The 21st Century Colorado River Hot Drought and Implications for the Future

South Platte River Urban Waters Partnership

May 4, 2017

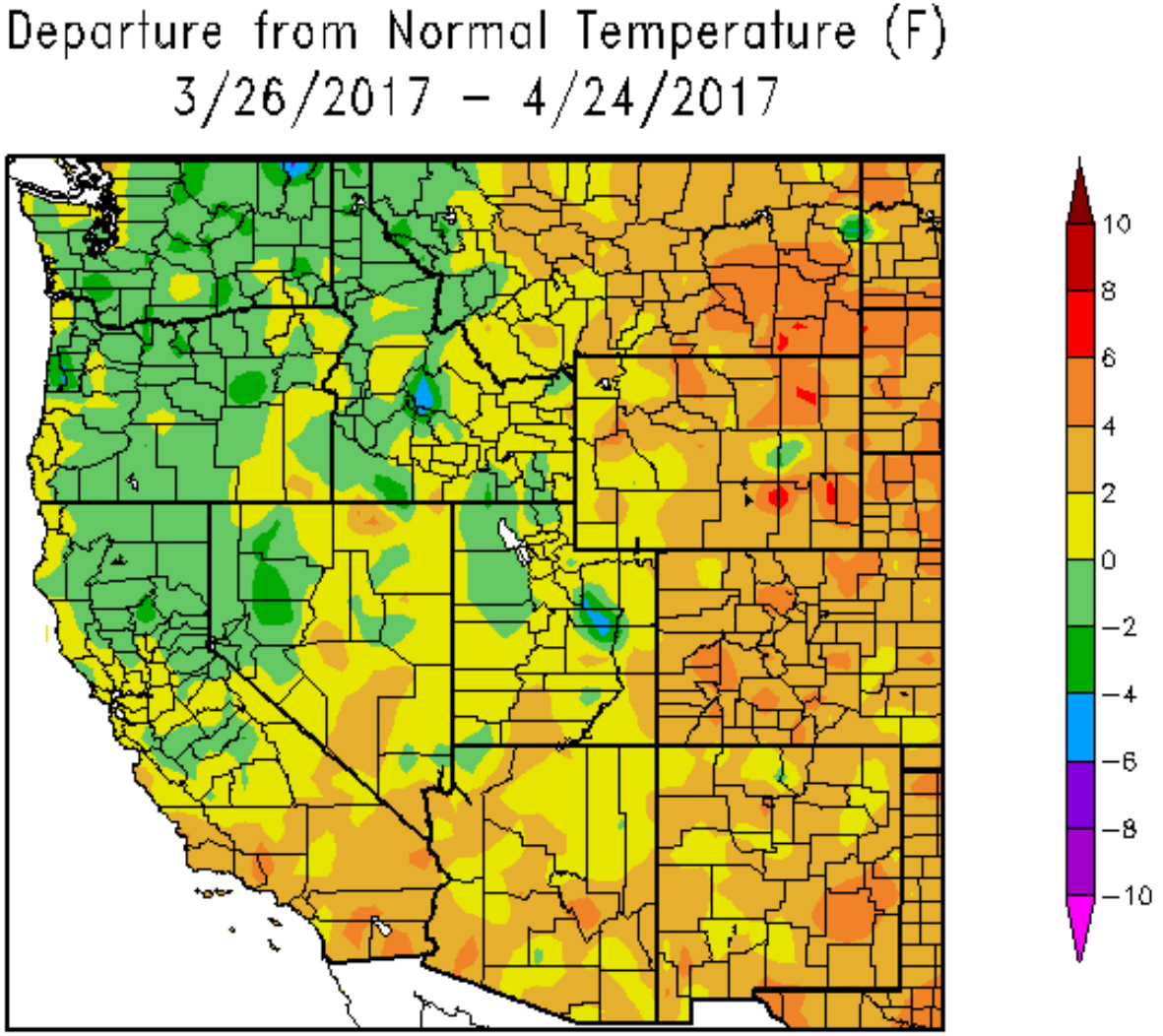
Brad Udall
Colorado State University
Bradley.udall@colostate.edu
@bradudall

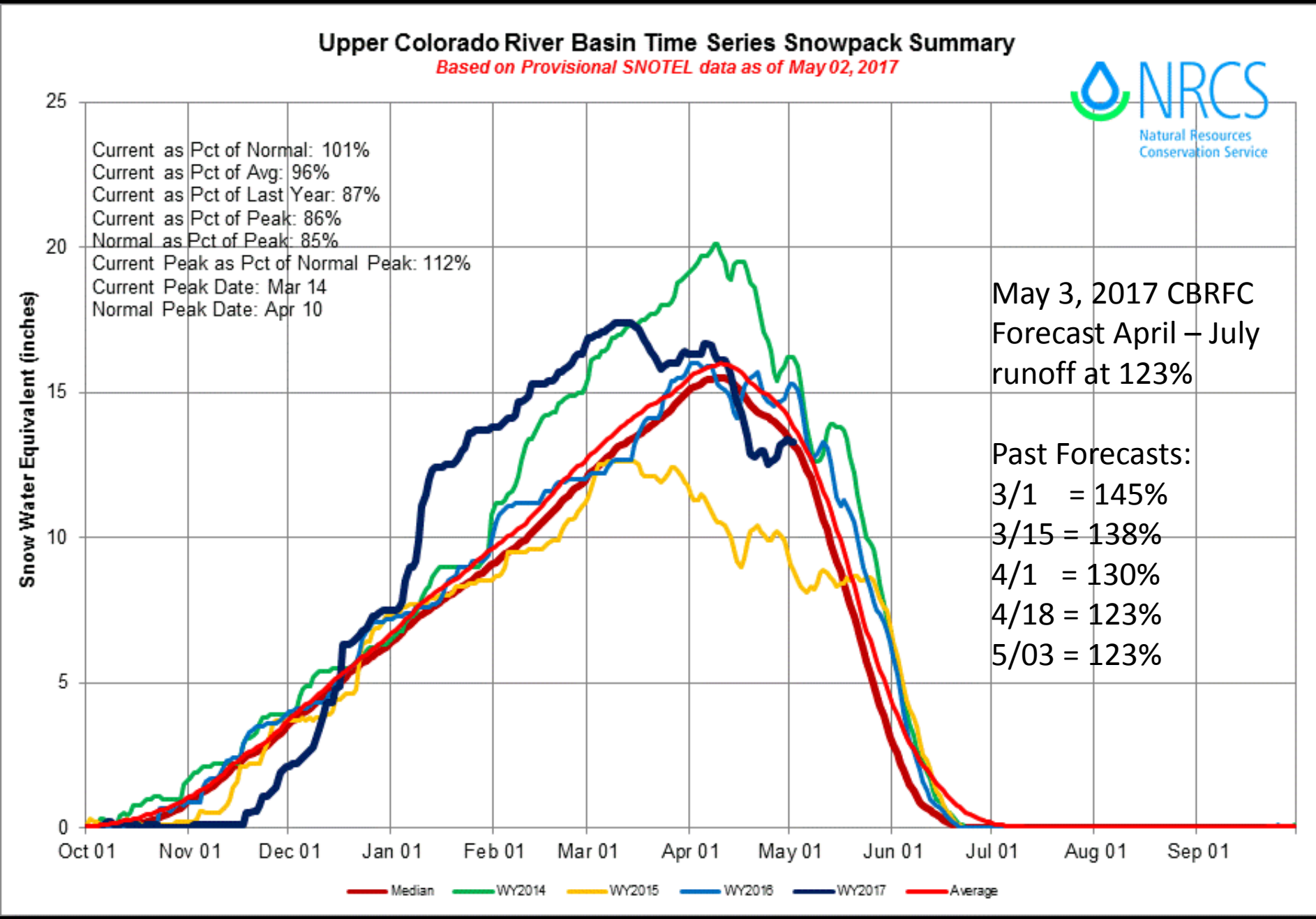
Coauthor: Jonathan Overpeck

March was Colorado's warmest ever recorded, Denver's third warmest

POSTED 6:44 PM, APRIL 6, 2017, BY MATT MAKENS, *UPDATED AT 06:45PM, APRIL 6, 2017*

FOX31 DENVER




Upper Colorado River Basin Time Series Snowpack Summary
Based on Provisional SNOTEL data as of May 02, 2017
NRCS
Natural Resources Conservation Service
Current as Pct of Normal: 101%
Current as Pct of Avg: 96%
Current as Pct of Last Year: 87%
Current as Pct of Peak: 86%
Normal as Pct of Peak: 85%
Current Peak as Pct of Normal Peak: 112%
Current Peak Date: Mar 14
Normal Peak Date: Apr 10
May 3, 2017 CBRFC Forecast April – July runoff at 123%
Past Forecasts:
3/1 = 145%
3/15 = 138%
4/1 = 130%
4/18 = 123%
5/03 = 123%
Snow Water Equivalent (inches)
25
20
15
10
5
0
Oct 01
Nov 01
Dec 01
Jan 01
Feb 01
Mar 01
Apr 01
May 01
Jun 01
Jul 01
Aug 01
Sep 01
Median
WY2014
WY2015
WY2016
WY2017
Average

Colorado snowpack is off to its worst start in more than 30 years; ski areas feel the pinch

AP Associated Press

November 18, 2016 / 1:31 pm / Business, Denver news

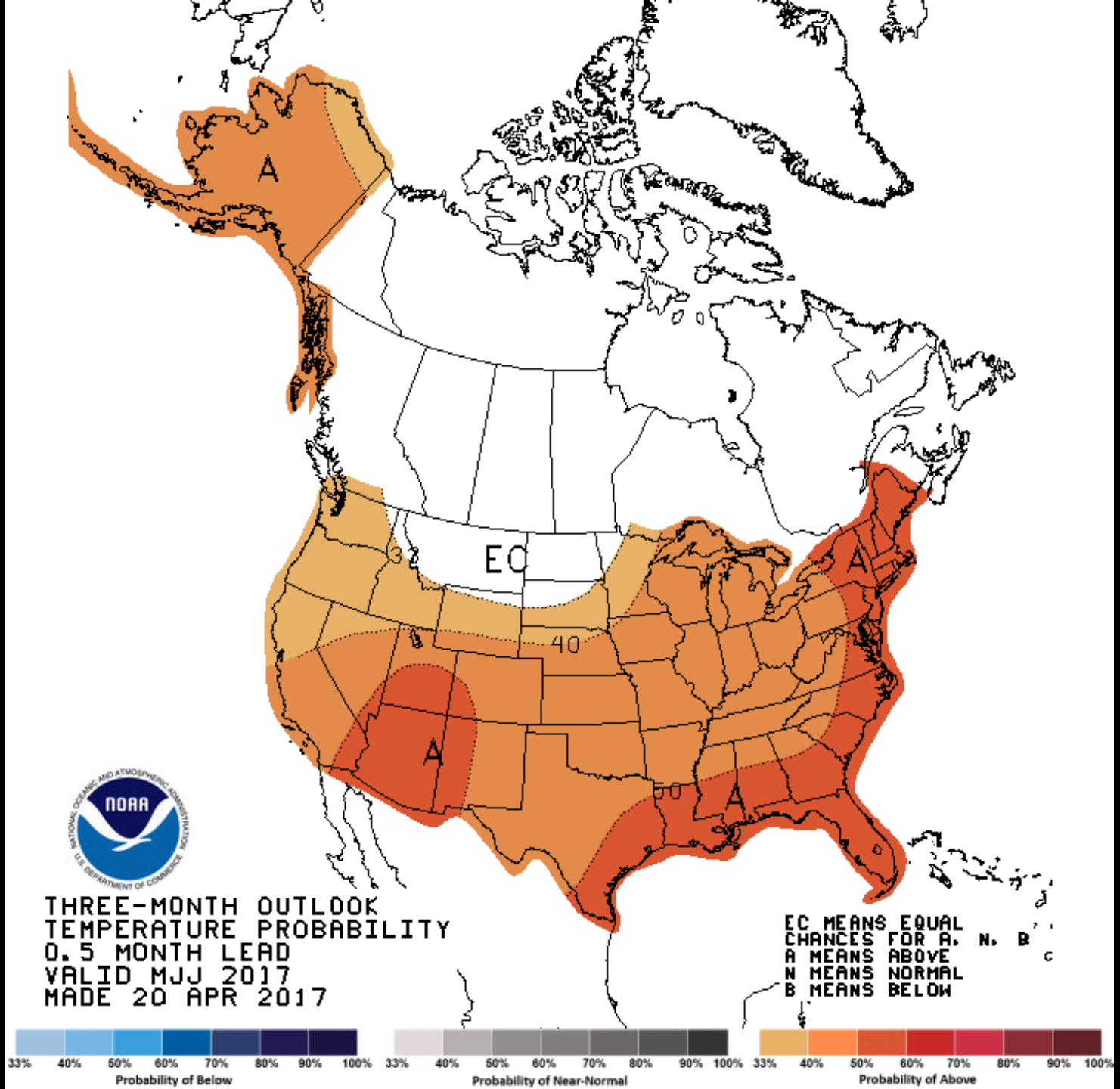
The Colorado snowpack is off to its worst start in more than 30 years, said Brian Domonkos, who supervises the U.S. Department of Agriculture snow survey in the state.

Snowpack boon for Powell

By Todd Glasenapp Sun Correspondent Feb 7, 2017 1

ARIZONA Daily Sun

Heavy snowfall on Colorado's Western Slope and Utah's Wasatch Range in December and January boosted snowpack in the five-state Upper Colorado River Basin to 157 percent of average.


A
EC
40
A
A
A
NOAA
THREE-MONTH OUTLOOK
TEMPERATURE PROBABILITY
0.5 MONTH LEAD
VALID MJJ 2017
MADE 20 APR 2017
EC MEANS EQUAL CHANCES FOR A, N, B
A MEANS ABOVE
N MEANS NORMAL
B MEANS BELOW
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Below
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Near-Normal
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Above

AGU PUBLICATIONS

Water Resources Research

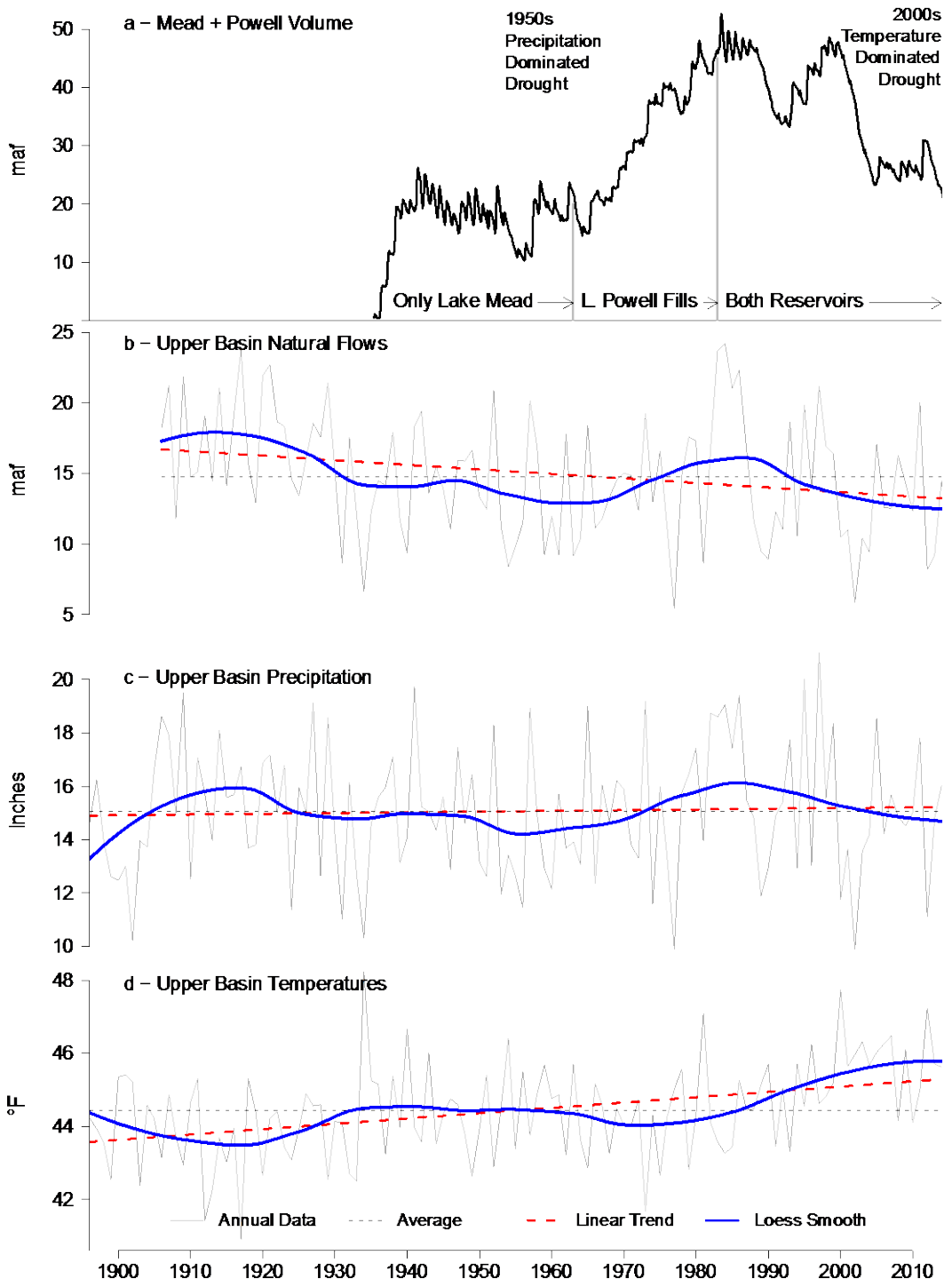
The twenty-first century Colorado River hot drought and implications for the future

Bradley Udall[1,2] and Jonathan Overpeck[2,3]

[1]Colorado Water Institute, Colorado State University, Fort Collins, Colorado, USA, [2]Colorado River Research Group, Boulder, Colorado, USA, [3]Department of Geosciences and Department of Hydrology and Atmospheric Sciences, Institute for the Environment, University of Arizona, Tucson, Arizona, USA

Key Points:

- Record Colorado River flow reductions averaged 19.3% per year during 2000–2014. One-third or more of the decline was likely due to warming
- Unabated greenhouse gas emissions will lead to continued substantial warming, translating to twenty-first century flow reductions of 35% or more
- More precipitation can reduce the flow loss, but lack of increase to date and large megadrought threat, reinforce risk of large flow loss



Hydrologic Sensitivities of Colorado River Runoff to Changes in Precipitation and Temperature*

JULIE A. VANO

Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington

TAPASH DAS+

Division of Climate, Atmospheric Sciences, and Physical Oceanography, Scripps Institution of Oceanography, La Jolla, California

DENNIS P. LETTENMAIER

Department of Civil and Environmental Engineering, University of Washington, Seattle, Washington

Calculated Temperature Sensitivity and Precipitation Elasticity with 6 different runoff models

Temperature Sensitivity: Change in Flow per Degree Increase in Temperature. Is a Negative Percent

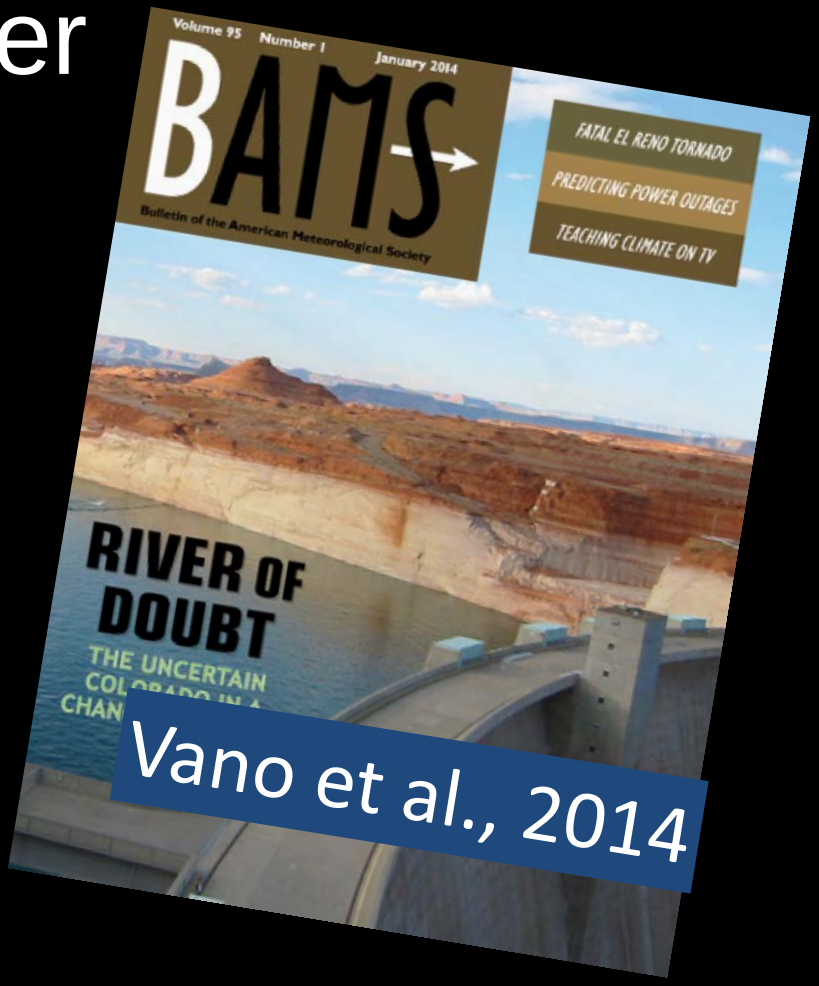
Precipitation Elasticity: Percent Change in Flow per 1% Change in Precipitation. Is a unit-less number

Temperature Sensitivity and Precipitation Elasticity are roughly additive

An interdisciplinary team reconciled the future of the Colorado River

Warming alone will drive Colorado River flow declines of -6.5% +/- 3.5% per ºC

Precipitation Elasticity at 2 to 3



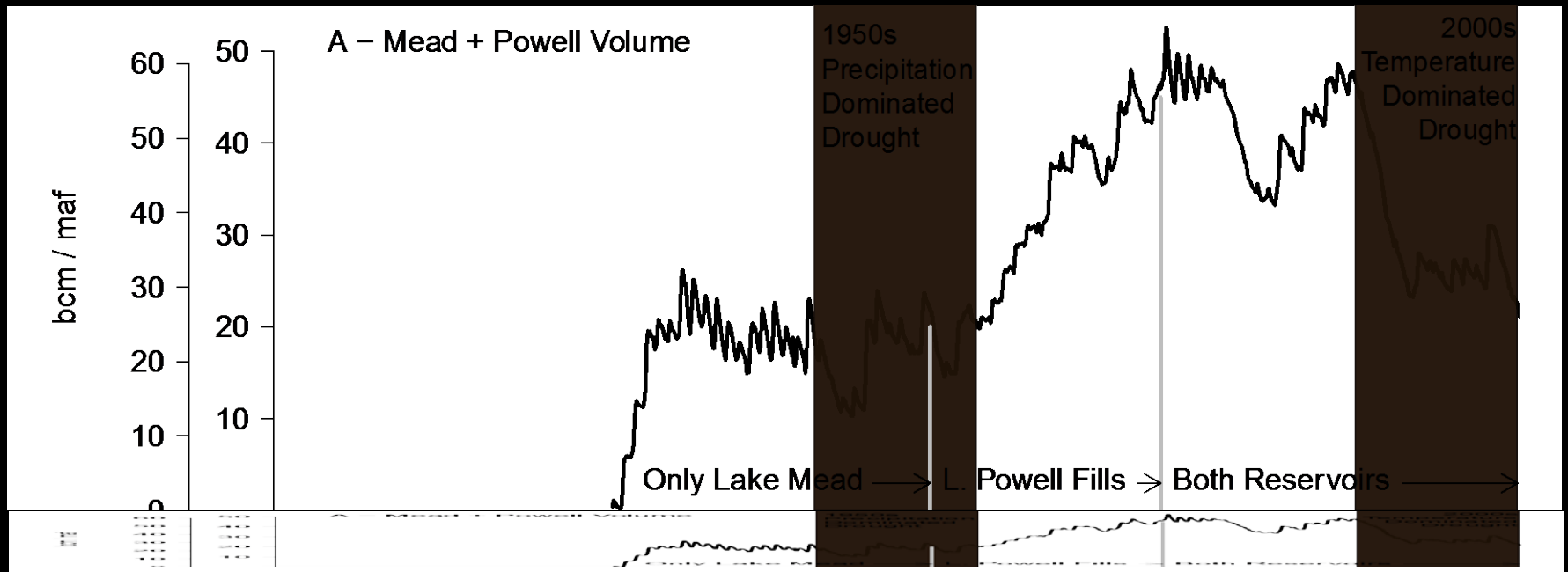
Bulletin of the American Meteorological Society, January 2014 issue

Contents of the Two Largest Reservoirs in the United States

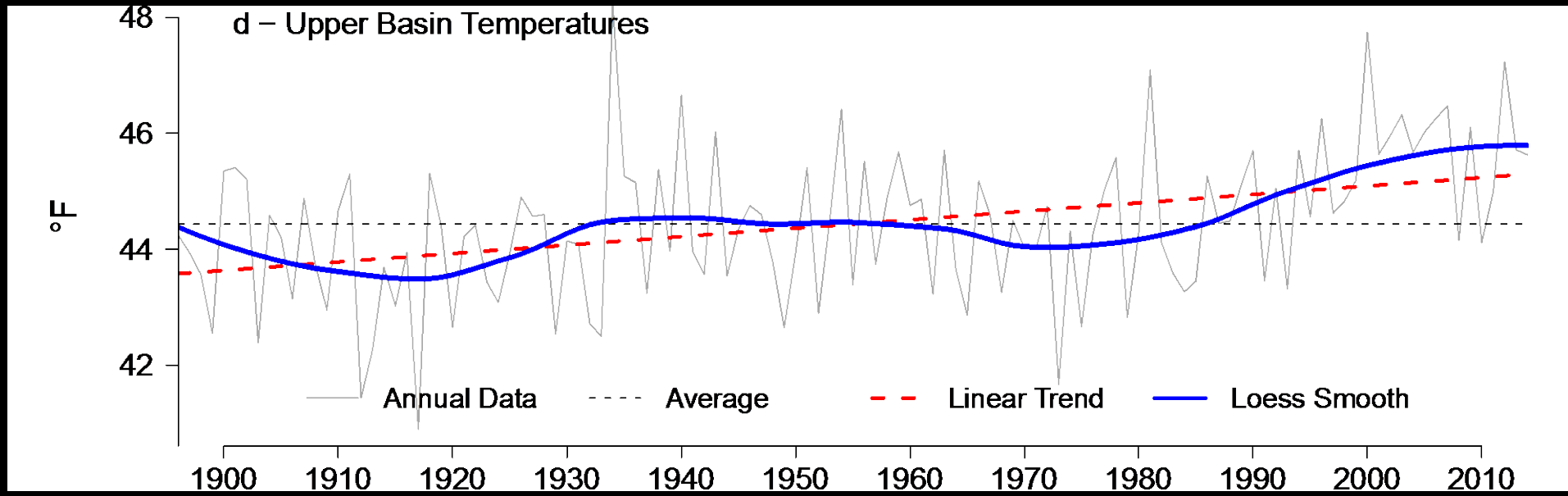
2000 = Full
2015 = ~ 40%

Most Serious Drought since records kept

Causes…
Lake Powell: Drought
Lake Mead: Structural Deficit (“overuse”)



Temperatures Key to 2000s Decline



2000-14 Temperatures are 1.6°F above 1906-99 Average

Temperature Sensitivity Explains 1/6 to ½ of the current runoff reduction. 1/3 is mid point of 1/6 and 1/2

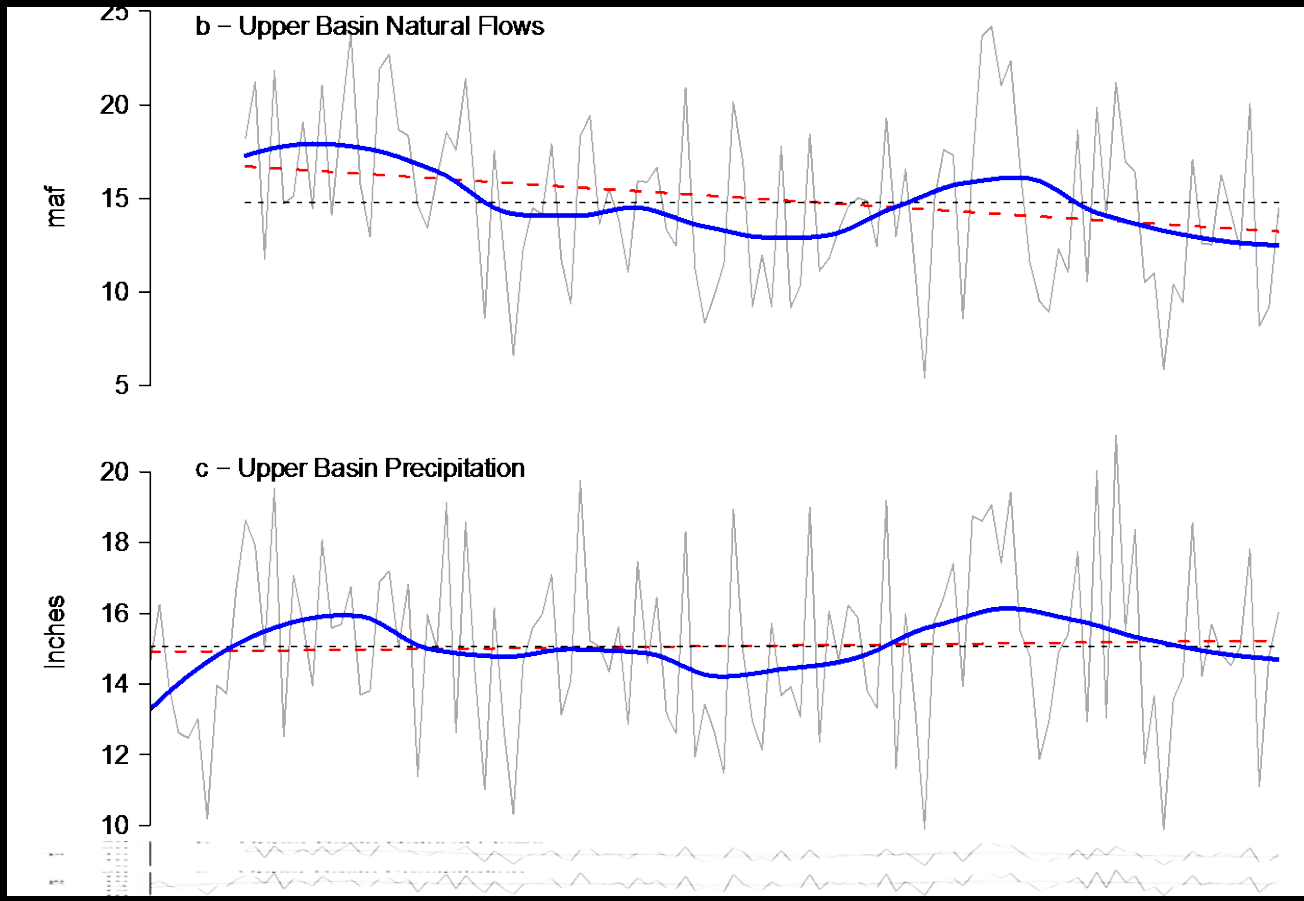
Source: Udall & Overpeck 2017, PRISM Temperatures

Two Droughts – Two Different Causes

1953-1967 Drought
- 18% Flow Decline
- 6.1% Precipitation

2000-2014 Drought
- 19% Flow Reduction
- 4.6% Precipitation

Note:
2000s Drought is only 75% of the Precipitation Decline in the 1950s Drought



Source: Udall & Overpeck, 2017; flow data from Reclamation, PRISM Precipitation

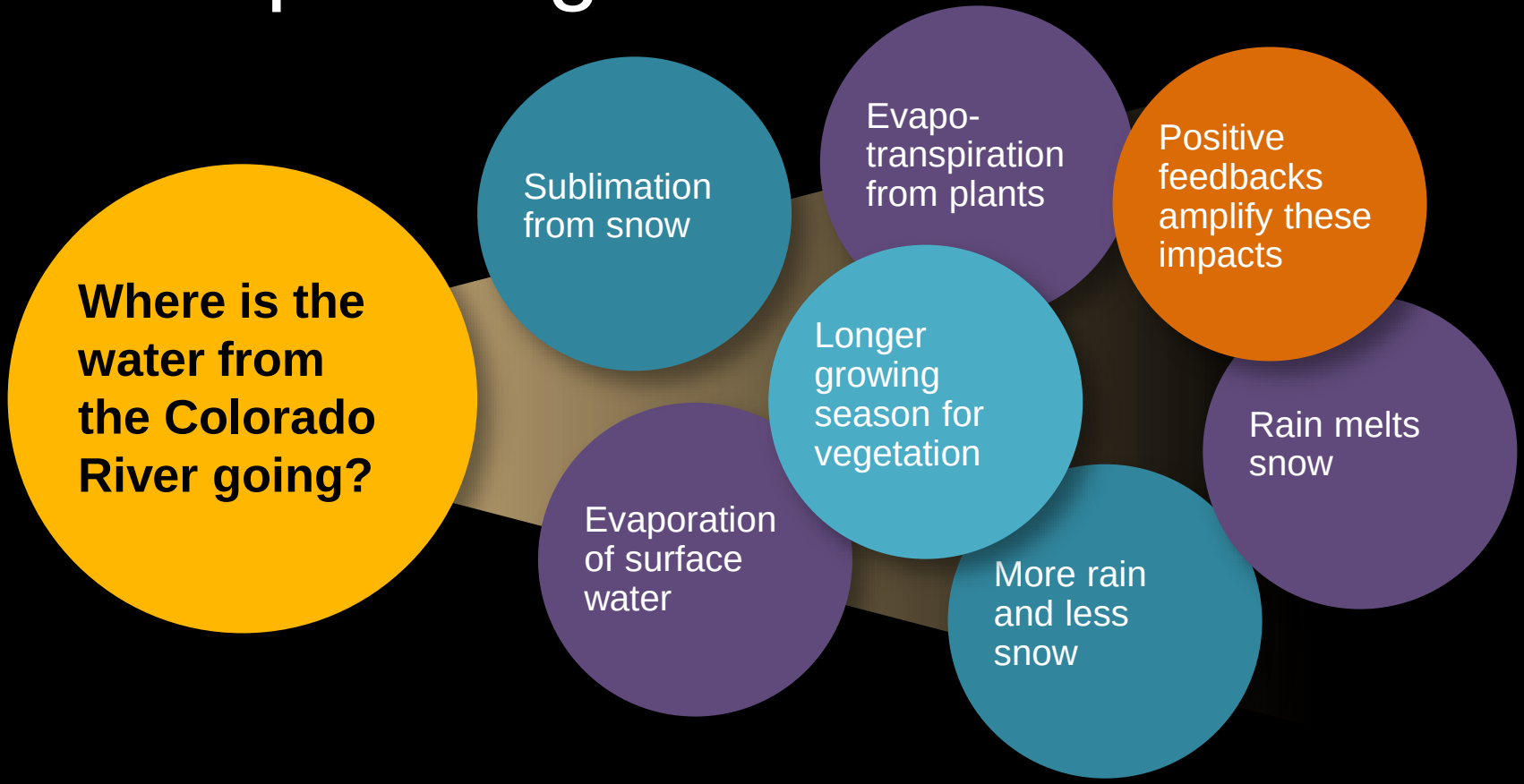
How is atmospheric warming vaporizing our snow & water?

Or…

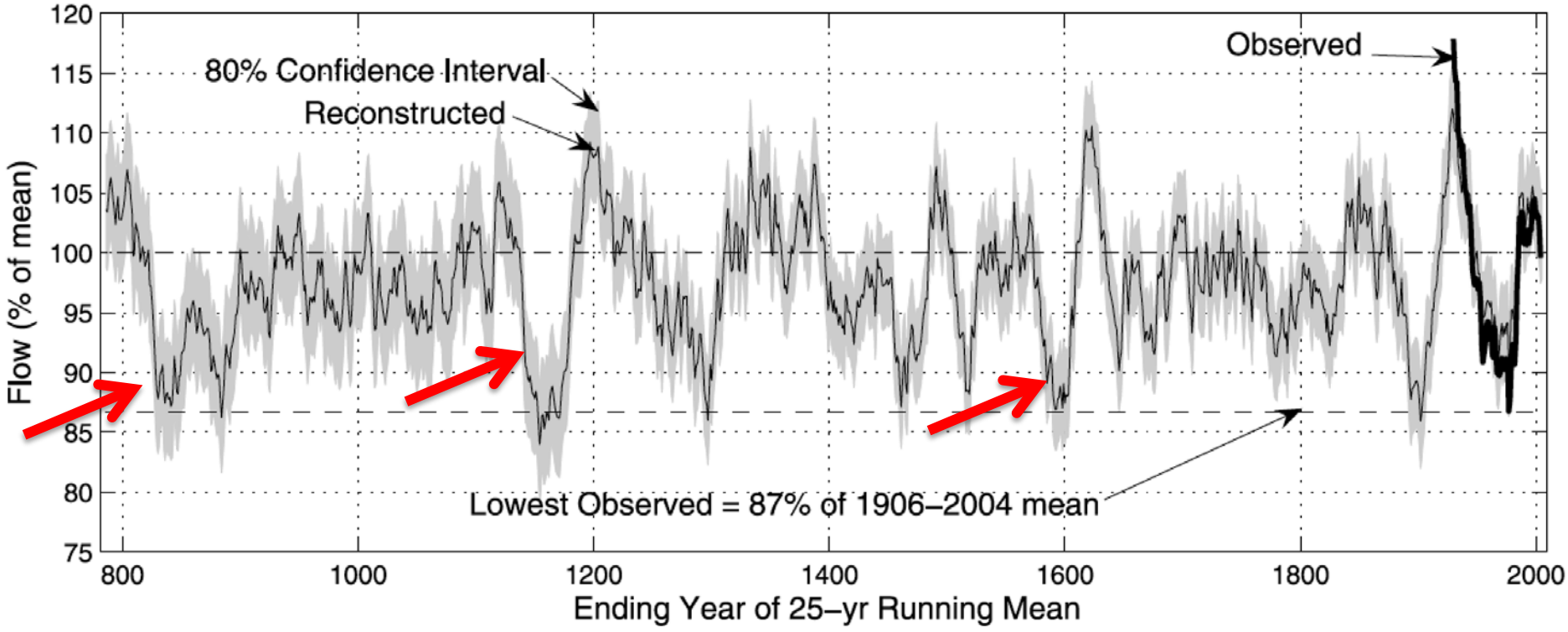
Where is the water from the Colorado River going?

The warming atmosphere demands more moisture

How is atmospheric warming vaporizing our snow & water?



The Upper Colorado River Basin is Megadrought Country – 1200 years of Colorado River flow thanks to tree rings



Meko et al., (*Geopysical Research Letters*, 2007)

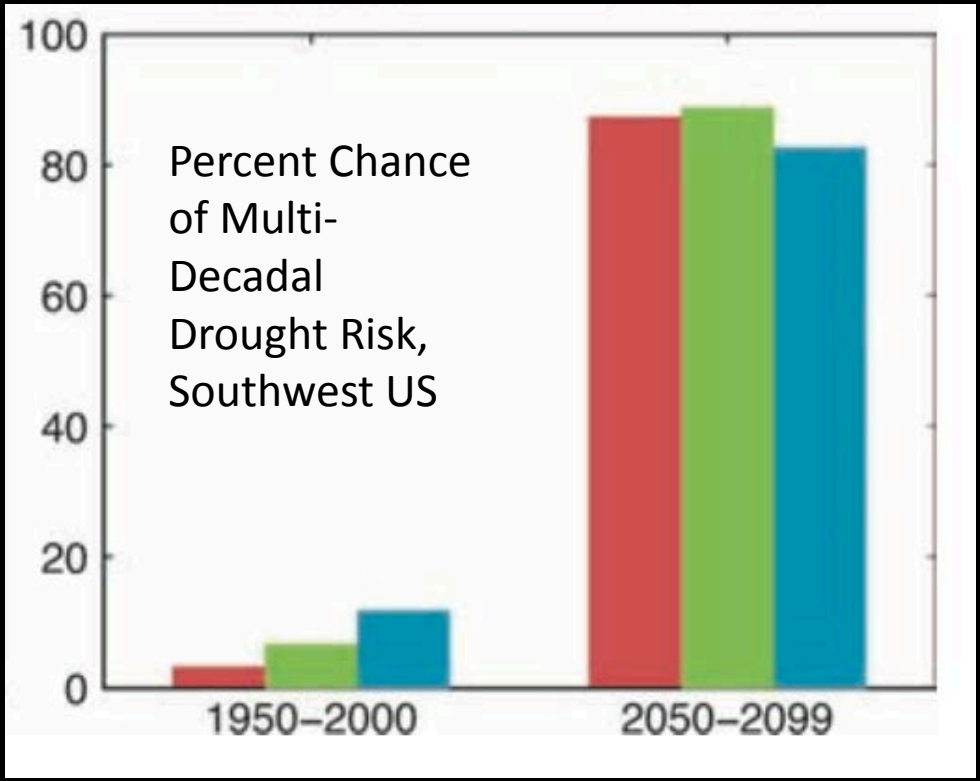
CLIMATOLOGY

Unprecedented 21st century drought risk in the American Southwest and Central Plains

Benjamin I. Cook,[1,2]* Toby R. Ault,[3] Jason E. Smerdon[2]

In both Central Plains and Southwest, Multi-decadal Drought Risk* exceeds 80% in 21st Century

* Defined as Drought lasting 35 or more years



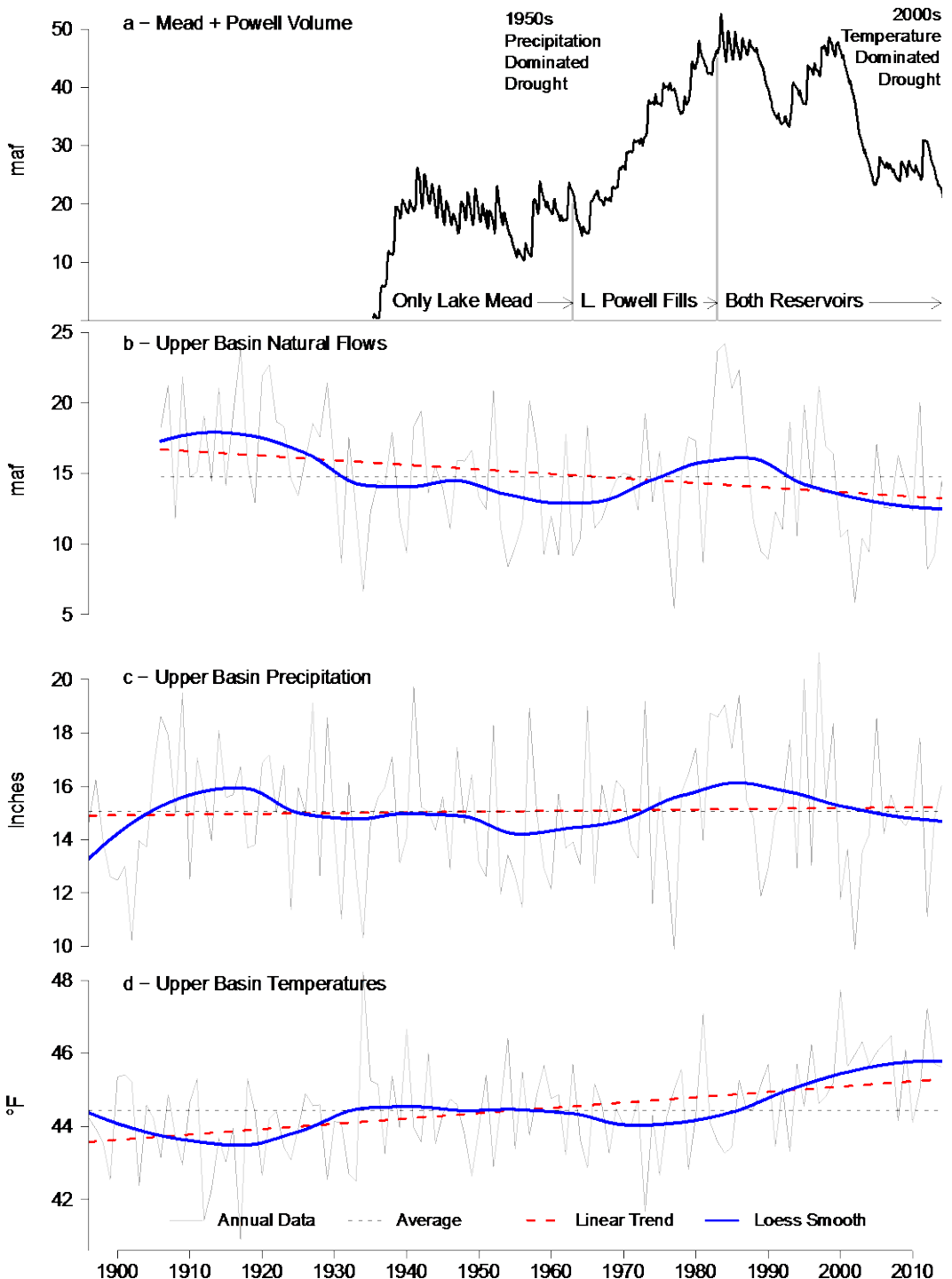
The Complete Picture…

You have to invoke higher temperatures to explain the current drought.

AND….

This does not bode well for the future…

Source: Udall & Overpeck 2017

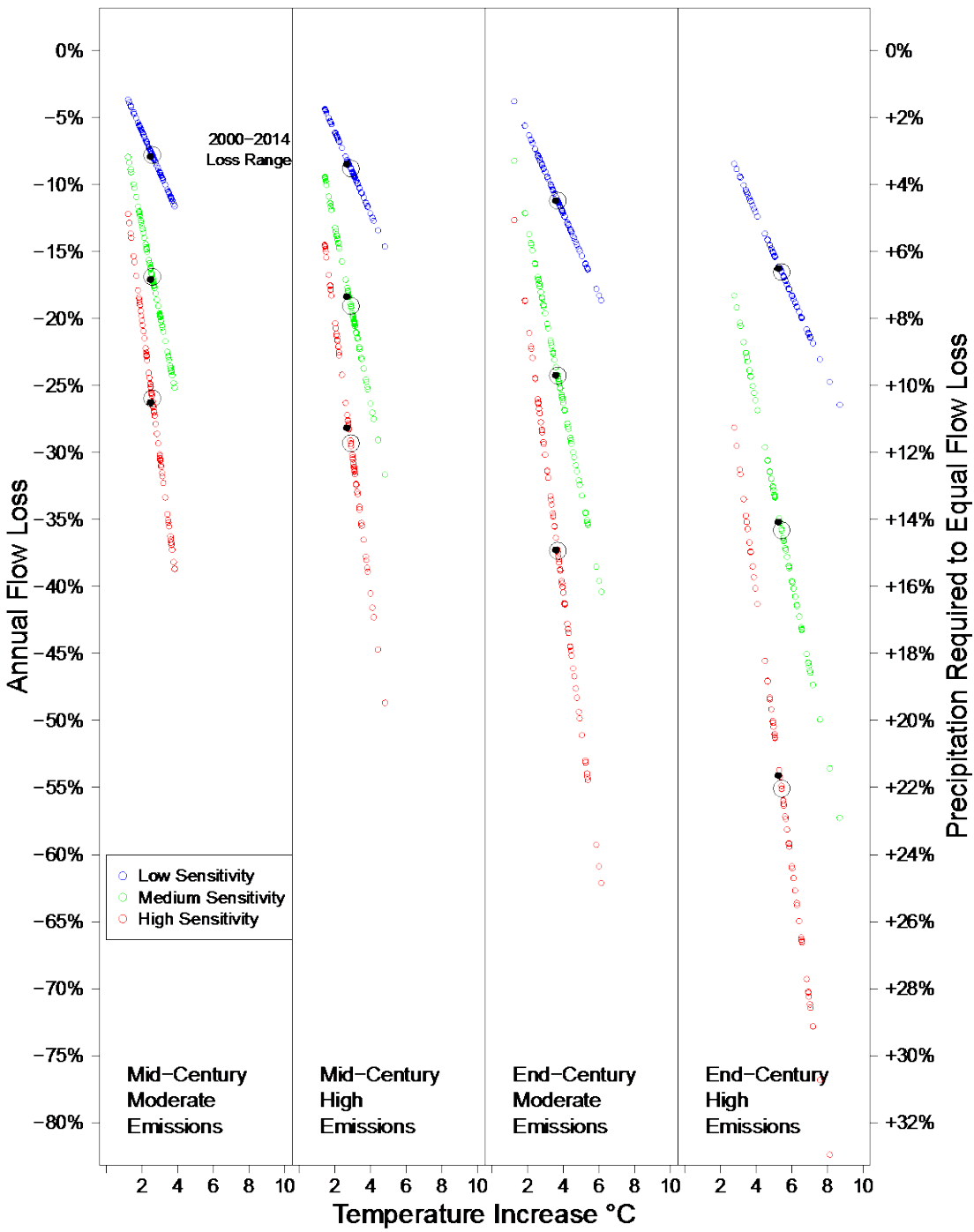


Colorado River Future Flow Losses

Climate Change a combination of …

1. For-Sure Temperature Rise -> Flow Losses

2. Not-Sure Precipitation Change -> Flow Gains or Losses



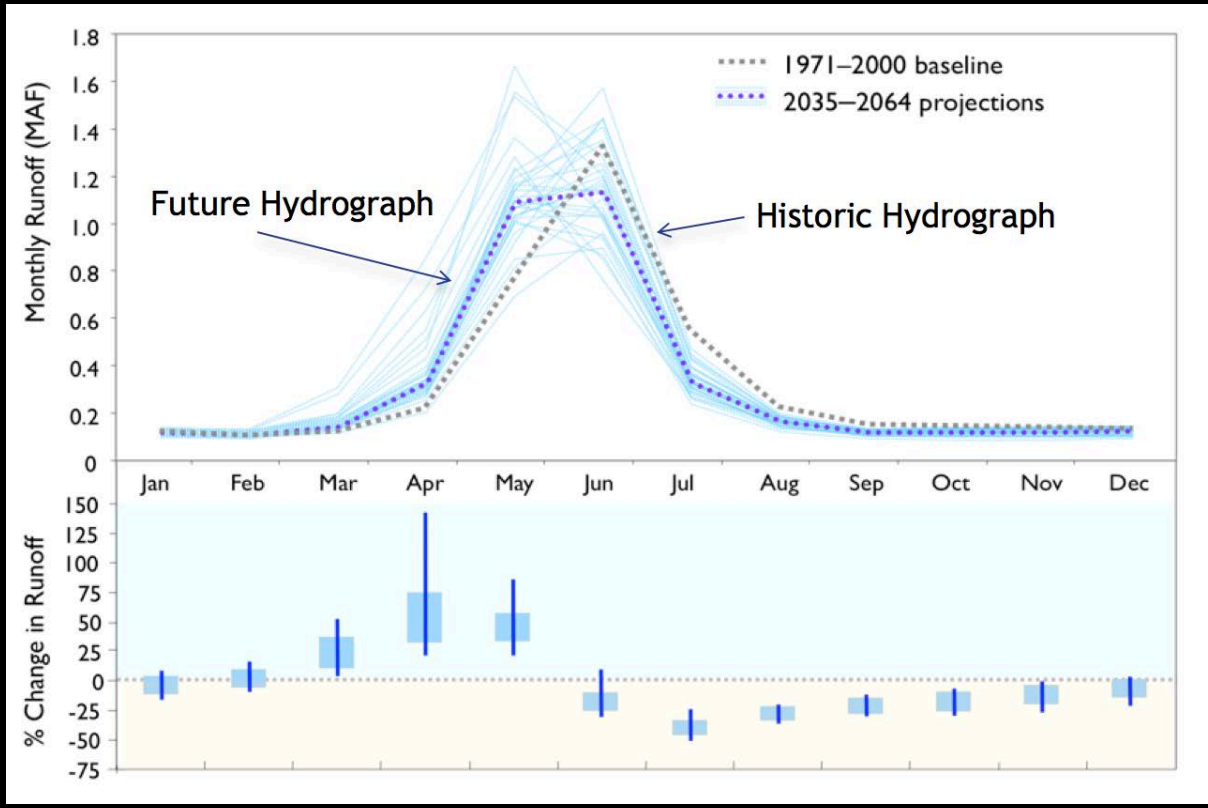
Key Additional Points

Our results are generally comparable to Reclamation's most recent results when considering the full range of our analysis when both precipitation and temperatures are included. However, our focus and emphasis is on the large near-certain temperature-induced flow declines with a separate analysis of precipitation. Reclamation, by contrast, has a focused on climate multimodel-ensemble median declines, including medians calculated across emission scenarios [*Reclamation*, 2013, 2012]. Decision makers often treat these median outcomes as a proxy for risk despite the fact that the median obscures the wide range of results and lumps wet and dry, warm and hot, large and small emission increases and, most critically, near certain temperature increases and very uncertain precipitation changes.

We assert that the large precipitation increases necessary to offset substantial temperature-induced flow decreases appear unlikely to occur for a number of reasons. These reasons include the potential for storm tracks to go north of the basin due to Hadley Cell expansion, the high potential for megadrought to increase evaporation while reducing precipitation and runoff for extended periods, the large size of the needed precipitation increases, especially when compared to decadal historical increases, the consistent identification by global assessments of the Southwest as an area likely to dry, and finally the lack of any trend over the last century or last 16 years (Figure 2c). Hence, we choose to focus on highly likely temperature-induced declines with separate analysis of the precipitation needed to offset these declines.

Water Quality Implications

- Lower Flows = Warmer Water
  - Stress on Aquatics
- Ripple Effects
  - ESA Issues
  - Fires
  - Legal Winners and Losers



AGU PUBLICATIONS

Water Resources Research

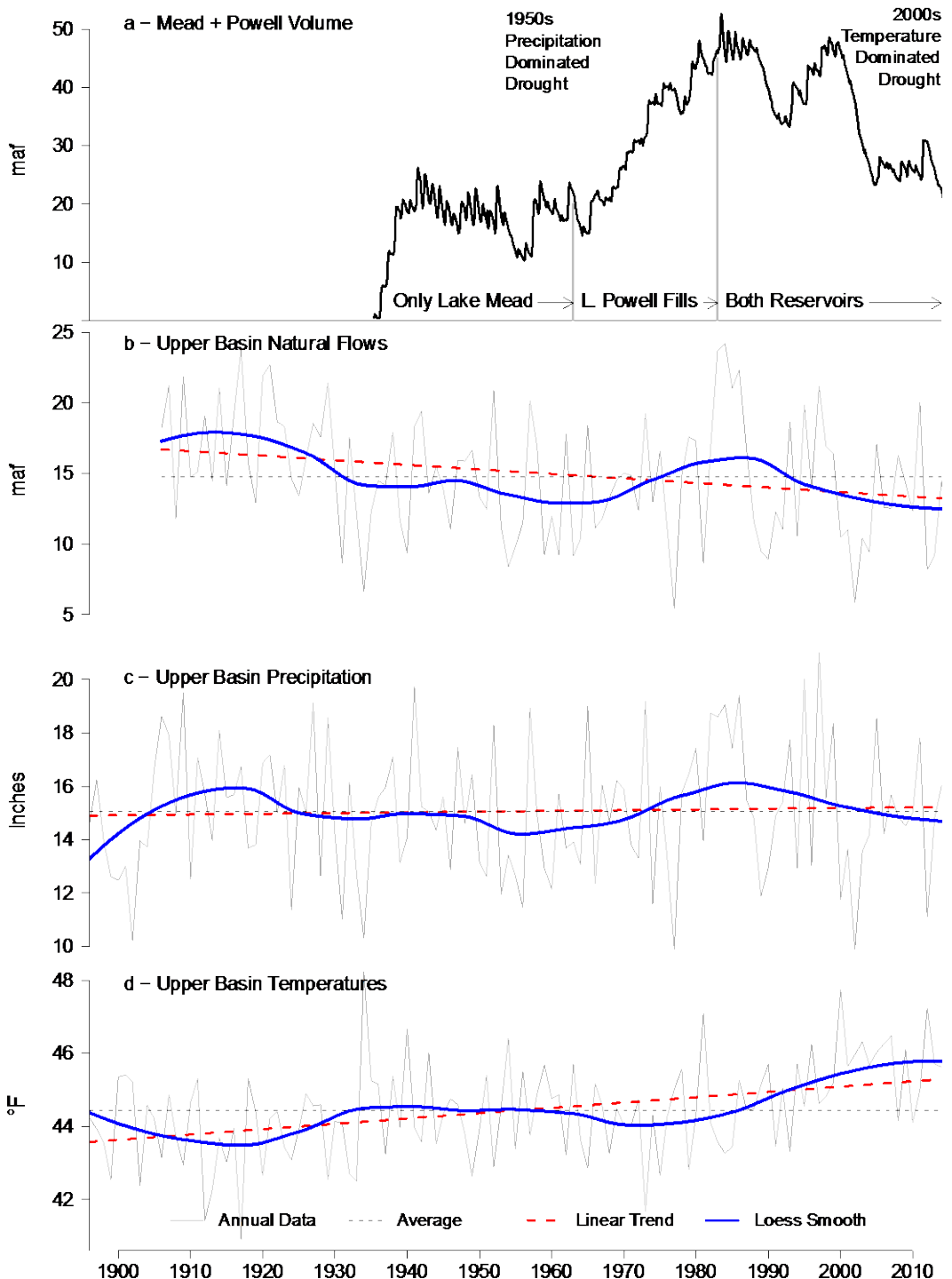
The twenty-first century Colorado River hot drought and implications for the future

Bradley Udall[1,2] and Jonathan Overpeck[2,3]

[1]Colorado Water Institute, Colorado State University, Fort Collins, Colorado, USA, [2]Colorado River Research Group, Boulder, Colorado, USA, [3]Department of Geosciences and Department of Hydrology and Atmospheric Sciences, Institute for the Environment, University of Arizona, Tucson, Arizona, USA

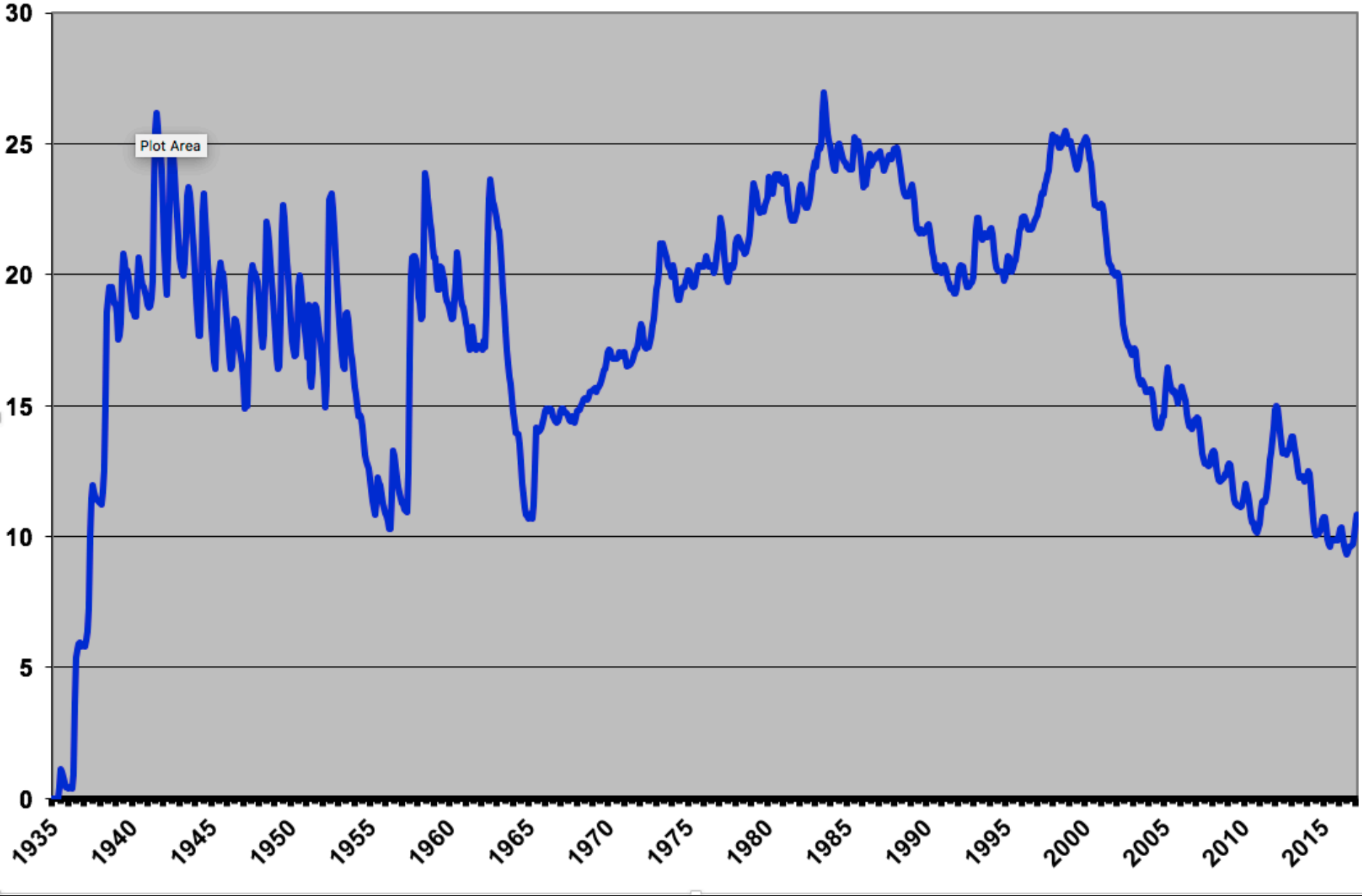
Key Points:

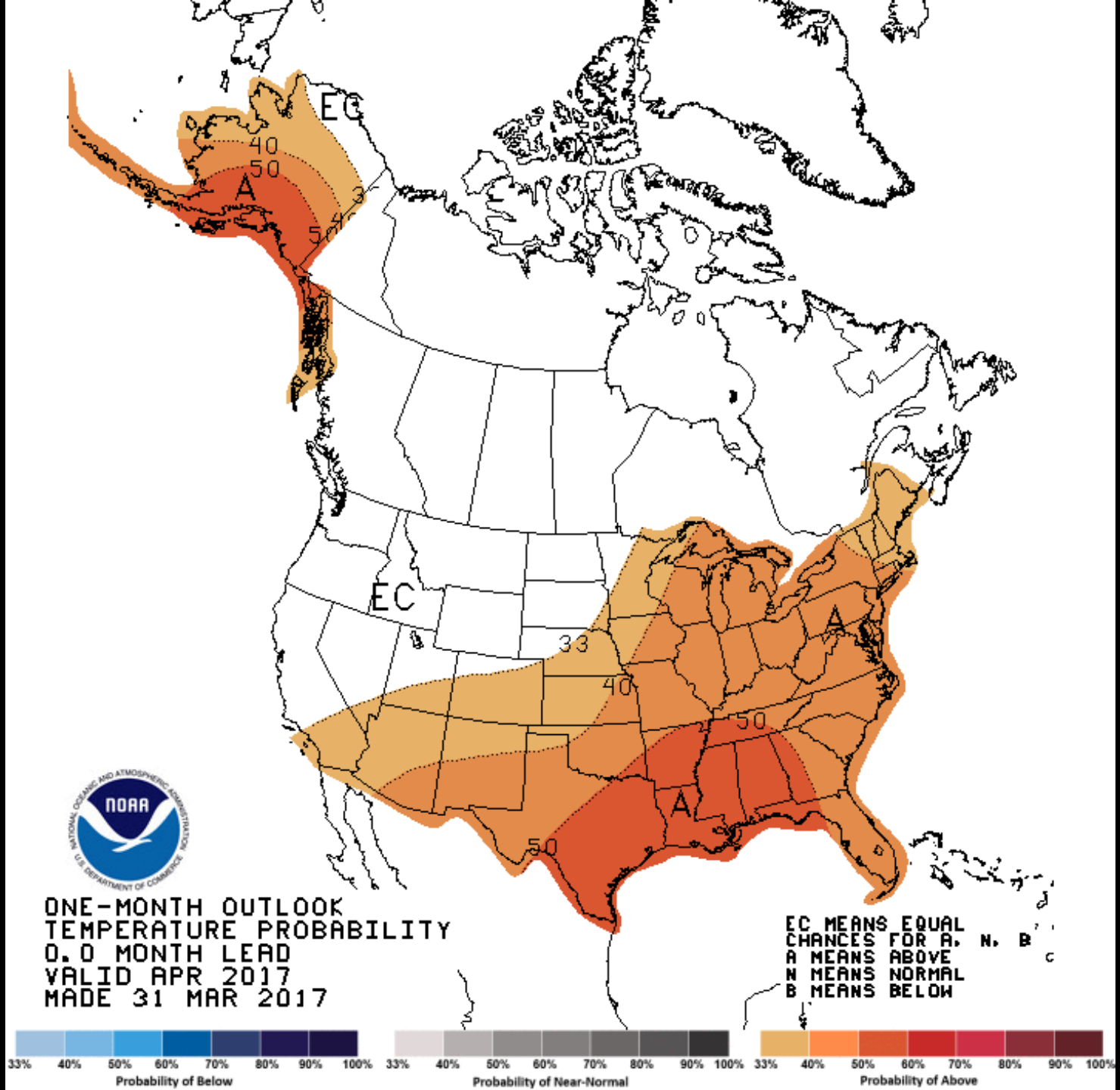
- Record Colorado River flow reductions averaged 19.3% per year during 2000–2014. One-third or more of the decline was likely due to warming
- Unabated greenhouse gas emissions will lead to continued substantial warming, translating to twenty-first century flow reductions of 35% or more
- More precipitation can reduce the flow loss, but lack of increase to date and large megadrought threat, reinforce risk of large flow loss



End

Lake Mead Volume in Millions of Acrefeet 1935-2017



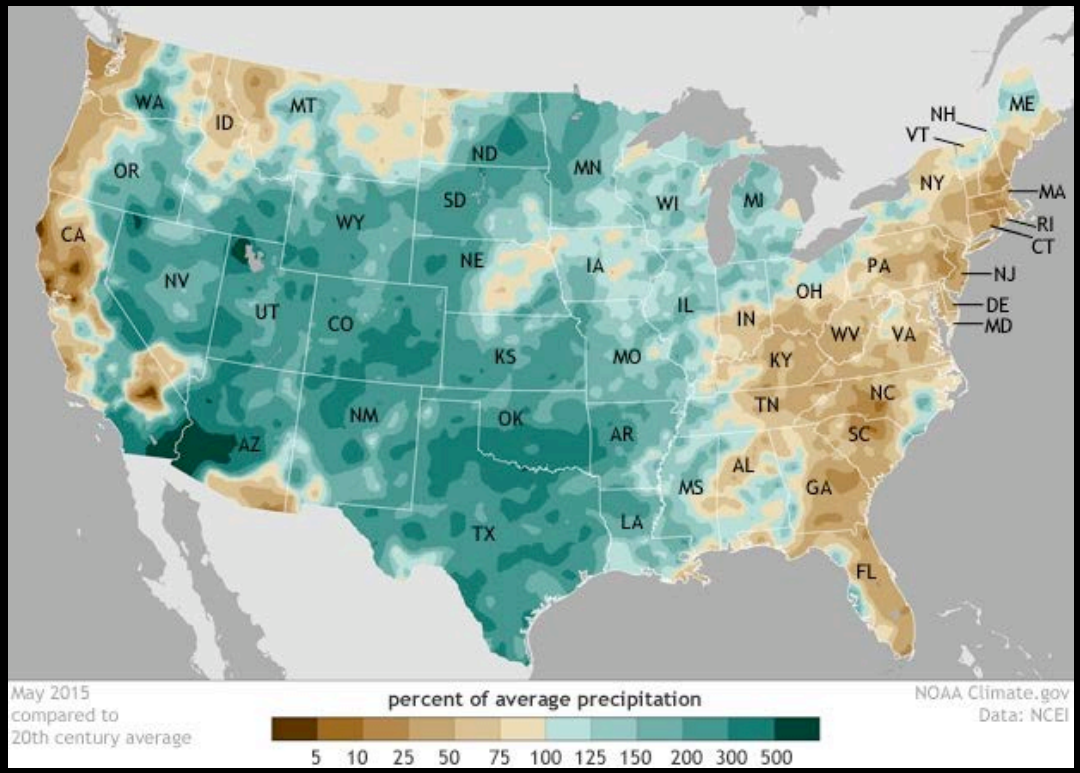

EC
40
50
A
EC
33
40
50
A
A
50
NOAA
ONE-MONTH OUTLOOK
TEMPERATURE PROBABILITY
0.0 MONTH LEAD
VALID APR 2017
MADE 31 MAR 2017
EC MEANS EQUAL
CHANCES FOR A, N, B
A MEANS ABOVE
N MEANS NORMAL
B MEANS BELOW
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Below
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Near-Normal
33% 40% 50% 60% 70% 80% 90% 100%
Probability of Above

May 2015 was wettest month ever recorded in U.S.

Friday, June 12, 2015

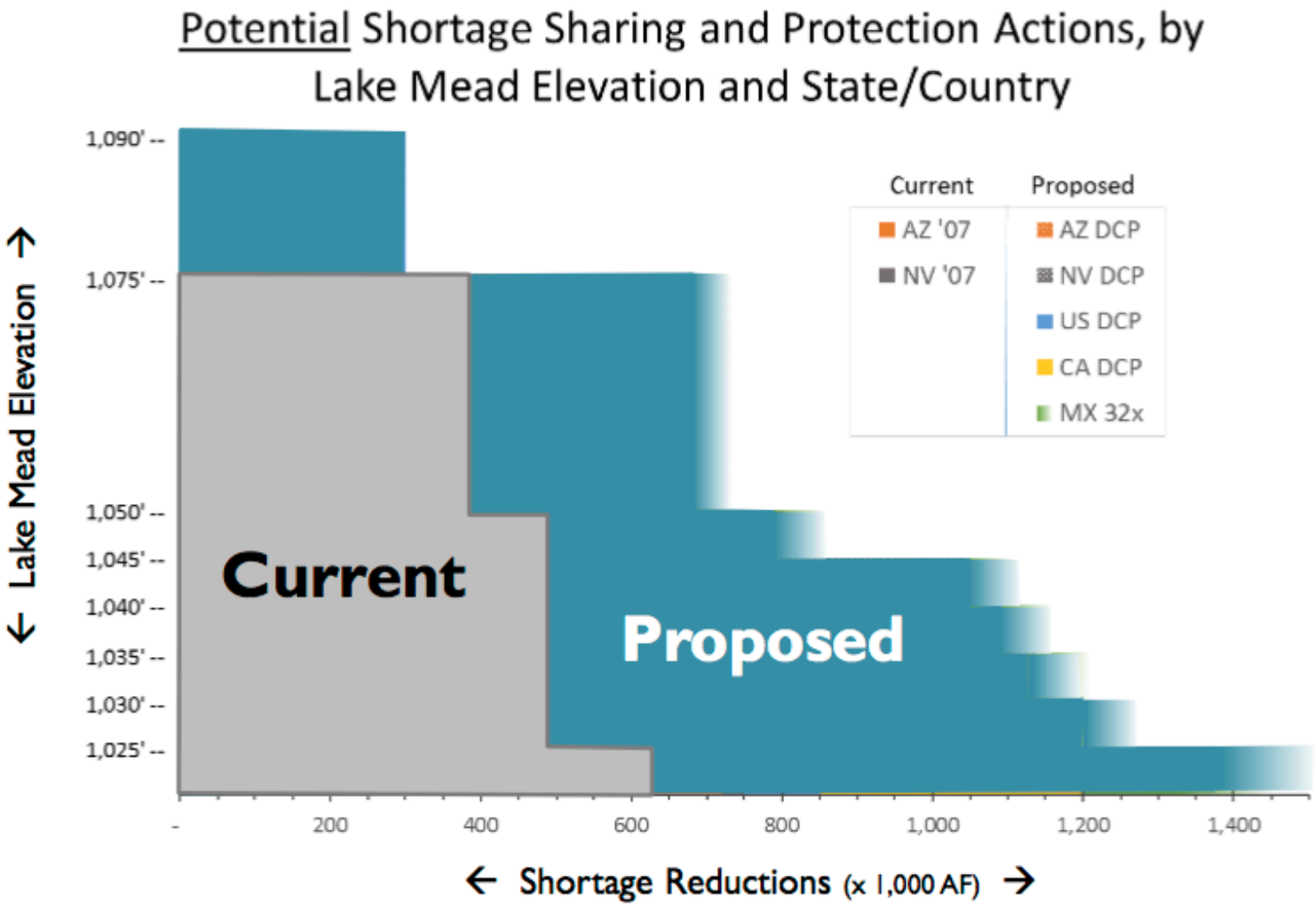
May 2015 was the country's wettest May since records began 121 years ago.

In fact, it was the wettest month ever recorded!



https://www.climate.gov/news-features/featured-images/may-2015-was-wettest-month-ever-recorded-us

Drought Contingency Proposal



Big snowstorms put Colorado River drought plan on ice

By Tony Davis Arizona Daily Star Mar 19, 2017 Updated Mar 20, 2017

"The improved hydrology has changed the landscape and given us a reprieve," said Suzanne Ticknor, CAP's water-policy director

Other water users disagree with this position, including the Arizona Department of Water Resources (DWR), the Tucson and Phoenix water utilities and the Gila River Indian Community, which controls the largest share of CAP water.

Lake Mead to get above-average flow of Colorado River water

By Dan Elliott The Associated Press
April 18, 2017 - 8:51 am

LAS VEGAS REVIEW-JOURNAL

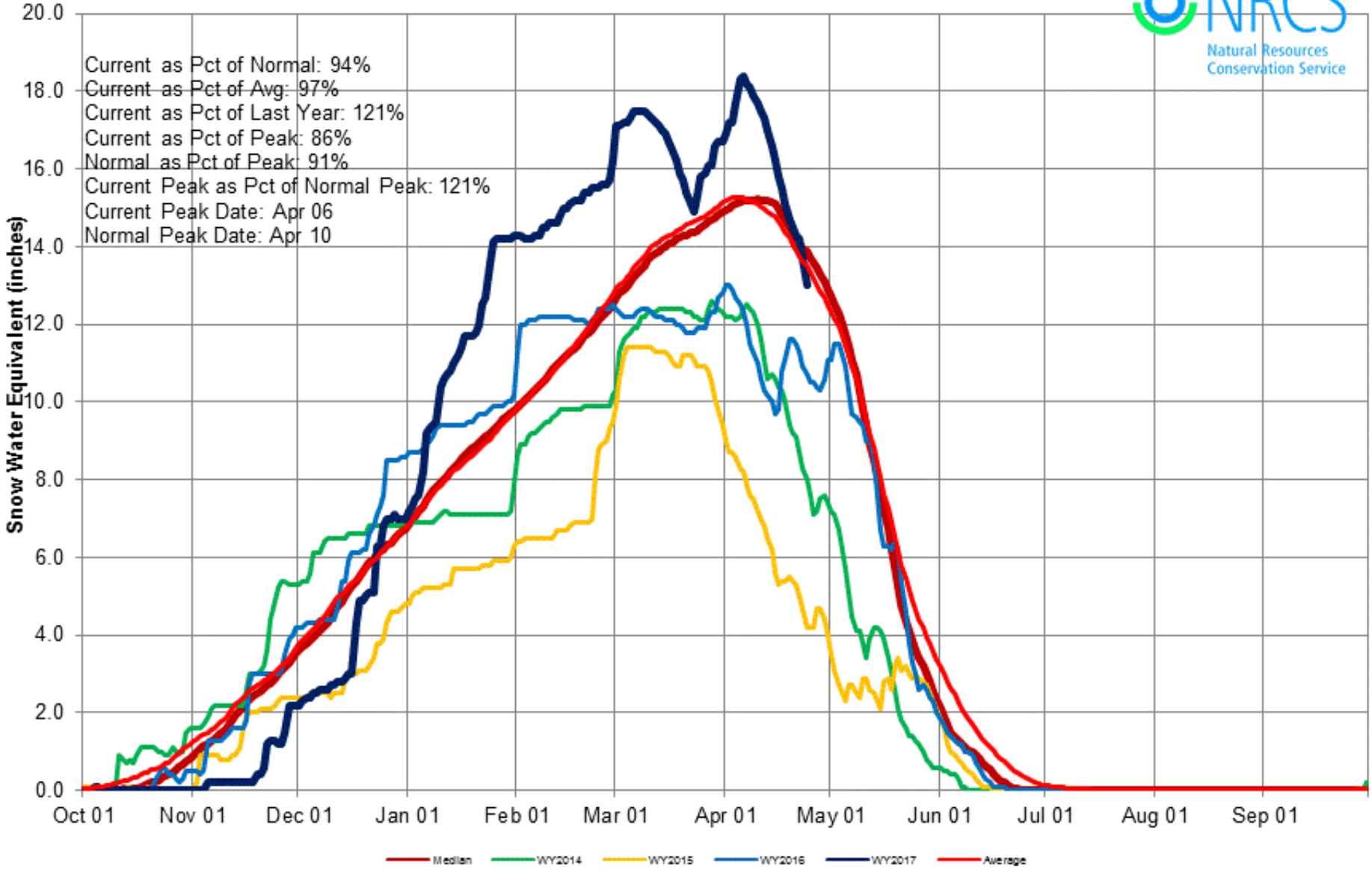
The federal government plans to release an above-average amount of Colorado River water into Lake Mead this year, but it's less than many hoped after a healthy snow season across much of the West.

The Bureau of Reclamation, which manages dams and reservoirs on the Colorado River, said Monday that it will release 9 million acre-feet (enough water to cover an acre of land one foot deep) from Lake Powell, sending it down the Colorado to Lake Mead, where it will be tapped by Arizona, California and Nevada.

Last month, the agency projected it could release 11.1 million acre-feet from Lake Powell, but a dry early March reduced the amount of snow in the mountains that feed the river.

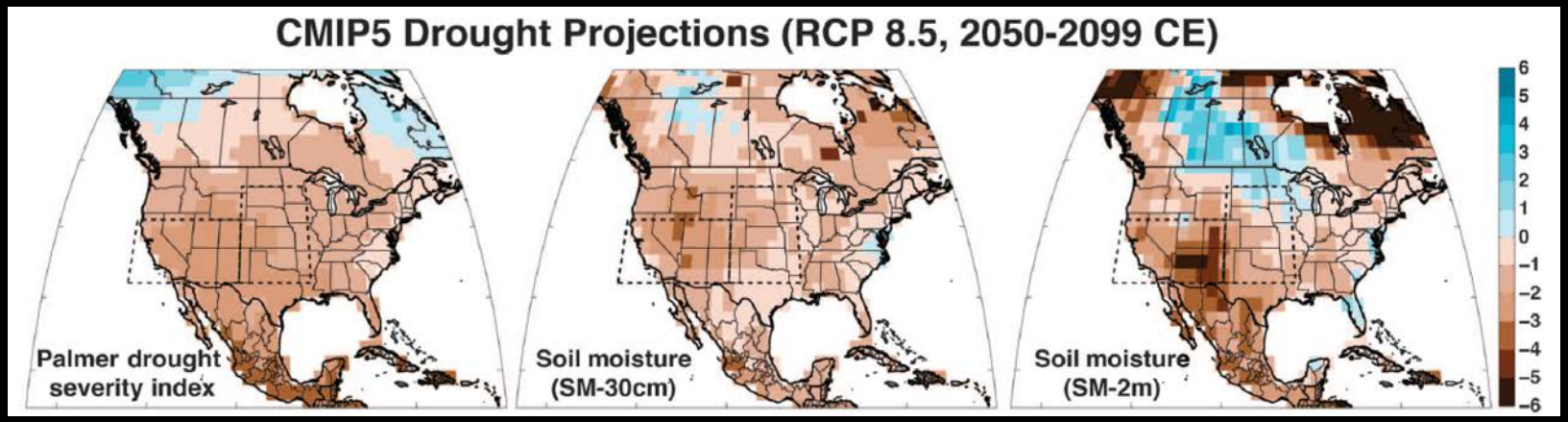
Upper Rio Grande Basin Time Series Snowpack Summary

Based on Provisional SNOTEL data as of Apr 24, 2017



Unprecedented 21st century drought risk in the American Southwest and Central Plains

Benjamin I. Cook,[1,2]* Toby R. Ault,[3] Jason E. Smerdon[2]



Science Advances (2015)

A Mega-Drought Is Coming to America's Southwest

The Atlantic

Unless carbon emissions plummet soon, the risk of a region-altering disaster in Arizona and New Mexico will exceed 99 percent.

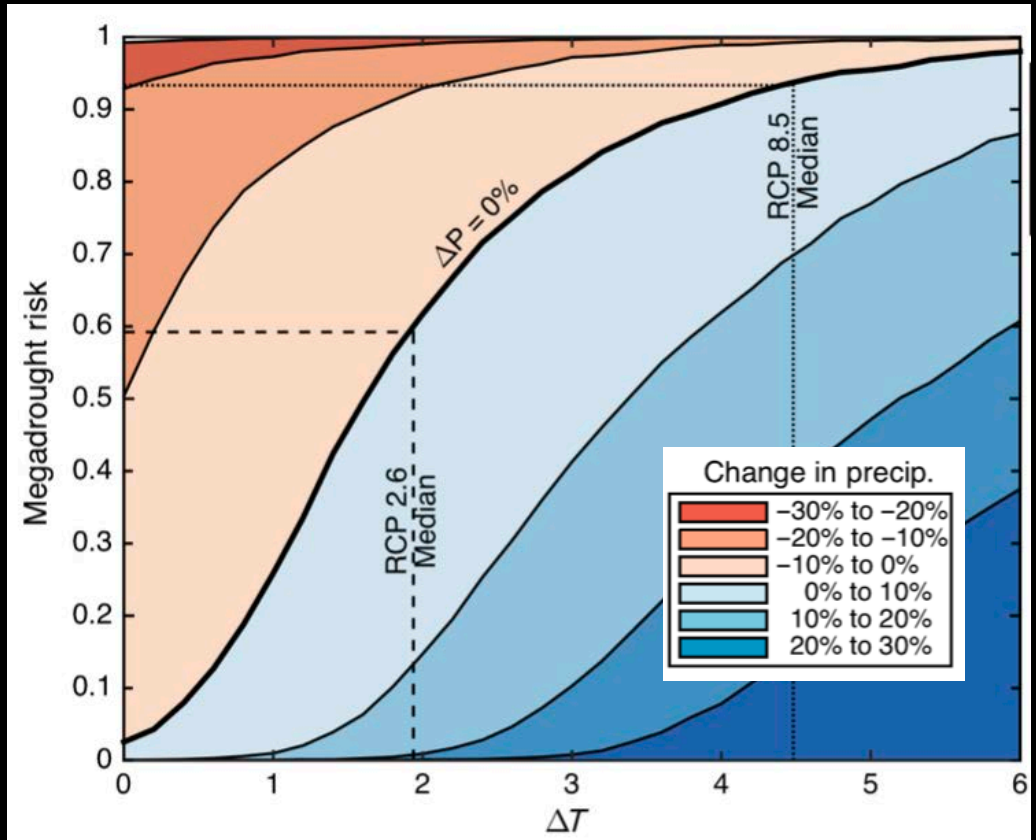
ROBINSON MEYER | OCT 11, 2016 | SCIENCE

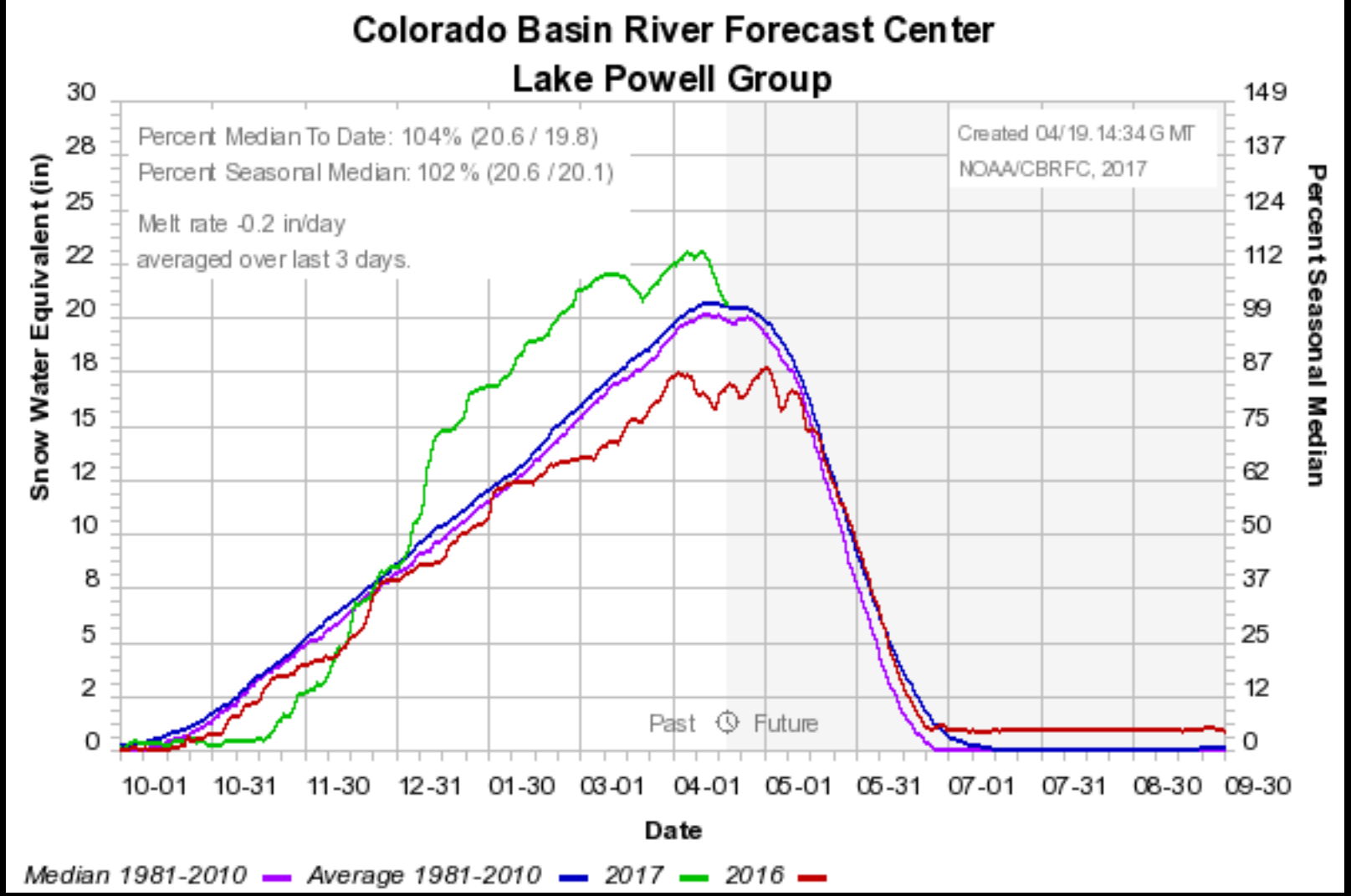
CLIMATOLOGY

Relative impacts of mitigation, temperature, and precipitation on 21st-century megadrought risk in the American Southwest

Toby R. Ault,[1]* Justin S. Mankin,[2,3] Benjamin I. Cook,[2,3] Jason E. Smerdon[2]

Ault *et al.*, *Sci. Adv.* 2016;**2**:e1600873 5 October 2016





April 18, 2017 CBRFC Forecast April – July runoff at 123%

Past Forecasts: 4/1=130%, 3/15= 138%, 3/1= 145%, 2/15= 137%, 2/1= 134%

CLIMATE CHANGE

Dry Times Ahead

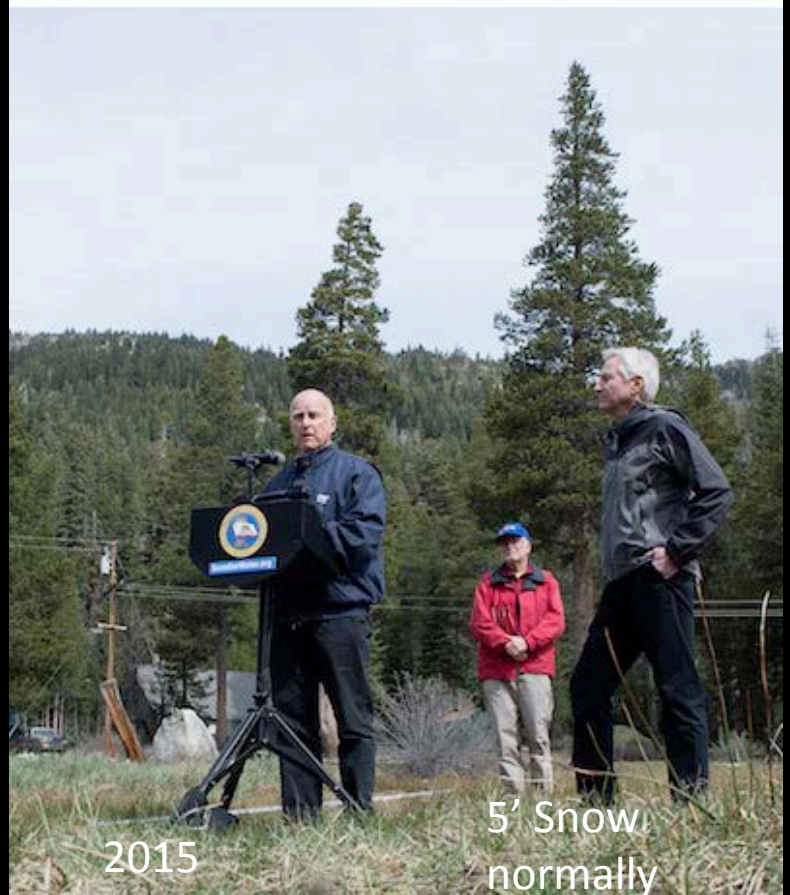
Jonathan Overpeck[1] and Bradley Udall[2]

The climate of the western United States could become much drier over the course of this century.

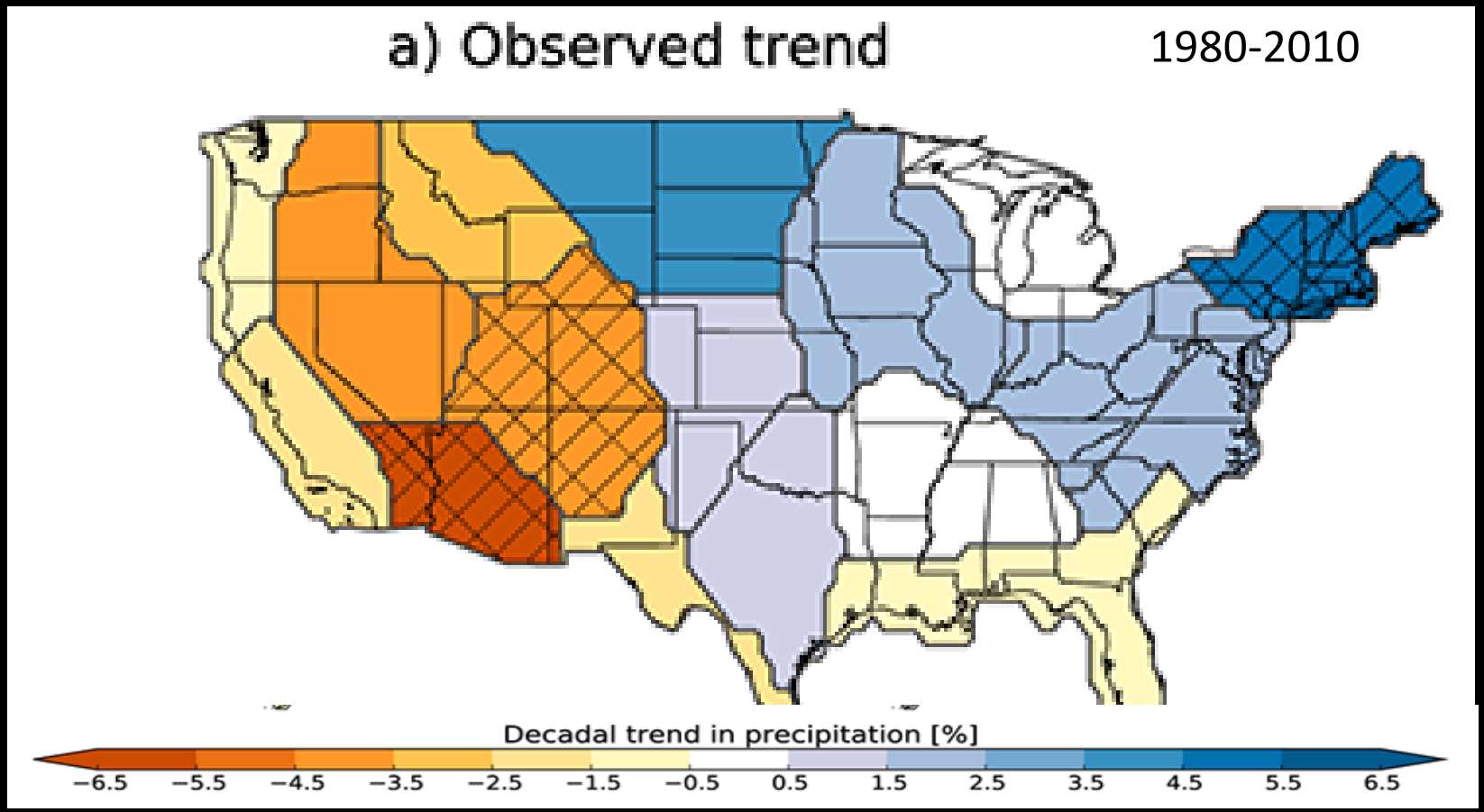
- 2F Warming since 1900
- Snowpack Reductions and Changes in Runoff Timing Already Present
- Most Severe Drought since records kept
- Powell and Mead at 50% of capacity now, full 2000
- Tree Mortality Rates High
- Increase in Wildfire Frequency
- Drought may be natural, but exacerbated by higher temperatures
- Snowpack Reductions and Runoff Timing attributed to climate change
- Continued drying likely as temperatures increase and storm tracks shift
- Megadroughts independent of climate change a possibility with severe consequences if combined with warming

California Winter 2014-2015 Drought

- Winter Temperatures
  - Sierra Winter Above 32 F,
  - (1st time >32F in 120 years)
- Sierra Precipitation
  - Rain, not Snow
  - Not the driest!
  - (40% to 90% of normal)
- Snowpack
  - Lowest Ever - 5% on April 1
  - (1977 at 25%)
  - 500-Year (?) Return Period
- Drought
  - Worst in 1200 (?) Years
- Water Deliveries
  - Record Low to CVP Contractors



Running dry: The U.S. Southwest's drift into a drier climate state



Weather Patterns that provide winter precipitation are becoming less frequent due to Hadley Cell Expansion. Southwest Precipitation has declined by 25%.

Prein et al, 2016

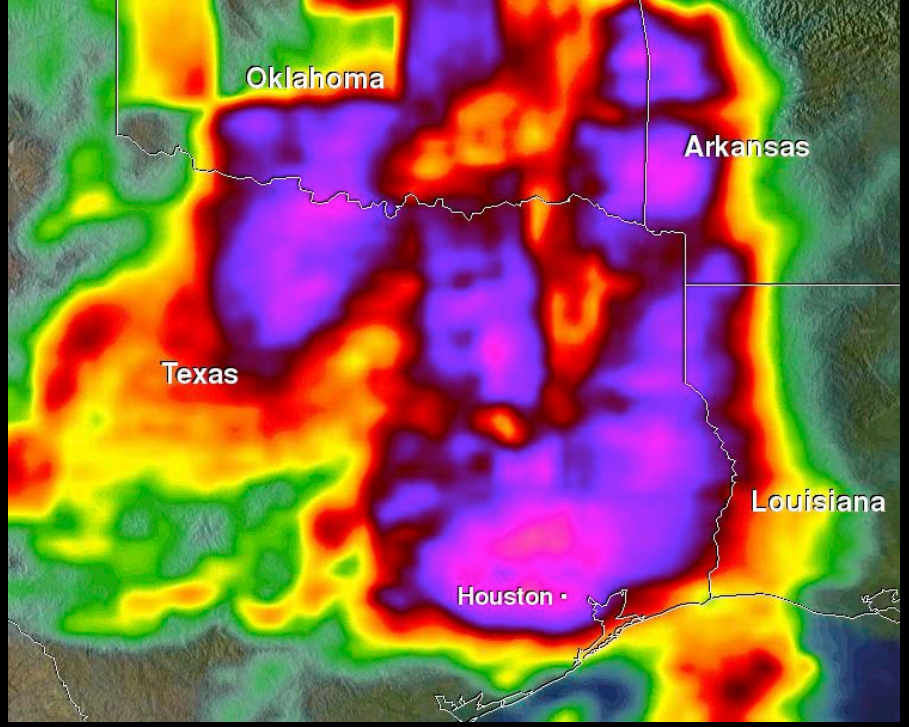
Anthropogenic warming has increased drought risk in California

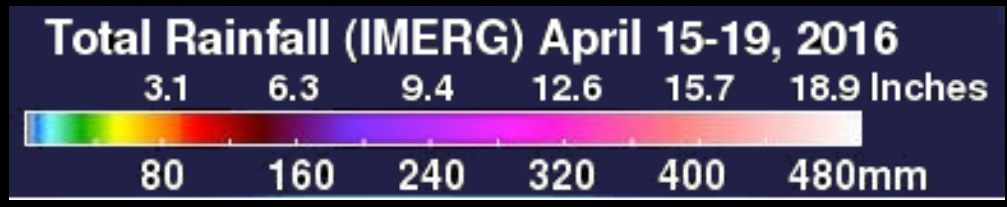
Noah S. Diffenbaugh[a,b,1], Daniel L. Swain[a], and Danielle Touma[a]

[a]Department of Environmental Earth System Science and [b]Woods Institute for the Environment, Stanford University, Stanford, CA 94305

Edited by Jane Lubchenco, Oregon State University, Corvallis, OR, and approved January 30, 2015 (received for review November 22, 2014)

- No change in precipitation over last few decades
- But the occurrence of drought has increased in last two decades over previous century
- The probability that precipitation deficits occur with warm temperatures has increased





Texas Floods
April 15-19, 2016

Louisiana
Floods
August 8-14, 2016