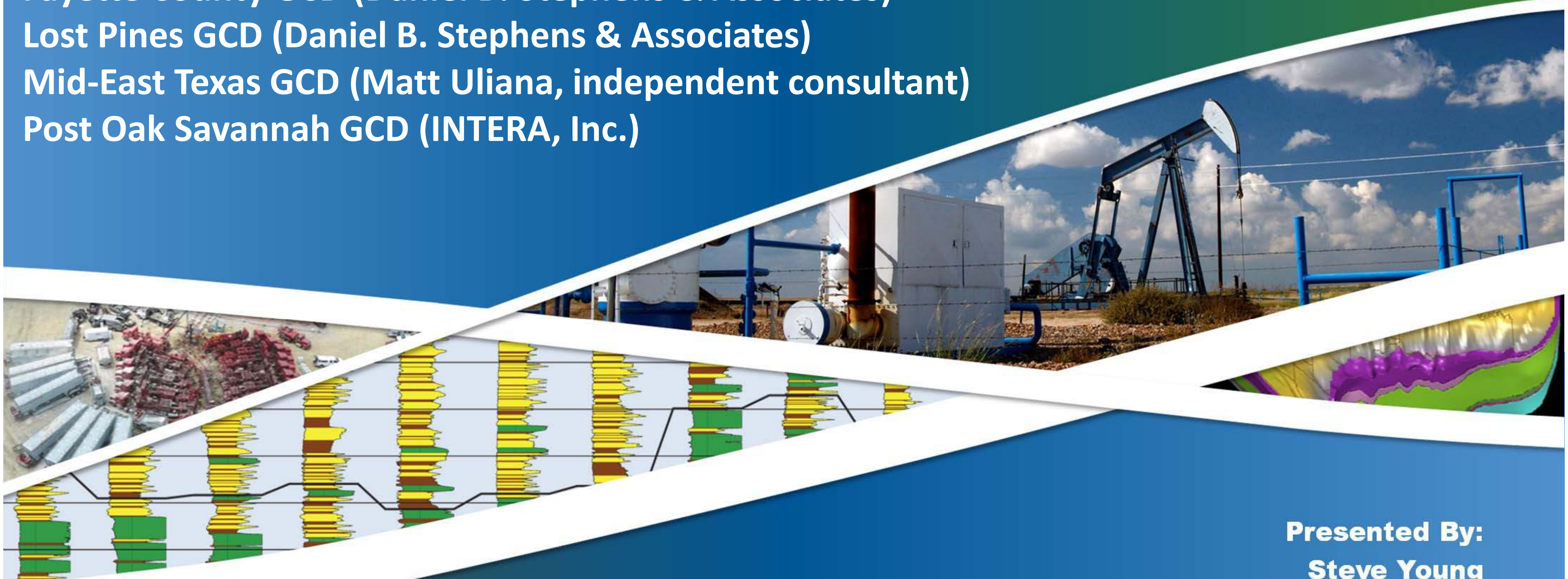
PRESENTATION TO GMA-12: Environmental Impact Considerations

By consultants for the:
Brazos Valley GCD (LBG-Guyton Associates)
Fayette County GCD (Daniel B. Stephens & Associates)
Lost Pines GCD (Daniel B. Stephens & Associates)
Mid-East Texas GCD (Matt Uliana, independent consultant)
Post Oak Savannah GCD (INTERA, Inc.)



Presented By:
Steve Young

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

August 13, 2015

APPROACH

- Introduction to Groundwater Flow System
- Measured GW/SW Interaction
- Measured Spring Flow
- Overview of GMA 12 Aquifers and Their Numerical Representation
- QCSP GAM Simulated GW/SW Exchange
- QCSP GAM Simulated Spring Flow
- Summary of Key Environmental Issues

INTRODUCTION TO GROUNDWATER FLOW SYSTEMS

- Definition of Terms
- Groundwater Flow Zones and Flow Paths

DEFINITION OF UNSATURATED AND SATURATED GROUNDWATER ZONES

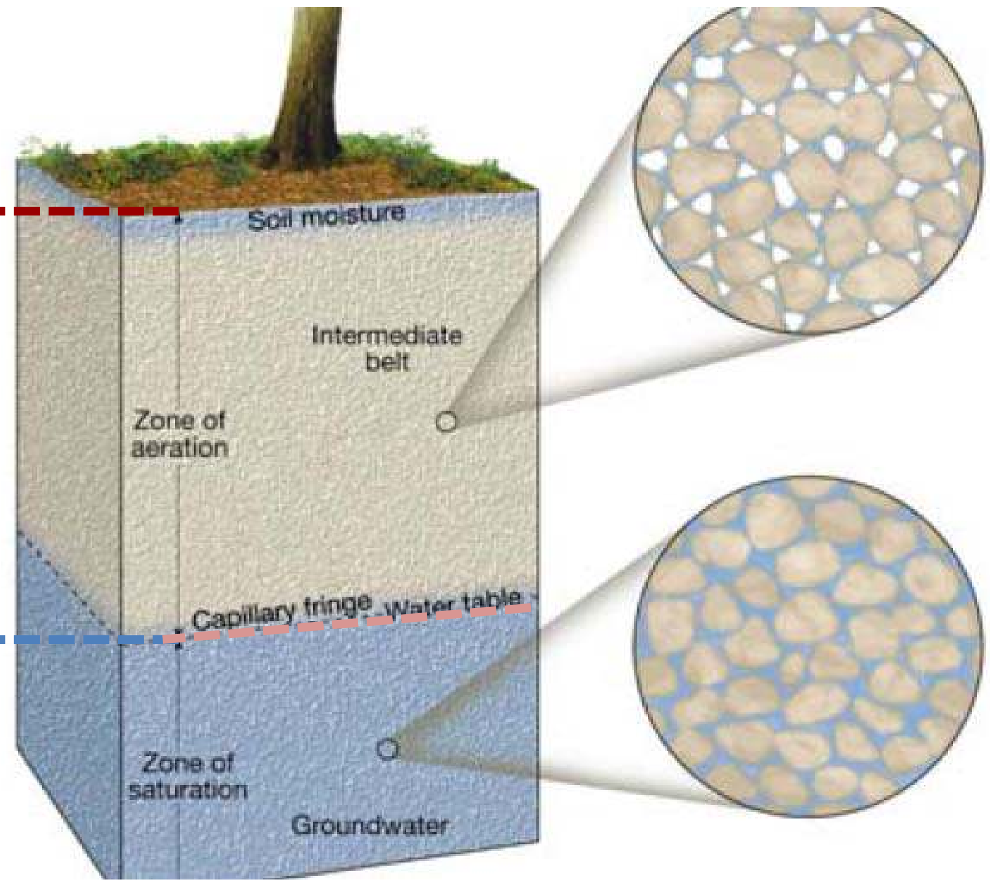
- The unsaturated zone is beneath land surface where pore spaces are partially filled with water and air.
- The saturated zone is beneath a water table where pore spaces are filled with water.

Ground Surface

Pore spaces are occupied by air and soil moisture

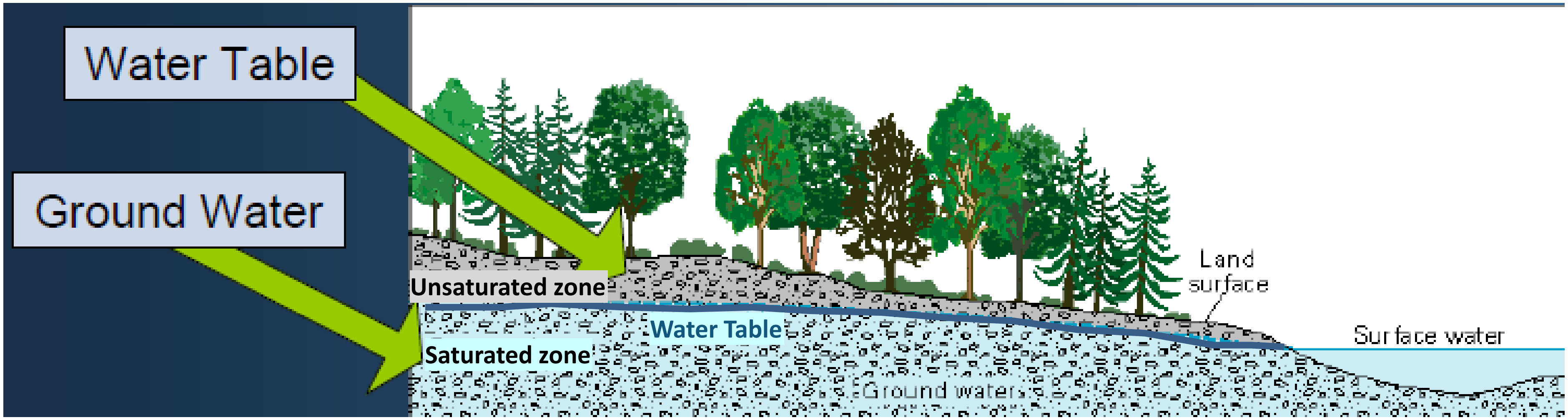
Water Table

Porosity is occupied by groundwater

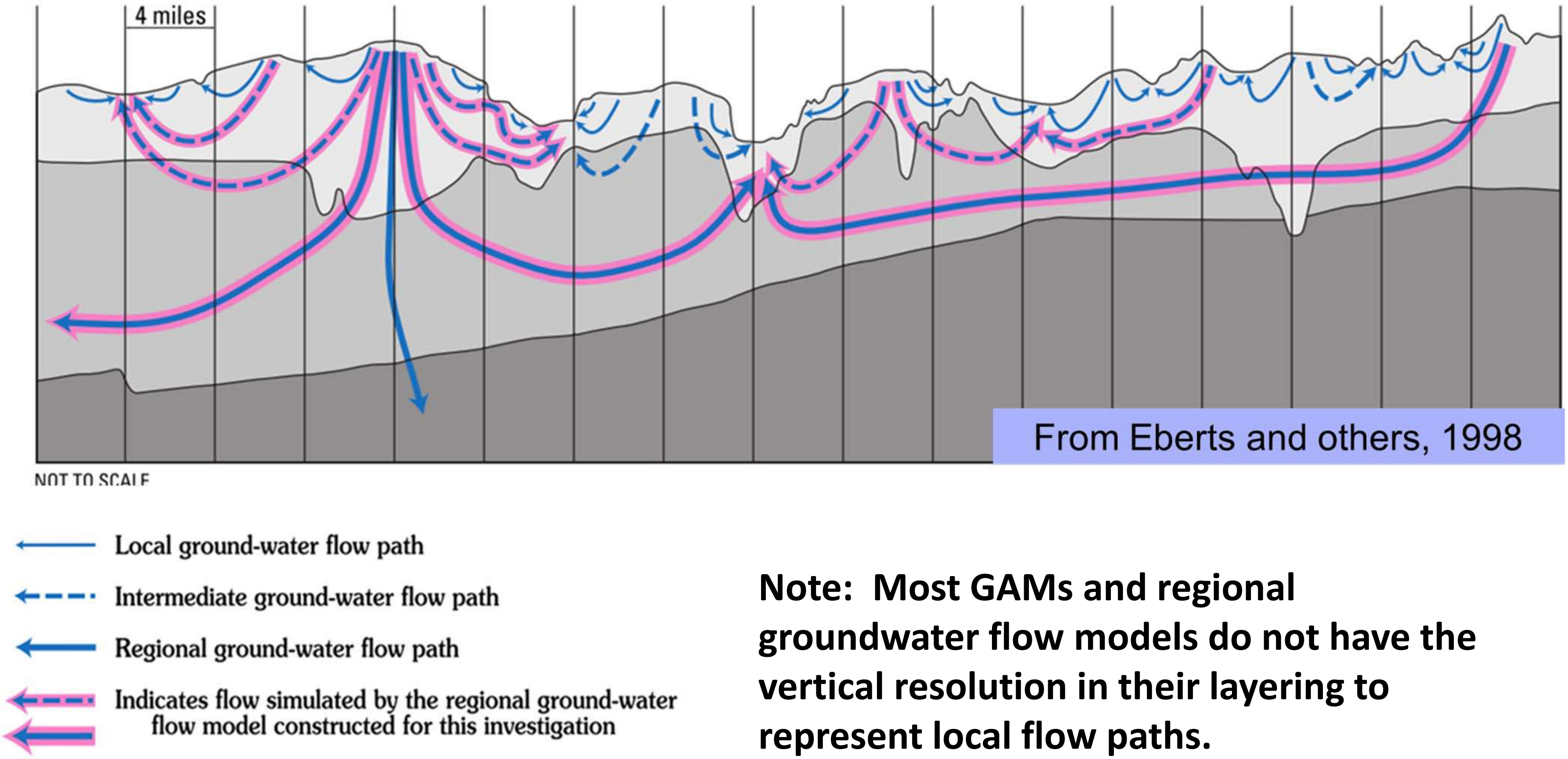


DEFINITION OF A WATER TABLE

- A water table is where the saturated zone meets the unsaturated zone
- A water table occurs where the groundwater is under atmospheric pressure
- Water table is the upper boundary of the shallow groundwater flow zone; it contains the groundwater that supports spring flow and interacts with rivers and lakes

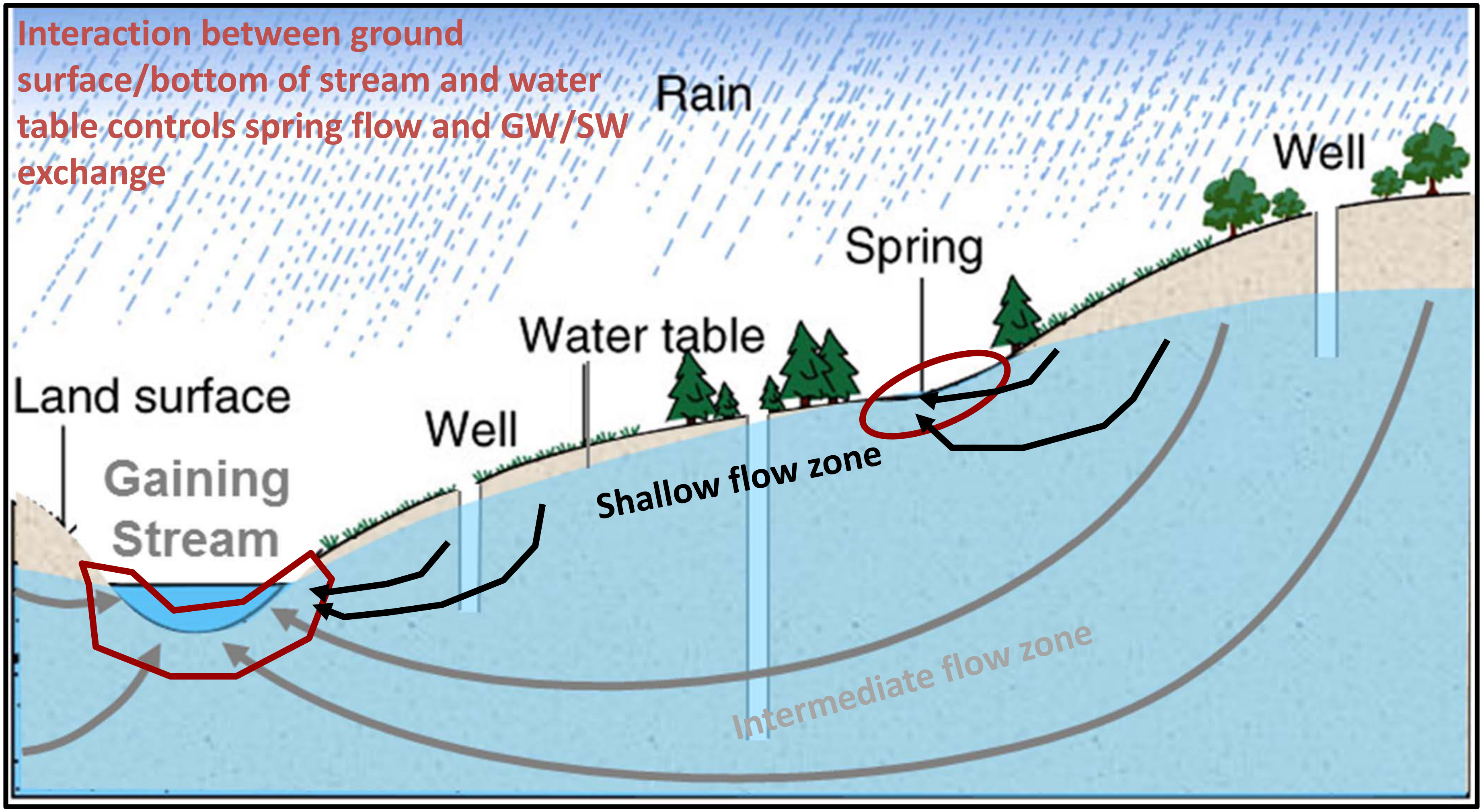


HEIRARCHY OF GROUNDWATER FLOW SYSTEMS



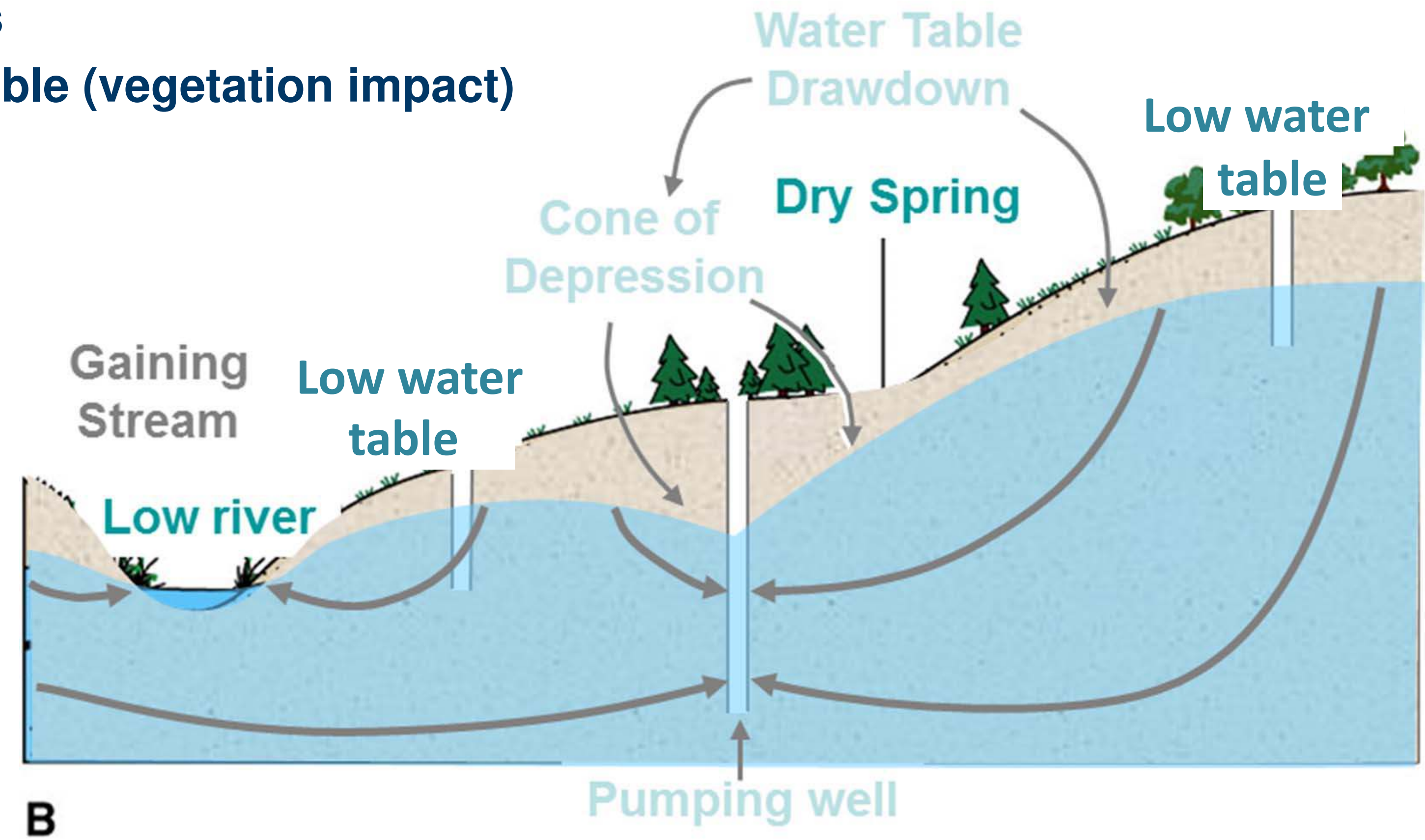
Note: Most GAMs and regional groundwater flow models do not have the vertical resolution in their layering to represent local flow paths.

LOCATION OF GW-SW INTERACTION AND SPRINGS

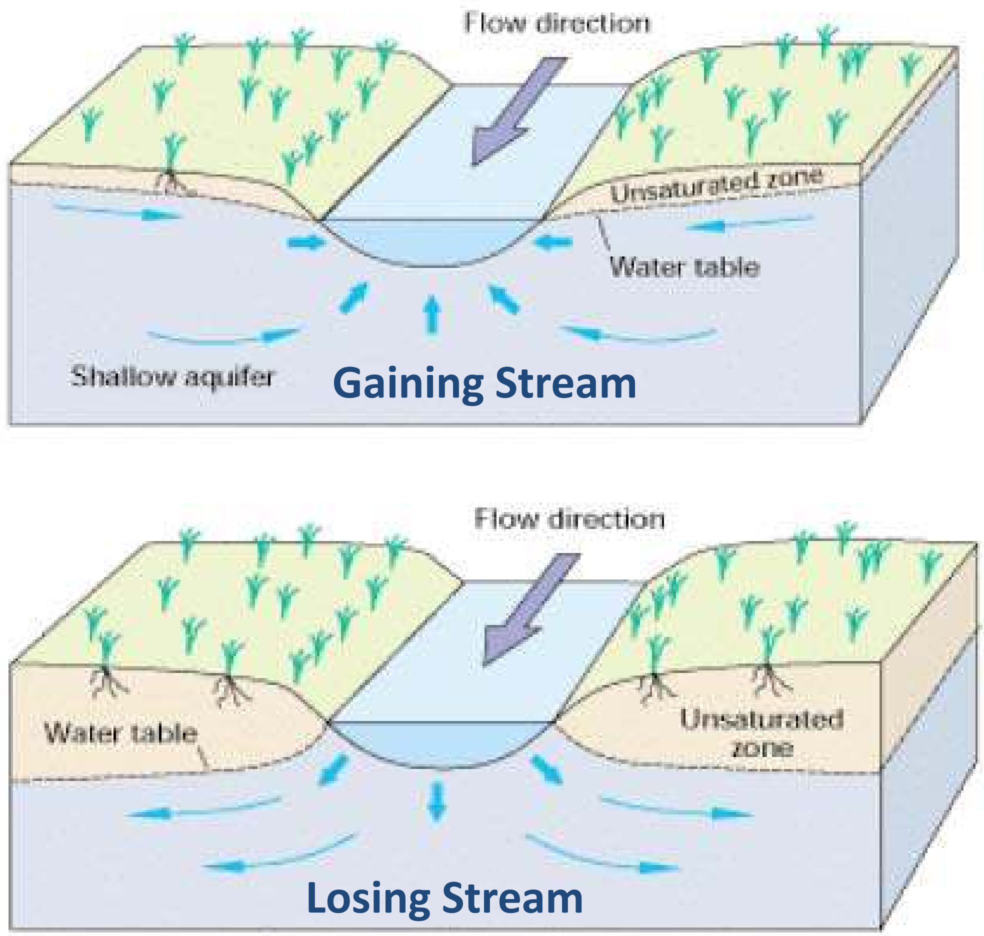


ENVIRONMENTAL CONCERNS ASSOCIATED WITH PUMPING

- Reduced flows to rivers
- Withdrawal from rivers (losing streams)
- Reduced spring flows
- Dried springs
- Low Water Table (vegetation impact)



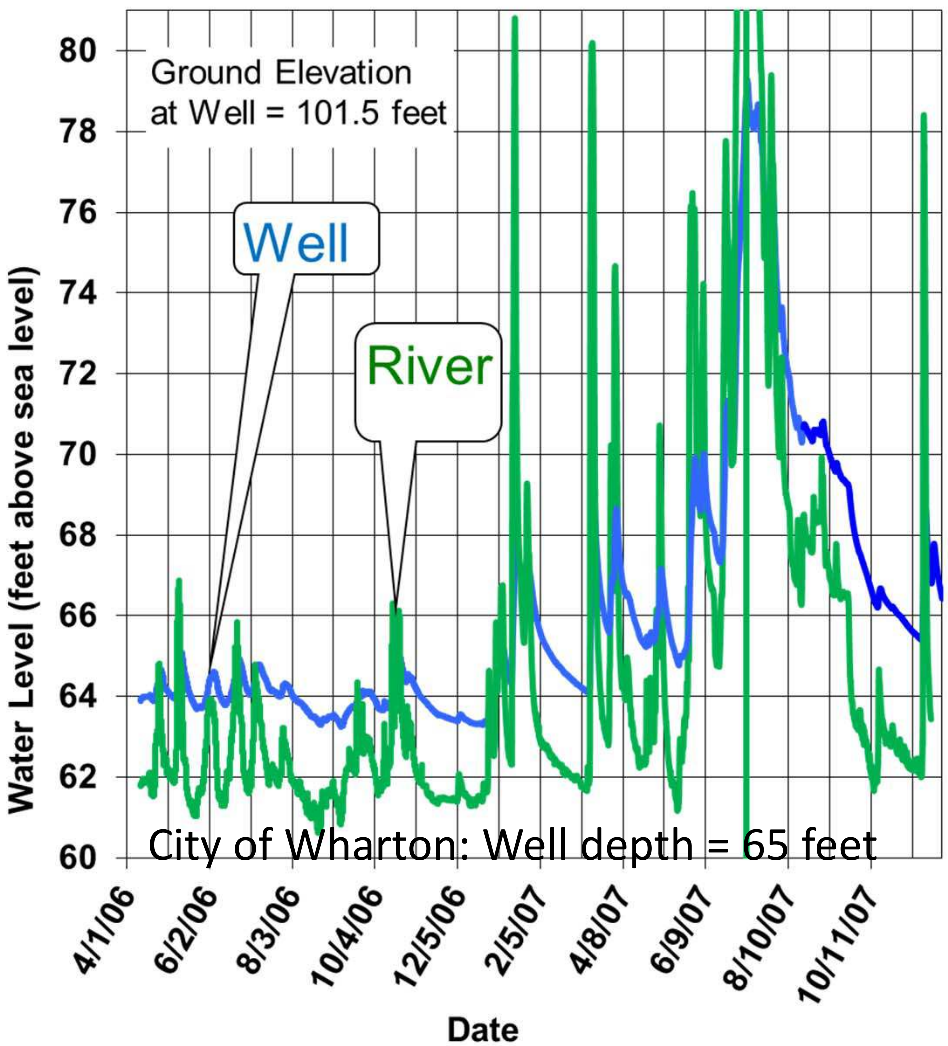
GAINING AND LOSING STREAMS

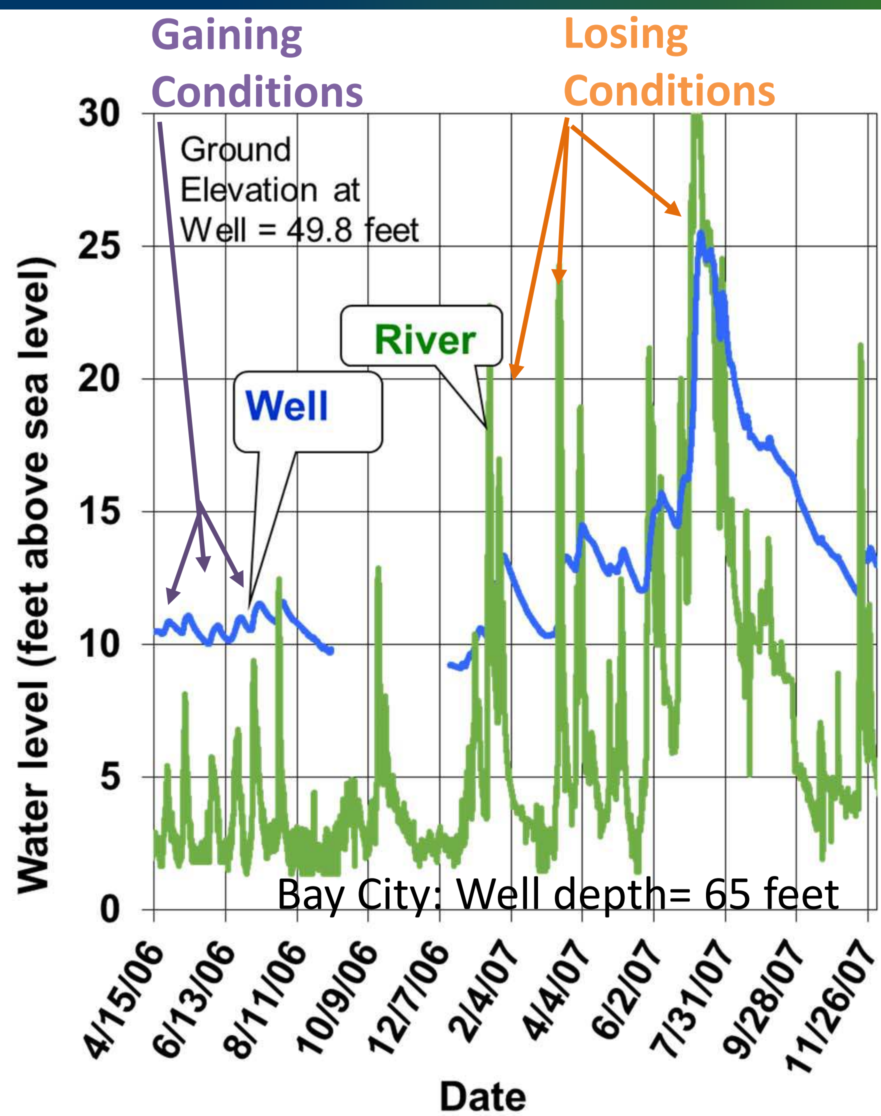


USGS Circular 1186, 1999

- Gaining:
  - Net discharge of groundwater to surface water "base flow"
- Losing:
  - Net discharge of surface water to groundwater "recharge"

COMPARISON OF COLORADO RIVER LEVELS AND WATER LEVEL IN SHALLOW WELLS:





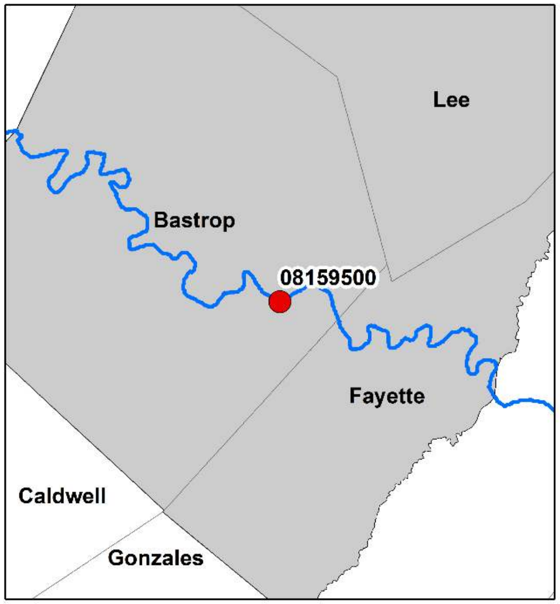
INTRO TO GW SYSTEM: SUMMARY POINTS

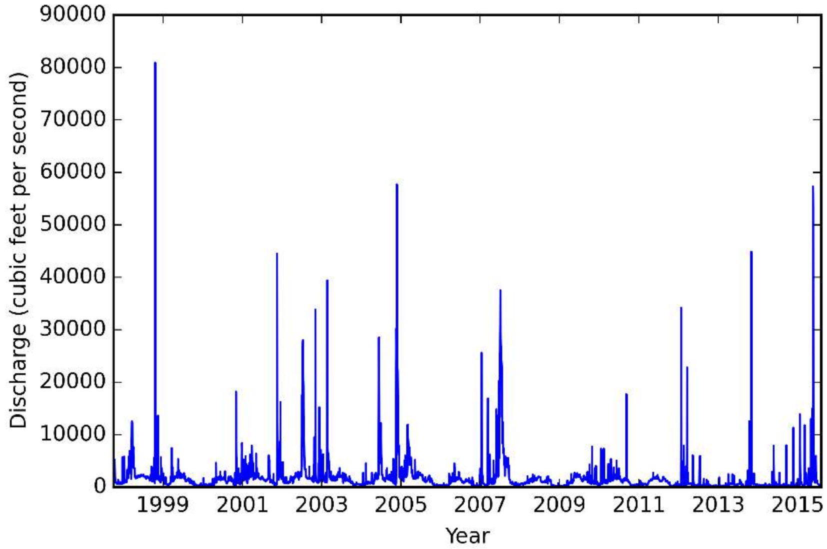
- Basin-scale groundwater systems have a shallow, intermediate and deep flow system
- Most regional groundwater computer models do not have sufficient vertical layering to represent a shallow flow system accurately
- The water table is the upper boundary of the shallow flow system
- Spring flow and GW/SW exchange occurs primarily where the ground surface or bottom of a stream intersects the water table

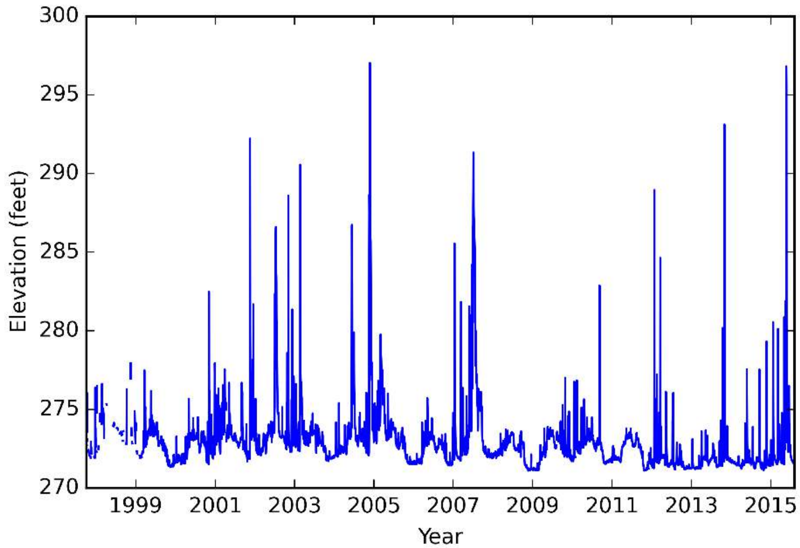
MEASURED GW/SW EXCHANGE

- River Gage Hydrograph
- Approaches to Measuring GW/SW Exchange
  - Gain/Loss Study
  - Hydrograph Separation
- Groundwater Contribution to River Baseflows
  - Colorado River
  - Streams in POSGCD
  - Brazos River

STREAM DATA FROM THE COLORADO RIVER



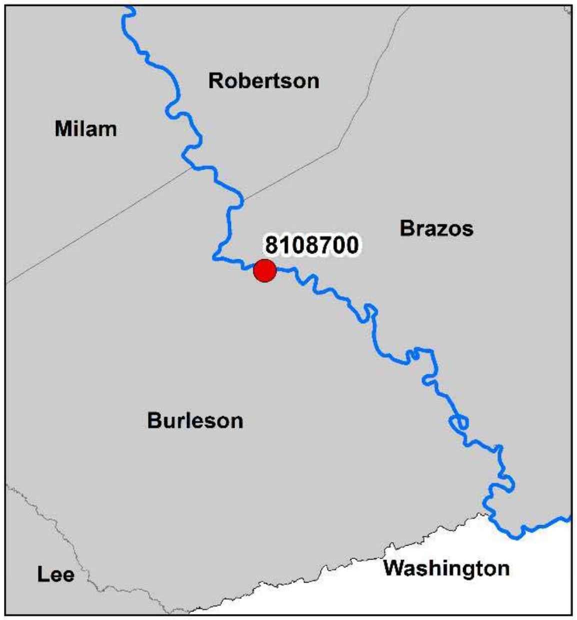




Example Gage on Colorado River

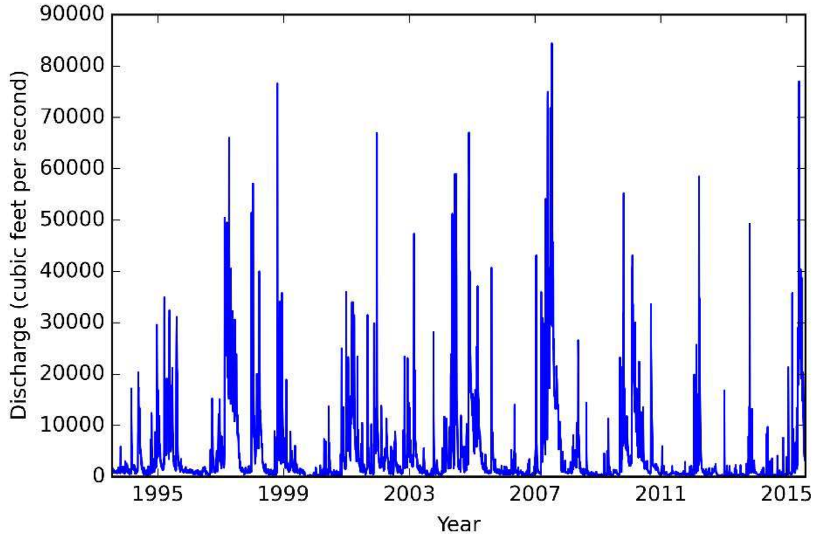
10 CFS = 7,240 AFY

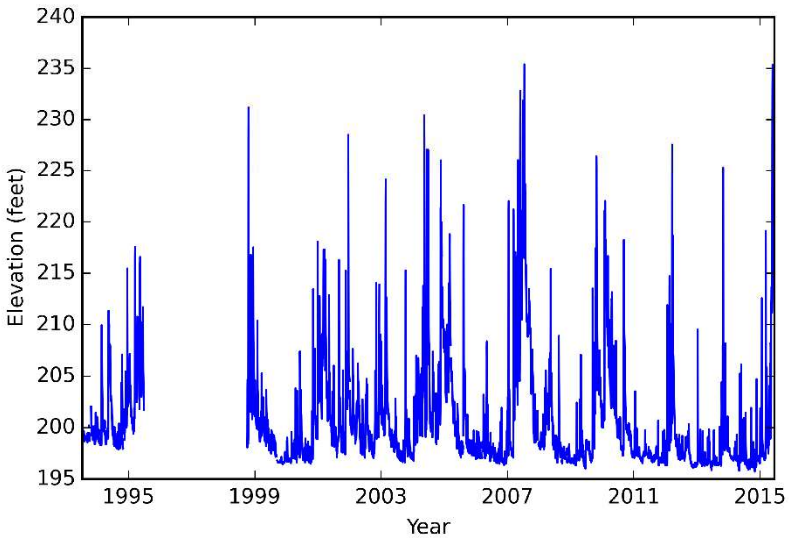
STREAM DATA FROM THE BRAZOS RIVER



Example Gage on Brazos River

10 CFS = 7,240 AFY



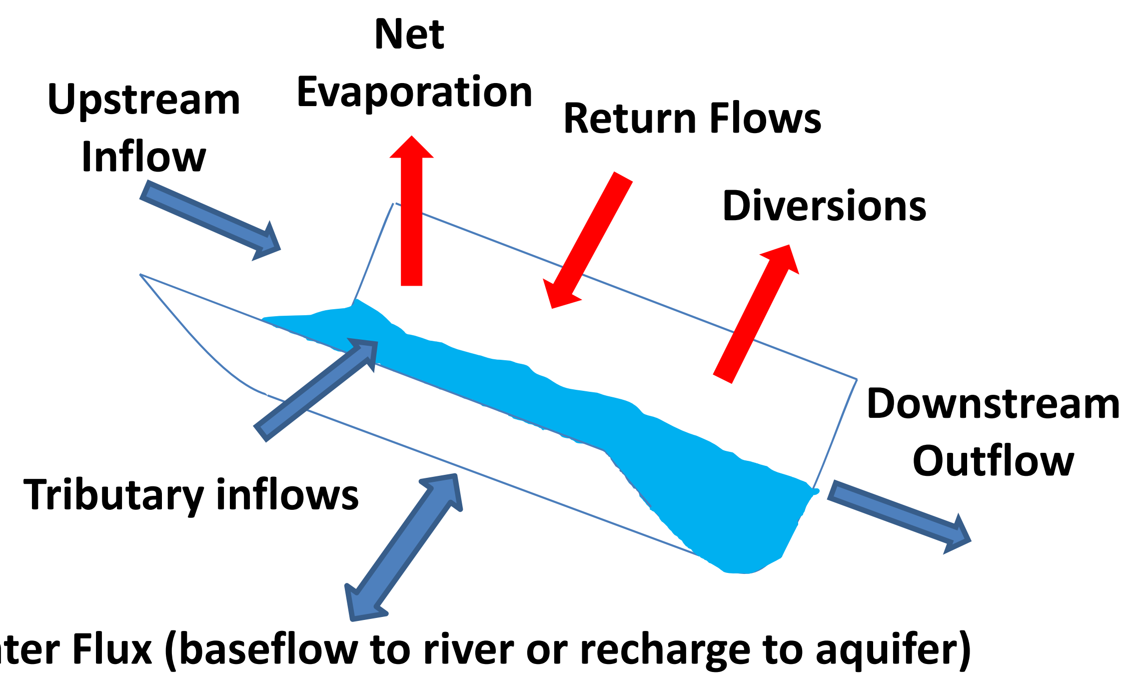


COMMON METHODS TO EVALUATE SURFACE-GROUNDWATER INTERACTION

- Stream Gain/Loss Study
  - Measure flow in stream at several locations at one time
  - Perform a water balance that should account for diversions or returns
- Hydrograph Separation
  - Measure stage (discharge) in stream at a single location (hydrograph) over a large time period
  - Separate flow into event flow (runoff) and a base flow component

STREAM GAIN/LOSS STUDY

Groundwater Flux = Downstream River Flow
+ River Outflows (ET, diversions)
– Upstream River Flow
– River Inflows (tributaries, return flows)

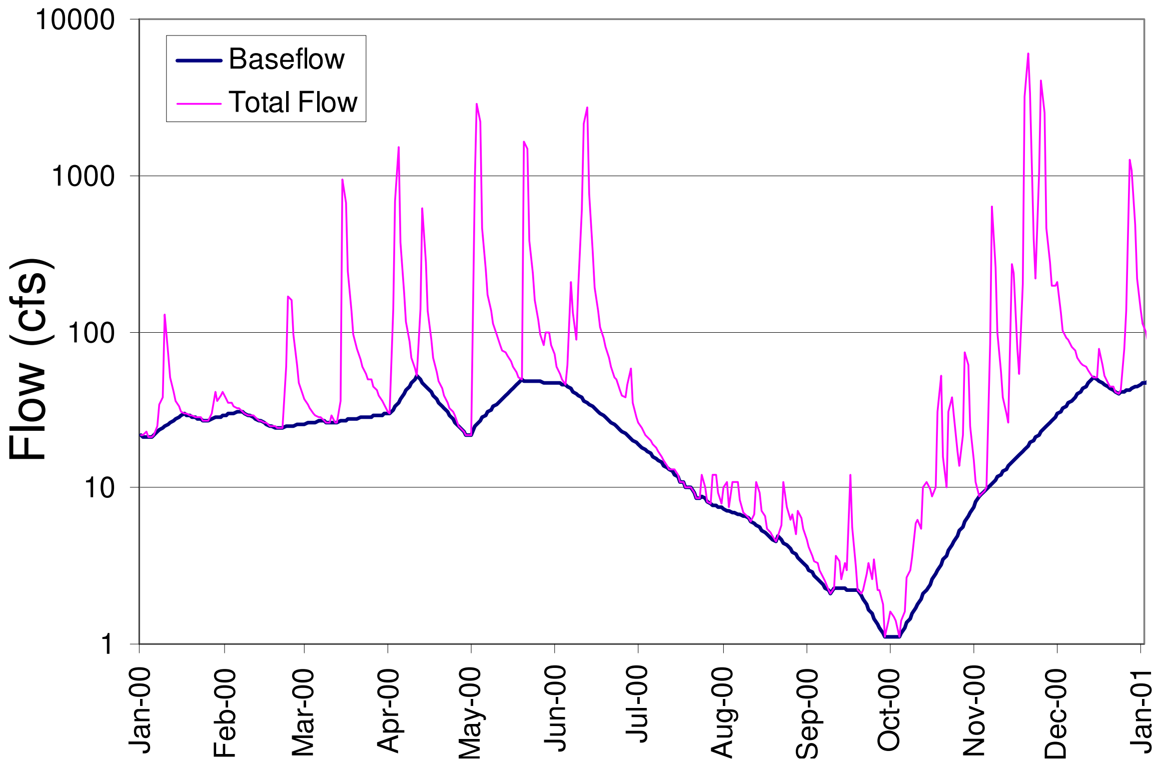


HYDROGRAPH SEPARATION APPROACHES

- Groundwater Models: TWDB GAM Program
  - Identifies GW component of river flow
  - Attempts to separate river discharge into runoff and baseflow component
- Surface Water Models: TCEQ Instream Flow Program
  - Does not identify GW component of river flow
  - Attempts to separate river discharge into five flow stream categories

TWDB GAM PROGRAM: BASEFLOW SEPARATION USING DATA FROM A SINGLE RIVER GAGE

Lavaca Basin (Gage 8164000)



10 CFS = 7,240 AFY

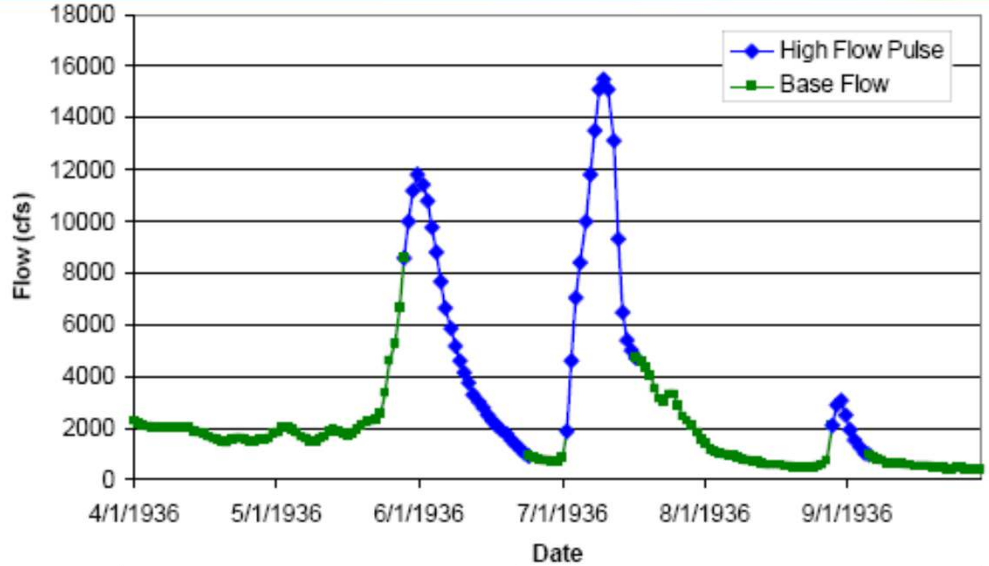
- **Event Flow**
  - Runoff from precipitation events
  - Reservoir releases
- **Base Flow**
  - Groundwater discharge
  - Reservoir releases
  - Return flows
  - Bank flows
  - Seasonal variations
- **Computer Program**
  - Base Flow Index (BFI)
  - Calculates ratio of baseflow to runoff

TCEQ INSTREAM FLOW PROGRAM

- Perform statistical analysis of flow data to identify one of five river flow regimes per day using a computer program
  - Indicators of Hydrological Alterations (IHA)
  - Hydrology-based Environmental Flow Regime (HEFR)

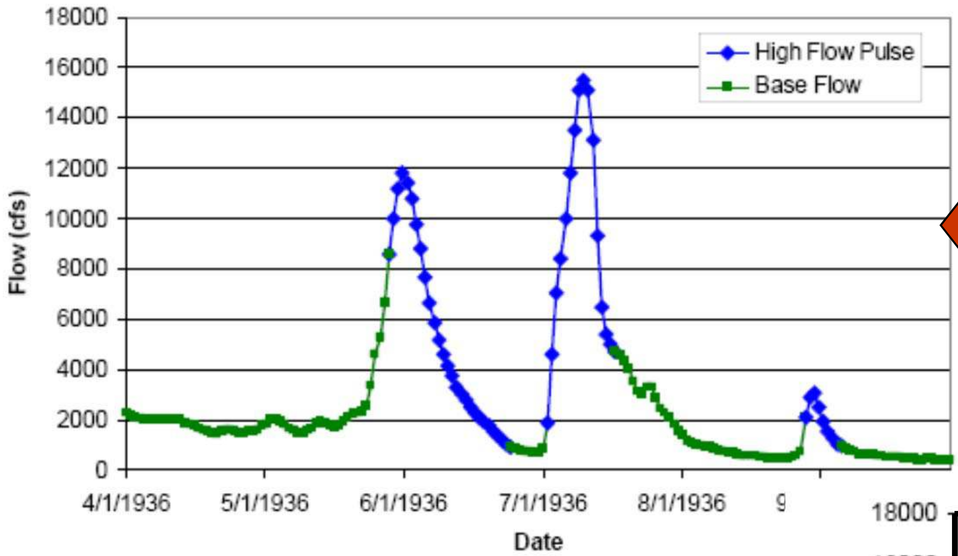
- Source of river water is not a factor in determining flow regimes

- Groundwater could be an important component of subsistence and critical flow regimes in some basins



Regime	Hydrologic Condition
Overbank Flows	NA
High-Pulse Flows	Wet
	Average
	Dry
Base Flows	Wet
	Average
	Dry
Subsistence Flows	Subsistence
Critical Flows	Critical

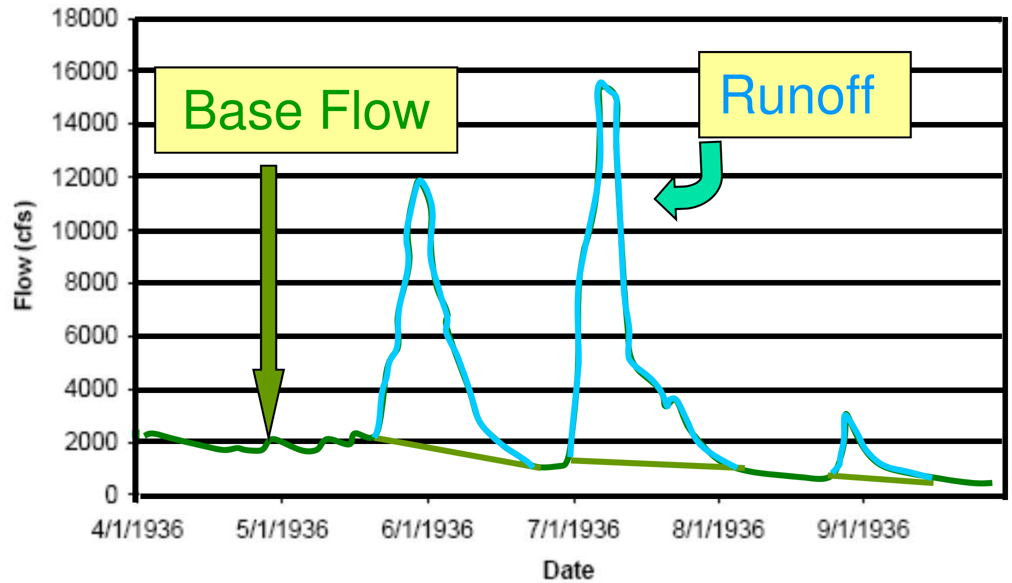
DIFFERENCE BETWEEN HYDROGRAPH SEPARATION



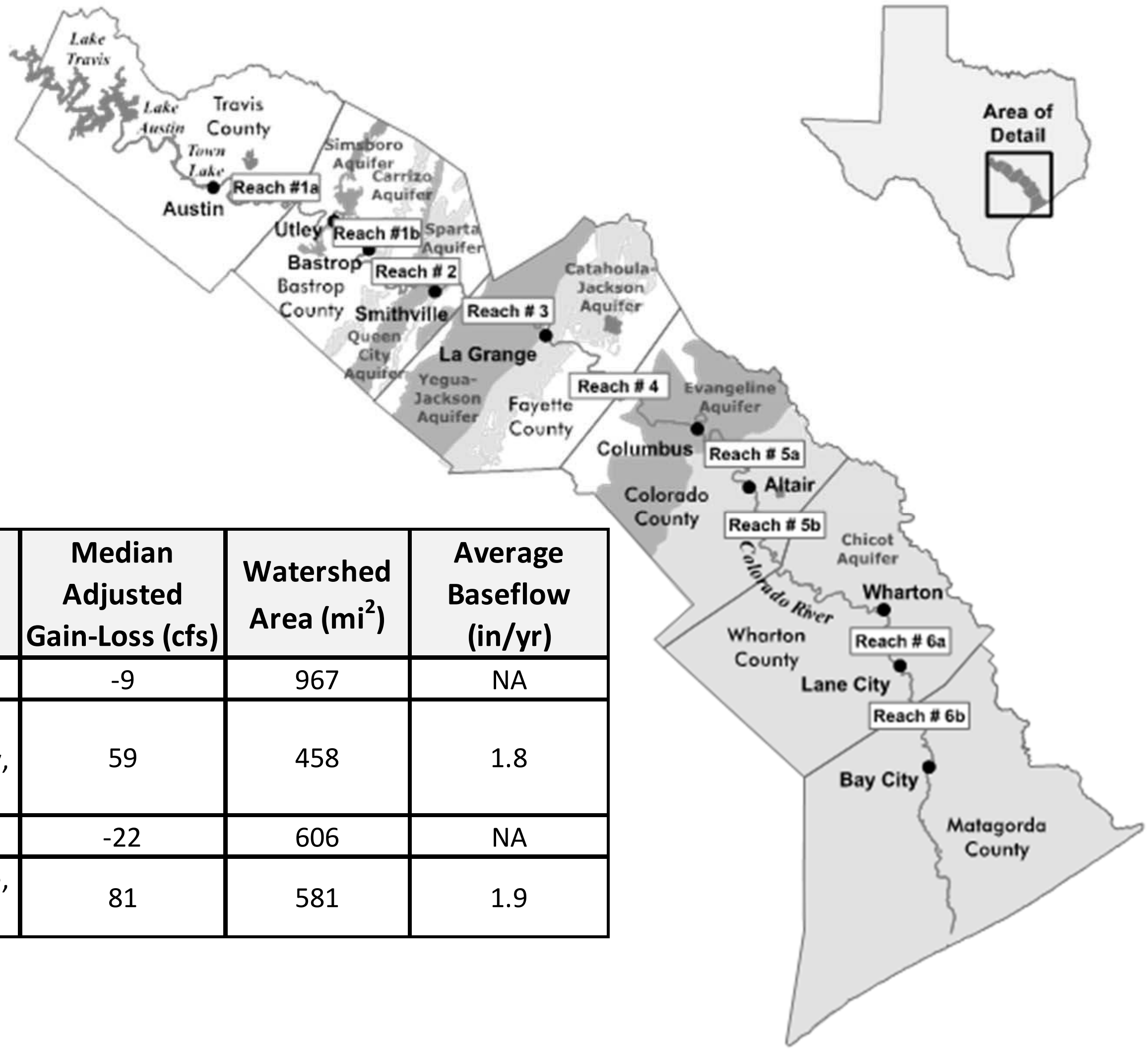
TCEQ hydrograph separation segregates hydrograph into different flow regimes – one for each day

Does not attempt to segregate groundwater discharge

Groundwater hydrograph separation segregates hydrograph into groundwater discharge and runoff



COLORADO RIVER GAIN-LOSS STUDY (SAUNDERS, 2006)*

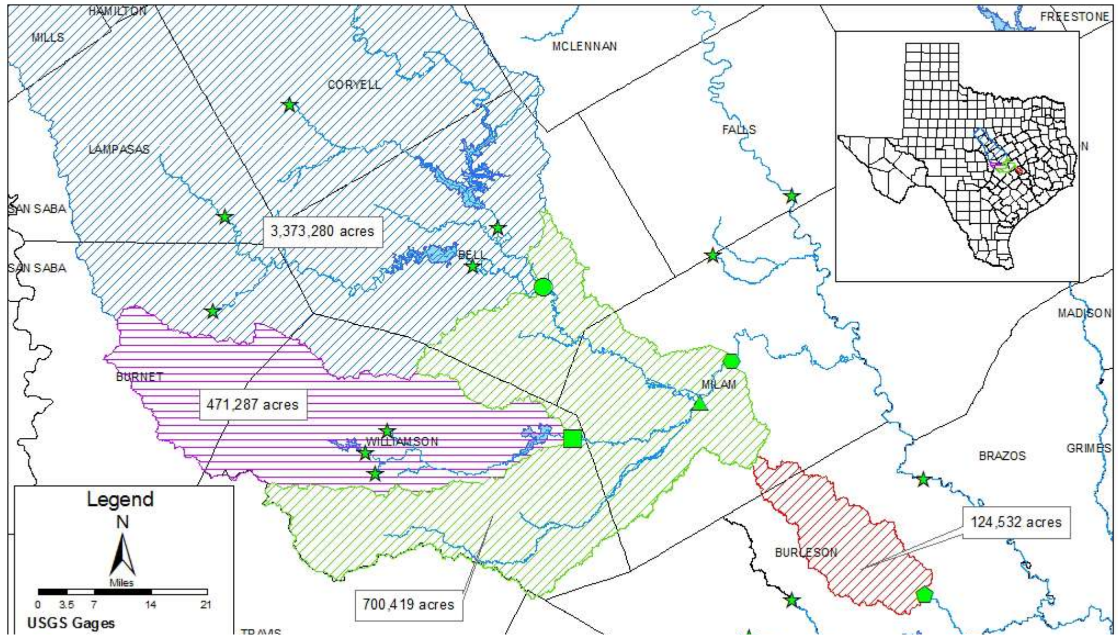


Description	River Mile Length (mi)	Water-bearing units	Median Adjusted Gain-Loss (cfs)	Watershed Area (mi^2)	Average Baseflow (in/yr)
Austin-Bastrop	54	Simsboro	-9	967	NA
Bastrop-Smithville	25	Calvert Bluff, Carrizo, Queen City, Sparta	59	458	1.8
Smithville-LaGrange	36	Yegua-Jackson	-22	606	NA
LaGrange-Columbus	41	Catahoula, Oakville, Goliad	81	581	1.9

10 CFS = 7,240 AFY

*** Based on 1999 and 2005 data**

GAIN-LOSS STUDY IN VICINITY POSGCD

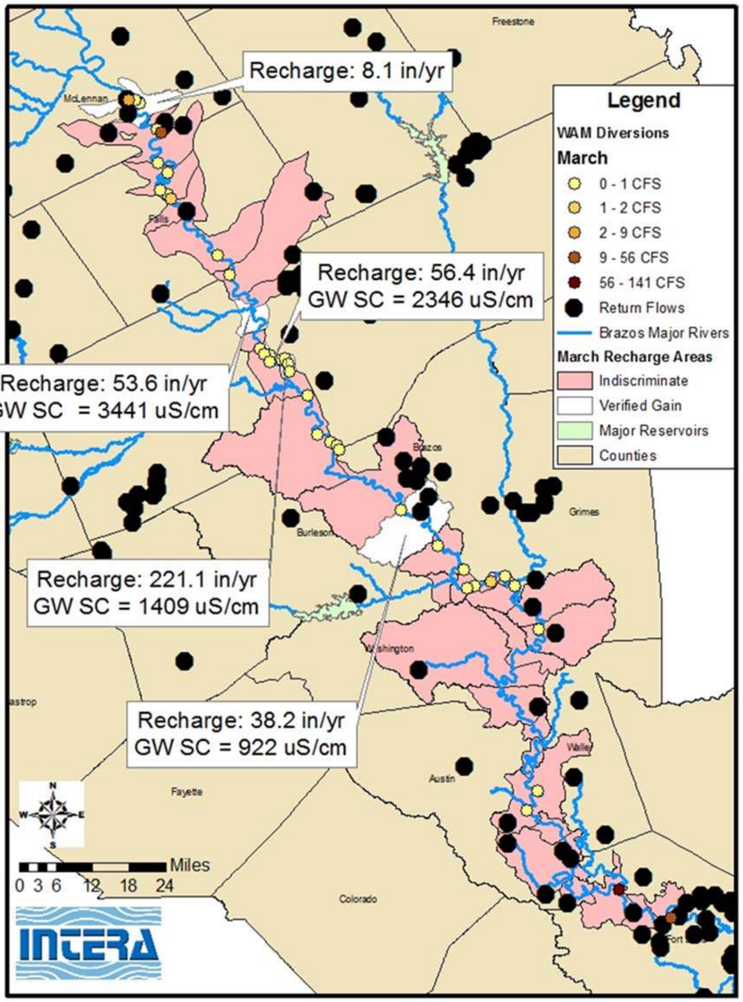


Gage #	Gage Name	Area (acre)	Avg. Precip. (in/yr)	Avg. Runoff (in/yr)	Avg. Baseflow (in/yr)	% Precip. as Baseflow
08110100	Davidson Ck nr Lyons, TX	124532	40.39	5.10	0.23	0.57%
08104500	Little Rv nr Little River, TX	3373280	32.43	3.02	1.62	4.99%
08105700	San Gabriel Rv at Laneport, TX	471287	34.56	4.82	1.39	4.01%
08106350	Little Rv nr Rockdale, TX	633128	Insufficient Data			
08106500	Little Rv nr Cameron, TX	700419	35.43	3.59	2.01	5.68%

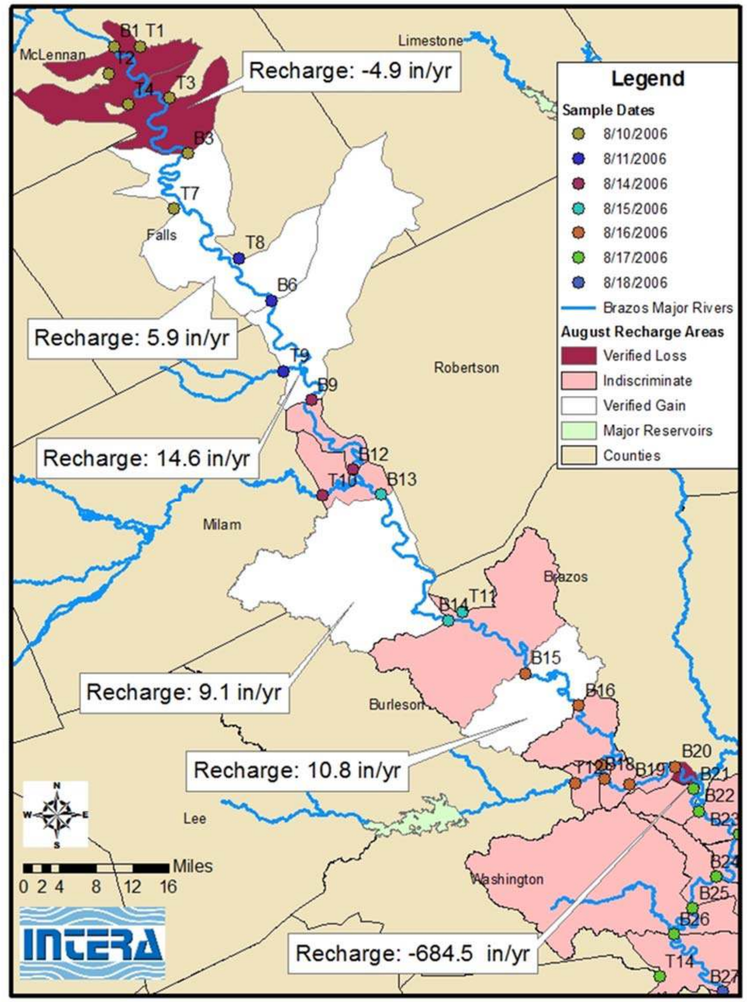
April 5, 2011

ANALYSIS OF STREAM GAINS FROM (TURCO, 2007)

March Recharge

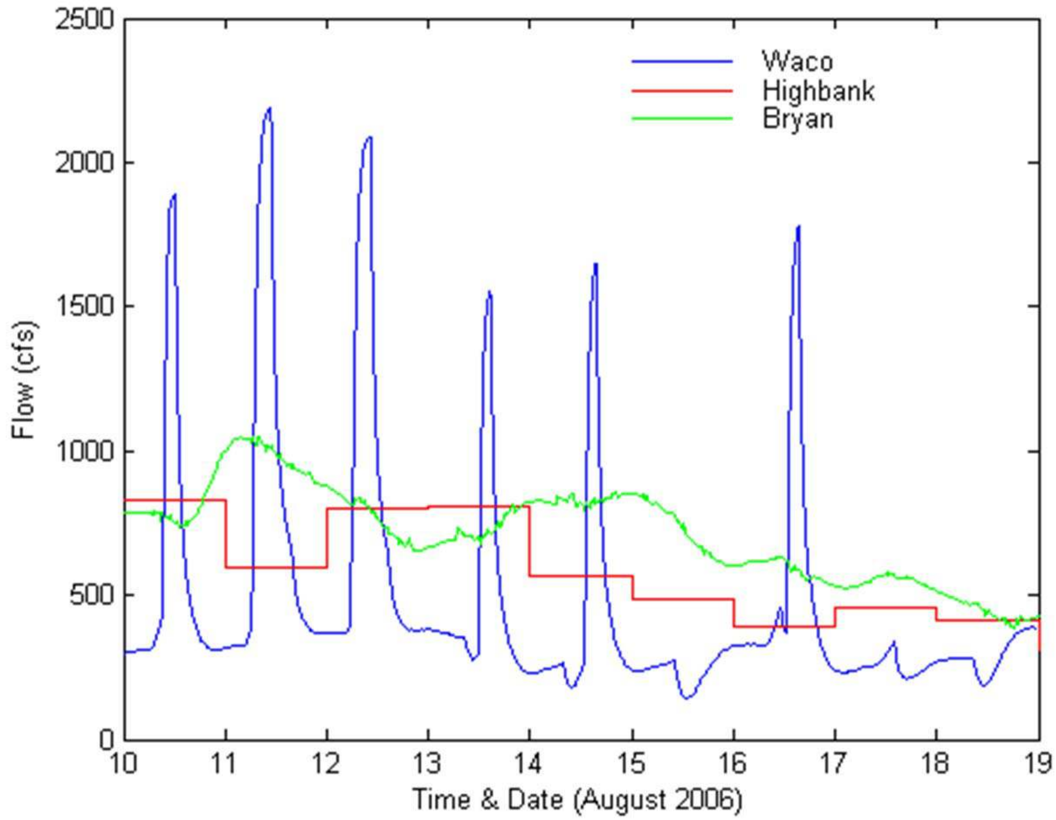


August Recharge



POTENTIAL PROBLEMS OF BRAZOS RIVER GAIN-LOSS STUDY (TURCO, 2007)

- Gain-loss studies performed when river flow was not steady and uniform
- Pulsing river flow was not considered as part of data collection or analysis
- Data analysis did not properly consider diversion and return flows



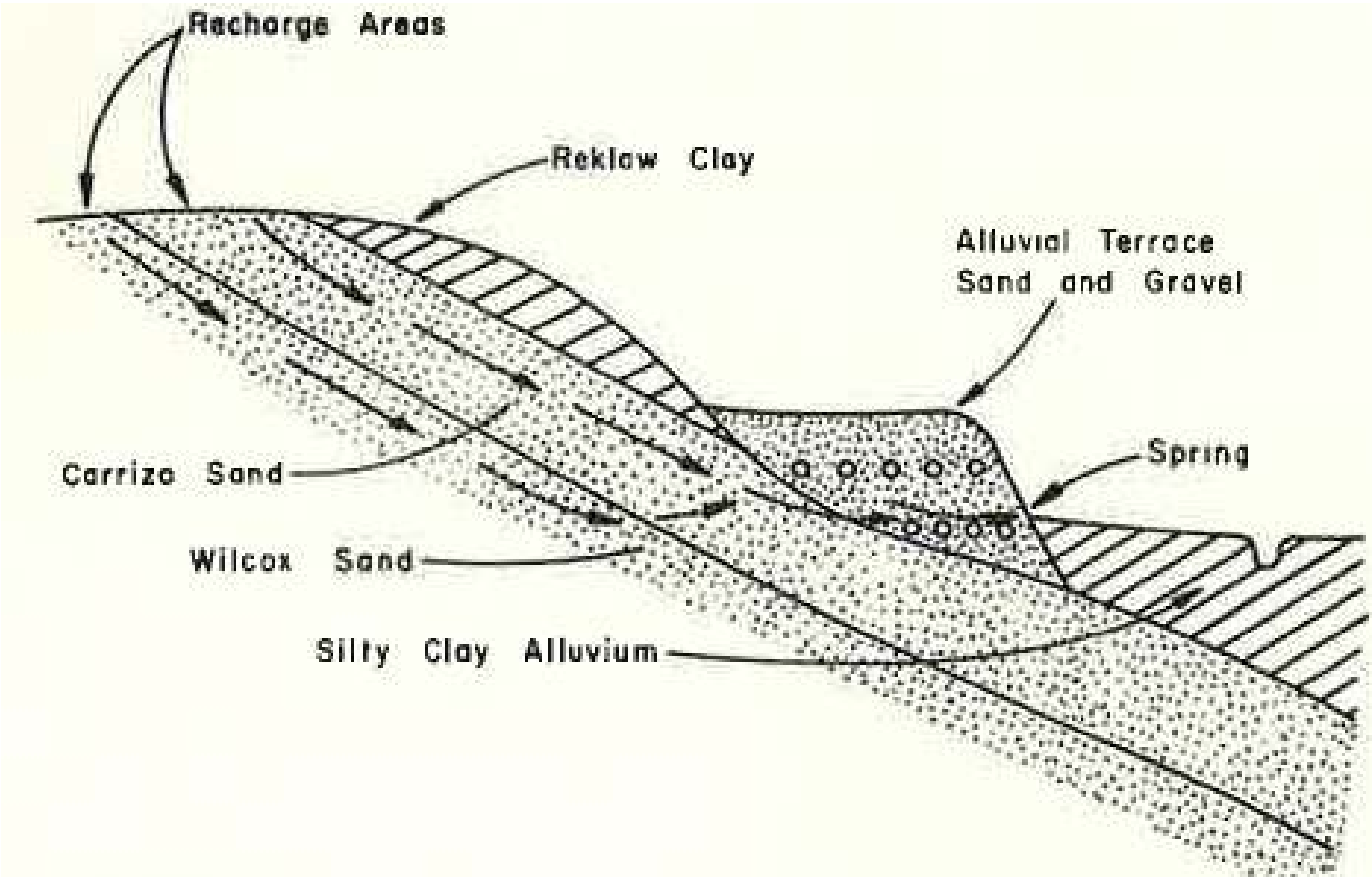
MEASURED GW/SW EXCHANGE: SUMMARY POINTS

- Stream flows in Colorado and Brazos River have a large temporal variability component
- Geohydrologist and surface water hydrologist have different approaches for evaluation river gage hydrographs
- Stream gain-loss studies should be performed during well controlled, steady-flow conditions
- High quality stream gain-loss studies are difficult to conduct and relatively few good studies exist
- Brazos River gain-loss study should be used with caution because it has not been properly adjusted for return flow, diversions, and unsteady flow effects
- Stream studies can be used to obtain lower estimates of recharge across a watershed

MEASURED SPRING FLOW

- Spring Mechanics
  - Regional Aquifer
  - Perched Aquifer
  - Required Conditions
- Review of Literature Regarding Springs
  - Location
  - Discharge Rates

SPRINGS AND SEEPS

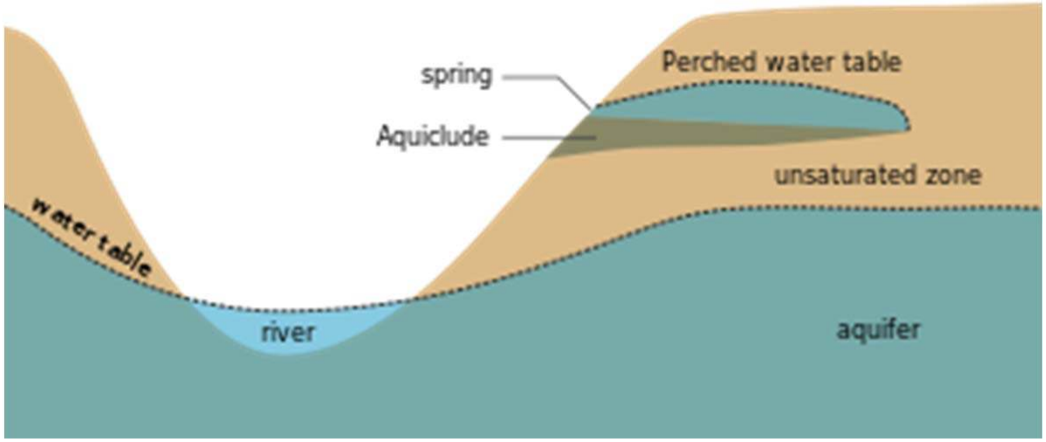


Schematic of a spring in Carrizo-Wilcox sand and terrace sand and gravel (1981, Brune)

PERCHED WATER TABLE

A perched water table is a water-bearing unit that occurs above the regional water table, in the unsaturated zone where there is an impermeable layer of sediment (aquiclude) above the main water table/aquifer.

If a perched aquifer's flow intersects the earth's dry surface, at a valley wall for example, the water is discharged as a spring



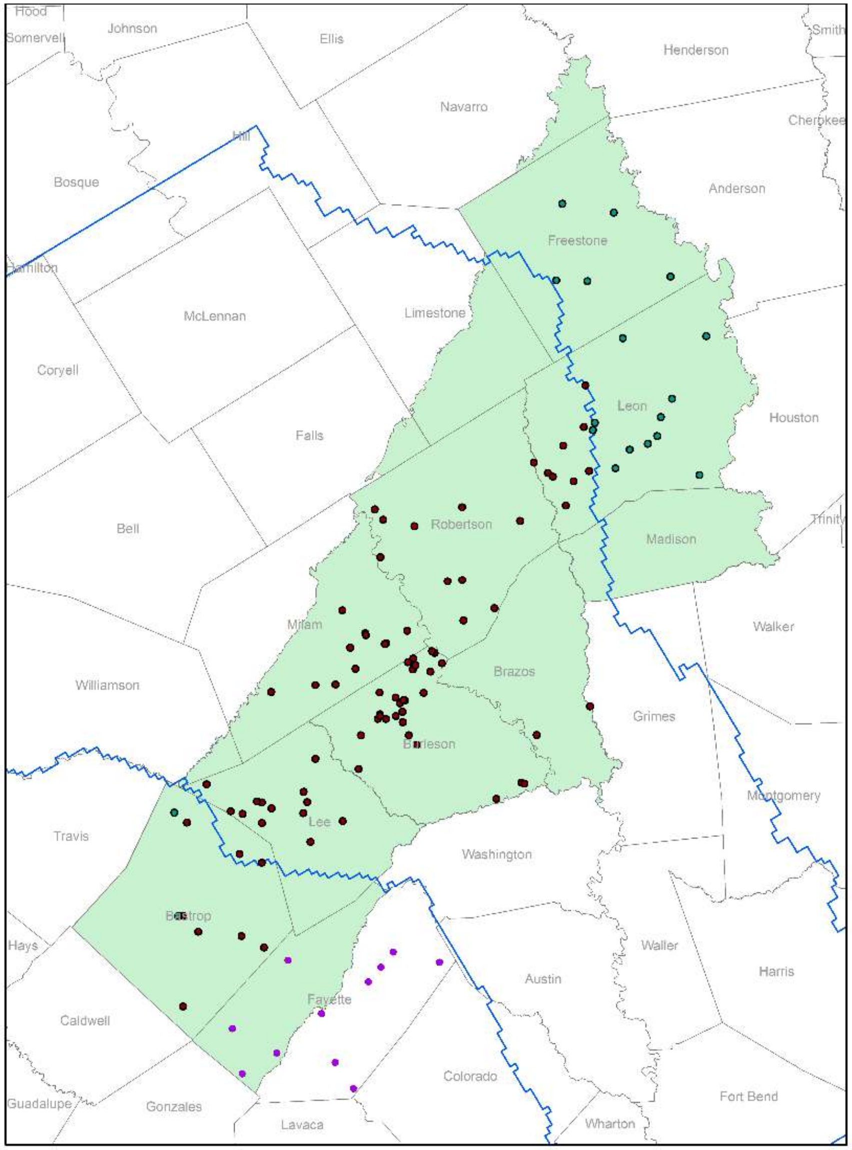
Schematic of a spring connected to a perched water table (2015,https://en.wikipedia.org/wiki/Water_table)

REQUIREMENTS FOR A SPRING TO OCCUR IN THE GEOLOGICAL FORMATIONS IN GMA 12

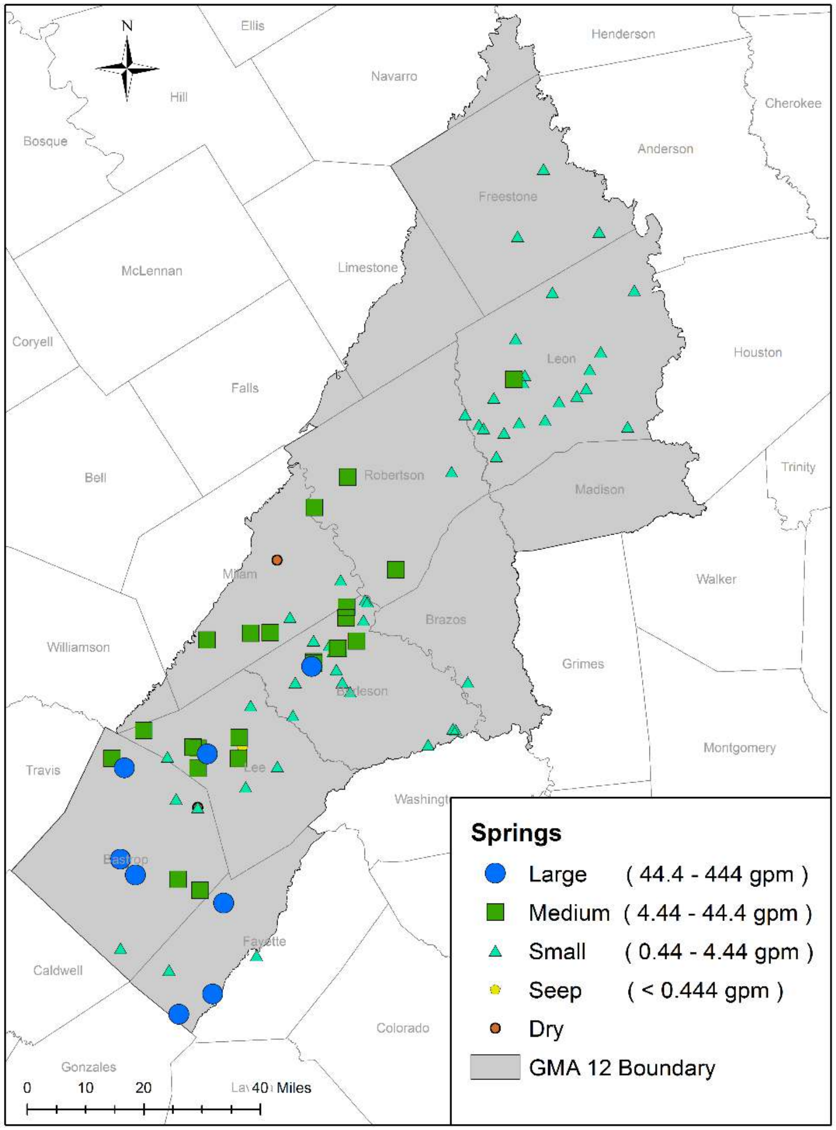
- Aquifer to deliver water to a spring
- Sufficiently large recharge area
- Sufficient hydraulic pressure gradient between recharge and discharge area to cause flow
- Water table intersected by ground surface

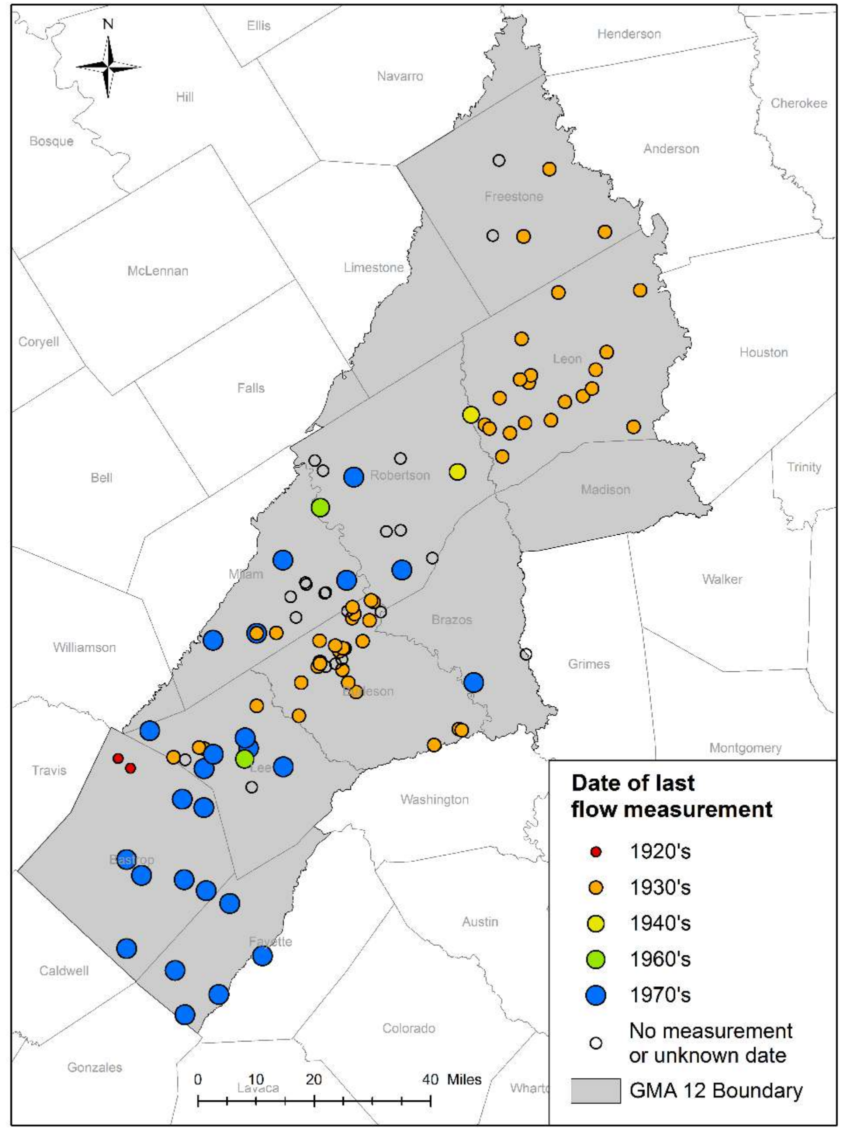
IDENTIFIED SPRING IN GMA 12

- Sources
  - Springs of Texas, Volume 1 (2002, Brune)
  - Database of historically documented springs and spring flow measurements in Texas(2003, Heitmuller and Reece)
  - TWDB Groundwater Database (March, 2014)



IDENTIFIED SPRING IN GMA 12 (CONT.)





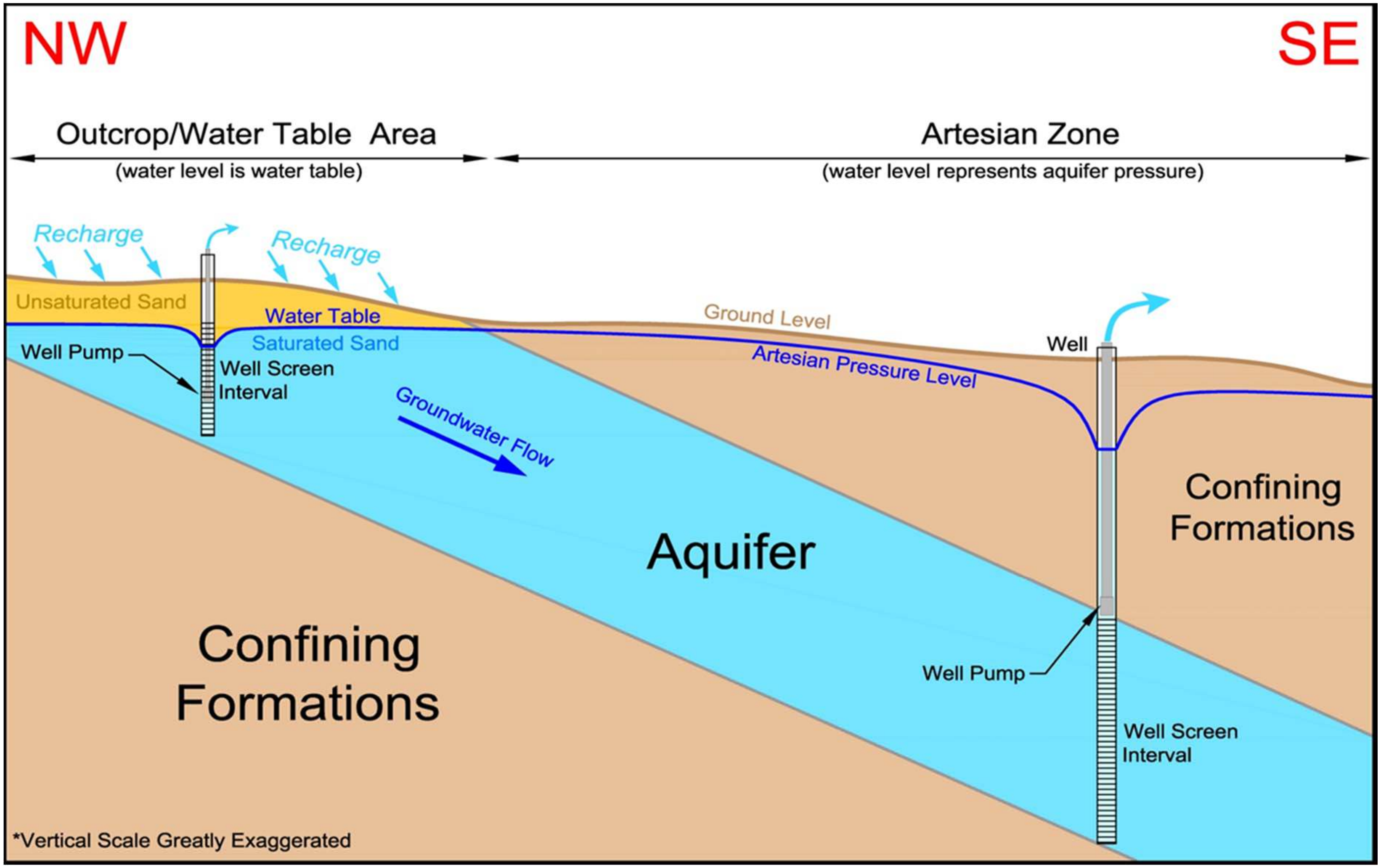
MEASURED SPRING FLOW: SUMMARY POINTS

- Springs are typically controlled by localized site-specific topographic, hydrologic, and geological conditions
- Perched and regional water tables can be a source of springs
- Extremely limited spring flow data collected since 1970s

OVERVIEW OF GMA 12 AQUIFERS AND THEIR NUMERICAL REPRESENTATION IN THE GAM

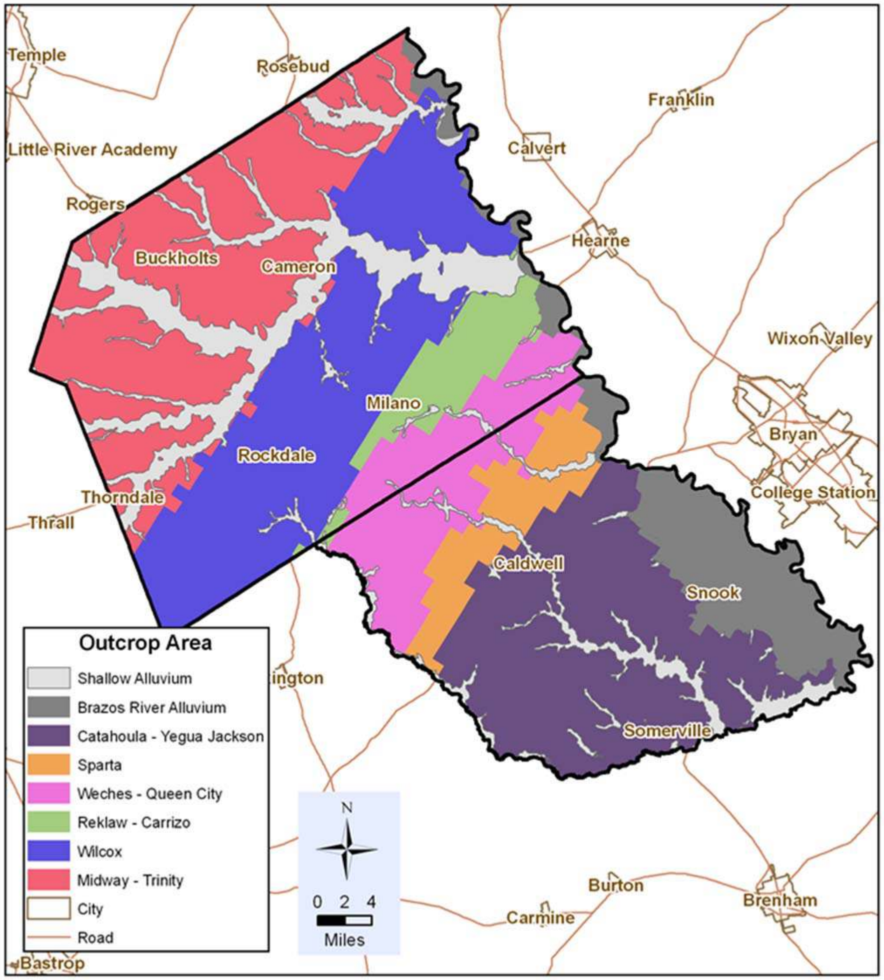
- Aquifer Outcrop
- Vertical Hydraulic Gradients
- Potential Problems with Developing Numerical grids for Models
- Summary Points

SCHEMATIC OF DIPPING AQUIFER

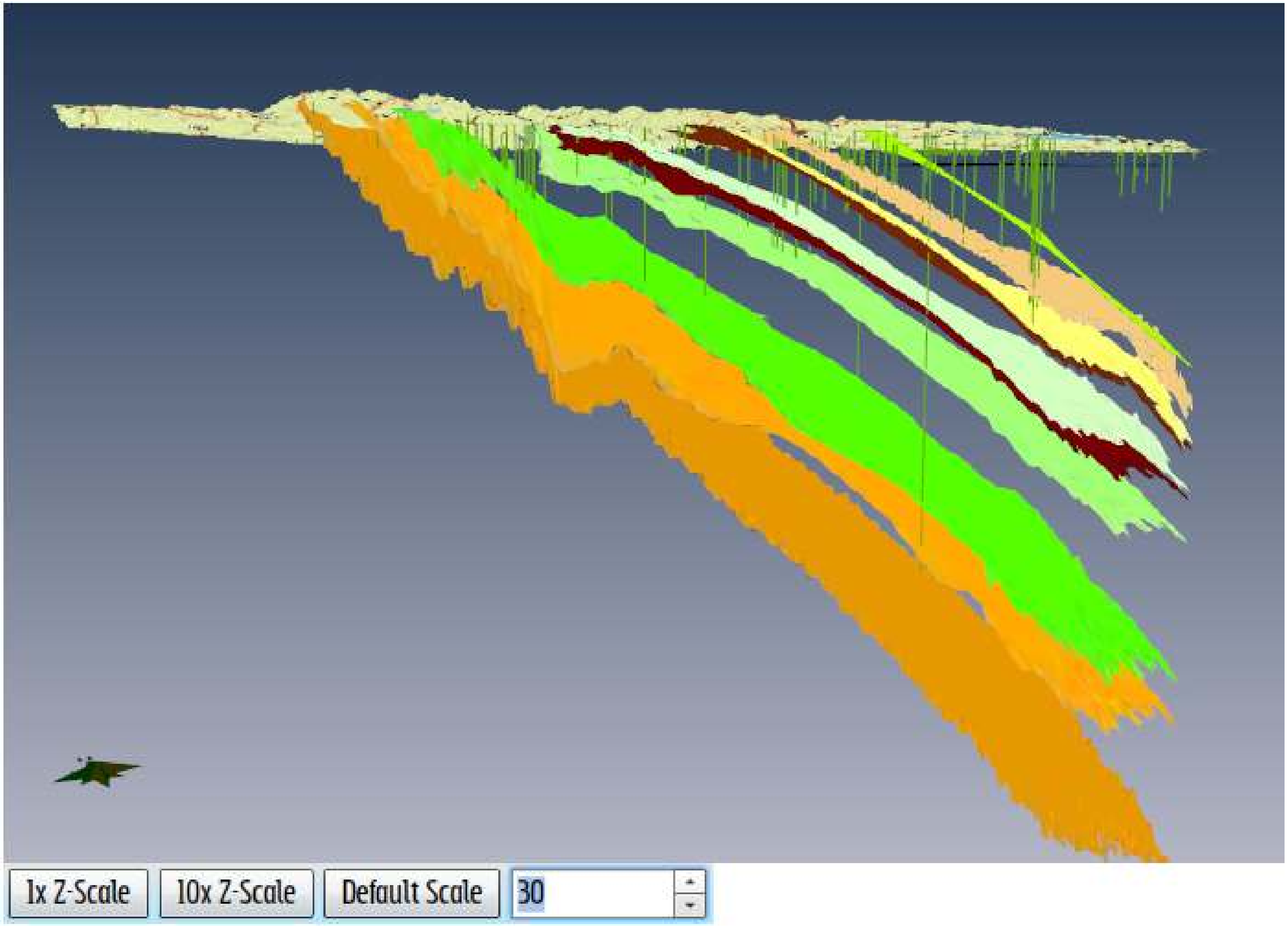


Slide provided by Harden & Associates

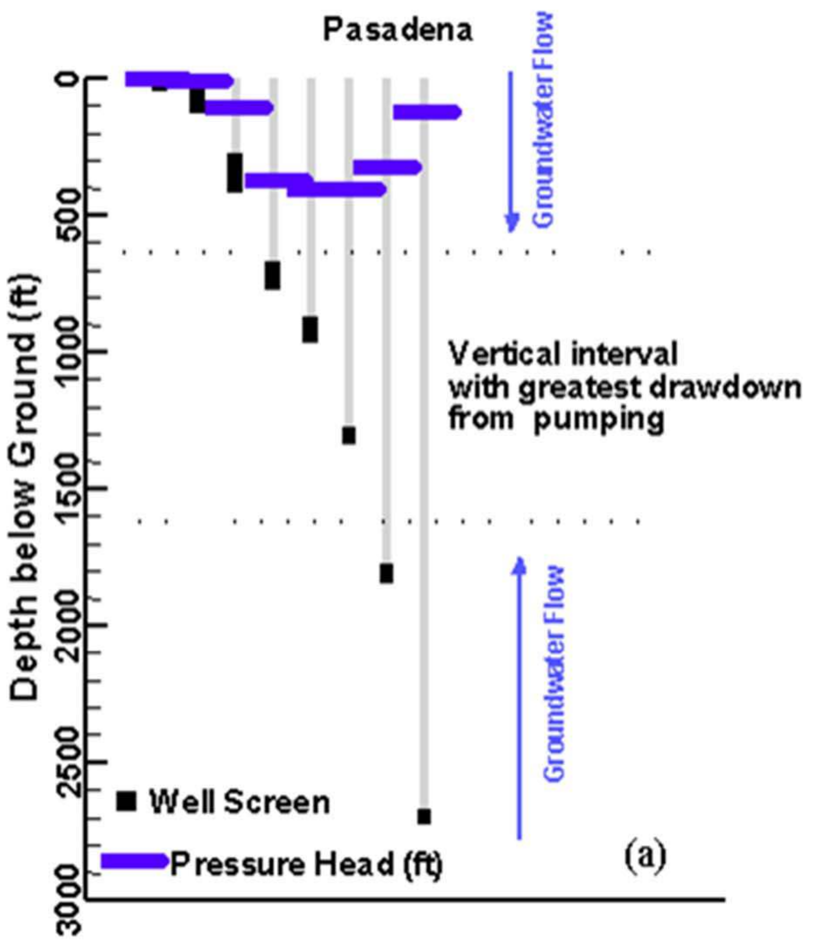
FOOTPRINT OF AQUIFER OUTCROPS

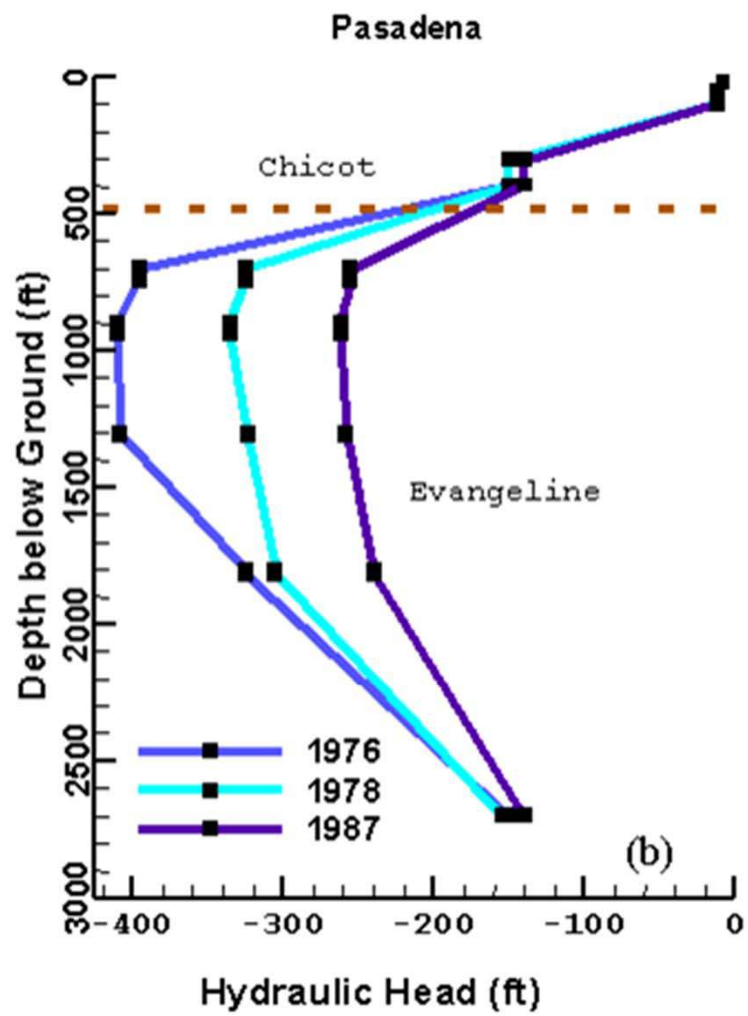


VERTICAL CROSS-SECTION THROUGH MILAM AND BURLESON COUNTIES

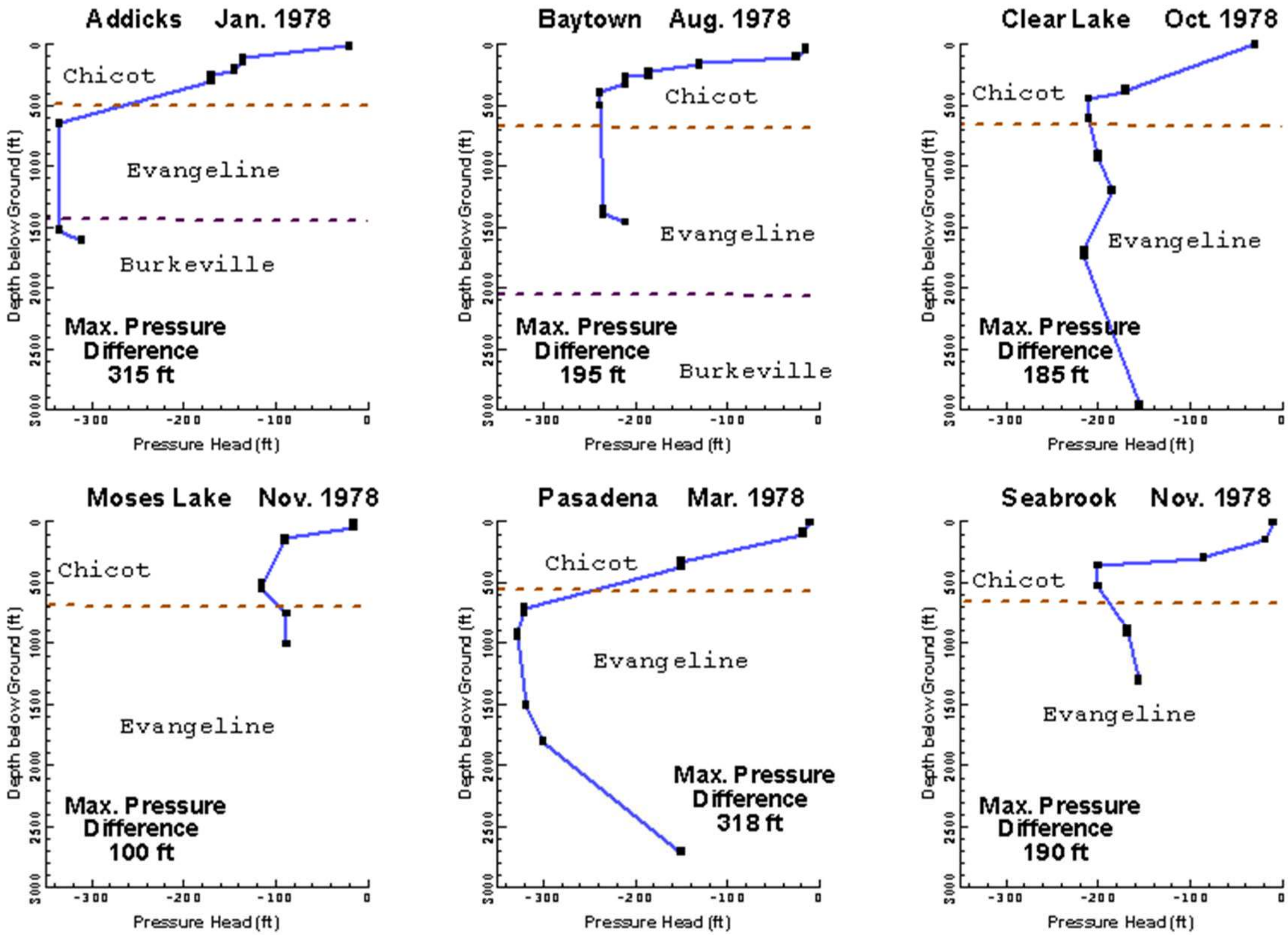


WATER LEVELS FROM CLUSTER MONITORING WELLS IN HARRIS COUNTY



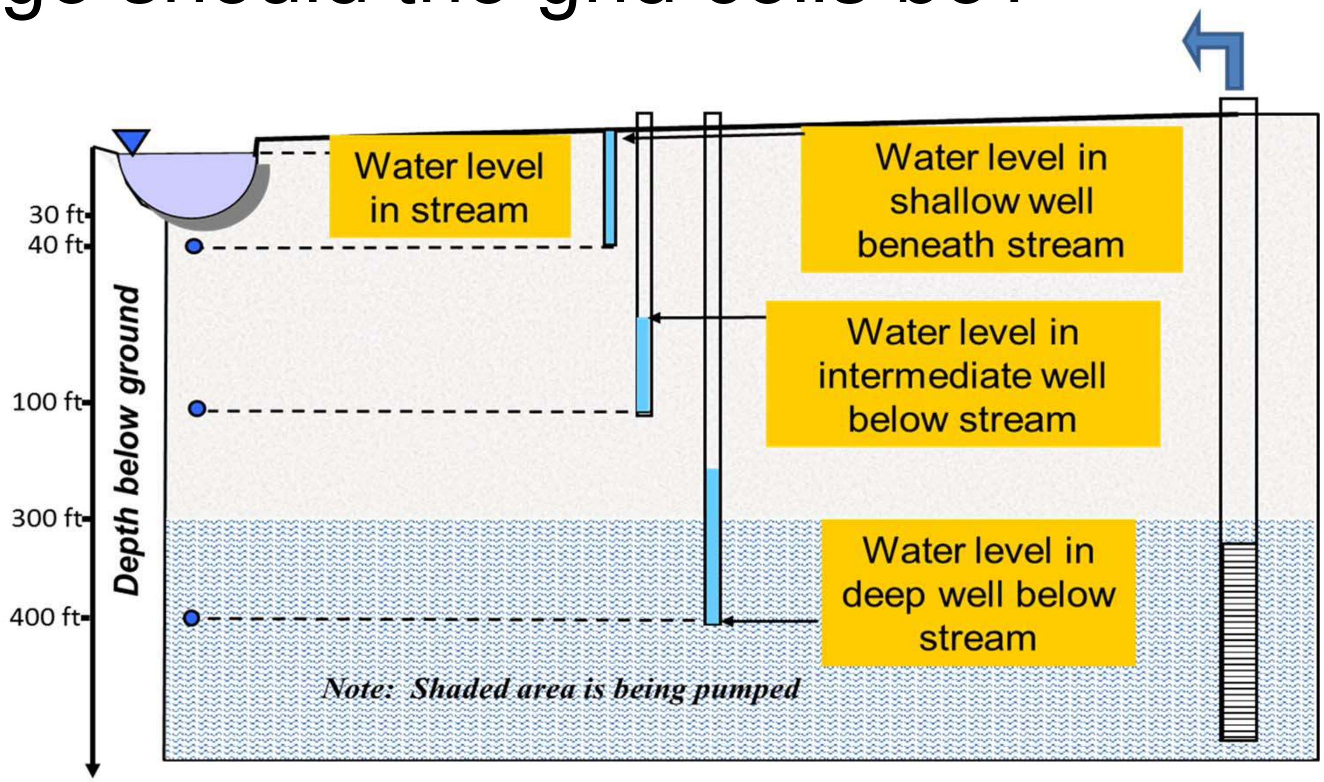


WATER LEVELS FROM STAGED MONITORING WELLS IN HARRIS COUNTY (CONT.)



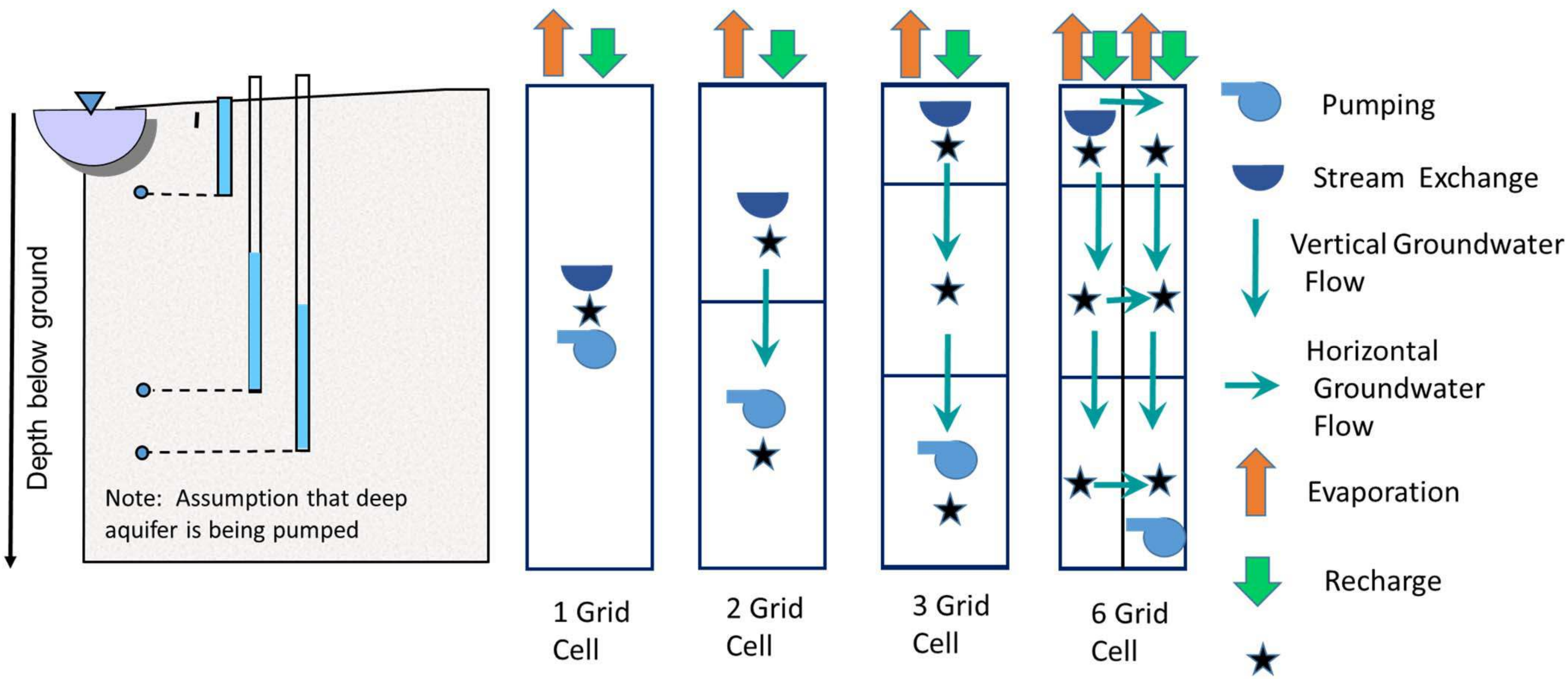
FUNDAMENTAL PROBLEM WITH DEVELOPING REGIONAL MODEL TO ADDRESS LOCAL ISSUES

- Where shallow water level is different from deep water level near a river– how thick and large should the grid cells be?

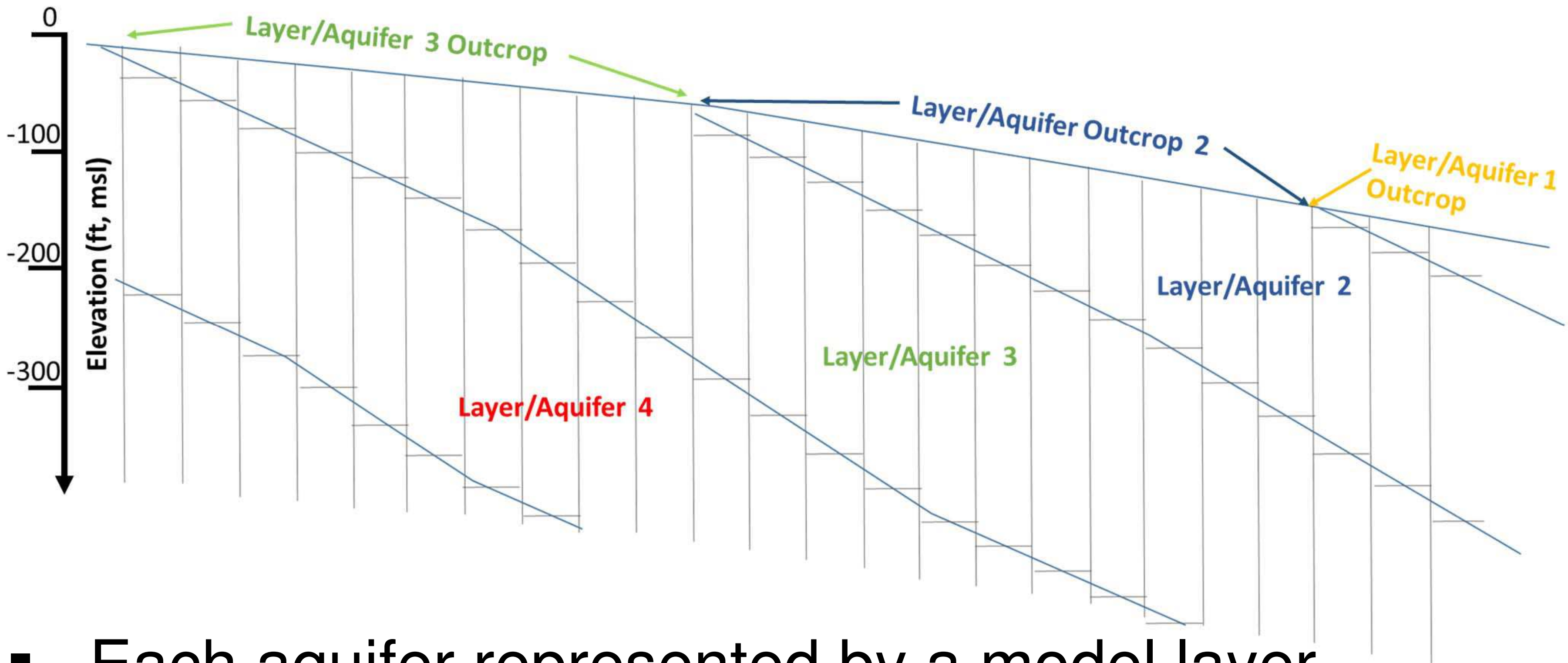


FUNDAMENTAL PROBLEM WITH DEVELOPING REGIONAL MODEL TO ADDRESS LOCAL ISSUES

- Some options for grid cell construction near a stream. Which options provides the best option for representing shallow flow paths? Which options requires the most effort and data to create?

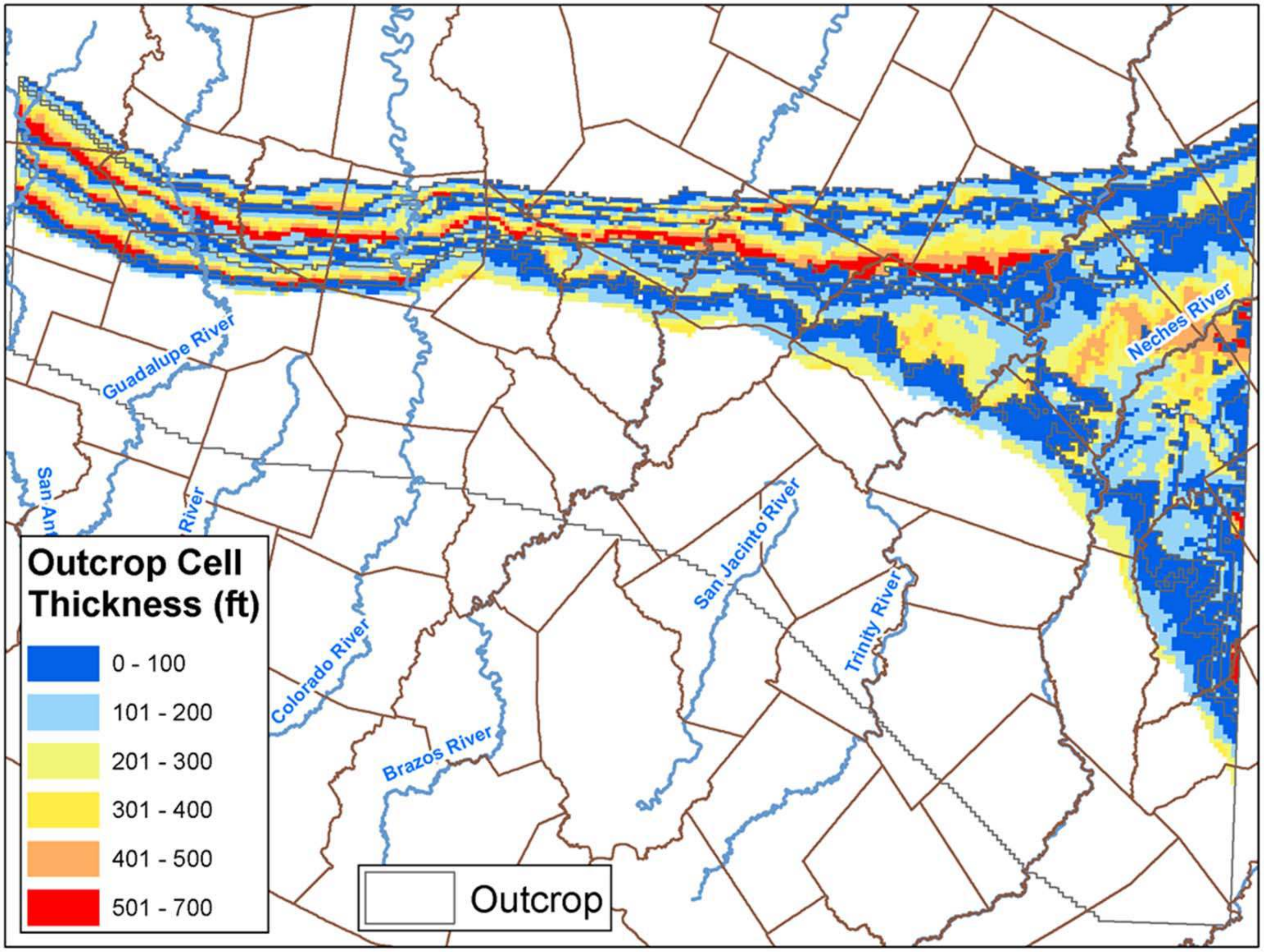


A GENERIC APROACH TO DEVELOPING A REGIONAL GROUNDWATER MODEL



- Each aquifer represented by a model layer
- Along an outcrop, the grid cells get thicker
- Where the grid cells are thick, the model loses ability to represent a shallow groundwater flow paths

THICKNESS OF GRID CELL REPRESENTING OUTCROP AND WATER LEVEL ELEVATION



AQUIFER AND GAM GRID CONSTRUCTION: SUMMARY POINTS

- The GMA 12 aquifers are dipping and therefore include both an unconfined (outcrop) and confined component
- Where there is pumping, there will be large vertical hydraulic gradients, so model layering is an important design criterion
- Spring flows and GW/SW exchange are largely controlled by the water table the outcrop
- The GAM has numerous grid cells representing the outcrop that are over 300 feet thick
- Thick grid cells in the outcrop can lead to problems with accurately simulating spring flows and GW/SW interactions
- Arbitrary decreases in grid sizes does not necessarily improve a model performance but a well designed numerical grid can have a major important in how well a model can perform

SPARTA/QUEEN CITY/CARRIZO-WILCOX GAM SIMULATED GW/SW EXCHANGE

- Representation of Streams and Springs
- Simulated GW/SW Exchange
- Summary Points

REPRESENTATION OF STREAMS

MODFLOW Stream Package

- Located only in aquifer outcrops
- Assigned a stream water level that changes annually
- GW/SW exchange based on difference between aquifer and stream interaction

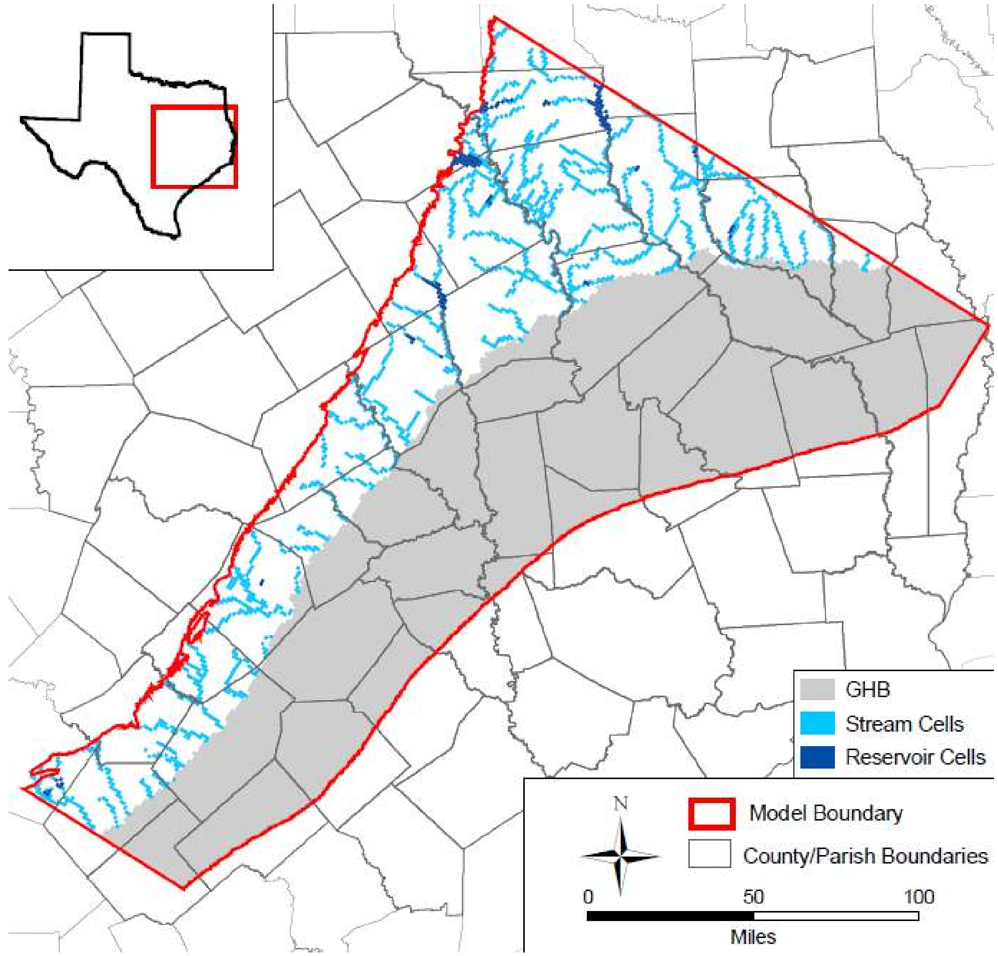
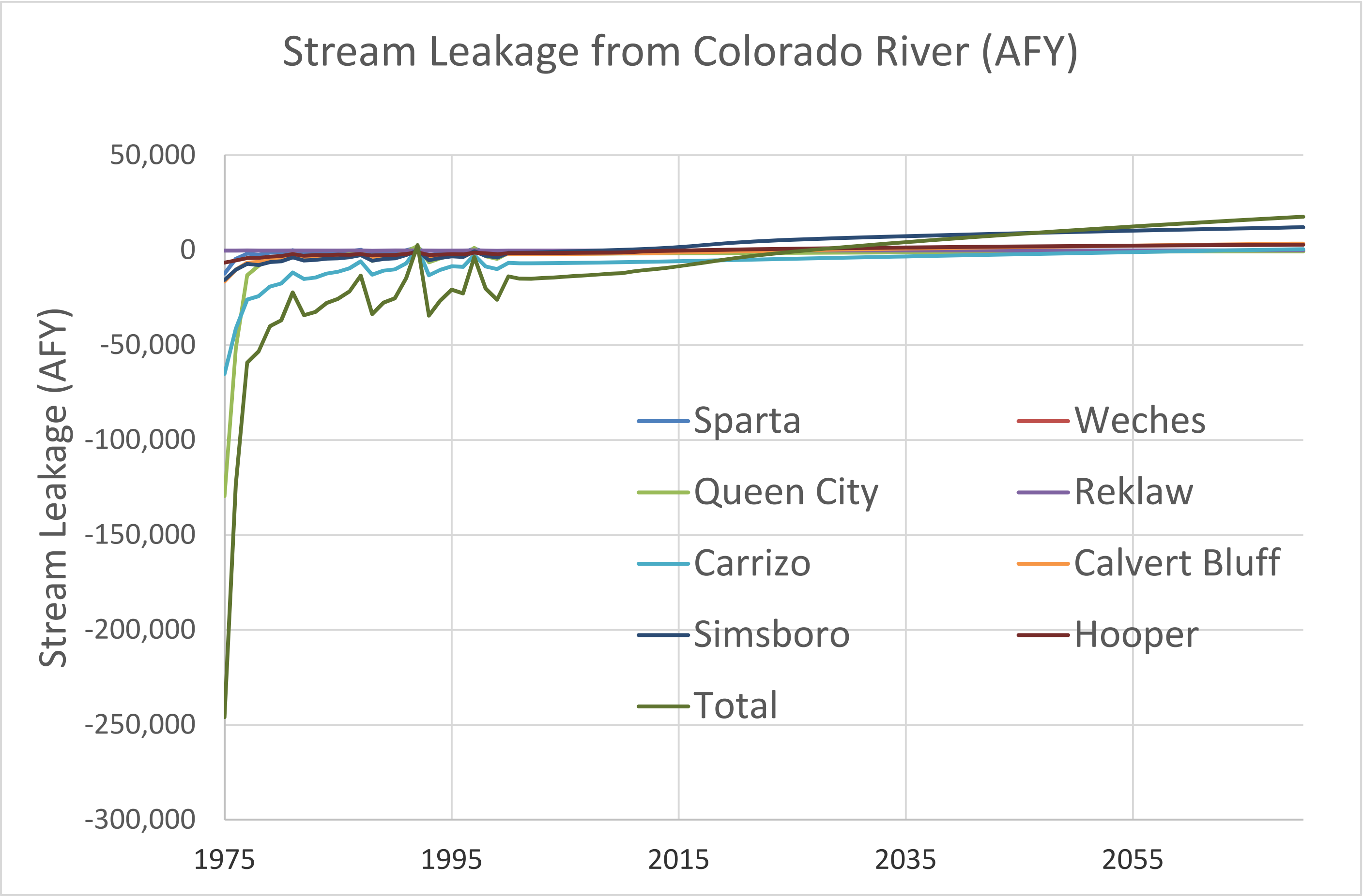


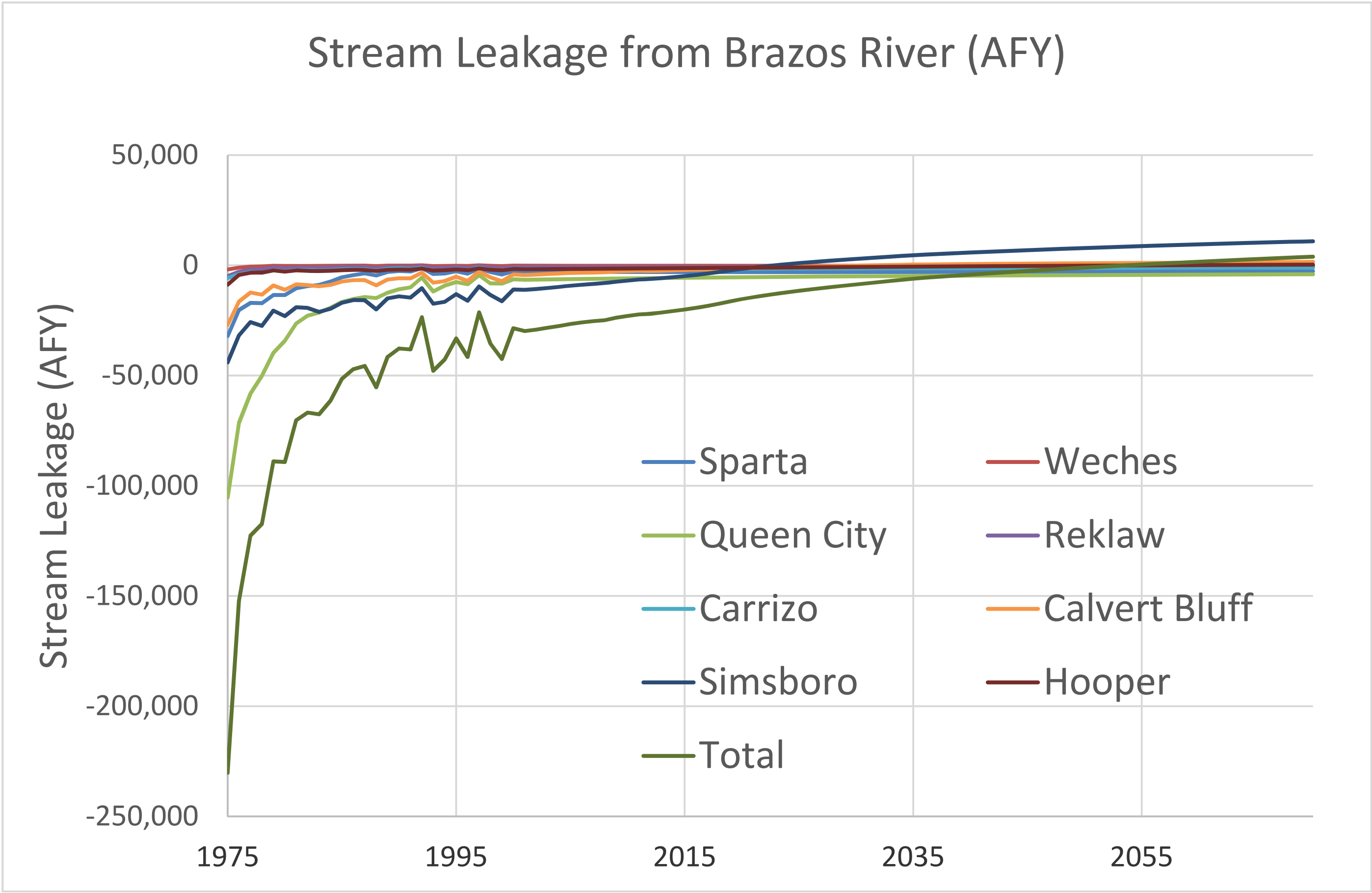
Figure from Kelley and others (2004)

SIMULATED GW/SW EXCHANGE: COLORADO RIVER & TRIBUTARIES



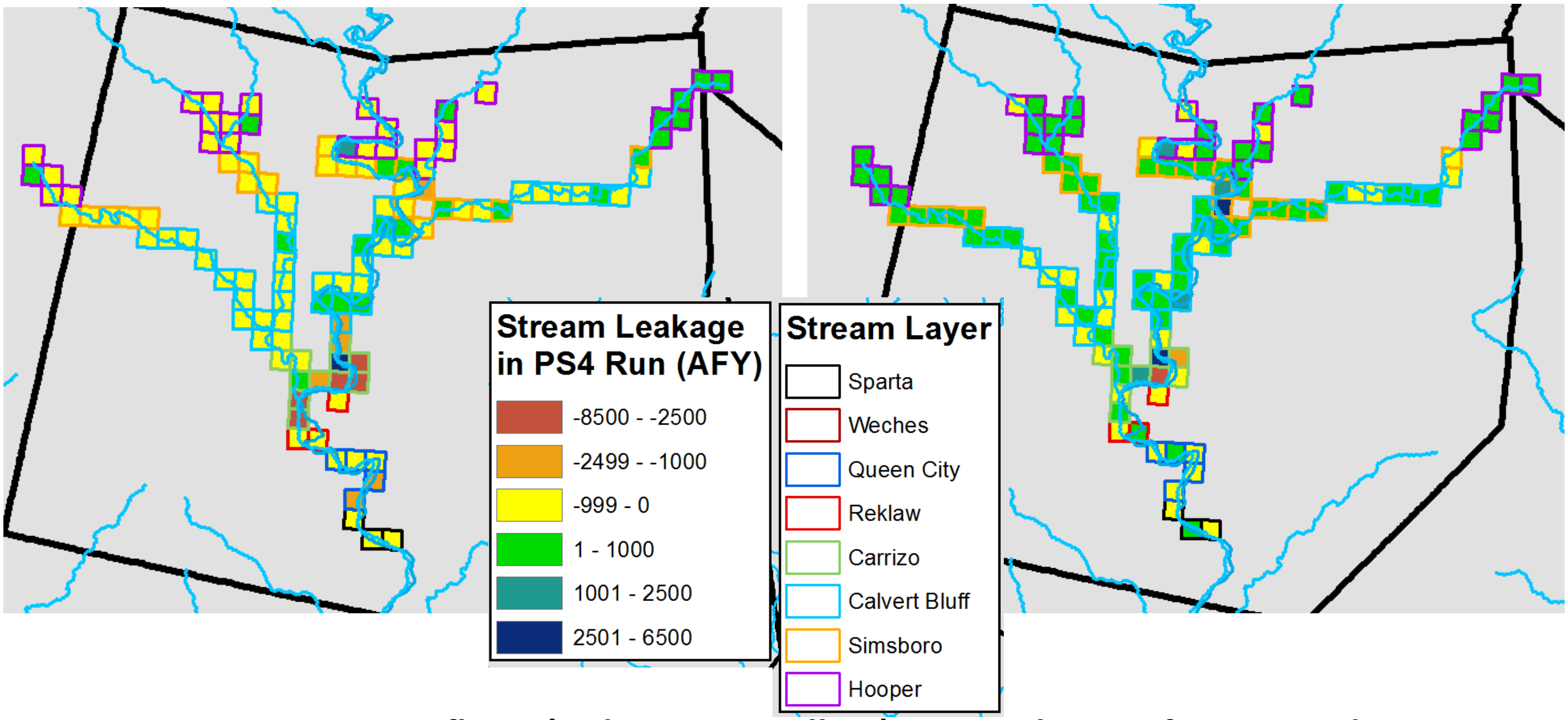
Note: Negative flows means the aquifer is providing groundwater to the stream – so stream is gaining.

SIMULATED GW-SW EXCHANGE: BRAZOS RIVER AND TRIBUTARIES



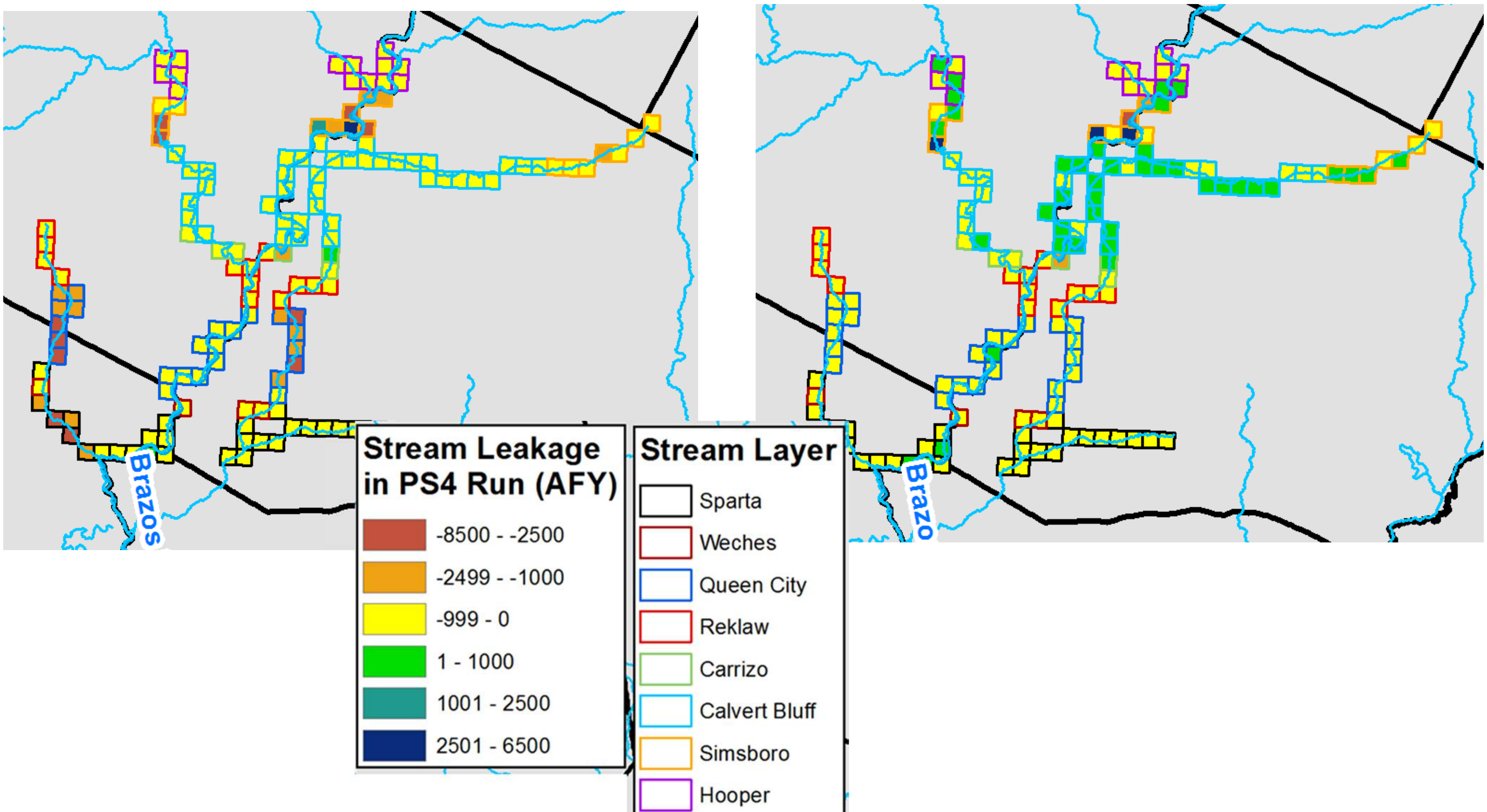
Note: Negative flows means the aquifer is providing groundwater to the stream – so stream is gaining.

LOCATION OF GAINING AND LOSING STREAM CELLS (1980 & 2070) FOR COLORADO RIVER



Note: Negative flows (red, orange, yellow) means the aquifer is providing groundwater to the stream – so stream is gaining. Positive flows (greens and blues) means the aquifer if receiving water from the stream – so stream is losing.

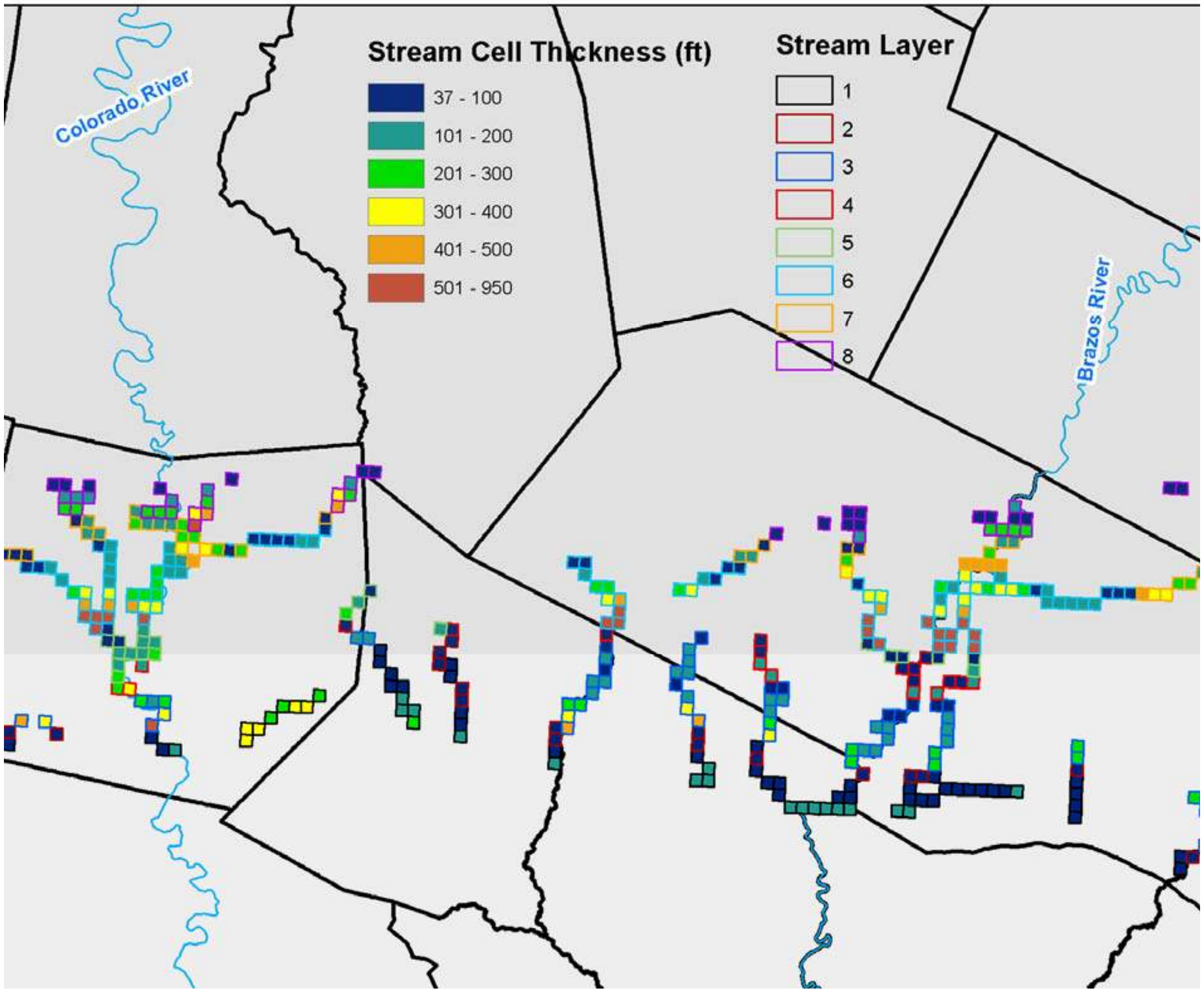
LOCATION OF GAINING AND LOSING STREAM CELLS (1980) FOR BRAZOS RIVER



Note: Negative flows (red, orange, yellow) means the aquifer is providing groundwater to the stream – so stream is gaining. Positive flows (greens and blues) means the aquifer if receiving water from the stream – so stream is losing.

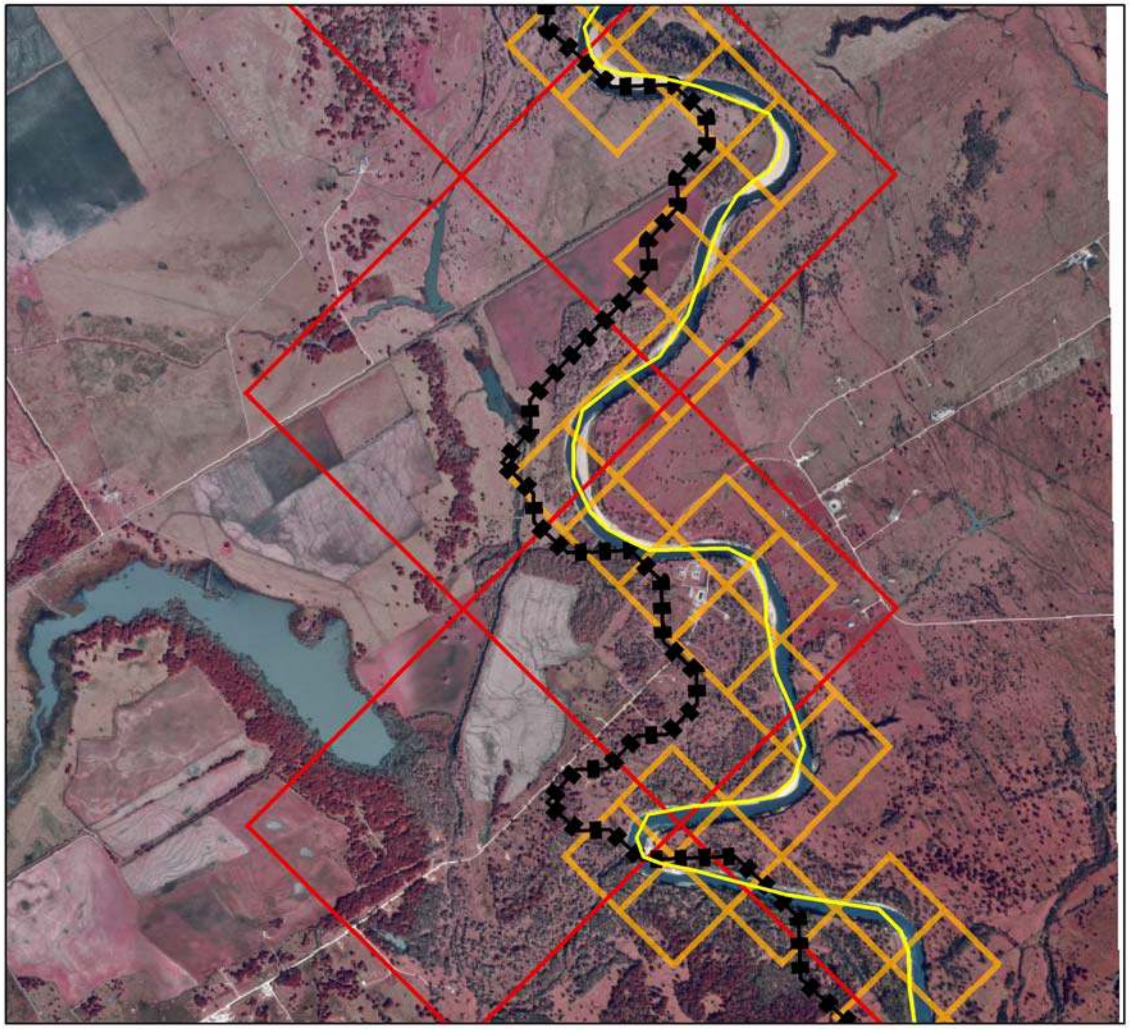
POTENTIAL PROBLEM WITH REPRESENTING GW/SW INTERACTION IS THICKNESS OF GRID CELL

- Numerous grid cells have thicknesses > 200 feet
- Thick grid cells prevents model from simulation shallow groundwater flow zone
- If “deep” pumping occurs in a thick grid cell, river acts as a source of recharge for aquifer
- Because of model grid construction, there is a question if the losses are an artifact of the thick grids



POTENTIAL PROBLEM WITH REPRESENTING GW-SW INTERACTION IS BOTH THICKNESS AND SIZE OF GRID CELL

Example is Lower Colorado River



GAM 1 mile by 1 mile grid

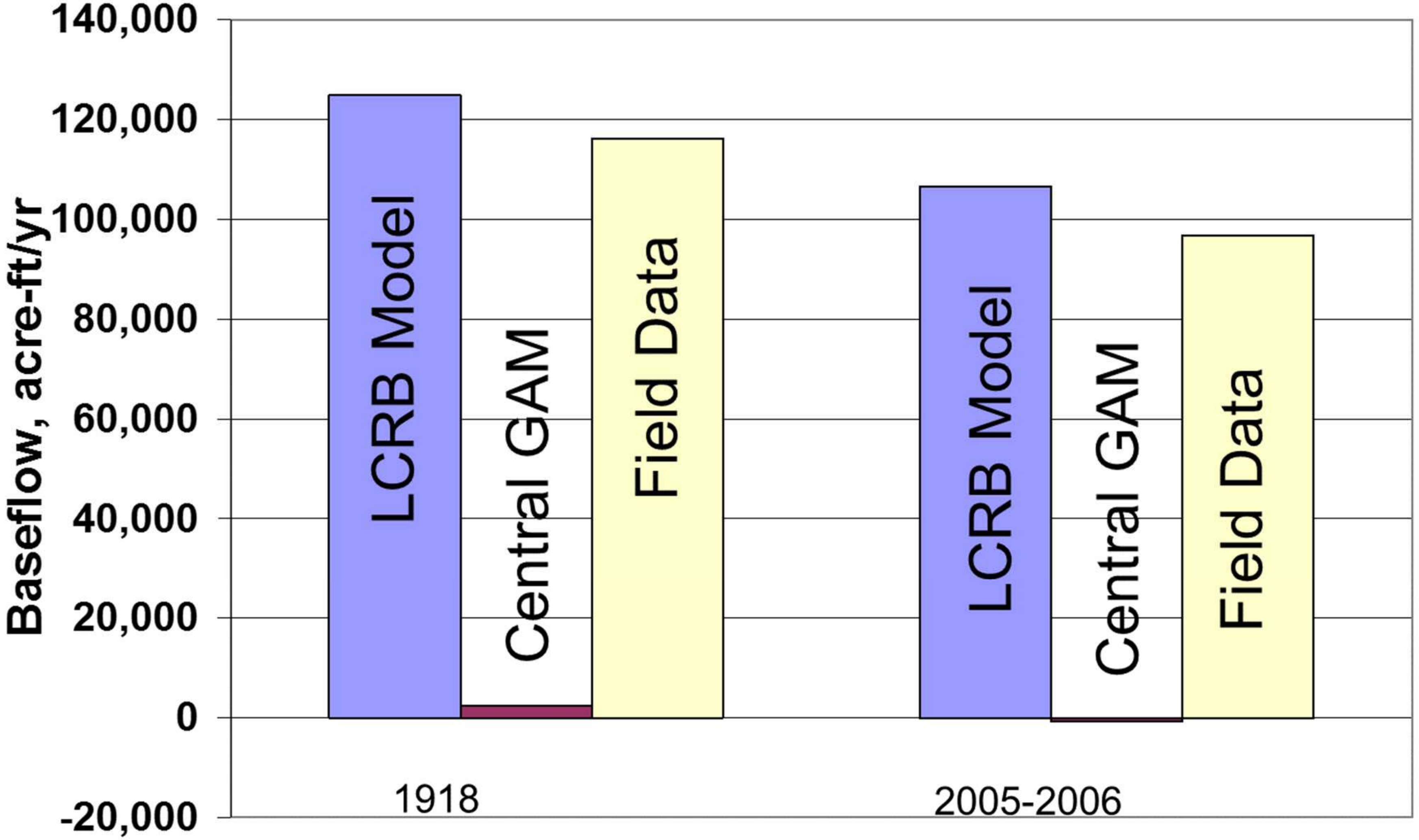
LSWP 0.25 mile by 0.25 mile grid

EPA RF1

National Hydrography Database

Note: Grid size affects the location of river to wells

EXAMPLE OF IMPROVED PREDICTION OF GW/SW INTERACTION BY REFINING GRID CELL SIZES



COMPARISON OF NUMERICAL GRID BETWEEN THE LCRB MODEL AND THE CENTRAL GULF COAST GAM

Chicot Aquifer

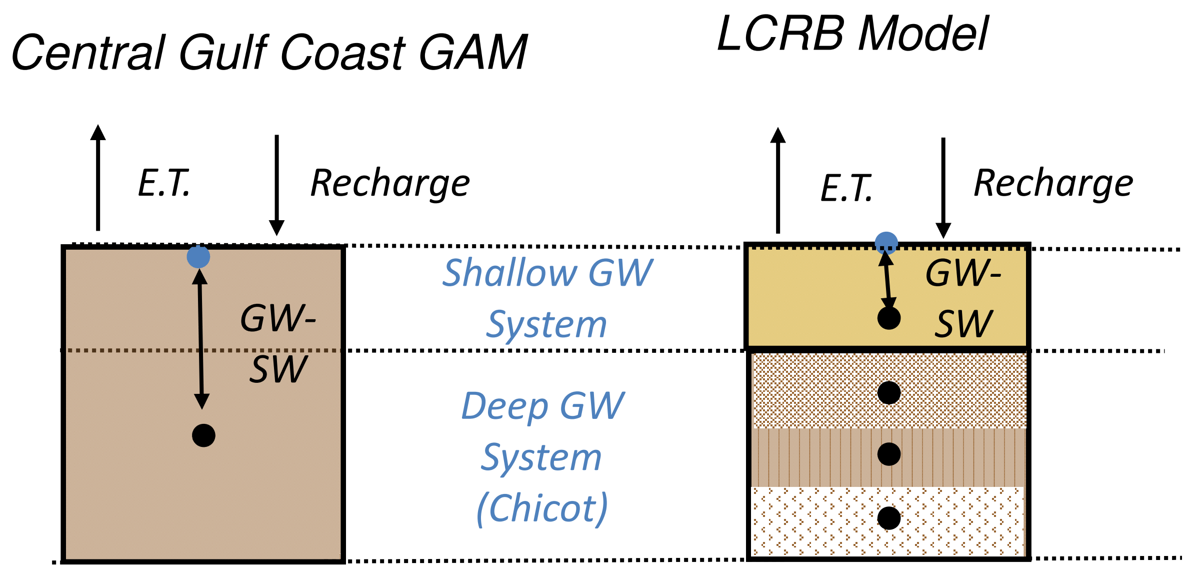
- GAM = 1 layer with thickness up to 1000 ft
- LCRB = 4 layers with shallow 50 to 100 ft thick

GAM (1 layer)

- one hydraulic head value
- all same aquifer property
- all wells intersect the entire layer thickness

LCRB (4 layer)

- four hydraulic head value
- four unit with different aquifer properties
- wells located in 1 to 4 layers



One cell total

R, ET, and GW-SW process interact directly with deep system

Four cells total

R, ET, and GW-SW processes interact directly with shallow system

QSCP GW-SW INTERACTIONS: SUMMARY POINTS

- Many grid cells in aquifer outcrop are too thick to represent a shallow flow system accurately
- Modeling in Gulf Coast demonstrates the importance of modeling a shallow groundwater system
- Because of model grid construction, there is a question of what portions of the predicted pumping impacts on river are an artifact of the model construction
- 1-mile by 1-mile grid cell size inhibits accurate assignment of river locations and elevations
- Little data for representative estimates of GW/SW exchange to help model development
- Large flow (~250,000 AFY) in 1975 from aquifers into rivers raises a few questions

SPARTA/QUEEN CITY/CARRIZO-WILCOX GAM SIMULATED SPRING FLOW

- Representation of Springs
- Simulated Spring Flow
- Summary Points

REPRESENTATION OF SPRINGS AWAY FROM STREAMS

MODFLOW Drain Package

- Located only in aquifer outcrops
- Assigned an elevation based on topographic low
- Spring flow based on difference between aquifer and drain elevation

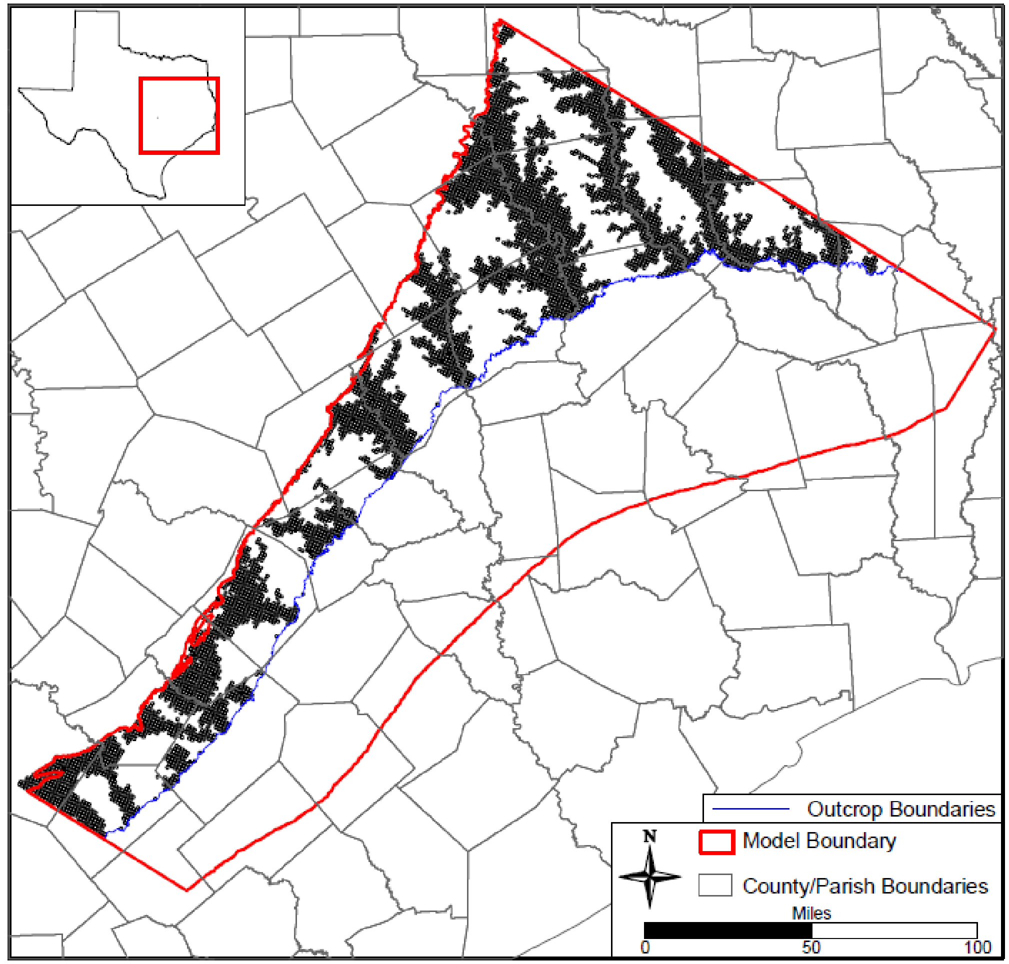
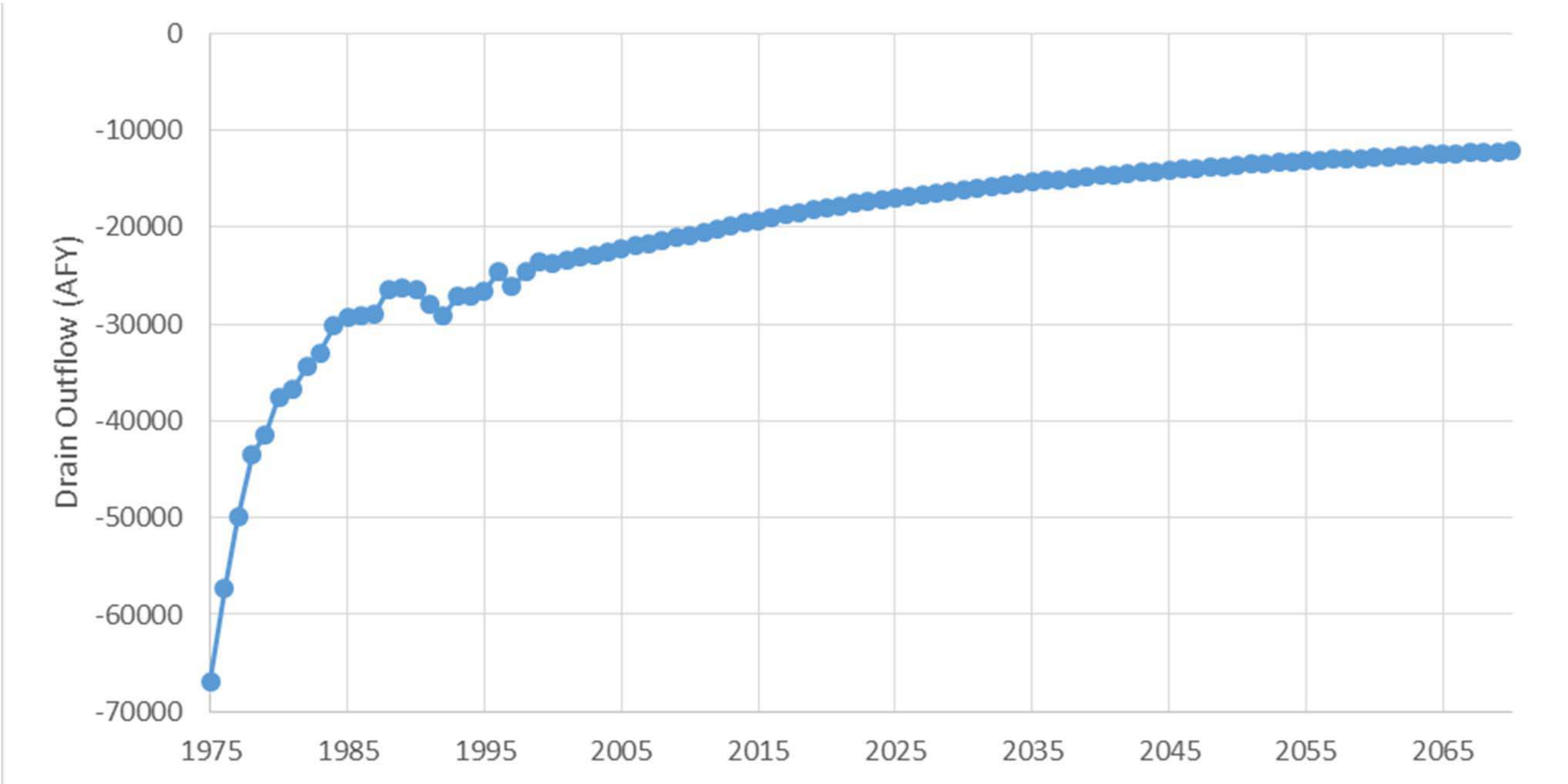


Figure from Kelley and others (2004)

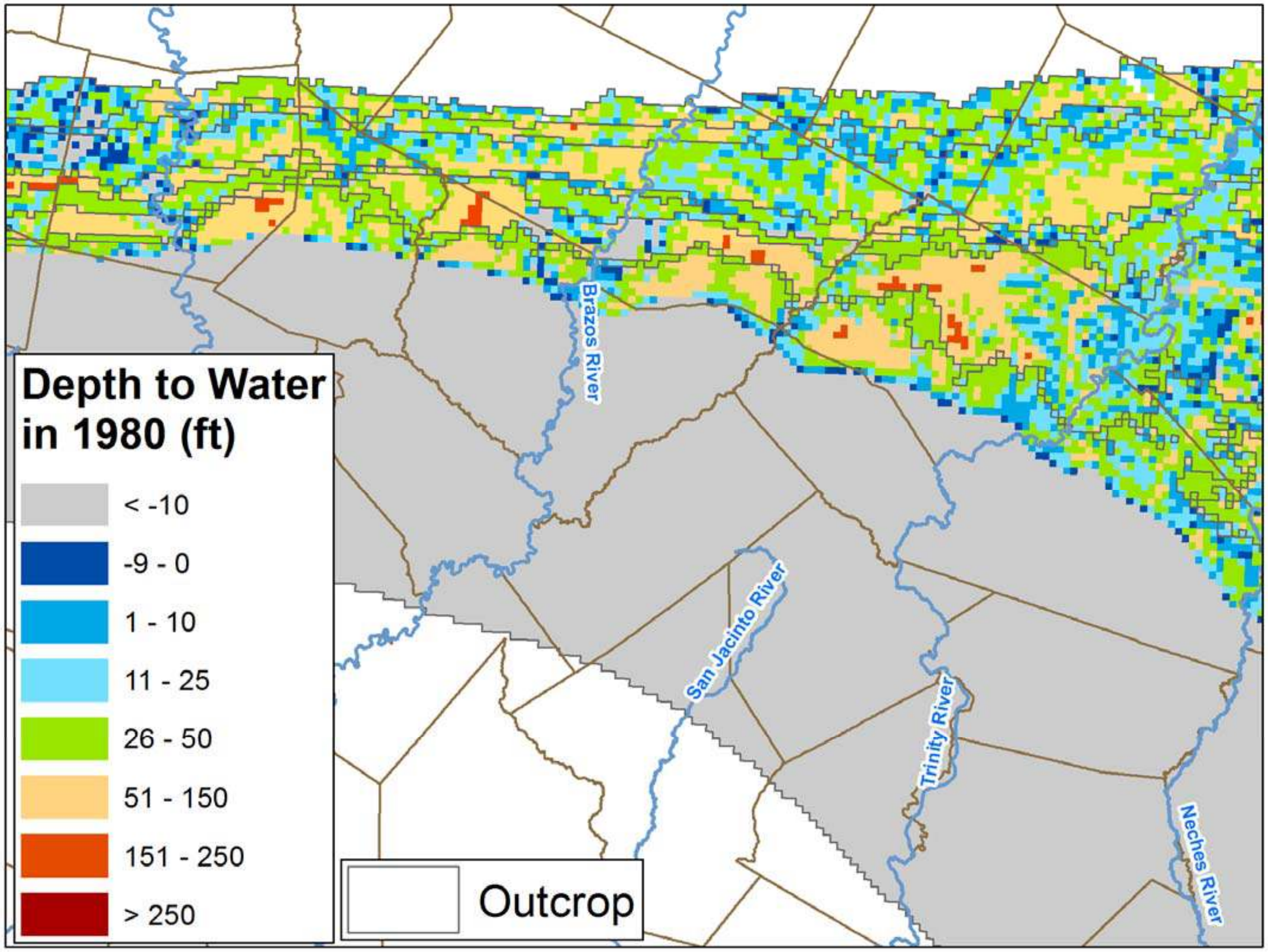
SIMULATED GROUNDWATER FLOW FROM DRAINS



Drain flow represents about 0.3% of water balance for GMA 12

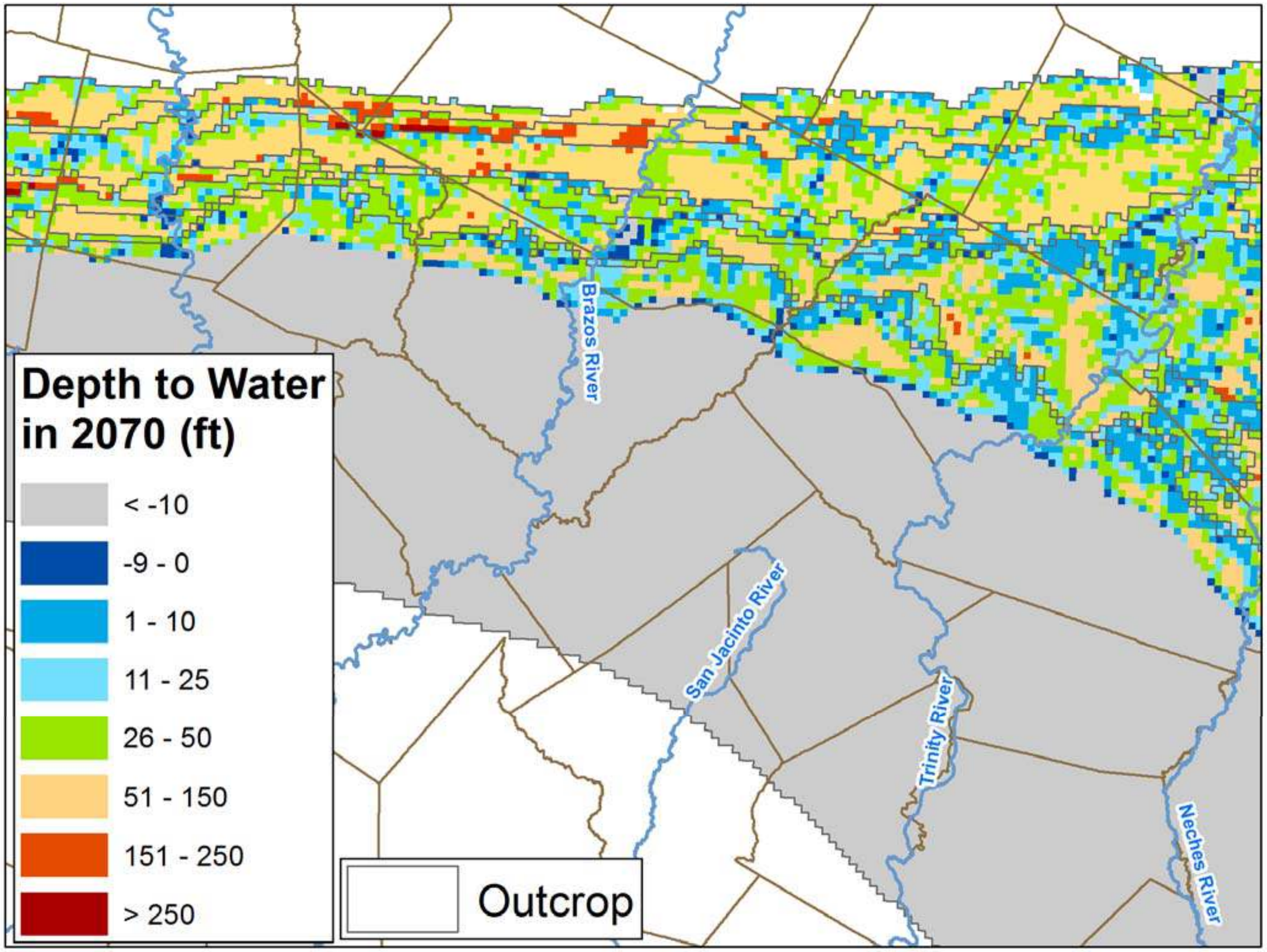
Assumed that all drains represent springs. Modelers may have used drains to limit recharge rates.

SIMULATED DEPTH TO WATER TABLE IN THE AQUIFER OUTCROP (1980)



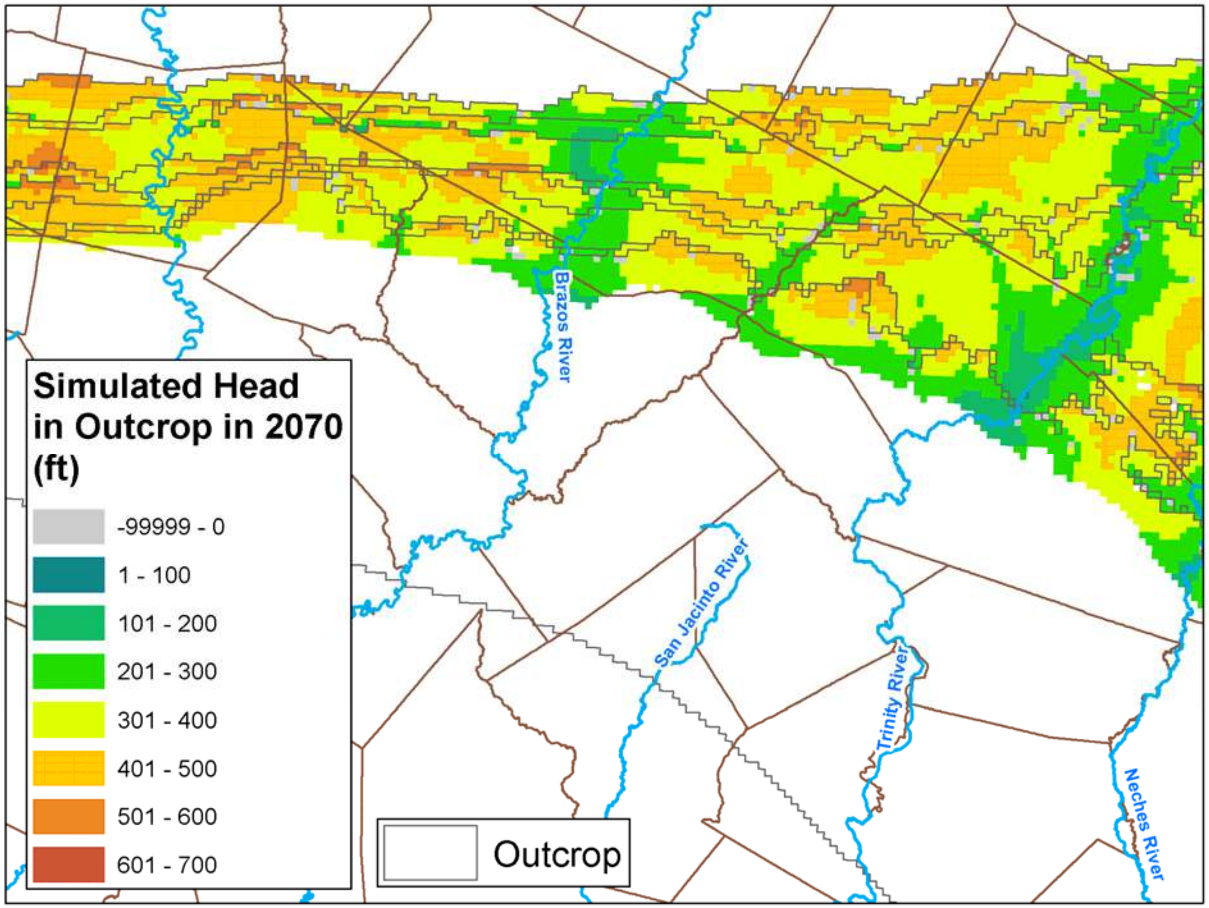
Note: In down-dip reaches of some of the aquifer outcrops, the depth to the water table exceeds 150 feet in 1980

SIMULATED DEPTH TO WATER TABLE IN THE AQUIFER OUTCROP (2070)



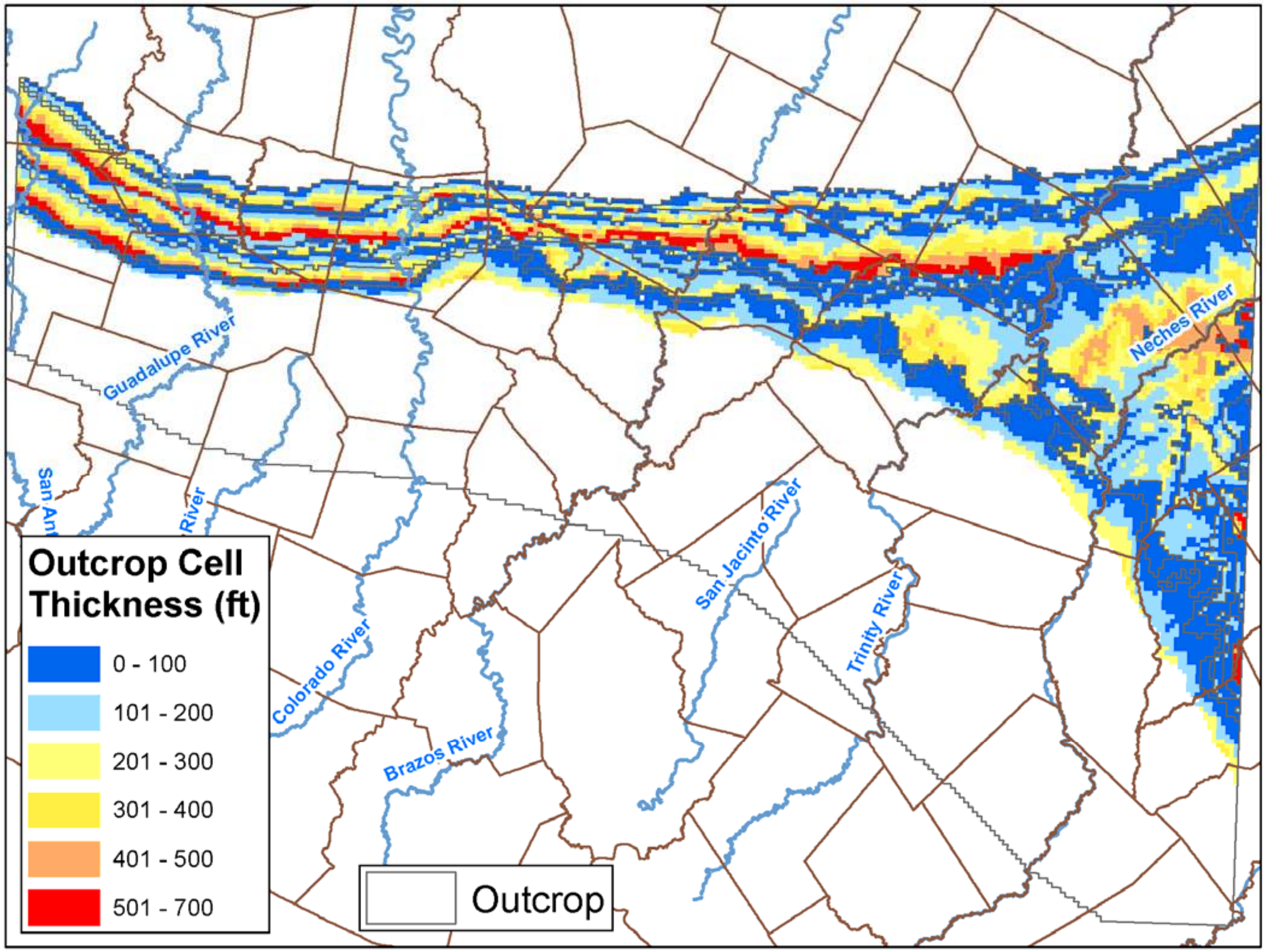
Note: In down-dip reaches of much of the Simsboro outcrop, the depth to the water table exceeds 150 feet in 2070

SIMULATED WATER TABLE (FT, MSL) IN THE AQUIFER OUTCROP (2070)



Note: In the aquifer outcrop, there is strong correlation between the model layering and outcrop location and the water table elevation

THICKNESS OF GRID CELL REPRESENTING OUTCROP AND WATER LEVEL ELEVATION



QSCP SPRING FLOW: SUMMARY POINTS

- Spring flow is estimated to be about 70,000 AFY in 1975 and 20,000 AFY in 2010
- Future pumping in PS4 run will reduce spring flow to 12,000 AFY in 2010
- No springs identified in GMA 12 that are tied to endangered species
- Many grid cells in the aquifer outcrop are too thick to represent a shallow flow system
- Thick grid cells in the aquifer outcrop area have the potential to cause spring flow to be under predicted where pumping occurs near the spring
- There is insufficient field data to evaluate the accuracy of the GAM to predict the impact of pumping of spring flow

SUMMARY OF KEY ENVIRONMENTAL ISSUES

SUMMARY OF KEY ENVIRONMENTAL ISSUES

- Spring Flow and GW-Stream Exchange are potentially important environmental issues
- Accurate prediction of pumping impacts on spring flow and river flow requires accurate predictions of a shallow groundwater system, including a water table
- The QSCP GAM is not a good simulator of water tables or shallow groundwater flow systems because of thick grid cells in the aquifer outcrop

SUMMARY OF KEY ENVIRONMENTAL ISSUES

- Collection of representative stream gain-loss data is expensive. Very limited good gain-loss data exists in GMA 12
- Brazos River gain-loss study should be used with caution because it has not been properly adjusted for return flow, diversions, and unsteady flow effects
- LCRA gain-loss study should also be used with care because it was measured during low flow conditions and it not likely representative of other flow conditions

SUMMARY OF KEY ENVIRONMENTAL ISSUES

- TCEQ Environmental Instream Flow program is set up to protect the health of the Colorado and Brazos Rivers
- River authorities are currently managing in-stream flows in Colorado and Brazos rivers
- Groundwater flow into streams can be an important contributor for helping river authorities maintain critical or subsistence flows
- Springs' flows are poorly documented; no substantial flow measurements done since 1970s


Consultants for the
Brazos Valley GCD (LBG-Guyton Associates)
Fayette County GCD (Daniel B. Stephens & Associates)
Lost Pines GCD (Daniel B. Stephens & Associates)
Mid-East Texas GCD (Matt Uliana, independent consultant)
Post Oak Savannah GCD (INTERA, Inc.)