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# Modeling the Integrated Water Cycle in CESM

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# Water in the human-Earth system



- Water underlies and influences many important climate processes and feedbacks – a leading cause of uncertainty in projecting future climate

**Water vapor and cloud feedback**

**Snow-albedo feedback**

**Aerosol-cloud interactions**

**Carbon-water interactions**

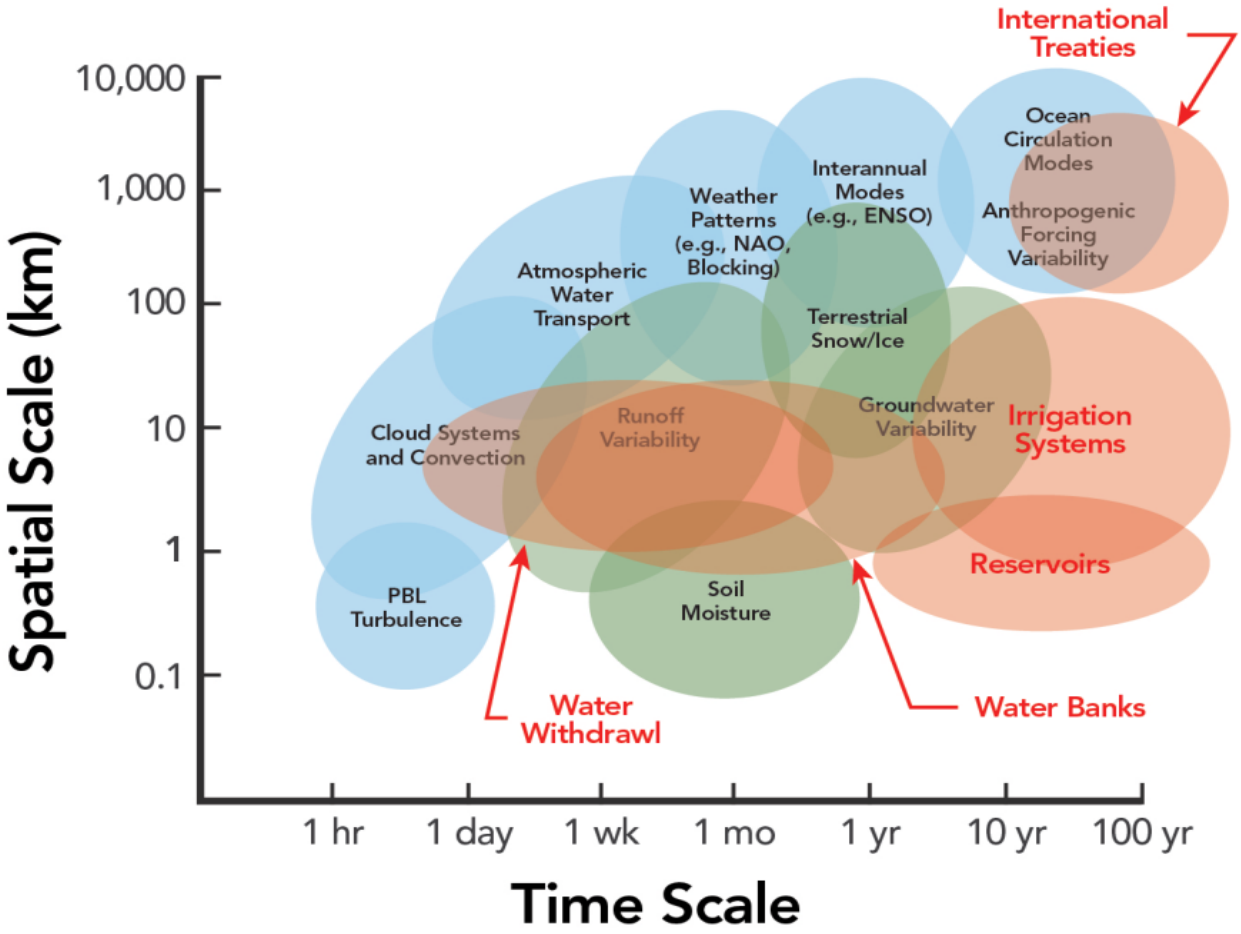
- Water is essential for energy systems, ecosystem services, and a wide range of life sustaining and other critical human activities

- Global and regional water cycles are influenced by natural processes as well as the human systems – how will they co-evolve in the future?

# Processes in the integrated water cycle



- Challenge: How to represent the multi-scale, dynamic interactions among the atmosphere, terrestrial, and human systems



# Modeling the integrated water cycle



- Objectives
  - Represent the dynamic interactions between the human and earth systems and their influence on the water cycle
  - Use the models to investigate the nexus of climate, energy, water, and land under climatic and societal changes for sustainable energy and water in the future

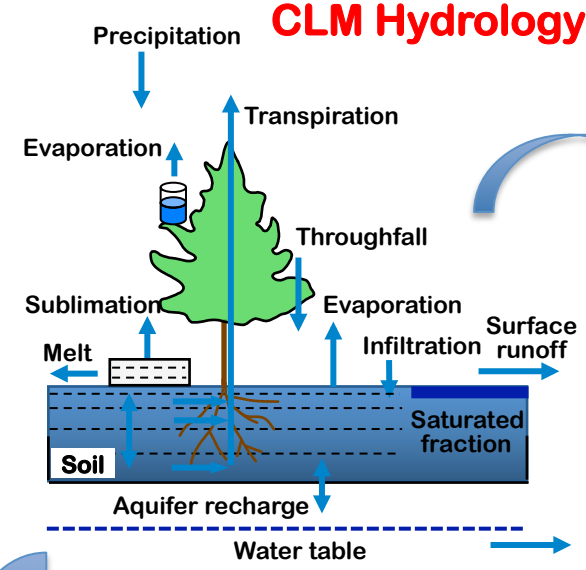
- Approach
  - Improve model scalability to address the multi-scale atmospheric and terrestrial water cycle processes
  - Add human components (water management, water use, water demand) of water cycle processes in CESM

# CLM coupled with river routing and water management

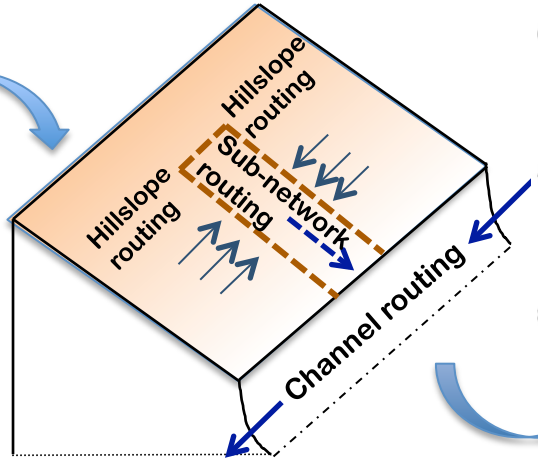


- Improve and add new capabilities in Community Land Model (CLM) to represent hydrology and human – water cycle interactions at multiple time and space scales

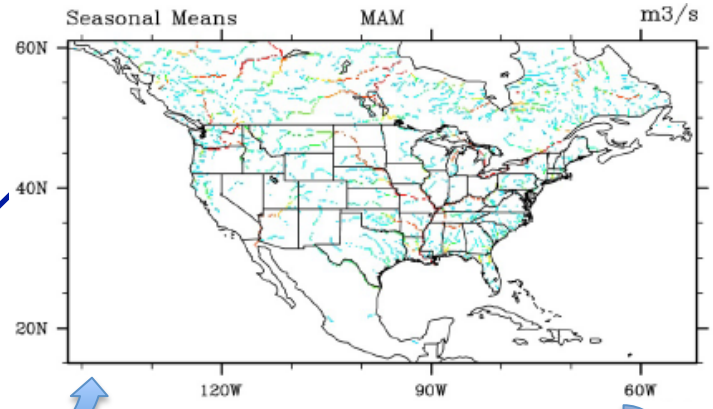
## CLM Hydrology




## River Routing Model

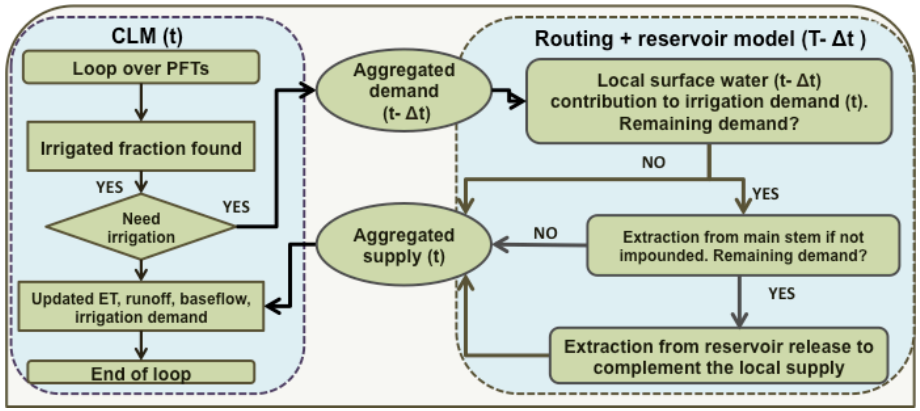



## Coupled CLM-Routing Simulation




Irrigation water demand

## Water Management Model



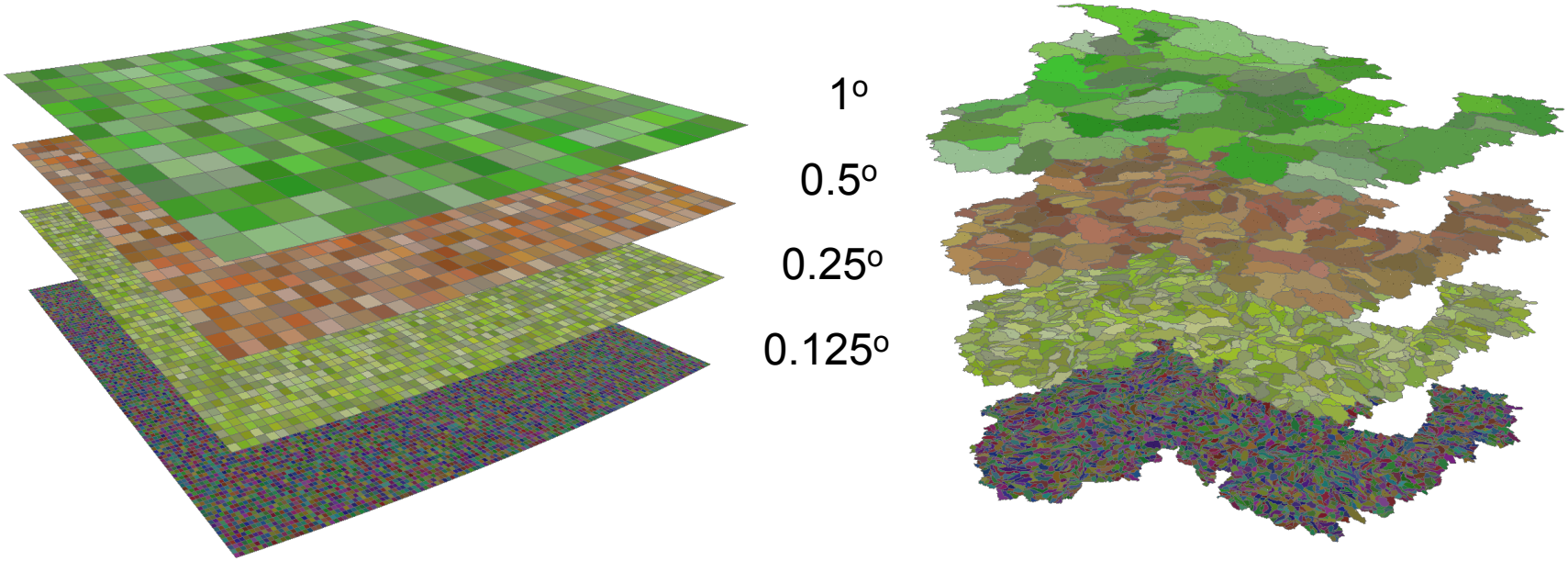

Reservoir operations

# Comparison of grid vs subbasin representations



- Land surface heterogeneity such as topography has a dominant influence on hydrological processes
- Using subbasins as the computational units eliminates the needs to represent the redistribution of soil moisture between units and improve the accuracy for estimating the topographic index used in the TOPMODEL parameterizations of surface and subsurface runoff

**Grid-based representation (CLM)** **Subbasin-based representation (DCLM)**

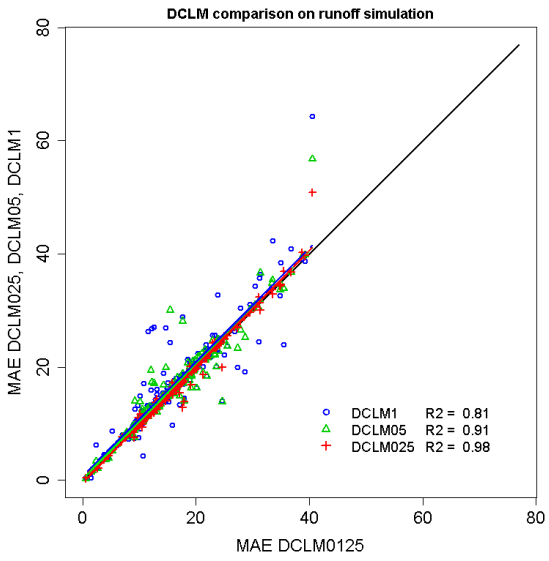


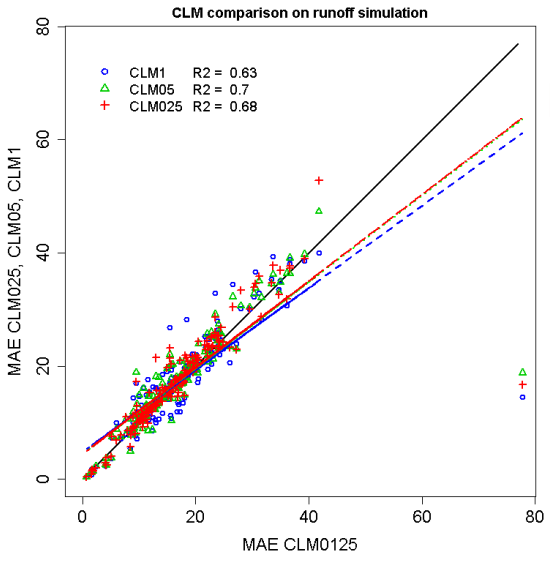
# The subbasin representation improves scalability



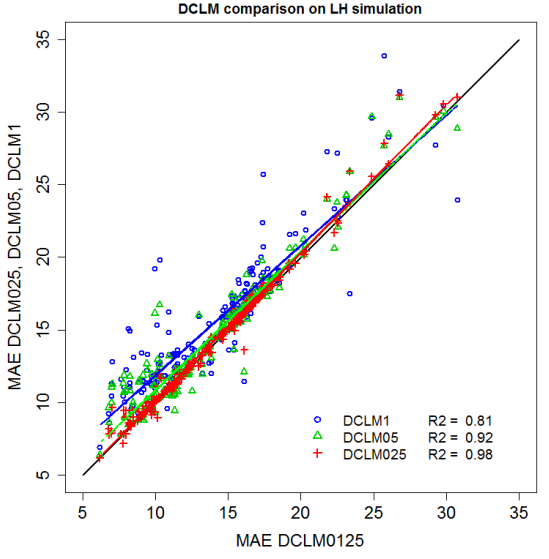
**Subbasin (DCLM)** | **Grid (CLM)**

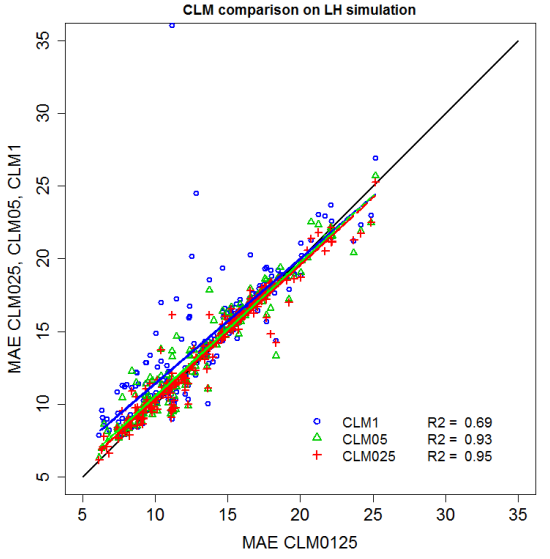
**Runoff**




**Latent heat flux**

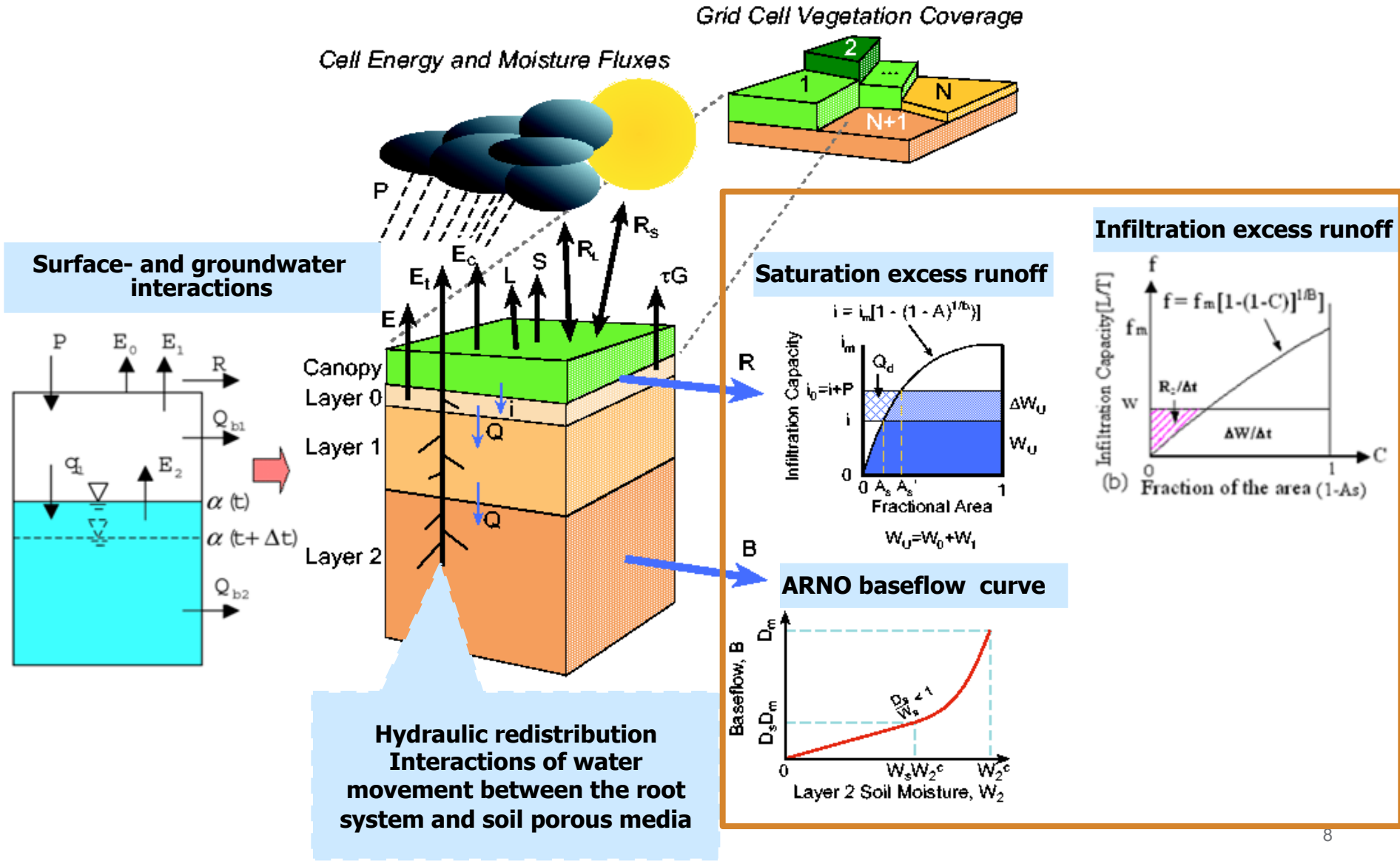



- Model skills (MAE) at different resolutions are more strongly correlated and model skill increases systematically with resolution in the subbasin representation but not the grid representation

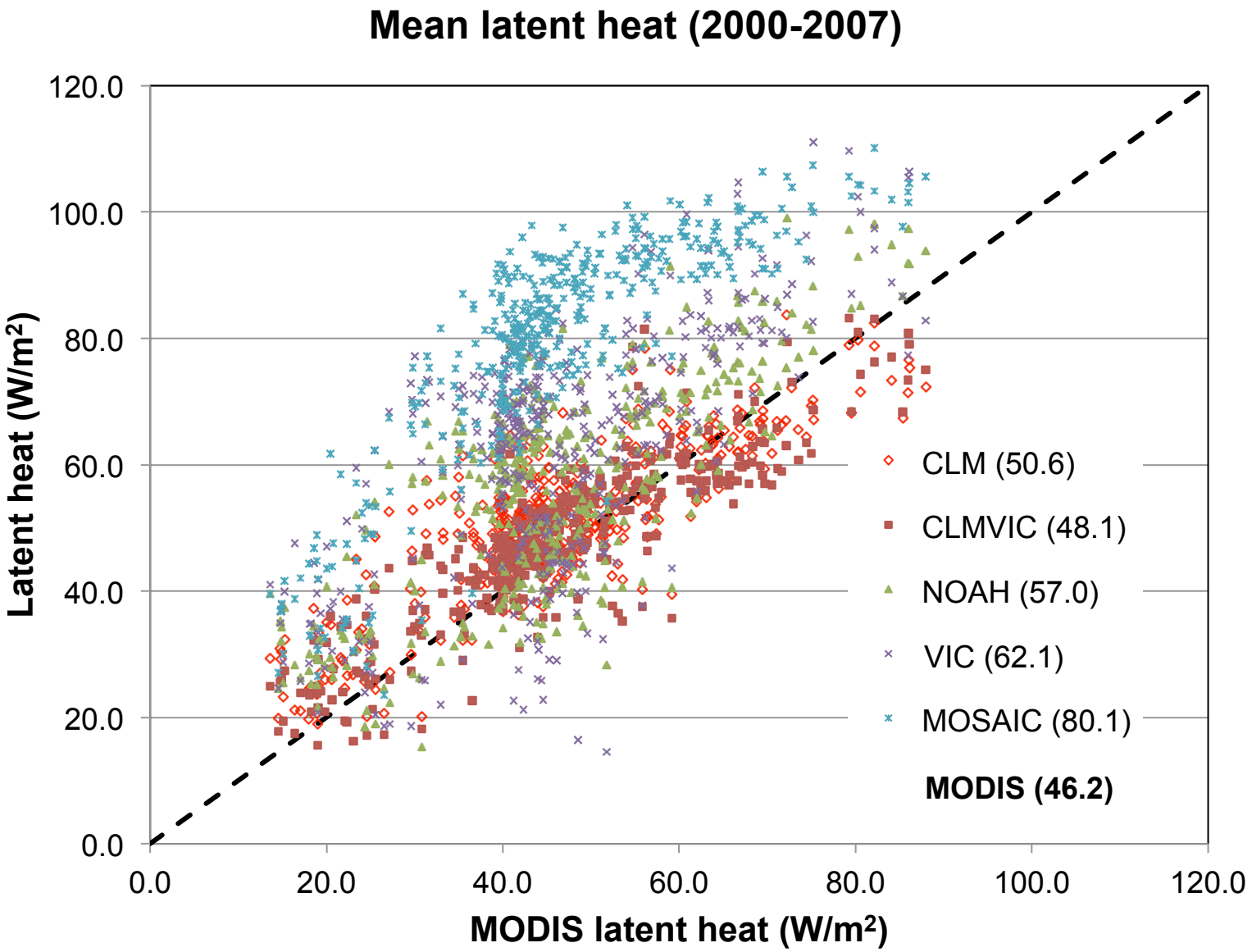
# Merging of CLM and VIC (Li et al. JGR, 2011)





# Comparison of observed and simulated annual LH over MOPEX basins: CLM, CLMVIC, and other NLDAS models

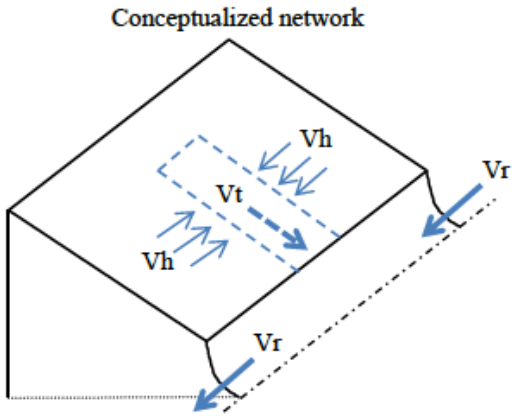




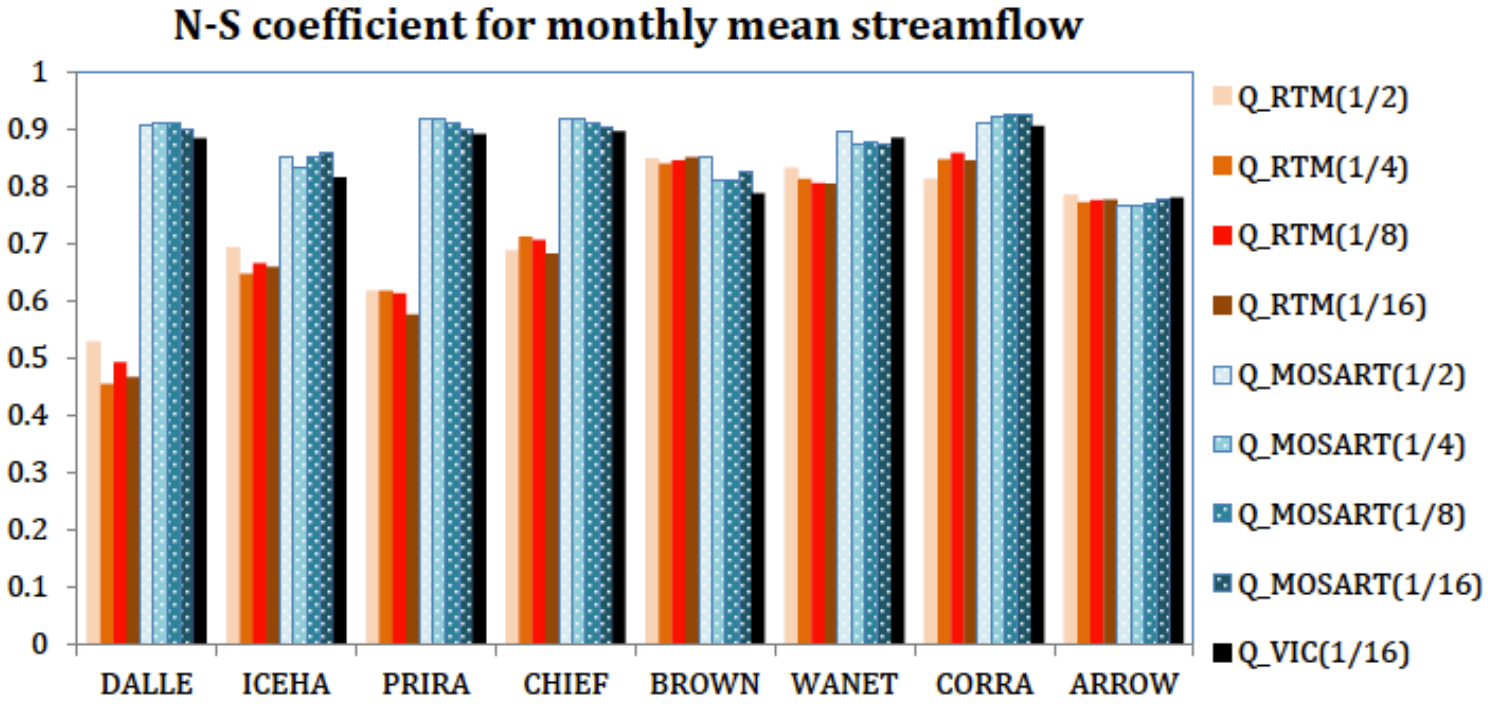
# Model for Scale Adaptive River Transport (MOSART) (Li et al. 2013, JHM, in press)



- MOSART is physically based and explicitly represents subgrid and channel routing in a scale-consistent way
- It simulates channel water depth and velocity for modeling in-stream biogeochemistry, sediment transport, and floods
- It serves as the cornerstone for integrating human and earth system components



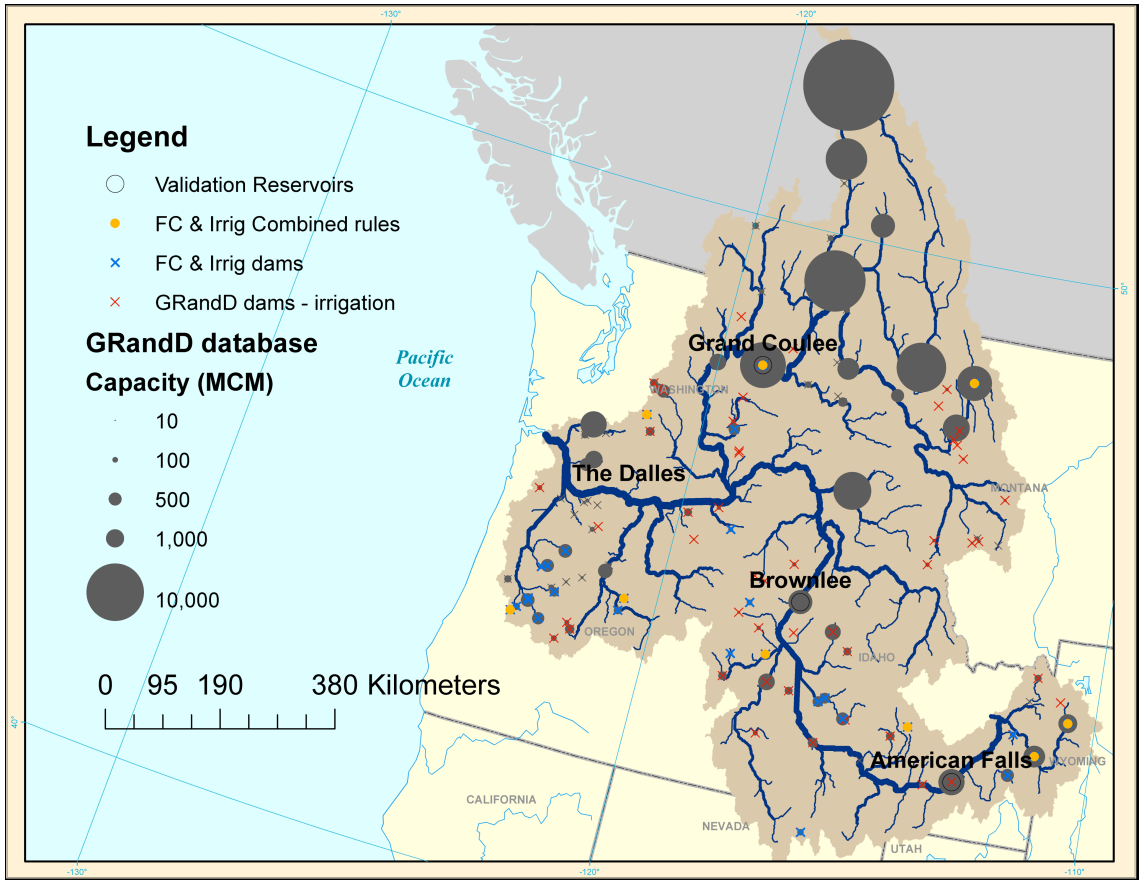

**MOSART is more skillful in simulating streamflow compared to RTM**



# Water management model (Voisin et al. 2013, HESS, submitted)

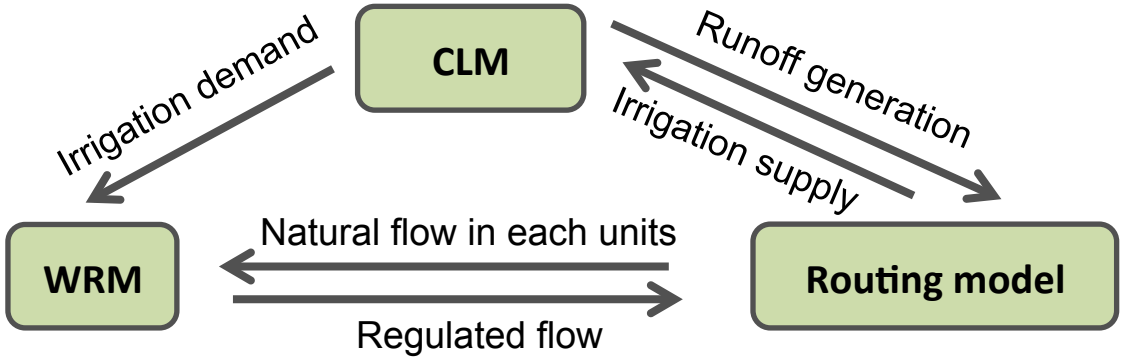


- Designed for full coupling in an earth system models
  - Assume no knowledge of future inflow
  - Use generic operating rules

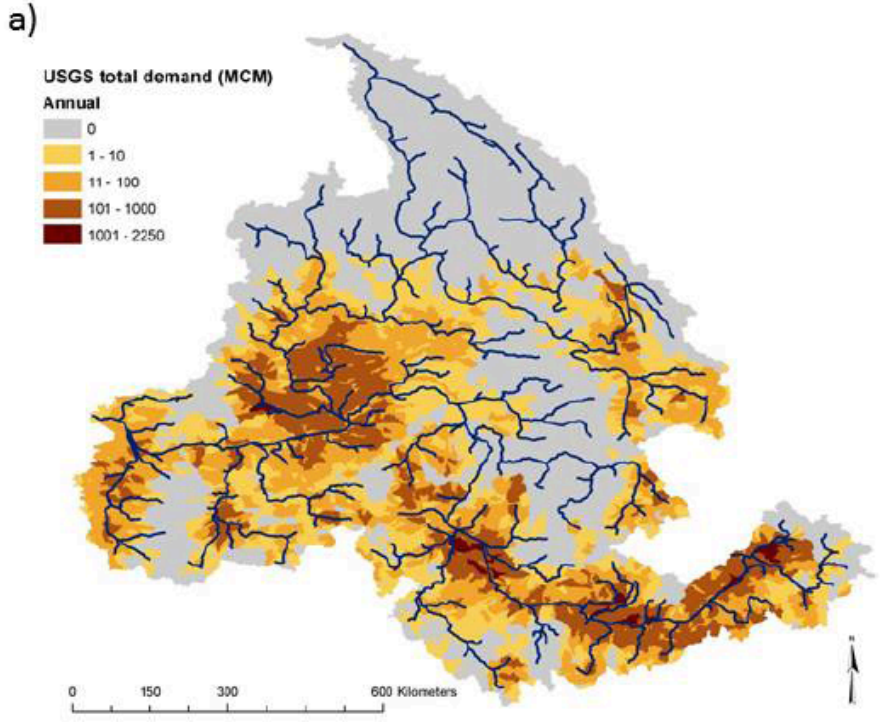


# Water management model

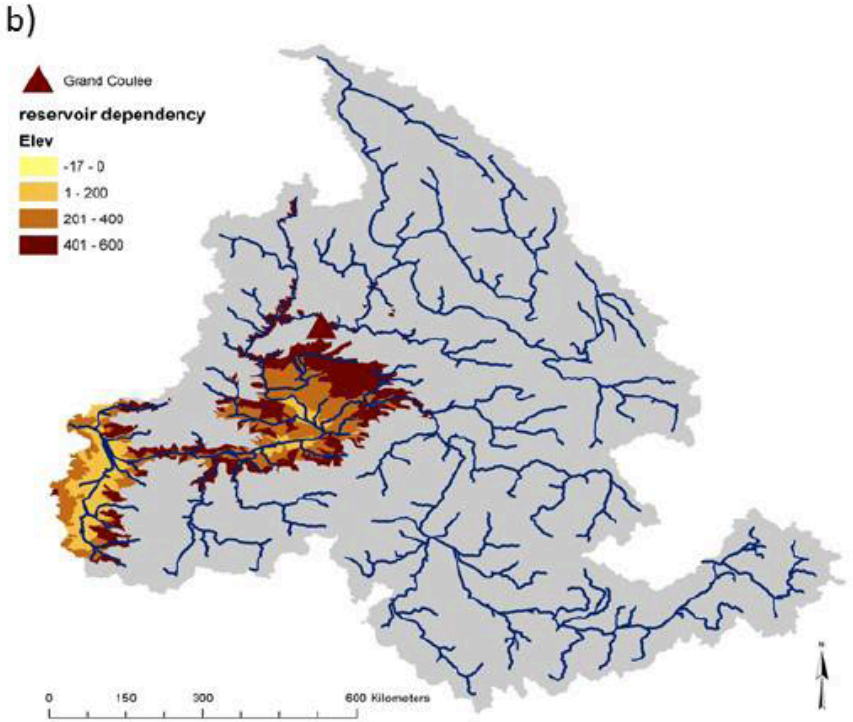





## Total water demand



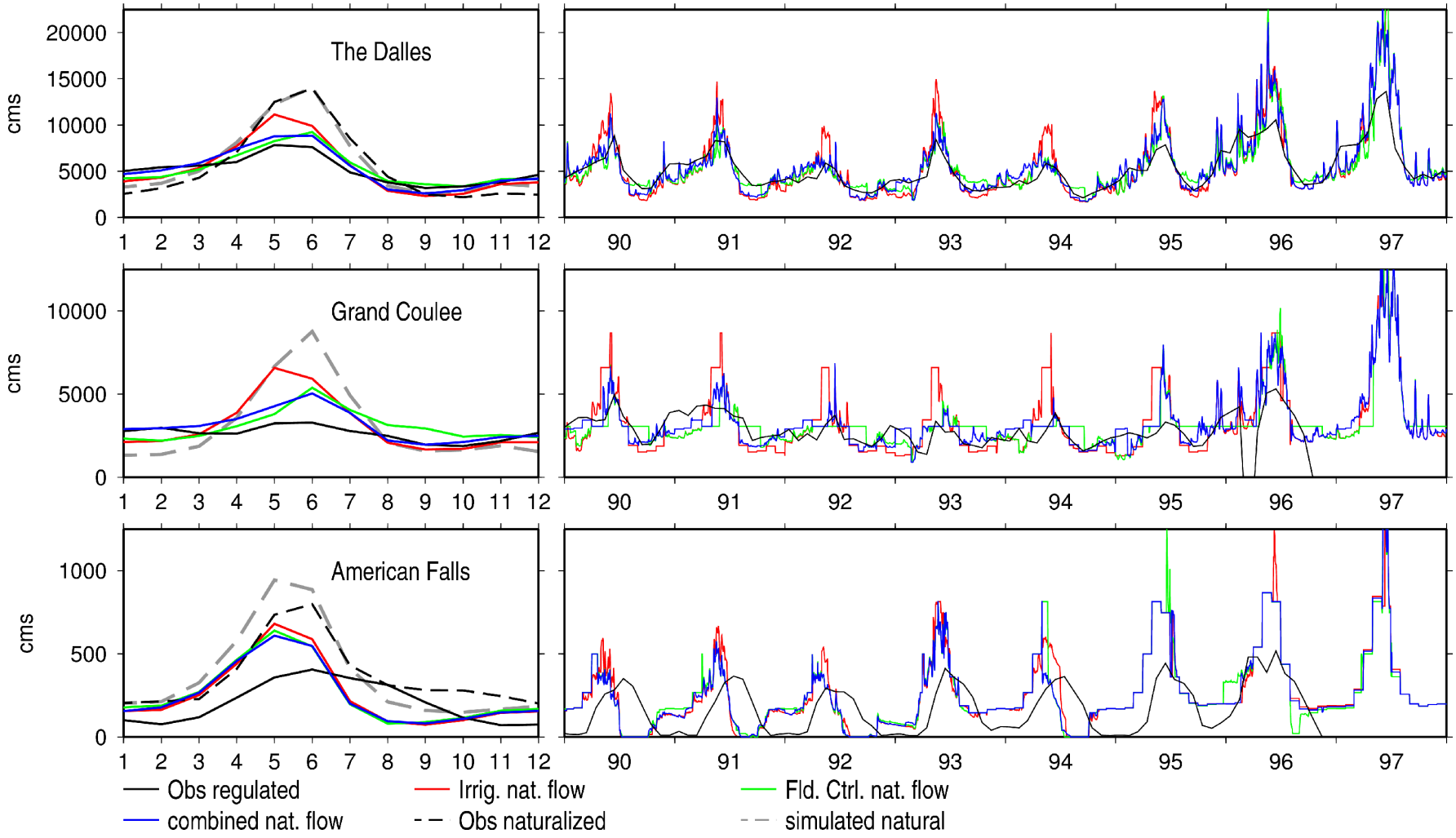

## Reservoir dependency



# Natural and regulated flow

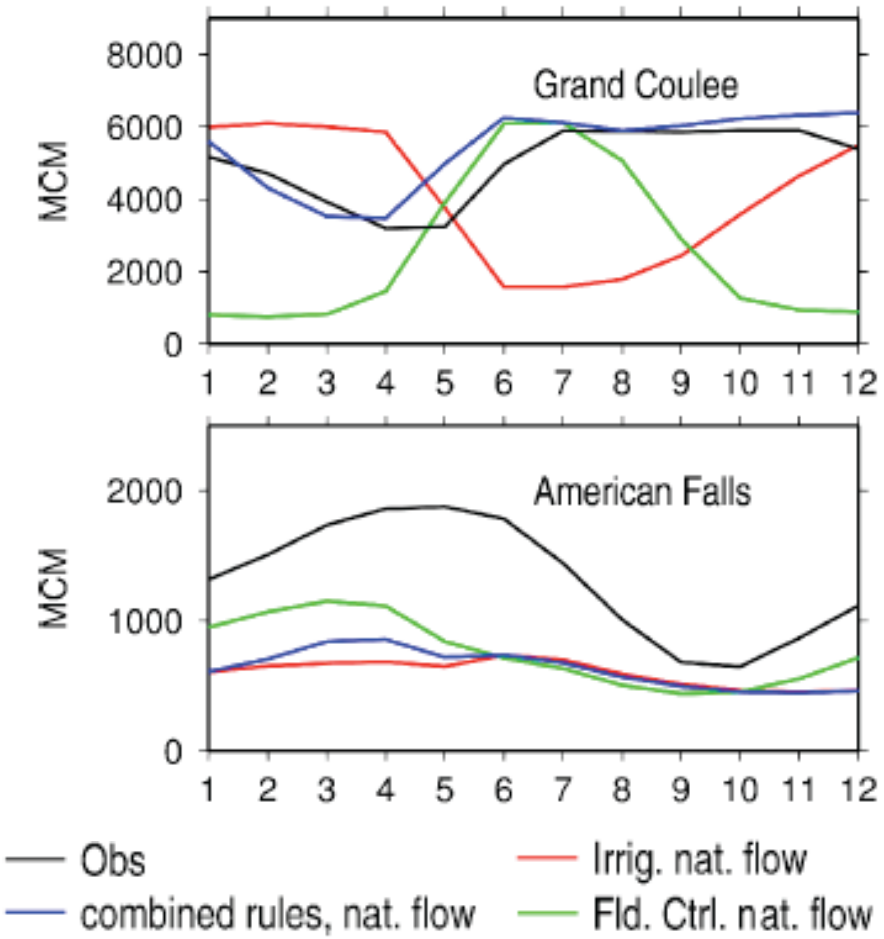


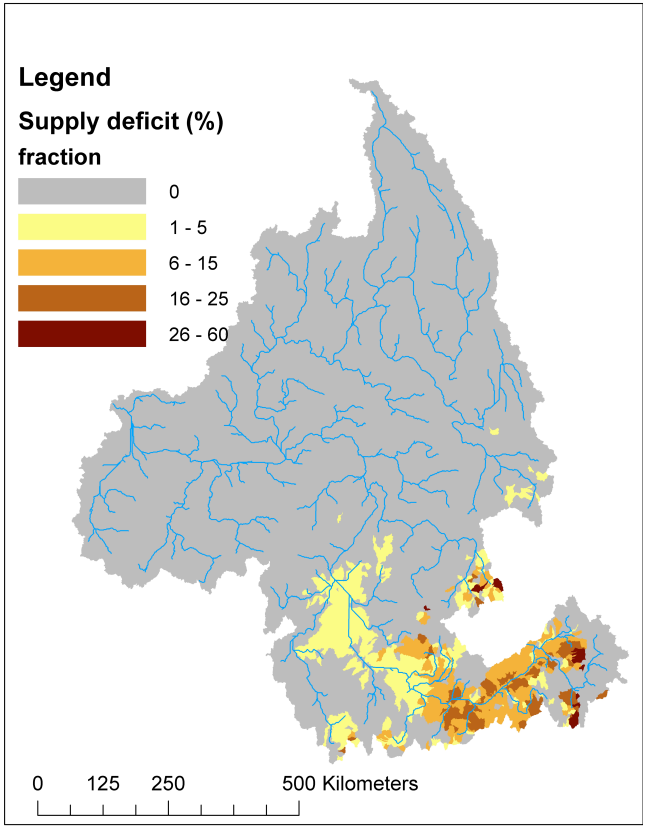
## Combining flood control and irrigation objectives in operating rules best capture the observed regulated flow in the Columbia river basin



# Reservoir storage and supply deficit



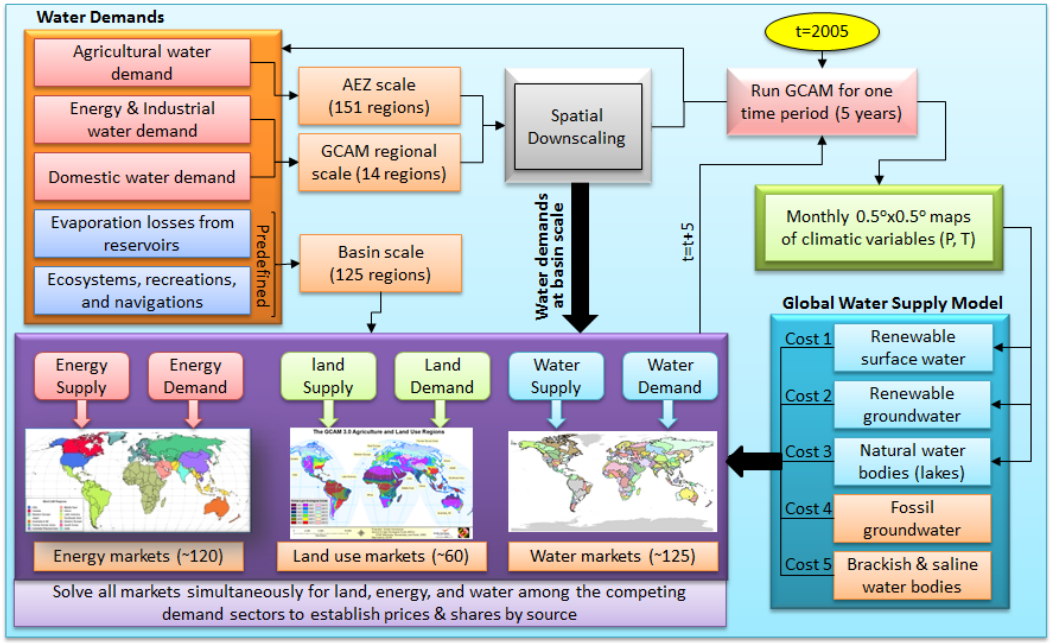


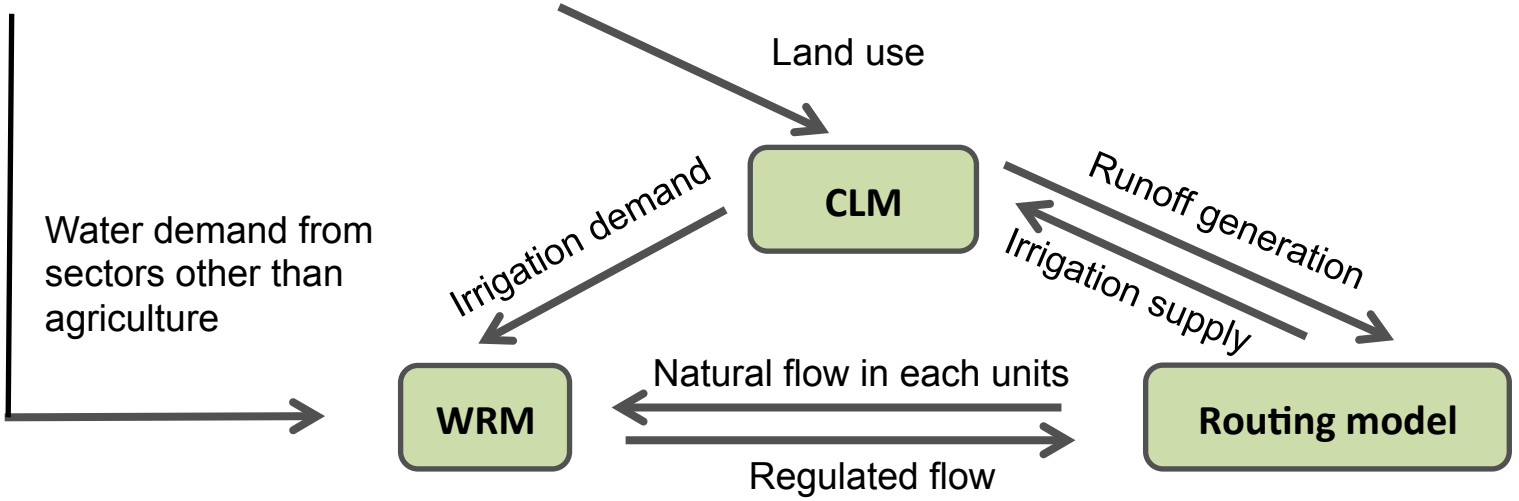

- Reservoir storage is only reproduced using operating rules that combine flood control and irrigation priorities
- At the American Falls, supply deficit is related to groundwater use

# Integrating with IAM: Water market and water demand






- Water demand for various sectors driven by energy demand, GDP, and agricultural land demand is simulated by IAM (GCAM)
- GCAM also solves the energy market, land market, and water market simultaneously to establish prices and shares by source



# Summary



- On hydrologic modeling and model scalability:
  - Subbasin representation offers some advantage in scalability
  - The new river routing model (MOSART) represents hillslope, tributary, and channel routing and works well across scales
  - A new CLM subgrid structure is being developed to account for subgrid PFT, elevation, and inundation
- On representing the dynamic interactions between human and earth systems:
  - Developed a coupled system including CLM, river routing, and water management to represent irrigation water use and water management
  - Ongoing research to represent water demand, water use, and water market using the coupled CESM - GCAM
- Global implementation and evaluation underway