



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

A Presentation to:

**Stakeholder Advisory Forum  
San Antonio River Authority  
San Antonio, Texas  
August 7<sup>th</sup>, 2001**

# Outline

- Review of GAM Project, Objectives, and Expectations
- Description of the Conceptual Model for the Northern Carrizo-Wilcox Aquifer
- GAM Schedule - SAF Meetings & Project Milestones

# Southern Carrizo-Wilcox Aquifer GAM Team

- **Duke Engineering & Services**
  - Project Lead, Stakeholder Communication
  - Model Development
- **Freese and Nichols**
  - GW Pumpage, Recharge
- **Parsons Engineering Science**
  - GIS, Water quality
- **Waterstone**
  - Modeling support
- **Senior Technical Experts**
  - Dr. Graham Fogg (UC—Davis)
  - Dr. Steven Gorelick (Stanford)



# GAM Objectives

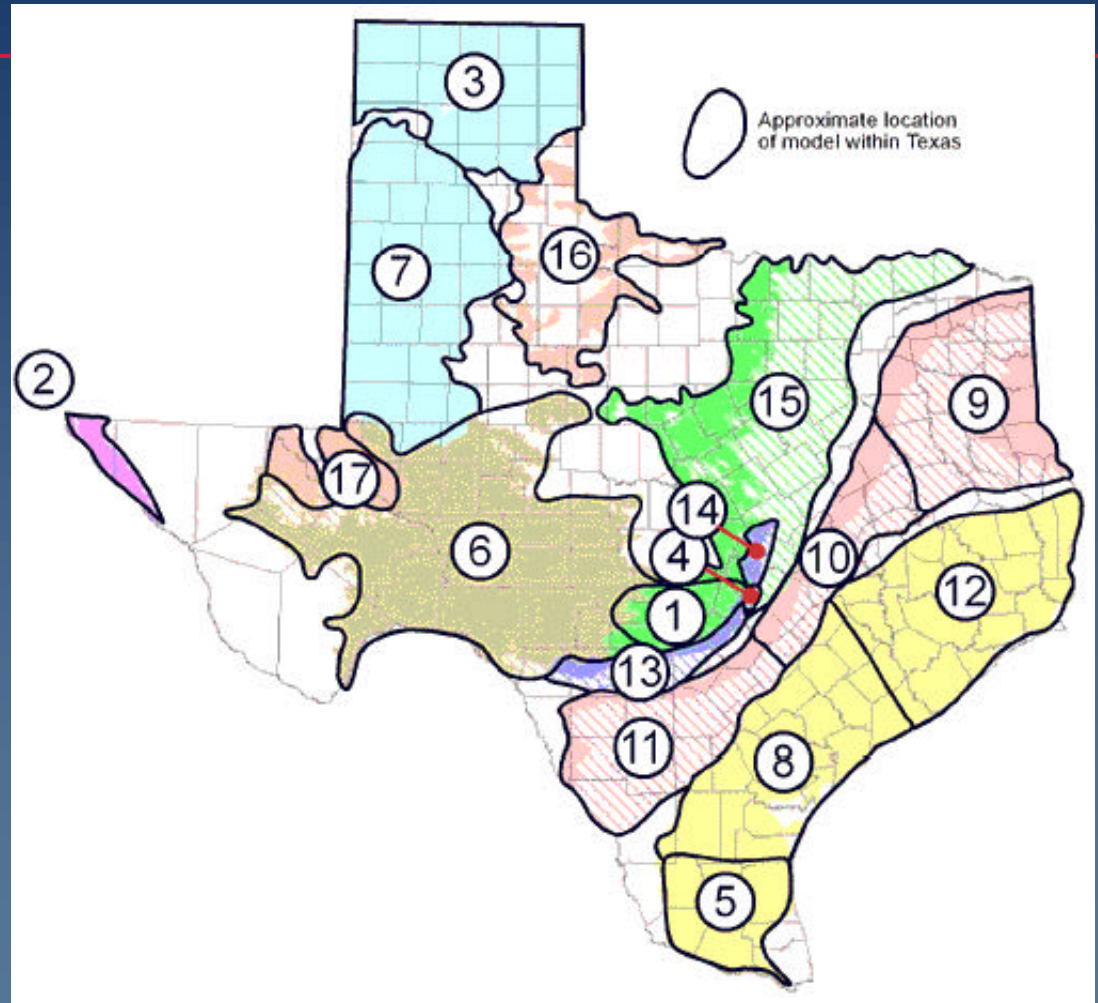
- GAM is a tool that will be used to provide reliable and timely information on GW availability to ensure adequate supplies or recognize inadequate supplies through 2050
- Develop realistic & scientifically accurate GW flow models representing the physical characteristics of the aquifer and incorporating the relevant processes

# GAM Expectations

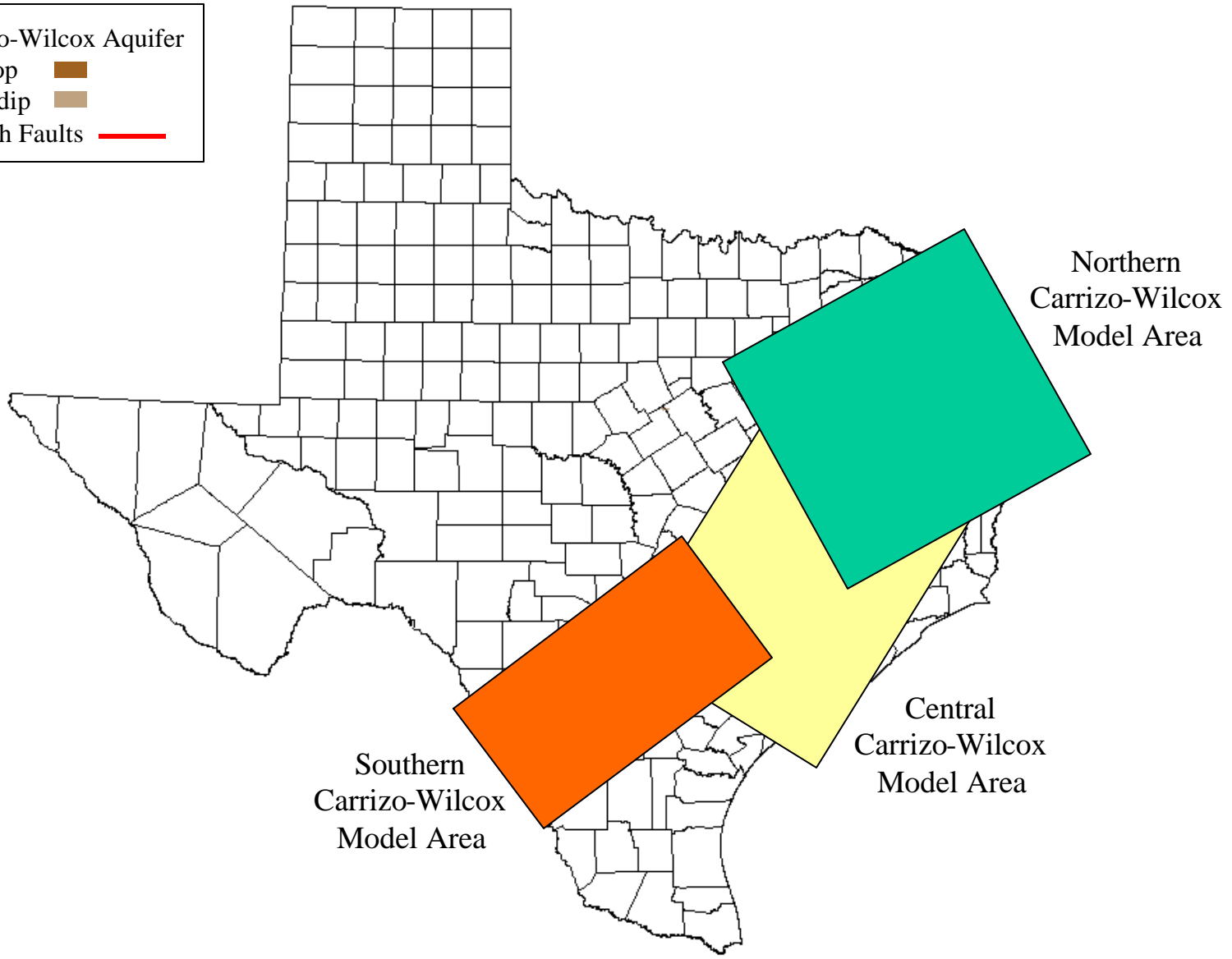
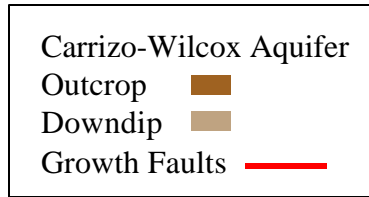
- Result in standardized, thoroughly documented, and publicly available numerical GW models and data
- Include stakeholder input to ensure the models include relevant data and address relevant issues, so they can be used as a water management tool for RWPGs or GWCDs

# GAM Models

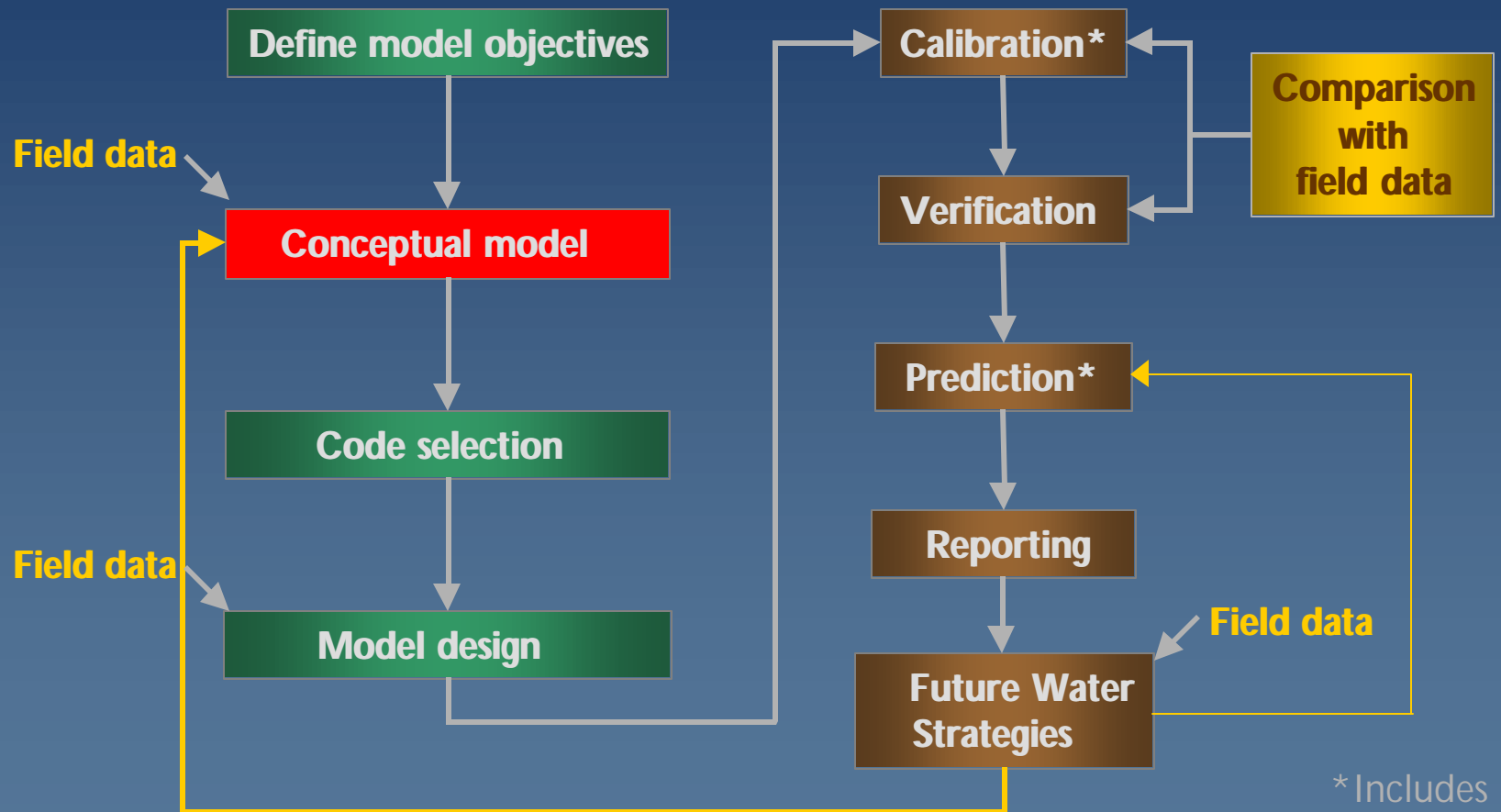
- Ongoing:
  - Carrizo-Wilcox (9-11)
  - Ogallala south (7)
  - Gulf Coast central (8)
  - Gulf Coast north (12)
  - Lower Rio Grande (5)
  - Edwards Trinity (6)
- Completed:
  - Trinity HC (1)
  - Hueco Bolson (2)
  - Ogallala north (3)
  - Edwards - BS (4)



# Carrizo-Wilcox GAM Model Domains



# Modeling Protocol



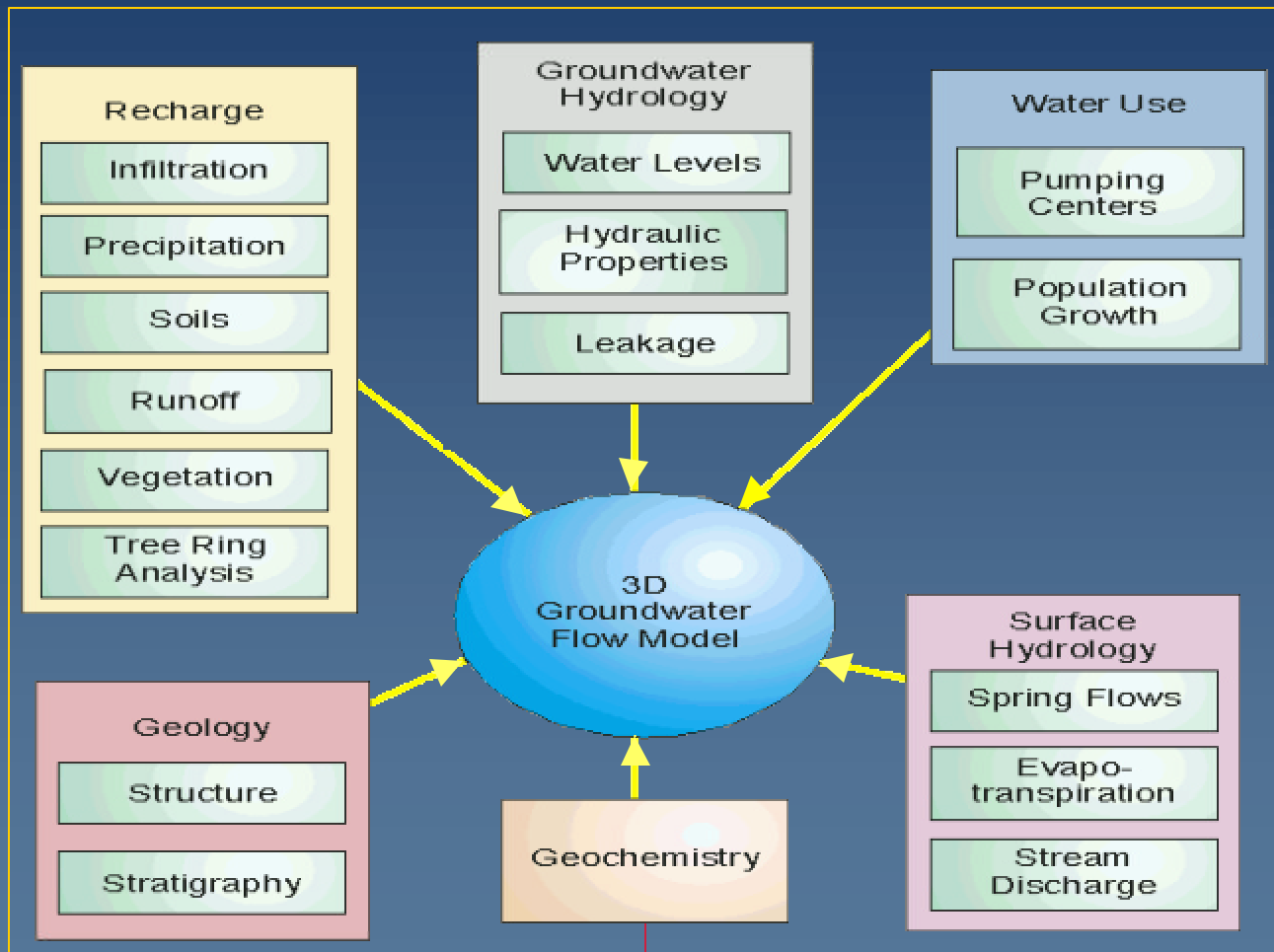
\* Includes sensitivity analysis



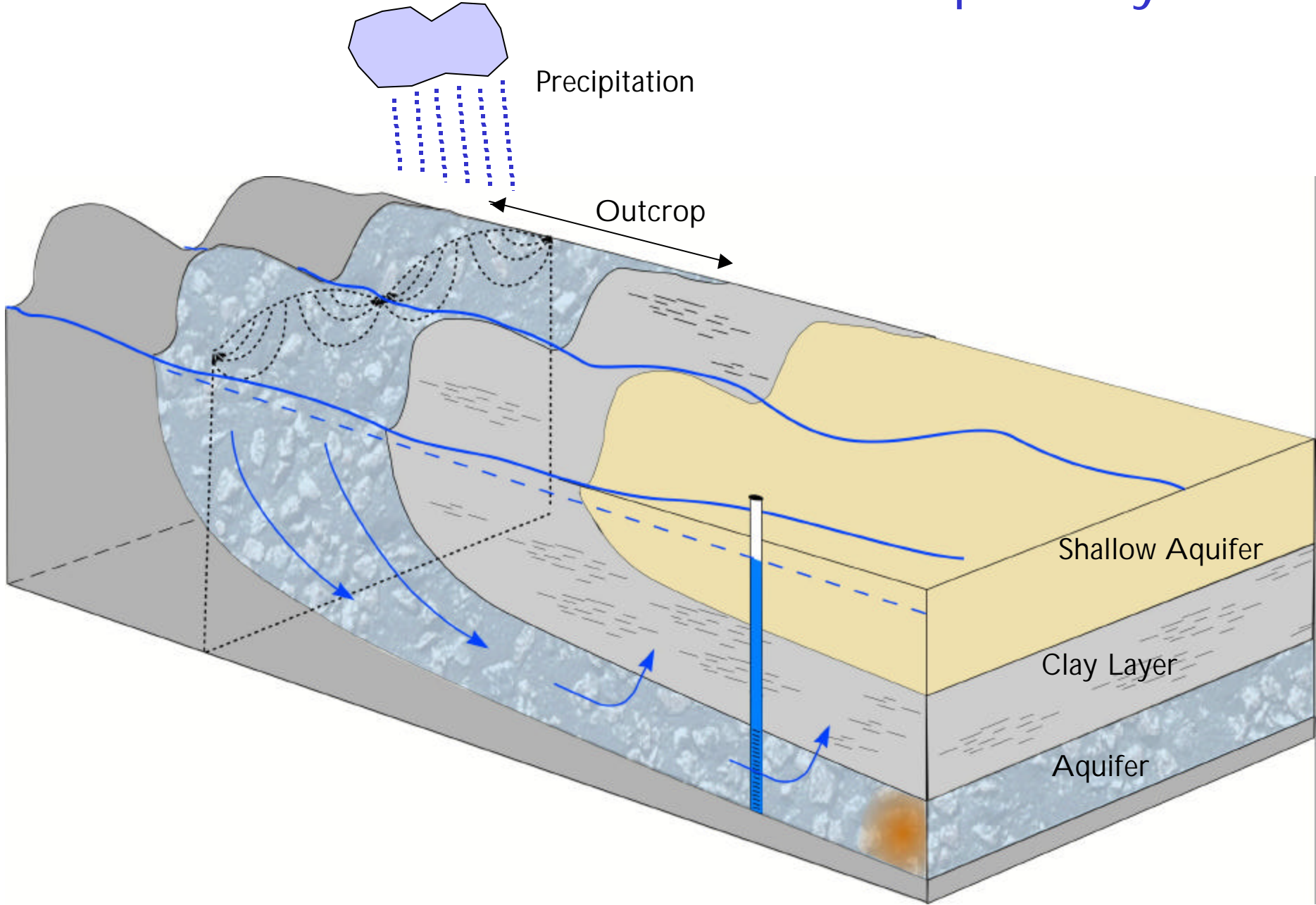
# Conceptual Model Description

- Major components of flow in the aquifer
- Aquifer Geometry
  - Hydrostratigraphy
  - Geology, Structure, and Boundaries
- Aquifer Properties
- Physiography and Climate
- Recharge/Discharge
- Surface/groundwater interaction
- Water levels and regional groundwater flow

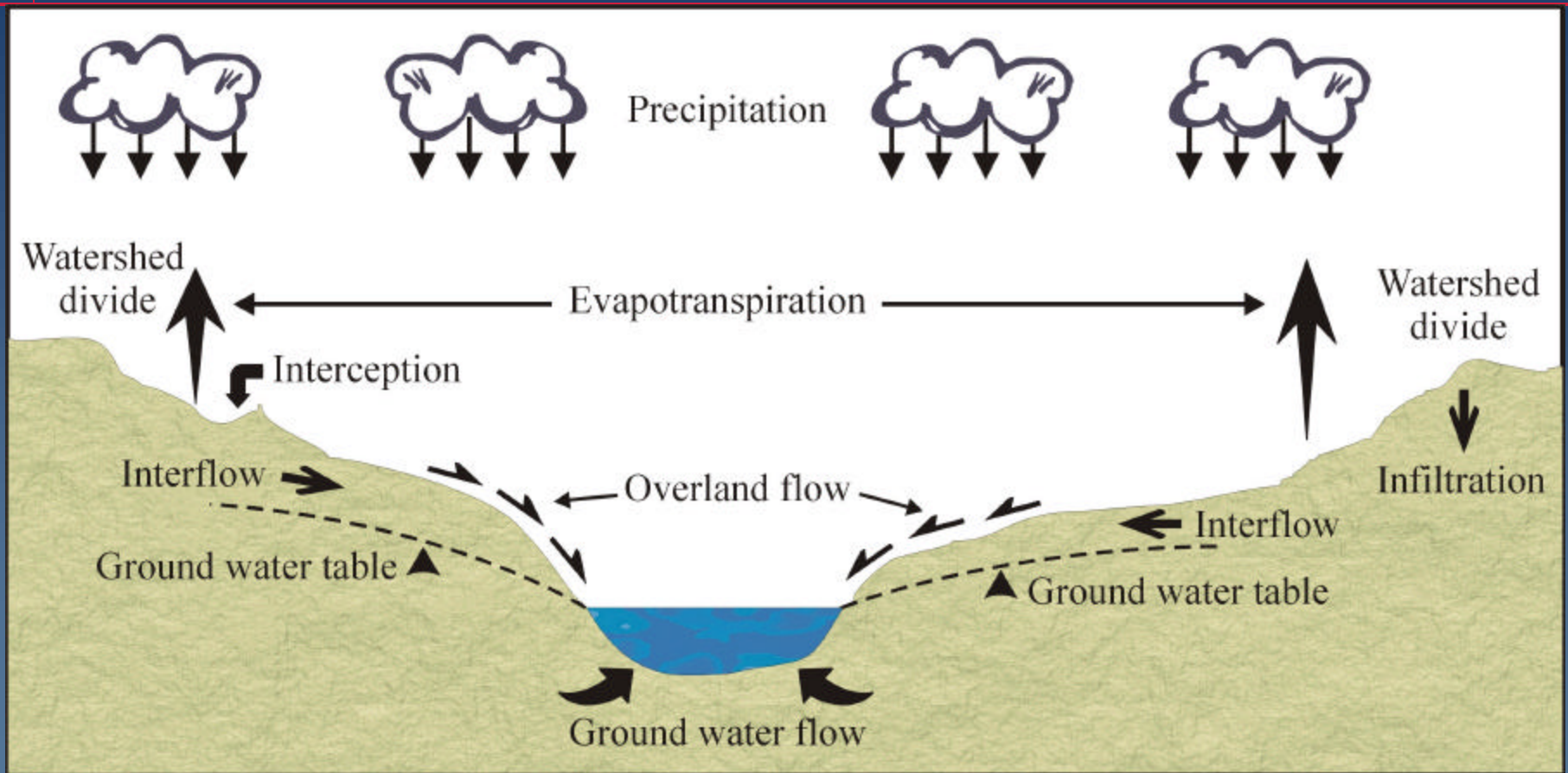
# Groundwater Model Input



# Schematic Aquifer System



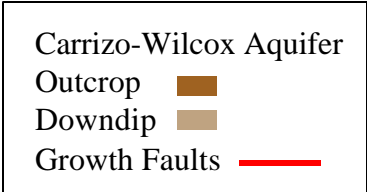
# Shallow Aquifer Flow System



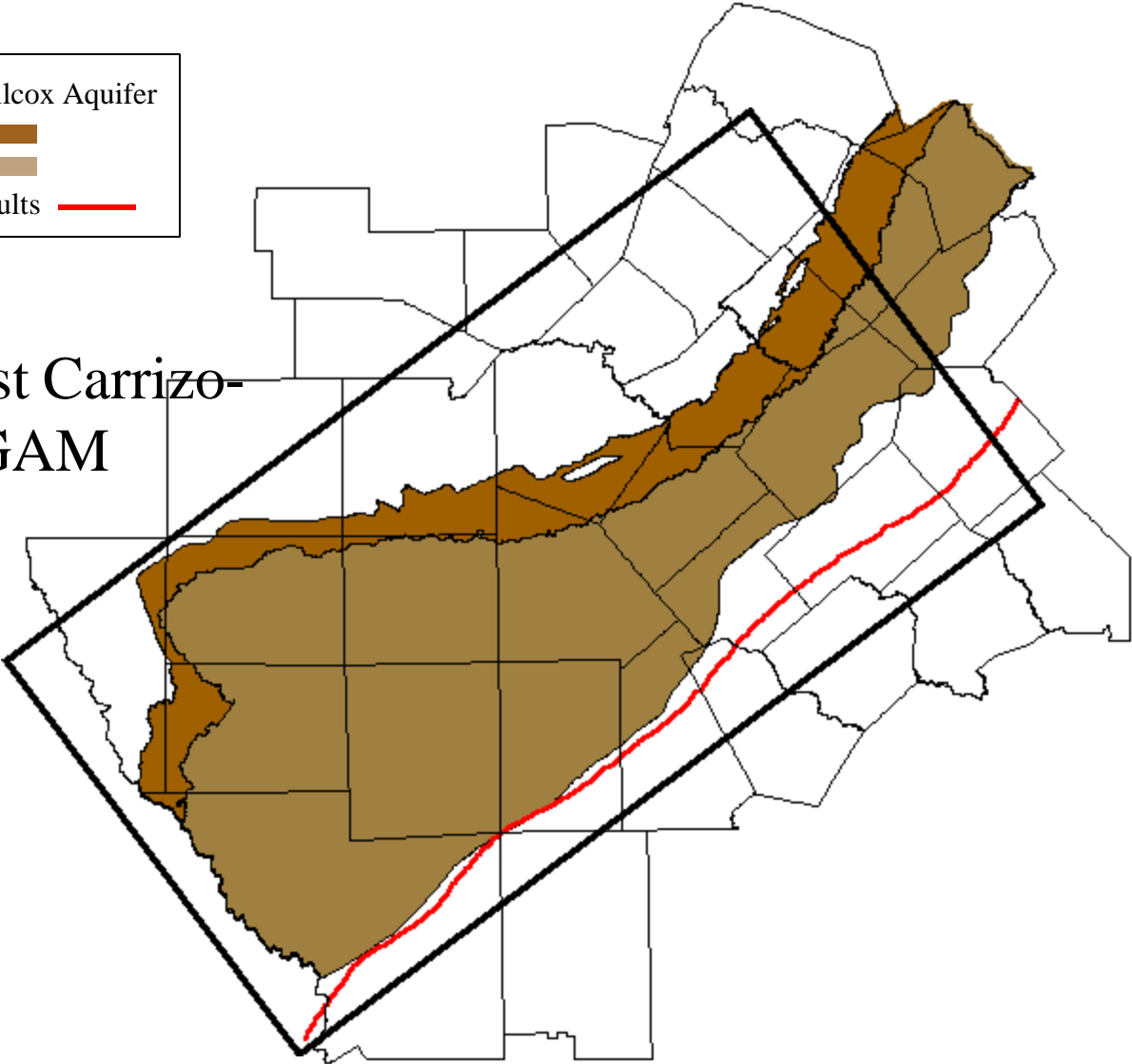
# Aquifer Geometry

- Geology and Structure
- Hydrostratigraphy
- Boundaries

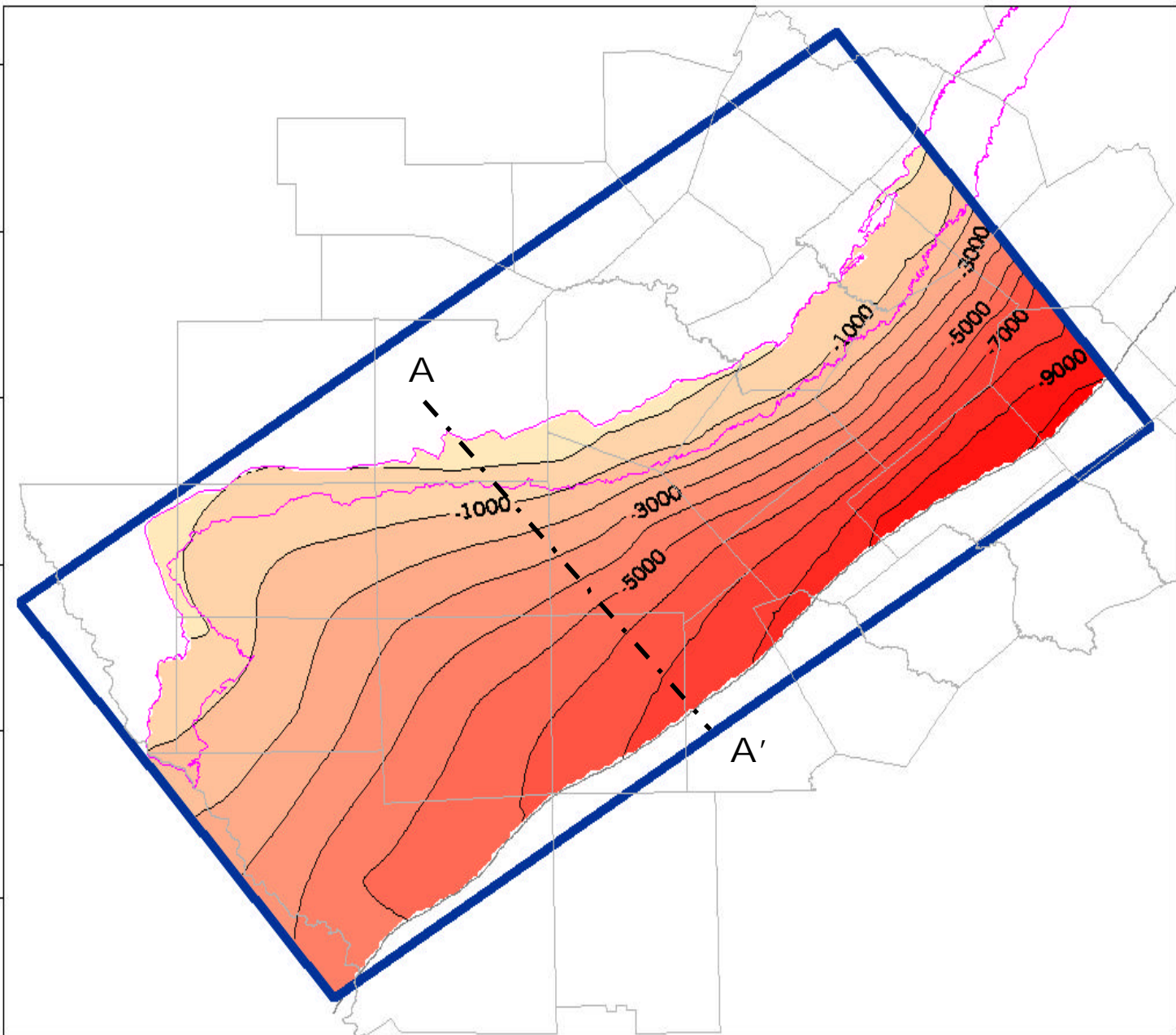
# Southwest Carrizo-Wilcox GAM Model Domain



Southwest Carrizo-  
Wilcox GAM



# Base of Wilcox







# Model Layers

- Total of six layers
  - Carrizo
  - Distinguish Upper, Middle and Lower Wilcox
  - Reklaw: major confining unit
  - Shallow aquifers above Reklaw
- West of Frio River:
  - Reklaw → Bigford Fm.
  - Queen City/Weches → Bigford/El Pico
  - Sparta → Laredo Fm.

	Series		Southwest		Model Layer	
TERTIARY	Eocene	U	Jackson Group			
		M		Yegua Fm.		
				Laredo Fm.	Cook Mtn. Fm.	
				El Pico Clay	Sparta Sand	6
				Bigford Fm.	Weches Fm.	
		L		Queen City Sand		
			Reklaw Fm.		5	
	Paleocene	L		Carrizo Sand	Upper Wilcox	4
						3
		U		Middle Wilcox		2
			Lower Wilcox		1	
	L	Midway Formation				

# Stratigraphic Data Sources

## ▶ Data Base

- Klemt (1976)
  - Carrizo Aquifer (Carrizo & Upper Wilcox)
- Hamlin (1988)
  - Carrizo Aquifer (similar to Klemt)
- Guyton & HDR (1998)
  - 3-D Model:
    - Carrizo-Upper Wilcox (Klemt Model)
    - Wilcox Unit (estimated?)
    - shallow units

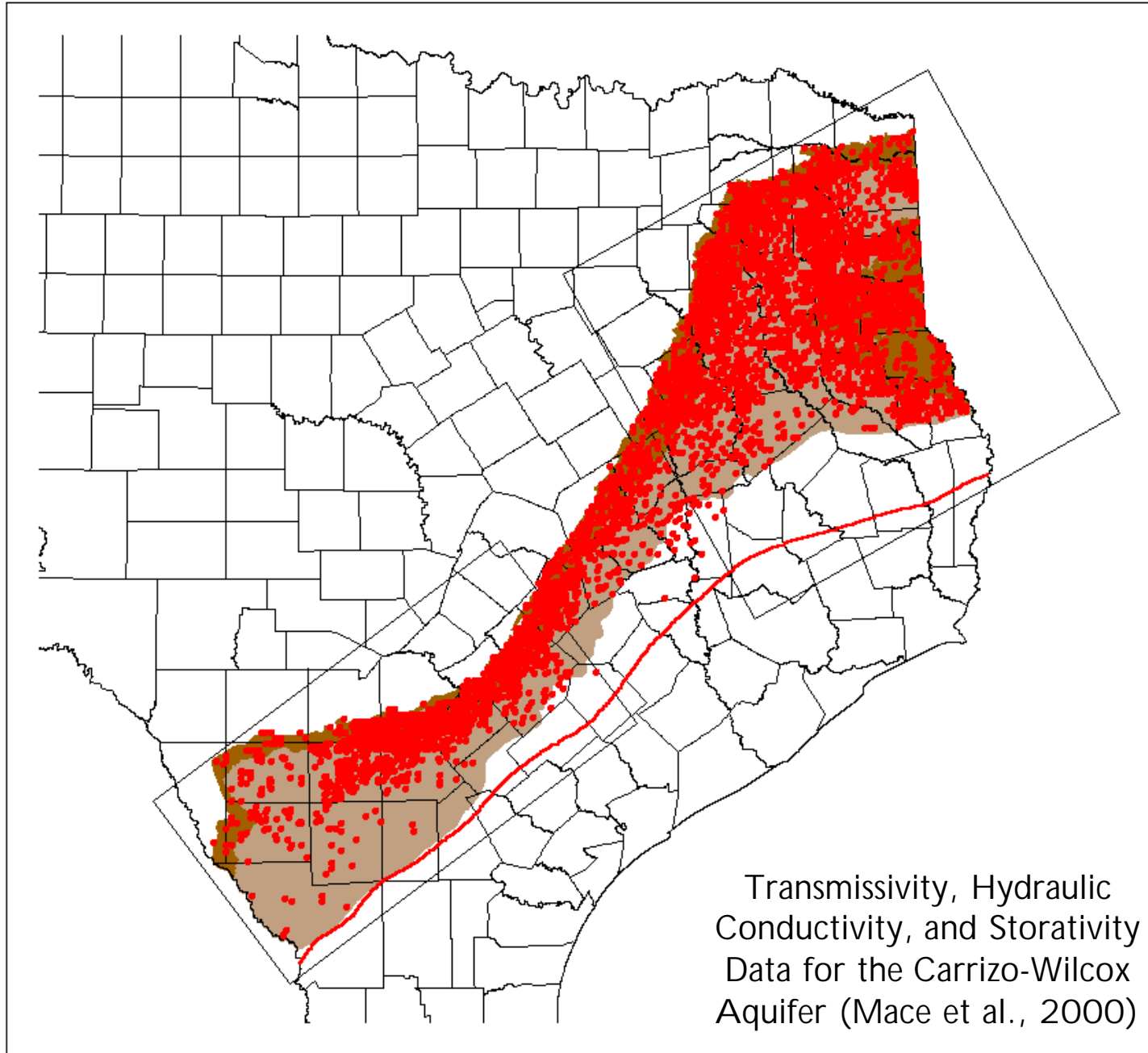
# Aquifer Properties

## ■ Hydraulic Conductivity

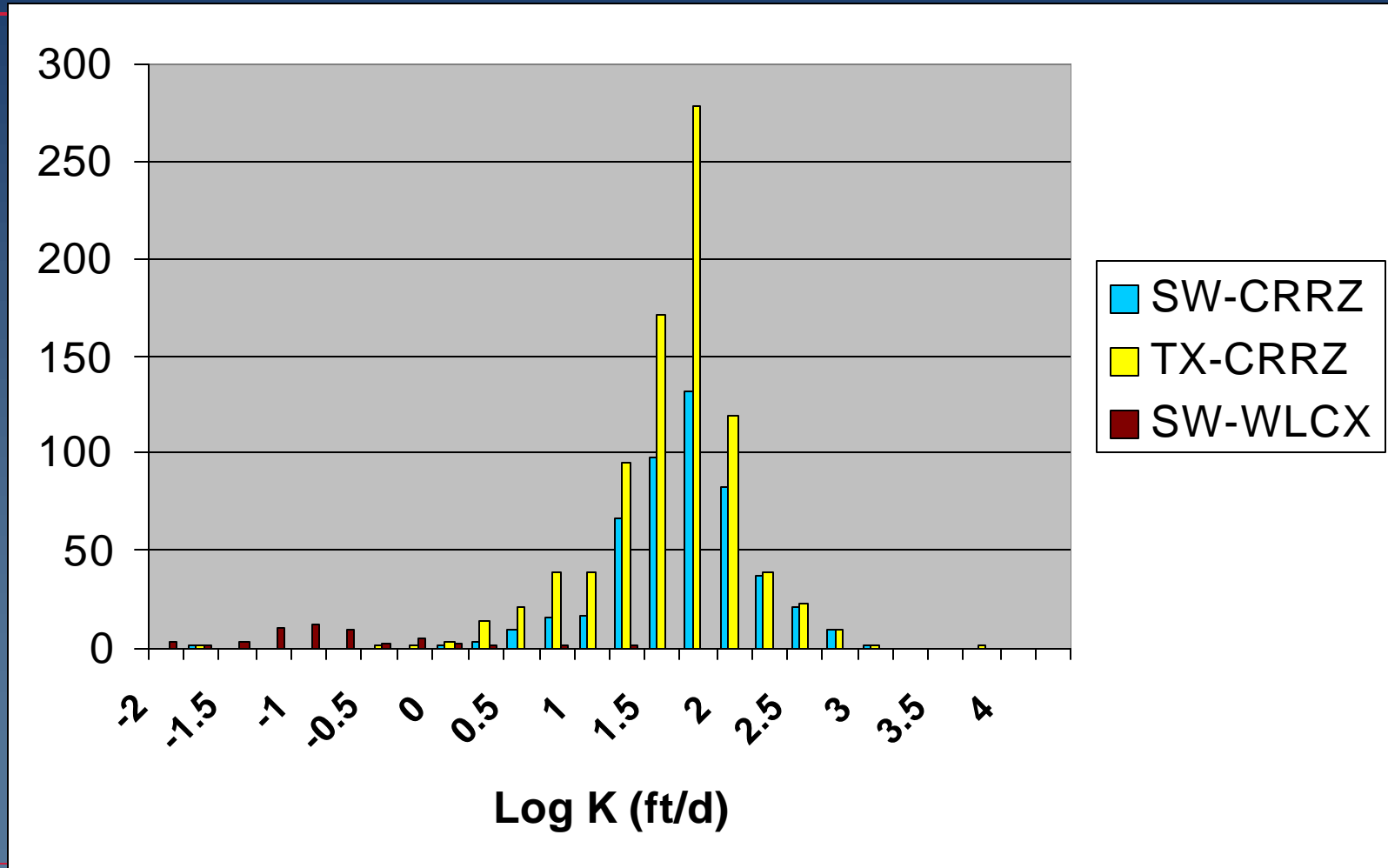
- horizontal
- vertical

## ■ Storativity

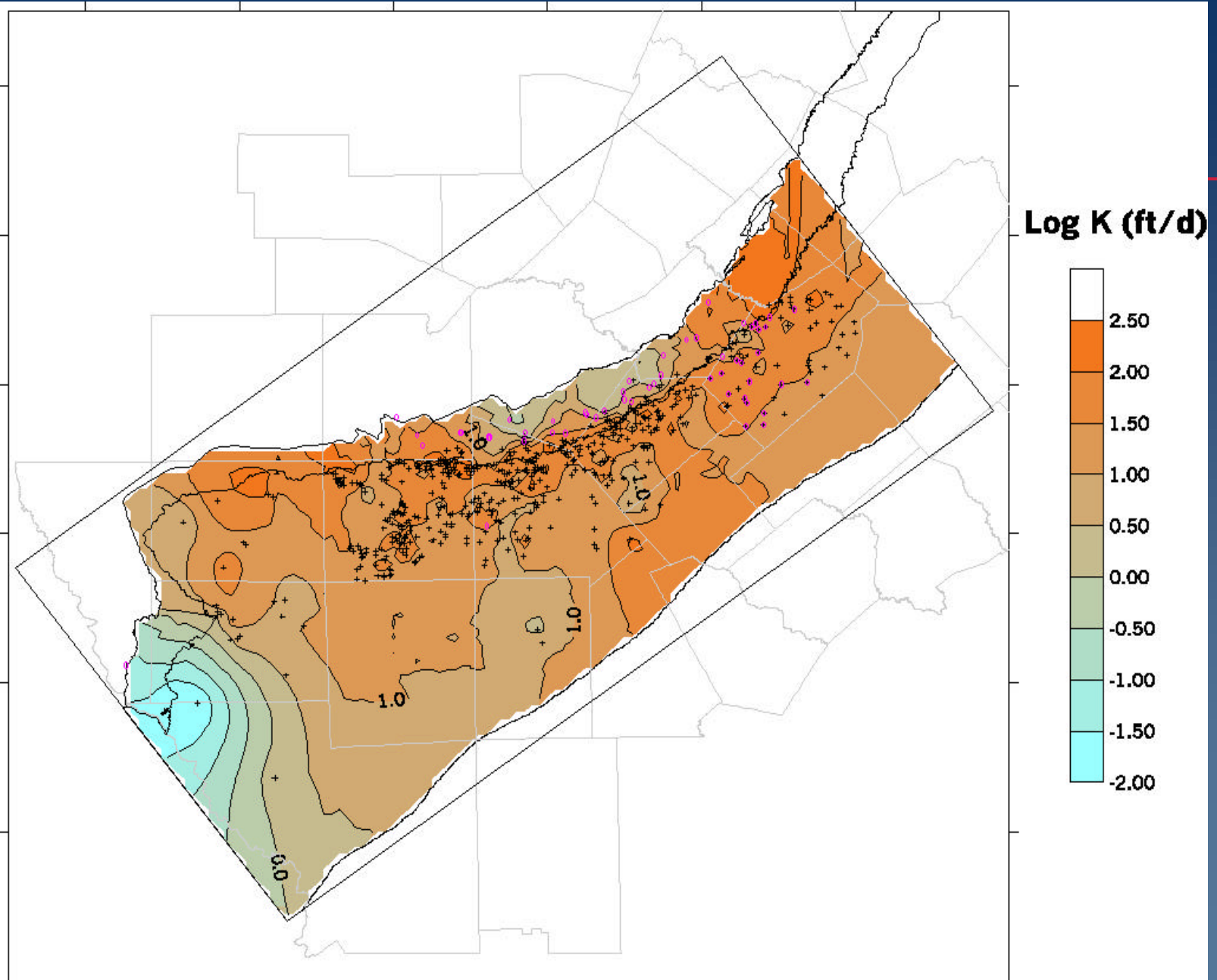
- unconfined (specific yield)
- confined



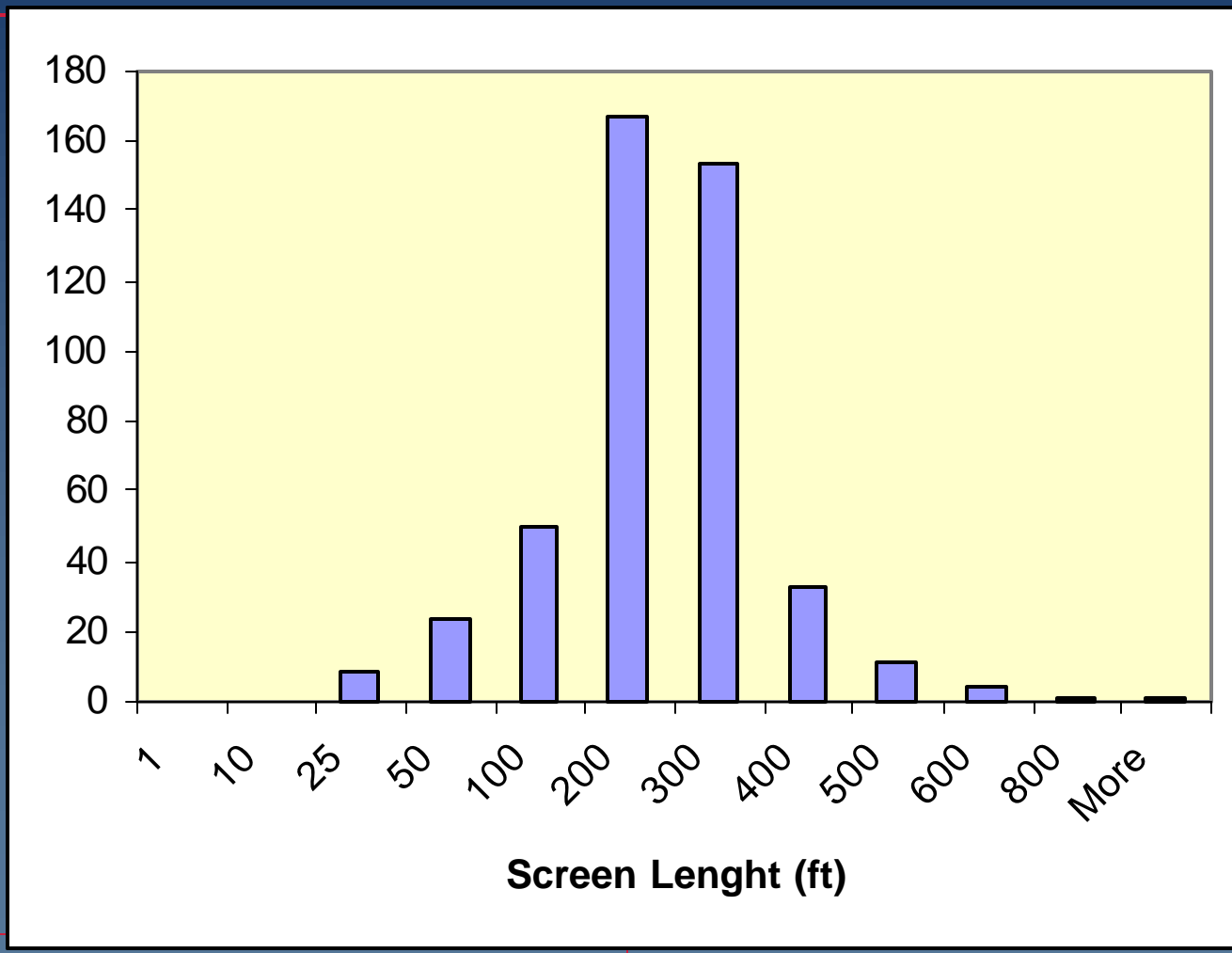
# Hydraulic Conductivity Data



# Carrizo: Hydraulic Cond.



# Carrizo - Wells



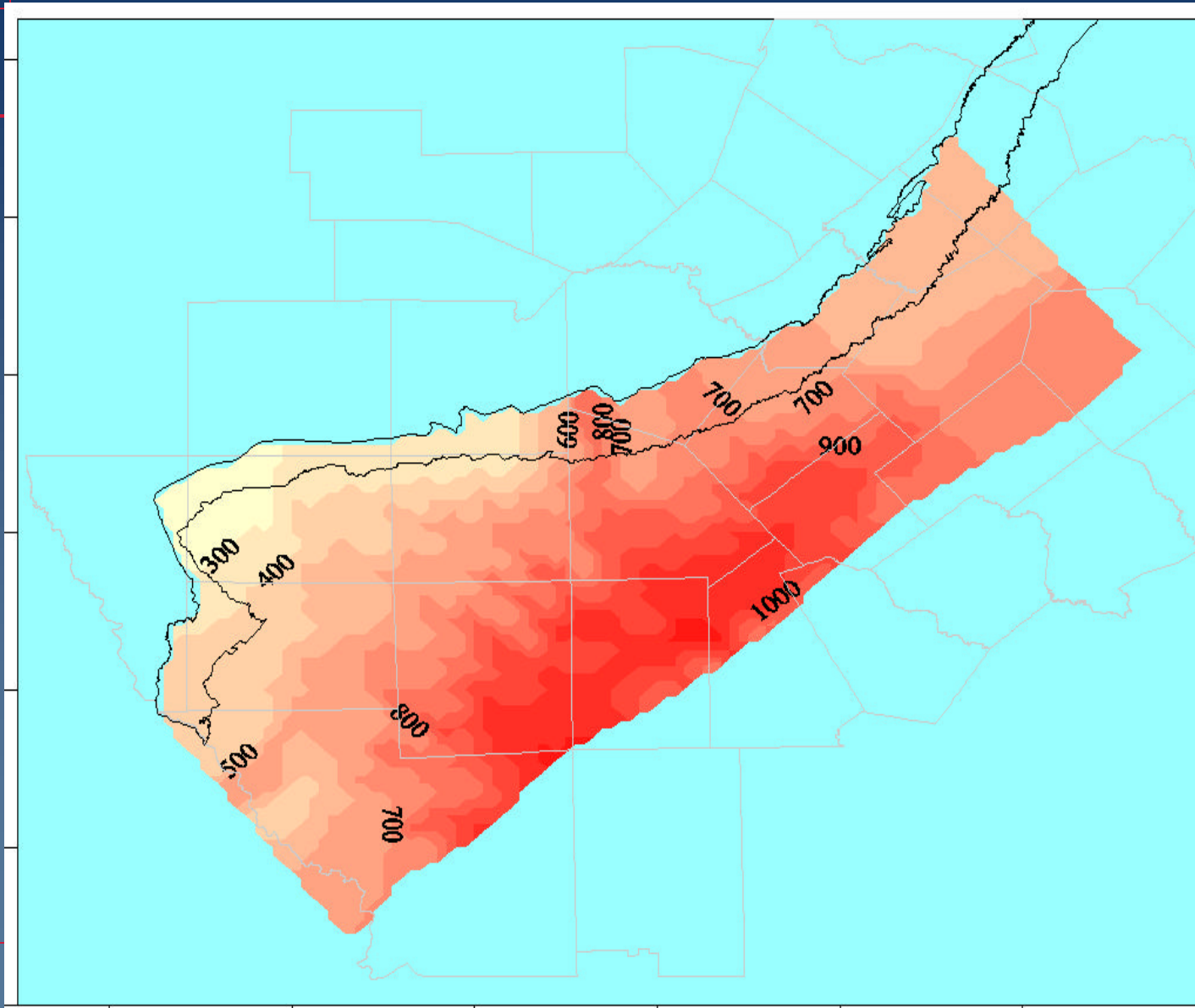
# Sources for Sand Distribution

## – SE Model:

- sand distributions for Carrizo-Upper Wilcox from Hamlin (1982)
- sand distribution for lower Wilcox from Bebout (1982)



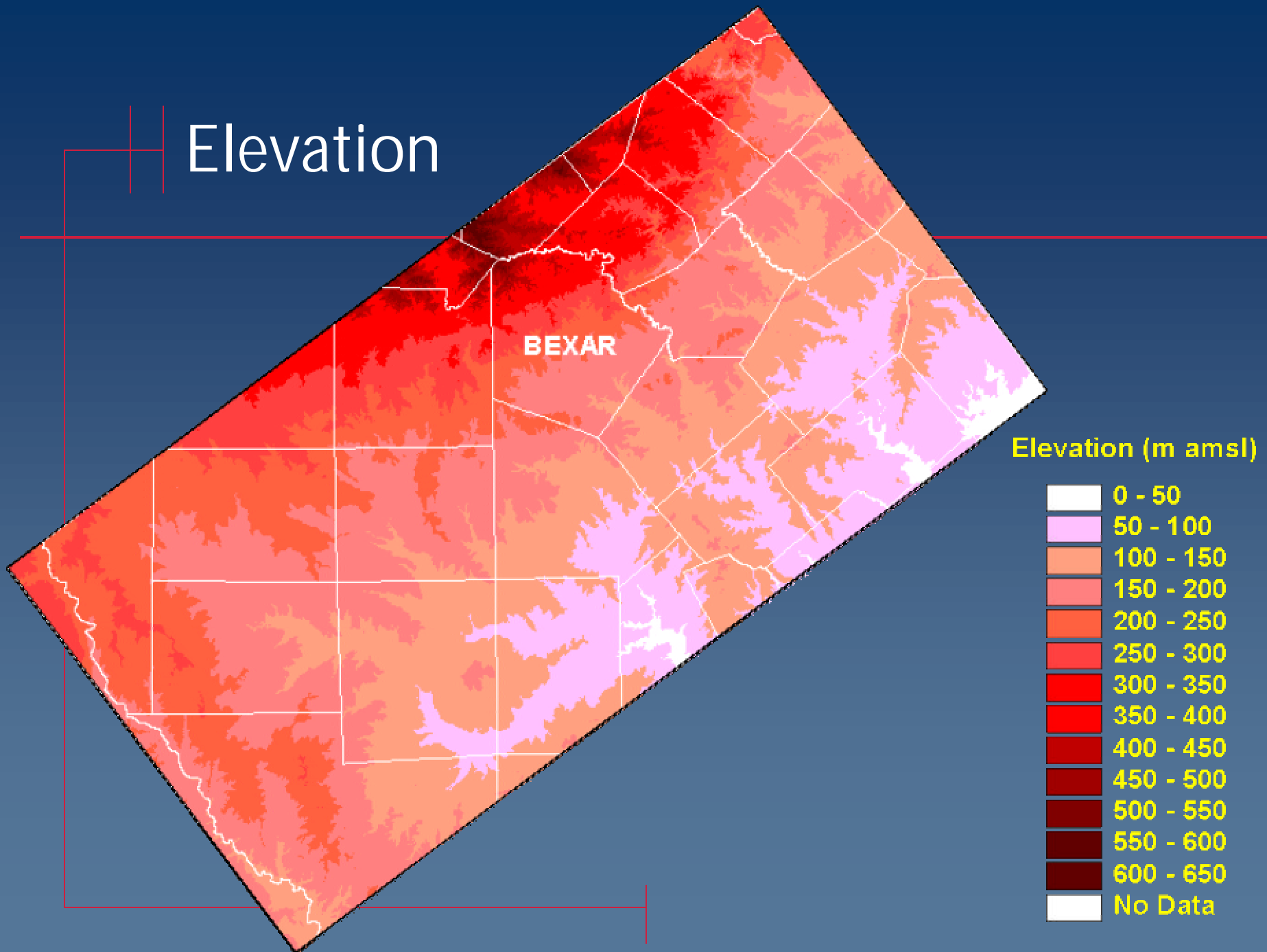
# Carrizo - Upper Wilcox: Net Sand (ft)



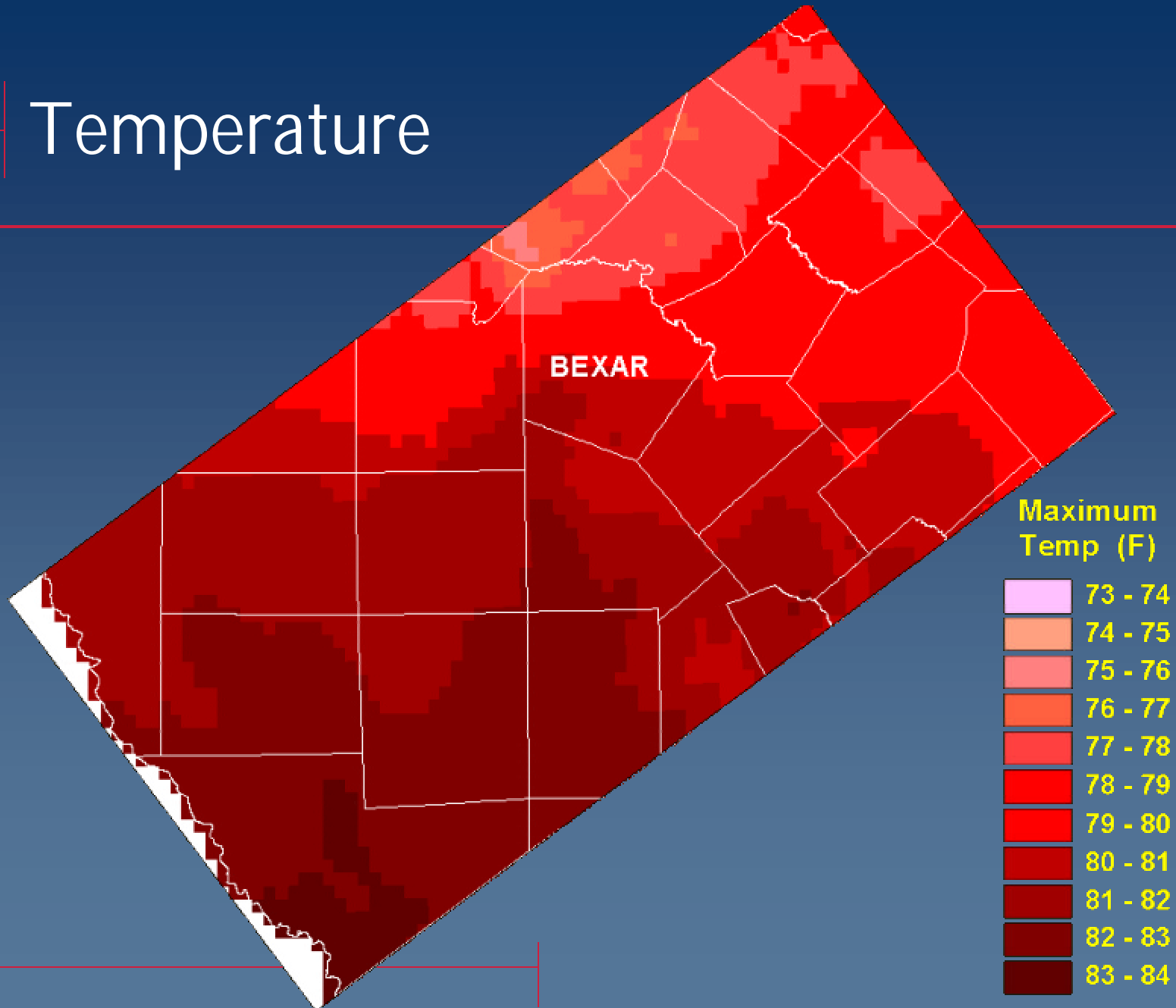
# Physiography and Climate

- Landsurface Elevation
- Temperature
- Precipitation

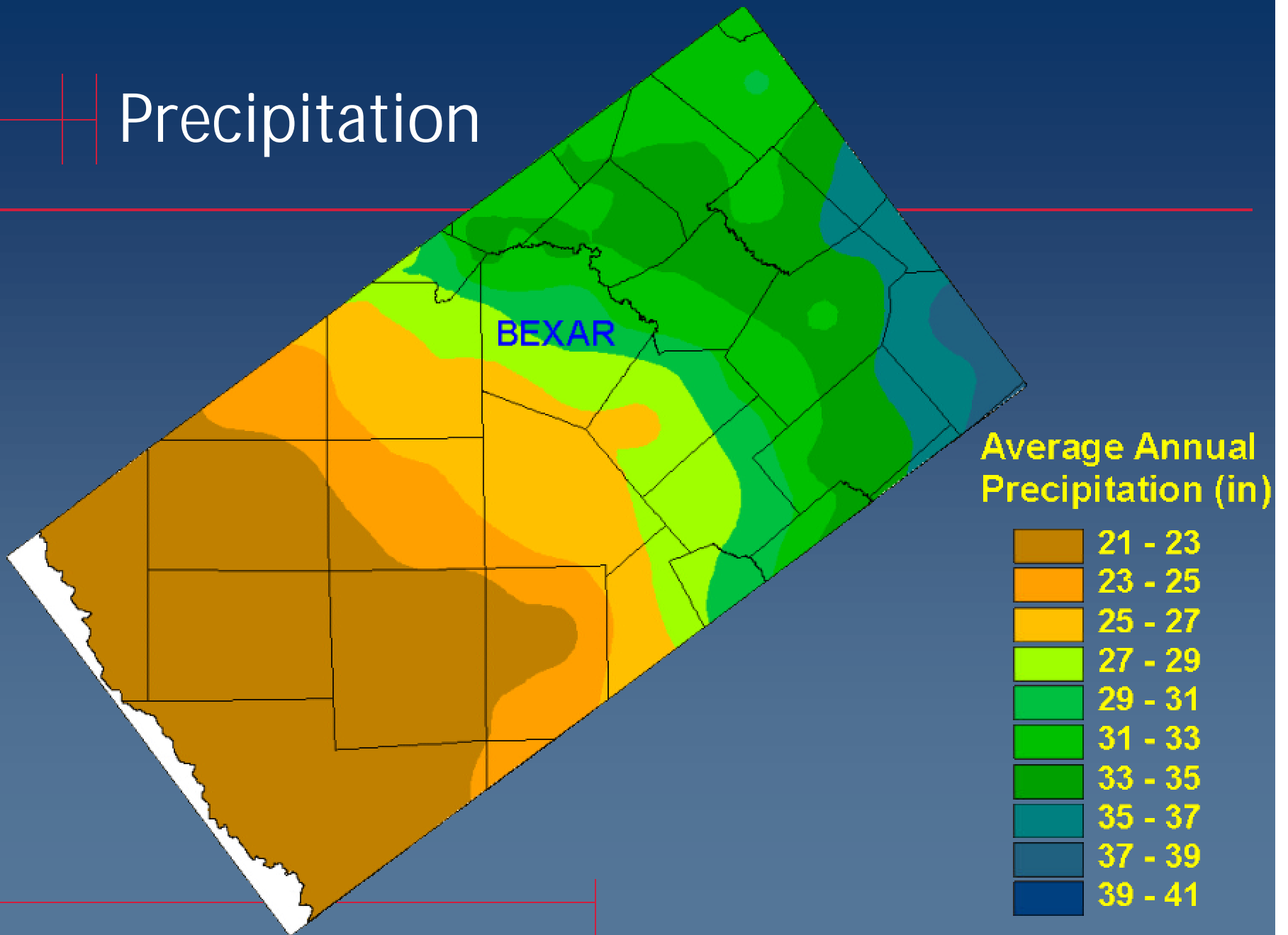
# Elevation



# Temperature



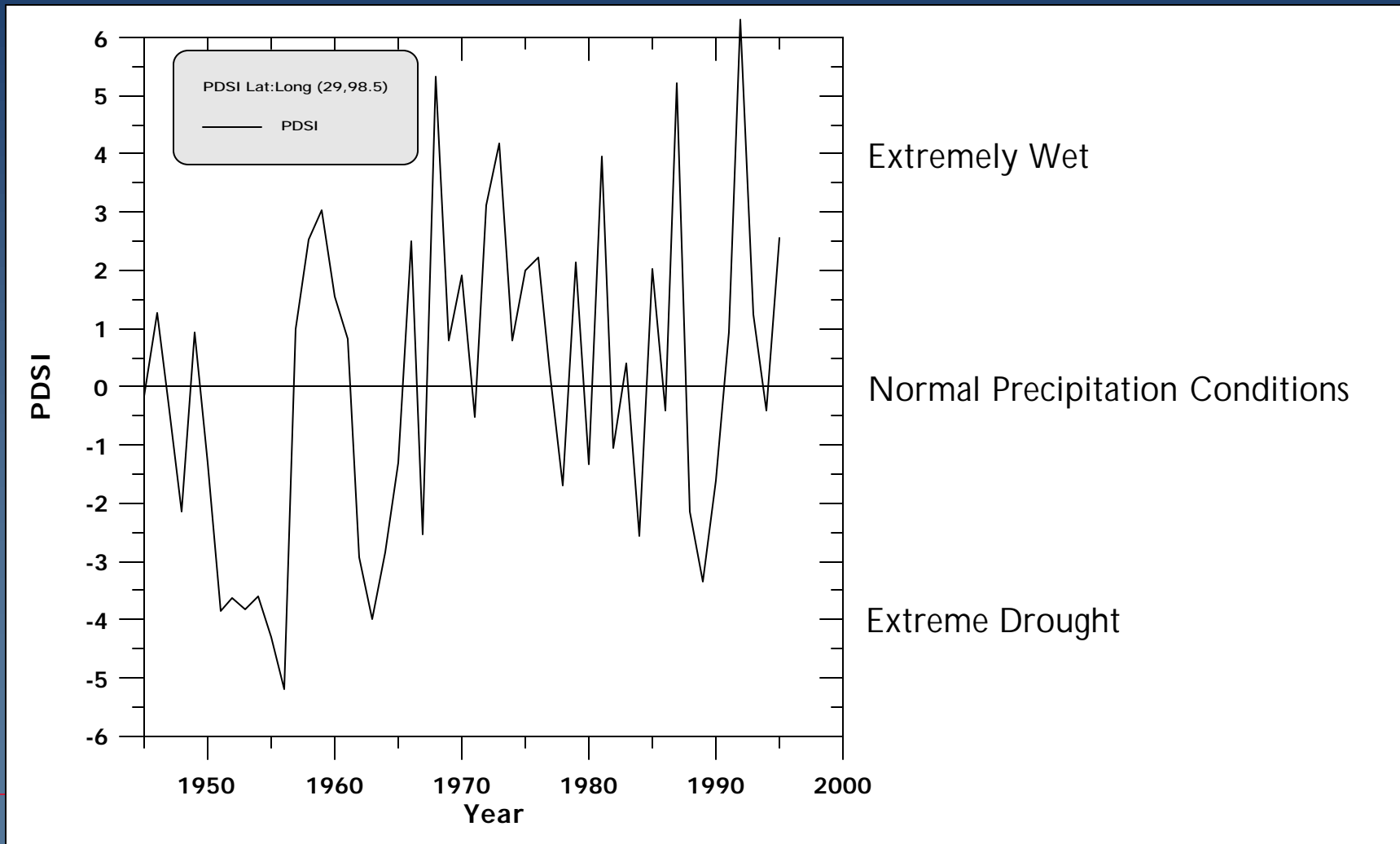
# Precipitation



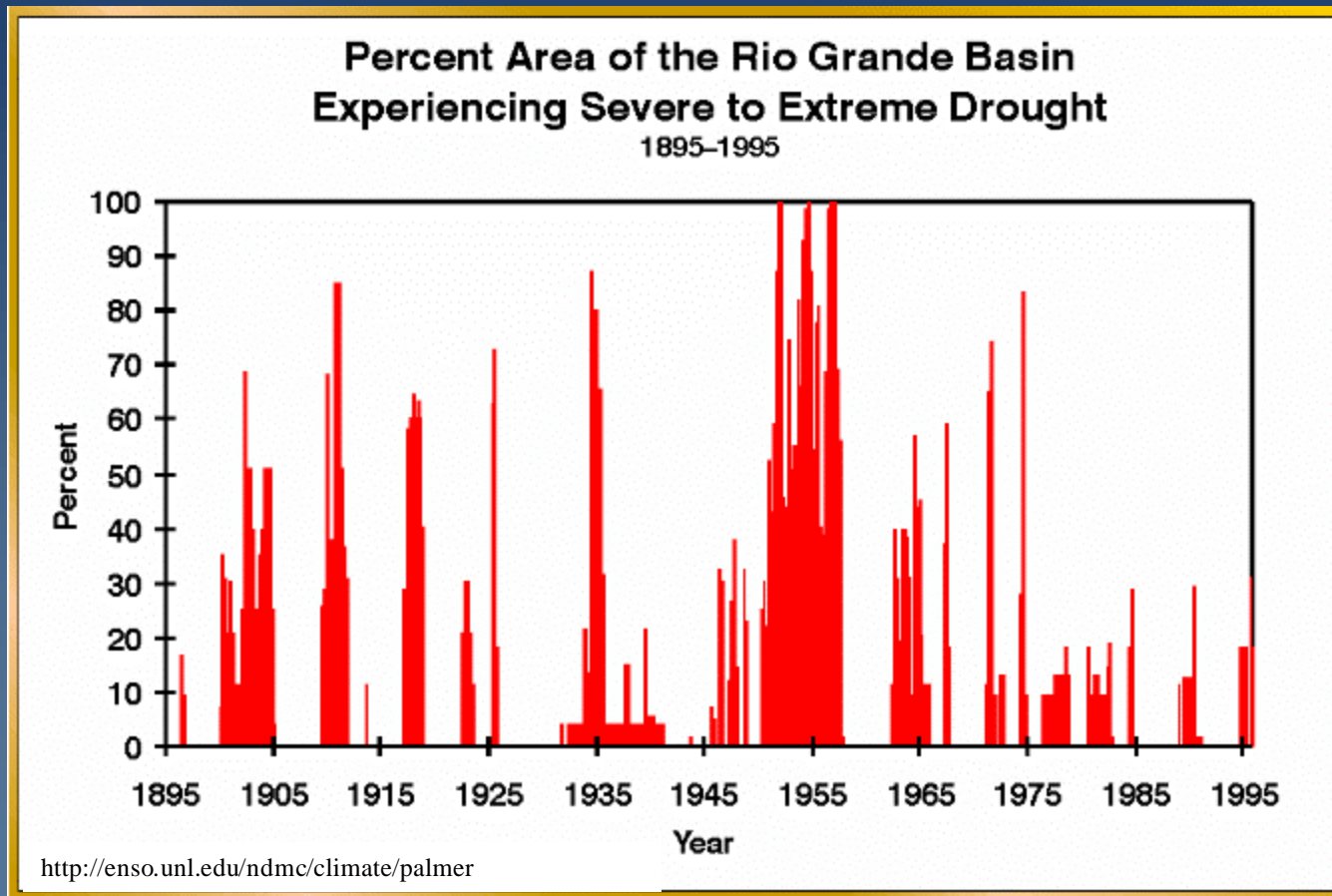
# Climate Characterization

- GAM requires definition of a period representing the drought of record (DOR) for our model area.
- Future model simulations (years 2000-2050) will incorporate a climatic period equivalent to the DOR
- We are currently reviewing precipitation, streamflow, and agricultural drought indices to define DOR

# Palmer Drought Severity Index (PDSI) - Lat. 29, Long. 98.5



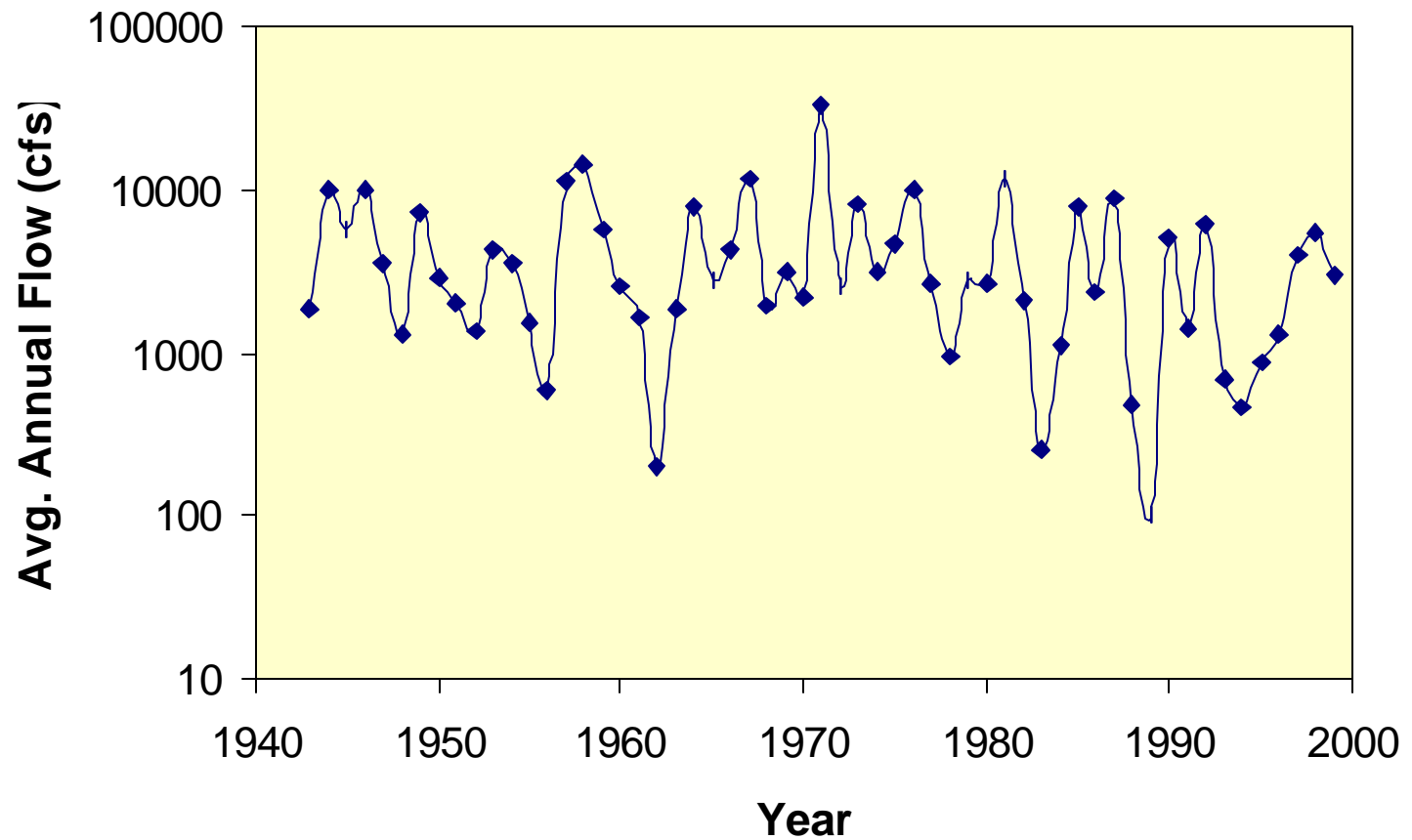
# Drought, A Historical Perspective





# Stream Flow

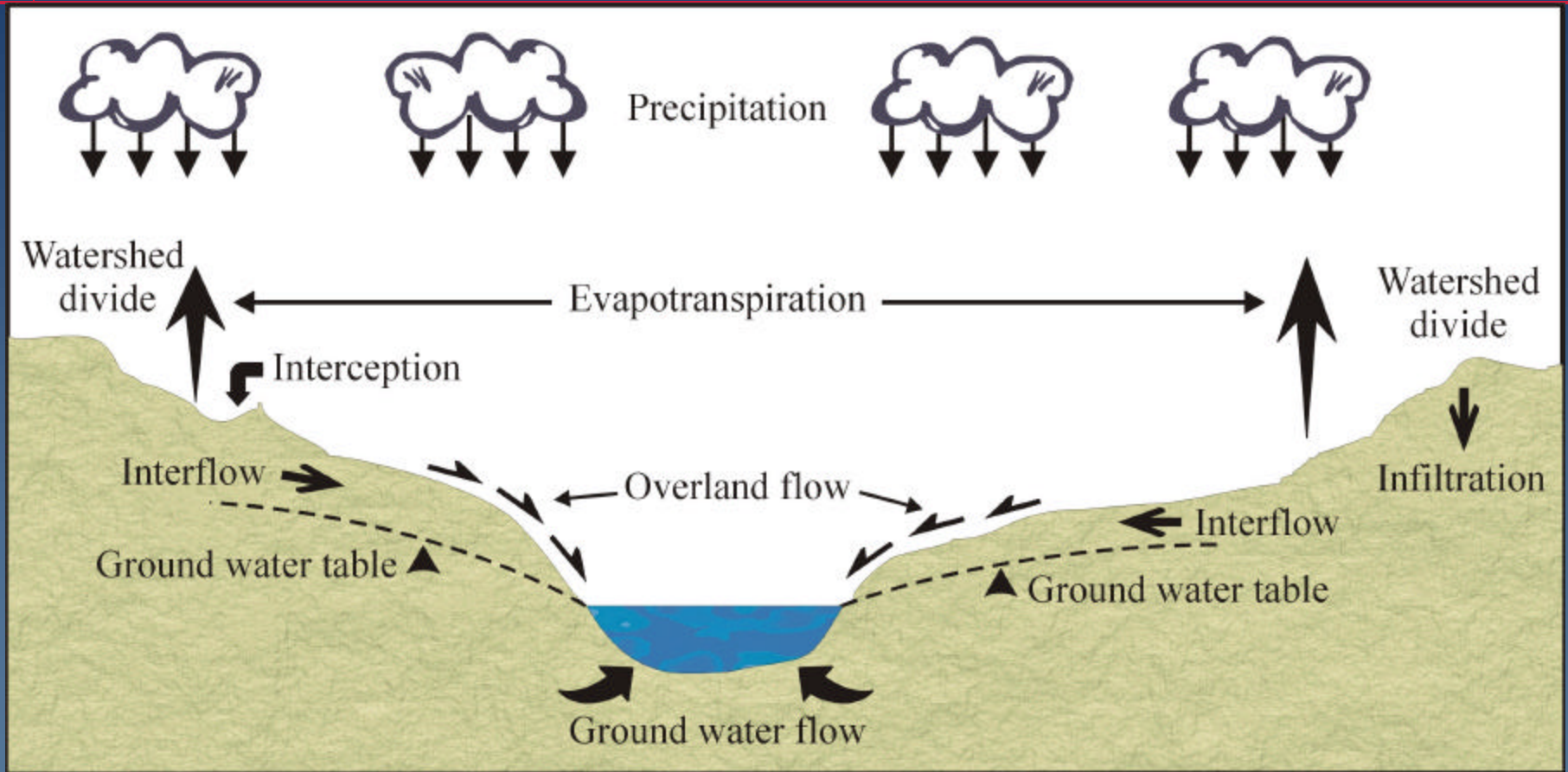
**Nueces River: USGS Gage, Tilden, Tx.**



# Recharge/Discharge

- Approach
- Limitations
- Model Calibration

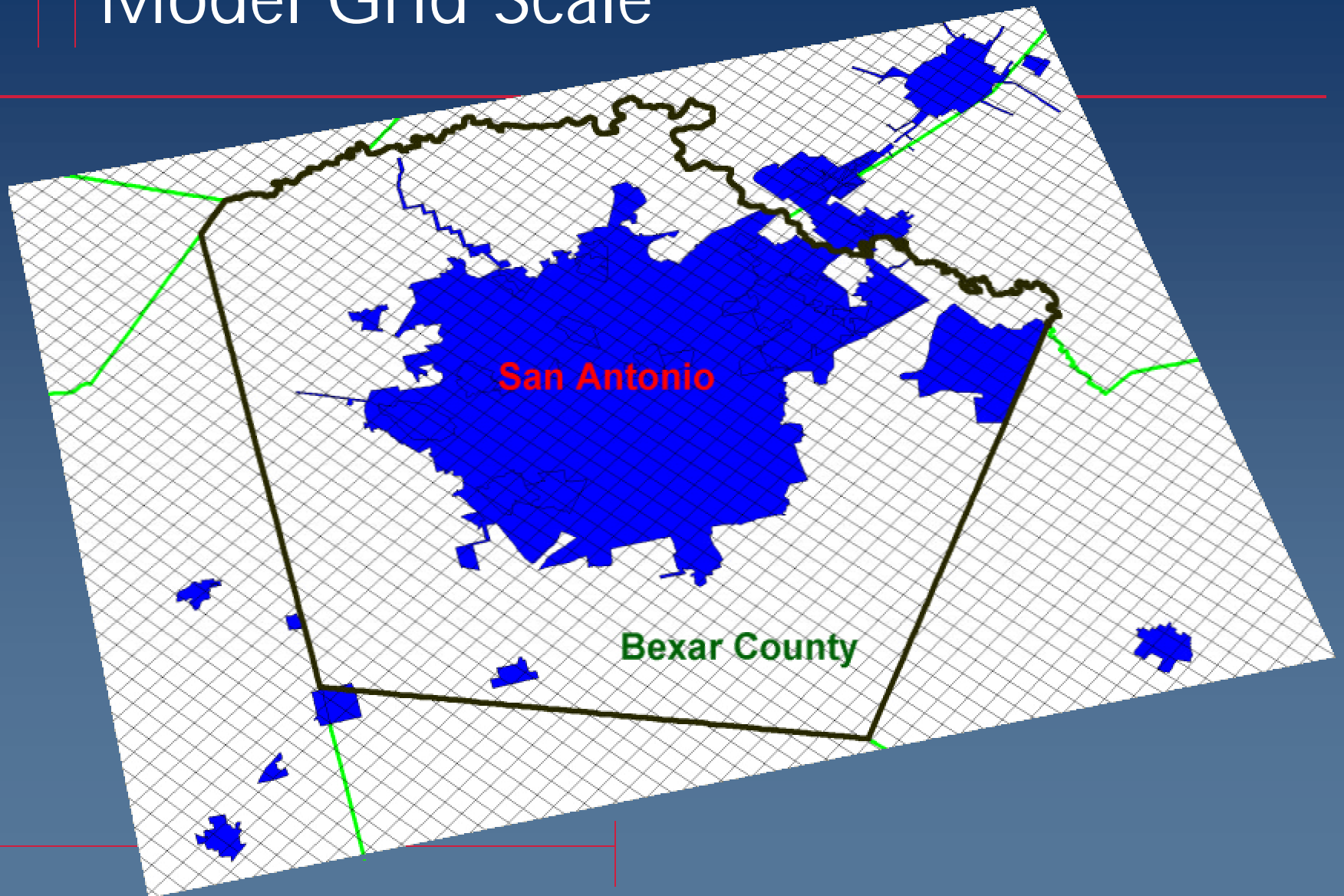
# Hydrologic Cycle and Recharge



## Recharge - Approach

- Recharge is a complex function of precipitation, evapotranspiration, and runoff and varies with location and time
- Develop an overlay technique capable of integrating spatial heterogeneity to determine recharge:
  - transiently (monthly analysis)
  - a per grid cell basis

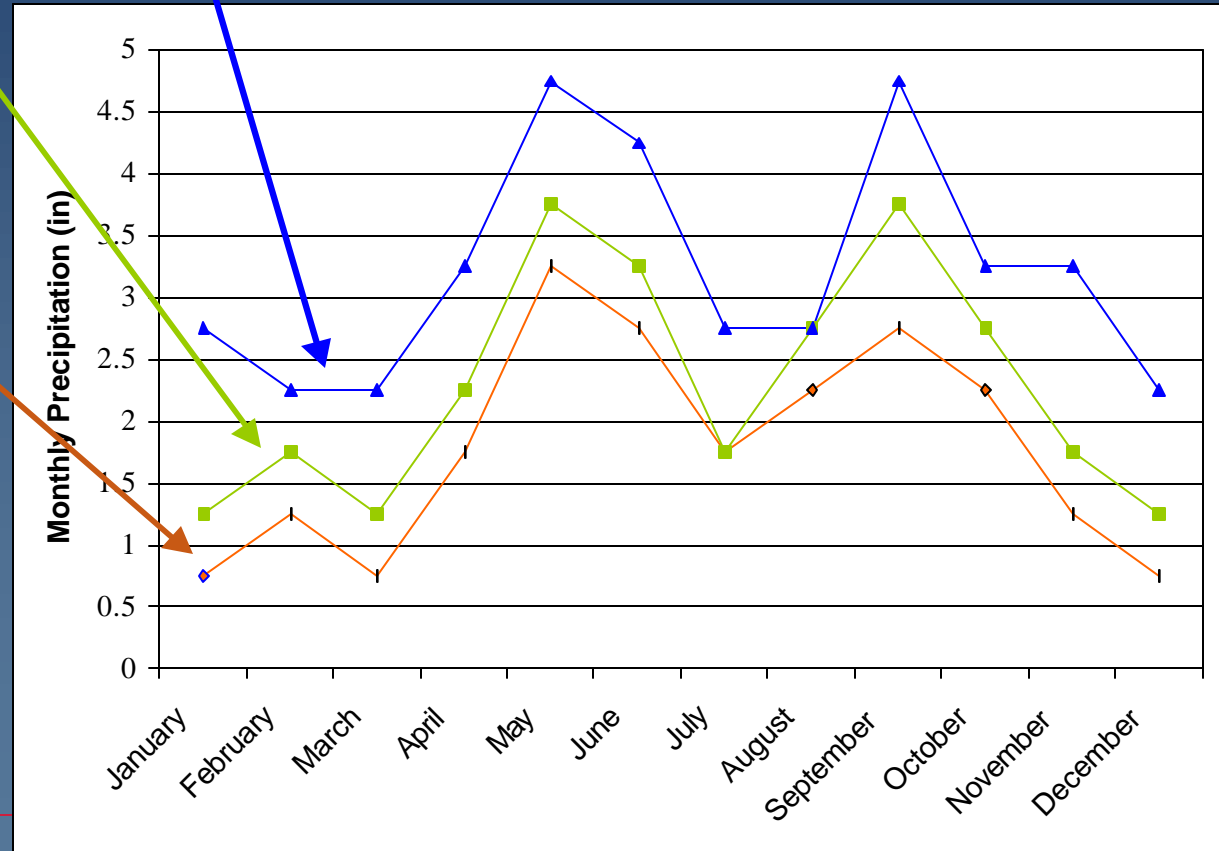
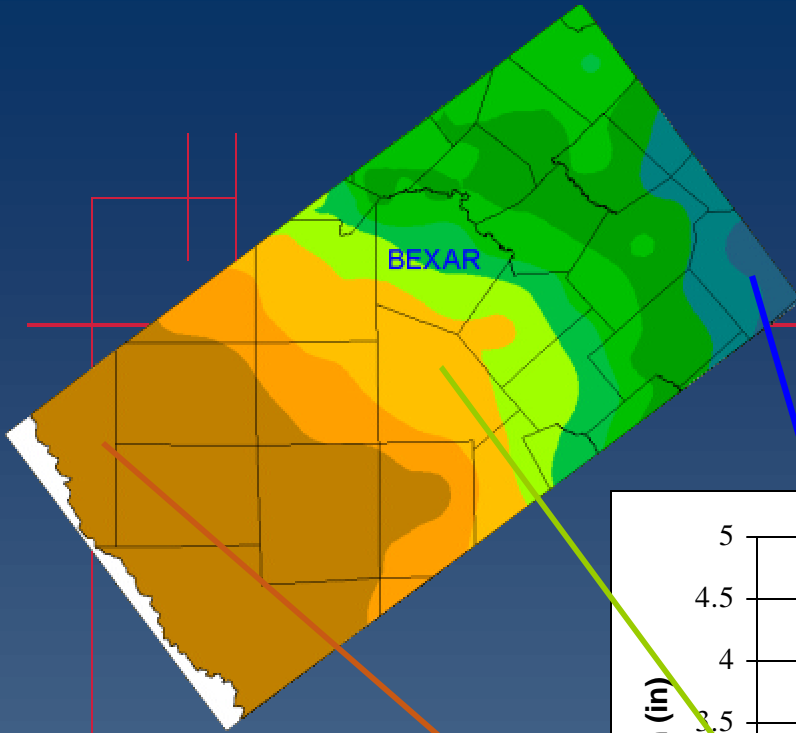
# Model Grid Scale



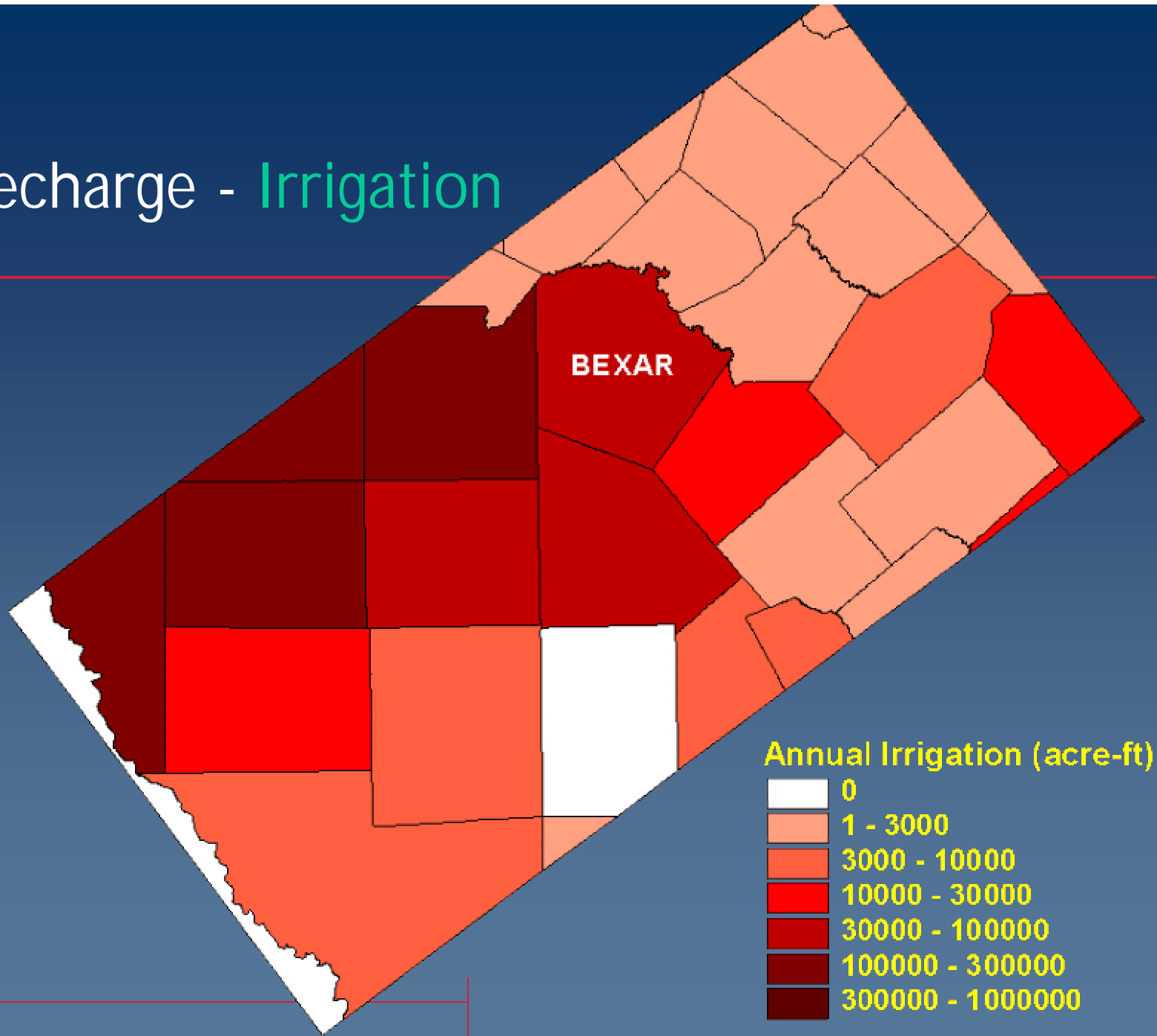
# Recharge - Approach

- On a grid cell basis estimate:
  - precipitation and irrigation
  - runoff
  - Evapotranspiration
- Infiltration = Precipitation - Runoff
- Recharge = Infiltration - ET

# Precipitation



# Recharge - Irrigation





# Recharge - Evapotranspiration

- Reference ET ( $E_{rc}$ ) from pan measurements

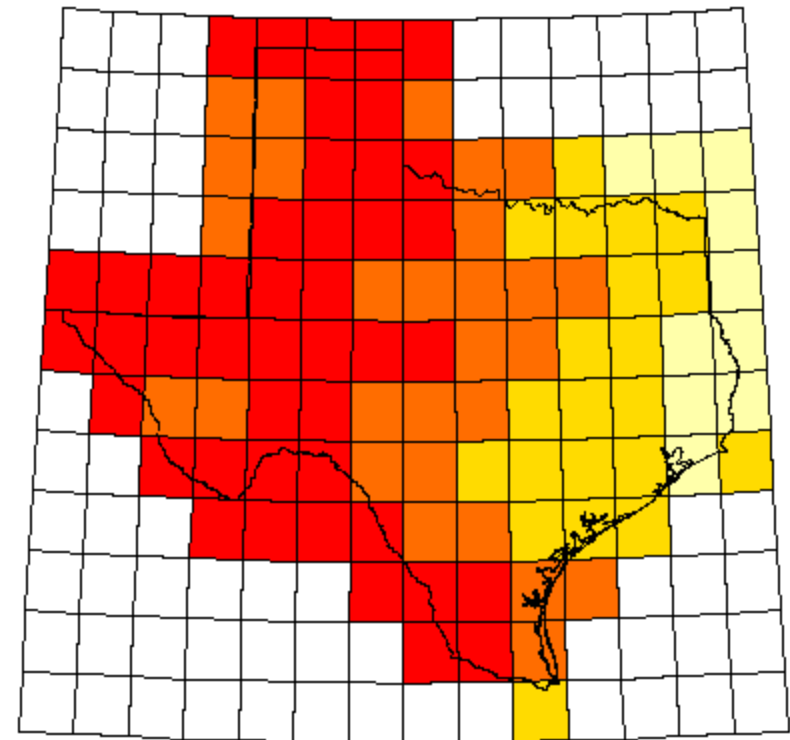
$$E_{rc} = k_{pan} E_{pan}$$

- Actual ET ( $E$ ) determined by:

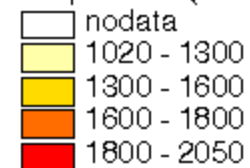
$$E = K_s K_{co} E_{rc}$$

- $K_s$  is soil moisture
- $K_{co}$  is the crop coefficient, function of season and vegetation type

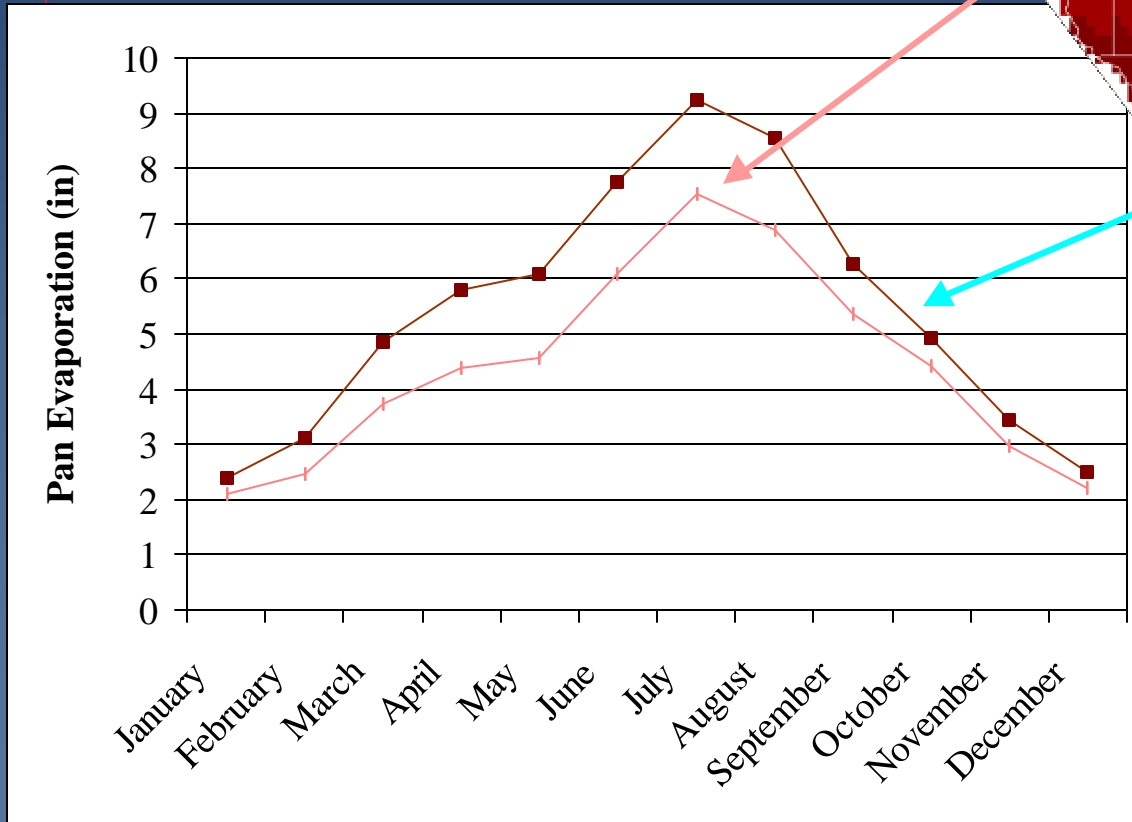
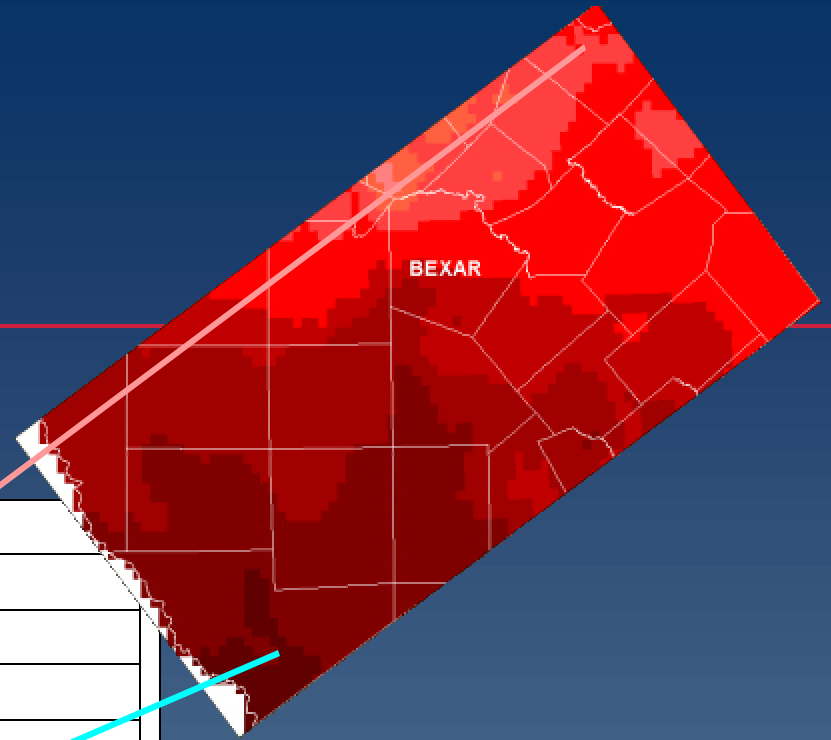
- Varies with location and time



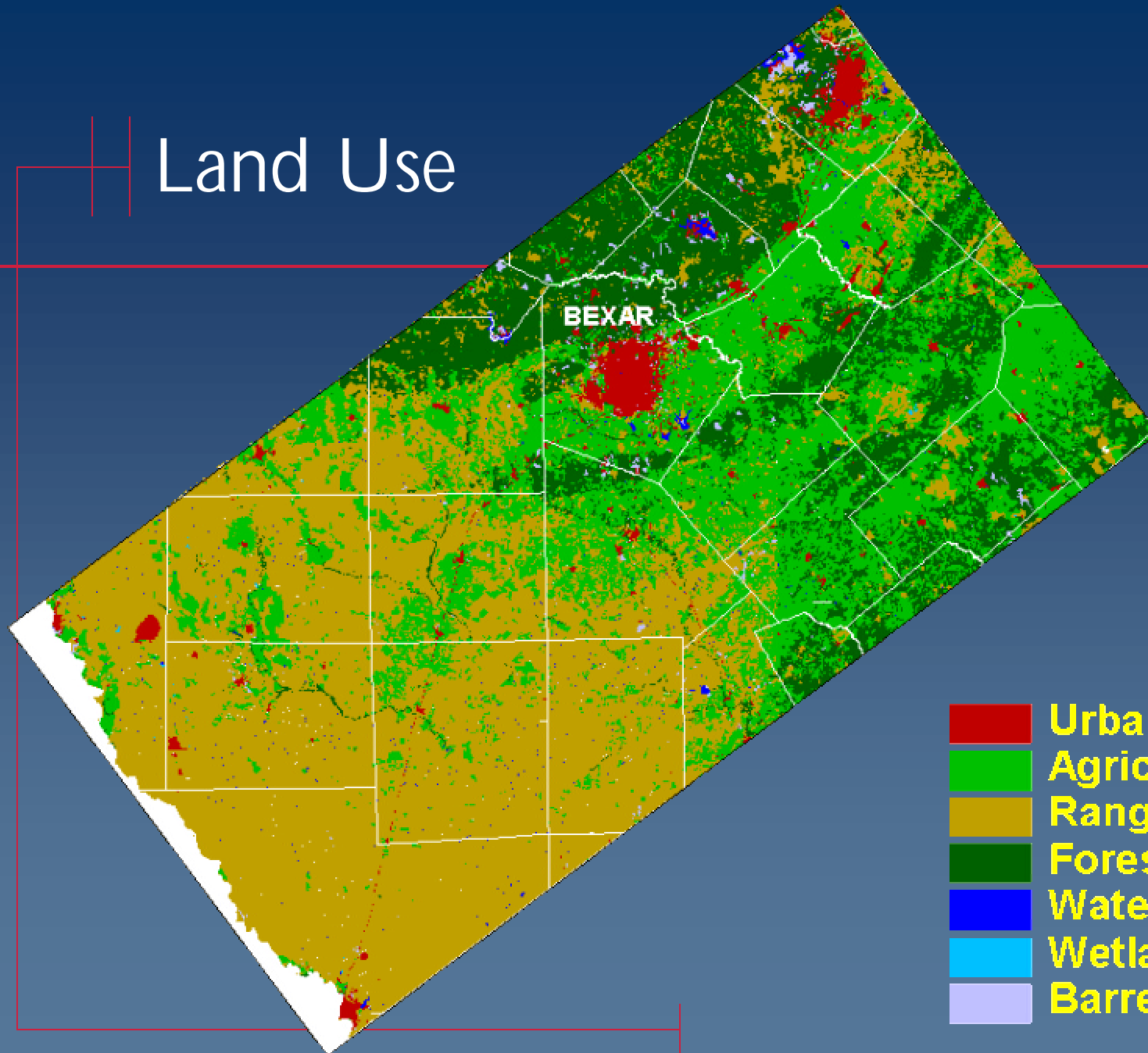
Evaporation (mm/year)



# Pan Evaporation



# Land Use



- Urban
- Agriculture
- Rangeland
- Forest
- Water
- Wetland
- Barren Land

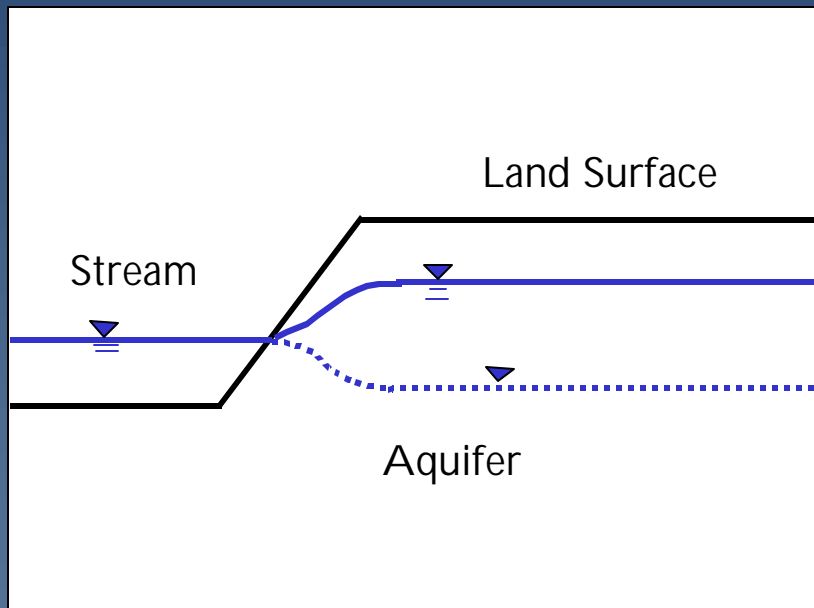
# Recharge - Validation Approach

- Compare model recharge estimates to:
  - Past modeling studies
  - Survey data compiled by Scanlon
  - Baseflow studies (USGS)
- Compare runoff estimates to streamflow data
- Water table fluctuation methods
  - Calibrate to a few select hydrographs in the unconfined portion of the aquifer which show significant fluctuation with climate
- LANDSAT 7 SEBAL estimates of actual ET

# Discharge to Surface Water

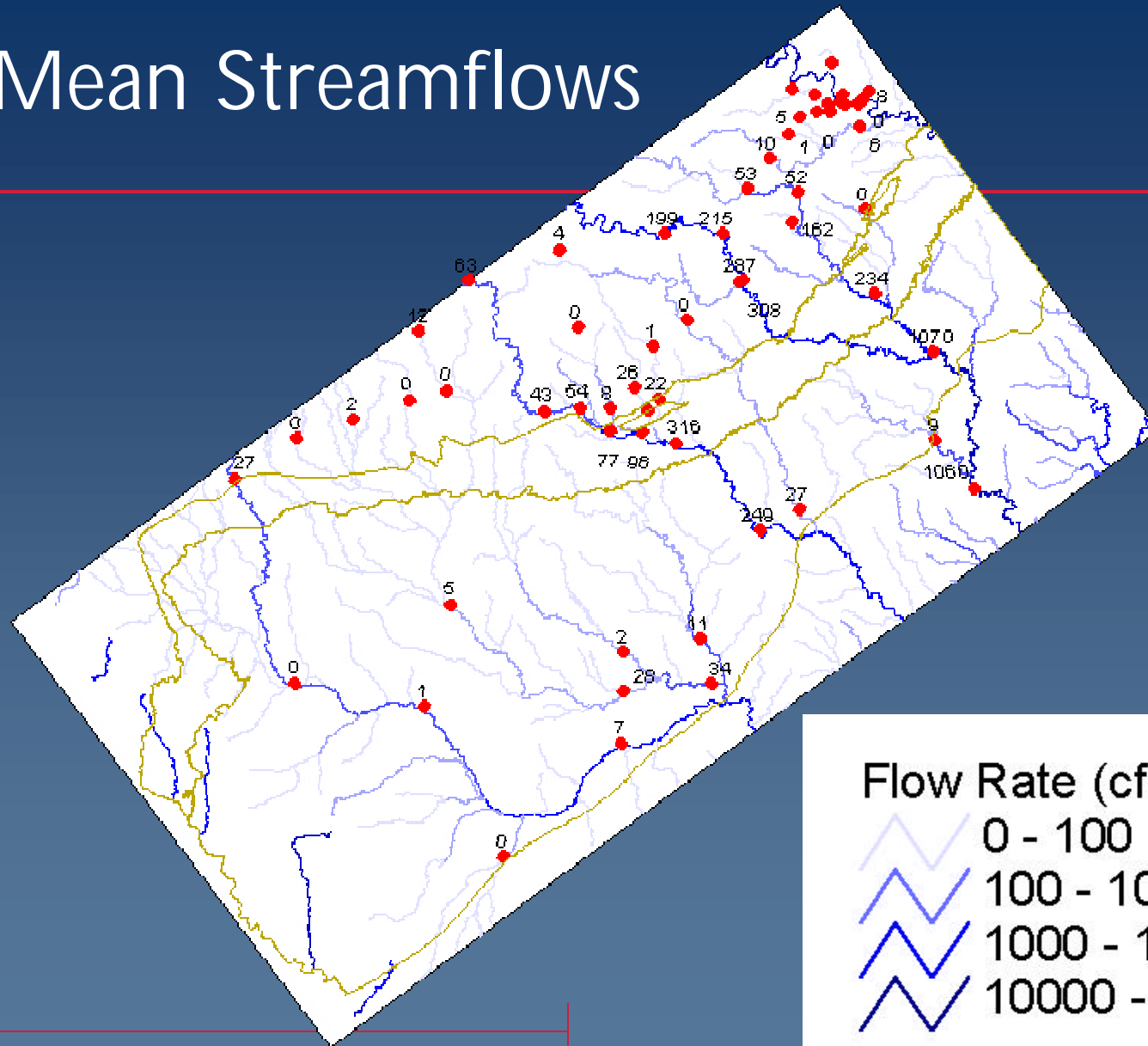
- Surface water/ Groundwater interaction is an important process to the Southern Carrizo/Wilcox Aquifer
- Streams in the model area are losing (recharge) or gaining (discharge)
- Several Reservoirs which are an important part of the surface water system
- Limited number of Springs

# Aquifer Stream Interaction



- **Losing Stream**
  - recharge
- **Gaining Stream**
  - discharge from:
    - Surface Runoff
    - Groundwater (baseflow)

# Mean Streamflows



# Discharge from Pumping

■ Pumping is distributed to the 1 mile square model grid based upon:

– Specific Wells

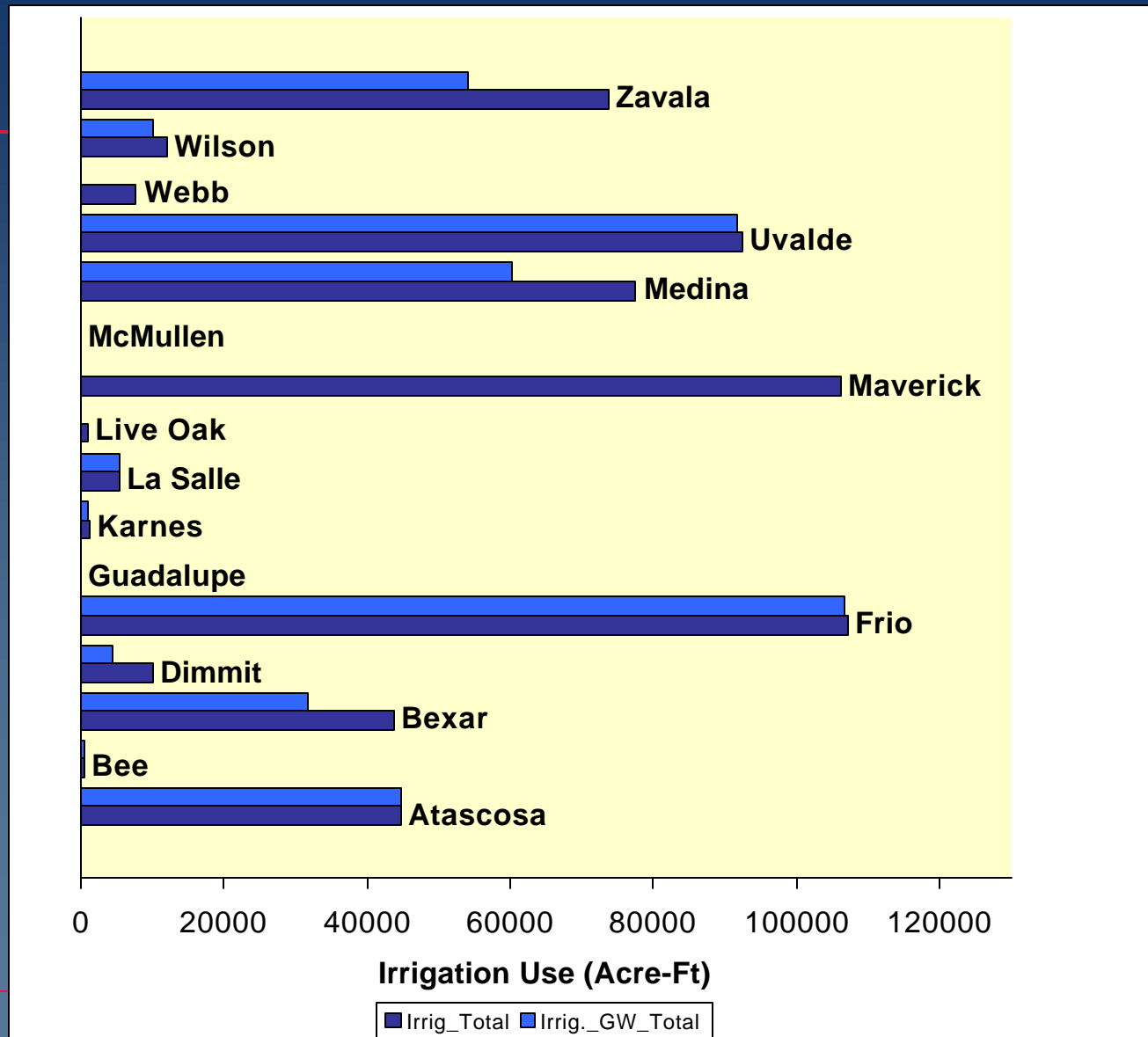
- Power
- Mining
- Manufacturing
- Municipal

– Land Use/ Population Density

- Rural/Domestic
- Livestock
- Irrigation



# Irrigation Use by County



# Water Levels and Regional GW Flow

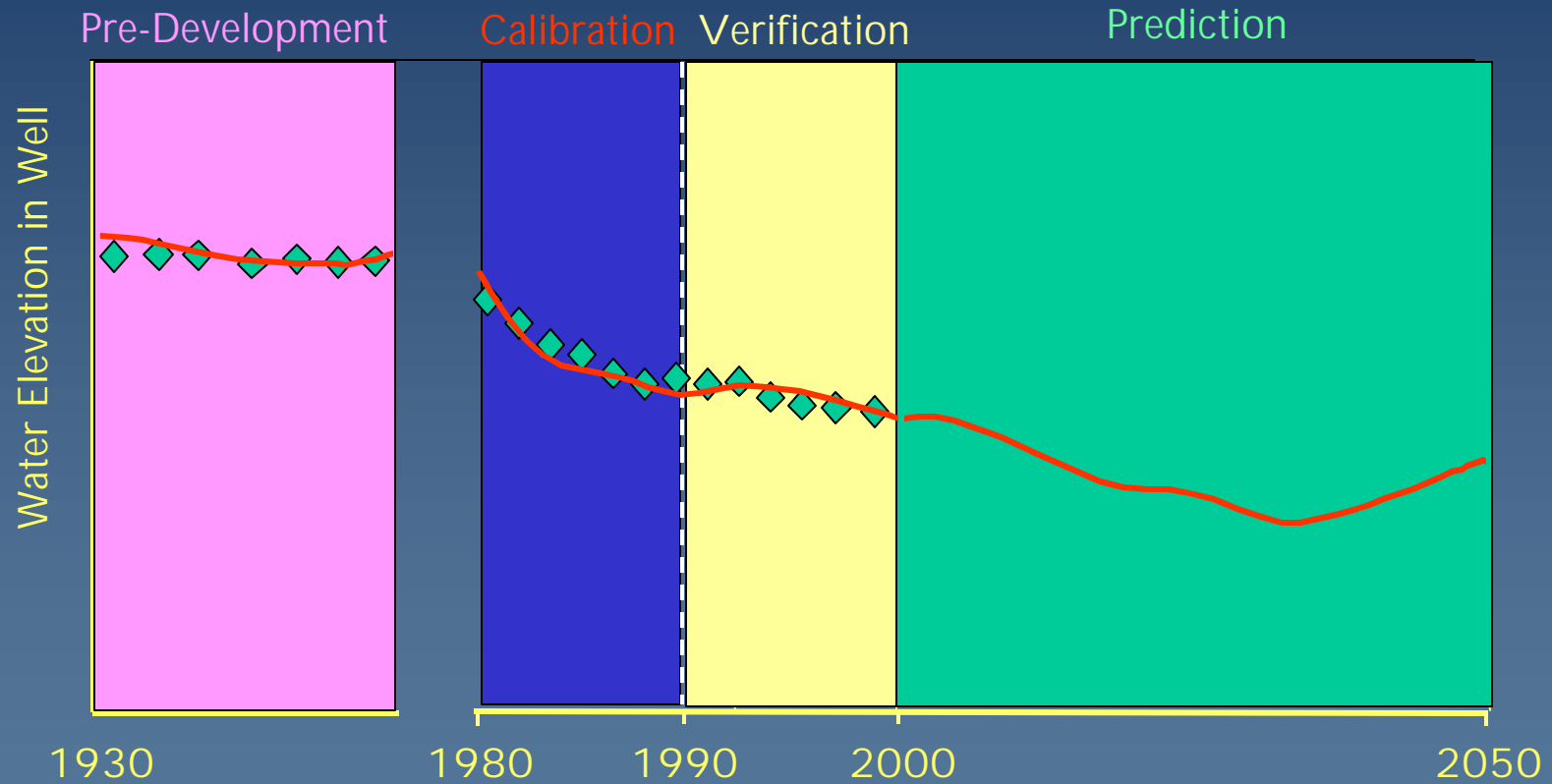
## ■ Objectives

- Develop potentiometric maps:
  - Predevelopment water levels for model initial.
  - 1990 water levels for model calibration
  - 2000 water levels for model verification
- Select hydrographs for calibration
- Assess transient water level changes for use as boundary conditions
- Evaluate cross-formational flow

# Modeling Periods

## LEGEND

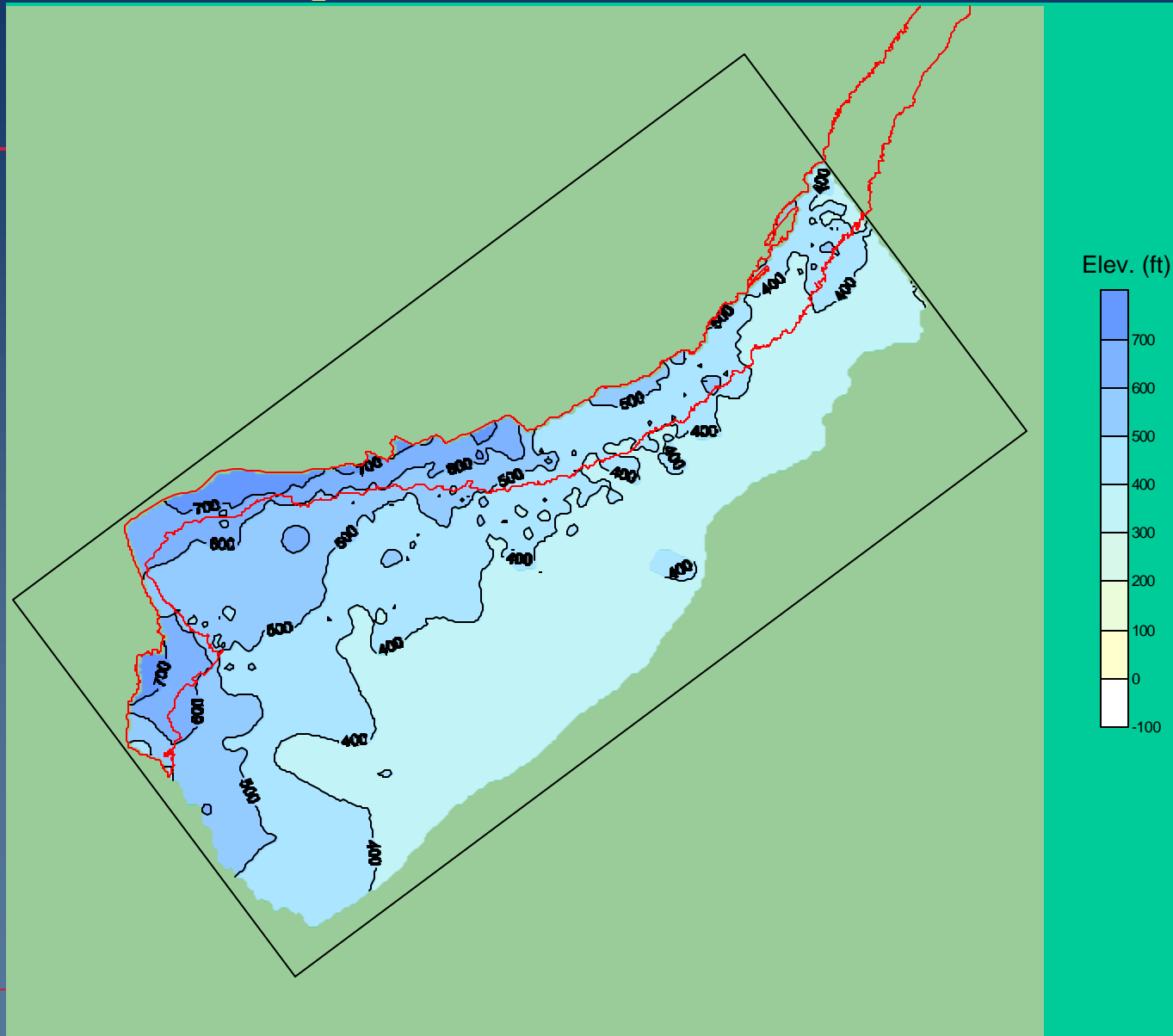
- ◆ Observed Water Level
- Model Water Level



# Approach for Predevelopment WL Contours

- Combined all Carrizo Sand, Wilcox Group, and Carrizo-Wilcox, undifferentiated data
- Selected maximum value measured in each well regardless of measurement date
  - Carrizo Sand - 1777 data points
  - Wilcox Group - 531 data points
  - Carrizo Sand and Wilcox Group, undifferentiated - 68 data points
- Removed data points if they were located updip of the outcrop
- Several data points were removed because the measurement point elevation was incorrect in the database
- Used a total of 2118 water-level measurements to develop contours

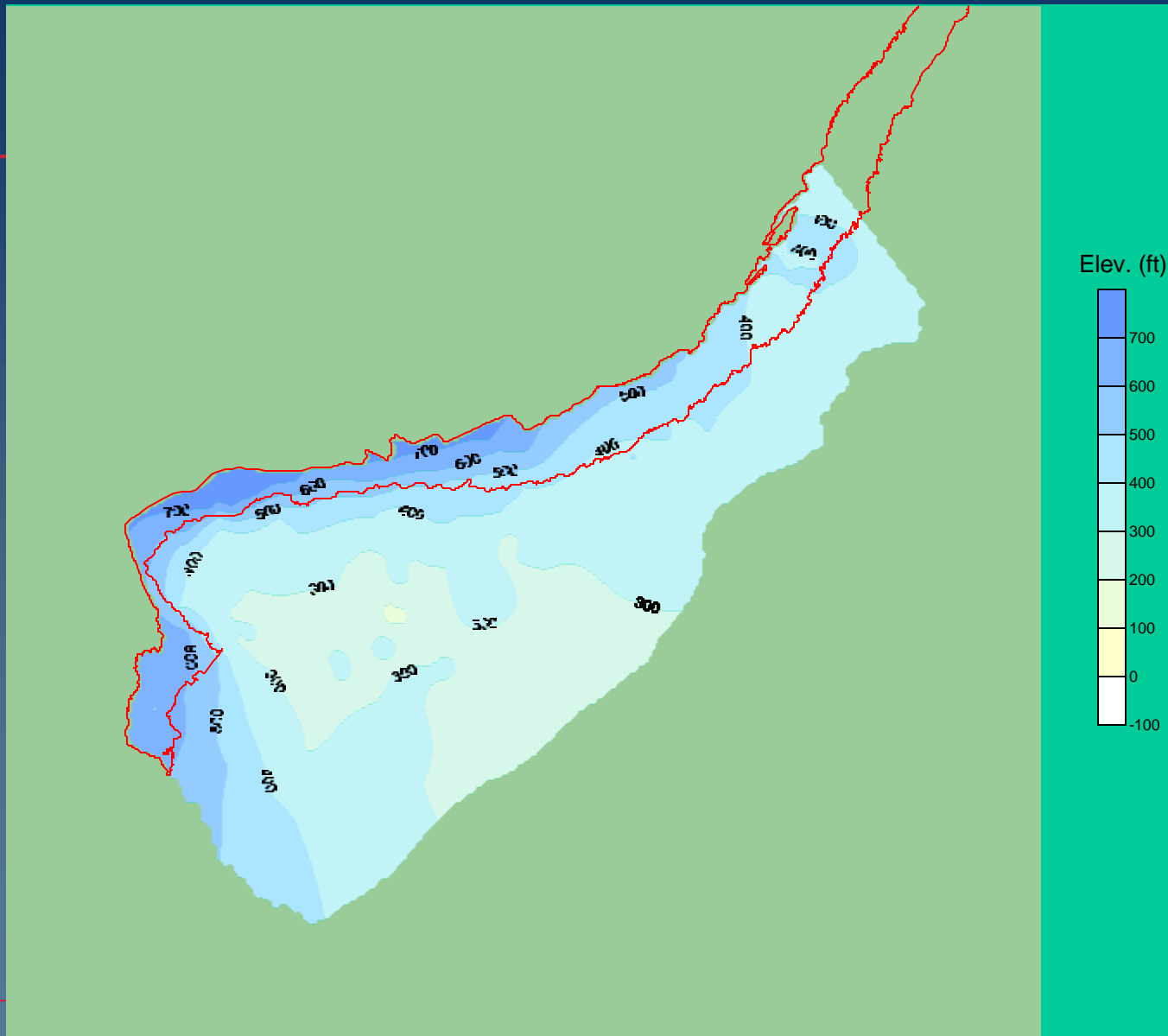
# Carrizo Sand and Wilcox Group Predevelopment Water Level Elevations



# Approach for 1990 WL Contours

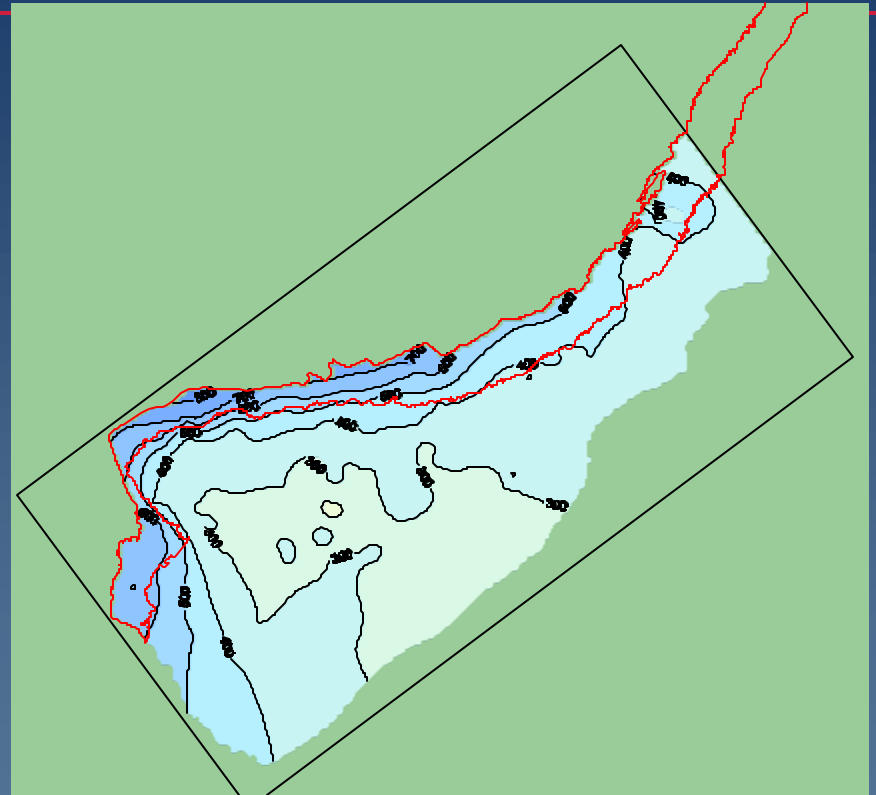
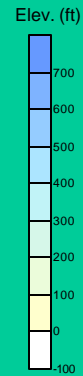
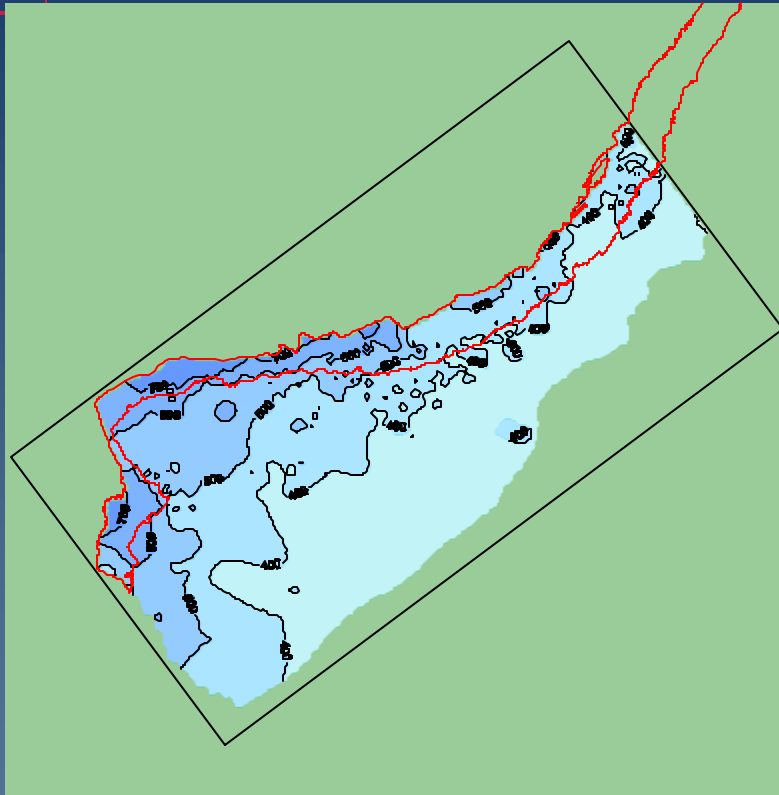
- Combined all Carrizo Sand, Wilcox Group, and Carrizo-Wilcox, undifferentiated data
- Calculated average water-level elevation for the years 1988 through 1992
- Removed data points located updip of the outcrop
- Several data points were removed because the measurement point elevation was incorrect in the database
- Used a total of 284 water-level measurements to develop contours

# Carrizo Sand and Wilcox Group 1990 Water Level Elevations



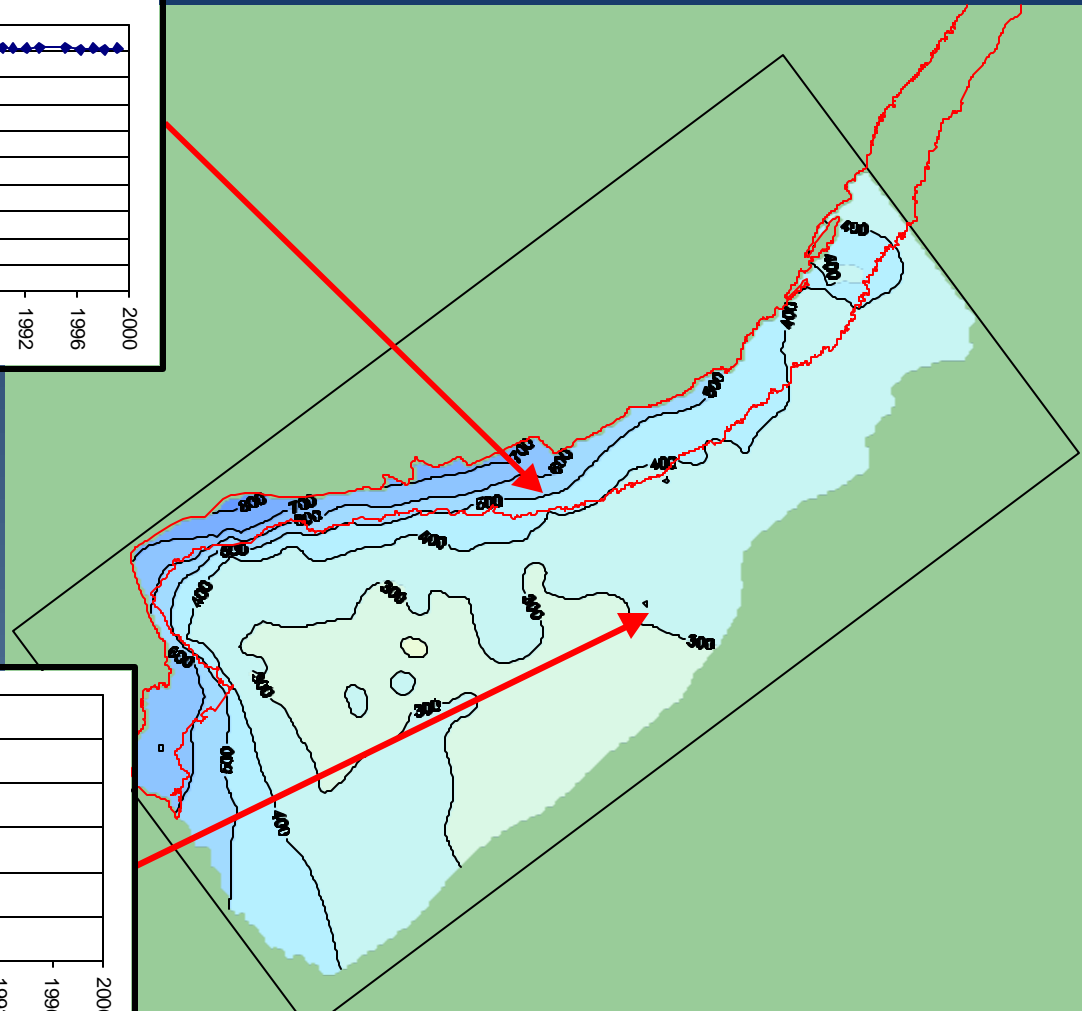
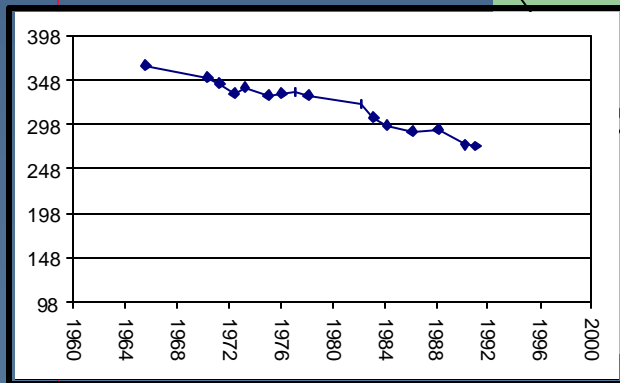
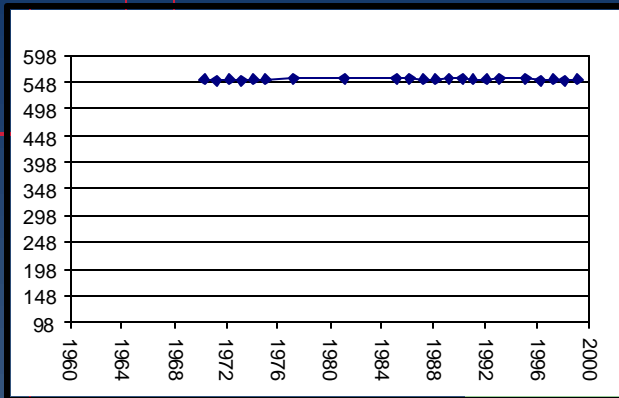
Predevelopment

1990





# Sample Hydrographs for Model Calibration



# Water Quality

- The GAM model does not explicitly account for groundwater quality differences through concentration or density
- As part of the GAM effort, we are developing water quality distributions for TDS and another constituent of interest to stakeholders.....feedback





# Southern GAM Schedule - Revised

2007

SAF 1 — April 24 

SAF 2 — Aug 7 

SAF 3 — Nov 

 Aug 13 — Conceptual Model

 Dec. — Initial model design

 Jan. — Calibrate steady-state model

2002

SAF 4 — Jan. 

SAF 5 — Apr. 

SAF 6 — July 

SAF 7 — Oct. 

 May — Calibrate transient model

 Aug. — Complete model predictions

 Sept. — Prepare draft report

 Dec. — Present SAF Model Seminar

2003

SAF 8 — Jan. 

 Jan. - Deliver Final Product

## ATTACHMENT A: SIGN-UP SHEET SAF 2

Name	Affiliation
Barry Miller	GCUWCD
Steve Musick	TNRCC
Diane Savage	Wilson County Water Action Project
Mary Katherine Robinson	Wilson County Water Action Project
Marvin & Alene Quivvy	Wilson County
Bill Klemt	LBG-Guyton
Mike McHoney	Evergreen UWCD
Steve Snider	Evergreen UWCD
Tony Malik	City of Stockdale
Carl Lambeck	City of Stockdale
Amond D Brownlow	Evergreen UGWCD
Gaylon Click	Wilson County Action Project
Grant Snyder	URS Corporation
Jeff Irvin	URS Corporation
Larry French	URS Corporation
Eliseo Valdez	Webb County Engineering City of Laredo
Ned Troshanov	Edwards Aquifer Authority
Steve Raabe	SARA

<b>Name</b>	<b>Affiliation</b>
Ronnie Hernandez	SARA
Fred Arce	SAWS
Mike Brinkmann	SAWS
George Rice	GRGH
John Waugh	SAWS
Linda Perez	Wilson Co. resident

**Meeting Minutes for the  
Second Southern Carrizo-Wilcox Groundwater Availability Model (GAM)  
Stakeholder Advisory Forum (SAF) Meeting**

**August 7, 2001**

**San Antonio River Authority**

**San Antonio, Texas**

The second Stakeholder Advisory Forum (SAF) Meeting for the Southern Carrizo-Wilcox Groundwater Availability Model (GAM) was held on August 7<sup>th</sup> from 2:00 until 5:00 PM at the San Antonio River Authority (SARA) Board Room in San Antonio, Texas. Attachment A of these meeting minutes provides a list of all participants who signed up as attending the meeting.

The purpose of the second SAF meeting was to present the conceptual model of the Carrizo-Wilcox aquifer for the Southern Carrizo-Wilcox GAM to interested stakeholders and to review the GAM objectives and expectations. The presentation material is available at the TWDB GAM website ([www.twdb.state.tx.us/gam](http://www.twdb.state.tx.us/gam)).

**Meeting Introduction: Ted Angle, TWDB**

The meeting was initiated by Ted Angle of the Texas Water Development Board (TWDB). He addressed specific concerns that were voiced during the first SAF meeting on April 24<sup>th</sup>, 2001. The specific concerns were related to the Aquifer pumpage and storage project by the San Antonio Water System (SAWS) whereby river water would be injected into the aquifer for later pumpage during drought conditions. This particular project was initially not included in the Region L water demand projections and consequently was not intended to be included in the GAM. The TWDB conferred with the contractor (DE&S) for the Southern Carrizo-Wilcox GAM on the possibility of including the SAWS project for a preliminary assessment into the GAM prior to the completion of the GAM project. Ted Angle informed the stakeholders that TWDB's Groundwater Availability Section will assist the contractor to implement SAWS aquifer storage and pumpage project into the GAM as soon as the transient model is developed and will provide the results of the particular modeling to the stakeholders.

**SAF Presentation: Rainer Senger, Duke Engineering and Services (DE&S)**

After the introduction by Ted Angle, Rainer Senger of the Duke Engineering and Services Southern Carrizo-Wilcox Team presented a prepared presentation. The presentation was structured according to the following outline:

1. Review of the GAM Project, Objectives, and Expectations
2. Description of the Conceptual Model for the Southwest Carrizo-Wilcox Aquifer
3. GAM Schedule – SAF Meetings and Project Milestones



The presentation is available on the GAM website ([www.twdb.state.tx.us/gam](http://www.twdb.state.tx.us/gam)).

**Questions and Answers: Open Forum:**

Q. Why 3 layers for the Carrizo-Wilcox formation?

A. To maintain the consistency of the aquifer geometry across all the models: Northern, Central, and Southern Carrizo-Wilcox GAMs.

Q. Will the planned Sparta GAM be a “breakout” from the SCW GAM?

A. All data and applicable information will be included in the Sparta GAM, but it will be a stand alone model.

Q. Question/concerns regarding the movement of high TDS waters “invading” areas of increased pumping, example Karnes County.

A. The model will not explicitly simulate migration of high TDS water, but will examine potential flow from beyond the postulated downdip limit of potable water as defined by the TWDB

Q. B. Klemt asked about layers and formations west of the Frio River and if more work would be done further identifying them.

A. Current modeling will rely on published interpretations west of the Frio River, where the Reklaw disappears and is replaced by the Bigford Fm.

Q. Are we revisiting sand thickness maps?

A. All sand thickness data (from Hamlin, 1988) are being evaluated and the appropriate data will be used for analysis of hydraulic property distributions to be used in the model.

Q. What information are used to evaluate the drought of record (DOR)?

A. Historical data based on stream flows and climate data will be used to define the DOR conditions

- Q. Will you look at the shorter, but just as intense DOR like periods?
- A. Yes, short drought periods will be incorporated in the 50 year predictive runs, where the identified DOR period will be added to a 10, 20, 30, 40, and 50 year period with average climatic conditions.
- Q. Will the 1950's DOR be run over the entire 50 year predictive run?
- A. No.
- Q. Where in the model run will the DOR be located in the 50 year predictive run?
- A. The conditions of the DOR will be defined for the entire model area, recognizing that there are local variations in terms of precipitation/climate and streamflow. At the moment, we are not sure, if it is possible to incorporate localized DOR events without introducing inconsistency in the model.
- Q. The swing in irrigation pumping in the Edwards is great. What about in the CW? Will it be accounted for?
- A. Yes.
- Q. How much data is based on actual, current measurement? Are you actively collecting new data for the model?
- A. Very little new data is being collected for the model, much of the data being used has been previously published. Additional data/information will be included as it becomes available
- Q. Stockdale City manager Carl Lambeck offers all WL measurements on a used city well.
- A. Accepted.
- Q. How will the model introduce recharge?
- A. With MODFLOW's Stream and Recharge software package.

General discussions:

- Bill Klempt made mention of a number of flowing wells in Gonzales county that should be considered as discharge for the model.
- General concern about the accuracy and representativeness of reported irrigation pumpage in the TWDB data base
- Potential impact of water-level declines on nearby gas and oil fields in Carrizo Fm.

A: Known location of these oil/gas fields are being marked to determine potential water-level declines in order to assess its impact on ground-water.

## ATTACHMENT A: SIGN-UP SHEET

Name	Affiliation	Contact Information (including email address, if available)
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**Meeting Minutes for the  
Second Southern Carrizo-Wilcox Groundwater Availability Model (GAM)  
Stakeholder Advisory Forum (SAF) Meeting**

**August 7, 2001**

**San Antonio River Authority**

**San Antonio, Texas**

The second Stakeholder Advisory Forum (SAF) Meeting for the Southern Carrizo-Wilcox Groundwater Availability Model (GAM) was held on August 7<sup>th</sup> from 2:00 until 5:00 PM at the San Antonio River Authority (SARA) Board Room in San Antonio, Texas. Attachment A of these meeting minutes provides a list of all participants who signed up as attending the meeting.

The purpose of the second SAF meeting was to present the conceptual model of the Carrizo-Wilcox aquifer for the Southern Carrizo-Wilcox GAM to interested stakeholders and to review the GAM objectives and expectations. The presentation material is available at the TWDB GAM website ([www.twdb.state.tx.us/gam](http://www.twdb.state.tx.us/gam)).

**Meeting Introduction: Ted Angle, TWDB**

The meeting was initiated by Ted Angle of the Texas Water Development Board (TWDB). He addressed specific concerns that were voiced during the first SAF meeting on April 24<sup>th</sup>, 2001. The specific concerns were related to the Aquifer pumpage and storage project by the San Antonio Water System (SAWS) whereby river water would be injected into the aquifer for later pumpage during drought conditions. This particular project was initially not included in the Region L water demand projections and consequently was not intended to be included in the GAM. The TWDB conferred with the contractor (DE&S) for the Southern Carrizo-Wilcox GAM on the possibility of including the SAWS project for a preliminary assessment into the GAM prior to the completion of the GAM project. Ted Angle informed the stakeholders that TWDB's Groundwater Availability Section will assist the contractor to implement SAWS aquifer storage and pumpage project into the GAM as soon as the transient model is developed and will provide the results of the particular modeling to the stakeholders.

**SAF Presentation: Rainer Senger, Duke Engineering and Services (DE&S)**

After the introduction by Ted Angle, Rainer Senger of the Duke Engineering and Services Southern Carrizo-Wilcox Team presented a prepared presentation. The presentation was structured according to the following outline:

1. Review of the GAM Project, Objectives, and Expectations
2. Description of the Conceptual Model for the Southwest Carrizo-Wilcox Aquifer
3. GAM Schedule – SAF Meetings and Project Milestones

The presentation is available on the GAM website ([www.twdb.state.tx.us/gam](http://www.twdb.state.tx.us/gam)).

**Questions and Answers: Open Forum:**

Q. Why 3 layers for the Carrizo-Wilcox formation?

A. To maintain the consistency of the aquifer geometry across all the models: Northern, Central, and Southern Carrizo-Wilcox GAMs.

Q. Will the planned Sparta GAM be a “breakout” from the SCW GAM?

A. All data and applicable information will be included in the Sparta GAM, but it will be a stand alone model.

Q. Question/concerns regarding the movement of high TDS waters “invading” areas of increased pumping, example Karnes County.

A. The model will not explicitly simulate migration of high TDS water, but will examine potential flow from beyond the postulated downdip limit of potable water as defined by the TWDB

Q. B. Klemt asked about layers and formations west of the Frio River and if more work would be done further identifying them.

A. Current modeling will rely on published interpretations west of the Frio River, where the Reklaw disappears and is replaced by the Bigford Fm.

Q. Are we revisiting sand thickness maps?

A. All sand thickness data (from Hamlin, 1988) are being evaluated and the appropriate data will be used for analysis of hydraulic property distributions to be used in the model.

Q. What information are used to evaluate the drought of record (DOR)?

A. Historical data based on stream flows and climate data will be used to define the DOR conditions



- Q. Will you look at the shorter, but just as intense DOR like periods?
- A. Yes, short drought periods will be incorporated in the 50 year predictive runs, where the identified DOR period will be added to a 10, 20, 30, 40, and 50 year period with average climatic conditions.
- Q. Will the 1950's DOR be run over the entire 50 year predictive run?
- A. No.
- Q. Where in the model run will the DOR be located in the 50 year predictive run?
- A. The conditions of the DOR will be defined for the entire model area, recognizing that there are local variations in terms of precipitation/climate and streamflow. At the moment, we are not sure, if it is possible to incorporate localized DOR events without introducing inconsistency in the model.
- Q. The swing in irrigation pumping in the Edwards is great. What about in the CW? Will it be accounted for?
- A. Yes.
- Q. How much data is based on actual, current measurement? Are you actively collecting new data for the model?
- A. Very little new data is being collected for the model, much of the data being used has been previously published. Additional data/information will be included as it becomes available
- Q. Stockdale City manager Carl Lambeck offers all WL measurements on a used city well.
- A. Accepted.
- Q. How will the model introduce recharge?
- A. With MODFLOW's Stream and Recharge software package.

General discussions:

- Bill Klempt made mention of a number of flowing wells in Gonzales county that should be considered as discharge for the model.
- General concern about the accuracy and representativeness of reported irrigation pumpage in the TWDB data base
- Potential impact of water-level declines on nearby gas and oil fields in Carrizo Fm.

A: Known location of these oil/gas fields are being marked to determine potential water-level declines in order to assess its impact on ground-water.

