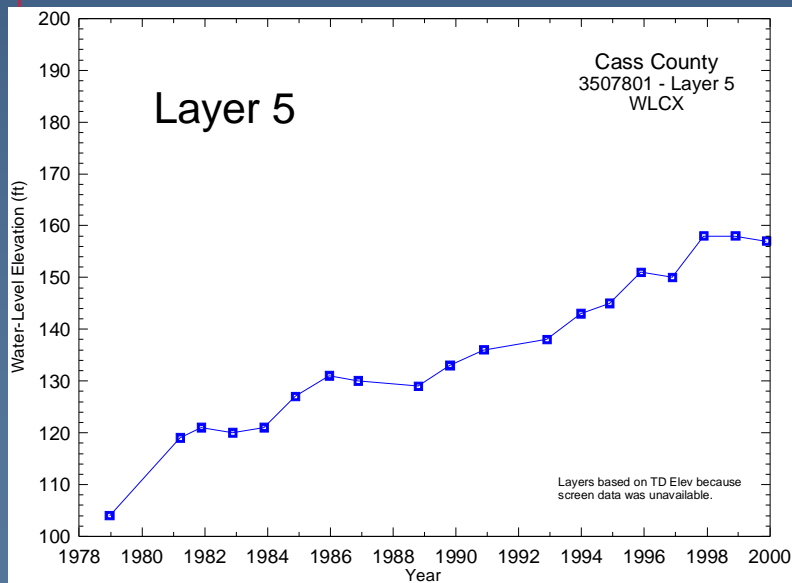
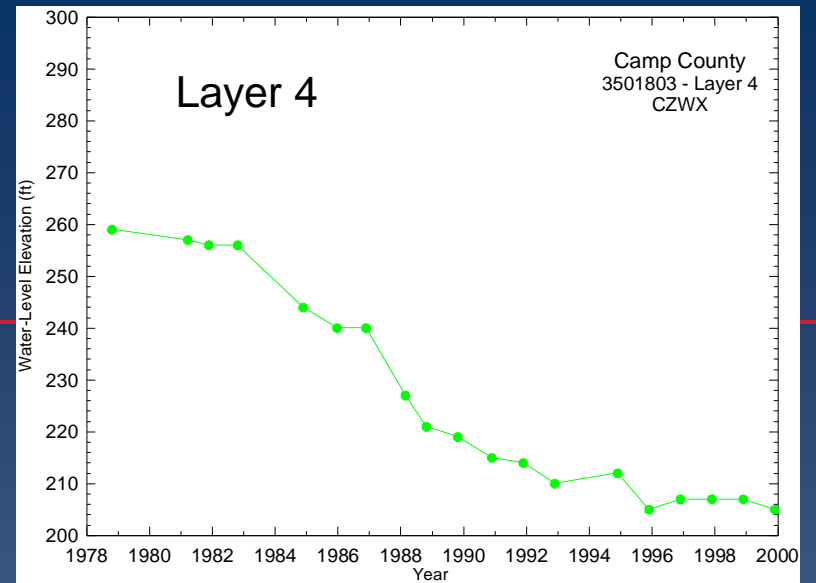
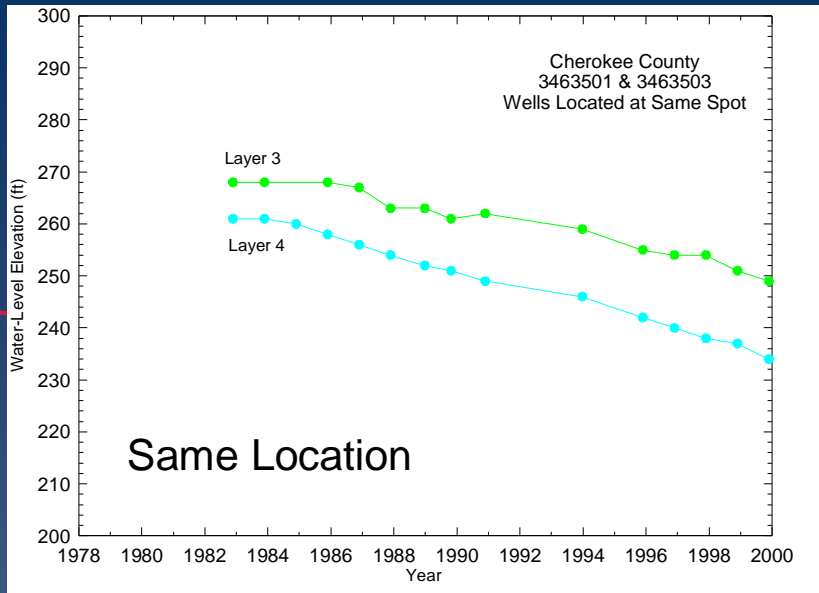
- Calibration targets will consist of selected hydrographs from various lateral and vertical locations within the model region

Locations of Potential Transient Calibration Targets - Carrizo



Locations of Potential Transient Calibration Targets - Wilcox





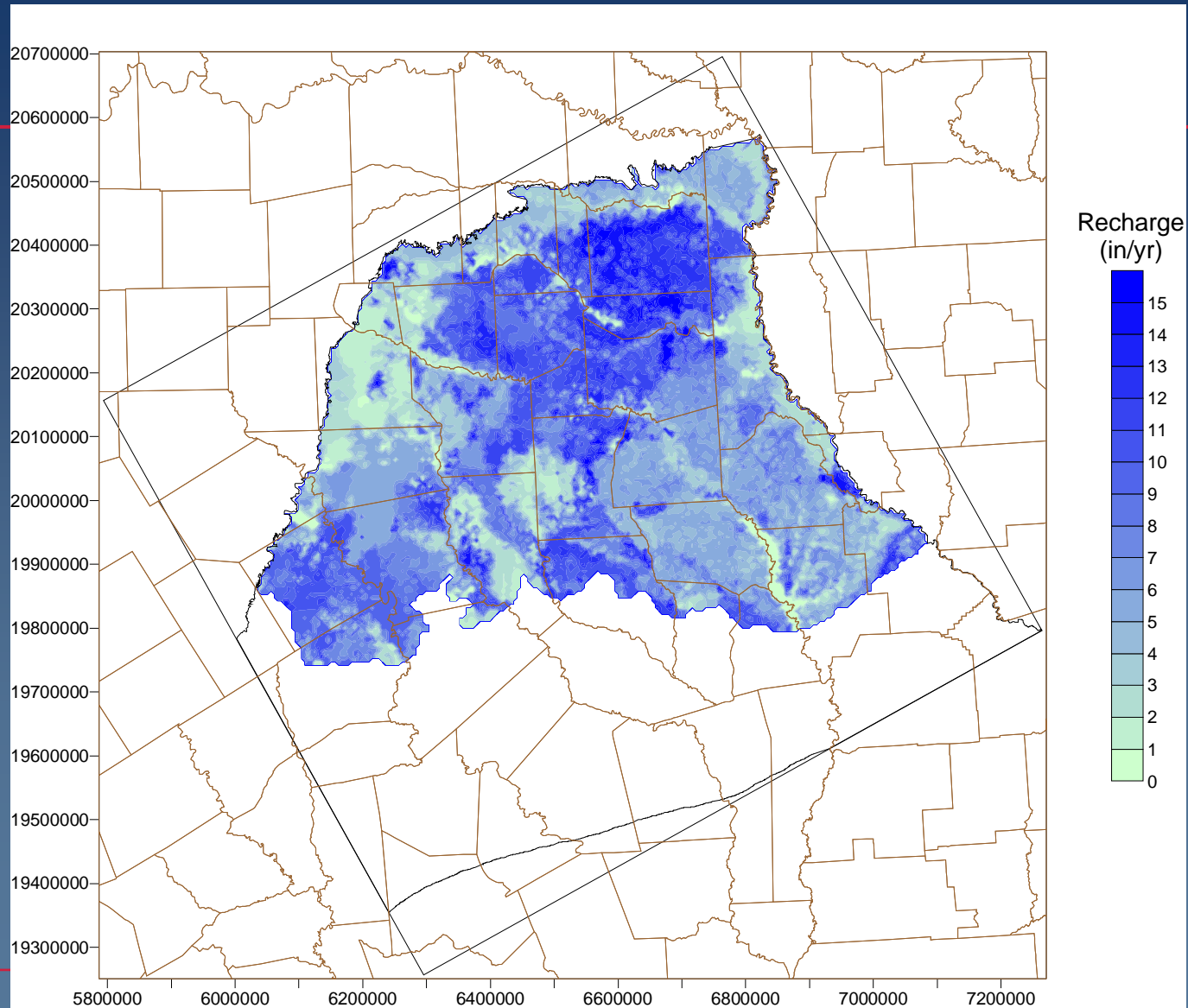
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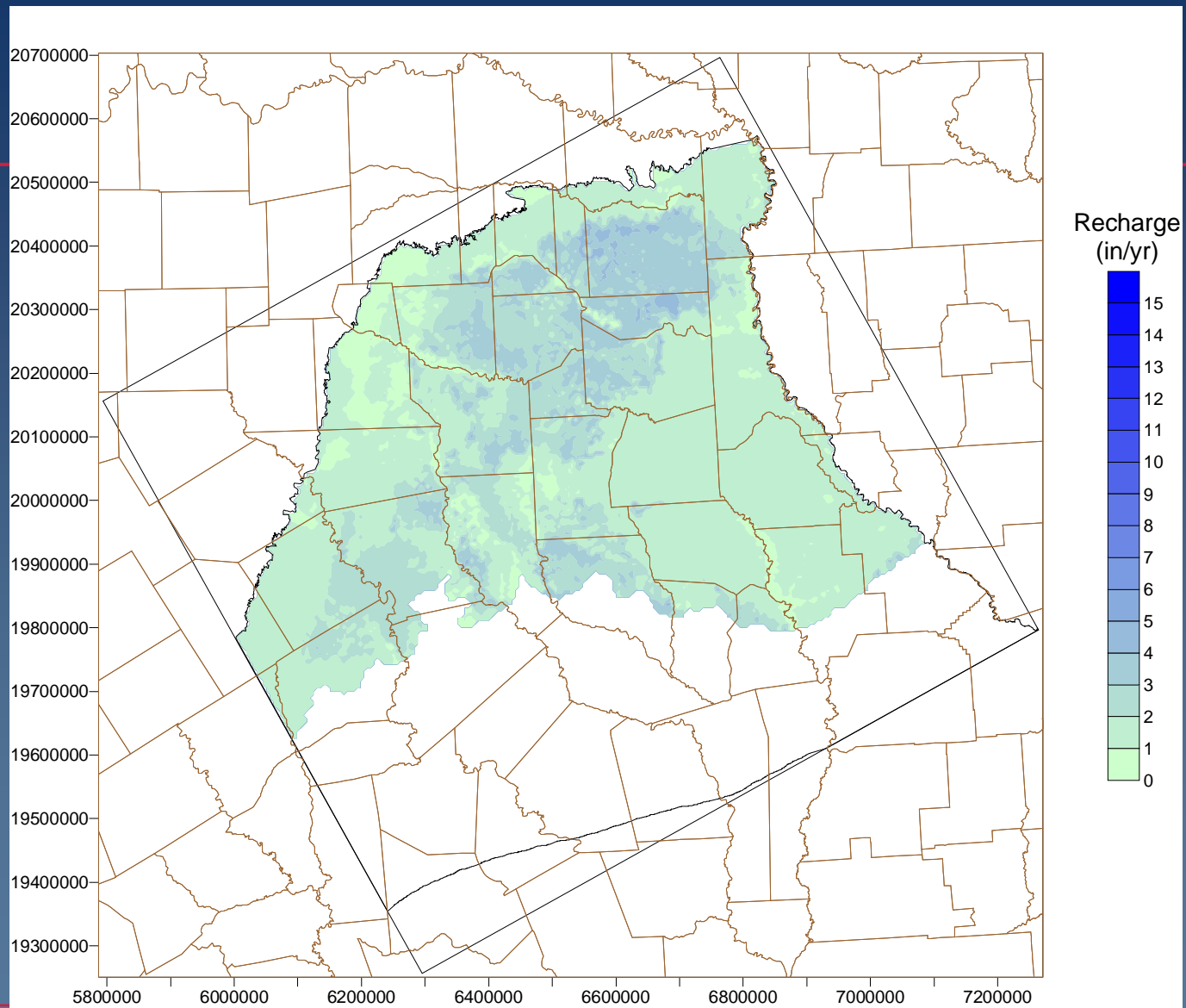
Recharge Estimation: SWAT (Soil and Water Assessment Tool)

- SWAT developed by 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
- $\text{Recharge} = \text{Infiltration} - \text{Evapotranspiration}$
- Steady-State Model: Neglect runoff (initially)

Recharge Estimated by SWAT

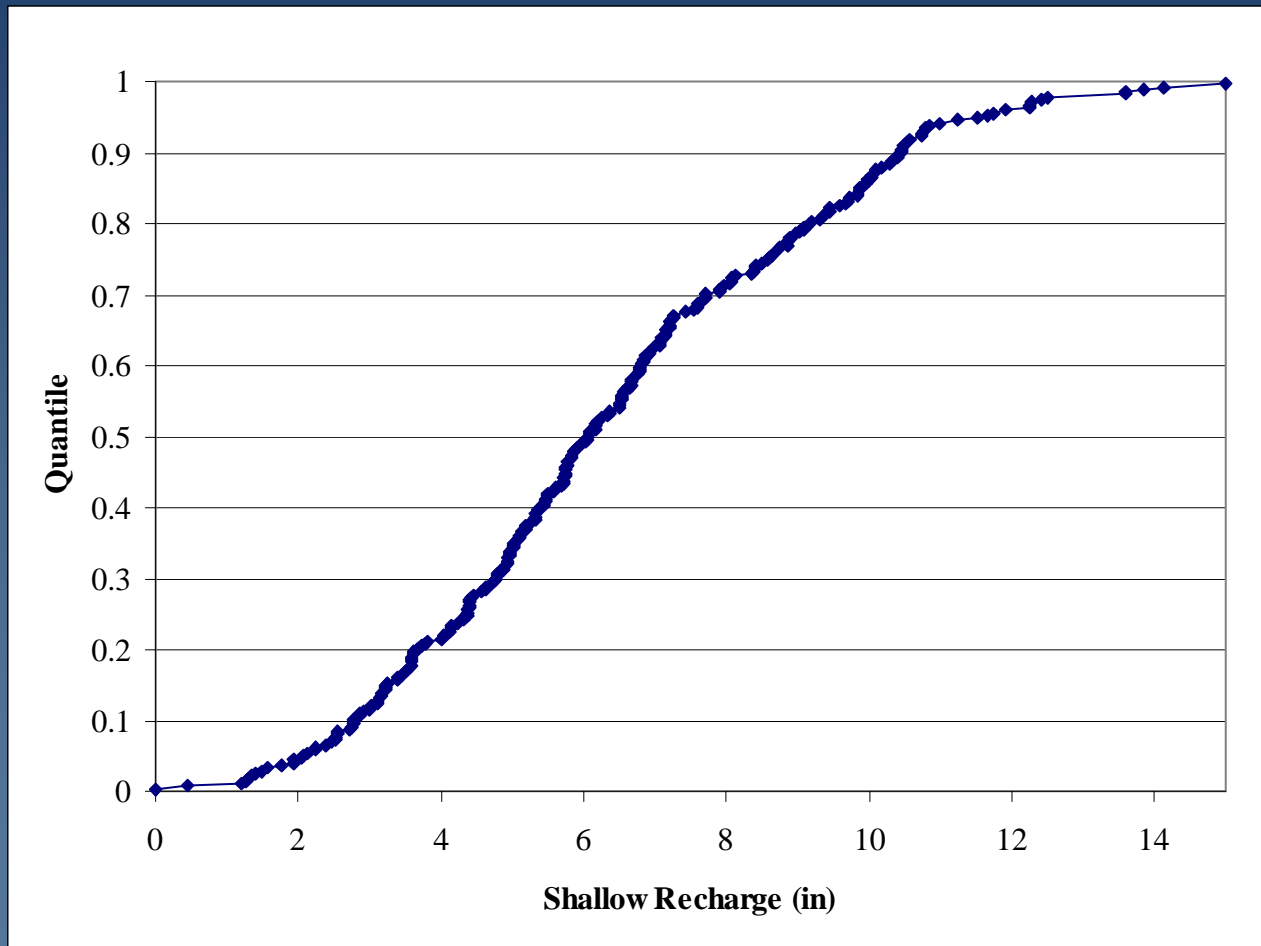


Model Calibrated Recharge



SWAT - Example Results

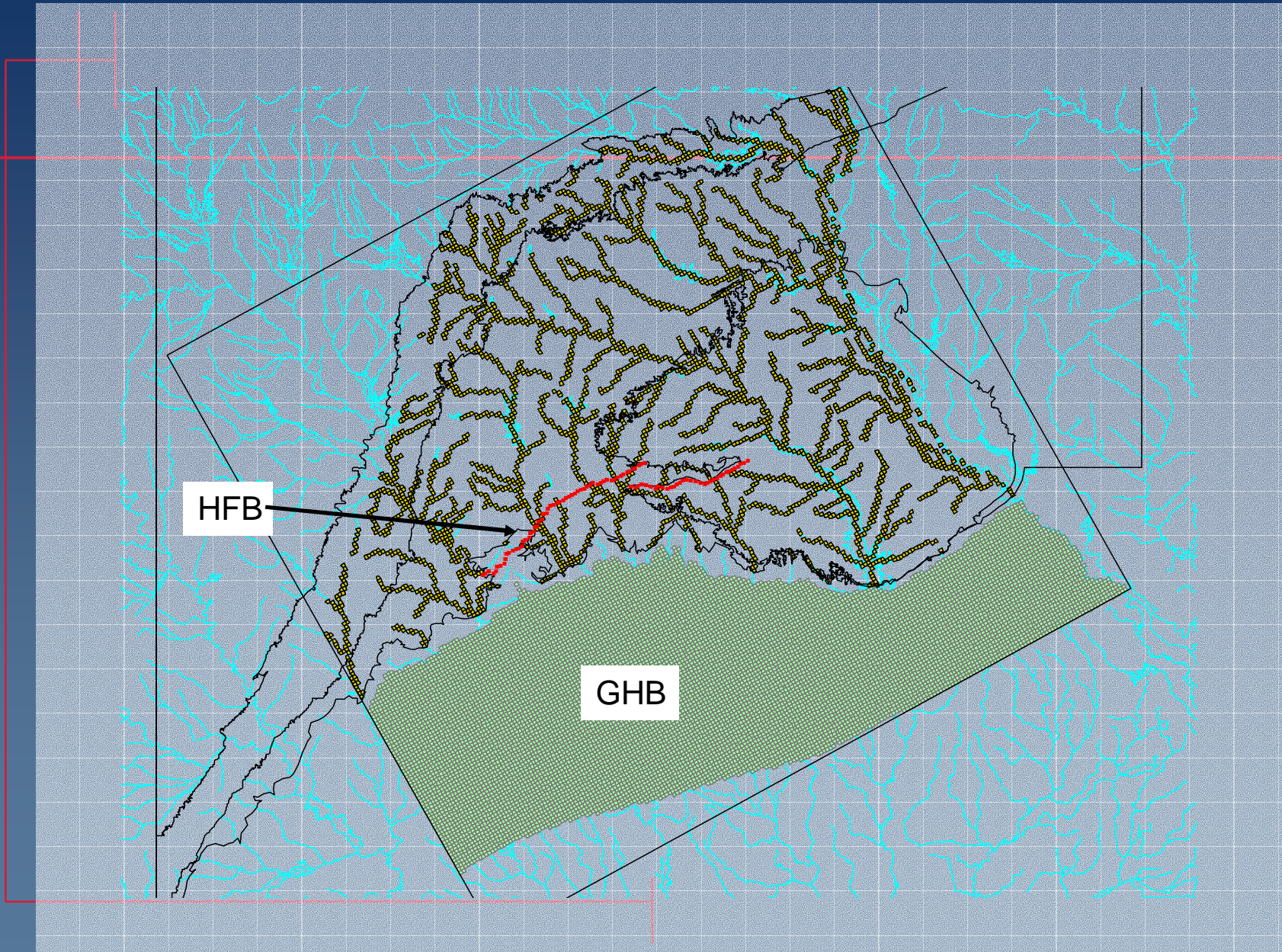
25-year average annual *shallow* recharge



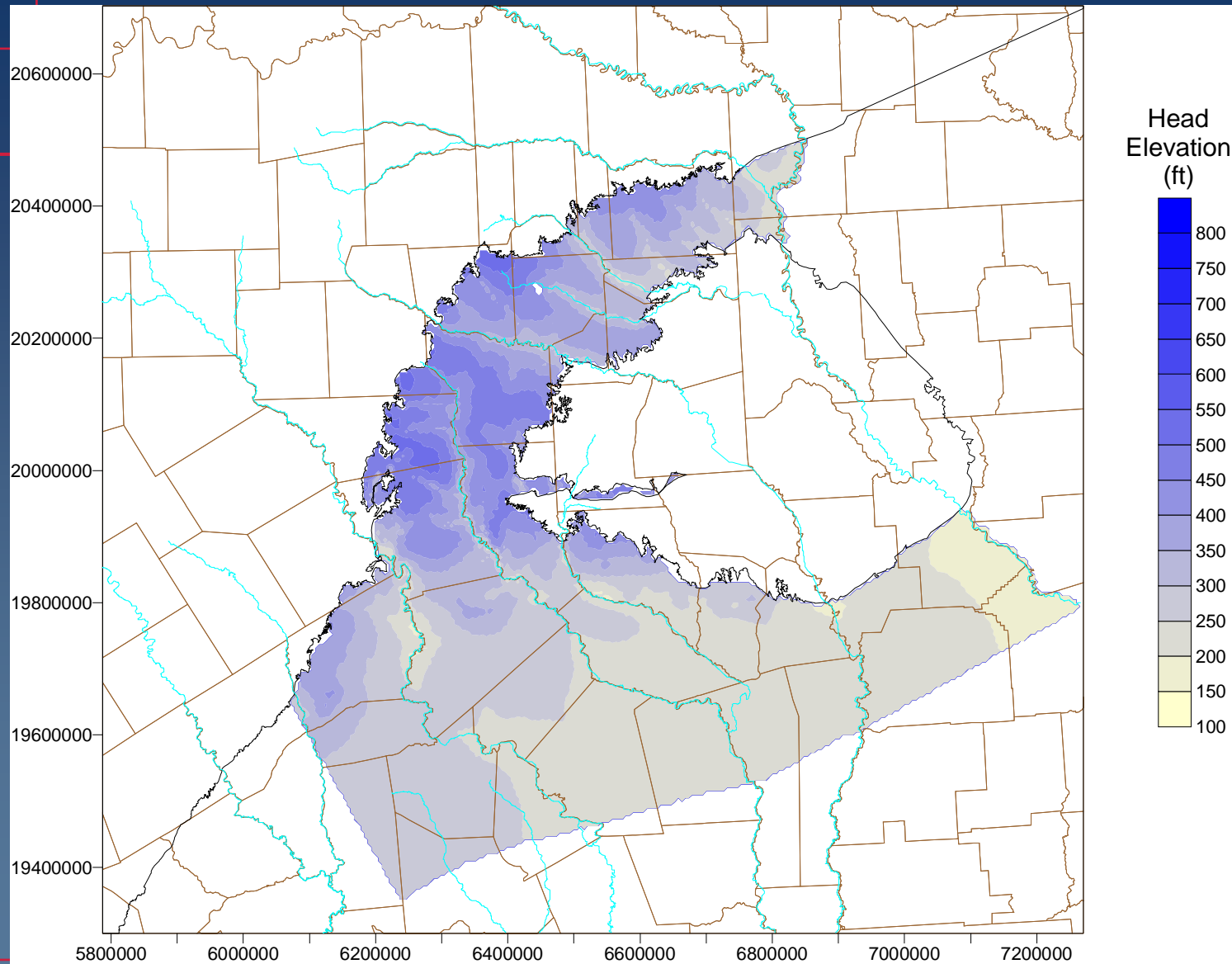
Presentation Outline

- GAM Review
- Conceptual Model Revisions
- Hydraulic Properties
- Pre-Development Hydraulic Heads
- Recharge Estimation
- Steady-State Model Results
- Future SAF meeting

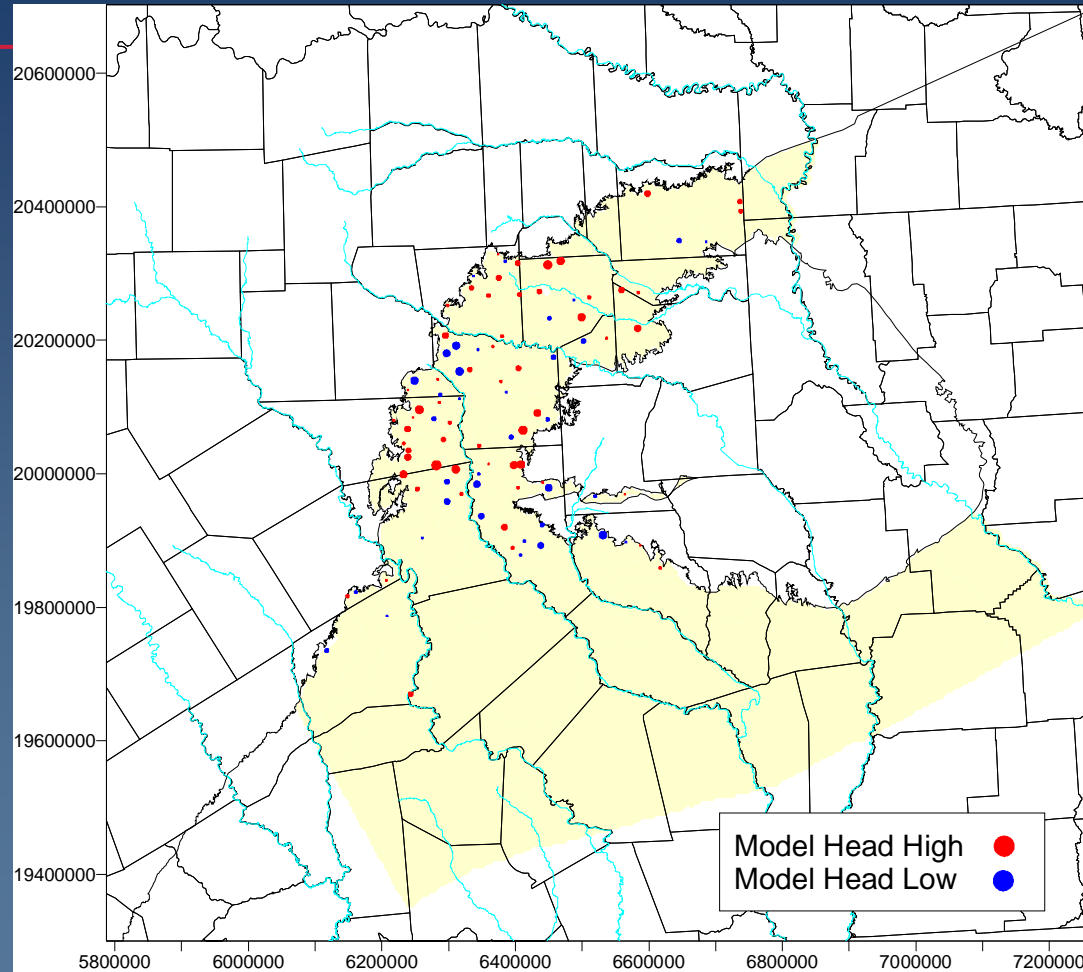
Model Boundary Conditions



Queen City Head Elevations

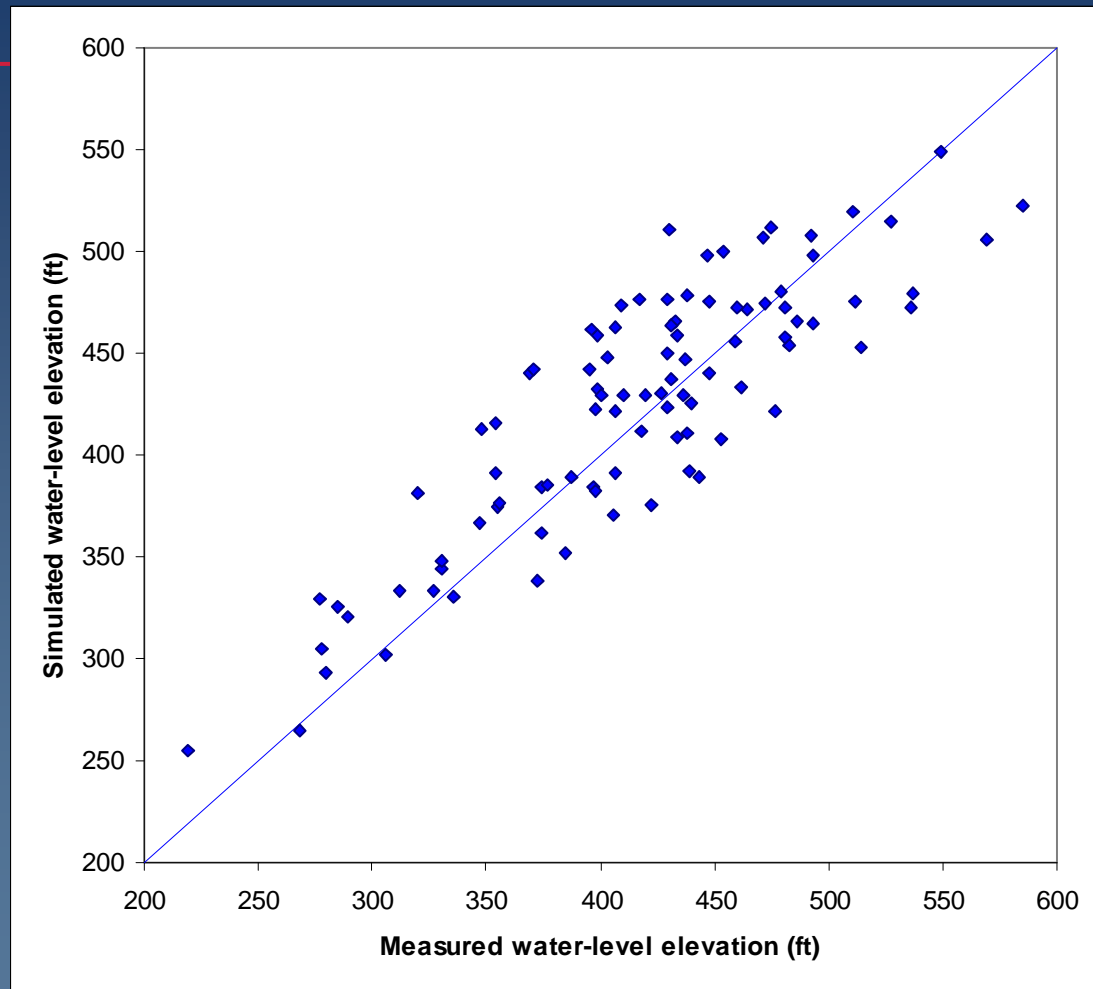


Queen City Head Targets



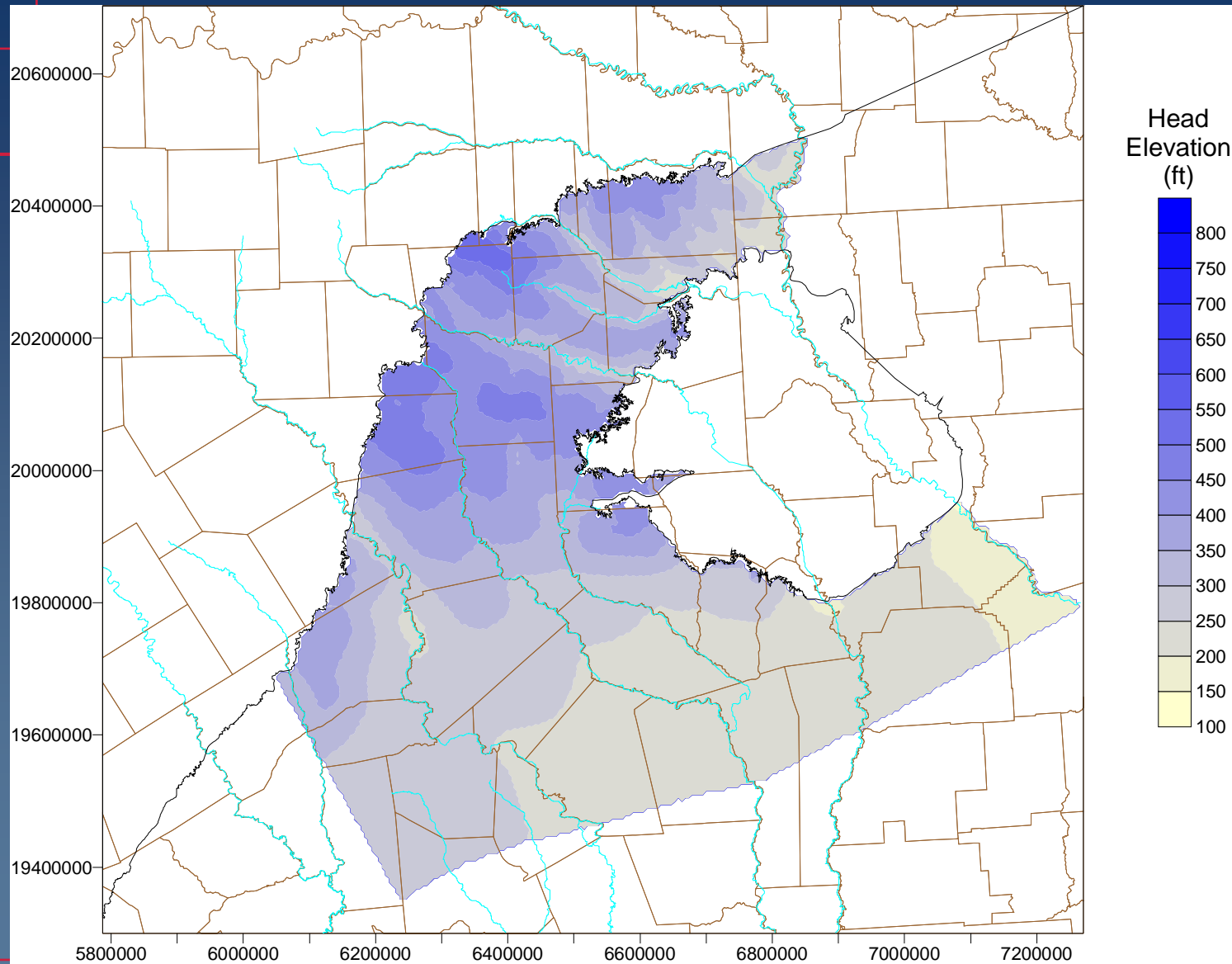
Number of Targets	94
Minimum Residual	-80.84
Maximum Residual	63.87
Residual Mea	-8.29
Absolute Residual Mean	29.76
RMS	36.40
Observed Head Range	366
RMS/Observed Head Range	0.099

Queen City Head Targets

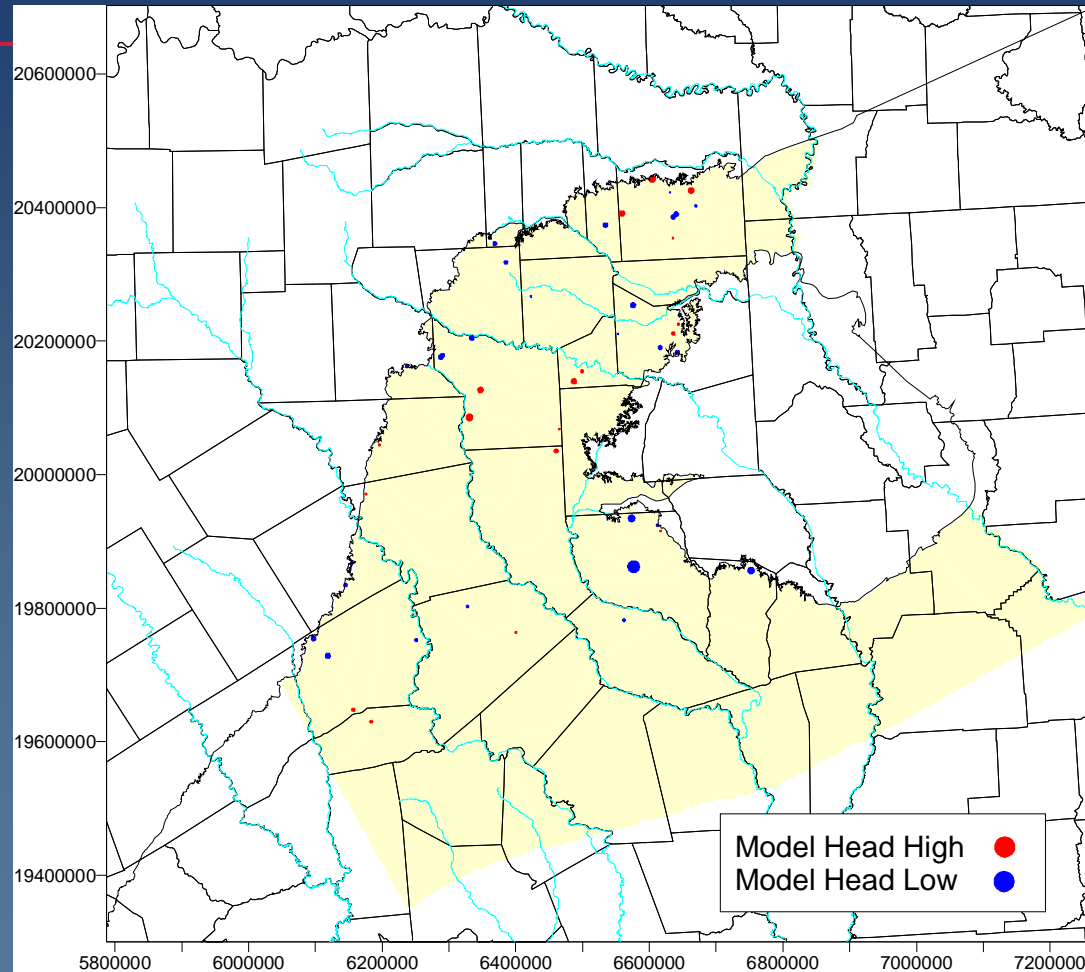


Number of Targets	94
Minimum Residual	-80.84
Maximum Residual	63.87
Residual Mean	-8.29
Absolute Residual Mean	29.76
RMS	36.40
Observed Head Range	366
RMS/Observed Head Range	0.099

Carrizo Head Elevations

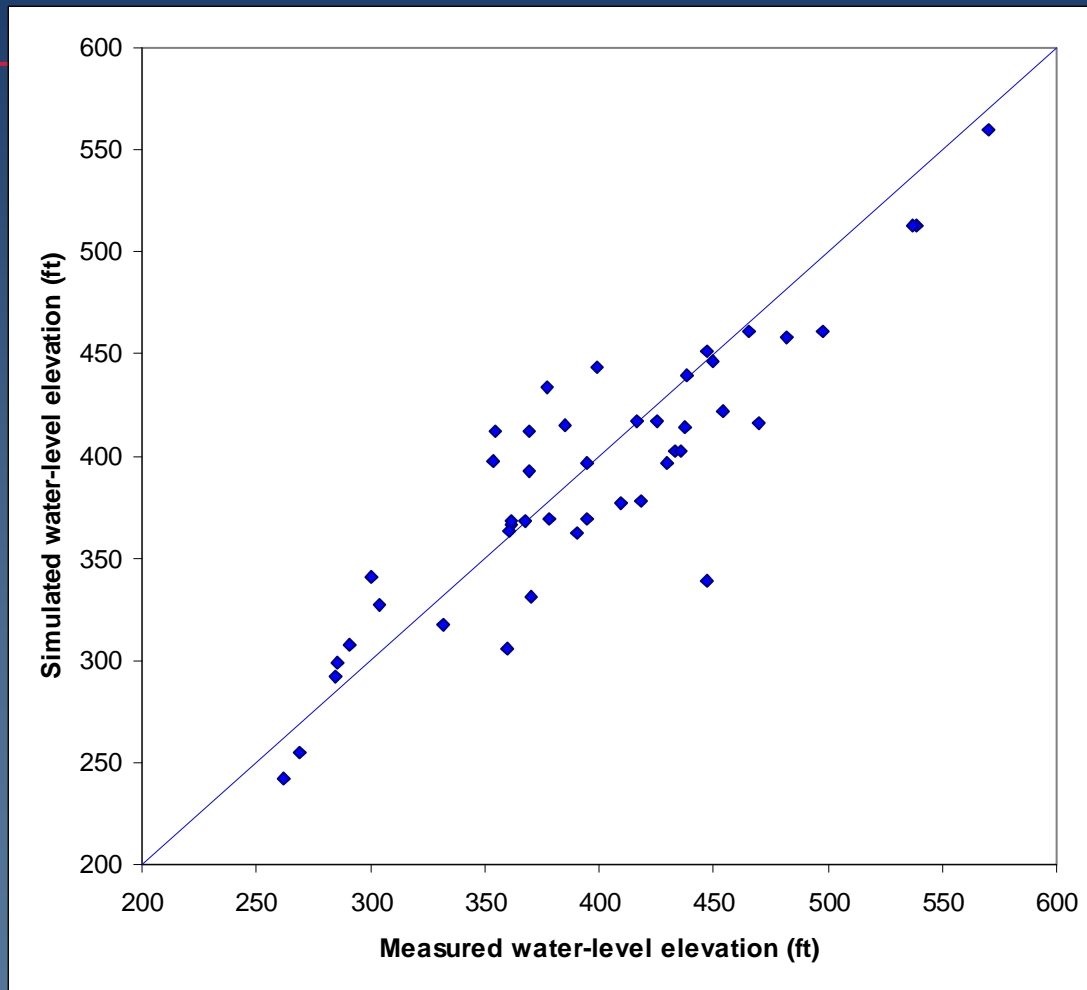


Carrizo Head Targets



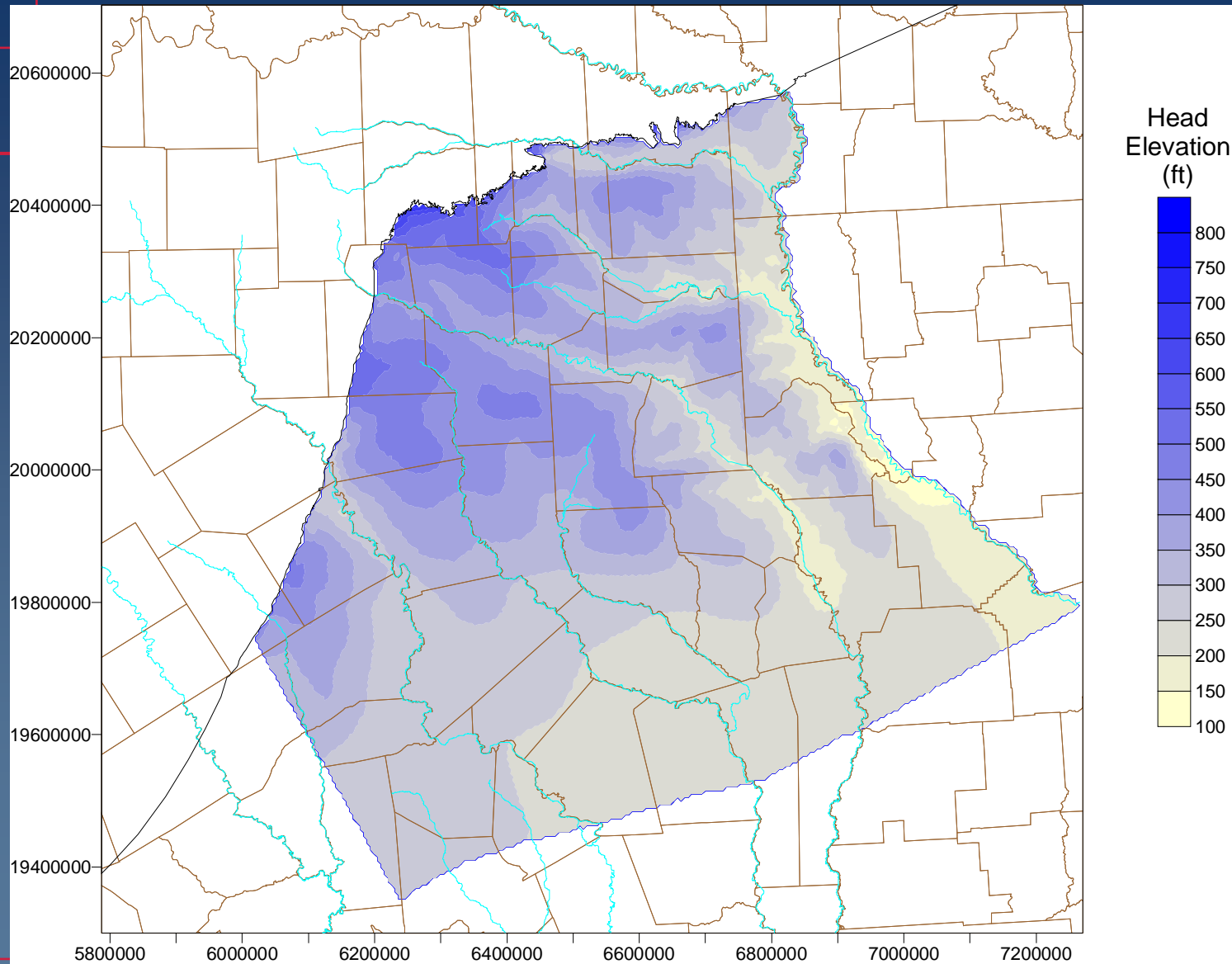
Number of Targets	45
Minimum Residual	-57.64
Maximum Residual	108.49
Residual Mea	6.92
Absolute Residual Mean	25.59
RMS	32.93
Observed Head Range	308
RMS/Observed Head Range	0.107

Carrizo Head Targets

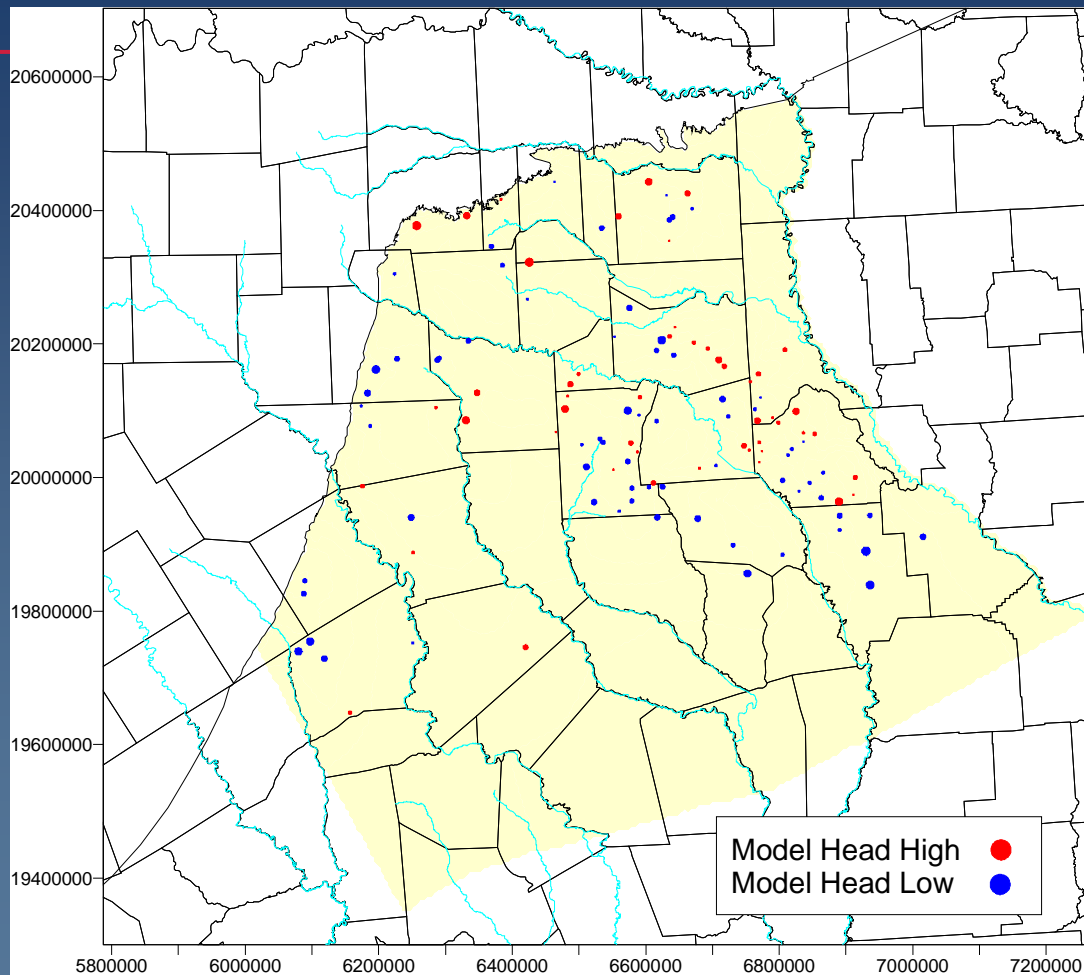


Number of Targets	45
Minimum Residual	-57.64
Maximum Residual	108.49
Residual Mean	6.92
Absolute Residual Mean	25.59
RMS	32.93
Observed Head Range	308
RMS/Observed Head Range	0.107

Middle Wilcox Head Elevations

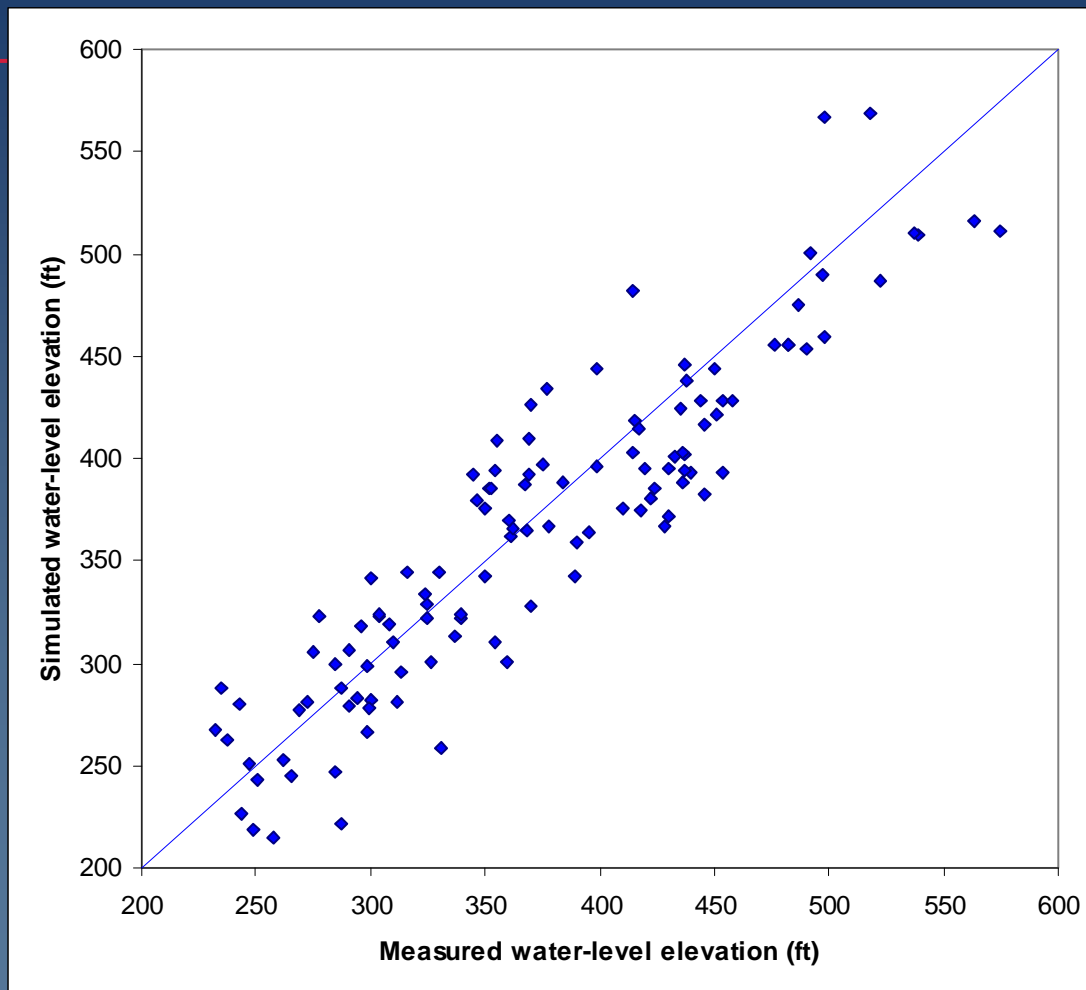


Wilcox Head Targets



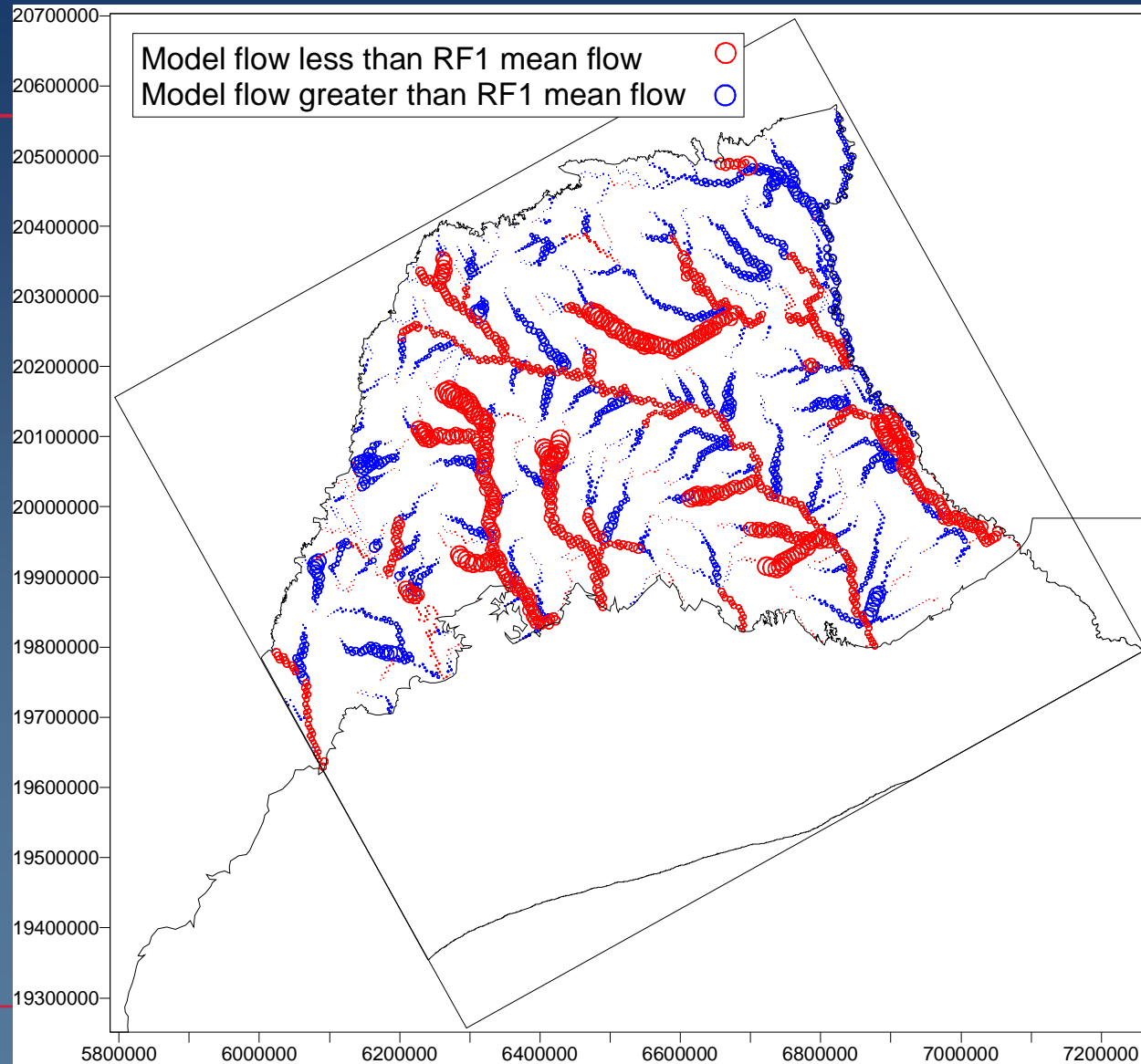
Number of Targets	118
Minimum Residual	-68.79
Maximum Residual	71.99
Residual Mean	6.31
Absolute Residual Mean	28.24
RMS	33.70
Observed Head Range	419
RMS/Observed Head Range	0.081

Wilcox Head Targets

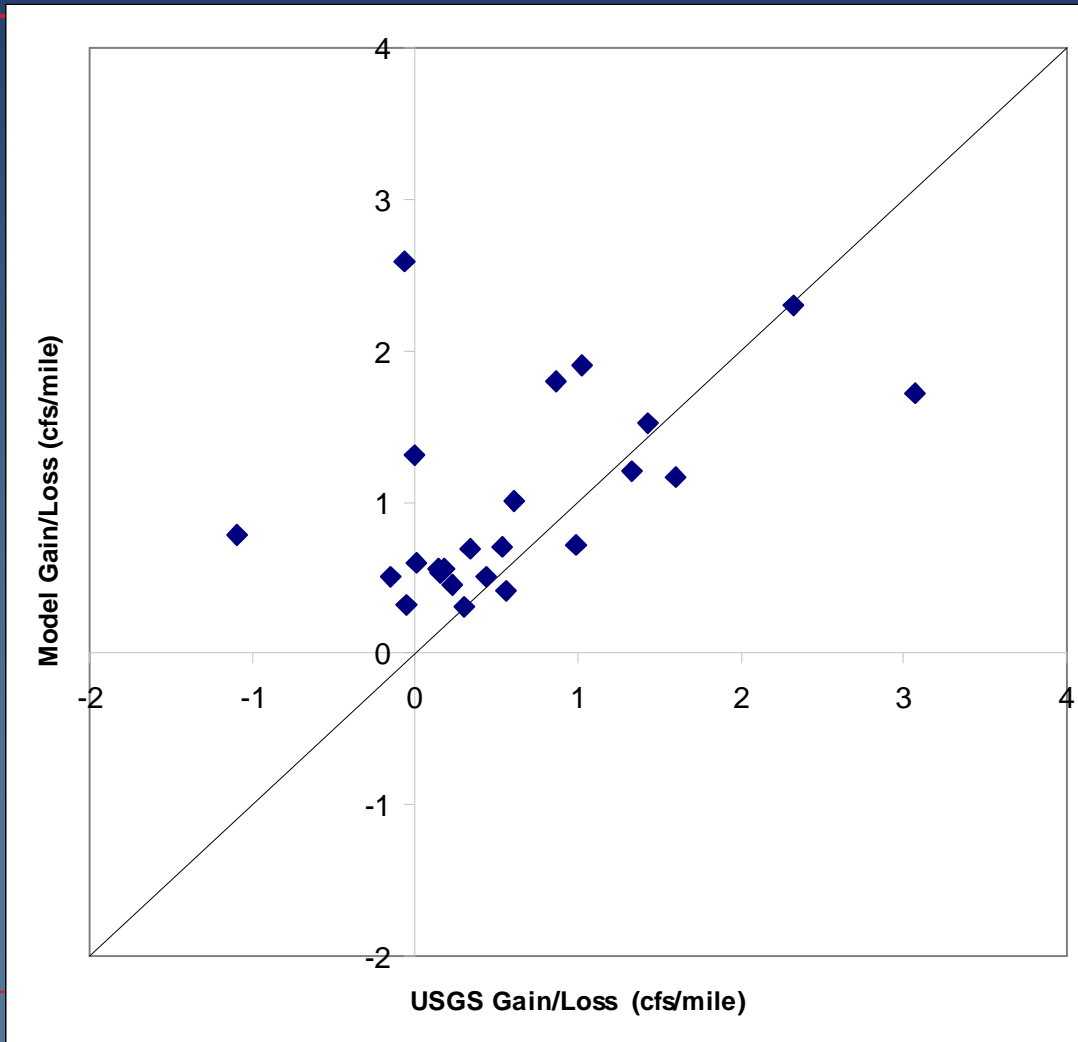


Number of Targets	118
Minimum Residual	-68.79
Maximum Residual	71.99
Residual Mean	6.31
Absolute Residual Mean	28.24
RMS	33.70
Observed Head Range	419
RMS/Observed Head Range	0.081

Comparison of Model Stream Flows to RF1 Mean Flows



Comparison of Model Stream Gain/Loss for the Sabine River to Gain/Loss Values from Slade et al., 2000



USGS	Model
1.33	1.21
1.02	1.90
2.32	2.30
3.06	1.72
-17.78	2.25
1.43	1.52
0.86	1.79
0.61	1.01
0.18	0.56
-0.06	0.32
0.30	0.31
1.60	1.16
-1.10	0.78
57.18	1.90
0.15	0.56
0.16	0.55
0.01	0.60
0.56	0.42
0.34	0.69
0.23	0.45
0.44	0.50
-0.16	0.50
0.99	0.72
0.00	1.31
0.15	0.54
0.53	0.71
-0.07	2.59

Model Mass Balance (ft³/day)

Inflow						
	Recharge	Top	Bottom	GHB	Stream	Total
Queen City	101149782	0	58147870	9075392	1092706	169465750
Reklaw	26196198	69042736	69631515	0	479425	165349875
Carrizo	11745063	77101688	63079463	0	410799	152337013
Upper Wilcox	36418344	72383401	56036425	0	1925693	166763862
Middle Wilcox	49298982	58940724	14708890	0	1053562	124002159
Lower Wilcox	5326256	13116092	0	0	37835	18480183
Model	230134625			9075392	5000021	244210038
Outflow						
		Top	Bottom	GHB	Stream	Total
Queen City		0	69042736	13211950	87211090	169465776
Reklaw		58147870	77101688	0	30100323	165349882
Carrizo		69631515	72383401	0	10322106	152337021
Upper Wilcox		63079463	58940724	0	44743733	166763921
Middle Wilcox		56036425	13116092	0	54849678	124002194
Lower Wilcox		14708890	0	0	3771305	18480196
Model				13211950	230998235	244210186

Model Mass Balance (Percent)

Inflow as Percent

	Recharge	Top	Bottom	GHB	Stream
Queen City	59.7	0.0	34.3	5.4	0.6
Reklaw	15.8	41.8	42.1	0.0	0.3
Carrizo	7.7	50.6	41.4	0.0	0.3
Upper Wilcox	21.8	43.4	33.6	0.0	1.2
Middle Wilcox	39.8	47.5	11.9	0.0	0.8
Lower Wilcox	28.8	71.0	0.0	0.0	0.2
Model	94.2			3.7	2.0

Outflow as Percent

	Top	Bottom	GHB	Stream
Queen City	0.0	40.7	7.8	51.5
Reklaw	35.2	46.6	0.0	18.2
Carrizo	45.7	47.5	0.0	6.8
Upper Wilcox	37.8	35.3	0.0	26.8
Middle Wilcox	45.2	10.6	0.0	44.2
Lower Wilcox	79.6	0.0	0.0	20.4
Model			5.4	94.6

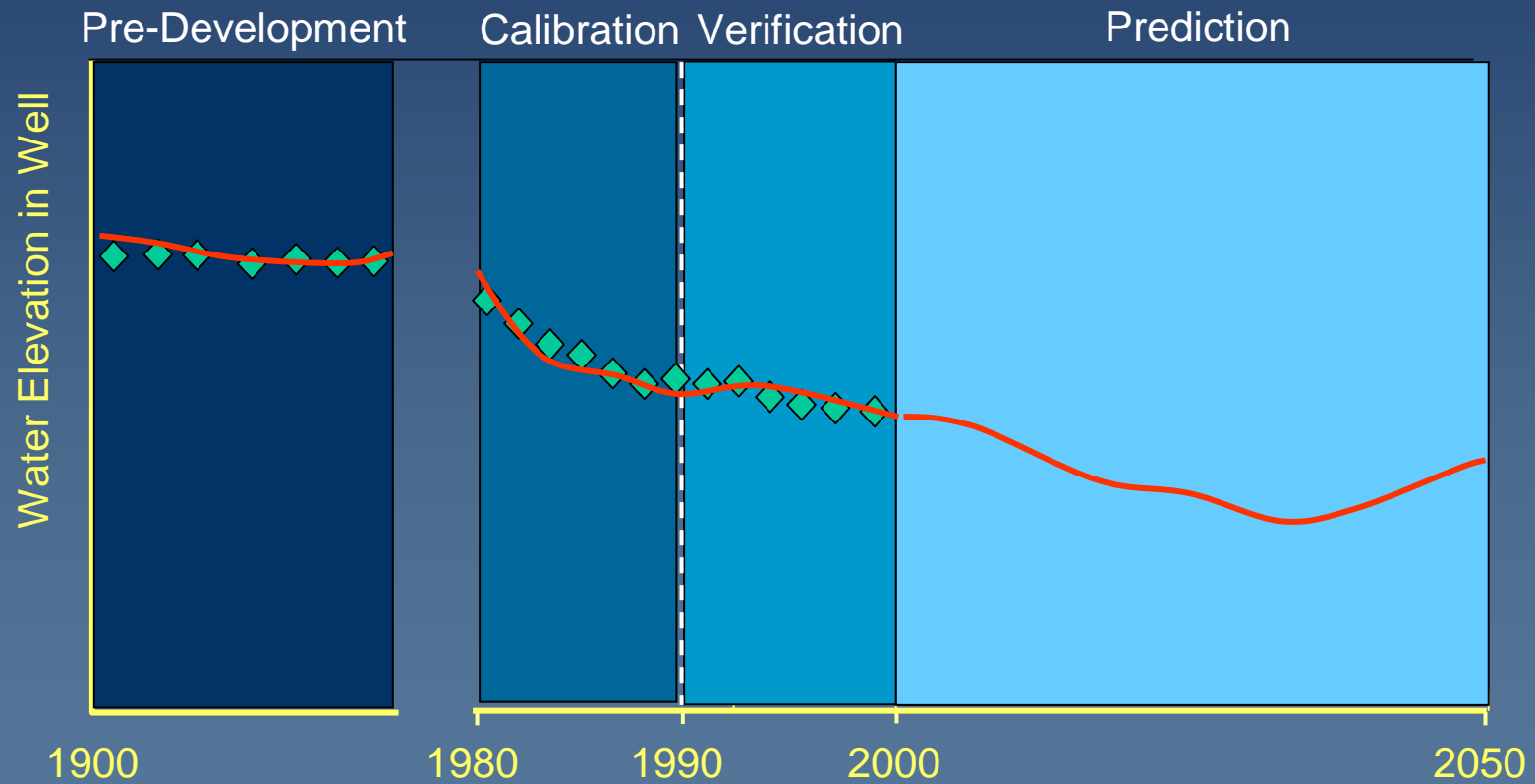
Expected SAF-6 Discussion

- Transient model parameterization
- Transient model calibration
- Stream flow routing

Modeling Periods

LEGEND

- ◆ Observed Water Level
- Model Water Level



Northern GAM Schedule

2001

SAF 1 — May 9



Mar. 13 — Kickoff Meeting

SAF 2 — Aug. 1



Aug. 13 — Conceptual Model

SAF 3 — Nov. 19



Dec. — Initial model design

2002

SAF 4 — Feb. 28



May 7 — Steady-state model review

SAF 5 — May 21



July 15 — Transient model review

SAF 6 — July 29



Aug. 30 — Model predictions review

SAF 7 — Oct. 10



Nov. 14 — Draft report review



Dec. — Present SAF Model Seminar

2003

SAF 8 — Jan. 9.



Deliver Final Product

SIGN-UP SHEET

Northern Carrizo-Wilcox Aquifer Groundwater Availability Modeling (GAM) 5th Stakeholder Advisory Forum

May 21, 2002
Diboll, Texas

Name	Affiliation
Rainer Senger	INTERA Inc.
Tony Almeida	Halff Association
Jack Furlong	Halff Association
Kelly Mills	TNRCC, Austin
Buzz Patrick	TIFPC
David Smith	City of Nacogdoches
Walter West	Sierra Club
Sanjeev Kalaswad	TWDB

List of Stakeholders Questions
5th SAF - Northern Carrizo-Wilcox GAM
May 21, 2002
Diboll, Texas

1. Are the black dots on the Kh/Kv map well points?
 - Yes, these are locations of wells from which tests were available providing information on hydraulic conductivity. Some of the points indicate a regularly spaced pattern, which are TNRCC wells for which the well locations were given by the 2 ½ minute quadrangle well number system.

2. Was dry-well information used in the preparation of the model?
 - No, information on dry wells was not used in the preparation of the model because it doesn't indicate that there is no water, but too little water for the well to be a producing well.
 - In the Wilcox, we do consider the relative amount of sand and shale/mudstone to estimate an average hydraulic conductivity for the particular layer in the model. However, this cannot necessarily be used to identify locations of wells that would produce significant amounts of water. The local-scale heterogeneity of the sand/shale system cannot be represented in the 1 by 1 mile grid block. On the other hand, the model incorporates the major sand distributions that give an indication of where the major sands are located.

3. Was structure in the northern and central model areas matched in the overlapping areas?
 - Yes, an attempt was made to match the structure tops and bottoms of the different layers in the overlapping areas between the central and northern Carrizo-Wilcox GAM. We don't expect noticeable differences.

4. Will an estimate of storage capacity be made during the modeling effort?
 - Storage capacity, or storativity, of the aquifer units will be calibrated during transient simulations taking into account the seasonal changes and pumping stresses on the system.

5. How many cells are there in the model area?
 - The Northern Carrizo-Wilcox model consists of 210 by 195 grid blocks per layer, which amounts to a total of 245,700 grid blocks.

6. Does MODFLOW allow vertical conductivity to be changed?
 - The vertical conductivity of the different grid blocks can be varied in MODFLOW.

7. Can you comment on the changes, if any, in water levels between the early part of the last century and at present?
 - We do see significant declines in the water levels mainly in parts of the confined section as compared to predevelopment water levels, which is attributed to pumping. On the other hand, there are areas, mainly in the outcrop, where water levels showed little or no changes over the years.

8. If a user had a well field in the overlapping portion of two model areas, which model would they utilize?
 - They can use whichever model is most appropriate; that is, covers the area of interest and the main features that may affect groundwater flow to that particular well field.
 - They may want to compare the results from both models and hopefully they produce similar results.
 - Needless to say, depending on the specific location within the overlap area, either one model may produce more representative results.

9. What was the earliest well record found in the area?
 - The earliest well record from the northern GAM are from 1914 reported in a USGS publication (Deussen, 1914).

10. Why are there no permeability data points from Angelina County? The City of Lufkin may have data available.
 - We will check and compare our data base with potential information from the City of Lufkin