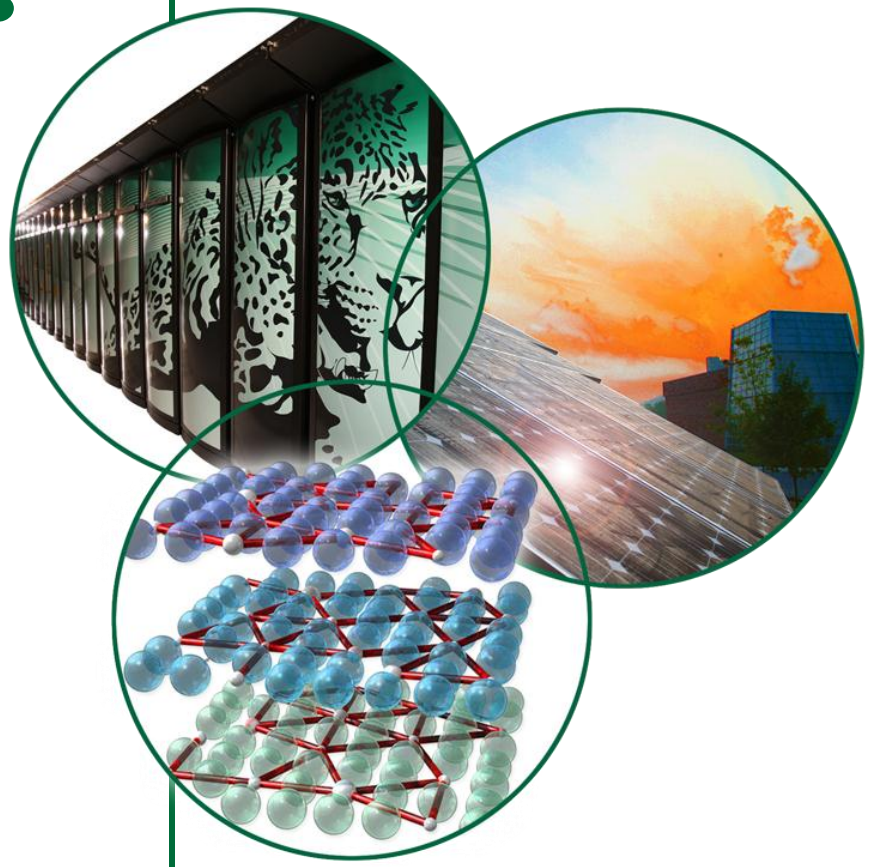
A Quantitative Assessment Framework for Potential Climate Change Impacts on National Hydropower Generation



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SECURE Water Act of 2009

"SECURE Water" = Science and Engineering to Comprehensively Understand and Responsibly Enhance Water

Section 9501. Findings

Section 9502. Definitions

Section 9503. Reclamation Climate Change and Water Program

– ***Reclamation's 9503 Report to Congress***

Section 9504. Water Management Improvement

Section 9505. Hydroelectric Power Assessment

– ***DOE's 9505 Report to Congress***

Section 9506. Climate Change and Water Intragovernmental Panel

– ***USGS's 9506 Report to Congress***

Section 9507. Water Data Management by the U.S. Geological Survey

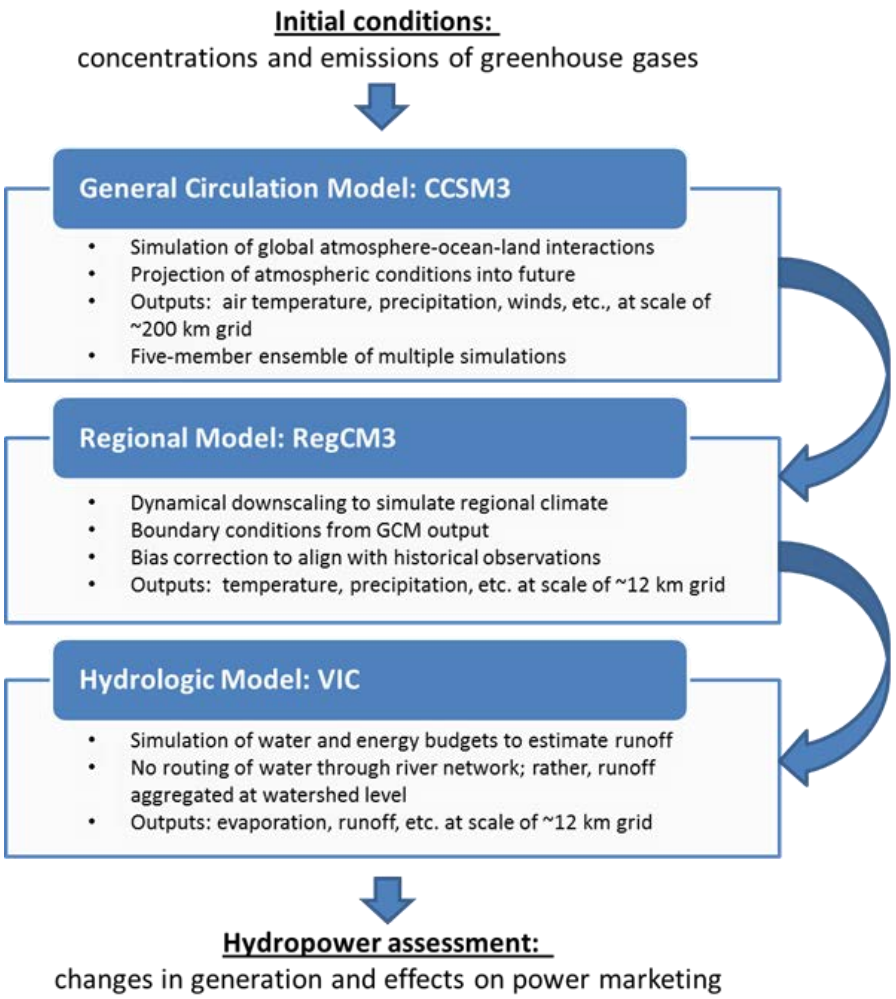
Section 9508. National Water Availability and Use Assessment Program

Section 9509. Research Agreement Authority

Section 9510. Effect

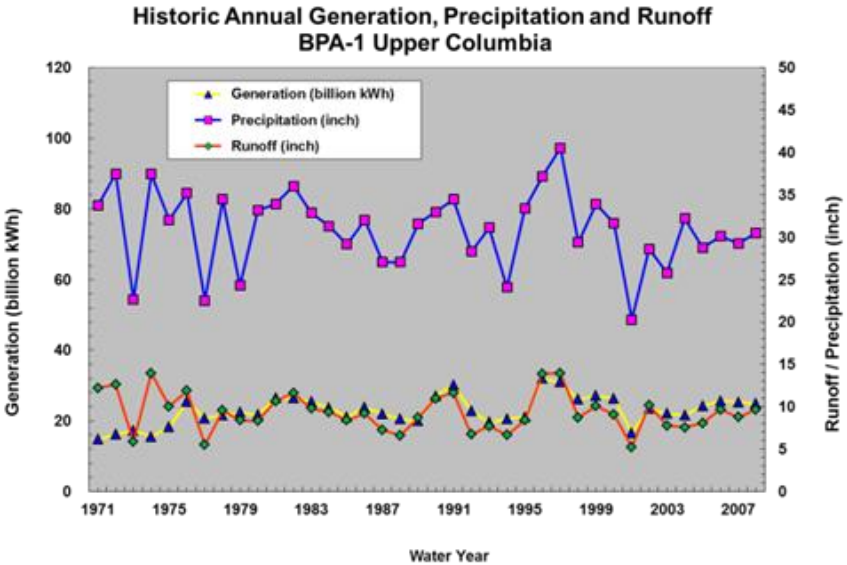
9505 Technical Approach

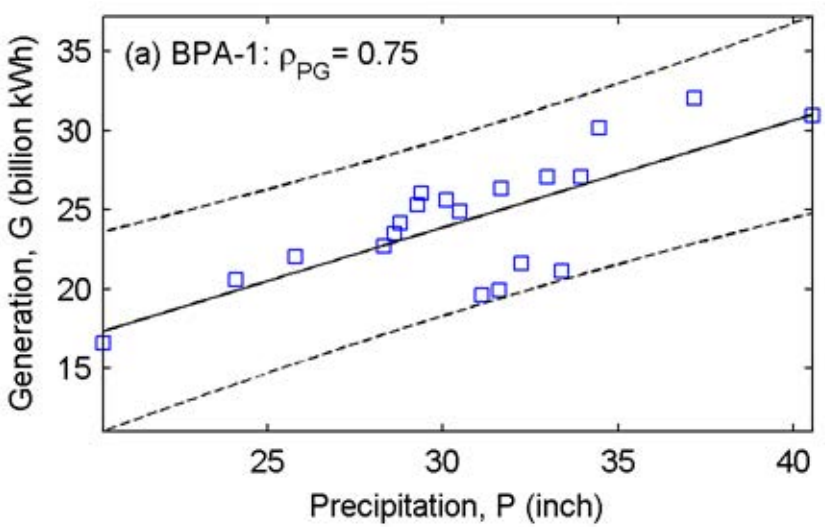
- Define regions of analysis
- Describe existing power systems, including their hydrologic sensitivity
- Review climate change research and assessments
- Design analysis approach that is consistent across regions
- Work with existing data and on-going activities
- Consult with USGS, NOAA, state agencies, plus USACE and Reclamation, to obtain best-available scientific data

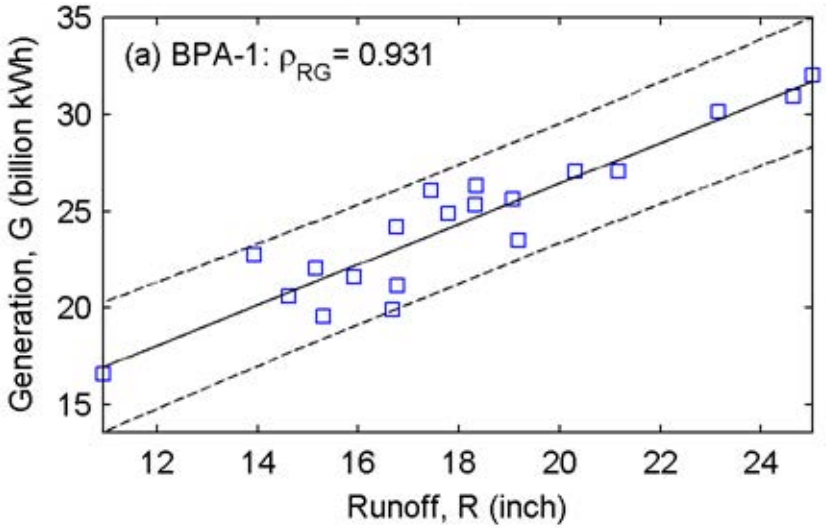


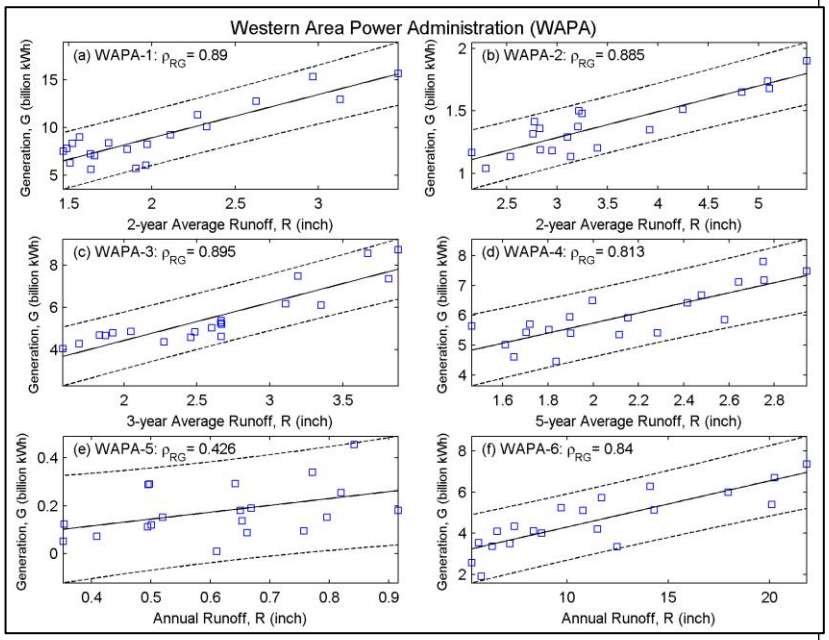
Hydrologic Sensitivity

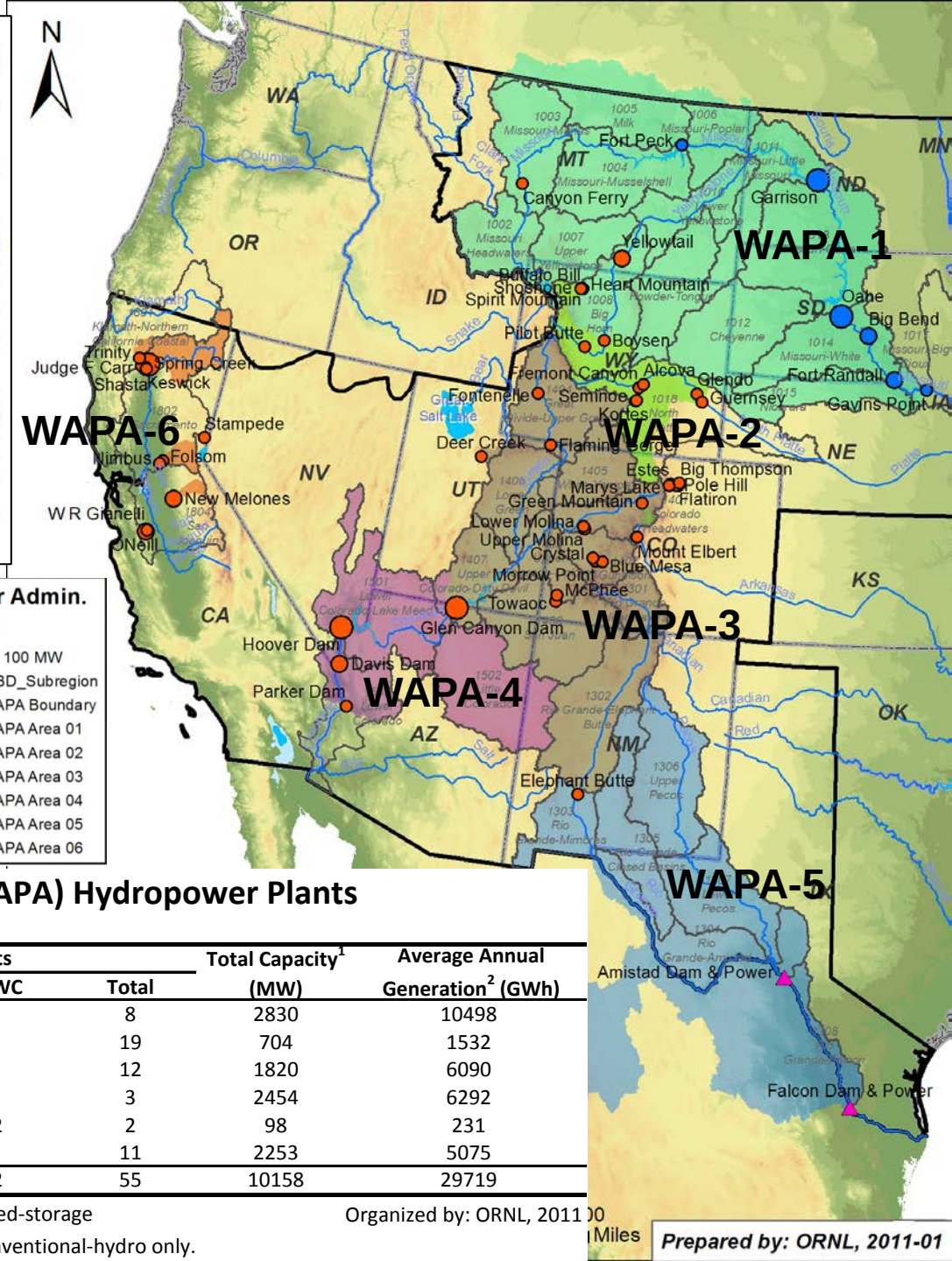
- Hydropower generation is highly variable year-to-year
- Annual runoff is a good predictor of annual generation
- Regression formula are derived for PMA and HUC02 Subregions.
- Potential of direct runoff reduction by climate change











Summary of Western Power Administration (WAPA) Hydropower Plants

Area #	Major Watersheds	Number of Plants				Total Capacity[1] (MW)	Average Annual Generation[2] (GWh)
		USACE	Reclamation	IBWC	Total		
01	Upper Missouri	6	2		8	2830	10498
02	Platte-Yellowstone		19		19	704	1532
03	Upper Colorado		12		12	1820	6090
04	Lower Colorado		3		3	2454	6292
05	Rio Grande			2	2	98	231
06	California Central Valley		11		11	2253	5075
Total		6	47	2	55	10158	29719

[1] EIA 2008 total nameplate capacity. Include both conventional hydro & pumped-storage

[2] EIA average annual generation from Oct. 1970 to Sept. 2008 (fiscal year). Conventional-hydro only.

Organized by: ORNL, 2011

Several Recent U.S. Climate Studies

	SECURE Water 9505 (DOE)	SECURE Water 9503 (Reclamation)	RMJOC (BPA et al)
Global Climate Projections	1 GCM, 5 climate projections	16 GCMs, 112 climate projections	10 GCMs, 18 climate projections
Emission Scenarios	A1B (medium)	A2 (high), A1B (medium), B1 (low)	A1B (medium), B1 (low)
Downscaling Approach and Outputs	Dynamical, daily T & P from 1960 to 2039	Statistical, monthly T & P from 1950 to 2099	Statistical, monthly T & P from 1950 to 2099
Hydrologic Simulation	VIC (without routing)	VIC	VIC
Resolution	12km	12km	6km
Study Area	Contiguous U.S.	Western U.S.	Pacific Northwest
Operation Evaluation	No	No	Yes

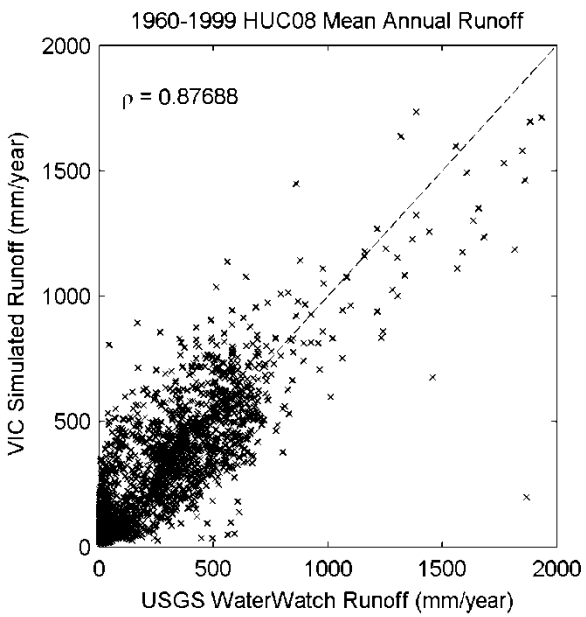
Next Steps

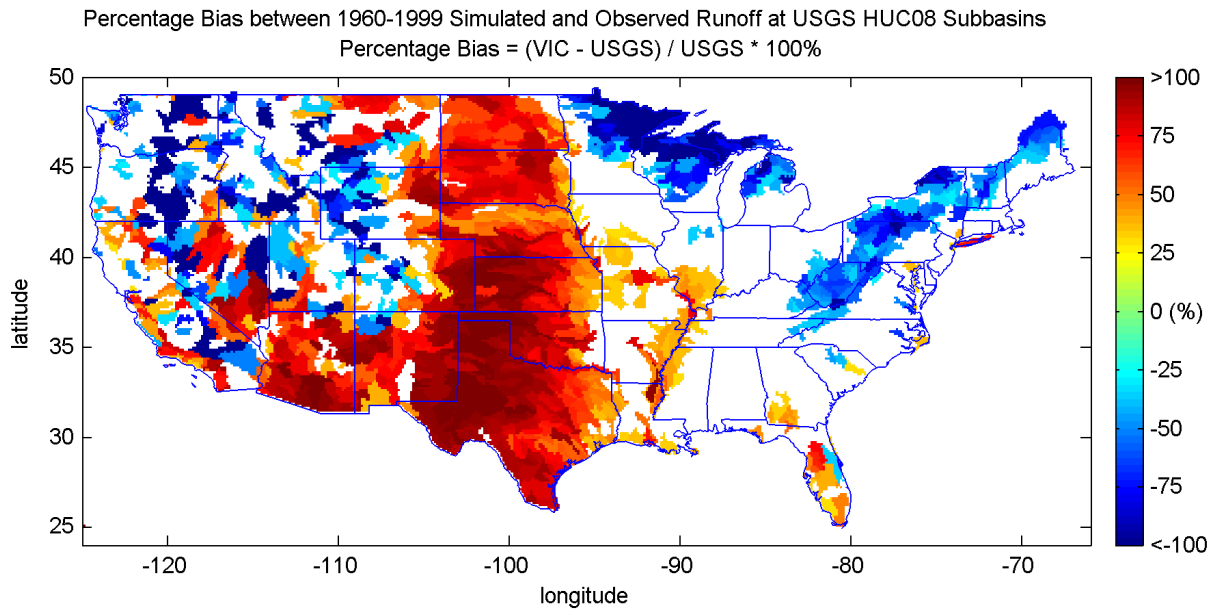
- How to better quantify the uncertainty of hydro-climate projections?
  - Future emission scenarios and climate models
  - Downscaling approaches
- How to upgrade from regional assessment to site-specific assessment?
  - Hydrologic modeling and resolution
  - Storage and seasonal variability
  - Connections among projects
  - Comprehensible modeling of multi-use water management.
- How to include the short-term extreme events into the assessment framework?

Challenge 1 – Regional Downscaling

- A hierarchical regional modeling framework for decadal-scale hydro-climatic predictions and impact assessments (PI: Moetasim Ashfaq, ORNL)
  - A computationally-intensive framework for multi-GCM/RCM/HM hydro-climate projection
  - Continental U.S. and South Asia
  - 18-km resolution
  - One reanalysis and three CMIP5 GCMs (expected in FY13)
  - Two regional models: WRF and RegCM4
  - Hindcast period 1975-2005; Projection period 2005-2035
  - Bias-correction to 4-km resolution (by Daymet) for hydrologic simulation

Challenge 2 – Hydrologic Modeling

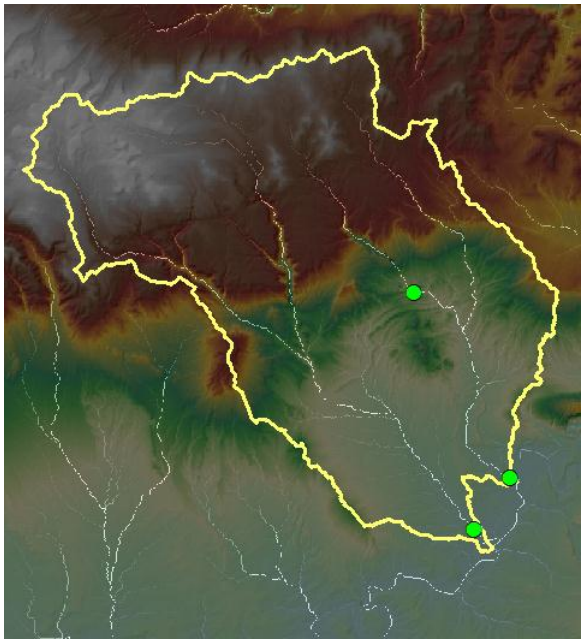




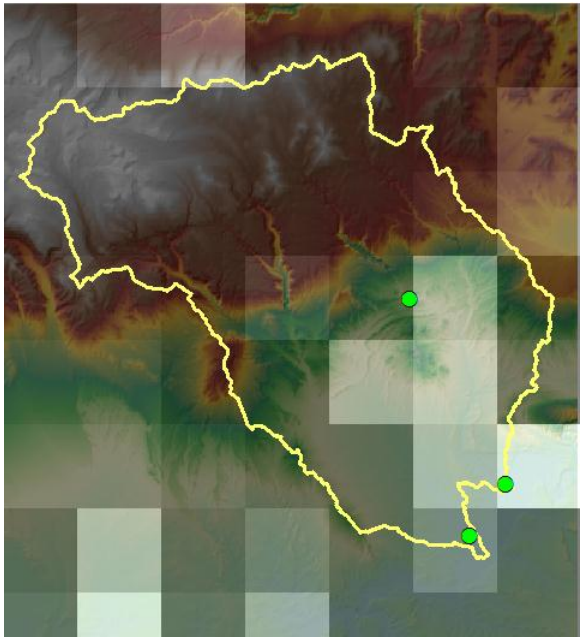
- **Seeking improvement from the current 12-km VIC simulation**
- **The USGS WaterWatch Runoff is used for model evaluation**
- **Both modeled and observed 1960-1999 mean annual runoff (mm/year) are computed at each USGS HUC8 Subbasins. Correlation coefficient is around 0.88**

Resolution Matters

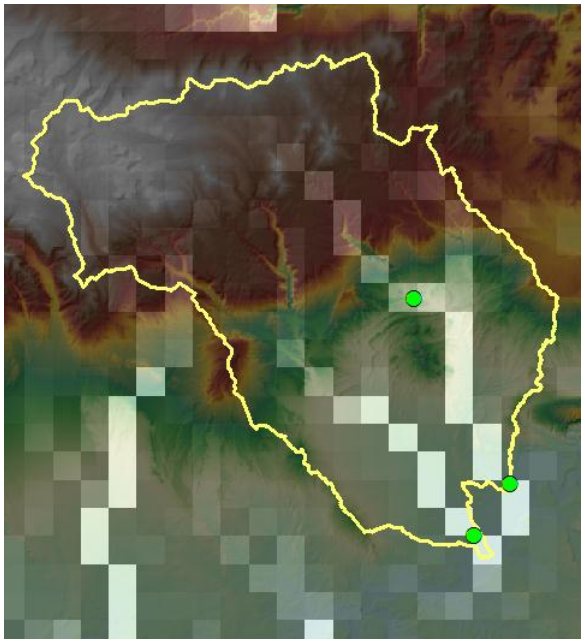
- Example: Ashley basin – upper Colorado
- River routing cannot be done under coarse resolution, neither for validation through USGS gage observation
- Need fine resolution to model local, short-duration extremes. Dynamical downscaling is also required.



100-m routing



12-km routing

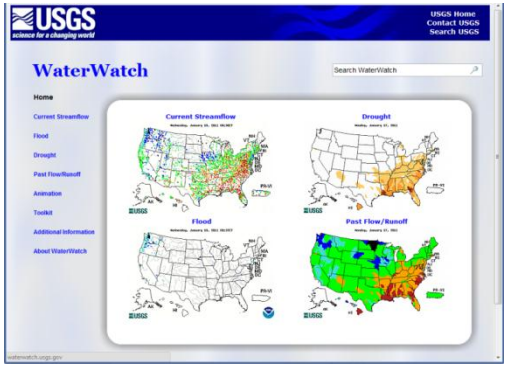


4-km routing

Framework for Multi-Hydrologic Models

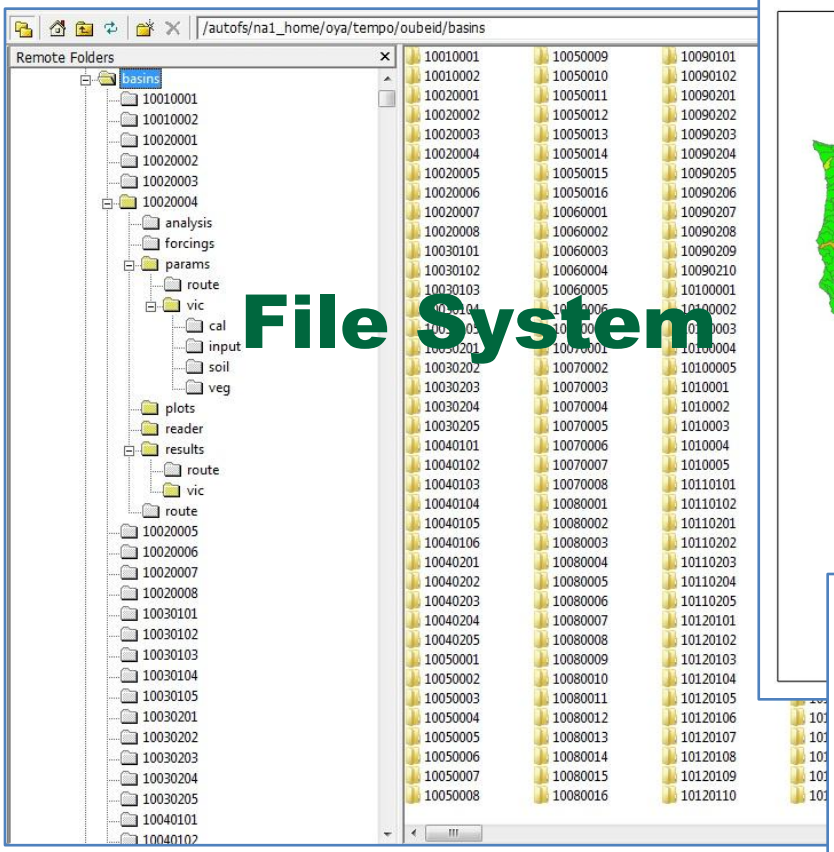
- 4-km VIC is selected as the starting point.
- Observed meteorological forcings

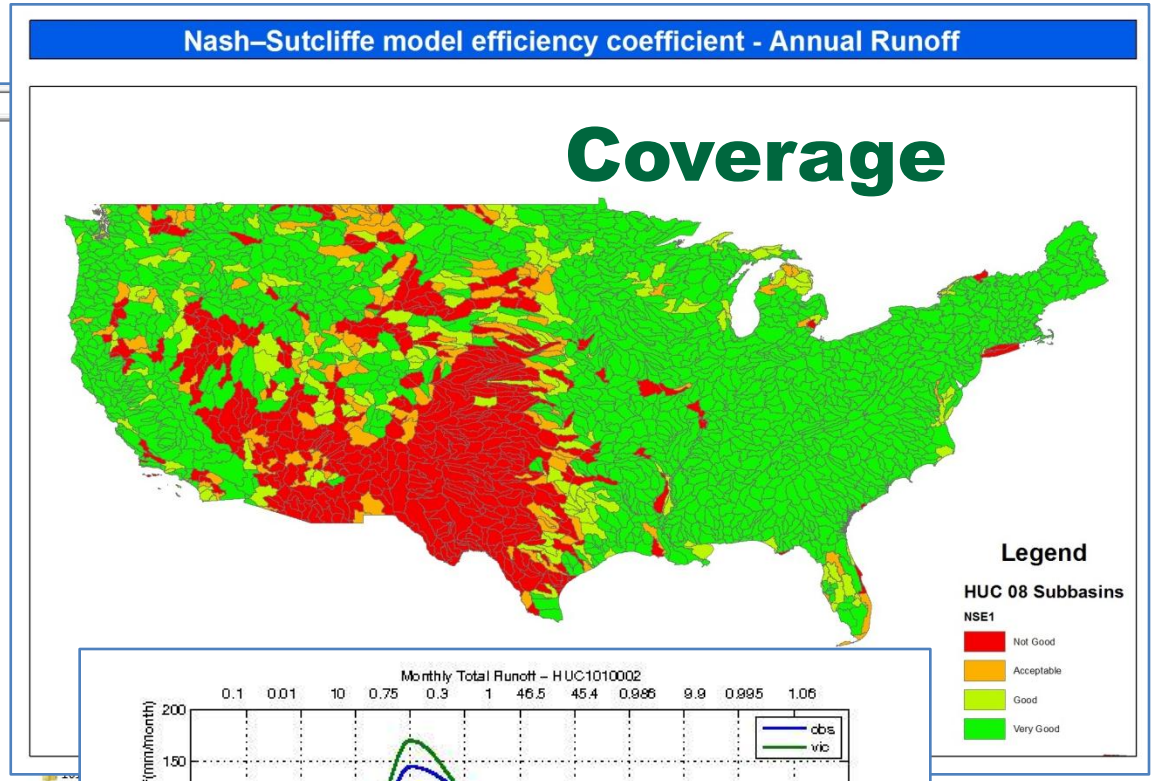
  - DAYMET: 1-km resolution, daily precipitation, maximum and minimum temperature
  - NARR: 36-km resolution, daily wind speed
  - 1980-2008, 1TB at rescaled 4-km resolution

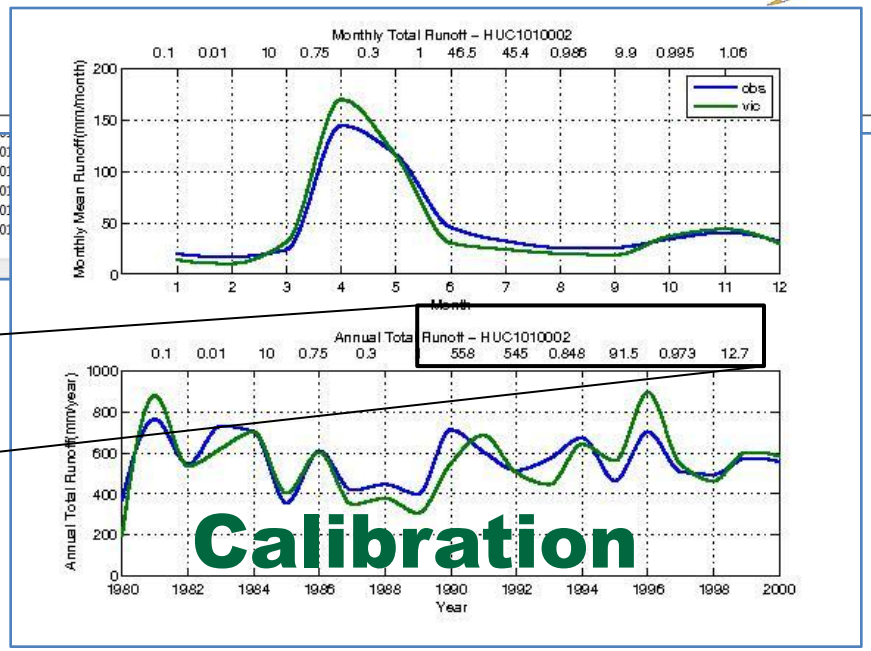


- Observed runoff
  - USGS WaterWatch HUC8 runoff, derived from the NWIS gage stations nation-wide (~22,000)
  - Same unit with precipitation
  - Monthly time-series, 1901-2009
- Calibrating runoff for all HUC8s (~2100 subbasins)

Computational Framework







Obs. Runoff

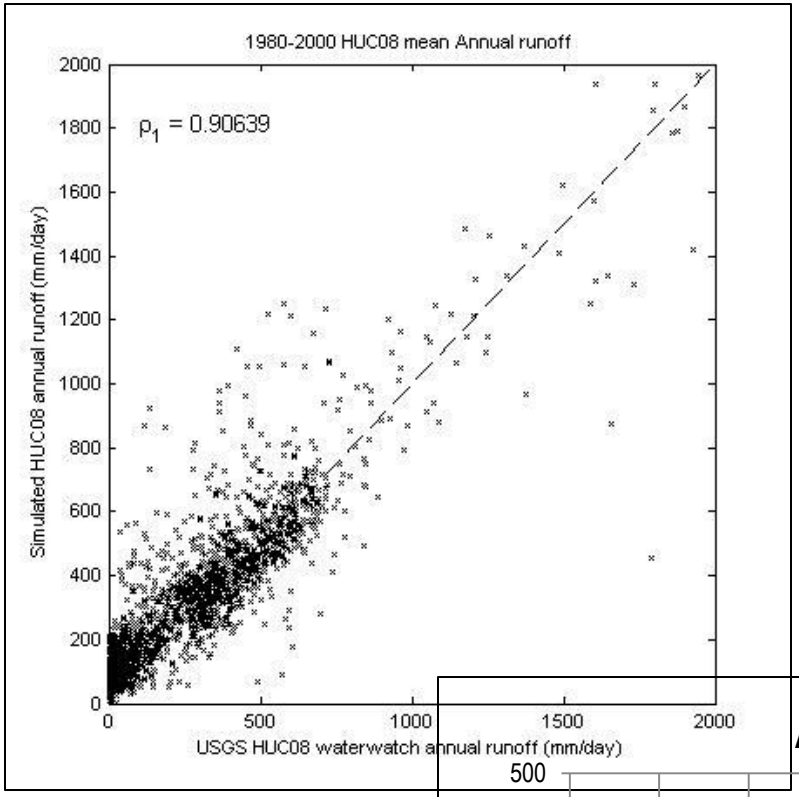
Runoff – HUC1010002

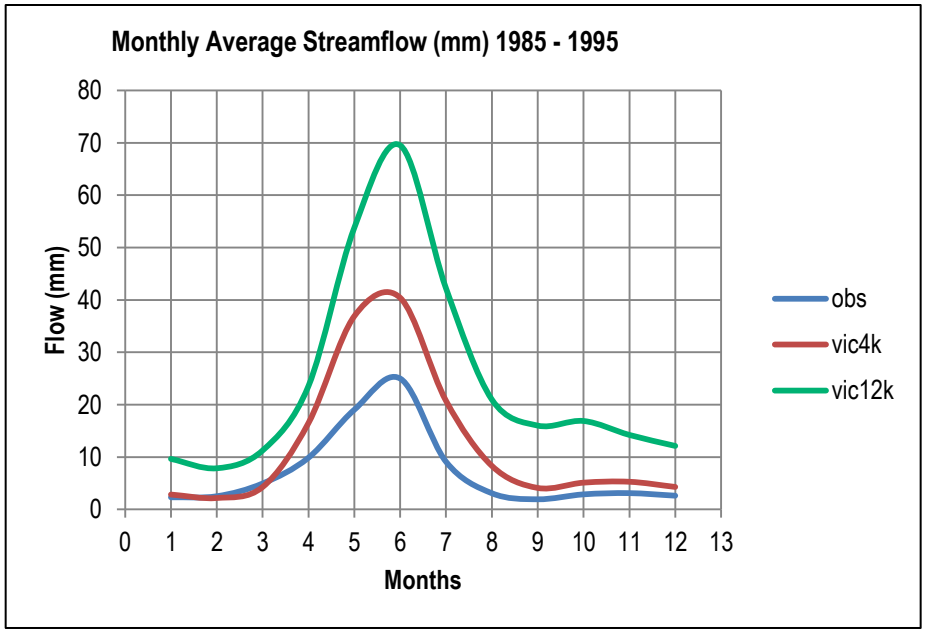
558 545 0.848 91.5 0.973 12.7

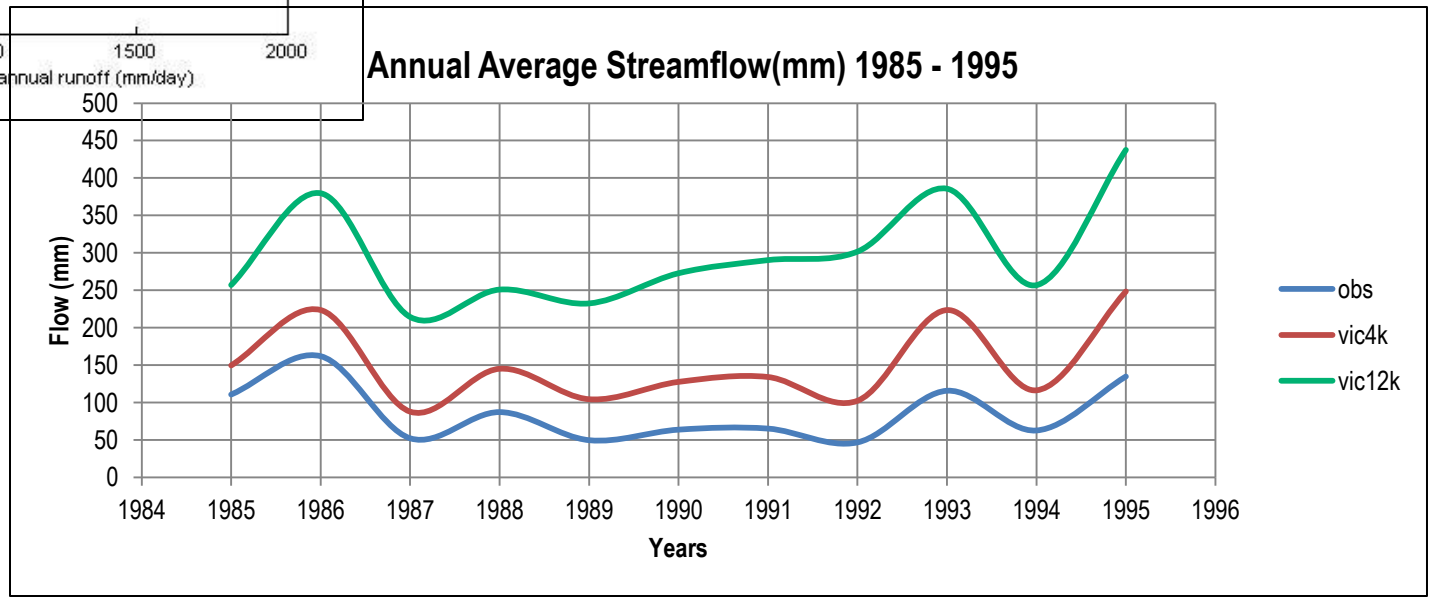
Mod. Runoff

Mod. Efficiency

Preliminary Results

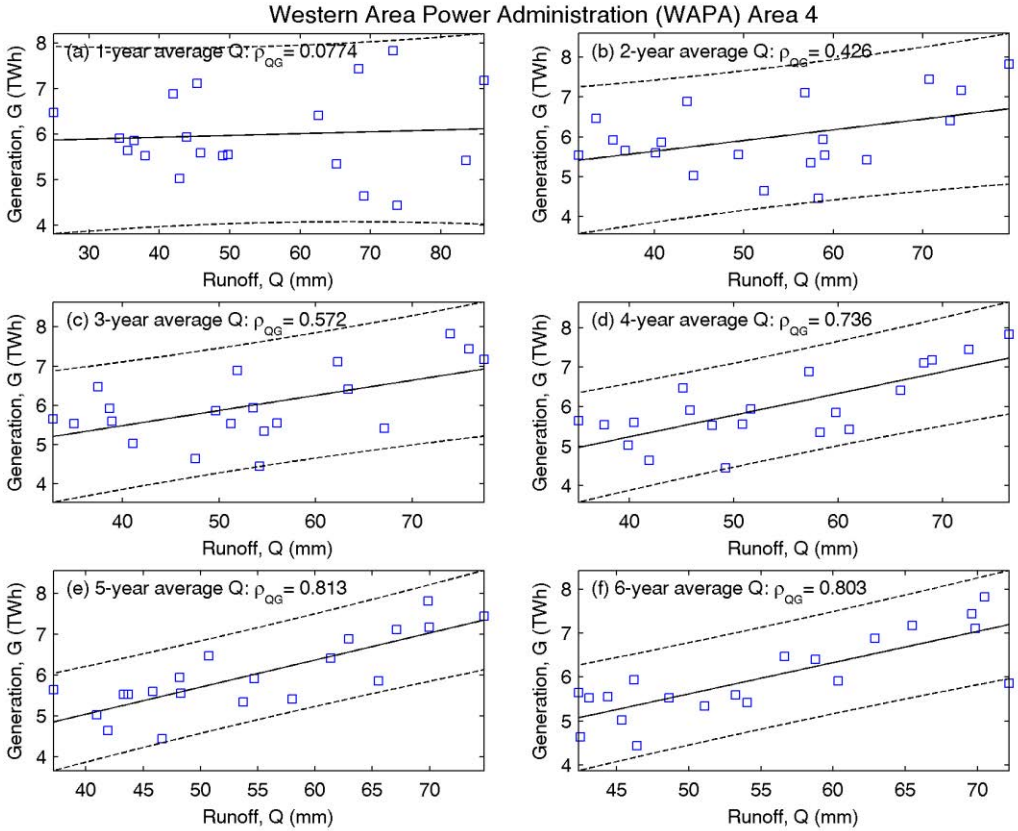






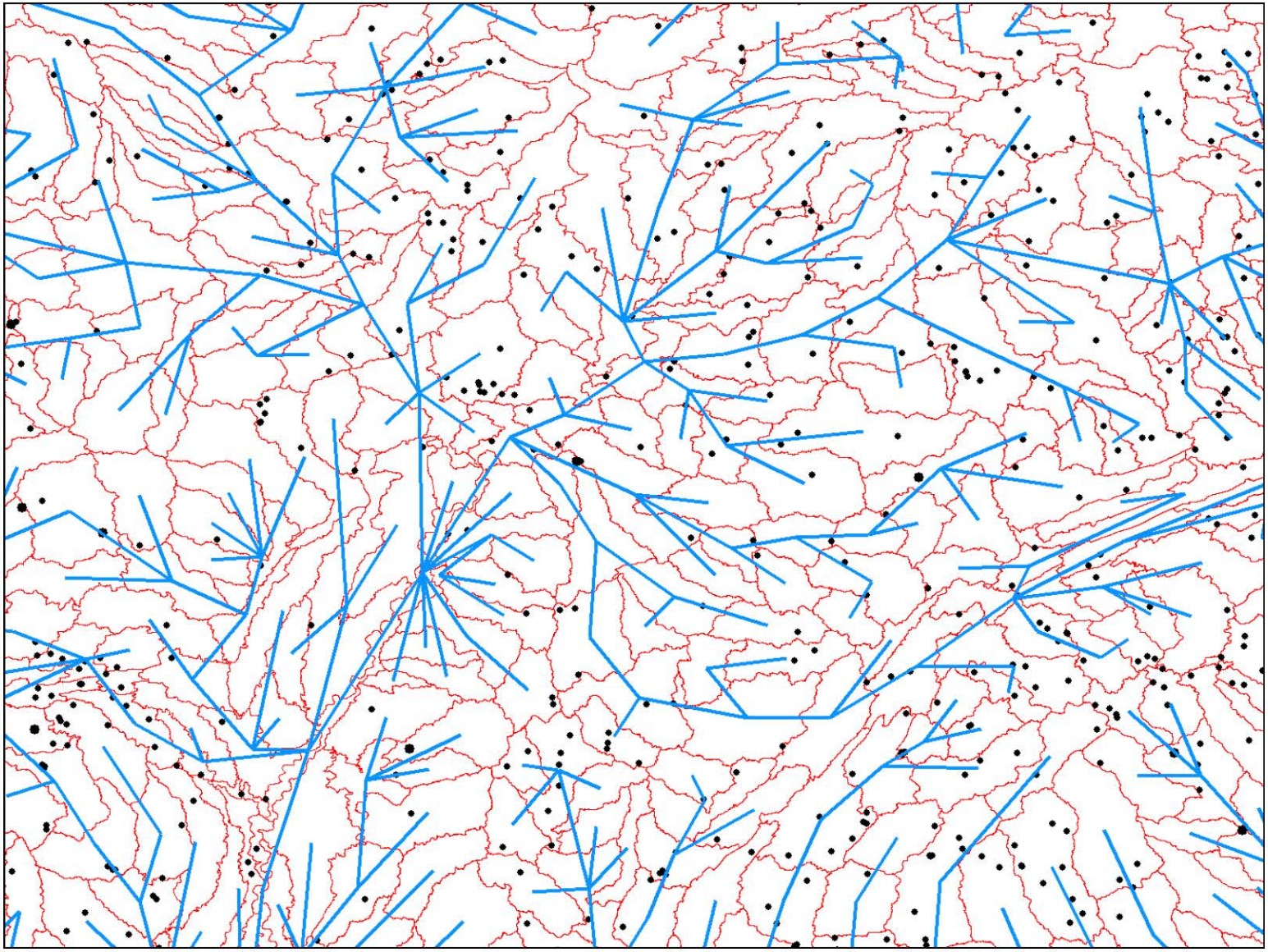
Challenge 3 – Storage

- **Example: The 5-year running average runoff is found better correlated to the annual generation, indicating the importance of storage**



- **Unless the reservoir operation is accounted, the hydrology downstream of existing dams can be wrong**

The Complexity Increases when Combining Reservoirs with River Networks



Summary / Conclusion

- A basic framework has been established to support the national / regional climate change impact assessment on hydropower generation.
- Continuing efforts required on:
  - Data collection, data management and analysis
  - Multi-model assessment and uncertainty quantification
  - Refining the modeling accuracy and resolution
  - Better modeling for water-power systems
    - Integrated water management at river basin level
    - River connectivity and cumulative impacts
  - Short-term and long-term extremes

Thank you
Questions?

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