Stakeholder Advisory Forum - 3

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

Carrizo Springs Civic Center

Carrizo Springs, Texas

November 27, 2001

Duke Engineering & Services
A Duke Energy Company

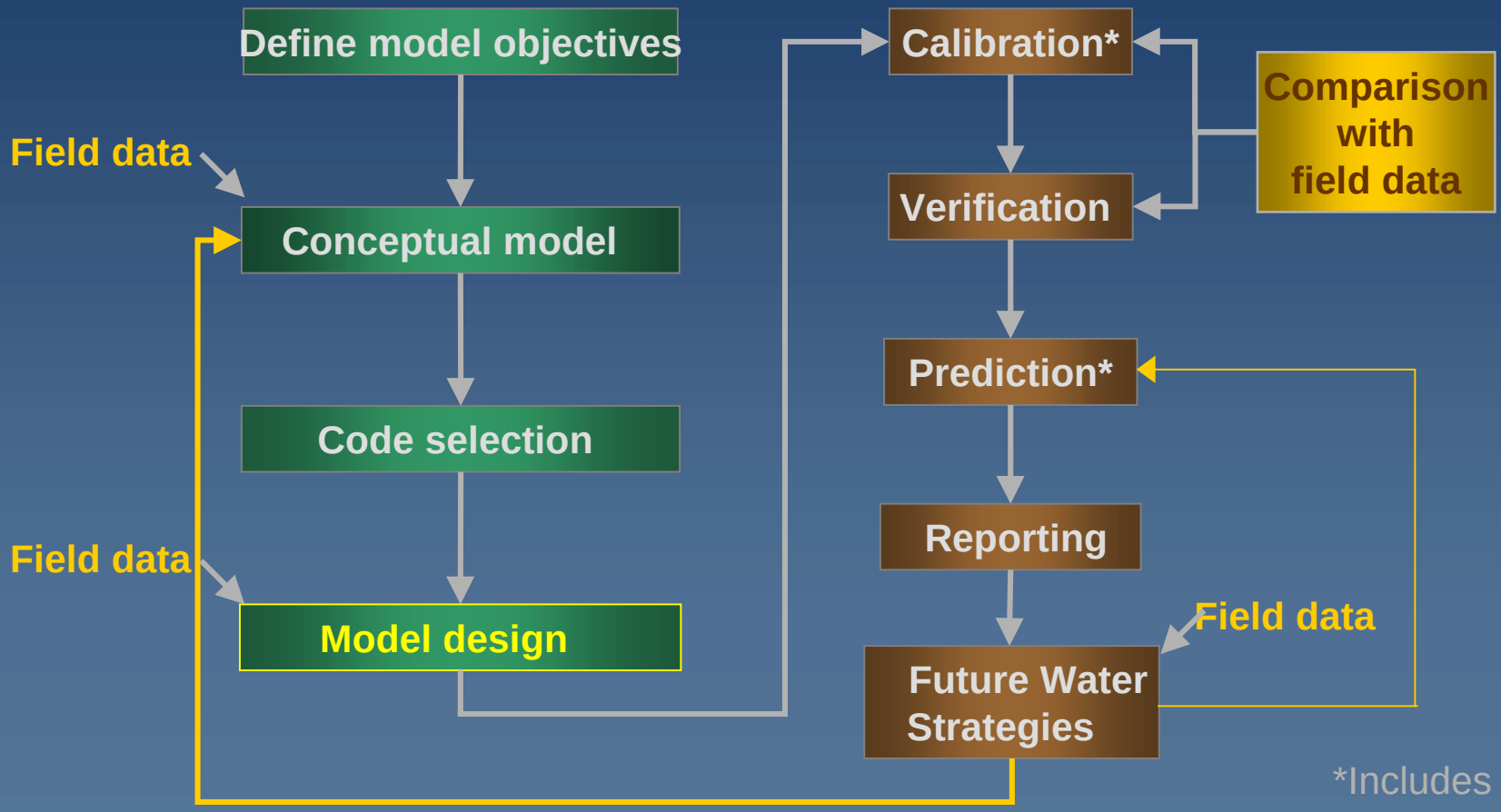
PARSONS

WATERSTONE
Environmental Hydrology and Engineering, Inc.

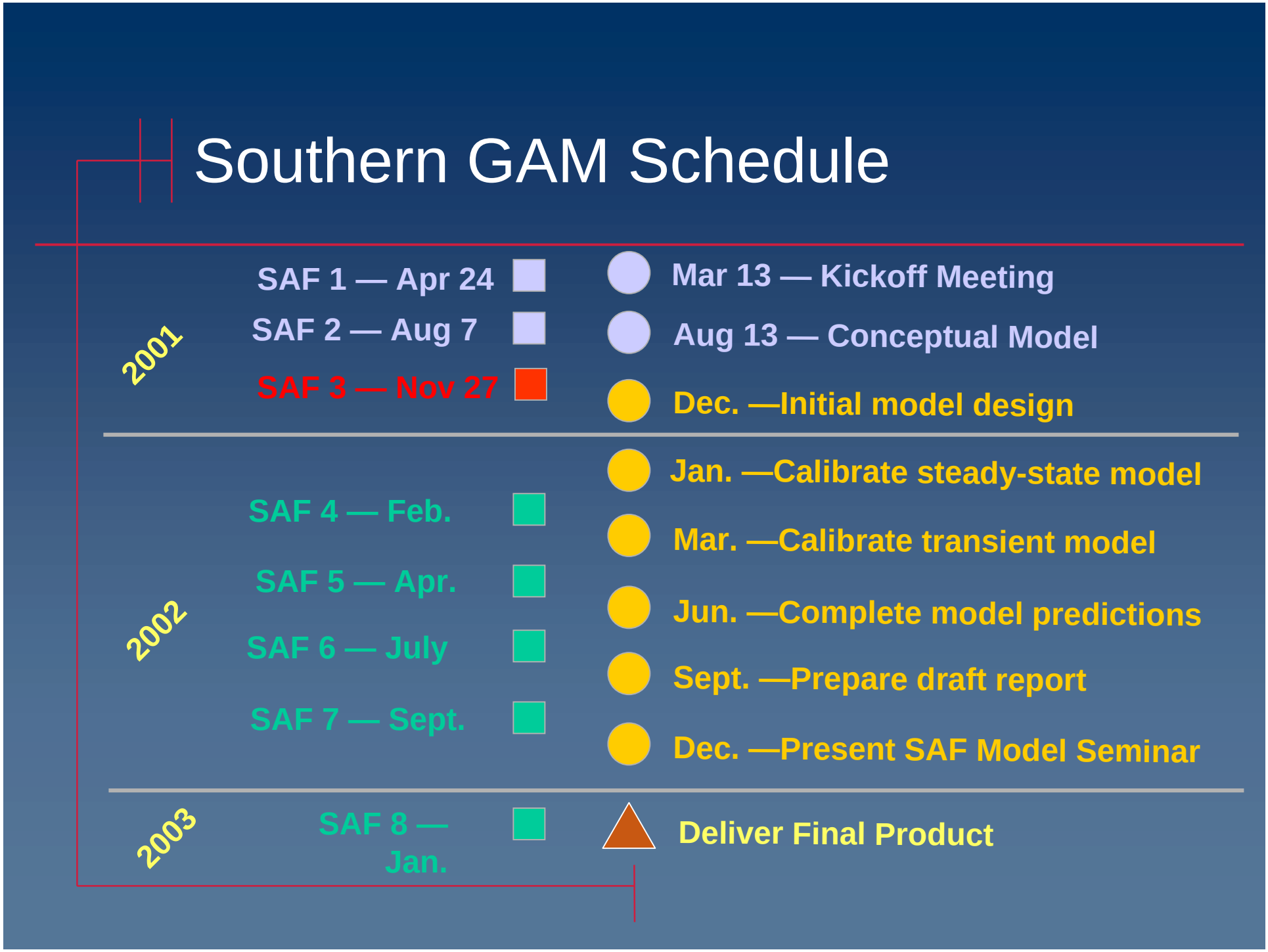
GAM Objectives

- 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



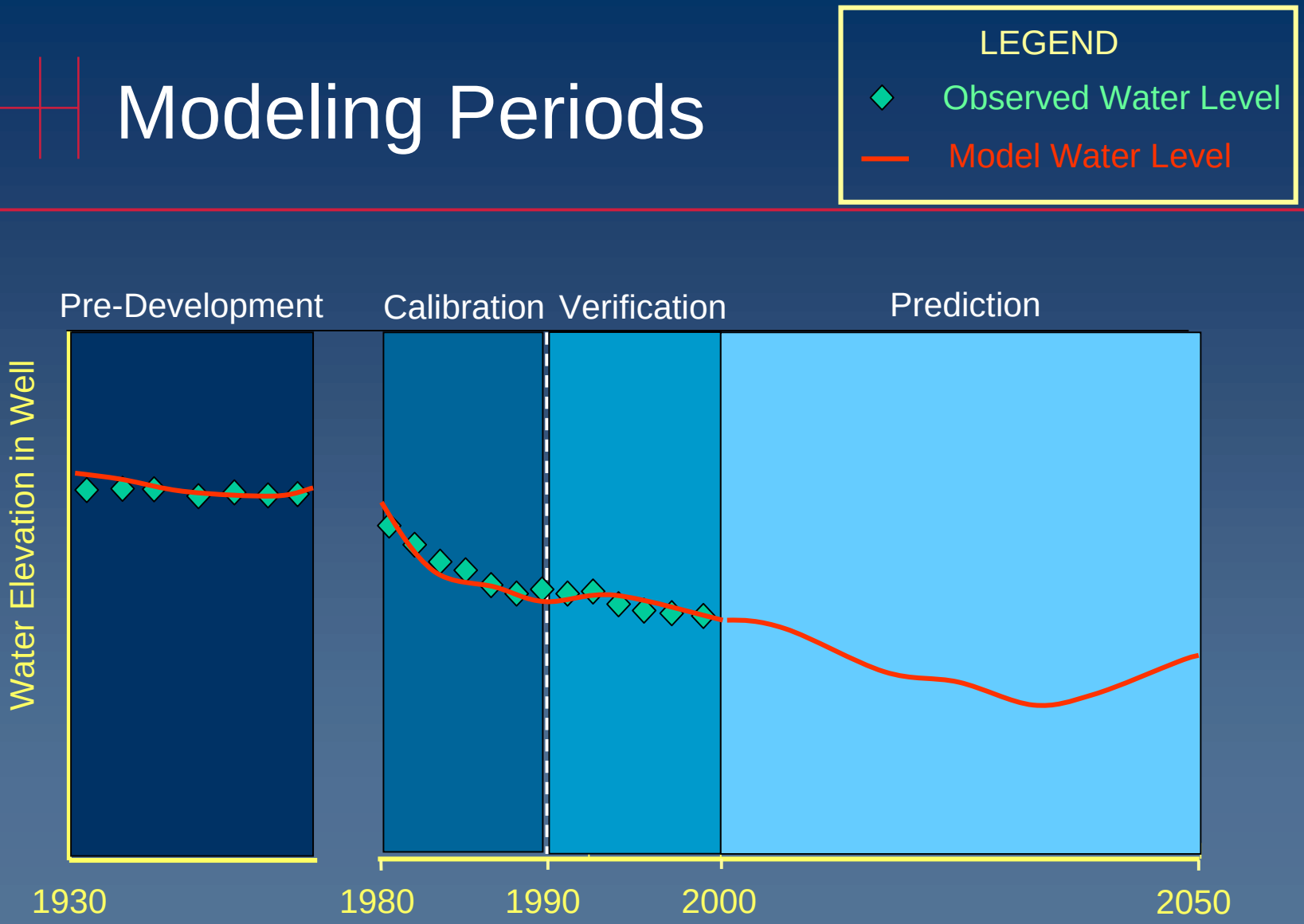
Southern GAM Schedule



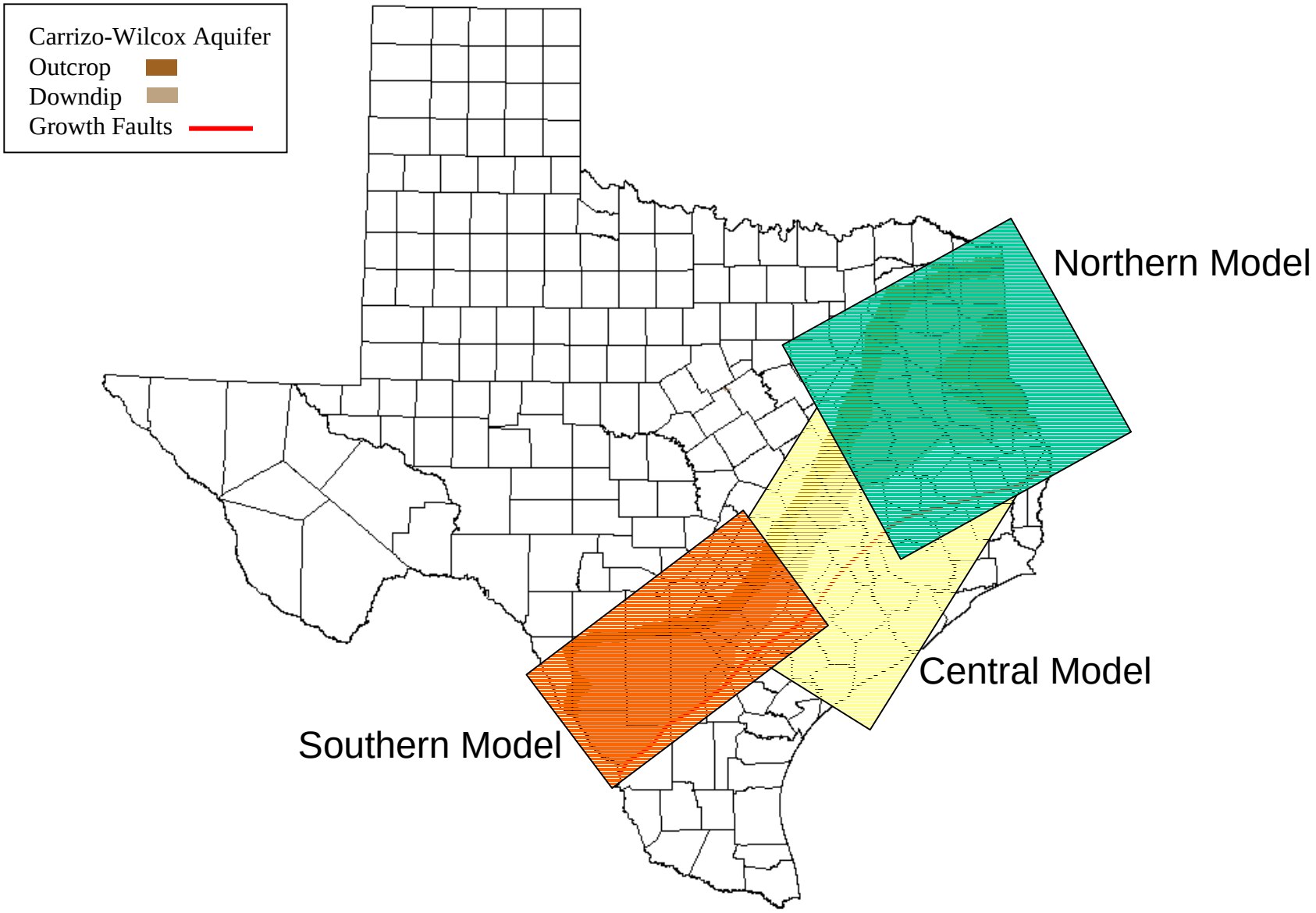
Model Specifications

- 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
- Calibration to within 10% of head drop

Modeling Periods



Carrizo-Wilcox GAM Model Domains

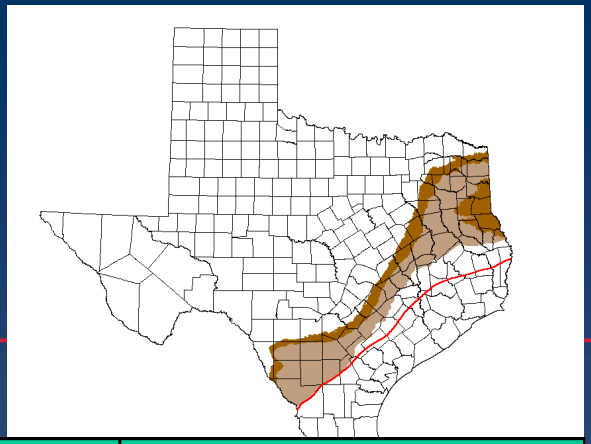


Model Design

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

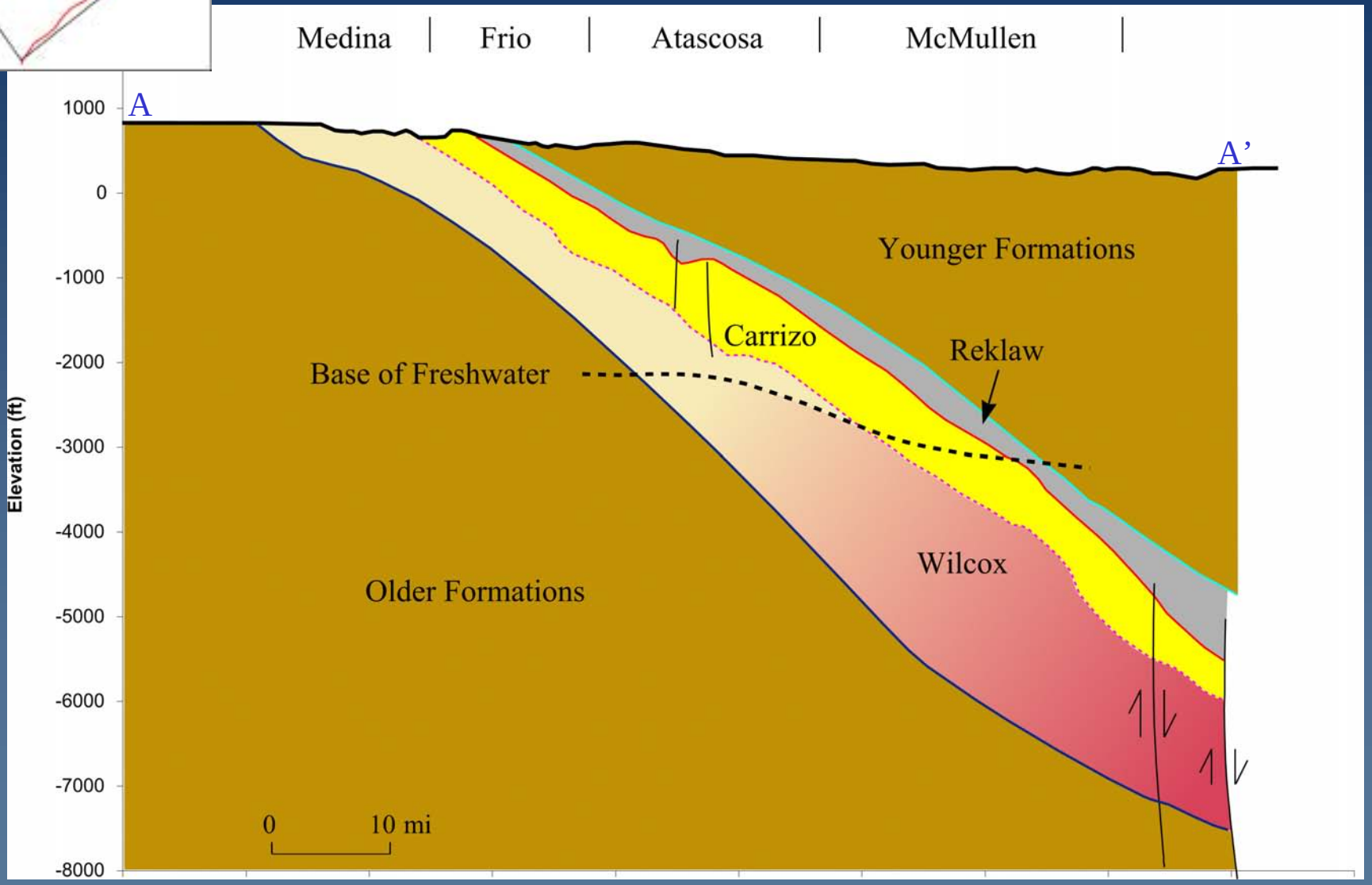
Aquifer Geometry

Geologic Framework — Stratigraphy



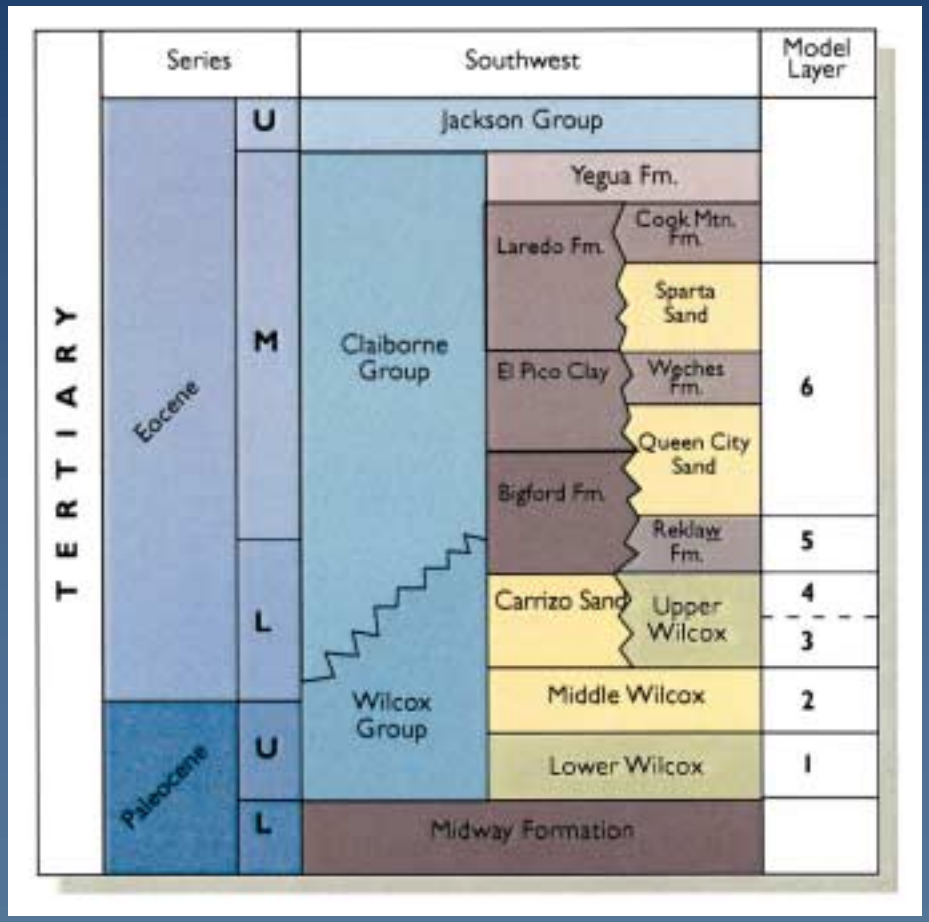
	Series		South Texas		Central Texas	Sabine Uplift
Tertiary	Eocene	U	Jackson Group		→	→
		M	Claiborne Group	Yegua Formation	→	→
				Cook Mtn. Fm.	→	→
				Sparta Sand	→	→
				Weches Formation	→	→
				Queen City Sand	→	→
				Recklaw Formation	→	→
		L	Wilcox Group	Carrizo Sand / Upper Wilcox	Carrizo Sand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

Carrizo-Wilcox Aquifer Down-dip Boundary



Model Layers

- Total of six layers
  - Carrizo
  - 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.

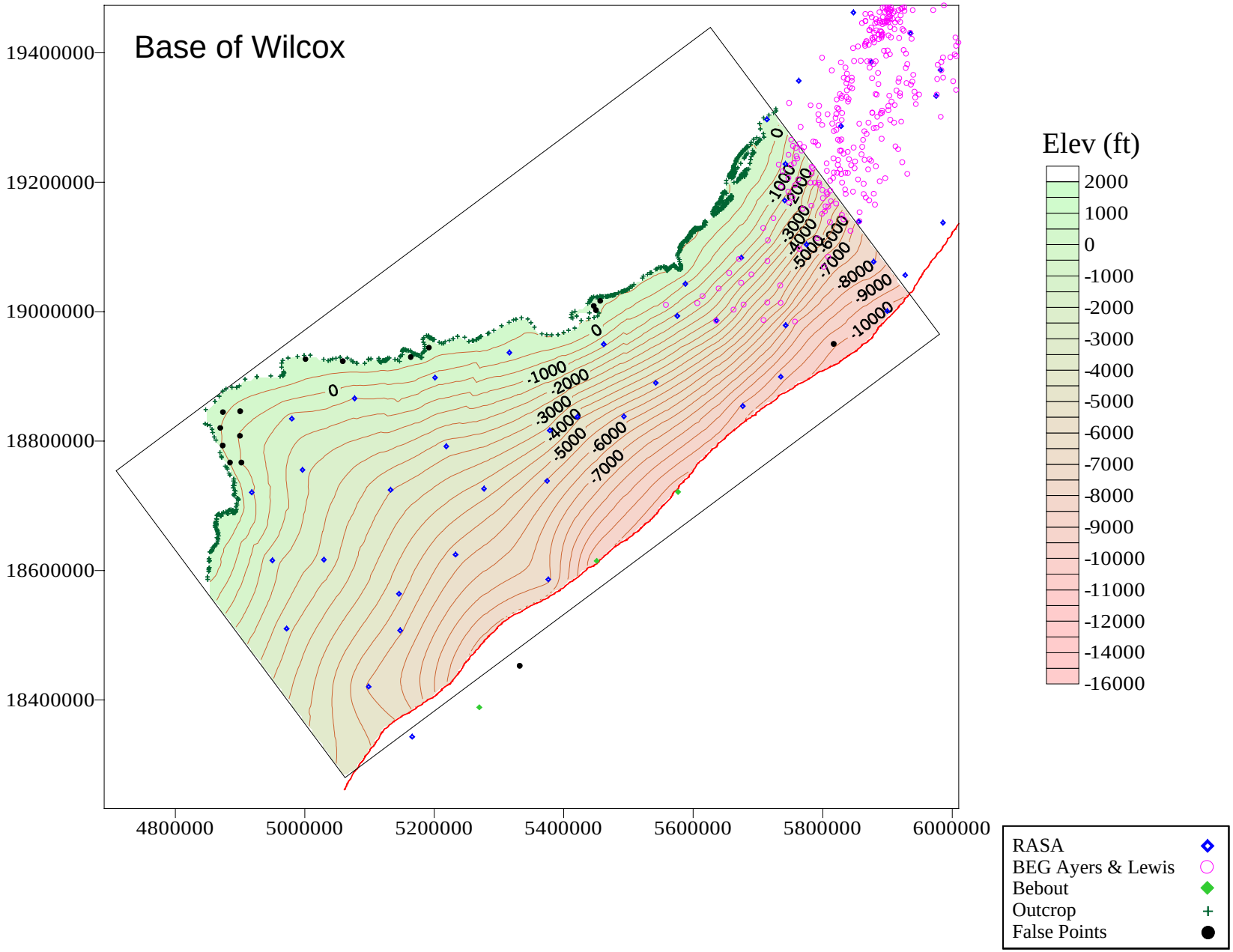


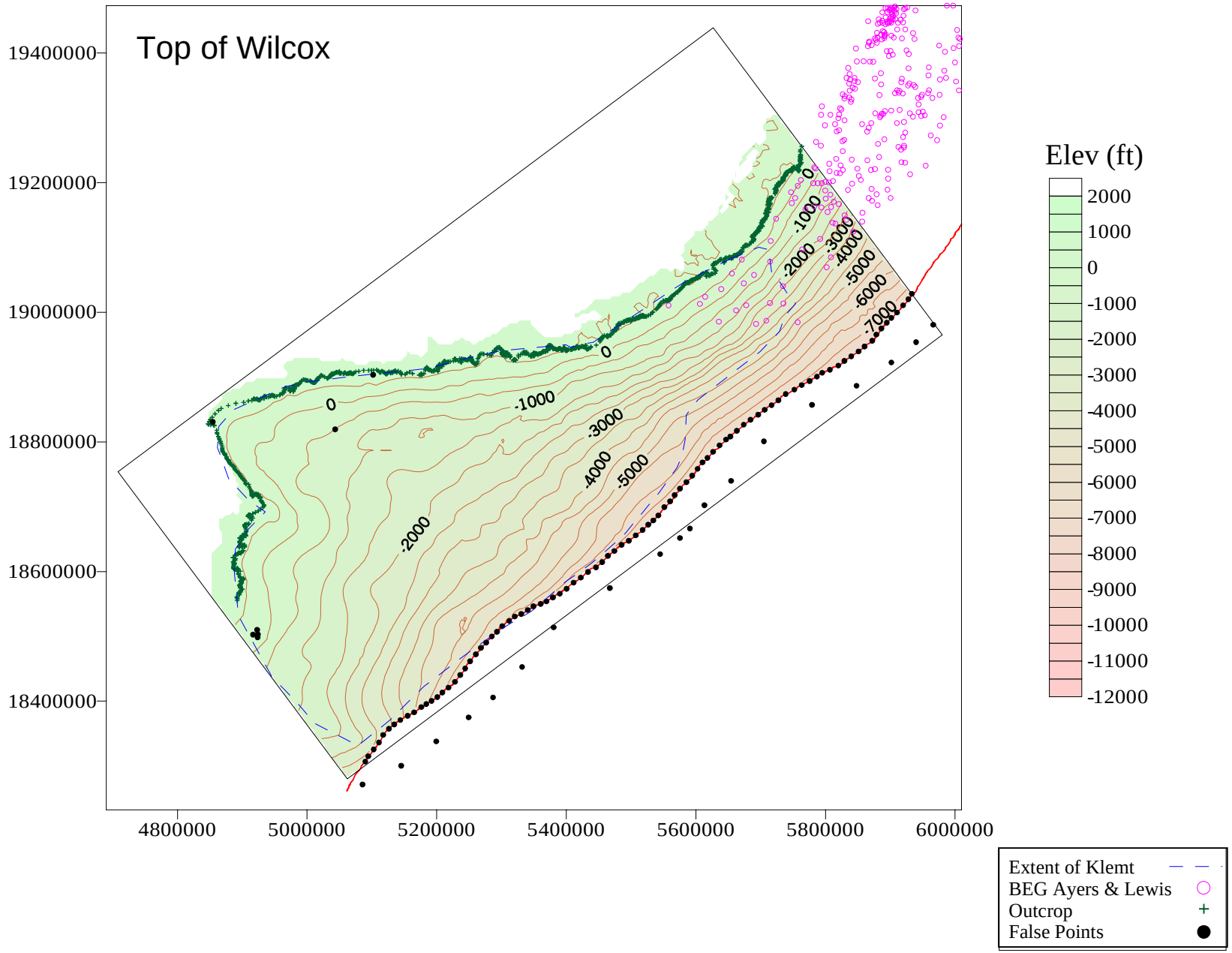
Stratigraphic Data Sources

- Data Base
  - Klemt (1976)
    - Carrizo Aquifer (Carrizo & Upper Wilcox)
  - TWDB Report 157 (1972)
    - Top of Carrizo-Wilcox
  - USGS RASA (Texas - LA - MS))
    - Middle Wilcox (TX: entire Wilcox)

Stratigraphic Data Sources

- Bebout et al. (1982) (Texas)
  - 3 layers for Wilcox (in cross sections)
  - Upper Wilcox includes the Carrizo Sand (SW)
- BEG - Ayers and Lewis (1985)
  - 3 layers for Wilcox (Calvert Bluff, Simsboro, Hooper)
- TWDB County Reports
- Gonzales Co. GWCD data


Base of Wilcox
19400000
19200000
19000000
18800000
18600000
18400000
4800000
5000000
5200000
5400000
5600000
5800000
6000000
Elev (ft)
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-11000
-12000
-14000
-16000
RASA
BEG Ayers & Lewis
Bebout
Outcrop
False Points


Top of Wilcox
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19200000
19000000
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18600000
18400000
4800000
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5200000
5400000
5600000
5800000
6000000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
Elev (ft)
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-1000
-2000
-3000
-4000
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-10000
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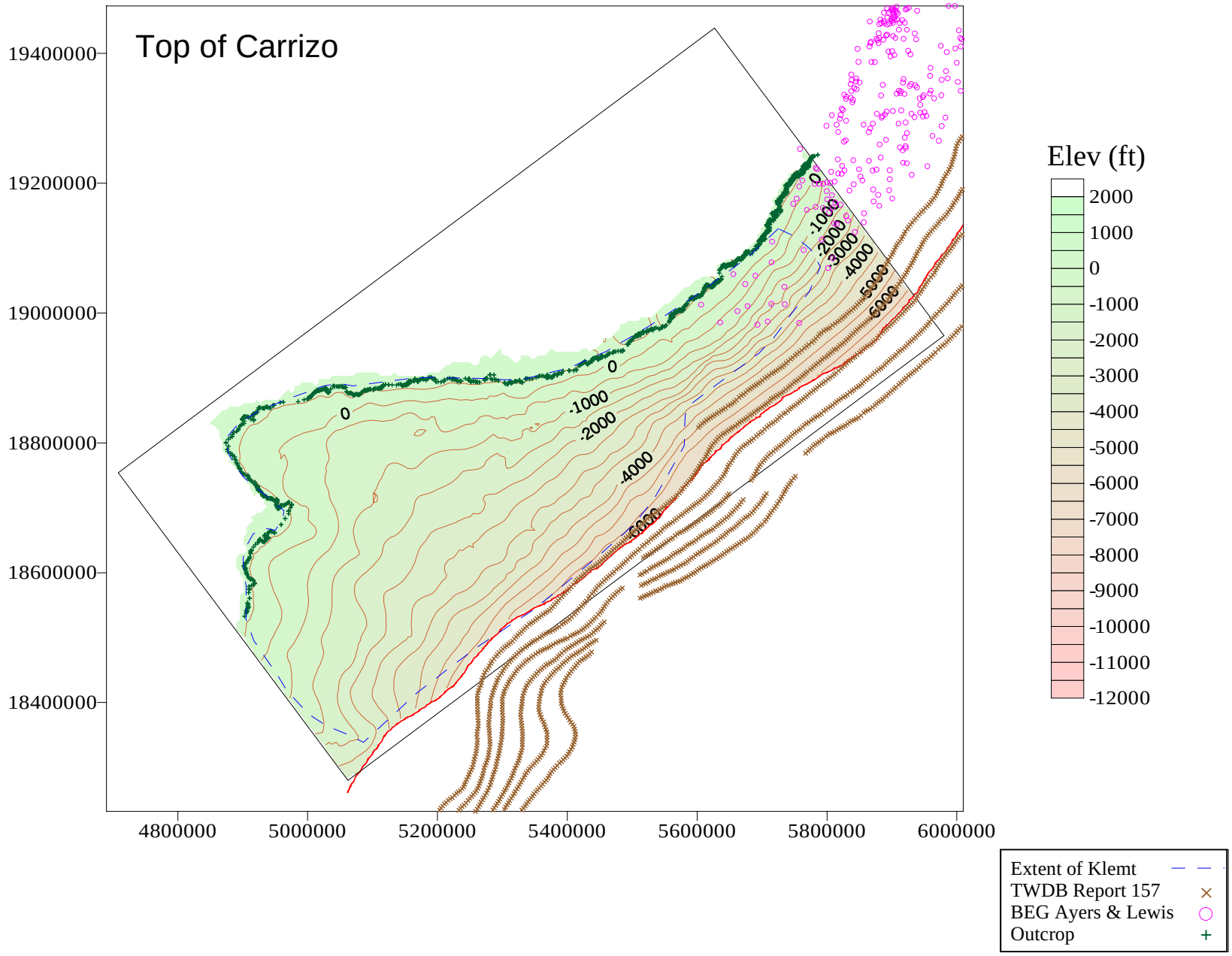
-12000
Extent of Klemt
BEG Ayers & Lewis
Outcrop
False Points


Top of Carrizo
19400000
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Elev (ft)
2000
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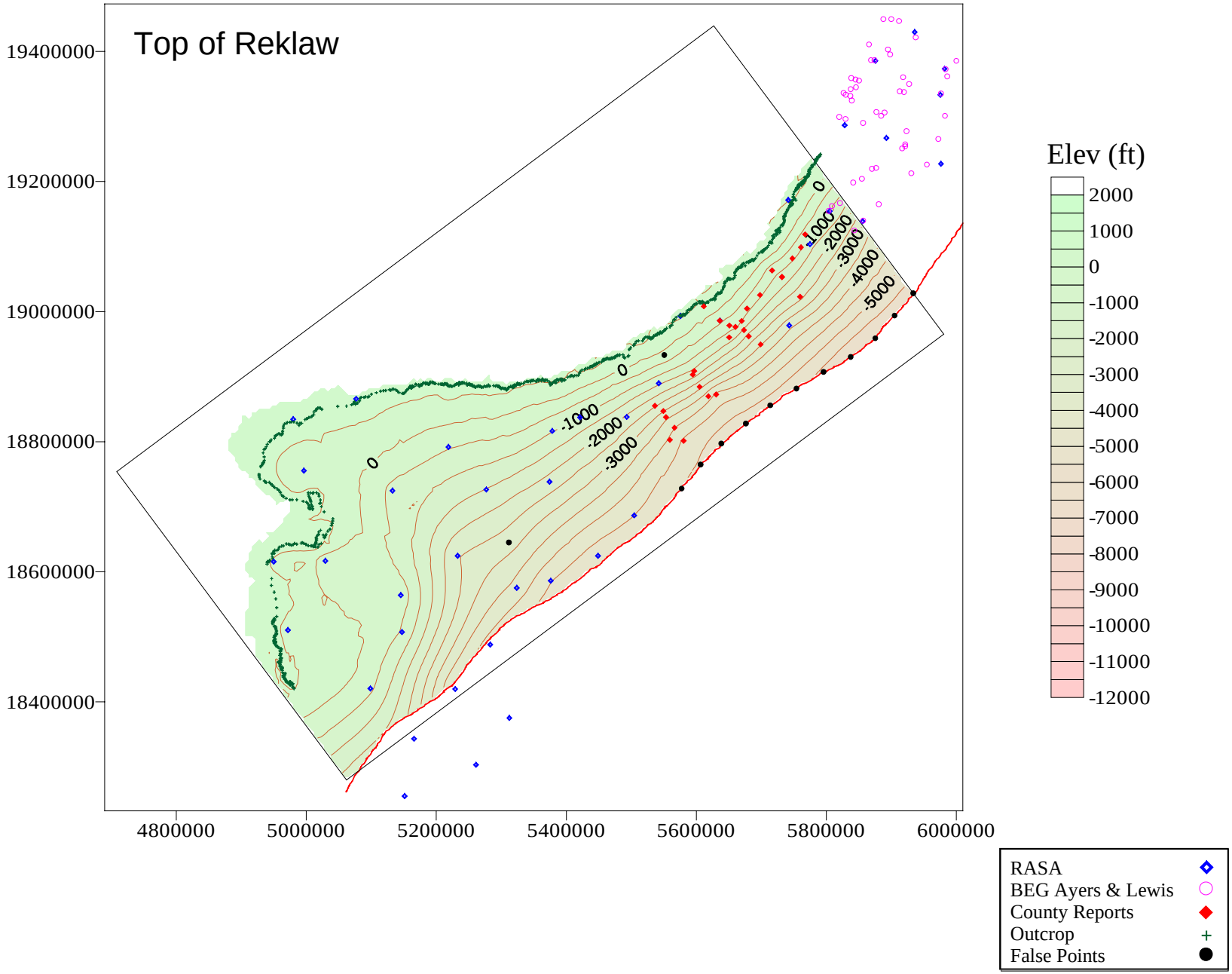
-10000
-11000
-12000
Extent of Klemt
TWDB Report 157
BEG Ayers & Lewis
Outcrop


Top of Reklaw
19400000
19200000
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18600000
18400000
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5200000
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0
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-3000
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-5000
Elev (ft)
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
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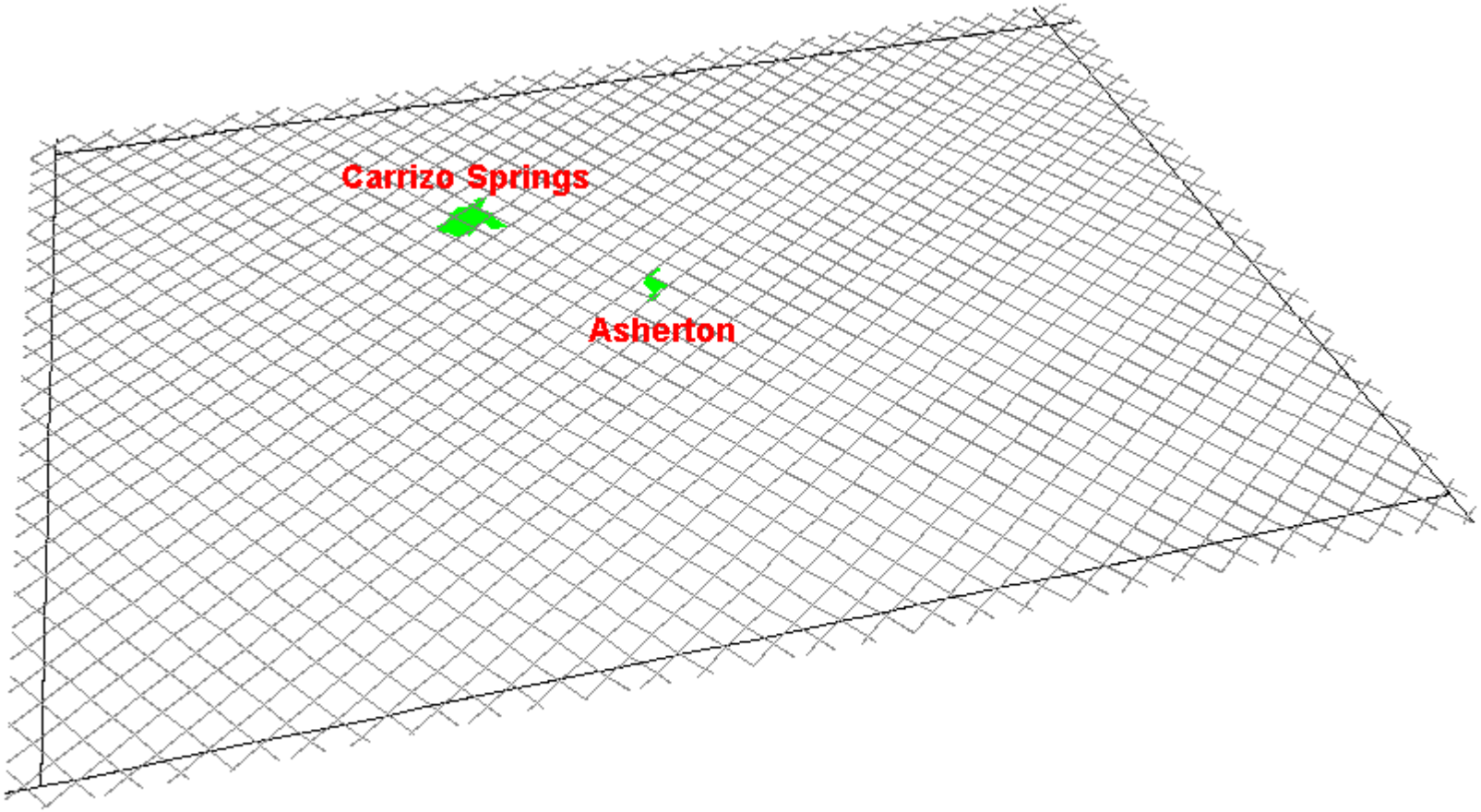
-10000
-11000
-12000
RASA
BEG Ayers & Lewis
County Reports
Outcrop
False Points

Model Grid Scale



Aquifer Geometry - Status

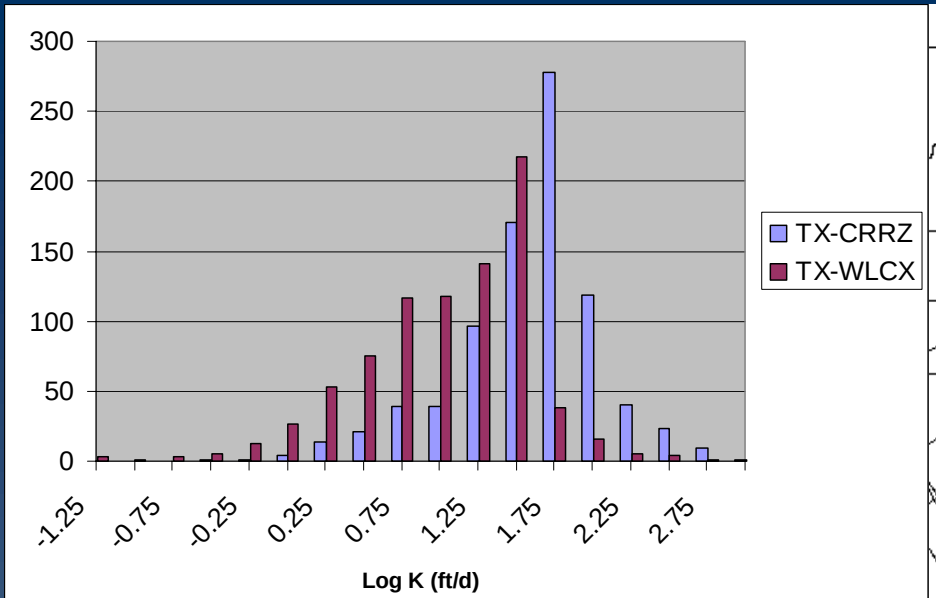
- Data sources identified
- Preliminary model structure is nearly complete
- Data QA/QC nearly complete
- In Progress:
  - development of 3D model grid
  - incorporation of Gonzales county data

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

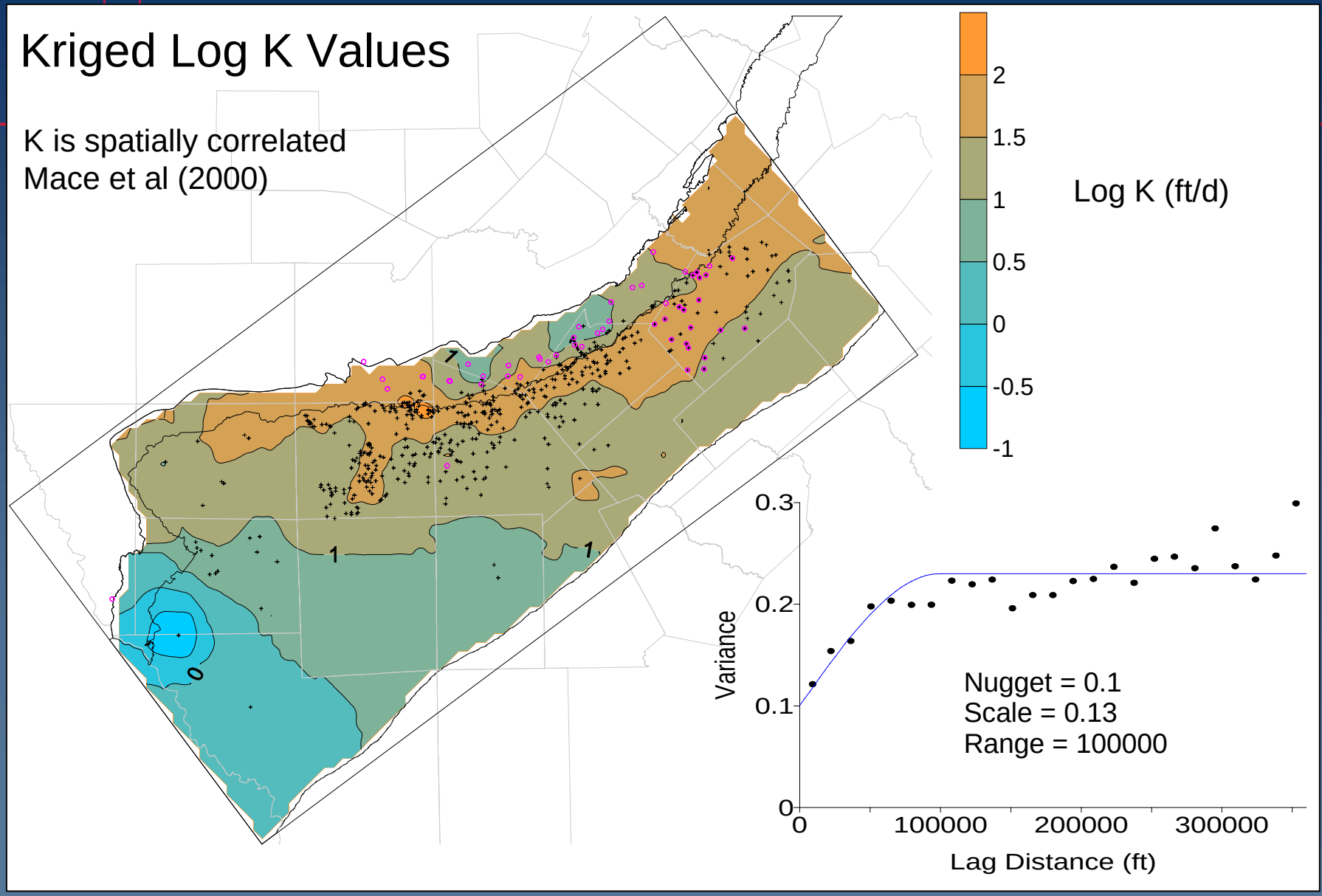


Formation	K (ft/d)
Texas - Carrizo	29.3
Texas - Wilcox	8.3

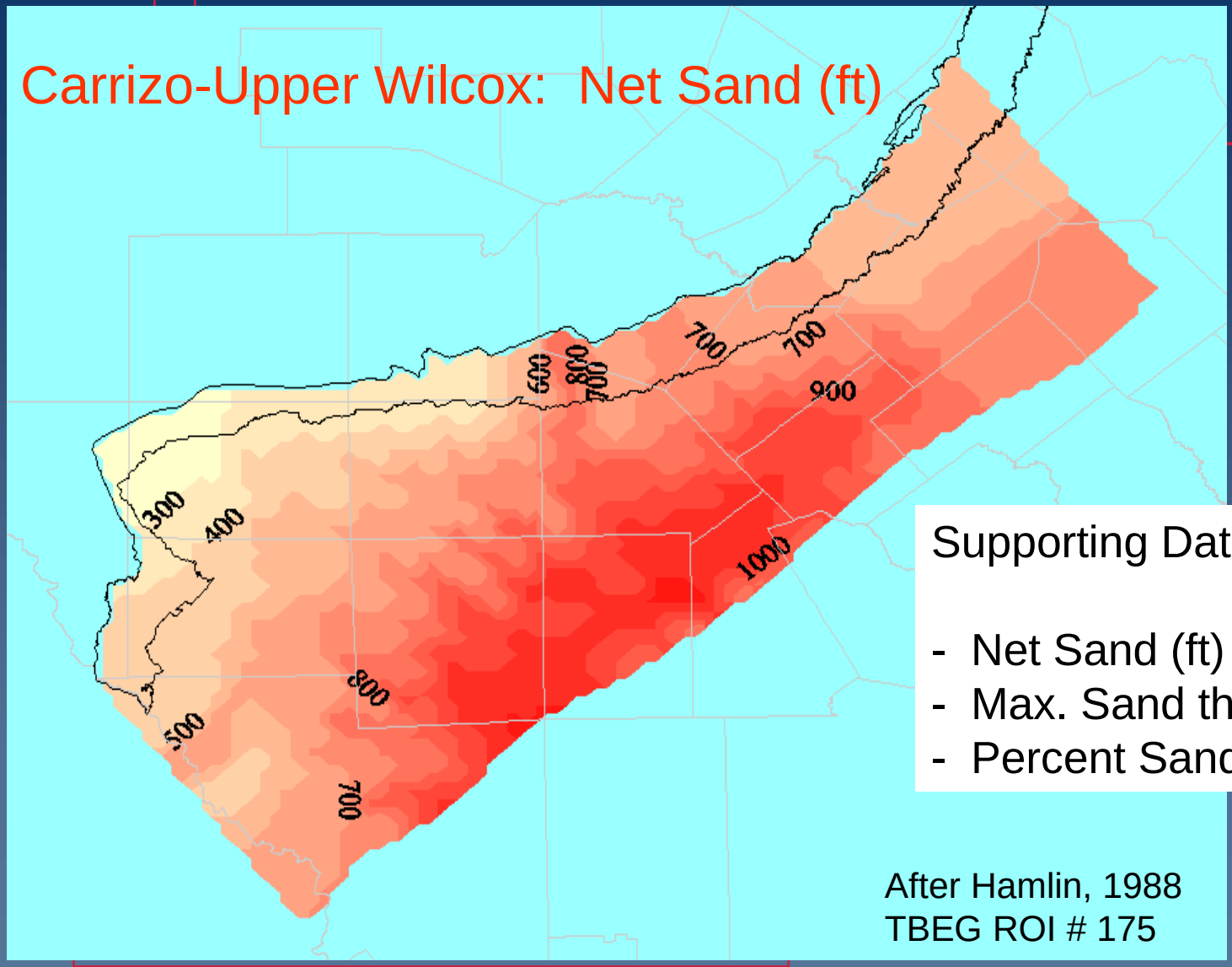
Transmissivity, Hydraulic Conductivity, and Storativity Data for the Carrizo-Wilcox Aquifer (Mace et al., 2000)

SW Carrizo: Hydraulic Conductivity

Hydraulic Conductivity Approach



Hydraulic Conductivity Approach



Supporting Data:

- Net Sand (ft)
- Max. Sand thickness (ft)
- Percent Sand

After Hamlin, 1988
TBEG ROI # 175

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

$K_{clay} <= K_{other} < K_{sand}$

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

Hydraulic Properties - Status

- Hydraulic conductivity data has been spatially analyzed
- Sand thickness/depositional maps have been projected to model grid
- In progress:
  - Block Kriging to estimate sand hydraulic conductivity (awaiting new pump tests)
  - Effective grid block properties will be estimated

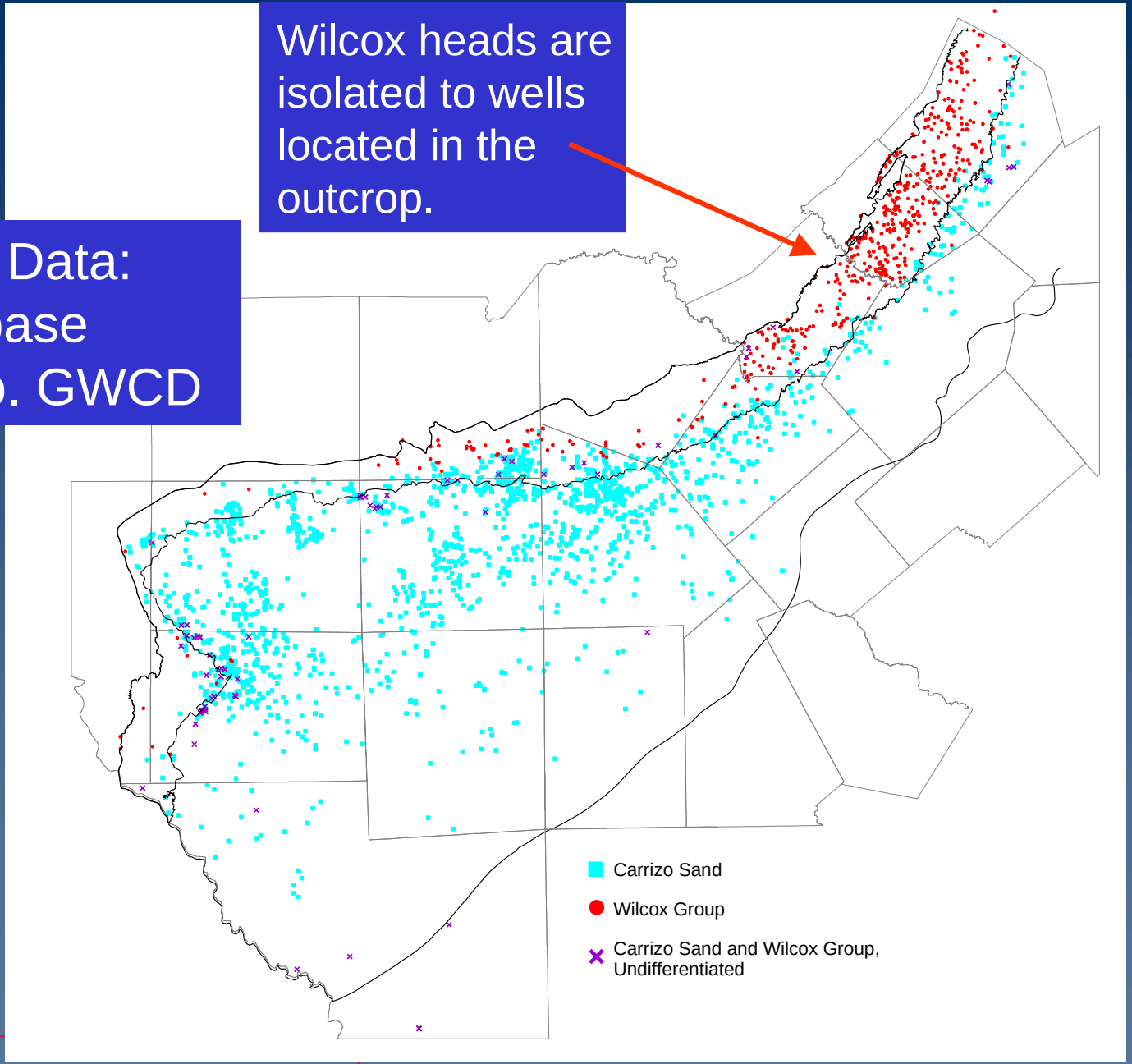
Water Levels and Regional Groundwater Flow

Water Levels and Regional Groundwater Flow

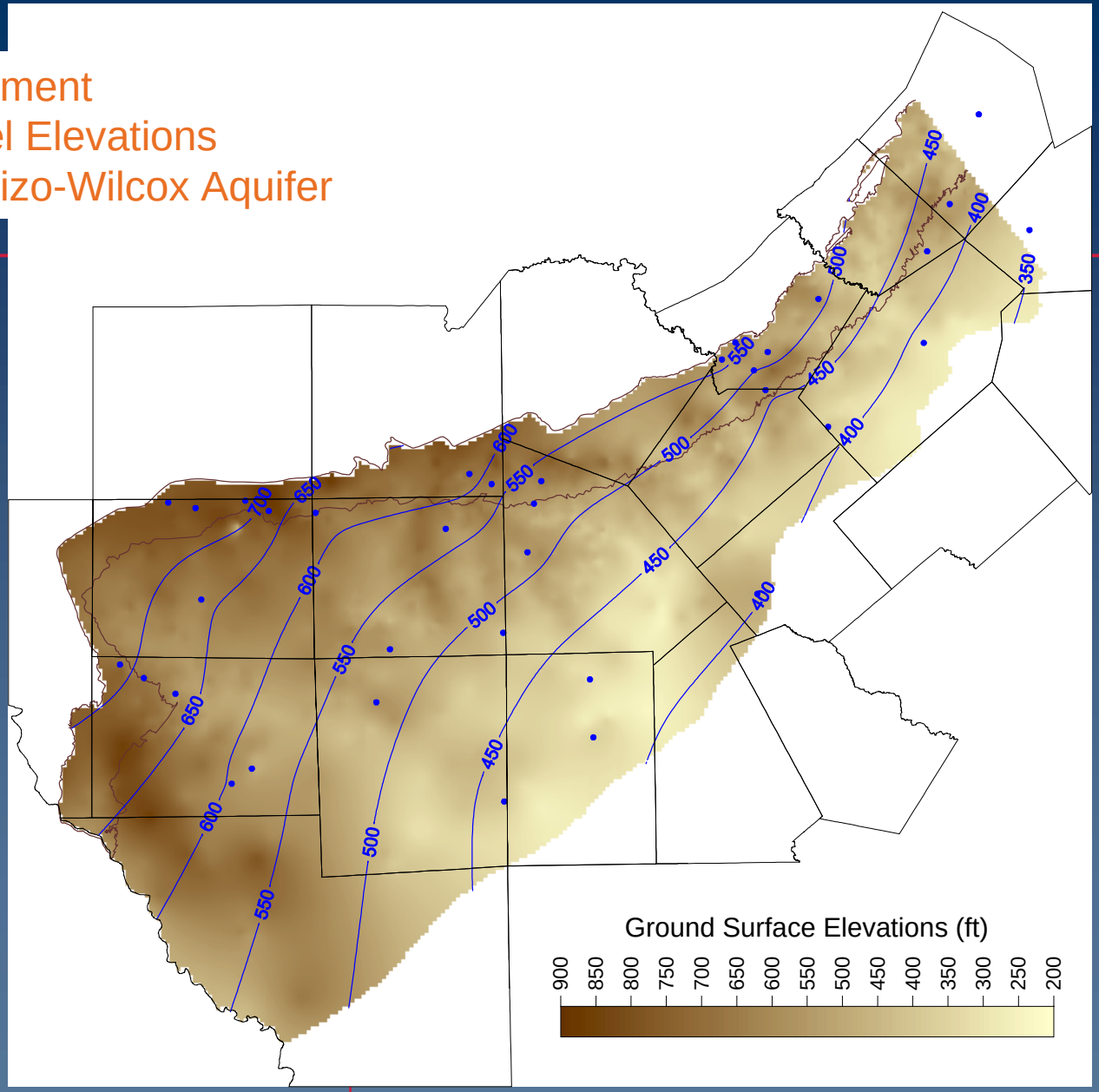
- Objectives
  - Develop potentiometric contours of water-level elevation
    - Predevelopment levels for model initialization
    - 1980 levels for model calibration
    - 2000 levels for model verification
  - Select hydrographs for use as calibration targets
  - Generate transient water level changes for use as boundary conditions
  - Evaluate cross-formational flow

Source of Head Data:
- TWDB database
- Gonzales Co. GWCD

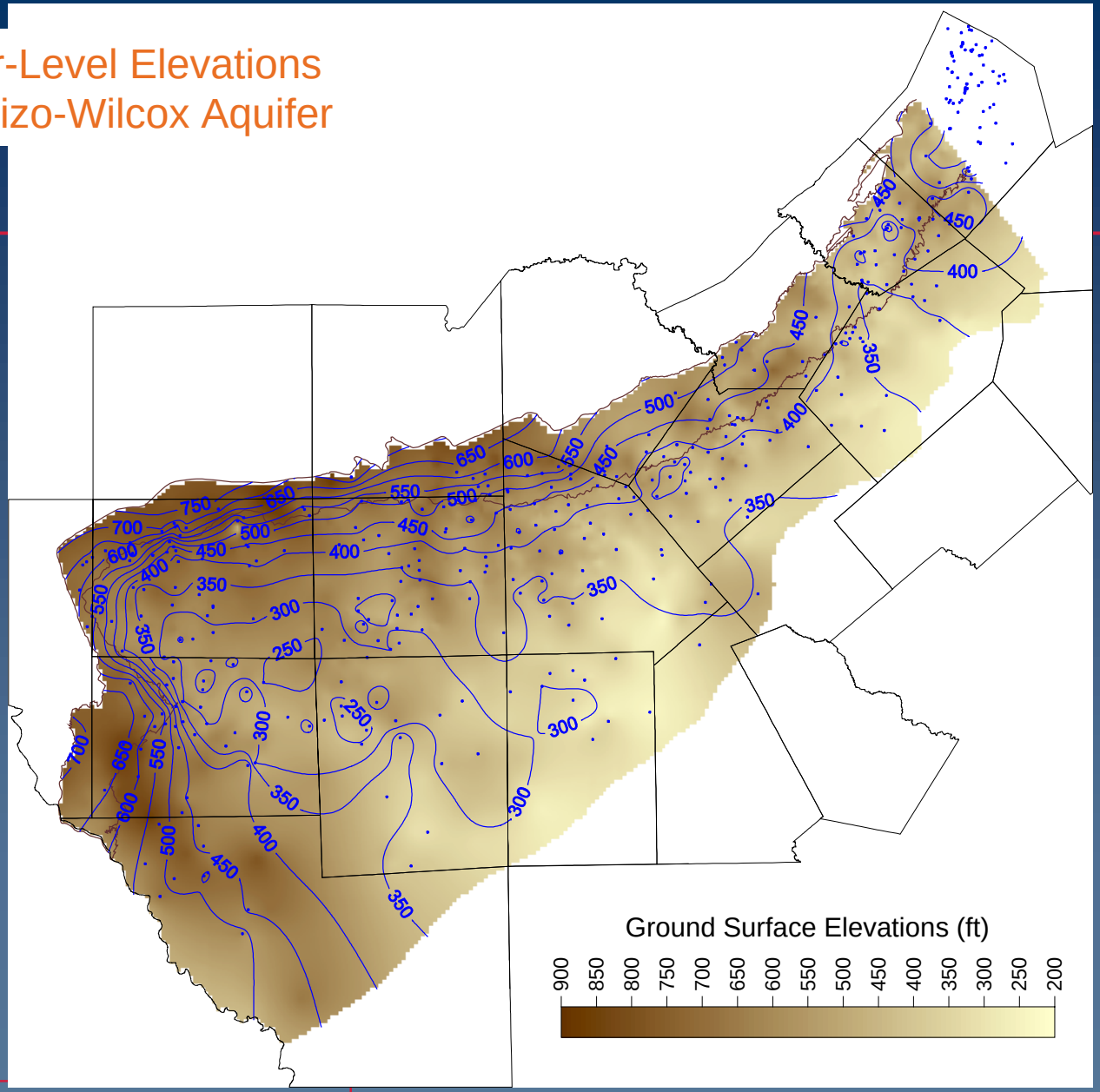
Wilcox heads are isolated to wells located in the outcrop.

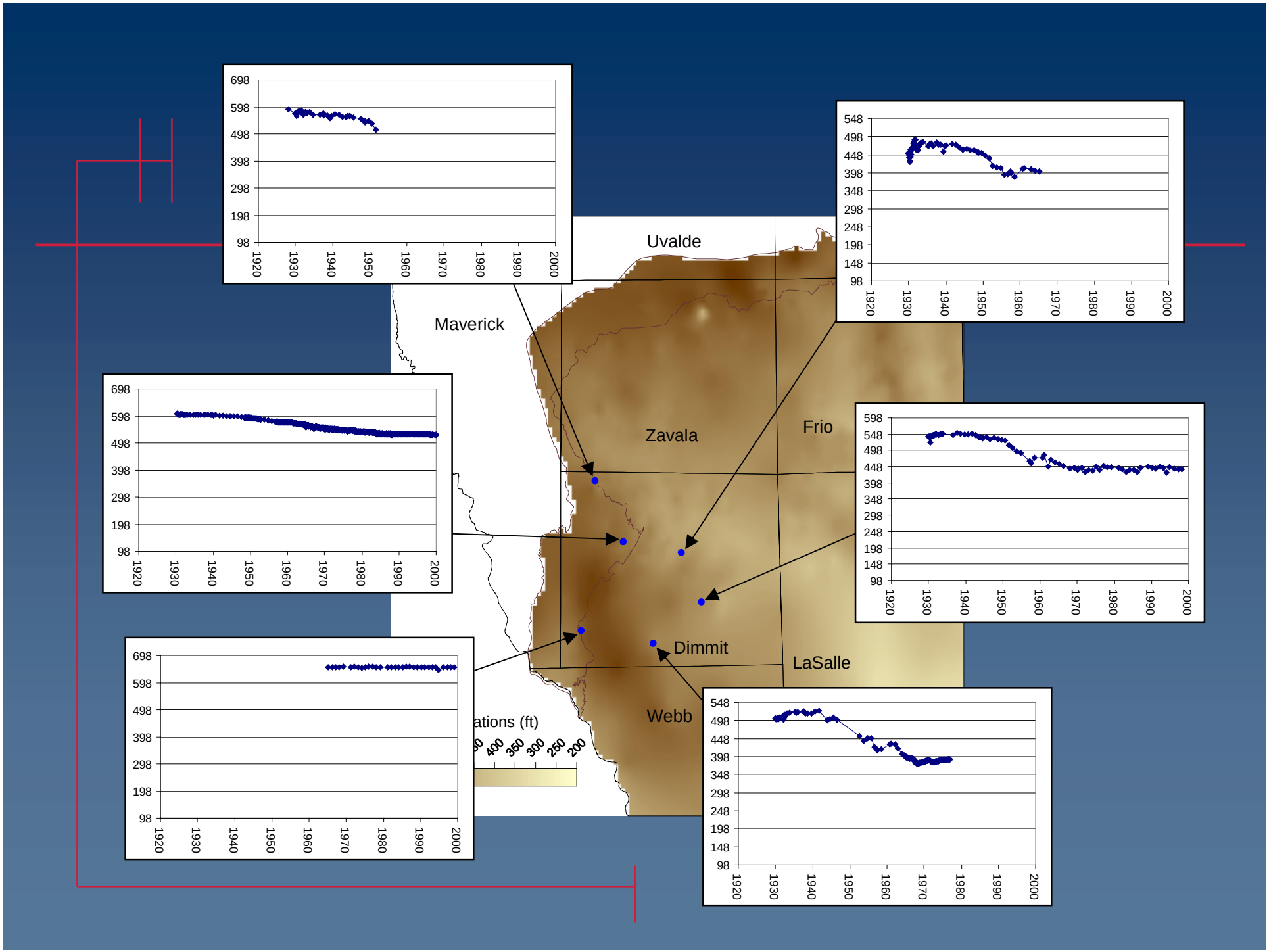


Predevelopment Water-Level Elevations for the Carrizo-Wilcox Aquifer



1980 Water-Level Elevations for the Carrizo-Wilcox Aquifer




698
598
498
398
298
198
98
1920
1930
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1950
1960
1970
1980
1990
2000
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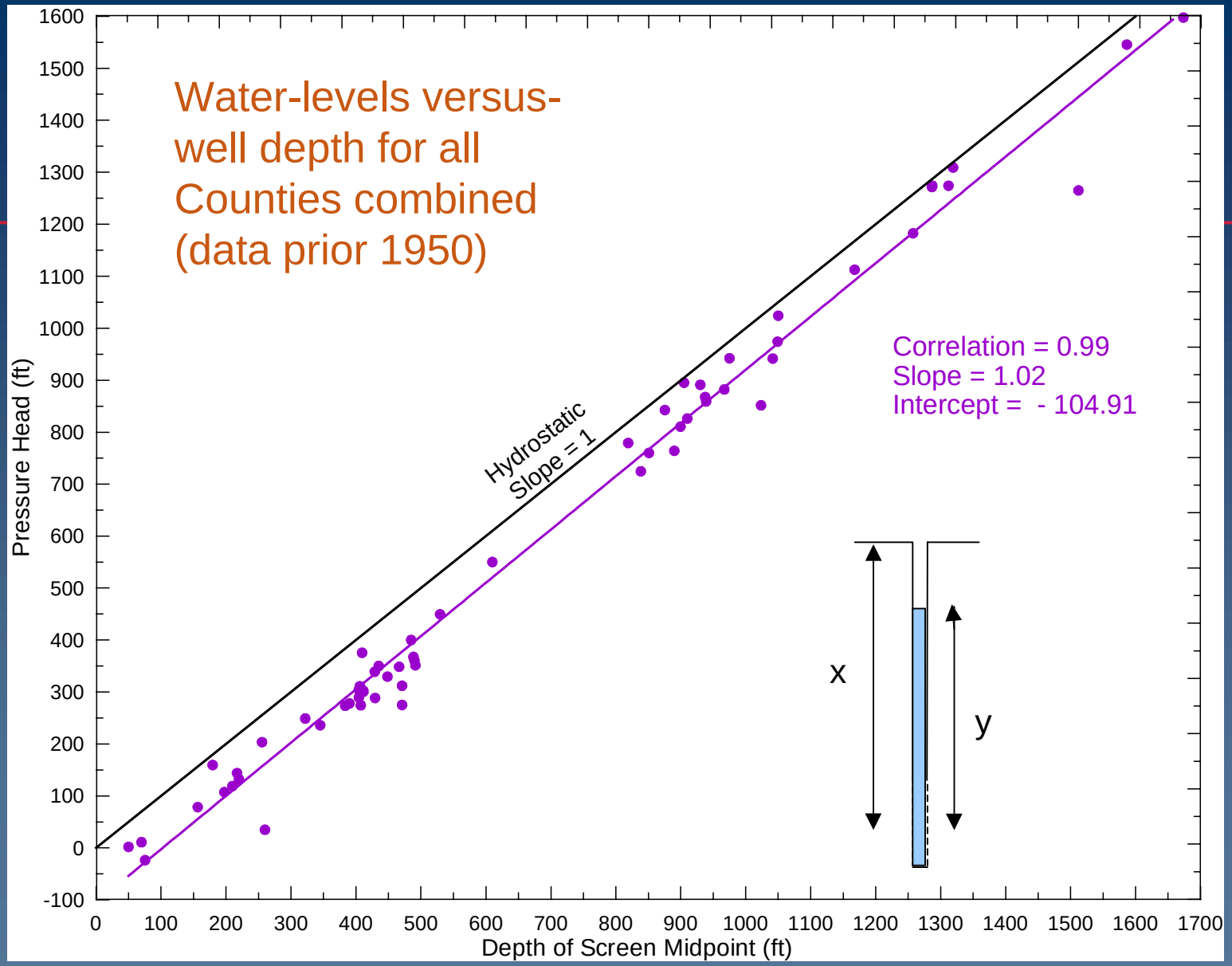
498
448
398
348
298
248
198
148
98
598
548
498
448
398
348
298
248
198
148
98
Uvalde
Maverick
Zavala
Frio
Dimmit
LaSalle
Webb
ations (ft)
400
350
300
250
200

Water Levels and Regional Groundwater Flow (cont.)

- Approach for Pressure-versus-Depth Analysis
  - Obtained water-level and well data from the TWDB database
  - Looked at data prior to 1950 and at all data
  - Includes only data with knows screen intervals
  - Compared WL vs. depth trends for different areas for the data prior to 1950 (e.g., counties)


Water-levels versus-
well depth for all
Counties combined
(data prior 1950)
Correlation = 0.99
Slope = 1.02
Intercept = - 104.91
Hydrostatic
Slope = 1
Pressure Head (ft)
Depth of Screen Midpoint (ft)
x
y
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
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400
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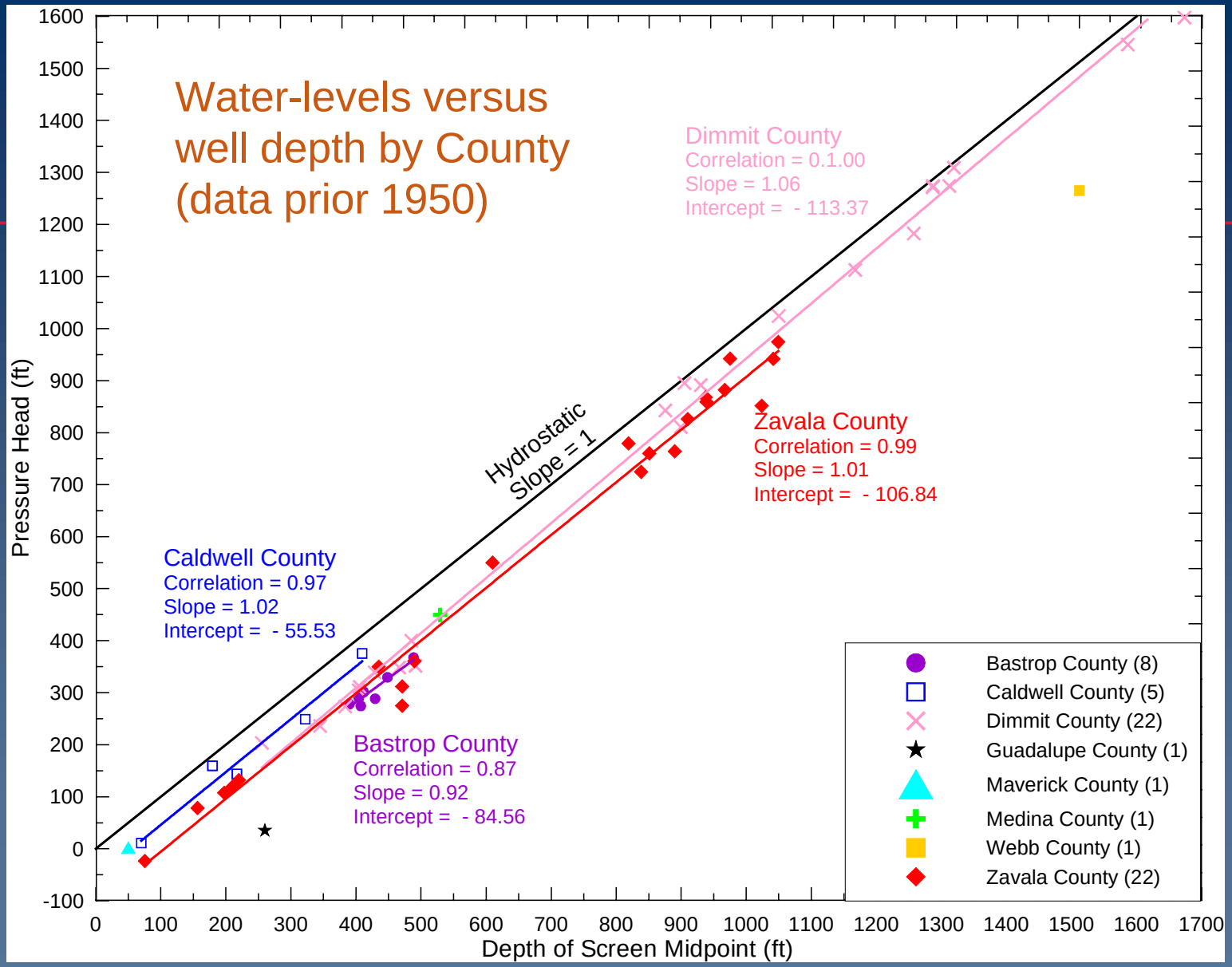
Water-levels versus well depth by County (data prior 1950)
Dimmit County
Correlation = 0.1.00
Slope = 1.06
Intercept = - 113.37
Zavala County
Correlation = 0.99
Slope = 1.01
Intercept = - 106.84
Hydrostatic
Slope = 1
Caldwell County
Correlation = 0.97
Slope = 1.02
Intercept = - 55.53
Bastrop County
Correlation = 0.87
Slope = 0.92
Intercept = - 84.56
Bastrop County (8)
Caldwell County (5)
Dimmit County (22)
Guadalupe County (1)
Maverick County (1)
Medina County (1)
Webb County (1)
Zavala County (22)
Pressure Head (ft)
Depth of Screen Midpoint (ft)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
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-100
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100
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500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

Water Levels - Status

- Data reviewed and QA/QC'ed
- Preliminary head surfaces are developed for predevelopment and historical times
- Hydrographs developed
- In Progress:
  - Pressure depth analysis
  - Estimation of lateral head boundaries
  - Development of calibration hydrographs

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

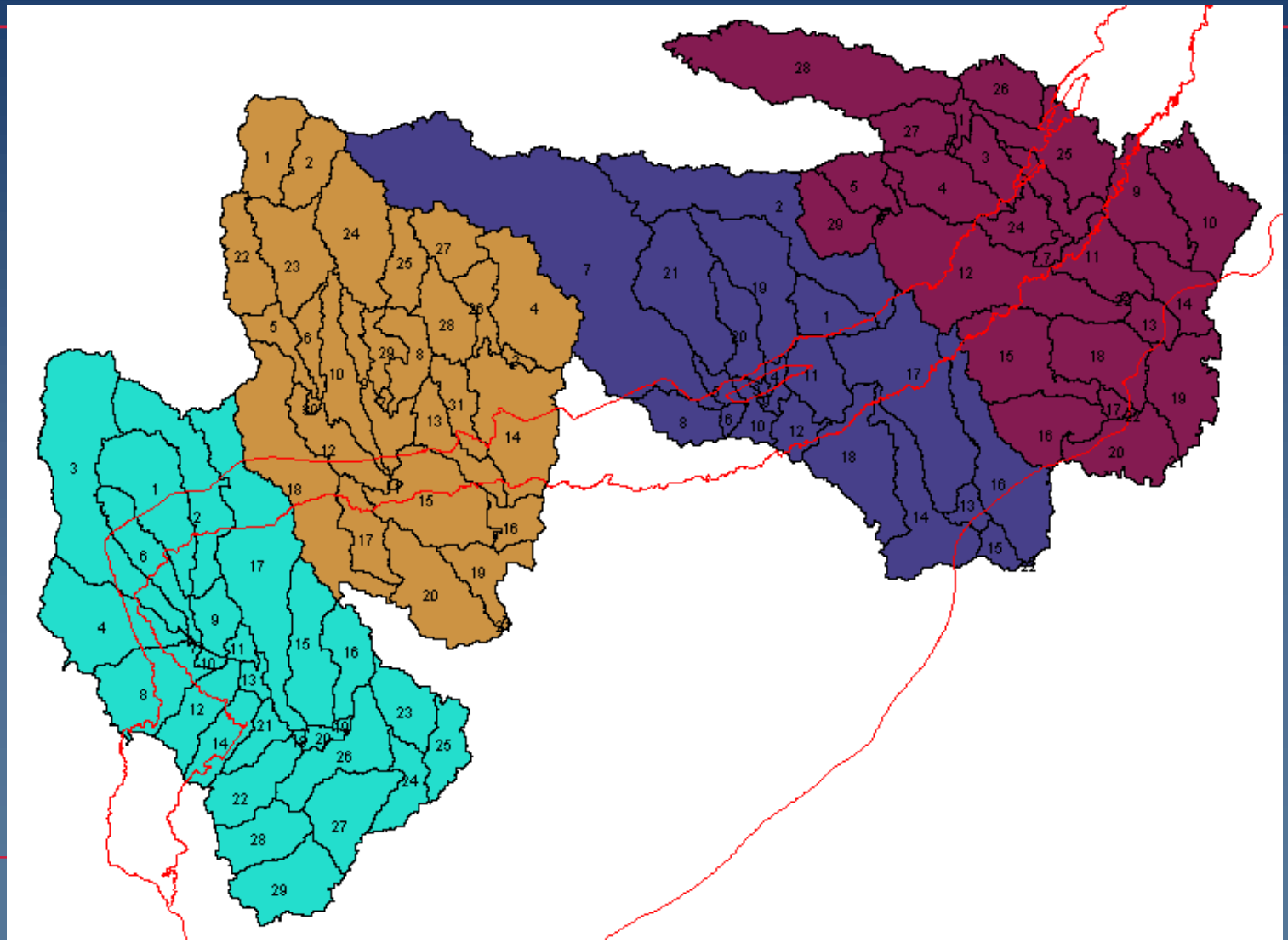
Soil and Water Assessment Tool

- 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

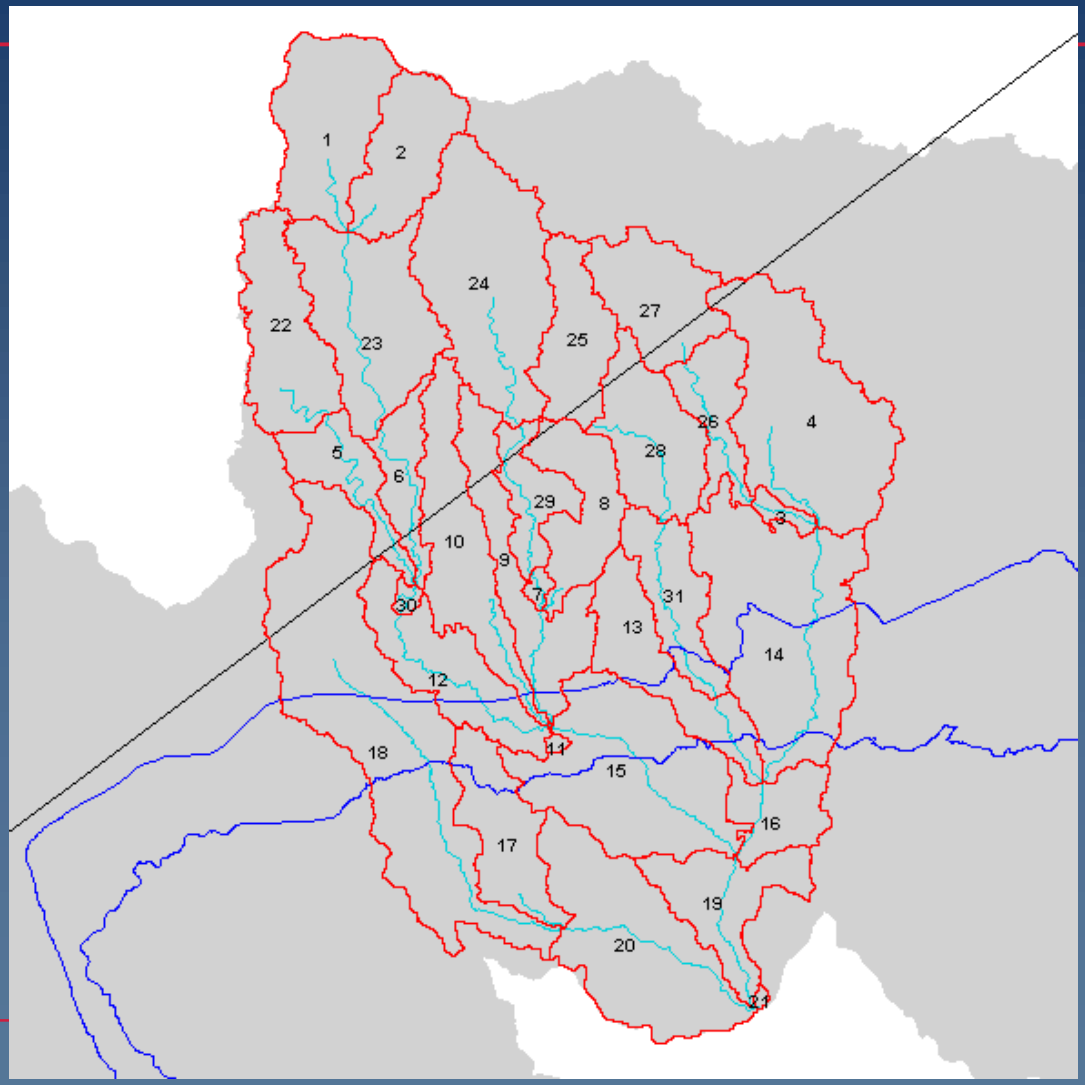
SWAT GIS Interface



Recharge Approach

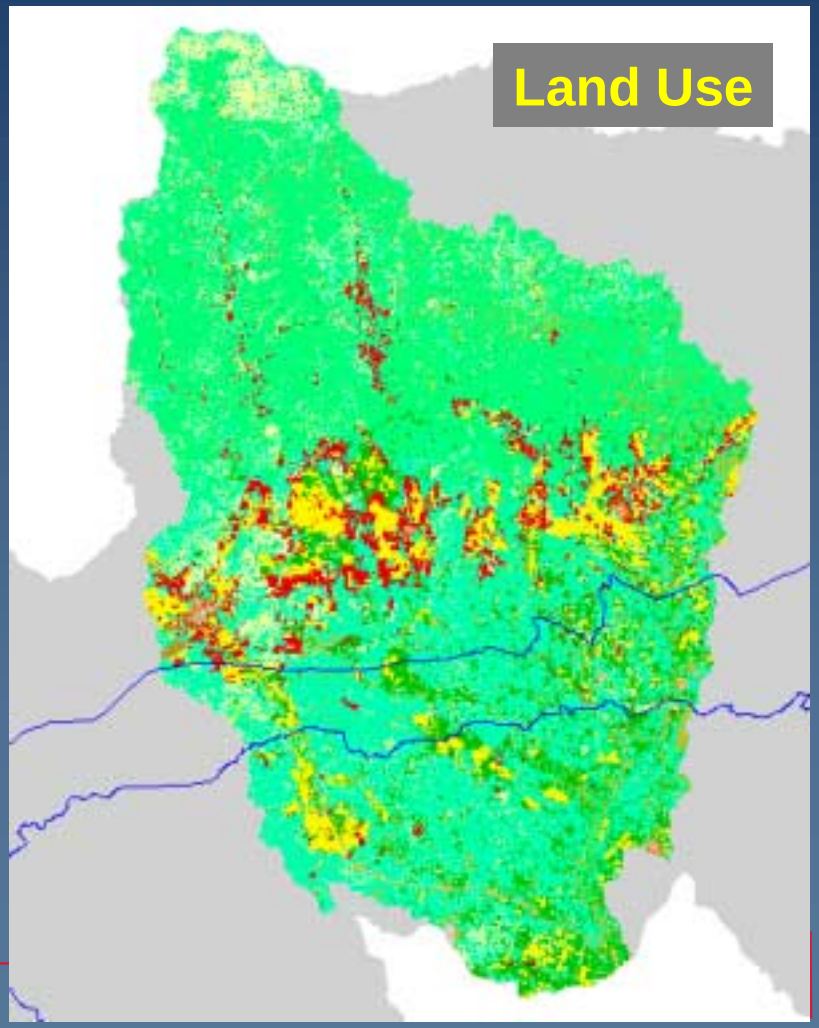
SWAT Inputs

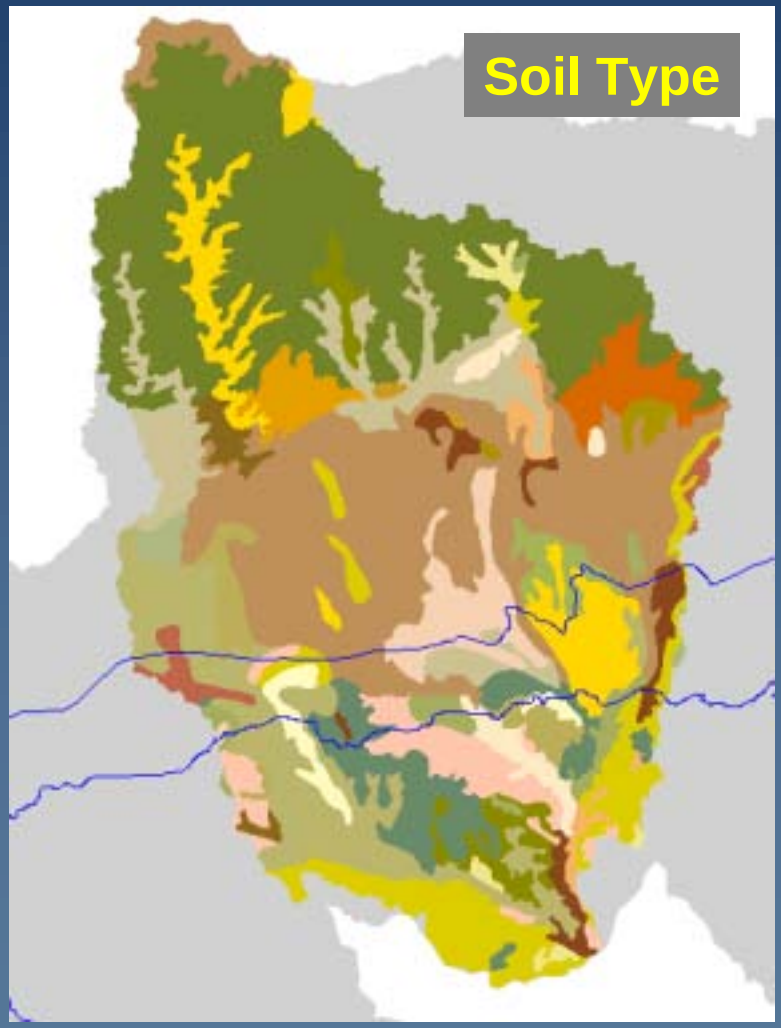
- Sub-basins are delineated
- Stream routing segments established
- Stream volumes can be compared to gage values



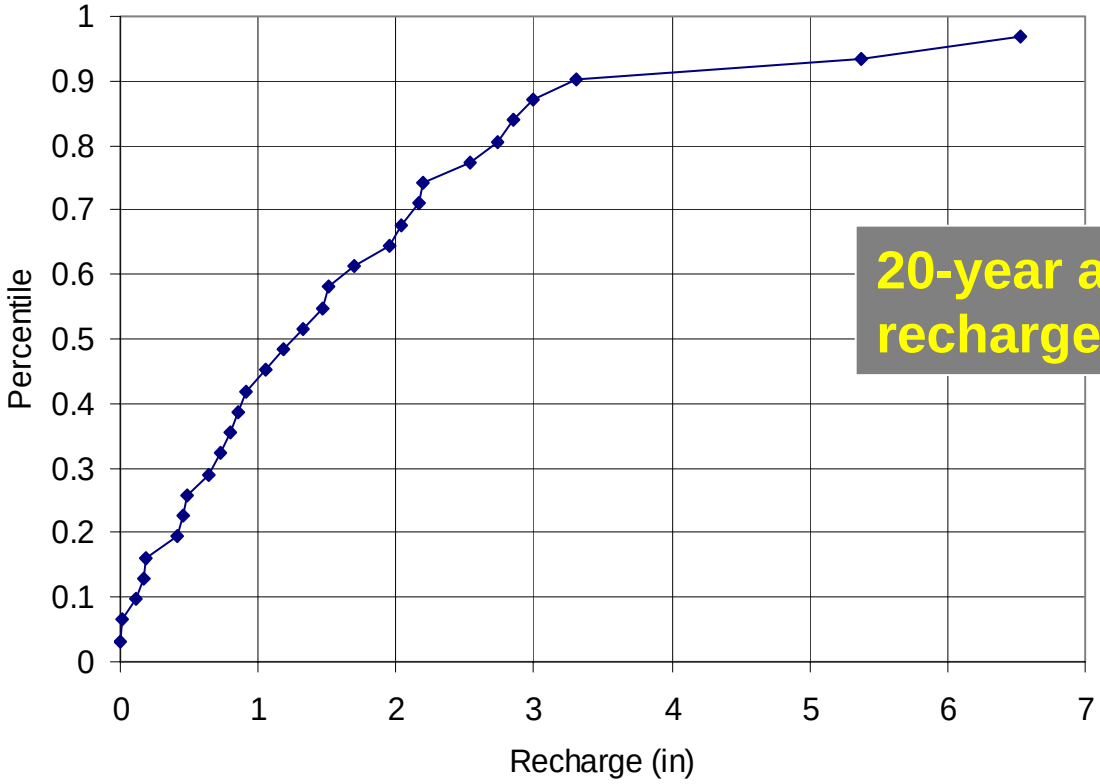
SWAT Inputs

Recharge Approach



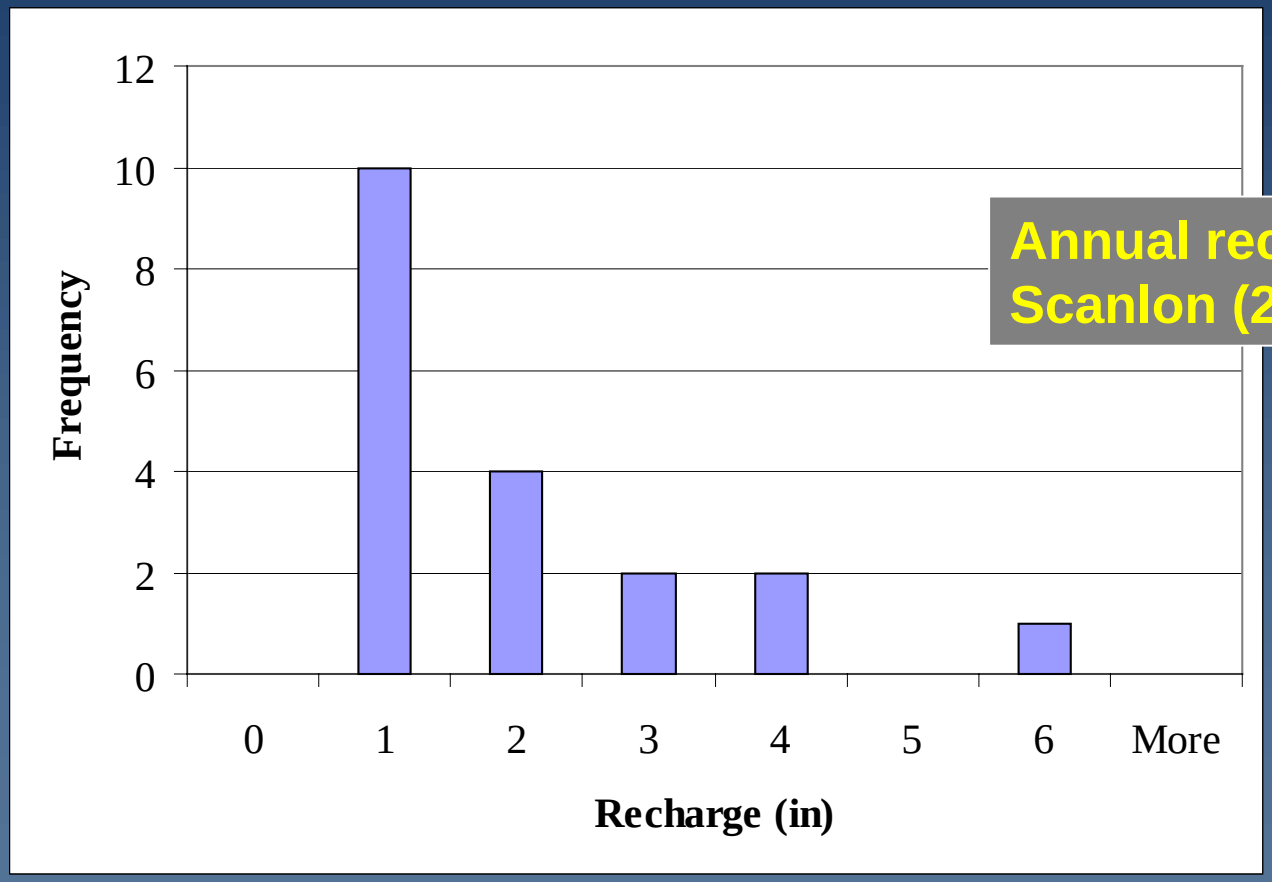


SWAT — Example Results



20-year average annual recharge for 30 subbasins

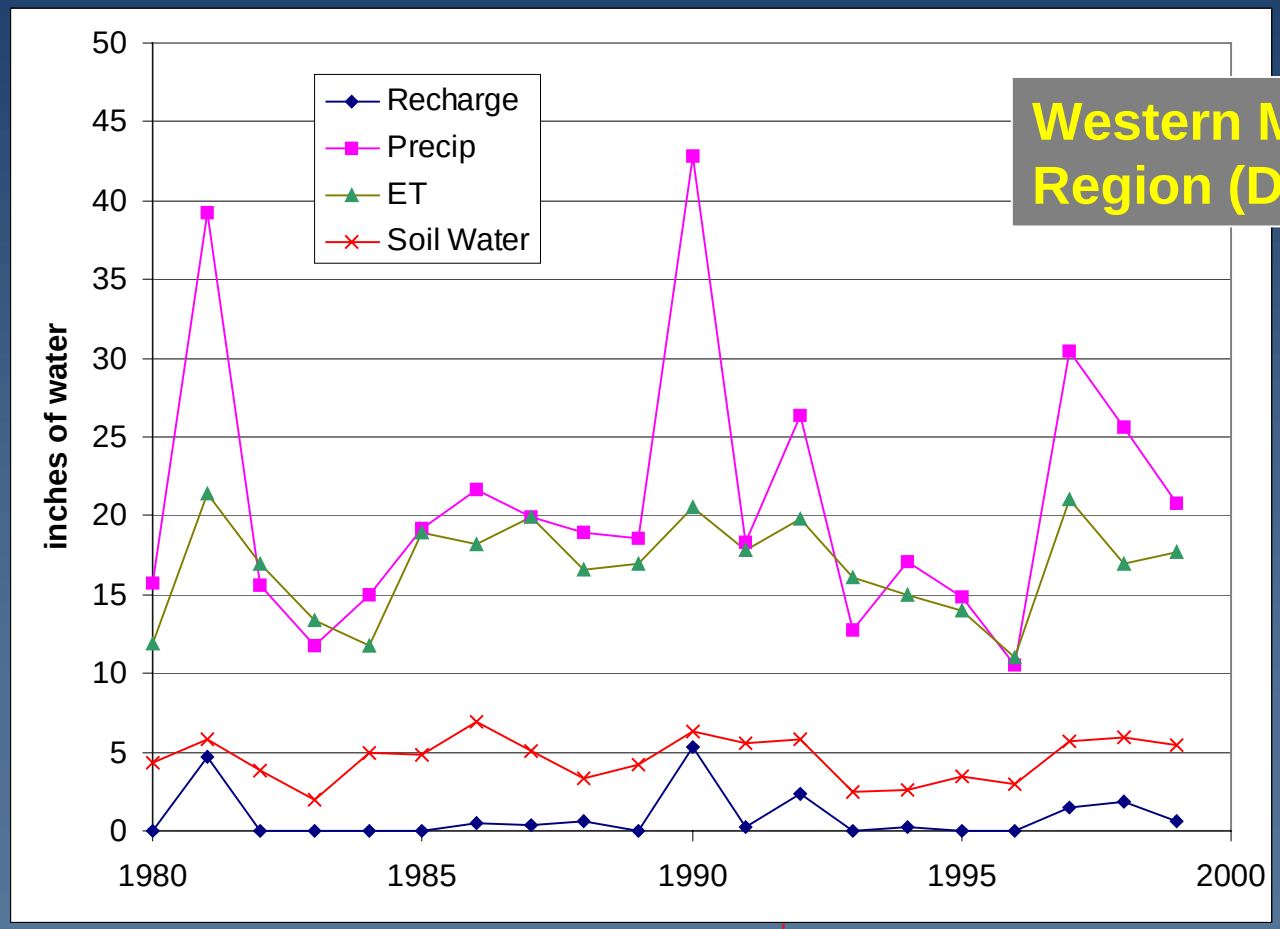
Recharge Comparison



Annual recharge from Scanlon (2001)

Recharge Approach

SWAT — Example Results



Western Model Region (Drier)

Recharge - Status

- Initial SWAT Runs (1980-2000) Complete
- Work in Progress
  - Sensitivity and importance analysis (i.e. what drives recharge)
  - Development of technique to port results to MODFLOW
  - Average and DOR condition recharge

Surface/Groundwater Interaction

Stream-routing

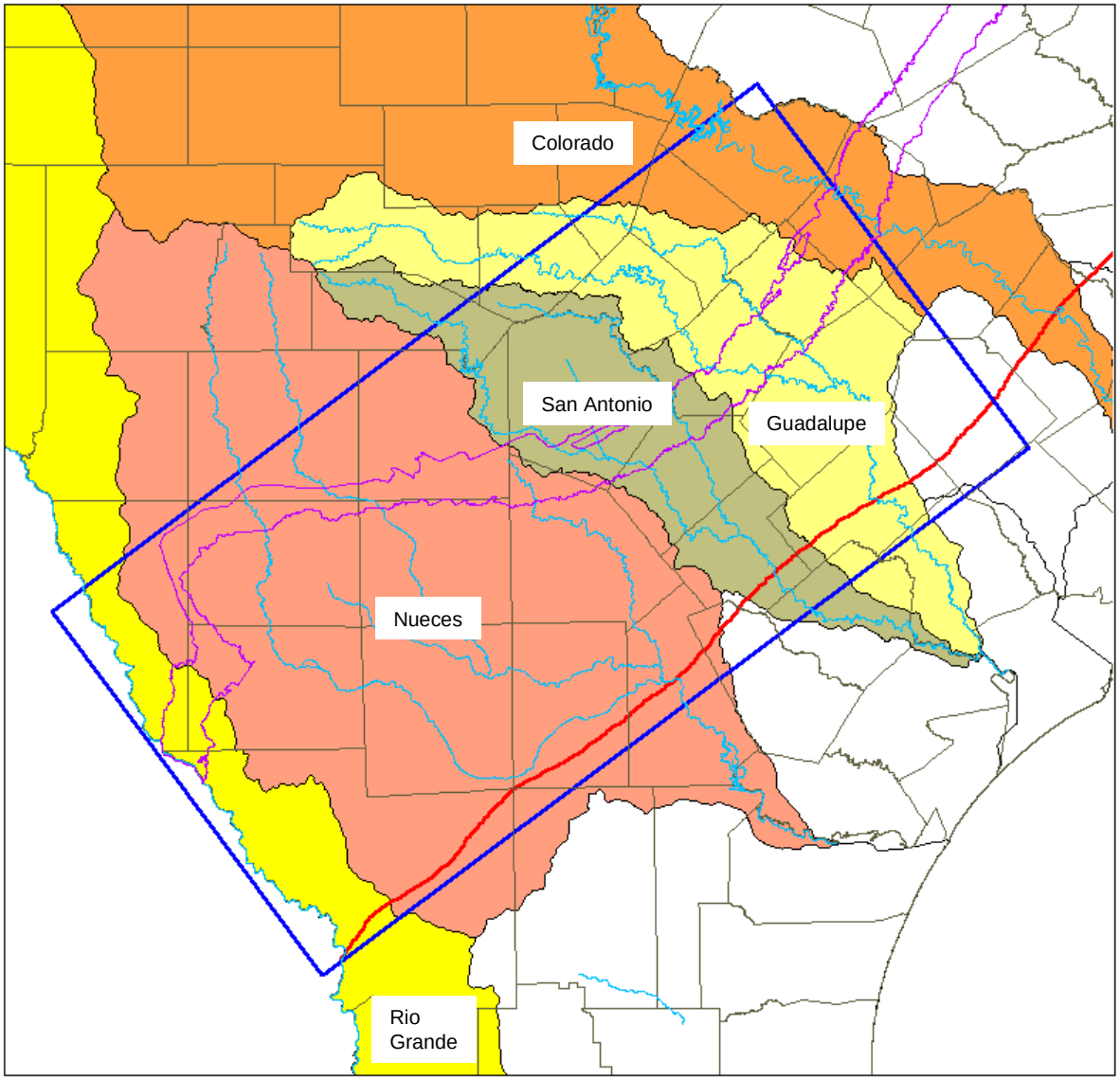
Stream Routing

- 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)

River Basins

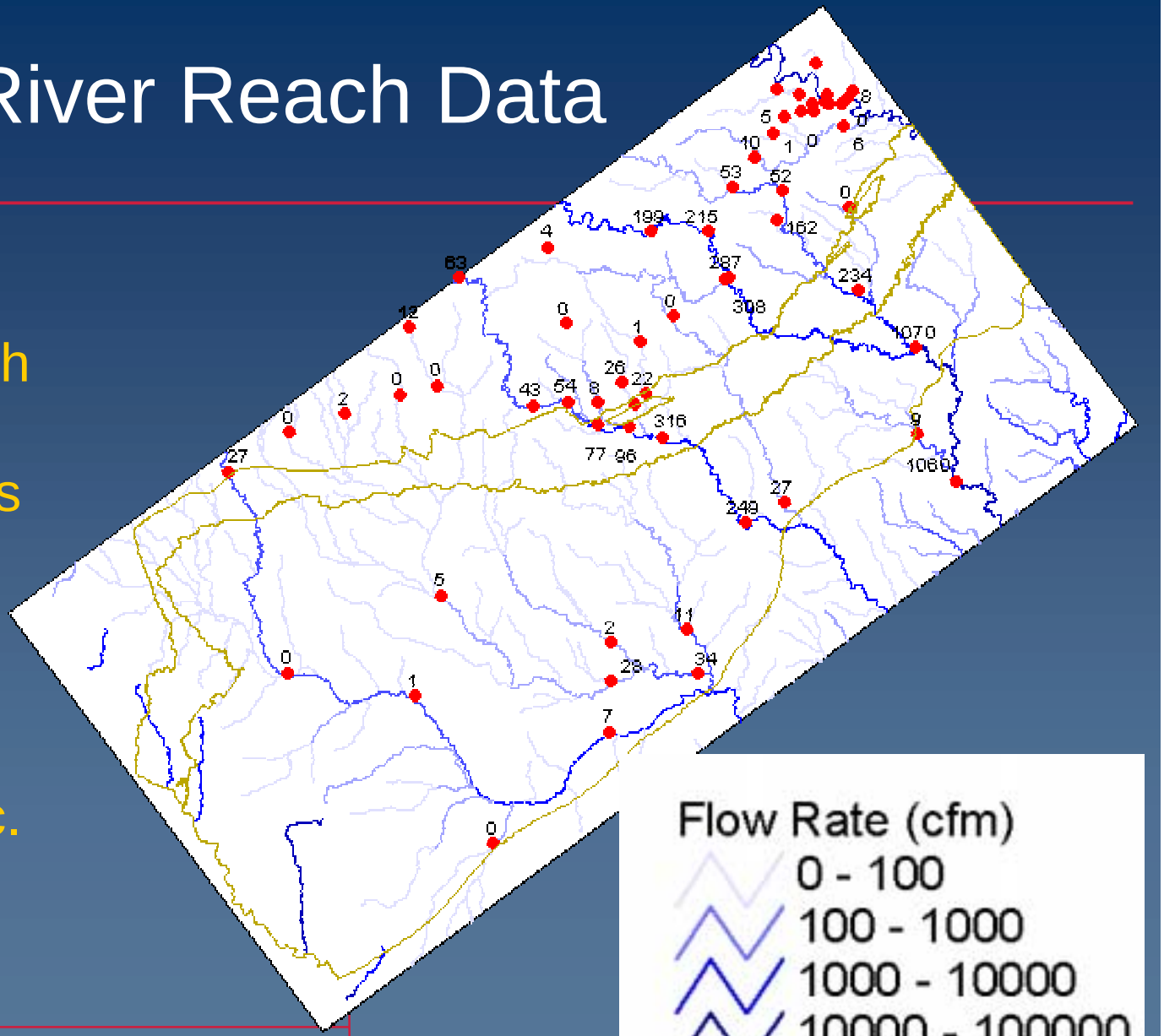
Principle Streams Crossing the Carrizo-Wilcox outcrop (South to North):

- Rio Grande
- Nueces R.
- Frio R
- Atascosa R
- Medina R
- San Antoniu R
- Cibolo Cr
- Guadalupe R
- San Marcos R
- Colorado R

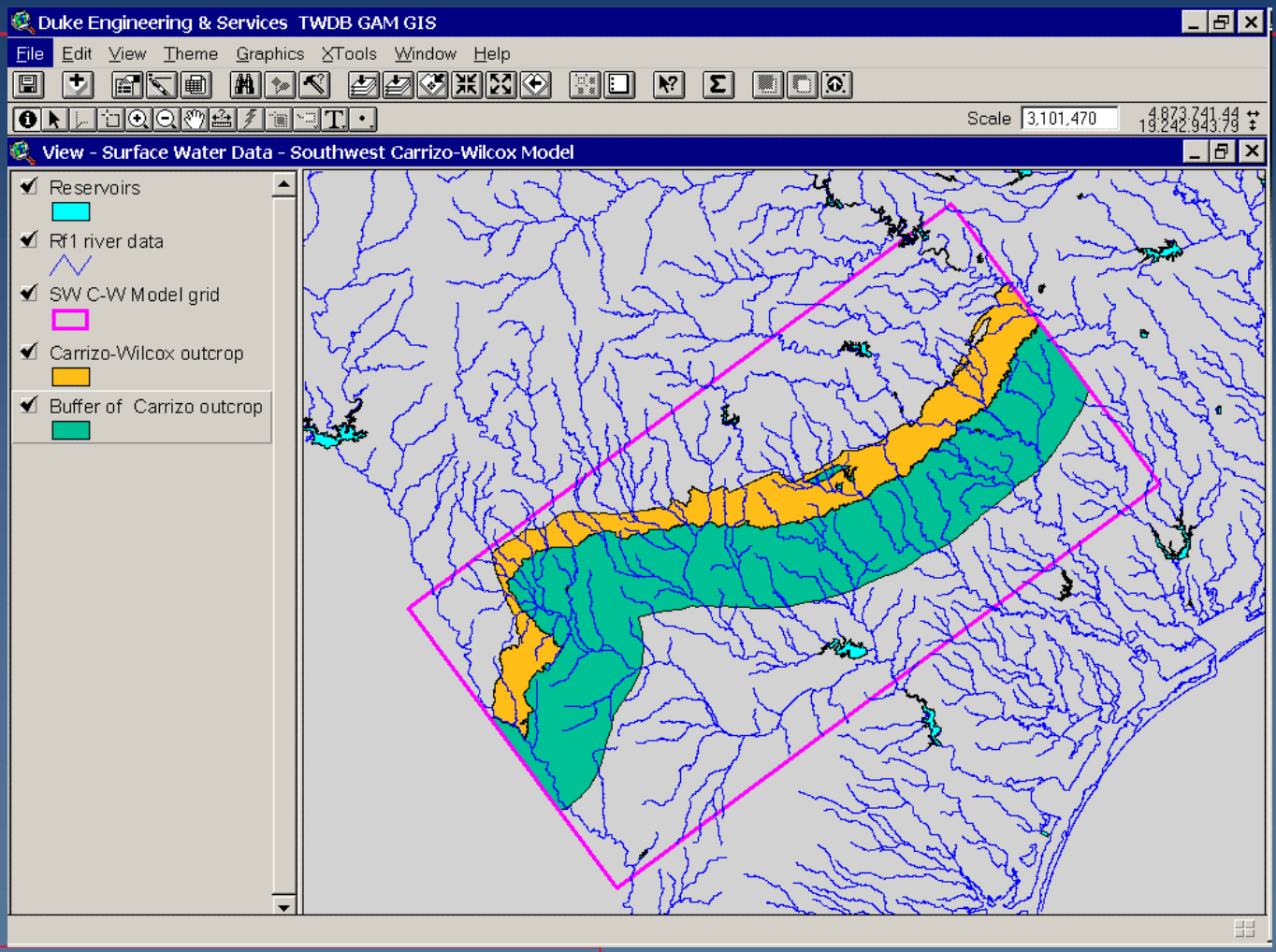


EPA River Reach Data

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

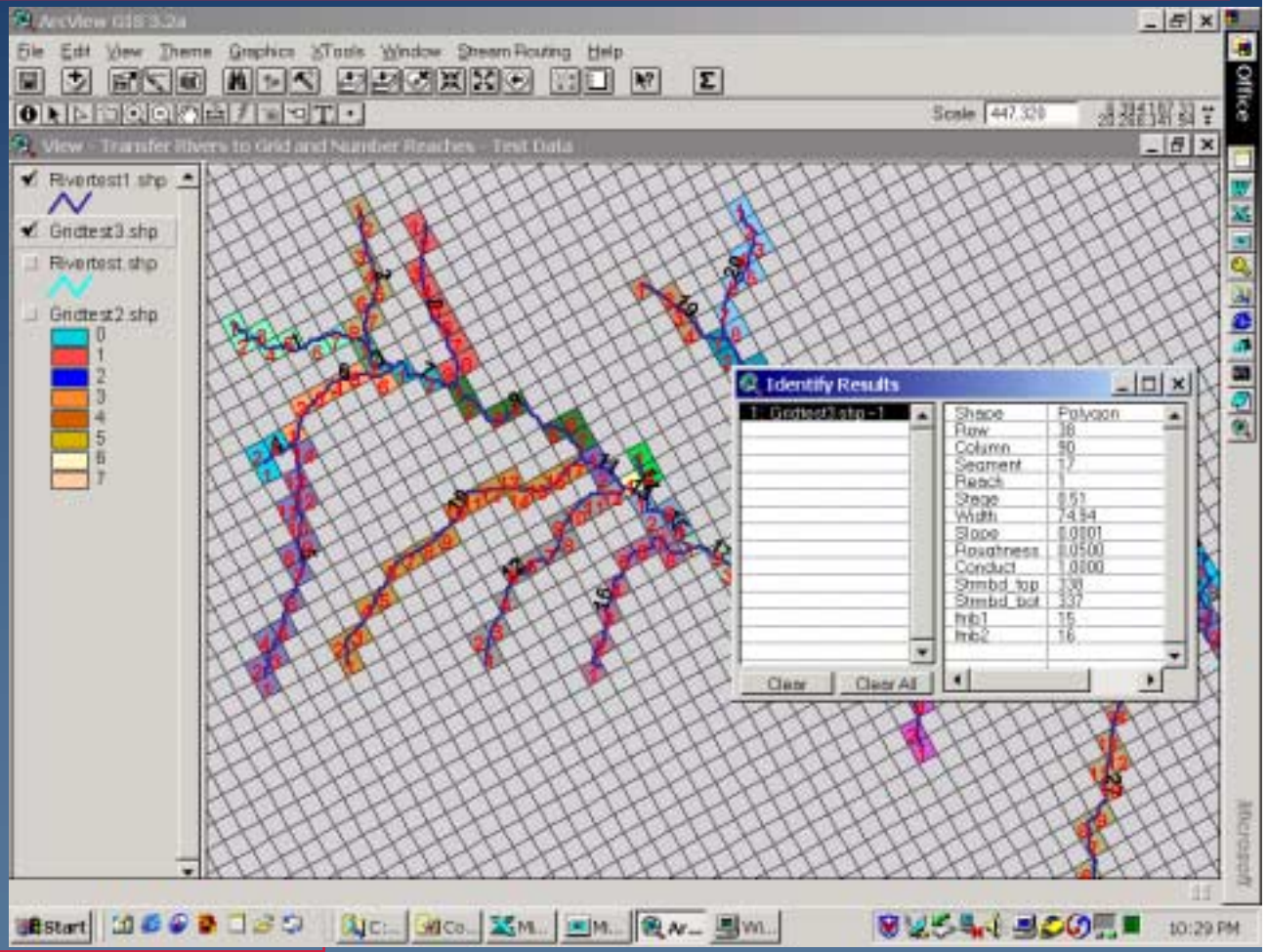


Selection of Rivers to Simulate



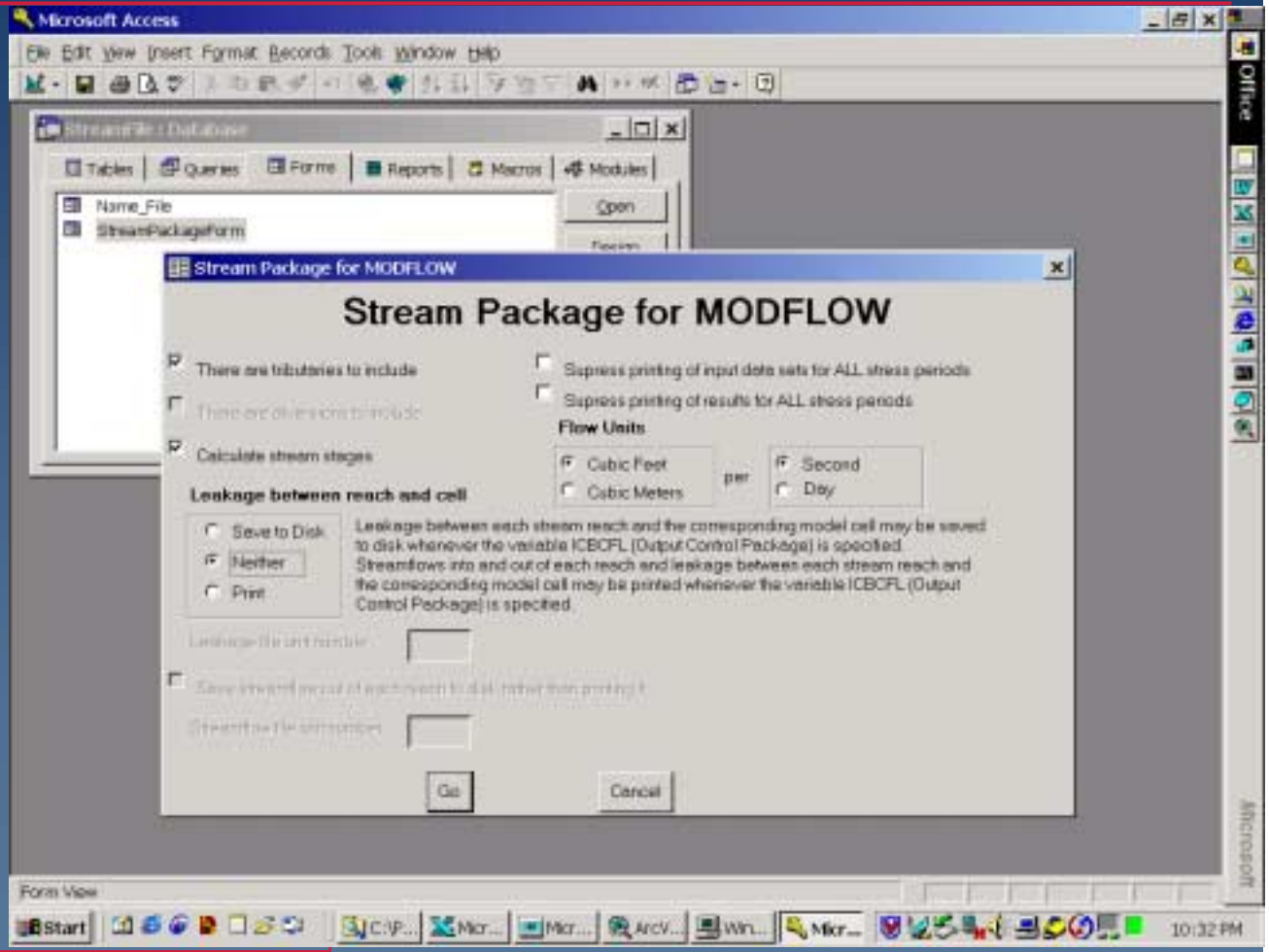
ArcView to MODFLOW input

Stream and reach numbering are done auto - matically using ArcView



ArcView to MODFLOW input

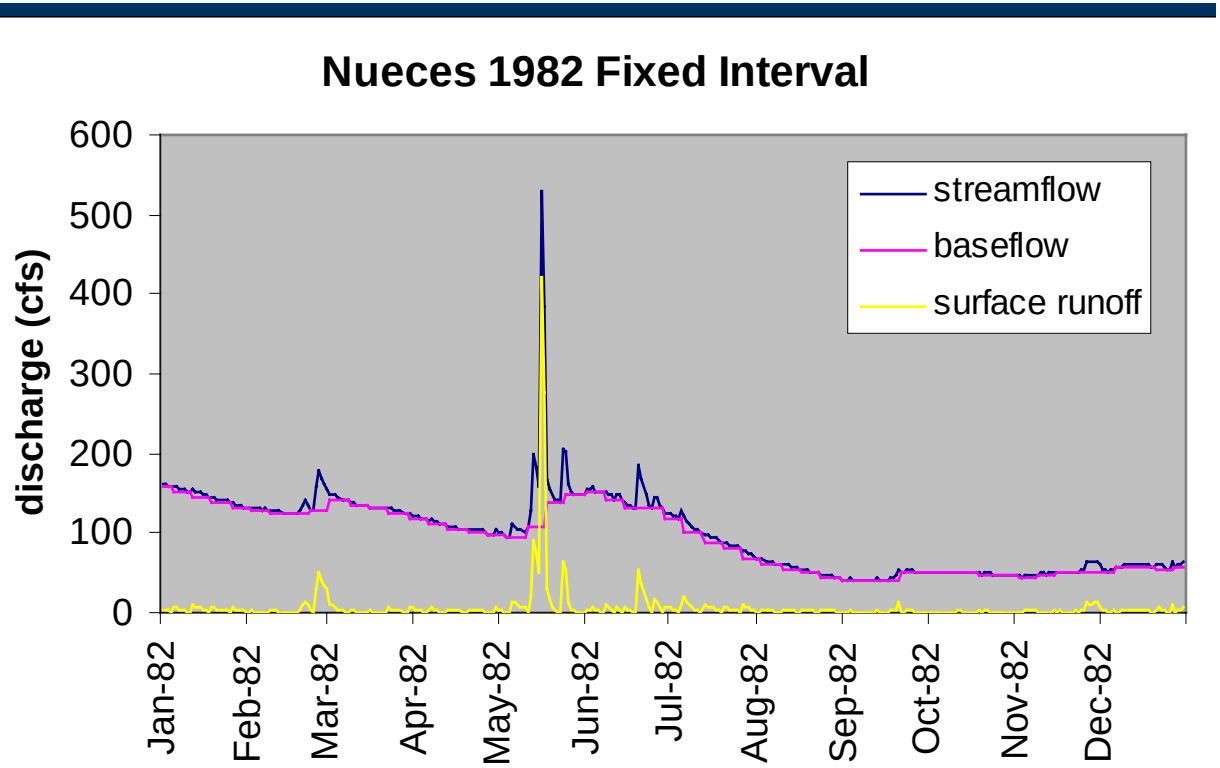
- Then, Access is used to read the ArcView data and convert it directly into MODFLOW text input files.

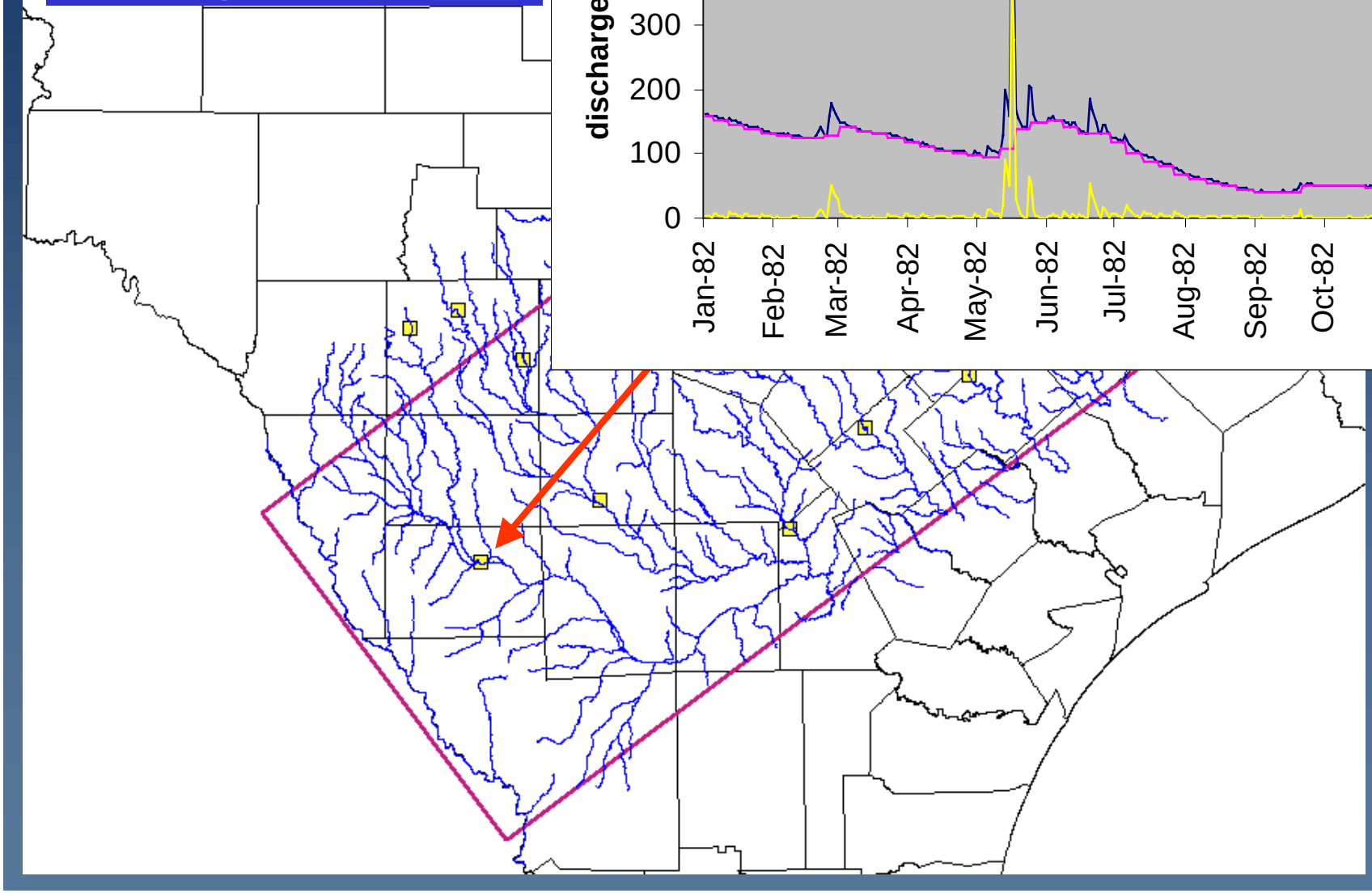


Stream/Aquifer Conductance

- Goal -- Calibrate streambed conductivities to match known losses/gains
- Sources of Gain/Loss Data
  - USGS (Slade) data
  - Hydrograph Separation (HYSEP)
  - Water balance between upstream and downstream gages
- Conductance data
  - Colorado River studies by Hibbs
  - Conductivity estimates based on channel/aquifer material after Calver (2001)

Baseflow Analysis

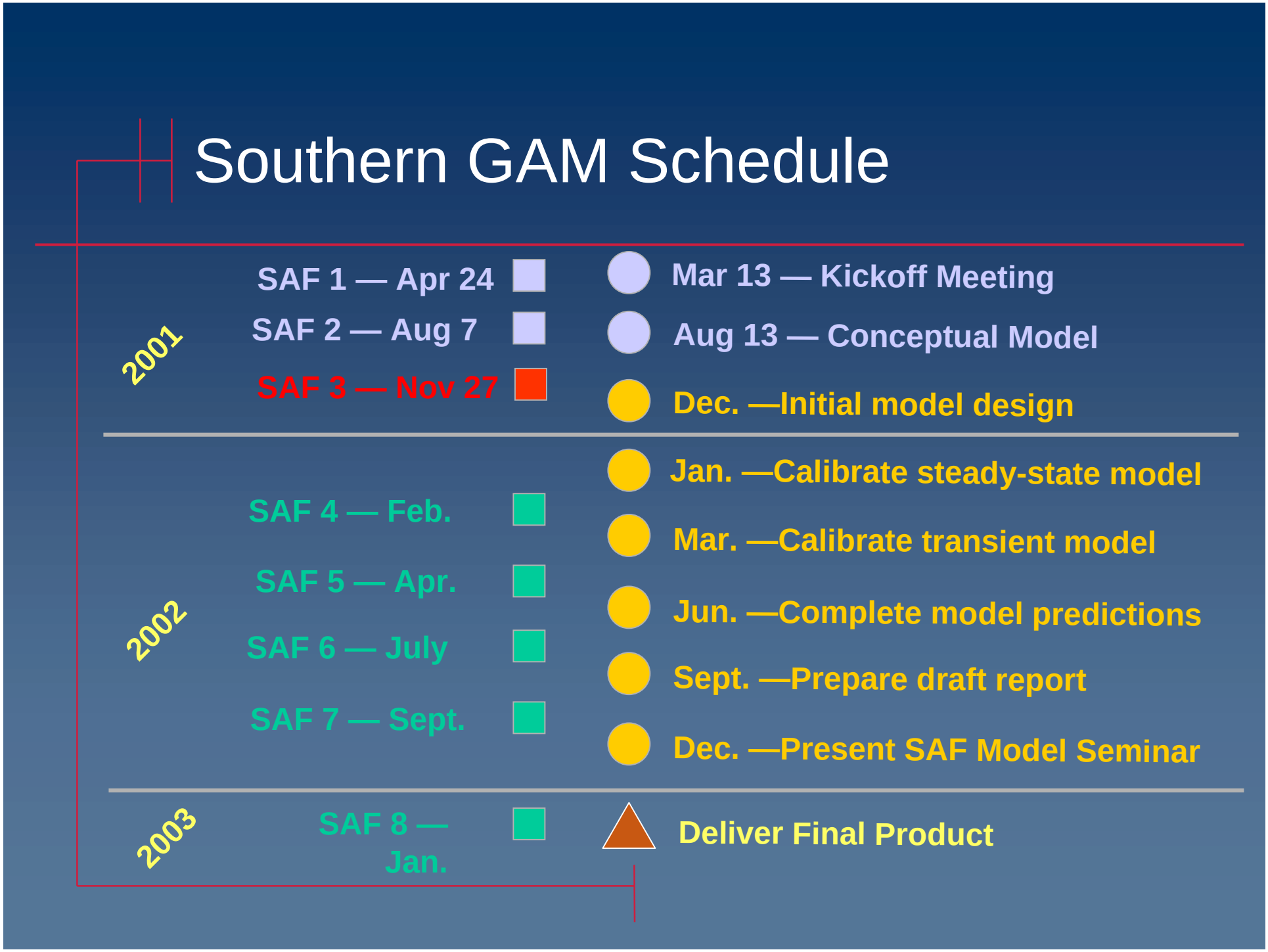




Surface Water - Status

- Streams to be modeled selected
- Stream data compiled & analyzed
- Automated routines and a GUI have been developed for ease of input development
- In Progress:
  - Stream data still being analyzed (HYSEP)
  - MODFLOW data decks

Southern GAM Schedule



Expected SAF-4 Discussion

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

ATTACHMENT A: SIGN-UP SHEET SAF 3

Name	Affiliation
Kevin Morrison	San Antonio Water System
Melissa Forey	San Antonio Water System
Steve Raabe	San Antonio River Authority
Mike Mahoney	Evergreen UWCD
Gaylon Click	Wilson Co. Water Action Project
Grant L. Snyder	URS
Robert Mace	TWDB

Meeting Minutes for the

Third Southern Carrizo-Wilcox Groundwater Availability Model (GAM) Stakeholder Advisory Forum (SAF) Meeting

November 27, 2001

Carrizo Springs Civic Center

Carrizo Springs, Texas

The third Stakeholder Advisory Forum (SAF) Meeting for the Southern Carrizo-Wilcox Groundwater Availability Model (GAM) was held on November 27th from 1:00 until 3:00 PM at the Carrizo Springs Civic Center in Carrizo Springs, Texas. Attachment A of these meeting minutes provides a list of all participants who signed up as attending the meeting.

The purpose of the third SAF meeting was to present a more in-depth review of model design 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).

Meeting Introduction: Dr. Robert Mace, TWDB

The meeting was initiated by Dr. Robert Mace of the Texas Water Development Board (TWDB). Dr. Mace provided a brief overview of upcoming GAMs and a brief summary of progress on currently active GAMs.

SAF Presentation: Van Kelley and Dennis Fryar, Duke Engineering and Services (DE&S)

After the introduction by Dr. Mace, Van Kelley and Dennis Fryar 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 – Van Kelley
2. Model Design: Aquifer Geometry – Van Kelley and Dennis Fryar
3. Model Design: Aquifer Properties – Van Kelley
4. Model Design: Water Levels and Regional Groundwater Flow – Van Kelley
5. Model Design: Recharge – Van Kelley
6. Model Design: Surface / Groundwater Interaction – Van Kelley
7. GAM Schedule – SAF Meetings and Project Milestones – Van Kelley

The presentation is available on the GAM website (*www.twdb.state.tx.us/gam)*.

Questions and Answers: Open Forum:

Q. Why does the Central Carrizo-Wilcox model extend so far to the south?

A. The southern extent of the Central model was determined by the location of the updip limit of the growth fault zone. The orientation of the Central model was chosen so that the grid would be aligned along the primary flow direction. These two factors combined with MODFLOW's requirement for a rectangular grid resulted in the large footprint of the model. However, grid cells south of the growth faults will be inactive.

Q. What are growth faults?

A. Growth faults are syndepositional normal faults that characteristically have much thicker stratigraphic sequences on the downthrown side.

Q. Are the lines in Atascosa County faults? (This question refers to the cross section shown on the slide "Carrizo-Wilcox Aquifer Downdip Boundary")

A. Yes, these lines represent faults. However, the cross section is a general representation and does not show actual structure.

Q. Will all sediments younger than the Reklaw Formation be modeled as one layer?

A. Yes.

Q. Will sediments younger than the Reklaw Formation be modeled as SB-2 minor aquifers?

A. Yes.

Q. What does the zero contour line indicate?

A. Contour lines indicate elevation. The zero line is at sea level.

Q. Is DE&S aware of the TNRCC Surface Casing well log library?

A. Yes.

Q. Is the circular area of low hydraulic conductivity in Webb and Dimmit Counties real? Is it supported by depositional environment data? (This question refers to the hydraulic conductivity map shown on the slide "SW Carrizo: Hydraulic Conductivity")

A. The circular area of low hydraulic conductivity is based on only one well. However, hydraulic conductivity generally decreases to the southwest. Sandstone maps of the Carrizo-upper Wilcox and paleogeographic reconstructions presented in Hamlin (1988) indicate that the area in question would probably have significantly lower hydraulic conductivity than areas farther to the northeast.

Q. Is DE&S aware of well tests performed by CH2M HILL in the Larado area?

A. No. DE&S will determine if these well tests are available and incorporate them in the hydraulic conductivity database if they are.

Q. What is the date of the LBG-Guyton Report on the Winter Garden Area model?

A. August, 1998.

Q. When will DE&S know which stream reaches are gaining/losing?

A. The analysis of the modeled stream reaches should be near completion by the next SAF meeting.

Q. How will future pumping be determined? Can simulations be run using historical data to guide the distribution of pumping? Will drought conditions be used? Can pumping distributions be easily changed?

A. Future pumping for model predictive runs will be based on RWPG water-demand projections. Historical data are considered during the development of RWPG water-demand projections. Some predictive runs will use drought of record conditions. Pumping distributions can be modified by anyone familiar with MODFLOW input.

Q. Will the method for distribution of pumping be discussed at the next SAF meeting? Will there be opportunity for feedback on the pumping volumes?

A. A detailed discussion on the methodology used to distribute pumping will be provided at the next SAF meeting. Pumping volumes for model predictive runs will be based on RWPG water-demand projections as provided to DE&S by the TWDB. Any feedback relating to pumping volumes can be provided to the TWDB directly or through DE&S for consideration in future water-demand projections.

Q. The South Central Texas (Region L) Regional Water Plan includes recharge values that are twice the volume being pumped, but water levels are dropping. Will new recharge data be used?

A. Recharge for the Southern Carrizo-Wilcox model is being determined using the SWAT (Soil and Water Assessment Tool) model. The Region L recharge estimate will not be used for modeling.

Q. Is SWAT being done in-house? Has it been used much for flow modeling?

A. The SWAT calculations are being done in-house. SWAT has been previously used in conjunction with MODFLOW and has even been combined with MODFLOW in a modeling package called SWATMOD.

Q. Does the model account for streamside evapotranspiration (ET)?

A. ET is included in the SWAT recharge calculations. A more thorough discussion of ET will be provided at the next SAF meeting.