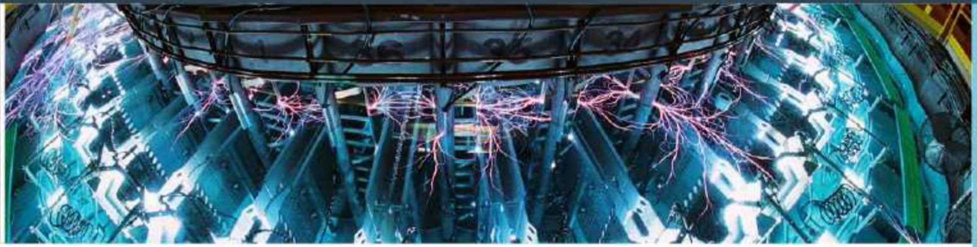
SAND2019-14493C

Importance of Water Operations and Water Rights in Assessing Future Climate Impacts



PRESENTED BY

Vincent Tidwell, Tom Lowry: Sandia National Laboratories

Todd Vandegrift: Precision Water Resources Engineering

Dagmar Llewellyn, Susan Behery: US Bureau of Reclamation

Katrina Bennett, Richard Middleton: Los Alamos National Laboratory

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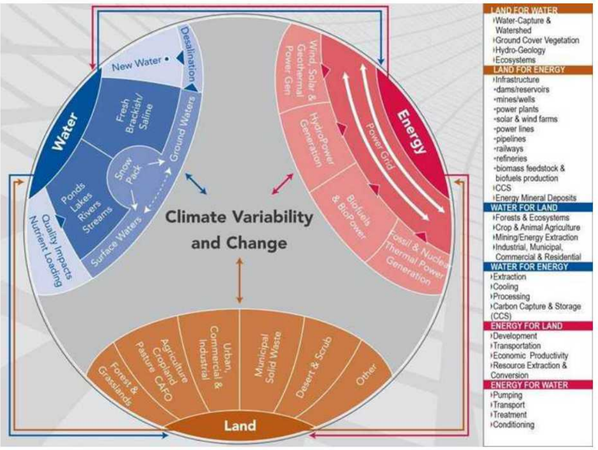
Energy and Water System Dynamics



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 INVESTORS SERVICE

- 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 & 2018 costliest weather year: $653B

CBS Jan. 22, 2019

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

U.S. DEPARTMENT OF ENERGY
Office of Science

Pacific Northwest NATIONAL LABORATORY

Sandia National Laboratories

NCAR

NREL NATIONAL RENEWABLE ENERGY LABORATORY

COLORADO SCHOOL OF MINES EARTH ▲ ENERGY ▲ ENVIRONMENT

UMASS AMHERST

LEHIGH UNIVERSITY

MONTANA STATE UNIVERSITY

IM3 Vision

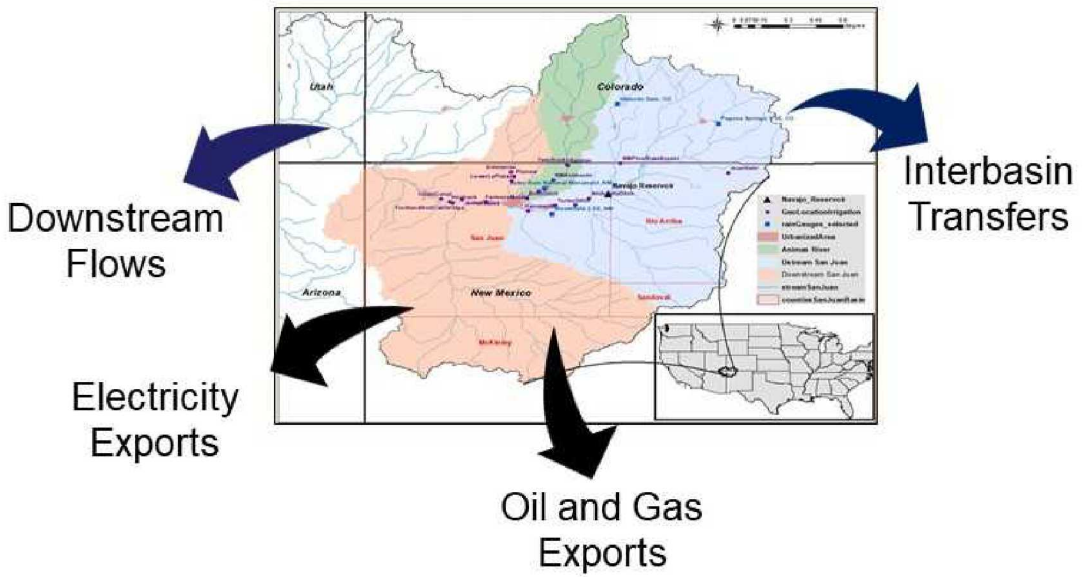
- Develop a ***flexible and integrated modeling framework*** that captures the dynamic multi-scale interactions among energy, water, land, weather/climate, socioeconomics, infrastructure, and other sectors
- Use this framework to ***study the vulnerability and resilience of coupled human and natural 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

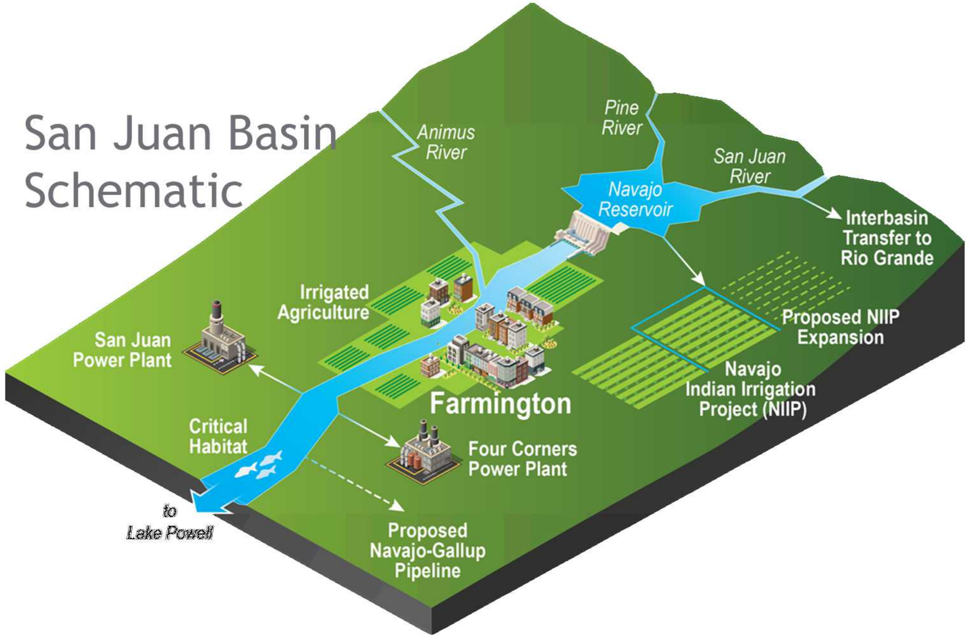
Study Site

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

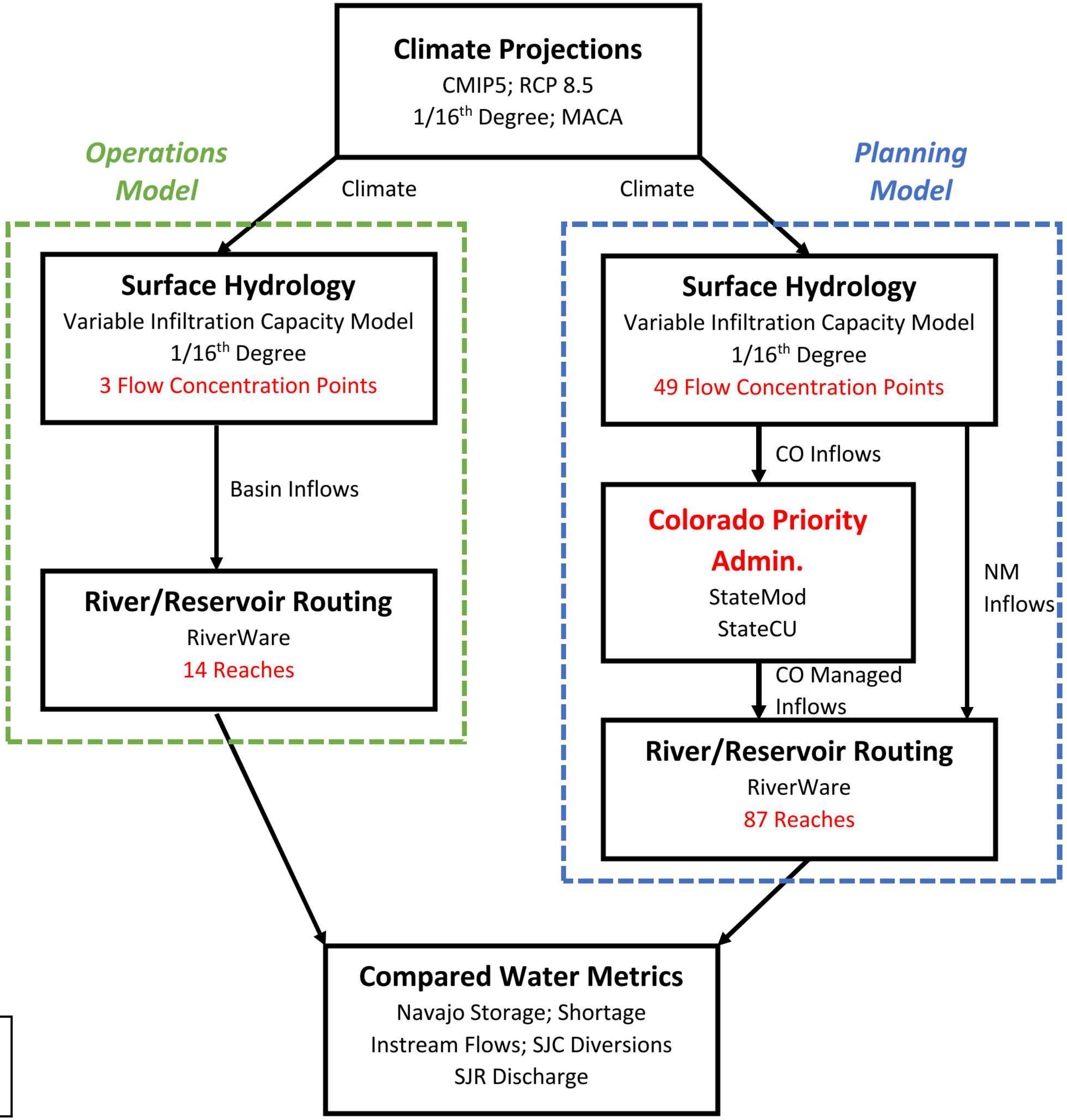




- San Juan River in Four Corners Region of Southwestern United States.
- Runoff originates in San Juan Mountains (83%). Largely snow melt dominated system.
- Primary management feature is Navajo Reservoir.
- Major water users include:
  - Native American
  - Irrigation,
  - Multiple power plants and 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.
- Simulations performed and compared across platforms of differing model fidelity in representation of water infrastructure and operational protocols:
  - Operations Model (lower-fidelity)
  - Planning Model (high-fidelity)

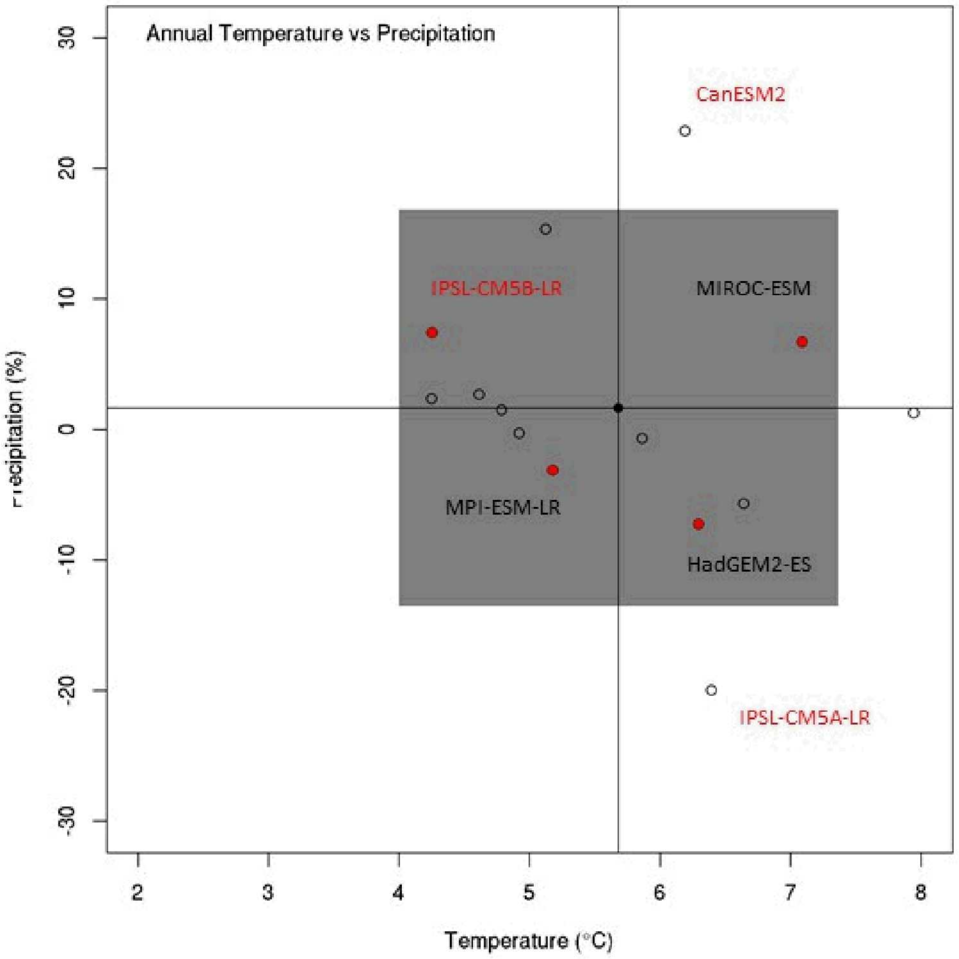


Bennett, K.E., Tidwell, V.C., Llewellyn, D., Behery, S., Barrett, L., Stansbury, M. and Middleton, R.S., Threats to a Colorado River provisioning basin under climate and societal scenarios, Environ. Res. Commun. (1), DOI: 10.1088/2515-7620/ab4028.

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

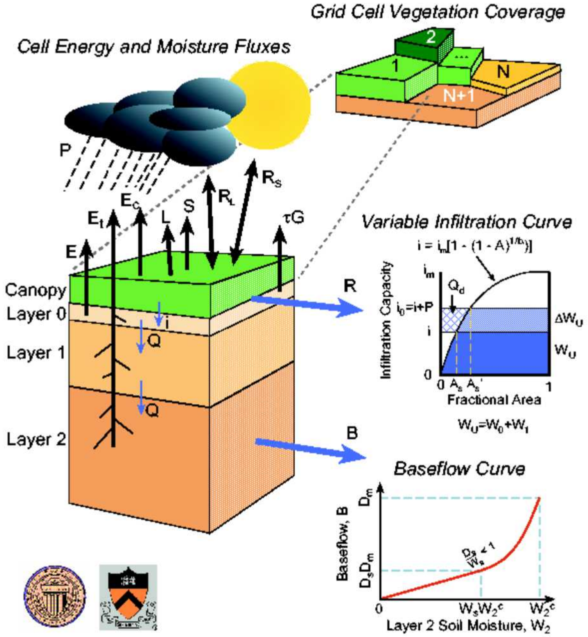
Six Climate Models (RCP 8.5)

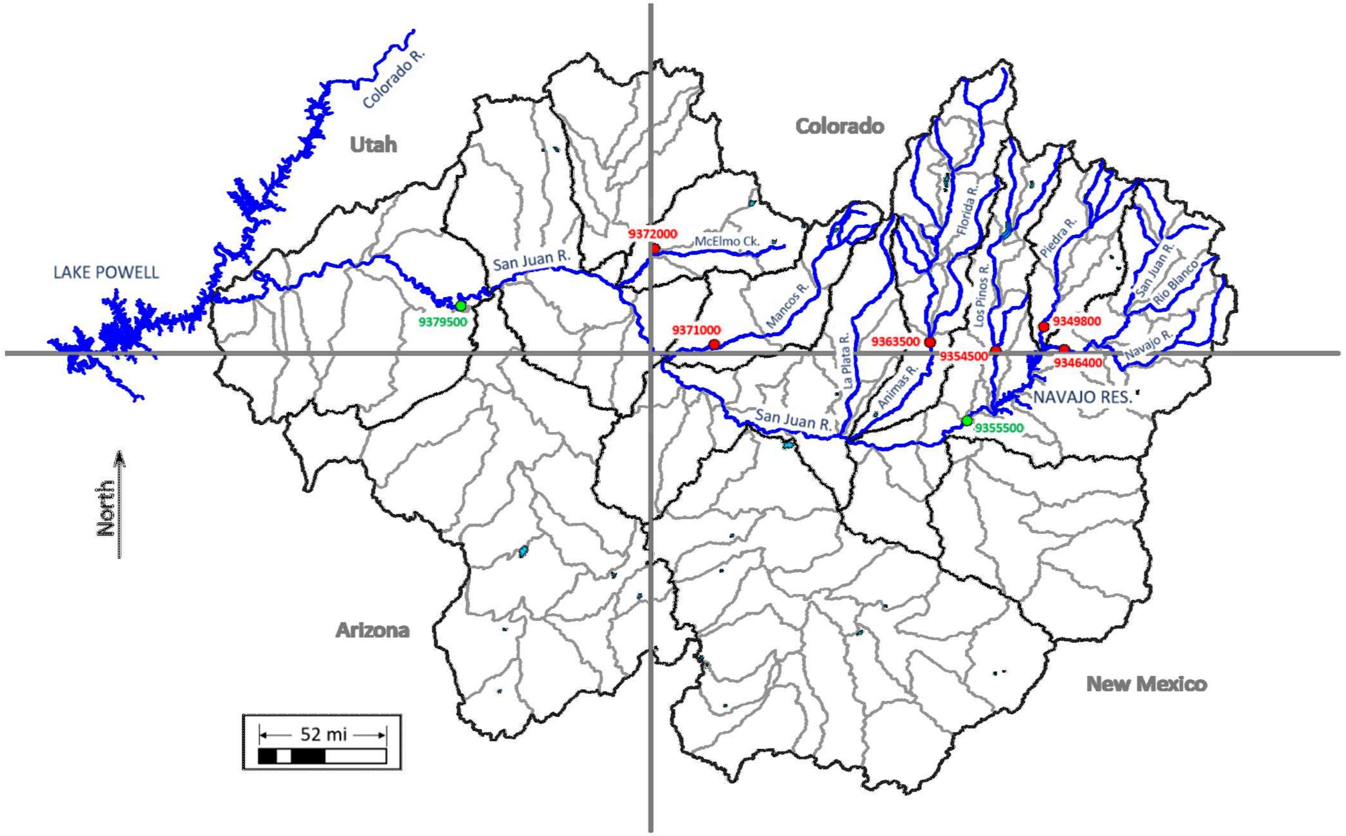


Non-Local	**Local**
Colorado River	*Storage*
Rio Grande	*Instream Flows*
	Water Deliveries

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

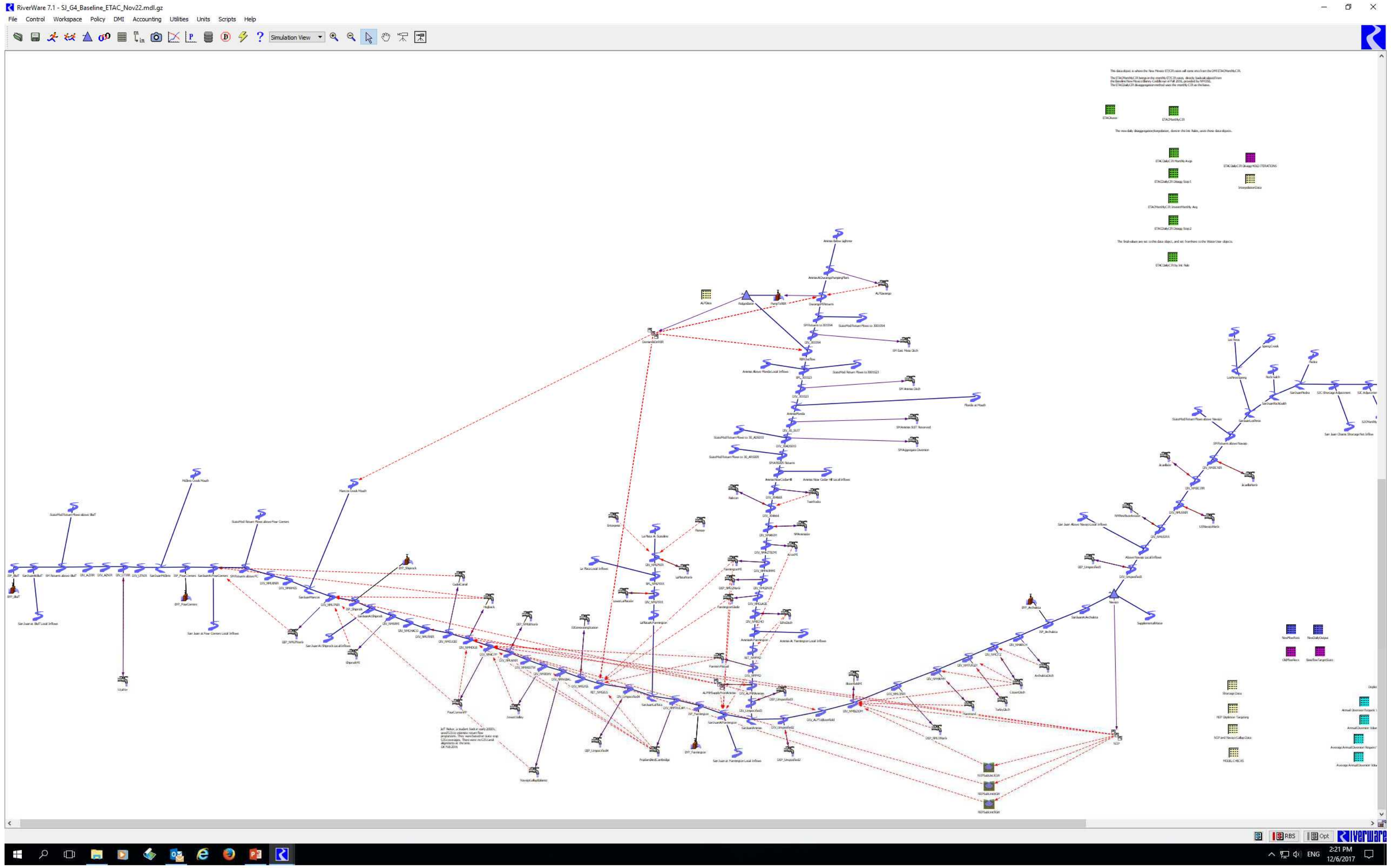




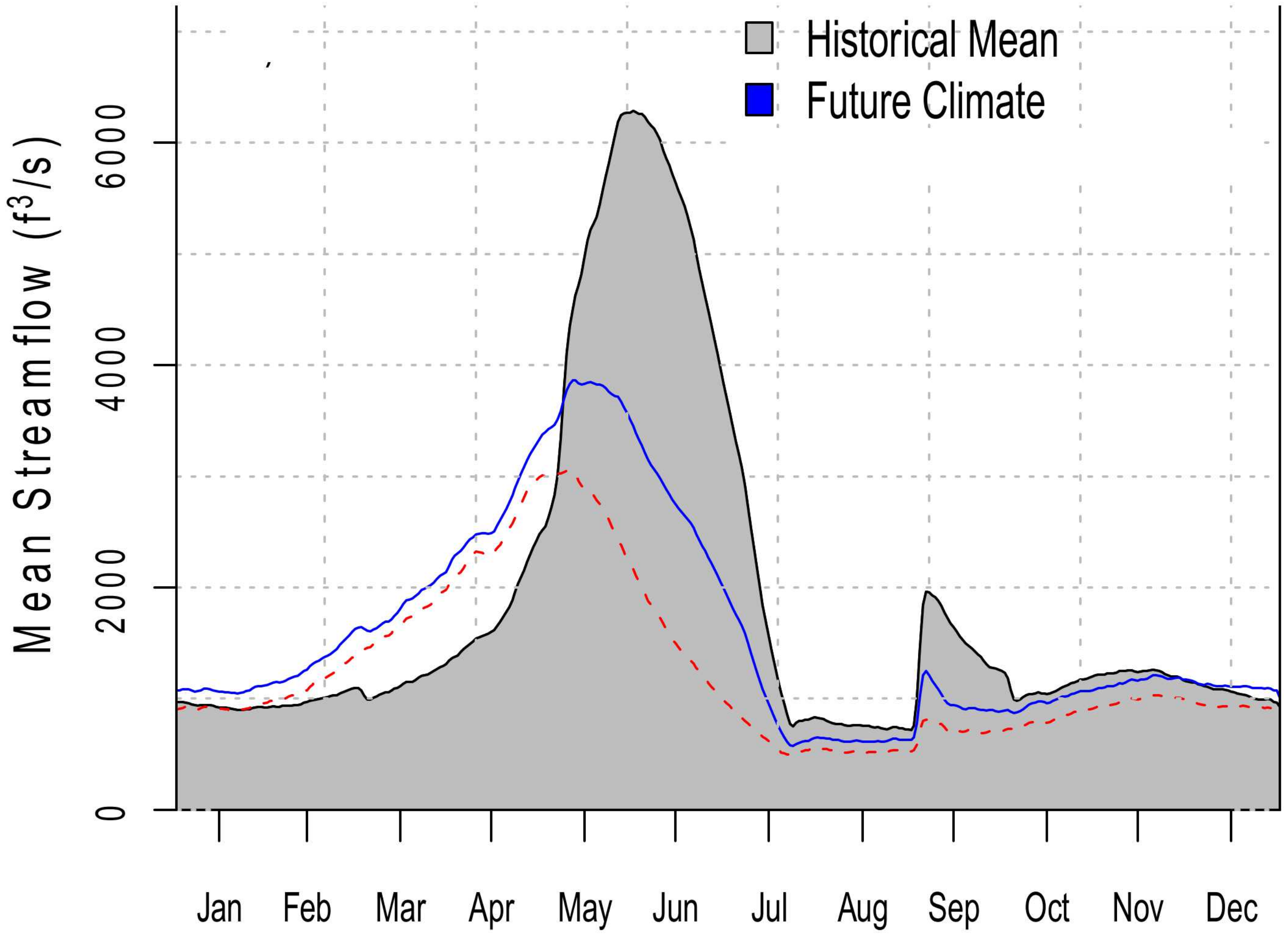
- Downscaling using Mutivariate Adaptive Constructive Analogues (MACA) data set (Abatzaglou and Brown, 2011)

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



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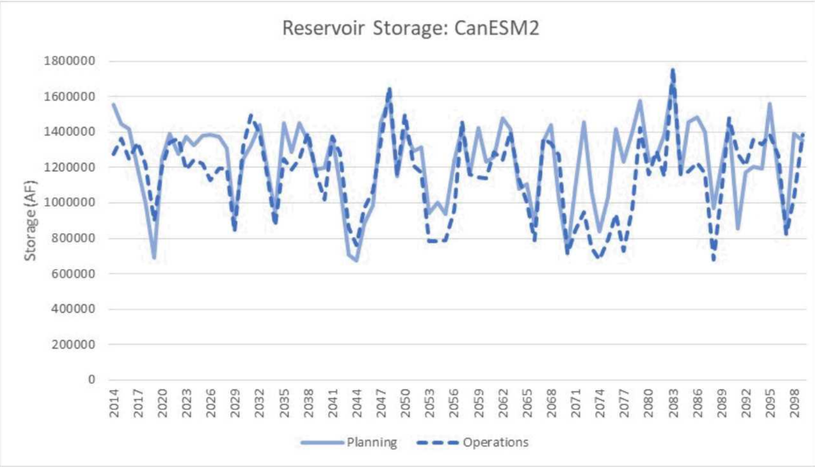
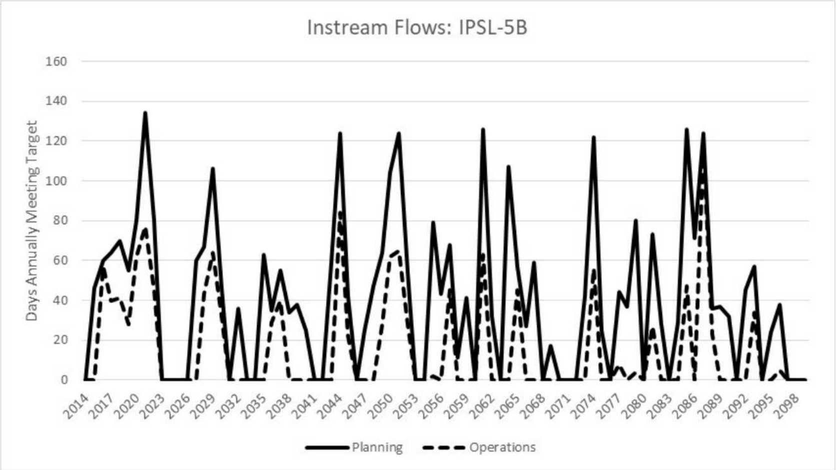
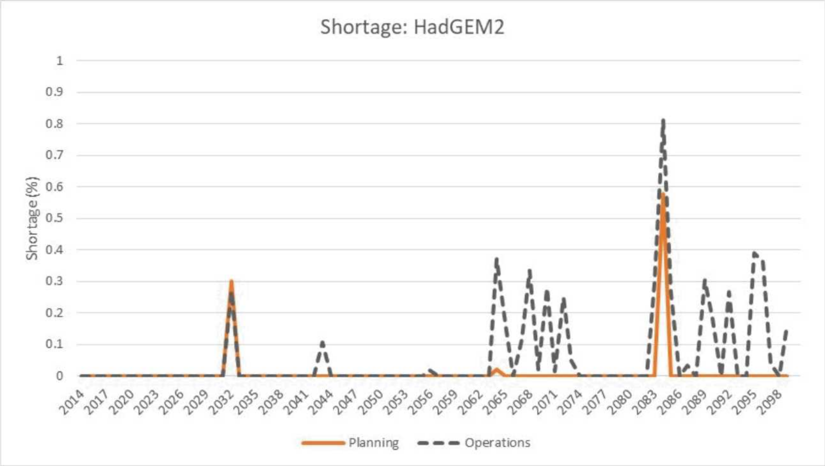
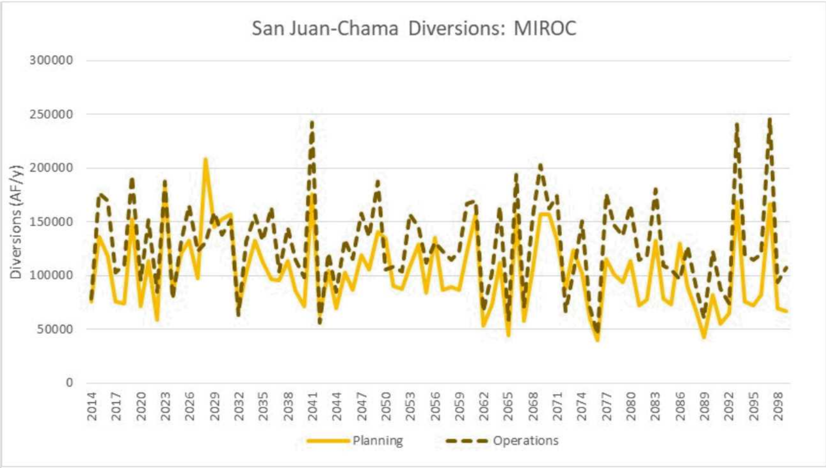
Role of Model Fidelity

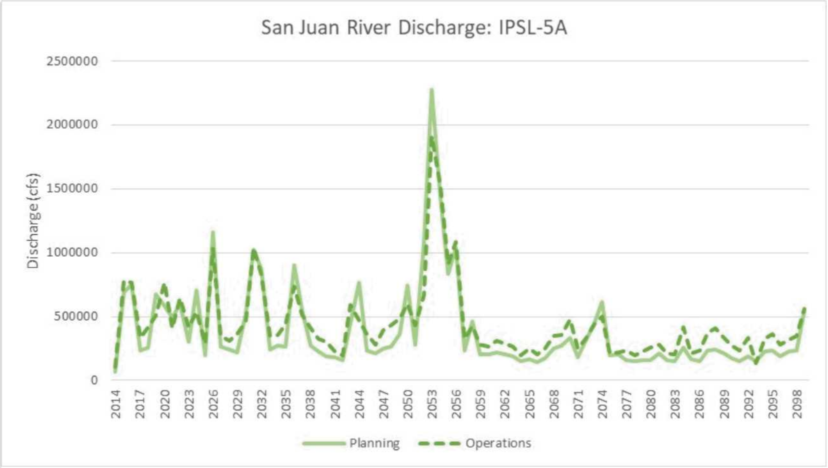
- Traces of annual averages for the five system metrics.
- Comparison drawn between high and low fidelity models for different ESMs
- Models (high vs. low fidelity) show striking similarity in response to evolving climate











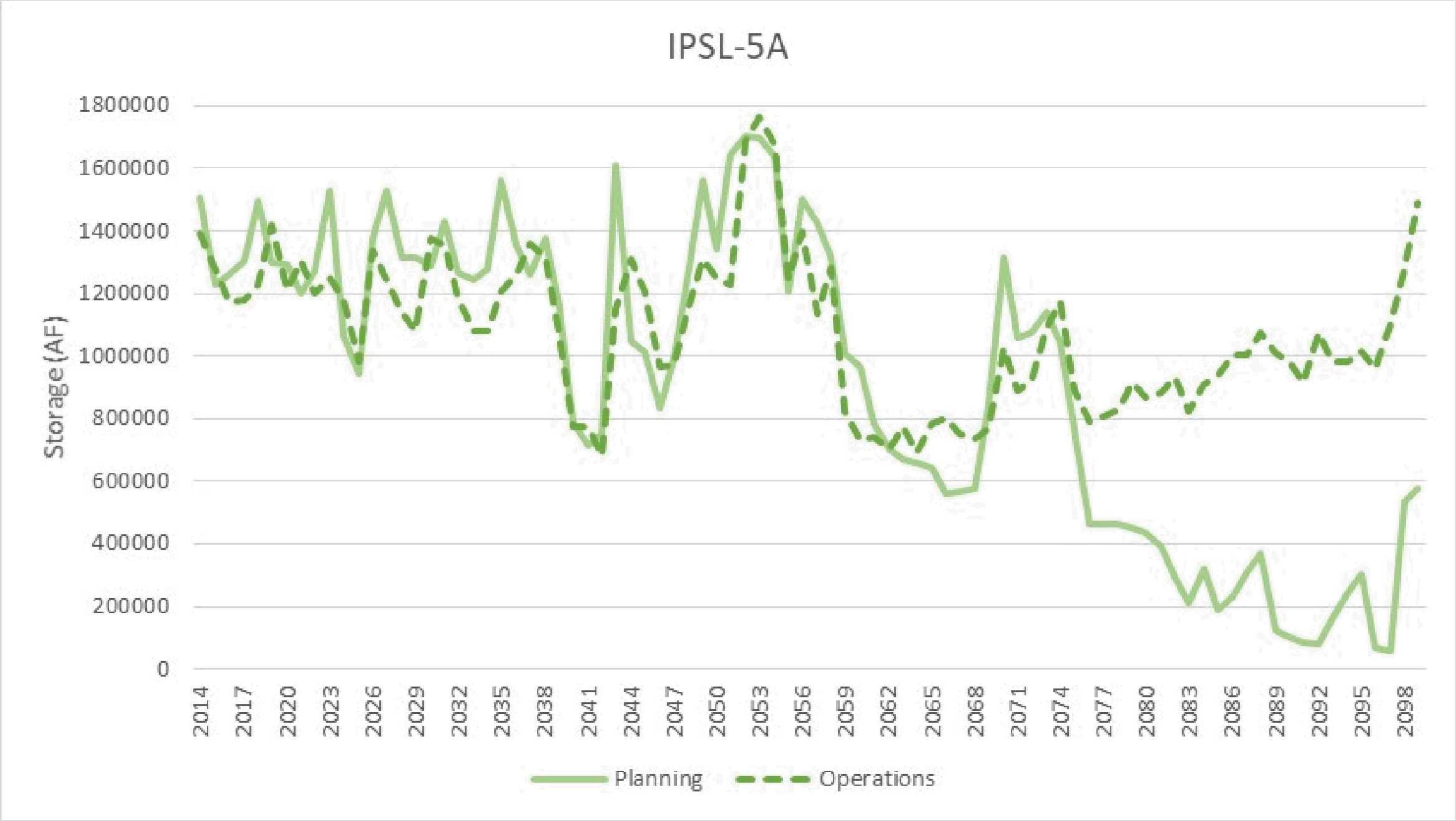
Projection of Impacts

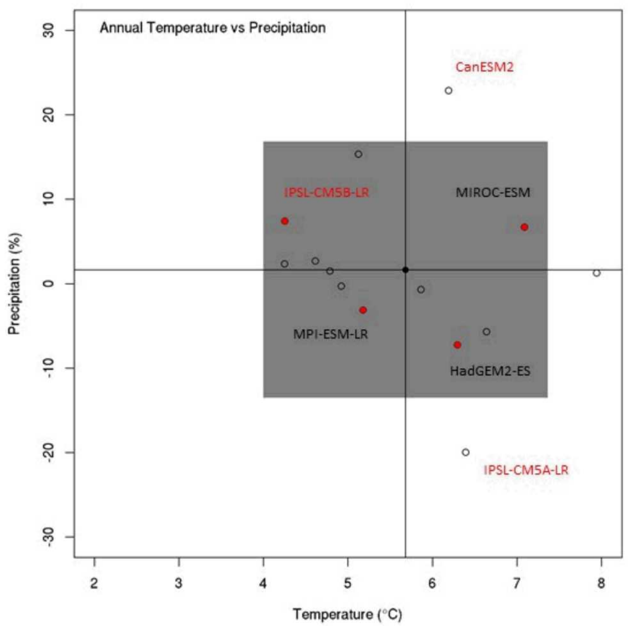
- Lower-fidelity Operations Model consistently projects more sever basin impacts relative to the higher-fidelity Planning Model:
  - Five water metrics,
  - Five climate models, and
  - Two water use scenarios.
- One exception to this rule.

	Climate Scenario									
	HadGEM2 Operations	HadGEM2 Planning	CanESM2 Operations	CanESM2 Planning	IPSL-5A Operations	IPSL-5A Planning	IPSL-5B Operations	IPSL-5B Planning	MIROC Operations	MIRO Planni
Navajo Storage (km³)	1.49	1.65	1.56	1.59	1.58	1.49	1.58	1.74	1.64	1.78
Shortage (Number Years)	2	0	2	2	35	10	2	0	1	0
Shortage (Average Intensity)	0.22	0.00	0.03	0.32	0.39	0.10	0.00	0.00	0.11	0.00
Instream Flow Violations (Number Years)	58	32	56	28	66	53	46	19	32	11
SJC Diversions (km³/y)	0.13	0.086	0.15	0.11	0.11	0.076	0.15	0.11	0.16	0.13
SJR Discharge (km³/y)	0.62	0.70	0.86	0.87	0.57	0.58	0.74	0.87	0.87	1.03
	Climate with Full Use Scenario									
	HadGEM2 Operations	HadGEM2 Planning	CanESM2 Operations	CanESM2 Planning	IPSL-5A Operations	IPSL-5A Planning	IPSL-5B Operations	IPSL-5B Planning	MIROC Operations	MIRO Planni
Navajo Storage (km³)	1.32	1.50	1.42	1.52	1.33	1.14	1.48	1.65	1.54	1.72
Shortage (Number Years)	23	3	11	5	38	27	5	0	3	0
Shortage (Average Intensity)	0.22	0.30	0.17	0.019	0.050	0.48	0.25	0.00	0.22	0.00
Instream Flow Violations (Number Years)	74	51	57	40	72	62	59	29	50	21
SJC Diversions (km³/y)	0.13	0.086	0.15	0.11	0.11	0.076	0.15	0.11	0.16	0.13
SJR Discharge (km³/y)	0.54	0.55	0.74	0.74	0.53	0.48	0.67	0.73	0.78	0.87

Tipping Points

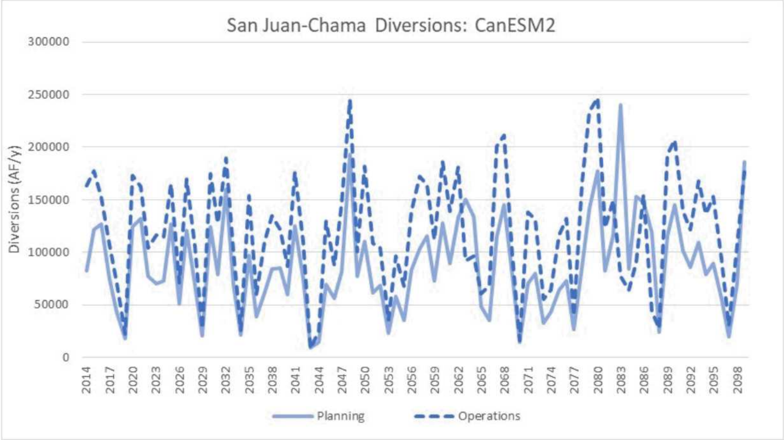
- Under the most extreme and prolonged dry conditions the higher-fidelity Planning Model was unable to execute.
- Operational rules within the Planning Model had to be adjusted.
- Improved resolution in basin infrastructure and operational rules enhanced model sensitivity and thus aided in identification of system tipping points.





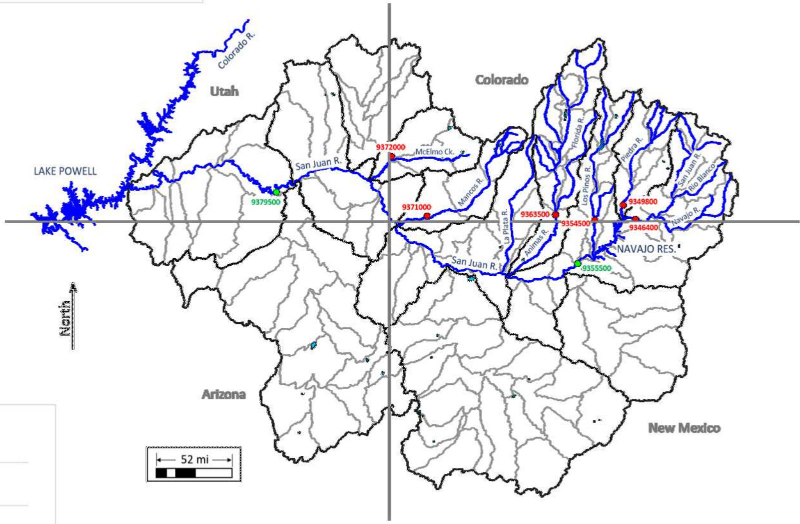
Contributing Factors

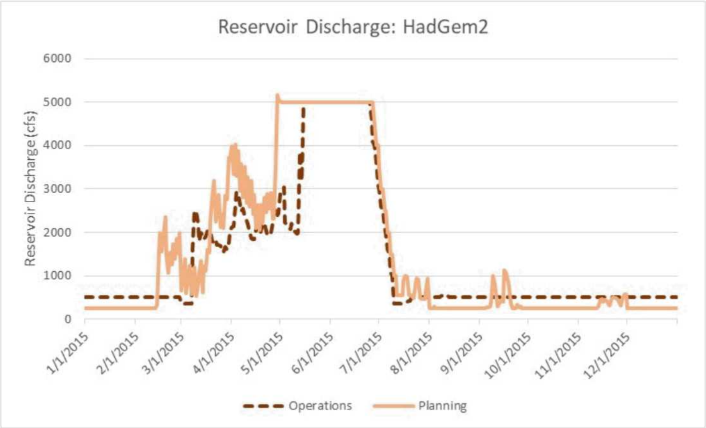
- Modeling of SJC infrastructure in Planning Model reduced San Juan River depletions relative to Operations Model (25-50%).
- Explicit simulation of water depletions in Planning Model vs. statistical regression in Operations Model.
- Model inflows were much more geospatially distributed in the Planning Model.
- Reservoir operational rules are more detailed in the Planning Model.



25-50% more San Juan-Chama depletions by lower-fidelity Operations Model

3 verses 49 tributary inflow points

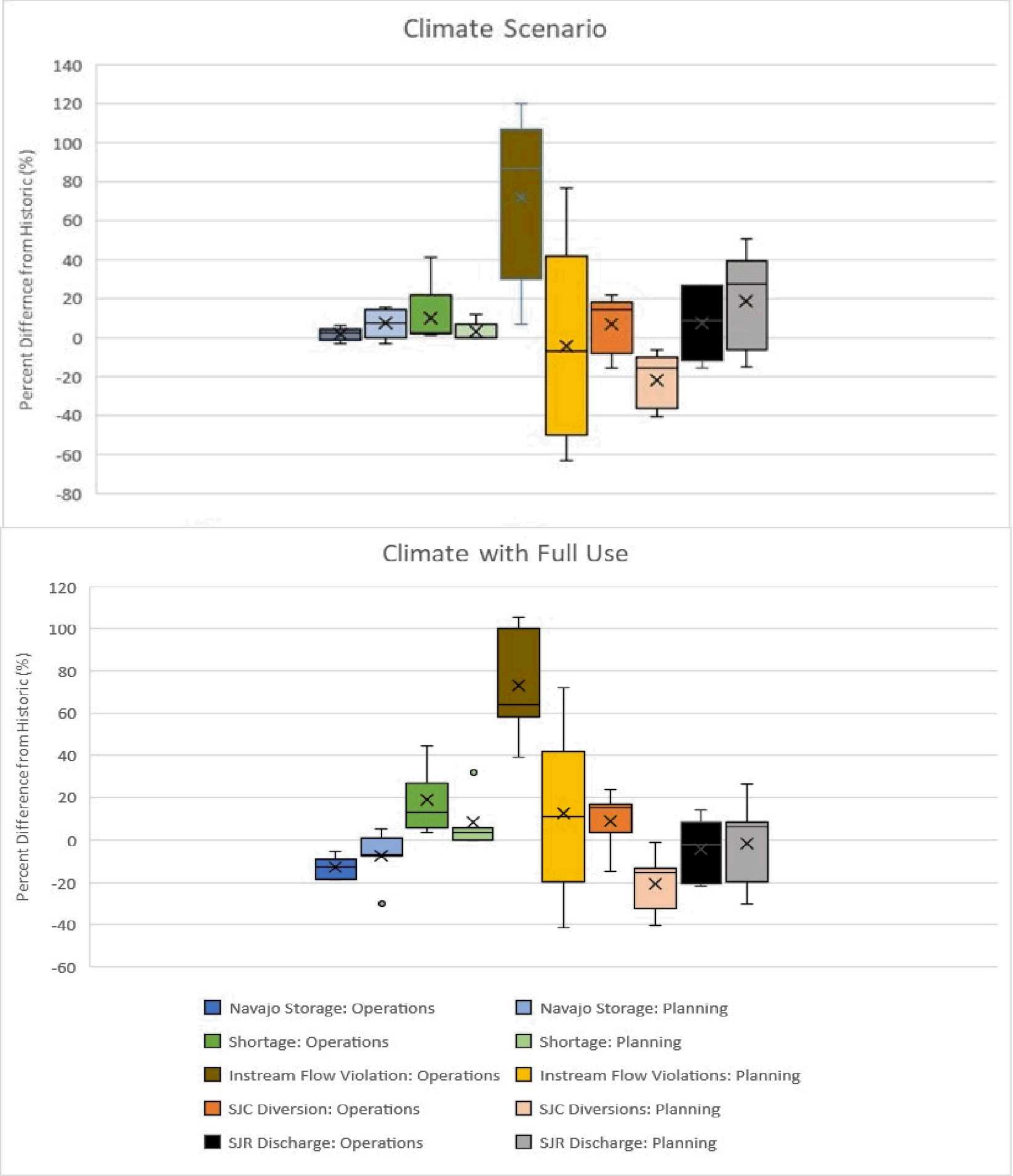




Reservoir regulation improves system efficiency

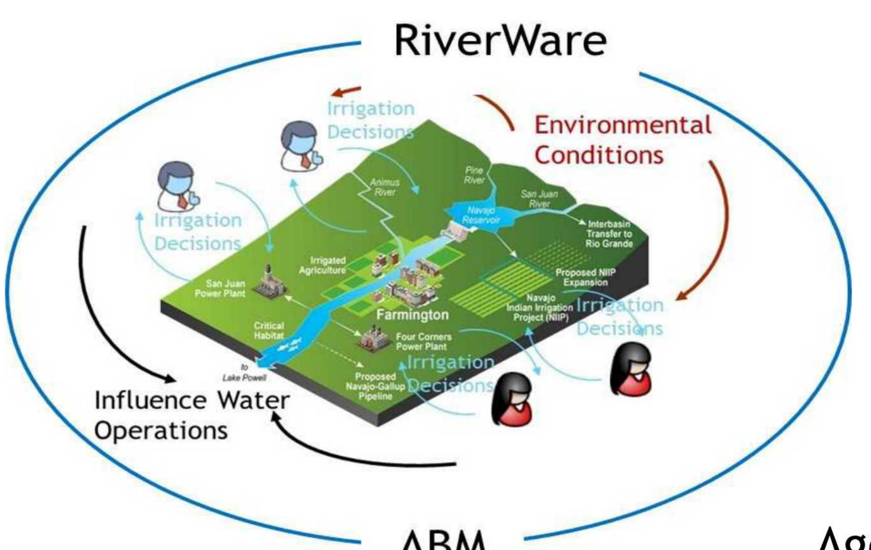
Role of Model Fidelity

- Plotted is the percent difference between the projected mean metric value (average 2014-2099) and its corresponding historic value (1950-2013).
- Box and whisker plots show the range in values across the five ESMs.
- Generally negative impacts from climate change and increased water use on all five metrics.
- Multi-model system that ***lacked a full accounting*** of system infrastructure and management operations consistently ***overestimated water-related risks***.
- Similar trends are ***expected in other basins***, as the purpose of these interdependent water infrastructure and management operations is to ***buffer impacts in times of drought***.
- However, ***large uncertainty persists*** across possible climate futures



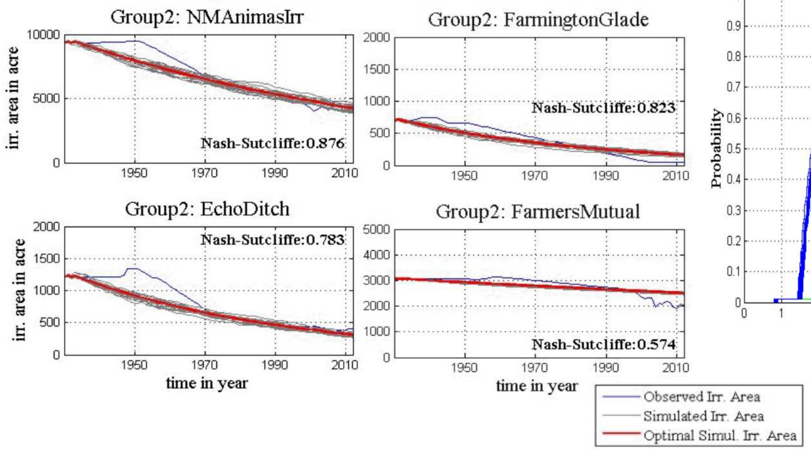
Downstream Implications

Agent Response

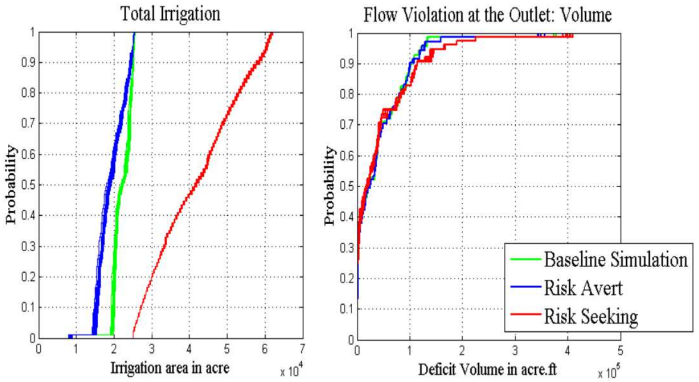


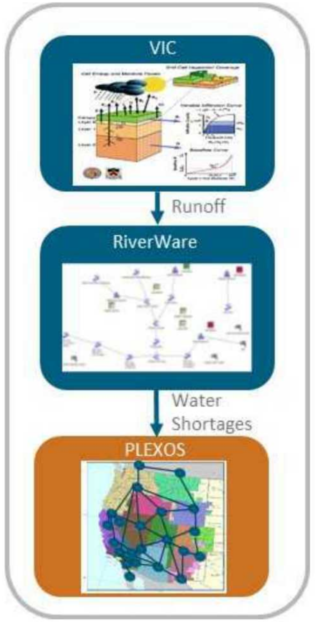
Incorporating risk, perception, previous experiences and environmental information in the decision-making process

Agent Calibration



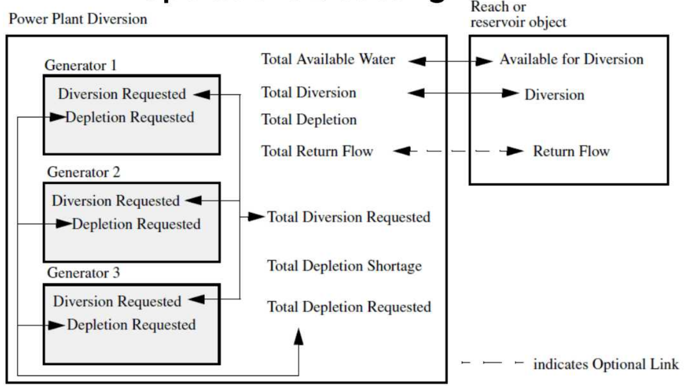
Agent Risk Perception



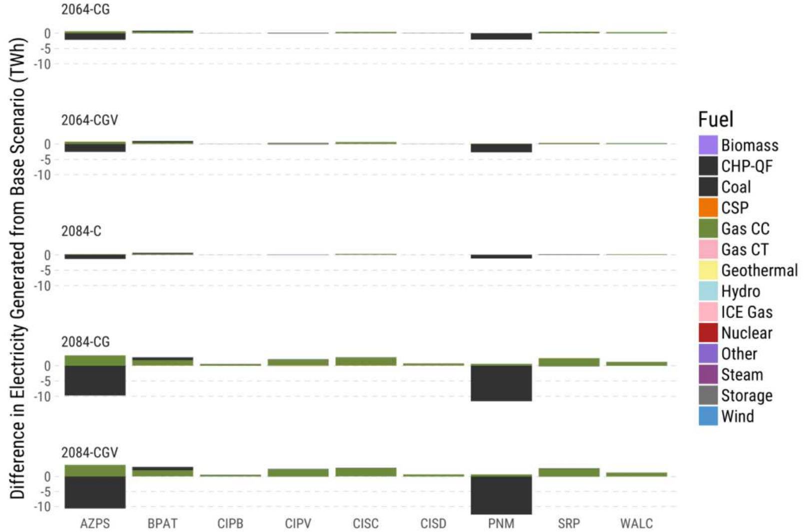


Grid Response

Tightly Coupling Power Plant - River Operations Modeling



Regional WECC Generation Differences due to Localized Water Shortages



Quantifying the adaptive water management decision in the San Juan River Basin under climate change
Yi-Chen Ethan Yang, Lehigh University, Bethlehem, PA, United States, Kyongho Son, University of California, Santa Barbara, Santa Barbara, CA, United States and Vincent Carroll Tidwell, Sandia Natl Laboratories, Albuquerque, NM, United States **Poster on Monday afternoon**

Climate-Water Impacts on Interconnection-Scale Electricity System Planning
Stuart Michael Cohen, Ana Dyreson, Jordan Macknick, Ariel Miara, Vincent Carroll Tidwell, Nathalie Voisin, Sean William Donald Turner and Michael Bailey, **Poster on Tuesday afternoon**

Takeaways

- Compared simulation platforms of differing model fidelity in their representation of water infrastructure and operational protocols.
- Simulated five future climate projections and two water use cases.
- Models (high vs. low fidelity) show striking similarity in response to evolving climate.
- Lower-fidelity Operations Model consistently projects more sever basin impacts relative to the higher-fidelity Planning Model.
- Improved resolution in basin infrastructure and operational rules enhanced model sensitivity and thus aided in identification of system tipping points.