Hydrogeology and Simulation of Groundwater Flow in the Eastern Arbuckle-Simpson Aquifer

- Presentation intended for general public
- Some more technical material
- Preliminary results, subject to revision

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Agenda: Hydrogeology

- Geology (already described by Noel)
- Aquifer hydraulic properties (especially storage coefficient)
- Watersheds: Surface and subsurface
- Recharge

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Agenda: Simulation of Groundwater Flow

- What is a model?
- Why use models?
- Computer program: MODFLOW
- The eastern Arbuckle-Simpson aquifer MODFLOW model
- How recharge is implemented in the model

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Agenda: Simulation of Groundwater Flow

- Simulations of distributed groundwater withdrawals (pumpage)
- Effects of groundwater withdrawals on streams and springs
- Distributed groundwater withdrawals compared to concentrated groundwater withdrawals

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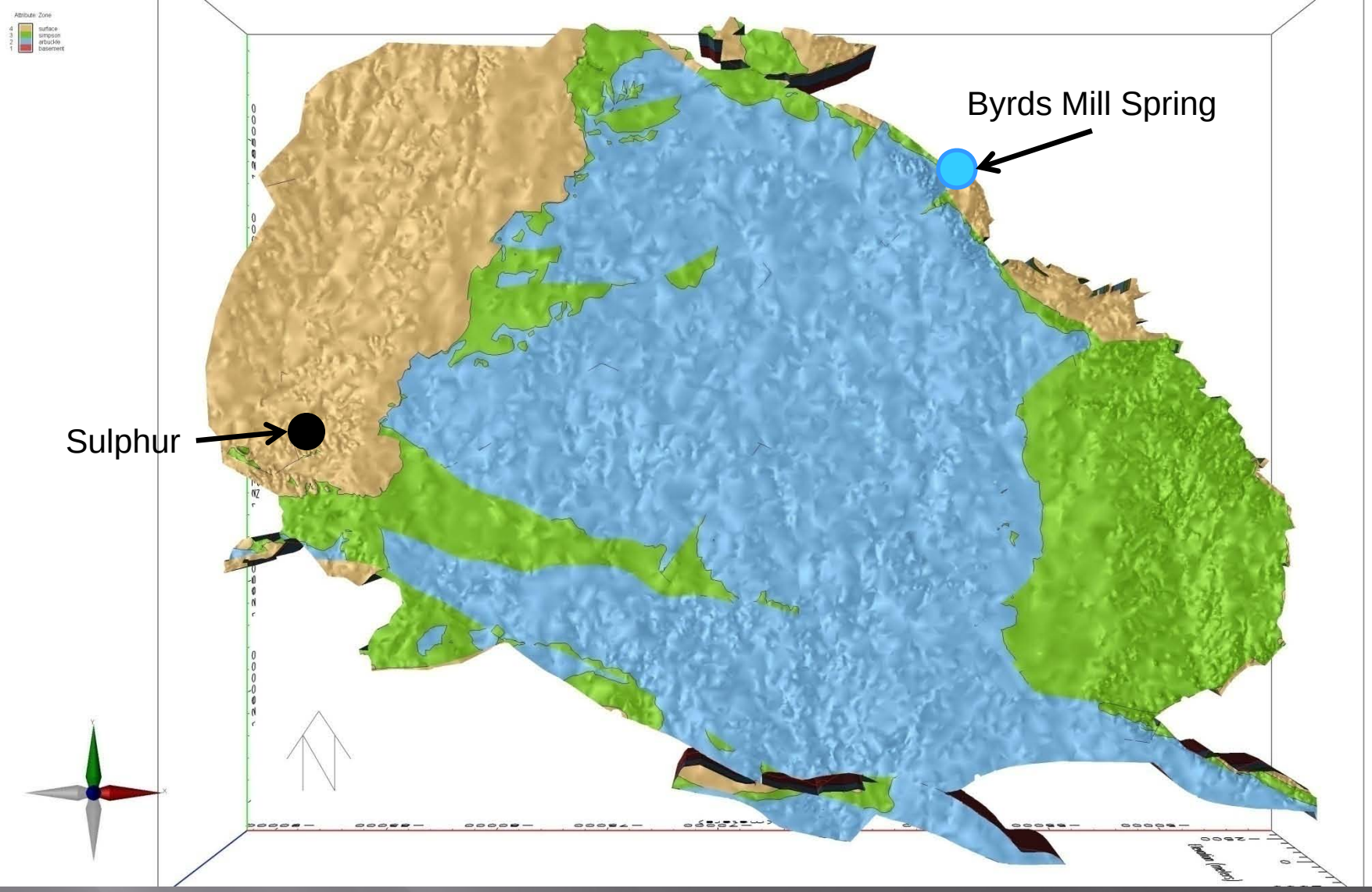
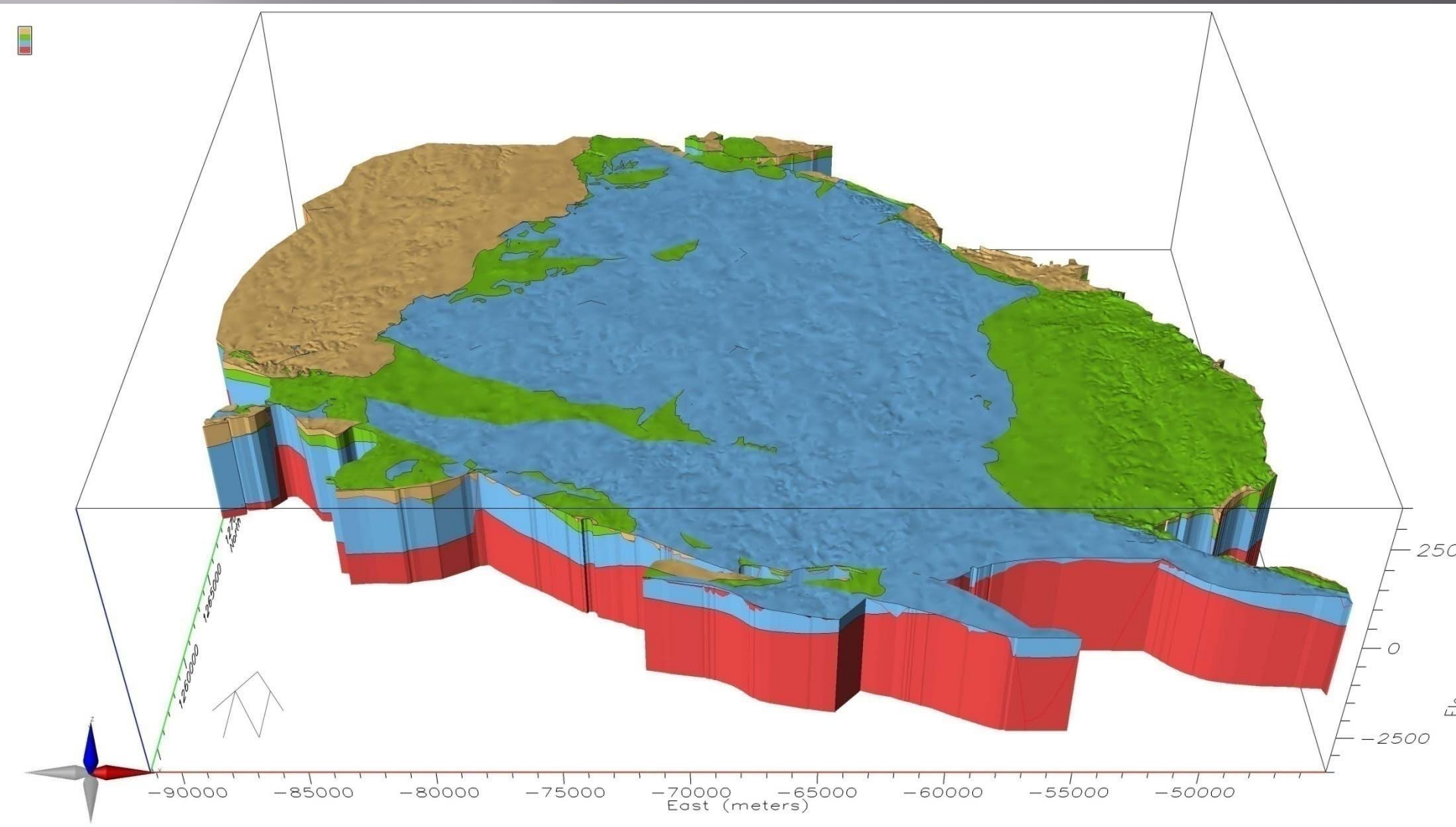


Hydrogeologic Framework Model

Preliminary results, subject to revision

USGS and OSU

Dr. Jim Puckette, Jason Faith, Dr. Chuck Blome



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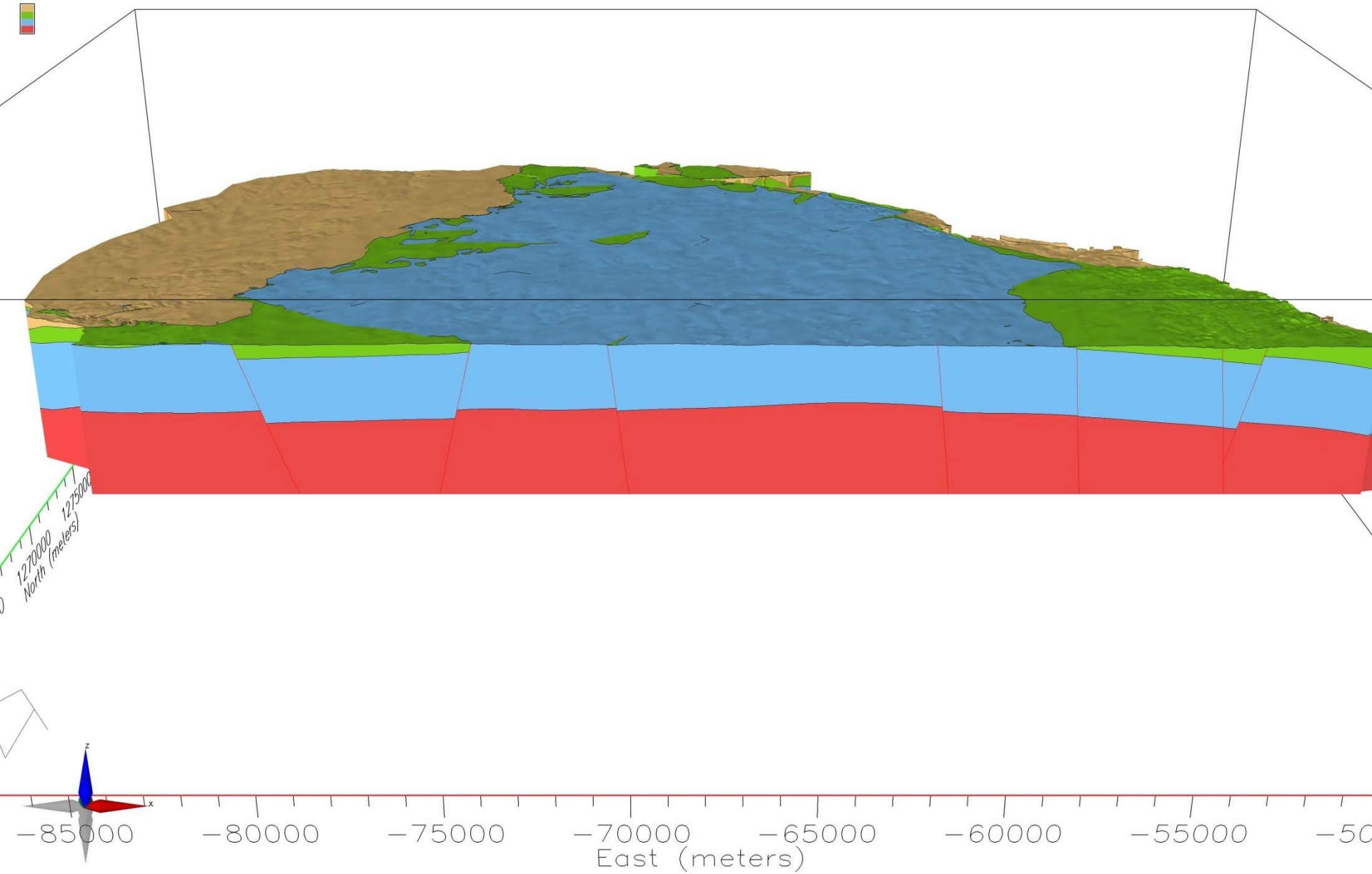
1270000
North (meters)
z
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−70000
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−60000
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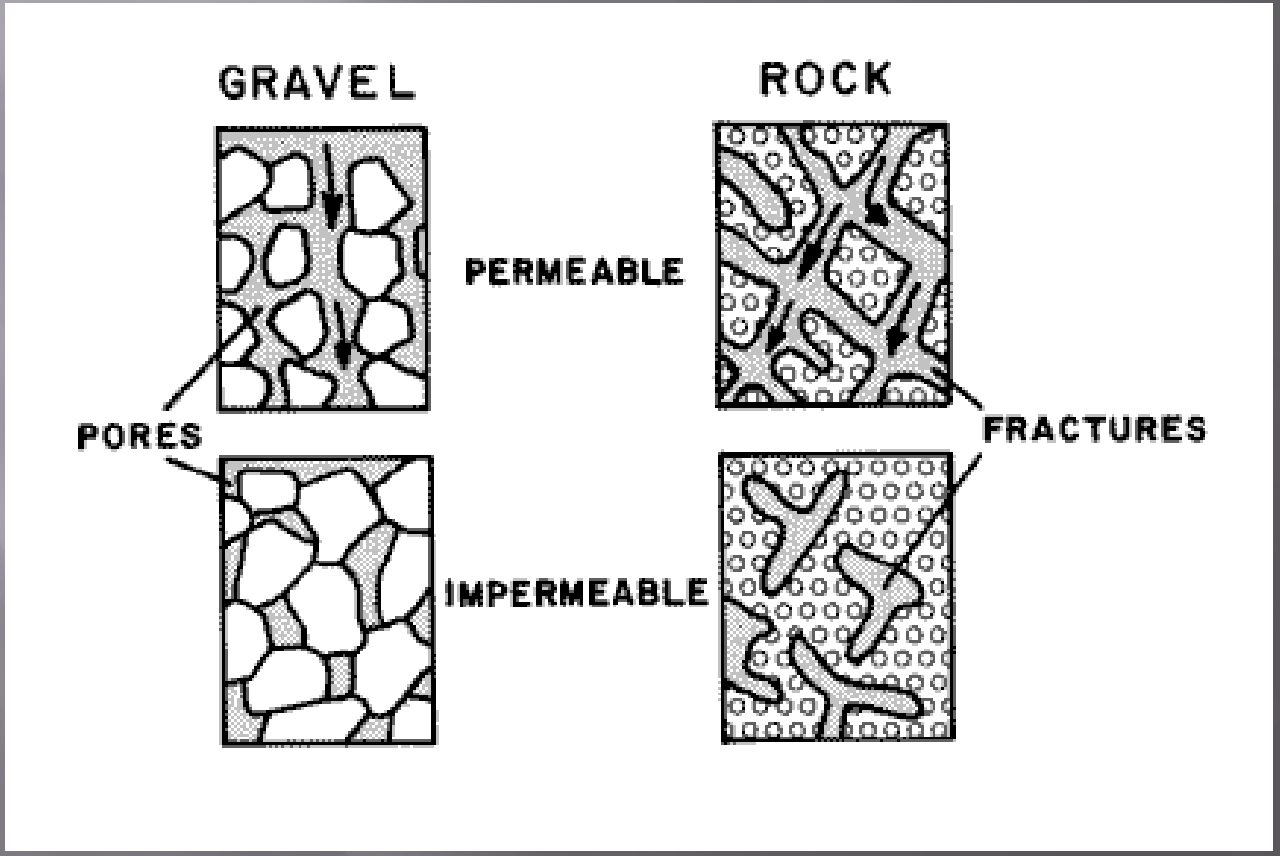
East (meters)

Aquifer hydraulic properties are related to geology



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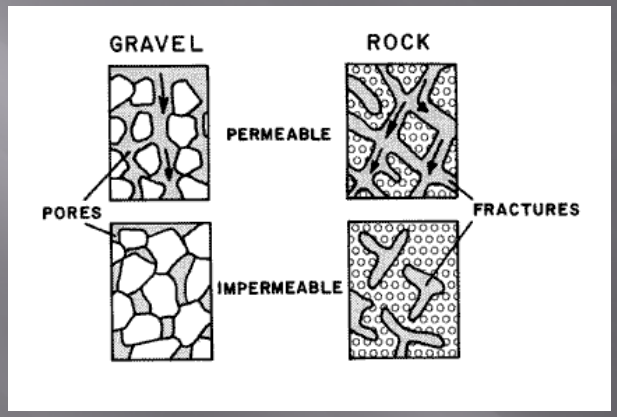
Aquifer hydraulic properties: Storage coefficient



The volume of water given up per unit area of an aquifer per unit drop of the water-table or potentiometric surface.

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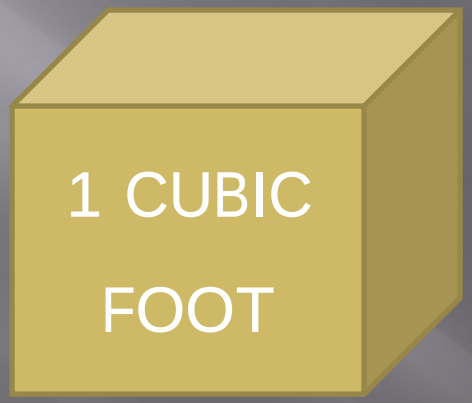
Aquifer Hydraulic Properties: Storage Coefficient

Alluvial aquifer	0.2
Arbuckle-Simpson aquifer	0.008



Alluvial aquifer

1.5 gallons

Arbuckle-Simpson aquifer

1 cup

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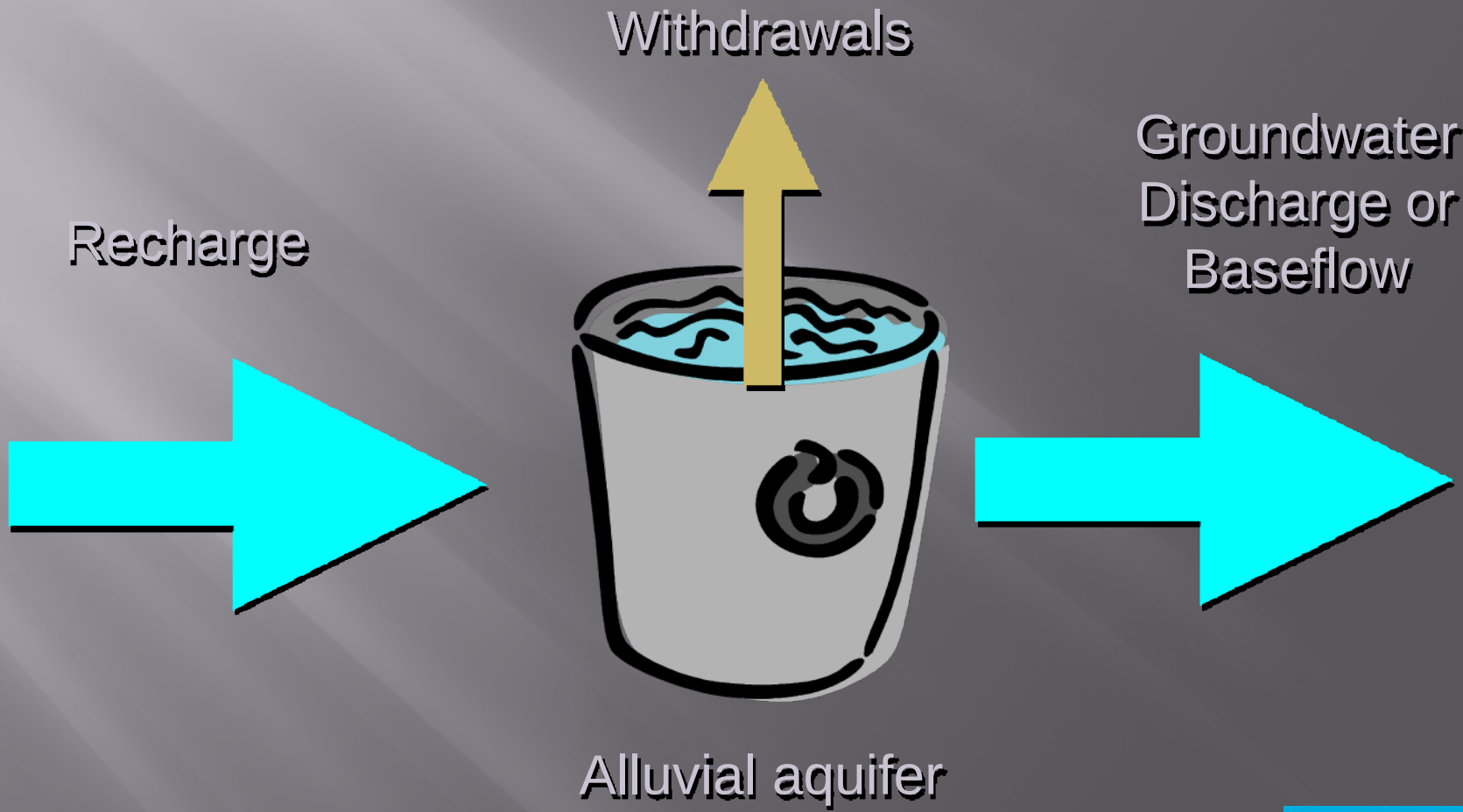
Aquifer Hydraulic Properties: Storage Coefficient



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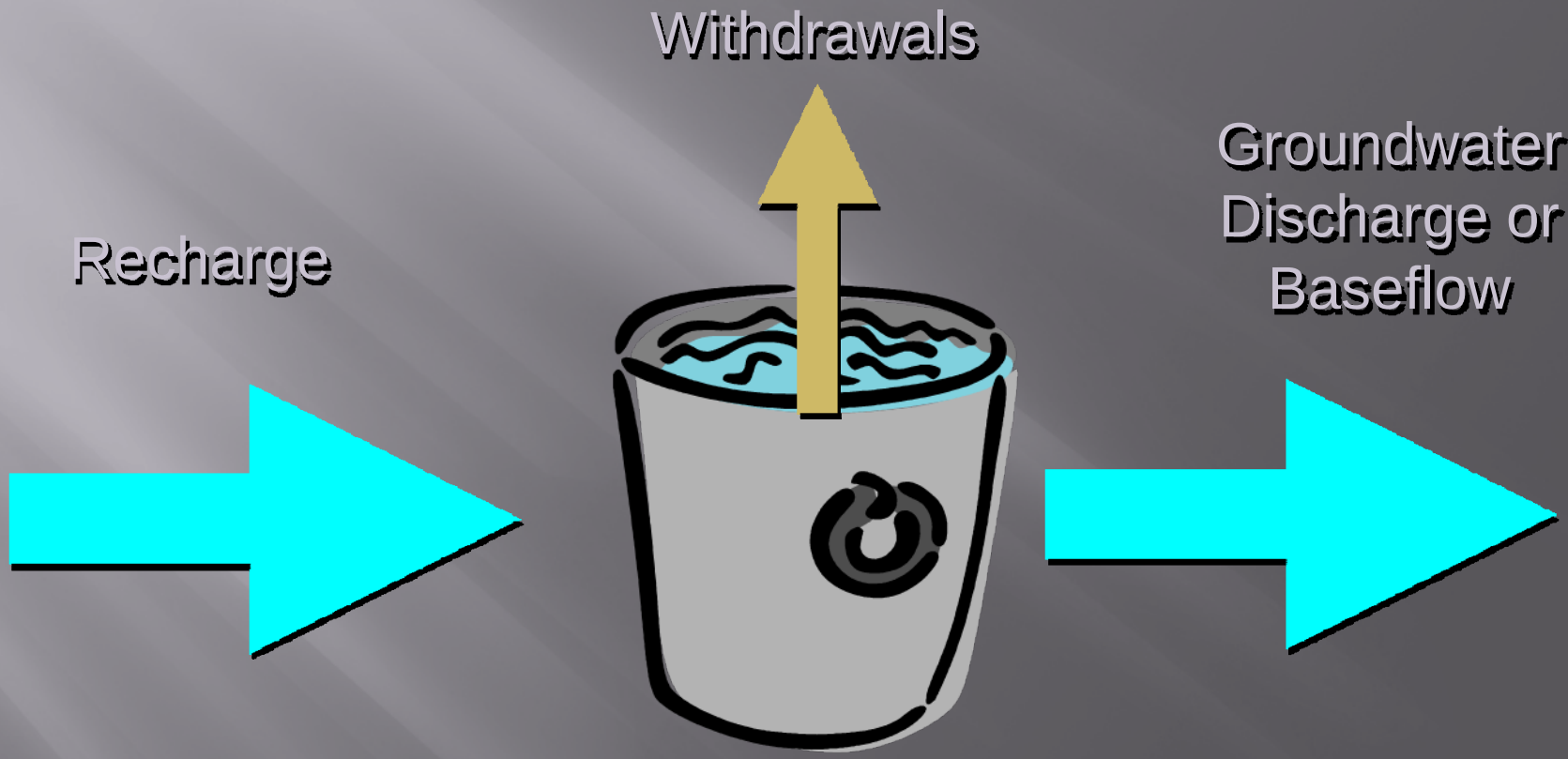
Aquifer Hydraulic Properties: Storage Coefficient



Arbuckle-Simpson Aquifer

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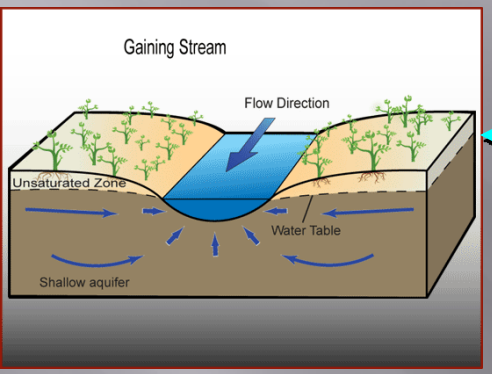
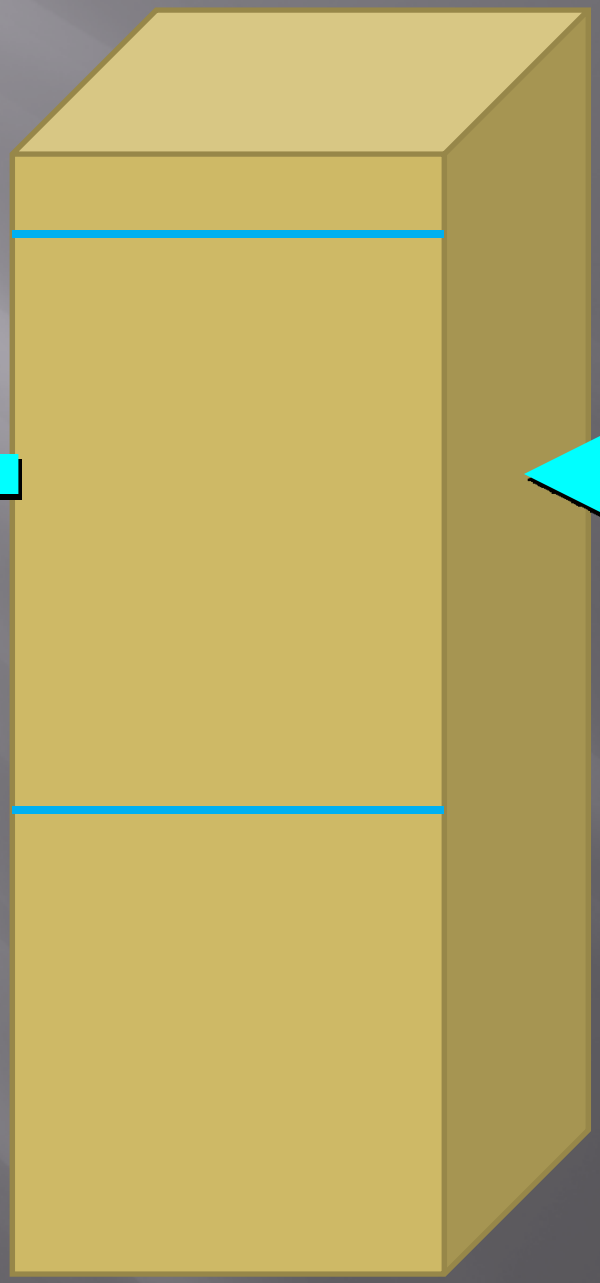
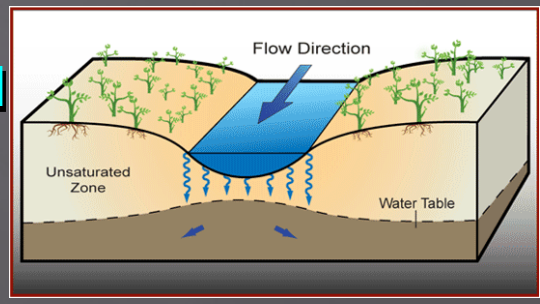
Alluvial aquifer
Storage coefficient 0.2
Withdraw 1.0 foot

5 feet of drawdown





Arbuckle-Simpson aquifer
Storage coefficient 0.008
Withdraw 1.0 foot



125 feet of drawdown

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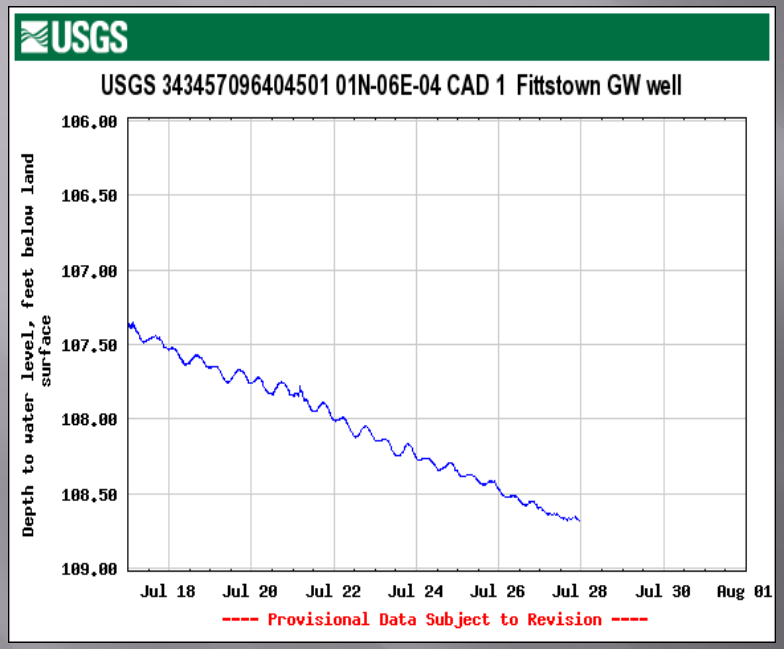
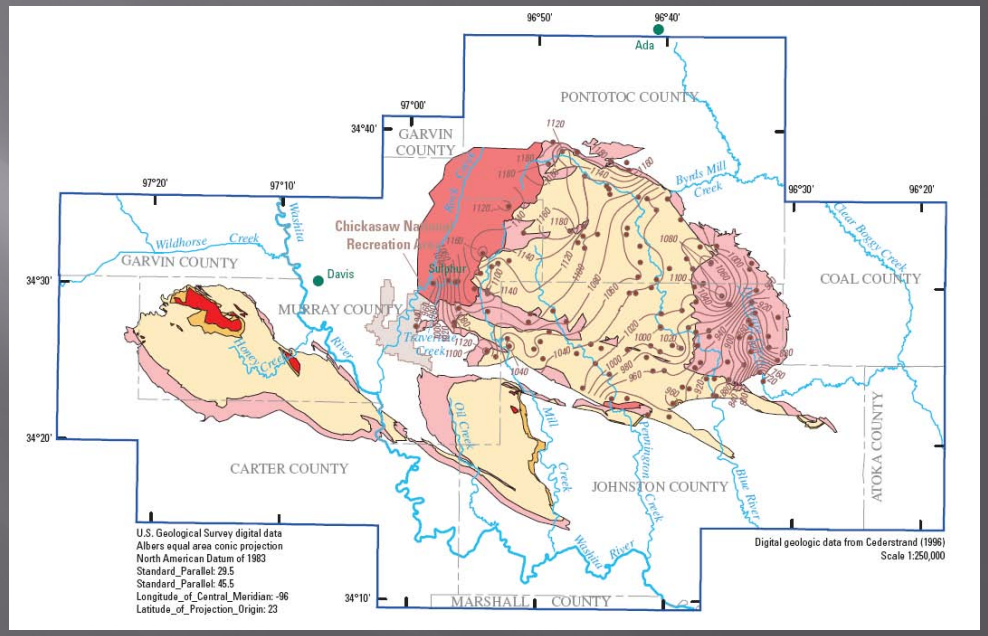
Aquifer Hydraulic Properties: Methods to Determine Storage Coefficient



Earth Tides



Decline in Water Table

Preliminary results, subject to revision

Recharge

Withdrawals

Recharge

Groundwater Discharge or Baseflow

Arbuckle-Simpson Aquifer

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Recharge

- Circular 91 reported an average recharge rate of 4.7 inches/year
- Stop thinking of recharge as a constant!
- Recharge varies in time and space

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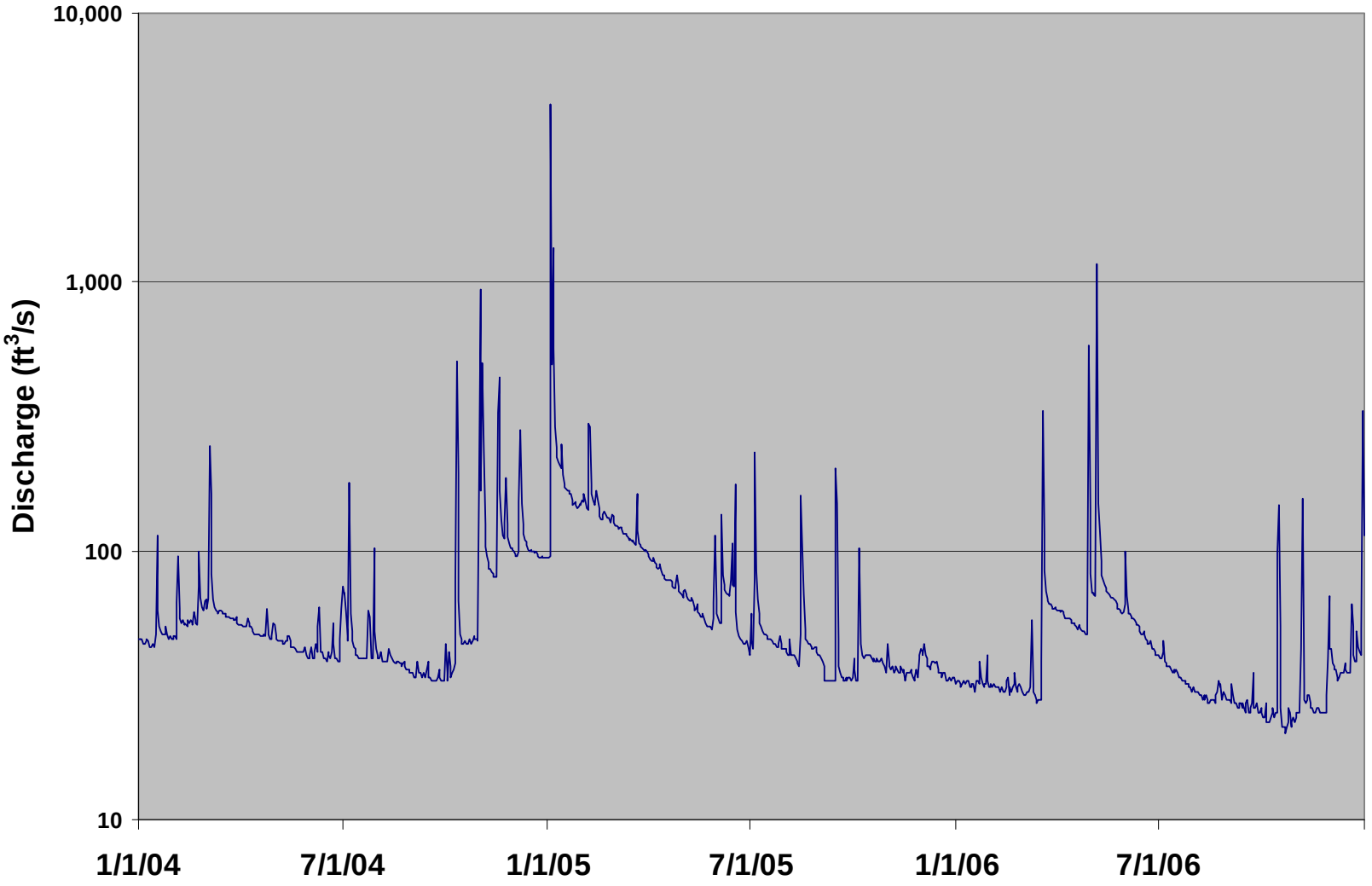
Blue River at Connerville



Preliminary results, subject to revision

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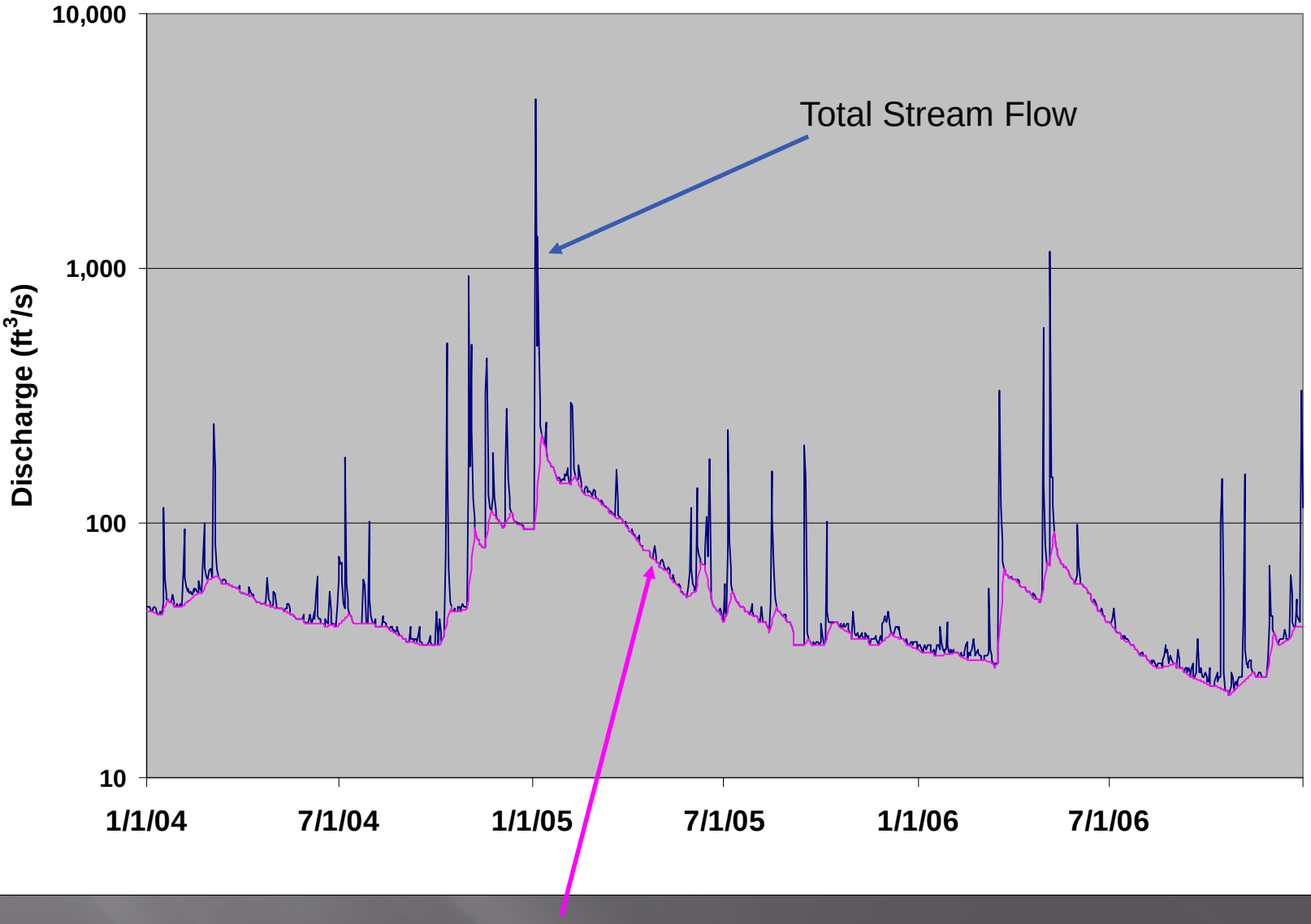
Blue River at Connerville



Groundwater Component of Stream Flow: Baseflow

Preliminary results, subject to revision

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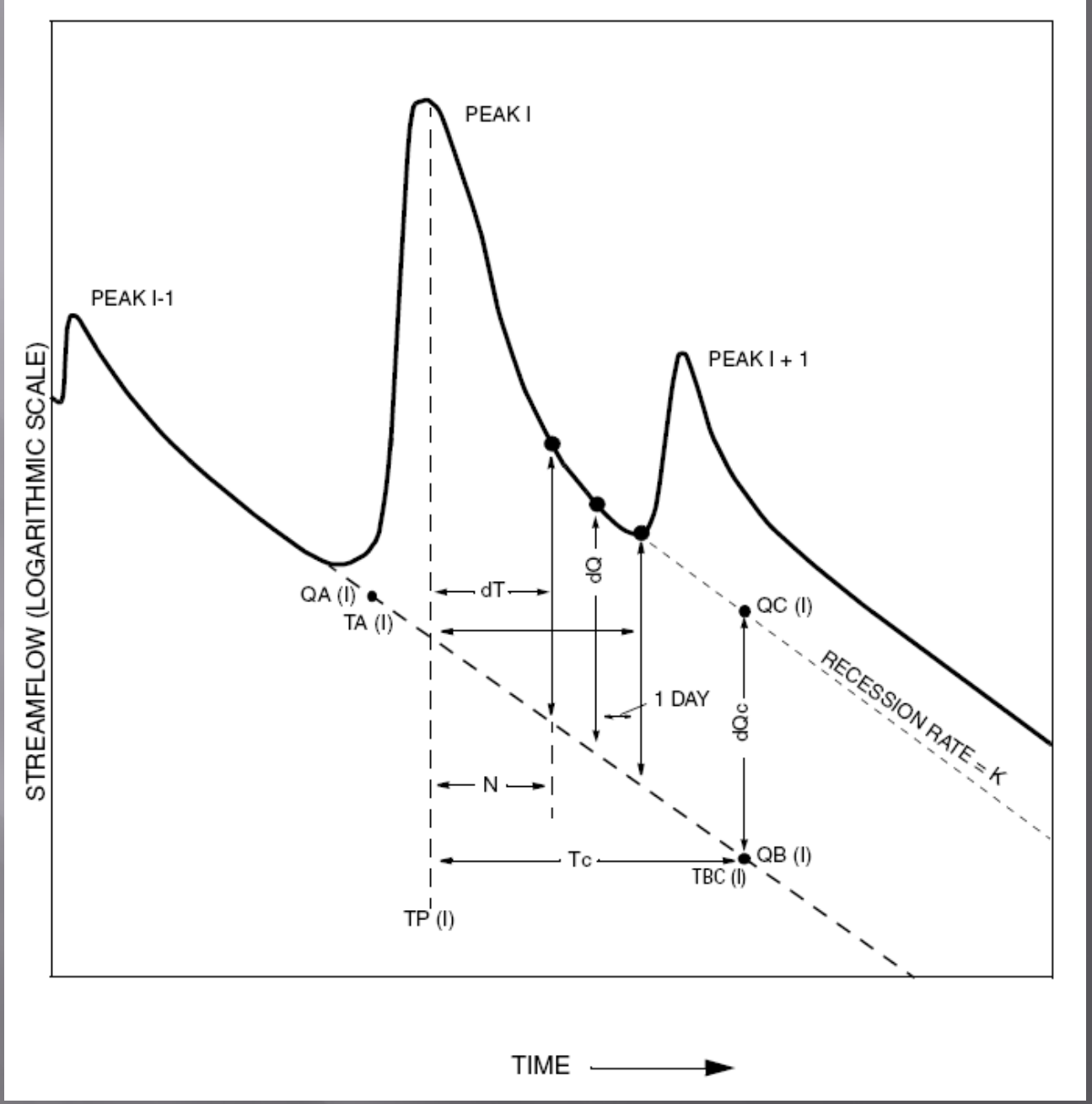

Hydrograph Displacement Method

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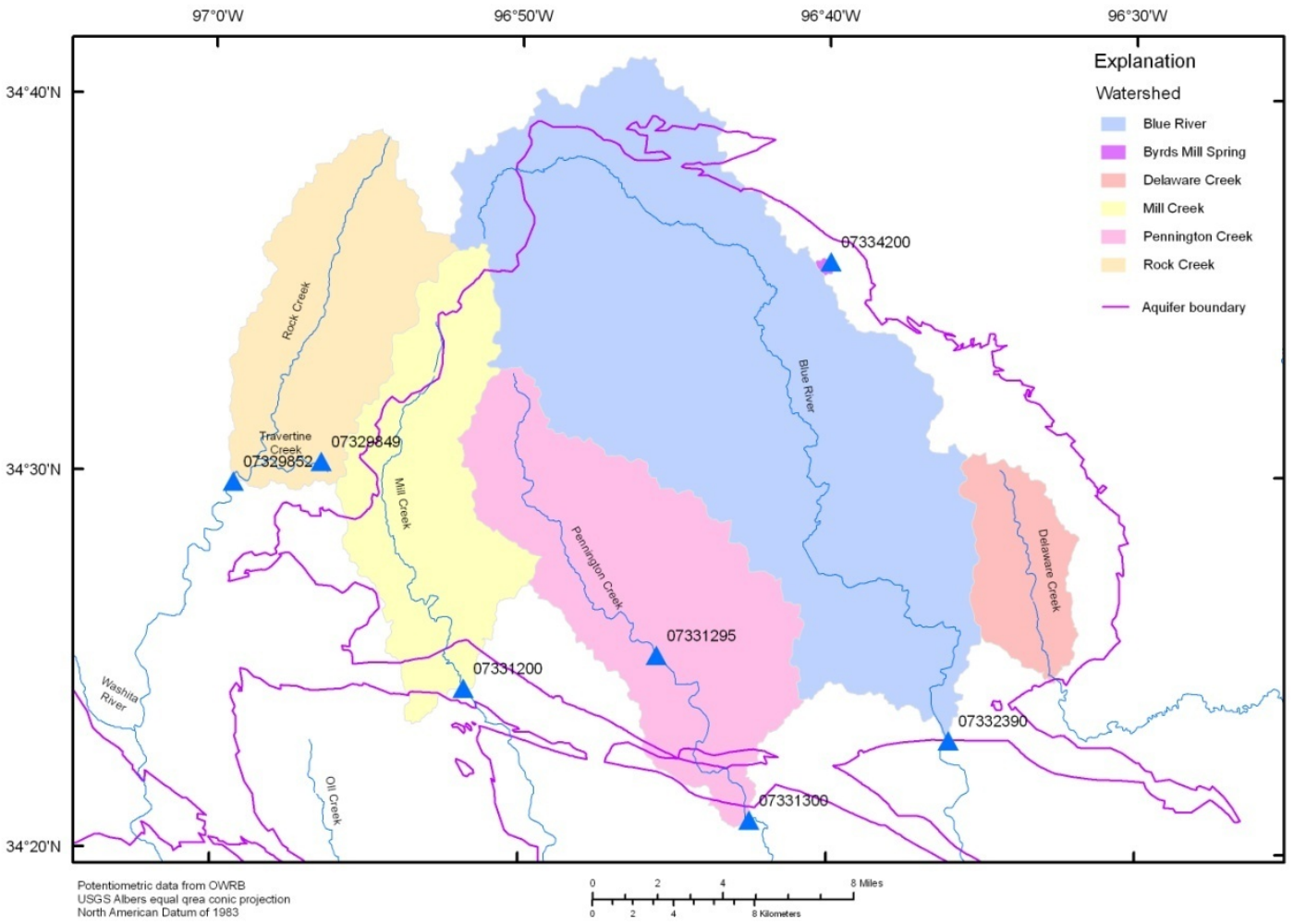

Surface Watersheds

Preliminary results, subject to revision

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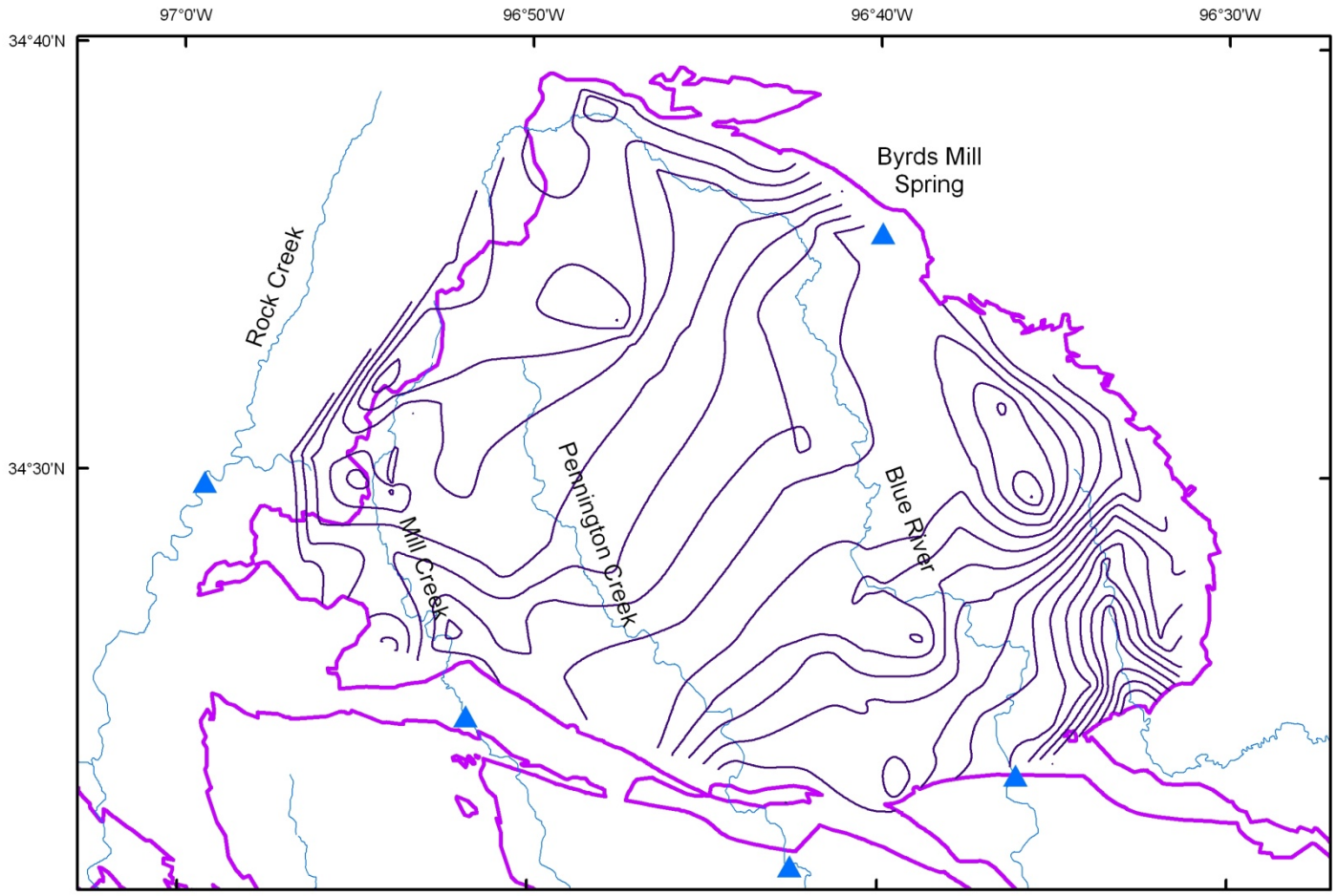
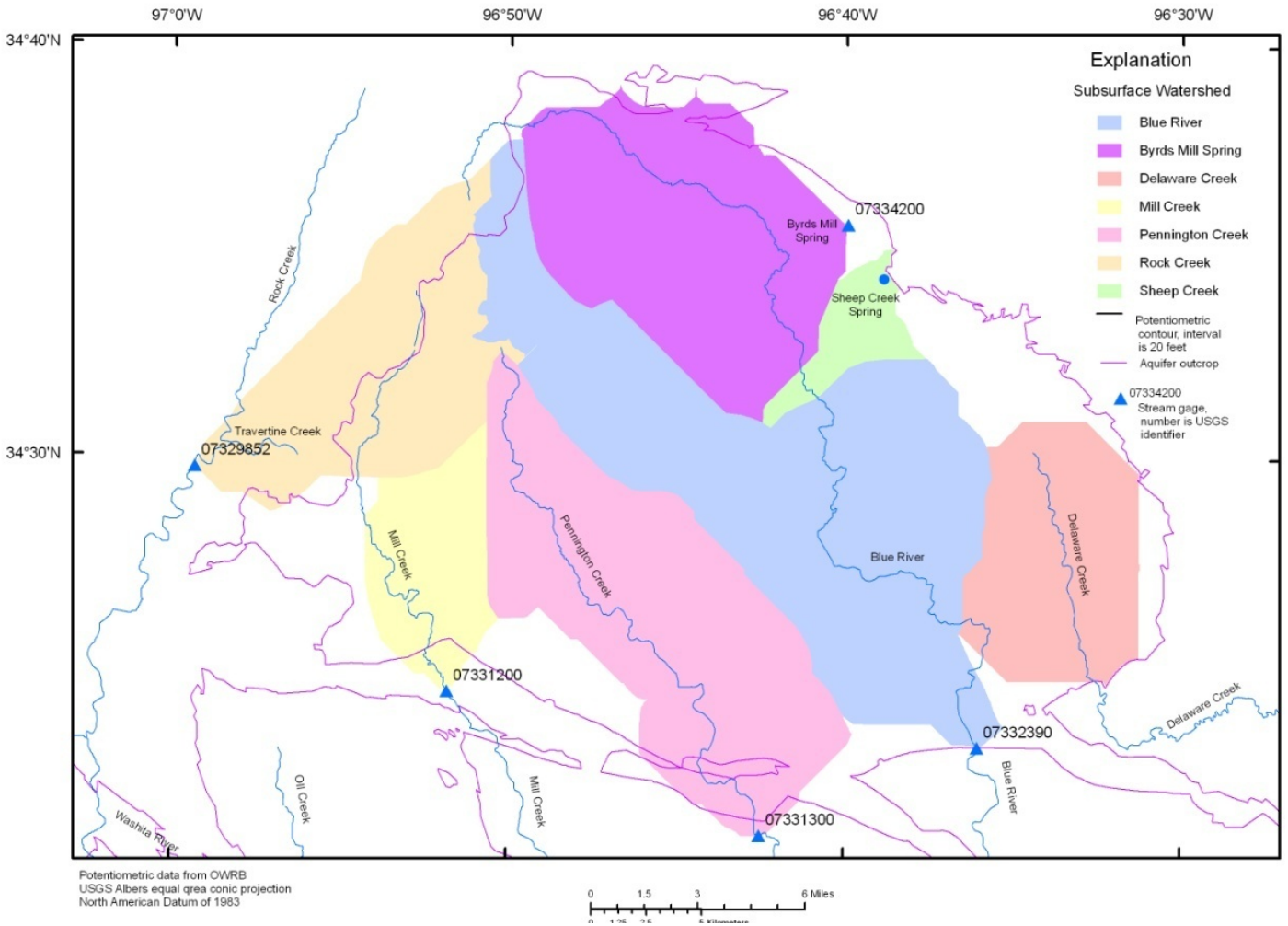
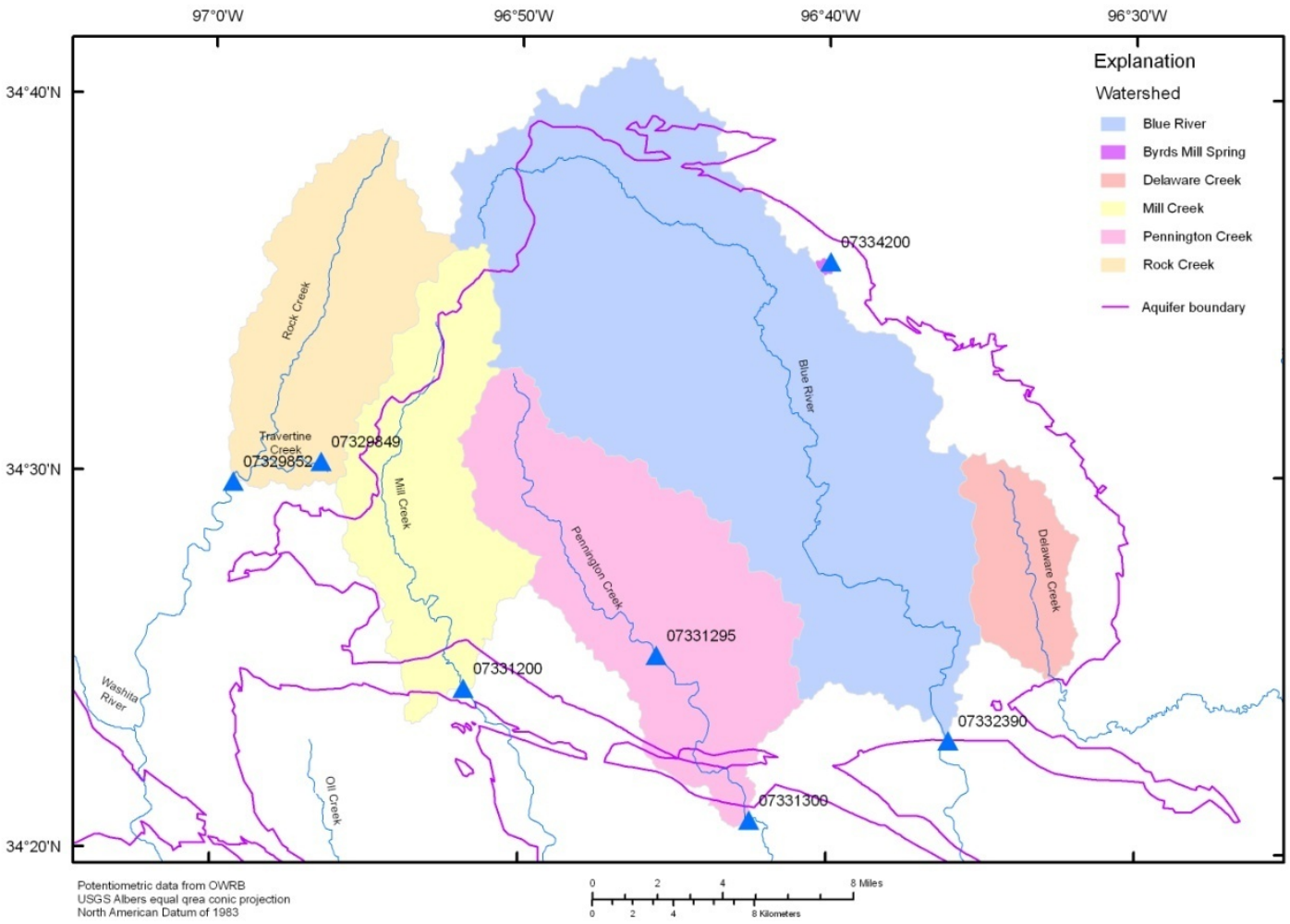


Water Table September 2006



Subsurface Watersheds



Surface Watersheds

Preliminary results, subject to revision

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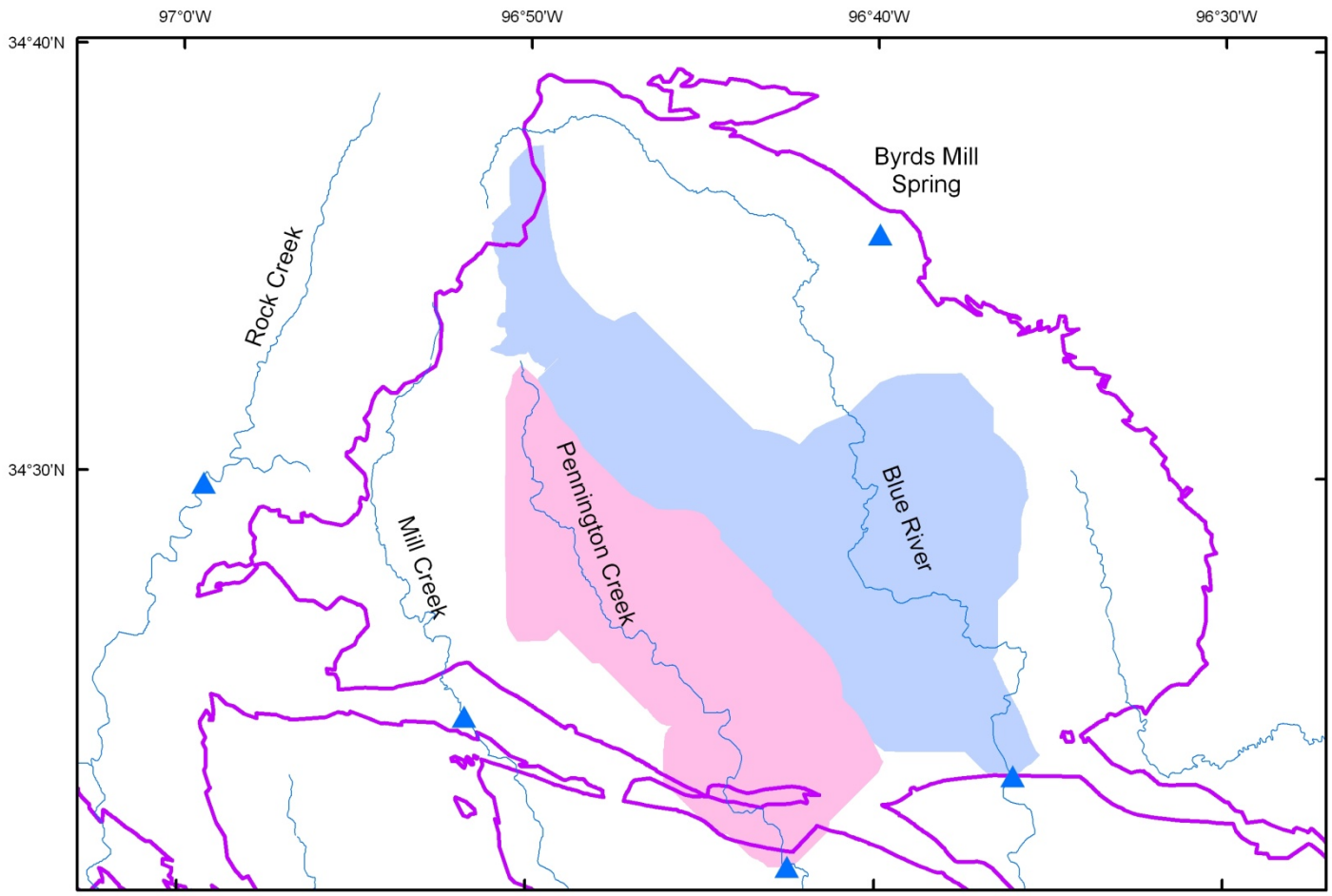
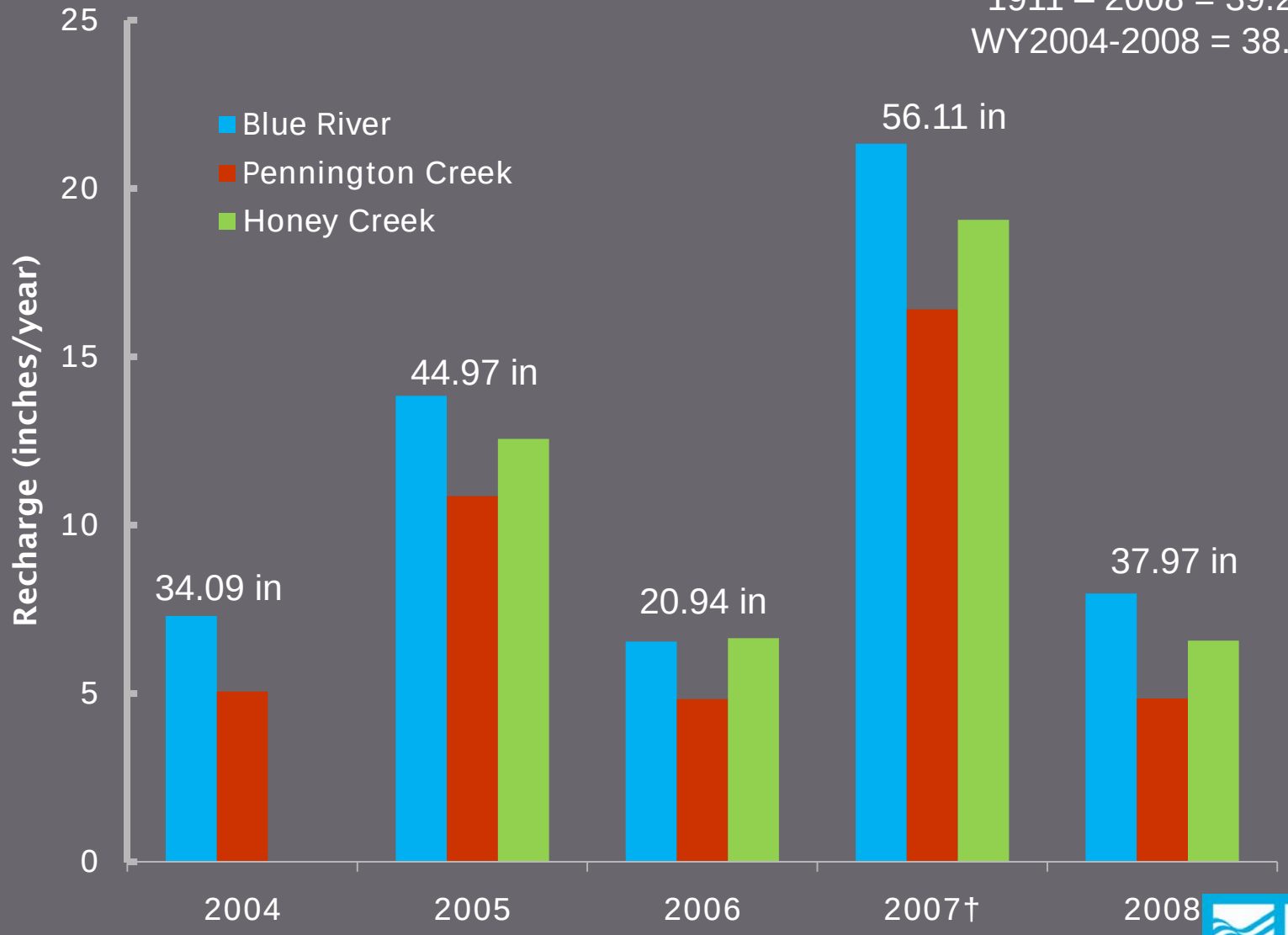


Subsurface Watersheds

Annual Recharge at Stream Gages Based on Subsurface Watershed Areas

Average Precipitation at Ada
1911 – 2008 = 39.29 inches
WY2004-2008 = 38.82 inches



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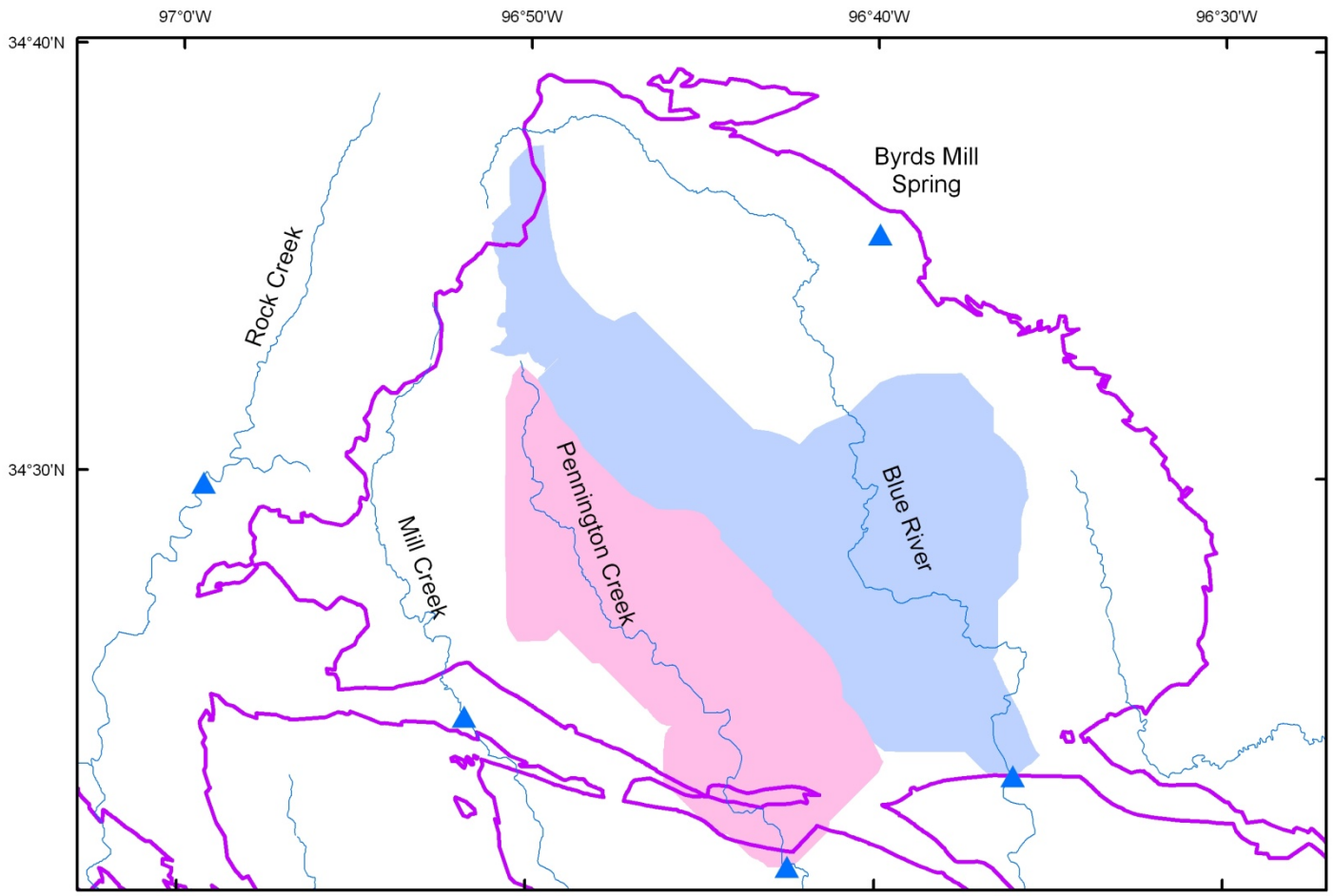
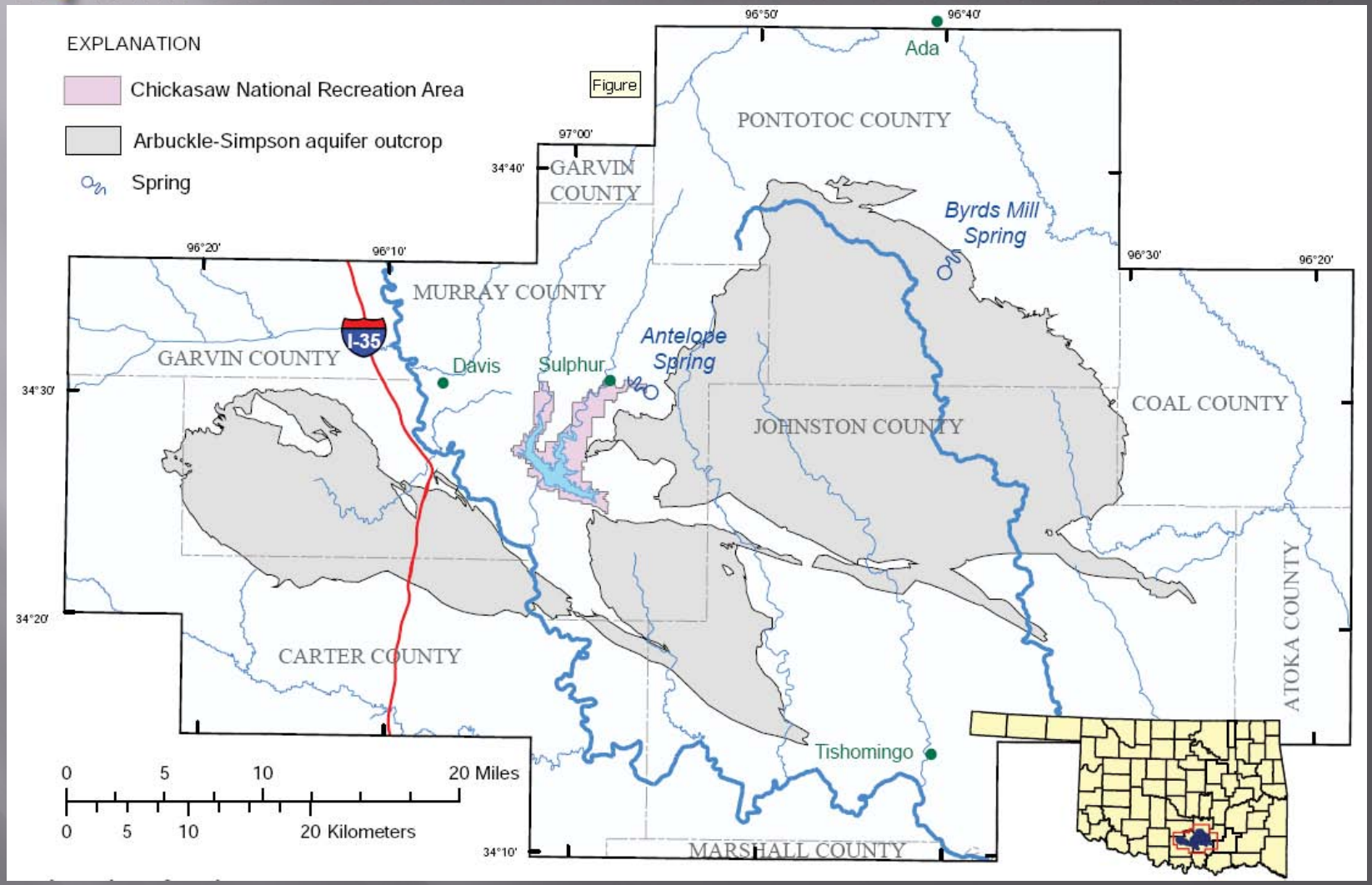


Subsurface Watersheds

Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model



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Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model Why only the eastern part?

- The eastern Arbuckle-Simpson aquifer is the largest part of the Arbuckle-Simpson aquifer, most of the current water use from the Arbuckle-Simpson aquifer is from the eastern Arbuckle-Simpson aquifer
- Hydrogeologic data needed to build a model are very sparse in the western and central Arbuckle-Simpson aquifer
- Constraints imposed by time and budget

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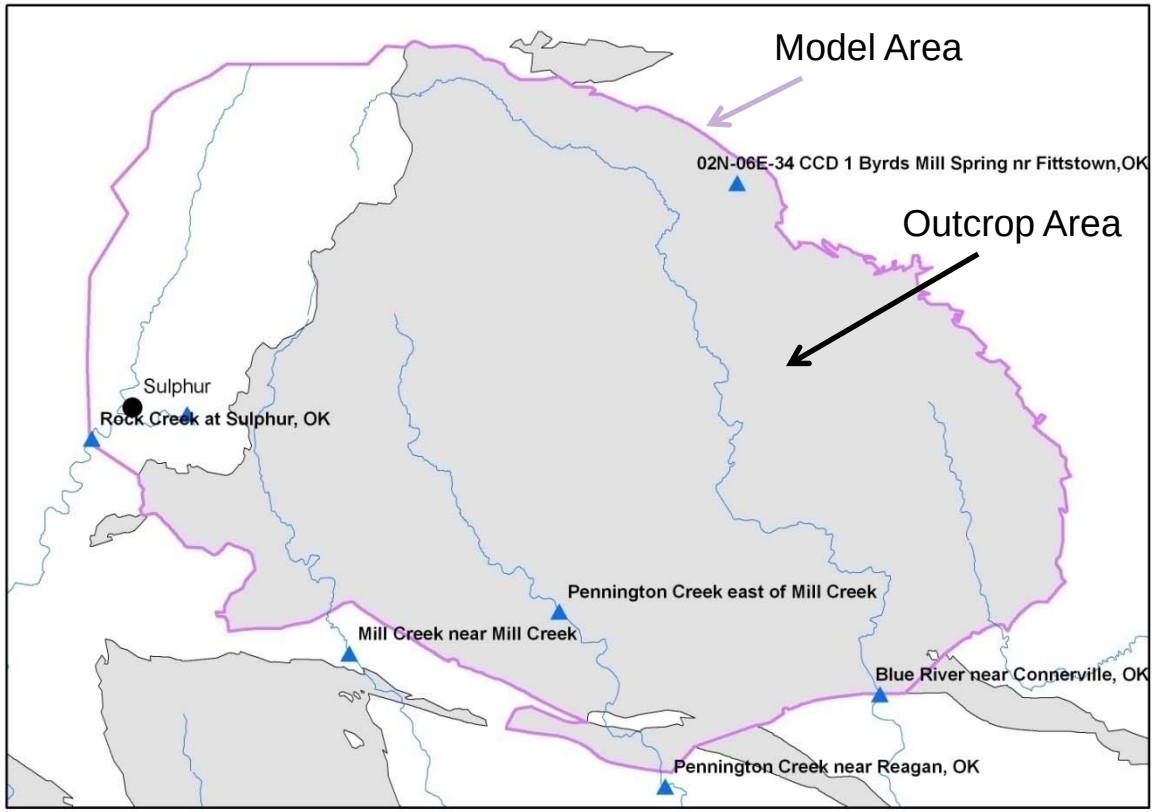
Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model



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Why do we use groundwater flow models?

- Many reasons
- A calibrated groundwater-flow model enables users to test the effects of different management options on a hydrologic system
- For the Arbuckle-Simpson aquifer, we can test the effects of groundwater withdrawals on stream discharge

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Eastern Arbuckle-Simpson Groundwater Flow Model

- MODFLOW
- Written and maintained by USGS
- Public domain
- Program is available to everyone at no cost
- Source code is available
- MODFLOW has been accepted in many court cases as a legitimate approach to analysis of groundwater systems

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Eastern Arbuckle-Simpson Groundwater Flow Model

- Equivalent porous media approach
- Finite-difference method

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Data Used in the Arbuckle-Simpson Groundwater Flow Model

- Geology and hydrogeologic model
- Hydraulic properties (hydraulic conductivity and storage coefficient)
- Fluxes (Stream flow, recharge, and water use)
- Head observations

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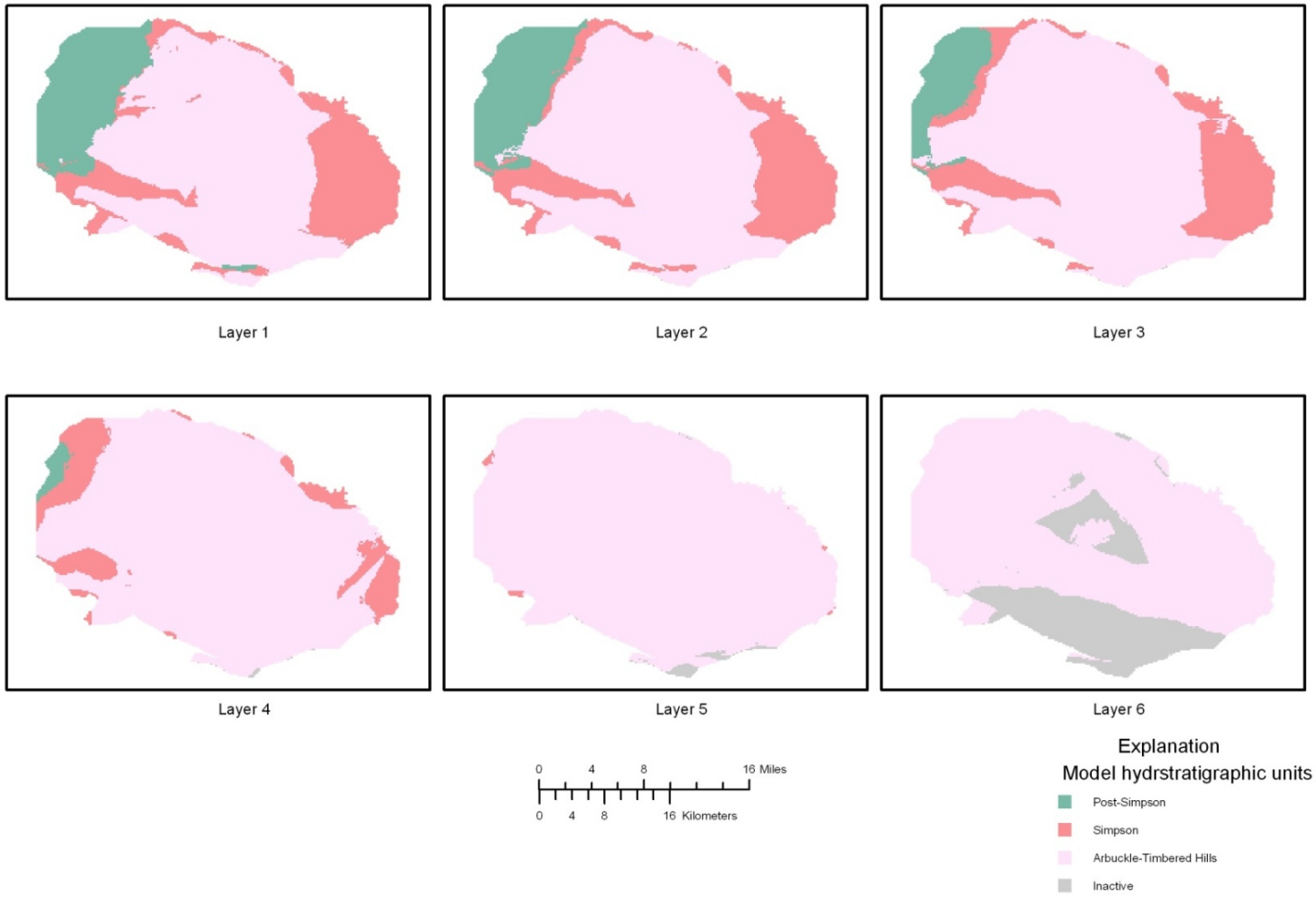

Model Layers

Model Calibration

- Consists of adjusting model parameters to match observations (head and stream flow)
- Used non-linear regression (parameter estimation)

Model Results

- Observed water table compared to the computer water table

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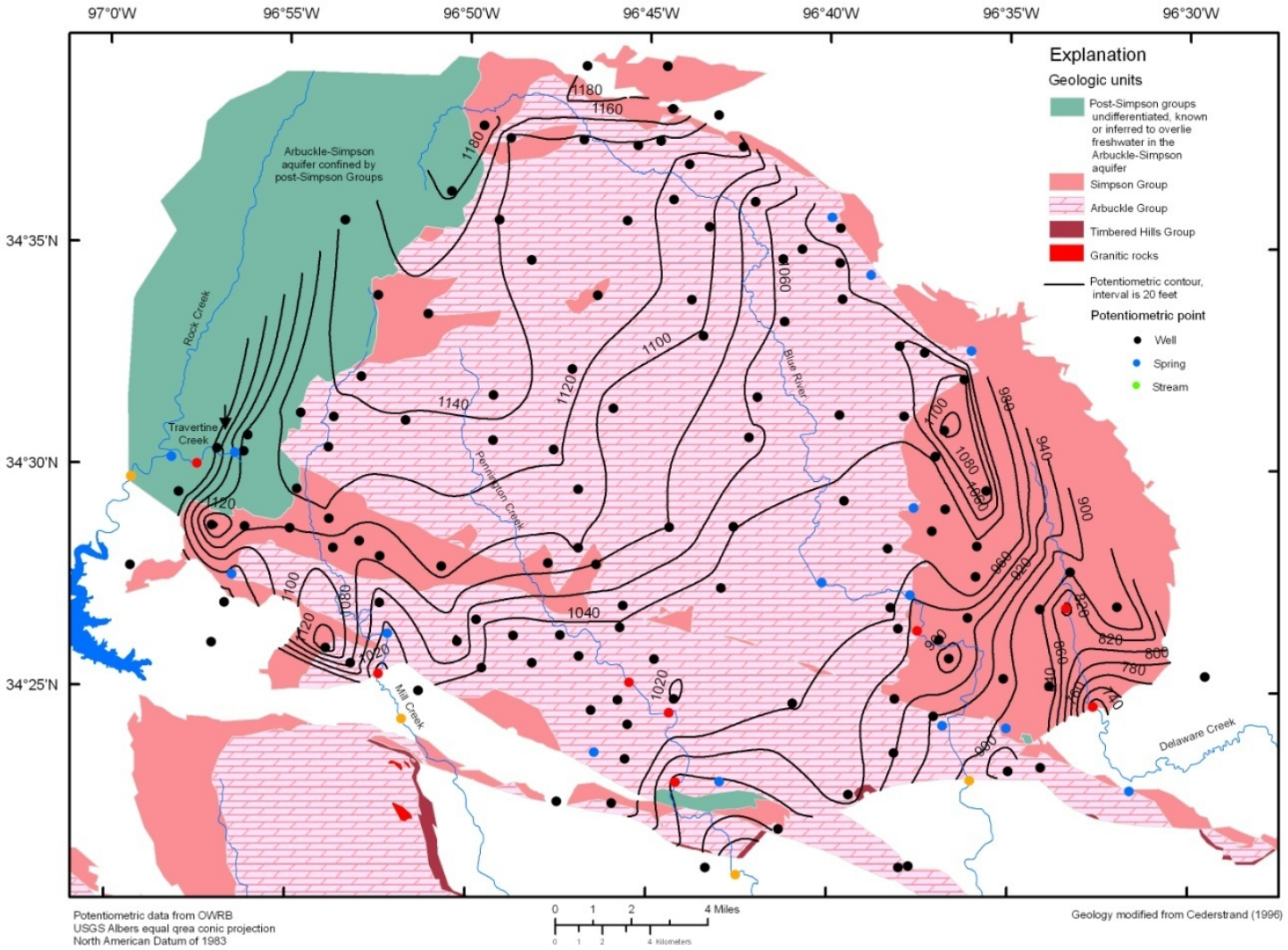

Potentiometric Surface, August 1995

Preliminary results, subject to revision

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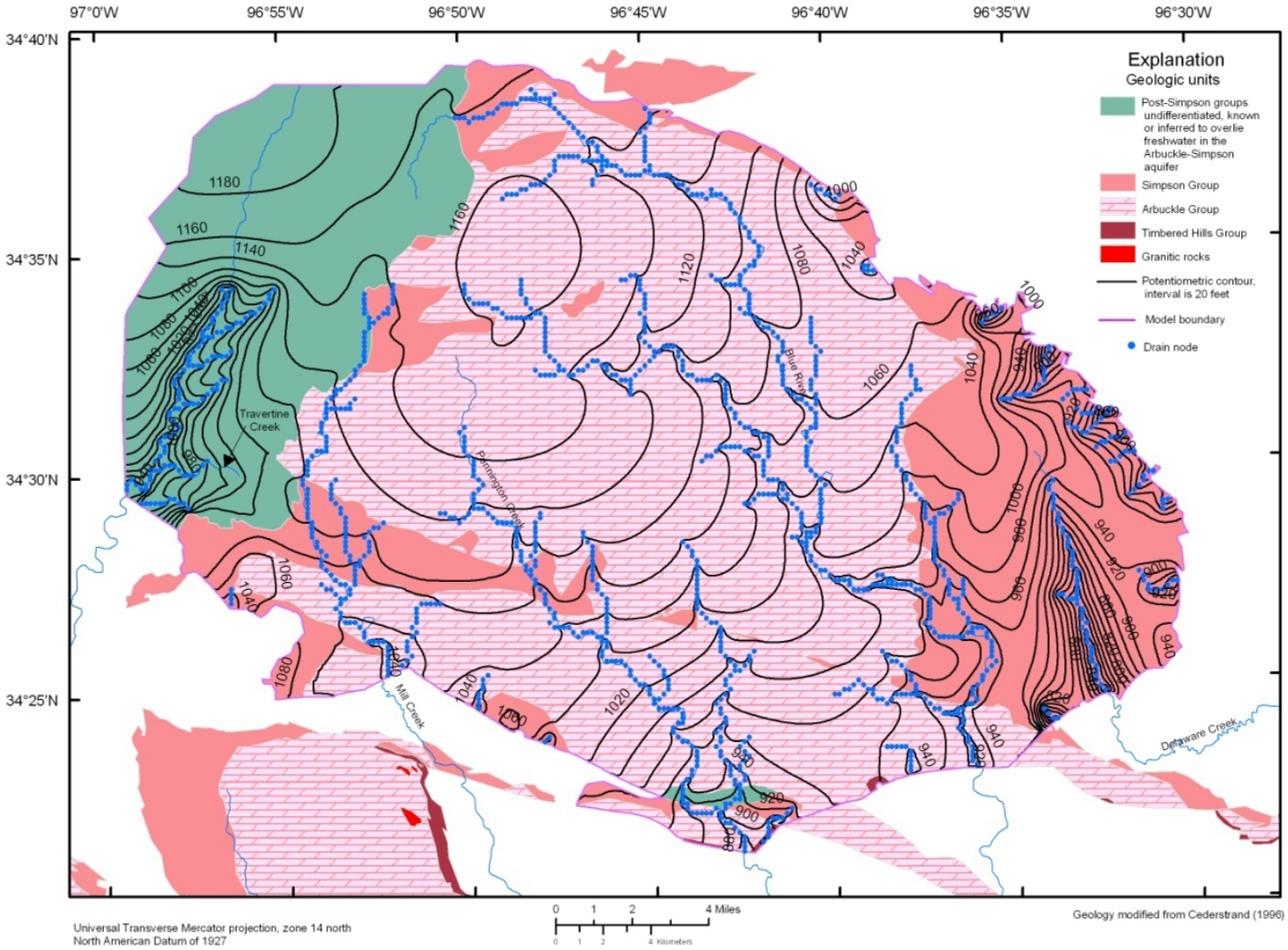

Potentiometric Surface, August 1995

Preliminary results, subject to revision

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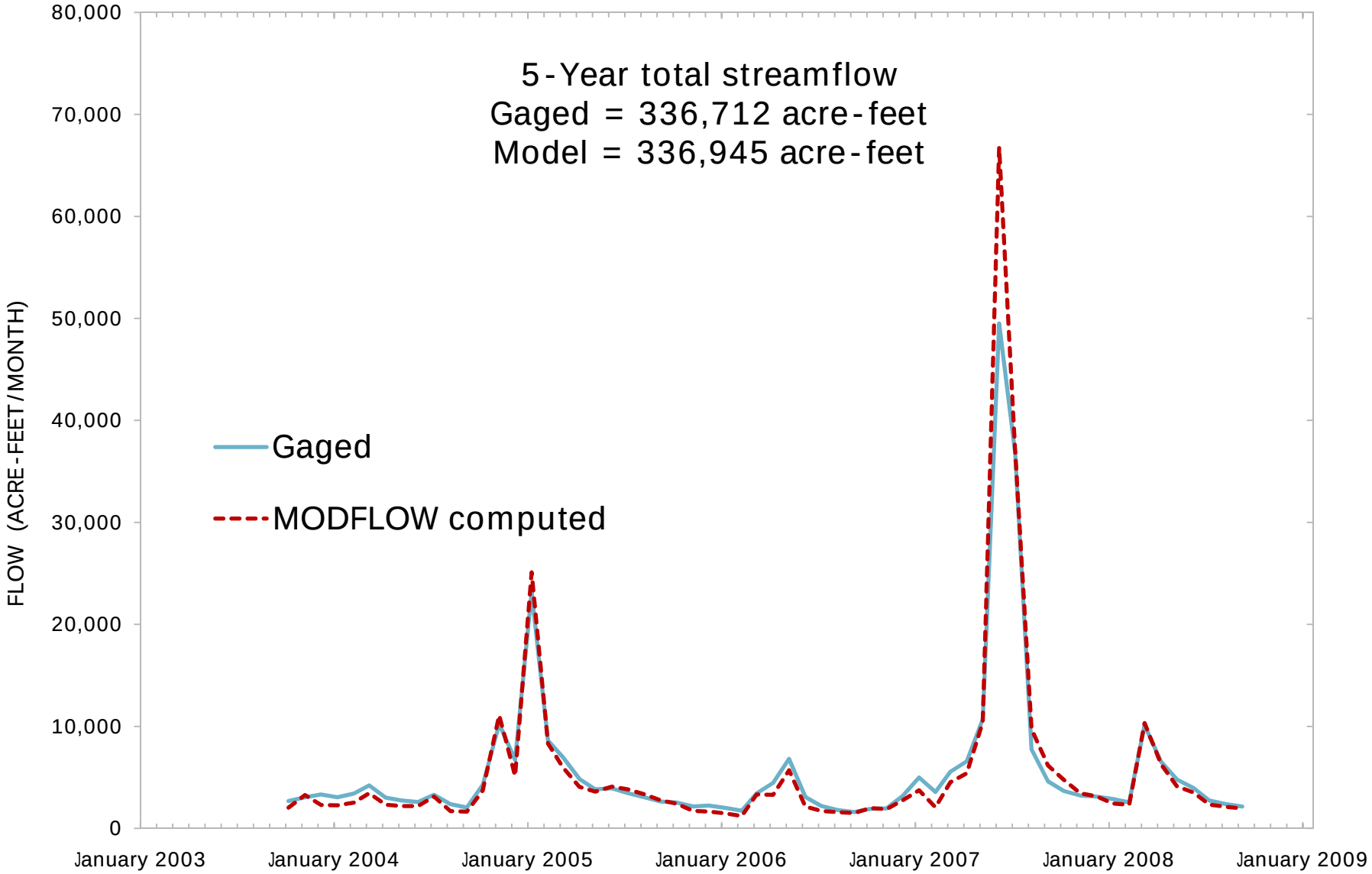
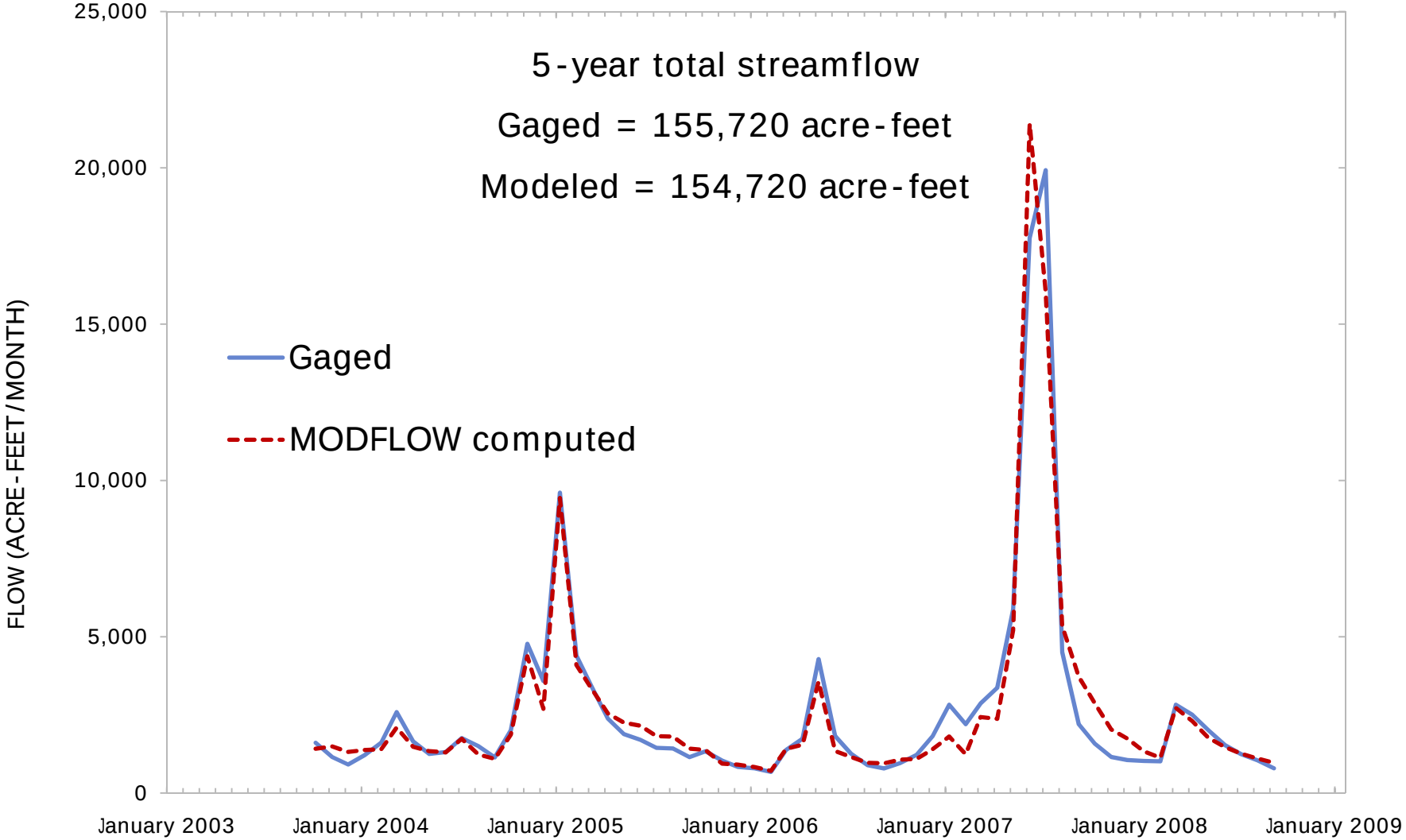
Model Results

- Monthly observed streamflow on Blue River near Connerville and Pennington Creek near Reagan compared to monthly computed streamflow on Blue River near Connerville and Pennington Creek near Reagan



Blue River near Connerville

Monthly gaged flow compared to modeled flow



Pennington Creek near Reagan

Monthly gaged streamflow compared to modeled flow

Model Results

- Flowpaths

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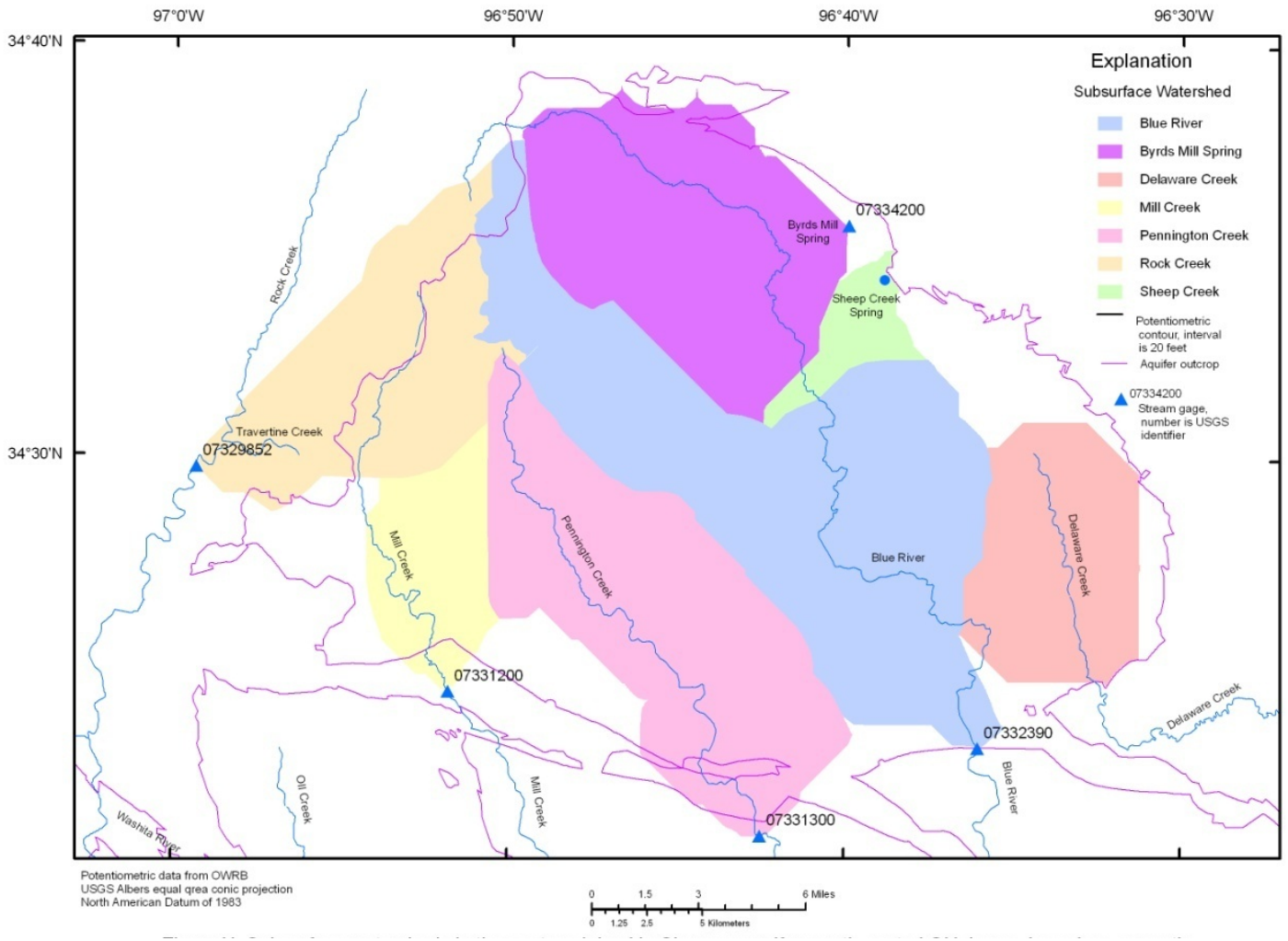

Subsurface Watersheds

Preliminary results, subject to revision

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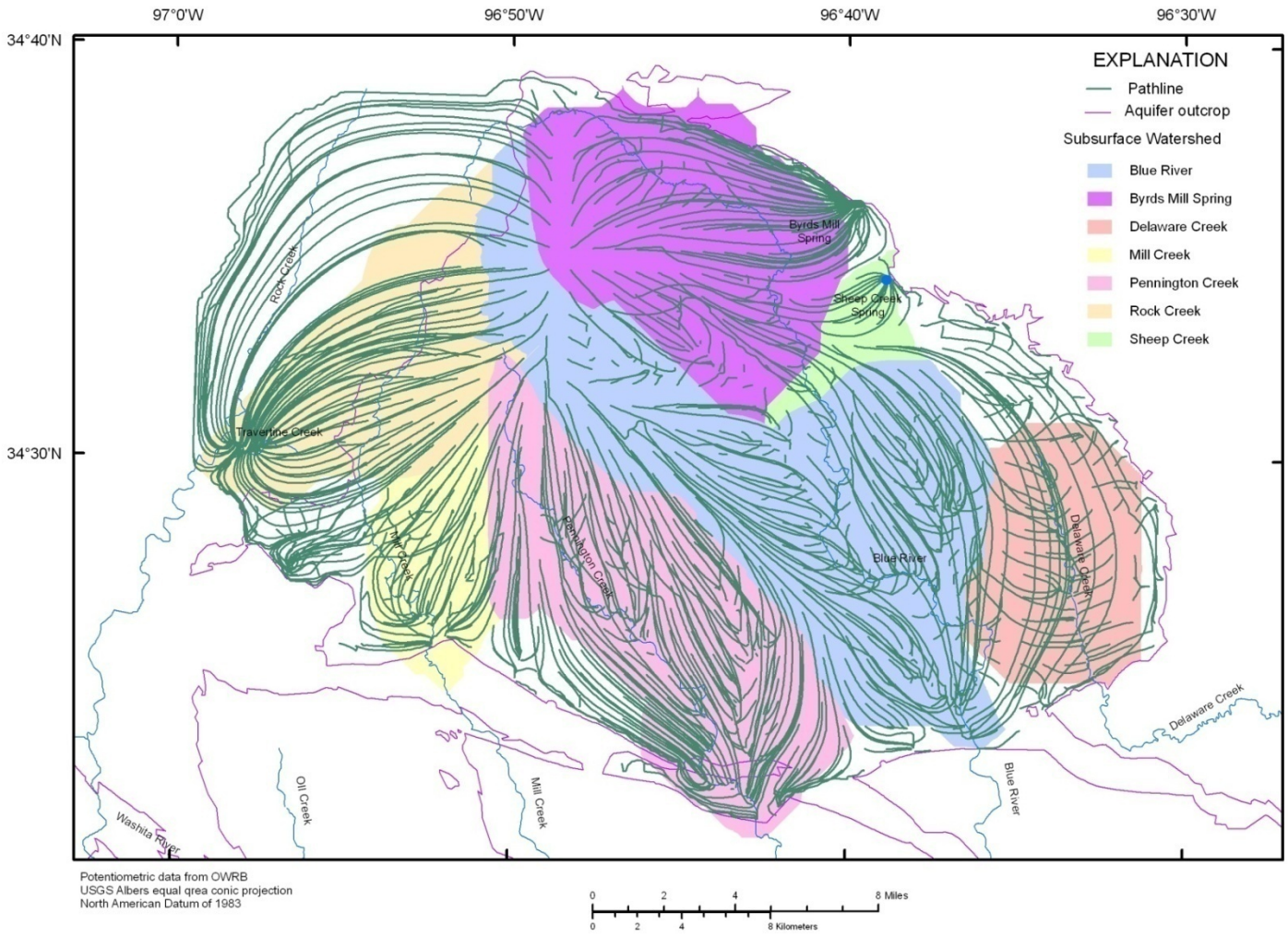

MODPATH flowpath simulation

Preliminary results, subject to revision

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Model Results

- Groundwater ages

Geochemistry of Vendome Well

- Major ion and trace element chemistry of Vendome Well was modeled as a mixture of 99 percent freshwater and 1 percent brine from an oil well completed in the Simpson Group 4 miles west of CNRA
- Age of water sample from Vendome Well was 10,500 years before present based on carbon-14 dating

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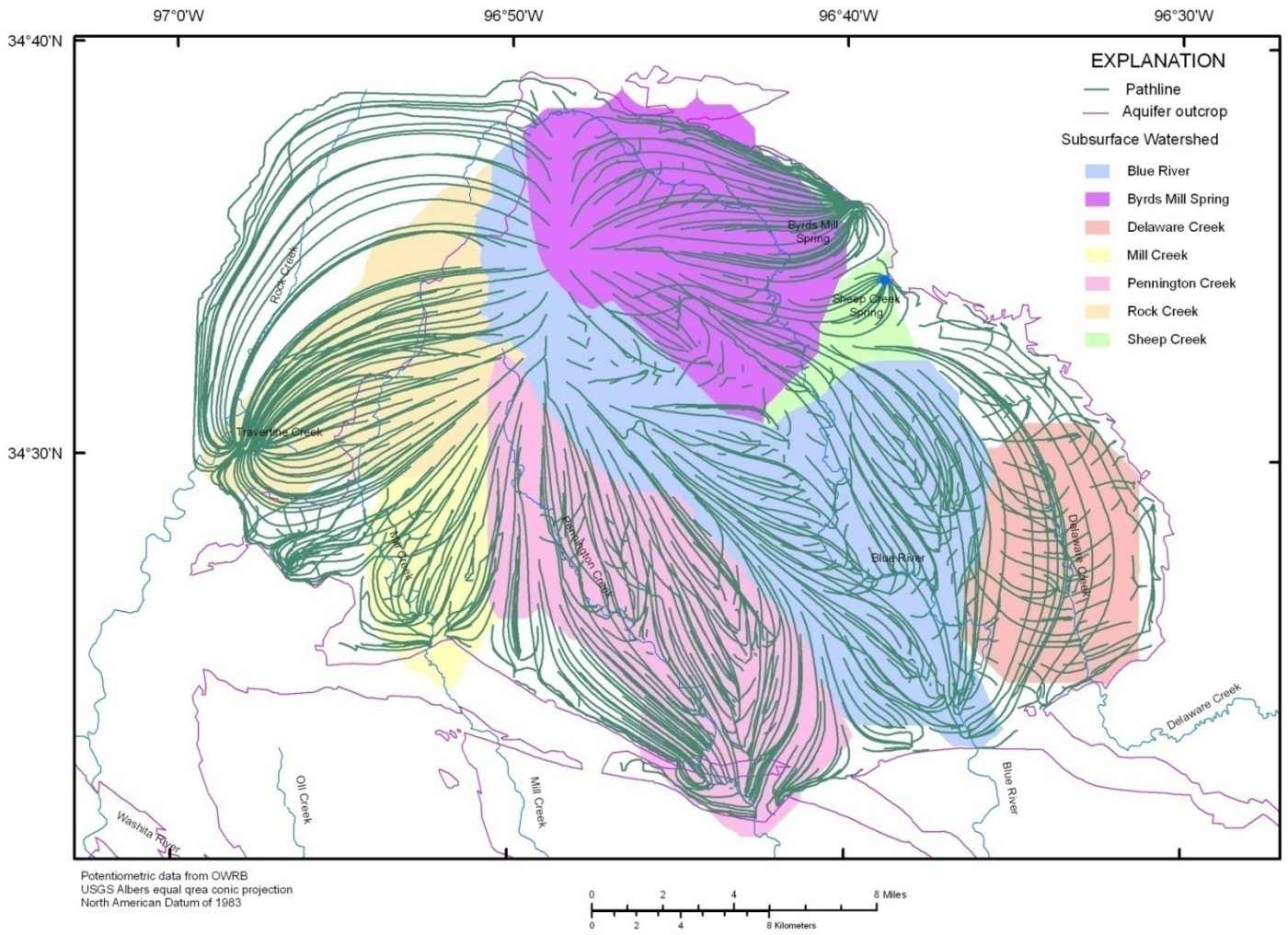

MODPATH flowpath simulation

Average particle age for particles discharge near Vendome Well

is 9,400 years

Preliminary results, subject to revision

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Model Results

- Recharge calculation for the entire eastern Arbuckle-Simpson aquifer

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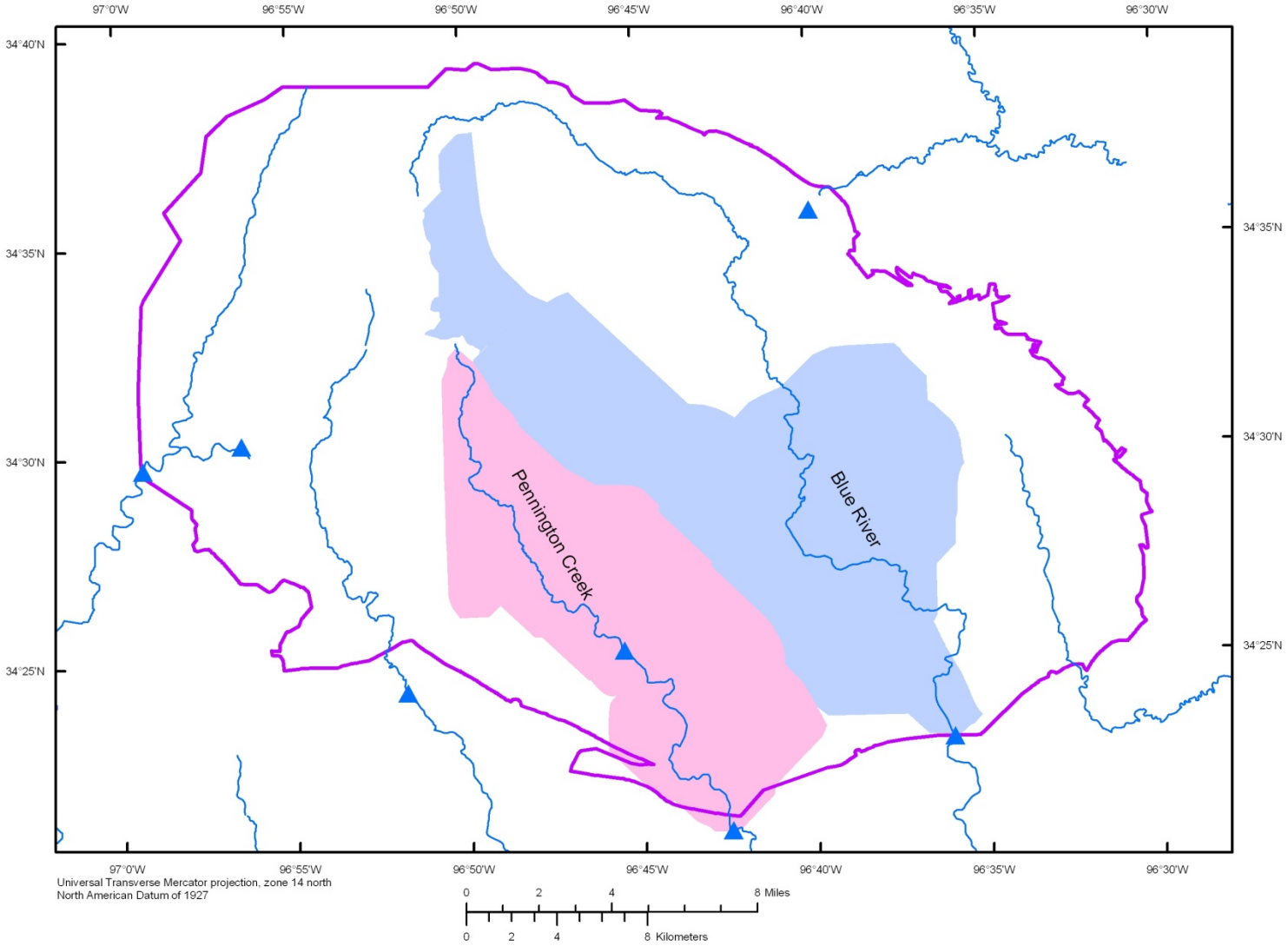
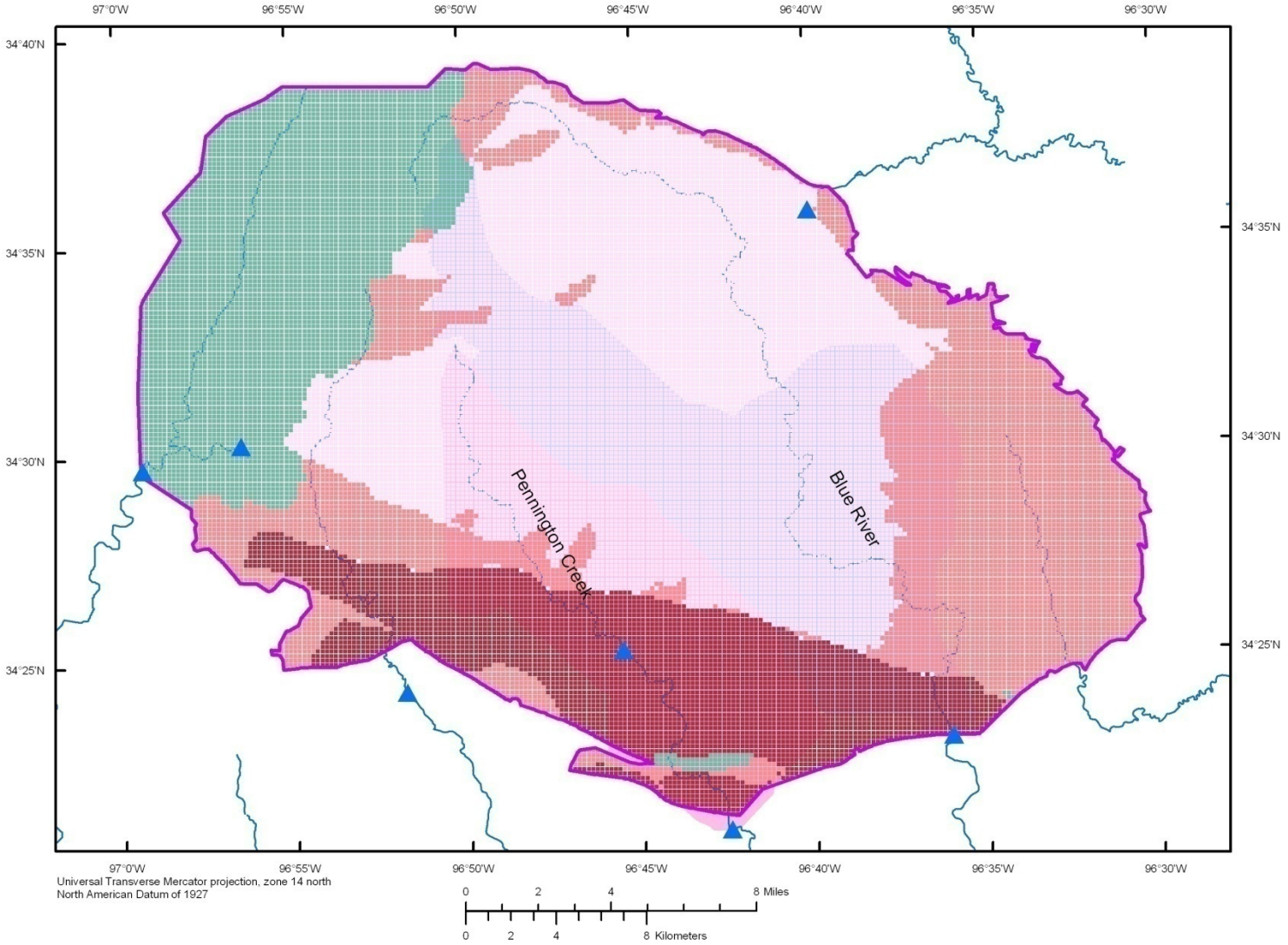
Recharge Calculations



Subsurface Watersheds

Preliminary results, subject to revision

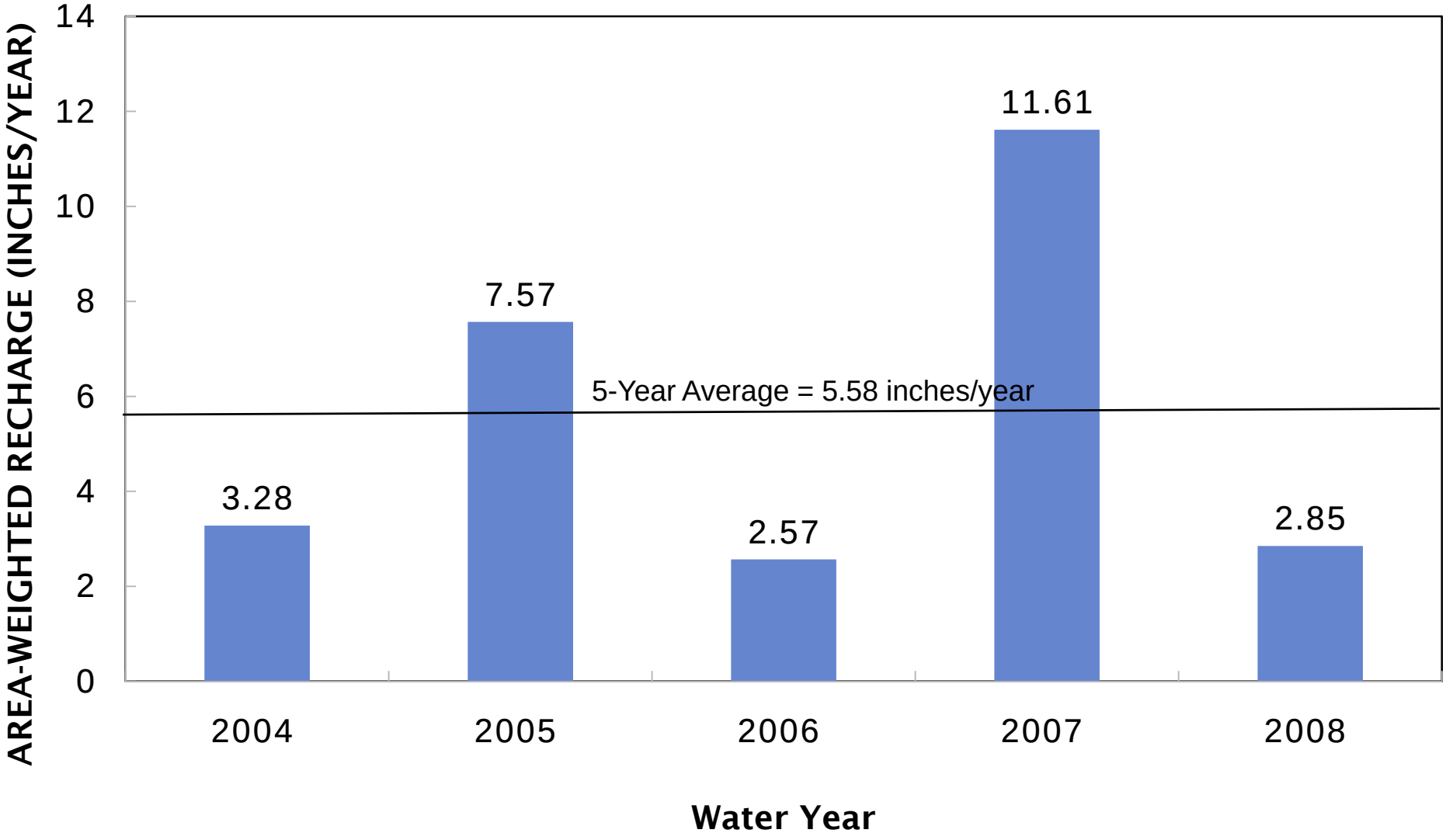
Recharge Calculations



Modeled Recharge

Preliminary results, subject to revision

Area-Weighted Recharge for the Eastern Arbuckle-Simpson Aquifer



Preliminary results, subject to revision

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Eastern Arbuckle-Simpson Aquifer MODFLOW Model

- Calibrated model is able to reproduce hydrologic observations
- Optimized to reproduce streamflow for Blue River and Pennington Creek
- What are the hydrologic effects of hypothetical distributed withdrawals?

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Eastern Arbuckle-Simpson Aquifer MODFLOW Model

- Senate Bill 288 is interpreted to limit groundwater withdrawal to protect surface-water flow
- Simulations tested by the model keep withdrawals less than recharge

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Groundwater Withdrawal Greater than Recharge

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Groundwater Withdrawal Less than Recharge

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Eastern Arbuckle-Simpson Aquifer MODFLOW Model

- Tested simulations do not exceed the Circular 91 recharge (4.7 inches/year or 0.392 (acre-feet/acre)/year)
- Tested simulations use recharge distribution *(not rate!)* for water years 2004 through 2008
- Simulations are repeated until a new equilibrium is achieved
- Withdrawals are simulated as an equal proportionate share

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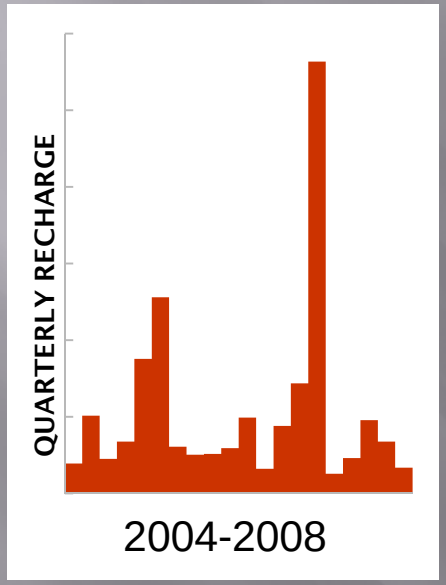
Quarterly Recharge

Pennington Creek near Reagan



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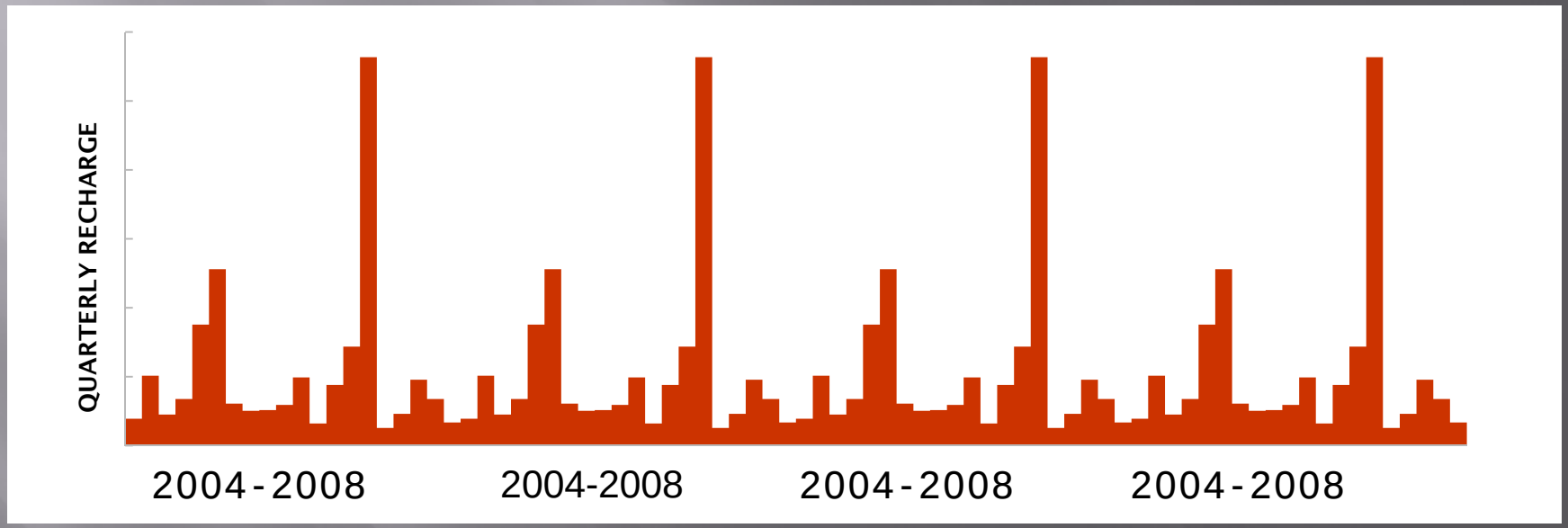
Quarterly Recharge

Pennington Creek near Reagan



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Model Results

- Assumes the aquifer is completely developed at some future time
- Distributed withdrawals
- Based on the equal proportionate share concept

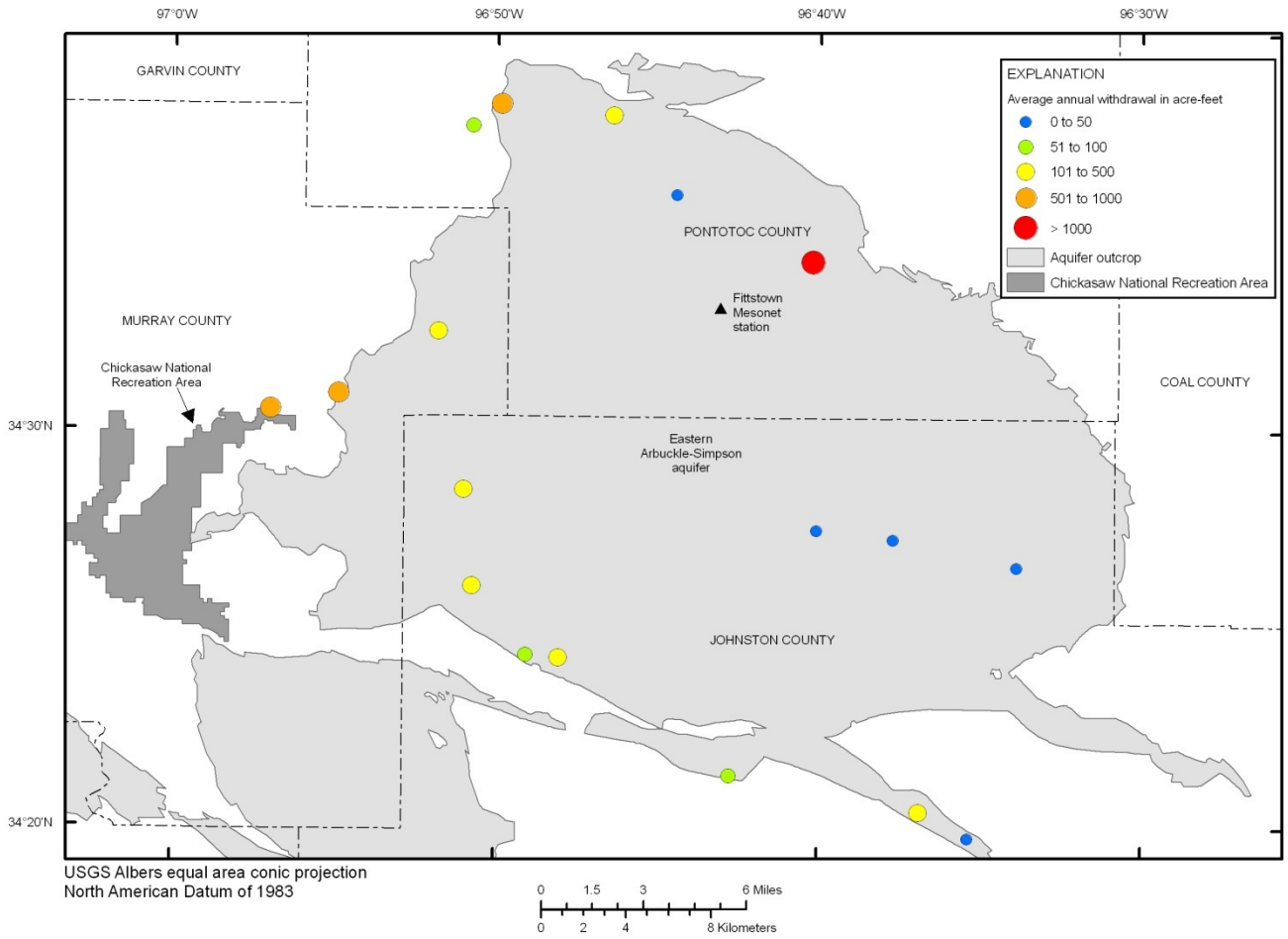

Figure X. Average annual groundwater use from the eastern Arbuckle-Simpson auifer from 2003-2008

Average Annual Reported Groundwater Use

Eastern Arbuckle-Simpson Aquifer

Preliminary results, subject to revision

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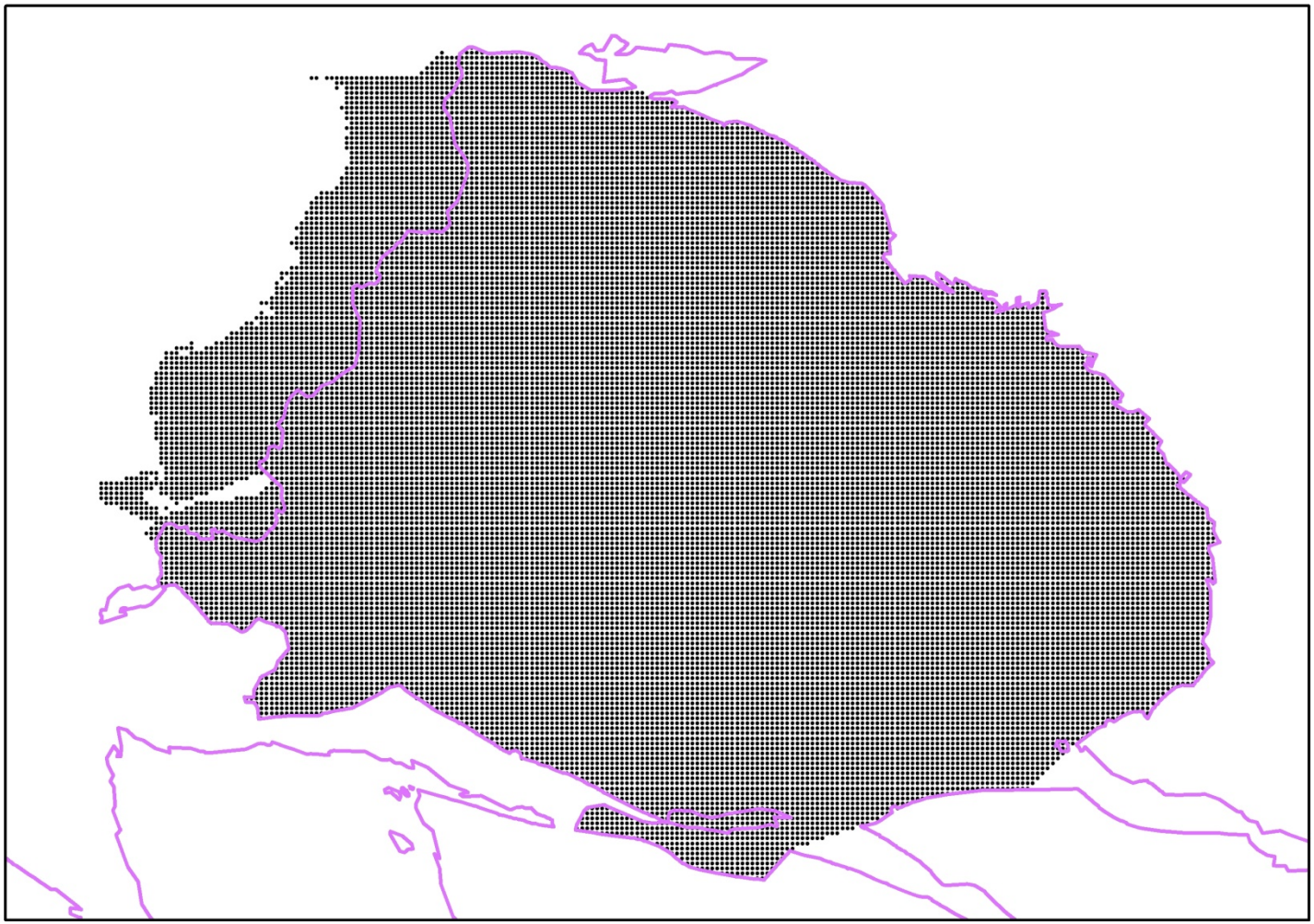

Locations of Wells Simulating Distributed Withdrawals

Preliminary results, subject to revision

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Model Results

- Distributed withdrawals
- Effects on daily hydrograph

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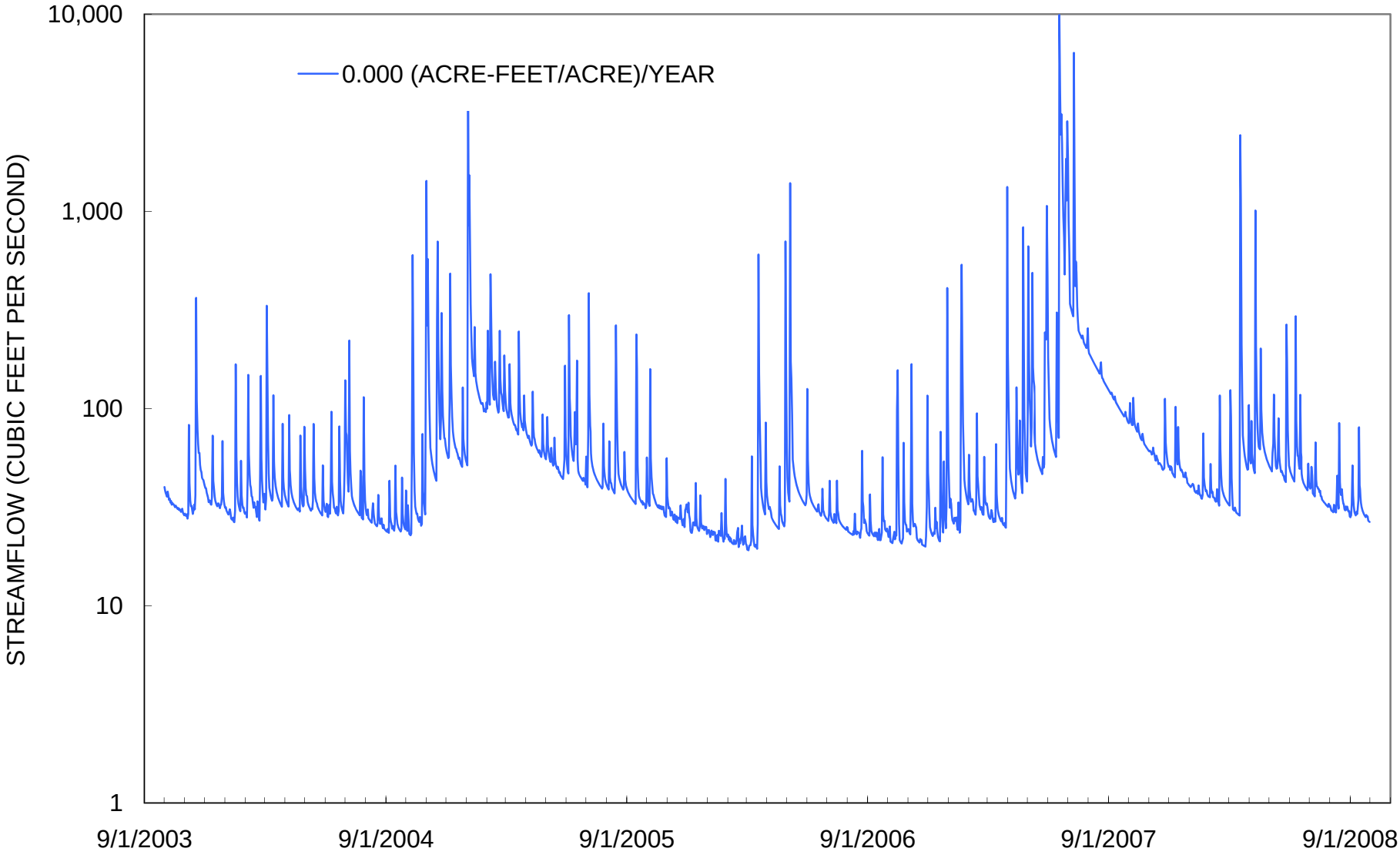
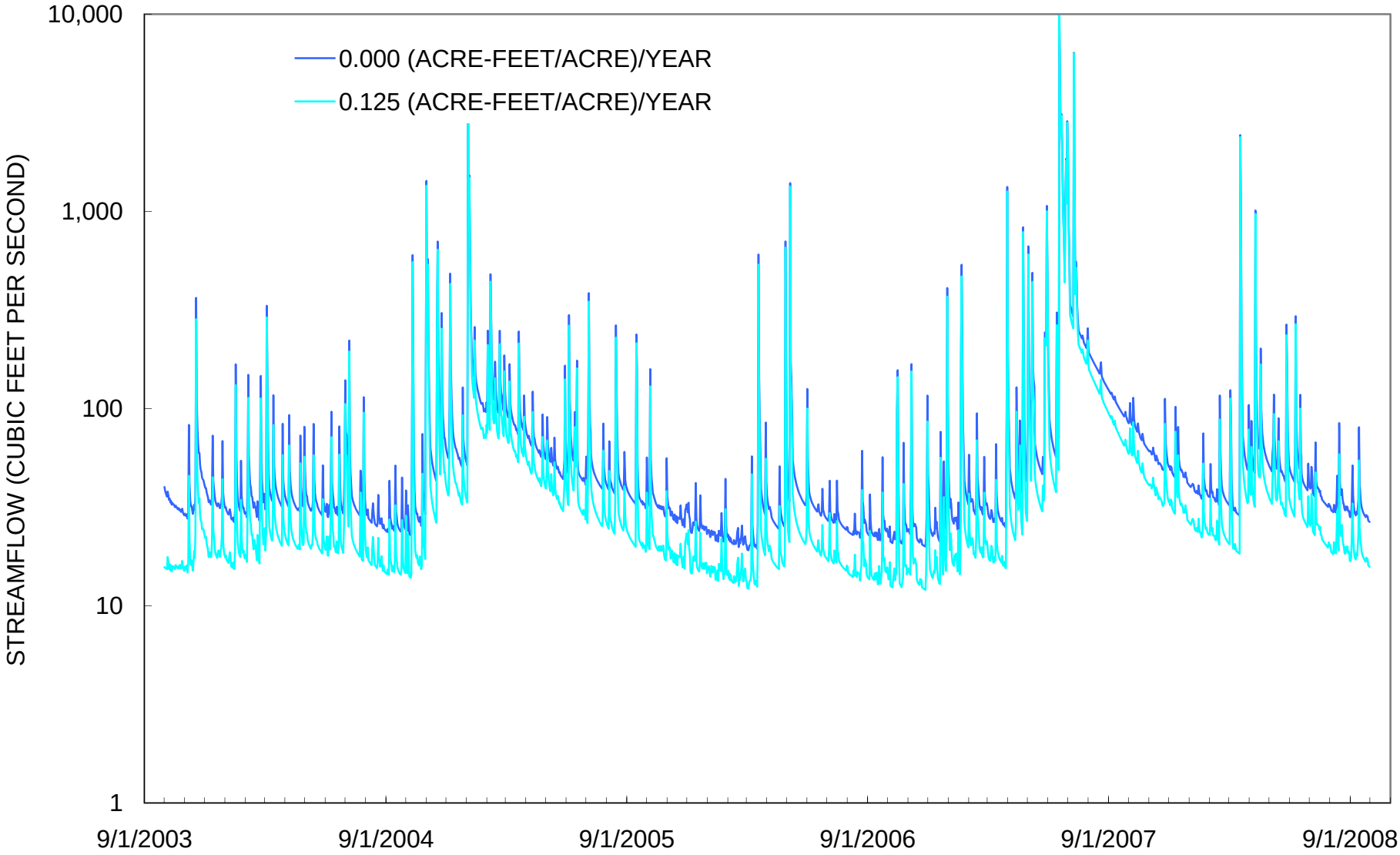


Figure X. Model calculated streamflow for Blue River near Connerville (07332390) for water years 2004-08 based on groundwater withdrawals distributed as an equal proportionate share



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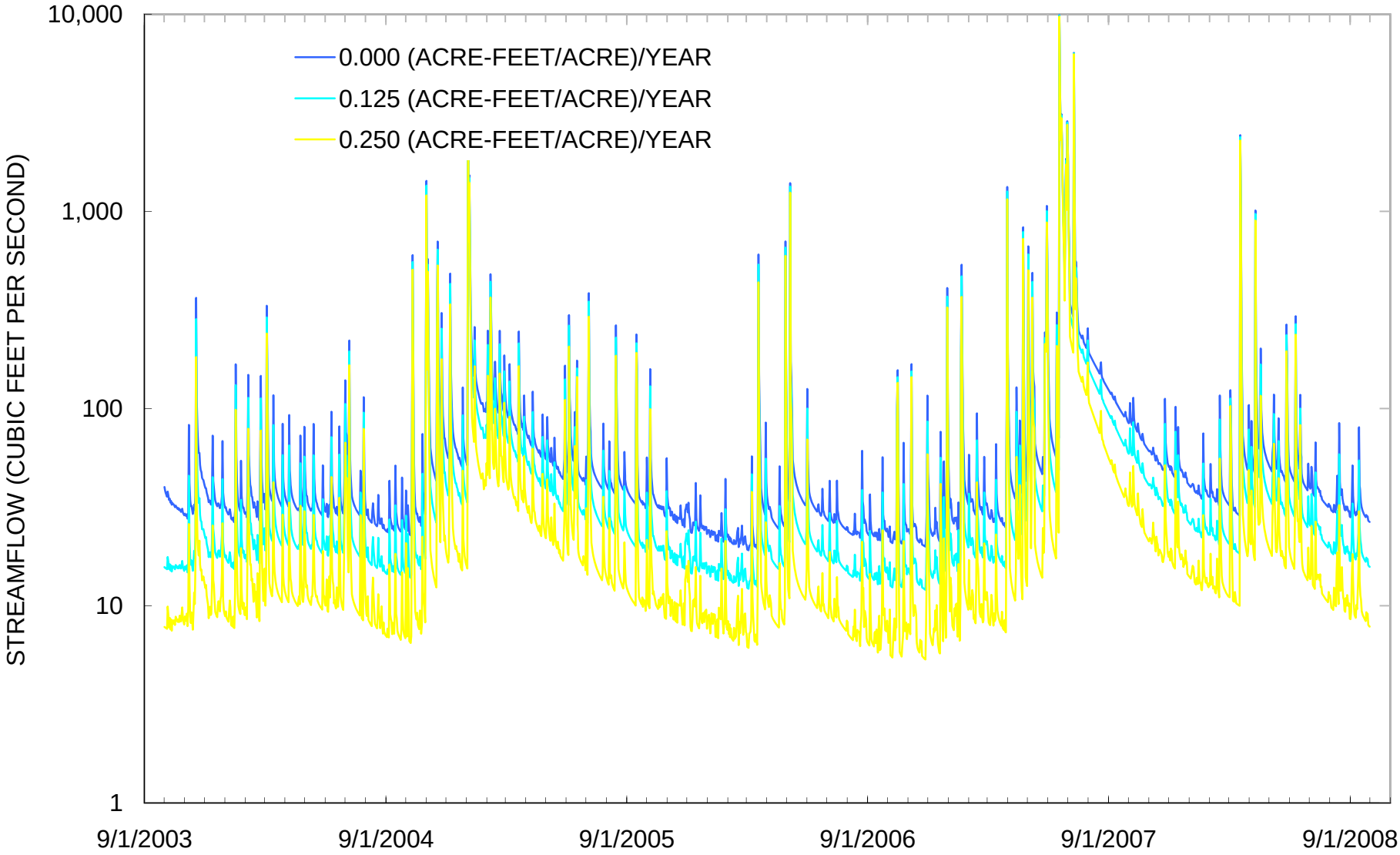

Figure X. Model calculated streamflow for Blue River near Connerville (07332390) for water years 2004-08 based on groundwater withdrawals distributed as an equal proportionate share

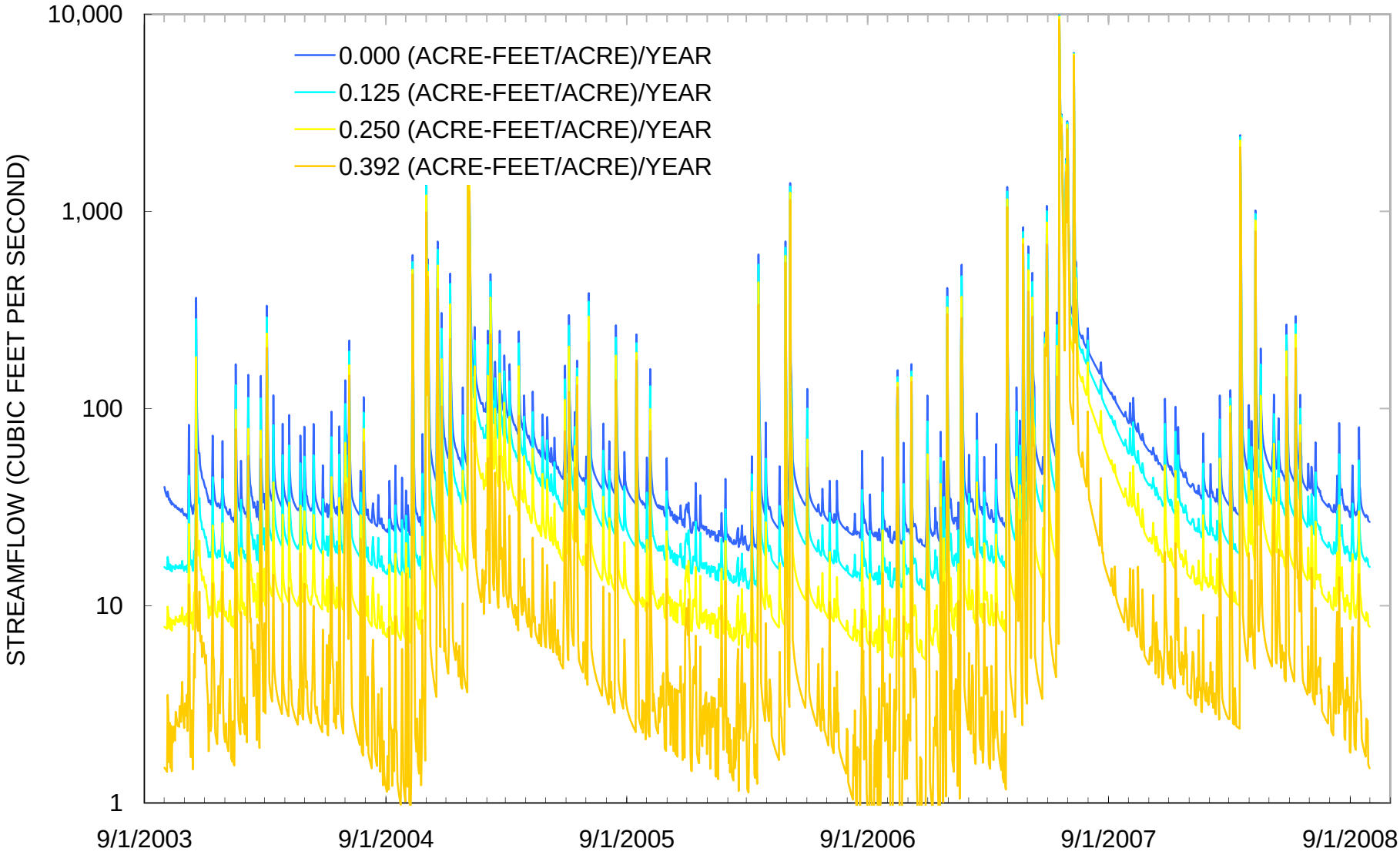

Figure X. Model calculated streamflow for Blue River near Connerville (07332390) for water years 2004-08 based on groundwater withdrawals distributed as an equal proportionate share

Model Results

- Distributed withdrawals
- Effects on 5-year (WY2004-2008) average flows on Blue River and Pennington Creek
- Baseflow (groundwater discharge)
- Streamflow (runoff + baseflow)

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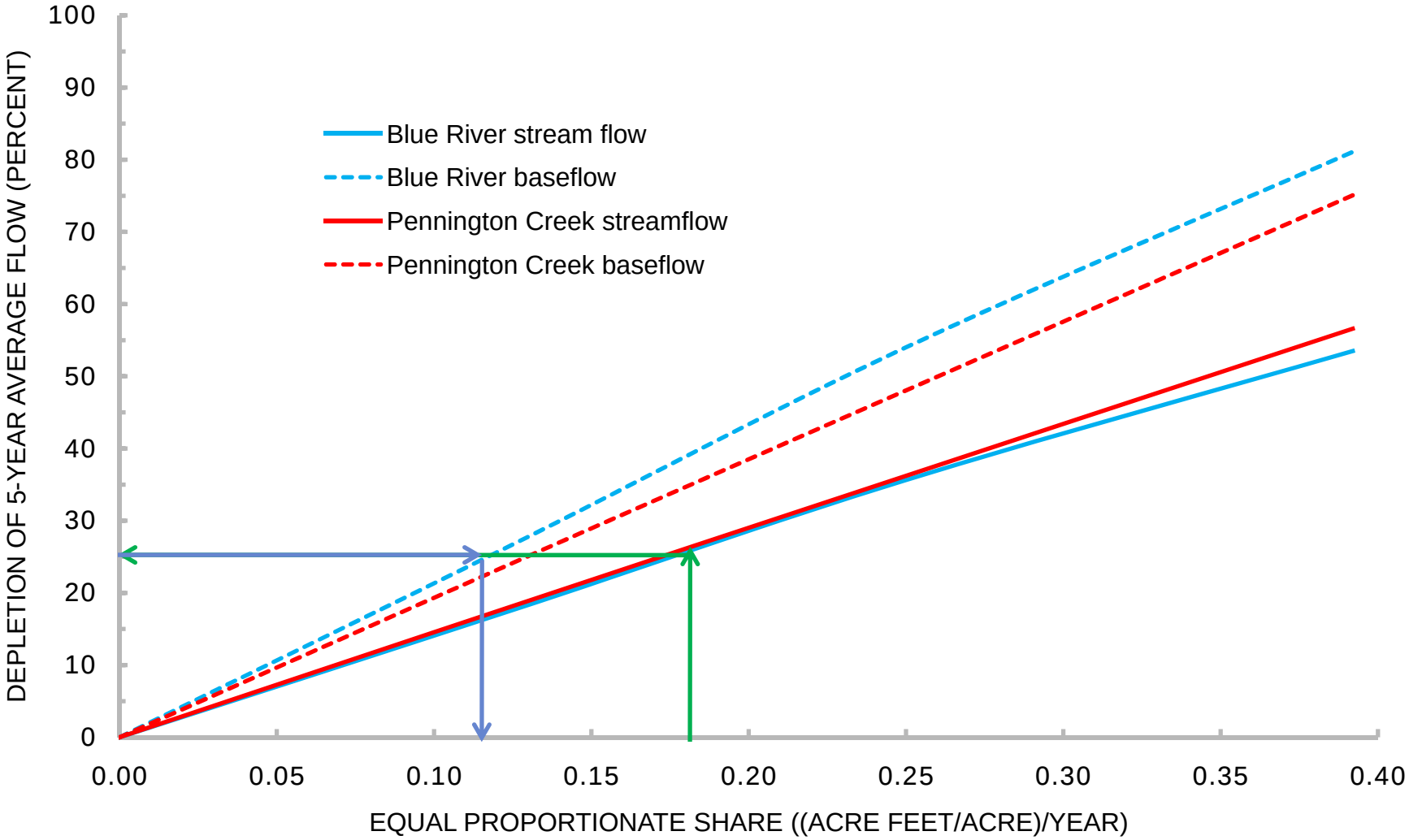

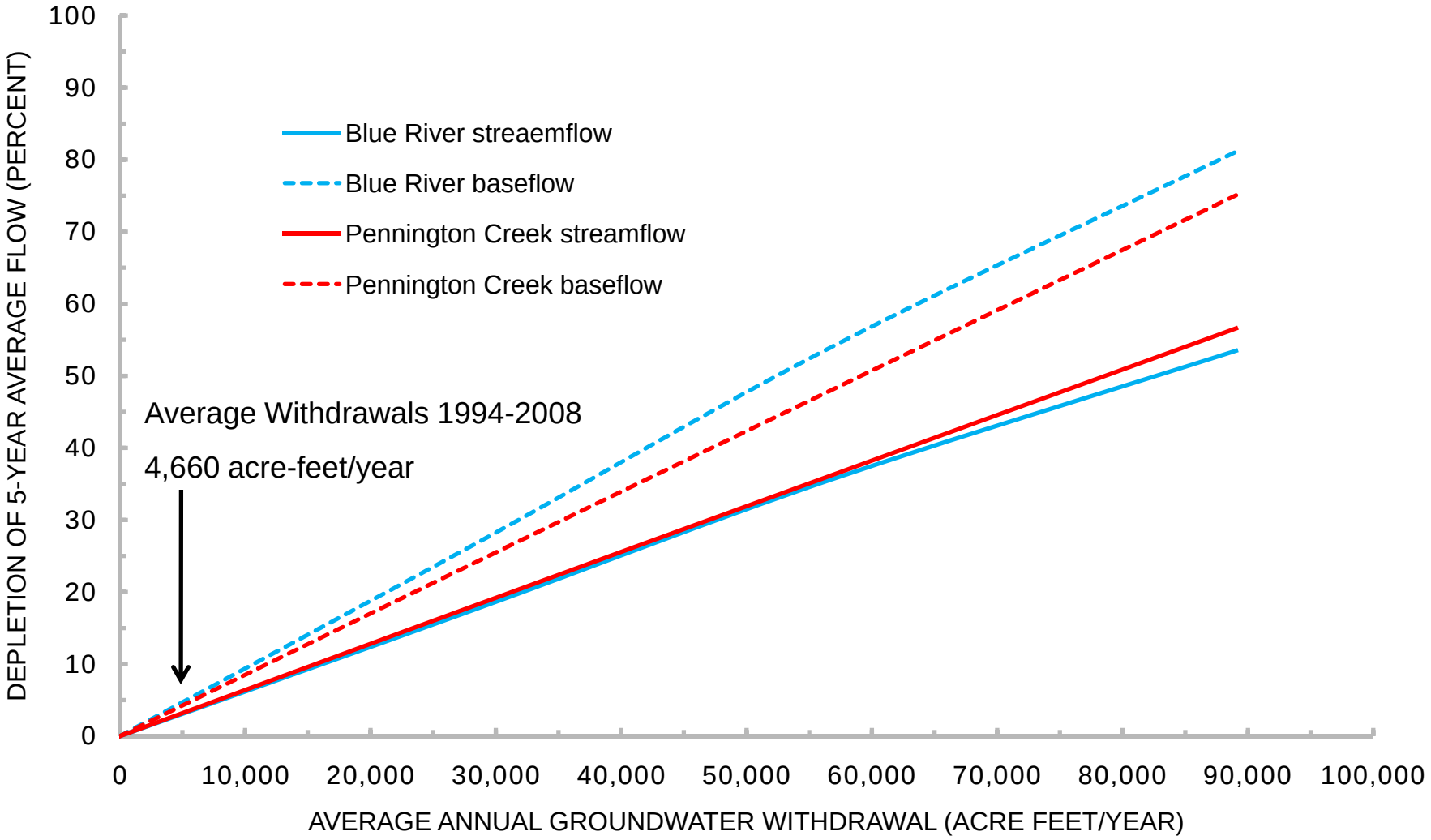

Model Results

- Distributed withdrawals
- Effects on 5-year (WY2004-2008) average baseflows for all streams
- Baseflow (groundwater discharge)
- Can not compute streamflow for streams without gages
- Model not optimized for streams other than Blue River and Pennington Creek

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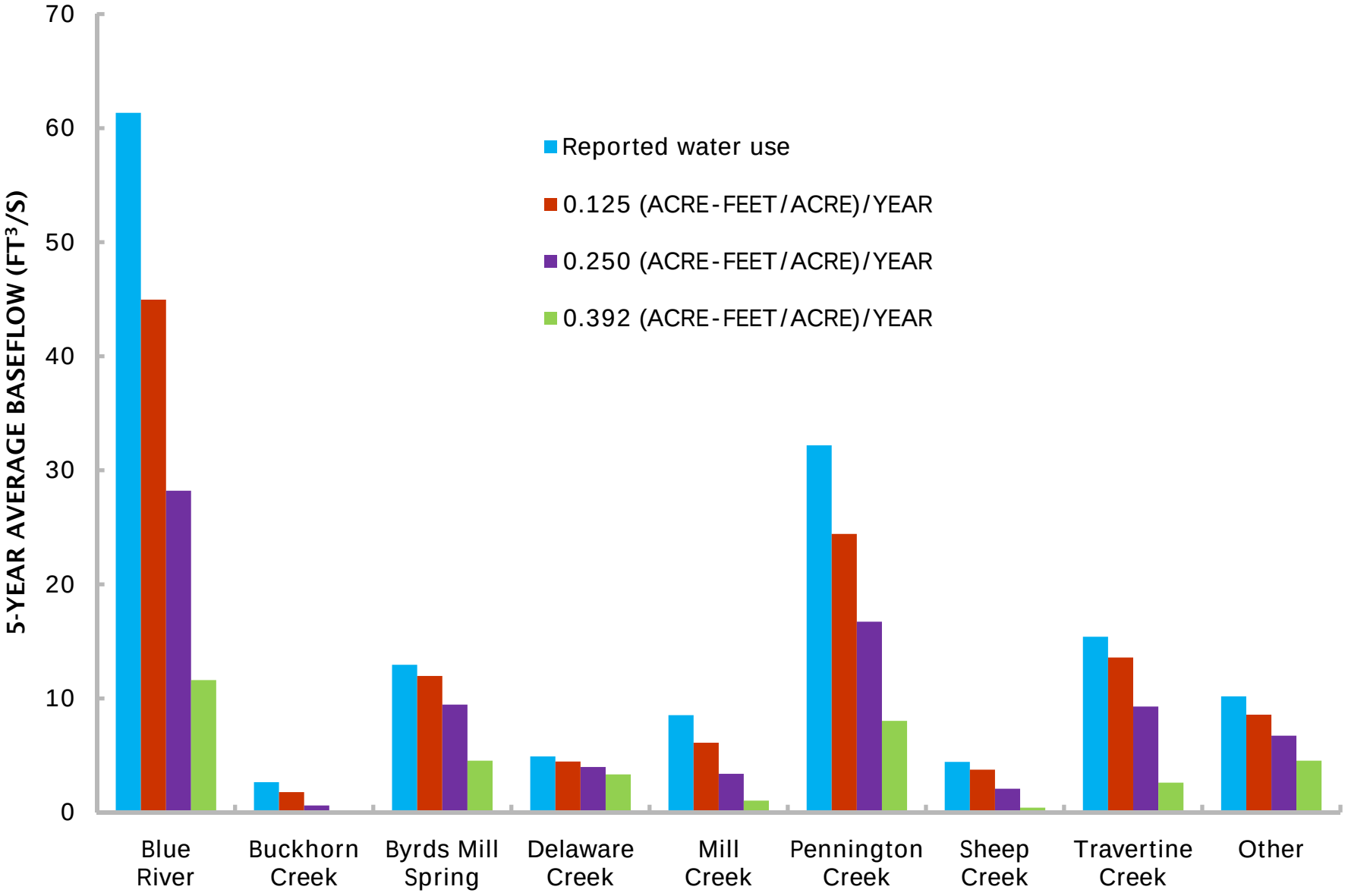

Change in 5-Year Average Baseflow Based on Simulations of Distributed Withdrawals

Model Results

- Distributed withdrawals
- Groundwater discharge on one specific day (August 10, 2005)
- August 10, 2005 is a day when Blue River near Connerville was discharging 40 ft^3/s, which is the 75 percent exceedance
- Shows where groundwater is discharging to stream channels
- Discharge greater than 1.0 m^3/d (0.18 gallon per minute)

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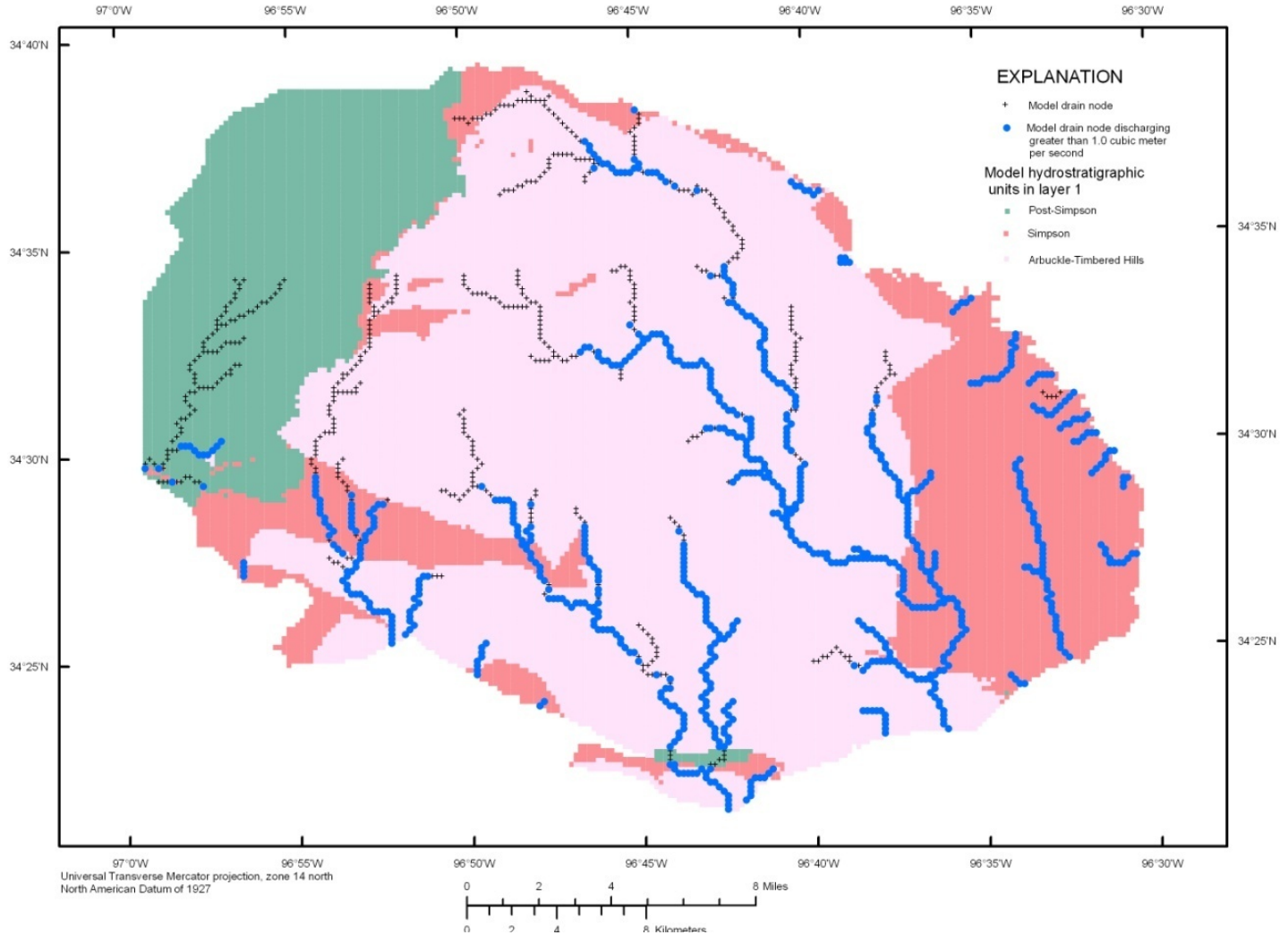
Reported Water Use



Drain nodes discharge more than 1.0 m^3/day August 10, 2005

Preliminary results, subject to revision

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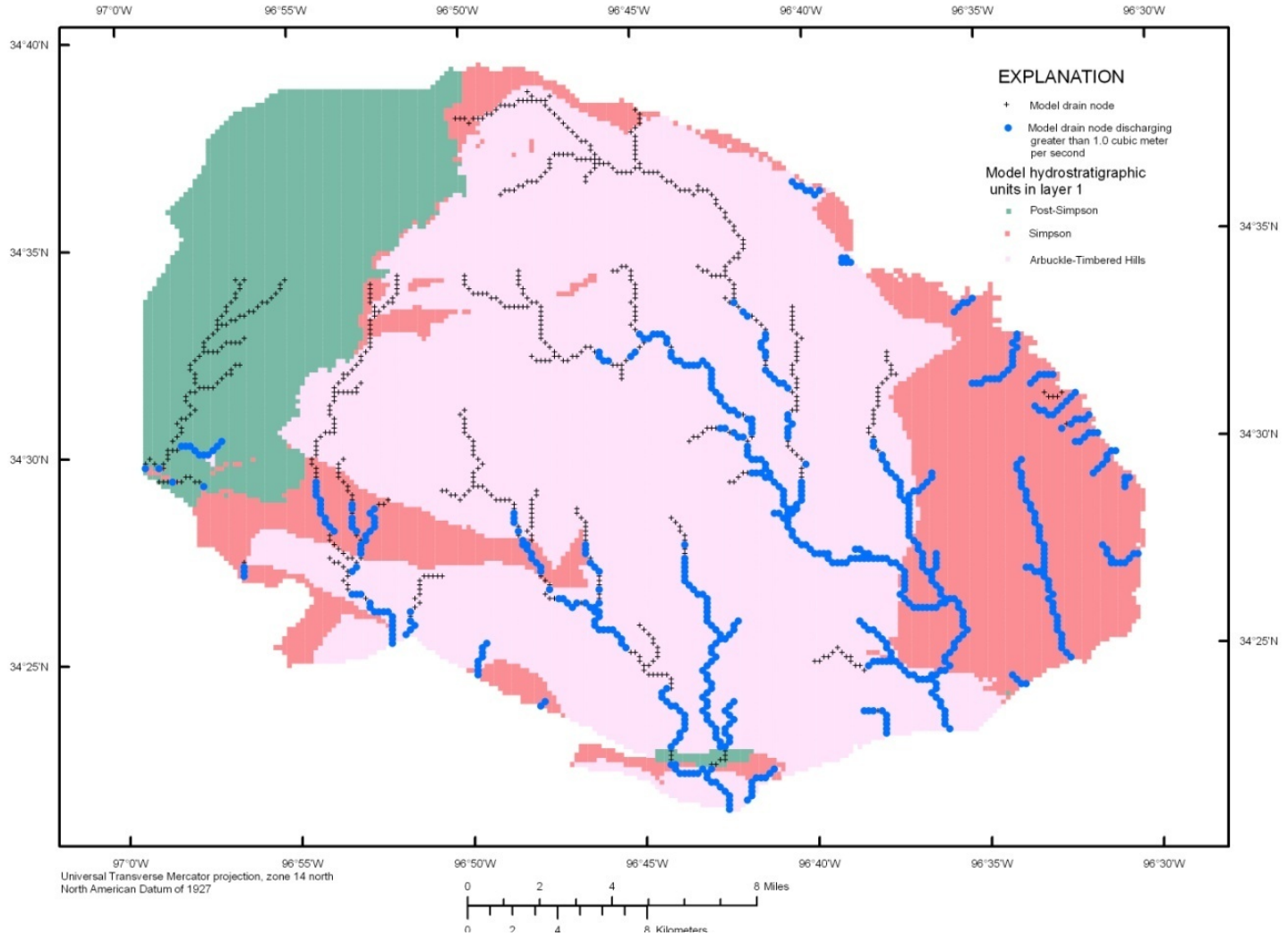
0.125 (ACRE-FEET/ACRE)/YEAR



Drain nodes discharge more than 1.0 m^3/day August 10, 2005

Preliminary results, subject to revision

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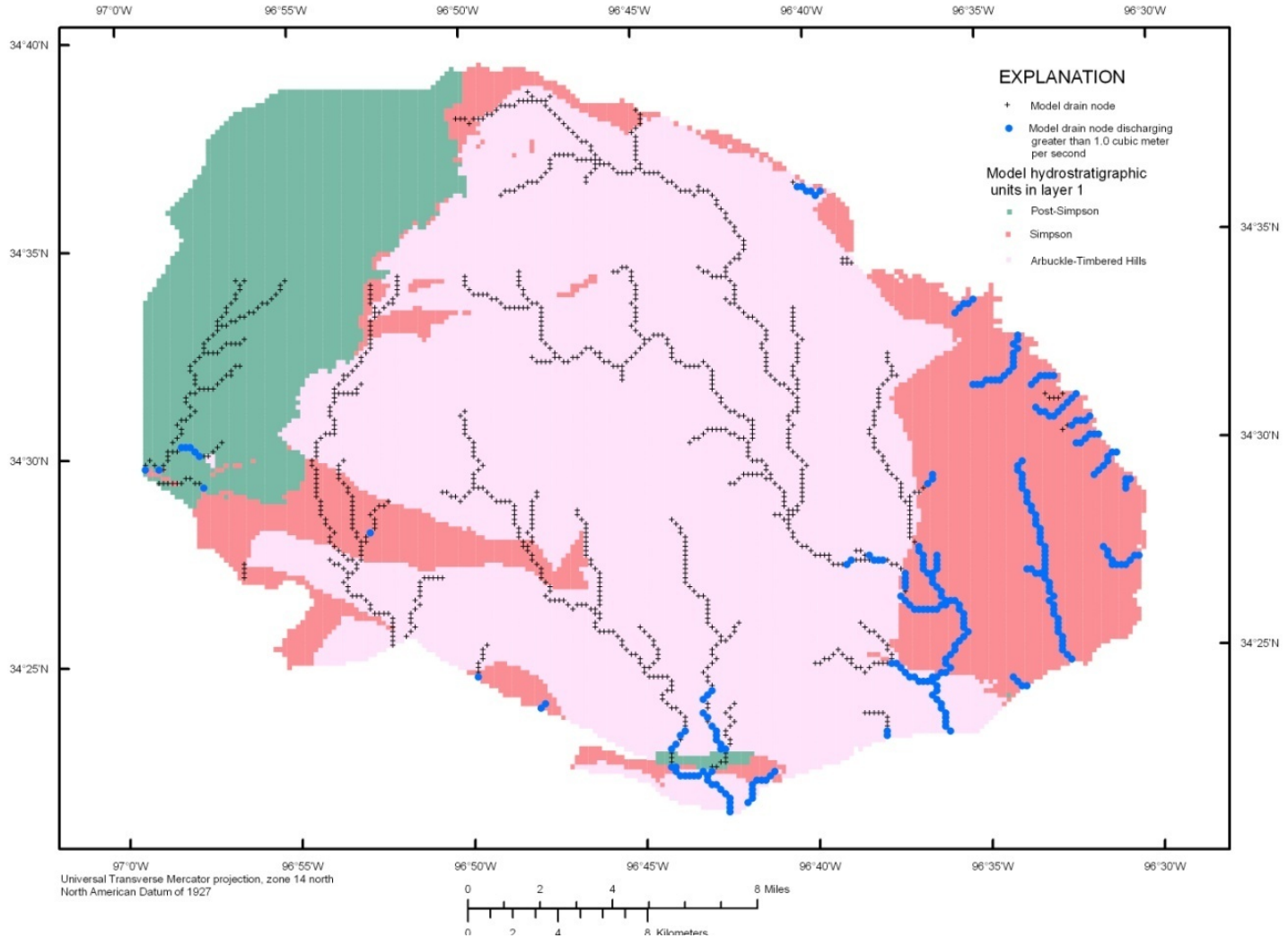
0.392 (ACRE-FEET/ACRE)/YEAR



Drain nodes discharge more than 1.0 m^3/day August 10, 2005

Preliminary results, subject to revision

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Eastern Arbuckle-Simpson Aquifer MODFLOW Model

- Concentrated withdrawals compared to distributed withdrawals
- Concentrated withdrawal equivalent to the distributed withdrawals
- Example using 0.392 (acre-feet/acre)/year

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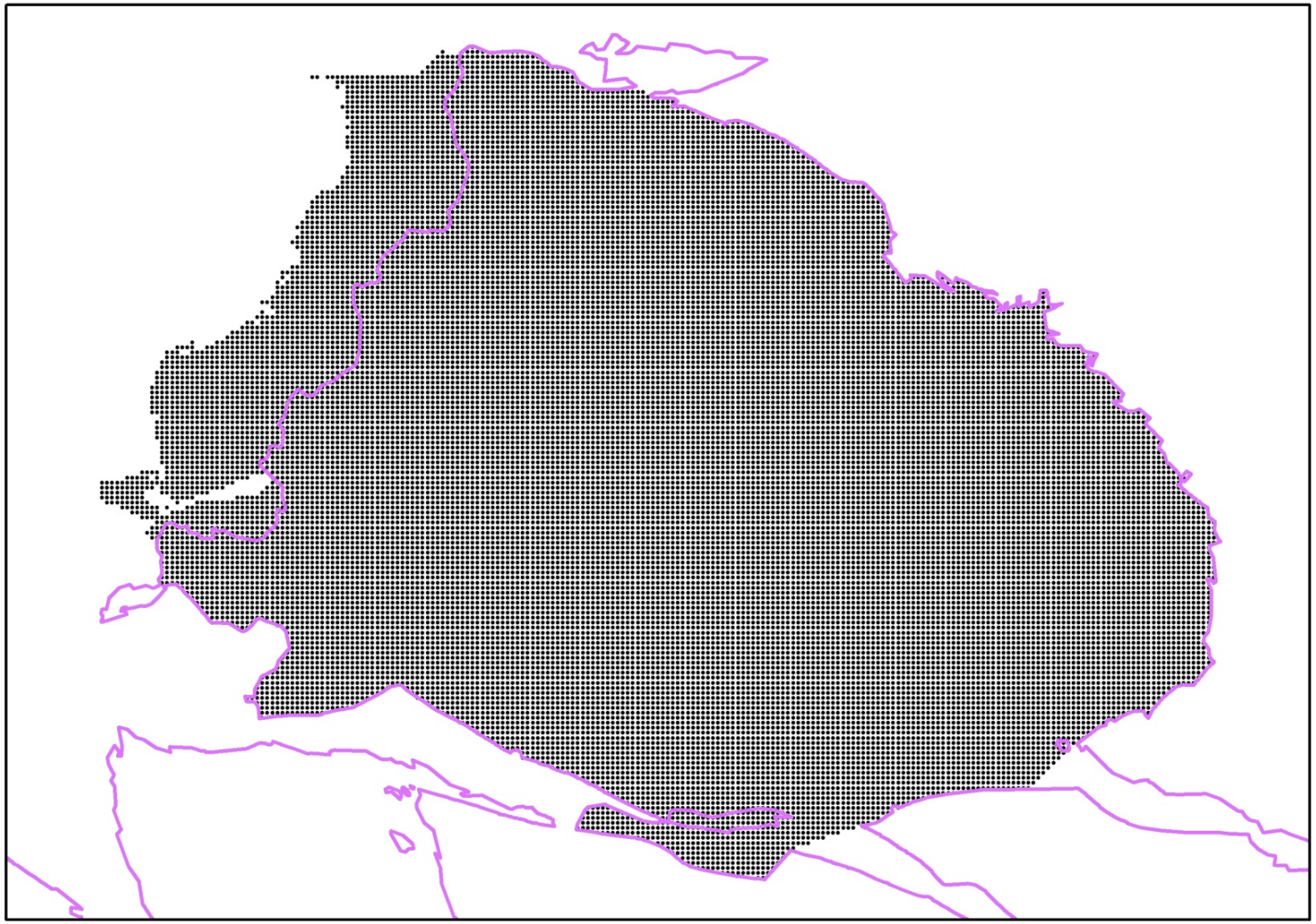

Locations of Wells Simulating Distributed Withdrawals

Preliminary results, subject to revision

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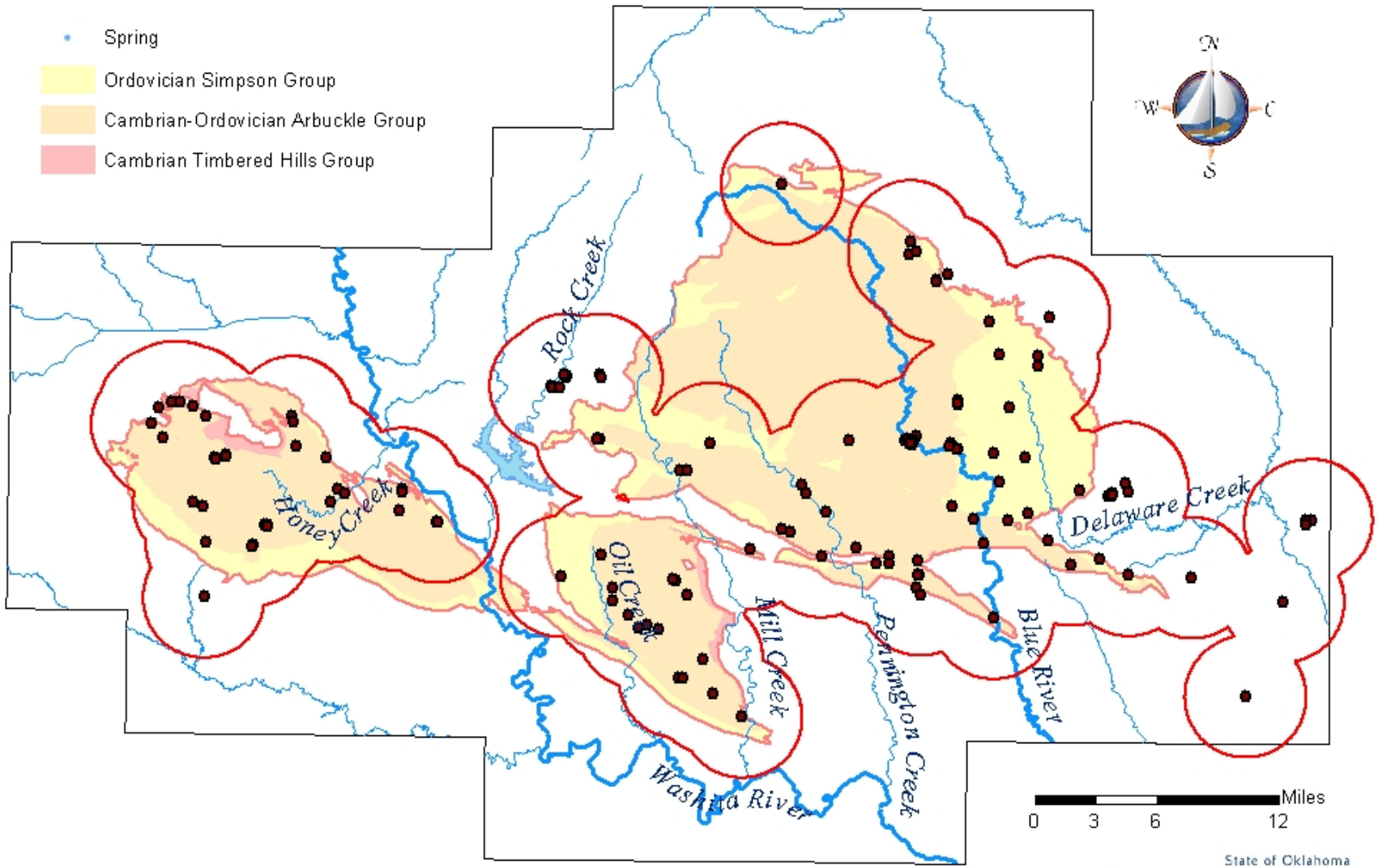

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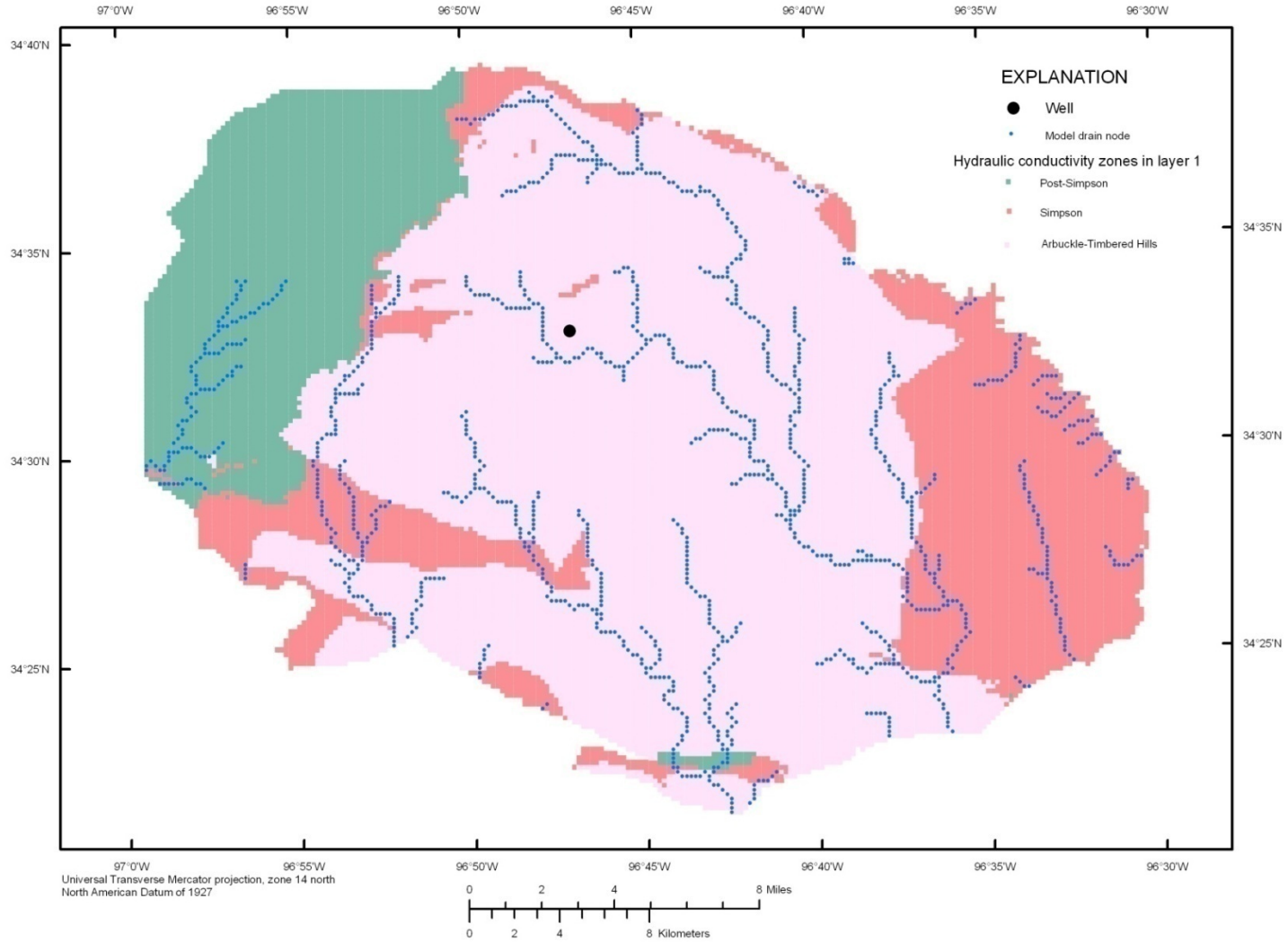
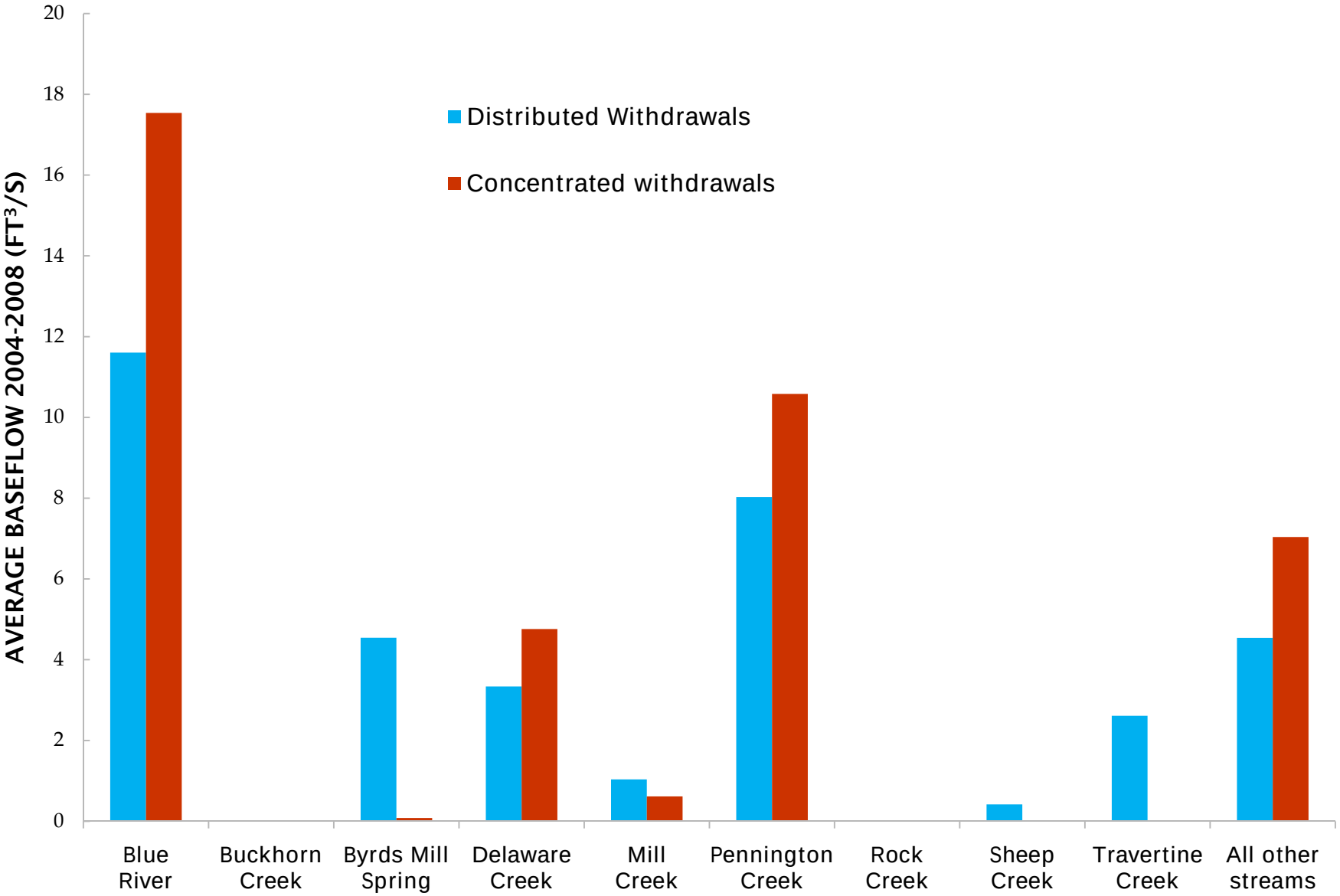
OWRB
WATER RESOURCES BOARD
the water agency

Buffer zones placed around springs

Preliminary results, subject to revision

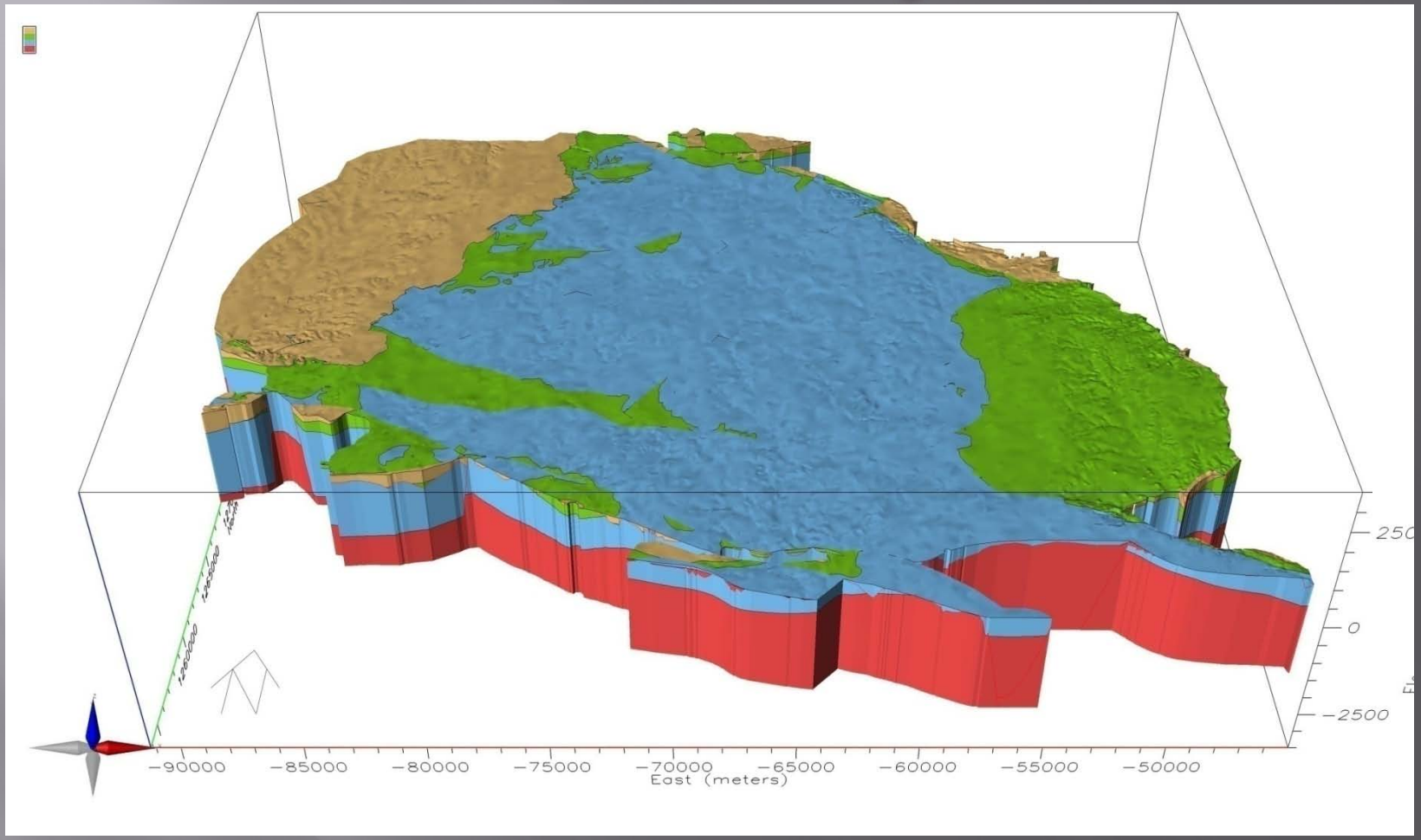


Location of single MODFLOW cell used to simulate concentrated withdrawals



Comparison of Distributed to Concentrated Withdrawals Equivalent to 0.392 (Acre-Feet/Acre)/Year)

Summary



Arbuckle-Simpson Hydrology Study made significant advances in our understanding of the Arbuckle-Simpson aquifer

OSU

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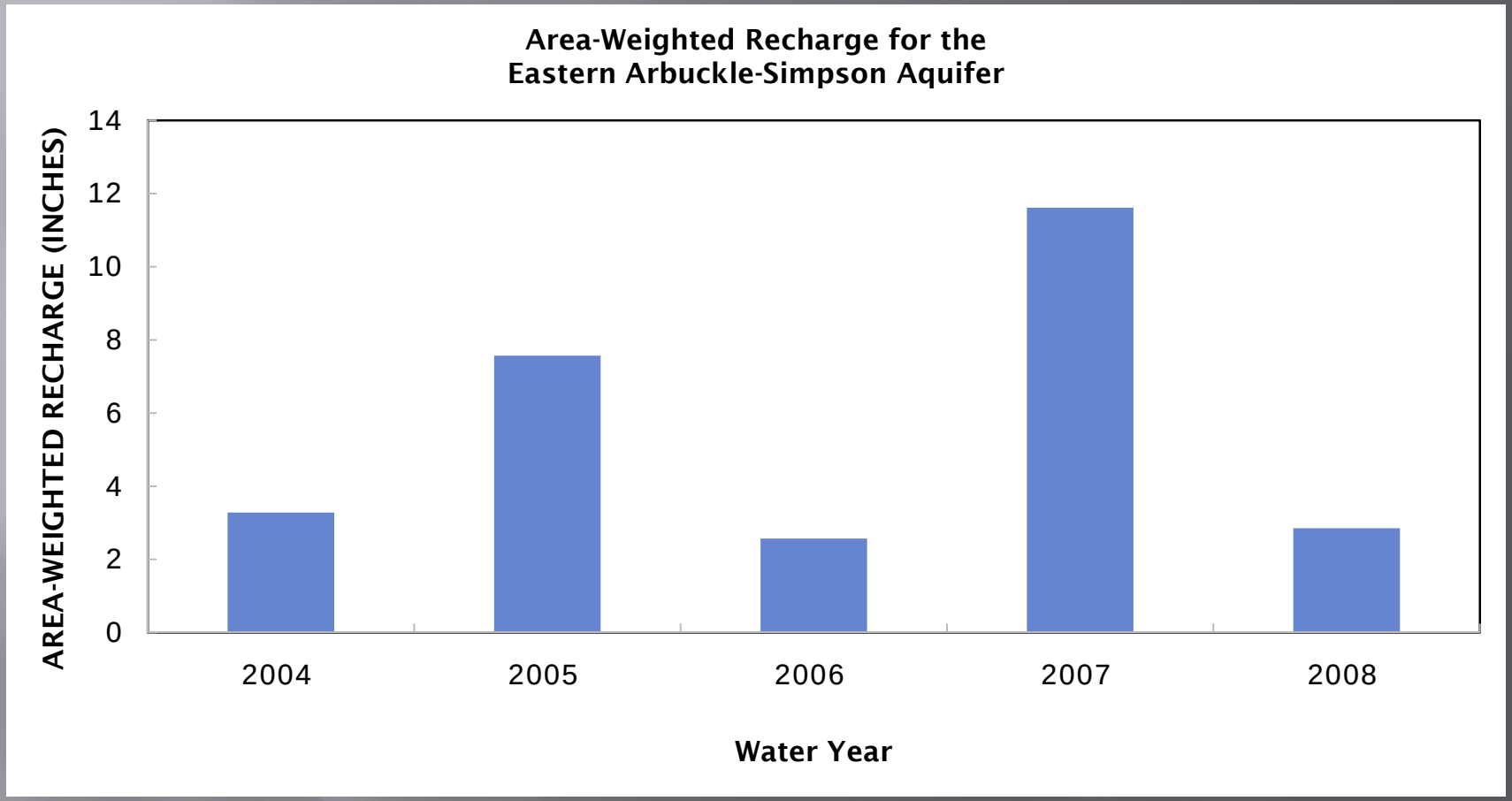
Summary



Recharge varies in time and space

Stop thinking of recharge as a constant!

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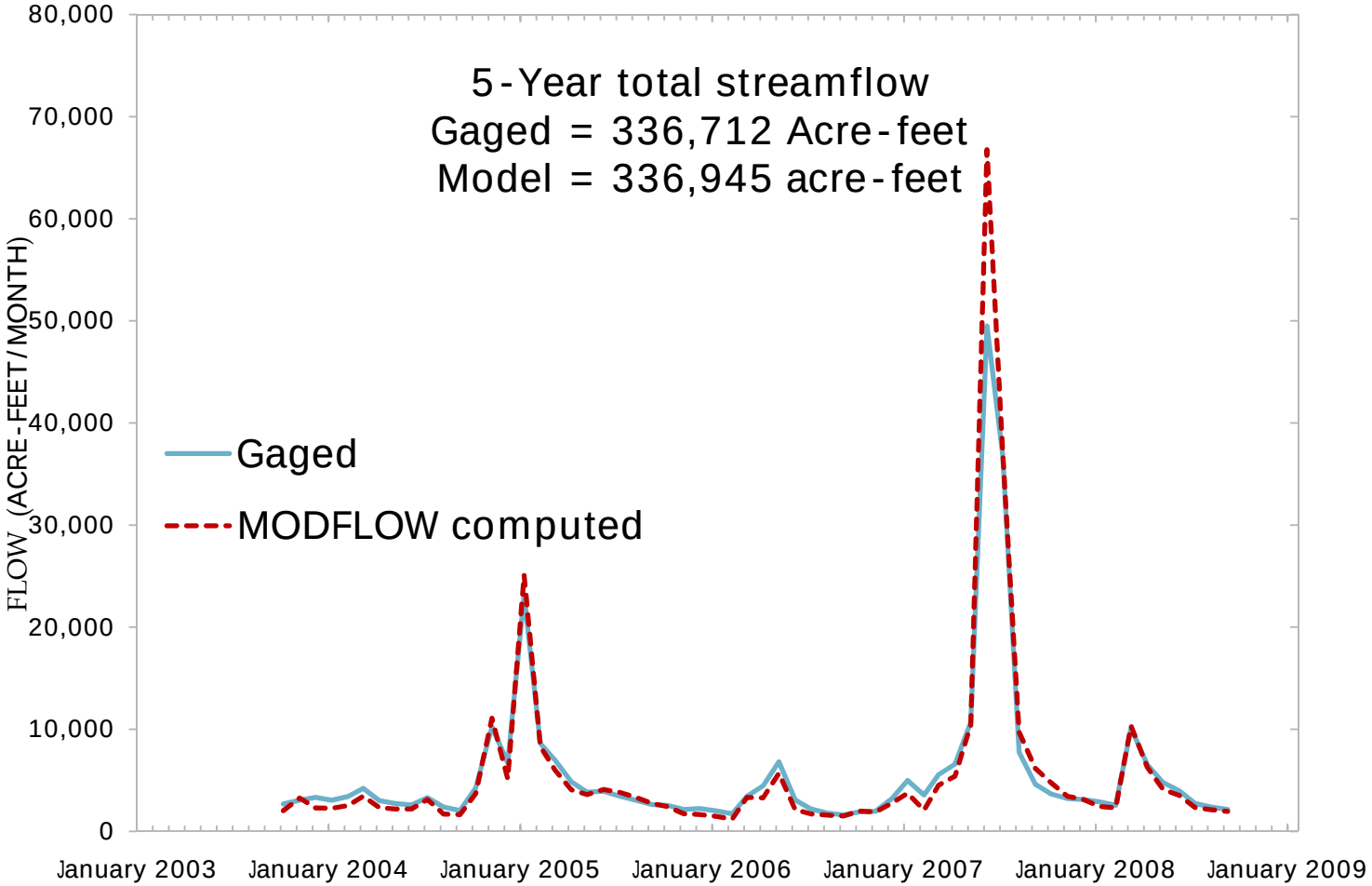
Summary



Blue River near Connerville

Monthly gaged flow compared to modeled flow

MODFLOW model can reproduce hydrologic observations

In the eastern Arbuckle-Simpson aquifer

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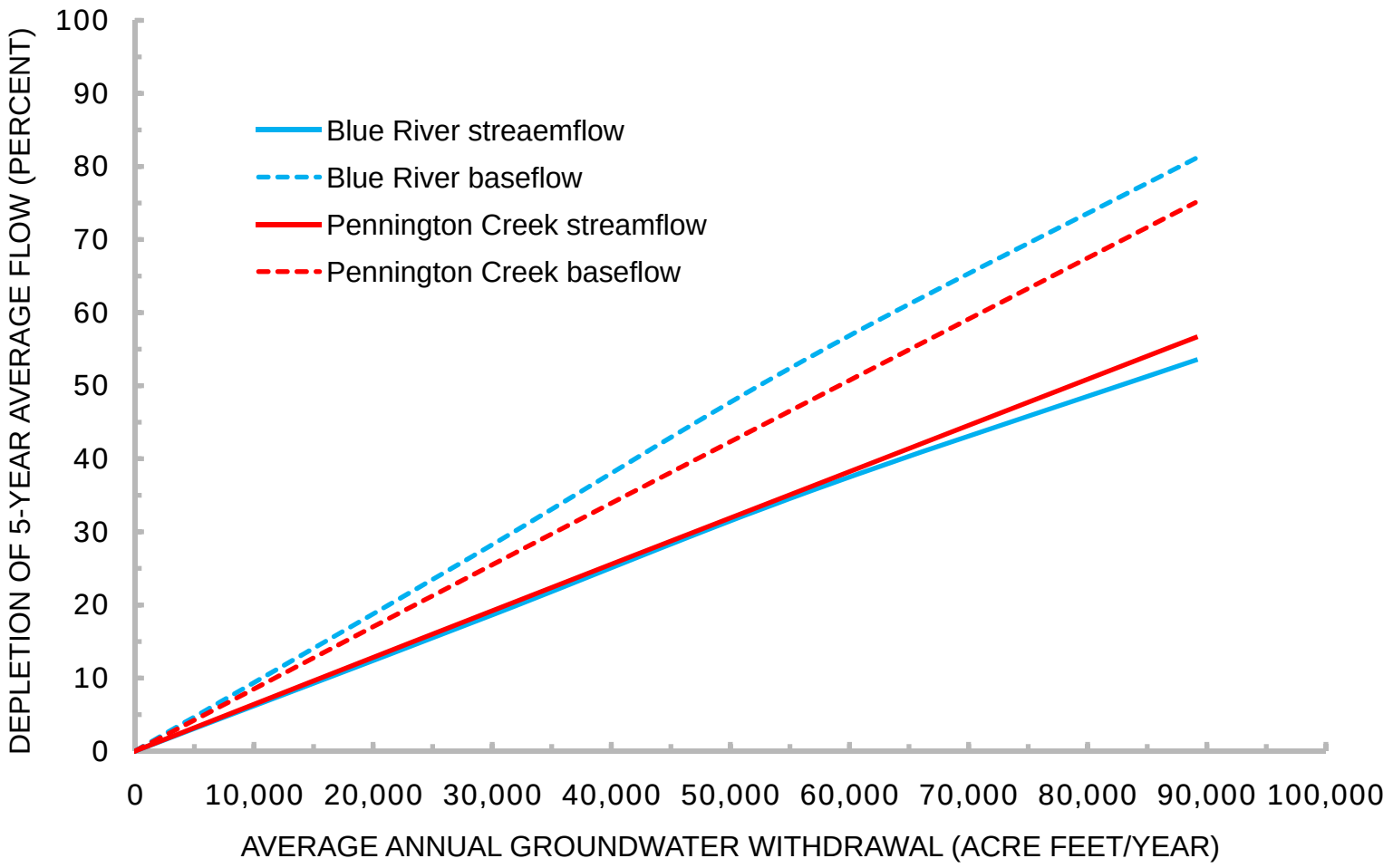
Summary



Groundwater withdrawals will cause depletion of flow of the streams and springs that discharge from the aquifer

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Acknowledgements

- Landowners for access to their property
- Cities (Ada, Sulphur, Davis, others)
- Federal and State governments
- Taxpayers
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- University of Oklahoma (Baxter Vieux, Maria Moreno, Roger Young, and students)

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- Oklahoma Water Resources Board (Bob Fabian, Chris Neel, Derek Smithee, and Mike Sughru)

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- Concerned Citizens

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