An Integrated Hydrologic Model to Assess the Impact of Conservation Practices and Programs on Groundwater Resources for the Northern High Plains Aquifer in Central Nebraska

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Rainwater Basin Joint Venture
Informational Seminar
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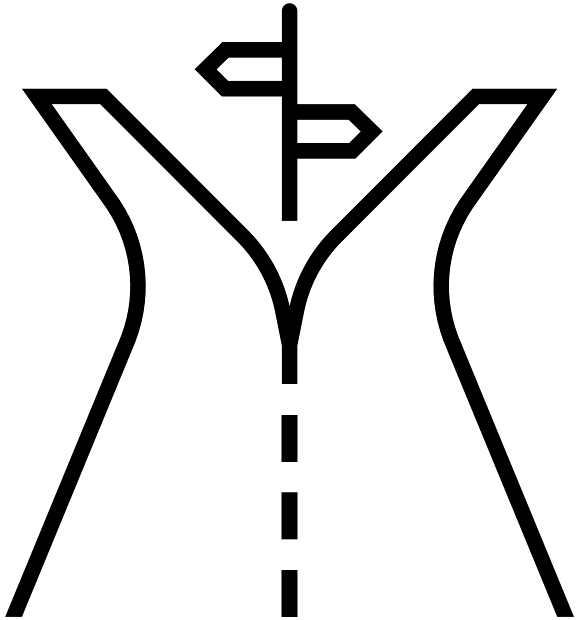
U.S. Department of the Interior
U.S. Geological Survey

Outline

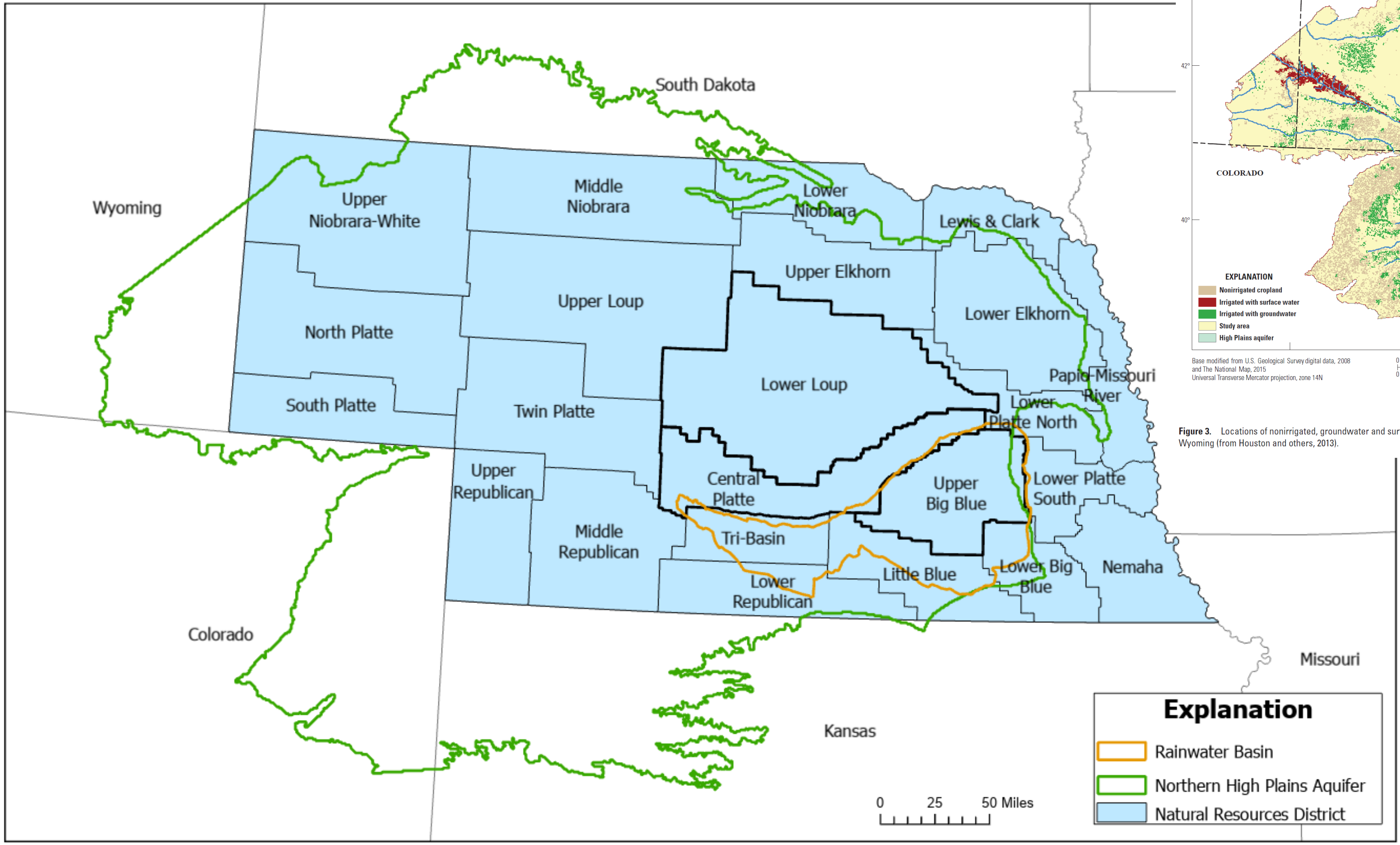
- Background
- Issues and Questions
- Project Objectives and Scope
- Technical workflow
- Outcomes, Key Results, and Products
- Potential uses
- Summary



Project Background

- **Collaboration with USGS Earth Resources and Observation Science Center (EROS)**
  - Leveraging EROS land use forecasting capabilities to improve modeling framework
  - Incorporating water availability into land use forecasting
- **Partnering with Rainwater Basin Joint Venture (RWBJV)**
  - Leverage the U.S. Geological Survey (USGS) numerical modeling capabilities to help RWBJV maximize impact with wetlands conservation/management
- **Collaboration with University of Nebraska-Lincoln (UNL)**
  - Leverage technical expertise and Farm Service Agency (FSA) funding to study the impact of the Conservation Reserve Program on High Plains aquifer health
- **Funding:**
  - Awarded Conservation Collaboration Cooperative Agreement (CCCA) grant via the U.S. Department of Agriculture – Natural Resources Conservationist Service (USDA NRCS)
  - RWBJV contribution
    - USGS Central Plains Water Science Center (CPWSC)
    - USGS Earth Resources and Observation Science Center (EROS)
- **Cooperators:**
  - RWBJV, NRCS, Nebraska Department of Natural Resources (NeDNR); and Central Platte, Lower Loup, and Upper Big Blue Natural Resources Districts (NRDs)

Study Area: Northern High Plains



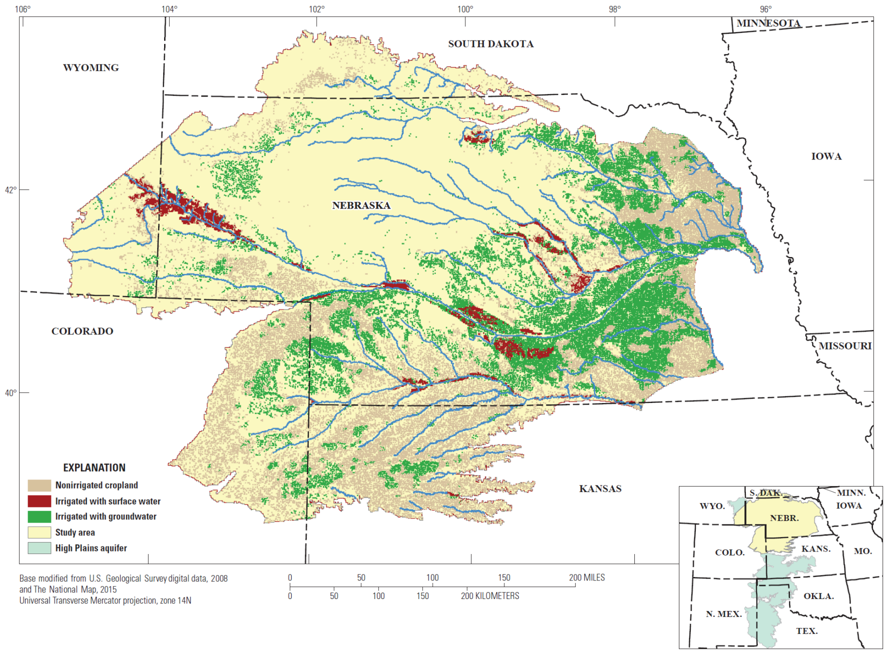


Figure 3. Locations of nonirrigated, groundwater and surface-water irrigated lands in 2008 for Northern High Plains aquifer, Colorado, Kansas, Nebraska, South Dakota, and Wyoming (from Houston and others, 2013).

From Peterson and others, 2016

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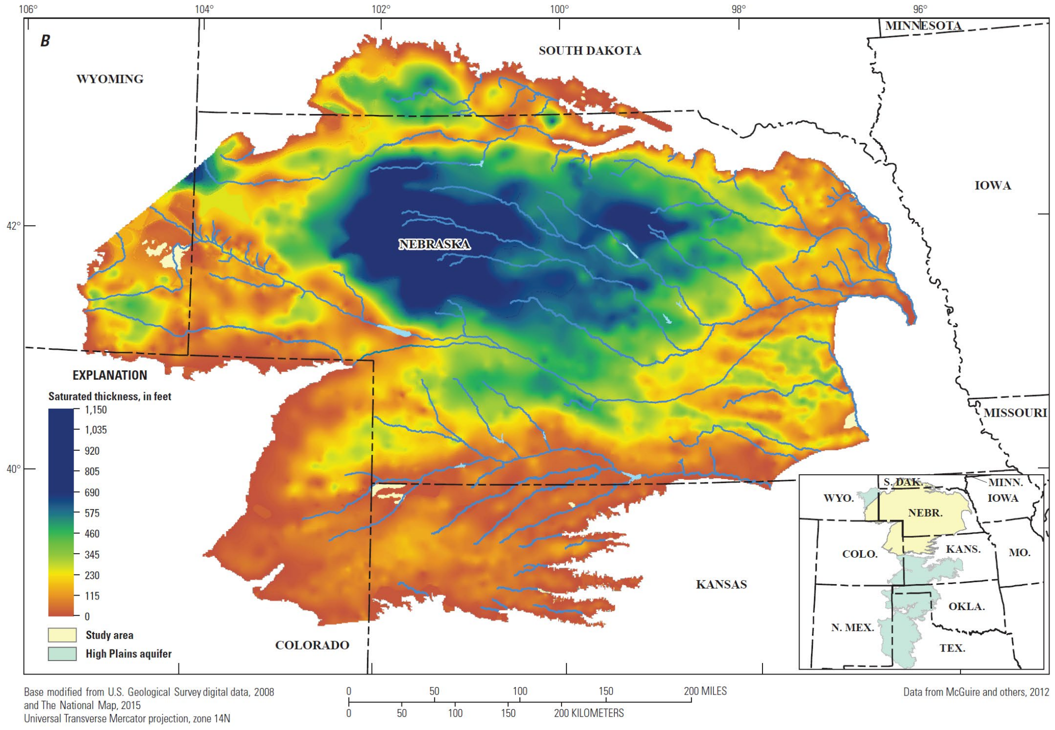
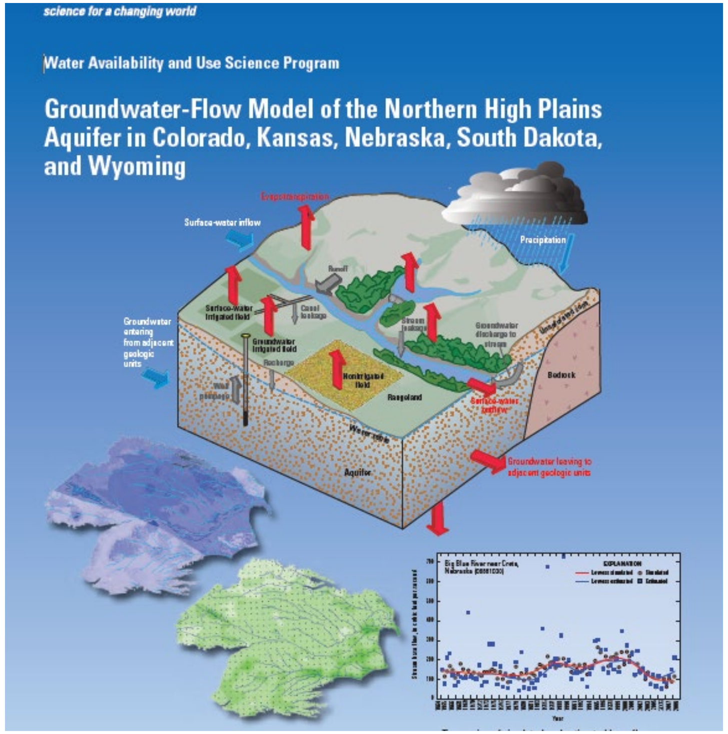
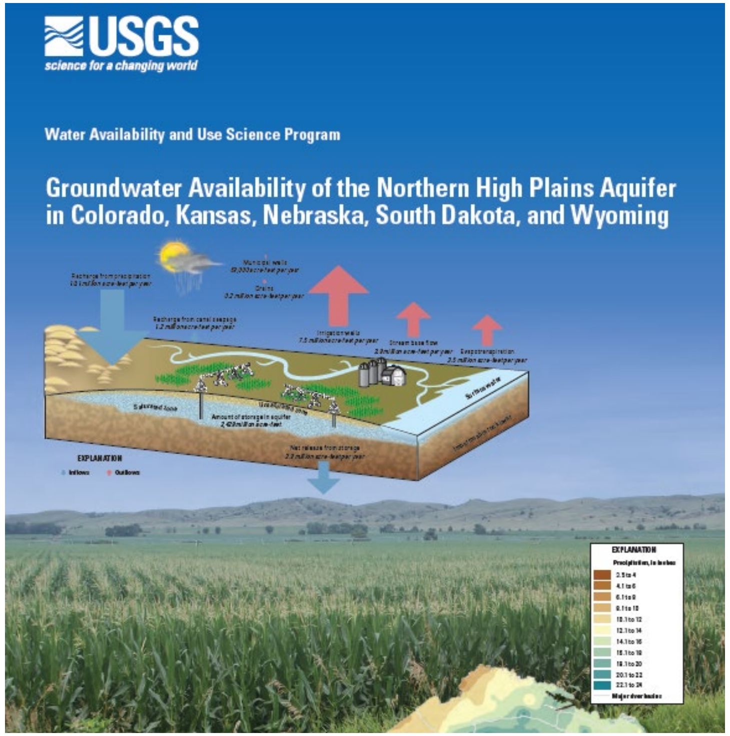
Previous Study: Northern High Plains aquifer groundwater-flow model

- U.S. Geological Survey model (Peterson and others, 2016; 2020)
- Historic simulation period 1940-2009
- Forecast scenario simulation period 2009-2050
- <u>Large, regional aquifer scale</u>, climate and land use forecast examples of impacts on:
  - Base flows, groundwater in storage, and water use/availability
- Model framework requires update to better answer management questions

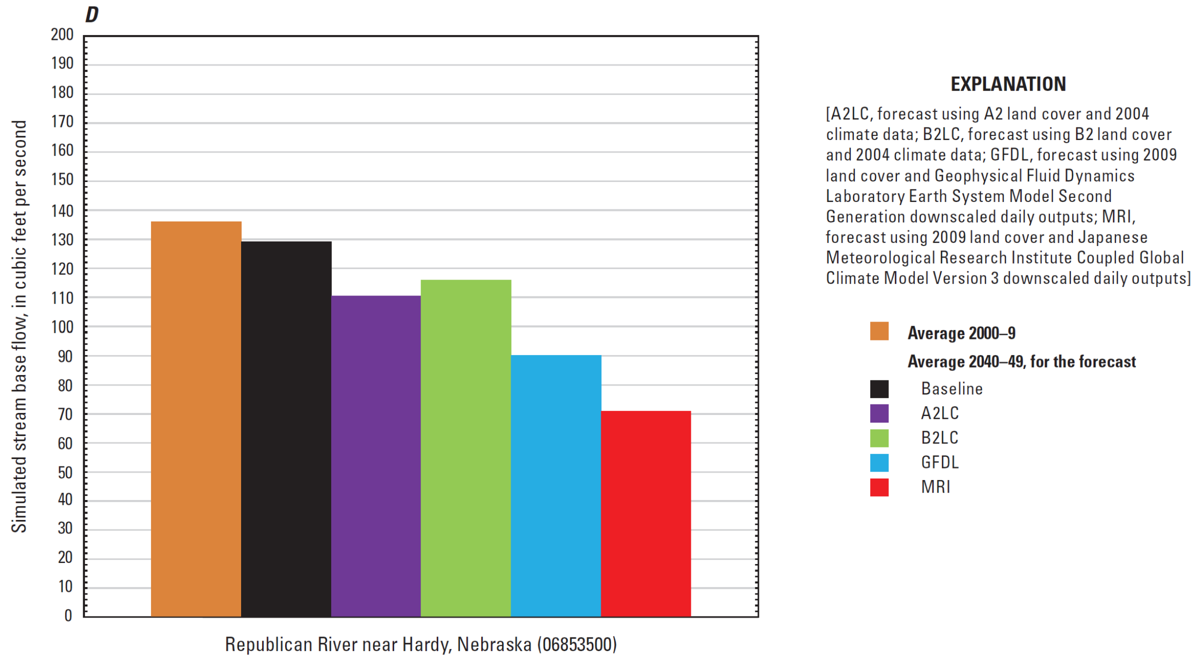


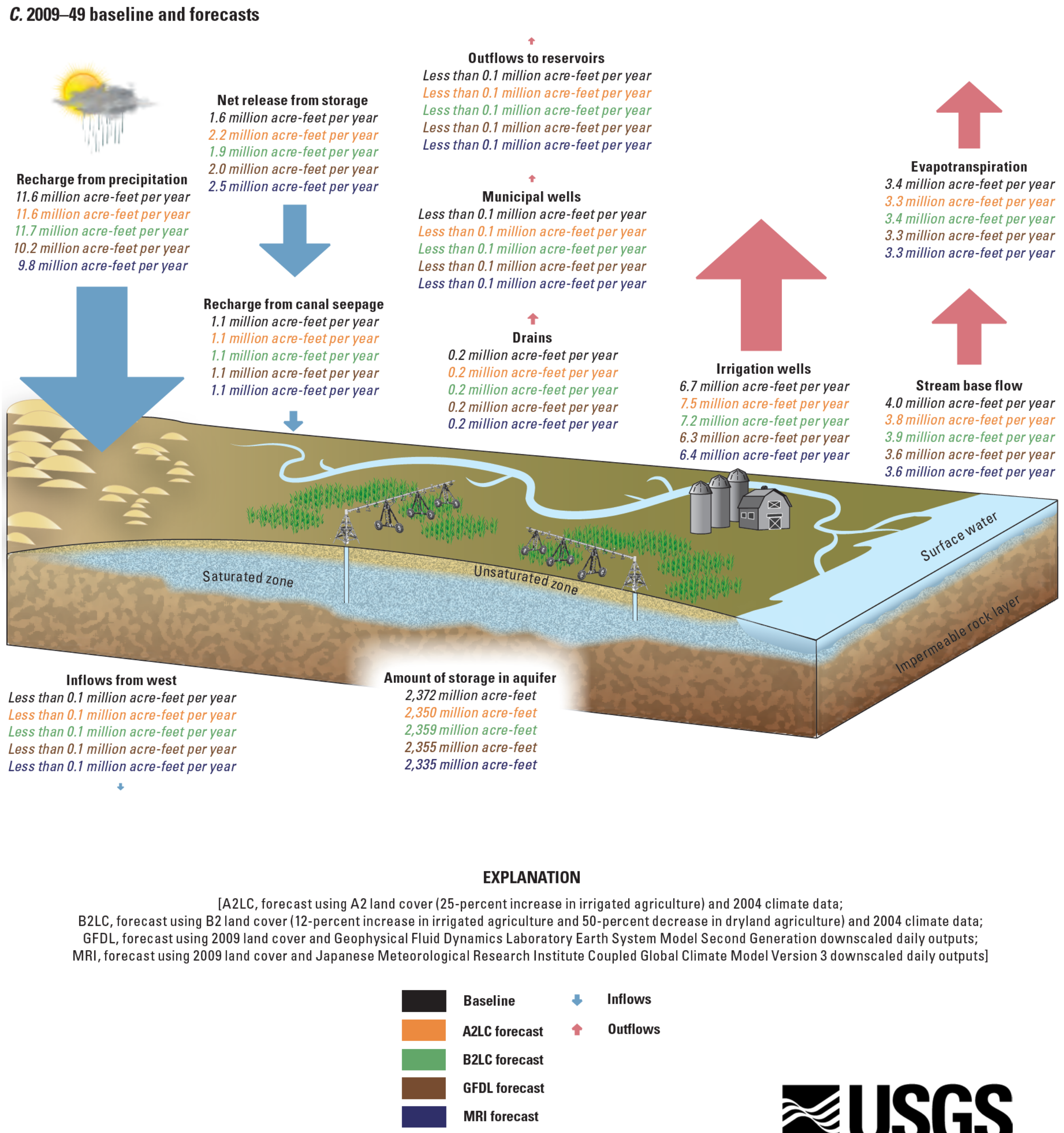




Previous Study: Results

- Forecasts included:
  - Baseline scenario (constant historic average climate and land use)
  - Two alternate climate scenarios (GFDL, MRI)
  - Two alternate land use scenarios (A2LC, B2LC)
- Forecast water budgets for each scenario (**right**)
- Forecast base flows by basin (**below**)





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Issues and knowledge gaps

- NRCS
  - No tools to assess the “before and after” impact of conservation programs on aquifer health/nitrate
- RWBJV
  - No tools available to understand how climate, cropping systems, and irrigation water use will affect wetland conditions in row crop agriculture-dominated landscape
- NRDs
  - No tools available to assess how management strategies can affect groundwater nitrate concentrations

https://waterforfood.nebraska.edu/news-and-events/news/2023/08/nitrate-management-in-nebraska-community-water-systems-is-a-complex-issue
https://nebraskapublicmedia.org/en/news/news-articles/nebraskas-nitrate-problem-is-serious-experts-say-can-we-solve-it/
https://outdoornebraska.gov/wp-content/uploads/2023/06/Wetland-Program-Plan_Nebraska_2015_Final.pdf

Example Science Questions

- NRCS
  - What extent do NRCS conservation programs need to be implemented to reduce groundwater nitrate in wellhead protection areas?
    - Goal: Improve drinking water quality in agricultural areas
- RWBJV
  - How will future climate, land use, and water use affect the distribution of wetlands in central Nebraska?
    - Goal: Better prioritize future wetland management
- NRDs
  - How will water quality management strategies affect future groundwater nitrate concentrations?
    - Goal: Better understand and manage water resources

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Project Objectives and Scope

Objectives

- Address habitat and water quality science questions for each cooperator using state-of-the-science computer modeling tools

Scope

- Develop an integrated hydrologic modeling tool for the Northern High Plains (NHP) aquifer
- Simulate recent historic conditions (2009-2023)
- Simulate future land use, water use, and climate impacts on hydrologic system (2024-2099)

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Project Engagement and Communication

- Technical Committee
  - Meet every ~2 months
  - Subset of technical experts from NRCS, RWBJV, Nebraska Department of Natural Resources (NeDNR), and Nebraska NRDs.
  - Broad-level technical topics such as datasets and model scenarios
- Strategic Partners and Cooperators
  - Meet every ~6 months
  - Subset of leadership from NRCS, FSA, NRDs, NeDNR, and Nebraska Department of Agriculture
  - Focus on higher-level progress updates and direction

Core Research Team

- Central Plains Water Science Center (CPWSC)
  - JP Traylor, Hydrologist, Lead Groundwater Modeler, *Project Lead*
  - Moussa Guira, Hydrologist, Lead Groundwater Modeler
  - Jace Kaminski, Physical Scientist
- EROS
  - Terry Sohl, Research Physical Scientist, Integrated Science and Applications Branch Chief
  - Greg Rouze, Research Physical Scientist
  - Jordan Dornbierer (contractor)
  - Michael Allen (contractor)
- UNL
  - Dr. Tirthankar Roy, Assistant Professor of Civil Engineering
  - Dr. Dan Uden, Assistant Professor School of Natural Resources
  - Layda Spor Leal, PhD student
  - Dilli Ram Bhattarai, PhD student

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Foundational tool: Living model (trunk of the tree)

- Not trying to build competing model,
  - Complementary to existing models
- Use latest techniques and methods
- Expand capability
- Can address other hydrologic questions down the road

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Technical workflow

- Update northern High Plains (NHP) groundwater-flow model from Peterson and others (2016; 2020)
- Create three-part model
- Calibrate to observations
- Build forecast scenarios to address cooperator questions

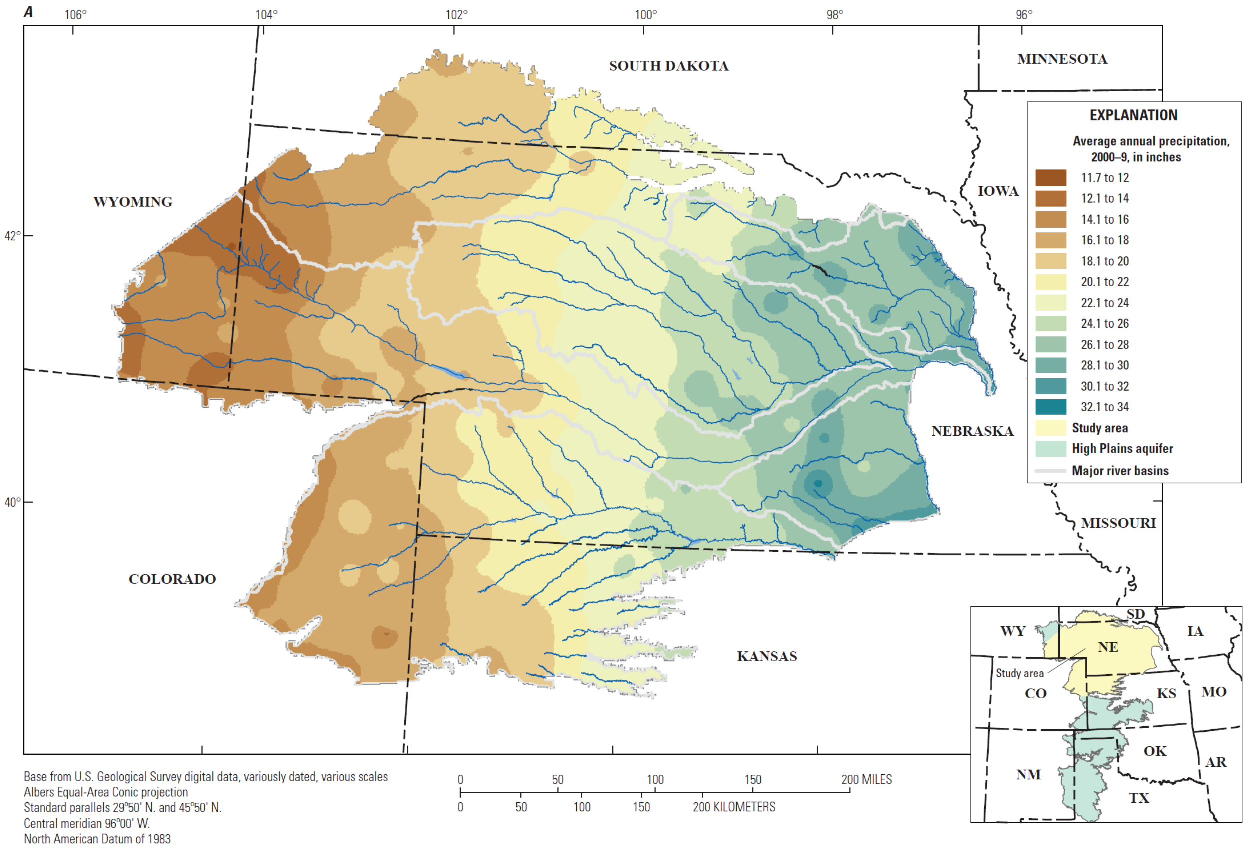

Figure 2. The distribution of precipitation for the Northern High Plains aquifer. *A*, average annual precipitation for 2000–9; *B*, precipitation for the 2002 growing season (May 1–September 30); *C*, precipitation for the 2009 growing season.

From Peterson and others, 2020

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Northern High Plains Integrated Hydrologic Model (NHPIHM)

FOREcasting SCEnarios of Land Use Change (FORE-SCE)

Landcover/land use

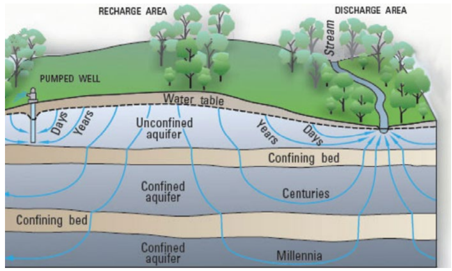
(FORESCE)

Soil Water Assessment Tool Plus (SWAT+)

Watershed/Soil

(SWAT+)

Modular Hydrologic Model (MODFLOW 6)



Groundwater

(MODFLOW 6)

Looped back to account for future conditions

Land use from https://www.lib.ncsu.edu/gis/lulc
Watershed from https://ldpwatersheds.org/understanding-our-watershed/watershed-u/what-is-a-watershed/
Groundwater from https://www.usgs.gov/media/images/conceptual-groundwater-flow-diagram

Requires coordination with strategic partners and cooperators

- Critical to model development
- To improve utility of model
- Forecast scenario land use dataset
  - Local management expectations included → more accurate land use dataset → more accurate simulation of crop water demand → more useful scenario results

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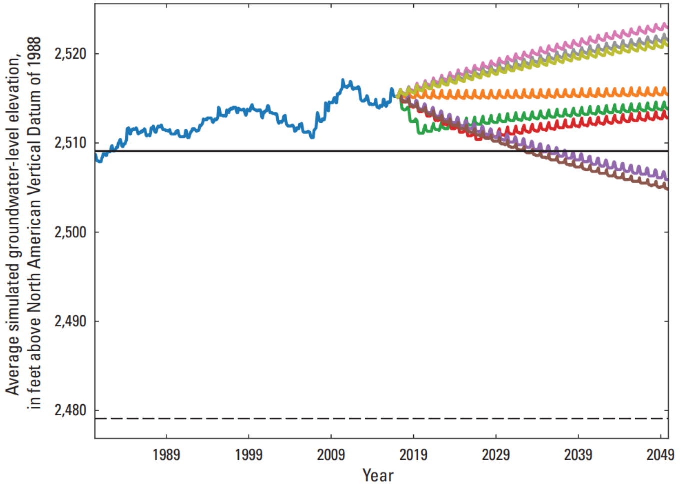
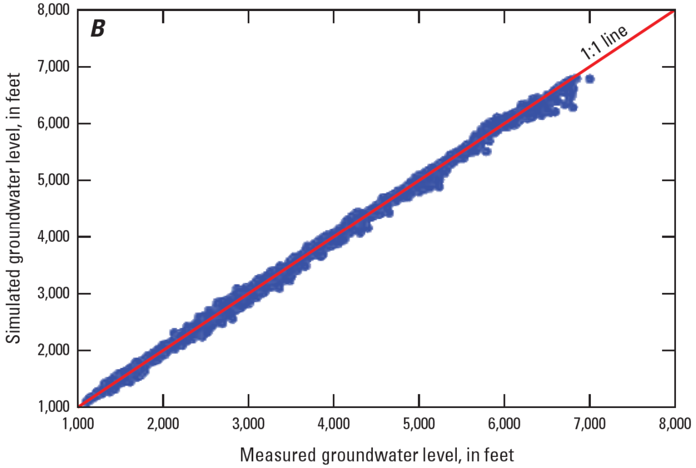
NHPIHM simulation periods



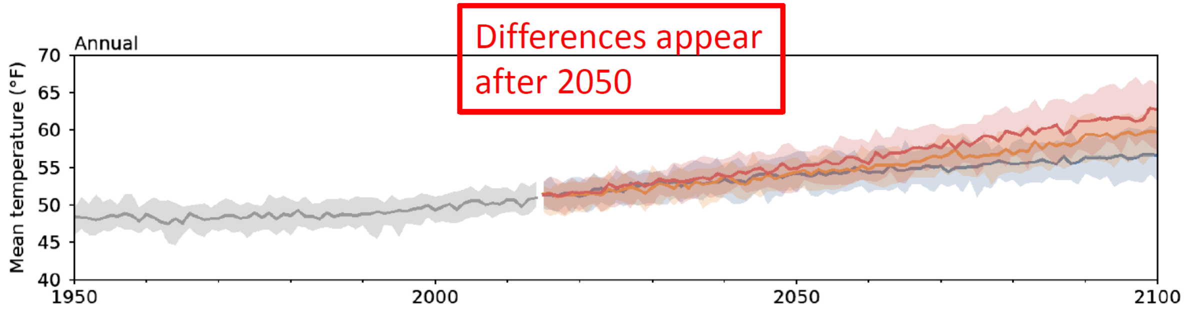
Calibration: May 1, 2009 – December 31, 2023



Forecast scenarios: January 1, 2024 – December 31, 2099

Figures from Traylor and others, 2023

Climate Scenarios



- <u>Every forecast scenario</u> requires climate inputs to the FORE-SCE and SWAT+ models
  - Downscaled GCMs → Coupled Model Intercomparison Project 6th Phase (CMIP6)
  - From Intergovernmental Panel on Climate Change (IPCC)

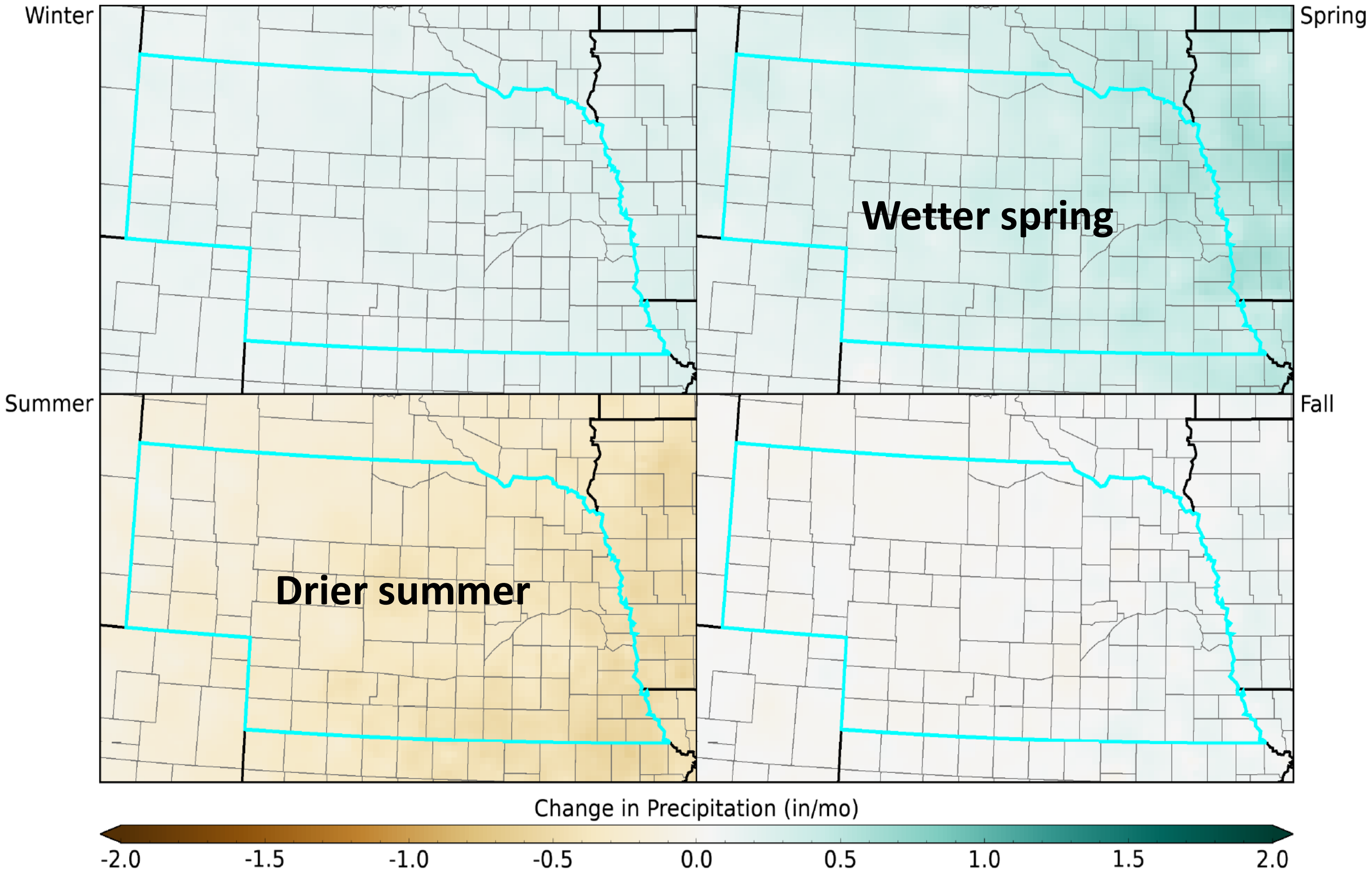


Figure 23: Seasonal maps of precipitation for ssp585 2050-2074 minus 1981-2010 for the ensemble mean of all CMIP6 models.

https://www.usgs.gov/tools/national-climate-change-viewer-nccv

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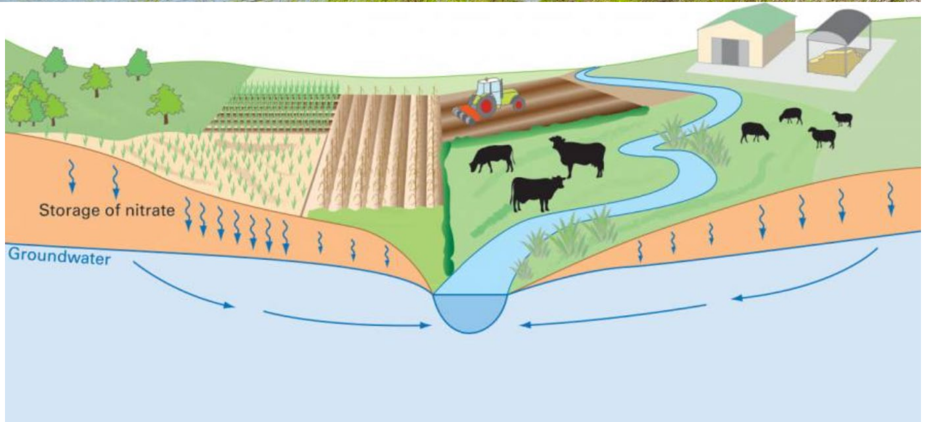
Conservation/Management Scenarios

- NRCS
  - Implementing NRCS conservation practices to see impact on groundwater nitrate concentrations in wellhead protection areas
- RWBJV
  - Wetland distributions in areas with hydric soils under future climate and water availability
- NRDs
  - Implementing NRD management practices to see impact on groundwater nitrate concentrations in phase areas
  - Example: Simulate 50 percent reduction in fertilizer application in NRD Water Quality Phase Areas using SWAT+, changes in nitrate leaching to groundwater passed to MODFLOW 6 → simulate changing nitrate concentrations through time and space



Pictures from https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives/news/nrcs-seeks-public-comment-on-8
https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/nebraska/news/nrcs-providing-funds-to-protect-and-restore
https://www.bgs.ac.uk/geology-projects/nitrate-time-bomb/

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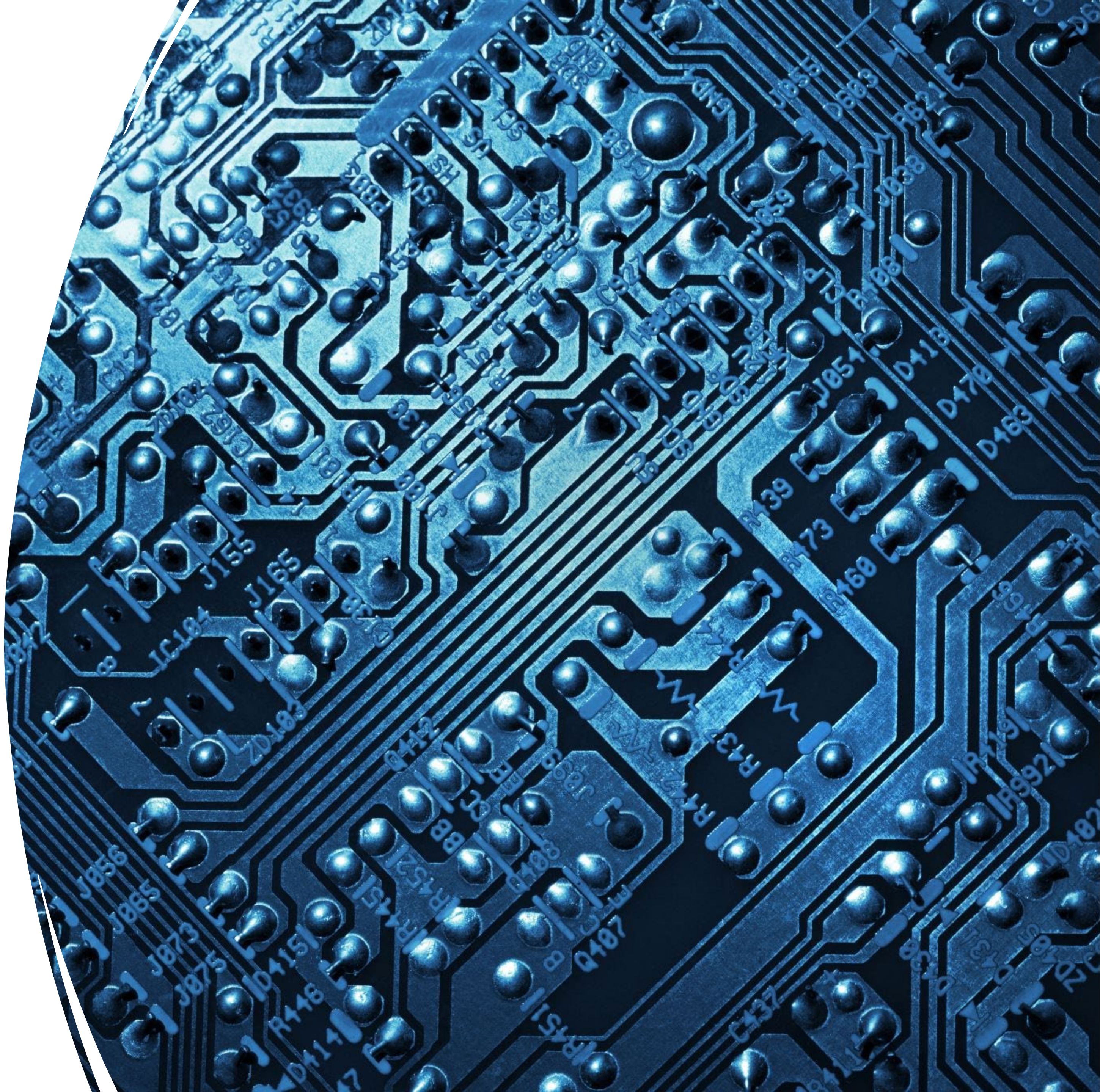
Appropriate scale of model application

- Spatial
  - Local: County or management area
  - Intermediate: Multi-county, NRD, RWB
  - Regional: Large watershed to NHP aquifer extent
- Temporal
  - Intermediate to long term
  - Intermediate/long time periods (multi-year, decadal, and longer)
  - Intermediate/long term trends (monthly for simulation period, etc.)

Overview of the models

- FOREcasting SCEnarios of Land use change model (FORE-SCE)
- Soil Water Assessment Tool Plus (SWAT+)
- Modular Hydrologic Model version 6 (MODFLOW 6)



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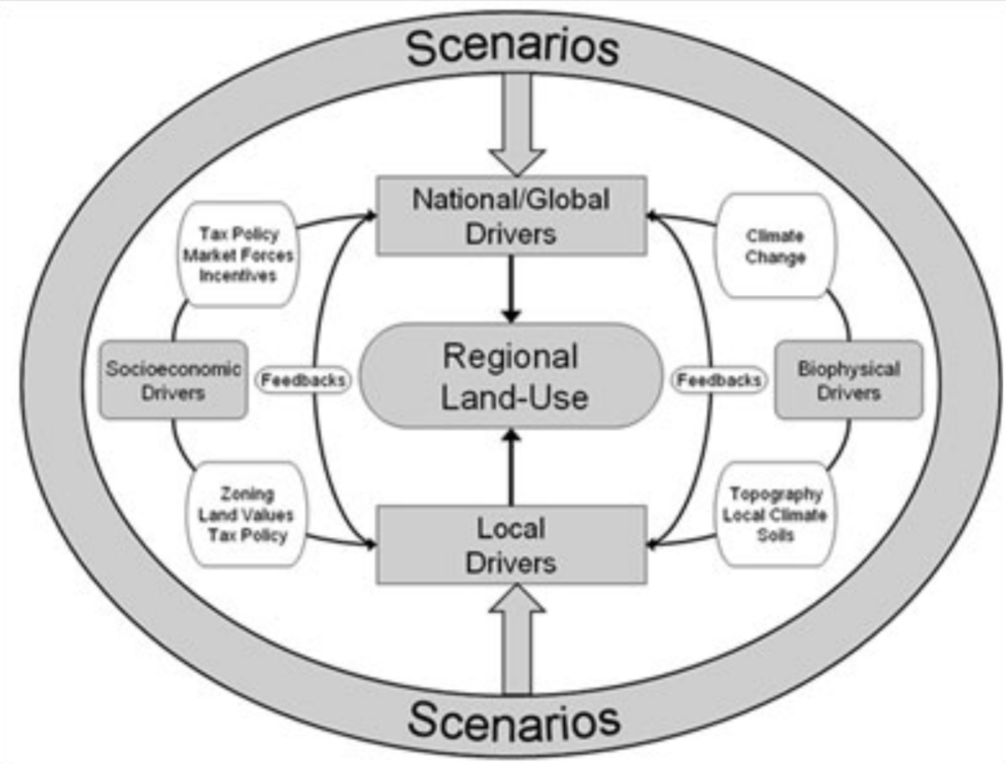
FOREcasting **SCE**narios of Land-use Change (FORE-SCE) (Sohl and others, 2019)

- Model projects forecasts of land-use and land-cover (LCLU) change
- "Top-down" and "bottom-up" approach
  - Large scale climate and physical drivers
  - Local scale LCLU trends
- Parcel/field scale
- LCLU class schema specific to NHP region
- Will consider groundwater availability



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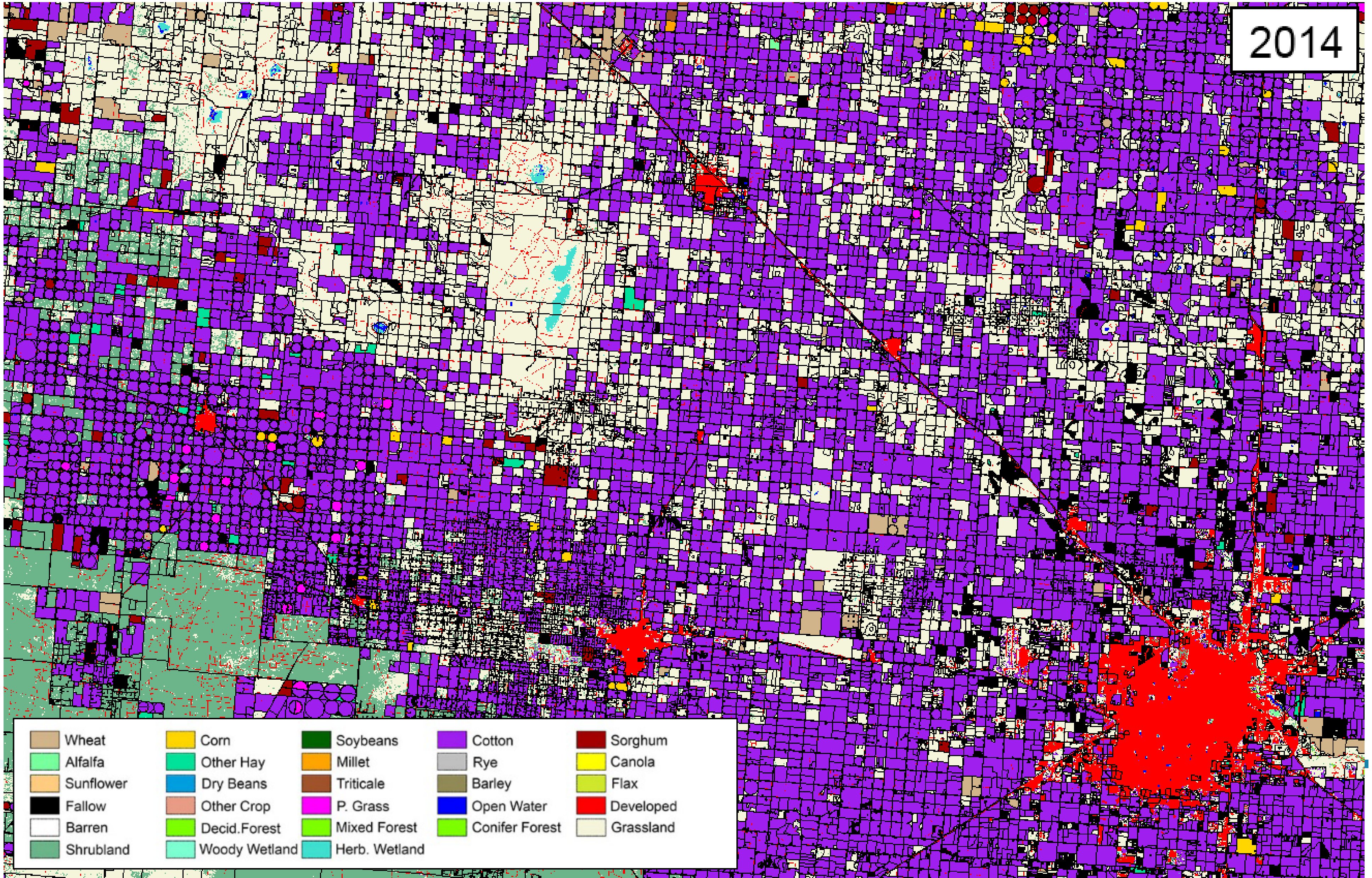
The end product - Long-term scenarios

Projected effects of Ogallala aquifer decline near Lubbock, TX



FOREcasting **SCE**narios of Land-use Change (**FORE-SCE**)

As the aquifer becomes depleted, irrigated cotton (purple) can no longer be supported, and ag fields shift either to dryland wheat, or revert to grass or shrub states.

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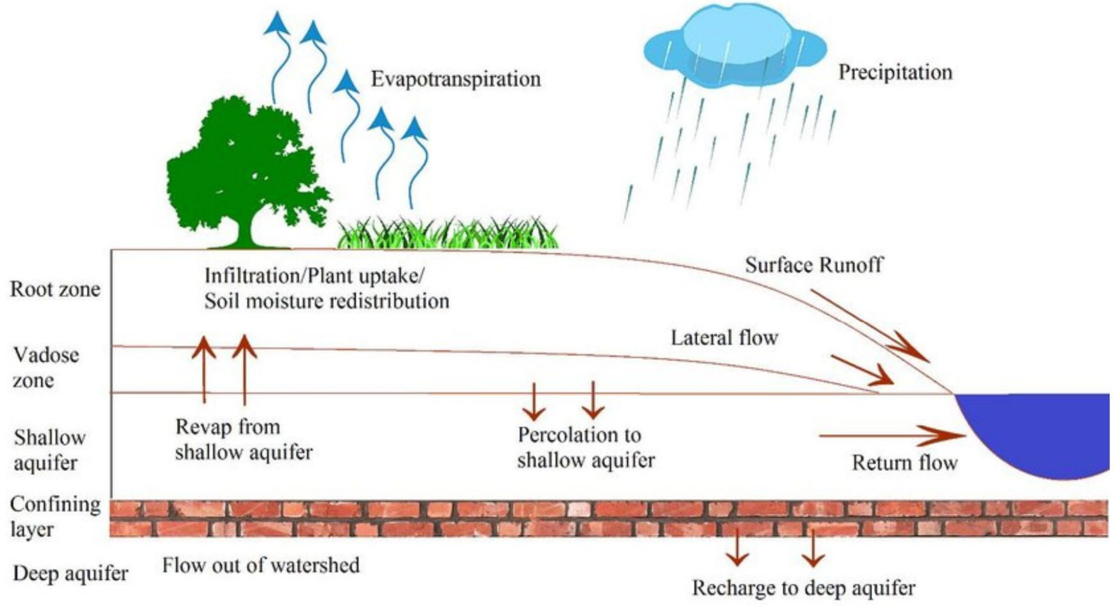
SWAT+ model

- Watershed and soil zone model for water quantity and quality (Bieger and others, 2017)
- Simulates landscape, surface water, and soil zone processes

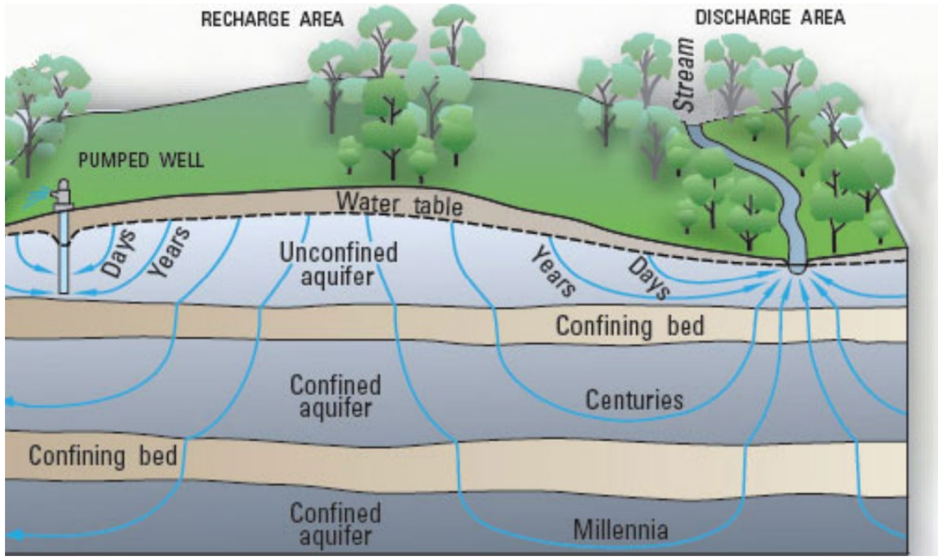


Overview of the SWAT model (edited from Neitsch et al,.2012)

https://www.researchgate.net/figure/Overview-of-the-SWAT-model-edited-from-Neitsch-et-al-2012_fig2_326234541

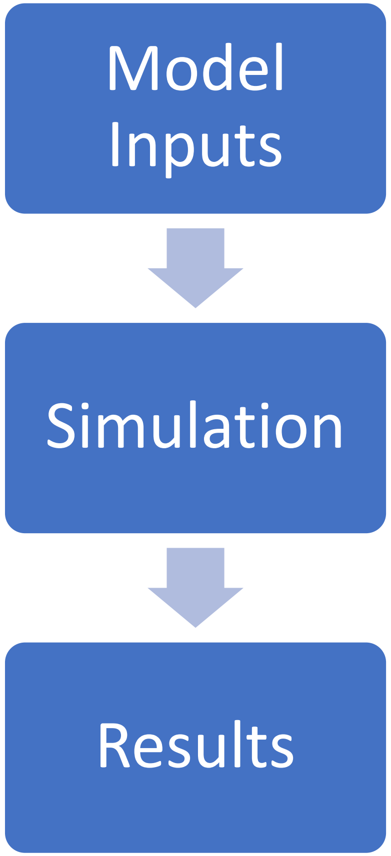
MODFLOW 6 model

- USGS Modular Hydrologic Model
- Simulates
  - Groundwater-flow processes
  - Groundwater/surface water interactions
  - Fate and transport of constituents (nitrate)



Outcomes and key results

- Land use: FORE-SCE
  - Land use distributions under different climate and land use scenarios
- Watershed/soil: SWAT+
  - Changes in evapotranspiration, soil nitrate concentrations, irrigation, and recharge under different climate and conservation/management scenarios
- Groundwater: MODFLOW 6
  - Effectiveness of conservation practices on groundwater nitrate concentrations under different climate and conservation/management scenarios



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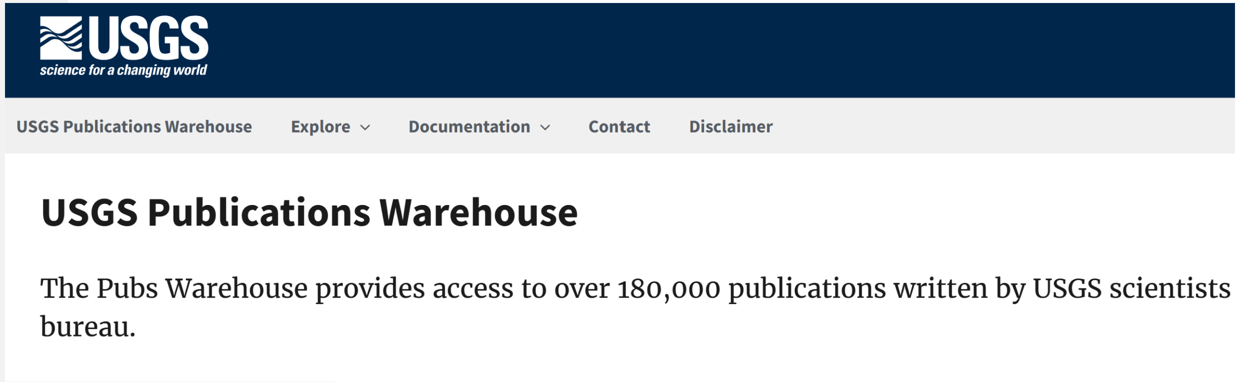
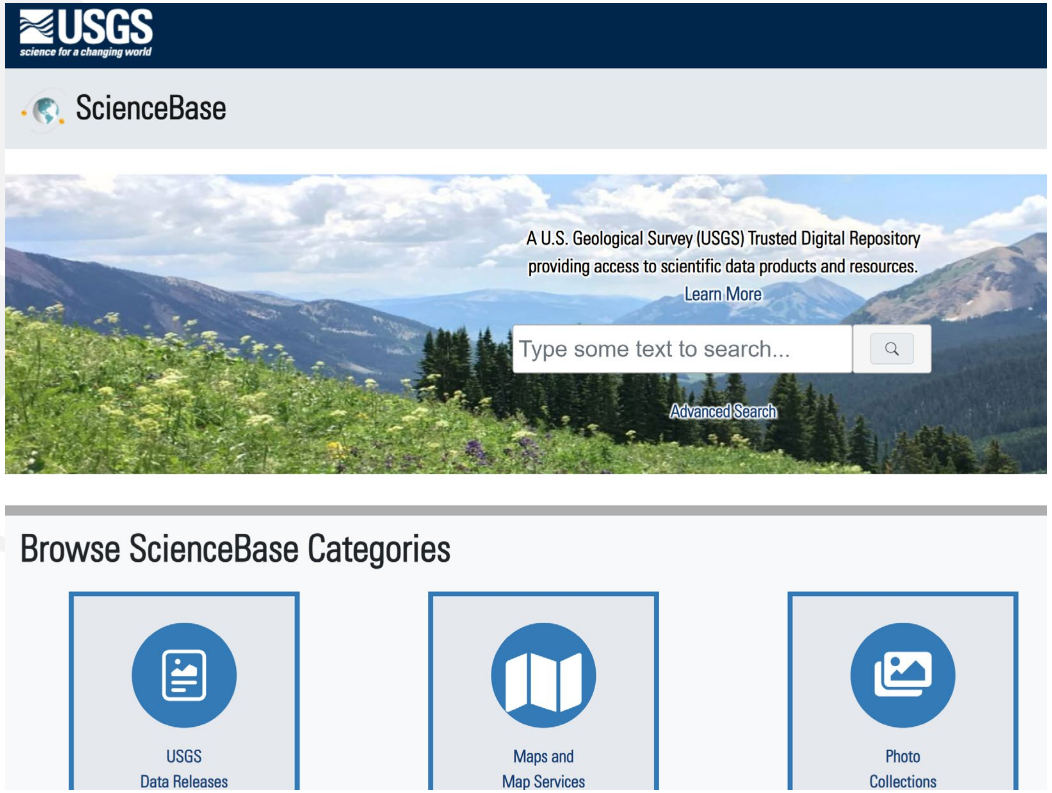
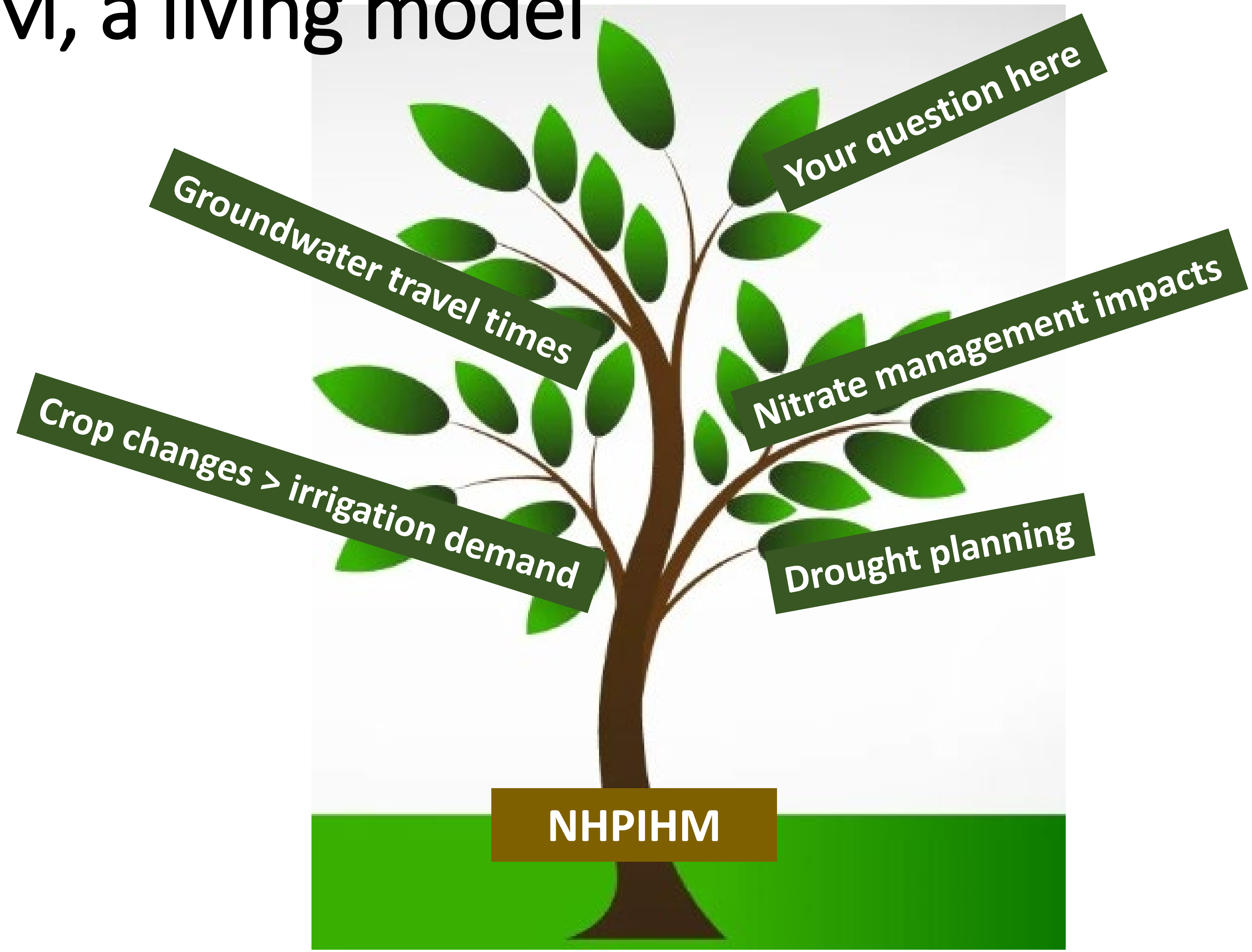
Products

- Reports (Publications Warehouse)
  - USGS Scientific Investigations Report documenting development, calibration, and scenario results of the NHPIHM
- Data products (ScienceBase)
  - Annual grids of projected LCLU 2024-2100
    - For each scenario
  - Model archive files
    - NHP aquifer extent SWAT+ model
      - Calibration model (2009-2023)
      - Scenario models (2024-2099)
    - NHP aquifer extent MODFLOW 6 model
      - Calibration model (2009-2023)
      - Scenario models (2024-2099)





NHPIHM, a living model



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Summary

- Three-part Northern High Plains Integrated Hydrologic Model
  - FORE-SCE, SWAT+, MODFLOW 6
- Cooperators: USDA NRCS, RWBJV, Central Platte, Lower Loup, and Upper Big Blue NRDs
- Address habitat and water quality questions
  - Impact of climate, land use, water use, and conservation management on wetlands and groundwater nitrate concentrations
- Forecast scenarios built based on cooperator input
- Publish report and model archive files

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Bieger, Katrin, Arnold, Jeffrey G., Rathjens, Hendrik, White, Michael J., Bosch, David D., Allen, Peter M., Volk, Martin, and Srinivasan, Raghavan, 2017. Introduction to SWAT+, a Completely Restructured Version of the Soil and Water Assessment Tool. Journal of the American Water Resources Association (JAWRA) 53(1): 115– 130. doi.org/10.1111/1752-1688.12482

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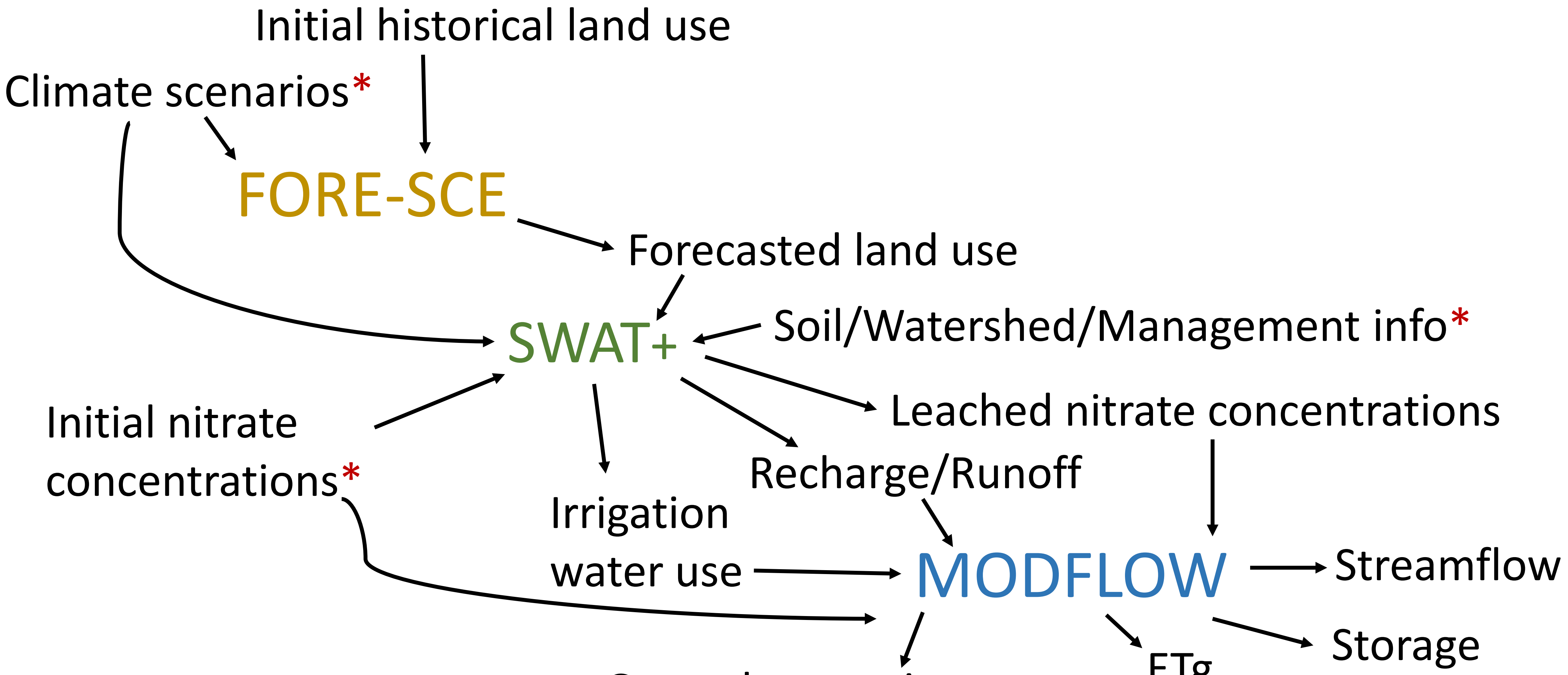
Questions

NHPIHM General Inputs/Outputs



* Indicates local knowledge from cooperators

MF6: Groundwater Transport

- simulates 3D solute transport of a single species
- calculate solute concentrations in both space and time
- processes simulated include
- 1) advective transport

  2) the combined hydrodynamic dispersion processes of velocity-dependent mechanical dispersion and molecular diffusion

  3) adsorption and absorption (collectively referred to as sorption) of solutes by the aquifer matrix

  4) transfer between the mobile domain and one or more immobile domains

  5) first-or zero-order solute decay or production

  6) mixing from groundwater sources and sinks

  7) direct addition of solute mass.
- represent advective solute transport through streams, lakes, multi-aquifer wells, and the unsaturated zone
- simulates chemical constituents in both mobile and immbole domains
- simulates dissolved/aqueous phase in both mobile and immobile domains