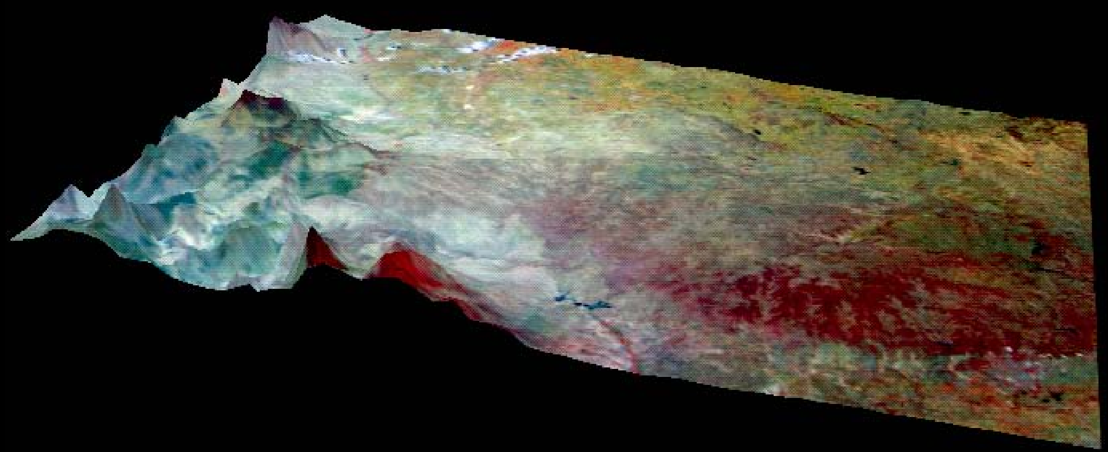
TEXAS WATER DEVELOPMENT BOARD

Welcome To The Sixth Edwards-Trinity & Cenozoic Pecos Alluvium Groundwater Availability Model Stakeholders Advisory Forum



ET&CPA
SAF 6

July 28, 2004

Texas Water Development Board

Groundwater Availability Modeling

Stakeholders Advisory Forum Objectives

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

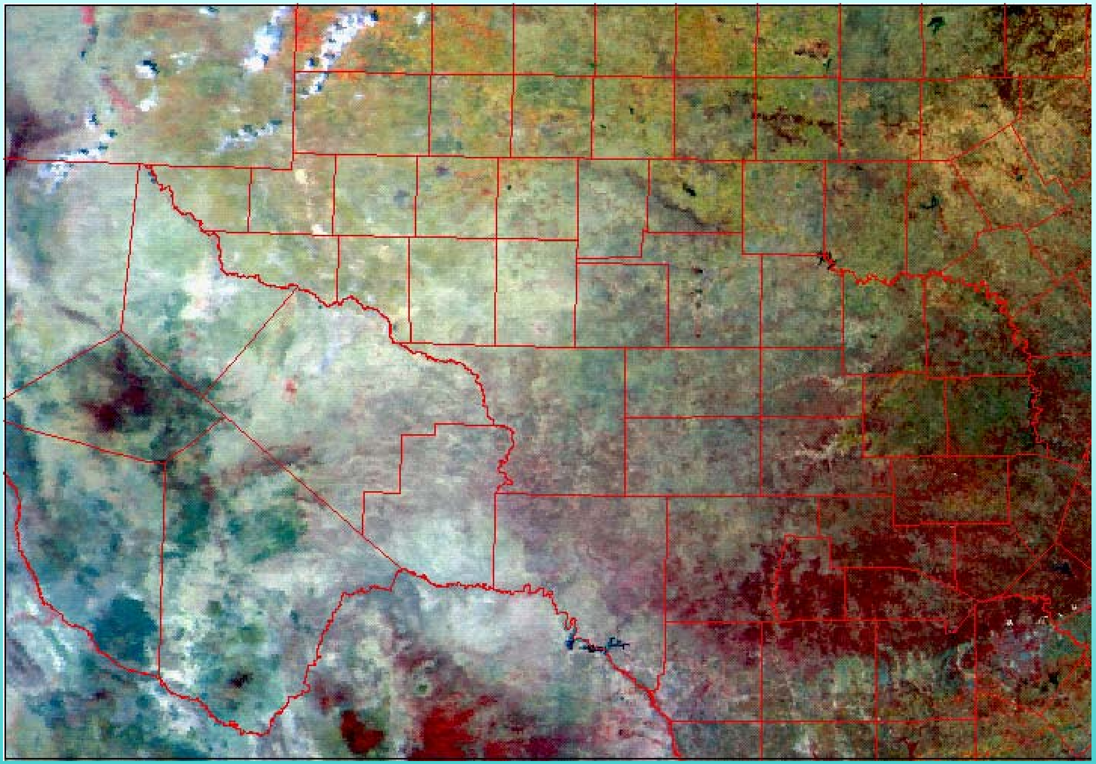
Today's Stakeholders Advisory Forum Topics

- Review of the Conceptual Model (Roberto)
- Brief Overview of MODFLOW (Roberto)
- Estimates of Recharge (Roberto)
- Estimates of Pumpage Withdrawls (Scott)
- Lunch Break (Dennis)
- Steady-State Model Calibration (Ian)
- Transient Model Calibration (Ian)
- Sensitivity Analysis (Ian)
- Model Predictions through 2050 (Ian)

Acknowledgements for the Edwards-Trinity and Cenozoic Pecos Alluvium GAM Study

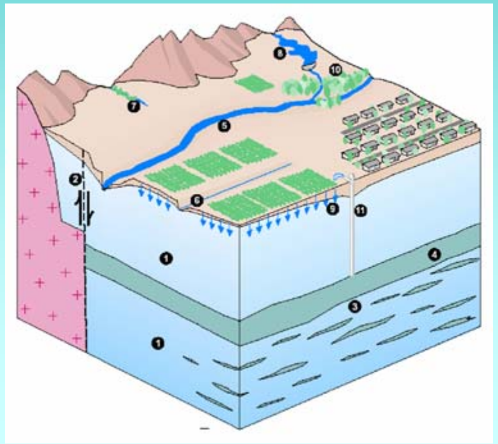
- **Stakeholder Forum Hosts**
  - Dennis Clark, Cindy Cawley, and Cindy Weatherby
- **Data Collection**
  - Doug Coker and Brent Christian
- **Data Processing**
  - Shirley Wade and Scott Hamlin
- **Model Development**
  - Roberto Anaya, Ian Jones, and Robert Mace

A Brief Review of the Conceptual Model for the Edwards-Trinity & Cenozoic Pecos Alluvium Aquifers



Roberto Anaya

Modeling Process



Purpose → Conceptualize Aquifer System

Characterize Model Parameters and Variables

Steady-State Model

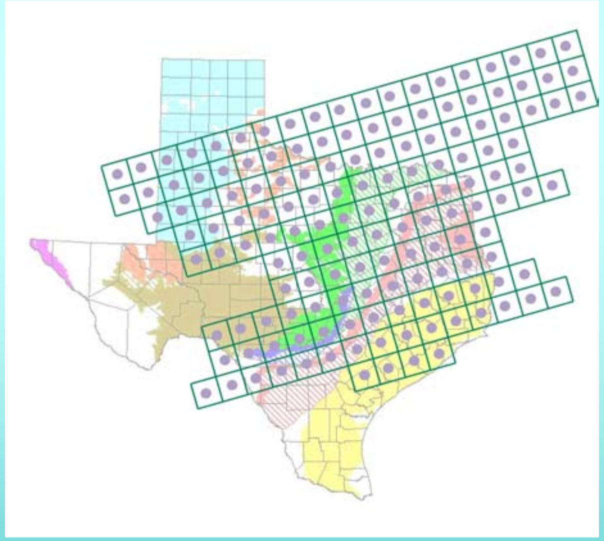
Calibrate to Measured Data

Transient Model (1980-2000)

Verify with Measured Data

Prediction Runs (2001-2050)

Collect New Field Data → Postaudit



What is a Conceptual Model?

- Generalized description of the aquifer system that defines:
  - aquifer boundaries
  - hydrogeologic parameters
  - hydrologic stress variables
- Helps to compile and organize aquifer data
- Simplifies the real-world aquifer into an easy to understand graphical representation
- Retains complexity needed to adequately reproduce aquifer behavior

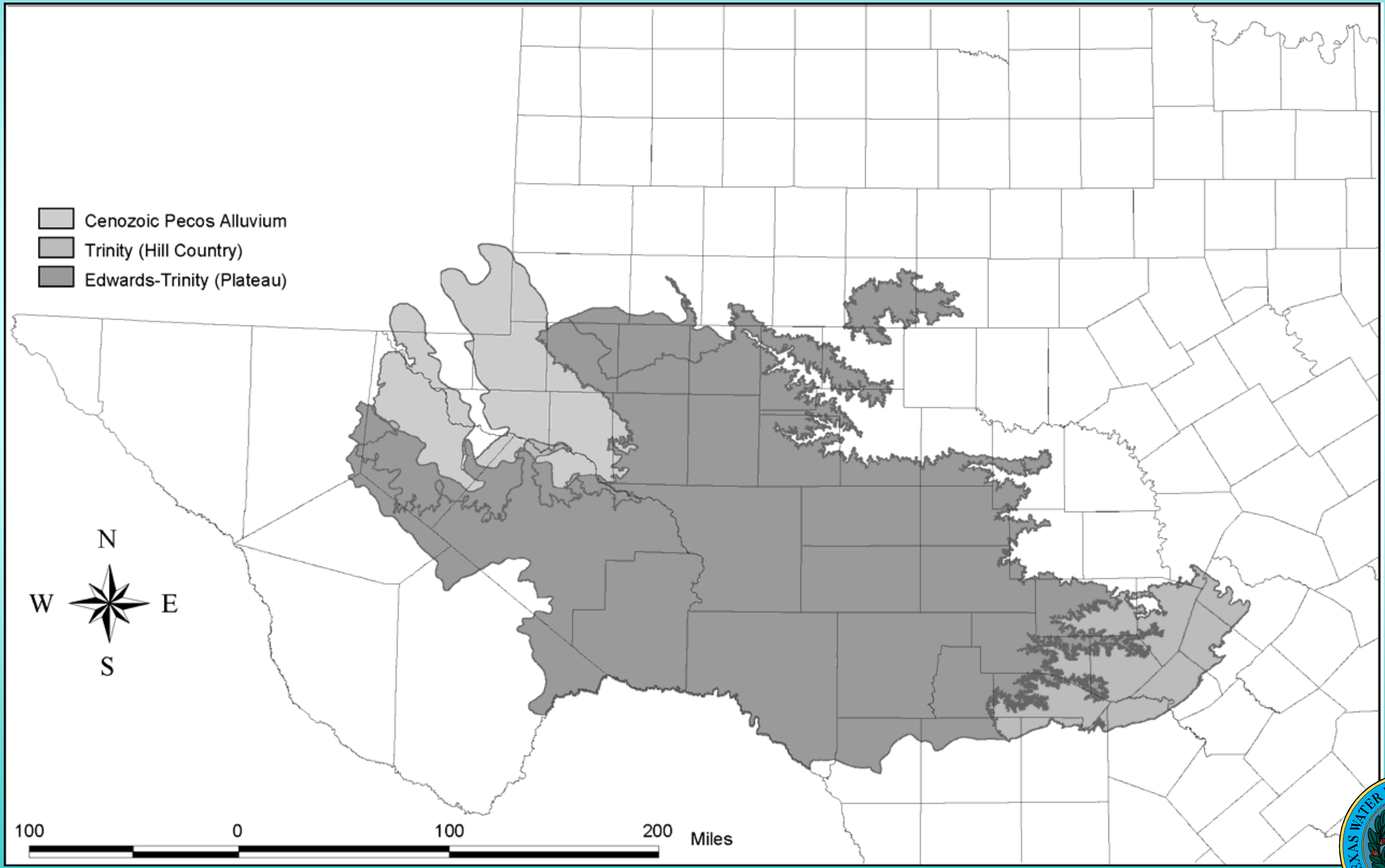
Development of a Conceptual Model

- Delineate study area
- Form and understanding of the physical landscape
- Review previous aquifer studies
- Collect and compile aquifer data and information
- Develop hydrogeologic setting
- Assemble the information into descriptive text, tables, maps, and diagrams

Geographic Setting

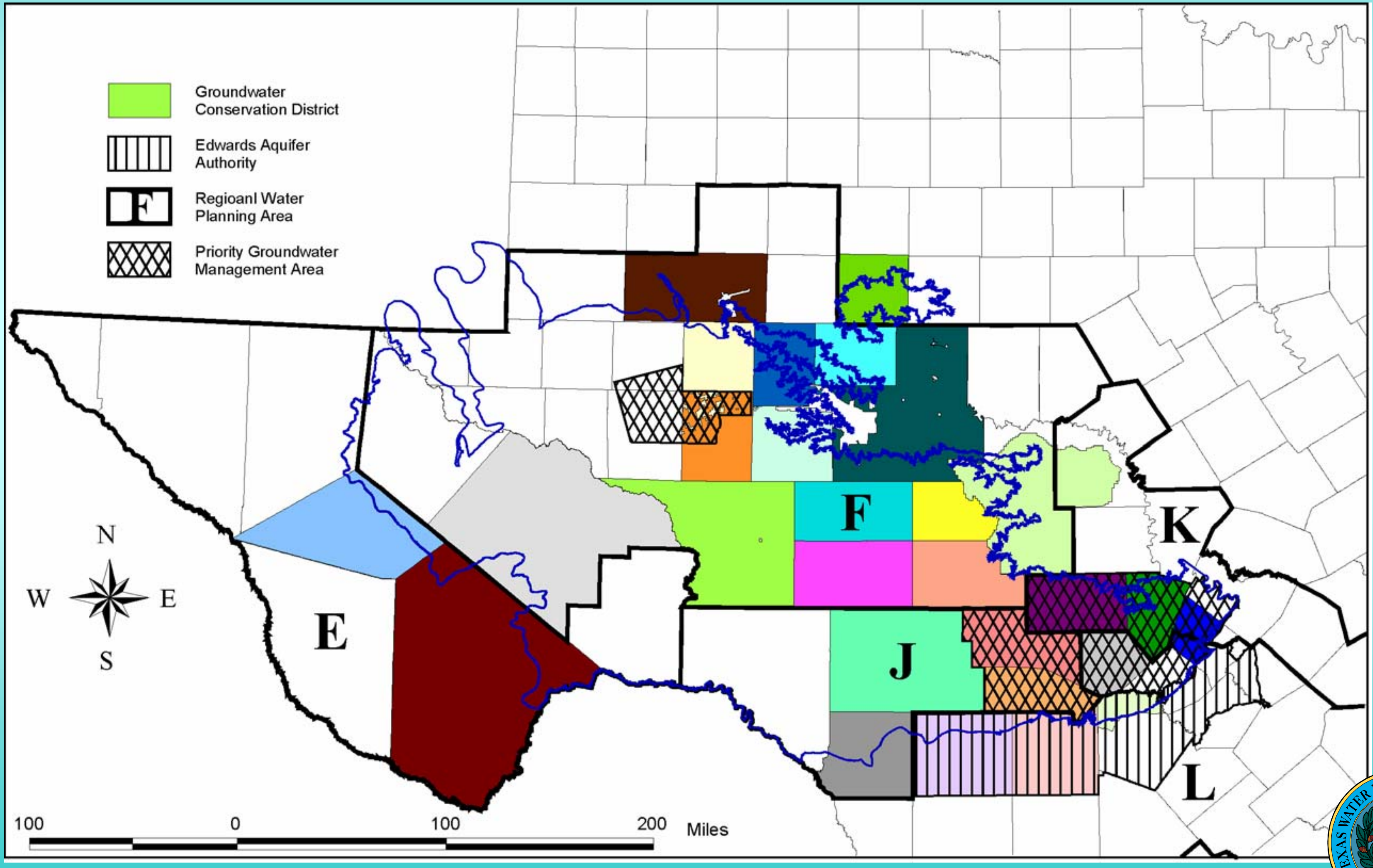
- Aquifer extent about 35,000 square miles
- Two Priority Groundwater Management Areas
- 29 Groundwater Management Areas
- Study area within five Regional Water Planning Areas, mostly in Region F and Plateau Region
- Beneath all or parts of 38 counties
- Sparse population concentrated in small towns, usually county seat

Study Area

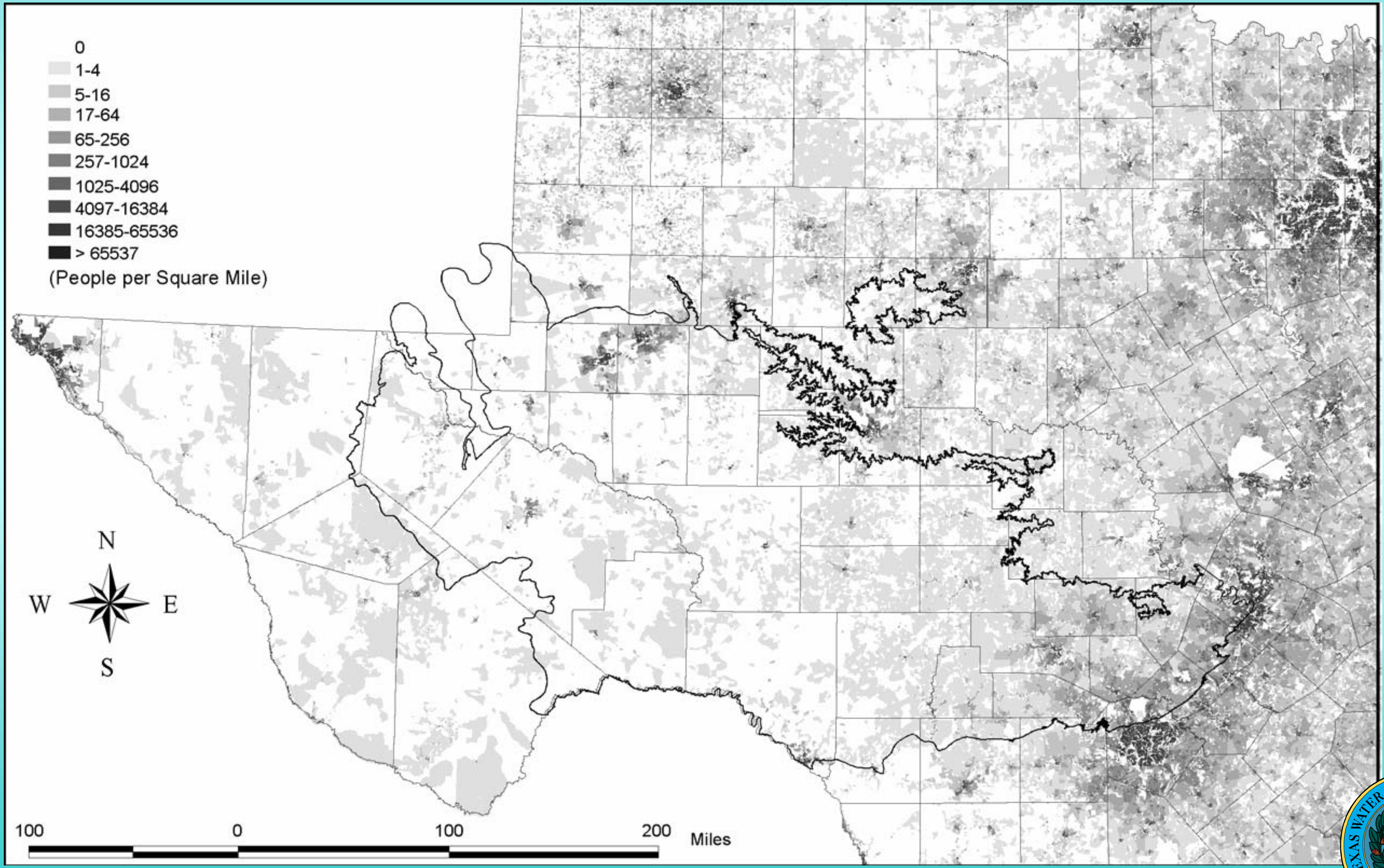


Cenozoic Pecos Alluvium
Trinity (Hill Country)
Edwards-Trinity (Plateau)
N
W
E
S
100
0
100
200
Miles

Political Boundaries

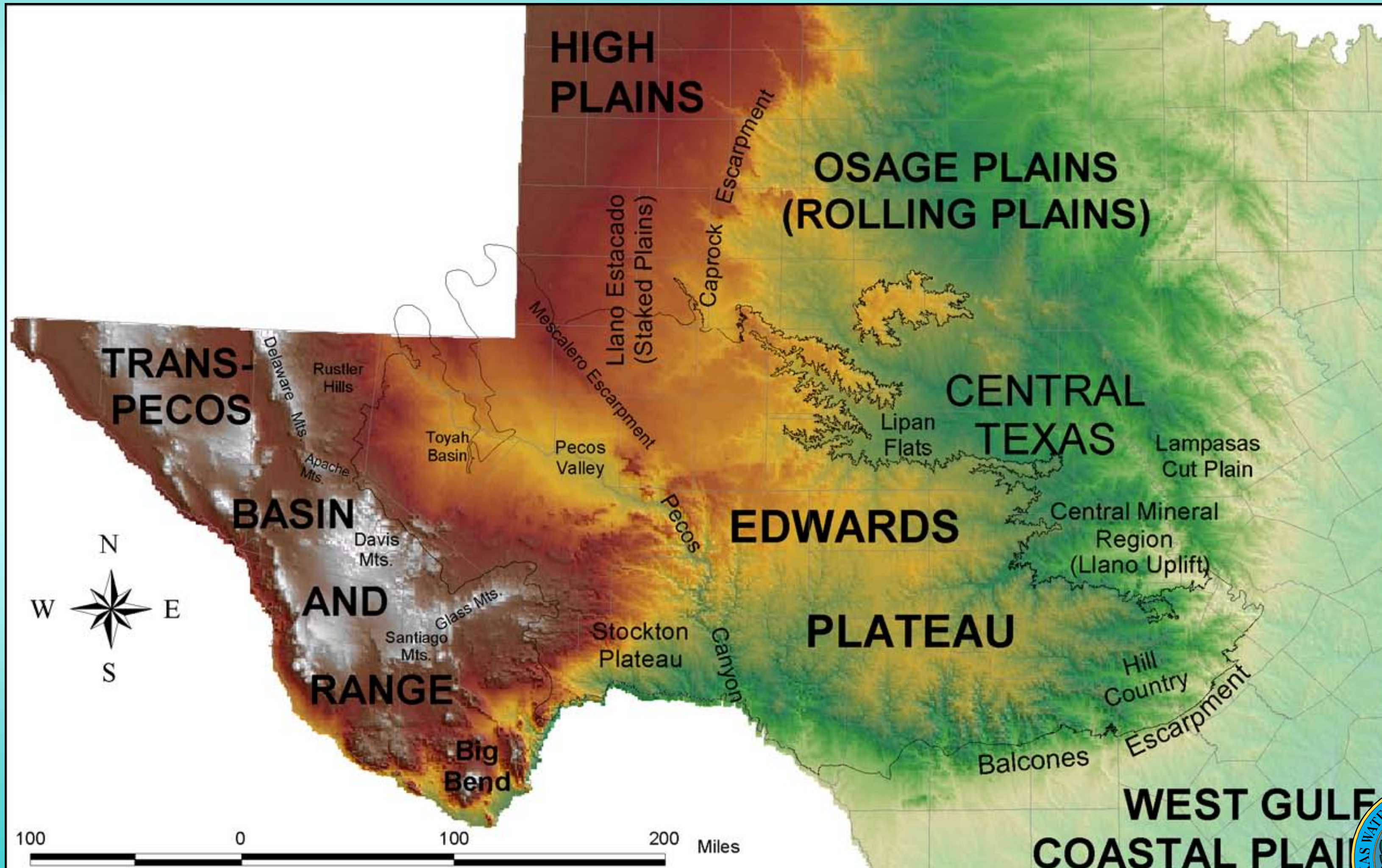


Population Density for 2000

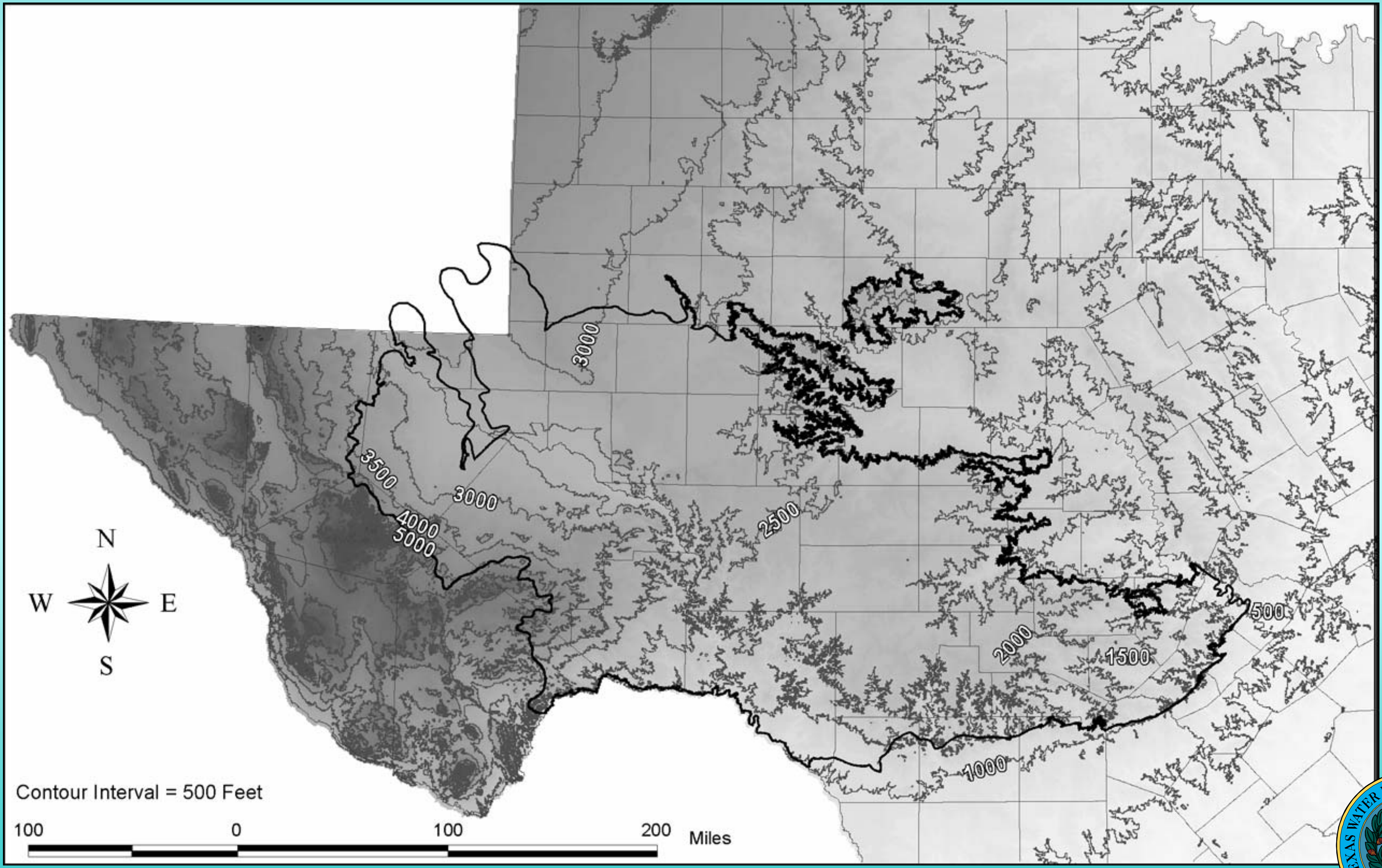


(Source data from 2000 US Census)

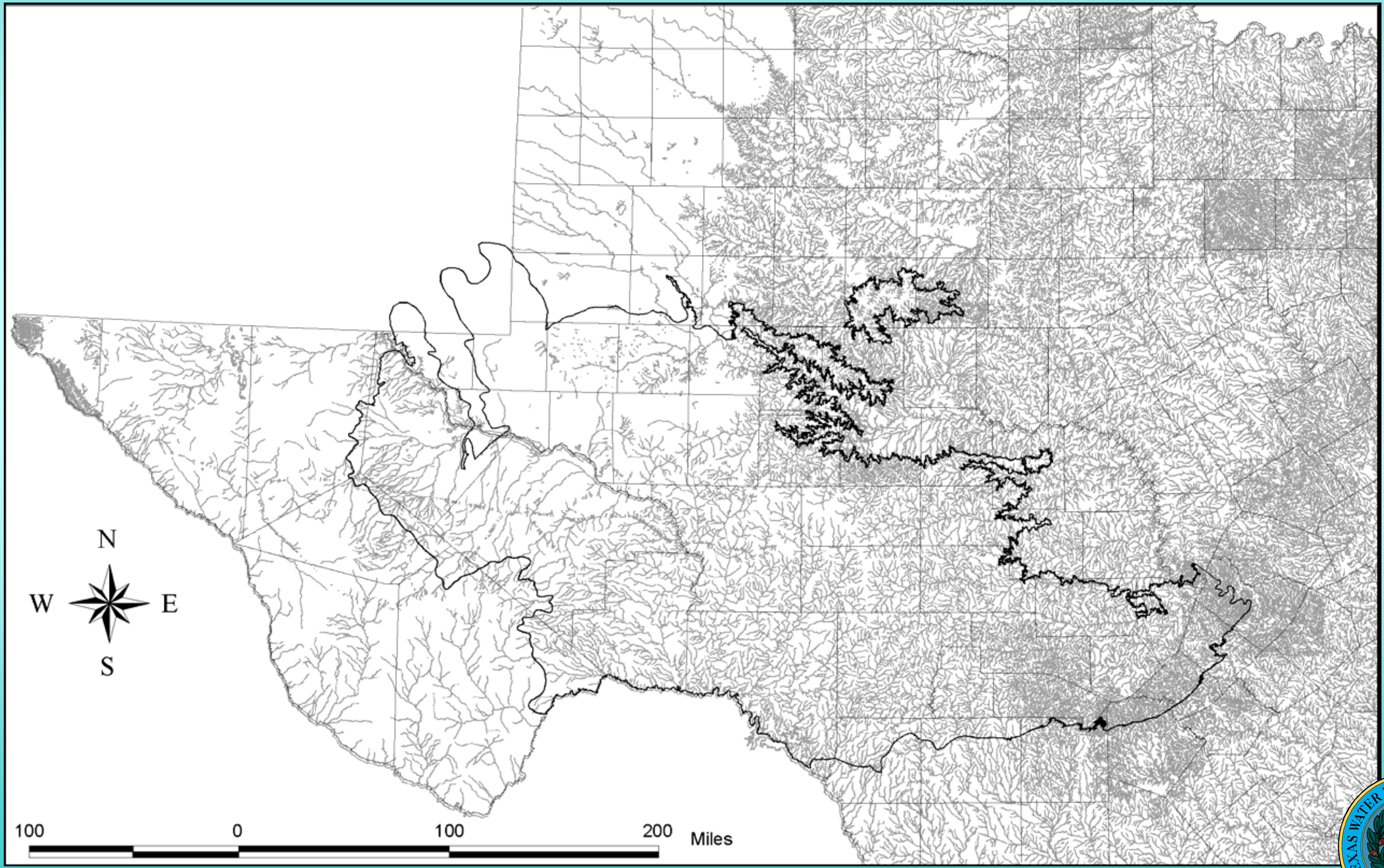
Physiography and Landforms



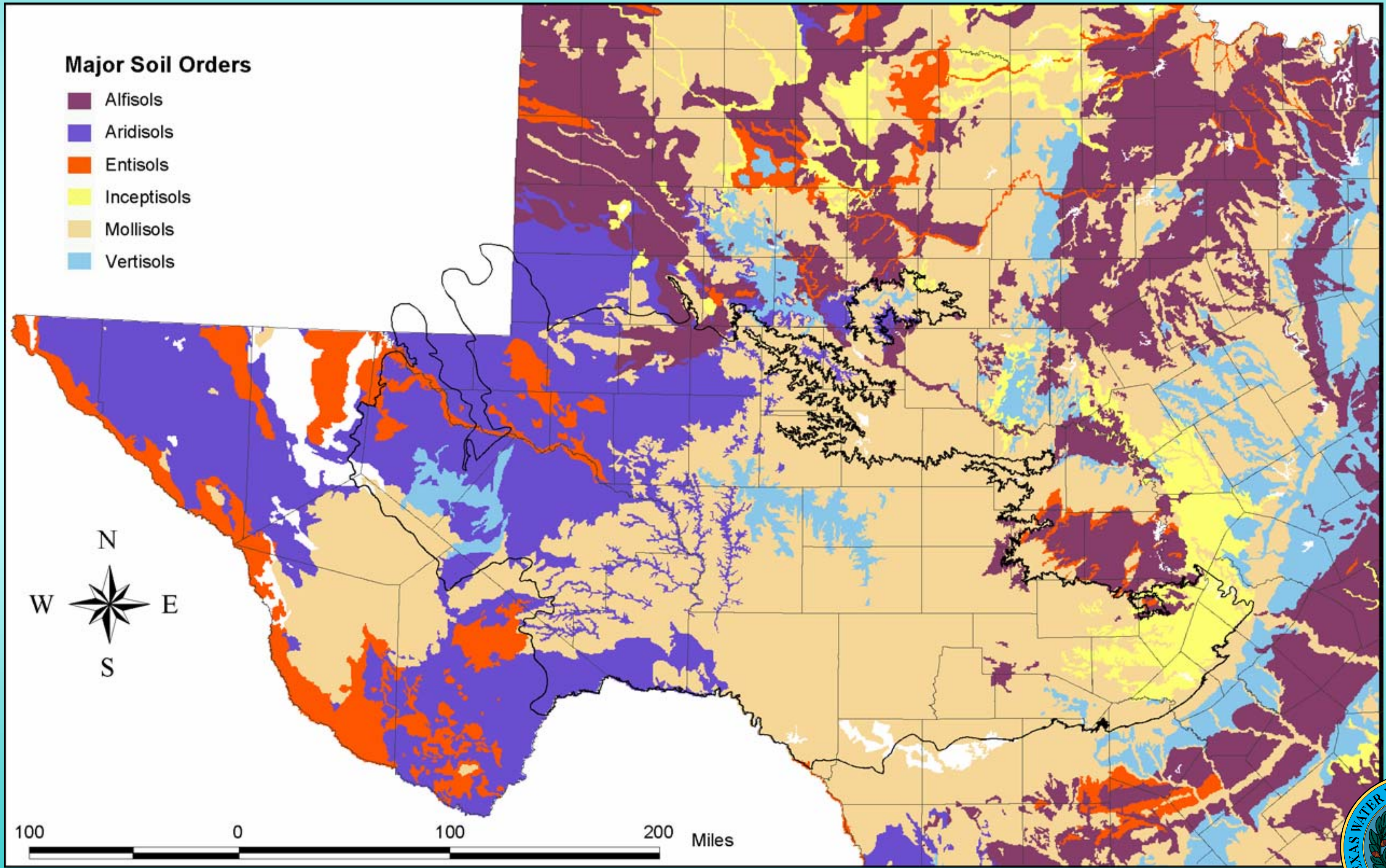
Topographic Elevations



Surface Water Drainage



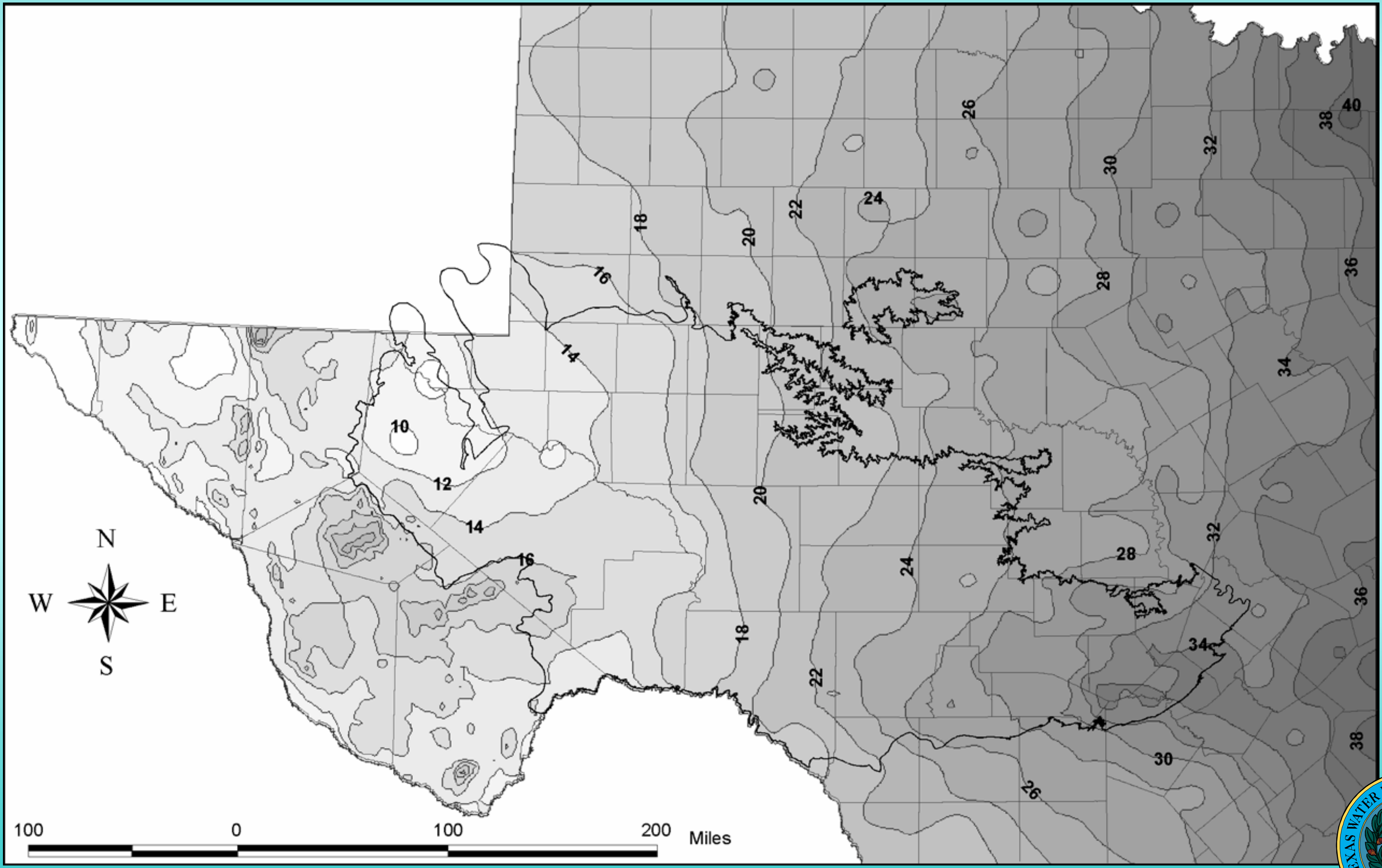
Major Soil Orders



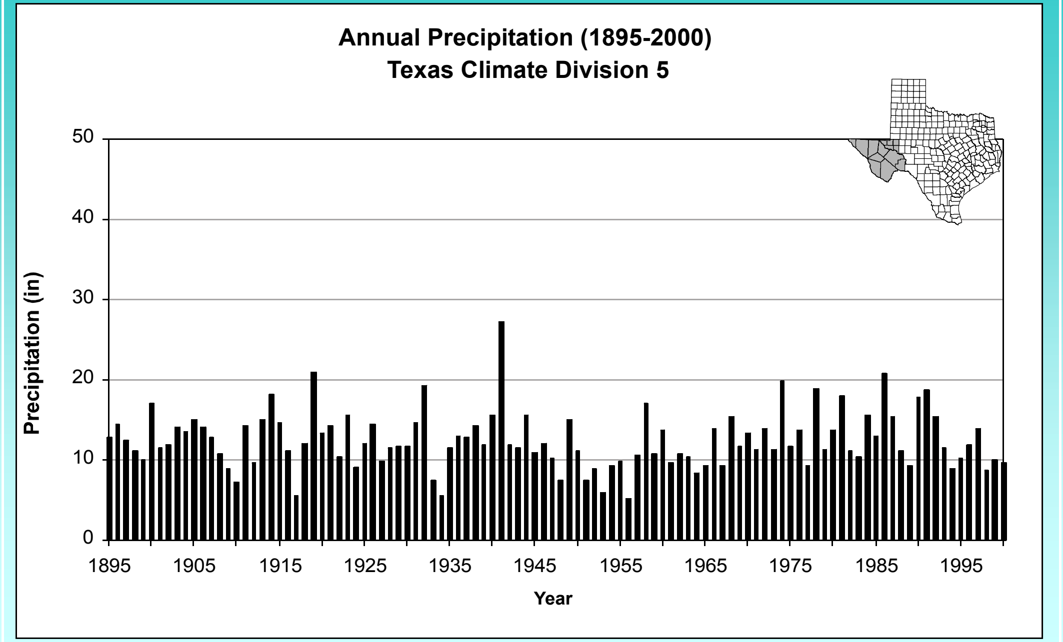
Climatic History

- Climate ranges from subhumid in the east to semiarid in the west
- Mean annual rainfall ranges from 34 inches in east to 12 inches in west
- Mean annual evaporation ranges from 63 inches in the east to 80 inches in the west
- Climate variability increases from east to west
- Drought of record occurred during 1950s

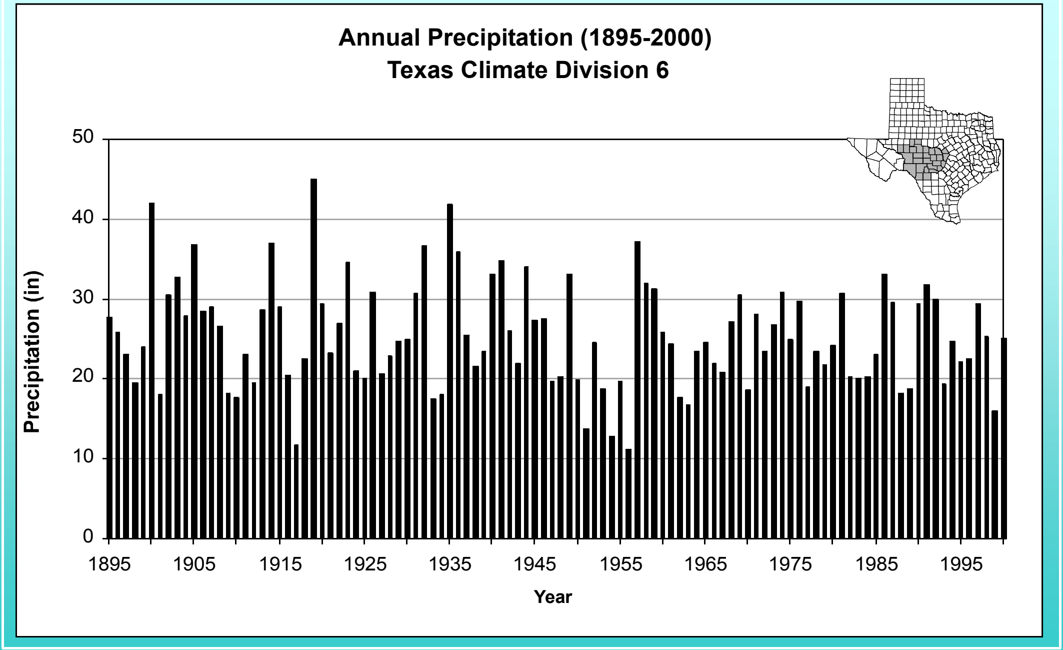
Mean Annual Precipitation (1961-1990)



Trans-Pecos



Historical Precipitation (1895-2000)

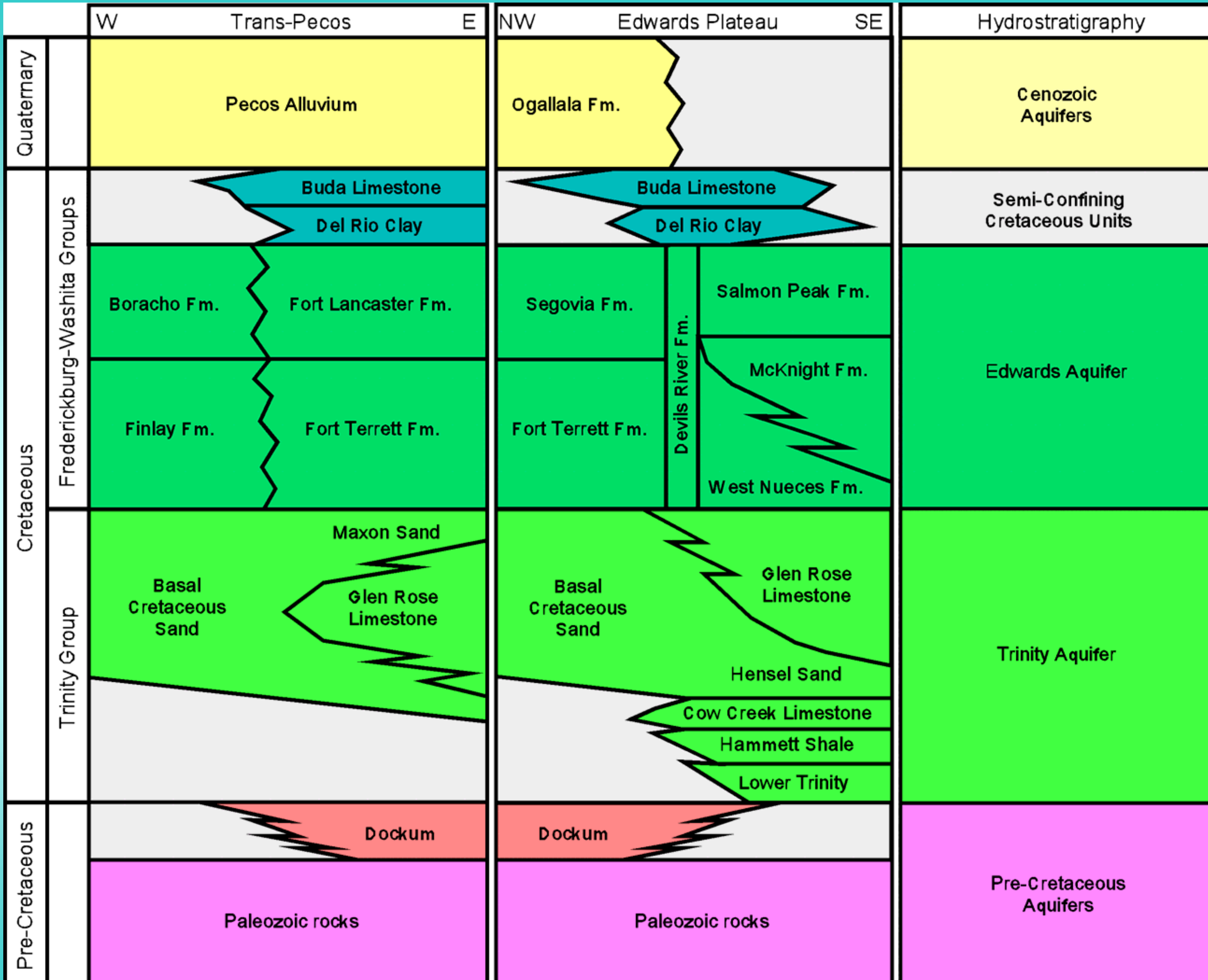


Edwards Plateau

Geologic History

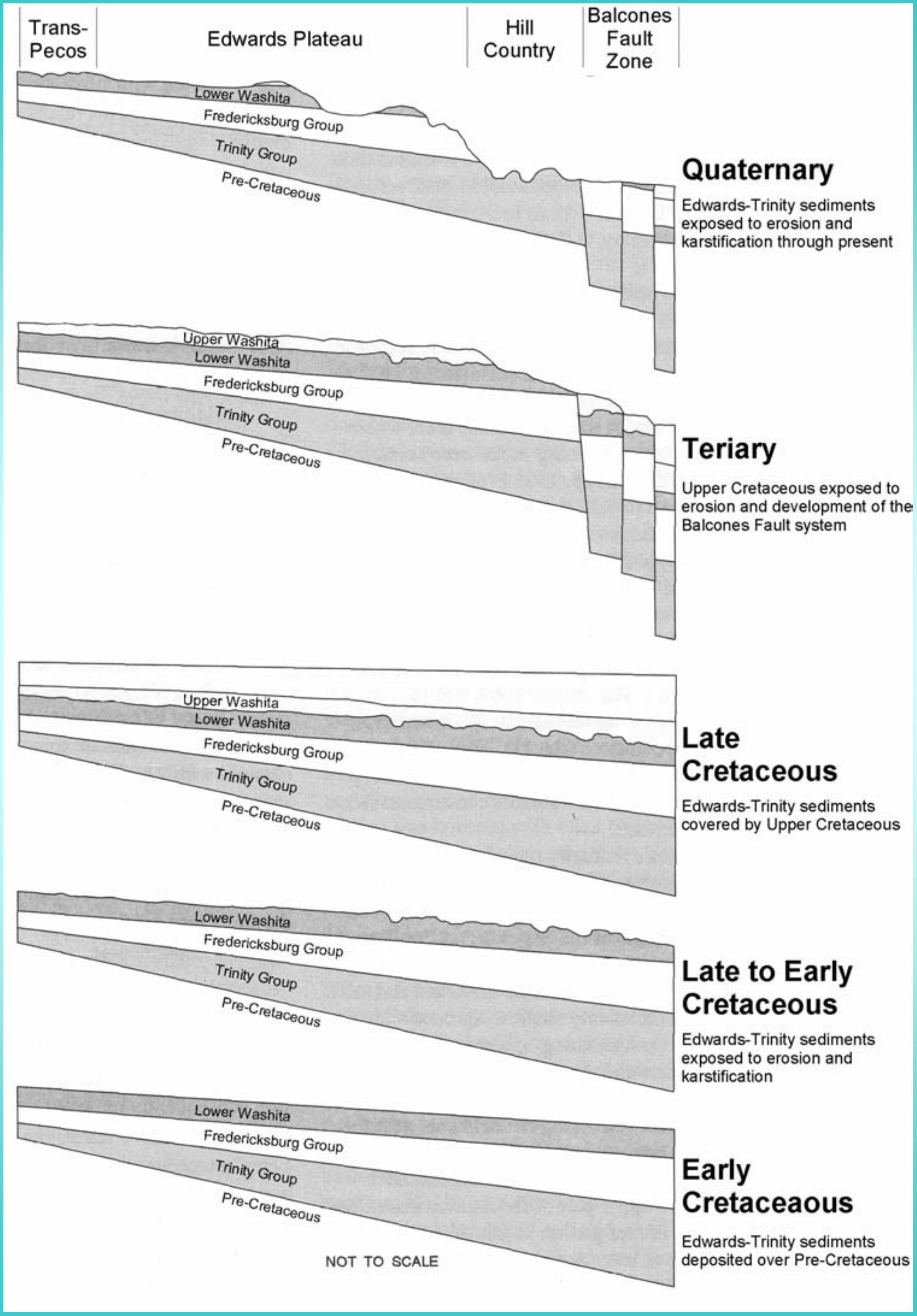
- Stratigraphy is the science of rock strata and it forms the fundamental basis for interpreting geologic history
- Stratigraphy is used to classify and organize rock formations based on original succession, age, composition, and other physical and chemical properties
- Stratigraphy allows us to map rock distributions and to interpret the mode of origin and/or the depositional environment of rock formations

Stratigraphic Chart



(Modified from Barker and Ardis, 1996)

Evolution of Edwards-Trinity Aquifer System



(After Barker and others, 1994)

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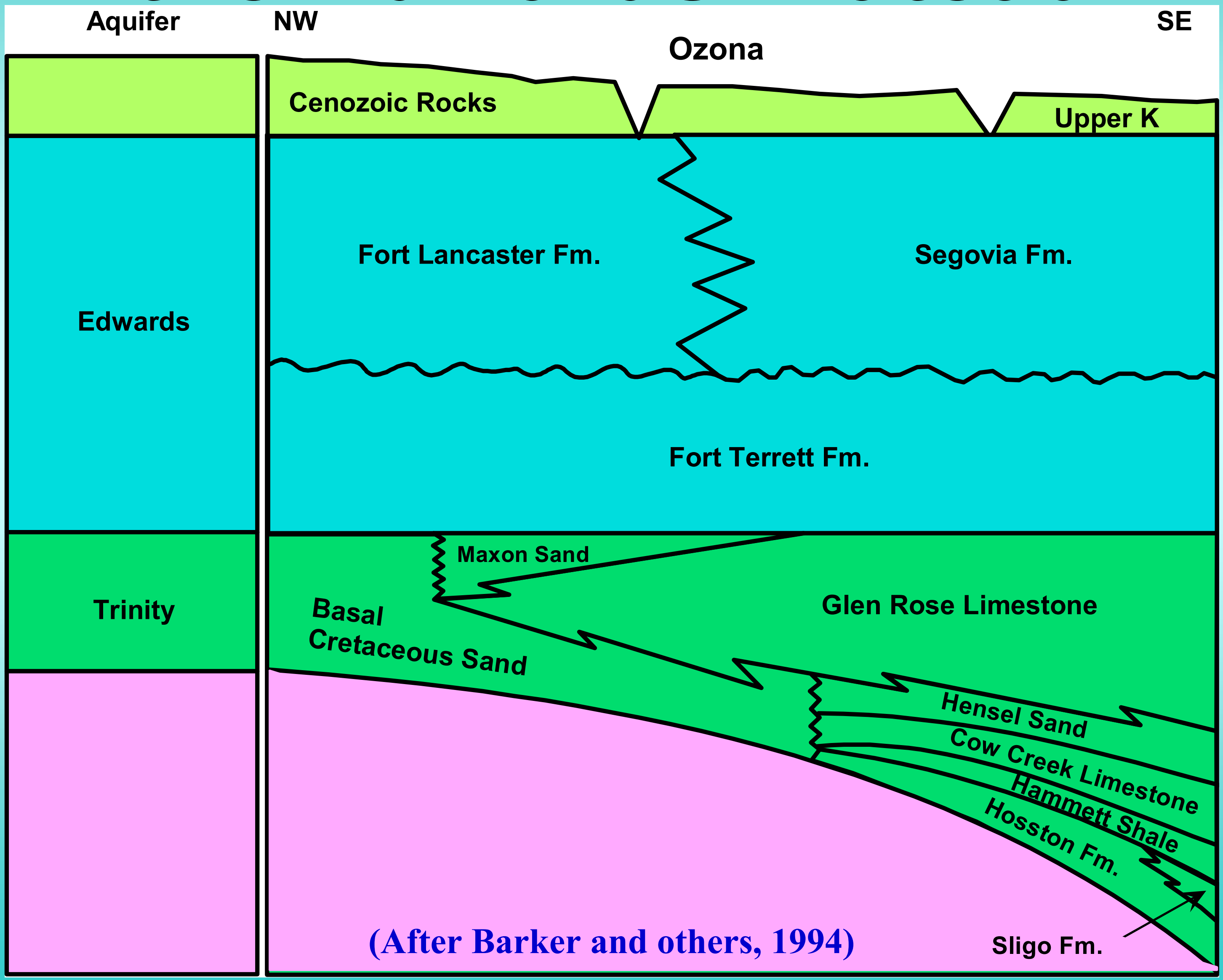
Previous Aquifer Studies

- 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
- R. A. Barker and Others, ***Geologic History and Hydrogeologic Setting of the Edwards-Trinity Aquifer System, West-Central Texas***, USGS Water-Resources Investigation Report 94-4039, 1994
- 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
- R. A. Barker and A. F. Ardis, ***Hydrogeologic Framework of the Edwards-Trinity Aquifer System, West-Central Texas***, USGS Professional Paper 1421-B, 1996

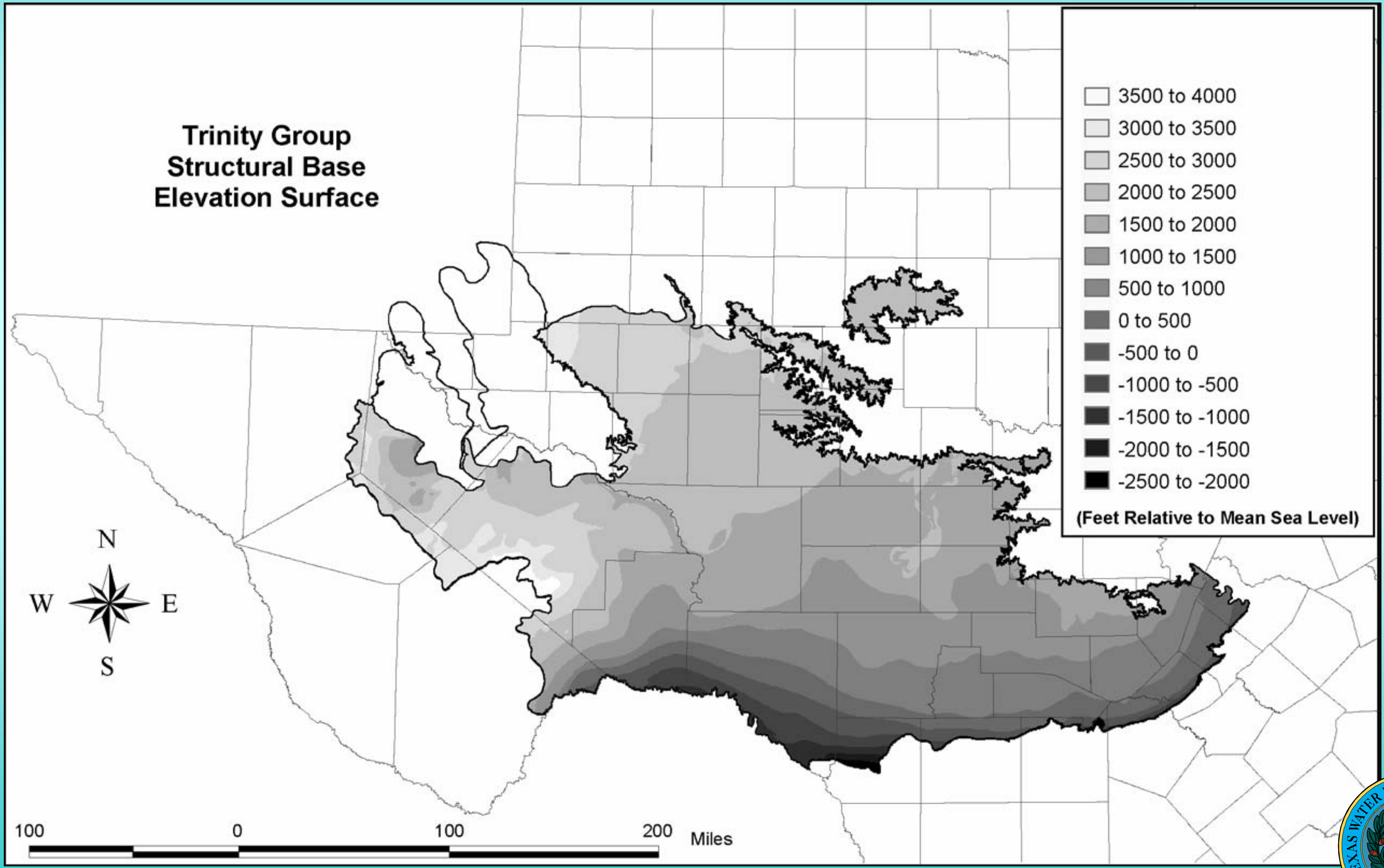
Hydrogeologic Setting

- Hydrostratigraphy
- Structural geometry
- Hydraulic properties
- Water levels and regional groundwater flow
- Recharge
- Interactions between surface water and groundwater
- Well discharge

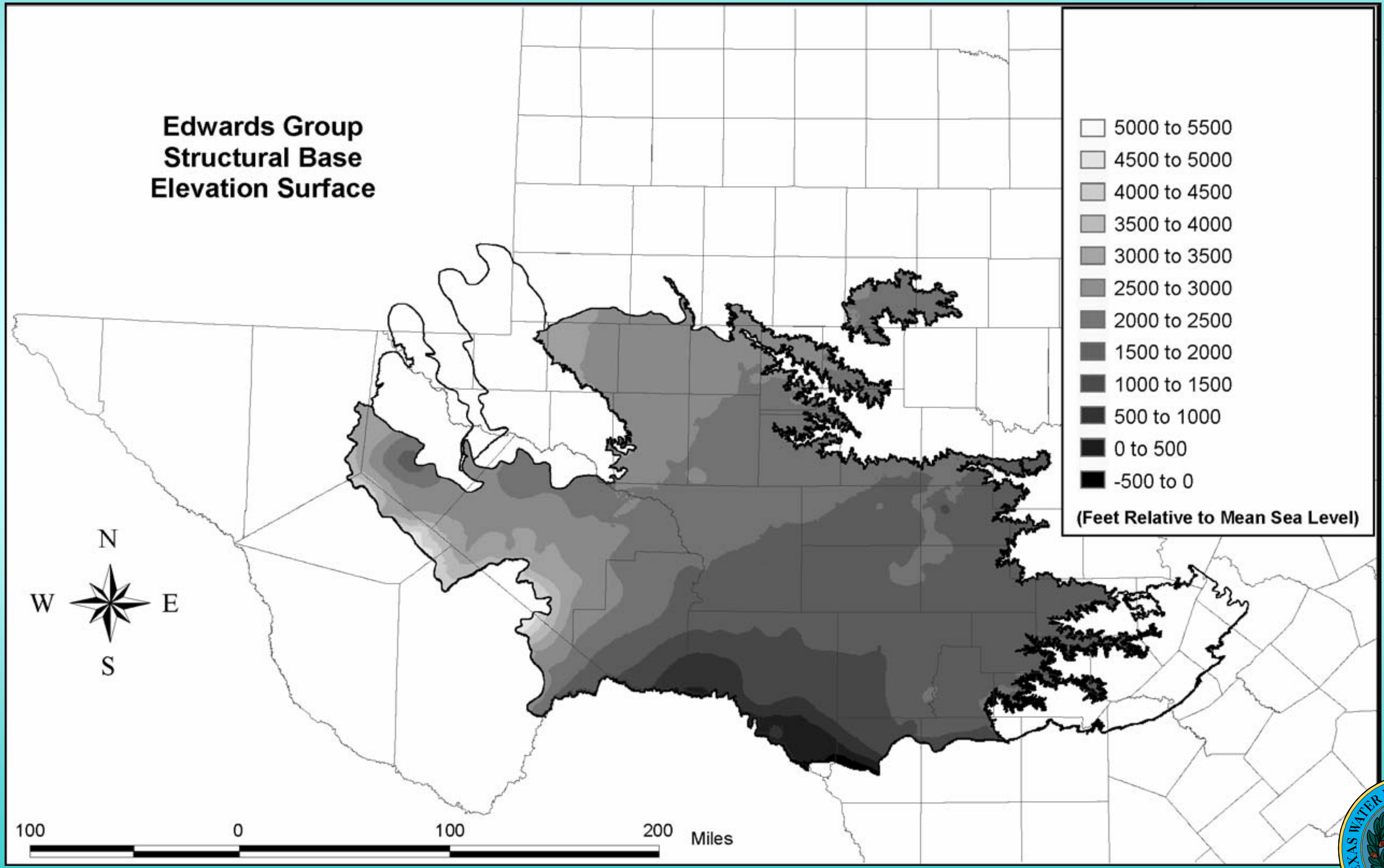
Hydrostratigraphic Units of the Edwards Plateau



Structural Base of Trinity



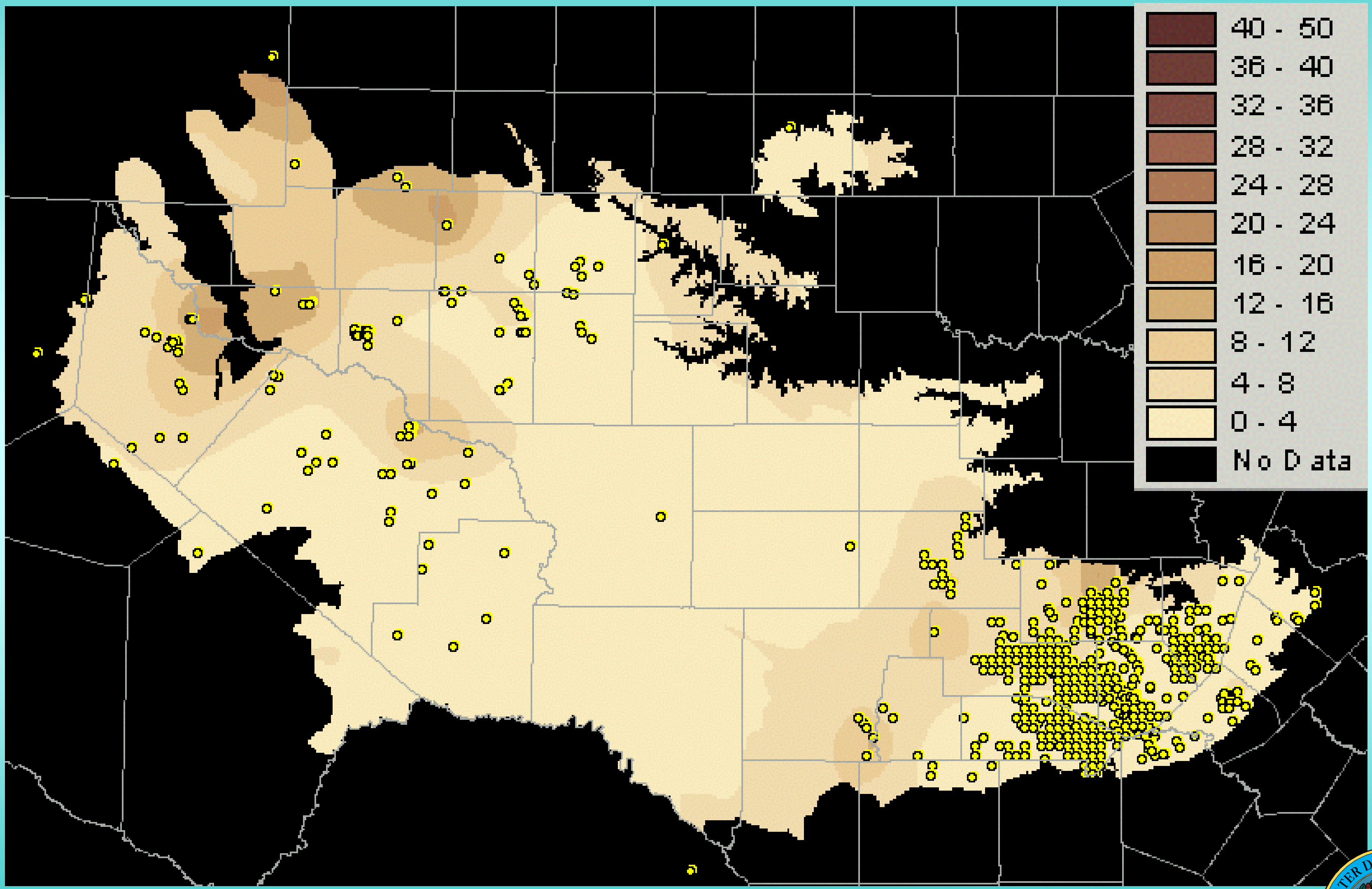
Structural Base of Edwards



Data Acquisition for Hydraulic Properties

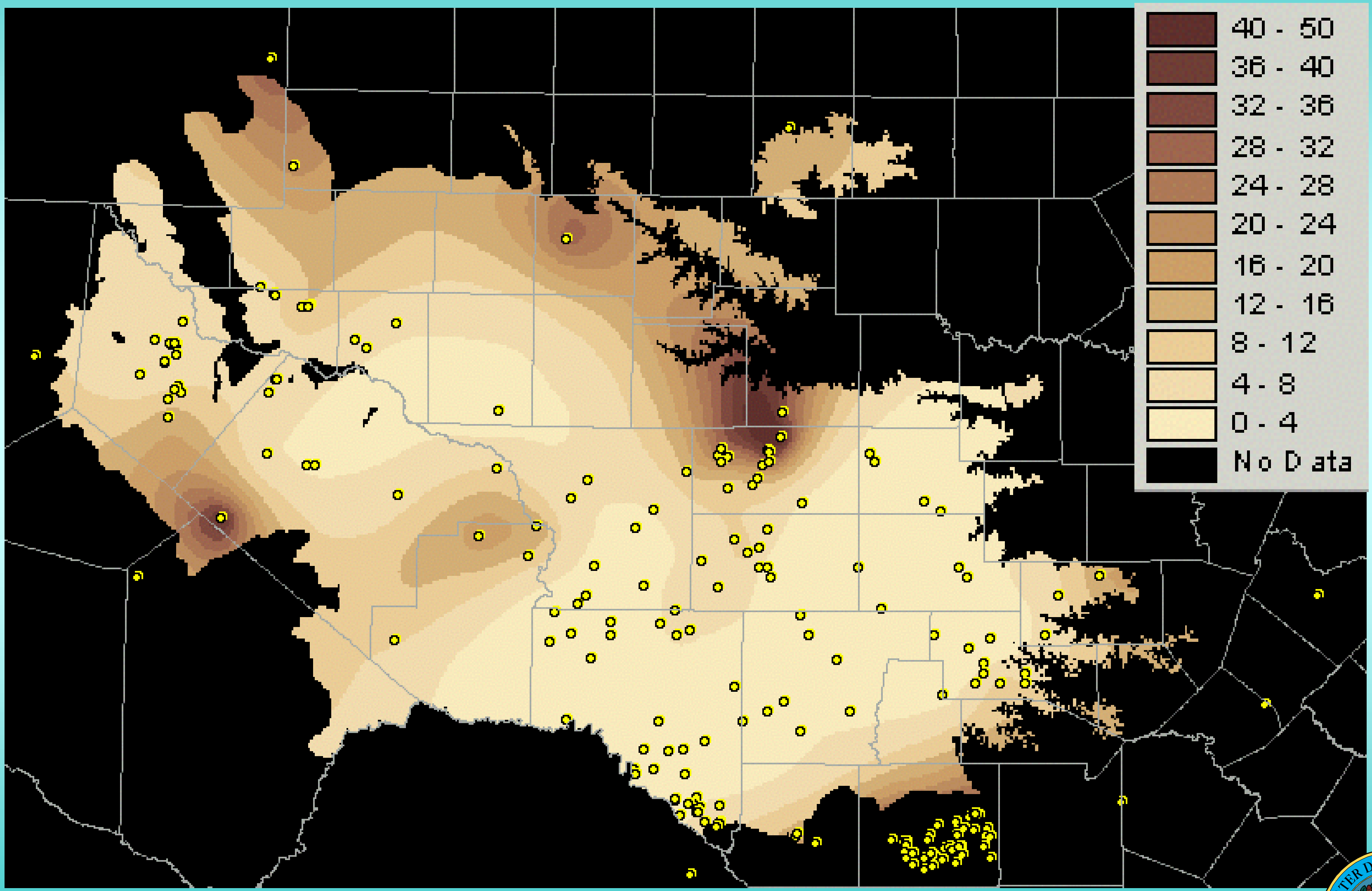
- TWDB Performed 39 New Pumping Tests on the Edwards-Trinity … 2 were Unusable
- TWDB groundwater Database Searched for Specific Capacity Tests resulted in about 600 Hits
- TNRCC Specific Capacity Tests Acquired for about 900 Wells
- Additional Hydraulic Data were Gleaned from the Literature Review for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

Trinity



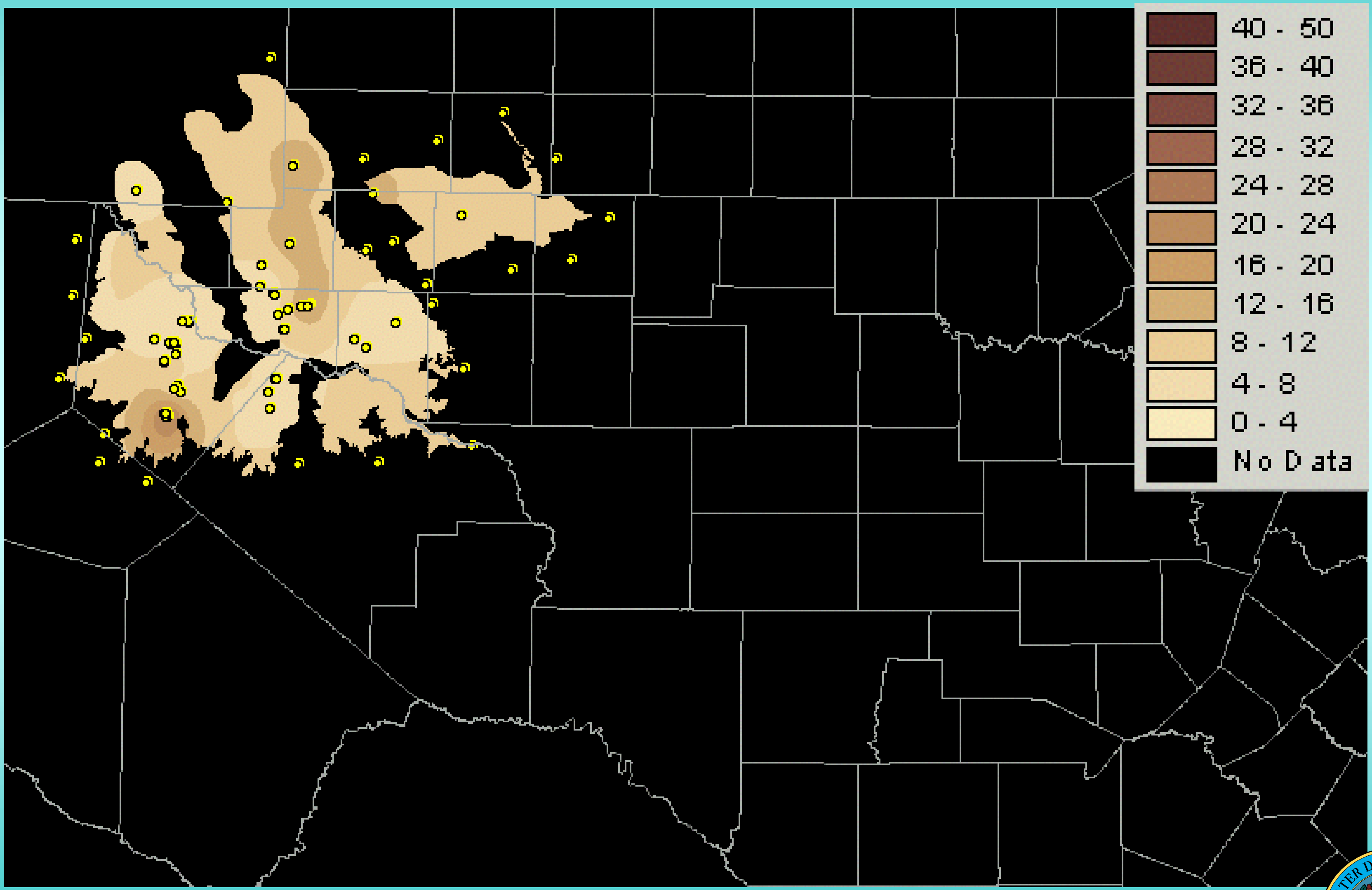
655 Control Points with Geometric Mean of 2.36 ft/d

Edwards



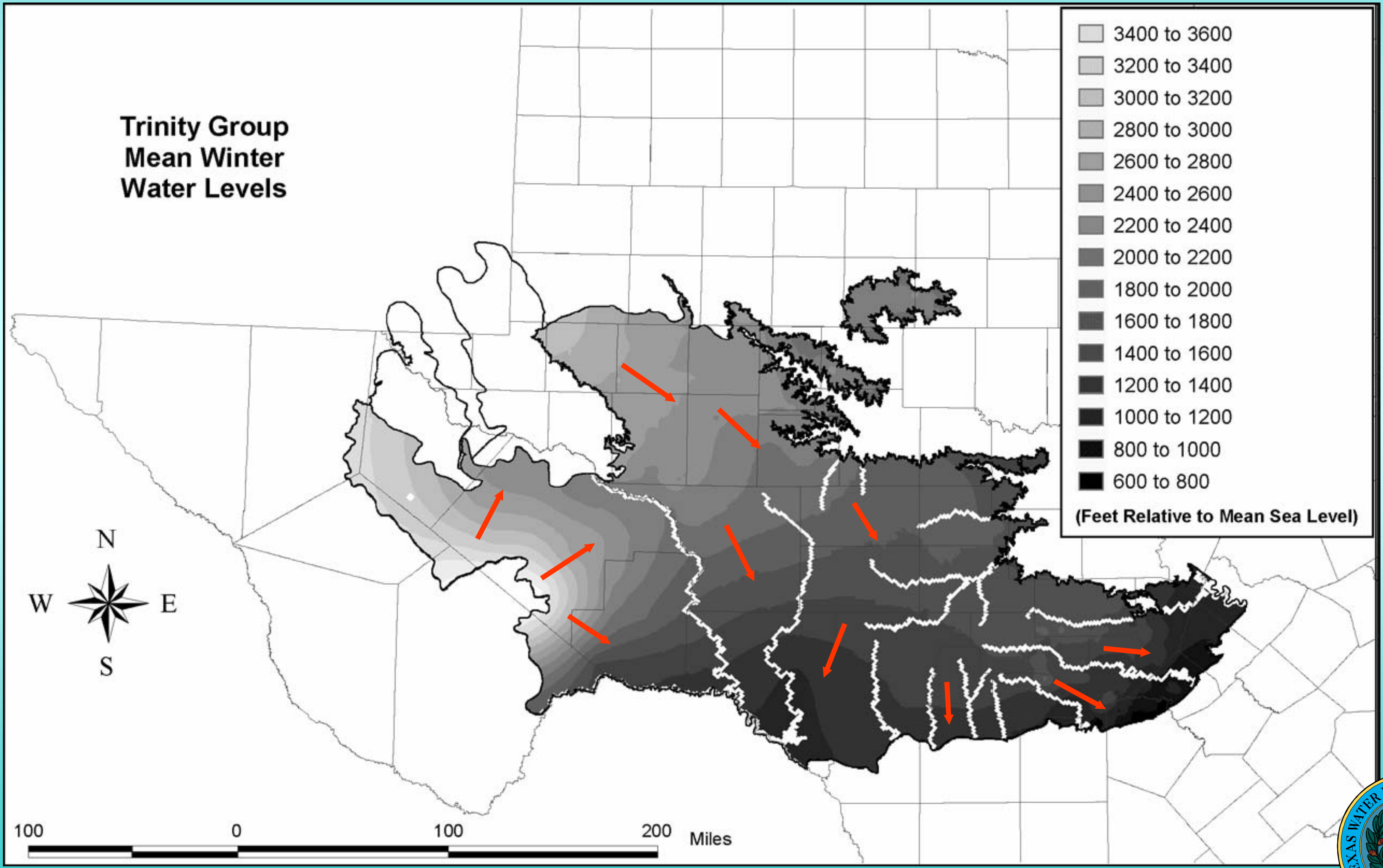
190 Control Points with Geometric Mean of 6.65 ft/d

Cenozoic Pecos Alluvium

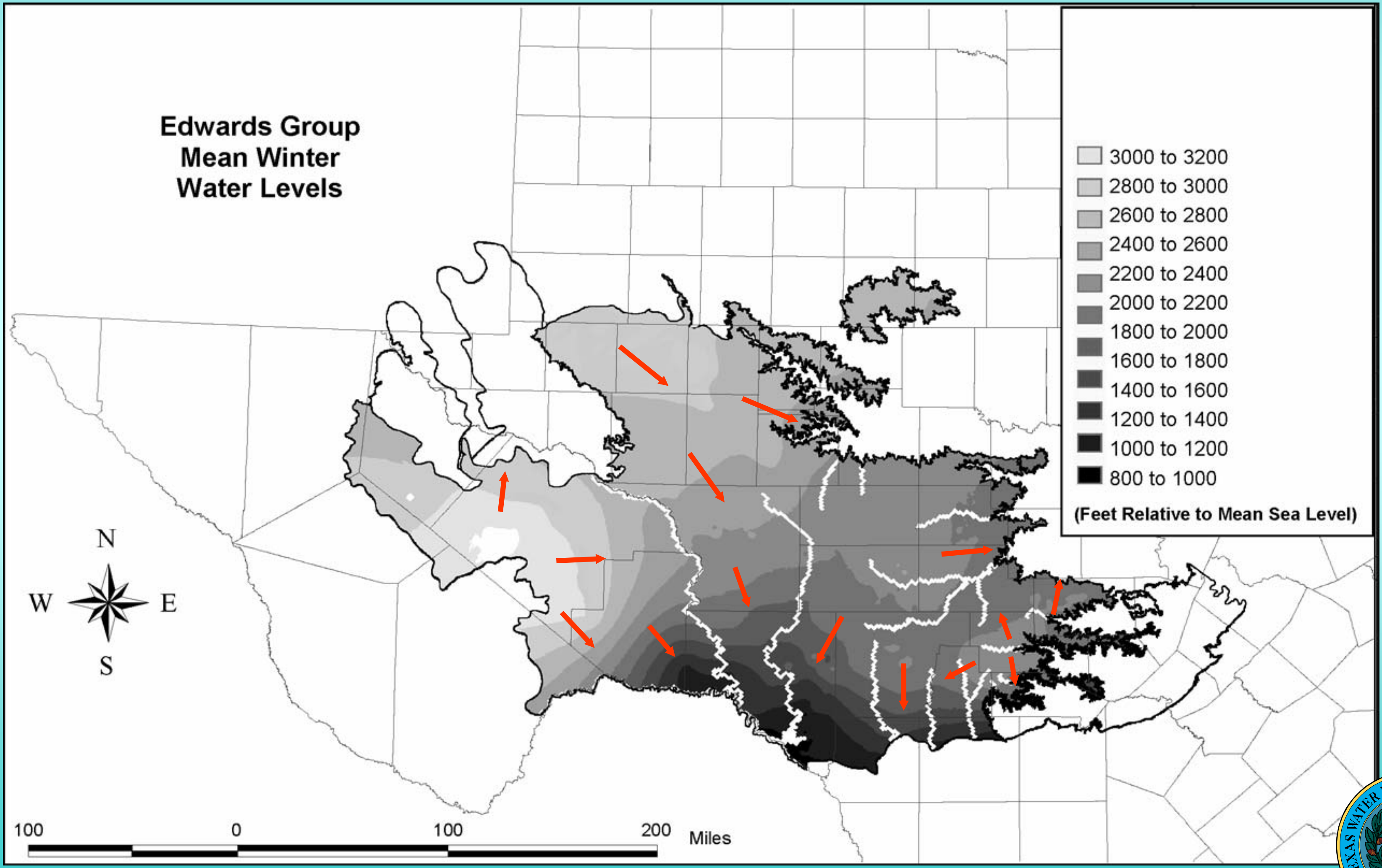


70 Control Points with Geometric Mean of 8.58 ft/d

Mean Winter Water Levels for Trinity Aquifer



Mean Winter Water Levels for Edwards Aquifer



Recharge

- Published estimates of recharge:

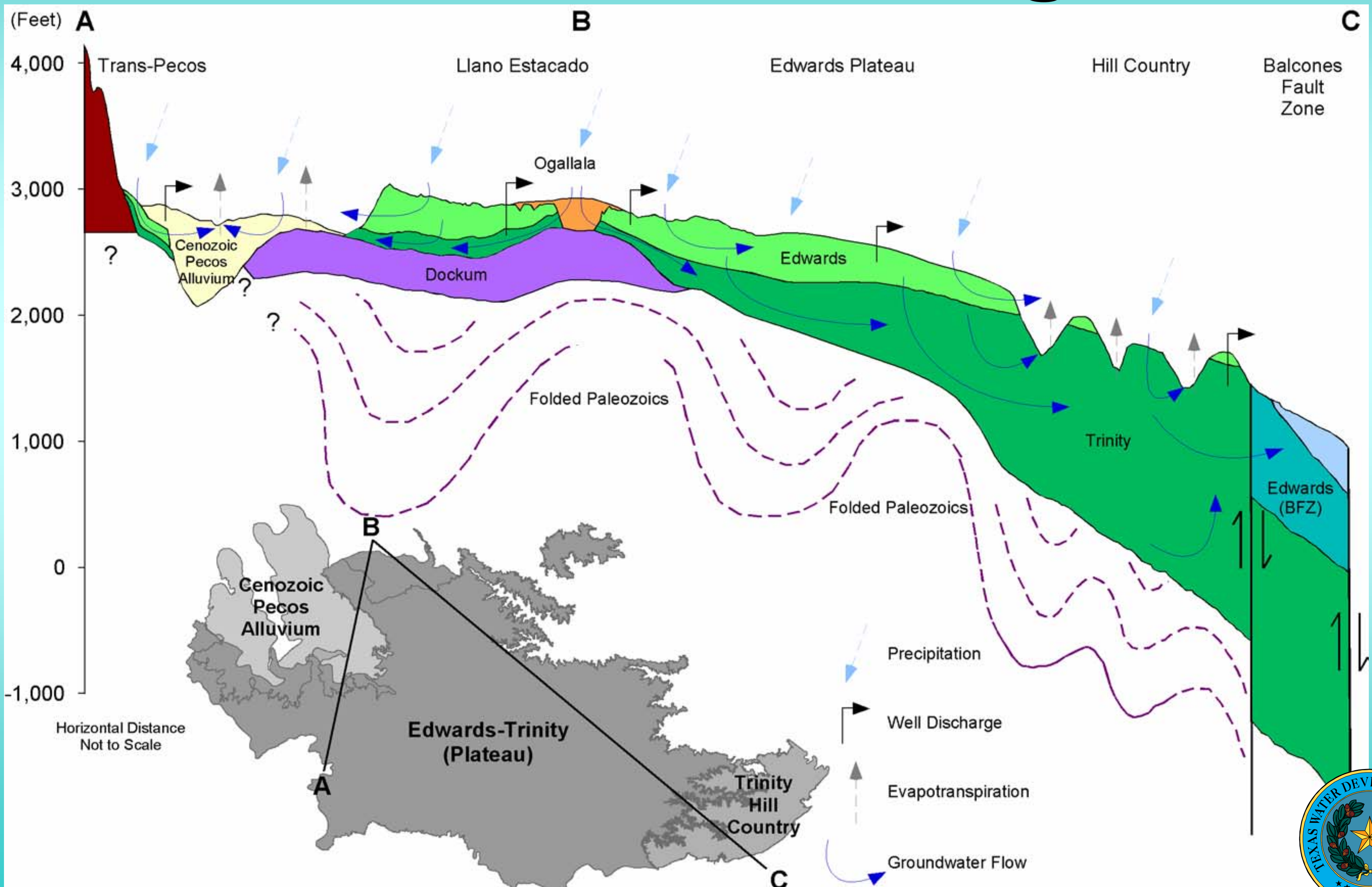
Area (County)	Recharge (percent rainfall)	Reference	Method
Crockett	1.6%	Iglehart, 1967	baseflow
Kinney	5.7%	Bennett and Sayre, 1962	baseflow
Kinney	11%	Mace and Anaya, 2004	baseflow
Real	7.5%	Long, 1958	baseflow
Kerr	3.7%	Reeves, 1969	baseflow

- Recharge to be determined through calibration of numerical groundwater model

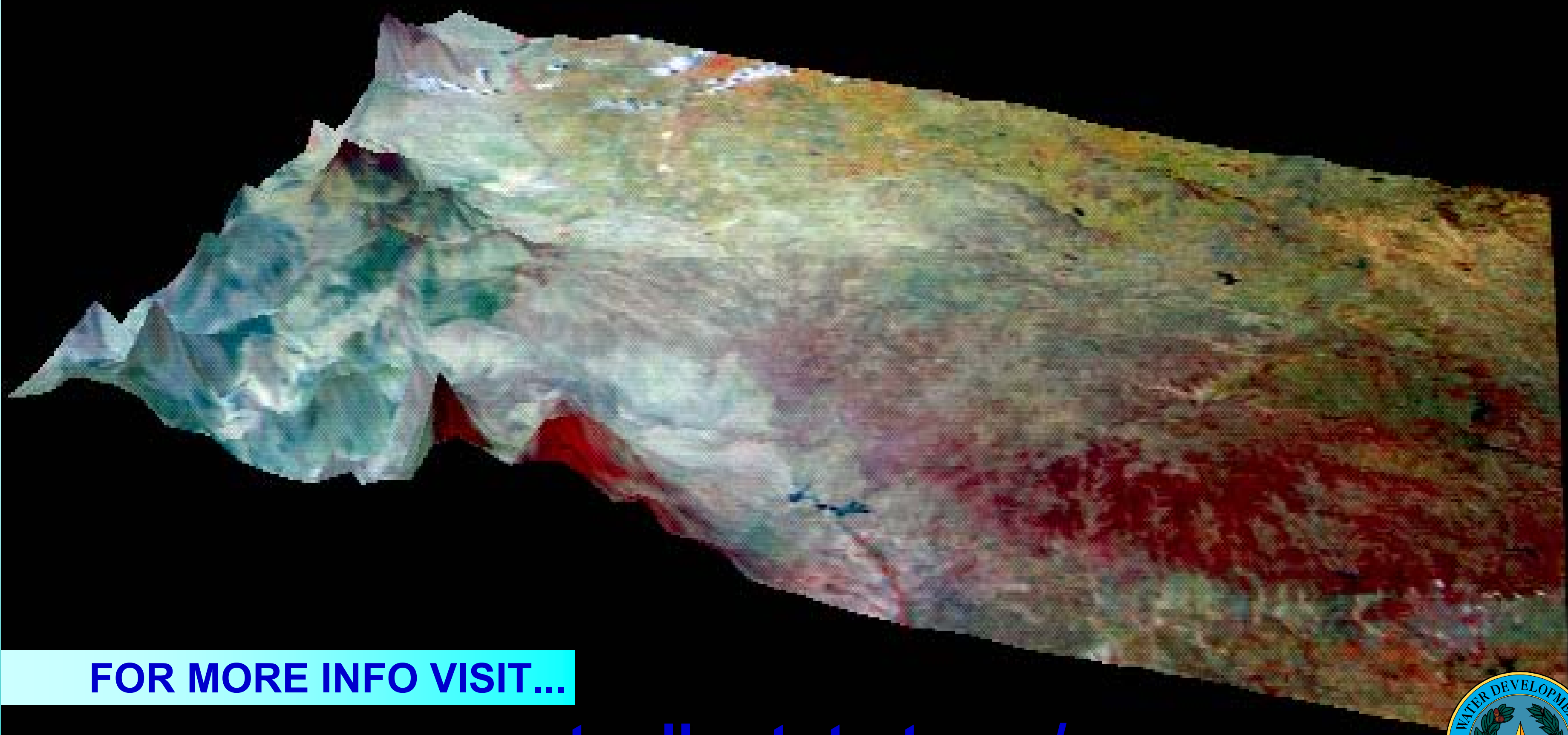
Interactions Between Surface Water and Groundwater

- Most stream reaches on the Edwards aquifer lose flow to the aquifer except in lower reaches of major streams
- Most stream reaches on the Trinity aquifer gain flow from the aquifer.
- Springs and seeps common along eastern contact between Edwards and Trinity
- Reservoirs and lakes gain water from the the aquifers beneath them

Conceptual Model Cross Sectional Diagram



Questions or Comments?



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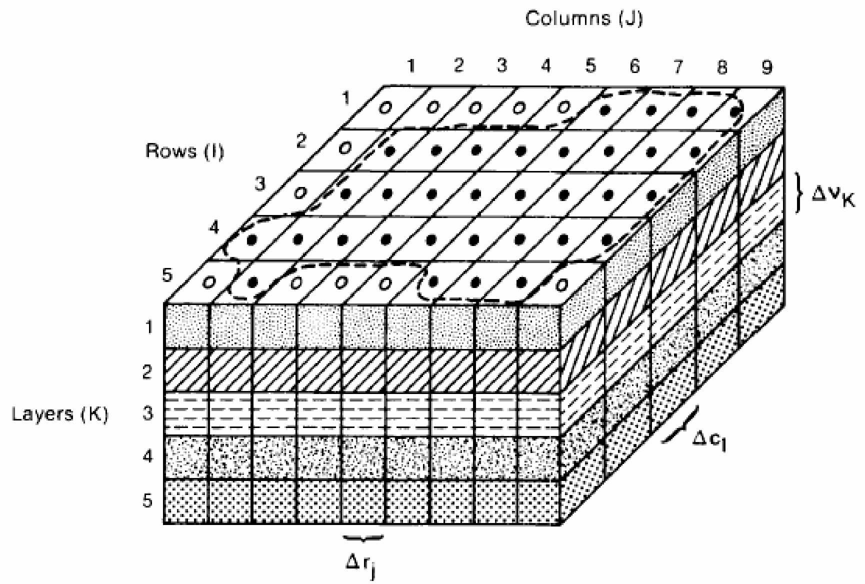
An Overview of MODFLOW



Explanation

- - - - Aquifer Boundary

• Active Cell

o Inactive Cell

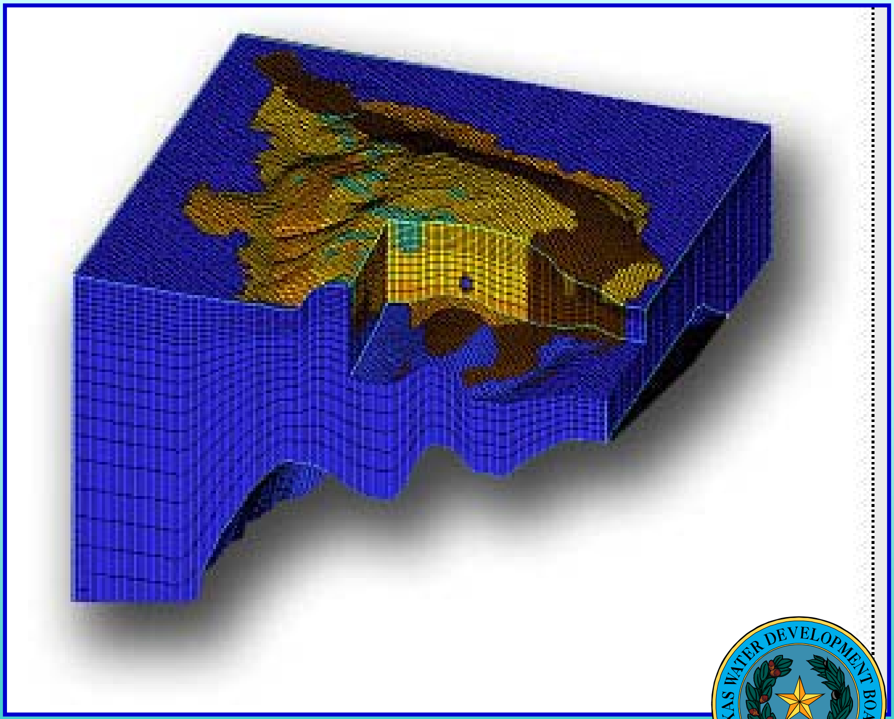
Δr_J Dimension of Cell Along the Row Direction. Subscript (J) Indicates the Number of the Column

Δc_I Dimension of Cell Along the Column Direction. Subscript (I) Indicates the Number of the Row

Δv_K Dimension of the Cell Along the Vertical Direction. Subscript (K) Indicates the Number of the Layer

MODFLOW
Computer Code

Developed by the United States Geological Survey



Implements the 3-D finite difference equations for groundwater flow using FORTRAN programming code

Numerical Equations for 3-D Groundwater Flow

$$Q_{in} + Q_{out} = 0; \quad Q_{in} + Q_{out} = Change\ in\ storage$$

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = 0$$

Steady-state modeling

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t}$$

Transient modeling

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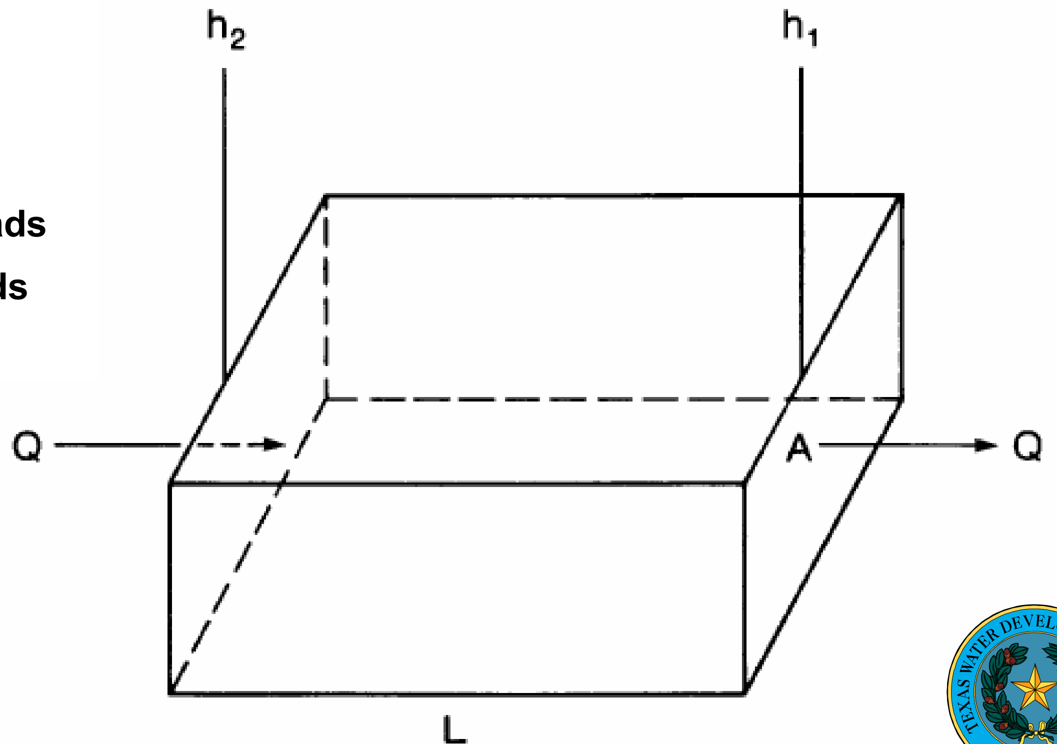
Cube of Aquifer Material Illustrating Darcy's Law

$$Q = \frac{KA\,(h_2 - h_1)}{L}$$

Where:

- Q = groundwater flow rate thru cube
- K = hydraulic conductivity
- A = perpendicular cross flow area
- $(h_2 - h_1)$ = difference in measured heads
- L = distance between measured heads



MODFLOW History

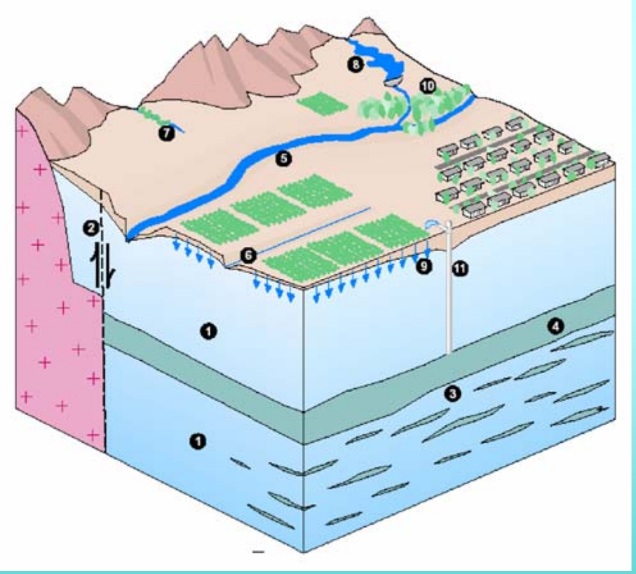
- MODFLOW (1984)
  - McDonald and Harbaugh, 1986
- MODFLOW 88 (1988)
  - McDonald and Harbaugh, 1988
- **MODFLOW 96 (1996)**
  - **Harbaugh and McDonald, 1996**
- MODFLOW 2K (2000)
  - Harbaugh et al, 2000

Why Use MODFLOW?

- Includes basic hydrogeologic processes
- Very well documented code
- Modular design allows for customization
- Fully tested and widely accepted
- Public domain (available for free)
- Most widely used groundwater flow model
- Many utility programs and Graphical User Interfaces (GUIs) are readily available

Modeling Processes

- ❖Confined and unconfined aquifer systems
- ❖Recharge and evapotranspiration
- ❖Pumpage and injection wells
- ❖Gaining and losing streams
- ❖Drains (springs)
- ❖Reservoirs (lakes)
- ❖Horizontal barriers (faults)



MODFLOW Packages

- Basic
- Block Centered Flow
- Recharge
- Well
- River
- Drain
- Evapotranspiration
- General Head Boundary
- Output Control
- Various Solvers
- Reservoir
- Stream Routing
- Transient Leakage
- Horizontal Barrier Flow
- Compaction

Model Inputs

- Boundaries
  - define the interaction between the aquifer model and the rest of the world
- Parameters
  - aquifer properties that do not change over the period being modeled
- Variables
  - aquifer stresses and/or boundaries that change over the period being modeled
- Initial conditions
  - aquifer stresses and/or boundaries that change over the period being modeled

Boundary Conditions

- Specified Head (Dirichlet)
- Specified Flux (Neumann)
  - No Flow: when flux = zero
- Head Dependent (Cauchy)

Aquifer Parameters

- ❖Aquifer tops and bottoms
- ❖Hydraulic conductivity or transmissivity
- ❖Specific yields and storage coefficients
- ❖Constant heads (specified head)
- ❖Drains (head dependent)

Stress and Boundary Variables

- Recharge (specified flux)
- Evapotranspiration (head dependent)
- Wells (specified flux)
- Streams (head dependent)
- Reservoirs (head dependent)
- General head boundary (head dependent)

Initial Conditions

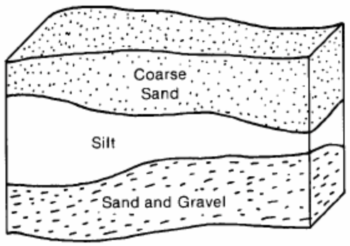
- Starting aquifer heads
- Starting stream heads
- Starting reservoir heads

Model Characterization of Boundaries, Parameters, Variables, and Initial Conditions

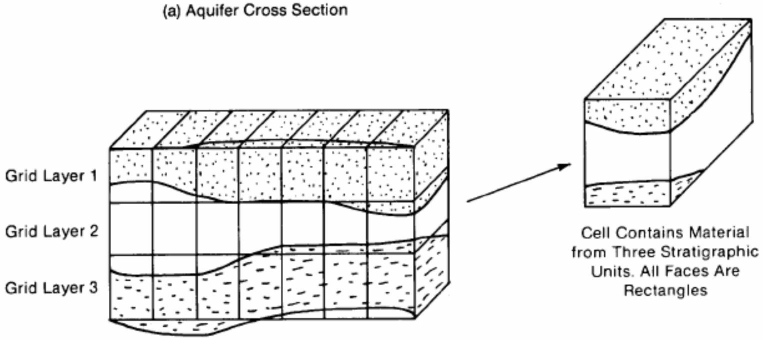
- May be assigned to groups or zones of model grid cells
- May be assigned to individual model grid cells
- May be assigned to model layers

Model Discretization

Vertical

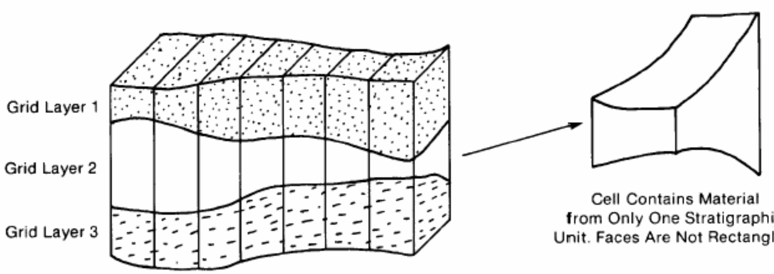


(a) Aquifer Cross Section



(b) Aquifer Cross Section With Rectilinear Grid Superimposed

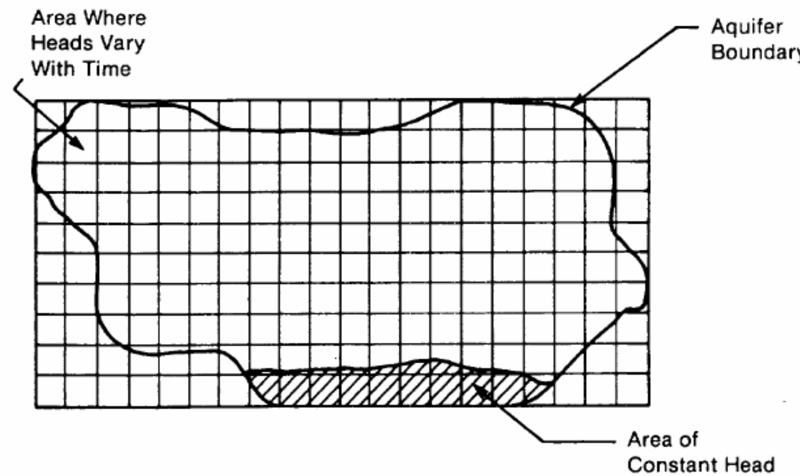
Cell Contains Material from Three Stratigraphic Units. All Faces Are Rectangles



(c) Aquifer Cross Section With Deformed Grid Superimposed

Cell Contains Material from Only One Stratigraphic Unit. Faces Are Not Rectangles

Horizontal

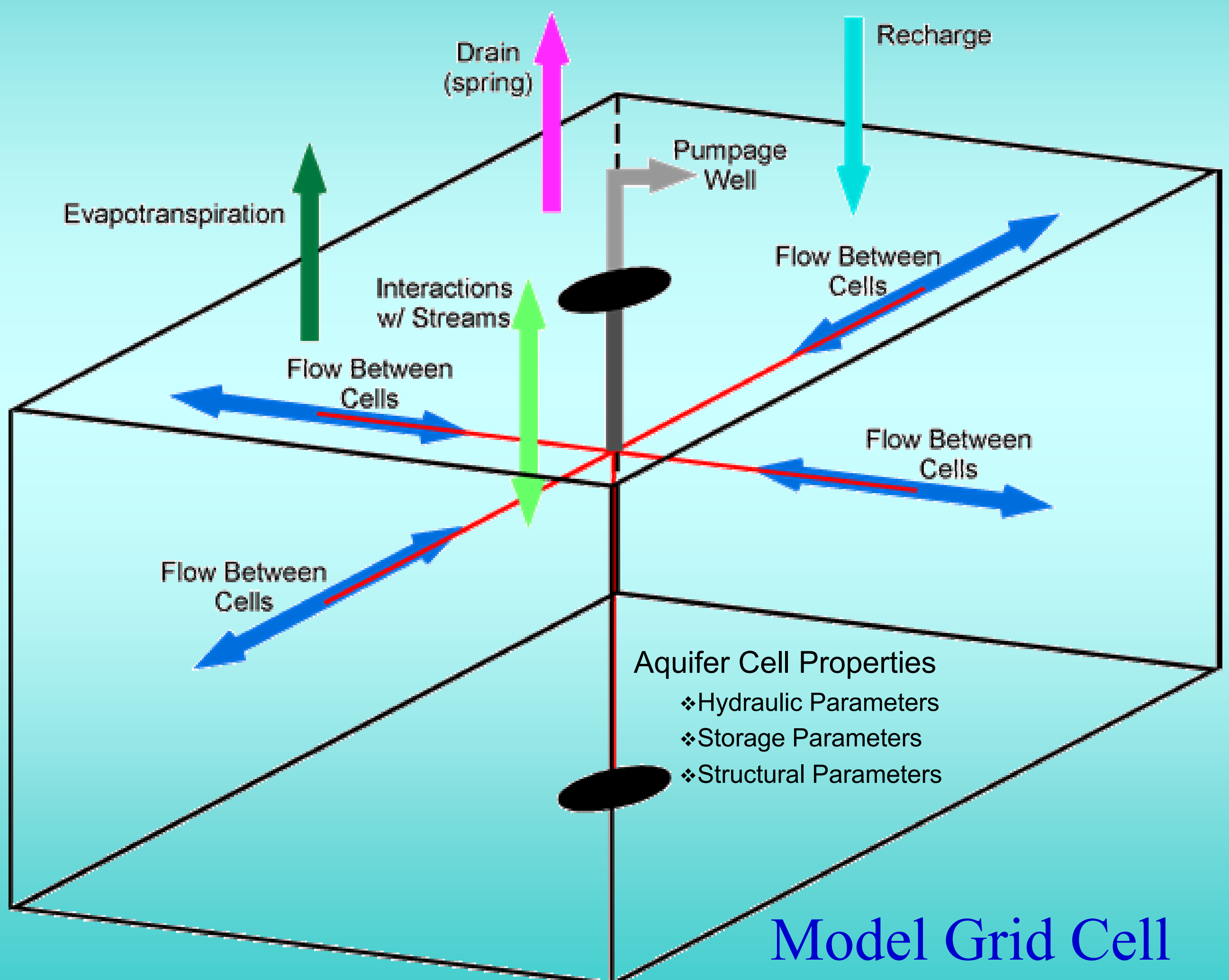


0	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0

IBOUND Codes

< 0 Constant Head
= 0 No Flow
> 0 Variable Head

MODFLOW Equations Calculate Head by Balancing Inflows with Outflows



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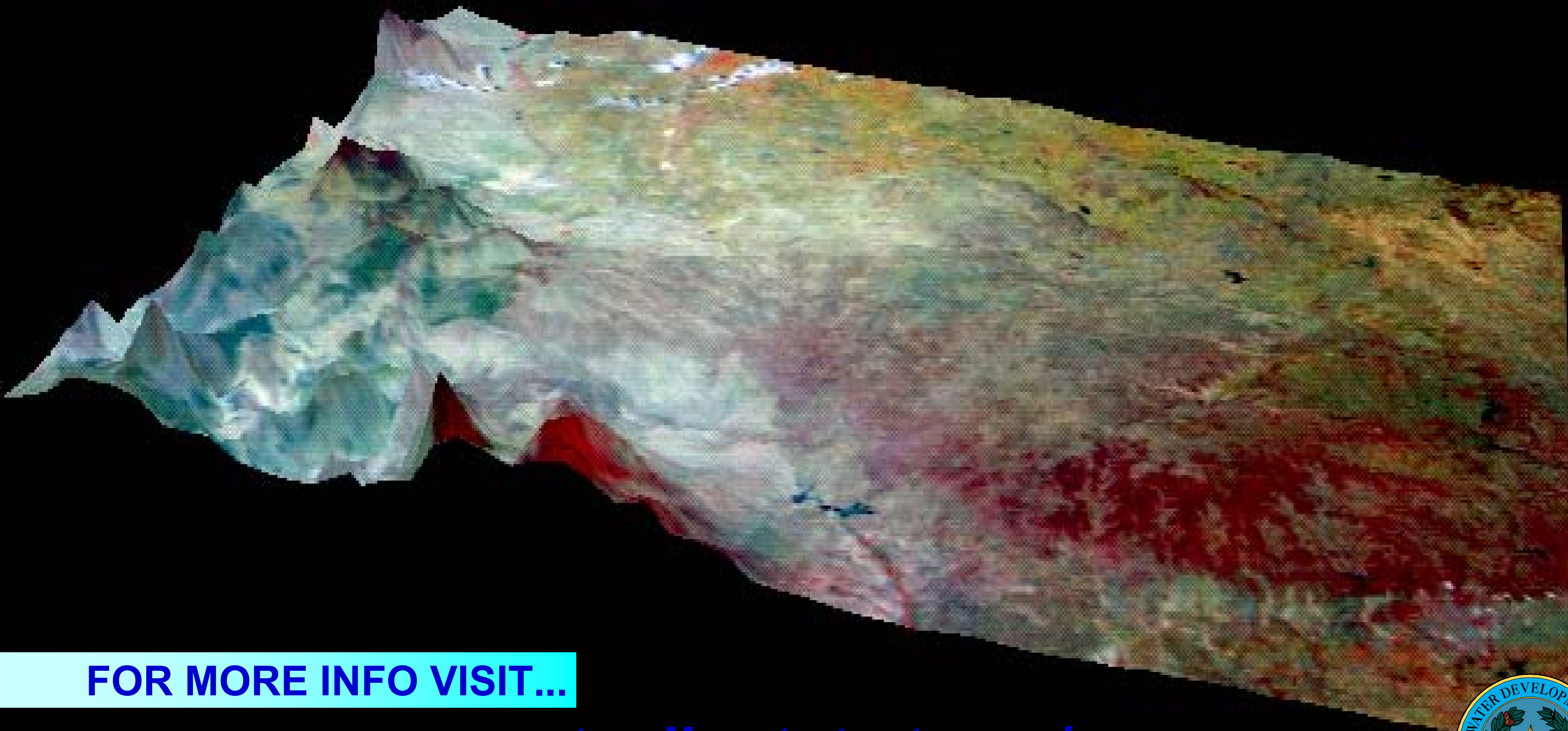

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Assumptions and Estimates of Recharge

Types of Recharge

- Direct (Diffuse) - Infiltration Derived from Areal 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

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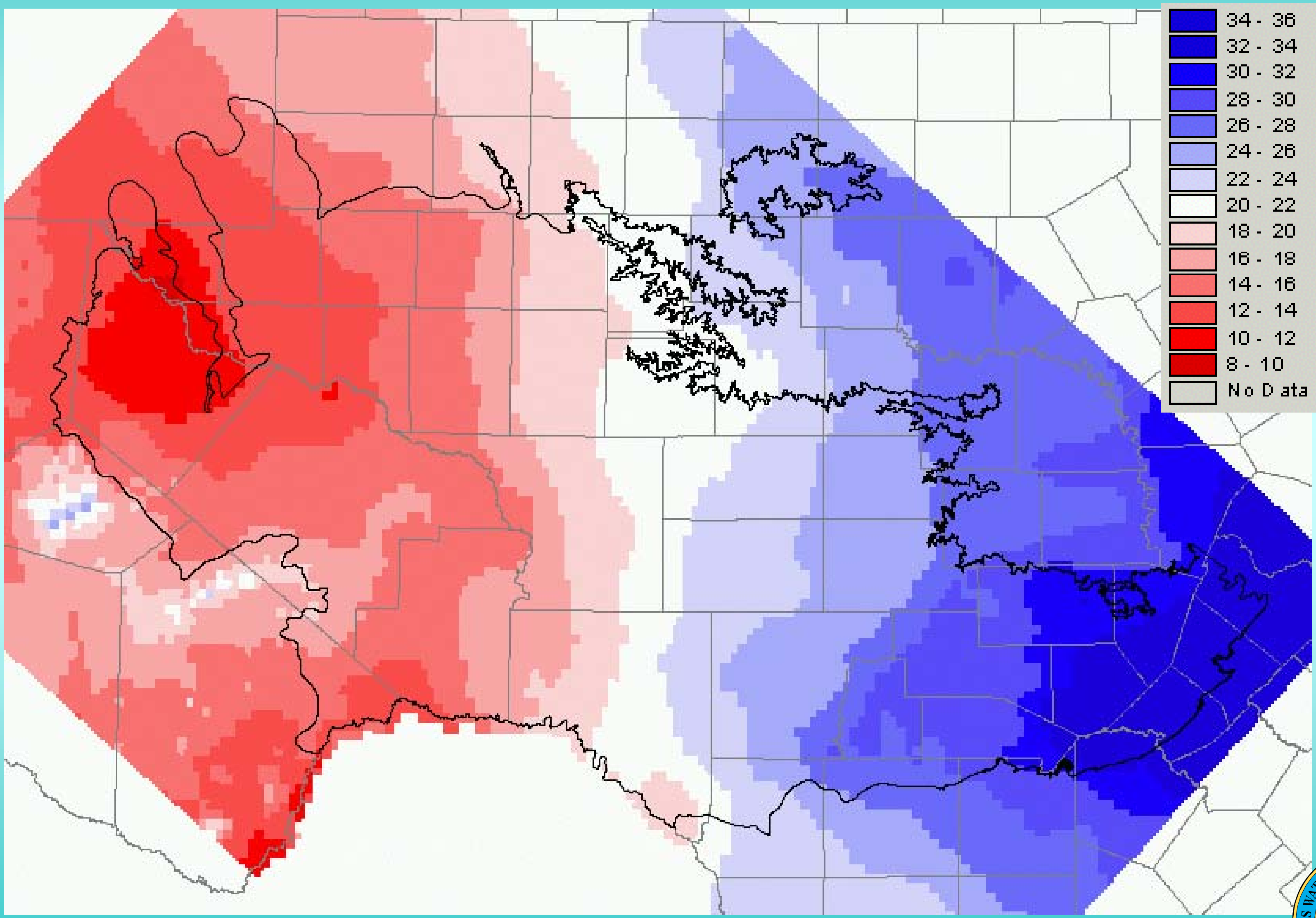
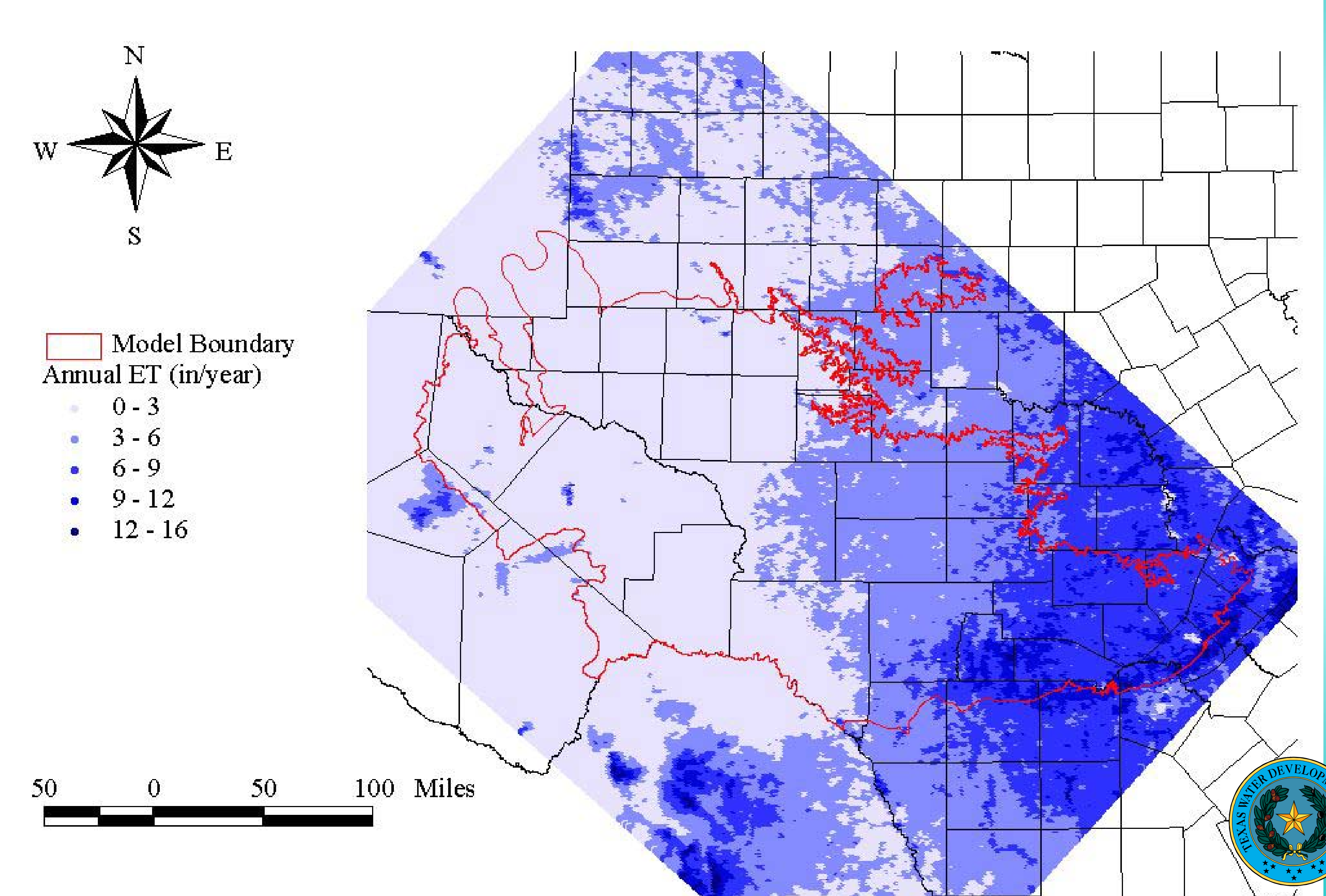
1960-1990 Mean Annual Rainfall (in)

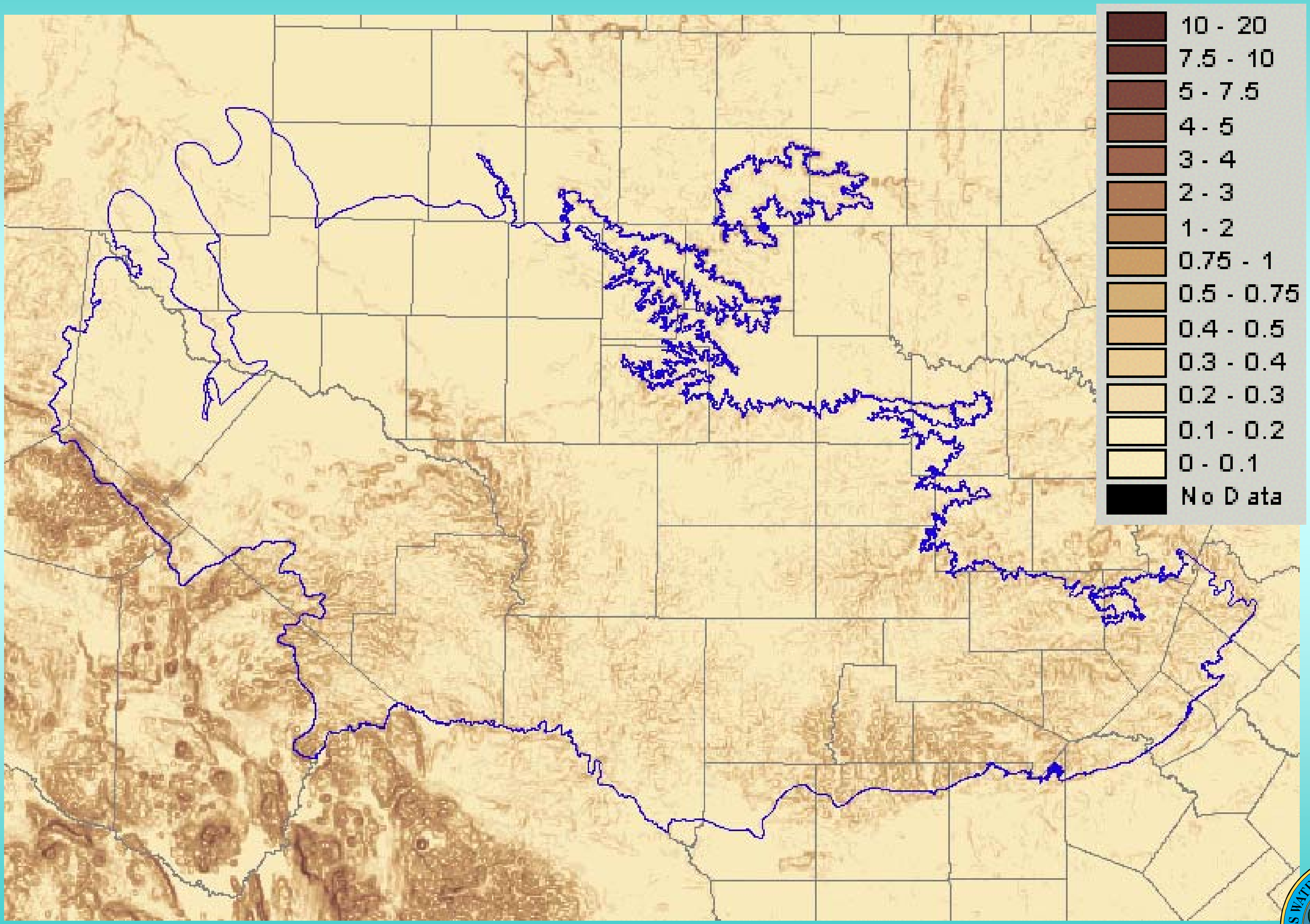


Data From Daly, Nielson, and Phillips, 1994; Daly, Taylor, and Gibson, 1997

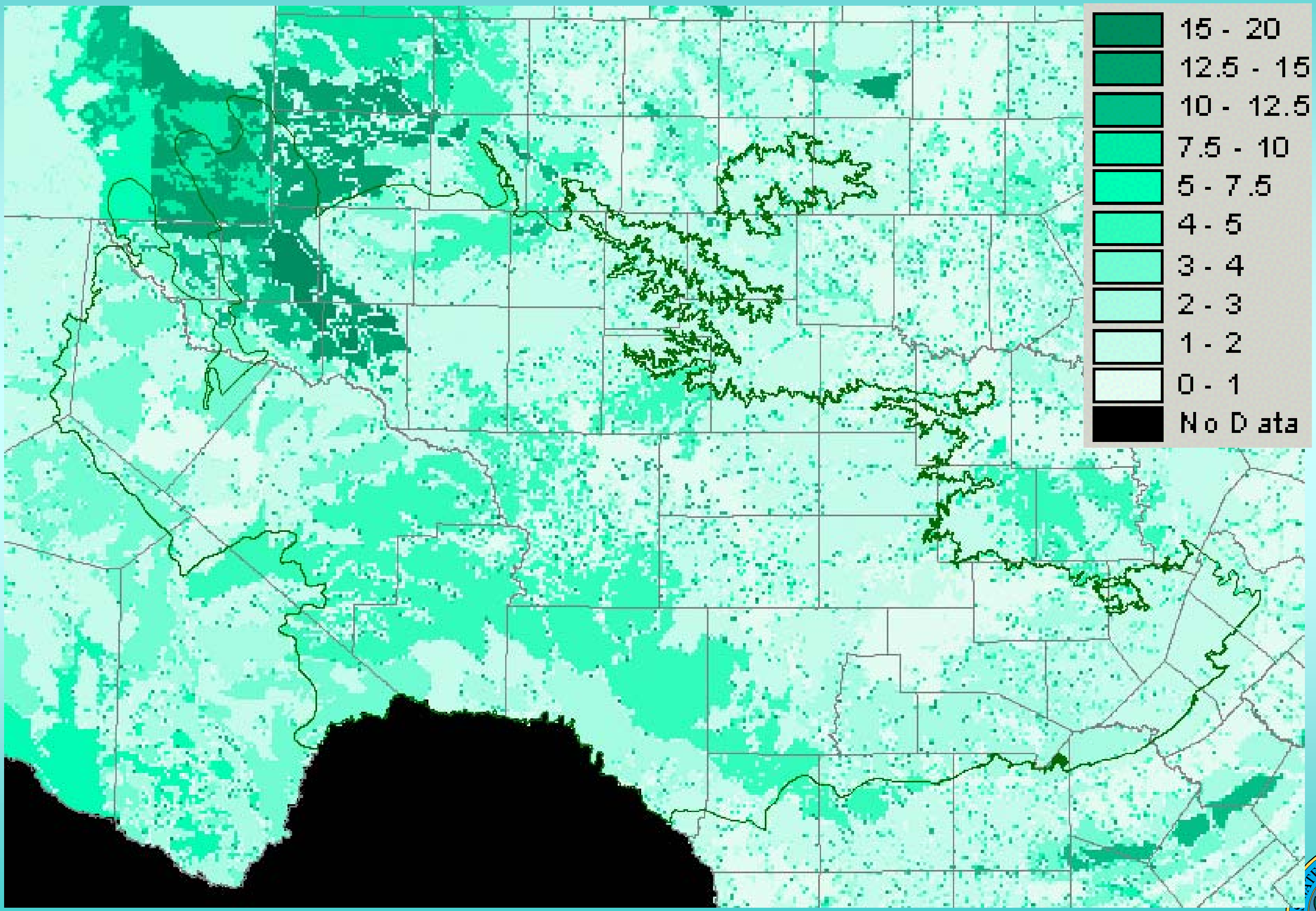
1990-1999 Mean Annual Evapotranspiration



Topographic Slope (%)

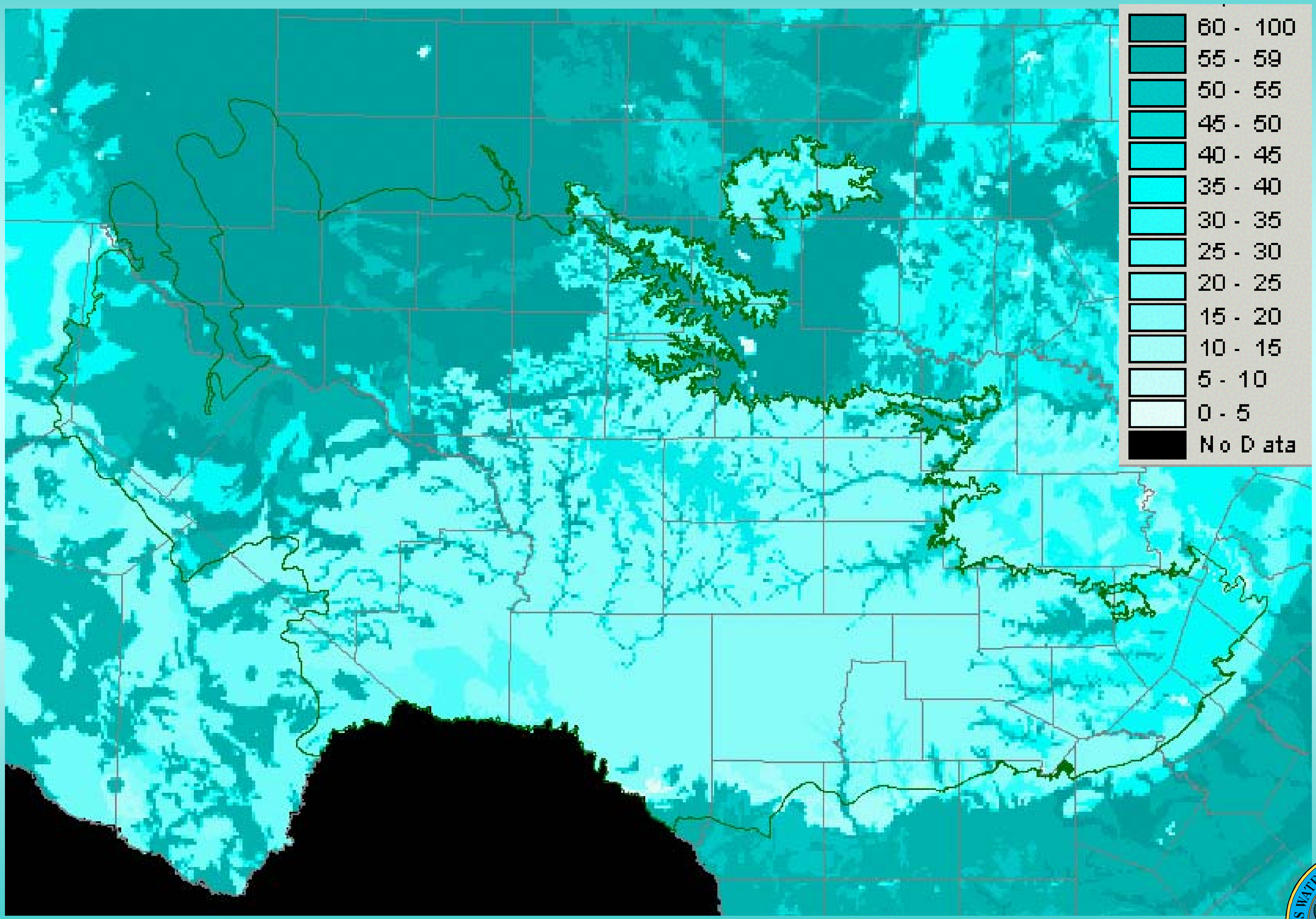


Soil Permeability (in)



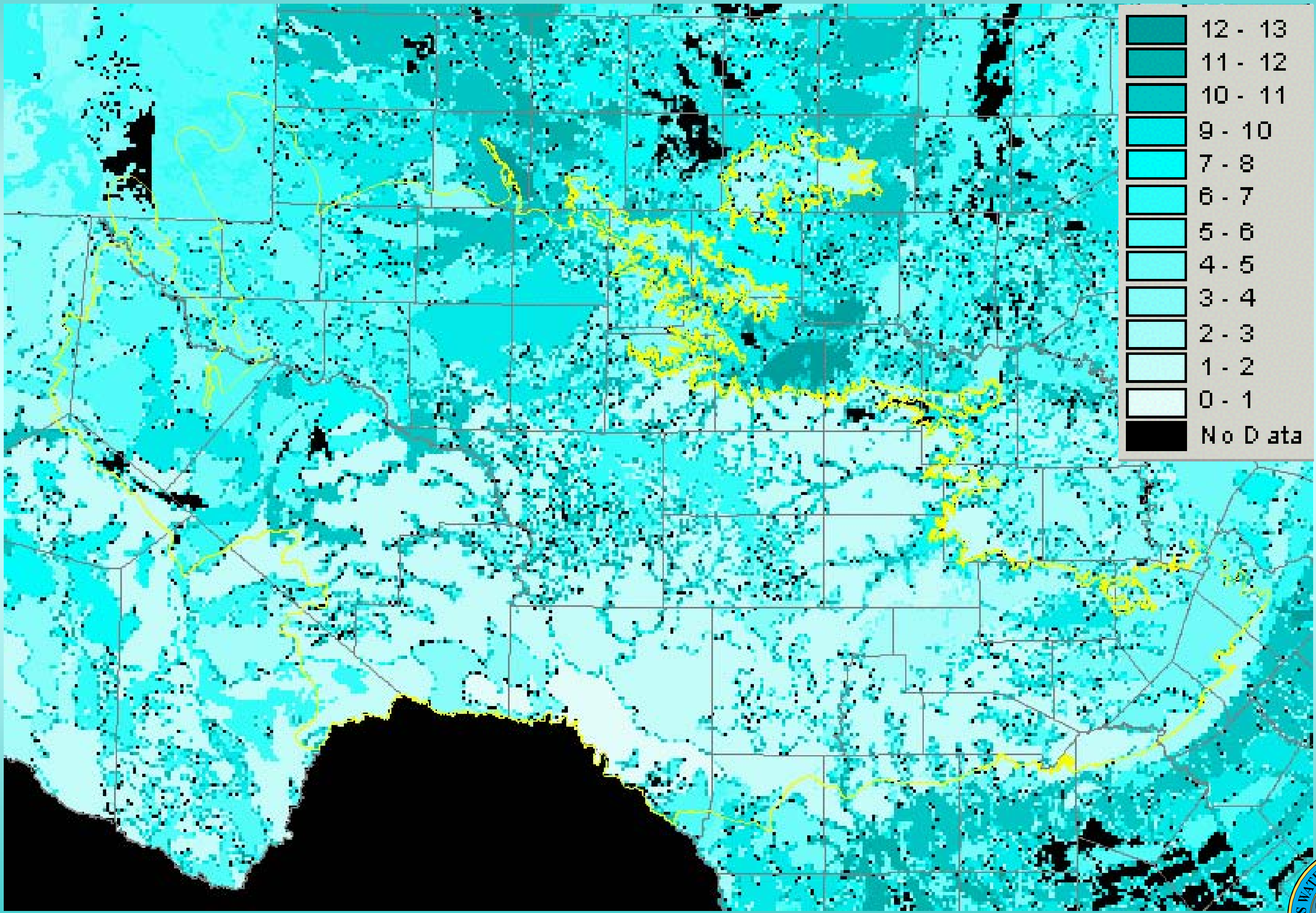
Data From Earth System Science Center, Penn State University

Soil Thickness (in)



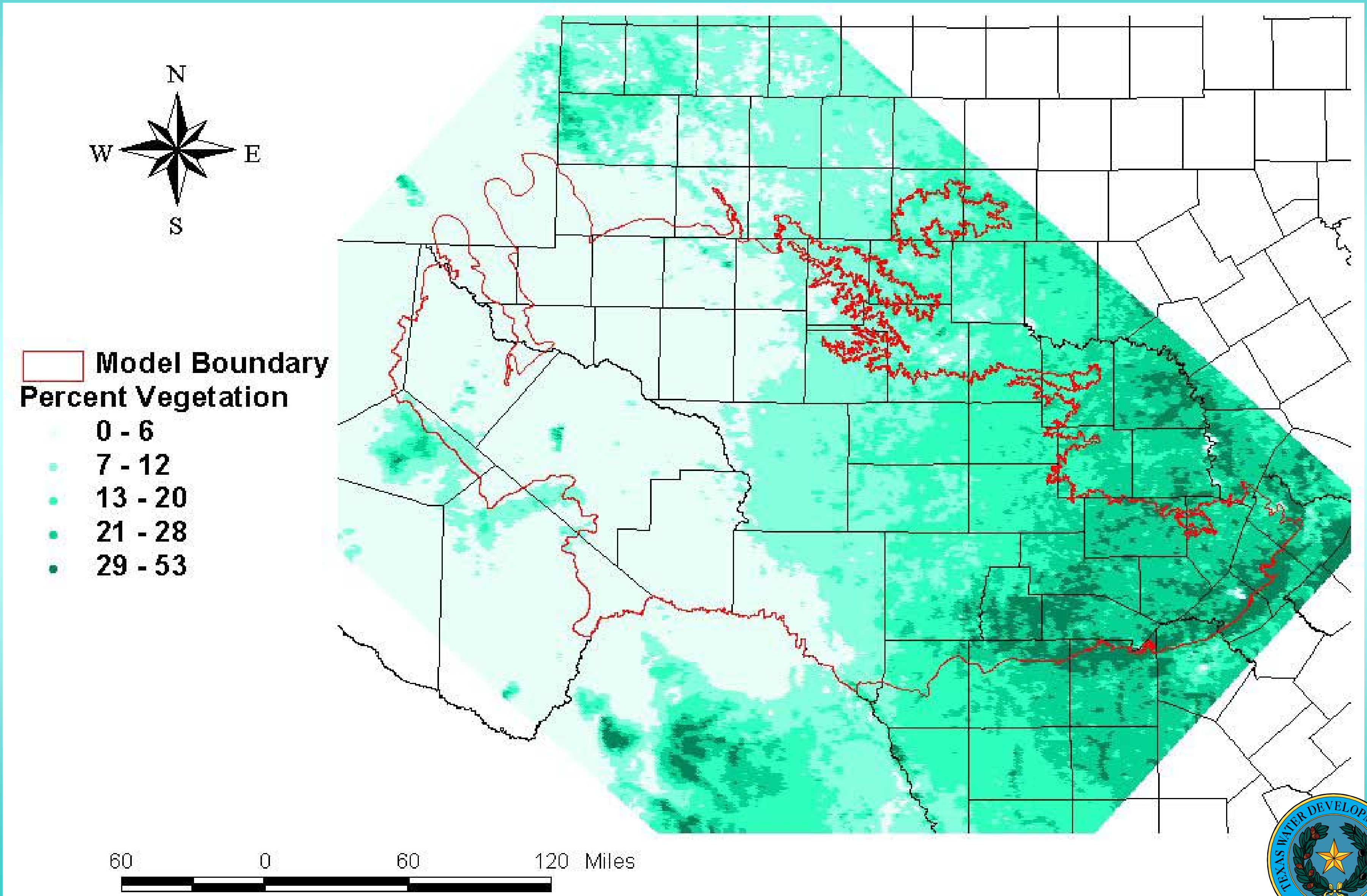
Data From Earth System Science Center, Penn State University

Soil Available Water Holding Capacity (in)

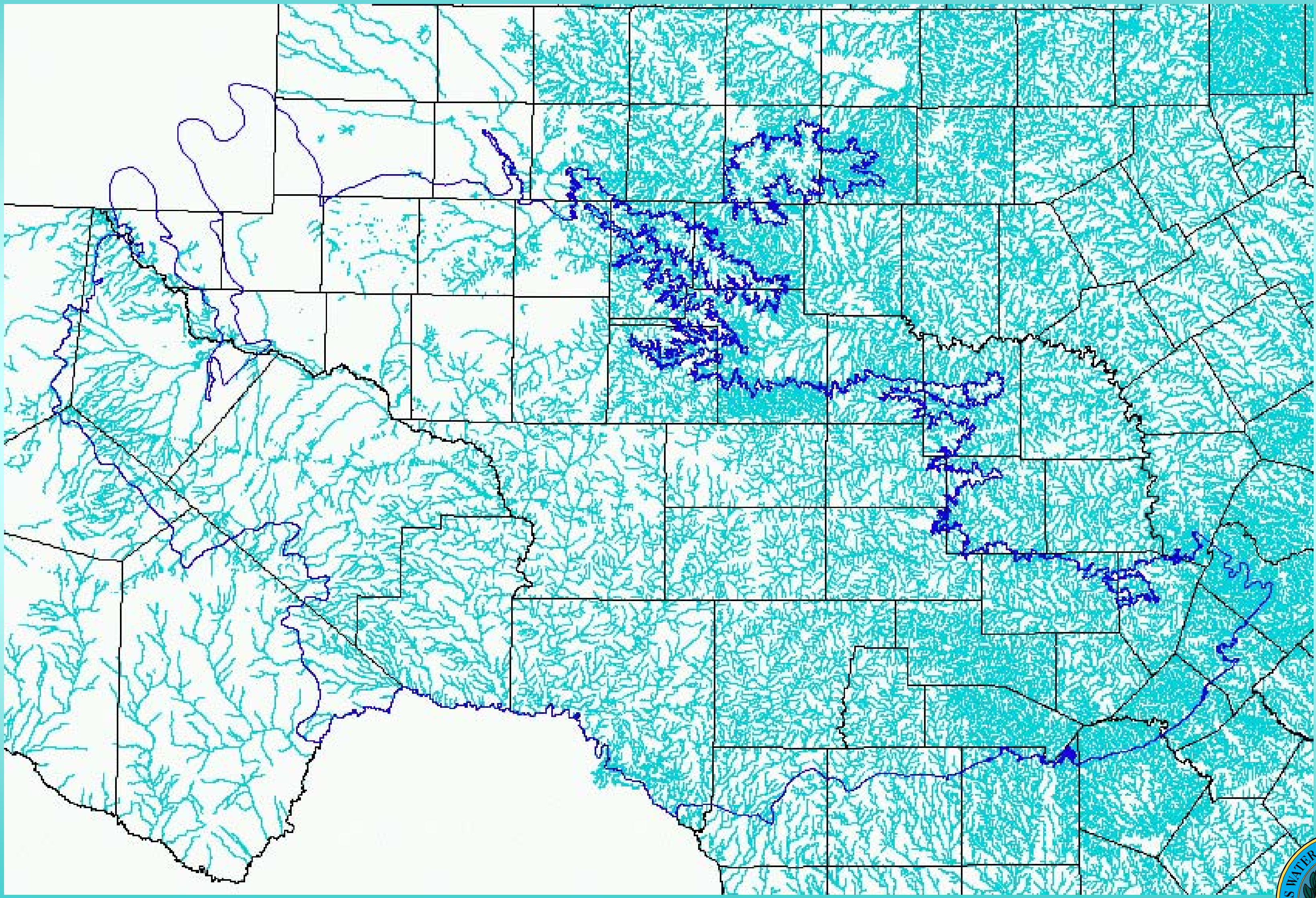


Data From Earth System Science Center, Penn State University

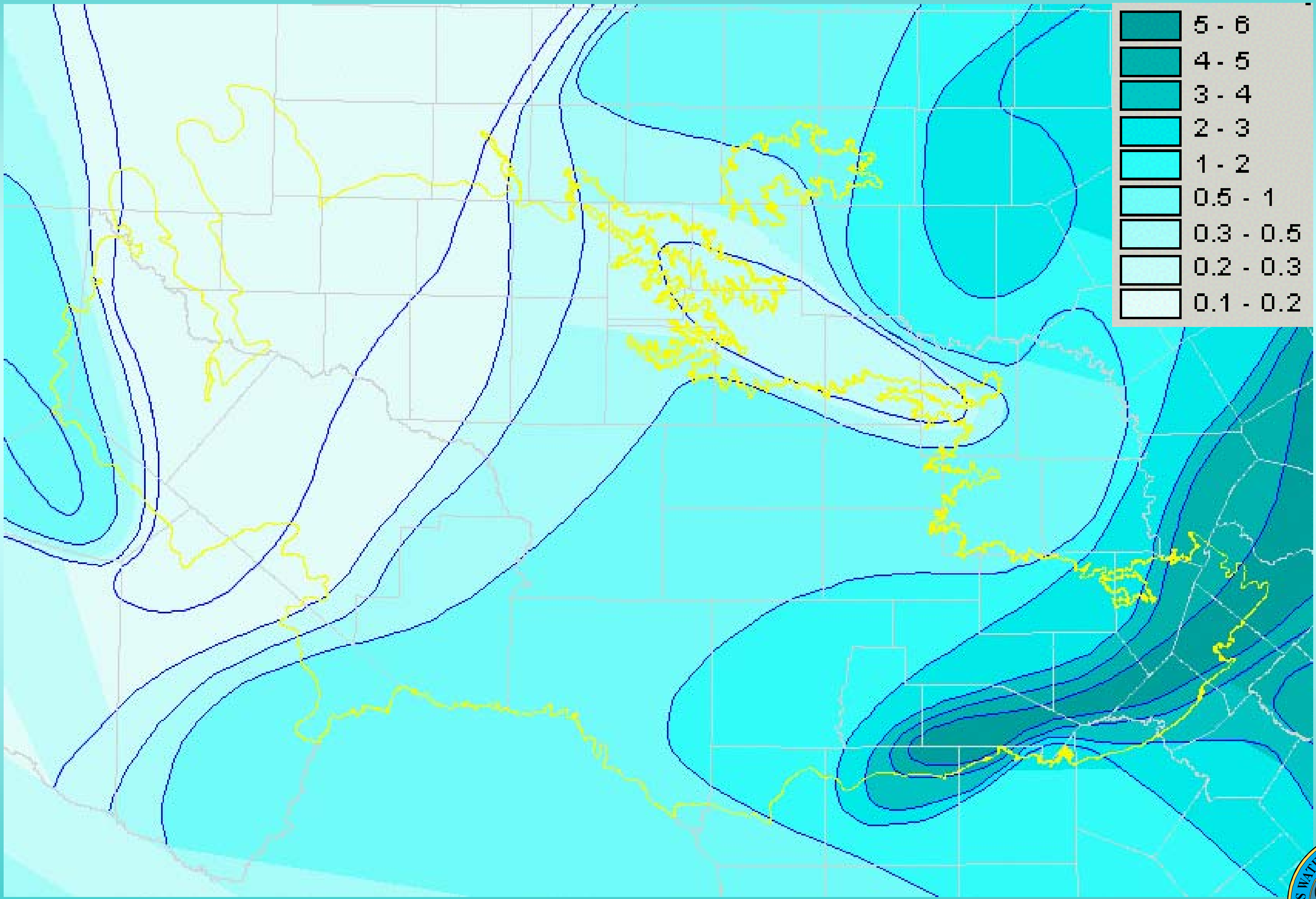
1990-1999 Mean Annual Percent Vegetation Cover



Drainage Density



1951-1980 Mean Annual Runoff (in)



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

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

- Our Goal is to Estimate 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

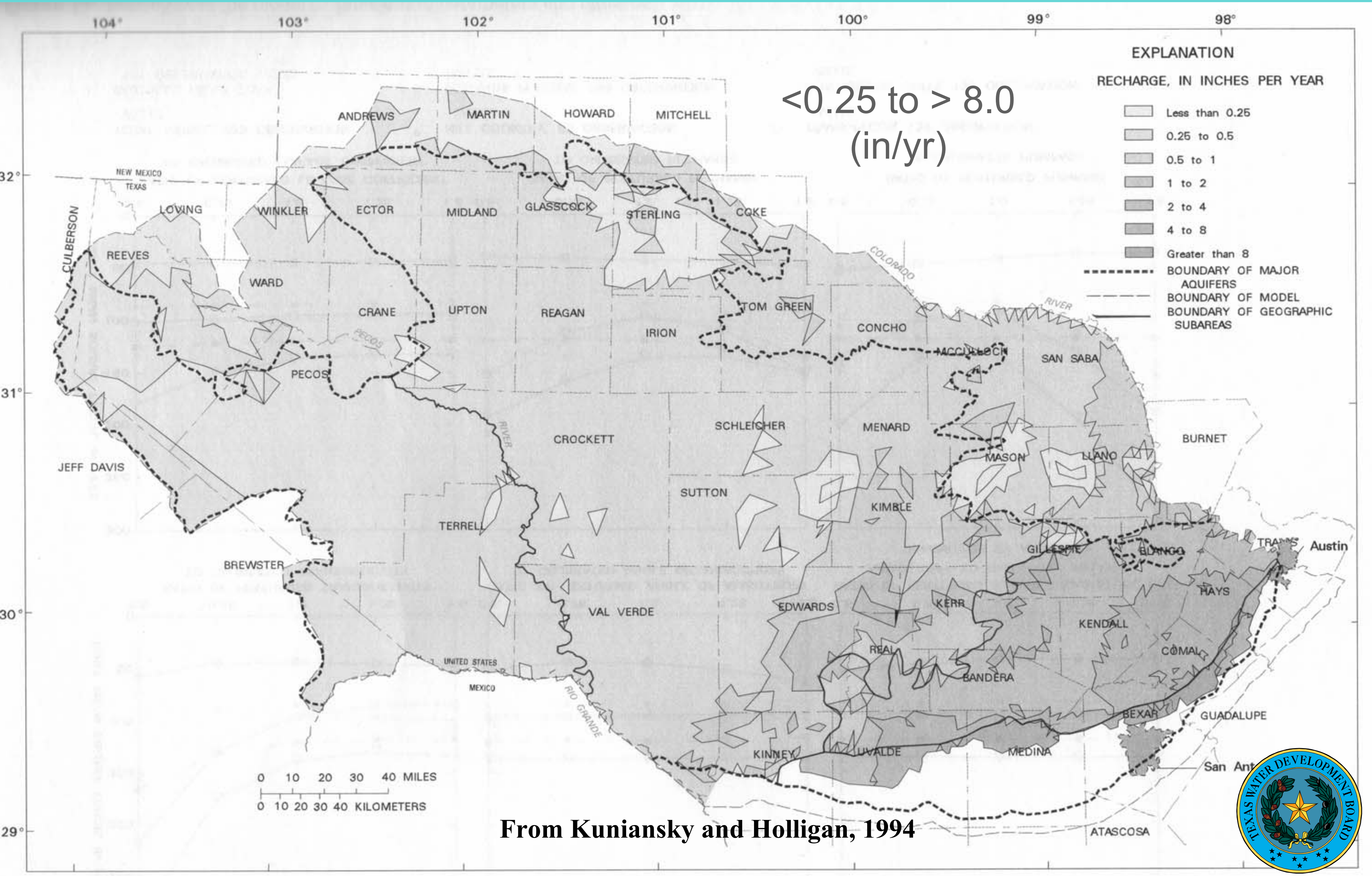
Other Recharge Estimates

- Published estimates of recharge:

Area (County)	Recharge (percent rainfall)	Reference	Method
Crockett	1.6%	Iglehart, 1967	baseflow
Kinney	5.7%	Bennett and Sayre, 1962	baseflow
Kinney	11%	Mace and Anaya, 2004	baseflow
Real	7.5%	Long, 1958	baseflow
Kerr	3.7%	Reeves, 1969	baseflow

- Recharge to be determined through calibration of numerical groundwater model

USGS Distribution of Estimated Recharge



From Kuniansky and Holligan, 1994

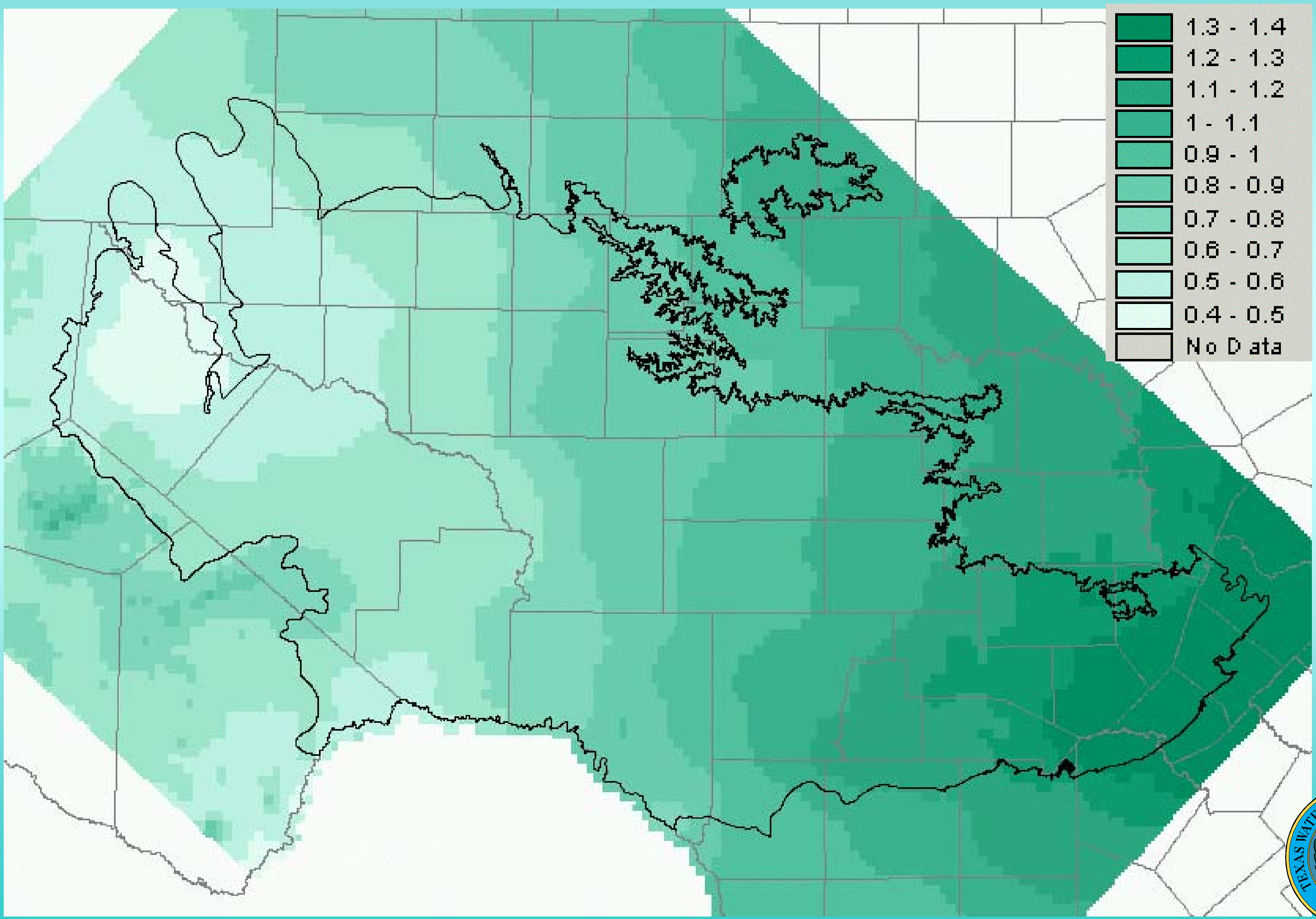
Estimating Recharge for the Edwards-Trinity Aquifer

- Approach to estimating recharge followed the principle of Occam's Razor
- Initial use of uniformly distributed recharge estimate of 4% of mean annual rainfall (1960-1990)
- Steady-State model calibration dictated the level of complexity for spatially distributing recharge
- Percent of rainfall was spatially adjusted by weighting to surface geology

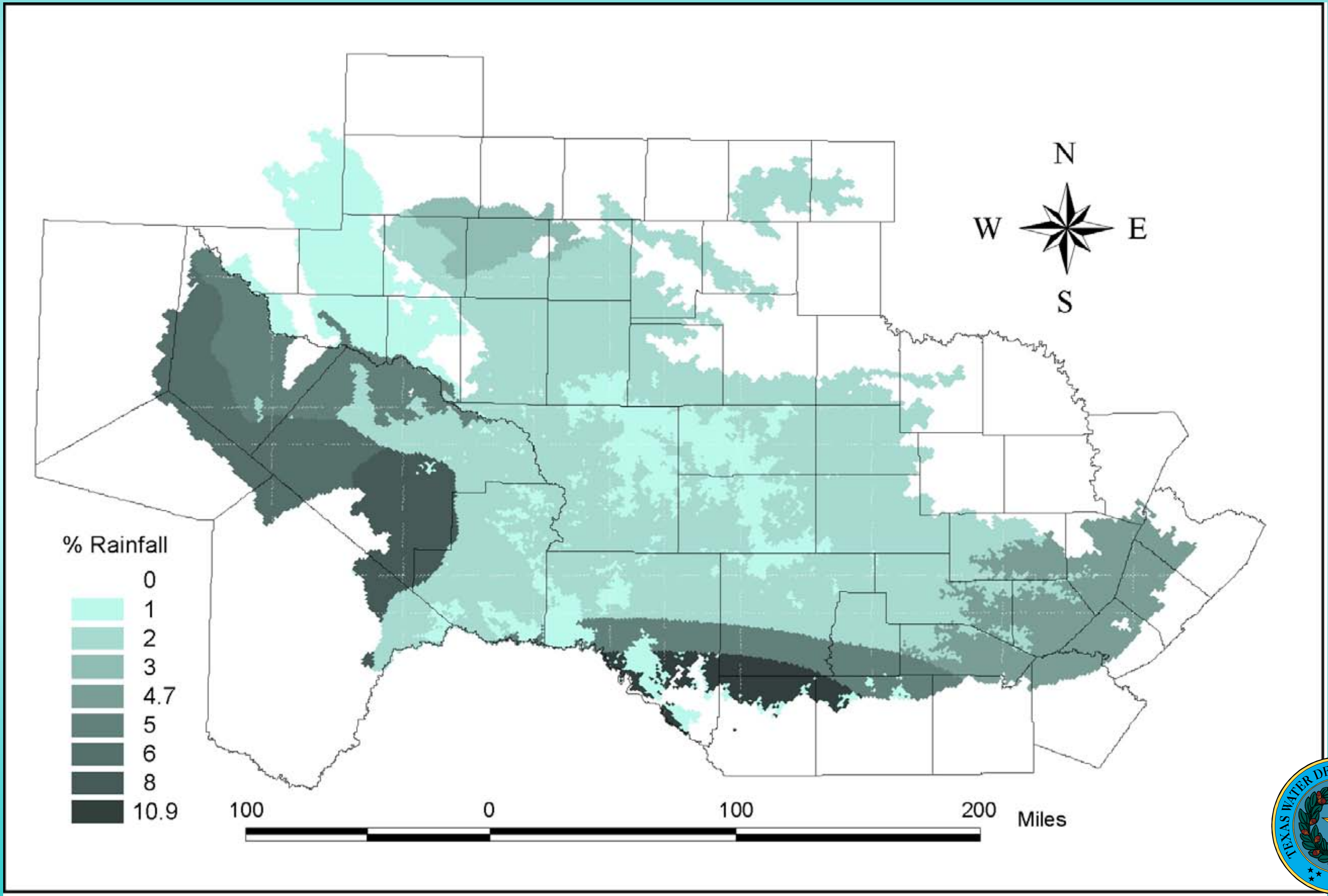
Principle of Occam's Razor

- 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 may be more accurate than the most complicated explanation
- "Everything should be made as simple as possible, but not any simpler" - Albert Einstein
- **Keep Things Simple!**

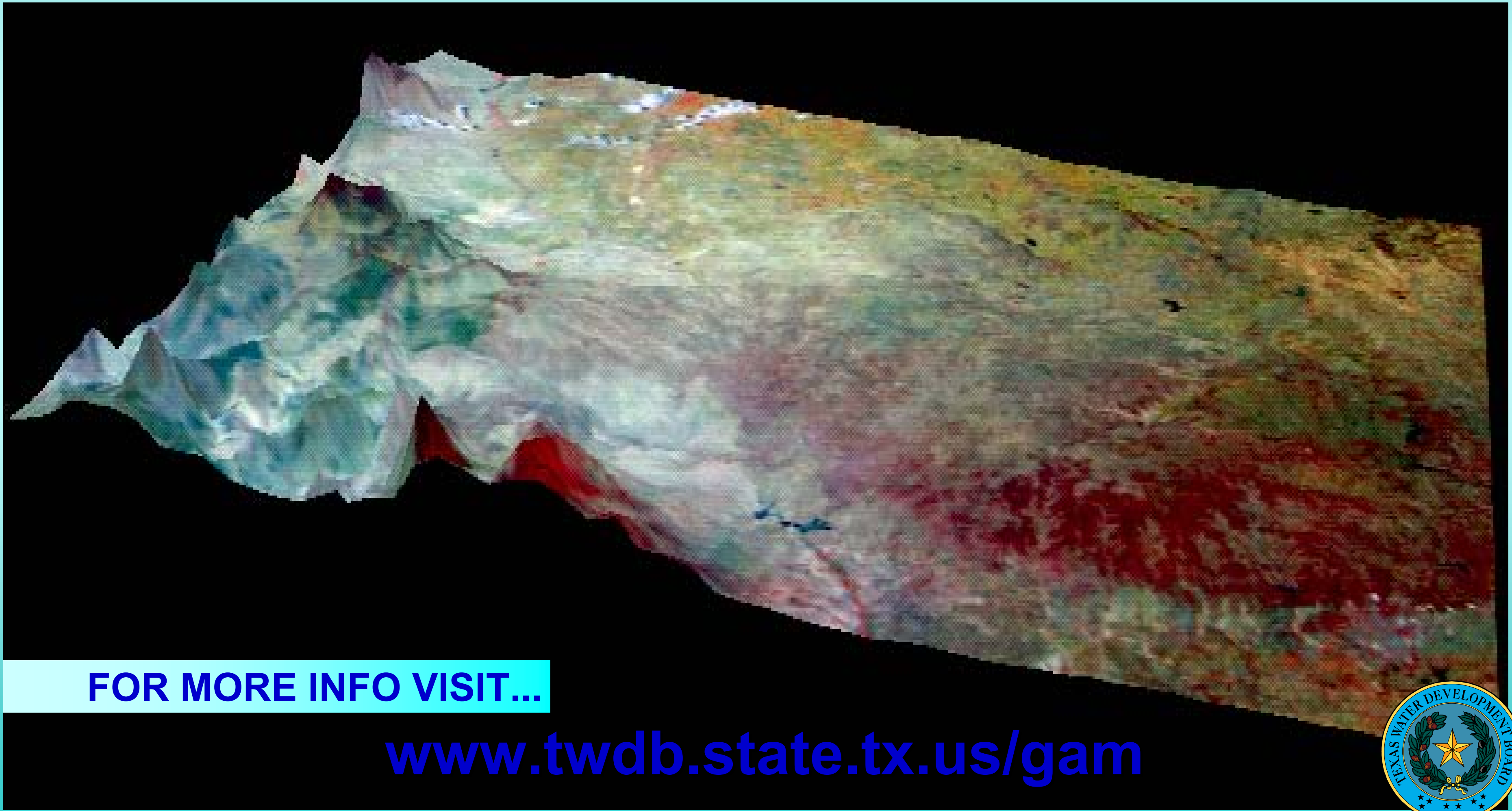
Edwards-Trinity Initial Recharge 4% of Mean Annual Rainfall (in)



Calibrated Recharge Distribution Percent of Annual Rainfall



Questions or Comments?

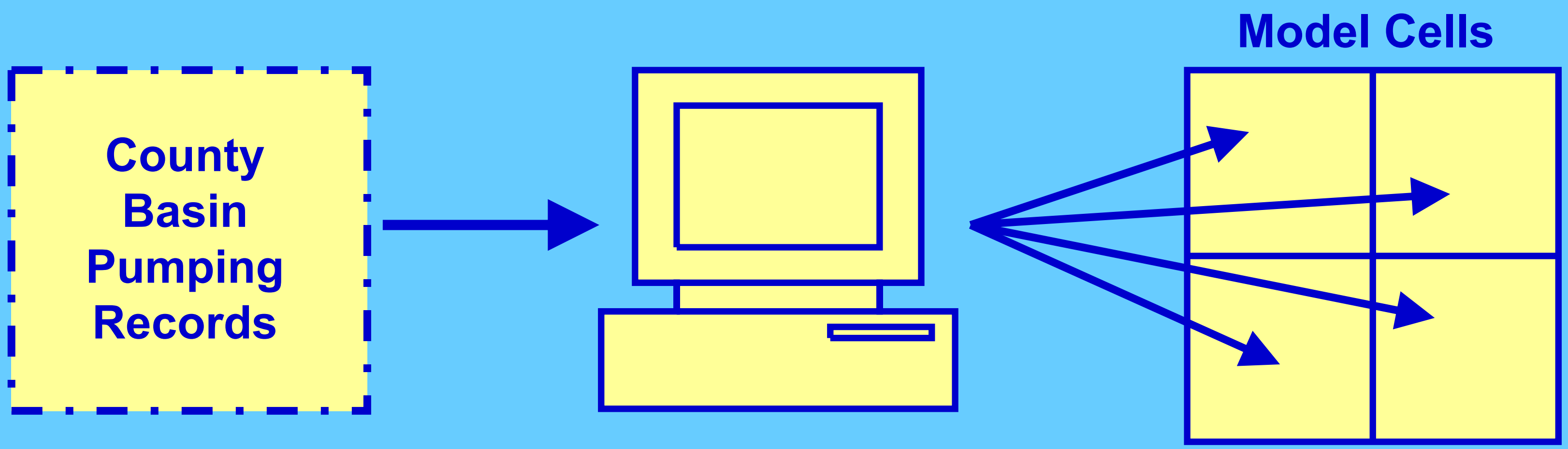


FOR MORE INFO VISIT...

www.twdb.state.tx.us/gam

EDWARDS-TRINITY GAM MODEL

ESTIMATING AND DISTRIBUTING PUMPING



Scott Hamlin
Texas Water Development Board

SOURCE OF PUMPING DATA

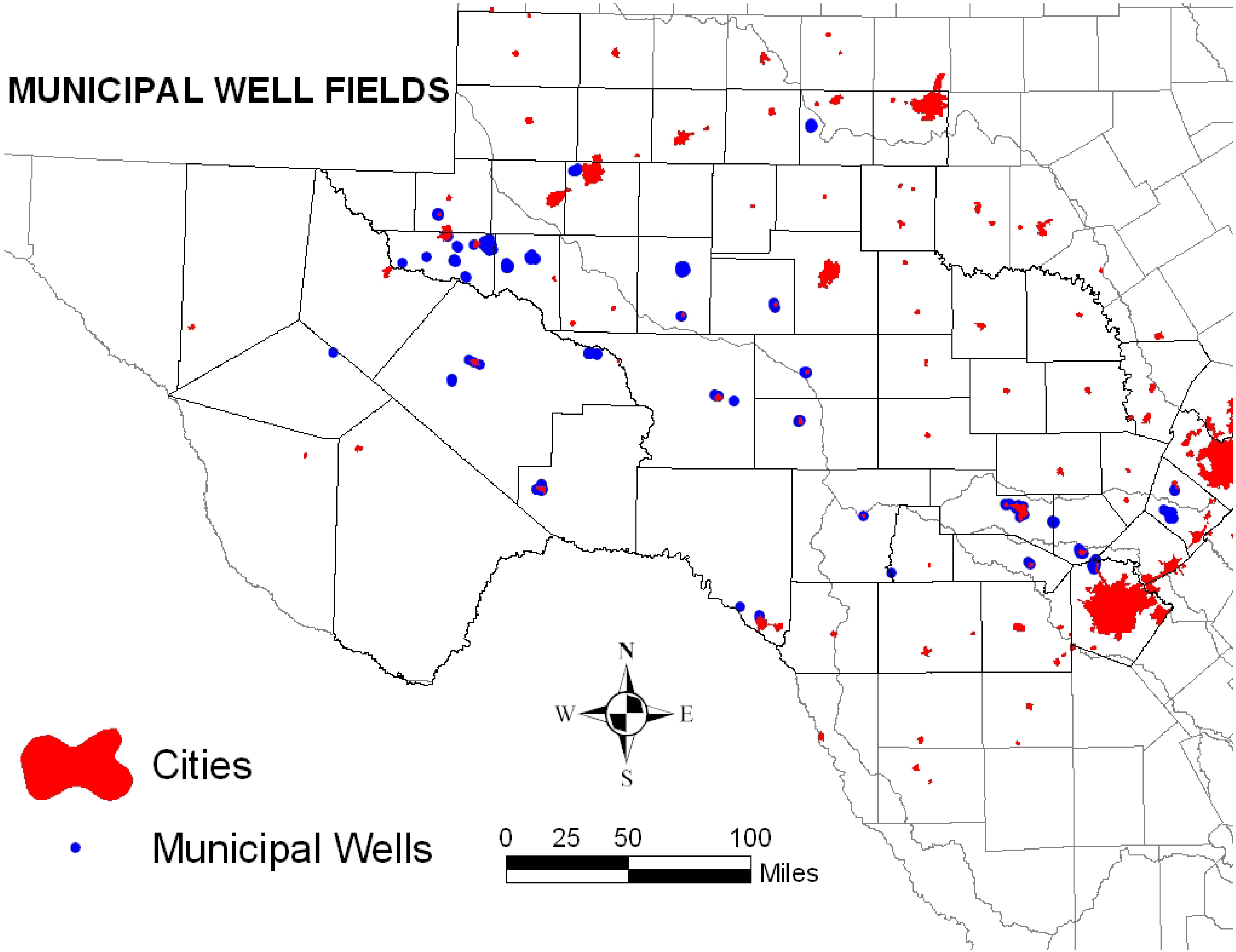
- Statewide groundwater production data compiled by TWDB
- Based on surveys of water usage (WUS)
- Organized by aquifer, county, river basin, and use categories

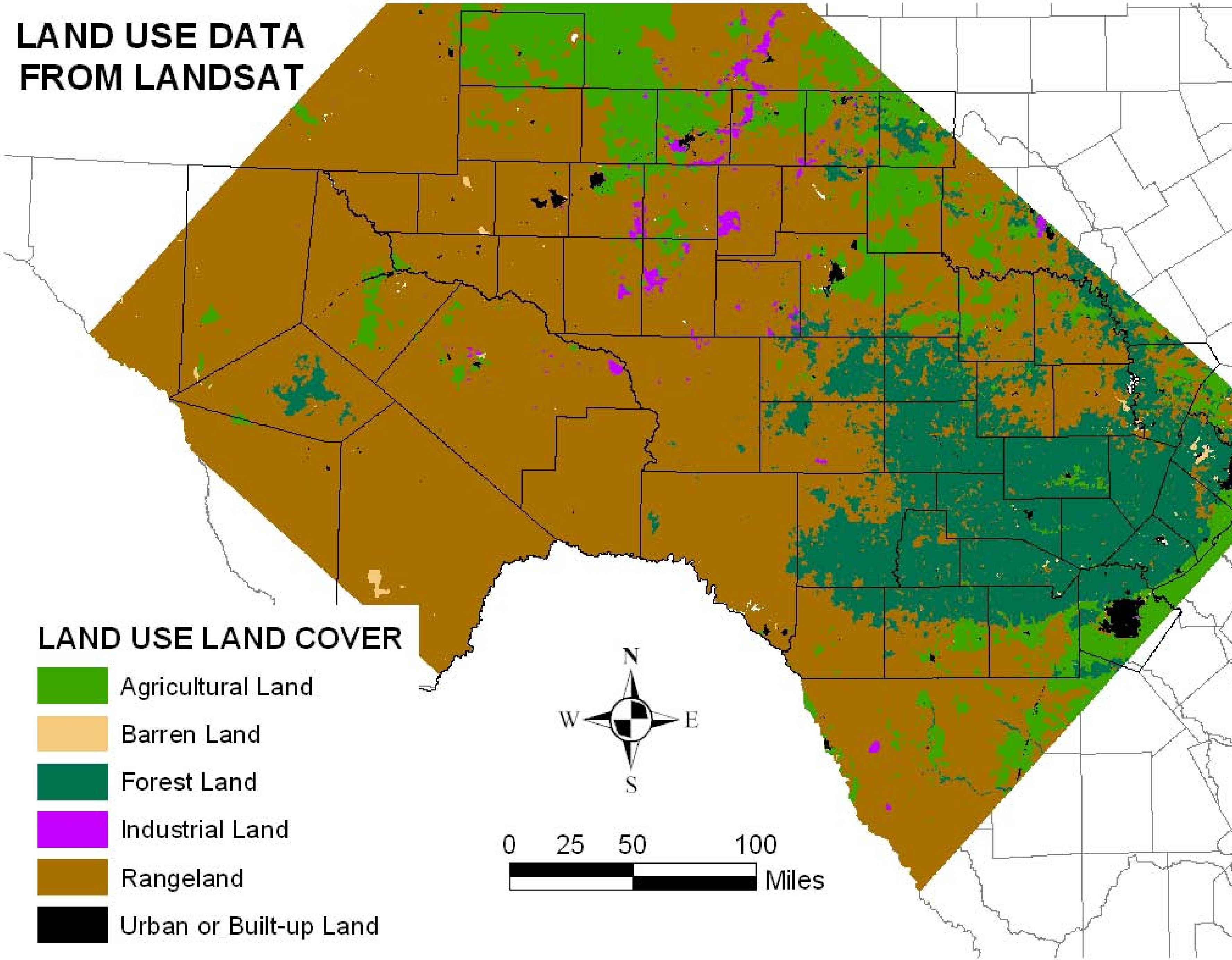
SPATIAL DISTRIBUTION OF PUMPING

- Well locations and production intervals (Municipal)
- Land use (Livestock, Irrigation, and Industrial)
- Population density (Rural domestic)

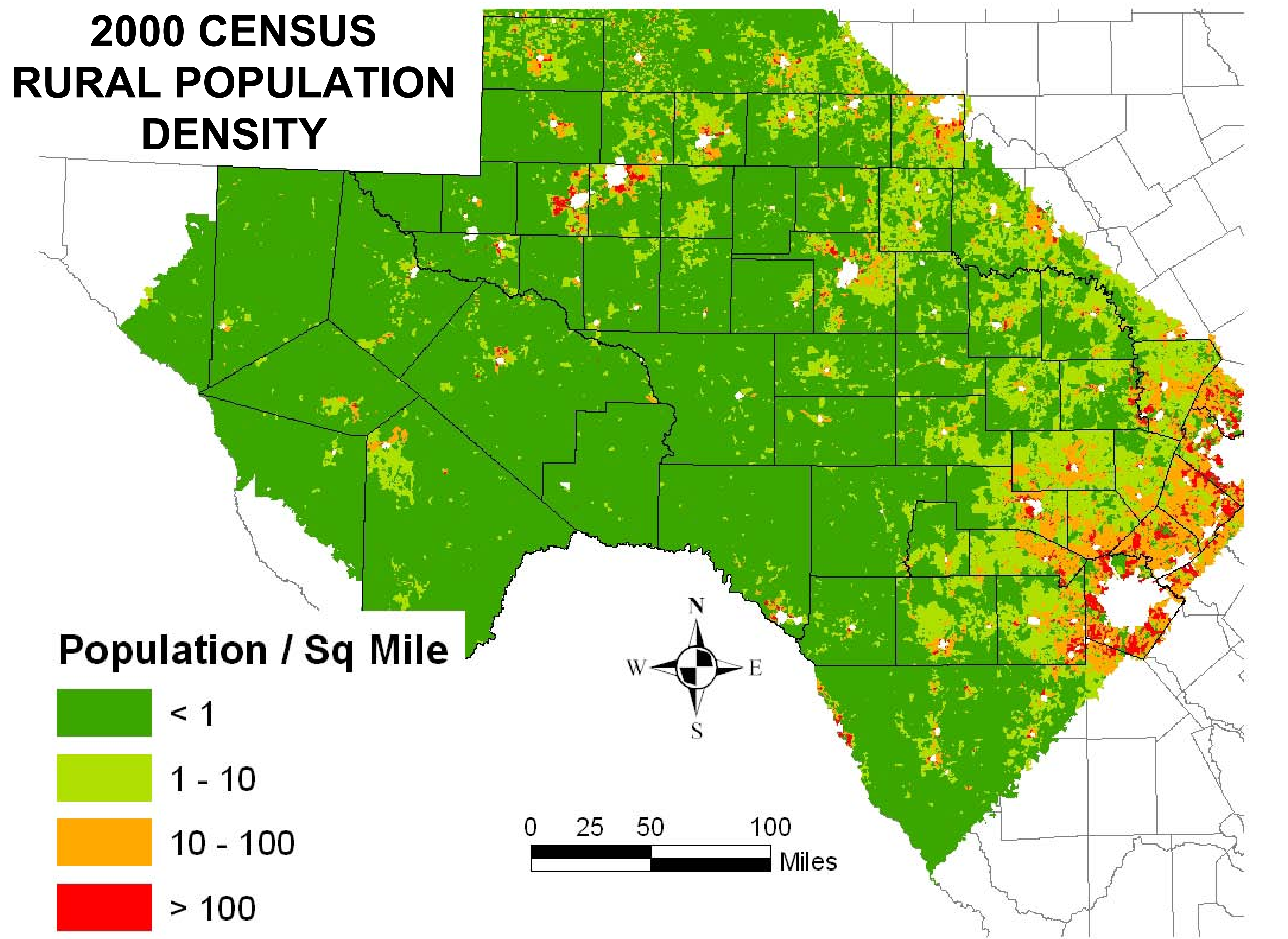
TEMPORAL DISTRIBUTION OF PUMPING

- Historical 1980 – 2000 annual use
- Predictive 2001 – 2050 demand projections


MUNICIPAL WELL FIELDS
Cities
Municipal Wells
N
S
W
E
0
25
50
100
Miles



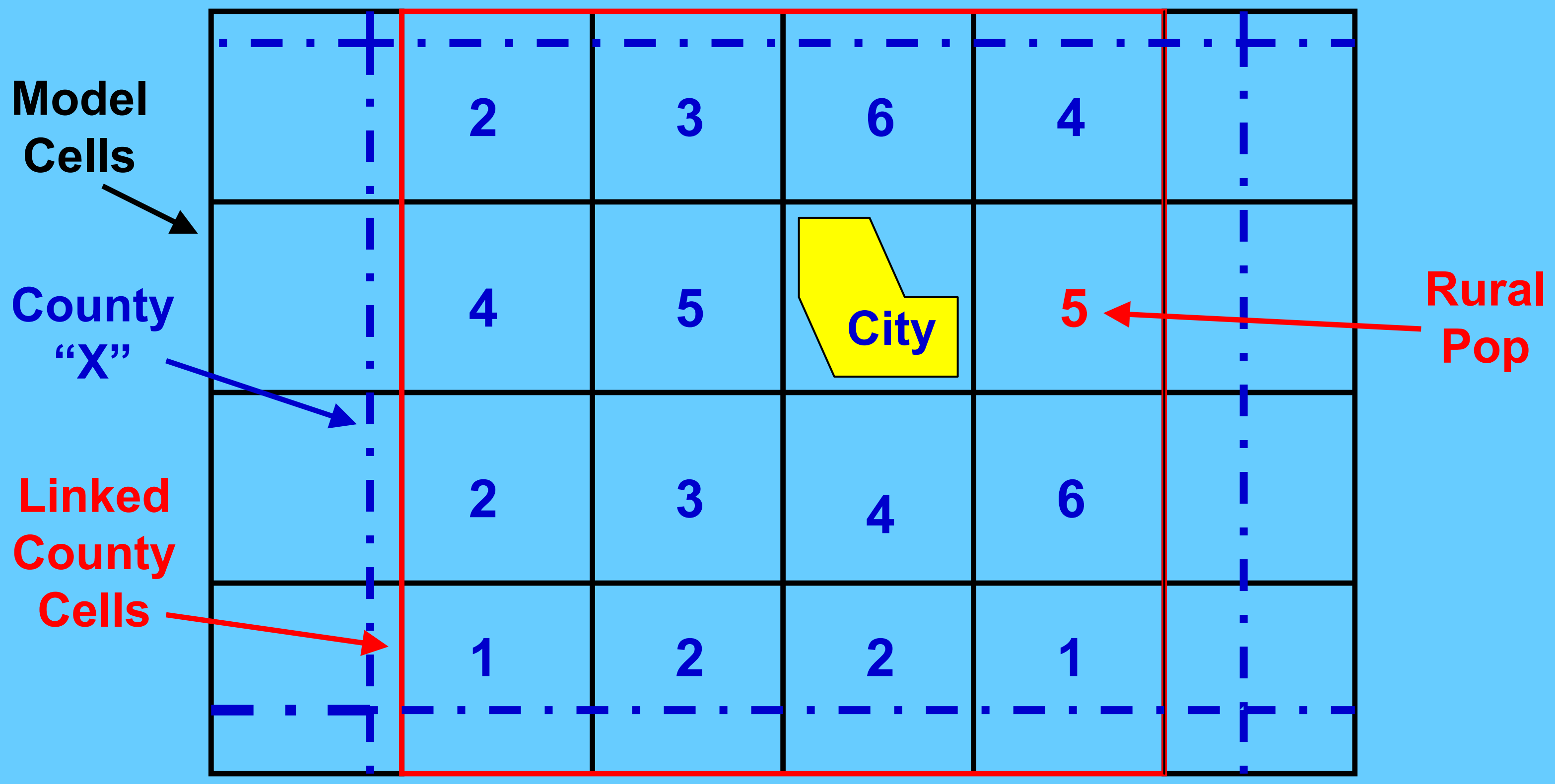
LAND USE DATA FROM LANDSAT
LAND USE LAND COVER
Agricultural Land
Barren Land
Forest Land
Industrial Land
Rangeland
Urban or Built-up Land
N
W
E
S
0
25
50
100
Miles


2000 CENSUS
RURAL POPULATION
DENSITY
Population / Sq Mile
< 1
1 - 10
10 - 100
> 100
N
W
E
S
0
25
50
100
Miles

SPATIAL DISTRIBUTION OF PUMPING
GIS-BASED ANALYSIS

- Link model grid to county river basins
- Link land use and population to model grid
- Calculate land use areas for each grid cell
- Calculate rural population for each grid cell
- Divide grid cell land use area by total for county basin
- Divide grid cell rural population by total for county basin
- Use weighting factors to assign pumping to each grid cell

SPATIAL DISTRIBUTION OF PUMPING BASED ON CENSUS POPULATION



Total Rural Pop = 50 Wt. Factor = 5 / 50 = 0.1

VERTICAL DISTRIBUTION OF PUMPING
GIS-BASED ANALYSIS

- Map Edwards and Trinity wells in TWDB water-well database

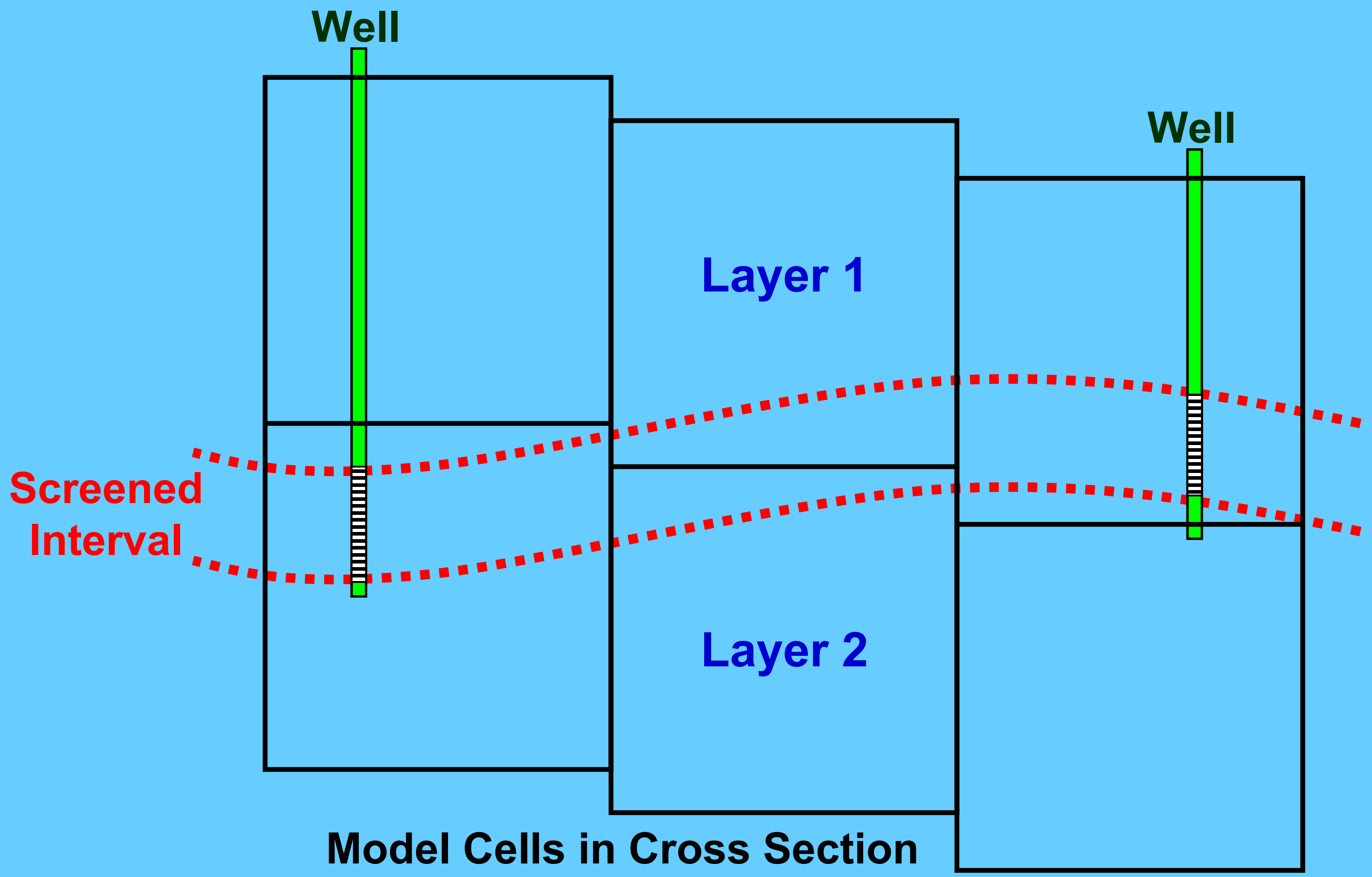
- Map spatial distribution of completions: Edwards, Trinity, dual

- In areas where dual completions are common:

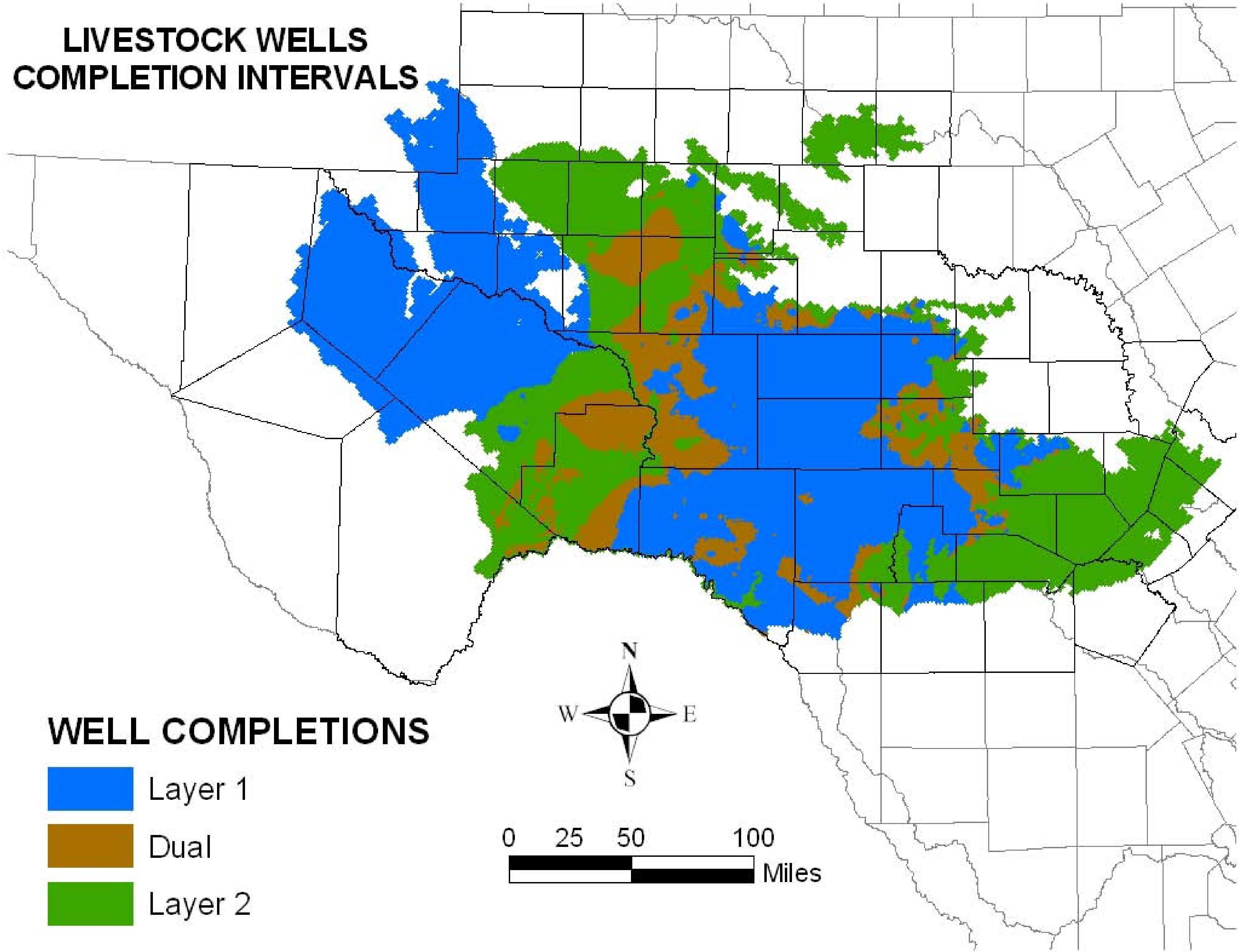
    - Contour surfaces for top and bottom of screened interval

    - Intersection with model layers determines vertical distribution

VERTICAL DISTRIBUTION OF PUMPING BASED ON CONTOURED SCREENED INTERVAL



Model Cells in Cross Section


LIVESTOCK WELLS
COMPLETION INTERVALS
N
W
E
S
WELL COMPLETIONS
Layer 1
Dual
Layer 2
0 25 50 100
Miles

ASSIGNING PUMPING TO MODEL CELLS AND LAYERS

Start with Master Tables:

1. TWDB pumpage table organized by WUG, category, county basin
2. Grid cell table with cell IDs, county basins, and weighting factors

Select pumpage records by aquifer (Edwards and Trinity)
Select pumpage records by county basins in model domain

Link each grid cell record to county basin pumpage records

Multiply county basin pumping volume by weighting factor

Build table of grid cell IDs and cell pumping volumes for Modflow

PREPARATION OF PUMPING TABLES FOR MODFLOW

Master Table from Water Users Survey

WUG_ID	CAT	RWPG	COUNTY	BASIN	YEAR	ACFT/YR
061005053	STK	F	53	23	1980	750.00
061005053	STK	F	53	23	1981	728.25

Linked

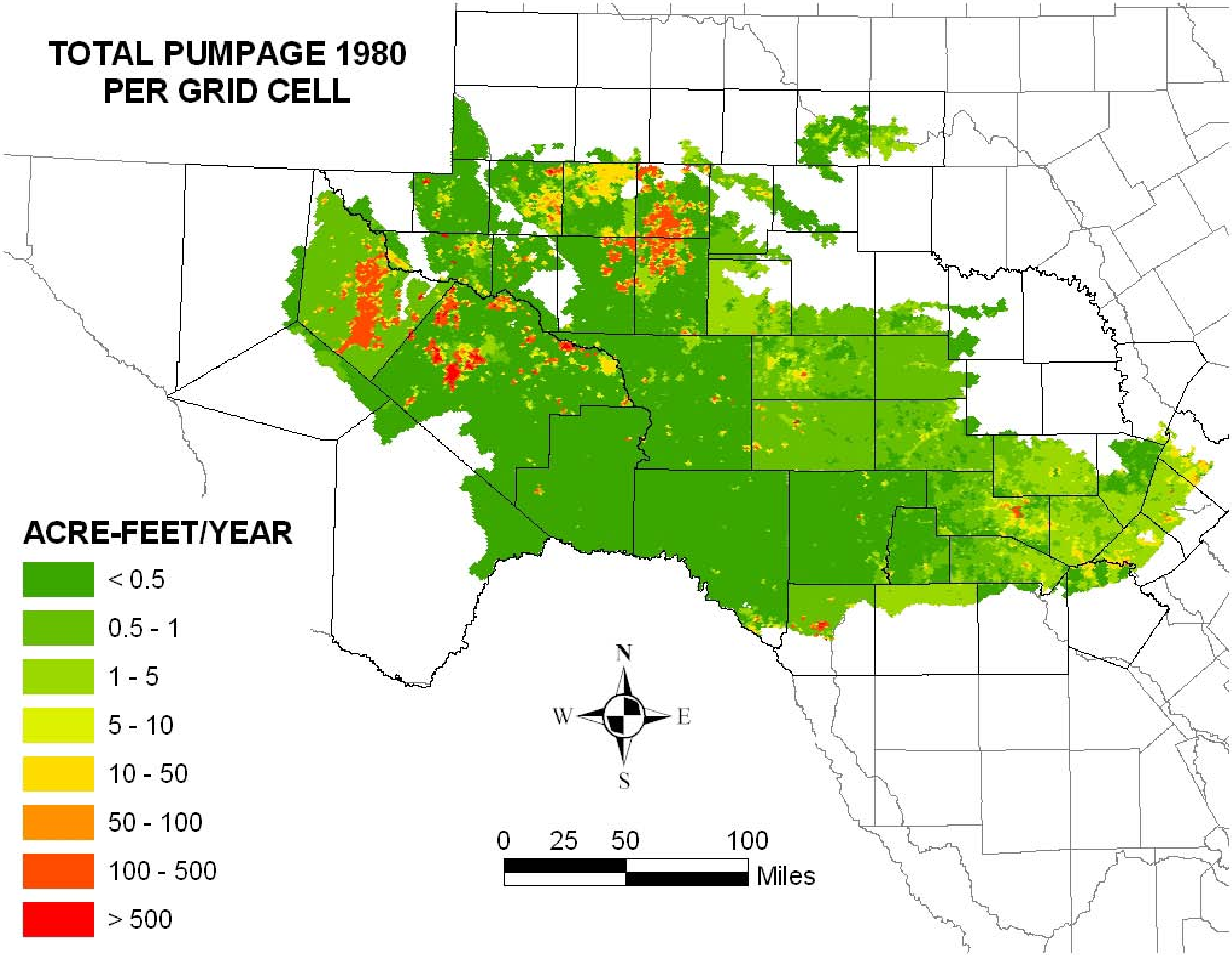
Modflow Data Table

ROW	COL	LAYER	YEAR	ACFT/YR
161	200	1	1980	0.1725
161	200	2	1980	0.1050

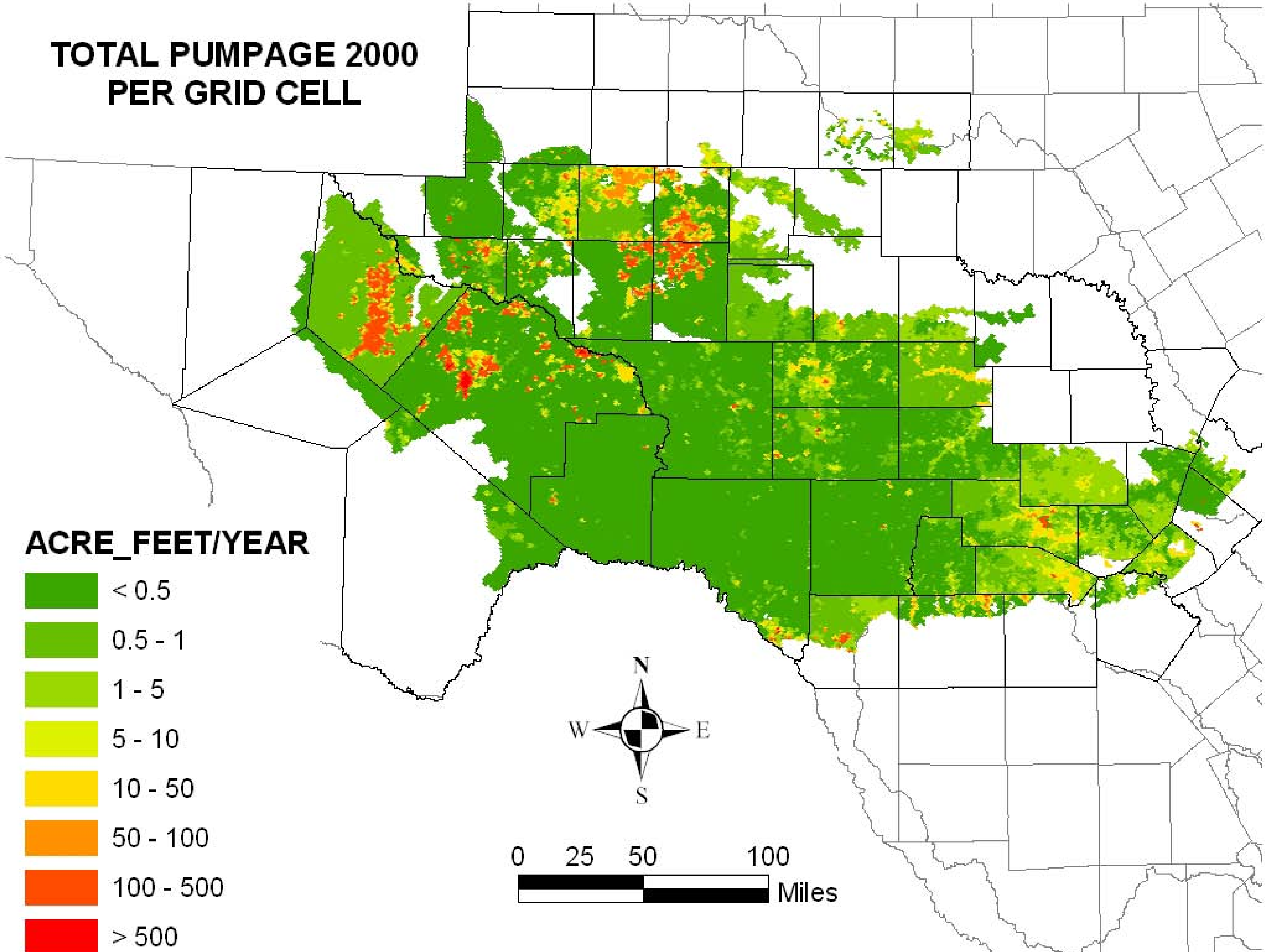
750.00
x 0.00023
0.1725

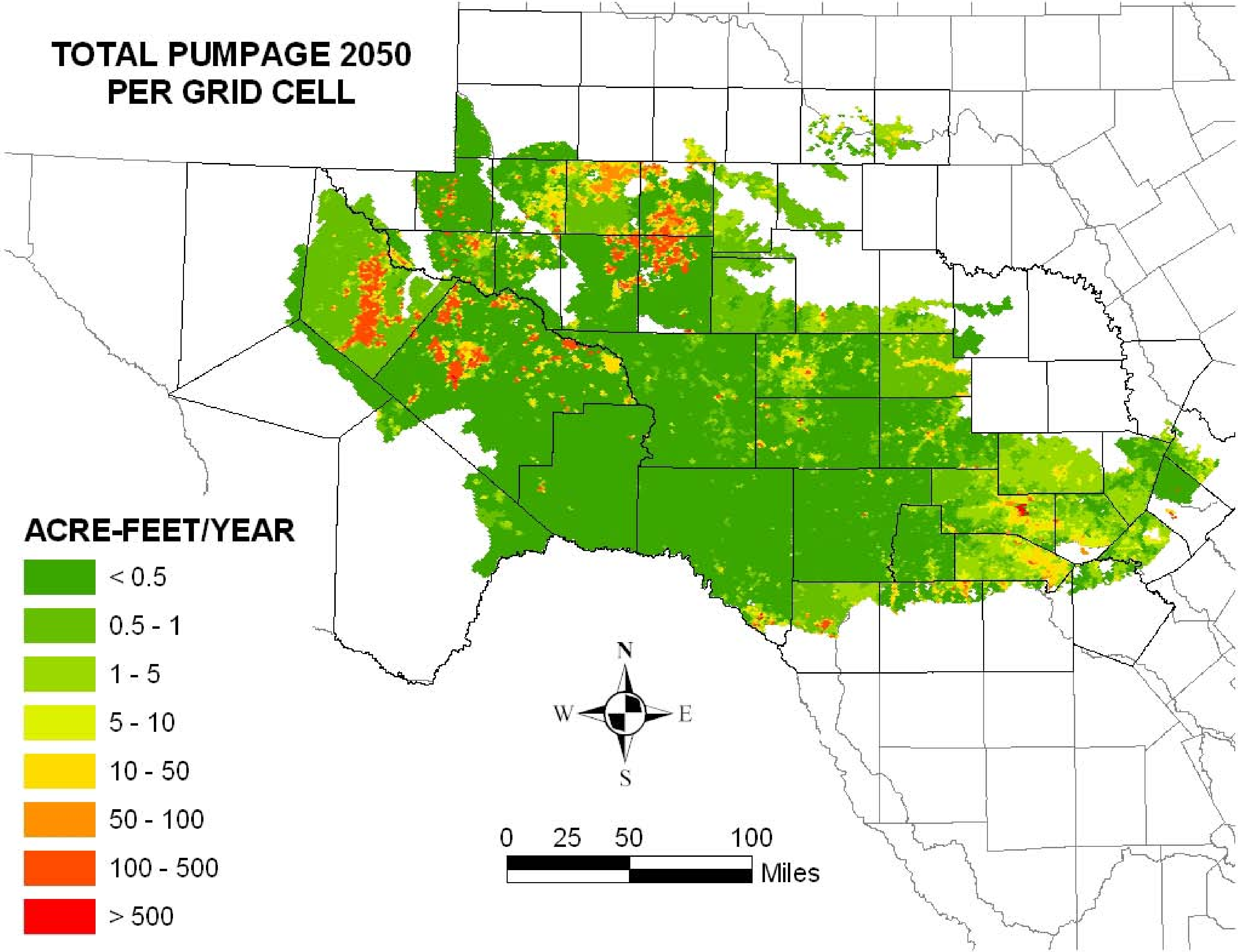
Table of Prepared Weighting Factors

ROW	COL	COUNTY	BASIN	STOCK1	STOCK2
161	200	53	23	0.00023	0.00014
161	201	53	23	0.00016	0.00021

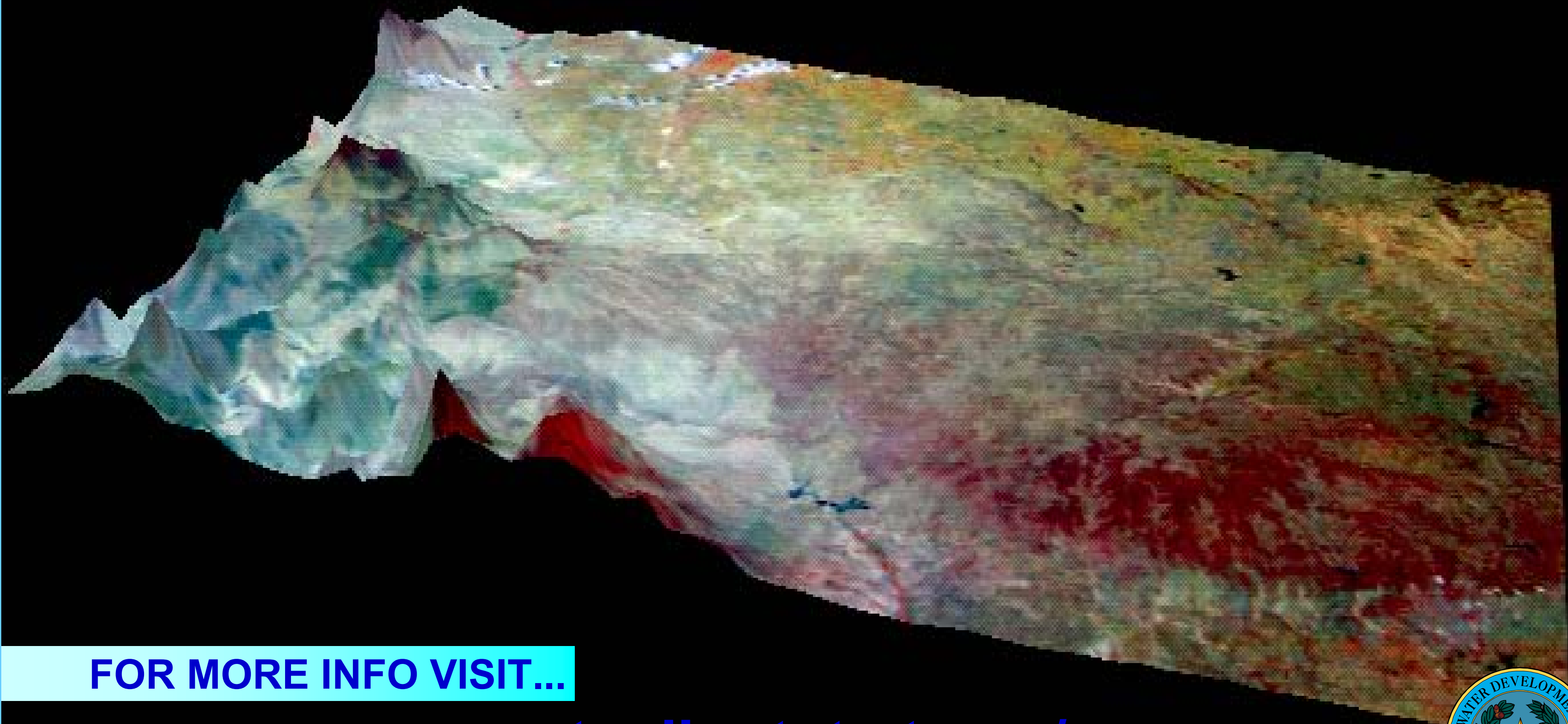


TOTAL PUMPAGE 1980
PER GRID CELL
ACRE-FEET/YEAR
< 0.5
0.5 - 1
1 - 5
5 - 10
10 - 50
50 - 100
100 - 500
> 500
N
W
E
S
0
25
50
100
Miles


TOTAL PUMPAGE 2000
PER GRID CELL
ACRE_FEET/YEAR
< 0.5
0.5 - 1
1 - 5
5 - 10
10 - 50
50 - 100
100 - 500
> 500
N
W
E
S
0
25
50
100
Miles


TOTAL PUMPAGE 2050
PER GRID CELL
ACRE-FEET/YEAR
< 0.5
0.5 - 1
1 - 5
5 - 10
10 - 50
50 - 100
100 - 500
> 500
N
W
E
S
0
25
50
100
Miles

Questions
or
Comments?



FOR MORE INFO VISIT...

www.twdb.state.tx.us/gam

Lunch Time!

90 Minute Break

We will reconvene to finish the discussion of the Edwards-Trinity and Cenozoic Pecos Alluvium Aquifer Systems Model

FOR MORE INFO VISIT...

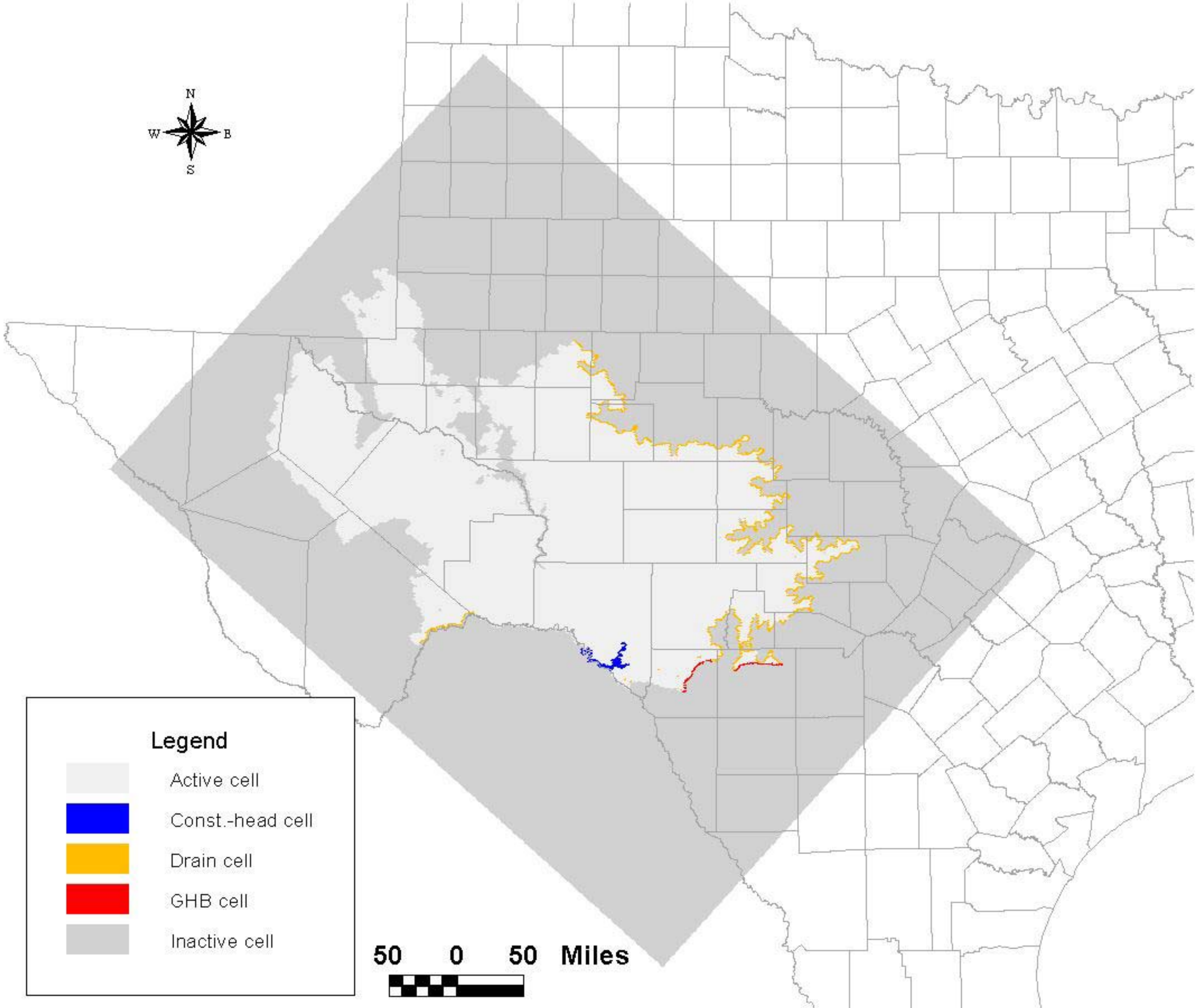
www.twdb.state.tx.us/gam

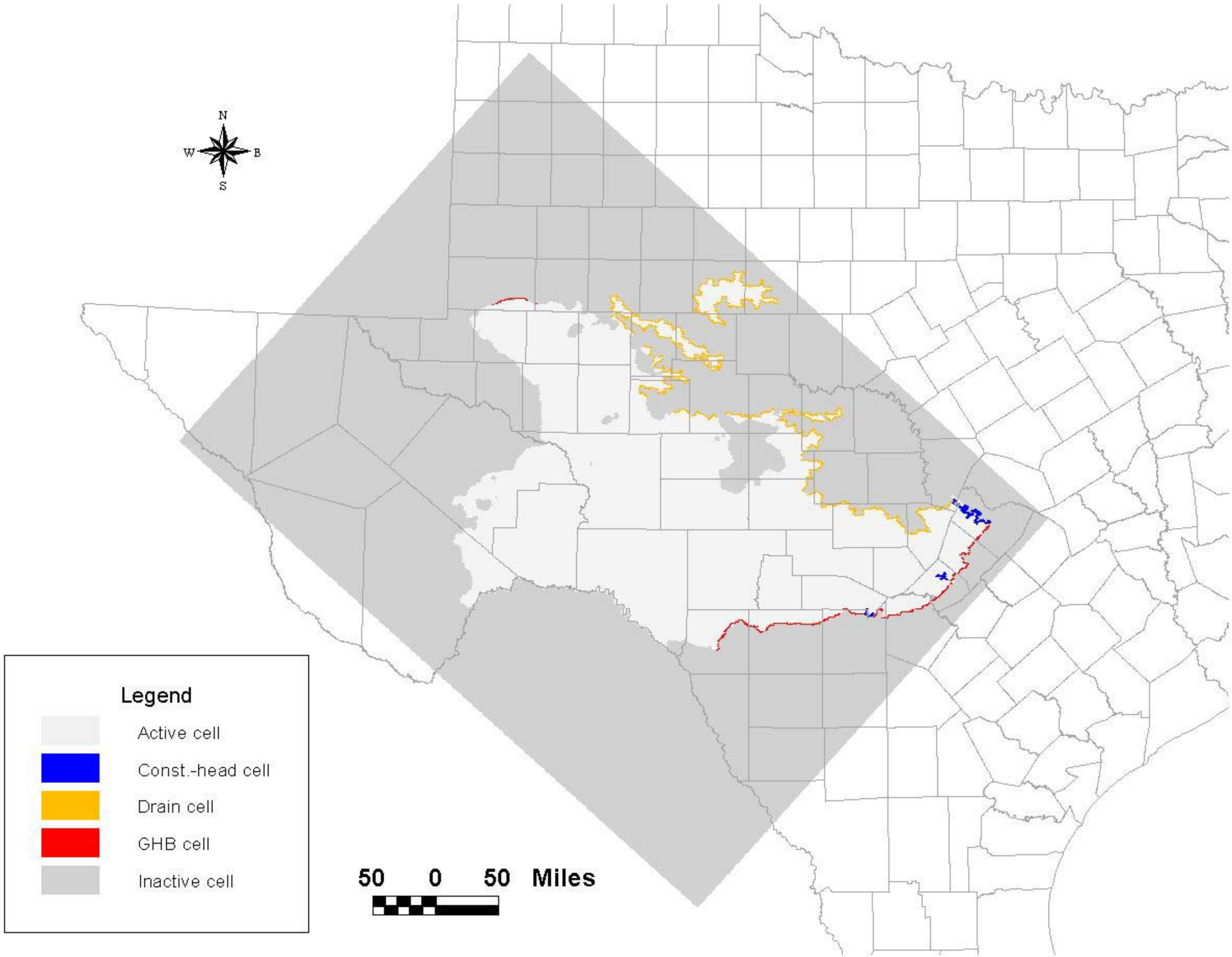
EDWARDS-TRINITY GAM MODEL RUNS AND RESULTS

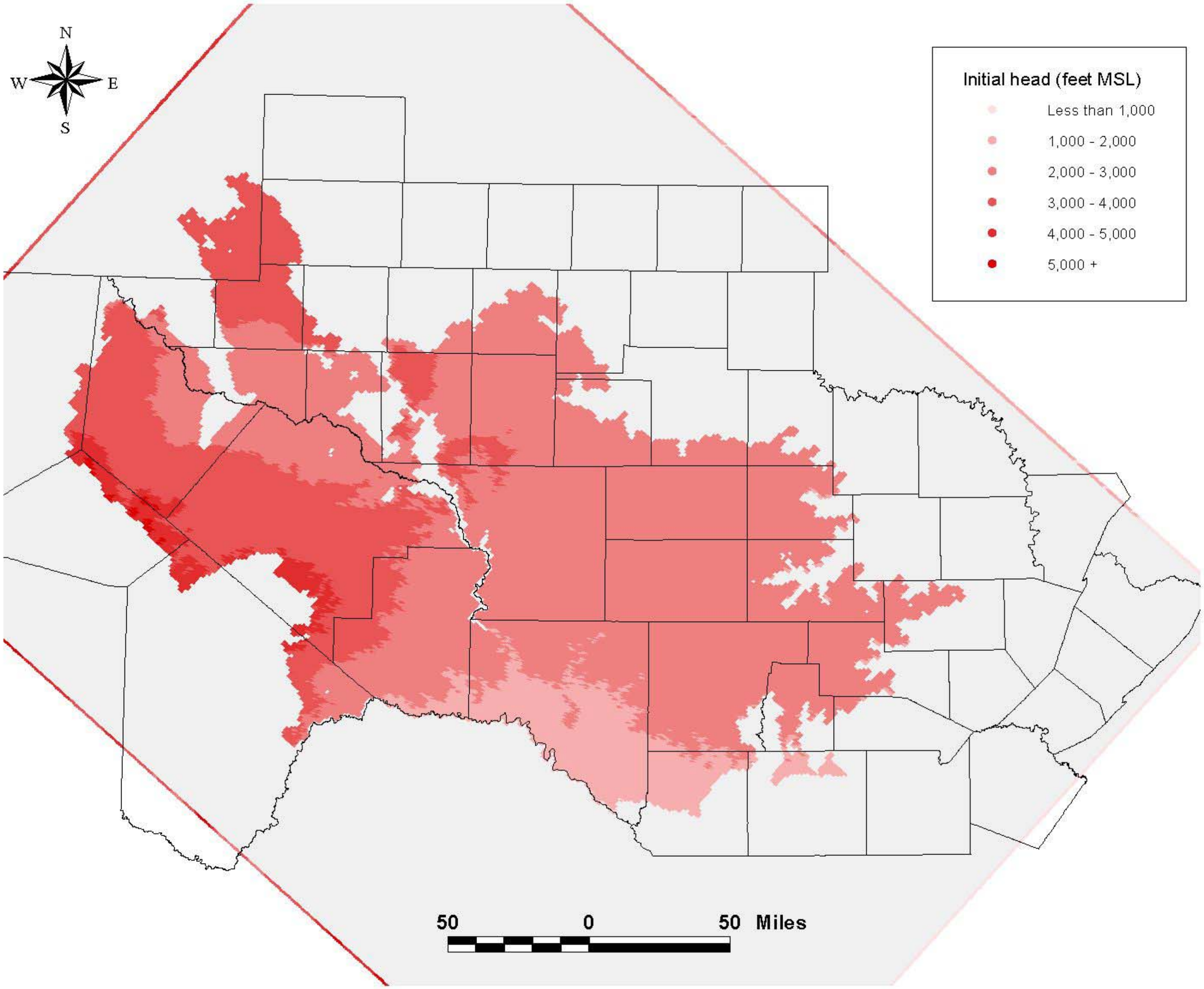
Ian C. Jones, Ph.D., P.G.

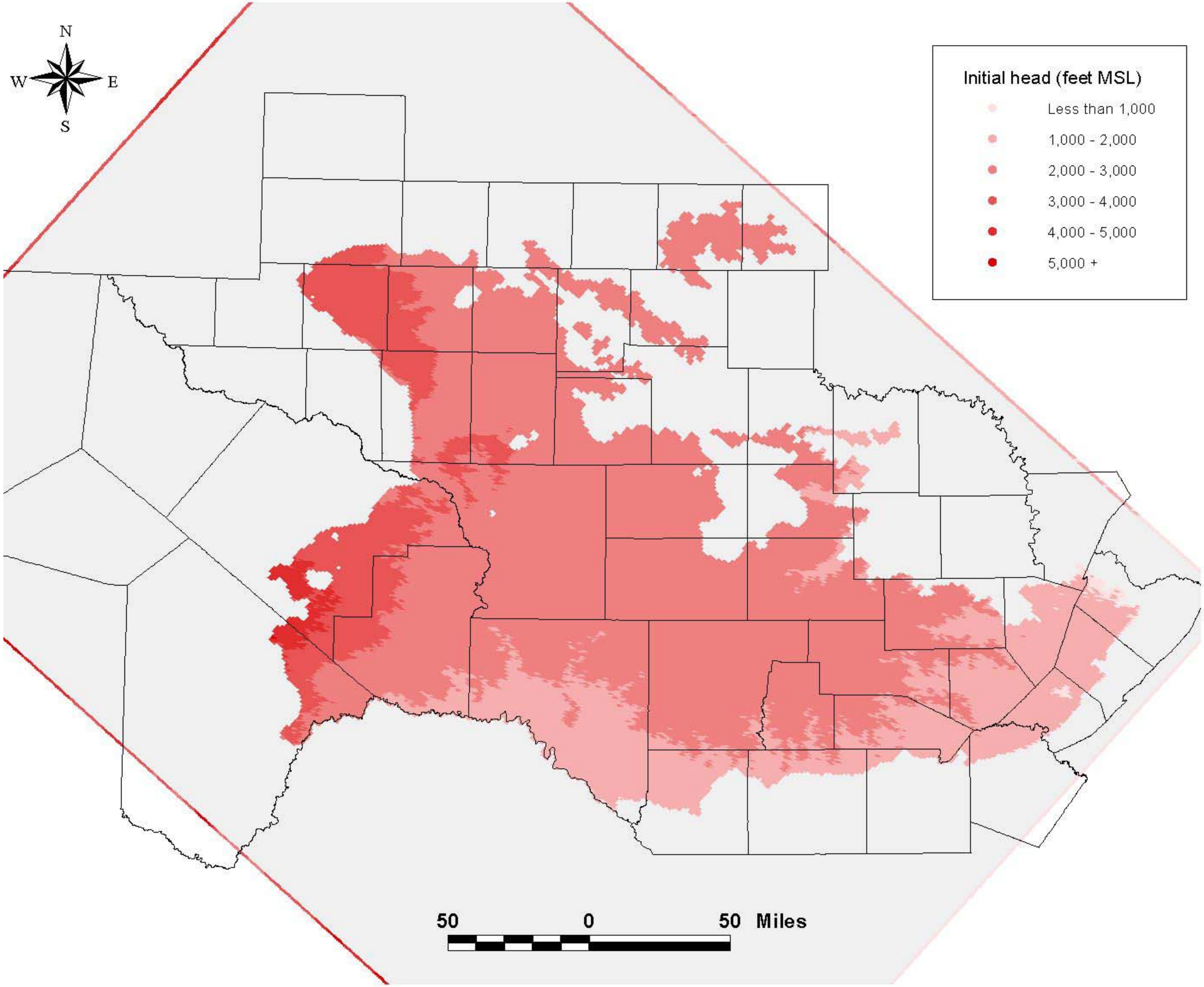
Texas Water Development Board

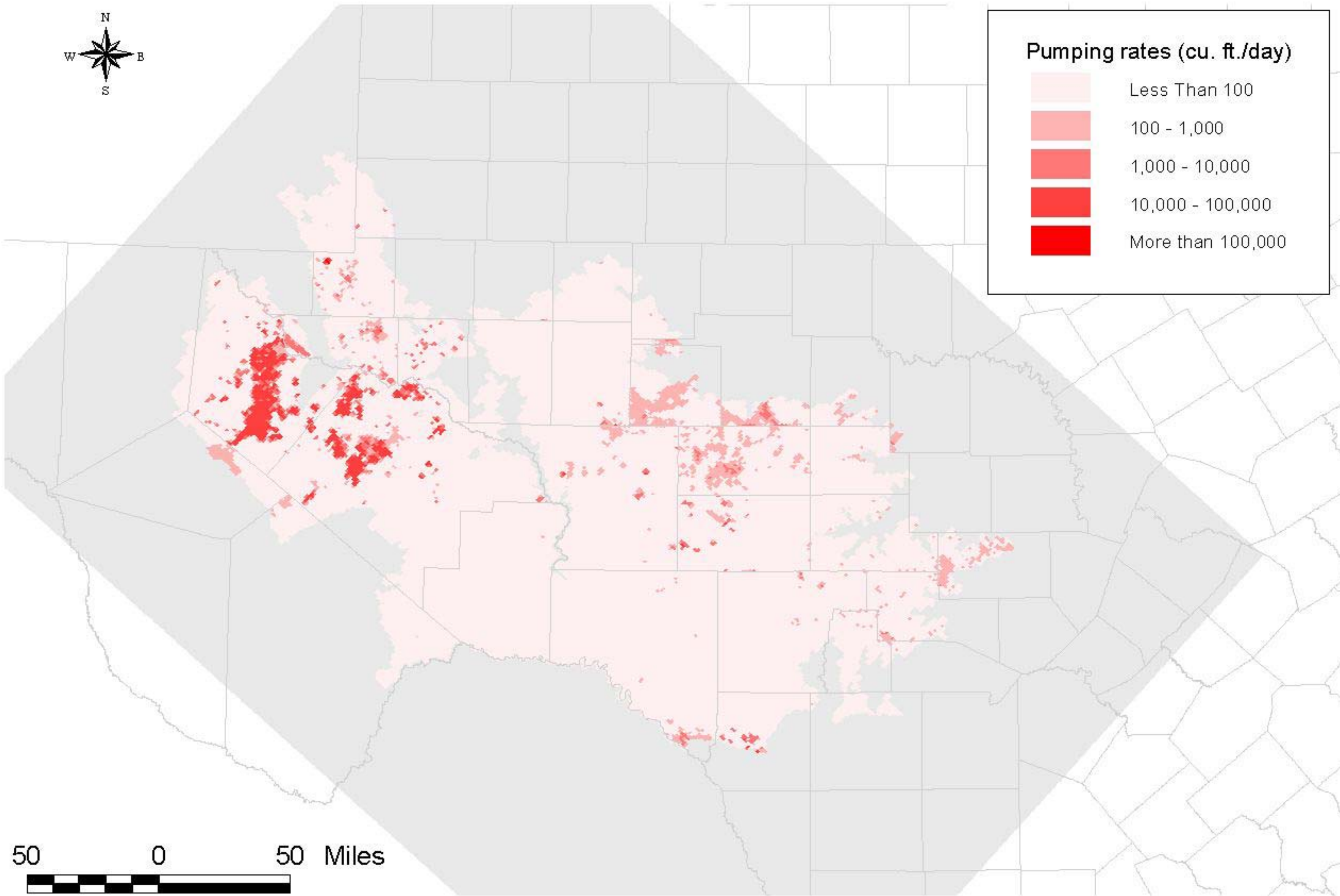
STEADY-STATE CALIBRATION


N
W
E
S
Legend
Active cell
Const.-head cell
Drain cell
GHB cell
Inactive cell
50 0 50 Miles

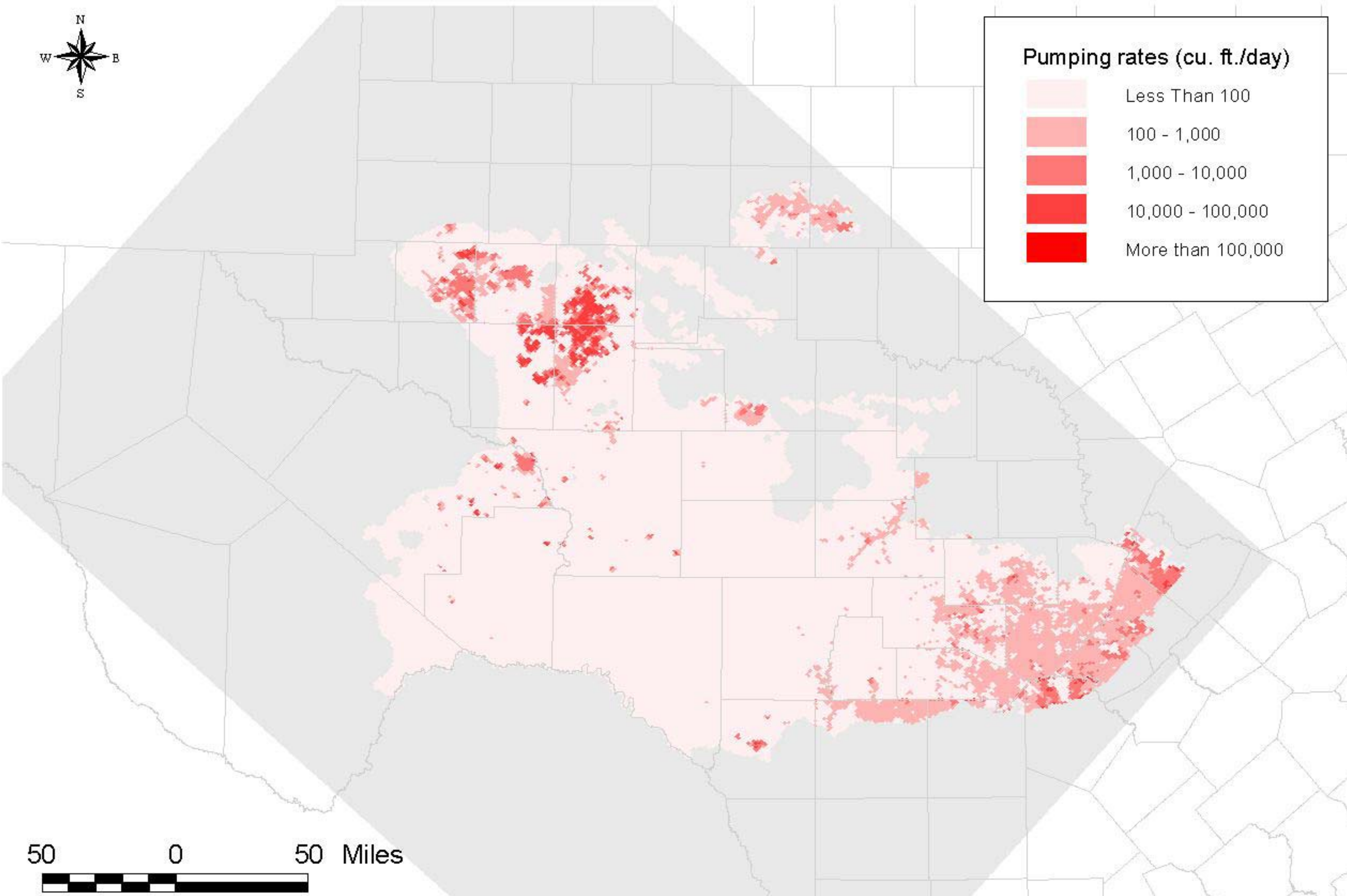

N
W
E
S
Legend
Active cell
Const.-head cell
Drain cell
GHB cell
Inactive cell
50 0 50 Miles

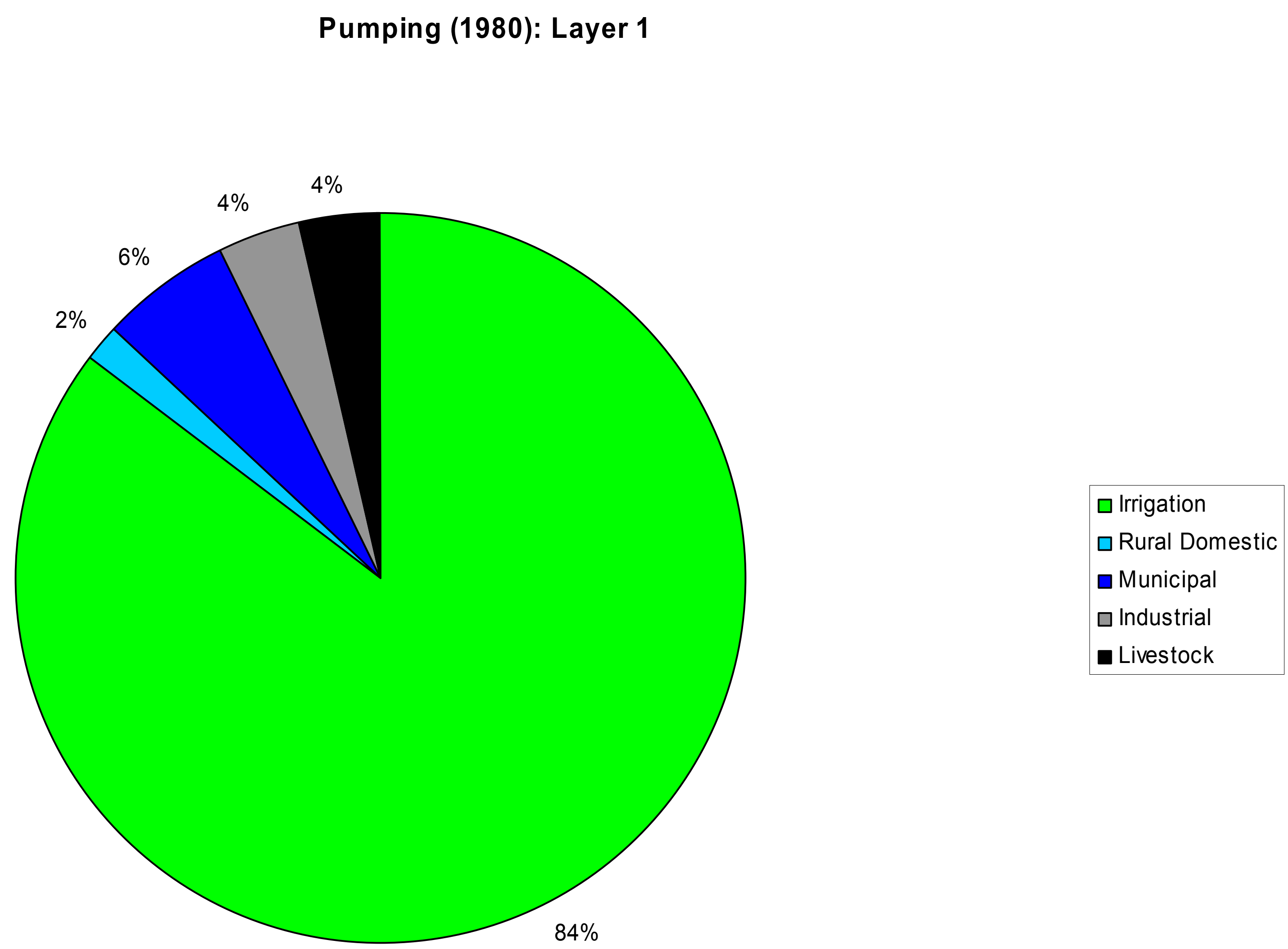

N
S
W
E
Initial head (feet MSL)
Less than 1,000
1,000 - 2,000
2,000 - 3,000
3,000 - 4,000
4,000 - 5,000
5,000 +
50 0 50 Miles

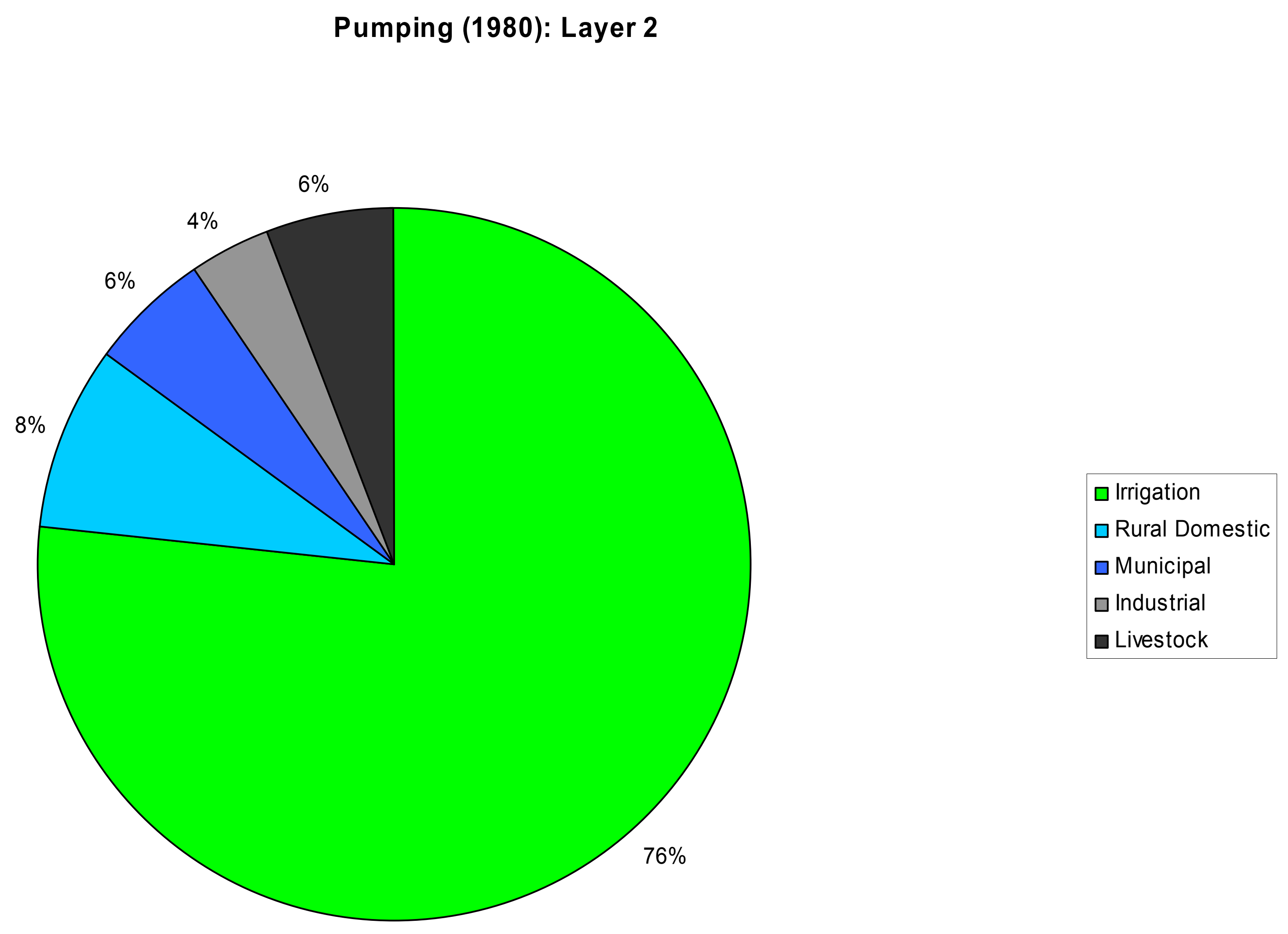

N
W
E
S
Initial head (feet MSL)
Less than 1,000
1,000 - 2,000
2,000 - 3,000
3,000 - 4,000
4,000 - 5,000
5,000 +
50
0
50 Miles

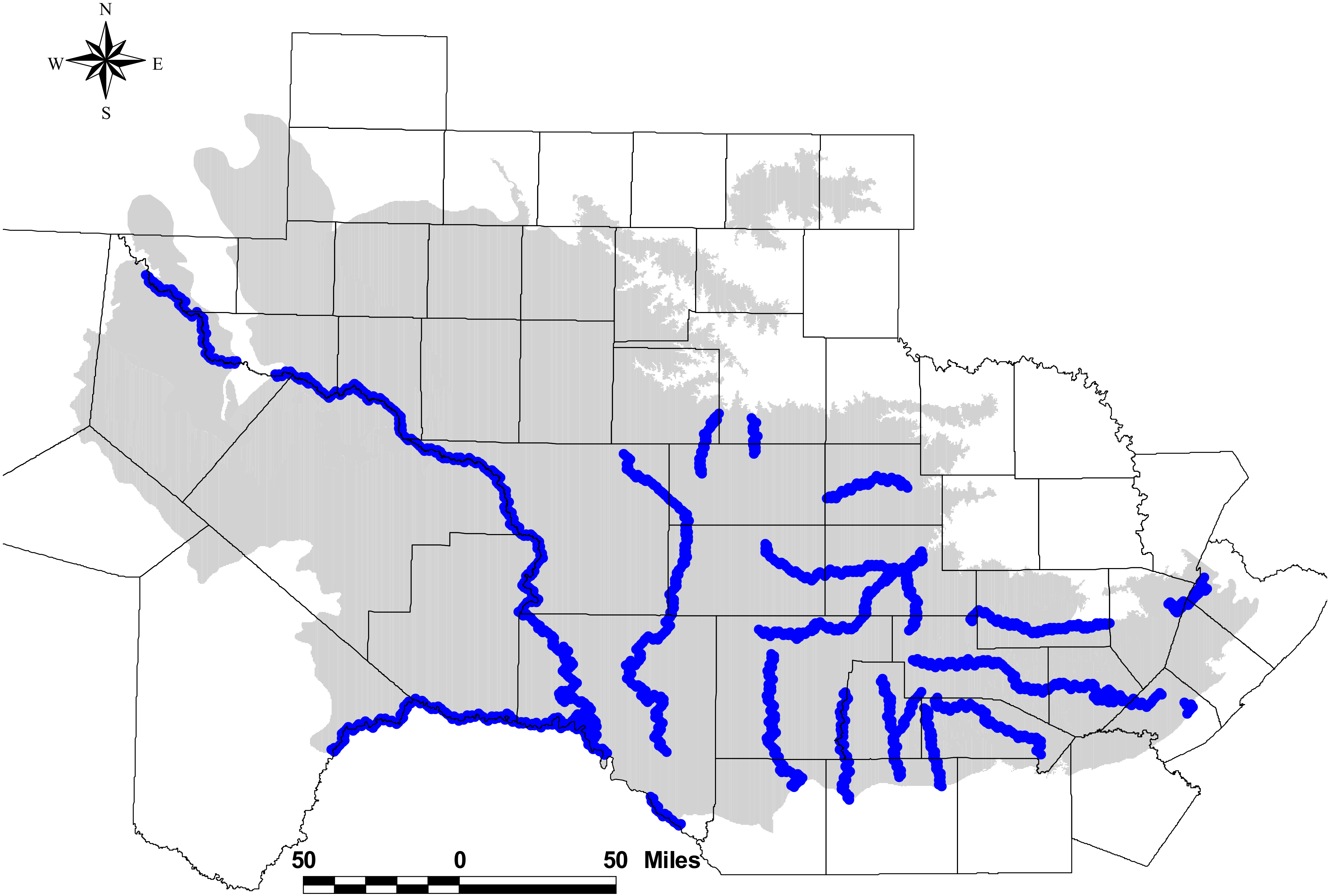


N
W
E
S
Pumping rates (cu. ft./day)
Less Than 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
More than 100,000
50
0
50
Miles

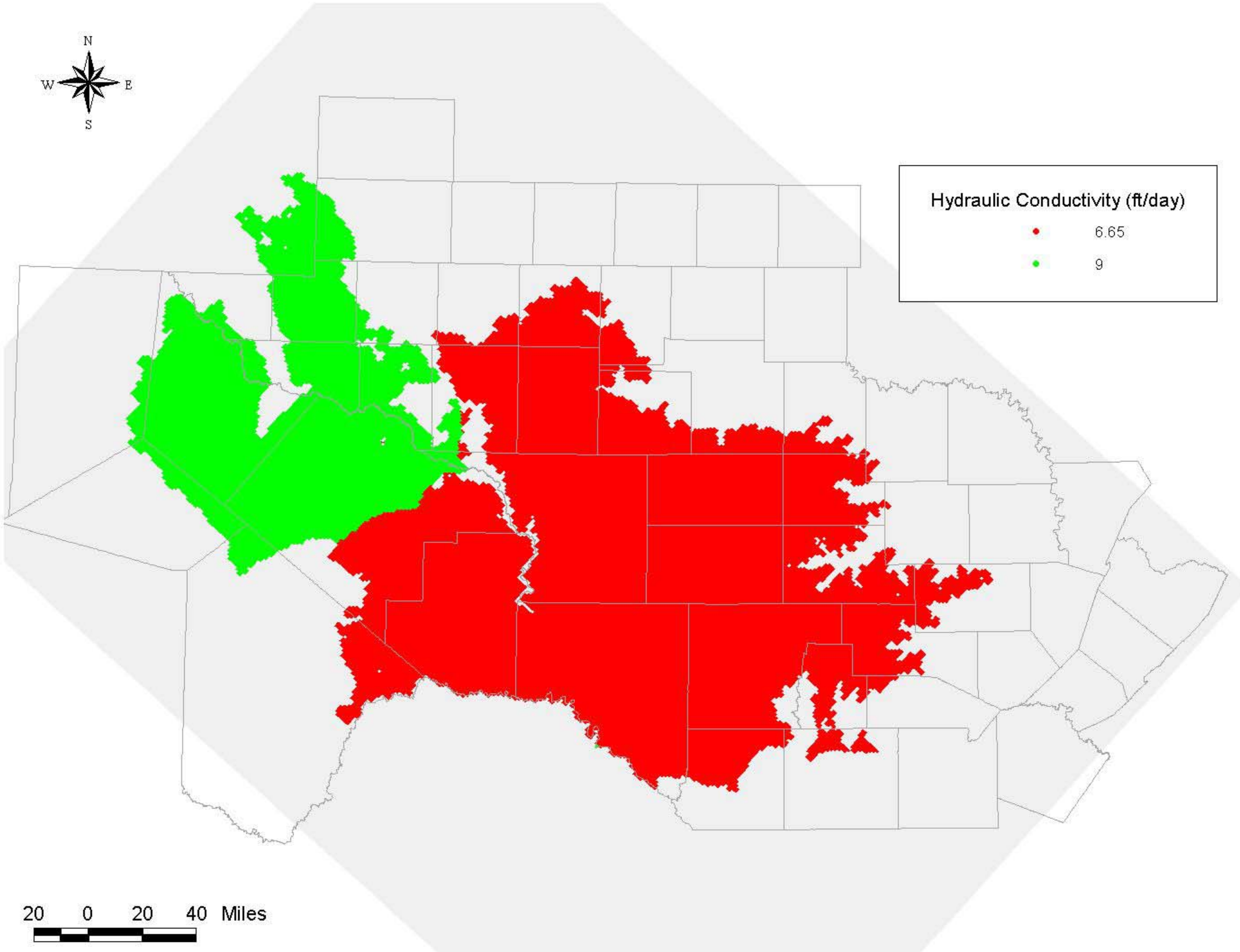

N
W
E
S
Pumping rates (cu. ft./day)
Less Than 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
More than 100,000
50 0 50 Miles

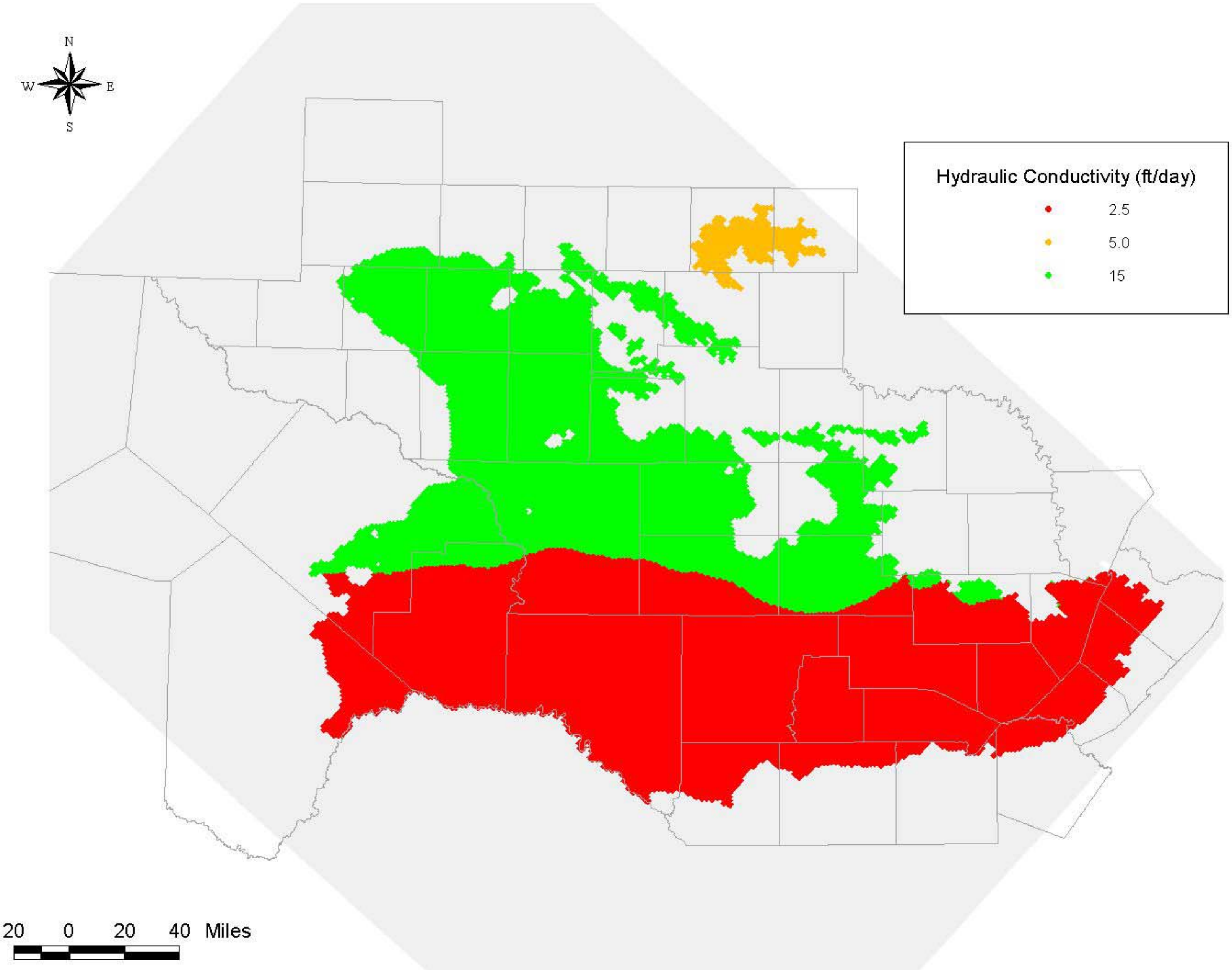

Pumping (1980): Layer 1
4%
4%
6%
2%
84%
Irrigation
Rural Domestic
Municipal
Industrial
Livestock

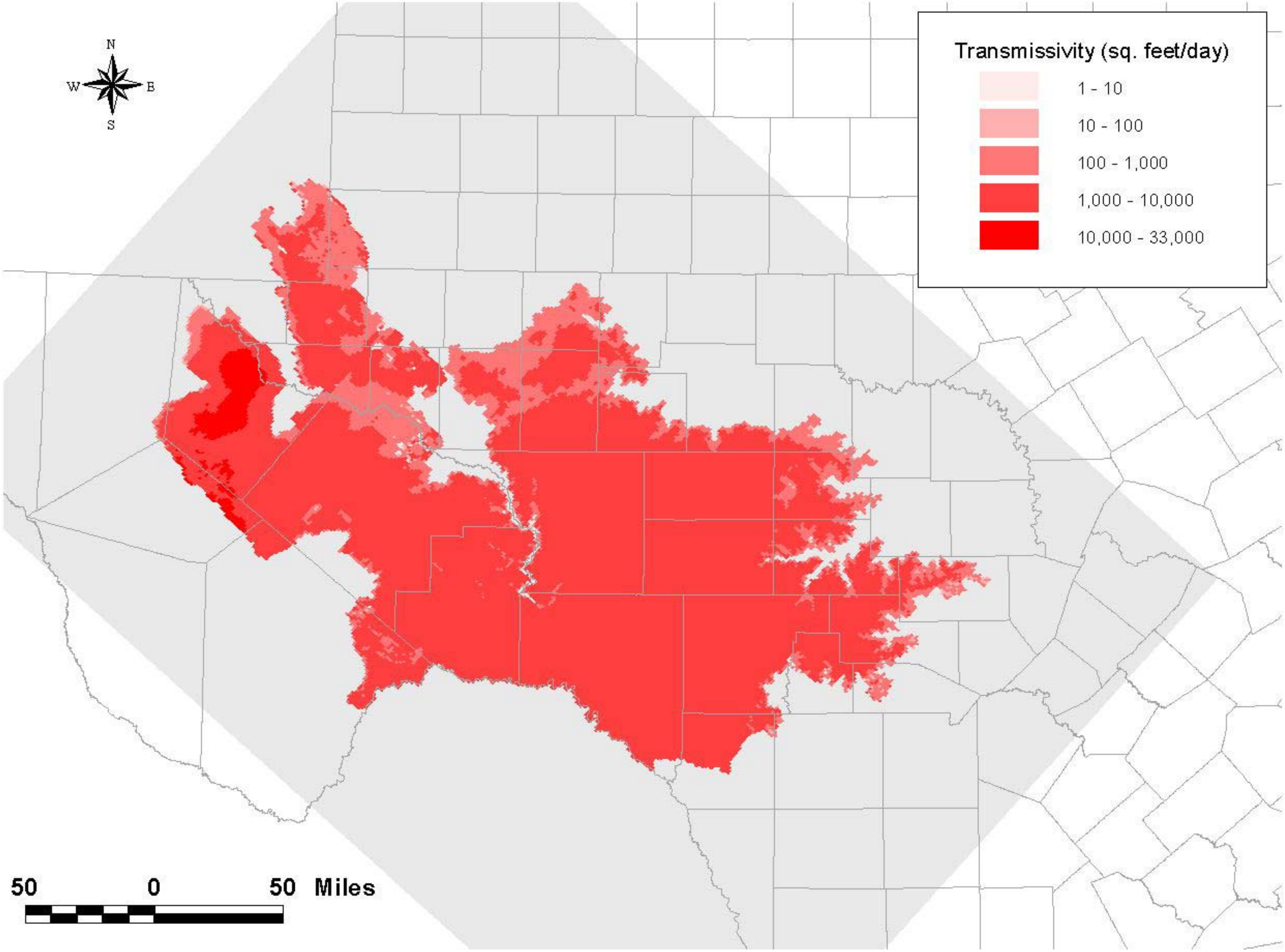

Pumping (1980): Layer 2
6%
4%
6%
8%
76%
Irrigation
Rural Domestic
Municipal
Industrial
Livestock

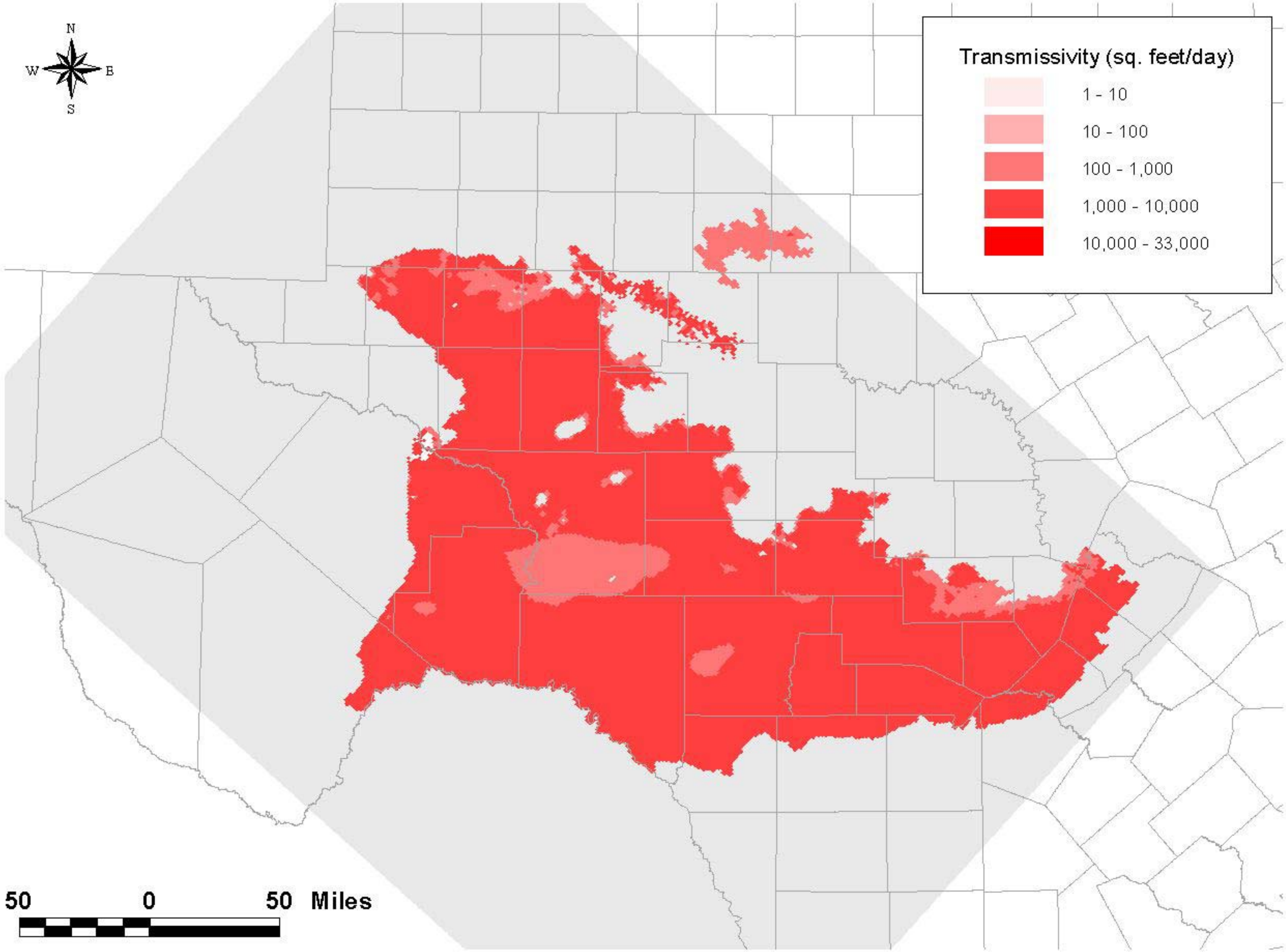


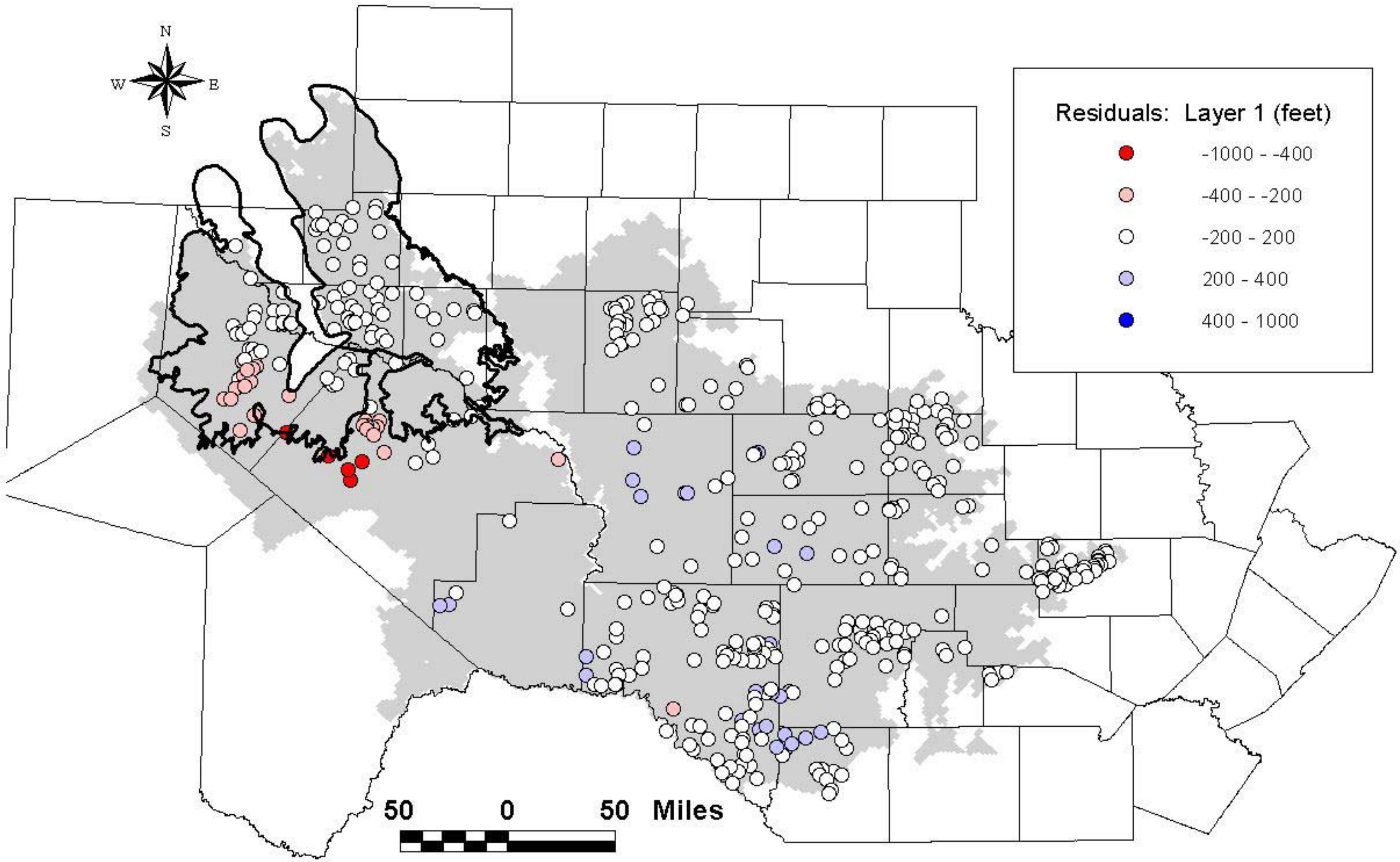
N
W
E
S
50
0
50 Miles

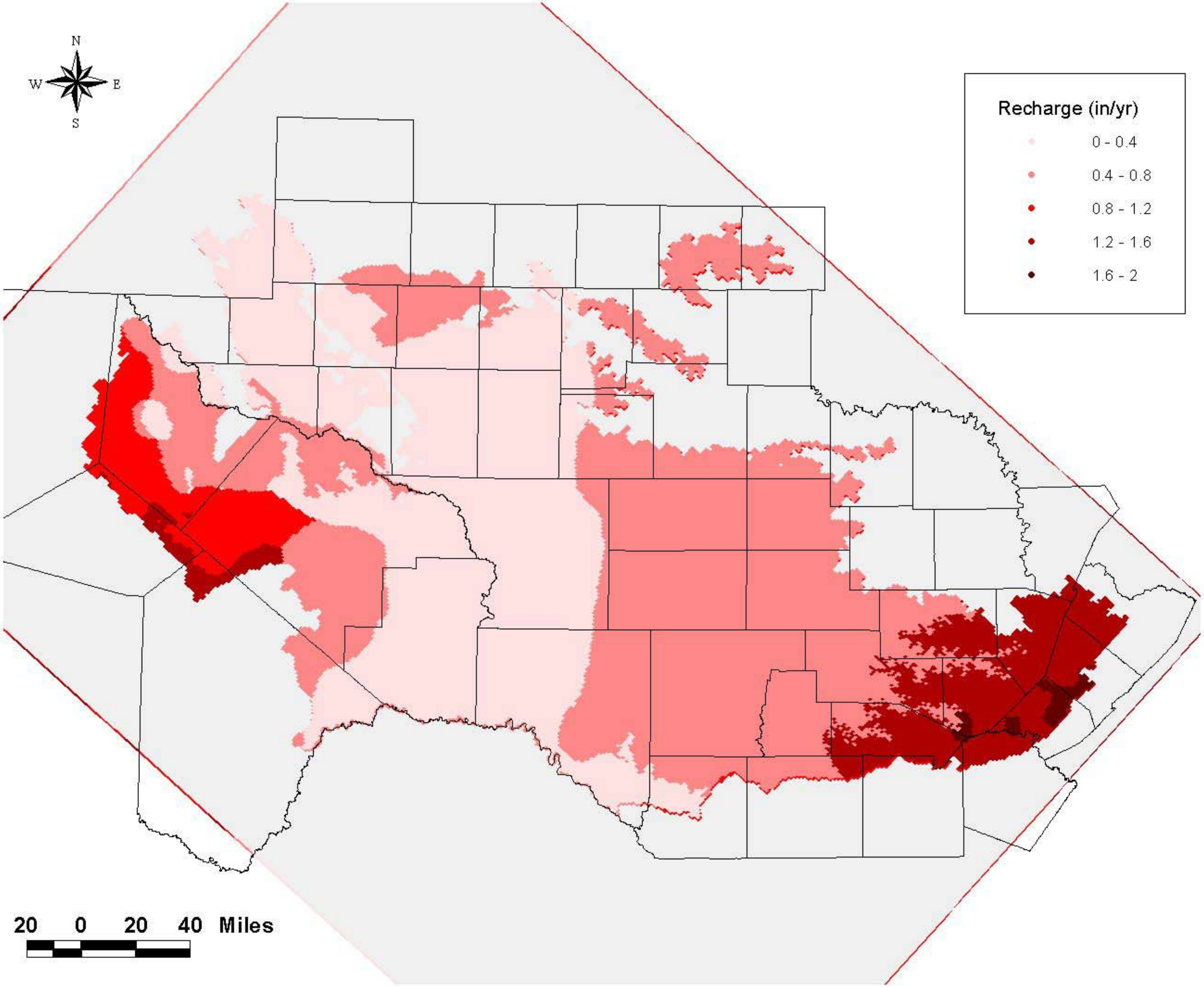

N
W
E
S
Hydraulic Conductivity (ft/day)
6.65
9
20 0 20 40 Miles

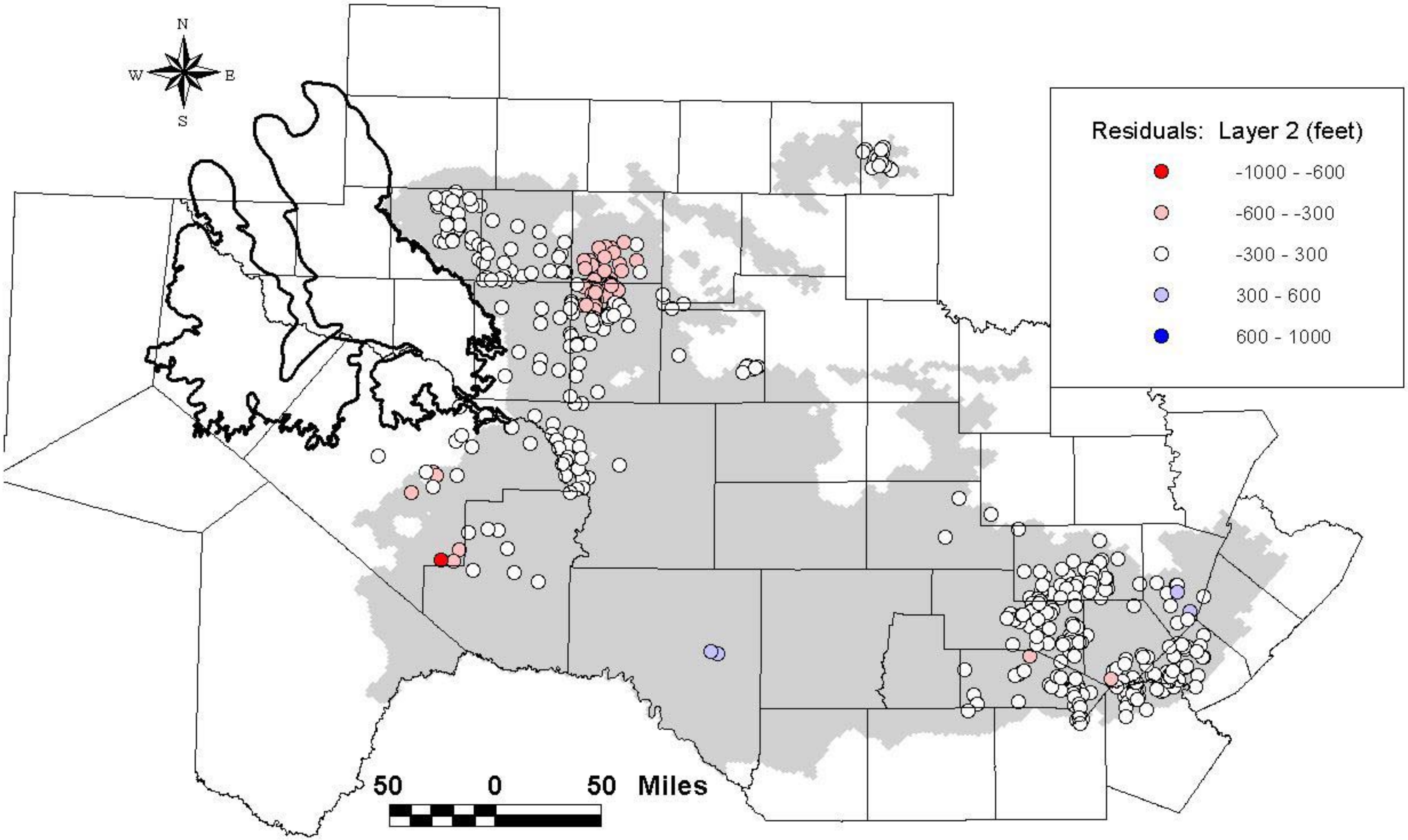

N
W
E
S
Hydraulic Conductivity (ft/day)
2.5
5.0
15
20 0 20 40 Miles

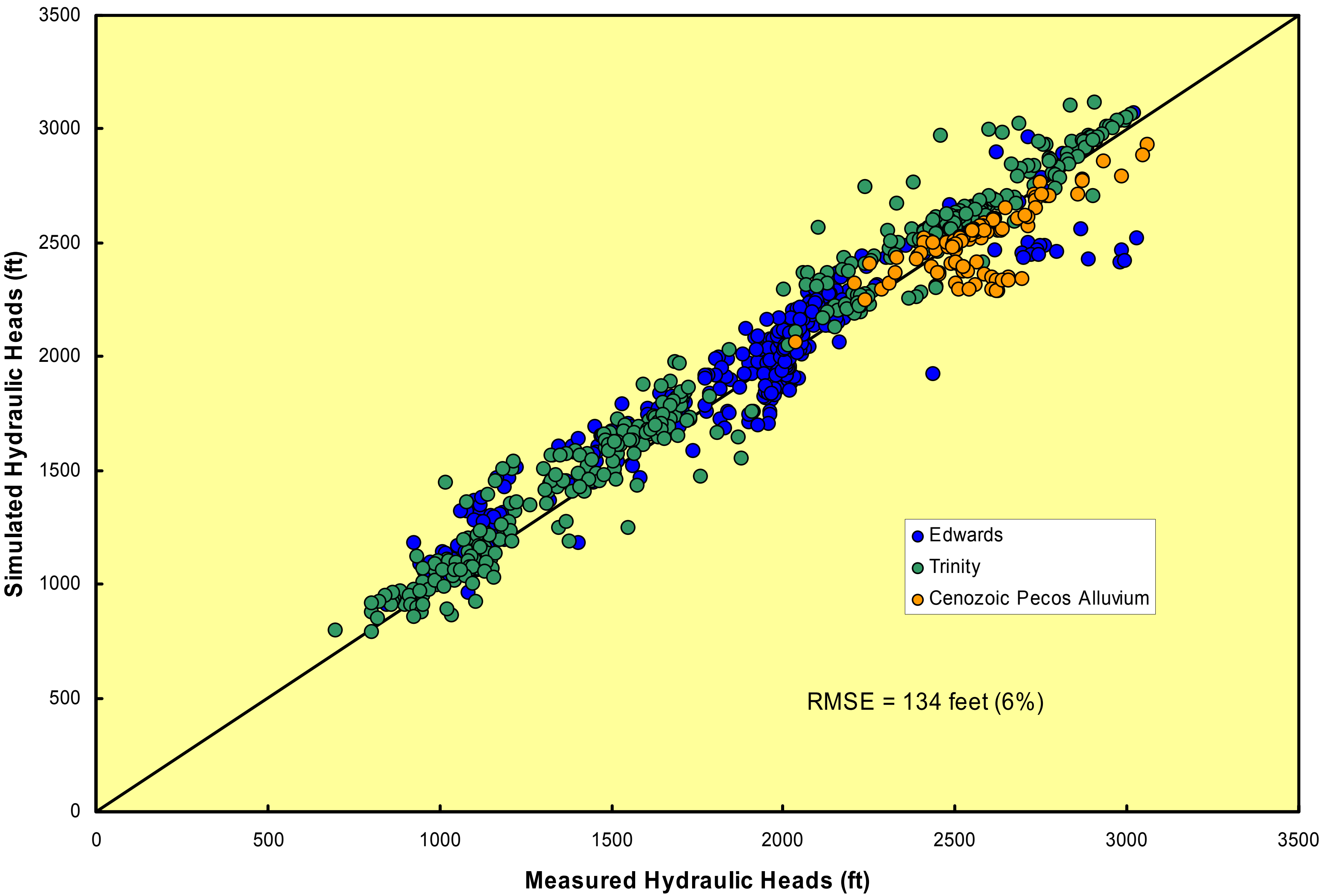

Transmissivity (sq. feet/day)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 33,000
N
W
E
S
50
0
50 Miles

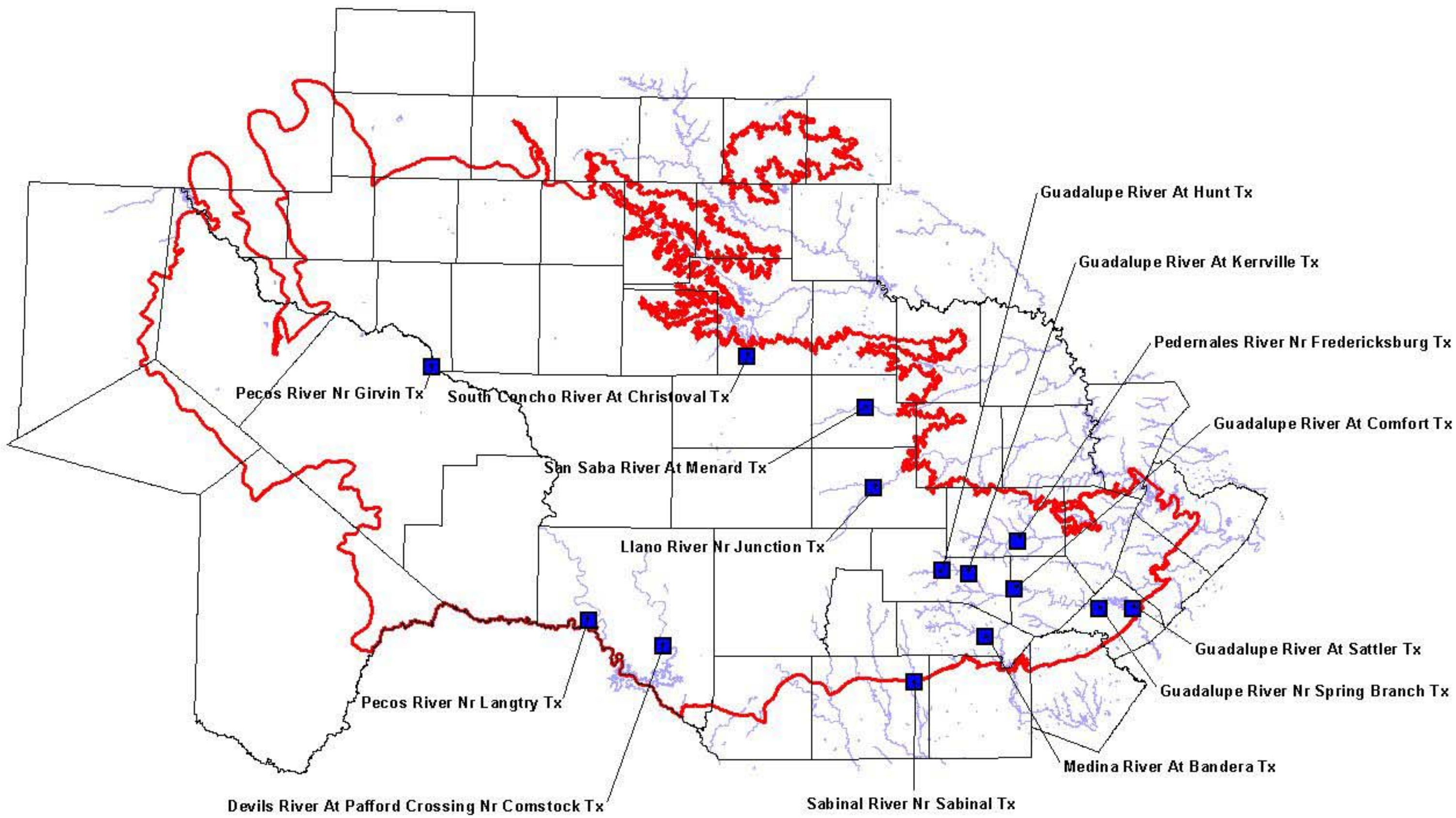

Transmissivity (sq. feet/day)
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 33,000
N
W
E
S
50
0
50
Miles


N
W
E
S
Residuals: Layer 1 (feet)
-1000 - -400
-400 - -200
-200 - 200
200 - 400
400 - 1000
50 0 50 Miles

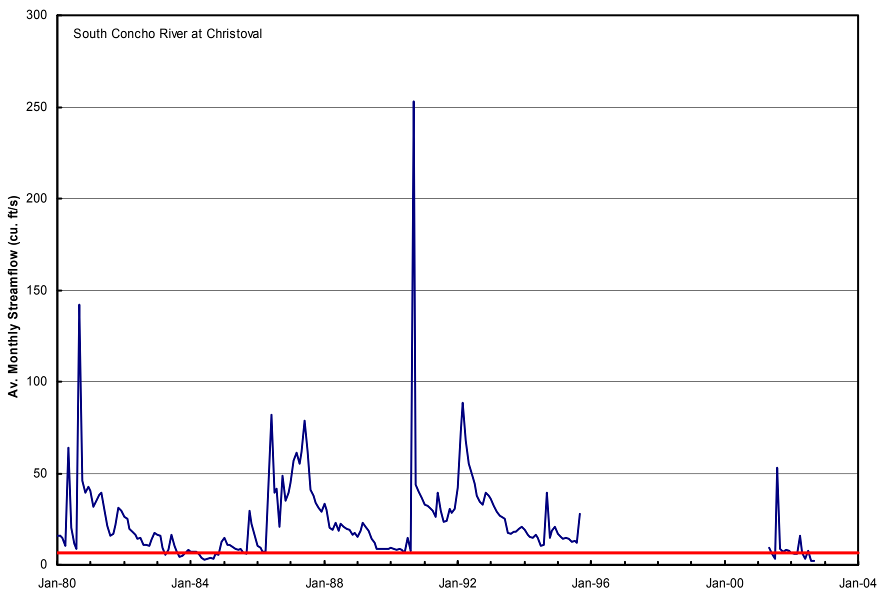

N
W
E
S
Recharge (in/yr)
0 - 0.4
0.4 - 0.8
0.8 - 1.2
1.2 - 1.6
1.6 - 2
20 0 20 40 Miles

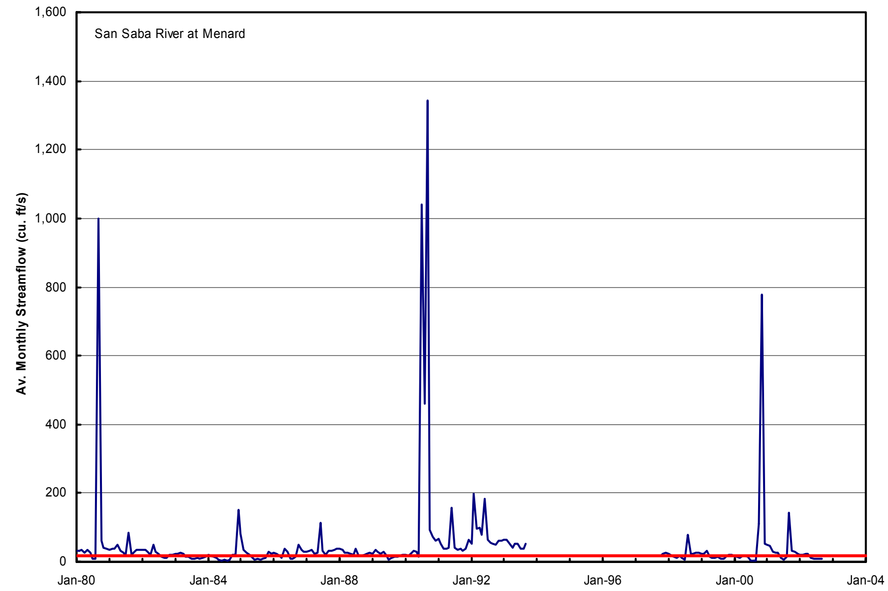

N
W
E
S
Residuals: Layer 2 (feet)
-1000 - -600
-600 - -300
-300 - 300
300 - 600
600 - 1000
50
0
50 Miles

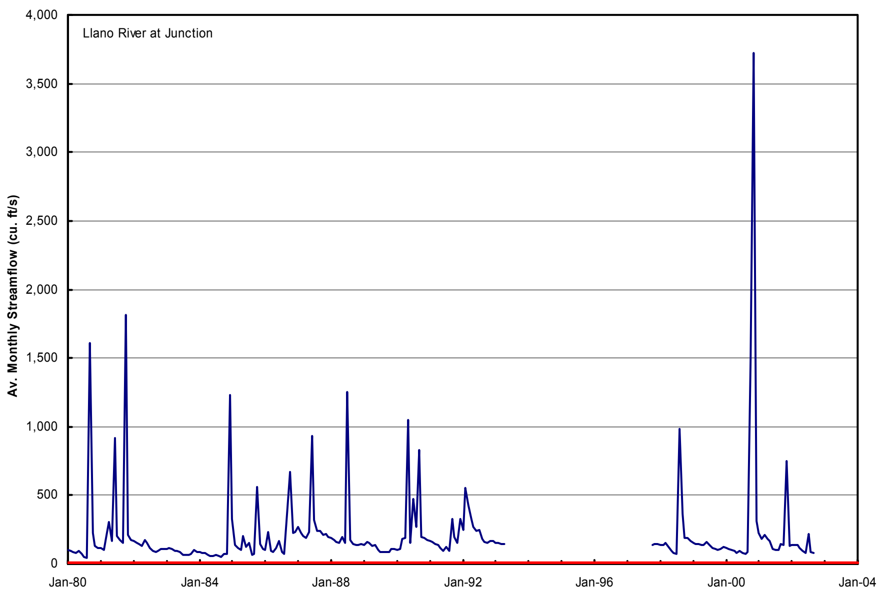

3500
3000
2500
2000
1500
1000
500
0
Simulated Hydraulic Heads (ft)
0
500
1000
1500
2000
2500
3000
3500
Measured Hydraulic Heads (ft)
Edwards
Trinity
Cenozoic Pecos Alluvium
RMSE = 134 feet (6%)

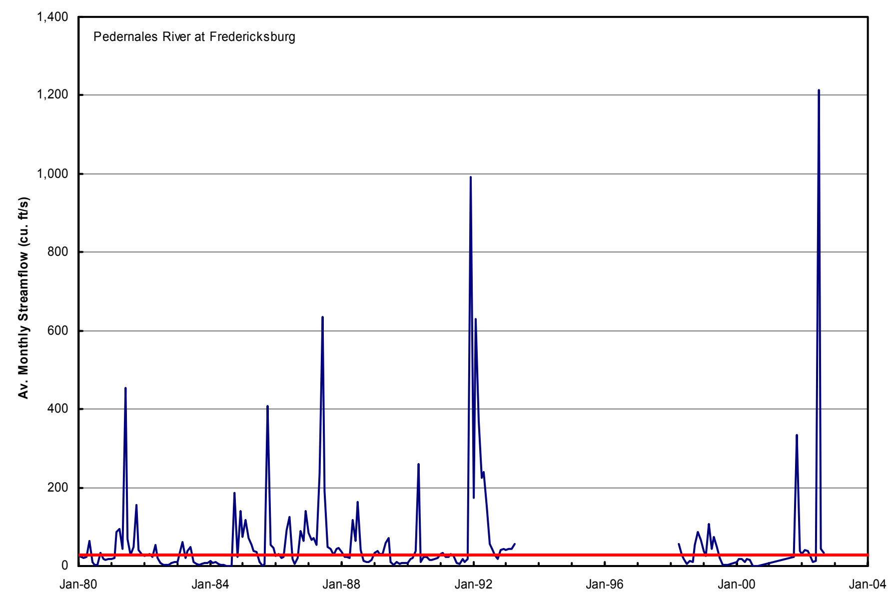


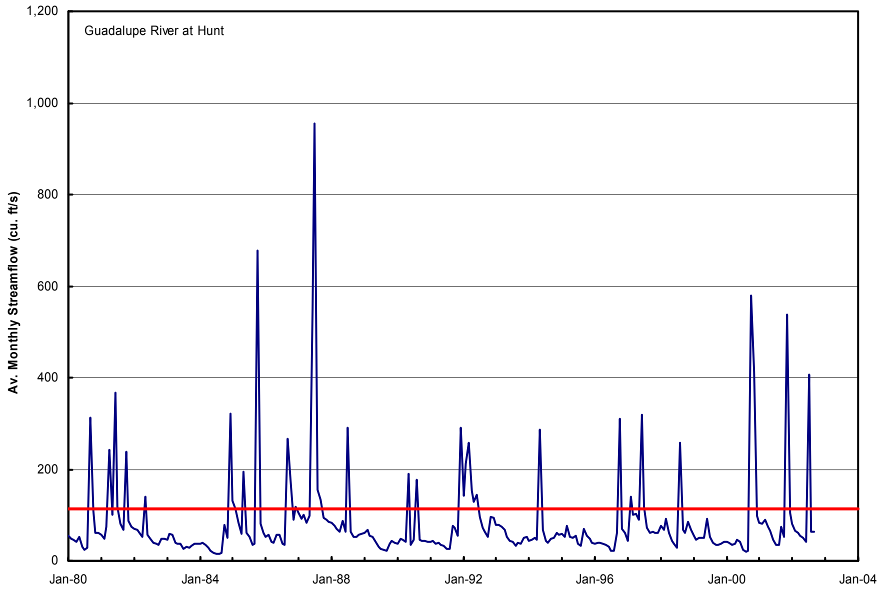
Guadalupe River At Hunt Tx
Guadalupe River At Kerrville Tx
Pedernales River Nr Fredericksburg Tx
Guadalupe River At Comfort Tx
Pecos River Nr Girvin Tx
South Concho River At Christoval Tx
San Saba River At Menard Tx
Llano River Nr Junction Tx
Guadalupe River At Sattler Tx
Guadalupe River Nr Spring Branch Tx
Pecos River Nr Langtry Tx
Medina River At Bandera Tx
Devils River At Pafford Crossing Nr Comstock Tx
Sabinal River Nr Sabinal Tx

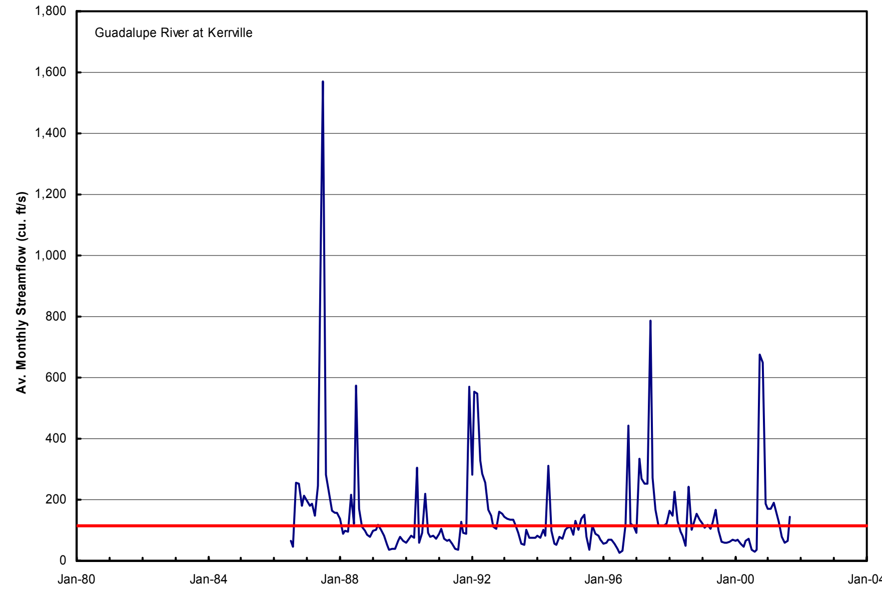

South Concho River at Christoval
Av. Monthly Streamflow (cu. ft/s)
300
250
200
150
100
50
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

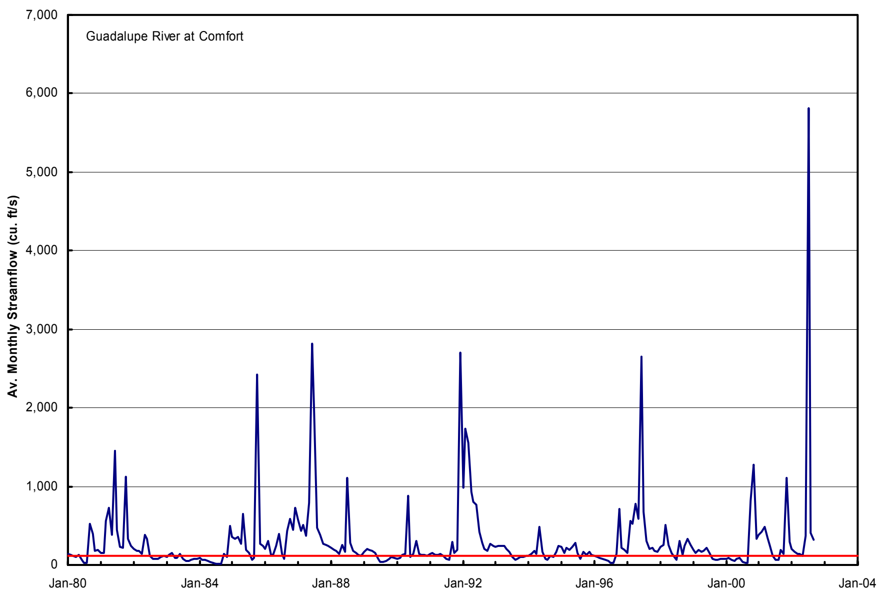

San Saba River at Menard
Av. Monthly Streamflow (cu. ft/s)
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

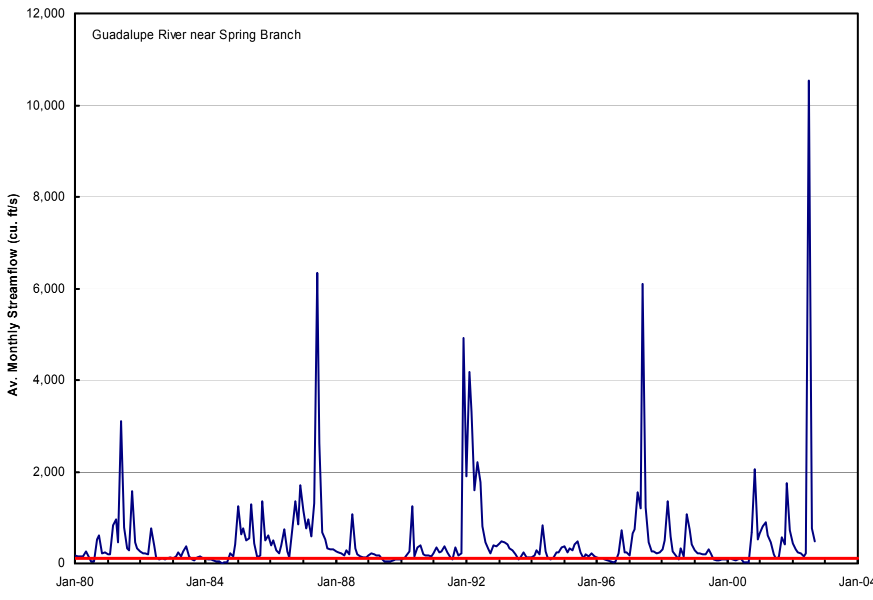

Llano River at Junction
Av. Monthly Streamflow (cu. ft/s)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

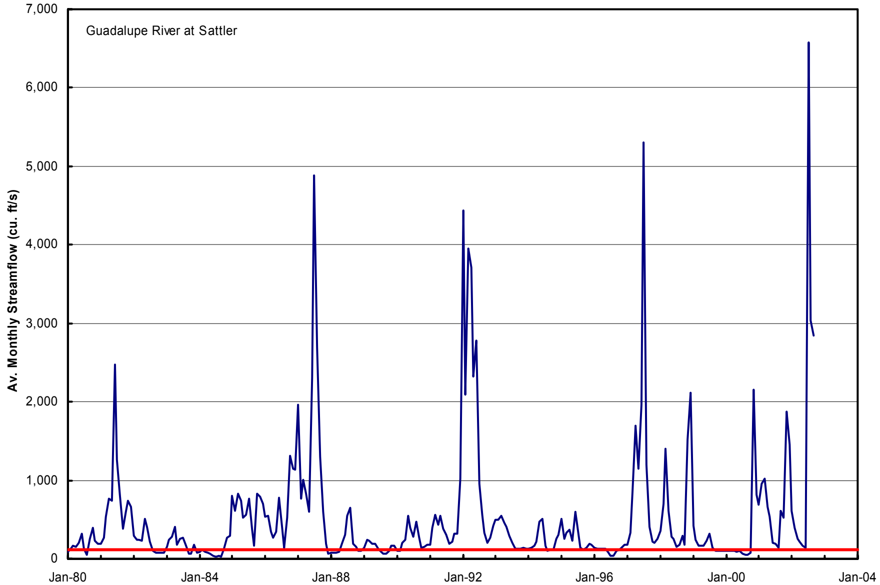

Pedernales River at Fredericksburg
Av. Monthly Streamflow (cu. ft/s)
1,400
1,200
1,000
800
600
400
200
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

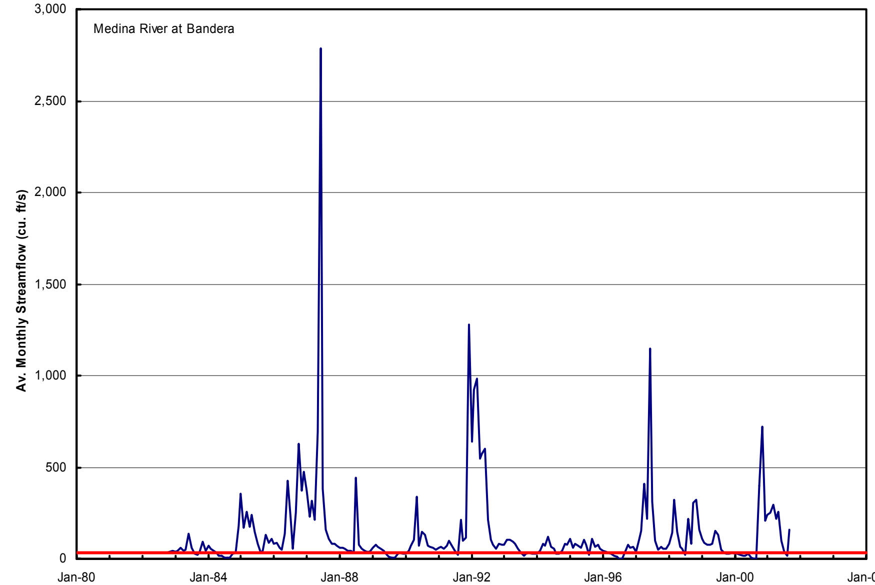

Guadalupe River at Hunt
Av. Monthly Streamflow (cu. ft/s)
0
200
400
600
800
1,000
1,200
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

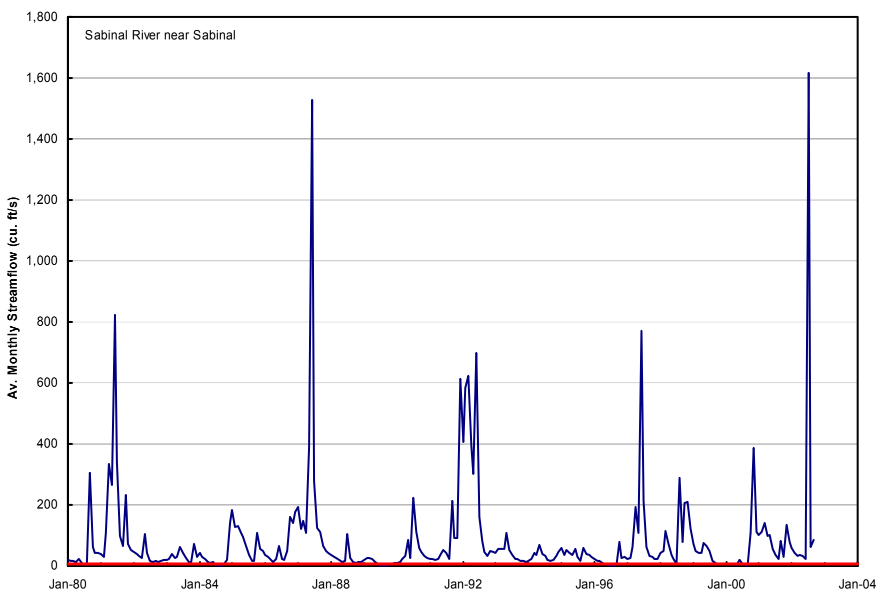

Guadalupe River at Kerrville
Av. Monthly Streamflow (cu. ft/s)
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

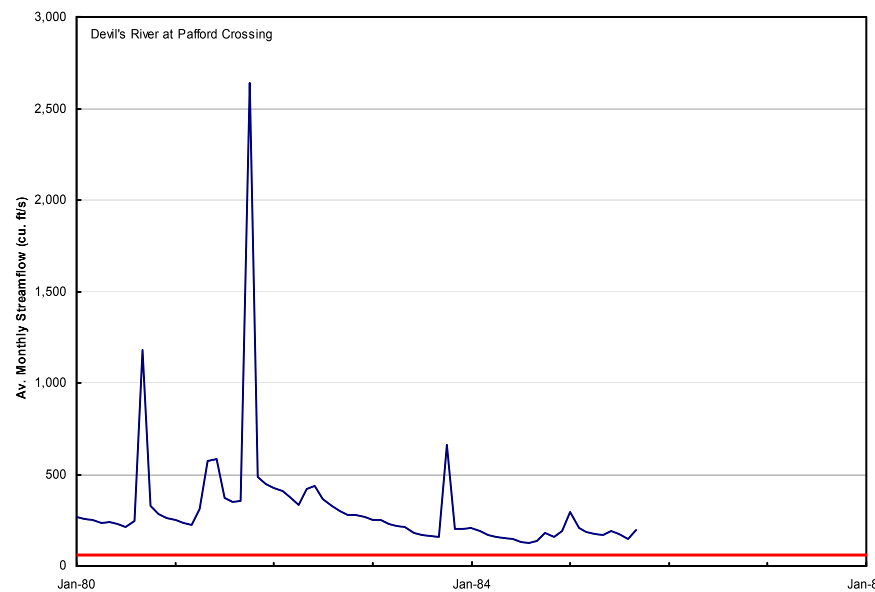

Guadalupe River at Comfort
Av. Monthly Streamflow (cu. ft/s)
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

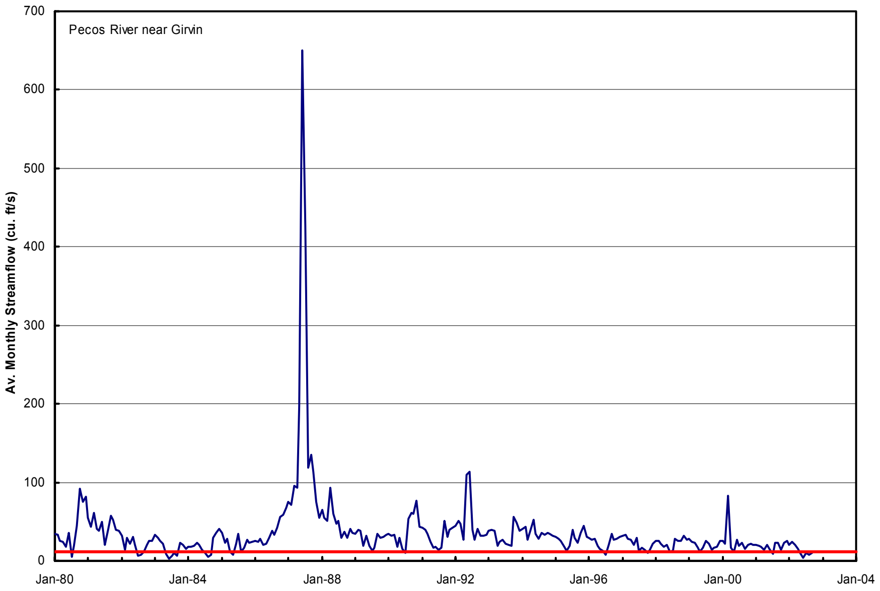

Guadalupe River near Spring Branch
Av. Monthly Streamflow (cu. ft/s)
0
2,000
4,000
6,000
8,000
10,000
12,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

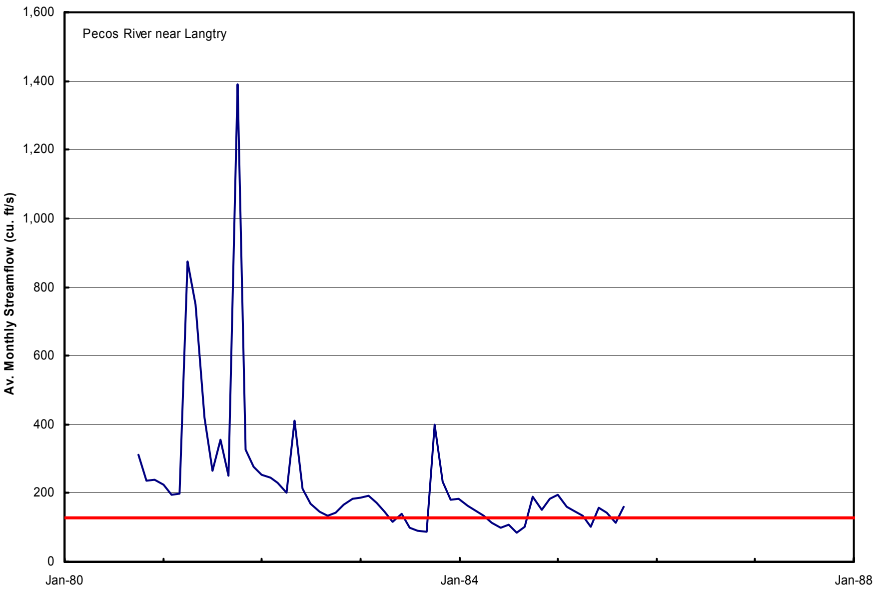

Guadalupe River at Sattler
Av. Monthly Streamflow (cu. ft/s)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

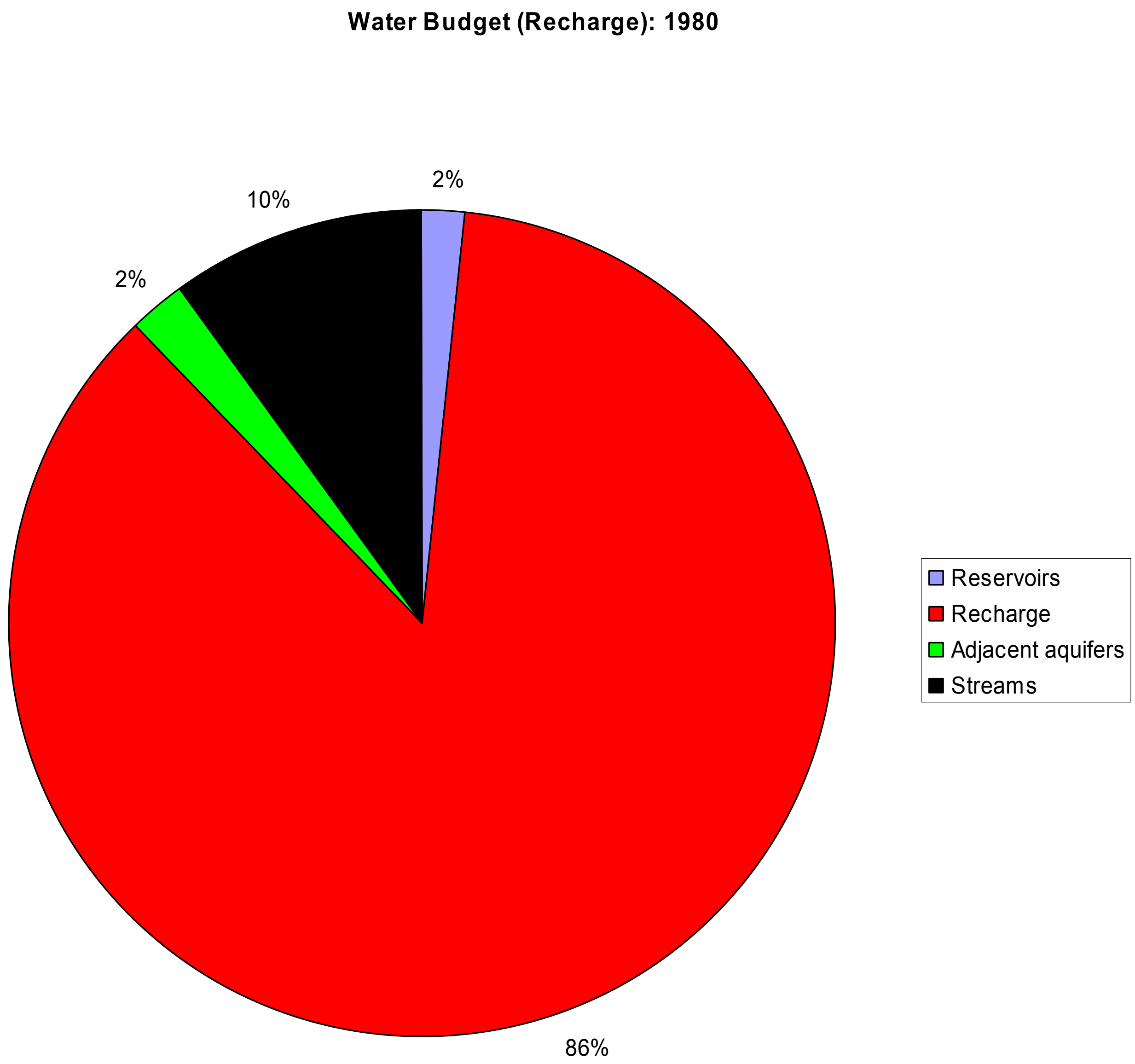

Medina River at Bandera
Av. Monthly Streamflow (cu. ft/s)
3,000
2,500
2,000
1,500
1,000
500
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04


Sabinal River near Sabinal
Av. Monthly Streamflow (cu. ft/s)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

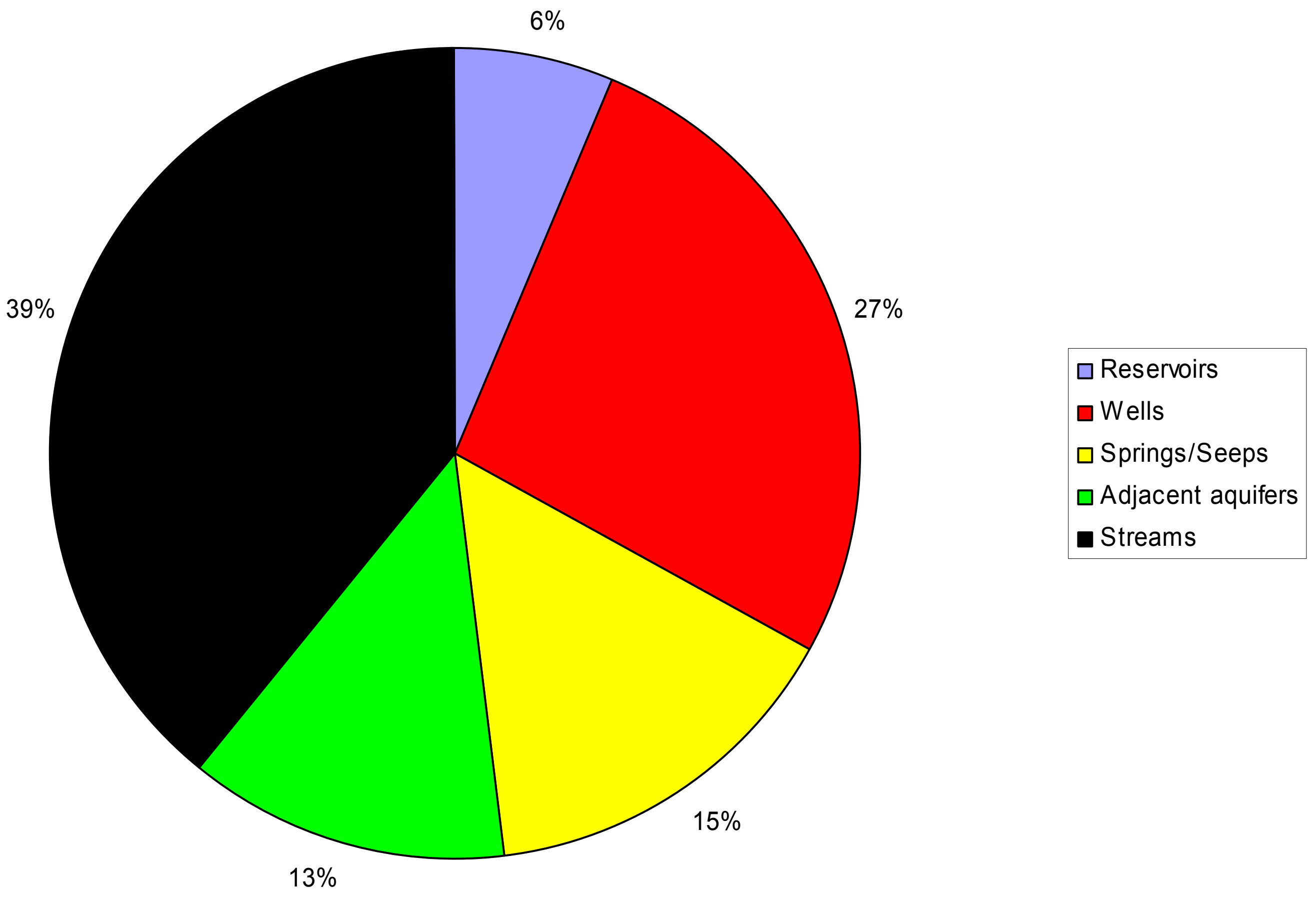

Devil's River at Pafford Crossing
Av. Monthly Streamflow (cu. ft/s)
3,000
2,500
2,000
1,500
1,000
500
0
Jan-80
Jan-84
Jan-88


Pecos River near Girvin
Av. Monthly Streamflow (cu. ft/s)
700
600
500
400
300
200
100
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

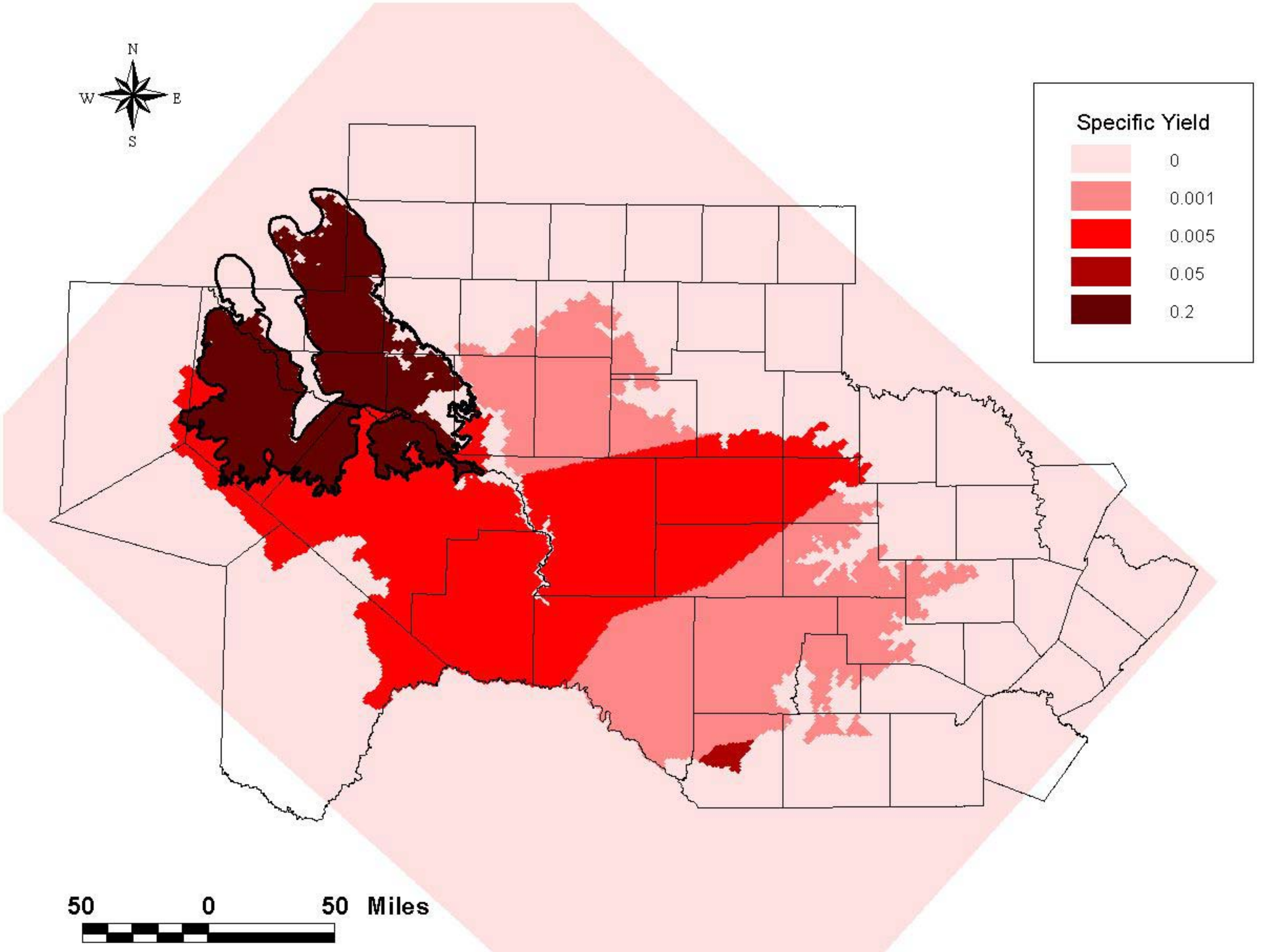

Pecos River near Langtry
Av. Monthly Streamflow (cu. ft/s)
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan-80
Jan-84
Jan-88


Water Budget (Recharge): 1980
2%
10%
2%
86%
Reservoirs
Recharge
Adjacent aquifers
Streams

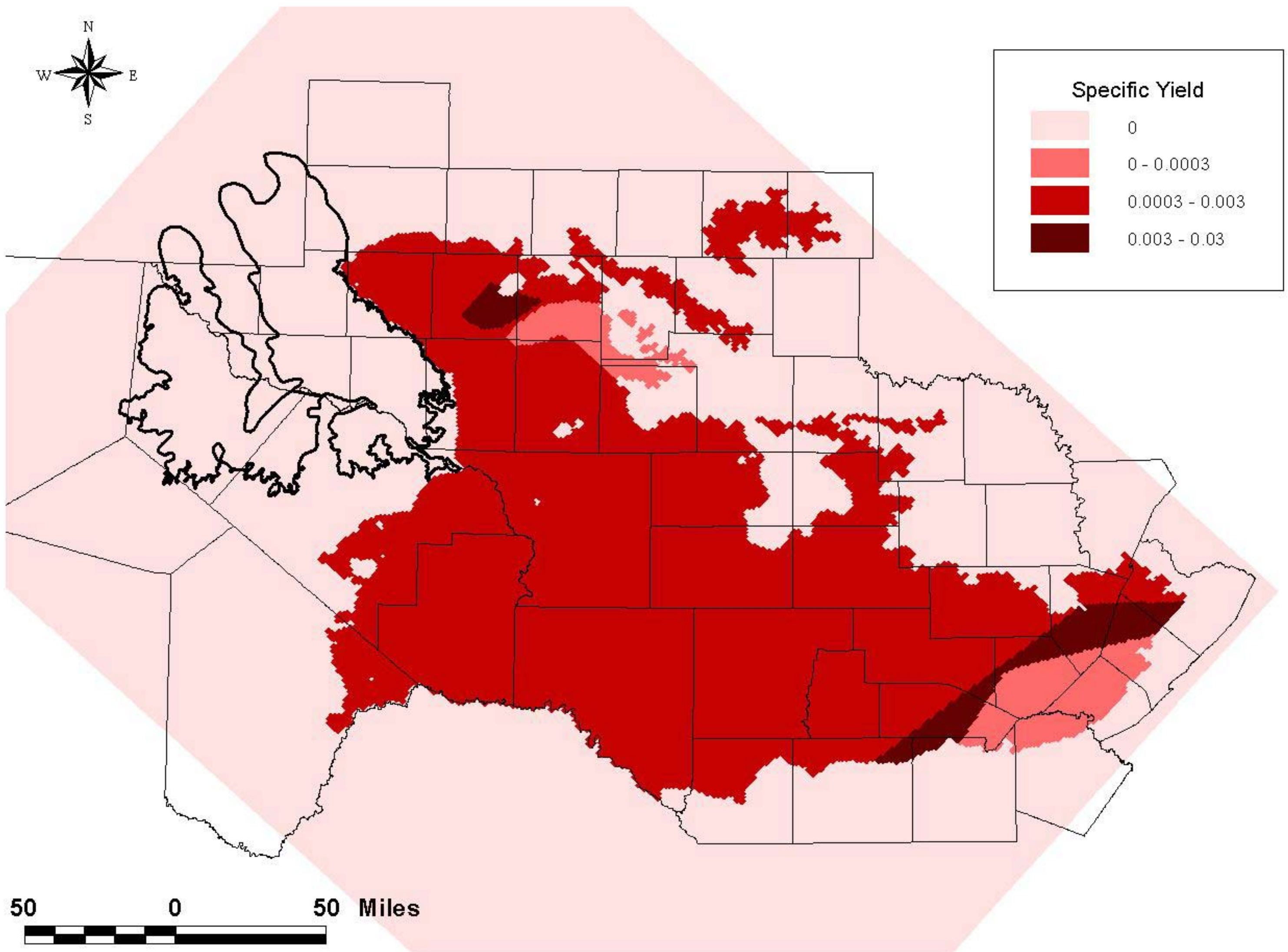
Water Budget (Discharge): 1980

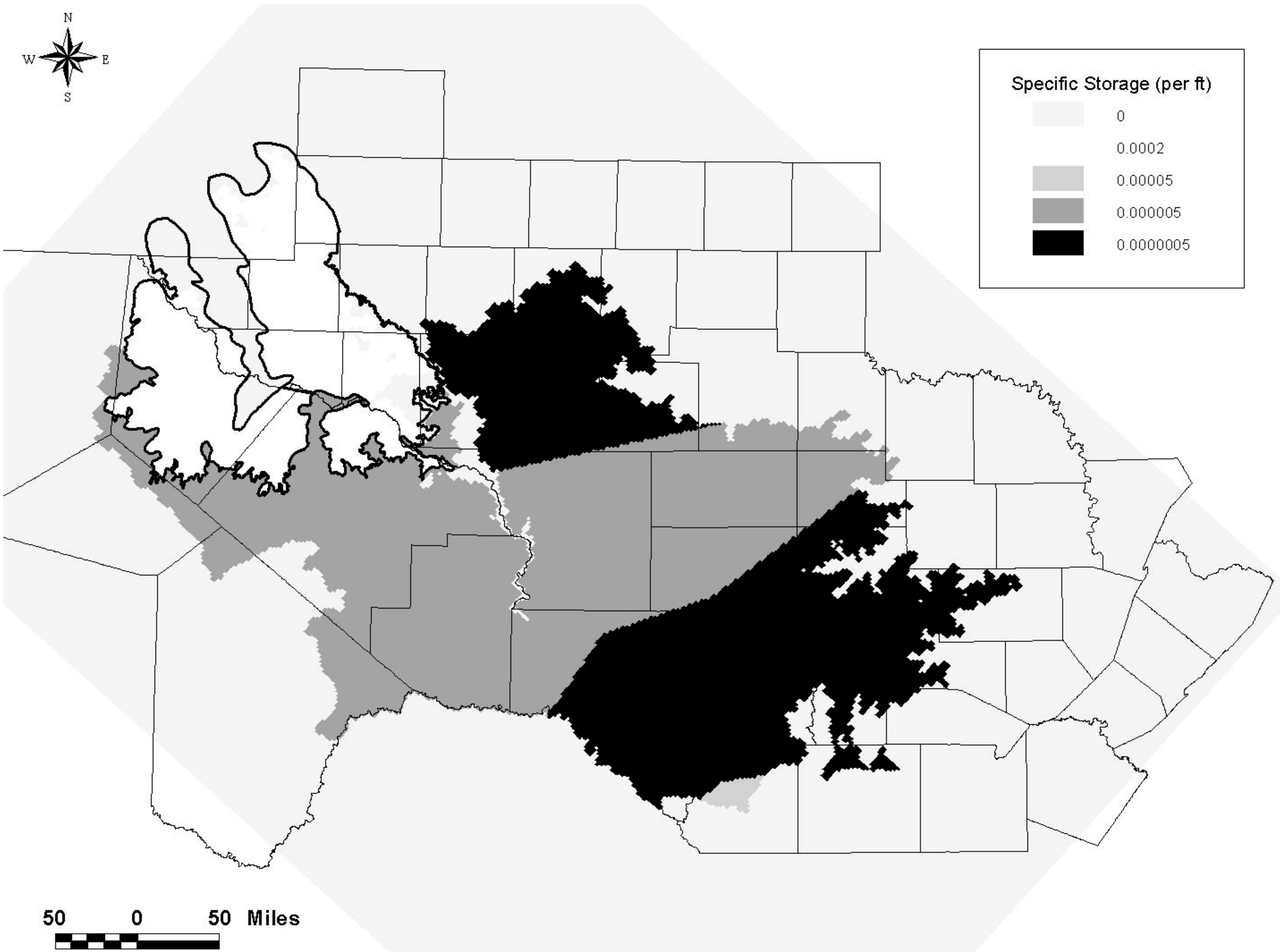


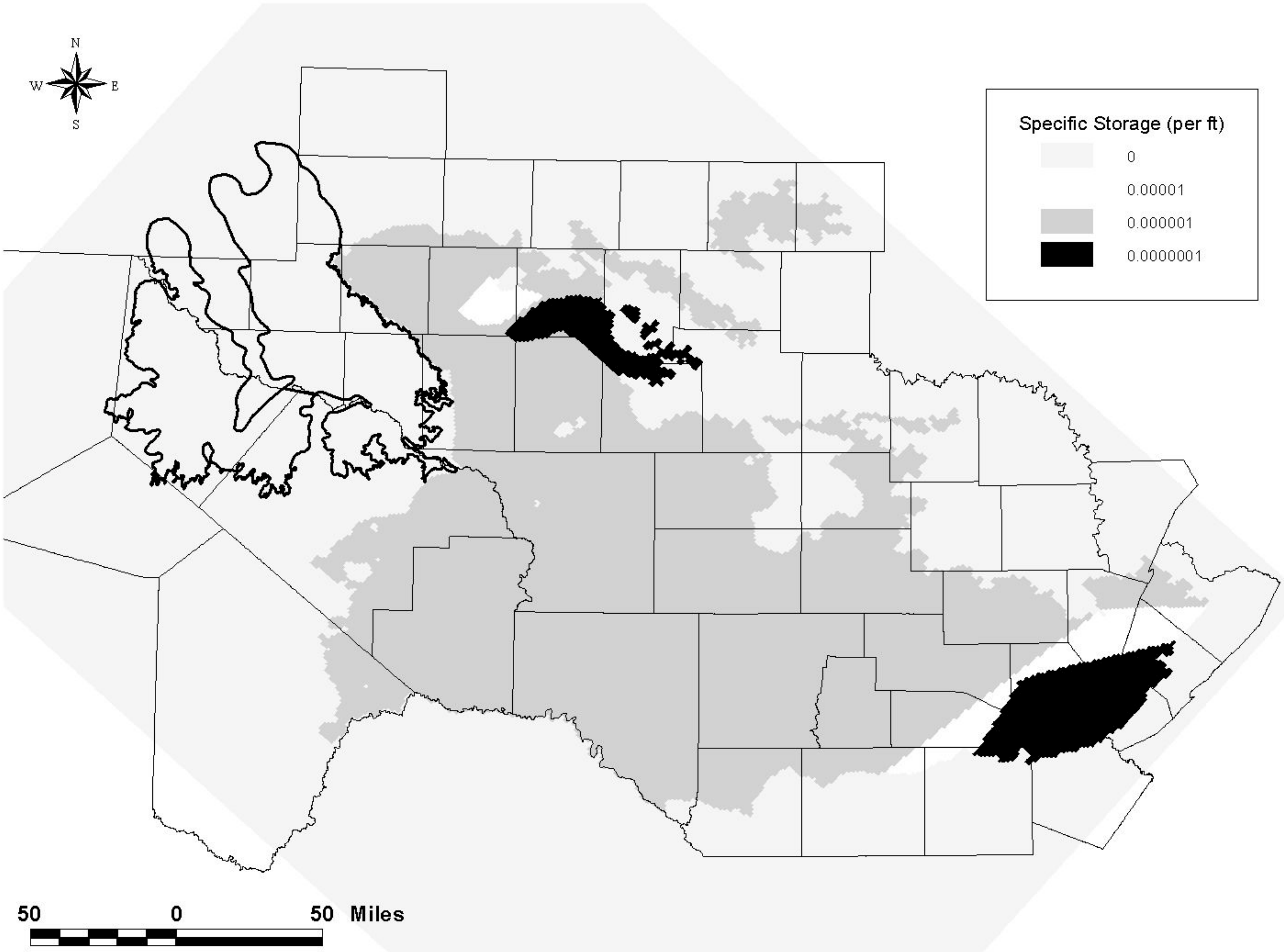
TRANSIENT CALIBRATION

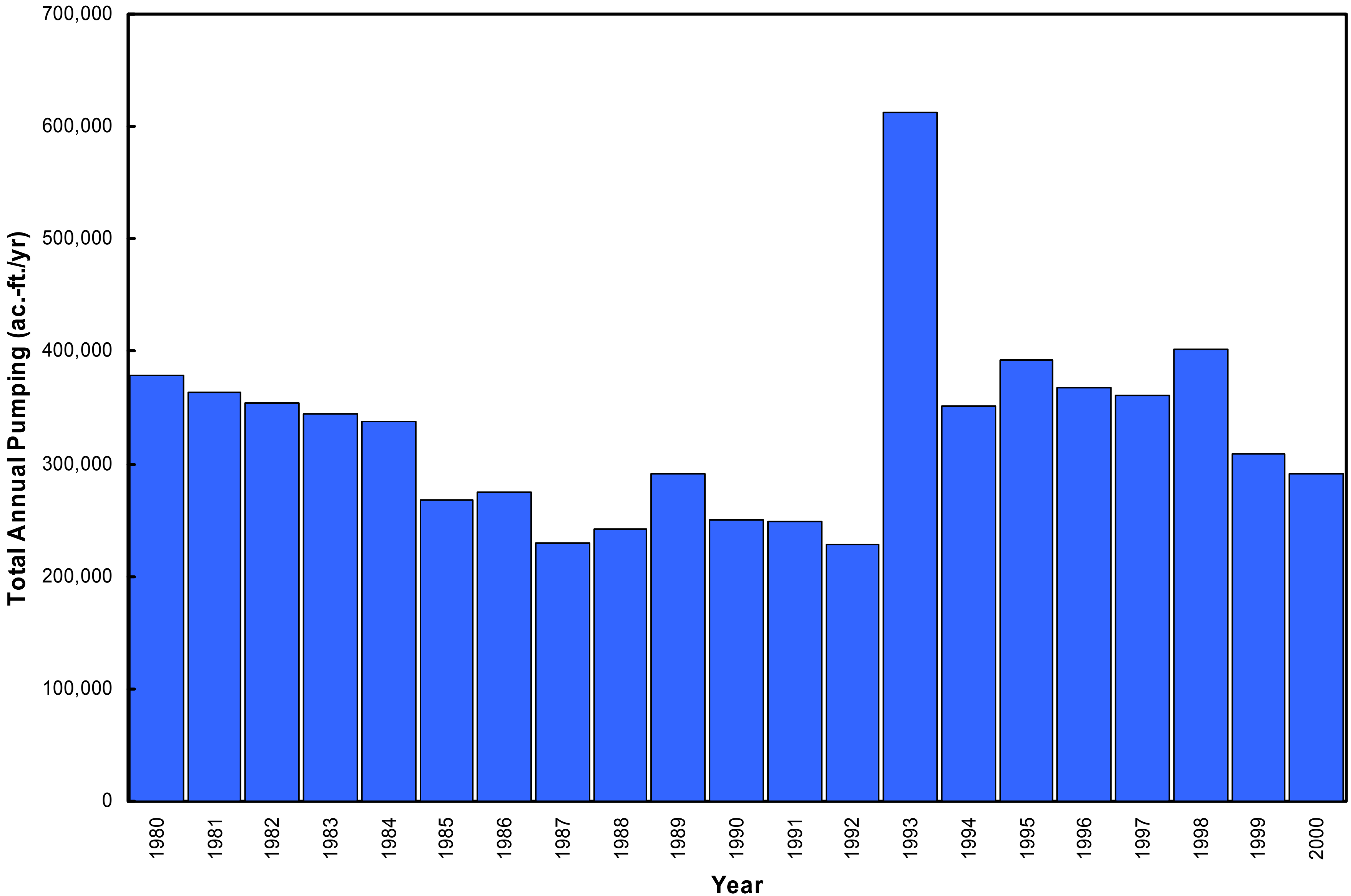


N
W
E
S
Specific Yield
0
0.001
0.005
0.05
0.2
50
0
50
Miles

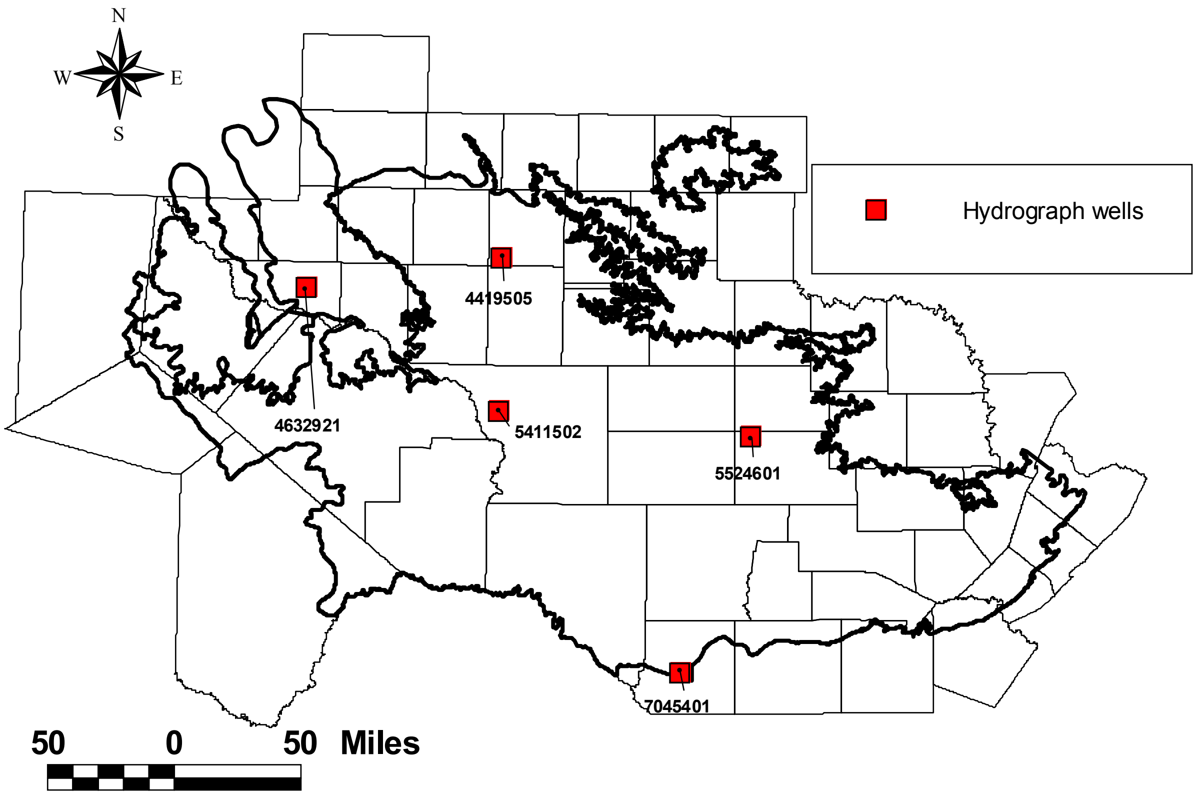

N
W
E
S
Specific Yield
0
0 - 0.0003
0.0003 - 0.003
0.003 - 0.03
50
0
50 Miles

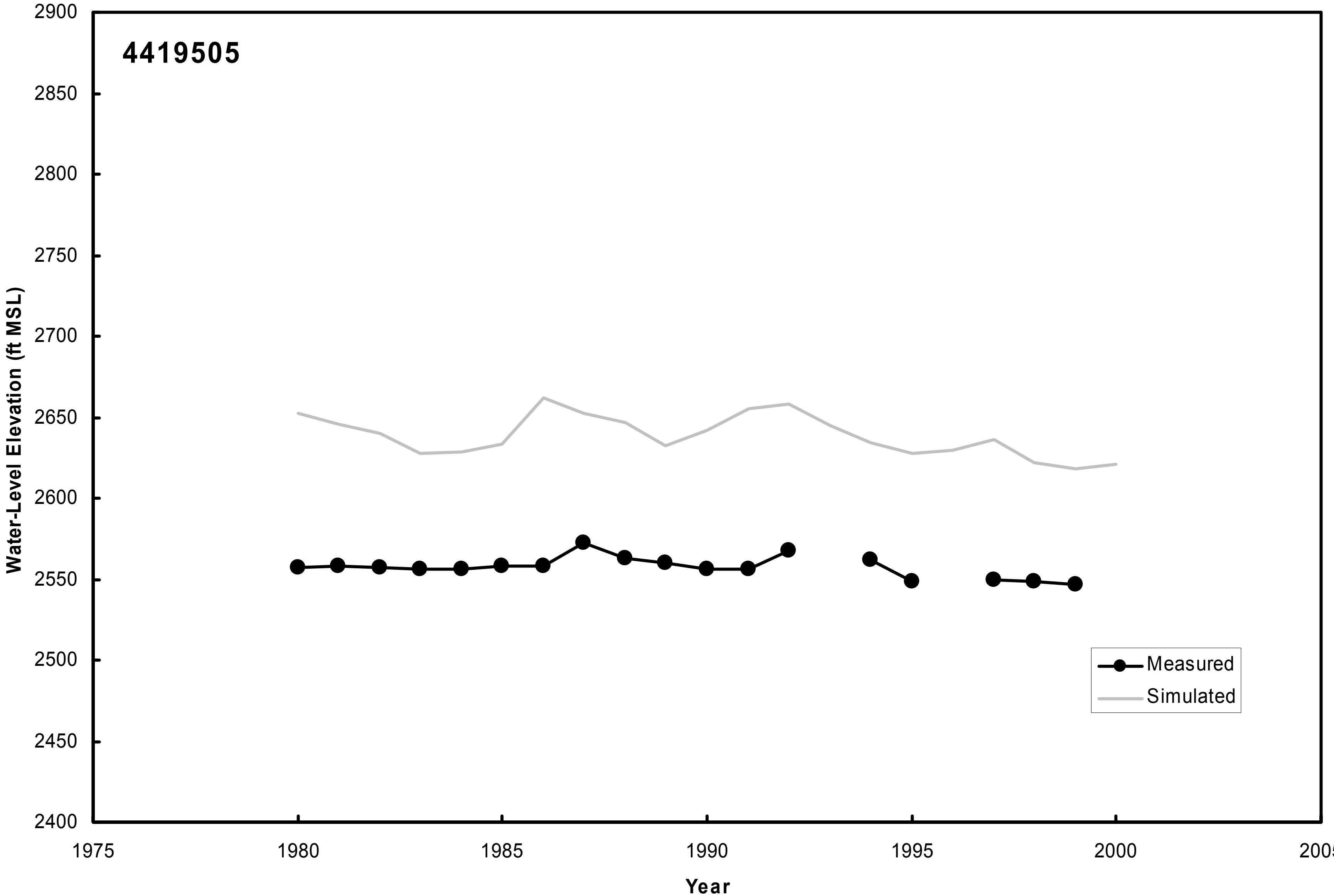

N
W
E
S
Specific Storage (per ft)
0
0.0002
0.00005
0.000005
0.0000005
50
0
50
Miles


N
S
W
E
Specific Storage (per ft)
0
0.00001
0.000001
0.0000001
50
0
50 Miles

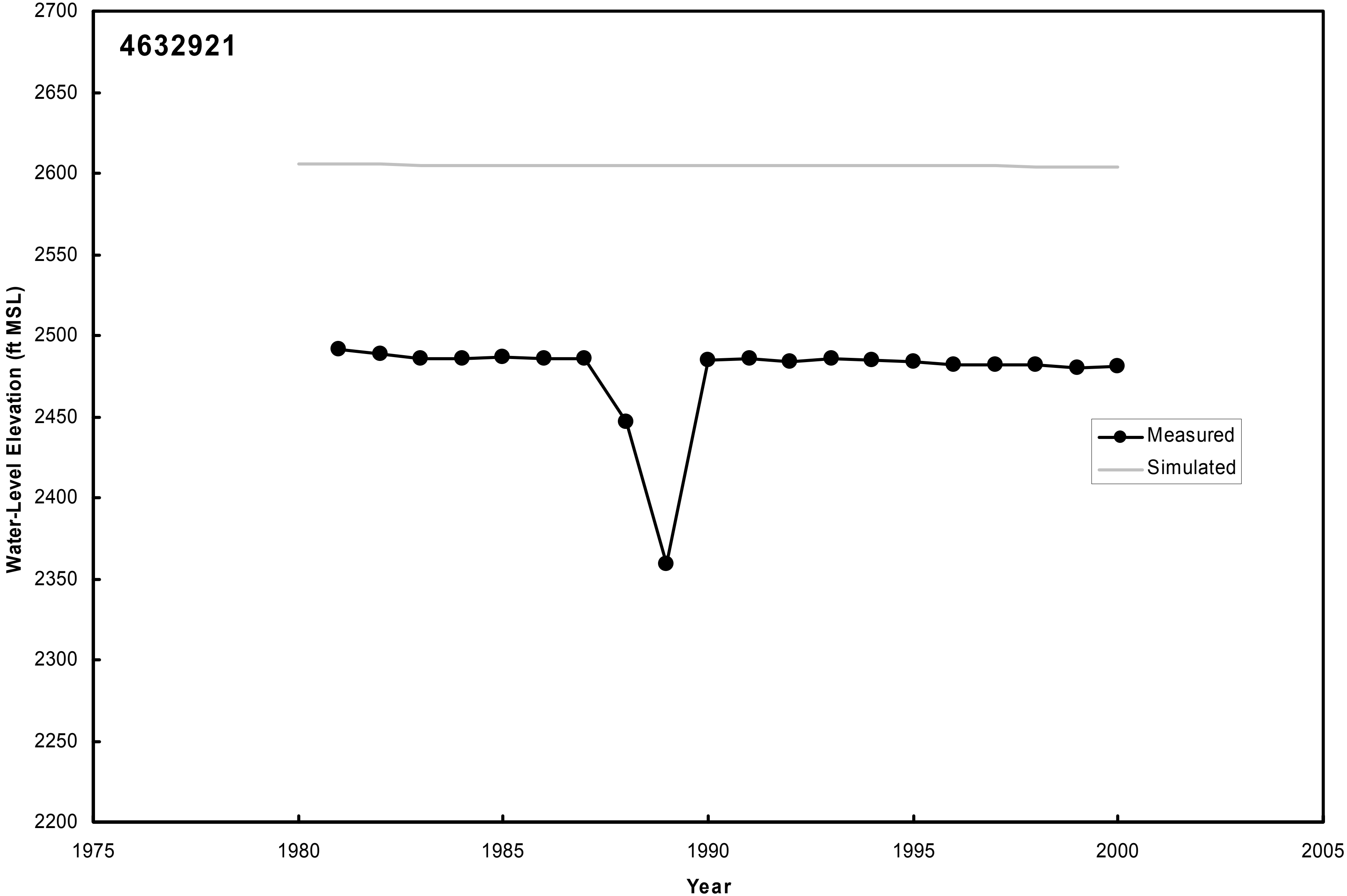


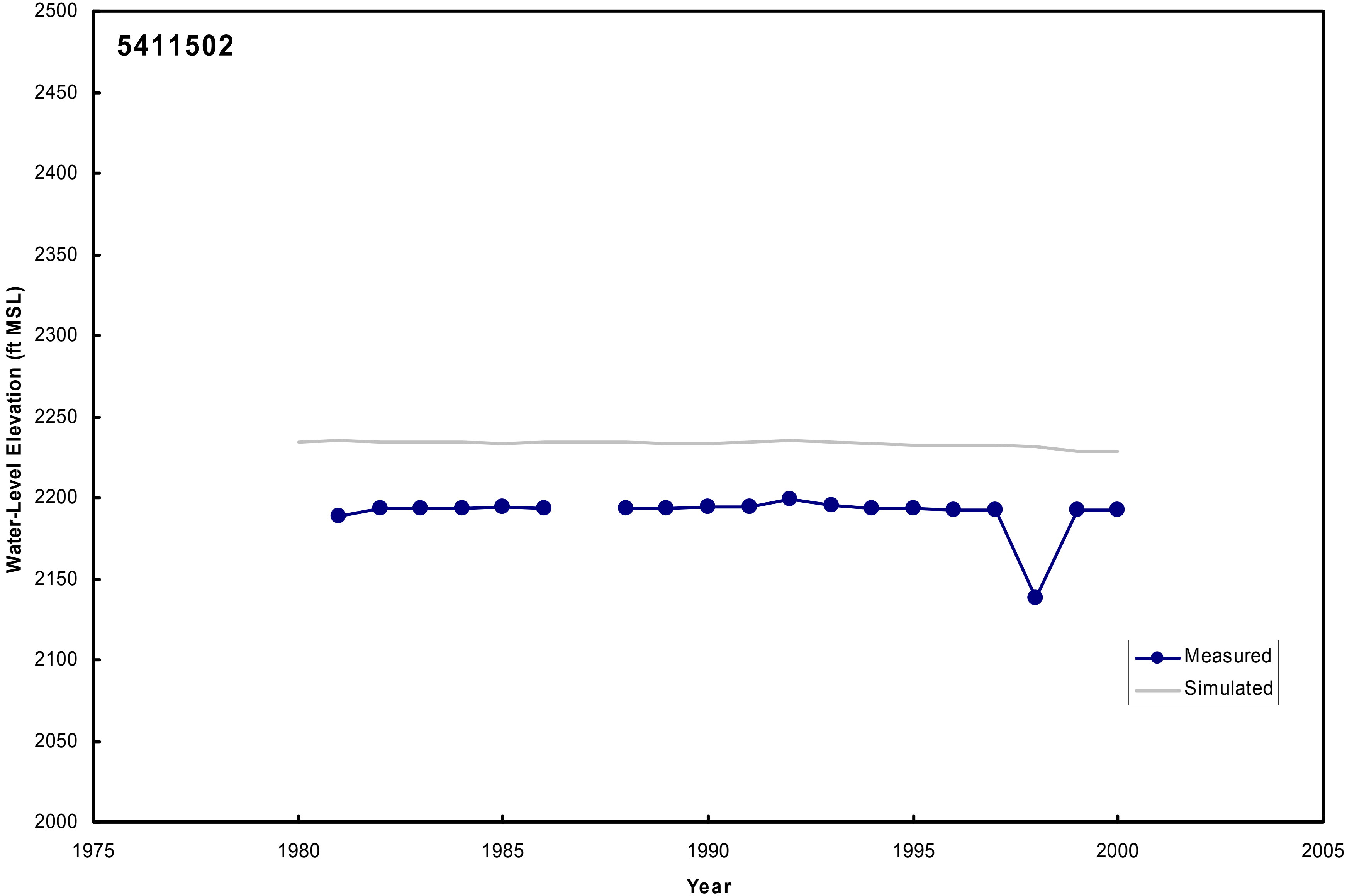
Total Annual Pumping (ac.-ft./yr)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year


N
S
W
E
Hydrograph wells
4419505
4632921
5411502
5524601
7045401
50
0
50
Miles

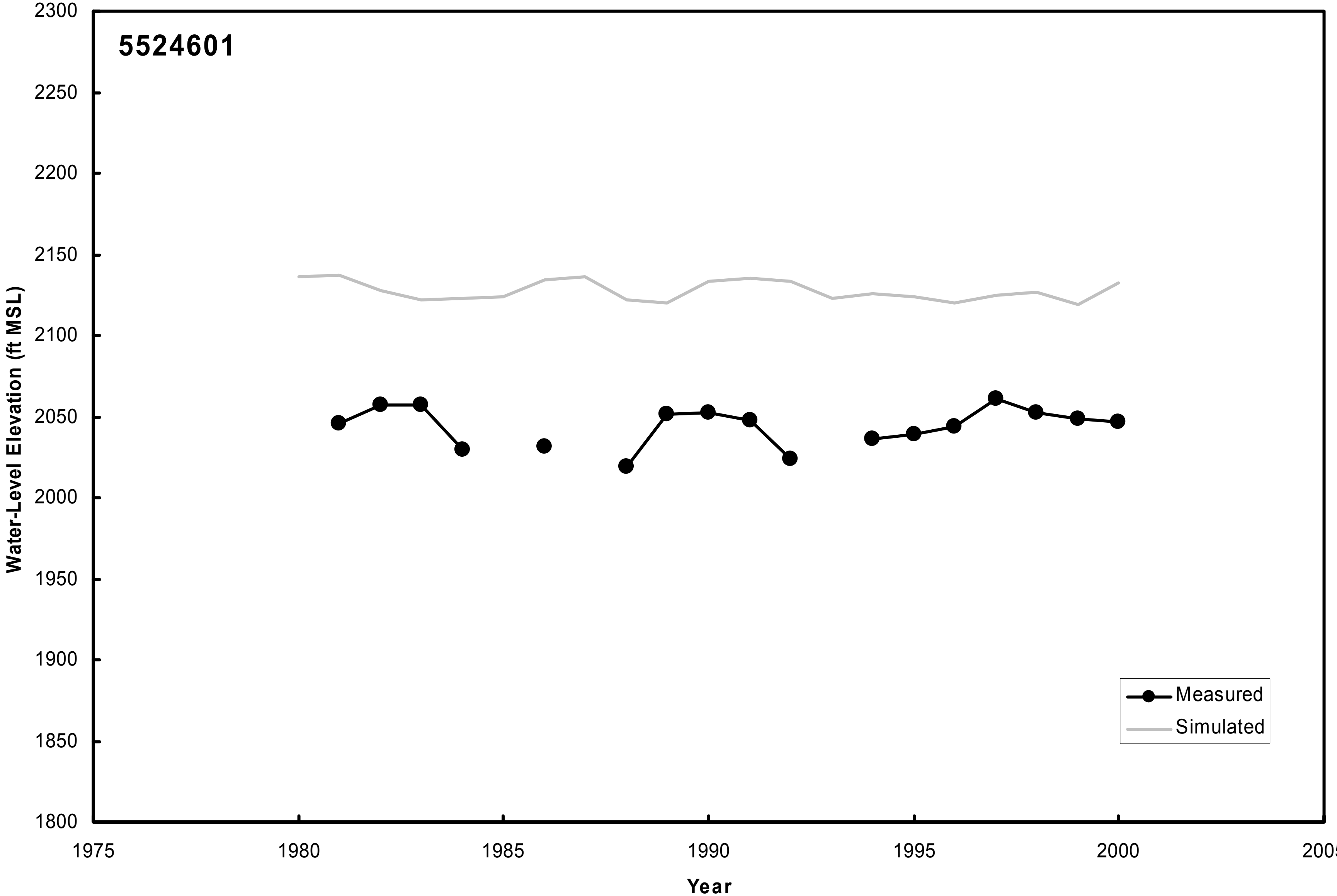


4419505
Water-Level Elevation (ft MSL)
2900
2850
2800
2750
2700
2650
2600
2550
2500
2450
2400
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

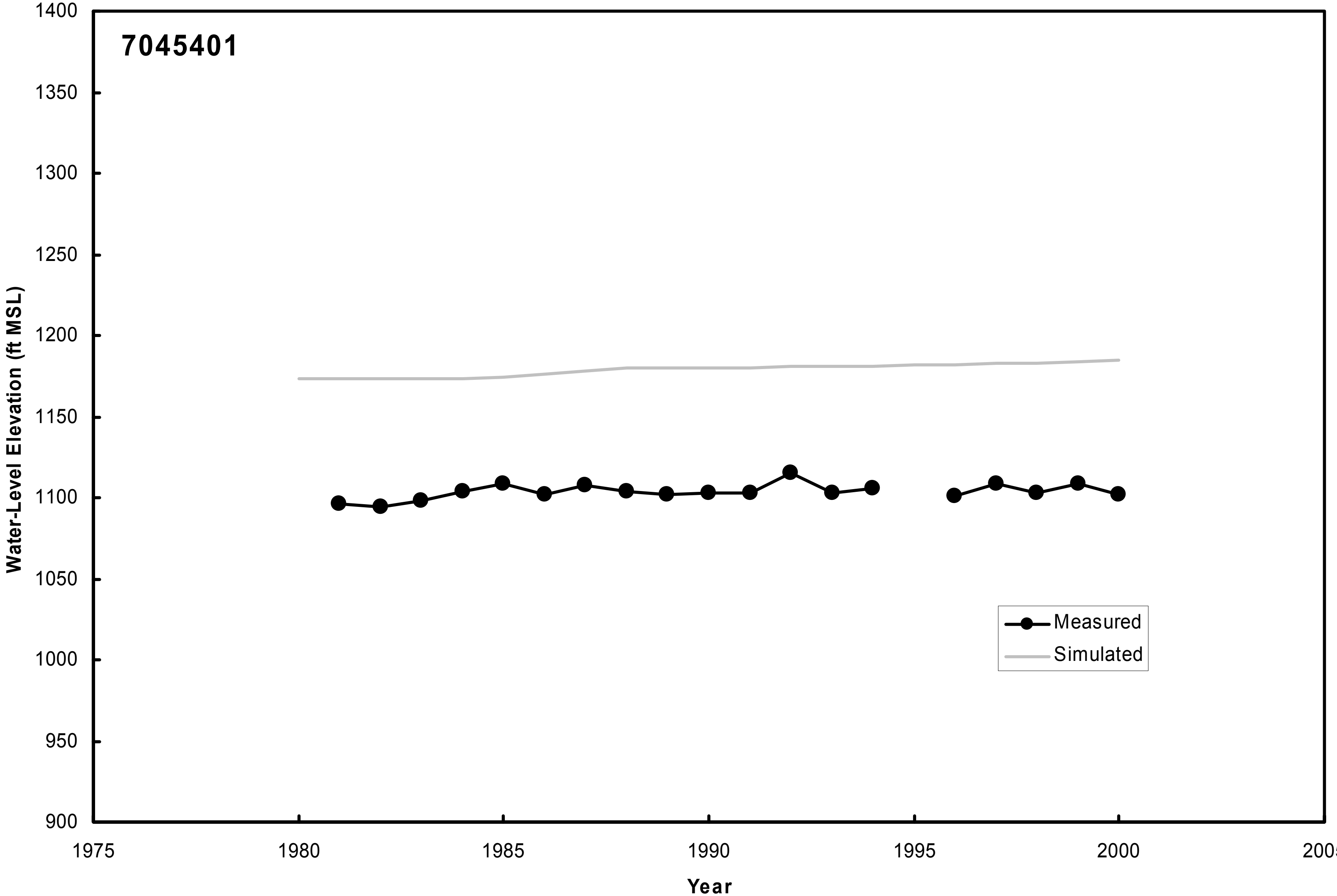

4632921
Water-Level Elevation (ft MSL)
Year
2700
2650
2600
2550
2500
2450
2400
2350
2300
2250
2200
1975
1980
1985
1990
1995
2000
2005
Measured
Simulated

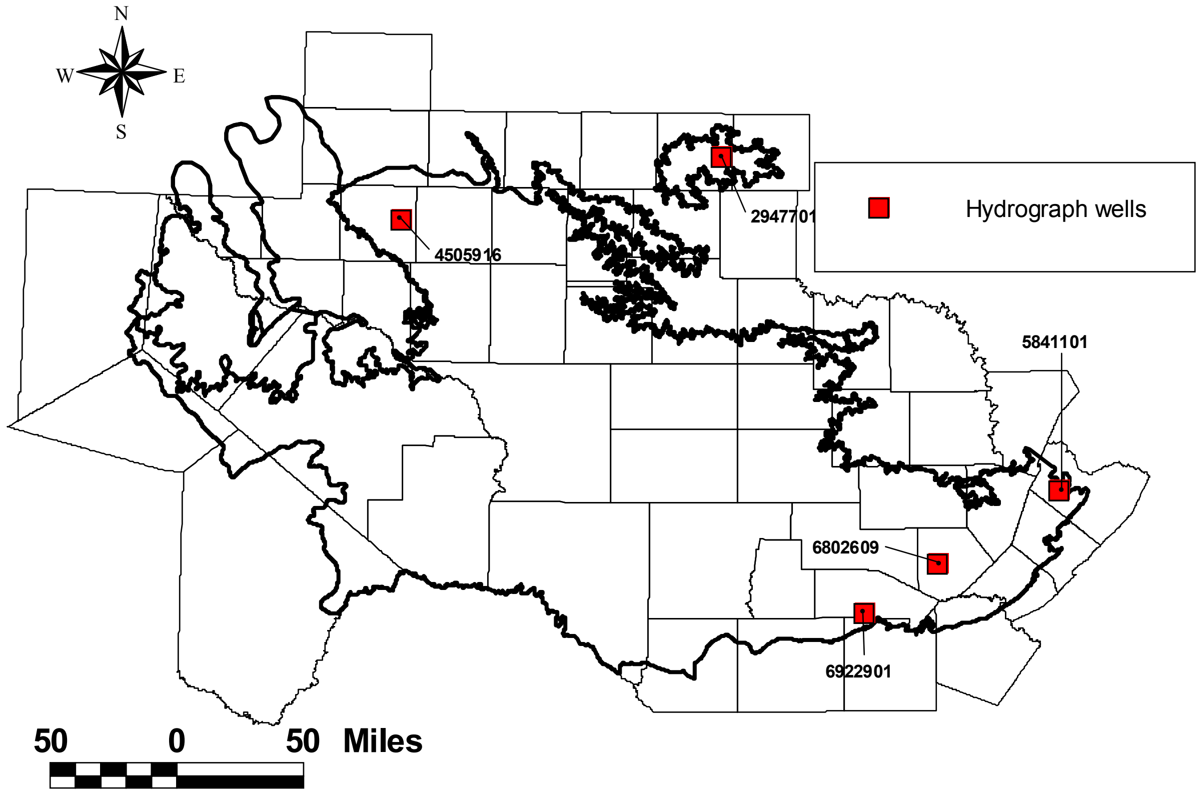


5411502
Water-Level Elevation (ft MSL)
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

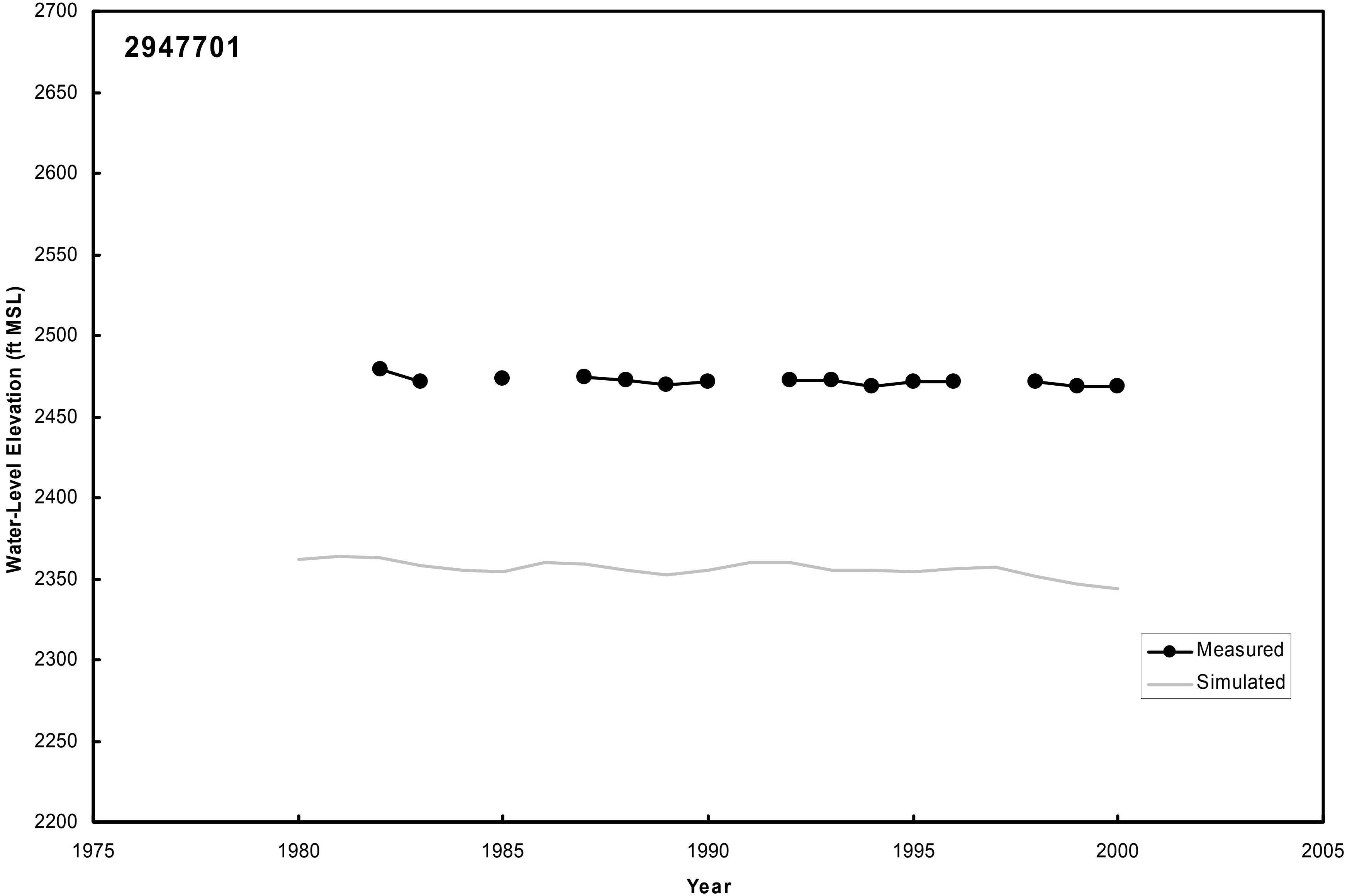


5524601
Water-Level Elevation (ft MSL)
Year
2300
2250
2200
2150
2100
2050
2000
1950
1900
1850
1800
1975
1980
1985
1990
1995
2000
2005
Measured
Simulated

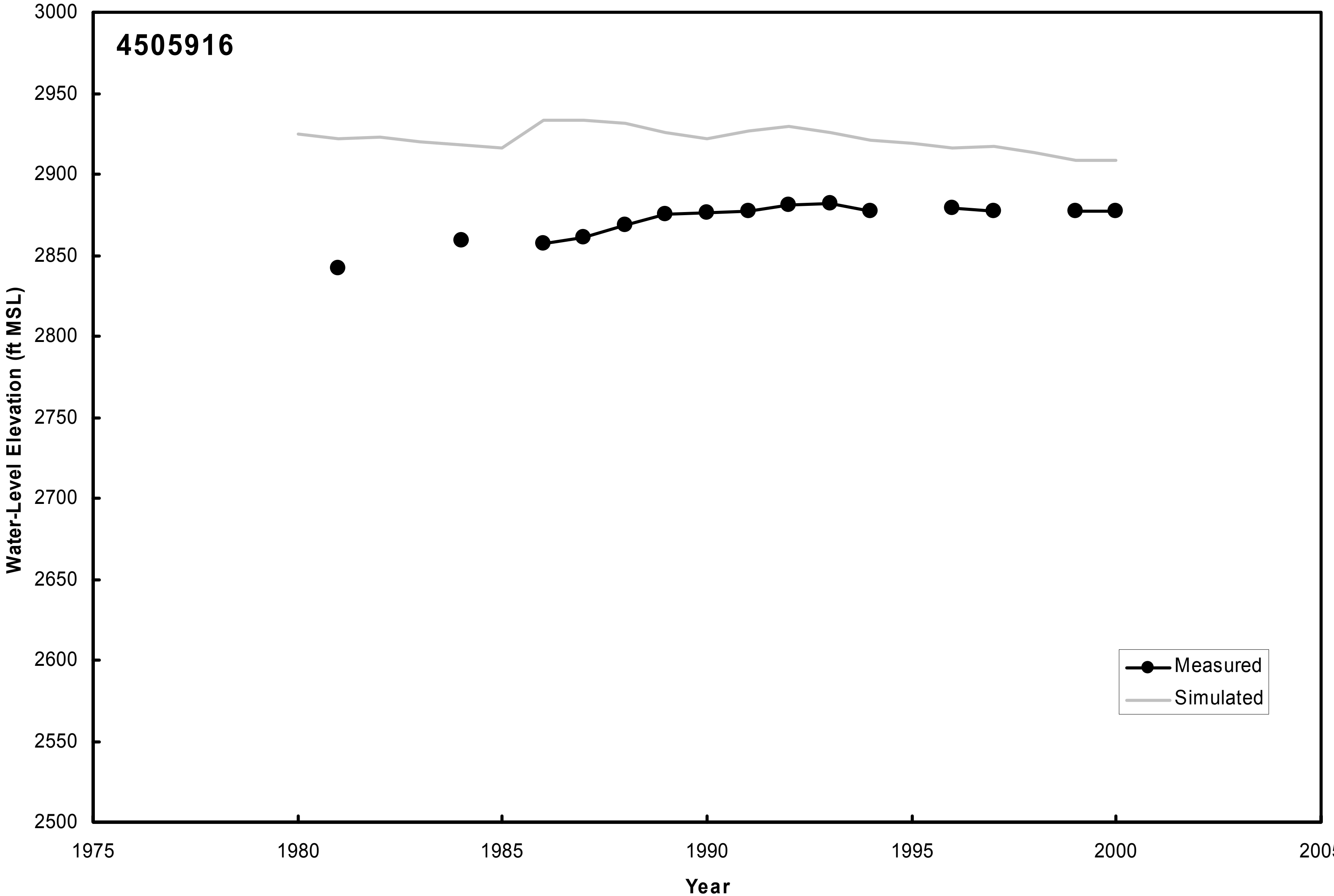

7045401
Water-Level Elevation (ft MSL)
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

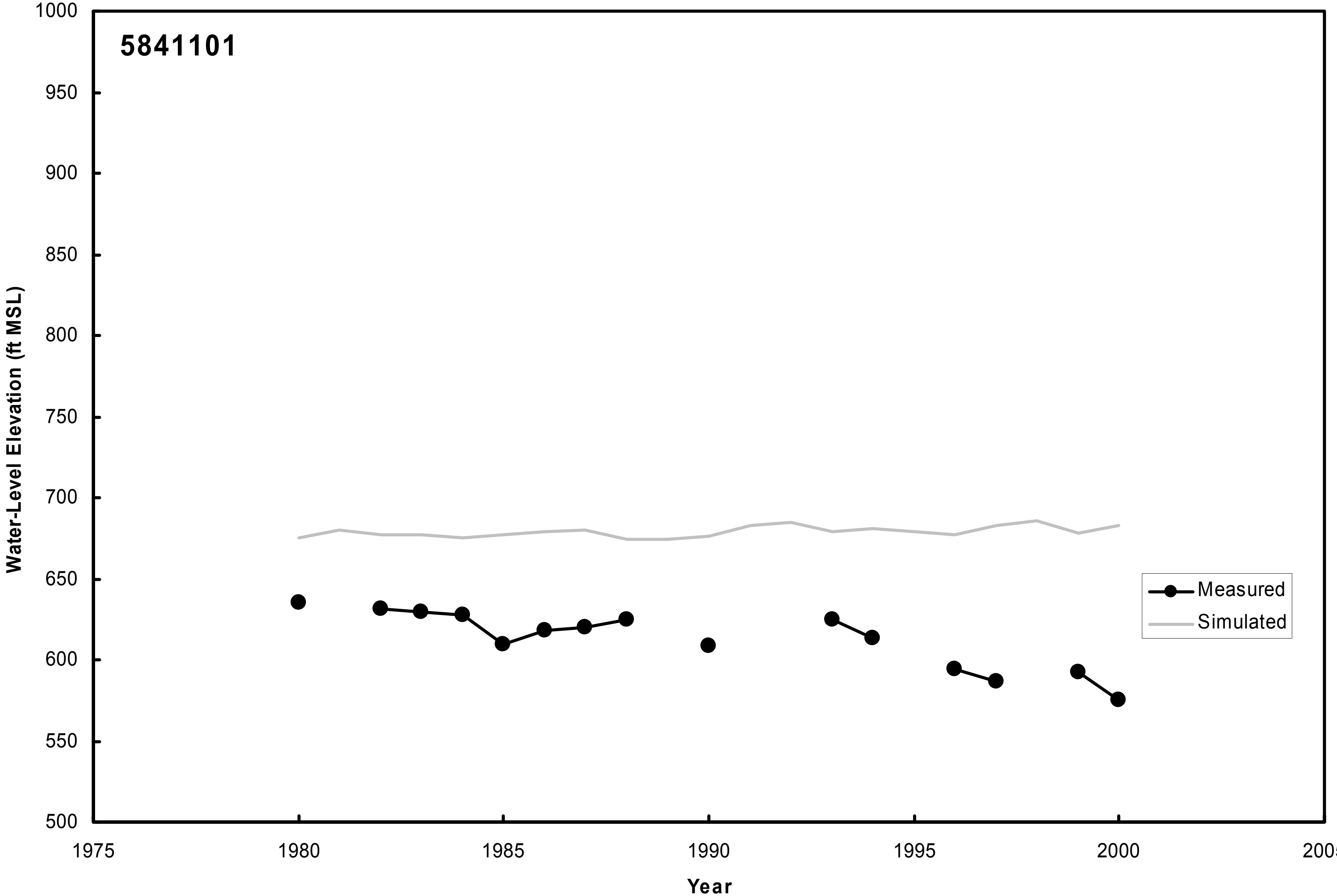


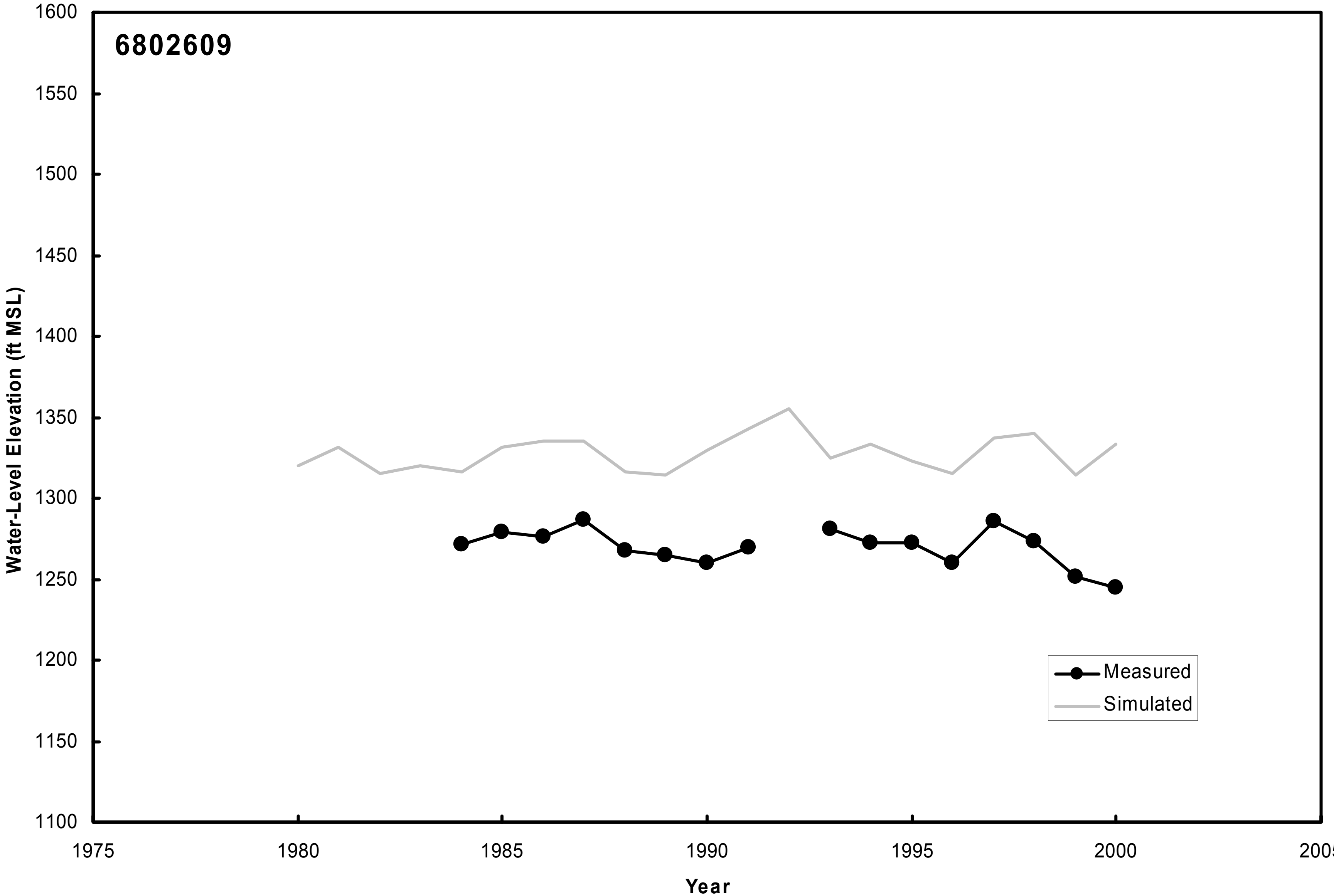
N
W
E
S
Hydrograph wells
4505916
2947701
5841101
6802609
6922901
50 0 50 Miles



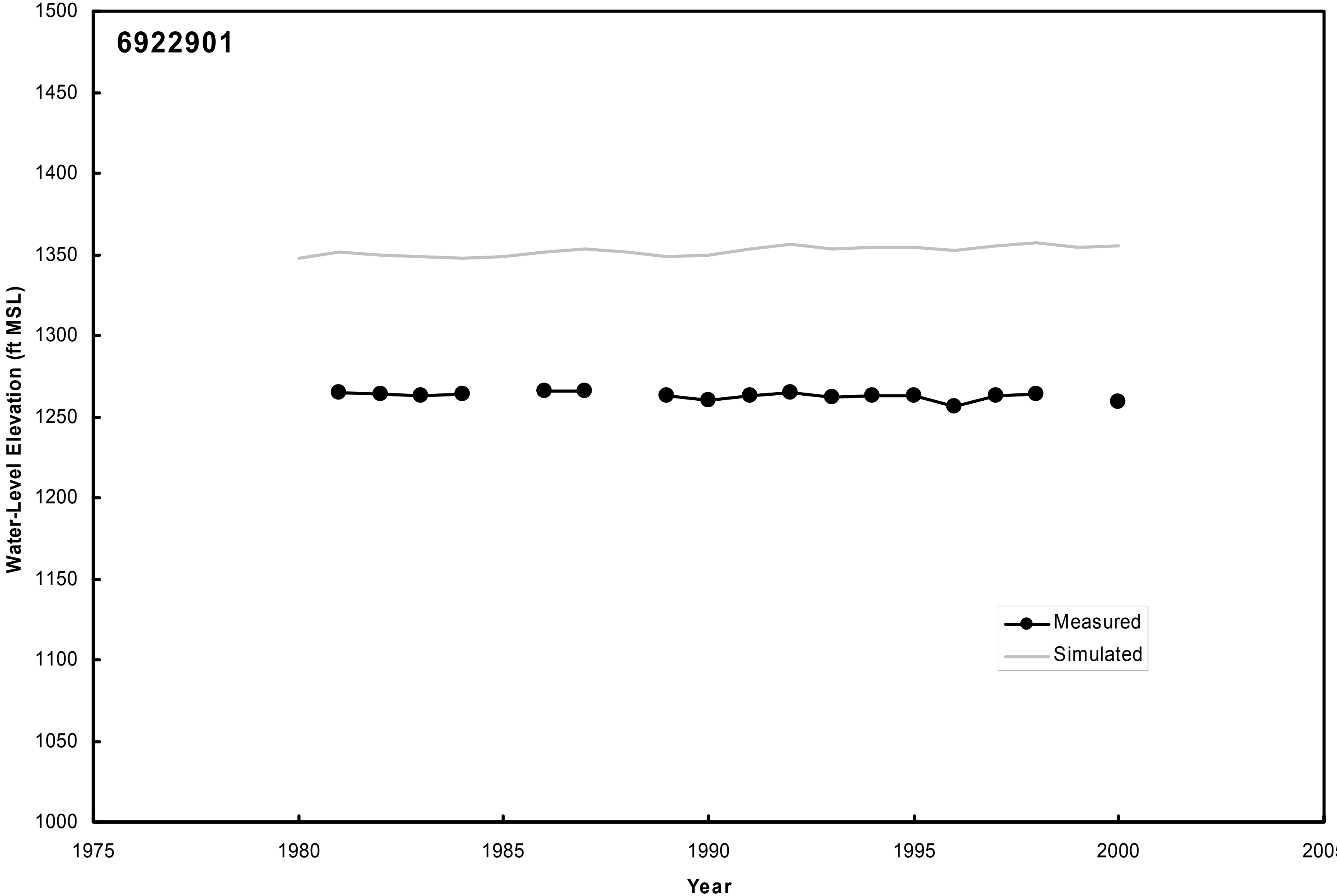
2947701
Water-Level Elevation (ft MSL)
Year
2700
2650
2600
2550
2500
2450
2400
2350
2300
2250
2200
1975
1980
1985
1990
1995
2000
2005
Measured
Simulated


4505916
Water-Level Elevation (ft MSL)
3000
2950
2900
2850
2800
2750
2700
2650
2600
2550
2500
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

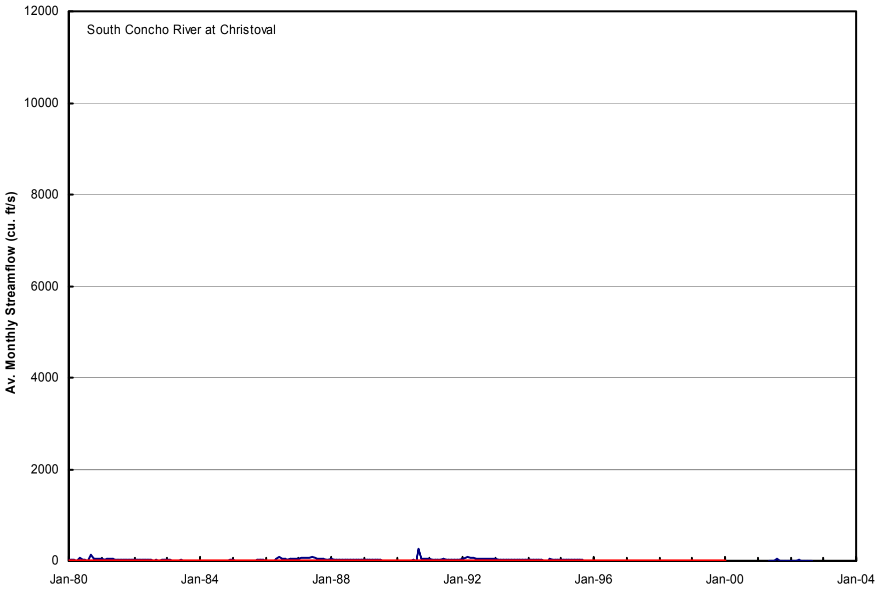

5841101
Water-Level Elevation (ft MSL)
1000
950
900
850
800
750
700
650
600
550
500
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

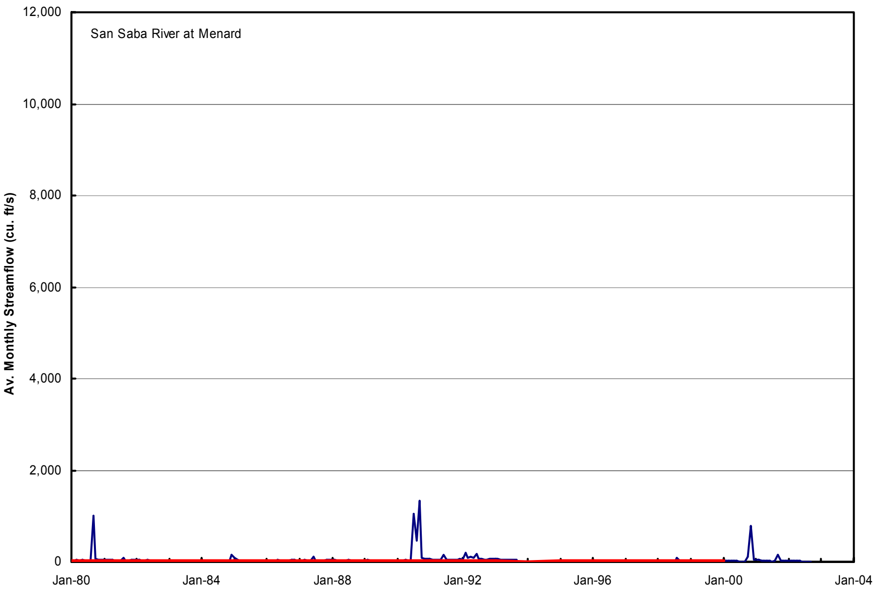


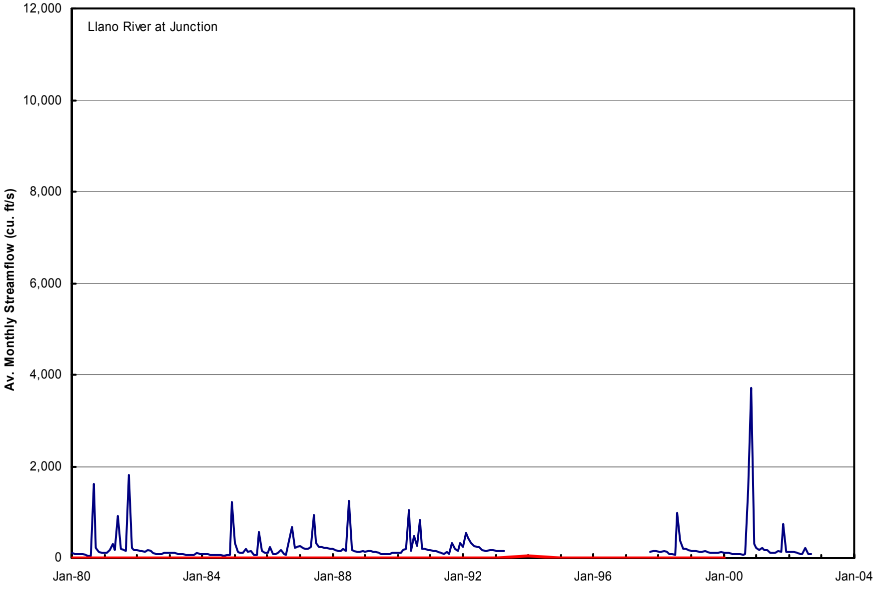
6802609
Water-Level Elevation (ft MSL)
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

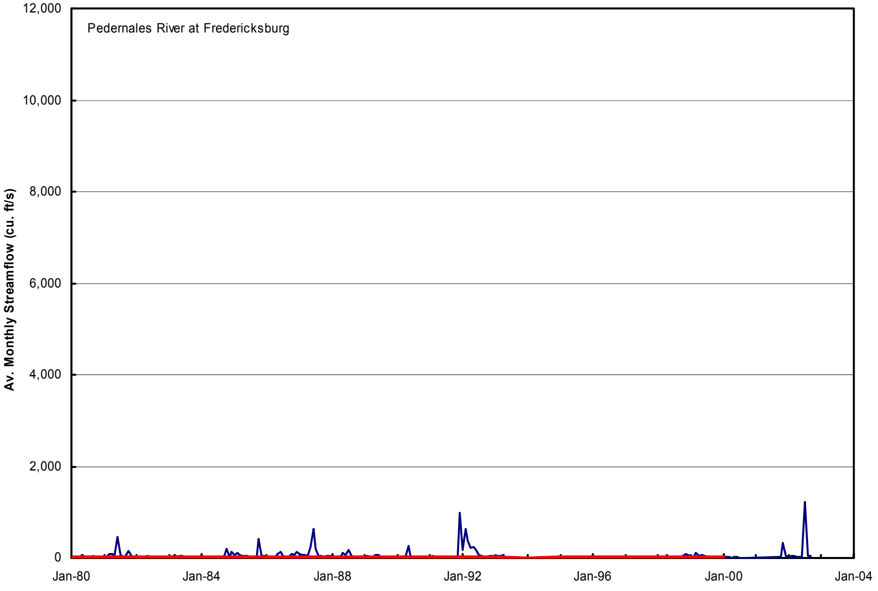


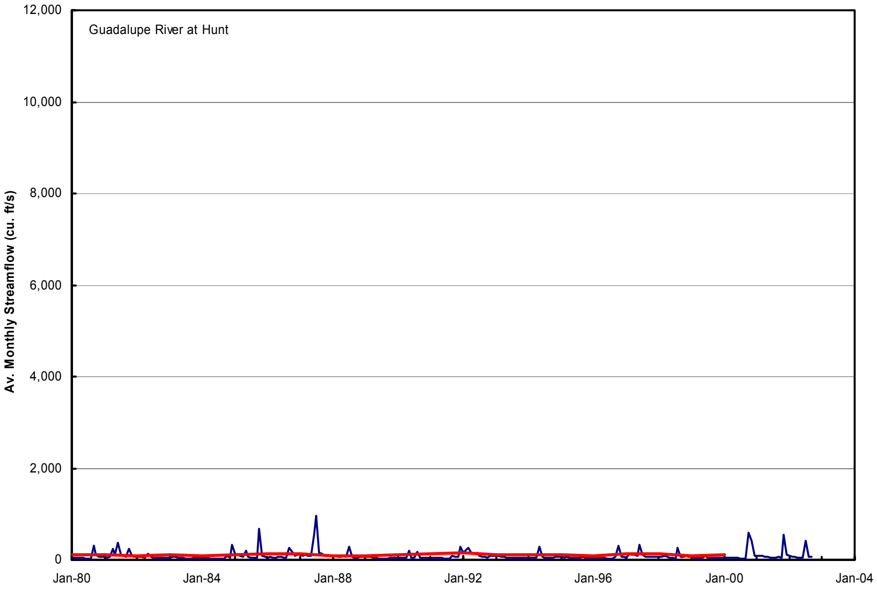
6922901
Water-Level Elevation (ft MSL)
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
1975
1980
1985
1990
1995
2000
2005
Year
Measured
Simulated

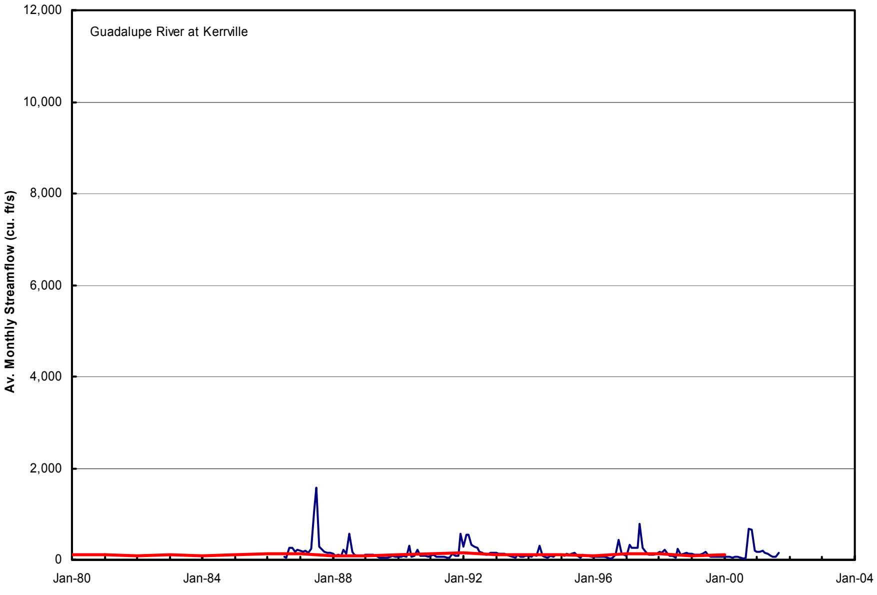

South Concho River at Christoval
Av. Monthly Streamflow (cu. ft/s)
12000
10000
8000
6000
4000
2000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

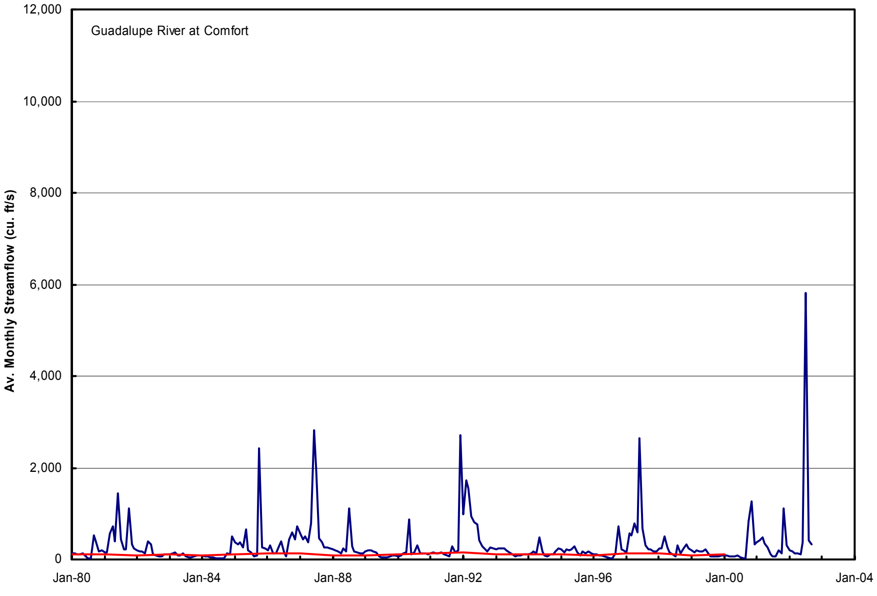

San Saba River at Menard
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

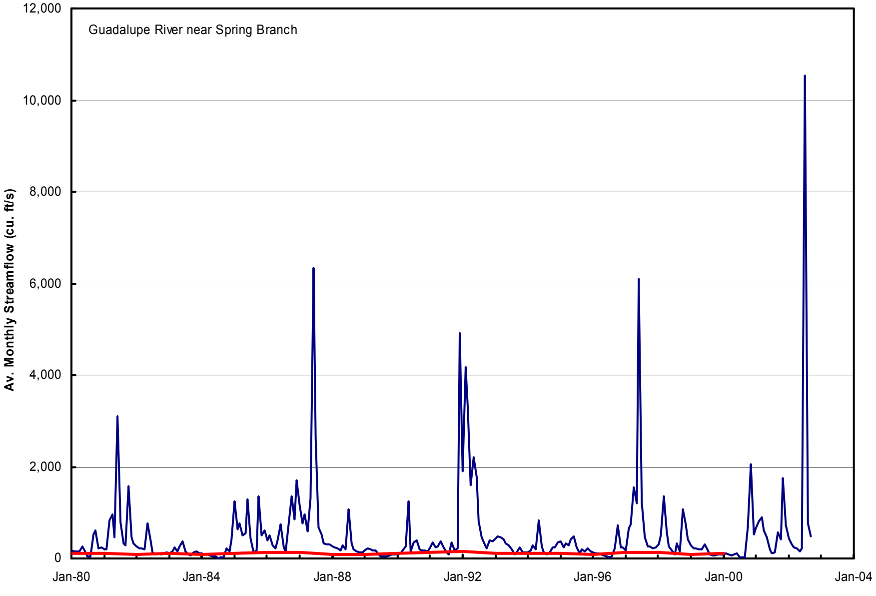

Llano River at Junction
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

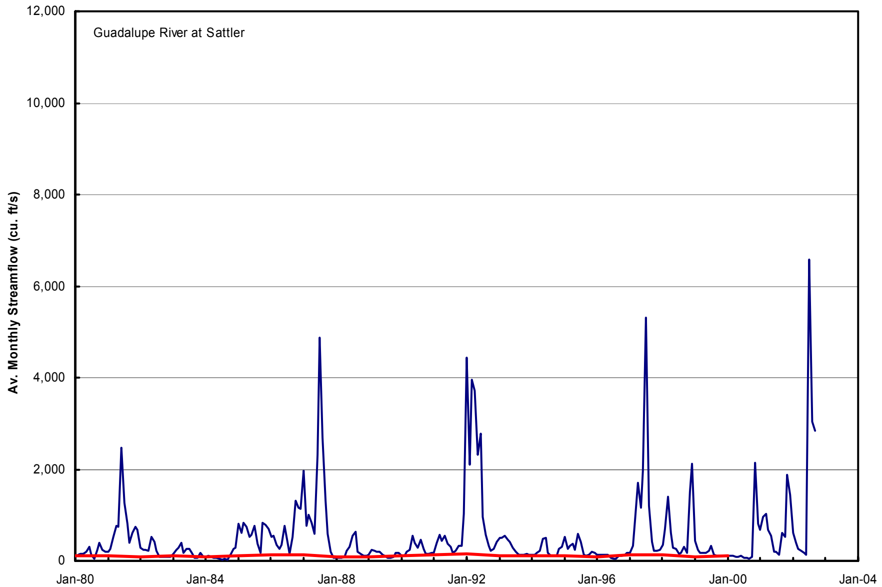

Pedernales River at Fredericksburg
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

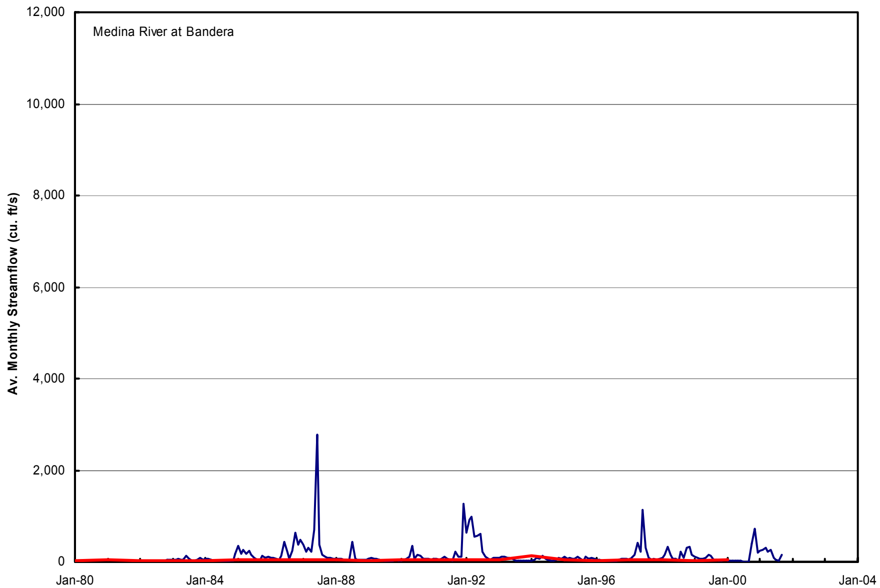

Guadalupe River at Hunt
Av. Monthly Streamflow (cu. ft/s)
0
2,000
4,000
6,000
8,000
10,000
12,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

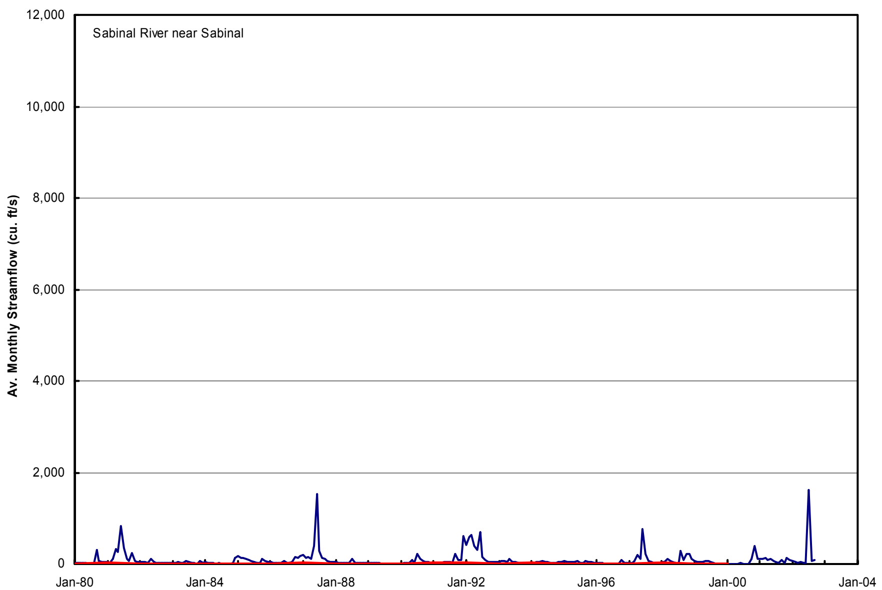

Guadalupe River at Kerrville
Av. Monthly Streamflow (cu. ft/s)
0
2,000
4,000
6,000
8,000
10,000
12,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

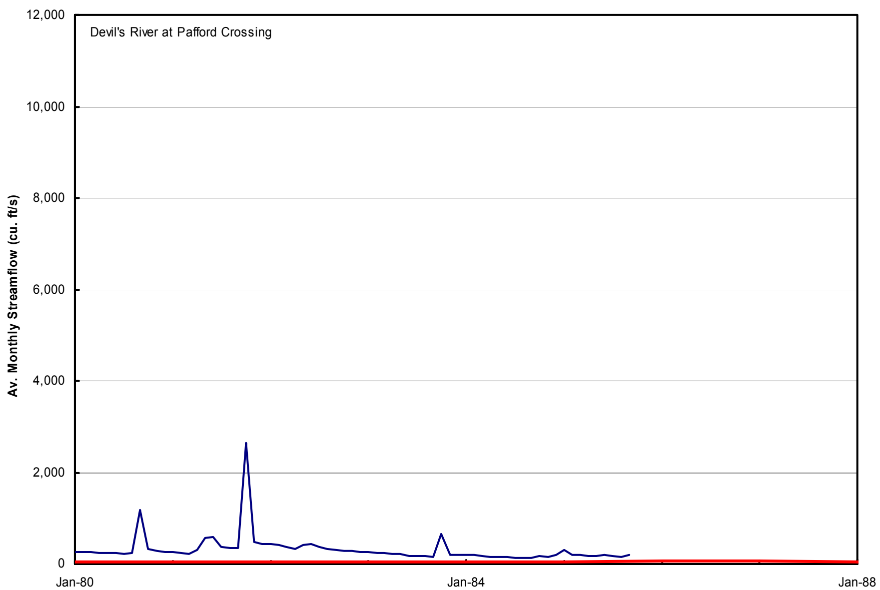

Guadalupe River at Comfort
Av. Monthly Streamflow (cu. ft/s)
0
2,000
4,000
6,000
8,000
10,000
12,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

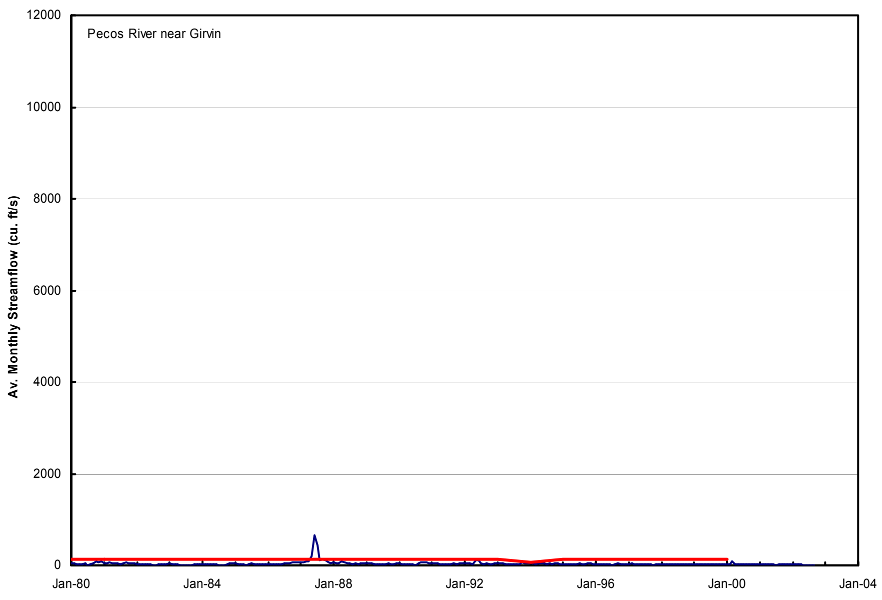

Guadalupe River near Spring Branch
Av. Monthly Streamflow (cu. ft/s)
0
2,000
4,000
6,000
8,000
10,000
12,000
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04


Guadalupe River at Sattler
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

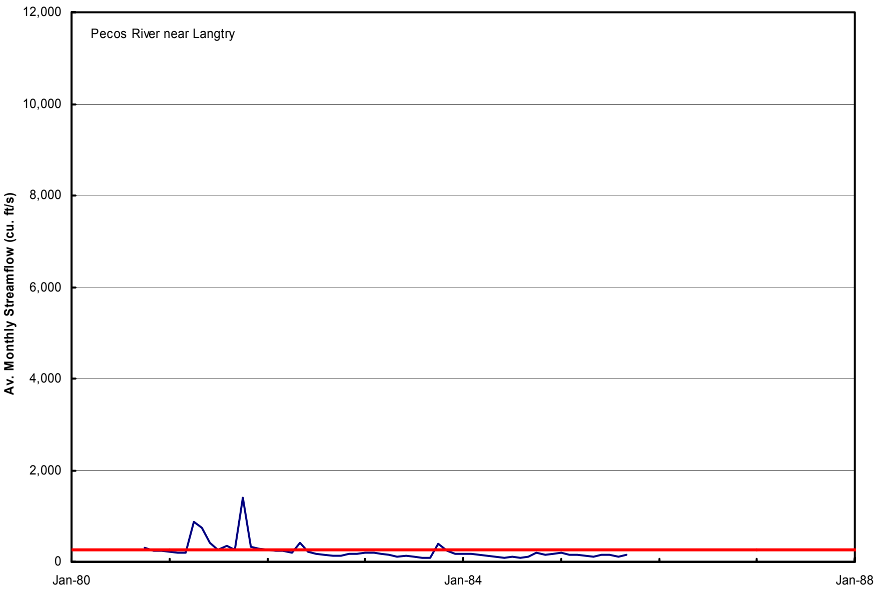

Medina River at Bandera
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04


Sabinal River near Sabinal
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04


Devil's River at Pafford Crossing
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88

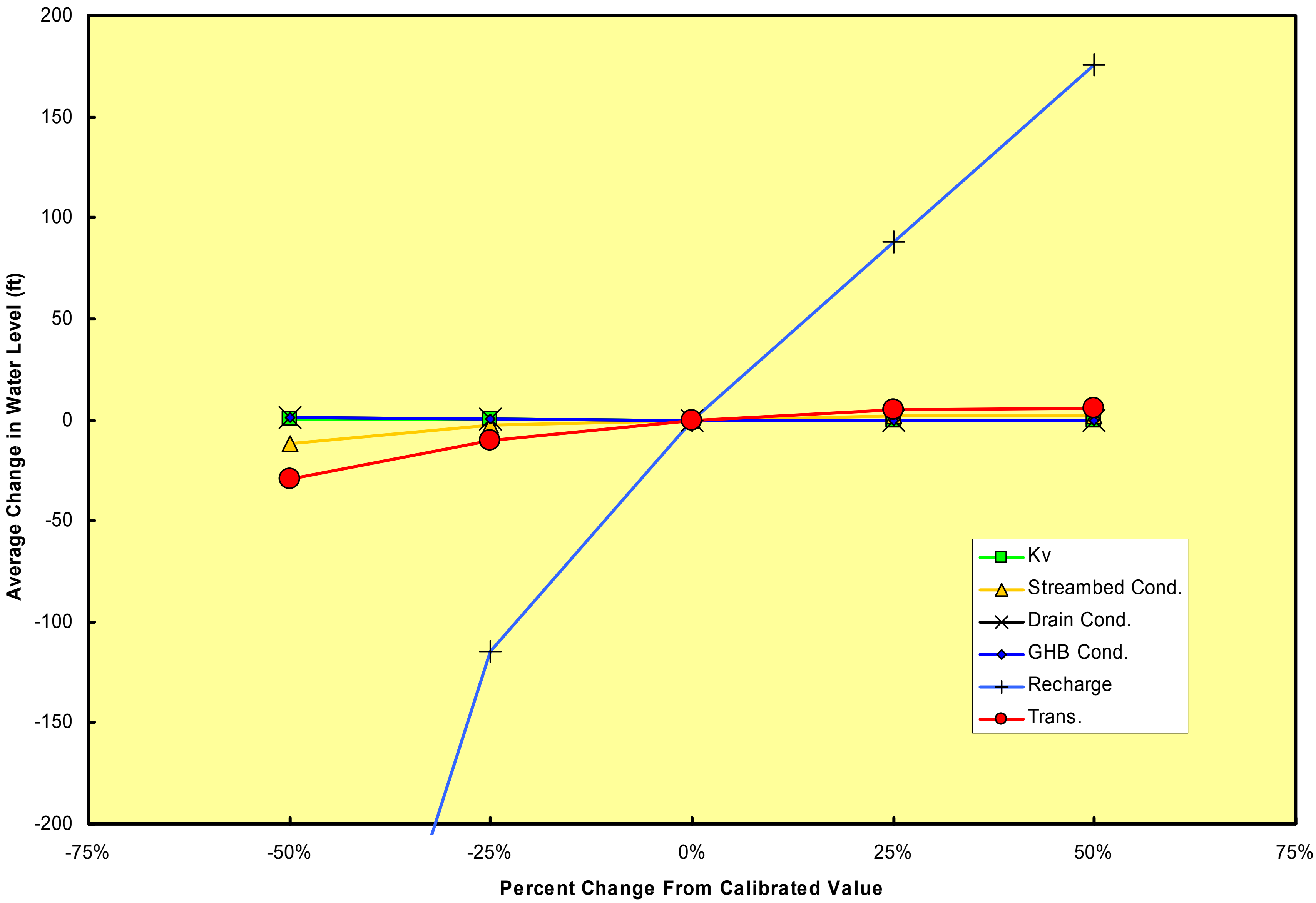


Pecos River near Girvin
Av. Monthly Streamflow (cu. ft/s)
12000
10000
8000
6000
4000
2000
0
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Jan-04

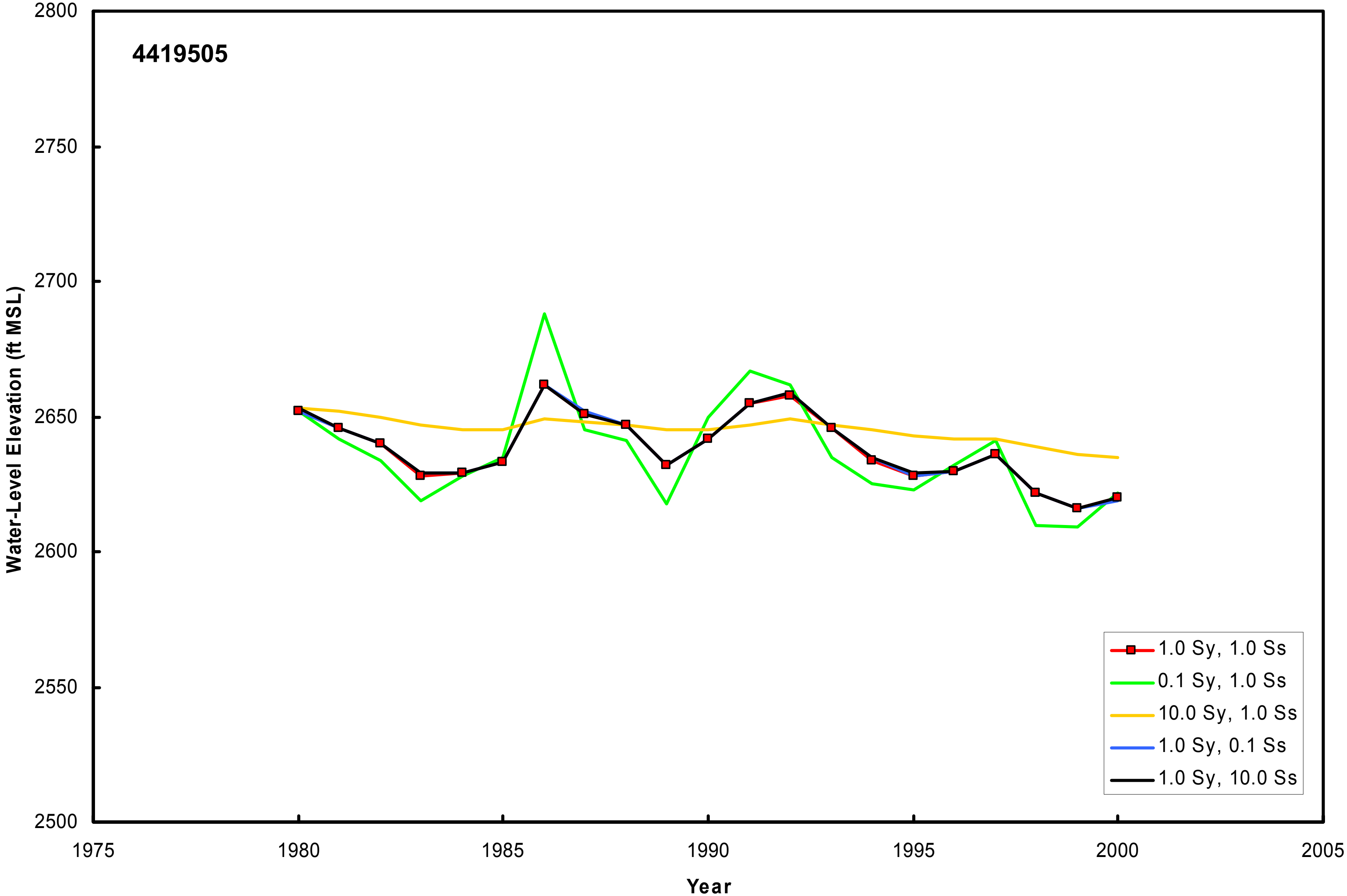


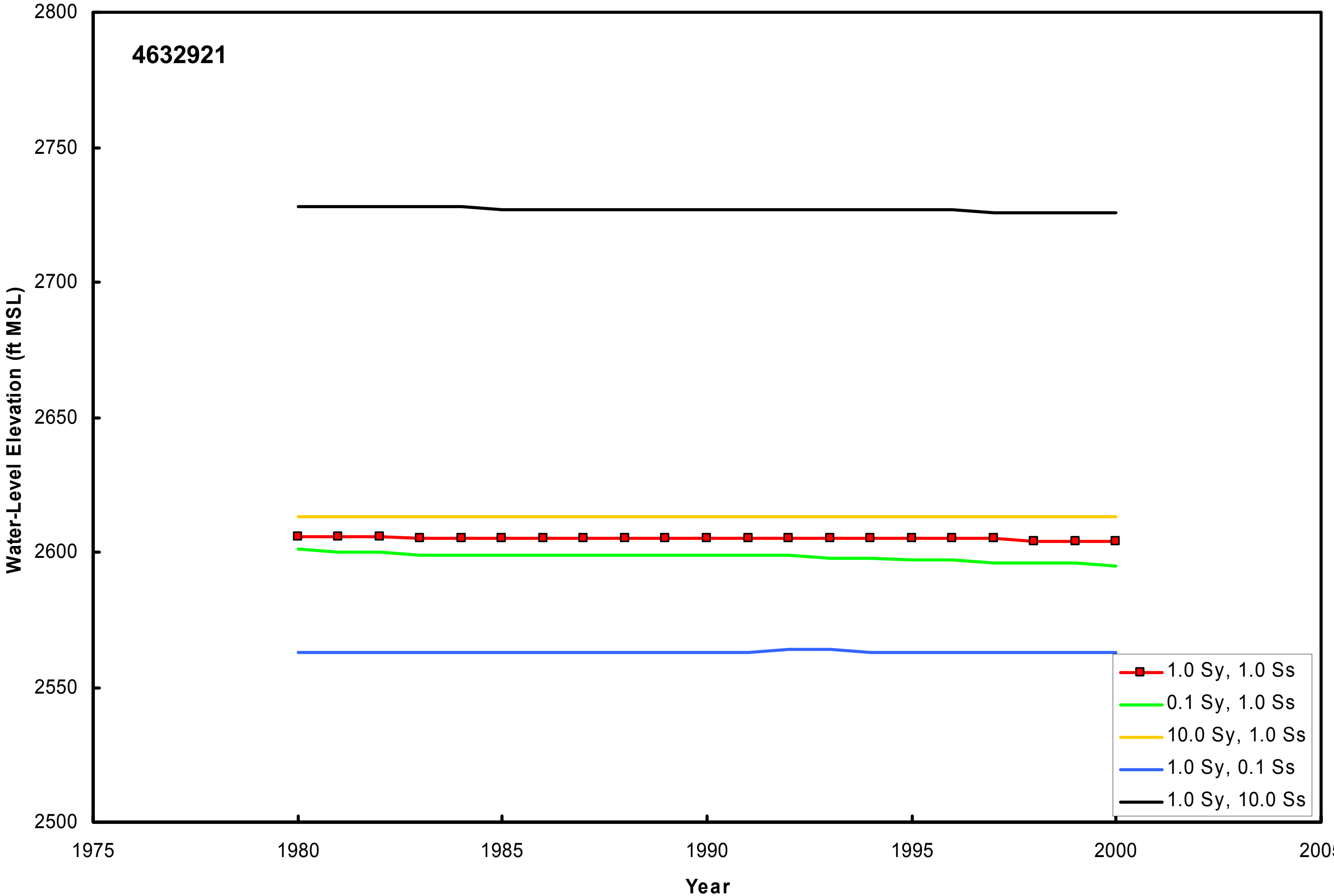
Pecos River near Langtry
Av. Monthly Streamflow (cu. ft/s)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-80
Jan-84
Jan-88

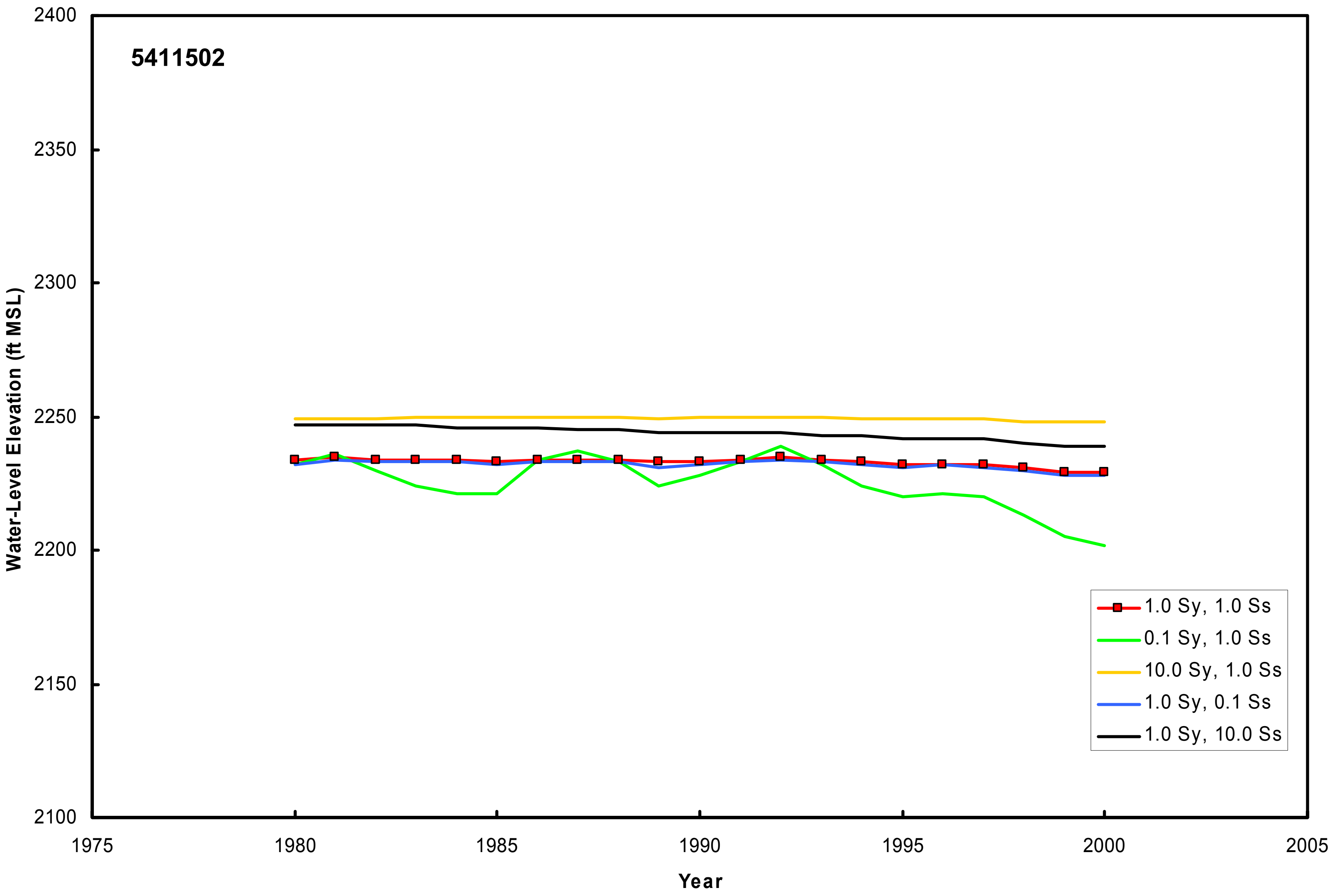
SENSITIVITY ANALYSIS/ MODEL LIMITATIONS



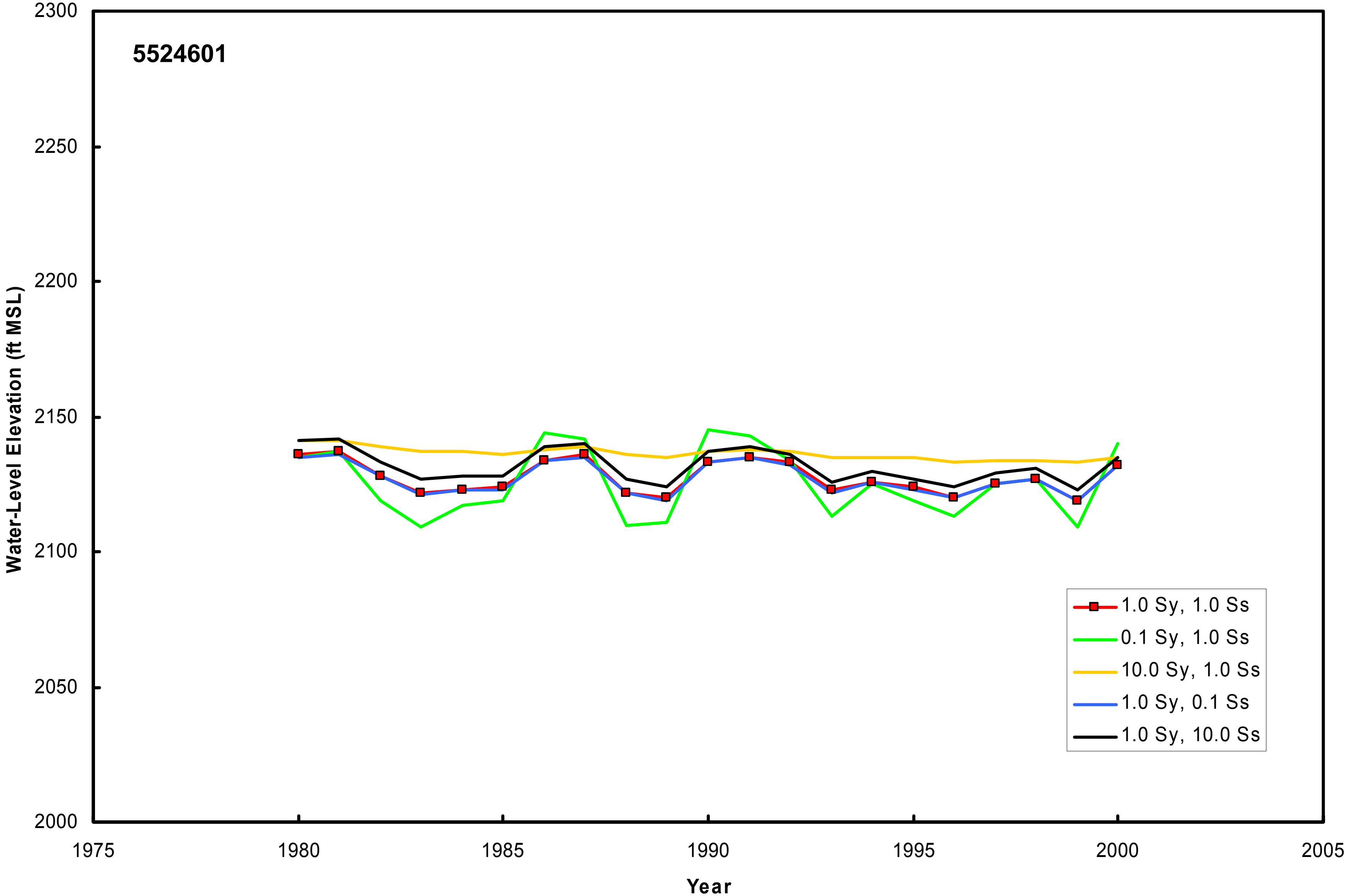
200
150
100
50
0
-50
-100
-150
-200
Average Change in Water Level (ft)
-75%
-50%
-25%
0%
25%
50%
75%
Percent Change From Calibrated Value
Kv
Streambed Cond.
Drain Cond.
GHB Cond.
Recharge
Trans.

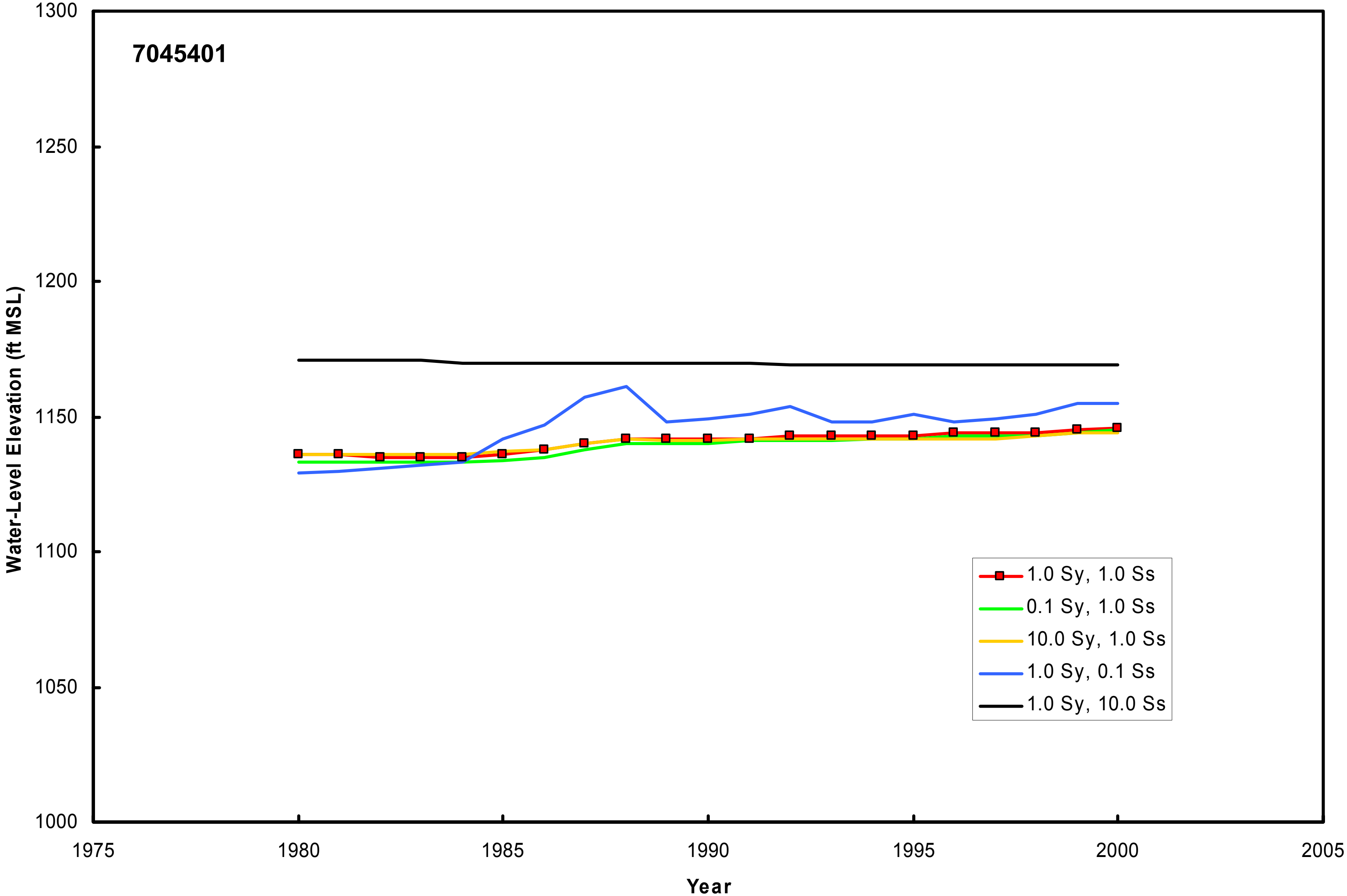

4419505
Water-Level Elevation (ft MSL)
Year
2800
2750
2700
2650
2600
2550
2500
1975
1980
1985
1990
1995
2000
2005
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

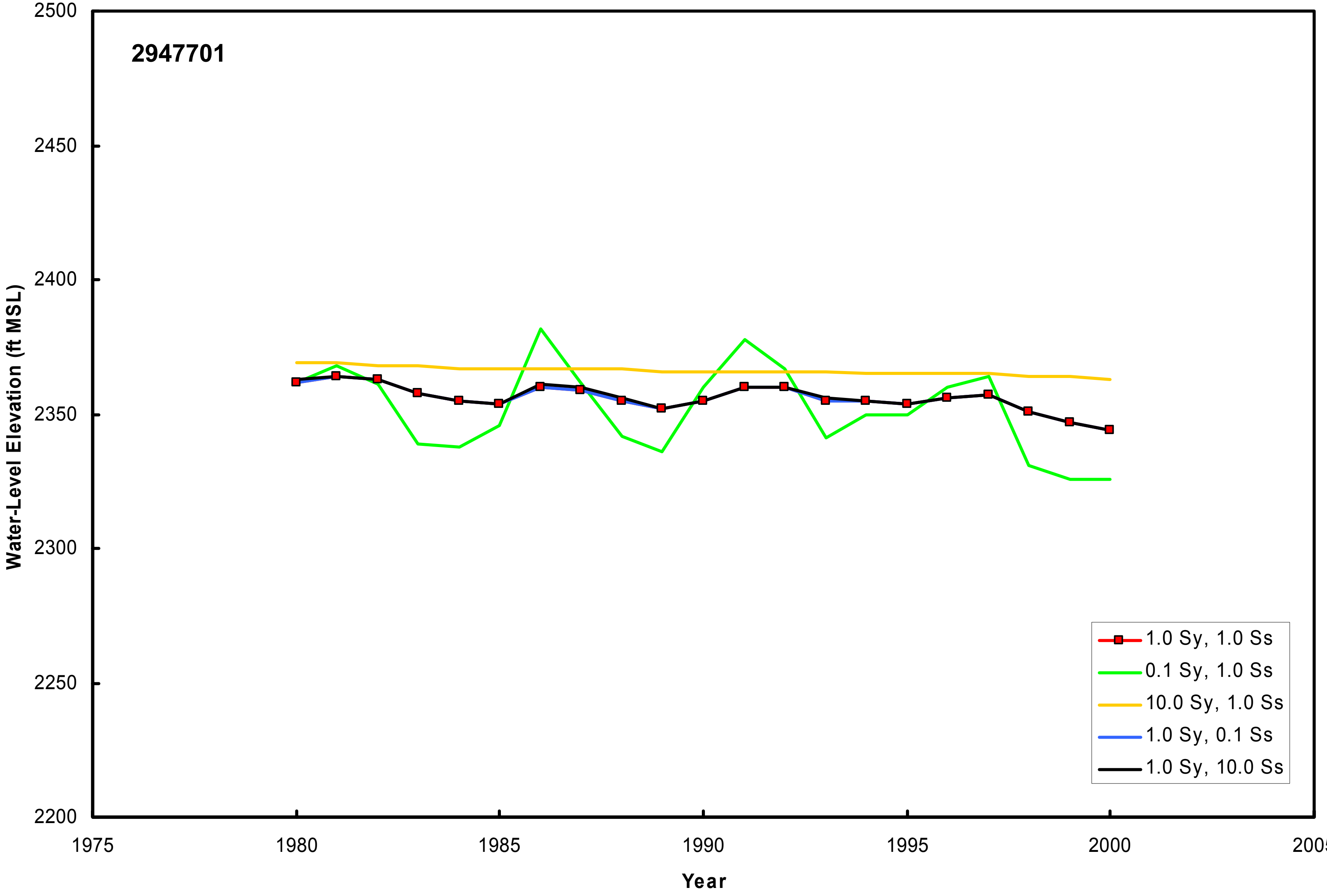

4632921
Water-Level Elevation (ft MSL)
2800
2750
2700
2650
2600
2550
2500
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

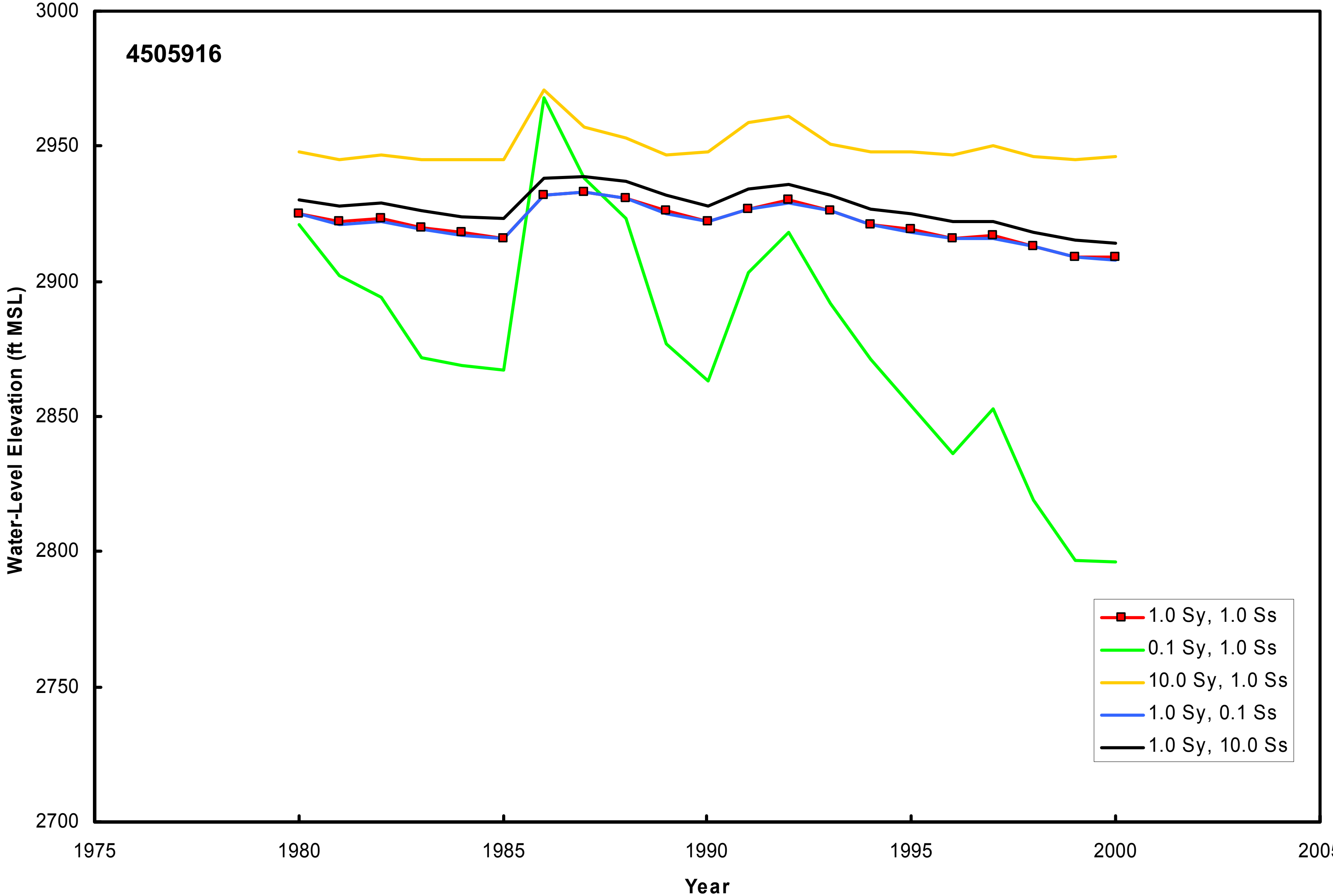


5411502
Water-Level Elevation (ft MSL)
2400
2350
2300
2250
2200
2150
2100
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

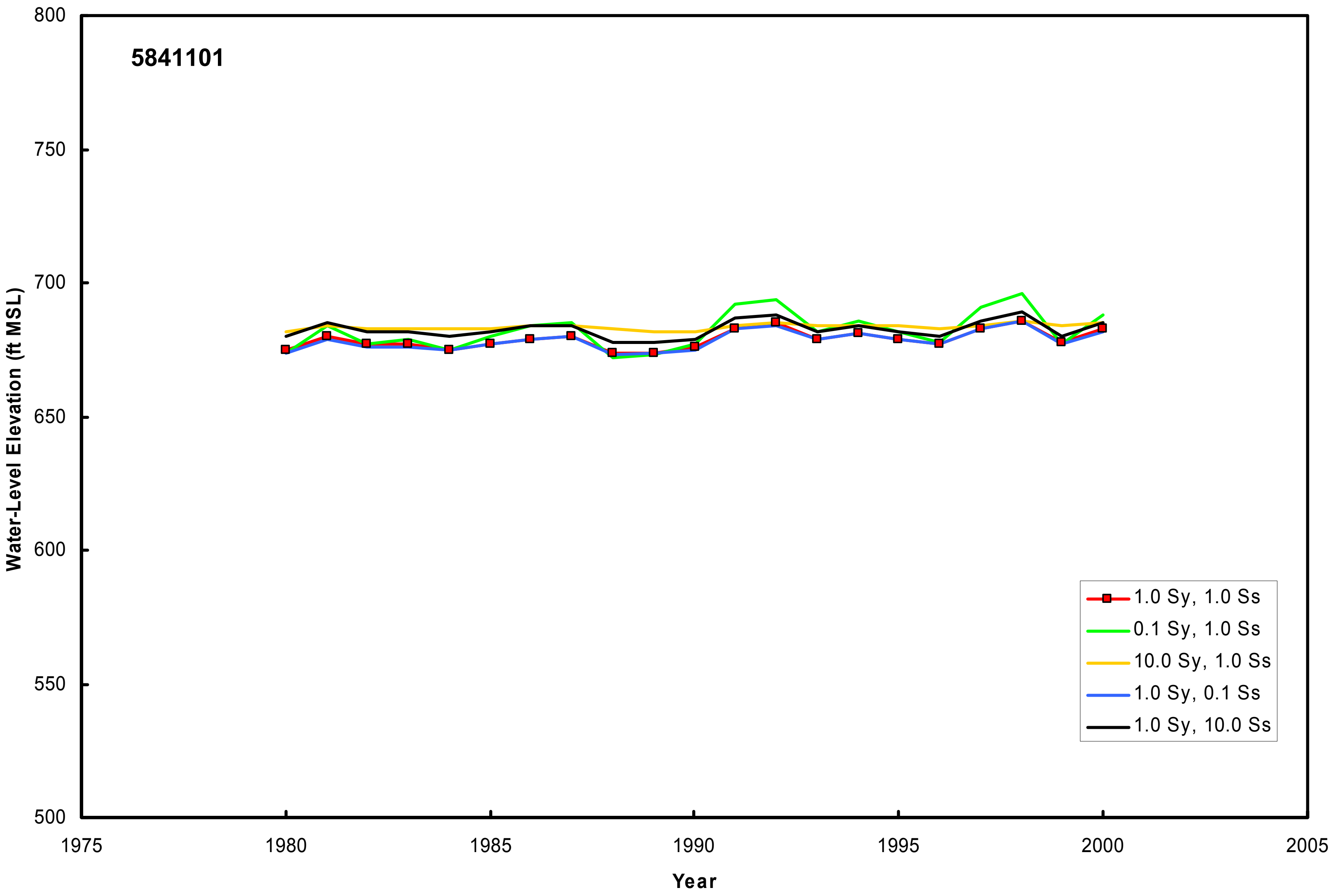

5524601
Water-Level Elevation (ft MSL)
Year
2300
2250
2200
2150
2100
2050
2000
1975
1980
1985
1990
1995
2000
2005
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

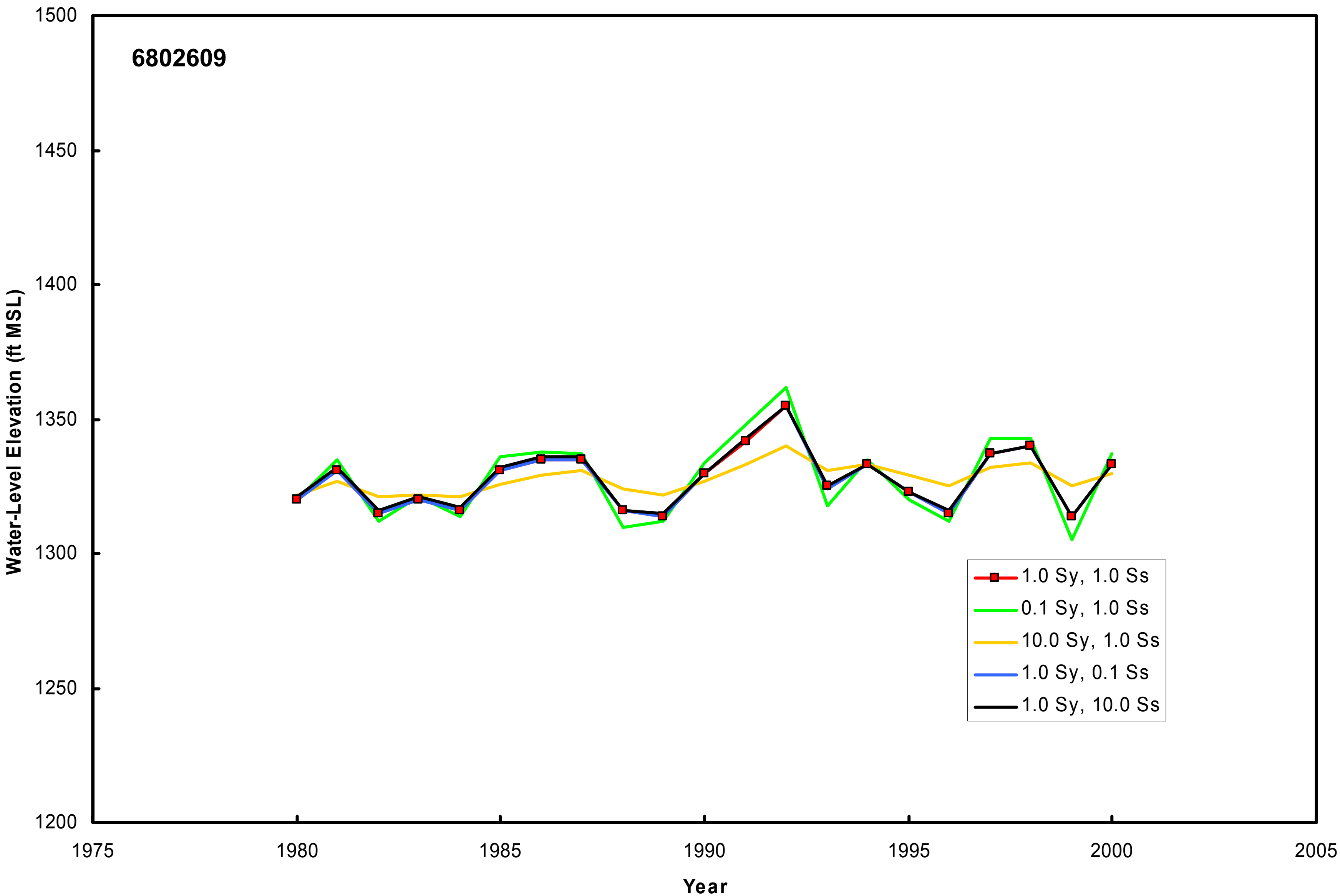

7045401
Water-Level Elevation (ft MSL)
1300
1250
1200
1150
1100
1050
1000
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

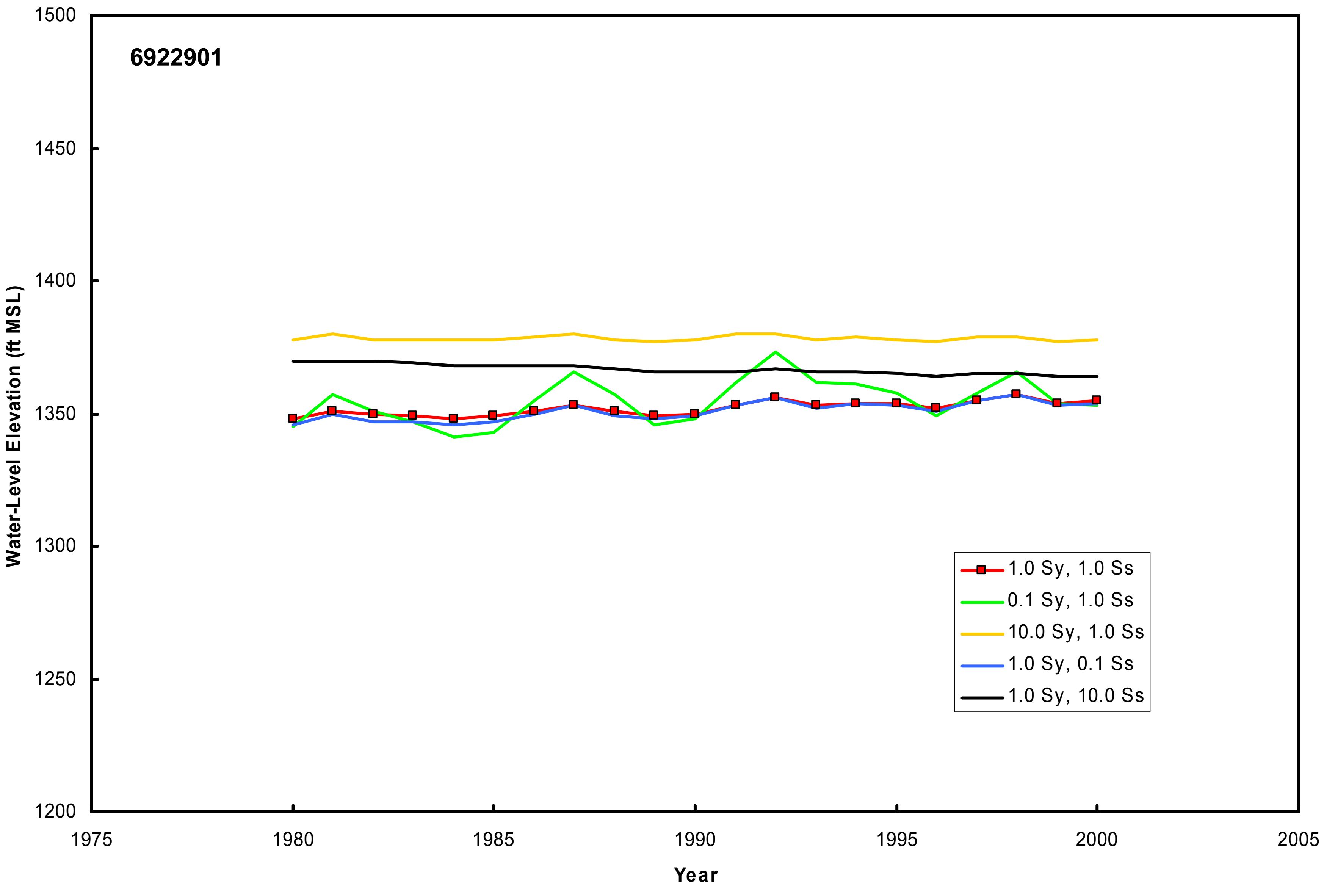

2947701
Water-Level Elevation (ft MSL)
2500
2450
2400
2350
2300
2250
2200
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss



4505916
Water-Level Elevation (ft MSL)
3000
2950
2900
2850
2800
2750
2700
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss


5841101
Water-Level Elevation (ft MSL)
800
750
700
650
600
550
500
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

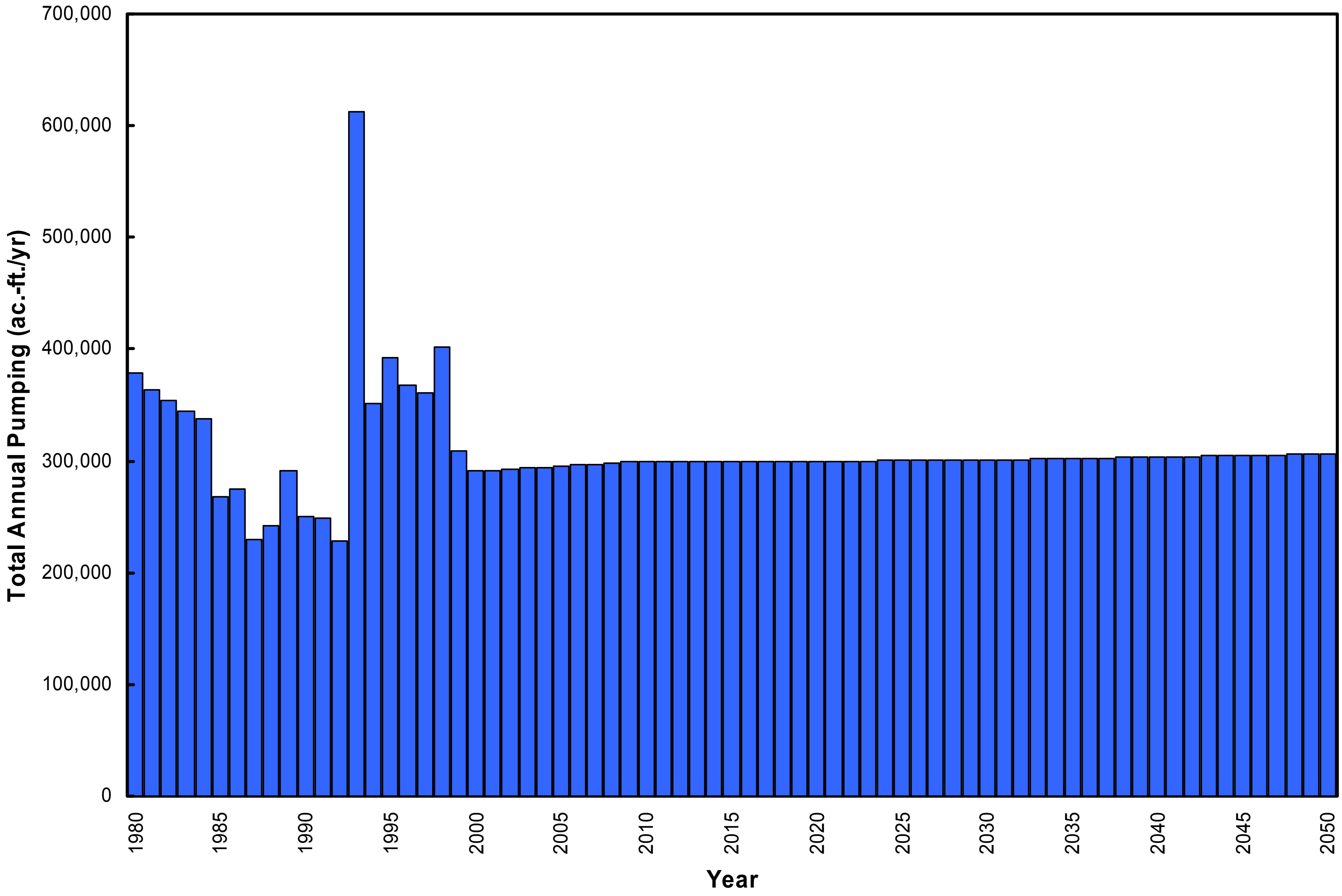

6802609
Water-Level Elevation (ft MSL)
1500
1450
1400
1350
1300
1250
1200
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

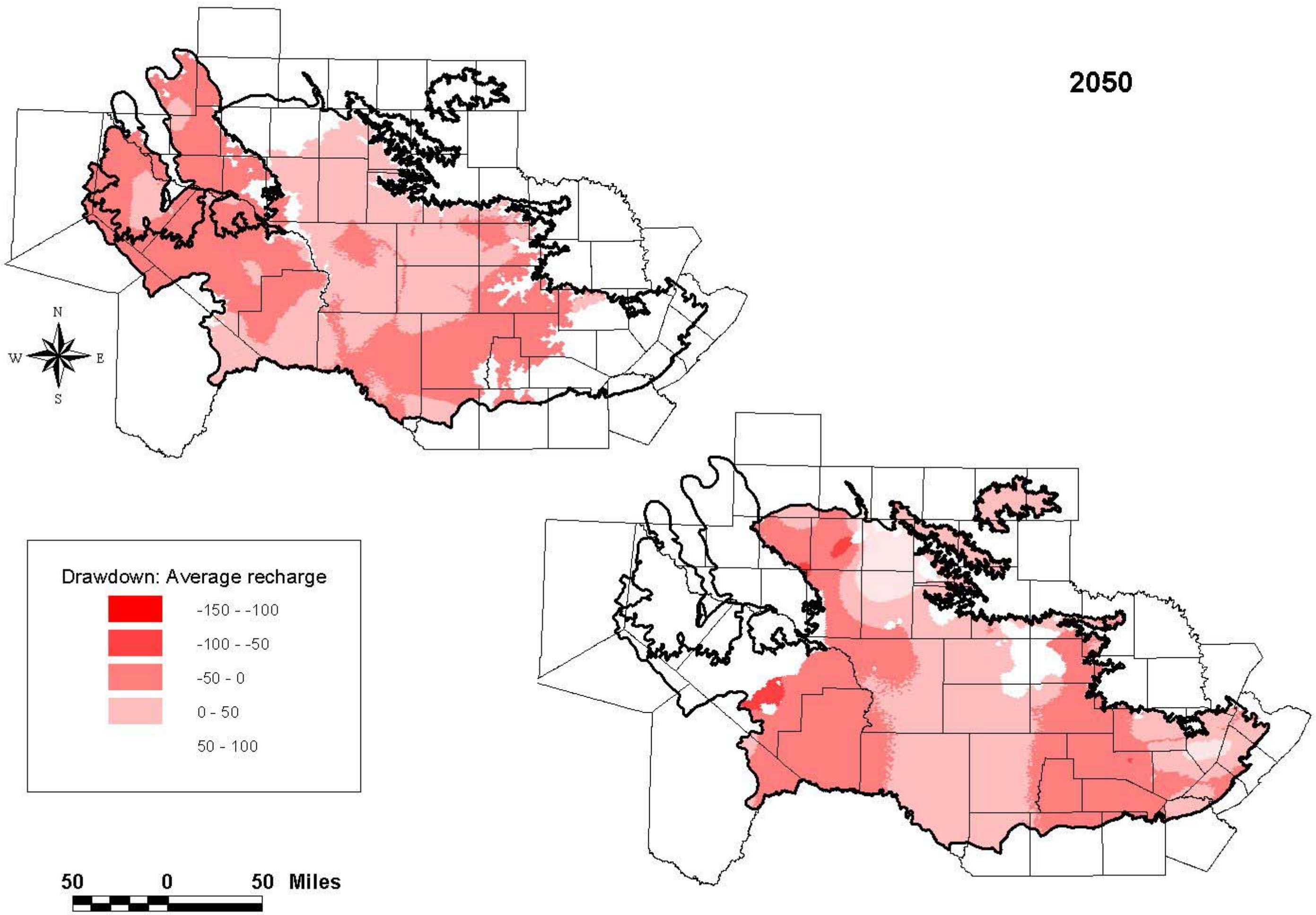

6922901
Water-Level Elevation (ft MSL)
1500
1450
1400
1350
1300
1250
1200
1975
1980
1985
1990
1995
2000
2005
Year
1.0 Sy, 1.0 Ss
0.1 Sy, 1.0 Ss
10.0 Sy, 1.0 Ss
1.0 Sy, 0.1 Ss
1.0 Sy, 10.0 Ss

LIMITATIONS

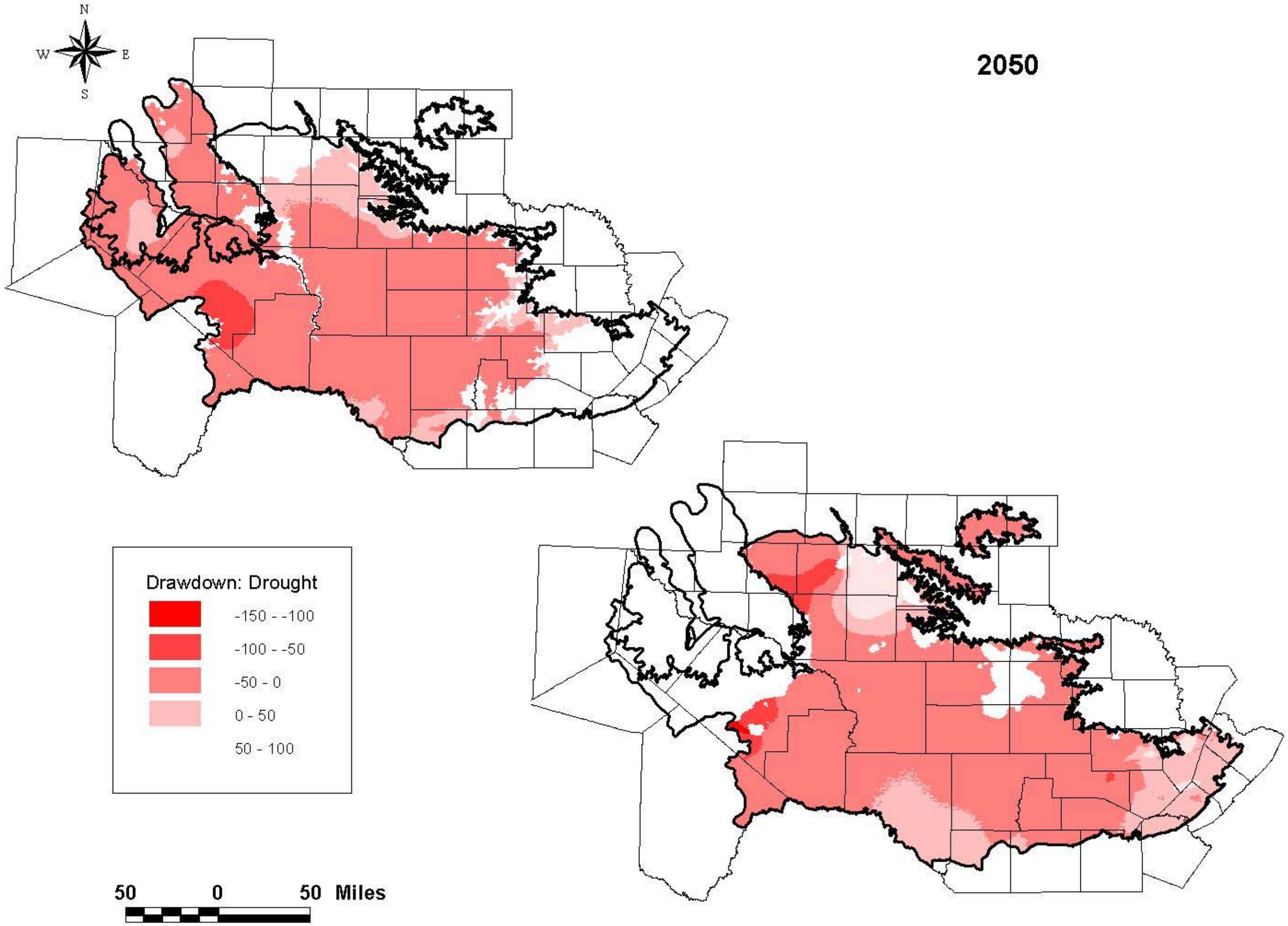
- Understanding of aquifer hydrology
- Availability/accuracy of input data
  – Transmissivity, recharge, storage, water levels, etc.
- Assumptions/simplifications used
  – GHB simulate cross-formational flow
  – Little interaction with Dockum, Rustler, Capitan, Hickory
- Scale of application
  – Regional-scale model

PREDICTIVE MODEL RUNS


700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Total Annual Pumping (ac.-ft./yr)
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year



2050
N
W
E
S
Drawdown: Average recharge
-150 - -100
-100 - -50
-50 - 0
0 - 50
50 - 100
50
0
50
Miles



N
W
E
S
2050
Drawdown: Drought
-150 - -100
-100 - -50
-50 - 0
0 - 50
50 - 100
50
0
50 Miles

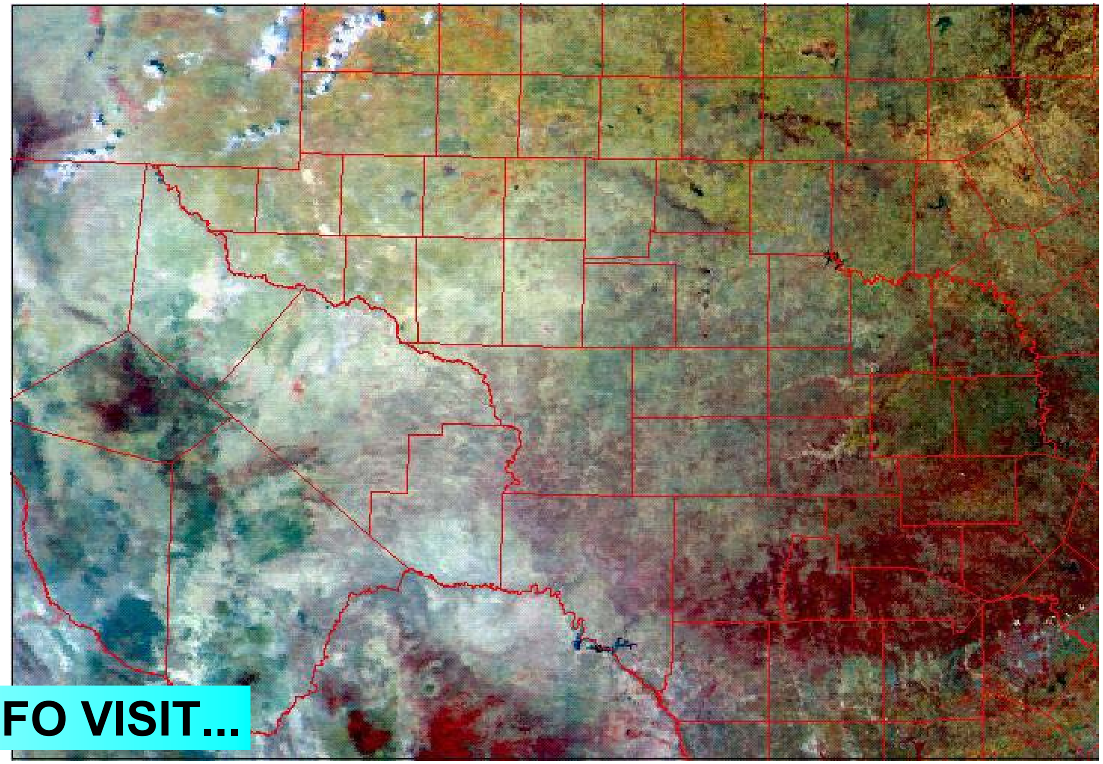
Primary Literature Sources

- 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 6!

Have a safe drive home ...



FOR MORE INFO VISIT...

www.twdb.state.tx.us/gam

Edwards-Trinity GAM Stakeholders Advisory Forum 6
July 28, 2004 – Ozona, Texas
List of Attendees

Name	Affiliation
Cindy Cawley	Sutton County UWCD / Plateau UWCD
Scott Holland	Sterling County UWCD / Irion County Water Conservation District
Grant Snyder	URS Corporation
Rick Harston	Glasscock County UWCD
Stan Reinhard	Hickory UWCD NO. 1
Dennis Clark	Emerald UWCD
Lee Sweeten	Real-Edwards Conservation and Reclamation District
GCD staff?	Real-Edwards Conservation and Reclamation District
Feather Wilson	Bandera River Authority and Groundwater District
Paul Tybor	Hill Country UWCD
Kelly Miller	Texas Commission on Environmental Quality
Roberto Anaya	Texas Water Development Board
Ian Jones	Texas Water Development Board
Scott Hamlin	Texas Water Development Board

Edwards-Trinity GAM Stakeholders Advisory Forum 6
July 28, 2004 – Ozona, Texas
Meeting Summary

About 10 people attended the sixth Edwards-Trinity Aquifer Groundwater Availability Modeling Stakeholders Advisory Forum, held in Ozona, Texas. The stakeholders present were representing 8 local groundwater conservation districts, 1 TCEQ representative and 1 consulting firm.

Roberto Anaya presented a review of the conceptual model, an overview of MODFLOW, and a discussion on the assumptions and methods of estimating recharge. Scott Hamlin then discussed the assumptions and methods of estimating pumpage for the model input. Ian Jones provided stakeholders with techniques and the results of steady-state and transient model calibrations, and the predictive simulations.

The next SAF meeting/training workshop was tentatively scheduled for the 16th of September in Austin, Texas. Participants will be shown the basics of making GAM runs with the Edwards-Trinity/Cenozoic Pecos Alluvium model.

Primary Stakeholder Issues Follow:

1) A stakeholder was concerned about the accuracy of the recharge distribution in the model.

ANSWER: There are many factors that control the distribution of recharge in both space and time. Although we have data on the many recharge controls such as climate, soil properties, vegetation, topography, and surface hydrology, quantifying the spatial-temporal effects that each control has on recharge is very difficult. A simplified approach was taken to calibrate recharge by weighting the spatial distribution of recharge with the spatial distribution of mean annual rainfall and surface geology. It is not a perfect approach, but until we have a better understanding of the individual effects that control recharge, it is the best we have at the moment.

2) A stakeholder was concerned with the accuracy of the pumpage demands used in the model. He believed that predictive demand numbers was not accounting for new developments. He also stated that seasonal groundwater usage such as recreational, hunting, and usage by exotic game ranching was not included in historical or predictive pumpage values. He suggested using electrical power usage as a surrogate for distributing domestic/other pumpage rather than population density and that we make a better effort to consider ALL groundwater usage in the model. Another stakeholder added that the predictive pumpage demands did not include a Mormon community in their district.

ANSWER: The predictive run(s) for this study were standard run(s) for all GAMs using RWPG pumpage demands under normal and drought-o- record climate conditions/recharge. The model is a tool intended to run what-if scenarios such as those with which the stakeholders are concerned about and other pumpage scenarios may be evaluated with the model.

3) A stakeholder was concerned about the accuracy of the springflow budget in the model.

ANSWER: Springs were modeled as drains all along the northern, eastern, and southern margin of the plateau. However, calibrating the model to springflows was not done because of the limited springflow data.

4) A stakeholder concerned with how he could use the model to determine sustainability of streamflows since not all “major” streams were included in the model for his GCD.

ANSWER: The streamflow routing packaged used in the GAM standard MODFLOW graphical user interface software, PMWIN 5.x, had a limitation of 25 streams segments and we selected the 25 “major” stream segments for the entire study area.

-Roberto Anaya, 07/29/04