Is a Perfect Storm Looming for Colorado River Storage?

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Based on a study with coauthors

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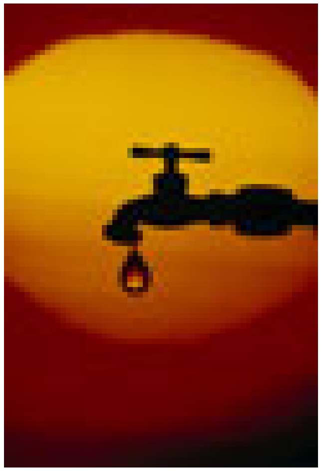

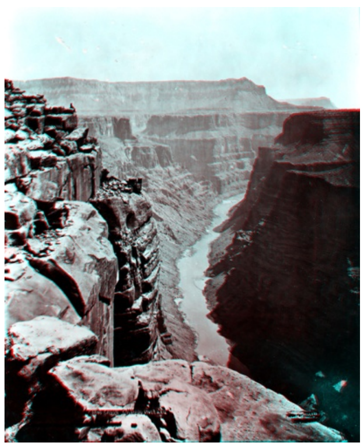

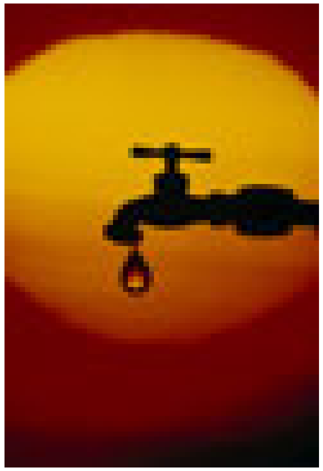

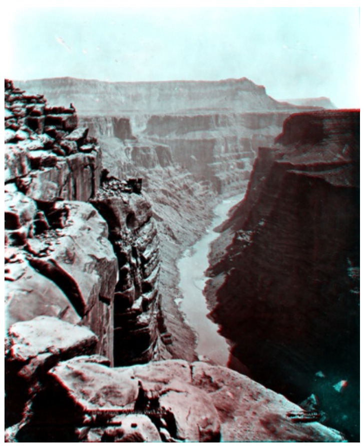

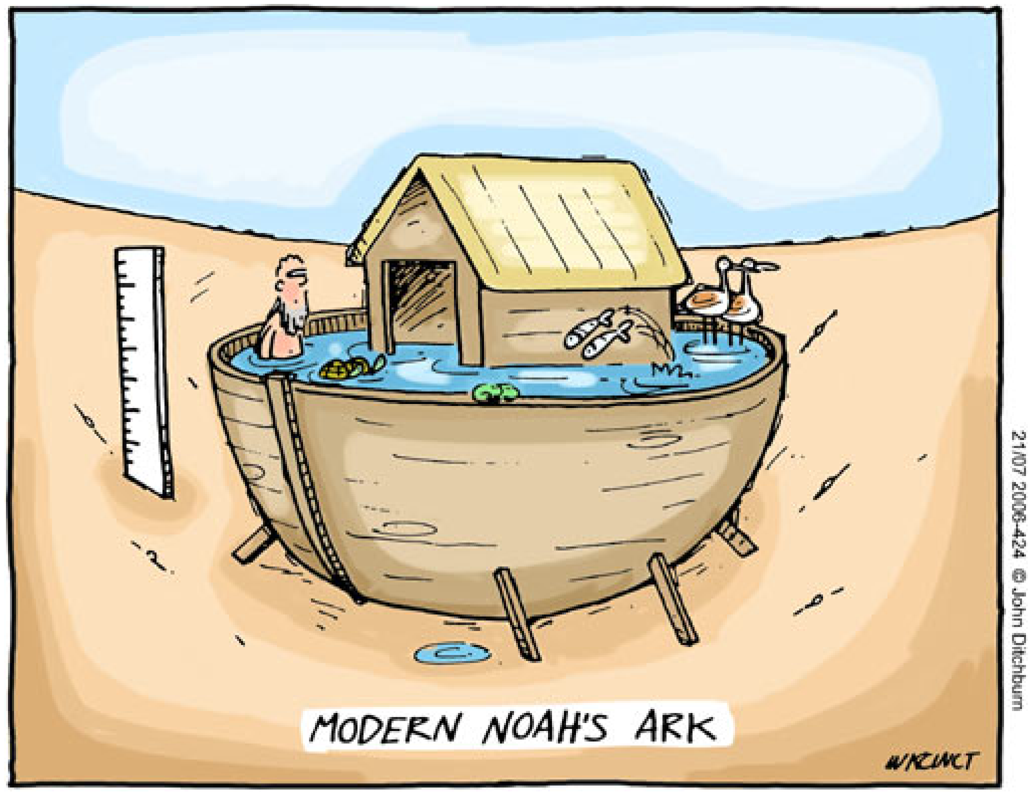
MODERN NOAH'S ARK
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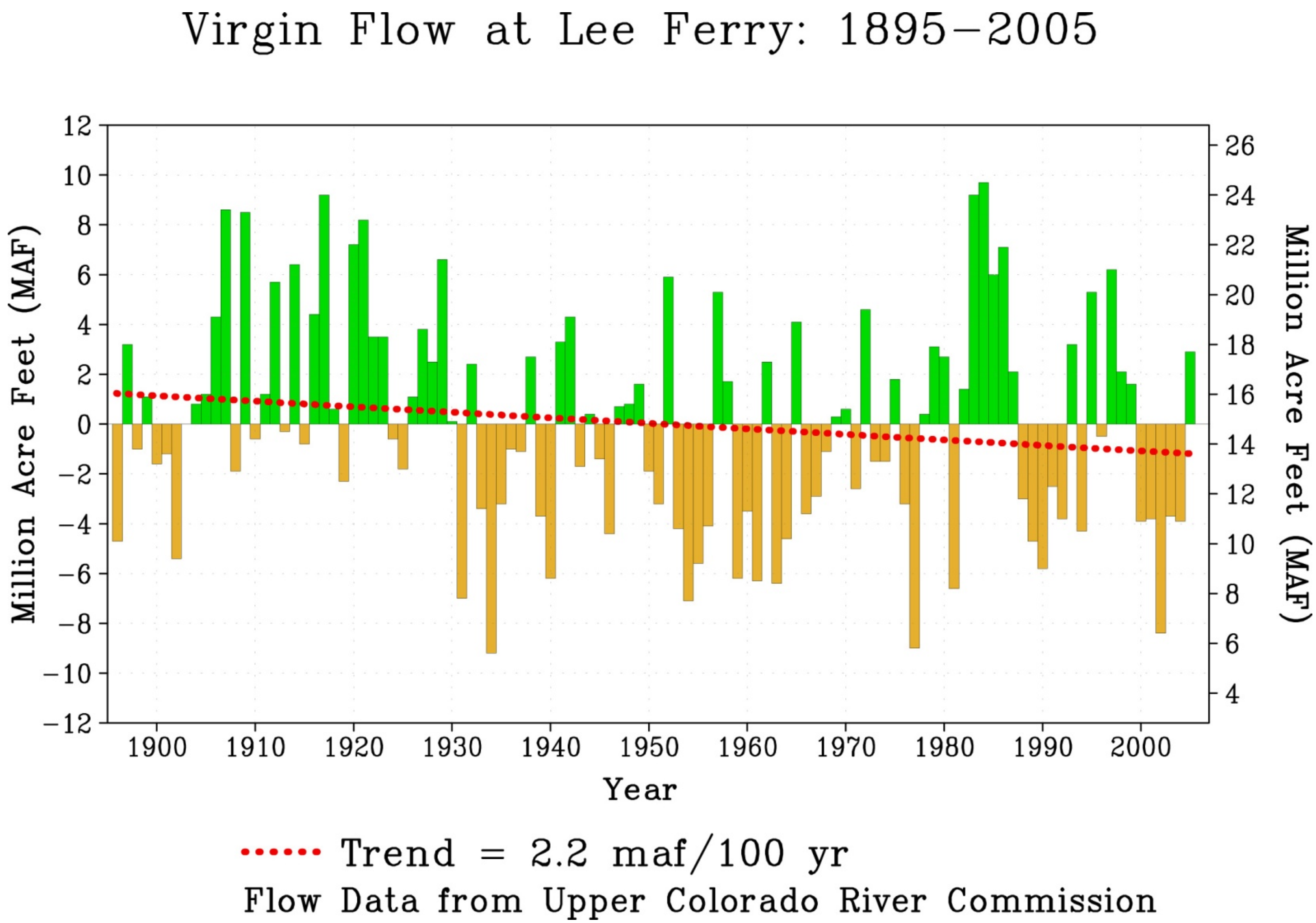
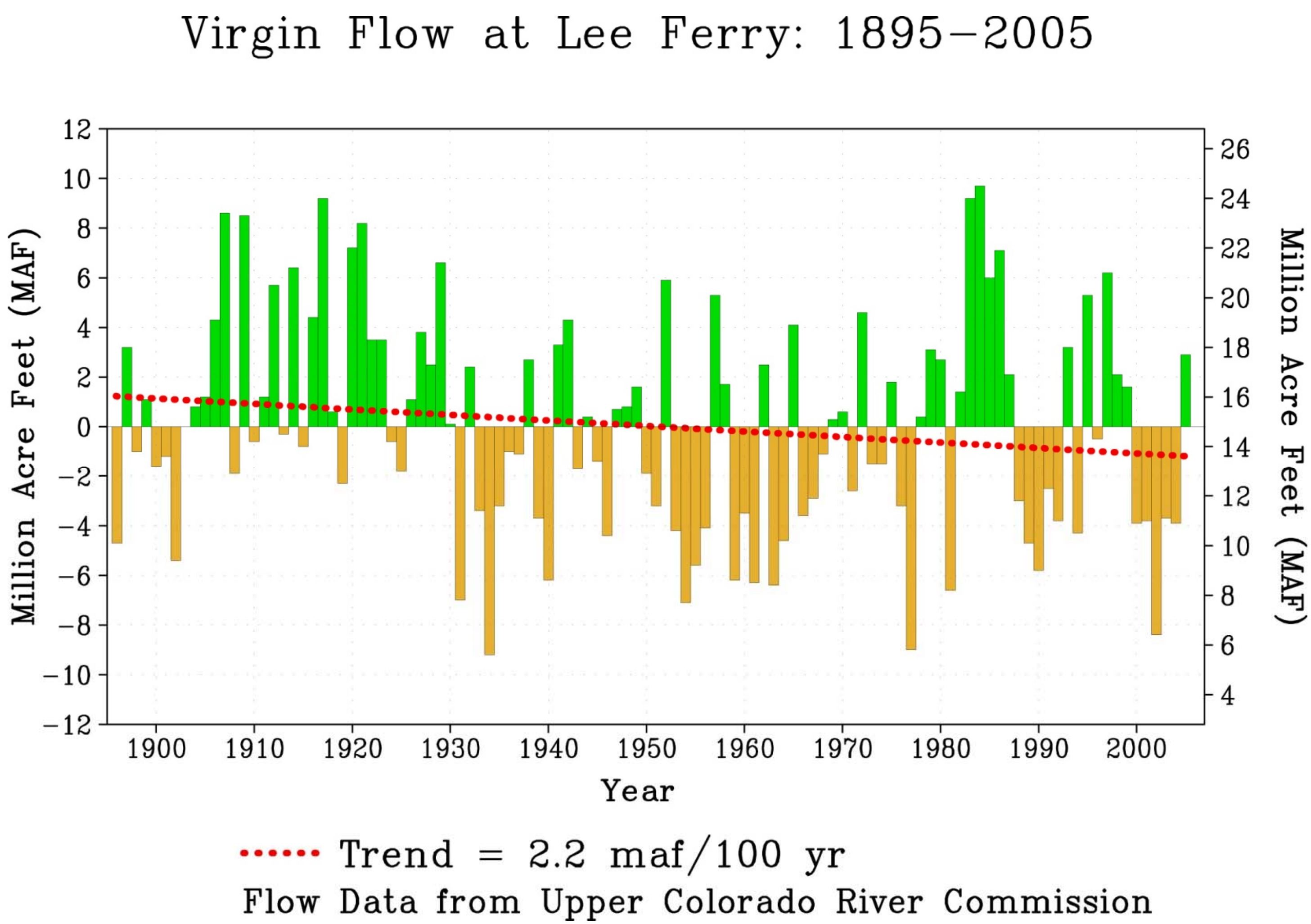

Virgin Flow at Lee Ferry: 1895–2005
Million Acre Feet (MAF)
Million Acre Feet (MAF)
Year
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
26
24
22
20
18
16
14
12
10
8
6
4
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Trend = 2.2 maf/100 yr
Flow Data from Upper Colorado River Commission



- Below normal flows into Lake Powell 2000-2004
  - 62%, 59%, 25%, 51%, 51%, respectively
    - 2002 at 25% lowest inflow recorded since completion of Glen Canyon Dam

How Resilient Is Colorado River Storage to Past Climate?

- Paleo reconstructions indicate
    - 20th century one of the wettest
    - Long dry spells are not uncommon
    - 20-25% changes in the mean flow
    - Rich variety of wet/dry spell sequences
    - All the reconstructions agree greatly on the ‘state’ (wet or dry) information

- *How will the future differ?*

Ongoing Scientific Challenges

- ***What, if any, changes in the frequency, severity, and duration of future drought in the West will occur?***

- ***How will water in the West respond to climate change?***

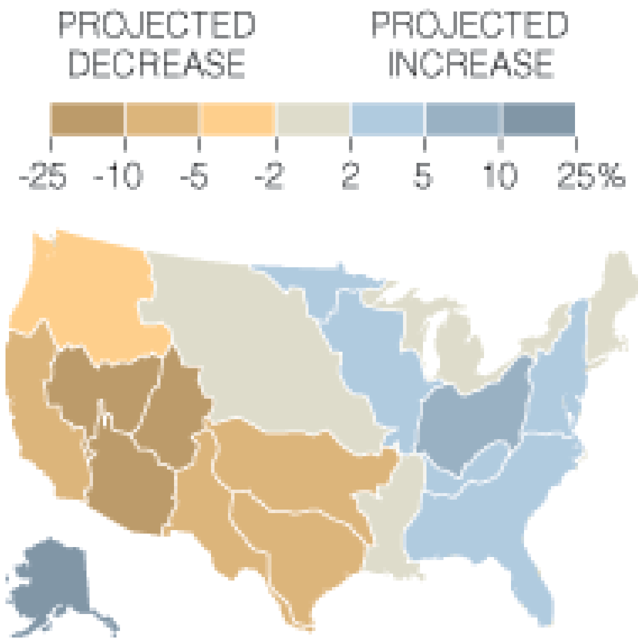
Study	Climate Change Technique (Scenario/GCM)	Flow Generation Technique (Regression equation/Hydrologic model)	Runoff Results	Operations Model Used [results?]	Notes
Stockton and Boggess, 1979	Scenario	**Regression**: Langbein's 1949 US Historical Runoff- Temperature-Precipitation Relationships	*+2C and -10% Precip = ~ -33% reduction in Lees Ferry Flow*		Results are for the warmer/drier and warmer/wetter scenarios.
Revelle and Waggoner, 1983	Scenario	**Regression** on Upper Basin Historical Temperature and Precipitation	+2C and -10% Precip= -40% reduction in Lee Ferry Flow		+2C only = -29% runoff, -10% Precip only = -11% runoff.
Nash and Gleick, 1991 and 1993	Scenario and GCM	**NWSRFS Hydrology model** runoff derived from 5 temperature & precipitation Scenarios and 3 GCMs using doubled CO2 equilibrium runs.	*+2C and -10% Precip = ~ -20% reduction in Lee Ferry Flow*	Used USBR CRSS Model for operations impacts.	Many runoff results from different scenarios and sub-basins ranging from decreases of 33% to increases of 19%.
Christensen et al., 2004	GCM	UW **VIC Hydrology model** runoff derived from temperature & precipitation from NCAR GCM using Business as Usual Emissions.	+2C and -3% Precip at 2100 = -17% reduction in total basin runoff	Created and used operations model, CRMM.	Used single GCM known not to be very temperature sensitive to CO2 increases.
Hoerling and Eischeid, 2006	GCM	**Regression** on PDSI developed from 18 AR4 GCMs and 42 runs using Business as Usual Emissions.	+2.8C and ~0% Precip at 2035-2060 = -45% reduction in Lee Fee Flow		
Christensen and Lettenmaier, 2006	GCM	UW **VIC Hydrology Model** runoff using temperature & precipitation from 11 AR4 GCMs with 2 emissions scenarios.	*+4.4C and -2% Precip at 2070-2099 = -11% reduction in total basin runoff*	Also used CRMM operations model.	Other results available, increased winter precipitation buffers reduction in runoff.

A Large Number of Studies Point to a Drying American Southwest

- Milly et al., 2005
- Seager et a.l, 2007
- IPCC WG1, IPCC WG2, 2007
- National Academy Study, 2007
- IPCC Water Report, 2008
- CCSP SAP 4.3, 2008

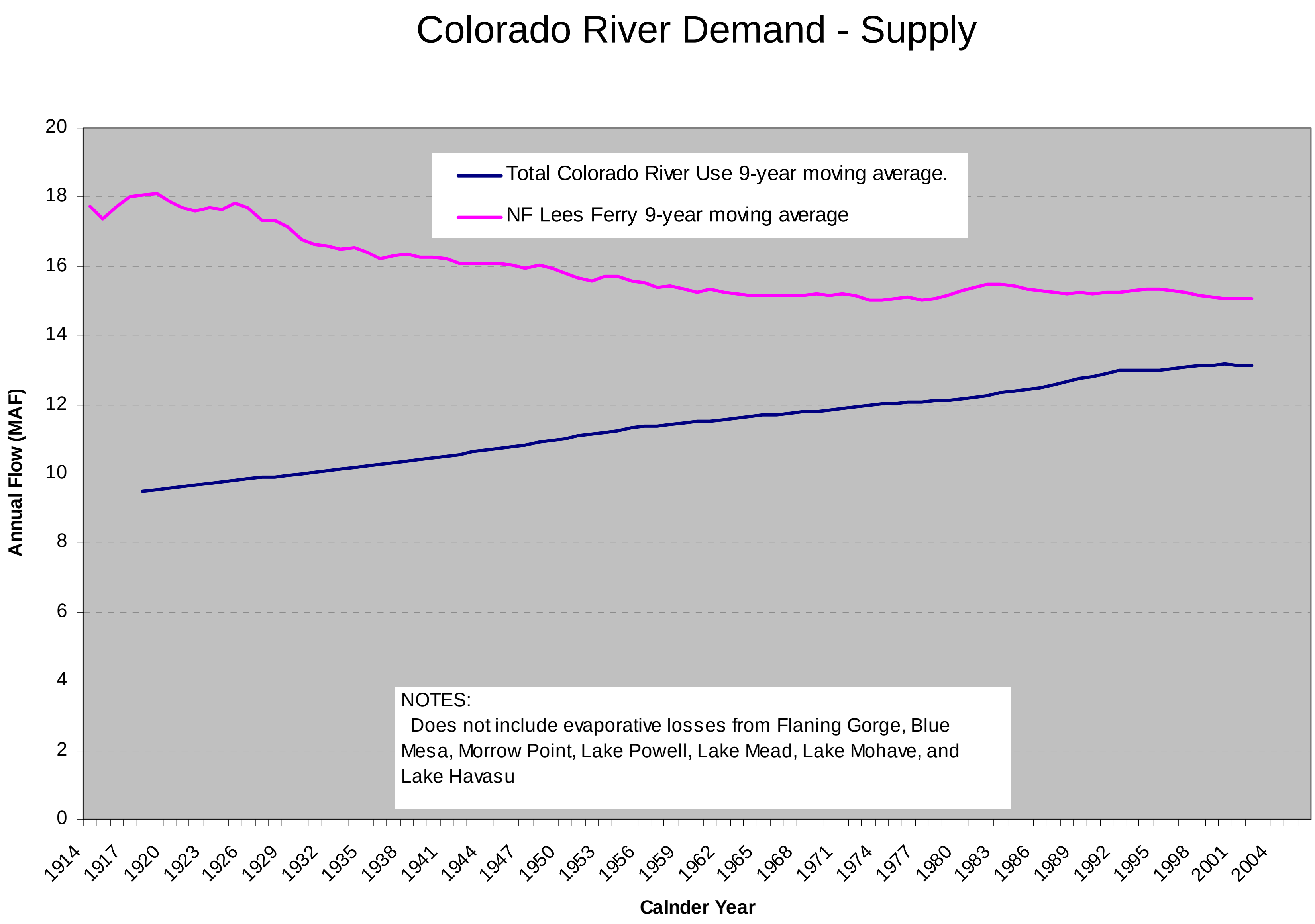
Water Flows in 2040-60

A new federal report compares water flows expected later this century with average water flows from 1901-70. The Southwest is likely to have less water from precipitation, while the Midwest and East are likely to have more.



Source: U.S. Climate Change Science Program

THE NEW YORK TIMES



Colorado River Demand - Supply
Total Colorado River Use 9-year moving average.
NF Lees Ferry 9-year moving average
NOTES:
Does not include evaporative losses from Flaning Gorge, Blue Mesa, Morrow Point, Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu
Annual Flow (MAF)
Calnder Year
0
2
4
6
8
10
12
14
16
18
20
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004

Water Supply System Risk Estimation

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Streamflow Scenarios
Conditioned on climate change
projections

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Water Supply Model
Management + Demand growth alternatives

Water Balance Model

(Modification of Barnett and Pierce, 2008)

Storage in any year is computed as:

Storage = Previous Storage + Inflow - ET- Demand

- **Upper and Lower Colorado Basin demand = 13.5 MAF/yr**
- **Lakes Powell and Mead modeled as one 50 MAF reservoir (active storage)**
- **Initial storage of 25 MAF (i.e., current reservoir content)**
- **Inflow values are natural flows at Lee's Ferry, AZ + Intervening flows between Powell and Mead and below Mead**
- **ET computed using Lake Area – Lake volume relationship and an average ET coefficient of 0.436**

Management and Demand Growth Combinations

1. *The interim EIS operational policies employed with demand growing based on the upper basin depletion schedule.*

INTERIM EIS		INTERIM EIS PLUS		NEW THRESHOLD	
Res. Storage (%)	Shortage (kaf)	Res. Storage (%)	Shortage (% of current demand)	Res. Storage (%)	Shortage (% of current demand)
36	333	36	5	50	5
30	417	30	6	40	6
23	500	23	7	30	7
				20	8

Management and Demand Growth Combinations

1. ***The interim EIS operational policies employed with demand growing based on the upper basin depletion schedule.***
2. 1. with the demand fixed at the 2008 level.
3. ***1. with larger delivery shortages post 2026 (EIS Plus).***
4. 3. with a 50% reduced upper basin depletion schedule.
5. ***4. with full initial storage.***
6. 4. with post 2026 policy that establishes new shortage action thresholds and volumes.
7. 6. with demand fixed at the 2008 level.

All the reservoir operation policies take effect from 2026

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Water Supply System Risk Estimation

Streamflow Scenarios
Conditioned on climate change projections

Water Supply Model
Management + Demand growth alternatives

System Risk Estimates
For each year

Risk of Reservoir Drying Under Natural Climate Variability
No Climate Change

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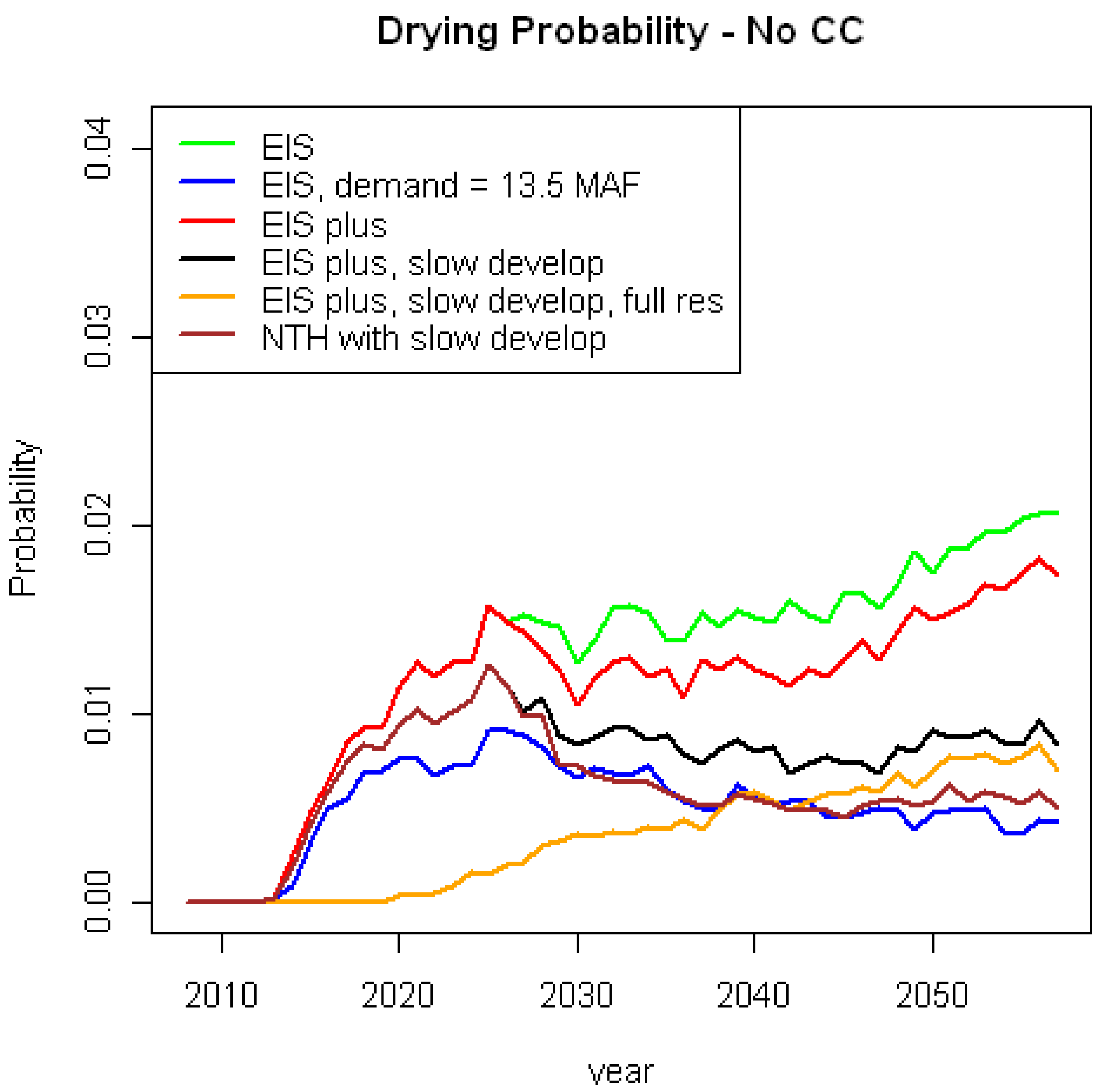
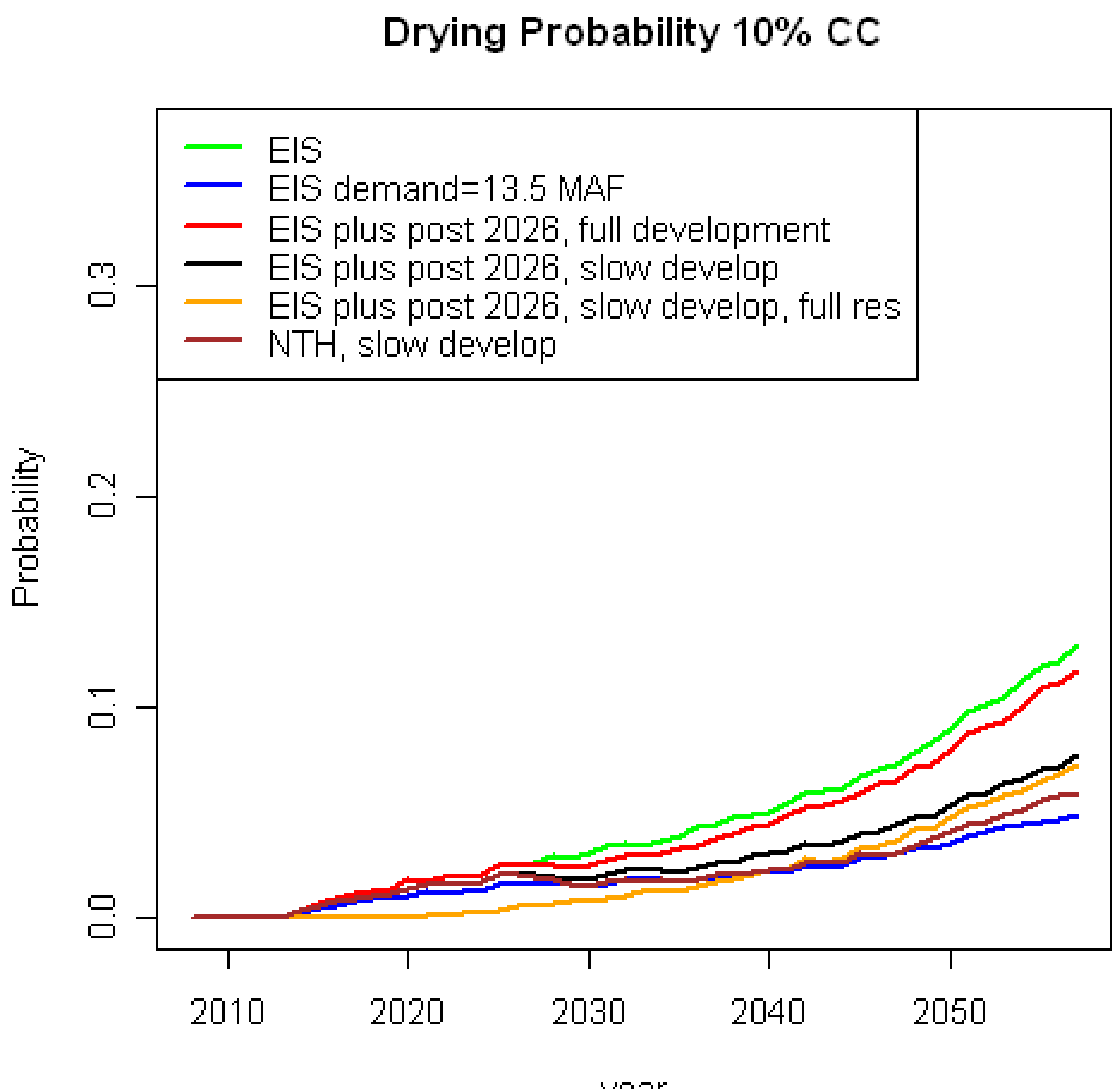


Risk of Reservoir Drying Under Natural Climate Variability Plus Climate Change (10% Flow Reduction by 2056)



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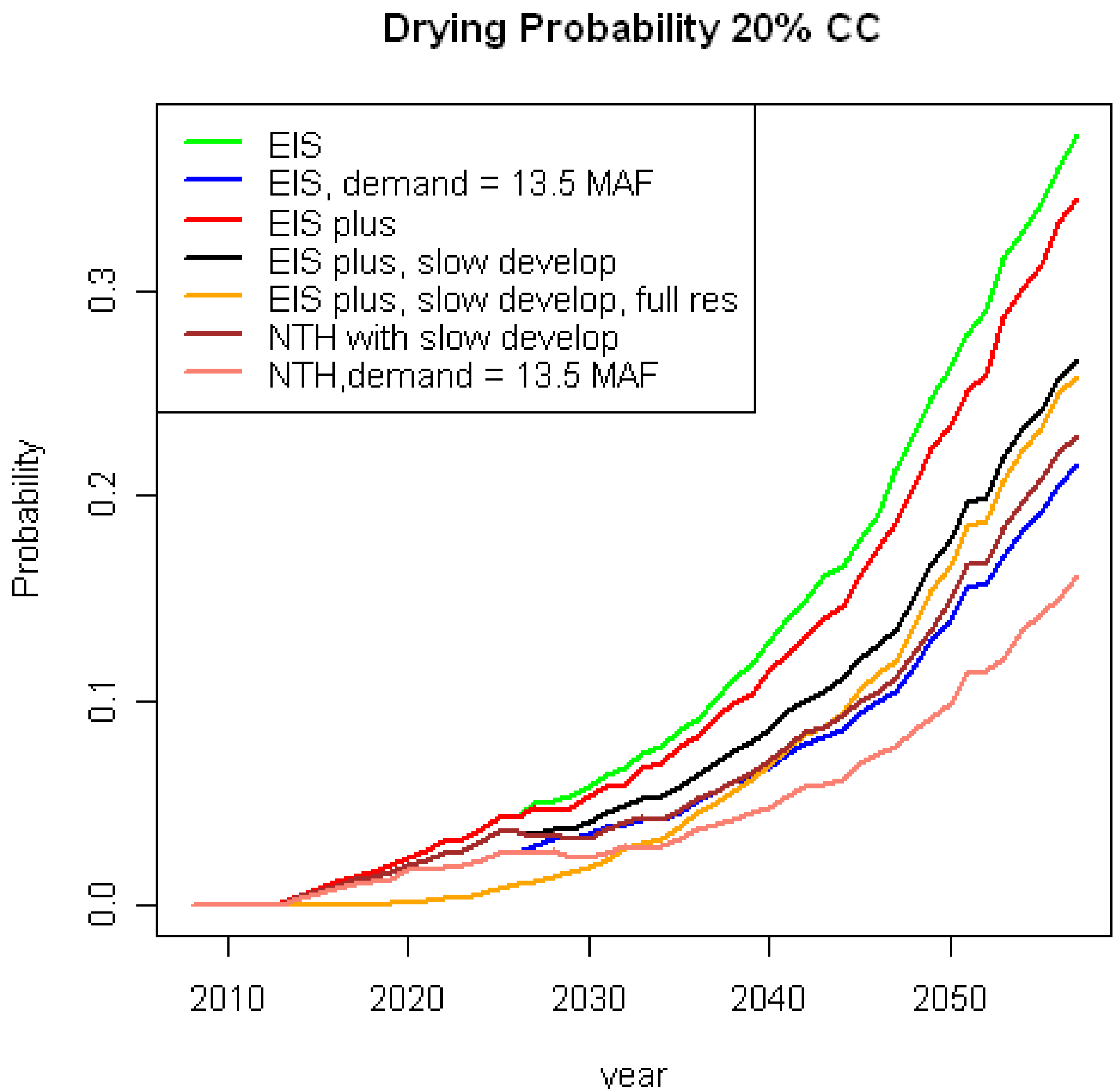

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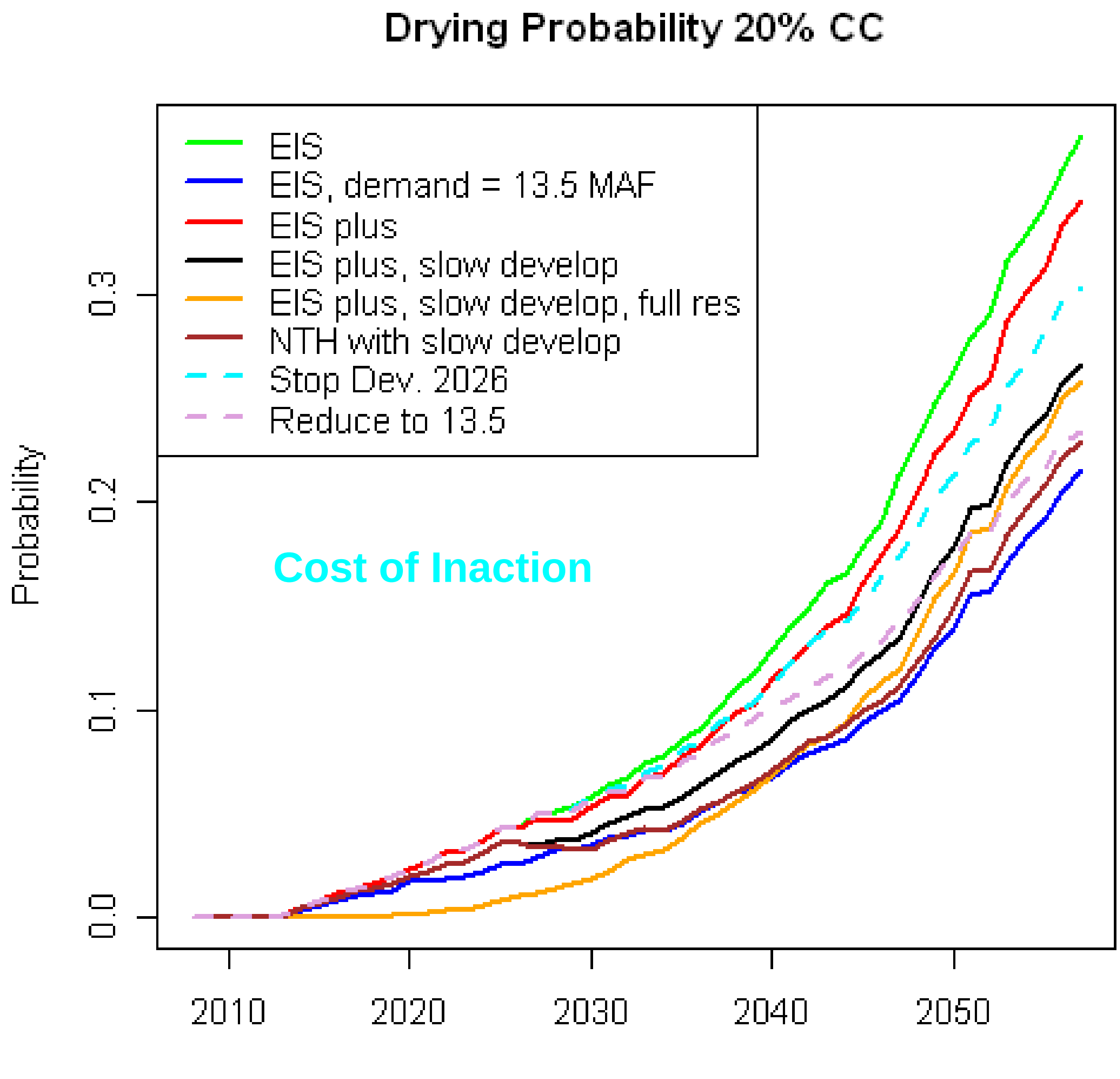

Summary

- Water supply risk (i.e., risk of drying) is small (< 5%) in the near term ~2026, for any climate variability (*good news)*

- Water supply risk remains small after ~2026, <u>only</u> if we assume no climate change.

- Risk increases 7-fold after 2026 if climate change induces a 20% decline in CR flow by mid-Century (*bad news)*

- Risk increase is highly nonlinear, and very sensitive to the intensity of climate change.

- There is flexibility in the system that can be exploited to mitigate risk.

- Delayed action can be too little too late

Strategies in the Face of Uncertainty

Earth System Research Laboratory

SCIENCE, SERVICE & STEWARDSHIP

Martin Hoerling, Meteorologist NOAA Earth System Research Laboratory

Dr. Martin Hoerling is a research meteorologist, specializing in climate dynamics, in NOAA's Earth System Research Laboratory located in Boulder, Colorado. He is the Convening Lead Author for the US Climate Change Science Plan Synthesis and Assessment Report on "*Attribution of the Causes of Climate Variations and Trends over North America"*, due for public release in early 2008. Dr. Hoerling is Chairman of the US CLIVAR (Climate Variability) research program. Dr. Hoerling served as Editor for the American Meteorological Society's *Journal of Climate*, and has published over 50 scientific papers dealing with climate variability and change.

His research interests include climate variability on seasonal to centennial time scales, focusing on air-sea interactions such as related to El Nino, and the role of oceans in decadal climate variation and climate change. He received his Bachelors, Masters, and PhD degrees from the University of Wisconsin-Madison, graduating in 1987. He is principal investigator on several research projects to understand the causes and origins for Earth's global climate variations during the last Century, and advancing capabilities to predict such variations. Dr. Hoerling has served as project manager for NOAA's Regional Integrated Science Assessment on Water, Climate and Society in the Interior Western United States that is studying this region's sensitivity and responses to climate variations, and the need for climate information by regional decision makers.