The water system in GCAM: Key developments and future directions

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Joint Global Change Research Institute (JGCRI)

College Park, MD

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Overview

- Overview of the water system in GCAM
- Key developments
- Future directions

The GCAM Global Hydrologic Model

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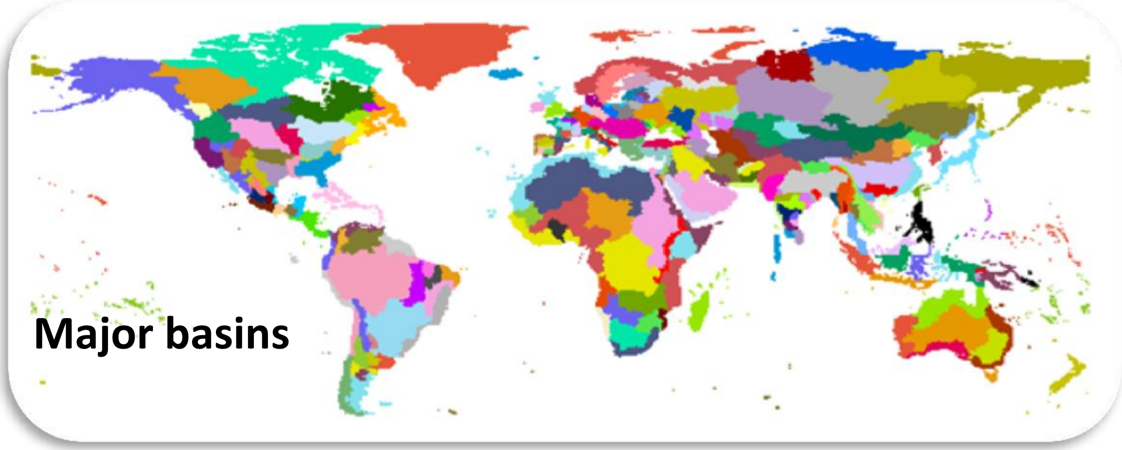
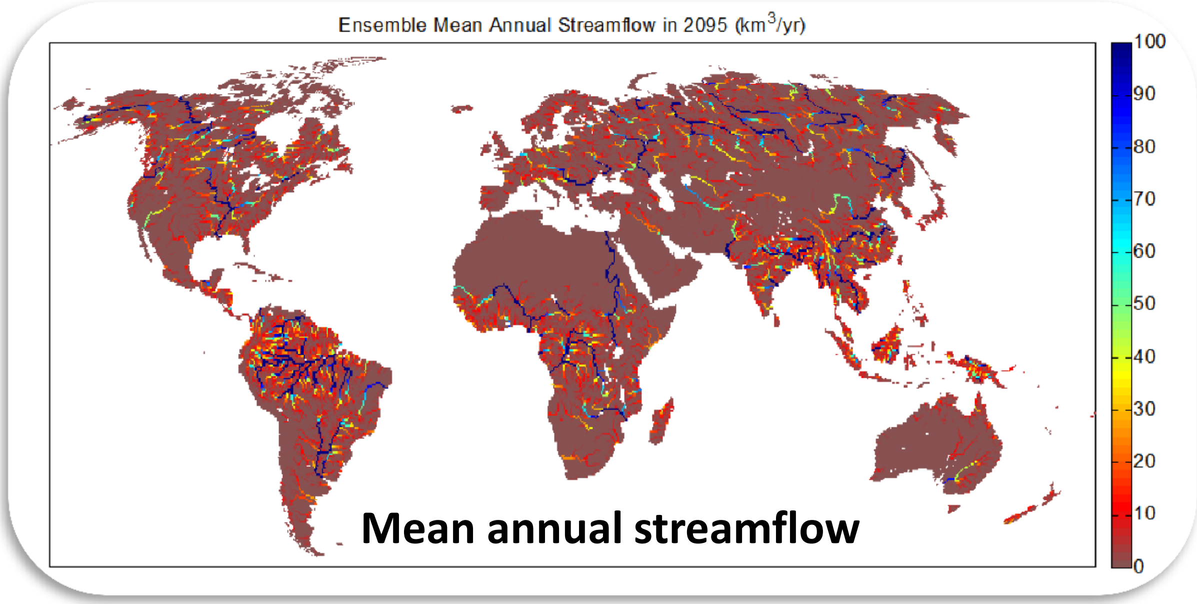
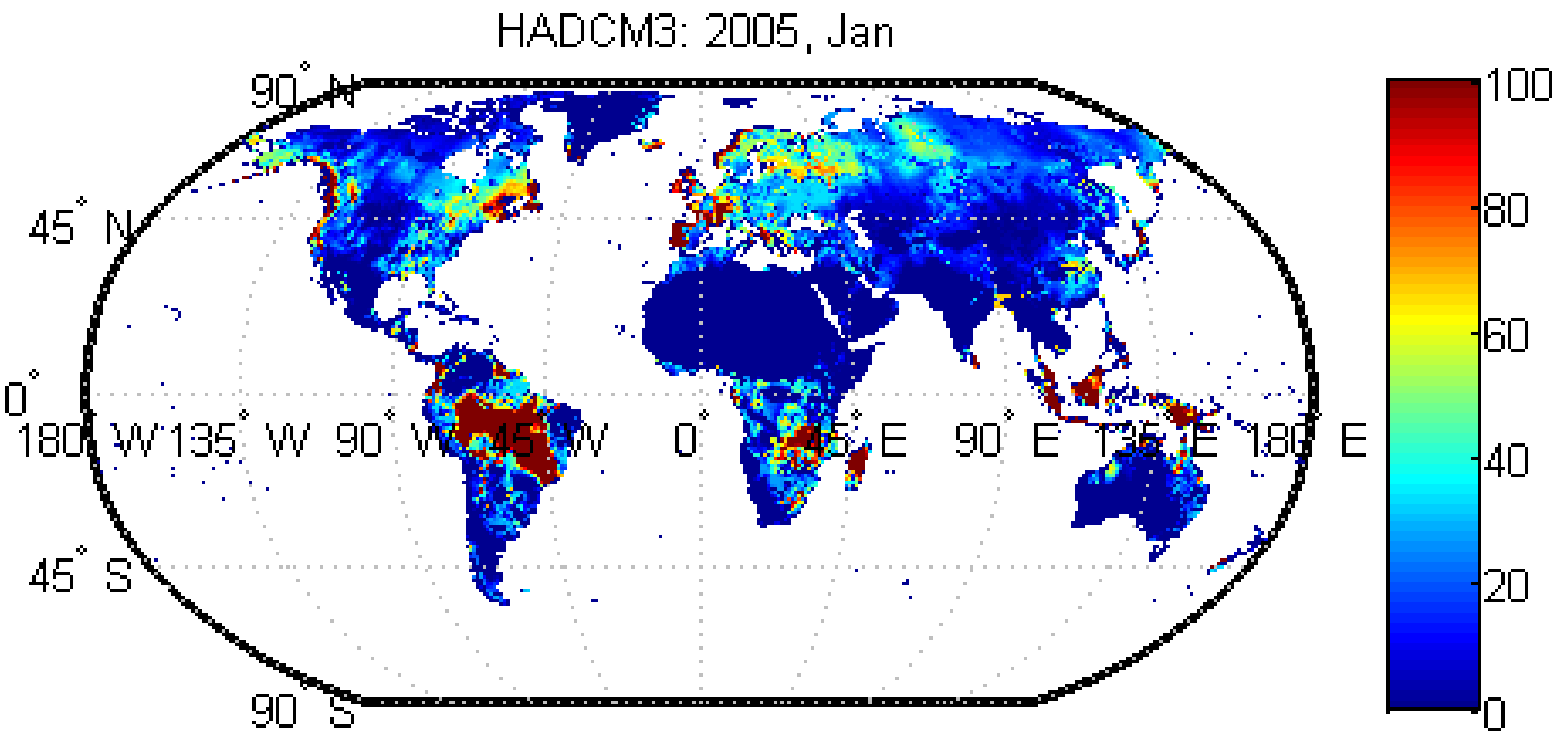


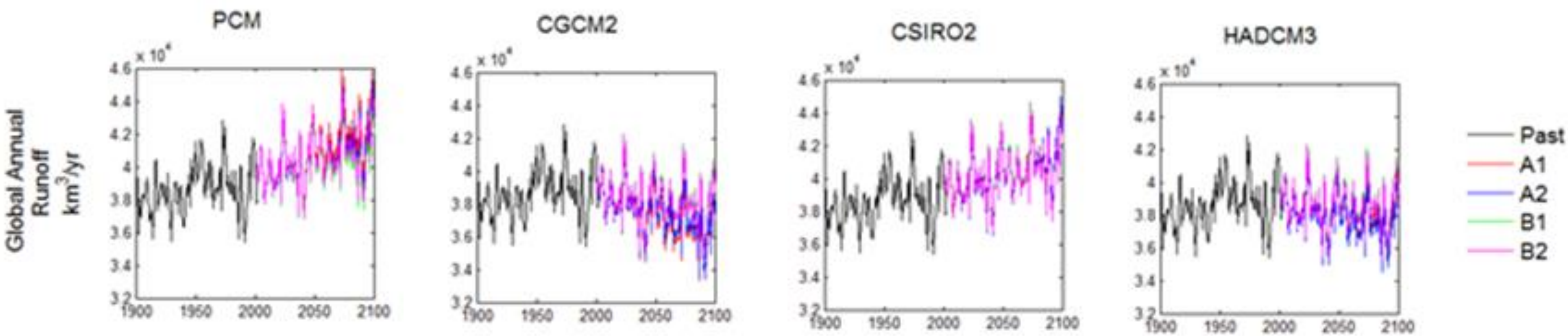


- GCAM has a macroscale global hydrologic model
- Modified River Transport Model scheme
- Simulates runoff and streamflow (1901-2100)
- Requires climate information from GCMs as inputs
- 233 basins globally
- 18 basins in the US consistent with the USGS WRRs
- Monthly temporal scale
- 0.5x0.5 degree spatial resolution

GCAM also accounts for non-renewable water sources such as fossil groundwater and desalinated water

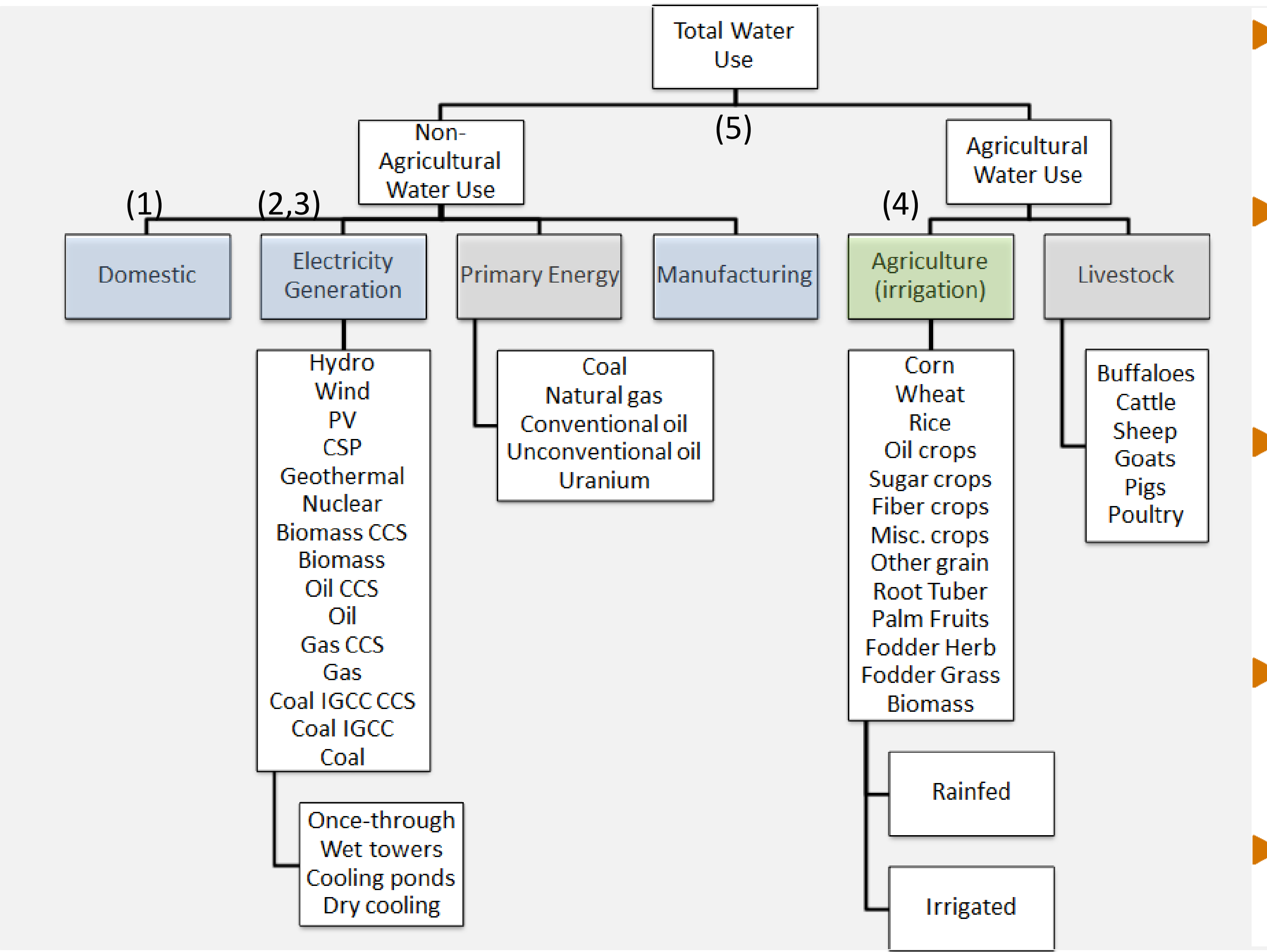
Projecting water supply under climate change





Hejazi et al. (2014). Hydrology and Earth System Sciences, 18, 2859-2883, doi:10.5194/hess-18-2859-2014

Global Water Demands



- Technologically detailed representation of water demand sectors
- Tracks water demands for several sectors, subsectors, and technologies
- Tracks water demands at various spatial scales (regions, state, agro-ecological zones)
- Tracks both annual withdrawal and consumptive water use
- Endogenously incorporated in GCAM

(1) Hejazi et al. (2013). Hydrological Sciences Journal.
(2) Kyle et al. (2013). International Journal of Greenhouse Gas Control.
(3) Davies et al. (2013). Advances in Water Resources.
(4) Chaturvedi et al. (2013). Mitigation and Adaptation Strategies for Global Change.
(5) Hejazi et al. (2014). Technological Forecasting and Social Change

14 GCAM Regions

151 AEZ scale

US (50-state)

Water Demand Projections

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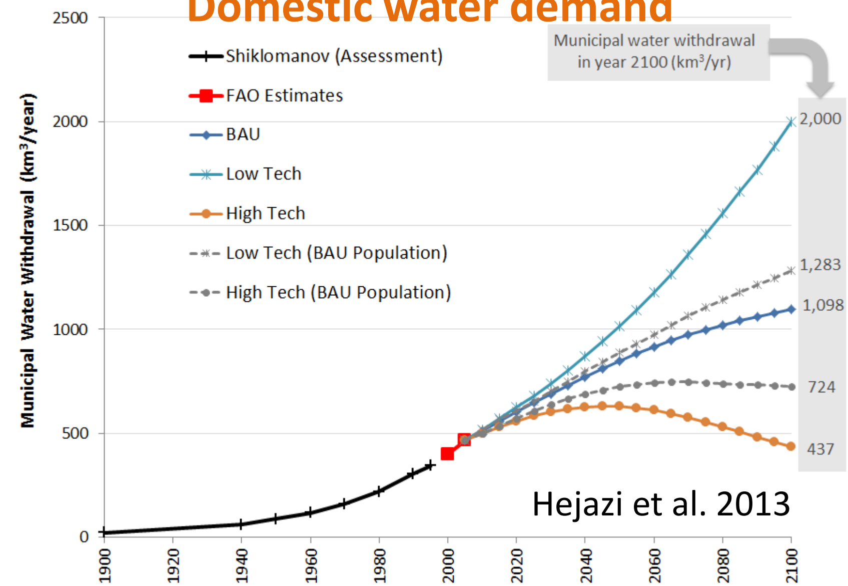
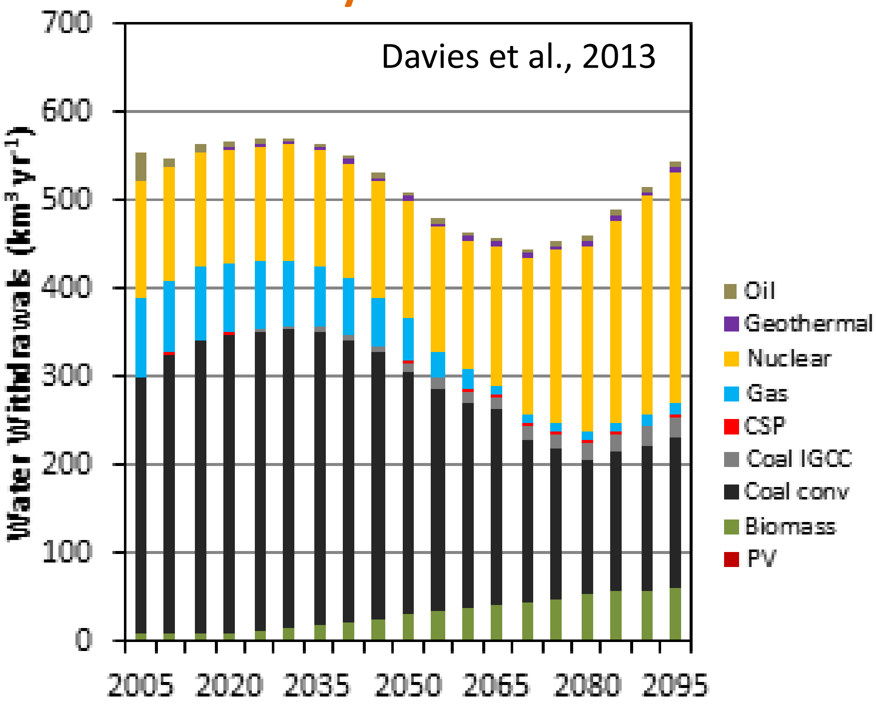
GCAM tracks water demands for several sectors, subsectors, and technologies, and at various spatial scales (regions, state, agro-ecological zones)

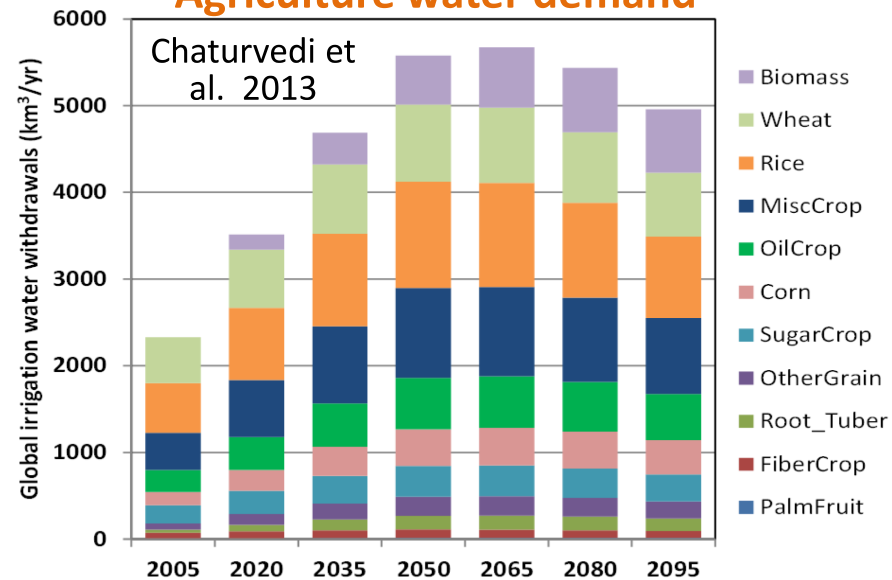
Domestic water demand



Electricity water demand

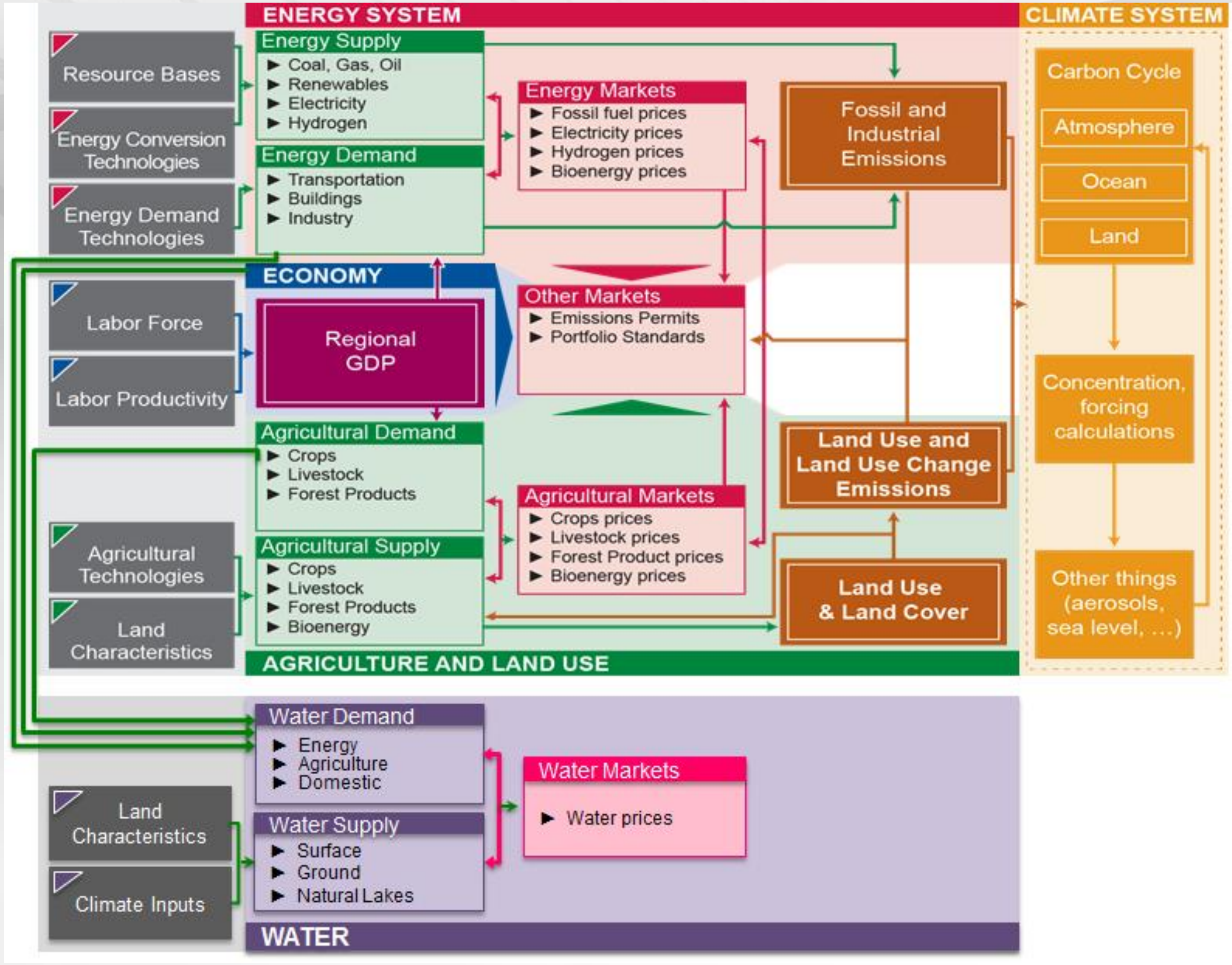


Agriculture water demand



- Closing the water system in GCAM
- Telescoping on regional issues
- Climate Change Impacts
- Providing gridded data products
- Improving the downscaling algorithms
- Uncertainty quantification

KEY DEVELOPMENTS



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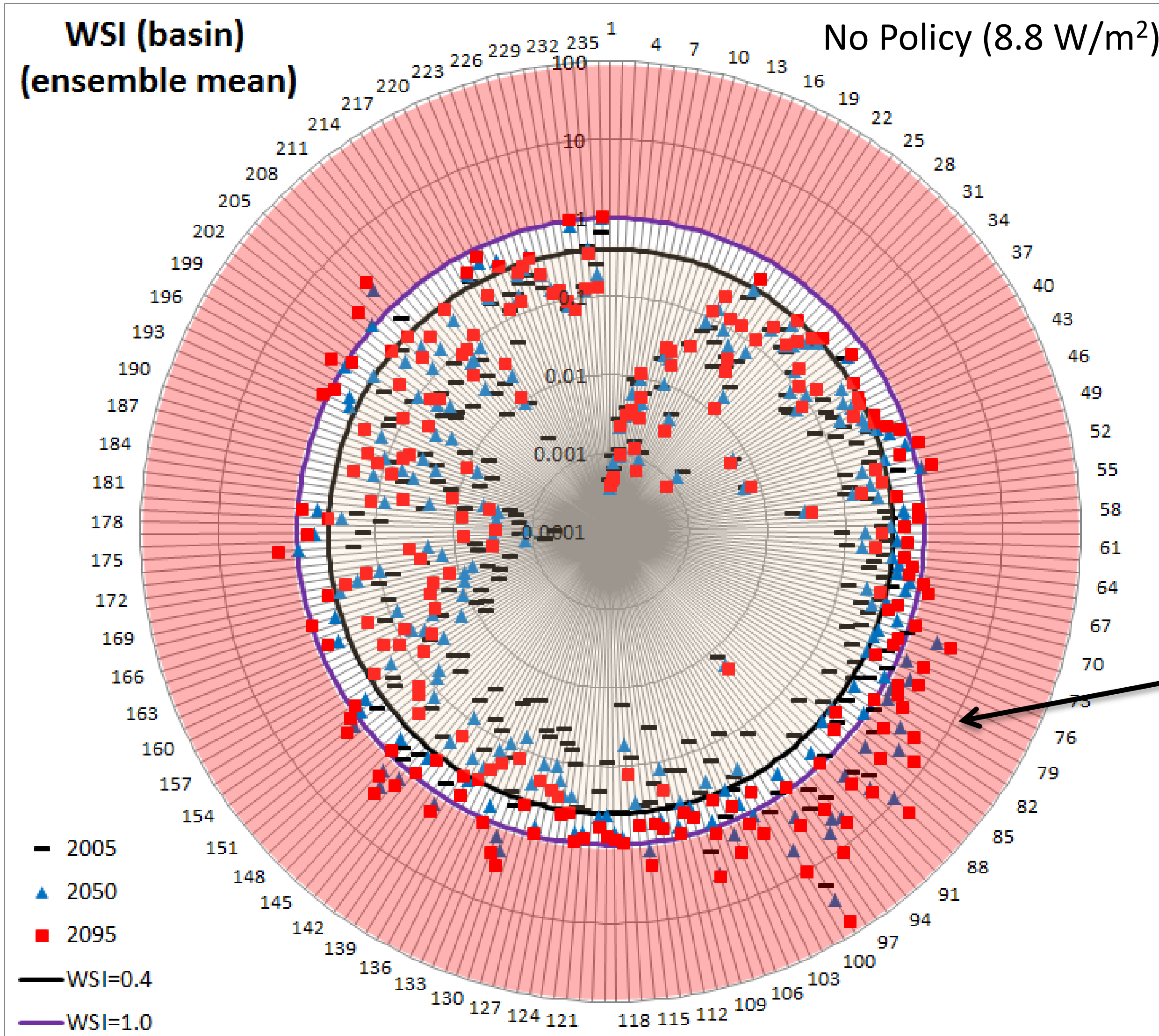
CLOSURE OF THE WATER SYSTEM IN GCAM

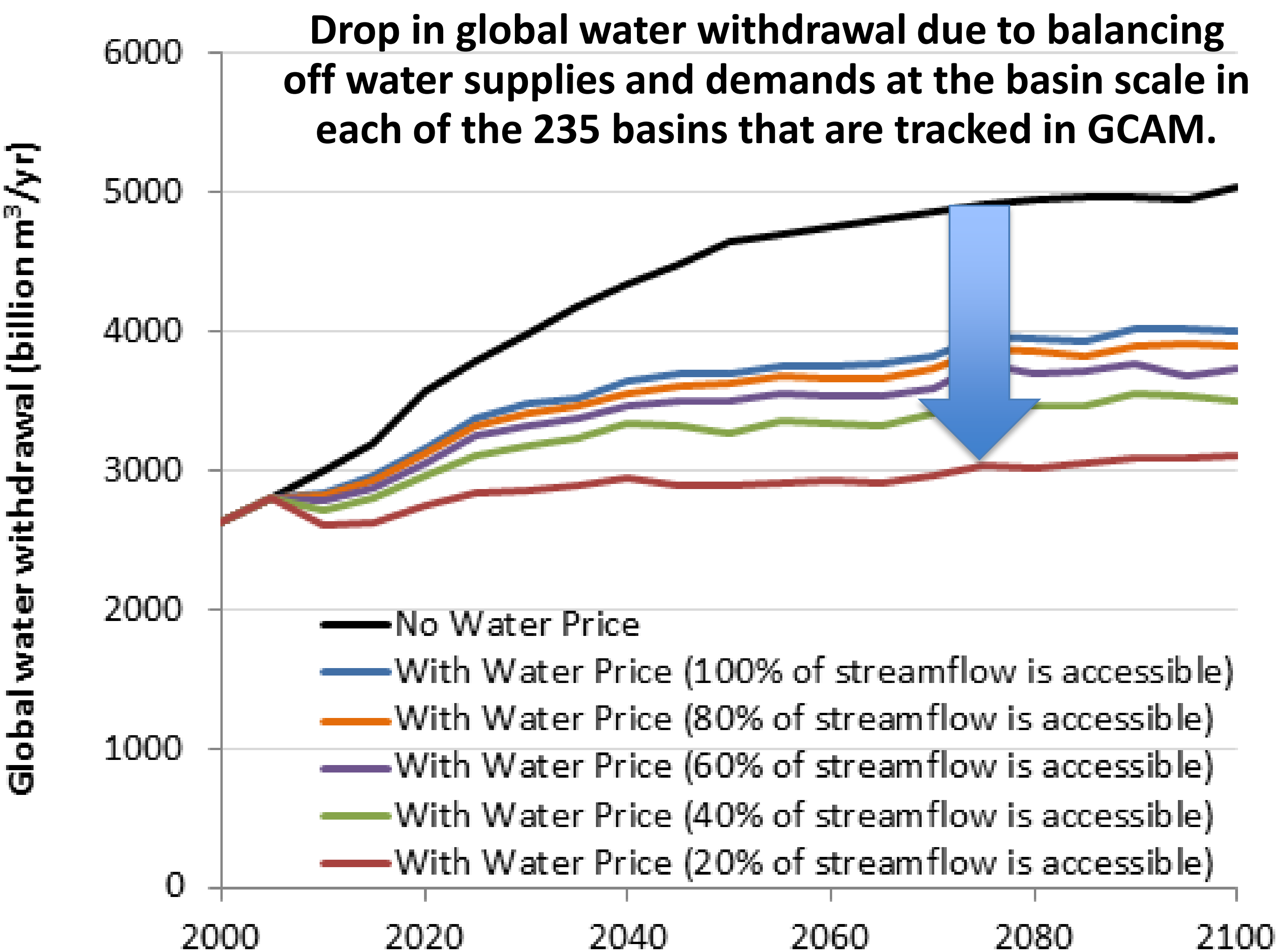
Tracking what happens at the basin scale – Water is a binding constraint in many basins

Estimating water scarcity at the basin level



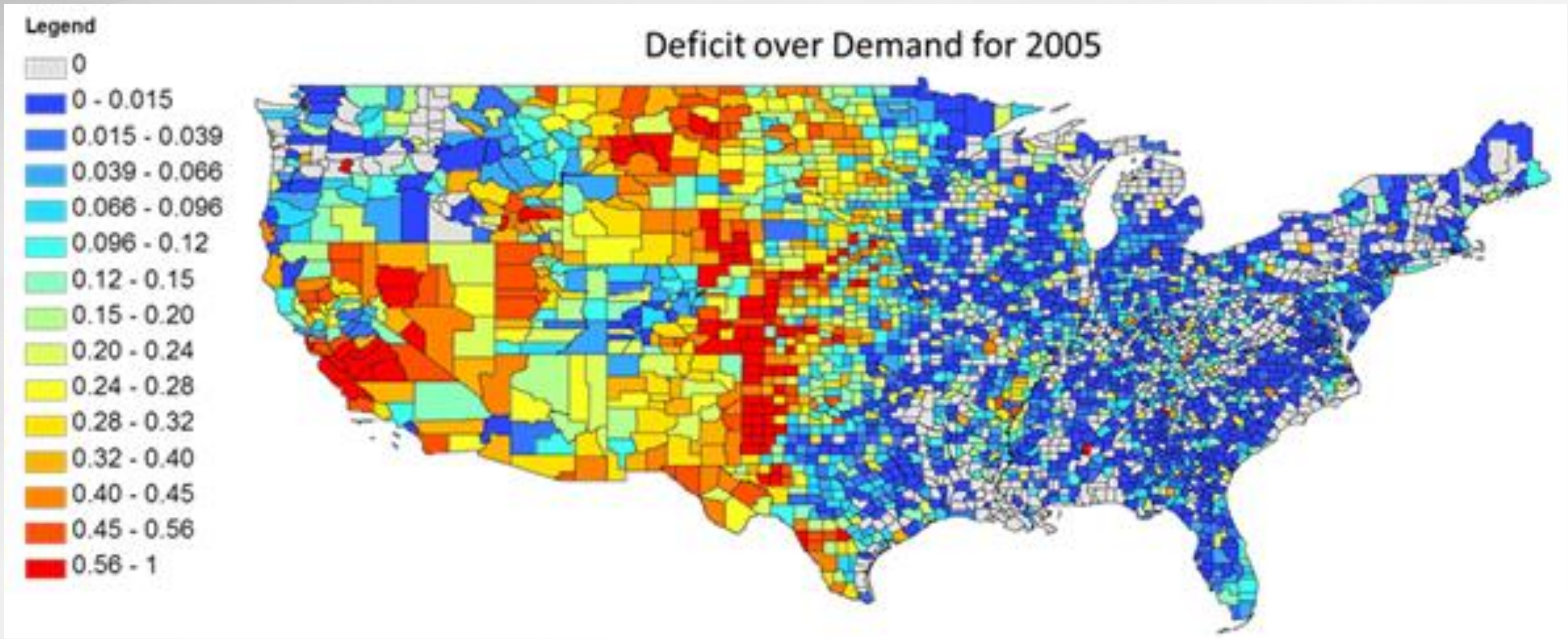
Demand exceeds supply in many basins and the situation worsens in the future

Reconciling water demand and supply at the basin level



- Mapping all the water demands from their native spatial scale to the basin scale
- Constraining the annual water demands to annual amounts of available water resources.
- Allowing basins to tap into non-renewable (fossil) groundwater and desalinated water as additional sources

Kim et al. (In prep.). On the closure of the water system in integrated assessment modeling: A water market approach.



TELESCOPING ON REGIONAL ISSUES

GCAM-USA: A regionalized version of GCAM for the U.S. with 50-state

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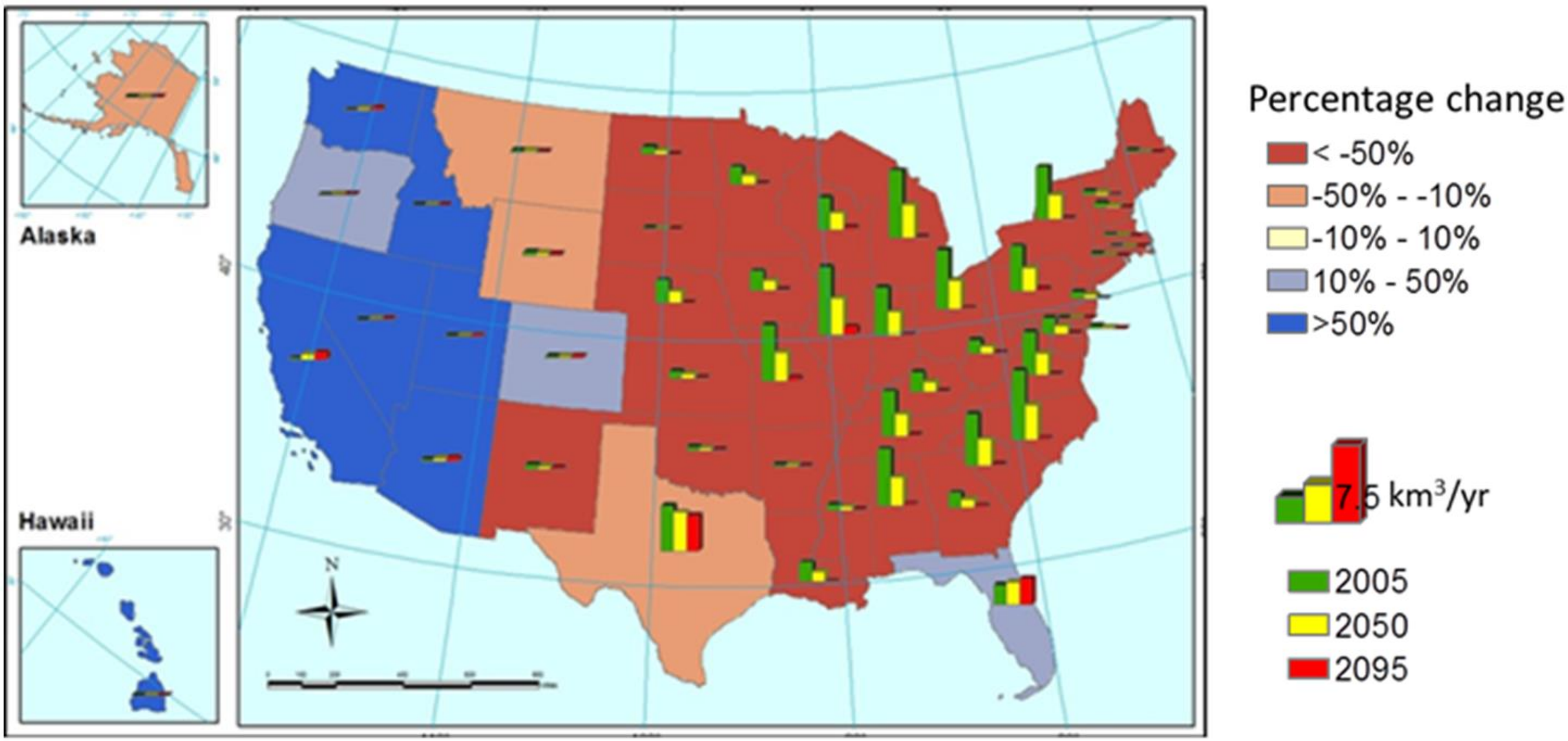
Changes in water withdrawals for electricity generation at the state level in the US



Liu et al. (conditionally accepted). An integrated assessment of energy-water nexus at the state level in the United States: Projections and analyses under different scenarios through 2095. Technological Forecasting and Social Change.

Model Interoperability: Replacing GCAM's Hydrologic Module with CLM-MOSART-WM

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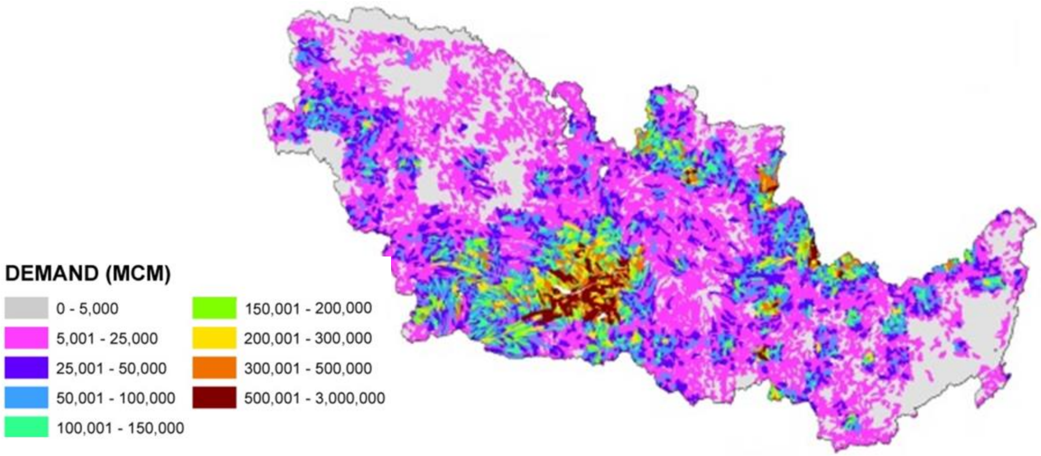
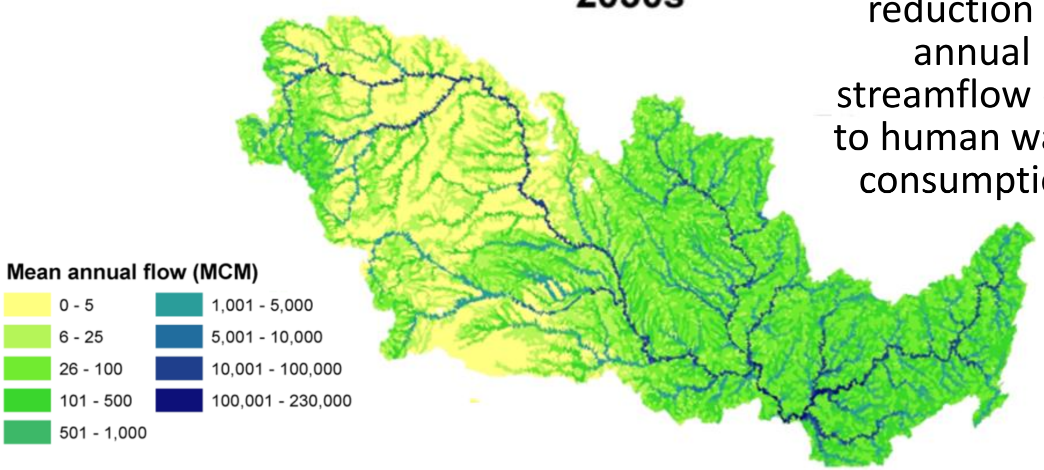
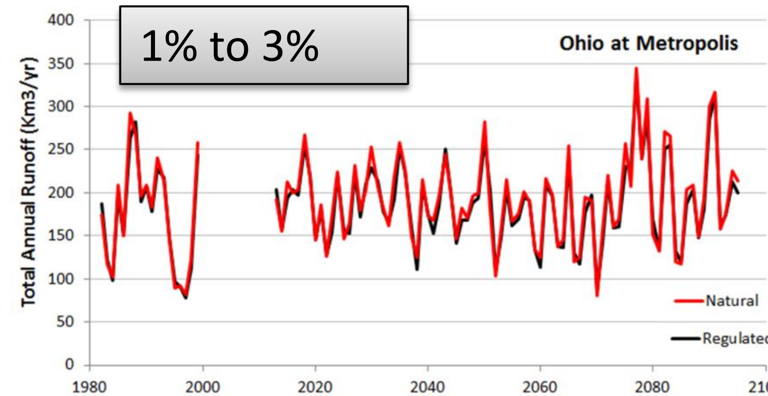
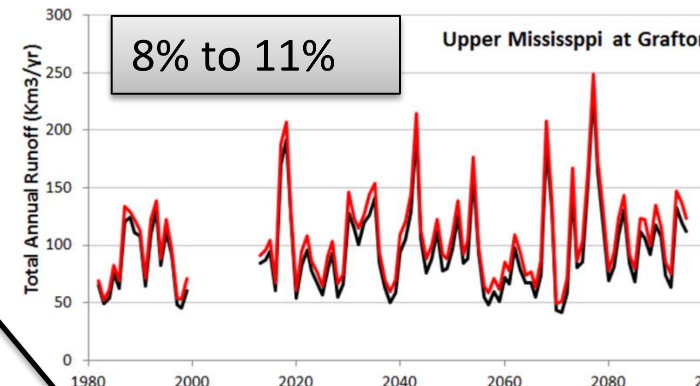


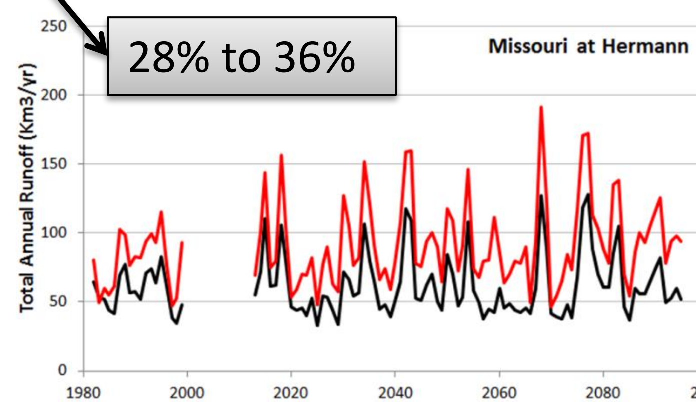
2030s







percent reduction in annual streamflow due to human water consumption

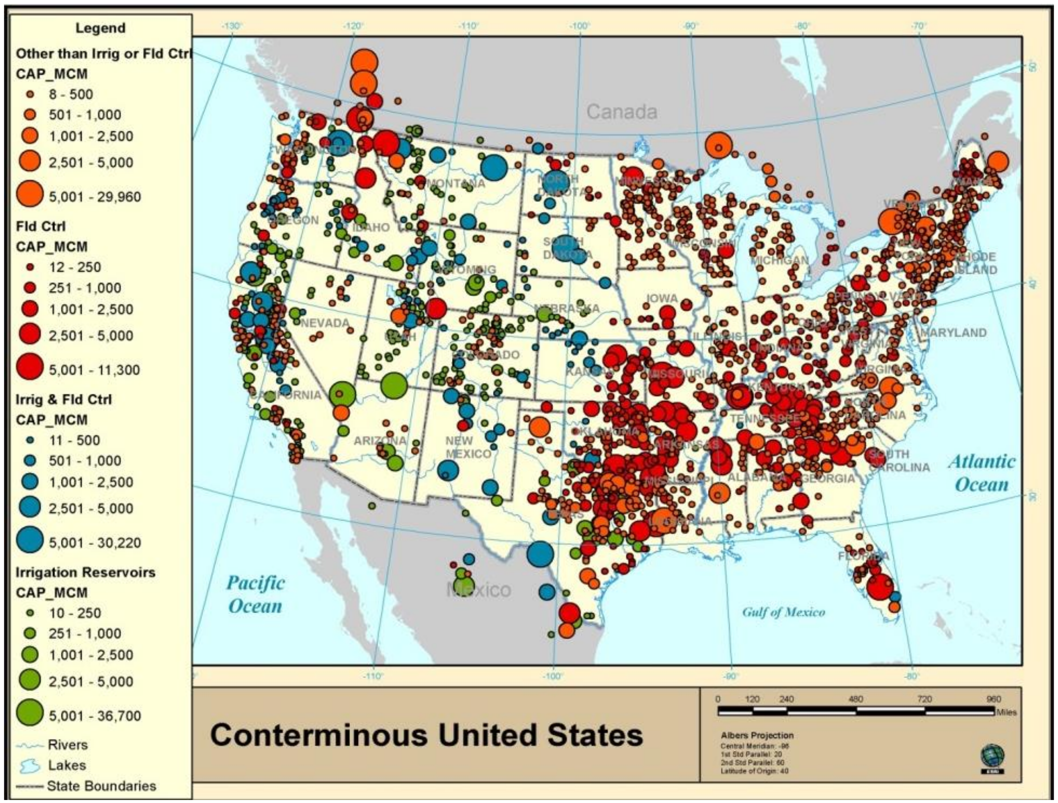


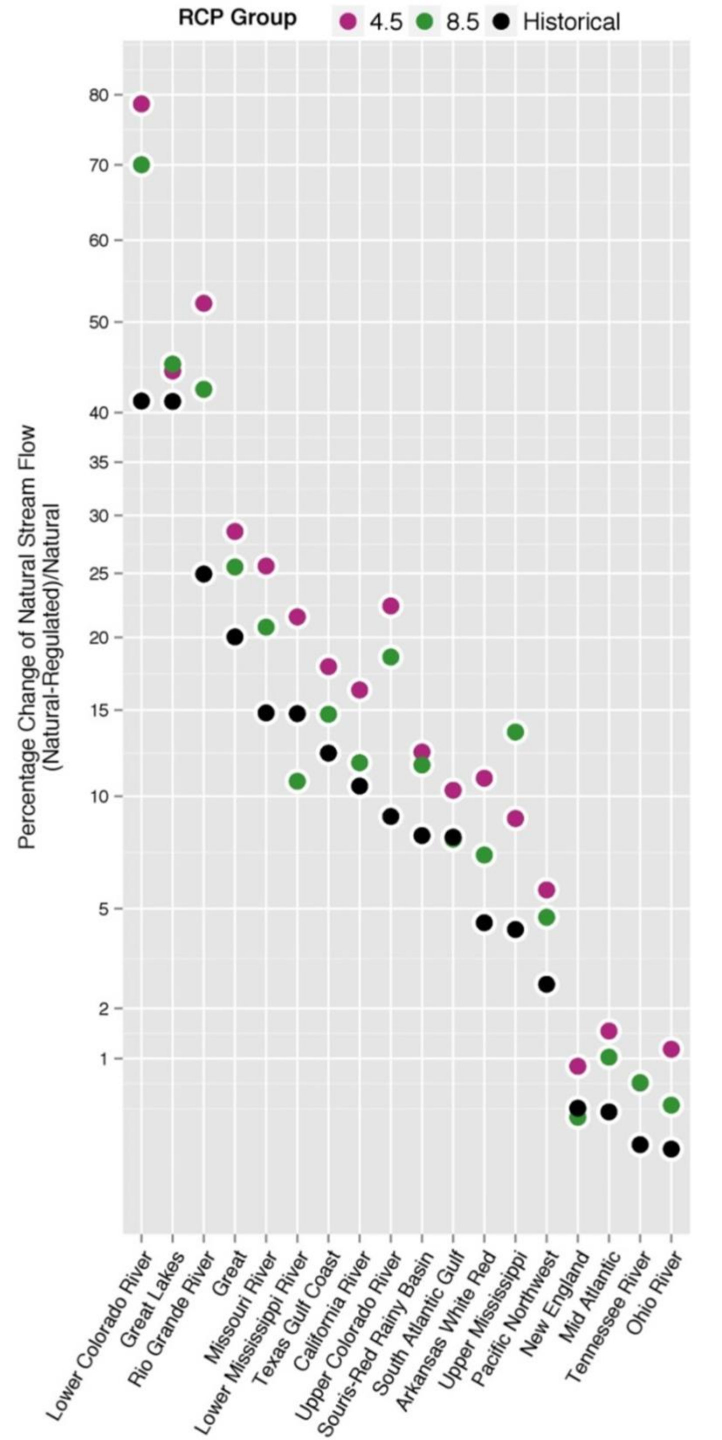
long term simulated time series of historical and future (B1) total annual regulated and natural runoff for the three regions and the Upper Midwest.

Voisin et al. (2013). Hydrol. Earth Syst. Sci., 17, 4555-4575.

Extended the framework to the US

Humans have a pronounced foot print on water resources especially in relatively dry regions





Hejazi et al. (in review). Climate mitigation exacerbates water deficits in the United States. Nature Climate Change.

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CLIMATE CHANGE IMPACTS & OTHER STRESSORS

Climate change impact on hydropower generation – A comprehensive assessment

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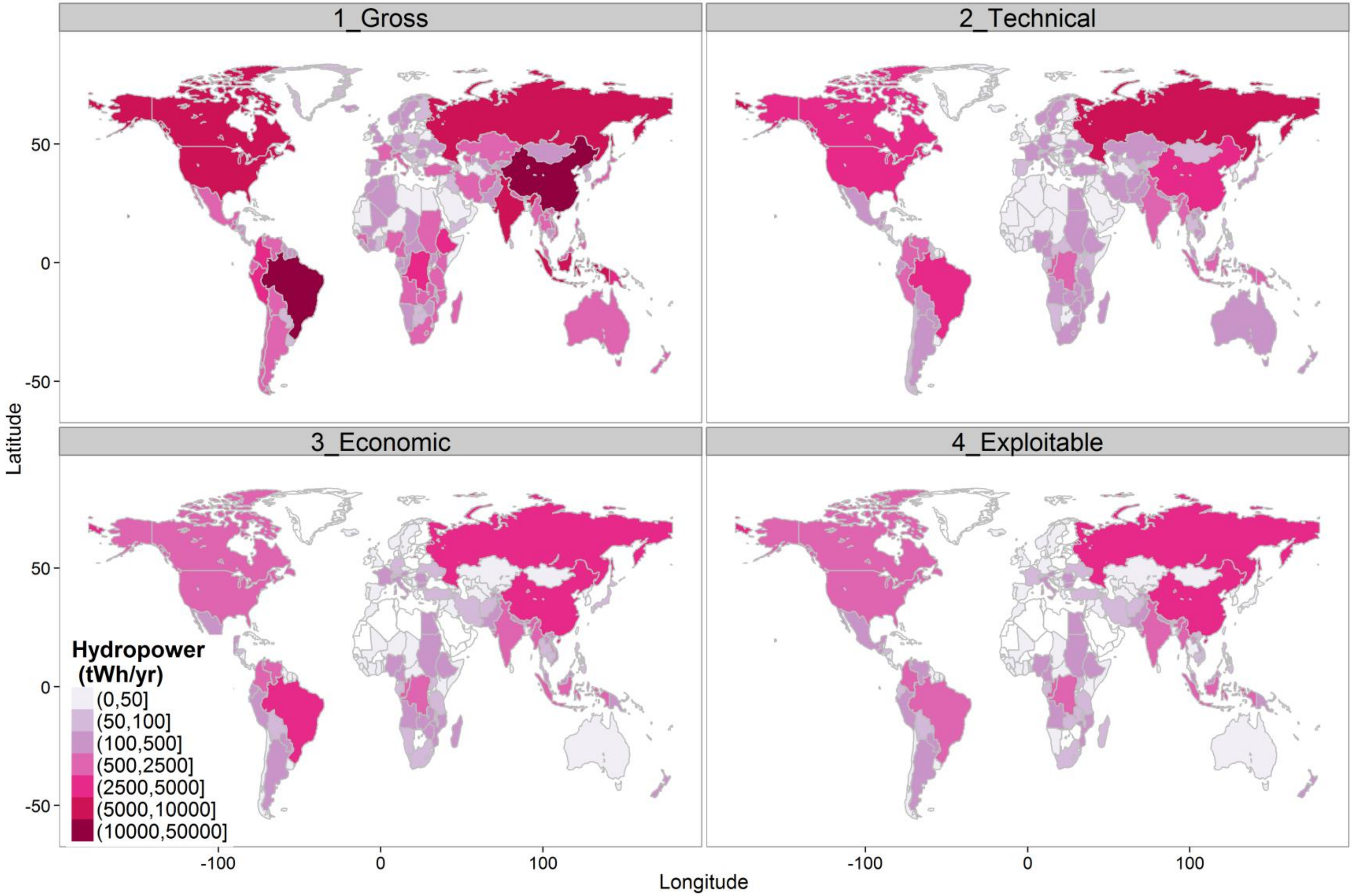
Long term mean annual hydropower potential (1971-2000) at the country scale



Zhou et al. (In prep.). A Comprehensive View of Global Potential for Hydro-generated Electricity.

The effects of climate change and mitigations on water scarcity – Mitigation type & target matter!

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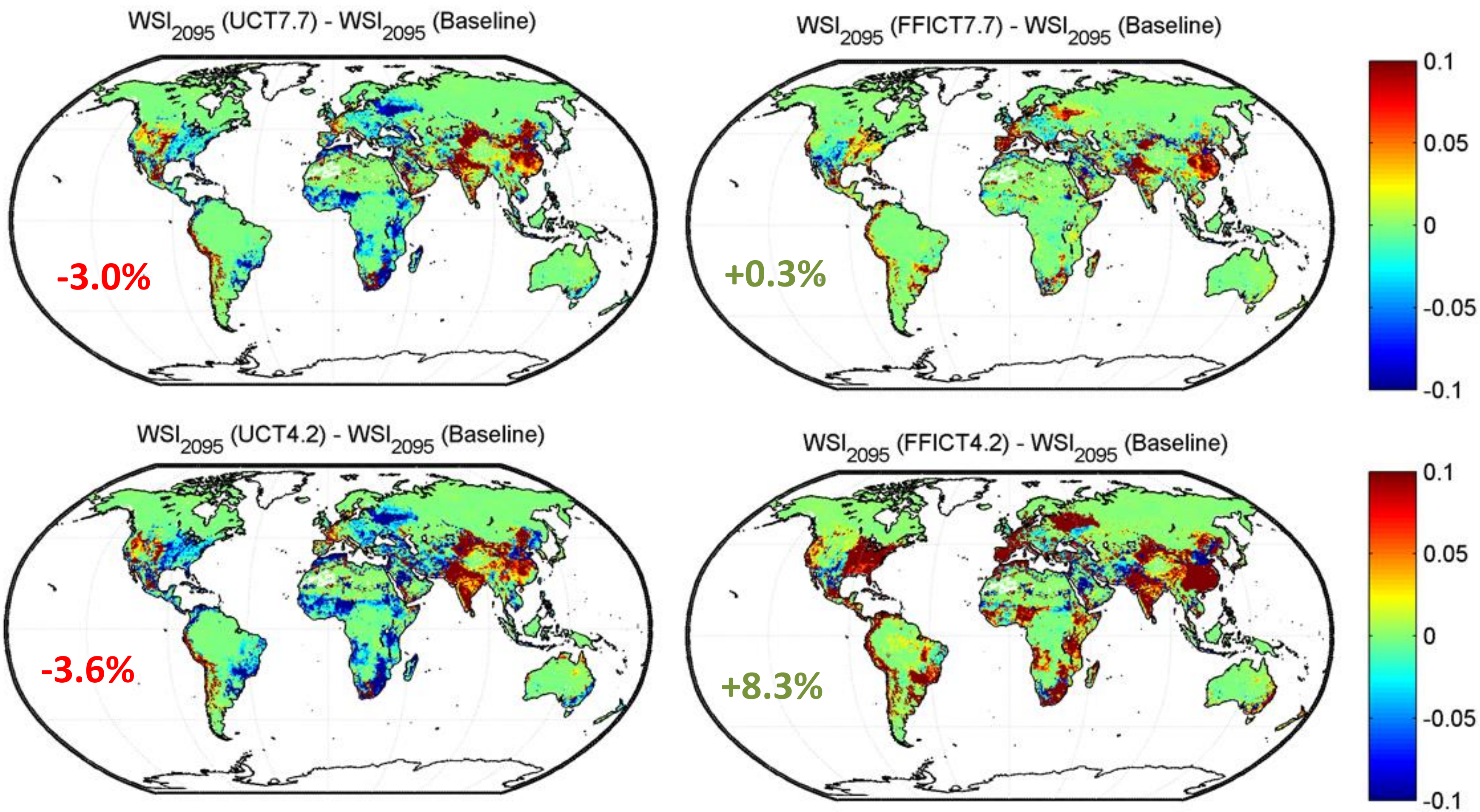
Climate mitigation **reduces** (**increases**) the number of people living under severe water scarcity under the **UCT** (**FFICT**) tax regime



Hejazi et al. (2014). Integrated assessment of global water scarcity over the 21st century under multiple climate change mitigation policies, Hydrology and Earth System Sciences, 18, 2859-2883, doi:10.5194/hess-18-2859-2014

A set of experiments on the relative effects of climate change and human activities on water scarcity globally

Baseline: current demands and current climate conditions in year 2005

	Baseline
Fixed	$Climate_{2005}$
Fixed	$Demand_{2005}$

The effect of climate change alone

	B1 (RF4.2)	B2 (RF5.5)	A2 (RF7.7)	A1Fi (RF8.8)
Variable	$Climate_{2095,\ B1}$	$Climate_{2095,\ B2}$	$Climate_{2095,\ A2}$	$Climate_{2095,\ A1Fi}$
Fixed	$Demand_{2005}$	$Demand_{2005}$	$Demand_{2005}$	$Demand_{2005}$

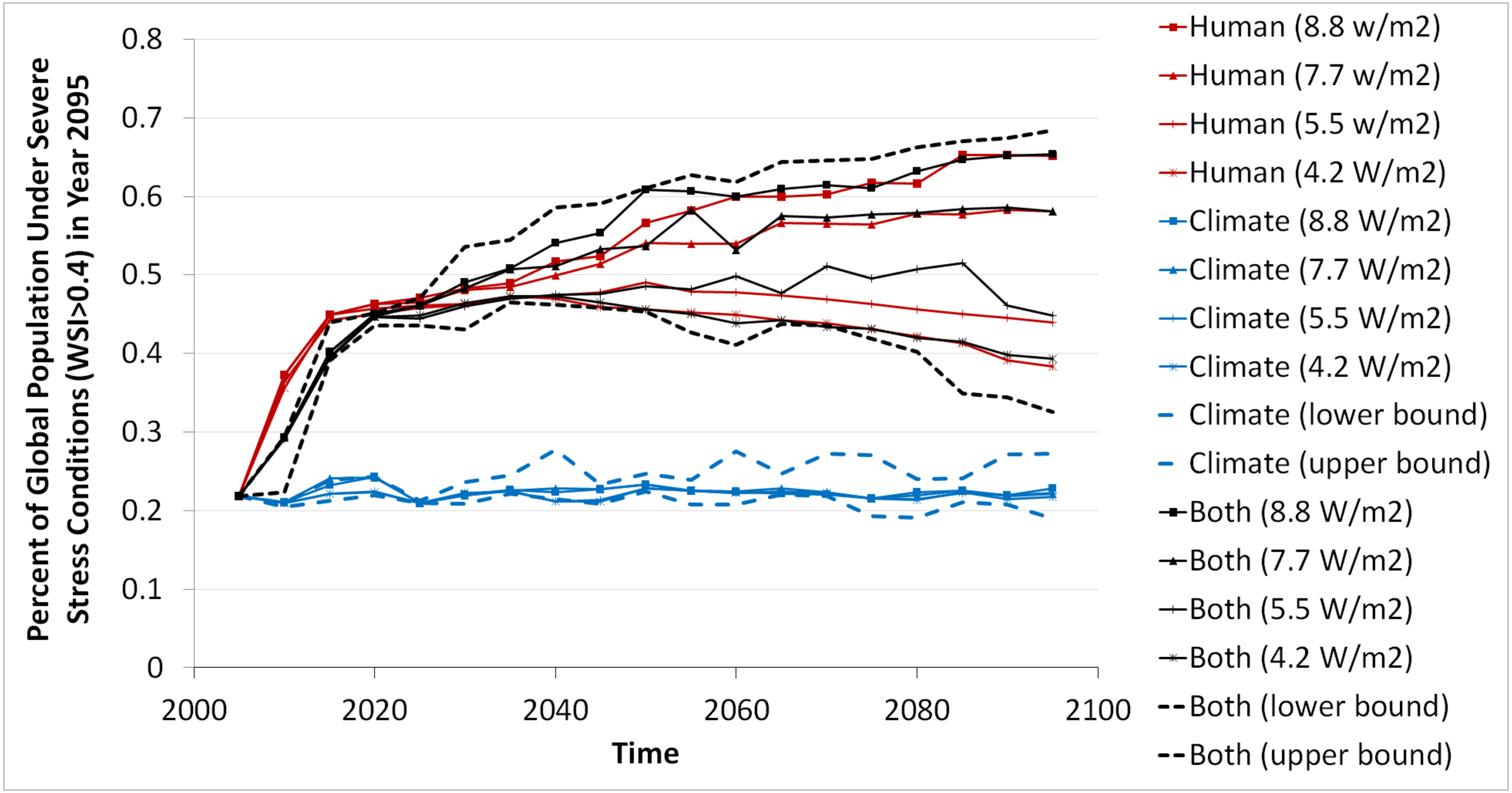
The effect of socioeconomic drivers alone

	B1 (RF4.2)	B2 (RF5.5)	A2 (RF7.7)	A1Fi (RF8.8)
Fixed	$Climate_{2005}$	$Climate_{2005}$	$Climate_{2005}$	$Climate_{2005}$
Variable	$Demand_{2095,\ 6-}$	$Demand_{2095,\ 6+}$	$Demand_{2095,\ 9+}$	$Demand_{2095,\ 14-}$

The effects of climate change and socioeconomic drivers together

	B1 (RF4.2)	B2 (RF5.5)	A2 (RF7.7)	A1Fi (RF8.8)
Variable	$Climate_{2095,\ B1}$	$Climate_{2095,\ B2}$	$Climate_{2095,\ A2}$	$Climate_{2095,\ A1Fi}$
Variable	$Demand_{2095,\ 6-}$	$Demand_{2095,\ 6+}$	$Demand_{2095,\ 9+}$	$Demand_{2095,\ 14-}$

Socioeconomics play a larger role than climate



Percent of Population Facing Water Scarcity (using ensemble mean GCM)

Humans play a larger role in water scarcity in 93% of the basins(89% of total land)

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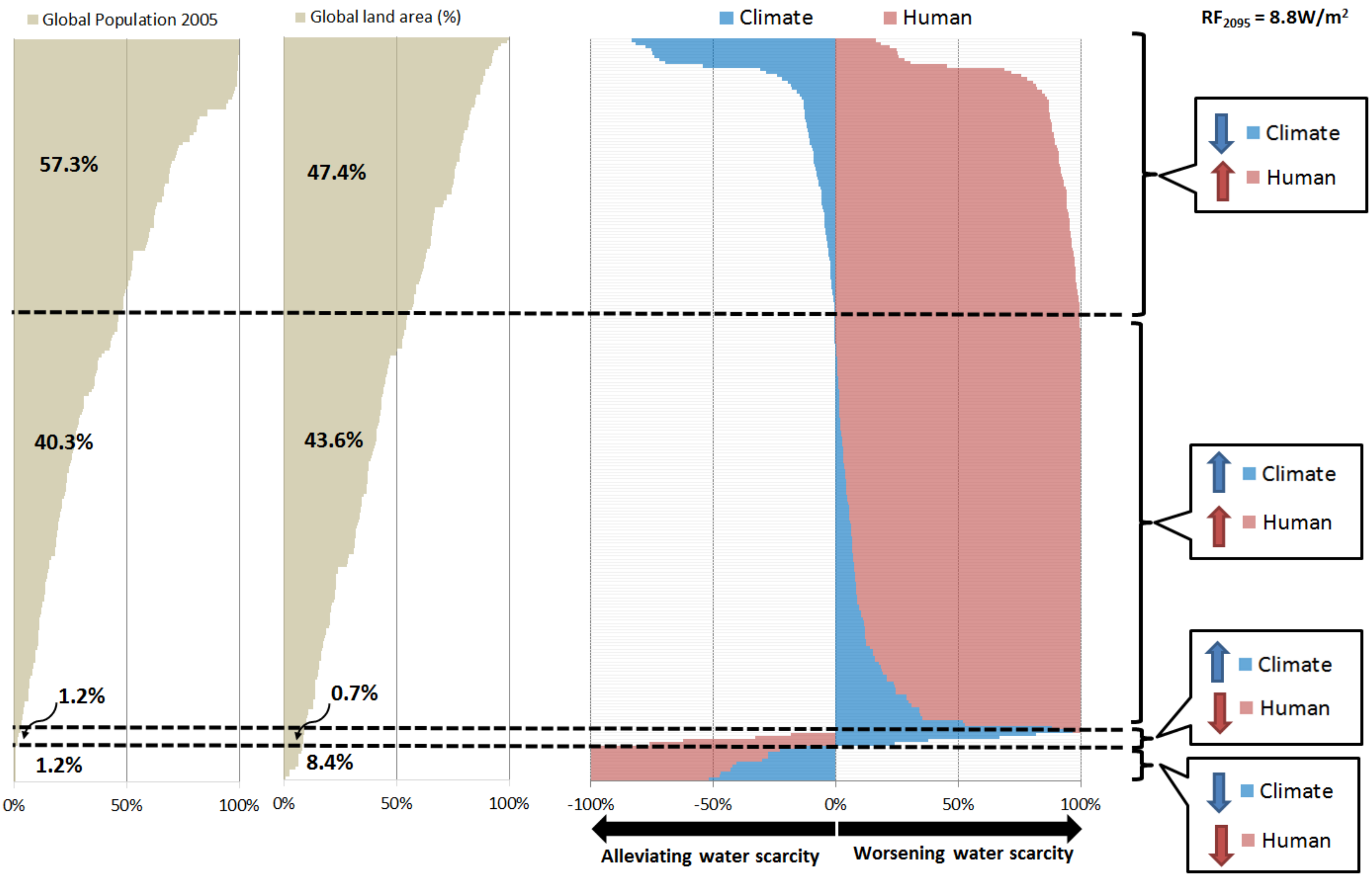
No policy (8.8 W/m^2 by year 2100)



Hejazi et al. (In prep.). On the relative impacts of climate change and socioeconomic drivers on global water scarcity in the 21st century.

OTHER DEVELOPMENTS

Providing gridded data products

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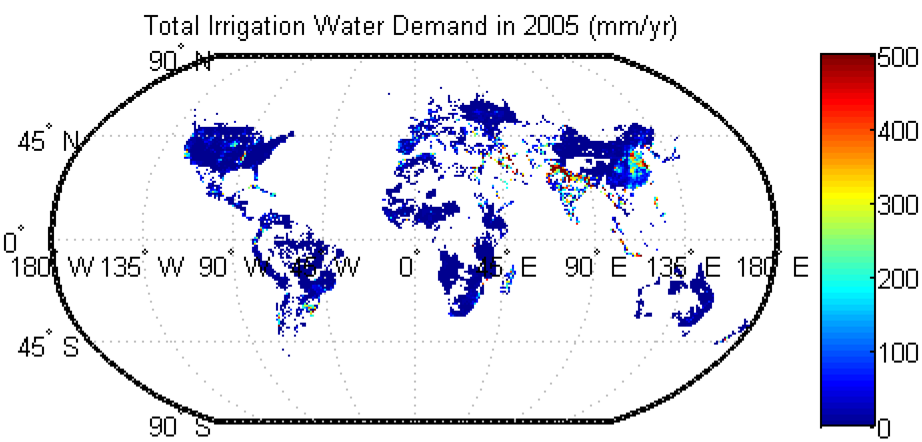
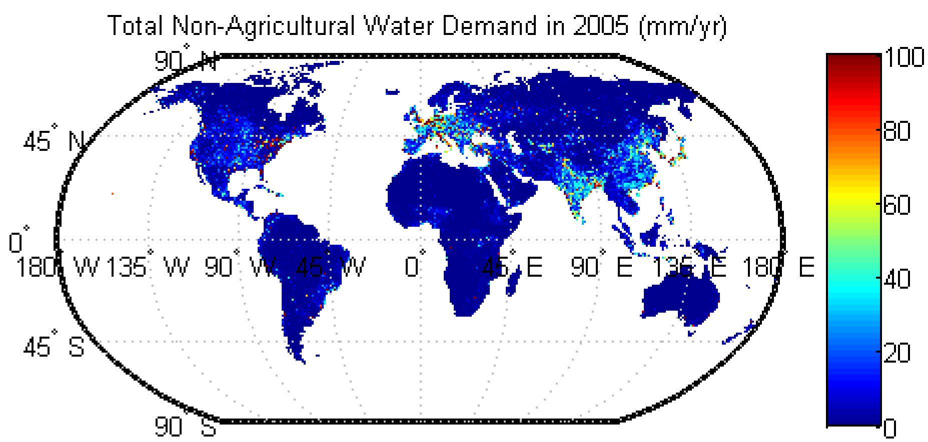
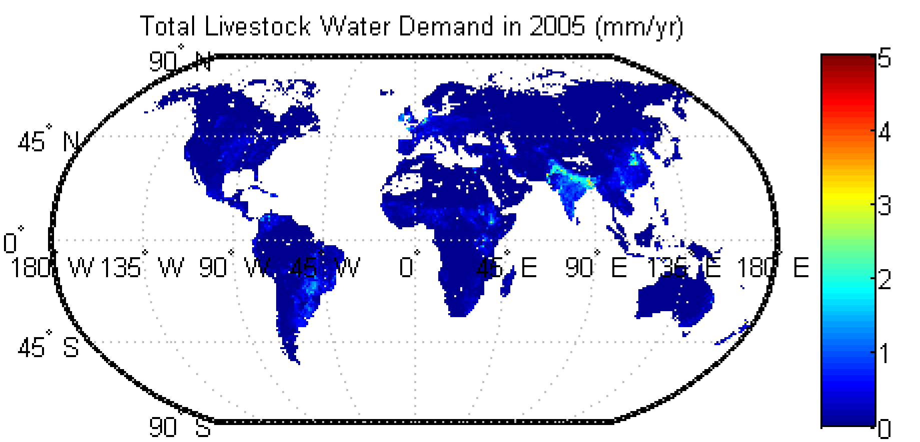
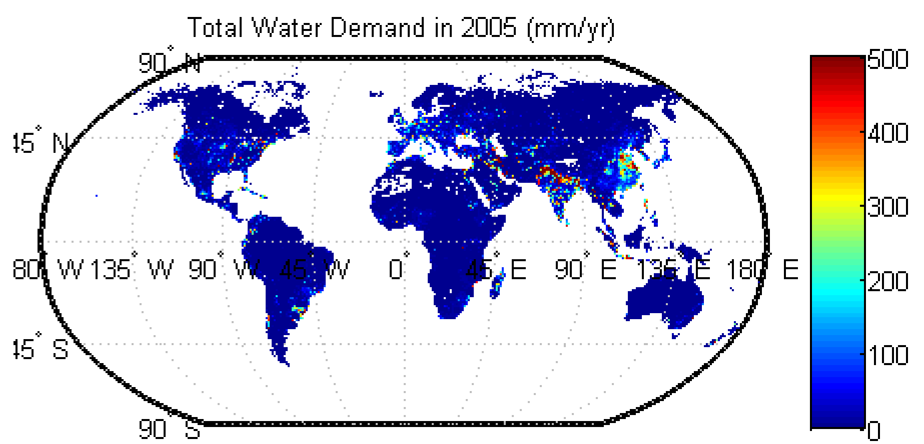
Downscaled water demands to finer scales are used by ESMs







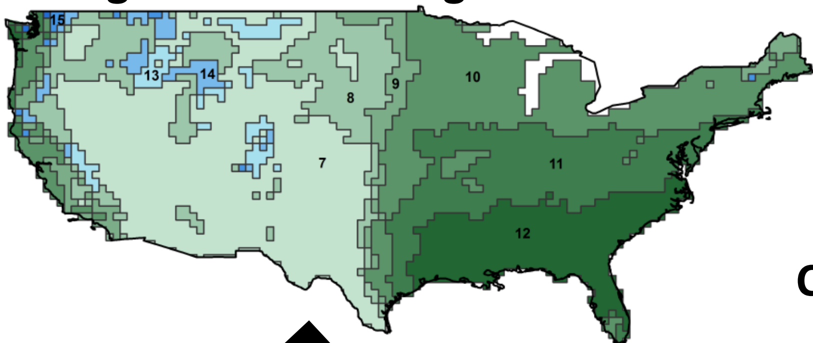


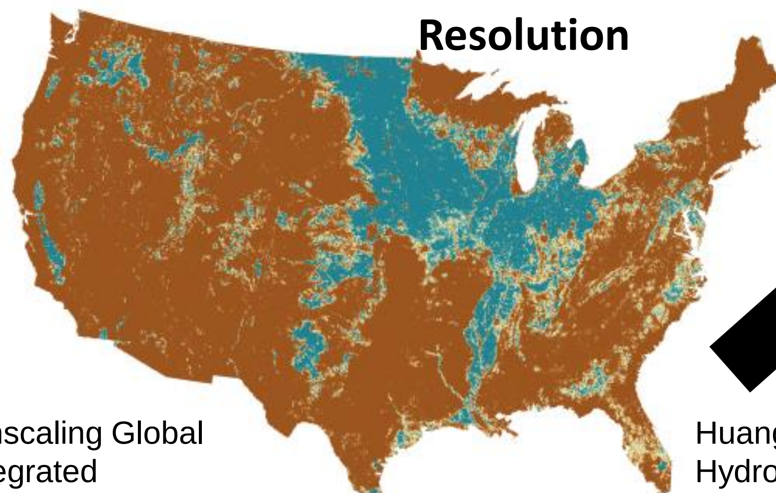
Hejazi et al. (2014). Integrated assessment of global water scarcity over the 21st century under multiple climate change mitigation policies, Hydrology and Earth System Sciences, 18, 2859-2883, doi:10.5194/hess-18-2859-2014

Providing gridded data products

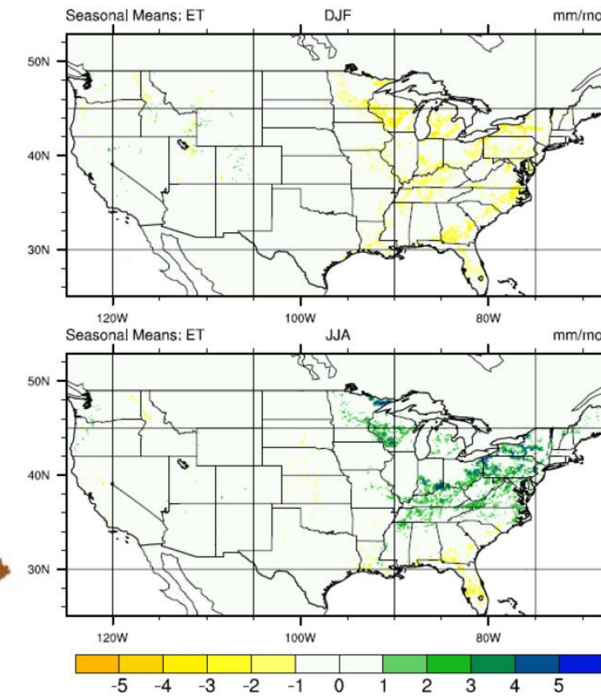
GCAM land cover decisions occur at 283 region resolution, but results are available at 0.05° resolution

9 AgLU Economic Regions in the USA





Cropland area in 2005 at a 0.05° Resolution

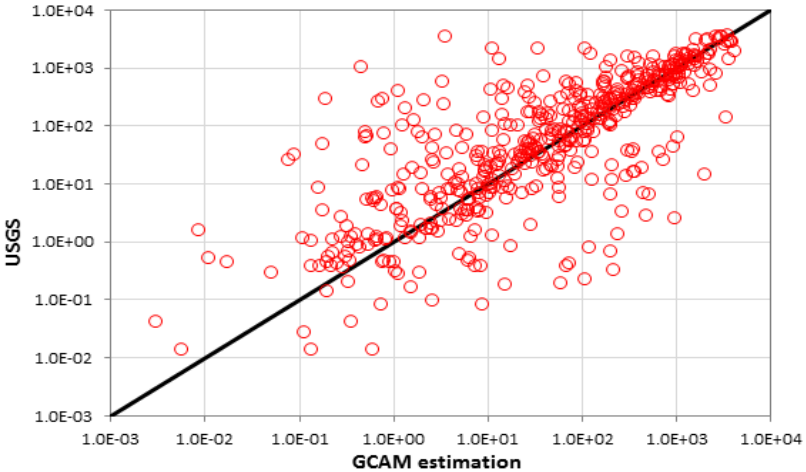


Change in ET due to land use change (RCP4.5, 2065-2094)

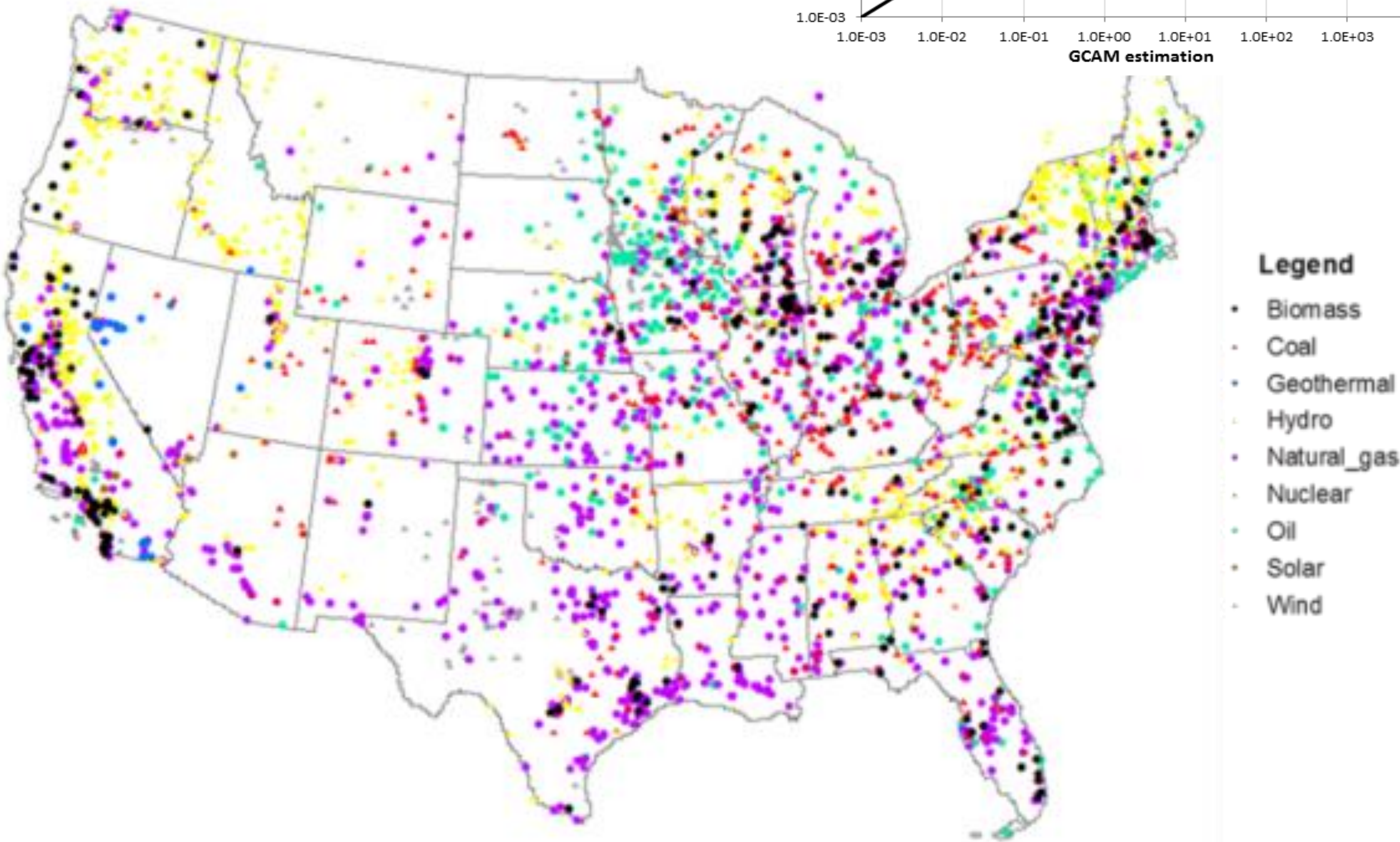
Tristram O. West et al. 2014. Downscaling Global Land Cover Projections from an Integrated Assessment Model for Use in Regional Analyses: Results and Evaluation for the US from 2005 to 2095. *Environmental Research Letters*.

Huang et al. 2014. Response Of Terrestrial Hydrology Over The Conterminous US To High-Resolution Scenarios Of Climate And Land Cover/Land Use Changes From 2005 To 2095. 19th annual CESM workshop, Breckenridge, CO

Improving the downscaling algorithms



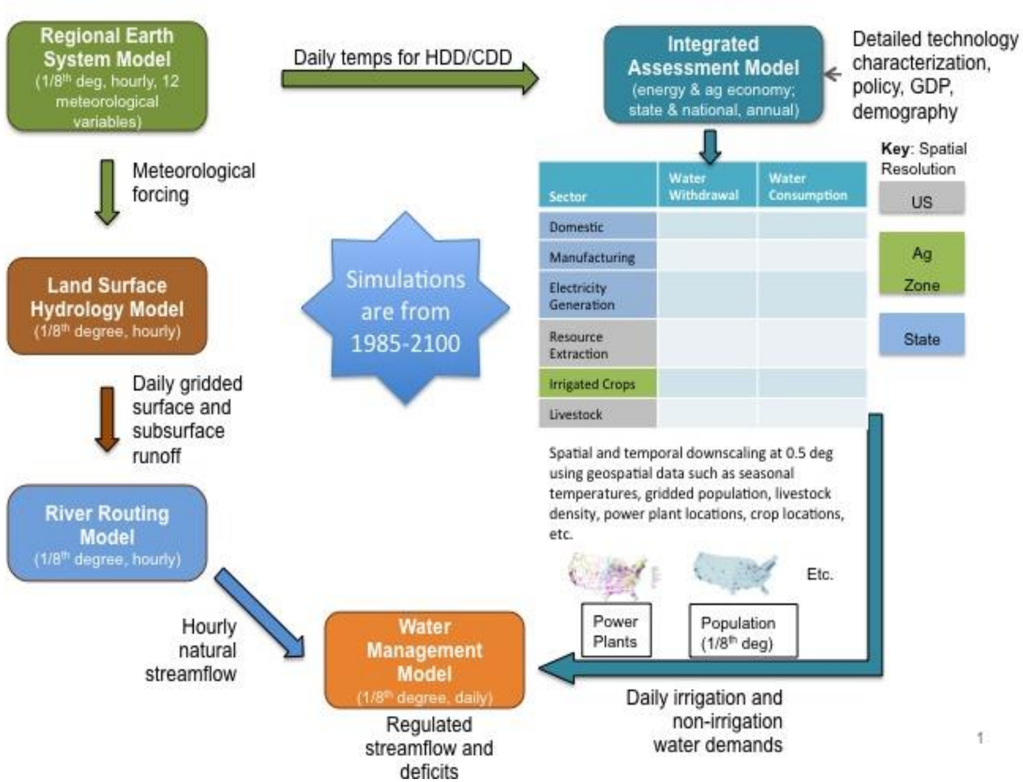
Location of power plants in the US



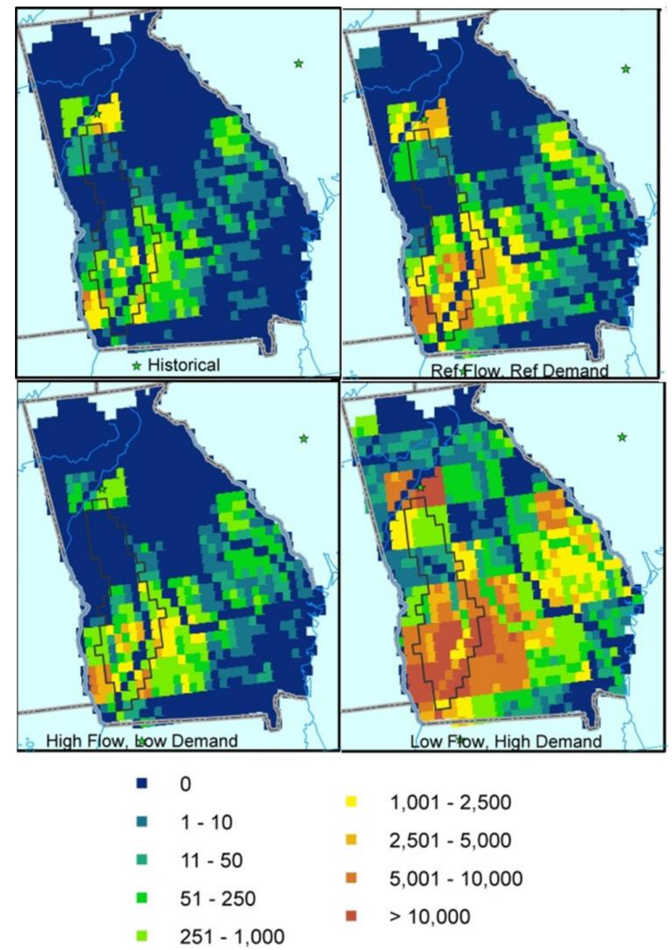
Hejazi et al. (in review). Climate mitigation exacerbates water deficits in the United States. Nature Climate Change.

Uncertainty Quantification

Investigating the effects of uncertain future climate and socioeconomic variables on prospective water demand and supply in Georgia



Average unmet annual water demand, historical and projected for 2040-2059 (m^3 per day)



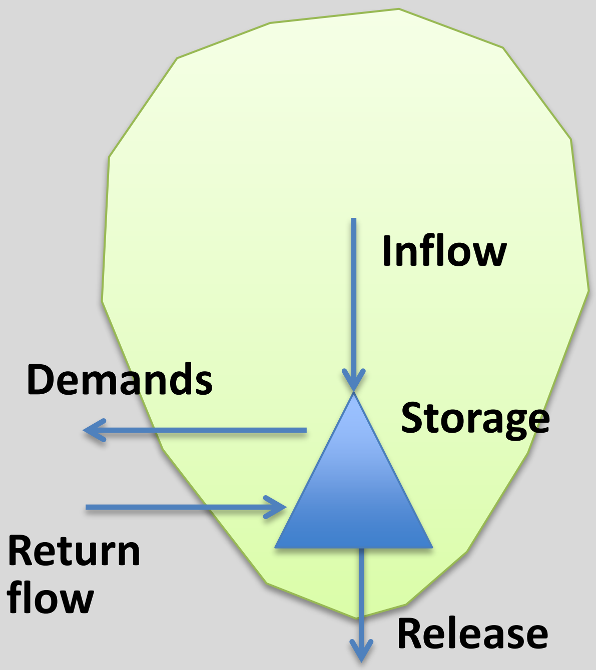
Scott et al. (in review). Potential Water Shortages in the South Atlantic-Gulf Basin: A Multi-Model, Structured Sensitivity Analysis of the Effects of Uncertain Future Climate and Socioeconomic Variables on Prospective Water Demand and Supply. Global Environmental Change.

- Monthly reservoir representation
- Choosing among cooling technologies
- Shale gas and water for fracking
- Designing water technology assumptions following the SSPs
- Connecting to detailed sectoral (electricity) models
- Others

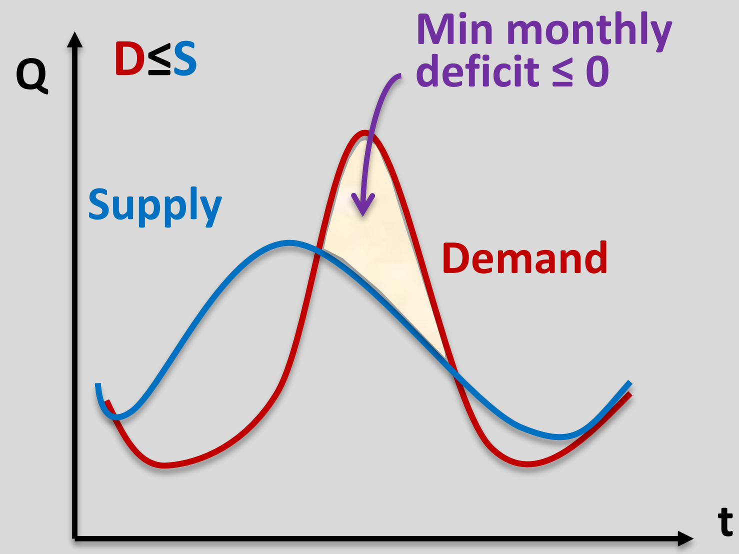
FUTURE DIRECTIONS

Monthly reservoir representation in GCAM

A simple conceptual reservoir model in GCAM



$$S_t = S_{t-1} + I_t - D_t - RL_t + RF_{t-1}$$

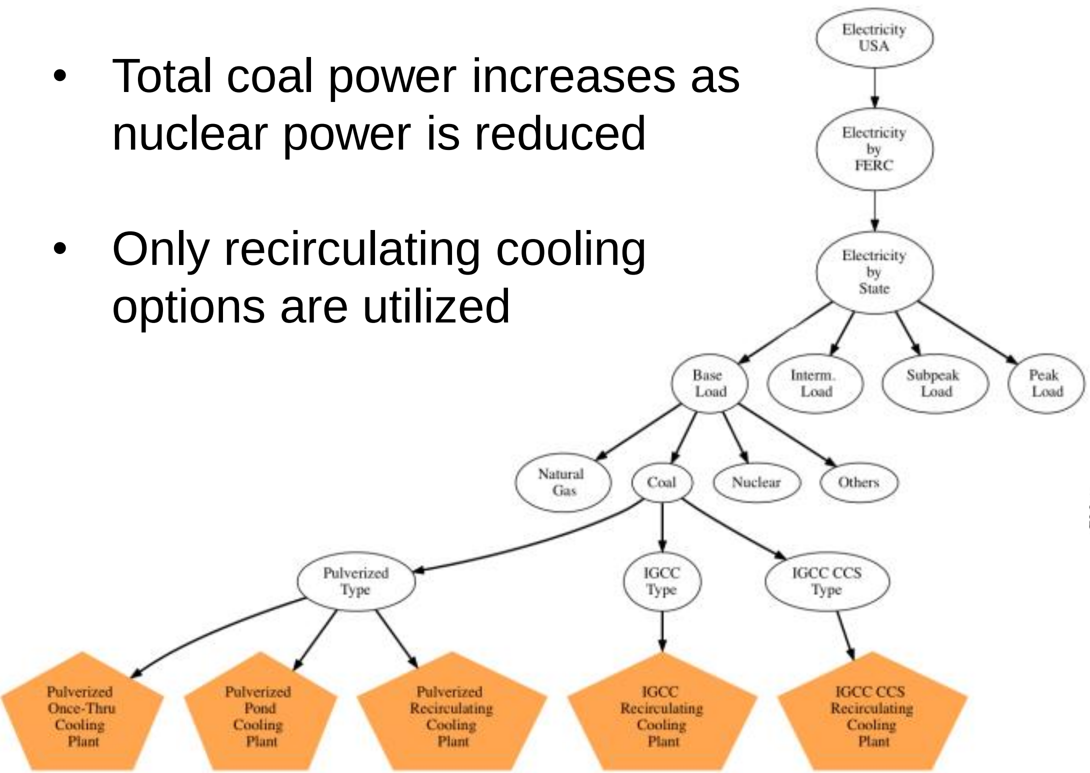


$S_m \leq S_t \leq C$	reservoir storage capacity
S_t	final storage
S_{t-1}	initial storage
I_t	total Inflow into the reservoir
D_t	total withdrawals
RL_t	total release to downstream users
RF_{t-1}	return flow (withdrawal – consumption)

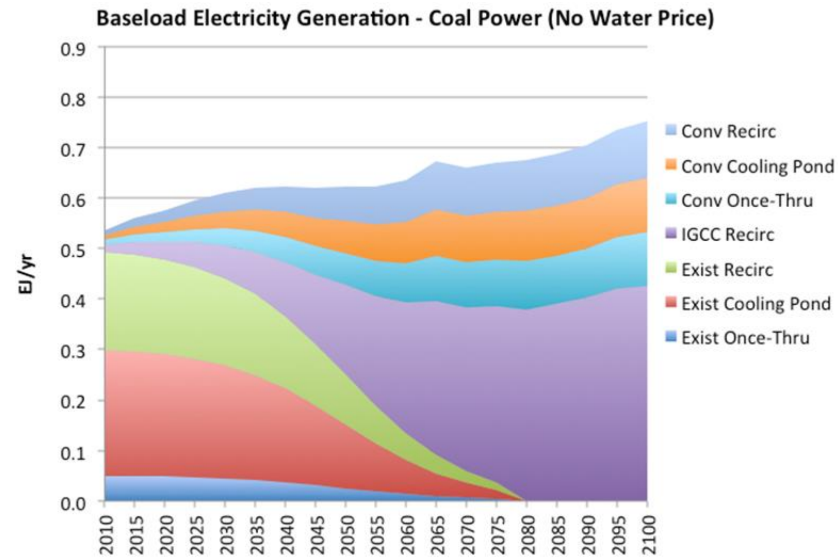
Choosing among cooling technologies – Preliminary results

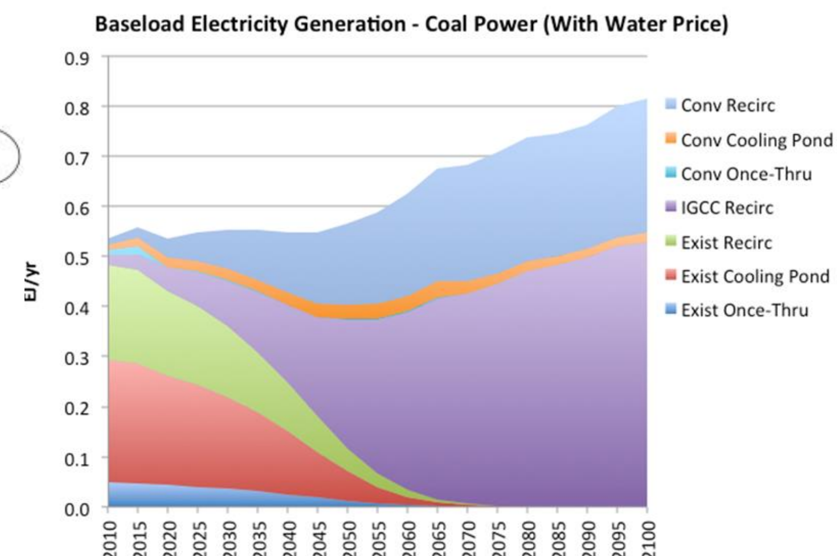
To enable GCAM-USA to dynamically choose among the water cooling technologies in the electric sector in the U.S. based on economics instead of being a model input

- Total coal power increases as nuclear power is reduced
- Only recirculating cooling options are utilized



Texas Base-Load Electricity Generation





Water for fracking (preliminary results)

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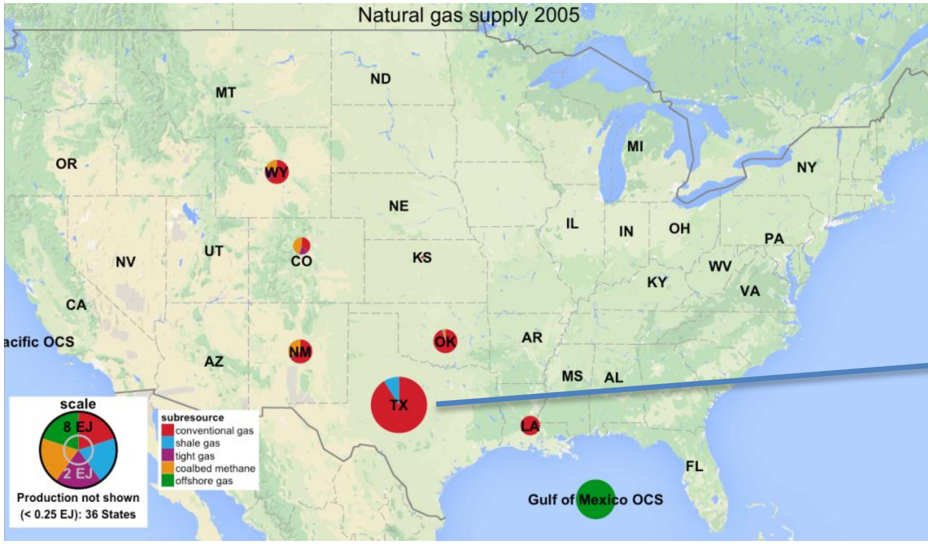
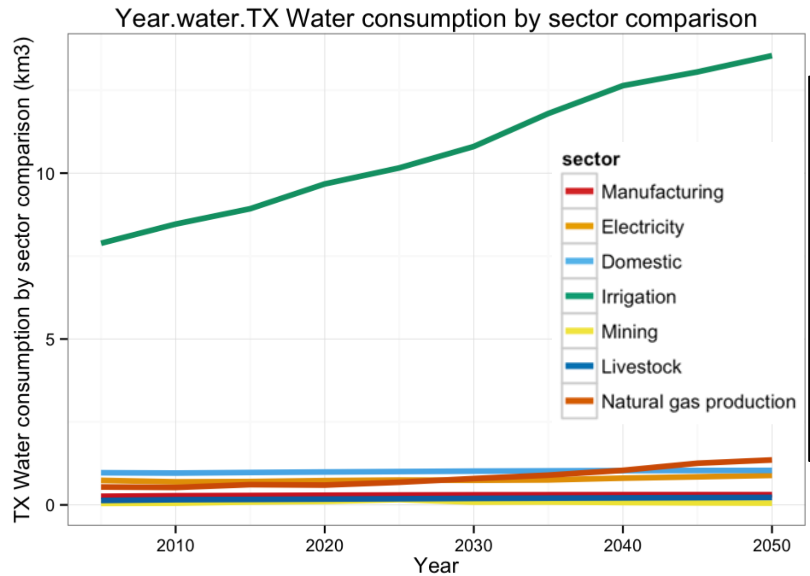
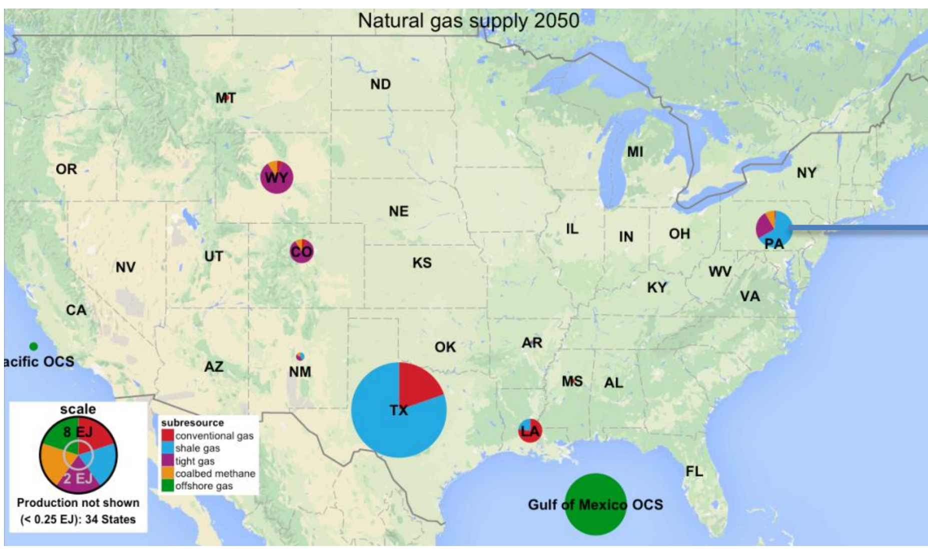
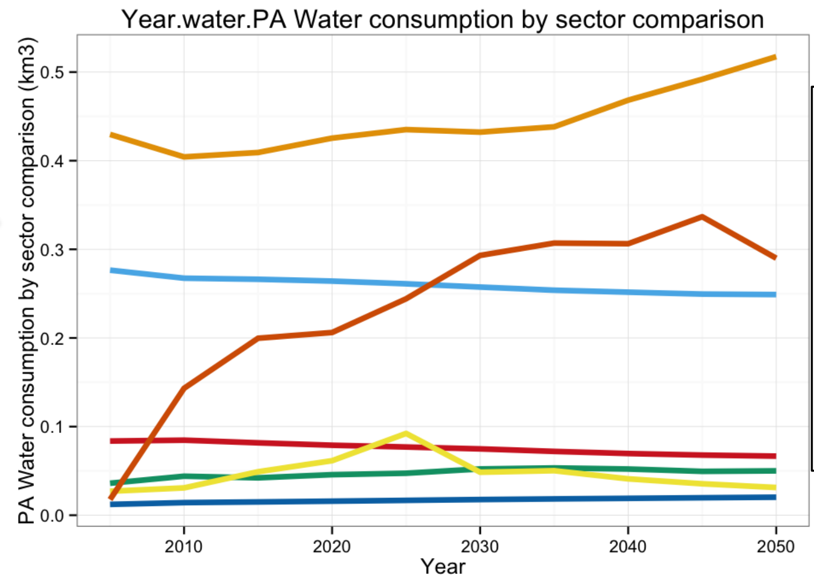




Texas

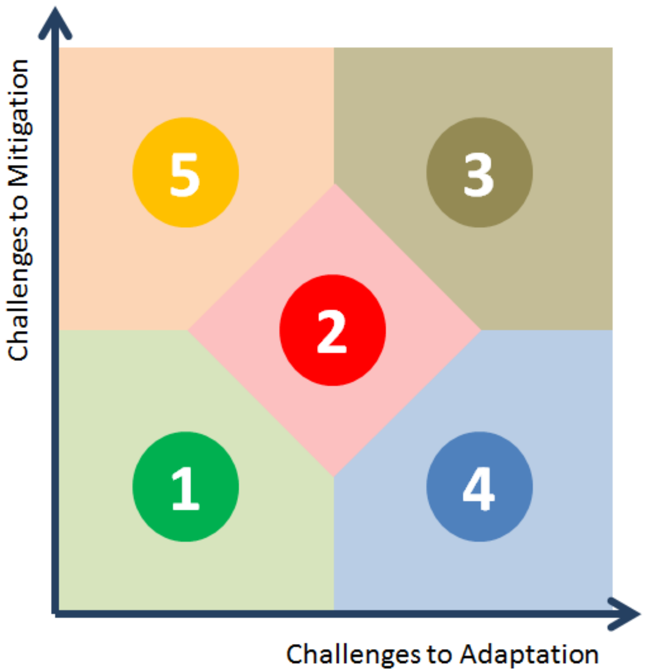




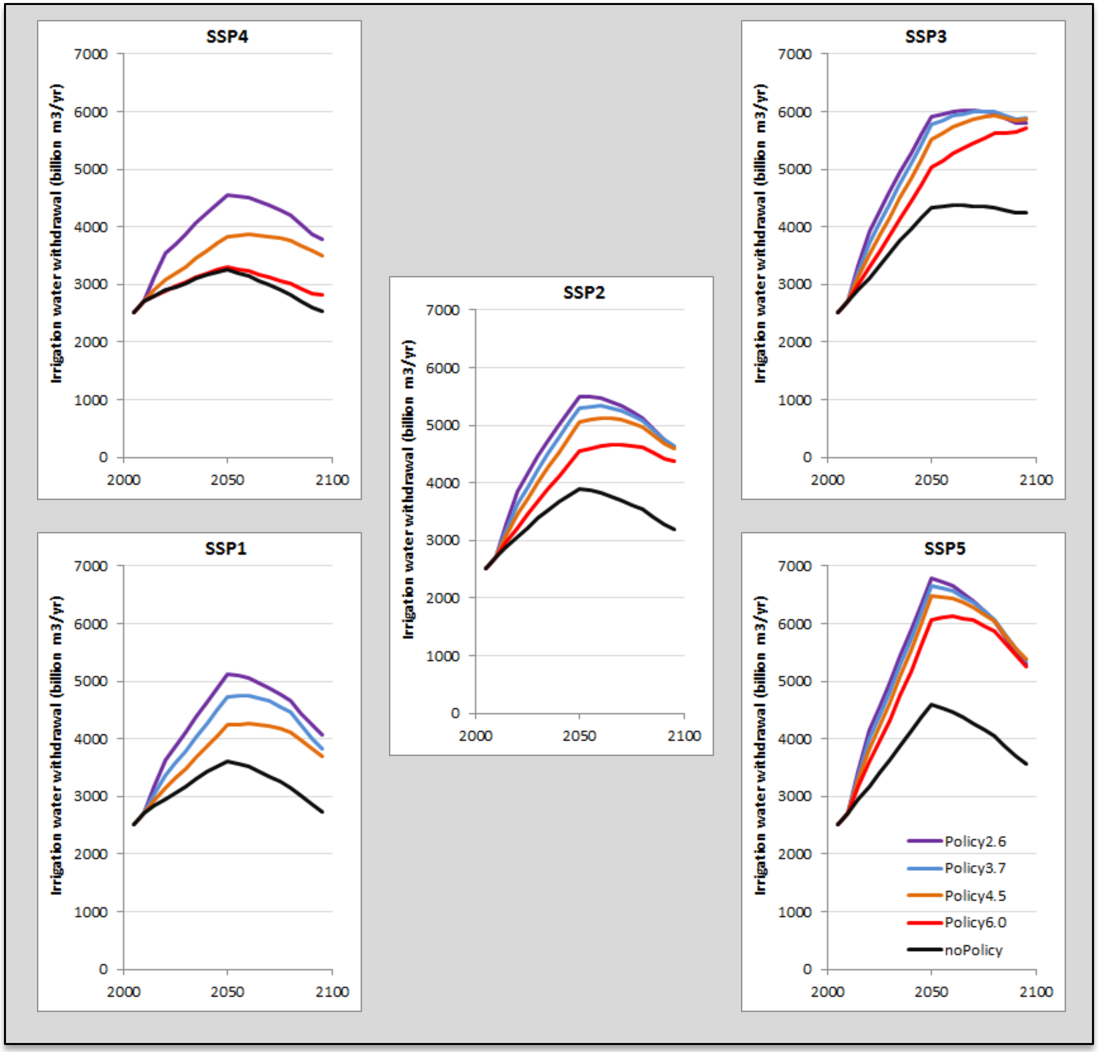
Pennsylvania

Designing water technology assumptions following the SSPs/RCPs

- Results follow population and food demands
- Mitigation yields more irrigation due to afforestation



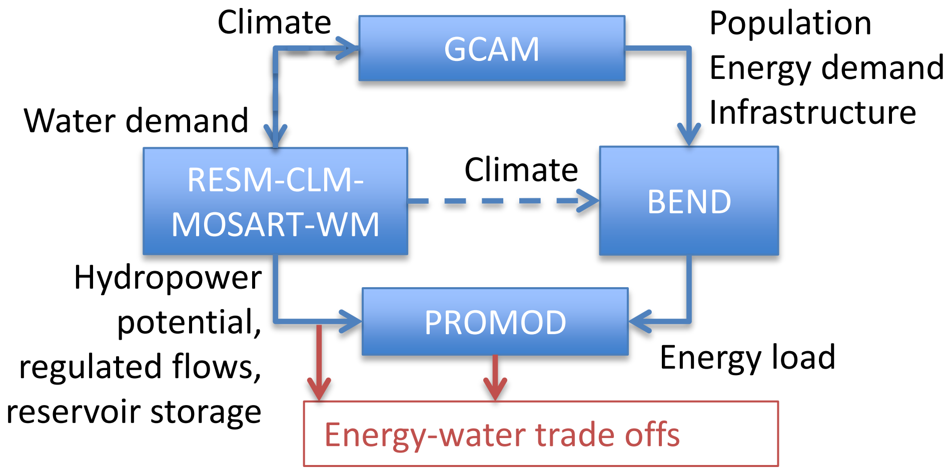
Global irrigation water withdrawal

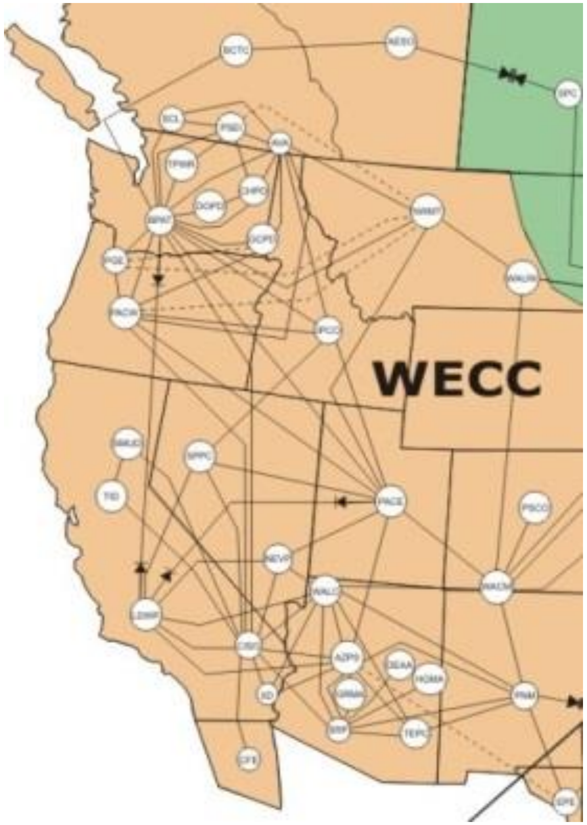


We still need to design water technology assumptions that are consistent with the SSP storylines

Connecting to detailed electricity models

Objective: To demonstrate the strong interdependence between energy and water during extreme events over the Western Interconnect.





GCAM: Global Change Assessment Model
RESM: Regional Earth System Model
CLM: Community Land Model
MOSART: Model for Scale Adaptive River Transport
WM: Water Management (Reservoir Operation Model)
BEND: Building Energy Model
PROMOD: Electricity Operation Model

Other Future Directions

- Improving fidelity of GCAM hydrologic modeling
- Water temperature impacts on cooling requirements
- Pattern scaling to adjust GCMs results to match GCAM's emission results
- Reconciling the downscaling algorithms for land, emissions, and water demand sectors
- Climate change impacts on crop water use efficiency
- Representing climate variability (Inter-annual & Intra-annual) and extreme events

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- U.S. Department of Energy, Office of Science, Biological and Environmental Research, the Integrated Assessment Research Program
- U.S. Department of Energy, Office of Science, Biological and Environmental Research, the Earth System Modeling Program
- The U.S. Environmental Protection Agency (EPA)
- PRIMA

QUESTIONS!