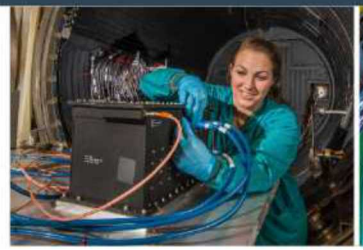
SAND2019-13819C

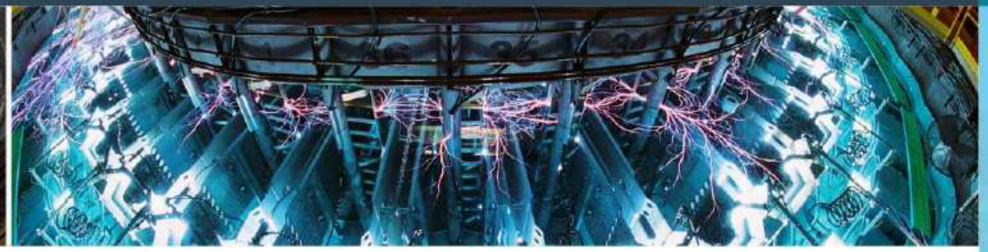
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Office of Science

Potential Climate Impacts on Connected Energy-Water Systems in the San Juan Basin





PRESENTED BY

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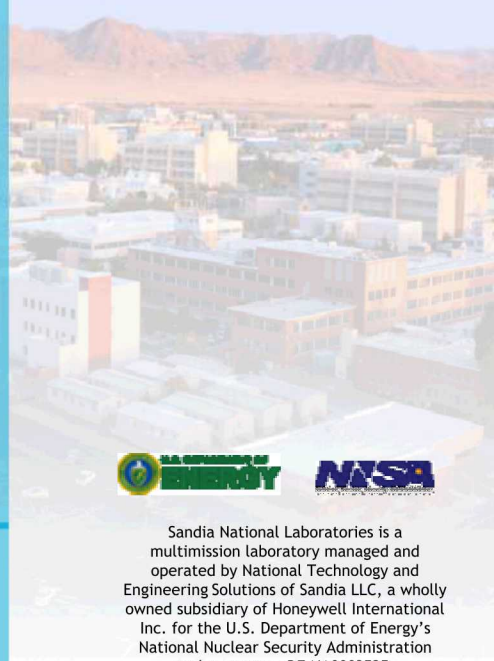
Dagmar Llewellyn, Susan Behery: US Bureau of Reclamation

Katrina Bennett, Richard Middleton: Los Alamos National Laboratory



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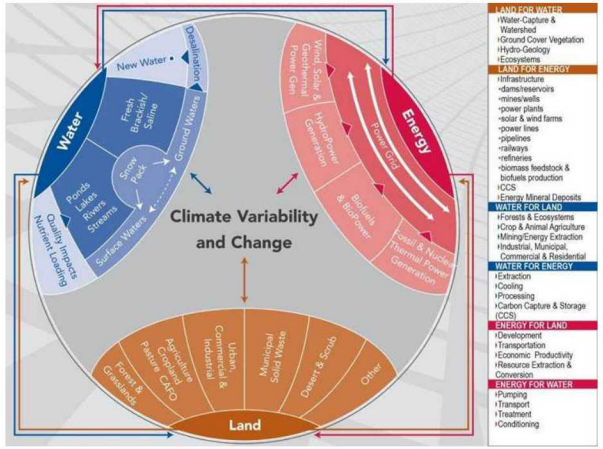
Energy and Water System Dynamics



MOODY'S
INVESTORS SERVICE

Announcement: Moody's: Climate change is forecast to heighten US exposure to economic loss placing short- and long-term credit pressure on US states and local governments

Global Credit Research - 28 Nov 2017

New York, November 28, 2017 -- The growing effects of climate change, including climbing global temperatures, and rising sea levels, are forecast to have an increasing economic impact on US state and local issuers. This will be a growing negative credit factor for issuers without sufficient adaptation and mitigation strategies, Moody's Investors Service says in a new report.

The report differentiates between climate trends, which are a longer-term shift in the climate over several decades, versus climate shock, defined as extreme weather events like natural disasters, floods, and droughts which are exacerbated by climate trends. Our credit analysis considers the effects of climate change when we believe a meaningful credit impact is highly likely to occur and not be mitigated by issuer actions, even if this is a number of years in the future.

Climate shocks or extreme weather events have sharp, immediate and observable impacts on an issuer's infrastructure, economy and revenue base, and environment. As such, we factor these impacts into our analysis of an issuer's economy, fiscal position and capital infrastructure, as well as management's ability to marshal resources and implement strategies to drive recovery.

Extreme weather patterns exacerbated by changing climate trends include higher rates of coastal storm damage, more frequent droughts, and severe heat waves. These events can also cause economic challenges like smaller crop yields, infrastructure damage, higher energy demands, and escalated recovery costs.

"While we anticipate states and municipalities will adopt mitigation strategies for these events, costs to employ them could also become an ongoing credit challenge," Michael Wertz, a Moody's Vice President says. "Our analysis of economic strength and diversity, access to liquidity and levers to raise additional revenue are also key to our assessment of climate risks as is evaluating asset management and governance."

One example of climate shock driving rating change was when Hurricane Katrina struck the City of New Orleans (A3 stable). In addition to widespread infrastructure damage, the city's revenue declined significantly and a large percentage of its population permanently left New Orleans.

"US issuer resilience to extreme climate events is enhanced by a variety of local, state and federal tools to improve immediate response and long-term recovery from climate shocks," Wertz says.

For issuers, the availability of state and federal resources is an important element that broadens the response capabilities of local governments and their ability to mitigate credit impacts. As well, all municipalities can benefit from the deployment of broader state and federal aid, particularly disaster aid from the Federal Emergency Management Agency (FEMA) to help with economic recovery.

Moody's analysts weigh the impact of climate risks with states and municipalities' preparedness and planning for these changes when we are analyzing credit ratings. Analysts for municipal issuers with higher exposure to climate risks will also focus on current and future mitigation steps and how these steps will impact the issuer's overall profile when assigning ratings.

The report "Environmental Risks -- Evaluating the impact of climate change on US state and local issuers," is available to Moody's subscribers at http://www.moodys.com/researchdocumentcontentpage.aspx?docid=PBM_1071949.

MOODY'S
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- Energy-Water systems are a particularly good example of a connected infrastructure system that is inherently complex, interdependent, and co-evolving requiring multi-sector, multi-scale analysis.
- These infrastructure systems are under unprecedented stress from growing demands, extreme weather and aging.
- Identifying vulnerabilities and cost effective adaptive measures is a first order science challenge.

2017 costliest weather year: $306B

CNN Jan. 8, 2018

Integrated Multi-Sector, Multi-Scale Modeling (IM3) *Asset Scale Modeling*

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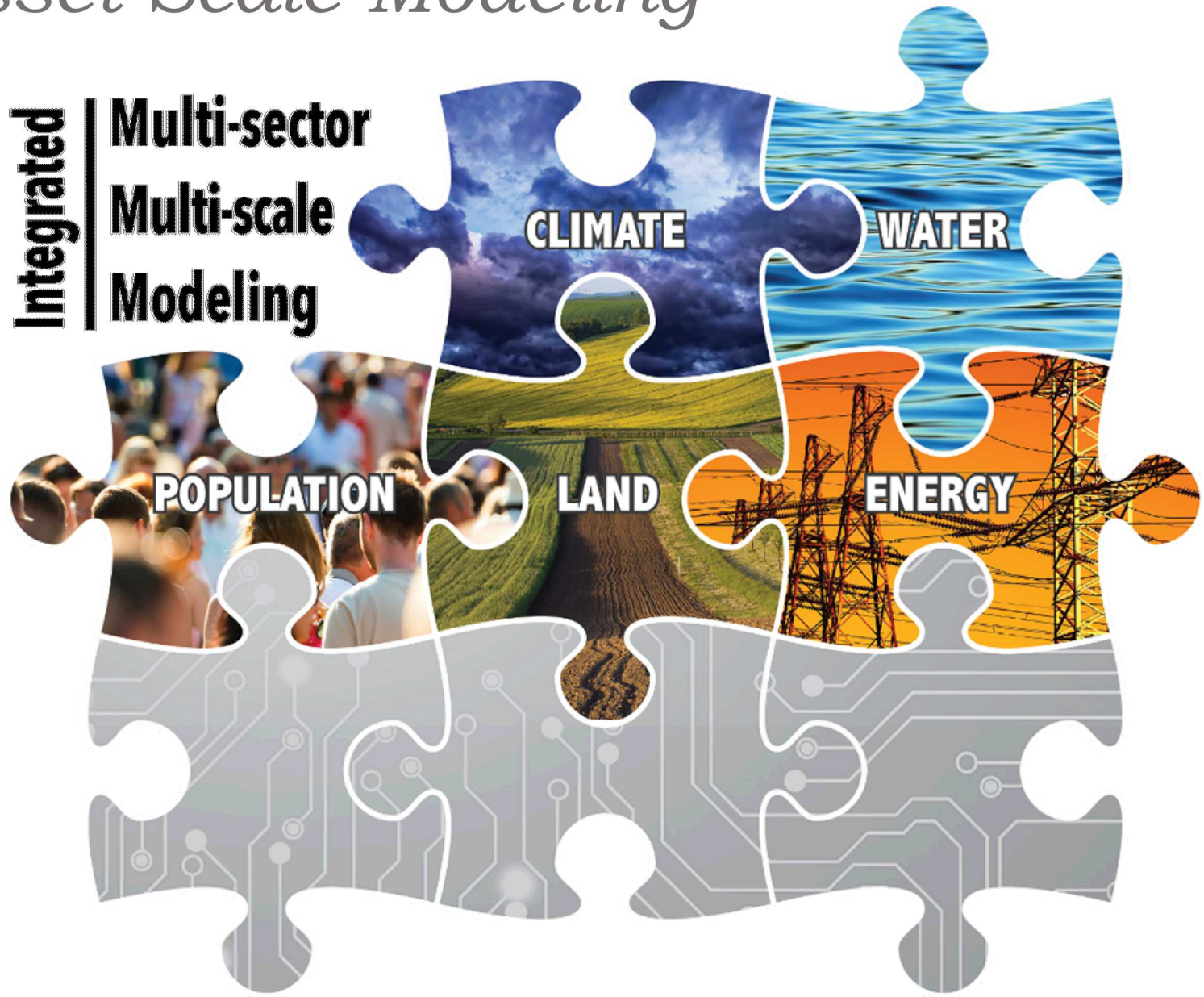
COLORADOSCHOOLOFMINES EARTH ENERGY ENVIRONMENT

UMASS AMHERST

LEHIGH UNIVERSITY

MONTANA STATE UNIVERSITY

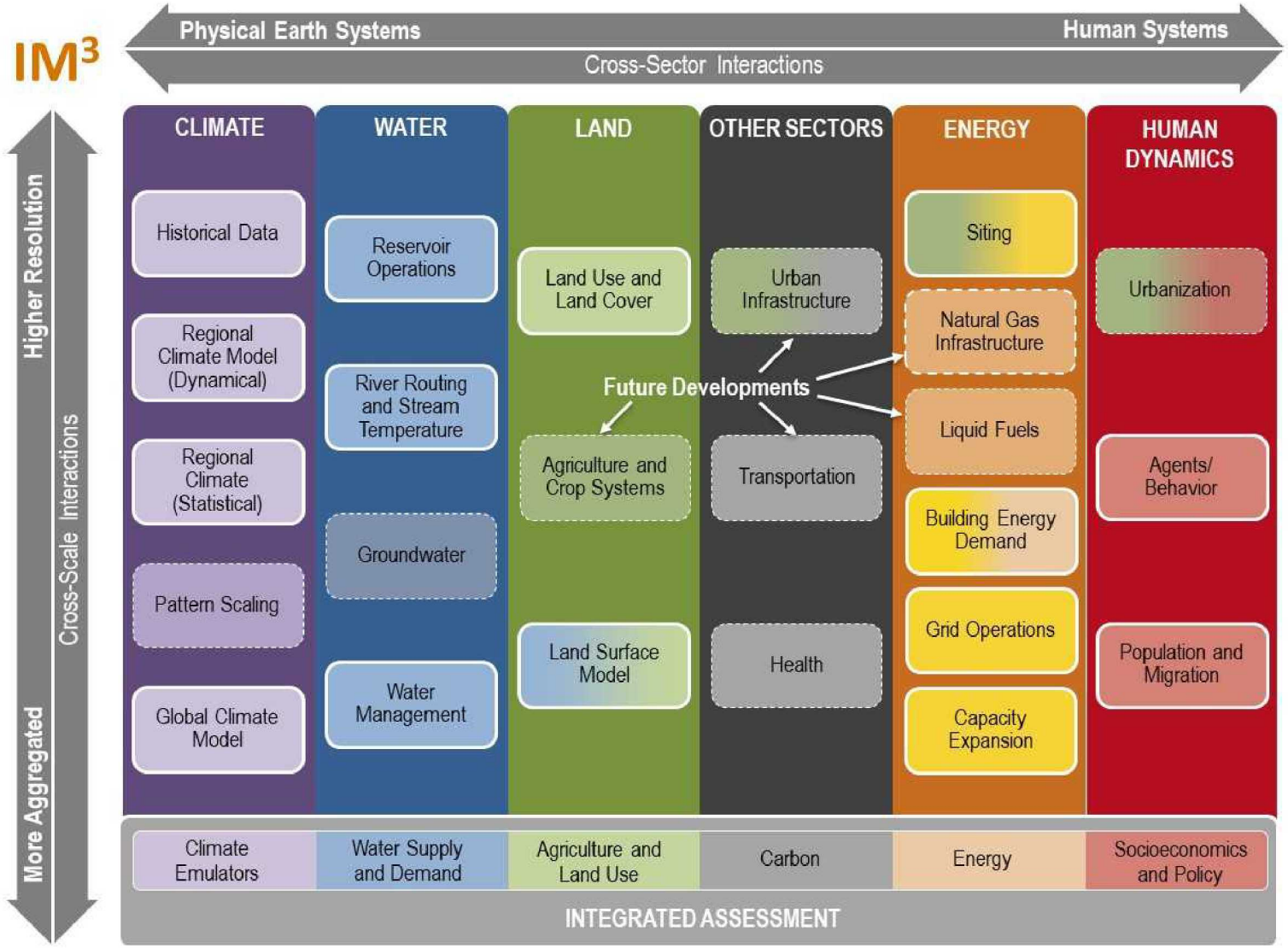


IM3 Vision

- Develop a ***flexible and integrated modeling framework*** that captures the dynamic multi-scale interactions among energy, water, land, weather/climate, socioeconomics, infrastructure, and other sectors
- Use this framework to ***study the vulnerability and resilience of coupled human and natural systems*** from local to continental scales under scenarios that include short-term shocks, long-term stresses, and feedbacks associated with human decision-making
- Explore how different ***model configurations, levels of complexity, multi-model coupling strategies, and spatiotemporal resolutions*** influence simulation fidelity and the propagation of uncertainties across a range of sectors, scales, and scenarios

Integrating Experiment

- Coupling multiple sectors, with emphasis on:
  - Energy Sector,
  - Water Sector,
  - Linkages to land and population.
- Also coupling models across scales:
  - Global,
  - Regional,
  - Watershed or asset.

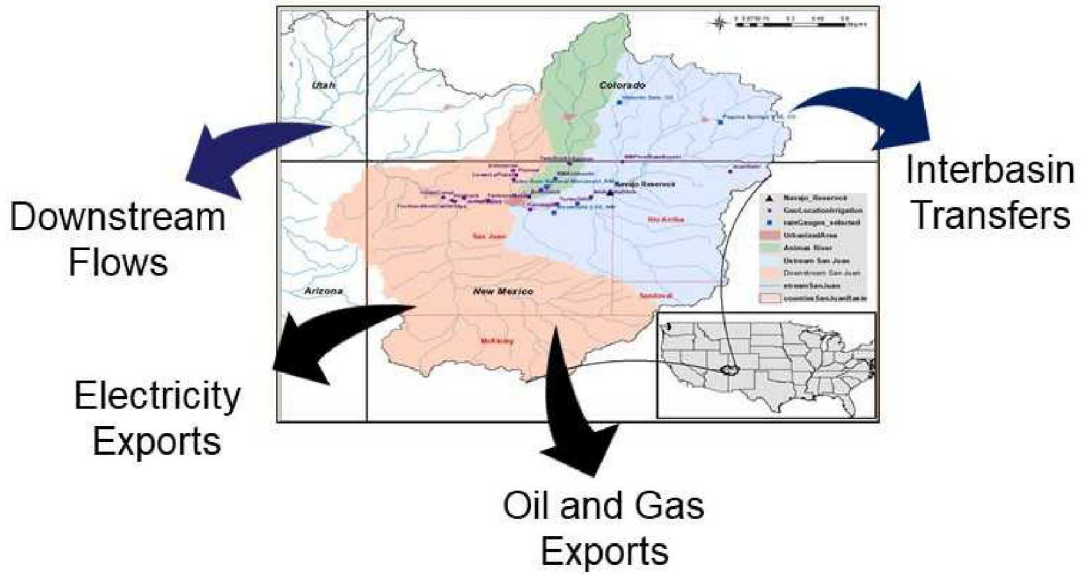


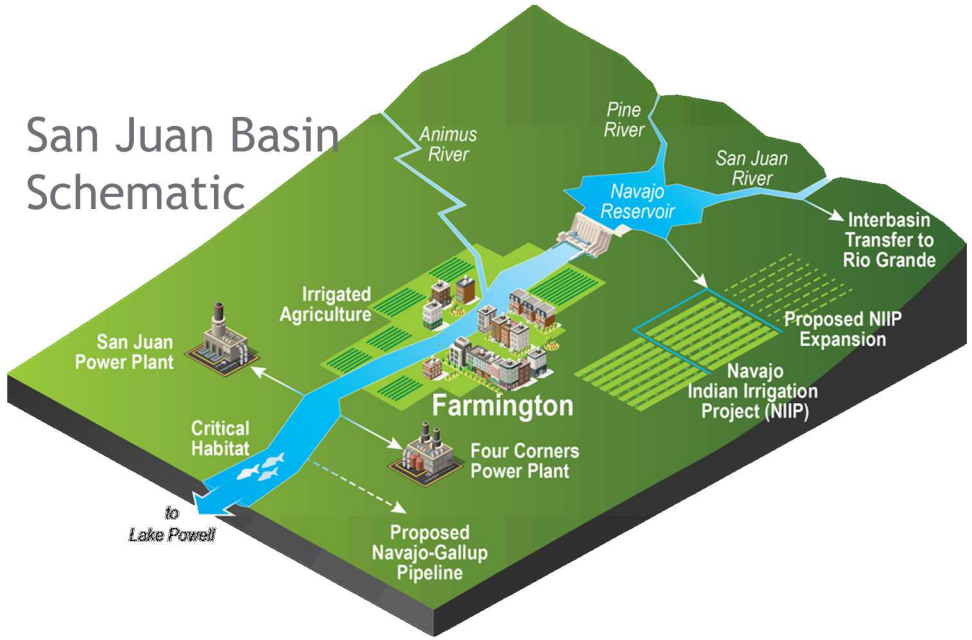
Study Site

Provisioning Watershed

- San Juan is example of resource provisioning watershed exporting much of the water, energy and other goods produced.
- Potential for cascading impacts "downstream".
- Growth in water use is not driven by new development by full utilization of committed water rights.

San Juan River Basin

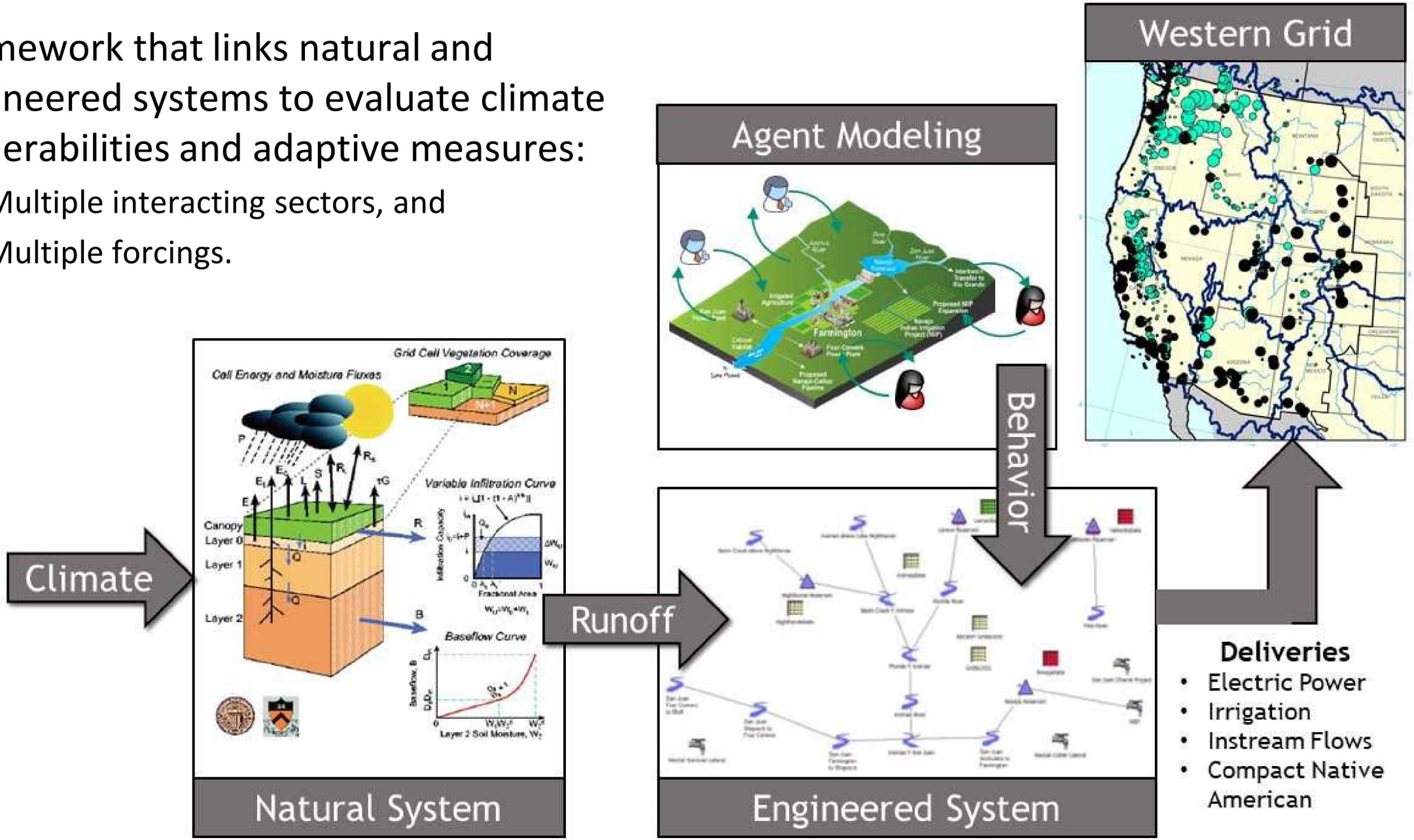




- San Juan River in Four Corners Region of Southwestern United States.
- Runoff originates in San Juan Mountains (83%). Largely snow melt dominated system.
- Primary management feature is Navajo Reservoir.
- Major water users include:
  - Native American
  - Irrigation,
  - Multiple power plants and limited hydropower,
  - Municipalities,
  - Interbasin transfers

Multi-Model Platform

- Framework that links natural and engineered systems to evaluate climate vulnerabilities and adaptive measures:
  - Multiple interacting sectors, and
  - Multiple forcings.



Scenario Analysis

- Planned experiments provide a unique opportunity to understand how interdependent multi-sector, multi-scale systems respond to changes in drought.
- How response differs among impact metrics

Non-Local

Colorado River

Rio Grande

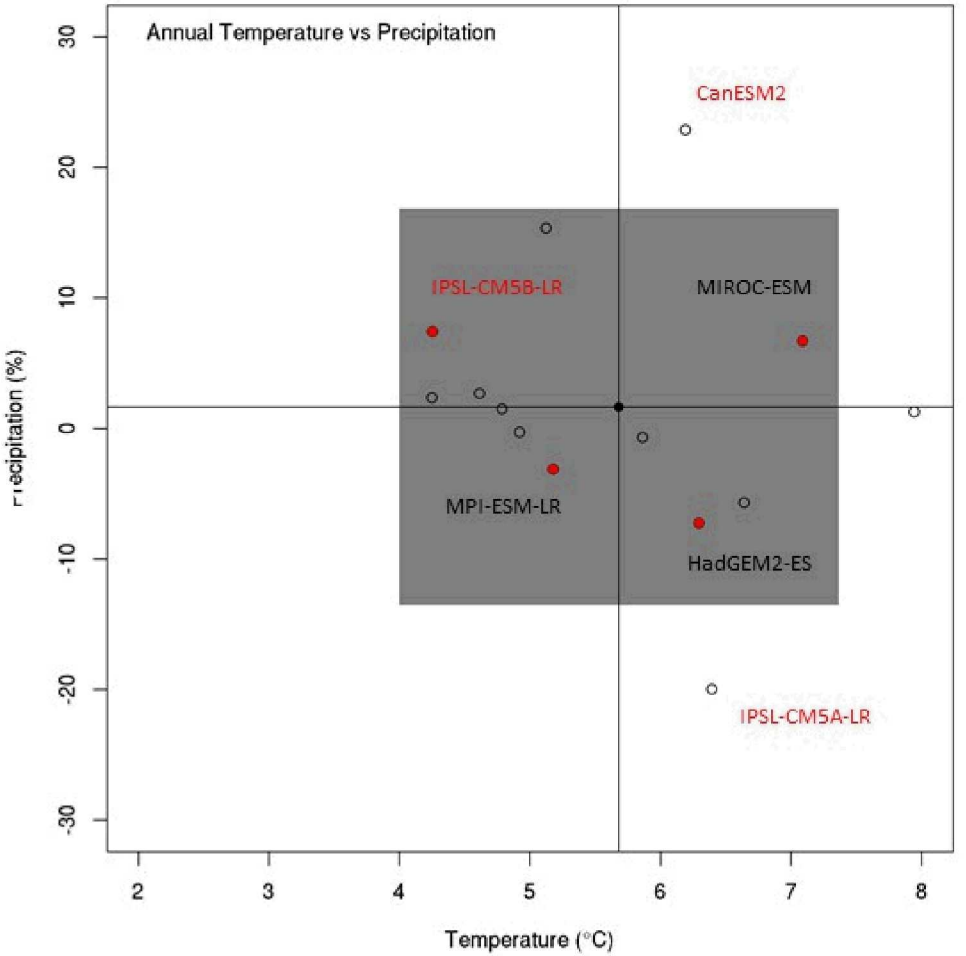
Local

Storage

Instream Flows

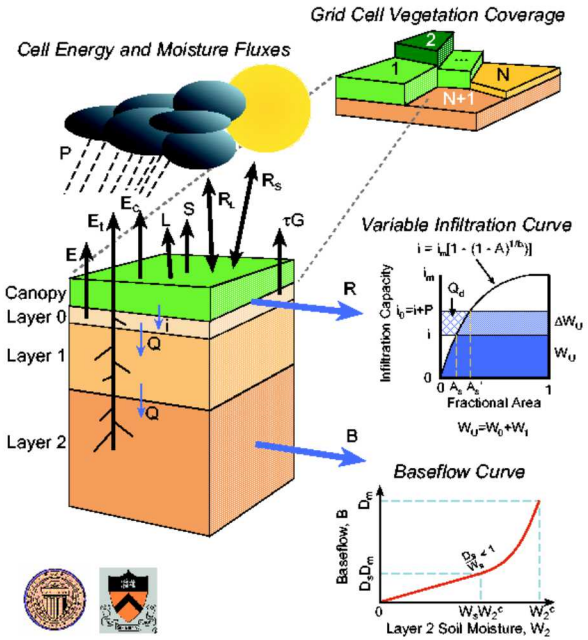
Water Deliveries

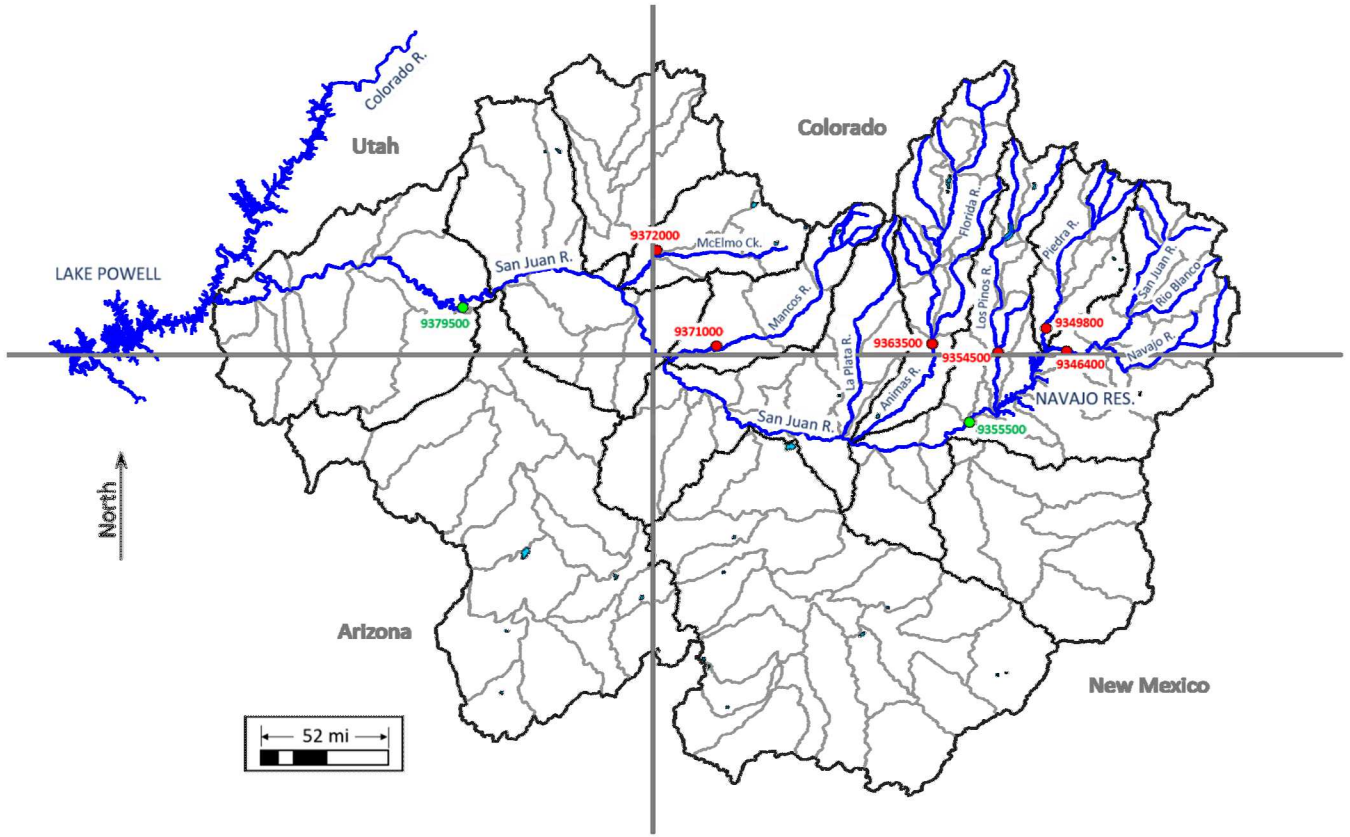
Six Climate Models (RCP 8.5)



Hydrology

- Variable Infiltration Capacity (VIC) model at 1/16th degree
- New MODIS data, including time series for each grid cell for albedo, vegetation spacing and LAI

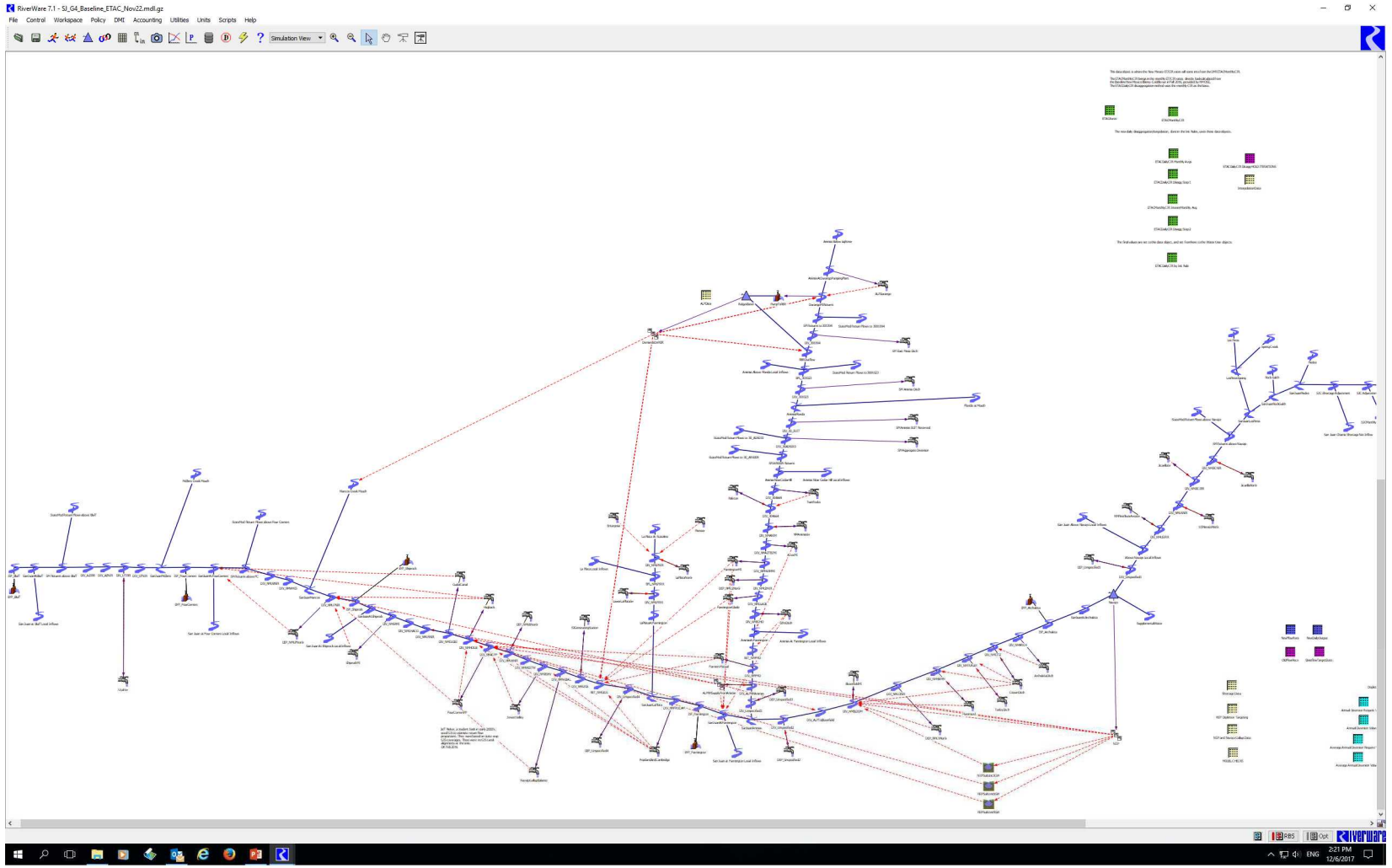




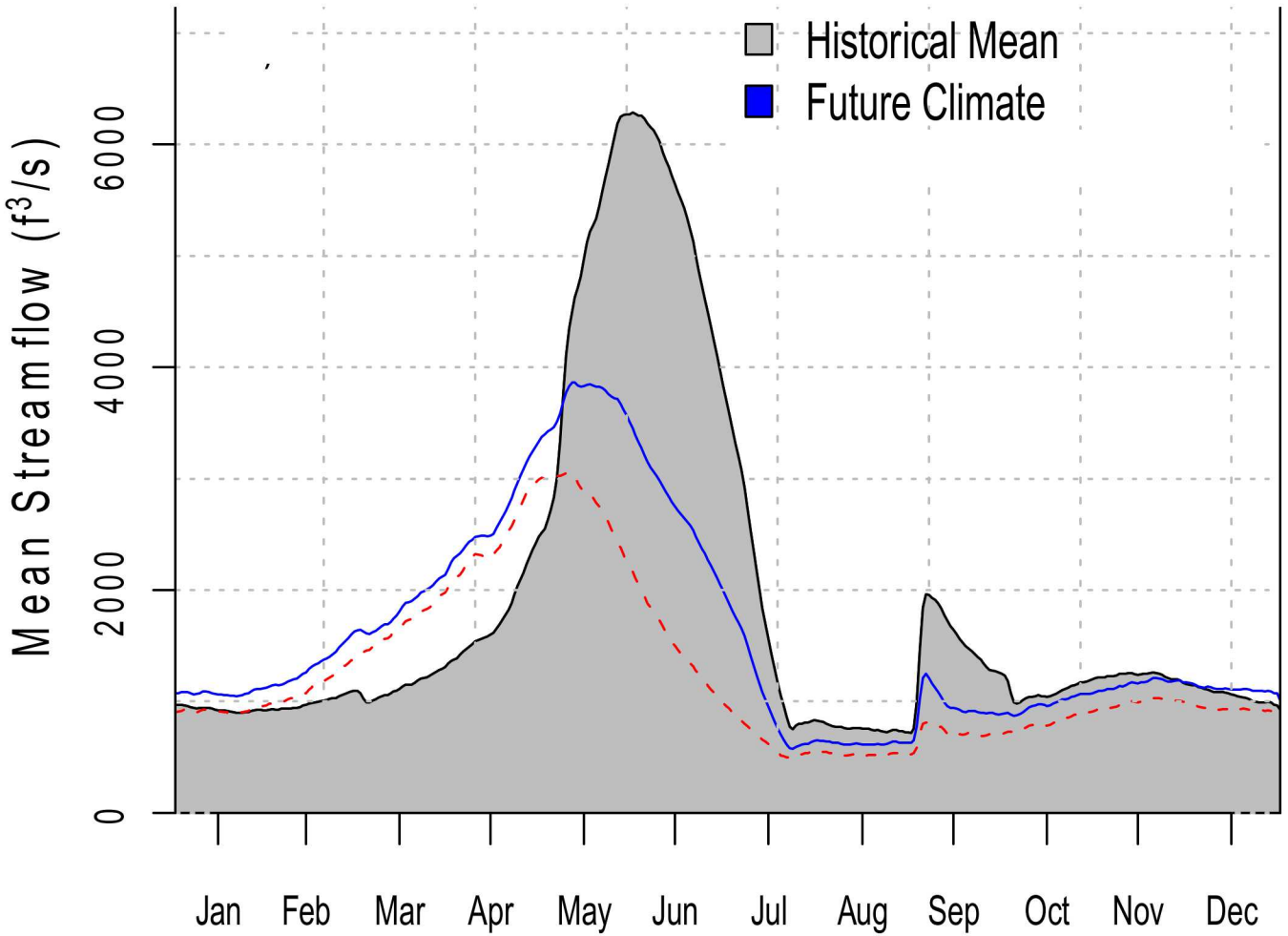
- Downscaling using Mutivariate Adaptive Constructive Analogues (MACA) data set (Abatzaglou and Brown, 2011)

River-Reservoir Routing

- San Juan Baseline Model constructed in RiverWare
- Colorado reservoirs and priority administration modeled with StateMod
- Three reservoirs
- 87 River reaches
- 30 Water users



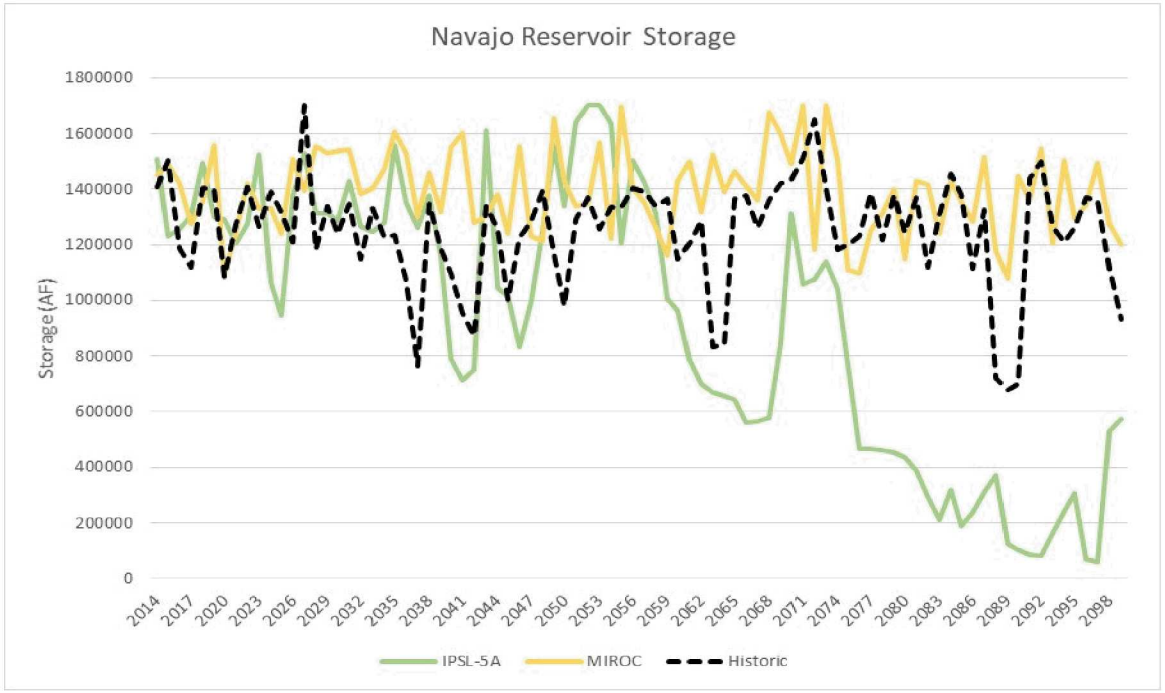
Climate Impact on Streamflow

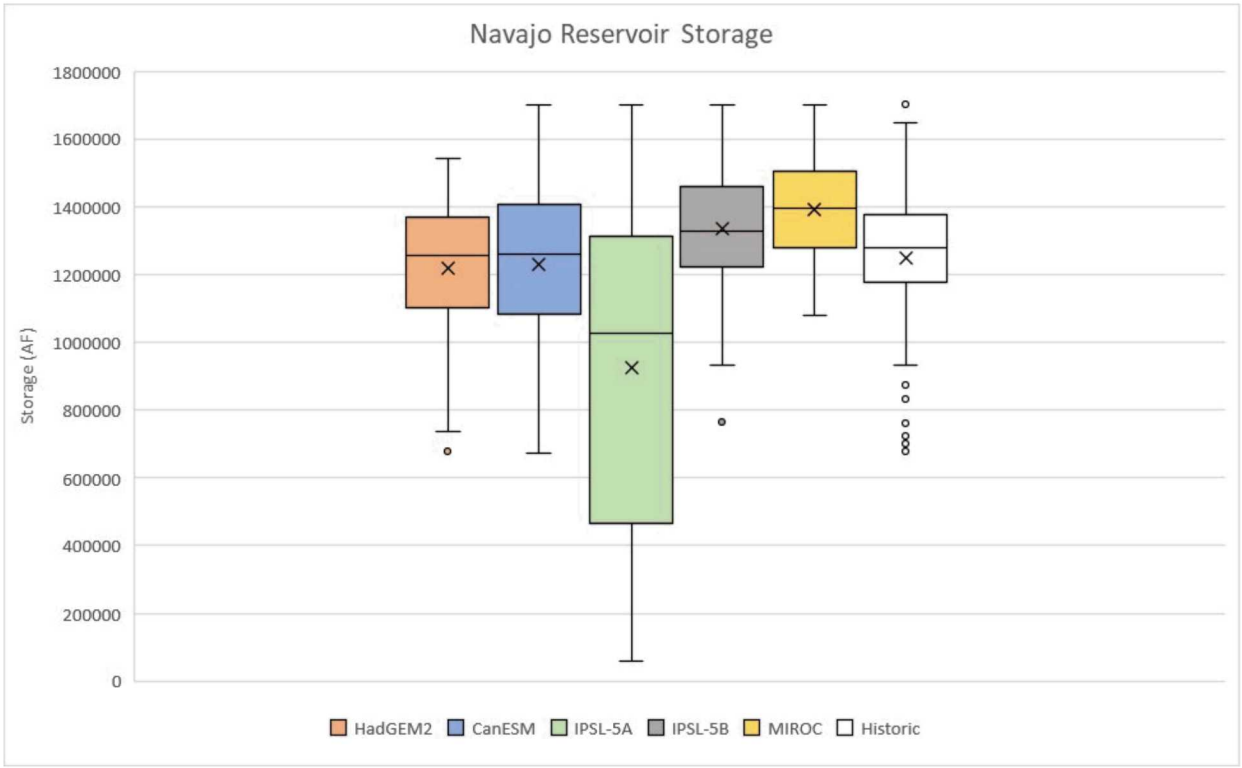


Bennett, K.E., Tidwell, V.C., Llewellyn, D., Behery, S., Barrett, L., Stansbury, M. and Middleton, R.S., Threats to a Colorado River provisioning basin under climate and societal scenarios, Environ. Res. Commun. (1), DOI: 10.1088/2515-7620/ab4028.

Navajo Reservoir Storage

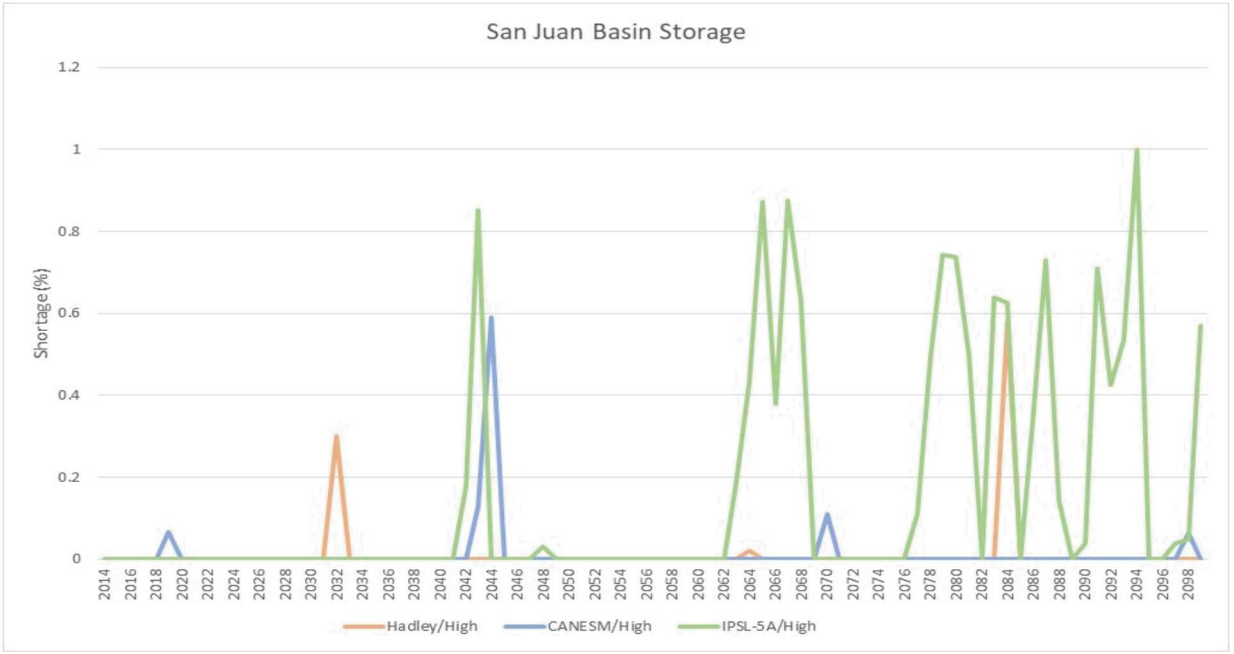
- Limited impact for all but one climate model (25% decrease).
- Slight increase in annual variability.
- Some models result in increased Navajo storage (6-9%).
- One case challenges current water management regime.

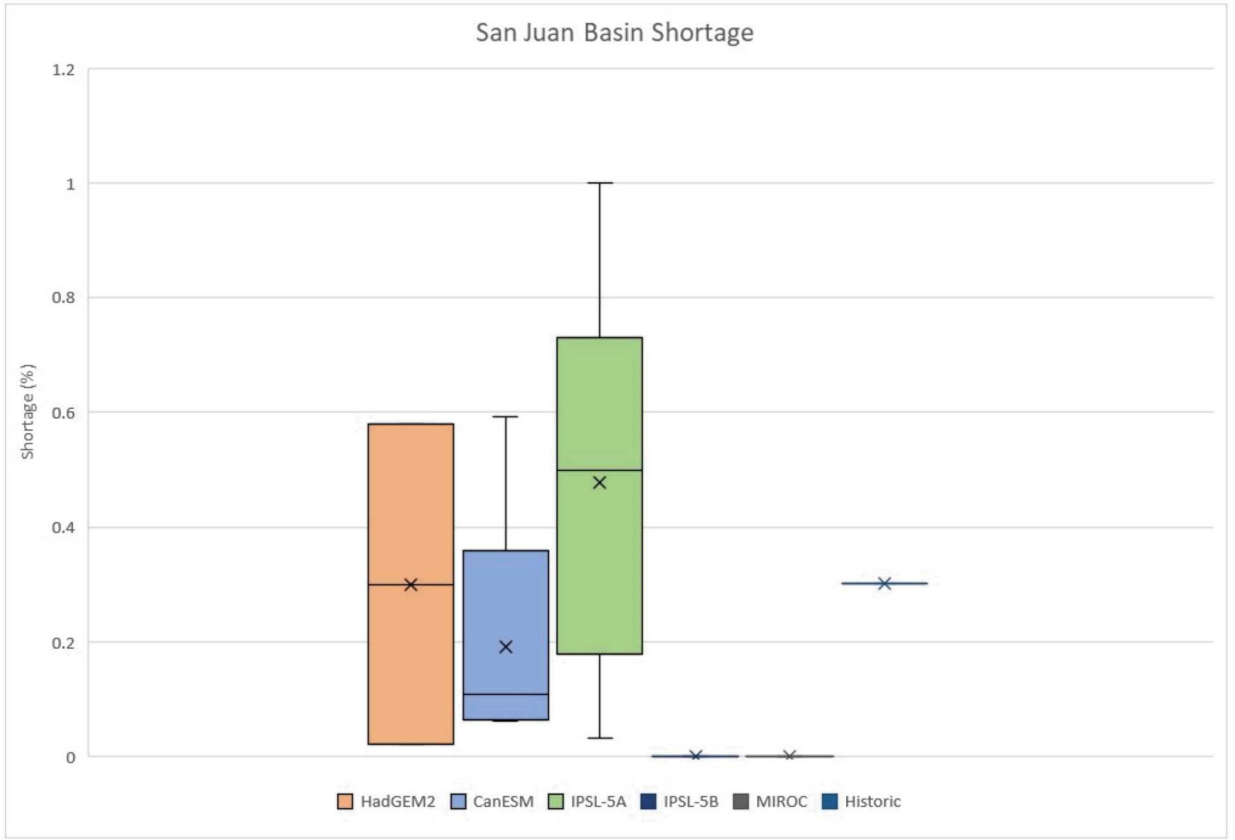




San Juan Basin Shortage

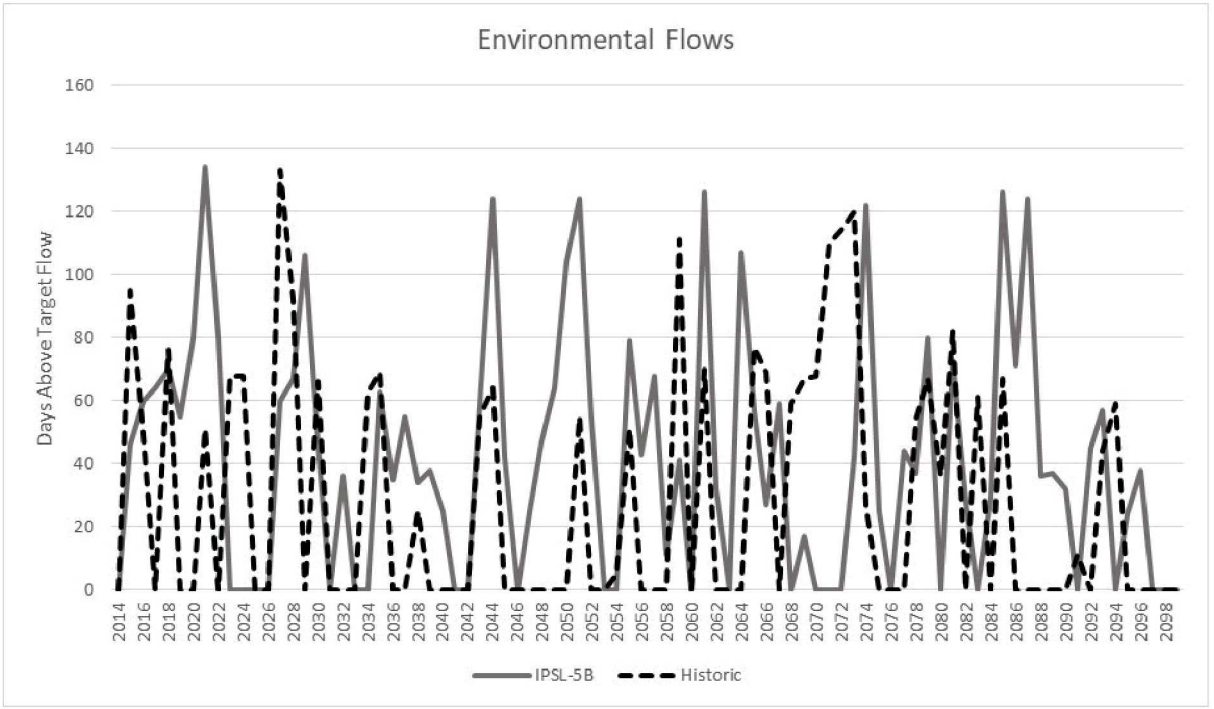
- Based on basin Shortage Sharing Agreement.
- One shortage projected under historic climate with full water rights utilization.
- Only one climate model projects a significant occurrence of shortage.
- Two climate models project no future shortages.

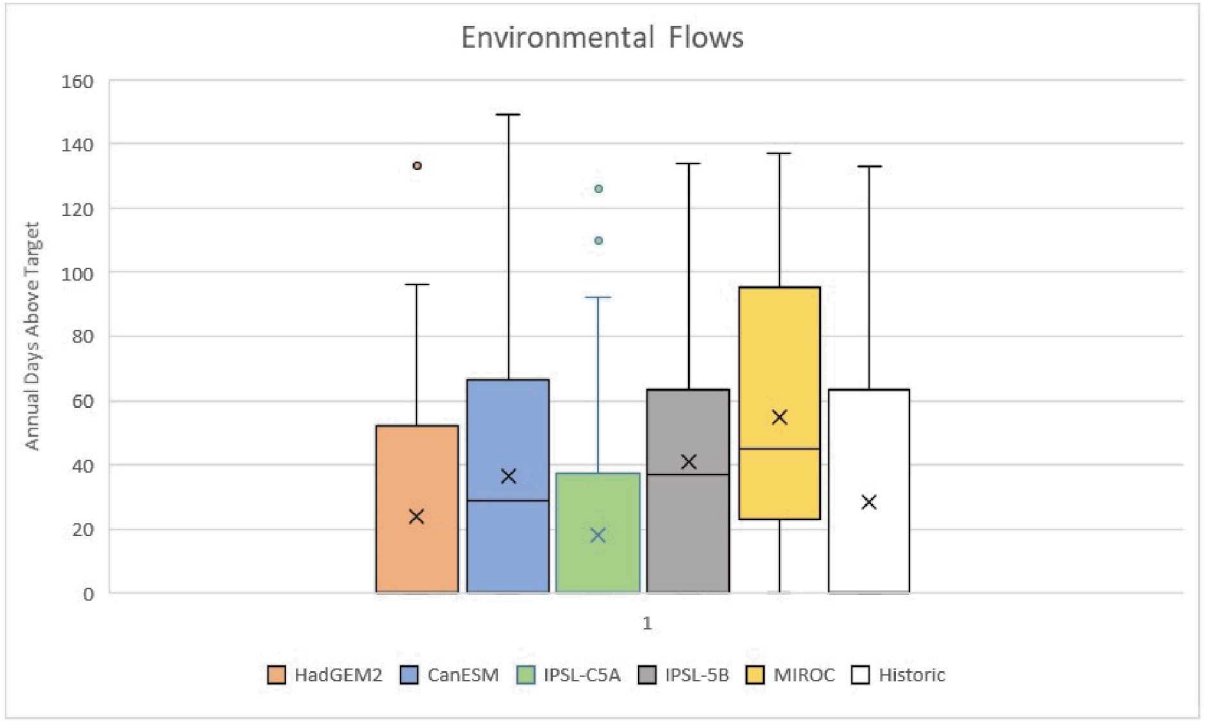




Environmental Flows

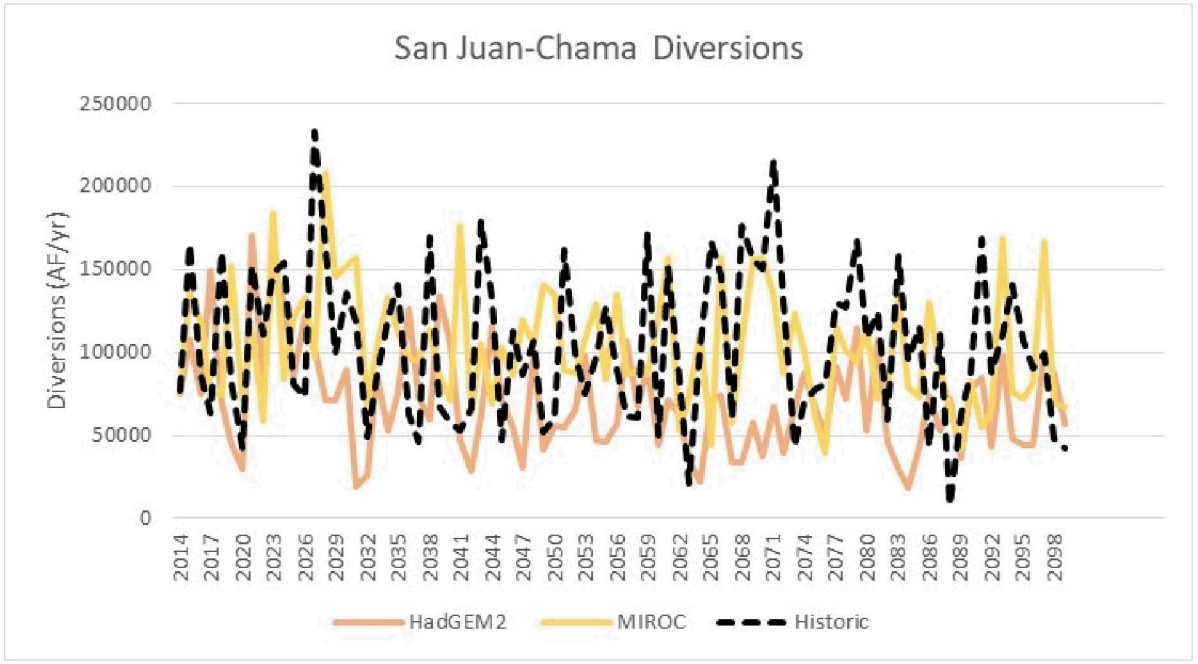
- Measured at the Four Corners Gauge
  - Days above 5000cfs
  - March-July
  - Target is 21 days per year.
- One model results in increased violations.
- Three climate models result in more years meeting target flows.

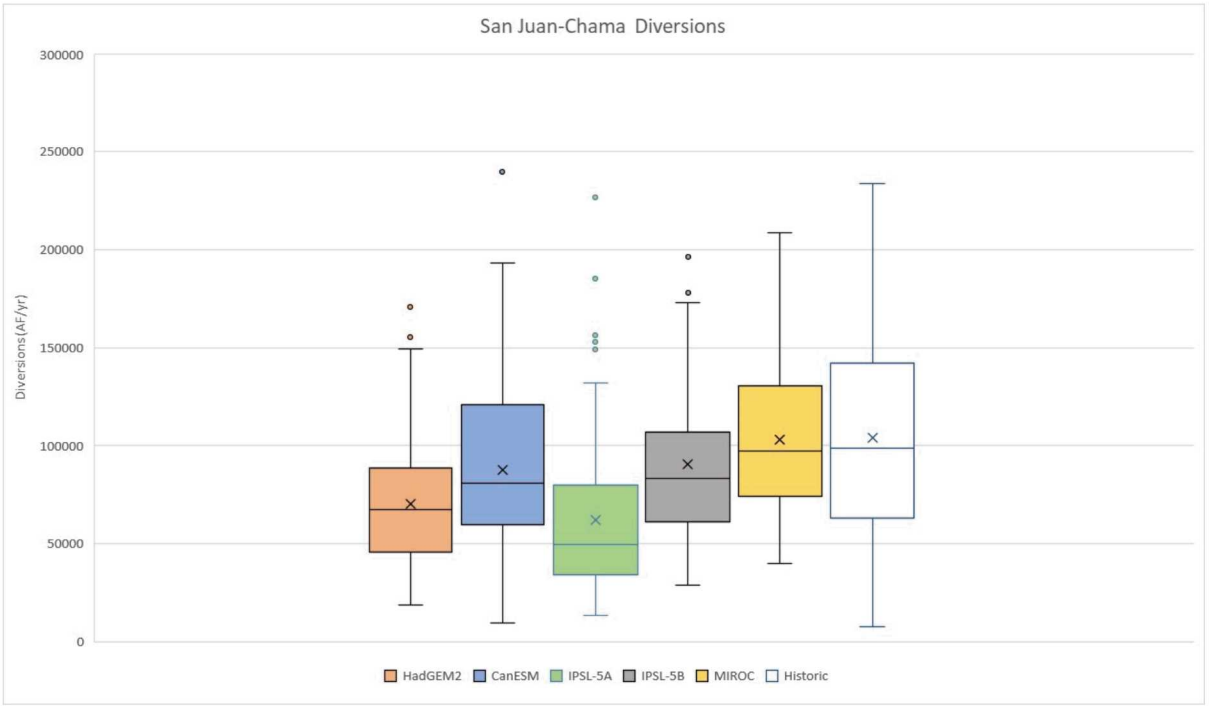




San Juan-Chama Deliveries

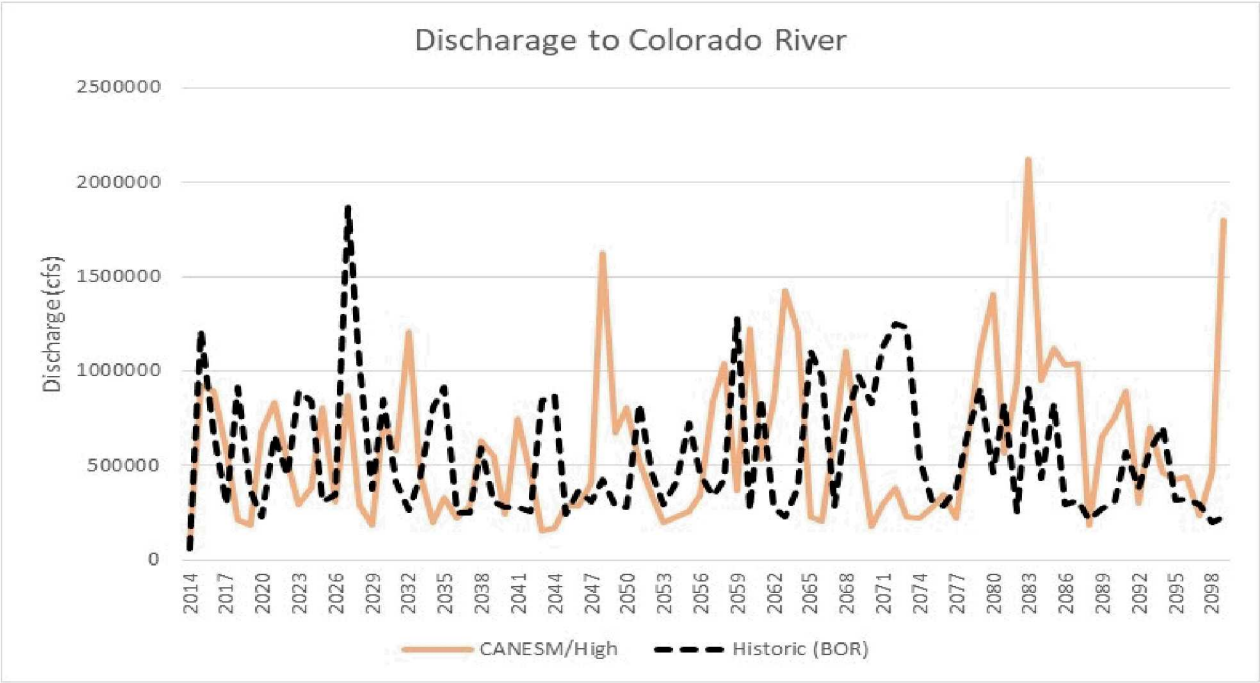
- All climate models result in reduced diversions to the San Juan-Chama Project (1-40%).
- Year-to-year variability in diversions is reduced.
- Additional analysis is required to determine potential shortages to downstream contractors.

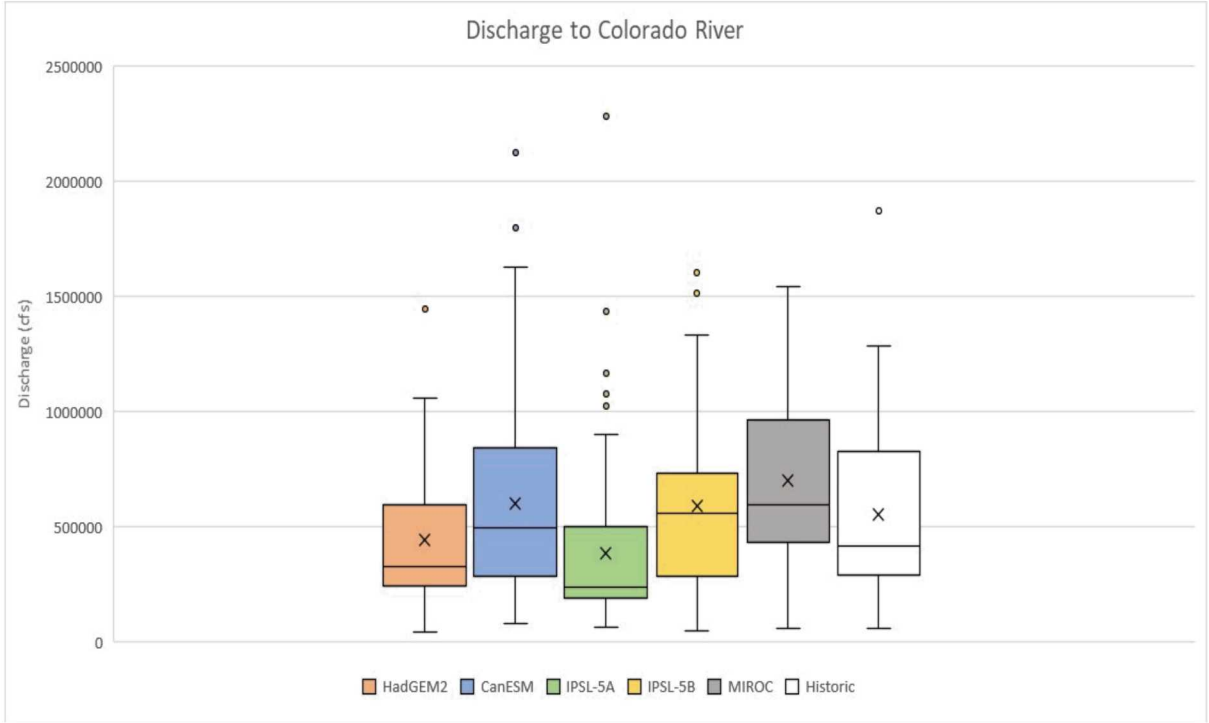




Discharge to Colorado River

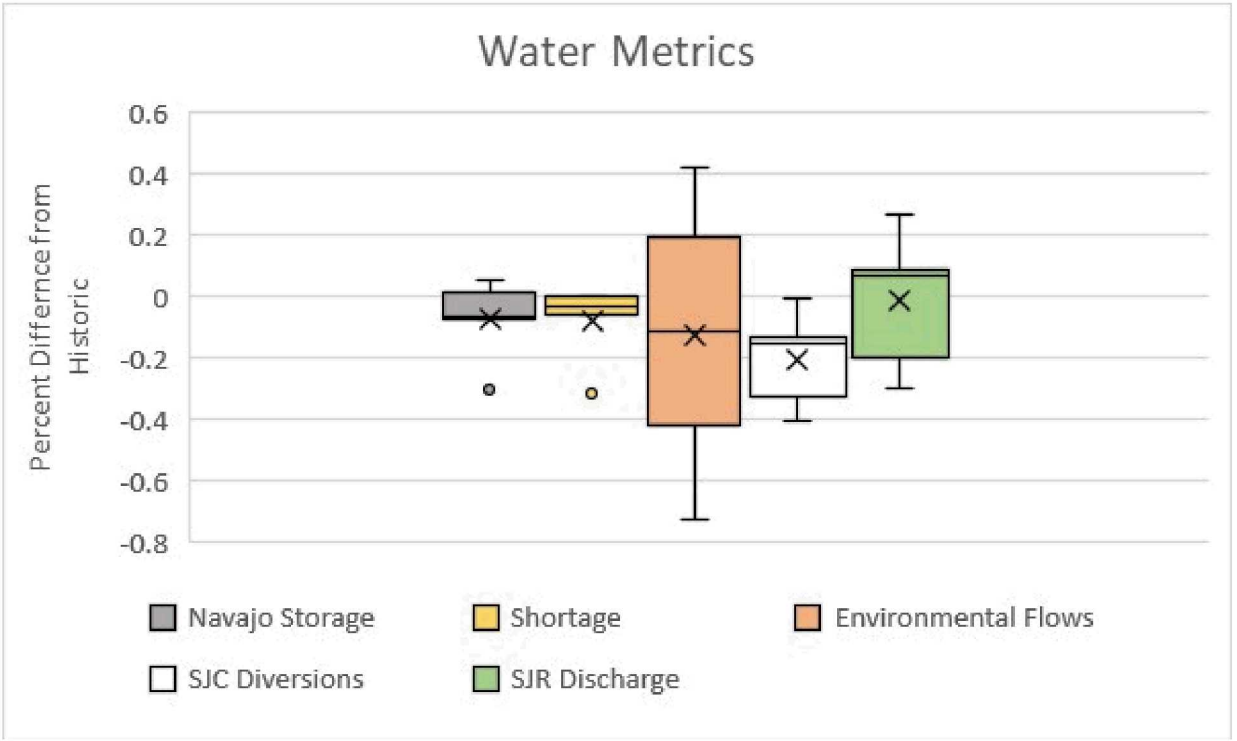
- San Juan discharge is on average 15% of Colorado flow at Lee's Ferry
- Two models project decreasing flow (20-30%).
- Three models project an increase in flows (6-26%).





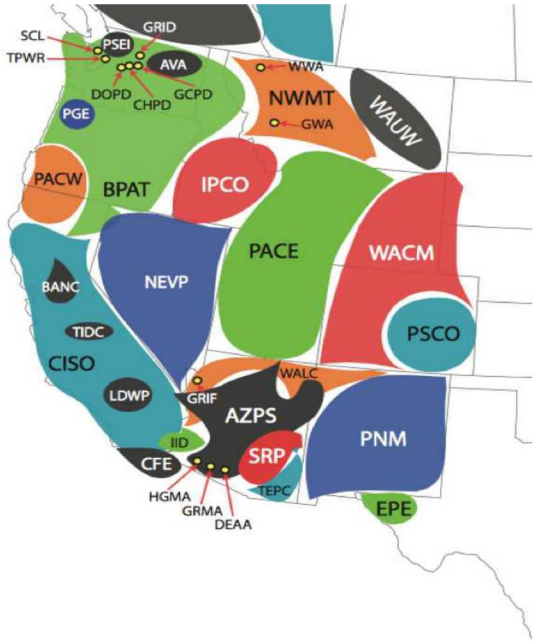
Summary of Impacts

- ***Uncertainty:*** Significant differences in projected impacts were consistently evident across climate models.
- ***Uneven Impacts***: Impacts differ significantly by metric due to position in basin and the institutional controls dictating its operations.
- ***Non-Local Impacts***: Local effects of climate change spilled over to other basins:
  - Lower Colorado River, and
  - San Juan- Chama diversion to Rio Grande Basin.



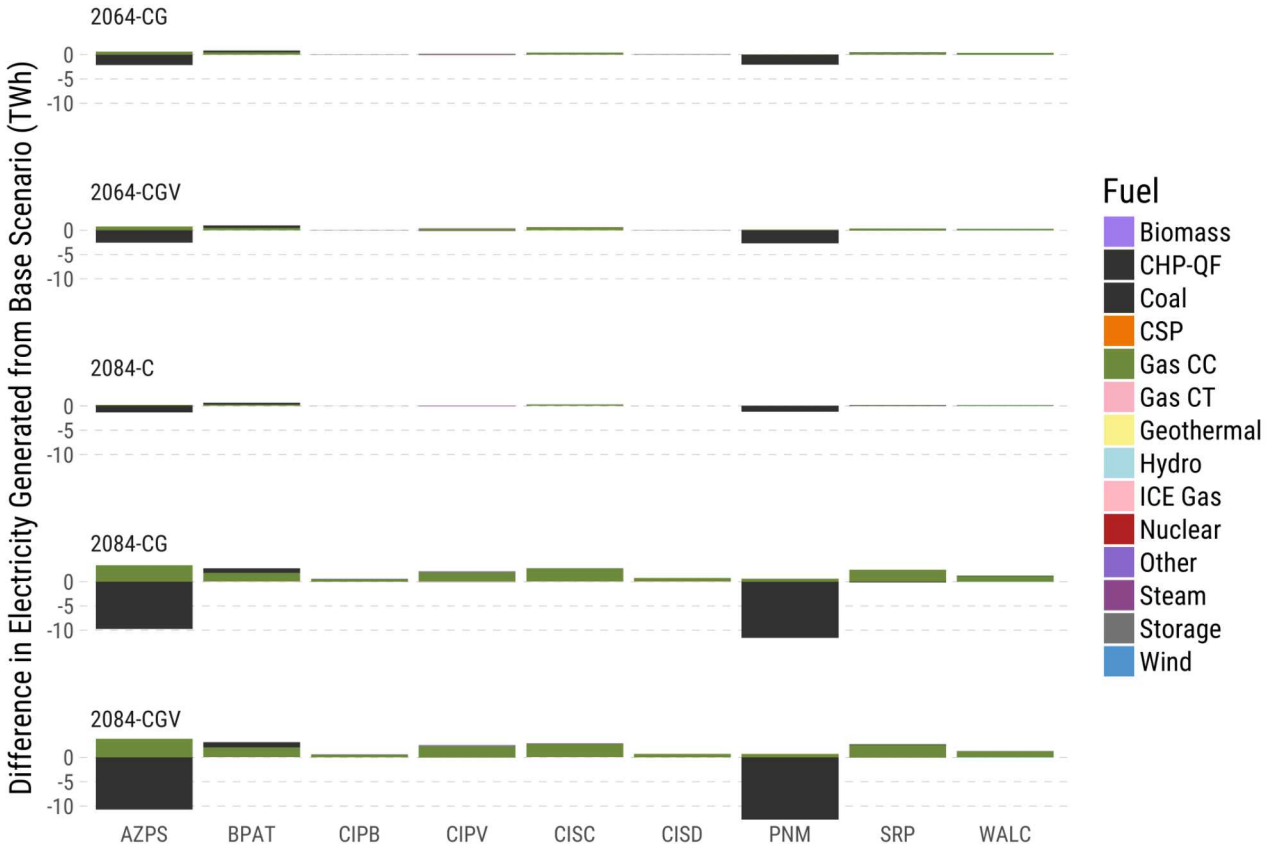
Impacts to Power Generation

- Localized water changes affect local power generation patterns that cascade through other regions
- Power system operations changes lead to transfers of costs, water usage, and emissions from one region to multiple others
- Power system models alone cannot capture dynamics of water shortages



WECC Balancing Regions

Regional WECC Generation Differences due to Localized Water Shortages



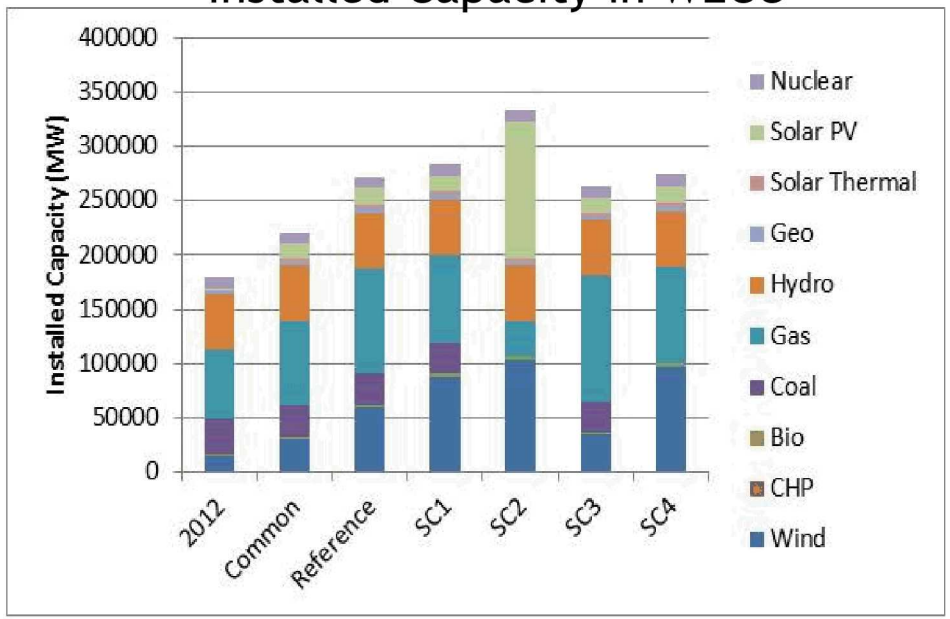
Difference in electricity generation from base scenario across WECC balancing authorities. AZPS and PNM decrease generation due to water shortages and other balancing authorities increase generation to accommodate.

Impacts on Capacity Expansion

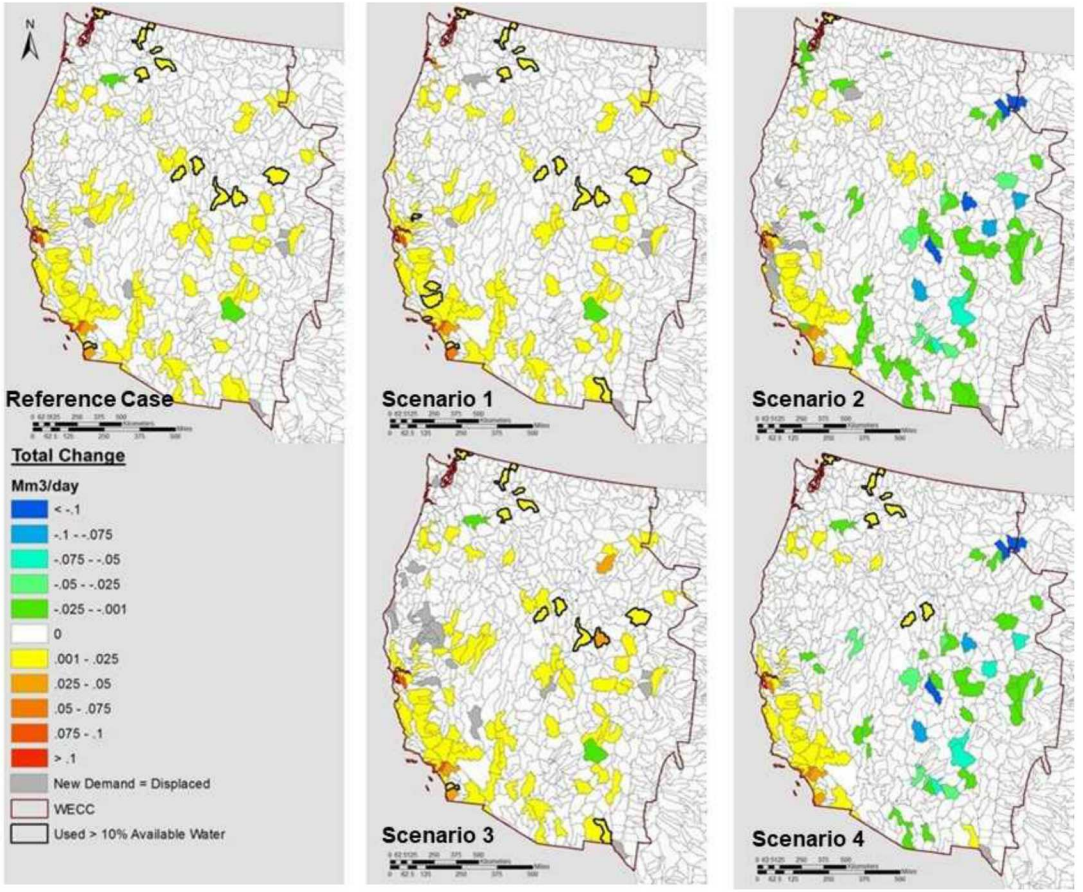
- How will climate impact decisions on where to place new power plants?
- Under current investigation.
- Decisions are couched in context of other constraints such as:
  - Cost of alternative generation technologies,
  - Demand,
  - Transmission, and
  - Policies.

Capacity mix varies by future assumptions.

Installed Capacity in WECC



Change in Electric Sector Water Demand

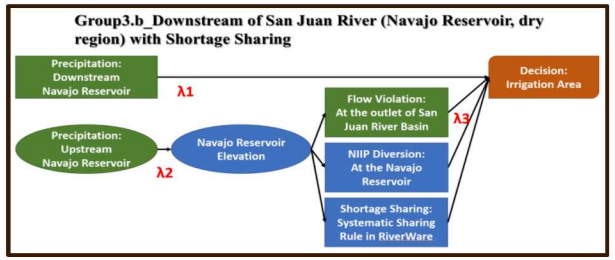


Future generation choices impacts water demand, cost of operations, and reliability of grid.

Agent (Farmer) Reaction

Current models assume essentially static water use, Agent Based Modeling (ABM) allows integration of dynamics of human decision making.

Bayesian Inference Network

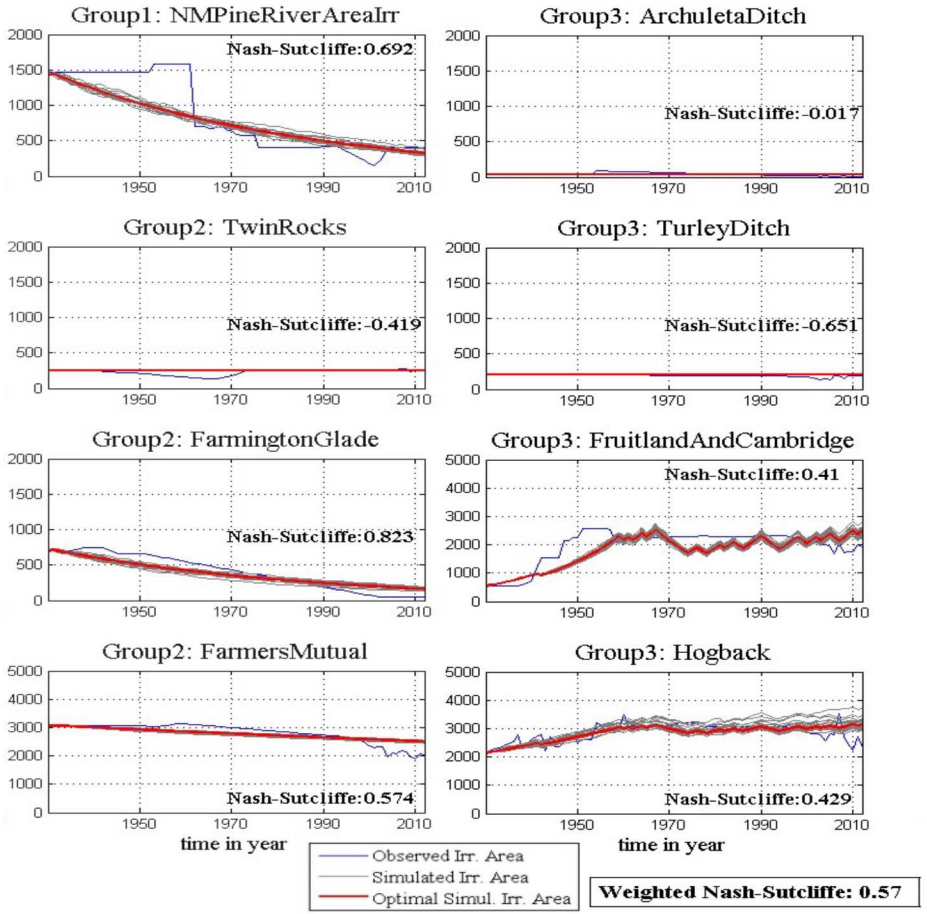


Cost-Loss Model

	Decision	
Action	*1-P*	*P*
Increase	C	C
Decrease	0	L

1. ABM is coupled (two-way) with RiverWare to evaluate impact of human behavior uncertainty on water resources management.
2. The ABM quantifies decision-making process with Bayesian Inference Network (risk taking) linked to a Cost-Loss Model (economic context for decision).
3. The decision variables of agents' are annual irrigated area which are affected by snowpack forecast, reservoir water level and water management policy

Unique to analysis was treatment of agent's perception of risk. Calibration results suggest farmers in region are highly risk adverse.

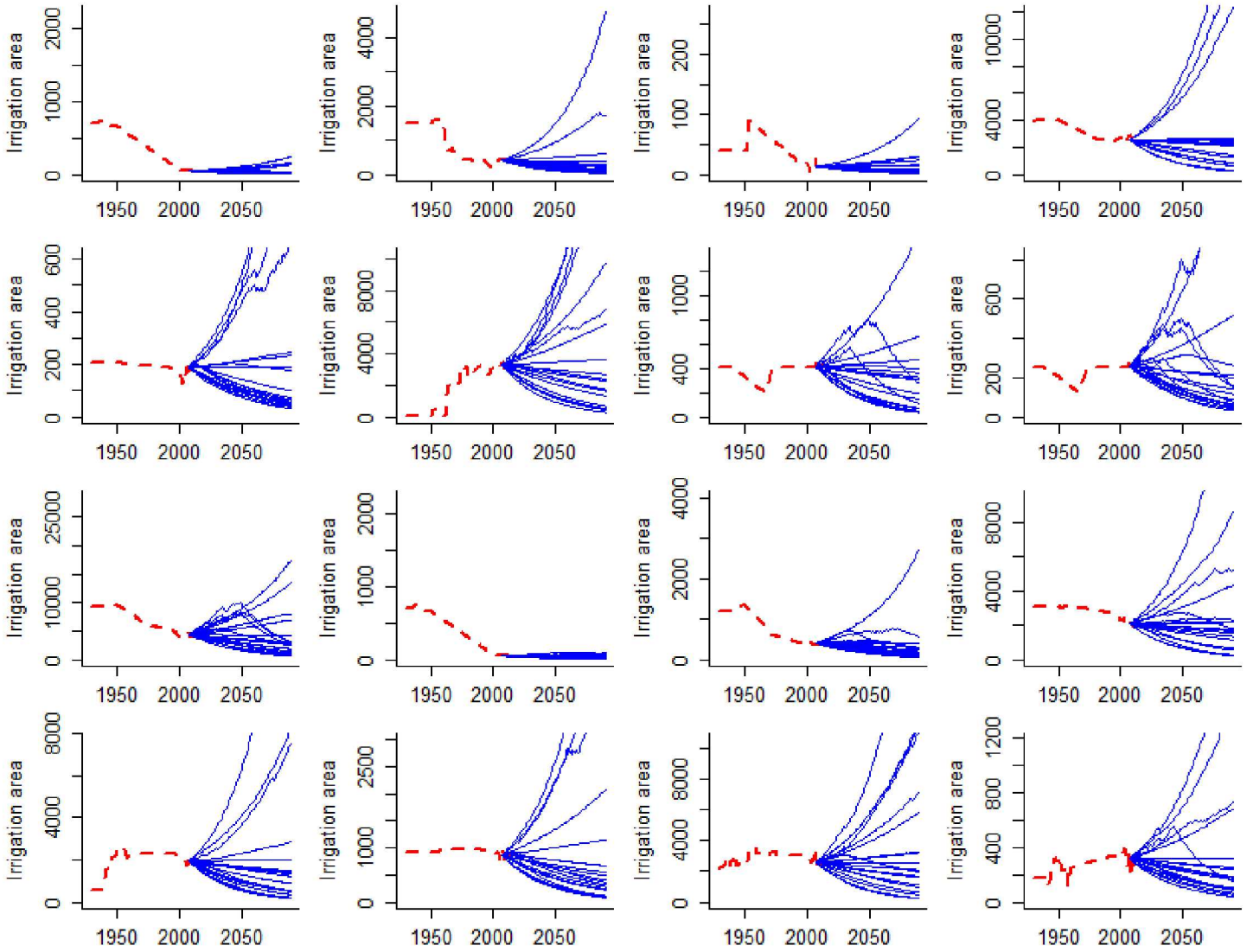


Calibration results for eight of sixteen agents (irrigation ditches). Blue line is observed data, red is simulated.

Hyun JY, SY Huang, YCE Yang, V Tidwell, and J Macknick. 2019. "Using a Coupled Agent-Based Modeling Approach to Analyze the Role of Risk Perception in Water Management Decisions," *Hydrology and Earth System Science*, 23:2261-2278. DOI: 10.5194/hess-23-2261-2019.

Agent (Farmer) Reaction

Trajectory of Irrigated Acreage by Ditch

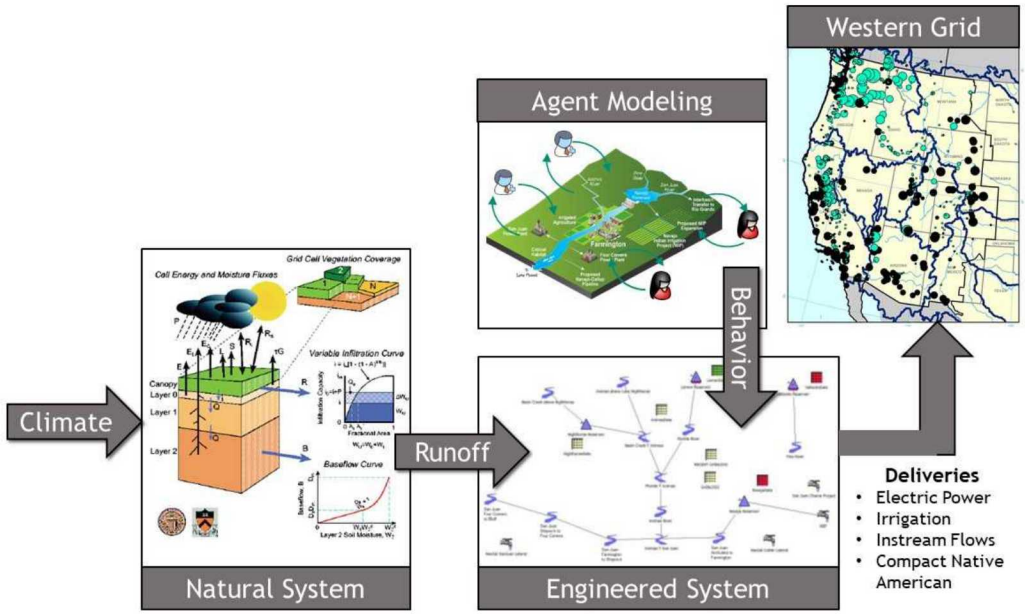


- Results for MIRCO climate model (hot-wet case).
- Different paths correspond to uncertainty in model parameters.
- Shift in acreage will, in turn, impact where and how water is used in the basin.

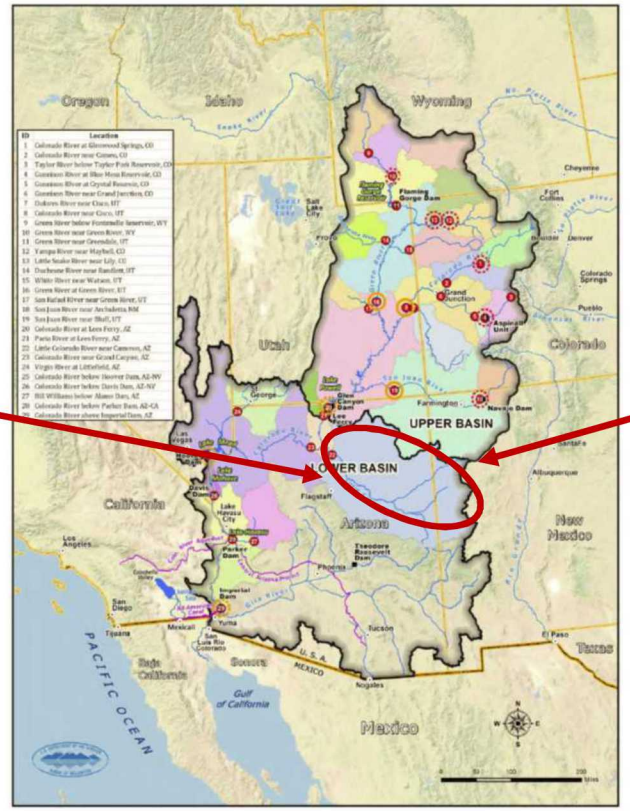
Red Dotted Line: Historic
Blue Line: Future

Summary-Next Steps

San Juan River Basin

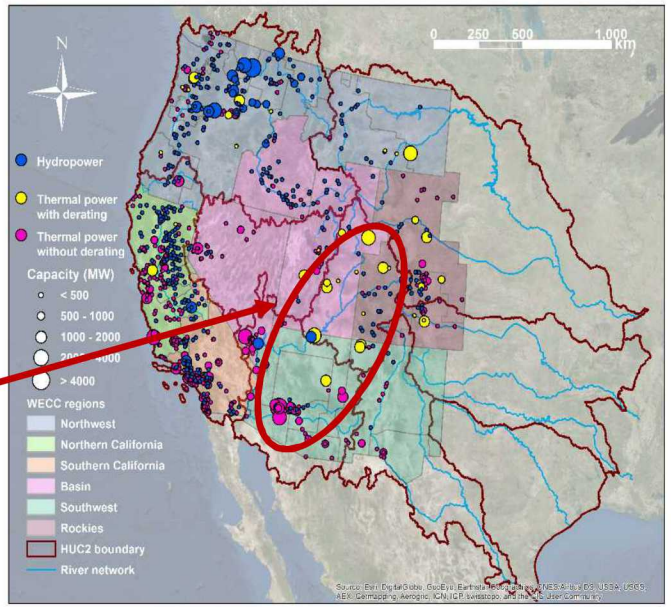


Colorado River Basin

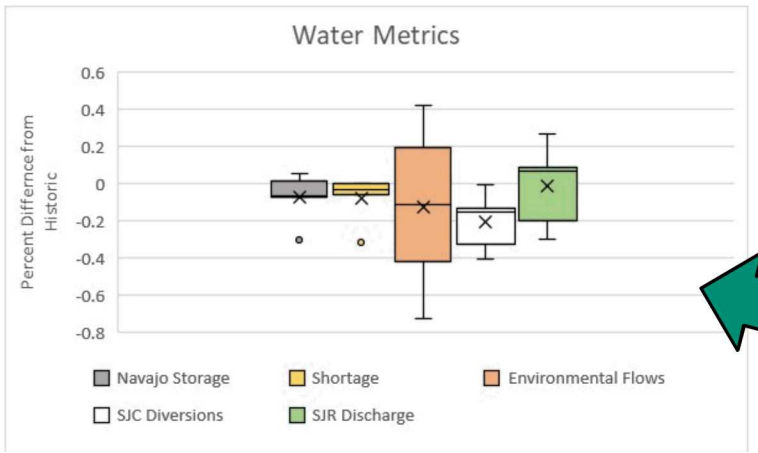


VIC-StateMod-RiverWare

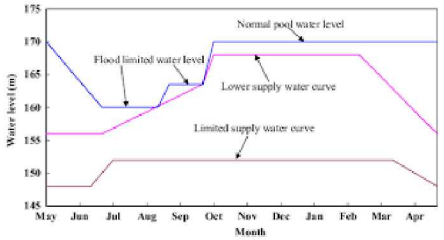
Western Grid



VIC-MOZART-WM



Agent Scaling



Emulators

- Identify metrics
- Verify comparable simulations
- Interpret differences
- Develop scaling rules