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
Geology (already described by Noel)
Aquifer hydraulic properties (especially storage coefficient)
Watersheds: Surface and subsurface
Recharge
What is a model?
Why use models?
Computer program: MODFLOW
The eastern Arbuckle- Simpson aquifer MODFLOW model
How recharge is implemented in the model
School: 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
Hydrogeologic Framework Model

USGS and OSU

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

Preliminary results, subject to revision
Preliminary results, subject to revision
Aquifer hydraulic properties are related to geology.
The volume of water given up per unit area of an aquifer per unit drop of the water-table or potentiometric surface.
Aquifer Hydraulic Properties: Storage Coefficient

Alluvial aquifer 0.2
Arbuckle-Simpson aquifer 0.008

1 CUBIC FOOT

Alluvial aquifer
1.5 gallons

Arbuckle-Simpson aquifer
1 cup
Aquifer Hydraulic Properties: Storage Coefficient

- Alluvial aquifer
- Recharge
- Withdrawals
- Groundwater Discharge or Baseflow
Aquifer Hydraulic Properties: Storage Coefficient

Recharge

Withdrawals

Groundwater Discharge or Baseflow

Arbuckle-Simpson Aquifer

USGS science for a changing world
Arbuckle-Simpson aquifer
Storage coefficient 0.008
Withdraw 1.0 foot
125 feet of drawdown

Alluvial aquifer
Storage coefficient 0.2
Withdraw 1.0 foot
5 feet of drawdown
Aquifer Hydraulic Properties: Methods to Determine Storage Coefficient

Decline in Water Table

Earth Tides

Preliminary results, subject to revision
Recharge

Withdrawals

Groundwater Discharge or Baseflow

Arbuckle-Simpson Aquifer

USGS
Stop thinking of recharge as a constant!

Circular 91 reported an average recharge rate of 4.7 inches/year

Recharge varies in time and space
Blue River at Connerville

Discharge (ft³/s)

1/1/04 7/1/04 1/1/05 7/1/05 1/1/06 7/1/06

Preliminary results, subject to revision
Blue River at Connerville

Groundwater Component of Stream Flow: Baseflow

Preliminary results, subject to revision
Hydrograph Displacement Method
Preliminary results, subject to revision
Surface Watersheds

Preliminary results, subject to revision
Subsurface Watersheds

Preliminary results, subject to revision
Annual Recharge at Stream Gages Based on Subsurface Watershed Areas

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

- **Blue River**: 34.09 in, 44.97 in, 20.94 in, 56.11 in, 37.97 in
- **Pennington Creek**: 34.09 in, 44.97 in, 20.94 in, 56.11 in, 37.97 in
- **Honey Creek**: 34.09 in, 44.97 in, 20.94 in, 56.11 in, 37.97 in

Preliminary results, subject to revision.
Subsurface Watersheds

Preliminary results, subject to revision
Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model

EXPLANATION

- Chickasaw National Recreation Area
- Arbuckle-Simpson aquifer outcrop
- Spring

Map showing the Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model with a legend indicating Chickasaw National Recreation Area, Arbuckle-Simpson aquifer outcrop, and Spring locations.

Acknowledgments:
OWRB (State of Oklahoma Water Resources Board) and USGS (US Geological Survey).
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.
Eastern Arbuckle-Simpson Aquifer Groundwater Flow Model
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
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
Eastern Arbuckle-Simpson Groundwater Flow Model

- Equivalent porous media approach
- Finite-difference method
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
Model Layers

Preliminary results, subject to revision
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
Potentiometric Surface, August 1995

Preliminary results, subject to revision
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.
5-Year total streamflow
Gaged = 336,712 acre-feet
Model = 336,945 acre-feet

Blue River near Connerville
Monthly gaged flow compared to modeled flow
5-year total streamflow

Gaged = 155,720 acre-feet
Modeled = 154,720 acre-feet

Pennington Creek near Reagan
Monthly gaged streamflow compared to modeled flow
Model Results

- Flowpaths
Subsurface Watersheds

Preliminary results, subject to revision
MODPATH flowpath simulation
Preliminary results, subject to revision
Model Results

- Groundwater ages
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.
MODPATH flowpath simulation

Average particle age for particles discharge near Vendome Well

is 9,400 years

Preliminary results, subject to revision
Recharge calculation for the entire eastern Arbuckle- Simpson aquifer
Subsurface Watersheds

Recharge Calculations

Preliminary results, subject to revision

Universal Transverse Mercator projection, zone 14 north
North American Datum of 1927

OWRB
State of Oklahoma
WATER RESOURCES BOARD
the water agency

USGS
science for a changing world
Recharge Calculations

Modeled Recharge
Preliminary results, subject to revision
Area-Weighted Recharge for the Eastern Arbuckle-Simpson Aquifer

AREA-WEIGHTED RECHARGE (INCHES/YEAR)

Water Year

2004 3.28
2005 7.57
2006 2.57
2007 11.61
2008 2.85

5-Year Average = 5.58 inches/year

Preliminary results, subject to revision
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?
Senate Bill 288 is interpreted to limit groundwater withdrawal to protect surface-water flow.

Simulations tested by the model keep withdrawals less than recharge.
Groundwater Withdrawal Greater than Recharge

Withdrawals

Recharge

Groundwater Discharge or Baseflow

Arbuckle-Simpson Aquifer
Groundwater Withdrawal
Less than Recharge

Withdrawals

Recharge

Groundwater Discharge or Baseflow

Arbuckle-Simpson Aquifer
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
Quarterly Recharge
Pennington Creek near Reagan

Preliminary results, subject to revision
Quarterly Recharge
Pennington Creek near Reagan
Model Results

- Assumes the aquifer is completely developed at some future time
- Distributed withdrawals
- Based on the equal proportionate share concept
Average Annual Reported Groundwater Use
Eastern Arbuckle-Simpson Aquifer

Preliminary results, subject to revision
Model Results

- Distributed withdrawals
- Effects on daily hydrograph
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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Distributed withdrawals
Effects on 5-year (WY2004-2008) average flows on Blue River and Pennington Creek
Baseflow (groundwater discharge)
Streamflow (runoff + baseflow)
Figure X. Percent depletion of 5-year (water years 2004-08) average flow of Blue River near Connerville and Pennington Creek near Reagan based on MODFLOW simulated management options expressed as an equal proportionate share.

- Blue River stream flow
- Blue River baseflow
- Pennington Creek streamflow
- Pennington Creek baseflow
Figure X. Percent depletion of 5-year (water years 2004-08) average flow of Blue River near Connerville and Pennington Creek near Reagan based on MODFLOW-simulated withdrawals distributed as an equal proportionate share.
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
Change in 5-Year Average Baseflow Based on Simulations of Distributed Withdrawals

Reported water use
- 0.125 (ACRE- FEET/ACRE)/YEAR
- 0.250 (ACRE- FEET/ACRE)/YEAR
- 0.392 (ACRE- FEET/ACRE)/YEAR

Preliminary results, subject to revision
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)
Reported Water Use

Drain nodes discharge more than 1.0 m³/day August 10, 2005

Preliminary results, subject to revision
0.125 (ACRE-FEET/ACRE)/YEAR

Drain nodes discharge more than 1.0 m³/day August 10, 2005

Preliminary results, subject to revision
Drain nodes discharge more than 1.0 m³/day August 10, 2005

Preliminary results, subject to revision
Concentrated withdrawals compared to distributed withdrawals
Concentrated withdrawal equivalent to the distributed withdrawals
Example using 0.392 (acre-feet/acre)/year
Locations of Wells Simulating Distributed Withdrawals

Preliminary results, subject to revision
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

Preliminary results, subject to revision
Arbuckle-Simpson Hydrology Study made significant advances in our understanding of the Arbuckle-Simpson aquifer.
Area-Weighted Recharge for the Eastern Arbuckle-Simpson Aquifer

Recharge varies in time and space
Stop thinking of recharge as a constant!
5-Year total streamflow
Gaged = 336,712 Acre-feet
Model = 336,945 acre-feet

MODFLOW model can reproduce hydrologic observations
In the eastern Arbuckle-Simpson aquifer
Groundwater withdrawals will cause depletion of flow of the streams and springs that discharge from the aquifer.
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