

Coupled surface/subsurface hydrologic modeling with SWAT+ and the new groundwater module: current approaches and applications

Ryan Bailey, Colorado State University

Salam Abbas, Colorado State University

Muhammad Raffae, Colorado State University

Jeffrey Arnold, USDA-ARS, Temple, TX

Michael White, USDA-ARS, Temple, TX

Natalja Cerkasova, Texas A&M AgriLife

Jungang Gao, Texas A&M AgriLife



**COLORADO STATE
UNIVERSITY**





Outline of Presentation

1. SWAT+ *gwflow*: history and brief methods overview
2. SWAT+ *gwflow*: features and applications
 - Groundwater pumping in irrigated regions
 - Subsurface drainage (tile drains)
 - Floodplain-aquifer exchange
 - **National modeling results, USA** (National Agroecosystem Model)

History and Brief Methods Overview



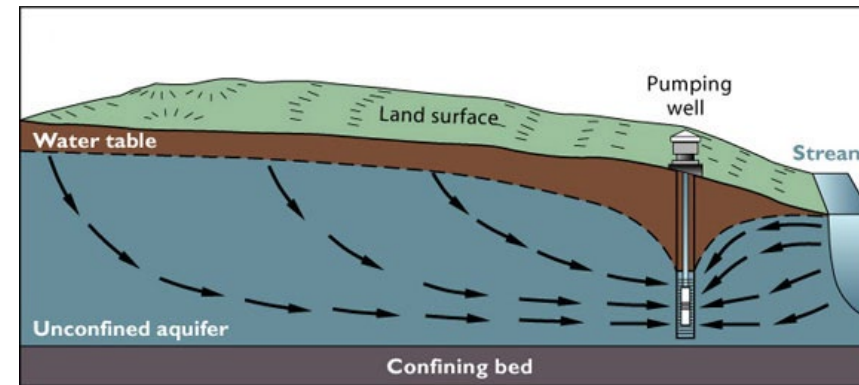
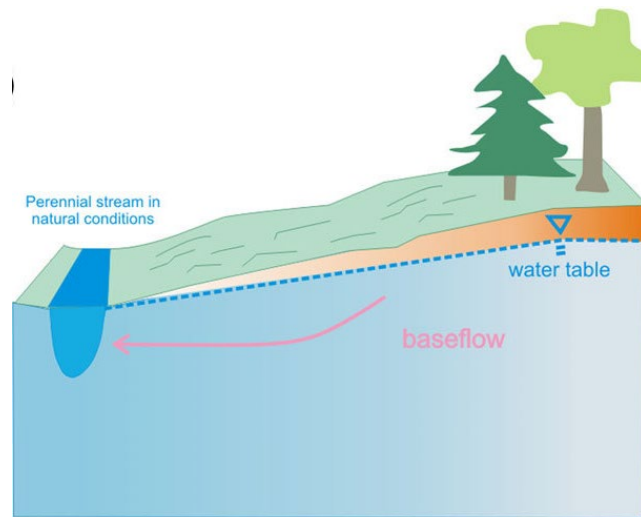
Problem Statement: (potential) problems with simulating groundwater...



- Interaction between groundwater and surface water not based on head gradient
- Groundwater leaves aquifer only if gw storage > specified threshold
- Groundwater head does not respond to pumping



- May produce inaccurate results when quantifying groundwater/surface water exchange
- May produce inaccurate results when quantifying impact of conservation practices in groundwater-driven watersheds



History and Brief Methods Overview



Problem Statement: (potential) problems with simulating groundwater...

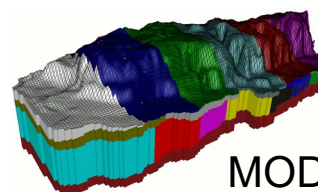


- Interaction between groundwater and surface water not based on head gradient
- Groundwater leaves aquifer only if gw storage > specified threshold
- Groundwater head does not respond to pumping



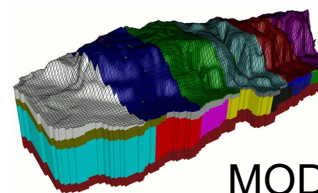
- May produce inaccurate results when quantifying groundwater/surface water exchange
- May produce inaccurate results when quantifying impact of conservation practices in groundwater-driven watersheds

2013-2019: Development of SWAT-MODFLOW



MODFLOW

2018-2020: Development of SWAT+/MODFLOW



MODFLOW

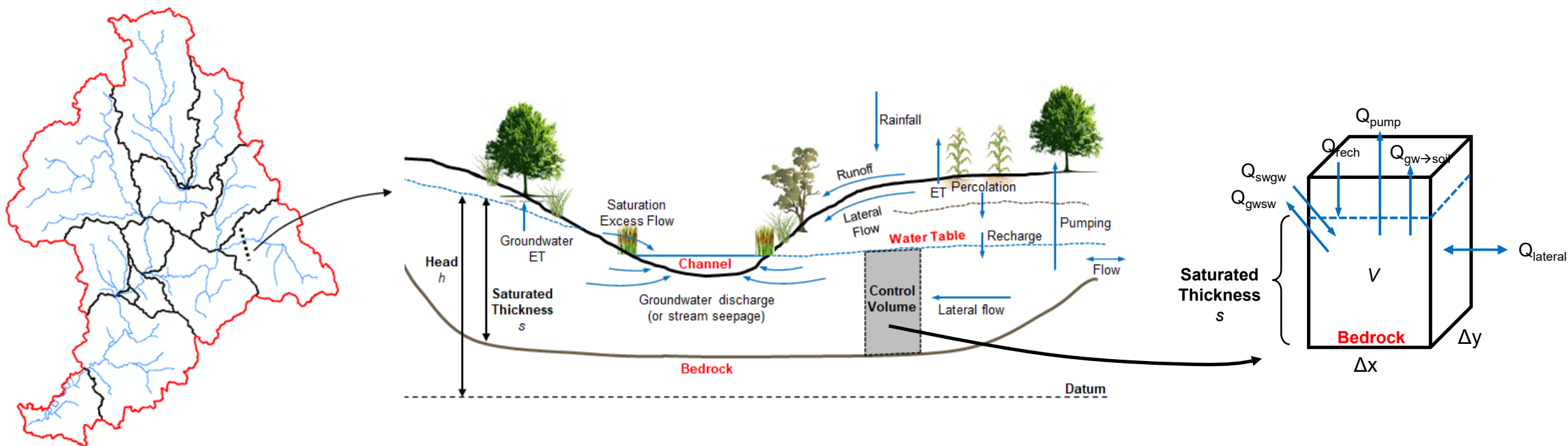
Need something simpler for the SWAT+ code...

History and Brief Methods Overview



2020-present: Development of *gflow* module for SWAT+

- Physically based spatially distributed groundwater modeling
- Divide the watershed aquifer into discrete “cells” (volumes); quantify groundwater inflows and outflows for each cell
- Cells interact with **HRUs** (recharge), **channels** and **reservoirs** (exchange), **irrigated fields** (pumping), and **channel floodplains** (exchange)



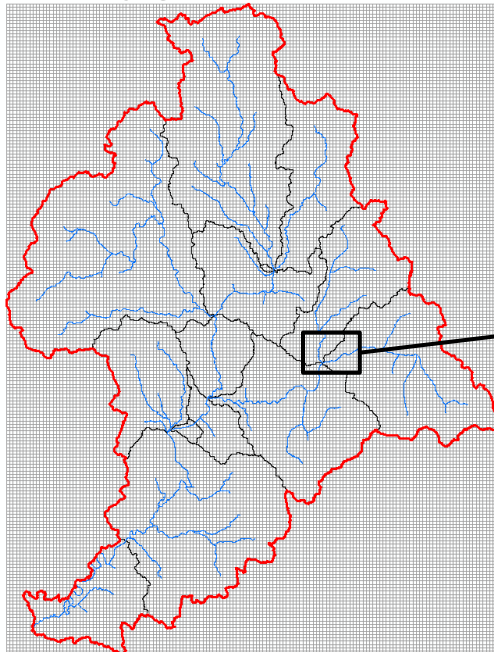
History and Brief Methods Overview



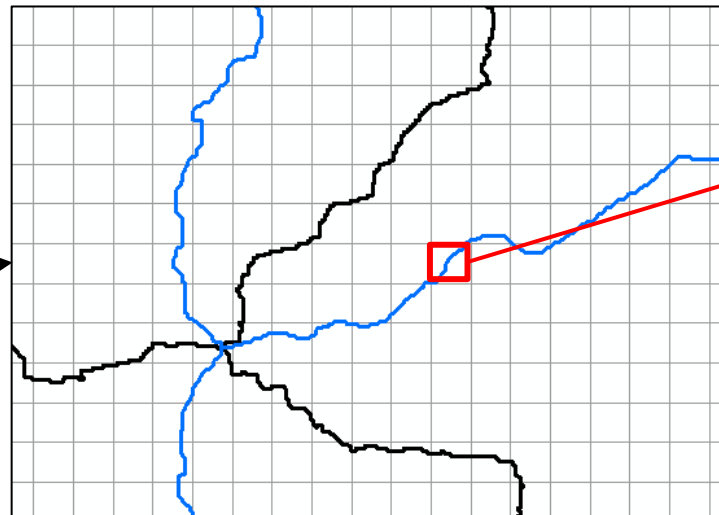
2020-present: Development of *gflow* module for SWAT+

- Physically based spatially distributed groundwater modeling
- Divide the watershed aquifer into discrete “cells” (volumes); quantify groundwater inflows and outflows for each cell
- Cells interact with HRUs (recharge), channels and reservoirs (exchange), irrigated fields (pumping), and channel floodplains (exchange)

Overlay grid



(user decides cell size)



$$\frac{\Delta V}{\Delta t} = \sum Q_{in} - \sum Q_{out}$$

Recharge	Groundwater ET
Lateral flow	Lateral flow
Stream seepage	Pumping
Lake seepage	Discharge to streams
Floodplain seepage	Discharge to lakes
Canal seepage	Discharge to tile drains
	Transfer to soil profile

Update V (and head) for each grid cell, during each time step of the simulation

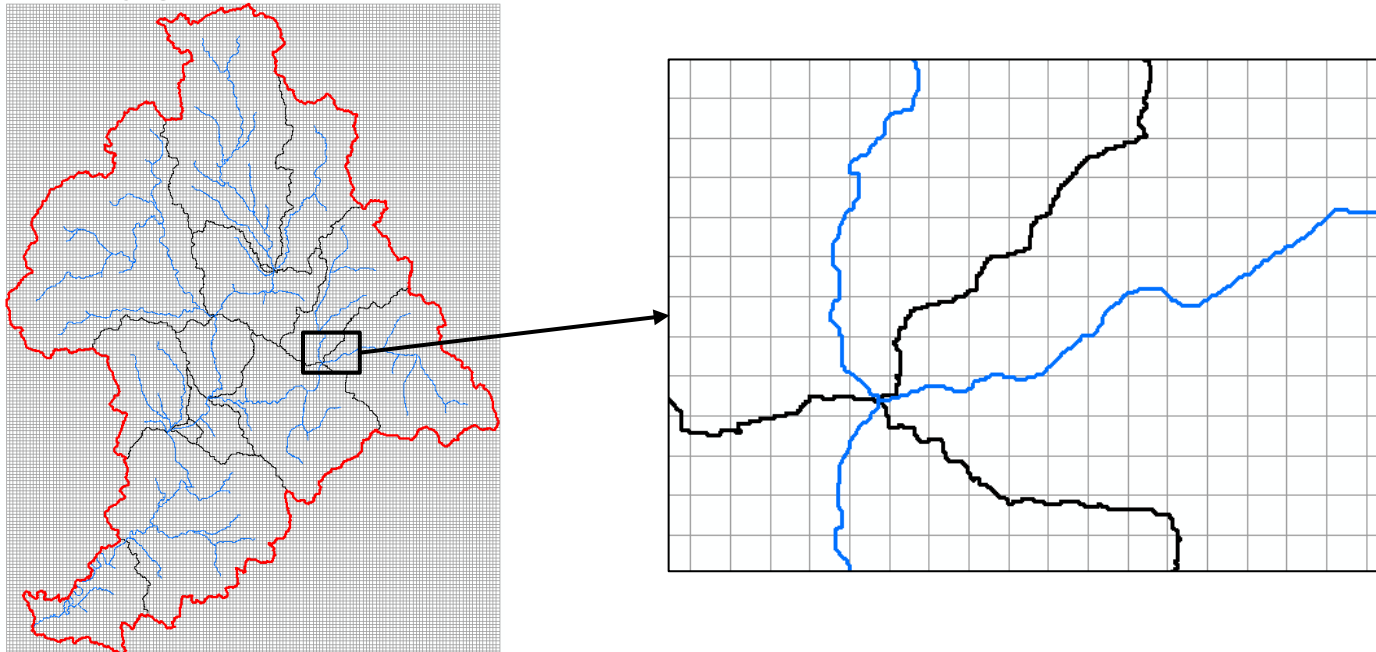
History and Brief Methods Overview



2020-present: **Development of *gflow* module for SWAT+**

- Physically based spatially distributed groundwater modeling
- Divide the watershed aquifer into discrete “cells” (volumes); quantify groundwater inflows and outflows for each cell
- Cells interact with **HRUs** (recharge), **channels** and **reservoirs** (exchange), **irrigated fields** (pumping), and **channel floodplains** (exchange)

Overlay grid



Each cell needs:

- Thickness (ground surface to bedrock)
- Hydraulic conductivity (m/day)
- Specific yield
- Initial groundwater head (m)
- Spatial connections with HRUs, channels, reservoirs

History and Brief Methods Overview



Basic code structure of SWAT+:

Read input files

Read gwflow files (gwflow.input, gwflow.hrucell, gwflow.rivcells, gwflow.rescells)

Annual, daily loops:

command

hru_control (HRUs)

ru_control (Routing Unites)

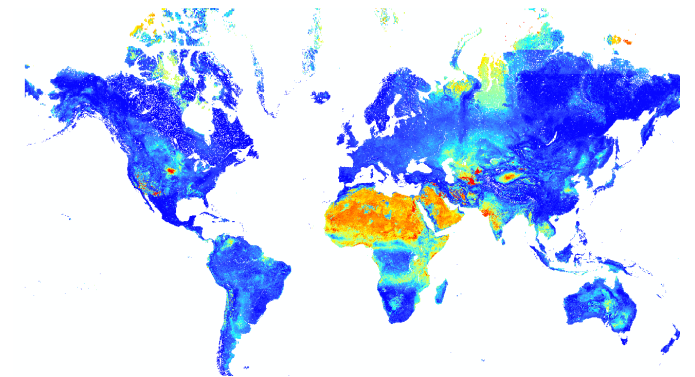
gwflow_simulate: calculate inflows/outflows for each cell; water balance for each cell; update storage and head; write out balances and fluxes

res_control (Reservoirs)

sd_channel_control (Channels)

Tutorial: combination of QGIS, Excel, and text editor



- Create grid
- Populate cell properties (global datasets for aquifer thickness and hydraulic conductivity)
- Perform spatial connections with SWAT+ objects





Article

A New Physically-Based Spatially-Distributed Groundwater Flow Module for SWAT+

Ryan T. Bailey ^{1,*}, Katrin Bieger ² , Jeffrey G. Arnold ³ and David D. Bosch ⁴ 

¹ Dept. of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO 80523, USA

² Blackland Research & Extension Center, Texas A&M AgriLife, Temple, TX 76502, USA; kbieger@brc.tamus.edu

³ Grassland Soil and Water Research Laboratory, USDA-ARS, Temple, TX 76502, USA; jeff.arnold@usda.gov

⁴ Southeast Watershed Research, USDA-ARS, Tifton, GA 31794, USA; david.bosch@usda.gov

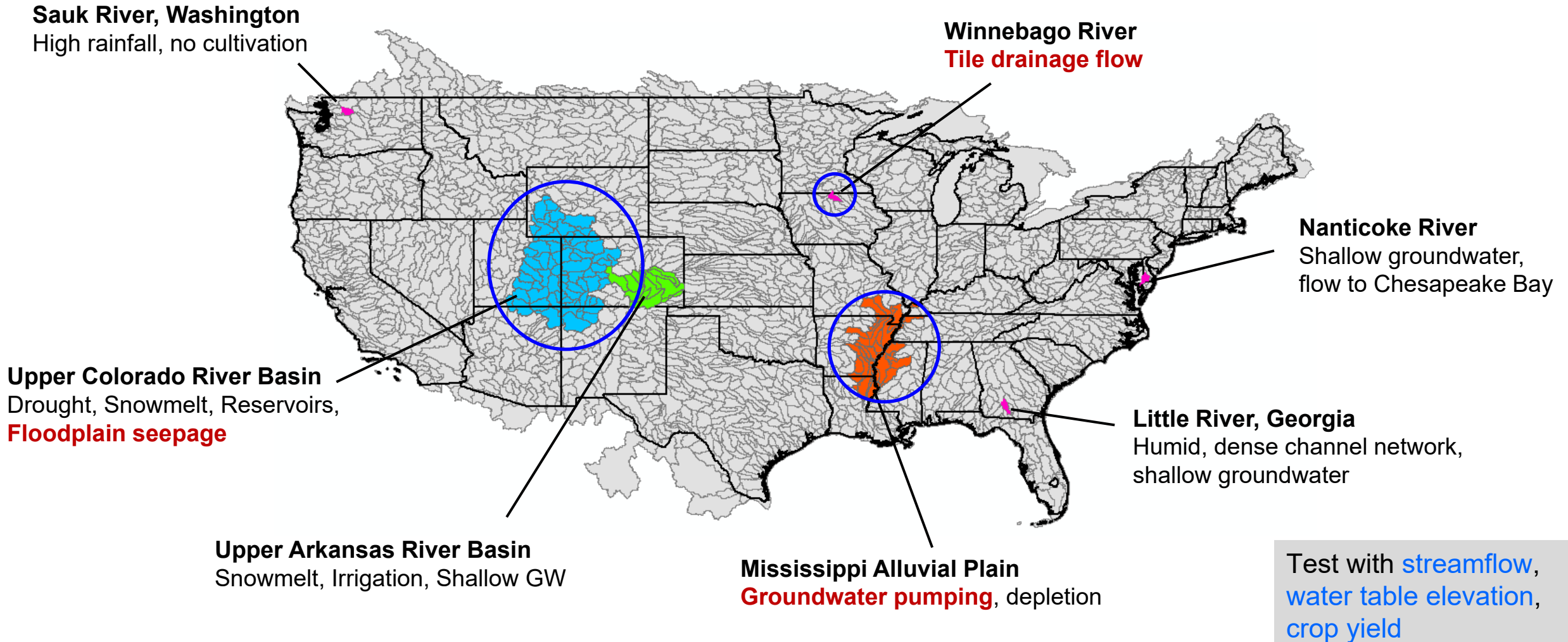
* Correspondence: rtbailey@colostate.edu



Features and Applications



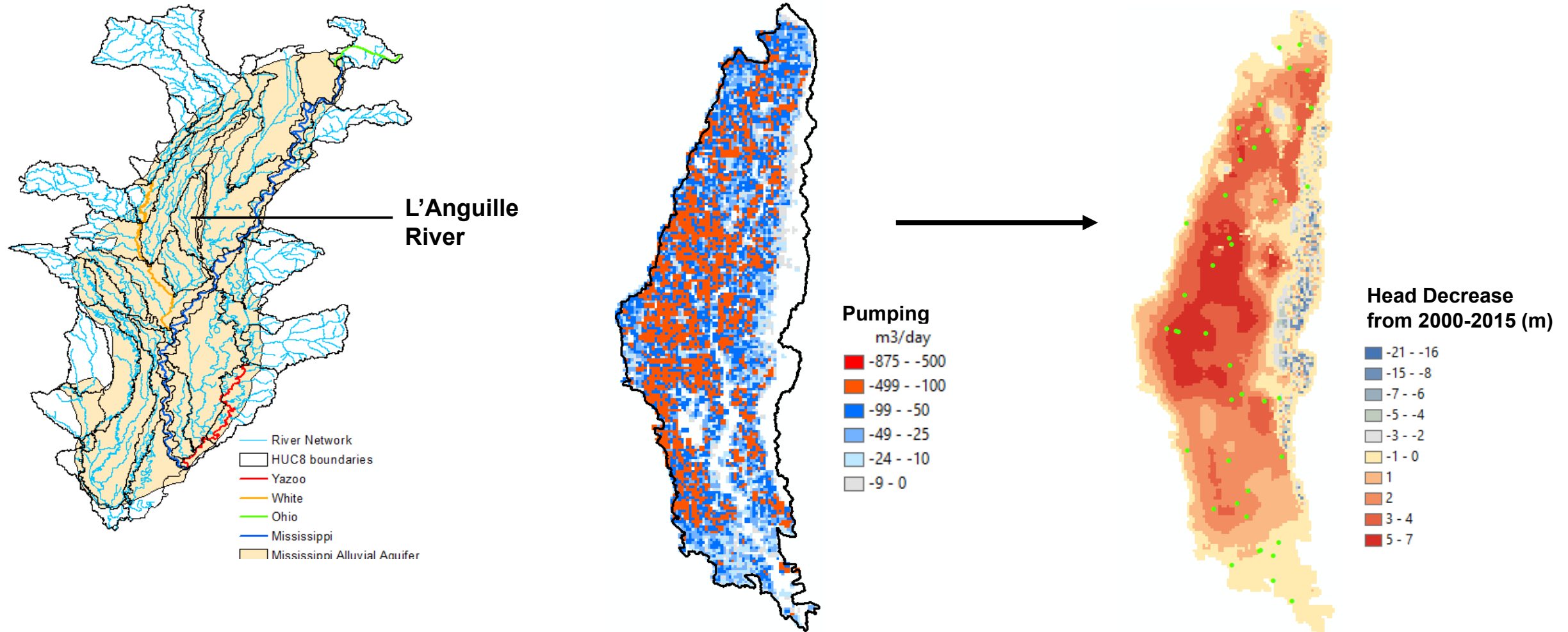
Current Applications (my research group)



Features and Applications



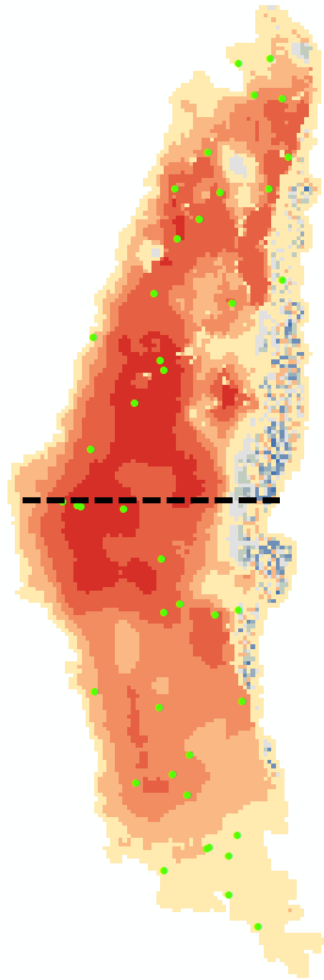
Groundwater Pumping (Mississippi Alluvial Plain)



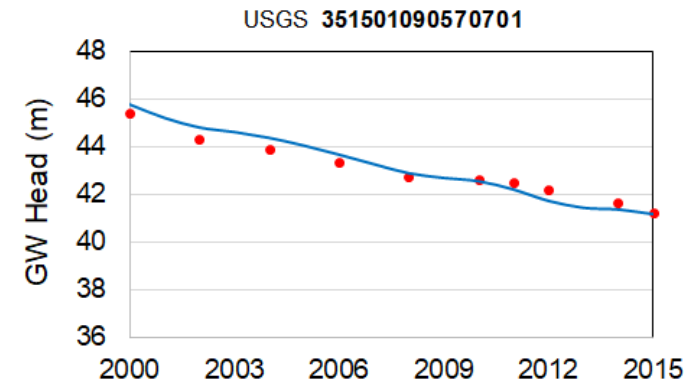
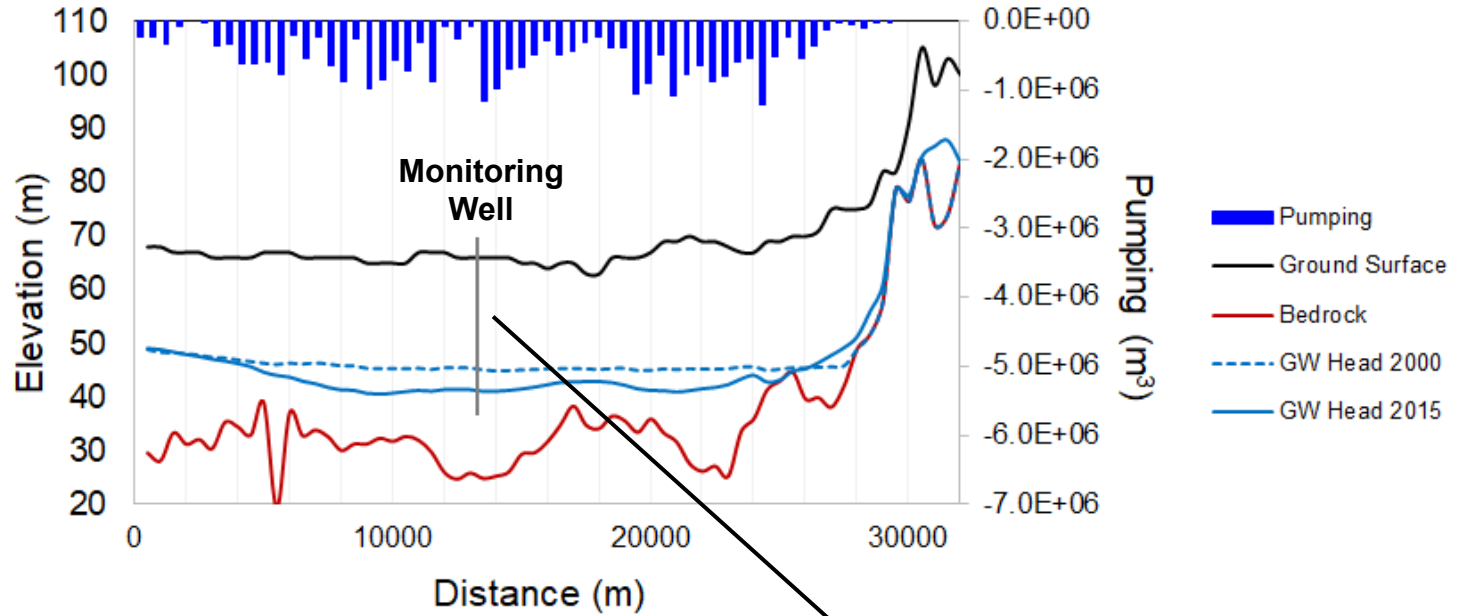
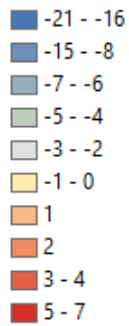
Features and Applications



Groundwater Pumping (Mississippi Alluvial Plain)



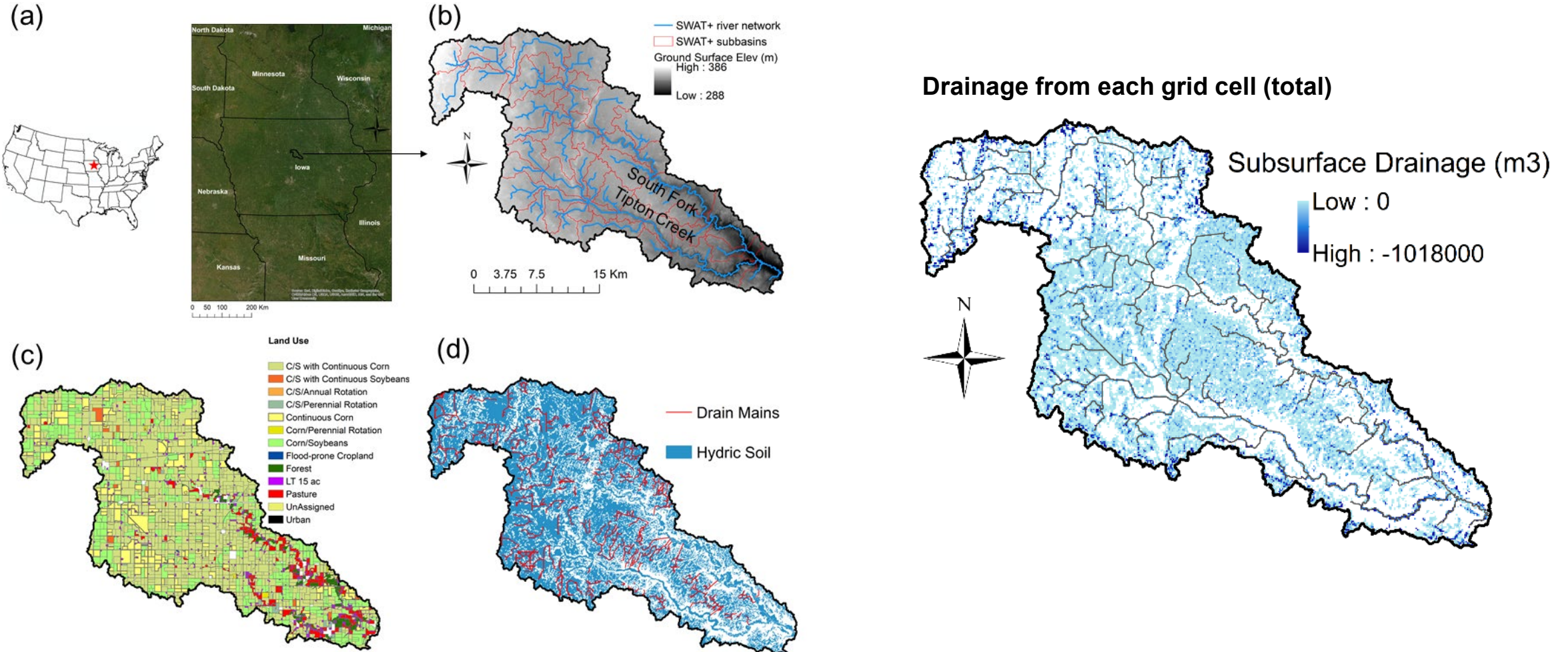
Head Decrease from 2000-2015 (m)



Features and Applications



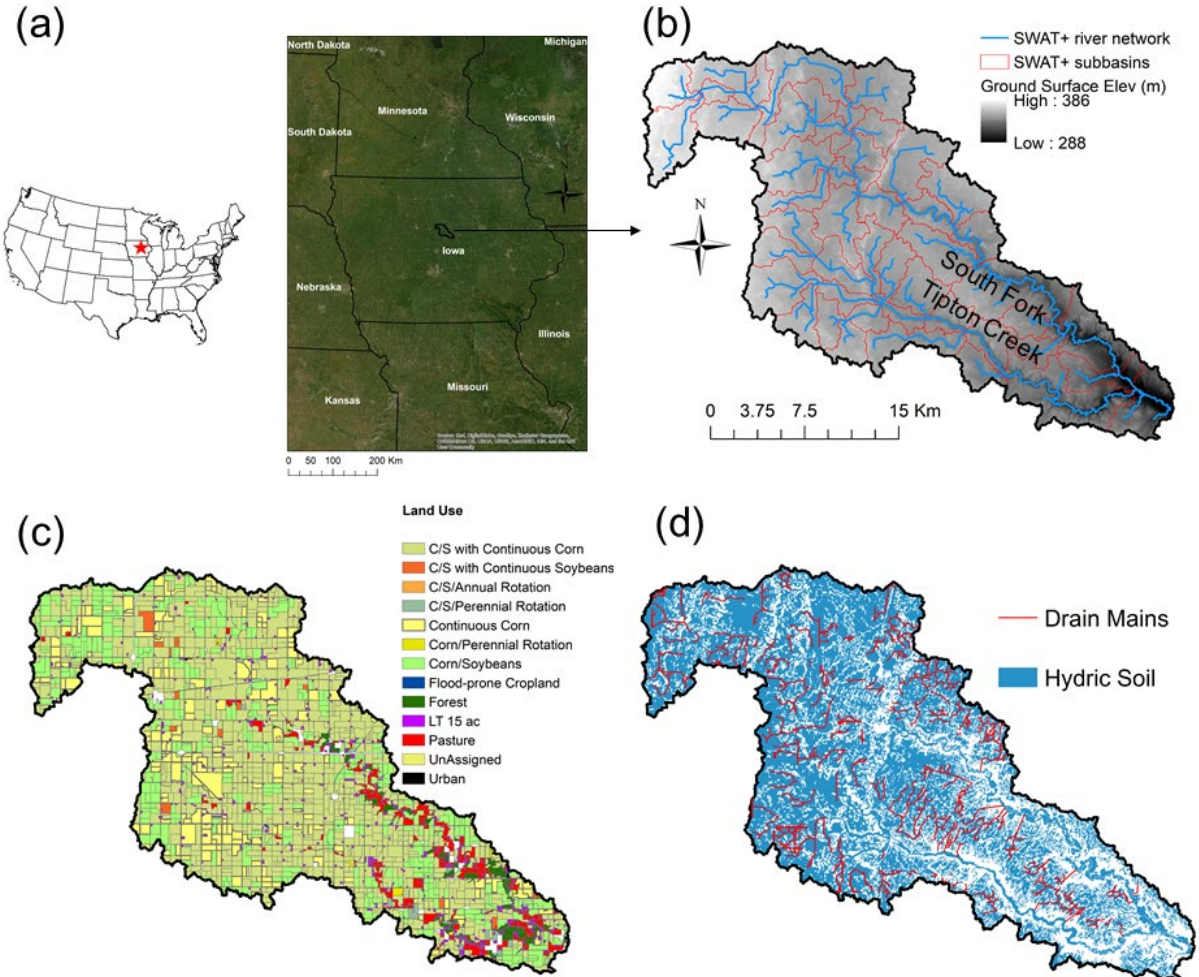
Subsurface Tile Drainage (South Fork, Iowa)



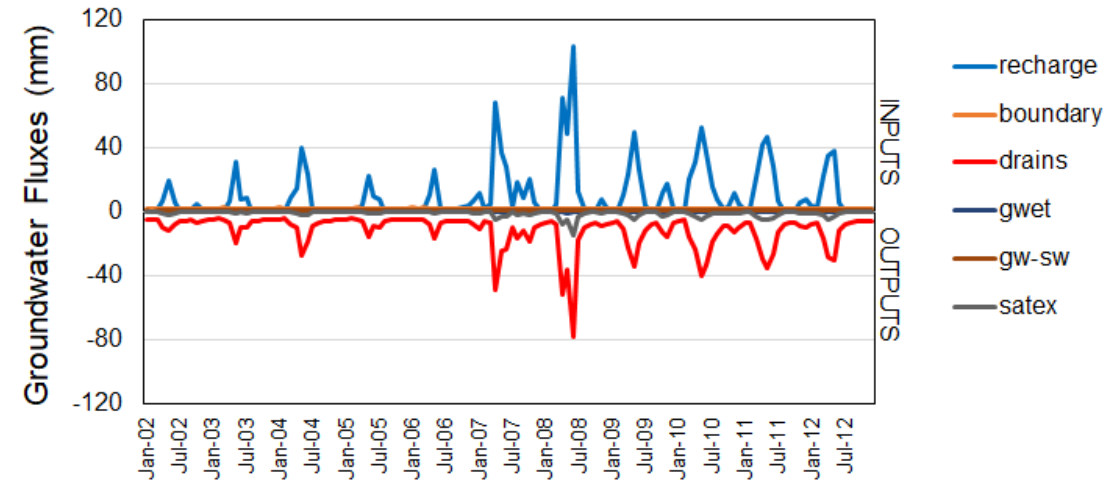
Features and Applications



Subsurface Tile Drainage (South Fork, Iowa)



Daily groundwater fluxes

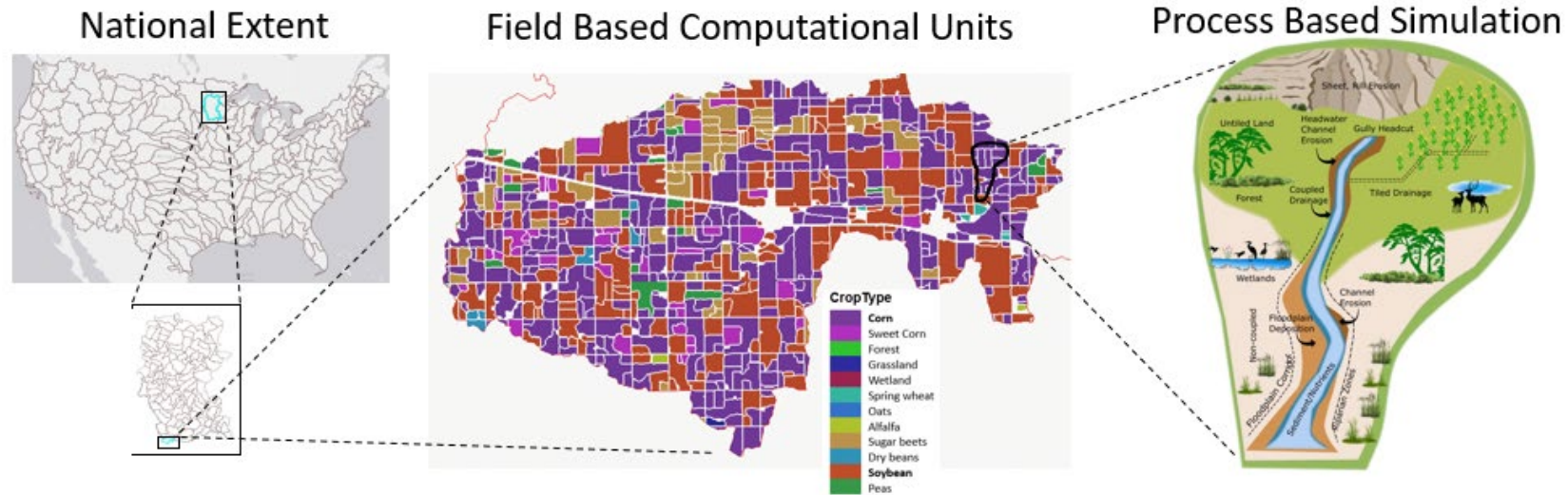


Features and Applications



National-scale application, USA (National Agroecosystem Model)

Jeffrey Arnold, Michael White (USDA-ARS)



Objectives with *gwflow*:

- Improve groundwater flow simulation for watersheds; simulate pumping in irrigated regions
- Apply at the national scale for assessment of land use, land management, water management, and climate on **water supply** and **nutrient loads**.

Features and Applications

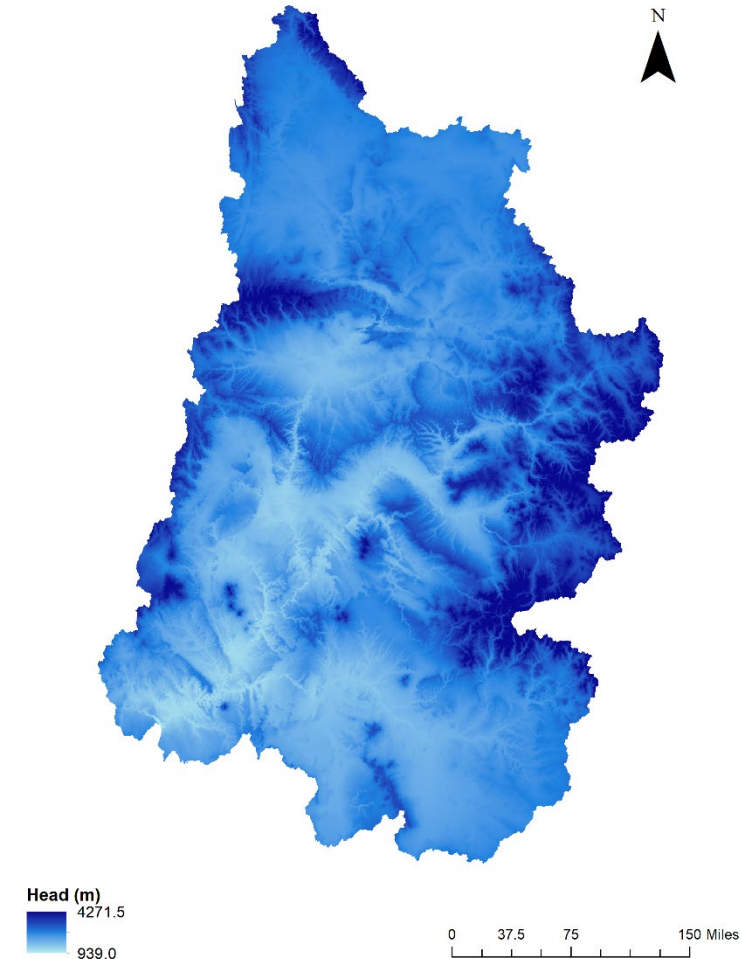


Floodplain-Aquifer Exchange



- Drought
- Climate change
- Irrigation management
- Floodplains

Groundwater head (each grid cell)



Features and Applications

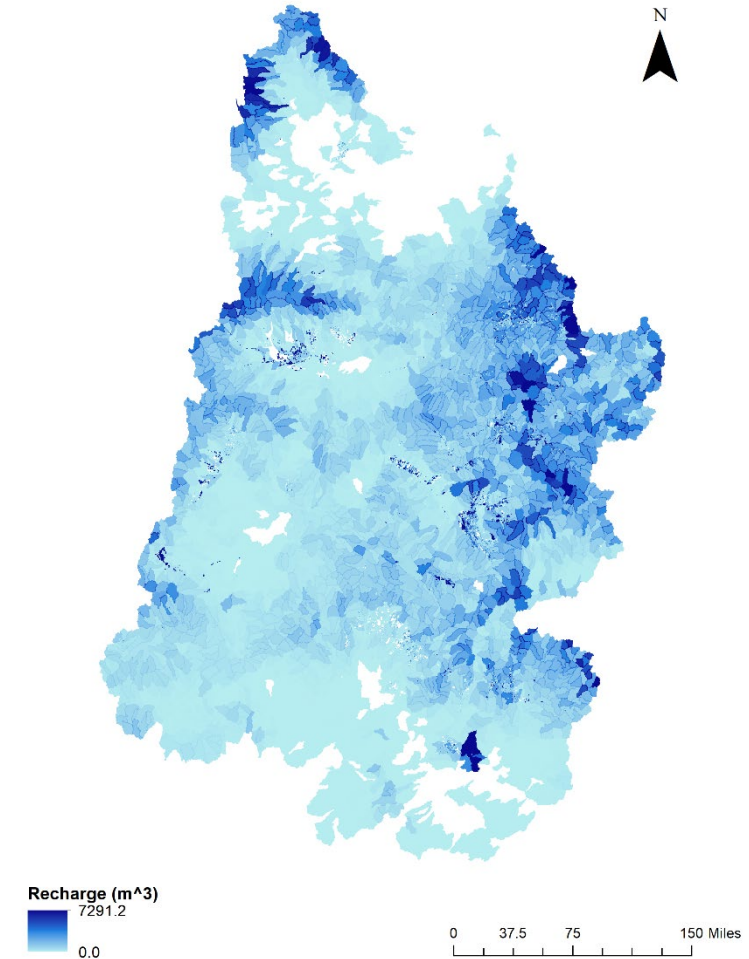


Floodplain-Aquifer Exchange



- Drought
- Climate change
- Irrigation management
- Floodplains

Recharge (from HRUs)



Features and Applications

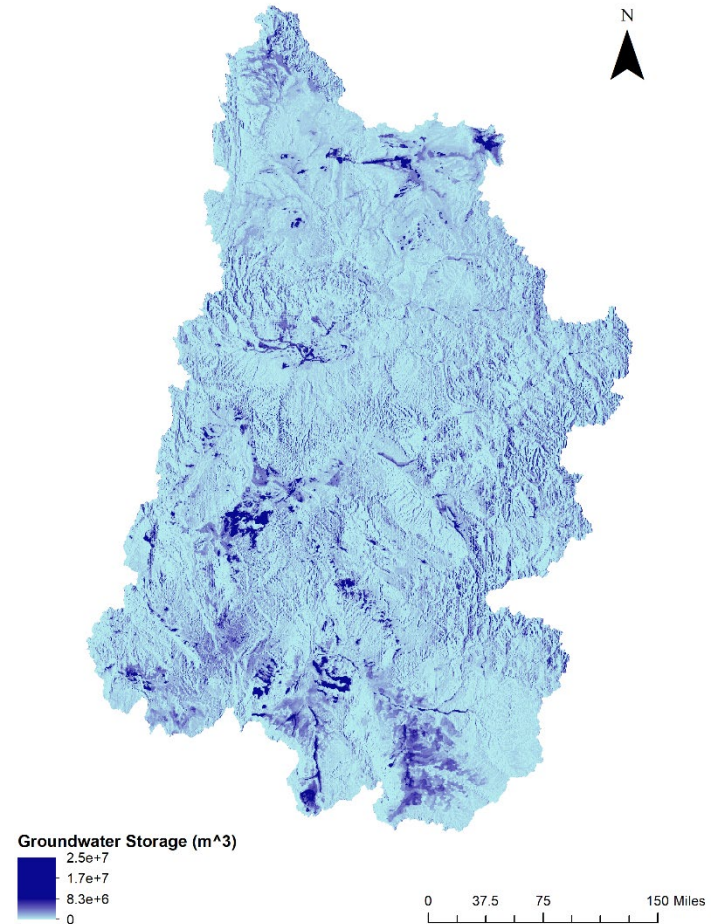


Floodplain-Aquifer Exchange



- Drought
- Climate change
- Irrigation management
- Floodplains

Groundwater Storage



Features and Applications

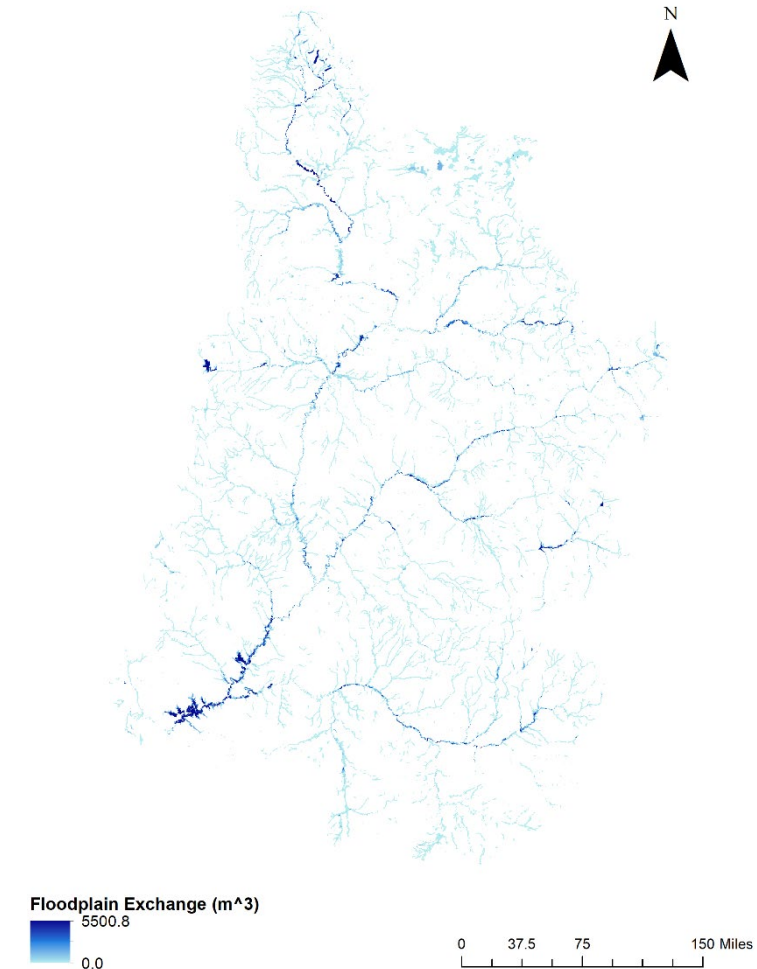


Floodplain-Aquifer Exchange



- Drought
- Climate change
- Irrigation management
- Floodplains

Floodplain exchange (recharge)



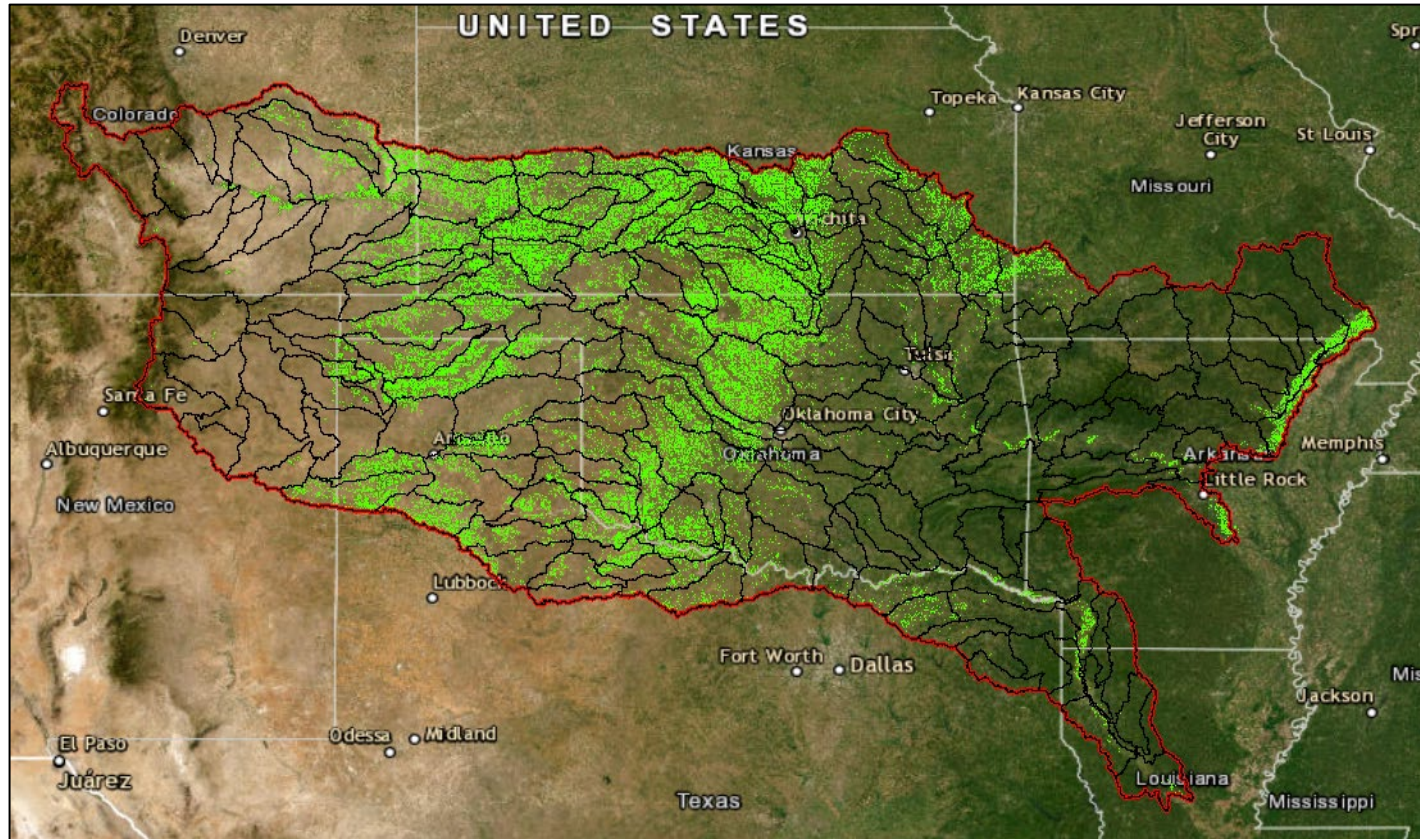
Features and Applications



National-scale application, USA (National Agroecosystem Model)

Jeffrey Arnold, Michael White (USDA-ARS)

Arkansas-White-Red Region (11)



- SWAT+ models have undergone “soft” calibration (water balance data)
- Prepared *gwflow* inputs
- Preliminary simulation: 2000-2002
- Irrigation for each field: streams or groundwater; extensive groundwater pumping



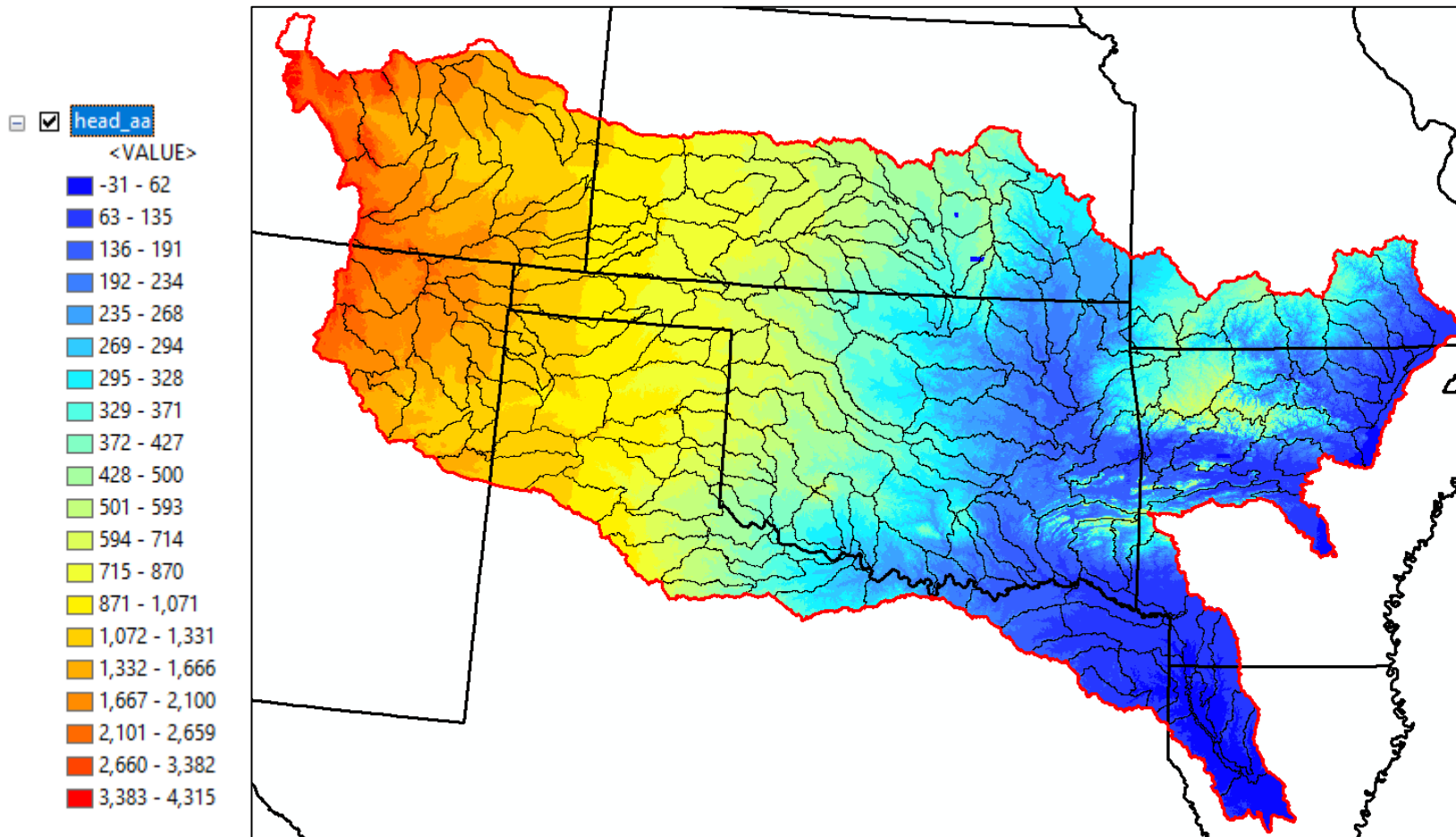
Features and Applications



National-scale application, USA (National Agroecosystem Model)

Jeffrey Arnold, Michael White (USDA-ARS)

Arkansas-White-Red Region (11)



Water Table Elevation (m)

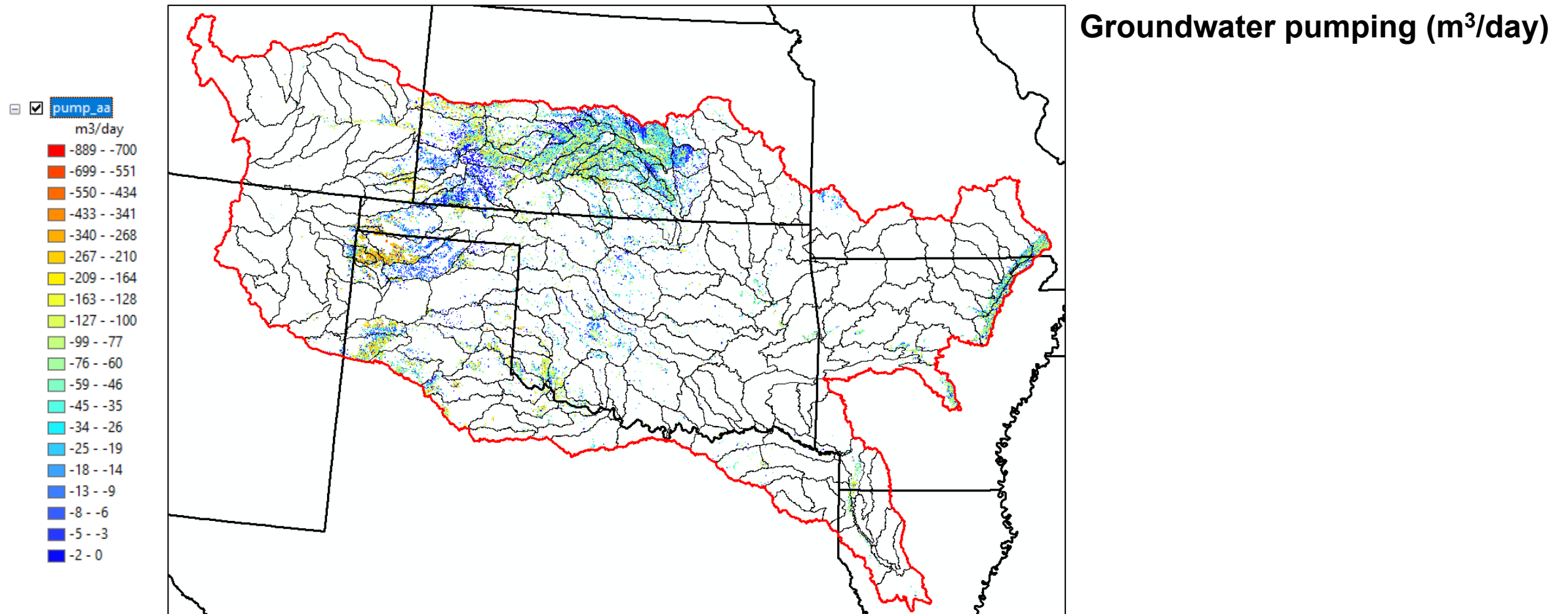
Features and Applications



National-scale application, USA (National Agroecosystem Model)

Jeffrey Arnold, Michael White (USDA-ARS)

Arkansas-White-Red Region (11)





- Many thanks to SWAT+ developers
- Please let me know if you need help with *gflow*! (rtbailey@colostate.edu)

Thank you!

