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Managing Water in the West

Projected Impacts of Climate Change on Water Resources in the Upper Rio Grande Basin

Presentation to the New Mexico Academy of Science, New Mexicans for Science and Reason, and the NM Museum of Natural History and Science Voices in Science Series.

Dagmar Llewellyn, Reclamation Albuquerque Area Office

And Jesse Roach, Sandia National Labs

July 10, 2013

U.S. Department of the Interior
Bureau of Reclamation

Sandia National Laboratories

"TONIGHT'S LECTURE: "THE DANGERS OF GLOBAL WARMING"
POSTPONED
H. PAYNE

The Rio Grande, 2012

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Elephant Butte Reservoir

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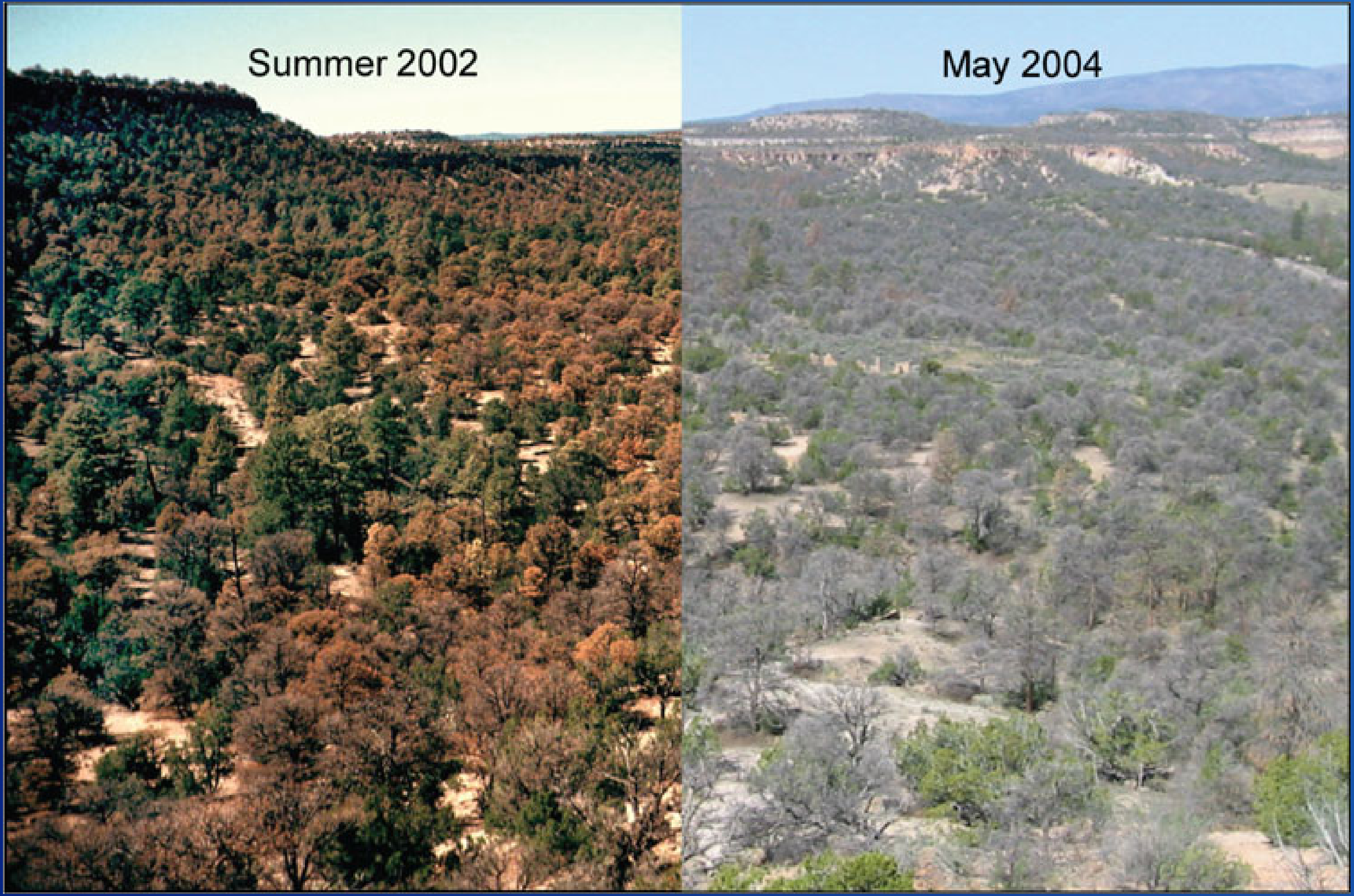
Loss of Pin~on Pines



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Jemez Mountains – Ponderosa Pines

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Las Conchas Fire

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Watershed Conditions after Las Conchas Fire

…and only a small amount of rain

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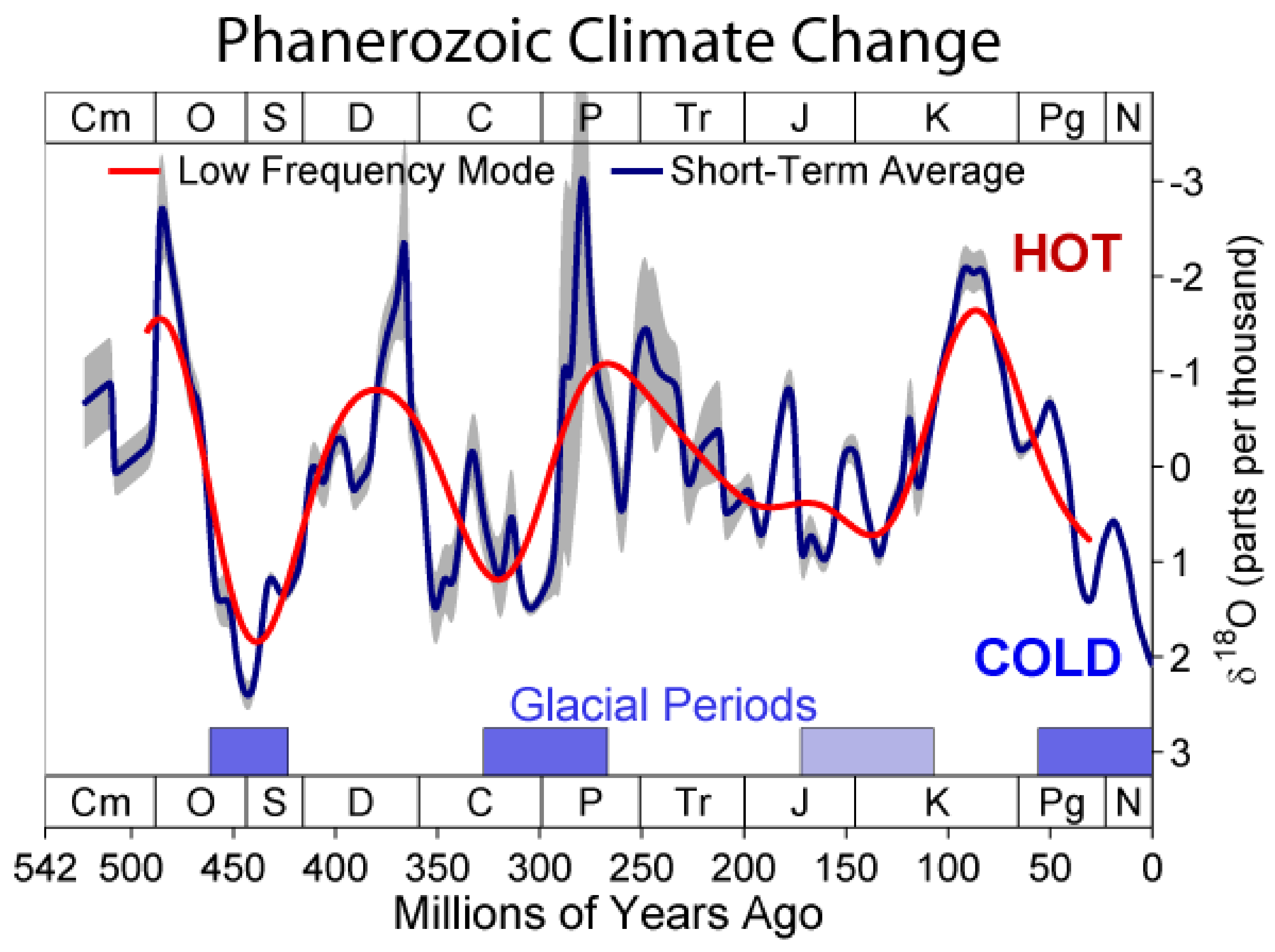

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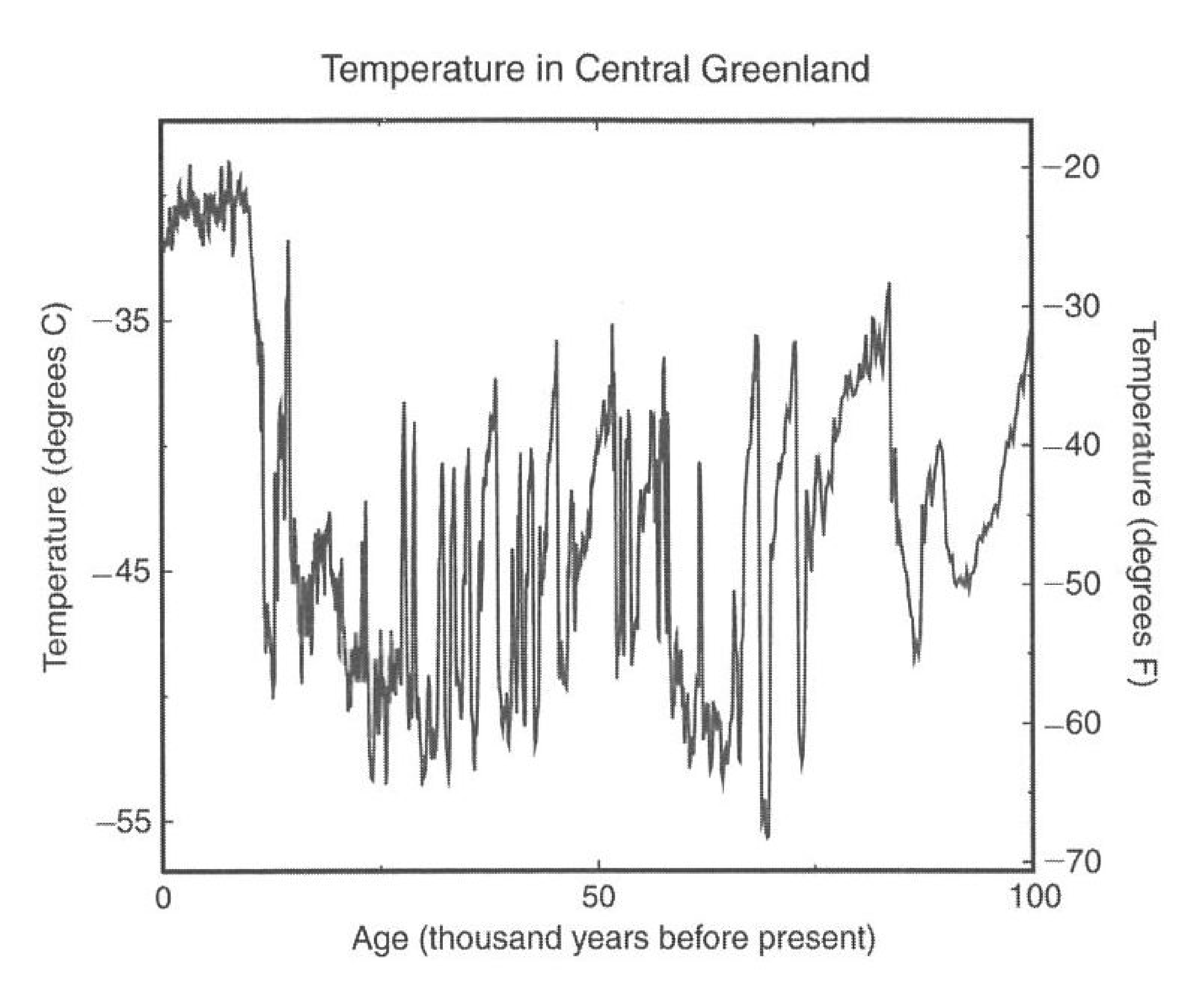

Source: Richard Alley, 2000

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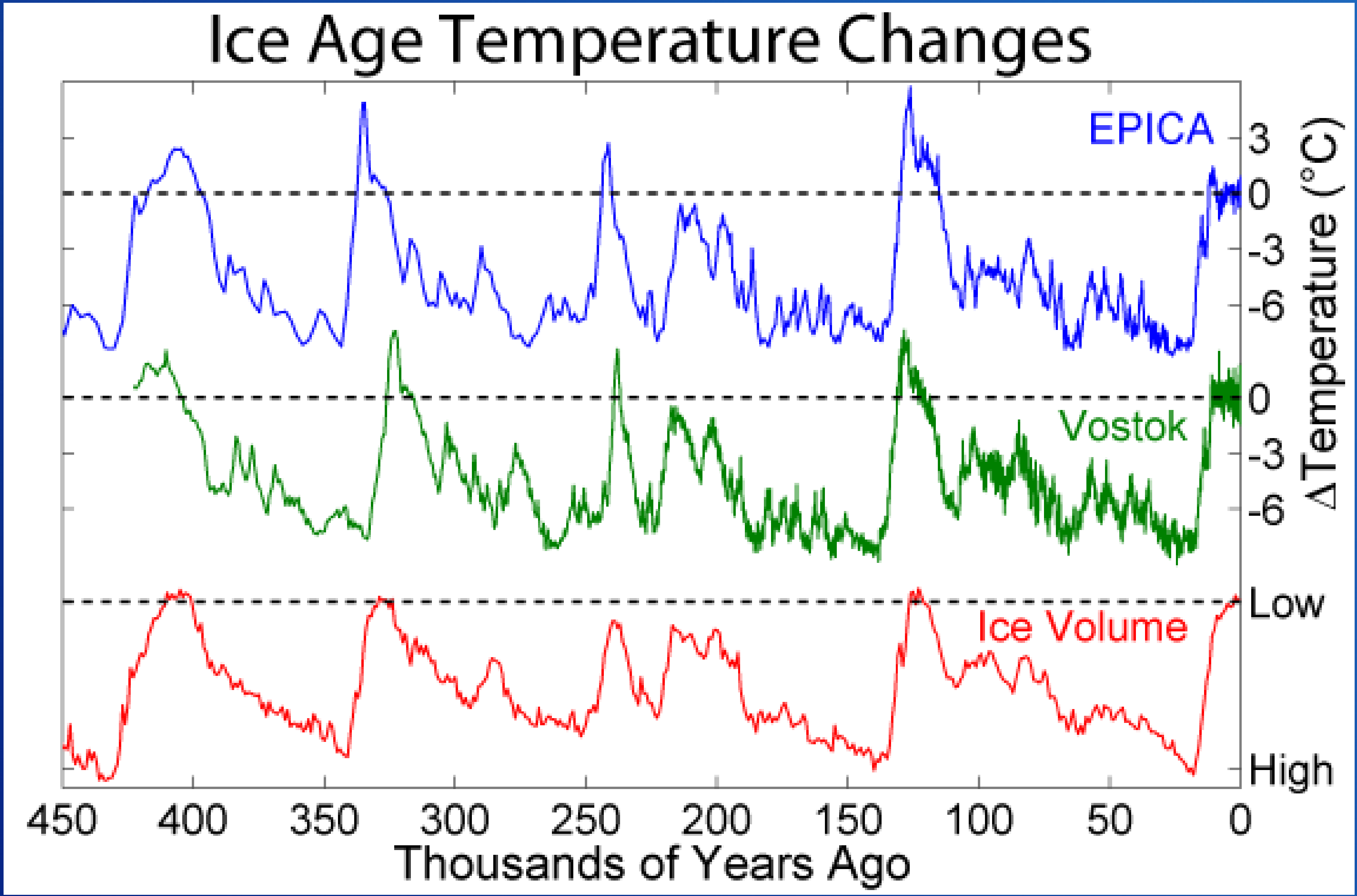

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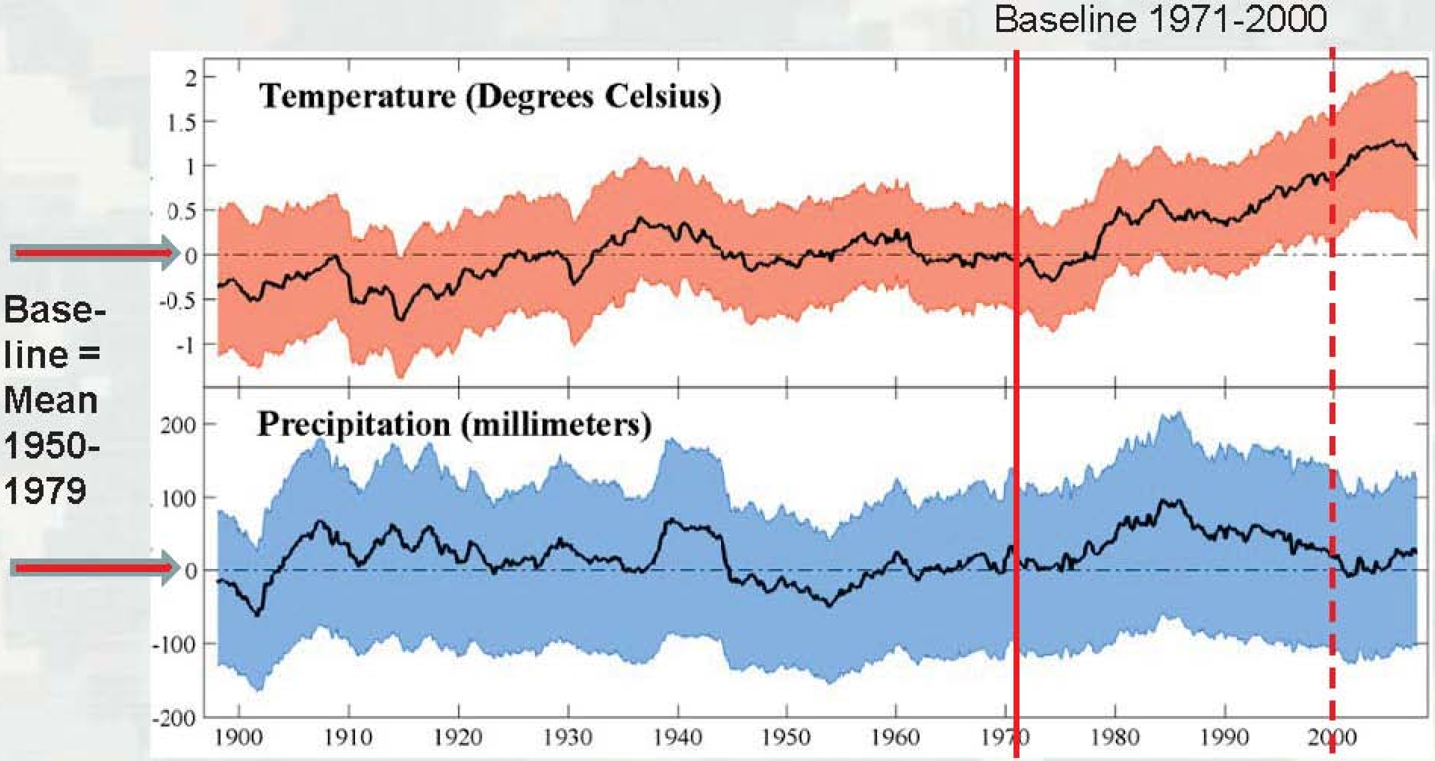
Weather vs. Climate (Southwestern U.S.)



Source: Ariane Pinson, US Army Corps of Engineers

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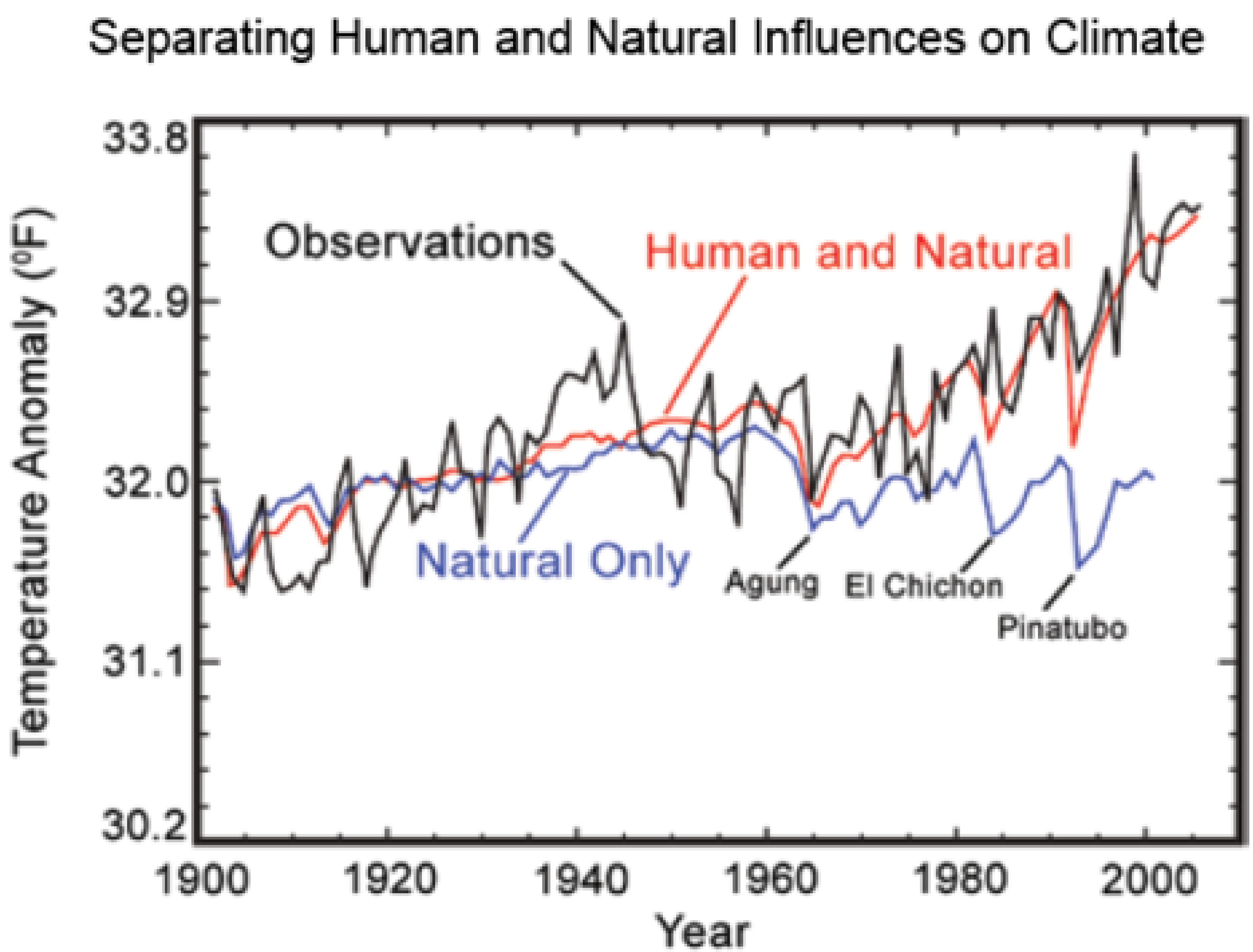
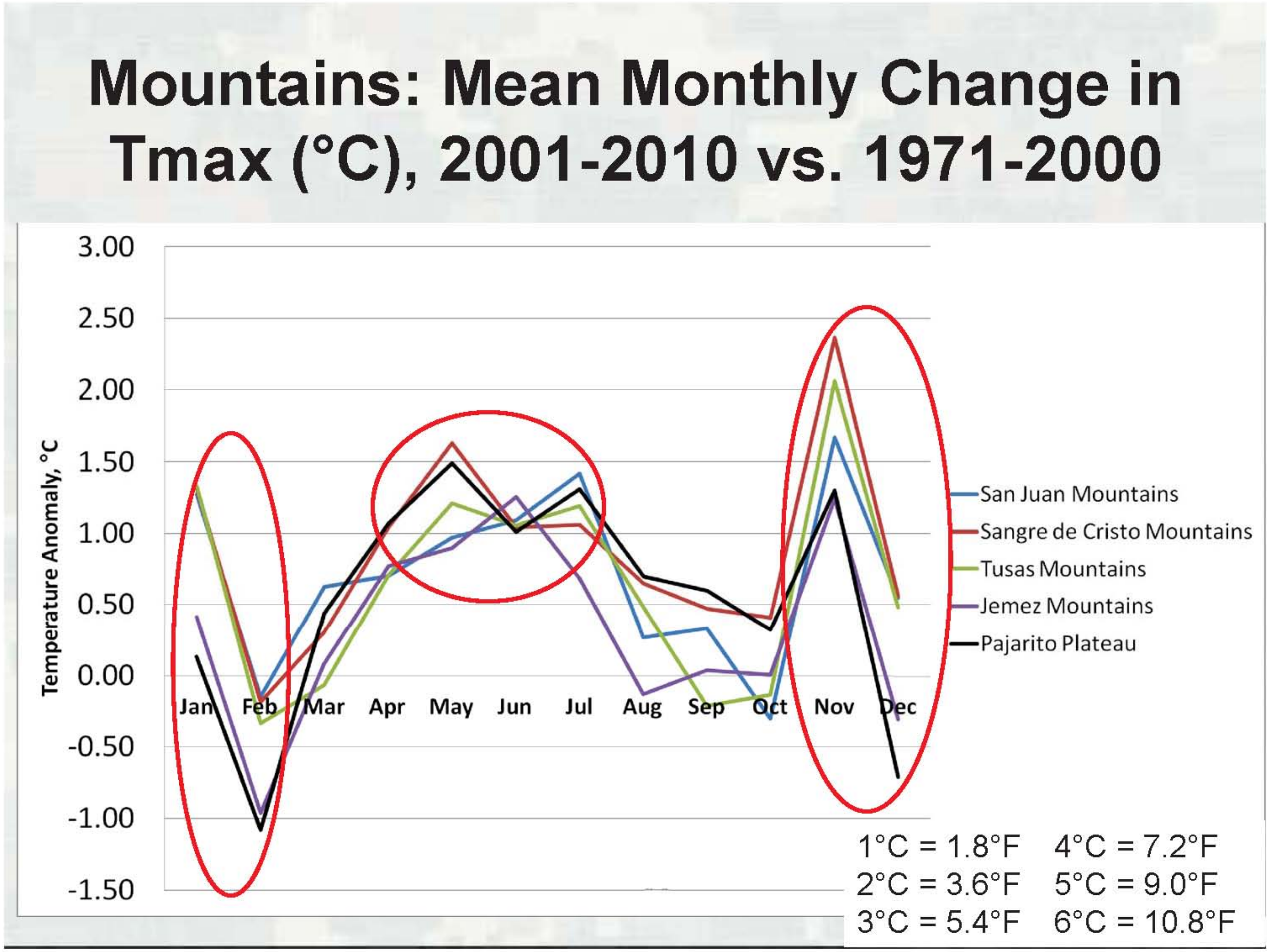
Climate models and their depiction of the causes of recent changes.



The blue line shows how global average temperatures would have changed due to natural forces only. The red line shows the effect of human and natural forces as simulated by climate models. The black line shows actual observed global average temperatures. As the blue line indicates, without human influences, temperature over the past century would actually have first warmed and then cooled slightly.

Temperature Trends in the Upper Rio Grande Basin - Mountains



Source: Ariane Pinson, US Army Corps of Engineers

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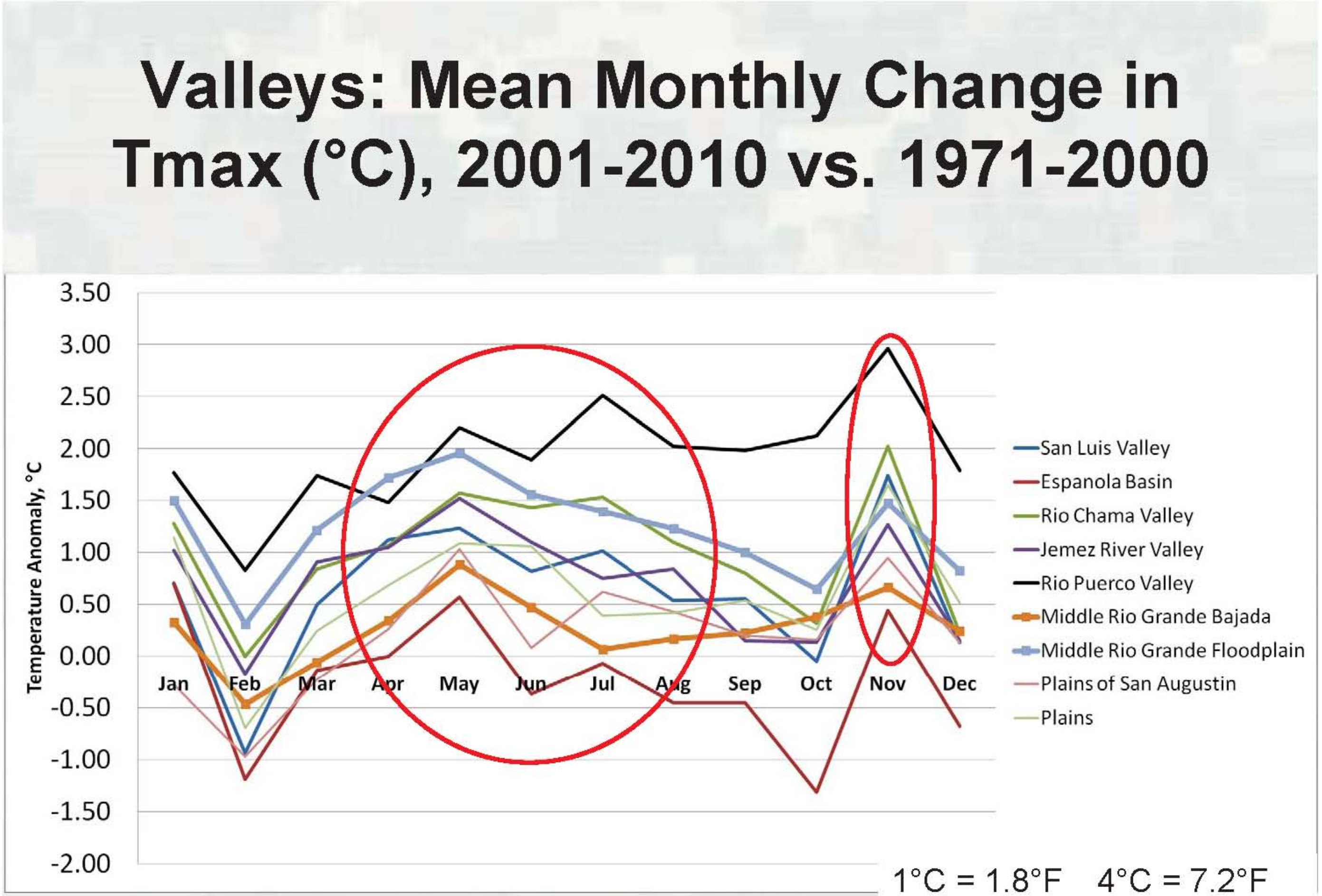
Temperature Trends in the Upper Rio Grande Basin - Valleys



1°C = 1.8°F 4°C = 7.2°F
2°C = 3.6°F 5°C = 9.0°F
3°C = 5.4°F 6°C = 10.8°F

Source: Ariane Pinson, US Army Corps of Engineers

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POLICY FORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2, 3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4, 5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gains and losses of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11, 12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12, 14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17, 18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4, 20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21, 22*), the assumption of stationarity was

Published by AAAS

“Climate change **undermines a basic assumption** that historically has facilitated management of water supplies, demands, and risks.”

Stationarity assumes that the statistical properties of hydrologic variables in future time periods will be similar to past time periods

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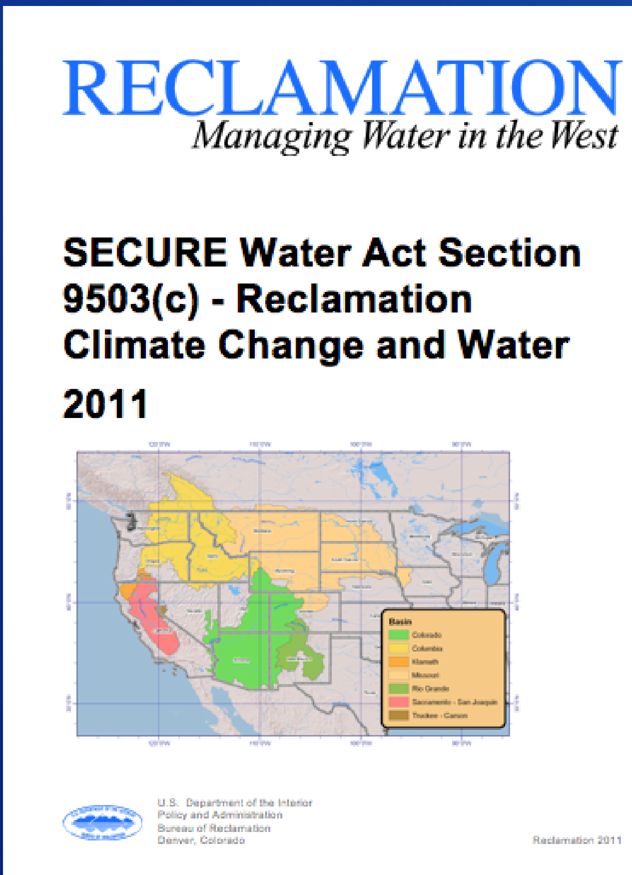
WaterSMART Basin Study Program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SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water

2011

U.S. Department of the Interior
Policy and Administration
Bureau of Reclamation
Denver, Colorado

Reclamation 2011

LCCs ↔ Basin Studies

SECURE Reporting on
Risks / Impacts / Strategies / Feasibility

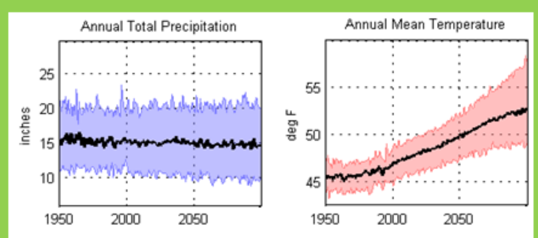
(Coordinated through West-Wide Climate Risk Assessment)

Climate Change Analysis

112 runs
1950-2099

General Circulation Model (GCM)

112 Statistically Downscaled Regional Projections of ΔP and ΔT



112 Runoff Projections Using Rainfall Runoff Model

Variable Infiltration Capacity Model (VIC)

Post processing bias correction of flows (224 hydrographs)

Operations model (URGSiM)

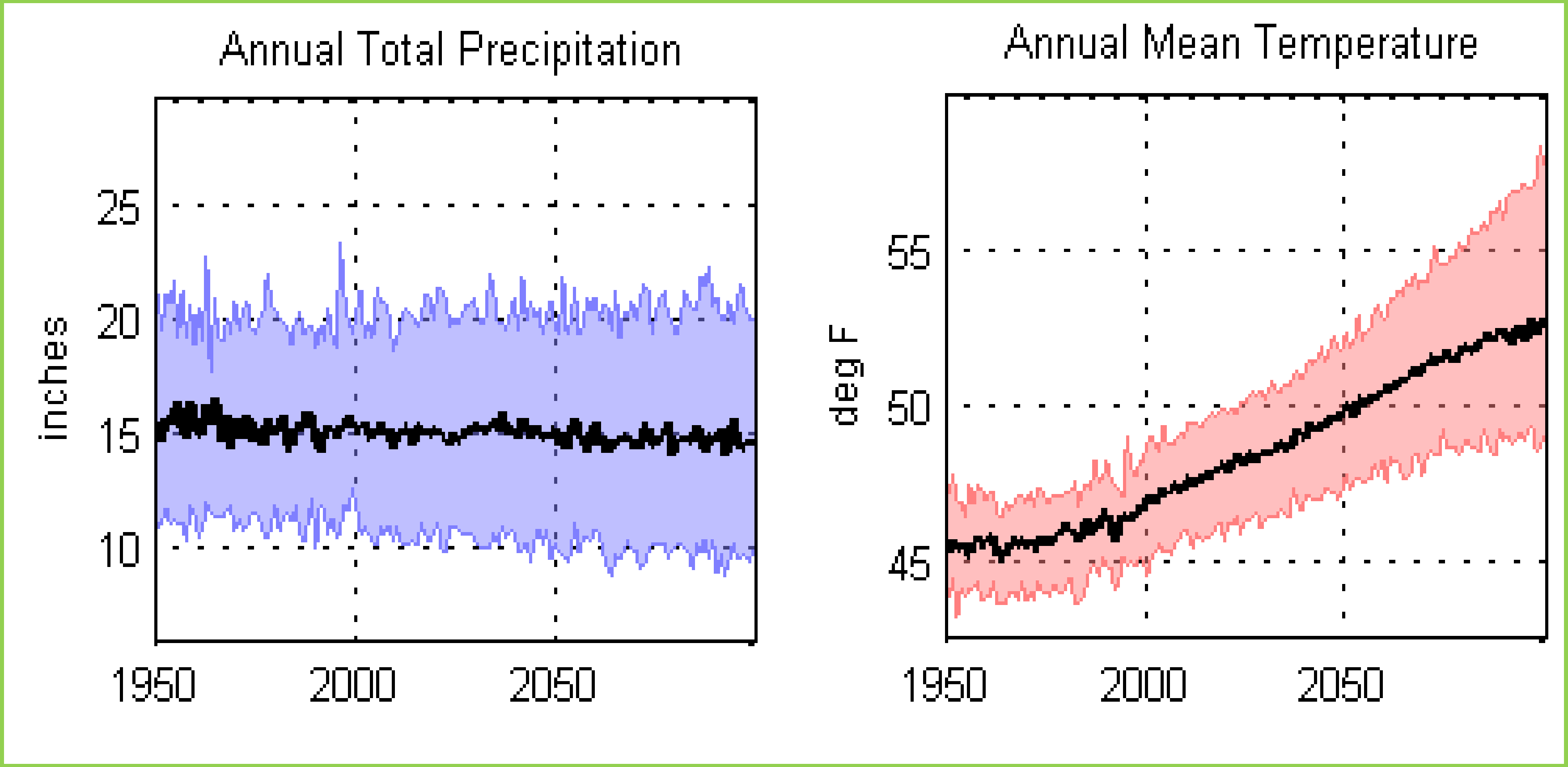
Impacts to water deliveries, flows, and reservoir levels.

Study Partners:

- **Reclamation Office of Policy, Technical Services Center, and Albuquerque Area Office**
- **Sandia National Labs (Jesse Roach)**
- **U. S. Army Corps of Engineers (Ariane Pinson)**

Basin-mean Climate Projections: Warmer, similar precipitation

112, 1/8 Degree Regional Projections of ΔP and ΔT



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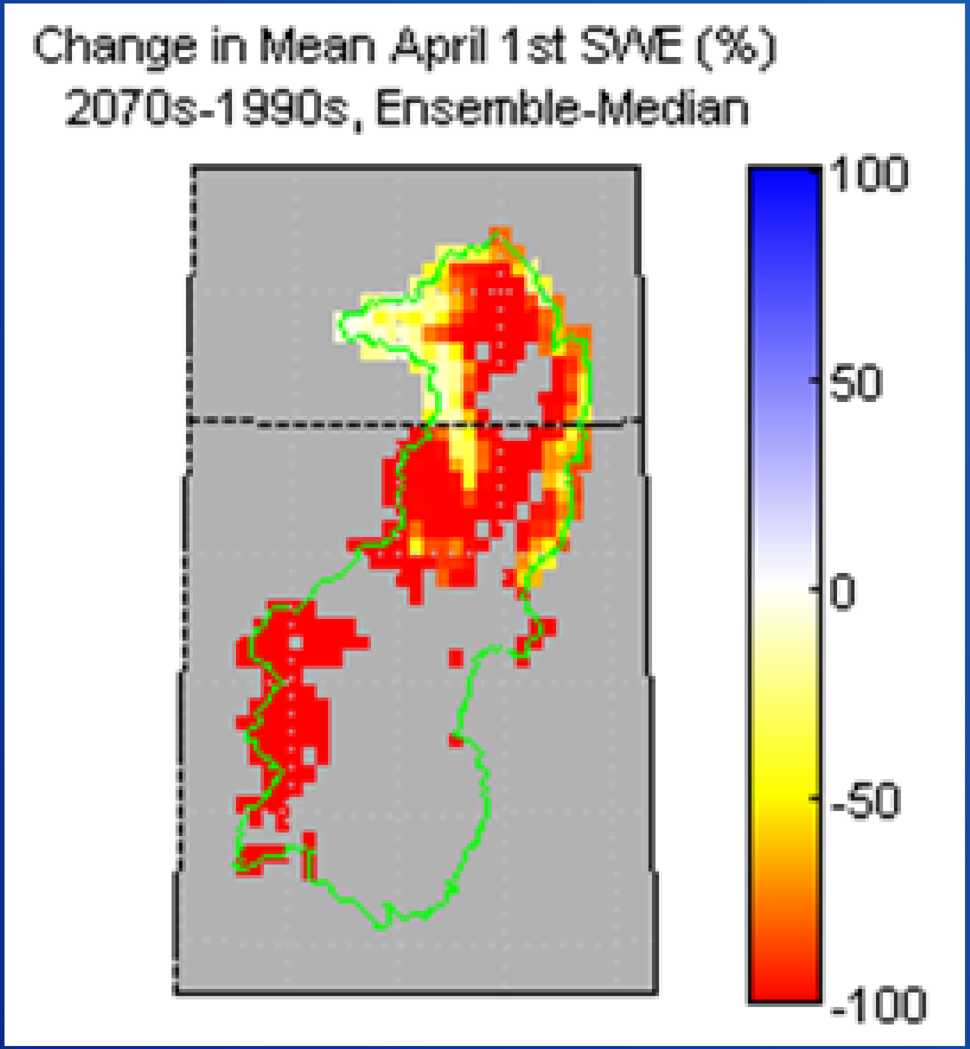
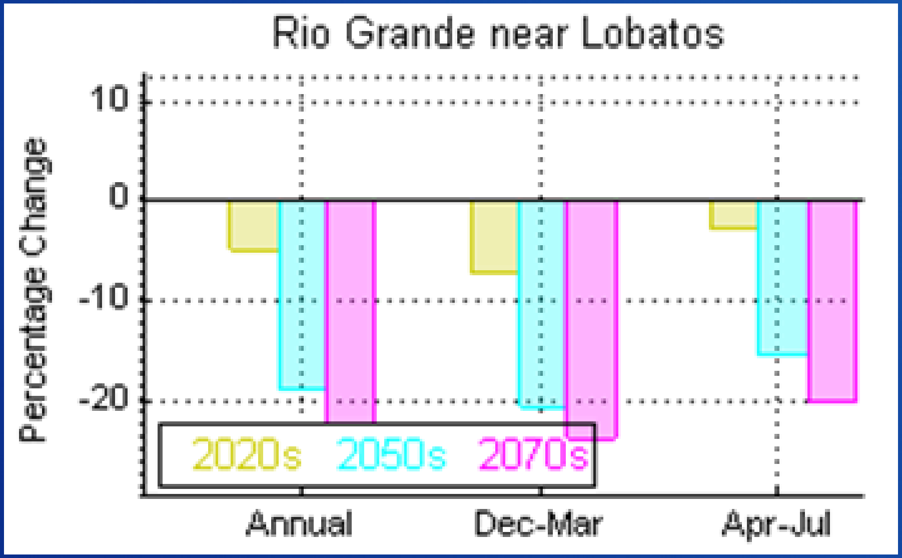
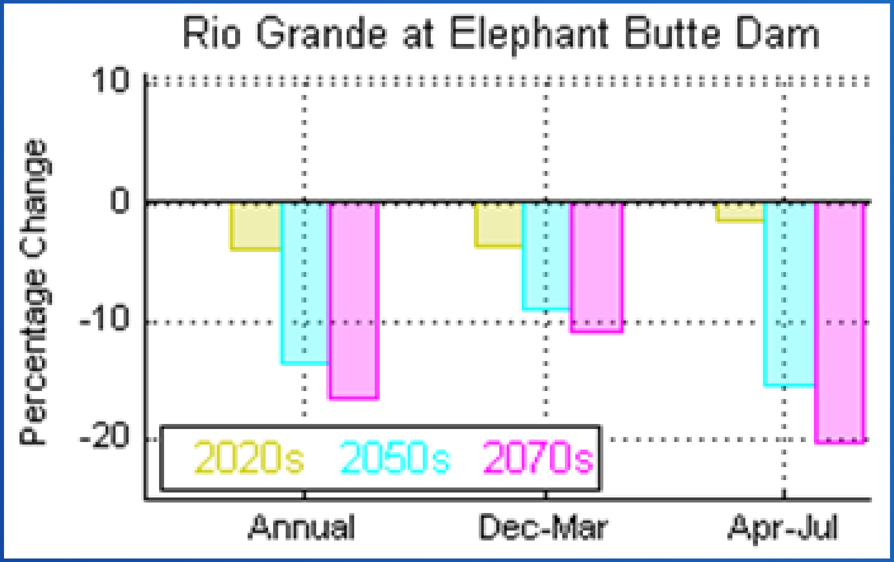
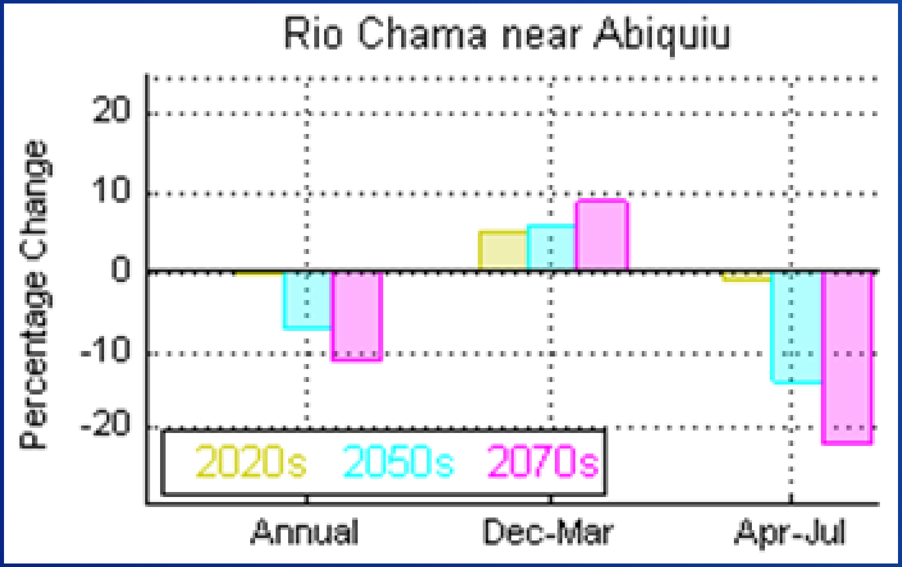
Future Climate:
Basin-Distributed Snow (2070s):



Projected Impacts to Flow Timing







- Decreased annual runoff throughout basin
- Some regions have increased cool season runoff and reduced warm season runoff

Competing Questions

- Floods - Increased storage needed
- Storage – greater need to store for summertime/dry season

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Summer Monsoons…?

Some evidence suggests that the summer monsoons on the Rio Grande may intensify under warmer conditions.
Available climate models are not yet able to simulate the monsoons accurately, so this remains a significant unknown.

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URGSiM

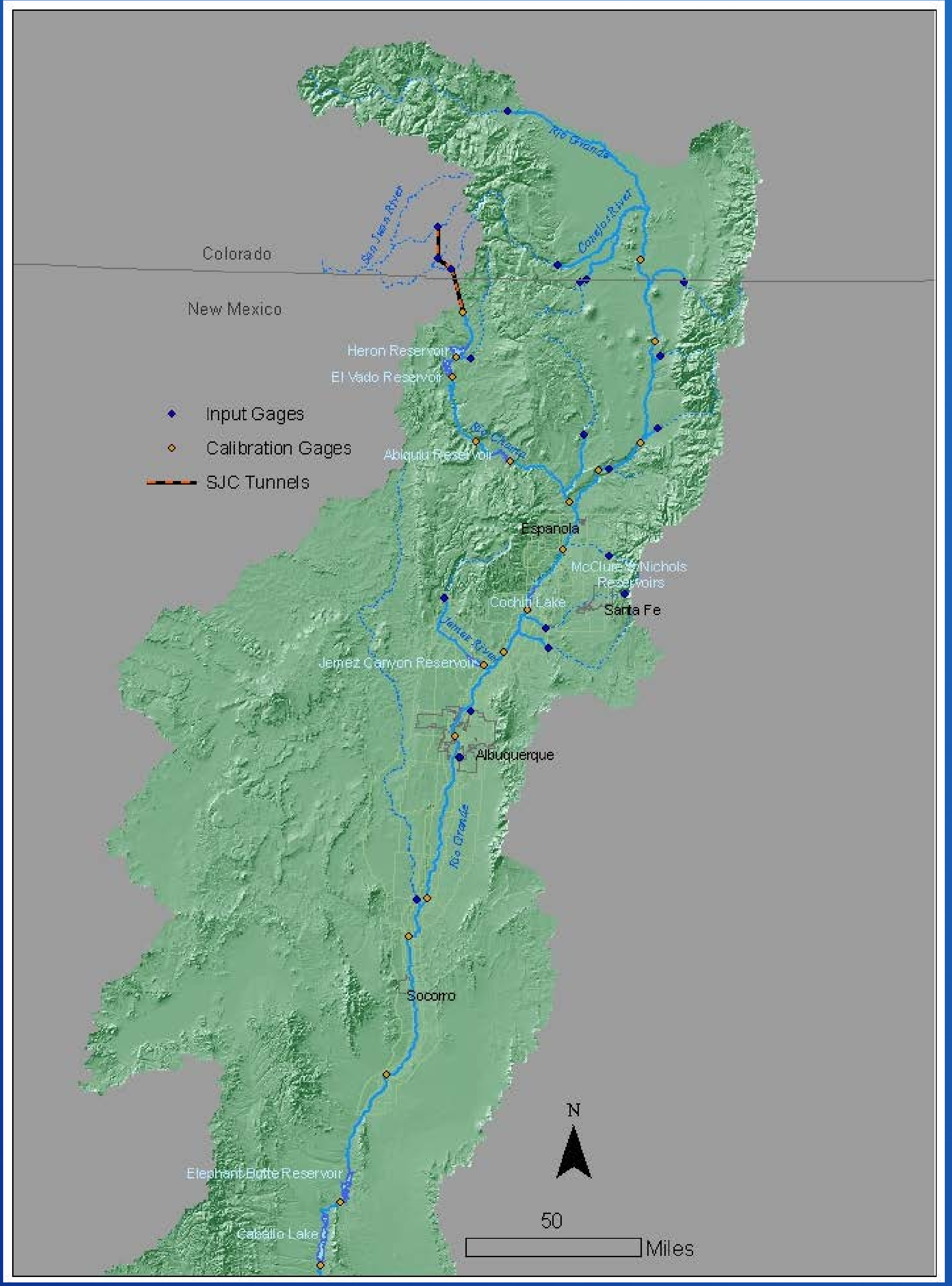
Spatial Extent & Resolution:

Mass Balance Units:

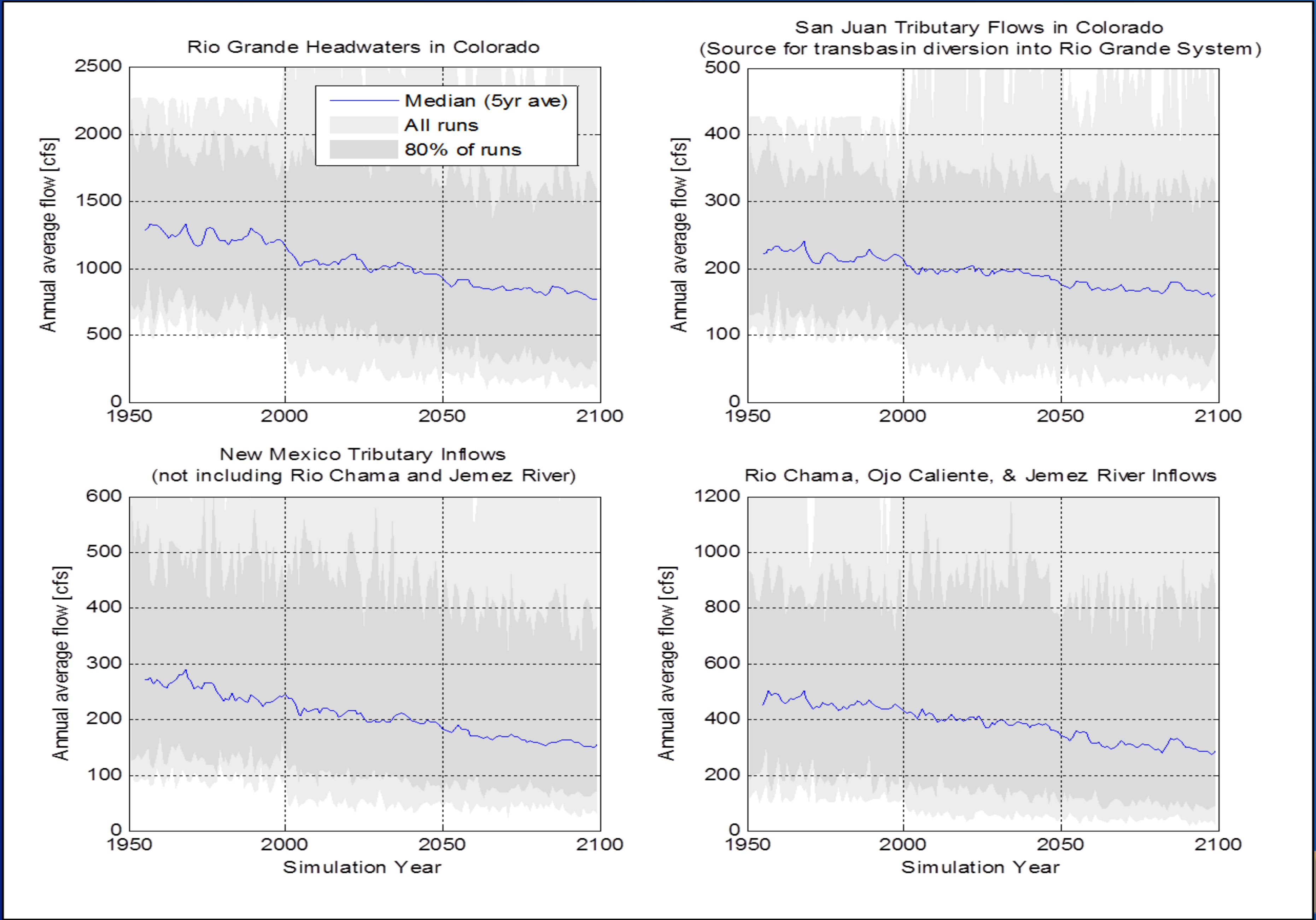
17 river reaches
- 13 Rio Grande
- 5 Rio Chama System
- 1 Jemez River

8 reservoirs
- Heron
- El Vado
- Abiquiu
- McClure + Nichols
- Cochiti
- Jemez
- Elephant Butte
- Caballo

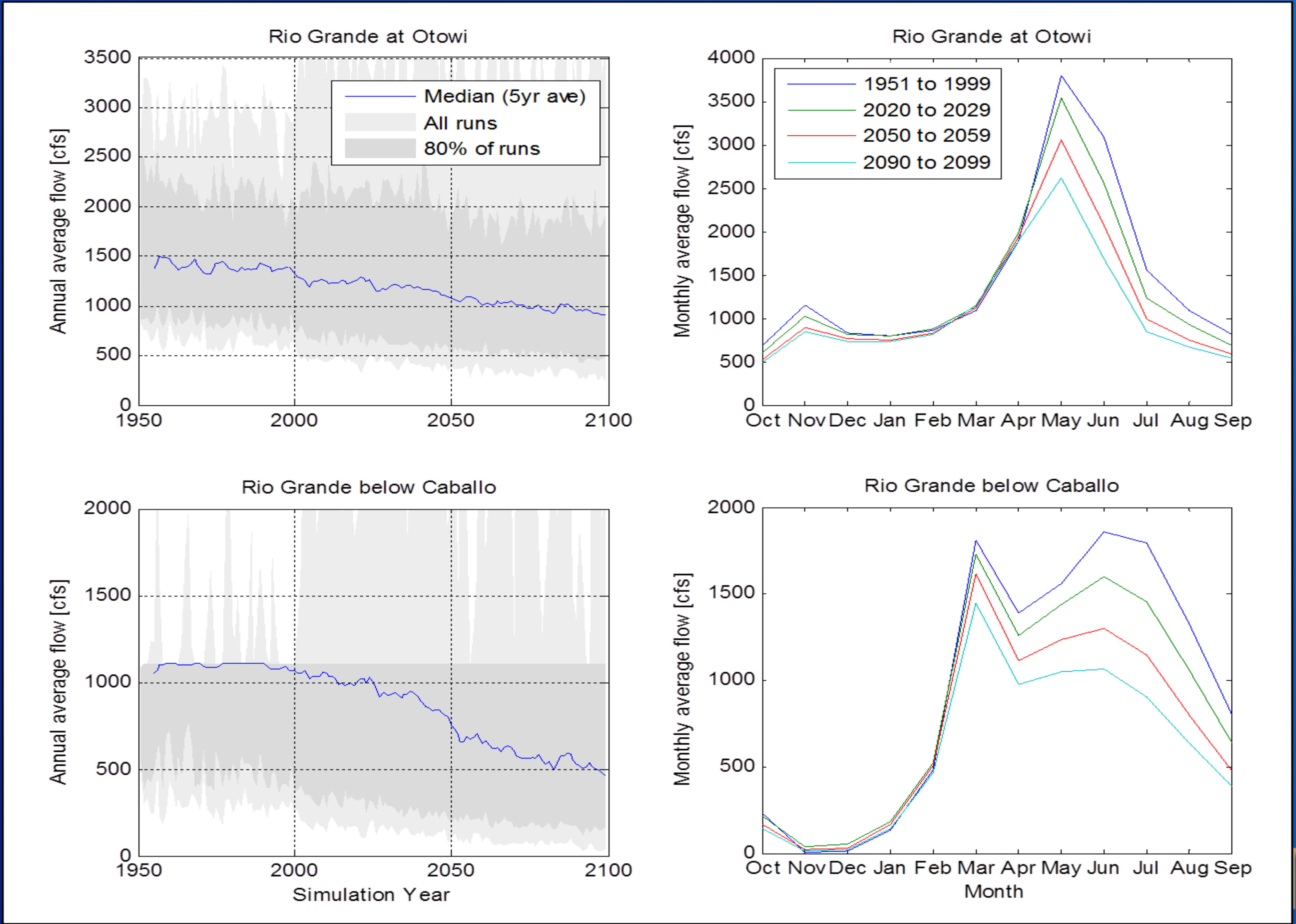
3 regional groundwater aquifers
- Espanola (16 zones)
- Albuquerque (51 zones)
- Socorro (12 zones)



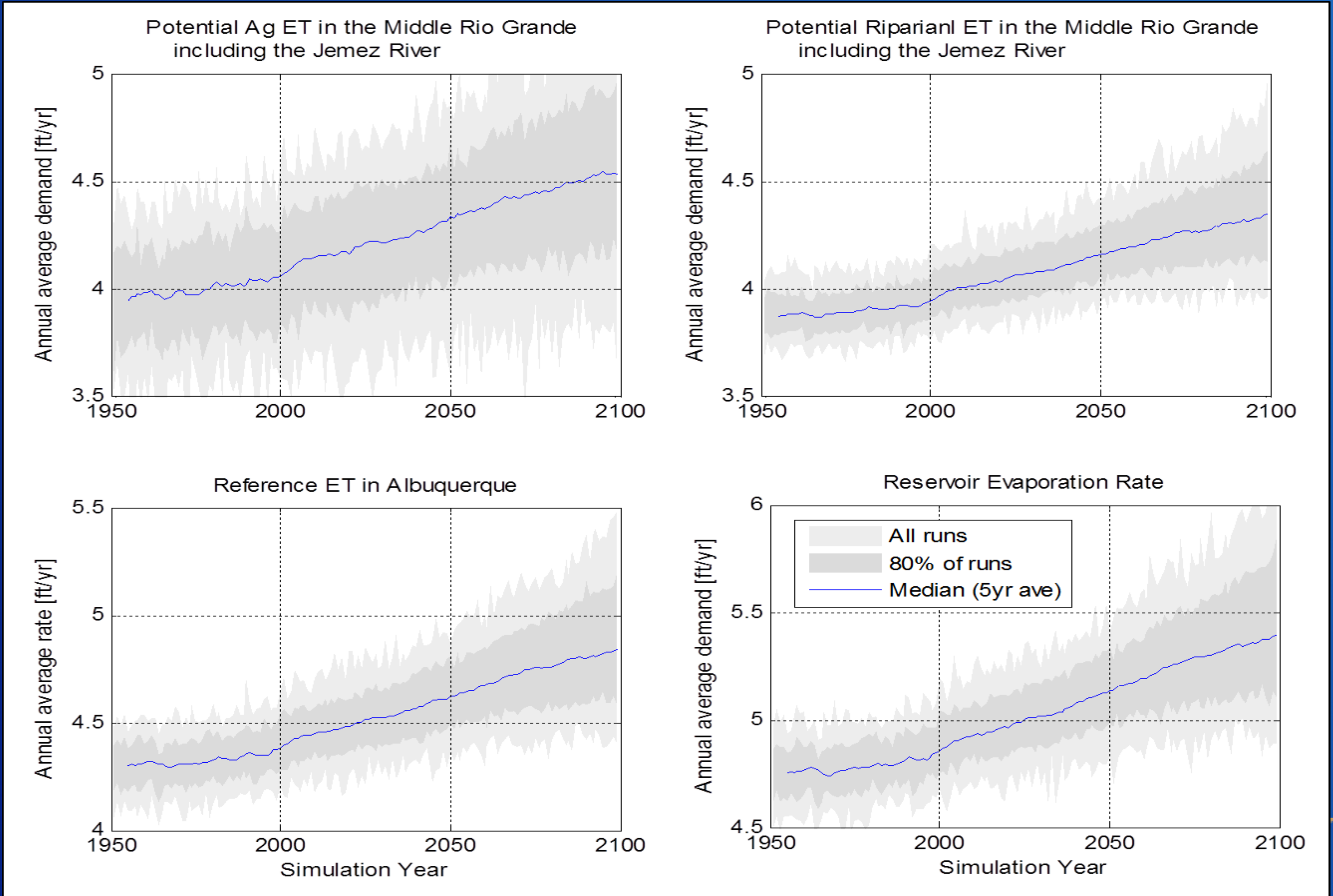
Models Project Reduced System Inflows



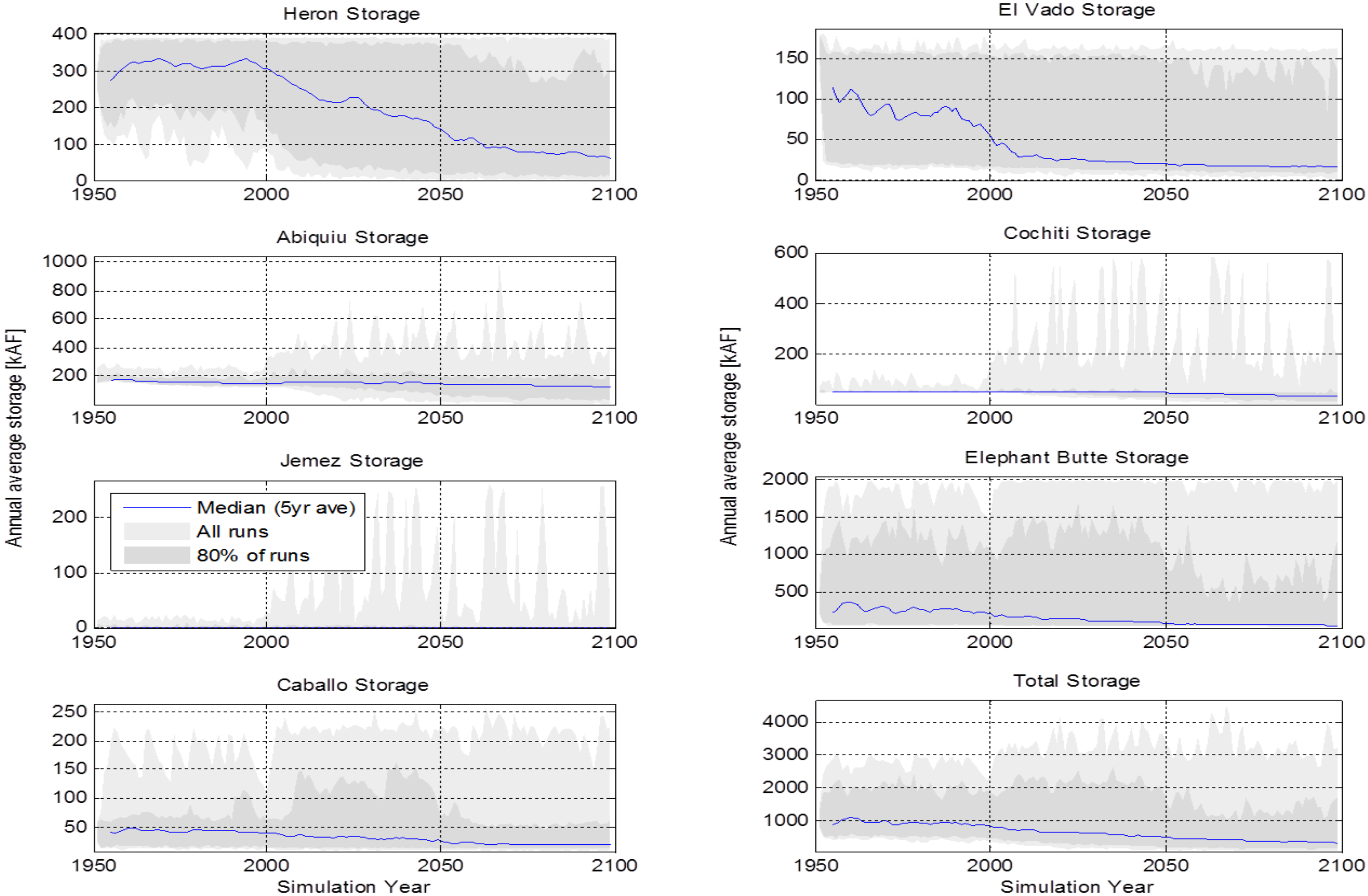
Model-Projected flows at key locations in study area



Models Project Increases in Demand: Agricultural, Riparian, and Reservoir Evaporation



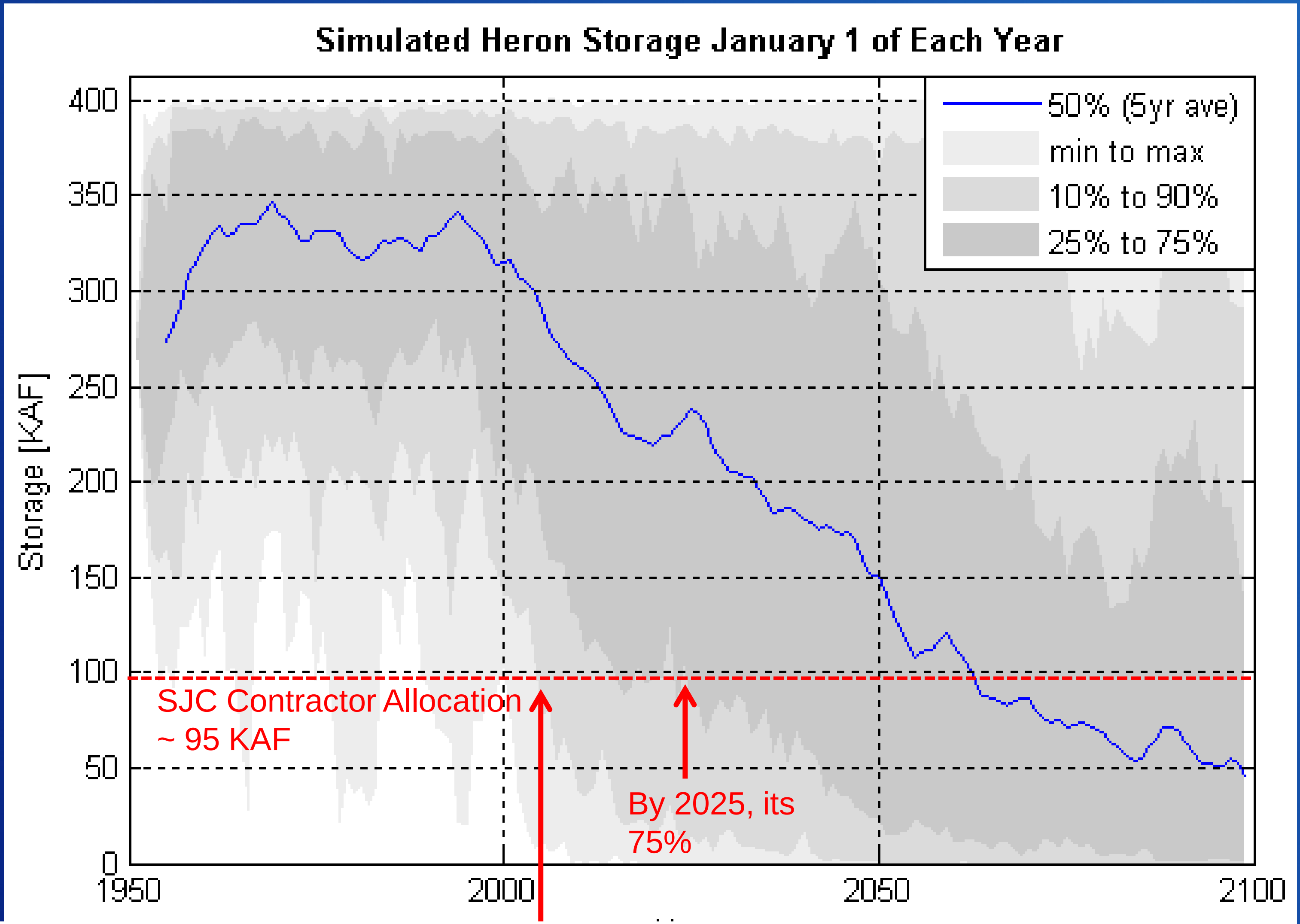
Models Project Decreases in Reservoir Supply



San-Juan Chama Trans-mountain Diversion

- 96,200 acre-feet per year of water that must be consumed in the Middle Rio Grande Valley.
- Has been used to supplement municipal, industrial, agricultural, tribal, and environmental supplies.
- Is projected to be more reliable than the native supply

Model Projections of Storage in Heron Reservoir



(No dead pool in URGSiM representation)

Starting in about 2005, less than 90% of runs start the year with sufficient storage for a full initial allocation

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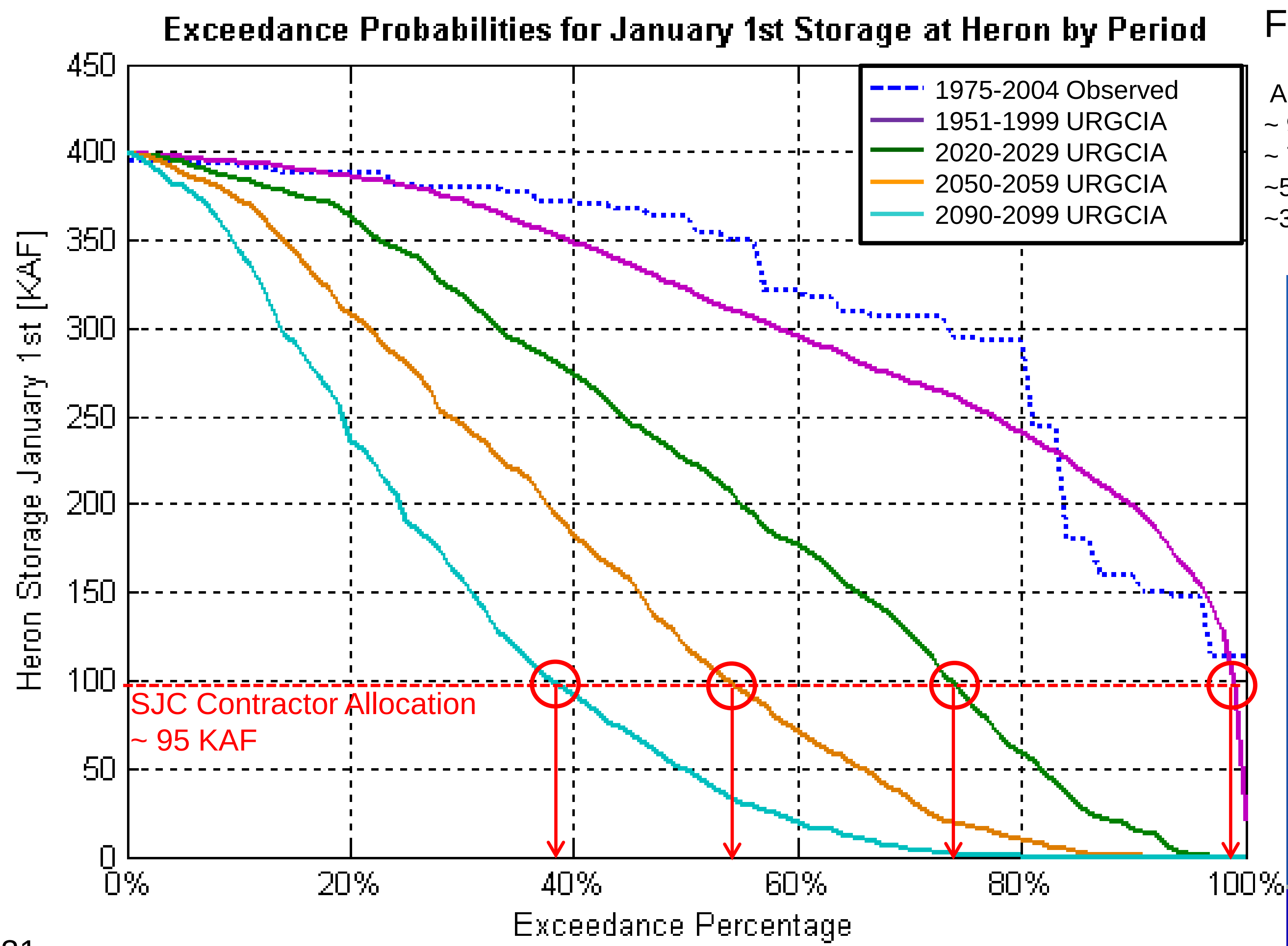
Percent of Years Projected to have a Full Allocation at the Start of the Year.



Full allocation

All years
~ 99% of years
~ 75% of years
~55% of years
~39% of years

Summary of Projected Impacts on Water Management Systems

- **Water Infrastructure, Operations, and Delivery**
- **Hydropower Generation**
- **Flood Control Operations**
- **Water Quality**
- **Fish and Wildlife Habitat**
- **Endangered Species**
- **Flow- and Water-Dependent Ecological Resilience**
- **Recreation**
- **The Rio Grande Compact**

Water Infrastructure and Operations, and Water Delivery:

- The reduced surface-water inflows to the Upper Rio Grande system describe above, coupled with increased irrigated agricultural and riparian vegetation demands, is projected to result in decreased reservoir storage throughout the system, with commensurate impacts on water delivery.

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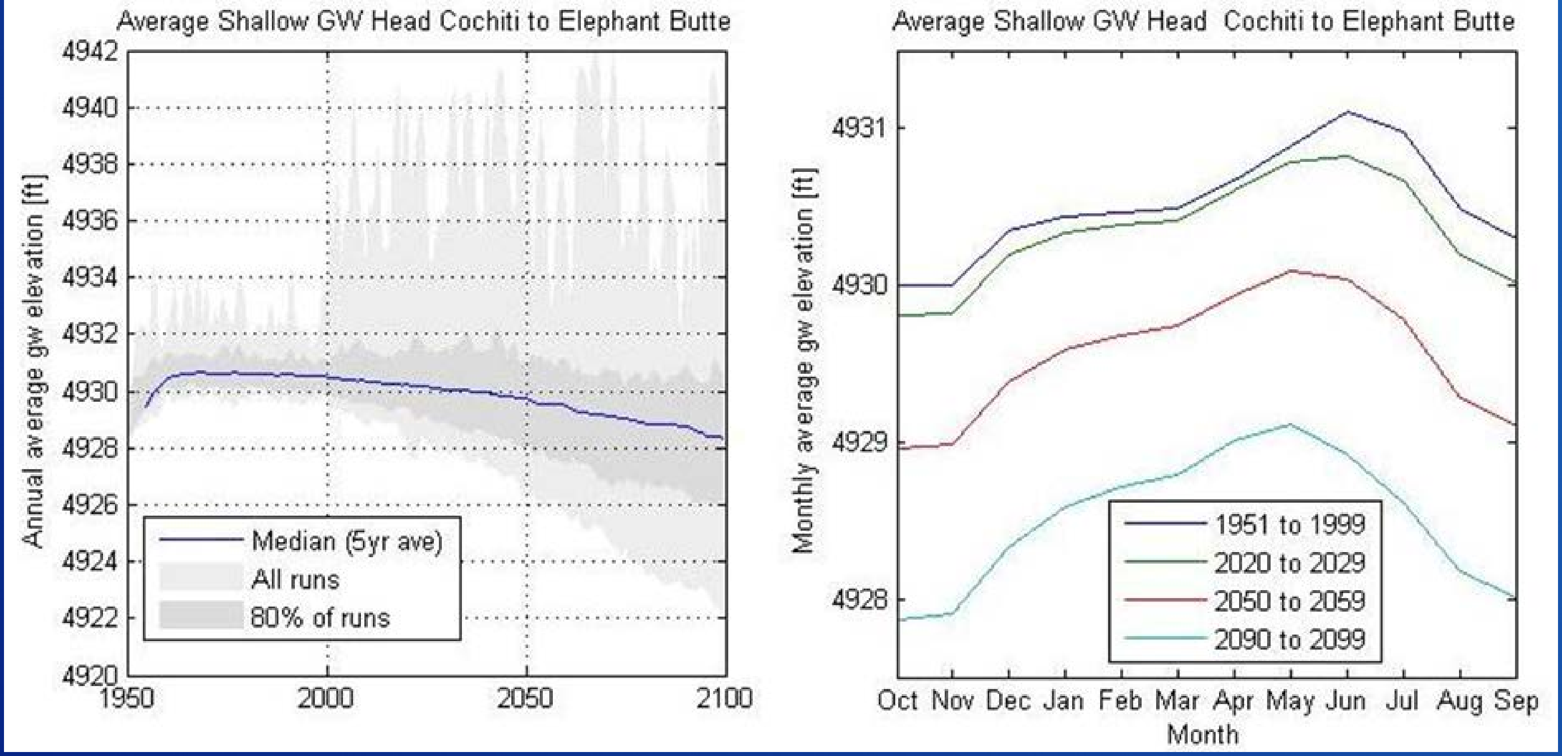
Groundwater Recharge

- **Groundwater receives less primary impact from climate change than surface water, but decreases in surface water availability may lead to increased reliance on groundwater supplies.**



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Hydropower Generation:

- **Lower flows and lower reservoir levels associated with climate change are projected to lead to less hydropower generation. The projected decrease is substantial, from an initial generation within the Upper Rio Grande system of around 15 MW, the rate drops almost 50% to around 8 MW by the end of the century, with most of the decrease coming during the months of May through September**

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Flood Control Operations:

- **Extreme flows are projected to become more extreme with climate change, and thus flood control operations would occur more often going forward.**

Water Quality:

- Concentrations of nitrogen, phosphorus, suspended solids, and salt, may increase in the future under projected warming scenarios in response to increased evaporation rates for surface water and increased "flashiness" resulting from more intense monsoonal precipitation capable of washing a greater volume of pollutants into the river.

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Fish and Wildlife Habitat, including Endangered Species Act (ESA) Listed Species and Critical Habitat:

- **Climate change is projected to cause a reduction of available water in the Upper Rio Grande system. This reduction in water is expected to make environmental flows in the river more difficult to maintain, and reduce the shallow groundwater available to riparian vegetation. Both of these impacts have implications on the habitat of fish and wildlife in the Upper Rio Grande riparian system.**

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Flow and Water-Dependent Ecological Resiliency:

- Ecological and human systems within the basin already operate close to thresholds related to available water supply. In the future, if water supplies decrease and demands increase, water availability thresholds may be crossed, and key systems may undergo regime shifts. It is possible that some systems in the basin have already undergone regime shifts.

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Recreation:

- **Water-based Recreation at Reclamation reservoirs, and river-based recreation, including whitewater rafting and fishing, may be negatively impacted by the projected decreases in flows.**

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Model Simulation of Compliance under the Rio Grande Compact:

- **Colorado** is modeled to utilize its ability for priority administration to assure its obligations are met under the Rio Grande Compact. This results in significant impacts to modeled irrigated acreage.
- **New Mexico** would need to take additional management actions in order to meet its obligations under the projected conditions. A number of methods were modeled showing how NM might meet those obligations, including decreases in irrigated agriculture, decreases in the area of riparian forest, or lining of the river. A combination of these and others methods would likely be used by New Mexico to achieve compliance.

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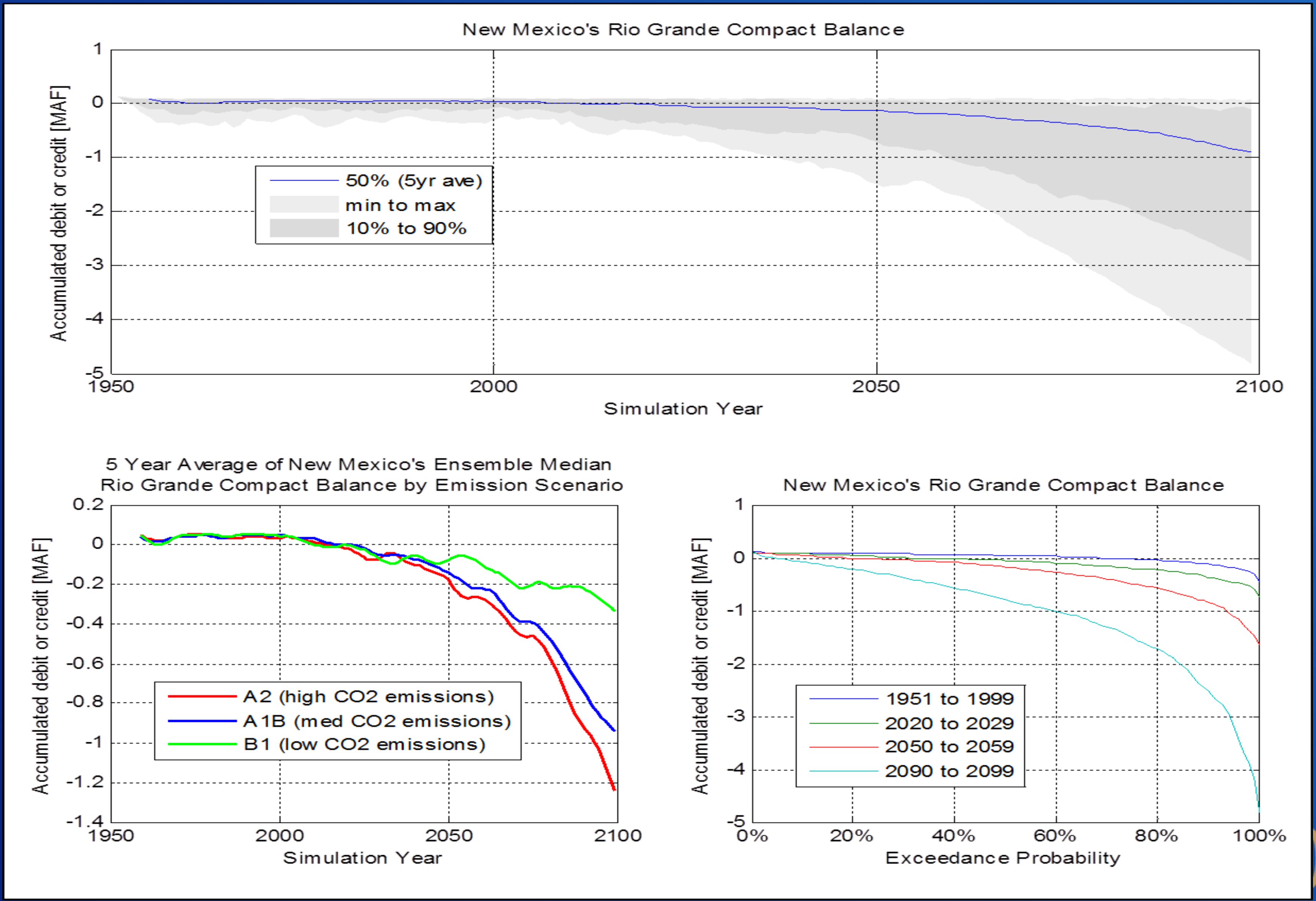
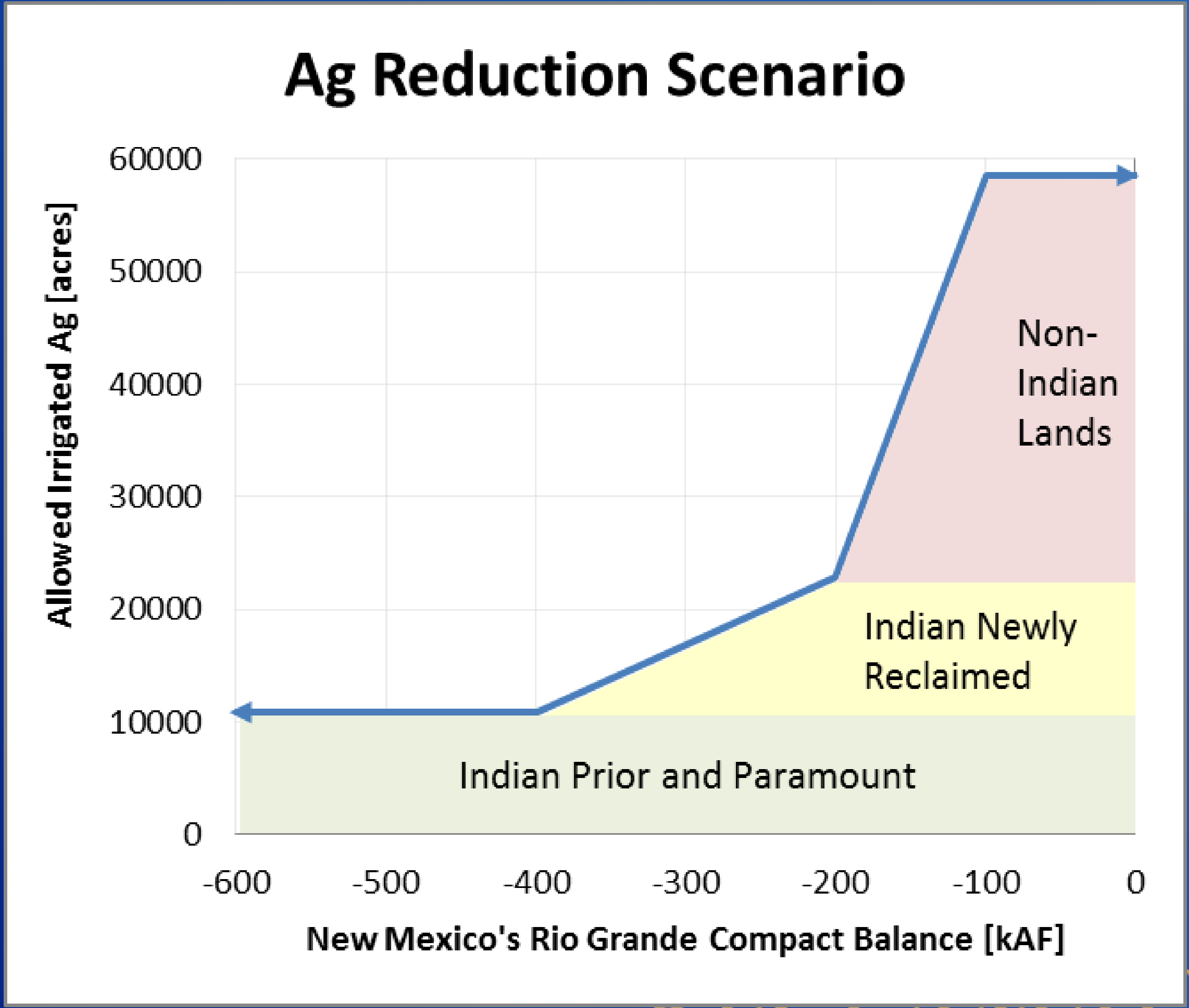
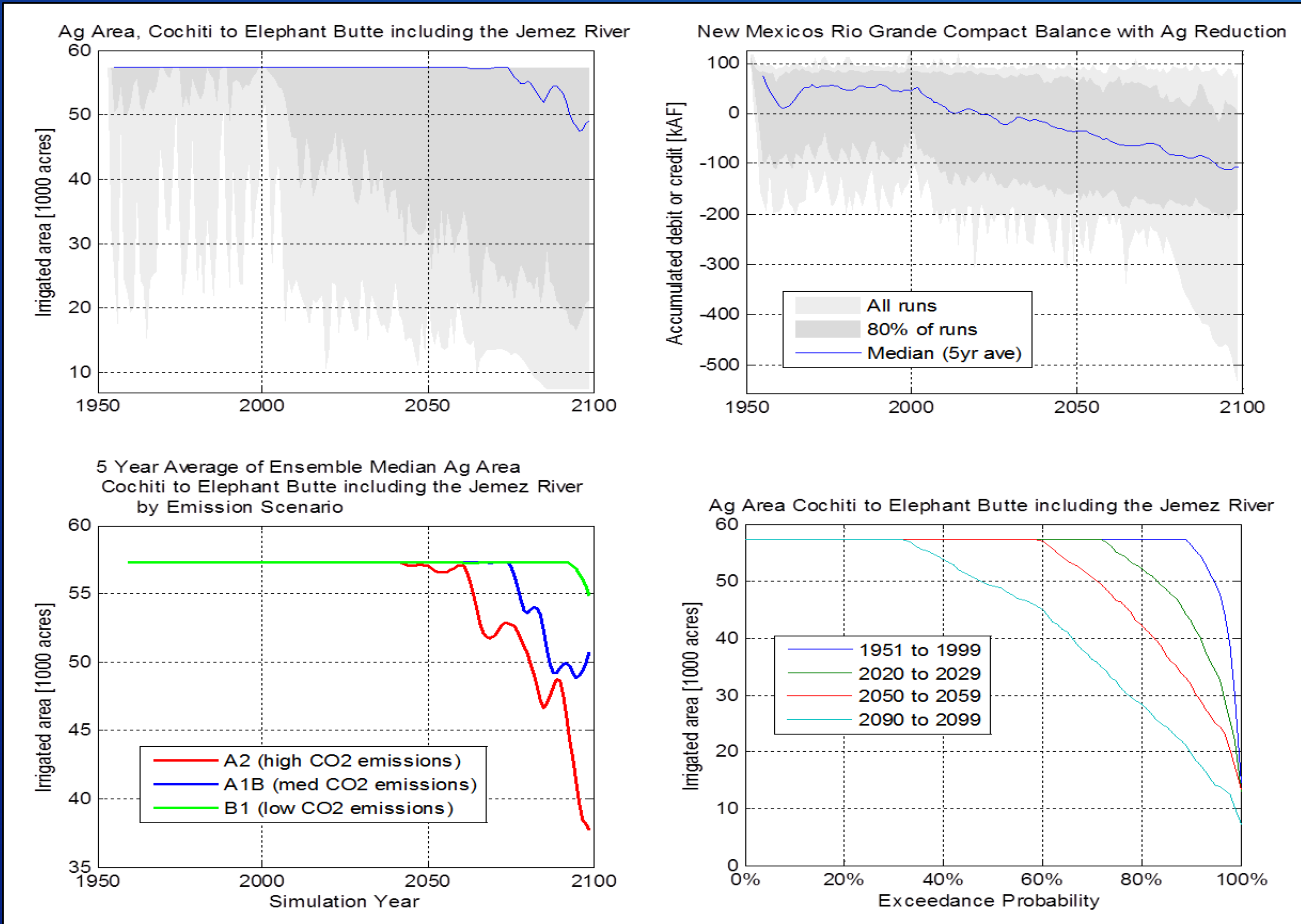
Hypothetical Scenarios: Methods to achieve compliance under the Rio Grande Compact



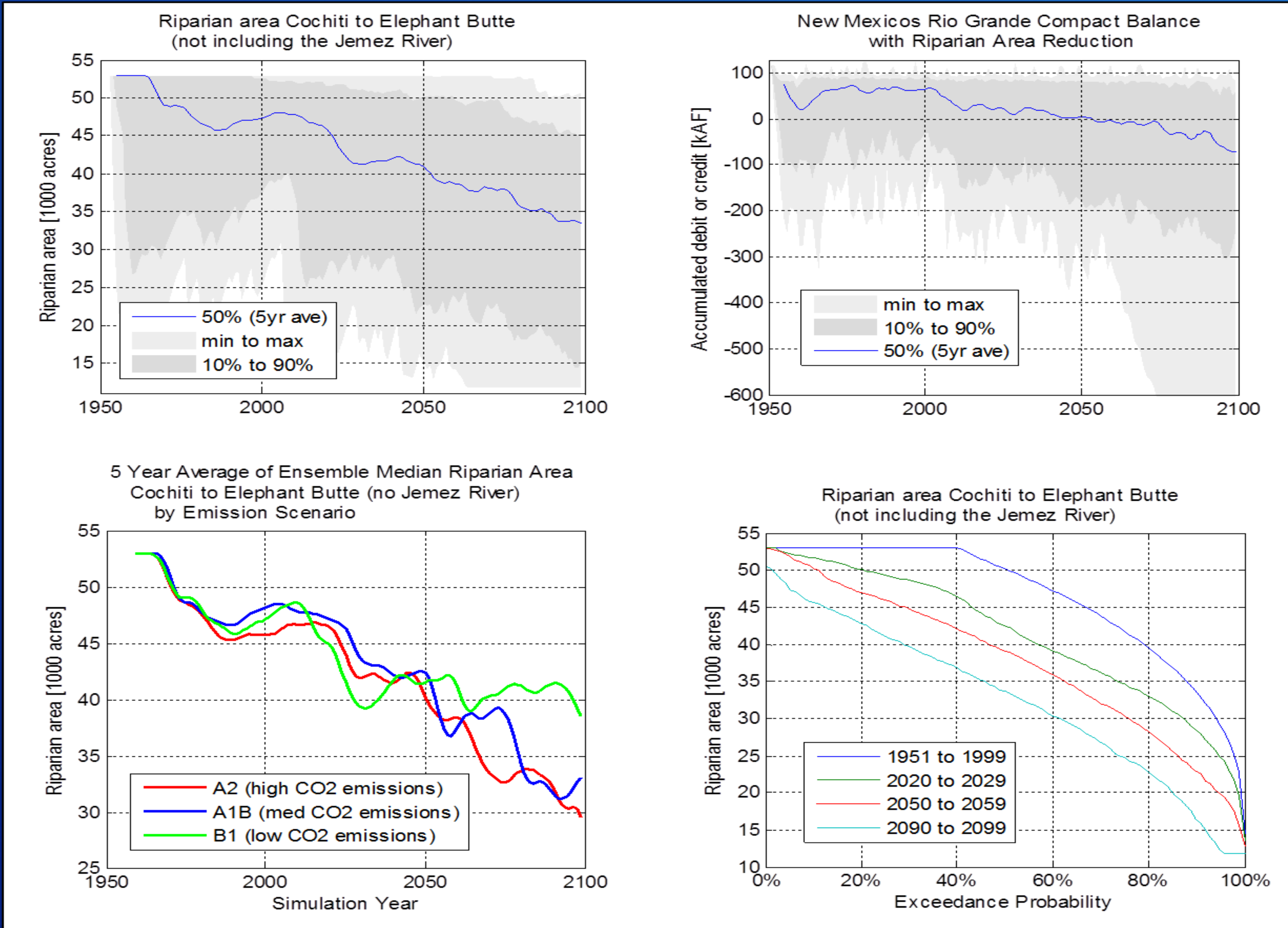
Agricultural Reduction Scenario:



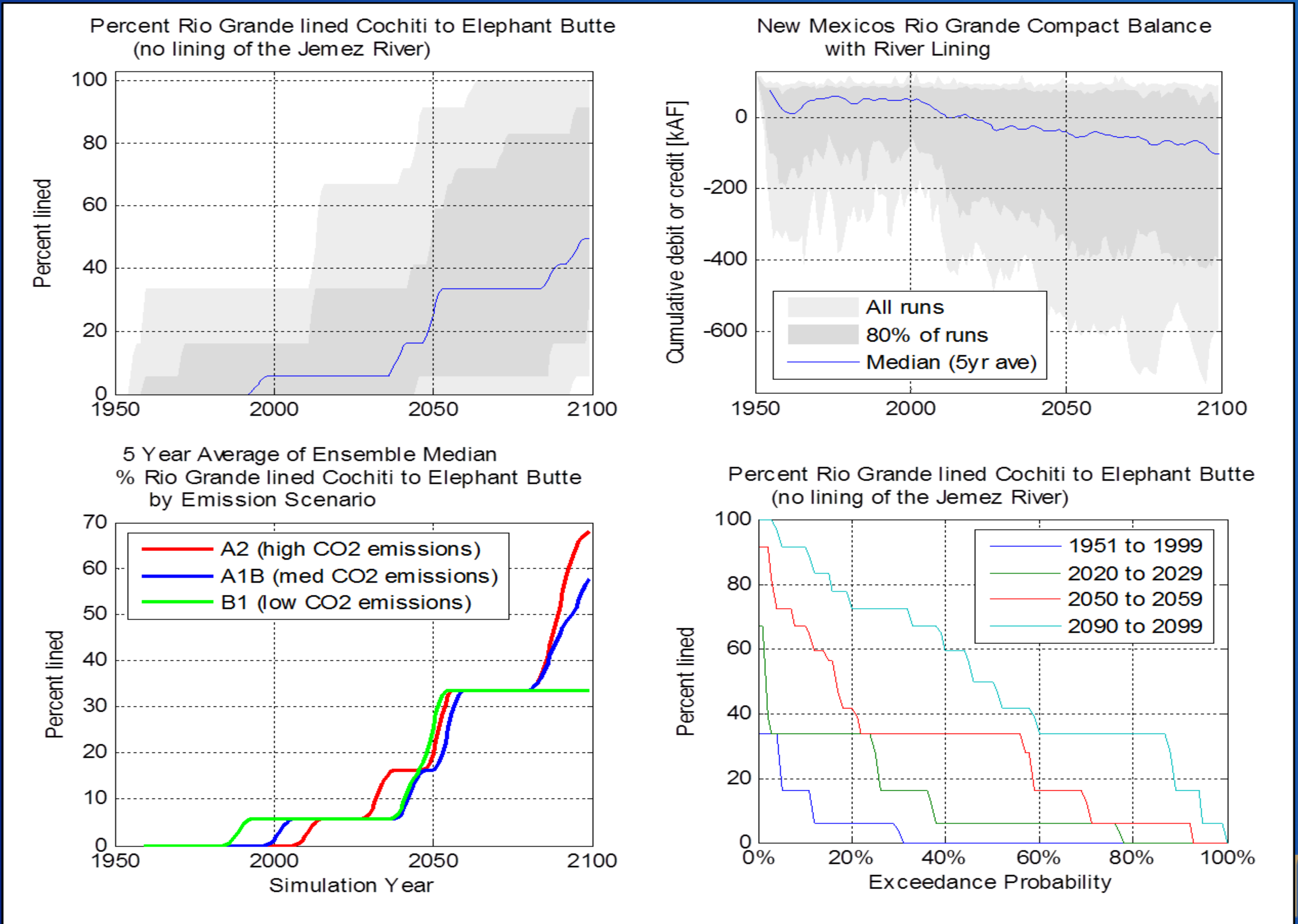
Maintenance of Compliance through Agricultural Reduction



Maintenance of Compliance through Bosque Reduction



Maintenance of Compliance through Concrete River Lining



Overall Changes Projected in Model Runs

- Our usable, manageable water supply will decline, especially winter snowpack; Monsoons remain a significant unknown.
- Our water supply will be subject to increased variability and uncertainty.
- There will be changes in spatial and temporal distribution of water.
- Feedbacks can lead to cascading impacts (as recently seen in New Mexico).
- Everything is confounded by all of the other things that humans do.

Uncertainty

Taking action under Uncertainty involves risk…but so does taking no action.

HE ONLY HAD ENOUGH MONEY FOR ONE, AND FOR THE LIFE OF HIM HE COULDN'T REMEMBER THE DIFFERENCE.

Next Steps: Development of Adaptation and Mitigation Strategies, in partnership with local water-management entities, through the Basin Studies Program

- Identification of Resilience thresholds (tipping points)?
- Enhancement of resilience through increased storage?
- Enhanced conservation and water-use efficiency?
- Prioritization of water uses:
  - Maintenance of irrigated agriculture?
  - Tribal water uses?
  - Urban development?
  - Environmental preservation and endangered species?


OH NO! I'M EVOLVING TO THINK ABOUT INSOLUABLE PROBLEMS!
JOSH '10

Thanks for your attention

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