Simulating the Land Surface Response to Drought and Climate Change Across the High Plains

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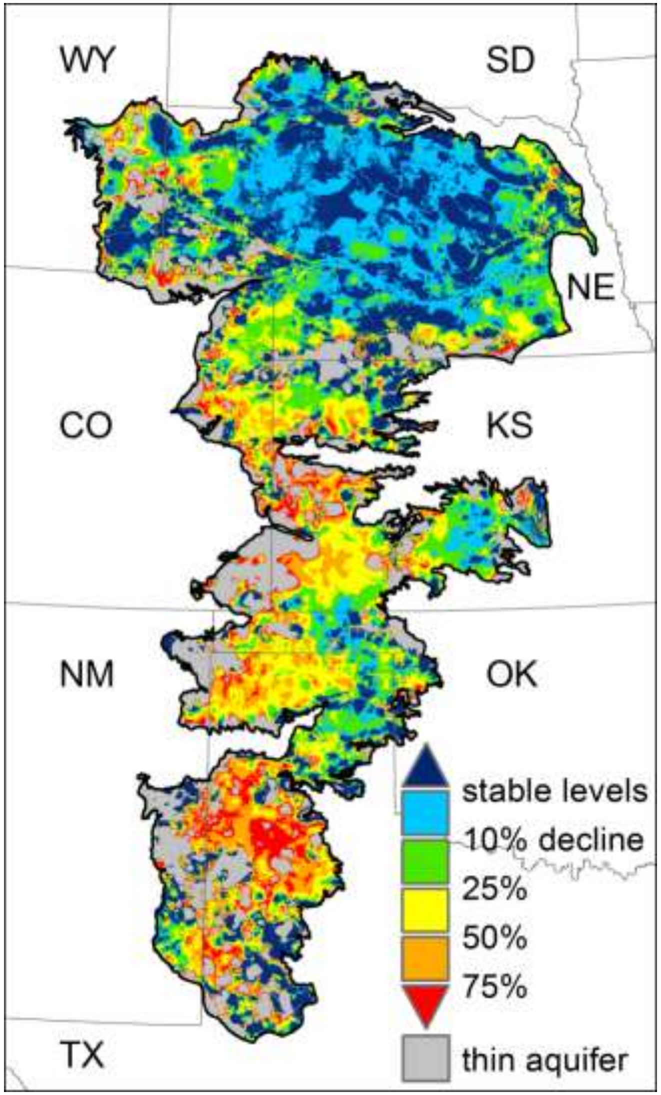
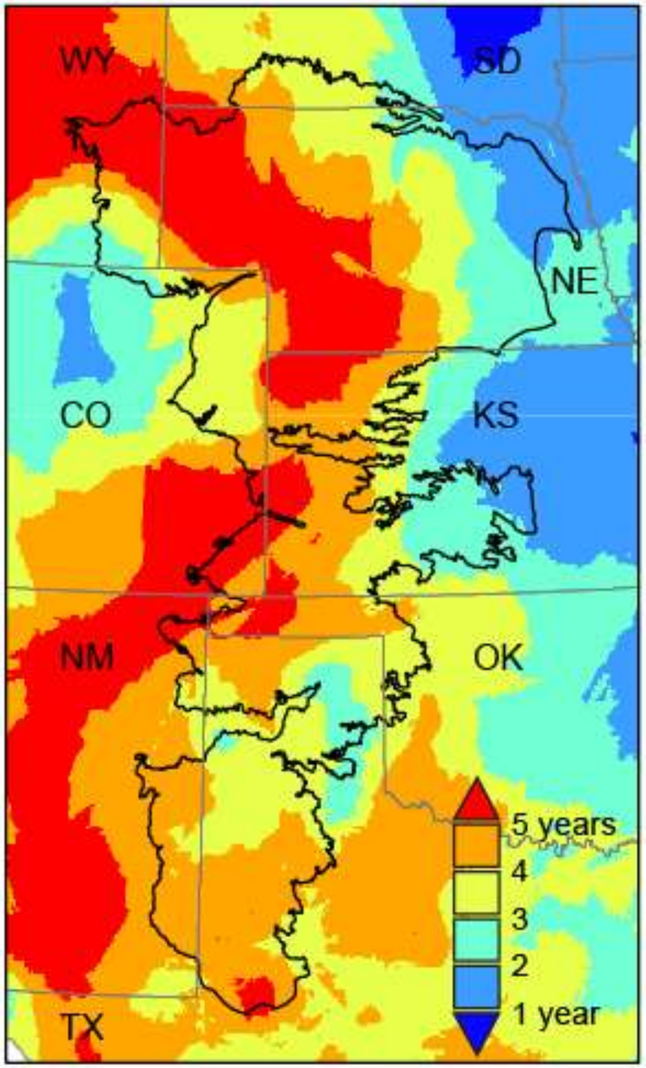
Water levels are declining rapidly



Data: USGS, KGS, TWDB

- High Plains Aquifer (HPA) is extensively used for irrigation
- Levels in the Southern and Central HPA have been steadily declining for decades
- Increasing attention at the state, local, and grassroots levels on “sustainable” use

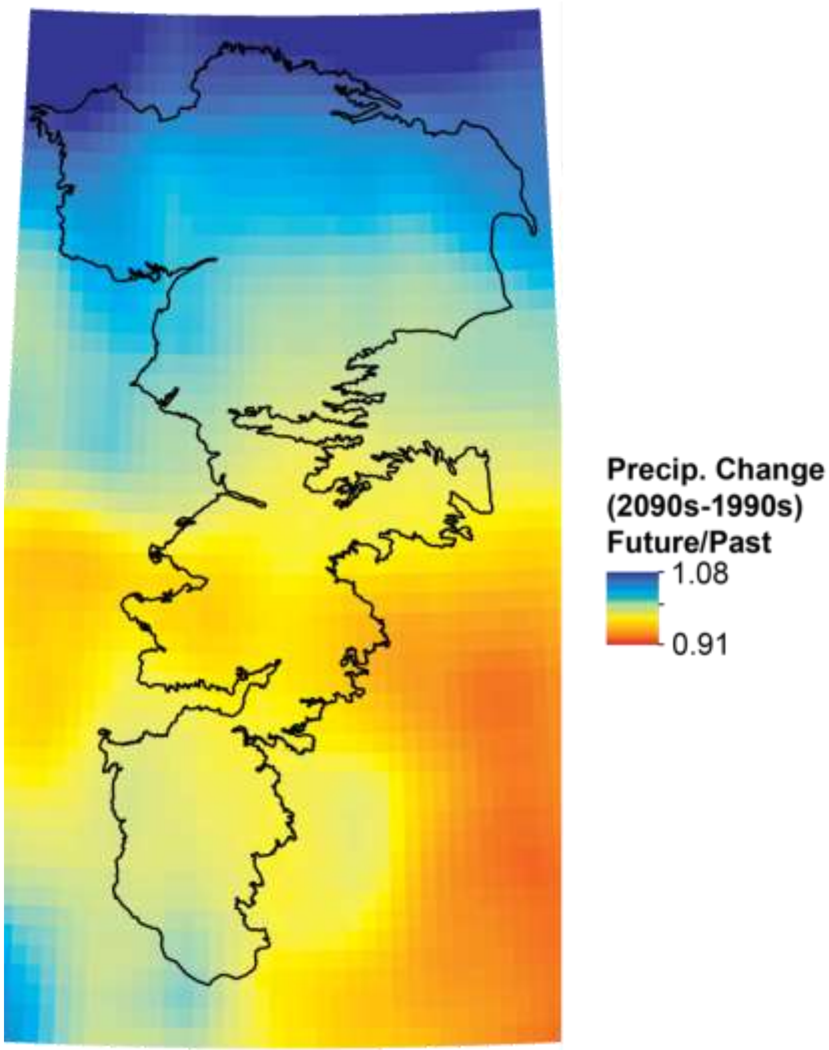
Persistent droughts are common

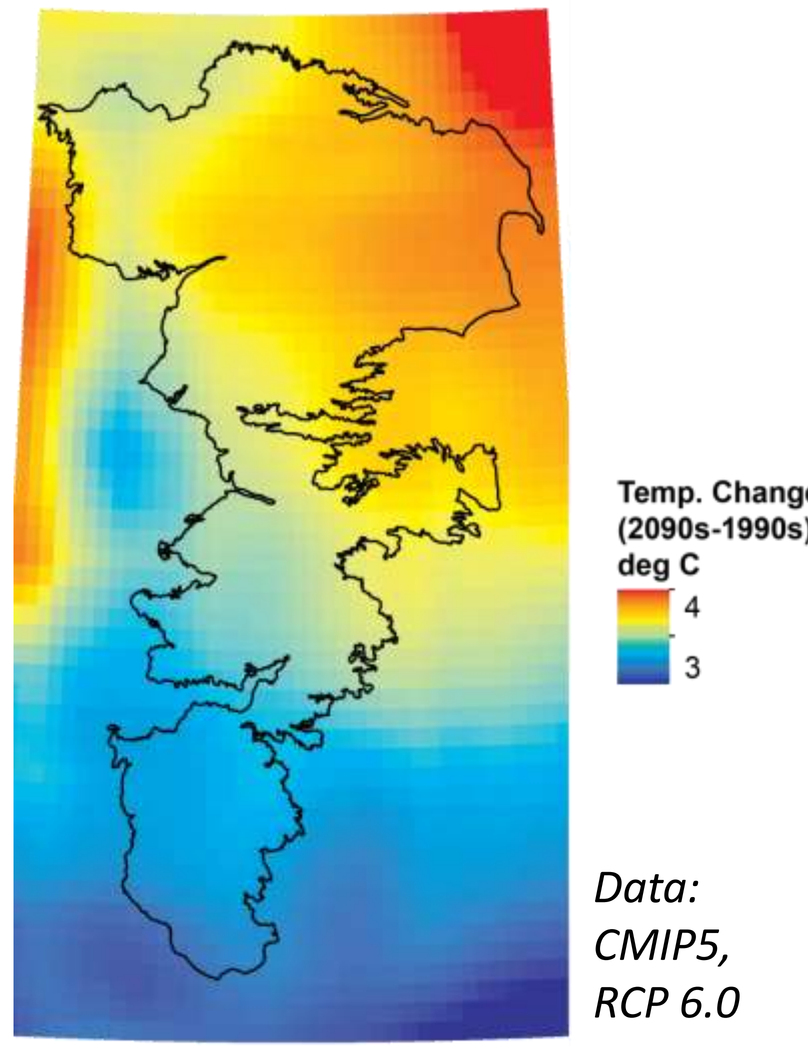


Period of "severe" or worse drought
UNL Drought Monitor (2000 - Aug 2014)

- “Normal” precipitation of the 1900s probably wasn’t so normal
- Region is likely susceptible to long-term droughts like those seen in the last 15 years
- These extreme events may become more frequent

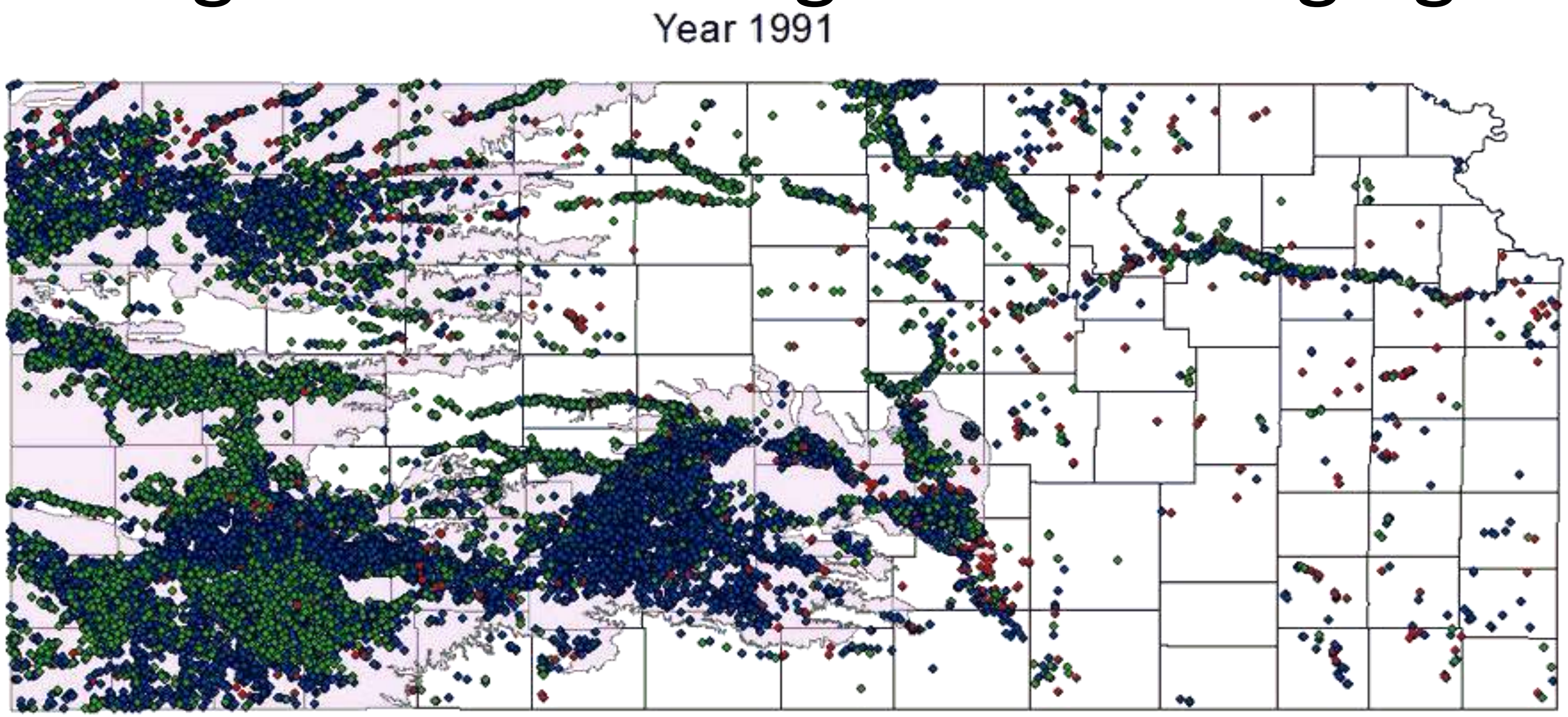
Climate is forecast to become warmer, and precipitation more variable





Data: CMIP5, RCP 6.0

Irrigation technologies are changing



Data: KGS, Graphic: Hoayang Li, MSU

Not to mention changes in

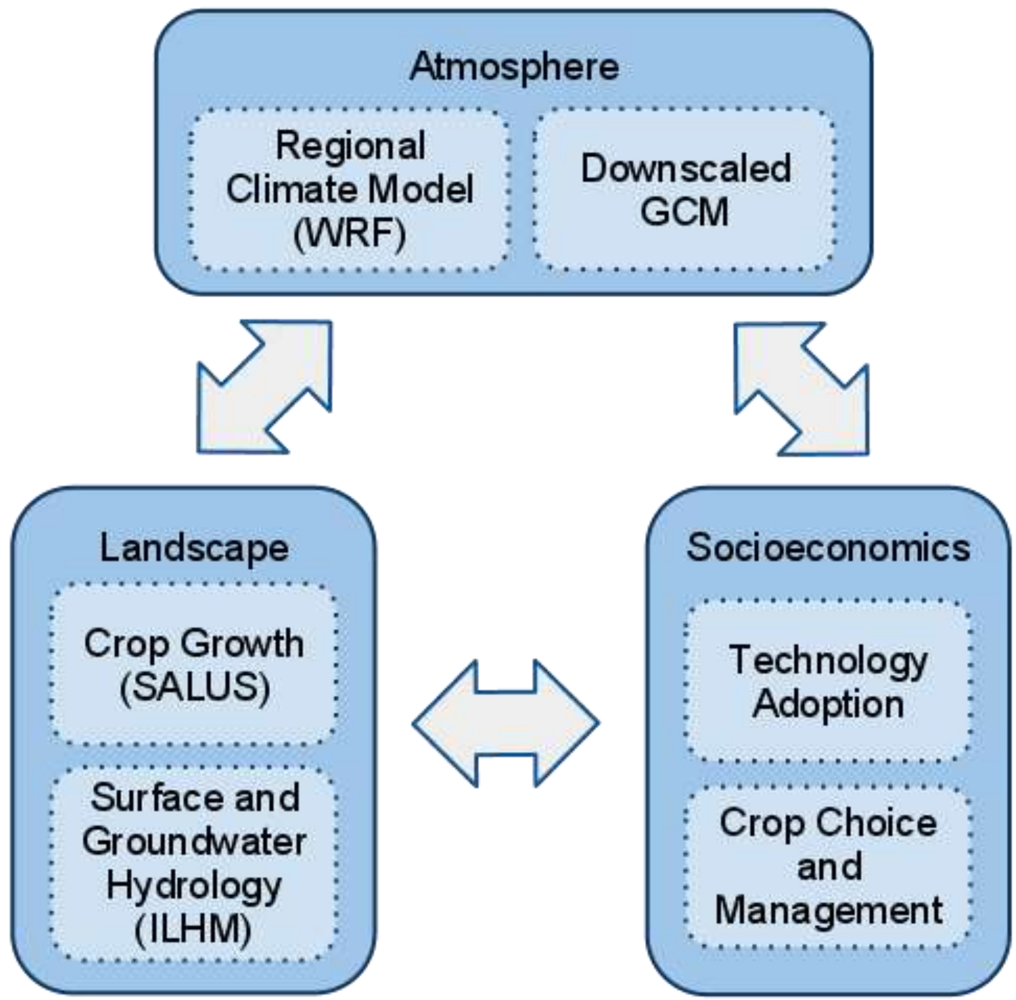
- Water use restrictions, some grassroots organized
- Enforceable long-term targets at state and district levels
- Interstate compacts
- Crop choices due to shifting regional and global markets
- And so on…

HPA Coupled Land Atmosphere and Socioeconomic Systems (CLASS)

Funded by the NSF in 2010

Goals:

- Synthesize data and research
- Link climate, hydrology, crop, and economics models
- Explore historical changes, understand feedbacks
- Predict impacts of changes in climate, technologies, policies, and management on:
  - Water resources
  - Crop yields and economic output



HPA CLASS Project Team

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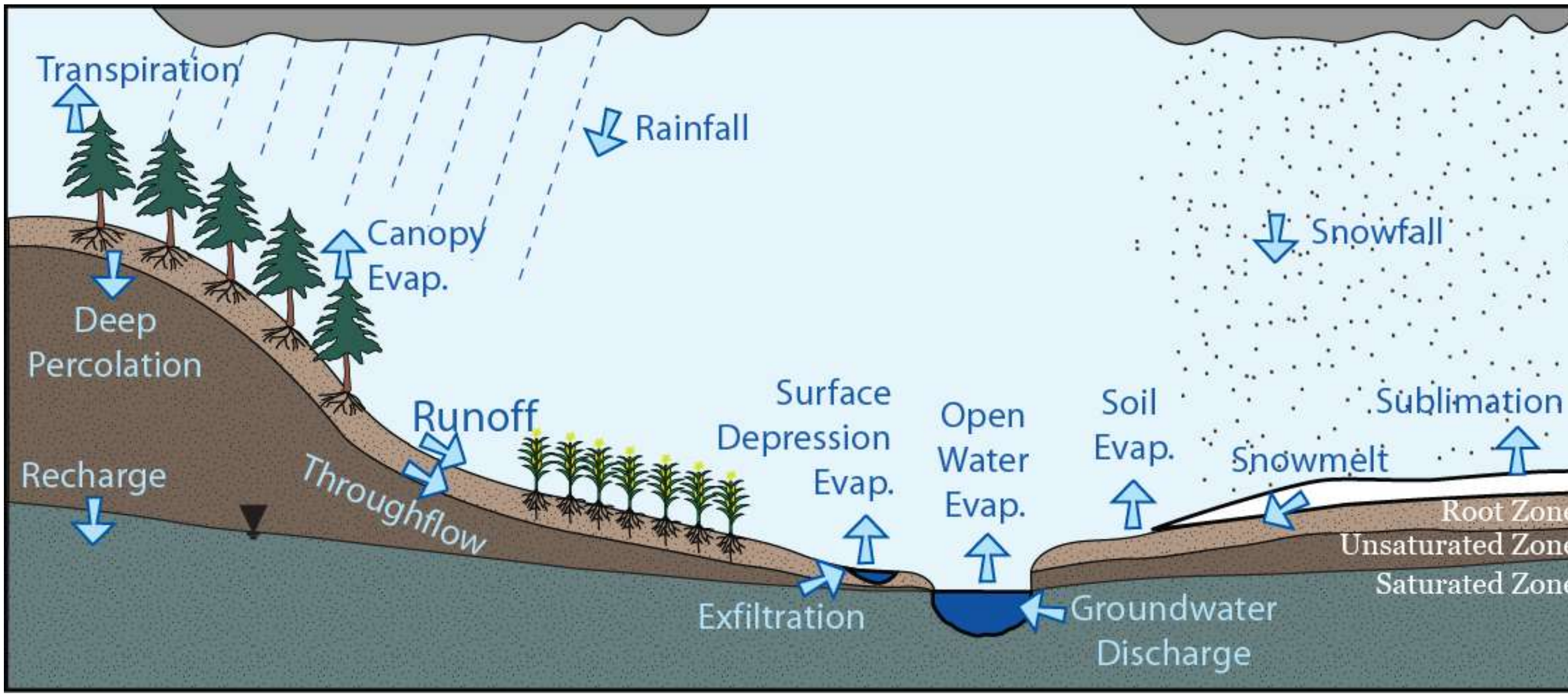
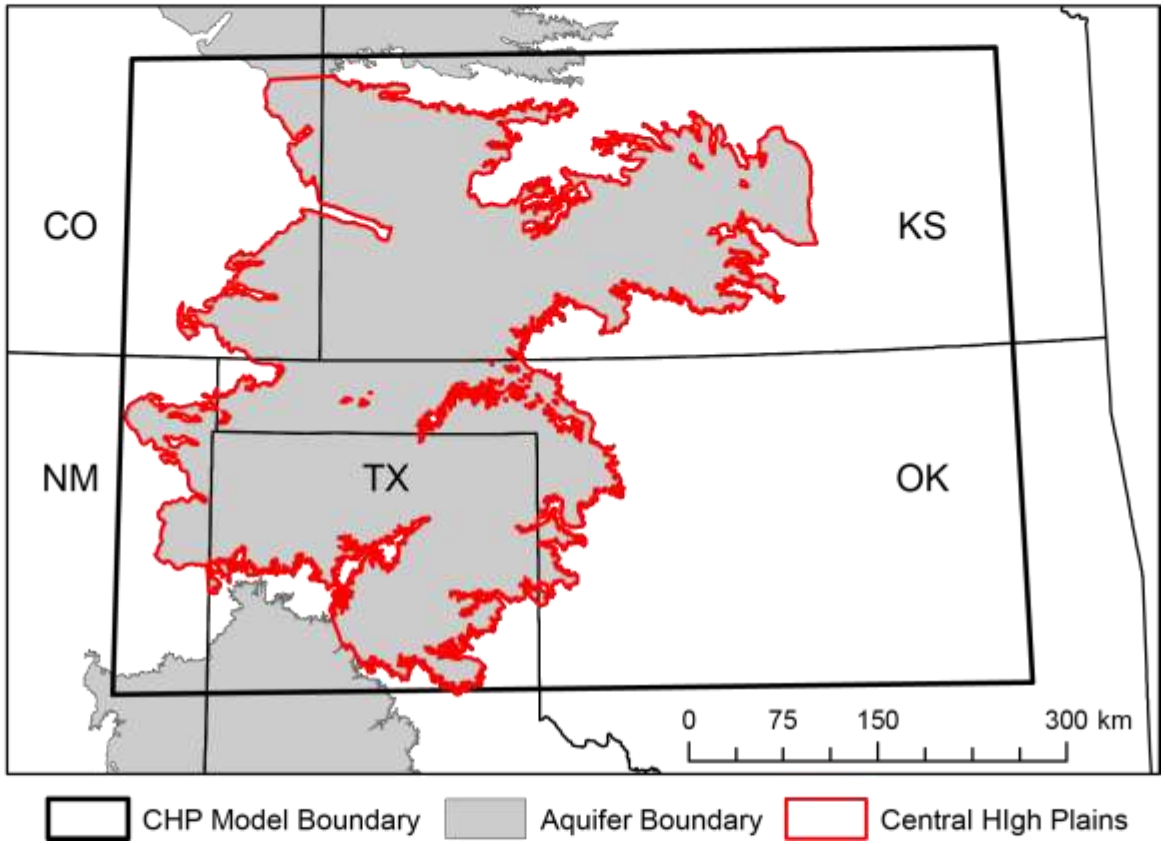
Landscape Hydrology Model (LHM)



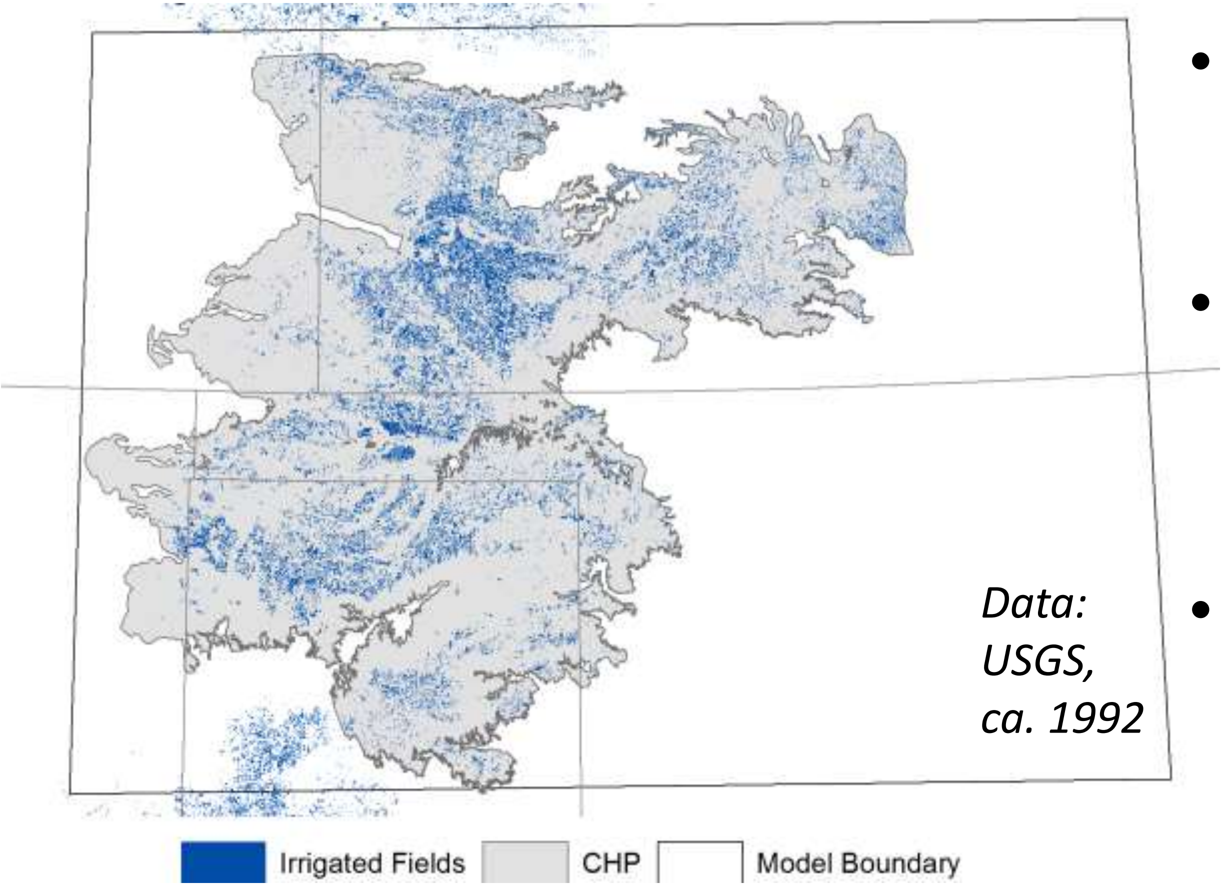
- Spatially-explicit simulation model, predicts water fluxes and temperatures
- Large, regional simulations possible on modest computer hardware
- Integrates SW and GW domains, uses MODFLOW for GW

Central High Plains LHM Domain



- Model expanded beyond CHP for climate model coupling: ~385,000 km^2, 1 km^2 cells

New irrigation module in LHM

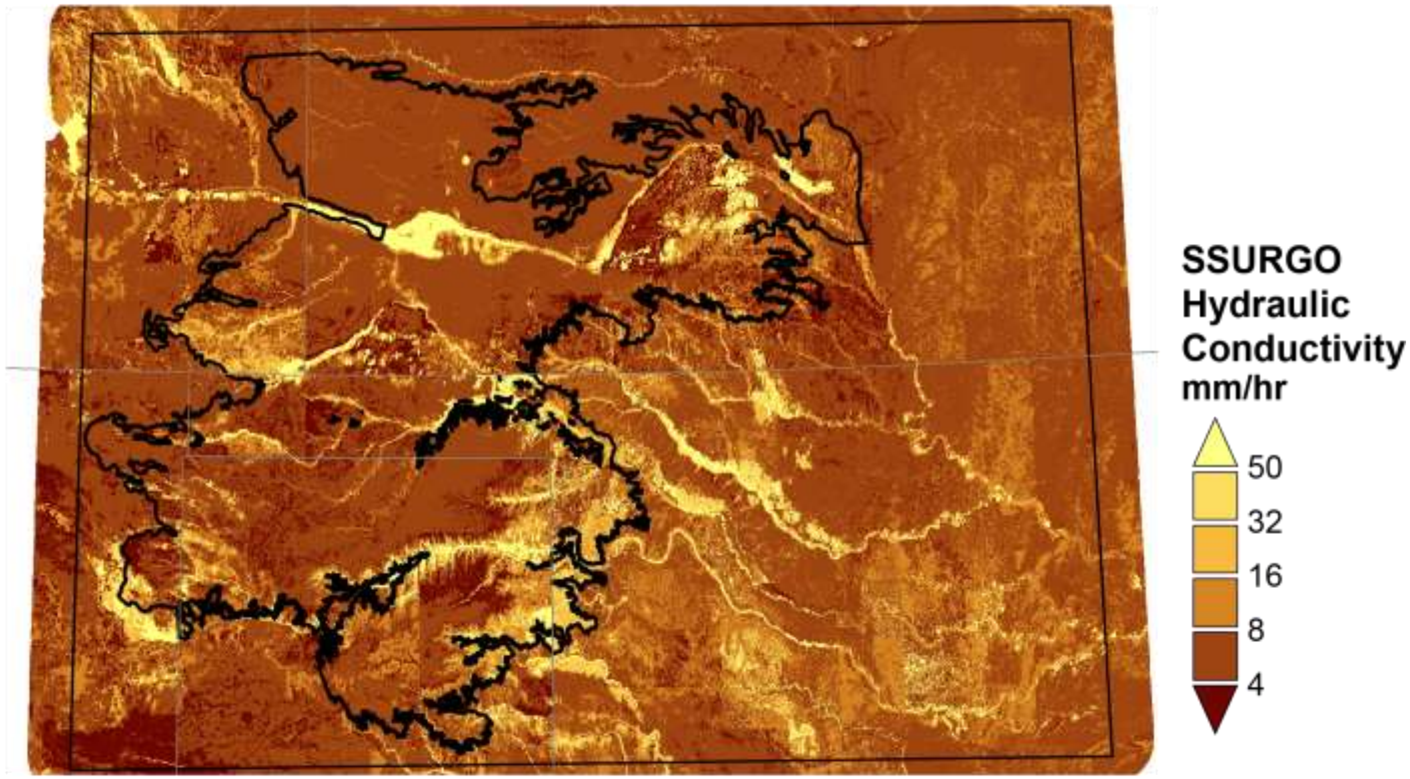


Data: USGS, ca. 1992

- Automatic irrigation, can be scheduled also
- Triggered by soil moisture threshold
  - Here, 33% of plant available water
- Each event:
  - 5 cm (2 in) of water
  - 2 cm (0.8 in)/hr

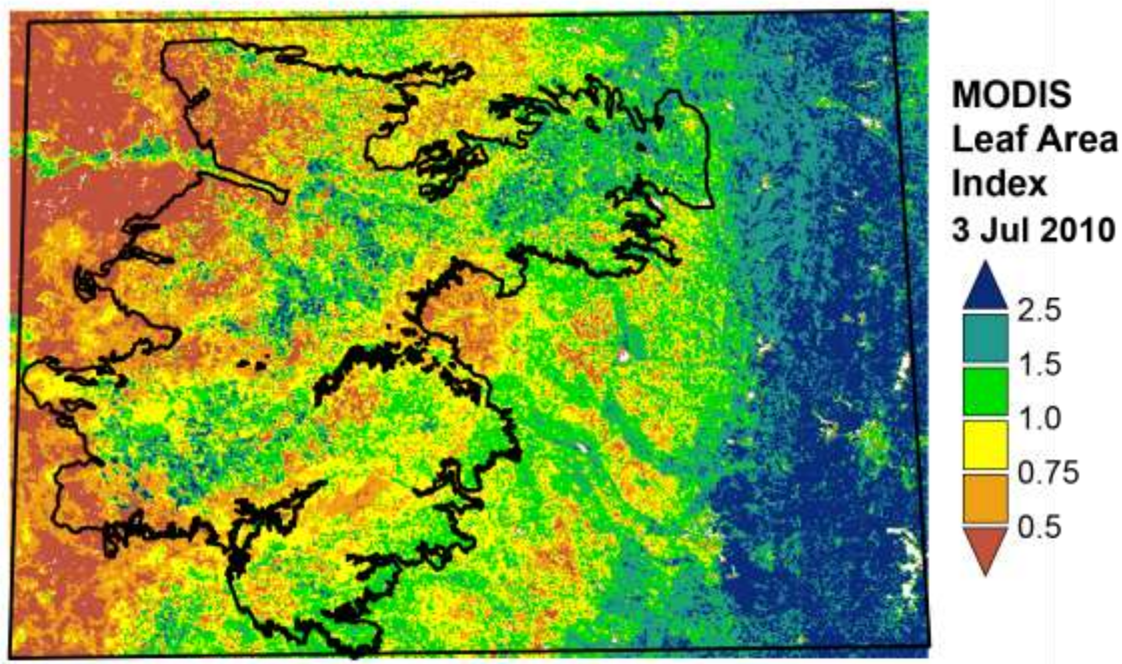
- Responds to changes in soil moisture, plant transpiration from climate

Select LHM Inputs: Soils



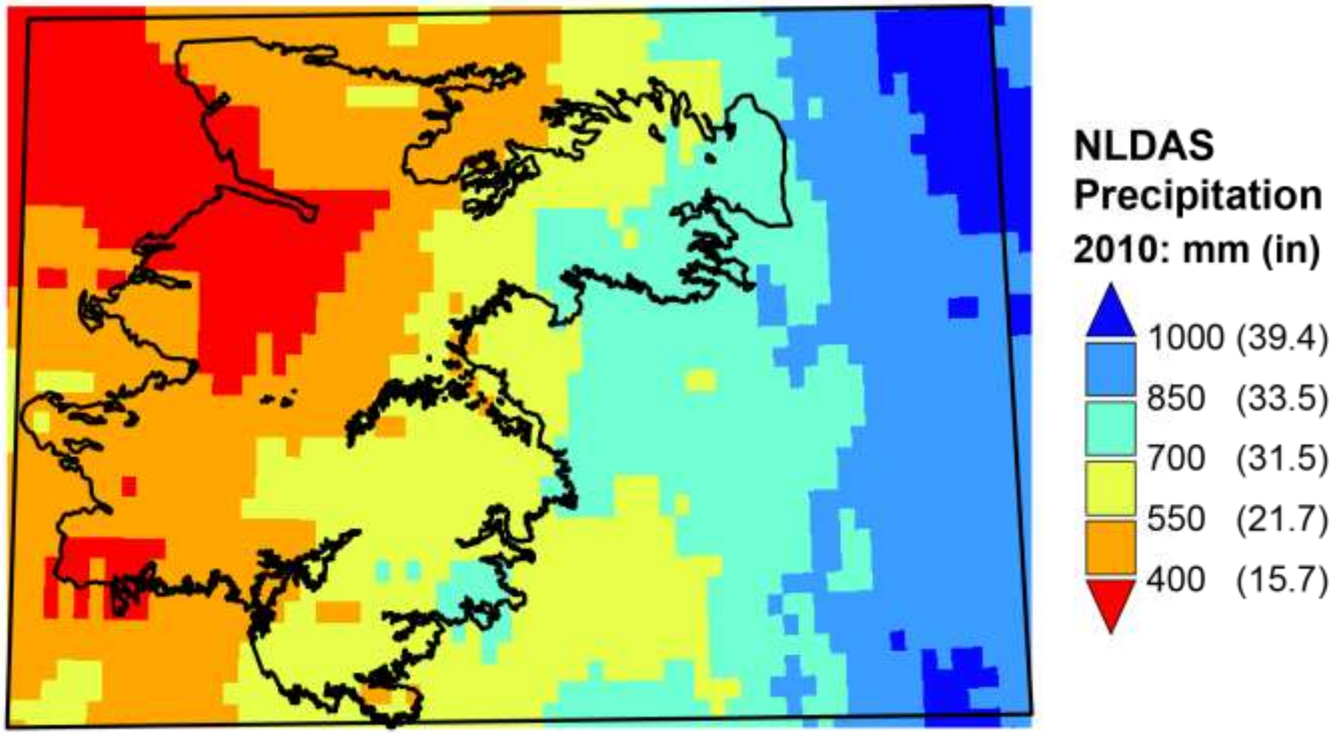
- Soil polygons from SSURGO
  - Hydraulic properties mapped to soil texture
- An extraordinary but challenging dataset to incorporate into hydrologic models

Select LHM Inputs: Leaf Area Index



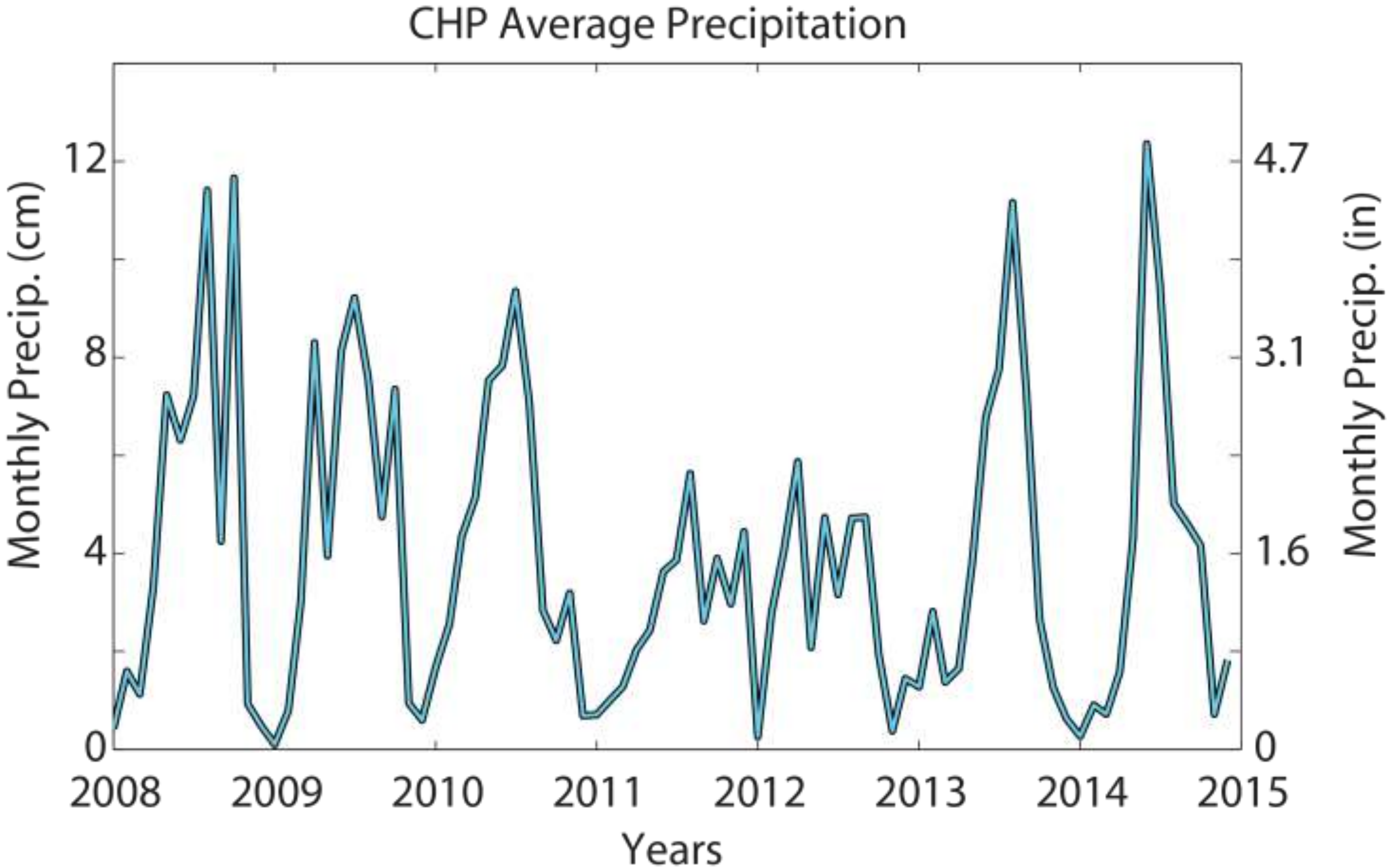
- LAI data from MODIS sensor
  - Every 8 days at 1 km resolution since 2000
- Irrigated agriculture clearly visible as higher LAI

Select LHM inputs: precipitation



- Use model/data fusion products such as NLDAS
  - provides consistent, hourly weather inputs since 1979
- Significant climate gradients across the domain

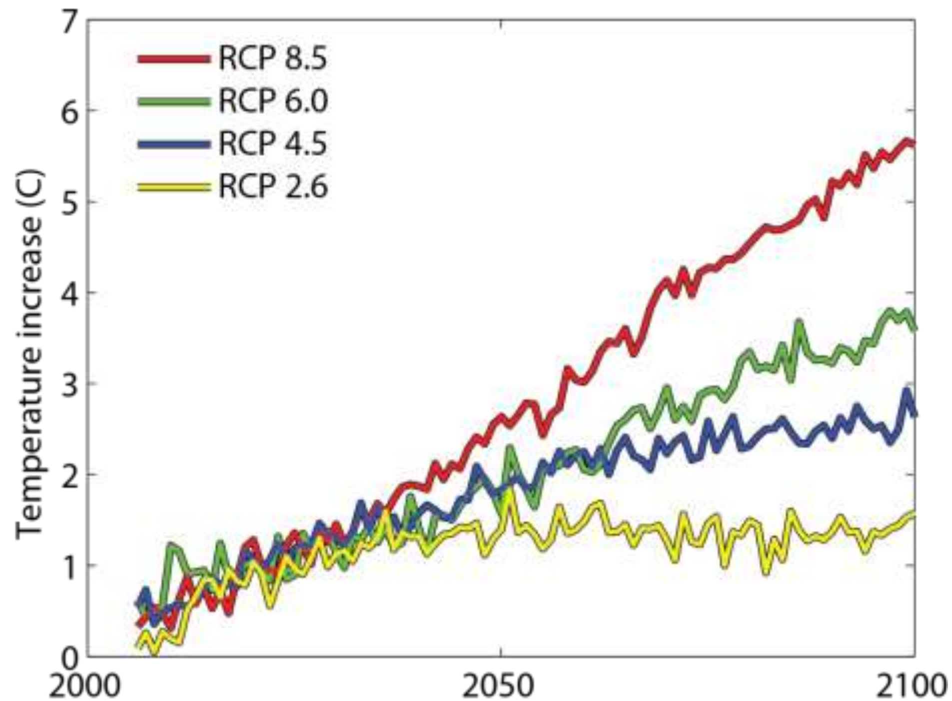
7-year simulation period



- Normal: 2008 – 2009: ~55 cm (22 in)/year
- Drought: 2011 – 2012: ~35 cm (17 in)/year

Climate change scenarios

- Build scenarios from the Climate Model Intercomparison Project 5 (CMIP5) GCM runs
  - Used in IPCC's latest report
- Select the RCP 6.0 scenario, closest to current trajectories
- Run 7-year model with 2090s climate

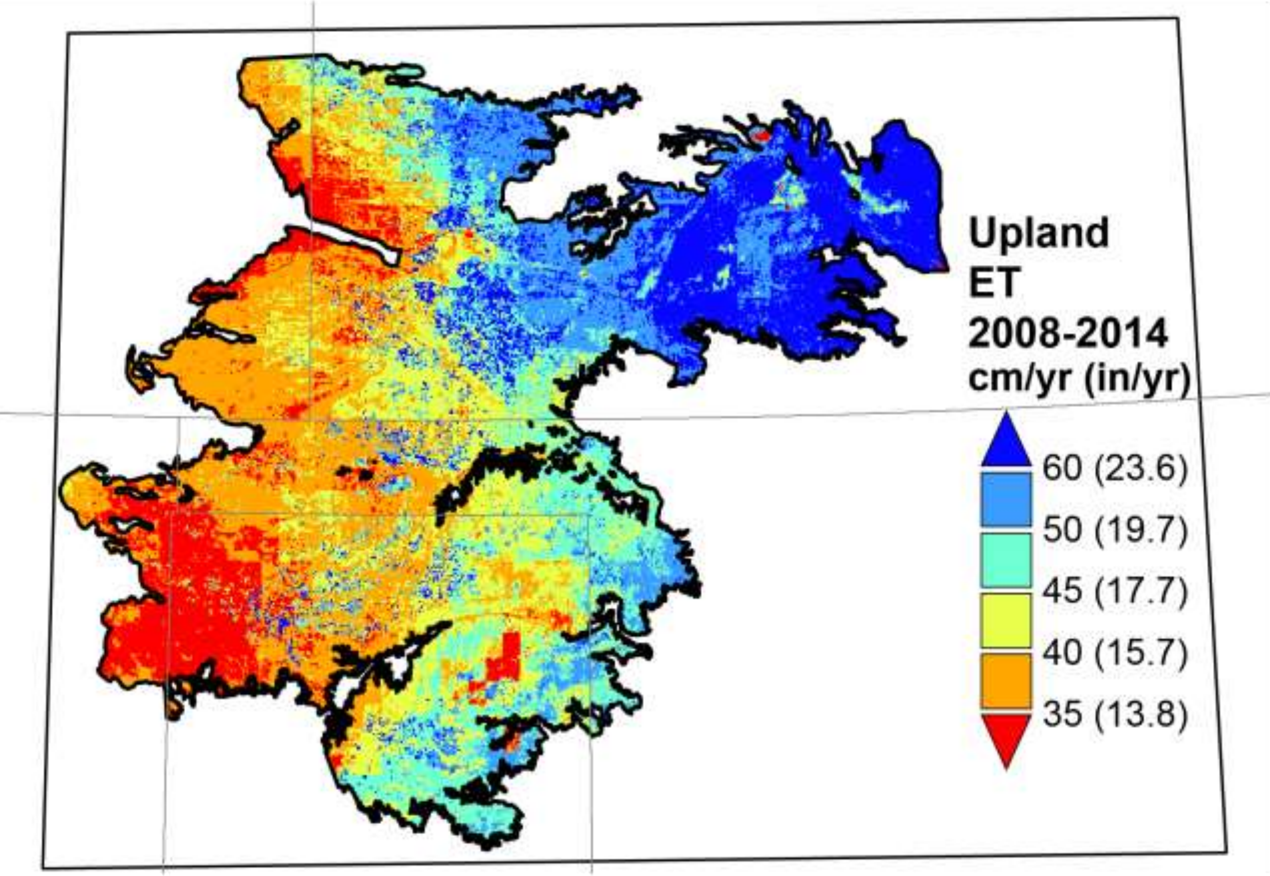


Data: Ensemble of all CMIP5 RCP 6.0 monthly runs, HPA averages

LHM Predictions

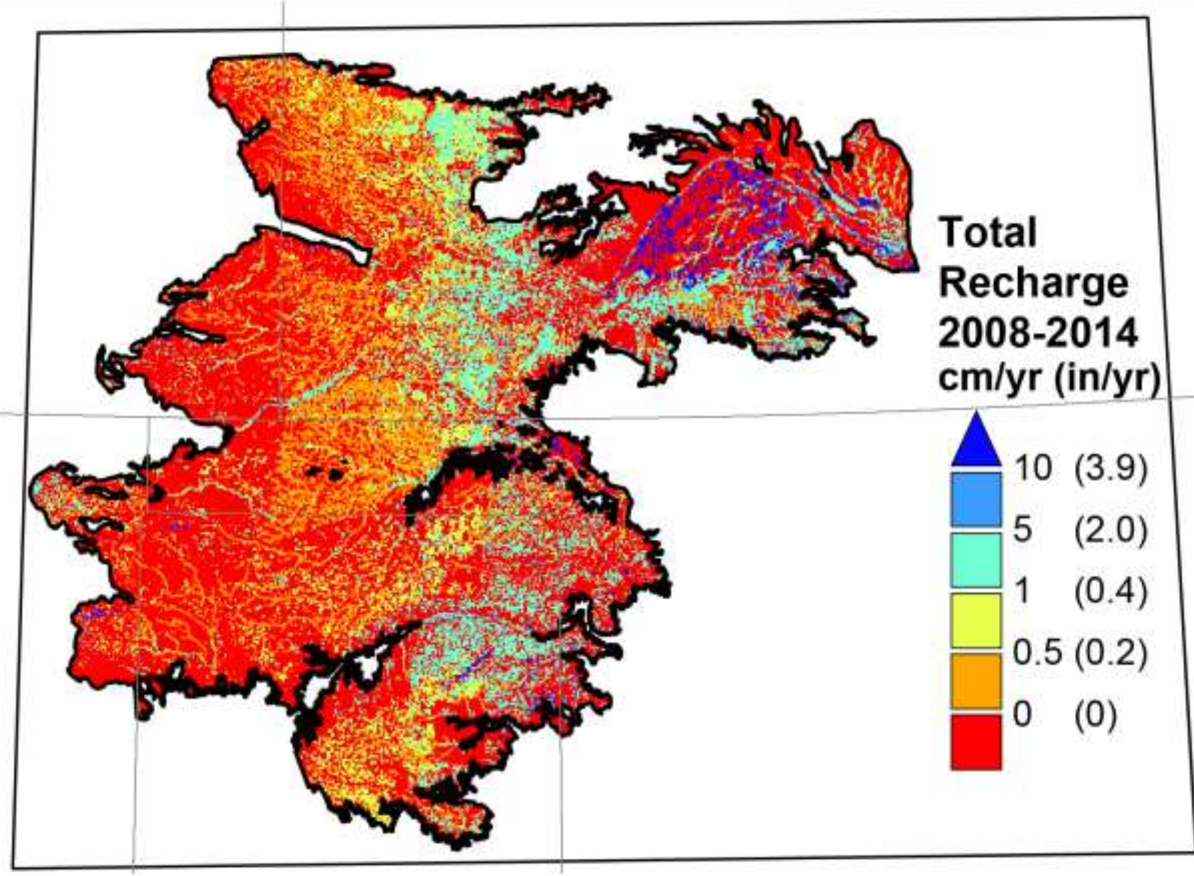
- Three analyses:
  - Baseline (7-year climate, 2008-2014)
  - Drought impacts (2-year normal vs. 2-year drought)
  - Climate change impacts (baseline vs. shifted climate)
- No site-specific model calibration involved
  - Validation will involve groundwater, stream, and soil moisture data
- Just land surface component
  - Groundwater simulation coming soon

Baseline evapotranspiration (ET)



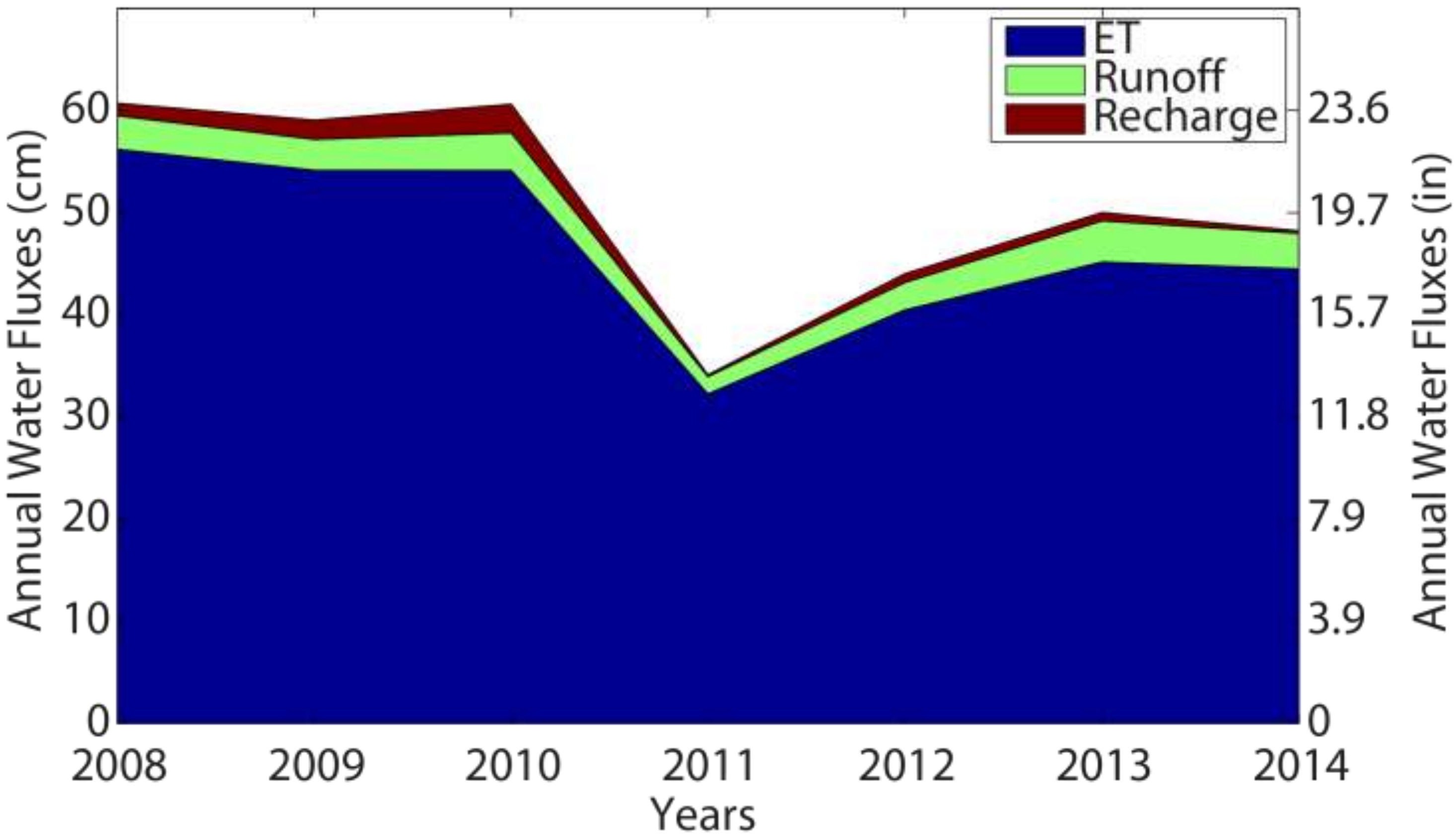
- Dominant portion of the water budget
- Limited by LAI
- Irrigated areas clearly visible

Baseline groundwater recharge



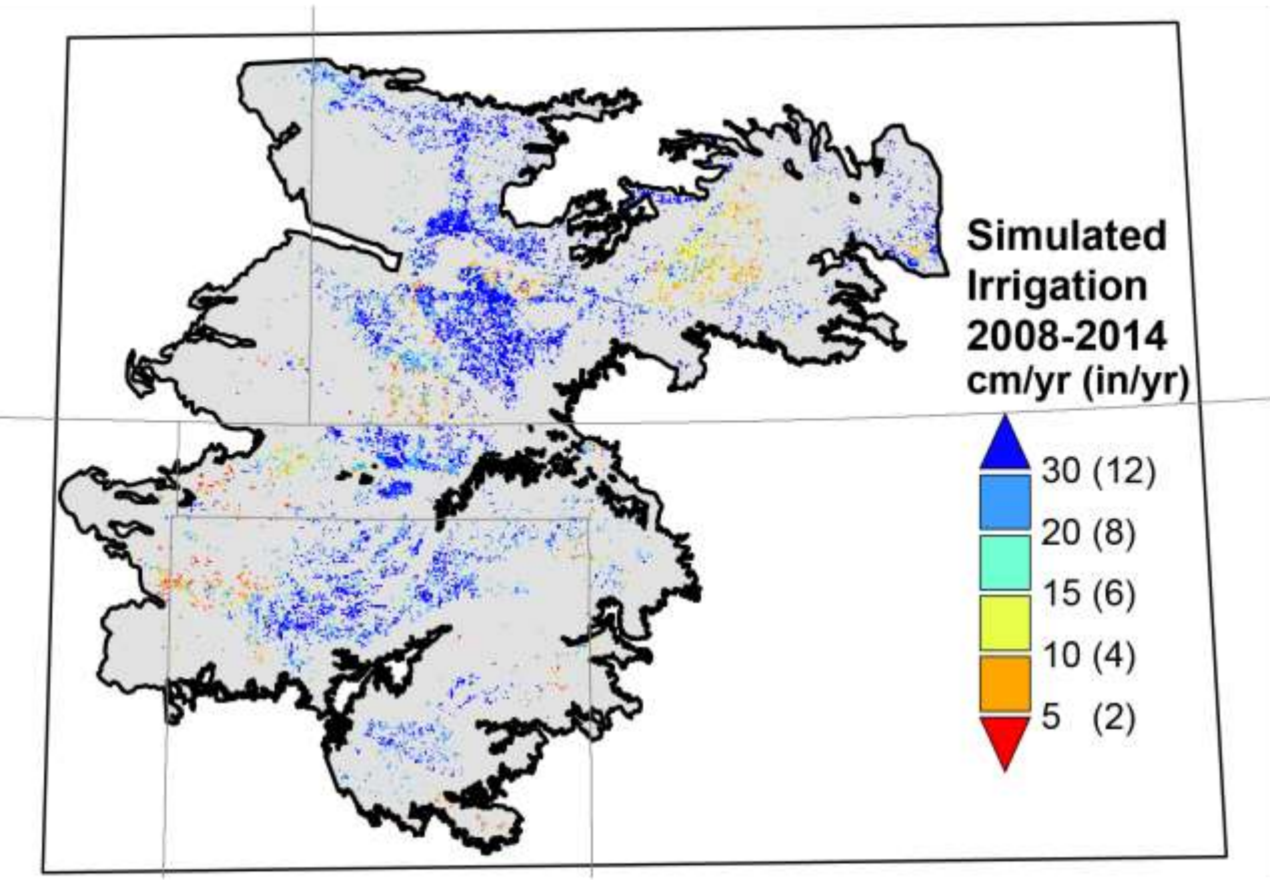
- Strong recharge gradient
- Most recharge occurs in wetlands
- Will feed into groundwater models

Dynamic Annual Water Budgets



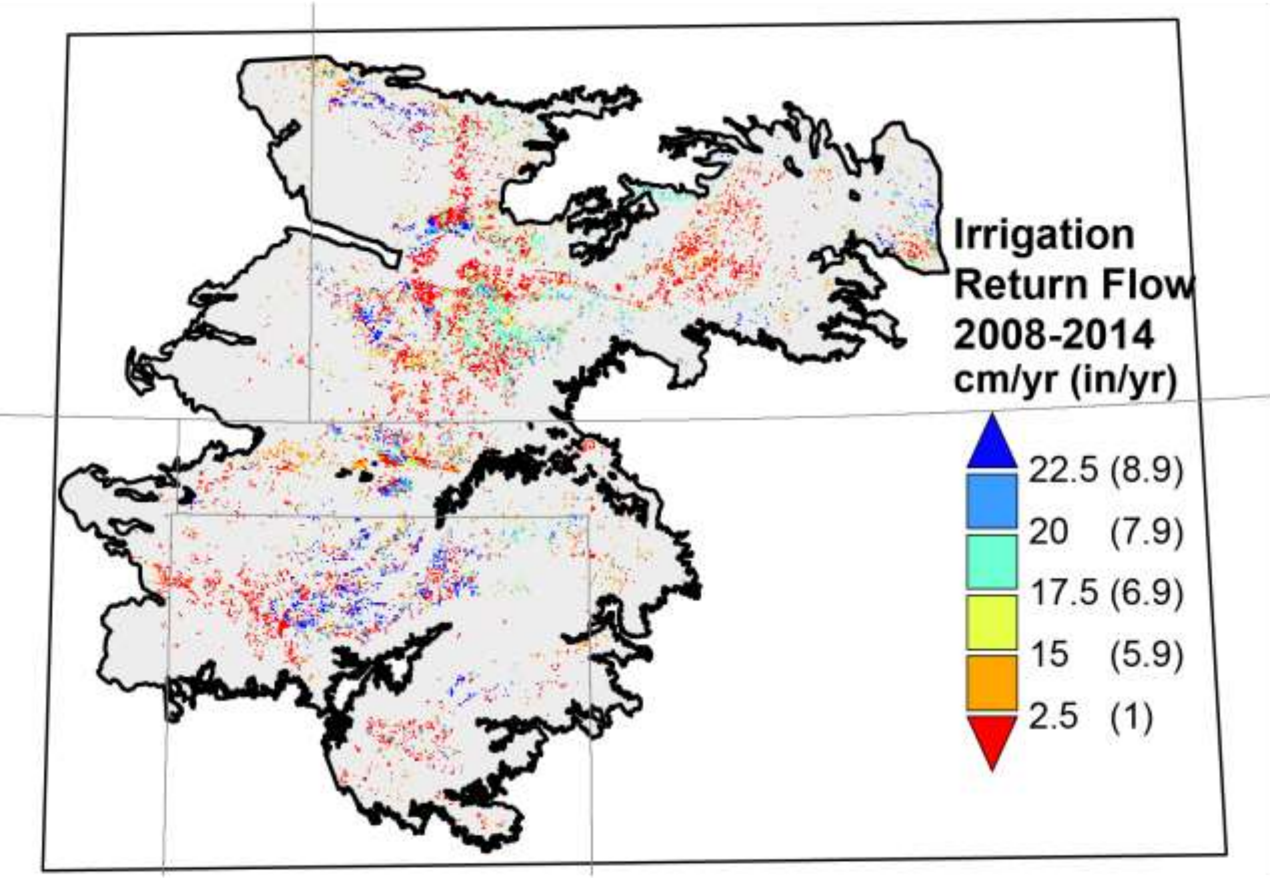
- Significant variability year to year
- Drought sensitivity in all three fluxes

Model-predicted irrigation demand



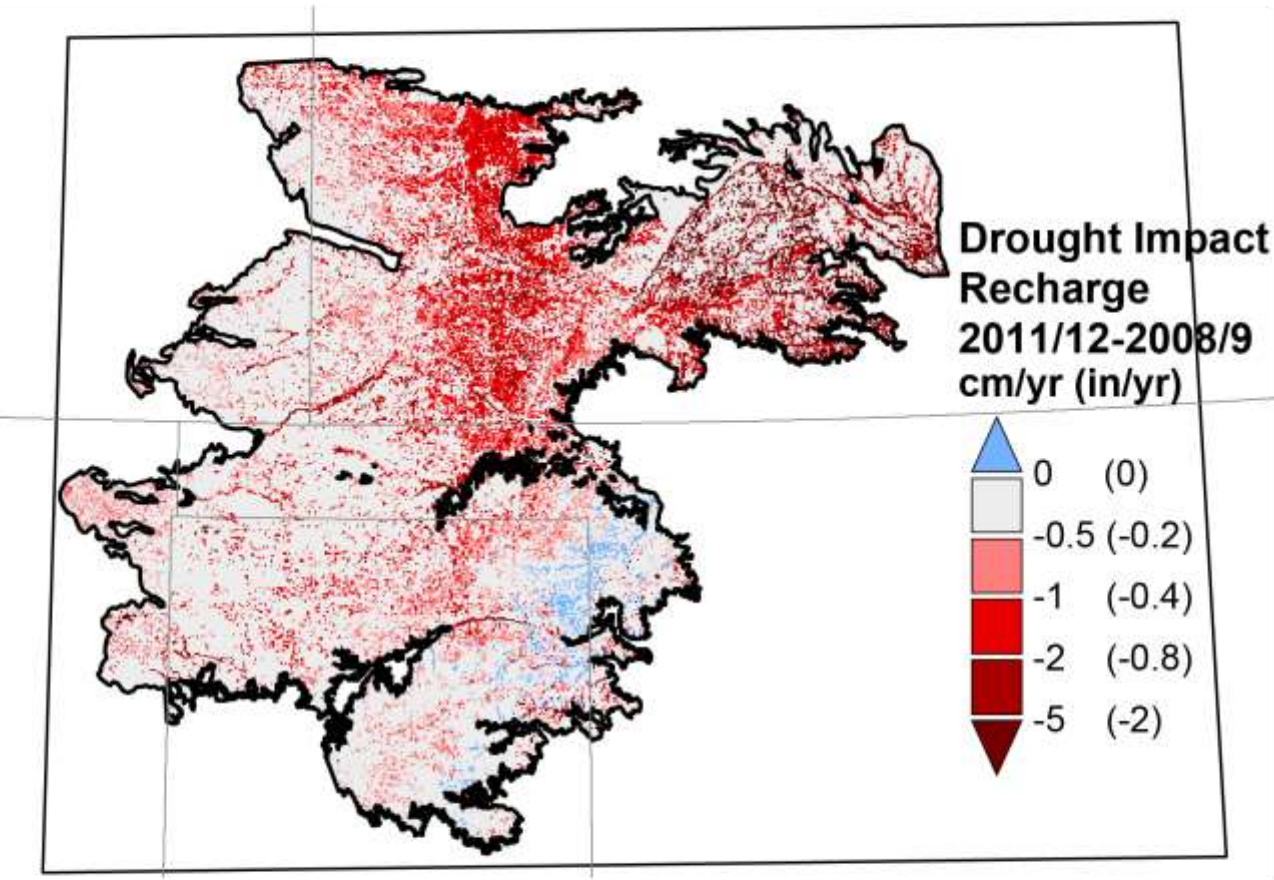
- Binary behavior: either irrigate to limit, or much less
- Strongly controlled by soil hydraulic properties

Irrigation return flow



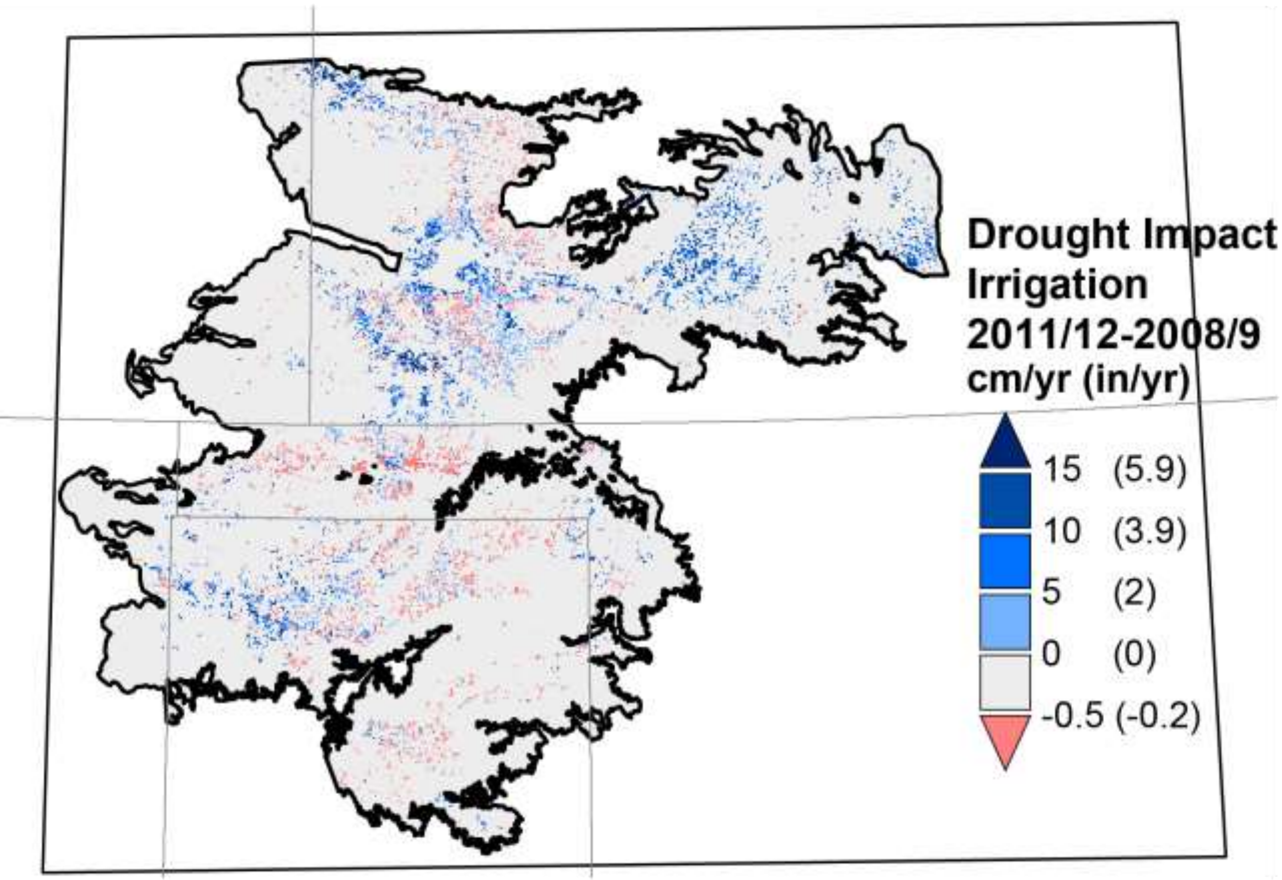
- Can directly quantify return flow
- In sandier soils, greater return flow proportion
- Only significant upland recharge source
- Will lead to improved recharge estimates

Drought impact: recharge



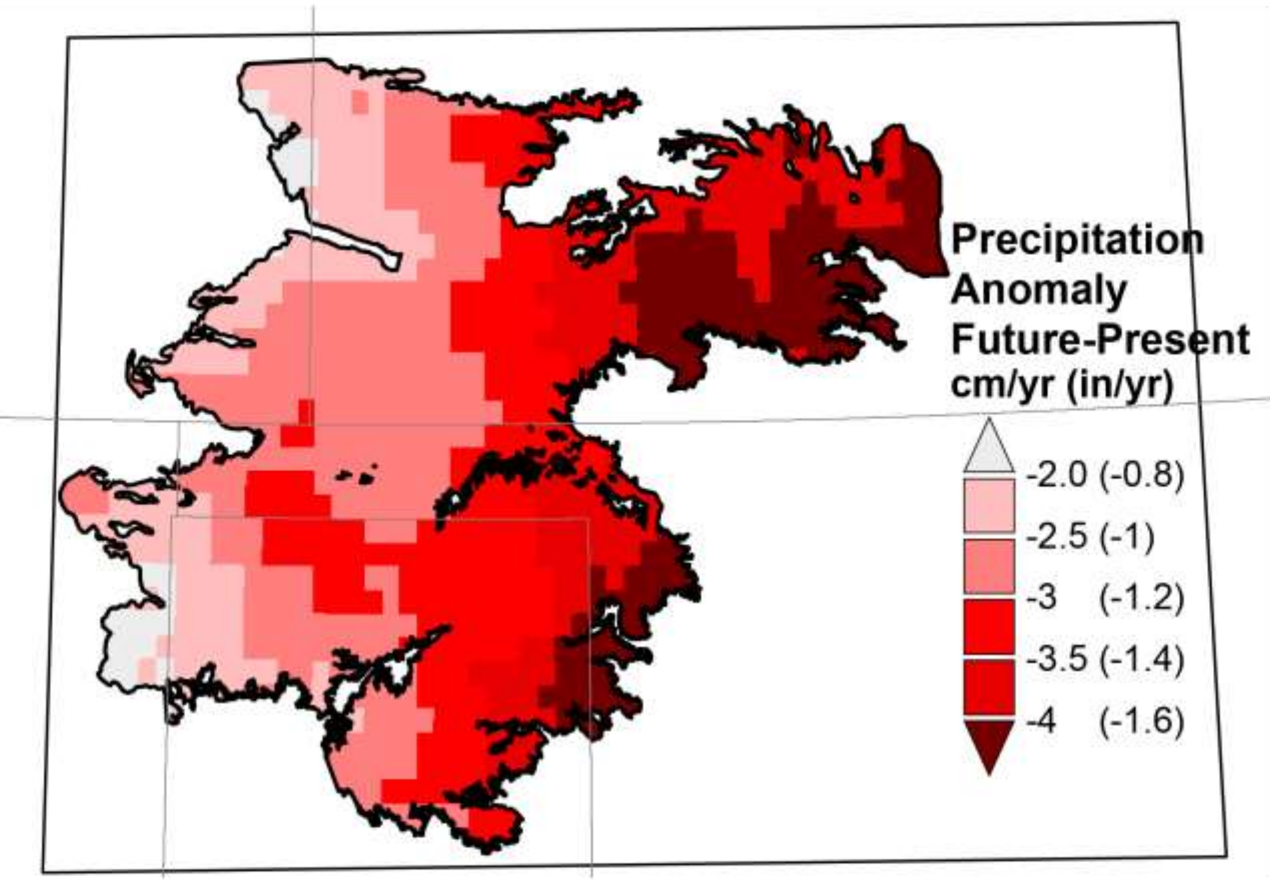
- 2011-2012 drought significantly reduced recharge
- Impacts are greater in irrigated areas
- Eastern aquifer more impacted due to greater initial recharge

Drought impact: irrigation



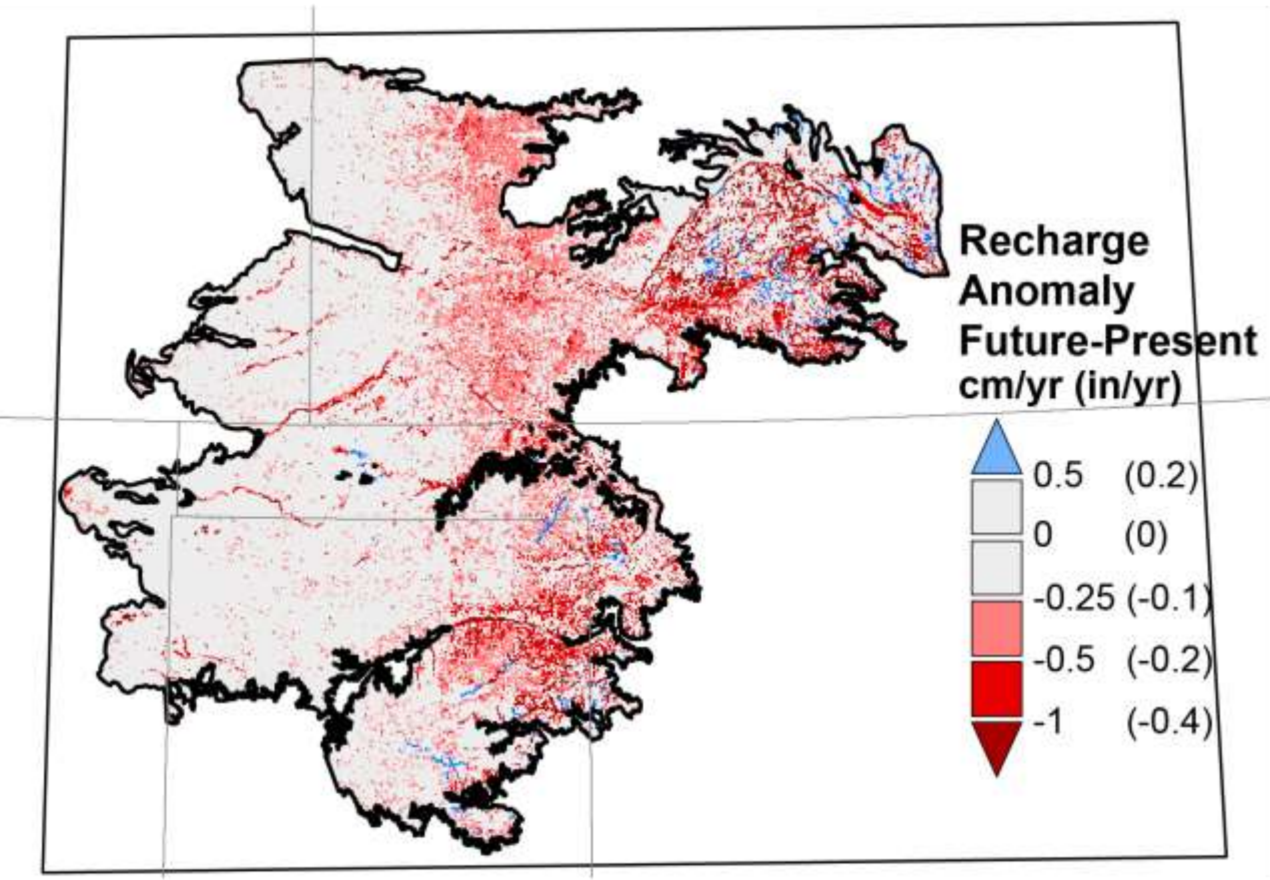
- Higher water demand expanded
  - Eastern and western portions of the aquifer
- Total irrigation water demand declined (not shown)
  - Less robust crops
- 14-inch limit hit in many more locations

Climate change impact: precipitation



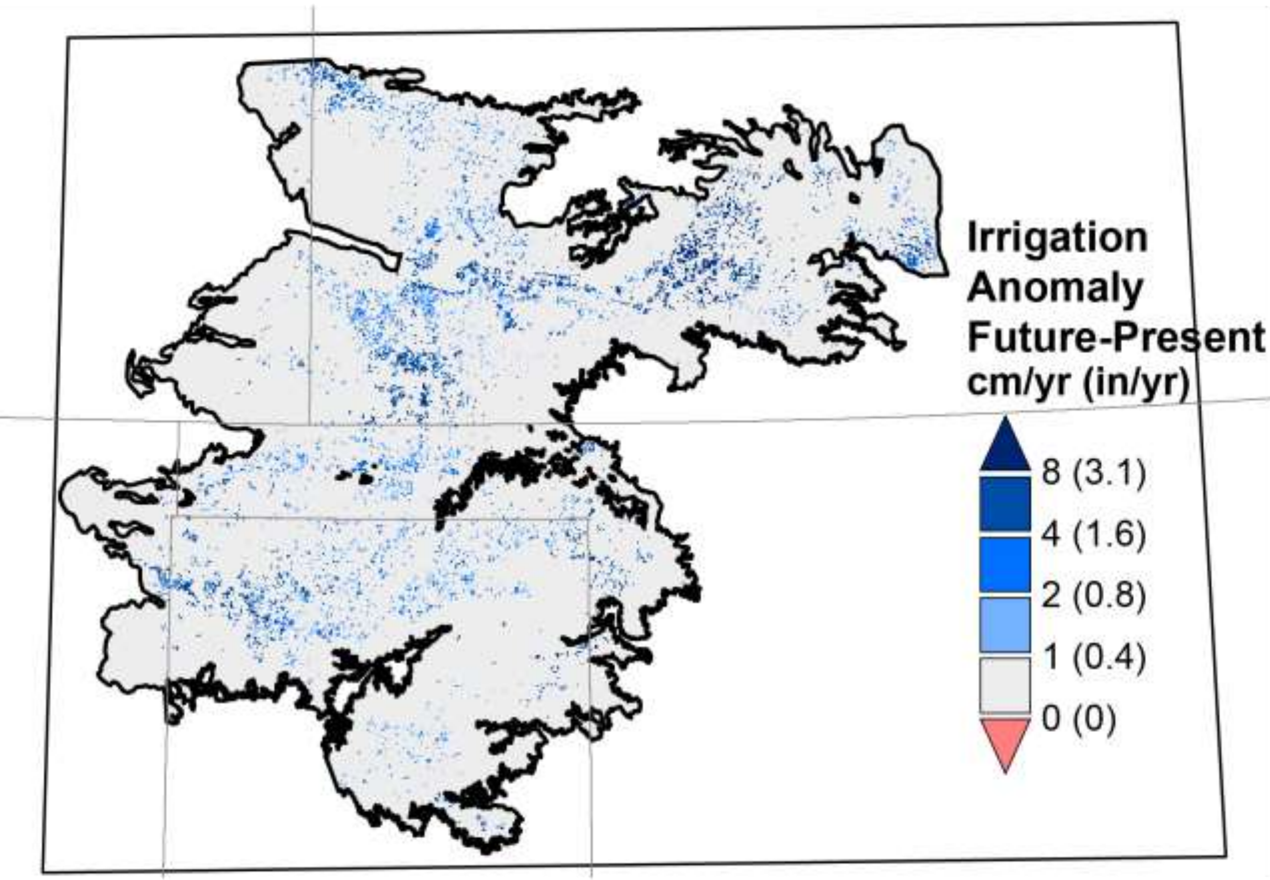
- On average, precip. lower everywhere in this scenario
  - 2095, RCP6.0
- Greatest declines in the east, relatively uniform percentage declines

Climate change impact: recharge

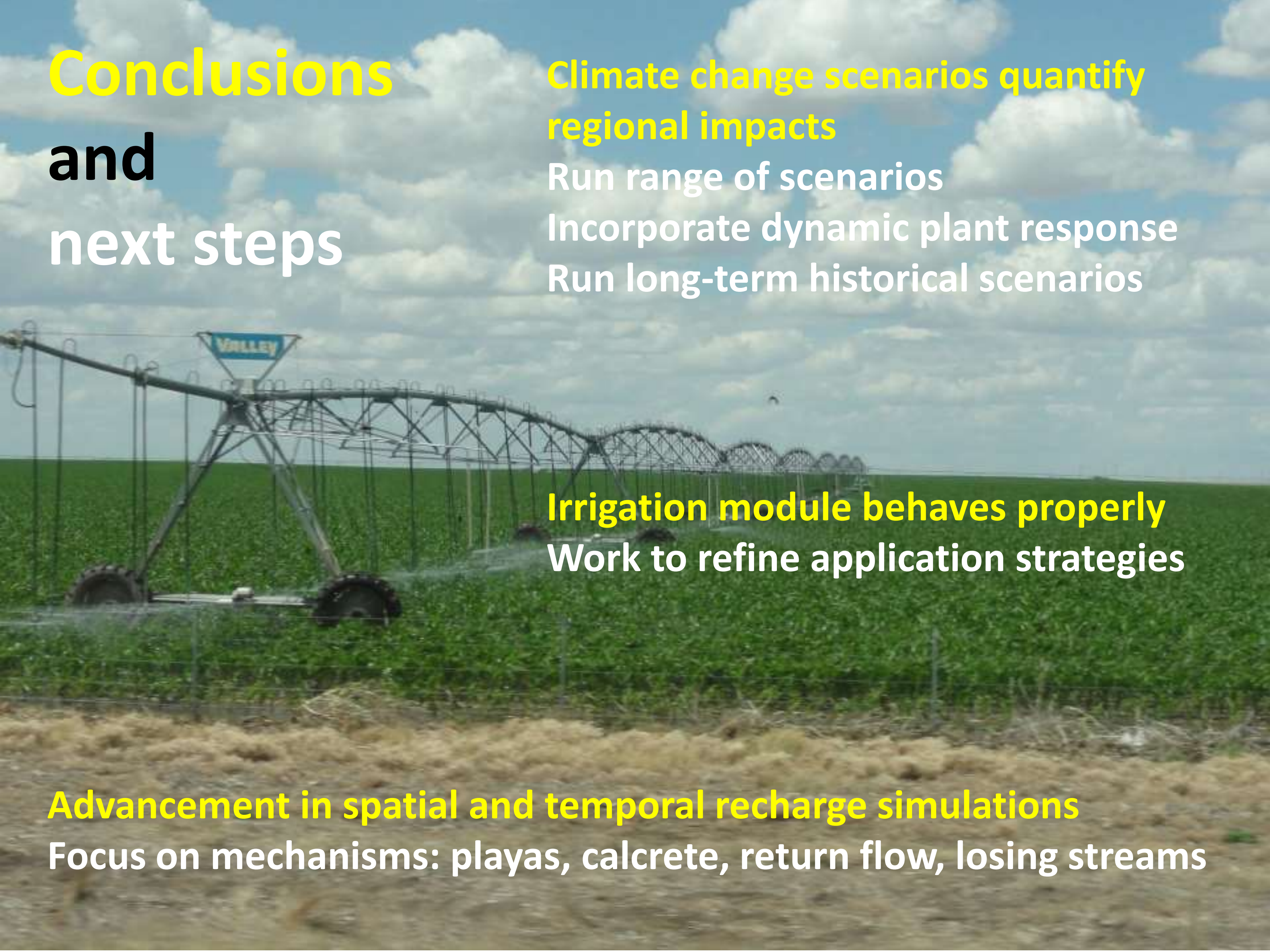


- Recharge declines significantly
- Impact greater in east
- Pattern similar to drought impacts
  - Order of magnitude less per year

Climate change impact: irrigation demand



- Irrigation demand expands eastward and westward
- Similar pattern to drought
  - Roughly ½ the magnitude per year
- Does not take into account lengthened growing season (yet)



Conclusions and next steps

Climate change scenarios quantify regional impacts

Run range of scenarios

Incorporate dynamic plant response

Run long-term historical scenarios

Irrigation module behaves properly

Work to refine application strategies

Advancement in spatial and temporal recharge simulations

Focus on mechanisms: playas, calcrete, return flow, losing streams