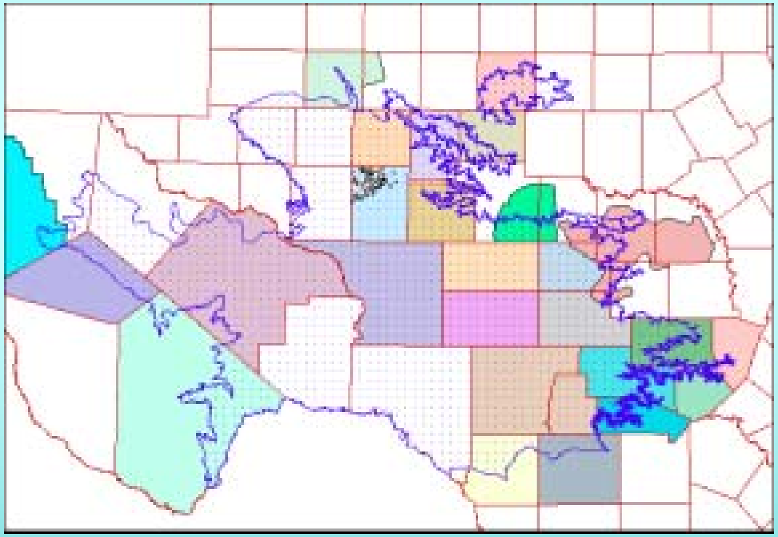
TEXAS WATER DEVELOPMENT BOARD

Welcome To The Fifth Edwards-Trinity Aquifer Model Stakeholders Advisory Forum



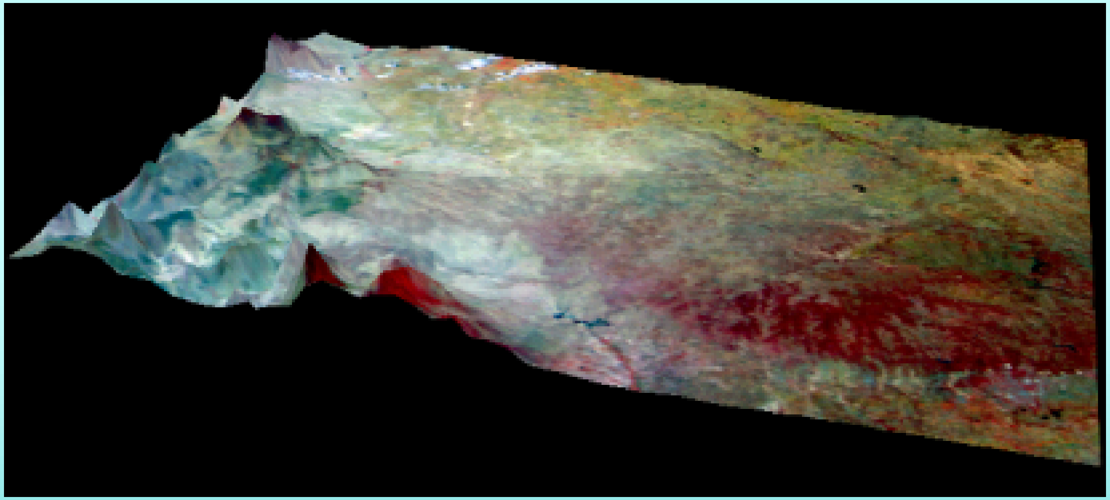
ET SAF 5

November 7, 2002

Texas Water Development Board

Groundwater Availability Modeling

A Groundwater Flow Model for the Edwards-Trinity Aquifer of West-Central, Texas



Texas Water Development Board

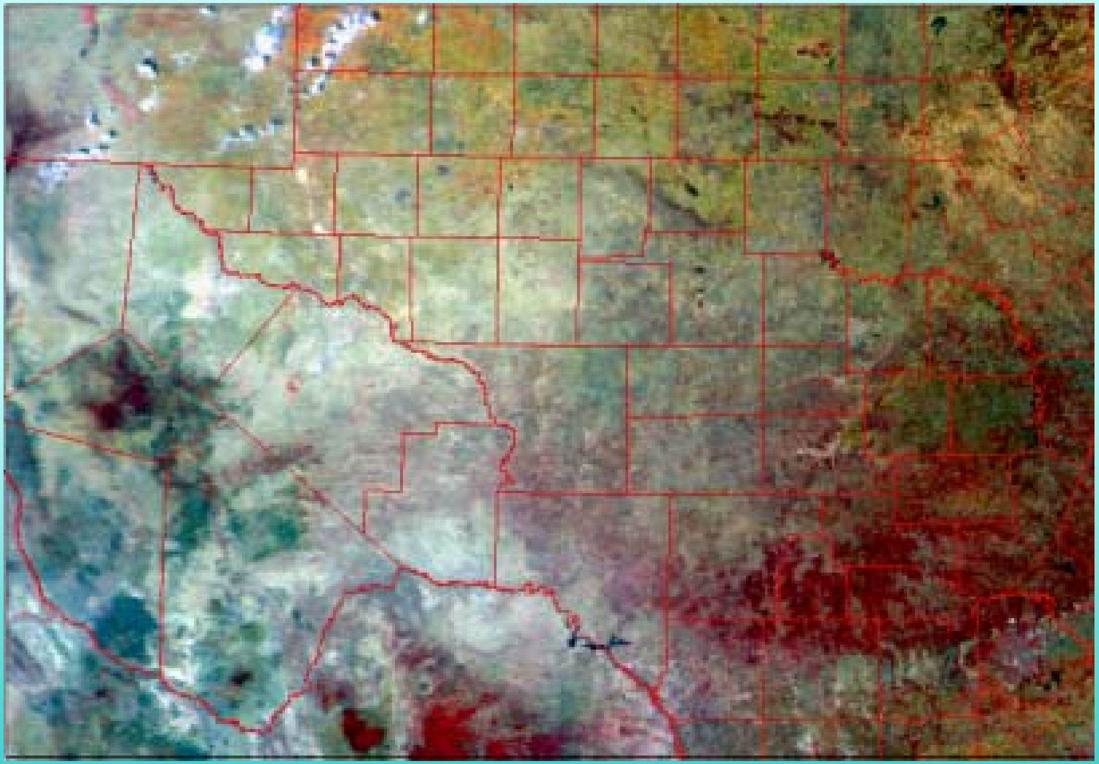
Edwards-Trinity Stakeholders Advisory Forum Objectives

- Provide Public Awareness of GAM
- Update Interested Participants
- Solicit Data and Information
- Encourage Comments and Criticism

Today's Stakeholders Advisory Forum Topics

- Status of Current Modeling Project
- Final Structural Geometry for the Model Layers
- Estimation of Areal Recharge
- Pre-Development Water Levels
- Estimation of Areal Evaptranspiration
- Stream-Routing Parameters for the Model
- Distributed Hydraulic Conductivity for the Model
- Approach for Calibrating to Steady-State

Status of the Edwards-Trinity Modeling Project



Roberto Anaya

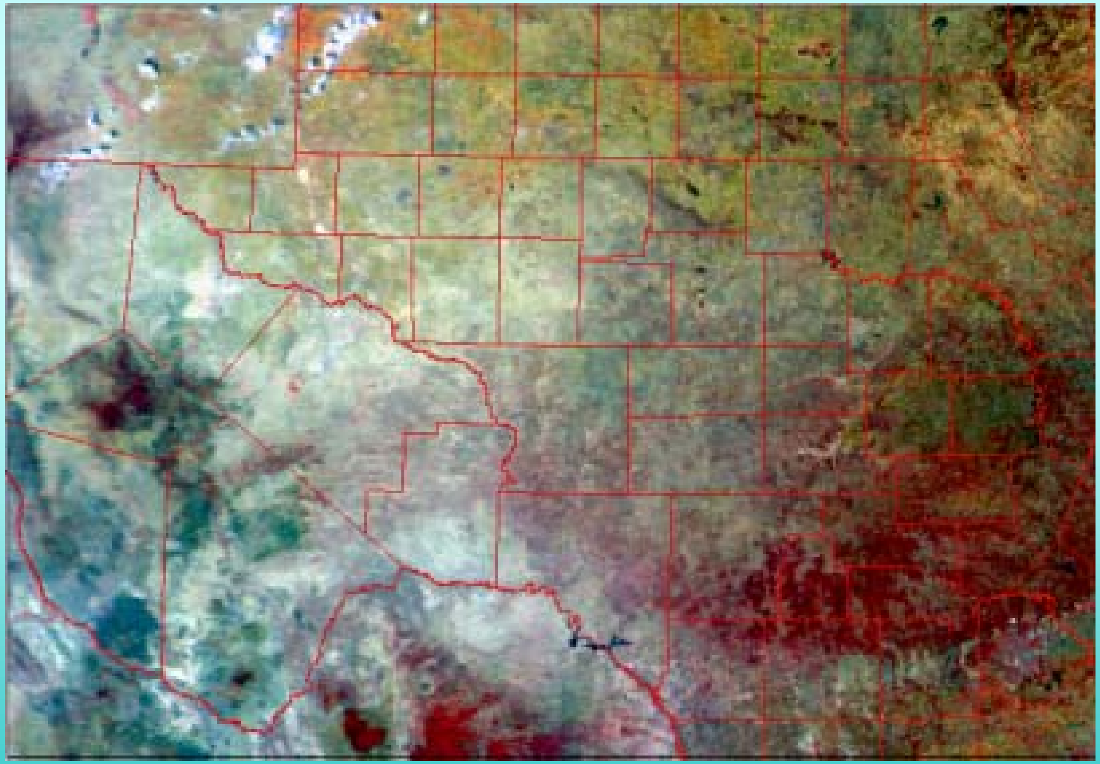
Current Status of the Edwards-Trinity Model

- **Old News -** The Modeling Project still remains Behind Schedule
- **Set Backs -** Due to Conceptual Model Issues such as Addition of both Pecos Alluvium and Trinity Aquifers
- **Also -** Unexpected Workload associated with other state GAM Projects
- **Good News -** Added new Modeler to GAM Staff this year
- **And -** Model is just About Ready for Steady-State Calibration … This Month!

Revised Project Schedule

- Complete Steady-State Calibration by End of Year 2002
- Develop Data Sets for Transient Calibration and Predictive Simulations by Early January 2003
- Complete Transient Calibration by Late January/Mid February 2003
- Complete Predictive Simulations by End of March 2003
- Complete Report and hold Modeling Workshop by End of May 2003

Final Structural Geometry for the Model Layers



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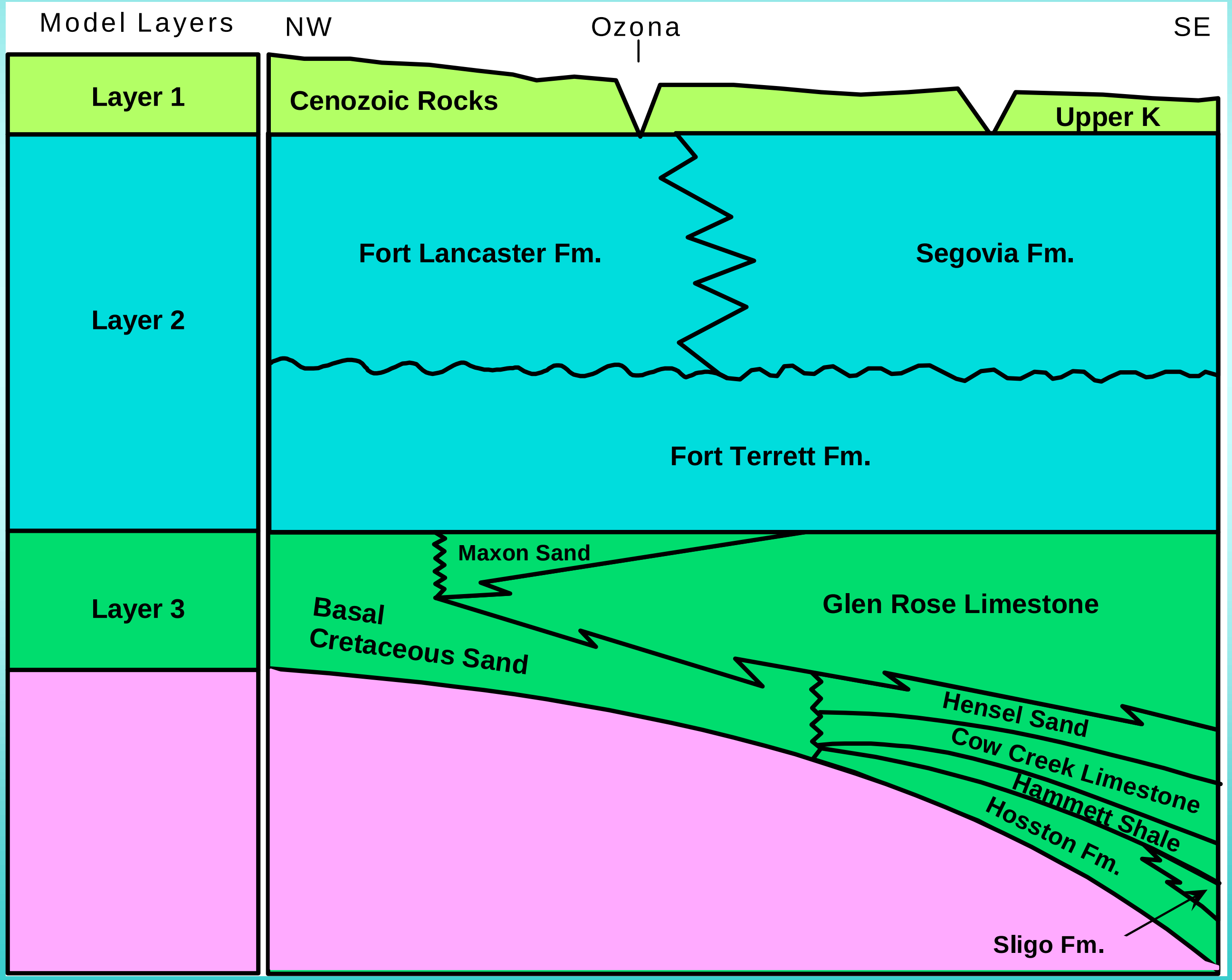
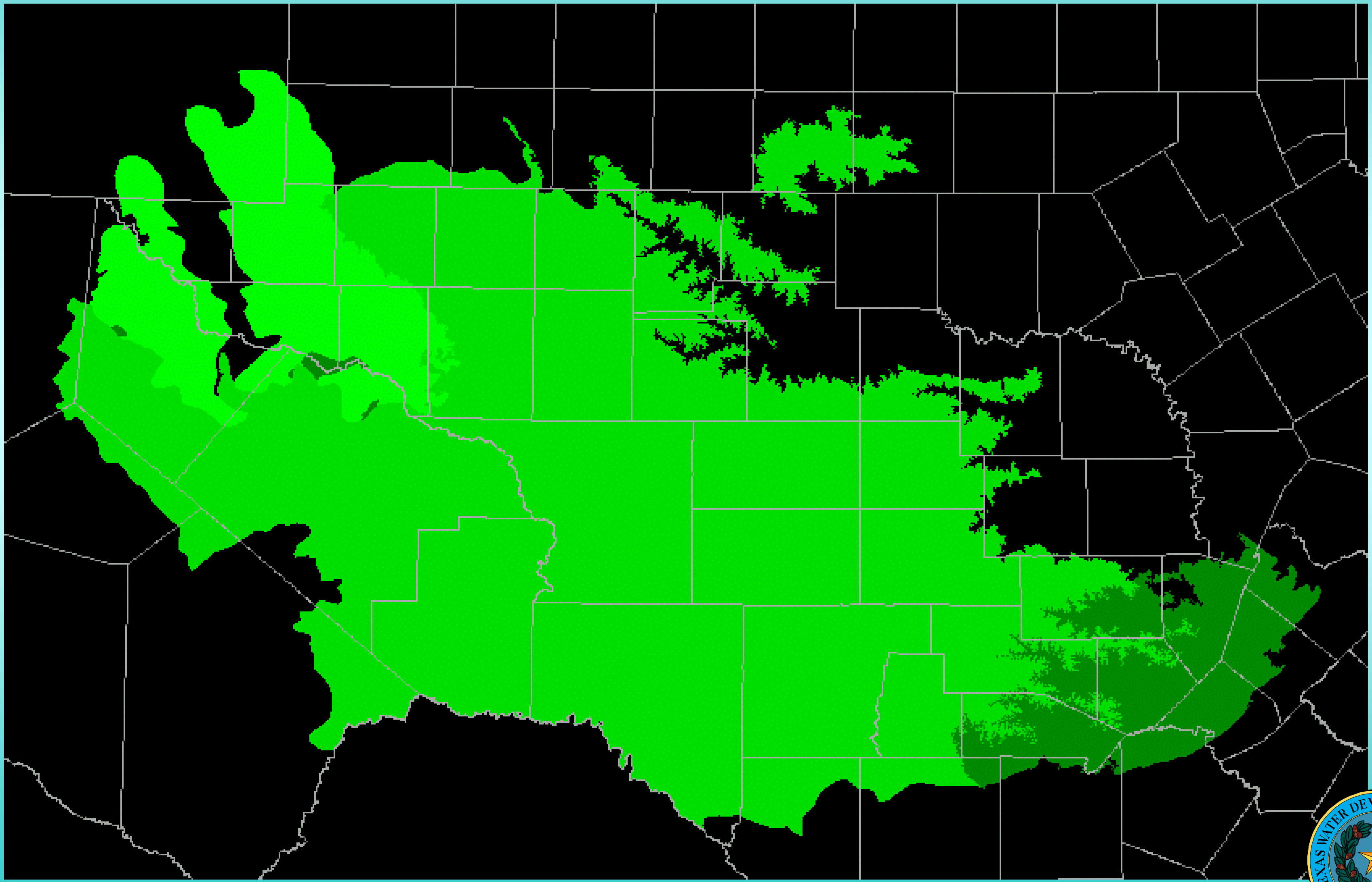
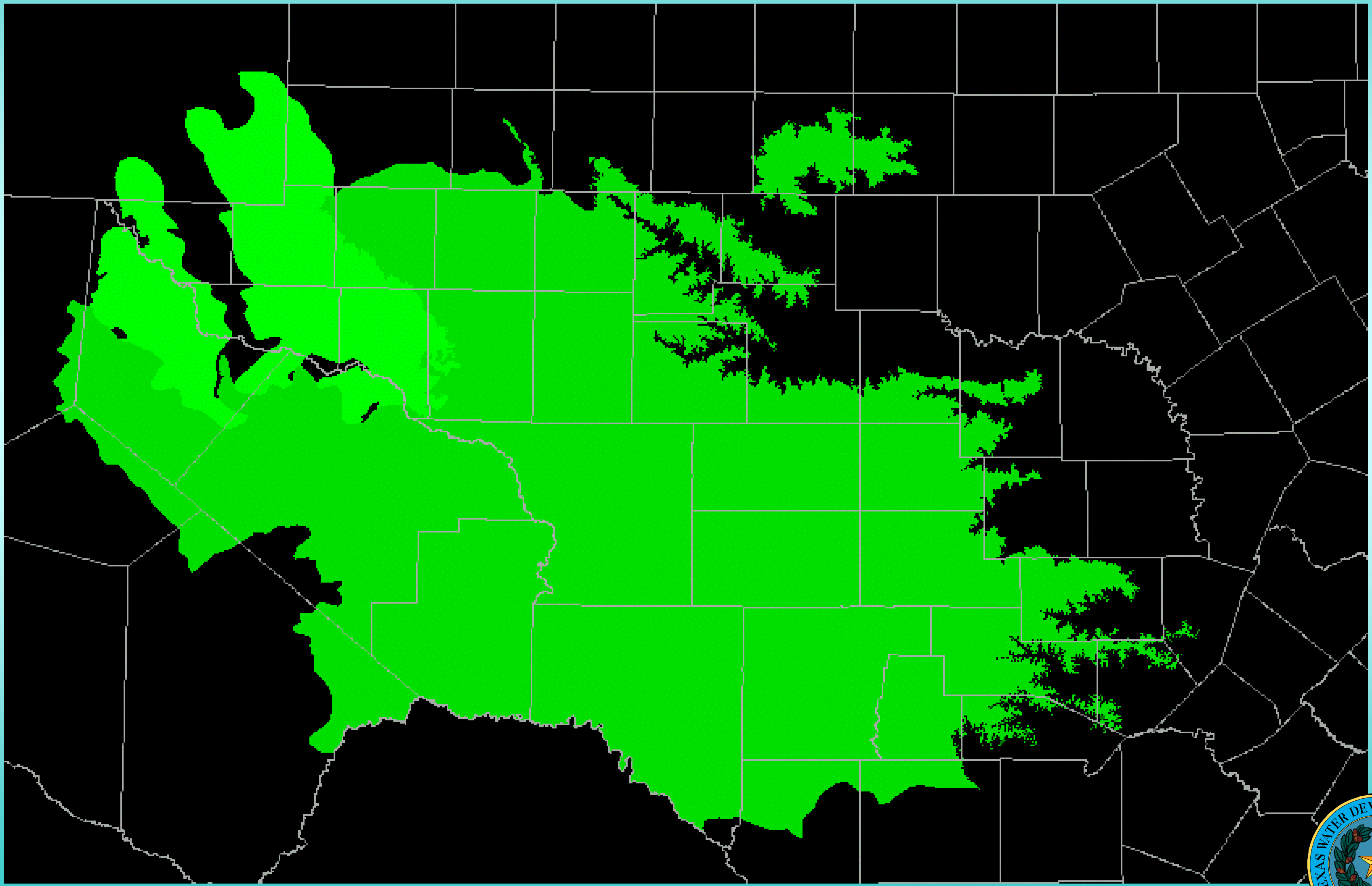
Proposed Model Layers for the Edwards-Trinity Aquifer Model



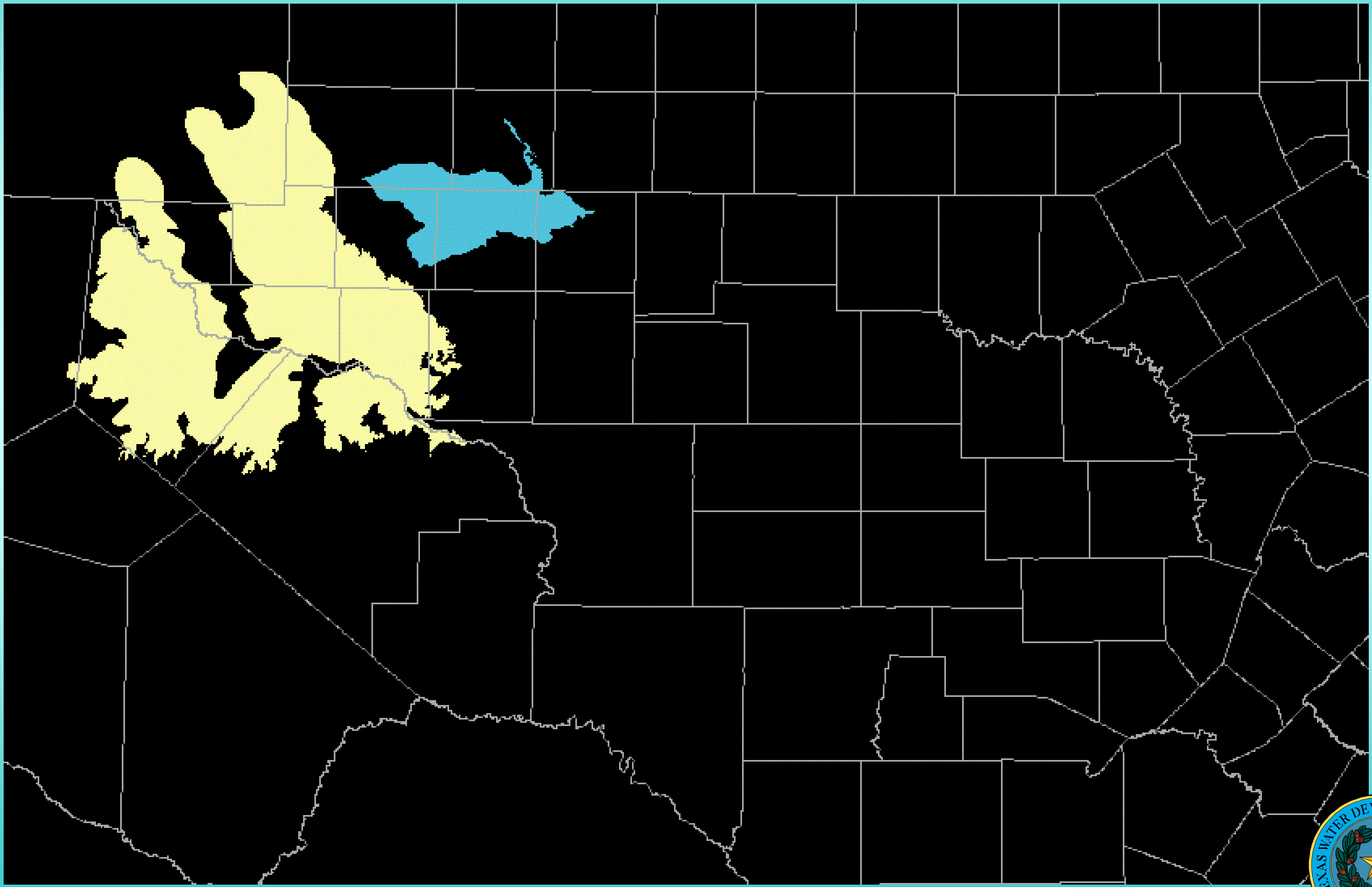
Extent for Model Layer 3



Extent for Model Layer 2



Final Extent for Model Layer 1



Developing the Structural Geometry for the Model

- Layer 3 (Base of Trinity) Data Sources acquired mostly from USGS-TNRCC SWAP Project then enhanced with BEG GAT sheets, USGS and TWDB report Cross-sections and Maps
- Layer 2 (Base of Edwards) Data Sources acquired mostly from USGS and TWDB report Cross-sections and Maps then enhanced with BEG GAT sheets and a few Geophysical Logs

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Developing the Structural Geometry for the Model

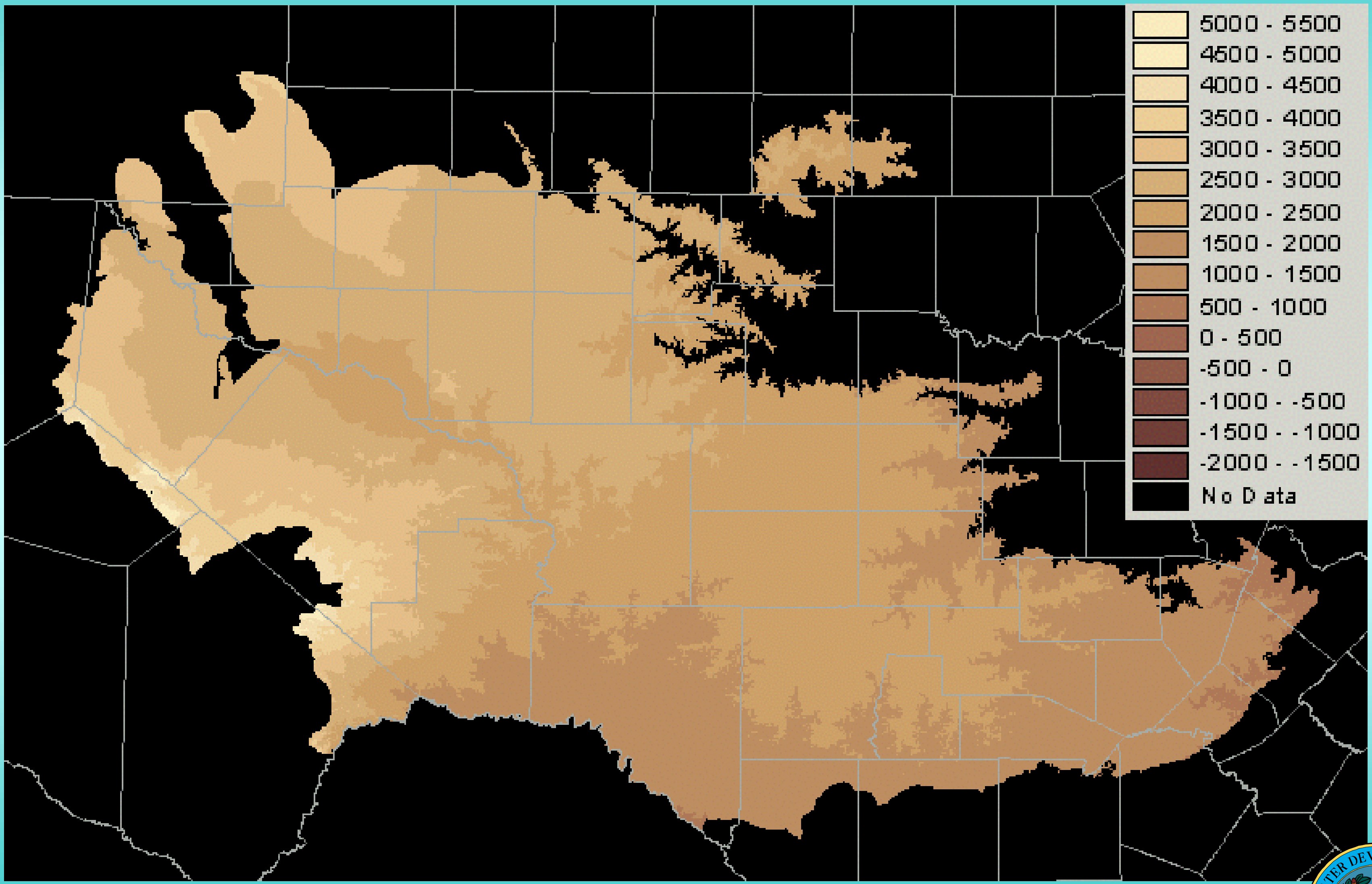
- Layer 1 (Base of Pecos Alluvium/Ogallala) Data Sources acquired mostly from USGS-TNRCC SWAP Project then enhanced with BEG GAT sheets, USGS and TWDB report Cross-sections and Maps
- 1:250,000 Scale DEM used for the Top Portions of Layers Not Overlain by Layers 1 or 2

Developing the Structural Geometry for the Model

- All Data was Compiled into Point Locations
- All Data was then Checked for Outlier Significance
- A Trial and Error technique was used to Interpolate Structural Surfaces with advance Geostatistical Methods
- Structural Surfaces were Checked again for Accuracy and Geologic Soundness

Top of Layers Not Overlain by Layers 1 & 2

(DEM)



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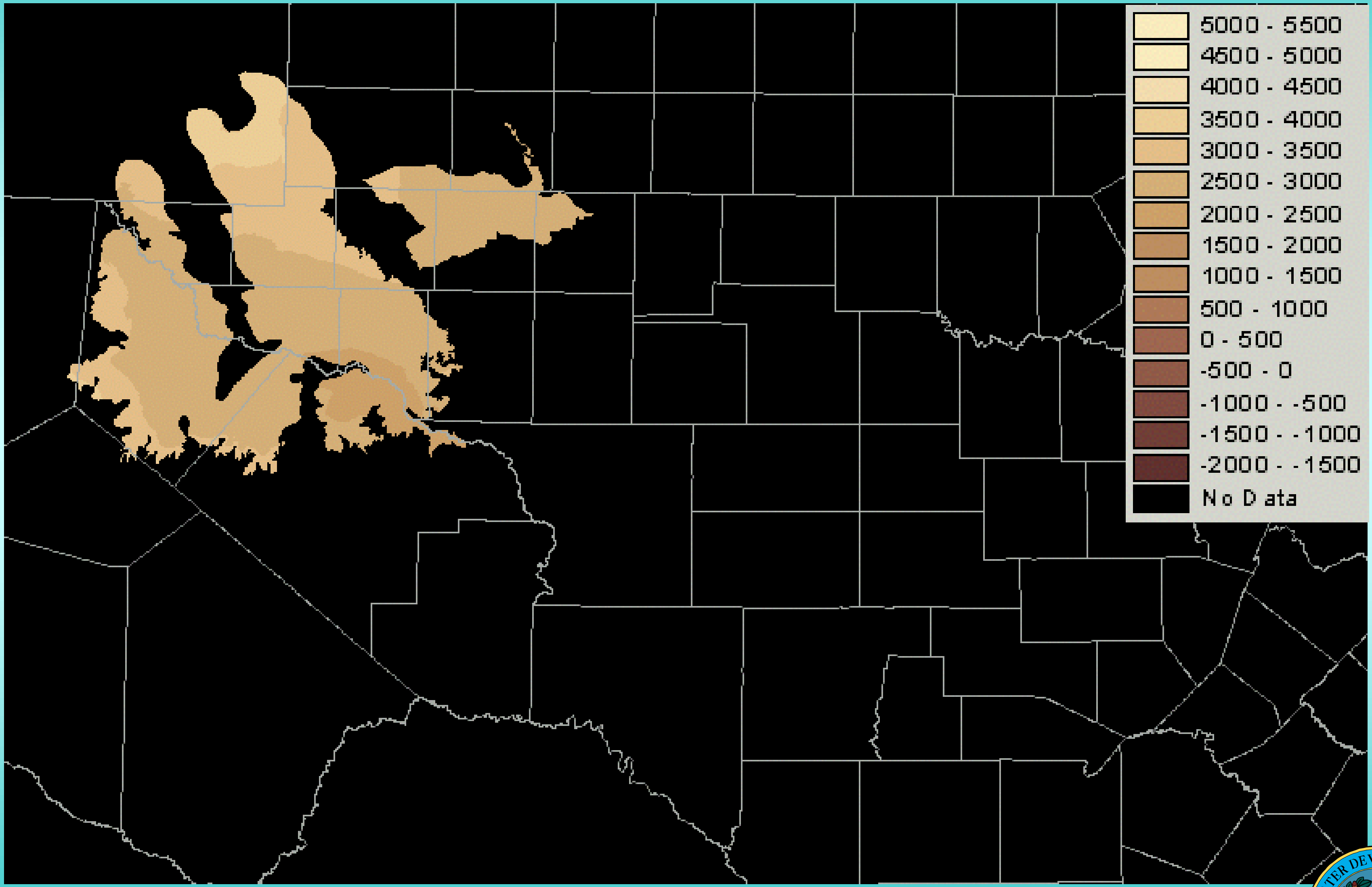
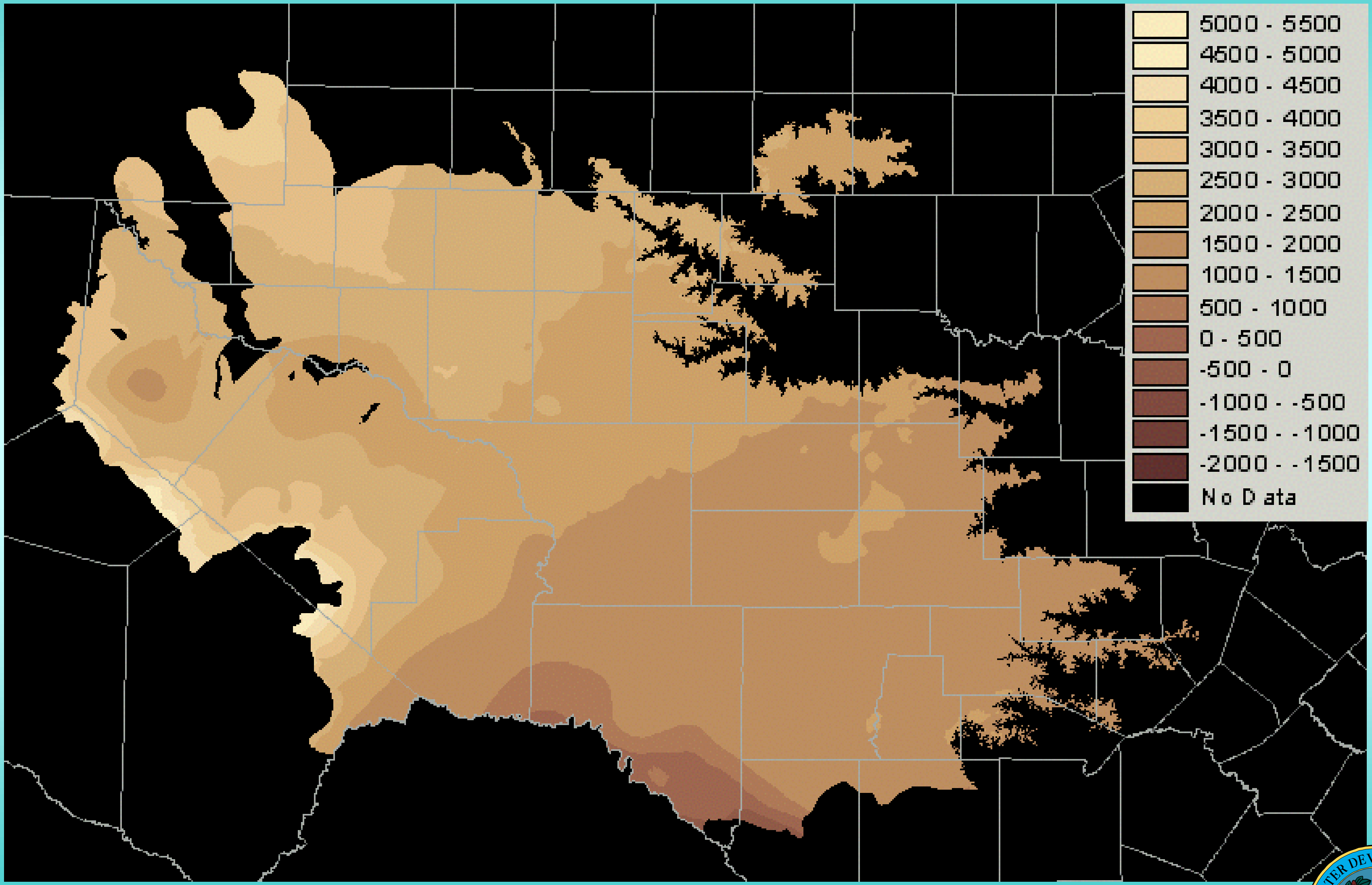
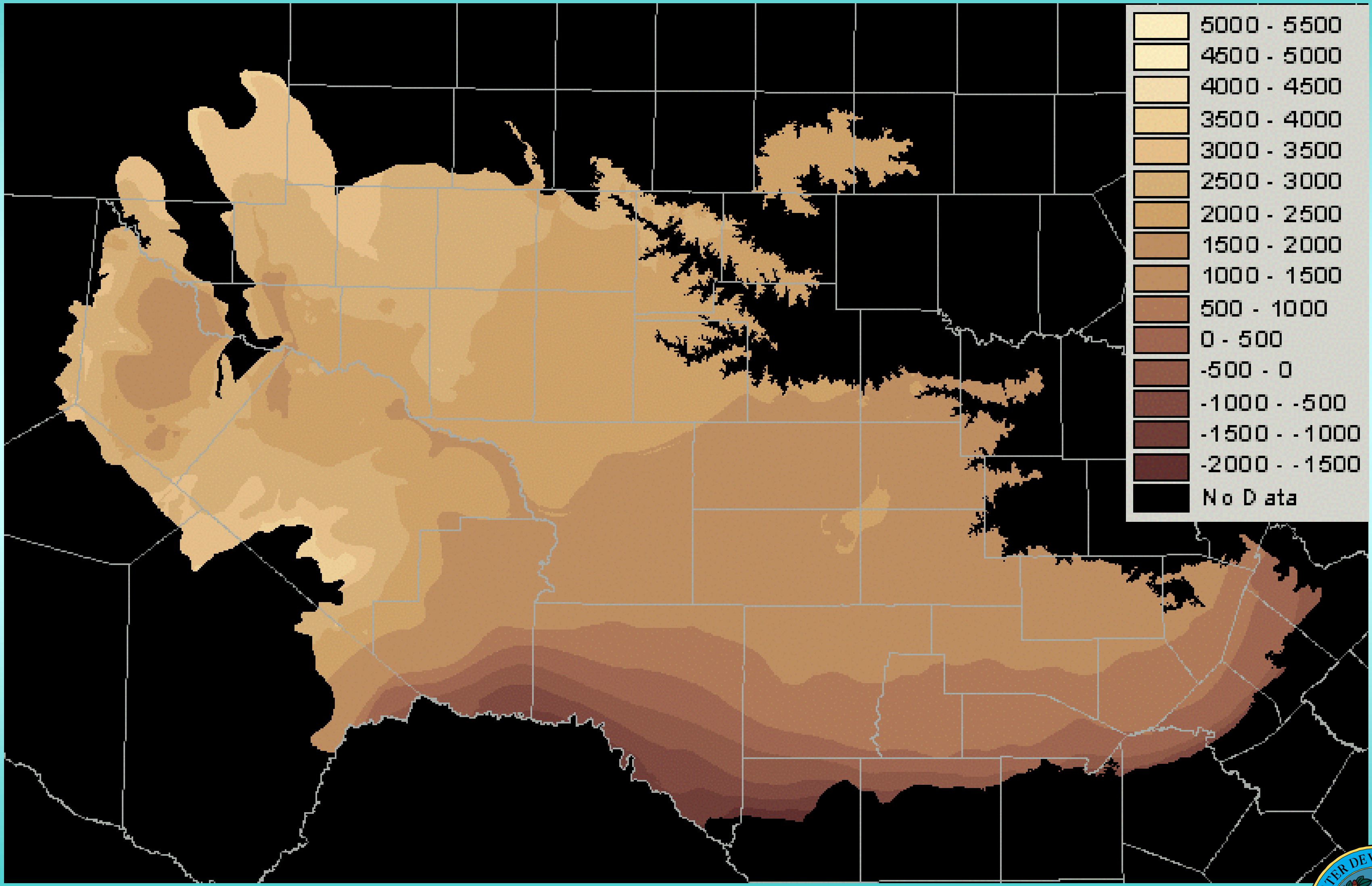
Bottom of Layer 1



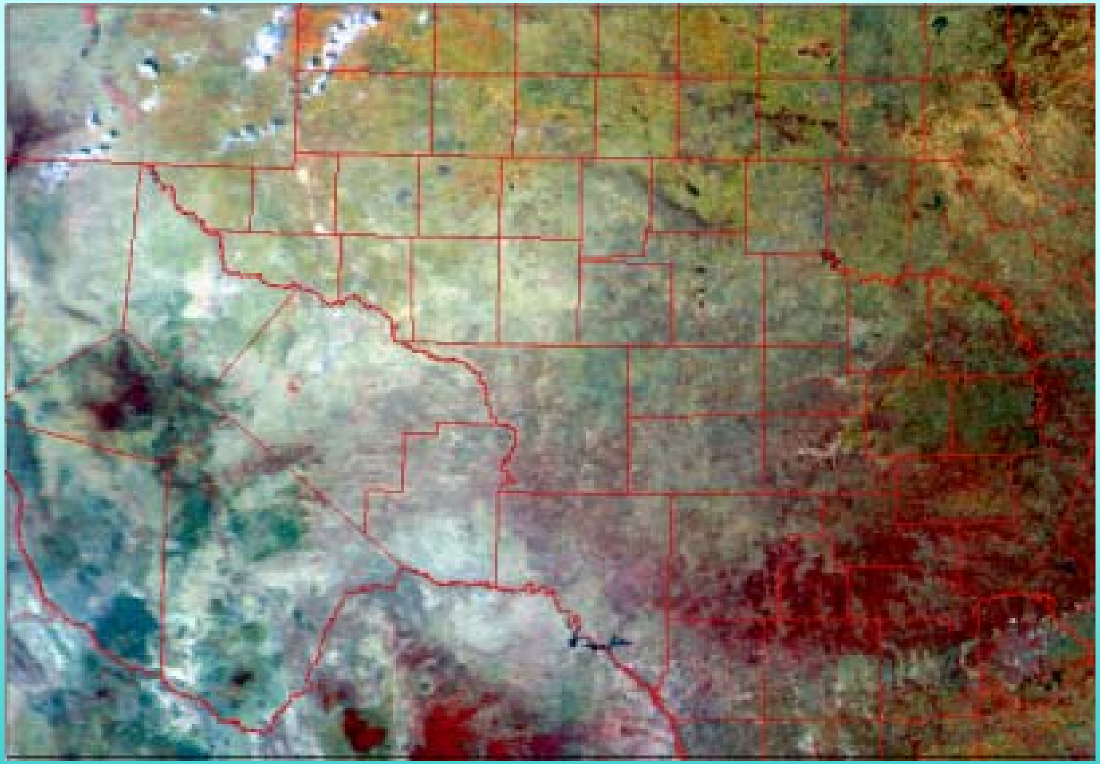
Bottom of Layer 2



Bottom of Layer 3



Approach to Estimating Areal Recharge for the Edwards-Trinity Aquifer



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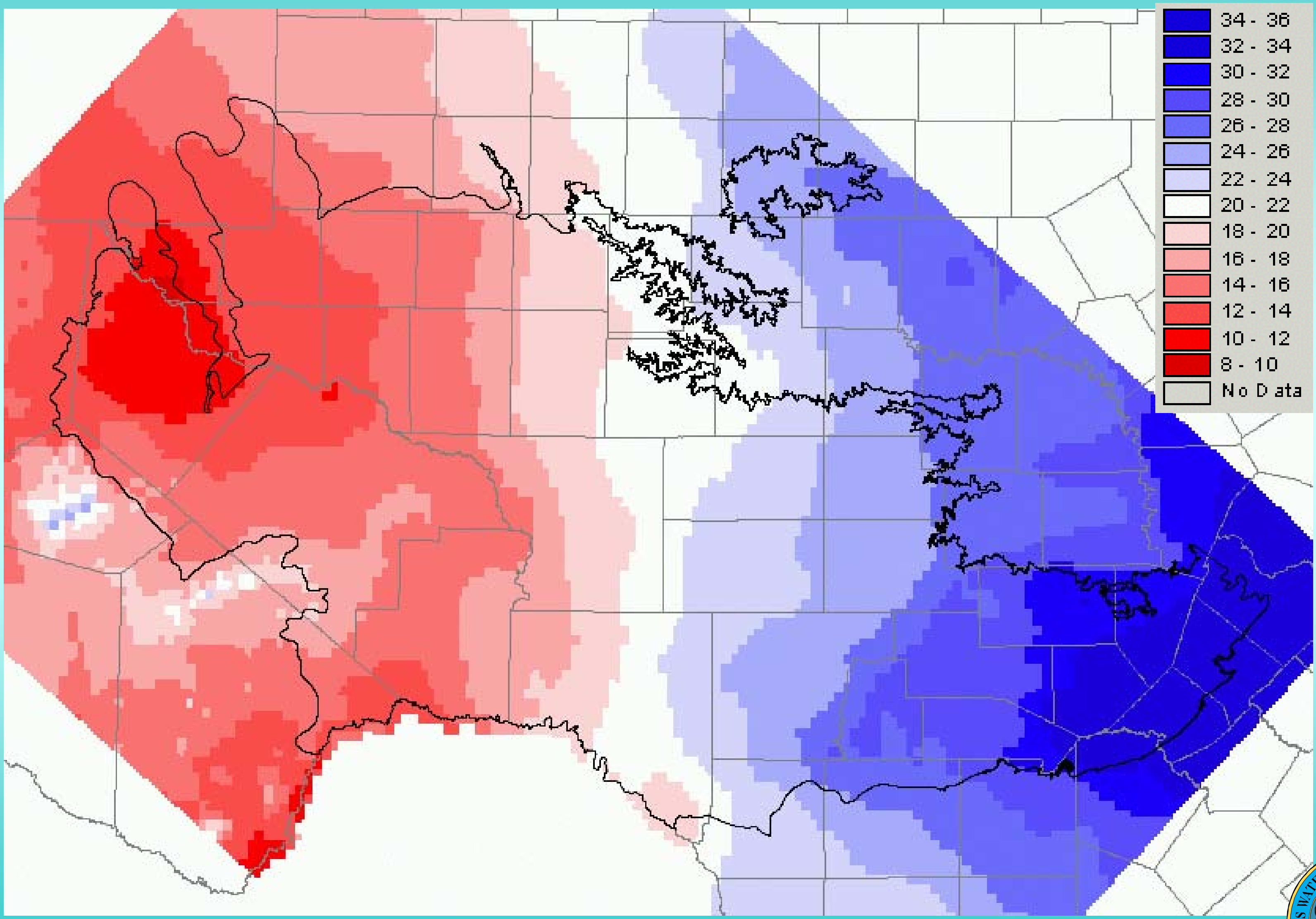
Types of Recharge

- Direct (Diffuse) - Infiltration Derived from Distributed Precipitation through the Vadose Zone
- Localized (Focused) - Infiltration Concentrated at Geomorphic Features such as Playas, Sink Holes, Faults/Fractures
- Indirect - Infiltration from Mappable Features such as Losing Streams and Leaky Reservoirs/Lakes
- Enhanced - Infiltration from Anthropogenic Processes such as Irrigation Return Flow and Well Injection
- Potential - May or May Not Reach the Water Table
- Actual - Actually Reaches the Water Table

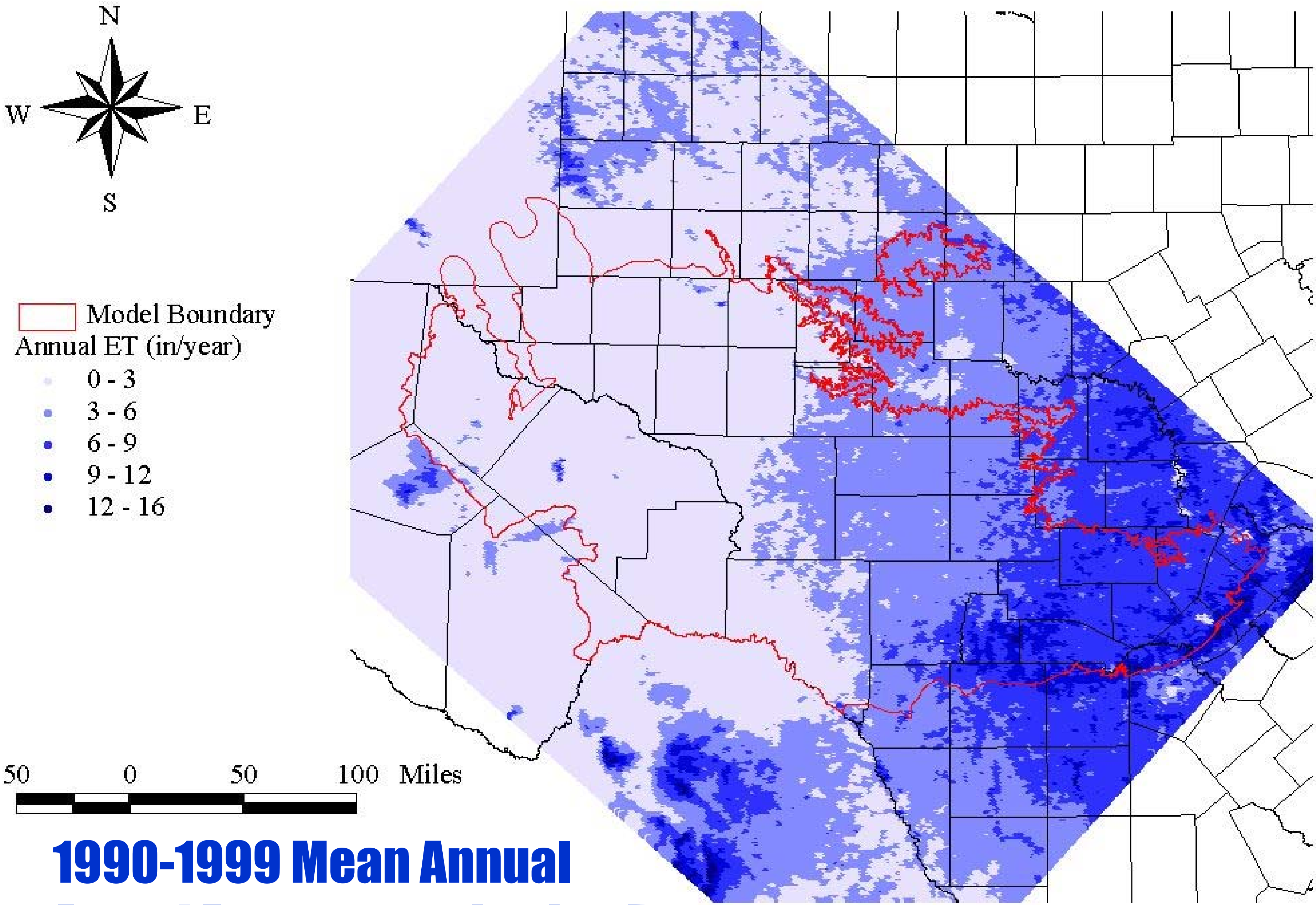
Potential Controls of Recharge

- Climate - Precipitation and Evapotranspiration Rates
- Topography - Slope, Cuvature, Convexity/Concavity
- Soil - Thickness, Permeability, Water Holding Capacity
- Vegetation - Density, Leaf and Root Characteristics
- Surface Hydrology - Stream Channel, Basin, and Flow Characteristics
- Geology - Lithologic, Structural, and Hydraulic Characteristics
- Landuse - Agricultural and Urban Development

1960-1990 Mean Annual Rainfall (in)

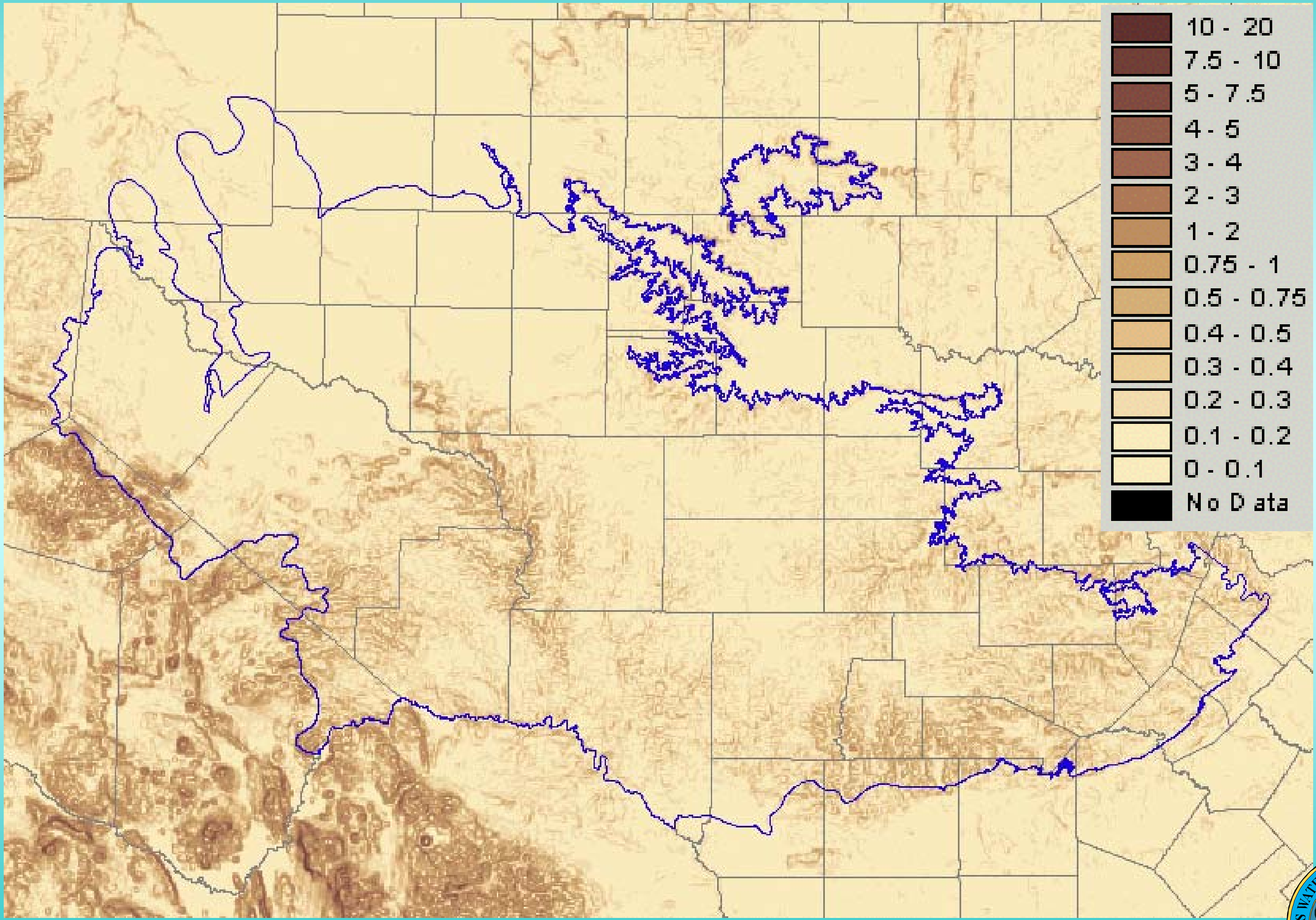


Data From Daly, Nielson, and Phillips, 1994; Daly, Taylor, and Gibson, 1997

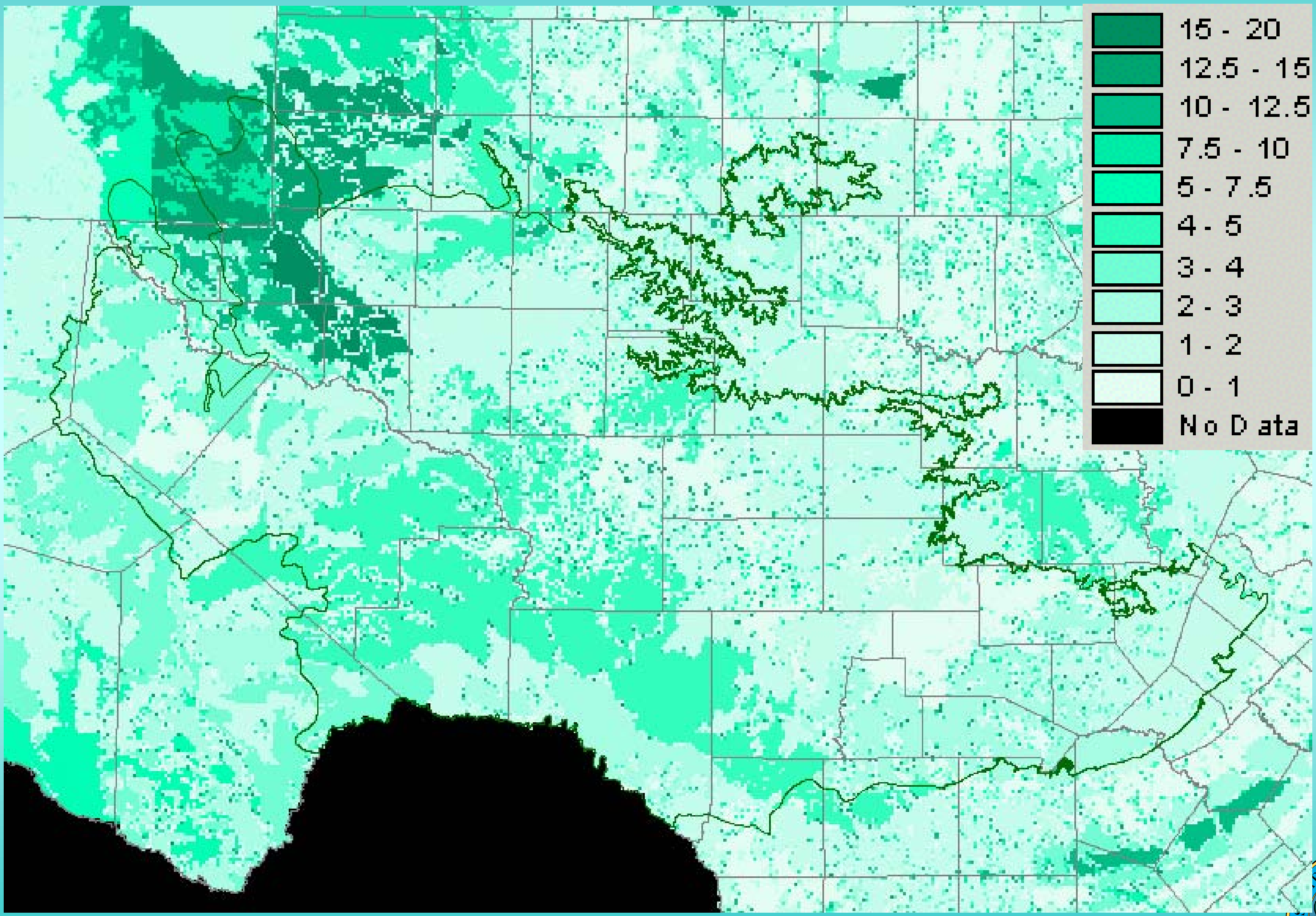


1990-1999 Mean Annual Actual Evapotranspiration Rate

Topographic Slope (%)

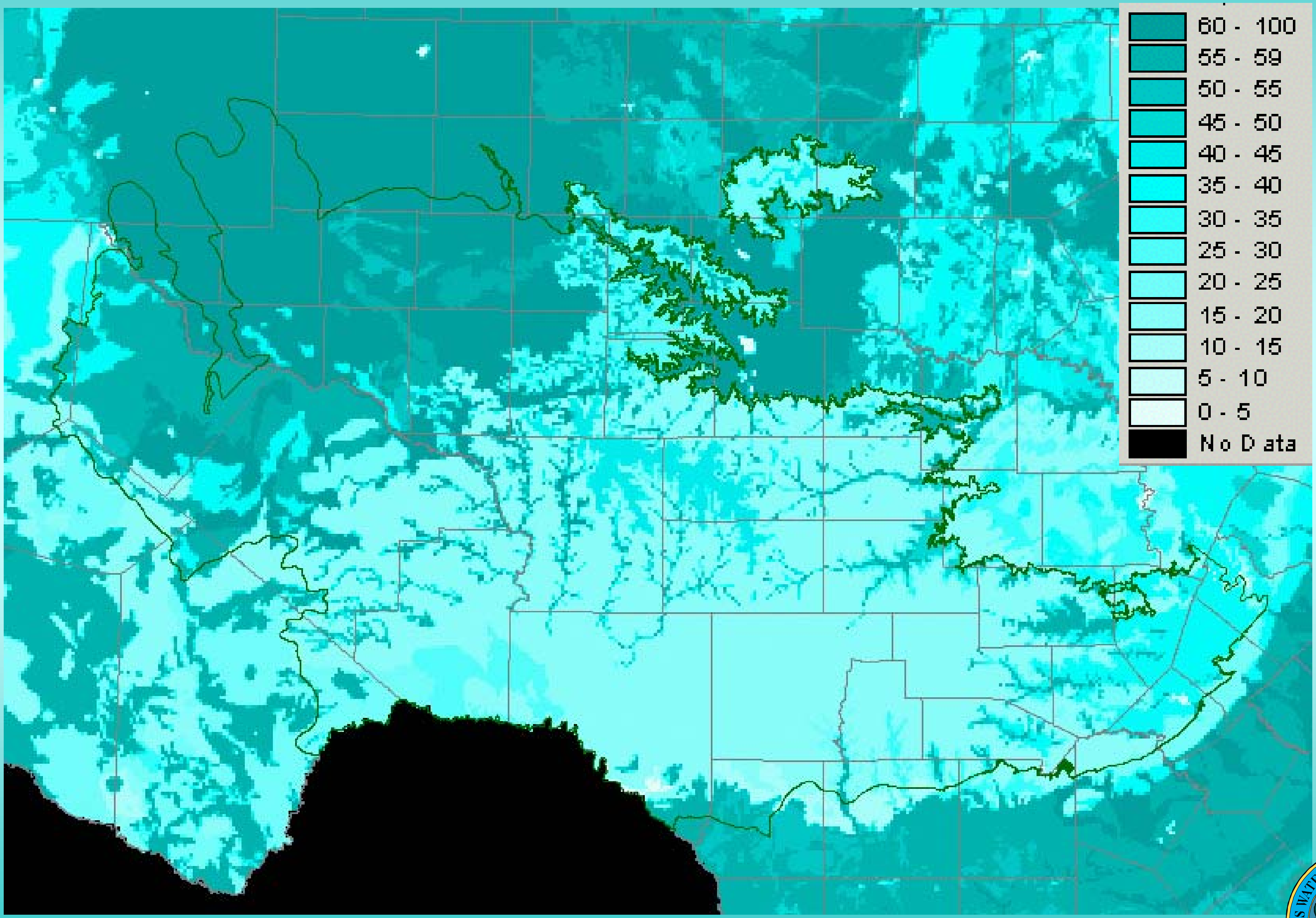


Soil Permeability (in)



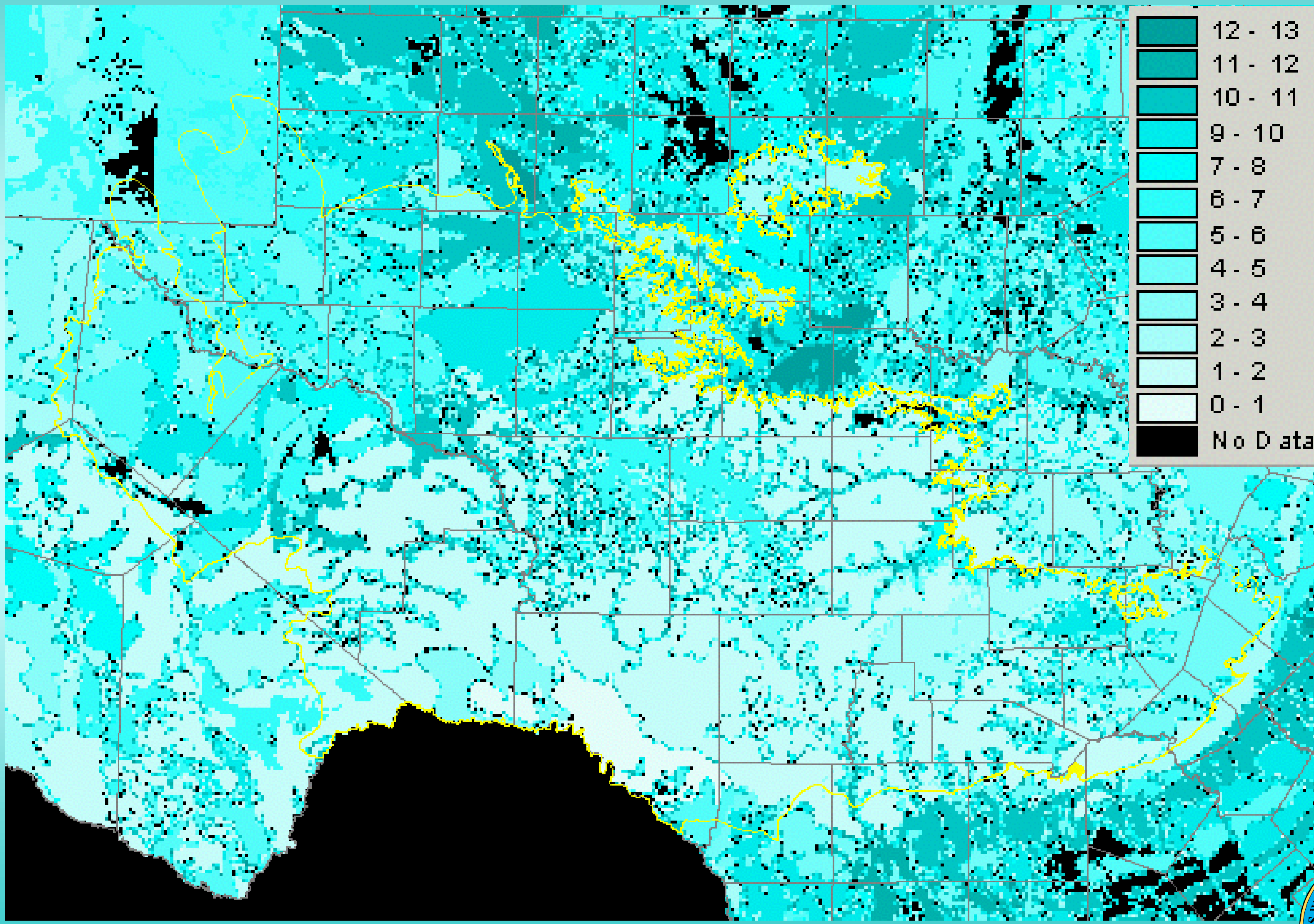
Data From Earth System Science Center, Penn State University

Soil Thickness (in)

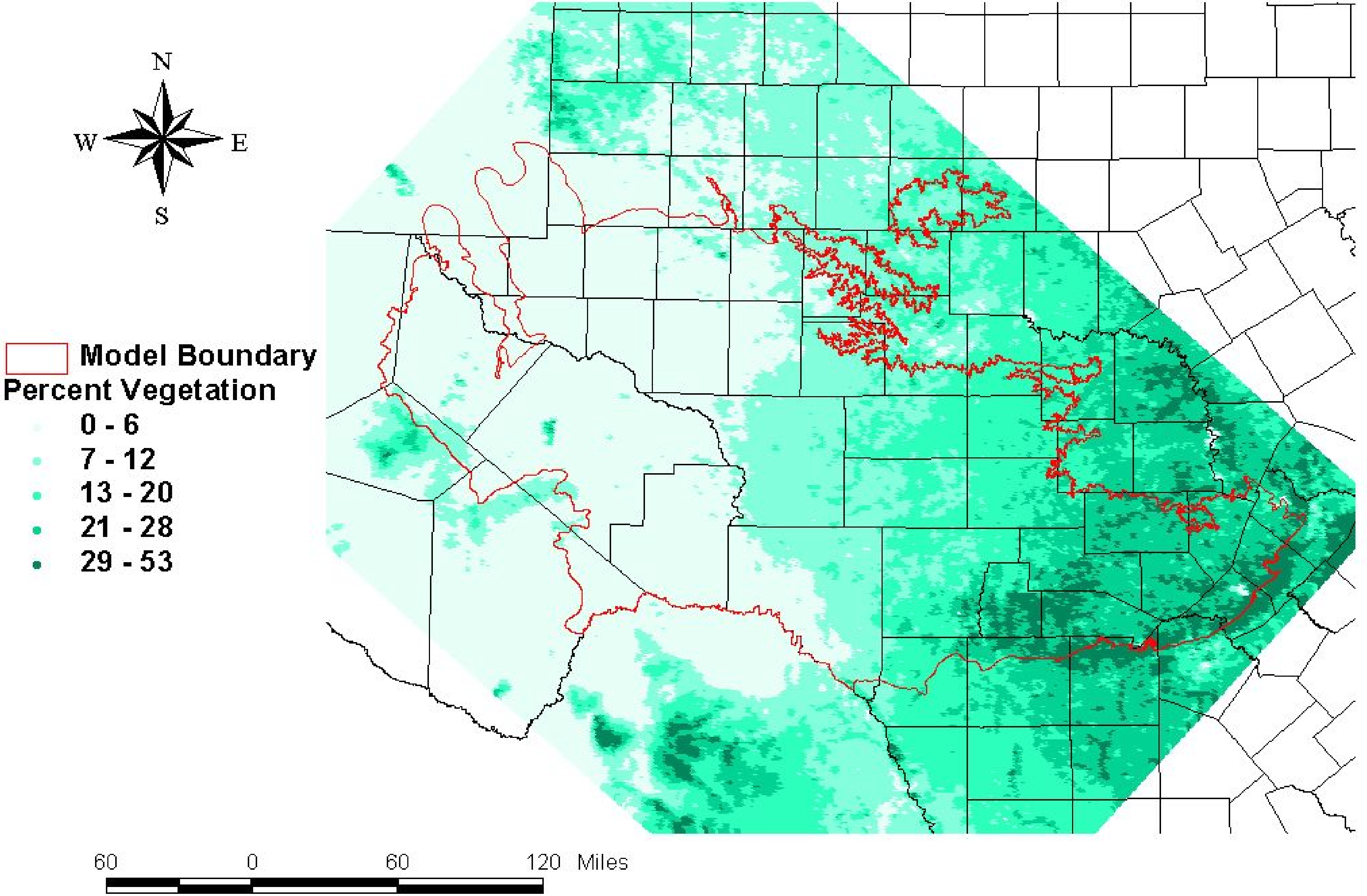


Data From Earth System Science Center, Penn State University

Soil Available Water Holding Capacity (in)

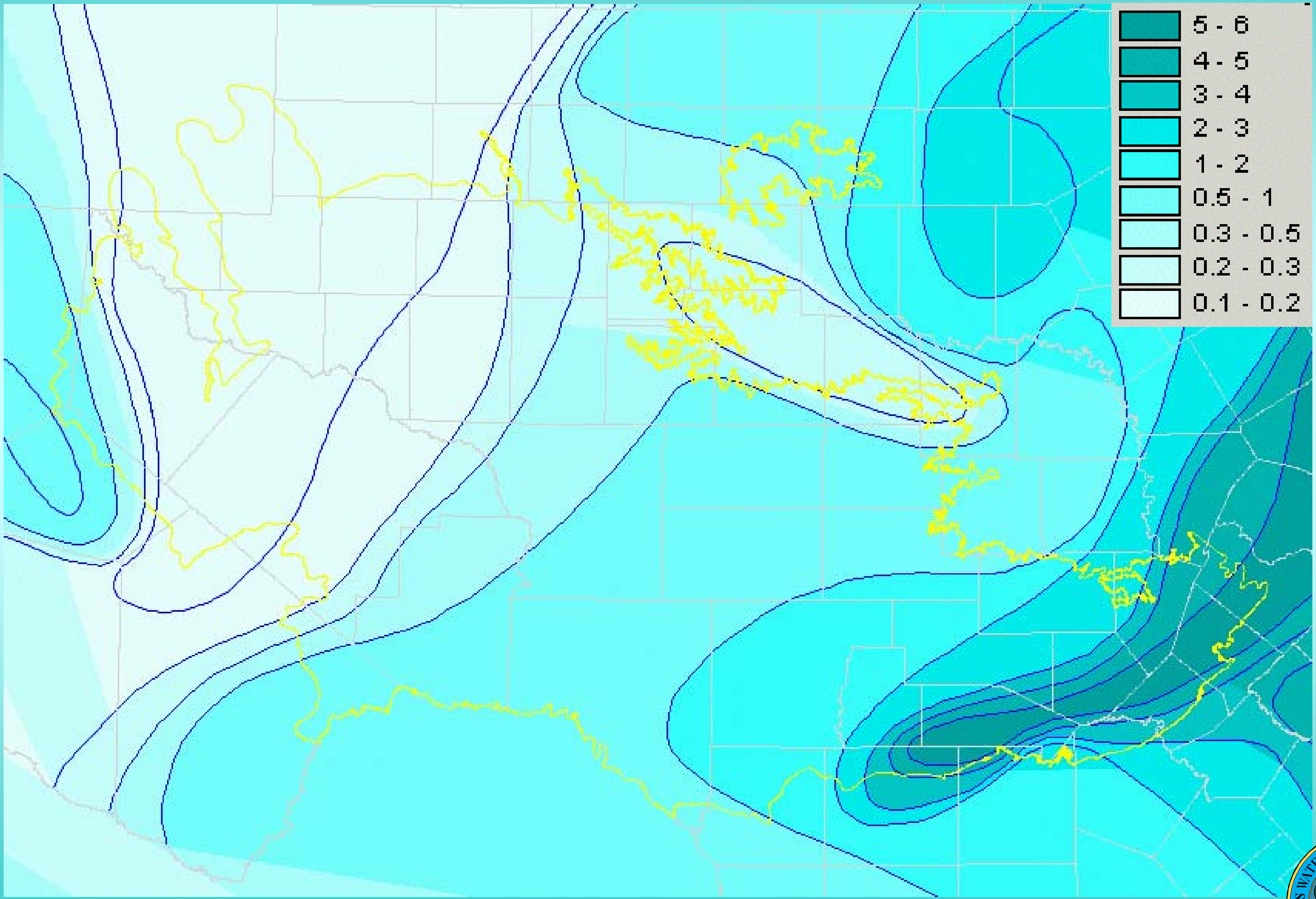


Data From Earth System Science Center, Penn State University



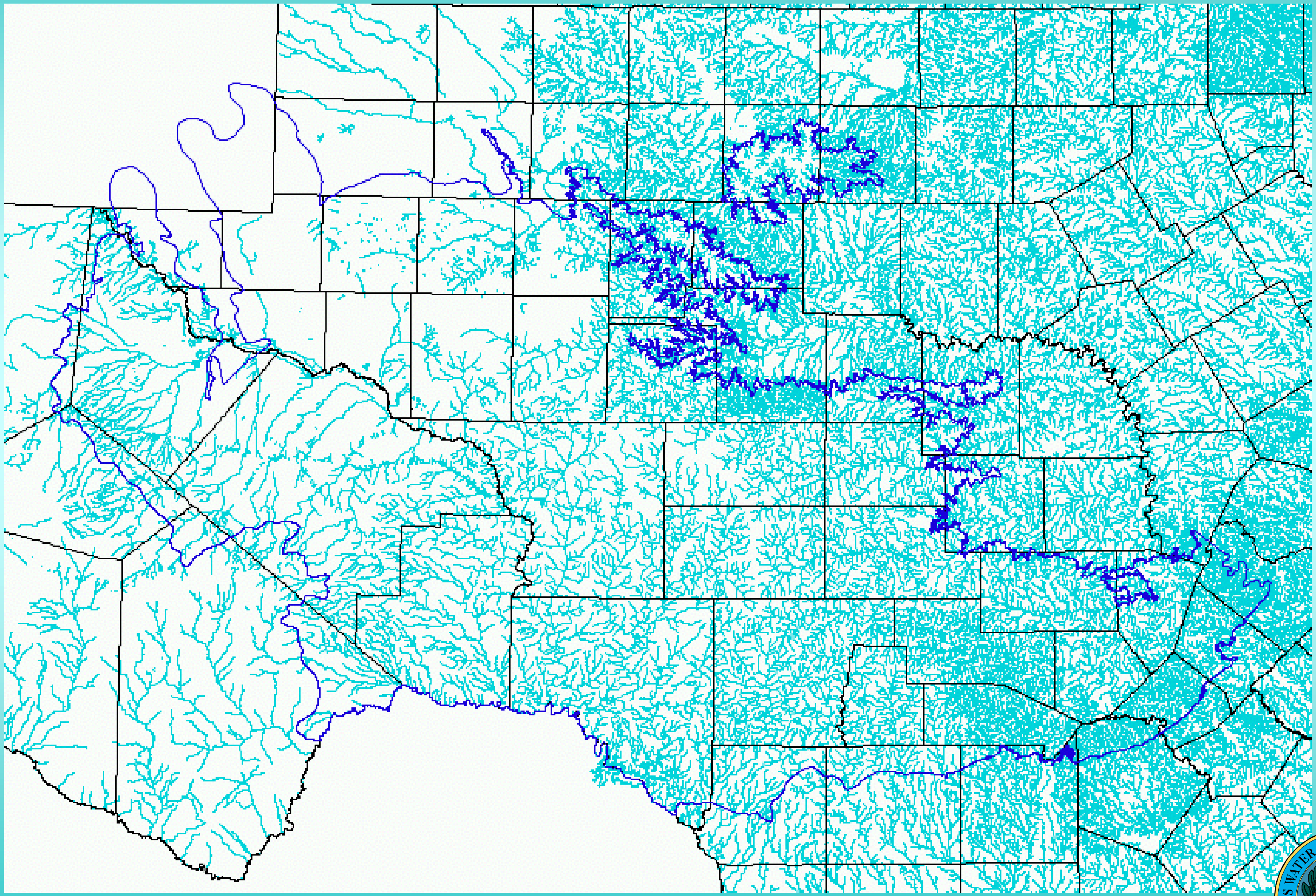
1990-1999 Mean Annual Percent Vegetation Cover

1951-1980 Mean Annual Runoff (in)



Data From USGS Water Resources Divsion

Drainage Density



Data From USGS Water Resources Divsion

Common Techniques For Estimating Recharge

Three Basic Techniques:

- Surface Water
- Unsaturated Zone
- Saturated Zone

Surface Water Methods

- Channel Loss/Gain Studies
- Baseflow Analysis
- Seepage Meters
- Tracers - Thermal and Chemical
- Rainfall/Runoff Modeling

Unsaturated Zone Methods

- Lysimeters
- Analytical Methods - Darcy’s Law, Zero Flux Plane
- Chemical Tracers - Applied, Historical, Environmental
- Soil Moisture Modeling

Saturated Zone Methods

- Water Table Fluctuation
- Analytical Methods - Darcy's Law
- Chemical Tracers - Applied, Historical, Environmental
- Groundwater Modeling

Other Factors to Consider When Estimating Recharge

- Time Domain - Short vs Long
- Spatial Domain - Regional vs Local
- Climate Domain - Arid vs Humid
- Depth to Water Table - Shallow vs Deep
- Data Availabiltiy - Quantity vs Quality
- Accuracy - Time vs Expense

Techniques for Estimating Recharge Based on Climate Domain

	Humid	Arid/Semi-Arid
Surface Water	Channel Water Budget Seepage Meters Baseflow Analysis Chemical Tracers Watershed Modeling	Channel Water Budget Seepage Meters Thermal/Chemical Tracers Watershed Modeling
Unsaturated Zone	Lysimeters Analytical Methods Chemical Tracers Soil Moisture Modeling	Lysimeters Analytical Methods Chemical Tracers Soil Moisture Modeling
Saturated Zone	Chemical Tracers Water Table Fluctuation Analytical Methods Groundwater Modeling	Chemical Tracers Groundwater Modeling

Modified From Scanlon, Healy, and Cook, 2002

So What Method Should Be Used for Estimating the Complexity of Areal Recharge?

- Our Goal is to Estimate Monthly and Annual Recharge for a Large Region with a Sub-Humid to Sub-Arid Climate
- The Water Table is Relatively Deep
- Data Availability is Limited for Most Techniques
- Time and Money are Relatively Sparse
- Scanlon and Others Suggest Multiple Approaches

Previous Estimates of Recharge for the Edwards-Trinity Aquifer

Source	Location	Method	Rech (in/yr)	Rech (%P)
Bennet & Sayer, 1962	Kinney	baseflow	1.4	5.8
Iglehart, 1967	Crockett	baseflow	0.3	1.6
Long, 1958	Real	baseflow	2.0	7.4
Reeves, 1969	Kerr	baseflow	1.0	3.5

From Scanlon and Dutton, 2002

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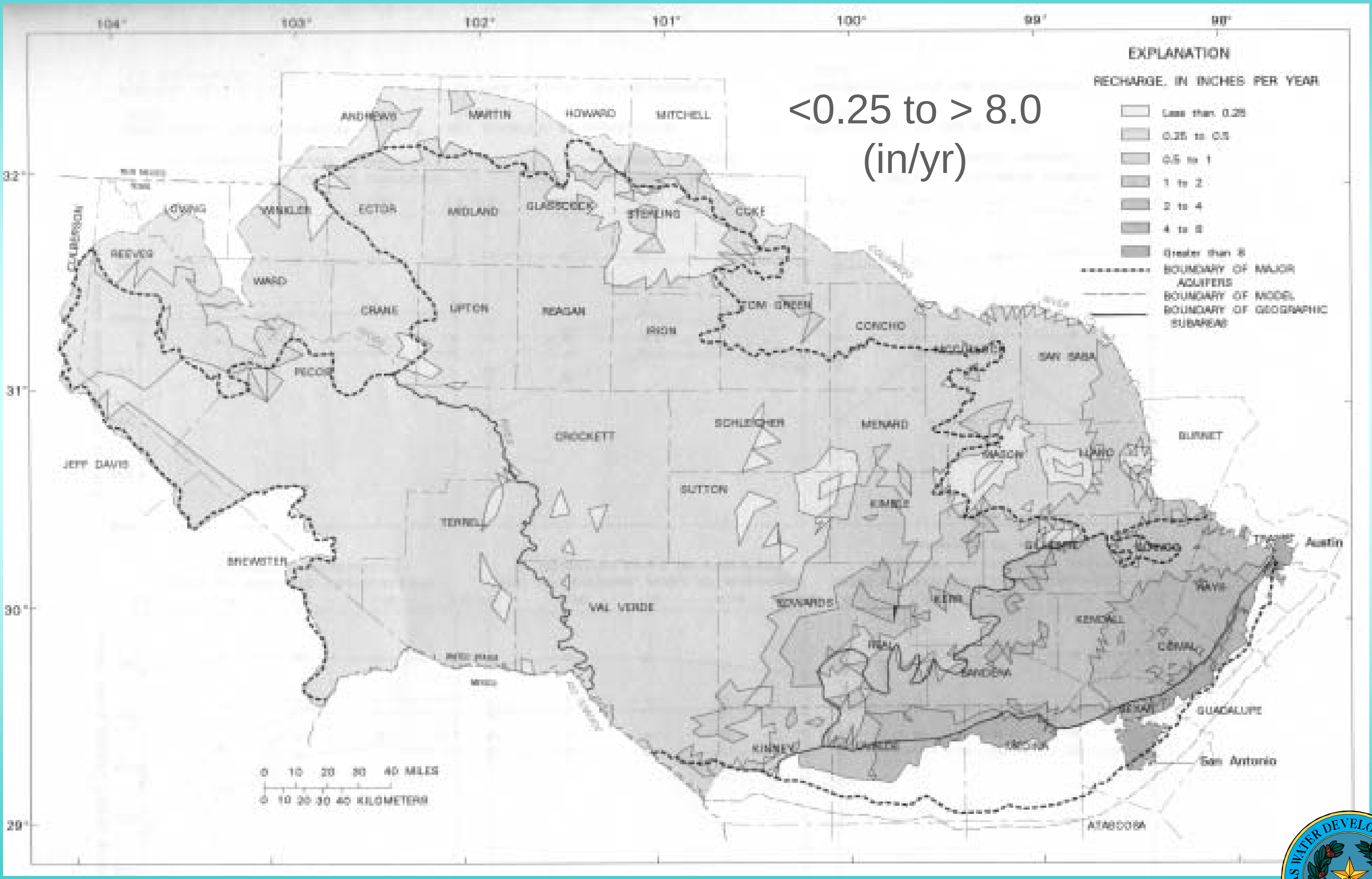
USGS Distribution of Estimated Recharge



From Kuniansky and Holligan, 1994

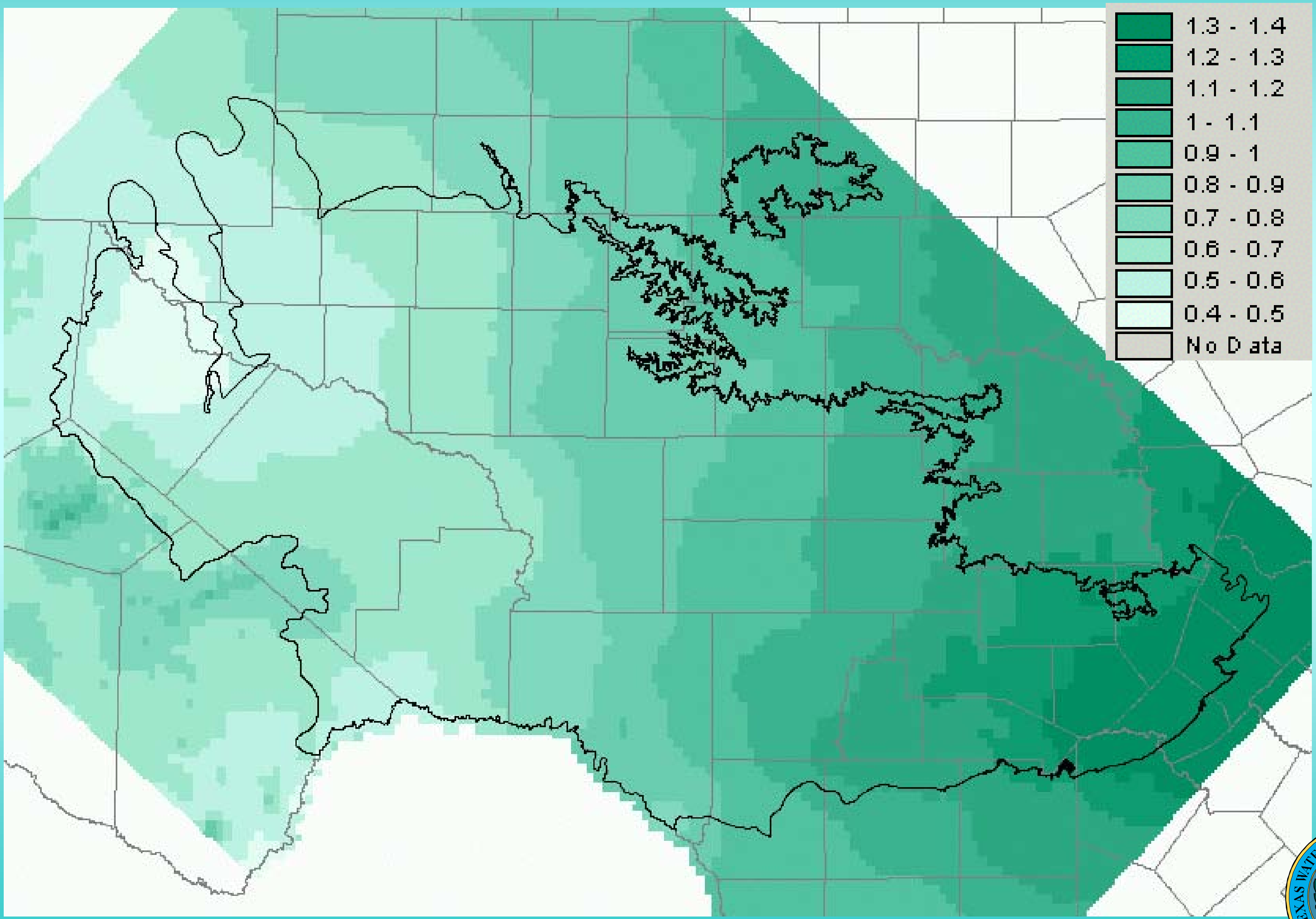
Principle of Occam’s Razor

- A 14th century English Franciscan Friar named ... William of Occam
- "Entia non sunt multiplicanda praeter necessitatem"
- “Entities should not be multiplied unnecessarily”
- The simplest explanation for some phenomenon may be more accurate than the most complicated explanation
- Scientists should use the simplest means of arriving at their results
- **Keep Things Simple!**

Estimating Recharge for the Edwards-Trinity Aquifer

- Approach to Estimating Recharge will follow the Principle of Occam’s Razor
- An Initial Recharge Estimate of 4% of Mean Annual Rainfall (1960-1990) will be used first
- Steady-State Model Calibration will Dictate the Level of Complexity for Spatially Distributing Recharge
- Percent of Rainfall May Be Adjusted By Spatially Weighting to Other Potential Recharge Controls such as Topography, Soils, Vegetation, Geology, Surface Hydrology, and/or Landuse

Edwards-Trinity Initial Recharge 4% of Mean Annual Rainfall (in)



Estimating Recharge for the Edwards-Trinity Aquifer

"Everything should be made as simple as possible,
but not any simpler."
- Albert Einstein

Distributing Predevelopment Water Levels for the Model Layers of the Edwards-Trinity

Shirley Wade

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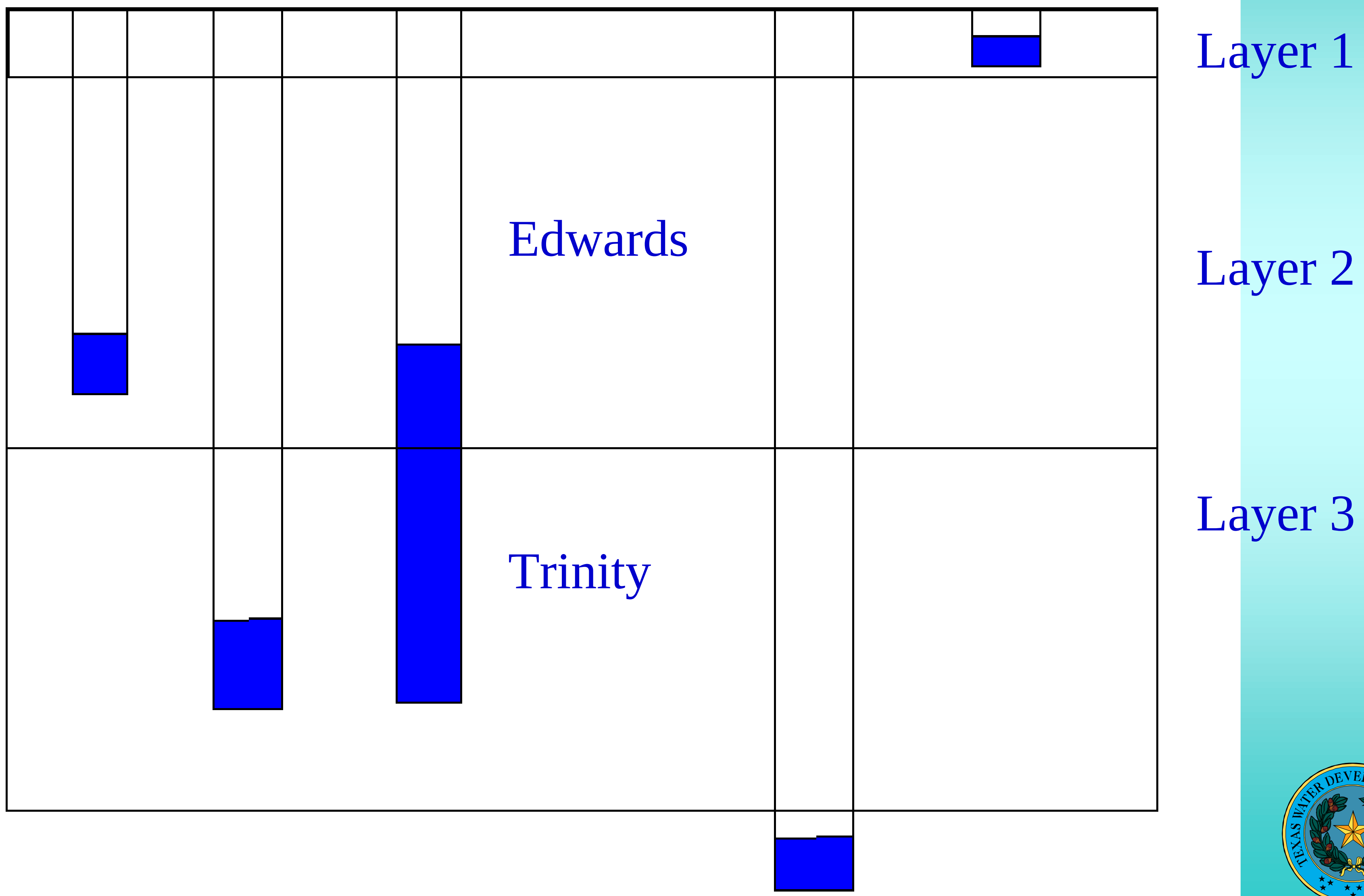
Pre-development Water Levels

- Wells coded as Edwards and/or Trinity were selected from the TWDB database
- A subset of the earliest recorded winter water levels were selected
- Measurements during droughts of 1933 – 1936 and 1951 – 1957 were excluded

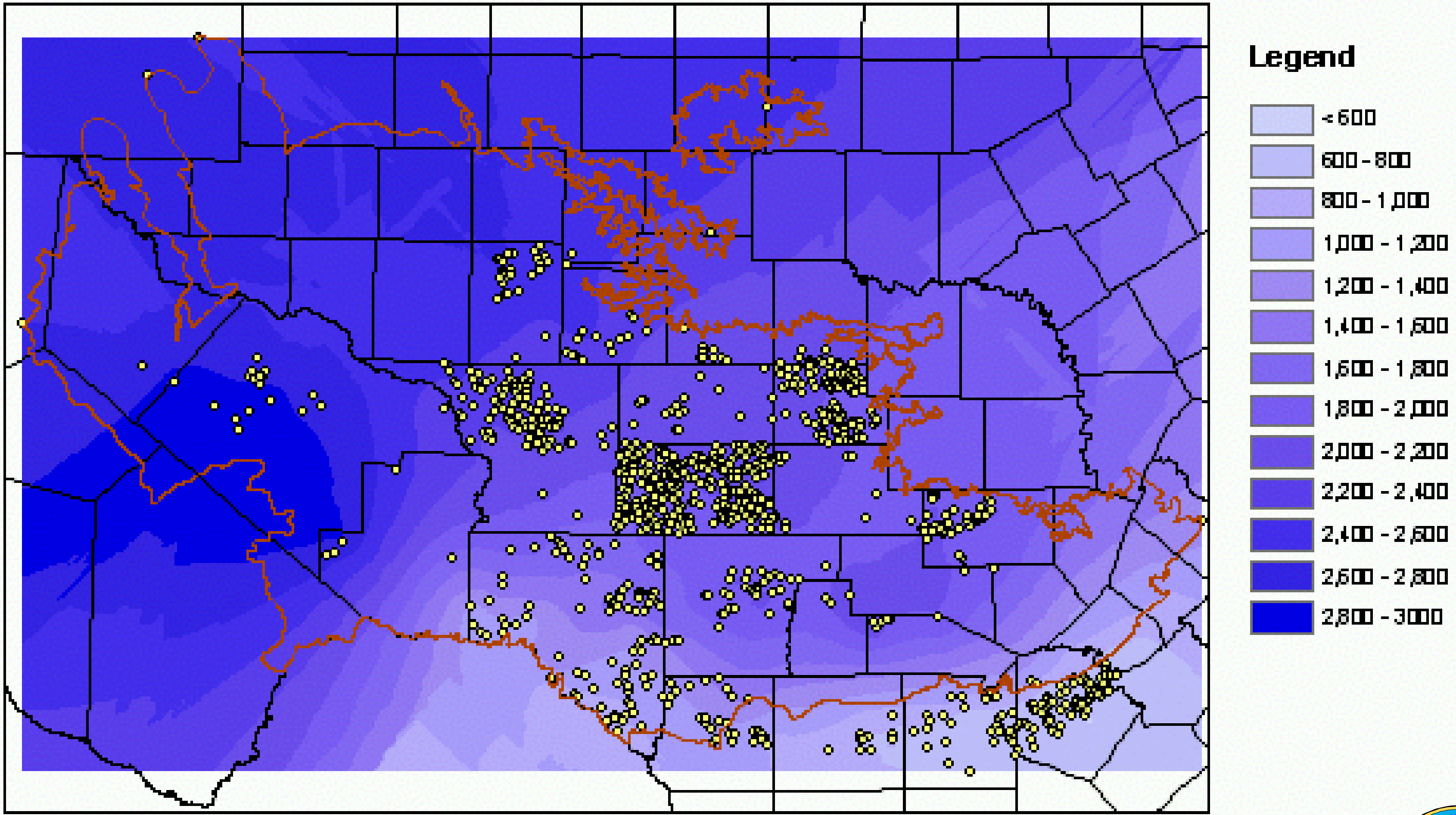
Distributing Water Levels

- Wells were distributed into model layers two or three depending on screen depth and/or water level
- Wells were selected as screened in Edwards or Trinity by comparing the model structure with the well depth and/or water level
- A few wells were excluded because they are screened below the Trinity, above Layer 2 or because they are screened in both Edwards and Trinity

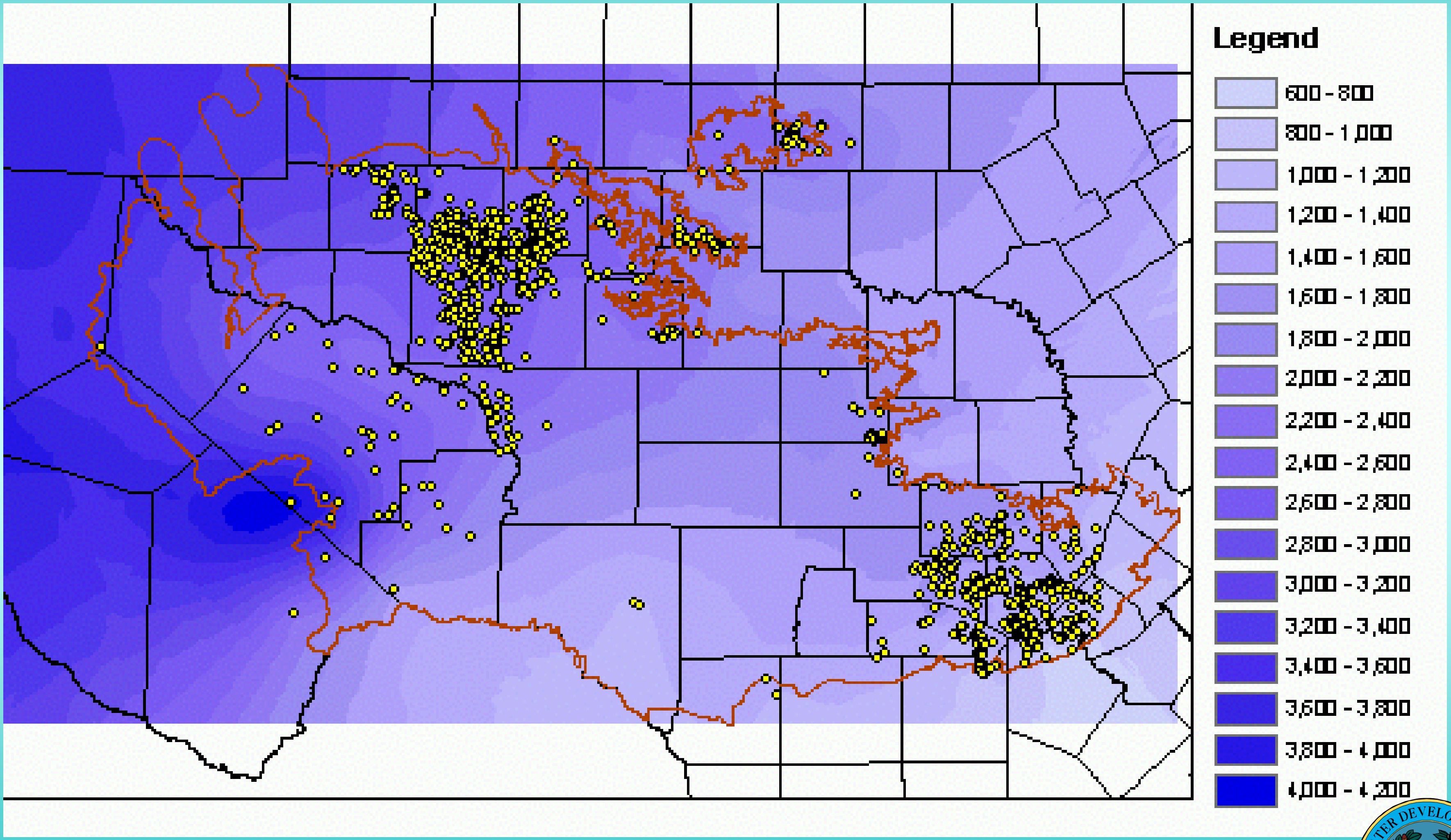
Distributing Water Levels



Edwards Predevelopment Water Levels



Trinity Predevelopment Water Levels



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Lunch Time!

90 Minute Break

We will reconvene to finish the discussion of the Edwards-Trinity Aquifer Model

FOR MORE INFO VISIT...

www.twdb.state.tx.us/gam

Estimating Evapotranspiration from the Edwards-Trinity Groundwater

Shirley Wade

Evapotranspiration

- Evaporation from soil and transpiration of soil and groundwater by plants are combined into the term evapotranspiration or ET
- Phreatophytes have their roots below the water table and act as a source of groundwater discharge
- Field studies have shown that depending on plant type and season many plants will preferentially use groundwater over soil or surface water

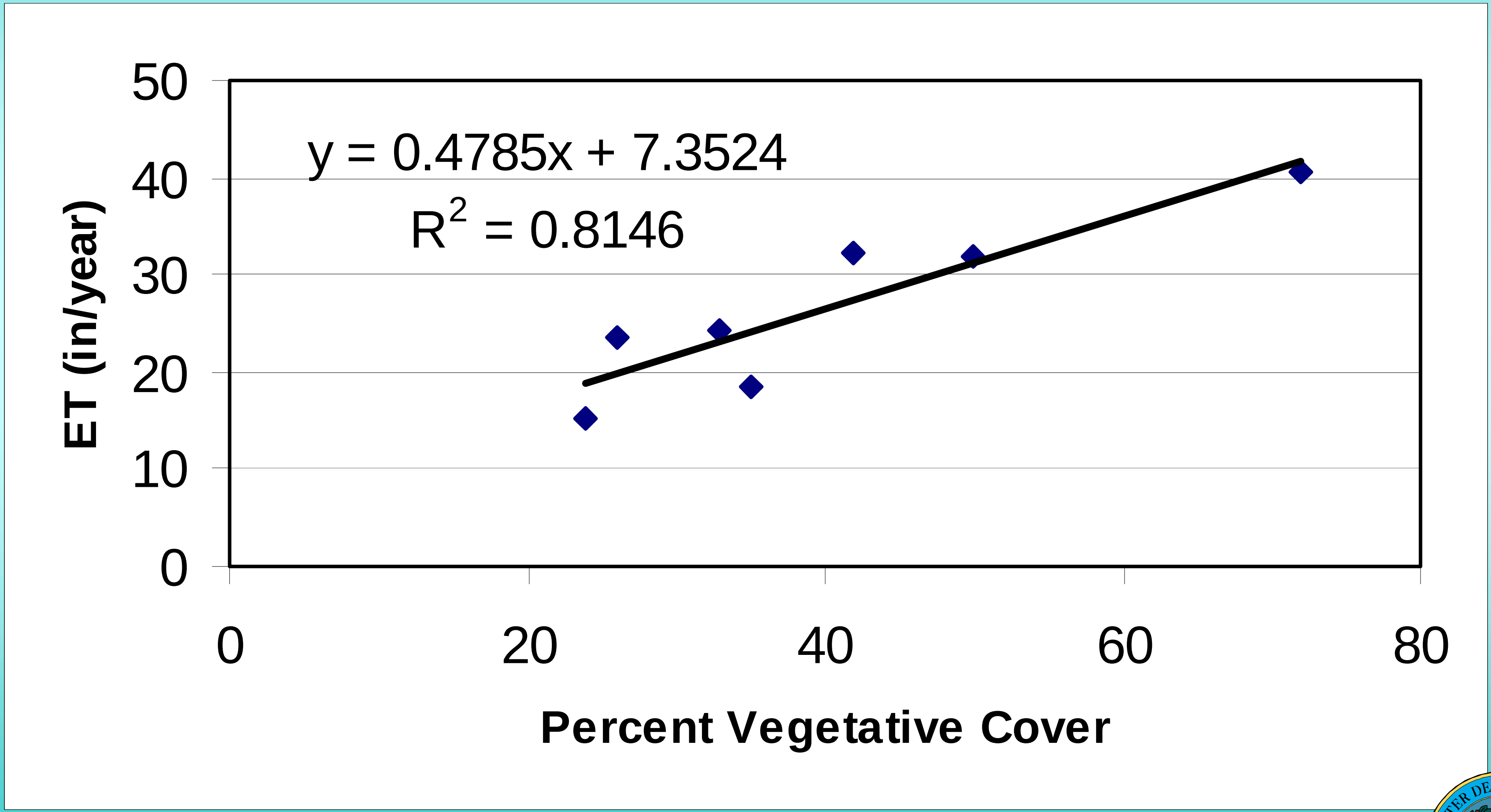
Estimates of ET Rates for Plants Found in Model Region

Plant	Min (in/year)	Max(in/year)	Reference
Juniper	23.3	25.0	Dugas *et al.* (1998)
Oak	30.2		Dolman (1988)
Mesquite	19.2	24.3	Duell (1990)
Mesquite	8.8	18.4	Tromble (1977)
Honey Mequite	13.7	25.4	Ansley *et al.* (1998)
Fourwing Saltbush	28.5	68.8	McDonald and Hughes (1968)
Fourwing Saltbush	14.9	25.4	Cable (1980)
Creosote	10.6	14.9	Cable (1980)
Fourwing Saltbush	11.5		Cable (1980)
Black grama grass	37.0		Borrelli *et al.* (1998)
Crops (Trans Pecos)	30.8		Borrelli *et al.* (1998)
Crops (Edwards Plateau)	23.3	25.0	Dugas *et al.* (1998)

Approach

- Most of the ET data is based on local field studies
- For the Edwards-Trinity GAM we need a method of estimating temporal and spatial distribution of evapotranspiration for the entire model area
- Satellite imagery can be used to estimate vegetative cover
- Two California Owens Valley field studies show an approximately linear relationship between percent vegetation and evapotranspiration

Vegetation Cover and ET



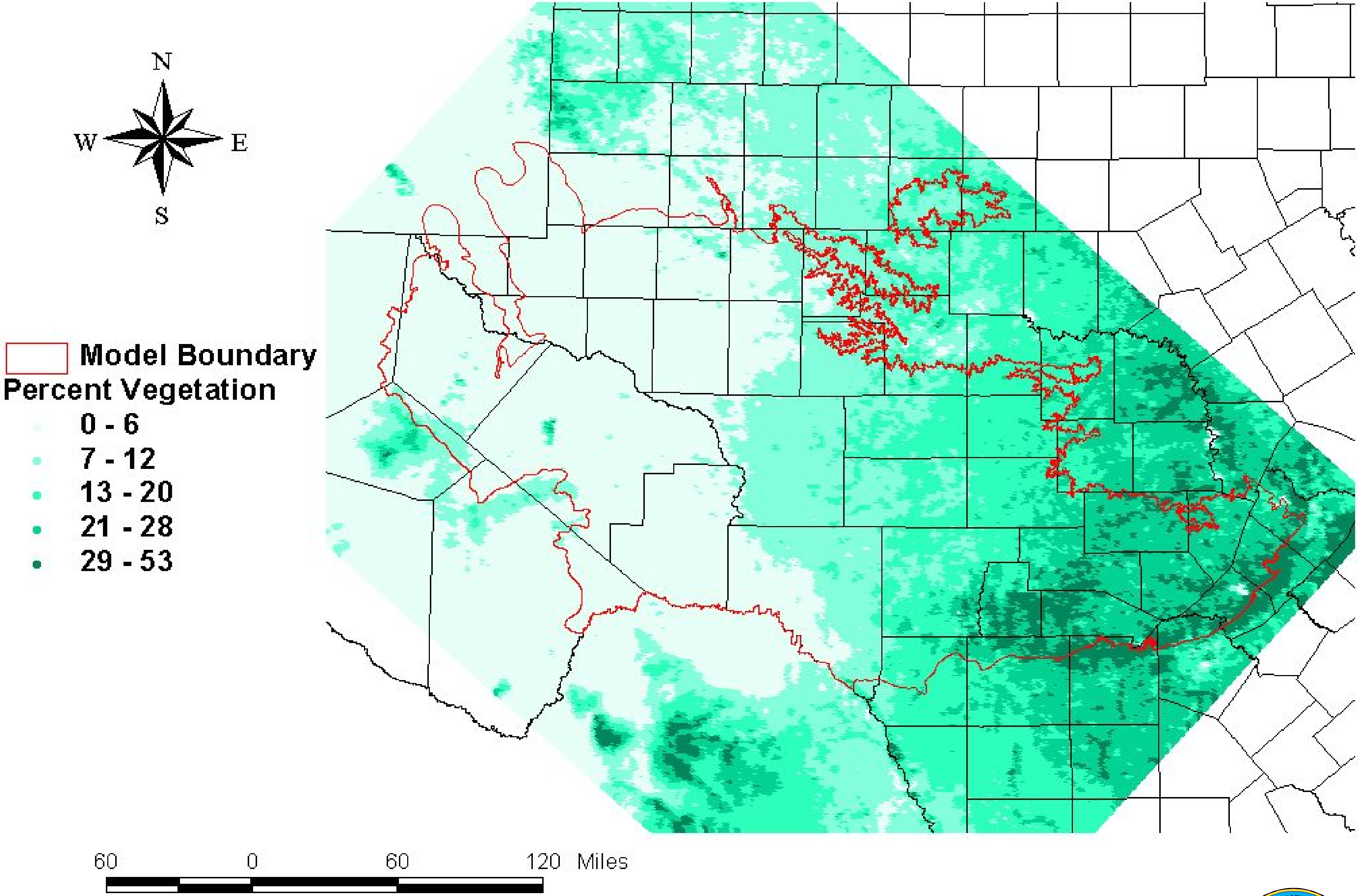
(data from USGS Water Supply Paper 2370-H, Danskin, 1998)

Satellite Data

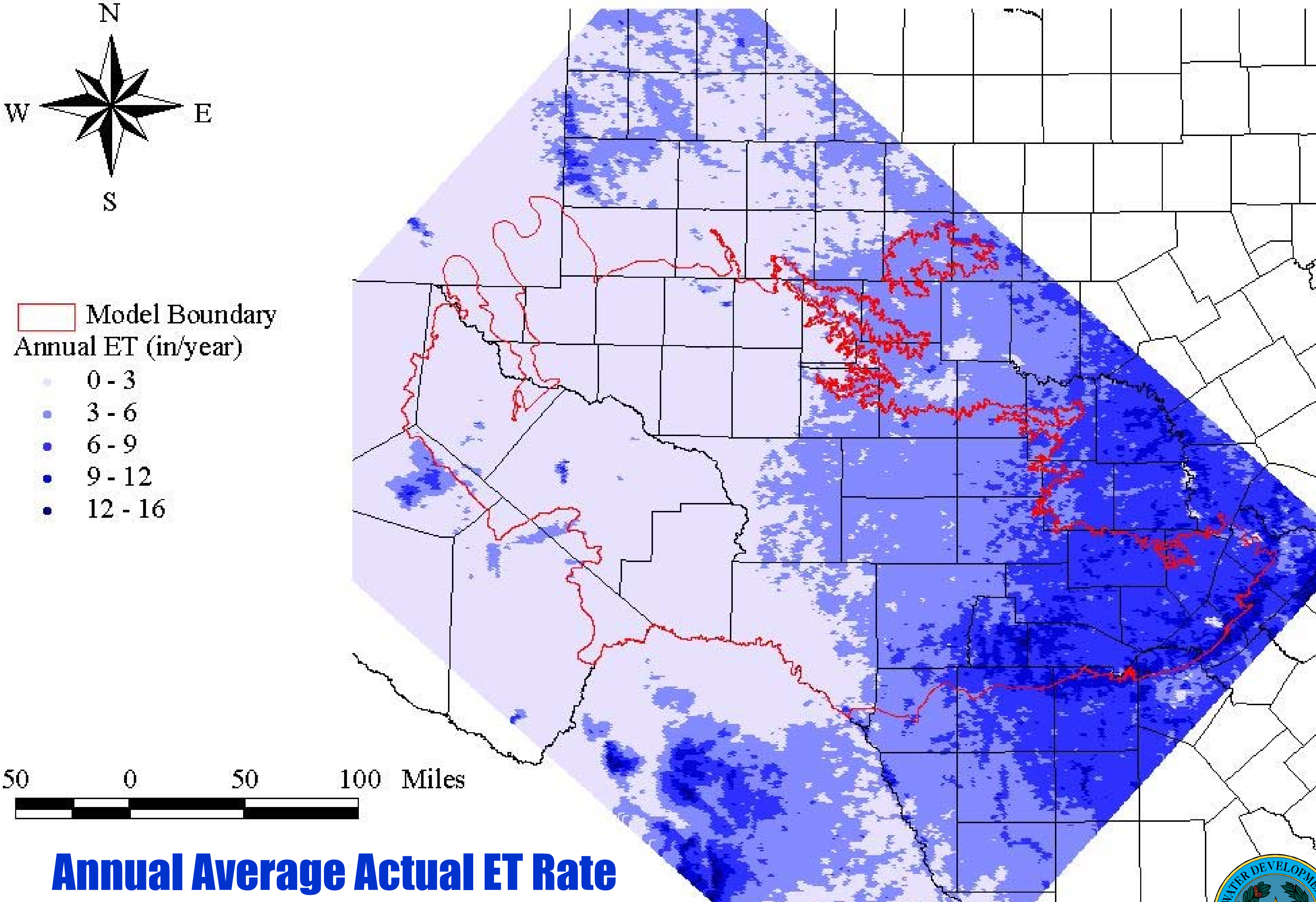
- Advanced Very High Resolution Radiometer (AVHRR) sensor detects infrared and visible light
- Penn State Univ's Earth System Science Center (ESSC) converts AVHRR output to fractional vegetation coverage
- Data has been recorded biweekly from 1990 – 1999

Monthly and Annual Vegetation Fraction Map

- Satellite Data were downloaded from ESSC website
- Biweekly data were combined into monthly data
- 10-year average monthly fractions were created using all data from 1990 – 1999
- Finally, annual 10-year average map was created
- The Distribution of ET in the model area was then calculated from the average vegetation map using the regression equation from Danskin's (1998) data

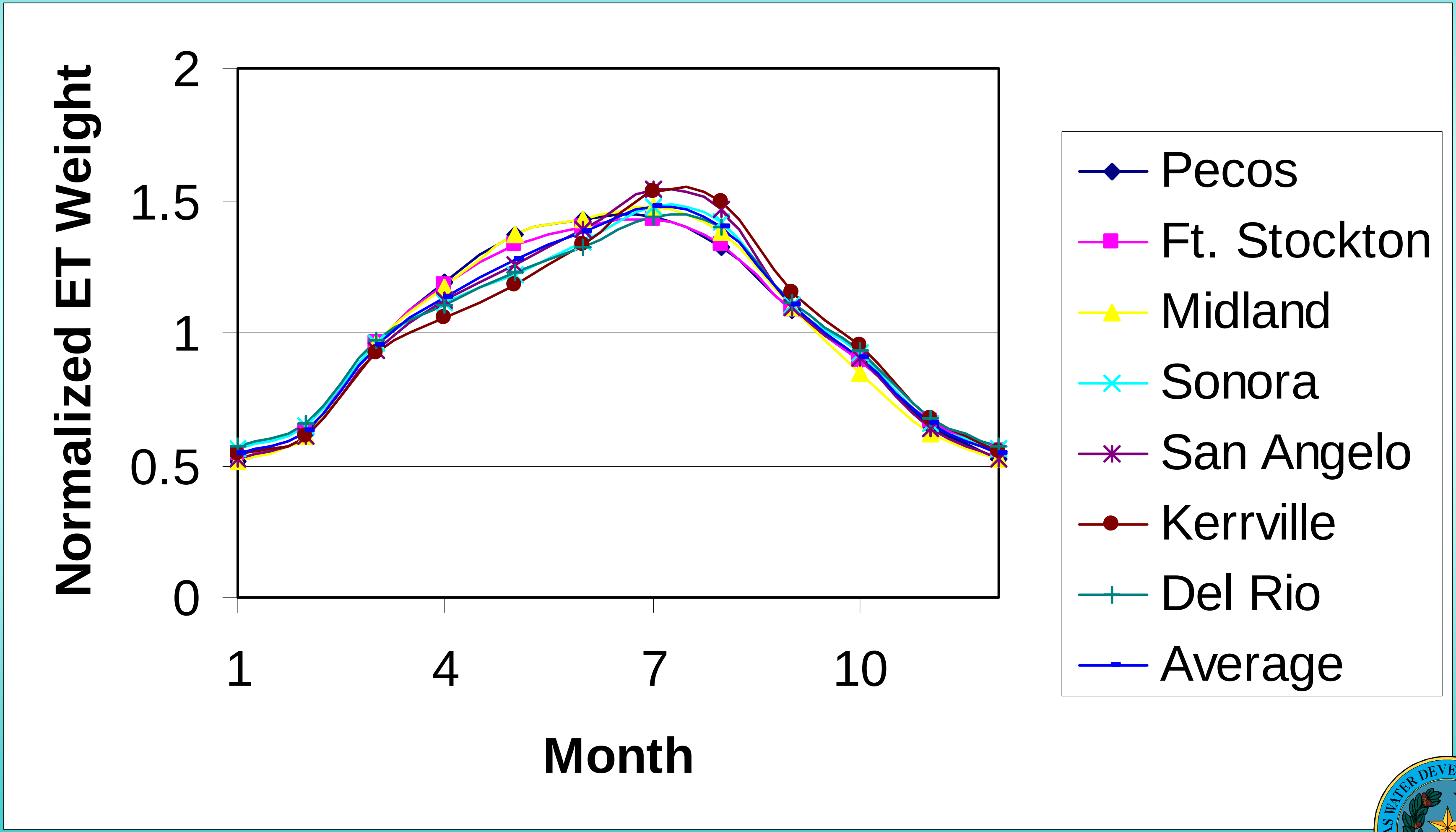


Annual Average Percent Vegetation Cover



Annual Average Actual ET Rate Calculated from Regression

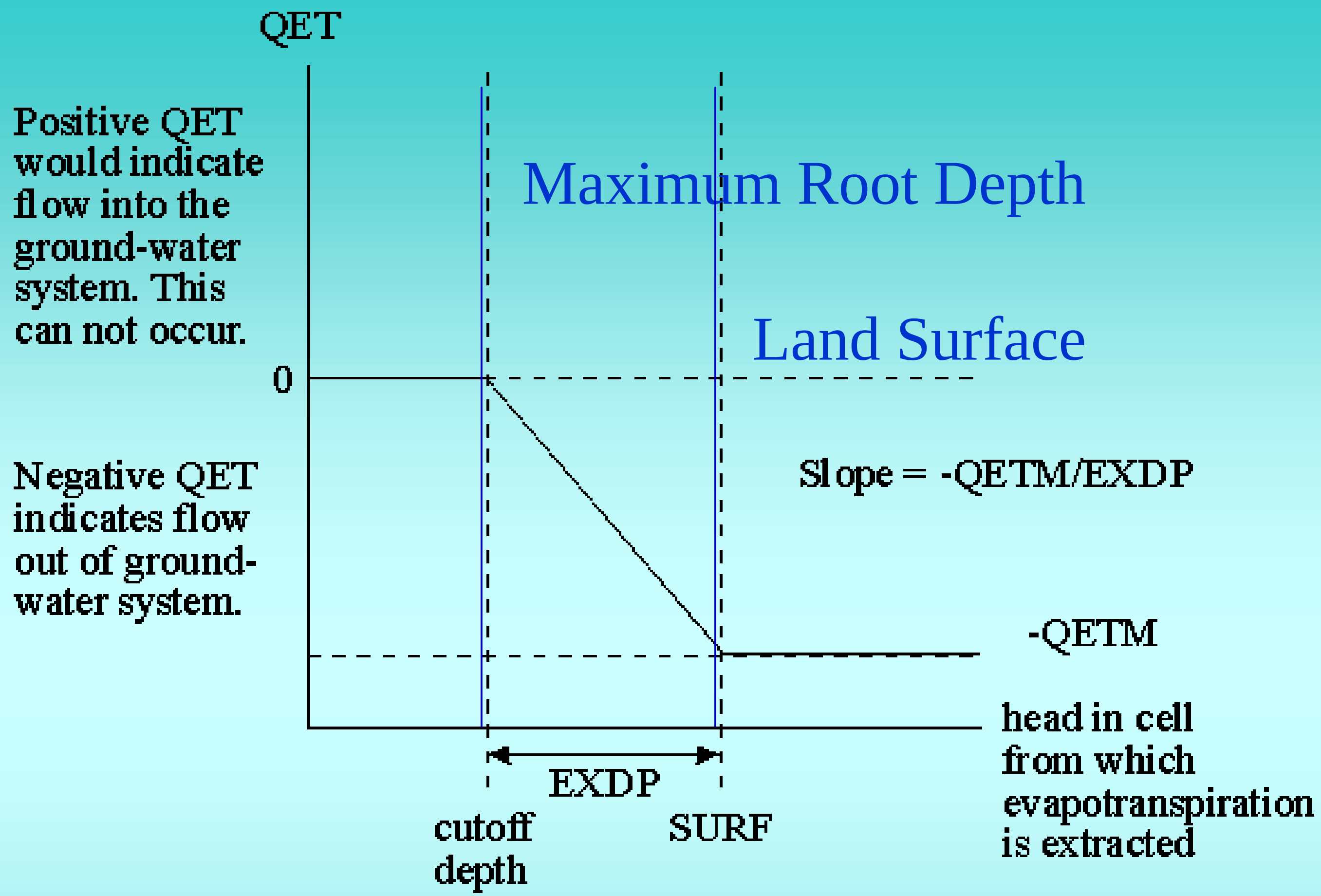
Monthly Weights based on Reference Grass Crop ET Rates



(from Borelli et al., 1998)

Groundwater ET Extraction in MODFLOW

- When the head in a model cell is at the ET surface (land surface) the rate is at a maximum
- Below a cutoff depth the rate is zero
- Between land surface and the cutoff depth the groundwater extraction is a linear function of the water table depth.



QET = volumetric evapotranspiration
QETM = maximum evapotranspiration
SURF = elevation of the evapotranspiration surface
EXDP = evapotranspiration extinction depth

ET in MODFLOW

(Figure from Richard B. Winston, MODFLOW Help File, 1997)

ET cutoff depth

- The cutoff depth for evapotranspiration will be based on maximum observed rooting depth for specific plant types.
- TPWD map of The Vegetation Types of Texas was used to determine the predominate plant type in an area.
- Canadell and others (1996) have compiled rooting depth data for 253 plant species.

Rooting Depth Data Summary

Vegetation	Average Maximum Root Depth (feet)
Mesquite (arid climate)	46.9
Temperate oak trees	13.1
Mesquite and Tamarix	45.3
Oak trees and mesquite	41.0
Oak shrubs and mesquite	39
Poplars	7.5
Oak - arid climate trees	31.8
Oak - arid climate shrubs	23.6
Desert	31.2
Temperate grassland	8.5
Temperate coniferous	12.8
Temperate deciduous	9.5
Arid Climate shrubs and trees	17.1
Crops (wheat, soybean, alfalfa, barley)	6.9

(data from Canadell and others, 1996)

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Development of Stream-Routing Parameters for the Edwards Trinity Model

Shirley Wade

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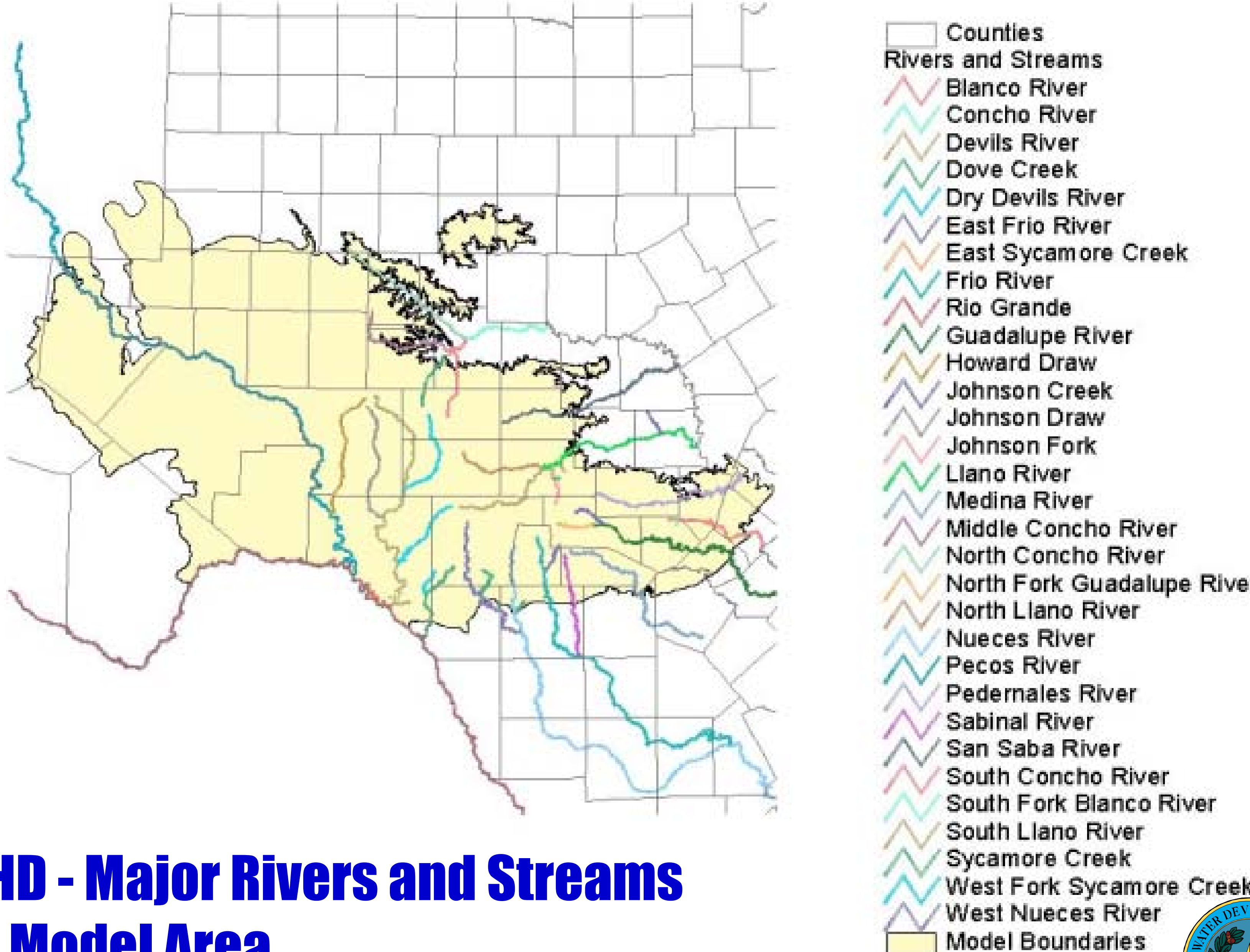
Digitizing Streams for Edwards-Trinity GAM

- Major rivers and streams in Edwards-Trinity GAM area were selected from the National Hydrography Dataset (NHD)
- The NHD is a high resolution, 1:100,000-scale digital spatial data of surface water features
- The NHD streams were overlayed on the model grid and model cells were selected to correspond to stream reaches



NHD - Major Rivers and Streams in Model Area

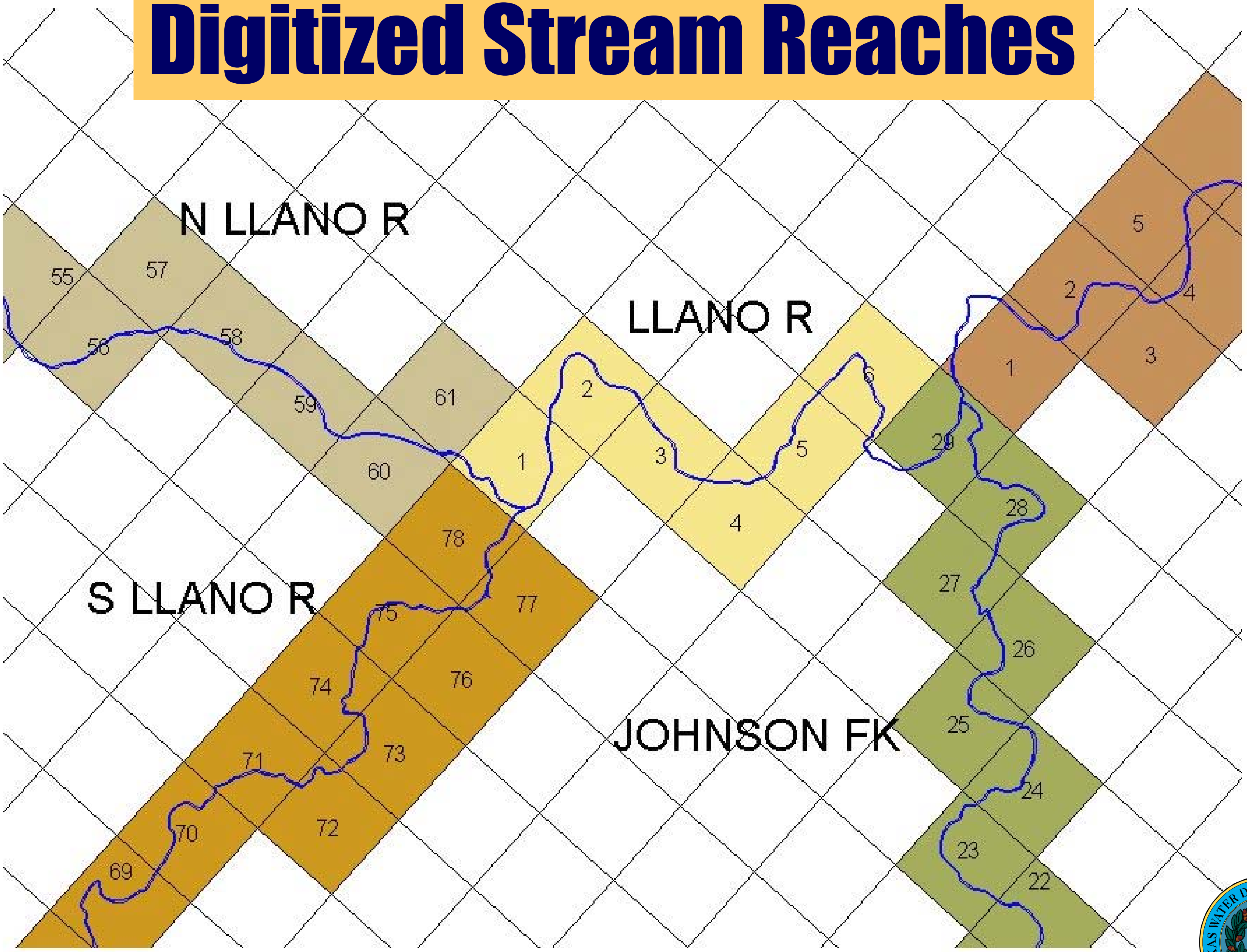
Stream-Routing in MODFLOW

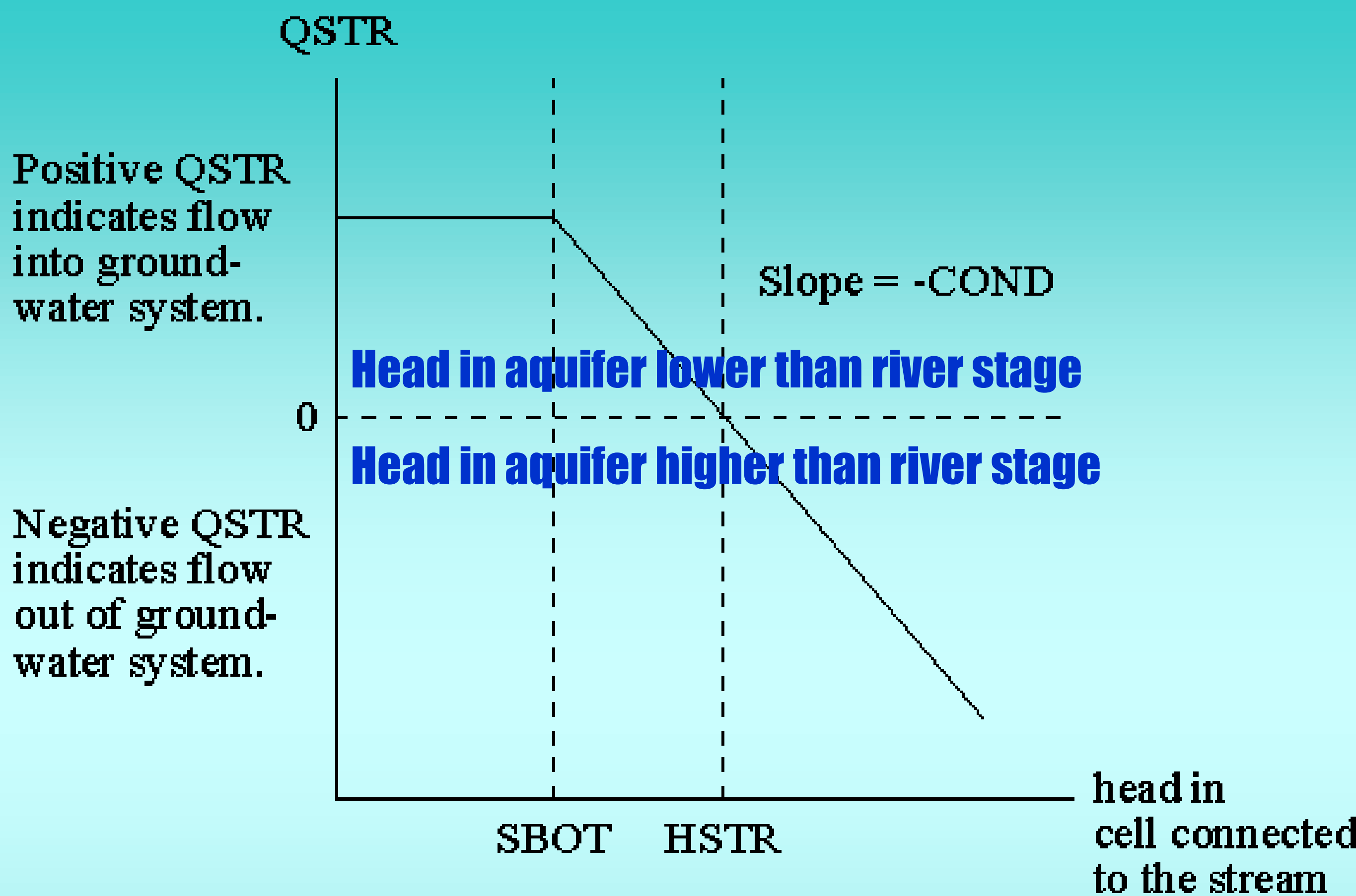
- Streams are divided into segments and reaches
- A segment is a group of reaches connected in downstream order
- Each reach corresponds to a model cell

Stream-Routing in MODFLOW (cont.)

- Flow is specified in the first reach of each segment
- Streamflow in downstream reaches is calculated from upstream inflow plus or minus leakage from or to the aquifer
- Stage in each cell or reach is calculated from stream flow and Manning's roughness coefficient

Digitized Stream Reaches

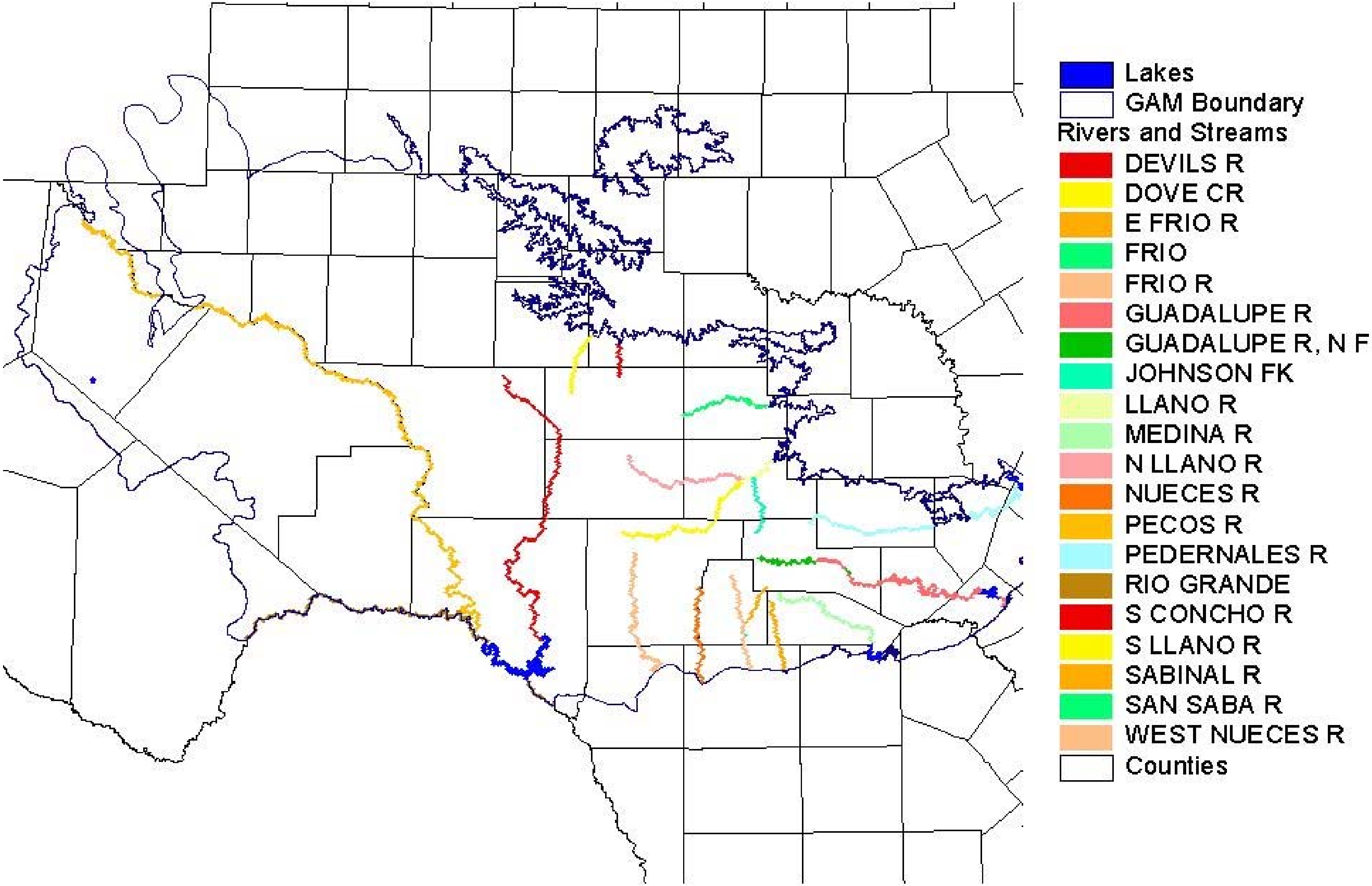




QSTR = flow out of stream
SBOT = elevation of the base of the stream bed sediments
HSTR = stream stage
COND = streambed conductance

Flow Between Stream and Aquifer

(Figure from Richard B. Winston, MODFLOW Help File, 1997)

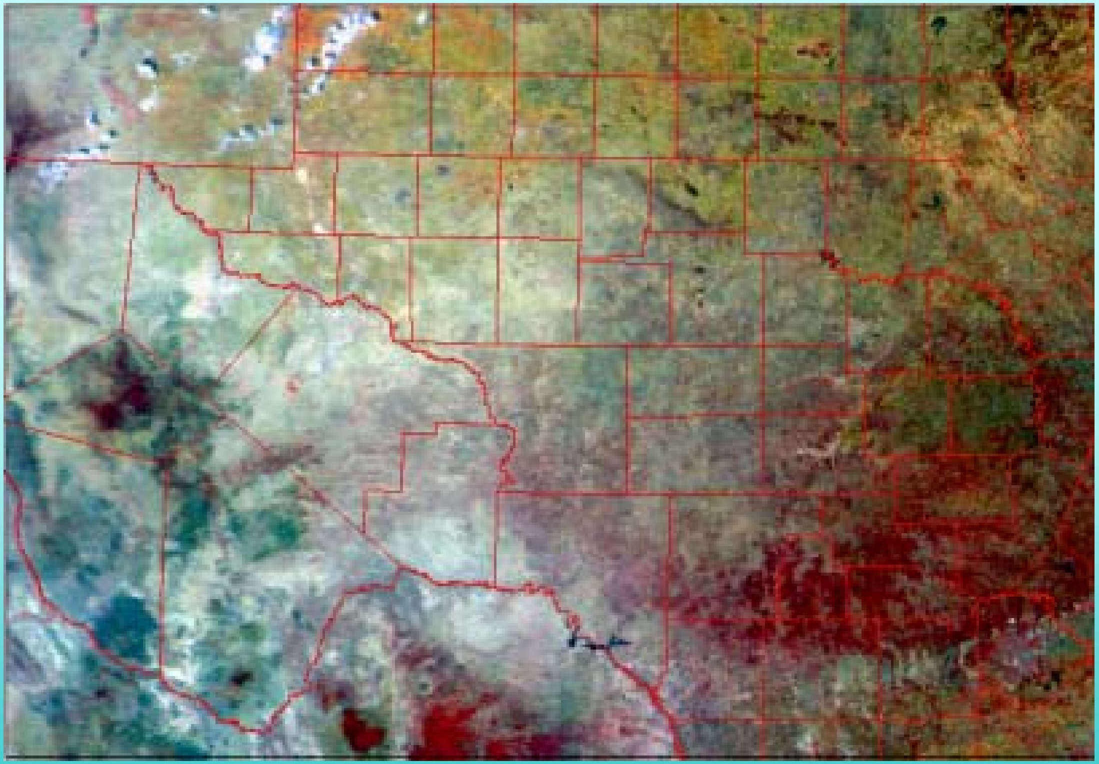


25 Reaches Assigned for the Edwards-Trinity Model

EPA River Reach Files

- EPA River Reach files are a predecessor to the NHD.
- Stream width, mean stream flows and Manning's coefficient are attributes listed in river reach files (rf1)
- The river reach files were overlayed onto the model river cells in ArcView and values for stream width, Manning's coefficient, and mean flows were transferred to the model river cells

Distributed Hydraulic Conductivity for the Model Layers

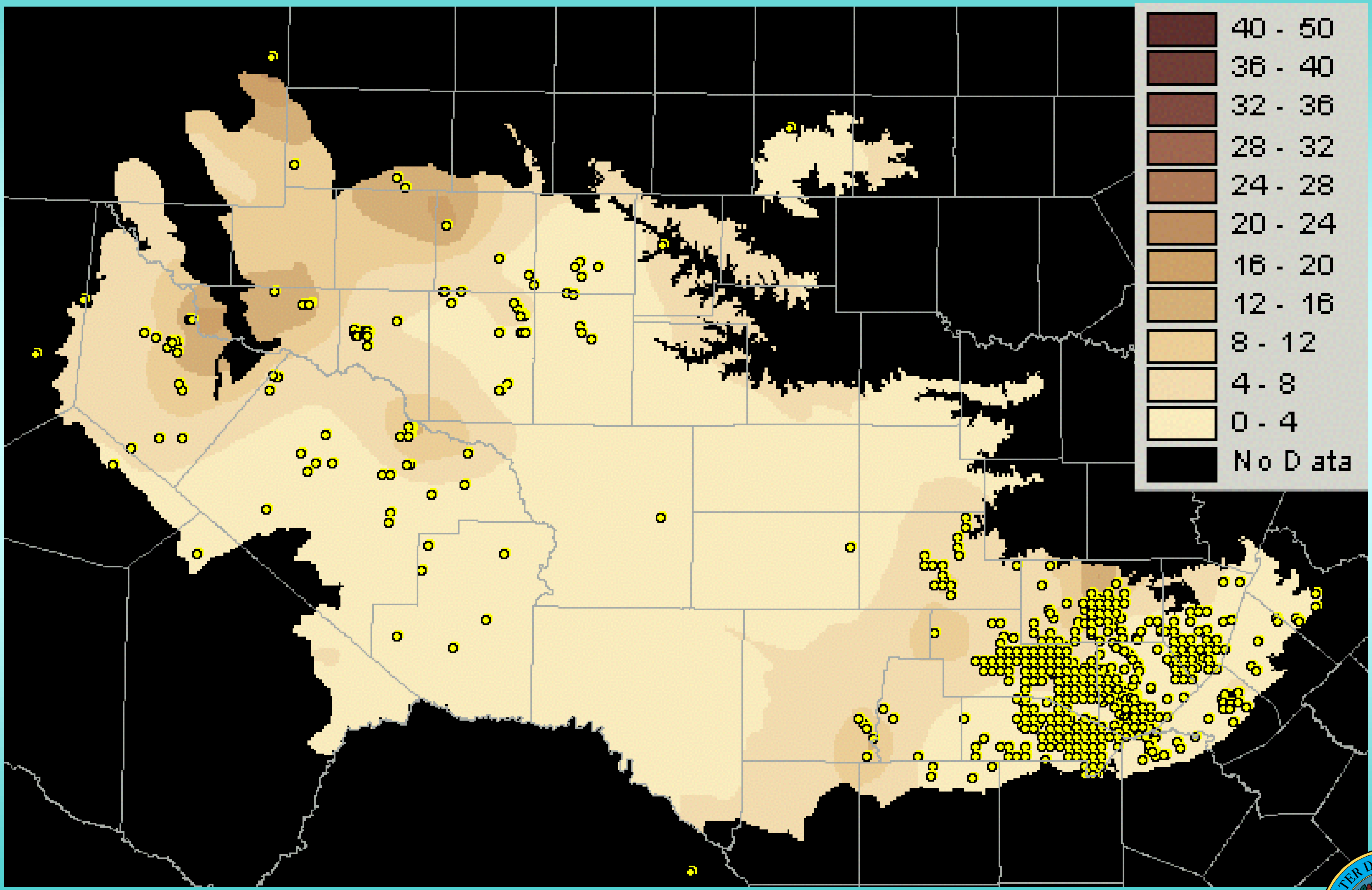


Roberto Anaya

Data Acquisition for Hydraulic Properties

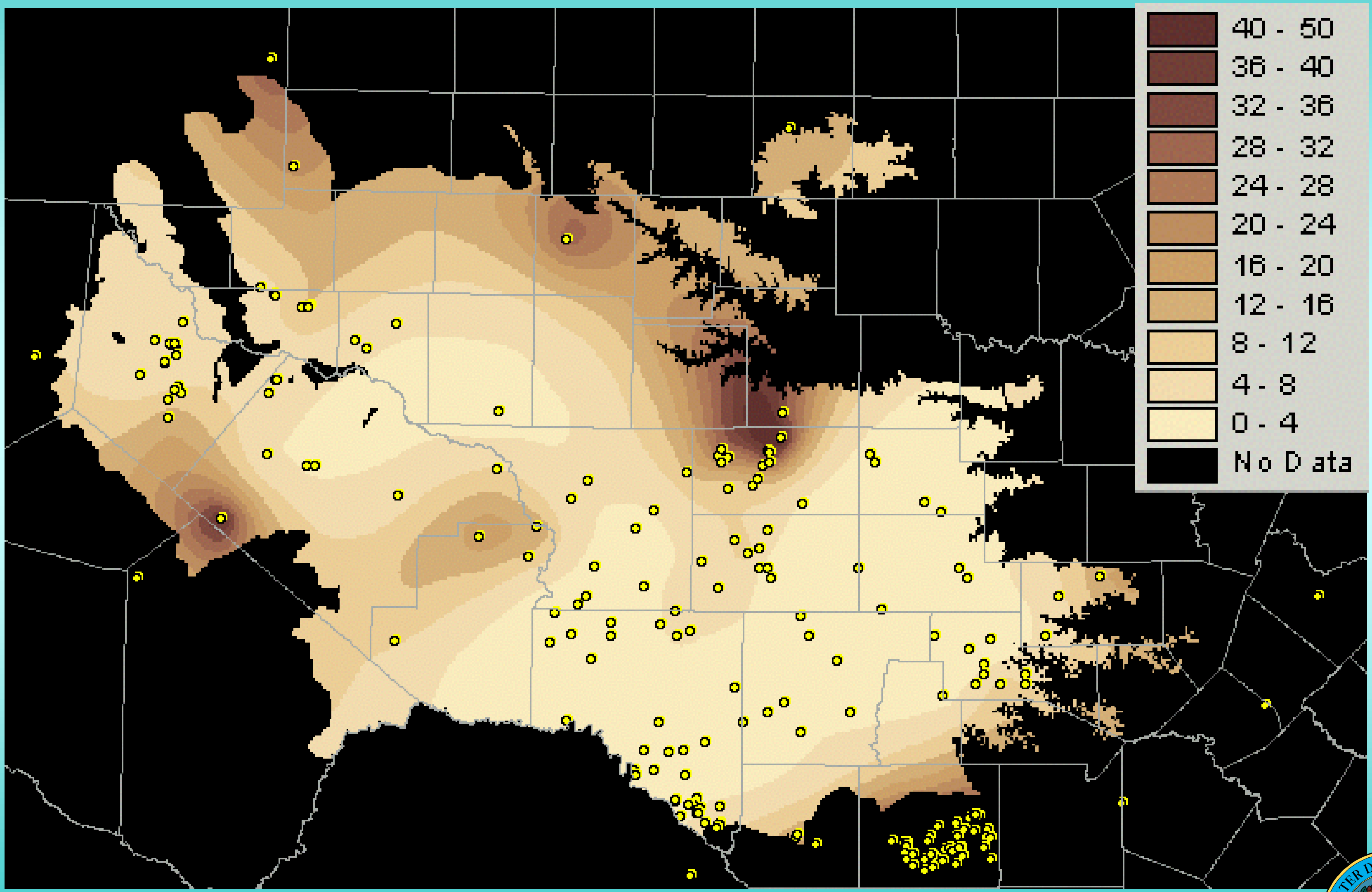
- TWDB Performed 39 New Pumping Tests on the Edwards-Trinity … 2 were Unusable
- TWDB groundwater Database Searched for Specific Capacity Tests resulted in about 600 Hits
- TNRCC Specific Capacity Tests Acquired for about 900 Wells
- Additional Hydraulic Data were Gleaned from the Literature Review for a Total of about 1600 Initial Control Points
- Only 915 Control Points used for Final Data Set

Hydraulic Conductivity Layer 3 (ft/d)



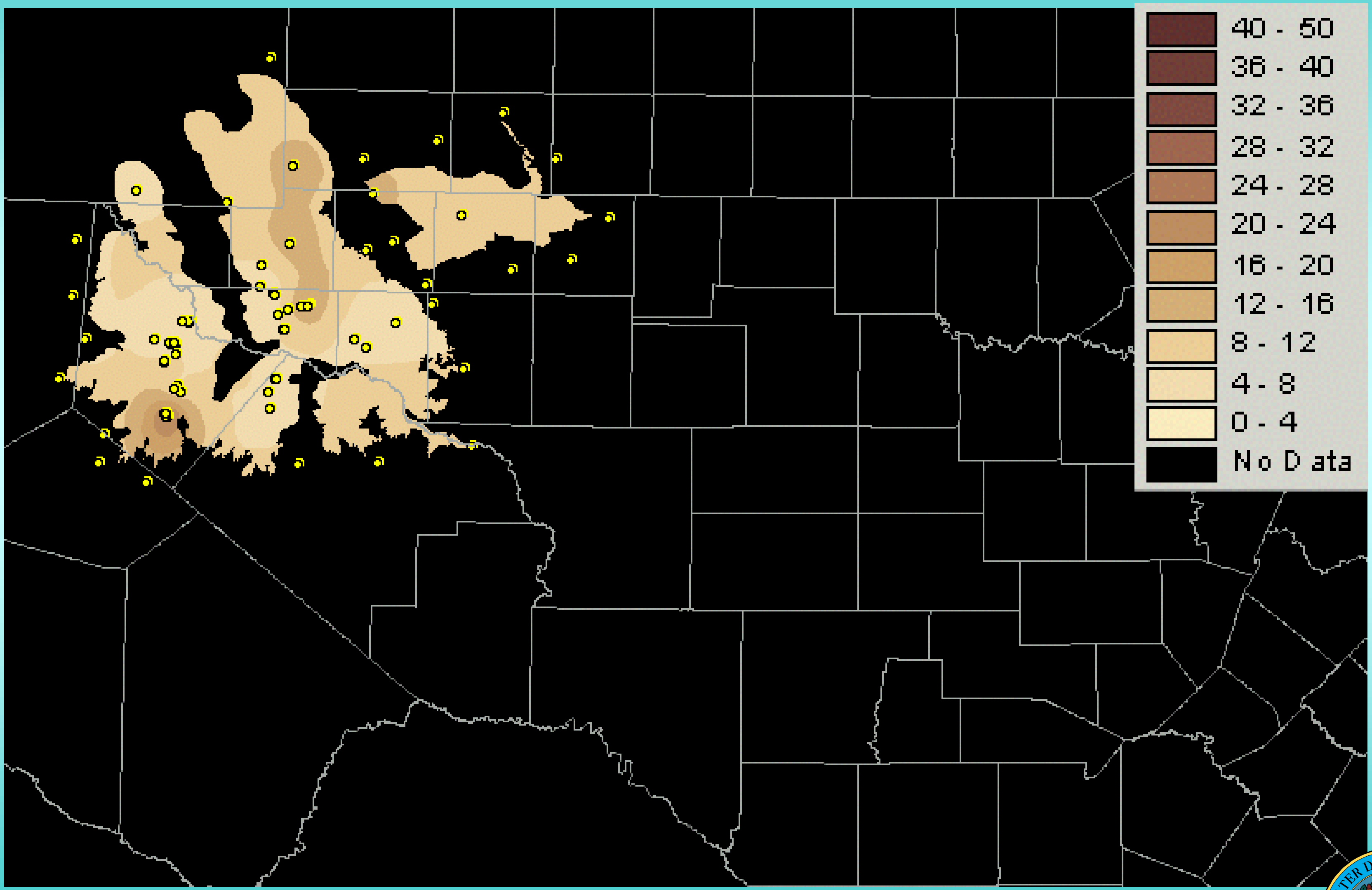
655 Control Points with Geometric Mean of 2.36

Hydraulic Conductivity Layer 2 (ft/d)



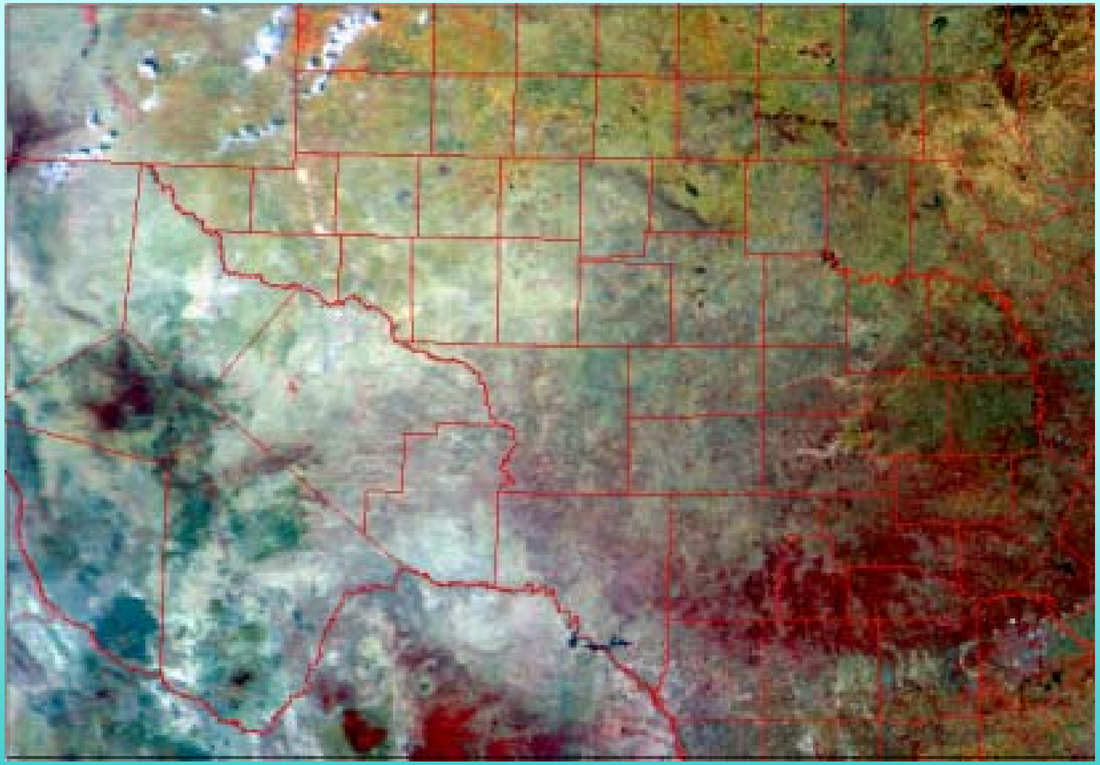
190 Control Points with Geometric Mean of 6.65

Hydraulic Conductivity Layer 1 (ft/d)



70 Control Points with Geometric Mean of 8.58

Approach for Calibrating the Model to Steady-State



Roberto Anaya

Calibrating Model for Steady-State Conditions

- Select Wells with the Assumption that Earliest Winter Season Water Level Measurements taken Prior to 1980, Excluding Droughts of the 30's and 50's, Represents Steady-State Aquifer Conditions
- Estimate as Accurately as Possible All Parameters, Stresses, and Boundary Conditions for Aquifer System
- Using Trial and Error Method, Adjust Parameters, Stresses, and Boundary Conditions to Match Steady-State Water Levels with Minimized Error

Calibrating Model for Steady-State Conditions

- Use Simulated vs Observed Plots and Residual Maps to Check Calibration Adjustments
- Perform Adjustments One Stress or Parameter At A Time, One Layer At A Time, and Record all Adjustments on Plots and Maps
- Begin Trial and Error Adjustments with Parameters, Stresses, and Boundary Conditions Having Minimal Level of Confidence in Accuracy (ie. Recharge and Hydraulic Conductivity)

Calibrating Model for Steady-State Conditions

- In Addition to Matching Water Levels, Attempts are made to Match Natural Discharge, Streamflow, and Lake Level Measurements when available
- Eventually, the Model Begins To Communicate It’s Needs to the Calibrator
- Once the Best Calibration is Achieved, a Sensitivity Analysis is Performed on Each Parameter and Stress

Potential Topics For ET SAF 6

- Steady-State Calibration Results
- Pumpage Estimates and Distribution
- Transient Calibration Approach
- Transient Calibration Results
- Predictive Simulations to 2050 ??

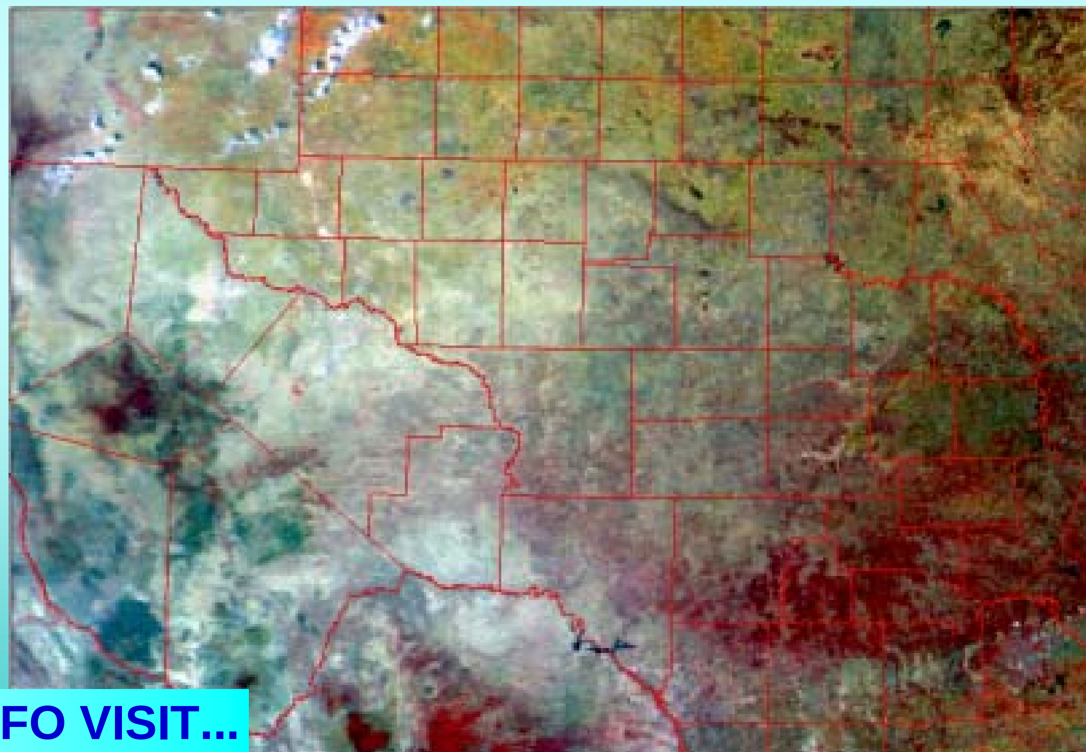
Primary Literature Sources

- R. A. Barker and A. F. Ardis, ***Hydrogeologic Framework of the Edwards-Trinity Aquifer System, West-Central Texas***, USGS Professional Paper 1421-B, 1996.
- L. E. Walker, ***Occurrence, Availability, and Chemical Quality of Groundwater In The Edwards Plateau Region of Texas***, Texas Department of Water Resources Report 235, 1979.
- R. Rees and A. W. Buckner, ***Occurrence and Quality of Groundwater In The Edwards-Trinity (Plateau) Aquifer in the Trans-Pecos Region of Texas***, Texas Department of Water Resources Report 255, 1980.
- E. L. Kuniansky and K. Q. Holligan, ***Simulation of Flow in the Edwards-Trinity Aquifer System and Contiguous Hydraulically Connected Units, West-Central Texas***, USGS Water-Resources Investigation Report 93-4039, 1994.

Questions or Comments?

End of ET SAF 5!

Have a safe drive home ...



FOR MORE INFO VISIT...

www.twdb.state.tx.us/gam

Edwards-Trinity GAM Stakeholders Advisory Forum 5
November 7, 2002 – Big Lake, Texas
List of Attendees

Name	Affiliation
Wendell Moody	Private Citizen
Scott Holland	Sterling County UWCD / Irion County Water Conservation District
Stan Reinhard	Hickory UWCD NO. 1
Johnny	Reagan County 4-H Administrator
Caroline Runge	Menard County UWCD
Winton Milliff	Coke County UWCD
Allan Lange	Lipan-Kickapoo Water Conservation District
Roberto Anaya	Texas Water Development Board
Shirley Wade	Texas Water Development Board
Ricky Harston	Glasscock County UWCD
Cindy Weatherby	Santa Rita UWCD
Amy Armstrong	Santa Rita UWCD

Edwards-Trinity GAM Stakeholders Advisory Forum 5
November 7, 2002 – Big Lake, Texas
Meeting Summary

About 12 people attended the fifth Edwards-Trinity Aquifer Groundwater Availability Modeling Stakeholders Advisory Forum, held in Big Lake, Texas. The stakeholders present were representing 8 local groundwater conservation districts, and local landowners.

Roberto Anaya presented a status report of the model and a revised schedule for completion of the remaining tasks. Roberto Anaya then presented the finalized structural geometry of the model followed by the approach used and initial estimate of recharge to be used in the steady-state model calibration. Shirley Wade presented the finished water level analysis as well as the approach used and initial evapotranspiration values to be used in the steady-state calibration. Shirley also presented the methods used and the initial parameters to be used in the stream-flow routing package. The meeting was wrapped up with a presentation on the methods used and initial distribution of hydraulic conductivity for all model layers and an introduction into the steady-state calibration process.

The next SAF meeting was tentatively scheduled for March 2002 in Austin, Texas. The groundwater district managers will determine the exact date, as they become familiar with the state legislative hearing schedule. Potential topics for the next forum include 1) steady-state calibration results; 2) pumpage estimates and distributions; and 3) transient calibration approach and results; 4) Approach used for the predictive data sets.

Primary Stakeholder Issues Follow:

1) A stakeholder was concerned about the number of assumptions made with the model inputs and the accuracy of the model output.

ANSWER: It was explained that for the scale at which the model is to be used, the assumptions being made should not diminish the accuracy of the model output.

2) A stakeholder asked if there a trend for depth to water to increase from east to west was found during the water level analysis.

ANSWER: It was not a specific task during the water level analysis, however it does make logical sense that such a trend should exist.

3) A stakeholder asked if the model could accurately predict sections of stream known to be dry even though USGS gages record flow above and below these dry stream sections.

ANSWER: Yes. As long as the parameters of the streamflow-routing package are calibrated correctly the model should simulate dry stream reaches where they should normally occur.

-Roberto Anaya, 11/07/02