The representation of water systems in GCAM: A perspective of the human dimension in CESM

Mohamad Hejazi

Kate Calvin, Leon Clarke, Jae Edmonds, Maoyi Huang, Sonny Kim, Page Kyle, Ruby Leung, Hongyi Li, Lu Liu, Pralit Patel, Teklu Tesfa, Nathalie Voisin, Marshall Wise

Joint Global Change Research Institute (JGCRI)

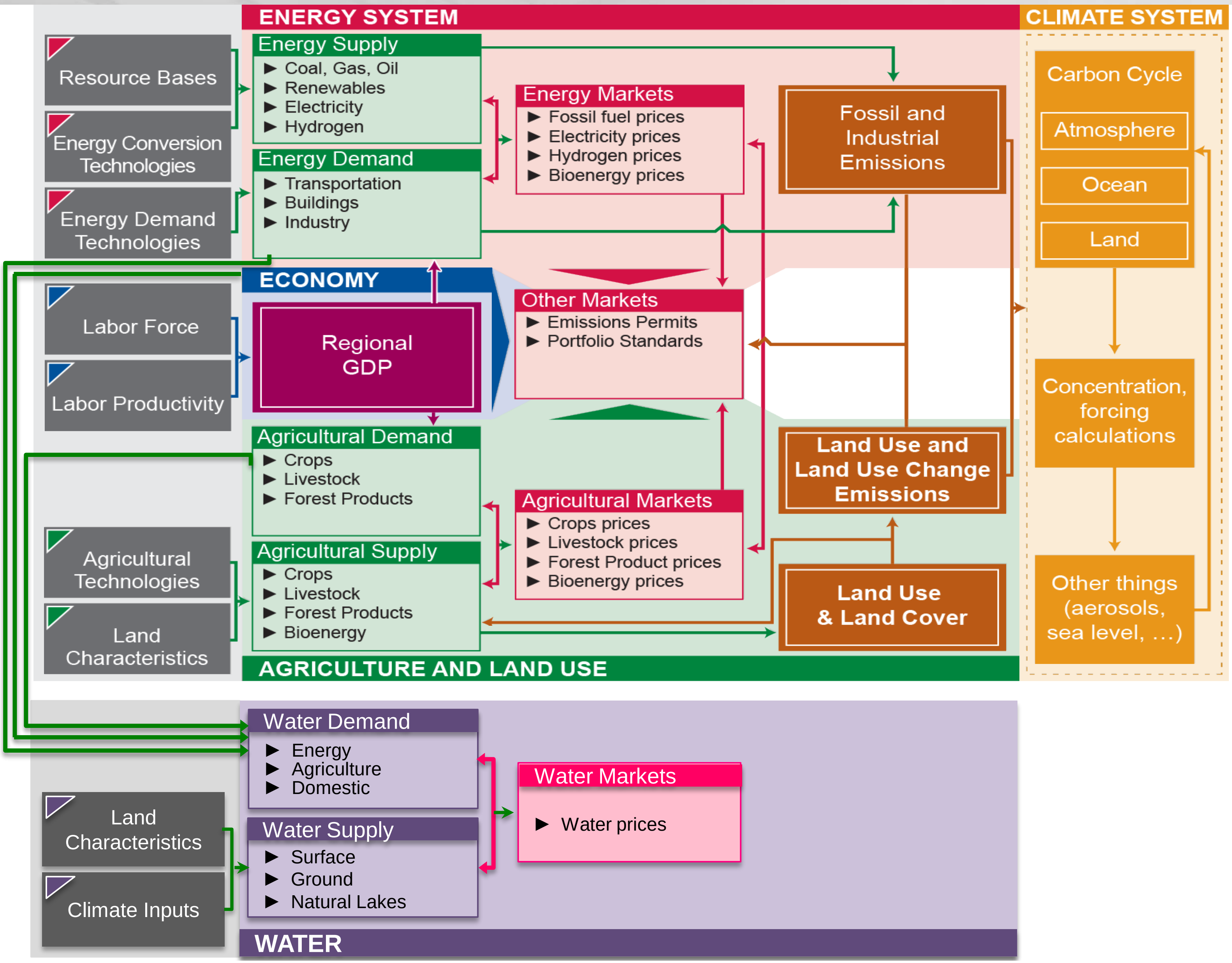
Pacific Northwest National Laboratory (PNNL)

CESM SDWG Meeting, Feb 26-27, 2014

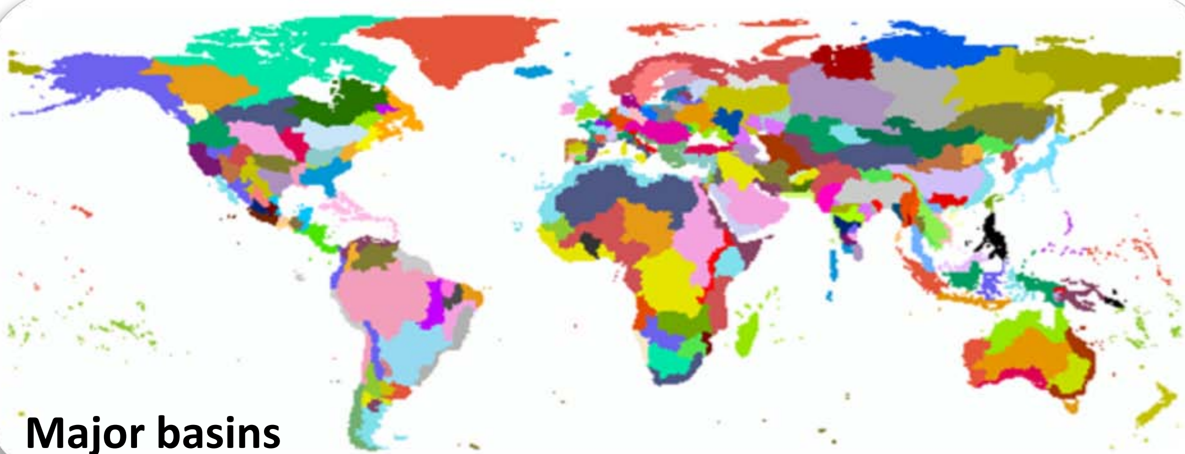
Overview—Roadmap to the Presentation

- GCAM
  - The representation of the water system in GCAM
  - GCAM experiments pertaining to water
- Coupling GCAM to CESM (CLM-MOSART-WM)
  - Level of handshaking
  - The US Midwest Experiment
  - Future directions

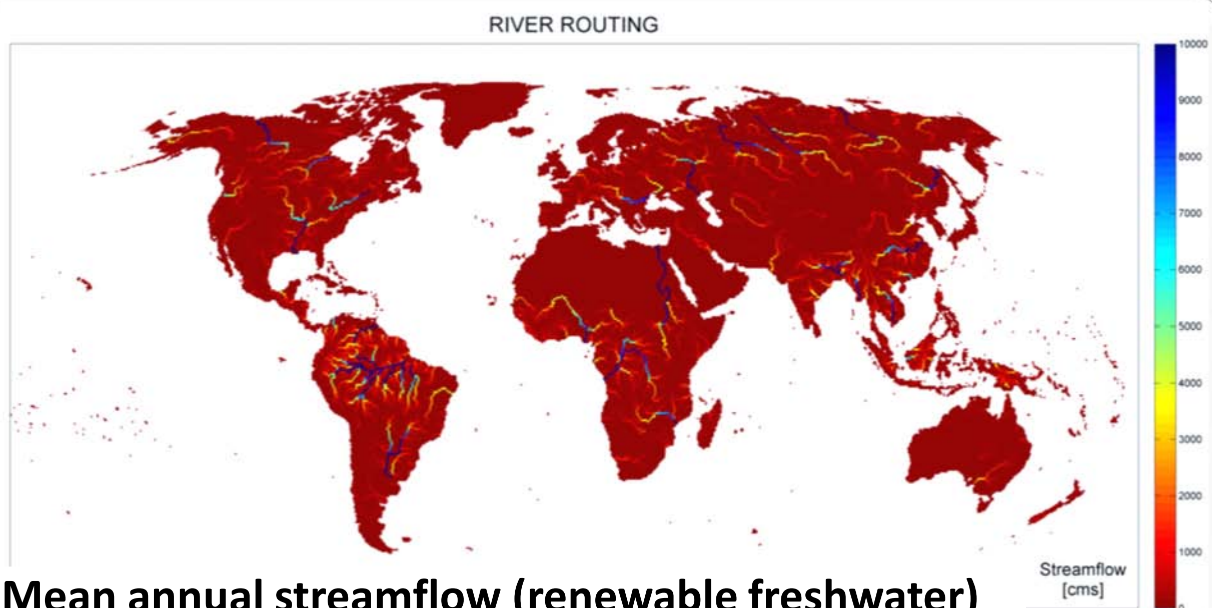
Water in GCAM



Water Supply – A Global Hydrologic Model



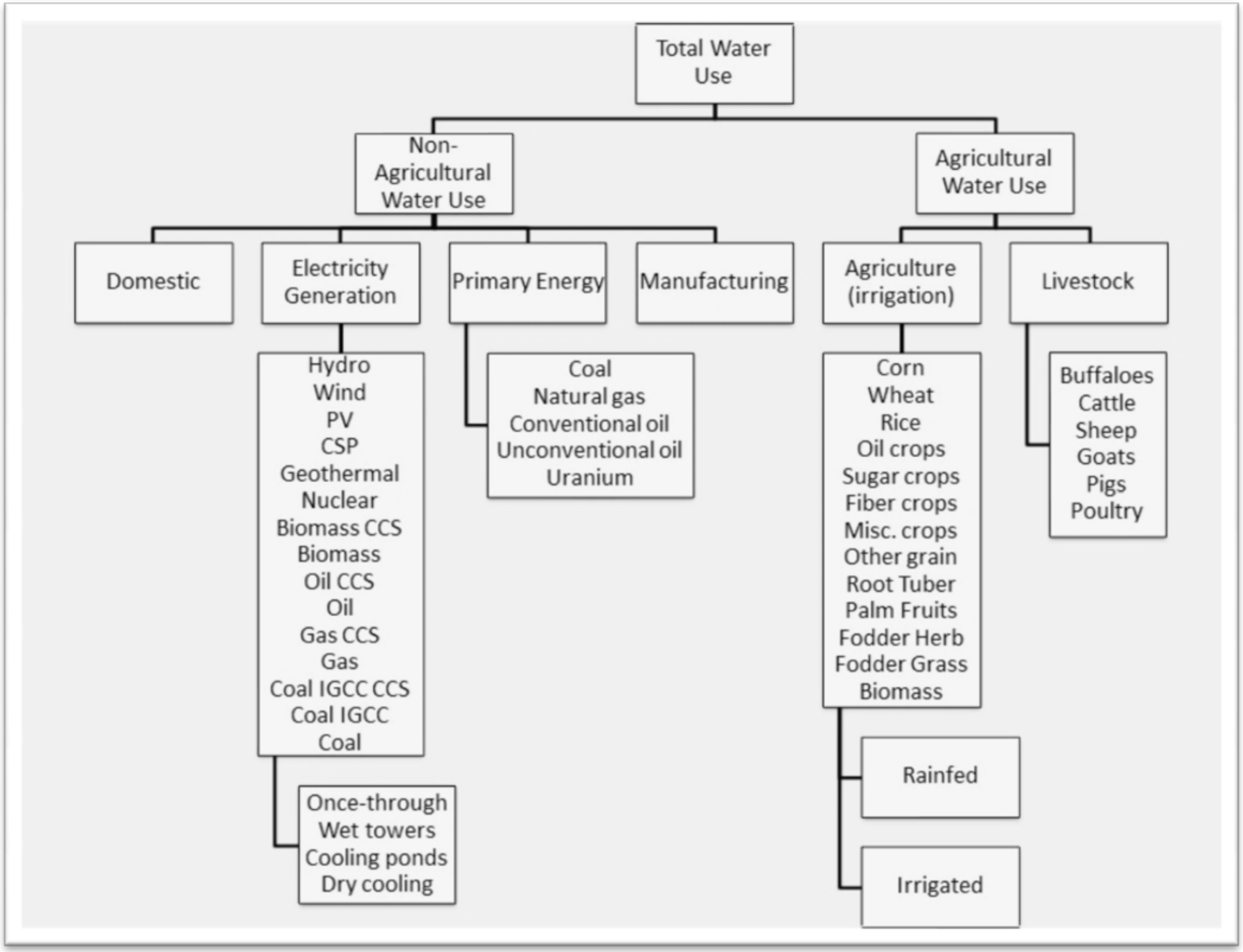
Major basins



Mean annual streamflow (renewable freshwater)

- GCAM has a macroscale global hydrologic model
- 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

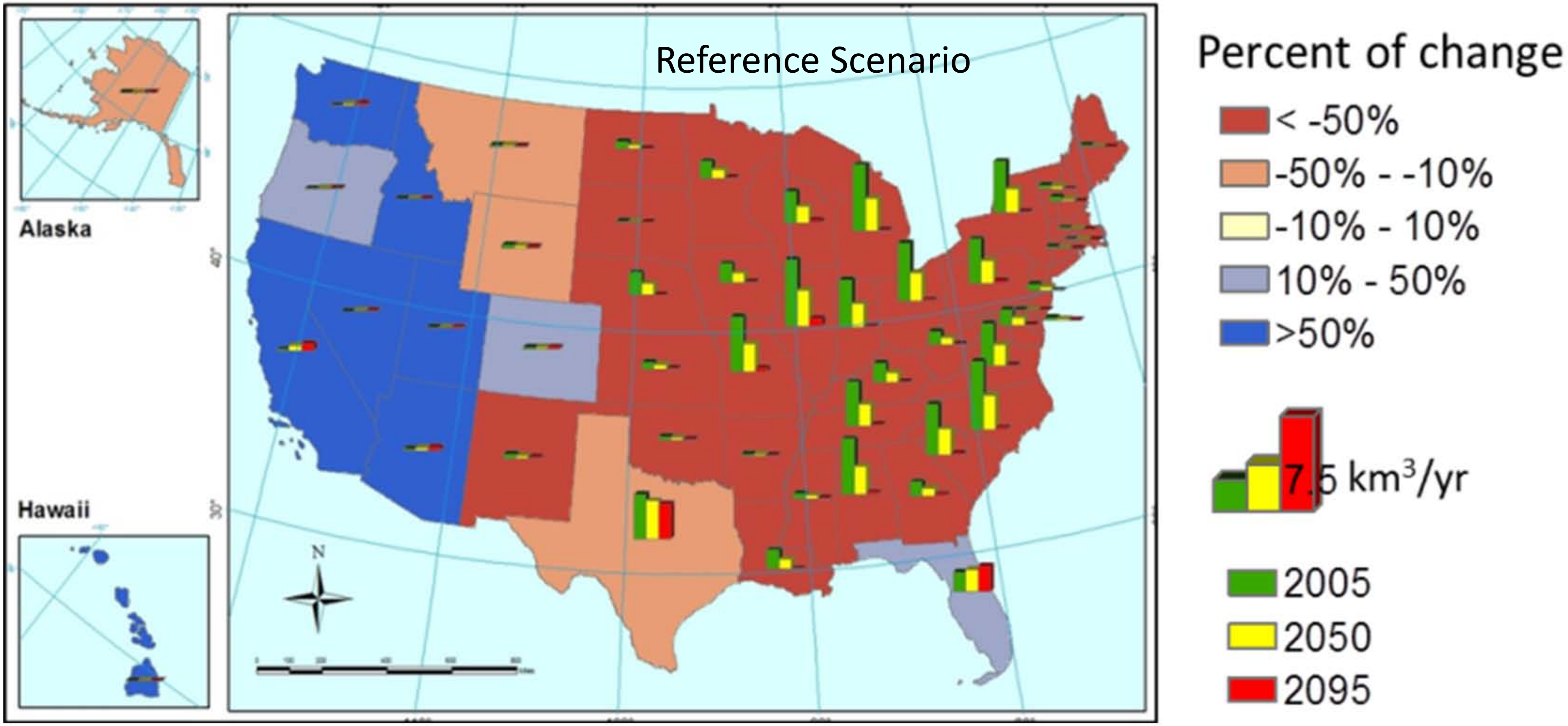
Water Demands in GCAM



- ❑ **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**

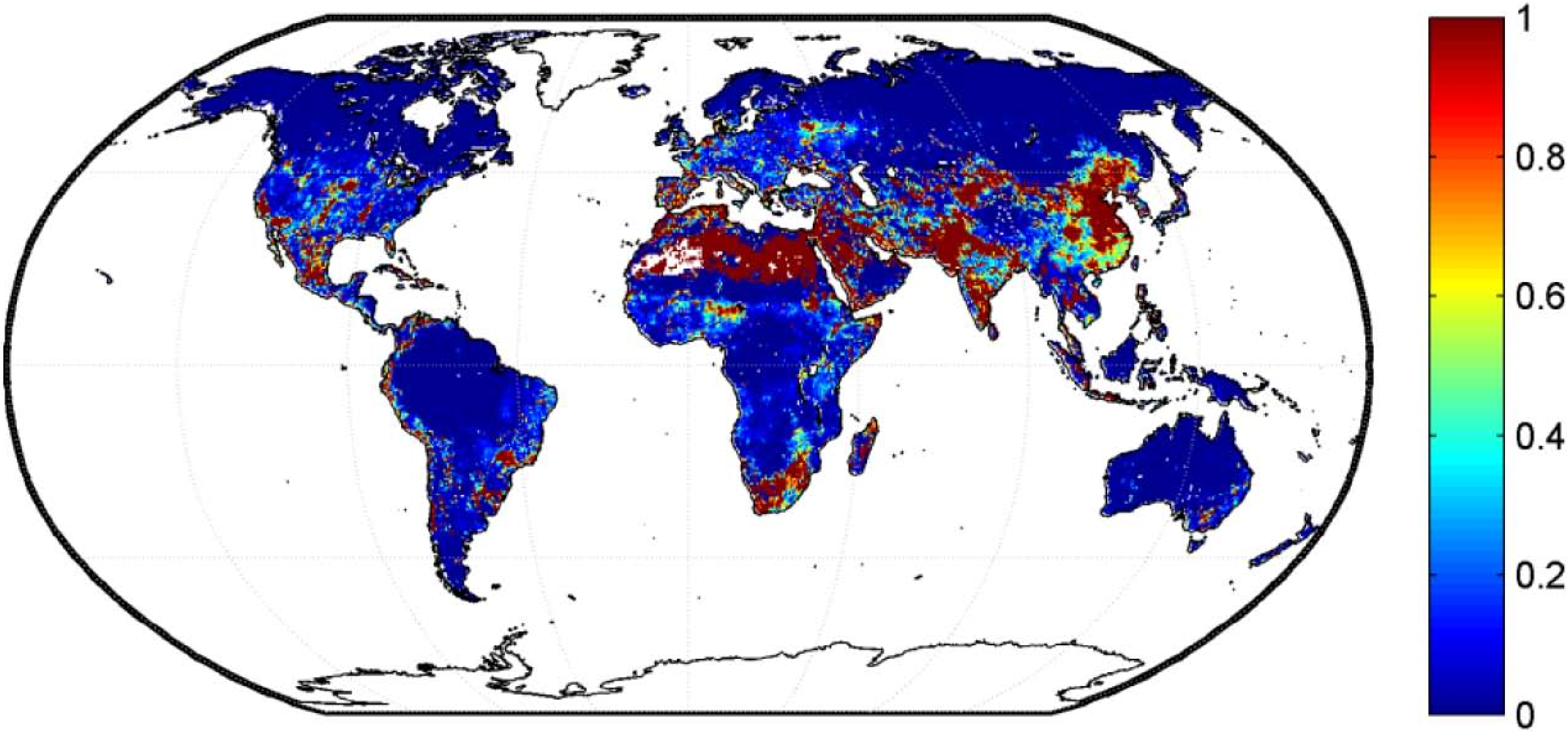
U.S. Electricity Water Use—By State

- Electricity water withdrawals will increase in the west and decrease in the east (factors: population movement, GDP, cooling techs, fuel mix, etc.)
- There is a trade-off between consumption and withdrawals (not shown)



Superimposing water demand and supply at finer spatial scale – Water scarcity in 2100

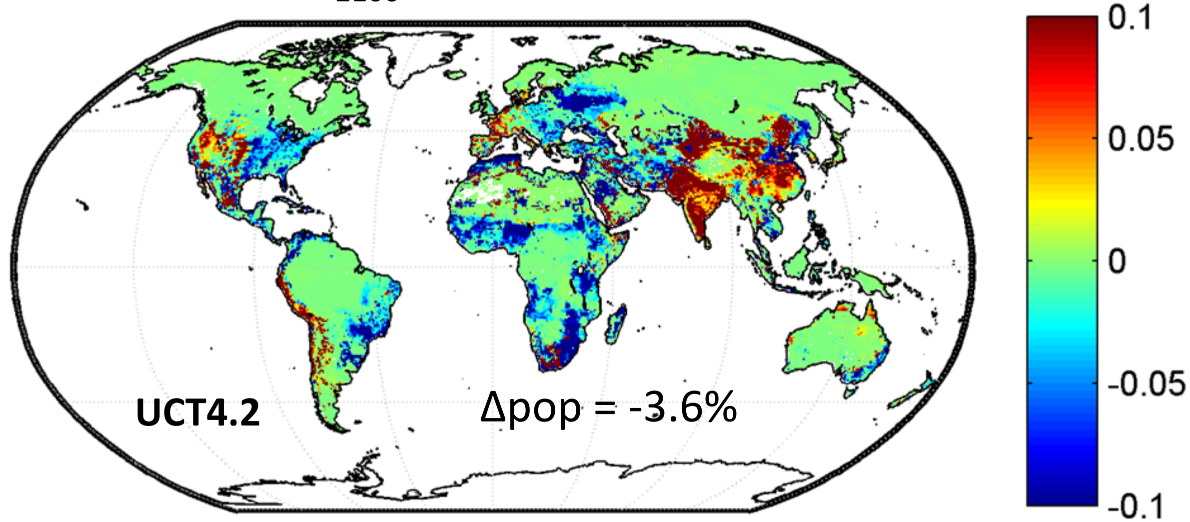
- GCAM water demand results are downscaled to grid scale using a suite of downscaling algorithms and proxy information



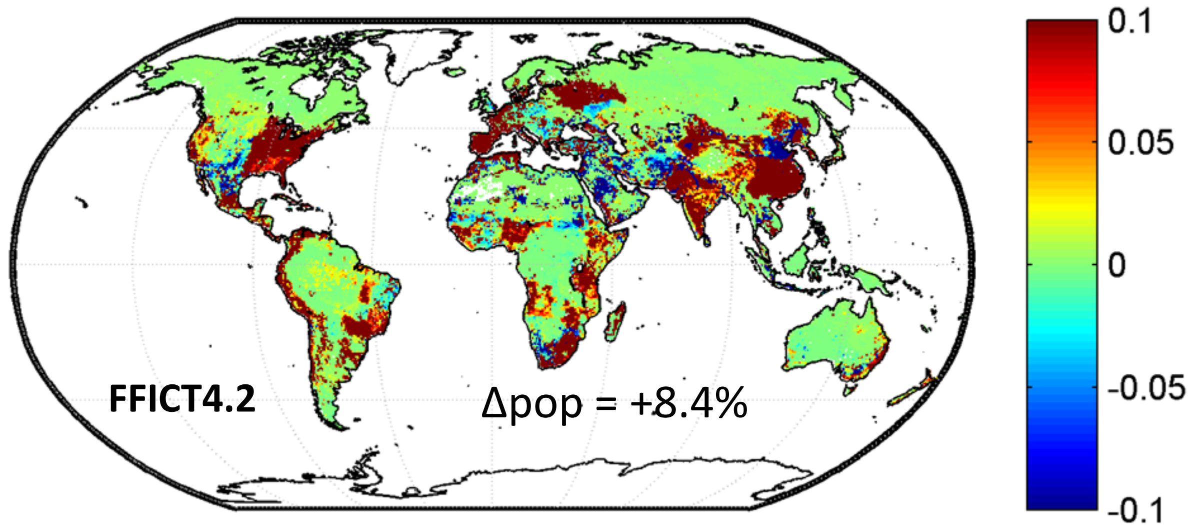
Climate mitigation policies will change the geography of the water scarcity map

- Climate mitigation will affect water scarcity
- The type of climate policy and stringency of target matter
- Climate mitigation will generally alleviate water scarcity. But, policies favoring bio-energy will exacerbate water scarcity
- Location matters – there are winners and losers

ΔWSI_{2100}(Policy –Reference)



ΔWSI_{2100}(Policy –Reference)

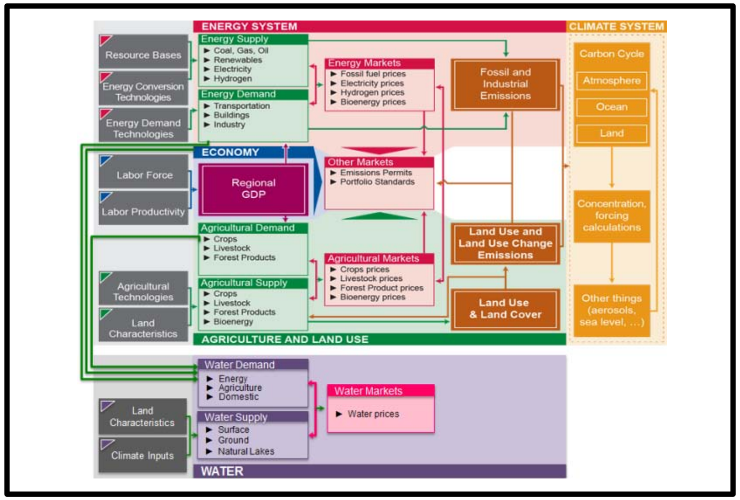


GCAM-CESM coupling (a water focus)

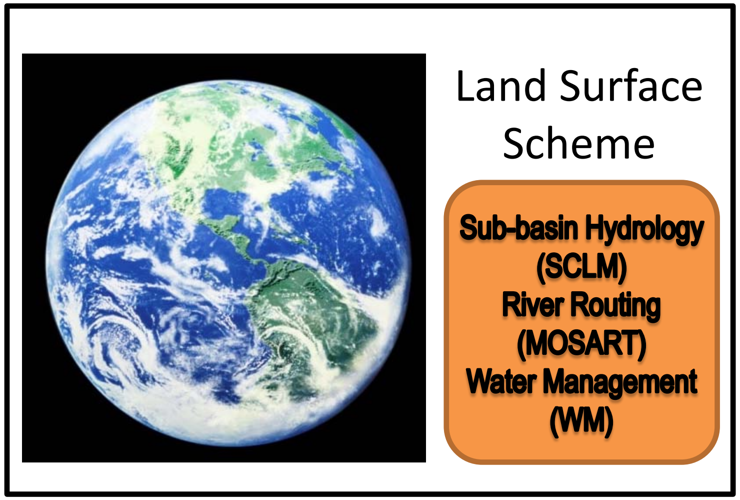
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- Objectives:
  - The linkage of the Global Change Assessment Model (GCAM) and the land surface component of Community Earth System Model (CESM) – including the Community Land Model (CLM), the MOdel for Scale Adaptive River Transport (MOSART), and the Water Management (WM) components
  - The propagation of human decisions pertaining to water demand per sector and technology from the GCAM decision framework to CESM at the appropriate temporal and spatial scales

Global Change Assessment Model

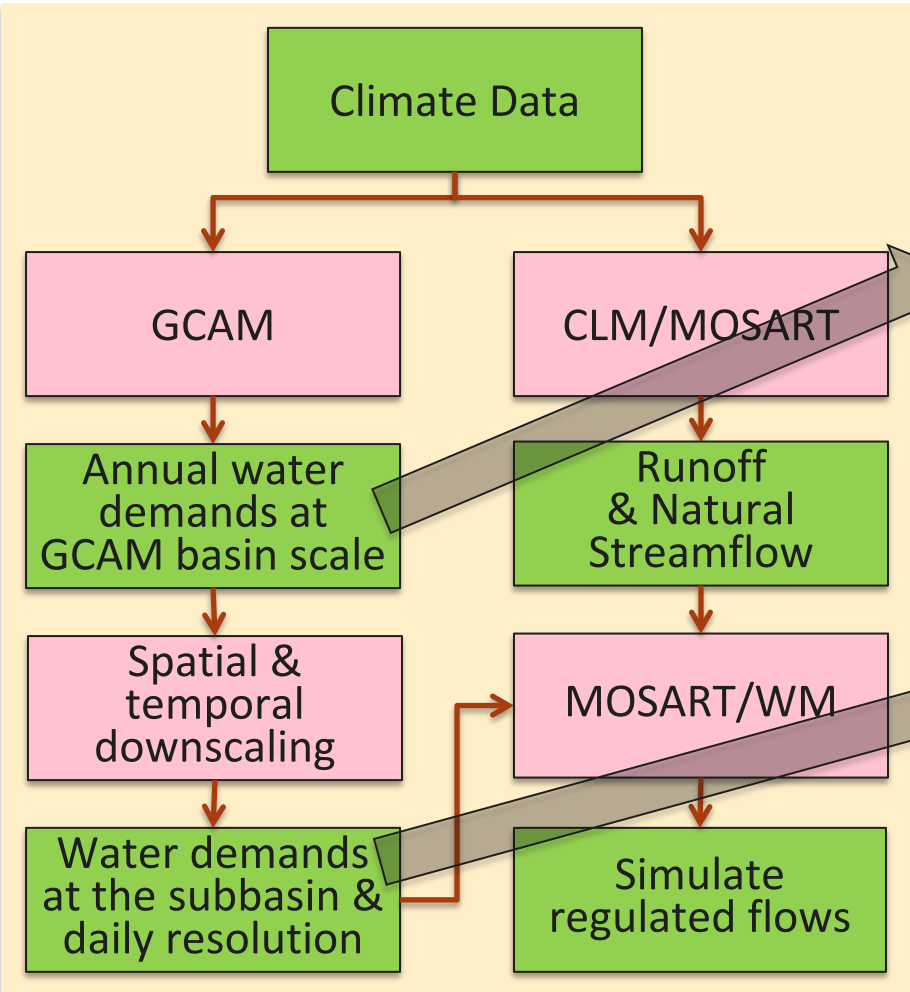


Community Earth System Model

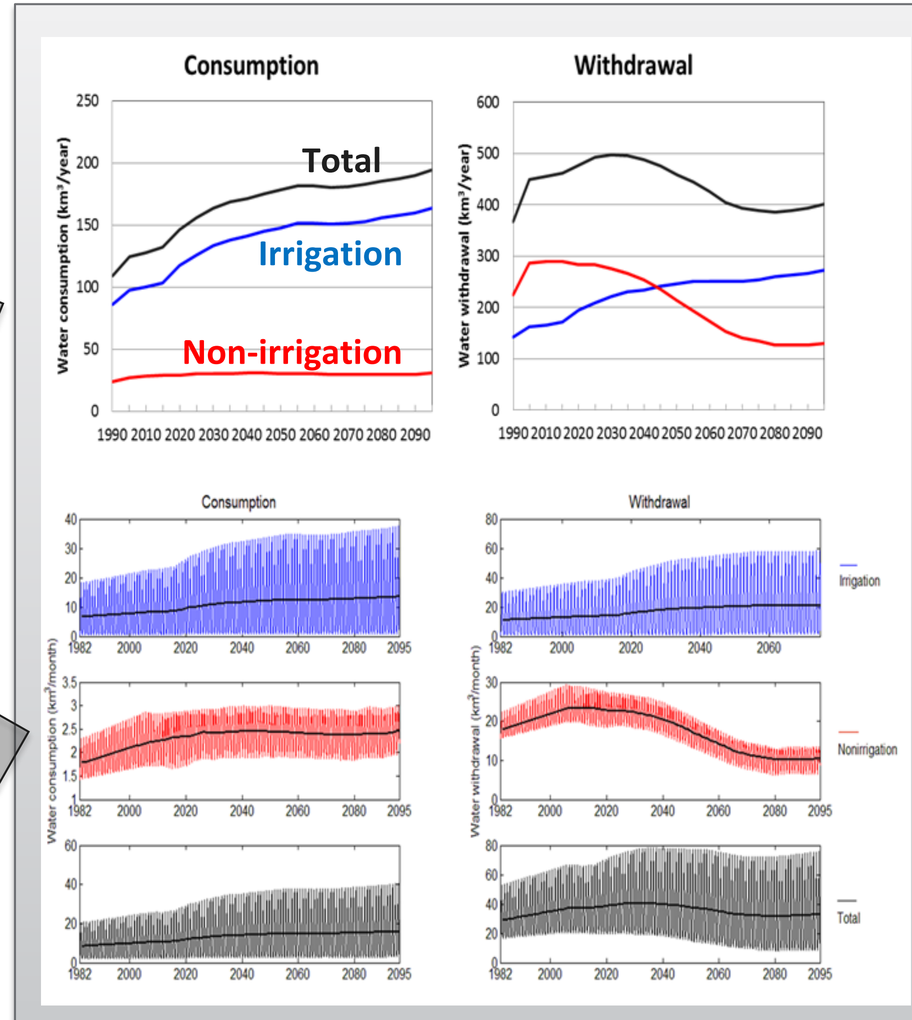


Flow Diagram and Results (US Midwest)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

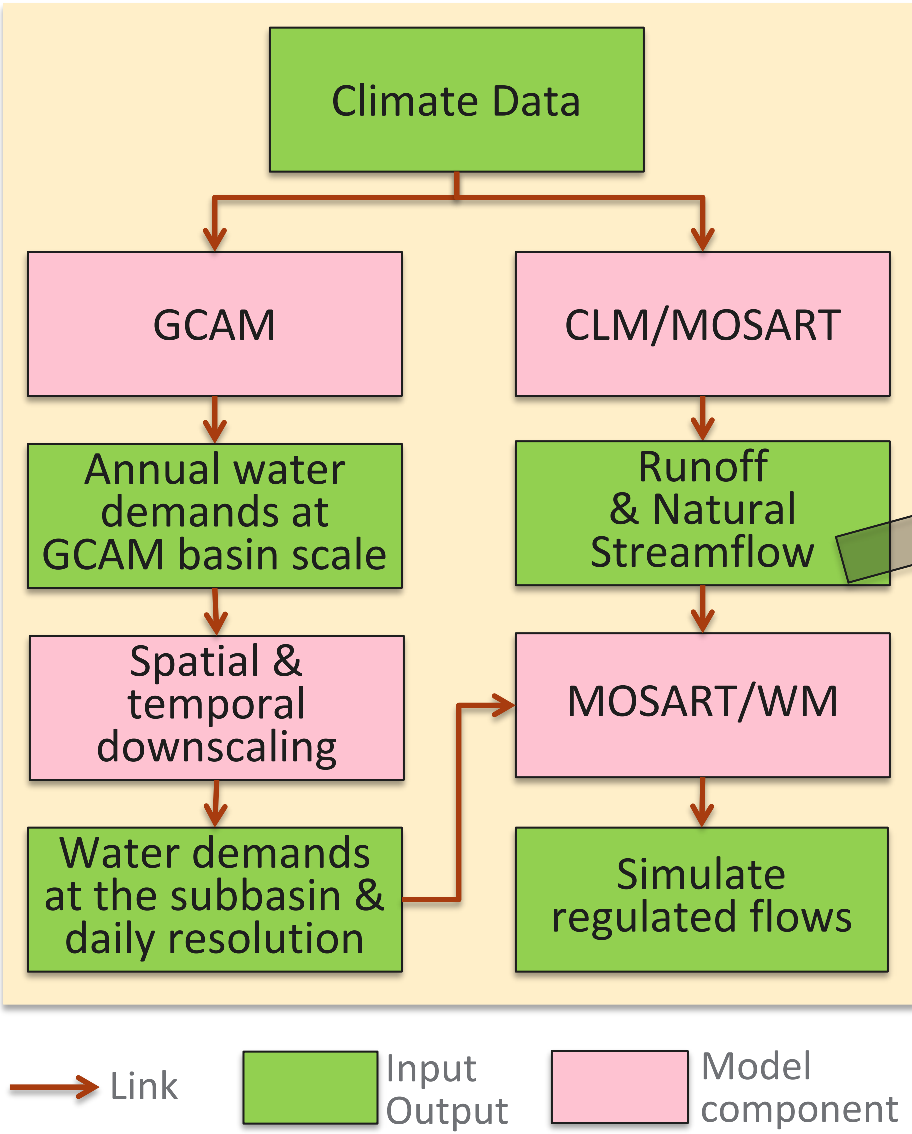


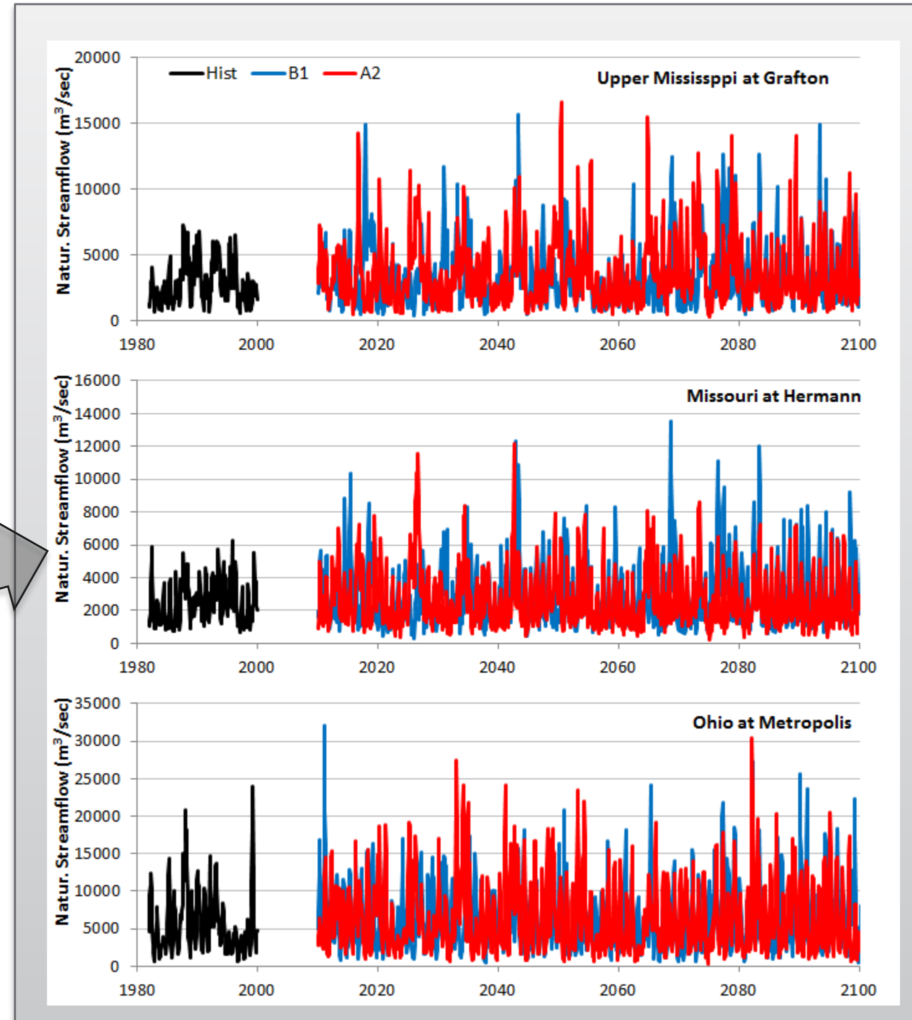
Link | Input Output | Model component



Annual water demand by sector from GCAM for the time period of 1990-2095 (upper panel), and monthly downscaled water demand by sector for the time period of 1982-2095 (lower panel).

Flow Diagram and Results (US Midwest)

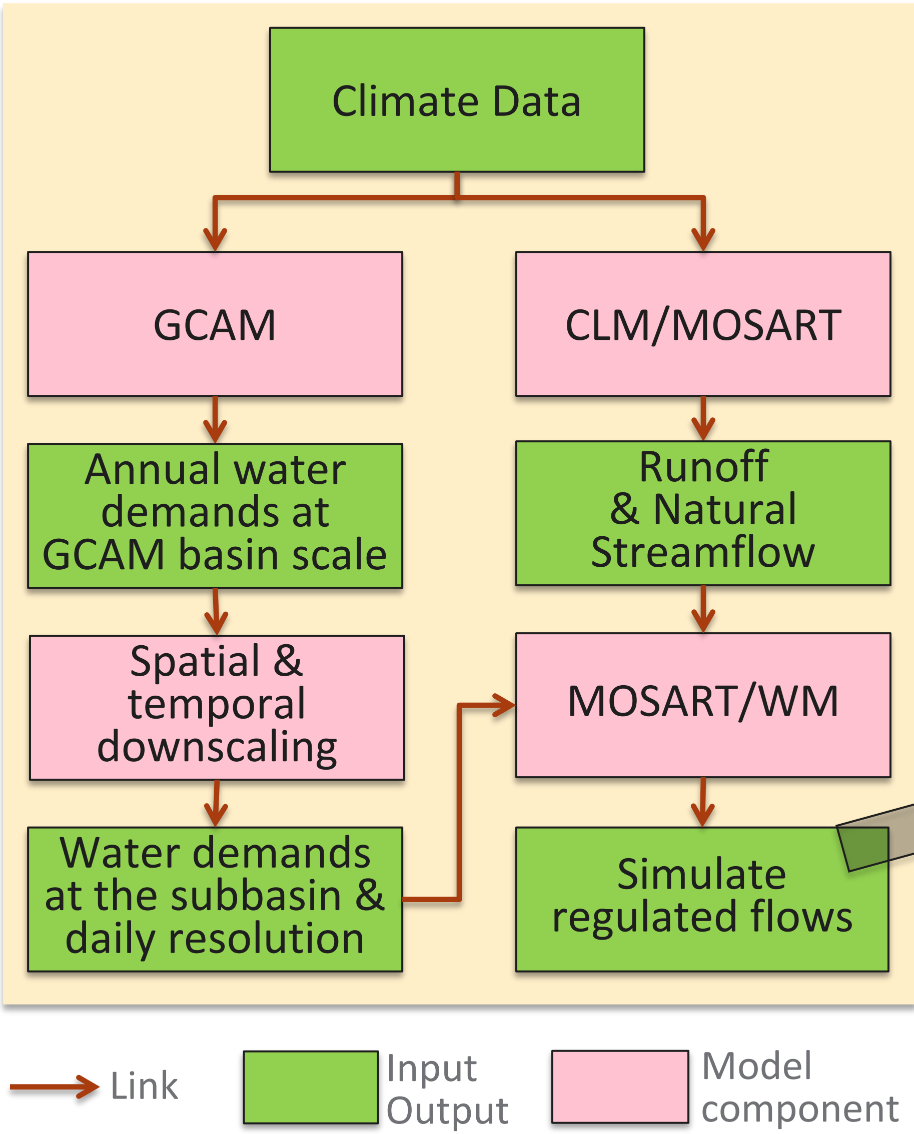


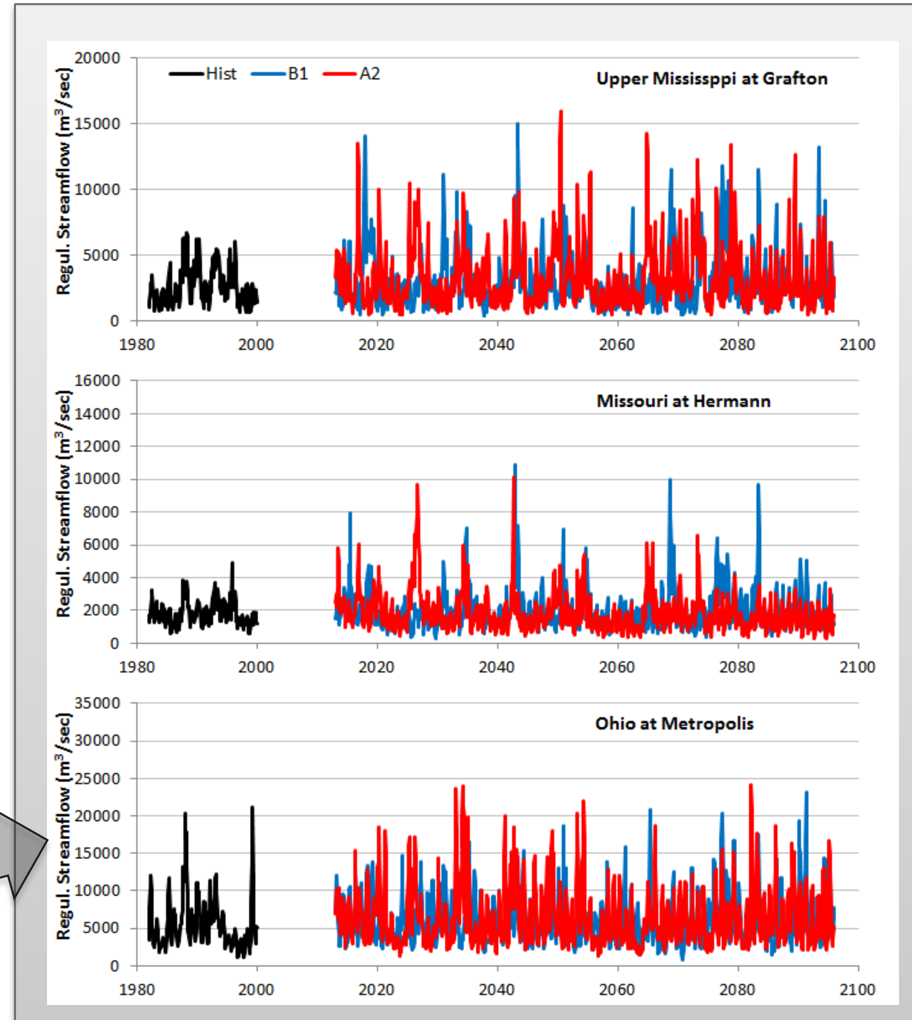


Monthly natural streamflow for the time periods of 1982-2009 (hist) and 2010-2100 (B1 and A2 scenarios).

Flow Diagram and Results (US Midwest)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

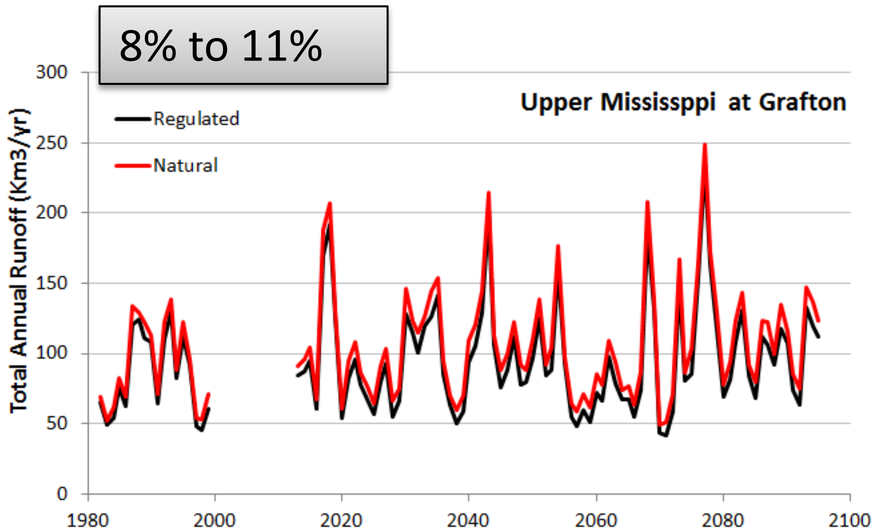


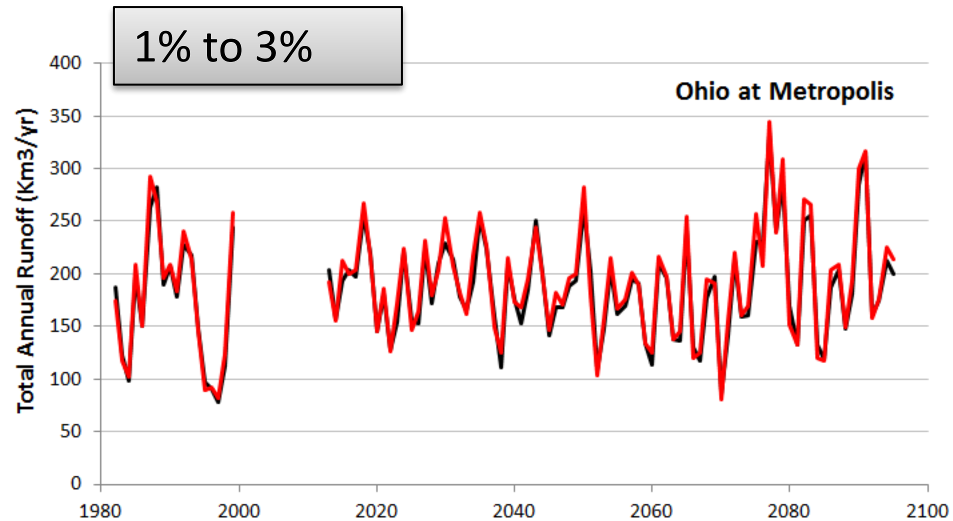


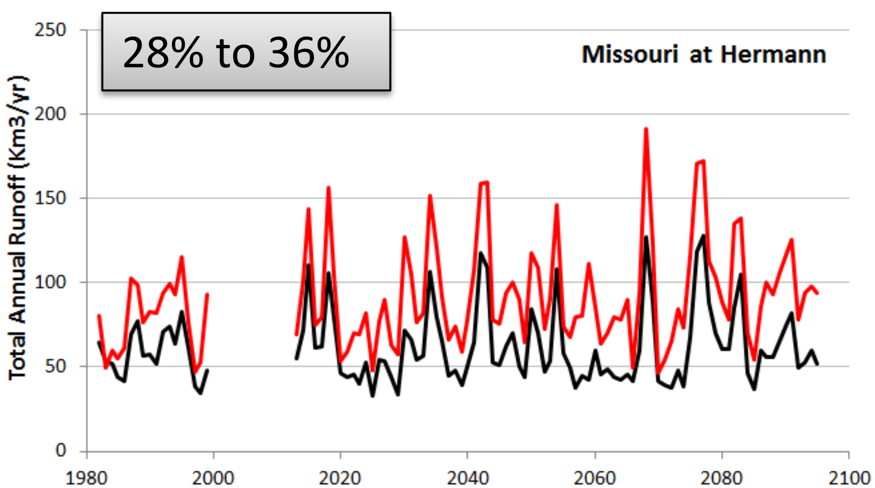
Monthly regulated streamflow for the time periods of 1982-2009 (hist) and 2010-2100 (B1 and A2 scenarios).

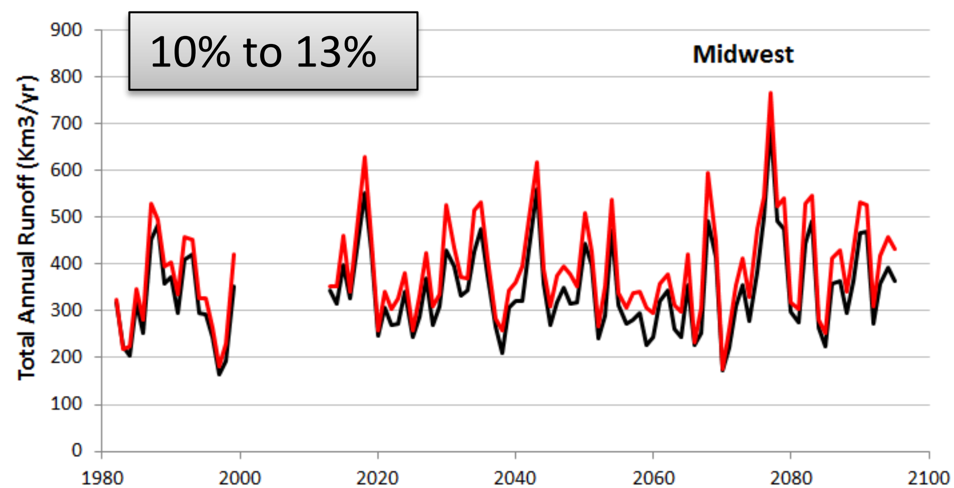
Results: Regulated vs. Natural Flows (B1)

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



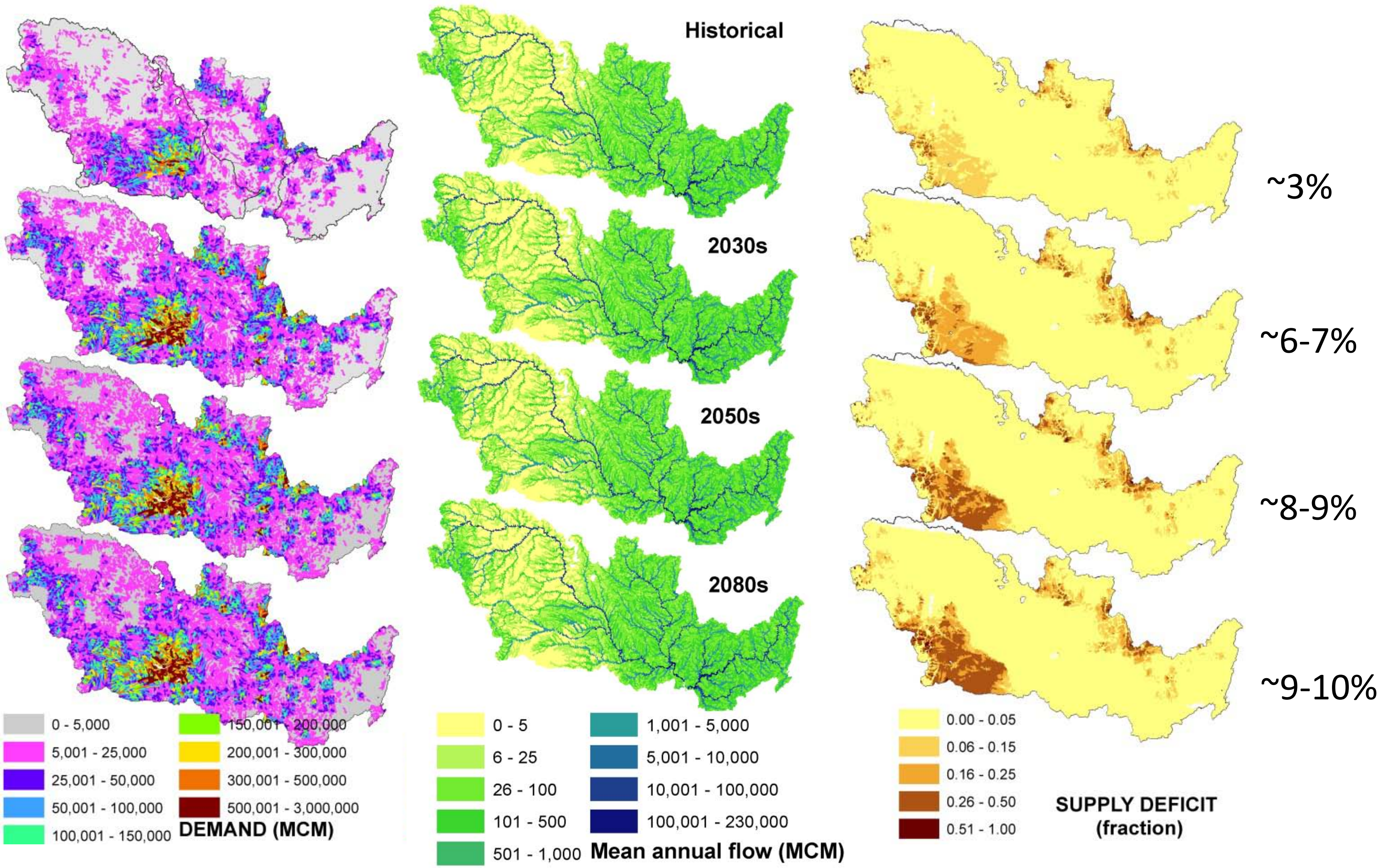






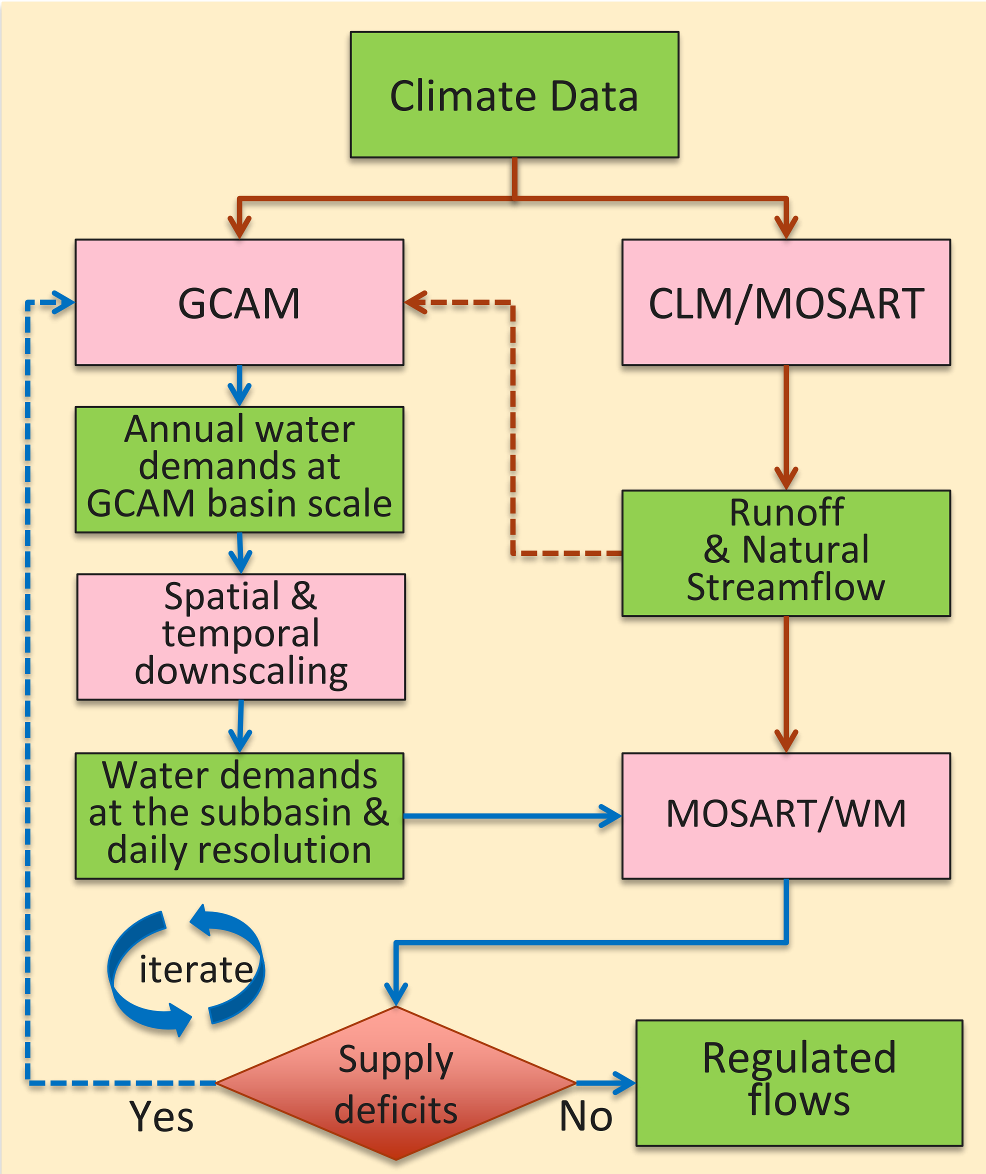
long term simulated time series of historical and future (B1) total annual regulated and natural runoff for the three regions and the Upper Midwest.

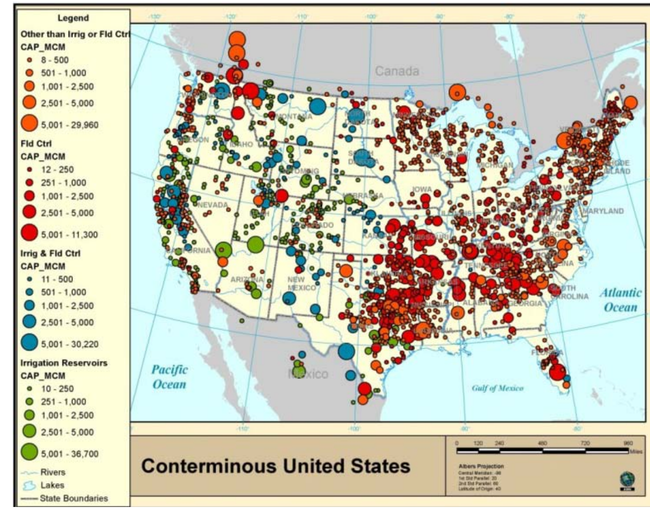
Results: Spatial Distribution of Water Supply Deficit (B1)

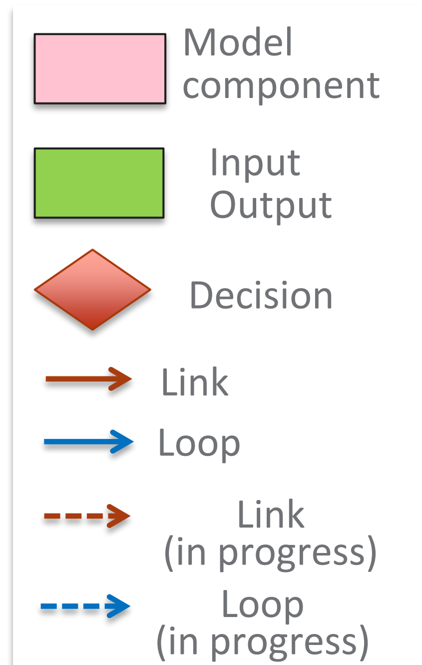


Annual total water demand (left) and water supply (center) in cubic meters, and fractional water supply deficit for historical and future B1 periods.

Moving forward: The next numerical experiment – A two way coupling over the U.S.







Moving forward

- GCAM
  - Extending the downscaling algorithms (spatial/temporal) to global scale at finer spatial resolution
  - Enhancing the spatial downscaling to be consistent with the land use and emission downscaling algorithms
  - Incorporating a conceptual reservoir module to account for seasonality and storage capacity
  - Run GCAM with an annual time step

- CESM (CLM-MOSART-WM)
  - Accounting for return flow and ground water vs surface water use
  - Returning information about crop yields, biophysical water use, crop seasonal patterns
  - Providing GCAM with water supply and water deficit information
  - Provide GCAM with initial reservoir storage and total capacity
  - Extend the WM module to include Hydro and reconcile with GCAM

Summary

- GCAM includes a detailed representation of water demands by sector, subsector and technology level and a macro-scale global hydrologic modules and is able to investigate the effect of climate mitigation on water scarcity
- Coupled a global integrated assessment model (GCAM) in a one-way fashion with a land surface hydrology – routing – water resources management model (SCLM-MOSART-WM)
- A spatial and temporal disaggregation approach is developed to downscale the annual regional water demand simulations into a daily time step and grid representation that is needed by CLM
- Work is in progress to perform a two-way coupling over the entire U.S.
- The work will be extended to global domain through ACME

References

1. Hejazi et al. (**2013**). Scenarios of Global Municipal Water Use Demand Projections over the 21st Century, *Hydrological Sciences Journal*, doi:10.1080/02626667.2013.772301
2. Davies et al. (**2013**). An integrated assessment of global and regional water demands for electricity generation to 2095. *Advances in Water Resources* 52, 296–313.
3. Kyle et al. (**2013**). Influence of climate change mitigation technology on global demands of water for electricity generation. *International Journal of Greenhouse Gas Control*, 13:112–123. doi:10.1016/j.ijggc.2012.12.006
4. Chaturvedi et al. (**2013**). Climate mitigation policy implications for global irrigation water demand. *Mitigation and Adaptation Strategies for Global Change*, doi: 10.1007/s11027-013-9497-4.
5. Hejazi et al. (**2013**). Long-term global water use projections using six socioeconomic scenarios in an integrated assessment modeling framework, *Technological Forecasting and Social Change*, 81, 205–226, http://dx.doi.org/10.1016/j.techfore.2013.05.006.
6. Hejazi et al. (**2013**). Integrated assessment of global water scarcity over the 21st century: Global water supply and demand under extreme radiative forcing, *Hydrology and Earth System Sciences Discussion*, 10, 3327–3381, doi:10.5194/hessd-10-3327-2013.
7. Hejazi et al. (**2013**). Integrated assessment of global water scarcity over the 21st century: Climate change mitigation policies, *Hydrology and Earth System Sciences Discussion*, 10, 3383–3425, doi:10.5194/hessd-10-3383-2013.
8. Voisin et al. (**2013**). One-way coupling of an integrated assessment model and a water resources model: evaluation and implications of future changes over the US Midwest, *Hydrol. Earth Syst. Sci.*, 17, 4555–4575, doi:10.5194/hess-17-4555-2013, 2013.

THANKS!

For more information…

Hydrol. Earth Syst. Sci., 17, 4555–4575, 2013
www.hydrol-earth-syst-sci.net/17/4555/2013/
doi:10.5194/hess-17-4555-2013

Hydrology and Earth System Sciences
Open Access

One-way coupling of an integrated assessment model and a water resources model: evaluation and implications of future changes over the US Midwest

N. Voisin[1], L. Liu[2], M. Hejazi[2], T. Tesfa[1], H. Li[1], M. Huang[1], Y. Liu[1], and L. R. Leung[1]

[1]Pacific Northwest National Laboratory, Richland, WA, USA
[2]Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD, USA

Correspondence to: N. Voisin (nathalie.voisin@pnnl.gov)

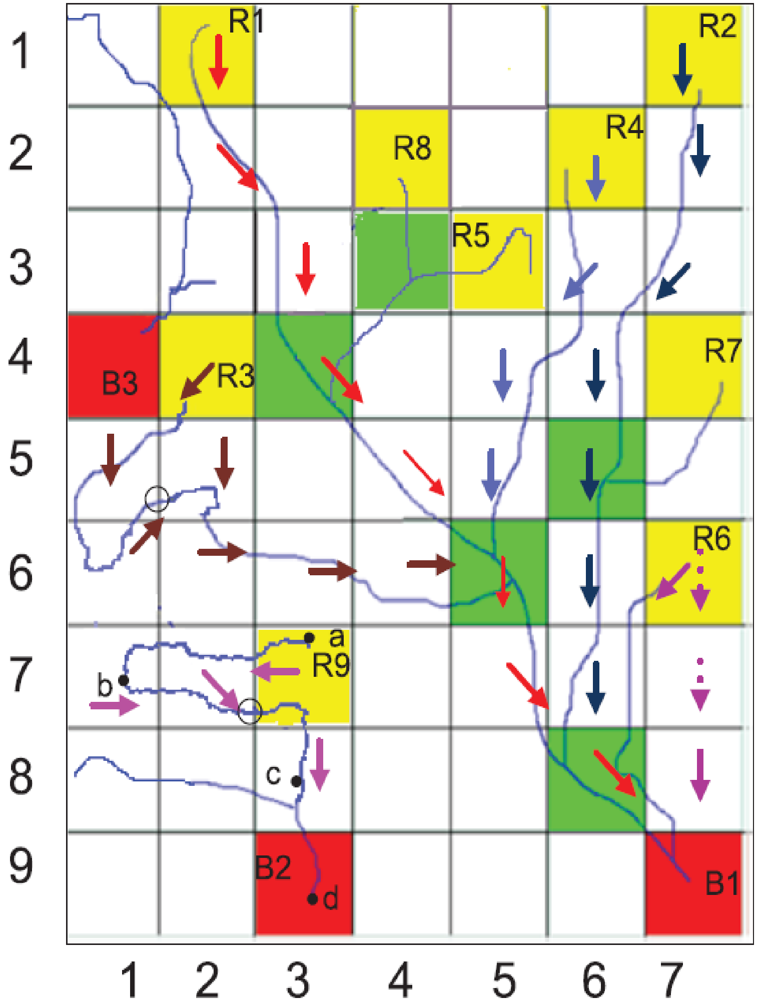
Received: 2 April 2013 – Published in Hydrol. Earth Syst. Sci. Discuss.: 22 May 2013
Revised: 14 September 2013 – Accepted: 10 October 2013 – Published: 18 November 2013

Mohamad Hejazi
mohamad.hejazi@pnnl.gov

Implementation of River Routing in GCAM

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Modified River Transport Model scheme

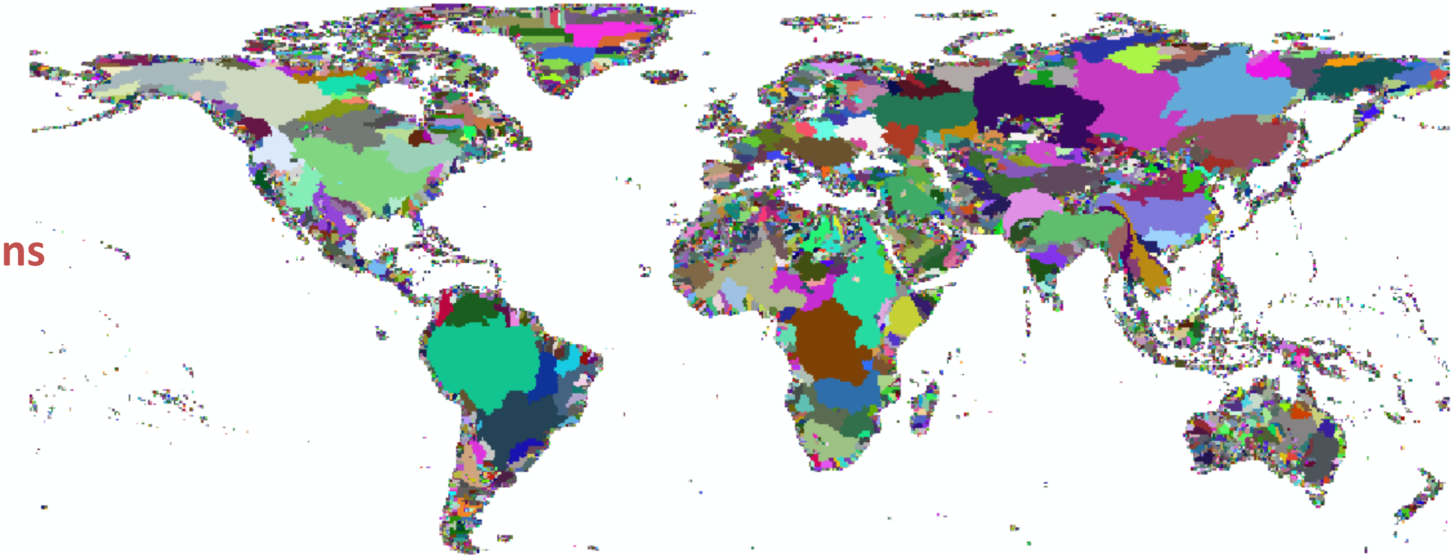


Adapted from Wu et al., 2011

- Cell-to-cell routing with a linear advection model
- Realistic river network delineated with a hierarchical dominant river tracing algorithm
- Low computational cost
- Flexible to be extended to represent human activities (e.g., reservoirs, thermal power plant etc.)

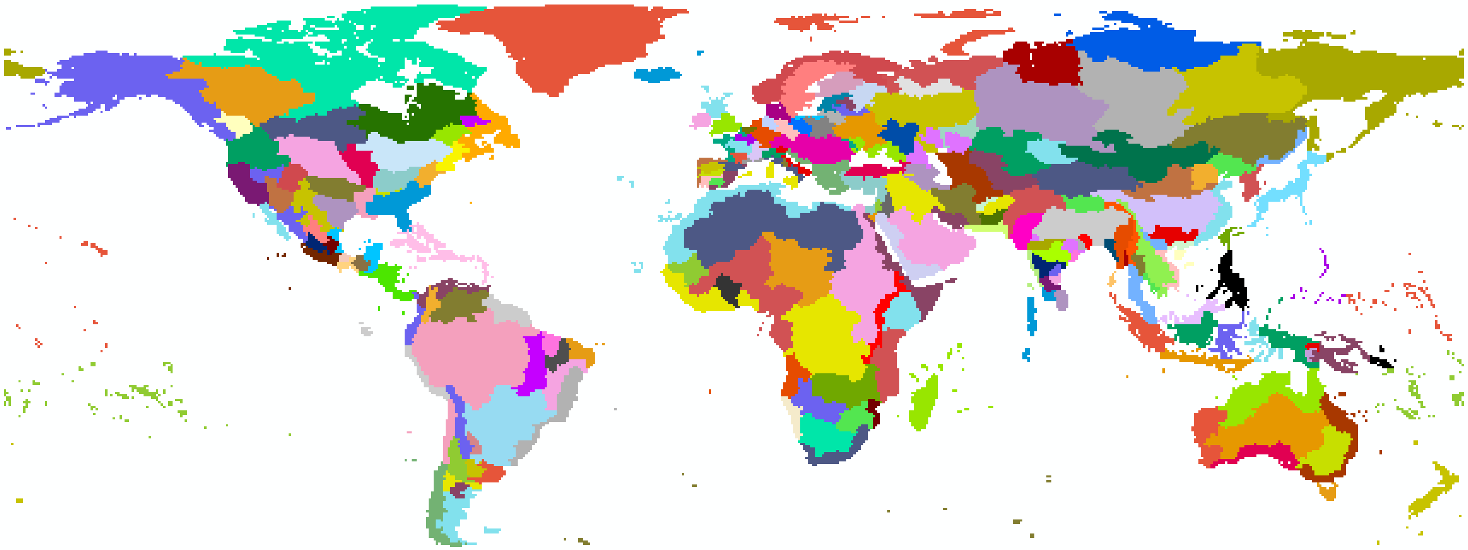
Harmonize databases

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



14259 basins
in CLM

233 basins
in GCAM



Reservoirs and water use in the study region

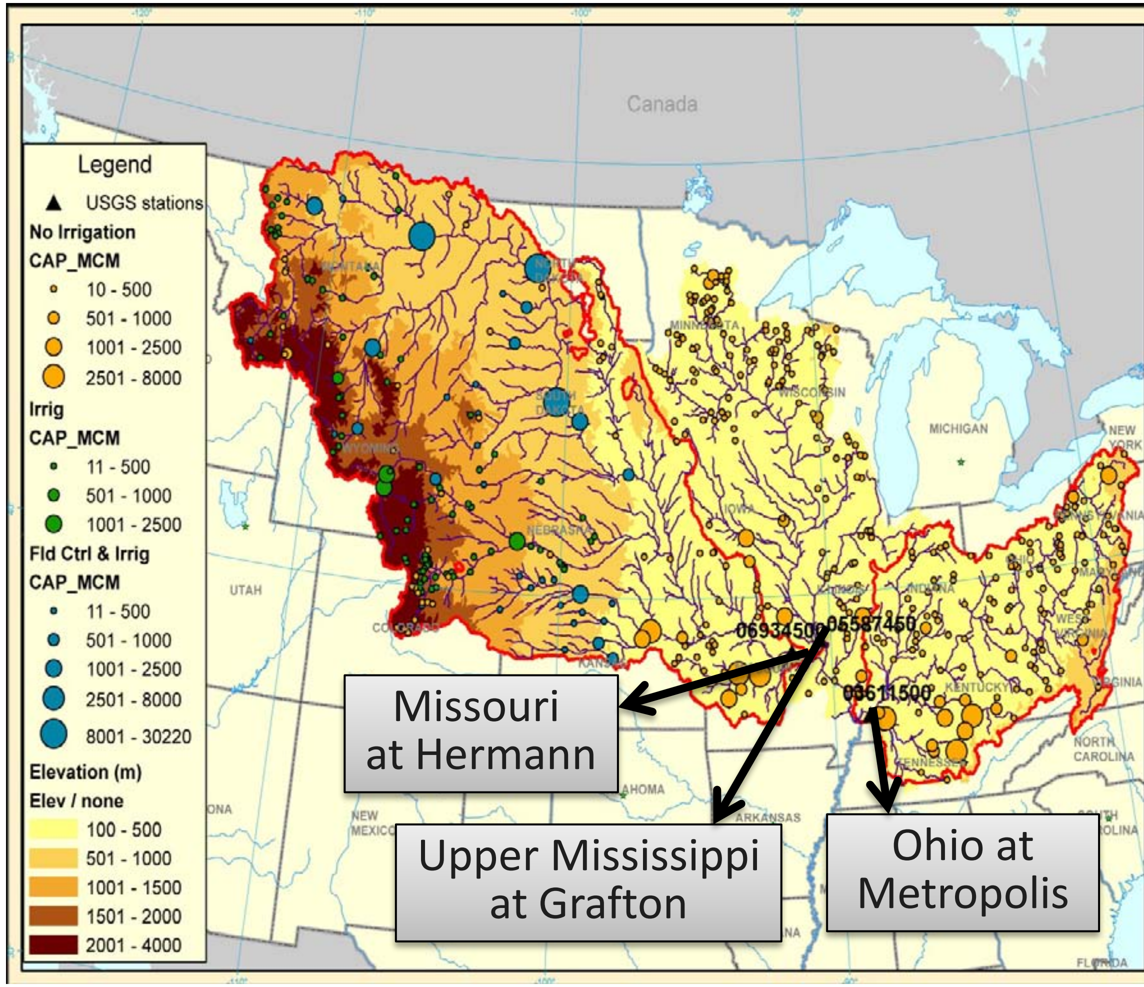
The reservoir database by type of operating rules

Missouri (194):
- Irrigation (125)
- Irrigation and Flood Control (29)
- Other uses (40)

Upper Mississippi (220):
- Irrigation (0)
- Flood Control (25)
- Other uses (195)

Ohio (131):
- Irrigation (0)
- Flood Control (71)
- Other uses (60)

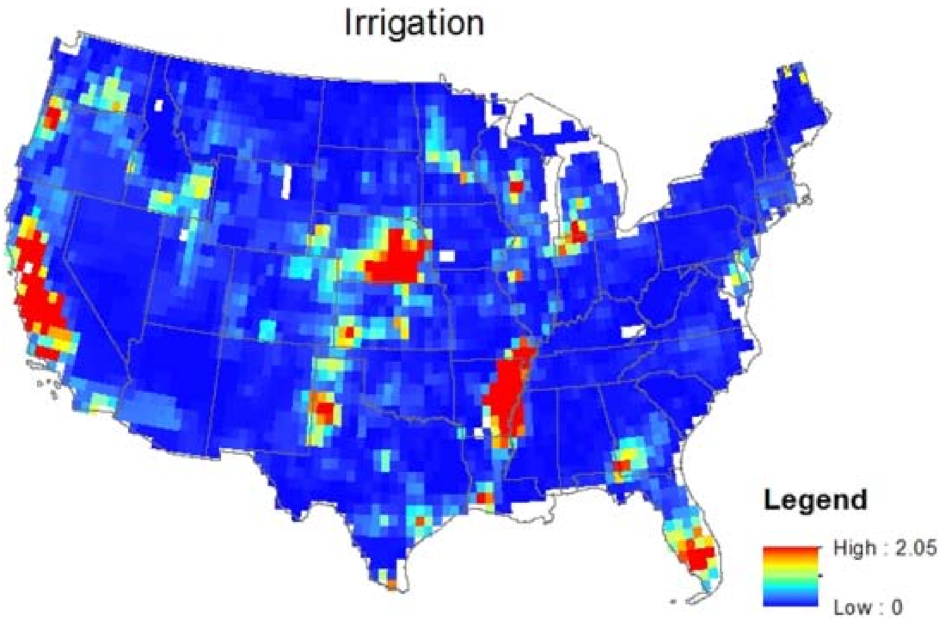
*Other uses: hydropower, navigation, municipal water supply, recreation

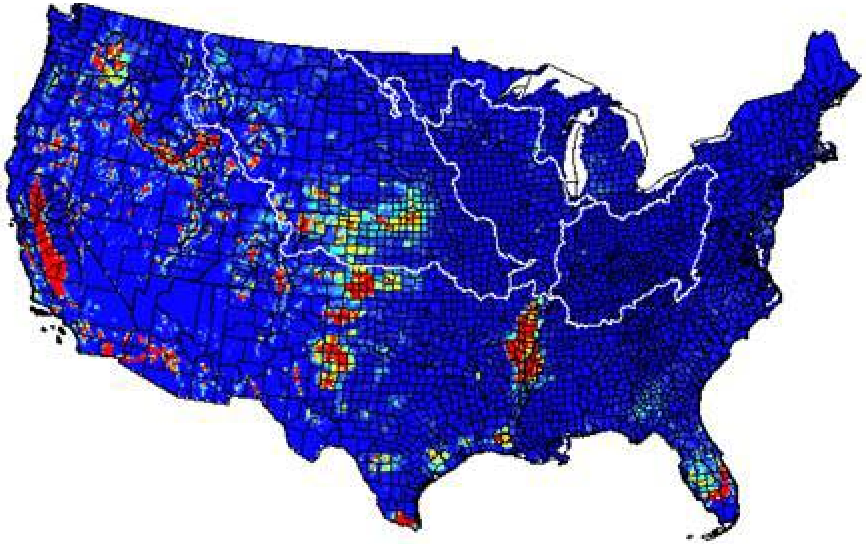


Flow is validated at the outlet of the three regions: Missouri at Hermann, Upper Mississippi at Grafton and Ohio at Metropolis.

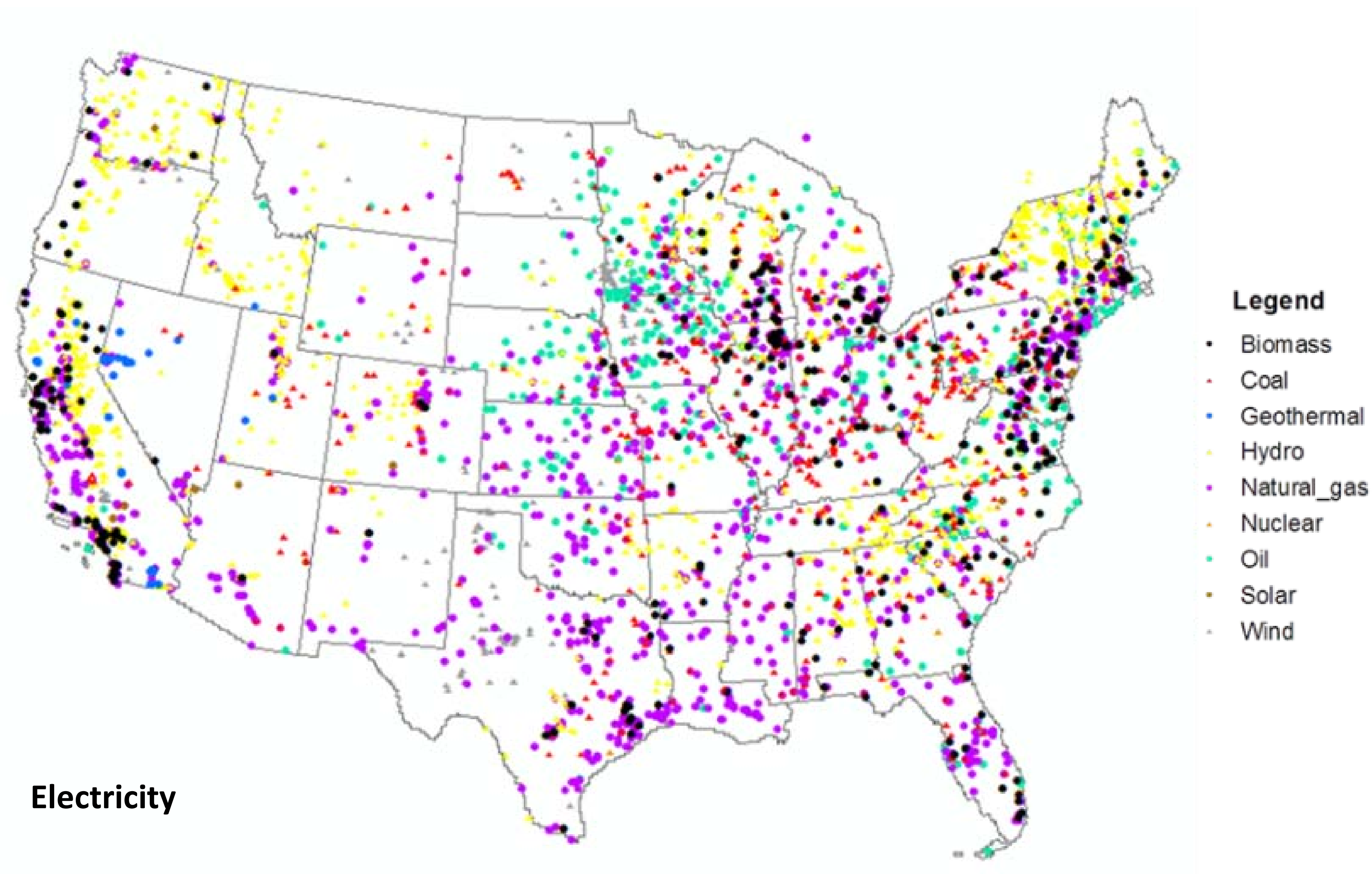
Comparison with USGS Irrigation

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



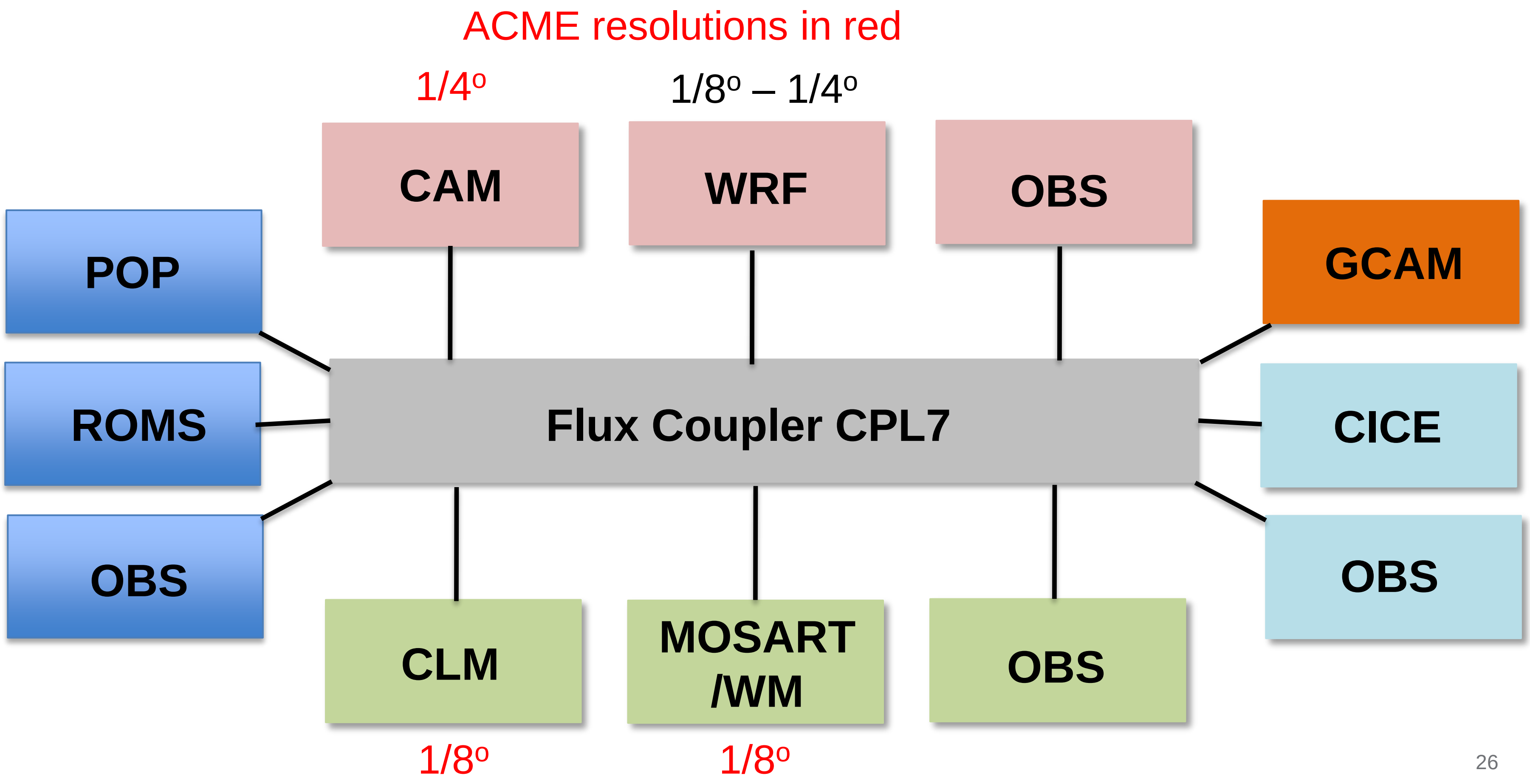


Improving Spatial Downscaling for Electricity Generation in the U.S.

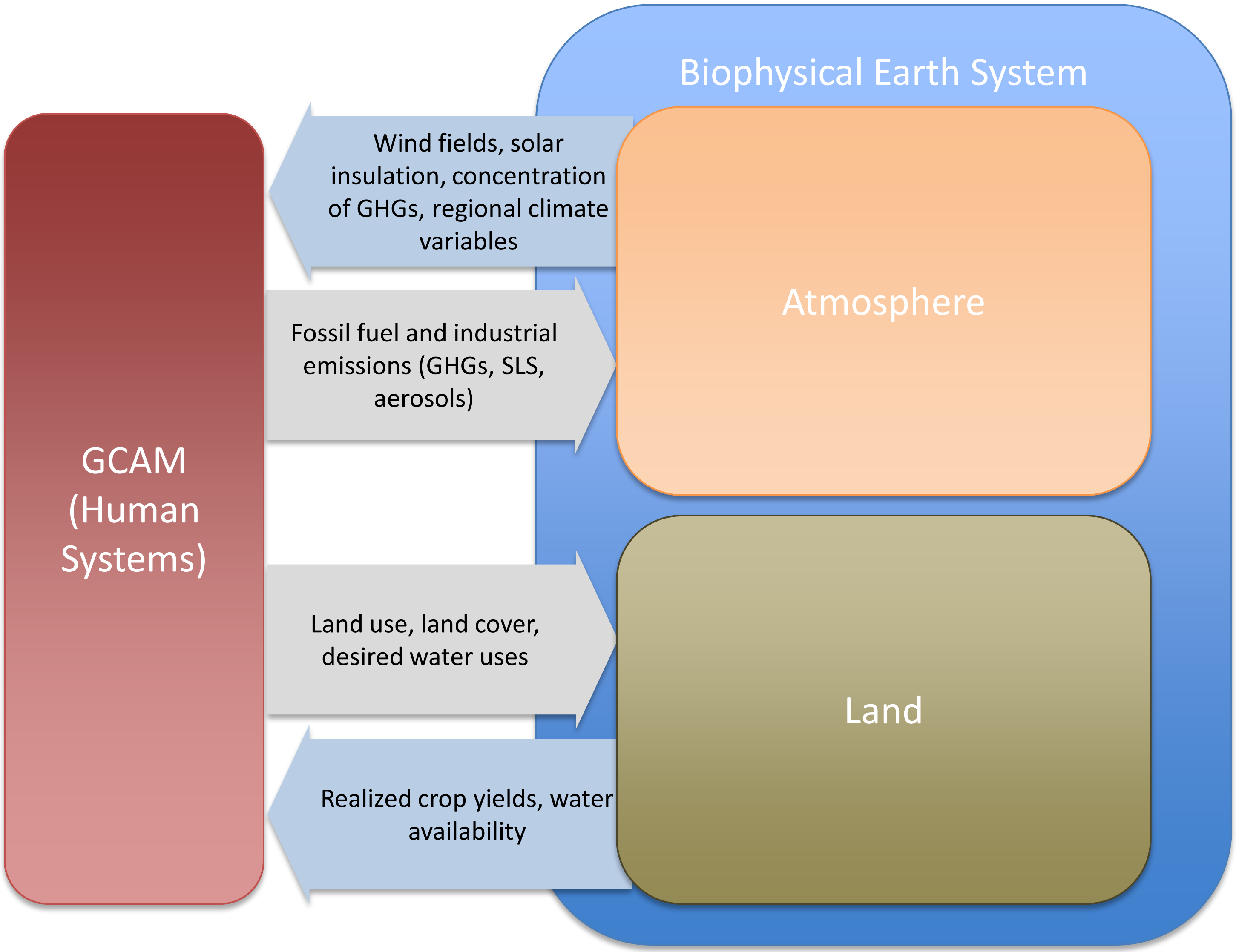


Model coupling

- Currently coupling of GCAM with CLM/MOSART/WM is achieved through PRIMA developed scripts
- In future, all model coupling will be achieved through the CESM flux coupler framework under ACME



Moving forward: ACME—Accelerated Climate Modeling for Energy



- ACME will couple human systems with biophysical Earth systems.