NORTHERN SEGMENT OF THE EDWARDS AQUIFER GROUNDWATER AVAILABILITY MODEL

GAM Stakeholder Training Nov. 2003

OUTLINE

- Introduction to finite-difference modeling
- Introduction to PMWIN
- Overview of Northern Edwards aquifer model
- Hands-on modeling exercise

INTRODUCTION TO GROUNDWATER FLOW MODELING

WHAT IS AN AQUIFER?

- **Rock or sediment from which usable amounts of water can be extracted**

WHAT IS A GROUNDWATER FLOW MODEL?

- Mathematical representation of an aquifer
- Uses basic laws of physics that govern groundwater flow
- Calculates the hydraulic head at discrete locations (grid)
- Calculated model heads can be compared to hydraulic heads measured in wells

WHY ARE GROUNDWATER FLOW MODELS NEEDED?

- Groundwater flow is difficult to observe
- Aquifers are typically complex in terms of spatial extent and hydrogeological characteristics
- Means of integrating available data for prediction of groundwater flow

MODEL INPUT DATA

- Geology
  - Stratigraphy
  - Structure
- Water levels
- Surface water
  - Spring discharge
  - Stream discharge
- Aquifer properties
- Water use

MODELING SKILLS

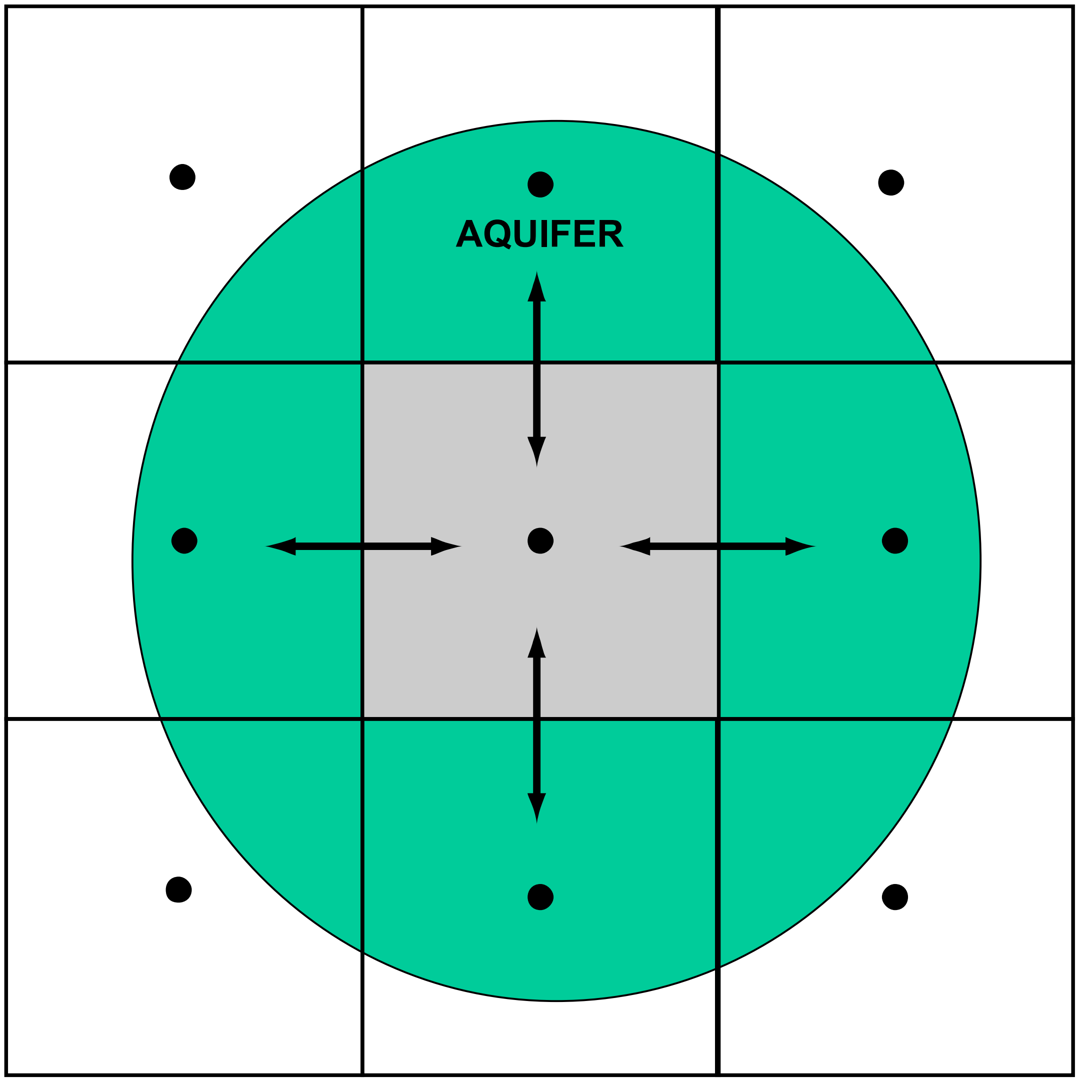
- GIS
- Programming
- Geology
- Groundwater hydrology

MODELING PROCESS

- Define model objectives
- Develop conceptual model
- Design model
- Calibration and verification modeling
  - Comparison with observed data
- Predictive modeling
  - Predict impacts of projected growth
    - 2000 - 2050

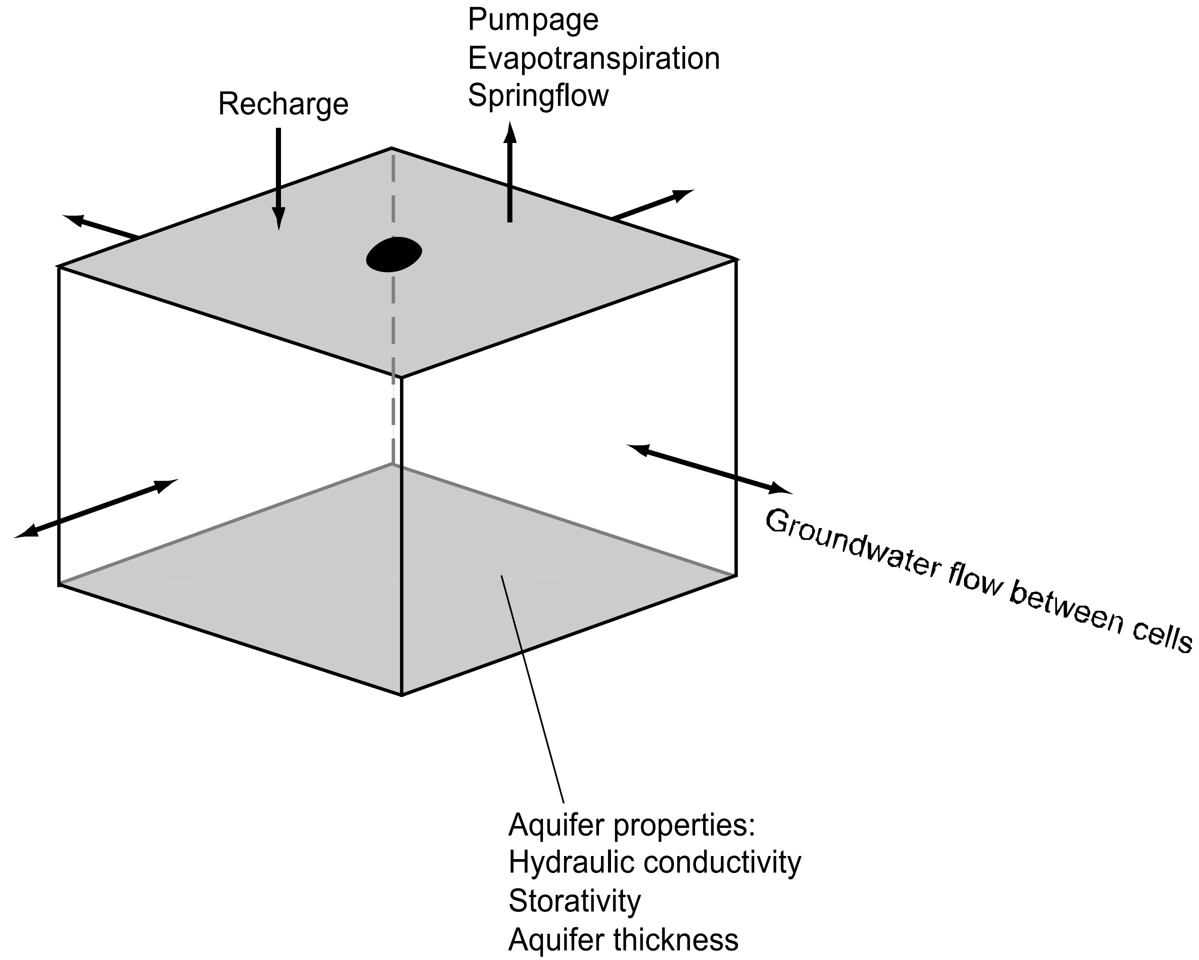
MODEL LIMITATIONS

- Approximation of the real system
  - Regional scale
- Uncertainty in the input data
  - Grid resolution
  - Incomplete data



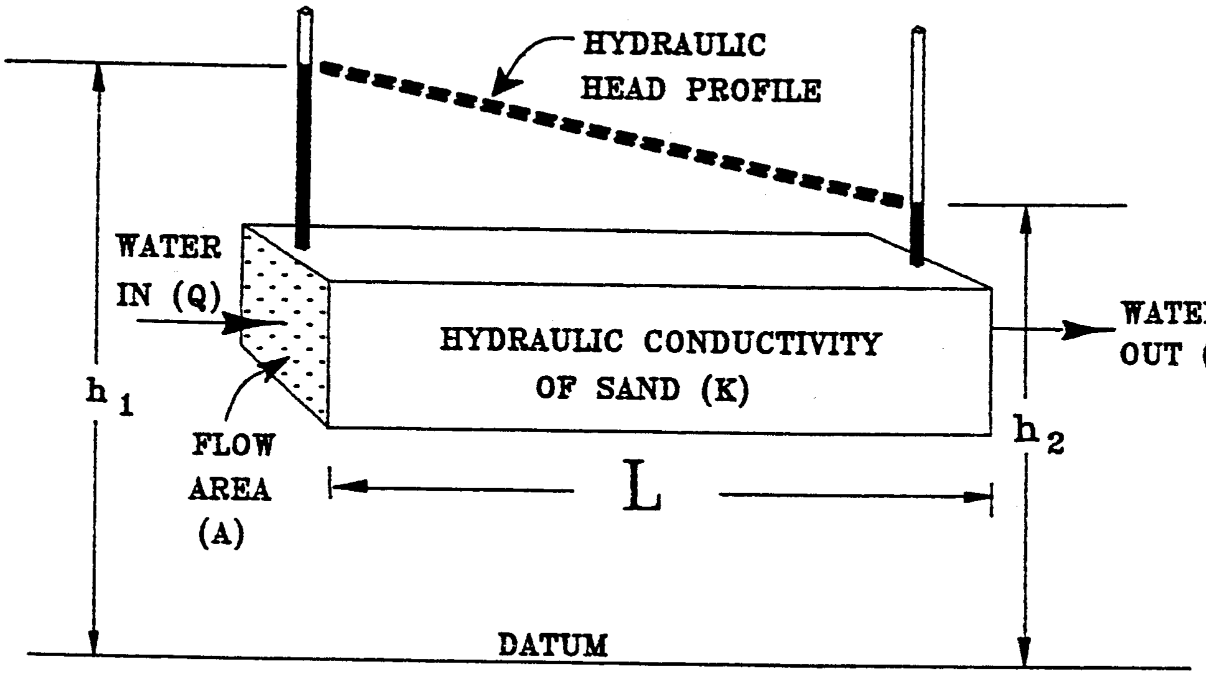
MODEL CELL

Hydraulic head calculated by balancing water inflows and outflows



MODEL CELL

Darcy's Law



Hydraulic Gradient $I = (h_1 - h_2)/L$

$$Q = KIA$$

PORE WATER VELOCITY $v = \frac{KI}{\text{porosity}}$

Main Equations of 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

INTRODUCTION TO PMWIN

PROCESSING MODFLOW

- **PMWIN**
  - Pre/Post-processor (data entry/evaluation)
- **MODFLOW**
  - Modular 3-D groundwater flow model
- **MOC3D** - Solute-transport model
- **MT3D** - Solute-transport model
- **MT3DMS** - Solute-transport model
- **PEST** - Inverse model
- **UCODE** - Inverse model
- **PMPATH** - Advective transport model

PMWIN

- Grid
  - Grid size
  - Layer type - Unconfined or Confined/Unconfined
  - Boundary conditions - Active/Inactive cells
  - Top of layer
  - Base of layer

PMWIN (cont.)

- Parameters
  - Time units
  - Initial hydraulic heads
  - Boreholes/observations
  - Horizontal hydraulic conductivity
  - Vertical hydraulic conductivity
  - Specific storage
  - Transmissivity
  - Vertical leakance
  - Storage coefficient
  - Effective porosity
  - Specific yield

PMWIN (cont.)

- Features
  - Density
  - Drains
  - Evapotranspiration
  - General-head boundary
  - Horizontal-flow barrier
  - Interbed storage
  - Recharge
  - Reservoir

PMWIN (cont.)

- Features
  - River
  - Streamflow routing
  - Time-variant specified head
  - Well
  - Wetting capability
  - Output control
  - Solvers
  - Run

PMWIN (cont.)

- Post-processing tools
  - Presentation
    - View model output data
  - Water budget
  - Graphs
    - Head-time
    - Drawdown-time
    - Compaction-time ...

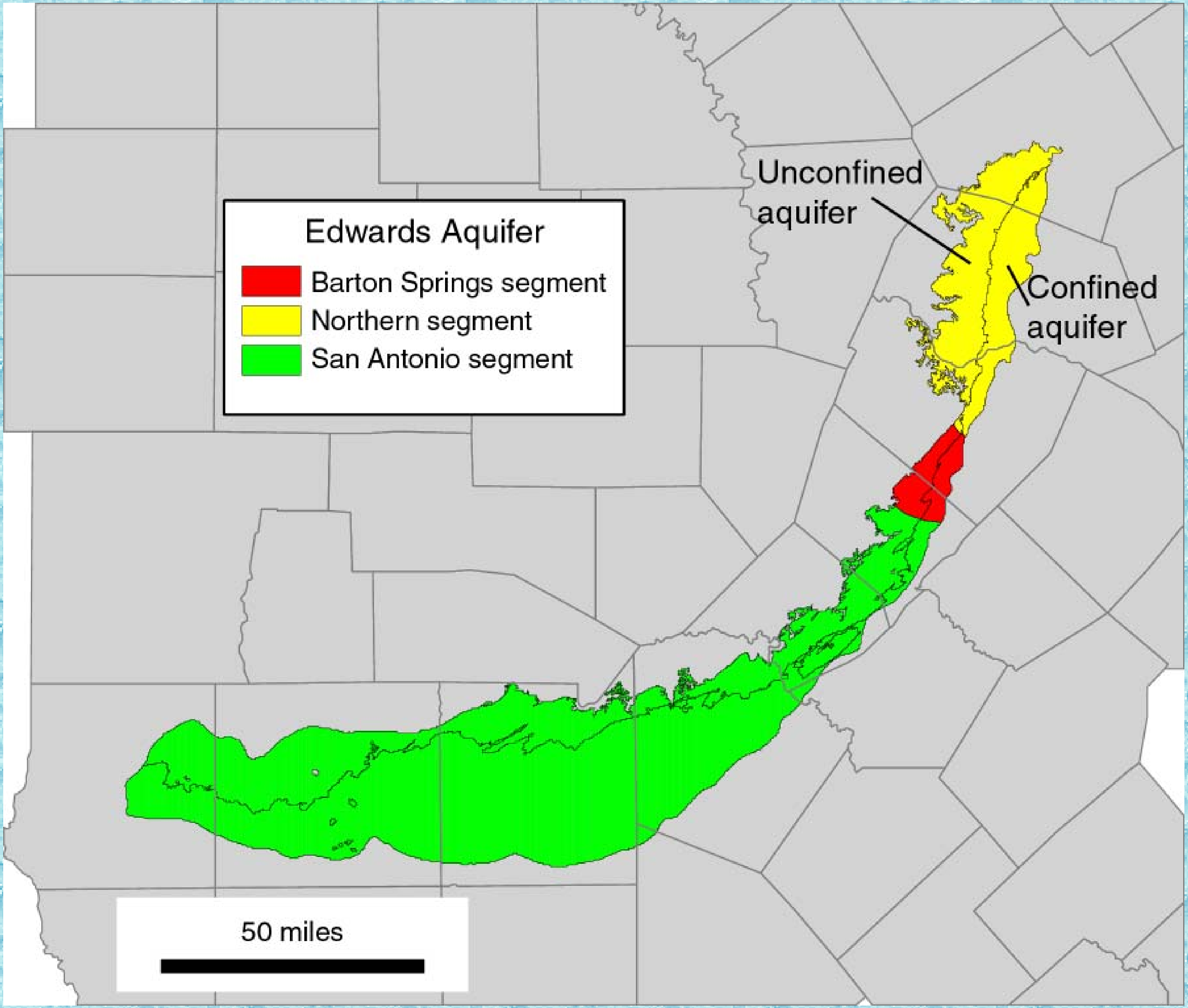
MODFLOW

- Modules
  - **Basic Package**
  - **Block-Centered Flow Package**
  - Density Package
  - Direct Solution Package (Solver)
  - Drain Package
  - Evapotranspiration Package
  - General-Head Boundary Package
  - Horizontal-Flow barrier Package
  - Interbed-Storage Package
  - **Output Control**

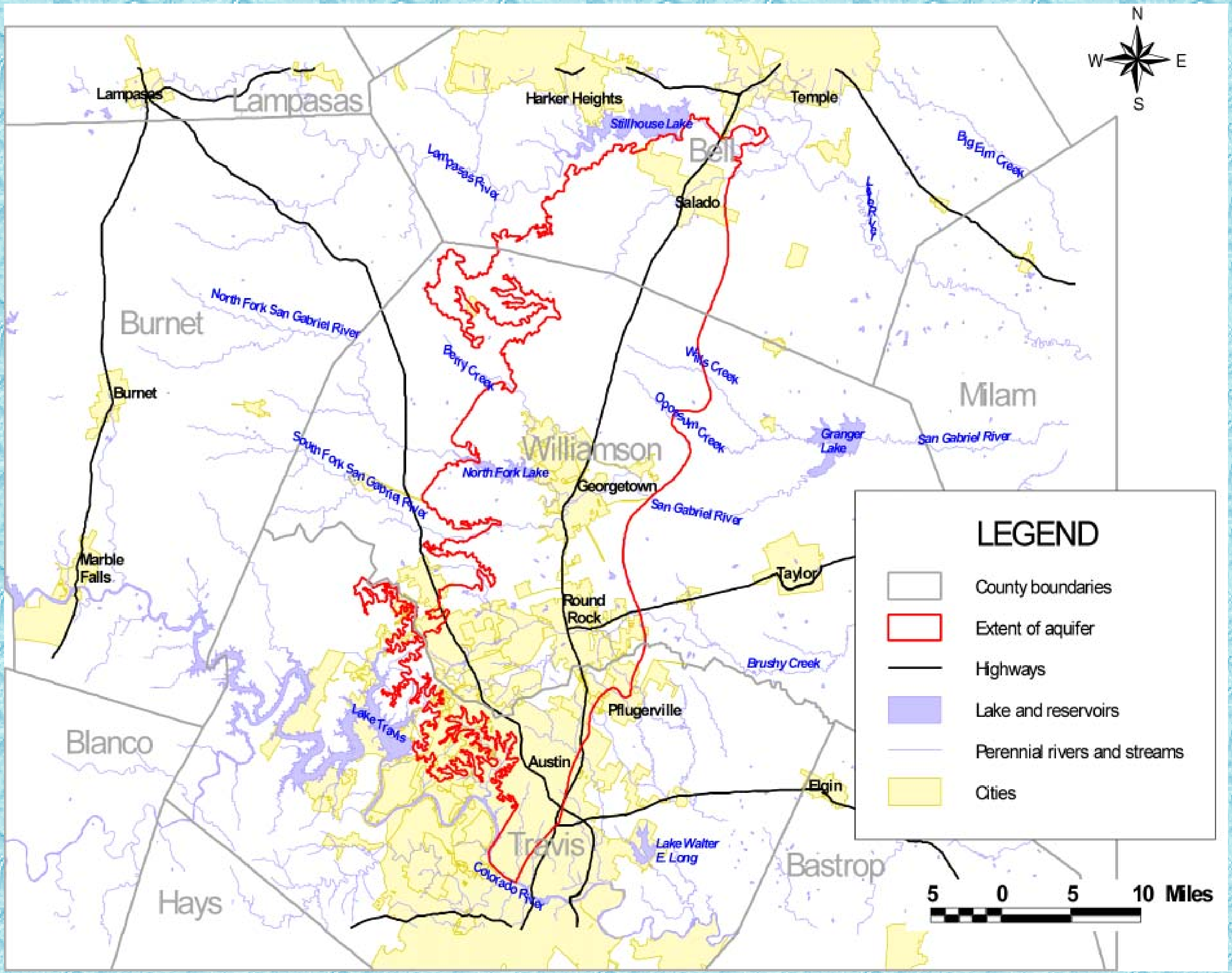
MODFLOW (Cont.)

- Modules
  - Preconditioned Conjugate Gradient 2 Package
  - River Package
  - Recharge Package
  - Reservoir Package
  - Strongly Implicit Procedure Package (solver)
  - Slice-Successive Overrelaxation Package (solver)
  - Stream-Routing Flow Package
  - Time-Variant Specified-Head
  - Well Package

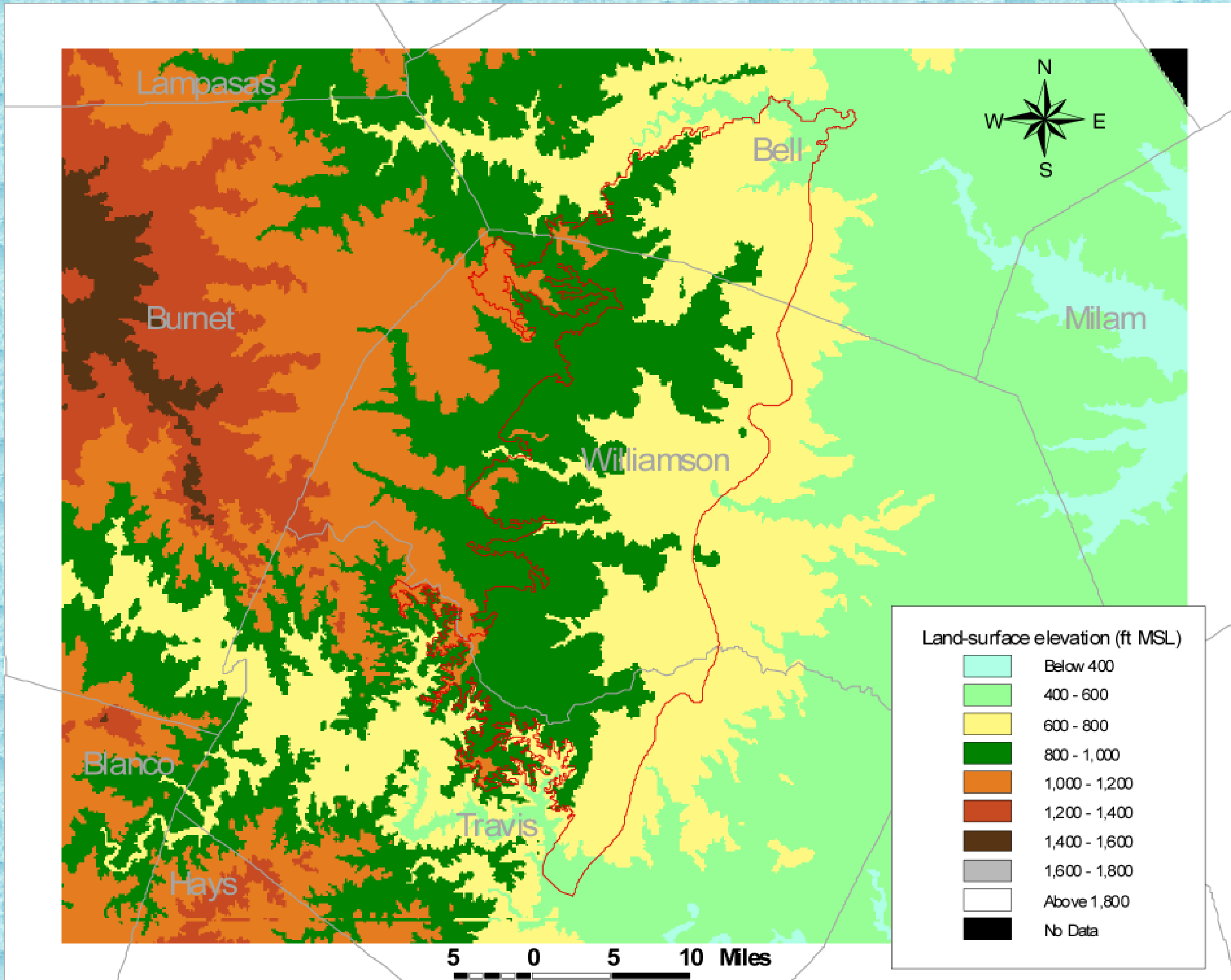
NORTHERN EDWARDS AQUIFER MODEL



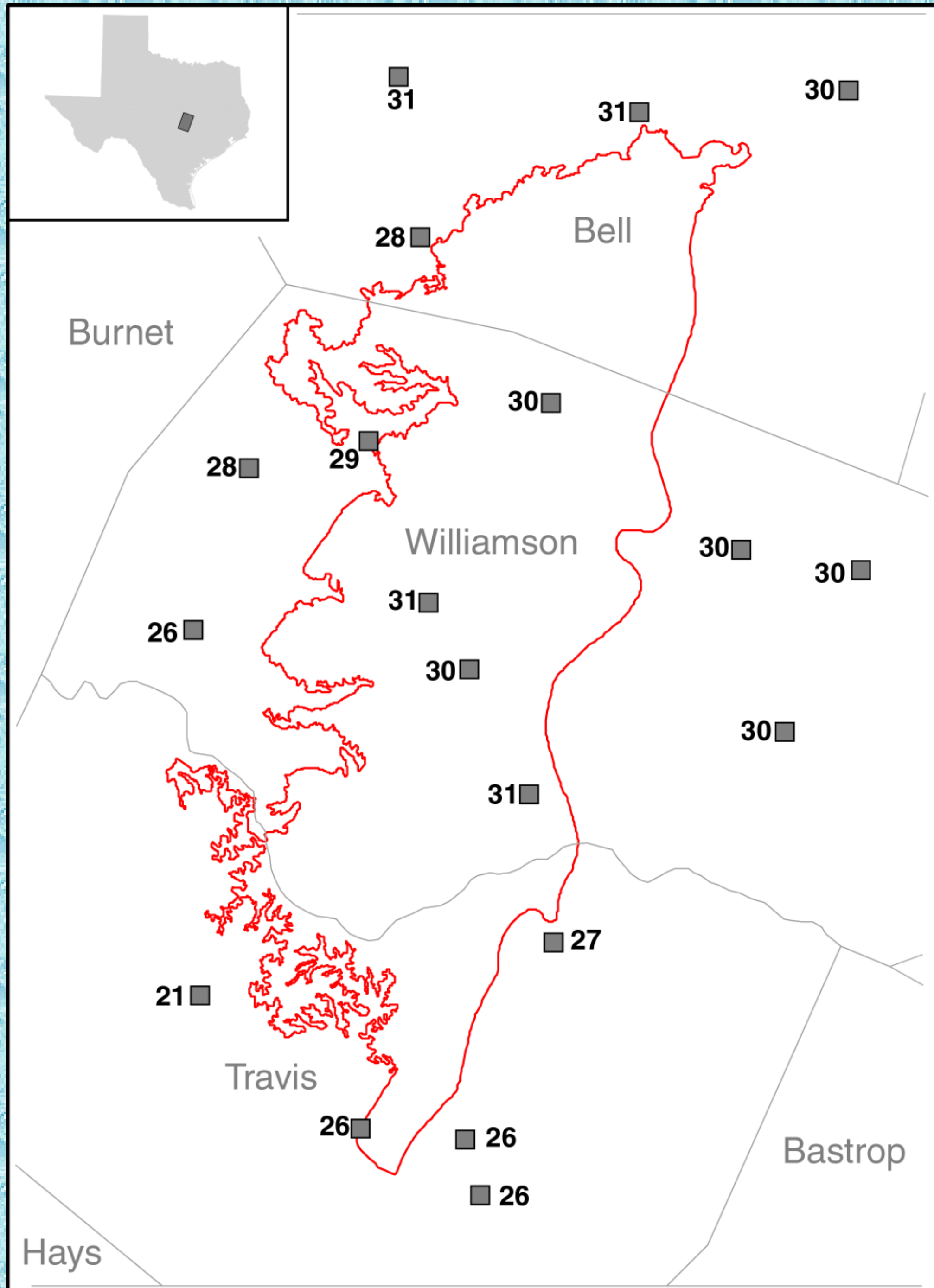
EDWARDS AQUIFER


N
W
E
S
Lampasas
Lampasas
Harker Heights
Temple
Stillhouse Lake
Bell
Lampasas River
Salado
Big Elm Creek
Leon River
Burnet
North Fork San Gabriel River
Berry Creek
Willis Creek
Milam
Burnet
Opossum Creek
Granger Lake
San Gabriel River
South Fork San Gabriel River
Williamson
North Fork Lake
Georgetown
San Gabriel River
Marble Falls
Taylor
Round Rock
Brushy Creek
Pflugerville
Lake Travis
Blanco
Austin
Elgin
Travis
Lake Walter E. Long
Bastrop
Colorado River
Hays
LEGEND
County boundaries
Extent of aquifer
Highways
Lake and reservoirs
Perennial rivers and streams
Cities
5 0 5 10 Miles

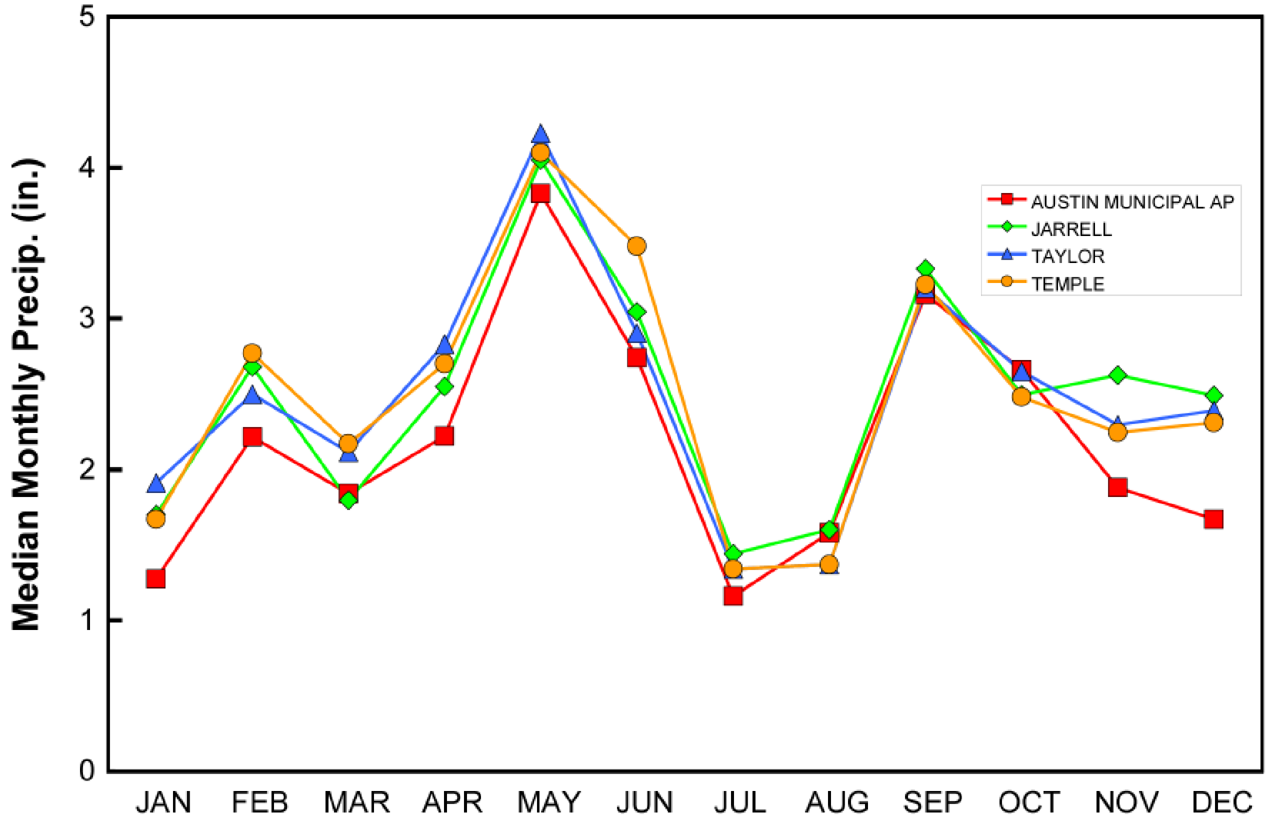
STUDY AREA


Lampasas
Bell
Burnet
Milam
Williamson
Blanco
Travis
Hays
N
W
E
S
Land-surface elevation (ft MSL)
Below 400
400 - 600
600 - 800
800 - 1,000
1,000 - 1,200
1,200 - 1,400
1,400 - 1,600
1,600 - 1,800
Above 1,800
No Data
5 0 5 10 Miles

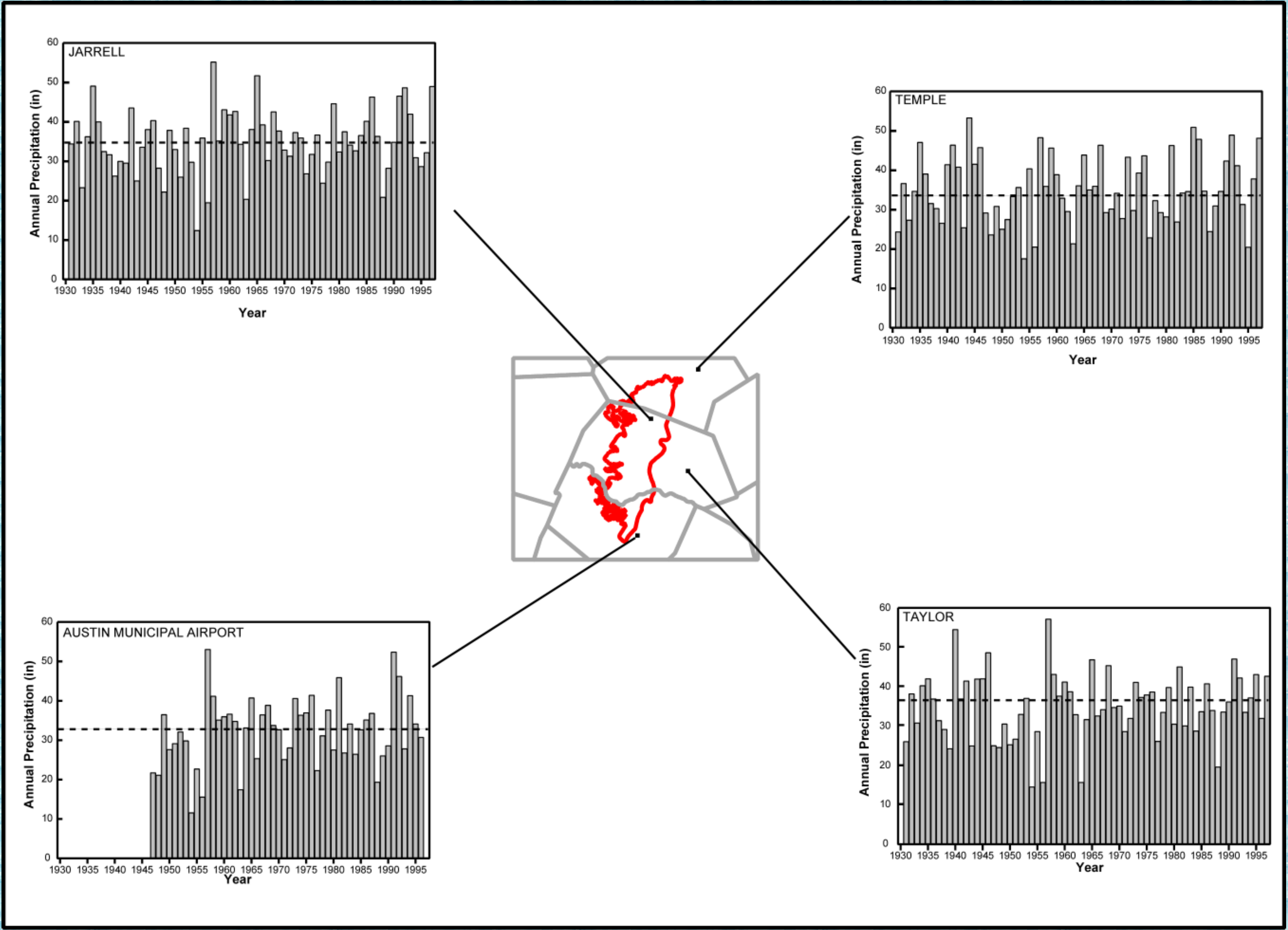
TOPOGRAPHY



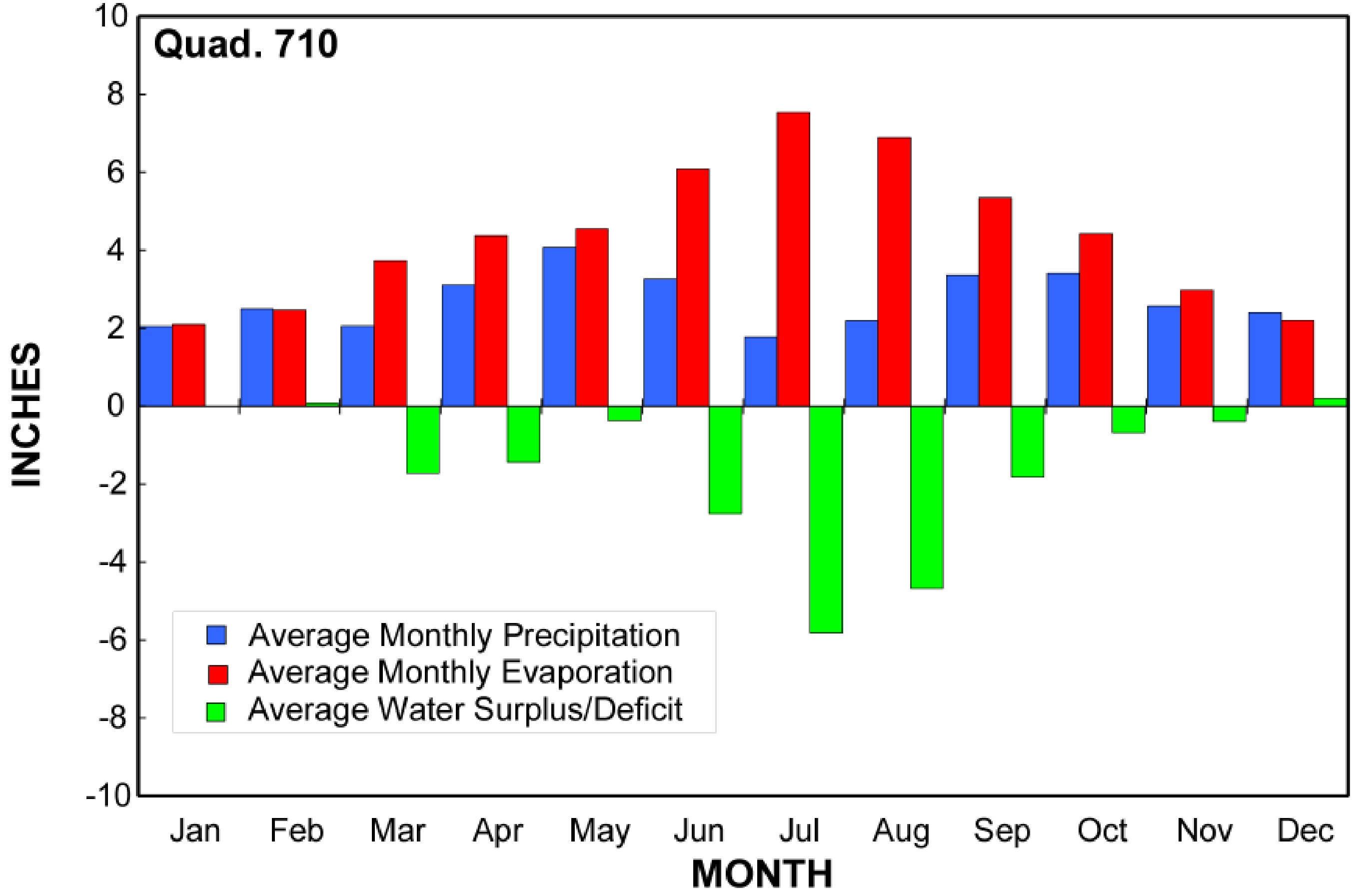
AVERAGE ANNUAL PRECIPITATION



SEASONAL PRECIPITATION



HISTORIC PRECIPITATION

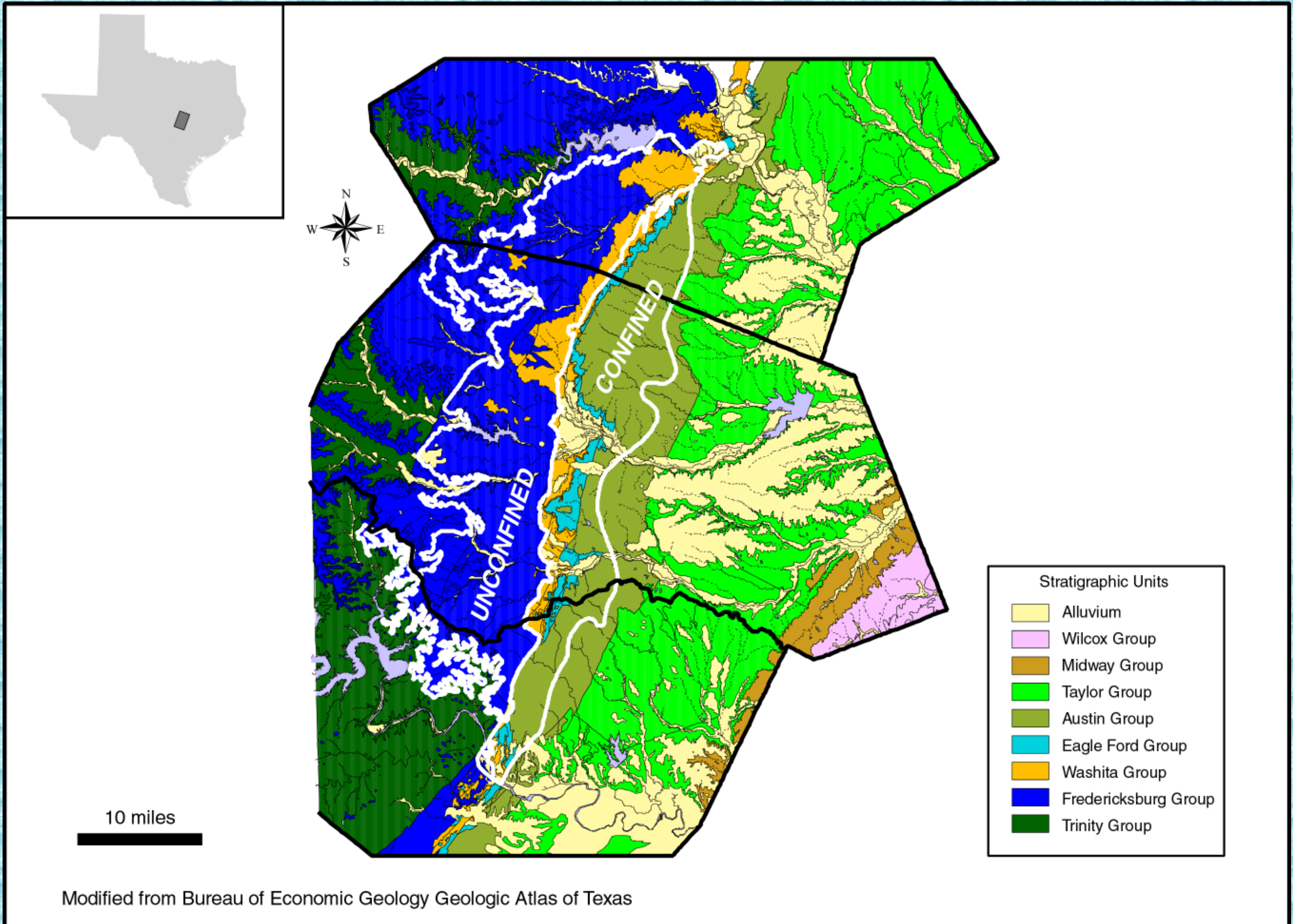


EVAPORATION

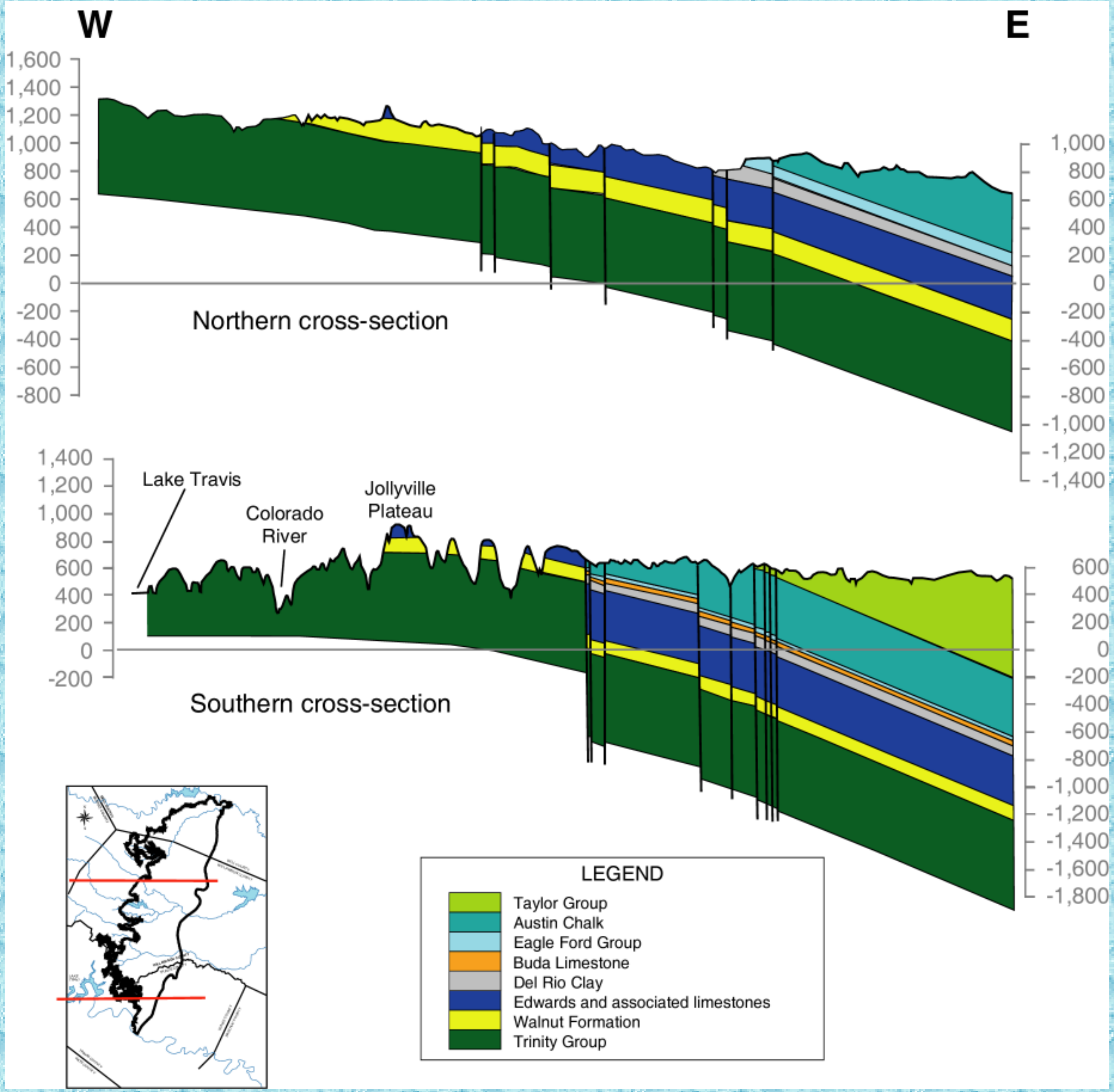
HYDROGEOLOGY

Series	Group	Stratigraphic Unit		Hydrologic Unit	Maximum Thickness (feet)
Gulf	Navarro			Navarro and Taylor Group	850
	Taylor				
	Austin			Austin Chalk	450
Comanche	Eagle Ford				50
	Washita	Buda Limestone			50
		Del Rio Clay			60
		Georgetown Formation		Edwards and associated limestones	100
	Fredericksburg	Edwards Limestone			200
		Comanche Peak Limestone			50
		Walnut Formation			150
	Trinity	Paluxy Formation		Upper Trinity	10
		Glen Rose	Upper Member		450
			Lower Member	Middle Trinity	450
		Travis Peak	Hensell Sand Member		100
			Cow Cr. Limestone Member		100
			Hammett Shale Member		50
			Sligo Member	Lower Trinity	150
			Hosston Member		850

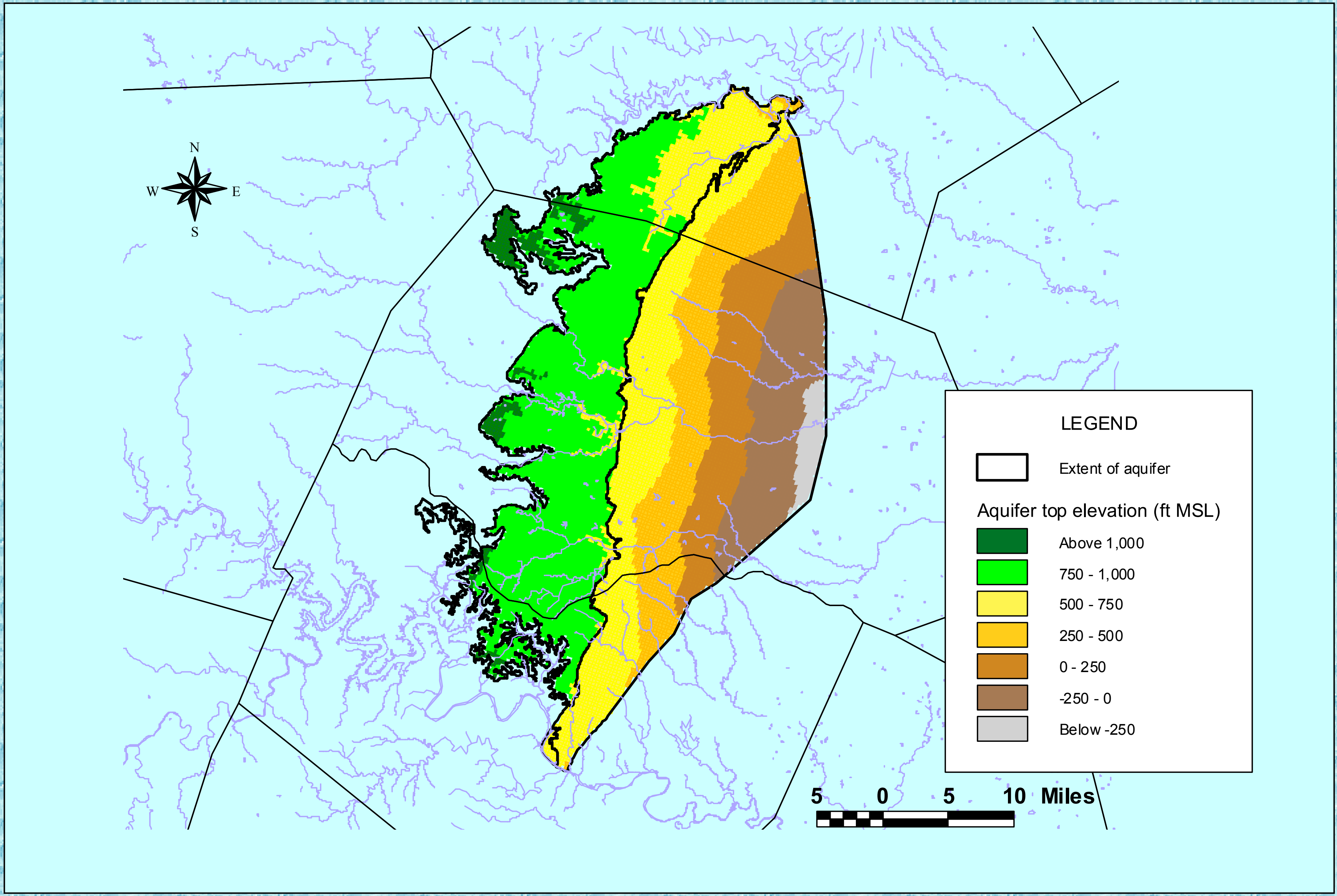
HYDROSTRATIGRAPHY



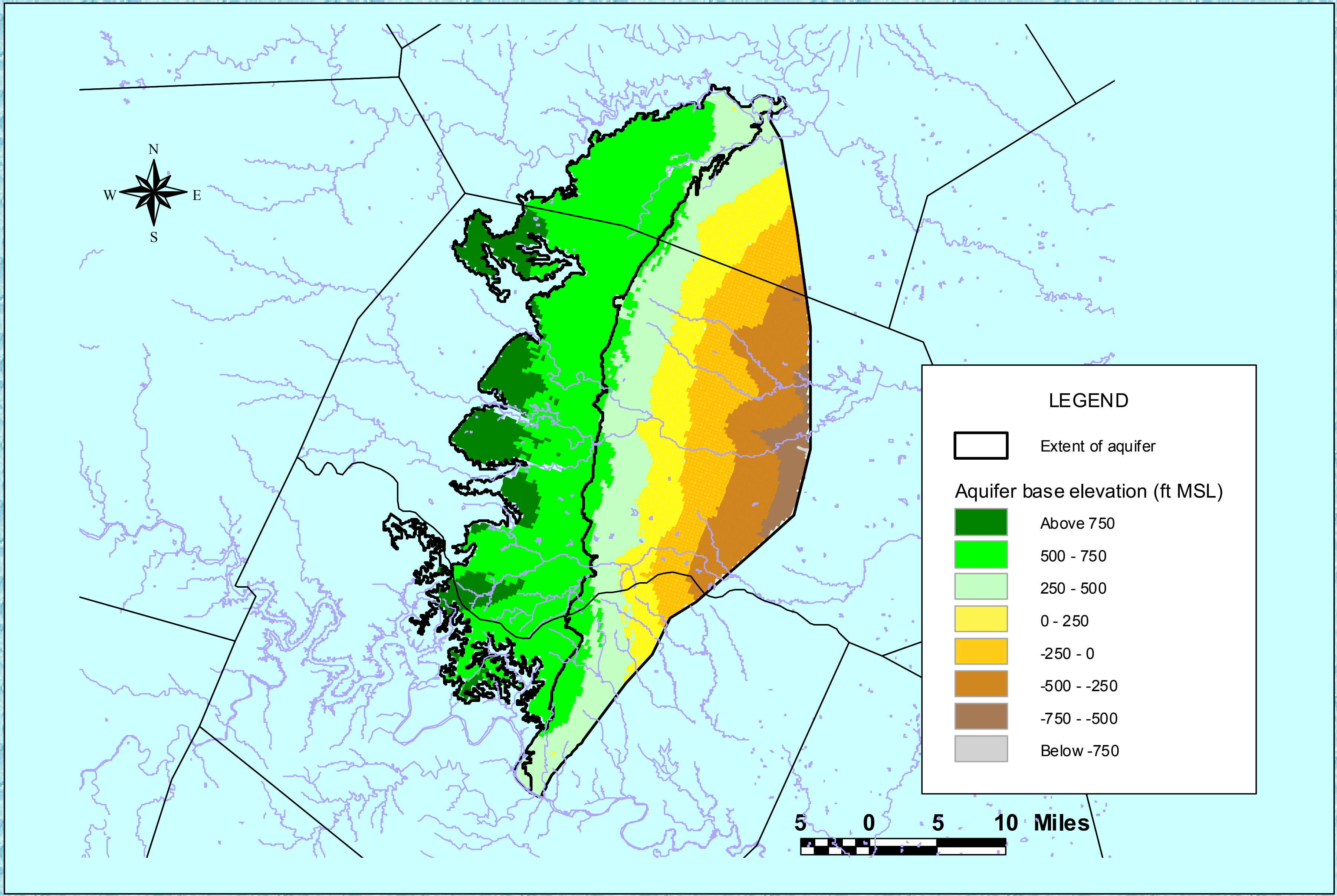
SURFACE GEOLOGY



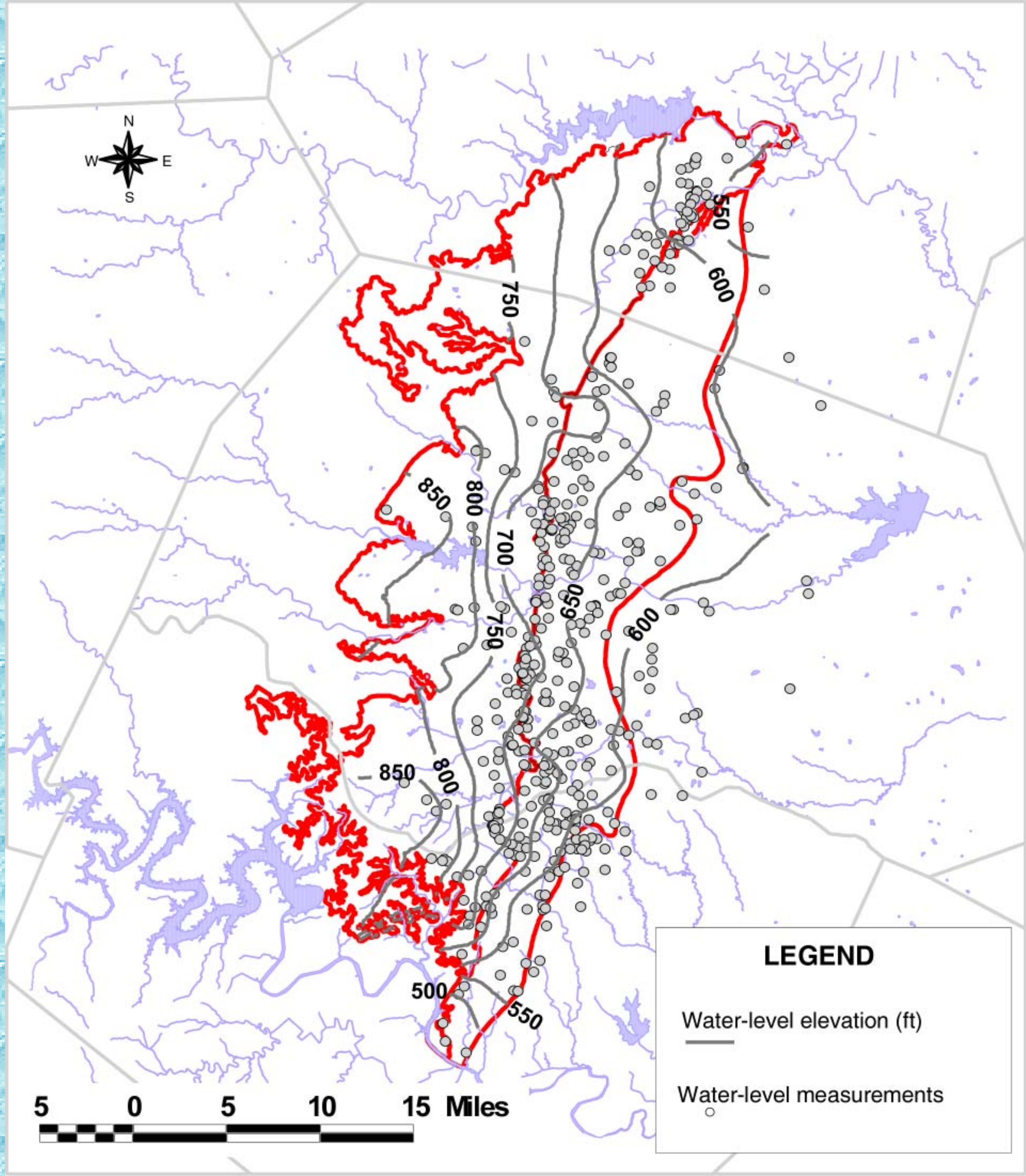
GEOLOGIC CROSS SECTIONS



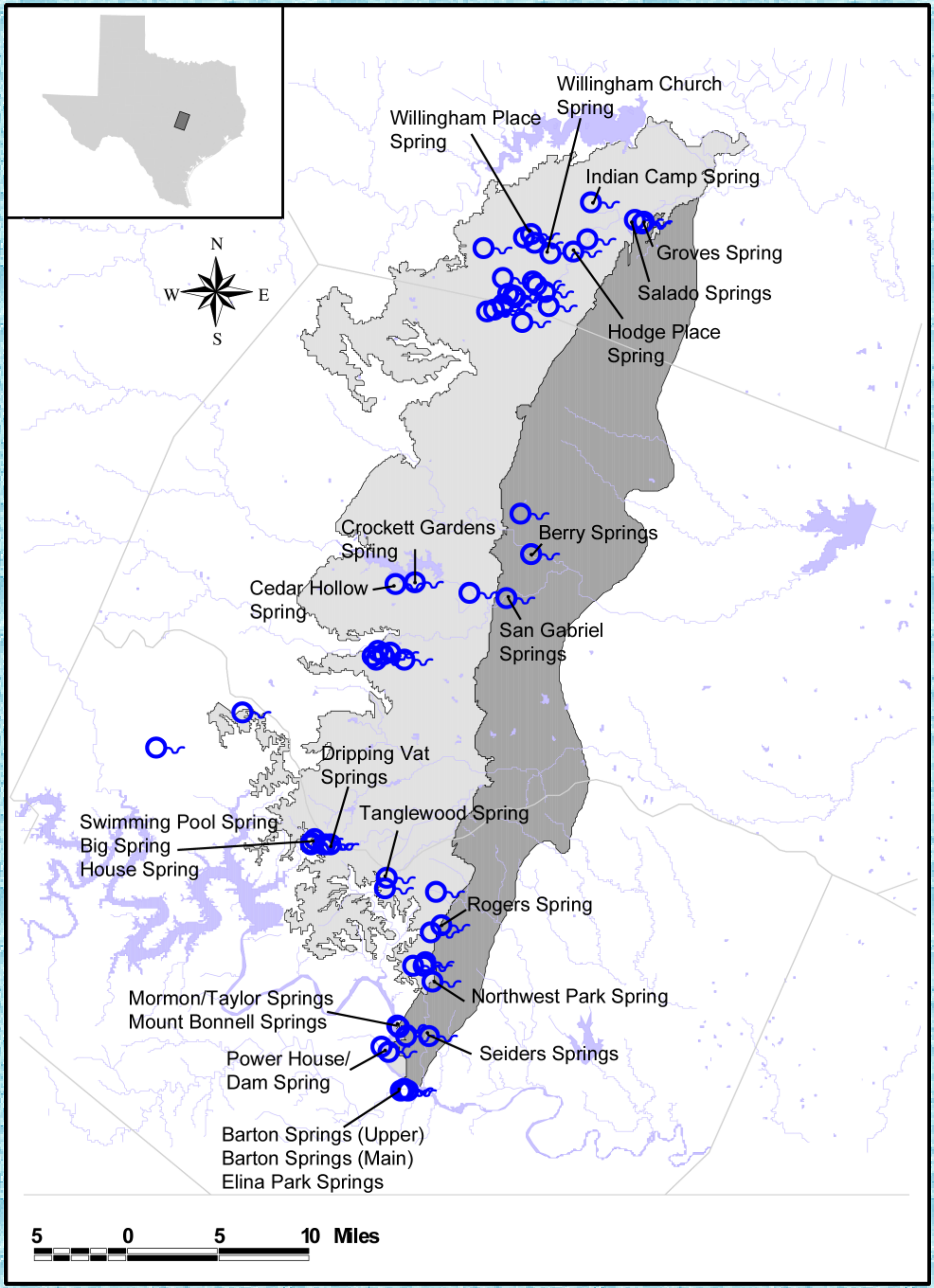
AQUIFER TOP ELEVATION



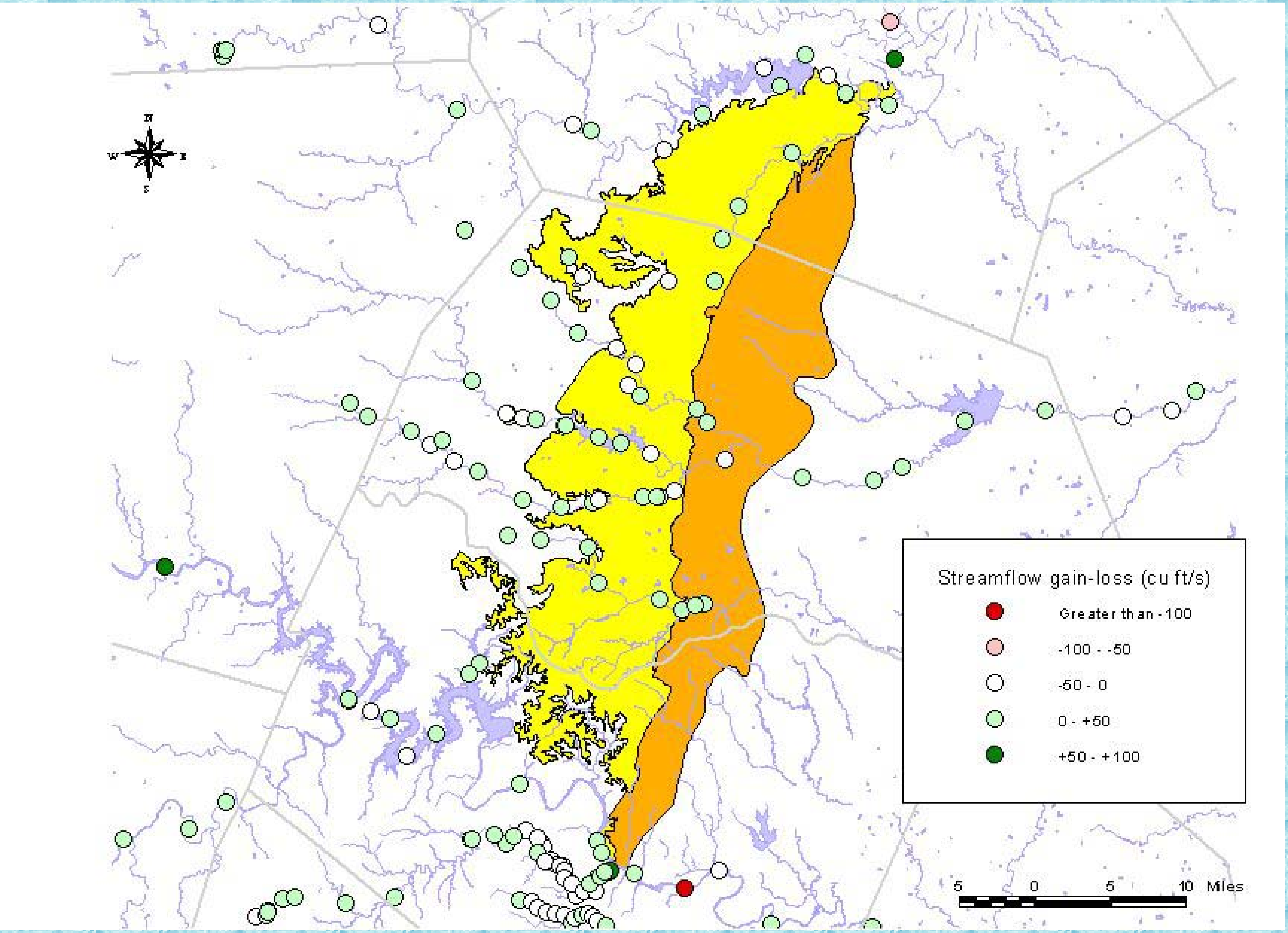
AQUIFER BASE ELEVATION



WATER LEVELS

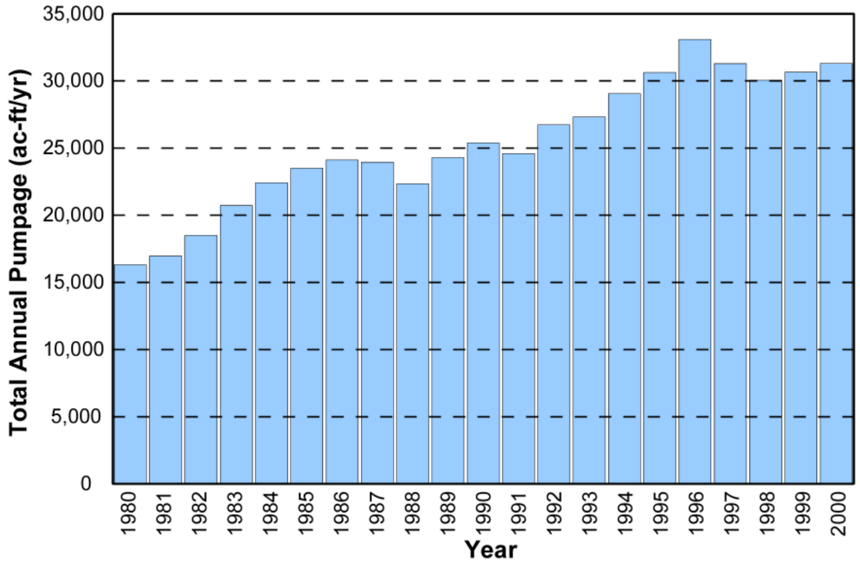


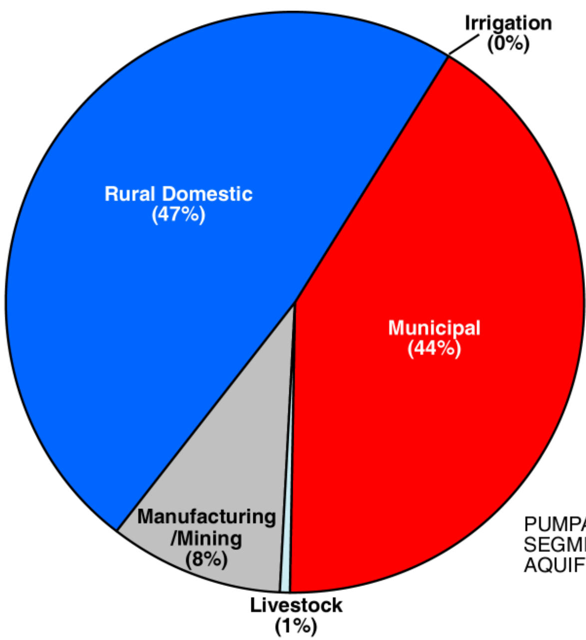
MAJOR SPRINGS



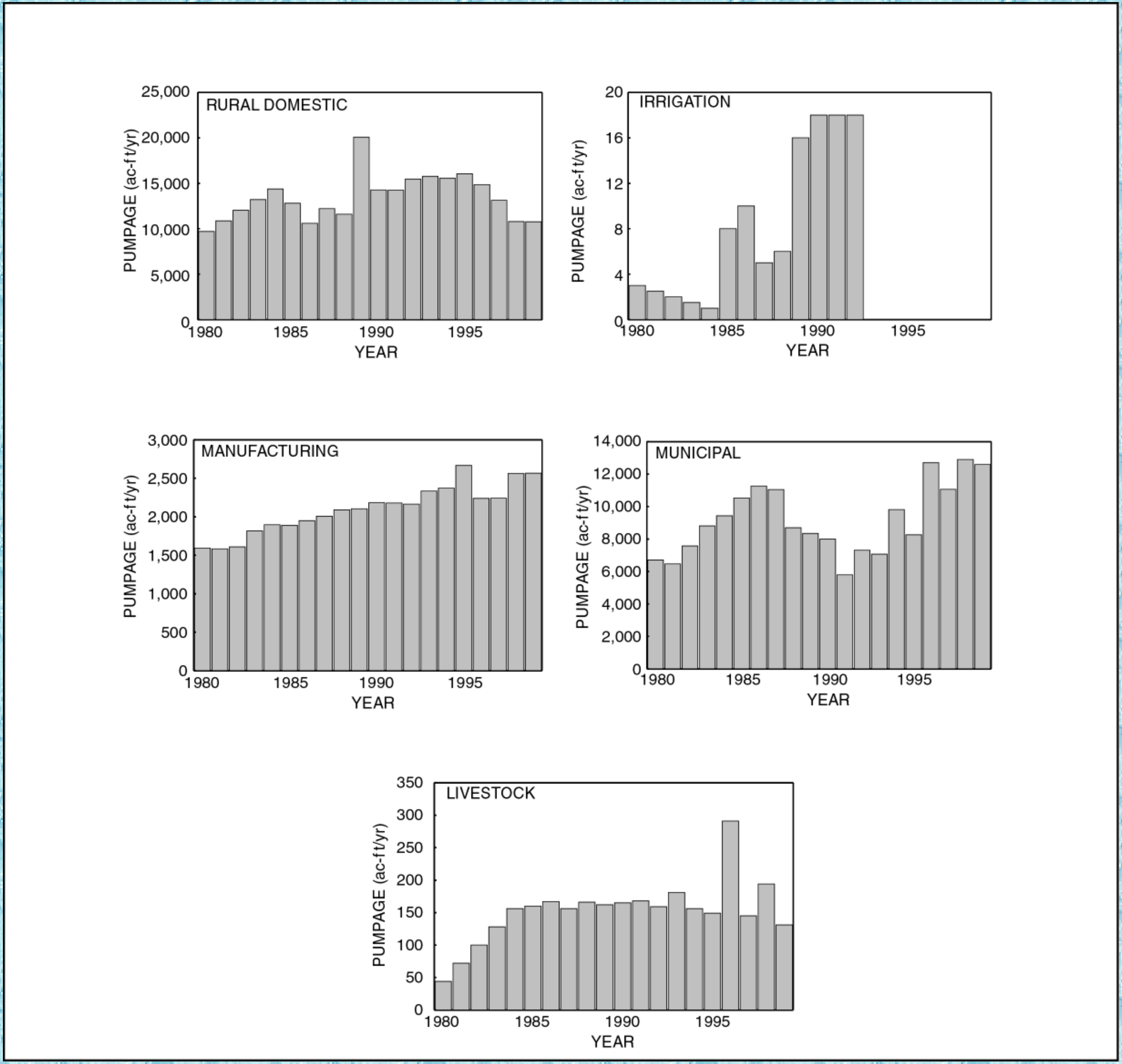
STREAMFLOW GAIN-LOSS

HISTORIC PUMPAGE: TOTAL

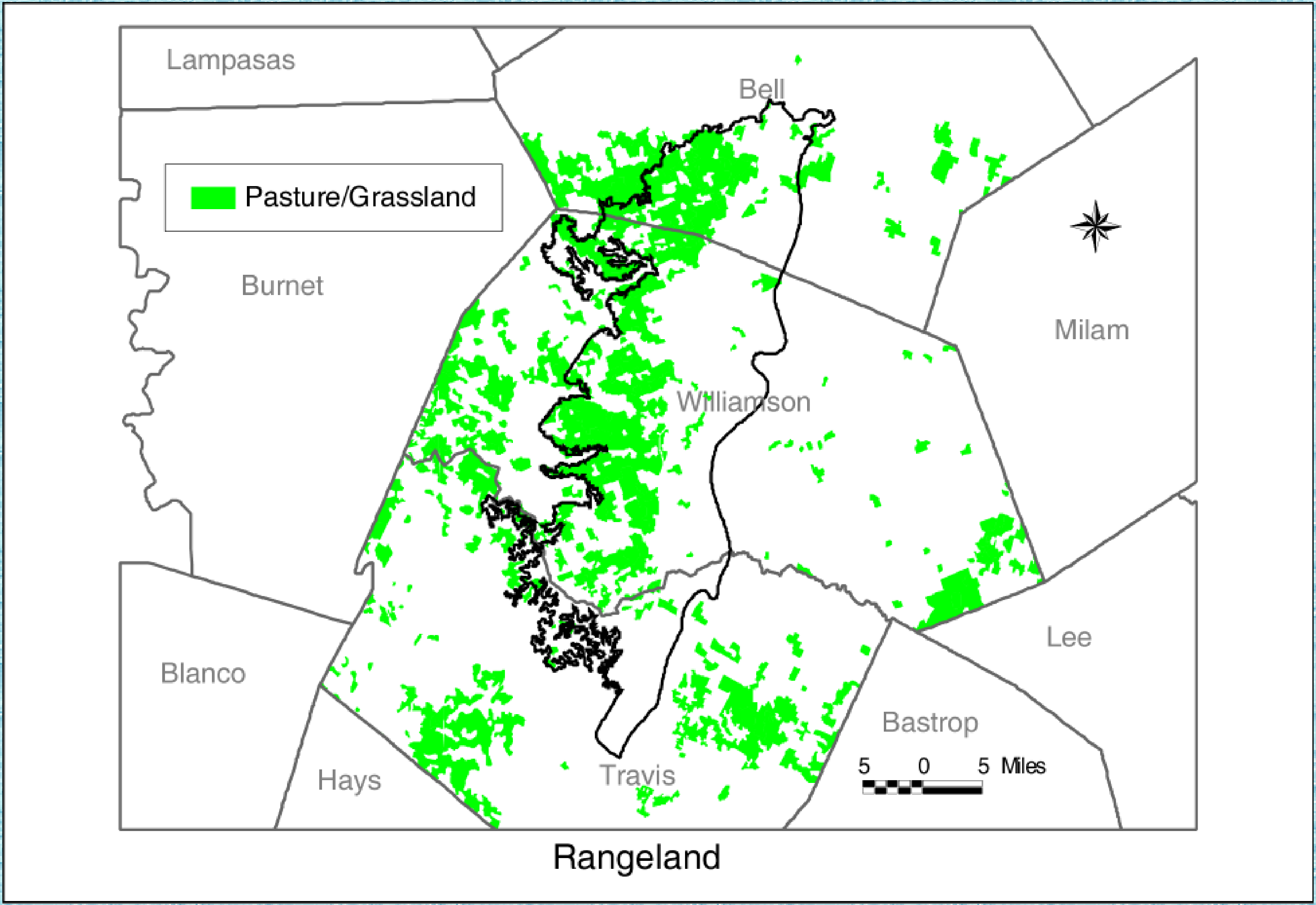




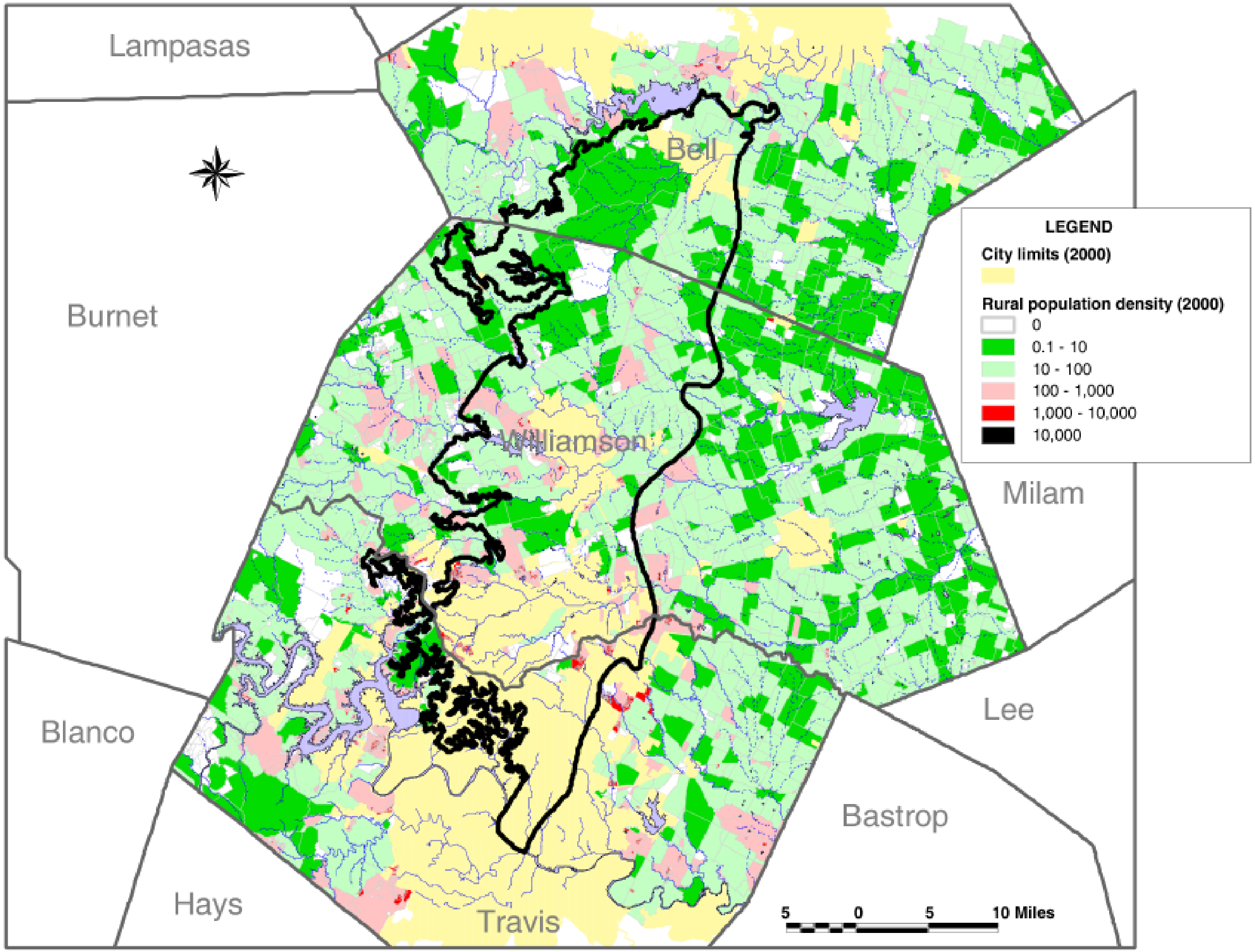
PUMPAGE FROM THE NORTHERN SEGMENT OF THE EDWARDS AQUIFER (1999)



HISTORIC PUMPAGE

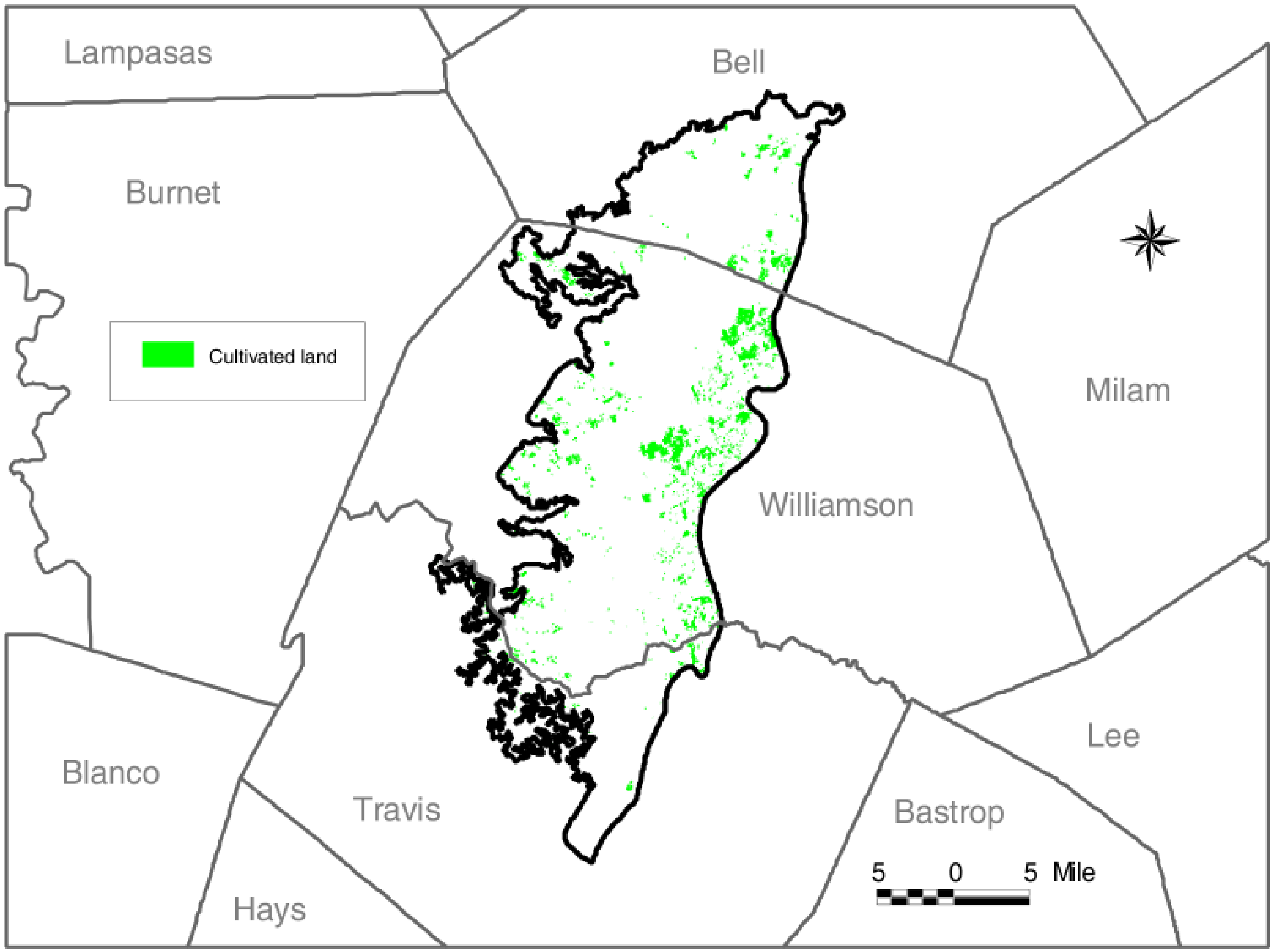

Lampasas
Bell
Pasture/Grassland
Burnet
Milam
Williamson
Lee
Blanco
Bastrop
Hays
Travis
5 0 5 Miles
Rangeland

RANGELAND



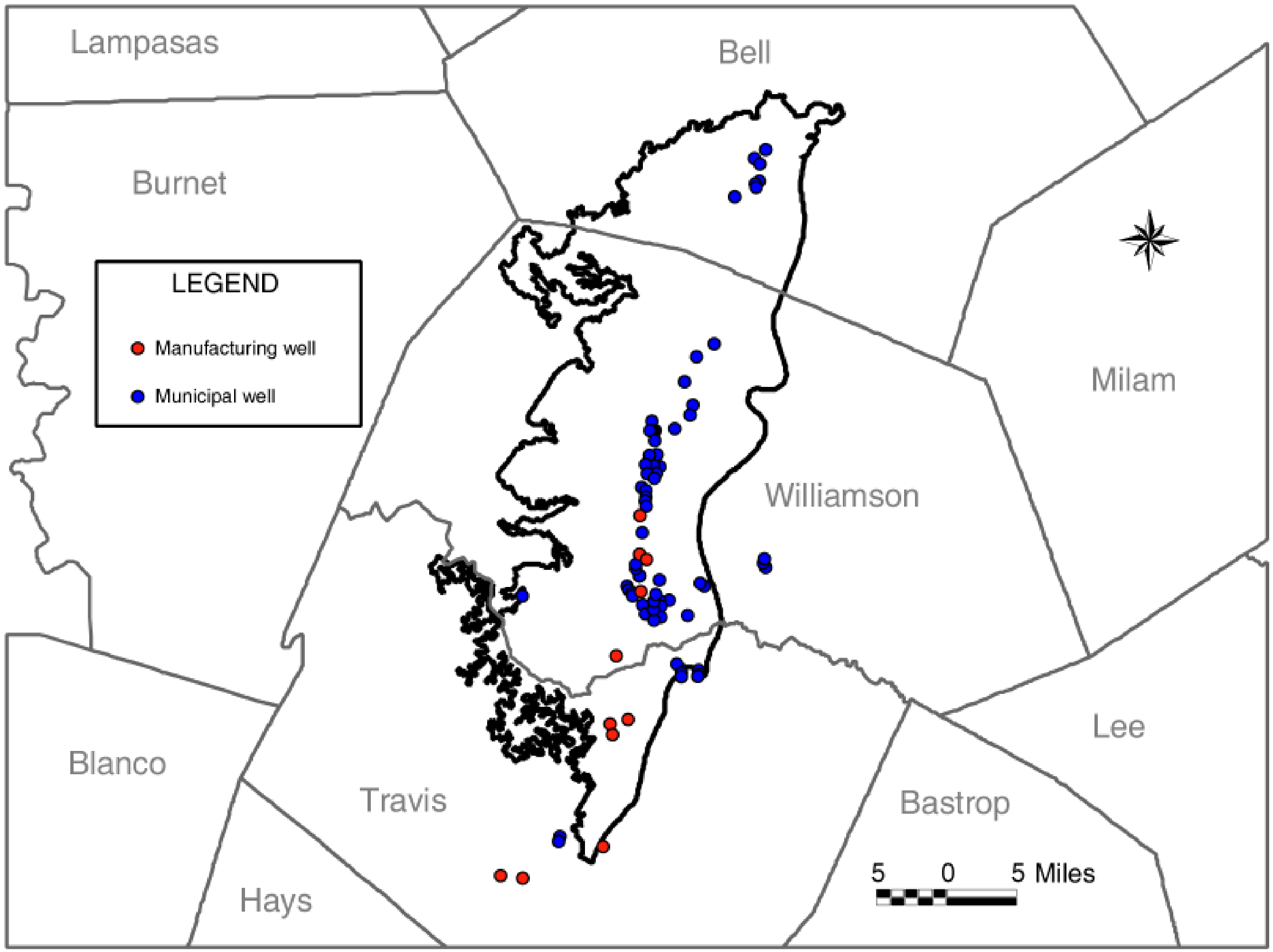
Rural population distribution

RURAL POPULATION



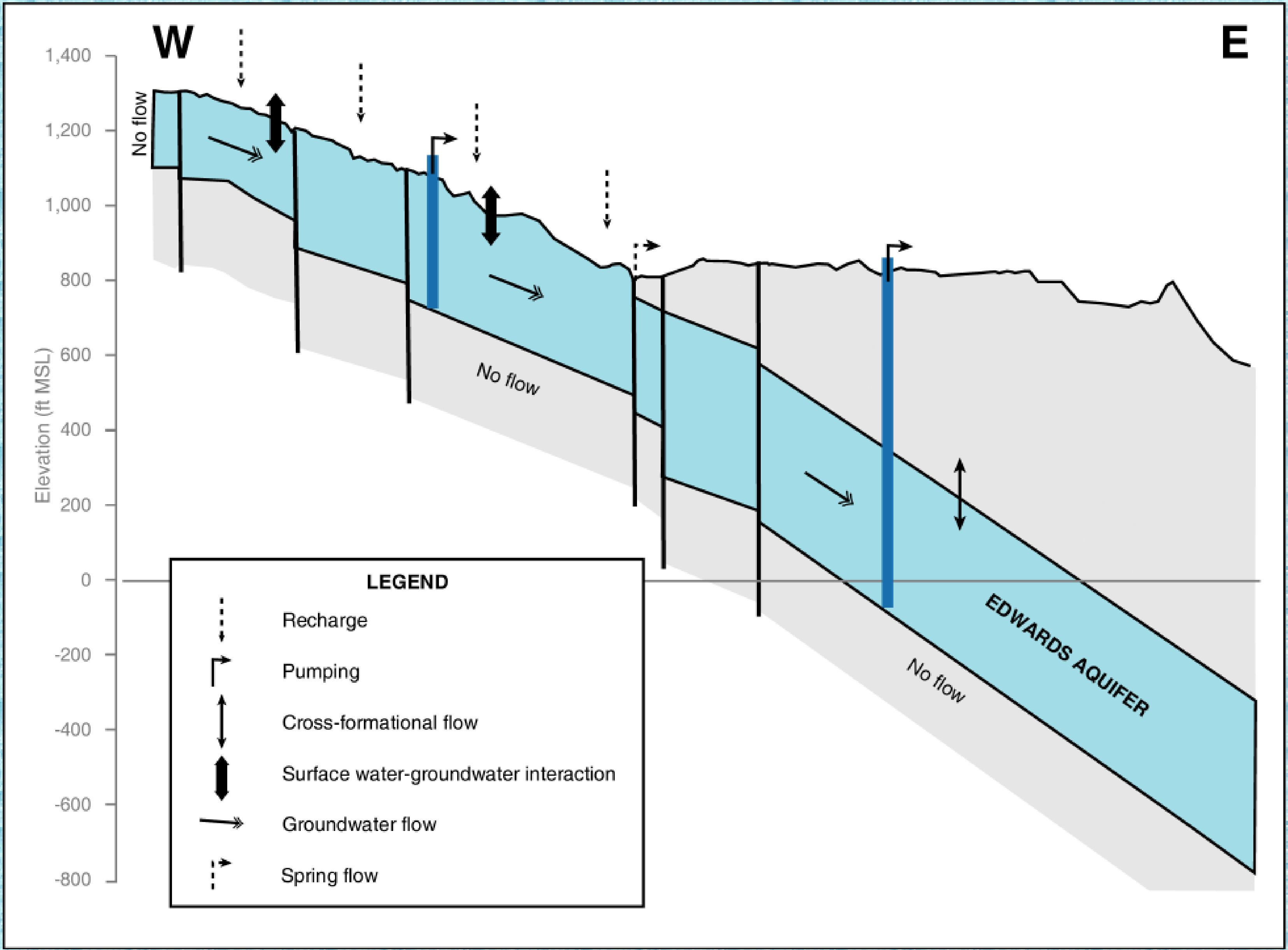
Cultivated land

CULTIVATED LAND



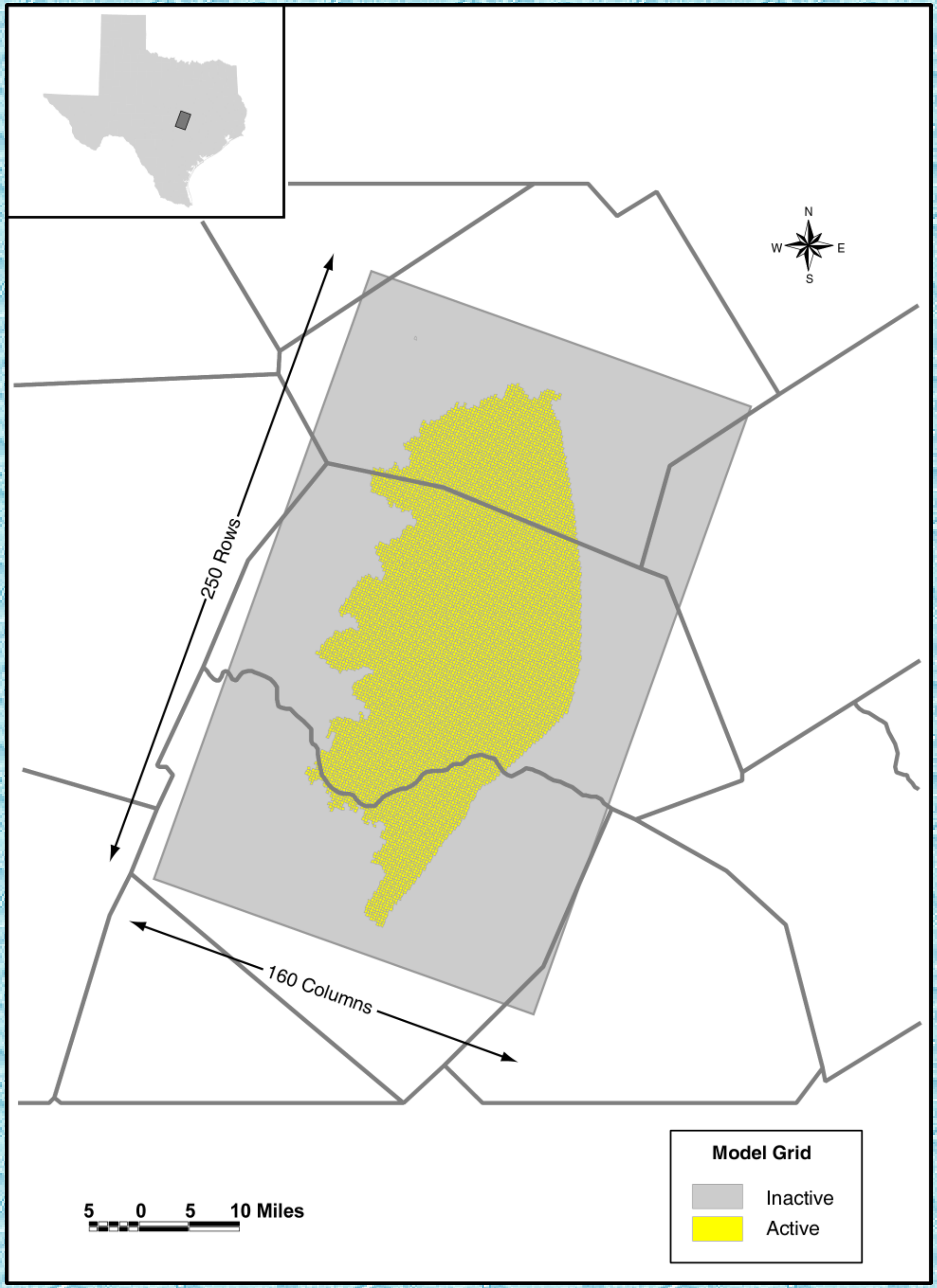
Industrial and municipal wells

INDUSTRIAL/MUNICIPAL WELLS



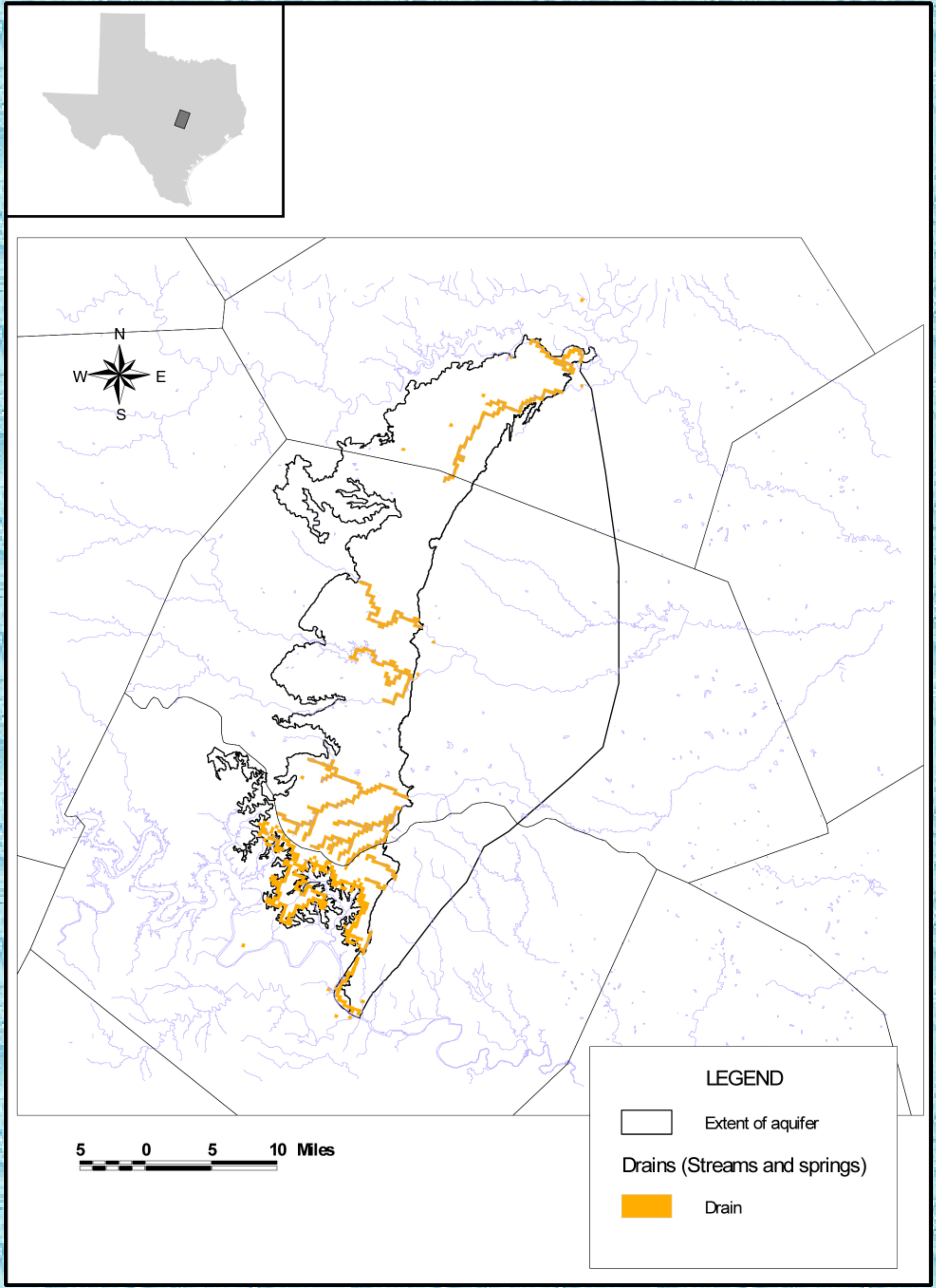
CONCEPTUAL MODEL

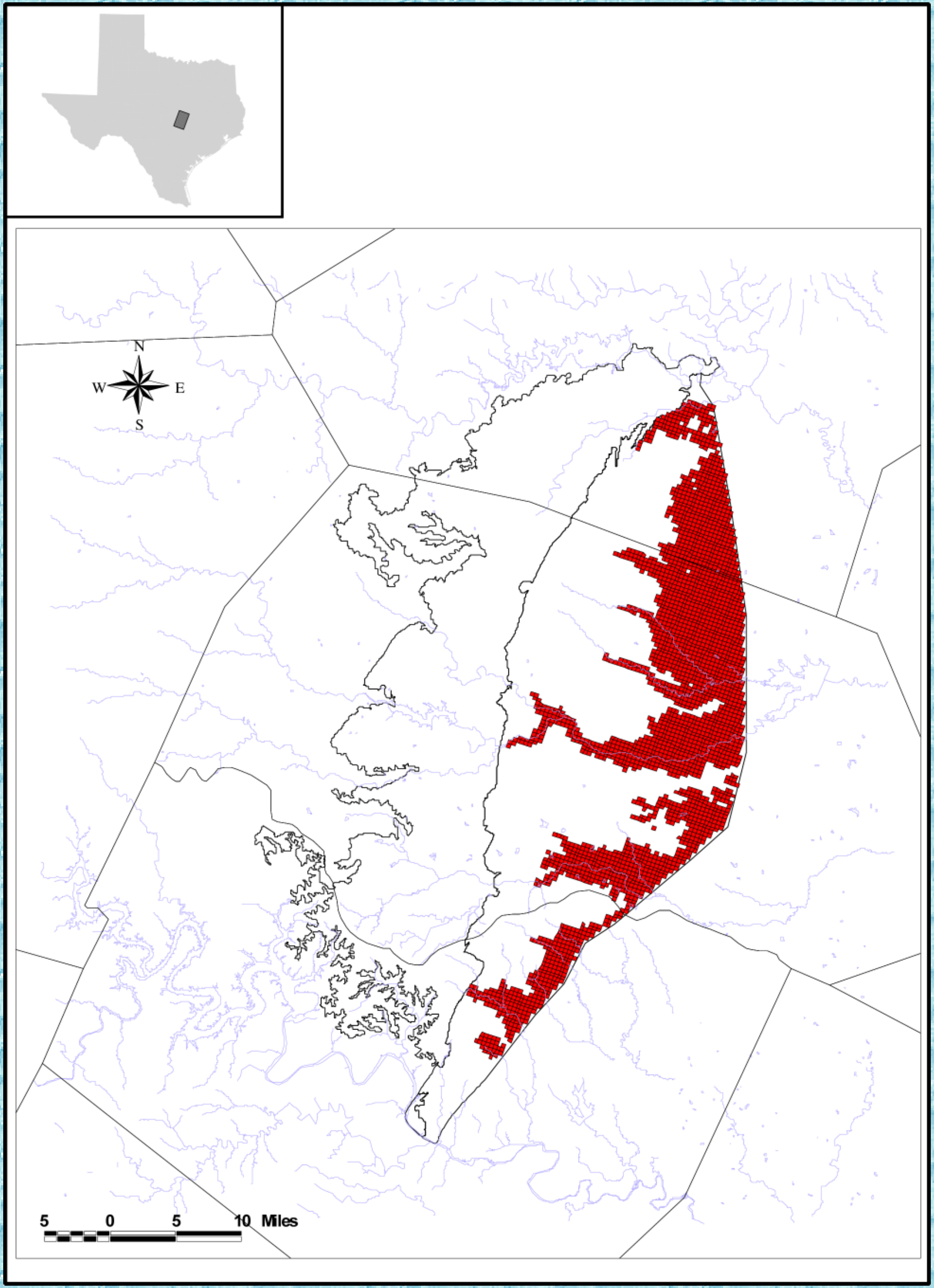
MODEL


N
W
E
S
250 Rows
160 Columns
Model Grid
Inactive
Active
5 0 5 10 Miles

MODEL GRID

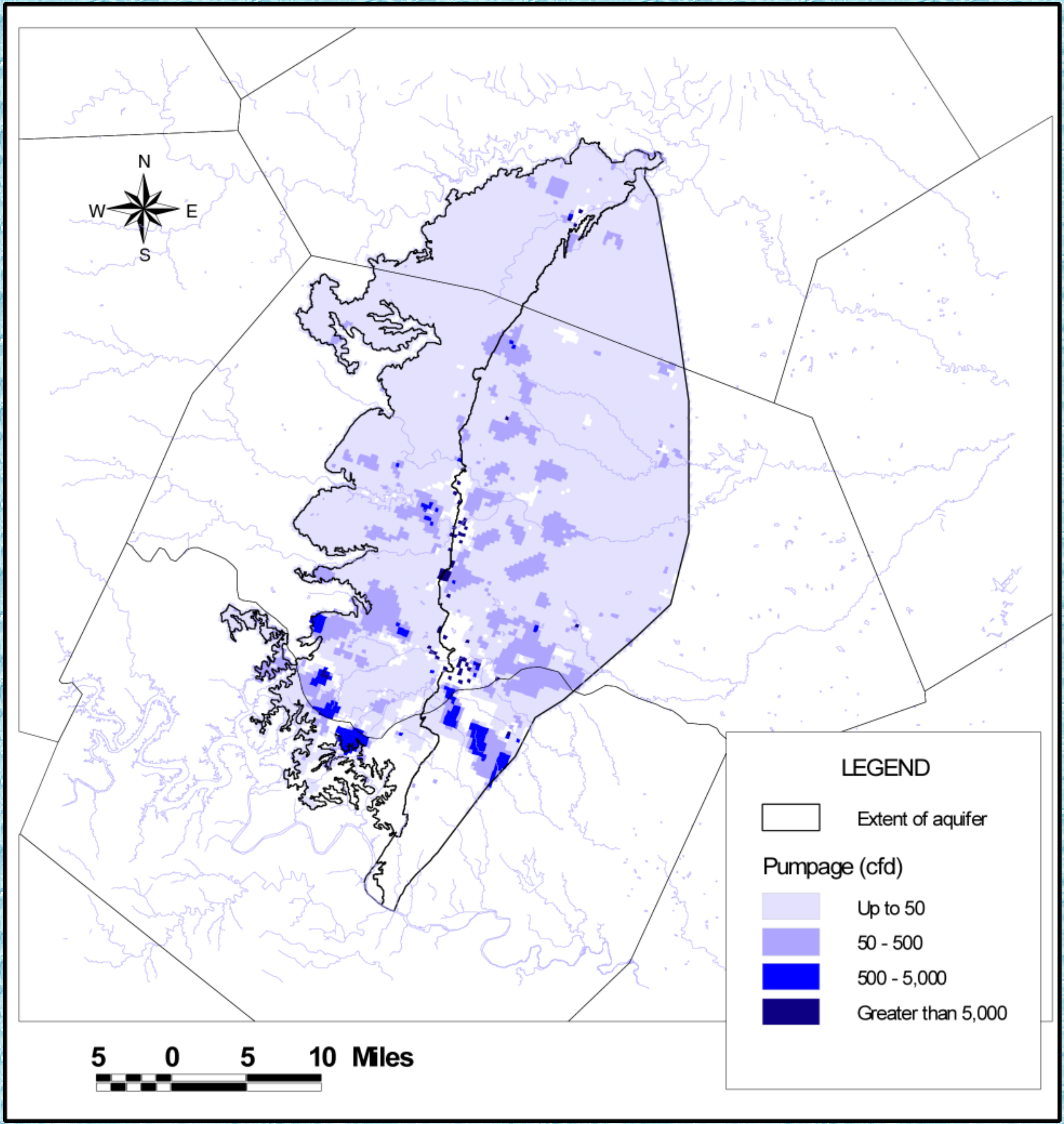
DRAINS (STREAMS)



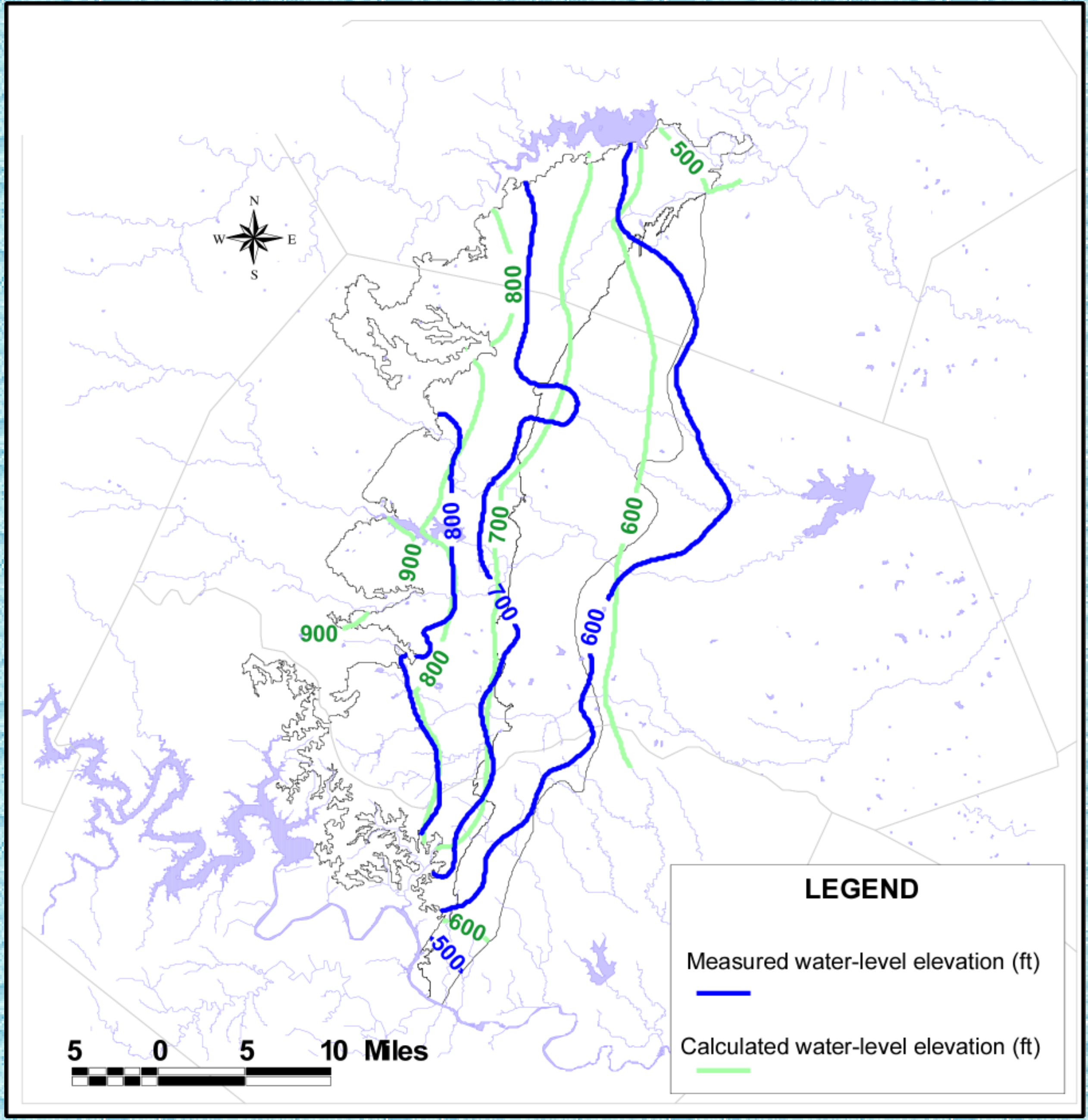


GENERAL-HEAD BOUNDARY (INTER-AQUIFER FLOW)

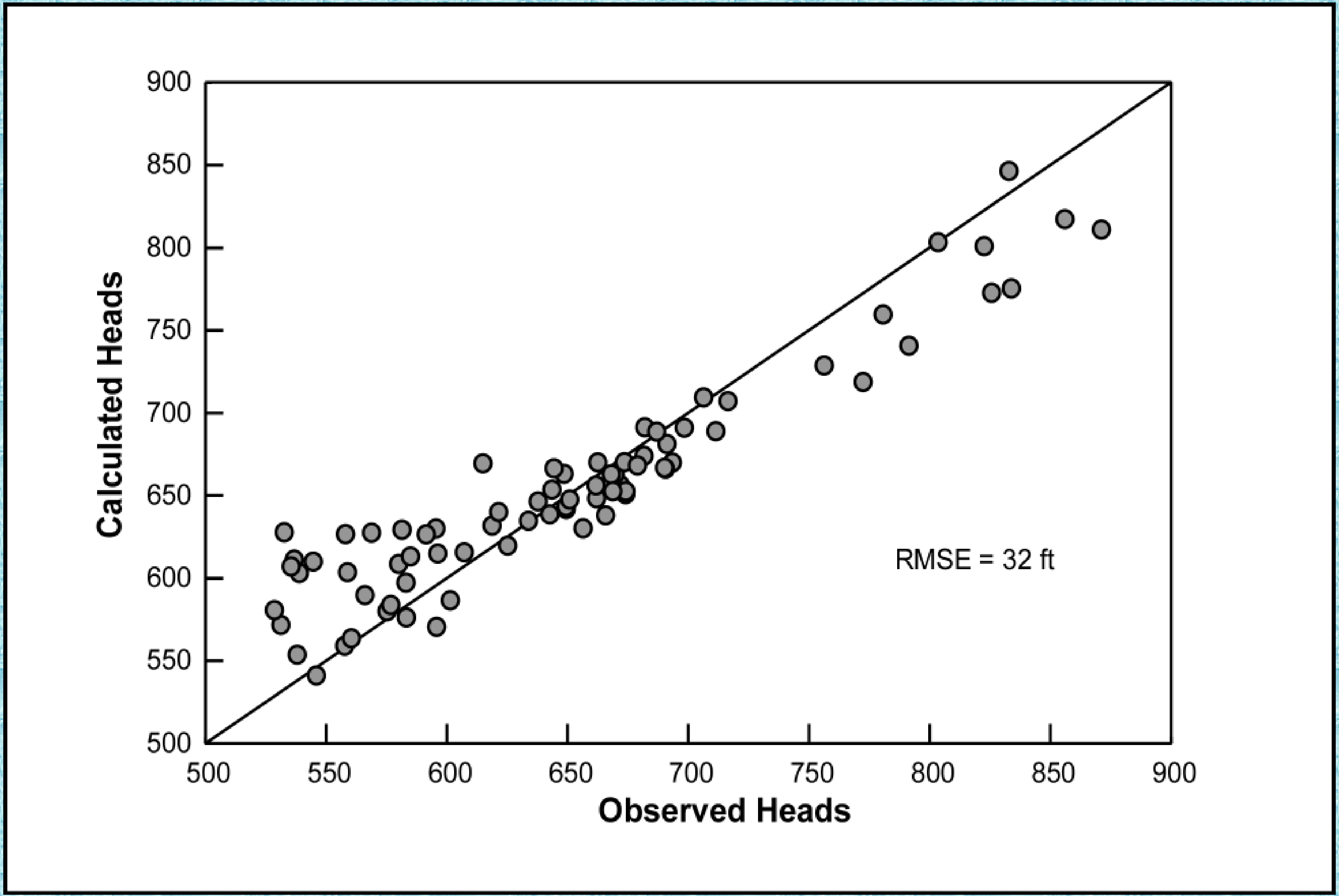
TOTAL PUMPAGE



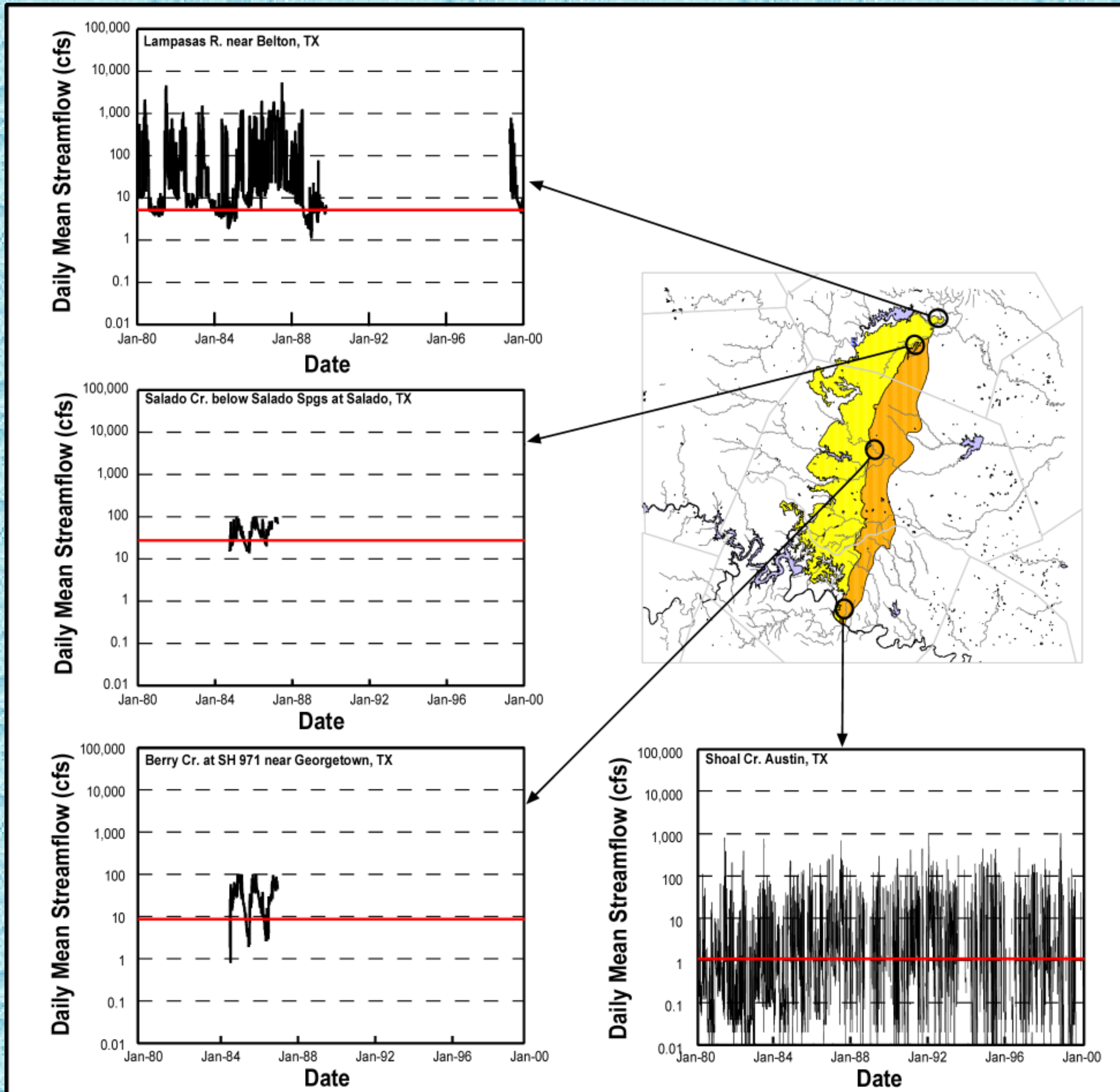
MODEL RESULTS: STEADY-STATE MODEL



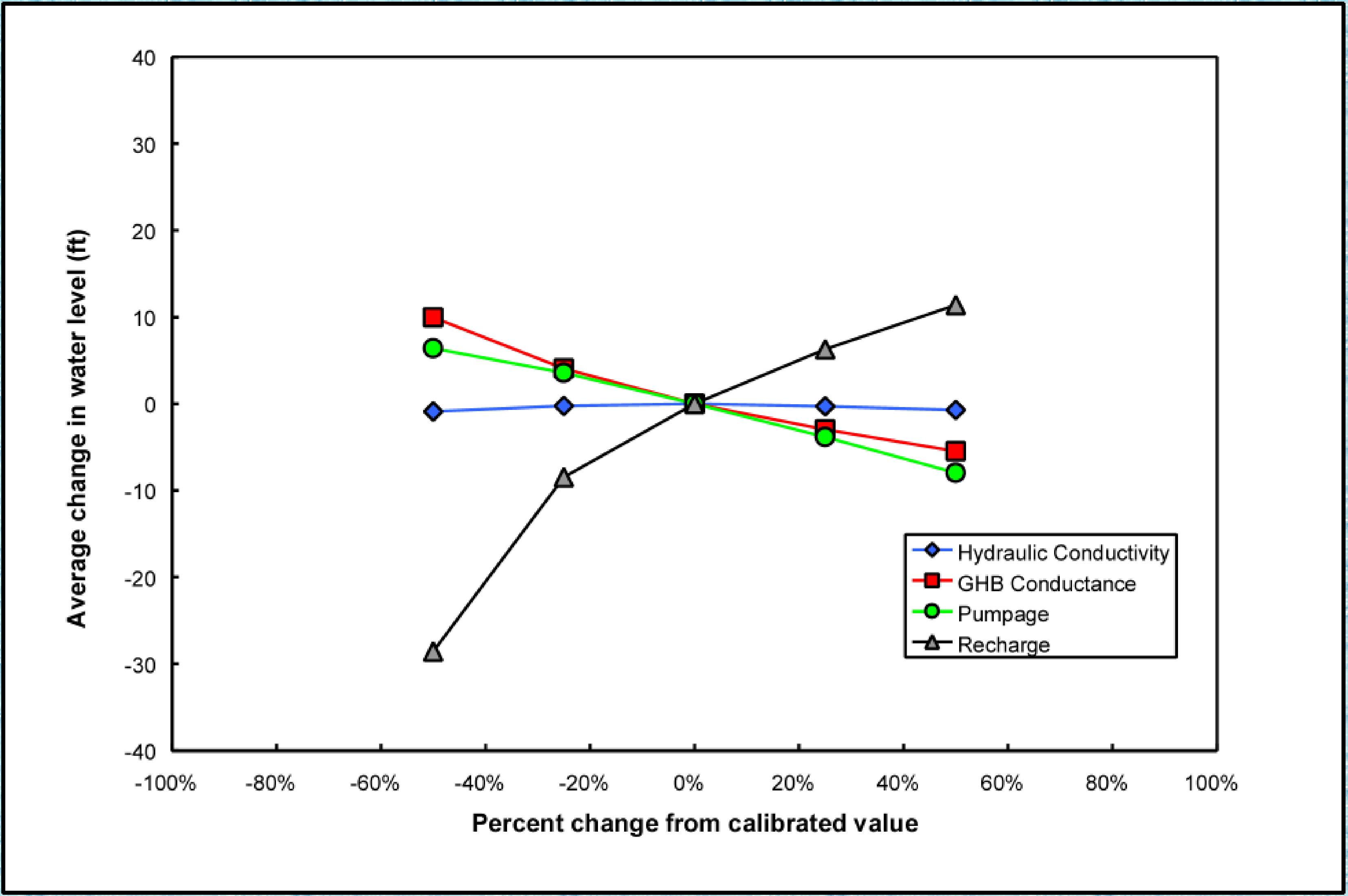
MEASURED vs. SIMULATED WATER LEVELS



MEASURED vs. SIMULATED WATER LEVELS



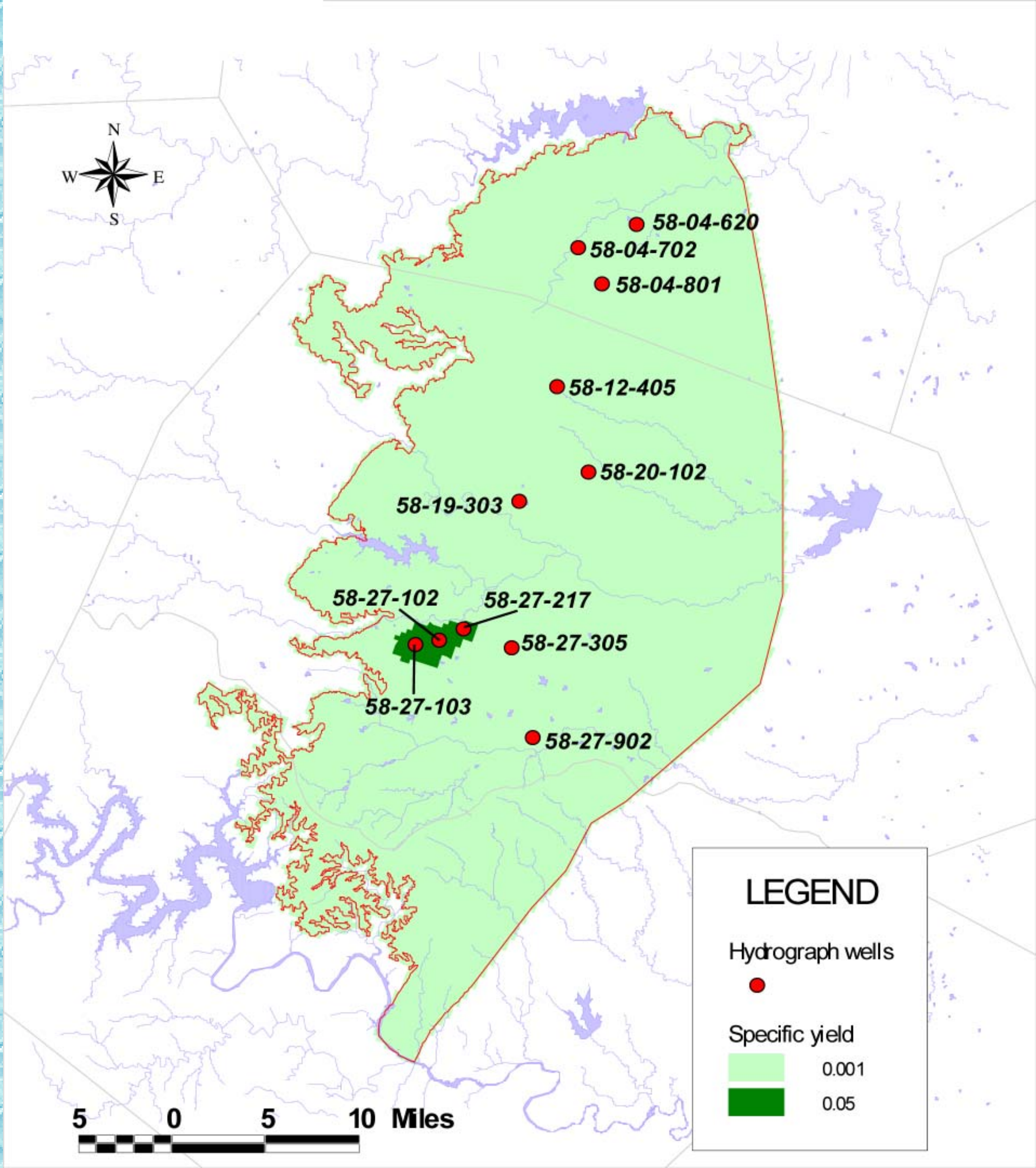
MEASURED vs. SIMULATED STREAM DISCHARGE

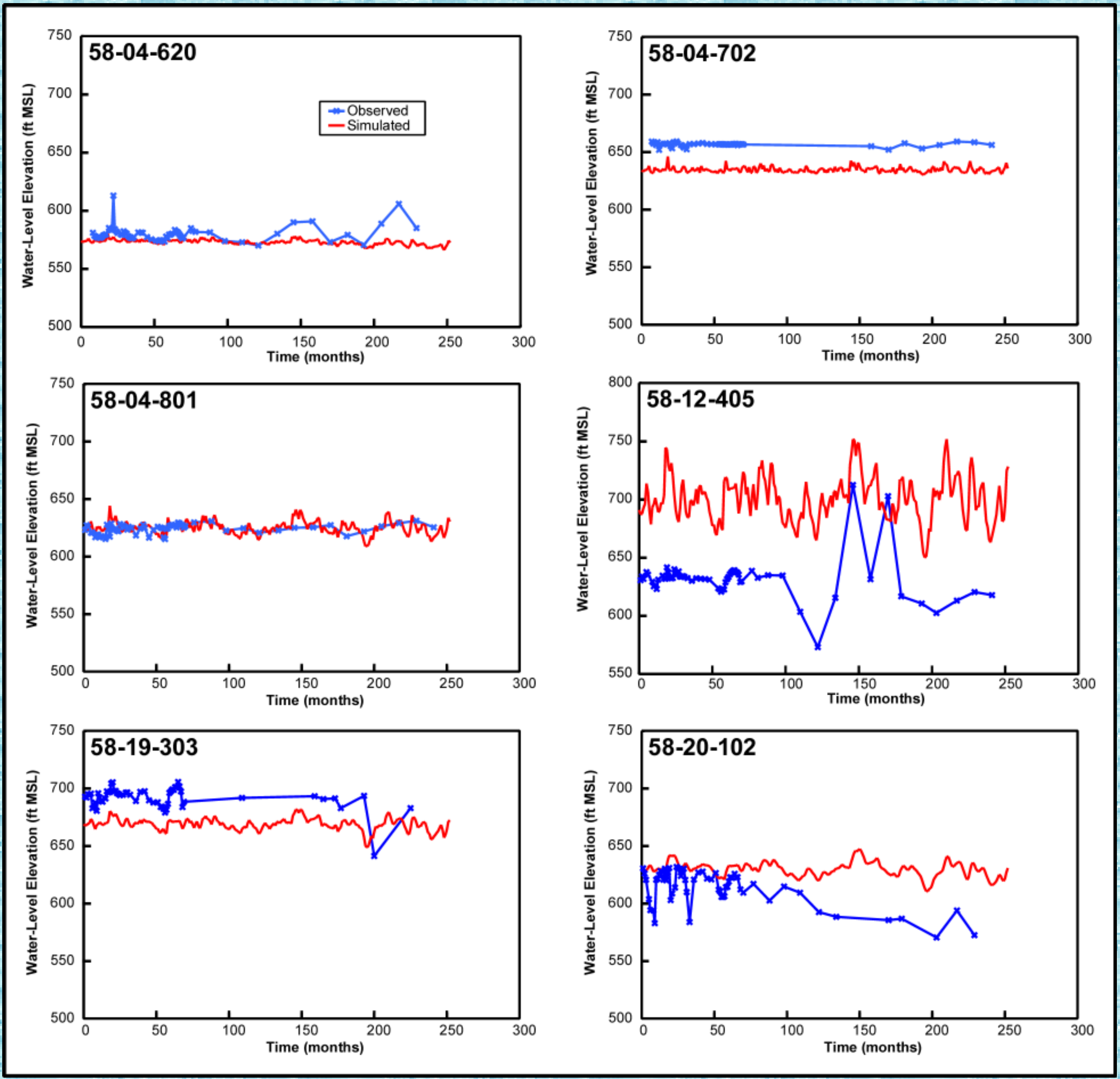


SENSITIVITY ANALYSIS: STEADY-STATE

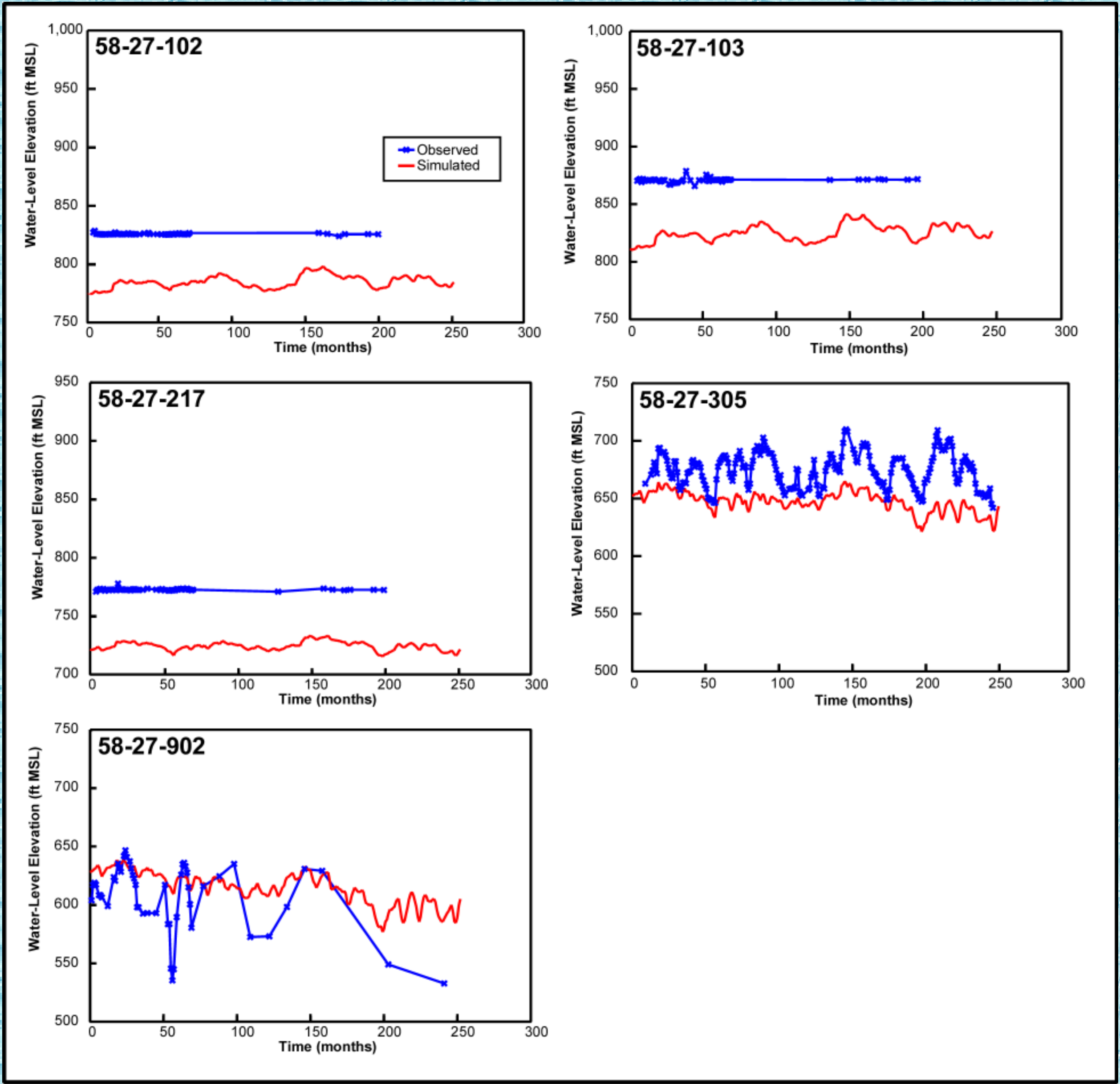
MODEL RESULTS: TRANSIENT MODEL

SPECIFIC YIELD

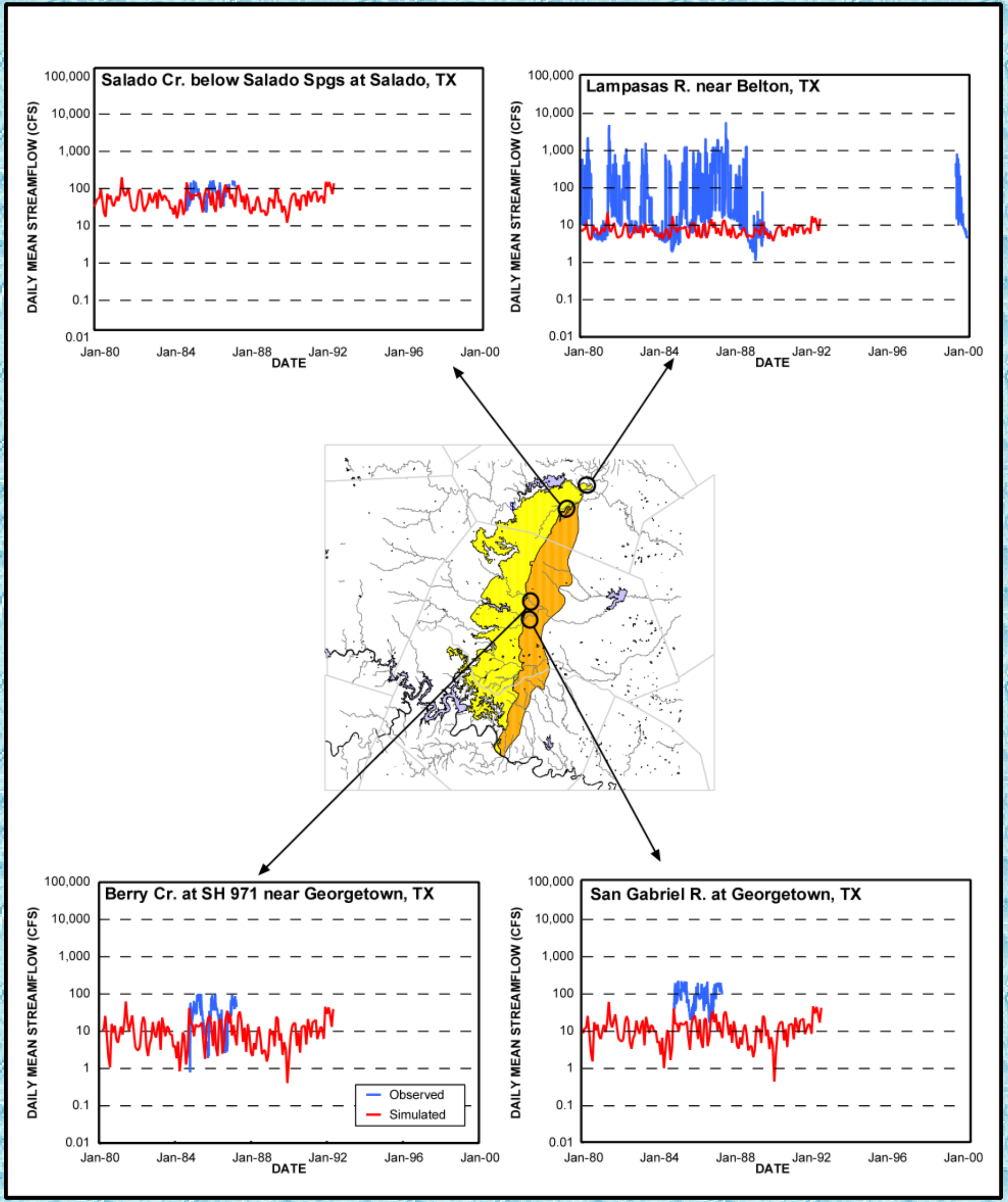




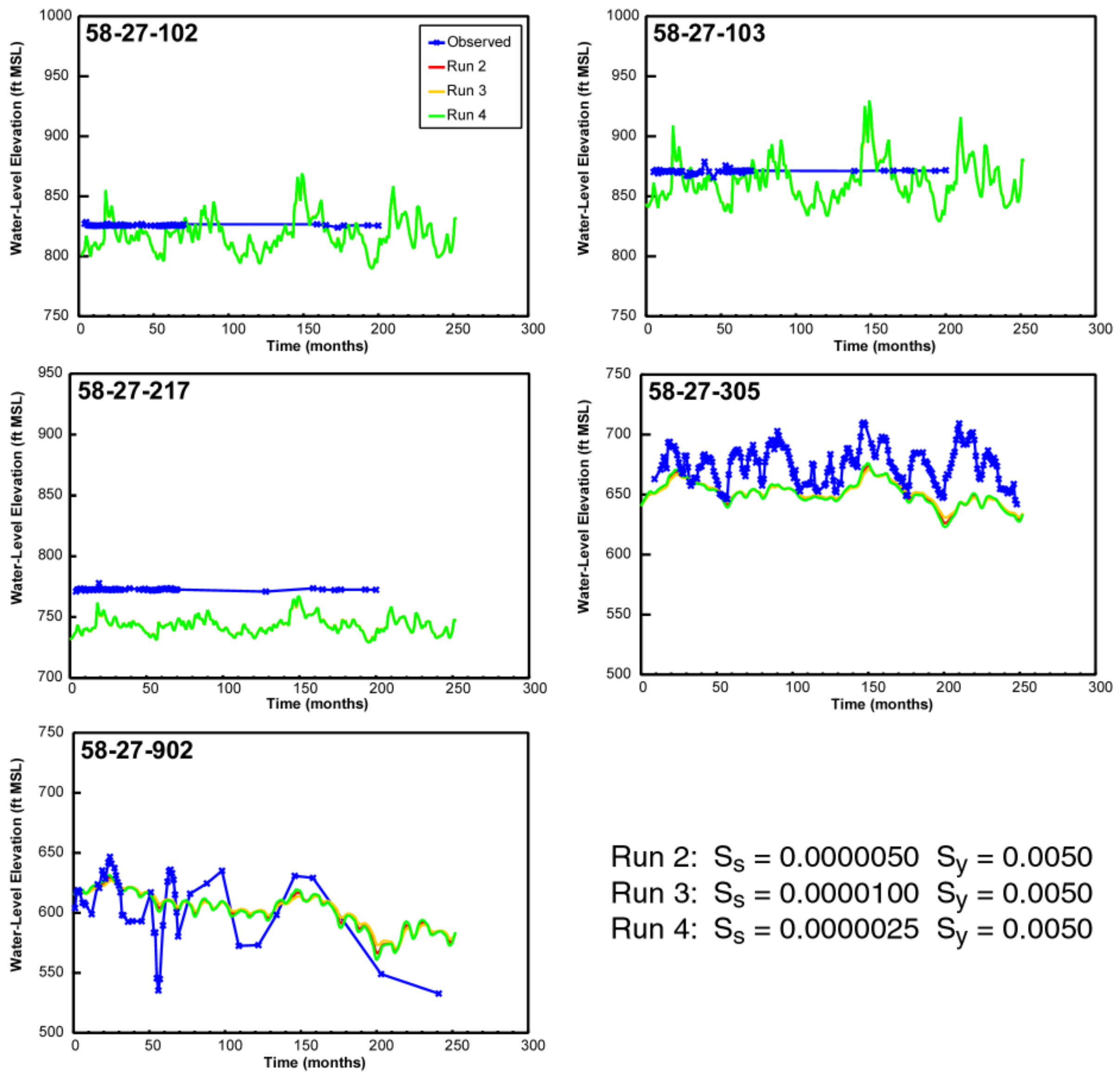
MEASURED vs. SIMULATED WATER LEVELS



MEASURED vs. SIMULATED WATER LEVELS

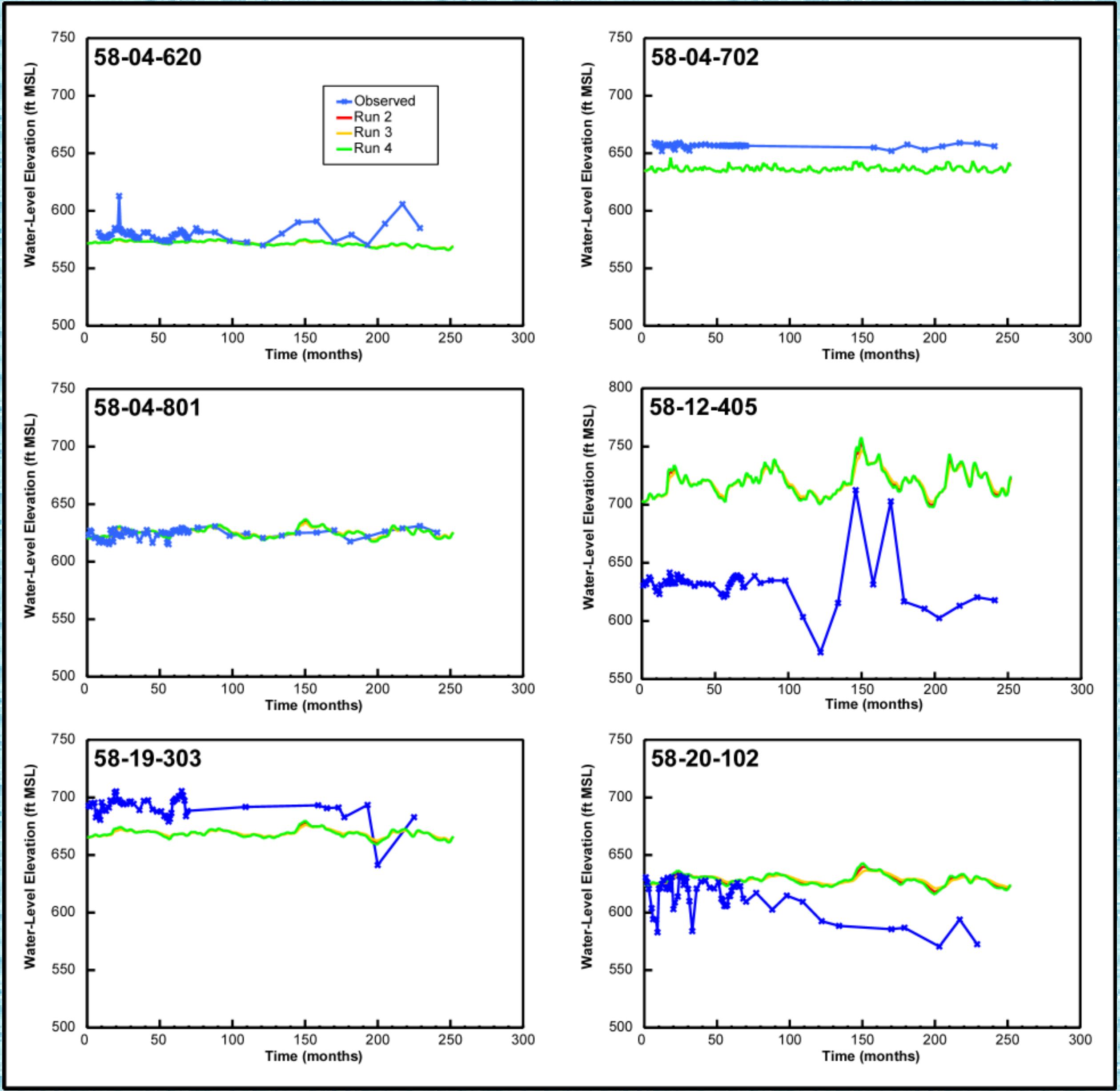


MEASURED vs. SIMULATED STREAM DISCHARGE

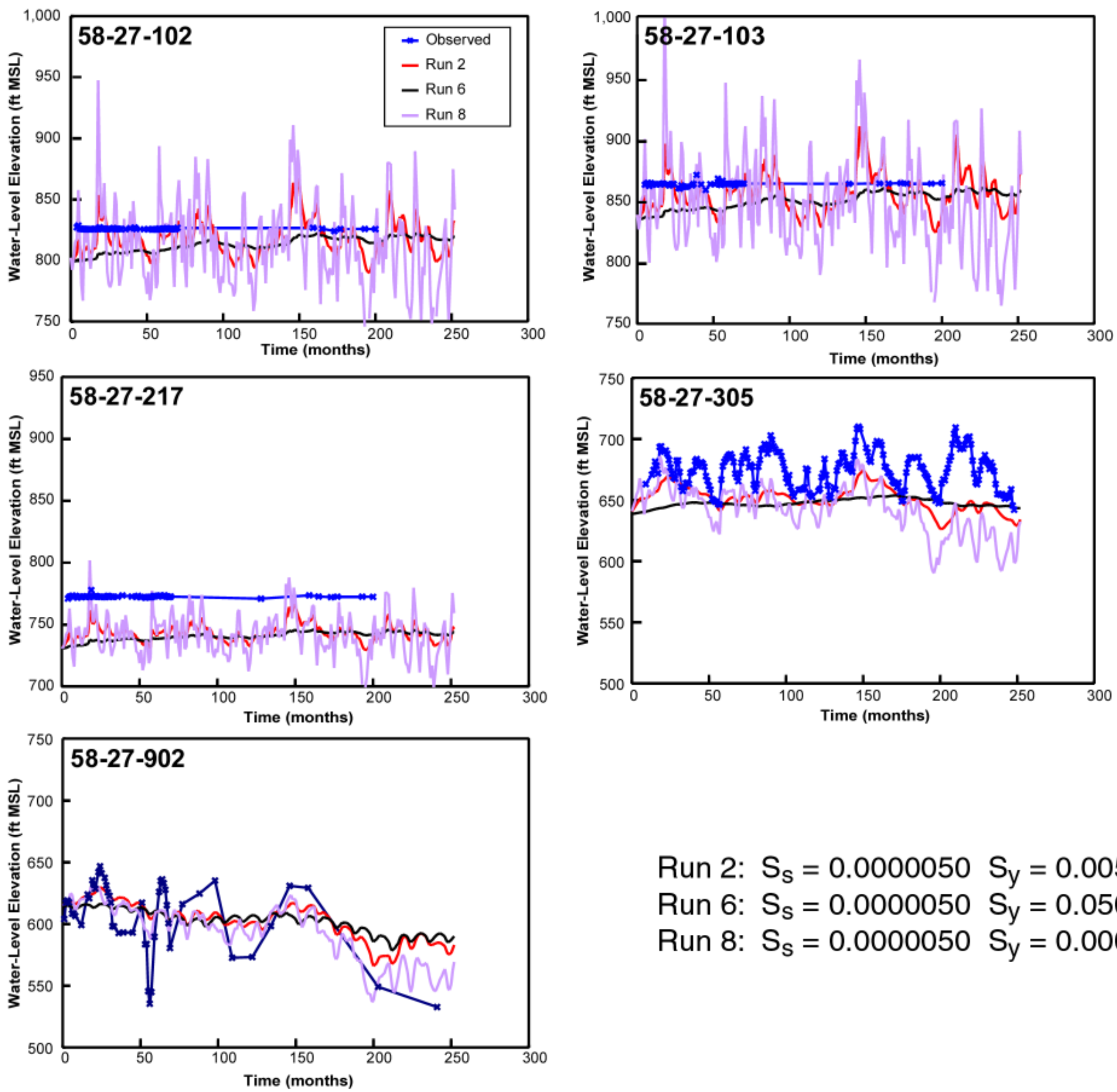


Run 2: $S_s = 0.0000050$ $S_y = 0.0050$
Run 3: $S_s = 0.0000100$ $S_y = 0.0050$
Run 4: $S_s = 0.0000025$ $S_y = 0.0050$

SENSITIVITY ANALYSIS: SPECIFIC STORAGE

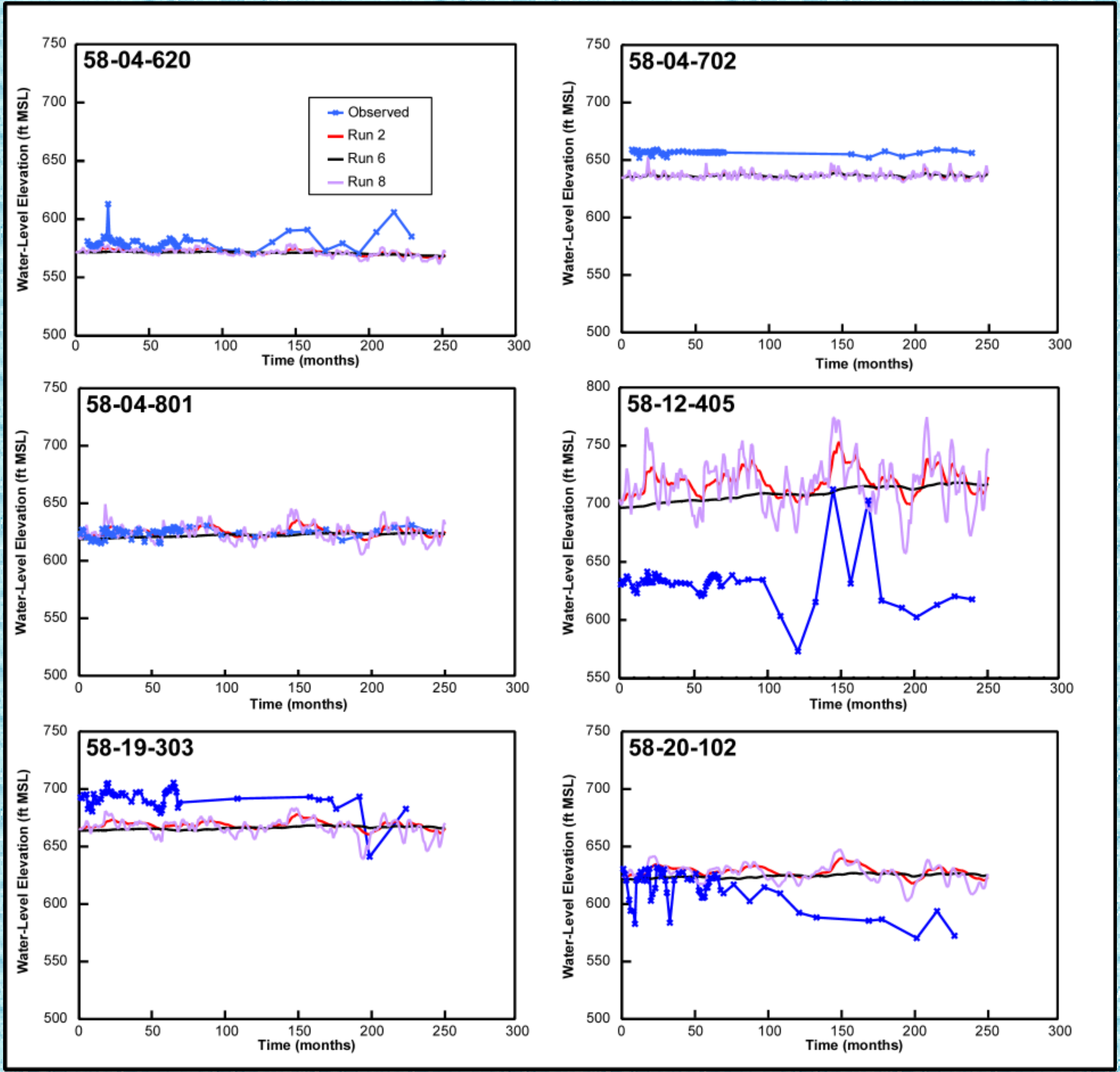


SENSITIVITY ANALYSIS: SPECIFIC STORAGE



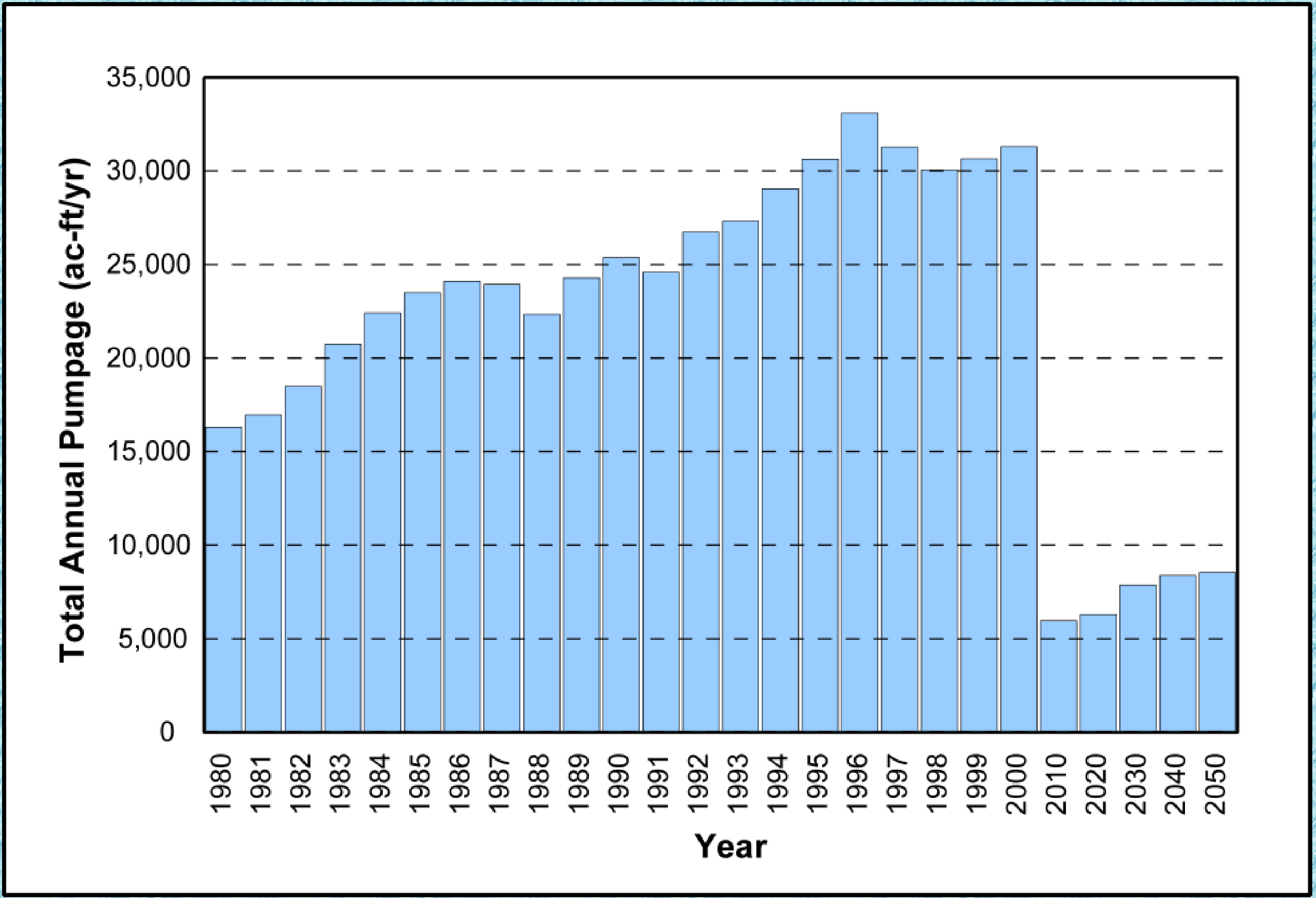
Run 2: S_s = 0.0000050 S_y = 0.0050
Run 6: S_s = 0.0000050 S_y = 0.0500
Run 8: S_s = 0.0000050 S_y = 0.0005

SENSITIVITY ANALYSIS: SPECIFIC YIELD

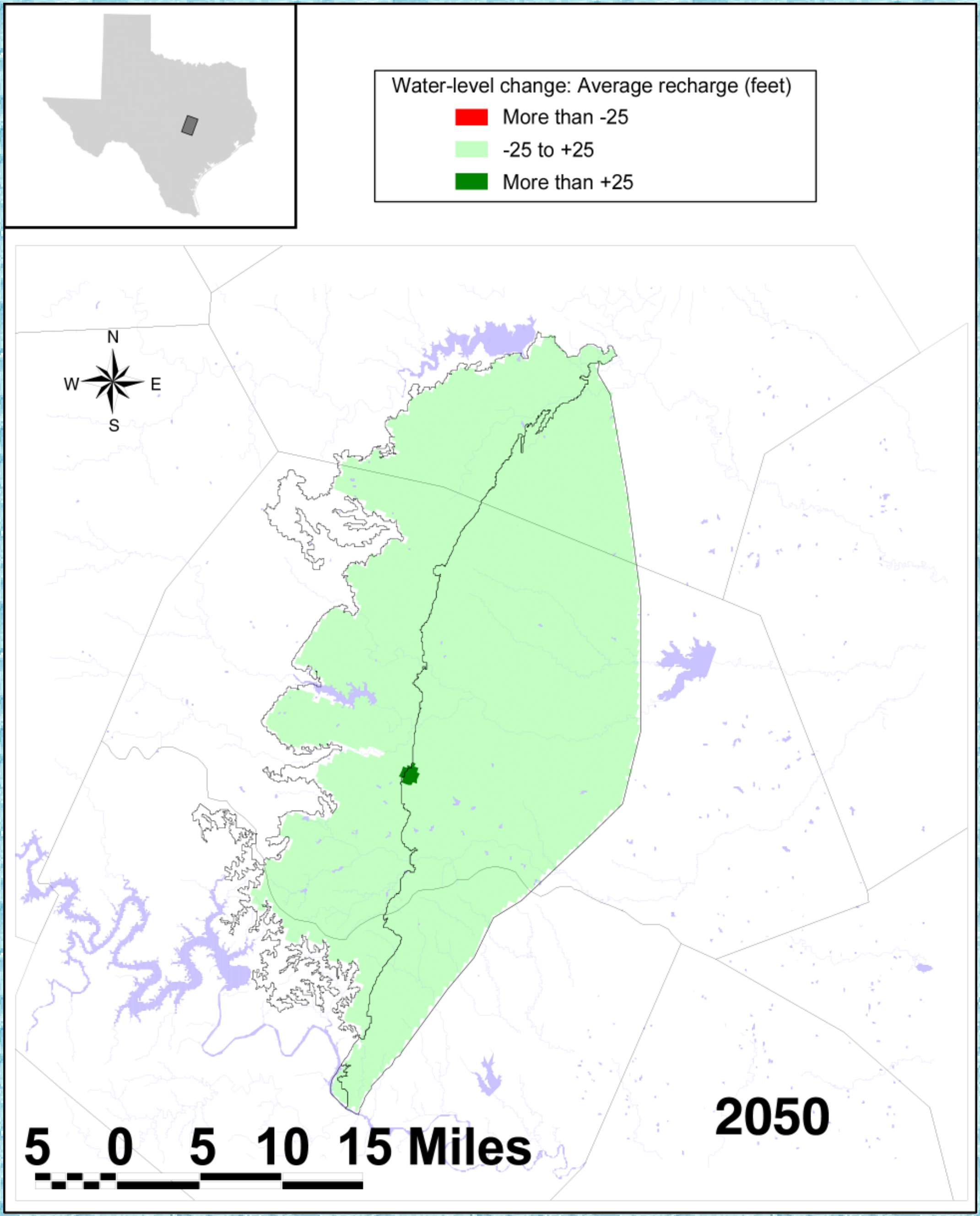


SENSITIVITY ANALYSIS: SPECIFIC YIELD

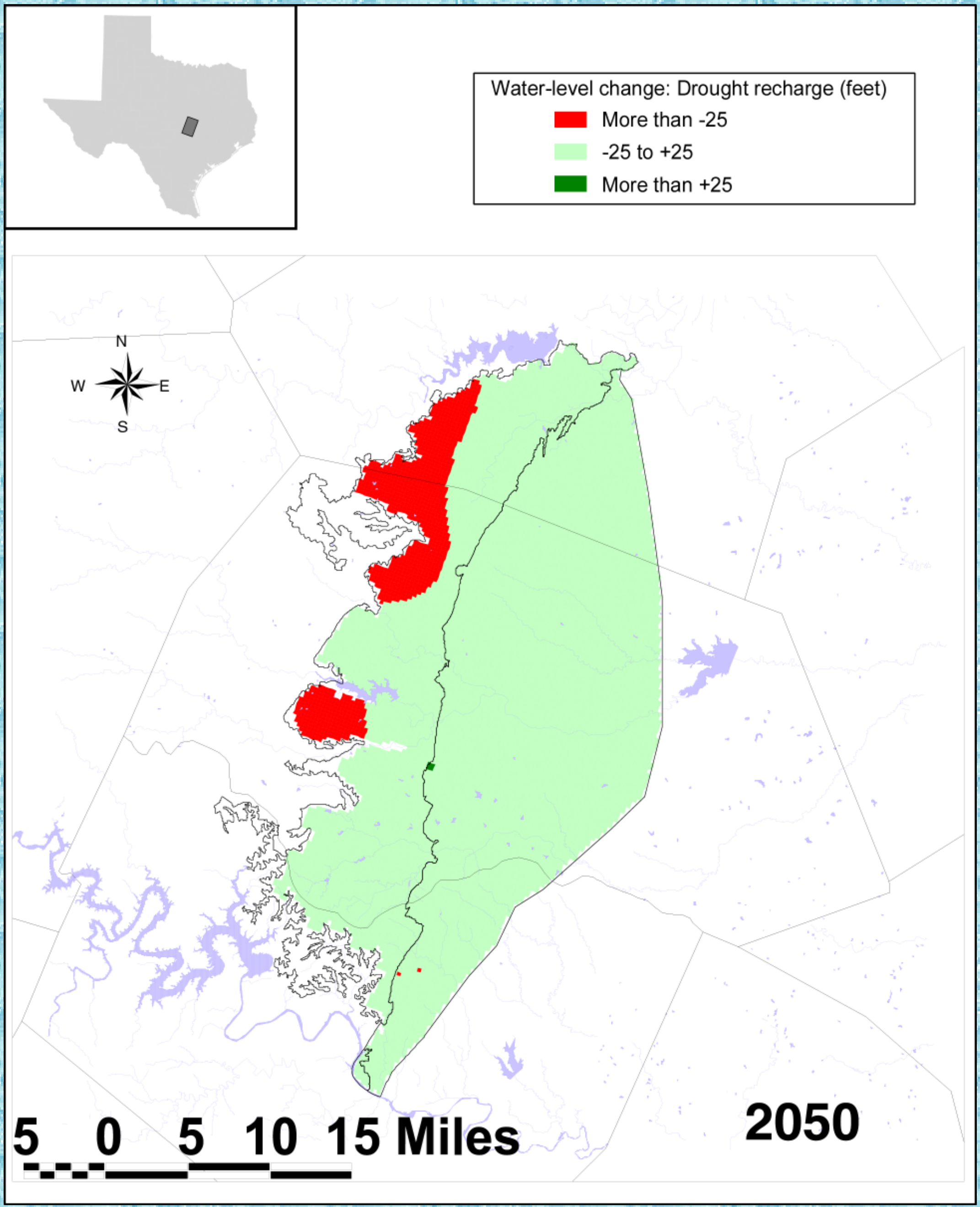
MODEL RESULTS
PREDICTIVE MODEL



TOTAL PUMPAGE



WATER-LEVEL CHANGES: AVERAGE RECHARGE



WATER-LEVEL CHANGES: DROUGHT RECHARGE

CONCLUSIONS

- Tool to evaluate groundwater resource management strategies
- Based on available geologic and hydrologic data
- Steady-state and transient runs
  - Average recharge of 20% annual precipitation
  - Approximately 50-70% of groundwater flow in unconfined part of aquifer
  - Groundwater extraction less than 20% of discharge
- Predictive model runs (2000-2050)
  - Average recharge conditions
    - Water-level rise throughout most of model area
  - Drought-of-record conditions
    - Water-level declines in unconfined part of aquifer
    - Water-level rise associated with lower pumping rates